Appendix 3

FOCAL THEME & SUB THEMES

Focal Theme

The New Space Age:
Bridging Science, Technology & Society

Sub-Themes

1. Our Cosmic Neighbourhood
The Solar System: Exploration & Discoveries (2010 –present)

2. A. Stellar Physics (2010 – present)
B. High-Energy Astrophysical Events (2010 – present)

3. Exoplanets & the Science of Habitability (1992 – present)

4. Emerging Space Technologies & Indigenous Launch Capabilities (2010 – present)

5. Mathematical Modelling & Computational Tools in Astronomical Research (2010 – present)

6. Astronomy Education, Citizen Science & Science Communication in India

Sub-Theme -1

1. Our Cosmic Neighbourhood – The Solar System: Exploration & Discoveries (2010 –present)

1. Earth's Moon: The Lunar Renaissance

- ISRO (Chandrayaan Program): Chandrayaan-2 (2019–Present); Candrayaan-3 (2023)
- CNSA (Chang'e Program): Chang'e 3 & 4 (2013, 2019); Chang'e 5 & 6 (2020, 2024)
- NASA (LRO & Artemis): Lunar Reconnaissance Orbiter; Artemis I (2022); Artemis II (2026)

2. The Sun: Heliophysics and Solar Dynamics

- NASA (Parker Solar Probe, 2018–Present): Touching the Sun
- ESA/NASA (Solar Orbiter, 2020–Present):
- ISRO (Aditya-L1, 2023–Present)

3. Inner Planets: Mercury & Venus

- NASA (MESSENGER, 2011–2015):Mercury
- JAXA (Akatsuki, 2015–Present): Venus

4. Mars: The Search for Ancient Habitability

- NASA (Curiosity, InSight, Perseverance): Curiosity (2012); InSight (2018–2022); Perseverance & Ingenuity (2021–Present):
- ISRO (Mangalyaan / Mars Orbiter Mission, 2014–2022):
- CNSA (Tianwen-1 & Zhurong, 2021):
- UAE Space Agency (Hope Probe, 2021–Present)

5. Small Bodies: Asteroids, Comets & Planetary Defense

- JAXA (Hayabusa & Hayabusa2, 2010, 2020):
- NASA (OSIRIS-REx & DART): OSIRIS-REx (2023); DART Mission (2022); NASA (Dawn, 2011–2018)
- ESA (Rosetta & Philae, 2014–2016)

6. The Outer Solar System: Gas Giants & Ice Giants

- NASA (Juno, 2016–Present): Jupiter
- NASA/ESA/ASI (Cassini-Huygens, 2010–2017): Saturn
- NASA (New Horizons, 2015, 2019): Pluto and Kuiper Belt Objects

7. The James Webb Space Telescope (JWST Solar System Observations, 2022–Present)

Sub-Theme -2

2. A. Stellar Physics (2010 – present)

1. The Stellar Lifecycle & Asteroseismology (Starquakes)
   - ESA (Gaia, 2013–Present)
   - NASA (Kepler/K2 & TESS, 2010–Present)

2. Neutron Stars, Pulsars & Magnetars
   - ISRO (AstroSat, 2015–Present)
   - NASA (NICER, 2017–Present)
   - ISRO (XPoSat, 2024–Present)
   - CNSA/CAS (Insight-HXMT, 2017–Present)

3. Black Holes & X-Ray Binaries (Microquasars)
   - NASA/ASI (IXPE, 2021–Present)
   - JAXA (MAXI, 2010–Present)

2. B. High-Energy Astrophysical Events (2010 – present)

1. Supernovae & Stellar Demise (Core-Collapse)
   - NASA (NuSTAR, 2012–Present)
   - NASA/ESA/CSA (JWST, 2022–Present)
   - JAXA/NASA (XRISM, 2023–Present)

2. Gamma-Ray Bursts (GRBs) & Kilonovae
   - Multi-Agency Triumph (GW170817 Kilonova, 2017): The LIGO/Virgo gravitational wave observatories
   - NASA's Fermi and ESA's INTEGRAL space telescopes.
   - Global Effort (The B.O.A.T. - GRB 221009A, 2022): Fermi, Swift, and Insight-HXMT.

Sub-Theme -3

3. Exoplanets & the Science of Habitability (1992 – present)

1. Indirect Detection Technologies (Measuring Stellar Influence)

- Transit Photometry (The Primary Workhorse):
- Radial Velocity / Doppler Spectroscopy: HARPS (High Accuracy Radial velocity Planet Searcher) at La Silla Observatory, ESPRESSO at the VLT.
- Gravitational Microlensing: OGLE (Optical Gravitational Lensing Experiment), MOA (Microlensing Observations in Astrophysics).
- Pulsar Timing Array:
- Astrometry: The ESA Gaia mission.

2. Direct Detection Technologies

- (Direct Imaging): Starshade Mission (Proposed).
- Ground-Based Adaptive Optics: The Very Large Telescope (VLT) in Chile, the Keck Observatory in Hawaii, and the Gemini Observatory.

3. Dedicated Space Missions & Observatories (1992–Present)

- The Pioneers: CoRoT (ESA, 2006–2013)
- The Revolution: Kepler Space Telescope (NASA, 2009–2013); K2 Mission (NASA, 2014–2018)
- The Modern Era: TESS - Transiting Exoplanet Survey Satellite (NASA, 2018–Present); CHEOPS (ESA, 2019–Present)
- Atmospheric Characterization: Hubble & Spitzer Space Telescopes; JWST - James Webb Space Telescope (NASA/ESA/CSA, 2022–Present)

4. The Science of Habitability & Atmospheric Characterization

- The Circumstellar Habitable Zone (CHZ)
- Transmission Spectroscopy
- M-Dwarf Habitability Challenges
- Biosignatures vs. Abiotic Processes

Sub-Theme -4

4. Emerging Space Technologies & Indigenous Launch Capabilities (2010 – present)

1. Reusable Launch Vehicles (RLVs) & Autonomous Landing Systems

- Vertical Takeoff, Vertical Landing (VTVL) Dynamics: SpaceX Falcon 9/Heavy boosters, Blue Origin New Shepard
- Winged Reusable Testbeds: ISRO’s RLV-TD / Pushpak missions, ESA’s Space Rider
- Mid-Air Recovery Systems: Rocket Lab's Electron recovery
- Project Ideas for Students: Simulating descent trajectories; Designing shock-absorbing landing legs; Developing AI-based optical navigation for pinpoint autonomous landings.

2. Next-Generation & "Green" Propulsion Systems·Electric & Ion Propulsion: Starlink’s krypton/argon thrusters, ISRO’s Electric Propulsion System EPS

- Green Chemical Propellants: Non-toxic monopropellants (like LMP-103S or ASCENT); Advanced bipropellants (Methalox – liquid methane and liquid oxygen); ISRO’s developing Methalox engines).
- 3D-Printed Rocket Engines: Agnikul Cosmos’s Agnilet engine, the world's first single-piece 3D-printed semi-cryogenic rocket engine).
- Project Ideas for Students: Designing micro-thrusters for CubeSats; Testing new nozzle geometries for 3D printing; Simulating the efficiency of plasma-based propulsion.

3. The Small Satellite Revolution: CubeSats & Constellations

- Micro/Nano-Satellite Architectures
- Mega-Constellations & Swarm Intelligence: Starlink, OneWeb
- Dedicated Small Satellite Launchers: ISRO’s SSLV - Small Satellite Launch Vehicle, Skyroot Aerospace’s Vikram-S
- Project Ideas for Students: Designing a 1U CubeSat payload for environmental monitoring; Proposing a constellation topology for disaster management in Tamil Nadu or India; Developing deployable solar panel mechanisms for micro-satellites.

4. In-Orbit Servicing, Assembly, and Manufacturing (ISAM)

- Autonomous Docking & Space Tugs: ISRO’s SPADEX - Space Docking Experiment
- Active Space Debris Removal (ADR): Harpoons, robotic arms, magnetic tethers, and drag sails like ISRO's POEM orbital platform experiments
- In-Space Manufacturing
- Project Ideas for Students: Simulating robotic arm kinematics for catching tumbling debris; Designing lightweight drag-sails for end-of-life satellite disposal; Proposing collision-avoidance algorithms.

5. Advanced Spacecraft Avionics & "Edge AI"

- Software-Defined Radios (SDR) & Satellites
- AI for Earth Observation (Edge Computing): Indian startup Pixxel's hyperspectral imaging satellites
- Advanced Star Trackers & Navigation
- Project Ideas for Students: Training a machine learning model to detect forest fires from raw satellite imagery; Training a machine learning model to detect floods from raw satellite imagery; Designing a low-power, radiation-hardened microcontroller architecture for CubeSats.

6. Indigenous Space Ecosystems & Private Startups (Developing Nations)

- India's Private Space Sector: Under IN-SPACe: Skyroot Aerospace, Agnikul Cosmos, Bellatrix Aerospace, Dhruva Space
- Emerging Space Nations: African and Latin American nations (e.g., Kenya's Taifa-1, launched in 2023).
- Project Ideas for Students: Conducting a feasibility study on establishing a commercial launch pad in southern India (like the Kulasekharapatnam spaceport); A policy framework for integrating private university research with ISRO missions.

Sub-Theme -5

5. Mathematical Modelling & Computational Tools in Astronomical Research (2010 – present)

1. Differential Equations & Orbital Dynamics (N-body Simulations)

- Mathematical Focus: Ordinary and Partial Differential Equations (ODEs & PDEs), Symplectic Integrators, Runge-Kutta methods (RK4).
- Astronomical Applications: Simulating the long-term stability of the Solar System or newly discovered exoplanet systems; Trajectory optimization for spacecraft
- Project Idea for Students: Use a numerical integrator in Python to solve the restricted three-body problem.

2. Numerical Methods & Hydrodynamics

- Mathematical Focus: Finite Difference, Finite Volume, and Finite Element Methods; Navier-Stokes equations; Magnetohydrodynamics (MHD).
- Astronomical Applications: Modeling the interior convective zones of stars; Simulating the shockwaves of supernovae expanding into the interstellar medium.
- Project Idea for Students: Develop a 1D computational fluid dynamics (CFD) simulation using finite difference methods to model the propagation of a blast wave (supernova simulation) through a uniform gas density, tracking pressure, temperature, and velocity over time.

3. Signal Processing & Fourier Analysis

- Mathematical Focus: Fast Fourier Transforms (FFT), Wavelet Analysis, Cross-Correlation, Matched Filtering.
- Astronomical Applications: Radio Interferometry: Combining signals from multiple radio dishes (like the upcoming Square Kilometre Array); Pulsar Timing: Using FFTs to find the hidden periodic signals of rapidly spinning neutron stars in noisy radio data; Gravitational Waves: Using matched filtering to find the exact "chirp" signature of merging neutron stars within the noisy data streams of LIGO and Virgo.
- Project Idea for Students: Download raw, noisy light-curve data from the Kepler or TESS archives. Apply a Fast Fourier Transform algorithm to "clean" the data, filter out stellar noise, and successfully isolate the periodic dip of a transiting exoplanet.

4. Statistical Inference & Bayesian Astrostatistics

- Mathematical Focus: Bayesian Inference, Markov Chain Monte Carlo (MCMC) algorithms, Gaussian Processes, Chi-Square minimization.
- Astronomical Applications: Estimating the exact mass and radius of an exoplanet based on radial velocity data; Determining the age of a star cluster by statistically fitting isochrone models to a scatter plot of its stars on a Hertzsprung-Russell diagram.
- Project Idea for Students: Write an MCMC algorithm to fit a theoretical mathematical curve to a set of real, scattered astronomical data (e.g., a star's radial velocity over time).

·5. Machine Learning & Big Data (Astroinformatics)

- Mathematical Focus: Convolutional Neural Networks (CNNs), Principal Component Analysis (PCA), Random Forests, Support Vector Machines (SVM).
- Astronomical Applications: Automated classification of stellar spectra (O, B, A, F, G, K, M types); Real-time anomaly detection to spot supernovae, tidal disruption events, or gamma-ray bursts moments after they happen in sky surveys.
- Project Idea for Students: Train a standard Convolutional Neural Network (CNN) using publicly available databases (like the Sloan Digital Sky Survey). The student's model should be able to automatically ingest raw spectral data and accurately classify whether the object is a main-sequence star, a white dwarf, or a quasar.

6. Industry-Standard Computational Frameworks

- Astropy: The core Python library for astronomy (handles celestial coordinates, FITS image files, and cosmological calculations).
- MESA (Modules for Experiments in Stellar Astrophysics): A powerful open-source suite for 1D stellar evolution. Students can simulate the entire life cycle of a star from a molecular cloud to a white dwarf.

Sub-Theme -6

6. Astronomy Education, Citizen Science & Science Communication in India

1. Citizen Science: Democratizing Astronomical Research

- The RAD@home Indian Collaboratory: Data from the Giant Metrewave Radio Telescope (GMRT) in Pune
- Asteroid Search Campaigns (IASC): To analyze Pan-STARRS data
- Project Ideas for Students:
- Form an official search team, participate in a verified citizen science campaign, and present a paper documenting the methodology of identifying true near-Earth objects versus false visual signatures.
- Analyze data from the RAD@home database and present a case study on a specific active galactic nucleus (AGN) feedback mechanism.

2. Astronomy Education & Curriculum Analysis

- NCERT & UGC Curriculum Gaps: Practical observational astronomy.
- Vernacular Science Communication: For rural students in regional languages.·Importance of hands-on-activities and models: For school teachers·Project Ideas for Students:
- Analyze the current physics curriculum and propose a structured, low-cost practical astrophysics module.
- Develop a vernacular science communication portfolio – translating high-level space science terminology into Tamil to aid rural outreach for grassroots organizations like the Tamil Nadu Astro and Science Society (TASS).
- Design and build low-cost models and hands-on-activities using only locally sourced materials, along with teaching manual of astronomy for high school teachers.

3. Dark Sky Awareness & Astro-Tourism in India

- The Hanle Dark Sky Reserve (HDSR)
- Light Management Plans
- Project Ideas for Students:
- Conduct a localized light pollution study (Bortle scale mapping) comparing an urban center like Coimbatore with a high-altitude observational site like the Kodaikanal Solar Observatory.
- Draft a comprehensive socio-economic and scientific proposal for establishing a "Dark Sky Park" in the Western Ghats, modelling it strictly after the community-engagement framework of the HDSR.

4. Indigenous Astronomical Heritage (Archaeoastronomy)

- Siddhantic Astronomy & The Kerala School:
- Folk Astronomy & Regional Literature:
- Project Ideas for Students:
- Mathematically decode a specific planetary algorithm used in the Surya Siddhanta and run a computational comparison against modern predictive models to determine its margin of error.
- Conduct a literature review of ancient Tamil Sangam texts to catalog specific references to planetary motions, constellations (Nakshatras), and maritime celestial navigation.
- Research the architectural alignments of local historical or megalithic sites to prove intentional solstitial or equinoctial alignments.