**ASTRONOMY (ASTR)**

* ASTR 030b, Search for Extraterrestrial Life  
  Staff
  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 040a / PHYS 040a, Expanding Ideas of Time and Space  
  Meg Urry
  Discussions on astronomy, and the nature of time and space. Topics include the shape and contents of the universe, special and general relativity, dark and light matter, and dark energy. Observations and ideas fundamental to astronomers’ current model of an expanding and accelerating four-dimensional universe. Enrollment limited to first-year students. Preregistration required; see under First-Year Seminar Program.  
  SC

* ASTR 080a, Current Research in Astrophysics  
  Charles Bailyn
  This first-year seminar explores what 21st century astrophysicists study, and how they study it. We focus on the Astro2020 report recently released by the National Academy of Sciences, which lays out research opportunities for the coming decade. Along the way, we explore research currently being conducted here at Yale; the relationship between observational, theoretical, computational, and instrumental modes of research; the dynamics of collaborative research, from small groups to large international collaborations; success strategies and obstacles along the career path of scientists from undergraduates through senior investigators; presentation and dissemination of scientific results; the sources, politics and finances of grant funding; diversity and inclusion in the astronomical community. Some acquaintance and facility with high-school physics is recommended. Enrollment limited to first-year students. Preregistration required; see under First-Year Seminar Program.  
  SC

ASTR 105b, 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  
  Michael Faison
  Astronomy 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  
  Staff
  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 155a, Introduction to Astronomical Observing  
  Michael Faison
  A hands-on introduction to techniques used in astronomy to observe astronomical objects. Observations of planets, stars, and galaxies using on-campus facilities and remote observing with Yale’s research telescopes. Use of electronic detectors and computer-aided data processing. Evening laboratory hours required. One previous college-level science laboratory or astronomy course recommended.  
  SC ½ Course cr

ASTR 170a, Introduction to Cosmology  
  Priyamvada Natarajan
  An introduction to modern cosmological theories and observational astronomy. Topics include aspects of special and general relativity; curved space-time; the Big Bang; inflation; primordial element synthesis; the cosmic microwave background; the formation of galaxies; and large-scale structure. Prerequisite: a strong background in high school mathematics and physics.  
  QR, SC

ASTR 180b, Introduction to Relativity and Black Holes  
  Staff
  Introduction to the theories of special and general relativity, and to relativistic astronomy and 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 210a, Stars and Their Evolution  
  Robert Zinn
  Foundations of astronomy and 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 255a / PHYS 295a, Research Methods in Astrophysics  
  Hector Arce
  An introduction to research methods in astronomy and astrophysics. 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. Prerequisite: background in high school calculus and physics. No previous programming experience required.  
  QR, SC
ASTR 310b, 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 320a, Physical Processes in Astronomy  Frank 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 330a, Scientific Computing in Astrophysics  Marla Geha and Imad Pasha
Scientific computer programming in Astrophysics with a focus on the Python Programming language. Algorithms and workflows for reducing and analyzing Astrophysical datasets, both observational and computational. Emphasis is placed on best coding practices, including readability, version control, documentation, and computational efficiency. Weekly lectures, in-depth tutorial/workshops, and invited outside expert guest speakers. Students complete a programming project based on real astrophysical datasets. Prerequisite: ASTR 255 or permission of instructor. Some basic programming experience in Python is strongly recommended.

ASTR 355b, Observational Astronomy  Pieter van Dokkum
Optics for astronomers. Design and use of optical telescopes, photometers, spectrographs, and detectors for astronomical observations. Introduction to error analysis, concepts of signal-to-noise, and the reduction and analysis of photometric and spectroscopic observations. Prerequisite: one astronomy course numbered above 200, or permission of instructor. Previous experience with computer programming recommended.  QR, SC RP

* ASTR 375a, Exoplanets  Gregory Laughlin
Planet formation, exoplanet detection techniques, and the modeling of observations of exoplanet atmospheres. Solar system architecture compared with other planetary systems. From an Earth-centric perspective, habitability factors of rocky planets and the implications for life elsewhere. Prerequisites: MATH 120 and PHYS 201 or equivalents, and one astronomy course numbered above 200.  QR, SC

ASTR 380b, Stellar Populations  Robert Zinn
The stellar populations of our galaxy and galaxies of the Local Group. Topics include the properties of stars and star clusters, stellar evolution, and the structure and evolution of our galaxy. Prerequisites: PHYS 201 and MATH 120, and one astronomy course numbered above 200. Taught in alternate years.  QR, SC RP

ASTR 385b, Introduction to Radio Astronomy  Hector Arce
Introduction to the theory and techniques of radio astronomy, including radio emission mechanisms, propagation effects, antenna theory, interferometry, and spectroscopy. Discussion of specific sources such as Jupiter, radio stars, molecular clouds, radio galaxies, ETI, and the microwave background. Includes observational exercises with a small radio telescope. Prerequisites: MATH 120 and PHYS 201 or equivalents.  QR, SC

* 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 430a, Galaxies  Jeffrey Kenney
A survey of the contents, structure, kinematics, dynamics, and evolution of galaxies; galaxy interactions and the environments of galaxies; properties of active galactic nuclei. Prerequisites: PHYS 201 and MATH 120, 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.