RESEARCH AREAS IN SPACE

RESPOND & AI

Capacity Building Programme Office
ISRO HQ, Bengaluru

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A Document for Preparing Research Project Proposals

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MESSAGE

Investments in Research and Development (R&D) are the key requirements for the economic growth of any country. Right since the inception, ISRO has forged a strong relationship with academia and industry to carry out Research and Development projects which can contribute incessantly towards the ongoing activities of Indian Space Programme. This partnership is crucial in taping the potential existing in academia for meeting the National demand in the niche areas of space programme.

At present, ISRO is venturing into many newer challenging areas like advanced high throughput satellites, navigation systems, planetary exploration missions, reusable launch vehicles, Gaganyaan programme etc., which demands a more focused and output oriented research. In this aspect, it is essential to not only strengthen the existing interface with academia but also to expand the footprint of space activities in the country.

In this regard, I am delighted that Capacity Building Programme Office, ISRO Headquarters has taken the lead in bringing out ***"Research Areas in Space"*** document, consolidating the inputs received from ISRO/DOS centres, highlighting the current and upcoming R & D areas. This document will orchestrate the prospective researchers of Space Technology Cells (STCs) and Regional Academic Centre for Space (RAC-S) to prepare focused research proposals feeding to ISRO's programmatic goals.

I warmly welcome the academic community and encourage them to take a lead in the marvelous journey of Indian Space Programme.

कै.शिवन 30/12/2020

Dated: December 30th, 2020 **(कै. शिवन / K. Sivan)**

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Dr. P.V. Venkitakrishnan
Director, CBPO

PREFACE

ISRO Academia Day aims at showcasing the emerging research and development areas of ISRO, for the faculty of the academic institutions to take up the research projects in the niche areas of their specialization and expertise. I am elated to see the overwhelming participation from academia during the last ISRO Academia Day-2018 held at IIRS Dehradun and the keenness of academia for taking up challenging research problems from the Research Areas in Space document released that time through Sponsored Research (RESPOND) Programme of ISRO.

The second in the series, ***"Research Areas in Space"*** *is* being brought out to enable the enthusiastic researchers from Space Technology Cells (STCs) and Regional Academic Centre for Space (RAC-S) to choose the research topics to prepare project proposals.

"Research Areas in Space" is a comprehensive document highlighting ISRO's major programmes, current and upcoming R&D requirements of ISRO. This document will exclusively cater to the advanced research requirements of ISRO wherein Space Technology Cells (STCs) and Regional Academic Centres for Space (RAC-S) established at various IITs/NITs and premier institutes across the country can select and generate R&D proposals. The faculty of these institutes is encouraged to submit their project proposal in these diverse research areas.

The "Research Areas in Space" document encompasses five major Programmes of ISRO parting the document into Launch Vehicle, Satellite Communications, Earth Observations, Space Science and Meteorology. The document has been compiled and worked out in a precise manner by RESPOND Team, CBPO, ISRO HQs in consultation with ISRO/DoS Centres.

I wish all the best and warmly invite academia to come forward and participate in R& D programme of ISRO.

P V Venkitakrishnan

General Instructions

1. ***"Research Areas in Space"*** is a comprehensive document highlighting ISRO's major programmes, current and upcoming R&D requirements of ISRO. This document will exclusively cater to the advanced research requirements of ISRO wherein Space Technology Cells (STCs) and Regional Academic Centre for Space (RAC-S) established at various IITs/NITs and premier institutes across the country can select and generate R&D proposals. The faculty of these institutes are encouraged to submit their project proposals in these diverse research areas.
2. To enable the faculty to prepare suitable proposals of relevance to space programme, a detailed list of R & D areas /sub areas/topics and a brief write up about the topic have been given in this document.
3. The concerned ISRO/DOS centre interested in the research topic is given in brackets after the areas/sub areas/problems.
4. The faculty of these STCs and RAC-S may submit the proposals to the convener of their respective STCs /RAC-S. Further, the submitted proposals will be subjected to critical evaluation by ISRO/DOS Centres. The proposal will be evaluated on the basis of novelty, methodology, approach, deliverables, experience of the PI in the subject area, duration of the project, budget etc.
5. The evaluation reports of the proposals received from the ISRO/DOS centres will be further reviewed by the Joint Policy Committee (JPC) of STC and Joint Policy Management Council (JPMC) of RAC-S before its recommendation for funding support.
6. The age limit for the Principal Investigator is below 65 years (sixty-five) including the project period.
7. One hard copy and a soft copy of the proposal shall be submitted to the respective STCs/ RAC-S.
8. "Application for Grant of Funds including the project proposal" and "Form-C" shall be submitted in the prescribed formats only. Formats are given in the Annexure -1 & 2.
9. Conveners of STC/RAC-S shall submit a hard copy and a soft copy of the proposal to the respective ISRO/DOS centre. The addresses and e-mail ids of Respond Coordinators of respective ISRO/DOS centres are given in Annexure -3.
10. The proposals may be submitted by the faculty of STC and RAC-S institutions based on the call for proposals by the respective institutes.
11. For any other information kindly visit ISRO website (https://www.isro.gov.in/capacity-building/sponsored-research).

CONTENTS

Launch Vehicle

A	Area	Aerospace Engineering (VSSC)
A1	Sub Area	Aerodynamics and Aero Thermal Engineering (VSSC)
A1.1	**Estimation of gaseous radiation during interplanetary missions (VSSC)** Planetary entry missions involve penetration of its atmosphere at very high entry velocities. The external surface of entry body is exposed to extreme heating rates owing to dissipation of its large kinetic energy. Strong shocks are formed ahead of the entering body increasing the internal energy of entrapped gas. Gas within the shock layer attains very high temperature levels leading to thermochemical non-equilibrium. Gaseous radiation becomes significant in such conditions. Both equilibrium and non-equilibrium air radiation have to be modeled for estimation of radiative heating. Number densities of various chemical species, translational, rotational and vibrational temperatures of heavy particles and electrons are to be evaluated for modeling emission and absorption characteristics of air under these conditions. Available database on radiative properties incorporating spectral absorption and emission behavior of gases at high temperature are to be used. The proposed study should focus on establishing a methodology for evaluation of gas radiation for planetary entries. Comparison of estimated gas radiation levels with available measurements in literature is essential for validation.	
A1.2	**Flow field over a double delta wing configuration (VSSC)** Heat flux data for the double delta configuration is important, especially for regions of shock-shock interaction, leeward region flow, base flow, fuselage wing interaction for accurate distribution of TPS and for mass optimization. It is proposed that experimental heat flux measurements on the above region on ISRO's RLV may be attempted at flow enthalpies of about 2 MJ.kg, M = 6.6, To = 1700 – 1800 K. Diagnostic shall be (a) heat flux (b) liquid crystal thermography/IR thermography (c) Flow visualization. The generated data shall be compared with the predictions, and suggestions for improving the prediction may also be attempted.	
A1.3	**Influence of back pressure fluctuations on the unsteady transonic shock wave boundary layer interaction (VSSC)** A study of shockwave boundary layer interaction in a constant area duct is proposed to understand the effect of back pressure rise on the unstart of typical ramjet/scramjet air intakes. One important factor which affect the large scale motion of the shock and shock wave/boundary later interaction (SWBLI) is the downstream pressure perturbations. Hence a proposal is invited to understand the response of shock wave and SWBLI to downstream perturbations to mitigate its ill effects.	
A1.4	**Supersonic Retro Propulsion (VSSC)** In order to reduce the peak dynamic pressure on the stage during its recovery or to reduce the speed of entry modules during planetary entry, supersonic retro propulsion is an attractive option. This is especially true for entry in planetary atmospheres like that of Mars, which	

	has low-density and does not provide adequate drag to slow down the entry vehicle before touch-down. It has very practical applications in stage recovery where the high dynamic pressure of the recoverable stage is reduced using the impulse provided by propulsion in the supersonic / hypersonic regime of flight. The rocket motor exhaust exhausts into the opposing high speed free stream. The aim of optimal supersonic retro propulsion is to maximize the axial force exploiting the interaction between propulsion and aerodynamics and also to assess the aerodynamic and thermal impact on the parent stage / vehicle. Proposals are solicited for design, analysis and testing of deceleration system with Supersonic Retro Propulsion with single-jet and multi-jets (clustered configurations) to optimize the axial force for stage recovery and planetary entry conditions.
A1.5	**Simulation and studies of soil mechanics for understanding supersonic jet impingement and subsequent dust generation for planetary missions (VSSC)** The search for extra-terrestrial life is being explored on a larger scale. This involves visiting other celestial bodies and exploring for signs of life. Generally, a propulsion system would be used to carry landing on the planed/meteoroids. Understanding the interaction of jet exhaust with the soil during the terminal descent phase is critical for nominal system performance. Proper physics modelling of soil and mechanics of soil-jet interaction, soil particulate formation and dust propagation form major parts of such a study. From this project it is expected that the capabilities would be developed for understanding and modeling of soil erosion and dust particle generation for future interplanetary missions to Moon, Mars, Titan and Venus. This could be in the form of a stand-alone code or be a feature addition to the current framework of PARAS-3D.
A1.6	**Development of an engineering procedure to account for the ground proximity effect on Aerodynamics for the small aspect ratio wing body configuration using CFD database (VSSC)** The aerodynamic characteristic of the wing body configuration is influenced by the ground proximity effect. The ground proximity effect changes the aerodynamic lift, moment and drag coefficients of the wing body configuration. Therefore, it is essential to characteristic the vehicle in the presence of ground and also the associated aerodynamic loads has to be considered for the vehicle design. Ground proximity effect is measurable, when the height is below the one wing span of the vehicle. In general, the ground proximity effect increase the lift-curve slope, decrease the drag due to reduction in the induced drag, and increase or decrease the pitching moment of the wing-body configurations. Nevertheless, the above ground effect is a function of the given configuration and may increase/ or decrease the aerodynamic coefficients. Hence, the ground effect is highly configuration dependent and it has to characterised using wind tunnel testing or CFD simulations with appropriate wall boundary conditions. A CFD based database code has to be developed to account for the ground proximity effect for various angle of attack and height from the ground. The basic coefficients can be given us input. The code has to handle the re-entry type of wing-body configuration with small aspect ratio, blunt swept double delta wing platform and vertical tail.

A2	Sub Area	Aerodynamic Design (VSSC)
A2.1	**On Scramjet Experimental Vehicle (SEV) (VSSC)** Towards long duration demonstration of powered hypersonic flight, ISRO is proposing liquid fuel Isrosene (similar to JP-7) powered scramjet flight vehicle accelerating from Mach 6 to Mach 7. This project envisages demonstration of supersonic combustion on a simple model scramjet at an inlet Mach number of 2, with either liquid kerosene droplet injection / vapour injection with the use of struts. Apart from conventional pressure and heat flux measurements, optical diagnostics of H2O and OH are preferable. Also, measurement of Thrust for the model combustor, estimation of skin friction in presence of combustion is also the part of the project.	
A2.2	**Super sonic parachute design (VSSC)** For payload and stage recovery missions, including planetary entry vehicles, providing deceleration in the supersonic and hypersonic regimes is very important. In planets with low density atmospheres, unless adequate deceleration is provided at high speeds, the touch down speeds can not be reduced to desired safe levels. Similarly, stage recovery missions lead to very high dynamic pressures at high Mach numbers, unless deceleration is provided using either a drag device or propulsion. Often, entry modules become dynamically unstable at transonic Mach numbers. Parachutes are efficient drag decelerators because of their low mass and high drag. Also, supersonic parachutes are used to provide static and dynamic stability to modules descenting at high speeds. However, the design of supersonic parachutes is challenging. Proposals are solicited to design, analyse and test supersonic parachutes which can work at transonic, high supersonic, and if possible, hypersonic Mach numbers. The proposals are solicited in the areas of aerodynamic, flight dynamic, structural and thermal Multi-Disciplinary Design Analysis & Optimization design and testing.	
A2.3	**Infltable aerodynamic decelerator design, analysis fabrication and flight testing (VSSC)** Inflatable Aerodynamic Decelerators (IAD) are promising for payload recovery, planetary entry and other missions. It enables substantial reduction in peak dynamic pressure, heat flux and heat load due to very low ballistic coefficient (BC = m/C_DS) with minimal structural mass for the aerodynamic decelerator. The design of these decelerators has multiple challenges, namely optimal external configuration design, trailing distance, structural design, flexible thermal protection system design, inflation system design, etc. Analysis challenges include aero-thermo-elastic analysis of highly deformable structures, dynamic stability analysis, multi-body dynamics, etc. Fabrication methodologies as well as testing methodologies of various inflatable aerodynamic decelerator components, including high pressure toroids or multi-chamber inflatable structures, their leak proofing, inflation system design, structural and environment testing, wind tunnel testing etc. also need to be developed. Researchers are encouraged to take up Multi-disciplinary analysis & design optimization and testing studies for IAD. Researchers are encouraged to take up Multi-disciplinary analysis & design optimization and testing studies for IAD.	

A2.4	**Airbags for impact attenuation (VSSC)** During the recovery of space modules and launch vehicle stages on land or on water, it is essential to attenuate the impact. Otherwise, the impact loads will be transferred to the payload, structure, instrumentation or crew in the vehicle. Often Air-bags are used for this purpose. Proposals are invited for design, analysis and testing of air-bags or any other impact attenuation devices for use in ground / water landing recovery missions. Following candidate areas can be addressed in the proposals: structural design, ground impact analysis / testing, water impact simulations / testing, dynamics during and after impact, inflation system design, energy dissipation analysis during impact, packing configuration, etc.
A2.5	**Intake design for Scramjet Experimental Vehicle (SEV) (VSSC)** Intake plays a very important role in capturing the incoming air flow efficiently and directing it towards the combustion chamber. The intake efficiency can be assessed based on pressure recovery, mass capture and kinetic energy efficiency. Intakes are of two types namely outward and inward turning intakes based on the complete external, internal or mixed compressions. Currently, SEV intake is outward turning intake with three ramp system followed by two successive expansion corners. To turn the flow into the engine, a shock generates at the inlet's cowl lip and impinges on the engine floor resulting into separation bubble and total pressure loss. The intake is mainly designed to provide the flow conditions required for the self-ignition of fuel air mixture. In addition, the intake is also responsible for issuing high quality flow into the combustion for adequate heat production that result in the large increase in static pressure as well as the internal energy of the flow required for generating large kinetic energy and flow velocity through nozzle expansion. This will lead to high thrust owing to large change in momentum. The ignition delay is proportional to temperature. The self ignition temperature of kerosene which is used as fuel is around 600k at STP. The ignition delay at 600k temperature will demand very high combustor length that leads to weight increase. So care should be taken through proper intake design to ensure sufficient reduction in ignition delay to reduce the combustor length and hence the weight. The intake cowl configuration design should be carried out in concurrence with the expansion corners. The cowl drooping may be necessary for incorporating two subsequent compression to reduce the shock strength and hence the total pressure losses. The cowl lip angles and expansion corners should be properly arranged to have the cowl shocks impinge on the expansion corners to reduce the adverse effect of shock reflections. An intake can be designed at one particular hypersonic Mach number to have the shocks at the lip to avoid the spillage and divert the maximum possible mass flow in to the engine at a given altitude. If the Mach number varies from Mach 6,0 to 7.0 during the SEV operation and the intake is designed at Mach number 6.5, the intake remains under-critical at Mach 6.0 and super-critical at Mach 7.0. During the under-critical operation the flow spillage results into spillage drag with the reduction in Mass flow entering into the engine, while in the case of super-critical intake, the ramp shocks enter inside the inlet creating a possibility of flow separation due to shock and incoming boundary layer interaction.

This will result into severe total pressure loss and higher unsteady pressure levels. The disadvantages in the off design Mach numbers should be addressed in the intake design.

The optimal intake design should cater to all these above aspects

The constraints:

1. Cowl height varies between 0.5 to 0.6m
2. The intake length including ramps and expansion corners vary between 2m to 3m
3. Mach number after cowl shock impingement should be ~ 2.5

Design parameters: Maximization of mass flow rate, minimization of total pressure losses and maximum kinetic energy efficiency.

SEV is intended to fly between Mach number 6 to 7. So the selection of the design Mach number is left to the designer.

A2.6 **Isolator Design (VSSC)**

The isolator isolates the combustor and the intake to avoid the upstream influence of the consequences of the heat addition in the combustor. The isolator length should be optimized to reduce the weight penalty and isolator drag.

Selection of isolator length also depends on the shock train spreading along the isolator with the gradual reduction in successive shocks' strength to almost negligible to provide uniform flow at the entrance of the combustor. The additional pressure and temperature rise owing to shock train should be accounted for the combustor entry condition.

The isolator length depends on the ratio of combustor pressure and intake's internal pressure. It also depends on boundary layer parameters. Higher the boundary layer thickness in the combustor, higher should be the length of the isolator.

The only physical parameter it depends on is combustor height. The proposal should bring out a methodology for isolator length determination which suites to our configuration.

The constraints are : combustor height 100mm, pressure rise between 2 to 4 bar, Mach No to combustor entry between 1.75 to 2.0, design parameter is isolator length.

A3	Sub Area	Development of Tools (VSSC)

A3.1 **Development of a flow through balance (VSSC)**

This project envisages development of a flow through balance towards measurement of six component forces / moments in a supersonic / hypersonic wind tunnel with jetpassing through the core. The balance shall allow a clear diameter of 20mm for passing the jets and the outer diameter shall be restricted to 45mm. The balance shall be so designed such that the jet reaction is not passed to the metric portion. For balance design, following loads may be considered.

Outer Diameter of the Balance	=	45mm (preferably)
Flow passage	=	20mm
No of components	=	6
Balance Ranges		

	Axial Force : 100 kg Side Force : 200 kg Normal Force : 100 kg Rolling Moment : 150 kg-cm Pitching Moment : 600 kg-cm Yawing Moment : 450 kg-cm Medium : Dry air at maximum temperature of 60 deg C Factor of Safety : >2.0 Dynamic loads : Balance will be used in NAL 4’ x 4’ tunnel, hence subjected to start / stop loads. Factor for dynamic loads shall be taken as per practice. Mach No : 0.8 to 4 Inside air pressure : 150 bar (max) FS sensitivity : 0.5mV/V to 1mV/V Excitation : 5 V DC Accuracy : ±0.25% FS Interaction : <5% of FS Natural Frequency : Along with a model of ~15 kg weight, the balance + model fist mode in both pitch and yaw plane should be around 25 Hz Model end fiity : Cylinder (TBD) Earth end fiity Earth end fixity : - Morse taper (TBD)
A3.2	**Development of two stage light gas gun for simulating hypervelocity impacts (VSSC)** Space debris consists of all defunct objects in orbit around earth. These objects are real threat for all space related activities especially in low earth orbit. • Two stage light gas gun is used to simulate the hypervelocity impacts in ground. An analytical tool need to be developed, that can simulate the gas dynamics of a two stage light gas gun for different gas media considering the movement of piston and projectile for estimating the mass and velocity achieved by the projectile for given loading conditions. • Development of an analytical tool to simulate the hydrodynamic behavior of solids when subjected to hypervelocity impacts
A3.3	**Development of high temperature Fiber Bragg grating sensors (VSSC)** Fiber Bragg Grating (FBG) strain sensors offers several advantages over conventional resistance strain gauges in terms of their size and serial multiplexing capability. High temperature FBG sensors are state of the art technology essential for thermo-structural qualification and health monitoring of hot structures in future reusable launch vehicles (RLV). They offer the inherent advantage of distributed strain measurement with minimum mass penalty. Annealed single mode optical fibers with gold coating as cladding are used for making the high temperature FBGs capable of strain measurement up to 800^{0}C

A3.4	**Development of robust algorithm for CFD simulation of supersonic and hypersonic flows around complex geometries on unstructured meshes (VSSC)** Supersonic and hypersonic flows around complex geometries of launch vehicles and re-entry vehicles are of interest to VSSC as it forms an important part of characterization of launch vehicles. An unstructured finite volume 3D RANS solver is under development in VSSC. This solver has popular upwind scheme such as AUSM, Roe etc. with SA and SST turbulence models. Explicit as well as implicit time integration schemes are available. Currently, some issues are observed in convergence of supersonic and hypersonic flows while simulating flows at higher altitudes with low pressure and density. As part of this project, a robust algorithm is to be developed to simulate supersonic and hypersonic flows in particular, that can be implemented in the in-house finite volume solver. The algorithm should be demonstrated on an unstructured grid finite volume 3D RANS solver that is either open-source or developed by the Principal Investigator. Convergence of the simulations using this algorithm should be shown on a generic launch vehicle geometry for various free-stream conditions including those with low pressure and density (higher altitudes). The algorithm should be able to work with upwind schemes such as AUSM, Roe etc. and popular turbulence models like SA and SST in both explicit and implicit time integration. Details of the algorithm can range from changing the values of closure coefficients in the turbulence model, update in the flux difference splitting schemes to development of a separate module that modifies the cell updates based on certain criterion. The project can be divided in two parts: 1. Algorithm for supersonic flows $2.0 < M \leq 4.0$ and 2. Algorithm for hypersonic flows $4.0 < M \leq 8.0$. Separate algorithm can be developed for these two or one algorithm can be developed that suites both these regimes.
A3.5	**Adjoint based grid adaptation algorithm (VSSC)** The solution-adaptive mesh refinement feature allows the user to refine and/or coarsen grid based on geometric and numerical solution data. The unstructured data format allows incorporating solution-adaptive refinement for better resolution. The main issue in the design of the refinement algorithm is to minimize the reduction in grid quality of the adapted mesh, since high quality meshes are often desired for numerical reasons. The boundary layer transition prediction methods require well resolved boundary layer profiles including accurate higher order derivatives and inflection points. The properties of the boundary layer are not known before the solution is computed. This makes grid adaptation uniquely suited to ensuring that the first cell height and the outer portions of the boundary layer are properly resolved. Using a rigorous mathematical approach to automate the grid resolution required within the boundary layer would have a dramatic impact on complex design and analysis applications. Recent trend is towards adjoint based unstructured grid adaptation. The basic idea of the adjoint-based adaptation method is to construct an adaptive sensor from a more robust and accurate error estimation. It is seen that the adjoint solutions provide a very powerful approach to compute output error estimation as well as to systematically adapt grids to reduce

	spacial discretization errors. In adjoint-based adaptation there is a significant reduction in unnecessary grid points compared to the feature-based adaptation in both 2D and 3D flows. The focus of the work should be towards a feature/ adjoint based grid refinement algorithm which can operate in all types of flow regime (subsonic, transonic till hypersonic flows). The algorithm should resolve the flow features like shocks, wakes and vortices with relative ease and should be automated with minimal human intervention. The grid adaptation logic is to be designed in such a way that the cell quality should not deteriorate beyond the baseline grid.
A3.6	**Lattice-Boltzmann methods (VSSC)** In recent years, the Lattice Boltzmann (LB) method has been developed as an alternative method of Computational Fluid Dynamics (CFD). This method originates from kinetic theory and has several advantages in modeling fluid flows in complex geometries and multiphase flows. In addition, the explicit and local interaction makes it amenable for parallel realizations in large scale simulations. The utilization of lattice-Boltzmann has been focused on incompressible flow since the deviations of the many lattice-Boltzmann model are proportional to the square of Mach numbers. The effort to recover the Navier-Stokes equations of compressible flow has become successful for flows with medium Mach numbers near one using the Hermite polynomials as the expansion basis. In the early development the equilibrium distribution function is chosen to be a small-Mach number expansion containing a few coefficients. This approach has achieved great success for the continuity and momentum equations. The effort of recovering the energy equation has met some difficulties due to numerical instability. There are some models that aim to simulate Euler and Navier-Stokes equations and are recovered by the finite difference LB method. The focus of the work would be towards development of a parallel and efficient algorithm for simulating single-phase, multiphase fluid flows for supersonic flows ($M > 1.0$) with finite Knudson Number.
A3.7	**Laminar to turbulent flow transition- modeling and implementation (VSSC)** Majority of the flows encountered in regular aerospace problems are turbulent in nature. The understanding of how a fluid flow develops 'turbulent' properties is not fully understood. The flow transition from laminar to turbulent on reentry bodies like Reusable Launch Vehicle (RLV), Crew Modules etc. is required for accurate prediction of aerodynamic coefficient as well as heat flux distribution. The aim of this work is to develop the better models to be incorporated in 3D unstructured grid Finite Volume based CFD solver.
A3.8	**Turbulence chemistry interaction studies (VSSC)** The turbulent combustion is an interdisciplinary and broad topic. It combines turbulent flow described by the fluid dynamics equations, and complex chemical kinetics. Turbulence enhances mixing of reactants; on the other hand, the chemical reaction involving temperature rise due to heat addition enhances the turbulence levels of the flow itself. Therefore, aside of mass and heat transfer, the coupling between turbulence and chemistry plays a crucial role in turbulent reacting flows.

	In order to deal with the problem of turbulent reactive flow, one has to solve the system of closed equation of motion, species transport and energy conservation. The key difficulty in mathematical modeling of turbulent combustion is the source term in the species transport equation. The reaction is based on the Arrhunious law which is highly non-linear, and it is not easy to express it as a function of mean values. Expanding the mean reaction rate as Taylor series of the temperature fluctuation leads to various difficulties and is not commonly used. Therefore existing models are based on physical analysis, comparing chemical and turbulent time scales, and most of them classified as one point statistics, geometrical analysis or turbulence mixing approach. Assumed probability density function, Steady laminar flamelet, Eddy dissipation concept and partially stirred reactor model are being used in RANS to bring out the effect of turbulence chemistry interaction. Assessment of the turbulent chemistry interaction can be made by using commercially available software like Fluent or CFD++. Or separate module can be developed and incorporated in open source CFD softwares like openfoam or SU2 or in house CFD code like PARAS.	
A4	**Sub Area**	**Trajectroy Design (VSSC)**
A4.1	**Development of analytical tool for low thrust interplanetary mission trajectories (VSSC)** Spacecraft trajectories are obtained from the integration of the spacecraft's equations of motions, which contain terms for the external forces that are acting on the spacecraft and for the thrust force. The convergence behavior of trajectory optimization methods depends on an adequate initial guess of the solution, which is often hard to find. An efficient analytical tool can provide with good initial approximation which can reduce exhaustive numerical computation.	
A4.2	**Re-entry trajectory design and analysis of two closely following bodies with a possibility of a break ups (VSSC)** Re-entry trajectory design is complex as large amount of heat has to be dissipated and structural integrity of the body has to be ensured. Design becomes challenging when two bodies closely follow each other. This typically occurs in one of the missions where crew module and cryostage enters the Earth's atmosphere and are in close vicinity. In this TDP, possibility of cryostage breakup during the re-entry is to be analysed. Number of pieces during the break-up are to be evaluated based upon detailed structural analysis of the cryo stage components. The survivability of these pieces and the effect of impact of these pieces on the ongoing crew module is to be assessed.	
B	**Area**	**Propulsion (LPSC/VSSC)**
B1	**Sub Area**	**Solid Propulsion (VSSC)**
B1.1	**Study on interaction of fluid-structure and resulting pressure and thrust oscillations in segmented solid motors (VSSC)** The thrust oscillations resulting from the chamber pressure oscillations in large solid boosters of launch vehicles is a perennial problem. In solid motors there are several	

	reasons for pressure oscillations- The oscillations resulting from the three dimensional and uneven nature of the propellant grain surfaces (paretal oscillations), oscillations due to the burn rate variations and resulting combustion instability, the pressure fluctuations arising from the vortex formation due to the protruding inhibitions between the segments are some of the major reasons. Among them, the third one is the most severe one causing the largest amplitudes in pressure fluctuations. These fluctuations in pressures may be amplified several times in thrust. When the solid motors are used in paired mode (like S200 motors GSLV Mk III) the thrust oscillations pause issues in controllability also. Hence, the study of the pressure oscillations in solid motors become very significant. In segmented solid motors, the segment inhibition made of rocasin or similar material will not burn along with the propellant grain and will remain there for a long time. This will cause formation of eddies and recirculation zones in the vicinity of inhibitions. The periodic shedding of the eddies result in the pressure oscillations. The inhibition material and the propellant grain also will respond to the pressure fluctuation in the port. Hence the phenomenon of pressure and thrust oscillation in segmented solid motor is to be studied in a coupled manner considering the effect of fluid dynamic oscillations and oscillations of inhibitions and propellant grain deformations. The Objective of the proposal would be : i) To bring out the frequency and magnitudes of pressure and thrust oscillations within the solid motor considering the fluid-structure interaction of the port flow gases, protruding inhibitions and deformation of the propellant grain. ii) The problem has to be addressed in a transient, quasi-steady manner considering the grain surface evolution. iii) The validation has to be done with the available test data of subscale tests or flight measured data.
B1.2	**CFD Simulation studies of Multi Phase Flows and Gas Entrapment during casting of Solid Propellant (VSSC)** The solid propellant slurry is a non-Newtonian fluid with HTPB resin and AP particles of varying sizes and many other chemical additives. During the casting of this solid propellant slurry to make the propellant grain, hot gases evolve from the fluid. Even though the casting is done at a vacuum environment, there are chances that the gases may get entrapped within the cast propellant causing voids. The cast grains with voids above certain sizes are not acceptable for healthy operation of the motors, and hence these grains are liable for rejection, causing loss of materials and time. Hence the gas entrapment during propellant casting is an active area where studies are to be attempted. The casting rate, size of the propellant grain, viscosity, surface tension and vacuum levels, etc may be some of the factors that play important roles in deciding the chances of gas entrapment. Because of the nature and constitution of the slurry, it is a complex multi-phase flow that is occurring during casting. To have an understanding on the factors that cause the gas entrapment and to suggest the means to reduce such flaws, study has to address all the complexities involved.

	The Objectives of the project would be i) Formulation and simulation of the complexities involved in the solid propellant slurry casting through CFD. ii) Identify the factors that are responsible for the gas entrapment during the propellant casting. iii) Suggest the possible means to reduce the gas entrapment in a typical casting process.	
B2	**Sub Area**	**Liquid Propulsion (LPSC)**
B2.1	**Control of combustion instability in liquid engines (LPSC)** Combustion instability is a phenomenon that sometimes occurs in liquid engines and can lead to damage/destruction of the hardware. It can be controlled by passive techniques such as slots, baffls and resonators. To widen the range of operating conditions under which control is effective, active control techniques such as anti-sound and secondary fuel injection can also be used. It is necessary to characterize the performance and stability of passive/active control techniques to evaluate suitability for liquid engines.	
B2.2	**Supersonic film cooling of nozzle divergent (LPSC)** The Nozzle divergent of ISRO upper stage engines are cooled by dump cooling. Dump cooling needs double wall construction, which is having higher weight penalty. Moreover overall Isp of the engine is reduced as the dump coolant is expelled at low temperature. The existing dump cooling method can be upgraded by introducing supersonic film cooling, in which coolant will be injected in the nozzle divergent in the form of a thin slit. This method of cooling needs only single wall structure. Also the coolant will expand through main nozzle at high temperature, which will result in higher Isp.	
B2.3	**Theoretical modeling of atomisation in cryogenic injectors (LPSC)** Development of the primary atomization model to predict the droplet size as well as to have the secondary droplet formation, vaporization etc. for the complex gas-liquid flow existing in the cryogenic engine injectors of CE20 and CUS, where the engines are operating in supercritical conditions of the propellant. Some common approach could be of generation of spray model by full Lagrangian approach, or the phenomenological approach of the Ω-Y model or the hybrid approach using VOF-Lagrangian coupling. The model generated can be validated through experimental data in actual hardware.	
B2.4	**Development of throttleable injector element for liquid engines (LPSC)** Throttleable injectors are necessary for missions requiring soft landing or stage recovery. Various types of swirl configurations as well as pintle type of injectors which will have control over the orifice opening area for flow control and thus control over thrust developed by engine are employed. This could find application in LOX-Methane engine design concept which requires soft landing type of operations for future space missions. Modeling and experimental characterization of the injectors for various operating conditions are to be studied.	

B2.5	**Development of a theoretical model to determine the characteristic frequency of feed line coupled-oscillations in liquid rocket engine (LPSC)** This project is intended to study the vibration response of metallic pipelines conveying propellants to a liquid engine. The pipelines will have the added mass of the fluid inside it. During operation of the engine (hot firing) it will generate vibrations predominantly in the axial direction. The vibratory response of these lines is to be investigated.
B2.6	**Regenerative cooling analysis with kerosene for semicryogenic thrust chamber to study coking characteristics (LPSC)** For semi-cryogenic engine the coolant used for regenerative cooling is refined version of kerosene (equivalent to RP1). The kerosene is a mixture of many hydrocarbons. During passing through the coolant channels the temperature of kerosene increases. However, when kerosene comes in to contact with high temperature walls, it decomposes and leaves behind a sticky rubber like substance called coke. This coke can clogg the injector element holes, which are very small in size (~0.8 mm). Hence the coking characteristics is to be studied thoroughly for different operating conditions.
B2.7	**Mathematical modelling of liquid migration under Zero ‘g’ condition and the associated heat transfer with warm tank wall and pressurent gas is essential to predict the rate of pressure build up in LH2 tank (LPSC)** In cryogenic propulsion Stage residual liquid migration in LH2 tank is generally observed after engine shut down. This causes higher tank pressure due to mixing of liquid hydrogen with warm pressurent gas and heat transfer with warm tank wall.
B2.8	**The complete thermal modelling of the thruster (LPSC)** The monopropellant hydrazine thrusters are used in reaction control system of IRS projects. The monopropellant hydrazine thrusters use the principle of dissociation of hydrazine using catalyst to produce the exhaust gases. These exhaust gases are expanded through the nozzle to produce thrust. The complete hydrazine dissociation model for the monopropellant thruster is required for thruster design and optimization. Based on the dissociation model, the complete thermal modelling of the thruster to be carried out.
B2.9	**Modelling of film cooling / sweat cooling in liquid rocket engines (LPSC)** All high thrust liquid rocket engines employ fim cooling along with regenerative cooling to reduce the heat flux at throat. As the film coolant undergoes phase change and gradually takes part in combustion, it is difficult to predict the overall effectiveness in different operating conditions. Also higher film cooling rate reduces engine specific impulse. Hence a detail CFD analysis is required for all ISRO liquid engines to optimise film cooling flow rate.

B2.10	**Numerical modelling of nonlinear thermo acoustic instability in liquid rocket engine (LPSC)** Numerical modelling of nonlinear thermoacoustic instability is required as instability is inherently nonlinear. Work has already been done in computational modelling using Unsteady Reynolds Averaged Namier Stoke technique (URANS). The use of Large Eddy Simulation (LES) and Direct Numerical Simulation (DNS) techniques is to be investigated to improve accuracy.
B2.11	**Optimization of passive suppression devices for thermo acoustic instability inliquid rocket chambers (LPSC)** Passive suppression devices for suppressing thermoacoustic instability such as baffles and resonators are being used in rocket motors worldwide. LPSC needs to investigate the damping characteristics of baffles, resonators. etc. for application to our engines, in paticular, semi cryogenic engines.
B2.12	**Two phase flow modeling in cryogenic propellant feed lines (LPSC)** Cryogenic engines make use of propellants such as liquid hydrogen and liquid oxygen at very low temperatures in order to obtain a high specific impulse and controllable thrust. The feed lines are to be chilled to cryogenic temperature prior to the start of engine operation to avoid undesirable flow oscillation. The flow of cryogenic fluids through a feed line is complex due to two phase flow, heat in leak in the feed line and boils off at the source. The flow of cryogenic fluids is complicated because surface tension makes all the dynamics nonlinear. Moreover, the density of the two phases differs considerably and compressibility becomes important due to the large change in density. Flow induced pressure drop can lead to further change of phase. In addition, various types of instabilities may develop. Methods are available for modeling of two phase flow using numerical techniques such as volume of fluid method, level set method, front tracking and the Lattice-Boltzmann methods. However, modeling of two phase cryogenic flow incorporating properly phase change and heat transfer as well as fluid dynamics is still a developing field. Specialized models for cryogenic engines will have to be developed considering the actual fluids and operating conditions. New methodologies may have to be investigated to accurately capture the flow behavior.
B2.13	**Conjugate heat transfer analysis in cryogenic engine systems (LPSC)** 1. Development of liquid film cooling model for cryo and non-cryo engines. Detailed model for helical chemical regenerative cooling in LOX-LH2 propellant along with fim cooling. 2. Ablative throat charring analysis in conjugate model.
B2.14	**Spray interaction effects in a multi-element injector head of a liquid rocket engine (LPSC)** Multi-element swirl injectors are used in high thrust liquid rocket engines. The intraelement characteristics of the swirl injector is mainly Influenced by geometrical and flow parameters. The injector elements are arranged in a specific pattern based on the thrust per injector element of the rocket engine. In addition, the conical spray from an injector element

	interacts with the spray formed in its neighbouring elements. The performance and stability of liquid rocket engine is influenced by both intra-element and inter-element spray characteristics. Spray interaction in multi-element injector head depends on both the intra-element spray characteristics as well as combustion chamber operating conditions. For simulating the spray interaction in a multi-element injector, experiments and analyses need to be carried out at different operating conditions.
B2.15	**Studies on deflagration to detonation transition (LPSC)** Combustion can be classified into deflagration and detonation based on whether the flame is travelling at subsonic or supersonic speeds respectively with respect to the unburned medium. Deflagration is associated with low overpressure where as detonation is explosive in nature having high overpressure associated with a shock wave. In conventional liquid rocket engines, deflagration occurs whereas in scramjets and pulse detonation rocket engines, detonation can occur. Dynamics of deflagration and detonation waves have been investigated extensively. However, under certain conditions a deflagration wave may accelerate and transform into a detonation wave. The mechanism of this transition is not well understood. It is necessary to obtain a deeper understanding of the deflagration to detonation transition in scramjets and detonation based rocket engines using numerical and experimental techniques. The data would be required for design and optimization of these systems.
B2.16	**Modeling of atomization of coaxial injectors, impinging jet injectors (LPSC)** Coaxial injectors are mainly selected for gas-liquid propellant combinations in both the Cryo and Semi cryo engines. The impinging injector finds application in the earth storable engines where the injectors are operating in liquid-liquid mode. Flow modeling of atomization of coaxial or impinging jets and parameters affecting the atomization, mixing, vaporization of the propellant is to be studied. Theoretical studies with experimental correlation can be carried out.
B2.17	**Effect of acoustics on spray characteristics of swirl coaxial injectors (LPSC)** Combustion instability is characterized by large pressure perturbations with attendant large thermal stresses and is one of the most important challenges for liquid rocket engine design. Low and medium frequency combustion instability is believed to be caused by the dynamic processes in supply system or combustion. Dynamic processes with specific reference to atomization are to be studied & modeled as it plays important role.
B2.18	**Transient chill down analysis of regeneratievely cooled thrust chambers (LPSC)** The Thrust chambers of cryo engines are preconditioned by low and high flow rate chill down before engine firing. This is a highly transient phenomena involving conjugate heat transfer, radiation and phase change. A proper flow analysis is essentially required to optimize the coolant flow rate during the chill down as this coolant is drawn from the fuel tank during flight. Optimizing chill down flow rate can significantly improve the payload carrying capability as it will reduce the fuel loading from the upper stage engine.

B2.19	**Development of a mathematical model for characterizing the dynamic behavior of a check valve under different operating conditions (LPSC)** Check valves sometimes exhibit chattering under flow conditions which is not desirable. For double poppet check valves which are two check valves in a series mode this phenomenon is complex and hence needs to be studied. Modelling of double poppet check valves preferably using specialized tools like AmeSIM to 1. Characterize check valve chattering under different input conditions for the given design and 2. Characterize and optimize the valve design parameters for eliminating chattering Check valve chattering
B2.20	**Design & development of solenoid coils for liquid helium applications (LPSC)** Liquid helium storage under pressurized condition and on-board isolation will call for a fast response electromagnetically actuated solenoid valve. At these temperatures because of the low viscosity of liquid helium sealing is a concern. The valve envisages the usage of superconducting winding wires wherein the current carrying capacity is amplified many times due to a drastic drop in coil resistance accompanied by minimal increase in power at around liquid helium temperatures. The valve design can make use of magneto-strictive actuator. Development of valve with super conducting coil and achieving leak tightness for Liquid Helium application is a challenge.
B2.21	**Development of a mathematical model for propellant tank pressurization system chain for cryogenic application (LPSC)** Complex thermodynamic processes occur in the ullage Propellant volume of cryogenic tank during pressurization process and propellant outflow from tank. Hence analysis of cryogenic tank pressurization system requires development of a mathematical model for the pressurization process of cryogenic tank addressing heat transfer between cold tank wall and warm ullage gas, heat transfer between liquid free surface and ullage gas, enthalpy of pressurant gas supplied for tank pressurization, tank geometry, propellant outflow rate during engine operation etc. This thermal model computes temperature gradient in tank wall and ullage gas column with respect to liquid expulsion time and thereby predicting mass flow rate variation of pressurant gas with liquid expulsion time. This input is necessary for designing the pressurization system including the gas bottle for pressurant gas storage.
B2.22	**Theoretical Investigation of pressure waves generated by heat addition in a gaseous medium (LPSC)** Heat addition in a combustible mixture involves various processes. The first process is heating of the mixture. When the temperature reaches the auto-ignition temperature, the mixture ignites, and combustion occurs resulting in deflagration or detonation depending on whether the flame propagation velocity is subsonic or supersonic respectively. Both these processes can generate pressure waves which should be investigated theoretically to ensure they are not detrimental to the system. Once the mixture reaches the steady

	state, under certain conditions, combustion instability may set in. This may involve the constructive interaction of the heat release of the flame and the corresponding pressure perturbations which are amplified by the acoustics of the combustion chamber. Alternatively, the heat release fluctuations may generate entropy waves which can subsequently be converted to pressure waves when they are accelerated in a nozzle. The characteristics of pressure waves generated during the thermo-acoustic and entropy-acoustic combustion instability is to be theoretically investigated in a detailed and comprehensive manner. The deliverables shall include (i) Model of detonation and deflagration waves in a combustible mixture and their transition (ii) Detailed model of thermo-acoustic instability for a rocket combustion chamber and different propellant combinations (iii) Detailed model of entropy-acoustic instability for different combustion conditions and nozzle geometries.
B2.23	**Development of a numerical model to estimate stagnation point heat transfer due to supersonic flow impingement in rarefied flow regime (LPSC)** Highly under-expanded plumes of attitude control thrusters impinge on the spacecraft surfaces resulting in heating of the surfaces. Evaluation of the plume impingement heat transfer is critical and necessary for spacecraft design. In view of this, a validated model for rarefied flow regime needs to be developed to fulfill the following objectives: 1. Estimation of thruster plume expansion in high vacuum. 2. Estimation of heat transfer on surfaces due to supersonic plume impingement. The model must be generalized to predict the plume impingement heat transfer characteristics for any arbitary shape surface. **Deliverable:** A validated numerical model for rarefied flow to predict supersonic plume impingement.
B2.24	**Development of Void Fraction meter for cryogenic two-phase flows (LPSC)** Cryogenic two-phase flows are encountered during chilldown of cryogenic stage feedline, mixing of hot vapor with cryogenic liquid in the exit line of semicryogenic engine booster pump, etc. Information of vapor void fraction along with the distribution of vapor and liquid phases is required for estimating the system performance and its optimum design. Experimental data of the vapor and liquid phase distribution is also required to validate the two-phase flow models. In this regard, a void fraction meter is required to be developed that can provide distribution of the vapor and liquid phase at a section or volume of the feedline having cryogenic two-phase flow. Deliverable: A cryogenic void fraction meter to provide distribution of vapor and liquid phases at a section / Volume of the pipe. The design methodology and calibration details of the equipment has to be provided along with the void fraction meter.

B2.25	**Study, design & optimization of clearance seals used in high speed turbo machinery operating in cryogenic fluids and vacuum conditions (LPSC)** Clearance seals are used in cryogenic turbopumps which work in Liquid Hydrogen/ Liquid Oxygen environment during chilling phase and in vacuum conditions during operation of turbopumps. The vibration, friction and wear characteristics of seal/runner combination play a vital role in the turbopump performance. Minimum wear and heat generation and maximum life are the desirable properties of clearance seals used in turbopumps. Detailed study in this area is required to optimize the existing seal designs/ configurations and material selection. Expected deliverable will be the optimized design of the clearance seal/runner and its material selection for use in cryogenic turbopumps.
B2.26	**Development of damper seals for turbopumps (LPSC)** The proposed research is for the development of damper seals for cryogenic turbopumps. The damper seals, in addition to leak control are required for dampening and controlling the excess rotor response which occurs during critical speed crossings in high speed turbopumps. Damper seals of various geometry namely honeycomb, pocketed, hole pattern etc. are currently in experimental phase worldwide. We need to develop a seal of this category, experimentally demonstrate its performance and optimize its geometry for use in high speed cryogenic turbopumps. Expected deliverable will be the optimized damper seal design which works in cryogenic fluids (Liquid Oxygen & Liquid Hydrogen). A mathematical model for evaluating the seal parameters like damping coefficients, stiffness etc. will also be developed. Experimental setup for evaluating the performance of damper seals.
B2.27	**Liquid- liquid combustion modelling for hypergolic propellants (LPSC)** A combination of hypergolic propellants (generally derivatives of hydrazine and nitrogen tetra-oxide) is used for satellite/lander propulsion applications of ISRO. Combustion modelling of such thrusters is imperative to understand combustion performance and film cooling effectiveness during nominal and off-nominal operating conditions. Hypergolic combustion is largely influenced by chemical kinetics/finite rate chemistry but with non-negligible effect of turbulence. A robust combustion model is required which can accommodate droplet flow physics, detailed chemical kinetics of hypergolic reactions, effect of turbulence and liquid/gas phase combustion. The effect of turbulence on chemical reaction rates should be accounted well. The model should highlight film cooling effectiveness in presence of high temperature combustion gases. The model should be validated with ISRO in-house/literature data for major observable test parameters. The model should be capable of predicting combustion performance in off-nominal/throttled flow rate conditions.

B3	Sub Area	Electric Propulsion (LPSC)
B3.1	**Modelling of Magneto Plasma Dynamic Thruster (LPSC)** Magneto Plasma dynamic thruster (MPD) is a plasma thruster where the ions accelerated with magnetic force. MPDs are mainly operates at very high power in the range of 10 kW to one MW. Though it is possible to realize MPD's less than 10kW range, the performance of the thruster will not be as good as Gridded Ion thruster or Stationary Plasma thruster. Pulsed Plasma thruster, VASMIR are the examples of MPD. There are mainly two types of MPD thruster. 1. Self-induced MPD 2. External magnet MPD In the self-induced MPDs, the magnetic field generated by the high current plasma with in the thruster accelerated the ions by Lorenz force. The classical example is Pulsed Plasma Thruster. (PPT). In PPT a very high current plasma discharge between the cathode and anode induces the magnetic field and accelerates the ions produced. The thrust generated by PPT is of the order of 500 micro newtons and there is no precise thrust measurement system available. Considering this modelling of the plasma in terms of plasma generation, the magnitude of ion current, magnitude of magnetic field generated, and thrust production mechanism etc. needs to be modeled. MPDs with external magnets are the devices where strong magnetic field is generated which complements the induced magnetic field. In this type of thruster also the thrust production mechanism is being the same, modelling of the magnetic field generated and applied magnetic field along with the modelling of plasma and its acceleration is important for the design of the thruster and understanding the thruster behavior. Last but not the least, to understand the main technical challenge associated with MPD i.e. erosion of cathode a very good model of MPD is essential.	
B3.2	**Modelling of plasma and its interaction with vacuum chamber during Hall thruster firing (LPSC)** Hall thrusters are being used for in-space propulsion functions on spacecraft. The ground experiments of electric thrusters is to predict the behaviour of the thruster in space. Exact space conditions simulation in laboratory is a high end task. Though a standard low pressure conditions are set as a scale for operation of thrusters, the interaction of plasma plume with background gas and chamber boundaries is inevitable. In this regard, the effects of back ground pressure and chamber boundaries (facility effects) on the Hall thruster performance attains crucial role in estimating the actual behaviour in space. The background pressure increases the neutral collisions and hence plasma plume divergence and the electron transport are affected. Hence the simulations of interaction of plasma plume and effects on electrons transport with background pressure and chamber boundary is needed. The following are expected deliverables: 1. Simulation of facility effects on plasma plume and electron transport using hybrid particle-fluid approach.	

	2. Study of plume divergence and thrust obtained with facility background pressure. 3. Effects on electron transport from external hollow cathode to discharge channel by facility background pressure.
B3.3	**Modelling of Plasma instability in Hall Thrusters (LPSC)** Hall thruster is a rich source of plasma oscillations with diverse phenomena involved in it. Breathing mode and rotating spokes mode are of primary interest exist in Hall thruster. Breathing modes are the strong oscillations whose frequency falls in the range 1-20 kHz and quite sensitive to the entire circuitry including power processing unit. Rotating spokes are azimuthal oscillations (5-20 kHz) anchored in the anode region and may extend to throughout discharge. Both phenomena are believed to be related to ionization processes and it is uncertain how they interact or feed off each other, however, it is strongly suspected these modes greatly affect anomalous electron transport. The behaviour of these oscillations as a function of magnetic field is of great importance in understanding and predicting the thruster characteristics. The following are expected deliverables: 1. Model to predict breathing mode oscillations and their characteristics in Hall thruster. 2. Model to predict Rotating spokes modes and their characteristics in Hall thruster. 3. Investigation of interaction between these modes and their influence on electron transport.
B3.4	**Modelling of plasma and its dynamics inside hollow cathode in Hall thruster (LPSC)** Hollow cathode is one of the most important component of Hall thrusters which is an electron source for plasma discharge and beam neutralization. The life and performance of hollow cathode directly resembles thruster's life and performance. The hollow cathode can be divided into orifice region, insert region and plume region. Plasma density and temperature inside the hollow cathode decides the discharge current that can extract from the cathode. The insert temperature of the cathode is provided by orifice heating, ion heating and electron heating in heater less operation mode. Hence models that quantitatively describe the trends of plasma parameters with varying operating conditions and to simulate discharge parameters (discharge voltage and cathode temperature) is needed. The following are expected deliverables: 1. Thermal model of Hollow cathode using orifice heating, ion heating and electron heating phenomena. 2. Qualitative description of trends of plasma parameters with varying operating conditions and simulate discharge parameters (discharge voltage and cathode temperature).
B3.5	**Multi-plume interaction studies of Clustered Hall Thrusters (LPSC)** Clustering is favourable because of several merits including a cheaper manufacturing cost, less demanding requirement from test facilities, more robustness and an ability to tolerate failure of single thrusters. The performance of a thruster in a cluster may be different from a standalone situation. One interest is to investigate the plume interactions, especially in the

	complex and important near field locations. To accurately simulate the plasma plumes from a cluster of Hall thrusters requires an accurate modelling of the complex physical plume mechanism on three-dimensional meshes. Traditionally, the computational simulation of plasma plume flows into vacuum is performed with a hybrid particle-fluid approach. The direct simulation Monte Carlo (DSMC) method models the collisions of the heavy particles (ions and atoms) while the Particle In Cell (PIC) method models the transport of the ions in electric fields. This study is intend to simulate the detailed three-dimensional plume structures and plume interactions.
B3.6	**Characterization and development of new thermionic material for hollow cathode of electric thruster which cannot easily get poisoned (LPSC)** Hollow thermionic material is a critical element in the development of cathode for electric propulsion. Cathodes are electron source for plasma generation and neutralization in EP thrusters. Thermionic material made of inorganic refractory material. i.e. Lanthanum hexaboride LaB6 with work function of about 2.6 eV emit electron as bulk material without any chemical reaction. Further it is less sensitive to impurities and air exposure. LaB6 cathode has long life in thruster application because of low evaporation rate. At present this material imported. Hence indigenization material required with well understanding of surface properties, emission characteristic and temperature profile to operate the cathode for various thruster discharge current. Expected Deliverables are : Material development, Characterization of emitter material for work function, surface properties & mechanical properties
B3.7	**Modelling of anomalous electron transport in Hall thruster (LPSC)** Anomalous electron transport is one of the prominent mechanism in Hall thruster. Various explanations like cross-field diffusion, Bohm diffusion, near wall conductivity and azimuthal electric fields are attempted to understand the electron transport. The real cause likely to be combination of all. The complex behaviour of electrons in cross-field hall thruster can be handled by categorizing in the following way: (1) Electron mobility in the discharge channel (in the near-anode, ionization and acceleration zones), (2) Azimuthal Hall current (electron propagation around the channel) and (3) electron mobility in the plume. Since these regions are characterized by different magnetic field strength and orientation, each region has to be handled differently. The first part of the study reveals the efficiency of ionization and thrust generation mechanism, second part gives the information of electron confinement in the channel and last part gibes the electron transport from external cathode to the discharge channel across and along the magnetic field. The following are expected deliverables: 1. Simulation of electron mobility in discharge channel of Hall thruster with different magnetic field topology. 2. Simulation of Azimuthal Hall current with different magnetic field topology.

	3. Simulation of electron transport in plume along and perpendicular to the magnetic field. 4. Prediction of suitable magnetic configuration for better operation of Hall thruster from the simulation results.	
C	**Area**	**Propellants, Polymers & Chemicals (VSSC/SDSC-SHAR)**
C1	**Sub Area**	**Propellants (VSSC)**
C1.1	**Development of software for modeling/simulation of mechanical/ballistic properties of solid rocket propellants (VSSC)** Objective is to develop a code/software to accurately predict the mechanical properties and burn rate of HTPB-Al-AP based composite solid propellant. This may be effected in two phases: - Phase I: In this phase, the concept and general framework of a modelling/simulation code for the propellant should be established. Phase II: In this phase a working code containing a full graphical user interface (GUI) and capable of running on a multi-processor platform should be provided. The code should predict the mechanical properties of the propellant and burn rate at a given pressure with a minimum of empirical correlations.	
C1.2	**Ultra-fast reaction monitoring of energetic materials (VSSC)** The basic understanding of decomposition kinetics and dynamics of energetic materials in the ultrafast time regime (femto, 10^{-15}/pico, 10^{-12} seconds). Theoretical understanding of the reaction mechanism using computational tools. Elucidation of the ignition behaviour, reaction pathways, complex combustion phenomenon, measurement of species and flame structure profile etc of solid, liquid (storable and cryogenic) propellants.	
C1.3	**Development of Hydrophobic Coating for Ultrafine Ammonium Perchlorate for Enhanced Shelf Life and Improved Safety (VSSC)** Composite solid propellants are processed using multi-modal distribution of oxidizer particles to maximize the loading of oxidizer particles to ensure 'near' optimum oxidizer to fuel ratio to achieve the requisite combustion efficiency and burn rates with high specific impulse. Multi-modal distribution of the ammonim perchlorate (AP) particles being used in the propellant formulations mainly consists of coarse grade particles (200 to 350 microns), fine grade particles (30 to 50 microns) and ultrafine grade AP (UF-AP) particles (4 to 15 microns). Considering its hygroscopic nature, the coarse grade AP particles are usually provided with a hydrophobic coating in a fluidized bed coater immediately after crystallization during production process. This ensures extended storage life for the coarse grade AP without agglomeration if stored in closed containers with desiccant bags. However, fine grade AP and UFAP produced by grinding coarse AP are highly susceptible to agglomeration	

	and hence have very limited storage life. Thus, quality of fine grade AP and UFAP during processing of the propellant has always been a matter of concern, especially in high humidity conditions, to realize a defect free propellant grain. Besides this, UFAP is highly sensitive towards friction and impact forces requiring utmost care while handling. Objective of the proposed study is to develop the most suitable coating material for UFAP which not only improve its storage life without agglomeration but also reduce its friction and impact sensitivity without affecting its combustion / ballistic characteristics and subsequently developing a technology for uniform application of the coating to UFAP particles. Following deliverables are expected from this activity: ► Development of apromising coating materials for UFAP based on detailed literature survey ► lab scale coating experiments using the identified promising coating materials ► Shelf life / storage studies of the coated UFAP at different humidity conditions ► Development of a technique for uniform coating of the identified material on the UFAP particles ► UFAP level thermal / combustion ballistic studies ► Propellant level trials for evaluating mechanical / interface properties and burn rate rates	
C2	**Sub Area**	**Liquid Propellant Storage and Service (SDSC-SHAR)**
C2.1	**Alternative method of Scrubbing / Neutralizing UH25 & N2O4 vapour (SDSC-SHAR)** Currently UH25 & N2O4 (hazardous, toxic & hypergolic liquids) are scrubbed by using tower packing column of ceramic balls. Alternative method for neutralizing these vapours is to be studied.	
C2.2	**Enhancing the existing method UH-25, MMH, N2O4& MON3 effluent treatment (SDSC-SHAR)** Currently the effluent treatment of the propellant effluents is being carried out in batch process mode using reaction tank. Instead of batch process, continuous method of treatment with improved chemical method is being looked for.	
C3	**Sub Area**	**Solid Propellant Plant (SDSC-SHAR)**
C3.1	**Simulation of Ammonium Perchlorate cleavage by inter-particle and surface impacts in Hammer Mill under different operating conditions (SDSC-SHAR)** Ammonium Perchlorate (AP) is used as oxidizer in Solid Propellant processing with wide particle size distribution. Coarse AP of ~300 microns average size is ground into fine of 50 micron average particle size. The microscopic properties of the material define fine tuning of end product properties. Simulation of Particle breakdown during grinding in hammer mill due to impact with particle to particle, and housing surfaces under different operating conditions like rotor speed, air velocity, feed rate, number of particles is required.	

	This can be used to optimize the process conditions for wide particle size distribution, surface area control, packing density etc. and thus better tuning of final product towards our requirement.	
C3.2	**Method to get uniform Particle Size by innovative size reduction method for AP at lab scale (SDSC-SHAR)** Ammonium Perchlorate is currently being ground by Hammer mill. This gives a wide distribution of partcle size. AP fine product control is achieved with great difficulty due to various factors like residency of the grinder usage, selection of RPMs and screens. It is difficult to get the desired PSD in the range of less than ±1 weight percentage,even with great care. With the requirement of control burn rate between paired motors, the variation in PSD upto the extent of ±1 weight percentage may not be meeting our requirement. Hence, it is proposed to explore for alternative methods to achieve the required specifications.	
C4	**Sub Area**	**Polymers /Composites (VSSC)**
C4.1	**Development of Fluoro Oil for use in Liquid Engines (VSSC)** Fluoro Oils are being used in the liquid engines of ISRO's Launch Vehicles. It requires the development of two different grades of fluoro oils with varying density and viscosity characteristics. Grade 1 fluoro with a density of 1.80 g/cc and absolute viscosity of 17cps and Grade 2 with 1.87g/cc and 140cps.	
C4.2	**Development of polyamic acid resin suitable for optically transparent Polyimide films (VSSC)** Transparent polyimide film has better resistance to radiation when compared with conventional polyimide, making it ideal for use in certain space applications like in satellite antennas, reflectors, solar sails etc. and also for societal applications like semiconductors. Transparent PI film has lower coefficient of thermal expansion (CTE) <15 ppm/°C when compared with conventional PI film <30 ppm/°C, it is structurally stable in composite sub systems like solar panel substrate, camera structure, DGR Antenna hardware etc. Transparent polyimide film offers light- transmission properties (i.e., greater than 90% at 550 nm) when compared with conventional PI film. This means enhanced orbital life of spacecraft components. Proposal is to synthesize fluorinated polyamic acid resin and polyimide film of >95 % optical transparent with similar mechanical, electrical, thermal & outgassing properties of Kapton film. **Scope and objective:** Development of colorless & optically transparent polyimide film. **Expected deliverables:** Optically transparent polyimide film **Expected properties of colorless & optically transparent polyimide film Application:** satellite antennas, reflectors, solar sails & camera structure	

Fluorinated Polyamic Acid Resin Properties	
Property	**Specification**
Viscosity (cP)	20000 cP – 50000 cP
Inherent Viscosity (dl/g)	0.5 to 1.5
Colorless and optical transparent polyimide film properties	
Transmittance	> 95 %
Tg	> 300°C
TGA	Stable upto 500°C
Tensile Strength (MPa)	> 140
Tear Strength (150 kgf/cm)	> 150
Elongation (%)	> 20 %
TML	< 1 %
CVCM	< 0.1 %
CTE	< 15 ppm/ °C
Dielectric Constant @ 1 kHz	< 4.0
Volume resistivity	> 7.8 x 10^{14} Ohm-cm

C4.3 Development of silicone surfactant as a foam (VSSC)

General-purpose surfactant for rigid, semi rigid and Semi flexible foam applications; it can also be used for footwear (shoe sole) and integral skin applications.

- **Scope and objective:** To synthesis different variety of silicone surfactant as a foam stabilizer.
- **Expected deliverables:** Silicone surfactant for rigid, semi rigid and Semi flexible foam applications.
- **Expected surfactant properties:**

Property	Unit	Specification
Viscosity at 25°C	mPa.s	305-340
Calculated OH #	mg KOH/g	0-75
Specific Gravity at 25°C		1.04-1.08
Water Solubility		Soluble/Insoluble
Flash Point, Pensky-Martens Closed Cup	°C	139
Characteristic Appearance		Clear – hazy yellow with no particulates

- **Application:** Manufacturing of various types of foam including polyimide foams, polyurethane foams, polypropylene foam etc.,

<table>
<tr><td>C4.4</td><td colspan="2">Development of thermoplastic liners for helium gas bottle (VSSC)
At present, liners of helium gas bottles are fabricated using titanium alloy. Titanium alloy based liners attract large production delay, high cost and fabrication difficulties. In order to save time and cost in realizing such liners, it is proposed that the liners can be fabricated using suitable thermoplastic materials. Two important criteria for selecting the thermoplastic polymer for such applications are the helium gas barrier property and linear elasticity in the range of 10-20%. The thermoplastic polymers of choice are high density polyethylene, polyetherether ketone, nylon etc. In order increase the gas barrier properties, the polymer needs to be reinforced with platelet type fillers (nanoclay, grapheneetc) in such a way that the helium leak rate of 10 E-8 mbar lit/sec/cm2 or better is achieved. The processing of layered material incorporated thermpolastic liners can be optimized using twin screw extrusion followed by injection molding of the two halves to get spherical liners. The plastic welding process also needs to be optimized so that there is no leakage of helium gas through the weld area and only maximum 5% drop in strength due to welding.</td></tr>
<tr><td>C4.5</td><td colspan="2">The following monomers are required in bulk for the processing polymers and composites for ISRO applications. A scale-up plan and demonstration in scale-up level is also required. The list of monomers for the synthesis and scale-up are (VSSC)
1. 2,4,6,8-Tetramethyl-2,4,6,8-tetravinylcyclotetrasiloxane (D4V)
2. 2,4,6,8-Tetramethylcyclotetrasiloxane (D4H)
3. Diphenyl dichlorosilane
4. Dimethyl dichlorosilane
5. Trimethyl chlorosilane
6. Dimethyl vinyl chlorosilane
7. Diphenyl dimethoxysilane
8. Diphenyl diethoxysilane
9. Vinyl triethoxysilane
Complete synthesis strategy, characterisation, scale-up are to be included in the proposals.</td></tr>
<tr><td>C5</td><td>Sub Area</td><td>Energy Systems for Satellite & Launch Vehicles (VSSC)</td></tr>
<tr><td>C5.1</td><td colspan="2">Analysis of different gas-water separation techniques for oxygen and hydrogen gases with regard to space applications of fuel cells (VSSC)
Fuel Cell system for space application requires gas – water separation and recirculation of gases, mainly Oxygen gas. The requirement involves analysis of different techniques for separation of liquid water from exhaust oxygen gases at variable flow rates in the range of 0.l to 20 slpm Oxygen gas in microgravity environment. The deliverables shall be detailed design of the system or model or both.</td></tr>
</table>

C5.2	**Development of high energy electrode materials (VSSC)** Power requirements of satellite and launch vehicle programs of ISRO calls for the development of efficient battery technology, especially advanced Lithium-ion cell technology. Thus, to improve the energy density of present-day Li-ion cells (150 Wh/kg) to >400 Wh/kg, realization of newer electrode materials with light weight and high energy storage capacity is essential. Suitable anode materials like nano-sized silicon, reduced grapheme oxide encapsulated silicon, lithium alloys of Silicon and/or tin, etc. and suitable cathode materials such as sulphur, carbon-sulphur composites, fluorophosphates, LiNix or $_yCo_xMn_xO_2$ –NMC 111, NMC811 etc. need to be developed, characterized and evaluated. The developed materials should offer anode level specific capacity > 600 mAh/g (vs SOA: 372 mAh/g), cathode level sp. capacity: > 180 mAh/g (vs SOA: 150 mAh/g), cycling stability (> 1000 cycles) etc. towards achieving cell level energy density > 250 Wh/kg.
C5.3	**Development of high voltage electrolyte (VSSC)** As a part of realizing high energy Li-ion systems, it is essential to develop electrolytes that can perform satisfactorily with chemical and electrochemical stability under a wide electrochemical window from 0 – 5 V, like sulfones, sulfoxides, fluorinated carbonates, etc. are suitable for high voltage cathodes. LMNO, Lithium cobalt phosphate cathodes and other systems. The developed materials should offer higher electrochemical potential window (4.5-5.5 V) and proven cell performance with cycling stability > 500 cycles. Desired Ionic conductivity > 10mS/cm and physiochemical properties, Thermal stability shall be in line with present SOA electrolytes.
C5.4	**Development of durable and smart catalyst layer structures of LT PEM Fuel Cell (VSSC)** Cathode catalyst accounts for major share of performance and durability issues associated with PEM fuel cells. The proposed work shall develop high durable ORR catalyst layers capable of greater than 400 mW/cm^2 within 0.6 V for air cathode with 0.1 mg /cm^2 loading at fuel cell MEA level. The deliverables shall include performance data and sample material (~10g), with electrode processing conditions, for evaluation at VSSC.
C5.5	**Development of efficient OER catalyst for LT PEM Water Electrolysers (VSSC)** OER catalyst forms the key in achieving energy efficient water electrolysis. The work is about establishing a synthesis route for high durable catalyst and realizing OER catalyst layer with the same and demonstrate electrode level performance of 1 A/cm2 or greater within 1.70 V for Low temperature (<80°C) PEM water electrolyser. The deliverables shall include performance data and sample material (~10g), with electrode processing conditions, for evaluation at VSSC.

C5.6	**Development of catalyst for electrochemical reduction of carbon dioxide gas to methane in Proton Exchange Membrane (PEM) cells (VSSC)** Energy efficient conversion of CO_2 gas to methane is highly relevant in manned space missions as well as mars missions. It also assumes significance in terms of carbon sequestration and recycle. PEM cell based electrolytic conversion of CO_2 gas selectively to methane using water and electricity forms a potentially attractive solution in this regard. It is envisaged to develop efficient electro-catalyst for selective reduction CO_2 to methane in PEM electrolytic cells.The deliverables shall include optimal catalyst chemistry based on studies using theoretical simulations or performance data and sample material (~10g), with electrode processing conditions, for evaluation at VSSC.
C5.7	**Control algorithm for High Power PEM fuel cell systems (VSSC)** The proposed work envisages developing robust control algorithm for High Power PEM fuel cell system operation. It includes control of the system parameters such as pressure, humidity, temperature, mass flow rates etc., required for optimal operation of Fuel cell systems. The stack parameters such as voltage, current and temperature shall be taken as feedback to regulate the system parameters. Suitable algorithm shall be formulated by interlinking the inter-related fundamental parameters, including those listed above, to derive optimal performance from the fuel cell system. Deliverables shall include the algorithm of controller.
C5.8	**Development of solid electrolytes for fluoride ion battery (VSSC)** The ever increasing demand for high energy storage devices has prompted the search for alternative chemistries capable of better performance than the currently used Li ion battery technology. Recently, the most electronegative Fluoride ion mediated reversible batteries are predicted to outperform today's lithium-ion battery. With suitable electrode combinations, the Fluoride ion batteries can theoretically provide volumetric energy density of more than 5000 Wh L^{-1}, which is eight times as much energy per volume as the current lithium ion batteries. F- ion based solid electrolytes with high room temperature conductivity are required for improving the performance and safety of fluoride ion batteries.
C5.9	**Development of cathode for Li-O_2 batteries (VSSC)** Lithium-oxygen batteries are gaining importance in view of their high theoretical energy density compared to state-of-the-art Li-ion cells. The lithium–oxygen battery comprises a lithium-metal anode, a lithium conducting electrolyte and a carbon-supported (with or without catalyst) oxygen electrode. High capacity cathode materials with specific capacity>1000 mAh/g and cycle life are required for developing Li-O_2 cells with high energy density.
C5.10	**Development of solid electrolytes (VSSC)** Solid state lithium batteries that make use of solid electrolytes rather than a liquid electrolyte can provide higher energy density cells and can eliminate the safety issues of present-day cells. Hence, Lithium ion conducting solid electrolytes with ionic conductivity of the order of 10^{-3} S/cm at room temperature need to be developed. This development

	shall lead to realization of thin, flexible batteries and thus pave the way for processing versatility of cells. The developed material shall offer ionic conductivity > 10^{-3} S/cm with good cycling stability (> 1000 cycles), electrochemical voltage window > 4.5 V and better safety characteristics (non-flammable nature, tolerance to abuse operating conditions).
C5.11	**Materials for advanced Supercapacitors for space applications (VSSC)** Towards improving the power density and energy density of supercapacitors, development of high surface area materials such as activated carbon, carbon aerogels, carbide derived carbon, pyrolytic graphite, etc. need to developed. The developed material shall offer sp. surface area: > 1500 m^2/g, particle size: 5-10 µm, pore size distribution: 0.6-3.0 nm, specific capacitance: > 60 F/g (in fuel cell configuration), operating voltage: > 2.5 V.
C5.12	**Development of Electrolytes/Ionic liquids (VSSC)** In line with improving the energy and power density of present day supercapacitors, hybrid ion capacitors are advancing by invoking the principles of battery as well as supercapacitors. Suitable electrolytes/ionic liquids shall be developed with high voltage and conductivity capabilities for implementation in device level applications. The developed electrolyte should exhibit ionic conductivity: > 50 mS/cm, thermal window: -40 to +70°C, voltage window: > 3.0 V with material specific capacitance: > 60 F/g (for SOA AC in fuel cell configuration).
C5.13	**Development of Sodium – sulphur battery based on solid electrolyte (VSSC)** Solid-state batteries provide a promising choice to the next generation of devices because of their enhanced safety and high-energy and high-power densities. Sodium has low reduction potential and is cheap and abundant and is an ideal candidate for cheap high energy batteries. Sodium batteries generally comprise four components: cathode, anode, electrolyte, and separator materials, while in the case of solid state sodium batteries, solid electrolytes serve the purpose of electrolyte and separator simultaneously. Solid electrolyte provides improved safety compared to conventional liquid electrolytes. Sulphur is a high capacity cathode material and is cheap and abundant. Therefore, sodium-sulphur batteries with solid electrolyte will provide high energy density and improved safety at a lower cost. The developed cell chemistry shall exhibit with good cycling stability (> 1000 cycles) and energy density >250 Wh/kg with better safety characteristics.
C5.14	**Development of electrode materials for Sodium ion batteries and hybrid capacitors (VSSC)** On the basis of material abundance and standard electrode potential, and similar chemical nature of sodium to lithium, sodium-ion based batteries (SIBs) and hybrid capacitors (NIC's) have been extensively investigated as most promising alternative power sources to the lithium ion-based storage technologies. Developing desirable electrode materials viz. anodes (hard carbon, NTO etc.) and cathodes (oxides, pyrophosphates, fluorophosphates etc.) for high performance sodium-based energy systems is an urgent need towards the realization of such systems for practical applications. The developed sodium intercalation type materials should exhibit anode sp. capacity > 250 mAh/g and

	Cathode Specific capacity: > 150 mAh/g and should able to deliver cell level operating voltage: > 3.5 V with energy density > 125Wh/kg. Desired cycling stability at electrode level shall be > 500 cycles against metallic Sodium in coin cells and cell level > 1000 cycles in actual scaled up configuration.	
C6	**Sub Area**	**Ceramics (VSSC)**
C6.1	**Modeling of siloxane-derived PDCs (VSSC)** Siloxanes and borosiloxanes is a class of ceramic precursors, which are easy to synthesize, scale-up and use in realizing high temperature thermostructural components, light-weight structures, etc. for aerospace and ground applications. These ceramic precursors form ceramics with nano-domains of crystalline ß-SiC, B2O3 and C, in an amorphous matrix of SiOC and SiBOC. The relative concentration of carbon, boron, silicon and oxygen in these polymer derived ceramics (PDCs) is critically responsible for their high temperature properties like weight loss, sinterability, viscosity, creep, thermal conductivity, etc. There is a lot of research ongoing currently on this topic due to numerous possibilities arising from the variation in the composition, and correspondingly obtaining a wide range of ceramic properties. These materials have also found interest in creating ductile nano-ceramics through additive manufacturing. Recently, modeling works have been attempted by some researchers. In one such attempt, a model was developed based on reactive force field (ReaxFF) with parameters for Si/O/C/H/N, to study mechanics of PDCs. The models and experiments were found to compare favorably in terms of elastic modulus. Such modeling studies, combined with experimental works being carried out at VSSC, can help in optimizing the elemental compositions of the PDCs and their processing methodologies, resulting in the possibility of developing super-strong PDC structures through additive manufacturing and conventional processes.	
C7	**Sub Area**	**Catalysis (VSSC)**
C7.1	**Development of Effective Catalysts and Reaction Kinetic Models for Carbon Dioxide Reduction Reaction: (VSSC)** The Sabatier reaction, also referred to as carbon dioxide methanation, involves reacting carbon dioxide and hydrogen in presence of a catalyst producing water and methane. Number of catalysts have been reported in the literature for the reaction. Development of highly efficient catalyst with high methane selectivity, lower on set temperature and minimum pressure drop is solicited. Towards this objective, bimetallic or tri-metallic catalysts on suitable supports are required to be designed. Either wash-coating on monoliths or support on metal based mesh for enhanced heat transfer properties may be attempted for realization of the catalyst system with the desired efficiency. Further, reaction kinetic studies for the developed catalyst(s) are required to be undertaken based on which kinetic models should be developed / formulated. These kinetic models shall form the basis for designing of the reactor for undertaking carbon dioxide methanation reaction.	

C8	Sub Area	Human in Space Programme and Mars Exploration (VSSC)
C8.1	**Development of Catalysts for Splitting of Carbon Dioxide: (VSSC)** Atmosphere of Mars is reported to comprise mainly (95%) of carbon dioxide. It is suggested that oxygen for propulsion (for return flight to Earth) can be produced in Mars by catalytic splitting of carbon dioxide into carbon monoxide and oxygen. Another method is to reduce carbon dioxide using hydrogen (transported from Earth) to produce oxygen and methane. Development of catalysts for these reactions and optimisation of reaction conditions will go a long way in realizing Mars explorations.	
C8.2	**Studies on biofilms and its effect on Human Space Flight components /Astronauts (VSSC)** Micro organisms like bacteria are often found attached to surfaces living in communities known as biofilms. Bacteria within biofilms are protected by a tiny matrix that they secrete. Most of bacterial biofilms are harmless. But some of them (like Pseudomonas type) threaten human health and safety. Biofilms can exhibit increased resistance to the immune system's defenses or treatment with antibiotics. They also can damage vital equipment aboard spacecraft by corroding surfaces or clogging air and water purification systems that provide life support for astronauts. Biofilms cause similar problems on Earth. NASA studies reveal that biofilms grown in space contained more cells, more mass and were thicker than the control biofilms grown on Earth. When they viewed the microscopy images of the space-grown biofilms, the researchers saw a unique, previously unobserved structure consisting of a dense mat-like "canopy" structure supported above the membrane by "columns." The Earth grown biofilms were uniformly dense, flat structures. These results provide the first evidence that spaceflight affects community-level behavior of bacteria. Studies on Pseudomonas aeruginosa were carried out by NASA. In view of the above, it is imperative to do a systematic study on biofilms, its growth, its effect on life supporting systems, equipments and on astronauts.	
C9	Sub Area	Electro-active Actuators (VSSC)
C9.1	**Development of electro-active actuators for positioning & control of aerospace components (VSSC)** Electro-active actuators are necessary for shaping, tuning and positioning of reflectors/ antennae/ solar panels in aerospace field. Polymers actuatable by current/voltage can lead to shape memory or shape changing polymers. The response is based on the ionic movement or electrical conduction capability of specially designed polymers. The movement of ions/electrons facilitates the actuation of mechanical shape. Compared to common actuation by heat, it is superior in control and accuracy. Also, development of enhanced electro- active polymer material (based on dielectric polymers such as silicone and PVDF) based sensors and actuators with improved adaptability for space-related applications are required.	

C10	Sub Area	Shaped Fillers (VSSC)
C10.1	**Development of shape controlled inorganic fillers for thermal interface materials** Thermal interface materials are very critical for the miniaturization of electronic components. In order to enhance the thermal conductivity of the interface thermal pad, conductive fillers like alumina and boron nitride are being used. The shape of filler significantly contributes to the thermal conductivity. The objective is to synthesise the platelet and spherical shaped fillers and development of electrically insulated thermal pad.	
D	**Area**	**Materials & Metallurgy (LPSC/VSSC)**
D1	**Development of ceramic coating to prevent metal burning in high temperature and oxygen rich environment (LPSC)** Metal burning in hot oxygen environment is an important issue which is not yet solved. Ceramic coating containing oxides is one of the solution for preventing metal burning. Adhesion of the coating to the metal substrate is an important aspect. Addition of metal particles to ceramic will help to improve the ductility of the coating so that it will not fracture under tensile loads.	
D2	**Development of new thermal barrier coating to reduce heat flux in Semi Cryogenic Engine Thrust Chamber (LPSC)** Thermal barrier coating (TBC) for Semi-cryogenic thrust chamber is mandatory requirement to bring down the coolant channel temperature below the coking limit of the coolant (fuel). Heat flux to thrust chamber material (copper alloy) can be minimized by TBC. TBC can be any material which has got conductivity less than chamber material (copper alloy).	
D3	**Development of coating materials used in high temperature environment (LPSC)** For high temperature application, two kinds of coatings are required. One is TBC for super alloys including Co base or Ni base alloys which has got melting point less than 1400°C. Other is oxidation protection coating which is needed for refractory alloys like C103 or Mo/Ta alloys.	
D4	**Material behavior at hot Hydrogen environment (LPSC)** Gaseous Hydrogen embrittlement of metals and alloys are possible at ambient to 200°C. In order to avoid this, new alloy design which is compatible with hydrogen is required. Existing alloys shall be given coating which is not permeable for hydrogen.	
D5	**Physical property measurement at low temperature up to 20K (LPSC)** Physical properties like modulus, thermal, electrical and expansion/contraction measurement are mandatory requirement for all materials used up to 20K.	

D6	**Development of materials/alloys including coatings for high pressure Oxygen environment (LPSC)** New alloys or coatings for existing materials are required handling high pressure oxygen. Coatings can be of noble metals whose oxides are unstable or ceramic coatings which will be never ignited in high pressure oxygen. New alloys should have very high ignition temperature so that it will ignite in normal operating temperature.
D7	**Development of thermal barrier coating with Nano materials (LPSC)** Using Nano materials, TBC can be made with superior mechanical properties as compared to conventional powders. Even with air plasma spraying Nano powdered TBC shows mechanical properties similar EB-PVD.
D8	**Finite Element Analysis (FEA) of cold/hot forming of formed components (with thickness >6 mm) (LPSC)** The cold and hot forming are normally chosen depending on section thickness and geometry of hardware. The forming involves shaping the component with plastic deformation with suitable tooling. However, the problems associated with formed components are spring back, distortion, residual stress etc., which create problem during subsequent stage of fabrication (i.e welding and assembly). Hence for subassembly or hardware realization, there exists a need to carry out FEA based analysis of forming of components with higher thickness (>6 mm). This will help to optimize the processing windows of forming with respect to temperature, no of stages and extent of deformation in each stage so as to have minimum residual stress and distortion of final products.
D9	**Validation of processing maps by microstructural characterisation and mechanical testing of samples from trial forgings (LPSC)** Processing map is an accepted scientific tool for optimization of hot deformation processing of metallic materials. However, for optimization of raw material processing at plant scale, it is essential to validate the processing map with sample drawn from trial forging processed at various temperature and strain rates. The scope of the project includes microstructural and mechanical characterization of samples from trial forgings, its correlations with microstructure of hot compressed samples used in development of processing map and subsequent validation of processing map. Processing map of the proposed materials and trial forgings would be provided by LPSC.
D10	**Flammability, Ignition and Combustion behavior of nickel base superalloys used for high temperature applications in oxygen rich atmosphere (LPSC)** Appropriate material selection is a crucial aspect in design and maintenance of a safe system. To ensure the safety of any system involving hot oxygen, the system designer must have a thorough understanding on the compatibility of materials with the liquid oxygen (LOX) and gaseous oxygen (GOX) atmospheres, at various temperatures and

	pressures. The project envisages development of a test facility to comprehensively study the ehavior of materials in oxygen rich atmosphere under varying temperature, pressure and with particle impingement.
D11	**Development and characterization of oxidation resistant coating on refractory alloys for high temperature (2000°C and above) applications (LPSC)** Refractory alloys possess excellent high temperature mechanical properties due to which they are widely used materials for satellite thruster. However they lack oxidation resistance due to formation of volatile oxides at elevated temperatures. Hence oxidation resistant coatings are inevitable to prevent oxidation. The proposal is for the development of a suitable high temperature oxidation resistant coatings, that can protect refractory materials from oxidation upto 2000°C employing state of the art material systems, and scalable to component level (with complex contours).
D12	**Development of functionally graded multi-material components for aerospace applications through additive manufacturing (LPSC)** Multi-material structures can provide unique functional requirements and solutions that single materials cannot fulfill. By combining two or more different materials, distinct properties of two different materials such as thermo-physical, mechanical, electrical, optical and oxidation properties can be utilized together. In past bi-metallic materials were either ehavior through fusion welding techniques or solid state joining processes. However, these processes have their own limitations of high heat input requirement leading to wide HAZ, distortions, cracking etc. With advances in additive manufacturing processes it is now possible to ehavio multi-material components in single step. The proposed study aims at realization and characterization of multi-materials components for launch vehicle thrust chamber applications.
D13	**Analysis of phase stability and phase transformations in HEA by CALPHAD approach (LPSC)** The concept of high entropy alloy (HEA) opens up a vast unexplored composition ranges for alloy design. It has attracted tremendous amount of attention to develop new-generation low-density structural materials for aerospace applications. In spite of intensive investigations in the past few years, the phase stability within this HEA system is still poorly understood and needs to be studied in detail, which poses obstacles to the discovery of promising HEAs. The project envisages employing CALPHAD approach to study the phase stability and phase transformation within the systems such as Al-Co-Cr-Cu-Fe-Ni and Mo-W-Al-Cr-x. The phase-stability mapping coupled with density contours shall be constructed within the composition-temperature space, so as to provide useful guidelines for the design of low-density HEAs with desirable properties.
D14	**Processing and property evaluation of High entropy alloys (HEAs) for aerospace engine components (LPSC)** High entropy alloys (HEAs) are materials with complex compositions of multiple elements and striking characteristics in contrast to conventional alloys and their high configuration

	entropy mixing is more stable at elevated temperature. Conventional alloys are produced by melting route while HEA have the tendency to form hypoeutectics that separates itself from the other elements and defects formed in the casting. The project envisages the development of HEA for aerospace application through additive manufacturing route and studies to understand their microstructure-property-processing correlations.
D15	**Study on structure-property-processing correlations for precipitation hardenable stainless steels used in liquid propulsion applications (LPSC)** Precipitation hardenable stainless steels are indispensable material for heavily stressed aerospace components. This class of material is being used for numerous critical components and sub-systems in launch vehicles. The properties of the material (ranging from mechanical behavior and corrosion resistance) naturally depend on the microstructure. However, unlike the other classes of stainless steels, the microstructural analysis of the precipitation hardenable stainless steel of steels is rather complicated because of hierarchical microstructural features of the martensite structure. Current practice of microstructural analysis lacks clarity and there exists a serious need to develop well defined criteria for microstructural analysis of PH stainless steels. The project envisages studies to develop microstructure-property correlations (employing EBSD to analyse microstructure and linking prior austenite grainsize with block size) and subsequently behavior manufacturing processes and acceptance criteria.
D16	**Development of graphene based coating for use in regeneratively cooled copper alloy thrust chamber (LPSC)** Due to its extraordinary high thermal conductivity of graphene (in the range of 3000-5000 W/m/K), graphene based coatings can enhance heat transfer in regeneratively cooled thrust chamber and thereby improve thermal management and increase the life of hardware during service. The project envisages development of grapheme coating on copper substrates (scalable in component level) and characterization of its mechanical and thermal behavior.
D17	**LASER ultrasonics for Titanium EB weld evaluation (LPSC)** Spacecraft propellant tank is a Ti6Al4V alloy construction. The Electron beam welds of thickness 3-4 mm are to be evaluated for porosity, cracks and LOF. The present technique of conventional PA-UT is proposed to be replaced by LASER based ultrasound generation. The research shall be carried out on generation of ultrasound, optimizing the parameters in terms of power, pulse width etc. in order to achieve detectability of LOF of a/2c=0.1, a=0.5 and better and porosities of 0.3 mm or smaller. The technique shall be in-situ inside the EB chamber with or without vacuum and the set-up shall be portable to be able to move across EB machines. The change in properties of the test article in the ablation regime for ultrasound generation (if considered) shall also be studied.

	The deliverables at the end of research and study shall be the LASER source, suitable interferometer and the processing systems.	
D18	**Sub Area**	**Foundry Technology (VSSC)**
D18.1	**Solidifiation behavior and grain refinement of cast superalloys (VSSC)** Superalloys are used for making many cast components used at turbine side of the turbo-pumps. Investment casting is the process used for making these components. Grain coarsening happens due to inherent slow cooling involved in the process. Suitable grain refinement techniques are needed to control the grain size for better fatigue and strength properties and weldability. Detailed study is envisaged to understand the solidification behavior, homogenization parameters and ageing characteristics for the Ni-base and Ni-Fe base superalloys.The project deliverables would be optimized process parameters for grain refinement.	
D18.2	**Development of Ultrasonic technique for locating casting defects (VSSC)** Many critical components are made through casting route. Complex castings get few unacceptable defects which are to be repaired through welding. It is necessary to locate the defect precisely in the wall of the casting to avoid unnecessary gouging. Ultrasonic technique can be very effective in this regards. But due to cast structure low frequency probes only can be used. Also response of the cast material is not good to Ultrasonic testing. Considering these limitations a suitable technique/procedure is to be developed for defect detection using UT. The deliverables would be the detection technique/ methodology and relevant documentation.	
D18.3	**Optimization of Heat treatment parameters & characterization of super alloys (VSSC)** Various cast superalloys (XH43, IN 718, XH62, and XH67) are being used in our space programme. It is necessary to take up extensive studies on characterization of these superalloy and optimization of heat treatment parameters and compositions for better performance. Material for heat treatment studies shall be provided by VSSC in the form of test bar. The project deliverables would be the heat treatment cycles/parameters that would meet specified properties and test results.	
D18.4	**Simulation of SLM (Selective Laser Melting) process for prediction of defects and parametric control in printing of components (VSSC)** Selective Laser Melting is process for making complex shaped components in very less time. Process optimization and modeling is very important for improving reliability of the process. Models should be based on thermal imaging of the melting passes and should be able to predict the effect of parameters on discontinuities in the product. The deliverables would be software model and simulated data / test results, for laser melting process.	

D18.5	**Design of alloys for powder base additive manufacturing processes (VSSC)** Powder base additive manufacturing processes involves high solidification rates. It can lead to design of new alloys which cannot be processed through conventional processes but can be processed through SLM/LENS process into a component. It can lead to development of component in alloys with exotic properties and significant weight saving. Under this project, few alloys can be selected for light weight, high strength, stiffness for light weight and high temperature capability.	
D18.6	**Modeling of solidifiation for various cast alloys (VSSC)** Cast alloy solidification modeling should aim for prediction of the solidification modes, different phases and shrinkage characteristics for different cooling rates. It shall also aim to get details like effect of various parameters on fluidity of cast alloys.	
D19	**Sub Area**	**Welding Technology (VSSC)**
D19.1	**Improving tensile properties and controlling of residual stresses in 2219 and 2014 aluminum alloy FSW weldments by laser shot peening (VSSC)** Friction Stir Welding is considered as potential welding processing to realize aerospace hardware without hot cracking and porosities. The scope of work is to improve the mechanical properties of Al alloys (2219 and 2195) FSW welds by laser shot peening. Data shall be generated on the effect of laser shot peening on tensile properties and residual stresses in weldments. FSW welded plates will be supplied by VSSC	
D19.2	**Brazing of alumina to metals using reactive brazing foils (VSSC)** Generally, a layer of Mo-Mn and Ni coatings are provided on the ceramic (Al_2O_3) substrate to enhance the wettability. Alternatively, active braze alloys (ABAs) can be used for metal-ceramic brazing easily by eliminating complicated metallization process. These ABAs contain some titanium, which activates or reacts with the surface of the ceramic base material facilitating good wetting. Metals to be bonded are Kovar, copper, and molybdenum. Study involves selection of suitable ABAs and optimization of brazing process. Scope also includes extensive characterization of brazed samples as per AWS guidelines. VSSC can extend vacuum brazing support.	
D19.3	**Magnetic Pulse Welding (MPW) of AISI 321 stainless steel to AA2219 Aluminium alloy (VSSC)** Solid state welding processes are widely used to join dissimilar materials like stainless steel and aluminum alloys. MPW, a recent addition to the family of solid-state welding processes has enormous potential over the conventional explosive bonding to produce bimetallic adaptors (AISI 321/AA2219). Scope of the work involves design, analysis, fabrication, and demonstration of suitable magnetic coils and field shapers to realize bimetallic adaptors of various sizes. Realized bimetallic adaptors have to be subjected to extensive pressure and leak test at ambient and LN2 temperatures. The scope of study	

	also includes detailed mechanical and microstructural investigation of the weld joints. Materials (AISI 321, AA2219, Cu alloy for coil) of the trials can be supplied from VSSC. VSSC can also extend support for pressure and leak test.	
D20	**Sub Area**	**Materials Processing (VSSC)**
D20.1	**Development of NDT technique to evaluate bond quality of explosive welded AA2219/SS321 bimetallic joints (VSSC)** Explosive welded SS321 stainless steel and AA2219 aluminum alloy bimetallic joints (pure Al OR pure Cu as interlayer) are being used for cryogenic application. Detailed characterization of joint interface viz. AA 2219+pure Al/Cu and SS321+pure Al/Cu needs to be carried out which includes (i) Establish NDT technique to evaluate the interface quality and validate w.r.t He-leak test (ii) NDT result correlation with mechanical properties, microstructural features.	
D20.2	**Development and characterization of hexagonal phase boron nitride powder through chemical route (VSSC)** Hexagonal phase boron nitride powder is being used as raw material for metal matrix composite seals towards realization for space borne components. The objective of the proposal is to develop a process technology through chemical route and characterization for phase purity, average particle size, particle size distribution etc.,	
D21	**Sub Area**	**Materials Characterisation (VSSC)**
D21.1	**Secondary electron measurement of BN/Silica composite for electric propulsion application (VSSC)** Secondary electron emission characteristics of the discharge chamber wall material have a significant role in determining the plume characteristics and hence the thruster efficiency of stationary plasma thruster for electric propulsion. Measurements to quantify the secondary electron emission from BN/silica are very important to select the wall material. At present BN/silica composite is being used as wall material for ISRO's electric propulsion system. Understating the variation of secondary electron emission with varying the silica content of the composite will help to select the appropriate composition of the composite material as discharge chamber wall.	
D21.2	**3D atom probe analysis of precipitates in age hardenable aluminium alloys (VSSC)** Three-dimensional atom probe (3DAP) is an established tool for the identification of size, volume fraction and location of specific elements or fine strengthening precipitates in materials. The aim of this project is to study the precipitates in high strength aluminium and aluminium-lithium alloys of aerospace grades. The changes in the sub-microstructure by the effect of thermo-mechanical processing on these materials and role of minor element additions have to be studied. Al alloys will be supplied by VSSC.	

D21.3	**Development of space radiation resistant materials (VSSC)** Exposure of critical and vital components of spacecrafts to external radiation leads to degradation of the properties of the structural and electronic materials, thereby jeopardizing the flightworthiness of the spacecrafts. Hence it is critical for the identification of significant property changes induced as a result of the radiation exposure in the aforementioned materials. The purpose of this project is to develop and understand the radiation effects on the physical, mechanical, thermal and optical properties of materials (metallic and composite).The deliverables would be the technology and process to make radiation resistant materials for use in deep space long duration missions.
D21.4	**Development of ultrafine grained magnesium alloys by friction stir processing (VSSC)** Magnesium alloys are widely used for light weight applications in satellites and launch vehicles for electronic housings. Friction stir processing is an advanced materials processing technique by which grain refinement can be obtained in both cast and wrought alloys leading to improvements in mechanical strength. The objective of the present project is to develop ultrafine grained magnesium alloys through friction stir processing.
D21.5	**Studies on hydrogen permeation and trapping in high strength steels (VSSC)** The deleterious effect of hydrogen on the mechanical behavior of high strength steels is well known. The hydrogen embrittlement resistance is closely related to the microstructural features such as dislocation density, grain boundary, carbides and inclusions. These features are generally classified as diffusive, reversible and irreversible traps. Understanding the influence of these traps on the HE resistance of steel materials is very important towards improving the microstructure with improved HE resistance. On this aspect, hydrogen permeation and Thermal Desorption Spectroscopy (TDS) are widely used for obtaining quantitative information on the hydrogen effect on steels. The purpose of this is to study the HE resistance using the above techniques.
D21.6	**Development of graphene reinforced zinc rich nano composite coating for the corrosion protection of aluminum alloys (VSSC)** In recent years, graphene and graphene oxide reinforced polymer coatings have attracted several researchers for the fabrication of high performance polymeric coatings with enhanced thermal, mechanical and corrosion properties. There is growing interest in using graphene reinforcement with Zn rich coatings towards obtaining efficient cathodic protection as well as improved barrier properties. Hence it is of interest to develop modified Zn rich coating with graphene reinforcement and to study its corrosion properties using DC and AC electrochemical methods to be used for light alloy structures of aerospace industry.

D21.7	**High temperature oxidation behavior of laser coated NiCrAlY bond coating on Nibase alloys (VSSC)** Ni based superalloys are being used in the aerospace industry for high temperature structural applications. In order to use them for high temperature applications, a coating system consists of a bond coat (BC) and a thermal barrier coating (TBC) is fabricated over the alloy through plasma spray coating or other methods. The overall oxidation resistance of the coating depends on the preferential formation of alumina coating between BC and TBC. Recently, BC fabrication using laser aided manufacturing (LSM) has been reported with improved properties. Hence there is interest towards using the above method of coating and to examine the oxidation resistance and mechanical properties of the coating for Ni base alloys in the aerospace industry.
D21.8	**Quantitative analysis of environmental assisted cracking behavior of high strength steels using direct current potential method (VSSC)** High strength steels are being used in the aerospace industry for the fabrication of pressure vessels and their weldments. The susceptibility of steels and their weldments need to be evaluated through crack growth measurements and threshold stress intensity (K1scc) based on fracture mechanics concept. Although qualitative analysis using constant load and slow strain rate techniques are being used for stress corrosion cracking tests, quantitative information by dynamic methods using direct current potential drop (DCPD) is needed towards characterizing the alloy resistance to environment cracking behavior in marine environment.
D21.9	**Development of Environmentally friendly conversion coatings for corrosion protection of aerospace grade aluminum alloys (VSSC)** Anticorrosion pretreatments such as chromate conversion coatings are widely used for the corrosion protection of aluminum alloys in the aerospace industry. However, the toxicity and carcinogenic nature of hexavalent chromium is strictly prohibited globally. Hence there is growing interest towards developing environment friendly alternate coatings and to explore the corrosion resistance for light alloy structures.
D21.10	**Room and elevated temperature fretting wear behaviour of superalloys (VSSC)** Materials subjected to fretting at room temperature and elevated temperatures are subjected to premature failure than regular fatigue or friction. The brief scope of the study is as follows a) Evaluate the amount of material removal as a function of force, temperature and the amplitude. b) Test temperature can be from RT to at maximum of 600°C. Temperatures upto 800°C if possible is also can be considered in this study. c) Evaluate the metallurgical factors that influence the fretting characteristics

	d) Research outcome: research outcome is to develop a model as the function of above variables to predict the fretting wear. e) The materials to study are XH42 and XH53 alloys. VSSC will provide the raw material. f) Heat treatment conditions is standard aging cycle and standard brazing cycle, VSSC will facilitate the heat treatment of coupons. g) Specimen fabrication and surface preparation is in the scope of responding agency.
D21.11	**Evaluation of Mixed mode fracture toughness of high strength aerospace materials (VSSC)** Structures commonly experience mixed mode fracture in real engineering applications. Mode I fracture properties are significantly used in engineering calculations since it is worst case scenario. However, knowledge of mixed mode fracture characteristics of materials will enable designers to decide the actual margins in actual engineering applications. The scope of the study is as follows a) Evaluate Mode I and Mode II, Mode I and Mode III stress intensity factors with different ratios. b) Evaluate Pure Mode I, Mode II using novel specimen and fixture technique. If possible, pure Mode III also can be evaluated. c) Study the influence of mixed mode using classical and FEM models and that of the experimentally evaluated. d) Make scientific/Engineering assessment and correct the FEM by appropriate factors based on experimental data (if applicable) e) The material proposed to study are Maraging steel (M250) and ESR15CDV6 both parent and weld. Material and welded coupons for the study will be provided by VSSC. f) Responding agency is requested to use minimum quantity of material as it is scarce. g) Specimen design, fabrication, fixture design and fabrication, testing, data evaluation, metallurgical analyses are in the scope of responding agency.
D22	**Sub Area** — **Thermal Protection System (VSSC)**
D22.1	**Thermal modelling of Aerogel based Hybrid MLI Thermal Protection System (VSSC)** MLI is used as radiation thermal protection in almost all satellites and spacecrafts for shielding the inner electronics from the extreme temperatures encountered by the spacecraft while orbiting the Earth (-150 to +150°C). Aerogel sheets are low density, flexible and hydrophobic insulation material developed in VSSC capable for use from -200 to +300°C. Aluminum sheets/panels are often used for debris protection in ISS and various spacecraft either by itself or along with Kevlar and Nextel fabric. A Hybrid TPS is being proposed which will not only act as insulation material, but will also act as a

	dampener for retarding and decelerating the micrometeoroid debris particle and protect the spacecraft structure from damage. It is suggested to model the thermal characteristics of the hybrid TPS and obtain the right combination of materials and optimum thickness.	
D23	**Sub Area**	**Electronic Materials(VSSC)**
D23.1	**Spinel or Garnet ferrite thin films for satellite applications (VSSC)** Spinel and Garnet ferrites are inevitable in the present satellites for circulators/isolator applications as bulk components. For millimeter wave requirements, thin films can only meet desired electro-magneto properties. Synthesis and optimizing critical process parameters to cater satellite requirement is an interesting topic of research. Doping with suitable divalent/trivalent cation or anion substitute play pivotal role in tailoring functional properties. Crystallographic understandings and interface engineering on thin films with respect to suitable substrate are also to be studied. Line width, Spin line width and other physical properties specifications have very tight tolerance. The deliverable will be optimization of above said ferrite thin film process, effect of dopant concentration, FMR testing and fundamental material characterization results.	
E	**Area**	**Transducers and Sensors (LPSC)**
E1	**Development of nano-technology based pressure & strain sensors (LPSC)** Various nano material and nano structures can be used for strain/pressure sensing. Selection of suitable substrate, nano material/structure, synthesis, characterization, packaging etc. are envisaged. Sensors based on nano technology is to be developed for measuring pressure of propellant and gases in the range 1 to 1000 bar under harsh environment, cryo temperature etc.	
E2	**Development of thin film based cryogenic temperature & level sensors/probes on flexible substrate for propellant gauging application (LPSC)** Presently used level sensors in ISRO's cryogenic tanks are basically discrete in nature or the effective measurement range is limited to maximum of 700mm. This prevents continuous measurement of cryogenic propellant level & there by restricting the accuracy in estimation of propellant gauging or utilization. A thin film based sensor deposited on suitable flexible insulating substrate can be extended from top to bottom of the tank to enable continuous measurement of temperature & level. The proposal envisages Selection of cryo compatible light weight, flexible and insulating substrate Identification of cryo compatible target material for thin films that can detect change in temperature with respect to liquid and vapor phase of the fluid Arriving at the transduction principle for temperature & level measurement Development & demonstration of the probe along with industrial grade signal conditioning electronics, data acquisition & processing Expertise & infrastructure in the thin film deposition & characterization is mandatory.	

E3	**Design and development of Piezo electric material and sensor for high temperature dynamic pressure measurement (LPSC)** Presently, imported Piezoelectric based dynamic pressure sensor is used for the measurement of fast varying pressures of non-aggressive liquids & gaseous media in terms of electrical signal for liquid propulsion engine performance analysis. The aim of the project is to develop dynamic pressure sensor based on Piezo electric material for sensing the fast varying sensing media pressure. This final packaged sensor need to have higher sensitivity & faster response time & temperature stability in the range of 20°C to 200°C. The proposal envisages 1. Selection/fabrication of high sensitivity Piezo electric material for pressure sensing for dynamic range of 5 KHz or better. 2. Deposition/bonding of the developed piezoelectric material to mechanical sensing element/diaphragm & providing lead wires from the sensor for electrical contact. 3. Calibration & demonstration of functionality of developed transducer in high temperature environment.
E4	**Indigenous Development of Thin film based fast response temperature sensor (LPSC)** Platinum-based RTD is used for precise measurement of cryogenic propellant's temperature in cryo stages of launch vehicle. The aim of the project is to develop platinum-based thin film temperature sensor with excellent sensitivity & faster response time and long-term stability in the range of -253°C to 50°C. The proposal envisages 1. Fabrication of 500 Ohms & 1000 Ohms Platinum Thin films (RTD) on suitable substrate (or) fabrication with excellent insulation resistance (>10GΩ) between sensing film and substrate. 2. Fabrication of sensing material with fast response time (Less than 1Sec) 3. Providing electrical contact & lead wire extension from the sensor 4. Characterization & demonstration of the sensor sensitivity, response time & stability in cryogenic temperature.
E5	**Fabry-Perot type Fiber optic absolute pressure transducer for 0-1 bar range (End use for measuring in 15 mbar) (LPSC)** Presently the transducers being realized by LPSC for supply to Launch vehicle and satellite projects are absolute pressure transducers. The BFSG (Bonded foil technology) type transducers like 21NA (Ranges: 3,5,7,10,15,20, 30 in low pressure. In high presssure it is 50, 70, 100, 150, 200, 300, 330 bar) and IDLV (Range: 50 to 400 bar (any pressure transducer can be designed since it is inhouse design). For semi cryo 600, 700 and 800 bar are qualified and under production) are supplied to Launch vehicle projects. The NL+H of 21NA is 0.75%FSO - 0.85% FSO. The NL+H of IDLV is <0.5% FSO (achieved is 0.3 % FSO).

	MEMS 1 bar pressure transducer is supplied to FADS (Flush air data system) in RLV and Aerodynamic pressure measurement in GSLV Mk3. The NL+H is< 0.3% FSO. IDPT (BFSG technology) is supplied to satellite projects in two ranges 30 bar and 300 bar. The over total error banc is < 1% FSO (includes NL+H, thermal errors, vibration errors and thermovac errors. Metallic diaphragm based sensors cannot be designed for low pressure due to tin canning effect of the diaphragm and the strain will be in the non linear regimen of the stress strain curve. **Project relevance:** The low pressure range of 0-1 bar is for High resolution pressure sensor (better than 0.001 mbar) in the low-pressure range (4-14mbar) with accuracy of 0.03mbar. This will be of use in MARS rover. **Problem definition:** Design of Fabreyperot cavity with suitable material, design of fiber coupling, Packaging the sensor for pressure interfacing and signal acquisition. Design of signal conditioner and calibration. **Project purview:** The preview of the project is to design the pressure transducer and do strain analysis. Fabrication of prototype, packaging for ground use and proof of concept.
E6	**Development of strain transfer model for strain sensing in FBG Principle of Pressure sensing with FBG based strain sensor (LPSC)** The FBG strain sensors, interrogation techniques and their application fields are discussed. The investigation begins with the analysis of the measurand (i.e., strain). Strain is a normalized measure of the deformation, which represents the displacement between particles in the matter with respect to a reference length. Pressure in FBG based pressure sensors is transduced into strain by application to a mechanical sensing element. The strain induced in the transducer due to pressure is measured as a measure of pressure applied. The FBG pressure transducer consists of ametallic sensing element to which the FBG is bonded. When pressure is applied to the sensing element, the strain induced in the sensing element is sensed by the FBG as a wavelength shift. this is linearly proportional to tha applied pressure. **Project relavance:** This model is essential for all FBG based strain or pressure measurement. **Problem definition** The FBG written fiber is bonded to the host by an adhesive. The strain transfer from the host to the FBG depends on the Host material, the adhesive, the cladding and their properties.

	The various parameters involved in the strain transfer are the properties of each layer like Young modulus, poissons ratio, shear strain involved, the cladding properties, the properties of the adhesive. The photo elastic effect must be considered for model optimisation. This model should enable prediction of strain transferred depending on the selection of the fiber and adhesive and give a guideline for glue line. Given the host material, this model should enable selection of fiber, cladding material dimensions and properties along with the adhesive properties. The adhesives must be available commercially. Model should be validated experimentally. **Project Purview:** An analytical model should be built and validated with the commercially available fiber and adhesives. This model should also be practically validated to enable optimisation.
E7	**Fiber optic based humidity sensors (LPSC)** FBG is highly sensitive to humidity. Humidity absorbed on the coating of the FBG causes strain in the FBG. Strain in FBG will cause wavelength shift. This wavelength shift will be proportional to the humidity levels. **Project relevance:** Humidity level for robotic and manned outer space, lunar and Mars mission. **Problem definition:** Humidity sensing will require choice of appropriate FBG, coating of fiber and additional coating highly sensitive to humidity. There should be mechanism to desorb the humidity too. The humidity measurement at various ambient pressures also needs to be understood. Humidity measurement at various ambient temperatures should be understood. Cross sensitivity to temperature needs to be addressed **Project Purview:** 1. Design of Humidity sensor for ambient pressure and ambient temperature. 2. Selection of appropriate FBG and its Coating. 3. Packaging to avoid cross sensitivity due to other gases. 4. Incorporating mechanism for cyclic absorption and desorption of humidity.
E8	**Development of a quantity sensing system and cryo compatible electrical heater for a cryogenic super critical storage vessel (Hydrogen & Oxygen) in space environment (LPSC)** A super critical storage system with a double walled tank for hydrogen and oxygen is to be developed. The container will spherical in shape with approximately 1 m inside diameter. The storage pressure will be higher than 1.3 MPa for LH2 & 5.1 MPa for LOX. Pressure inside the container shall be maintained above critical pressure using electrical heaters. A cryo compatible electrical heater and an accurate quantity sensing system

	for cryogenic fluids have to be developed. The sensor system should be able to give dependable results in the following scenario: At ground in the loading condition with the liquid in saturated condition. During operation in space environment with the fluid in super critical phase in varying temperature conditions. The tank pressure will be above critical values.
F	**Area** — **Mechanical Design & Analysis (LPSC)**
F1	**Experimental evaluation of damping in fluid conveying pipelines immersed in fluid environment (both theoretical empirical relation & experiments) (LPSC)** Most of the pipelines carrying fluids are immersed in fluid environment. To design these properties, the damping is very important parameter. In order to evaluate the effect of added mass on frequency & viscosity on damping, it is envisaged to design a vibration test setup to carry out experiments. By doing experiments, it is proposed to evaluate dynamic behavior of pipelines immersed in fluid.
F2	**Crack growth studies in propellant tanks through experiments & theoretical modeling (LPSC)** This study plans to address the fracture behavior of Aluminum and titanium alloys used in pressure vessel materials in rocket engines. The behavior of this sections containing part through cracks under tensile stresses is to be explored at ambient and Cryo temperatures through tests and simulations.
F3	**Finite element simulation of non-linear, high strain forming processes of metals like deep drawing, flaring etc. (LPSC)** This study is for evaluating the state of stress and strain in sheet metal work undergoing high plastic strains as in deep drawing and flaring. FEA based simulations and tests are required to assess the structural integrity of the work piece so as to optimize the process parameters.
F4	**Life cycle prediction of thrust chamber for reusable, regenerative cooled liquid engines (LPSC)** This project is to study the cyclic life of double walled regenerative cooled thrust chambers of liquid rocket engines. Theoretical and experimental investigations are required to study the thermo mechanical behavior of different thrust chamber materials in the parent metal and welded forms for this at different temperatures and strain rates. Damage mechanics has to be incorporated in the studies.
F5	**Experimental evaluation and constitutive modeling to simulate structural behavior and failure criteria for dissimilar weld joints (LPSC)** This study plans to address the structural behavior and failure of dissimilar material weld joints commonly encountered in liquid rocket engine combustion chambers. Material combinations such as SS- Copper, Copper-Nickel, SS- Nickel have to be addressed. Different thicknesses have to be accounted for. FEA based simulations have to be done to predict the failure of such joints.

F6	**Evaluation of damage criteria for AA2219 welds under bi-axial stress field from experimental and simulation (LPSC)** This project plans to address the damage modelling and failure prediction of AA12219GTA welds and parent metal under biaxial state of stress. Both tests and simulations based on FEA are required for this. Different biaxial stress rates have to be addressed. Tests have to be conducted for different specimen thickness commonly encountered in liquid propellant tanks.	
F7	**Estimation of torque co-efficient and load distribution in threaded joints (LPSC)** This project is to study the mechanical behavior of bolted joints at Cryo, ambient and elevated temperatures under the combined action of bolt pre-torque, internal pressure and axial loads. Experimental and numerical studies have to be carried out considering different nut factors and bolts/flange materials.	
F8	**Development of a mathematical model for estimation of crimping loads for different material and design configurations (LPSC)** It is planned to develop material models for metals and non-mechanical materials used for crimping. It will be based on mechanical tests done on the materials at the applicable temperatures (cryo, room, elevated etc.). These models have to be implemented in FEA codes like ANSYS.	
G	**Area**	**Control, Guidance & Simulation (VSSC)**
G1	**Sub Area**	**Control System (VSSC)**
G 1.1	**Development of Control algorithms for autonomous mobile robotic manipulator** The research proposal is for developing advanced control algorithms for an autonomous mobile robotic manipulator which consists of a six degree of freedom (6 DOF) robotic manipulator mounted over a four wheel mobile robot with the wheels having independent drive and steering control. Conventional control, and intelligent control shall be hybridized to develop a hierarchical control and vision-based control for robots. The control algorithm provides dynamic coordination of manipulator arm joints and mobile robot wheel drives to execute precision tasks in unstructured environments using multiple sensor feedback. With the development of multilayered control architecture, the robot should be able to automatically compute its motions from the high level description of tasks. The proposed R&D also aims to develop algorithms for Simultaneous Localization and Mapping for the navigation and locomotion of mobile robot.	
G2	**Sub Area**	**Control & Guidance (VSSC)**
G 2.1	**Rendezvous and docking (VSSC)** To achieve docking during the final phase of the mission, the relative position and velocity of the target spacecraft and chaser spacecraft has to be brought to zero. To ensure proper alignment of the docking port, the relative angular orientation needs to	

	be precisely aligned. Moreover, relative angular rate of the target and chaser are to be very close to zero for successful docking. Simultaneous control of the translational and rotational dynamics is required to achieve the docking conditions.	
G3	**Sub Area**	**Simulation (VSSC)**
G 3.1	**Multi-body Dynamics Simulator (VSSC)** Launch vehicle simulations require solving multi-body dynamics for addressing scenarios such as space transportation missions, crew module ejection, stage separation, booster/strap-on separation, satellite separation etc. All individual bodies having its own inertial systems and are bound to possess independent mass-inertia characteristics, propulsion systems, aerodynamic properties, guidance and control algorithms, control power plants etc. Simultaneous solving of translational and rotational dynamics for each body (during ascent and descent phase) is required with real-time plotting of trajectory parameters and other critical states. Software model can follow modular or component architecture where by system modules can be plugged in and used as required.	
H	**Area**	**Composites/Launch Vehicle Structures (VSSC)**
H1	**Sub Area**	**Modelling of CC Composites (VSSC)**
H1.1	**Inelastic Finite element model of multidirectional carbon carbon composites to predict the metarial charactiristics and behavior (VSSC)** Multidirectional C-C composites (3D, 4D) are composite materials wherein the reinforcing fibres act as reinforcement at various directions. 4D C-C composites has found successful applications in solid rocket nozzles especially as ITE's. The material behaviour of nD C-C composites are highly anisotropic and shows nonlinear elastic behaviour. Most of the work carried to assess the behaviour of multidirectional C-C composites is evaluated through destructive testing, hence limited data is generated for the mechanical properties. In this, limited work has been carried to theoretically predict the mechanical behaviour of the material and corresponding material properties associated with this class of material. Since at VSSC, nD C-C composites are envisaged to have application as SRM throat inserts and also as TPS material for certain applications, it is planned to initiate the micromechanical model studies to theoretically predict the material behaviour vis-a-vis the mechanical properties. Scope of work includes development of an elastoplastic finite element model, including homogenised mono-axial stiffness that can predict the material properties as has been referred in literature and, available tested material properties.	
H2	**Sub Area**	**Process Optimization of Isothermal CVI process (VSSC)**
H2.1	**Process optimization of isothermal CVI process (VSSC)** One of the most promising and common methods of fabrication of thinner Carbon-Carbon & Carbon-Silicon Carbide Composites is through vapor phase densification of porous	

	structure of carbon fibers acting as reinforcement. During CVI process, the hydrocarbon gases or vapors of silanes decompose to produce the desired carbon /Silicon carbide matrix within the pores of the preform and thereby increase the density. The density aimed after the final densification is based on the targeted mechanical and thermal properties required for the specific use of application of the product. Practically, the major hindrance of realisation of C-C/ C-SiC products through CVI process is the long processing duration required to achieve the desired density. Further more the process must be intermediately interrupted to permit surface machining or heat treatment at high temperature in order to open the pores for further densification. Scope of work includes development of a comprehensive numerical modelling to simulate and optimise the processing parameters to achieve the required density and also to reduce the long process duration.	
H3	**Sub Area**	**Composite Materials / Process Development (VSSC)**
H3.1	**Development of C-SiC Composite through CVI using Mono-Methyl-Silane (VSSC)** Carbon-Silicon Carbide is considered as an ideal material for future Thermo-Structural applications, considering the various advantages offered by the material. SiC matrix is derived presently using Methyl-Trichlo-Silane, having drawbacks in due to high corrosive nature of the chemical and by-products of chlorides which are formed during the process. To meet the future requirements of C-SiC composites and also to provide SiC coating over Carbon-Carbon Composite products for various space applications, it is envisaged to use Mono Methyl Silane (MMS) as precursor for Chemical Vapour Infiltration/Deposition method. MMS is considered to be advantageous compared to other MTCS and Silane precursors, considering the chemical nature (Low Molecular Weight), processing under low temperature (~800 ºC) and being less hazardous, non corrosive and non toxic. The scope of work in this program includes the following: • Development of process Technology to provide SiC coating on C-C product through CVD using MMS as a process precursor. • Development of process technology to densify Carbon preform with SiC matrix through CVD using MMS as a process precursor. • Evolve details of storage, handling and usage of MMS for CVI and CVD processes.	
H3.2	**Noble Metal Coating over Carbon-Carbon Composite (VSSC)** Carbon-Carbon Composite materials are coated with SiC to protect from oxidation when the applications temperature is higher than 400ºC. However due to numerous applications of the material above 1700ºC, development program to coat Carbon-Carbon Composite with Noble Metals is initiated. Also during thermo-structural applications which demands leak tightness of C-C products like C-C combustion chamber, coating of Iridium on C-C composite is considered to be an ideal solution. Iridium (Ir) is considered as promising candidate for oxidation resistant materials at elevated temperature due to its high melting point (2430ºC), good chemical stability, low oxygen permeability, impermeability to gases,	

	good chemical compatibility and low carbon solubility below the eutectic temperature of 2100–2300ºC. Considering the various merits offered by electrodeposition (ED) method for coating, it is proposed to develop the coating of Iridium (Ir) on Carbon-Carbon (C-C) Composite through ED. Also to overcome the problem of CTE mismatch between C-C and Ir, interlayer coating of Rhenium shall be provided through the same methodology. Scope of Work: • Development of Coating Methdology of Iridium on Carbon-Carbon Composite Samples through electrodeposition • Development of Interlayer Coating of Rhenium through electrodeposition • Microstructural & Compositional Characterisation of Coating • Demonstration of the process on various geometries (Conical & rectangular)
H3.3	**Development of C-C derived CMC through Reactive Melt Infiltration (VSSC)** CMC's derived from C-C composites are considered as ideal materials for thermo-structural products and dimensional stable structures for space applications. Incorporation of ultra-refractory materials into C/C composites is an effective route to enhance structural capability, ablation resistance and to maintain dimensional stability. For realisation of UHTC's using C-C as base material, reactive melt infiltration (RMI) is considered one of the potential processes. The utilization of polymeric/hydrocarbon precursors densifies porous carbon preform and leads to formation of specific characteristic in micro-structure of porous carbon/carbon composites after pyrolysis/infiltration, showing discrete translaminar capillary channels. In these channels, capillary force driven fluid transport allows good penetration of the preform by liquid silicon/zirconia. This enables high infiltration velocities and mounting heights densifying the porous C-C to desired density levels. Exothermic reactions between a porous carbon matrix with an infiltrating melt provide an economic solution for grain-boundary diffusion to synthesize ceramic matrix composites (CMC's). The fast conversion kinetics that are generally observed enables to manufacture reaction-bonded silicon /zirconia carbides through capillary infiltration of molten silicon or zirconia. However to ensure the optimal structural behaviour of the final CMC, the content of the refractory matrix in the CMC's shall be properly controlled. The scope of work towards Development of C-C derived CMC through Reactive Melt Infiltration (RMI) involves the following: 1. Demonstration of densification of porous C-C having density with SiC/ZrC and SiC-ZrC matrix. 2. Optimisation of process conditions based with respect to different carbon matrix of C-C composite. 3. Investigation of Morphology & microstructural features of matrices in the Composite. 4. Thermostructural behaviour of CMC's realised through RMI.

H3.4	**Out of autoclave processing of prepreg based fires reinforced composites (VSSC)** Conventionally composite products for satellite structure applications are realised by Autoclave curing Processes. The prepreg layup is completed on a tool/mould under room temperature conditions. The curing is completed under higher temperatures of the order of 175ºC.The inherent disadvantage of this process is the likely curing stresses induced in the composite part. Scope of work includes development of prepregs which can cure under UV light OR using conventional prepregs but curing outside autoclaves using more energy efficient methods.	
H4	**Sub Area**	**Composite Process Modeling (VSSC)**
H4.1	**Hydroclave cure modelling of Phenolic composites** Carbon-Phenolic and Silica-Phenolic composites are widely used for ablative thermal protection of rocket nozzles and re-entry bodies. Condensation cured Phenol-Formaldehyde resin used in these composites because of its higher char yield. The prepreg is cut into tapes and wound on mandrels to get the required geometry. Typically, the thickness of these ablative composites are considerably higher which requires curing in Hydroclave at pressures in the range 30 to 70 bar to get defect-free products. Also, long curing cycles are employed to keep thermal gradients lower. A detailed cure model is essential to optimize the curing cycle. The scope of the proposed research work is to develop a thermal-chemical-pressure model for the curing of Phenolic compositesinHydroclave to get defect-free products. The model should provide optimum temperature and pressure cycles for the given cure setup, with a user friendly interface. Evaluation of the required material properties for the resin/reinforcement being used by VSSC is also part of the scope of work.	
H4.2	**Modelling of Resin Transfer Molding of Benzoxazine resin in Carbon preform (VSSC)** Benzoxazine resin is a potential candidate for ablative application, which is also amenable for resin transfer molding (RTM). RTM process has established itself as a cost effective method for producing good quality composite parts. Prediction of flow patterns of the resin in the preform is essential to identify the locations for placement of injection and vent ports. The scope of this research work is to develop mathematical model for RTM of Benzoxazine resin in Carbon preform. The preform will be either stack of bidirectional woven fabric, needled felt of a multi-directional preform. The evaluation of required material properties is part of the scope of work. The developed model should provide inputs for the placement of injection and vent ports for complete filling of the cavity and pressures required for getting defect-free products.	

H5 | Sub Area | Structural Health Monitoring (VSSC)

H5.1 Structural Health Monitoring of Composite Structures using Optical fibres with Bragg Grating sensors (VSSC)

Optical fibres with Bragg Grating sensors are the leading candidate technology for Structural Health Monitoring (SHM) since they have minimal mass penalty for extremely large numbers of sensors. There are many advantages like compatibility with the composites, low Electro Magnetic Interference (EMI), multiple sensing capabilities with a single fibre etc. This sensor technology will be useful in present as well as our future launch vehicle applications.

Scope:

- Supply of optical fibres with Fibre Bragg Grating (FBG) sensors.
- Work out a Design and plan for SHM of a typical Aerospace Composite Structure
- Demonstrate the plan on a typical Aerospace Composite Structure.

H6 | Sub Area | Piezoelectric Actuators (VSSC)

H6.2 Piezoelectric actuators for position/shape control applications (VSSC)

Piezoelectric materials produce voltage when stress is applied. This effect is also reversible in manner, i.e. a voltage across the sample will produce stress within the sample. Because of this reversible property, piezoelectric materials can act both as sensor as well as actuator.Piezoelectric actuation can be used in precision (small strain, fast response time) applications. One application envisaged is the precision position control of mirrors used in optical structures of satellites.

Scope of work is development and demonstration of closed loop control algorithm for precise position control of an object mounted over a tubular composite tripod structure.

H7 | Sub Area | Modelling and Study of Large Antenna (VSSC)

H7.1 Large Deployable/ Inflatable/Unfurlable Structures in space -Design & Analysis / Development (VSSC)

Large antenna reflectors and other deployable structures are being used in increasing numbers for satellite applications. The sizes range from dia.5.0m and upwards to 20.0m. During Launch phase these reflectors will be stowed so that launch envelope interfaces requirements are not violated. In space these structures get deployed by suitable mechanism of energy release like inflatables, Unfurlables,Unfoldables etc.

Scope of work includes development of a Physical model to capture and demonstrate Geometry of these structures, and a mathematical model to capture and model the kinematics of the members /linkages involved, Finite element modeling of the structure.

	to capture its dynamic, static and thermal distortion behaviour under space conditions, studies to control the shape and behaviour of these membrane structures under various orbital conditions	
H8	**Sub Area**	**Assessment of Composite Structures (VSSC)**
H8.1	**Nano meter Level Measurement and Assessment of Space Composite Structures (VSSC)** An increasing demand for high-quality, low cost Earth imagery has led to the requirement for improved structural stability of the satellite instruments providing the imagery. This translates into camera structures capable of maintaining very high levels of dimensional stability order of few micron (<10μ) for a length of 1m over their lifetime. CFRP is one of the materials for dimensionally stable space structures. The “theoretical” zero CTE is only approximated as well as the manufacturing precision allows. So in ultra stable structure where micron level dimensional stability is required, there is a need for quantitative assessment of the magnitude of change in dimensions. Scope of work includes nano meter level measurement setup with all associated analytical software and hardware fully integrated, meant for specimen level as well as assembly level evaluation of the payload and camera structure.	
H8.2	**Micro meter Measurement Facility for Evaluation of Thermal Expansion Coefficient and Moisture Expansion Coefficient for Satellite Structures (VSSC)** Optical support structures require very high stability under the constraints of thermal and moisture variations. Various subsystems of the optical structures are mounted at required orientations and relative positions with respect to each other. The mounting planes must retain their geometrical conditions under the constraints of varying temperature in space and moisture removal due to extreme vacuum. The support structures are designed to meet coefficient of thermal expansion requirement (CTE) of less than 0.1x10^-6 m/m/ºC and hence the measurement system must be capable of measuring less than 0.5 μm for a temperature variation of 10ºC and should be able to measure less than 0.5 μm deformation under full moisture desorption. The structure volume is limited to 0.3 x 0.3 x 0.3 m to 1.3 m x 1.3 m x 3 m. Scope of work is to establish a precision measurement system capable of measuring CTE and also should be able to measure total moisture deformation under full moisture absorption/desorption of composite structures realised out of carbon fibre/polymer matrix resin system. Portable measurement system is required so that the measurement points can be taken anywhere in the structure and deformation in all three directions can be measured between any two tangible locations. The system should be capable of operating under vacuum and temperature variation of 10ºC to 60ºC.	
H9	**Sub Area**	**Shape Memory Composites (VSSC)**
H9.1	**Development of Shape Memory composite Reflector Antenna (VSSC)** Shape Memory Composites (SMC) are a sub set of the broad class of Smart Materials namely shape memory materials. Shape memory effect in materials is essentially the	

	capacity to recover a "memorized" strain state upon application of external stimuli like heat, light, moisture, magnetic, electricfield etc. Shape Memory Polymers (SMP) are a group of polymeric materials which are capable of recovering the memorized shape when triggered by an external stimulus. Unreinforced SMPs have much lower stiffness and recovery potential, however in combination with a reinforcement (fibers, fabrics, and mats made of Carbon, Glass and Kevlar) the mechanical properties of SMPs remarkably increase. Composites of SMPs with high performance reinforcing fibers find use in self-deployable structures for spacecraft applications. SMPCs used for such applications are also called Elastic Memory composites. These composites can be compacted on earth, stored in a compact shape, and then self-deploy in space. Applications include support structures for telecommunication subsystems. Scope of work includes development and demonstration of SMPComposite for a paraboloidreflector of 1m diameter with a stowage volume of ~25%.	
H10	**Sub Area**	**Composites 3D Printing (VSSC)**
H10.1	**Development of Automation Head for 3D printing of Continuous Fibre Composites (VSSC)** Fibers used as reinforcement in high strength/high-performance Composites application are primarily long fibres. Their one-dimensional nature make them amenable for automation methods such as filament winding and fiber placement. However, the use of thermoset resin warrant a mandrel or support structure during processing. With recent developments in 3D printing using thermoplastic resins, time is ripe to jive the high-strength long fibers with thermoplastic or similar resin system, to 3-D print Composite products. Attempts of infusing short fiber as chopped strands in the existing 3D print filaments, marginally improves the resin capability but nowhere near the continuous fiber based composite products. R& D efforts are already on by many groups (ex. Owens-Corning with Kuka) towards the long fiber based print process. Scope of work is to realize a winding head that can be mounted to a robotic system or similar mechanism, that can dispense long fibers (carbon, glass or aramid), impregnated with thermoplastic resin, for free-form (without mandrel) material deposition. Alternate resin system shall also be explored, but with capability to be in-situ cured instantaneously to facilitate uninterrupted 3D printing.	
H11	**Sub Area**	**Design and development of thin shell flexible substrate (VSSC)**
H11.1	**Design, Analytical Modelling and Development of Foldable Solar panel Substrate (VSSC)** Most of the satellites are powered by photovoltaic solar cells which are mounted on array of solar panel substrates. Presently these substrates are rigid sandwich structures which are stowed during launch and deployed in orbit by suitable mechanism. However, to generate high power, the space constraint in launcher demands the mounting of flexible thin shell solar blanket of large surface area with minimum stowed volume in spacecraft.	

	CFRP composite flexible/foldable thin solar panel substrates are required to be developed for the same which are to be folded during launch and deployed using tape spring energy or Piezoelectric actuators. Scope of work is to design, model, analyse and demonstrate the folding and deployment of thin flexible shell solar panel substrate such that the substrate along with flexible solar cells is able to withstand launch load of vibration during stowed condition and capable of deploying without failure and maintain the stiffness in orbit after deployment.	
H12	**Sub Area**	**Experimental Mechanics (VSSC)**
H12.1	**Identifiation of type of failure from global Acoustic Emission (AE) data using ANN/ clustering approach (VSSC)** AE monitoring is being used for the integrity evaluation of various flight hardware during their proof pressure test for example, Titanium alloy Gas Bottles, Aluminium alloy Prop Tanks, Maraging steel and 15 CDV6 chambers etc. Implementation of an automated AE analysis on the stored data with ANN/Neural Network for the integrity evaluation of the hardware helps in reducing the total dependence on human expertise and speed up analysis. The AE corresponding to different failure types have to be segregated using ANN. This is to be compared with AE from the test results of similar hardware tested with PAC AE DAQ system which can be made use of in training the algorithm.	
H12.2	**Background noise elimination from global acoustic emission data to segregate genuine Acoustic Emission (AE) signature corresponding to defects using Spectral content analysis or any other advanced technique (VSSC)** In online AE monitoring, differentiating the genuine AE signals from pneumatic pressurisation noises is a big problem for the real time AE evaluation of flight propellant tanks during pressure tests. This is especially troublesome in case of pneumatic pressurisation. Due to the noise, the initiation of any defects like crack, yield etc. is difficult to be identified during the pressurisation / loading phases. Since some of the noise signals are similar to genuine AE signals, identifying these noise signals in real time is a tedious job. Implementing a criterion for online filtering of these noises using Spectral content analysis or any other advanced technique making use of previous test data is the need of the hour. This can help in monitoring the health of the hardware during pressurization time and help in averting failures.	
H12.3	**Development of online Acoustic Emission (AE) instrumentation for proof pressure test of titanium alloy gas bottles at cryo and elevated temperature (VSSC)** Presently AE monitoring is being used for the integrity evaluation of Ti alloy Gas Bottles during their Room Temp proof pressure test. Implementation of AE instrumentation suitable for CRYO Temp/ elevated Temperature of Ti alloy Gas Bottles is expected to help the integrity evaluation of the Ti-alloy gas bottles using AE for flight use.	

H12.4	**Through thickness measurement of non-uniform residual stresses in metallic components with suffiient resolution for aerospace applications (VSSC)** The current technique of incremental hole drilling technique measures the residual stress to a depth of 2mm only. The development envisaged is the implementation of an accurate method for measuring residual stress through thickness for metallic materials for thickness more than 5 mm to 10 mm with a resolution better than 10 MPa. Use of a combination of different techniques also can be pursued.	
H12.5	**Development of an algorithm and codes for measurement of non-uniform residual stresses in composite components using the method of incremental hole drilling (VSSC)** The current technique of incremental hole drilling technique measures the residual stress to a depth of 2mm only in metallic materials. With analysis methods like integral method the results are available for a depth of less than 1 mm only. The development envisaged is the implementation of an accurate algorithm including codes for measuring residual stress in composite materials for thickness up to 2 mm with a resolution better than 20 MPa.	
H12.6	**Theoretical studies on the prediction of failure incorporating measured residual stress data to service loads in aerospace components (VSSC)** Residual stresses on parent material /weld in components can be measured through various techniques like hole drilling technique. Theoretical study on the effect of such residual stresses on the structural behaviour under service loads to predict the failure.	
H12.7	**Implementation of post processing of FBG sensor data using ANN / suitable algorithms to detect failure signature (VSSC)** Strain / displ Strain / displacement / acceleration data from a network of FBG sensors mounted on a structure need to be analysed to ascertain its health. An analysis methodology has to be developed through structural models with and without defects along with algorithms to predict the life of structure through ANN like approaches.	
H12.8	**Development of optimized design strategies to make use of the strength parameters determined through biaxial testing of aerospace materials (VSSC)** Biaxial cruciform testing of samples in different biaxial ratios is expected to generate realistic strength parameters for use in optimized design of structures. A study on making use of these parameters to generate broad design strategies to evolve optimized launch vehicle structures like interstages, propellant tanks, gas bottles.	
H13	**Sub Area**	**Structural Analysis (VSSC)**
H13.1	**Active Noise Control for Composite Payload Fairings (VSSC)** Acoustic loads are one of the important environments for launch vehicles. The acoustic load transmission into the vehicle, particularly inside the heat shield needs to be attenuated for the proper functioning of satellite. The magnitude of acoustic loads transmitted to the	

	payload is a function of external environment as well as design of payload fairing and its sound absorbing treatments. At present, passive acoustic blanket is used to reduce the internal acoustic field. The use of composite payload fairing has the advantage of reducing mass, but it has detrimental effect on acoustic levels inside the payload fairing especially at low frequencies. Passive approaches for acoustic attenuation are limited at low frequency because of sound absorption is limited in low frequencies. Active control offers an attractive approach for low frequency acoustic noise attenuation inside payload fairing. The proposed study is to develop structural actuators such as piezoelectric patches for noise control inside composite payload fairing.	
H14	**Sub Area**	**Structural Modelling / Design (VSSC)**
H14.1	**Health monitoring of structures using vibration data (VSSC)** Monitoring the health of a structure subjected to severe dynamic load condition is essential particularly for assessing the reusability of the structure. Health monitoring is a process aimed at providing accurate information concerning the structural condition and performance. It consists of continuous or periodic recording of representative parameters like vibration measurements over short or long duration. The measured responses can be used for assessing the damage of the structure, if any. Damage can be defined as changes introduced in the system that adversely affects its current or future performance. The damage will alter the stiffness, mass or energy dissipation properties of a system, which in turn alter the measured dynamic response of the system. From these vibration measurements, the health of the system can be assessed. Damage detection and health monitoring scheme have to be developed for aero- space structures using vibration data. The scheme includes data acquisition, feature extraction and information condensation and statistical discrimination of features for health monitoring of structures.	
H14.2	**Development of analytical techniques for the design of impact resistant structures (VSSC)** In the future missions of ISRO like reusable launch vehicles, human space flight, etc., the structural components will be subjected to impact loads during orbital and landing operations. These structures should be designed with highest probability of human, package and critical component survival. Design and analysis methodologies including structural, material and environment modelling needs to be established for effective design of impact resistant structures. Analytical methodologies to assess response of human body and critical packages to impact load needs to be developed.	
H14.3	**Development of advanced element types (VSSC)** VSSC/ISRO is developing indiegeneous finite element software. The software has to be further enhanced in terms of various fiite element types. This project is proposed for the formulation and implementation of cable element, damper element, elements for	

	modelling joints, pipe element and elements for delamination studies. The source code can be in Matlab or C++ programming language.	
H14.4	**Development of adaptive finite element method (VSSC)** VSSC/ISRO is developing indigenous finite element software. The software has to be further enhanced with adaptive finite element method. This project is proposed for the formulation and implementation of adaptive mesh modification schemes and error estimation methods. The source code can be in Matlab or C++ programming language.	
H14.5	**Prediction of structural response due to Pyro-shock (VSSC)** Establishment of numerical approach/methodology for predicting pyro shock induced response on the launch vehicle and package locations. The approach shall be capable of simulating the elastic wave propagation phenomena in 1D, 2D and 3D environments accounting for the attenuation due to material and structural discontinuities, joints, lumped masses, shock absorbers, etc. The method shall be capable of modelling isotropic, honeycomb and composite materials. Different numerical approaches are to be considered to predict the near, mid and far field shock environment to cover the entire frequency range considered for package qualification. This is required to predict the response at critical locations on the launch vehicle and packages due to various separation induced shocks.	
H14.6	**Development of fast and efficient iterative linear/eigen solvers for large order sparse systems on parallel computing platforms (VSSC)** The solver should be compatible for Finite element system matrices for computing deformations and extracting eigen values efficiently. The computing platform should be a distributed parallel system suitable for HPC cluster. The program should be developed in C++ and use threading and multiprocessing for job distribution.	
H15	**Sub Area**	**Structural Testing (VSSC)**
H15.1	**Development of a noise-canceling headphone using active noise control (VSSC)** Noise cancelling headphones reduce unwanted ambient sound or acoustic noise using Active Noise Control (ANC). This involves using a microphone placed near the ear, a signal processing circuitry which generates an ‘antinoise’ so that the noise within the enclosed volume is cancelled. This is useful for an operator working in noisy environment such as vibration test facility, machine floor etc. The cancellation may be achieved using filtered X-LMS algorithm using some DSP processor. The minimum requirement of sampling is 12KHz with cut-off frequency of 5KHz. The required reduction is 40dB in the band of 100Hz to 2000Hz. The system should operate in battery and the electronics should be miniaturized and kept inside the headphone. This can be extended to reduce acoustic noise inside payload fairing.	

H15.2	**Control algorithm for multi axial vibration testing (VSSC)** Vibration testing is done to ensure that the flight structures and system will work satisfactorily in its service environment. In conventional vibration testing the vibration in each axis is separately simulated using single axis shakers using vibration controllers. But to simulate the actual vibration condition in flight, techniques to be developed to excite the structure in all the three axes simultaneously using three shakers in mutually perpendicular axes. For this a special vibration controller to control all the three shakers is required. The proposed work is to develop the control algorithms for sine and random multi shaker vibration testing. All the required algorithms have to be developed, implemented with suitable DSPs (Digital Signal Processor) and tested.	
H16	**Sub Area**	**Structural Design & Analysis (VSSC)**
H16.1	**Development of mathematical model to study the effect of residual stresses on fatigue crack growth and life estimation (VSSC)** Residual stresses are generated at weld joints during welding and local weld repairs. They significantly influence the fatigue and fracture behavior of the material. A mathematical model becomes important to study the effect of residual stresses on fatigue crack growth and life estimation. An analysis methodology to be developed for simulation of crack propagation in the presence of residual stresses. Specimen level tests shall be carried out to validate the analytical model. Viewports are very essential for viewing the surroundings in space or underwater exploration modules. Wide range of materials are commercially used for viewport construction such as Aluminosilicate, fused silica etc. which are brittle in nature. Based on the kind of operating conditions viewport material will be subjected to tensile or compressive stress fields alongwith the residual stress field generated due to the tempering process. The verification of all such potential fracture critical glass components, shall include an analysis of crack growth under combined conditions of the stresses and the environments encountered during their service life. Both sustained stress as well as fatigue crack growth data are to be generated for these materials and fracture based design criteria established for structural components.	
H16.2	**Optimal shaping of cutout corners in non-linear range (VSSC)** In launch vehicle structures, cutouts are called for, to meet different requirements. These cutouts are mostly, rectangular in shape. The structures being highly optimized for mass and being highly stressed, very high stress concentrations are observed in the cutout corners, which is very much local in nature. If not attended properly, this zone can be cause failure initiation and further propagate to a catastrophic failure of launch vehicle. Normally designers overcome this stress concentration problem by giving liberal fillet. Useful size of fillet to overcome the stress concentration, blocks the free entry of large object and defeat the purpose for which the cutout is intended. There is no quantification of allowable or safe stress in this type of zones. AJ Durelli, K. Rajaiah et. al. have done extensive research in shaping the cutout in the elastic stress range	

	through photo elastic methods. As the material is stressed in the non-linear range in a launch vehicle structure, the shape proposed through this study is inapplicable. The stress in cutout corner is also very much local in nature which is also not considered in the study. Hence there is a need to shape the cutout including fillet considering the stress in the non-linear range and nature of the stress field at the cutout corner. Theoretical determination and experimental validation is expected. Efficient shape of a cut-out will be different in different structural configurations like isogrid, waffle, closely stiffened and semi-monocoque. The study is expected to arrive at a parametric definition of minimum fillet radius 'r' for different structural configurations, based on geometry of cutout like a/b ratio, r/a or r/b etc., for using it in all sizes of cut-outs of different height 'a' and width- 'b'.
H16.3	**An assessment of knock down factors for cylindrical shells used in launch vehicles based on energy barrier approach (VSSC)** The current design of launch vehicle structure which are compressively loaded is based on the knock down factors and subsequent qualification tests. However, due to the improvement of computation methods, better estimates of collapse load are now possible and the knock down factors applied on theoretical computations are believed to be conservative. Some estimates show that the current design under-predict the buckling load carrying capacity by about 20%. The lack of reliability (lack of repeatability and the non-availability of a non- destructive testing technique) of cylindrical shell buckling experiments is a major contributing factor for this under estimation. The need for high-fidelity estimates of the buckling loads of shell structures is of critical importance for reliance or to increase payload capability. Methods based on energy barrier can be used as a non-destructive and non-invasive technique for determining the shock sensitivity and stability of thin-walled structures. Energy barrier method for shell buckling problems is a new approach for estimating the stability characteristics of cylindrical shells. This method has promising applications in the space industry for predicting the buckling load carrying capacity and the robustness of a cylindrical shell subjected to external undulations. Information about a structure's stiffness and robustness against buckling in terms of energy and other force parameters can be arrived using this technique. In simple terms, the energy barrier is the energy that needs to be supplied to drive the shell over buckling. And the determination of this energy barrier in a way helps us to find the buckling load carrying capacity and the shock sensitivity of the structure. The energy barrier of a structure can be determined from simple experiments or numerical procedures by introducing transverse perturbation to cylindrical shell preloaded by axially compressive force.
H16.4	**Design / analysis of membrane structures like parachute canopy for different loading conditions (VSSC)** In present time, use of membrane structures is widely increased in field of science and aerospace technology. Parachutes form one of the major parts of recovery subsystems in field of Human Space Missions, whereas hot air balloons are widely used for atmospheric studies and navigation. The mentioned membrane structures come in the category of tensile structures where stresses in the structures determine the shape as fabrics used in the design have no appreciable stiffness out of the plane it lies in and no appreciable

	bending stiffness. Design of such structures is sensitive to its geometry, material properties and patterning (fabrication) direction. The mechanical behaviour of fabrics used in realization of such structures is nonlinear and time dependent, with assumed or highly simplified material properties commonly used for analysis. The scope of the proposed project is to emphasize on the design criteria for membrane structures such as parachute canopy, to develop an analysis methodology for estimation of canopy stresses and loads in the canopy reinforcement using available / independent analysis tools.
H16.5	**Estimation of residual stresses induced in components during additive manufacturing process (VSSC)** Additive manufacturing is being widely used to fabricate functional metal parts in automobile, aerospace, energy, and medical device industries due to its flexible process capacity including complex geometry, functionally graded materials, and free usage of tool. Additive manufacturing refers to a process by which digital 3D design data is used to build up a component in layers by depositing material. Additive manufacturing builds up components layer by layer using materials which are available in fine powder form. A range of different metals, plastics and composite materials may be used. Additive manufacturing can be used in launch vehicle program especially in the upper stages. This will reduce the number of components in the assembly and hence the time and cost of realization of hardware. Residual stresses which get induced in a realised component due to thermal loads generated during deposition of layers during additive manufacturing puts restrictions in the usage of it especially for launch vehicle structures. Minimizing the residual stress build-up in metal-based additive manufacturing plays a pivotal role in selecting a particular material and technique for making a component. An accurate estimation of residual stresses and distortion is necessary to achieve dimensional accuracy and prevent premature fatigue failure, delamination and buckling of components. Since many process variables affect the amount of residual stress getting induced during additive manufacturing and experimental measurement of residual stresses and distortion are time consuming and expensive, development of numerical thermo-mechanical models for their estimation is highly essential.
H16.6	**Damage tolerant designs for laminated composite structures used in aerospace structures (VSSC)** The initiation and propagation of manufacturing induced or service induced damage in the structural design of laminated composites are of primary concern for aerospace structures. The laminated composite wing and fuselage structure with low transverse strength, low inter-laminar shear strength and no plastic deformation are more susceptible to damage growth. A stress-based criterion can determine the locations of potential damages followed by fracture analysis to predict the initiation of delamination. Based on suitable failure criterion, the failure is predicted. A thorough understanding is required to predict the multiple complex failure mechanisms in composite structures which are used especially in aerospace industry such as the wing structure. Virtual Crack Closure Technique (VCCT), Cohesive Zone Modelling (CZM) and Progressive Failure Analysis (PFA) are the techniques to predict the failure followed by the

	experiments to validate the criterion. A series of aerospace materials ranging from the metals to composites has to be tested and predictions through analytical and numerical method have to be carried out for the better understanding for future requirements.
H16.7	**Thermo-mechanical response of polymer matrix composites under high heating rates (VSSC)** Thermo setting polymer matrix composites are used in the aerospace industry as thermal insulation liners for nozzles system as well as heat shields for re-entry vehicles. These composite materials experience rapid heating during operational time, i.e. they are exposed to very high temperature in short duration. The polymer resin constituent undergoes thermochemical decomposition (charring). During this endothermic charring process, the polymer chain is broken down and decomposed into water vapour, pyrolysis gases and a solid carbon residue. Development of mathematical model to predict the thermo-mechanical response of ablation of polymeric materials during thermo chemical decomposition is planned in this proposal. Ablation analysis should capture simultaneously thermo-chemical and thermo-mechanical response of the Silica-Phenolic / carbon – Phenolic ablative systems.
H16.8	**Structural health monitoring through classifiation of strain patterns using Artificial Neural Network (VSSC)** Structural health monitoring technology has become an important approach to increase the safety and reduce the maintenance costs of high-performance composite structures used in aircraft and re-entry vehicles. There is a requirement to develop the tools to detect damages such as fiber failure, matrix cracking, de-laminations, skin-stiffener de-bonds in composite structures. Neural network is one of the tools. Tool will be used to classify sensor malfunctioning and structural failure(s) based on the observed static strain patterns of the healthy and unhealthy structures. Analytical and experimental studies have to be made to validate the adopted methodology.
H16.9	**Biaxial testing of visco elastic material (VSSC)** Solid rocket systems are used in launch vehicle. Solid propellant grains are strained / stressed due to thermal, gravitational, flight acceleration and ignition pressure loads. Behaviour of the solid propellant is visco elastic in nature. Study of biaxial behaviour of this visco elastic material under biaxial testing is proposed.
H16.10	**Development of design/analysis criterion for aerospace structures subjected to shock loads of varying intensities and duration (VSSC)** Usually in aerospace structural engineering, the structures need to be designed to withstand transient dynamic loads and shock excitation loads. Sometimes the health of the designed hardware needs to be assessed by finite element analysis for specific transient dynamic / shock loads, before the clearance of hardware for launch. Tests on AA 2014 alloy plates has shown plastic yielding in metallic plates. Hence a clear understanding on the dynamic stress response of structures for varying time duration of shocks and intensities and its relation with the structural health is required for an

	optimum structural design. The Objectives of the study is to develop a methodology for design of aerospace structures subjected to varying shock loads and to develop an analysis methodology for health assessment of structures subjected to shock loads of varying peaks and time duration.	
I	**Area**	**Avionics (VSSC)**
I1	**Sub Area**	**Motors (VSSC)**
I1.1	**Space vector PWM control for PMSM motor (VSSC)** Space vector PWM technology is being widely used in industrial application owing to the inherent advantages of better DC utilization and improved harmonic performance. As part of optimizing the systems for aerospace applications improving the efficiency by reducing the losses is the prime focus. On this background the usage of SVPWM technique for PMSM drives can offer significant advantage.	
I1.2	**Fault tolerance of five phase BLDC/PMSM motor (VSSC)** The motor industry is witnessing the migration of machines from three phases to increased number of phases on account of decreasing the current per phase thereby bring down the losses and the inherent fault tolerance. The inherent fault tolerant capability of a five phase BLDC/PMSM motor has to be established through simulations and experimental validations for the technology to be adapted to the aerospace industry. A comprehensive study of the failure modes, performance assessment, reconfiguration if required etc. are to be part of the study.	
I1.3	**Design and development of 25kW quadruplex BLDC motor with quadruplex hall sensor sets (VSSC)** 25kW quadruplex BLDC motor with quadruplex hallsensor sets is planned as a driver for linear electro-mechanical actuators generating high actuation forces. The scope includes • Design of motor and controller for the input requirements • Modeling and analysis using finite element analysis software to validate the motor performance • Generation of fabrication drawings and PCB layout • Procurement of components needed for the motor and controller • Realisation, assembly and testing of motor and controller	
I1.4	**Design and development of Dual redundant 22.5^{o} stepper motor for the rotary actuator (VSSC)** The scope includes • Design of motor for the input requirements • Modeling and analysis using finite element analysis software to validate the motor performance • Generation of fabrication drawings • Procurement of components • Realisation, assembly and testing of motor	

<table>
<tr><th>I2</th><th>Sub Area</th><th>Actuators (VSSC)</th></tr>
<tr><td>I2.1</td><td colspan="2">Magnetic levitation based linear actuators (VSSC)
For the present day electromechanical actuation systems, the weakest element in the system is the rotary to linear conversion mechanism. The disadvantage offered by the rotor inertia being reflected in the engine also offer challenges as majority of the power in the system is utilized in overcoming the self inertia of the system. On this back ground the feasibility of developing a magnetically levitated linear electromechanical actuator of 4T force capability. The detailed simulation study bringing out the configuration and performance assessment is to be carried out. A proto model to be developed and demonstrated.</td></tr>
<tr><td>I2.2</td><td colspan="2">Design and analysis (static & dynamic) of a planetary roller screw (VSSC)
Planetary rollerscrews having double nut configuration are used in high power electromechanical actuators for converting the rotary motion to linear. The scope of project includes
Mechanical design of the roller screw based on input requirement which includes detailed specification and outer dimensions of Rollerscrew
Generation of 3D CAD model
Kinematic analysis and estimation of slip
Static analysis (Finite Element Analysis), stiffness and efficiency
Dynamic analysis (Using solvers like ADAMS)
Fabrication drawing of all components</td></tr>
<tr><td>I2.3</td><td colspan="2">Design and analysis of harmonic drive (VSSC)
Harmonic drive replaces the conventional gear train of the rotary actuator. The scope includes
Mechanical design of the harmonic drive for the input requirements
Modeling and quasi-static analysis using finite element analysis for the tooth mesh conditions [for stress, strain and stiffness]
Kinematic and kinetic analyses using ADAMS like software
Tooth profile optimization for maximizing performance
Generation of fabrication drawings
Procurement of components (like elliptical bearings, circlip, etc, needed for the assembly)
Realisation, assembly and testing.</td></tr>
<tr><th>I3</th><th>Sub Area</th><th>ASIC/FPGA (VSSC)</th></tr>
<tr><td>I3.1</td><td colspan="2">Custom ASIC design of asynchronous RISC processor (VSSC)
As the ASIC technology scaling continues, the effect of leakage and dynamic power consumption of the CMOS gets more consideration. Moreover the clock requirement for the new designs goes on increasing although the majority of the internal logic does not</td></tr>
</table>

	clock in the same speed. In such scenarios, the use of asynchronous circuit design gains importance.	
I3.2	**Indigenous FPGA (VSSC)** As a part of import substitution efforts, it is required to design an Indigenous anti fuse FPGA in-house for the future ISRO missions. The design involves the following steps. Universal logic cell design Creating synthesis library Programmable interconnect design Modeling programmable interconnect Place and route software tool development FPGA fabrication FPGA programmer hardware and software development	
I4	**Sub Area**	**Onboard Computers (VSSC)**
I4.1	**Software modeling of on-board computer hardware (VSSC)** VIKRAM1601 is a 16-bit microprocessor based on-board computer indigenously developed by ISRO. A suitable software model, that would accurately simulate all the features of the system, is required to be developed. This is required for plugging into checkout systems for doing software validation of integrated flight software. This eliminates the requirement of hardware packages during software testing.	
I4.2	**Formal methods for flight software specification and verifiation (VSSC)** Formal methods for software specification and verification are based on mathematical methods and offer a more rigorous approach for software development and verification. In order to ensure consistency of requirements and provide proof of correctness, formal methods are to be used to supplement the traditional techniques followed for specification and verification of flight software for launch vehicles.	
I4.3	**Model-based software development for safety-critical systems (VSSC)** Model-based approach to Software Development involves a mathematical and visual method of addressing problems associated with designing complex systems. It provides a common design environment for all development agencies, facilitates rapid proto-typing and early detection of errors as well as design re-use. One of the safety-critical elements of flight software is to be developed using the model-based software development paradigm, as a pilot project.	
I5	**Sub Area**	**Power System (VSSC)**
I5.1	**Integrated on chip multi output DC-DC converter with soft switching topology (VSSC)** The scope of the project includes the modelling, analysis, design and development of miniaturised multiple output isolated DC-DC converter with soft switching topology for aerospace applications. These converters should have efficiency greater than 85%. The	

	scope of the project includes the design of on chip PWM controller for the proposed control algorithm. The proposed scheme shall be verified by simulation and hardware implementation.	
I5.2	**Wireless power transfer (VSSC)** The project aims at the design and development of wireless power transfer technique to transfer power from battery to various subsystems for aerospace applications. The project aims at the study of existing technologies of wireless power transmission and to arrive at a suitable technique to transfer power in the following cases 1) Low power at a distance of few centimeters (charging of batteries etc) 2) Medium power at a distance of few meters. The proposed scheme has to be verified by hardware implementation.	
I6	**Sub Area**	**Robotics (VSSC)**
I6.1	**Modeling, simulation, analysis and design of a controller for a robotic manipulator having five degree of freedom for lunar mission (VSSC)** Robotic manipulator having five degree of freedom forms part of a lunar exploration rover. The scope of project includes, • Generation of a mathematical model and its analysis which includes forward and inverse kinematics, work space analysis, trajectory planning, static and dynamic analysis • Design of a controller and simulation of certain predefined tasks • Hardware realization of the controller (control electronics to drive the manipulator) • Experimental demonstration of the predefined tasks (Robotic manipulator will be provided for this purpose)	
I6.2	**Determination of space debris, its shape and orientation and distance using image processing through stereo camera (VSSC)** • Image processing through stereo camera to determine the shape and dimensions of space debris in orbit • Estimation of altitude, angular velocity and tumbling axis of the debris. Machine learning could be used to achieve the goal • Date update frequency should be more than 25Hz • Camera configuration, Processor and algorithm should be defined accordingly • Algorithm should be platform independent so that it can be exported to the controllers having different architecture	
I6.3	**Design, analysis and experimental verification of a force and slip controller for the object grasp by an underactuated three fingered robotic hand (VSSC)** • Design of force and slip controller (including selection and procurement of appropriate sensor / sensors) • Simulation of grasp (Spherical, Cylindrical & Planar) with objects of various sizes and shapes	

	• Experimental demonstration of grasp (Spherical, Cylindrical & Planar) with objects of various sizes and shapes (Underactuated robotic hand will be provided for this purpose)	
I7	**Sub Area**	**Sensors & Instrumentation (VSSC)**
I7.1	**Sensors based on RF transduction principles for Remote Wireless Sensing (VSSC)** This project aims at realizing sensors using RF techniques such as resonance and propagation phase shift. Development of such techniques allows non-invasive measurement of a variety of parameters. The project involves design and development of such sensing systems and the associated electronics so as to enable wireless remote sensing of parameters for aerospace and industrial applications.	
I7.2	**Integration of sensors and electronics - analog, digital, RF & antenna on flex substrate for complete wireless sensing system (VSSC)** This project aims at realizing integrated sensors on flexible substrate. This involves design and development of a process flow that will allow Sensing elements, Analog, Digital, RF and Antenna elements to be implemented on the same flexible substrate base. Suitable placement, routing and fabrication techniques to be developed that will allow all these elements of diverse domains to work with minimal interference effects such as cross-talk and noise pickup that can affect the signal integrity in individual domains. The end goal is to develop technologies required for design and fabrication of smart, conformal wireless sensing systems for applications such as aerospace, industrial IOT and structural health monitoring.	
I7.3	**Sensors based on nanotechnology principles (VSSC)** The focus of this project is to design and develop sensors based on Nanotechnology principles. This will involve identification of suitable materials, process flow for fabrication and optimization of device characteristics. Characterization of sensors thus developed for performance parameters like linearity and sensitivity will also be part of the project. The sensors thus developed need to be of low volume, mass, power consumption and cost for them to be useful for future applications in ISRO missions.	
I7.4	**Design, fabrication, testing and realization of a Nanomaterial (CNT/Graphene) based gas sensor (VSSC)** The project aims to develop nanomaterial based gas sensors with high sensitivity and selectivity. As nanomaterial sensors are reliable, accurate and fast to respond, they are preferred. The output of the sensors can be either as electrical resistance variation or current, depending upon the exposure of the corresponding gas. The various gas sensors that is required for monitoring the Crew module environment are the following 1. H_2 2. N_2	

	3. CO_2 4. CO These are to be monitored for estimating and regulating the module environment. The sensing elements are to be developed for detection and estimation of the above gases.
I7.5	**Design, fabrication, testing and realization of Erbium Doped Fiber (EDF) Edge filter (VSSC)** The Erbium Doped Fiber (EDF) Edge filter is to be developed. The component is for interrogating (Fiber Bragg Grating grating) FBG sensors. EDF will be used to convert the Bragg wavelength shift to optical intensity variation. The Edge filter band width coverage : 1525 to 1565nm or more The EDF response should be temperature independent Variation of power over wavelength : 1dB/nm
I7.6	**Algorithms for structural health monitoring of launch vehicles (VSSC)** This project encompasses the development of techniques required for evaluating theHealth of Launch Vehicle Structures suitable for an Integrated Vehicle Health Management (IVHM) system. This consists of identifying the instrumentation requirements, development of suitable data analysis techniques in various domains such as time and frequency and study of relevant algorithms based on Dynamic System theory (such as State Estimation – Kalman filter), Statistical techniques (like Regression methods), Decision Making techniques (such as Dempster-Shafer) and those based on Neural Networks and Fuzzy Logic. The developed algorithms have to be demonstrated on flight data as well as test data with faults injected and their efficacy established.
I8	**Sub Area** **Analog Phase Modulator (VSSC)**
I8.1	**Miniaturized wideband analog phase modulator using Phase Locked Loop (PLL) (VSSC)** The project aims at the implementation of wideband continuous analog phase modulator capable of handling 2 Mbps data rate using PLL technique. Phase modulation (PCM/PM) is presently being employed for ISRO launch vehicle telemetry applications. The modulator subsystem is the major contributor in the size and mass of the telemetry transmitter. The objective of this research is to miniaturize the present telemetry transmitter system by developing a new method of modulation inside the PLL. The major advantages of implementing such a system will be a significant reduction of size, mass and cost of the transmitter. The present system employs PLL based frequency synthesizer for carrier generation in S band (2.2-2.3 GHz). The present proposal is for the state-of-art in the fild which is the implementation of modulation within the carrier generation loop itselfusingfractional-N frequency synthesizer chip with integrated VCO.

J	Area	Advanced Inertial Systems (IISU)
J1		**Development of Precision Blowtorch Micro-Glass Moulding Process Technology for advanced sensors of Inertial Systems (IISU)** This program is aimed to develop a precision micro-glass moulding process for realization of structural elements for Inertial Systems. The blowtorch moulding process attributes to miniature, atomically smooth, and symmetric 3D structures, in contrast to micromachining and conventional manufacturing processes. The process is intended to operate on highly thermally stable (low thermo-elastic damping, low thermal coefficient) materials like fused quartz (FQ), glass, fused silica (FS) and ultra-low expansion Titania silicate glass (ULE TSG). The intrinsic material properties and process dependent symmetricity attributes to realization of highly stable and structural elements for inertial systems. This technology aims to realize critical materials for advanced sensors of miniature navigation-grade inertial measurement units for launch vehicle and spacecraft applications. Objectives Design of set-up and fixtures, generating drawings i) Establishing blowtorch moulding process set-up. ii) Realization of fixtures, assembly and integration of the set-up. iii) Closed-loop control of blowtorch parameters with temperature of mould/substrate. iv) Optimization of blowtorch moulding process parameters. v) Demonstration of micro-glass blowing process. vi) Characterization of structures. The proposed development would enable realization of miniaturized highly stable and 3D symmetric structures in fused silica, glass, and fused quartz for navigation-grade gyroscope structures.
J2		**Development of Pressure Sensor (IISU)** arometer is a pressure sensor with range of 1 Bar to measure the atmospheric pressure. This can be used to estimate altitude autonomously. Also, Barometer can be used for aiding INS solution and damping vertical errors. To have altitude estimation error limited to few meters, measurement accuracy of pressure sensor needs to be in order of mbar. The applications are Aiding of INS for future Aircraft INS and other applications like Wind tunnel etc. Once development of this sensor completed, the design and development of MEMS smart barometer with 2 mbar measurement accuracy can be taken up. Activities in progress: • Tear down analysis • Diaphragm Optimization in progress. • Sensor Configuration Design in progress. **Test Setup Development:** Precision pressure calibration setup is being developed for evaluating sensors.

K	Area	Launch Vehicle Tracking System, Range Operation and Safety Engineering (SDSC- SHAR)
K1	Sub Area	Ground Safety (SDSC-SHAR)
K1.1	**Study on radiant heat flux from propellant fires and its effects (SDSC-SHAR)** Estimation of Heat flux around the propellant burning areas through experimental setup will help us to validate our theoretical estimation, thereby it helps us to provide input for ensuring the adequacy of protection to our personnel and systems.	
K1.2	**Design of fire alarm and detection system for high bays based on smoke modelling (SDSC-SHAR)** To design optimal and effective Fire Alarm detection systems for High rise and highbay based on smoke modeling. Also to optimize the location of the sensors and detection mechanisms for a faster detection.	
K1.3	**Risk analysis for liquid propellant storage facilities (SDSC-SHAR)** The Siting of Liquid propellant storage facilities are based on the quantity distance criteria, fire ball diameter calculations etc., considering the worst case scenario. Risk analysis studies add can be used for estimating the risk levels of the liquid propellant storage and handling in bulk as well as the adequacy of safety system and its protection levels.	
K1.4	**Smoke extractor system for solid motors exhaust gas during testing (SDSC-SHAR)** As a part of qualifiation trials for the solid motor testing of Agni motors have increased manifolds. As the solid motors exhaust gases contain traces of toxic Products like HCl gas, Al2O3 and CO. In order to protect the environment and personnel from these exposures it is proposed to have a smoke extractor system for safe collection of exhaust gases for disposal.	
K1.5	**Experimental studies on dispersion of solid rocket motor exhaust gases (SDSC-SHAR)** The Exhaust gases dispersion studies can we used for understanding the behavior of gas dispersion based on which static testing of solid motors safety criteria's can be evolved with aim to prevent the dispersion of exhaust gases towards land mass. Also to protect the public /operational personnel from toxic gases as well as to protect the flora and fauna of Sriharikota.	
K1.6	**Experimental studies on oxygen deficiency environments due to accidental spillage or release of gases (SDSC-SHAR)** The Box model sub- scale gases dispersion studies will help us to understand the behavior of gas dispersion. This can be used for estimating the concentration levels at various elevations and distances etc. Also to optimize the location of the sensors and detection mechanisms for a faster detection.	

K1.7	**Experimental studies on liquid propellant dispersion due to accidental release or spillages (SDSC-SHAR)** The Exhaust gases dispersion studies can be used for understanding the behavior of gas dispersion based on which safety criteria's can be evolved with an aim to estimate the toxic corridors and pollution levels form the source of leak. Also to optimize the location of the sensors for a fatser response and for initiating the safing actions at a faster detection.	
K2	**Sub Area**	**Solid Motor Performance & Enviornmental Test Facility (SDSC-SHAR)**
K2.1	**Developing a jet noise source localisation technique using a microphone array with appropriate beam forming algorithms (SDSC-SHAR)** Locating the jet noise sources in the lift-off scenario of a launch vehicle will benefit highly in the suppression of the noise sources. Present method proposes to use an array of microphones and employ suitable algorithm and develop a code to locate the noise sources.	
K2.2	**Fatigue life estimation of structural members under random vibrations through strain gauge measurements (SDSC-SHAR)** The launch complex structures are huge and undergo random vibration loading. The objective is to estimate the fatigue life through strain gauge measurements.	
K2.3	**Modelling and evaluation of damping in threaded joints of load cells and its impact on measuring dynamic force components (SDSC-SHAR)** During static test, the thrust load transfer is through threaded joints. The thread damping is important with respect to the dynamic thrust measurement. The objective is to model and experimentally evaluate the threaded joint damping for unsteady load transfer.	
L	**Area**	**Testing of Liquid Propulsion Systems (IPRC)**
L1	**Design, Development & testing of innovative robotic system for inspection, leak detection, surveillance in test facilities & launch pad (IPRC)** Testing of rocket systems & launching of rocket is highly complex. It involves various hazardous operations being carried out in test facilities, launch pad, propellant transfer & storage areas etc. In test facilities/launch pad, human inspection/intervention after propellant filling, with high pressure & at inaccessible locations etc are sometimes unavoidable during exigencies. Hence possible human intervention can be avoided, if robotic systems are used. In addition the innovative robotic system developed can be used for various applications such as leak detection & surveillance. Objective of the work is aimed at development of innovative robot which can carry out inspection, leak testing and detect leakages in propellant storage, propellant transfer, hazardous areas, near fire locations & high pressure systems etc.	

L2	**Structural health monitoring of high pressure cylinders using Acoustic Emission Techniques for various materials (IPRC)** Periodic requalification of high pressure cylinders is mandatory for certifying the usage of the cylinders for prolonged periods at various establishments. has many potential advantages. Objective of the work is to develop structural health monitoring of high pressure cylinders using AET during periodic requalification mainly involves the following • Configuration of Acoustic Emission Technique for high thickness material, different composition of materials • Configuration of instrumentation & data acquisition system • Development of software to analyze the test data & assess the health of the hardware
L3	**Design and demonstration of a prototype system for Gaseous Helium recovery from waste gas streams (IPRC)** IPRC is having the state-of-the-art facilities for carrying out the developmental, qualification and acceptance testing of cryogenic rocket engines and stage system in both component level and at an integrated level, involving cold flow and hot fire testing. Cryogenic rocket engine uses Liquid Oxygen (LO2) and Liquid Hydrogen (LH2) as propellants. Due to the extremely cold cryogenic conditions of this environment, an inert gas, gaseous helium, is used as a purge for the engine since it can be used without freezing in the cryogenic environment. Large quantities of helium are used during testing each year. Being gaseous helium as a non-renewable natural resource, cost of helium is increasing as the supply diminishes. The cost and shortage of helium shall give the impact for testing of the rocket engines for the space propulsion systems in future. Innovative solutions are needed for efficient, in-situ methods to recapture helium used during engine purging and testing processes. Recaptured helium shall be cleaned to ultra-high level purity and re-pressurized for reuse. Research into technologies in these areas, demonstration of the technology capability, and conceptual design for the technology installation at IPRC are desired to assist in the helium conservation. Expected deliverables: • Scrutinize the economically viable processes for helium recovery and reuse • Propose a system that will recover helium from the waste gas streams (normally mixture of GH2, GHe, GN2 and moisture) and purify it to a level where it can be recycled for practical usage • Vent gas flow rate and its process condition for design of a prototype system shall be considered based on IPRC's input during the course of development • Design, engineering, realization and demonstration of a prototype helium recovery system from the vent gas • Helium recovery technology shall be demonstrated for the process conditions prevailing at IPRC

L4	**Design of flame deflector for conducting ground testing of cluster nozzle stages (IPRC)** Flame deflectors are used in rocket test facilities and launch pad to avoid the damage to the engines or rocket from the reflected engine plume. Flame deflectors experience very high temperatures due to the impingement of jet on the deflector plates from the engine exhaust. Presently stages with maximum twin engine configuration is being used and tested in the test facility with 'J' type jet deflector. ISRO is planning to have cluster nozzle configuration stages to increase the payload capabilities. Ground testing of Cluster nozzle stages requires the jet deflectors to accommodate the engine without any plume reflections from the deflector. A detailed study is required to develop the model for the jet deflector to test the cluster nozzle in the ground test facility. This includes computational studies, experiments using the proto model and generating the empirical correlations to suite the real time applications.
L5	**Studies on enthalpy augmentation and jet engine based ejector system (IPRC)** Ejectors are used to sub cool the cryogenic fluids and generating the vacuum during the ground testing of rocket engines. The duration of testing of CE20 engine is limited to the storage capability of the drive gas system which supplies GN2 at the flow rate of 400kg/s. through four nozzles. The mass flow rate of the ejector fluid can be reduced by heating the gas before entering into the ejector nozzle. An alternatively jet engine can be used to generate the hot gas which can be used as a drive fluid for the ejector system. This includes computational studies, experiments using the proto model and generating the empirical correlations to suite the realtime applications.
L6	**Polyurethane Foam Waste Reduction and Recycling (IPRC)** Cryogenic stages of Satellite Launch Vehicles are insulated in order to reduce "boil off" of cryogenic propellant inside the stage tanks. The insulation material used is generally closed cell structure of polyurethane foam. During the process of applying the polyurethane foam on the outer surface of the stage tank, huge foam waste is generated in the form of dust and large volume of foam layer. Since the number of cryogenic stages required to meet the increasing launch rate of Launch vehicles year by year, the waste of foam also increasing exorbitantly. Also new development of insulating materials further adds to wastage. Presently, these waste foams are recycled through landfills which affect the environment. Hence, a new method needs to be developed to minimize waste and to reduce environmental pollution. For this, a bench scale device shall be developed and demonstrated for effective reuse of foam waste by recycling or any other novel method.
L7	**Detection of hazardous environment and its mitigation using wireless sensor networks (IPRC)** The earth storable hypergolic propellants that are used for propelling the rockets are highly toxic and hazardous. Therefore, monitoring the leakage of propellants during

	storage, transportation, filling and draining is very much essential. In the present scenario, hydrazine sensors are deployed in the test stands of rocket engines to detect the leakage of propellants. The existing system doesn't have any monitoring system and network structure to alert the concerned person immediately. Hence the monitoring can be done with the help of wireless sensor networks and IoT enabled system. The wireless sensor network consists of various components like sensor nodes, controllers, actuators, interfacing software, data hub, network (Intranet) from which data is transmitted to the control center and the concerned personnel through SMS. The sensor nodes are mounted at the critical areas like near the valves of the fuel tank, oxidizer tank and joints. If the propellant leakage exceeds the threshold limit, the sensor nodes inform to the appropriate authority with the data or videos. Certain Time limit will be provided to view the data. If the concerned authority fails to view the video or data within that time, the mode will be transformed to alarm mode to alert the concerned authority, who can initiate the necessary steps to activate the actuator system by spraying water or any chemicals to mitigate the effect of leakage.If the authority again fails to activate the actuator the IoT enabled system automatically activates the actuator to mitigate the effect of leakage. The proposed system can able to: 1. monitor and detect the leakage 24x7 during storage, transportation, filling and draining operations in test stand. 2. mitigate the effects like fire, explosion etc. in the quickest possible time. 3. determine the exact location and severity of the hazard without any false alarm using data fusion techniques. 4. identify the exact location of the incident with the help of GIS (Geographical Information System) embedded with multimedia content. 5. alert the concerned authority with the help of IoT enabled smart control system.
L8	**Additive Manufacturing of Metamaterials (IPRC)** Materials with designed three-dimensional micro-architectures offer multiple beneficial properties such as low weight, high stiffness and strength, negative poisson ratio and energy absorptions and can open up a myriad of material by design applications from flexible armor, responsive materials to bio-mimetic materials. Ultimately, one would like to 3D print functional device or components that incorporate multiple material constituents without the requirement of excessive assembling procedures such as gluing, aligning, fitting, and welding. Apart from enhancing spatial resolution and printing speed, achieving this goal requires the ability to incorporate an array of different material properties within a manufacturing platform. In analogy to typical 2D color printers that can integrate multiple colors from mixing a few colors (magenta, cyan, yellow), a three-dimensional fabrication platform should not only be able to integrate multiple colors, but also be capable of spatially integrating encoded material properties and compositions from mixing only a limited number of feedstock materials.

	A strategy to achieve unusual mechanical properties through coupling variable elastic moduli from a few GPa to below KPa within a single tissue to be evolved. The ability to produce multi-material, three-dimensional (3D) micro-architectures with high fidelity incorporating dissimilar components has been a major challenge in man-made materials. The multi-modulus metamaterials whose architectural element is comprised of encoded elasticity ranging from rigid to soft. In contrast to ordinary architected materials whose negative Poisson's ratio is dictated by their geometry, these types of metamaterials are capable of displaying Poisson's ratios from extreme negative to zero, independent of their 3D micro-architecture. The resulting low density metamaterials is capable of achieving functionally graded, distributed strain amplification capabilities within the metamaterial with uniform micro-architectures. Simultaneous tuning of Poisson's ratio and moduli within the 3D multi-materials could open up a broad array of material by design applications ranging from flexible armor, artificial muscles, to actuators and bio-mimetic materials.	
L9	**Numerical modelling of two-phase interaction between water and supersonic exhaust plume of rocket engine (IPRC)** Certain applications related to Rocket engine testing involve interaction of supersonic exhaust plume of rocket engine and water. This project intends at development of numerical model to predict the interaction between these two phases i.e. primary and secondary break-up of water jet, mixing of two-phases and phase-transformation. At present these analyses are carried out with coupled Eulerian-Lagrangian approach which has its own limitations. New methodologies may be investigated to accurately predict the flow behavior.	
M	**Area**	**Rocket systems including human space probes (IPRC)**
M1	**Design & Development of liquid helium based system for pressurization of cryogenic propulsion stage tanks (IPRC)** Composite Overwrapped Pressure Vessels (COPV) are used in cryogenic/semi cryogenic propulsion rocket stages for stage tank pressurization. Very high pressure gases are stored in multiple COPVs. Any failure of COPV's will result in mission failure. Hence an alternative system is essential. The Objective of the work is aimed at design & development of innovative, reliable & less weight liquid helium based pressurization system for pressurization of cryogenic rocket stage, resulting in replacing of COPVs. It consists of liquid helium storage system, transfer pipes, heating elements, flow components, instruments etc. Being a complex system, intensive design & analysis need to be carried out. A prototype also shall be demonstrated & need to be flight proven.	
M2	**Development of micro fluidic propellant feed system for electro spray thruster (IPRC)** Development of electrospray thruster is in progress for micro and nano satellite propulsion. The propellant feed system of the electrospray thruster to be used in space craft requires	

	the development of a pressurization scheme for the active flow of the propellant. The pressurization system requires to be of light weight with capability to withstand temperature and pressure. This includes development of concept, design, modeling and realization of the membrane and its bonding to electrospray thruster.
M3	**Development of tele-operated robotic bulldozers (IPRC)** Moving humans and cargoes to Moon for Moon colonization due to scarcity of resources in our mother Earth will not be achieved with expendable rockets. Affordable access to Low Earth Orbit (LEO) and beyond is needed. Reusable launch vehicles, a space station at LEO, transportation of Cargoes with low thrust electric drives to reach Moon but with very little propellant must be developed. Even though the cost of transportation to Moon in the future might be small fraction when compared with today's cost, yet it will still be expensive. Hence, the use of lunar resources for development on the Moon, a technique called 'bootstrapping'. Before achieving the goal of lunar colonization and send back lunar resources to Earth, technologies related to bootstrapping lunar resources to be developed well in advance. One of the foremost things is to prepare a site for lunar colonization. Based on lunar mapping by various spacecraft, a suitable site shall be located. However, to prepare a selected site, tele-operated robotic bulldozers which can work in low electric power using solar power shall be developed and send in-advance before human mission to Moon. Thus, a prototype of tele-operated robotic bulldozers shall be developed and a technology shall be demonstrated for operating miniaturized tele-operated robotic bulldozers with electric power generated from solar panels.
M4	**Design, fabrication and Spray Characterization of movable Pintle Injector for liquid rocket engines (IPRC)** As we move from the era of expendable launch vehicles to Reusable launch vehicles, many technological challenges lie ahead. One major challenge is recovery of spent stages of launch vehicles back from space to earth using thrust control system of the rocket engines in the stages. Thrust control is a complex activity for liquid rocket engines in order to achieve mission requirements such as: a. Vertical landing and recovery of lower stage rocket engines. b. Space rendezvous and docking, etc. For a given mission requirement, in order to achieve a very precise control over the trajectory, thrust regulation is the key. With the use of fixed area injectors, it is very difficult to efficiently control the thrust owing to some problems like • Maintaining stable combustion • Maintaining an adequate pressure drop across the injector, which is necessary to provide propellant atomization and mixing, • Cavitation, stall, surge, rotor dynamics, and structural dynamics for turbo machinery

	• Valves and actuators design that can achieve accurate flow control at all thrust levels • The amount of nozzle flow separation that can be tolerated at low thrust levels for ground testing The pintle injector employs injector area variation to achieve engine throttling. By varying the flow area of the injected fluids, it is feasible to achieve the desired flow velocities in the combustion chamber while maintaining adequate pressure drop at all thrust levels. This allows for optimized injection at all power levels without having to impose stringent requirements on the feed system or reducing chamber pressure. One added advantage of this configuration is the replacement of large injector plate with several injector elements by a single injector unit. The use of pintle injector is limited not only to variable thrust engines but also to fixed thrust engines. Its use in fixed thrust engines eliminates the manufacturing complexities of injector plate with multiple injectors. By suitably designing and conducting CFD analysis, the following shall be delivered. • Report on Spray characterization with water and some cryogenic fluid • Design procedure based on stable performance of engine under all throttling conditions • Demonstration of throttling on sub-scale engine of thrust 50-100 N for a short duration at IPRC
M5	**Development of a compact Hydrogen Fuel Cell for powering onboard-systems of crewed flight and fulfilling water requirement as a by-product (IPRC)** Currently, all our space-crafts are powered using in-house proven technology of solar cells. Manned missions to Moon and eventually Mars are under study for accomplishment. To power these space-crafts and crew modules of the missions, some alternative power sources like radioisotope thermoelectric generator, fuel cells, lithium ion batteries, etc. needs to be explored. Carrying lithium-ion battery packs for manned missions is a matter of concern from weight and battery management system point of view. Hydrogen fuel cells can prove to be a good alternative. Whether it is proton-exchange-membrane fuel cells or regenerative fuel cell, water is a by-product of the chemical reaction in addition to the generation of power which can be used for on-board computers, actuators, orbiter sub-systems, payloads, etc. Also, the heat released can be harnessed for warming the crew module. The use of hydrogen fuel cell is attractive for manned mission because oxygen is already supplied to the environmental control and life support system for crew cabin pressurization. Carrying hydrogen (lightest element known) storage vessel with oxygen storage vessel shall aid in producing electricity, water and heat all of which is useful for manned mission.

	This proposal can be considered as an alternative source of power and a means of fresh water source for crew module. A theoretical study, feasibility analysis and Safety analysis of using fuel cells in space shall be conducted and a compact working model of hydrogen fuel cell shall be realized for demonstration purpose.
M6	**Design & Fabrication of Universal Docking mechanisms, adaptors, Training Simulator followed by demonstration of Rendezvous and Aerial Docking (IPRC)** Recently, ISRO has announced its plans for building its own Space station. Building a space station is critical, challenging and complex task to accomplish. This calls for multiple docking to integrate smaller modules in space to build a space station. This requires transposition, docking and extraction of space-crafts. Whether it's a transfer of fuel to space station, transfer of crew, resources for re-supply and augmentation of existing space station, docking is essential. Docking is essential not only to space station, but also to satellites placed in orbits. As the service life of satellites comes to an end, their life can be extended by replenishing their propellants from other space-crafts in same orbit by automated rendezvous and docking. This will bring down the cost of placing satellites in orbit while all its payload is fully functional. To cut short, Docking is required for: • Servicing of existing space-crafts • Extension of mission of space-crafts The life-extension service can be helpful in expansive technology development plan. Docking can not only extend the life of satellites, but also provide other services such as inclination changes and spacecraft inspections, as well as use of advanced robotics technology to perform additional functions such as in-orbit repair and assembly. To start with, this technology can be demonstrated on micro-satellites in low earth orbit using PSLV. A universal docking mechanism and associated adaptors shall be designed, fabricated and demonstrated the feasibility of docking in manual and autonomous mode. Also, a training simulator shall be developed and Aerial docking flight using quad copters/drones shall be demonstrated. This project demands expertise from multiple domains like mechanical engineering, computer science, electronics engineering.
M7	**Demonstration of Multiple Restarts in Pressure-fed liquid propellant engines with torch igniter/acoustic resonance igniter (IPRC)** ISRO has already established its capability of multiple restarts with its fourth stage of PSLV which uses a hypergolic propellant mixture. Such technology of multiple restarts is still to be demonstrated with cryogenic upper stages which use liquid hydrogen and liquid oxygen as its key propellants.

	Multiple restart capability is required for injecting / keeping satellites in • Different orbits. • Different inclinations. In addition, it is vital to reusable launch vehicles where multiple ignitions are required during different stages of descent. Keeping in mind ISRO's plan of augmenting its fleet of cryogenic upper stages and space-crafts with multiple restart capability, it is important to demonstrate such capability. This capability can be achieved in many ways. Few among them are the use of Hydrogen-Oxygen torch igniter and acoustic resonance igniter. The proposal aims at development of igniters using a mixture of H2-O2, followed by testing on small-scale pressure-fed thruster with a capability of generating 50-100N thrust at sea level. A Small-scale pressure-fed engine of 50-100 N capability with a Hydrogen-Oxygen torch igniter and Acoustic Igniter (optional) shall be developed, fabricated and tested to demonstrate multiple restart capability for short duration.	
N	**Area**	**Electronics and measurement for testing rocket systems (IPRC)**
N1	**Development of Integrated Power processing and Digital Control Unit for Electrospray thruster (IPRC)** Development of electrospray thruster is in progress for micro and nano satellite propulsion. This requires the development of compact and miniaturized circuit for power processing unit and digital control unit of the electrospray thruster. It should be capable of providing the required potential difference for the operation of the thruster, receive thrust commands and also send back thruster telemetry to a primary motherboard. This includes development of concept, design, modeling, realization and testing of the electronic package.	
N2	**Rocket engine test article measurement of low varying parameters using wireless sensor networks (IPRC)** Rocket engines use different instrumentation sensors for pressure monitoring, temperature monitoring, flow of liquid, acceleration of rocket engine. In the present scenario, wired cables of hundreds of meters in length are used to transmit the test data to the control center. Obstacles are faced in maintenance of these wired cables. Maintenance of these wired cables of hundreds of meters length altogether and acquiring error free data at control center is a crucial task. To overcome these issues, wireless sensor networks, is utilized that provide easy connectivity in acquiring the data from all the mounted sensors. The wireless communications platform is a cost-efficient solution for gathering and transmitting information using communication technologies and infrastructures. They supply all data sets collected from sensors reliably to the control center. The sensors mounted on these rocket engine monitor parameters such as load, flow, pressure,	

	temperature and vibration and ensures that the processed data are transmitted from cable termination room to the control center through reliable wireless technology. The received data and processed data are transmitted to the control center reliably and to the appropriate authority. Suitable data acquisition software will also be developed to acquire, format, transmit, receive and strip the test data. The proposed system can • Replace wired cables using wireless networks and to reduce the risk of maintenance of wired cables • Collect, process, stores and communicate information related to various activities of rocket engine through wireless networks • Provide secure, low power, long range communication using wireless spread spectrum techniques • Transmit the new processed reliable data to control center using wireless spread spectrum techniques • Develop data acquisition software to process and analyze, acquire, format, transmit, receive and strip the test data
N3	**Reinforcement Learning Approach for Transient Control in Liquid Rocket Engine (IPRC)** In the current era, usage of control systems in liquid rocket engines has an at most priority for reusable engines to make them economical. Optimal control of engine operation including the transient phase, determines the performance of the system and the existing control sequences are inefficient in the closed loop control system. This control system in the steady state phase needs to maintain a desired combustion chamber pressure, mixture ratio for the optimal propellant consumption rated for the designed pay load capability. Till date, most of the launch vehicles are operated with the pneumatic actuators in the steady state of the engines. Hence, transient state control of launch vehicle is highly demanding and towards this, a Model Predictive Control (MPC) was proposed in the literature in which controller completes the start-up and can track the end-state references with sufficient memory, to meet the reusability requirements. However, this model is limited to control multiple operating conditions and hence, an efficient intelligent algorithm is highly essential. Thus, we propose to develop Deep Reinforcement Learning (RL) algorithms as they can automatically generate the optimal transient sequences. The deep reinforcement learning controller achieves the highest performance and requires only minimal computational effort to calculate the control action, which is a big advantage over approaches that require online optimization, such as model predictive control. From a control perspective, reinforcement learning converts the system identification problem and the optimal control problem to machine learning problems and can easily address complex online operational problems to compute the action. Training the control loop using RL minimizes computational effort and can work effectively on multiple objects,

	multiple regime that are considered as complex tasks. RL for engine control offers the advantages of no derivation of a suitable state-space model, model order reduction, easy adoption and implementation of non-linear simulation models, ease of adoptability in the complex or critical stages. Successful control of rocket engines using RL and coupling them with health monitoring systems in the transient phase can increase the reliability of control requirements, better performance and cost reduction.
N4	**Soft-sensor based Measurement parameters' estimation (IPRC)** Soft-sensor based measurement parameter estimation normally use three techniques viz. i) estimation using Mathematical models (using first principles of the system) ii) Data-driven models, and iii) Hybrid models, using the expertise from the Mathematical and data-driven models. Data-driven models are based on the system data, to find the relationship between the system input and output variables. So, knowledge of the physical behaviour of the system is not required with this approach, and hence exact physical modelling of the system or process is also not required. Data-driven models depend on the experimental or industrial data of the system or process, and attempt is made to learn the physical relationships that describe the system directly from the data. The advantage here is that, any data related to the process, or another similar process can be relevant and can be used to predict any parameter related to the process. This approach takes care of not only the inherent non-linearities of the system, but also the external or environmental disturbances. The developed model can be trained with more data-set, which will gradually improve the accuracy of the system with more and more training data. This approach ensures the capability of the model for making accurate predictions with the new sets of data. Data-driven models are becoming more and more popular with the availability of increasing amount of data as well as due to the continual advancements in the understanding of the versatile algorithms, and also the increased computational availability. Presently, the state estimation methods are not yet matured to be used in the industry in full. This approach has several advantages and challenges. Some of the advantages are, they are suitable for predicting any transient and dynamic patterns of the data and can work fairly with noisy measurement data, which can be properly pre-processed and used. Other major challenges include designing good models and tuning these models with appropriate data, in order to increase the accuracy. In future, there is a feasibility and potential for combining the mathematical model with the data-driven models in order to get the required accuracy and precision for the industrial usage. The soft sensor estimation can be used for the prediction of different pressure, temperature, flow, load-cell and level measurements, provided we have the related measured parameters available for a particular system/hardware. This is achievable with various Artificial Neural Networks (ANNs) using the data fusion techniques. There are several advantages of using neural networks for the prediction, viz. dynamic estimation

	of the parameter is instantaneously available, which can be used for on-line and real time applications such as control loop feedback. Following are the advantages of the proposed system. • The installation maintenance and operational cost of the physical sensor is exempted. • The estimated value can be made very close to the actual measurements by training with more and more relevant data.
N5	**Design and realization of measurement system for temperature field and species mapping of combustion zone in rocket engine combustion chambers (IPRC)** Combustion process is multidisciplinary in nature involving various engineering domains viz. fluid dynamics, heat transfer, reaction chemistry, compressible medium thermodynamics, thermo-acoustics etc. Despite the existence of rigorous mathematical models, analytical tools and experimental data available on liquid rocket combustion systems, design and development of a liquid rocket engine have been identified with many challenges, lack of a rational design framework involving first principle approach for mitigating many of the problems in rocket engine realization, leads to time consuming and costly “cut and try” design methodology. Traditional temperature and species measurements are intrusive, limited by their nature to provide point data and their physics, restricts the fastest event that is measurable. Lasers diagnostic measurements are non-intrusive and hence do not alter any of the process parameters. They can measure species concentration and temperature field in a point, plane or a volume (1D, 2D or 3D). They are capable of detecting and measuring even the fastest events in the process limited only by the pulse width of the laser and the sampling rate of the detection system. In general, they offer higher spatial and temporal resolution than any conventional diagnostic techniques. Such measurements are useful in multitude of problems in combustion chamber design and stability some of which are described here. Temperature mapping of combustion zone near injector face plate will lead to better structural & thermal budgeting. The species and temperature field measurement in the combustion chamber will give better insight in mitigating the combustion instability and heat transfer problems in the design of combustion chambers. Expected deliverables: • A windowed combustor suitable for LOX/Methane & LOX/LH2 combustion up to a chamber pressure of 200 bar (abs). • LASER diagnostic system for spatial and temporal mapping of temperature field in the combustion chamber. • Computing hardware for process control, data acquisition and data processing. • Software for data analysis and visualization,

O	Area	Management (SAC)
O1	**Knowledge Management in Research and Development (SAC)** Knowledge Management helps organisations grow in a competitive and an ever-changing environment. Knowledge management is a process of capturing, developing, sharing and effectively using organisational knowledge. It involves a multi-disciplinary approach to achieve organisational objectives by making the best use of the explicit and tacit knowledge of researchers. The suggested research topics are: • Exploring various Knowledge Management Systems (KMS) programs in different R&D organisations. • Designing a framework for effective Knowledge Management System. • Investigating interactions between knowledge management and human intellectual capital.	
O2	**Crowdsourcing, an emergent tool for Knowledge Management in a R&D organisation (SAC)** Crowdsourcing principles when applied in R&D may result in technological innovations, which can enhance the knowledge management. 'Collective wisdom' through crowdsourcing gradually evolve into focussed problem solving. Crowdsourced R&D inputs may offer hitherto undiscovered potentialities for solving societal problems; in particular using space technology. Due to the increasing complexity of our world and the way change occurs "faster" than we can evaluate the changes, let alone respond to them, the process of crowdsourcing may yield timely capabilities and policies to support the systems in a R&D organisation.	
O3	**Research Productivity Assessment and Evaluation of Research at Govt. R&D organisation (SAC)** The main objective of research is to produce new knowledge. A research activity is a process with human intellect, tangible (scientific instruments, materials etc.) and intangible (accumulated knowledge, social networks etc.) resources used as inputs. The output in form of 'new knowledge' has a complex character of both tangible nature (publication, patent, database, paper presentations etc.) and intangible nature (tacit knowledge, experience gained etc.). Thus, research is a multi-input and multi-output process. To study existing management practices adopted for Research Productivity Assessment and design and develop tools and matrices for research productivity assessment.	
O4	**Work flow design/ management (SAC)** Under this researcher should study work flow of the various electronics &Mechanical Fabrication and suggest the improvements. Also designing of the web-based tracking mechanism for the effective management.	

O5	**Monitoring & Evaluating Projects: Contemporary Methods (SAC)** Projects Management and Monitoring: Measuring Performance: Earned Value Analysis Methods and other methods like trend analysis etc.
O6	**Human Resources Development (SAC)** An organisation is responsible for ensuring that its employees have the appropriate competencies to fulfil the organization's strategic and operational objectives. Training and Development (T&D) strategy aims to develop competencies of employees. National Training Policy has also emphasized competency framework in Training & Development. The possible research work may include design and development online course content on various themes with implementation on suitable LMS and development of competency framework for various categories of people. The other research areas in Human Resource Development includes organizational commitment, employee engagement, profiling new generation S&T personnel with suitable instruments and also linking these data with Training & Development. Other topics • Technology Forecasting with respect to State of the Art Technologies • Organisational communication • Information dissemination methods • Learning & Development • Development of Competency Framework for different categories of people • Profiling New Generation S&T people • Employee Engagement • Organisational Commitment • Research on Planning and development strategies
O7	**Fostering Innovation through Research in Science and Technology (FIRST) (SAC)** A scientific invention is a new idea or concept generated by research and development. The scientific convention when transformed and applied as a socially useable product becomes an innovation. An intrapreneur is a visionary inventor who pursues the idea into a profitable reality. Developing innovation and intraprenurship culture in Govt. R&D Organizations may be a thoughtful approach for skill development and improving the research quality with growing organisational needs and future challenges. Fostering a creative and intrapreneurial environment is the requirement of the current times. The implementation strategy may include translational research domains relating to both enabling science and technology as well as government's citizen centric priorities in various fields viz. agriculture, environment, natural resources management, disaster preparedness and management etc.

Satellite Communications

A	Area	SATCOM & Navigation Payload (SAC)
A1	Sub Area	Digital Systems in Advance Satellite Technology Research (SAC)
	Onboard digital signal processing has potential for offering innovative satellite services. Managing mass, power, complexity, functionality and reliability for such payload is of paramount importance for offering services at acceptable cost. There is a need of developing techniques for : • Innovative and efficient spectrum processing and sensing algorithms • Innovative techniques, protocols and architecture • Innovative business models.	
A2	Sub Area	Communication Satellite Related Technology (SAC)
A2.1	**Advanced Coding and Modulation for Satellite Communication (SAC)** Recently the terrestrial communication system of fiber optical cables has grown tremendously. In order to develop a harmonious infrastructure with terrestrial communications systems, the speed of satellite communications must be increased to meet the speed of terrestrial communications system. **Current Situation and challenges** Most of the communication satellite in ISRO like INSAT and GSAT class of series satellites used mostly QPSK and BPSK modulation system. The reason of using these modulation systems is because of their simplicity and better performance compared to other modulation systems in satellite communication scenario. There are two major approaches for modulator design heterodyne and homodyne. But now current state of art design is based upon homodyne approach. The challenge to use these modulation is to handle high data rate, where the hardware or component used earlier design will not be useful. The other challenges are reduction of size and power consumption of such system. So, high data rate system using current modulation scheme with reduced size and power is the current challenge.	
A2.2	**Channel coding for satellite communication (SAC)** **Current Situation and challenges** Currently most of the satellite made by ISRO used convolutional code with different code rate 1/2, 3/4, 7/8 in concatenation with RS code in some of the satellite. However due to increase in demand of quality of service and several upcoming deep space explorations, it is now essential that change channel codec for future mission. For our satellites and deep space mission Turbo convolutional code and LDPC code are the two main area of thrust for future mission	

	• **Turbo Convolution Code** **Parallel-Concatenated Convolutional Codes** (PCCC), known as turbo codes, allows structure through concatenation and randomness through interleaving. ISRO is planning to use this turbo code for human space program. • **Low Density Parity Checks Code (LDPC)** The another important error correcting code, whose performance close to Shannon limit is known as low density parity check code. LDPC codes have a remarkable performance with iterative decoding that is very close to the Shannon limit. When compared to the decoding algorithm of convolution code, LDPC decoding algorithm has more parallelization, low implementation complexity, low decoding latency, as well as no error-floors at high SNR as turbo code. The next generation satellite communication systems e.g. digital video broadcast satellite/terrestrial (DVB-S2/T2) have readily adopted LDPC code for FEC, mostly due to its near Shannon performance at very low signal to noise ratio. However, the channel code performance also depends upon the modulation scheme. The use of advanced channel coding techniques (e.g. TC and LDPC codes) is the state-of-the-art technology used in current satellite systems to provide broadcasting services to fixed terminals in the Ku/Ka frequency bands into two-ways (i.e. DVB-S2 in the forward link and DVB-RCS in the return link, respectively), in which the AWGN channel is usually assumed.	
A3	**Sub Area**	**Navigation Satellite Related Technology (SAC)**
A3.1	**Modulators for Navigation Satellites (SAC)** The project Indian Regional Navigation Satellite System (IRNSS) envisages establishment of regional navigation system using a combination of GEO and GSO spacecraft's. NavIC is already providing two types of services restricted and unrestricted services or public domain services in L5 and S Band. Binary Offset Carrier (BOC) and Binary Phase Shift Keying (BPSK) is use for these services. However, in future NavIC satellite ISRO is going to transmit L1 band signal also for better interoperability and compatibility. It is required to comply the power spectral density of MBOC modulation.	
A3.2	**Coding Scheme (SAC)** In NavIC signal, it is being planned to transmit L1 band signal for better interoperability and compatibility. So there will be a need to develop custom channel coding of navigation signals.	
A3.3	**Optical Interconnects for High Speed Signal and LO distribution (SAC)** There is a need for High Bandwidth (BW) serial data transmissions. Optical Interconnects are required to minimize power consumption, mass and volume. They are practically lossless propagation in an optical fiber within a Digital sub-systems module. The other significant advantages are Immunity to Electromagnetic Interference (EMI) and Electro Magnetic Compatibility (EMC), are mechanically flexible and galvanically isolated and provides low phase noise degradation.	

A3.4	**High-Performance DSP for Software Defined Payloads (SAC)** To meet the requirement of high speed and to reconfigure software defined payloads, a high performance DSP processor which can meet space electronics quality guidelines are required. Their performance should be benchmarked for following applications. 1. DVB-S2 modem: 2 Gb/s transmit, 1 Gb/s receive 2. FFT (complex 16 bit fixed-point): 150 GOPS (Giga Operations Per Second)
A3.5	**Digital Cancellation Scheme for High-Order Passive Intermodulation Interference (SAC)** Passive InterModulation (PIM) is a phenomenon that additional signals at new frequencies (not only the harmonic frequencies) are generated when signals containing two or more different frequencies are processed at the passive devices, such as duplexes, cable connectors, waveguides and antennas. PIM would worsen the antenna Gain-to-noise-Temperature (G/ T) value, thereby further disrupting the whole system. A full-digital PIM canceling adaptive scheme can be explored based on LMS algorithm.
A3.6	**Onboard Clock Ensemble for clock anomaly handling (SAC)** To improve the clock accuracy in future navigation payloads it is required to generate the output frequency signal based on an ensemble of input clocks with optimized performance and improved robustness by clock anomalies handling. Following three algorithms can be developed: Measurement Filtering (MF), based on a cascade of low-pass recursive filters with exponential window functions. Clock Fault Detection and Correction (CFDC), with associated logic based on MF outputs, onboard Clock Ensemble (ONCLE), based on weighted averaging according to filtered frequency information covering clock anomaly handling.
A3.7	**FPGA/ASIC Design Methodology (SAC)** Following areas for research in FPGA/ASIC Design for onboard signal processing: • 65 nm, 28 nm FD SOI to be evaluated for low power ASIC development for future high speed Digital Subsystems • Formal Verification to Verify SEU Mitigation Techniques for increasing design reliability • High Level Design Methodology for faster design rollout
A4	**Sub Area** — **Photonic Communication Technologies (SAC)**
A4.1	**Implementation of advanced Quantum Key Distribution (QKD) protocols (SAC)** Quantum key distribution is an emerging technique in the field of quantum communication, which guarantees sharing of an unconditionally secured key between two parties by exploiting fundamental no-cloning principle of quantum mechanics. QKD will be highly required in the field of banking, defence and other key strategic area of any country for a secure communication in coming future due to the advancement of computing power.

	For sharing the key, various steps such as qubit exchange, public discussion, key distillation processes etc. are required to be followed as per the underlying QKD protocol. For some of the well-known protocols such as BB84, B92, decoy state etc are already being in test bed / demonstration stage for implementation. It is required to explore more advanced QKD protocols with salient features such as higher efficiency, robust against eavesdropping attack, highly secure along with higher secure key distribution rates for advanced implementation.
A4.2	**Development of Single photon sources (SAC)** One of the critical components of quantum communication systems is the single-photon source. Other than the popular weak-coherent pulse lasers and entangled photon sources, some other current technologies that need to be developed to generate single photon-like emissions.
A4.3	**Heralded Photon Source (SAC)** An input pump photon gets down converted to two photons via spontaneous parametric down-conversion (SPDC), within a non-linear medium under appropriate phase-matching conditions. One of the photon of the pairs is detected to determine the emission of the other with a high probability, this is called heralding. With proper research in improving the count rate with a high heralding efficiency, it can be used as a pseudo-on demand single-photon source.
A4.4	**Semi-conductor based single-photon source (SAC)** Exciting an electron in a quantum confined semiconductor from valence to conduction band, the excited state is called an exciton. Spontaneous decay of this exciton emits single-photon. This is basic principle of Quantum Dot (QD) single photon sources. This decay of exciton can also be stimulated with an external pump. Current state of the art QD-single photon sources use III-V semiconductors (InAs, GaAs, etc.), with various types of photonic structures. The state-of-the-art research is also pushing towards QD based heralded sources.
A4.5	**Single photon detectors (SPD) (SAC)** Single-photon detectors typically work by sensing an electrical signal that results from the absorption of a photon. Single photon detectors or single photon counting modules with high detection efficiency and low noise are desirable for visible (~800nm) and IR region (~1550nm). The developed SPD or single photon-counting module should have features like high detection efficiency, high-count rate, low dead time, very low dark counts/dark noise with operation over visible and/or IR wavelength range.
A4.6	**Simulation CODE for satellite based QKD architecture (SAC)** A suitable CODE is needed which can help to design and accurately model the experimentation of the existing QKD protocols and deliver the required analysis. Besides

	a system-engineering toolkit for modelling, simulation, analysis and operation of satellite based QKD architecture, the simulation code/toolkit should be well structured to enable detailed modelling architecture for the analysis of a full system (including link budget analysis, QBER, secure key rate etc) for different QKD protocols.
A4.7	**Microwave photonic True-Time Delay Beam forming (SAC)** Photonics allows the implementation of TTD beam forming networks with advantages e.g. lightweight, small size, wideband operation, flexibility, remote capability, and immunity to EMI without problems associated with microwave implementations. In many applications, fast beam steering is required to track Earth stations from Low Earth Orbit (LEO) satellites. MEO and GEO applications will also be benefited from fast steering. Two popular architectures are: 1) Optical beam former based on a fast tuneable laser and 2) Optical beam former based on a fast switch and dispersive fibre. At present OBFN with Photonic Integrated Chip (PIC) is also realized which promising approach for practical PS implementation based on microwave photonics, due to increased stability, drastically minimized size and weight, and possibility of low operating power. The scope of the work shall include theoretical background, design and development of OBFN with possible measurements in Ka/W/V bands.
A4.8	**Microwave photonic Phase Shifter (SAC)** MicroWave Photonics (MWP) holds great promise for many applications including Radio Frequency (RF) phase shifters and filters. MWP benefits from established photonic phase manipulation techniques and has the inherent advantage of broad bandwidths and immunity to RF interference. Hence, it is desirable to have an MWP phase shifter that can induce a continuously tunable 360° phase shift over a broad bandwidth with minimal insertion loss, small amplitude fluctuations and is preferably integrated on a chip with a small footprint and overall low power consumption.
A4.9	**Microwave photonic wide band tuneable filters (SAC)** Very wide continuous tuning range together with very high-resolution, has been a difficult challenge to achieve using traditional electronic filters as they are usually fixed, both in central frequency and bandwidth. This sometimes limit the flexibility of the overall SatCom system. Microwave photonic signal processing offers the means to mitigate this problem. Efforts are needed to conceptualize and design for wide tuning range as well as the high Q with photonics technologies. The re-configurability of microwave photonic filters is attractive because of its potential to enable more dynamic microwave photonic systems. Hence, it is desirable to have: a). Single passband and multi-pass band filters of both band pass and band notch type having features like: ultra-wideband continuous tunability (Ku/KaW/V), low loss, capable of RF gain, high resolution, large stopband rejection, low noise figure and reconfigurability of 3-dB bandwidth.

	b) Single/Multi-passband filter that is feature rich as described above but is also switchable between a bandpass filter and a stopband notch filter using simple and rapid control.
A4.10	**Microwave photonic Analog-to-digital conversion (SAC)** Although there is a significant progress in analog-to-digital conversion, the sampling speed of the state-of-the-art electronics is still the bottleneck. This is where the use of optical /photonics technologies to achieve analog-to-digital conversion is of great interest due to the technological breakthrough in pulsed laser sources, which can produce ultra-narrow and high rate optical sampling pulses with a timing jitter significantly below that of its electronic counterpart. The flexibility required for future telecom payloads will require aggregate data throughputs will have to be handled onboard, creating the need for effective, ADC/DSP high speed links. Hence it is desirable to have a Photonically-Assisted ADCs (PADC) that can offer significant advantages in terms of high speed sampling, high bandwidth, high SNR and SFDR range, ultra-low jitter, immunity to EMI/EMC etc. for superior performance in SatCom microwave bands.
A4.11	**Microwave photonic generation of arbitrary microwave waveforms (SAC)** Generation of specialized waveforms has several applications such as communication (multiple access, high speed, multipath propagation, channel measurement), high resolution imaging (biology, medical tomography and spectroscopy) etc. Electronic Arbitrary Waveform Generation (AWG) is widely used and based on high speed and high-resolution Digital to Analog Converter (DAC) which is limited by the speed of DAC, has high timing jitter, limited Time Bandwidth Product (TBWP) and is susceptible to Electromagnetic Interference (EMI). To circumvent these issues, photonic techniques for arbitrary waveform generation can be leveraged due to its inherent advantages associated with photonic technologies such as broad bandwidth, compatible with fibre signal distribution, reconfigurability, tunability, immunity to EMI and small size and light weight. Thus, it is desirable to have arbitrary waveform generator developed using MWP techniques that would significantly improve their key features like timing jitter, Time Bandwidth Product (TBWP), enables scalability and long-term stability.
A4.12	**Optical Frequency Comb (SAC)** Optical Frequency Comb (OFC) is a laser source whose spectrum consists of a series of discrete, equally spaced frequency lines where stability of the line spacing is controlled by a radio frequency or microwave source. OFCs are now central to a new generation of optical clocks that are 100 times more accurate than today's best time-keeping systems. Applications: A frequency comb allows a direct link from radio frequency standards to optical frequencies. Current frequency standards such as atomic clocks operate in the microwave region of the spectrum, and the frequency comb brings the accuracy of such clocks into the optical part of the electromagnetic spectrum with more precise GPS technology and high-precision spectroscopy.

A4.13	**Ultra low noise optical amplifiers (SAC)** Optical amplifiers using erbium doped fibres are used to enhance optical power either at transmitting end or to boost the power at the receiving end. The photonic devices used for detection have sensitivity of typically -24dBm. In this case a very low noise amplifier are needed which can detect the feeble signal and increase the sensitivity of system to a level of -60/65 dBm or less.	
A4.14	**Forward Error Control (FEC) Schemes for high data rate optical communications (SAC)** To enhance the performance optical communication system Forward Error Correction (FEC) schemes like Low Density Parity Check (LDPC) codes, Reed-Solomon (RS) codes, Turbo codes, convolutional codes, Trellis-Coded Modulation (TCM) etc. are important. The net coding gain offered by these schemes could be in the range of 3 to 6 dB with hard decision decoding of the component codes for an output bit-error rate (BER) of 10^{-9} for the data rates of up to 1 Gbps or more. Further improvement in coding gain can be achieved by soft decision decoding. The area of research includes simulation of these FEC schemes to provide sufficient coding gain and to validate the outcomes by implementation on hardware for the data rates of upto few Gbps and the BER of ~ 10^{-9}.	
A4.15	**Photonic integrated circuits (SAC)** Photonic integrated circuits are chip-scale, low-power, and light weight in developments. Current trends in spacecraft engineering are towards miniaturization of payload sub-systems and microwave photonic components (e.g. oscillators, filters, mixers, beam formers) can be attractive only if they are manufactured by integrated micro photonic technologies. Different processing technologies are used for variety of optical components. Like, Silicon on Insulator (SOI), SiO2/SiN, InP, GaAs and LiNbO3 are the major technologies used for Optical components. This vision is for the development of an integrated optical chip consisting of upto major six significant components such as laser source, waveguides, optical modulator, CMOS intelligence, photo-detector and passive assembly etc. This is to envisage to have continuous increase in On-Chip densities resulting high data rates.	
A5	**Sub Area**	**Atomic Clock-Navigation Related Technology (SAC)**
	SAC is pursuing the R&D of indigenous atomic clocks for India's navigation programme – IRNSS (NavIC). The key concepts of atomic clocks involve atomic spectroscopy; RF & microwave electronics; microwave cavities; optics; low noise detection schemes and digital electronics. In view of supporting the in-house R&D activities, further detailed theoretical modelling can aid the practical work.	

A5.1	**Rubidium atomic clock modelling and theoretical studies on fundamental limitations in detection schemes and stabilities of atomic frequency standards (SAC)** A detailed analytical modelling of rubidium atomic clock is to be performed. This should include the modelling of atomic signal and its features and the locking of crystal oscillator using the atomic signal. The signal-to-noise ratio in an atomic clock depends on the detection noise present in the system. Low noise detectors and low noise electronics have to be employed in order to reach better clock stabilities. Thorough studies on the best possible detection schemes is needed to employ the efficient methodology in compact space clocks.	
A5.2	**Coherent Population Trapping based schemes for atomic clocks (SAC)** In the Coherent Population Trapping scheme, the use of microwave cavities can be avoided to build atomic clocks. This can, in principle, bring down the size to a considerable extent. The recent advances in chip-scale atomic clocks has been possible due to CPT methods. Initial theoretical and experimental studies are required towards the space based atomic clocks.	
A5.3	**Studies on light-shift effects in atomic clocks and analyses of onboard clock jumps (SAC)** Rubidium atomic clocks are the widely used clocks in GNSS for space based navigation. These Rb clocks are prone to onboard frequency jumps, which results in the error on the navigation signals. It is of utmost importance to understand the source of the jumps in the Rb clocks. The primafacie understanding has brought to notice that light-shift effect is the main cause of these jumps. However, a detailed study is needed to quantitatively understand the physics behind these jumps. Moreover, in this study the other potential parameters such as the radiation effect, magnetic effects etc need to be addressed which may result in giving rise to clock frequency jumps.	
A6	**Sub Area**	**Development of Ferrite Material for Space Use (SAC)**
A6.1	Microwave circulators and isolators are used in communication payloads to improve impedance matching and to avoid multiple reflections. Ferrite material is used in the waveguide junctions because of its non-reciprocal properties, resulting in circulation when magnetized. The scope of the proposed research: 1. Low power and High power Wideband Coaxial circulator 2. High power waveguide circulator at Q-V band and millimeter wave 3. Ferrite Phase shifter 4. High power and low power Ferrite switches	
A7	**Sub Area**	**Amplifier Technology (SAC)**
A7.1	The next generation satellite communication systems requires high output power, small size, low weight, high efficiency and high reliability amplifiers. The amplifiers utilized in	

various communication & navigational payloads includes low, medium & high power amplifiers over the different frequencies ranging from UHF to Q/V-bands. GaAs and GaN based Monolithic Microwave Integrated Circuits (MMICs) technologies and discrete devices are being utilized for the design & realization of amplifier circuits. In addition to amplifiers, few MMIC based circuits like digital attenuators, phase shifters, voltage variable attenuators, switches etc. are also designed, realized and successfully used in various payloads in the development of channel amplifiers and Solid State Power Amplifiers (SSPA). At the lower end of frequency spectrum, at UHF to C-band, availability of GaN technology is offering newer breakthrough in realizing the power amplifiers which may even be replacing TWTA in future satellites. The Indian Regional Navigational Satellite System (IRNSS) provides regional navigation satellite system using a combination of GEO and GSO spacecraft over the Indian region. GaN based SSPA are emerging as a viable alternative to TWT amplifiers especially at L and S-band used in these navigation satellites.

- Wideband, high power SSPA and channel amplifiers in L, S, C, Ku, Ka & Q-bands.
- GaN based high power compact SSPAs at L & S-Band.
- High power amplifier MMIC designs.
- State-of-the-art technology for design & development of compact SSPA at Q/V-band with waveguide RF interfaces.
- Spatial power combining techniques at millimetre wave frequencies.
- High efficiency CW SSPAs with associated thermal & power management.
- Thermal modelling & thermal simulations of MMIC power amplifiers.
- Modelling & simulation of entire amplifier module consisting of MMICs for the effects of bond-wires, package cavity etc. on RF performance at Ku-band & beyond.
- Design & development of ASIC for the tele-command interface control circuit for channel amplifier & SSPAs.
- Design & development of high isolation switches and voltage variable attenuators at Ku & Ka-band.

A8 Sub Area: Reconfigurable Filters for Satellite Communication (SAC)

The use of reconfigurable payloads in satellite provides significant advantage over current state-of-art satellite configurations. Re-configurability of payload allows for multimode and multifunctional operation. Agility opens the way for reconfigurable payloads that can be tuned during mission time while in orbit. The ability to reconfigure the operating frequency band offers key advantage to adapt long-lifetime satellites to rapidly evolving user requirements.

A8.1 Mechanically Tunable waveguide cavity filters (SAC)

a) Bellow-Mounted Tunable Filters:

Waveguide cavity filters have been widely used in satellites, due to the high-Q and high-power handling capability. In addition, cross-coupled circular-waveguide dual-mode filters, typically operating in TE113 mode, offer mass and size reduction and

	excellent RF performance. Mechanically tunable waveguide cavity filter maintains both High-Q and high-power-handling capabilities. A mechanically tunable waveguide filter can be implemented using bellows. The bellows-mounted tunable filter offers a very low loss performance over a wide tuning range. A very stable transmission response over a very wide tuning range is also a distinctive feature of this technique. However, there is a tradeoff between RF and mechanical performance when designing a bellows profile. Mechanical operating characteristics are maximized by increasing the number and amplitude of convolutions, whereas RF performance relies on bellows with fewer convolutions. **b) Fully Tunable TE011 Cavity Filters** A fully tunable filter for a completely flexible transponder requires tunability of both the bandwidth and center frequency of the filter. RF performance of the filter should be maintained over wide tuning range. In cylindrical cavity filter operating in TE011 mode, electric field strength and current distribution approach zero at the edge of the cavity end walls making it possible to use tuning discs without Q degradation, which in turn leads to the potential for incorporating small and low power consumption motors due to the contactless tuning feature. A movable plunger with diameter smaller than or equal to that of the cavity is used for filter tuning. The A contactless plunger is used to provide a reactive short-circuit condition at the back of the metal disc ensuring good electrical contact, creating a near short circuit condition. This type of plungers consists of quarter-wavelength transformers. The three-section plunger incorporates two low-impedance sections and one high-impedance section. Providing an RF enclosure to the resonator prevents unwanted modes from interfering and degrading the operating TE011 mode. The achieved Q of approximately 10,000 for a Ku band filter is reported in the literature. This design, however, has narrow spurious free window due to presence of low-Q TM111 mode.
A8.2	**Coaxial Tunable Filters (SAC)** Coaxial resonators offer moderate-Q and have been implemented for satellite channel-filtering applications. Coaxial technology is suitable for tunable filter applications because of the ease of tuning, which is a well-known characteristic of coaxial resonators.
A9	**Sub Area** — **Synthesis and Analysis of Microwave Filters Based on Available Computational Methods (SAC)**
A9.1	To design a microwave filter, synthesis of electrical circuit is required. Synthesis generates complex polynomial for filter transfer function. Coupling matrix synthesis is a popular approach for extraction of the electrical parameters from the complex polynomials. The extracted parameters of coupling matrix are the circuit building blocks for a required filter response realization. The coupling matrix can be configured/modified for any desired topology of the filter and its corresponding (transmission/Reflection) response. Prospective and retrospective use of the coupling matrix for any desired RF response for adaptive resonator topology can be very helpful for time efficient and better electrical performance designs.

	Software development for numerical electromagnetic analysis and optimization of standard geometries like rectangular, circular, coaxial resonator based microwave filters with GUI will initiate efforts towards indigenization of EM solvers. Numerical electromagnetic techniques like Mode matching, FEM, FDTD can be used depending the nature of geometry. The existing Commercial EM tools are highly expensive and hence good amount of foreign exchange can be saved after successful completion of this activity.	
A10	**Sub Area**	**Channelized Power Output Configuration Design and Analysis of EPC for Synthesizers (SAC)**
A10.1	The next generation of digital subsystems require very high current channelized power, high reliability protection mechanisms, stringent load regulation, fast dynamic response over wide range of load variations, good power efficiency and compact size. This requires an optimized power converter design along with a suitable channelization network. Power converter design has challenges of handling very high output currents with help of synchronous rectifiers, high bandwidth closed loop response with type-2 compensation network, tight regulations over line-load-temperature variations, Minimal PARD and high efficiency. Whereas, Channelization network has challenges of handling high power switch operations and designing sophisticated protection mechanisms. The scope of the proposed research: • converter with detailed close loop stability analysis. • Power loss optimization techniques for high current outputs. • Isolated feedback network design with minimal stability implications. • Low noise cascaded filter designs for attenuation of switching ripples. • Reverse voltage protected high power switch design, with load current sense and fold back protection circuits. • ASIC/HMC based solutions for single high power output DC-DC converter.	
A11	**Sub Area**	**Theoretical Analysis & Realization of Singular Electronic Power Conditioner (EPC) Approach for Integrated Pay-loads in Communication Satellites (SAC)**
A11.1	The scope of the proposed research: • Complete theoretical analysis of EPC including modelling and simulation with suitable topology selected • Incorporation of advanced techniques to miniaturize the size and increase the efficiency of the EPC like soft switching etc. • Designing of efficient PCB layout maintaining signal integrity and minimum noise in sensitive low voltage high current lines like those of an FPGA • Design and implementation of turn-on and turn-off delay circuits between various output voltage lines which are within a subsystem like FPGA and between two or more subsystems	

	• Design and implementation of separate telecommand circuit to enable switching of transmission supply of EPC on-board • Realization and delivery of EPC with compliance of electrical specifications of all of the subsystems.	
A11.2	**Integrated EPC for Multiple Subsystem Stacks: Individual Control of Commanding, Over Current Protection and Other Protection Mechanisms for EPC and Intended Subsystems (SAC)** The scope of the proposed research: Theoretical study and analysis of advanced EPCs, which can supply power to multiple subsystem stacks, which involve several challenges viz. • Electrical circuit modelling and simulation of circuit. • Supplying power to multiple subsystems and meeting output voltage sequencing requirement of each individual. • Dynamic switching load with fast transient response and converter stability. • Selectable RF load at spacecraft through Telecommand. • Protection of EPC in case of single/ multiple subsystem failures such that there is no impact on remaining subsystems if one or multiple subsystems fail to which EPC is supplying power. • Thermal effects of subsystem failures on EPC.	
A12	**Sub Area**	**Switching GaN based EPC for High Power SSPA (SAC)**
A12.1	The scope of the proposed research: • Study of Gate drive circuit of GaN HEMT devices • Spice based modeling and simulation of GaN HEMT driver circuit. • Power circuit topology for efficient use of GaN HEMT devices. • High output power EPC of 300-500W working at high Switching frequency. • Use of Hybrid planer magnetics for miniaturization. • Thick film hybrid HMC for realization of control circuit for further miniaturization of package.	
A13	**Sub Area**	**Travelling Wave Tube Amplifier (SAC)**
A13.1	Travelling Wave Tube Amplifier is one of the critical technology element used for efficient high power amplification in space borne payloads. Amongst all microwave amplifiers, TWTA offers unique combination of power, gain, efficiency and bandwidth. Research opportunity in the field of TWTA is primarily oriented around development of large signal simulation tools, study & development of special UHV grade materials & special coating techniques on UHV material suitable for high temperature brazing, characterization of Secondary Electron Emission & work function of various metallic & non-metallic surfaces & methods for improving SEE characteristics, high temperature stress & strain	

	measurement techniques in complex shapes, design & development of long life high reliable space cathode. Future roadmap is directed towards very high peak power Pulse TWTAs for radar applications, Q/V band CW TWTAs, folded waveguide TWTA and Coupled cavity TWTAs for higher frequency band power amplification. Research is also needed for brazed Helix technology useful for higher CW power. Apart from conventional Helical slow wave structure based TWTA, thrust is required to explore new technology domain in this area which includes cold cathode TWTA for better thermal management, Flexible TWTAs for dynamic allocation of frequency, BW & power, Filtered Helix TWTA to have clean harmonic performance, Seredyne TWTA with inbuilt frequency conversion & Mini/compact TWTA for better real estate management.	
A14	**Sub Area**	**Receiver & Frequency Sources Technologies (SAC)**
A14.1	The scope of the proposed research: 1) Beam Forming Receiver 2) Receiver Design for Doppler Shift 3) Flexible Receivers in terms of frequency and bandwidth 4) Design and development of RF switches, VVA and VGA upto Q/V band 5) Fully integrated Receiver (RF, LO & DC/DC in single package) 6) Medium Power Beacon Sources 7) Design of Synthesizer ICsf	
A15	**Sub Area**	**System Engineering (SAC)**
A15.1	**System Studies on Free space optical communication (SAC)** The scope of the proposed research: • Development of Antenna Tracking and Pointing (ATP) module along with ATP algorithm, to maintain narrower beam-width line of sight between transmitter and receiver stations irrespective of disturbances created due to satellite platform and atmosphere. • As the atmosphere greatly affects the optical link, studies on cloud free field of view to supplement cloud free line of sight (CFLOS) Cover for Free-space optical link over Indian region is required. • System studies related to different Modulation Schemes like PPM, PSK, etc. for efficient transmission and development of optical modulators with these modulation schemes • Development of High Power Laser transmitter to support interplanetary links. • Design of miniaturized optics and optoelectronics for compact optical terminals.	

A15.2	**Software Defined radio based Satellite architectures for Future Satcom systems (SAC)** The scope of the proposed research: • Common RF transceiver (single chip/module) having RF front end and Digital subsystems (direct sampling based ADC and DAC modules) to operate from UHF to Ku band frequencies. • Studies and implementation of different signal processing algorithms for regenerative processing and flexibility in terms of channelization and bandwidth. • Development of integrated wideband RF front end with LNA, Bandpass Filters & PLL on RF Transceiver module. • Development of Direct Sampling based ADC and DAC modules which can be integrated with wide band RF front end.
A15.3	**Hybrid Satellite/Terrestrial networks and their compatibility with 5G cellular system (SAC)** The scope of the proposed research: • Studies on Satellite – Terrestrial system architecture compatible with 5G Networks. • Channel modelling considering both land-mobile and earth-to-space channels. • Investigation of MIMO, precoding and other signal processing techniques for enhancing capacity of mobile satellite systems and ensuring coexistence of terrestrial and satellite systems. • Protocol level integration of satellite and terrestrial system and development of satellite-5G testbed. • Investigations on satellite platforms and terminal architectures complementing terrestrial 5G networks.
A15.4	**Development of signal processing and resource allocation algorithms for multi gigahertz on-board processors (SAC)** The scope of the proposed research: • Development of signal analysis algorithms for wideband signals (multi-gigahertz bandwidth). Sparse signal analysis/compressed sensing based algorithms can be targeted. • Development of translucent processing algorithms which bridge transparent and regenerative payloads through partially decoding packets on satellite. • Development of algorithms for beam-hopping, digital beamforming, and precoding for efficient spatial allocation of on-board resources. • Satellite system design and architecture for multi-gigahertz signal processing payload.
A15.5	**Studies on Advanced Navigation systems (SAC)** The scope of the proposed research: • Use of IRNSS signals for navigation with “signals of opportunity” of terrestrial networks.

	• Systems studies for autonomous satellite navigation. • Development of simulation tools for situation awareness for navigation end users supporting their mission planning. Such tools will consider the complete navigation systems and provide the information about the system accuracy, availability, integrity and reliability for any operational situation. • End-to-end performance analysis of IRNSS signals in LMS channels using software/ hardware simulation platform. • Research on security features of navigation signals such as anti-spoof and message authentication. • Studies on navigation signal generation and multiplexing using multicarrier constant envelope modulation schemes. • Research in utilizing space service volume capability of GNSS signals. • Clock ensemble algorithm development for improvement of on-board timing system performance.	
A15.6	**Microwave Photonics development subsystems for: (SAC)** • RF-Photonics Conversion • Photonics RF Filtering • Wavelength Division Multiplexing/de-multiplexing • Optical non-blocking Switch network to cater multi-beam switching. • Optical Beamforming Network	
A16	**Sub Area**	**Digital Technology (SAC)**
A16.1	**Digital Processors for High Throughput Satellites (SAC)** The scope of the proposed research: 1. Development of integrated wideband, direct sampling data converters and RF transceivers. 2. Development of on-board partially or fully reconfigurable, failure tolerant, ultra-scale FPGA based signal processing system 3. Development of multi-channel wideband signal processing system for digital beamforming and channelization in broadband multibeam communication payloads.	
B	**Area**	**SATCOM and SATNAV Applications and associated technologies (SAC)**
	Satcom and Navigation Applications Area (SNAA) of SAC mainly focuses on satellite Navigation as well as communication related applications as well as enabling technologies.	
B1	**Sub Area**	**SATCOM Applications and Technology Development (SAC)**
	Space Applications Centre, ISRO, Ahmedabad is responsible for SATCOM Applications and Technology development for eventual use of Societal and Strategic users of the country. Besides meeting the application needs, the Centre continues to work on	

	development of state of the art technologies for SATCOM with an intent to indigenise the technology and product development. The centre focuses on development of indigenous technologies and capacity building to support all types of SATCOM services within country.	
B1.1	**Sub Area**	**Baseband Technology Development (SAC)**
B1.1.1	**Design, Simulation and Development of Ground Receiver with improved probability of ship detection for space (Satellite) based AIS (Automatic Identification System) network (SAC)** The scope of the proposed research: • System design and Performance Analysis with advanced S-AIS payload configuration (other than store and forward payload implemented by ISRO). The proposal should include end-to-end system design, advance payload configuration, expected performance and performance comparison with respect to store and forward payload backed by suitable mathematical analysis and simulation. • Advanced AIS receiver design to improve probability of ship detection. The proposal should clearly bring out the targeted specifications, design methodology and novelty to make it more effective. Researchers are encouraged to include techniques like waveform cancellations and demodulation techniques under low SNR conditions in their proposal. Architecture for its real-time implementation will add value to the proposal.	
B1.1.2	**Non Orthogonal Multiple Access (NOMA) based Multi-beam High Throughput Satellite /Ultra High Throughput Satellite System (SAC)** NOMA-based multi-beam satellite systems including mathematical analysis and the applicability of integrating NOMA to satellite systems from a system-level point of view.	
B1.1.3	**Algorithm and Implementation of real-time Wideband Spectrum Sensing (WSS) and Automatic Modulation Recognition (AMR) system for Blind Signal Detection (SAC)** Efficient spectrum sensing coupled with automatic modulation recognition system. Another problem of interest includes blind scrambler identification and channel coding technique identification.	
B1.1.4	**Advance Baseband Technologies for Mobile Satellite Service (SAC)** To analyse the different channel models and “propose, develop & implement” efficient protocol stack for voice communication between terrestrial and MSS network. It is envisaged to propose technologies to use upcoming 5G technologies and ISRO MSS network for IoT and M2M communication applications.	
B1.1.5	**Baseband Technology for Search And Rescue (SAR) systems of ISRO (SAC)** The proposed research areas in this field are: • Development of MEO-SAR emergency locator transmitters with their LUT processing algorithm.	

	• Development proposal in interference resistant waveform for sensor data reporting in burst mode of transmission that can offer better quality of service. • Proposal on development of Mixed signal ASICs for SAR user terminals are encouraged.
B1.1.6	**MSS/DRT Network for data collection from Oceanic Platform (SAC)** To innovate and propose design of ASICs, Low profile planer antenna system with beam-forming capability and suitable waveform for robust communication and leading to low power miniaturized system realization. A very low bit rate (25-300 bps), fast acquisition, spectrally efficient spread spectrum burst demodulator design will add value to the proposal.
B1.1.7	**Baseband Sub-systems of Ground Network with multi-homing capabilities for Gaganyaan (SAC)** To propose a custom protocol stack for seamless multimedia communication over multi-homing network.
B1.1.8	**Design and Simulation of digital beam-forming / electronic beam steering-techniques for high frequency COTM/SOTM (Communication on the Move / Satcom on the Move) applications (SAC)** To design and develop efficient electronic beam steering system with interference protection features for S/Ku/Ka band of operations. The research is proposed for mechanically steerable antenna system of small size as well as hybrid system for aero-mobile applications.
B1.1.9	**Design and Development of Header Compression and QoS Mechanism for IP data communication services over satellite network (SAC)** Header compression is a mechanism that compresses the IP header in a packet before the packet is transmitted. Header compression reduces network overhead and speeds up the transmission of either Real-Time Transport Protocol (RTP) or Transmission Control Protocol (TCP) packets. The RTP Header Compression over Satellite Links feature allows to use RTP header compression over an asymmetric link (such as a satellite link), where the uplink and downlink connections are on separate interfaces. This feature provides improved system performance by reducing network overhead and speeding up transmission of RTP packets. Quality of Service (QoS) is the collective effect of service performance, which impacts the degree of satisfaction of a user of the service. QoS is to the ability of a network element (e.g. an application, host or router) to have some level of assurance that its traffic and service requirements can be satisfied. To enable QoS requires the co-operation of all protocol layers from top-to-bottom, as well as every network element from end-to-end.
B1.1.10	**Development of indigenous baseband technology (MF-TDMA with DVB-S2x tech) (SAC)** To offer innovative solution in form of algorithm, hardware implementation or system level design as part of their proposal and be the co-pilot in indigenous development efforts being put up by ISRO.

B1.1.11	**Development of baseband signal processing elements for aero-mobile terminals (SAC)** To offer innovative design of UHTS class of Modem Technology (wide and faster acquisition with capability to support large drifts) supporting state of the art access schemes, Mobility management techniques for aero-mobile broadband and other signal processing techniques for low cost terminal realization.	
B1.1.12	**Enhanced Spread Spectrum Aloha Technology Development (SAC)** To submit proposal for ESSA system simulation and Receiver design and implementation plan.	
B1.1.13	**Development of low bit rate DSSS/CDMA burst and continuous mode communication modem (SAC)** The spread spectrum technology is one of the promising candidate for many SATCOM networks as it offers many advantages of anti-jamming, PSD reduction & secure communication etc. Low bit rate (50bps to 16kbps) Direct Sequence Spread Spectrum modem can be directly utilized in low aperture Ku/Ka-Band terminals in VSAT networks & Voice/Data communication for IDRSS Network. Burst DSSS modem has challenging design in terms of optimized preamble & acquisition time for low bit rate operations. Another enhanced version may incorporate interference cancellation feature for improving efficiency in ALOHA mode of operation. Burst Modems can be used in different applications utilizing burst mode communications such as messaging/asset tracking etc. Whereas continuous DSSS modems have additional design challenge of acquisition in presence of data modulation, highly agile loops for handling extremely low SNR & higher signal dynamics (Doppler rate/jerk etc.). These modems provide reliable & continuous connectivity for voice/data communication applications.	
B1.1.14	**IoT enabled terminal development (SAC)** Implementation of IoT/M2M via satellite deals with mainly two issues: First, the physical layer level: terminal related constraints (limited in power, energy, and antenna size), channel (potentially with masking and multipath) and the space segment to ensure proper Implementation of low power, low cost terminals, waveforms and other sub-system technology to support IoT over Satellite & Terrestrial networks.	
B1.2	**Sub Area**	**Ground Segment Network and Hardware Technology Development (SAC)**
B1.2.1	**Indigenous VSAT sub-systems technology development (SAC)** To innovate and submit proposal for indigenous design and development of following sub-system of VSAT technology: • Mass manufactural efficient low cost design solutions of RF Sub-systems (BDC, BUC, SSPA etc.). • Rapid Deployable VSATs: Rapidly deployable VSAT terminals is another important technology for quick emergency disaster communication. These design of such terminals involves advanced antenna & RF technology including supported by state	

	of the art baseband technology for quick antenna pointing & establishing reliable communication link from a mobile platform having limited power/space availability. These terminals should also extend interface to terrestrial devices for providing backhaul connectivity through satellite.
B1.2.2	**Development of Low Profile Ku/Ka band terminal for Mobile Satellite Service (SAC)** To submit proposal for Ka-band Mobile Satellite Service system solutions with their feasibility and recommendations; Proposals for terminal design, Proposal for protocol stack development for seamless overlay with existing MSS services, in case needed. Innovative ideas are encouraged from researchers towards providing reliable MSS services in Ka-band along with sub-system design proposals.
B1.2.3	**Portable HUB baseband system development (ESIM) (SAC)** Recognising that there is a need for global broadband mobile-satellite communications and that part of this need could be met by allowing ESIMs to communicate with fixed-satellite services (FSS). The advances in satellite and earth station technology make ESIMs the best solution for users on the move and bring the benefits of high performance FSS networks to communities that have yet to benefit from true broadband offerings. Proposed research is: Proposal for design, development and implementation of different ESIMs.
B1.2.4	**Internet Protocol for Satellite Network (SAC)** The scope of the proposed research: • Reducing the routing overhead of a dynamic QoS routing in a different traffic is a challenge. • GEO satellites have advantage of technological maturity and good coverage but due to high delay and attenuation limits, transmitting real time information becomes a problem. A single layer LEO satellite network has bad performance on transmitting long distance. How to combine advantage of both the satellite to improve network performance. • Multicasting datagram in the satellite networks to achieve larger coverage area on the terrestrial infrastructure.
B1.2.5	**Adaptive protocol (SAC)** The scope of the proposed research: • End-to-end protocol design that dynamically switches from one interface to the other, transparently to the application and its user. • Protocol stack development to support adaptiveness • Development of principles to allow on-the-fly protocol selection in wireless mobile networks. Identify techniques for deciding when to select a new protocol, for switching protocols, and for efficiently implementing this feature in software and hardware.
B1.2.6	**SATCOM in Non-Terrestrial Network (NTN) of 5G system and sub-system design for facilitating NTN component in 5G using SATCOM (SAC)**

B1.2.7	**Q/V Band Propagation Study (SAC)** Very High Impairments, No models available for Indian Region, will serve as vital input for future satellite designs and deciding QOS and availability figures. Modelling and Associated Mathematical studies, Development or Realization of RF Subsystems, Beacon from satellite, Pan India study; Academia & Foreign Collaboration may be explored.	
B1.3	**Sub Area**	**ASIC Technology Development (SAC)**
B1.3.1	**Design and Development of miniaturized, multiband S, L, UHF band) / S-band Low Power Wideband Transceiver Mixed Signal ASIC for SATCOM terminal (SAC)** The scope of the proposed research: • The mixed signal ASIC will comprise of comprise of front-end LNA, filter, transceiver with built-in LO for full duplex operations, gain& filter blocks, ADC-DAC etc. The selected architecture should have all imbalance measurement and compensation techniques built into it. The device calibration feature will be an added advantage. • The research proposal should address the development of low power, low cost custom RF wideband transceiver ASIC in S/L/UHF-band to support communication using miniaturized handheld and battery operated SATCOM terminals. The proposal should include all specifications of each sub-block, the reconfiguration parameters etc.	
B1.3.2	**Design and Development of RF-ASIC to support implementation of low-power, cost-effective electronic beam steering capabilities for aero- mobile communication in Ka/Ku band (SAC)** The research in the field is required in the design and implementation of RFIC for miniaturized, power and cost efficient terminal implementation.	
B1.3.3	**Development of low cost terminal with COTS ASICs for RF front-end (MMIC and LTCC based RF Frontend for miniaturization) (SAC)** The scope of the proposed research: • Modem ASIC development for Ultra High Data Rate System (100 Mbps- 2 Gbps). • Mixed Signal ASIC development with built-in low cost SATCOM transceiver for various low power IoT applications.	
B1.3.4	**Power Saving technique (Backend ASIC design) of ultra-low power SDM ASIC (SAC)** The research in the field is required to implement various power saving technique in frontend/backend ASIC design to suspend functionality of partial design or full design based on applications.	
B1.4	**Sub Area**	**Applications and Tools Development (SAC)**
B1.4.1	**Development of Hybrid Network for Real-time Person or Asset Tracking using Machine to Machine Communication Technology and Indian Navigation System (SAC)** The scope of the proposed research: • Development of Spectrum and Waveform Analysis tool using low cost SDR platforms.	

	• Hub NMS, NCP and Web-based tools for effective Decision Support System. • Propagation studies, Advance FMT development and inclusion for improved QoS. • SATCOM System definition, Unified protocol stack and Test Bed development of 5G with NTN element. • NTN standardization efforts and Capacity Development Activities. • Development of Mobility management algorithm and Hub Network Management System for different application.	
B1.5	**Sub Area**	**New Frontiers in SATCOM (SAC)**
B1.5.1	**Development of Proto-type for Quantum Key Distribution System (SAC)** Research Arears for developing Core Technology elements: (i) Bright Single Photon Source (ii) Bright Entangled Photon Source (iii) Single Photon Detectors with high efficiency and low dark counts (iv) Polarization Compensation (v) Quantum Homodyne Detection (vi) Quantum Interferometers (vii) Study and development of efficient QKD protocols for Satellite to Ground quantum link (viii) Feasibility study and development of efficient protocols for Satellite based quantum imaging (ix) Feasibility study and development of efficient protocols for Satellite based quantum radars (x) Quantum range and angle sensing technique (xi) Stealth target design (xii) Quantum technologies at microwave frequency etc. Apart from above core areas, following are some associated area of research: (i) Quantum-resistant encryption algorithms (ii) Quantum Image Processing (QIP)	
B1.5.2	**Development of HDR/UHDR modems for Home broadband service (SAC)** The major design challenges for such UHDR modems include reconfigurable hardware platform & high-speed data processing subsystems including demodulation loops, high throughput advanced FEC Encoder/Decoders & multi-core baseband data processing engines.	
B1.5.3	**Indigenization of Future HTS Gateways (SAC)** It is proposed to innovate and propose efficient design of 9/11m antenna system, RF-sub-systems, NavIC based TFGU, Hub Monitoring and Control System, Antenna Tracking System etc. which can reduce design and production lead time, be cost effective and mass producible design.	

B2	Sub Area	SATNAV Applications and Technology Development (SAC)
	NavIC signals in general may be prone to interference with other GNSS satellite signals such as GPS, Galileo and Beidou and NavIC S-band signal in particular may experience interference from commercially used S band spectrum by Wi-Fi and WiMax services. Therefore, interference/jamming detection and mitigation algorithms and techniques need to be developed.	
B2.1.1	**Interference/Jamming Detection & Mitigation (SAC)** The scope of the proposed research: 1. Pulse Blanking 2. Adaptive Notch Filtering 3. Control Radiation Pattern Antenna (CRPA) 4. Spectral filtering using FFT/IFFT 5. Short time Fourier Transform 6. Wavelet Transform 7. Robust Statics	
B2.1.2	**Spoofing Detection/Mitigation (SAC)** Spoofing of GNSS signals has drawn a lot of attention due to increased risk among GNSS users especially by defense and strategic users. Spoofing is the intentional transmission of fake GNSS signals to divert users from their true position. This may fool a receiver to output wrong position. This may be fatal in a strategic scenario. The scope of the proposed research: 1) AGC gain monitoring 2) Spoofing Detection using RAIM with/without INS Coupling 3) Angle of Arrival Discrimination 4) Signal Spatial Correlation 5) Correlation of Propagation-Dependent observable 6) Polarization Discrimination or Dual Polarization Antenna (DPA) 7) Sum of Squares (SOS) Detector 8) Cross-checks between code & carrier-phase measurements from different frequency bands	
B2.1.3	**Configurable GNSS Universal Correlator Architecture ASIC (SAC)** New GNSS Baseband ASICs process maximum civilian GNSS signals due to multiple advantages such as increased PVT accuracy, availability etc. A universal configurable correlator architecture comprising of acquisition and tracking channels is therefore required to process civilian GNSS signals which have: 1) Various modulations (BPSK, MBOC, TMBOC, QMBOC, AltBOC) 2) PRN code length, 3) Chip rate	

B2.1.4	**GNSS-INS Integration (SAC)** GNSS signals are highly vulnerable to jamming but provide very accurate position. However, INS cannot be jammed but position accuracy degrades after some time. Therefore, GNSS-INS integration is one of the most robust solutions to be offered to navigation users. Such kind of receivers are very useful where GNSS signals are obstructed such as inside long tunnels, indoors, etc. Following are the techniques which can be addressed: 1) Loosely-coupled GNSS and INS integration 2) Tightly-coupled GNSS and INS integration. 3) Deep Coupled integration
B2.1.5	**GNSS weak signal Acquisition & Tracking (SAC)** [A] High Sensitivity Receiver The sensitivity of a baseband signal processing (acquisition & tracking), is critical for a GNSS receiver to function in weak signal environments. Typical Line of Sight (LOS) GNSS signals power is around -130 dBm. Attenuation due to foliage, tall buildings results in signal power level upto -160 dBm or lower. Very efficient FPGA hardware implementation is required. High Sensitivity Navigation Receiver for Commercial Applications GNSS Receiver Algorithms for Space Service volume/Lunar mission type applications [B] Open Loop Navigation Signal Processing
B2.1.6	**Development of CMOS /BiCMOS RFIC (SAC)** To develop CMOS/BiCMOS RFIC to have multi-chip module solution along-with indigenous baseband ASIC and to have miniaturized NavIC Rx. for various applications. Commercial and space grade RFIC is required with the following blocks: 1) Tri band integer PLL/ Fractional PLL. 2) Triband / wideband LNA 3) Image reject Mixer Narrow band and wideband 4) Variable gain amplifier 5) Low drop out regulator 6) Complex filter for IF range 7) SPI interface to control the overall receiver block 8) Multibit ADC: Multibit low power ADC is required to meet high Anti-jamming capability. ADC specifications: a. Bit resolution: 16 bit b. SFDR: 86dB c. Sampling clock: 50MHz d. ENOB: >14 bits 9) MEMs based TCXO: Satellite application of space grade Navic receiver required high acceleration sensitive TCXO. MEMs based TCXO can meet the 0.5 ppb/g acceleration sensitivity. MEMs based capacitive resonator is suitable choice for space application and piezo resistive resonator can meet ground application.

B2.1.7	**Construction and selection of balanced and near balanced Pseudorandom Sequences with lower correlation values and large linear complexity (SAC)** To establish a method for selection and to search a set of candidate codes for the upcoming navigation satellites: Considering future navigation signals there is an increasing demand of spreading codes families of various Length, family size, and correlation properties. Following are the codes which may be studied and new codes with optimum properties may be developed: 1) Concatenations and Truncations of Gold codes, 2) Weil codes with padding insertion and cyclic truncation 3) Z4 family codes 4) Random Codes 5) Kasami Sequence 6) BCH codes 7) LDPC Codes This work involves selection criteria determination and to compare the performance of a set of codes against the performance parameter matrix to find optimum codes. Performance parameters for code selection include auto- and cross-correlation histograms at various Doppler offsets, excess line weight and values for the low delay auto-correlation functions.
B2.1.8	**Multi constellation and multi frequency GNSS positioning algorithms (SAC)** The scope of the proposed research: Satellite Selection, triple Frequency for Ambiguity resolution, Inter system/signal/ frequency bias estimation.
B2.1.9	**GNSS Security, Vulnerability, Encryption, Authentication (SAC)** The scope of the proposed research: 1) Key exchange Algorithms: IRNSS RS service involves encryption and to improve security, encryption keys are changed regularly to avoid brute force attack and cryptanalysis from unauthorized users. IRNSS RS receivers deployed in field will have to be communicated with changed keys. 2) Key Distribution/Key management for GNSS Strategic applications 3) RAIM, Advanced RAIM and TRAIM Algorithms 4) Spreading Code Encryption for very long code using stream/block ciphers 5) Block-chain technology for authentication/security of GNSS services 6) Geo-encryption 7) Message Authentication Techniques for NavIC
B2.1.10	**Navigation Simulators (SAC)** The design and development cycle of GNSS Receivers is highly dependent on the signals provided by GNSS Simulators right from conceptualization to product development cycle. Following are important research area in Navigation Signal Simulation:

	1) Low cost NavIC Simulator 2) Handheld GNSS Simulator 3) Interference Simulator for GNSS bands 4) Low cost Navigation Educational Kit 5) Seamless indoor/outdoor navigation with NavIC and other Signals of Opportunity/ Technologies
B2.1.11	**Software Defined Radio (SDR) based NavIC system Development (SAC)** The scope of the proposed research: 1) NavIC-GNSS receiver 2) NavIC-GNSS simulator 3) SDR for RTK and PPP 4) SDR for Pseudolite-based navigation System.
B2.1.12	**Pseudolite-NavIC-GNSS receiver algorithm Development (SAC)** Following topics may be taken for development of new algorithms: 1) Successive Interference Cancellation to mitigate near-far problem in Pseudolite 2) Pseudolite-NavIC-GNSS hybrid user position algorithm/EKF/UKF based algorithms 3) Time Synchronization algorithms 4) Signal acquisition & tracking in Pulse-CDMA mode 5) Pseudolite Indoor positioning algorithms 6) Multipath mitigation algorithm 7) Algorithms for bi-directional Pseudolite based system for Mars, Moon etc.
B2.1.13	**Differential Positioning & RTK Receiver Algorithm Development for NavIC (SAC)** Following algorithms may be developed: 1) Integer Ambiguity (AI) resolution in carrier-phase measurements 2) Carrier Phase Based Positioning 3) Low-cost single frequency RTK receiver algorithms 4) RTK correction generation & dissemination module in RTCM format 5) GNSS Corrections: RTK, RTK-PPP, PPP 6) Network RTK for India 7) NTRIP based interface for NavIC 8) High accuracy Post-processed RTK positioning algorithms
B2.1.14	**Precise Point Positioning (PPP) Receiver Algorithms (SAC)** Precise Point Positioning (PPP) is a technique using Global Navigation Satellite System (GNSS) satellites to achieve decimetre level or better position accuracy using a single receiver. This technique relies on the availability of precise ephemeris and clock products from a network of reference receivers without using a base station. PPP also requires a dual frequency receiver with precise carrier range measurements. However, now a day's single frequency PPP is also being attempted by the researchers. Precision usually in this case means a horizontal position accuracy of 10 cm or better.

	1) Precise ephemeris & clock product generation & dissemination 2) EKF-based PPP algorithms 3) Low-cost single-frequency PPP algorithms 4) Multi-constellation PPP 5) PPP-AR (Ambiguity Resolution) algorithms 6) High accuracy Post-processed PPP algorithms 7) PPP-INS positioning algorithms 8) PPP-RTK positioning algorithms
B2.1.15	**Atmospheric Studies (SAC)** NavIC L5 and S Band signals along with other GNSS signals can be used to estimation of better ionospheric TEC and model development. These signals are useful for ionospheric scintillation studies and also for tropospheric model development. • Ionospheric Studies Over the Indian Region a. Real-time ionospheric TEC & scintillation map generation b. Ionospheric Tomography model development • Tropospheric Studies a. Tropospheric model development for Indian region • Tropospheric mapping function development
B2.1.16	**Other Topics (SAC)** 1) Short delay Multipath Mitigation Techniques in GNSS Receivers 2) S band interference in Satcom and Satnav applications 3) Spoofing Detection: Using Multiple antennas, Signal time of arrival 4) NavIC data processing in RTKLIB 5) Robust positioning with Civilian GNSS signals. 6) Ground Testing of Rubidium Atomic Clocks. 7) Navigation Solution with Multi-Constellation. 8) Ground Characterization of On-board Atomic Clock performance. 9) Effect of Wi-Fi, 3G/4G/5G on NavIC/GNSS Signals. 10) Design of Global Indian Navigation constellation. 11) Cooperative & peer to peer positioning 12) Positioning for Autonomous systems (robot, drones, marine vehicles) 13) Time to First Fix (TTFF) reduction in GNSS receivers 14) Assisted NavIC 15) Design and development of NavIC Data Post-processing Tools (GAMIT, Berneze, RTKLIB like s/w) 16) Design of NavIC Advisory generation and dissemination (like GPS's NanU)

B2.2	Sub Area	GNSS Applications (SAC)
B2.2.1	**Precision Agriculture: (SAC)** India is an agricultural country. Produce of agricultural products can be optimized using GNSS techniques such as RTK and PPP. Following algorithms/solutions may be developed: 1) RTK based precision agriculture solutions. 2) PPP based precision agriculture solutions.	
B2.2.2	**Mobile Application Development (SAC)** The proposed research areas in this field are: • Mobile applications can be developed for fusion of GNSS and sensor data for location based services. • NavIC-GNSS mobile App for location based services using GIS map • Mobile-based train tracking App for Railways • NavIC/GNSS based Navigation App for blind/physically impaired person • Android Studio based positioning using raw NavIC/GNSS observables • NavIC/GNSS Anomaly reporting	
B2.2.3	**Scientific Applications (SAC)** The proposed research areas in this field are: 1) Modelling Equatorial TEC perturbation 2) Forecasting of ionospheric Scintillation 3) Integrated Water Vapour (IWV) estimation using GNSS 4) Cyclone tracking & Precipitation prediction 5) Seismic studies using TEC	
B2.2.4	**Other Applications (SAC)** 1) Marine Applications 2) Disaster Management using GNSS & GAGAN 3) NavIC/GNSS based navigation for UAV 4) GIS application involving NavIC/GAGAN and Bhuwan 5) GNSS based spacecraft attitude determination 6) Application/software for vehicle parking system 7) NavIC based biometric bracelet 8) Low Cost Surveying and Land Record Mapping using NavIC & GAGAN Receivers 9) GNSS for Smart City 10) IRNSS Messaging based Applications 11) Timing Applications of NavIC	

B3	**Location based applications using NavIC Data (NRSC)** Satellite navigation systems offer important contributions to variety of scientific research work. New and improved data analysis techniques, jointly with a growing variety of available measurements encouraged development of more and more scientific applications in various fields. It is expected that evolving new systems such as NavIC and Galileo will contribute to further improvements in the current available applications as well to promote new applications.Location Based Services (LBS) include applications that depend on the user location to provide a service/information that is relevant to the user at that location. LBS normally use mobile devices with positioning ability to provide the service or information to the user.
B4	**Local TEC model for NER through IRNSS + GPS + GAGAN Receiver (NESAC)** Using current DF IRNSS + GPS + GAGAN Receivers, generation of local TEC modeland characterization of Ionospheric Anomalies. This will provide reliable delay calculation which may lead to better positional accuracy. Earthquake induced TEC anomaly will be also tried to study so that any usable earthquake precursor may be identified and used for earthquake early warning.
B5	**Wireless communication channel noise characterization for hilly urban areas (NESAC)** A study of the various noise effects impairing wireless communication in a hilly urbanenvironment like Shillong is to be modeled and characterized. This may help in mobiletower location optimization and transmit power and modulation scheme optimization.
C	**Area** — **Antenna Systems (SAC)**
C1	**Multi-Feed per Beam (MFB) Feed Cluster Design for Multiple Beam Antennas (SAC)** To develop various types of coupling mechanisms of orthogonal dominant mode couplers in feed cluster configurations, while orthogonality between different feed clusters are maintained. The interested bands are Ka, Ku, C-bands of satellite communication.
C2	**Partially Reflecting Surface (PRS) focal plane feed array for multiple beam antennas (SAC)** To develop various types of PRS surfaces for illumination of reflector antennas at S, Ka, Ku, C bands. Use of metasurface may also be explored in enhancing the bandwidth of antenna.
C3	**Wide angle Scanning with Low scan loss Rotating Reflector antenna systems (SAC)** To develop a reflector only rotation antenna system having the properties of low scan loss and wide angle scanning. Literature study indicates bifocal and multifocal single or dual reflector antenna systems can be potential candidates. Preferred antenna band is Ka-band.

C4	**Contoured Beam Microstrip Reflectarray Antennas at Ku and Ka-bands (SAC)** To develop a contoured beam phase synthesis technique for reflectarray antenna. SAC is interested in RF design & development of a Ku-Tx-Rx band Contoured beam reflectarray antenna system.
C5	**Membrane based planar array antenna for onboard applications (SAC)** To develop a material to build membrane based planar array antenna to cater in C-band and S-band applications for interplanetary missions. The research proposals are sought on the development of such membrane antennas which can address high efficiency, bandwidth, power handling capabilities and stowing and deployment features.
C6	**Gap Waveguide based Feeding Network (SAC)** To develop a high efficiency planar array antenna systems at higher frequencies viz. Ka, Q/V band and mm wave frequencies with advanced technologies like GAP waveguide array antennas. Gap waveguide antenna systems has the advantage of easy fabrication with conventional techniques and comparable loss with its waveguide counter parts.
C7	**Design and Development of antenna systems based on Graphene technology (SAC)** To develop antenna systems at THz frequencies using graphene material. The interested areas are beam scanning and frequency agility. Moreover, research proposals are also invited for usage of graphene technology for enhancing the antenna performance at Ka-band applications.
C8	**Antenna Measurement using Time Domain Method to Mitigate Multipath Reflections (SAC)** The research problem involves the use of Antenna Time-Domain Measurement Technique employing for radiation pattern measurements and applying suitable algorithms to mitigate multipath reflections. Simulation modelling is required to be developed to compute the reflected wave from nearby scatterers and then minimize these with proper selection of pulse width, duration, rise time etc. The proposal shall include the development of software gating algorithm as well as its implementation for the development of hardware gating controller to mitigate the limitation in dynamic range. This technique is essentially required to carry out measurements at low frequencies viz. UHF so that it can avoid the need of large size absorbers at such low frequencies.
C9	**Machine Learning in Antenna design (SAC)** Machine learning can provide accelerated antenna design process while maintaining high accuracy levels, with a minimization of error and time saving, along with a possible prediction of the antenna behavior, a better computational efficiency and reduced number of necessary simulations. In smart antenna arrays, the objective of the graceful degradation of the beamforming and beam steering performance, can

	be achieved by reconfiguring the array when an element is found to be defective. This reconfiguration can be obtained by optimization using Machine learning and Support Vector Machines (SVM). SVMs are a good candidate for the solution of antenna array processing problems such as beamforming and the angle of arrival estimation, because these algorithms provide superior performance in generalization ability and computational complexity.	
C10	**Far field Mathematical Absorber Reflection Suppression (F-MARS) for Antenna Test Ranges (SAC)** The development of MARS algorithm for suppressing the effect of reflections in antenna test environment mainly due to absorber layout and the change in incidence angle. Algorithm need to be developed considering the Far-field antenna test facility, its positioners and other control instruments. These ranges are to be modeled and ripples in the measured Radiation pattern (Both amplitude and Phase) are to be minimized. Modelling of chamber absorber layout and the mechanical Pedestals being used for Antenna Mounting are to be modeled and computation of regular/irregular sampled data followed by suitable Equivalent Multipath Level (EMPL) technique to obtain data in regular grid with upper bound uncertainty level.	
D	**Area**	**Electro-Optical Sensor Technology (SAC)**
D1	**Sub Area**	**EO Sensor System Design, Simulation and Characterization (SAC)**
D1.1	**Development of physics-based models for simulation of Electro-Optical Sensors (SAC)** An end-to-end model shall be developed starting from simulation of ground targets, illumination conditions, observation geometry, intervening medium/atmosphere, at-sensor radiance, sensor characteristics, boundary conditions (under which the sensor is performing) leading to digital counts. The input scene to the sensor model can be typical laboratory targets, actual ground 3D targets or images acquired from the other sensors.	
D1.2	**Design and development of on-board calibration system for absolute calibration of EO sensors (SAC)** To design and develop on-board calibration sources e.g. Blackbody for IR calibration (high emissive nano-particle coating), diffuser plate for VIS/NIR calibration, doped diffusers or active sources for spectral calibration. These systems are required to be compact and stable over long period of time. This can significantly help in improving the accuracy of payload data	
D1.3	**Design and development of a proto-type LIDAR system (SAC)** Design and development of high power continuous and pulsed lasers, large optical apertures, focal plane based on time gated detectors and interferometry systems leading to proto-type development of LIDAR system.	

D1.4	**Image Simulators and Algorithms for Characterization of Imaging Sensors (SAC)** Design and development of hardware and software system for generating suitable synthetic scenes having required dynamic variations, development of methods/algorithms for EO sensor performance estimation using the sensor output and evaluation in terms of image quality metrics, etc.	
D1.5	**System configuration and simulation studies for Sparse Aperture telescope (SAC)** **Common Secondary Mirror Multi Telescopes** This emerging field offers significant research opportunities in terms of studying feasible system configuration, perform extensive simulation studies, develop advanced processing techniques for generating improved resolution imagery from the acquired data, etc. The research will lead to development of a small-scale prototype for demonstration and validation of design and processing techniques.	
D1.6	**System design, simulation studies and control system development for Segmented mirrors based EO sensor (SAC)** To develop a small-scale prototype for demonstration and validation of the involved technology elements, and processing techniques.	
D1.7	**Extending Super Resolution concept to Spectral Domain (SAC)** To develop models and simulation studies to demonstrate the concept and also develop a proto-type system to study hardware implementation aspects.	
D1.8	**Design and development of Active cavity radiometers (SAC)** Study active cavity radiometers, define feasible system configuration, perform extensive simulation studies and develop a proto-type model for demonstration.	
D1.9	**Long range 3D imaging using flash LIDARs (SAC)** To design and develop a proto-type 3D flash LIDAR imaging systems that involves system configuration studies, simulation studies, realization of small scale proto-type with COTS components, development of electronics system with embedded processing capabilities, performance characterization and field studies.	
D1.10	**Design and development of high-resolution imaging system with active optics correction elements (SAC)** To design and develop an active optics correction based EO sensors for future missions.	
D2	**Sub Area**	**Focal Plane Detection Systems (SAC)**
D2.1	**CCD and CMOS sensor fabrication process modelling and simulation studies (SAC)** Modelling of CMOS and CCD based optical image sensor fabrication process to estimate key performance parameters such as quantum efficiency, cross talk, sensitivity, dynamic range, charge handling capacity, etc.	

D2.2	**Modelling and simulation studies on Superlattice structure-based SWIR and MWIR sensors (SAC)** TCAD and MATLAB modelling of Type-II superlattice structure for sensitivity in IR ranges, development of methodologies for higher temperature operation by suitably modifying stack to reduce dark current and development of techniques for enhancement of Quantum efficiency beyond 50%.
D2.3	**Design and development of high power NIR and SWIR LASER modules (SAC)** To design and development of laser head, amplifier circuits, pump sources, drivers, diffractive optical elements, cooling system etc for long distance 3D measurement and flash LIDAR applications.
D2.4	**Thermal Background modelling for Integrated IR Detector Cooler Assembly (IDDCA) (SAC)** Development of physics-based model for estimation of thermal background in a given IDDCA configuration using various software tools such ray-tracing tool, thermal analysis tool, result visualization and quantitative estimation in Labview/Matlab etc. These modelling efforts will help in understanding the source of thermal background and enable improved design of IDDCA and the imaging system.
D2.5	**Design and development of drive circuits for CCD sensors (SAC)** To design and develop CCD based image sensor drive circuitry for minimization of noise floor and clock induced charges. The design shall adopt different circuit design techniques for shaping CCD clocks (-10V to +15V, drive capacitance: 500pF, frequency: 10MHz) for maximization of stable video and reference sampling zones.
D2.6	**Design and development of Photonics Integrated Circuits (PIC) based system on chip (SAC)** To design and develop integrated circuits for clock and data multiplexing / demultiplexing, modulation/ demodulation, laser driver, laser and photodetector, packaging of imaging detector with PIC based chipset to miniaturize focal plane detector proximity electronics.
D2.7	**Design and development of High speed Event detector (SAC)** To design and develop of CMOS image sensor pixels for automatic thresholding, target detection and tracking applications.
D2.8	**Development of process flow for CMOS chip debug (SAC)** The research opportunities exist in the de-processing, micro-surgery, hot electron imaging active micro-probing, and IR microscopy, etc for debugging of CMOS chips. To develop some of the chip debug tools to be able to debug complex chips. These sort of tools and technologies would also help to identify possible reasons for yield reduction.
D2.9	**CMOS pixel process development at 180nm (SAC)** The research opportunities exist in Pinned photodiode-based pixel (7 to 50micron pitch) development to meet charge handling requirement from 30ke to 3Me. This research will lead to development of pixel process for TDI CMOS focal plane arrays.

D2.10	**Packaging of Infrared detector arrays for multispectral application (SAC)** This research focuses on development of techniques using industry for butting of smaller arrays to form large arrays, integration of filter / cold shield / lens, assembly of detector onto cold table mounted with flexible thermal link for cooling down to 50K and minimization of thermal load by utilizing new interconnect materials.
D2.11	**Design and development of Ultraviolet detectors based on wideband gap semiconductors (SAC)** The scope of research includes comprehensive review of literature in the field, understand the mechanism of these sensors, inherent advantages and disadvantages of those detectors, explore suitable materials for producing these detectors, etc.
D2.12	**Development of curved sensors (SAC)** The scope of research includes exploring various fabrication process technologies, carry out design and simulation studies for pixel architecture for curved sensors, address issues/challenges in the field and attempt to develop proto-type curved sensor for characterization studies. This research will lead to adaption of such curved sensors in the future spaceborne missions.
D2.13	**Metamaterial based absorber surfaces for image sensors applications (SAC)** To explore CMOS compatible metamaterial absorber structure, simulation of absorption characteristics of these materials, explore fabrication feasibility, etc.
D3	**Sub Area** — **Design and Development of Optical Systems (SAC)**
D3.1	**Optical systems using freeform surfaces (SAC)** To utilize freeform surfaces to design future telescopes with wide field of view. One particular study can be carried out to show how the freeform optics can be used to miniaturize/improve the performance of an optical system. Another interesting research activity is the fabrication and testing of free form surfaces (IR/ Visible range).
D3.2	**Chalcogenide optics in dual-band IR Applications (SAC)** The scope of the proposed research: • Study of feasibility for use of chalcogenide glasses for spaceborne remote sensing application. • Design of dual band IR common optics using chalcogenide glasses that will image both MWIR and LWIR on the same or different imaging sensors. • Collaboration with indigenous industry and universities for realization of Chalcogenide optics via. Fabrication, assembly and testing for achieving the desired performance goals.
D3.3	**Adaptive test techniques for Aspherics and Freeform surfaces (SAC)** Deformable mirrror will be developed and characterised by industry/academia, which can further be integrated in to the test set up at SAC.

D3.4	**Test set up using Spatial Light Modulator (SAC)** The DM-based null test is adaptive and economical compared to CGH; however, DM has limited range of stroke of actuators and can only compensate mild free form departures. A high-definition (i.e., >1080 pixels, <5 μm pitch) spatial light modulator (SLM) circumvents the limitation of the DM. The phase conjugation algorithm is additionally utilized for turning resolvable fringes into null ones. Finally, local severe surface figure error is extracted from the SLM phase and the null test result by reverse optimization based on ray trace model. TDP is already going on. Collaboration is sought on development of algorithm. The commonly used algorithms for such applications are widely used in Machine Learning applications. Some of the algorithms are • Stochastic Parallel Gradient Descent • Simplex Optimization • Genetic Algorithm • Simulated Annealing Simulation can be carried on supplied data and later verified experimentally at SAC.
D3.5	**Tilted Wave Interferometer (SAC)** The use of aspheric and freeform surfaces becomes more and more important in the design of modern optical systems. These surfaces offer additional degrees of freedom to the optical design, allowing to improve the optical imaging as well as to reduce the number of surfaces needed for an optical design. However, testing of such surfaces is still a difficult task. This issue can be addressed using the technique of Tilted Wave Interferometer.
D3.6	**Optical Design of telescope for space observatory for study of Exoplanets (SAC)** Planets that orbit around other stars are known as Exoplanets. Exoplanets are very hard to see directly with telescopes. They are hidden by the bright glare of the stars they orbit. Therefore, indirect methods such as radial velocity, transit photometry/spectroscopy and timing variation methods are used to detect exoplanets. In some cases, direct imaging method is also used to find exoplanets. Research in this field is invited for the development of optical systems for upcoming exoplanet missions.
D3.7	**Design and development of Volume Holographic Grating (VHG) (SAC)** The scope of the proposed research: • Modelling of the grating with peak efficiency at required wavelength mainly catering to VNIR and SWIR, fabrication and characterization. • Indigenous/ in-house development of the holographic exposure system to record fringe pattern of desired frequency and orientation using photo-polymer coated plane/ curved glass substrate.

	• Indigenous / in-house development of photo-polymer or gelatin like films. • Development of a suitable processing technique so that modulation pattern is accurately reproduced after a wet-dry processing cycle. • Exploring feasibility for space usage and carrying out related testing.
D3.8	**Computer Generated Holograms (CGH) (SAC)** The scope of the proposed research: • Resist (e-beam or photo resist) coating • Electron beam / Direct Write Laser (DWL) Lithography for resist patterning • Resist development, Metallization (E-Beam evaporation) • Lift-off or Wet Chemical Etching for Amplitude CGH and Glass dry etching for Phase CGH.
D3.9	**Design and development of Strip Filters in VNIR spectral range (SAC)** Strip filters are interference filters. The strip filter assembly can be developed using butcher block technique.
D3.10	**Development of band pass filters with controlled thickness variation across the filter length (SAC)** The design of these filters will be done in house. Development of the controlled thickness variation of the coating across the filter will be taken up in collaboration with Academic institutions.
D3.11	**Development of IR filters (SAC)** The proposal is to design the filters in house and get it coated with the help of institutions within India. At present, the thin film lab does not have the facilities to develop the coatings in the IR spectral range.
D3.12	**Development of Rugate Notch Filters (SAC)** Notch filters are optical filters that selectively rejects a portion of the spectrum, while transmitting all the other wavelengths. Notch filters based on the principle of optical interference can be fabricated using Rugate dielectric stack, which provides high reflection in a narrow wavelength region and high transmission outside.
D4	**Sub Area** — **Electronics System Design and Development (SAC)**
D4.1	**Development of Integrated Circuits for Harsh Environment Operation (SAC)** Harsh Environments are defined as environments, which are characterized by high/low temperatures, extreme vibration loads, harsh chemical environment, high radiation etc. The electronics or systems required to operate under such harsh/extreme conditions have application such as in aircraft engines, automotive, oil-well drilling and space exploration like near to Sun and planets like Venus where the surface temperature is appx. >400^{0}C. Hence, there is a requirement of development of electronics and sub-systems (both commercial and space) which can operate under extreme environments.

D4.2	**System Modelling and Controller Development for IR Payloads (SAC)** To develop an executable model of the system including the plant using first principle methods or other methods (using experimental data). MATLAB or other modelling tools can be used for developing the executable model.
D4.3	**ASIC: Design, Simulation, Fabrication and Modelling (SAC)** The scope the activity covers Analog, Digital and Mixed signal ASIC design, simulation, verification, layout, tape-out and fabrication. The main motivation is miniaturization and indigenization of electronics in the form of low power ASICs and ROICs with objective of integrating multiple functionality in a single device. The ultimate goal is to integrate individual blocks to realize "System on Chip (SOC)"
D4.4	**Modelling of Special Components, Interfaces, Hardware (SAC)** Modelling of various state of the art mixed signal devices, detectors, interfaces etc is envisaged. Development of various models of components, detectors, interfaces taking into account mechanical constraints, layout, routing, signal integrity, thermal issues, pcb size, circuit topology, grounding scheme, hardware in the vicinity etc needs to be developed. The development of this kind of integrated model will help in better understanding of the system performance at early stage and faster realization of the hardware.
D4.5	**Generic Multi-Channel Front-End and Digital PID Controller with actuator interface ASIC for Temperature Control (SAC)** Any digital domain based temperature controller has (a) Temperature Sensor (b) Signal conditioner (c) Digitizer (d) PID or On/Off control logic (e) Interface control signals for actuator driver (f) Driver for actuator excitation. ASIC proposed for blocks (b), (c), (d) and (e) is multi-channel (typically eight) independent temperature signal conditioning channel ASIC, with versatile and generic design, planned to support multiple application of temperature control. Offset and gain control in signal conditioner blocks is required to allow temperature control using PRT and Thermistors. 3 PRT, 3 Thermistor and 2 Transistor based channels are planned. Digital interface (LVCMOS/LVDS) is planned for actuator driver control. 2 On/Off actuators control, 4 PID actuator control and 2 motor actuator control are planned. Digital PID controller should be programmable using CAN or any other interface for adaptability to multiple applications.
D4.6	**ASIC development of Generic N-channel MOSFET drivers and PWM generator with integrated Current and Hall Effect sensing mechanism and sigma delta ADC (SAC)** The main objective of development of this ASIC is complete indigenization of space grade motor drive electronics. Generic design of MOSFET driver is aimed for half bridge control. The ASIC envisaged also has integrated current sense amplifier, hall effect sensing, PWM generator and ADC.

D4.7	**Reconfigurable System-On-Chip based solution for satellite on-board computing (SAC)** The scope of the proposed research: • Design and development of On-board computer hardware encompassing mainly Programmable System on chip (PSOC), Rad hard FPGA, high end memories and all standard interface CAN/Spacefibre/Serdes/LVDS interfaces along with SI and PI analysis with industry collaboration. • Soft cores IP design for standard interfaces and Logic • Standard Memory DDR2/3, ONFI controller designs. • External peripheral interfaces design &development. • Embedded processsor/LEON/ARM processor interface with FPGA. • Onboard partial n selective configuration. • Space fibre codec n network design and development.
D4.8	**Real time image processing in on-board Space systems (SAC)** The scope of the proposed research: a. Study and implementation of object detection algorithm for low SNR targets and its real time implementation in on-board FPGA hardware. b. Tracking algorithm development: Kalman for tracking and trajectory prediction. c. Study/development of Optical Flow algorithm for planetary landing. d. DSP based real /near real time data processing for signal analysis and image processing. e. Real Time decision making for Landing System. f. Machine learning techniques along with computer vision techniques need to be studied and implemented for the targets required for obstacle detection, landing site and surveillance. g. Real Time Operating System (RTOS) optimisation for on board I
D4.9	**Power supply systems for Space missions (SAC)** The following technologies are of particular interest in future Power Supply electronics development a. Very Low noise (≤5mV), Low power (<10W), highly efficient (>80%) complying with EMI 461E standard, space grade isolated power supply /module. b. Multi-output (3 to 4 voltage lines in range 3.8V to 24V), high efficiency (>80%), Medium Power (25W – 100W), Low noise (≤15mV) complying with EMI 461E standard isolated space grade power supply c. Development of Hybrid Micro Circuit (HMC) based miniaturised dual output (+3.8V and +5.6 V) DC-DC converters with high efficiency (>75%), medium power (> 30 W), inbuilt EMI filter and having EMI/EMC compliance to MIL-STD-461E.

	d. Development of housekeeping and protection circuitry in the form of HMC to monitor and protect power supply electronics from various fault conditions such as Overvoltage and under-voltage protection, Over temperature protection, Overcurrent protection and Output Short circuit protection e. Development of Rad-hard non-isolated synchronous buck converters for wide input voltage (10-30VDC), adjustable output voltage (from 3V to 80% of Vin) and high output current (>10A).	
D5	**Sub Area**	**EO sensor System AIT and Performance Characterization (SAC)**
D5.1	**Design and development of smart test setups (SAC)** Research and development is proposed for smart test setups for EO sensor testing. The smart setups are easily reconfigurable to cater to variety of sensors, they have fault tolerant designs, and are self-calibrating to enable faster turnaround time and ensure precision measurements of EO sensor performance parameters.	
D5.2	**EMI analysis and mitigation techniques (SAC)** To design and develop EMI analysis tool, which accounts for various noise sources in the sensor chain including electronics component level noise, crosstalk, signal coupling effects, ground noise coupling, engineering noise coupling, etc. and helps to analyse complex EMI scenario, identify the noise sources and help in developing suitable mitigation techniques. Available COTS software modules can be suitably used in the proposed analysis tool.	
D5.3	**Development of new methods for EO sensor performance evaluation (SAC)** SNR and MTF are two key performance parameters that are used as performance markers for comparative studies. Many methods exist for performance evaluation in terms of MTF and SNR, however, considering the stringent requirements of EO sensor performance in upcoming future missions, many new methods are required to be developed. This offers significant research opportunity in this field. We need to develop efficient, simple and robust methods for SNR and MTF measurements. Also, study shall identify new performance markers and develop suitable methods for its implementations.	
D5.4	**Thermal analysis model of harness assemblies (SAC)** Thermal analysis of EO sensors and spacecraft systems are carried out to evolve suitable thermal design and implementation approaches. Generally, thermal analysis of all electronics subsystems are carried out to evolve suitable thermal implementation scheme. However, thermal modelling and analysis of harness assemblies are generally ignored, although they are passive dissipating element in every spacecraft system. Thermal modelling of harness assemblies is very critical as it helps derive rerating specifications, avoid potential arching conditions, helps in improving performance of thermal control system.	

D5.5	**Design and development of machine/deep learning methods for payload test data analysis (SAC)** Large amount of data is acquired during ground testing of EO sensors. These data sets help in analysing EO sensor performance under various operating and environmental conditions. However, analysing huge data sets to bring out minute but potential performance degradations is very difficult with traditional approaches. There is an opportunity to develop machine learning techniques to analyse large amount of data acquired for various EO sensors.
D5.6	**Machine Learning Techniques for Fault Diagnosis using TM data (SAC)** Machine learning techniques can be developed to analyse the large amount of TM data to observe even subtle performance deviations that can help in diagnosing the faults in the operations of EO sensors.
D5.7	**Development of harness embedded panels for plug and play AIT (SAC)** To develop harness embedded panels for Indian remote sensing sensors. The proposed research work involves exploring innovative design of harness embedded panels, structural analysis, usage of smart materials and proto-type development, etc.
D5.8	**Development of efficient algorithm for image reconstruction for compressive imaging sensor (SAC)** To develop efficient algorithm for image reconstruction using the images acquired by a compressive imaging sensor and carry out extensive bench marking against available methods.
D5.9	**Development of robust image quality metric and suitable methods for its estimation using in-orbit images (SAC)** In-orbit image quality evaluation of EO sensors is a continuous evolving research field. This research work envisages development of a robust image quality metrics and suitable methods for its estimation from in-orbit images.
D5.10	**Development of methods for accurate estimation of SNR and MTF from in-orbit images (SAC)** EO sensors undergo extensive ground testing during development phase. However, post launch performance deviations are generally observed due to various instrument effects due to launch loads and orbital environmental conditions. On-board and vicarious calibration methods are employed to assess the in-orbit SNR and MTF performance of EO sensors. However, the achieved accuracies in deriving performance parameters always suffer from limitations either from measurements or the methods itself. The proposed research work will first study the available methods and suggest new approaches for accurate estimation of these performance parameters.

D5.11	**Development of techniques for quantitative estimation of MTF contributions from various elements in the EO imaging sensor chain (SAC)** This research work envisages development of methods/techniques to quantitatively measure/derive MTF contribution from each element in the EO sensor chain. Also, extensive validation studies to be performed using available EO sensor data.	
D5.12	**Design, development and characterization of Spacefiber interface-based data transmission board (SAC)** This research work envisages comprehensive study of Spacefiber interface, design and development of a bread-board functional model and extensive characterization of the developed data transmission board.	
D6	**Sub Area**	**Ground Checkout Systems for EO Payload Testing (SAC)**
D6.1	**Computer based Multichannel High Speed Digital Data Acquisition System (SAC)** Design & development of High Speed Data Acquisition System which involves Data formatter (Data Input – Multi channel, SerDes interface) along with the Data Acquisition Application can be taken up for data transfer rate upto 4.0 Gbps using camera link i/f in-house which will be very useful during the testing of High Resolution EO cameras.	
D6.2	**Comprehensive Automation of Test Benches (SAC)** A scheme is proposed which has a generic architecture to combine instrumentation, data acquisition, parametric evaluation and a final output generation. The 1553 bus based instrumentation provides both the TC and TM functions.	
D6.3	**Knowledgebase Creation and Information Extraction (SAC)** A huge database of information is available for all E/O payloads developed so far by SEDA. This information contains automatically archived test results, TM data, raw data, logs and manually uploaded documents. The information is structured at sub-system level and project level under categories such as Results, Issues, Discussions and Solutions. This will provide contents for to create a knowledge base for future generation projects. An interface on top of this, using Natural Language Processing (NLP) techniques can be developed. This interface shall accept the queries in human-understandable natural language and provide answers by processing the information.	
E	**Area**	**Microwave Sensor Technology (SAC)**
E1	**Sub Area**	**Microwave Sensors (SAC)**
E1.1	**System Study & Analysis (SAC)** The proposed areas of research: • Simulations and system studies to improve the Scatterometer spatial resolution, wind speed range with a target of multi-frequency configuration. • Study of different quantization schemes that can be applied to SAR data that can help in data rate reduction. Also an impact/tradeoff study of the same using simulated/	

	available SAR data keeping in mind different applications such as polarimetry/ interferometry/crop classification. • Software for GPR return signal simulation providing flexibility of changing Soil properties (including soil mixtures as well as layering), variable transmit signal properties (Pulsed/ SFCW) as well as different antenna response.
E1.2	**Transmitter & receiver Technology (SAC)** Various technologies/components/subsystems required for the development of RADAR, Altimeter, scatterometer, humidity/temperature sounder and radiometer for current and future mission of earth observation and planetary program has been developed. The proposed areas of research: 1. Microwave Transmitter & Receiver Technology 2. Millimeter/Submillimeter & Terahertz sensor technology 3. High Power RF Subsystems
E1.3	**In-house developed MMICs (SAC)** Wide spectrum Multi-function MMICs from DC to W-Band namely Low Noise Amplifier, True Time Delay Shifter, Digital Attenuator, Digital Phase Shifter, Sub-Harmonic Mixer, Voltage Controlled Oscillator, Multi Throw Switches, High Power Protection Switch, Multipliers, Driver Amplifier, Multifunction Core Chips.
E1.4	**Indigenously developed LTCC based Trans-receive Integrated Modules (SAC)** Transmit Receive Module are the basic building blocks of an active phased array antenna providing transmit signal, high power amplification and receive signal low noise amplification with digitally controllable amplitude and phase in both transmit and receive paths. C-Band Dual Polarized Transmit Receive Integrated Module with two TR Module (V &H Pol.) with in-situ TR controller in single Package. TR Module realized using indigenous GAETEC Chipset, SAC Designed MMIC High Power Amplifier, Low Noise Amplifier and SAC Fabricated LTCC Substrate. S band Transmit Receive Integrated Module (TRiM) comprises of SAC fabricated LTCC Module having Transmit, Receive Amplification, Digitally controlled Gain and Phase, and In-built Switch Matrix for TRiM Calibration; High Power Duplexer Module with Passive Protection, and GaN based High Power Transmit Module.
E1.5	**LTCC based Receivers (SAC)** S-Band Direct CM Module, a miniaturized heterodyne Receiver is a blend of low power RF front section LTCC Drop-in Module and MIC based wideband, high gain IF amplification section in a compact size for Down converting the received signal to IF level.
E1.6	**Integrated Frequency Generator and Receivers (SAC)** Dual Channel Receivers (V and H polarized) and Frequency Generator of each frequency band is housed in a single Package. Miniaturized integrated package has been realized

	by using Multi-Chip Module based Gain Blocks and Direct Modulation / Demodulation technique. The salient features of this integrated package are that it has a capability of providing High Rx Gain and Low Noise with 10W CW Protection.	
E1.7	**High Frequency Transmitter and Receiver (SAC)** Miniaturized & Light-weight Ka-Band Transmitter comprises of in-house designed MMIC based Frequency Generator & Power amplifier housed in a single package. It generates 1-Watt CW Linear Frequency Modulated (LFM) Tx O/P, LFM LO for Receiver & Clock for Digital Systems using high stability TCXO as reference.	
E2	**Sub Area**	**Microwave sub-systems (SAC)**
E2.1	**Collaborative work with indigenous MMIC foundry for development of GaN MMIC foundry process with Process Design Kit (SAC)** Indigenous availability of GaN MMIC foundry will be extremely useful to reduce dependence on foreign foundries. Following GaN MMIC processes can be targeted i. 250nm gate length process for design of MMIC circuits up to Ku-Band. ii. 100-130nm gate length process for design of MMIC circuits up to Ka-Band.	
E2.2	**Development of discrete GaN devices for High Power Amplifiers (SAC)** GaN devices is the very much the device that is going to be backbone of power amplifiers development, especially for space use. Collaborative work with indigenous organizations and academia for the development of discrete GaN devices for High Power Amplifiers development could be extremely useful. Development work involves the following: i. Development of discrete GaN high power devices up to Ku-Band. ii. Development of non-linear models of these devices required for power amplifier design.	
E2.3	**Spatial Power Combiner (SAC)** Efficient power combining techniques for high power transmitters involving solid state power amplifiers is very much required to improve overall transmitter efficiency and thereby reducing the DC power requirements as well as making the thermal management easier. Especially with the trend of small SAR payloads picking up over the globe, this becomes even more important. Spatial power combiner development would be useful in achieving that goal.	
E2.4	**Waveguide and Coaxial Electromechanical DPDT Switches: Design and development of waveguide and coaxial Electromechanical payloads for future microwave remote sensing payloads, involving the following scope of work (SAC)** The scope of the proposed research i. Design, software modelling and simulation of waveguide and coaxial electromechanical switches at various frequency bands, taking usage in space into consideration. ii. Fabrication, development and qualification of switches.	

E2.5	**RF Absorber sheets for use in RF discrete, LTCC and MMIC packages** The scope of the proposed research i. Design and development of absorber sheets with specified rejection over broadband frequency range. ii. Design and development of multiple absorber sheets with specified strong rejection over narrowband frequency ranges..
E2.6	**C-type and Pi-Type line filters/Feedthroughs for use in RF packages can be taken up to reduce dependence on foreign sources (SAC)**
E2.7	**High power Waveguide Terminations at various frequency bands to provide matched termination for high RF power at termination ports of various subsystems (SAC)**
E2.8	**Core-Chips for Transmit-Receive Module (SAC)** Wideband (10% fractional bandwidth), high power Miniaturized GaAs/GaN based single chip solution for L, S, C and X-Band TR Modules consisting of high-power protection switch, LNA, digital phase shifter, digital attenuator, driver amplifier and power amplifier. The high-power protection switch should be able to handle at least 10 W of input power. Digital phase shifter and digital attenuator, each will be 6 bits with LSB phase shift and attenuation of 5.6250 and 0.5 dB respectively. Power amplifier at all the bands should be able to deliver a minimum 12 W output power for S, C and X-Band. L-Band power amplifier module of the core-chip should be able to deliver at least 40W output power.
E2.9	**Multi-functional RF Module (SAC)** RF-CMOS based programmable Frequency Generator and Central Receiver at L, S and C-Band in a custom-built hermetic package. It should be tele-commandable to select the operational frequency band. Multi-functional module should cater, for each band, a frequency generator and a homodyne receiver. The frequency generator will have a quadrature modulator to upconverter the in-phase and quadrature phase baseband chirp input, a minimum 125 MHz bandwidth, to corresponding microwave frequency. The frequency generator should also generate LO signal for receiver. The homodyne receiver of the multi-functional module should have a high-power protection switch at the input followed by low noise amplifier. The integrated noise figure of the receiver should be better than 4dB. The receiver should have a quadrature demodulator providing the base band in-phase and quadrature phase output. The receiver should have a manual gain control with 30.5dB range and 0.5 dB resolution.
E2.10	**Fractional PLL Synthesizer (SAC)** RF-CMOS based programmable fractional frequency generator covering frequency range from S-Band to X-band. Integrated chip will consist of an ultra-wide band tunable VCO consisting of bank of variable capacitors. High power output, approx.15dBm, for its direct integration with power amplifier module of Transmitter and LO of Receiver. The reference input frequency range of the PLL should be from 5MHz to 250 MHz. It is requested to provide an application to calculate the off-chip loop filter bandwidth.

E2.11	**Ultra-Stable Oscillator (USO) (SAC)** Design and development of USO, it should meet the stringent frequency stability requirement of < 1 part-per-trillion and output power > 10dBm. USO can be either an OCXO or a Rb clock. USO should be followed by a buffer amplifier to reduce its frequency pulling. Operating temperature range of the USO should be -150C to 750C.	
E2.12	**Transmit and Receive Core-Chips at Ka-Band (SAC)** This activity is to design and develop Transmit and Receive Core-chips using GaAs/ GaN at Ka-Band. The transmit core chip should up-convert the baseband in-phase and quadrature phase chirp input signal to 35 GHz. Local Oscillator for up conversion should be generated in the core-chip by using either a PLL or a convention multiplication technique. The reference frequency input should be 250MHz. It should have an output power of 1 W. Receiver core chip should consist of low noise amplification and IQ demodulation for de-ramping of received input. The noise figure and gain of the receiver should be less than 5 dB and better than 85 dB respectively.	
E3	**Sub Area**	**Millimeter, Submillmeter & Terahertz Sensors Technology (SAC)**
E3.1	**mm-wave technology development up to 200GHz (SAC)** Thermal protection systems for long term interplanetary orbiter and lander missions. Understanding atmospheric conditions of various candidate planets/moons Modeling of heat transfer under these conditions Materials development and testing (including effects such as corrosion, etc.) Combined active/passive thermal control systems.	
E3.2	**Design and development of Schottky Barrier Diode-based sub-harmonic Mixers up to 750GHz (SAC)** This project deals with design and development of sub-harmonic mixers at any of three frequency bands covering 450-500GHz, 550-600GHz and 660-720GHz frequency ranges; and able to operate in cryogenic temperatures. The mixers should offer minimum conversion loss and minimum noise temperatures required for meeting the desired system performance.	
E3.3	**Design and development of Schottky Barrier Diode-based frequency multipliers up to 400GHz (SAC)** This project deals with design and development of mm/sub-mm wave frequency multipliers covering 235GHz, 285GHz and 345GHz frequency ranges and are able to operate at cryogenic temperatures of ~80K. The frequency multipliers should offer optimum efficiency and output power required for generating the LO drive for mixer.	
E3.4	**Design and development of Electronically Tunable frequency synthesizers for wide-band receiver (SAC)** Sub-mm wave sources use microwave oscillators followed by amplification and frequency multiplication stages with appropriate filtering to generate LO signals. This project aims	

	at design and development of electronically tunable LO (~10-15% BW) at 225-250GHz; 275-300GHz, 330-360GHz for sub-harmonic mixers at 450-500GHz, 550-600GHz and 660-720GHz respectively.
E3.5	**Design and development of GUNN-diode oscillator based frequency synthesizers (SAC)** This project deals with design and development of Gunn diode based oscillators required for generation of mm-wave LO signals.
E3.6	**Simulations and design of SIS-junction based mixers up to 500 GHz (SAC)** This project deals with design and development of cryogenically cooled (operating at ~ 4K) SIS based mixers at 225-250GHz, 330-360GHz and at 450-500GHz respectively.
E3.7	**Design and development of InP-HEMT based LNA MMICs at mm/sub-mm wave frequencies using MMIC foundry services (SAC)** This project deals with design and development of InP-HEMT based LNA MMICs at mm/sub-mm wave frequencies spanning from few GHz up to 750GHz using suitable MMIC foundry services.
E3.8	**Design and development of Wideband 6-way Power Divider (0.5 - 17GHz) (SAC)** This project deals with design and development of power divider (6-way power divider), which require approximately 20:1 bandwidth with good inter-channel isolation (better than 18 dB) and good insertion loss (max. 5 dB) using strip-line configuration over an ultra-wide frequency band ranging from 0.5 to17GHz.
E3.9	**Design and development of High-speed Digital board for high-end Spectrometers to be used for earth observation and astronomy (SAC)** This project deals with design and development of a modular scalable multichannel ADC board catering to requirement of 3GHz of bandwidth for acquisition with an FPGA for spectrum generation.
E3.10	**System configuration design of Interferometric array telescope (including long baseline interferometry) (SAC)** This project deals with system configuration design, addressing detailed specifications for sub-systems; Interferometric Configuration of telescopes; Phase coherence of the signal received at these telescopes; Different calibration mechanisms; Data Processing of the correlator output.
E3.11	**System configuration design of MM/Sum-mm wave Hyperspectral Atmospheric Sounder for earth's and other planetary atmospheres (SAC)** This project deals with system configuration design addressing detailed specifications for sub-systems; weighting functions for these molecules in different atmospheric conditions; Vertical resolution; channel placement on absorption profiles; Required bandwidth for each channel.

E4	Sub Area	Digital Controls, Data Acquisition, Processing (SAC)
E4.1	**On board control Sub-systems of microwave remote sensing payloads (SAC)** All microwave remote sensing payloads have a central control sub-system called as Payload Controller (PLC). PLC is responsible for control, coordination and status monitoring of all sub-systems of payload. PLC has Mil-Std-1553 Interface with spacecraft On Board Computer, through which it accepts all tele-commands and provides telemetry.	
E4.2	**Rad-Hard by Design (RHBD) Memories IP development (SAC)** **Following RHBD memory IPs for 180nm CMOS process are required for future ASICs:** • Design & Characterization of RHBD volatile memories like Single Port SRAM, Dual port SRAM with size of 32KB to 1MB. • Design & Characterization of RHBD non-volatile memories like EEPROM/Flash and OTP with size of 16KB to 256KB.	
E4.3	**Real Time Operating System (RTOS) optimization for on board Payload Controller (PLC) (SAC)** This proposal is to customize standard RTOS for PLC applications. Open-source RTOS may be customized in terms of optimization for resources (like memory, power, etc) & performance (timing, accuracy, etc) so that it fits in existing PLC hardware. Fault Tolerant (FT) features to be incorporated in design to enhance reliability for space borne applications.	
E4.4	**System on Chip for distributed controller (SAC)** This proposal is to design System on Chip (SoC) with embedded processor, floating point coprocessor, differential I/Os, ADC, oscillator, SRAM and Non volatile memory, etc. This SoC should have fault tolerant features like EDAC, watchdog timer, lock-step processor so that it is usable in space environment. 180nm CMOS process or other suitable process technology may be chosen for design. This SoC is targeted for single chip implementation of T/R module controller for phased array SAR. Integration of digital SoC with RF chip to miniaturization should also be explored.	
E4.5	**On board Wireless data transfer tranceivers (SAC)** This proposal is for design & development of wireless data transfer transceivers for space applications. Wireless transceivers should operate in ISM (2.4GHz) band or other open frequency bands for data rate of 1Mbps with range of 10m. Applications of such transceiver is in intra-satellite data transfer between rotating to stationary sub-systems or Tile control sub-systems. The design should be done with target of fault tolerance so that it is suitable for space applications.	
E4.6	**EDAC IP for FPGA of Solid State Recorder (SAC)** This IP will be useful for design and development of a Solid State Recorder (SSR) based on NAND Flash memories for onboard usage. Flash memories are prone to random bit	

	failures, error correction and detection algorithms needs to be employed to maintain data integrity and reliable operation of these solid state recorders. The main aim of the research would be to develop an efficient error detection/ correction algorithm for NAND flash based Solid State Recorders. Also the research must focus on real time optimal implementation of the ONFI (Open NAND Flash Interface) and EDAC algorithm on FPGA/ASIC.	
E4.7	**Sub Area**	**Advanced Synchronization techniques for distributed sub-systems (SAC)**
	Clock and timing signal synchronization techniques for distributed sub-systems. Both cases of single platform distributed system with wired connection and different platform distributed sub-systems without any connection should be addressed. GNSS disciplined oscillator for clock & timing signal synchronization techniques for space borne application should be explored.	
E4.7.1	**GNSS –Reflectometry Instrument (SAC)** Development of a digital control and processing hardware based on FPGA platform comprising of Navigation Processor, Science Processor and reconfigurable digital processor for GNSS Reflectometry Applications. This H/w platform will also be useful for POD (Precise Orbit Determination) application for LEO satellites.	
E4.7.2	**Signal Processing Platform for Navigation (SAC)** Future generation of landing craft will autonomously map the surface, using a vision or laser based sensor, during the terminal phase of powered descent and then, in real-time, choose and divert to a safe landing site in order to avoid hazards using Hazard Detection and Avoidance techniques. This will also require accurate position and velocity data during descent phase in order to ensure safe soft landing at the pre-designated sites. A suitable digital Hardware platform having control (for controlling sensors), processing (for processing sensor data to detect hazards) and storage (for storing pre-known features of the landing sites) capabilities needs to be evolved to cater to future interplanetary missions for implementing various HDA schemes.	
E4.7.3	**Onboard SAR processor (OBSP) (SAC)** In order to leverage the benefits of onboard processing for SAR missions, the **first and foremost requirement is the ability to generate precise SAR images onboard** the spacecraft. One of the primary benefits of onboard SAR image generation apart from various onboard applications (like target detection, flood inundation map generation for Disaster management) is that, it substantially reduces the SAR sensor data rates for medium and low resolution modes. This capability is particularly essential for various planetary missions wherein downlink rates and earth visibility time are at a premium. The scope of the proposed research: • Processing Element and Hardware Configuration • FPGA configuration and architecture amenable for Real Time SAR processor implementation	

	• Design of various SAR processing IP cores with radiation-tolerant features • Design of fault tolerant SDRAM/DDR/DDR3/DRR4/FLASH memory controllers for space use • Design and development of full ASIC based SAR processor • Configuration, Architecture, interfaces and data distribution scheme for multi-processor based system **Onboard Signal Processor Algorithm:** • Efficient SAR processing algorithms amenable for onboard implementation catering to various SAR operating modes (Spotlight, Stripmap, ScanSAR, Mosaic etc.). • Low latency SAR image generation algorithm for spotlight & sliding spotlight modes with limited bit precision • Design of robust processing algorithms (with low precision arithmetic) for image generation in the absence of accurate spacecraft attitude/pointing/ velocity estimates • Use of High Level Synthesis (HLS) tools for onboard SAR processor implementation on FPGA • Raw SAR Data simulator with the ability to simulate SAR data with motion and attitude errors.
E4.7.4	**Integrated RADAR Digital Receiver and Signal processor (SAC)** Typical functional requirements for any baseband digital subsystems of a RADAR payload include high bandwidth linear frequency modulated signal generation, high speed multi-channel digitization, real time signal processing and high speed data transmission. These functionalities are currently realized using multiple discrete devices/subsystems. The requirements for signal synthesis and acquisition are as follows 1. ADC Sampling Frequency: 750 MHz 2. ADC Resolution: 8 bits or higher (Better than 7-bits ENOB) 3. Number of ADC Channels: 2/4 4. DAC Reconstruction Clock: 1 GHz 5. DAC Resolution: 10 bits or higher 6. Number of DAC Channels: 2 7. Processing Functionality: Data Compression using BAQ (Block Adaptive Quantization) o Design and development of high speed mixed signal ASIC with multi-channel ADC, DAC and with high speed SERDES o Design and development of a System in Package (SIP) module with integrated multi-channel ADC's, DAC's, high speed SERDES along with embedded programmable logic.
E4.7.5	**Raw SAR data compression techniques (SAC)** Raw SAR data is characterized by enormous data volume and high data rates. In order to reduce the onboard data rates and data volume raw data compression based on Block Adaptive Quantization (BAQ) is employed onboard.

	• Identification of efficient and optimal raw data compression algorithms and techniques to achieve better compression ratio without compromising on Signal to Quantization Noise Ratio (SQNR) • Efficient hardware/FPGA implementation of SAR data compression algorithm.	
E4.7.6	**Onboard programmability of Processing elements (SAC)** Current implementation of onboard programmability is limited to tweaking a few programmable onboard parameters and flags. However, for a complex full-fledged onboard processing system, complete onboard programmability of the processing software is essential to cater to data dependent processing (which may be known only after launch). • Design and development of an efficient hardware for complete reprogramming of the onboard signal processing system.	
E4.7.7	**Onboard processing for Application product generation (Disaster management & strategic applications) (SAC)** Onboard implementation of application products deserve priority if fast turn-around time is required. The following are some of the research areas for onboard product generation • **Flood-map generation:** This is a crucial disaster management application. These products are required to be generated at fast turn-around times, hence call for onboard product generation. This processing requires masks for existing water-bodies, so that inundation areas can be clearly demarcated. The extent of flooding can also be derived onboard and downlinked with corresponding lat/long coordinates • **Ship-detection:** This is an important strategic application which can be met by processing co- and cross-polarization data with CFAR / machine learning techniques to generate the ship-location maps. In this case, in addition to the processed maps, the coordinates of ships and their RCS can be downlinked. • **Artificial Intelligence (AI) techniques:** Application of machine learning and deep learning techniques not limited to the following ▪ **Onboard target identification/detection on processed images.** ▪ **Payload anomaly detection mechanism: To detect and identify any anomaly on the payload based on limited telemetry.**	
E4.7.8	**Signal Processing algorithms for RADAR Altimeter (SAC)** MRSA/SAC has developed a Ka-band RADAR altimeter based on FMCW technique. Apart from altitude measurement, estimation of unambiguous velocity from the altimeter is a challenging task with ample scope for research. **Processing algorithms and schemes for real time unambiguous velocity estimation from a FMCW RADAR Altimeter.**	
E5	**Sub Area**	**Power Electronics (SAC)**
E5.1	**Following research areas are identified which can be taken up currently under respond programe (SAC)** Analysis, modelling and optimization of EPC circuit design and package design for Radiated Emission (RE) compliance as per MIL-STD-461E.	

	Present day high density satellite payloads demand strict EMI compliance and poses challenges to the EPC designer. SAC will provide details of existing EPC design including the mechanical package. Work is required to be done for meeting the Radiated Emission specifications. 1. Miniaturized circuit protection module for DC-DC converters for Aerospace applications. The protection circuit comprises of Resettable eFuse, Input pug-in inrush current limiter and Under Voltage Lock-out (UVLO). Work involves design, simulation and optimization of Generic front-end protection circuit for DC-DC converters. The final circuit may be implemented on a power ASIC or HMC. 2. Development of software tool for design, modelling and analysis of planar power transformer and power inductor. 3. Study of design topologies and packaging aspects of GaN MOSFET based high voltage EPC for pulsed TWTA. The work involves study, simulation and comparison of various design topologies/ configurations for high voltage EPC for multi collector pulsed TWT with Beam focus electrode for pulsed operation. The work also involves study and comparison of space grade high voltage potting materials and packaging aspects. 4. Digitally controlled energy efficient multi-output DC-DC converter with fast transient response. The work involves design, simulation and proto-type development of highly efficient multi-output EPC for high speed digital circuits with FPGAs. The EPC should have programmable output ON/OFF sequencing with fast transient response.	
F	**Area**	**Electronics and Microelectronics Design, Fabrication and Testing Technologies (SAC)**
F1	**Sub Area**	**Active and passive device and component technologies**
F1.1	**Simulators for SAW filter design (SAC)** The scope of the proposed research work, hence, shall be to develop accurate simulation tools for the prediction of SAW filter performance. Target specifications and fabrication support shall be provided by SAC. The accuracy of the developed tools shall be checked against the measured performance of fabricated filters.	
F1.2	**Fabrication and performance optimization of Thin Film Bulk Acoustic Wave (BAW) resonators and filters (SAC)** The scope of the proposed research work shall be to carry out the fabrication of FBAR/ SMR based BAW filters, based on the target filter specifications provided by SAC. The researchers shall be responsible for carrying out resonator stack design and optimization, resonator RF performance prediction, optimization of fabrication processes and finally fabrication of resonators/filters. The performance of the fabricated resonators/filters shall be verified against target specifications.	

<table>
<tr><td>F1.3</td><td colspan="2">Development of temperature dependent models for HEMTs and HBTs valid up to Cryogenic temperatures (SAC)
The proposed research work shall include development of accurate temperature (including cryogenic ones) and frequency dependent small signal, noise and non-linear models for GaAs/GaN/InP/SiGe HEMT/HBT devices, for use in active RF circuit design.</td></tr>
<tr><td>F2</td><td>Sub Area</td><td>Micro and diffractive optical component technologies (SAC)</td></tr>
<tr><td>F2.1</td><td colspan="2">Development of Precision Slits / Apertures / Bar Targets (SAC)
Precision slits, apertures and bar targets are one of the essential components for realization / calibration of optical imaging cameras. These components when fabricated with high precision provide a well-defined desired image without problems like beam scattering etc.
The scope of the proposed research:
a. Survey and selection of required materials as per detailed SAC requirements.
b. Development of fabrication process, typically Si through etch / LIGA based processes.
c. Process, component demonstration and qualification.</td></tr>
<tr><td>F2.2</td><td colspan="2">Development of Deformable Mirror (SAC)
Deformable mirror is an integral part of a variety of modern adaptive optics system, which are used to correct the optical aberration of the wave front. It is carried out by deforming the shape of a membrane (mirror) in response to an applied control signal.
A PolyMUMPS type or similar process is to be developed for Fabrication and Packaging of the deformable mirror array device. It is desirable that fabrication and packaging be followed by relevant characterization steps to validate the performance of the device.
The scope of the proposed research:
a. Survey and selection of required materials and process as per detailed SAC requirements.
b. Development of the fabrication process.
c. Process, component demonstration and qualification.</td></tr>
<tr><td>F2.3</td><td colspan="2">Development of Reflective Optical Coating over PMMA Resist (SAC)
To achieve required reflectance in the desired wavelength range appropriate reflective optical coatings are used. This application requires reflective optical coating on 2D/3D shapes fabricated over PMMA, a polymer.
This work requires the development of optical coating over 950K PMMA Electron Beam Sensitive Resist. The structure shall have either binary or greyscale resist pattern over planar or non- planar substrates of irregular sizes. The coating shall have excellent adhesion with resist (PMMA) and shall preferably be abrasion free.
The scope of the proposed research:
• Survey and selection of required materials as per detailed SAC requirements.
• Development of optical coating process over Patterned PMMA Resist Structures.
• Process, coating performance demonstration and qualification.</td></tr>
</table>

F3	Sub Area	Microfabrication process technologies (SAC)
F3.1	**Development of Electron Beam Sensitive and Dry Etch Compatible High Resolution Resist (SAC)** The scope of the proposed research: A dry etching compatible electron beam sensitive resist with its developer is to be prepared. The activity shall include the following: • Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements. • Process, material demonstration and qualification - Process with Aluminium Deposition, Electron Beam Lithography, Aluminium Dry Etching over an area of 15mm x 15mm with 70nm half pitch (preferable 40nm) Binary Grating structures.	
F3.2	**Development of Electron Beam / Photo Lithography and Dry Etch Compatible Resist with High Stability at Elevated Temperatures (SAC)** In certain applications, it is required to perform multiple processes such as Etching, Deposition and further lift off in a single lithography step. This demands the resist to be not only dry etching compatible, withstand subsequent high process temperature during deposition process but also support lift off afterwards. The scope of the proposed research: Resists with suitable developer (as per detailed SAC requirements) are needed to be synthesized that should be dry etch compatible, withstand high temperature deposition process without getting deformed and then support lift off process in a single lithography step. The activity shall include the following: • Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements. • Process, material demonstration and qualification.	
F3.3	**Development of Dry Film Resist for Thin Film Integration on LTCC (SAC)** Low temperature co-fired ceramic is a useful technology for RF applications. Integration of multilayer structure in LTCC is based on thick film processing. Development of dry film resist (DFR) is required for thin film integration on LTCC. This is needed for the fabrication of certain circuit elements having smaller (<100µm) features. The scope of the proposed research: A Dry Film Resist is to be developed and using it process needs to be demonstrated meeting SAC requirements. The LTCC contains slots (cavities) and may have process-induced warpage, bow etc. The activity shall include the following: • Survey, selection and development of required materials, resists, developer, plating chemistries, suitable equipment etc. • Development of fabrication process, which includes seed-layer deposition, DFR lamination, lithography, electroplating, seed layer etching etc. • Process demonstration and qualification.	

F3.4	**Electrically controlled tunable integrated devices using Magneto-Electric (ME) composites (Thin film/Bulk & Thin film/thin film) for microwave integrated circuit applications (SAC)** The Magneto-Electric (ME) effect, is a very attractive subject for novel microwave circuit applications. It is proposed to develop suitable composite material system with at least one component in thin film form and demonstrate dual-tunable integrated microwave components like tunable inductor, phase-shifter, attenuators, filters etc. using the developed material system.
F3.5	**Process modeling and simulation for compound semiconductor device fabrication for microwave applications (SAC)** Technology CAD (TCAD) is popular platform for modeling and simulation of this group of processes, individually as well as collectively. This activity aims at precise and accurate process analysis, modeling and simulation using appropriate TCAD platform which may help to reduce process iterations and improves process yield.
F3.6	**Studies on energy dependent Secondary Electron Yield of Carbon Nanotube (CNT) coatings on OFHC Copper for high frequency (Ka band) TWT (SAC)** The activity aims to develop suitable method for CNT synthesis, deposition of CNT coating on OFHC cupper collector surface and characterizing the SEE.
F3.7	**Development of Nanostructured Magnetostrictive thin films for Surface Acoustic Wave Applications (SAC)** Research involves the development of high quality thin films of giant magnetostrictive materials (e.g. Fe-Si) which exhibit high magnetostriction coefficient suitable for low insertion loss SAW devices.
F3.8	**Brazing/Attachment media for Ceramic /Quartz substrates for high reliable micro assembly (SAC)** This work shall include selection of reliable micro assembly Candidate material based on thermomechanical modelling and experimentations for the following applications: A) Void free low temperature (~ 300^{0}C) attachment media and process of large ceramic substrate (1”x1 “to 3”x5”) attach over metallic carrier plates suitable to withstand -55 to +125^{0}C temperature cycle regime. Configuration study and recommendations on metallic carrier mechanical properties are also to be devised for reliable assembly for a given substrate configuration/design. Simulation & experimental study of attachment void v/s over RF performance up to Ka Band Amplifier circuit made with discrete elements and alumina substrates. Void free, thin bond line thickness (~ 200 nm) attachment media and process of quartz substrate (with 25:1 aspect ratio) attachment on metallic carrier plate, suitable to withstand 0 to – 4K temperature cycle regime.

F4	Sub Area	Electronic circuit simulation (SAC)
F4.1	**Functional Verification of Digital circuit and Model development for Equivalence checking at Gate level with RTL logics (SAC)** The problem related to the functional simulation of the digital device and circuit, Functional simulator is required which can perform various tasks viz. static timing analysis, gate level simulation and transistor-level or circuit-level simulation. By this methodology, it is expected to verify the logic level functionality of the critical devices like as FPGA, DDR, ADC/DAC, and otherdigital devices. However, for this type of simulation, specific device model like SPICE/VHDL-AMS and other suggested suitable model is required. This will enable to do better analysis so that PCB board shows least deviation after final test and evaluation. It will also give understanding of the complexities of digital devices which can't be resolved with the help of Behavioral level simulation. This is performed mainly at post layout thus enabling us to reduce time and save our effort.	
F4.2	**Design and Simulation of Embedded passive technology (EPT) based PCB (SAC)** Under this project, advanced design and simulation of EPT based PCB layout along with critical components Like FPGA, ADC, DDR and DAC having passive components (i.e. Termination & pull up/down resistors & decaps) is envisaged. One of the challenges in designing embedded passives is the lack of availability of good Computer Aided Design (CAD) tools. Most CAD tools only allow components to be placed on the outer surfaces of the PCB/ substrate. Thus the development of design tools and knowledge base to design these parts fit well with the requirements for embedded passives in PWBs.	
F5	Sub Area	Electronic calibration (SAC)
F5.1	**Calibration of Test & Measuring Equipment used in the field of Optical Communication (SAC)** SAC is involved in development of optical communication devices like optical amplifier, photonics Analog to Digital convertor, optical switches, O-E & E-O convertors which are used in high speed optical links etc. For Testing of these devices Test & Measurement Equipments are used like Tuneable Laser Sources, Optical Power Meter, Optical Attenuator and Optical Spectrum Analyzers. So seeing increase in optical payload activity; SAC calibration facility is working for upgradation in the field of optical communication. For this Calibration lab is trying to establish the traceability for optical parameter especially in the band of 1550±20 nm and trying to find out the ways for calibration/validation of test & measuring equipment in optical communication field.	
F6	Sub Area	Surface Treatment Process Technologies (SAC)
F6.1	**Process Development to realize Electroforming Process for Aluminium Component (SAC)** Propsals are invited to carry out in depth feasibility study to realize electroforming process of Aluminium components and develop detailed process & setup for the same. This process can be used for mm-wave components.	

F6.2	**Non-cyanide based Electroless Silver Plating Process Development (SAC)** Proposals are invited in the area of non-cyanide based Electroless silver plating chemistry for plating aluminium 6061T6 alloy components with plating thickness of >=2 microns of silver inside complex multi planar wave guides.	
F6.3	**Development of Electroless Gold Plating Process (SAC)** Proposals are invited in the area of Electro less gold plating process using either cyanide based or non-cyanide based chemistry for plating aluminium 6061T6 alloy components/ Kovar substrates with plating thickness of >=2 microns of gold. Once developed, this process will be used for all ISRO projects as per requirements	
F7	**Sub Area**	**Space Environment Simulation and testing technologies (SAC)**
F7.1	**Thermal Control System (SAC)** The scope of this research work shall involve design, simulation, analysis & development of compact, liquid nitrogen based, close loop controlled, highly energy efficient thermal systems for direct use with existing thermal vacuum chambers as well as climatic test chambers. The operational temperature range for thermal control system is targeted to be from -150^{0}C to +150^{0}C with ~ 2kW of heat handling capability at lowest temperature.	
F7.2	**Super Insulated Cryogenic Transfer Lines (SAC)** The scope of this work will involve development for non-metallic, light weight; low loss cryogen transfers lines especially for efficient distribution of Liquid nitrogen. The functional temperature range to be considered for the SI lines should be -196^{0}C to +50^{0}C.	
F7.3	**Pulse-Tube Cryo Cooler (SAC)** The scope of this work shall entail development of compact, low cost single stage/ double stage Pulse Tube cryo-coolers to facilitate testing tiny devices at low temperature as well as for low cooling requirement for IR/CCD detectors. Expected cold tip temperature for this development activity is 80K with ~10-watt cooling capacity @80K, which can be verified in existing facilities at SAC with appropriate set-up.	
F7.4	**ThermoAcoustic Cooler (SAC)** The scope of this work will involve development of acoustic coolers for small detector cooling application and handling heat from the heat sinks etc.	
F7.5	**ThermoElectric Coolers-TECs (SAC)** The researchers shall be responsible for conceptualization, design, simulation/analysis and realization and testing of thermoelectric coolers. The performance of the realized system will be tested and verified against the target specifications. The targeted temperature range for TEC system is -40^{0}C on the lower side with 25-watt cooling capacity on a 100mm x 100mm area.	

F7.6	**Mixed Gas Refrigeration System (SAC)** The scope of this work shall involve development of mixed gas refrigeration based thermal system for compact climate test chambers and thermal vacuum chambers. The researchers shall be responsible for design, simulation, analysis, optimization & realization and testing of thermoelectric coolers. The expected lowest temperature for mixed gas refrigeration system is -150^{0}C in cascade mode. The performance of the realized system will be tested and verified against the target specifications.
F7.7	**Contamination Control study (SAC)** The present proposal entails a study, simulation and analysis of various forms of contaminations like surface and airborne particulates, surface and airborne molecular contaminants in and around thermo-vacuum chambers. Carryout in–depth measurement of such contaminants using APC, PFO, RGA, TQCM available and carry out detailed process study as well as make recommendations in this regard for implementation.
F7.8	**Liquid nitrogen consumption and optimization study (SAC)** The present proposal will involve Study and analysis of Liquid Nitrogen consumption in Thermo-vacuum test facility with respect to different type of tests being carried out in different LN2 based thermo-vacuum chambers. Study and analyze transfer, static and flash losses taking place in various system elements during thermo-vacuum tests and carry out detailed process study as well as make recommendations in this regard for implementation.
F7.9	**InfraRed imaging system for temperature monitoring (SAC)** The present scope of work involves a development of IR mapper-based temperature measurement system for monitoring the package temperature inside a thermal vacuum chamber, thereby eliminating the need of physically temperature sensor mounting. The required temperature range for the measurements is, from -40^{0}C to +85^{0}C.
F7.10	**Design and realization of XHV system (SAC)** The present scope of work will involve development of a small experimental cavity/ volume XHV system for achieving better than 1e-12 mbar vacuum.
F7.11	**Zero-Boil-Off System (SAC)** The present study will involve study of different options, simulation and analysis of ZBO system, realization of an experimental system to validate the theoretical models and to make proposal for an operation system.
G	**Area** — **Mechanical Engineering Systems (SAC/URSC)**
G1	**Development of High Thermal Conductivity material for space use (SAC)** There is ever increasing need to do fundamental research in the materials for space use meeting the stringent multi-disciplinary demands to be met in operational life time of the space-borne payload. The work comprises of research in identification of suitable material with following properties.

<table>
<tr><td></td><td colspan="2">Targeted specifications :-
1. Themal conductivity >200W/m/^{0}C
2. Density <5 gm/cm^3
3. Coefficient of Thermal Expansion (CTE) ~ 5-6 (micron/m)/^{0}C
Additionally Material has to be machinable to achieve the final net shape and should be compatible to gold electroplating post finish machining.</td></tr>
<tr><td>G2</td><td colspan="2">Design and Realisation of compact Cryo- cooler for Tera- Hertz application (SAC)
In case of Radio astronomy observations in Terrahertz frequency band there is a requirement of cooling the Low Noise Amplifiers (LNA) to cryo temperatures. There is a requirement to design and realise the close compact cryostats to maintain the required temperatures.
Targeted specifications :-
1 . To maintain 30K @0.5W dissipation.
2. To maintain 80K @1W dissipation.</td></tr>
<tr><td>G3</td><td>Sub Area</td><td>Shape Memory Alloys (SMA) based Space payload mechanisms (SAC)</td></tr>
<tr><td>G3.1</td><td colspan="2">Reusable SMA actuated non-explosive hold down and release mechanism (SAC)
Hold down mechanism is required to hold the deployable antenna structure during the launching phase in order to prevent from excessive launch vibration and acoustic levels. After the satellite is injected into desired orbit, these deployable systems are released to deploy antenna reflectors. In this process, it is vital to ensure a reliable release mechanism.</td></tr>
<tr><td>G3.2</td><td colspan="2">SMA based Frangibolt (SAC)
The Frangibolt is a non-explosive release device which uses Shape Memory Alloy (SMA) to forcefully break a bolt in tension. Frangibolt actuators are a simple and effective way to support and release loads up to 20,000 lbf.</td></tr>
<tr><td>G3.3</td><td colspan="2">SMA based Pin Puller Actuators (SAC)
Pin Puller actuators are low-shock non-explosive SMA based mechanical devices in which a pressure cartridge causes a pin or piston to retract inside the structure frame, usually against a side load. In the extended position, the pin or output shaft can be seen to be loaded by a compression spring</td></tr>
<tr><td>G3.4</td><td colspan="2">SMA based Vibration control mechanism (SAC)
During the launch, a payload experiences heavy transient and vibration acceleration loads. Pseudo-elastic behaviour of SMA based vibration isolators can be used to design to reduce these loads with savings in weight and launch costs as well as improve the system's reliability. The vibration control device proposed in literature, originates from the NiTi based passive dissipation device.</td></tr>
</table>

G3.5	**SMA hinges damper and latch mechanism (SAC)** A mechanism consists of many number of revolute hinges for transformation of force and motion from one link to another. These hinges play a vital role in proper functioning of a mechanism. While continuous usage of these mechanism, the conventional hinges tend to wear out due to friction present in mating parts. This friction will lose lot of transmission power and energy. This problem is solved with design of flexure hinges which are actuated using SMA material.	
G3.6	**Self-folding origami structures using SMA actuators (SAC)** Origami technique is widely explored in folding and deploying of thin layer of patch antenna which require a large area in fully spread sheet. Origami structures using SMA actuators fold/deploy automatically when get heated to phase transformation temperature. **SMA wire characteristics:** • Thermo-mechanical characteristics: Determination of Austenite and Martensite phase transformation temperature (As, Af, Ms, Mf) Elastic Modulus estimation in different phases: EM and EA Specific heat constant determination: Cp Block recovery stress estimation • Thermo-electric characteristics: Determination of electrical resistances in Martensite and Austenite phases (RM, and RA) • Fatigue strength of SMA wire **SMA spring characteristics:** SMA springs provide larger displacement than spring wire due to their complex geometrical ability, which enhances the applications of SMA springs for the Origami structures and Robotic. Due to the unavailability of the mathematical model limits the application of SMA springs. In the proposed study, mathematical modelling of SMA spring can be carried out so as the applications of SMA springs can be enhanced. The modelling required following characteristics to determine for the SMA springs: • Determination of Energy loss in Hysteretic effect of SMA springs • Determination of Electrical resistance in different phases of SMA springs (RA and RM) during loading and unloading conditions. • Cyclic loading study of SMA springs: Since SMA experiences cyclic load, so the fatigue analysis of SMA spring is required as the permanent strain keeps on increasing with the number of cycles.	
G4	**Sub Area**	**Development of Mechanically Pumped Fluid Loops (MPFL) for Spacecraft Thermal Control (SAC)**
G4.1	Mechanically Pumped Fluid Loops (MPFL) the most useful for spacecraft thermal control whenever heat pickup/rejection of high capacity, control of this capacity, testability and/or mechanical integration are the driving factors.	

	The key difference between traditional means of thermal control of spacecraft and the use of MPFL lies in the connection between the thermally controlled components and the heat loss surface (radiator). Here the connection is 'convective'instead of conductive or radiative. Here Fluid flowing through tubes connected to the two sets of surfaces (source/sink) convectively picks up heat at source/sources and dissipates it at sink. A mechanical pump is the prime mover of the fluid. This technology is the closest one comes to a true THERMAL BUS where we can both pick-up and reject heat simultaneously and automatically at multiple locations. Versatility: Can be used for a variety of diverse missions.	
G5	**Sub Area**	**Development of Hybrid (Solid-solid PCM & Heat Pipes) Honeycomb Panel (SAC)**
G5.1	Presently honeycomb panels along with heat pipes are used as Heat sink or radiator for spacecraft heat management. Core of honeycomb can be filled with suitable PCM (preferably Solid-Solid PCM) for better iso-thermalization of panel, more heat transfer and higher heat flux transfer. Detailed numerical modeling and experimentation along qualification under cyclic loading need to be carried out for developing this technology.	
G6	**Sub Area**	**Development of different Heat Pipes: Loop heat Pipe, Pulsating Heat Pipes, Micro Heat Pipes & Hybrid Heat Pipes (SAC)**
G6.1	Grooved heat pipe are extensively used in thermal control systems of several space missions. But grooved heat pipes have two main drawbacks- 1. Its performance is sensitive to orientation in the presence of gravity. 2. They generate only limited capillary pressure due to large pore radius. Traditional grooved heat pipes cannot work on rover mission of Lunar and Mars. So there is an urgent need to accelerate the research and development of special heat pipes which do not have limitations of grooved heat pipes.	
G7	**Sub Area**	**Development of wickless Flexible Heat pipes (SAC)**
G7.1	For ordinary liquids, the surface tension is a decreasing function of the temperature. For dilute aqueous solutions of these alcohols (the so-called self-rewetting fluids) the surface tension, as a function of the temperature, goes through a minimum and there is a range of temperature in which the surface tension increases. In addition, since these solutions are in non-azeotropic compositions, alcohol preferentially evaporates in the course of liquid/vapor phase change. The surface tension gradient along the liquid-vapor interface, caused by both temperature and concentration gradients, is therefore expected to spontaneously transport liquid towards hot regions on heater surfaces; the expression "selfrewetting fluid" comes from such particular surface tension-oriented liquid behaviour. One of the most interesting applications is the use of self-rewetting fluids in wickless heat pipes under reduced / zero gravity conditions.	
G8	**Sub Area**	**Space Radiators with variable Emittance (SAC)**
G8.1	Future space missions will include constellations of spacecraft, including nano and picosatellites, where adaptive thermal control systems will be needed that fit the	

	constraints of space applications with limited power and mass budgets. Space Radiators with variable emittance can be developed employing suitable coating having Temperature sensitive emissivity or sizing the radiators according to the condition and heat to be rejected.	
G9	**Sub Area**	**Development of Thermal Switches of different nature (SAC)**
G9.1	There are many thermal switch configurations that have been developed in the past for thermal control. Each configuration is based on a different working principle, but the purpose of all of them is to engineer the thermal contact between a heat source and heat sink. New generation, highly sophisticate Thermal s/w can be developed embedding MEMS and SMA (Smart Materials Alloys).	
G10	**Sub Area**	**Development of Deployable Radiators and thermal joints between fix & deployable/ Rotating Surfaces (SAC)**
G10.1	Relatively limited available external surface area on small satellites (compared to heavier satellites) reduces the potential for creating radiative surfaces on satellite external surfaces. For a system that requires a large amount of heat dissipation, a passive deployable radiator that is lightweight and simple in design would greatly enhance thermal performance by increasing the available radiative surface area. Thermally efficient deployable radiators for small spacecraft is to integrate an isothermal radiator surface with a high conductance hinge/thermal joint for higher thermal efficiency. Detailed thermal design of isothermal radiator surface & thermal joints between fix and rotating/deployable surface, numerical modeling and experimentation along with qualification for various heat load need to be carried out for developing this technology.	
G11	**Sub Area**	**Development of flight worthy payload components using composites (SAC)**
G11.1	**Improvement of Thermal and electrical conductivity of CFRP products (SAC)** CFRP structures are characterised by high stiffness and lower mass which makes them an ideal candidate for the structural members. In case of payload components, which involves the passage of RF through them, CFRP material can be used to reduce the overall mass by lower density and thin wall construction. Apart from that the low CTE (Coefficient of thermal expansion) allows less distortion during temperature excursion. The only disadvantage of composite material is its poor thermal and electrical conductivity as compared to metals like Aluminium. A research can be taken to address this and ways to improve the thermal and electrical conductivity of the material by innovative material processing techniques. This will enable CFRP material usage in payload components with high dissipating power.	
G11.2	**Fabrication Method for mass production of wave guide components from CFRP (SAC)** Many RF components fabrication can be converted from metal to CFRP (once thermal and electrical properties are improved). As they required in large quantity per payload	

	(in communication). A dedicated research is required to explore the best possible mass production technique for achieving the components economically meeting all the quality standards.	
G11.3	**Metallic coating of inside surface of conical or cylindrical CFRP components (SAC)** The research area involves exploration of different metallisation/coating techniques on CFRP viable for space usage. Surface treatment like gold and silver plating is required on CFRP RF components for better RF performance.	
G11.4	**Desire property achievement by combing GFRP and CFRP at product level (SAC)** To reduce the cost of components fabricated from CFRP, a thought can be given to fabricate the parts using combination of glass and carbon fibres without compromising the stiffness and mass. The research involves exploring the feasibility of usage of hybrid composites in a single component for best usage of the properties and optimise the total cost.	
G11.5	**Recycling of CFRP (SAC)** While making the products from CFRP, it is observed that lot of material is wasted while cutting the prepreg in particular angle for layup sequence and during machining the laminates. CFRP disposal is not easy. There is strong need to recycle one can tackle the issue of disposal and high cost of CFRP. A feasible, cost effective and environmental friendly solution for safe disposal as well as recycling of the CFRP is need of the hour.	
G12	**Sub Area**	**Thermal (URSC)**
G12.1	**Development of super thermal insulating material (AEROGEL) based flexible blanket system for the inter-planetary missions with gaseous convective environments (URSC)** Aerogels are a diverse class of porous, solid materials that exhibit an uncanny array of extreme materials properties. Most notably Aerogels are known for their extreme low density and very low thermal conductivity. These kind of synthetic porous and ultralight Aerogels are derived from a gel, in which the liquid component of the gel has been replaced with a gas. The result is a solid with extremely low density (< 0.1 g/cm3); and thermal conductivity (0.01W/mk) with High Solar Transmission: > 95% and High compressive strength. The envisaged uses of Aerogel are: • As a highly efficient thermal barrier (insulator) • To be used as insulating blanket material (in gaseous environment of Planets Mars, Venus, Jupiter etc. by incorporating / embedding Aerogel material in a flexible fibrous material. • As a porous micro-structure for stopping/capturing like High Velocity Particles (HVPC) **Development Requirements** • Technology for impregnation / embedding Aerogel material in a flexible fibrous material (Flexible fibres to withstand higher temp. > 400^{0}C.)	

	• The flexible composite layer should be optically opaque (200-2500 nm WL) with adequate mechanical integrity. • Human rated materials may also be explored to be used in human based space program.
G12.2	**Development of high emittance and high absorption surfaces (URSC)** Ultra high absorber CNT based super black spray coatings with a reflectance of typically 0.2% in the visible spectrum(@700nm) to be achieved by Spraying techniques that allow to produce super -black coatings on almost any stable material surface such as polymers, as well as to large and complex shapes. The application process needs to be much more flexible than producing CNT coating applied in a vacuum chamber using Chemical Vapor Deposition (CVD) technique. Development Requirements • Technology to synthesize CNTs (either SWCNT (Single Wall CNT) or MWCNT (Multi Wall CNT)) in bulk. • Technology to functionalize CNTs and mixing with proper polymer resins without agglomeration. • Successful synthesis of suitable spray chemical system
G12.3	**Electrochromic Device/materials (URSC)** Electro-chromic device is typically a multi-layered system incorporating two Electro Chromic (EC) layers separated by an electrolytic layer sandwiched between two conducting electrodes. One of this EC layer function as an ion storage layer in the device. These devices can be fabricated on rigid as well as flexible substrates. When a small voltage is applied, ions move from the ion storage layer through the electrolyte in to the electro-chromic layer, or vice versa, resulting in a redox reaction. This ion intercalation and ion extraction from the active layers changes the optical properties Typical thin film electrochromic Layers used in such devices include: WO_3 MoO_3, Nb_2O_5, TiO_2 etc. (Cathodic) and NiO, IrO_2, CoO_2, MnO_2etc (Anodic) • These devices offer the functionality of mechanical louvers but with decreased mass, cost and mechanical complexity. • Using these coatings, it is possible to actively control emissivity values (0.2 to 0.9) by applying a very low voltage DC power. It is lightweight (1.6 kg/sq.m compared to mechanical louver system (4 to 10 kg/sq.m). • It is reversible and repeatable. • This work involves fabrication of device using thin film and wet chemistry processes, characterization and testing. **Development Requirements:** • Technology of such multi-layered materials coatings. • Technology to develop it as a device for application. • To develop and establish the required test and characterization facilities.

G12.4	**Continuous roll coating or similar facility of thin film deposition to coat bigger substrates on thin flexible polymeric sheets (URSC)** Single/multiple layers of thin film coating technologies s i.e., SiO2, ITO, Al, Ag, VO2, Germanium, NiCr, Al2O3 etc, are developed in-house on flexible polymeric substrates such as polyimide and FEP for specific applications and functional requirements. **Development Requirement** The in-house developed thin film coating technologies to need to be scaled-up to coat on larger size substrates (1.5 m Width, continuous roll) of flexible polymeric materials such as Kapton, polyester, FEP etc).
G12.5	**Thermal / plasma spray (PS) based functional coatings (URSC)** As the deposition yield is very high and thermal spray (HVOF / Plasma Spray etc) has the ability to coat high temperature ceramics and possible to coat composite as well, this technique can be utilized to develop several functional coatings (high emittance with high temperature resistant surface, High solar absorptance, Corrosion resistance, Erosion resistance etc). **Development Requirement** • Development of Alumina-titanium ceramics, carbide, boride, super alloy, composites etc. based coatings on flat and contour shaped metals and alloys such as Al6061/2024, SS304, Ti6Al4V etc. • Process development parameters have to established and developed.
G12.6	**Development of an advanced solver for coupled fluid flow and heat transfer with conduction, radiation (participative and non-participative) and convection (URSC)** Spacecraft use various optical devices that consist of mirrors, lenses, prism, etc. New devices under design are often exposed to high intensity irradiation viz., mirrors in Coronagraphpayload,corner-cubeinspacecraft, Earth sensor, payloads in inter-planetary mission(during transfer orbit), etc. **Development Requirement** • Solver development to accurately estimate the temperature of various optical elements under harsh radiative and convective environment. • Radiative energy transport in participating medium needs to be established.
G12.7	**Studies on Degradation of thermo-optical properties, by high energy particles, atomic oxygen and UV on the thermal elements used in Spacecraft (URSC)** The thermal materials used in spacecraft thermal control application is prone for degradation w.r.t the thermo-optical properties due to harsh environment of high velocity high energy particles bombarding on the surface and also exposure to UV. Also there is potential impact of atomic erosion and reaction with the exposed materials in low earth orbit satellites.

	Development Requirement To develop and establish suitable equipment / system, to measure and characterize coatings and materials for: • ATOX resistance • Stability against UV radiation
G12.8	**Development of light weight engines for spacecraft application to generate power using waste heat (URSC)** Development of high efficiency engines for space power generation using waste heat of nuclear sources is essential for inter-planetary missions beyond Mars, where sun intensity is very low to generate required power. **Development Requirement** • Study of suitable thermodynamic cycles such as Stirling,Brayton,Rankine,etc. for the system. • Thermo- fluid modeling of these systems • Development & characterization of working fluids • System design, fabrication of proto-model, space qualification and performance demonstration.
G12.9	**Development of Liquid Droplet / Sheet Radiator (URSC)** Liquid Droplet Radiator (LDR) utilizes electric or magnetic fields to control droplet trajectories of fluids such as silicone oils (FC75/DC705) for heat removal from electronics. Heat is absorbed from the heat source by the working fluid. The hot liquid then enters into a droplet generator that generates fine liquid droplets (size: 200-300 pm). These droplets reject heat to space and the cooled droplets are collected by a droplet collector. The collected liquid is circulated back using a pump. The concept of Liquid Sheet Radiator (LSR) is same as that of LDR, except that LSR uses thin liquid sheet (~100 pm) as radiating surface (through narrow slits). These can handle heat load sinkW. **Development Requirement** • Design and development of LDR / LSR for space application • Fabrication and testing of proto model of LDR / LSR • Space qualification and performance demonstration.
G12.10	**Thermo-Chromic Variable Emittance Coating (URSC)** Small spacecraft have low thermal capacitance subject them to large temperature swings when either the heat generation rate or the thermal sink temperature changes. This needs modulating the heat rejection rate. Variable emittance thermal control coatings change the effective infra-red emissivity of a thermal control surface to allow the radiative heat transfer rate to be modulated (adaptive or “smart’ thermal control of spacecraft). These are useful thermal control coatings, whenever fluctuating heat loads are experienced.

	Thermo-chromic materials and Pervoskite materials changes its properties by sensing the heat/temp. **Development Requirements** • Technology to develop the thermo-chromic (vanadium oxide or Pervoskite/ LSM based) coatings on flexible (Polyimide) /rigid (Aluminized quartz and Polished Al alloy) substrates with a targeted smart and reversible transition temperature in between 20 to 40 °C. • Coating must be stable, reversible and repeatable for several cycles. • Scale up possibilities must be addressed. • To develop suitable characterisation tools.
G12.11	**Materials / surface engineering against atomic oxygen erosion (URSC)** **Silylation of polymers for space application** The silylation process is defined as a process of “replacement of an active hydrogen atom of a protic group (- OH, - NH, - SH) with a substituted silicon (Si) atom”. Polymers and polymer-based composite materials are extensively used in spacecraft applications due to both their weight and performances. Without protection from the deleterious effects of space environment, these materials suffer erosion from physical-chemical interaction with UV and atomic oxygen and experience a loss of performance. Hence a method of surface modification of inactive polymer-based materials, based on a “silylation process”, is needed. This technology allows one to create polymers with high erosion stability against atomic oxygen. **Development Requirements** • The 3-Step Silylation process, viz, activation of polymers, silylation, stabilization replaces the labile hydrogen with a Si linkage which can be oxidized in place, without destruction of the polymer surface, thereby protecting the polymer by forming an SiO, surface. The ultimate goal of this substitution is to obtain a modified material which is very stable in an oxidizing environment. This is accomplished by the stable, silica-like top layer, formed on the material surface after the modification process. • Expertise on - silylating agent - transport solvent -diffusion enhancer • Facility to carry out silylation technique.
G12.12	**Space qualified surface treatment on different base metals to absorb stray light for optical imaging systems (URSC-LEOS)** Development of Stray light absorbing Baffle for star sensor optics is essential requirement. The suitable surface treatment on Aluminum alloy, Stainless Steel, Titanium etc to absorb 99.9% incident light in the visible spectrum from 400 to 900 nm. The surface treatment shall sustain stringent set of space environment. High precision lens mount to survive space environment: A lens mount which can retain the optical element or multi elements closer to the specifid optical axis needs to be developed. The developed system shall survive satellite launchand operational environments.

G12.13	**Electro Hydrodynamics (EHD) based pumped fluid loop (URSC)** Mechanically Pumped Fluid Loop (MPFL) used in the thermal management of spacecraft comprise active pumps which require huge power for its operation. Utilizing an Electro Hydrodynamic (EHD) pump, which has no moving parts, brings an added advantage of vibration free and longer service life to the pumped fluid loops. Electro hydrodynamics is the study of the interaction between electric field and dielectric fluids. This interaction can be utilized to generate the fluid movement. The fluid flow rate is controlled by the strength of internal electric field generating the EHD flow in the loop. Although the pump is driven by externally applied electric field, the required input energy is very low (~1 W). **Development Requirement:** • Proof of concept, design and development of EHD based pump for space application • Fabrication of proto-model and testing for space qualification Performance demonstration.
G12.14	**Development of Micro heat pipes for space application (URSC)** Micro heat pipes are potential devices for removal of hot spots from electronic chips with high heat flux densities and achieve better iso-thermalization. Microchannels etched on silicon wafers act as the fluid carrier and provide necessary capillary action. These devices are very much essential for thermal management of high flux electronic chips / devices in future spacecraft. **Development Requirement:** • Design and development of micro heat pipe for space application • Fabrication of proto-model and testing for space qualification • Performance demonstration
G12.15	**Development of Flexible heat pipe for space application (URSC)** Similar to heat pipe / loop heat pipes, capillary pressure of the working fluid developed in the wick of flexible heat pipes drives the flow. However, the difference lies in the use of flexible bellow type tubes for vapor / liquid transport. The advantages of flexible heat pipes are flexibility in assembly and alignment unlike conventional heat pipes and loop heat pipes that are limited by the number of bends and better vibration isolation between heat source and heat sink. **Development Requirement:** • Design and development of flexible heat pipe for space application. • Fabrication of proto-model, testing for space qualification and performance demonstration.
G12.16	**Vapor chambers (URSC)** A vapor chamber is a planar heat pipe, which can spread heat in two dimensions. They are typically used when high powers and heat fluxes are applied to a relatively small evaporator area. During operation, the heat input into the evaporator vaporizes liquid within the evaporator wick. The vapor then flows throughout the chamber, creating an isothermal heat spreader. The vapor then condenses on the condenser surfaces, where

	the heat is removed by forced convection, natural convection, or liquid cooling. Capillary forces in the wick then return the condensate to the evaporator. **Development Requirement:** • Design and development of Vapor Chamber for space applications. • Fabrication of proto-model, testing for space qualification and performance demonstration.
G12.17	**Cryogenic heat switches (URSC)** Thermal management applications in the field of cryogenic engineering and related sciences are crucial. Often required is the heat switch, a novel device with an externally controlled variable heat conduction, working in a prescribed temperature range from about 50 mK to near 400 K. Heat switches can alternatively provide high thermal connection or ideal thermal isolation to the cold mass. Heat switches are used to minimize heat loads on the cooling system by disconnecting components when cooling is not required, or disconnecting redundant refrigerators that are turned off or failed. Heat switches also provide the vital thermal connection between objects and the cooling system as needed. **Development Requirement:** • Design and development of Cryogenic Heat Switch for space applications. • Fabrication of proto-model, testing for space qualification and performance demonstration.
G12.18	**Development of material and joining processes for Spacecraft thermal applications (URSC)** The following materials and joining processes are very important in realizing thermal fluid loops for spacecraft applications: • Metallic porous structures • Electron beam welding of Al alloy to Al alloy • Welding between porous materials to non-porous materials • Welding between porous materials to porous materials **Development Requirement:** • Design and development of porous metallic structures and the above specified joining processes for spacecraft applications. • Production of porous materials and characterization for space qualification. • Demonstration and qualification of the above joining processes.
G12.19	**Variable Conductance Multi-Layer Insulation (URSC)** Variable Conductance Multi-Layer Insulation (VCMLI) is a very effective thermal protection system that can be used in ambient and vacuum conditions. VCMLI uses dynamic beam discrete spacers and provide novel insulation systems with unique properties, including higher in-air performance than competing insulations such as Aerogels, with less thickness and less mass for equal heat leak, robust, high strength structure that can self-support thin, flexible vacuum shells, support high strength ballistic layers for

	micrometeoroid protection, or support vapor cooled shields for advanced zero boil-off cryogenic storage systems. **Development Requirement:** • Design and development of VCMLI for space applications. • Fabrication of proto-model, testing for space qualification and performance demonstration.	
G12.20	**Thermal properties of solid materials at high temperatures and extreme environmental conditions (URSC)** Thermal properties at high temperatures and in extreme environmental conditions are important input for the design and development of thermal control missions for terrestrial missions. Experimental and computational nanoscale phonon and electron transport that can lead to computational framework to predict the thermal properties of solid materials at high temperatures and extreme environmental conditions. **Development Requirement** • Development of computational framework that can accurately estimate the properties of various solid materials at high temperatures and extreme environmental conditions. • Validation of the computational framework.	
G12.21	**High conductive heat spreader plate (URSC)** High conductive heat spreaders are very essential in spacecraft thermal management. Computationally identify and experimentally realize isotopically pure Boron Nitride as an ultrahigh thermal conductivity material, with applications to heat spreaders etc. **Development Requirement:** • Design and development of ultrahigh thermal conductivity material for space applications. • Fabrication of proto-model, testing for space qualification and performance demonstration.	
G13	**Sub Area**	**Mechanisms (URSC)**
G13.1	**High Stiffness Hinge for boom deployments of Unfurlable Antenna (URSC)** Very large deployable antenna need to be positioned away from spacecraft to meet the optical geometry of antenna and feed system. Long carbon composite booms are used in positioning unfurlable antennas away from satellites. Due to launch envelope constraints, these long booms are split into two or more units and held along one face of satellite during launch by hold downs. Upon reaching orbit, the booms are deployed using a motor in the hinge and the hinge is finally latched, thereby creating a single boom of longer length (~6m). Two of the important parameters which govern the design of hinge mechanism are the latching accuracy and deployed natural frequency. These requirements demand developing a suitable compact hinge meeting the deployed natural frequency for different configuration of the booms which latches with required accuracy. Generally a motor with cam based locking mechanism are used for hinge mechanism. A	

	large cam radius would provide sufficient locking accuracy however this design result in a large hinge mechanism. A compact multiple link mechanism driven by a motor has also been used which provides compact design meeting the deployed stiffness and locking accuracy. **Objective** The objective of the program is 1. Developing a suitable hinge which satisfies the above requirements. 2. Developing a mathematical model of the hinge and boom in a FE software and carrying out frequency analysis. 3. Developing a prototype of the hinge and boom and show by tests that the development meets the requirements specified. 4. Develop subroutine for configuring the hinge for different size of boom and different angles between the boom.
G13.2	**Development of Robotic Arm for Autonomous Berthing of two Spacecrafts (URSC)** Docking of spacecrafts refers to joining of two space vehicles for replenishment of fuel, propellant, power, food, man transfer or maintenance for space systems. Docking can be temporary or partially permanent. Presently, two types of docking concepts are in practice. In the first type, the relative velocities between the chaser and target spacecraft are used to activate the docking mechanism and it is known as “Impact Docking”. The second type of docking is the low impact docking concept. Berthing of spacecrafts falls in the category of low impact docking. The ‘Berthing’ scheme refers to the use of an intermediate system, typically a robotic arm to capture the target vehicle. Further, the robotic arm performs the manoeuvres required to position the vehicles for the desired interface and subsequently docks the target Spacecraft to chaser Spacecraft by means of motor driven latches provided on the chaser spacecraft. This activity has a potential application in India’s future space station development. **Objectives:** 1. Development of a 6 DOF Robotic arm with a finger type gripper capable of performing berthing of two small spacecrafts. 2. Demonstration of berthing capability of robotic arm using a Helium balloon based or any novel zero-g system to simulate nearly 6 DOF on ground. 3. Closed loop simulation of robotic arm using encoders & feedback from sensors (Vision sensors, tactile sensors e. g. force & torque sensors, vision cameras), Programming, path sensing, simulation studies of robotic arm.
G13.3	**Numerical Simulation and Test Correlation of Low Velocity Impact of Flexible Body on Granular Soil (URSC)** Soft landing of spacecraft on planetary body is a complex task. Generally the landers need to be designed to survive residual horizontal and vertical velocities along with angular orientations after the completion of retro rocket firing. The low velocity impact touch down induce acceleration on the lander structure which needs to be reduced to

	acceptable levels for payloads. Hence landers are configured with flexible legs and honeycomb absorbers in order to limit the overall acceleration during landing. The pre-crushed honeycombs absorb a part of landing energy by plastic deformation. The honeycomb dampers need to be modelled, analysed and tested for prediction of overall accelerations using flexible-rigid body model of the lander. The granular regolith also absorbers some portion of the energy due to landing. The horizontal velocity component induces bulldozing motion on the soil which results in potential stability problems for the lander. Mathematical models of the honeycomb dampers along with a good test correlated model of the granular soil provide valuable input at the early stages of design and also reduce the system level test efforts. **Areas of Research:** • Numerical modeling and test correlation of honeycomb damper energy absorption with respect to geometry, impact velocity and momentum. • FEM/DEM Impact modeling of the soil and test correlation. • Numerical modeling and test correlation of flexible-rigid body dynamics	
G13.4	**Mathematical Modeling and Test Correlation of Deployment Dynamics of Large Deformation Deployable Space Mechanisms (URSC)** Large space structures are stored compactly and deployed on orbit due to launcher envelope constraints. Traditionally rigid body links and joints are used to stow the structure. However due to the advancement of functional composites, the option of stowing the structure by large deformation and obtaining the required deployed shape is available with the designer. High stored strain energy due to large deformation results in uncontrolled deployment which needs to be evaluated. And also the structure would be tested for deployment several times before being launched and hence need to be designed for fatigue life as well. The stowed structure needs to survive the launch loads before reaching the orbit. The above requirement needs to be met with suitable analysis using Finite Element Methods. The numerical simulation becomes challenging due to large stain energy release which needs to be correlated with testing. **Areas of Research:** • Design and development of mathematical models for Large deformation of composite deployable structures • Development of Test methodology for deployment dynamics correlation. • Test correlation of the dynamic behavior	
G14	**Sub Area**	**Spacecraft Structures (URSC)**
G14.1	**Advanced composite materials with higher stiffness and higher strength for structural applications (URSC)** Carbon fibre reinforced plastics is widely used in spacecraft structure. Properties along the fibre direction reached a near maximum and there is a need to increase the properties across the fibre as well as in the resin matrix. Carbon nanotubes known for their very high strength, stiffness as well as conductivity to be introduced in the carbon fibre or	

	resin matrix or both in the making of CFRP prepreg for light weight satellite structural applications is envisaged. Development of composites with metal matrix reinforced with carbon fibres to improve properties in matrix dominated direction preferably with lower density is also envisaged.	
G14.2	**Inflatable structures for space applications (URSC)** Inflatable structures find newer applications. Its mathematical modelling is a challenge with inter-disciplinary work and non-linear material behaviour. The models are required even for maintaining the required shape. Look for collaboration in this field.	
G14.3	**Impact load response measurement (URSC)** Impact load response measurement and Spilt Hopkinson bar design & development for characterizing CFRP laminates and sandwich in tension and compression. Wave propagation parameters corresponding to strain rates of 100 per second shall be possible.	
G14.4	**Proof testing of potted inserts in sandwich panels (URSC)** Proof testing of adhesively potted insert joints using Acoustic Emission signal processing to be looked into. Applying of only 30-40% failure load is preferable. Failure load prediction methodology to be ascertained. Only adhesive joint coupons support from URSC will be given and the proposer shall have AE system probes and software in his institute.	
G14.5	**Studies of Sandwich Panels for Impact Loading (URSC)** Structural behavior of sandwich panels under Low velocity and hypervelocity impact is of interest in this work. In space applications, Aluminum honeycomb cores are being generally used for developing sandwich panels. Honeycomb core's influence to resist external impact is negligible, mainly because of its open cell form. Of late, closed cell aluminum foams are also available. It is necessary to understand the capability of these cores in resisting impacts, especially for micro debris or meteoroid impacts. Different Modeling/simulation, development, characterization and tests are required to understand the behavior.	
H	**Area**	**Systems Reliability (SAC)**
H1	**Sub Area**	**Research Areas in Systems Reliability (SAC)**
H1.1	**Reliability and life estimation of Mechanical Systems and Parts (SAC)** Mechanical subsystems used in the satellites have to operate continuously and are "mission critical" (i.e. Rotary Joint). Reliability of these subsystems are very important, as they cannot be repaired in case of any failure. Space subsystems are expected to be purely metallic or a combination of metallic and composite structures. These structures are likely to experience different types of loading such as static, dynamic, fatigue, thermal and thermo elastic etc. Further above such structures are expected to undergo testing with varying intensities and duration. These combinations of hardware configuration, operating environment and test severities dictate the life of a product.	

	The scope of the proposed research: • Define the most suitable methods to analyse and assess the reliability and life of mechanical parts. • Provide methods and procedures for reliability and life verification by testing (Accelerated testing). • Provides inputs for development of a handbook on reliability and life assessment of mechanical systems and parts, which can be used for future missions also.
H1.2	**Development of flexible waveguide for space applications (SAC)** Waveguide plays crucial role in satellite functionality and transmission of Microwave signals within the satellite. In the confined space of the satellite, or in the large satellite with long waveguide lengths; integration of these interconnecting elements needs critical alignment. Mismatches in waveguide flange joint results in large stresses at various interfaces. Additionally, thermal excursion results in large stresses in the assembly. Flexible waveguides provide the required solution to mitigate the joint stresses in waveguide assembly. The scope of the proposed research: • Development of flexible waveguide in Ku and Ka band through detailed study of materials and processes suitable for low losses in RF signal and operating in space environment for long life. • Performance demonstration under defined environmental conditions.
H1.3	**Non-contact method for estimation of Preload in Bolts in the assembled Condition (SAC)** Assembly of large number of electronics subsystems with the satellite panels is done through bolts. In addition to the subsystems, waveguides, RF cables etc. also form the part of payload. To ensure long and reliable life of each junction; the applied torque is to be verified for each and every fastener / bolt. After integration, there is limited accessibility for verification of the applied torque; and any novel technique to verify torqued stress would overcome this problem, and be very useful to quickly assess integrity in cases of suspected loosening of bolts. The scope of the proposed research: • Development of a non-contact method for estimation of the stress/ load/ looseness in the bolts in the assembled condition.
H1.4	**Automated Assembly Inspection using Artificial Intelligence in Image Correlation (SAC)** A typical space hardware consists of multiple parts in a functional arrangement through various types of joints and processes. All the parts and processes used needs to be evaluated through inspection. In cases of large number of identical subsystems, automation in inspection offers a suitable solution in saving time and achieving consistency in inspection standard. It is proposed to develop a concept of using Artificial Intelligence in the automation of inspection process of space hardware.

	The scope of the proposed research: • Preparation of setup including Algorithm, Code and related hardware including camera and respective data acquisition hardware etc.	
H2	**Sub Area**	**Material and Process Development (SAC)**
H2.1	**Additive manufacturing (3D printing) using Carbon Allotropes (SAC)** With the advancement in manufacturing technology and material, production time and cost can be reduced manifold by introduction of 3D printing technology. Currently worldwide aerospace industry is producing parts through 3D printing for commercial flights, with same reliability as conventional method. Carbon Allotropes such as carbon nanotubes (CNT), graphene and metal particles, allows one to build objects with multifunctional properties having good electrical conductivity, thermal conductivity, mechanical strength, and stiffness at a relatively low cost. The scope of the proposed research: • Development of standard prototype part and performance demonstration under defined environmental conditions.	
H2.2	**Development of Nano material based components for Space Applications (SAC)** Satellite payloads require a large range of mechanical elements. Some are having structural requirements with critical CTE (brackets, spider etc) others require resilient to thermal excursions (feeds, Filters and cavities etc) or high thermal conductivity with zero CTE (for mounting of heat sinks / pipes for detectors and other high power devices) and many are serving as enclosures for electronics. Nanomaterials such as CNT, Fullerenes, Graphene, Quantum Dots are used as reinforcement in composites such as metal matrix, ceramic matrix and polymer matrix to achieve required bulk properties. Further, surface properties can be tailored using nano materials like Titanium dioxide, Gold & Silver nano particles, Zinc oxide as surface treatment for future aerospace components. The scope of the proposed research: • Theoretical study, optimization and testing of nanomaterial reinforced composite structures for space applications. • Demonstration of these material for typical payload structures in terms of customisation of desired properties coupled with miniaturization.	
H2.3	**Failure Modes & Strength characterization of Composite Sandwich constructions for Space Applications (SAC)** Currently Space hardware developed from Composite sandwich constructions using aluminium alloy core with aluminium skin and CFRP skin. Qualification tests evaluates the Mechanical Properties and strength for different types of loading for characterization. The strength Properties are useful to simulate the design of Space Hardware to determine the margins and failure modes.	

	Further, Process & Product Qualification carried out as per ASTM Standard, determines the criteria for Process repeatability evaluation on witness coupons. The scope of the proposed research: • Understanding and interpretation of failure modes vis-à-vis types of loading through analysis and experimental validation. • Optimization of CFRP laminate pattern and vis-à-vis core thickness.
H2.4	**Metallisation of CFRP for Space Hardware (SAC)** CFRP (Carbon Fibre Reinforcement Plastic) materials are used for fabrication of space hardware such as Feed horn, Waveguide, Antenna reflectors etc. due to light weight and high strength to weight ratio. Since, CFRP is electrically nonconductive, metallization is necessary to improve RF performance through electrical conductivity and in some cases, to enable its soldering of electronic parts to such CFRP elements. The scope of the proposed research: • Development and qualification of Metallisation (Copper/ Nickel / Silver) process on CFRP laminates. • Demonstration of RF performance including adhesion on a standard component.
H2.5	**An Assessment of NDE (Non-Destructive Evaluation) Capability for Materials & Processes Characterization for Complex Additive Manufacturing & Analyse Physics of Failure Mechanism in Aerospace Components (SAC)** To develop a technique for Inspection, testing or evaluation of materials, components or assemblies made through Additive Manufacturing (AM) for discontinuities or different characteristics without destroying for serviceability of the part or component. NDE is technique for Inspection, testing or evaluation of materials, component or assemblies for discontinuities or difference characteristics without destroying for serviceability of the part or component. NDE like Ultrasonic, Radiography, Computed tomography etc. have to be adopted for real time in-process monitoring to insure proper Quality Assurance and Control activities for defect free space component. Moreover, such techniques are required to understand the physics of failure of electromechanical assemblies. Currently there are no universally accepted or commercially available IQIs for industrial NDE. Reverse approach by using advanced NDE techniques to ascertain AM material build defects and limitations. The scope of the proposed research: • Develop a set of tools to assess NDE system performance to measure & defect detection for bluntness, resolution or contrast sensitivity. • Identify materials and design internal features useful for assessing inspection capabilities. • Model development for AM Fabricated Image Quality Indicators (IQIs) to simulate defects and parts features. • Analyse IQI volume data to assess NDE detectability limits, contrast sensitivity and resolution.

	• Development of in-situ QA methodologies for qualification of AM process leading to development of parts. This is for total understanding of materials and processes correlations, process capability, variability aspects as applicable to failure modes. • Generation of defects library & documents of cause and effects of defects. • Detection of failure mechanism with its co-relation to physics of failure, through layer by layer detection of discontinuities, thermal environment simulation to measure the performance degradation and break down in internal circuitry of electronic components. NDE methods to check the integrity of component and their functionality and performance • Reverse approach by using advanced NDE techniques to ascertain AM material build defects and limitations.
H2.6	**Development of new smart materials for space applications (SAC)** Smart materials possess adaptive capabilities to external stimuli, such as loads, force or environment, with inherent intelligence. Smart materials which possess the ability to change their physical properties in a specific manner in response to specific stimulus input. The stimuli could be pressure, temperature, electric and magnetic fields, chemicals, hydrostatic pressure or nuclear radiation. The associated changeable physical properties could be shape, stiffness, viscosity or damping. Smartness describes self-adaptability, self-sensing, memory and multiple functionalities of the materials or structures. **Probable Applications:** Spacecraft & Antenna deployment, shape control, flexible structure vibration control, jitter isolation, precision pointing, etc. Smart materials, regardless of technology field, can be broken down into the following categories ► Sensing - System Identification - Health Monitoring ► Quasi Static - Deployment - Positioning - Shape Correction ► Vibration Control - Structural - Acoustic The scope of the proposed research: ► Development of new material processes ► Testing & qualification methodology
H2.7	**Development of fast curing epoxy based EMI shielding material (SAC)** Study involves development of fast curing epoxy as a shielding material reinforced with thermally and electrically conductive materials to replace existing EMI shielding materials with longer curing times.

	The scope of the proposed research: • Activity involves identification of suitable materials, finalization of their chemical composition, process optimization, material fabrication and characterization. • The epoxy will be used to improve shielding effectiveness of the metallic enclosures/ connector flanges of electronic hardware. Thus, the material should have high electrical & thermal conductivity and also provide high attenuation/ absorption to Microwave signals from L-band to Ku-band frequency range. Subsequently, the epoxy may be further optimized for higher frequency ranges like Ka-band. Possibility for usage of nano-composites shall be explored.	
H3	**Area**	**Research Areas in Software Engineering (SAC)**
H3.1	**An Empirical Analysis on Deriving Test Cases from Natural Language Text using Model Based Testing (MBT) Approach (SAC)** The scope of the proposed research: • Implementation of Machine Learning techniques like natural language processing for review of Software Requirements Specification (SRS) Quality and improving it. • Study and implementation of different MBT techniques for automated test case generation based on design models from SRS to enable effective software testing. • Different MBT techniques needs to be studied, established and applied in different project contexts. • Study and implementing the above mentioned research point will help in analysing and evaluating the applicability of MBT approaches and will streamline the process of deriving test cases from the software requirements specification (SRS) using natural language (NL) requirements.	
H3.2	**Development of Automated GUI testing Environment for Desktop, Mobile and Flash based applications (SAC)** Many GUI based applications are being developed and continuously evolved on regular basis in SAC for use within ISRO, as well as external user community for outreach to academia or industry. The testing of these GUI Desktop/ Flash/ Mobile based applications is a challenging task in terms of its test repeatability for multiple versions; evaluating the GUI controls written in multiple programming languages and technologies. Therefore, a test automation framework is desired to be implemented for carrying our regression testing of GUI based Desktop/ Flash/ Mobile applications. This helps in analysing an application from user's point of view for all the GUI controls available on the screen. The scope of the proposed research: • Establishment of GUI testing techniques for automated regression testing of desktop, mobile and flash based applications. • Establishing an integrated functional, performance and security software testing techniques with provision of automated testing of web-based applications also. • Development of Generic software framework for parallel test execution environment.	

<table>
<tr><td>H3.3</td><td colspan="2">Mining Software Repositories for Software Testing (SAC)
The scope of the proposed research:
The goal of this project will be to mine software repositories data set and models can be generated based on outcome of mined data. Such system will improve approaches in test generation, so that we can learn from the evolution of test suites and past bugs to make test generation more effective and more efficient.
The motivation of this project is to introduce a collaborative sharing platform for software datasets that supports inter-datasets integration.
The field of mining software archives, such as code repositories, bug reports, documents, mailing lists, documents, etc., is concerned with the automated extraction, collection, abstraction and interpretation of events and artefacts created and recorded during software development.
The mining of software repository involves the extraction of both basic and value-added information from existing software repositories.</td></tr>
<tr><td>H3.4</td><td colspan="2">Automating Scenario Based Testing with UML and Aspect Oriented Programming (AOP) (SAC)
The scope of the proposed research:
The main goal of this project work will be to develop approaches and tools for the automatic generation of executable tests from UML behavioural models (particularly interaction diagrams), taking advantage of existing unit testing frameworks and aspect oriented programming techniques for test execution. These approaches and tools should enable a new generation of “model based test driven development (TDD)”, that is, a TDD approach in which test are specified in UML.
Intercept run-time behaviour and check conformance with the UML specification, using Aspect Oriented Programming (AOP) techniques
User interaction testing in distributed and concurrent systems
Support for complex features in UML interaction diagrams and the generation of executable tests in different platforms using Model-Driven Architecture (MDA) concepts.</td></tr>
<tr><td>I</td><td>Area</td><td>Mission Development (URSC)</td></tr>
<tr><td>I1</td><td>Sub Area</td><td>Mission (URSC)</td></tr>
<tr><td>I1.1</td><td colspan="2">New tools and techniques for automation of multi satellite operations (URSC)
With the ever-increasing assets of ISRO in space in terms of remote sensing/ communication/scientifi satellite, automation of on-orbit operations of spacecrafts are very essential. ISRO has already established certain softwares and systems to facilitate this automation to a certain extent. Efforts are on within ISRO to extend the automation to different areas. Academic/research institutions can contribute towards design and development of tools encompassing automatic decision making utilizing vast amount of spacecraft Knowledge and also latest IT technologies for building systems for automation.</td></tr>
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I1.2	**Attitude determinations using filtering techniques (URSC)** In-house attitude determination is by concentrating around discrete determinations using star sensor data and earth sensor data. Using filtering techniques, one can improve the attitude determinations to a good extent like enhanced Kalman filtering techniques by using star sensor data and Gyrodata.
I1.3	**Filtering techniques for onboard applications (URSC)** For many on-board applications steady state filters with limited state parameters are being tried in our missions. The effect of such implications are not giving enough observability with respect to many parameters. Full-fldged filters development with continuous time tracking with appropriate gain tuning shall be studied for onboard applications.
I1.4	**Earth's terrain mapping – development of models (URSC)** When high-resolution imageries are collected at the required terrain, the height information & the shape of the surfaces also need to be uplinked. Work is to obtain digital elevation model for the total country by making use of Cartosat data and the model update with required resolutions and with respect to time (required to understand the tectonic motions).
I1.5	**The spacecraft attitude profiles for landmarks tracings (URSC)** Spacecraft needs to compute its attitude as a function of its position w.r.t static or dynamic objects. Academic / research institutions can support with development of certain algorithms to do the above. It may be augmented with design of control systems for the optimal tracking of above with optimization of maneuvering / time.
I1.6	**Secure transfer and access to mission data (URSC)** On-orbit operations of satellite in space are conducted through ground segment spanning different networks. There are issues currently with respect to providing access to the archived satellite data as well as real-time data anytime/ anywhere to any users viz. satellite designers, ground segment developers etc. This requirement will be important in future. Issues related to data security are primarily dictating these restrictions. Academic/ research institutions can help in terms of robust IT technologies to establish connectivity among various nodes and also design of mechanisms/tools for providing secure access to valuable data with encryption related to different missions.
I1.7	**In-Orbit satellite data utilization from academia (URSC)** Spacecraft provide very voluminous data with respect to external environment. The data information, modeling on the environment, usage of the payload data sets can happen in a big way with the participation of academic data sets, performance modeling evaluations on a non-operational spacecraft.

I1.8	**Natural Language Query based Data Analysis and Control in Spacecraft Mission Health Management and Operations (URSC)** 1. Development of Natural processing model for Spacecraft Data Analysis. The model interprets query, interacts with offline or real-time software, format results and present in desired or specified formats. 2. Development of Natural processing model for Spacecraft Command and Control,where the system in whole interprets the query, connect to databases; bring out combination of commands and uplink to spacecraft. 3. Development or Explore models for speech to text and vice versa to make system conversational.	
I2	**Sub Area**	**Navigation (URSC)**
I2.1	**Determination of Spacecraft orbit for Inter – Planetary Mission through Optical Navigation (LEOS)** The Spacecraft will navigate autonomously by using optical data taken by onboard camera to determine its orbit and use this information to predict its future trajectory and make necessary corrections. The objective of the study is to develop a methodology to determine the spacecraft's position and velocity for intermediate cruise and target encounter phase. Intermediate cruise phase navigation is based on image celestial bodies (called beacons) through Line of Sight (LOS) measurements in the background of stars whose Helio Centric Positions are known in order to estimate the Spacecraft Position and Velocity. Target encounter phase where the object (beacon) LOS measurements are made through image processing techniques either by computing Center of Mass (COM) for known image types, Centre of Brightness (COB) for unknown image types and limb measurement for the images than do not fit fully in FOV and estimate the Spacecraft Position and Velocity. The study involves systems design, Framing Camera Specifiations, Image Processing, Navigation and Guidance and Software implementation.	
I2.2	**Navigation satellite autonomous maintenance (URSC)** Algorithm development of Inter-satellite ranging and onboard orbit estimation and satellite clock bias computation, onboard broadcast navigation parameter generation.	
I2.3	**Broadcast signal Anti-Spoofing techniques (URSC)** Design of Long PRN code (like GPS P(Y)) for secured application Design of different types of PRN codes for GNSS signals (Gold code, kasami) Message Authentication	
I2.4	**Big data processing (URSC)** System architecture – storage and computation Compressed and multiple Image formats handling Signal Processing methodologies FFT, Wavelets etc. Video Processing Big data Analytics CBIR, Robust Classifirs, Object Detections etc.	

J	Area	Communication and Power (URSC)
J1	Sub Area	Communication (URSC)
J1.1	**CMOS based broadband RF down converter (URSC)** Realisation of integrated RF down converter using CMOS / Bi-CMOS technologies for S, C-band Receive down converters. Design, Simulation and fabrication of the chip shall be carried out and system performance to be demonstrated using Digital Signal Processing based demodulation. Design simulation files shall be shared periodically. Single chip down converter shall be delivered to URSC.	
J1.2	**Design of RF packages for High Power Transmitter (URSC)** Mechanical package design of light weight (<1Kg) and high RF power handling capability (20 Watts CW) for spacecraft applications. The mechanical design shall comply with EMI /EMC Mil standards.	
J1.3	**GNSS receivers for Lunar Applications (URSC)** Design and development of ultra-high sensitive (< 8 dB-Hz CNDR) GNSS receiver algorithms in DSP for Lunar orbiter and Rover position determination. The work shall have compatibility to be integrated with URSC receiver hardware based on Virtex-5 FPGA platform.	
J1.4	**Low insertion loss SAW filters at VHF & L-band (URSC)** Surface Acoustic Wave filters are used in microwave receivers in spacecraft applications for providing high selectivity performances. Conventional SAW filters are having sharp rejection characteristics but their insertion loss is very high. Development of new materials and new fabrication techniques in these filters area result in low insertion loss and high frequency operations as per literature. SAW filters in UHF and L-Band are required with low insertion loss performances for future receivers of spacecraft applications. SAW filters with bandwidth of 1 MHz and insertion loss of 3 dB are to be developed at L-band frequencies within 10 mm2 size.	
J1.5	**Electromagnetic analysis of antenna radiation patterns in the presence of metallic appendages in spacecraft environment (URSC)** Computational electromagnetic methods are essential for predicting the radiation patterns of the omni directional antennas in the presence of other satellite subsystems like solar panels, metallic structures, and spacecraft body. Presently commercial EM solvers / softwares are being used for the prediction of antenna patterns for the spacecraft. High frequency techniques like Geometrical Theory of Diffraction, Uniform Theory of Diffraction, Physical Theory of Diffraction, Uniform Asymptotic Theory, Equivalent Current Method, Hybrid MoM and UTD techniques can be used for the antenna analysis or combination of two or more computational electromagnetic techniques can also be used for solving the above scattering problem. A generic electromagnetic software /codes shall be developed to take the inputs like, spacecraft geometry, materials and location of the omni directional antenna for predicting the radiation patterns of the antenna. Selected computational code (s) shall be accurate in prediction and shall take moderate time for computation.	

J1.6	**Protocols for reconfigurable communication system on ultra-massive MIMO architecture (URSC)** The mm-wave/ THz band Ultra-Massive MIMO (UM-MIMO) technology opens avenues for a variety of reconfigurable communication systems for short-range communication, between various packages/ devices and any human interfaces, in a networked environment. Various advantages such as avoidance of cabling complexity, inherent channel redundancy, lower power requirements, physical re-configurability, faster set-up time, etc. are all attributed to this type of a system. Protocols shall be developed for such a reconfigurable communication system, based on existing / proposed industry protocols, operating on an ultra-massive MIMO architecture to set-up a network of such devices and enable reconfigurable communication channels between the various elements of the network. The networking shall be made possible wirelessly using the UM-MIMO concept.	
J1.7	**High-accuracy algorithm for localization from multiple direction of arrival bearings (URSC)** Electromagnetic sensors placed on a satellite platform are capable of determining the Angle of Arrival / Direction of Arrival (AoA/ DoA) of EM waves from the emitting source. Multiple such bearings received by a satellite along the orbit, can be combined to obtain a localization on the emitting source. Further, the localization can be achieved from a network of time synchronized spacecrafts, receiving the emissions simultaneously. Various mathematical/ interferometry techniques such as Time of Arrival, Time Difference of Arrival (TDOA), Angle of Arrival (AoA) etc. and a combination of these techniques, are presently used for a triangulation/ trilateration in such localization applications. A high accuracy and resource efficient localization model shall be developed which would use the multiple bearing readings for its calculation.	
J2	**Sub Area**	**Power (URSC)**
J2.1	**Radio isotope thermo-electric generator (URSC)** Radioisotopes decay provide continuous source of energy independent of orientation and hence are very useful for long deep space missions. Radioisotope thermoelectric generator (RTG, ~100 W) based on plutonium-238 have been used in space since 1961,with typical performance of 3-5 W /kg, 6 % effiiency and over a 30-year demonstrated life. These are static in operation providing very high reliability and long life.	
J2.2	**Development of pouch type lithium ion cell (URSC)** Design of batteries using pouch type lithium polymer cells which give the advantage of better packing of cells for future space usage such as human rated space flght, interplanetary missions etc.	

K	Area	Integration and Checkout (URSC)
K1	Sub Area	Integration (URSC)
K1.1	**Development of system capable of measuring the 3D co-ordinates of markers / 3D objects (URSC)** The system should be capable of measuring the 3D co-ordinates of the markers on the object.	
K1.2	**Design and development of cable coupling analysis program (URSC)** Satellite is made up of a large amount of harness carrying various types of signals, frequencies and power levels. The harness design should achieve Electro Magnetic Compatibility between the various functions and facilitate the functioning of the satellite system. As a fist step in this direction it becomes incumbent to quantify the coupled signals. Once this is done measures can be taken to reduce the coupling. Software needs to be developed to quantify the quantum of coupling.	
K1.3	**Automation of integration testing (URSC)** Scope exists to automate satellite testing. Though the monitoring points are spread out, there exists scope to electronically switch, monitor and record the measured readings, wave forms etc. This is the subject matter of development. As a spin off, the data archiving, retrieval, data tagging follow.	
K1.4	**Design and development of test equipment (URSC)** In addition to standard test equipment available in the market, a good number of dedicated test equipments get developed. Scope exists for universities or organizations to contribute to design and development of test equipment.	
K1.5	**Mechanical ground support equipment (URSC)** A large number of mechanical ground support equipment (viz., Satellite handling systems, panel handling systems, Satellite transportation containers, physical parameter measurement machines etc.,) connected with physically measured parameters like Centre of Gravity, moment of Inertia. Measurement of Misalignments of sensors, actuators and payloads and applying corrections to meet thespecifiations is another area where scope for design and development exists.	
K2	Sub Area	Checkout (URSC)
K2.1	**EMI/EMC compliance for the checkout equipment / systems (URSC)** Comprehensive guidelines, Design aspects a PCB level, equipment level and total system level, Testing the equipment and system for compliance.	
K2.2	**Design and realization of high data rate payload data reception system (URSC)** The requirement is to come out of single vendor dependency. Design of RF sections and high bit rate digital circuits are involved.	

L	Area	Controls and Digital (URSC)
L1	Sub Area	Control Dynamics (URSC)
L1.1	**Control algorithms for high pointing and stability for advanced remote sensing satellites (URSC)** This involves 2 stages:- Multi-level Cascaded control architecture for fied pointing involving coarse and fine controls ; Highly robust control incorporating active disturbance rejection, damping of solar arrays to provide quick settling and Isolation of structural androtating elements are needed.	
L1.2	**Development of control algorithms for autonomous station keeping single/ multiple satellites (URSC)** The autonomous station keeping / Orbit Manoeuvring is proposed for LEO satellites using GPS, accelerometer, star sensor and gyro as sensor and thrusters/electric propulsion as actuation. This is applicable for single satellite autonomous station keeping, formation control with two satellites and Rendezvous and docking where autonomous stringent orbit corrections are required. Constellation/Formation Control of multiple satellites signal delays, Communication failure and FDIR for formation to be developed.	
L1.3	**Modelling & simulation of multibody systems (URSC)** A complete and high reliable model with vibration, flxibility, non-inertial Influences, external environment disturbances etc., to be developed.	
L1.4	**Structural flexible mode control (URSC)** Large Structural Flexible Mode control (active /passive) using Adaptive Filters for large appendages vibrations.	
L1.5	**Smooth trajectory planning for time-bound (track to track) reorientation of agile spacecraft (URSC)** Present Guidance algorithm used in on-board Carto series is iteration based and change over between maneuver and imaging is not smooth resulting in settling time requirement (Wait Phase) post reorientation. With development of non-iterative guidance, this problem can be avoided. The term Track to Track means both initial and final rates are non-zero	
L1.6	**Guidance and control algorithms for rendezvous & docking/formation fling etc (URSC)** Interface development for driving the simulator from dynamics computer. Study and implementation of various sensor interfaces and their stimuli simulators.	
L1.7	**Study of CASE tools for automatic generation of onboard software codes (URSC)** Identifiation of CASE tools for space qualified space software / protocol development and study on the efficiency / optimization of automatically generated software code with that of Non-auto generated software.	

L1.8	**Development of statistical based algorithms for providing fault detection isolation and reconfiguration using Unscented Kalman Filter (UKF) (URSC)** Model based fault diagnosis techniques have been applied in recent years. Kalman, EKFand UKF filters are the main workhorse for stochastic fault diagnosis.	
L1.9	**Fault tolerant techniques (URSC)** Fault Tolerant by Multi Processing (FTMP) and Fault Tolerant by Parallel Processing (FTPP) etc. for onboard computers.	
L1.10	**Development of robust control system using Linear Matrix Inequality (LMI) concept for single / multiple satellites (URSC)** 1. System development to meet high pointing requirements with minimal ground loop delays. 2. Building autonomy in HILS testing	
L1.11	**Networking of space resources (URSC)** Net-centric architecture for space resources using appropriate networking protocols to interoperate with other networks. The approach could be routable or demand access routable architecture instead of manually confiurable point to point network at present. The DTN (Delay Tolerant Networking) model or subscribe / publish message transfer model or any similar new concept may be considered for interplanetary / deep space exploration type of networking application.	
L2	**Sub Area**	**Control & Digital Electronics (URSC)**
L2.1	**System on chip and mixed signal processing (URSC)** Study and Implementation of System on Chip (SoC) as well as Mixed Signal ASICs development for analog data processing and data acquisition.	
L2.2	**Quad redundant fault tolerant system studies (URSC)** Study on systems, algorithms, fault tolerant logics for Quad redundant platforms.	
L2.3	**Active microvibration control (URSC)** Studies related to measurement and control of micro-vibrations on Imaging sensors. Active Micro-vibration control for High Bandwidth sensing and actuation.	
L2.4	**Reconfiurable hardware (URSC)** Studies related to Reliable, evolutionary reconfiurable hardware systems that can be applicable to long drawn missions.	
L2.5	**Anti-jamming using spread spectrum technique for telecommand links (URSC)** The objective of the work should be design of spread spectrum system with anti-jam capability for the uplink of telecommands in CCSDS format. The system design should ensure to have minimal impact on the CCSDS tele-command system.	

L2.6	**Low on resistance MOSFET for ASIP development (URSC)** Development of MOSFETs with low ON resistance for minimizing the power dissipation in a device when used in ASIP (Application Specific Integrated Package) type of application in large numbers.	
L2.7	**Fault tolerant computer architecture (URSC)** Study and comparison of available fault tolerant computer architectures comprising hardware, software and network solution for achieving Ultra-High reliability. (Complete system that is suitable to meet ultra-reliable onboard requirement with realistic estimate of achievable reliability).	
L2.8	**Safety critical buses for space usage (URSC)** Study and comparison of different safety critical buses for satellites / space vehicles /manned vehicles. Reinforcement of terrestrial protocols (like Ethernet, etc at MAC layer,IP etc at Network layer) for its usage in space environment.	
L2.9	**Quad redundant fault tolerant system studies (URSC)** Study on systems, algorithms, fault tolerant logics for Quad redundant platforms.	
L2.10	**Machine learning and AI (URSC)** Application of machine learning for fault detection or prediction in telemetry	
L2.11	**Study of reconfigurable hardware design and AI concepts in embedded systems (URSC)** Studies related to Reliable, reconfiurable hardware systems.	
L3	**Sub Area**	**Digital Systems (URSC)**
L3.1	1) **New generation still image compression algorithm (lossy / lossless) for space application / Advanced Audio / Video coding, beyond the CCSDS wavelet image compression & H264 coding.** 2) **Advanced channel coding/decoding techniques beyond the LDPC & TCM techniques.** 3) **Onboard image processing techniques for feature extraction, change detection etc. (URSC).**	
L3.2	**Advanced audio / video coding (URSC)** Advanced audio / video coding like MPEG 4 for satellite communications that may be extended for manned missions.	
L3.3	**Encryption / decryption (URSC)** Development of advanced encryption methodology.	
L3.4	**Image compression (URSC)** Research and development of an efficient image compression algorithm (lossy/lossless) for space applications. The objective is to develop a new data compression algorithm to meet the high speed implementation requirements with less power and having high performances.	

<table>
<tr><td>L3.5</td><td colspan="2">Onboard data processing (URSC)
Reduce data by volume, smart acquisition, capture only ROI requested by users, engage with captured data for achieving best compression, discarding unwanted data at onboard level.</td></tr>
<tr><td>M</td><td>Area</td><td>Reliability and Components (URSC)</td></tr>
<tr><td>M1</td><td>Sub Area</td><td>Indigenization and Components (URSC)</td></tr>
<tr><td>M1.1</td><td colspan="2">Development and Fabrication of Acoustic Wave Devices (URSC)
Acoustic Wave devices are based on the principle of Acoustic wave generation in Piezoelectric wafers on application of electric field. Metal electrodes are deposited on the surface of the substrates to excite acoustic waves whose wavelength is proportional to the metal electrode pitch in surface wave generation and substrate thickness in bulk wave generation process. The fabrication of such devices is based on Photolithography technique already established in IC industry. Hence a proposal is invited in the field of development and fabrication of Acoustic Wave devices.</td></tr>
<tr><td>M1.2</td><td colspan="2">Nanoscience and Nanotechnology for Space applications (URSC)
For Space applications, nanoscience and nanotechnology potentially transform the approaches and practices. Application areas include light-weight strong materials, efficient adhesives, heat-spreaders, radiation-shields, high-density memories, high-K dielectrics, highly sensitive sensors, rovers, energy storage and distribution, eco-friendly processes etc. Challenges exist in their integration and packaging. Synthesis, characterization, modification, system level performance measurement of nanomaterials and NEMS offer new avenues for exploration.</td></tr>
<tr><td>M1.3</td><td colspan="2">Hermetic Laser Sealing of Controlled Expansion Alloy Packages (URSC)
Most of the microwave modules for space applications are being realized by assembly & packaging of MMIC dice in hermetic packages. Choice of material for package depends on matching thermal coefficient of expansion (TCE) to that of semiconducting material with which MMIC is made, high thermal conductivity, low density, ease of machining, resistance to corrosion etc. Conventional materials used for Microwave module packages are Aluminium & Kovar. CE alloys are composed of silicon-aluminium and their coefficient of thermal expansion (CTE) can be controlled to a chosen value between 7.5 and 20 ppm/°C, simply by adjusting the proportions of these two constituents. Thermal conductivities of the CE alloys are higher than Kovar and having matching TCE to that of GaAs substrate used in MMIC dice. Realization of Microwave modules in hermetically sealed housings of CE alloys eases the system in Package realization of Communication subsystem of the spacecraft. Thin Films Division of URSC is looking for an academic institute having Pulsed Nd:YAG laser welding facility (~70 Watt output, ~ 7 kW Peak power, ~0.5-20 ms pulse width) with nitrogen/Argon purging to carry out hermetic laser sealing of CE Alloys.</td></tr>
</table>

M2	Sub Area	Reliability (URSC)
M2.1	**Contamination modeling and kinetics studies (URSC)** Contamination of spacecraft and instruments can cause performance degradation and even limit the useful life. Spacecraft sensitive surfaces like thermal control surfaces, sensor, optics, lenses, etc are particularly vulnerable. Polymeric materials like adhesives, paints, potting compounds, coatings etc that are used on the spacecraft, outgass under Space environment. The outgassed material can deposit on a surface and thus alter the absorptance, transmittance, reflctance and emittance and/ or intercept the field of view of a sensor or experiment and either scatter, emit or absorb electromagnetic radiation. Besides outgassing, in-orbit contamination can also occur due to plume impingement and photo enhanced deposition.	
M2.2	**Trends and techniques in electronic packaging area (URSC)** Electronic packaging is a major discipline within the fild of electronic engineering which includes a wide variety of technologies right from materials to interconnecting and packaging techniques. It refers to enclosures and protective features built in to the equipment itself including the packaging techniques of devices used in the realization of equipment. Miniaturization, low operating voltage and power consumption with increase in speed/frequency requirements has driven the electronic packaging industry to the development of device packaging styles having large I/O pin count. In order to meet the increased demands for miniaturization and increased performance, research is needed in the area of Materials, Design Approaches, Methods, and Techniques used in device packaging and assembly techniques interconnect design and manufacturing to realize the Hi-Rel Electronic hardware.	
M2.3	**High Density Interconnect (HDI) PCB qualifiation and testing (URSC)** High Density Interconnect PCBs are used for the realization of miniaturized electronic assemblies. There are several construction methods for the realization of HDI PCBs. Hence detailed study is needed to identify the failure mechanisms, accelerated testing techniques in the HDI PCBs and to bring out a process qualifiation and acceptance testing method to use HDI PCBs in the electronic assemblies.	
N	**Area**	**Production of Spacecraft Systems (URSC)**
N1	**Sub Area**	**Systems Engineering (URSC)**
N1.1	**Automation in test systems for various space conditions (URSC)** Spacecraft electronic packages (simulation, Analysis) and data logging	
N1.2	**Development of new materials for lubrication as an alternative to MOS2 (URSC)** MoS2 is sensitive to moisture. New materials with similar characteristics but having no sensitivity to moistures as an advantage.	

N1.3	**Modular High frequency multiple output universal DC-DC converter for Space use (URSC)** The proposed hermetic hybrid design shall have a switching frequency of 1MHz, high reliability and shall meet MIL-PRF-38534 Class K requirements. The design practices shall follow military standards and de-rating guidelines. The design shall have Built in EMI and output common mode filters to meet MIL-STD-461, UVP/OVP/OCP protection features, Guaranteed TID performance up to 100Krad, Single Event Upset (SEU) characterised up to 85meV/mg/cm2, guaranteed operation under neutron and prompt dose radiation environments. It shall be Compliant with 26 and 70V Satellite bus, maximum 4 output with an output power range of 1W-50W and an efficiency of more than 80%. Detailed simulation and design, Worst case analysis using Monte Carlo method, sensitivity analysis, thermal analysis, stress analysis, radiation and reliability analysis shall be provided.	
N2	**Sub Area**	**Micro Circuit & ECAD (URSC)**
N2.1	**Development of System on Chip (SoC), Analog and Mixed Signal ASICs, and Multimillion gate ASICs comply with DFT, Low Power, High Performance, IR Drop, EM analysis and RAD Hard requirements to develop miniaturized electronic subsystems (URSC)**	
N2.2	**ECAD Layout designs (URSC)** ECAD Layout designs (highly complex) with fine vias, fine line complying with Signal Integrity, Power Integrity, EMI/EMC, and Thermal Integrity checks.	
N2.3	**Development of Re-configurable Hardware for Prototyping Digital Designs (URSC)** Development of an indigenous Re-configurable Hardware (RCH) which can facilitate the quick and easy realization of moderate-sized digital designs.	
N2.4	**Artificial Intelligence based Deep Neural Network Development (URSC)** Design and development of software based neural networks for object recognition and tracking in high-resolution images. The algorithm should be DNN based and preferably built around standard architectures like YOLO-net and SEG-net.	
O	**Area**	**VLSI Design (SCL)**
O1	**Sub Area**	**ASIC Design (SCL)**
O1.1	**Design of Instrumentation Amplifier (SCL)** A High-Precision Instrumentation Amplifier with large CMRR is required for the Sensor Signal conditioning applications. Instrumentation amplifier is a versatile device used for amplification of small differential mode signals while rejecting large common mode signal at the same time. In a typical signal conditioning chain, the output of the sensor goes to	

	the instrumentation amplifier. The instrumentation amplifier amplifies the small output signal of the sensor and gives it to the ADC for digitization. **Target Specification:** • Supply Voltage: 3.3V • Temperature Range: -40 degC to 125 degC • Programmable Gain: 1 to 1000 • Low noise < 0.3µV p-p at 0.1 Hz to 10 Hz • Low non linearity < 20ppm (Gain = 1) • High CMRR (Common Mode Rejection Ratio) > 90dB (Gain=1) • Low offset voltage < 100µV • 3 dB Bandwidth: 1MHz (at Gain = 1) The design of the proposed Instrumentation Amplifier is to be carried out in SCL 180 nm process.
O1.2	**Design of a Current Feedback Amplifier (CFA) (SCL)** Opamps come in two types: the Voltage-Feedback Amplifier (VFA), for which the input error is a voltage; and the Current-Feedback Amplifier (CFA), for which the input error is a current. The CFA noninverting amplifier is relatively free from a gain-bandwidth trade-off. Additional advantage of CFAs compared to VFAs is the absence of slew-rate limiting. CFA is primarily used where both high speed and low distortion signal processing is required. CFAs are mainly used in broadcast video systems, radar systems , IF and RF stages and other high speed circuits. Although CFAs are harder to design as compared to VFAs but they offer more bandwidth and DC precision. **Target Specification:** High speed: 1650 MHz (G = +1) Low voltage offset: 0.7 mV Low input bias current: 7µA High O/p drive : 100 mA
O1.3	**Design of Low Noise Amplifier (LNA) (SCL)** In wireless applications, a low-noise amplifier (LNA) is an active network that increases the amplitude of weak RF signals to allow processing by a receiver. In a receiver chain, the first amplifier after the antenna contributes the most to the system noise figure. Although amplifiers are known to add noise and distortion to the desired signal, RF low-noise amplifiers (RF LNAs) are designed to increase the desired RF signal amplitude without adding distortion or noise. A typical LNA may supply a power gain of 100 (20 dB)while decreasing the signal-to-noise ratio by less than a factor of two i.e. 3dB noise figure. **Target Specification:** • Power Supply = 1.8V • Flat gain of 25dB from 1 to 3 GHz • Noise figure less then 2dB • Input and output return losses less then -15dB

O1.4

Design of 12 bit 1 GSPS DAC in SCL's 180nm Technology (SCL)

Digital to Analog Converter (DAC) is a device that transforms digital data into an analog signal. The digital data may be produced from a microprocessor, Application Specific Integrated Circuit (ASIC), or Field Programmable Gate Array (FPGA), but ultimately the data requires the conversion to an analog signal in order to interact with the real world. This DAC should cater test and Measurement, Imaging and high-Precision, high-Speed data acquisition applications with these features in Junction temperature range -40 °C to +125°C

Target Specifications:

- Resolution 12 bits
- Speed 1 GSPS
- FSR Current 2 mA-20 mA
- SFDR >74 dBFS at 70 Msps
- DNL < ±0.5LSB
- INL < ±1LSB
- Gain DAC Monotonicity Guaranteed
- Offset Error < ±0.01 % of FSR
- Gain Error < ±2 % of FSR
- Output Compliance range -1 to +1 V
- Offset Error < ±0.01 % of FSR @ Mid Code
- Power supply 1.8/3.3 V
- Technology SCL 180 nm

O1.5

Design of 14 bit 500 MSPS DAC in SCL's 180nm Technology (SCL)

Digital to Analog Converter (DAC) is a device that transforms digital data into an analog signal. The digital data may be produced from a microprocessor, Application Specific Integrated Circuit (ASIC), or Field Programmable Gate Array (FPGA), but ultimately the data requires the conversion to an analog signal in order to interact with the real world. This DAC should cater test and Measurement, Imaging and high-Precision, high-Speed data acquisition applications with these features in Junction temperature range -40 °C to +125°C

Target Specifications:

- Resolution 14 bits
- Speed 500 MSPS
- FSR Current 2 mA-20 mA
- SFDR >74 dBFS at 70 Msps
- DNL < ±0.5LSB
- INL < ±2LSB
- Gain Error < ±2 % of FSR
- Output Compliance range -0.5 to +1 V @ Full Scale Current = 20 mA
- Offset Error < ±0.01 % of FSR @ Mid Code

	• Power Dissipation < 600 mW • Power supply 1.8/3.3 V • Technology SCL 180 nm
O1.6	**Design of 8-Bit 1GSPS Flash ADC (SCL)** The flash analog-to-digital converter (ADC) architecture is the most popular topology for video processing, telecommunications, digital imaging etc. designs because it gives highest speed. This design of ADC should cater imaging as well as communication applications with these features in Junction temperature range -40 °C to +125 °C **Target Specifications:** • SNDR >46 dBFS at 1000 Msps • SFDR >60 dBc at 1000 Msps • DNL <±0.5LSB • INL <±0.5LSB • No missing Code • Gain Error<±0.5LSB • Offset Error<±0.5LSB • Output data format in LVDS or CMOS **Deliverables:** i. Design Details along with all schematics and layout ii. GDSII file of Design iii. Test results and evaluation board
O1.7	**Design of PLL with VCO (SCL)** A PLL is a circuit that causes a particular system to track with another one. More precisely, a PLL is a circuit synchronizing an output signal (generated by an oscillator) with a reference or input signal in frequency as well as in phase. In the synchronized-often called locked-state the phase error between the oscillator's output signal and the reference signal is zero, or remains constant. If a phase error builds up, a control mechanism acts on the oscillator in such a way that the phase error is again reduced to a minimum. In such a control system the phase of the output signal is actually locked to the phase of the reference signal. This is why it is referred to as a phase locked loop. The project requires a square-wave output frequency generator with primary application of PLL as Frequency multiplier by multiplying the frequency of the reference oscillator. **Target Specifications:** • Output clock frequency range 40Mhz to 1800Mhz Mhz • Output Jitter (RMS) : 1.2% UI • Output Jitter (Total) : 8% UI • Supply voltage : 1.8V • Multiple output frequency rations : 2,4,8 • Inverter output frequencies : YES

O1.8	**Design of Adjustable high performance Radhard Negative Voltage Regulator (SCL)** This is adjustable high performance Radhard negative voltage regulator. It is specifically intended for space and harsh radiation environments. It should provide exceptional electrical performances, high speed and low dropout voltage. Input supply ranges from - 3V to - 12 V. It also provide logical control/ monitor functions (inhibit, output monitor, short-circuit control) from/to external positive voltage signals, while the entire device adjustable analog functions are biased at negative voltages with respect of ground pin. **Target Specifications:** • The device should operate in Junction temperature range -40°C to+125°C. • 3 A low dropout voltage • Over temperature and over current protection • Adjustable over current limitation • Load short circuit monitoring • Adjustable output voltage • Inhibit (ON/OFF) TTL-compatible control • Programmable output short-circuit current limitation **Deliverables:** i. Design Details along with all schematics and layout ii. GDSII file of Design iii. Test results and evaluation board
O1.9	**Design of Controller area network (CAN) serial communication physical layer (SCL)** The CAN Controller is block providing Controller Area Network (CAN) functionality compliant with the CAN Specification. The CAN Controller features a programmable bit rate to support applications that require a highspeed (up to 1 Mbit/s) or a low-speed CAN interface. Fifteen message buffers, each configurable for transmit or receive, and programmable acceptance filtering provide support for both Full-CAN and Basic-CAN operation. Host-accessible control registers provide CPU control of bit rate, diagnostic functions, enabling/disabling the CAN Controller, CAN pin logic level, CAN bittime partitioning, incoming message filtering, transmit message prioritization, and enabling/ disabling interrupts. Status registers provide CAN node,interrupt, and error/diagnostic status. The CAN bus interface consists of serial transmit and receive signals that connect to an external transceiver through chip-level I/O pads. To reduce chip-level pin count, the transmit and receive signals can be shared with other on-chip functions through a General Purpose I/O (GPIO) Controller. **Key Features** • Programmable bit rate—up to 1 Mbit/sec • Standard or extended frames • 15 message buffers—each configurable for transmit or receive

	• Remote frame support • Automatic transmission after reception of a Remote Transmission Request (RTR) • Automatic receive after transmission of an RTR • Programmable acceptance filtering • Global mask for message buffers 0–13 • Individual mask for message buffer 14 Programmable transmit priority • Time stamp counter—programmable for automatic reset on transmit/receive • Interrupt capabilities • Interrupts available for message buffer transmit/receive and CAN error conditions • Interrupts can be individually enabled/disabled • Diagnostic functions • Error identification • Loopback (internal or external) • Listen-only mode for initialization **Applications** • Passenger vehicles, trucks, buses (gasoline vehicles and electric vehicles) • Agricultural equipment • Electronic equipment for aviation and navigation • Industrial automation and mechanical control • Elevators, escalators • Building automation • Medical instruments and equipment • Pedelecs • Model Railways/Railroads
O1.10	**Design of ultra-low-noise, high-precision voltage reference < 1ppm/°C Drift with 1.8V VDD in SCL's 180nm Technology (SCL)** Band gap references are widely used in CMOS integrated circuits such as A/D convertors, DRAMS, flash memory circuits for their high precision and temperature independence. The reference voltage is required to be stabilized over supply voltage and temperature variations, and also to be implemented without modification of fabrication process. The bandgap reference which generates the reference voltage achieves the requirements mentioned above.Regarding the circuit performance, the demand for low-power and low voltage operation is strongly increasing due to the need of battery-operated portable systems.
O1.11	**Design of ultra-low-noise, high-precision voltage reference (1.2V) <5ppm/°C Drift with 3.3V VDD in SCL's 180nm Technology (SCL)** Band gap references are widely used in CMOS integrated circuits such as A/D convertors, DRAMS, flash memory circuits for their high precision and temperature independence. The

	reference voltage is required to be stabilized over supply voltage and temperature variations, and also to be implemented without modification of fabrication process. The bandgap reference which generates the reference voltage achieves the requirements mentioned above. Regarding the circuit performance, the demand for low-power and low voltage operation is strongly increasing due to the need of battery-operated portable systems.
O1.12	**Design of Radiation Hardened Dual port SRAM – Different Cuts (SCL)** DPRAM Cuts of following variations are needed which can be used as Embedded Solution or Stand-alone Memory Chip Voltage Levels – 1.8 V / 3.3 V Access Time - < 5 ns Address Bit Range – 4 Bits to 14 Bits Data Bit Range – 4 bits to 72 Bits Radiation Tolerance – TID >300 Krad (Si), SEL > 80 MeV-cm2/mg, SEU > 50 MeV-cm2/mg
O1.13	**Forward Error Correction (FEC) multi bit Memory error correction techniques in Radiation environment (SCL)** To design SRAM memory cuts (SPRAM & DPRAM) using SCL's 180nm CMOS standard process for use in space radiation environment with following **Radiation Tolerance –** TID > 300 Krad (Si), SEL > 80 MeV-cm2/mg, SEU > 50 MeV-cm2/mg. For the mitigation of the data upsets, any of the following mentioned Error Correcting Technique can be used: **1.Single Parity-Bit Code** The simplest form of error detection requires only one additional parity check-bit per data word. The check-bit ensures that the total number of 1's in a stored codeword is always even. For this reason, single-parity-bit codes are also known as even parity code. **2.Hamming SEC Code** This code is capable of correcting all single bit errors. Constructing a Hamming SEC H-matrix requires that all column vectors be unique and non zero. To meet these requirements, $n \leq 2r - 1$ where n is the codeword length, and r is the number of checkbits. **3. Hamming SEC-DED Code** A Hamming SEC code can be extended to detect double-random-bit errors in addition to its single-bit error correcting property to form a Hamming SECDED code. The code adds an overall even parity check-bit to an existing Hamming SEC code. The overall parity-bit provides an even parity check for the entire codeword, including both the data and check-bits. This is used in conjunction with the standard SEC check-bits to provide the DED functionality when decoding the syndrome.

	4. Hsiao SEC-DED Code Hsiao SEC-DED codes, also known as odd-weight-column codes, provide the same level of coding efficiency as Hamming SEC-DED codes in terms of check-bit overhead but provide improvements in terms of speed, area, and reliability of the decoding logic. Improvements are realized through the implementation of the code's double error detection functionality. **5. BCH Code** Bose, Ray-Chaudhuri, Hocquenghem (BCH) codes provide error correcting capabilities beyond those of the Hamming and Hsiao SEC-DED codes. They were invented independently by Hocquenghem in 1959 and by Bose and Ray-Chaudhuri in 1960.These polynomial based codes provide error correction for multiple random bit errors at the expense of an increase in the number of check-bits and decoder complexity. **6. Reed-Solomon Code** Reed-Solomon (RS) codes are a subclass of non-binary BCH codes in which error correction is performed on symbols, or bytes, as opposed to individual bits .Each byte consists of a cluster of b-bits, and any sized burst error contained within a given byte can be corrected.
O1.14	**Development of Memory Compiler (Radhard) for DP SRAM – to generate all views like .db., .lib, .v, .sdf, etc (SCL)** Able to generate Radiation Hardened Synchronous Dual Port SRAM (DPRAM) instances with specified Radiation tolerance levels for SCL 180 nm standard process. The generated SRAM cut must have the following pins for both ports: VDD –Power Supply, VSS – Ground, I(n) – Data Input Pins, O(n) – Data Output Pins, I/O(n) – Data Input/Output Pins (only in case when input and output pins are not separate), A(n) – Address Pins, CSB – Chip Select, OEB – 3-state output enable, WEB – Write Enable, CLK – SRAM clock sensitive to either rising or falling edge (edge to be selected by option) Able to generate memory cut of size ranging from 64 bits to 256Kbits (Single Bank). Able to generate any word size ranging from 4 bits to 32 bits (39 bits, in case EDAC option is used). Generate memory cuts upto which can operate in the range of 150MHz to 200MHz of clock frequency at core level. Ability to cater the power supply voltage range of 1.62 V – 1.98 V for full performance and even functional at 1.2 V with reduced performance. The typical operating voltage is 1.8 V. Option of adding Built-in Self-Test (BIST) interface at data and address pins of the generated memory cut thus making it BIST enabled. Option for Addition of error check & control (ECC) features is must. ECC includes SECDED error detection and correction, with error detection output pin. Complete package should

	have integrated solution related to Error Detection and Correction(EDAC) included within the SPRAM compiler Must provide multiple front-end & back-end views like .v, .vhd, .lib, .db, .lef, MBIST models, datasheet, .gdsii, lvs/spice netlist, etc, required by EDA flow from various major vendors. **Required Radiation Tolerance Levels:** • TID Tolerance > 300 Krad (Si) • SEL Immune, LETth > 80 Mev-mg/cm2 • SEU Rate < 10e-10 upsets/bit-day
O1.15	**Design of High Speed CMOS Standard Cell Library in 180nm SCL process (SCL)** Standard cell library contains a collection of components that are standardized at the logic or functional level, and consists of cells or macro –cells based on the unique layout. The importance of standard cell library design methodology is growing with very-large-scale integration (VLSI) technology advancement due to its usage in VLSI EDA flows. In high performance standard cell library, the main objective is to increase performance of logic cells that satisfies the given specifications. The benefit of high performance cell library is used in processors, high computational IC's etc. designs where density will be neglected to meet the performance. **The Standard Cell library should include the following criteria :** 1. Static CMOS Library 2. PVT variation : not more than 20% 3. D flipflops in the library should be working upto 2GHz clock frequency 4. Library should have Multibit D FlipFlops : 2bits, 4 bits, 8bits 5. Tracks –> 9 or 12 (any one for complete library) 6. Multiple drive strength of the cells 7. Multiple inputs and various cell combination 8. Supply Voltage 1.8V 9. Temperature range -40°c to 125°c 10. Views and files required in the library: **The delivery should have:** • cdl – cdl netlist for LVS with VDD and VSS defined as local and cdl netlist for LVS with VDD and VSS defined as global. • doc – datasheets • gds – gds for all cells • lef – lef abstract • liberty – 27 corners timing information (PVT combinations) in both CCS and

	NLDM (CCS-P, CCS-N to be 11ncluded). • spc – spice netlist for all cells • spc_simple – spice netlist for all cells without parasitics. • verilog – verilog model for all cells
O1.16	**High Voltage Difference Amplifier (SCL)** It is a precision difference amplifier with a very high input common-mode voltage range. It can accurately measure small differential voltages in the presence of common-mode signals up to ±275 V. The inputs are protected from momentary common-mode or differential overloads of up to 500 V. **Applications :** • High-Voltage Current Sensing • Battery Cell Voltage Monitoring • Power-Supply Current Monitoring • Motor Controls • Launch vehicle • Replacement for Isolation Circuits **Target Specifications:** 1) Common-Mode Voltage Range: ±275 V 2) Programmable Gain = 0.05, 0.1, 0.4, 1 3) CMRR > 90dB from –40°C to +125°C 4) PSRR > 80 dB 5) 3 dB Bandwidth > 1MHz (at Gain = 1) 6) Non-linearity < 0.01% (at Gain = 1) 7) Maximum Gain Error Drift: 10 ppm/°C or differential overloads of up to 500V
O1.17	**Design of DSP Processor in 180nm SCL process (SCL)** A digital signal processor (DSP) is a specialized microprocessor chip, with its architecture optimized for the operational needs of digital signal processing. They are widely used in audio signal processing, telecommunications, digital image processing, radar, sonar and speech recognition systems, etc. The goal of a DSP is to measure, filter or compress continuous real-world analog signals. Most general-purpose microprocessors can also execute digital signal processing algorithms successfully, but may not be able to keep up with such processing continuously in real-time. Also, dedicated DSPs usually have better power efficiency, are more suitable in portable devices because of power consumption constraints. DSPs often use special memory architectures that are able to fetch multiple data or instructions at the same time. DSPs often also implement data compression technology. DSPs are designed to execute complex math in parallel, which is common in many signal processing applications. By having hardware and an instruction set

	architecture (ISA) optimally designed for the FFT, the FFT is executed with higher performance in shorter time—and at lower energy. Power is directly proportional to the clock frequency and voltage squared. To run the clock at a higher frequency requires a higher voltage, which leads to an exponential increase in power draw. Hence, it is desirable if DSP is able to run at low clock frequencies while delivering high performance through hardware multi-threading, and by maximizing work per clock cycle.
O1.18	**Design of Memory controller and other microprocessor peripherals (SCL)** Peripherals are devices that aid the microprocessor to accomplish a given job. They serve as accessories to the microprocessor. They maybe located inside the SoC of a micro-controller, called on-chip peripherals, or located outside the SoC but on the same PCB, called off-chip peripherals. It is essentially useful to integrate as many peripherals as possible on the CHIP so that many issues relating to ISI and noise may be avoided at high speed of operation. Some peripherals with limit I/O ports and low speed of operation may be integrated on IC package. **Common embedded peripherals that most systems include** • GPIO controllers • Timers • PWM controllers • DACs • ADCs • Serial Communication Controllers for UART, SPI, I2C, USB, and Ethernet • Memory Controller • Interrupt controllers and • Direct Memory Access controllers (DMA)
O1.19	**Design of Radiation Hardened DF-DICE Flip-Flops (SCL)** DF-DICE(Delay Filtered Dual Interlocked Storage Cell) RH Flip-Flops **Target Specifications :** • Both Positive Edge Triggered and Negative Edge Triggered DF-DICE RH D-Flipflops. • Without Preset & Clear, With Preset Only, With Clear Only, With Both Preset & Clear • Scan Equivalent of all of above flip flops too. • Radiation Tolerance – • TID >300 Krad (Si), SEL > 80 MeV-cm2/mg, SEU > 50 MeV-cm2/mg
O1.20	**Read Out Circuit for Capacitive Accelerometer (SCL)** A high precision Read Out Circuit for Capacitive Accelerometer is required for MEMS based Capacitive Accelerometer. The capacitance to be measured will be directly

	connected to the device input. The device should be able to measure the single ended and differential ended capacitance and provide a digital output. The data rate (at which the digital code will come) requirement is 4 KSPS (samples per sec). The design of the device is to be carried out in SCL 180 nm CMOS process. **Target Specifications :** • VDD: 3.3V • Full Scale (Changing) Capacitance Range : ±4pF • Common mode Capacitance (Not changing): up to 20 pF. • Accuracy > 4fF • Linearity < 0.01% of F.S. • Data Rate: 4 KSPS • SPI/I2C Compatible Serial Interface	
P	**Area**	**Process Technology (SCL)**
P1	**Sub Area**	**CMOS Process (SCL)**
P1.1	**Design/PDK enablement of new devices in SCL's 180nm CMOS Process (SCL)** Software files need to be developed for various IC design elements while working with EDA tools. Following IC design elements are part of PDK library: Device symbols, CDF parameters, SKILL codes, Layout programmable cells (PCELLs), DRC, LVS, PEX verification rule decks. Software files need to be developed for these design elements for any device which needs to be integrated inside IC design flow. Skill set required for this work is good knowledge of EDA software programming along with background knowledge in semiconductor and IC domain.	
P1.2	**Technology Development of High Power RF LDMOS Device (SCL)** SCL has initiated in-house development of high Power RF LDMOS devices. In this work development of two different RF LDMOS devices for 650MHz(~500Watt) and 325MHz (1kWatt) operations has been initially targeted. In this regard SCL requires support for following topics: 1. Device Design for state of the art and reliable, rugged High voltage (~50V) RFLDMOS. 2. Process & Implant conditions (must be supported with TCAD simulated results). 3. Test chip for RF LDMOS process integration. 4. RF characterization and Reliability analysis of developed devices.	
P1.3	**Enablement of dual supply (1.8V/3.3V) PDSOI CMOS process at 180nm node (SCL)** SCL has achieved operational 1.8V PDSOI MOSFETs in 180nm technology. SCL is looking forward to next level of performance optimization. This should be demonstrated with - design of test chip comprising of structures required for SPICE model generation	

	- test circuits like ring oscillator, registers, SRAM, etc. for dc/ac/radiation performance evaluation - scalable SPICE model applicable to range of voltage, temperature (-55C to 125C) and frequency - I/O pads - test structures for reliability assessment to be part of test chip - test structures for RF performance evaluation	
P1.4	**Modeling of High Voltage (10-20, 40-60V) N /P LDMOS devicesdeveloped at SCL in 180nm CMOS baseline process technology (SCL)** Process development work at SCL is in progress for the process integration of LDMOS (VDS: 10-20, 40-60V; VGS:3.3-5V) devices (n and PMOS) in standard 180nm baseline process. Once the devices are enabled, SPICE device models are required for the above LDMOS devices for circuit design implementation. The developed models should be accurately predicting both DC and AC performance of the devices over a range of voltage, temperatures (-55 to 125C) and frequencies.	
P2	**Sub Area**	**CCD Process (SCL)**
P2.1	**Modelling of buried channel MOSFET (SCL)** The existing CCD process development at SCL is based on buried channel technology to cater the need of high Charge Transfer Efficiency with high SNR. The output stage of CCD comprises ofmultiple stage source follower amplifier connected with sense node to produce voltage equivalent of collected charge with greater sensitivity. To design CCD output amplifier, modelling of n-buried channel MOSFET is required using SPICE.	
Q	**Area**	**Compound Semiconductor Technology (SCL)**
Q1	**Development of process technology for Germanium–via heterogeneous integration with silicon (SCL)** It is required to develop a growth method of Ge on Si integration using Chemical Vapour Deposition (CVD) with the aim to achieve reasonable quality for electronic and photonic applications. Once the Ge/Si heterostructure with the desired properties is obtained, it is required that their electrical and optical properties need to be studied by fabricating active devices. The proposed development work should cover materials study, growth/ fabrication, and device characterization.	
Q2	**Si-on-GaAs: Monolithic Heterogenous Integration of Si-CMOS with GaAs Optoelectronic Devices using EoE technology (SCL)** As electronic technology becomes faster and denser, electrical interconnects (wires) have begun to limit the performance of the systems that depends on them. In order to alleviate this problem, optical interconnects are being considered as an alternative. Some	

	of the benefits of optical interconnects include higher speeds of operation with low drive requirements and minimal power dissipation, reduced size weight and cost, freedom from electromagnetic interference, crosstalk and ease of layout and routing. Inorder to implement optical interconnects, optoelectronic integrated circuits (OEICs) which integrate both electrical devices (transistors) with optical devices (optical detectors and emitters) must be created using electronic integrated circuits. However, due to intrinsic structure of silicon, this material is not capable of emitting light efficiently. Compound semiconductors such as GaAs on the other hand can be used to make LEDs and Lasers. Efforts are on without much success to develop technology that would support the monolithic integration of these two types of semiconductors. Therefore, it is proposed to develop a new technology which can combine silicon and GaAs substrates by wafer bonding or Epitaxy on Electronics (EoE).
Q3	**Use of engineered substrates to realize high quality Gallium Nitride epitaxial FinFET devices for power electronics (SCL)** Gallium Nitride (GaN), being a wide bandgap semiconductor, has gained unprecedented interest in recent times for its desired figures of merits in power and opto electronics and RF applications. The advent of 5G and miniaturization of power devices is expected to give a further impetus to the proliferation of GaN based technology. This project proposes the use of engineered substrates to realize high quality GaN based FinFET devices.
Q4	**Wireless power transmission based on Solar Power Satellites (SCL)** More than 70% of electrical energy requirements in India are met through fossil fuel based power plants. Due to the adverse environmental impact of fossil fuels based energy generation, requirements to generate sustainable renewable energy has become a dire need of this decade. Several research groups around the globe have reported different renewable energy generation and transmission schemes. The approach of using solar power satellites (SPS) to generate renewable energy is one such scheme, which will be required to develop or co-developed with the partner institute and SCL.
R	**Area** — **MEMS Design & Process Technology (SCL/URSC-LEOS)**
R1	**Micro Fluidics: Simulations to capture following behaviours (SCL)** Movement of ionic fluid (EMI-BF4) in a micro-capillary under the influence of electric field. Formation of Taylor's Cone at the capillary tip under the influence of electric field. Spray formation & droplet movement under the influence of electric field.
R2	**Design and Development of Micro/Nano technology based Sensors for space applications (SCL)** The horizon of nanotechnology based sensors and devices for use in space is expanding continuously. New ideas and proposal that utilize MEMS/NEMS technology towards design & development of sensors, micro-mechanism, micro propulsion devices, micro fluidics can be proposed.

R3	**Design/Development/Testing of Silicon Nanowire based biosensor (BioFET) for clinical diagnostics in space (SCL)** Includes simulation of the response of a Si-nw BioFET sensor both as fabricated and when exposed to analyte.Identification, development, testing etc of bio-markers/analytes alone, compatible for use in BioFETs, can also be considered.
R4	**Design and development of MEMS pressure sensor for high temperature, high radiation, corrosive media applications (SCL)** Pressure measurement onboard satellites require radiation hardened sensors. Some measurements also require pressure sensors to sustain high temperature (in the range of 400^0C-500^0C). This work requires selection of suitable transduction principle, sensor design and development. Piezoresistive transduction & SiC [Silicon Carbide] substrate is one of such suitable combination.
R5	**Design & development of micro-fabricated oxygen gas sensor based on ZrO2 electrochemical cell technology for space applications (SCL)** Requirement is to develop a miniaturized oxygen gas sensor, based on ZrO2 electrochemical cell technology. Scope of work can include design, fabrication and testing of device. Other novel ideas for sensing Oxygen can also be proposed; impact of radiation, cross sensitivity with other gases and recovery time after Vaccum cycling shall be considered.
R6	**Design and development of a miniaturized atomic frequency standard (URSC-LEOS)** High accuracy frequency standards are the heart of many advanced space applications. Some typical examples include satellite navigation systems and precision clocks for high speed communication networks. In addition, many scientific missions also need high accuracy timing that is not possible using conventional crystal oscillators, present day atomic frequency standards for space applications comprise of complex gas filled cells and discharge lamps. Presently used atomic frequency standards are based on 'opitcalpumping' technique that involve the use of a microwave cavity where the frequency of the microwave signal is locked to selected ground state hyperfine level via feedback through a resonant optical absorption. The atomic system is that of an alkali metal vapor form (Rb87 or CS 133). The conventional atomic frequency standards cannot be miniaturized beyond a limit due to the minimum size constraint of microwave cavity. In recent years, frequency standards based on the Coherent Population Trapping (CPT) resonance technique has been demonstrated. One of the key components of the frequency standards or clock is the vapor cell that holds the alkali vapor in a gaseous state. MEMS based technologies are now being used to develop miniaturized vapor cells. Vapor cell development Areas of collaboration with academic partners: Development of experimental techniques to characterize the miniature alkali vapor cells developed in LEOS using absorption spectroscopy and CPT spectroscopy. Design and development

	of methods of integrating optical sources, thermal control and detectors to the vapor cells to develop a miniaturized "physics package" capable of being used as an atomic frequency standard. It is expected that the project will result in establishment of experimental techniques, designs, methods of modeling and systematic documentation that will pave the way towards the development of miniaturized atomic frequency standards for space applications.	
R7	**Development of a micro heat pipe for electronics cooling (URSC-LEOS)** Heat pipe is one of the efficient examples of thermal management systems. It operates by taking the advantage of phase change. Conventional heat pipes are larger in size and not suitable for transferring heat from localised hot spots in electronics. MEMS based heat pipes have the advantage of fabricating channels and structures down to few microns' dimensions. Embedded directly on the hot spots in electronic circuits, microheat pipes can act as a passive heat transferring thermal management system which has wide range applications in space based systems as they are compact and lighter. From the operational perspective, the heat pipe is a closed cycle where within an evacuated closed tubular chamber fluid evaporates at the hot end and condenses at the cooler end, thus enabling heat transfer. Work done in LEOS so far includes designing and fabrication of micro heat pipes, charging them appropriately, sealing and testing them to study its heat transferring properties.Photolithographic masks were designed with respect to the ideas obtained from literature and Silicon based Micro heat pipes were fabricated and tested with in house MEMS fabrication facility and testing facility. There is a further scope to improve upon design and testing methodology to have bette runderstanding on these promising devices to make them suitable for space application. Areas of collaboration with academic partners: Design of Micro heat pipe, addressing specifially evaporator condenser and reservoir and developing analytical models or carrying out simulations for the same. Development of suitable methods to correctly meter the fluid charge and characterization of micro heat pipe for various heat inputs based upon different fluids and fluid charges. Packaging to minimize joints and providing leak tight interface to suite to end applications.	
S	**Area**	**IC Package Design & Development (SCL)**
S1	**Design of High speed Bus interface for SerDes application (SCL)** For substrate design of high frequency signals, special mechanism to be devised for avoiding skew mismatches that can lead to system timing issues. Issues such as signal integrity, power usage, and timing can all have significant affect on design of high speed interfaces. **Target Specification:** 1 Gbps data communication on substrate	

S2	**Optimisation of electrical design in HTCC package with mutidrop Lines (SCL)** In case of multichip substrate design having mutidrop connections, it becomes paramount to optimize the floor plan to meet assembly & fabrication constraints while getting optimum electrical performances. Parametric studies for varying dielectric thicknesses, trace widths, metallization thicknesses, via sizes, pin outlines CQFP or PGA etc. **Target Specification:** Design multi die package having processor, memory, digital ASIC, analog ASIC, MEMS sensor, Signal conditioner IC, power die etc. • Power Distribution Network Impedance <= 0.2ohm • Speed of operation 200MHz or better
S3	**Design and Development of deposition type MultiChip Moduleusing silicon (SCL)** One of the promising multi die substrates are Deposition type (MCM-D)on semiconductor material. Design and realisation of this substrate on Silicon for ICs like Processors, ASIC and Analog ICs to be taken up with promising electrical performances of complete module. **Target Specification:** Design multi die package having processor, memory, ASIC, transceiver and power die on silicon substrate. • Design must follow 180 nm SCL Fab Design guidelines. • Power Distribution Network Impedance <= 0.5ohm. • Operation frequency 100MHz or better
S4	**Development of multi layer IC package using 3-D printing advanced technologies (SCL)** Custom development of multilayer substrate having buried power planes and vias using Additive technologies is an open area to meet the design evaluation requirements. In addition to high packaging efficiency the substrates to meet specifications as per performance specifications of MIL 38535 and test conditions of MIL883 for hermetic space grade reliability & applications.
S5	**Material development and characterisation of substrates of high temperature co fired ceramics used in multi layer IC packages (SCL)** Ceramic IC packages are required for hermetic packaging of ICs for high reliability applications. These materials are tape casted for thick film printing applications used in fabrication of ceramic packages. Material development and characterization to get the desiredmechanical & electrical performances are required so as to get the desired specifications. **Target Specification:** High Temperature Co-fired Ceramic (HTCC) package specification **Specification of dielectric layer:** • Thermal conductivity > 14W/mK

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- Thermal expansion (RT-400 deg C) < 7e-6/K
- Dielectric Constant (1MHz) > 10
- Flexural Strength ≈ 380 MPa
- Young's Modulus of Elasticity ≈ 300GPa

Specification of metal plane layer:

- Conductivity > 86MS/m

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<tr><th>T</th><th>Area</th><th>Human Spaceflight Programme (SAC)</th></tr>
<tr><td>T1</td><td colspan="2">

Development of measurement systems and sensors for gas concentration (SAC)

Human Spaceflight requires continuous measurement of concentration of major air constituents (O2, CO2, CH4, NH3 & CO) and more than 200 trace gases including trace volatile organic compounds (VOC) at ppm to ppb levels, which are relevant to astronaut's health. These are by-products of metabolism/combustion/chemical reactions in the cabin.

Measurement of these gases can be achieved by discrete sensors for each gas or by holistic techniques like spectrometry. Both approaches have their own advantages. Handheld measurement systems can use discrete sensors to build compact, light-weight and battery powered systems. Other techniques can be used to measure array of gases from the same sample. Indigenous development of compact and lightweight sensors and other systems using laser, chromatography, Fourier transform techniques etc have good potential for present and future applications in HSP.

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<tr><td>T2</td><td colspan="2">

Development of mitigation techniques for Communication blackout during re-entry (SAC)

Practical experiments may be conducted in the suitable plasma environment to validate the following:

- Dependence of EM wave attenuation on plasma profile.
- Dependence of EM wave attenuation on operating frequency w.r.t. plasma frequency.

Development of techniques to enable communication during this phase or to mitigate complete communication black-out can help existing and future missions of HSP. Experiments and finding that can aid to the understanding of phenomenon also can be seen as value addition.

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<tr><td>T3</td><td colspan="2">

Development of wireless communication systems (SAC)

It is required to develop wireless systems that demonstrate reliable data transfer across avionics components, subsystems, and interfaces to simplify system integration, reconfiguration, and testing. Solutions that enable new avionic architectures and provide capabilities that expand mission performance while decreasing the Size, Weight, and Power consumption and cost of the resulting spacecraft are highly desirable.

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	Applications include sensors communication within habitat volume, communication during Extra Vehicular Activities, video capturing of separation events etc.
T4	**Study and simulations to identify and modify material flammability limits in low-g environment (SAC)** Development of instruments, setups and carrying out tests, generation of data related to material flammability, odour, outgassing and off gassing etc. on ground as well as in microgravity can be useful for present and future HSP missions.
T5	**Study of In-flight identification and quantification of species in water for long term space missions (SAC)** Development of apparatus, test setups for experiments related to above subject, evaluation of data received from such experiments and development of mitigation techniques for observed ill effects can help in current and future missions of HSP.
T6	**Assessment of flame spread of large scale microgravity fire (SAC)** Understanding nature of flame, process of combustion, rate of spread, mass consumption, quantity and rate of heat release etc can be taken up as study. Additionally, apparatus, test setups and identification of methodology, both on ground as well as in micro gravity also is needed to further the understanding of the subject.
T7	**Microbial monitoring in microgravity environment i.e Non- culture based in flight monitoring with species identification and quantification (SAC)** Microgravity can affect the growth and survival of microbes. The research on this topic is essential to achieve safe and healthy long duration space habitation. Non-culture based in-flight monitoring with identification and quantification of microbial species is targeted for the development. This research would help in understanding the relationship between humans and microbes, which may be affected hugely in microgravity. It will enable the understanding of how and where microbes proliferate in confined environment in space. Test setups and instrumentation required for remote observations can be developed to achieve the above mentioned purpose followed by findings and conclusions that may become input or directive for future missions.
T8	**Disinfection technique and technologies for microbial control of water systems and environment in microgravity (SAC)** The disinfection systems based various technologies like the Ultraviolet Germicidal Irradiation (UVGI) method etc. are essential for long duration space missions/Space Stations for disinfection/removal of microorganisms. Other alternate techniques also can be developed which are safer and more efficient.
T9	**Application of AI and ML in crewed missions (SAC)** exploring possibilities of AI and ML in HSP is encouraged with all potential applications. Some are listed below.

	1. Voice based system commanding mechanism without restricting/requiring use of any limb action. 2. An early warning system which learns from previous data to warn on possible occurrence of a hazard.
T10	**Compact fire suppression systems for crewed missions for micro gravity applications (SAC)** On board fire in HSP is one of the most serious on-board hazards. Every HSP mission carries fire suppression system. FSS should be safe for humans, should be quick and efficient in dousing fire, should be clean and its application should be safe for onboard electronics. Fine water mist based FSS is in use onboard ISS now. Indigenous development of compact, portable, easy to use and safe FSS is needed for current and future HSP missions.
T11	**Microgravity experiment platforms to simulate microgravity on earth (SAC)** Research in microgravity is indispensable to disclose the impact of gravity on biological processes, organisms, materials, fire and functional systems. “True” weightlessness, for more than a few seconds at least, can only be achieved in space or zero-g flights in atmosphere. Drop towers, drone based agile platforms etc. have potential to bring out microgravity experiment platform. Test setups, approaches, new ideas to carryout such tests can be used in existing and future missions of HSP.
T12	**Next generation fire detection systems (SAC)** Fire is one of the most critical on-board hazard for any HSP mission. Detection fire is of paramount importance. Sensors must have very high sensitivity to variety of fire, flame and electric spark. At the same time, it should offer high immunity to false detection. Most mission experiences have reported early detection by humans through smell, rather than on-board sensors. Development of “Electronic Nose” which can detect very low concentrations of combustion products can help in early detection of fire. Fire is detected by measurement of concentration of specific gases, heat, temperature, flame etc. Novel approaches n detection, new parameters that can aid to detection of fire also is needed to enhance the fire detection scenario.
T13	**Display and other situational awareness technologies (SAC)** Development can be focused on fixed and portable display devices with higher efficiency (lower size, mass and power) and better human centric aspects, taking advantage of advancement in display panel technology like flexible films displays etc. Augmented reality based devices can be used to provide context based information to the crew for information such as visual alert, holographic communication and object information. AI and ML can be included in such systems to make them more efficient and effective.

T14	**Personalized instrumentation for astronauts (SAC)** Personalized instruments like wearable health monitors etc. are essential for all human spaceflight missions. Variety of sensors are flown with astronauts for monitoring of crew health parameters like Blood Pressure, Oxygen Saturation, Pulse Rate, Exhaled Breath Analysis etc. Wearable medical devices need to be developed for continuous monitoring and transmission of these parameters to ground. This is essential for both long term and short term missions. Apart from its on-board application, they are equally useful during training and simulation studies. These instruments would have immense applications in all kinds of human spaceflight missions for safe, reliable and continuous health monitoring of all crew. – Wearable sensors – Breath Sensor System
T15	**Instrumentation for docking (SAC)** ISRO envisages development of technologies to support automated or assisted docking while in orbit. Laser based or other types of ranging systems, camera based video systems, RF based systems are required for beacons, altimetry or distometry, velocimetry, optical flow techniques, close range photogrammetry and other parameters of situational awareness either in assist mode or in close loop mode for automated docking. Development of sensors, integrated systems and demonstration models can help in future docking missions of HSP.
T16	**Space suit related Instrumentation (SAC)** Space suit is an integral element of any HSP mission. Variety of sensors including health parameter monitoring systems are part of an integrated spacesuit. Personal communication systems, integrated display systems, tools for articulations during EVA (Extra Vehicular Activity) and other accessories helpful to accomplish routine and specific tasks of astronauts are needed to be developed for all HSP missions.

Earth Observations

A	Area	Remote Sensing, Signal and Image Processing and Software Development (SAC/NRSC/NESAC)
A1	Sub Area	Signal & Image Processing and Data Products (SAC/NESAC)
A1.1	**Onboard Imaging with Joint Deblurring, Denoising and Compression (SAC)** ‘In the context of satellite imaging, the classical chain consists in compressing the image onboard and in restoring the decompressed image at the ground station. A main disadvantage of this solution is that the deconvolution process amplifies quantization noise. The joint deblurring-denoising and compression scheme, proposes to perform the deconvolution before the compression and thus avoiding this drawback. Since this requires the deconvolution step to run onboard, the algorithms have to be as fast as possible.	
A1.2	**Satellite Imaging Chain based on Compressed Sensing (CS) (SAC)** Compressed sensing is a new emergent sampling theory whose purpose is to perform acquisition and compression of the signal at the same time. CS could indeed drastically simplify the process of image acquisition by providing a reduced number of measurements, directly received from the sensor, therefore saving an important quantity of resources. It is also valuable to point out that the CS framework provides an acquisition technique whose performances depend mainly on the reconstruction algorithm done on the ground. Thus, optimal onboard acquisition scheme and on-ground algorithms needs to be built to improve quality.	
A1.3	**Automatic Cloud detection for high resolution satellite stereo images for generating DEM (SAC)** The automatic extraction of terrain from high-resolution satellite optical images is very difficult under cloudy conditions. Therefore, accurate cloud detection is necessary to fully use the cloud-free parts of images for terrain extraction. An algorithm for automatic detection and rejection in DEM generation is required.	
A1.4	**On-board Image Compression Algorithms with locally adjustment quality (SAC)** Many compression algorithm onboard based on DWT like JPEG 2000 or CCDS recommended compressor are all based on fixed bit rate where the compression ratio is decided either based on mission data rate constraint or is adjusted on initial set of images in the initial phase of satellite operation. In order to optimize the bit-rate on every part of the image, it is required to have compression algorithm with quality adjusted locally. It should adapt the compression rate to local features in the image and should be implemented in FPGA to be put onboard.	
A1.5	**3D Information from Radiometric Measurement (SAC)** Input is the intensity image and the output is 3D properties of a surface in the scene is ill-posed and extremely difficult to solve in most cases. Instead of solving it, a side-step is	

	taken and objects in the image are segmented using some semantic information, but not directly the image formation physics. Nevertheless, there are special situations in which the inverse task to image formation has a solution. The first approach is **shape from shading,** and the second one **photometric stereo.**
A1.6	**Optimization Techniques in Recognition (SAC)** In image recognition and understanding, the best image representation is sought, or the best match between image and model is required, or the best image understanding is the goal. Whenever 'the best' is considered, some objective function of goodness must be available, implying that an optimization technique can be applied which looks for the maximum. The design of the objective function is a key factor in the performance of any optimization algorithm.
A1.7	**Coupled Hidden Markov Model (HMM) for multi temporal image understanding (SAC)** The Hidden Markov Model (HMM) approach has proved enormously popular because it is straightforward to understand and implement, and maps so successfully onto a wide range of applications. The power of the model and its analysis techniques far outweigh the problems associated with the inadequacy of its assumptions in assuming a time independent model, and first order behavior. Nevertheless, the obvious limitations of a simple HMM make it natural to extend the idea to compensate for its weaknesses. One way is to invest it with more memory, which may be done by building a model based on a second (or higher) order assumption, the current state then depending probabilistically on some number of predecessors. It is easy to see how this might be expected to improve performance.
A1.8	**Mathematical Morphology for Image Processing (SAC)** Mathematical morphology is a well-established area of image-analysis that stands separately from the mainstream. It is based on the algebra of non-linear operators operating on object shape and in many respects supersedes the linear algebraic system of convolution. It performs in many tasks—pre-processing, segmentation using object shape, and object quantification—better and more quickly than the standard approaches.
A1.9	**Deep Reinforcement Learning Guided Feature Assimilation for Efficient Poverty Mapping (SAC)** With the advent of deep neural networks, reinforcement learning has proven broadly useful for a wide variety of tasks including object detection, localization, tracking, cloud removal, super-resolution, band synthesis, wetland delineation and water monitoring. It is proposed to regulate the process of poverty mapping through deep reinforcement learning.
A1.10	**Optimization for Machine Learning on Remote Sensing Imagery (SAC)** Intersection of machine learning and remote sensing is an emerging field with positive societal consequences. While multitude of tasks are being addressed effectively using machine learning on remote sensing imagery, the theoretical understanding of all these.

	methods remains elusive. It is to be noted that the complexity of these learning problems increases drastically with non-convex and non-smooth nature of empirical risk landscape While recent studies focus on analyzing the dynamics of trainable parameters, the assumptions made in these asymptotic bounds are far from practical scenarios. It is proposed to understand the role of randomly initialized gradient descent to find a global convergent point on various remote sensing applications.
A1.11	**Automatic extraction of 3D city models using LIDAR/ Satellite data (NESAC)** Extraction of buildings in undulating terrain is a more challenging task in comparison to plain region. The proposed research would be useful for preparing smart city planning in all hilly cities.
A1.12	**3D surface modelling and features capturing of UAV/UAS data (NESAC)** A user friendly and robust UAV/UAS data processing software/model would help in using the UAV data more efficiently and more diversified field. In-flight geometric calibration & processing of UAV data will help in reducing the total output generation time significantly.
A1.13	**Feature Extraction Algorithms for 3D Scene Reconstruction (NESAC)** 3D scene reconstruction is an important area in computer vision applications. Drones are able to help in gathering 2D images of large scenes. Accurate and precise feature extraction from overlapped 2D images is an important initial step in 3D scene reconstruction. The output key correspondences will then be used for generation of initial sparse 3D point cloud representing the 3D scene of the area. There are challenges in precise feature detection and matching of the images especially when the scene represents mixed natural scenes with uneven terrains like North East of India. Further, there can be wide variations in the images with regard to scale, orientations, rotations or illuminations in the images captured by aerial drones. There is need to find new computer vision based algorithms for feature detectors, descriptors and feature matching suitable for various kinds of scenes captured by drones and devise an intelligent processing of these images for 3D scene reconstruction.
A1.14	**Classification and Semantic Segmentation of 3D Point clouds derived from Image Based Modeling (NESAC)** 3D Point Cloud Segmentation is an important area for general scene understanding for wide variety of applications ranging from remote sensing to computer vision and robotics. 3D point cloud segmentation is the process of classifying point clouds into multiple homogeneous regions. The segmentation is challenging because of high redundancy, uneven sampling density, and lack explicit structure of point cloud data. Successful and accurate solution to this problem can then be applied to many applications for 3D geospatial analysis and measurements. The ability to effectively segment these highly unstructured point clouds is challenging. Further, the available segmentation methods are difficult to apply specially for the point clouds consisting of different scenes such as trees and other objects with no geometrical shapes. A proper machine learning algorithms or deep learning based approach should be developed to automatically classify and segment the objects in the real world.

A2	Sub Area	Image Processing and Pattern Recognition (NRSC)
A2.1	**Advanced sensor models for optical & microwave data Geo-referencing (NRSC)** Georeferencing is the process of assigning spatial location to each pixel of an image using sensor models or GCPs. Precise georeferencing is a major issue especially in highre solution optical and microwave imagery. Presently, rigorous sensor models and rational function models are widely used in optical imagery geo referencing. For microwave sensors the range Doppler method is generally employed for assigning precise geolocation. This method corrects the imagery for foreshortening and layover effects by utilizing the topology, orbit and velocity measurements from satellite and assigns a geolocation to each pixel. We welcome proposals that defines new methods/models and implementation of any of the above algorithms both for optical and microwave imagery.	
A2.2	**Atmospheric correction procedures implementation for Visible & NIR & HySI (NRSC)** Atmospheric correction is key image processing step to retrieve surface reflectance values from spectra recorded by remote sensing space borne sensors. This further helps in standardizing physical variables, thus facilitating comparisons across time series of such variables. Presently, Atmospheric correction of all bands of Resourcesat-2 AWIFS and LISS III sensors is being carried out utilizing water vapor, ozone data products from MODIS, Aerosol optical depth from INSAT satellites using 6S RTF algorithm. The atmospheric correction has improved our estimation of normalized difference vegetation index by a factor of 50% with respect to TOA. There are possibilities of improving these estimations further by modeling the Bidirectorial reflectance distribution functions, using reflectance references from Drones or physics based models. We invite proposals in any of these areas that aim to minimize the influence of atmospheric effects in estimation of physical variables.	
A2.3	**Deep Neural networks for remote sensing applications (NRSC)** In recent years, several types of remotely sensed data, e.g., optical multi-spectral and hyper-spectral images, Synthetic Aperture Radar (SAR) and in many cases with extensive time series are increasingly available. All these remotely sensed data is motivating the development of large repositories and, most importantly, the development of advanced methods and algorithms for data analysis and processing. On the other hand, Deep Neural Networks (DNNs), commonly called Deep Learning (DL) models, are showing very high potential in the recognition of spatial and temporal patterns in a wide range of remotely sensed applications (e.g., in scene classification, object detection, spectral un-mixing, spatial super-resolution, pixel classification, dimensionality reduction, etc.), providing a great variety of algorithms, procedures and models, under different learning strategies (supervised, unsupervised, semi-supervised). In particular, Convolutional Neural Networks (CNNs), a type of DNNs, currently constitutes the-state-of-the art in image classification, object detection and instance segmentation. Generative adversarial networks (GANs) are showing promising results in the mapping of the terrestrial surface and in super-resolution problems. Recurrent Neural Networks (RNNs)	

	are also showing good results in identifying patterns in time series and in forecasting meteorological events. However, due to the huge amount of parameters that need to be learned by DL models, the complex nature of DL models, the complexity of the remotely sensed data itself (e.g., high dimensionality) and the lack of labeled datasets, these approaches must deal with important problems, which can lead to inadequate generalization and loss of accuracy. Analyzing multi-band images acquired from diverse sensors using one or a combination of several Deep Learning models, solution to be implemented for Remote sensing Image classification for Land use/Land Cover mapping Image reconstruction / Image Restoration by Image Learning.
A2.4	**Signal and Image Processing solutions for Remote Sensing Images (NRSC)** Remote Sensing data can be multidimensional signals, multispectral, hyperspectral images, radar data, time series and video sequences. Efficient data analytics in these signals is crucial in order to exploit all historical archives as well as the newly acquired observations in near real-time. The applications are vast including numerous environmental monitoring tasks, agriculture, safety, security, engineering, etc fields. Using Signal and Image Processing for Remote Sensing, development of the cutting-edge multi-resolution, multi-temporal multispectral and hyperspectral data harmonization techniques, advanced image processing algorithms for restoration and de-noising.
A2.5	**Advance Image Processing (NRSC)** • Development of the cutting-edge multi-resolution, multi-temporal/ multispectral and hyperspectral data harmonization techniques, advanced image processing algorithms for restoration and de-noising. • Development of algorithms for DSM/DEM/DTM extraction from High resolution satellite stereo imagery and their validation. • Development of New open-source based advanced solutions for multi high resolution imagery automated geometric processing using bundle adjustment. • Deep Neural Networks for Remote Sensing Applications
A2.6	**Cloud Computing (NRSC)** NRSC is having huge data archive amounting to petabytes acquired over the years right from 1988. Moreover, with upcoming satellites like GISAT that will be downlinking data 24*7 of the tune of 5-6 TB per day, data and metadata storage, cataloguing and search becomes a daunting challenge. • Processing Online on CLOUD computing infrastructure forquick archival and retrieval of remote sensing data utilizing lossless data compression techniques. • Generation of super resolution images with multi temporal low resolution and high resolution images.
A2.7	**Web GIS and Data Dissemination (NRSC)** With an ever-increasing wealth of earth science data produced from various sources and platforms including earth observation, modeling and forecasts, the opportunities to

	exploit such vast amounts of data to produce valuable information products are challenging and exciting. These data are widely used for monitoring, simulation and analysis of measurements that are associated with physical, chemical and biological phenomena across the ocean, atmosphere and land. The capabilities to share geospatial data and information products to meet the need of varying levels of users is accomplished through Web GIS, which is an architectural approach, for implementing a modern GIS. It is powered by web services that deliver data and capabilities as well as connect components. It can be implemented in the cloud, on-premises, or more typically as a hybrid combination of the two, leveraging the best of both worlds. The following research areas facilitates to provide solutions for user community. • Augmented Reality, • Indoor Mapping with WiFi/Bluetooth, • Passive GIS sync with Social media, • Sensor Web with Uniform Resource Identifier, • Opensource data centre computing, • Geointelligence(quality score, categorisation) of crowd sourced information Trend Analysis on Time series thematic data.	
A3	**Sub Area**	**Image Map Generation Using Remote Sensing Satellite-Data (NESAC)**
A3.1	Remote sensing satellites have provided continuous images with improving resolution since 1985. Currently, CartoDEM and Carto-ortho images are available for Indian region. Intention is to generate image map of cities and other area of interest using the available data sets as mentioned above. Cartosat series (images) data panchromatic (PAN) and multispectral (MX) can to used. Image captured by means of remote sensing are a very important source of geospatial information. Image map is defined as a special map portraying geographic space in aparticular cartographical projection and map scale where its content consists of two basic components- image and symbol components. Image component is represented by remote sensing image(s), while symbol component is represented by cartographic symbols. As it is well known that SOI topographic maps are old surveyed and so very less information is available specially in the maps of Indian cities. Satellite data provides latest information which can be encashed for various applications. By means of image map generation user can get better, latest and additional information from the image map. Topographic maps contain the representation of ground features in symbol form but in case of image map beside latest features, one can study and analyse the ground terrain effect also. Image maps can be generated at following scales a) 1:50000, b) 1:25000 and c) 1:10000	

	Specifications Positional accuracy: Aim of this proposal is to generate Image map for Indian cities. As per the scale, image map accuracy will be different. But with same input satellite datasets, goal can be targeted <10m accuracy specifiations. Map projection & Datum: The Image maps are planned to be generated in World Geodetic System (WGS-84) Datum and will be projected in UTM Map Projection. Radiometric resolution of resultant images will be 10 bit. Methodology Open map series concept to be adopted in image map generation for map sheet numbering. Map grid tile generation with image map number is required. For a particular map grid no.fist select the corner coordinates and collect respective area CartoDEM and orthoimages. a) Generate DEM mosaic and orthoimage mosaic. b) In ERDAS s/w, using “map composing tool” generate image map. Image maps can be archived in a database and as per the requirement hardcopy can be printed.	
A4	**Sub Area**	**Data Registration (NRSC)**
A4.1	**Techniques for multi-date data registration and mosaics (NRSC)** Image-registration can be defined as ‘the process of overlaying images (two or more) of the same scene taken at different times, from different view points, and/or by different sensors’. It plays an essential role in remote sensing as it is a prerequisite for the analysis of multidate image sequences. Image co-registration issues might seriously influence the final quality of the remote sensing analysis and products because small misalignments in the input data could give large errors in the final outputs. e.g. for change detection applications. Image-to-image methods have two important advantages. The fist one concerns the analyzed data: many applications require the comparison of multi-temporal and multisource data that should be precisely aligned. The relative co-registration of different images is therefore more important than their absolute geo-referencing. Secondly, image to-image co-registration methods are based on the analysis of dataset of the same type. This leads to a general simplifiation of the co-registration process especially in the case automatic co-registration techniques are used. The co-registration essentially required for Bhuvan portal, where the multiple images has to match each other previous layer. It includes free download of AWIFS and LISS-3 orthorectified products and High Resolution satellite of multiple years, which are being used for feature extraction. The co-registered product enables automatic updation of newly identified features in latest images.	
A5	**Sub Area**	**UAV Data Processing (NESAC)**
A5.1	**Vision based Multi Object Detection and Localization from Aerial/Drone Imagery (NESAC)** Object detection is a foremost and stimulating problem in computer vision that seeks to classify object instances from a large number of predefined classes in natural images. Interpreting the object detection problems means placing a bounding box over around those objects and placing the correct object category with each bounding box.	

	In computer vision, deep learning is the futuristic method to perform object detection. Although in the past, major advances in object detection happened in natural scenes, such triumph is slow in aerial imagery, not only because of variations in the scale, shape, and orientations of the object instances on the images but also due to the shortage of well-annotated datasets of aerial scenes. Proper research with Vision based Deep Learning can be adopted for detection and localization of objects. The output of research can be applied to numerous applications such as a wide range of measurement systems in traffic management, urban planning, defense, agriculture, military applications, and environmental management, and so on with the use of UAVs. Also, the final model can be used for various applications of machine learning projects where object detection plays a vital role.	
A6	**Sub Area**	**Photogrammetry (NESAC)**
A6.1	**3D Surface Models from 2D Drone Images (NESAC)** There's increasing need for large scale mapping for city/urban/rural planning. Further, there's need for immediate or near real time cloud-free aerial images/videos for disaster management activities for all areas in NER including highly complex terrain regions. The drones are perfect for image acqusition and generates high resolution images. There's need to process these data and generate 3D surface models and other largce scale data products for use in different applications. A customizable software with clear process pipelines for drone data processing should be helpful to generate Analysis Ready Data including 3D models.	
A7	**Sub Area**	**Remote Sensing Applications (Agriculture) (NESAC)**
A7.1	**Crop damage assessment in North Eastern Region of India using geospatial technique (NESAC)** Geospatial techniques comprising of Remote Sensing, GIS and GPS can play a vital role in crop damage assessment due to natural hazards like floods, drought, bankline erosion, pests, diseases etc. Both Satellites based and UAV based multispectral, hyperspectral and SAR data can effectively be used for mapping and quantitative monitoring and assessment of crop damage. In addition, web technology in terms of geo-portals acts as a single window platform for storage, assimilation and dissemination of information with GIS capabilities. Large volume of field data may be transmitted through mobile Apps and stored in high-end servers.	
A7.2	**Crop stress management for precision agriculture using hyper spectral data (NESAC)** Hyperspectral remote sensing data helps in assessing various crop biochemical parameter as well as soil properties especially nutrients, mainly due to the information contained in large number of contiguous bands with a narrow spectral bandwidth. Differences in crop parameters and nutrient concentrations cause spectral response variations, which can be captured and modelled using different statistical techniques. These techniques help us in real time mapping of various crop stress at different region of management as part of precision agriculture.	

A7.3	**Crop discrimination in Hilly terrain using remote sensing technique (NESAC)** Crop discrimination from scattered field crops, horticultural crops, medicinal and aromatic plants in hilly terrain using multispectral, hyper spectral and SAR data (Including UAV multispectral and Hyperspectral data).	
B	**Area**	**Mission development and Remote Sensing-Sensor Technology (URSC-LEOS)**
B1	**Sub Area**	**Micro Fabrication for Optics (URSC-LEOS)**
B1.1	**Deformable mirror by micro fabrication for phase correction in adaptive optics (URSC-LEOS)** Deformable Mirror (DM) is an important sub system of adaptive optical instrumentation which helps in improving the optical performance of an imaging system by actively correcting the measured wave font errors. The surface fiure of a deformable mirror isactively controlled and modifid such that it cancels out the measured surface error ofsystem. It is made up a flxible Si wafer with thin fim piezoelectric actuators fabricated on the back side using micro lithography techniques. This technology has multiple applications in improving imaging performance, optical communicated and ophthalmology.	
B1.2	**Micro mirror array for wave front phase sensor (URSC-LEOS)** Micro mirror array is an important optical device with multiple applications. Realizing the fabrication technology of this device will be a signifiant step in the development of morecomplex instruments such as Shack Hartman Sensor etc.	
B2	**Sub Area**	**Spectroscopy Instrumentation and Application (URSC-LEOS)**
B2.1	**Optical design and development of compact spectrograph for spectroscopy (URSC-LEOS)** Aberration corrected spherical surface gratings for specifi spectroscopy application can be designed and the groove pattern can be realized using direct-write electron beam lithography. It is possible to fabricated analog depth diffractive optics in thin fims of polymethyl methacrylate. Diffractive optic fabrication on non-flat (to date convex spherical) substrates can be fabricated utilizing the large depth of field inherent in E-beam lithography. Realization of this technology will help in realizing compact, high performance spectrograph with minimum number of optical components.	
B2.2	**Raman spectroscopy application in earth and planetary atmosphere studies (URSC-LEOS)** The gaseous composition of earth and planetary atmospheres are required to be studied and analyzed on a regular basis to understand the climatic changes that are happening. LIDAR instrument based on Raman spectroscopy can give us valuable information on gaseous distribution along the attitude. Laboratory simulated atmosphere studies of gaseous planets and also experimental Raman LIDAR spectroscopy studies of earthat mosphere are of interest.	

B2.3	**Raman spectroscopy based studies on optical materials and minerals (URSC-LEOS)** It is now well established that most of the covalently bonded optical materials and minerals have their characteristic Raman spectrum which can be used to identify the compound. Proposal to do mineralogical study using Raman spectroscopy are useful to collect sufficient data and develop techniques to analyze and identify mineral compositions of any unknown minerals. These results and experience will help in future moon / mars mineralogy using Raman instrument.	
B3	**Sub Area**	**Sensor Electronics (URSC-LEOS)**
B3.1	**On Orbit mounting estimation of star sensor (URSC-LEOS)** Star Sensor Mounting Estimation using on orbit / in-situ measurements The star sensor provides attitude accurate to 10'' in measurement axes and 40" in bore-sight axis, leading the spacecraft pointing and control of 36" in body frame at about 4/8Hz update rate. The mounting / mechanical stability contributes to about 4-6'' uncertainty. Also due to various factors like thermal, effects of structural stability etc., the SS mounting varies by small amount cyclically in orbit/season. Towards providing further improved attitude accuracy of about 10" (in all three axes inbody frame), it is proposed for research studies the problem of estimating the star sensor mounting on orbit/in-situ, using star sensor measurements, so that mounting updated at every attitude solution cycle, can be delivered along with estimated attitude solution to AOCS for signifiantly improving the pointing control accuracies of spacecraft & location accuracies of imageries.	
B4	**Sub Area**	**Optical Thin Films (URSC-LEOS)**
B4.1	**Studies on transition metal oxide thin fim coatings (URSC-LEOS)** Transition metal oxide coatings are potential candidates for their applications as infrared detector sensing elements, switching devices, radio-frequency transparent thermal control coatings, etc. Studies on optical, electrical and thermal properties of the thin fims will lead to development of devices for space applications.	
B4.2	**Laser damage threshold studies on optical thin film coatings (URSC-LEOS)** The optical coatings such reflctor coatings, antireflection coatings, interference filter coatings, etc have their applications in laser based instruments for ground as well as space applications. Based on the energy of the laser the coatings may be damaged. The studies on laser damage threshold of optical coatings give an insight into the durability aspects of the coatings for laser applications.	
B4.3	**Studies on hydrophobic/ dust repellent coatings (URSC-LEOS)** Optical thin fim coatings are essential for space based reflctive / refractive electrooptics systems. The front optical elements being exposed to space environment, they need to be protected from dust and condensable vapours which seldom detrimental to the performance of payloads. These coatings will also be useful in interplanetary missions during landing the instrument over the surface of the planet. Hence the study of hydrophobic/ dust repellent coatings field space applications.	

B4.4	**Infrared optical coating technologies for filters, anti reflectance coatings etc for IR optics (URSC-LEOS)** Space qualified optical coating technologies to produce filters and ARCs in different spectral bands in the near IR, SWIR and far IR for the imaging and spectroscopy instruments that are being envisaged in the future space programs are required to be developed.
B4.5	**Thin film solar cells and thin film batteries for satellite power requirement (URSC-LEOS)** It is already recognized that Thin film solar cells based Cu-In-Ga-S (CIGS) materials coatings are highly advantageous for space power application as these panels have high specific power (Watts / Kg) and are highly radiation resistant. Development of this technology for space usage will help in signifiantly reducing the weight contribution due to solar power requirements.
B4.6	**Nano technology based optical / gas sensors (URSC-LEOS)** Nano technology based rechargeable Thin film batteries which can be charged and store the power generated by solar cells are under development for space application. With this combination failures due to lack of power can be significantly reduced.
B4.7	**Optical material, coatings and components for NIR or Visible LASER development (URSC-LEOS)** Indigenous development of LASER for space application in an ongoing process at LEOS which requires lasing materials, damage resistant coatings and Thin film based laser diodes etc., research and development in realizing these technologies can be very useful.
B4.8	**Ultra narrow band pass and notch filters for a single wavelength of a laser line (URSC-LEOS)** These filters are required for Raman Spectroscopy Instrumentation where the incoming laser should be spectrally stable with a very narrow band width and without any side lobes. This can be possible only with a very narrow band pass fiters placed in front of the laser. Similarly the Rayleigh scattered radiation from a laser illuminated sample has the same wavelength as the laser. In order to observe the Raman Spectrum, this component needs to be filtered out completely using a very narrow band notch filter centered at the laser wavelength. Development of these filters will help in indigenous realization of Raman instrument for space application.
B4.9	**Glancing angle deposited optical films with unique optical properties and their applications (URSC-LEOS)** Porous nano-engineered thin films fabricated using GLAD have a wide variety of opticalapplications. Helical fims exhibit intriguing chiral optical properties, including circular Bragg effects and optical activity. GLAD fims with grade index can be used for wide band antireflction coatings exhibiting transmittance in excess of 99.7% over a 460 nm wavelength range, rugate filters with wide stopbands, spectral hole fiters with narrow passbands, and even optical humidity sensors with superior performance response time and sensitivity to many commercial available sensors. The square spiral chiral fim can be used to produce photonic crystals with a complete, three dimensional bandgap.

B5	Sub Area	Fusion Algorithm for computation of Spacecraft Attitude with Multiple – Head Star Trackers (URSC-LEOS)
B5.1	**Development of optimized fusion algorithms and techniques to combine the images obtained from multiple heads, compensate for thermo-elastic distortions between heads and compute spacecraft attitude (URSC-LEOS)** Higher attitude measurement accuracy is obtained by using the star image captured from multiple star tracker heads that are mounted with different relative orientations. The accuracy is improved with the availability of more number of stars from multiple heads and different orientations of star tracker heads that offset bore-sight errors. The diffiulty in multiple heads confiuration is the results may be affected by thermo – elastic distortions between the heads.	
B6	Sub Area	Micro Aircraft for Mars-2 (URSC-LEOS)
B6.1	**Development of Unmanned Aerial Vehicle (UAV) which can fly using solar power (URSC-LEOS)** It will have imaging payload and an RF link with the orbiter spacecraft. It should have adjustable propellers to fl forward as well as for hovering. It should be built with non-corrosive and light weight material. The Mars is having lot of attention from the researchers for its exploration, related to existence of life. Typically the exploration is carried out in two phases. A spacecraft orbiting over Mars and taking images with very high resolution images, which are bulky to find the area of interest. But this has limitations. The dust and clouds make a thick layer and make the visibility poorer for the attitude of a spacecraft. After finding the region of interest a rover is made to land on the surface and the rover does the soil study in very limited area. There can be one intermediate stage to find out area of interest on Mars surface by a low attitude Arial survey. Since Mars is having atmosphere an Aeroplane can fly over here. This plane should be solar powered, built with light weight non corrosive materials and carries small camera for surveillance and RF link with the satellite should have Mars upto 3 kg. It's propellers should be adjustable to front direction fly as well as for hovering. The Aero plane is deployed from the satellite into the Mars atmosphere and the plane performs high resolution survey on a wide area with miniature cameras. In case the area is found to be unsuitable the plane can be made to hover at a different area. This makes the search very economical for the desired landing spot for a rover, since the higher resolution images can be obtained with a much smaller payload when a low attitude survey is carried out.	
B7	Sub Area	Vision System (URSC-LEOS)
B7.1	**Three dimensional geometry and pose estimation using computer vision based techniques (URSC-LEOS)** Vision System has become integral sensor for future robotic missions as it provide important information to function automatically in unstructured environment. Computer Vision based	

	techniques can be used to generate three dimensional geometry (relativerotation and translation) from image processing based techniques and algorithms. This algorithm can be implemented on stereo/ multi view camera or using depth camera or fusing of depth camera and stereo camera. This technique will be helpful to navigate and perform specific task by robotic systems, hazard avoidance, optimal path planning, autonomous rover or lander movement in unknown terrain for interplanetary mission within an autonomous process. Development of robust algorithm to generate relative pose of the objects in a scene with respect to camera in an automated manner and it should be processed in hardware in real time.	
C	**Area**	**Remote Sensing Applications in Geosciences (IIRS)**
C1	**Sub Area**	**Planetary Geology (IIRS)**
C1.1	**Reflectance spectroscopy of planetary surfaces – 1 (IIRS)** Detailed surface composition study of the Moon and Mars for mineralogy and mineral mapping. Spectral analysis of various surface features including impact craters and volcanic features using data from multispectral and hyperspectral sensors from lunar and Martian missions.	
C1.2	**Reflectance spectroscopy of planetary surfaces – 2 (IIRS)** Detection of mineralogy and geochemistry of Lunar and Martian surfaces using reflectance spectroscopy: Remote sensing experiments analyzing the sunlight diffused by planetary surfaces can be used to derive the mineralogical composition and physical properties of the surface regolith. Mineral mapping of the Lunar surface provides insights into the composition and evolution of the crust and also provides important information on the primordial crust in the Earth-Moon system. India`s in-orbit Chandrayan-2 mission with enhanced capabilities will enable addressing some of the questions raised by the results obtained from the Chandrayaan-1 and other recent lunar missions and gather new data to further our understanding of the origin and evolution of the moon. With this background, the proposed work plan is envisaged to use data from IIRS payload, on-board Ch-2 to cater to understanding of lunar mineralogical composition of target sites, mainly using reflectance spectroscopy.	
C1.3	**Reflectance spectroscopy of planetary surfaces – 3 (IIRS)** Mineralogical characterization of SPA basin using reflectance spectroscopy.	
C1.4	**Remote sensing-based surface geology of Moon and Mars (IIRS)** Geological characterization of lunar and Martian surface features for morphological, topographical and structural interpretation. It includes, identification, classification, geomorphic evolution and chronological study of various crustal features using high-resolution optical and elevation data.	

C1.5	**Planetary analogue studies (IIRS)** Ground based study of landforms on Earth such as volcanic, impact features, layered deposits to understand and correlate their mineralogy, composition, formation conditions and environment in similar setup at the Moon and Mars.	
C2	**Sub Area**	**Mineral targeting using hyperspectral remote sensing (IIRS)**
C2.1	**Development of spectral library and reflectance spectroscopy for mineral exploration in parts of Proterozoic mineral rich belts of India. (IIRS)** The proposed topic focuses on usage of multispectral, hyperspectral RS for mineral targeting, mapping and exploration with a focus on: 1) Rock, mineral, mine tailings spectra collection in situ as well as laboratory condition and analysis and 2) Hyperspectral data processing of air borne hyperspectral data and space borne data (Hyperion, ASTER, ETM including new data sets like PRISMA etc.) using ENVI, Data processing for mineral identification and abundance. The standard mineral library will enable comparison of unknown minerals. As for the other results, mineral map developed in ore rich area can help in taking major decisions on exploration, when integrated with other data (Geophysical and Geochemical).	
C3	**Sub Area**	**Igneous Petrology and Hyperspectral remote sensing (IIRS)**
C3.1	**Mineralogy and petrology of igneous rock exposures using hyperspectral data and spectroradiometer (IIRS)** Spectral-compositional study of various igneous exposures (such as kimberlites, ophiolites, komatiites, bonninites, carbonatites) in conjunction with geochemical study for petrology and petrogenesis.	
C4	**Sub Area**	**Landslide modelling using earth observation data (IIRS)**
C4.1	**Numerical simulation and modelling of rainfall triggered debris flows/ landslides in Uttarakhand Himalaya (IIRS)** Debris flows and debris rushes have become a major natural hazard process in hilly regions which are complex, gravity-driven, water and sediments with extreme moveable capacity. Debris flow modelling is a dynamic area of research and the major principle can be applied to a variety of processes including debris flows, mud flows, snow slip and even rock falls. It has found significant role in disaster management and mitigation. The topic focuses on usage of EO and ground truth data for numeral modelling of different types of landslides.	

<table>
<tr><th>D</th><th>Area</th><th>Microwave Remote Sensing Applications in Agriculture, Soil Moisture, Forestry & Wetland Ecosystem (IIRS)</th></tr>
<tr><td>D1</td><td>Sub Area</td><td>Monitoring of crop growth, retrieval of crop biophysical parameters, Crop yield estimation, Soil moisture retrieval (IIRS)</td></tr>
<tr><td>D1.1</td><td colspan="2">Crop growth monitoring & crop biophysical parameters retrieval (IIRS)

All weather capability of SAR data which ensures uninterrupted data supply, when coupled with unique sensitivity of SAR data towards physical, geometrical and dielectrical properties of various crops along with penetration capability of SAR make it a perfect choice for crop growth monitoring and crop biophysical parameters retrieval for various crops. Use of multi-parametric SAR and advance SAR techniques like SAR Interferometry (InSAR), SAR Polarimetry (PolSAR) & PolInSAR allow to retrieve various crop biophysical parameters like LAI, Crop height, Crop volume, Crop water content, Crop fresh biomass, crop density etc. Use of various Machine Learning Techniques can further improve the retrieval accuracy..</td></tr>
<tr><td>D1.2</td><td colspan="2">Crop yield estimation (IIRS)

Unique sensitivity of SAR data towards physical, geometrical and dielectrical properties of crop along with all-weather & penetration capabilities of SAR can successfully be used for crop yield estimation by incorporating various agro-climatic parameters in crop yield models.</td></tr>
<tr><td>D1.3</td><td colspan="2">Soil moisture retrieval (IIRS)

Large difference between dielectric constant of water and dry soil & penetration capability of Radar signal are the key factors behind the fact that microwave remote sensing is the best tool for large area soil moisture retrieval / mapping. However, along with dielectric constant/water content of soil, SAR is also sensitive towards many other target properties like surface roughness, vegetation cover and soil texture. These parameters act as noise while retrieving soil moisture using microwave remote sensing data. Therefore, it is necessary and also challenging to retrieve soil moisture with high accuracy by incorporating the effects of noise parameters in the soil moisture retrieval model. Use of multi-parametric SAR along with advance SAR techniques like Interferometric coherence, Hybrid polarimetry, fully polarimetry, PolInSAR can successfully retrieve soil moisture under variety of agricultural heterogeneities. Use of advance Machine Learning Techniques are expected to further improve the soil moisture retrieval accuracy.

Passive microwave remote sensing data can also be used for very large area soil moisture estimation but due to very poor spatial resolution, soil moisture retrieval accuracy is relatively lower than SAR data and it's also difficult to apply it on farmers' fields. However, advantage of fine temporal resolution of passive microwave RS data and advantage of fine spatial resolution of SAR RS data can be combined to generate daily soil moisture maps at relatively finer spatial resolution.</td></tr>
</table>

D2	Sub Area	Forest biophysical parameters retrieval & Forest type discrimination (IIRS)
D2.1	**Forest species discrimination & forest biophysical parameters retrieval (IIRS)** Penetration and all-weather capability of SAR along with sensitivity of SAR data towards physical, geometrical and dielectrical properties of forest trees and plantations of various shapes, sizes and structures along with all-weather & penetration capabilities of SAR can successfully be used to retrieve various biophysical parameters of forest like forest above ground biomass, tree height etc. Availability of multi-parametric SAR along with advance SAR techniques like SAR Interferometry, Hybrid polarimetry, fully polarimetry, PolInSAR, SAR tomography etc. can be used successfully for various other forestry applications along with detailed forest type discrimination in mixed forest type scenario.	
D3	Sub Area	Wetland Ecosystem (IIRS)
D3.1	**Assessment, Monitoring and Management of Wetland Ecosystem using Radar Remote Sensing (IIRS)** Wetlands play an important role in ground water recharge and also provide unique habitats for wide range of flora & fauna. Therefore, wetlands have significant biodiversity resources. However, the recognition of biodiversity conservation values of the wetlands has been neglected for a long time. As a result of this, there is an alarming loss of wetlands. The alarming loss of wetlands all over the globe had initiated an inter-governmental treaty which provides the framework for National action and International cooperation for the conservation and wise use of wetlands and their resources. This treaty was signed in Ramsar, Iran, in 1971 and is known as 'Ramsar Convention'. In order to monitor wetlands, on local, regional and national levels, there is an urgent need to develop user friendly and cost effective tools. Remote sensing can play an important role for assessment, monitoring and management of wetland ecosystem. Lot of work has already been done in the field of wetland studies using data from conventional remote sensing sensors operating in optical and infrared region of the electromagnetic spectrum. However, for studies of wetland, optical remote sensing data exhibit a few limitations. In contrast to radar remote sensing, the major limitation with optical data is uncertainty of getting cloud free data during monsoon (rainy) season. The analysis during monsoon season is of prime importance as it is the main source of water that controls the ecosystem of most of the inland wetlands. Moreover, sensitivity of optical data for physical, geometrical, dielectrical and textural variation of vegetation (both terrestrial and aquatic) is also limited as compared with Radar data operating in the microwave region of the electromagnetic spectrum, which is highly sensitive for these properties of various components of a wetland ecosystem. Capability of microwave signals transmitted from the Synthetic Aperture Radar (SAR) sensor to penetrate vegetation cover and to sense the moisture content of the earth materials, allows microwaves to monitor the wetland ecosystem more accurately as compared to optical remote sensing tools.	

D4	Sub Area	Development of Image Processing Algorithms (NRSC/ NESAC)
D4.1	**Automatic image registration (NRSC)** Image registration is an important image processing technique in remote sensing applications. It has been widely used in change detection, image fusion and other related areas. In order to integrate different kinds of sensor data and different temporal data, image registration is an indispensable preprocessing tool in integrating multi-source and multi-temporal images. In change detection process, the image registration accuracy directly influences the accuracy of change detection result. This research should cater to multi-temporal, multi-resolution and multi-spectral imagery registration with a specified accuracy for each category with a sub-pixel accuracy.	
D4.2	**Hyper spectral image analysis (NRSC/NESAC)** Modern hyperspectral imaging systems produce huge datasets potentially conveying a great abundance of information; such a resource, however, poses many challenges in the analysis and interpretation of these data. This research intend to development of techniques of hyper spectral analysis for EO and planetary applications.	
D4.3	**Bundle block adjustment of aerial/satellite imagery (NRSC)** A technique development for operational bundle adjustment of large number of satellite imagery. This should cater to the multi-resolution and multi-resolution satellite imagery should make use of a distributed processing environment including the state of the art computer architecture.	
D4.4	**Advanced models for satellite data pre-processing methods (NRSC)** The availability of remote sensing big data and cloud computing services provides new opportunities for the preprocessing, analysis, and visualization of satellite images. The preprocessing of data is a crucial step in the remote sensing analytical workflow and is often the most time consuming. This research shall focus on innovative high resolution image processing algorithms like image restoration, noise elimination, blur reduction and other quality improvements including advanced geometric correction models for satellite imagery.	
D4.5	**Development of techniques of hyper spectral analysis for EO and planetary applications (NRSC)** Hyperspectral sensing is a method of extracting information about an object or scene innarrow spectral bands using imaging spectroscopy. Since the object or scene is imaged in narrow bands of wavelengths the neighboring pixel values are highly correlated. Further, the imaging conditions play a vital role in extracting end members for specific applications such as crop classification, mineral mapping, and urban scene analysis. A range of hyperspectral sensors are flown by ISRO namely Hyper spectral imaging camera of ISRO (HySI - ISRO) is flown on IMS-1, and Chandrayan-1 having a spectral	

	range from 0.4 to 0.95 micro meter at 10nm spectral resolution, Chandrayan 2 mission Imaging Infra-Red Spectrometer for studying mineral mapping on moon. The present challenges facing the hyperspectral imagery processing and analysis being (i) datafusion, (ii) spectral unmixing, (iii) Data reduction, (iv) fast computing, and (v) data mining.	
E	**Area**	**Information Extraction and Geospatial Modelling (IIRS)**
E1	**Sub Area**	**Information Extraction from Multi-Source/Multi-Sensor data for spatial modelling (IIRS)**
E1.1	**Surface parameter extraction of vegetative, urban/rural and water surfaces such as 2D/3D parameter extraction and modelling of urban/rural objects/ trees/plantations, water (IIRS)** Exploring advanced techniques of information extraction, their performance evaluation for automated mapping, analyzing objects (buildings, trees, etc.) and other resources, their quantification and parametrization, and proper inventorization, building accurate databases and 3D models of man-made and natural resources is the ultimate goal of this research.	
E2	**Sub Area**	**Analysis & Modelling of Geospatial phenomena (IIRS)**
E2.1	**Investigating methods for mapping, modelling of spatial phenomena (IIRS)** For analysis & modelling of Geospatial phenomena such as pollution dispersion, disease spread, spatial networks of utilities, population distribution, land-use growth and change, exploring, developing and evaluating advanced methods of geospatial modelling (such as advanced methods of spatial modelling, geostatistical modelling, multi-dimensional modelling (surface modeling, time-series analysis and modelling), network modelling, etc.) is the need of time for utilizing huge information being derived from available repositories of satellite data. Proposals addressing investigation of models for modeling of such phenomena will enable appropriate and efficient use of the available space based, aerial and ground based data repositories.	
E3	**Sub Area**	**Earth Observation Data Processing (NESAC/ NRSC)**
E3.1	**Cloud avoidance scheduling (NRSC)** Payload programming makes the optimum use of satellite resources to satisfy User requirements. The various capabilities of the IRS satellites and its resources call for a meticulous planning. Payload programming is successful only when it results in acquisition which cater to user requirements in terms of data quality, correct area of coverage (targeting accuracy), timeliness (within the period of interest) and cloud free acquisition. Cloud cover is one of the major problems in the acquisition of optical satellite remote sensing data and has a negative impact on the efficiency of data scheduling. The necessary global cloud information (on a daily / hourly basis) derived from meteorological satellites has to be incorporated in the planning system to improve the planning efficiency.	

E3.2	**Algorithms for time series analysis of satellite data (NRSC)** National Remote Sensing Centre has been archiving all remote sensing data right from IRS 1A mission of ISRO till date. The datasets have all the characteristics that may constitute a time series and hence is a good resource for long term studies related to climate change and change detection etc. One of the possible applications of a time series data is to build models for forecasting. Statistical Methods such as ARIMA and GARCH are popular in predicting time series but they are far from satisfactory in terms of precision. Recent developments in machine learning algorithms and its use in regression and classification problems have paved a way for their use in forecasting time series. We invite proposals that incorporate the state-of-the-art algorithms for remote sensing applications, characterization of sensors and reconstruction of data.
E3.3	**Semi-empirical modelling for forest biophysical characterization using PolSAR data (NESAC)** Influence of slope in forest biophysical characteristic of hilly regions needs to be understood properly.
E3.4	**Characterization of opencast mining areas using various polarimetric decomposition techniques (NESAC)**
E3.5	**Urban Feature/metallic extraction using fully polarimetric data (NESAC)**
E3.6	**Generation of Time series Data stack from medium multi-resolution IRS and non-IRS sensors (NRSC)** An accurate Inter sensor harmonization techniques are required using hybrid approaches and ML techniques for Surface Reflectance from IRS to achieve interoperability with foreign sensors. There does not exist any model for operational output for Indian region. Calibrated backscatter SAR data will be put in the stack to overcome the limitations of optical sensors. This research shall focus to generate a time series surface reflectance stack of fixed resolution for land use Land cover monitoring for India and surroundings. This study will open up huge number of Artificial Intelligence and deep learning applications for land and Ocean applications. Many thematic applications is the need of the hour for agriculture, horticulture, Ocean applications. All the Resourcesat series data, Ocean sat series data and RISAT series data will be used and On-Demand Data services can be built on NRSC Bhoonidhi portal.
E3.7	**A unified time series based cloud database using cloud identification using deep learning methods on satellite imagery for cloud tracking, satellite data planning and weather applications (NRSC)** An accurate Inter sensor harmonization techniques are required using hybrid approaches and ML techniques for Surface Reflectance from IRS to achieve interoperability with foreign sensors. There does not exist any model for operational output for Indian region. Calibrated backscatter SAR data will be put in the stack to overcome the limitations of optical sensors. This research is intended to generate cloud data from various satellites and store it in a unified geospatial database for satellite data planning, cloud tracking and weather applications.

E3.8	**Automatic Feature Extraction from High Resolution data using Deep Learning Techniques (NRSC)** The objective of the study is to automatic feature extraction from high resolution data using deep learning techniques. The objective is to train deep learning models using transfer learning (Unet, Segnet) to identify features like buildings, Roads and trees in an image, based on their spatial and spectral properties. The scope of the work is to develop algorithms to extract automatically features from high resolution remote sensing data. Automatic feature extraction for different classes of landuse/landcover from high resolution data for change detection and in real time for disaster applications.		
E3.9	**New Advanced Techniques in High Resolution Imagery Processing (NRSC)** In the last twenty years, the exponential growth of high-resolution (HR) and very-high-resolution (VHR) satellite, UAV and terrestrial images and the advances in open and close source software and algorithms have stimulated methodological research in this field. High-resolution satellites with stereo and tri-stereo capabilities have been implemented to satisfy the increasing need for higher accuracy and larger area coverage for digital model production. These recent advances in sensor technology and algorithm development enable the use of HR remote sensing imagery for development of various product such as DTM/DEM and DSM, orthophoto and orthophotomosaics, three-dimensional photogrammetric models. The application fields are increasingly developing from landslide and landfill monitoring to archaeological applications, monitoring an active volcanic area, morphological studies and so on. Independently of application, each product must be validated in order to define the metric level of precision and accuracy. In fact, high and very-high resolution images are affected by deformation mainly due to camera distortions and acquisition geometry, then they must undergo a geometric rectification process in order to be used for metrical purposes. Development of algorithms for DSM/DEM/DTM extraction from High resolution satellite stereo imagery and their validation. Development of New open-source based advanced solutions for multi high resolution imagery automated geometric processing using bundle adjustment.		
F	**Area**	**Satellite Data Reception and Ground Station (NRSC)**	
F1	**Sub Area**	**Design and Development of Antenna for data reception (NRSC)**	
F1.1	**Very high data rate (up to 2GBPS) demodulator & Bitsynchronizer systems with programmability for multiple modulation & encoding schemes (NRSC)** Design & development of Demodulator using Parallelism techniques for handling Highdata rate(2GBPS). Proposed FPGA demodulator is based on the Advanced High speed Design Methodologyusing the Parallelism techniques. Based on Hard limited Costas Loop development for Carrier and Clock Recovery. Simultaneous Demodulation and Bit-synchronization Continuous programmability of data rates, Modulation Schemes decoding and adaptable base band filtering.		

F1.2	**Three axis azimuth-elevation-train (variable tilt axis) axis tracking pedestal forantenna system (NRSC)** IMGEOS facility consists of four 7.5 mtr antenna systems for multi-mission data reception. Out of the 4 Antenna systems, 2 have tilted pedestals and 2 have un-tilted pedestals. Tilted pedestals have the capability to avoid the Zenith /overhead passes and can track the high elevation passes without any diffiulty. The limitation/drawback of field tilt mechanism is that, if the satellite trajectory is in the opposite direction of tilt direction, then the line of sight at horizon/low elevation gets reduced and cannot avoid the zenith/overhead zone. By providing a programmable tilt to the pedestal up to 7 degree tilt, a distinct advantage of adjustment of Tilt in any direction (unlike field tilt) as per the satellite trajectory is achieved and totally eliminates cone of silence/ dead zoneof Elevation over Azimuth Mounts. This programmable tilted pedestal is also called as Train axis/3-axis mount (Az, El and Train axis) and is essential for tracking the future missions like Cartosat – 3/3A/3B which will transmit the data in Ka band frequency (25.5 – 27.0 GHz).
F1.3	**Adaptive servo control systems for Ka-Band data reception antennas (NRSC)** Adaptive Servo control System design is based on LQG controller, which is a Linear Quadratic Gaussian controller. It is an optimal and model based controller. Antenna Control servo system (ACSS) is used to control the motion of antenna. Present ACSS is based on PID (Proportional, Integral, Derivative) controller. This LQG controller over comes the limitations of PID controller in terms of configurability of certain design parameters like rise time, settling time, Overshoot, servo error and disturbance rejection properties. Present PID based controller is not sufficient to meet the Ka and Ku bandtracking requirements in view of its narrow beam width.
F1.4	**FPGA implementation of CCSDS standard DWT-based image decompression (NRSC)** DWT based image compression technique is a compression standard used onboard satellites to improve transmission effiiency and for reducing storage requirements. This technique is very efficient to preserve the original image quality. On ground, the reverse process has to be done to retrieve the original data ie. DWT based decompression. This project work is VLSI Design of DWT based image decompression so that the design can be implemented in FPGA hardware. This hardware implementation will improve the ground data processing speed and hence the Turn around Time.
F1.5	**Hardware based high speed Real Time Remote sensing satellite data acquisition & Preprocessing System (NRSC)** Implementation of computation intensive functions (Error decoding, Decryption and Image decompression) in FPGA based hardware that enables real time satellite data acquisition & preprocessing without using high end computer systems. This system will reduces the processing chain turnaround time significantly for High data rate mission like Cartosat-3S and NISAR. It also reduces the requirement of high end computing system for executing similar functionality in software. This project includes- Design and fabrication of custom FPGA based PCI Express hardware with 10G Ethernet interface.

	Design and development of IP core for Error decoding, data decryption and Image data decompression. It also includes data acquisition and image data display software which controls the custom PCIe hardware & provides real time image data visualization. The Custom PCIe hardware is built with convention ECL data clock interface as well as 10G Ethernet interface enabling high datarate transmission between demodulator.	
F1.6	**Model Prediction Control algorithm for full motion 7.5 M antenna (NRSC)** The main objective is to receive satellite data in S,X and Ka-bands using Program Track mode with 7.5M antenna by developing a dynamic model of the system by using System Identification approach. It will address the nonlinear errors like backlash, friction, wind, thermal errors. However the linear errors continue to be controlled by conventional PID. The tracking chain electronics will be made very simple and there is no need for mono pulse tracking with this approach. The output shall be a Model Prediction Control algorithm for S-band, X-band and Ka-band.	
F1.7	**Firmware development for higher level satellite data processing (NRSC)** Study of multi-spectral data fusion techniques, suitability of techniques for type of data inputs and implement in FPGA hardware for near real time data processing for value added products. To develop identified image fusion algorithm and enhancement in Hardware descriptive language (Verilog), simulation and verify the results in FPGA using Altera Quartus software. This will facilitate reduction in Turn Around Time (TAT) for Value Added Product generation along with the automation in processing.	
F1.8	**Tools development in payload programming for the effective utilization of satellites (NRSC)** Development of tools to address the following parameters: A) Auto cloud cover Estimation B) Multi-mission pay load proposal generator C) Weather integration for all future satellites while planning This research shall address to automatically access the cloud cover for the optical high resolution satellites. The module will be run along with the level-0 operations so that automatically the cloud cover is updated and stored. This will reduce the load on browsing and also help in future planning. Methodology will be developed to access the cloud cover for high resolution sensors. At present we have implemented successfully for RS2 & RS2A kindly of satellites. Develop methodology and implement in the payload planning system the weather information which will be useful while planning future collects. Software for Weather information integration in Pass programming for all future satellites while planning. This will be useful in optimal utilization of satellites during emergencies, when the user needs data from any satellite that is possible.	
F2	**Sub Area**	**Satellite Image Data Compression & Decompression (NRSC)**
F2.1	**Development of high speed CCSDS image compression / decompression technique (NRSC)** The CCSDS has established a recommended standard for a data compression/ decompression algorithm applied to two-dimensional digital spatial image data from	

	payload instruments and to specify how this compressed data shall be formatted into segments to enable decompression at the receiving end. The steps followed can be briefed as: performing an image de-correlating operation (DWT) and then encoding the coefficients in various stages in order to obtain the compressed image. The compressed image has to be decoded with the knowledge of the segment header. Rate regulation needs to be done in order to adjust the compression rate. The decoded coefficients are correlated back (inverse DWT) to get the reconstructed satellite image. All the future Cartosat missions follow the CCSDS image compression/decompression technique and there is a need for the high speed implementation of the same. The requirement is the implementation of all the compression and decompression steps using General Purpose Graphics Processing Unit (GPGPU) and CUDA software.	
F3	**Sub Area**	**Error Correction Coding (NRSC)**
F3.1	**Reed Solomon decoding software development for satellite data (NRSC)** Satellite communication channels are subject to channel noise, and thus errors may be introduced during transmission from the source to a receiver. Error detection techniques allow detecting such errors, while error correction enables reconstruction of the original data. Reed Solomon decoding algorithm is one of the error correcting algorithms to correct the received data with errors. Different formats of RS decoding standard algorithms are available like (247,255), (223,255). These things work in two modes one in CCSDS format and the other in traditional standard mode. Because of huge volume of satellite data and large mathematical computation it is time consuming to decode the data by using the traditional methods of Reed Solomon decoding algorithm. Hence there is a need for the high speed implementation of the same. The requirement is the parallelism of the Reed Solomon algorithm in General Purpose Graphics Processing Unit (GPGPU) and by parallel approach in Central Processing Unit (CPU).	
F4	**Sub Area**	**Distributed Workflow Management (NRSC)**
F4.1	**Autonomous multi agent job scheduling algorithms for distributed systems (NRSC)** Large scale processing and knowledge extraction from data requires execution of complex workflows in a distributed environment. A generic framework needs to be evolved for collaborative computing among the resources to obtain maximum throughputs from the systems. Development of (i) multi-agent system architecture for processing data in a distributed network environment (ii) models for a multi agent communication (iii) schemes for automatic configuration of agents based on the dynamics of the real time job scheduling and (iv) Resource optimization algorithms to improve the processing timelines.	
F5	**Sub Area**	**Data Mining (NRSC/ NESAC)**
F5.1	**Algorithms for knowledge extraction from big data (NRSC /NESAC)** Large volumes of data that cannot be stored in normal relational databases are being generated every day from the remote sensing satellites. Many software elements extract information from the raw data generating information in unstructured form such	

	as images,log files, user orders in pdf, word etc. There is a need for developing efficient data mining algorithms to tag the data sets for facilitating efficient build up of archival and retrieval. In general data mining algorithms work on data sets that are of reasonable size and cannot handle BIG data. Develop Parallel Algorithms for mining the classification rules to facilitate data archival in an optimal manner. Develop mining algorithms that are Incremental and can learn and unlearn from the continuous satellite data acquisitions Develop algorithms for extracting meaningful trends in the customer ordering, build customer satisfaction index, predict the future sales or potential sensors or popular products etc.	
F6	**Sub Area**	**Software Engineering (NRSC)**
F6.1	**Software reliability modelling and metrics (NRSC)** There is a need to develop automated tools to extract different metrics from various software packages developed by ISRO to estimate their reliability and predict if possiblethe failure rates from the version history. Develop customized metrics for different types of software packages including real time,near real time, post processing, workflow software and distributed software. Develop algorithms for estimating the software reliability numbers and predictive modelsfor forecasting the failure conditions.	
G	**Area**	**Earth, Ocean, Atmopshere, Planetary Sciences and Applications (SAC)**
G1	**Sub Area**	**Physical Oceanography (Development of Blue Economy) (SAC)**
G1.1	**Assimilation of satellite/in situ data in numerical ocean prediction models: Observation System Studies Experiment (OSSE) (SAC)** Advance research is being carried out for assimilation of satellite derived parameters (salinity, temperature, sea level, wave height, ocean color and wave spectrum) in ocean prediction models. This involves development of various assimilation techniques for improving the initial condition in the models. Apart from satellite data, lot of in situ measurements (glider, HF Radar, wave rider buoys etc.) are also being taken in the present. It will require intensive modelling and testing optimization techniques towards performing OSSE to ascertain the importance of satellite-based and in situ-based observations. Advanced assimilation techniques that include assimilation of high resolution images are under development.	
G1.2	**High resolution oceanography (SAC)** In the view of high resolution (temporal and spatial) satellite observations from synthetic aperture radar, forthcoming swath altimetry, radiometer-based sea surface temperature and optical imageries, high resolution oceanography is fast becoming a reality. Synergistic use of these information will be key to understanding many unresolved processes at sub	

	mesoscale level, which can help in better ocean estimation. Interaction of mesoscale dynamics (eddies) with sub-mesoscale is another interesting area of research for energy cascading. Region specific high resolution models with relocatable grids will be utilized for this purpose.	
G1.3	**Ocean Reanalysis and Air Sea interaction studies (SAC)** One of the future goals is to develop a methodology to generate high quality three dimensional ocean reanalysis product for last 30 years based on satellite observations and numerical ocean model. This will be utilized not for various oceanic process studies but also to initialize seasonal prediction coupled models. To understand some of the atmospheric and oceanic processes near ocean surface, air sea interaction (wind-SST coupling) study is very important. It is important to assess the validity of existing exchange algorithms (bulk formulations) for different regions of the oceans. Because of scarcity of observed data over the ocean, it is important to understand these processes with the help of satellite data. However, in situ data will form an important data set for validation. This involves diagnostic studies of the processes with the satellite data and numerical model outputs.	
G1.4	**Study on coastal dynamics using satellite and high resolution numerical models (SAC)** Coastal dynamics are extremely important to understand as it has significant implications on coastal population. Coastal processes such as, storm surge, rip currents, extreme waves, oil-spill trajectory forcecasts need to be studied systematically with the help of high resolution data and numerical modelling and techniques based on Lagrange coherent structures.	
G1.5	**Seasonal ocean prediction with coupled atmosphere-ocean models (SAC)** Forecast of anomalous oceanic conditions (Dipole/El Nino) at least one season in advance is of high importance as it has direct influence on the Indian Summer Monsoon. These seasonal to long term forecasts are required to be done by making synergistic use of satellite observations and couple Ocean-Atmosphere models. Effect of satellite data assimilation on the skills of these forecasts are also required to be assessed.	
G2	**Sub Area**	**Geophysical Parameter Retrievals (SAC)**
G2.1	**Retrieval of geophysical parameters from satellite data (SAC)** ISRO has planned for launching a number of meteorological and oceanographic satellites in near future. Presently it has,Megha-Tropiques, INSAT-3D/3DR and SCATSAT satellites in the orbit. In near future, it has plans to launch many satellites in Geostationary and polar orbits for the same. This includes many advanced sensors such as Microwave Temperature Sounding Unit (TSU) and Humidity Sounding Unit (HSU) in future missions. There is also possibility of inclusion of an advanced microwave radiometer similar to GPM Microwave Imager (GMI) in future missions. It is a challenging work to retrieve geophysical parameters from the sensor data of these satellites. This involves Radiative Transfer modelling, Geophysical Model Function development and the Inverse modeling techniques.	

G2.2	**IRNSS/GNSS applications (SAC)** IRNSS/GNSS offers unique opportunity to retrieve atmospheric geophysical parameters such as TPW. ISRO may also develop satellite-borne receivers for IRNSS/GNSS reflectometry, which has potential to provide various surface parameters including sea surface height, intense sea surface wind speed and direction under severe weather conditions, soil moisture, ice and snow thickness, etc. Theoretical modelling and simulations of the reflectometry observations is desired for the retrieval of the parameters. Until IRNSS receivers are not available, International missions such as TDS-1 and CYGNSS can be used to validate the simulation studies and retrieval algorithms.
G2.3	**Merged data products (SAC)** Develop data fusion methods to derive most optimized products using a synergy of observations. The examples are (a) Optimized temperature/humidity profiles using IR and microwave sounders (b) Optimized SST and rainfall products from IR and Microwave imagers.
G2.4	**Advanced system study for new sensor defiition (SAC)** For measurements of atmospheric and Oceanic parameters, new advance sensors have to be defined for future satellites. System studies are being done with the help of Radiative transfer models to define the appropriate frequency, NEDT/SNR and bandwidth of new sensors. Sensitivity analysis is also being carried out to understand the error budget and appropriate resolutions (both spatial and temporal) required for the retrieval of geophysical parameter.
G2.5	**Development of Procedures for Long Term Records of Essential Climate Variables (SAC)** Long term records of essential climate variables such as SST, wind, radiation budget, water vapour, clouds, ozone, precipitation, sea surface salinity, sea level, sea state, etc., which are defined by Global Climate Observing System (GCOS), are necessary for characterising the trends in earth's climatic variations. Measurements from different satellite instruments suffer from different accuracies and biases due to evolution/ performance of the instruments and/or retrieval algorithms. Thus there is need to inter-calibrate the instruments/parameters to reduce the measurement biases among them.
G2.6	**Other Research Areas related to Parameter Retrieval (SAC)** • Cloud/Rain type classification using INSAT/Kalpana observations. • Study of cloud micro physics using 157 GHz of MADRAS and INSAT data • Combination of INSAT-3D Imager and Sounder products to improve the quality of a few critical atmospheric products, such as atmospheric stability, total WV contents, SST etc. • Improved tracer selection, tracking and height assignment methods for Atmospheric Motion Vectors (AMV) retrieval from VIS, MIR, WV, TIR1 channels. • Retrieval of high-resolution winds is a challenging research area that may be attempted with GISAT satellite.

	• INSAT-3D/3DR 3.9 μm channel provides a cleaner atmospheric window compared TIR channel for superior low-level cloud detection at night. It also has batter sensitivity to temperature gradients. However, due to its susceptibility to reflected sunlight from cirrus and especially low-level cumulus clouds limits its usefulness at night-time applications only. Question is to investigate by retrieving 3.9 μm winds at day-time, how much the accuracy is affected, with respect to low- level winds retrieved using TIR channels? Whether this can be useful for any other applications which can't be resolved by the winds from TIR or VIS channels?	
G3	**Sub Area**	**Hydrology (SAC)**
G3.1	**Automatic detection of wetlands for National wetland Inventory and Assessment (SAC)** Regular Wetland inventory at national scale is important activity required by Ministry of Forest Environment and Climate Change. This involve development of automatic algorithm to delineate wetland and its type based on advanced techniques such as Deep learning/ machine learning etc.	
G3.2	**Groundwater Assessment (SAC)** Assessment of ground water potential zone and its dynamics is important to regional water resource planning. There is need to develop hydrological model incorporating aquifer properties to simulate the infiltration and ground water variations in different hydrological regime. It is required to develop tools to relate the groundwater fluctuations with GRACE water equivalent height information, existing surface water components and groundwater recharge and abstraction scenario.	
G3.3	**Flood Inundation modeling and Forecast (SAC)** Extreme events are increasing due to global warming and it results in frequent floods in many rivers and urban areas. Satellite data helps in delineation of flood prone region but due to limitations of revisit period there are some gaps in observations. There is need to develop flood inundation modeling system using meteorological data, high resolution DEM and historical records of flood conditions for major flood region of India. Efforts are required to have weather forecasting coupled hydrological system (WRF HYDRO) for forecasting river discharge and water inundation.	
G3.4	**Water Level and Discharge Modeling (SAC)** Monitoring Water level from space platform is important to augment existing ground network in remote and inaccessible regions including Trans-boundary rivers. There is need to develop advanced approach to estimate water level from Nadir Microwave as well as LIDAR based altimeters. Estimation of water velocity and discharge is challenge from remote sensing. Methods need to be developed to address Swath altimetry which consists of nadir altimeter as well as two SAR system working in interferometric mode (SWOT) to assess water height and inundation volumes simultaneously.	

G3.5	**Water quality Assessment (SAC)** Hyperspectral remote sensing is known to have potential to estimate some of the water quality parameters of rivers and reservoirs. It involves development of radiative transfer modeling and simulations. There is need to develop method and carryout model simulations to assess the water quality issues of important rivers like Ganga and Yamuna.	
G3.6	**Isotope Hydrology (SAC)** Partitioning Evaporation and Transpiration in terrestrial vegetation is a concern. Hyperfine spectroscopy provides information on isotopic composition of water molecules. There is need to develop methods to estimate the evaporation and transpiration components of major forest ecosystem as such measurements help in more accurate assessment of water cycle and Land surface processes.	
G3.7	**Submarine Ground Water Discharge (SGD) (SAC)** Quantification of water flow into ocean through sub marine ground water discharge is a challenge for Indian coast. Thermal remote sensing data provide initial signals of SGD in coastal region. There is need to explore the regions of SGD in Indian coast and model the discharge of water into the ocean.	
G4	**Sub Area**	**Geosciences (SAC/ NRSC)**
G4.1	**Geo-Hazards (NRSC)** • Research leading to development of early warning systems to geo-hazards. • Crustal deformation studies using InSAR and GPS. • Interseismic deformation modelling along active plate boundaries for earthquake hazardassessment. • Volcanic deformation studies. • Understanding land subsidence due to groundwater/coal exploitation. • Active fault detection and monitoring using InSAR. • Developing methods for coastal vulnerability assessment due to natural and man-madehazards. • Desertifiation and Land Degradation Vulnerability assessment • Development of techniques to retrieve gravity/geoid using satellite altimetry over marineregions • Modeling gravity/geoid data for understanding lithospheric structure and geodynamicprocesses. • Integrated geophysical study of Indian continental margins to understand its geologica levolution with specifi utility to off-shore oil exploration. • Geophysical investigations of the Andaman-Sumatra subduction zone to understand geodynamics and seismo-genesis.	
G4.2	**Geo hazards (SAC)** It is required to develop techniques for early warning of geo-hazards using space technology and geo-informatics. In this context, one of the most challenging research area	

	is to understand mechanism of earthquake triggering geodynamic processes. Study of geodynamic processes using advanced space based techniques is required to understand regional seismic hazard vulnerability in regions like the Himalayas and active seismic zones in peninsular India. Research related to quantification of the active tectonic deformation, modelling inter-seismic slip and strain rate and estimating moment-build up rate from geodetic, seismological and paleo-seismic data is required. Inter-seismic deformation measurement from space geodesy, their analysis and advanced modelling techniques are required to be developed. Study of land subsidence due to over exploitation of ground water, coal, hydrocarbons and crustal deformation associated with volcanos and slow-moving landslides using geodetic measurements for hazard assessment is another potential research area.
G4.3	**Marine Geosciences (SAC)** Offshore exploration using satellite altimetry is a major research area. Altimeter derived geoid undulation and free-air gravity anomalies over Indian Ocean needs to be utilised to understand plate tectonic processes relating to oceanic ridges, subduction zones, formation of marine sedimentary basins and the evolution of continental margins. There is a need to improve the marine geoid and gravity data by including high precision altimeter data in geodetic mode for detailed work. The structural frame work of the Indian Ocean is quite complex with numerous fracture zones, abandoned spreading centers, aseismic ridges, seamounts and subduction zone. The Indian Ocean lithosphere is constantly under stress due to spreading activity south of it, resulting in fractures and intense deformation in this region. The thick sediment deposits in the Bay of Bengal mask the underlying crust and pose severe restrictions in constructing the geodynamical history of the basin. Splitting the geoid data into different wavelengths and correlating them with geology/tectonics and also their modeling may help to better understand structure and dynamics of the Indian Ocean lithosphere and may also help in offshore hydrocarbon exploration.
G4.4	**Coastal Geosciences (SAC)** Coastal zones are the interface between land and ocean and are dynamic fragile ecosystem, where interaction among complex natural coastal processes, coastal hazards, vital habitats and human activities occur and integrated studies for sustainable coastal zone management are required for protecting life, property and environment. Some of the major coastal geoscience research area includes coastal sediment transport modelling using satellite retrieved parameters, understanding coastal processes and causes of coastal erosion, dynamics of various coastal processes and its impact on evolution of coastal geomorphology, modeling coastal erosion and developing methods to predict shoreline changes, use of advanced automated methods to delineate shoreline (HTL/LTL) from satellite data, understanding impact of coastal processes on critical/vital habitats, understanding impact of predicted sea level rise on coastal zone, understanding coastal hazards and vulnerability/risk assessment, developing techniques for automated

	coastal landforms/wetlands/land use/land cover mapping, detecting and monitoring coastal pollution, understanding impact on coastal ecosystem and developing models for integrated coastal zone management.
G4.5	**Mineral Exploration (SAC)** Although large part of the country has been conventionally surveyed and location of most of the economic mineral deposits have been investigated in detail, still new mineral deposits needs to be explored to meet ever-increasing demand of the industries. Mineral exploration using conventional techniques involve geological mapping followed by geophysical and geochemical investigations, pitting, trenching, exploratory drilling, estimating reserves etc. Remote sensing based methods have been so far limited to updating the existing geological/structural maps and in identifying hydrothermal alteration zones as a useful guide. Alteration halo is much more widespread of rocks surrounding a mineral deposit that are caused by solutions that formed the deposit. Research is required to explore integrated use of multi-spectral, hyperspectral, thermal and radar data along with high resolution DEM (space-borne as well aerial), geochemical and geophysical data sets in diverse geological and environmental settings to identify and map new mineral prognostic zones. Methods for automated mapping of minerals associated with alteration zones, development of spectral-geochemical relationship using spectral and geochemical datasets need to be developed.
G4.6	**Geo-Archaeology (SAC)** Space based geo-archaeological exploration along with geo-spatial tools is one of the most fascinating geoscience application. It involves interpretation of multi-sensor satellite data to explore new archaeological sites, understand development, preservation and destruction of archaeological sites in context of regional scale environmental changes, evolution of physical landscape and impact of human groups by applying concepts and methods of geosciences (especially geology, geomorphology, hydrology, sedimentology, pedology and exploration geophysics). Research is required to develop methods/ approach to explore archaeological sites using multisensor satellite data (Radar and high resolution multispectral data in particular) in conjunction with geospatial database of known archaeological sites. It is required to understand impact of neo-tectonic activities and palaeo-climatic changes on evolution of ancient civilisations.
G4.7	**Environmental Geosciences (SAC)** Desertification and land degradation constitutes one of the most alarming geo-environmental global problem affecting two third countries of the world on which one billion people live (one sixth of world's population). Land degradation is reduction or loss of productive land due to natural processes, climate change and human activities. Desertification is land degradation in arid, semi-arid and dry sub-humid areas (also known as Drylands). The processes of desertification and land degradation are observed to have accelerated during recent years globally. There is a need to stop and reverse the

	process of desertification and land degradation. It is required to develop advanced digital classification techniques using object based approaches, machine learning/artificial neural network for automated land degradation mapping using muli-temporal and multi-sensor satellite data, vulnerability and risk assessment and developing action plans to combat land degradation.	
G4.8	**A study of mangrove change dynamics using satellite images (NRSC)** Mangrove forests, which are essential for stabilizing coastal ecosystems, have been suffering from a dramatic decline over the past several decades. Mapping mangrove forests using satellite imagery is an efficient way to provide key data for mangrove forest conservation. Since mangrove forests are periodically submerged by tides, current methods of mapping mangrove forests, which are normally based on single-date, remote-sensing imagery, often underestimate the spatial distribution of mangrove forests, especially when the images used were recorded during high-tide periods. The mangrove forest ecosystem acts as a shield against the destructive tidal waves, preventing the coastal areas and other properties nearby from severe damages. All types of measurements related to the mangrove forest ecosystem, such as detection of land cover changes, species distribution mapping and disaster observation should take advantage of the advanced technology; for example, adopting the digital image processing algorithm coupled with high-resolution image available nowadays. Thus, remote sensing is a highly efficient, low-cost and time-saving technique for mangrove forest measurement. The application of this technique will further add value to the mangrove forest and enhance its in-situ conservation and protection programmes in combating the effects of the rising sea level due to climate change. This research study is aimed to understand the changes in Mangrove area, analyze the probable factors causing the changes and identify the zones where periodic monitoring and special attention required to protect Mangrove ecosystem using multi-temporal satellite datasets. This study is also to understand change in land use/ land cover patterns and various factors affecting Mangrove areas.	
G5	**Sub Area**	**Cryosphere Science (SAC/NESAC)**
G5.1	**Himalayan snow (SAC)** SAC has generated a large amount sub-basin wise snow cover products using AWiFS data since 2004, snow products with best spatial and temporal resolution so far in the world. The products have been used in snow melt runoff estimations, in understanding of accumulation and ablation pattern of snow in different climatic zones of HKH region, and in assessing the snow cover trends from climate change point of view. These snow products can be also be used as an input in various climate models for projections of snow cover in future. Yet, there are other important challenging areas in which research is required. These are estimation of annual seasonal snow mass using DEMs generated from photogrammetric, radargrammetric and interferometric techniques or radiative	

	transfer modelling using SAR data, selection of sites for micro hydroelectric projects depending on snow melt runoff using geospatial modelling and development of models for estimation of real time snow melt runoff estimation for Indian rivers exclusively by use of satellite data.
G5.2	**Himalayan glaciers (SAC)** Inventory and monitoring of Himalayan glaciers within periphery of IGB basins has been a foremost requirement of our nation to know the stock of glacier stored water, and variations in dimensions of glaciers as an impact of climatic variations. SAC has carried out extensive work in this direction using data from Indian sensors such as AWiFS, LISS III and LISS IV. The glacier inventory in IGB basins can be visualized in VEDAS portal of SAC. Glacier mass balance estimations have been done using Accumulation Area Ratio (AAR) approach for large number of glaciers, but one area which requires extensive research is development of AAR-Mass balance relations for all sub-basins in HKH region, mass balance estimations with high accuracy by geodetic methods utilizing DEMs from Indian (Cartosat-1 and future stereo missions) and other data , ice velocity estimation and its application in assessment of mass changes of glaciers and modeling the glacier changes with temperature and mass balance.
G5.3	**Himalayan Permafrost (SAC)** The permafrost is very important element of Cryosphere studies. The distribution and changes occurring in the permafrost land in the mountainous HKH region as a result of climatic variations needs to be known in view its importance in ecology and land cover changes. Exploration of Permafrost might give new insights of its importance. Exploration is best possible through the use of thermal and active microwave data. In view of forthcoming satellites by ISRO, there is a ample scope of utilizing earth observation data in inventory, digital mapping, monitoring and science of permafrost in high altitudes of HKH region.
G5.4	**Polar ice sheets (SAC)** One of the most challenging areas of research in polar ice sheets is estimation of ice sheet mass changes and resulting sea level rise. State of art techniques, development of algorithms utilizing SARAL/AltiKa data and analysis of results have been demonstrated through studies carried out at SAC. It needs to be expanded further by using altimetry data from multiple missions. There has been extensive work in knowing the dynamics of major glaciers of Antarctica using optical and SAR data, monitoring of ice shelves and spatial and temporal variability of surface melting derived from Scaterrometer data but these areas of work have to be further explored by using more data in domain of time and space. One important area of research is to include results from these studies in Numerical Ice sheet modeling.
G5.5	**Polar sea ice (SAC)** One of the major contributions of SAC is in polar ice studies is extraction of sea ice area from ISRO's Scaterrometers data and understanding its spatial-temporal variability.

	Technique development has been demonstrated to measure sea ice thickness using data from altimeter and its application in sea ice advisories required for safer navigation of ships of Indian expedition to Antarctica. More research is required to address sea ice drift estimation, sea ice energy exchange and understanding of oceanic and atmospheric driving factors in global sea ice variability.	
G5.6	**Effect of Climate Change on Snow melt and run-off for incorporating in flood forecasting model (NESAC)** Temporal study of climate change and Land use change impact on snow melt run-off and overall run-off in important flood causing sub-basins of Brahmaputra valley. A detailed study to be carried out by correlating the atm. temperature, rainfall and land use / land cover pattern on the discharge of the catchment. A hydrological modelling to be carried out by taking into consideration of snow component in the upstream of the catchment. This study should reveal the following, • Impact of rainfall on snow cover change. • Impact of seasonal temperature change in snow melt run-off. • The impact of land use land cover on discharge and snow cover of catchment.	
G6	**Sub Area**	**Geology, Structure and Geomorphology (NRSC/NESAC)**
G6.1	**Sub-surface geo / archaeological features using GPR data sets (NRSC)** With the Indus Valley civilization and several subsequent empires and kingdoms, India is one of the world's archaeological gems. Be it ancient forts or some of the world's oldest universities, India has more than a thousand known/ excavated archaeological sites over diverse geological provinces. Many of the sites with its extent are yet to be excavated and or mapped. Synergetic usage of Earth Observation (EO) satellite data and ground geophysical observation (Ground Penetrating Radar) has proven to be an effective tool for detection, delineation and mapping of shallow sub surface geo-archaeology and ancient cultural sites with its extent. Proposed study will help in building up scientific understanding and to correlate EO data and GPR signatures of geo-archeological features in known archeological sites (in fluvial Aeolian and coastal regions) to detect, delineate and map the extent of the buried cultural heritage sites.	
G6.2	**Spectral library generation of rocks & archiving from various geological terrain invisible and thermal region (NRSC/NESAC)** In this research domain, research is to be carried out to understand the role of mineralogy in shaping diagnostic absorption features imprinted on the reflectance/ emittance spectra of rocks and how mineral spectra of dominant to minor minerals contribute in shaping absorption, kinks in the mineral spectra. Research also should assess the role of linear or non-linear mixing arising due to textural change and how these hamper/influence the diagnostic absorption feature. Research attempt can also be made to prove/assess the utility of spectrometric parameters of absorption/emissivity features in estimating grade of the ore bearing samples.	

G6.3	**Development of an automatic technique using satellite data and DEM for identifiation of landforms in different geomorphic provinces of India (NRSC)** Understanding the landforms present in different geological provinces like Fluvial, Glacial, Coastal, Denudational, Aeolian etc based on terrain analysis and classification of precise DEM using various satellite and aerial data sets. Exploring the semi-automatic and automatic techniques like Machine based methods, Artificial Neural Network, Object Based classification, Fuzzy logics etc. for automatic classification of the landforms by reducing the manual delineation efforts and time as well as to support the modeling of processes as hydrological modeling, geomorphic modeling etc.
G6.4	**Numerical modelling for crustal deformation using GPS vectors (NRSC /NESAC)** NRSC operated Continuously Operated Reference stations in 6 locations within the HPand Uttarakhand Himalayas. Differential movement as recorded by GPS observations indicate towards active convergence in the region. Further, as a resultant of such differential movement, it may be possible, that there is signifiant strain accumulation in the region, pervasively or localized to certain areas. These areas are then prone to future earthquakes. To understand the state of strain in the area, estimation and modeling of the same is important. For this, numerical models (Finite Element) are to be created to ingest the GPS vector data, the fault geometries with the crustal rheological properties and simulate the strain accumulation in the region.
G6.5	**Hyper spectral response characterization of intimately mixed geological samples occurring in complex geological terrain (NESAC)**
G6.6	**Derivation of innovative sub-pixel mapping algorithms to identify rarely occurring class indicating mineralisation (NRSC)** Under this research domain, focus should be on the derivation of the effective subpixel mapping method which may help to identify the spectrally diagnostic target which occupies 20 to 30 percent of the pixel but. Algorithms should be effective for processing both hyperspectral and multispectral data. These algorithms should also account to characterize complex (stochastic) character of background.
G6.7	**Implementation of algorithms to derive spectrometric parameters of each pixel of hyperspectral data (NRSC)** In this research domain, we require develop image processing tools (in IDL language preferably) which can be used to derive different image products for different spectrometric parameters like absorption depth, width and asymmetry (pixel by pixel basis) from any hyperspectral data once spectral range and wavelength minima of the absorption features are specified. These spectrometric parameter enhancing products would be ideal for geological target detection like alteration zone etc.
G6.8	**Development of regional landslide early warning system based on rainfall threshold (NRSC/NESAC)** Landslides are mainly triggered by rainfall. Daily as well as antecedent (cumulative) rainfalls are responsible for saturation of soil and subsequent landslide in hillyareas.

	Therefore, a rainfall intensity-duration relationship was developed by NRSC for experimental landslide early warning. Bhuvan platform is currently used to disseminate daily landslide early warning for selected road corridors in the Himalayas. Daily 72 hrs rainfall forecast received from IMD or SAC (MOSDAC) is used as an input to the landslide early warning model. Then the available landslide susceptibility map is integrated with rainfall probability to generate landslide early warning in Bhuvan. Early warning in four categories (Warn, watch, advisory and no warning) are issued regularly through Bhuvan. Currently the landslide earlywarning system is operational experimentally in selected routes of Himachal Pradesh, Uttarakhand, Meghalaya, Assam and Mizoram. Further development of rainfall intensity-duration relationship is required specific to different landslide prone areas of India.
G6.9	**Automatic identifiation of earthquake and landslide induced terrain changes from high resolution satellite data (NRSC)** Earthquake cause subsidence or upliftment of land in the seismic prone areas. Similarly, landslides, particularly the creeps (slow moving landslides) cause persistent damage to road and buildings in hilly areas. Object-based change detection technique was used to identify new landslides using Resourcesat-2/2A LISS-IV Mx satellite data. CartoDEM (10 m) was additionally used to eliminate several false positives using slope criteria. Characterisation and identifiation of terrain changes due to earthquakes and creeps can be done effectively by differential SAR interferometric techniques. The outputs of the same in the terms of displacement maps and velocity fields with are used to model the prediction of debris flow path in the case of complete slope failure. Advanced processing methods like PsINSAR or STamPS will be attempted to overcome problem related to coherence loss or atmospheric interferences.
G6.10	**Correlation of landforms with mineral composition on planetary surfaces (NRSC)** It is widely recognised that understanding of Mars must begin by using the Earth as a reference. Therefore terrestrial analogues, places on Earth that approximate the geological and environmental conditions on Mars; hold the key for understanding the evolution of Martian geology. Off late, detection of water or aqueous environments in Mars is of primary interest for researchers across the world. Therefore, the study will primarily focus on detection of key minerals indicating hydrous past of Mars and establishing it suitable analogues on earth with respect to mineral composition and landform distribution. Further, certain minerals are associated with distinctive landforms, thus indicating the occurrence of that mineral. The study also aims at demarcating such landforms so that first pass mineral deposit identification can be done.
G6.11	**Vulnerability profiling of capital cities of NER (NESAC)** Urban areas are susceptible to disasters (man-made or natural). It is the need of the hour to make a rapid vulnerability assessment of urban areas in order to understand what is required for building disaster resilience community. The potential impact of different parameters on urban services arising from the geographical setting of a city; the nature, size and density of its settlements; and the existing coping capacity of its society and governance system can be studied to create vulnerable profile of urban areas.

G6.12	**Downscaling of Coarse Resolution Satellite-derived Soil Moisture (NRSC)** Soil Moisture is a key variable in hydrological processes and its accurate estimates provide better quantification of energy and water exchange between land surface and atmosphere. The most accurate satellite-based soil moisture estimates are derived through passive microwave remote sensors, however, they have very coarse spatial resolution. For example, Level 2 soil moisture estimates are available at 15km spatial resolution and that of SMAP are available at 10km and 36 km. The very coarse resolution of these datasets makes their applicability very limited in hydrological applications. To overcome this, a study on evaluation of different models to downscale coarse soil moisture estimates from SMOS and SMAP is required. This research shall focus on evaluation of satellite datasets-based disaggregation methods and statistical methods to downscale SMOS and SMAP surface soil moisture products to finer spatial resolutions 1km, 3km, and 5.5km.	
G7	**Sub Area**	**Visualization of Earth Data & Archival System (VEDAS) (SAC)**
G7.1	**Algorithms / procedures for time series visualization (SAC)** VEDAS is responsible for archival and dissemination of thematic data and data products available within SAC. Large amount of spatial time series data is collected over time and visualization of available spatio-temporal data is essential for exploring and understanding structures and patterns, and to identify unusual observations or hidden patterns. However, the volume of data available and number of concurrent users that may be accessing the data challenges current time series map visualisation. The start and end time of episodic events or span of intensive observations may also be dynamic. So algorithms are required to be developed and modern techniques are required to be used for visualization of large spatio-temporal (ST) datasets ordered in time for animated mapping. This will be further used for exploring or monitoring unusual observations in large datasets like NDVI, snow, temperature, solar insolation etc.	
G7.2	**Data analytics and knowledge discovery (SAC)** To understand and appreciate a natural phenomenon and attach cause and effects to an evolution, there is a growing demand of rendering “on the fly” multi-layer information. There may be concurrent users accessing same set of data. So there is motivation to parallelize computation to improve turn around time of a service. The research initiatives will be useful steps towards achieving this goal. Design & Development of parallelizable algorithms for interactive geospatial data analysis with high temporal resolution. Design & Development of parallel execution frameworks and/or distributed computing libraries for geospatial data processing operations. Design and Development of scalable general purpose systems/algorithms for removing noise from spatiotemporal datasets. Design and Development of scalable general purpose systems/algorithms for predictive analytics from spatiotemporal datasets. Design and Development of data-mining algorithms for spatial-temporal datasets.	

	Design and Development of scalable techniques for semantic segmentation of orthoimagery.	
G7.3	**Super resolution image generation (SAC)** Super Resolution is an Image Processing technique which is used to enhance the image resolution of scene from a number of lower resolution images of same area by reducing effects of noise in the reconstructed image. In case of satellite images, this can be seen as a powerful tool of getting high resolution multi-spectral images (spatial) from low resolution panchromatic images. This will facilitate improved (in spatial scale) Land cover for better natural resource management.	
G7.4	**Web enabled sensor system for efficient resource management (SAC)** There is need to develop a prototype and demonstrate the applicability of wealth of information that can be gathered by set of remotely located instruments. Instruments can measure the meteorological conditions as well as ambient conditions and transmit the data to a central hub. Air quality monitoring of a region is a one such example where measurements of PM2.5 and PM10, concentrations of target gases (NOx and SOx – for example), their dispersal (based on wind direction and speed), temperature and humidity are all required by administrators and managers to issue advisory and / or take pro-active preventive measures.	
G8	**Sub Area**	**Urban Studies (SAC/NRSC/PRL/IIRS)**
G8.1	**Urban feature extraction: Road network delineation (SAC)** Transportation networks such as roads and railway lines are important for several urban applications including disaster management, urban planning, impervious surface extraction, urban growth modelling etc. The automatic methods such as template matching, object-based classifiers and machine learning methods such as neural networks, support vector machines, deep learning etc. can be used to efficiently extract road network from very high-resolution optical and SAR images acquired by Indian Remote Sensing satellites.	
G8.2	**Urban feature extraction: Impervious surface / urban area mapping (SAC)** The mapping of urban land cover remains a challenging task owing to the high spectral and spatial heterogeneity of urban environment. The accuracy of urban area extraction can be improved by combining multi-temporal, multi-resolution and multi-sensor optical and SAR earth observation data.	
G8.3	**Urban feature extraction: 3D building reconstruction (SAC)** The 2D and 3D information of buildings and other urban structures are needed not only for impressive visualisation of urban areas, but also as an input in several urban applications like population estimation, roof-top solar energy potential assessment, visibility studies etc. Building extraction from high-resolution satellite images in urban areas is an intricate problem. Techniques are to be developed for automatic extraction of buildings from Very High Resolution optical data. The availability of very high-resolution imagery from Cartosat series data necessitates development of techniques and algorithms for 3D building reconstruction.	

G8.4	**Urban Heat Island (SAC)** Spatial and Temporal Distribution of Urban Heat Islands on Land Surface and Near Surface Atmosphere Development of models for deriving day-time and night-time air temperature from satellite-derived land surface temperature and vegetation indices can assist in identification and analysis of spatial and temporal distribution of urban heat islands. **Impact of Land Cover Types on Urban Heat Islands** The changes in land use-land cover pattern and declining vegetation cover in cities are predominant factors influencing the growth of urban heat islands in the cities. Satellite data derived land use land cover information can be compared with the temperature profiles to assess the impact of land cover on urban heat islands.
G8.5	**Geo AI for convergence of development activities and effective planning (NRSC)** Convergence of crowd sourced data for identifying gaps and for better developmental activities. Leveraging geospatial artificial intelligence (GeoAI) and Geoinformatics for convergence of developmental planning activities and implementation. This will facilitate integration of governance application like MGNREGA, HFA, PMKSY, PDMC etc. Tools to collate the available crowd sourced information, visualization of aggregated information with Gaps, Scenario generation and decision making tools.
G8.6	**Anthropogenic and biogenic sources of Volatile Organic Compounds (VOCs) in urban regions of India (PRL)** The lack of representative local and regional parameterization of VOC emissions is one of the largest sources of uncertainty in the chemistry-climate model. Emission and photochemical processes of VOCs over the South Asia region are not well understood mainly due to the lack of comprehensive measurements. The dependence of both emission and atmospheric processes of VOCs on the key meteorological/environmental parameters is poorly understood over India and surrounding oceanic regions. Emissions of VOCs from primary the anthropogenic, secondary and biogenic sources are important to estimate in urban regions of India. The research objectives of PRL involve measurements of various VOCs using state of the art instruments such as the Proton Transfer Reaction-Time of Flight-Mass Spectrometer (PTR-TOF-MS) and Thermal Desorption-Gas Chromatography-Flame Ionization Detector (TD-GC-FID) in urban regions of India.
G8.7	**Urban micro and meso-scale climate modelling and urban canopy parameters estimation (IIRS)** Study several factors such as urban morphology and density, properties of urban surfaces, vegetation cover, etc. The urban built-form due to its dense development and high-rise character, and the increase in impervious and of urban climate is important at local and global scale, which is influenced by absorptive surfaces are responsible for the trapping of heat and reduction in evaporative cooling due to decrease in vegetated, soft, pervious surfaces in urban areas. The study of urban climate is also gaining further importance in the scenario of climate change.

G8.8	**Urban Flood Hazard, Vulnerability Analysis and Risk Modelling (IIRS)** Reliable and timely prediction of flood extents in urban catchments is a challenging issue. Various modelling approaches are available ranging from data driven to physically based, from conceptual to detailed 1D-2D modelling. These approaches are then embedded in wider context of flood risk assessment and disaster management. An integrated model that simulates the sewerage-network, river-network and 2D mesh-network are desirable to obtain flood extents in urban areas so that whenever overflows occur due to insufficient drainage capacity, the resultant surface flooding and/or levee break could be predicted.
G8.9	**Urban Seismic Risk Assessment (IIRS)** Urban areas are growing at a rapid pace and as a consequence, urban areas have encroached upon in areas not suitable for urban growth. There is an urgent need to quantify the urban risk due to seismic activities in terms of damage to buildings, infrastructure, etc. These analysis will provide inputs for the disaster preparation and mitigation processes.
G8.10	**Linking Urban Air Quality with Built-form Using Geospatial Techniques (IIRS)** Air pollutants occur both, outdoor and indoor, and can be natural or man-made. The major indicators of air pollution are SO2, CO, NO2, O3, NH3, H2S, particulate matters (PM2.5 and PM10), etc. The major sources of air pollution in urban areas are vehicular emission, solid waste burning, domestic fuels, power station, industries, etc. which are ever rising and causing serious health and environmental hazards.
G8.11	**Species and vegetation health assessment and development of indices for Urban Green Spaces (IIRS)** Objective assessment of urban green spaces for planning purposes are necessary for understanding the optimal distribution of urban green spaces and Smart City planning.
G8.12	**Understanding of Urban Heat Island (UHI) Phenomena in Urban Areas (IIRS)** Urban expansion involves land conversions from vegetated moisture-rich to impervious moisture deficient land surfaces. With growing urbanization, the local weather and climatic conditions of the urban areas are varying considerably.
G8.13	**Urban sprawl, growth and change modelling using advanced algorithms (IIRS)** The recent thrust on urban growth modelling using geospatial data and techniques are- i) to implement cellular automata (CA) based models to simulate urban growth in Indian cities, ii) to evaluate the efficacy of Artificial Neural Networks (ANN) in formation of transition rules for CA based modelling and its comparison with the traditional Multi-Criteria Evaluation (MCE) based CA model, iii) to investigate the effects of different neighbourhood sizes and neighbourhood types in calibration of CA based models, iv) to evaluate the performance of CA based models using Moran, Percent Correct Match and Shannon's Entropy and v) to generate ANN based urban growth zonation maps depicting zones of urban growth potential.

G8.14	**Solar Potential Assessment in Urban Areas (IIRS)** World's energy problem and the huge scarcity of sources producing energy, drifts our attention towards renewable energy sources. Recent research has shown that net-zero energy buildings are achievable if site analysis and various climatological factors are taken into consideration while designing a building, house or a community.	
G8.15	**Urban Water Distribution Modelling for Smart City Planning (IIRS)** Advanced water network modelling combined with Supervisory Control and Data Acquisition (SCADA) enables a real-time operational management system in urban areas. The benefit of this system enables proactive online operation, pressure management, reducing leakage, access to critical information and key performance indicators (KPIs) and contingency management, i.e. incident and risk reduction.	
G9	**Sub Area**	**Calibration and Validation (SAC)**
G9.1	**Optical sensor calibration (SAC)** • The optical sensor calibration exercise is performed by vicarious (absolute), relative and inter-sensor calibration methods. The absolute calibration is performed through simulation of top-of-Atmosphere radiance for calibration gain and offset calculation. For this purpose we developed ocean site at Kavaratti and land site at Little Rann of Kutch (partially campaign). In each aspect of operational methods are based on R&D carried out here. • The relative sensor calibration exercise for radiometric performance monitoring is performed through land, ocean, snow and deep convective cloud targets. • The sensor performance is also cross verified with contemporary sensors using synchronous nadir pass and its measurements. These exercises is performed by normalizing the central wavelength and out off band contribution in case of optical sensors. • Radiative modeling of satellite sensor measured radiance though ground truth measurements. • Periodic monitoring and updating of radiometric performance of optical sensor through terrestrial surface radiance measurement and model simulation. • Radiometric performance monitoring using moon, deep convective clouds, desert and ocean sites for optical sensors (both high and coarser resolution).	
G9.2	**Microwave sensor calibration (SAC)** • Synthetic Aperture Radar (SAR) radiometric calibration is one of the important aspects to characterize and maintain image quality throughout the mission and to provide stable, quantifiable image products to the users. • Radiometric parameters of SAR sensors like sigma0, speckle index and radiometric resolution are monitored over invariant, distributed calibration targets like Amazon rainforest, Boreal forest, Antarctica for the data sets with same instrumental	

	parameters (beam, polarization). This exercise is used to estimate noise equivalent sigma0 to ensure the data quality. • Corner reflector based calibration is done to compute the impulse response parameters. A regular and systematic analysis helps to estimate the radiometric accuracy and stability using corner reflector based data. • Monitoring of SAR instrument subsystem components is used to study gain variations or linearity. • Generic software for estimation of calibration parameters using SAR images and orbital parameters over synchronized satellite pass with various Corner reflectors. • A novel approach for Data quality evaluation of Scatterometer (OceanScat or upcoming mission ScatSat-1) is being worked out where one can relate the parameters available at different levels of product to geophysical parameters. • Scatterometer calibration includes the monitoring of on-board calibration data to keep a check on transmitted power. Invariant sites like Amazon rainforest, Sahara Desert, Antarctic snow are required to be monitored regularly and time series of backscattered or brightness temperature can be generated to check the system behaviour.	
G9.3	**Geo-physical products validation (SAC)** • The most important exercise of validating sensor derived geo-physical products are done using community vetted matchup methodology and qualifying various data sets (in-situ, contemporary missions, climate data sets, data from various collaborative agencies, etc.) • Protocol development on measurements, instrument operation, quality control, and calibration standards. • Inter-comparison of rainfall estimates measurements made by various ground based instruments like Micro Rain Radar, Disdrometer and rain-gauges over a validation site. • Optimization of disdrometer/ rain-gauges distribution and number for addressing beam filling problem in validation of satellite derived rainfall estimates. • Satellite derived geo-physical products plays an important role in making effective use of satellite data by various user community. These activities are achieved through partnership of collaborative agencies, autonomous measurement systems (land, ocean) and also through special measurement campaigns.	
G10	**Sub Area**	**Hyperspectral Techniques Development (SAC)**
G10.1	**Machine learning models for Hx classification (SAC)** Following challenges are needed to be taken up; • To explore Residual-3D-CNN, standard computer vision models such as LeNet-5, AlexNet, VGG, Darknet, Squeezenet to Hx classification with different learnable filters such as using 1D, 2D and 3D to see their effectiveness for remote sensing data classification.	

	• Another relevant challenge is to integrate spatial-contextual information in spectral-based classifiers for hyperspectral data to take advantage of the complementarities. For Example: 3D deep convolutional neural networks (CNN). • The Challenge in Vegetation (multi-crop, forest species) classification now is learning temporal information from time series hyperspectral data. The addition of the time domain to the learning model apart from contextual and spectral information adds an additional dimension to the input data making the learning process much more challenging. • Current research on simultaneous contextual information extraction and temporal information extraction can also be further explored by combining the concept of Convolutional and RNN such as Convolutional LSTM or Convolutional GRU to the temporal image data. This can be very effective for time series data classification. • Physics inspired Deep-Learning based Inversion models for geophysical parameter retrieval.
G10.2	**Challenges in Hyperspectral-Multispectral Data Fusion (SAC)** There is a trade-off between Spatial Resolution and Spectral Resolution as can be seen in the case of Hyperspectral data and Multispectral data. In order to fully utilize the advantage from both the sensors like having data with both high spatial resolution and high spectral resolution data fusion is required. Another challenge is the introduction of noise in the dataset during the fusion process. Current methods often fail to address the issue of registration errors and are widely ignored thereby in the future comprehensive modelling and compensation of realistic noise and registration error can also be addressed. • To explore hypersharpening based methods for denosing which are based on Component Substitution (CS) and Multiresolution Analysis (MRA). • The unmixing based strategies such as Hyperspectral Image Superresolution via Subspace-Based Regularization (HySure) and CNMF (Coupled Non Negative Matrix Factorization) have great potential even when Spectral Response Function (SRF) has limited overlap. • A possible future for further performance improvement lies in developing hybrid approaches that combine the advantages of different classes of methods such as MRA and Unmixing. Current Unmixing approaches rely mostly on the assumption of Linear Unmixing Model which can be further extended to Bi-linear or Non-Linear based models. • VNIR-Hx and thermal-Hx data Fusion and Hyperspectral, LIDAR and SAR data fusion for precision agriculture, soil characteristics, forest biomass etc. studies.
G10.3	**Spectral Nonlinear Unmixing (SAC)** Spectral unmixing is the most important and challenging in hyperspectral imaging. It is known as blind source separation problem. The spectral unmixing problem includes two major tasks a) Identifying the pure pixels (materials) called end members b) Estimates their corresponding fractional quantities (abundance) presented in the mixed pixel.

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There is need to develop robust models for non-linear spectral unmixing where light typically interacts with more than one component as it is multiple scattered such as the case of minerals, soil grains etc.

A complete physics based approach tononlinear unmixing would involve the inversion of the radiative transfer theory (RTT), which is an extremely complex ill-posed problem. Therefore we need to take up following challenges
• To develop physics-inspired and sparse based non-linear un-mixing models.
• Real-Time robust spectral unmixing algorithm and tools (Which can be used in airborne or drone based sensor).
• Development of high performance / parallel computing model for spectral unmixing (Sparse unmixing models depend on spectral library which takes too much time).
• Dictionary Learning based Estimation and data recovery for sub-pixel classification of Hx data. For eg. soil property estimation from mixed pixels.
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<tr><td>G10.4</td><td colspan="2">
Aerosol retrievals, atmospheric corrections and air quality (SAC)
Aerosol and atmospheric corrections involves following challenges:
• Aerosol and dust characterization.
• Atmospheric corrections of VNIR sensors is a challenge in absence of SWIR channels. In this direction, there is need to develop methods for AOD and surface reflectance retrieval for VNIR sensors such as AWiFS, LISS-III, Cartosat-2 etc.
• Mapping and analysing the patterns of ground level particulate matter (an important factor to determine the ground level Air-Quality) using satellite data and modelling. Development of models to estimate particulate matter using satellite data specifically for Indian atmosphere. The quantification of factors leading to harmfully high levels of particulate matter.
Challenges/Opportunities
• Requirement of hyperspectral CubeSat-constellation for high-temporal hyperspectral data
• Development of on-board Parallel/FPGA algorithm for real-time application of hyperspectral data.
• Simulation of synthetic hyperspectral data using Radiative Transfer and Ray tracing models.
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<tr><td>G11</td><td>Sub Area</td><td>Microwave Techniques Development (SAC)</td></tr>
<tr><td>G11.1</td><td colspan="2">
Potential areas of research:
• Development of techniques to simulate GeoSAR data and its processing algorithms, to study geophysical parameters retrieval accuracies.
• Development of object/feature detection techniques using GPR and Wall-Penetration radars, and their performance evaluation.
• Development of processing methodologies for Rail-mounted Interferometric SAR system for land-subsidence monitoring; system development, demonstration of processing methodology and its performance evaluation
</td></tr>
</table>

	• Full-wave numerical Maxwell Model 3D simulations for microwave scattering from forests including detailed 3D modeling of forest canopy structure. • Signal processing techniques for forest mapping using 3D-SAR Tomography and Higher dimensional SAR Tomography; applications of SAR tomography for forest mapping in plains and hill slopes. • Tree height and structure mapping and species diversity mapping from LIDAR and fine resolution optical data. • Classification and discrimination of vegetation types from time series vegetation profiles; Vegetation phenology mapping for assessing the vegetation characteristics for studying impact of climate. • Long time series monitoring of crop sowing shifts and impact on the potential yield of crops. • Detection of vegetation disturbance and generation of alert system; Dryland agriculture and yield gap analysis. • Data Driven Techniques development for Daily Real Time Soil Moisture Estimates and Forecast using Deep Learning • Development of techniques for root-zone soil moisture estimation • Development of Polarimetric SAR models for Permafrost characterization in Himalayan regions. • PS- and DS-InSAR based algorithms for land-deformation estimation; Algorithms for Landslides damage assessment from SAR data; development of regular monitoring system with alert generation capability	
G12	**Sub Area**	**Marine Biology and Ecosystem (SAC)**
G12.1	**Bio-Optical Parameter Retrieval for Optically Complex Waters (SAC)** a) Development of bio-optical algorithms for optically complex marine waters which includes coastal turbid and shallow waters, estuarine and backwaters, coastal wetlands of the Indian region. b) Accurate estimation of optically active constituents such as chlorophyll–a concentration, Coloured Dissolved Organic Matter (CDOM) absorption and total suspended sediments with error budget. c) Atmospheric correction models for turbid and optically shallow waters and retrieval of water leaving radiances. d) Hyperspectral inherent optical properties, and hyperspectral characterisation of optical constituents e) AI based techniques for retrieval of optical constituents	
G12.2	**Aquatic carbon and biogeochemical dynamics in ocean-coastal ecosystems (SAC)** a) Study of various components of the aquatic carbon in diverse coastal-ocean ecosystems (TOC, DOC, DIC, POC, Pyto C, Det C) b) Study of nitrogen components of the aquatic system	

	c) Nutrient dynamics in estuarine coastal and oceanic regions and the effect of density, salinity and temperature on nutrient dynamics d) Study of photosynthetic rate parameters for modeling primary production e) New production modelling. f) Modelling biogeochemical pathways in marine ecosystem g) Composition of dissolved organic carbon in various ecosystems
G12.3	**Marine Living Resource Management (SAC)** a) Modelling of fish habitats using remotely sensed parameters and fishery data b) Marine spatial planning of fishery resources in GIS c) Habitat identification of endangered marine organism using geospatial information d) Site suitability for mariculture using RS and GIS e) Role of remote sensing in zooplankton and secondary production f) Microbial ecosystems and remote sensing g) Role of remote sensing in benthic fisheries.
G12.4	**Biodiversity and ecosystem Studies (SAC)** a) Micro algal community structure (size and functional classes), using microscopic, b) Optical, chromatographic and remote sensing techniques, c) Biodiversity studies of micro and microalgae of Indian marine waters d) Environmental impacts on bio-diversity, e) Optical and biological studies of algal blooms f) Environmental and biological studies of micro/macro-algae useful for biofuels, g) Bioactive components h) Optical and biological characteristics of benthic ecosystems (Sea grass Seaweeds, benthic microalgae) i) Phytoplankton fluorescence and physiological studies.
G12.5	**Bio-physical process studies (SAC)** a) Effect of oceanographic features on phytoplankton productivity and community structure b) Impact of large scale climatic events on phytoplankton biomass and community c) Oceanographic processes (coastal upwelling, open ocean divergence, convective mixing etc) on ecosystem structure d) Impact of episodic events (cyclones, dusts) and open ocean ecosystems e) Ocean acidification studies f) Marine pollution studies and effect on phytoplankton community

G13	Sub Area	Agriculture, Terrestrial Biosphere and Environment (SAC)
G13.1	**Agriculture (SAC)** **Crop mapping:** Opti-SAR data fusion and development of AI-based techniques for improved crop discrimination and statistics, development of advanced algorithms for crop mapping in insurance unit, minor and scattered field crops, horticultural crops, medicinal and aromatic plants using high resolution time series optical (multi-spectral, hyperspectral) and synthetic aperture radar (SAR) data. **Precision agriculture:** Farm-scale water and nutrient foot-printing, canopy radiative transfer modelling for retrieving crop biophysical parameters, ensemble two-source surface energy balance modelling for crop stress combining multi-spectral, thermal and hyperspectral data, drone-based automatic stress detection, trajectory modelling for predicting desert locust migration. **Crop yield estimation and prediction:** Development of satellite data assimilation techniques to crop growth simulation and agro-hydrological models, Predictive modelling for crop phenology and agrometeorological parameters, Development of inversion schemes for retrieval of above ground crop biomass estimation using SAR.	
G13.2	**Terrestrial biosphere and Environment (SAC)** **Climate Change and Terrestrial Ecosystem:** Development of climate change impact indicators or alerts for ecosystem health of mangroves/forest, coral reefs, wetlands, grasslands; Estimation of forest fuel and fire risk potential, automated forest type detection, modelling long-term change in forest phenology, bio-geochemistry modelling, growing stock, stress vulnerability and risk quantification in agro-ecosystem. **Climate Resilience and Terrestrial Environment:** Development of prediction models of air quality parameters using long-term satellite-derived criteria pollutants, Geo-spatial modelling of environmental impact on human health, Urban micro-climate characterization and modelling, Interaction of surface ozone and methane over agro-ecosystems, Inverse modelling of surface methane and N2O fluxes, source-dispersion modelling for air pollution and quality assessment. **Retrieval of Land Surface Parameters:** Land surface temperature and emissivity separation, thermal anisotropy, development of retrieval techniques for vegetation fluorescence, GHG and non-GHGs, high-repeat high-resolution soil moisture, Photosynthetically Active Radiation (PAR) in different sky conditions, Development of LiDAR-based retrieval techniques for 3D forest structure and air pollutants.	

G14	Sub Area	Geospatial Data and Information Science (SAC/NRSC)
G14.1	**Advanced data and computing architecture (SAC)** • Optimized Data Cubes for multi-dimensional aggregation of satellite images and their spatio-temporal analysis. • Techniques for forecasting and in-painting in Data Cubes. • High Performance Computing of satellite images on Cloud.	

G14.2	**Data visualisation and web processing (SAC)** • Advanced data rendering and fast visualization techniques of 2D and 3D satellite data. • Fast Tiling and caching techniques for visualization of satellite Images. • Development of techniques for automatic on-demand web mashup generation. • Cloud and Semantic enabling of Web Processing.
G14.3	**Data security and information dissemination (SAC)** • Data encryption and compression techniques for multicasting of satellite data. • Customization and optimization of multi-cast protocol using critical distance of client nodes to cater to requirements of real-time data dissemination. • Content based data multicastingInformation and Data security models for small devices. • Location aware satellite data dissemination for mobile devices.
G14.4	**Data mining and web analytics (SAC)** • Real time analytics for Big Earth Data • Pattern recognition based techniques for Event detection • Geospatial feature extraction using deep learning techniques • Automated event tracking (Cyclone, dust storm, etc.) using machine learning techniques • Region growing algorithms for identifiation and tracking of meteorological and oceanographic events (Fog, bloom, convective initiation, etc.
G14.5	**Data and information lifecycle management (SAC)** • Automated algorithms for value evaluation of data and information • Techniques for automatic Quality checking of data • Techniques for Persistent identifier management • Techniques for generation of Linked data • Faceted search and Browsing of satellite images • Semantic annotation and labelling of satellite images.
G14.6	**IoT and sensor network (SAC)** • IoT enabled sensor network for acquisition of weather data • Smart weather data acquisition systems • RTOS based Data acquisition system • Virtual Sensors for Weather data acquisition • Optimal data capture and processing in Sensor Network
G14.7	**Virtualization and cloud computing (SAC/NRSC)** • High Performance Cloud for Satellite Image Processing • Network Virtualization and Software Defied Network • Software Defied Storage.

	Integrated Multi Mission Ground-segment for earth observation satellites (IMGEOS) integrates data acquisition, processing and dissemination systems (of Satellite DataReception and Ingest Systems Area as well as Data Processing, Products, Archival andWeb Applications Area) and is configured with scalable 3-tier storage system to meetcurrent and near future Earth Observation missions. The main objective of the IMGEOSis to minimize human interaction by automating the activities. The services hosted at IMGEOS are traditionally carried out on dedicated servers. The requirements in this domain are dynamically varying with respect to the IT infrastructure resources. The dynamic provisioning of the IT infrastructure is possible by virtualizing and orchestrating the IT infrastructure resources. This method of dynamic provisioning is cloud computing. Under the Cloud platform, it is envisaged to provide the following services. a) Platform as a service (Virtualized Linux, Windows Servers) b) Data as a service (User Data Products) c) Software as a Service d) Bandwidth as a Service The following are some of the requirements for implementation of IMGEOS private and public Cloud Solutions : a. Data Product generation b. Data Products Regeneration c. Workflow Management d. ISRO Centers Users e. Global user services f. FTP Services g. Web Services h. Data products for free download i. Disaster Management Support Requirements Demonstrated proof of concept for Open Data Access services and FTP services delivery from IMGEOS. Installed and confiured 50 TB storage system in internet domain to be used Open Data Access services viz. Bhoonidhi in internet domain using 4 server. The FTP service for delivery of user products is reconfiured using new server and required storage with upgraded Operating System. Implementation of NRSC Public Cloud was completed and implementation of NRSC IMGEOS Private Cloud is in progress.
G14.8	**Automatic updating very large scale urban geospatial base maps (NRSC)** Development of ML/ AI for automatic updating AMRUT cities of year 2018 or 2019 base map from latest very high resolution satellite data. Under AMRUT very large scale GIS base maps at 1:4,000 for 500 cities being generated from very high resolution satellite data pertaining to year 2018 or 2019. Trained draftsman and RS&GIS trained personal used manual feature interpretation, and digitization method for preparation of GIS base maps. For creation of one sq.km area the estimated manual effort is 10 man hours. These maps have used by Urban Local Bodies for (1) Urban land use & infrastructure planning (2) municipal tax (3) identify unauthorised/ illegal constructions.

G15	Sub Area	Soil Resource Characterization, Land Use Planning and Watershed Management (NESAC)
G15.1	**Understanding shifting cultivation as a driver of LULC change (NESAC)** Shifting cultivation of northeast India is assumed to be major factor of LULC changes. However, a comprehensive study including the spatial changes, climatic and socioeconomic aspects will give more inside to the actual process and its mitigations.	
G15.2	**Terrain Characterization in Hydrological properties of soils (NESAC)**	
G15.3	**Soil Quality Assessment and Monitoring using hyper spectral data (NESAC)**	
G15.4	**Soil Nutrient Management for Precision Agriculture using hyper spectral data (NESAC)**	
G15.5	**Soil carbon sequestration (NESAC)**	
G16	**Sub Area**	**Forest and Environment (NRSC/ NESAC)**
G16.1	**Forestry and ecology- biophysical parameters (NESAC)** • Sub pixel tree cover estimates using multi sensor IRS imagery . • Observations on ecophysiological factors for tropical forests and parameterization ofbiome models for Indian forests. • Feature recognition of tree and canopy objects in IRS pan and multi spectral imagery. • Automated methods for estimation of tree allometry fie scale biomass and standstructure using laser measurements • Wildlife habitat evaluation for different endangered and endemic species • Mapping of forest composition and structure at large scale using UAV • In-situ conservation of timber species for climate resilience and sustainable management using space based & UAV remote sensing • Forest phenology and transition of forest type vis-à-vis climate change in NER • Large scale bamboo resource monitoring and assessment • Protected areas Management and conservation strategies • Annual Forest biomass stock and carbon sequestration	
G16.2	**Mapping at 1:10K or higher and identifiation of Eco-sensitive zones areas for conservation and management (NESAC)** As per MoEF&CC, the study is important for all National Park & Wildlife sanctuaries to conserve, protect and maintain its surrounding areas with some definite objectives.	
G16.3	**Wildlife habitat evaluation for different endangered and endemic species (NESAC)** Endangered species habitat modelling like Golden Languor, Hoolock gibbon, Feral Horses etc needs to be studied for insitu conservation and preservation.	

G16.4	**Mapping of forest composition and structure at large scale using UAV (NESAC)** High resolution images from UAV expected to give more inside on the forest composition and structure. Research required on optimum identifiation of understory and ground flora in a mixed forest type.
G16.5	**In-situ conservation of timber species for climate resilience and sustainable management using space based & UAV remote sensing (NESAC)** Understanding the forest fragmentation, patchiness, segmentation process of Indian forest and site suitability study for conservation of local species for climate resilience.
G16.6	**Forest phenology and transition of forest type vis-à-vis climate change in NER (NESAC)** To understand the process of forest transition and phenology due to long term and shortterm weather parameters.
G16.7	**Large scale bamboo resource monitoring and assessment (NESAC)** North East of India contains 60% of India's total bamboo but very less exercise has been done to make reasonably accurate estimation of total bamboo growing in the region.
G16.8	**Protected areas Management and conservation strategies (NESAC** A holistic approach is utmost required make assessment of current status of the protected areas, their inter-connectivity and specific habitat requirement for the important local wildlife species.
G16.9	**Annual forest biomass stock and carbon sequestration (NESAC)** The study is expected to come out a total estimate of biomass and carbon stock in NER and a model for annual/biannual change detection.
G16.10	**Forest meteorology and ecosystem modeling (NESAC)** Forest plays an important role in governing the energy and mass exchange over aregion. Quantifiation of energy fluxes helps in modeling regional climate. SAC is involved in development of 24 Micrometeorological station network in India which are taking continuous measurements in agriculture and natural vegetation system. There is need to develop land surface process models to quantify the fluxes with reference to surface and atmospheric forcing. Most of the biogeochemical modeling depends on phenological understanding of different vegetation types. There is need to carryout ground experimentation as well as satellite modeling to estimate the phonological matrices of different vegetation types. Such efforts would lead to develop the forest growth simulation models. Modeling NPP using satellite measurements such as INSAT-CCD is an important future thrust area. There is need to develop process based model to quantify the net primary productivity and ecosystem level productivity. Network of annual biomass measurements are needed to validate the NPP products. It is known

	that biomass modeling is limited with optical measurements due to saturation of optical light in denser canopy. Radar based approaches provide improved assessment. It is proposed to develop LIDAR based modeling to account the height of the forest in the estimation of forest biomass. Detection of forest fire and development of fire alarm system based on bioclimatic in dicesis an important research area which will be carried out using INSAT-3D satellite data.
G16.11	**Wetland Ecosystem (NESAC)** Wetlands mapping has been carried out by SAC at 1:50,000 scale for India. There need to develop scheme to map the wetlands using improved and integrated approach involving microwave and optical data. Wetland eutrophication needs to be studied using temporal high resolution optical sensors. Efforts on modeling Methane Emission from Wetlands is an important future thrust area.
G16.12	**Developing a Plant functional types based approach for use in biodiversity monitoring using earth observation data (NRSC)** Biodiversity is commonly measured by 'species richness', which is the number of species in a site or habitat, other measures include the structural and functional attributes. Measuring or characterizing biodiversity is needed for understanding and monitoring the temporal and spatial patterns and changes. A definitive understanding is required for state-of-the-art key 'biodiversity metrics' from space based observation for developing biodiversity monitoring strategies. Since species are not always readily identifible in remotely sensed data, it is useful to have a level of abstraction, plant functional types (PFTs) that can be used with RS datasets. It is necessary to identify parameters and develop a PFT characterization for India's forest vegetation. Satellite derived descriptions on the spatial distribution of plant functional types along with spatial descriptions of vegetation structure and function are likely to be a set of variables that are useful to understand the compositional, structural and functional aspects of biodiversity and its monitoring.
G16.13	**3D point cloud processing and analysis for towards forestry applications (NRSC)** Point clouds from photogrammetric methods, or active and Terrestrial LiDAR system (TLS) provides a fast and precise description of the area in three dimensions. In forestry, point cloud analysis from these sources can be used to for several applications: TLS derived point clouds could be used to detect and delineate trees, or to extract inventory parameters (such DBH, tree heights and crown shape parameters) at individual tree level; the recognition of individual trees from a combination of nadir looking and oblique point clouds is an interesting possibility; biophysical parameters such as Leaf Area Index, non-destructive tree volume estimates can also be realized. The processing methods of point clouds are still in developmental phase and are challenging research topics. Development of algorithms and open source tools for point cloud analysis for forestry applications is a priority area.

H	Area	Water Resources Studies (IIRS)
H1	Sub Area	Hydrological Modelling (IIRS)
H1.1	**Future climate data downscaling and hydrological modelling (IIRS)** Assessment of response from land system, especially hydrological, is essential for planning and management of resources. However, major limiting factor in utilizing future climatic forecast in land surface or hydrological models is the spatial scale mismatch. The present project aims at utilizing different (statistical and/or dynamic) downscaling techniques for improving spatial resolution of climatic inputs and use them in distributed hydrological models for assessment of impact of climate change on water resources. Special focus will be given to Himalayan region.	
H1.2	**Development of Hillslope Hydrological Model for Northwestern Himalaya Ecosystem (IIRS)** It is a well-known fact that hydrological response of hilly watershed is completely different than agricultural watersheds. Most of the popular models used in the field of water resources are originally meant for agricultural watersheds & temperate region, their accuracy degrades drastically in the hilly regions due to non-availability of techniques to simulate the dominant hydrological process occurring in the hilly watershed. The present study aims at development of dedicated hillslope hydrological model that can accommodate the hillslope processes viz. subsurface storm flow, saturation excess flow, overland flow, return flow and pipe storage. Special emphasis will be given on development and testing the model for Northwestern Himalayan region and development of experimental plots, watershed for observations.	
H1.3	**Ensemble Based Hydrologic Prediction and Data Assimilation of Remote Sensing Based Hydrological Parameters in Hydrological Models (IIRS)** The large variability in physical and climate characteristics of Indian river basins cannot be tackled by use of single RS data or single hydrological model with fixed mathematical representation of these hydrological processes (e.g., the prime hydrological processes governing river flow in Himalayan watershed with snow and glacier will be different than those found in arid watershed of Western India or rainforest dominated watersheds of Western Ghats). Similarly, the large amount of RS data and hydro data products (soil moisture, snow cover, water level etc.) which are generated at daily to monthly time scales, are not used in the hydrological models, which mostly uses only RS abased land use land cover (LULC), soil and elevation. Therefore, this project aims to develop ensemble of hydrological models, which can be used in integrated manner to address the major variations in hydrological variables at the watershed/basin scale, as well as develop suitable data assimilation techniques which will utilize in near real time, the RS based land surface and hydrological data products.	
H1.4	**Hydrological and Hydraulic Modeling and RS Data Based Hydrological Parameters Assimilation (IIRS)** The large spatial (cm to km) and temporal (few minutes to days) variation in watershed/ basin scale hydrological parameters and river scale hydraulic parameters cannot be	

	addressed fully by RS based data and data products. Therefore, many academic users and water professional uses hydrological and hydraulic models to simulate watershed/ basin scale hydrological and hydraulic process, and derives, multi-layer soil moisture, snowpack properties, river discharge and flood inundation as output from these models. This project indents to improve parameterization of these hydro models by using latest RS based hydro data in GIS environment, and also develop data assimilation tools which will utilize RS hydro data products in near real time, so as to improve overall simulation accuracy of hydrological/hydraulic models.	
H1.5	**Climate and LULC Change Impact Assessment on Water Resources (IIRS)** India has seen vast expansion of agricultural and industrial activities since 1990s. This expansion has happened in Climate change is likely to increase water demand while shrinking water supplies. The response of catchments towards this shifting balance would challenge water managers to simultaneously meet the needs of growing communities, sensitive ecosystems, farmers, ranchers, energy producers, and manufacturers. In some areas, water shortages will be less of a problem than increases in runoff, flooding, or sea level rise. These effects can reduce the quality of water and can damage the infrastructure that we use to transport and deliver water.	
H2	**Sub Area**	**Hydrometeorological Disasters (IIRS)**
H2.1	**Flood Mapping, Modeling/Forecasting & Risk Assessment using Geospatial Tools (IIRS)** Flooding during the monsoon season is a recurring problem in many parts of India. Different Indian states, especially North West Himalayan (NWH) states (J&K, HP and UK), along with other flood prone areas of India have experienced large number of hydro-meteorological disasters such as high intensity precipitation and subsequent flooding in downstream areas in the last few years. The flood of Bihar-Kosi (2008), Leh (2010), Uttarakhand (2012, 2013), J & K, Srinagar (2014), Parts of H.P. (2015, 2018), Gujarat (2015, 2017), Chennai (2015) and recent Kerala (2018), to name a few major floods. Therefore, this project aims to conduct systematic and scientific study of such flood prone areas, using multi-scale RS, weather forecast and hydro models, vulnerability curves and risk model, to generate timely flood forecast, long term flood vulnerability and flood risk maps in few of these sites.	
H2.2	**Soil Erosion and Sediment Yield Modeling Using Geospatial Tools (IIRS)** Accelerated rate of soil erosion is one side creating problem of loss of nutrient rich, productive top soil from the watershed and on the other, the water bodies and reservoirs are losing their capacity and operation life due to sediment yield from the watershed. The present study aims at developing tools and their implementation for distributed soil erosion and sediment yield modeling at varying using geospatial inputs (remote sensing and GIS). The spatially distributed soil erosion and sediment yield maps will be used watershed prioritization and selection of suitable conservation measures. The associated nutrient lose from the watershed will also be modeled. Spatial emphasis will be given towards developing models and techniques for ungauged catchments.	

H2.3	**Drought Assessment and Monitoring using Remote Sensing (IIRS)** Drought is classified as calamity that can affect economy and society at regional to national extents. Drought is a phenomenon having slow onset, progress and ending. For decades, it has always been a challenge for the decision makers to monitor the arrival and growth of drought and identify its end. Although the drought events are initiated by the deficit in precipitation, simply rainfall as an indicator for assessing severity of drought and its resultant impacts is insufficient. Combination of various reasonable indicators must be included with regular observation for an effective drought assessment system to examine both drought severity and its consequences. The present study aims at utilizing remote sensing data in conjunction with observed data for development techniques for drought assessment and its monitoring sub-monthly level throughout the growing seasons. Emphasis will be given on utilization/integration of satellite based data, model forecast data and ground observations for improving assessment and monitoring accuracy.	
H2.4	**Urban Flood Vulnerability Analysis and Risk Modelling (IIRS)** Reliable and timely prediction of flood extents in urban catchments is a challenging issue. The many cities in India has seen significant urban growth and increase in urban areas, which in turn reduces the open space, reduces the infiltration capacity of an area and increases surface runoff. Various modelling approaches are available ranging from data driven to physically based, from conceptual to detailed 1D-2D modelling. These approaches are then embedded in the wider context of flood risk assessment and disaster management. This project aims to develop an integrated urban flood model that simulates the drainage-network, river-network and 2D mesh-network to obtain flood extents in urban areas. This will help in identification of areas where overflows occur due to insufficient drainage capacity, the resultant surface flooding and/or levee break and finally prepare urban flood vulnerability and risk maps.	
H3	**Sub Area**	**Watershed Hydrology (IIRS)**
H3.1	**Watershed Characterization and Planning using RS-GIS (IIRS)** Watershed characteristics govern the hydrological response of the watershed. In the absence of detailed observed hydrological data characteristics help hydrologist in modeling watershed processes to estimate runoff, soil loss, etc. Traditionally topographical maps provided by Survey of India were used for delineation of watersheds and mapping of its resources, however the watershed resources change with time (e.g. land used land cover) their-by changing hydrological response of the watershed and the scale of top-maps govern the accuracy of watershed delineation & characterization. This projects aims at utilizing remote sensing data and products (multi-spectral images, high resolution images, DEM’s) for characterization of watersheds and its inventory mapping. The project also aims at assessment of DEM accuracy using field based DGPS survey, assessment of DEM scale impact on characterization of watersheds, development of guidelines for deciding stream generation threshold for different terrains and prioritization of ungauged watersheds based on RS&GIS derived characteristic.	

<table>
<tr><td>H3.2</td><td colspan="2">Site Suitability Analysis and Environmental Impact Assessment (EIA) for Water Resources Projects (IIRS)
Selection of best suitable sites for any water resources (WR) project (ranging from water harvesting structures in small watersheds to larger dams for irrigation & hydro-power) is a complex process. Many ecosystem variables play vital role in successful implementation of water resources projects. Hence, consideration of these ecosystem variables during selection of suitable sites for water resources projects (soil & water harvesting structures, river valley, flood control, irrigation, river interlinking and hydro-power projects) are essential. The present project aims at integrating RS & GIS based inputs for pre-feasibility analysis and selecting suitable sites for WR projects. The detailed EIA analysis of these projects will be carried out using geospatial and modeling based inputs.</td></tr>
<tr><td>H4</td><td>Sub Area</td><td>Hydrological Parameter Retrieval (IIRS)</td></tr>
<tr><td>H4.1</td><td colspan="2">Hydrological Parameters Retrieval using Remote Sensing (IIRS)
Each of the hydrological parameter plays an important role in our planet's water and energy balance system. Traditional techniques of measuring these parameters lacks in spatial and/or temporal coverage. Remote sensing has proven its capability in retrieval of many terrestrial and atmospheric parameters with high spatial and temporal resolution. Hence, this project aims towards development of algorithms and techniques for operational retrieval of hydrological parameter (viz. Evapotranspiration, Soil Moisture, Surface Runoff, change in Terrestrial Water Storage, snow depth, snow density, snow water equivalent, etc.) using remote sensing data. The calibration of these algorithms will be done using ground observed data and validated methodology will be made operational for continuous retrieval of these parameters. The focus will be towards utilizing Indian remote sensing data.</td></tr>
<tr><td>H4.2</td><td colspan="2">Estimation of River Discharge using Remote Sensing and GIS (IIRS)
Observed discharge in the streams is an essential inputs for all the hydrological studies and water management activities. However, due to limitations (financial, technical, etc.) number of ground observation points are limited in Indian river basins. Advancements in remote sensing and data analysis techniques have enabled the estimation of water level and river discharge using satellite observations. This project aims at utilizing satellite based multi-sensor observations (Altimeter, Microwave, etc.) for water level and discharge estimation. The focus will be on development and testing of methodology/ algorithms for estimation of water level and discharge using multi-sensor approach.</td></tr>
<tr><td>H4.3</td><td colspan="2">Space Based Precipitation Estimation (IIRS)
Precipitation is the most important element of the local and regional hydrologic cycle. Accurate estimation of precipitation helps in managing the supply and demand of sustainable water resources. Precipitation is also a critical input variable for hydrologic modeling and climate studies which are common tools to assess water-related risks, such as floods/droughts and monitor water resources. Therefore, availability and accurate estimation of precipitation is crucial for demand management, flood forecasting</td></tr>
</table>

	and drought preparedness. A number of different algorithms can be used to estimate precipitation amounts from remote sensing data. Research in the fields of quantitative precipitation forecasting is still in progress (for better understanding of the spatial and temporal distribution of precipitation which is critical to climatic, hydrologic, and ecological applications).
H4.4	**Reservoir Sedimentation Assessment using Remote Sensing and GIS (IIRS)** Reservoirs are generally constructed with multiple objectives e.g. water supply, irrigation, discharge regulation, power generation and flood control. However, every year reservoirs lose considerable amount of its storage capacity due to sedimentation. Assessment of this loss of capacity must be quantified at regular interval to update the water distribution/ utilization plans and flood management/response guidelines. This study aims at assessment of reservoir sedimentation using remote sensing data, further the area-elevation-capacity curves will be updated and optimal water utilization planes will be suggested for each reservoir operations. The focus will be on minimizing the dependence on ground observations by utilizing multi-sensor approach (optical, SAR, Altimeter, etc.)
H4.5	**Improving Mapping and Monitoring of Surface Water Body, Snow, Glaciers, Sea Ice and Ice Sheets using RS-GIS (IIRS)** The inland surface water consist of lakes/reservoirs, rivers and wetlands, and frozen part of water consists of seasonal snow cover, river ice and sea-ice, glaciers, polar ice sheets. The inland water is crucial for sustenance of mankind and overall health of environment, whereas inland snow and glaciers provides significant melt water during lean period for catchments, and polar sea-ice and ice sheet provides an important feedback to Planet Earth's climate and energy cycles. The regular mapping, monitoring and quantification of these water features can be at different spatio-temporal scales using remote sensing. This project will address the dynamics of water bodies (in terms of quantity and extent), snow (snow cover and water equivalent), glaciers (extent and velocity) sea-ice (extent and thickness) and ice sheets (extent and velocity) using existing and new Earth Observations (EO) sensors and retrieval algorithms.
H4.6	**Microwave Remote Sensing for Water Resources Studies (IIRS)** (SAR, altimeters, radiometer and scatterometer for snow/glacier physical properties, ice sheet & sea ice dynamics, water level and river flow estimation) The Microwave Remote Sensing (MW-RS) which operates in microwave region of electromagnetic spectrum from 1cm to 1m wavelengths, offers an unique opportunity to quantify various bio-geo physical parameters of Earth surface/sub-surface with variety of MW sensors such as synthetic aperture radar's, SAR, altimeters, radiometers and scatterometer's working in various MW frequencies and polarizations. This project aims to improve existing methods and develop new operational algorithms to retrieve hydrology and water related parameters using MW-RS such as snow physical parameters (snow wetness, depth, density and SWE), glacier/ice sheet velocity and elevation, water level and discharge and sea ice thickness. The derived hydro-parameters will serve as important input for hydrological modelers and water resources managers.

H4.7	**Hyperspectral Remote Sensing Application in Water Resources (IIRS)** Application of image spectroscopy in mapping and retrieval of water resources parameters e.g. snow grain size, type of snow (wet, dry), type of debris on the glacier, glacier facies, water quality, soil moisture and water stress are evolving research areas. ISRO has planned to launch space based Hyperspectral sensors of varying spatial and spectral resolution. This project aims at developing techniques for mapping and retrieval of water resources parameters using space based and aerial Hyperspectral data. Special emphasis will be given on generation of spectral library of various water resources parameters using field and laboratory observations.	
H5	**Sub Area**	**Irrigation Water Management (IIRS)**
H5.1	**Irrigation Water Management using Geospatial Tools (IIRS)** Irrigated agricultural gets the major share of fresh water (around 82%) annually. However, its overall operational efficiency is as low as 35%. The future sustainability of water sector hinges on increase of water use efficiency by irrigation sector up to 50-65% by 2050. Remote sensing hold tremendous in assisting irrigation section to bring this improvement. Present project aims at utilizing remote sensing data irrigation water management, which include infrastructure mapping and monitoring, IP assessment, spatial estimation of crop water requirement, performance evaluation of irrigation projects, water distribution assessment, conjunctive and deficit water use modeling, etc. Special emphasis will be given on developing standard method which can be replicated at other irrigation projects.	
H6	**Sub Area**	**Groundwater Water Modelling (IIRS)**
H6.1	**Ground Water Modelling and Assessment (IIRS)** Ground water is the primary source of fresh water. Traditionally numerical method based ground water models have been used to solve ground water assessment and development issues. These models use three dimensional ground water flow equations to simulate ground water flow under different hydrological stress scenarios and can be valuable predictive tools for management of ground water resources. Major applications of ground water modelling includes surface water-ground water interaction, sub-surface waterlogging assessment, seawater intrusion in coastal aquifers, prediction of ground water dynamics and impacts of sand mining on ground water. Integration of geospatial tools and ground water modeling tools in an upcoming topic. The present study aims at development of methodology to integrate geospatial inputs in groundwater modelling framework. The regional ground water availability will be assessed using modeling approach as well as remote sensing based analysis (satellite based gravity observations; GRACE-FO).	
H7	**Sub Area**	**Planetary Hydrology(IIRS)**
H7.1	**Planetary Water Ice and Hydrological Cycle Studies (IIRS)** The first planetary mission of India, Chandrayaan-1 confirmed the presence of water ice at polar and other regions of Earth's Moon. In the last 50 years many space based probes and RS missions have explored planets, moons and asteroid of our solar system,	

	along with space telescopes based search for Earth like planetary systems. In all these mission, the presence of water-ice, liquid water or historical or present sign of hydro-geological cycle are of great scientific interest, as this water can be used fuel and basic life sustaining resources for any future manned space exploration or colonization missions to these extra-terrestrial space objects. This project aims to develop RS (using optical, hyperspectral, MW and LIDARs/GPRs etc.) and modeling based techniques for identification, quantification of water/ice on planetary surface/sub-surfaces and use process based and customized hydrological models to simulate historic and present water cycle components.	
I	**Area**	**Geoinformatics (IIRS/NRSC)**
I1	**Sub Area**	**Geospatial Technology (IIRS)**
I1.1	**Spatial Databases (IIRS)** Several new types of location based data is being actively used in geospatial domain (UAV, sensor & equipment logging, video, IoT, and social media) apart from the conventional ones (satellite, aerial, GNSS, and weather). These require different types of ingestion: batch wise, streaming or event driven and can be of several formats (compressible/non-compressible, regular/sparse). Current research in this area deals with how best of make use of this location based data for its intended end use (real-time, in-memory, cache, and graph query based databases).	
I1.2	**Geodata Modeling (IIRS)** To complement legacy geospatial systems, loose coupling of new algorithms and technologies is the current demand in the geospatial landscape. Advances in the fields of machine learning and artificial intelligence are rapidly finding its applications in the geospatial domain. There is urgent need to adopt these techniques for better understanding of Earth processes.	
I1.3	**Spatial Data Mining & Multi- Criteria Decision Making (IIRS)** The geospatial practice has traditionally gained a lot from techniques such as knowledge data discovery and information mining. However, its potential has yet to be fully utilized in modern scenario of cloud based, distributed databases for elastic scale and real-time analytics.	
I1.4	**Open Source GIS (IIRS)** There has been spectacular growth and adoption of open source GIS primarily fuelled by secure & scalable on commodity hardware and easy to learn high level programming languages such as Python. Capacity building, documentation, quality assurance and stability are areas where more work is required. From the systems approach view-point, much research needs to be carried out to improve user experience and participation.	
I1.5	**Web Technology and WebGIS (IIRS)** The ecosystem of web technologies is exploding, and the geospatial component is yet to catch up. There are limited instances where latest frameworks such as Angular and Vue	

	are being employed to develop web interfaces. Also processing on the web / on-the-fly is being looked at with great eagerness. State of the art research with special emphasis on solving real world problems is the need of the hour.
I1.6	**Big Geospatial Data Analysis (IIRS)** The Big Geospatial Data architectural landscape is evolving rapidly. In the deluge of information, several technologies are being experimented with for deriving insights and inferences such as in-memory distributed processing (Spark), ultra-latency (Ignite), HDFS based data handling & storage (HBase, Hive). Computer science and geospatial technology need to collaborate to provide relevant, timely and reliable geospatial solutions.
I1.7	**Geospatial Visualisation (IIRS)** The final consumption of geospatial technology is through demand-driven reporting. Traditional methods (Maps, Reports, and Dashboards) are now giving way to newer interaction methods (Bots, API, Alerts). Out of the box ways of conveying geospatial information is where human computer interaction and information exchange should be focussing on.
I1.8	**Geostatistics (IIRS)** The core and indispensable component of any geospatial system is in its strong mathematical foundation. Advances in geostatistics need to be tested and validated in real world situations. This will yield new tools and methods for the collection, storage and processing of geospatial data and pioneer new applications of geospatial data to societal problems.
I1.9	**Characterizing Surface Water from Space with Microwave Remote Sensing (NRSC)** Accurate spatial representation of terrestrial surface water is of critical importance for management and conservation of biodiversity and other ecosystem services associated with freshwater. Furthermore, surface water maps representing dynamic characteristics of inundated areas are also valuable for the development of wetland inventories and to assess the role of wetlands as major natural sources of methane to the atmosphere. This research shall focus on the capabilities of satellite microwave remote sensing techniques to map hydrodynamic ecosystems and investigate related Earth-science questions. Regional-scale assessments shall be addressed with time-series SAR imagery across a variety of hydrodynamic regions that are conventionally very challenging to map.
I1.10	**Discrimination of Irrigated and Rain-fed crop areas using multi-spectral, weather and field data derived indices (NRSC)** This research is intended to develop an adaptive and dynamic technique to map irrigated and un-irrigated areas using multi-spectral, multi-temporal satellite data combined with terrain, weather parameters. It is required to develop an integrated approach combining satellite data derived multi-spectral indices with hydrological model derivatives, terrain & weather parameters to discriminate irrigated and un-irrigated/rain-fed crop areas. It is also required to estimate annual irrigation utilisation in major/medium command areas.

	The study has significant linkages to national development programmes such as PMKSY, NAPCC (NWM) and CADWM, etc. where in efforts are towards augmenting irrigation utilization with increased water use efficiency. Further, reliable information irrigated area helps in quantification of surface and ground water demand and utilization, water distribution and irrigation performance assessment. NRSC carried previous studies on irrigation command inventory, performance assessment & monitoring and potential utilization studies. The reserach would provide the development of methodology exploiting the multi-dimensional data sets from satellite and other sources for estimation of irrigated and un-irrigated areas.	
I2	**Sub Area**	**Oceanic Sciences and Climate (NRSC)**
I2.1	**Retrieval of IPAR & PAR film OCM-2 irregular basis and validation with measurements for different regions of tropical, sub tropical and Polar areas (NRSC)** Ocean colour remote sensing is a useful tool and it provides quantitative informationof seawater constituents on synoptic scale. ISRO's ocean colour missions namely OCEANSAT-1 and OCEANSAT-2 OCM have been extensively used for various societal and scientific applications like Potential Fishing Zone identification, ocean primaryproductivity estimation, algal bloom detection and studying the coastal processes etc. Photosynthetically available radiation (PAR) is one of the key parameter along with spatially invariant and uniform aerosol optical depth under clear sky condition has been used for estimating the ocean primary productivity models using OCM data. Thus, modeling PAR from OCM under variable aerosol loading and cloud conditionsis a desirable input parameter to estimate ocean primary production from OCM moreaccurately. The Instantaneous Photosynthetically Available Radiation (IPAR) is used as one of the input for estimating the PAR (400-700 nm) in some of the models.	
I2.2	**Retrieval of sea surface salinity from satellite data and validation (NRSC)** Sea Surface Salinity (SSS) is an essential climate variable. It is a key component of the water cycle, as a tracer of precipitation and evaporation, river outflow and ice melt/freeze. It is a key driver of the oceanic circulation through its role on the ocean density.It is also a critical parameter for understanding the variability of the ocean carbonfluxes, providing information on water masses and of their chemical properties. Salinity dominates seawater density and directly affects physical and biochemical processes.Having a reliable retrieval model is essential to provide frequent and accurate seasurface salinity (SSS) data for marine research. Remote-sensing techniques provide alternatives for SSS data retrieval with its advantages of wide area surveys and real-time monitoring. The past, present and the future ocean colour missions of ISRO can be used for addressing some of the key climate change issues like ocean acidification and carbon dynamics along with it's contemporary sensors like SST and altimeters. Hence, there is a need to develop the new algorithms or to evaluate and fine tune the SSS algorithms to address the above issues. 1. Ocean Surface salinity is one of the Essential Climate Variable (ECV) 2. L-Band Passive Microwave radiometers such as SMOS, Aquarius and SMAP have demonstrated the capability to retrieve salinity from brightness temperature data	

	3. Development of algorithms for retrieval of salinity using passive microwave radiativetransfer models 4. Validation of the retrieved salinity using Moored buoy, RAMA buoy and other in-situobservations.
I2.3	**Ocean surface characterization using SARAL Altika Data (NRSC)** A regional tidal model is formulated for the Indian coastal domain based on the barotropic mode of the Princeton Ocean Model (POM). The simulated tidal levels are used in combination with tide gauge measurements and global tidal solutions based on FES2012 for assessing tidal corrections associated with SARAL-ALTIKA along-track sea level measurements.The POM in its 3D mode is also implemented for simulating seasonal mean flow pattern in the GK and its surrounding coastal ocean. This modeling study is now extended to use SARAL-ALTIKA along track sea level data in order to constrain thes imulation for better understanding coastal ocean processes around India.
I2.4	**Meso-scale ocean eddy scale analysis (NRSC)** The term Eddy refers to rotational motion of water mass. The eddies with space scalesof 50-500 km and time scales of 10-100 days are called meso-scale eddies. They playa significant role in transporting water mass, heat and nutrients. Upwelling areas areassociated with cold core eddies, on the other hand downwelling is associated with warmcore eddies. An Eddy tracking method using satellite measured Sea Level data has been implemented following Chelton et al., 2011. Using this, identifiation of the eddy type (Cyclonic or Anti-Cyclonic) and their paths of the movement have been established in theTropical Indian Ocean. The characterization has been done by computing amplitude of eddies, number of Cyclonic and Anti-Cyclonic eddies formed and Vorticity etc.
I2.5	**Ocean wind, wave and current assessment in coastal waters (NRSC)** 1. Satellite Microwave instruments such as Scatterometers, Radiometers and Altimeters provide ocean surface wind, wave and current measurements which needs to be intercompared especially in the coastal regions. 2. Geostrophic and Ekman components of the currents can be estimated from altimeter derived SLA and Scatterometer wind data. 3. Seasonal and interannual variability of satellite derived wind,wave and currents data to understand the major governing processes for their variability. 4. Interaction of wind-wave-current in the coastal region leads to a complex dynamics which need through investigation for their individual contribution.
I2.6	**Satellite altimeter waveform analysis to improve geophysical parameters retrieval (NRSC)** 1. Altimeters are active microwave instruments which provide Sealevel, Wind and signifiant wave information through the measured waveform characterstics. 2. Altimeter waveforms are nothing but the variation of received power with respect totime. 3. Magnitude of the returned waveform power gives you the information of surface windspeed.

	4. Slope of the wave form gives the significant wave height information. 5. Waveform shape and characteristics differ for different targets such as ocean, land and Ice for which different models are needed to understand retrieve geophysical parameters from them.
I2.7	**Satellite altimeter data assimilation in ocean models (NRSC)** 1. Assimilation of satellite derived temp, salinity and sealevel is needed to improve the accuracy ocean model simulations of temp, salinity and currents and their vertical profiles. 2. Altimeters routinely provide information regarding sealevel, wind and wave information. 3. Altimeter derived sealevel can be assimilated using variational techniques such as 3Dvar and 4D var in ocean circulation models such as MOM, ROMS, MITGCM etc. 4. Altimeter derived significant wave height can be assimilated in ocean wave models suchas SWAN, WAVEWATCH etc., for improved prediction of waves along the Indian coasts
I2.8	**Derivation of Ocean surface currents utilizing data from SARAL AltiKa and OSCAT.Combining geostrophic currents from SSHA (from Altimeters) and wind drivencurrents from wind velocities (from Scatterometer), the ocean surface currents can be obtained (NRSC)** The scope of the current observations can be seen in the navigation and optimization of shipping routes, dispersion and drift of pollutants, particularly, algal blooms and oil spills, besides their use in tracing mass and heat distribution across the ocean boundaries. The ocean surface currents of the Global Ocean are estimated combining Ekman Surface Current (ESC) and Surface Geostrophic current (SGC). The ESC is derived from the ocean surface wind fields of Oceansat-2 Scatterometer (OSCAT) data products.
I2.9	**Ocean modelling (NRSC)** Investigation of the thermal inertia of the Indian Ocean. Ocean models can be used to investigate the thermodynamics of the oceans with emphasis on long term thermal evolution in the oceans. This would help in estimating the thermal inertia of the ocean, an indicator of effects on climate change.
I2.10	**Development of bio-optical algorithms in CASE-2 waters (NRSC)** With the availability of OCM-1 and 2 and for the future OCM-3 with more spectral bands a programme has been planned for reprocessing of ocean colour data sets for the development of ECV like chlorophyll-a, PAR and diffusive attenuation coefficient in coastal waters. Using large sets of in-situ underwater radiation measurements and associated bio-physical measurements coastal bio-optical algorithms has to be developed. Using this algorithm reprocessing of OCM data is to be planned.
I2.11	**Response of coastal system due to climatic change and its long and short term implications (NRSC)** Coastal ecosystems are key ecosystems considering their importance in providing goods and services. In addition to the aesthetic and recreational value provided by the

	coastal ecosystems, economic benefits provided by them in supporting human livelihood via food and materials, nutrient cycling, waste processing and other essential goods and services are quite important. Efficient monitoring of these ecosystems is critically important by utilizing advanced remote sensing and long-term climatic records for assessing climate change impacts and developing adaptation and mitigation strategies for effective restoration and conservation in Indian coastal zone.
I2.12	**Satellite based retrieval of geo-physical parameters for coastal processes assessment (NRSC)** 1. Coastal processes are more complex due to the interaction of bathymetry, wave, tides and land-sea breeze etc., 2. Satellite sensors such as Altimeter, Scatterometer, Radiometer and SAR etc., provides information regarding geo-physical variables. 3. Algorithms developed using radiative transfer models and statistical methods are needed to retrieve geo-physical parameters from these satellite measurements.
I2.13	**Eco-system change direction and responses due to coastal change using high resolution IRS-data sets (NRSC)** Understanding how the coastal ecosystems are changing due to changing coast is an area of importance in India due to natural as well as anthropogenic activities in coastal areas. Remote sensing can take an important role in quantifying and monitoring these changes at local to regional scale. The new high resolution remote sensing datasets from IRS series of satellites can take an important role in studying the changes happening in coastal ecosystems in India.
I2.14	**In-situ studies of phytoplankton cultures to understand changes in the absorption spectrum in response to different environment variables for developing methodologies for satellite retrieval (NRSC)** Retrieval of spectrum information of dominant phytoplankton groups from satellite oceancolour data especially for case 2 waters is complex and requires good amount of insitu studies from pure cultures to understand how this varies due to age of the culture, between different groups and also with nutrient manipulations. In recent years several methodologies have been developed to extract spectrum information from satellite ocean colour data however this requires important validation to make such techniques operational in the era of OCM.
I2.15	**Study of relationships between oxygen and C13 based primary productivity forIndian coastal waters to evaluate photosynthesis quotient for developing satellite based primary productivity model (NRSC)** Changes in oxygen concentrations over time can be used to estimate the rates of photosynthesis and therefore primary productivity. Carbon assimilation rates based on oxygen evolution often assumes a ratio of one moles of O2 produced for every moles of CO2 assimilation however this number is highly variable in the environment. Studie scan be undertaken to compare this classical techniques with modern C13 based primary productivity to understand the variability which can be used to develop satellite based PP model.

I2.16	**Measurement of particulate organic and particulate inorganic carbon in coastal and open ocean waters of northern Indian Ocean for development of satellite based algorithm (NRSC)** Particulate organic and inorganic (comprised of mainly cocolithophores) are important component of any oceanic system which influence the marine carbon cycle. Remote sensing measurements are now being used to characterise these component in basin scale due to its large spatial coverage however lack proper validation due less in-situ measurement. Both beam attenuation and in situ POC/PIC have been used to develop empirical relationship as early as 1988. Latest research suggests good relationship between oceanic POC concentrations vs. Rrs (443)/ Rrs (555). Opportunities are available for measuring POC/PIC by chemical or physical method (CTD, Beam Attenuation) for development and validation of satellite algorithm for Northern Indian Ocean.
I2.17	**Development of methodologies (statistical and numerical methods) for the generation of time series/ long period data base from the OCM sensors (Chl, PAR and AOT) over the Northern Indian Ocean in association with NRSC (NRSC)** ISRO had launched OCM-1 & OCM-2 and going to launch OCM-3 in near future for studying ocean color properties of Northern Indian Ocean such as Chlorophyll. To effectively use this data to study ocean color and climate change it is required to make long time series data combining OCM-1 and OCM-2 data and in future OCM-3. To effectively do this we need to reprocess data from these two sensors to bring them on a common platform to make them inter comparable and compatible. Work already initiated in this direction by developing methodologies for effectively inter comparing data from these satellites with that of Sea WiFS & MODIS (Two of NASA's Ocean color sensors with stable data and accuracy).
I2.18	**Development of methodologies for generation of near real time ocean surface currents using satellite derived winds, Sea Surface heights/ anomaly, SST and salinity for the Indian ocean (NRSC)** 1 At present there is no satellite technology which can provide ocean surface currents inreal time. 2. Satellite Altimeters only provide the information regarding the geostrophic currents. 3. Ekman component of the currents can be derived from scatterometer measurements. 4. Development of improved methodologies is needed to synergistically use different satellite derived parameters such as SST, Salinity, Sealevel and Winds to generate ocean surface currents in realtime such as OSCAR, GlobCurrent products.
I2.19	**Development of bio-optical algorithms in CASE-II waters using Inherent optical parameters and propagation to the top of atmosphere using appropriate radiative transfer models (NRSC)** ISRO had launched OCM-1 & OCM-2 to study chlorophyll and bio optical properties of North Indian Ocean, and going to launch OCM-3 soon. It is very important to have accurate algorithm to retrieve Geophysical products to effective utilization of satellites.

	Retrieving Ocean color properties from Case II waters (coastal waters) is very complex as these waters are highly influenced by coastal discharges and human influence etc. We are measuring Inherent & Apparent optical properties of coastal water column around India and developing these algorithms using the field data and radiative transfer modelling.
I2.20	**Use of satellite observation in ocean general circulation model for understanding regional circulation and heat budget in the Indian Ocean (NRSC)** 1. Assimilation of satellite derived temp, salinity and sealevel is needed to improve the accuracy ocean model simulations of temp, salinity and currents and their vertical profiles. 2. Altimeters routinely provide information regarding sealevel, wind and wave information. 3. IR and Microwave radiometers provide SST information which can be assimilated in ocean circulation model for understanding regional circulation and heat budget in the Indian Ocean. 4. Altimeter derived sealevel can be assimilated using variational techniques such as 3 Dvar and 4D var in ocean circulation models such as MOM, ROMS, MITGCM etc. 5. Altimeter derived signifiant wave height can be assimilated in ocean wavemodels such as SWAN, WAVE WATCH etc., for improved prediction of waves along the Indian coasts.
I2.21	**Development of eddy-resolving meso scale ocean model and potential fishing zone predictability (NRSC)** Ocean eddies are important features, which play a dominant role in ocean dynamics,nutrient transportation and modifiation of circulation patterns. The satellite observations have revealed their distribution and temporal variability. Modelling such eddies is underway using a Regional Ocean Modelling System (ROMS). The model has been setup and integrated with Winds, Temperature, Salinity and Surface heat fluxes data for simulation of eddies and regional circulation in the Indian Ocean.
I2.22	**Assimilation of satellite observation in Ocean general circulation model to reconstruct ocean state parameters (NRSC)** 1. Assimilation of satellite derived temp, salinity and sealevel is needed to improve the accuracy ocean model simulations of temp, salinity and currents and their vertical profiles. 2. Altimeters routinely provide information regarding sealevel, wind and wave information. 3. Altimeter derived sealevel can be assimilated using variational techniques such as 3D var and 4D var in ocean circulation models such as MOM, ROMS, MITGCM etc. 4. Altimeter derived significant wave height can be assimilated in ocean wavemodels such as SWAN, WAVEWATCH etc., for improved prediction of waves along the Indian coasts.

I2.23	**Development of real time coastal ocean analysis system through ocean general circulation model coupled with ocean Biogeochemical flux model (NRSC)** Tide and current interaction are very significant in the coastal ocean regions which are being neglected in most of the coastal circulation model studies. India has vast Exclusive Economic Zone (EEZ) with tremendous influence by anthropogenic activities including industrial and navigation activities. Coastal ecosystem is under stress. It is essential to monitor and maintain the health of the marine flora and fauna. In this regard, satellite observations combining with ocean general circulation model to be used for understanding regional circulation and ecosystem dynamics. 1. Establishing regional coastal circulation model driven by global ocean climate model analysis at the open boundaries along with tides and atmospheric forcing. 2. Establishment of Ocean Ecosystem Model and satellite data integration for monitoring health of the marine ecosystem in Indian EEZ. 3. Latest Ocean Circulation Models such as MOM5 have capabilities to simulate Ocean Circulation parameters including biogeochemical models available in their native confiuration. 4. Biogeochemical Flux Model can simulate the biogeochemical processes for improved understanding of marine ecosystem variability.	
I2.24	**Use of satellite observation for modeling and assessing regional carbon cycle for the Indian region (NRSC)** Carbon dioxide is a major greenhouse gas and various scientific investigations have revealed that increase in the concentration of CO2 is an important contributor to climate change. Understanding the carbon (C) sink or source potential of ecosystems and their variability in relation to climatic drivers are critical to elucidate and quantify climate-carbon feedbacks. Using satellite data inputs of NDVI, land-use-land-cover, CASA Terrestrial ecosystem model was used to simulate the terrestrial carbon budget over India for the period 1981-2016. GEOS-Chem Model was implemented to understand the atmospheric CO2 variability over India.	
I2.25	**Simulation of methane distribution and visualization in Mars atmosphere (NRSC)** Indian Mars mission will be carrying MSM (Methane Sensor for Mars) to map the methane sources and deriving concentration in Mars atmosphere by ppb accuracy. Simulations are planned using other Mars orbiter data like MGS etc. considering the specifiation of Indian MSM for visualization and understanding the data. This simulation is to be carried jointly with the help of Principal Investigator of MSM.	
J	**Area**	**Aerial Remote Sensing (NRSC/ NESAC)**
J1	**Sub Area**	**Automatic feature extraction from aerial images (NRSC)**
J1.1	**Automatic feature extraction from aerial images (NRSC)** The objective of this study would be to explore the possibilities of automatic feature extraction through the fusion of high resolution aerial digital camera images and DSM	

	either from Lidar technology or from photogrammetry. As per the literature, the fusion of DSM from Lidar scanners and image data from digital cameras showed promising results. The data from these two sources is complementary to each other and hence make a great combination.	
J1.2	**Local geoid estimation from multi-satellite data / models and /or terrestrial data (NRSC)** Satellite-borne gravimetric models have a global range, so regionally the accuracy is not satisfying when precise information is needed, even though using satellite gravimetric data is cost effective and quicker. A regional geoid model can be generated with combination of the satellite gravity data. The aim is to improve existing regional gravity field model for greater accuracy and higher resolution using satellite gravity data and from gravity missions such as GRACE FO, GOCE, GRACE, CHAMP and SLR data. Terrestrial gravity data and DT leveling data may be incorporated into the model wherever it is available. The model can be improved by attributing optimal weights to the terrestrial, airborne and satellite data based on the frequency and accuracy of the survey as well as local topographic conditions.	
J2	**Sub Area**	**Segmentation of Aerial / satellite data (NRSC/NESAC)**
J2.1	Segmentation becomes more important with increasing spatial resolution of imagery.Texture in high-resolution aerial and high resolution satellite images requires substantial amendment in the conventional segmentation algorithms. The potential applications of this segmentation process are (1) Automatic 3D model generation (2) automatic DEM generation from DSM (3) Automation in Quality Checking of vector maps and many more.	
J3	**Sub Area**	**Aerial Data Compression (NRSC)**
J3.1	**Development and incorporation of lossless compression algorithm(s)/ technique(s) (NRSC)** Development and incorporation of lossless compression algorithm(s)/ technique(s) for better handling, archival, effective usage and time critical data processing of aerial analog and digital data. The compression algorithm must meet the requirement of aerial compression system for storage and operation time. The compression techniques must reduce operation memory, and accelerate the processing speed without any data loss.	
J4	**Sub Area**	**Radiometric Calibration LiDAR Waveform (NRSC)**
J4.1	**Radiometric calibration (NRSC)** Radiometric calibration refers to the statistical process of deriving physically well defined radiometric quantities from the sensor's raw measurements. Waveform LiDAR system provides detail information about the backscattering properties of the observed targets by recording complete return signal. Even though waveform measurements have high content	

	of information, data acquired during different flight campaigns cannot be directly compared without a proper radiometric calibration. Model waveform Radiometric calibration requires formulation of LiDAR equation. This model may be useful for the retrieval of higher level data products.	
J5	**Sub Area**	**Aerial Remote Sensing using UAV (NESAC)**
J5.1	**Development of long range communication system for UAVs (NESAC)** Most of the commercial UAVs available today come with a communication range of 5-10kms in clear line of sight. However for some applications like medicine delivery in remote/disaster areas, river mapping/monitoring applications require long communication range 40-50 kms for real time transfer of telemetry and data. A low cost, low weight and range communication system will improve the capabilities of existing UAV systems.	
J5.2	**Improvements in battery capacity used in UAVs (NESAC)** Lithium Polymer batteries are being used as source of electric power in the present UAVsystems which gives a maximum flight endurance up to 1 hr with different combinations. It is required to develop low weight high capacity batteries to further improve upon the flight endurance of UAVs using different materials and techniques.	
J5.3	**Development of data processing software for high volume UAV data processing (NESAC)** Processing of UAV data is a unique challenge due to its large volume. Few of the commercial softwares used for generation of complete data products such as DEM/DTM, 3D point cloud, contour maps etc are very costly and require high end systems. There is a need for developing in house data processing software using open source tools with end to end data processing capabilities which do not require very high end computers.	
J5.4	**Real time UAV data processing for disaster monitoring applications (NESAC)** Data acquired from UAV surveys are downloaded after the survey and processed in the lab. Due to the high volume of data, the processing takes lot of time and real time quantitative analysis from the data cannot be made. A real time data processing technique where data is downloaded to ground station in real time as the flight progresses and put into software where maps/models are generated simultaneously and automatically will be helpful for quick disaster response and assessment.	
K	**Area**	**Earth and Climate Sciences (NRSC/NESAC)**
K1	**Sub Area**	**Atmosphere and Climate Sciences (NRSC/NESAC)**
K1.1	**Regional monitoring of Trace and Green house gases (NRSC/NESAC)** Trace and green house gases in earth atmosphere are important as they affect both airquality and radiation balance of the earth atmosphere system. Anthropogenic activities influence abundance of many of these gases in the atmosphere. In view of this, it is necessary to have continuous monitoring of these gases and changes in their concentrations over different regions to understand anthropogenic impacts on global climate change.	

K1.2	**Retrieval of green house gases using satellite data (NRSC)** By realizing the impacts of trace and greenhouse gases in air quality and radiation budget, it is necessary to have measurements of these gases with sufficient spatial coverage. Satellite remote sensing enables retrieval of trace and greenhouse gases over large regions to estimate their effects on earth atmosphere and contribution in climate change. Spatial distribution of abundance of these gases can be used to identify their major source regions and also to estimate long term trends in their concentration.
K1.3	**Transport of chemical constituents of atmosphere using WRF chemical transfer modelling (NRSC /NESAC)** Atmospheric dynamics lead to dispersion and transport of chemical constituents inatmosphere from their source regions to distant locations. In order to understand effects of chemical constituents in earth atmosphere, their transport from source regions to other locations has to be examined. Transport of chemical constituents in atmosphere can be investigated in detail using models such as WRF. Identifiation of trace gases and understanding their chemistry mechanism using available satellite and ground data. Study of trace gases dispersion using WRF model. Study of chemical mechanism between the species using WRF-Chem model. Generate alert mechanism on pollutant concentration and their transport.
K1.4	**Study of boundary layer dynamics (NRSC/NESAC)** Atmospheric Boundary Layer (ABL) is the lowest part of troposphere, which is directly influenced by earth surface and responds to surface forcing with a time scale of an houror less. Structure of ABL and associated dynamics are important to understand weather, climate, pollution dispersion and exchange processes between surface and atmosphere. The lower layer of the atmosphere, the boundary layer, acts as a conduit for exchange of energy and mass between the surface and the atmosphere. Measurements of the vertical profile of meteorological parameters are essential to study temporal variations in the boundary layer, especially in the lower layers. As the boundary layer varies greatly depending upon the surface characteristics, extensive sampling over different regions is required to accurately represent the boundary layer in numerical models. The 32m meteorological tower at NRSC, Shadnagar is an example of a boundary layer measurement system at a semi-arid region.
K1.5	**Aerosol characterization and its impact on solar radiation (NRSC/ NESAC)** Atmospheric aerosols, one of the major climate forcing agents, affect earth atmosphere radiation balance through aerosol radiation interactions and aerosol cloud interactions. Despite the efforts being carried out for past few decades, atmospheric aerosol remains one of the major sources of uncertainty in climate forcing estimates. Better understanding of aerosol impacts on weather and climate demands adequate incorporation of aerosol parameters in climate models, which needs accurate measurements of aerosol characteristics.

K1.6	**Surface energy budgeting using remote sensing (NRSC/NESAC)** Surface energy budgeting assumes importance as the surface energy balance is one of the major factors affecting hydrostatic stability and mixing of atmospheric constituents such as pollutants in lower atmosphere. Remote sensing can be used for surface energy budgeting over large spatial extends to understand changes in surface energy balance and related effects in earth atmospheric boundary layer characteristics and associated processes. An accurate picture of the global energy balance is necessary to detect perturbations inthe Earth's climate system. The top-of-atmosphere radiative energy balance has been relatively well determined by satellites, as compared to the surface energy budget where larger uncertainties exist as surface fluxes cannot be directly measured by satellites. The spatio-temporal variations in distribution of surface energy components such as radiative fluxes at the surface, the sensible, latent and ground heat fluxes are retrieved and examined using multi-year data records from geostationary and polar orbiting satellites. The algorithms for estimating surface energy balance components are evolved and validated against ground measurements carried out over different regions.
K1.7	**Impact of aerosol on agricultural productivity (NRSC/ NESAC)** Atmospheric aerosols alter energy balance of the earth atmosphere system through scattering and absorption of radiation and also by modifying cloud properties. Through scattering and absorption, atmospheric aerosols reduce surface reaching solar radiation, which in turn affect agricultural production. In addition aerosols affect large scale circulation systems such as Indian summer monsoon and associated rainfall. Changes in rainfall will have significant effect on agricultural production.
K1.8	**Retrieving vertical profile of temperature and humidity using Radio Occultation(RO) data (NRSC/ NESAC)** Vertical profiles of atmospheric temperature and humidity are important parameters in atmospheric research, especially for weather forecast and climate change studies. Radio Occultation technique is an effective method to retrieve these profiles by receiving radio signals from GPS navigation satellites. The method makes use of the fact that degree of refraction of radio waves while passing through the atmosphere depends on gradients in air density which in turn depends on temperature and humidity.
K1.9	**Climate change impact assessment (NRSC/ NESAC)** Anticipated/Ensuing climate change is expected to alter the water resources availability, demand and use patterns. Many uncertainties remain about the extent of these climatic changes, as well as about their societal implications. Assessment of vulnerability and resulting risk to water resources due to climate-change impacts is necessary to work out appropriate adaptation and mitigation strategies.
K1.10	**Aerosol optical thickness and atmospheric correction over land (NESAC)** Calibration and radiometric normalization is the key issue in future remote sensing activities related with biophysical parameter retrieval and climate change. Atmospheric

	correction of the satellite data is a challenge. Most important input for atmospheric correction involved estimation of Aerosol optical thickness (AOT) either from network of ground observations or satellite data. Retrieval of AOT sensors like Resourcesat series is a challenge. There is need to develop simplified correction approach including AOR inputs using dark dense vegetation approach. There is further need to develop instrumentation with capability of polarized measurements and LIDAR sensing.
K1.11	**Aerosol, trace gases asian monsoon and climate change over NER (NESAC)** Aerosol and Trace Gases Characterization, inventory analyses, 4D profiing of Aerosol and Trace Gases are very important for NER of India. In view of rapid industrialization it is required to study the impact of the industrialization on climate change over NER of India. The impact of Aerosol & Trace gases on Asian summer monsoon with special emphasis in North East India is also an important study. • Inventory study and quantifiation of green house gases and particulate matters from the industries of NER of India and study of physical & chemical characteristics. • Study and quantifiation of land use changes due to industrialization and its impact.4D profiing and characterization of Aerosol & Trace gases over NER • Generation of 4D Aerosol and trace gases model • Study of the impact of Aerosol & Trace gases in Asian Summer monsoon with specialemphasis in North East India. • Generation of climate change indices over NER of India. • Development of climate change advisory system for NER of India.
K1.12	**WRF-Hybrid data assimilation to simulate Summer Monsoon and heavy rainfall over India (NESAC)** Data assimilation process combines observation data and short range forecast to best estimate the atmospheric state for initialization of an NWP model. Among different data assimilation techniques some of the commonly used methods are 3DVAR, 4DVAR, EnKF etc. Although these methods are different in their formulation but their main objective is to model the error covariance matrices for background and analysis as accurately as possible. In the variational method the background error covariance is considered to be static and isotropic which contradicts the reality as the error varies substantially with the flow of the day. In Ensemble Kalman Filter where multivariate flow dependent background error covariance is computed from ensembles of short range forecasts represent the error of the day. However, it is reported that the use of finite number of ensembles in EnKF may introduce some statistical noise in the covariance field that will result in unsystematic errors in the estimate. This error may be reduced by increasing the number of ensembles, though in practical purpose for use in atmospheric and oceanographic modeling such huge number of ensembles are not affordable. As both these methods have their pros and cons, so another method called HYBRID has been evolved as one of the computationally suitable technique which combines the strength

	of both variational and EnKF to get the best out of the methods. WRF-HYBRID method with 80 ensemble members is used for simulation of Indian summer Monsoon and heavy rainfall events over different parts of India.
K1.13	**Atmosphere and Climate Sciences (NESAC)** Numerical weather prediction (NWP) models are used globally for early warning of weather events at different temporal scales such as long-range forecast, short-range forecast and nowcasting. NWP models are mainly consist of the dynamical module that models the atmospheric governing equations and the physical module that parameterizes the sub-grid scale atmospheric processes unresolved by the model at grid scale. In order to forecast events such as thunderstorms, heavy rainfall, lightning etc. on a very short term mesoscale period also termed as nowcast, the modules need to be run at very high resolution, and in such cases, the NWP models are constrained by high power computational facilities. To reduce the computational load, there is an alternative to the NWP model called an artificial neural network (ANN). ANN is a data-driven computer model system which is adaptive in nature and has learning capabilities based on prior knowledge and also provide reasoning about their decisions. Therefore, an appropriate machine learning model can be proposed by exploring different temporal modeling approaches of Recurrent Neural Networks (RNN) and Temporal Convolutional Networks (TCN), and evaluating its performance with respect to weather forecast models.
K1.14	**Spatio-temporal distribution of long-term climatological parameters (NRSC)** The scope of this project is to study the long-term climatological parameters for climate studies and also explore the analytics technologies.This project explores the data pertaining to the historic and current atmospheric and ocean such air temperature, SST and humidity will be studied in climate perspective. Studying the data pertaining to the climate change and environment is one of the objectives for climate change and environmental studies. This study will be used to detect changes in air quality parameters, identifying the causative factors the contribute to climate and pollution. • Exploration of latest technologies/studies on climatological parameters, spatial data processing methods, Spatio-temporal analysis methods, Advanced statistics and analytics, AI and Machine learning, computation of large data sets etc • Data Assimilation: Collection of long-term climatological parameters like Ozone, Carbon monoxide, Methane, Carbon dioxide etc. Design of framework for data organisation including data formats, meta data contents, parameters that can be extracted and data frequency. • Data Preprocessing: Pre-processing of the climatological parameters to achieve data consistency. i.e to put all the datasets accessible for given temporal and spatial resolutions. • Data Processing: Implementation of various statistical methods to identify and analyse the long term climatological parameters.

	• Data products: Generate products in terms of plots, graphs, maps and tables depicting the analytics results.
K1.15	**Radiative Impacts of Elevated Aerosols over India (NRSC)** Vertical distribution of aerosols assumes importance as the diabatic heating due to absorbing aerosols is higher at higher altitudes, because of the exponential decrease in atmospheric density. The present proposal aims to examine vertical distribution of aerosols over India, its spatial and seasonal variations and trends over Indian landmass using satellite and ground based measurements. The study also proposes to examine the radiative impacts of elevated aerosols over India. The research shall focus on the following: • Spatial and seasonal variations in aerosol vertical distribution over India • Quantitative assessment of free-tropospheric aerosol loading over India • Long term trends of elevated aerosol loading over India • Contribution of long range dust transport in elevated aerosols loading over India • Radiative impacts of elevated aerosol loading over India
K1.16	**Aerosol loading, Trends and Impacts over Himalayas (NRSC)** Aerosols, especially absorbing aerosols over Himalayas assume importance not only because of their enhanced radiative impacts when they reside over high albedo surfaces, but also due to their effects on snow whiteness and glacier retreat after deposition. In addition, absorbing aerosols over foot hills of Himalayas and Tibetan plateau are reported to have significant impacts on Indian summer monsoon and associated rainfall. Though several studies have been carried out, aerosol impacts on Indian summer monsoon are not yet clearly understood. In view of these, the present proposal aims at examining aerosol loading, trends, long range transport and impacts over Himalayan regions using satellite remote sensing, ground based measurements and reanalysis data. • Spatial and Seasonal variations of aerosol loading over Himalayas using satellite data • Climatology and trends of aerosols over Himalayas using satellite and reanalysis data • Quantification of different types of aerosols over Himalayas • Quantification of aerosol transport over to the Himalayan regions • Radiative forcing of aerosols over Himalayan region • Impacts of aerosols on snow albedo and glaciers
K1.17	**Satellite and in situ estimation of primary productivity/ carbon sequestration and estimation of pelagic fisheries potential of Bay of Bengal (NRSC)** The Bay of Bengal is traditionally considered to be a region of low biological productivity because of light inhibition resulting from turbidity and cloud cover. Unlike in the west coast of the Arabian Sea, upwelling in the Bay of Bengal is confined very close to the coast during the SWM, and offshore Ekman transport of upwelled waters is hindered by

	equatorward flow of the freshwater plume. Therefore, it is suggested that the primary production in the Bay of Bengal is strongly controlled by the availability of nutrients and lower than Arabian Sea. Therefore the long term primary productivity estimation and linkages to pelagic fish catch still remain in nascent stage from this part of the ocean. The present research shall carefully estimate the long term trends in primary productivity in open and coastal ocean of Bay of Bengal and decipher the linkages with respect to trends in pelagic fish catch both using satellite and in situ data. • Estimate the primary productivity and seasonal gradient associated with different regional biomes in Bay of Bengal through satellite and in situ measurements. • Understand the physical and biogeochemical controls associated with seasonal changes in primary productivity in BoB and its linkages pelagic fish catch in BoB and estimate the decadal trends in context to global change. • Estimate the carbon sequestration associated with seasonal blooms and implication in Bay of Bengal mixed layer carbon budget. • Development of integrated methodology for improvement in resource exploitation.	
K1.18	**Decadal studies of Aerosol Optical depth (AOD) over Indian region using latest (NRSC)** AI/ML Analytics The scope of this research is to study the spatial and temporal patterns of Aerosol Optical Depth (AOD) over Indian region, understand the sources and the parameters influencing AOD Study of Aerosol Optical Depth and the various factors that affect the AOD values over Indian region. The research shall address the following objectives: • Extraction of AOD from various satellite sensors like Moderate Resolution Imaging Spectroradiometer (MODIS), Multi-angle Imaging Spectroradiometer (MISR), Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), Ozone Monitoring Instrument (OMI), Ocean Color Monitor (OCM) etc based on the availability and requirement. • Exploration of latest technologies/studies on advanced statistics and analytics, AI and Machine learning methods, handling of large data sets and best data visualization methods. • Spatio temporal analysis of AOD values over Indian region. • Study of Anthropogenic and natural sources of AOD.	
K2	**Sub Area**	**Network of Volatile Organic Compounds (VOCs) Measurements in India: Biosphere-Atmosphere Exchange (PRL)**
K2.1	Volatile organic compounds (VOCs) play an important role in the photochemistry of the atmosphere by influencing ozone, hydroxyl radical (OH) concentrations and the conversion rates of nitrogen oxides (NOx). Measurements of VOCs are valuable to understand the emission and atmospheric processes impacting the climate in South Asia. Ambient air VOC composition data represents a complex mixture of numerous species	

	emitted from various anthropogenic and natural and sources. Network of comprehensive measurements of different types of VOCs will provide the quantitative estimation of the contributions from anthropogenic and biogenic sources. The main objectives of the measurements of C2-C12 VOCs at network stations are outlined here. 1. Biogenic Emissions: Emission fluxes of biogenic volatile organic compounds (BVOCs), such as isoprene, monoterpenes, toluene emitted from forest/plant/ocean will be characterized, particularly the impacts of monsoon circulations in the tropical regions. 2. Photochemistry: The data from a network of stations will provide quantitative estimates of VOC mediated photochemistry in the formation of ozone and precursors of organic aerosols. Contributions of various VOCs in diurnal and seasonal variations of ozone and organic aerosols in different regions of India will be estimated. The data will serve as key input in box model simulations. 3. Transformation: Chemical evolution of air VOCs at remote locations will be investigated as several pairs of VOCs can be used to get the information of origin and photochemical age. 4. Model: The data will be useful to validate the fluxes estimated using different models used to generate global emission dataset of biogenic volatile organic compounds BVOC. The global scale chemistry and climate models lack proper representation (of both inventory and photochemical mechanism) of VOCs. The measured BVOCs data will be useful to improve the model simulations of ozone and organic aerosols in the troposphere.	
K3	**Sub Area**	**Agriculture and Agro-ecosystem studies (NRSC/NESAC)**
K3.1	**Integrated approach (including remote sensing inputs) for multi-crop assessment in sparse cropped regions (NRSC)** Multi-crop assessment is important for holistic development of agricultural recourses and farmers livelihood. In sparse cropped area there is always a possibility to misclassify the crop using satellite imageries. This can only be improved by using extensive ground based observations, development of crop specific spectral signature, multitemporal hyperspectral images and cutting edge image processing techniques for crop classifcations.	
K3.2	**The remote sensing techniques of crop assessment in hilly terrains/ high altitudes (NRSC/NESAC)** Assessment of crop over the hilly is always very tricky as the satellite images are affected by lay over and fore shorting (in case of SAR) and hill shadow effect (in case ofoptical data). Further the agricultural land holdings are small in size and intermixed with forest/ other vegetation. The main challenges would be image correction for the above mentioned effect, ortho-rectifiation and image processing algorithms for improved crop mapping and condition assessment.	
K3.3	**RS based indices/techniques for agro-ecosystems characterization / evaluation (NRSC/NESAC** Agro-ecosystem characterization involves assessment of cropping system, crop calendar, crop phenology, agro-meteorological parameterization and soil & land. The aim	

	of the proposal should focus on the carbon sequestration, soil conservation, water use andlong terms changes/degradation. The proposal should also focus on the suitability of the agro-ecosystem in terms of the prevail soil, land, weather resources.
K3.4	**Ingestion of RS inputs/products in climate change analysis/modelling of agroecosystems (NRSC/NESAC)** It involves long term satellite and climate data analysis, indentify the trend and break points of the multi-temporal data. The proposal should involve crop growth simulation model, cropping system model, nutrient transport model. The model should be calibrated in the present condition and simulated under climate change scenarios. Emphasis should provide to use different RS based inputs into the models.
K3.5	**Development of GHG models for agro-ecosystems under different conditions (NRSC/NESAC)** It involves modeling of exchanges/fluxes of GHG like CO2, H2O, CH4, N2O etc from the agro-ecosystem at diurnal, seasonal and annual time scale using suitable field instrumentation and modeling techniques. It also involves to identify the driving parameters of the GHG fluxes and upscaling it at regional level using remotely sensed proxies.
K3.6	**Parameter retrieval techniques with hyperspectral data (NRSC/NESAC)** It involves analysis of hyperspectral data and development of narrow band indices sensitive to crop vigour and condition. Retrieval of crop bio-physical parameters like LAI, Biomass, chlorophyll content, surface wetness etc using empirical, semi-empirical or radiative transfer models.
K3.7	**Algorithm development for agro-ecosystems product generation from geostationary platform (NRSC)** Geostationary platforms provide the frequent observations of the land features and is very useful for kharif season monitoring to get rid of frequent cloud cover. The proposal should focus on use of geostationary platform especially INSAT series for generation of weather variables like Total incoming solar radiation, Net Radiation, Land surface temperature, NDVI etc which can be used in diffrent energy balance equations for retrieval of latent heat fluxes, LAI etc.
K3.8	**Concepts of multidate/multisensor fusion of different scales and resolutions and uncertainty analysis in relation to agro-ecosystems (NRSC)** Multisensor data fusion techniques help in enhancing the spectral/spatial information present in the satellite image. Different fusions techniques need to be explored and comparision is needed for applying in different agriculture monitoring projects. The pros and cons of the merging procedures need to be evaluated. The proposal should also cover the utilization of texture informations present in the fused image for characterizing agro-ecosystem.

K3.9	**Newer tools and techniques development for quick assessment of temporal dynamics of crops/vegetations using Indian multi temporal satellite data (NRSC)** Temporal optical/radar data provides informations on crop phenologies like start of the season, peak greenness, rate of senescence, date of harvesing etc. The proposal is needed for development of indicators derived from the temporal phenological curves for assessing crop growth stages. The project should involve the analysis of multi-temporal NDVI/EVI data, its smoothening, gap filing and extraction of phenometric using different tools/software.
K3.10	**Development of mathematical/matching algorithm in spectral library development using hyperspectral data (NRSC)** This includes development of the hyperspectral library of soil/crops with its physical and chemical properties. These libraries will be helpful in retrieving soil/crop properties of unknown spectra. There is need to develop different curve fitting and wavelet matching techniques for comparing the spectra with the spectral libraries. The proposal may focus on using leaf or canopy radiative transfer model for retrieving properties from the reflectance spectra.
K3.11	**Modelling soil carbon sequestration in relation to cropping systems and climate change (NRSC)** Soil carbon is one of the driving parameter for soil productivity and sustainability. Assessment of Soil carbon helps in understanding the carbon sequestration and its dynamics and its simulation in climate change scenarios. The proposal should incorporate the calibration and validation of biogeochemical models like RothC, DNDC, Century etc and simulating carbon sequestrations in different climatic and land-use scenerios.
K3.12	**Development of farming systems models with RS inputs/products (NRSC)** RS derived inputs strengthen any decision support system for agricultural applications. There is need to devise a farming system model where RS derived inputs can be fed to provide decision support to the farmer communities. The proposal may also explore any such existing models and can suggest necessary changes in terms of input or its structure.
K3.13	**Applications of RS/GIS in horticulture studies (NRSC/NESAC)** Horticultural crops are unique in nature due to its canopy structure and prevailing plant spacing. These are also grown in an orchards environment which are generally having a typical geometric shape. Using these criteria object based image analysis techniques can be proposed for rapidmapping of the horticultural crops. The proposal also should focus of the orchard age, its condition and yield modeling.
K3.14	**Geostationary data utilization in crop assessment (NRSC)** Geostationary data provides frequent observations and helpful during cloudy season. Geostationary imager data can be utilized for generation of temporal crop growth profile, start of the season and regional crop condition assessment. The focus should be given in large area assessment of crop generic condition assessment, drought monitoring etc.

K3.15	**Digital Soil Mapping (NRSC)** Detailed and accurate spatial soil information is required to address global and regional issues like for ensuring food security, assess climate change, land degradation, biodiversity loss, water resource management, ecosystem health, etc. Digital Soil Mapping (DSM) is the creation and population of spatial soil information by numerical models in terms of soil type and other properties. In recent years, significant progress has been made in different aspects of digital soil mapping. Although the digital soil mapping is now progressing in many countries to meet various demands of soil information, challenges exist, especially for highly heterogeneous and human-affected environments. This demands development of new theories and methodologies applicable to soil mapping. This study shall focus on the following objectives: 1. To organize the existing soil observations in to GIS database Validation of pedometric equations for soil hydraulic properties like field. 2. Validation of pedometric equations for soil hydraulic properties like field capacity, permanent wilting point, saturation. 3. Digital mapping of soil properties namely, soil depth, soil texture, pH, EC, organic carbon, field capacity, saturation, permanent wilting point, undisturbed bulk density at 30m spatial resolution. The major efforts in digital soil mapping are for spatial prediction of soil carbon, because of its importance in monitoring land degradation and global warming. Besides, the Soils & LRA division has a repository of soil analytical results of samples collected under various projects. Keeping the past effort in DSM and availability of soil analytical data, the present work is to develop DSM models and prepare soil property-wise maps for important soil properties. Digital Soil Mapping inputs play a critical in NICES ECs, optimal land use planning and hydrological modelling.
K3.16	**Evaluation of different crop modelling approaches and development of an ensembling technique for crop yield estimation at local scales (NRSC)** Timely and objective crop surveillance information is fundamental to minimise the impact of recurring crop risks. There are isolated efforts by various agencies to provide these kinds of information products and services, but the challenge lies in synthesising these efforts in to an integrated and modelling framework. This research project intends to develop and implement a crop modelling system in an integrated approach to develop a scalable model for large area implementation. The study shall address the following objectives: • Retrieval of crop biophysical parameters such as Leaf Area Index(LAI), LCC (Leaf Chlorophyll Content),Above Ground Biomass (AGB) and crop phenology using parametric, non-parametric and hybrid approaches. • Assimilation of these retrieved biophysical parameters into crop growth model for simulating crop growth, development and yield. • Implementation of primary productivity models for crop yield estimation. • Implementation of machine learning algorithms for crop yield estimation • To develop an ensembling technique for crop yield estimation

K3.17	**Satellite Derived Land Surface Parameters and Meteorological Variables (NESAC)**	
K4	**Sub Area**	**Environment Sciences and Hydrological Modeling (NRSC/ NESAC)**
K4.1	**Green House Gases estimation (NESAC)** One of the recent trends in remote sensing understands the climate change through spacemeasurements. Atmospheric Green house gases concentration and measurements offlx are important research Area. Currently available sensor system includes GOSAT,ENVISAT-SCIAMACHY, MOPITT etc. India has plans to launch such mission (ENVSATSeries) in future with other countries (OCO of USA, GOSAT-2 of Japan). There is need to develop radiative transfer scheme to model and retrieve the gases concentration.There is need to in situ measurement of CO_2, CH_4, N_2O etc flxes for validation ofsatellite products.	
K4.2	**Regional monitoring, mapping and inventory analysis of Trace and Green housegases (NRSC/NESAC)** 1. Establishment of trace gases measurements network across the country using cost effective technology. 2. Creating a consistent and reliable centralized long-term data base on trace gases for various stuides. 3. Ground based trace gases data to improve the satellite retrievals accuracy. 4. Identifiation of hotspots of trace gases and their causative factors.	
K4.3	**Retrieval of green house gases using satellite data (NRSC/NESAC)** 1. Retrievals of columnar GHGs namely CO_2, CH_4, CO, O_3 and N_2O from the satellites over the Indian region. 2. Comparative analysis of satellite retrievals against ground-based retrievals to improve the retrieval accuracy. 3. Precise columnar GHGs to predict and estimate source and sink regions of the Indian sub-continent. 4. Addressing seasonal and intra season variations using satellite retrieved columnar GHGs.	
L	**Area**	**Disaster Management (NRSC/ IIRS/ NESAC)**
L1	**Sub Area**	**Geo-hazards (NRSC /IIRS/ NESAC)**
L1.1	**Earthquake Precursor Analysis for moderate to high magnitude earthquakes inIndia for understanding the spatio-temporal likelihood of earthquakes (SAC / NRSC/ NESAC)** Earthquake prediction is still a challenging task, recent studies have shown that numerous geophysical and geochemical parameters are closely associated with earthquakes. When the earthquake happens, an energy transfer due to a breakdown between source and environment is made. These changes prior to the earthquake or along with it may	

	have different physical and chemical effects on the lithosphere, atmosphere and ionosphere. Occasionally and in the cases of large magnitude earthquakes, these changes are detectable. A large number of researchers across the world over the past decades have attempted in understanding such “earthquake precursors” from “Thermal Anomalies” and “Total Electron Count Variations” occurring in the lithosphere and the ionosphere. Thermalanomaly is an unusual increase in Land Surface Temperature (LST) that occurs around 1–24 days prior to an earthquake. In addition to this, Total Electron Content/Count (TEC) has emerged as one of prime candidates of earthquake pre-cursors studies that need to be thoroughly understood in order to get appropriate forewarning of earthquake events.Therefore, the two primary areas of focus will be “Thermal precursors” and “Total electroncount anomaly” prior to an earthquake event.
L1.2	**Early warning of landslides (NRSC/NESAC/IIRS)** Landslides are mainly triggered by rainfall. Daily as well as antecedent (cumulative) rainfalls are responsible for saturation of soil and subsequent landslide in hilly areas. Therefore, a rainfall intensity-duration relationship was developed by NRSC for experimental landslide early warning. Bhuvan platform is currently used to disseminate daily landslide earlywarning for selected road corridors in the Himalayas. Daily 72 hrs rainfall forecast received from IMD or SAC (MOSDAC) is used as an input to the landslide early warning model. Then the available landslide susceptibility map is integrated with rainfall probability to generate landslide early warning in Bhuvan. Early warning in four categories (Warn, watch, advisory and no warning) are issued regularly through Bhuvan. Currently the landslide early warning system is operational experimentally in selected routes of Himachal Pradesh, Uttarakhand, Meghalaya, Assam and Mizoram. Further development of rainfall intensity duration relationship is required specific to different landslide prone areas of India.
L1.3	**2D Flood Inundation Modelling - Simulation of flood inundated areas for a given discharge using DEM and other inputs from satellite data (NRSC/NESAC/IIRS)** To explore the applicability of hydro-dynamic equations in various conditions of over land flood wave propagation on different flood plain topographies. Inter comparison of different DEM products for 2 dimensional hydraulic simulations.
L1.4	**Flood Early Warning System (FLEWS) (NESAC)** Calibration and validations of all distributed river/tributary models in Brahmaputra and Barak river valleys with available hydro-logical and river geometry datasets. Sensitivity analysis of various model parameters to understand the hydrologic response of various types of river catchments in the said study area.
L1.5	**Flood Hazard zonation and risk assessment in major riverine and urban flood prone catchments (NESAC)** Applicability of various approaches of flood hazard zonation such as flood frequency based hydraulic simulations, inundation occurrence based FHZ and NESAC developed multi-criteria analysis in both riverine and urban flooding conditions.

L1.6	**Storm Surge Inundation Modeling for Disaster Risk Reduction (NRSC)** Coastal flooding or inundation due to storm surges is one of the potential hazardous elements that can have significant impact on any coastal zone. A storm surge is an offshore rise in the ocean associated with a low-pressure weather system, typically an intense tropical or extra tropical cyclone, which manifests itself as a large rise in water level at the shore as the storm hits. In India, nearly one-third of the population living in the coastal areas is at risk of cyclones, storms, heavy rainfalls etc. This research is intended to study the hydrodynamic modeling for spatial inundation due to extreme event induced storm surge using very high resolution DTM, generation of flood inundation simulations for different storm surge scenarios and storm surge flood vulnerability and risk assessment.

Space Sciences

A	Area	Space, Marine and Atmospheric Sciences (PRL)
A1	Sub Area	Investigations on Near-Earth Environment (PRL)
A1.1	**Solar wind and interplanetary processes (PRL)** The variability of alpha-proton ratio in the solar wind at 1 AU in small time scale (e.g. a few days during the passage of transient disturbance like ICME) as well as in large time scale (solar activity cycle) is investigated. This theme gets special importance in the context of the Aditya-L1 mission of ISRO. In addition, the generation, thermal anisotropy and acceleration of solar wind particles are of special importance that have been taken up. The generation of solar energetic particles and its association with the ICME and solar flares are also being looked into.	
A1.2	**Wave particle interaction at the radiation belt (PRL)** The wave particle interaction at the terrestrial radiation belt, acceleration of radiation belt electrons and the role of solar wind shocks are investigated.	
A1.3	**Equatorial-, middle- and high-latitude upper atmospheric phenomena (PRL)** The equatorial-, middle- and high-latitude processes are replete with unique atmospheric processes of their own. This is essentially due to the configuration of magnetic field lines which are different at different latitudes and thereby affect the neutral plasma motion in different ways at different latitudes. The horizontal nature of magnetic field orientation over geomagnetic equatorial-, and low-latitude regions generates dynamo effect which gives rise to equatorial electric fields and several associated processes such as the equatorial electrojet, plasma fountain effect/equatorial ionization anomaly, neutral anomaly, equatorial temperature and wind anomaly, and convective ionospheric irregularities, among others. Particle precipitation at high-latitudes during geomagnetic storms/space weather events present additional source of energy and momentum to the earth's upper atmospheric regions which contribute to the generation of neutral and plasma waves and setting up of winds and creation of plasma irregularities. Several state-of-the-art radio propagation techniques, magnetic measurements, and in-house built optical techniques are used to answer highly pertinent questions of global importance and global scales.	
A1.4	**Daytime upper atmospheric neutral wave dynamics (PRL)** The solar ionizing radiation incident in the daytime upper atmospheric regions gives rise to several phenomena due to availability of additional energy and differential heating that sets up driving forces in several directions. While radio measurements are available for the investigation ofthe ionized part of the upper atmosphere, the neutral part of the atmosphere can be studied by thenaturally occurring optical air glow emissions. New in-house built techniques and approaches have been evolved at to enable the	

	measurement of these airglow emissions in the daytime against the strong solar scattered background contribution. A new field ofdaytime optical aeronomy has emerged, wherein investigations of neutral gravity wave activity that exists in the daytime, is now possible. Several new insightful results have been obtainedand there exists a great potential in this nascent area of research.
A1.5	**Space Weather effects at high- and mid-latitude ionosphere thermosphere system (PRL)** The high- and middle-latitude ionosphere-thermosphere regions are especially affected by the particle precipitation at high latitude and ensuing electric fields and currents that are formed in the auroral oval wherein convective cells are formed. The local time dependence and simultaneous role of substorms, shocks, disturbance dynamo etc. in generating the extreme electric field disturbances in the ionosphere are investigated. Daytime polar cusp aurora, polar cap patches, stable auroral red arcs, stable auroral polarization streams, storm enhanced density plumes, and associated affects are of research interest in the characterization of space weather effects on the terrestrial ionosphere thermosphere system.
A1.6	**Impact of mid-latitude ionospheric processes and irregularities on low latitudes (PRL)** The impact of Medium Scale Travelling Ionospheric Disturbances (MSTID) on low latitude ionospheric electrodynamics is investigated. Further, the characterization of mid latitude irregularities at the transition region of low-mid latitude boundary is also being carried out in recent times.
A1.7	**Vertical coupling of atmospheric regions (PRL)** Earth's atmospheric regions are organized with respect to its temperature structure. Different regions are governed by different convective and dynamic processes and so have been conventionally considered to be behaving independent of one another. Due to multipronged daytime, nighttime, optical, radio, magnetic, re-analysis, and other global datasets it has been shown that efficiency in vertical (upward) coupling of atmospheric regions is solar activity dependent over long timescale with greater efficiency during low-solar activity epoch. On smaller time scales tropospheric convective storms (few hours) and stratospheric sudden warming events (several days) give rise to vertical coupling of atmospheric regions. Several ensuing processes, mechanisms, and consequences of such vertical coupling is a topic of research that's being pursued in PRL.
A1.8	**Investigations of Mesosphere Lower Thermosphere (MLT) region (PRL)** MLT region is dominated by the effect of waves (planetary, tides, gravity waves) that originate in the lower atmosphere and propagate upwards which consequently gain large amplitudes that leads to wave breaking and momentum deposition. Multi-wavelength air glow observations using optical techniques, measurements of mesospheric rotational temperatures using OH Meinel and O2 atmospheric bands

	(both ground and satellite based),and modelling studies are required for a comprehensive understanding of the processes in the MLT region. The topics of interest are: Couplings (vertical, latitudinal,longitudinal) of the atmospheres under varying geophysical conditions, atmospheric waves in the MLT region, long-term changes in the MLT region, effects of Sudden Stratospheric Warming (SSW) from high-latitude on global MLT dynamics, Mesospheric Temperature Inversion (MTI) and it's possible causative mechanism, high frequency waves in the MLT region.	
A1.9	**Dynamical coupling between lower and upper atmosphere (PRL)** Atmosphere is a very dynamic system that constantly undergoes changes due to the underlying physio-chemical processes occurring at various regions. Since it is a coupled system processes at one region greatly influence the dynamics of the adjacent atmosphere. Atmospheric waves and a few chemical species originated in the lower atmosphere can cause appreciable modification of the mean dynamical state of the upper atmosphere.	
A1.10	**Variability of upper atmospheric wind and temperature (PRL)** As the upper atmosphere is affected by the forcings from both top and bottom, the dynamical state of it varies significantly over various scales. The variability can be found effectively in the dynamical parameters, e.g. wind, temperature etc. Therefore, by investigating the variability of these parameters one can delineate the dominant processes occurring therein.	
A2	**Sub Area**	**Atmospheric Aerosols and Trace Gases (PRL)**
A2.1	**Radiative and Climate Impacts: Observations and Modelling (PRL)** To characterize different aerosol types and gaseous pollutants, their spatial and temporal variations, understand their linkages with physical, chemical and dynamical processes, and study their impact on environment, radiation budget and climate. 1) Atmospheric Aerosols: Characterization, Radiative and Climate Impacts 2) Biomass burning and Aerosols 3) Trace Gases: Chemistry, Transport and Effects	
A3	**Sub Area**	**Study of low latitude ionosphere using GNSS/NavIC (NARL)**
A3.1	**Propagation effects on L-band and S-band navigations signals due to low latitude ionosphere (NARL)**	
A3.2	**Estimation of TEC and electron density profile using GNSS/NavIC (NARL)**	
A3.3	**Quiet time day-to-day variability of ionosphere due to forcing from the Sun and the lower atmospheric processes (NARL)**	
A3.4	**Space weather effects on distributed network of GNSS/NavIC receiver performance due to ionospheric changes (NARL)**	

A3.5	**Study of changes in Electro-dynamics and Thermospheric processes leading to positive and negative ionospheric storms in low latitudes (NARL)**	
A4	**Sub Area**	**Atmospheric Sciences (SAC/NESAC/IIRS)**
A4.1	**Assimilation of Satellite Data in Numerical Weather Prediction Models (SAC)** Accurate prediction of high-impact weather events and the area of the greatest threat represent a major challenge for planners to minimize the loss of lives and damage to property. Advance research is being planned to carry out non-linear data assimilation of satellite derived parameters in numerical weather prediction models. ISRO is aiming at improving short to long range weather forecasting using satellite based observations. For this activity various satellite observations are ingested in Numerical Weather Prediction (NWP) model using various data assimilation (DA) techniques.	
A4.2	**Seasonal Prediction of Indian Summer Monsoon (ISM) using Climate Model (SAC)** In the Indian subcontinent, the most well-known seasonal phenomenon is the Indian summer monsoon (ISM) occurring every year from June through September. This is one of the most dominant features of the global hydrological cycle as well. Though the onset of the monsoon over Kerala in India takes place at the start of June with the seasonal reversal of wind over the Arabian Sea with a consistent manner from year after year, the monsoon rainfall is characterized by significant intra-seasonal and inter-annual variability over and around India. Therefore, there is a recognized need for seasonal prediction of ISM well in advance describing the spatial and temporal variability of rainfall in conjunction with the satellite and in-situ observations.	
A4.3	**Diagnostic Studies for Monsoon (SAC/NESAC)** The data from Indian satellites are extensively used to understand the meteorological and oceanographic processes that govern the Indian summer monsoon and its variability. A lot of diagnostic studies are being carried out using satellite data like rainfall, vertical profiles of atmospheric temperature and humidity. Better understanding of the monsoon processes also needs to be resolved by both NWP models and re-analysis data using high-resolution satellite data.	
A4.4	**Cyclone Track and Intensity Prediction Using Satellite Data and Numerical Models (SAC)** Advance and accurate prediction of tropical cyclones is highly important for issuing the warnings and saving the lives. Real-time winds obtained from scatterometer (SCATSAT-1) are used for tropical cyclogenesis predictions of all the low-pressure systems formed in the North Indian Ocean. The cyclone track and intensity prediction is being done using numerical models and satellite data that involves empirical and dynamic modelling and assimilation techniques. The cyclone centric satellite products are generated, which are very useful for cyclone positioning and its structure and intensity estimation.	

A4.5	**Impact of Atmospheric Chemistry on Weather Prediction (SAC)** Atmospheric aerosols have a large influence on air quality and, also in the well-being of human and ecosystem. Aerosols affect the earth-atmosphere radiation budget directly by scattering and absorbing the incoming solar radiation and indirectly by influencing the processes of formation of clouds and precipitation. Assimilation of satellite derived aerosols in NWP along with the chemical transport modelling have been planned.
A4.6	**Satellite derived Cloud Microphysical Parameters (SAC)** Clouds are modulators of Earth's climate and hydrological cycle. Microphysical parameters are also important for studying the evolution of high impact cloud system and understanding cloud-aerosol interactions. ISRO's and IMD Doppler Weather Radar data are planned for various studies of clouds and precipitation.
A4.7	**Satellite Based Weather Now casting for Heavy Rainfall Events (SAC)** Timely alert of extreme precipitation events has a huge societal impact. Data acquired from geostationary satellites are helpful in predicting the evolution of convective systems. Weather now casting over a time scale of few hours play a very important role. To further improve the skills of thunderstorm forecasting, new techniques will be developed using satellite data(Environmental, thermodynamic and stability parameters, Stability indices like Lifted Index, CAPE, CINE, K-Index), NWP model forecast and forthcoming dense DWR networks.
A4.8	**Predication of tropical cyclogenesis (IIRS)** The tropical cyclogenesis is a process in which some pre-existing, synoptic-scale or mesoscale weather feature in the tropics develops so as to take on the characteristics of a tropical cyclone. The following six environmental conditions are important for TC formation: warm sea surface temperatures, high relative humidity near the mid-troposphere, conditional instability, high low-level relative vorticity, weak vertical shear, and sufficient Coriolis force to sustain low pressure system (e.g., beyond 5° from equator in latitude). The tropical cyclone genesis statistics at long time scales are closely related to these conditions. Numerical modeling has been a very powerful way to hypothesize and test the physical mechanisms associated with tropical cyclone formation and intensification. As numerical models have shown the potential to improve tropical cyclone track and intensity forecasts, their ability to depict the processes that contribute to the formation of tropical cyclone can be examined. Due to limitation of the in-situ observations over the oceanic region, satellite observations play major role in numerical models during the early and transient stages related to tropical cyclone formation.
A4.9	**Predication of track and intensity of tropical cyclones (IIRS)** The tropical cyclones forecasting involves the prediction of several associated parameters, such as the cyclogenesis, track, intensity, landfall induced storm surges and rainfall. Among all these associated parameters, it is most important to know about the intensity, direction of a cyclone movement and landfall position so that the inhabitants of potentially

	affected areas can be warned well ahead of time and minimize the damage potential. Recently, numerical models have shown significant improvement in tropical cyclone forecasting due to high resolution, improved data assimilation techniques and more number of satellite data. The intensity forecast from numerical models is still challenging task. Satellite measurements are an important source of regional and global observations in support of numerical weather prediction models. Data assimilation uses both observations and short-term forecasts to estimate the initial conditions. In the modern numerical models, both traditional observations and satellite observations can be assimilated in the system, and provide useful atmospheric initial condition information for improving the forecasts. The use of high spatial and temporal resolution satellite observations in numerical weather models through advance data assimilation techniques can improve the track, intensity and landfall position of tropical cyclones.	
B	**Area**	**Atmospheric Dynamics and Coupling (NARL)**
B1	**Sub Area**	**Observations, Modelling and Simulations (NARL)**
B1.1	**Modelling of atmospheric tides (NARL)** Atmospheric tides are generated due to solar insolation absorption by water vapour, ozone, nitrogen and oxygen molecules. They play a major role in determining the thermal structure, circulation and ionospheric variabilities. The atmospheric tidal solutions can be obtained by solving Laplace tidal equations, which are basic fluid dynamical equations and necessary heating. The equations can be solved to get the height and latitudinal profiles of different modes of tides.	
B1.2	**Generation and propagation of atmospheric wave modes (NARL)** The upper atmosphere is governed by dynamics in addition to radiation and chemistry. The atmospheric waves play a major role in determining the dynamics of the upper atmosphere. The waves range from acoustic gravity waves to planetary scale waves. They have different generation mechanisms, namely, latent heat release in the deep convection, land sea thermal contract, orography, instability mechanisms etc. It is necessary to understand the generation mechanisms of different atmospheric waves and their vertical propagation, which depend on the background winds and thermal structure.	
B1.3	**Numerical simulations of stratospheric sudden warming and their global influence (NARL)** Sudden stratospheric warming is the sudden rise in temperature in the cold polar stratosphere during some winters. It occurs due to anomalous growth of planetary waves and their interaction with background wind. Though it occurs at high latitude stratosphere, it Influences globally. The occurrence of SSW and their effect needs to be understood through numerical simulations	
B1.4	**Gravity wave-tidal -mean flow interactions (NARL)** Tidal variability at mesospheric heights influences E-region electrodynamics, as the latter is mostly governed by tidal wind dynamo mechanism. The tidal variability can be influenced	

	by gravity wave tidal interaction. Momentum deposition by gravity waves can accelerate/decelerate the mean wind and affect the amplitude and structure of tides. The eddy diffusion of gravity waves can affect the tidal variabilities. It is important to understand how gravity wave stress affects tidal amplitudes and background circulation.	
B1.5	**Simulations of QBO, SAO and Intra-Seasonal Oscillation (NARL)** Equatorial middle atmosphere is characterized by quasi-biennial oscillation (QBO) in the lower stratosphere, semi-annual oscillation in the upper stratosphere and mesosphere. Besides, middle atmospheric parameters exhibit intraseasonal variability. The equatorial waves play major role in driving these oscillations. It is aimed to develop a model, which can simulate these long-period oscillations with realistic wave forcing and background wind parameters.	
B1.6	**Influence of lateral wave forcing on tropical weather and climate (NARL)** Tropical weather and clime is Influenced by potential vorticity intrusions. These intrusions trigger deep convection and control rainfall. How the extra tropical atmosphere Influences the tropical weather and climate needs to be understood quantitatively. In addition, annular modes can Influence the tropical weather. What is the impact of these extratropical forcing on Indian monsoon needs to be investigated.	
B2	**Sub Area**	**Cloud Research (PRL)**
B2.1	**Investigations of Atmospheric Clouds and Boundary Layer Characteristics (PRL)** To characterize different types clouds their structures, Cloud Base Heights, Wave-cloud interactions, Microphysics of clouds, Cloud dynamical features. Dynamics of atmospheric Boundary layer.	
B2.2	**Development of Indian Lidar Network (ILIN) (PRL)** To investigate Atmospheric Cloud characteristics, Boundary layer dynamics, Vertical distribution of atmospheric water vapor and other atmospheric constituents over different regions of India; we are establishing a network of Lidar laboratories (ILIN) in the different parts of India covering different regions (North, South, North East,West and Central India).	
C	**Area**	**Sun and Solar System (PRL/VSSC/NARL/SAC)**
C1	**Sub Area**	**Planetary Sciences (PRL)**
C1.1	**Dust Devils (PRL)** Convective vortices(dust devils) inject dust into the atmosphere, which is then transported by global winds and strongly moderates the Martian climate system directly through the radiative impact of local and global dust storms, and indirectly by affecting the complex ion photochemistry. We are studying the characteristics of such dust devils on Mars through modeling and remote sending observations.	

C1.2	**Photochemistry coupled GCM of Mars and Venus (PRL)** The current climate of Mars and Venus is controlled by interactions between chemical tracers (such as ozone), water vapour and dust aerosols, coupled through dynamics and radiative processes. Scientists at PRL are studying these interactions with varying levels of complexity. The latest efforts are to understand the couplings through a photochemistry coupled general circulation model (GCM). The current focus is also to understand boundary layer processes (through which the surface forcings influence the free atmosphere) through mesoscale modeling.
C1.3	**Planetary Lightning (PRL)** The electric fields due to dust charging could be an important source of lightning on Mars. Similarly, charging of sulfuric acid aerosols may play an important role to generate lightning on Venus. The lightning is of particular interest, as electrical discharges from lightning could help form new exotic species or even molecules needed to jumpstart life. Not much is know about these phenomena for which instrumentation and modeling are being developed. Microphysical modeling of the cloud layers of Venus will be used to study charging of the cloud layer, generation of possible lightning, and its effect on the photochemistry. This study is very important for India's future mission to Venus.
C1.4	**Planetary Remote Sensing (PRL)** Remote sensing data from Moon, Mars along with other planetary bodies are useful to understand the evolution of these planetary bodies. They are used to understand surface and geological processes such as impact cratering, glaciation and volcanic activities using surface and subsurface analysis.
C1.5	**Understanding planetary processes through meteorites and planetary samples (PRL)** Isotopic and noble gas studies of meteorites and planetary samples can help us understand the origin and formation process of planetary bodies. It also gives us time line of materials evolution in the proto solar system and time scale information in the early solar system. Analysis of organic matter from various meteorites can provide the constraints on thermal and aqueous alteration taking place at the Asteroidal region. Carbon isotopic studies in carbonaceous Chondrites can help understand the origin, identification of C bearing reservoir and migration of volatiles in early solar system
C1.6	**Planetary Environmental Simulations and Analogue Studies (PRL)** Laboratory measurements of planetary analogous materials under simulated environments provide key support to the definition of science and measurement objectives of ground-based, orbital, and lander observations; instrument design and calibration; mission planning; and analysis and interpretation of retrieved data. The main aspect of such a work would be to design and develop environmental chambers/facility of different scales and capabilities that can simulate astrophysical and planetary environments and conduct experiments using analogous samples under these environments. Study of analogues found on Earth can reveal processes we might expect on planetary bodies. For example,

	identification of new impact structures in Indian Subcontinent and meteorite expedition in hot and cold deserts in India could be useful areas of investigation.
C1.7	**In-situ technologies for planetary surface and sub-surface science (PRL)** We are at the verge of a new epoch of robotic exploration of solar system bodies. The next generation of scientific missions to planetary bodies of our Solar System requires development of advanced robotic technologies for in-situ surface and sub-surface science (for examples core drilling and sample collection techniques). These missions have also motivated initiation of the design and development of highly capable and miniaturized science instruments for carrying out in-situ surface and sub-surface science.
C1.8	**Outer solar system studies with emphasis on Icy bodies/satellites (PRL)**
C1.9	**Lunar Surface Sciences (SAC)** The main research themes include Lunar Surface composition, Lunar morphology, Hyperspectral data analysis for Lunar Surface, Thermal Remote Sensing of the Moon, Spectral characterisation of Lunar analogues, Lunar surface dating and lunar volcanism. Multi-frequency microwave SAR studies for H O / Ice detection on Lunar surface.
C1.10	**Lunar Gravity and Crustal Thickness Studies (SAC)** Using the surface elevation and satellite tracking data lunar gravity can be deduced and this gravity data can be further modelled using gravity reduction methods to find out the lunar crustal thickness, which provide information about the lunar interior processes. The main research themes include Lunar gravity modelling, inversion modelling for crustal thickness and lunar interior.
C1.11	**Studies related to Martian Surface, Polar Ice and Atmosphere (SAC)** Major research themes are Characterisation of Martian analogues in India, Hyperspectral analysis of Mars data, Thermal remote sensing of Mars, Martian Atmosphere. Surface composition of Mars, Remote sensing for Trace gases. Study of Phobos & Deimos (Moons of Mars).
C1.12	**Terrestrial Analogue Studies (SAC)** Geochemical, Spectroscopic, X-ray & astro-biological studies of the terrestrial analogues of Moon and Mars.
C1.13	**Development of Polarimetric SAR based Model for Lunar and Martian Surface Parameter Retrieval (SAC)** ISRO’s future planetary missions to Moon and Mars will be equipped with SAR payloads imaging the planetary surfaces/ sub-surfaces by multi-frequency polarimetric radars and radiometer. SAC is engaged in development of algorithms for retrieval of surface parameters such as dust/regolith roughness, thickness, dielectric constant and detection and quantification of sub-surface water-ice in the Lunar and Martian environment. New research is required for development of algorithms, simulation models and tools for retrieval of geo-physical parameters of Lunar and Mars surfaces.

C1.14	**Saturn's upper atmosphere (NARL)** Plasma in the Saturn's upper atmosphere, magnetosphere, radiation belts, interaction with its rings and moons, the rotation period of Saturn.	
C1.15	**Investigations on the problem of Methane on planetary atmospheres: Mars and Pluto (NARL)**	
C1.16	**Modelling the atmospheres of Venus ,Mars and other planetary atmospheres (VSSC)** Modelling of planetary atmospheres for atmospheric circulation, thermodynamics, ionospheric features, emissions and chemical composition, and escape of gases of different planetary atmospheres are gaining significance and are achieving rapid strides with several planetary exploration missions being planned and also plans for sample return. As a first step numerical simulation of the planetary atmosphere, its dynamics and climate systems can be attempted. The Global Circulation Models for planets can yield a simulation of the global atmosphere and the global climate. The challenging area in this topic is developing the limited area (meso/micro scales) to interpret landed space craft data and also to examine the meteorological systems in the planetary atmospheres on sub-global scales, which can simulate the boundary layer of the planets.	
C2	**Sub Area**	**Solar Physics (PRL)**
C2.1	Udaipur Solar Observatory, as the name suggests is a dedicated facility to study the sun, the nearest star. Investigations of the Sun at USO revolve around the central theme of solar magnetic and velocity fields, solar activity, solar eruptive processes and high resolution solar observations. Efforts are being made to get a handle on the forecasting of these violent solar events. Basic physical phenomena of the birth and development of active regions, and flare mechanism can also be studied. The major experimental facilities include the Global Oscillation Network Group (GONG), the Multi Application Solar Telescope (MAST) and the Compound Astronomical Low frequency Low cost Instrument for Spectroscopy and Transportable Observatory (CALLISTO).	
C2.2	**Helioseismology (PRL)** Helioseismology is based on precise measurements of solar acoustic oscillations. The study of the solar global oscillations during major flares have shown that such energetic transients taking place in the solar environment can generate pressure impulses in the Sun. The knowledge gleaned from these solar results can be useful in identifying the asteroseismic signatures of such transients in solar-like pulsating stars. The study of these acoustic oscillations in the sunspots during major flares have shown that abrupt changes in solar magnetic fields can lead to impulsive changes in Lorentz force acting on the sunspots, which results into inducing acoustic emission in the sunspots. These acoustic emissions could be helpful in better understanding of physical dynamics beneath the sunspots. Additionally, such magnetically driven acoustic emissions can travel upward into the solar atmosphere as magneto acoustic waves and thereby heat the active region atmospheres. It is also believed that acoustic waves can leak from the quiet-Sun network regions of the solar photosphere and travel upward into the chromosphere	

	thereby dissipating its energy in the form of shocks. A two-height simultaneous velocity observations in the solar photosphere and chromosphere at high resolution is required for a better understanding of the aforementioned wave heating process. Further, the study of velocity flows on the solar surface over the solar cycle can give an understanding of the effect of the evolution of solar magnetic fields on the dynamics of the Sun.
C2.3	**Flux emergence and the coupling of the solar atmosphere (PRL)** The emergence of magnetic fields on the solar photosphere occurs on a widerange of spatial and temporal scales. Investigating the processes of fluxemergence is essential for understanding how the magnetic field couplesthe solar atmosphere and in determining i) the heating of the transition region and corona, ii) the production of small-scale transients, and iii) the instabilities driving mass ejections from the Sun. This field of solar physics requires multi-wavelength andmulti-resolution observations which will provide an unprecedented view of the Sun and its magnetic field with the next-generation ground-based telescopes and space missions becoming operational within 2-3 years.
C2.4	**Magnetic field and velocity mapping for prediction of solar eruptions (PRL)** Solar surface magnetic field is measured to monitor magnetic energy storage and evolution of the stresses leading up to these eruptions combined with the velocity measurements on the surface. Above the surface, physical parameters of the chromospheric and coronal phenomena are being used to predict the geoeffectiveness of these eruptions.
C2.5	**Solar cycle variation, prediction of activity cycle (PRL)** The 11-year activity cycle is a dominant characteristic of the Sun and also the solar dynamo that generates the solar magnetic field. The discovery of solar magnetic fields introduced a 22-year periodicity, as the magnetic polarities of the polar regions change sign every 11 years. Correlations have been identified and quantified among all the measured parameters, but in most cases such correlations remain empirical rather than grounded in physical processes. For a better physical understanding of solar physics a systematic reassessment of solar activity indices and their usefulness in describing and predicting the solar activity cycle is required.
C2.6	**Study of solar rotation (PRL)** The differential rotation of the Sun plays a key role in the formation of sunspots and thereby governs the solar activity cycle. Recently it is shown that the solar corona also shows differential rotation with increasing height (or, temperature). Furthermore, the study of North-South asymmetry in the rotation of the Sun has indicated that this asymmetry leads the solar activity cycle. The study of chromospheric rotation with height and its variation over the solar activity cycle can improve our understanding about the differential nature of the solar rotation.

C2.7	**The heating of solar corona and transition region (PRL)** The tenuous outer atmosphere of the Sun commonly known as ‘corona’, is orders of magnitude hotter (> 1 MK) than the solar surface (< 6000 K). It is now widely accepted that magnetic field plays an important role in the heating of solar corona. Magneto hydrodynamic (MHD) waves and small-scale transients (e.g., microflare, nano-flare, spicules) are proposed to provide sufficient energy to maintain the hot corona and transition region. Although there exist ample observations of wave propagation and small-scale transients in the solar atmosphere, the exact physical processes/mechanisms behind their dissipation and contribution to the heating of coronal plasmas are still unclear and not fully quantified. Therefore, a thorough assessment of the role of each of these proposed mechanisms is required.
C2.8	**Transient Phenomena: Flares, Eruptive Filaments/Prominences, Coronal Mass Ejections (PRL)** CMEs inject large amounts of mass and magnetic fields into the heliosphere, causing major geomagnetic storms and interplanetary shocks, which are a key source of solar energetic particles. CMEs are often associated with erupting prominences and flares but our physical understanding of how and why CMEs are initiated is poor. It is important to carry out long term and high resolution studies of source regions of CMEs and also monitor their manifestations in the solar wind. Further, study of halo-like CMEs, which suggest the launch of a geoeffective disturbance toward Earth is also very important for space weather forecasting purpose. The fast and wide CMEs produce coronal and interplanetary shocks which are observed as type II radio bursts in meter and Decameter-hectometer (DH) wavelengths. The investigation of solar radio bursts in metric and DH wavelengths is also extremely important in view of probing the origin and propagation of CMEs.
C2.9	**Multi-wavelength studies of the Sun (PRL)** Our understanding of the solar interior, the visible outer layers, and the “invisible” corona are not complete. New developments in the observational techniques from ground and space in optical, X-ray, ultra-violet and radio regimes of the electromagnetic spectrum are expected to continuously extend the frontiers of knowledge of the Sun in particular the eruptive phenomena such as flares and CMEs. Further, the HXR spectroscopy of solar flares is of particular importance to explore the basic physics of particle acceleration and explosive energy release in solar flares. Combination of imaging and spectroscopic observations in X-ray regime would reveal the location and strength of accelerated electrons and ions besides that of the hottest plasma.
C2.10	**Numerical simulation for solar atmosphere (PRL)** The solar corona is intriguing because of its million degree Kelvin temperature and hosting eruptive processes which releases energy and mass which influence the space weather. In absence of any reliable measurement of the coronal magnetic field, it becomes important to numerically construct it using photospheric observations from ground and space based observatories. Additionally, state-of-the-art computer simulations are employed to explore the coronal dynamics.

C2.11	**Heliospheric evolution of CMEs and their space weather impact (PRL)** When coronal mass ejections or CMEs are launched from the Sun, they arrive at Earth within 1-4 days depending upon their initial speeds and their level of interaction with the ambient solar wind through which they travel. Research is being carried out for a better understanding of the expansion and propagation of CMEs in the inner heliosphere, thereby improving the forecasting of CME arrival and their impact on the Earth's atmosphere. Such knowledge is crucial, as energetic and high speed CMEs are known to be the major cause of severe disturbances of the Earth's space weather.	
D	**Area**	**Astronomy and Astrophysics (PRL)**
D1	**Sub Area**	**Comets (PRL)**
D1.1	Comets and asteroids form the major part of the population of small bodies of the Solar System. These objects were scattered into different directions during the proto-solar nebula phase as the planets formed. This has given rise to many reservoirs of comets and asteroids. As they come closer to the Sun, the material constituting the comet starts to sublimate and is thrown out. The ejected material develops into a coma and tail. The characteristics of the dust in coma can be studied by measuring the polarization induced by scattering of solar light by the dust. In order to ensure that the light being scattered (and polarized) is from the dust grains, one has to use narrow filter passbands that exclude the molecular emissions.	
D2	**Sub Area**	**Extra-solar planets (PRL)**
D2.1	A new program for detection and characterization of exoplanets using optical fiber-fed stabilized high-resolution spectroscopy was initiated at the Mt. Abu Gurushikar Observatory of PRL. The project is called PRL Advanced Radial-velocity Abu-sky Search (PARAS). PARAS have the capability to a level of sub-2m/s precision on bright stars (< 6.5 mag) and 5 to 10m/s on fainter stars up to 10th mag. PARAS was involved in the first detection of an exoplanet from the Country (India) which has a mass of a 27 Earth mass. In the near future we will have 2.5m telescope and PARAS-2 for sub-1m/s precision, which will be able to detect super Earths in close orbits around G and K dwarfs. We also have a 43cm wide field telescope for doing exoplanet transit observations. Apart from Exoplanet detections, research work on exoplanet atmospheres are also conducted through global collaborations and modelling of exoplanet atmospheres.	
D3	**Sub Area**	**Galactic Astronomy (PRL)**
D3.1	**Star Formation (PRL)** To explain the origin of massive stars (> 8 Msun) and young stellar clusters, a cloud-cloud collision process has been proposed in recent years as an interesting alternative against the existing competing theories of massive star formation. Multi-wavelength studies are being done from Radio to optical wavelengths to model and understand the physical processes inside the star forming molecular clouds.	

D3.2	**Studies on Asymptotic Giant Branch (AGB) stars (PRL)** Post-Asymptotic Giant Branch (PAGB) stars are rapidly evolving low and intermediate-mass stars (1-8 Solar mass) in the transition phase from the mass-losing AGB stars to the Planetary Nebulae (PNe) and are enshrouded by optically thick circumstellar matter that generally consists of molecular gas and dust. There exist a number of unresolved issues as to the physical processes that govern the evolution at these late stages. The chemistry of the circumstellar environment of these stars is highly dynamical due to the enrichment of the surface layers by the convective dredge-up process; initially oxygen-rich envelopes turning to carbon-rich.
D3.3	**Novae and Super Novae (PRL)** Cataclysmic events in the sky called Novae where a white dwarf accretes mass from a Giant star in a binary system and when the total mass of the white dwarf exceeds the Chandrashekar limit of 1.4 Solar Mass, hydrogen fusion flash happens on the surface of the white dwarf. Such astrophysical are extensively observed from Mount Abu facility using the PRL Near-IR camera and spectrograph and are studied in detail. Several interesting results were derived from these studies like detections of Dust, evolution of atomic and molecular species to understand the evolution and time scale of such astrophysical systems. NIR study of supernovae were initiated from early 2014 from Mt. Abu in the near infrared wavelengths with the outburst of Supernova 2014J which was the brightest and closest supernova Type 1a in the last four decades. Three bright supernovae namely SN2014J, SN2016adj and SN2017eaw are extensively observed from Mt. Abu facility both spectroscopically and photometrically and studied in detail.
D3.4	**X-ray Binaries and Pulsars (PRL)** Galactic X-ray binaries are among the brightest X-ray sources in the sky and are known to be variable over time scales ranging from milliseconds to years. However, over the intermediate time scale of few minutes to hours these sources, particularly the black hole binaries, are not known to vary significantly. We employed an innovative method of phased resolved spectroscopy with constrained system parameters which showed that, it is the high mass accretion rate that is responsible for the observed ‘heartbeat’ type variability. For this space-based X-ray telescopes are used like RXTE and XMM-Newton. Astrosat was used to measure the first polarization measurements in the CRAB pulsar in the X-ray wavelengths. The Crab pulsar is a typical example of a young, rapidly spinning, strongly magnetized neutron star that generates broadband electromagnetic radiation by accelerating charged particles to near light speeds in its magnetosphere. Despite the spectroscopic and timing observations over decades, the mechanism of the emission in pulsars remains poorly understood. Polarization analysis only within the off-pulse region of the pulse profile showed that the emission has slightly higher polarization with fraction of polarization 39.0 +/-10%. The high significance of polarization detection enables to examine the dependence of polarization characteristics with pulse phase.

<table>
<tr><th>D4</th><th>Sub Area</th><th>Extra-Galactic Astronomy (PRL)</th></tr>
<tr><td>D4.1</td><td colspan="2">Active Galactic Nuclei (PRL)
In a long-term program, Active Galactic Nuclei (AGN) have been studied to understand their structure and energy processes which lead to huge energy output from a very compact region. Blazars, a subclass of AGN, are used as tool in this study. Optical brightness and polarization variability studies enables us to make studies on the size of the inner region from where the central engine that is the black hole is located and indirectly infer the mass of the black hole.</td></tr>
<tr><td>D4.2</td><td colspan="2">Studies of High-redshift radio galaxies (PRL)
Deep radio surveys combined with auxiliary multi-wavelength surveys have helped the discovery of a new population of distant and dusty galaxies. These galaxies termed as Infrared-Faint Radio Sources (IFRSs) are detected at radio wavelengths but they are very faint or undetected in the optical, IR wavelengths. Notably, the surface density of IFRSs is found to be higher than that of radio galaxies. It was found that the IFRSs are high-redshift radio-loud active galactic nuclei at the redshifts $z = 1.7 - 4.3$, and a limit of $z \geq 2.0$ is placed on the IFRSs with no or faint optical counterparts. The discovery of this new population of galaxies is crucial to understand the galaxy evolution in the early Universe. Such observations are being carried out using the national facility of GMRT in the radio wavelengths, and then look for their optical counterparts. They also help us to understand the Universe at an epoch time of redshift of $z > 2.0$.</td></tr>
<tr><th>D5</th><th>Sub Area</th><th>Astrochemistry, Astrobiology (PRL)</th></tr>
<tr><td>D5.1</td><td colspan="2">Conditions commensurate to the ISM and Solar System icy bodies can be recreated in the laboratory in order to understand the physico-chemical nature of molecules that are largely frozen on to the cold ISM dust grains. A combination of closed cycle helium cryostat and UltraHigh Vacuum (UHV) condition is used to bring temperatures down to 4 K and pressures of the order of 10-10 mbar. An optical window, mimics the dust grain in these experiments. The nature of the optical windows depends on the wavelength that is used to probe the molecular ices, for example, Zinc Selenide (ZnSe) and Lithium Fluoride (LiF) is used for infraRed (IR) and Vacuum UltraViolet (VUV) probing / Spectroscopy, respectively. To simulate shock processing either shock in the ISM or impact induced shock, an 8-meter-long, high intensity shock tube is used. Samples processed in our shock tube can reach temperatures up to ~ 10000 K. Various facilities are used in order to mimic the condition experienced by astrochemical ices and astromaterials;
(i) electron from a commercial electron gun,
(ii) for ion irradiation we use the ECR facilities,
(iii) for the precious VUV photons from Synchrotron beamlines and
(iv) the shock processing from a gas gun driven shock tube.
Thus, the astrochemical icy conditions are recreated and the physico-chemical nature of astrochemical ices are probed by spectroscopy.
Proposals are invited in order to use these unique facilities mimicking (i) ISM cold dust and solar system icy surface conditions and (ii) shock processing of dust in the ISM and impact induced shock on planetary bodies.</td></tr>
</table>

	These facilities can be used to understand the survivability of biomolecules (and even microbes) under the extreme conditions that can be recreated in the laboratory, so proposal related to astrobiology are also invited.	
E	**Area**	**Space Instrumentation (PRL/URSC)**
E1	**Sub Area**	**Upper Atmosphere (Ionosphere/ Thermosphere) (PRL)**
E1.1	**Optical techniques (PRL)** 1. MISE (Multiwavelength Imaging Spectrograph using Echelle Grating): MISE is a high spectral resolution, large field-of-view (FOV; 140 degrees) instrument that is capable of retrieving faint dayglow emissions at multiwavelengths (OI 557.7, 630.0, and 777.4 nm) that are buried in the strong solar scattered background continuum. 2. NIRIS (Near Infrared Imaging Spectrograph): NIRIS is a large FOV (80 degrees) grating spectrograph that yields spectra in the 823 - 894 nm region. NIRIS is used for deriving nighttime Mesospheric OH and O2 emission intensities and their corresponding temperatures. 3. HiTIES (High Throughput Imaging Echelle Spectrograph: HiTIES yields nighttime spectra at multiple wavelengths of thermospheric interest are OI 557.7nm and OI 630.0nm and O1 777.4). 4. CMAP (CCD-based Multi-wavelength Airglow Photometer): CMAP is a narrow field of view photometer that provides nightglow emission intensities at multiple wavelengths spanning mesosphere to thermosphere. The emissions being Na 589.0nm, OI 557.7 nm, OI 630.0nm, OI 777.4 nm. 5. CPMT (CCD-based Photometer for Mesospheric Temperature): CCD-based photometer for Mesospheric Temperatures (CPMT) is a 5-filter photometer for focussed study of mesospheric temperatures corresponding to OH and O2 emissions. 6. PAIRS (PRL Airglow InfraRed Spectrograph): PAIRS yields nighttime spectra at multiple wavelengths. 7. ADIC (Automated Digital Imaging Cameras) have been developed to carry out simultaneous photography from 4 locations of rocket vapour cloud released from Thumba, India. 8. UVIS (Ultraviolet Imaging Spectrograph): UVIS was designed to obtain emission intensities at MgII 280.0 nm and OI 297.2 nm wavelength which originate in the height range of 85-110 km. It has a FOV of 80 deg with spectral resolution 0.2 nm at 297.2 nm. 9. Narrow Spectral Band, Narrow Field-of-view airglow photometer: This instrument is capable of enhancing the signal to noise ratio (SNR) of nighttime airglow emissions in the wavelengths of OI 630.0 nm and 777.4 nm by limiting the spectral bandwidth and brings out the small variations in the airglow intensity buried in the background by limiting the field of view. This philosophy is now being adopted for space-borne measurements on-board Indian Satelites.	

E1.2	**Radio techniques (PRL)** 1. DPS (Digisonde Portable Sounder): For ionospheric studies we use a digisonde wherein radio waves of different frequencies (0.5 - 20 MHz) are sent upwards and their return echo is monitored which yields information on the height of the ionosphere and the plasma densities therein 2. GPS/GNSS/IRNSS receiver based Total Electron Content (TEC) measurements: Three receivers measure TEC over this region using GPS, GNSS and IRNSS satellite transmissions at multiple frequencies (L1, L5, S band etc.) and are operational in the lab round-the-clock. 3. Langmuir Probe: The lab is also engaged in the design and fabrication of Langmuir probes for space plasma measurements on-board rocket and satellites. The speciality of this class Langmuir Probe is its capability to capture small changes in the electron density perturbations enabling the group to address various plasma irregularity processes in the ionosphere.
E1.3	**Earth' S Lower/middle Atmosphere (PRL)** 1. Aerosol Chemical Speciation Monitor (ACSM) 2. Ceilometer 3. Disdrometer 4. Dual wavelength dual Polarization LIDAR 5. Flame Ionization Detector (FID) 6. Gas Chromatographs 7. Greenhouse Gas Analysers 8. Hygroscopic Tandem Differential Mobility Analyzer (HTDMA) 9. LIDAR 10. Multiwavelength Radiometer 11. Single Particle Soot Photometer (SP-2) 12. Surface Trace Gas Analysers 13. Dual wavelength dual polarization Lidar 14. Multi wavelength sun photometer 15. Pyranometer 16. Pyrgeometer 17. Pyrheliometer 18. Proton Transfer Reaction- Time of Flight- Mass Spectrometry (PTR-TOF-MS)- The PTR-TOF-MS technique is used for the measurements of different VOC compounds present in atmosphere. The time of flight (TOF) mass spectrometer separates the ions according to their mass to charge ratio (m/z). The PTR-TOF-MS provides the mass spectra of many VOCs in a short time (<1 s). PTR-TOF is used for measurements of trace gases (ppt-ppb levels) in air and provides a high time resolution data. This is India's first Proton Transfer Reaction Time of Flight Mass Spectrometer (PTR-TOF-MS) system.

	19. Thermal Desorption-Gas Chromatography-Flame Ionization Detector/Mass Spectrometer Detector (TD-GC-FID/MSD)- The GC-FID/MSD system which is coupled with a Thermal Desorption-gas is used for the analysis of a class of VOCs known as Non-Methane HydroCarbons (NMHCs) for which PTR-TOF-MS based measurement is not possible. 20. VOC Analyzers-The VOC analyzer provides online gas chromatograph for the analysis and monitoring of trace amounts of C2-C12 hydrocarbons. VOC analyzers are portable and have been used in field experiments at remote places. This setup has been operated during ship-borne campaigns to study the remote atmosphere.	
E2	**Sub Area**	**Laboratory instrumentations (PRL)**
E2.1	• Development of electron and ion imaging spectrometer • Coincidence momentum imaging spectrometer, reaction microscope • Development of ions source/Ion gun • Laser produced plasma: Plume dynamics and plasma spectroscopy • Laser Induced Breakdown Spectroscopy: Fundamentals and applications • Development of Magnetic Bottle electron Spectrometer • Large area Position sensitive detectors for charged particles imaging Development of Piezo pulse valve (0 to 1 KHz rep rate) and plunger-based pulse valve (0 to 1KHz rep rate) for supersonic atomic/molecular beam generation	
E3	**Sub Area**	**Planetary Exploration (PRL)**
E3.1	**Atmosphere experiments (PRL)** 1. Charge particle measurements 2. Ion and Neutral Composition (Mass Spectrometer) 3. Vertical distribution of Electron Density 4. Vertical distribution of Species 5. Planetary Lightning experiment: To understand lightning on other planets like Venus and Mars. Research work can involve modelling, data analysis and instrumentation related to cloud charging, EM wave propagation in ionosphere, plasma waves, ground based experiment. 6. Radio Occultation Experiment to observe profiles of atmospheric parameters like temperature, density etc.	
E4	**Sub Area**	**Planetary Atmosphere (PRL)**
E4.1	**Surface measurements (Elemental composition) experiments (PRL)** 1. X ray Spectrometer 2. Laser induced breakdown spectroscopy 3. Surface & Subsurface Thermophysical properties of planets	

	4. Dust and surface charging The objective is to study lunar surface charging, dusty plasma, laboratory experiments, dust levitation, dust impact, escape study, instrumentation. 5. Microwave probing of surface and subsurface 6. Planetary Geophysical Studies – Experiments and Numerical Modeling (PRL)	
E5	**Sub Area**	**Astronomy (PRL)**
E5.1	**Instrumentation for ground-based and space-borne facilities (PRL)** 1. Visible and IR imaging with precision photometry, polarimetry, low resolution spectroscopy in IR and optical wavelength and high resolution optical fibre based spectroscopy for ground based 1.2 m and upcoming 2.5 m telescope. 2. X-ray instrumentation for space-based facilities (Imaging and Spectra and Polarization). 3. Gamma Ray Spectrometer for space-borne platforms. 4. Active optics for upcoming 2.5 m telescope. 5. Detector arrays for Visible, IR and X-ray regions.	
E6	**Sub Area**	**Solar Studies (PRL)**
E6.1	**Solar Wind Instrumentation (PRL)** Aditya-L1 mission is India's first dedicated science mission for the study of the Sun. Aditya-L1 will be placed at the first Lagrangian point (L1) of the Sun-Earth System. ASPEX payload on-board Aditya-L1 will be dedicated for the investigation of the characteristics of solar wind ions (H+, He++and few other ions) from low to high energies with directional information. Not only that, the arrival of interplanetary transient events(e.g. ICME) at the L1 point will be flagged by the enhancements in ioncounts in 3 channels beyond a pre-defined threshold and thus three distinct flags will be available as soon as telemetry allows. Therefore, ASPEX holds not only scientific promise but also the potential as a useful payload as far as space weather forecasting is concerned.	
E6.2	**Optical instrumentation for Solar observations (PRL)** A 50 cm telescope for solar observations. Specialised back-end instruments, namely a Narrow–band Imager to record simultaneous images of the photosphere and chromosphere, a Polarimeter to measure the magneticfields in sunspots and an Adaptive Optics system for image stabilisation and to achieve diffraction-limited performance.	
E6.3	**Active and adaptive optics for diffraction limited imaging (PRL)** To achieve high-resolution observations with ground-based telescopes, Udaipur solar observatory (USO) is engaged in the research and development of active and adaptive optics systems for compensation of atmospheric turbulence in real-time. A low-order adaptive optics system is already developed; to achieve the maximum possible resolution with existing telescopes at USO, the development of a high-order AO system is in progress.	

	In this regard, different mechanisms/techniques are being explored for wavefront sensing and wavefront reconstruction. Besides, off-line image restoration techniques such as blind-deconvolution and speckle masking techniques are being explored.	
E6.4	**Liquid crystal development for near infra-red spectroscopy (URSC)** National Large Solar Telescope (NLST) is a ground based system which requires a novel detector for faster Spectro-polarimetry as to minimize induced cross-talks. Development of Liquid Crystal controllers within India is a critical pre-condition for high accuracy polarimetry.	
E6.5	**Multilayer coated mirror characterization for X-ray optics–Process and charaterization (URSC)** X-ray multilayer mirrors is a critical technology involved in the use of Imaging Spectrometer for Solar Wind charge exchange from exospheres. Characterization of X-ray multilayer coated mirrors is required.	
E7	**Sub Area**	**X-ray transients (URSC)**
E7.1	**Timing and spectral studies of X-ray transients (URSC)** Timing and spectral studies of X-ray transients like Cataclysmic variables, searching for new QPOs and coherent pulsations in X-ray binaries using archival data. Some of the scientific problems that can be addressed under these studies are: Estimation of the mass of compact objects in binaries Modeling the complex emission mechanisms from accretion disk around Galactic and extragalactic X-ray sources	
E8	**Sub Area**	**Exo-planets: Exo-planet studies with archival data (URSC /PRL)**
E8.1	**Experiments to detect biosignatures of planetary / exoplanetary systems (PRL)**	
F	**Area**	**Remote sensing data analysis from planetary exploration missions (PRL/SAC)**
F1	**Sub Area**	**Moon (PRL/ SAC)**
F1.1	**Chemical, mineralogical and morphological studies (PRL)**	
F1.2	**Lunar surface sciences (SAC)** The main research themes for research includes Lunar Surface composition, Lunar morphology, Hyperspectral data analysis for Lunar Surface, Thermal Remote Sensing of the Moon, Spectral characterization of Lunar analogues, Lunar surface dating and lunar volcanism. Multi-frequency microwave SAR studies for H2O / Ice detection on Lunar surface.	
F1.3	**Lunar surface science (Impact Cratering, Volcanism, Space weathering) (PRL)** The main research themes includes Lunar Morphology, Surface composition via Hyperspectral data analysis, Thermal Remote Sensing of the Moon, Lunar surface dating using crater chronology, Spectral characterization of Lunar analogues, and Multi-frequency microwave SAR studies for H2O / Icedetection.	

F2	**Sub Area**	**Mars (PRL)**
F2.1	**Morphology, mineralogy, chronology and topography studies (PRL)**	
F2.2	**Studies on Martian analogue (PRL)**	
F3	**Sub Area**	**Mars (NRSC/SAC)**
F3.1	**Studies related to Martian surface and polar ice (SAC/ NRSC)** Major research themes are • Characterization of Martian analogous rocks in India, • Hyperspectral analysis of Mars data, • Thermal remote sensing of Mars, • Martian Atmosphere. • Surface composition of mars Remote Sensing for Trace gases. Study of Phobos & Deimos (Moons of Mars).	
G	**Area**	**Laboratory study of Astromaterials (PRL)**
G1	**Sub Area**	**Meteorites from asteroids (PRL)**
G1.1	**Early solar system processes and time scales (PRL)**	
G2	**Sub Area**	**Moon and Mars Meteorites (PRL)**
G2.1	**Composition, evolution and chronology (PRL)**	
H	**Area**	**Study of terrestrial analogues of Moon and Mars (PRL)**
H1	**To understand surface properties and aqueous processes on Mars (PRL)** Geochemical, Spectroscopic, X-ray & astro-biological studies of the terrestrial analogues of Moon and Mars.	
I	**Area**	**Payloads for upcoming planetary missions (PRL)**
I1	**Experiments based on EM radiation, particle irradiation and nuclear reactions can be devised to understand surface and subsurface composition and the equipment can be realized in a miniaturized space qualified form (PRL).**	
I2	**Radio Occultation Experiment (PRL)** This is to observe profiles of neutral density, temperature, ion densities in the atmospheres of Mars and Venus for future ISRO missions.	
I3	**Development of In-situ technologies for planetary surface and sub-surface science (PRL).**	

I4	**Experiments related to hypervelocity dust impact, micrometeorite detection, modelling and data analysis, study of space debris. Payloads are being developed to dust Interplanetary Dust Particles. (PRL).**	
I5	**Langmuir Probe (PRL).**	
I6	**Miniaturised Neutral Ion Mass Spectrometer (PRL)** To observe ions in the exosphere of Mars and Venus in ISRO's future missions.	
I7	**Energetic Ion Spectrometer (PRL).**	
I8	**Lightning Experiment (PRL)** Payload to detect and study lightning on Venus is being developed for future ISRO mission.	
J	**Area**	**Earth System Science Studies (PRL)**
J1	**Sub Area**	**Biogeochemistry (PRL)**
J1.1	**Biological N2 fixation in oxygen minimum zones (OMZs) of the Indian Ocean (PRL)** Nitrogen and oxygen are important elements for life and their cycling in ocean is interconnected. The distribution of oxygen in the ocean interior is controlled by an intimate interplay of physics and biology. Oxygen is transported by circulation and mixing processes into the ocean interior from near-surface waters, where it is produced by photosynthesis and exchanged with the atmosphere. Oxygen consumption by bacterial respiration of organic matter occurs throughout the ocean but most intense in oxygen minimum zones (OMZs). Recent observations suggest that the biological N2 fixation (major source of bioavailable nitrogen in open ocean) occurs in such OMZs. Both the supply and consumption of oxygen and bioavailable nitrogen are sensitive to physical parameters in ways that are not fully understood. Research carried out at PRL has led to substantial improvement in our understanding of the various transport and biogeochemical processes responsible for regulating N2 fixation in the Indian Ocean.	
J1.2	**Carbon: Nitrogen: Phosphorous stoichiometry in the Indian Ocean (PRL)** Availability of nitrogen (N) and phosphorus (P) determine the strength of the ocean's carbon (C) uptake, and variation in the N:P ratio in inorganic nutrients is key to phytoplankton growth. A similarity between C:N:P ratios in the plankton and deep-water inorganic nutrients was established in the last century. However, recent studies have suggested a variation in nutrients N:P ratio as well as cell species dependent phytoplankton C:N:P ratio. At present, our understanding of the (environmental) factors governing C:N:P stoichiometry remains poor. The northern Indian ocean due to its geographic setting and monsoonal wind forcing provides a natural biogeochemical laboratory to explore the effect of environmental and physical factors on C:N:P stoichiometry. Research carried out at PRL under the ISRO-GBP program has improved our understanding to some extent on the C:N:P ratio in bulk organic matter pools and nutrients. However, knowledge at the cellular level is still fragmentary, yet critical to identify the variation in the ratio.	

J1.3	**Trace element biogeochemistry in ocean (PRL)** PRL played a lead role and initiated studies on trace elements and their isotopes for the Indian Ocean region under the aegis of International GEOTRACES programme. As part of the Indian GEOTRACES and related programs, high-resolution sampling was performed in the Arabian Sea, the Bay of Bengal, and the Indian Ocean along with some major estuaries and rivers of India to understand biogeochemical cycling and distribution of trace elements. Trace elements in ocean are essential micronutrients and their abundances influence overall productivity of the ecosystem. Distribution of trace elements and their isotopes in oceans also provide information on physical and chemical processes such as water mass movement, redox condition, and sources and sinks of these elements. PRL intends to continue these studies in the northern Indian Ocean as this region is not well constrained vis-à-vis their geochemical cycling.
J1.4	**Nitrogen and carbon cycling in a tropical estuary and adjacent coastal region (PRL)** Estuaries and adjacent coastal regions are vulnerable ecosystems due to increased nutrient loading from anthropogenic activities. Excess nutrients enter the system as organic and inorganic N and P compounds through rivers and the atmosphere, and threaten coastal ecosystems. Anthropogenic inputs cause many estuarine-coastal systems to shift drastically from N limitation to an N surplus leading to eutrophication, a major threat to most of the estuaries and coastal waters around the world. At present, our knowledge of N and C cycling, particularly N uptake dynamics and its dependence on N and P distribution in tropical estuaries and the adjacent coastal waters remains rudimentary. Information about the rates of transformation of N and C in such systems is needed to develop mitigation strategies to restore and save the estuarine-coastal coupled systems from eutrophication. The research carried out in PRL in recent years at different estuarine-coastal coupled systems of India has added significantly to this knowledge.
J1.5	**Carbon and nitrogen fluxes in river systems of India (PRL)** Human activities are drastically altering water and material flows in river systems across India. These anthropogenic perturbations have rarely been linked to the carbon (C) fluxes of Indian rivers that may account for considerable percentage of the global fluxes. In this regard, a conceptual framework for assessing human impacts on Indian river C and N fluxes is needed. Lower reaches and tributaries of rivers, such as the Ganges, which drains highly populated urban centers, tend to exhibit higher levels of organic C and the partial pressure of CO2 (pCO2) than less impacted upstream reaches. Also, proper quantification of impacts of river impoundment on CO2 outgassing from the rivers of India is still lacking. Within this context, PRL has initiated a program to study C and N cycling in rivers of India, where movement of these important elements throughout the river continuum will be studied.
J1.6	**Nitrogen and carbon cycling in a terrestrial ecosystems of India (PRL)** In past few decades, human activities have altered many terrestrial ecosystems by increasing human derived N inputs which has caused shift in natural cycling of elements. This has eventually affected C fluxes and its storage capacity of soils, providing positive feedbacks to climate change. As N acts as an important growth limiting nutrient for plants

	and the biogeochemical cycles of N and C are coupled, it is important to understand N cycling in forest ecosystems in order to develop proper forest management practices. Production of NH4+ in soils can be studied by determining either net rates which shows the amount of nutrient remaining after consumption; or gross rates which allows quantification of total mineralized N. So far, many studies have been conducted on net rates of mineralization as it is considered to be the principal step which determines plant productivity but few studies exists vis-à-vis gross mineralization rates worldwide. For the first time in the southeastern Asian region, research carried at PRL using isotope dilution technqiue to quantify rates of gross mineralization and nitrification in the Himalayas, Western Ghats, Rann of Kutch, and Kerala has added significantly to our knowledge regarding natural pathways of nutrient production and consumption in different ecosystems of India.	
J2	**Sub Area**	**Paleoclimate (PRL)**
J2.1	**Coral as a Proxy for Sea Surface Properties (PRL)** Coral are organisms growing in shallow marine conditions and are sensitive to Sea Surface Temperature (SST). They form annual bands and record properties of sea surface conditions at very high-resolution and could prove to be a good calibration for paleoclimatic studies. Based on corals from the Andaman region, reservoir age correction was provided as applicable to radiocarbon dates of marine samples. Paired measurements of Sr/Ca and stable isotopes in corals from Andaman region have shown that these can be effectively used for calibration of SST and show signatures of Indian summer monsoon. Coral radiocarbon measurements for the period 1949-2013 have yielded air-sea exchange rates of CO2 for the Indian Ocean and shows relation with wind speed and alkalinity.	
J2.2	**Paleoclimatic Reconstructions from Marine Sediments of the Indian Ocean (PRL)** PRL has been at the forefront of research in paleoclimate reconstruction. Towards this, several marine cores from the northern Indian Ocean have been investigated. Based on studies of a sediment core from the western Arabian Sea, it was observed that variations in the Somali upwelling has relationship with southwest monsoon rainfall. Evidence of poor bottom water ventilation during LGM in the equatorial Indian Ocean was found from studies in the equatorial Indian Ocean. Recently, signatures of global climatic events and forcing factors for the last two millennia from the active mudflats of Saurashtra has been found. Similarly, cores from other regions of the Indian Ocean are under investigation.	
J2.3	**Past climate using speleothems (PRL)** Past monsoon conditions can be assessed from variations in oxygen isotope ratios and trace element compositions in cave carbonate deposits (stalagmites). Exploring new caves covering different geographical sites and monitoring variability in isotopic and geochemical compositions of modern cave seepage water can add to a very limited data set available on past monsoon from terrestrial records. Also, trapped water in the carbonate matrix represents the past water. Its isotopic composition can be utilized to interpret past hydrological conditions. Work is being carried out on the development of	

	vacuum technique to extract trapped water from the carbonate matrix along with dating technique utilizing U-Th decay series, which is presently unavailable in India. Overall, PRL has contributed significantly to paleomonsoon reconstruction using speleothems.	
J2.4	**Paleoglaciation records from the central and western Himalaya (PRL)** The mountain glaciers are active geomorphic agents to shape the landforms and are responsible for producing some of the most spectacular landscapes on the surface of the earth. Timing and amplitude of paleoglaciations represent important cornerstones of terrestrial paleoclimatic research as glaciers are arguably the most sensitive recorders of climate changes as they respond to the combined effect of snow fall and temperature. To reconstruct the history of glaciations, large scale field mapping of glacial deposits (moraines) along with geochronology using different techniques like optical chronology and cosmogenic radionuclides dating is being carried out at PRL.	
J3	**Sub Area**	**Atmospheric chemistry (PRL)**
J3.1	**Non-conventional stable isotopes in atmospheric carbon cycle research (PRL)** Precise quantifications of the sources and sinks of CO2 in the atmosphere are very important for modelling future climate. The existing studies, mainly based on the conventional stable isotope ratios and CO2 concentration are not enough to precisely quantify the CO2 budget because of their complex interactions with various reservoirs and contribution from multiple components with overlapping range of isotopic ratios. Clumped and triple oxygen isotopes in CO2 are two recently developed isotopic proxies and are found to be applicable to address many of the carbon cycle issues. Clumped isotopes in CO2 are molecules in which more than one isotopes are replaced by their rare counterparts and are mostly used as a proxy of CO2 formation/exchange temperature. The triple oxygen isotopes or 17O excess in CO2 is the excess abundance of 17O compared to that expected from mass dependent fractionation processes and is mostly acquired from the interaction of CO2 with ozone in the stratosphere. These two isotope proxies basically measure anomalies and are free from many terrestrial complex processes. With modern mass spectrometry techniques, very precise measurements of these isotope ratios are possible and hence can be used to estimate the contribution of CO2 from different sources and estimate the gross primary productivity, the total CO2 assimilated by plants. Geosciences division of PRL recently started developing techniques for measuring these nonconventional isotope ratios, along with the existing conventional isotope measurement facilities to precisely constrain the atmospheric carbon budget in India.	
J3.2	**Research on Aerosol Chemistry and Characteristics (PRL)** Aerosols are known to affect the Earth's climate (radiation budget, hydrological cycle), aquatic ecosystem (biogeochemistry of oceans and lakes), and air quality (visibility and human health). After emission and/or formation, aerosols react with other species during atmospheric transport that further lead to transformations in their chemical and physical properties. These processes not only affect their optical and hygroscopic properties but also the bioavailability of nutrients present in aerosols. However, the characteristics and	

	composition of aerosols remains poorly understood. Aerosol research at PRL focusses on understanding the physicochemical characteristics of ambient aerosols over different regions of India, and how they relate to atmospheric chemistry, clouds, climate, ecosystem, air quality, and human health. Chemical and isotopic compositions of aerosols as well as their characteristics using state-of-the-art online and offline measurements techniques over different parts of India and surrounding oceans are being studied. In addition, focus is specifically on studying emerging research areas such as secondary organic aerosols, brown carbon aerosols, and oxidative potential of aerosols. Such studies are not only important in understanding and assessing the effects of aerosols on air quality and climate, but also in validating/modifying regional and global climate models.	
J4	**Sub Area**	**Earth Surface Processes (PRL)**
J4.1	**Application of non-traditional stable isotopes to study Earth system processes (PRL)** It is important to understand the origin and temporal evolution of the Earth and its various systems. Recently, non-traditional stable isotopes have been used as a new tool to study various earth system processes. Some of the important aspects that can be explored using non-traditional stable isotopic systems are redox evolution of Earth's oceans and atmosphere (Fe, Mo and U isotopes), reconstruction of silicate weathering history and understanding the weathering regime (Li isotopes), reconstruction of seawater paleo-pH (B isotopes), paleo-volcanism (Hg isotopes), biomineralization of foraminiferal tests (Ca isotopes). The initial step to study these problems in Earth Sciences by suitable non-traditional isotopic proxies involve intensive field work for collection of appropriate samples (e.g., recent marine sediments and black shales for understanding recent and past ocean redox using Mo isotopes, river water and suspended sediments to understand weathering regime using Li isotopes) followed by sample preparation in laboratory for extraction and purification of element(s) of interest, their mass spectrometric analyses, and modelling of data. PRL has been involved in such studies and wishes to continue using emerging techniques as they are indispensable for understanding the Earth as a system.	
J4.2	**Catastrophic events across the Indian geological records (PRL)** At PRL, we aim to understand 'catastrophic events' such as mass extinction events across major boundaries (Permian-Triassic -250 Million Years ago, Cretaceous-Palaeocene – 65 Million year etc.) from the Indian geological records. Also, works on impact craters (Lonar, Dhala, and Ramgarh etc.) are underway, where the major objectives are to understand the processes responsible for such global events using the geochemical anomalies and chronological information along with proxies to pin point the factors responsible for such type of events.	
J4.3	**Present and past extreme events (PRL)** The extreme precipitation events, like of June 2013 in Uttarakhand, create flash floods in monsoon dominated Central Himalayan valleys. The fluvial deposits in the associated river basins are being studied at PRL to understand the past processes from the central	

	to western Himalayas during the late Quaternary period. Generally, sediment bulking in the monsoon dominated Himalayan rivers is caused due to (i) landslide dammed lake out bursting, (ii) the glacial lake out bursting, and (iii) recession of valley glacier deglaciation. In this program, we intend to quantify the spatial and temporal changes in the sediment provenance in order to ascertain the role of climate and tectonics in valley-fill deposits.	
J4.4	**Accelerator Mass Spectrometer: Application of Cosmogenic Radionuclides in Geosciences (PRL)** The Accelerator Mass Spectrometer Facility at PRL has been installed to measure 14C, 10Be and 26Al. Radiocarbon (14C) has been extensively used in application of earth, ocean, planetary and atmospheric sciences. Several samples from archaeological sites have been dated using 14C. Radiocarbon has been used as a tracer to understand various ocean processes. One of the major oceanic climatic process which governs the Earth's climate is ocean circulation. Based on radiocarbon dates of planktonic and benthic for a minifera in marine sediments, ventilation rates of the Indian Ocean have been established for the last 50 kyr. Radiocarbon dates of groundwater provide estimate of climatic conditions at the time of recharge. Meteoric 10Be has been used as chronological tool for dating marine sediments up to 10 million years. In-situ 10Be is being used for deriving the exposure age of glacier and gives understanding of glacier retreat or advance rates.	
J5	**Sub Area**	**Hydrology (PRL)**
J5.1	**Application of Oxygen and Hydrogen Isotopes to Understand Hydrological Processes (PRL)** There are complex hydrological processes which cannot be discerned by measuring volumes and fluxes of water across hydrological boundaries. Such processes are, for example, variation in vapour source for rainfall, evaporation from falling raindrop, continental recycling of water, surface water - groundwater interaction and exchange. These processes can be discerned by monitoring oxygen and hydrogen isotopic composition of water in different hydrological reservoirs such as groundwater, river water, rainwater, oceanwater and atmospheric water vapour. Spatio-temporal variation in isotopic composition of water in these hydrological reservoirs in conjunction with various geohydrological and hydrometeorological parameters can provide new insights in the hydrological processes. A Stable Isotope Ratio Mass Spectrometer laboratory set up under the National Programme on Isotope Fingerprinting of Waters of India (IWIN National Programme) is leading this long-term programme of isotopically characterizing water sources of India with a view to obtain new insights into hydrological processes. Some of the important scientific results from this research pertains to interaction between rain and vapour, relative contribution of vapour from the Arabian Sea and the Bay of Bengal, extent of evaporation from falling raindrops, identification of regions in which groundwaters do not seem to be recharged by freshwater during an annual cycle of groundwater hydrology.	

K	Area	Atomic, Molecular and Optical Physics (PRL)
K1	Sub Area	Spectroscopy (PRL)
K1.1	**Ultrafast science and technology (PRL)** The electron dynamics in atomic and molecular system is in attosecond (10^{-18} s) and the nuclear dynamics is ranging from picosecond (10^{-12} s) to femtosecond (10^{-15} s) time scale. Science at this time scale is named as ultrafast time. At atomic level, most of dynamical processes are in this time scale. Modern experimental techniques are needed to understand the ultrafast science. • Femtosecond stimulated Raman spectroscopy • Femtosecond transient absorption spectroscopy • Femtosecond-Laser Induced Breakdown Spectroscopy : nanosecond-LIBS, Nanoparticles Enhanced LIBS, Femtosecond-LIBS • Femtosecond micromachining	
K1.2	**Development of XUV/EUV light source using femtosecond laser (PRL)** • Development of XUV/EUV source based on Higher Harmonic Generation method • Higher Harmonic Generation from gas, solid, liquid and plasma • XUV-IR pump probe experiment • Photoionization of atoms and molecules using XUV/X-ray • Photoelectron Spectroscopy • Intense TW femtolaser light interaction with matter: Extreme photonics	
K1.3	**Attosecond science and technology (PRL)** • Attosecond Streaking • Attosecond transient absorption spectroscopy • Attosecond physics phenomena at nanometric tips	
K1.4	**Atomic collisions (PRL)** • Electron and ion impact processes in molecules • Study of atomic and molecular clusters	
K2	Sub Area	Photonics and nonlinear optics (PRL)
K2.1	**Quantum communication and quantum key distribution (QKD) (PRL)** Quantum mechanics provides ultimate security to the data by encrypting it with the key, which is distributed using principles of physics inbuilt into the quantum mechanics. This cannot be matched with the security provided by the present encryption techniques which are based on computational hardness of the problem and will be redundant with the advent of quantum computers utilizing enormous computing power along with intelligent quantum algorithms. The key distribution based on photonic qubit could be done through	

	the fibre as well as through the free space. However, to generate these keys one needs to make sources of single photons and entangled photons which are distributed using different communication protocols. At PRL, we are working on all aspects of quantum communication and QKD.	
K2.2	**Quantum sensing and metrology (PRL)** The measurement of quantum states interacting with a system can provide very precise knowledge about the system. One can use it for sensitive measurements of displacement, rotation, time intervals, magnetic fields as well as high-resolution imaging. All this requires creating quantum states such as superposition states and entangled states of photons or electron spins and their measurements. This is another theme, PRL is involved with under quantum science and technology.	
K3	**Sub Area**	**Luminance physics (PRL)**
K3.1	**Development of a compact online radiation dosimetry system for personal monitoring (PRL)** There are several instances like in case of nuclear accident or space missions where it is difficult but important to predict the radiation level and its effect on humans. In such cases, the use of the passive dosimeter may not be possible and even if it's possible, it will provide delayed results as samples need to be brought to laboratory to measure the dose. In such cases, the idea of making a compact system equipped with on spot radiation measurement mechanism can be very useful. The development of compact online dosimeter will be useful for the space program as an on-board tool to keep a check on the radiation dose, which will enable monitoring the radiation safety of crew. Further, the development of technology will be useful for persons working the other areas, associated with radiation hazard situations. Such a system will mainly require three components a) Heat and light stimulation system with associated electronics b) Dosimeter c) Detection system with dose analysis program and associated electronics. There are several dosimeters, like Al_2O_3:C, LiF etc. which are currently being used as a personal dosimeter due to their good radiation response and dosimetry linearity. Our group expertise in the dose estimation procedures and have some experience in development of ground based systems for measurements and analysis. In this regard, proposals are invited for designing a system, which is compact in size and can be useful for personal dosimetry for manned missions.	
K3.2	**Development of up-conversion and down-conversion phosphors (PRL)** Luminescent phosphors are nowadays widely used to tune the wavelengths of the incoming light in order to meet the desired results. The luminescent phosphors have capability to modify the spectrum of incoming radiations and enhance the output in desired wavelength range. One of the upcoming field in these phosphors is development of up-conversion and down-conversion phosphors. In up-conversion two or more low energy photons are combined to give a high energy photon and in down conversion high energy light photons are converted to low energy photons. This has significant	

	application in increasing efficiency of solar cells and will be especially useful in situation where light availability is less. Solar cells respond to visible region (400-700 nm) with maximum response in 600-700 nm. As a result, a significant part of solar spectrum is not used in conversion of energy. In some carefully designed materials the response can be further extended in near infrared region but leads to escalation of the cost. One of the easier approach for enhancing the efficiency of solar cells (conventional or improved materials) is by tuning the energy of unused part of solar spectrum viz. infrared and UV to visible region. A thin coating of phosphor layers on solar cells can suitably tune the solar spectrum for increasing the efficiency. Thus this project seeks development of such up-conversion and down-conversion phosphors which can be used for enhancing the efficiency of solar cells and will be useful for future space missions.
K3.3	**Earth Surface Landforms and Processes: Fluvial depositional environment and facies (PRL)** Rivers are one of the dominant agents of landscape modification as the flowing waters are continually eroding, transporting, and depositing sediments (Fluvial Processes) in the course of time. Fluvial geomorphology deals with the form and function of streams and the interaction between streams and the landscape around them. It depends on fluvial dynamics, sediment load, slope / slope stability, vegetation, surface runoff, climate, tectonics, etc. An architectural element may be a component of a depositional system, characterized by a distinctive facies assemblage, internal geometry, external form etc. Stream morphology is dynamic and constantly changing in both space and time. River based flooding is among one of the most frequent and widespread natural hazards of our country. Apart from studying palaeo-climates, studying fluvial deposits are important in economic aspects as they are characterized by good porosity and permeability, thus constitute excellent aquifers, placer deposits, coal, oil and gas reservoirs are hosted in fluvial units. The understanding of system dynamics will help us for planning for climate change. Thus, proposal is invited to understand fluvial processes and palaeoclimate changes.
K3.4	**Earth Surface Landforms and Processes: Coastal configuration changes and interaction with sea level and tectonics (PRL)** The long coastline of India makes it a suitable area to study the past surface, internal and climatic processes that shaped the present day coastline. Understanding the past response to various forcing are important to understand and model the present coastal dynamics in the view of ongoing threat of global warming, climate, sea-level changing scenarios. In view of this, it is important to understand the process taking place along the coast in past and present. The study of such processes will enable us to design the strategies for probable future issues and provide us the parameters which should be monitored via ground or satellite based observations. Sedimentary archives along the coast provide excellent proxies to study such processes in past. Such archives are need to be studied in order to develop understanding of coastal sedimentary processes. The proposals are thus invited for coastal sediment studies.

L	Area	Emerging Areas In Theoretical Physics (PRL)
L1	Sub Area	Ameliorating the Theoretical Frameworks of Fundamental Physics (PRL)
L1.1	**Scrutinising the validity of the standard models of particle physics and cosmology and their extensions by computing various observables and comparing them with the experimental data (PRL)** Some of the experimental evidence in the areas of particle physics and cosmology indicate that the known and established theoretical frameworks in these areas are not complete and adequate. Quantifying these inadequacies, modifying theoretical frameworks and testing their viabilities constitute a core of the theoretical physics programme emerging in the next couple of decades.	
L1.2	**Charge-Parity (CP) violation in the neutrino sector and origin of matter-antimatter asymmetry (PRL)** Several neutrino oscillation experiments are in the process of determining the amount of CP violation in the lepton sector and it is expected to be measured within the next 10 years. Whether the observed amount is enough to explain dominance of matter seen in our universe is a question of fundamental interest.	
L1.3	**Testing grand unification through Proton decay (PRL)** Hypothetical theories which unify the fundamental interactions predict unstable protons. Several ongoing experiments are searching for the proton decay and they are expected to give decisive results on some of the simplest frameworks of unification. Activities in this area are therefore going to increase in the coming years.	
L1.4	**Search for the theory of unconventional superconductivity (PRL)** Several superconducting materials have been discovered in the last couple of years which do not follow the known theory of superconductivity. It is one of the active areas where a radically new theoretical framework might be needed to describe the observations.	
L1.5	**Dense matter equation state and neutron stars (PRL)** Observation of about two solar mass neutron stars puts severe constraints on the Equation of States (EOSs) for dense nuclear matter/ hyperonic matter. Gravitational wave data related to neutron star merger and tidal deformability puts interesting constraints on EOS of dense matter. Searching for a proper EOS in the context of astrophysical compact objects is a challenging problem.	
L1.6	**Quantification of the properties of Quark Gluon Plasma (QGP) (PRL)** Quantifying the properties of Quark Gluon Plasma (QGP) produced in relativistic heavy ion collisions important and relevant for strong interaction physics as well as cosmology. Transport properties of QGP at finite baryon densities is a current challenging problem due to limitations of lattice QCD simulations at finite densities. This is relevant for the current and upcoming heavy ion collision experiments and hence will be relevant in coming years.	

L1.7	**Phase structure of dense matter (PRL)** Phase structure of dense matter at finite densities is very rich and will be very relevant in the context of heavy ion collision experiments as well as physics of neutron stars. Dense QCD is expected to have a very rich phase structure at high densities like various color superconducting phases, quarkyonic matter phase as well as various crystalline phases. Structure of these phases and their signatures will be some of the interesting and challenging problems in future.	
L2	**Sub Area**	**Fundamental Physics using Space-borne Experiments (PRL)**
L2.1	**Searching for Dark Matter through balloon/satellite/space-station based detectors (PRL)** Indirect searches of Dark Matter, through balloon and/or space borne experiments, can reveal useful information which is very difficult, and sometimes even impossible, to obtain from the ground based experiments.	
L2.2	**Precision measurement of Cosmic Microwave Background (CMB) (PRL)** Over the past two decades, space based missions like WMAP and Planck have provided very good understanding of the cosmic history by measuring temperature anisotropy in CMB radiation. A more precise measurement of the same is further required to validate the Standard Model of Cosmology and to resolve some pertaining unresolved issues like Hubble Tension etc.	
L3	**Sub Area**	**Data Science and Machine Learning (PRL)**
	This is one of the rapidly growing research areas of the current time. The efforts will be focused on	
L3.1	**Developing algorithms to train machines for efficient processing of big data (PRL)**	
L3.2	**Applying machine learning techniques in the areas of fundamental and space physics (PRL)**	

Meteorology

A	Area	Weather and Climate (NARL/ SAC/IIRS/ NESAC/ NRSC/PRL)
A1	Sub Area	Modelling and Computer Simulations for Weather Prediction (NARL)
A1.1	**Estimating wind and solar energy resources over Indian region and the development of forecasting system for predicting wind potentials using mesoscale Weather Research and Forecasting model (NARL)** Increasing concerns over the global warming and environmental pollution prompts the policy makers to look for the alternate energy resources in place of the conventional energy sources. Solar and wind energy are prominent renewable energy resources to us the last few decades, though considerable effort has been made to use renewable energy resources effectively in the western countries, Asian region still lags in the effective utilization of these alternate resources. One of the primary steps in renewable energy field is the resource assessments for identifying the optimal locations for extracting the winds and solar energies which needs high resolution wind and solar data sets.	
A1.2	**Development of fully coupled ocean-atmospheric model for improving the forecasts of Indian Summer Monsoon at medium-range and seasonal time scales (NARL)** The relative failures of numerical weather prediction models to capture the observed variability of Monsoon on medium range to seasonal time scale and failure to estimate the intensity of extreme events prompts to search for in-abilities of the atmospherics models. One of such problems in NWP models is the lack of precise ocean feedback to atmosphere which is highly essential for understanding and predicting monsoon behavior from long range to medium-range temporal scales. Development of fully coupled ocean-atmospheric model can certainly improve the forecast skill of NWP model for prediction Indian Summer Monsoon at medium-range and seasonal time scales.	
A1.3	**Analysis of extreme weather events over Indian region using numerical modelling tools (NARL)** Understanding tele-connections and the analysis dynamical and physical mechanisms behind the frequent occurrence of extreme rainfall events over Indian region is essential for improving the physical parameterizations in NWP models. The recent studies over Monsoon variability reveals the number of extreme weather events during monsoon seasonare increasing, potential mechanisms are extremely required to models these process and predicting accurately.	
A1.4	**Development optimal assimilation methods for assimilation X-band DWR in NWP models (NARL)** Commencement of dense network of X-band Doppler weather radar provides us opportunity to have various profiles of hydrometeors which can effectively assimilated in numerical weather prediction models using different assimilation strategies for improving	

	operational weather prediction systems. Development of optimal assimilation methods are highly essential for effective assimilation of hydro-meteors and radial velocities from the dual polarized Doppler weather radar (ISRO X-band DWR) data for improving the forecasts of mesoscale convective systems such as thunder storms, cyclones and extreme heavy rainfall events.	
A2	**Sub Area**	**Atmospheric sciences and climate (SAC/ NESAC)**
A2.1	**Climate prediction with coupled Atmosphere-Ocean-Land-Ice models (SAC/ NESAC)** For long term prediction of climate, Coupled model of Atmosphere, Ocean, Land and Ice is very important component. In these models, coupling is an important area of research as different components have different spatial and temporal variability.	
A2.2	**Atmospheric sounding (measurement and understanding of vertical distribution of physical properties of the atmospheric column such as pressure, temperature,wind speed and wind direction, pollution and other properties using remote sensing and in situ observation) (NESAC)**	
A3	**Sub Area**	**Convection/Precipitation/Boundary Layer (NARL)**
A3.1	**Understanding the decadal changes in solar radiation flux at surface and relation with sunspot activity/solar cycle (NARL)** Pyrheliometer can be used to measure direct beam radiation from the Sun and it can be used to measure the total hemispherical radiation (beam + diffuse radiation). The duration of sunshine intensity can be measured using a photoelectric sunshine recorder. Changes in solar radiation flxes during active Sun period vs. quiet period over a longer period of time is proposed to be studied for one or more latitudes.	
A3.2	**Understanding the decadal longwave emission by atmosphere and by earth (NARL)** Earth emits longwave radiation which is responsible for keeping the atmosphere warm. Longwave radiation from earth's surface can be measured using a pyrgeometer.Long term analysis needs to be done to understand the decadal changes in long wavee missions by the earth.	
A3.3	**Studies on logarithmic wind profile of boundary layer (NARL)** Wind speed and direction data obtained from anemometers field at logarithmic spacing in a 50 m tower is to be analysed to understand the log-profile of wind in the boundary layer. The study needs to extended over a longer period to understand the robustness and changes for the season and for different weather conditions.	
A3.4	**Understanding cloud characteristics and properties using lidars (VIS & IR) (NARL)** Visible and IR lidar data range-time-intensities need to be analysed to detect clouds passing over the location. Cloud characteristics like base, top height, thickness, optical thickness, frequency of occurrence, non-sphericity of particle can be studied for a longer period.	

A3.5	**Cloud radiative forcing studies over Gadanki (NARL)** The radiation fluxes reaching the earth surface measured using shortwave, long wave and broadband radiometers/ pyranometer, pyrheliometer could be utilised. Differences in fluxes in the presence and absence of clouds gives the cloud radiative forcing.	
A4	**Sub Area**	**Radiation, Aerosols and Trace gases (NARL/NESAC/NRSC/ PRL)**
A4.1	**Development of low cost nephelometer (NARL)** Nephelometer is an important instrument for aerosol optical properties which are needed to be known for the climatic effects. Current nephelometer technology uses halogen lamp and heavier parts, which are not suitable for balloon borne observations. Recent advancement in LED technology makes it possible to develop light weight low cost nephelomter with similar performance. This will be employed for the developing spaceborne nephelometer for the regular and campaign mode observations.	
A4.2	**Development of OH analyzer (NARL)** Hydroxyl radical (OH-) is an important oxidiser in troposphere and responsible for the removal of green house gases. However due to high reactivity, very short life time, their concentrations are diffiult to measure. Since there is no commercially available OH analyzer, it will be developed in house.	
A4.3	**Atmospheric modelling (NESAC)** Pixel based Aerosol Optical Depth (AOD) estimation by radiative transfer modelling using TOA radiance and validation with field instruments. Development of image based aerosol retrieval techniques over satellite imagery.	
A4.4	**Aerosol characterization and its impact on solar radiation (NRSC)** Absorbing aerosols over Himalayas assume importance not only because of their enhanced radiative impacts when they reside over high albedo surfaces, but also due to their effects on snow whiteness and glacier retreat after deposition. In addition, absorbing aerosols over foot hills of Himalayas and Tibetan plateau are reported to have significant impacts on Indian summer monsoon and associated rainfall.Though several studies have been carried out, aerosol impacts on Indian summer monsoon are not yet clearly understood. In view of these, impacts of aerosols over Himalayan regions are being examined using satellite remote sensing and ground based measurements. Aerosol vertical distribution and contribution of dust in aerosol loading over Himalayas are examined using multi-year satellite observations. Measurements of Black Carbon(BC) concentration in atmosphere; snow and changes inspectralalbedodue to BC deposition will be carried out by conducting field experiments over different regions of Himalayas.	
A4.5	**Modelling of Atmospheric Chemistry and Dynamics (PRL)** Atmospheric chemistry and dynamics play key roles in impacting the air quality and climate. In this regard, modelling over varying scales (local, regional, and global) and complexities (box, chemical transport, general circulation) are being performed at PRL	

	supported by Vikram HPC. In particular, the focus is on the modelling of atmospheric trace gases and aerosols over the South Asian region. A variety of natural and man-made emissions, together with improved representation of complex topography and detailed chemistry are included in complex earth system models. The simulations assist in interpreting observations and in predicting effects of possible scenarios. Feedbacks between atmospheric chemistry and regional climate, also through biogenic processes, are to be studied.	
B	**Area**	**Space Physics (VSSC-SPL)**
B1	**Sub Area**	**Atmospheric Studies (VSSC-SPL)**
B1.1	**Development of state-of-the-art inversion techniques for the retrieval of aerosol parameters over the ocean and land areas from the satellite-measured radiance (VSSC-SPL)** Assessment of the regional distribution of aerosols can be best carried out using satellite remote sensing of spectral radiances observed at the top-of-the-atmosphere. However, in addition to aerosols, theses radiances are contributed by several other sources, including surface reflectance, absorption, emission and scattering by air molecules, and multiple scattering by aerosols and molecules. Hence, determination of aerosol properties from satellite data requires several assumptions and adequate inversion schemes. Development of state-of-the-art inversion techniques for the retrieval of aerosol parameters over the ocean and land areas from the satellite-measured radiances (including polarization and angular measurements) observed at multiple wavelength bands, which incorporate multiple scattering, surface reflectance and absorption and scattering by aerosols and molecules is a challenging problem. The study can have two parts: (i) theoretical formulation, algorithm and software development, simulations and sensitivity analysis, (ii) inversion of the satellite data based on the above algorithm to derive aerosol properties and its validation based on comparison with other observations (including in-situ observations).	
B1.2	**Development of state-of-the-art inversion techniques for the retrieval of trace gases over ocean and land from the spectral radiances in the UV, visible, and IR wavelength bands (VSSC-SPL)** Three-dimensional distribution of trace gases, their time evolution and long-range transport is a major aspect to be studied in the contest of increased greenhouse gas emission and climate change. This can be achieved by satellite remote sensing of the spectral radiances observed at the top-of-the-atmosphere in suitable configurations (e.g., limb viewing, nadir viewing, solar occultation). Development of state-of-the-art inversion techniques for the retrieval of trace gases over ocean and land from the spectral radiances in the UV, visible and IR wavelength bands is a major problem which requires extensive radiation transfer simulations and development of appropriate mathematical inversion schemes. This study should comprise of theoretical formulation, algorithm and software development, simulations and sensitivity analysis, retrieval based on the available satellite data and its comparison with other observations.	

B1.3	**Numerical modelling of the impact of aerosols and trace gases on regional climate over the Indian region incorporating space-based observations (VSSC-SPL)** It is well known that the atmospheric aerosols and greenhouse gases play a crucial role in modifying the climate, including changes in the atmospheric and surface temperatures, cloud development and precipitation pattern. Quantification of this aspect is a major challenge in the present scenario. Numerical modelling of the impact of aerosols and trace gases on regional climate (including atmospheric and surface temperature, rainfall, extreme weather events) over the Indian region incorporating space-based observations can be a problem to be taken up. This also includes the potential impact on monsoon circulation and associated rainfall changes.
B1.4	**Modelling of the atmospheric boundary layer parameters and processes based on improved parameterization schemes for tropical regions (VSSC-SPL)** Dynamics and time evolution of Atmospheric Boundary Layer (ABL) plays a crucial role in the transfer of mass, momentum and energy from the surface to the atmosphere, mixing of aerosols, water vapour and pollutants (including trace species), exchange with free-troposphere, and development of convection and clouds. The boundary layer parameters and processes are parameterized in numerical models. Often, the ABL characteristics represented in models do not agree with those observed and is a major source of error in the numerical models, especially over the tropics. This requires the modification of the parameterization schemes for ABL parameters in numerical models. Modelling of the atmospheric boundary layer parameters and processes based on improved parameterization schemes suitable for tropical regions that reproduce the observed boundary layer fluxes and mixing height is a major problem that needs to be addressed.
B1.5	**Modelling of the propagation of atmospheric gravity waves and planetary waves, their dissipation and role in regulating the mean winds and temperatures in the middle and upper atmosphere (VSSC-SPL)** Atmospheric waves of various scales and sources generated in the lower atmosphere propagate through the middle atmosphere, carrying the momentum and energy to the middle and upper atmosphere. This is one of the most importance mechanisms of coupling between different atmospheric layers. Dissipation of these waves in the middle atmosphere is a major source for regulating the thermodynamics and circulation of the middle atmosphere. The generation of stratospheric Quasi-Biennial Oscillation (QBO) and stratospheric and mesospheric semi-annual oscillations are classical examples of these processes. Dissipation of these waves in the upper atmosphere is a major cause for the ionospheric variabilities. Modelling of the propagation of atmospheric gravity waves and planetary waves, their dissipation and role in regulating the mean winds and temperatures in the middle and upper atmosphere is a challenging problem.
B1.6	**Modelling the space weather impacts over the equatorial and low latitude regions (VSSC-SPL)** Earth's ionosphere plays a pivotal role in the propagation of radio waves and has applications in GPS navigation. This requires a detailed understanding and modelling of

	the ionospheric processes and characteristics. There are several important aspects to be investigated in this direction. This include the modelling of development and decay of different layers and phenomena (e.g., Spread-F, Counter Electrojet, Ionospheric ledges), spatio-temporal evolution of total electron content (TEC) over the low latitude and equatorial region, effect of dynamical forcing from the lower atmosphere, geomagnetic effects and space weather, and lateral and vertical coupling.	
C	**Area**	**Signal and Data Processing (NARL)**
C1	**Sub Area**	**Parameter Retrieval Algorithm Development (NARL)**
C1.1	**Lidar signal inversion methods (NARL)** There are different types of light scattering, namely, Rayleig, Mie, Resonance, and Raman. These scattered signals can be used to retrieve atmospheric parameters, namely temperature, scattered ratio, density of metal species, lidar depolarization ratio. Improvements in the retrieval methods are needed to retrieve these parameters more accurately.	
C1.2	**Retrieval of temperature and minor constituents in the atmosphere from the satellite based radiance measurements (NARL)** The radiance measured from the satellite borne radiometer at the limb viewing for different wavelength channels can be used to retrieve temperature and minor constituents. Usually the 15 um CO2 emission is used as the mixing ratio of CO2 is nearly constant. By inverting raditative transfer equation, the temperature and mixing ratios of chemical constituents can be derived.	
C1.3	**Radar signal processing (NARL)** From the time series of in phase and quadrature phase off the radar signals, noise removal and cogerent integration for desired number of pulses, spectrum is obtained to compute the mean Doppler, Doppler width. The Doppler frequency obtained from three non coplanar directions is used to obtain wind information and the Doppler width is used to study turbulence.	
C1.4	**Improvements in satellite rain retrievals using advanced statistical or physics based algorithms (NARL)** There was large variation among algorithms in the magnitude of the satellite-estimated rainfall, but the patterns of rainfall tend to be similar among algorithm types. Compared to the radar observations, most of the satellite algorithms over erestimated the amount of rain falling in the region, typically by about 30%. Patterns of monthly observed rainfall were well represented by the satellite algorithms.	
D	**Area**	**Radar and Lidar Instrumentation for Atmospheric Probing (NARL)**
D1	**Sub Area**	**Developoment of Radar and Lidar Accessories/Techniques (NARL)**

D1.1	**Time dependent attenuator for Lidar signal (NARL)** The time-dependent variable attenator is used to reduce the dynamic range of lidar signals. The attenuator consists of a Pocket cell between two crossed electronically to attenuate the large signals from close ranges but to transmit for-range signal returns to their full extent. The signal dynamic range can be reduced even by a factor of 100.
D1.2	**Delvelopment of a fiber optic based IF filter for lidar to solve the problem of temperature dependence of filters (NARL)** Optical fibers are made from silica (glass) and hence carry some ingerent advantages such as usability in harsh, high temperature and rugged environments and immunity to electromagnetic interference. Besides, silica is also a chemically passive material and hence it is not affected by corrosive factors that might be present in the environment. Multiplexing capabilities that allow distributed sensing applications.
D1.3	**Digital up-converters (NARL)** Analog Devices digital up/downs converters serve as the frequency translator and digital filter between data converters and digital signal processing blocks. These products enables highly programmable and configyrable receive and transimt signal chains, allowing multichannel, multicarrier radio platforms. They also meet the digital data conversion requirements for many types of radar and communication applications.
D1.4	**Digital synthesizer for radar exicter (NARL)** A radar exciter provide coherent frequency and timing relationships performed by direct digital synthesis, cpable of creating high-resolution wideband waveforms for radar systems. The exciter provides fully cogerent receiver local oscillator signals at radar frequency band as well as requisite, auxiliary high frequency clock signals.
D1.5	**Digital beam forming techniques (NARL)** Beam forming is a signal processing technique used in antenna arrays for directional signal transmission or reception by combining elements in an antenna arrays for directional signal transmission or reception by combining elements in an antenna array in such a way that signals at particular angles experience constructive interference while others experience destructive interference and it be used at both the transmiting and receiving ends in order to achieve spatial selectivity. Digital beamfoming has the advantage over its analog counterpart that the digital data streams can be manipulated and combined in many possible ways in parallel. To get many different output signals in parallel. The signals form every direction can be measured sitmultaneously, and the signals can be integrated for a longer time when studying far-off scatters and simultaneously integrated for a shorter time to study fast-moving scatterers. Imaging radars need to be tested with different beam forming techniques (Founder, capon to state a few) to select the technique, which will give high spatial and temporal resolution.

D1.6	**Clutter removal techniques (NARL)** Various non-atmospheric signals contaminate radar windd profiler data, which produce bias in estimation of moments and wind velocity. Especially, in Ultra High Frequency (UHF) wind profilers, ground clutter severely degrades wind velocity estimation. Moreover, noise dominates the clear air signal at higher heights. It is necessary to eliminate the clutter signal to detect the weak atmospheric signals buried inside the noise and to improve the SNR. Wavelet analysis is a powerful tool to differentiate the characteristics of the ground clutter and noise from the atmospheric turbluence echo at the time series level.
D1.7	Radar imaging radar is kind of radar equipment used for imaging. A typical radar technology includes emitting radio waves, receiving their reflection, and using this information to generate data. For an imaging radar, the returning waves are used to create an image. When the radio waves reflect off objects, this will make some changes in the radio waves and can provide data about the object, including how far the waves travelled and what kind of objects they encountered. Using the acquired data, a computer can create a two or three dimensional image of the scatterers. Current radar imaging techniques rely mainly on Synthetic Aperture Radar (SAR) and Inverse Synthetic Aperture Radar (ISAR) imaging. Monopulse radar 3-D imaging is an emerging technology.
D1.8	Dual –polarized broadband antenna array is used for UHF profiler radar applications. It needs to have differentially prove-fed, stacked patch antenna features high port-to-port isolation and correspondingly good cross-polarization characteristics. Besides, it should have high efficiency and good port-to-port matching. It has to give good polarimetric performance over a wide scan range without excessive calibration requirements.
D1.9	**Design and development of solid state TR modules for radar applications (NARL)** The transmit/receive (T/R) module is a key component of radar antennas. Significant improvements in T/R module efficiency will reduce overall power consumption, simplify the thermal design and increase reliability. By miniaturizing the T/R modules, they can be used for both conventional found based phased array antennas and in lightweight antennas for the ISRO space missions.

Annexure-1

Application for Grant of Funds

1.	Title of the Research Proposal	
2.	Name of the Principal Investigator (Address/Phone/E-mail)	
3.	Name(s) of other investigator(s) with the name(s) of their Institution	
4.	Name of the Institution with Full Address	
5.	Whether the Institution/University is a Government Institution or Non-Government Institution?	
6.	Is the Institution/University/Society managed by an NGO/Trust/Society If yes, provide the details	
7.	If the Institution/society is Non-Government: NGO Darpan Unique ID of the Institution* : PAN Number* : *(It is mandatory for all institutions/ professional societies other than Central/State Govt. Institutions / Departments)	
8.	Proposed duration of Research Project	
9.	Amount of grant requested (in Rs.) 1st Year, 2nd Year, 3rd Year & Total	
	Manpower	
	Equipment	
	Satellite Data/Data	
	Consumables & Supplies	
	Internal Travel	
	Contingency	
	Others	
	Overheads	
	Total	

10.	a) Bio-data of all the Investigators (Format-A). b) Brief description of the Research Proposal with details of budget (Format-B). c) Declaration (Format-C).
11.	I/We have carefully read the terms and conditions for ISRO Research Grants and agree to abide by them. It is certified that if the research proposal is approved for financial support by ISRO, all basic facilities including administrative support available at our Institution and needed to execute the project will be extended to the Principal Investigator and other Investigators.

Name	**Institution**	**Designation**
Principal Investigator		
Co-Investigator(s)		
Head of the Department/Area		
Head of the Institution		

Form A

Bio-data of the Investigator(s)

(Bio-data for **all the investigators** should be given, each on a separate sheet)

1.	Name	
2.	Date of Birth (dd/mm/yyyy)	
3.	Designation	
4.	Degrees conferred (begin with Bachelor's degree)	

Degree	Institution conferring the degree	Field(s)	Year

5.	Research/training experience (in chronological order)

Duration	Institution	Name of work done

6.	Major scientific fields of Interest	
7.	List of publications (Only the journal papers to be listed)	
8.	Email id and Telephone number of PI with STD Code	
9.	Email id of the Head of the academic institution	

Form B

1.	Title of the research proposal	
2.	**Summary of the proposed research** A Simple concise statement about the investigation, its conduct and the anticipated results in no more than 200 words	
3.	**Objectives** A brief definition of the objectives and their scientific, technical and techno-economic importance.	
4.	**Major Scientific fields of Interest** A brief history and basis for the proposal and a demonstration of the need for such an investigation preferably with reference to the possible application of the results to ISRO's activities. A reference should also be made to the latest work being carried out in the field and the present state-of-art of the subject	
5.	**Linkages to Space Programme and Deliverables to ISRO on successful completion of the project**	
6.	**Approach** A clear description of the concepts to be used in the investigation should be given. Details of the method and procedures for carrying out the investigation with necessary instrumentation and expected time schedules should be included. All supporting studies necessary for the investigation should be identified. The necessary information of any collaborative arrangement, if existing with other investigators for such studies, should be furnished. The principal Investigator is expected to have worked out his collaborative arrangement himself. For the development of balloon, rocket and satellite-borne payloads it will be necessary to provide relevant details of their design. ISRO should also be informed whether the Institution has adequate facilities for such payload development or will be dependent on ISRO or some other Institution for this purpose.	
7.	**Data base and analysis** A brief description of the data base and analysis plan should be included. If any assistance is required from ISRO for data analysis purposes, it should be indicated clearly.	
8.	**Available Institutional facilities** Facilities such as equipments, etc, available at the parent Institution for the proposed investigation should be listed.	

9.	**Fund Requirement** Detailed year wise break-up for the Project budget should be given as follows:

Fellowships*	**1st Yr**	**2nd Yr**	**3rd Yr**	**Total**
Research Scientist				
Research Associate				
Research Fellows				
Total				
*Note: please specify the designation, qualification and rate of salary per month for each				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Equipment**				
Total				
Please specify the various individual items of equipment and indicate foreign exchange requirement, if any				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Satellite data/data				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Consumables & Supplies				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
Internal Travel				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
	Total			
Contingencies				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
	Total			
Others				
Total				
	1st Yr	**2nd Yr**	**3rd Yr**	**Total**
	Total			
Overheads(Overhead Expenses of 20% of Total Project Cost not exceeding ₹3.00 lakhs)				
Total				

10.	Whether the same or similar proposal has been submitted to other funding agencies of Government of India. If Yes please provide details of the institution & status of the proposal.	Yes/No

**Justify each equipment. If computer is proposed, only desktop has to be purchased but not laptop.

Annexure-2

Form –C

Terms and Conditions of ISRO Research Grants

1. The approved funds should be utilized solely for the purpose for which they have been granted unless ISRO agrees otherwise. A Certification that the funds have been so used should be produced by the grantee Institution after the end of each year of the support.

2. Due acknowledgement to ISRO should be made in all reports and publications arising out of the part of the work supported by ISRO. The grantee will take prior permission of ISRO before publishing any work based on the ISRO supported project.

3. Two copies of all the publications resulting from the research conducted with the aid of the grant should be submitted to ISRO.

4. Any intellectual property rights or such information/knowledge being able to sustain or create or any such right arising out of the projects sponsored by ISRO will be held jointly by the Academic Institution/R & D institution and ISRO as per RESPOND norms. Academic Institute/R & D institution and ISRO shall inform each other before filing for any protection of any Intellectual Property Rights resulting from any of the project sponsored by ISRO. Academic institute/R & D institution and ISRO will ensure appropriate protection of Intellectual Property Rights generated from cooperation, consistent with laws, rules and regulations of India. The expenses for filling the Patent protection in India and abroad shall be borne equally between Institute and ISRO. Any/all financial accruals due to any commercial exploitation, of this patent shall be shared equally between them, on 50:50 basis. However any of the parties is free to utilize the IPR for their own use on non commercial basis.

5. The principal Investigator is required to submit two copies of yearly reports indicating the progress of the work accomplished. He is also required to submit two copies of a detailed technical report on the results of the research/development after the completion of the project. The reports will become the property of ISRO.

6. In addition, ISRO may designate Scientists/specialists to visit the Institution periodically for reviewing the progress of the work.

7. An inventory of items purchased from ISRO funds should be sent to ISRO, giving the description of equipment, cost in rupees, date of purchase and name of the supplier along with a purchase certificate from the Administration of the Institution. All items of equipments and unconsumable items costing more than Rs. 5,000/- shall remain the property of ISRO and ISRO reserves the right to transfer them or dispose of them on the termination of the project as ISRO may deem fit.

8. The accounts of the expenses incurred out of ISRO funds should be properly maintained and should be authenticated by an approved auditor. The final accounts statement in duplicate duly audit should be sent to the pay & Accounts Officer, DOS/Senior Accounts Officer, ISRO Headquarters, as the case may be, at the end of each financial year of support.

9. If the total amount sanctioned is not spent during the period of support, the remainder amount should be surrendered to the Pay & Accounts Officer, ISRO Headquarters, as the case may be, within one month after the completion of the project.

10. The assets acquired wholly or substantially out of the ISRO grant should not, without its prior sanction, be disposed off, encumbered or utilized for purposes other than that for which the grant is sanctioned.

11. A register of assets permanent and semi-permanent should be maintained by the grantee Institution, which should be available for scrutiny by Audit.

12. The grantee institution should not divert the grants-in-aid for utilization of the same for similar objects of another institution if it is not in a position to execute or complete the assignment. The entire amount of the grant should then be immediately refunded to ISRO by the institution.

13. The terms and condition of ISRO research grants are subject to change from time to time, but the funding of any project will be governed by the terms and conditions existing on the date of starting of the project with ISRO funds.

Declaration

I / We have clearly read the above terms and conditions and hereby agree to abide by the rules and regulations of ISRO research grants and accept to be governed by all the terms and conditions laid down for this purpose.

I / We certify that I / We have not received any grant-in-aid for the same purpose from any other Department of the Central Government / State Government / Public Sector Enterprise during the period to which the grant relates.

	Signature & Name	**Designation**
Principal Investigator		
Head of the Department / Area		

Annexure-3

One hard copy and a soft copy of the proposal shall be sent to the respective ISRO/DOS Centre to the addresses given below with a copy to Respond Office, ISRO HQs by the convener of the STC/RAC-S.

Sl. No	ISRO/DOS Centre	Name & Designation	Contact details
1.	VSSC	Shri S Sridharan, Respond Coordinator Vikram Sarabhai Space Centre, ISRO PO Thiruvananthapuram : 695 022	Tel: 0471-2564620 e-mail: s_sridharan@vssc.gov.in respond@vssc.gov.in
2.	SAC	Dr. (Smt.) Parul Patel Respond Coordinator Space Applications Centre Ambavadi Vistar PO Ahmedabad: 380 015	Tel: 079-26913338 e-mail: parul@sac.isro.gov.in
3.	URSC	Shri S Ganesan Respond Coordinator, U R Rao Satellite Centre HAL Airport Road Vimanapura PO Bengaluru: 560 017	Tel: 080- 23026427 e-mail: ganeshan@ursc.gov.in
4.	NRSC	Shri P Krishnaiah Head, TMD Respond Coordinator National Remote Sensing Centre, Balanagar Hyderabad: 500 037	Tel: 040-23884051 e-mail: krishnaiah_p@nrsc.gov.in
5.	LPSC	Shri Arun S Respond Coordinator, PPEG, MSA Entity Liquid Propulsion Systems Centre, Valiamala PO Thiruvananthapuram: 695 547	Tel: 0471-2567007 e-mail: arunsadanandan@lpsc.gov.in, respond@lpsc.gov.in
6.	IPRC	Shri Nagarajan C Engg. SF; Manager, HRD Respond Coordinator ISRO Propulsion Complex Mahendragiri: 627 133	Tel: 04637 281776 e-mail: nagarajan.c@iprc.gov.in

7.	PRL	Dr. Nandita Srivastava Professor and Deputy Head (Admin), Udaipur Solar Observatory Physical Research Laboratory Badi Road, Dewali Udaipur-313001 Rajasthan	Tel: 0294-2457211 e-mail: nandita@prl.res.in respond@prl.res.in
8.	SDSC-SHAR	Shri Bala Narayanan N R, Engineer, PPEG / MSA Respond Coordinator Satish Dhawan Space Centre-SHAR: 524 124 Sriharikota, Andhra Pradesh	Tel: 08623 22 6382 e-mail: nrbala@shar.gov.in
9.	SCL	Shri Ashwani Kr. Tuknayat Group Head – PPG/Respond Coordinator Semiconductor Laboratory Sector 72, SAS Nagar - 160071 (Near Chandigarh) Punjab	Tel: 0172 2236102 e-mail: gh_ppg@scl.gov.in
10.	IISU	Shri S Sivasubramony DD, MISA/ Respond Coordinator ISRO Inertial Systems Unit (IISU), Vattiyoorkavu PO Thiruvananthapuram: 695 013 Kerala	Tel: 0471 2569340 e-mail: s_sivasubramony@vssc.gov.in
11.	IIRS	Dr. Vandita Srivastava Scientist “SF” Respond Coordinator Indian Institute of Remote Sensing, 4 Kalidas Road Dehradun-248001 Uttarakhand	Tel:0135 2524137 e-mail: vandita@iirs.gov.in
12.	NESAC	Dr. K K Sharma Respond Coordinator Sci/Engr. SG North Eastern Space Applications Centre, Umiam: 793 103 Meghalaya	Tel : 0364 2570138 e-mail: sarmakk@gmail.com

13.	NARL	Dr. S. Sridharan Respond Coordinator National Atmospheric Research Laboratory Gadanki-517 112, Pakala Mandal, Chittoor District, Andhra Pradesh	TTel: 08585-272124 e-mail: susridharan@narl.gov.in

RESPOND & AI

Capacity Building Programme Office

ISRO HQ, Bengaluru