AcSIR ARIES Ph.D. Programme Coursework Syllabus

Course	Title (Term-II: Jan - Mid May)	Credits
	Mandatory Course – 6 Credits	
Course 1 Mandatory	1. Research Methodology 2. Research Publications and Ethics	4 2
	Inter-disciplinary/Cross-disciplinary Course – 2 Credits (Term-II: Jan - Mid May)	
Course 2 Elective	1. Astronomical Techniques 2. Atmospheric Chemistry, Modelling and Measurement Techniques 3. Physics of the Sun and Space Weather 4. Theory of Relativity and Cosmology	1 1 1 1
	Advanced Course – 6 Credits (Term-I: August - Mid Dec)	
Course 3 Elective*	1. Fundamentals of Astronomy 2. Introduction to Atmospheric Sciences 3. Numerical and Statistical techniques 4. Electrodynamics and Radiative processes in Astrophysics 5. Introduction to Fluid Mechanics and Plasma Physics	3 2 1 2 2
	Societal Program – 4 Credits (Term-II: Jan - Mid May)	
Course 4 Mandatory	Societal Program: Problem Understanding and Analysis	4

* All subjects under Course 3 are mandatory for ARIES students. Students will have the option to choose the best 6 credits from Course 3 for communication to AcSIR..

Note: *A course of one credit is equivalent either to one lecture hour per week (minimum fourteen contact hours), one tutorial hour per week (minimum fourteen contact hours) or two laboratory hours per week (minimum twenty-eight contact hours) or a combination thereof for the duration of the semester.*

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Course 1 – Mandatory

1. RESEARCH METHODOLOGY 4:0 credits
   [As prescribed by the AcSIR.]

   I) Safety and Behavior at Workspace, Laboratory and Institutional Campus: General safety and accident prevention guidelines, Good personnel safety practices, Laboratory safety practices (Do's and Don'ts), Fire safety principles and fire handling, Care in handling chemicals, Understanding materials safety data sheet (MSDS), Storing and indexing of materials & chemicals, Disposal of materials, chemicals and biological wastes, First aid, Reporting accidents and requisitioning help, Combating accidents. Awareness about members

of the Institutional Safety Committee and emergency contact numbers. Lab bench co-operation with colleagues and co-workers, cultivating practice of collectivism, shared responsibilities and team-spirit among fellow researchers, Advancing culture of scientific sharing and discussion in campus and lab.

II) Research Problem Identification and Research Design/Plan: Scientific methods, Types of reasoning (Logics) - Induction – Deduction –Abduction, Identifying a topic/area of research, Reviewing literature, Identifying a question to be answered/solution of a problem to be sought, Critically weighing investment (time, money and efforts) to reward (size and scale of answer/solution), Finalizing the research question/problem to be worked on, Cross-disciplinary thoughts and inter-disciplinary research approaches of addressing the question. Design of experiment/research work process and its implementation, Serendipity research.

III) Good Experimental, Observational and Data Analysis including Computer Applications: Maintenance of laboratory records & e-Note books, Management of data and self-navigation of research project and academic program progress (objectives, milestone as well as timeline compliance), Data integrity & archiving of observational data for re-tracing, Basic mathematical and statistical treatments of data for appropriate/rational interpretation, Reporting data in inference perspectives, Common computational tools like Process flow diagram, Chemical structure drawing, statistical analyses, Data tabulation and figure presentation (graph, bar diagram, Venn Diagram, heat maps etc.)

IV) Intellectual Property, Patent Database Search and Patent Writing: Innovation, Intellectual Property Rights (IPR), Pre-IPR system of intellectuality/trade protection: Secrecy/Trade guilds/Cartels, Basic forms of IPRs: ─ Patent, Copyright, Trademark, Designs, Evolution of IP statutes, Major patent databases/offices, CSIR-TKDL, Searching and indexing of patents from different databases, IPR for new technologies, Process patent *versus* product patent, Art of writing a patent/innovation and claims, Preliminary patent, White space mapping, CSIR & its patents strength.

V) Writing & Communication of Research Results and Inferences: Scientific writing (including Language proficiency), State-of-the-art scientific literature comprehension, Art and ethics of writing research report/paper, writing of an abstract for scientific community and general public, Skills of making Powerpoint presentations, Art of web-meeting interactions & presentations using latest video-meeting modes. Letter writing and official correspondence.

VI) Analytical Tools and Techniques in Research - A General Crossdisciplinary Exposure: Flexibility of the contents but it must be within the frameworks of different faculties of AcSIR (Biological Sciences, Chemical Sciences, Physical Sciences, Engineering Sciences, and Mathematical & Information Sciences). Further, the course content should be of basic level to serve the purpose of learning and awareness in a balance of breadth and depth of topics for the students with different backgrounds / interests with respect to subjects and faculties.

(*A brief of the tools and techniques to be covered by the Teaching Faculty shall be circulated to the students in advance and the same also shall be uploaded on AcSIR Website*)

VII) CSIR Guideline (2020) for "Ethics in Research and in Governance" Adopted by AcSIR: Full awareness about the guidelines (https://acsir.res.in/wp-content/uploads/2020/08/OM-Ethics-Guidelines.pdf) and their compliance and practice.

References:

- CSIR Guidelines for Ethics in Research and in Governance - CSIR (2019)

- Ethics in Science Education, Research and Governance- Kambadur Muralidhar, Amit Ghosh, Ashok Kumar Singhvi - INSA (2019)
- Research Design: Qualitative, Quantitative, and Mixed Methods Approaches by John W. Creswell and J. David Creswell
- The Craft of Research by Wayne C. Booth, Gregory G. Colomb, and Joseph M. Williams
- Research Methodology: A Step-by-Step Guide for Beginners by Ranjit Kumar
- Research Methodology: methods and techniques by CR Kothari & Gaurav Garg

Introducing Research Methodology: A Beginner′s Guide to Doing a Research Project by Uwe Flick

2. RESEARCH PUBLICATION AND ETHICS 2:0 credits

[As prescribed by the AcSIR.]

A) THEORY

I) PHILOSOPHY AND ETHICS:

1. Introduction to philosophy: definition, nature and scope, concept, branches
2. Ethics: definition, moral philosophy, nature of moral judgements and reactions

II) SCIENTIFIC CONDUCT:

1. Ethics with respect to science and research
2. Intellectual honesty and research integrity
3. Scientific misconducts: Falsification, Fabrication, and Plagiarism (FFP)
4. Redundant publications: duplicate and overlapping publications, salami slicing

Selective reporting and misrepresentation of data

III) PUBLICATION ETHICS:

1. Publication ethics: definition, introduction and importance
2. Best practices / standards setting initiatives and guidelines: COPE, WAME, etc.
3. Conflicts of interest
4. Publication misconduct: definition, concept, problems that lead to unethical behavior and vice versa, types
5. Violation of publication ethics, authorship and contributorship
6. Identification of publication misconduct, complaints and appeals
7. Predatory publishers and journals

B) PRACTICE

I) OPEN ACCESS PUBLISHING:

1. Open access publications and initiatives
2. SHERPA/RoMEO online resource to check publisher copyright & self archiving policies
3. Software tool to identify predatory publications developed by SPPU

Journal finder / journal suggestion tools viz. JANE, Elsevier Journal Finder, Springer Journal Suggester, etc.

II) PUBLICATION MISCONDUCT:

A. Group Discussions (2 hrs.)
    1. Subject specific ethical issues, FFP, authorship
    2. Conflicts of interest

3. Complaints and appeals: examples and fraud from India and abroad

B. Software tools (2 hrs.)

Use of plagiarism software like Turnitin, Urkund and other open source software tools

III) DATABASES AND RESEARCH METRICS:

A. Databases (4 hrs.)

1. Indexing databases
2. Citation databases: Web of Science, Scopus, etc.

B. Research Metrics (3 hrs.)

1. Impact Factor of journal as per Journal Citation Report, SNIP, SJR, IPP, Cite Score
2. Metrics: h-index, g index, ilO index, altmetrics

Course 2 – Elective – Inter-disciplinary/Cross-disciplinary Course

1. ASTRONOMICAL TECHNIQUES 1:0 credits

Methods of observation, Telescopes at different wavelengths, detectors at different wavelengths, resolution, sensitivity, noise, quantum efficiency, spectral response, Johnson noise, signal-to-noise ratio, background, aberrations, imaging, spectroscopy, polarimetry, calibration, atmospheric effects at different wavelengths, active/adaptive optics, interferometry, speckle interferometry, aperture synthesis, neutrino astronomy, gravitational wave astronomy.

Optical/UV/IR: Brief historical account; Introduction to the idea of multi-wavelength astronomy; Importance of visible/UV/IR observations from astrophysics point of view; Basics of telescope - collecting area, field of view, diffraction limit/resolution, seeing; Basics of detectors; Fundamental Techniques: Photometry, Spectroscopy, Timing and Polarimetry; Current research activities and upcoming instruments in visible/UV/IR.

Radio Astronomy: History of Astronomical observations in radio; Importance of radio observations from an astrophysics point of view; Fundamental Techniques used in radio: Imaging, Spectroscopy, Timing and Polarimetry; Single-dish and Array Telescopes; Aperture synthesis; Current research activities and upcoming instruments.

High Energy Astronomy: History of Astronomical observations in X-ray and gamma-ray; Importance of high-energy observations from an astrophysics point of view; Fundamental Techniques used in X-rays and gamma-rays: Imaging, Spectroscopy, Timing and Polarimetry; Current developments and upcoming facilities.

Suggested Readings:

1. Handbook of CCD Astronomy: S. B. Howell
2. Astrophysical T echniques: C. R. Kitchin
3. Telescopes and T echniques: C. R. Kitchin
4. Astronomy Method: Hale Bradt
5. Astronomical Polarimetry: Jaap Tinbergen
6. Observational Astrophysics: Pierre Lena
7. Astronomical Photometry: M. Golay
8. X-ray Astronomy: R. Giacconi
9. Frontiers of X-ray Astronomy edited: A. C. Fabian et al.
10. X-ray Detectors in Astronomy: G. W. Fraser

2. ATMOSPHERIC CHEMISTRY, MODELLING AND MEASUREMENT TECHNIQUES: 1:0 CREDITS

Chemical Kinetics (2 hours): Measures of Atmospheric Composition**,** rate expressions for gas-phase reactions, photolysis rates, Lifetime, Role of meteorology in reaction rates (stratosphere and troposphere)

Stratospheric Processes (4 hours): Stratospheric ozone, Production and Loss processes of stratospheric ozone, Ozone loss and Production at the North Pole and South Pole, Polar Stratospheric Clouds, Changes in CFCs, HCFCs, HFCs, Introduction to the upper atmosphere and Coupling Turbulence.

Trace Gases in the Troposphere (5 hours): Tropospheric Ozone, Oxidizing power of the troposphere, Role of different trace gases (including ozone precursor gases) and their Budget, Production and loss processes of tropospheric ozone, Greenhouse gases, Role of Meteorology and Dynamics in Trace Gases Evolution, Transport of pollutants, Role of the boundary layer dynamics, Geochemical Cycle.

Introduction to Aerosols (4 hours): Classification and properties of aerosols, Production and removal mechanisms, Concentrations and size distribution, Radiative and health effects, Secondary Organic Aerosols. Aerosol-Radiation and Cloud Interactions.

Radiative Transfer (3 hours): Absorption and scattering of solar radiation, Rayleigh scattering and Mie scattering, Bouguer-Lambert law, Principles of radiometry, Optical phenomena in the atmosphere, modeling for aerosols

Ground-based observational Techniques and Modelling (4 hours): Automatic weather station, temperature, humidity, radiation and wind measurements, Surface-Balloon-Satellite based observational techniques of trace gases, Physical and optical methods - Techniques for the chemical analysis of aerosols, aerosol observations, Box model, Regional and Global models, Back-air trajectory and its modelling.

Radiative transfer and remote sensing with satellites (3 hours): Solar and terrestrial radiation, Absorption, emission, transmission, Beer'slaw, surface radiation budget, effective temperature of Earth, Greenhouse effect. Satellite-based observational techniques, Classification of satellite orbits, different space-borne sensors and their application/data analysis.

Impact of Air Pollution and Climate Change (3 hours): Natural and anthropogenic sources of atmospheric pollutants; impacts of emissions on tropospheric chemistry; long-term trends in trace gases and aerosols; impact on human health, vegetation, ecosystem and climate change; urban heat island effect; climate change and its manifestations in the Himalayan region - glacier retreat, changes in snow cover, permafrost degradation, Glacial Lake Outburst Floods (GLOFs), cloudbursts, heatwaves, droughts, floods and other extreme weather events; adaptation, mitigation and sustainable air quality management.

Suggested Readings:

1. Atmospheric chemistry and climate change: Brasseur et. al.
2. Atmospheric Science: J. M. Wallace and P. V. Hobbs
3. Fundamentals of Atmospheric Modeling: M. Z. Jacobson

4. Atmospheric chemistry and climate change: Brasseur et al.
5. Introduction to Atmospheric Chemistry: D. J. Jacob

3. PHYSICS OF THE SUN AND SPACE WEATHER: 1:0 CREDITS

Sun-as-a-star basics: astrophysical context and fundamental, physical parameters — effective temperature, luminosity, mass, radius, energy source: Kelvin-Helmholtz time scale, nuclear fusion; energy transport, mean free path, photon, diffusion inside the Sun; radiative transfer, spectrum, photospheric absorption lines, limb darkening; photosphere, chromosphere, transition region, corona.

Interior Structure, Dynamics and Oscillations: The Sun and its evolution: Standard Solar Model (SSM) — Solar Oscillations -- Basics of helioseismology and tests of SSM, Connections to Asteroseismology. Interior dynamics: differential rotation, convection, meridional circulation. Helioseismology of interior dynamics and magnetism – local helioseismology of sunspots and subsurface dynamics.

Global Solar Magnetism: Solar Cycle, Large-scale Magnetic fields of the Sun, and Long-term variability. Basics of Magnetohydrodynamics — Dynamo Mechanisms - Theory, Models and Simulations.

Modern Observations and Data Analysis: Solar observation techniques: ground- and space-based telescopes and observations, adaptive optics and coronagraphic techniques. Multiwavelength (IR - X-rays) imaging and spectroscopy: velocity, temperature and density diagnostics. Solar radio astronomy. Spectro-polarimetry: magnetic field diagnostics through Zeeman and Hanle effects, weak field approximation, Milne-Eddington inversions.

Physics of the Solar Atmosphere: Photosphere – Sunspots and active regions - structure, evolution, and magnetic field topology. Granulation and supergranulation; network and internetwork magnetic elements. Flux emergence and small-scale magnetic fields. Chromosphere and Transition Regions: Radiative transfer and line formation diagnostics. Prominences. Chromospheric heating mechanisms- waves, reconnection, and turbulent dissipation. Wave phenomena and mode coupling. Fine-scale dynamics (e.g., spicules, fibrils, and jets) and their role in mass and energy transport. Corona: Coronal structure- loops, plumes, holes, and streamers. Coronal heating problem- wave-based and reconnection-based heating models, role of nanoflares and turbulence. Coronal waves and oscillations- types, diagnostics, and seismology applications. Magnetic reconnection and transient phenomena- jets, flares, and CMEs. Multi-wavelength and spectroscopic observations (EUV, X-ray) of coronal dynamics. Theoretical models and 3D MHD simulations of coronal structures and dynamics.

High-energy Phenomena: Magnetism and dynamics of solar eruptions — CMEs, flares, and solar wind: photospheric, chromospheric, coronal, and heliospheric processes. Observations: radio, optical, infrared, UV and X-ray; solar radio bursts as diagnostics of coronal dynamics and magnetism. Kinematic and thermodynamic evolution of interplanetary transients: CMEs and CIRs; Shocks in Heliophysics; Solar and interplanetary sources of particle accelerations; Cosmic rays and forbush decrease; Modern data analysis techniques and modelling.

Solar Wind and Space Weather Phenomena: origins and dynamics in the solar atmosphere, propagation dynamics and MHD phenomena; Turbulence in Space Plasmas; Planetary Magnetospheres; Space Storms and Radiation; Solar Spectral Irradiance; Ionospheres of the Terrestrial Planets; Solar Variability, Climate, and Atmospheric Photochemistry — observations (remote and in-situ) and data analysis.

Suggested Readings:

1. The Sun: An Introduction by M. Stix
2. Magnetohydrodynamics of the Sun by Eric Priest
3. Physics of the Solar Corona by M.J Aschwanden
4. Physics of Plasmas and Fluids by A. R. Choudhuri

4. THEORY OF RELATIVITY AND COSMOLOGY: 1:0 CREDITS

General Relativity and Relativistic Astrophysics:

- Salient features of Special Relativity; Postulates, obtaining the Lorentz transformation from the postulates, space time diagram and consequences of special relativity. Covariant EM theory, hydrodynamics in STR
- Basics of Newtonian mechanics and gravity,
- General Theory of Relativity -Principle of Equivalence; Principle of general covariance.
- General Tensors; Maxwell's Equations in curved space-time; Ideal fluids: Equations of motion
- Einstein field equations; Schwarzschild line elements and its consequences
- Stellar structure of relativistic stars, gravitational collapse. Neutron Stars, blackholes
- Kerr metric and its consequences
- Relativistic Accretion discs. Some of the outflow models

The basic framework of relativistic cosmology: the cosmological principle, Robertson–Walker (FRW) metric, cosmological redshift, Hubble's law and the Hubble constant, Friedmann equations and standard cosmological models (open, closed, and flat universes).
Evolution of the scale factor, age and geometry of the Universe. Thermal history of the Universe, Big Bang nucleosynthesis, phase-space distribution function, thermodynamics of the early Universe, decoupling of matter and radiation, Cosmic Microwave Background Radiation (CMBR), and a brief introduction to dark matter and dark energy.

Suggested Readings:

1. Gravitation and Cosmology: Weinberg
2. Problem book on relativity and gravitation: Priest et. Al.
3. Classical theory of Field: Landau and Lifshitz
4. A first course in general theory of relativity – Bernard Schutz
5. Classical Mechanics: H. Goldstein
6. Structure formation in the Universe: T . Padmanabhan
7. Cosmological Physics: J. A. Peacock
8. Introduction to Cosmology: J. V. Narlikar
9. Principle of Physical Cosmology: P . J. E. Peebles

Course 3 – Advanced Course

1. FUNDAMENTALS OF ASTRONOMY: 3:0 CREDITS

Coordinate systems: Astronomical observations: electromagnetic waves, cosmic rays, gravitational radiation; Earth vs. space-based observations, Spherical Trigonometry, Celestial sphere, Equatorial and Ecliptic coordinate systems. Astronomical Times - Sidereal time, Solar

time, Hour angle, Julian date, Astronomical twilight. Distance measurements: AU, parsec, standard candles, distance measurement by geometric means (parallax, distances to open clusters). Stellar Motions, Planetary motions, Parallax, Precession and Nutation, Astronomical Constants. Apparent, Absolute and Bolometric magnitudes, Extinction and Optical thickness, Color-index and luminosity of stars, Distances.

Fundamentals of radiation and Sun as a star: Radiation: geometric optics, specific intensity, luminosity/flux, radiative transfer equation, extinction and emission of light, opacity, optically thick/thin media, blackbody radiation, local thermal equilibrium between matter and radiation and its connection with blackbody radiation. Sun as a star (qualitative): Solar spectrum, effective temperature, luminosity, photospheric absorption lines, limb darkening; energy source: Kelvin time scale, nuclear fusion; energy transport in the Sun, Thomson scattering, mean free path, photon diffusion inside the Sun; photosphere, chromosphere, transition region, corona; X-ray emission, magnetic fields, Sunspots.

Interstellar medium and Stellar variability: Interstellar medium (ISM), Galactic gas and its detection, Phases of the interstellar medium, Interstellar dust: Extinction and thermal emission, properties of Grains**,** young stellar systems**,** effect of massive stars, H II regions, induced star formation, Local and large scale distribution of stars and interstellar matter, Diffuse Matter, Inter galactic Medium(IGM), Diffuse matter in Universe, Stellar populations, Stellar variability, Classification of variable stars, exoplanet.

Stars: Velocity dispersion, Stellar temperatures, Spectral Classification of stars, HR diagram. Stellar evolution, end products of stars: White dwarfs, Neutron Stars, Black holes. Observational signatures like supernovae, GRBs and classification of such events. Basics of accretion phenomena, its efficiency, continuum spectra. Binary star evolution, effective potential in rotating frame, Lagrange points, Roche lobe, Mass overflow, Type Ia supernovae

Galaxy and Extragalactic astronomy: Galaxy morphology, Galactic dynamics, Spiral structure, Density wave theory, galaxy classification schemes, Morphology and properties of different classes of galaxies. Galaxy luminosity functions. Stellar relaxation, Dynamical friction, Random velocity and random curves, Tully-Fisher relation, Galaxy rotation curve and dark matter; Milky Way components: gas, stars, magnetic field and cosmic rays, satellites, 21cm line, HII regions, phases and components of interstellar medium, cosmic rays. Active galactic nuclei (AGN) and classifications, Quasars emission and absorption line physics. AGN emission model, AGN surveys. Clusters of galaxies and superclusters.

Suggested Readings:

1. Fundamental Astronomy: Karttunnen, Kroger, Oja, Poutanen, Donner (Springer press)
2. The Physical Universe: an Introduction to Astronomy by Frank H. Shu (Univ. Sci. Books)
3. An Introduction to Modern Astrophysics: B. W. Carrol & D. A. Ostlie
4. Astrophysical Concepts: M. Harwit
5. Spherical Astronomy: W. M. Smart
6. An Introduction to Active Galactic Nuclei: B. M. Peterson (Cam. Univ. Press)
7. Quasars and Active Galactic Nuclei: Ajit Kembhavi, J. V. Narlikar (Cam. Univ. Press)

2. INTRODUCTION TO ATMOSPHERIC SCIENCES: 2:0 CREDITS

Atmospheric Science, classifications and meteorological observations:
Components of Meteorology and Climatology, Earth's atmosphere and its Composition, Thermal structure of the Atmosphere, Introduction to ionosphere, scales of motion in the atmosphere, Instruments for meteorological observations, Balloon soundings (RS/RW, pilot balloon etc.) (4 hrs)

Atmospheric Thermodynamics: Hydrostatic equation, Hypsometric equation, Concept of air parcel, Potential temperature, virtual potential temperature, Lapse rate, Static stability (3 hrs)

Meteorological processes and weather systems: Winds and air-mass trajectories, General circulation model, sea breeze, land breeze, fogs/smog, precipitation, fronts, cyclones and anticyclones, tropical cyclones, thunderstorms, monsoon dynamics (3 hrs)

Dynamic meteorology: Total differentiation, Fundamental forces, Basic conservation laws, Applications of the basic equations, Scale analysis, Circulations and vorticity, synoptic-scale motions, Quasi-geostrophic analysis. (4hrs)

Atmospheric oscillations: Baroclinicity, barotropicity and instability, Mesoscale circulations, El-Nino, La-Nina, ENSO, Polar vortex, Intertropical convergence zone (ITCZ), Rossby waves (3 hrs)

Atmospheric Boundary Layer: Mean boundary layer characteristics, Surface Energy Balance and surface layer characteristics, Vertical Structure, Evolution, Special Effects: Terrain/Sea Breezes, Canopy Effects, Urban Effects, Mountain meteorological flows (4 hrs)

Clouds Microphysics: Clouds- types and classification, Nucleation of Water Vapor Condensation, Warm Clouds processes and Microphysics, Cloud Liquid Content, Cold Cloud Microphysics, Artificial Modification of Clouds and Precipitation, Thunderstorm Electrification, Cloud and Precipitation Chemistry. (3hrs)

Radar/LIDAR principles: Classical radar equation and return signal, distributed targets, Doppler velocity measurements, Signal processing and detection, Application of radars to study atmospheric phenomena, Lidar equation, types of Lidar, Estimations of radiative forcing, applications of Lidar (4 hrs)

Suggested Readings:
1. Aeronomy of the middle atmosphere: G. Brasseur and S. Solomon
2. Atmospheric chemistry and climate change: Brasseur et al.
3. Meteorology for Scientist and Engineers: R. Stull
4. Atmospheric Science: J. M. Wallace and P . V. Hobbs
5. An introduction to dynamic meteorology: J. R. Holton
6. Meteorology for Scientist and Engineers: R. Stull
7. Tropical meteorology: G. C. Asnani (Vol I, II, III)
8. Introduction to radar systems: Skolnik
9. Radar Meteorology: S. Raghvan
10. Radar for Meteorologist: R. E. Rinehart

3. NUMERICAL AND STATISTICAL TECHNIQUES 1:0 credits

Numerical Techniques in Physics and Astrophysics: Numerical precision and computational errors, Interpolation and extrapolation, Numerical differentiation and integration, Solution of algebraic equations, Ordinary differential equations, Partial differential equations, Random number generation and its applications

Statistical Methods: Probability and probability distributions, Discrete and continuous random variables, Statistical moments: mean, variance, covariance and correlation, Gaussian, Binomial and Poisson distributions, Central Limit Theorem, Random walks and Poisson processes, Error propagation and uncertainty analysis

Data Analysis and Model Fitting: Least-squares fitting, Linear and nonlinear regression, Goodness-of-fit tests, Hypothesis testing, Levenberg–Marquardt method, Errors in estimated parameters, Robust estimation techniques, Multivariate analysis, Random processes in astrophysics

Time-Series Analysis and Monte Carlo Methods: Monte Carlo techniques, Fourier transforms and spectral analysis, Periodogram analysis, Wavelet analysis, Bayesian inference (basic concepts and applications).

Suggested Readings:

1. Practical statistics for Astronomers: J. V. Wall and C. R. Jenkins
2. Numerical Recipes-the art of scientific computing: W. H. Press et al.
3. Data reduction and Error analysis for the Physical Sciences: P . R. Bevington and D. K. Robinson
4. Astrophysical Concepts: Martin Harwit
5. Computer Programming in FORTRAN 90/95: V. Rajaraman

4. ELECTRODYNAMICS AND RADIATIVE PROCESSES: 2:0 credits

Radiation transfer: Definitions of specific intensity, mean intensity, flux and energy density; Equation of radiation transfer; solutions in some specific cases, optical depth; Thermal emission; Blackbody spectrum and its characteristics; Kirchhoff's law; Einstein coefficients

Radiation fields: Review of Maxwell's equations, Poynting theorem; Electromagnetic potentials; Green's function in Lorentz gauge; Retarded potentials; Fields in near zone and at far distances; Radiation from non-relativistic particles (Larmor's formula); Dipole approximation; Spectrum of dipole radiation; Scattering of EM waves, Thomson scattering, scattering by a bound charge; Polarisation; Stokes parameters.

Relativistic effects on radiation: Review of Lorentz transformation of E and B fields; Radiation from relativistic particles; Angular distribution of emitted power; Invariant phase volumes and specific intensity

Bremsstrahlung: Thermal Bremsstrahlung; free-free absorption; examples from astrophysics

Synchrotron radiation: Motion of charged particle in uniform B field; spectrum of synchrotron radiation; difference between cyclotron and synchrotron radiation; angular distribution and polarization; radiation from non-thermal electrons; synchrotron loss time; minimum energy estimates; synchrotron self-absorption

Compton scattering: Energy transfer from electrons at rest; Inverse Compton scattering; Scattered power and spectrum; Inverse Compton loss time scale; Comptonization; Basics of Sunyaev-Zeldovich effect; maximum brightness temperature.

Suggested Readings:

1. Radiative Processes in Astrophysics: Rybicki & Lightman
2. Radiation: F . Shu
3. Electrodynamics: Jackson

5. INTRODUCTION TO FLUID MECHANICS AND PLASMA PHYSICS 2:0 credits

Hydrodynamics (HD):

- Equations of motion of fluid - Euler and Navier Stokes equations, basic discussion;
- Kinetic Theory approach to obtain the equations of motion (Boltzmann equations to HD equations)
- Acoustic waves, shock waves;
- Kelvin's circulation theorem, laminar flow, turbulent boundary layers, Fluid instabilities Convective, rotational, Rayleigh T aylor; gravitational, and Kelvin-Helmholtz Instabilities;
- **Convection:** Thermal diffusivity and its effect on the entropy equation. Conductive and convective transport of heat equation. Mixing length theory and transport of heat, application to plane-parallel atmospheres and stars.
- Bernoulli's theorem; deLaval Nozzle; Bondi Flow, Parker wind;
- Jean's mass- self gravitating spherical masses; Application of hydrostatics: Virial theorem
- Accretion discs: example (i) Transonic accretion discs – Eq. Of motion, method to solve, solutions (ii) Sakura-Sunyaev disc - equations of motion and continuum spectra
- Method of characteristics and Riemann Problem, building blocks of CFD

Magneto Hydrodynamics (MHD):

- Plasma Orbit theory, motion of charged particles in EM field, Drift currents, guiding centre approach. Magnetic mirror, curvature drifts, Landau damping, plasma oscillation
- Basic Kinetic equation of collisionless plasma, Kinetic theory eqs to Vlassov Equations,
- Two fluids and its applications.
- MHD Equations from two fluid equations, flux freezing, MHD waves e.g., slow, fast and Alfven waves.
- Magnetostatics and Parker instability, Magnetic virial theorem.
- Weber Davis model of Solar wind
- Hydromagnetic shocks: jump conditions. Rotational discontinuities.
- Magnetic reconnection, basics of dynamo.

Suggested Readings:

1. Gas Dynamics: F . H. Shu
2. The Physics of Fluids and plasma: A. Rai Choudhuri
3. Fluid Mechanics: Landau and Liftshitz
4. Physics of fully Ionized Gases: L. Spitzer Jr.
5. Solar Magneto-hydrodynamic Priest