Indian Institute of Space Science and Technology

Curriculum and Syllabus for Master of Science in Astronomy and Astrophysics – Operative from 2018

SEMESTER–WISE CREDITS

Semester	I	II	III	IV
Credits	17	18	18	17

SEMESTER I

Code	Course Title	L	T	P	C
ESA611	Introduction to Astronomy and Astrophysics	3	0	0	3
ESA612	Astronomical Techniques	3	0	0	3
ESA613	Radiation Processes in Astrophysics	3	0	0	3
ESA614	Computational Astrophysics	2	0	6	4
ESA615	Planetary Sciences	3	0	0	3
ESA631	Data Analysis Astronomy Lab	0	0	3	1
	Total	14	0	9	17

SEMESTER II

Code	Course Title	L	T	P	C
ESA621	Structure and Evolution of Stars	3	0	0	3
ESA622	Galaxies (Structure, Dynamics and Evolution)	3	0	0	3
ESA623	Cosmology	3	0	0	3
ESA6XX	Elective I	3	0	0	3
ESA651	Seminar	0	0	0	2
ESA641	Observational Astronomy Lab	0	0	6	2
ESA 652	Comprehensive viva	0	0	0	2
	Total	12	0	6	18

SEMESTER III

Code	Course Title	L	T	P	C
ESA653	Seminar II	0	0	0	2
ESA654	Thesis Phase I	0	0	0	16
	Total	0	0	0	18

SEMESTER IV

Code	Course Title	L	T	P	C
ESA655	Thesis Phase II	0	0	0	17
	Total	0	0	0	17

LIST OF ELECTIVES

Code	Course Title
ESA661	Gas Dynamics
ESA662	Physics of Interstellar and Intergalactic Medium
ESA663	High Energy Astrophysics
ESA664	Estimation and Stochastic Processes
ESA665	Formation of Stars and Planets
ESA666	Advanced Astronomical Imaging
ESA667	Radiation Hydrodynamics
ESA668	Accretion Physics
ESA669	High Redshift Universe
ESA670	Polarization in Astronomy
ESA671	High Resolution Spectroscopy
ESA672	Time Domain Astronomy
ESA673	Exoplanets & Astrobiology
ESA674	Physics of the Sun

SEMESTER I

ESA611 Introduction to Astronomy and Astrophysics (3 – 0 – 0) 3 credits

Sky coordinates and motions: Earth Rotation - Sky coordinates - seasons - phases of the Moon - the Moon's orbit and eclipses - timekeeping (sidereal vs synodic period); Planetary motions - Kepler's Laws - Gravity; Light & Energy - Telescopes - Optics - Detectors; Planets: Formation of Solar System - planet types - planet atmospheres - extrasolar planets; Stars: Measuring stellar characteristics (temperature, distance, luminosity, mass, size) - HR diagram - stellar structure (equilibrium, nuclear reactions, energy transport) - stellar evolution; Galaxies: Our Milky Way - Galactic structure - Galactic rotation - Galaxy types - Galaxy formation; Cosmology: Expansion of the Universe - redshifts - supernovae - the Big Bang - history of the Universe - fate of the Universe.

Text / Reference Books:

1. BW Carroll & DA Ostlie, An Introduction to Modern Astrophysics, Latest Edition, Addison-Wesley.
2. Frank Shu, The Physical Universe, Latest Edition, University Science Books
3. Martin Harwit, Astrophysical Concepts, Latest Edition, Springer.
4. T. Padmanabhan, Invitation to Astrophysics, Latest Edition, World Scientific Publishing Co.
5. T. Padmanabhan, Theoretical Astrophysics vols 1-3, Latest Edition, Cambridge University Press.
6. Malcolm Longair, High Energy Astrophysics, vols 1-2, Latest Edition, Cambridge University Press.
7. Sparke and Gallaghar, Galaxies in the Universe: An Introduction, Latest Edition, Cambridge University Press.
8. Dina Prialnik: An Introduction to the Theory of Stellar Structure and Evolution, Latest Edition, Cambridge University Press.

ESA612 Astronomical Techniques (3 – 0 – 0) 3 credits

Telescopes and Detectors – optical, infrared, radio, x-rays, gamma-rays, neutrinos and cosmic rays; Gravitational radiation; Detection of dark matter and Dark Energy Astronomy from Space;

Imaging – focal plane imagers, PSF and deconvolution, interferometry Photometry, Spectroscopy, Polarimetry, Astrometry; Solar telescopes; Surveys, Astronomical databases, Virtual Observatory

Text/ Reference Books:

1. C.R. Kitchin, Astrophysical Techniques, CRC press.
2. M.Longair, High Energy Astrophysics vol 1, Cambridge University Press.

ESA613 Radiation Processes in Astrophysics (3 – 0 – 0) 3 credits

Concepts of Radiative Transfer – special relativity – Maxwell's equations – Wave equation – retarded potentials – radiation field – Poynting vector – radiation from accelerated charge – bremsstrahlung – Thomson and Compton scattering – synchrotron radiation – thermal and non-thermal distribution of radiating particles – non-thermal synchrotron radiation – self-absorption – synchrotron and Compton cooling – Inverse Compton catastrophe and brightness temperature limit – propagation effects: dispersion, faraday rotation, depolarization – Atomic and molecular spectra – fine structure and hyperfine transition

Text/ Reference Books:

1. G.B. Rybicki and A.P. Lightman, Radiative Processes in Astrophysics, Wiley.
2. F.H. Shu, The Physics of Astrophysics vol I: Radiative Processes, University Science Books.
3. W.H. Tucker, Radiation Processes in Astrophysics.

ESA614 Computational Astrophysics (2 – 0 – 6) 4 credits

Overview of numerical computation - Simple problems: data sorting, root finding etc. - Numerical solutions of algebraic equations - Numerical integration, interpolation/extrapolation - Numerical differentiation - Ordinary differential equations - Partial differential equations - Statistics, Least-squares fitting - Data crunching, dealing large data set - Fourier transform - Advanced Applications in Astrophysics: N-Body Methods, Hydrodynamics - Monte Carlo Methods

Text/ Reference Books:

1. Numerical Recipes in C, The Art of Scientific Computing, W.H. Press et al.
2. Numerical Methods in astrophysics: An Introduction, Bodenheimer et al., Taylor & Francis, 2007
3. Astrophysics with a PC: An Introduction to Computational Astrophysics, P. Hellings, Willmann-Bell, 1994
4. Data Reduction and Error Analysis for Physical Sciences, P. R. Bevington & K.K. Robinson, McGraw-Hill, 2003

ESA615 Planetary Sciences (3 – 0 – 0) 3 credits

Overview of Solar system - Dynamics: Two-body problem, Three-Body Problem (Lagrangian points) - Resonances - Tidal forces - Solar energy balance and transport: Radiative Equilibrium - Planetary Atmospheres: Structure, Composition, Atmospheric Escape - Planetary surfaces: Surface morphology - Impact cratering - Minor Bodies: Meteories, Asteroids, Comets, Minor planets, Trans-Neptunian Objects, Centaurs - Planetary rings - Planet formation: Evolution of protoplanetary disks, Growth of solid bodies, Formation of Terrestrial and Giant planets - Planetary Migration: - Extrasolar Planets: Detection techniques - Estimating planetary masses, sizes, orbital parameters -- Habitable zones: factors influencing habitable zone - continuously habitable zone - Missions to study Planets and Extrasolar planets: Overview and Results

Text/ Reference Books:

1. Fundamental Planetary Science: Jack Lissauer & Imke de Pater (Latest Edition) - Cambridge University Press
2. The Solar System: Therese Encrenaz and Jean-Pierre Bibring (Latest Edition) - Astronomy and Astrophysics Library, Springer
3. The Origin and Evolution of the Solar System: Michael M. Woolfson - IoP CRC Press
4. Moons and Planets, W.K. Houtmann, Wadsworth Publishing Company 4th Ed.
5. Exoplanets - Edited by Sara Seager - University of Arizona Press 2011

ESA631 Data Analysis Astronomy Lab (0 – 0 – 3) 1 credits

Tutorials on Fitting techniques (linear and non-linear, fits to data with experimental errors, evaluating goodness of fit, etc) and error analysis, Handling of data and getting familiar with data analysis packages like IRAF, AIPS and CASA. This includes an introduction, beginners tutorials and exercises in these softwares as well as and X-ray data analysis

SEMESTER II

ESA621 Structure and Evolution of Stars (3 – 0 – 0) 3 credits

Mechanical, Thermal and Nuclear time scales – Hydrostatic equilibrium (Newtonian and Relativistic) – Polytropic Equation of State – Lane Emden Equation – Degenerte matter Equation of State – White Dwafs and Chandrasekhar limit – Virial Theorem - Radiative Equilibrium – Schwarzschild convection criterion – nuclear energy generation – stages of nuclear burning – full set of stellar structure equations – example solutions – HR diagram and the main sequence – Schonberg-Chandrasekhar limit – post- main sequence evolution – Hayashi tracks – Horizontal branch – giant and asymptotic giant branches – planetary nebula formation – supernovae – compact objects.

Text/ Reference Books:

1. R. Kippenhahn and A. Weigert, Stellar Structure and Evolution, Springer.
2. A. Weiss et al, Cox and Giuli's Principles of Stellar Evolution, Cambridge Scientific Publishers.
3. Dina Prialnik, An introduction to the theory of stellar structure and evolution, Cambridge University Press.
4. S. Chandrasekhar, An introduction to the Study of Stellar Structure, Dover.

ESA622 Galaxies (Structure, Dynamics and Evolution) (3 – 0 – 0) 3 credits

Classification of galaxies – contents and dimensions – collisionless stellar dynamics – relaxation time, dynamical friction, violent relaxation – galactic potential and orbits – spiral density wave and Lindblad resonance – rotation curves – Tully-Fisher relation – Central Black Holes and fundamental plane relationship – Mass and Luminosity function – Press Schechter formalism –

Star formation history and chemical evolution – active galaxies and activity duty cycle – galaxies at high redshift - clusters and groups – evidence of dark matter

Text/ Reference Books:

1. L.S. Sparke and J.S. Gallagher, Galaxies in the Universe, Cambridge University Press.
2. J. Binney and S. Tremaine, Galactic Dynamics, Princeton University Press.
3. J. Binney and M. Merrifield, Galactic Astronomy, Princeton University Press.
4. A.K. Kembhavi and J.V. Narlikar, Quasars and Active Galactic Nuclei: An Introduction, Cambridge University Press.

ESA623 Cosmology (3 – 0 – 0) 3 credits

Principles of Relativity: Overview of Special Relativity - spacetime interval and Lorentz metric- four vectors - Introduction to general relativity (GR) - equivalence principle - notions of curvature - gravitation as a manifestation of the curvature of spacetime - gravitational redshift and clock corrections - orbits in strong gravity, light bending and gravitational lensing - concept of horizon and ergosphere, hydrostatic equilibrium in GR - gravitational radiation.

Cosmological Models: Universe at large scales – Homogeneity and isotropy – distance ladder – Newtonian cosmology - expansion and redshift - Cosmological Principle - Hubble's law - Robertson-Walker metric - Observable quantities – luminosity and angular diameter distances - Horizon distance- Dynamics of Friedman- Robertson-Walker models: Friedmann equations for sources with p=wu and w =−1, 0, 1/3, discussion of closed, open and flat Universes.

Physical Cosmology and Early Universe: Thermal History of the Universe - distribution functions in the early Universe – relativistic and nonrelativistic limits - Decoupling of neutrinos and the relic neutrino background - Nucleosynthesis - Decoupling of matter and radiation - Cosmic microwave background radiation (CMB)- Anisotropies in CMB - Inflation – Origin and growth of Density Perturbations - Formation of galaxies and large scale structures - Accelerating universe and type-Ia supernovae - The Intergalactic medium and reionization.

Text/ Reference Books:

1. Cosmological Physics, Cambridge University Press, J . A. Peacock
2. An Introduction to Relativity, J. V. Narlikar, Cambridge University Press, 2010 (For the

lectures on General Relativity and Cosmology).
3. Theoretical Astrophysics, Volume III: Galaxies and Cosmology, T. Padmanabhan,Cambridge University Press, 2002 (for lectures on Cosmology)
4. Classical Theory of Fields, Vol. 2, L. D. Landau and E. M. Lifshitz, Oxford : Pergamon Press, 1994 (For more material on General Relativity).
5. Introduction to Cosmology, J. V. Narlikar, Cambridge University Press, 1993 (For the lectures on Cosmology).
6. First course in general relativity, B. F. Schutz, Cambridge university press, 1985 (For material on General Relativity).
7. Structure Formation in the Universe. T. Padmanabhan, Cambridge University Press, 1995 (for material on Cosmology and Structure formation).

ESA641 Observational Astronomy Lab (0 – 0 – 6) 2 credits

CCD characterisation, Orbit maker and Virtual Observatory, Night sky observations (Polar alignment of an astronomical telescope, Estimating atmospheric extinction in different colours (filters), measuring period of binary, imaging star clusters with various filters and plotting on H-R diagram, Distance determination to Cepheid variables based on their light curves, Classification of stars based on their spectra and the use of spectral classification in deriving distances to stars, etc)

LIST OF ELECTIVES

ESA661 Gas Dynamics (3 – 0 – 0) 3 credits

Conservation laws – Euler's Equations – Common Equations of State – Hydrostatic Equiibrium – Isothermal sphere – Virial Theorem – linear perturbation theory – acoustic waves – Jeans' instability – Rayleigh Taylor instability – de Laval nozzle - Parker wind solution – Bondi accretion – Shock waves– Sedov solution – elements of plasma physics - Debye screening – orbit theory - elements of MHD – flux freezing – Alfven waves - Langmuir oscillations –dispersion relation of electromagnetic waves propagating in plasmas- plasma instabilities - transport phenomena

Text/ Reference Books:

1. F.H. Shu, The Physics of Astrophysics vol II: Gasdynamics, University Science Books.
2. M.J. Thompson, An Introduction to Astrophysical Fluid Dynamics, Imperial College Press.
3. Arnab Rai Choudhuri, The Physics of Fluids and Plasmas, Cambridge University Press.
4. Francis F Chen , Introduction to Plasma Physics and Controlled Fusion, Springer

ESA662 Physics of Interstellar and Intergalactic Medium (3 – 0 – 0) 3 credits

Occurrence and state of cosmic diffuse matter – ionized, atomic, molecular gas and dust – heating and cooling, equilibrium phases – probes of diffuse matter (line and continuum radiations at various wavelengths) – Thermal and ionization equilibrium of HII regions – UV shielding in molecular gas – extinction/reddening/polarization due to dust – dust heating and IR emission – star forming regions - cosmic rays and non-thermal synchrotron emission – recombination and re-ionization of IGM – Lyman alpha forest, Mg absorption systems – Gunn Peterson effect – Heating of intracluster gas – Sunyaev- Zeldovich effect – excess entropy problem and possible resolution

Text/ Reference Books:

1. M.A. Dopita and R.S. Sutherland, Diffuse Matter in the Universe, Springer.
2. D.E. Osterbrock and G.E. Ferland, Astrophysics of Gaseous Nebulae and Active Galactic Nuclei, University Science Books.
3. L. Spitzer, Physical Processes in the Interstellar Medium, Wiley.
4. D. Mihalas and J. Binney, Galactic Astronomy, Princeton University Press .
5. J.E. Dyson and D.A. Williams, The Physics of the Interstellar Medium, IOP publishing.

ESA663 High Energy Astrophysics (3 – 0 – 0) 3 credits

Radiation-matter interaction – Sources of high energy (UV-gamma rays) radiation in the universe - Detectors for high energy particles, X-rays, gamma rays and neutrinos – Space astronomy - Elements of General Relativity - compact stars – magnetospheric processes around neutron stars (pulsars and magnetars) – interacting binaries – Roche potential and accretion – Shkura-Sunyaev thin disk model – accretion phenomenology around compact

objects – stellar mass black holes vs supermassive black holes – AGN phenomenology and unified scheme – Jet production and superluminal motion – Supernova remnants and shock acceleration of relativistic particles – Gamma Ray Bursts

Text/ Reference Books:

1. M. Longair, High Energy Astrophysics, vol. 1 and 2, Cambridge University Press
2. F. Melia, High Energy Astrophysics, Princeton University Press
3. Ya B. Zeldovich and I.D. Novikov, Relativistic Astrophysics, vol. I, Stars and Relativity

ESA664 Estimation and Stochastic Processes (3 – 0 – 0) 3 credits

Elements of probability theory - random variables-Gaussian distribution-stochastic processes-characterizations and properties-Gauss-Markov processes-Brownian motion process-Gauss-Markov models - Optimal estimation for discrete-time systems - fundamental theorem of estimation-optimal prediction. Optimal filtering - Weiner approach-continuous time Kalman Filter-properties and implementation- steady-state Kalman Filter-discrete-time Kalman Filter-implementation-sub-optimal steady-state Kalman Filter-Extended Kalman Filter-practical applications. Optimal smoothing - Optimal fixed-interval smoothing optimal fixed-point smoothing-optimal fixed-lag smoothing-stability-performance evaluation.

ESA665 Formation of Stars and Planets (3 – 0 – 0) 3 credits

The interstellar medium and its phases - dust - molecular clouds - virial theorem analysis. Star clusters - OB associations - T and R associations - initial mass function. Heating and cooling of clouds - cloud thermal structure - build up of molecules - molecular transitions of H2, CO. Cloud equilibrium and stability - Jeans mass - isothermal spheres - basic magnetohydrodynamics - magnetic support - ambipolar diffusion - inside-out collapse - rotational effects. Collapse of dense cores - accretion - Deuterium burning - protostellar disks - fragmentation - formation of binaries and stellar groups - jets and molecular outflows – masers. Formation of massive stars - monolithic collapse - competitive accretion - stellar mergers. Effects of massive stars - hot cores - ultracompact HII regions - photoevaporation - induced star formation. Quasi-static contraction - nuclear reactions and stellar birth line - T-Tauri stars - Herbig Ae/Be stars - debris disks - planet formation in disks.

Text/ Reference Books:

1. The Formation of Stars by S. W. Stahler and F. Palla, 2004 – Wiley – VCH
2. The Origin of Stars and Planetary Systems, 1999, eds. C.J. Lada and N.D. Kylafis
3. Protostars and Planets V, 2007, eds. B. Reipurth, D. Jewitt, and K Kell
4. Accretion Processes in Star Formation, 1998, L. Hartmann
5. Astrophysics of Planet Formation, 2010, P. Armitage

ESA666 Advanced Astronomical Imaging (3 – 0 – 0) 3 credits

Imaging and detector basics - resolution, sensitivity, noise, dynamic range, efficiency, linearity - image formation at focal plane - Fourier transform - Deconvolution and Image reconstruction - Photography, CCD -- Large optical / IR telescopes and their designs - thin lens - segmented mirrors - Active optics - Designs of few upcoming large telescopes (eg. EVLT, TMT) -- Techniques to overcome atmopsheric turbulence - Fried parameter - Isophase patches and speckles - Adaptive optics - Lucky imaging - Speckle imaging -- Interferometry - Basic principles - Michelson stellar interferometer - Aperture synthesis - VLBI - New and Upcoming missions - eVLA, ALMA, SKA -- Non focussing methods - Tubular and modulation collimators, Coded masks, Fresnel zone-plates -- Astrotomographic techniques - Lunar occultation, eclipse mapping, doppler tomography, echo mapping

Text/ Reference Books:

1. Electronic Imaging in Astronomy: Detectors and Instrumentation - Ian S. McLean, Springer, 2008
2. Adaptive Optics for Astronomical Telescopes - John W. Hardy, Oxford Series in Optical & Imaging Sciences, 1998
3. Astrotomography: Indirect Imaging Methods in Observational Astronomy, Editors: H.M.J. Boffin, D. Steeghs, J. Cuypers, Springer Lecture series, 2001
4. Interferometry and Synthesis in Radio Astronomy - Thompson, Moran & Swenson, Wiley, 2001
5. Lucky Exposures:: Diffraction Limited Astronomical Imaging through the Atmosphere - Robert Tubbs, VDM Verlag Dr. Müller, 2010
6. Astronomical Image and Data Analysis - J.-L. Starck, F. Murtagh, Astronomy and Astrophysics Library, 2006

ESA667 Radiation Hydrodynamics (3 – 0 – 0) 3 credits

Introduction : How radiation affects the flow of matter -- Cooling, Heating, Momentum transfer, Matter density variation due to annihilation/pair-production. Review of gas dynamics: Ideal fluids, Transport terms - Viscosity & heat conduction, Sound waves, Shocks - Rankine-hugoniot relations. Review of radiation physics : Intensity, Flux, Energy density, Stress tensor, Transport equations, Diffusion approximation, Coupling terms in Euler's equations. Steady state transfer:Radiation-matter interaction : Einstein's coefficients, Scattering, Ionization/recombination, Opacity calculations, Spectral line transport. Polarized light in the equation of transfer :Hydrodynamics with radiation : non-adiabatic waves, atmospheric oscillations with radiation pressure, Relativistic hydrodynamics in the presence of a radiation field. Numerical techniques for radiation transport Examples : Ionization fronts, Comptonization, Radiating shock waves, Radiatively driven stellar winds

Text/ Reference Books:

1. Foundations of Radiation Hydrodynamics, Dimitri Mihalas, Dover Pbl.
2. Radiation Hydrodynamics, John I Castor, Cambrdige Press.
3. The equations of Radiation Hydrodynamics, Gerald C Pomraning, Dover pblcns

ESA668 Accretion Physics (3 – 0 – 0) 3 credits

Introduction: Accretion as a source of energy --- observational consequences. Accretion in binary system: Introduction --- Interacting binary system --- Roche lobe overflow --- Disk formation --- Viscous torque --- The α disk viscosity --- Low and high-mass X-ray binaries. Accretion disk (thin accretion disk) Theory: Basic concepts --- Structure of thin disk --- The emitted spectrum of steady α-disk --- Time dependence and stability --- the thermal disk instability model (dwarf novae) --- wind accretion --- Disk around young stars --- confrontation with observations. Accretion on to compact object: Boundary layers --- Accretion on to magnetized neutron star and white dwarf --- accretion column --- accretion on to black hole. Accretion disk in AGN: AGN models --- Radio, millimeter and infrared emission --- optical, UV and X-ray emission --- broad and narrow line region --- Extended and compact radio sources --- The Blandford-Znajek model. Thick discs: The limiting luminosity --- accretion tori --- self-gravitating disks and their stability --- astrophysical implication. Accretion flows: The governing equations --- A unified description of steady flow --- advection-dominated flows --- general

transonic accretion solution in presence of heating and cooling

Text/ Reference Books:

1. Accretion Power in Astrophysics by Juhan Frank, Andrew King, Derek Raine (Cambridge University Press)
2. Accretion Processes in Star Formation by Lee Hartmann (Cambridge Astrophysics)
3. Theory of Transonic Astrophysical Flow by Sandip K. Chakrabarti (World Scientific)

ESA669 High Redshift Universe (3 – 0 – 0) 3 credits

Basic cosmology - Expansion of the universe -- scale factor -- cosmological redshift -- descriptive overview of inflation, unification of forces and fundamental particles. Primordial nucleosynthesis -- elemental abundances : predictions and observations. Cosmic Microwave Background - detection, power spectrum, origin of CMB, anisotropies in the CMB and their origin -- overview of COBE and WMAP probes - mission and instrumentation. Reionization of the universe -- quasar absorption line observations -- Gunn Peterson trough -- sources of reionization -- first stars, AGNs, Lyman Break Galaxies -- the reionization process. Detection of galaxies at high redshift - radio, sub-mm, IR surveys -- photometric redshifts -- drop-outs -- Ly-alpha emitters. Comparison of high-z galaxy properties with the present universe -- morphology, stellar content, sizes, luminosity function, baryon budget etc. Clusters and groups of galaxies, morphology-density relationship, Butcher-Oemler effect. High Redshift Supernova -- observations used to discover and measure SNe Ia (supernova rates, light curves, spectroscopic data) -- standard candle (heterogeneity in SNe brightness and light curve shapes) -- SNe Type Ia data sets (SDSS, SNLS, HST etc) -- constrains on cosmological parameters mass density, dark energy density.

Text/ Reference Books:

1. The Early Universe (Frontiers in Physics) : Edward Kolb, Michael Turner, Wesview Press, 1994.
2. The Physics of the Cosmic Microwave Background : Pavel D. Naselsky, Dmitry I. Novikov and Igor D. Noyikov, Cambridge Astrophysics Series - 41.
3. Galaxies in the Universe : Linda Sparke, John Gallagher, Cambridge University Park
4. High Redshift Galaxies : Immo Appenzeller, Astronomy & Astrophysics LIbrary, Springer

ESA670 Polarization in Astronomy (3 – 0 – 0) 3 credits

Unpolarised light, Linear, Circular, Elliptical polarised light, Partially and fully polarised light, Stokes parameters, Dichroism, Birefringence, Poincare sphere - Mueller and Jones representations with applications - Complex plane of polarisation states.

Generation of polarised light in astronomy - polarisation by reflection, scattering geometry, magnetic fields - dependence on refractive index - synchrotron emission - Faraday rotation - Dust in ISM. Instrumental polarisation errors and their calibration

Optical/infrared polarimetry - Polaroids, Wave plates, Wollaston prism, Modulators - photoelastic modulators, liquid crystals, - compound zero order plates, achromatic retarders, fresnel rhombs, modulators with CCDs, Two beam analysers, Achromatic systems, imaging and spectropolarimetry

Radio polarimetry - Orthogonal dipoles as feeds, Native linear and circular feeds, correlation, synthesis array and VLBI. X-ray polarimetry - Bragg Polarimeters, Thompson/Compton Polarimeters, Gas Pixel Detector (GPD) solution, Time Projection Chamber (TPC) polarimeter solution, X-ray polarimetry--future missions .

Text/ Reference Books:

1. Astronomical Polarimetry - J. Tinbergen, Cambridege University Press
2. Polarized light by Dennis Goldstein (3rd Edition) Marcel Dekker Inc (ISBN: 0-8247-4053-X)
3. X-ray Polarimetry--Edited By Ronaldo Bellazzini Enrico Costa Giorgio Matt Gianpiero Tagliaferri Publisher: Cambridge University Press (2010)
4. Introduction to the theory of Coherence and polarisation of light - Emil Wolf

ESA671 High Resolution Spectroscopy (3 – 0 – 0) 3 credits

Atomic structure: review of Schrodinger equation - overview of single and multiple electron systems - perturbations and level splittings - parity - spin orbit coupling - zeeman effect - hyperfine structure - Boltzmann population of energy levels in thermal equilibrium - Saha equation. Radiative transitions: semi-classical theory - dipole approximation - Einstein coefficients and oscillator strengths - selection rules and transition rates. Molecular Structure: Born-Oppenheimer approximation - electronic binding of nuclei - H2 molecule - energy levels and selection rules for pure rotation spectra, rotation-vibration spectra and electronic-rotational-

vibrational spectra. Observational techniques for spectroscopy: linear and angular dispersion - dispersion elements: prism, diffraction gratings and echelles (chromatic vs slit limited resolution, free spectral range, pre-dispersers and cross-dispersers) - Fabry Perot etalon - Fourier Transform spectrometers - digital spectrometers - multi-object spectrographs (e.g. integral field spectroscopy). Applications of high resolution spectroscopy: Elemental abundances in stars - absorption line studies of cold ISM (radio) and IGM (Lyman alpha forest) - radial velocity searches for extra-solar planets - Zeeman effect - infall and outflow signatures in star forming cores.

Text/ Reference Books:

1. Radiative Processes in Astrophysics by Rybicki & Lightman
2. Spectra of Atoms and Molecules by Bernath
3. Astrophysical Techniques by Kitchin

ESA672 Time Domain Astronomy (3 – 0 – 0) 3 credits

Scientific background : Variable stars, binary stars and their evolution, supernovae, pulsars and associated phenomena (even include testing theories of gravity using pulsars), accretion and associated phenomena (like x-ray bursts), gamma-ray bursts, rotating radio transients (RRATS), jets & outflows (micro-quasars etc), AGNs-blazars-QSOs

A survey of missions and their ways of operation [can go to technical levels, to the operations of these instruments] :- Optical/IR surveys : Pan-STARRS (Panoramic Survey Telescope and Rapid Response System), PTF (Palomar Transient Factory), Transients search & robotic telescopes, High energy surveying missions: Swift, Fermi, AGILE, Radio surveys : LOFAR (Low-Frequency Array for Radio astronomy), SKA (Square Kilometre Array), Stellar variability studies : Kepler space craft, Future missions:- Gravitational waves & time domain astronomy (simultaneous GW and EM observations), LSST (Large Synoptic Survey Telescope**),** Data handling and analysis, Multi wave-band modeling [isis etc], Time series analysis.

ESA673 Exoplanets & Astrobiology (3 – 0 – 0) 3 credits

Properties of known exoplanets – exoplanet surveys – detection methods – formation, interior and evolution of planets – brown dwarf exoplanets connection – close orbiting exoplanets – multiple planet systems – planets in binary systems – moons of exoplanets

Origin of life – prebiotic molecules and development of life forms – habitable zone – Mars and life – Icy bodies (Europa and others) – Titan's atmosphere – detection of exoplanets – search for extraterrestrial life.

Text/ Reference Books:

1. Exoplanets: Detection, Formation, Properties and Habitability by John W Mason, Springer
2. Extrasolar Planets by Cassen, Patrick, Guillot, Tristan, Quirrenbach, A. Queloz, D.; Udry, S.; Mayor, M.; Benz, W. (Eds.), SAAS Fee Advance Course 31, Springer
3. An introduction to Astrobiology by I. Gilmour and M.A. Sephton, Cambridge University Press.

ESA674 Physics of the Sun (3 – 0 – 0) 3 credits

Characteristics of the Sun – internal structure – solar observations – solar atmosphere – oscillations – Convection – rotation – magnetism – chromosphere – corona – solar wind – quiet Sun – Active Sun – Helioseismology

Text/ Reference Books:

1. The Sun – An Introduction by Michael Stix, Second Edition, A & A Library, Springer
2. Fundamentals of Solar Astronomy by Arvind Bhatnagar and William Livingston, latest edition, World Scientific
3. Solar Astrophysics by Peter Foukal, Third Edition, Wiley-VCH