Roadmap of Astrophysics Major
Princeton University

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Contents

Chapter 1

Overview

The department covers all major fields in astrophysics – from planets, to black holes, stars, galaxies, quasars, dark matter, dark energy, and the evolution of the universe from the Big Bang to today.[department-astrophysical-sciences]

Academic Programs

undergraduate-program/major-requirements

Junior Papers, Senior Theses, Senior Thesis Defenses

University Certificate Program in Planets and Life

The Department of Astrophysical Sciences participates in the University Certificate Program in Planets and Life. This Program is an interdepartmental, multidisciplinary plan of study designed for students interested in these two fundamental subjects. The goal is to provide students with an understanding of the fundamental astrophysical, chemical, biological, and geological principles and engineering challenges that will guide our search for life in extreme environments on Earth and on other planets and satellites in the Solar System and among neighboring planetary systems. The cooperating departments from which the Program in Planets and Life draws faculty and other resources include Astrophysics, Chemistry, Ecology and Evolutionary Biology, Electrical Engineering, Geosciences, Mechanical and Aerospace Engineering, Operations Research and Financial Engineering, and the Woodrow Wilson School.

For more information, please visit astrobiology

Resources for Current Students

Guide to Junior Independent Work and Senior Thesis (Updated January 11, 2019) (Downloaded)
Research and Technical Resource Guide (Downloaded)

Extracurricular Research Opportunities

Undergraduate Summer Research Program (USRP)

courses undergrad + grad, home page
Courses of DoA - mainly undergrad?

Astrophysical Sciences - Permanent Courses
The Department of Astrophysical Sciences offers advanced training in astrophysics. The faculty and staff in the department conduct world-leading research in theoretical and computational astrophysics, observational astronomy, astronomical surveys and instrumentation (both hardware and software). The fascinating discoveries of modern astronomy challenge human understanding of the broadest possible range of physical phenomena. The graduate program in Astrophysical Sciences prepares students for scientific careers in astrophysics through a combination of classes and early and active participation in semester research projects, culminating in original thesis research.

The program length is five years, the first two years of which are dedicated to taking core astrophysics courses and working on up to four semester-long research projects with different faculty members. After the general exam at the end of the second year, the students are admitted to candidacy, select a thesis advisor, and work on their thesis research for the remaining three years.

Under the department's aegis, an extensive program of graduate research in fundamental plasma physics is also conducted at the renowned Princeton Plasma Physics Laboratory (PPPL), located on Princeton's Forrestal Campus. Please see Program in Plasma Physics page for information about applying for this program. Students interested in fundamental plasma physics and its laboratory and technology applications should apply to the Program in Plasma Physics. Students interested in astrophysical applications of plasma physics (including high energy astrophysics) should apply to the graduate program in Astrophysical Sciences.

useful tool – **Cource Offerings**

For example, I found: Numerical Algorithms for Scientific Computing
A broad introduction to numerical algorithms used in scientific computing. The course begins with a review of the basic principles of numerical analysis, including sources of error, stability, and convergence. The theory and implementation of techniques for linear and nonlinear systems of equations and ordinary and partial differential equations are covered in detail. Examples of the application of these methods to problems in engineering and the sciences permeate the course material. Issues related to the implementation of efficient algorithms on modern high-performance computing systems are discussed.

Material and examples are drawn from several well-known references, e.g Numerical Recipes (Press, Flannery, Teukolsky, & Vetterling). Introduction to Numerical Analysis (Neumaier) and others.

1.1 Prerequisites

Students interested in majoring in astrophysics are required to complete the following courses during their 1st and 2nd year

1.1.1 Physics 103 or 105: Mechanics

Physics 105
Physics 105 Course Format
STEM Textbook Index, include Kleppner

following two books downloaded:
Our textbook will be Kleppner and Kolenkow, with Tipler as a backup. You must have both books (we will use Tipler for two of our units), but we don't care what edition of Tipler you have.

Reserve books: I have placed several books on reserve in Fine Library. Besides the textbooks, these include:

- Feynman, The Feynman Lectures on Physics, vol. 1.
- Olenick, Apostol, and Goodstein, The Mechanical Universe.
- Resnick and Halliday, Basic Concepts in Relativity and Early Quantum Theory.
- Taylor and Wheeler, Spacetime Physics.

1.1.2 Physics 104 or 106: Electromagnetism

1.1.3 Physics 205: Classical Mechanics

1.1.4 Astrophysics 204: Topics in Modern Astronomy (strongly recommended)

1.1.5 Mathematics 103 and 104: Calculus

1.1.6 Mathematics 201 or 203 or 218: Advanced Multivariable Calculus

1.1.7 Mathematics 202 or 204 or 217: Linear Algebra

1.2 Required Cources

Eight upper level courses are required for completing an Astro major.

(a)Students should complete at least three of the following courses:

1.2.1 Astrophysics 301: General Relativity

1.2.2 Astrophysics 303: Deciphering the Universe: Research Methods in Astrophysics

1.2.3 Astrophysics 309/MAE 309/PHY 309/ENE 309: The Science of Nuclear Energy: Fission and Fusion

1.2.4 Astrophysics 401: Cosmology

1.2.5 Astrophysics 403: Stars and Star Formation

(b) Students should complete three of the following four courses:

1.2.6 Physics 208: Principles of Quantum Mechanics

1.2.7 Physics 301: Thermal Physics

1.2.8 Physics 304: Advanced Electromagnetism

1.2.9 Physics 305: Quantum Mechanics

(c) Students may select among the following (or other courses) to complete their eight required courses:

1.2.10 Physics 312: Experimental Physics

1.2.11 Physics 403: Mathematical Methods of Physics

1.2.12 Physics 405: Modern Physics I: Condense-Matter Physics

1.2.13 Physics 406: Modern Physics II: Nuclear and Elementary Particle Physics

1.2.14 Physics 408: Modern Classical Dynamics

1.2.15 Mathematics 301/MAE305: Mathematics in Engineering I (ODE's).

1.2.16 Mathematics 302/MAE306: Mathematics in Engineering II (OPDE's, complex analysis).

1.2.17 Mathematics 317: Complex Analysis

1.2.18 Mathematics 327/328: Differential Geometry

1.2.19 Geology 427: Introduction to Terrestrial and Planetary Atmospheres

1.2.20 Mechanical and Aerospace Engineering 341: Space Flight

1.2.21 Mechanical and Aerospace Engineering 342: Space System Design

1.2.22 Other upper-level science or math courses

(d) Other course selections or replacements allowed with departmental approval.

Recommended Courses in addition to the above:

1.2.23 Computer Science 126: General Computer Science

1.2.24 Math 309/ORF 309: Probability and Stochastic Systems

1.2.25 Mechanical and Aerospace Eng. 222: Mechanics of Fluids

1.3 Graduate-level Permanent Courses

Permanent Courses

Courses listed below are graduate-level courses that have been approved by the program's faculty as well as the Curriculum Subcommittee of the Faculty Committee on the Graduate School as permanent course offerings. Permanent courses may be offered by the department or program on an ongoing basis, depending on curricular needs, scheduling requirements, and student interest. Not listed below are undergraduate courses and one-time-only graduate courses, which may be found for a specific term through the Registrar's website. Also not listed are graduate-level independent reading and research courses, which may be approved by the Graduate School for individual students.

1.3.1 APC 503 Analytical Techniques in Differential Equations (also AST 557)

Local analysis of solutions to linear and nonlinear differential and difference equations. Asymptotic methods, asymptotic analysis of integrals, perturbation theory, summation methods, boundary layer theory, WKB theory, and multiple scale theory. Prerequisite: MAE 306 or equivalent.

1.3.2 APC 523 Numerical Algorithms for Scientific Computing (also AST 523/ MAE 507)

A broad introduction to scientific computation using examples drawn from astrophysics. From computer science, practical topics including processor architecture, parallel systems, structured programming, and scientific visualization will be presented in tutorial style. Basic principles of numerical analysis, including sources of error, stability, and convergence of algorithms. The theory and implementation of techniques for linear and nonlinear systems of equations, ordinary and partial differential equations will be demonstrated with problems in stellar structure and evolution, stellar and galactic dynamics, and cosmology.

1.3.3 APC 524 Software Engineering for Scientific Computing (also MAE 506/ AST 506)

The goal of this course is to teach basic tools and principles of writing good code, in the context of scientific computing. Specific topics include an overview of relevant compiled and interpreted languages, build tools and source managers, design patterns, design of interfaces, debugging and testing, profiling and improving performance, portability, and an introduction to parallel computing in both shared memory and distributed memory environments. The focus is on writing code that is easy to maintain and share with others. Students will develop these skills through a series of programming assignments and a group project.

1.3.4 AST 513 Dynamics of Stellar and Planetary Systems

Discussion of observations of stars in the solar neighborhood, the overall structure of our galaxy, and external galaxies; stellar populations and the evolution of the stellar content of galaxies; dynamical theory of the equilibrium and stability of stellar systems; and relaxation, dynamical friction, and the introduction to the Fokker-Planck equation; evolution of N-body systems.

1.3.5 AST 514 Structure of the Stars

Theoretical and numerical analysis of the structure of stars and their evolution. Topics include a survey of the physical process important for stellar interiors (equation of state, nuclear reactions, transport phenomena); macroscopic properties of stars and their stability; evolution of single and binary stars; mass loss and accretion of matter; and accretion disks. Emphasis is given to numerical modeling of various types of stars.

1.3.6 AST 517 Diffuse Matter in Space

Subject of course is the astrophysics of the interstellar medium: theory and observations of the gas, dust, plasma, energetic particles, magnetic field, and electromagnetic radiation in interstellar space. Emphasis will be on theory, including elements of: fluid dynamics; excitation of atoms, molecules and ions; radiative processes; radiative transfer; simple interstellar chemistry; and physical properties of dust grains.The theory will be applied to phenomena including: interstellar clouds (both diffuse atomic clouds and dense molecular clouds); HII regions; shock waves; supernova remnants; cosmic rays; interstellar dust; and star formation.

1.3.7 AST 520 High Energy Astrophysics

Astrophysical applications of electrodynamics, nuclear, and particle physics. Topics may include synchrotron emission and absorption, comptonization, pair plasmas, jets, extragalactic radio sources, compact objects, cosmic rays, and neutrino astrophysics.

1.3.8 AST 521 Introduction to Plasma Astrophysics

Introductory course to plasma physics, as it applies to space and astrophysical systems. Fundamental concepts are developed with mathematical rigor, and application to the physics of a wide variety of astrophysical systems are made. Topics include magnetohydrodynamics, kinetic theory, waves, instabilities, and turbulence. Applications to the physics of the solar wind and corona, the intracluster medium of galaxy clusters, the interstellar medium of galaxies, and a wide variety of accretion flows are given.

1.3.9 AST 522 Extragalactic Astronomy

A survey course covering the principal current areas of research on extragalactic objects, their physical properties, origin, evolution, and distribution in space. Topics covered include quasar physics, formation, evolution, and clustering of galaxies and the general problem of large-scale structure and motion in the universe.

1.3.10 AST 541 Seminar in Theoretical Astrophysics

Designed to stimulate students in the pursuit of research. Participants in this seminar discuss critically papers given by seminar members. Ordinarily, several staff members also participate. Often topics are drawn from published data that present unsolved puzzles of interpretation.

1.3.11 AST 542 Seminar in Observational Astrophysics

Students will prepare and deliver presentations and lead discussion about topics of current interest in observational astrophysics and techniques.

1.3.12 AST 551 General Plasma Physics I (also MAE 525)

This is an introductory course to plasma physics, with sample applications in fusion, space and astrophysics, semiconductor etching, microwave generation: characterization of the plasma state, Debye shielding, plasma and cyclotron frequencies, collision rates and mean-free paths, atomic processes, adiabatic invariance, orbit theory, magnetic confinement of single-charged particles, two-fluid description, magnetohydrodynamic waves and instabilities, heat flow, diffusion, kinetic description, and Landau damping. The course may be taken by undergraduates with permission of the instructor.

1.3.13 AST 552 General Plasma Physics II

Ideal magnetohydrodynamic (MDH) equilibrium, MHD energy principle, ideal and resistive MHD stability, drift-kinetic equation, collisions, classical and neoclassical transport, drift waves and low-frequency instabilities, high-frequency microinstabilities, and quasilinear theory.

1.3.14 AST 553 Plasma Waves and Instabilities

Hydrodynamic and kinetic models of nonmagnetized and magnetized plasma dispersion; basic plasma waves and their applications; basic instabilities; mechanisms of collisionless dissipation; geometrics-optics approximation, including ray tracing, field-theoretical description of continuous waves, and ponderomotive effects; conservation laws and transport equations for the wave action, energy, and momentum; mode conversion; quasilinear theory.

1.3.15 AST 554 Irreversible Processes in Plasmas

Introduction to theory of fluctuations and transport in plasma. Origins of irreversibility, Random walks, Brownian motion and diffusion, Langevin and Fokker-Planck theory. Fluctuation-dissipation theorem; test-particle superposition principle. Statistical closure problem. Derivation of kinetic equations from BBGKY hierarchy and Klimontovich formalism; properties of plasma collision operators. Classicaal transport coefficients in magnetized plasmas; Onsager symmetry. Introduction to plasma turbulence, including quasilinear theory. Applications to current problems in plasma research.

1.3.16 AST 555 Fusion Plasmas & Plasma Diagnostics

This course gives an introduction to experimental plasma physics, with an emphasis on high-termperature plasmas for fusion. Requirements for fusion plasmas: confinement, beta, power and particle exhaust. Tokamak fusion reactors. Status of experimental understanding: what we know and how we know it. Key plasma diagnostic techniques: magnetic measurements, Langmuir probes, microwave techniques, spectroscopic techniques, electron cyclotron emission, Thomson scattering.

1.3.17 AST 558 Seminar in Plasma Physics

Advances in experimental and theoretical studies or laboratory and naturally-occurring high-termperature plasmas, including stability and transport, nonlinear dynamics and turbulence, magnetic reconnection, selfheating of "burning" plasmas, and innovative concepts for advanced fusion systems. Advances in plasma applications, including laser-plasma interactions, nonneutral plasmas, high-intensity accelerators, plasma propulsion, plasma processing, and coherent electromagnetic wave generation.

1.3.18 AST 559 Turbulence and Nonlinear Processes in Fluids and Plasmas (also APC 539)

A comprehensive introduction to the theory of nonlinear phenomena in fluids and plasmas, with an emphasis on turbulence and transport. Experimental phenomenology; fundamental equations, including Navier-Stokes, Vlasov, and gyrokinetic; numerical simulation techniques, including pseudo-spectral and particle-in-cell methods; coherent structures; transition to turbulence; statistical closures, including the wave kinetic equation and direct-interaction approximation; PDF methods and intermittency; variational techiques. Applications from neutral fluids, fusion plasmas, and astrophysics.

1.3.19 AST 560 Computational Methods in Plasma Physics

Analysis of methods for the numerical solution of the partial differential equations of plasma physics, including those of elliptic, parabolic, hyperbolic, and eigenvalue type. Topics include finite difference, finite element, spectral, particle-in-cell, Monte Carlo, moving grid, and multiple-time-scale techniques, applied to the problems of plasma equilibrium, transport, and stability.

1.3.20 AST 562 Laboratory in Plasma Physics

The course helps students develop the skills, knowledge, and understanding of basic and advanced laboratory techniques used to measure the properties of behavior of plasmas. Representative experimentss include: low-pressure arc and cold-cathode plasma formation; ambipolar diffusion in afterglow plasmas; Langmuir probe measurements of electron temperture and plasma density; Fabry-Perot spectroscopy for ion energy measurements; optical spectroscopy for species identification; microwave interferometry and cavity resonances for plasma density determination; and momentum generated by a plasma thruster.

1.3.21 AST 565 Physics of Nonneutral Plasmas

This course provides a comprehensive introduction to the physics of nonneutral plasmas and charged particle beam systems with intense self fields. The subject matter is developed systematically from first principles, based on fluid, Vlasov, or Klimontovich-Maxwell statistical descriptions as appropriate. Topics include the development of nolinear stability and confinement theorems; experimental and theoretical investigations of collective waves and instabilities; phase transitions in strongly-coupled nonneutral plasmas; coherent electromagnetic radiation generation by free electron lasers, cyclotron masers, and magnetrons.

1.3.22 MAE 522 Applications of Quantum Mechanics to Spectroscopy and Lasers (also AST 564)

An intermediate-level course in applications of quantum mechanics to modern spectroscopy. The course begins with an introduction to quantum mechanics as a "tool" for atomic and molecular spectroscopy, followed by a study of atomic and molecular spectra, radiative, and collisional transitions, with the final chapters dedicated to plasma and flame spectroscopic and laser diagnostics. Prerequisite: one semester of quantum mechanics.

1.3.23 MAE 528 Physics of Plasma Propulsion (also AST 566)

Focus of this course is on fundamental processes in plasma thrusters for spacecraft propulsion with emphasis on recent research findings. Start with a review of the fundamentals of mass, momentum & energy transport in collisional plasmas, wall effects, & collective (wave) effects, & derive a generalized Ohm's law useful for discussing various plasma thruster concepts. Move to detailed discussions of the acceleration & dissipation mechanisms in Hall thrusters, magnetoplasmadynamic thrusters, pulsed plasma thrusters, & inductive plasma thrusters, & derive expressions for the propulsive efficiencies of each of these concepts.

1.3.24 PHY 564 Physics of the Universe (also AST 524)

This course spans a wide range of advanced concepts in contemporary cosmology including inflation, the cyclic universe, dark matter and dark energy, and how they can be explored through cosmological observations of the cosmic microwave background and large scale structure. The course will be closely linked to the Princeton Center for Theoretical Physics Fall 2008 program on the Big Bang and Beyond, including weekly precept meetings with seminar speakers.

1.3.25 SML 515 Topics in Statistics and Machine Learning (also AST 515)

The course provides an introduction to modern data analysis and data science. It addresses the central question, ”what should I do if these are my data and this is what I want to know”? The course covers basic and advanced statistical descriptions of data. It also introduces the computational means and software packages to explore data and infer underlying structural parameters from them. The topics are exemplified by real-world applications. Prerequisites are linear algebra, multivariate analysis, and a familiarity with basic statistics and programming (ideally in python).