Outlines for Graduate Core Courses in the Department of Astronomy and Astrophysics

YEAR 1

ASTR 30100 Stars (Autumn)

- Physical properties of the Sun as a star
- Observations: HR diagram
- Basic equations of stellar evolution
- EOS: Ideal gas, Fully electron degenerate, Relativistic electron degenerate, Radiation
- Simple polytropic models: Lane Emden equation
- The Chandrasekhar mass
- Principal Nuclear reactions
- Instabilities: Thermal, Dynamical, Convective, Thin layer
- Simple model of stellar evolution in the (core) log(T) -log (rho) plane
- Introduction to radiative transport. The specific intensity. Geometric and optical depth. Thermal radiation. Black body radiation
- Radiative diffusion approx. and the Rossland opacity
- Physical processes that contribute to the opacity: Electron scattering, free-free, free-bound, bound-bound, Kramer's formulae
- Eddington Luminosity
- Homologous stars and simple models of the main sequence
- Mass loss - Parker's wind equation
- Convection and the Hayashi zone
- Brief intro to star formation and pre-main-sequence evolution
- Post main sequence evolution: Red giant branch, Horizontal branch, Asymptotic giant branch, Planetary nebula phase and white dwarfs, Massive stars and supernovae progenitors
- Supernovae: Type1 Ia, Core collapse SN

ASTR 31000 Cosmology I (Winter)

- The FLRW metric, observables
- FLRW solutions for useful special cases
- Cosmological parameters
- Realistic universes
- Jeans instability, growth of structure
- Correlation functions, matter power spectrum
- Harrison-Zeldovich results
- Non-linear regime, halo models
- BBN basics, equilibrium equations, freeze-out conditions
- Inventory of particles, equilibrium conditions

- Recombination
- Pre-recombination dynamics, acoustic modes
- Last scattering surface, damping
- CMB overview, CMB power spectra, inflation

ASTR 30400 Galaxies (Spring)

- Morphological classification. Overview of galaxy properties: galaxy photometry, surface brightness, surface brightness profiles of spheroidal and disk galaxies.
- Distribution of galaxies in the m_app-z, Mabs-z plane. Cosmic web. The Malmquist bias. Luminosity function of galaxies. Evolution and k-corrections.
- Interpretation of galaxy spectra. Stellar population synthesis. Bi-modality of galaxy color and concentration.
- Gas and dust in galaxies. HI mass function of galaxies. Heavy element abundances of galaxies.
- Star formation in galaxies. Kennicutt-Schmidt relation. Properties of star formation regions. IMF.
- Scaling relations of galaxies: Tully-Fisher, Faber-Jackson, size-luminosity relations and the fundamental plane of spheroidal galaxies. Theoretical interpretation in terms of equilibrium equations. Global M*-SFR-Z correlation.
- Basics of orbital dynamics.
- Local Group and its local environment. Large-scale structure in galaxy distribution, galaxy clustering. Milky Way in the realm of galaxies
- Dependence of galaxy properties on environment (morphology-density relation, etc.).
- Evidence for dark matter in galaxies and galaxy clusters.
- Models of structure formation based on inflation and weakly interacting dark matter.
- Galaxy formation basics: initial density perturbations and the main features of
- their collapse. Halo mass function and clustering. Mass accretion histories of halos. Start building galaxy evolution model code.
- Early evolution of galaxies: reionization. Accretion of baryons onto galaxies and their dissipation into central disk. Dissipation processes and how to model them.
- Chemical evolution of galaxies. Gaseous halos of galaxies and the circumgalactic medium.
- Supermassive black holes and AGNs.

YEAR 2

ASTR 30300 Interstellar Matter (Autumn)

- Photo-ionization equilibrium
- Thermal equilibrium
- Interstellar radiation fields
- Emission line diagnostics
- Absorption-line analysis /HI gas, 21cm

- Molecular gas, H2/CO /dust, extinction laws
- Dust, extinction laws /stellar feedback (hydrodynamics, and shocks)

ASTR 31100 High Energy Astrophysics (Winter)

- High-Energy Radiation Processes
    - Bremsstrahlung: thermal and non thermal; black body
    - Synchrotron
    - Inverse-Compton scattering
    - Hadronic gamma-rays and neutrinos
- Compact Objects
    - White dwarfs: degenerate electron fluid
    - Neutron stars: Chandrasekhar mass; equation of state
    - Pulsars: Goldreich-Julian density; magnetosphere;
    - Black holes: orbits around BHs; jets
- Hydrodynamics
    - Strong explosion: self-similar solutions
    - Shocks: jump conditions
    - Spherical equilibrium: Eddington luminosity;
    - Disks: thin/thick disks; angular momentum transport, MRI
- Non-thermal particles
    - Cosmic rays: Galactic and extra-Galactic; propagation;
    - Fermi acceleration: second/first order
    - Diffusive shock acceleration
    - Magnetic reconnection
- Astrophysical objects
    - Microquasars - high-energy binaries
    - Supernovae: mergers vs core collapse; radio SNe
    - Pulsars and PWNe
    - Supernova remnants
    - Active Galactic Nuclei
    - Gamma-Ray Bursts

ASTR 30600 Radiation Measurements in Astrophysics (Spring)

- Radiation Theory
    - EM Waves and photons
    - Blackbody radiation
    - Atomic Interactions
- Light and Image Formation
    - How images are formed

    - Fresnel diffraction theory
    - Near field, far field regions
    - Fraunhoffer diffraction
- Signal Processing Theory
    - Random fields
    - Correlation functions
    - Orthonomal functions
    - Fourier functions
    - Probability theory/Bayesian statistics/Jaynes
    - Convolution and deconvolution
- Collecting Photons
    - Basic optics
    - Aberration theory
    - Telescope design
    - Atmospheric turbulence and adaptive optics
- Analyzing Light
    - Design of spectrographs
    - Photon detectors
    - How CCDs work
- Photometry
    - Stellar magnitudes
    - Atmospheric absorption
    - Background radiation
- Radio Astronomy
    - Van Cittert equation
    - Radio Interferometry