Indian Institute of Technology Kanpur

COURSES OF STUDY

2024

Indian Institute of Technology Kanpur
KANPUR-208016

DEPARTMENT OF S.P.A.S.E

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Course ID	**Course Title**	**Credits L-T-P-A-[C]**	**Content**
SPA201	Introduction to Astronomy and Astrophysics	3-0-0-0-9	This course will provide a foundation to UG students in the area of astronomy & astrophysics. Topics include a historical introduction, astrometry, universal physical principles and basics of radiation, observing tools, solar system and exoplanets, stellar structure and evolution, milky way and other galaxies, and basic introduction to cosmology.
SPA401	Galaxies and Observational Cosmology	3-0-0-0-9	Galaxy dynamics and evolution, tidal forces, stellar dynamics, virial theorem, interstellar medium; galaxy clusters, feedback mechanisms in clusters, intergalactic medium, Hubble's law and history of the Universe, cosmological parameters and parameter estimation.
SPA601	Space and Astronomical Instrumentation	3-0-0-0-9	Basic principles of space and astronomical instrumentation and detectors, electromagnetic wave and charged particle detectors, spectroscopy, spectroscopic techniques to deduce composition and physical properties, detector design, calibration, background, space qualification and data acquisition, detailed discussion of a few selected observatories, such as, AstroSat, Moon and Mars missions.
SPA602	Mathematical Methods in Space Sciences & Engineering	3-0-0-0-9	Vector analysis, vector di↵erential calculus, linear vector spaces, matrices, tensors, coordinate systems, Astronomical coordinate system transformation, ordinary diferential equations, stellar structure equations, special functions, Bessel function, Legendre function, spherical harmonics, application to cosmic microwave background radiation, Laplace trans-form, Fourier transform, Numerical Methods.
SPA603	Solar System Processes and Space Missions	3-0-0-9	Introduction ,Dynamics, Physics & Astrophysics: Two- and three- body problems; Thermodynamics; Stellar properties; Nucleosynthesis,Solar heating and energy transport: Energy balance and transport - conduction, convection, radiation ,Planetary atmospheres: Thermal structure; Composition; Molecular and eddy flows; Atmospheric escape,Planetary surfaces and interiors: Mineralogy & petrology; Interiors; Surface morphology, Impact cratering, examples.Magnetic fields: Sun; Solar wind; Planetary magnetospheres, Formation processes: Solar System - overview and constraints; Protoplanetary disk's evolution; Growth of solid bodies and gas giants; Migration; Planetary rotation; Asteroids, comets and moons; Exoplanets; Theory and observation,Major Space missions and their scientific contributions, Examples: Moon; Terrestrial planets; Gas giants .
SPA604	Numerical Methods in Space Sciences & Engineering	3-0-0-0-9	Numerical integration of functions, numerical root finding, numerical optimization of functions, integration of ordinary differential equations (ODE), Fast Fourier Transforms (FFT),

			Statistical parameter estimation, techniques for handling big data sets - potential and performance of parallel computing.
SPA610A	Fundamentals of Astronomy and Astrophysics	3-0-0-0-9	Historical introduction to astronomy, Multi-wavelength Observations, Astrometry, Coordinate systems, Photometry, Radiation from astronomical sources, Radiative transfer, Stellar spectra, Saha equation, HR diagram, Stellar Structure, Stellar nuclear reactions, Star formation and stellar evolution, Compact stars, Supernova explosions, Binary star systems, Milky Way galaxy, Introduction to galaxies, Large scale structure of the Universe.
SPA611A	Radio Astronomy	3-0-0-0-9	Fundamental of radio observations, radio antennas and receivers, antenna arrays, Response of an interferometer, cross-correlations, visibility function, calibration techniques, imaging, aperture synthesis, deconvolution, CLEAN algorithm, practical implementation on VLBI, VLA.
SPA612	Radio Astronomy Laboratory	0-0-9-0-9	Coax cable characterization, Filter characterization using oscilloscope and spectrum analyzer, 2-slit experiment in radio, designing and making a filter, Amplifier and mixer characterization, Design of Attenuator / Impedance Transformer, Observe HI line, Beam Pattern measurements, Antenna Design, Correlation, Power Divider / Combiner, Inter-ferometry to determine angular size of the Sun.
SPA615	Observational Techniques & Telescopes	3-0-0-0-9	This course will introduce students' observational techniques and telescopes in all major wavebands along with detectors and calibration aspects in astronomy. The Course will cover historically important instruments, optical and infra-red, radio, X-ray, multi-messenger astronomy, major observational facilities such as SKA, TMT, and LIGO, and description of various other observatories and planning aspects for securing observing time on international telescopes. There will be a few hands-on sessions using actual data and telescopes.
SPA620	Solar System Mechanics	3-0-0-9	Introduction to the Solar System, the 2-body problem, the restricted 3-body problem (R3BP), Applications of R3BP, Rotational and tidal effects, Applications to shapes of solar system and celestial bodies, Spin-orbit coupling, Perturbation methods and effects: The disturbing function, secular perturbations, resonance and chaos, Planetary rings.
SPA621	Planetary surface processes	3-0-0-0-9	Introduction ,Shapes of planetary bodies: Effect of rotation and tides; Topography, Continuum mechanics: Stress and strain; Linear elasticity; Bending and buckling of plates; Plasticity, Heat transfer: Fourier's law of conduction; Sources; Periodic heating and cooling; Stefan problem; Thermal stresses; Applications , Plate tectonics: Introduction; External and internal sources; Flexures and folds; Fractures and faults; Applications, Volcanism: Melting; Magma; Mechanics of eruption; Lava flows and domes, Impact cratering: Morphology; Cratering mechanics; Ejecta; Scaling laws; Atmospheric effects; Applications to landscapes, dating and evolution, Regolith and resurfacing processes: Growth; Heating; Weathering; Texturing; Creeping; Landsliding, Wind, water and ice on planetary surfaces.

SPA625	Space data acquisition and analysis	1-0-2-0-9	The course aims to introduce students to actual space data from space instruments in orbit. It will introduce the basic principles and techniques like; good or bad data and data selection, data analysis, instrument background, generating light curves, Power Density Spectrum (PDS), Energy spectrum and fitting of data using various emission as well as absorption models. Student will use data of LAXPC instrument onboard Astrosat. Using this data, Students will drive physical properites of the black hole and Neutron star X-ray bianries like source energy spectrum state: soft or hard, spectrum timing properites, thermonuclear burst, Neutron star spin frequency, High magnetic field of Neutron star, flux variation and others.
SPA660A	High Energy Astrophysics of Binary star systems	3-0-0-0-9	Review of stellar evolution and Compact stars, brief overview of Gas dynamics, plasma Physics and shock waves, binary stars, mass transfer through Roche lobe overflow and stellar wind, formation and structure 2 of accretion disks, steady α-disks, emitted spectrum, different X-ray states in compact star binaries, outbursts in X-ray binaries, detection of X-rays and gamma rays, space X-ray detectors, observations and study of X-ray binaries.
SPA661	Stars and Stellar Evolution	3-0-0-0-9	Introduction to Stars and interstellar medium, Stellar spectra and classification, Hertzsprung-Russell diagram, Stellar structure equations, Rosseland mean opacity, radiative pressure, stellar nuclear reaction, formation of stars, evolution on the main sequence and beyond, the end stages of stellar evolution, formation of compact stars, white dwarfs, neutron stars, black holes, supernova explosions, Binary stars.
SPA613M	Introduction to Celestial Observational Techniques	3-0-0-0-5	**Objectives:** The course will introduce basic concepts of Positional astronomy, observational techniques, signal properties with a few examples of observations of celestial sources. **Contents** (preferably in the form of 5 to 10 broad titles): • Positional astronomy: Night sky, celestial sphere, ancient astronomy, motion of planets, moon and comets, constellation and nakshtras, sidereal time, calendars, precession, proper motion and parallax, eclipses and transits, Astrometry, distance ladder, application of Stellarium software (7 lectures) • Measurements: Observations, brightness, intensity, flux, luminosity, magnitude scale, Photometry, spectroscopy (Doppler shift, spectral resolution, FWHM, convolution), filters, Atmospheric transmission windows on Earth, atmospheric seeing and extinction, effect of ionosphere (6 lectures) • Signal properties: - Signal & noise, wave and shot noise, sampling, VCZ theorem, coherence, Hanbury brown - Twiss effect, bunching of pli0tons (4 lectures) • Celestial objects (observational): Multi-wavelength observations of - solar system objects, exo-planets, stars (color-magnitude, HR diagram), Galaxies, large-scale structures. (4 lectures)

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<tr><td></td><td></td><td></td><td>Short summary for including in the Courses of Study Booklet: This course includes Positional astronomy, introduction to night sky, motions of celestial objects, measurement techniques, signal properties of celestial sources and their observations.

<u>Recommended Books:</u>
Astrophysical Techniques: C. R. Kitchin- To Measure the Sky: An Introduction to Observational Astronomy: Frederick R Chromey.</td></tr>
<tr><td>SPA614M</td><td>Introduction to Celestial Mechanics</td><td>3-0-0-0-5</td><td>This course helps describe various astronomical observations, primarily within the Solar System, employing relatively simple mechanical models. An introduction to galactic dynamics will also be given. The distribution is given below in terms of 50 minute lectures.
• Introduction to the Solar System, stars and galaxies — 1 lecture
• The 1- and 2- body problems: Kepler's laws, Newton's law of gravitation, Equations of motion, Mean and eccentric anomalies, Barycentric orbits, Orbital elements, Applications, e.g. Hohmann transfer — 4 lectures
• Introduction to galactic dynamics: Collisionless N-body system (Coulomb logarithm, relaxation time, dynamical crossing time), Examples of galactic potentials, Orbits of stars in axisymmetric and non-axisymmetric potentials, Lindblad resonances — 4 lectures
• The restricted 3- body problems: Equations of motion in a rotating frame, Tisserand relation, Jacobi integral, Lagrangian equilibrium points, Zero velocity curves, Perturbed orbits, Tadpole and Horseshoe orbits, Effect of drag, Applications to small moons — 6 lectures
• Rotational and tidal effects: Tidal bulge, Potential theory, Tidal and rotational deformation, Shapes of solar system bodies, Roche zone, Tidal torques, Application to small moons — 6 lectures

<u>Textbooks and references:</u>
• Bertotti, B. , P. Farinella and D. Vokrouhlicky 2003. Physics of the Solar System: Dynamics and Evolution, Space Physics, and Spacetime Structure. Springer.
• Binney, J. , and S. Tremaine 2008. Galactic Dynamics, 2^{nd} ed. Princeton U. Press.
• Danby, J. M. A. 1964. Fundamental of Celestial Mechanics. New York: Macmillan.
• Diacu, F. , and P. Holmes 1996. Celestial Encounters. Princeton U. Press.
• Fitzpatrick, R. 2012. An Introduction to Celestial Mechanics. Cambridge U. Press
• Gurzadyan, G. A. 1996. Space Dynamics. London: Taylor Francis.
• Murray, C. D. , and S. F. Dermott 1999. Solar System Dynamics. Cambridge Univ. Press.
• Roy, A. E. 2005. Orbital Motion, 4^{th} ed. CRC Press.</td></tr>
<tr><td>SPA617M</td><td>Space Instrumentation Laboratory</td><td>0-0-9-0-5</td><td><u>Objectives</u>: The course aims to provide hands-on experience on instrumentation techniques related to astronomy, planetary and space sciences and engineering.</td></tr>
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Students will be required to complete at least 2 experiments from each stream as described here –
• Detector characterization in X-ray/UV/optical/nearIR; experiments related to working of CCD, CMOS, PMT, X-ray detectors etc.
• Observing fundamental principles - Coherence, Van-CittertZernike theorem, Hanbury Brown intensity interferometer; Double slit experiment, Heisenberg uncertainty; Michelson/Fabry-Perot interferometer; Faraday effect; Young's modulus for different materials.
• Spectroscopy and polarimetry techniques - Characterization of filters, polarizing elements and dispersing elements; Brewster angle, wave-plates-Spectrometer and polarimetry; spectral reflectance from surfaces, rocks and minerals in different. illumination conditions; Spectra of various gases and flamesA' - emission/absorption experiment; fibre optics; optical telescopes.
• Radio detection techniques - Amplifiers, mixers, filters, noise & detection, phasing, antennas, RFI mitigation, impedance matching, transmission lines.

Short summary for including in the Courses of Study Booklet:
Experiments modules will consist of experiments related to electromagnetic wave detection and analyses in X-ray/UV/optical/IR/radio bands, observing fundamental principals (interference, diffracti011, coherence etc.), setting up spectroscopy and polarimetry experiments and carrying out related measurements applicable in field of astronomy, planetary and geological sciences.

<u>Recommended Books:</u>
Necessary reading material and instruction documents will be provided in the lab.</td></tr>
<tr><td>SPA618M</td><td>Introduction to radiative processes in space</td><td>3-0-0-0-5</td><td>Studying the universe is mostly done via understanding the electromagnetic radiation that each source emits. The nature of the spectrum indicates the underlying physical processes. This course intends to teach the processes that generate electromagnetic radiation and relevance in natural sources.

<u>Content</u>:

• Ionization processes (3 L): Basic quantum mechanics concepts (energy levels, wave-particle duality), Collisional ionization, photo-ionization, recombination, ionization equilibrium, HII regions (Stromgren sphere), Saha ionization
• Emission and absorption of thermal plasma (5 L): Bound-Bound transitions, Spontaneous/ stimulated transitions, Einstein's coefficient, emission/absorption lines, emissivity and absorption coefficient, doppler/Lorentz broadening, Free-Free emission, Thompson scattering, example of a spectrum and its features
• Heating and Cooling (2L): Physical conditions in different astrophysical systems (interstellar, intergalactic mediums),</td></tr>
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			Photo-heating, cooling curve, thermal equilibrium, thermal instability, multiphase gas (interstellar medium) • Radiative Transfer (6 L): Radiative transfer equation, thermal radiation (Kirchhoff's law, blackbody radiation, Rayleigh-Jeans law), brightness temperature, Scattering and diffusion, radiation as a fluid (Eddington approximation), gray atmosphere, green house effect • Non-Thermal Radiation (4 L): Synchrotron Radiation, beaming effect, polarization, Compton/ inverse-Compton Scattering Short summary for including in the course study booklet: Ionization states of a plasma, enussion and absorption processes, heating and cooling, radiative transfer. **Books and references:** • Physics ofthe Interstellar and Intergalactic Medium: Bruce Draine • Radiative Processes in Astrophysics: Rybicki & Lightman
SPA622M	Mathematical Techniques in Space Sciences & Engineering	3-0-0-0-5	**Objectives:** The course aims to introduce students to numerical techniques used in Space Science & Astronomy. **Contents** (preferably in the form of 5 to 10 broad titles): • Vector Analysis (3 lectures) Vector differential calculus, gradient, divergence and curl, surface and volume integrals • Matrix Algebra (6 lectures) Introduction to matrices, diagonalization, solution of linear equations using matrices. • Coordinate Systems (5 lectures) Curvilinear coordinates, coordinate transformation, applications to astronomy • Ordinary differential equations (6 lectures) First and second order ODEs and their solutions. Separation of variables method to solve PDEs and various types of boundary conditions - initial value problem vs boundary value problem etc. Short summary for including in the Courses of Study Booklet: vecor analysis, vector differential calculus, linear vector spaces, matrices, tensors, coordinate systems, Astronomical coordinate system transformation, ordinary differential equations, examples from Astronomy **Recommended Books:** • Mathematical Methods in Classical and Quantum Physics, T. Dass S. K. Sharma • Mathematical Methods for Physicists, G. B. Arfken, H. J. Weber and F. E. Harris, Elsevier, seventh edition. • Advanced Engineering Mathematics, E. Kreyszig, John Wiley & Sons, tenth edition.
SPA623M	Numerical Techniques in Space Sciences & Engineering	2-0-1-0-5	Space, Planetary and Astronomical Sciences and Engineering. **Contents** (preferably in the form of 5 to 10 broad titles): • Numerical Integration (2 lectures, 2 labs)

			Newton-Cotes formulae including trapezoidal rule and Simpson's rule, Gaussian quadrature, convergence and scaling of error, Monte Carlo Integration • Numerical Root finding (1 lecture, 1 lab) Bisection method, Newton Raphson method for single and multidimensional systems. • Integration of Ordinary Differential Equations (ODE) (3 lectures, 3 labs) Initial Value Problem Forward and backward Euler method, RungeKutta Method, Stiff system of equations, implicit vs. explicit schemes, shooting method for the Boundary Value Problem. • Numerical Interpolation of functions (1 lecture, 1 lab) Linear and higher order interpolation with polynomials, Spline Interpolation Short summary for including in the Courses of Study Booklet: Numerical integration of functions, numerical root finding, Solving Ordinary differential Equations, Numerical Interpolation **Recommended Books:** • Numerical Recipes: The Art of Scientific Cornputing Authors: Vertterling, Flannery, Press and Teukolsky. • Fundamentals of Numerical Computation Authors: Driscoll and Braun