

ASTRONOMY

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Astronomy is a quantitative physical science that applies physics, mathematics, and statistical analysis to observing, describing, and modeling the universe. The undergraduate courses and degree programs offered by the Department of Astronomy train students in research techniques and quantitative reasoning and develop creative problem solvers. Students who complete the major continue on to top-tier graduate programs in astrophysics or related science fields, and they are sought after by employers in a range of fields from health care management to the banking and investment industry. The department offers a B.A. degree in Astronomy and a B.S. degree in Astrophysics.

INTRODUCTORY COURSES

Introductory courses with no prerequisites The department offers a variety of courses without prerequisites that provide an introduction to astronomy with particular attention to recent discoveries and theories. Courses numbered below 150 are intended for students who desire a broad, nontechnical introduction to astronomy. These courses fulfill the science distributional requirement, and some also fulfill the quantitative reasoning distributional requirement.

Courses with numbers from 150 to 199 are topical rather than survey courses. Most of these offerings fulfill both the science and the quantitative reasoning requirements. ASTR 155 is a laboratory course that provides a hands-on introduction to astronomical observing. ASTR 160 and 170 provide an introduction to frontier topics in modern astrophysics and cosmology.

Introductory courses with high school calculus and physics prerequisites Students who have taken calculus and physics in high school may enroll in quantitative introductory courses. ASTR 210 and ASTR 220 focus on fundamental measurements and tools used in astronomy and include an in-depth study of stellar astrophysics (ASTR 210) or galaxies and cosmology (ASTR 220). These courses overlap in content, so students should take either ASTR 210 or 220 but not both. ASTR 255 provides training in data analysis and research techniques, including computer programming and numerical and statistical analysis.

PREREQUISITES

B.A. degree program The prerequisites for the B.A. degree are PHYS 170 and 171, or 180 and 181, or 200 and 201, and MATH 112 and 115.

B.S. degree program Prerequisites for the B.S. degree include an introductory physics sequence (PHYS 180 and 181, or 200 and 201, or 260 and 261); a physics laboratory sequence (PHYS 165L and 166L, or 205L and 206L); and the mathematics sequence MATH 112, 115, and either MATH 120 or ENAS 151. ASTR 155 may be substituted for one term of the physics laboratory sequence. All prerequisites should be completed by the end of the sophomore year.

Prerequisites for advanced electives Courses numbered 300 and above are more specialized and intensive. The prerequisites for these courses include ASTR 210 or 220, multivariable calculus, and two terms of introductory college physics.

REQUIREMENTS OF THE MAJOR

B.A. degree program The B.A. degree program in Astronomy is designed for students who do not plan to continue in a graduate program in astronomy, but who are interested in the subject as a basis for a liberal arts education or as a physical science background to careers such as medicine, teaching, journalism, business, law, or government. It allows greater flexibility in course selection than the B.S. program because the emphasis is on breadth of knowledge rather than on specialization.

Ten courses are required beyond these prerequisites, including either ASTR 210 or 220, ASTR 255, 310, one additional Astronomy elective numbered 150 or above, and the senior requirement (ASTR 492). Two of the ten courses must be advanced courses in mathematics, such as MATH 120 or ENAS 151, or courses in mathematical methods, including statistics or computer science, such as CPSC 112, MATH 200 or above, or ASTR 356. Three electives can be drawn from any of the natural, applied, or mathematical sciences (including additional astronomy courses); at least two of these must be advanced enough to have college-level prerequisites.

B.S. degree program The B.S. degree program in Astrophysics is designed to provide a strong foundation in astrophysics for students interested in graduate study or a career in astronomy, physics, or a related science.

Beyond the prerequisites, twelve term courses are required in astronomy, physics, and mathematics. Students complete at least six courses in astronomy, including either ASTR 210 or 220, 255, 310, 320, and a two-term senior project (ASTR 490 and 491). Students also complete three Physics courses numbered 400 or above, normally PHYS 401, 402, and 439. In addition, majors choose either one additional 400-level course in Physics or an Astronomy elective numbered 300 or higher. In mathematics, students complete a course in differential equations selected from MATH 246, PHYS 301, or ENAS 194, and either an additional mathematics course numbered 200 or above or a course in statistics or computing such as CPSC 112, 201, or ASTR 356.

Credit/D/Fail Courses taken Credit/D/Fail may not be counted toward the requirements of either degree program.

SENIOR REQUIREMENT

B.A. degree program The senior requirement consists of a senior essay or independent research project carried out for one term in ASTR 492 under the supervision of a faculty member.

B.S. degree program The senior requirement consists of an independent research project in astronomy carried out for two terms in ASTR 490 and 491 under the supervision of a faculty member.

ADVISING

Before entering the junior year, students must obtain approval of a course of study from the director of undergraduate studies.

Graduate work Graduate courses in astronomy are open to qualified undergraduates who already have a strong preparation in mathematics, physics, and astronomy. Students wishing to take a graduate course must first obtain the permission of the instructor and of the director of graduate studies.

REQUIREMENTS OF THE MAJOR**ASTRONOMY, B.A.**

Prerequisites PHYS 170, 171, or 180, 181, or 200, 201; MATH 112, 115

Number of courses 10 courses beyond prereqs, incl senior req

Specific courses required ASTR 210 or 220; ASTR 255, 310

Distribution of courses 1 astronomy elective numbered 150 or above; 2 advanced math courses; 3 science electives (may include addtl astronomy courses), at least 2 with college-level prereqs

Senior requirement Senior essay or senior research project (ASTR 492)

ASTROPHYSICS, B.S.

Prerequisites PHYS 180, 181, or 200, 201, or 260, 261; PHYS 165L, 166L, or 205L, 206L; MATH 112, 115; MATH 120 or ENAS 151

Number of courses 12 courses beyond prereqs, incl senior req

Specific courses required ASTR 210 or 220; 255, 310, 320

Distribution of courses 3 courses in physics numbered 400 or above; 1 addtl upper-level course in astronomy or physics; 2 courses in math or mathematical methods, as specified

Substitution permitted ASTR 155 for 1 term of physics lab prereq

Senior requirement Senior independent research project (ASTR 490 and 491)

FACULTY OF THE DEPARTMENT OF ASTRONOMY

Professors Charles Bailyn, †Charles Baltay, Sarbani Basu (*Chair*), Paolo Coppi, Pierre Demarque (*Emeritus*), Debra Fischer, Marla Geha, Jeffrey Kenney, Richard Larson (*Emeritus*), Gregory Laughlin, Priyamvada Natarajan, †C. Megan Urry, William van Altena (*Emeritus*), Pieter van Dokkum, Robert Zinn

Associate Professors Hector Arce, †Daisuke Nagai, †Nikhil Padmanabhan, Frank van den Bosch

Lecturer Michael Faison

†A joint appointment with primary affiliation in another department.

Courses

* **ASTR 030b, Search for Extraterrestrial Life** Michael Faison

Introduction to the search for extraterrestrial life. Review of current knowledge on the origins and evolution of life on Earth; applications to the search for life elsewhere in the universe. Discussion of what makes a planet habitable, how common these worlds are in the universe, and how we might search for them. Survey of past, current, and future searches for extraterrestrial intelligence. Enrollment limited to first-year students. Preregistration required; see under First-Year Seminar Program. WR, SC

ASTR 105a, The Earth in its Cosmic Context Gregory Laughlin

Study of the formation, evolution, and history of Earth, its solar system, and its role in a larger cosmic context. Consideration of thousands of other recently discovered planetary systems; the role of life in shaping the Earth and its environment; and the consequences of human activity from a systems perspective. SC

ASTR 110a, Planets and Stars Robert Zinn

An introduction to stars and planetary systems. Topics include the solar system and extrasolar planets, planet and stellar formation, and the evolution of stars from birth to death. No prerequisite other than a working knowledge of elementary algebra. QR, SC

ASTR 120b, Galaxies and the Universe Jeffrey Kenney

An introduction to stars and stellar evolution; the structure and evolution of the Milky Way galaxy and other galaxies; quasars, active galactic nuclei, and supermassive black holes; cosmology and the expanding universe. No prerequisite other than a working knowledge of elementary algebra. QR, SC

ASTR 130a, Origins and the Search for Life in the Universe Debra Fischer

Origins of the universe, stars, and planets; evolution of conditions that were conducive to the emergence of life on Earth; leading theories for the origin of life; the discovery of exoplanets; comparison of Earth's solar system with other systems that have been discovered; the

possibility of habitable conditions where life might have arisen on other worlds; methods of searching for life elsewhere. No prerequisite other than a working knowledge of elementary algebra. SC

[ASTR 135, **Archaeoastronomy**]

ASTR 156b / ENAS 156b, Introduction to Digital Dome Media Staff

The design and production of planetarium shows, art projects, or other immersive or interactive projects with a digital dome projection system, including the ScidomeHD digital system and the stereo projector system, both located at the Leitner Family Observatory and Planetarium (LFOP) and with the portable Starlab dome. Topics include real-time and scripted control of 3D graphics engines; mapping of images and video onto a spherical dome; 3D rendering using Blender, Processing, and vpython; audio and video editing for dome content; interactive projects; and basic design principles for narrative and interactive educational shows. Some programming or digital media experience is recommended. SC ½ Course cr

ASTR 160b, Frontiers and Controversies in Astrophysics Debra Fischer

A detailed study of three fundamental areas in astrophysics that are currently subjects of intense research and debate: planetary systems around stars other than the sun; pulsars, black holes, and the relativistic effects associated with them; and the age and ultimate fate of the universe. No prerequisite other than a working knowledge of elementary algebra. QR, SC

[ASTR 170, **Introduction to Cosmology**]

ASTR 180b, Introduction to Relativity Charles Bailyn

Introduction to the theories of special and general relativity, and to relativistic astrophysics. Topics include time dilation and length contraction; mass-energy equivalence; space-time curvature; black holes; wormholes; pulsars; quasars; gravitational waves; Hawking radiation. For students not majoring in the physical sciences; some previous acquaintance with high-school physics and/or calculus may be helpful, but is not required. QR, SC

ASTR 210b, Stars and Their Evolution Robert Zinn

Foundations of astrophysics, focusing on an intensive introduction to stars. Nuclear processes and element production, stellar evolution, stellar deaths and supernova explosions, and stellar remnants including white dwarfs, neutron stars, and black holes. A close look at our nearest star, the sun. How extrasolar planets are studied; the results of such studies. Prerequisite: a strong background in high school calculus and physics. May not be taken after ASTR 220. QR, SC

[ASTR 220, **Galaxies and Cosmology**]

ASTR 255b / PHYS 295b, Research Methods in Astrophysics Marla Geha

The acquisition and analysis of astrophysical data, including the design and use of ground- and space-based telescopes, computational manipulation of digitized images and spectra, and confrontation of data with theoretical models. Examples taken from current research at Yale and elsewhere. Use of the Python programming language. A background in high school calculus and physics. No previous programming experience required. QR, SC RP

ASTR 310a, Galactic and Extragalactic Astronomy Jeffrey Kenney

Structure of the Milky Way galaxy and other galaxies; stellar populations and star clusters in galaxies; gas and star formation in galaxies; the evolution of galaxies; galaxies and their large-scale environment; galaxy mergers and interactions; supermassive black holes and active galactic nuclei. Prerequisites: MATH 115, PHYS 201, and ASTR 210 or 220, or equivalents, or with permission of instructor. QR, SC

ASTR 320b, Physical Processes in Astronomy Franciscus van den Bosch

Introduction to the physics required for understanding current astronomical problems. Topics include basic equations of stellar structure, stellar and cosmic nucleosynthesis, radiative transfer, gas dynamics, and stellar dynamics. Numerical methods for solving these equations. Prerequisites: MATH 120 and PHYS 201 or equivalents, or permission of instructor. Previous experience with computer programming recommended. Taught in alternate years. QR, SC

[ASTR 343, **Gravity, Astrophysics, and Cosmology**]

[ASTR 355, **Observational Astronomy**]

* **ASTR 356a / PHYS 356a, Astrostatistics and Data Mining** Hector Arce

Introduction to the statistical tools used to analyze and interpret astrophysical data, including common data mining techniques for finding patterns in large data sets and data-based prediction methods. Use of publicly available high-quality astronomical data from large surveys such as SDSS and 2MASS, and from space-based observatories such as Spitzer, Herschel, and WISE. Coding with the Python programming language. Prerequisite: ASTR 255 or equivalent. QR, SC

ASTR 360b, Interstellar Matter and Star Formation Hector Arce

The composition, extent, temperature, and density structure of the interstellar medium (ISM). Excitation and radiative processes; the properties of dust; the cold and hot ISM in the Milky Way and other galaxies. Dynamics and evolution of the ISM, including interactions between stars and interstellar matter. Physics and chemistry of molecular clouds and the process of star formation. Prerequisites: MATH 120 and PHYS 201 or equivalents. Taught in alternate years. QR, SC RP

[**ASTR 375, Exoplanets**]

[**ASTR 380, Stellar Populations**]

[**ASTR 385, Introduction to Radio Astronomy**]

[**ASTR 418, Stellar Dynamics**]

ASTR 420a, Computational Methods for Astrophysics Paolo Coppi

The analytic, numerical, and computational tools necessary for effective research in astrophysics and related disciplines. Topics include numerical solutions to differential equations, spectral methods, and Monte Carlo simulations. Applications to common astrophysical problems including fluids and N-body simulations. Prerequisites: ASTR 320, MATH 120, 222 or 225, and 246. QR RP

[**ASTR 430, Galaxies**]

ASTR 450a, Stellar Astrophysics Sarbani Basu

The physics of stellar atmospheres and interiors. Topics include the basic equations of stellar structure, nuclear processes, stellar evolution, white dwarfs, and neutron stars. Prerequisites: PHYS 201 and MATH 120. Taught in alternate years. QR, SC

ASTR 465b, The Evolving Universe Pieter Van Dokkum

Overview of cosmic history from the formation of the first star to the present day, focusing on direct observations of the high-redshift universe. Prerequisites: MATH 120, PHYS 201, and one astronomy course numbered above 200. Taught in alternate years. QR, SC RP

* **ASTR 471a and ASTR 472b, Independent Project in Astronomy** Gregory Laughlin

Independent project supervised by a member of the department with whom the student meets regularly. The project must be approved by the instructor and by the director of undergraduate studies; the student is required to submit a complete written report on the project at the end of the term.

* **ASTR 490a and ASTR 491b, The Two-Term Senior Project** Gregory Laughlin

A two-term independent research project to fulfill the senior requirement for the B.S. degree. The project must be supervised by a member of the department and approved by the director of undergraduate studies.

* **ASTR 492a or b, The One-Term Senior Project** Gregory Laughlin

A one-term independent research project or essay to fulfill the senior requirement for the B.A. degree. The project must be supervised by a member of the department and approved by the director of undergraduate studies.