Astrophysics

Department Website: http://astro.uchicago.edu

Program of Study

Astronomy is the oldest of the natural sciences; since antiquity astronomers have sought to understand the origin and destiny of the universe and its celestial contents. How did the universe evolve from an early, almost uniform, state to the rich structure that we see at the present epoch? Where did the elements of the periodic table come from? How do stars, along with their systems of planets, form and how do they change with time? Do other life-bearing worlds exist? These questions have evolved over millennia, with answers now sought using the mathematical, technological, and computational tools of modern astronomy.

For students interested in examining fundamental questions through scientific study of the universe, the Department of Astronomy and Astrophysics offers several choices to explore. Options include general education courses, Study Abroad, the minor program in Astronomy and Astrophysics, and the major program in Astrophysics, with both BA and BS tracks.

General Education Courses

Many options are available for choosing two- or three-quarter sequences that satisfy the general education requirement in the physical sciences (http://collegecatalog.uchicago.edu/thecollege/physicalsciences/) from among six courses numbered in the 12000s. These courses present a range of foundational topics, from the grand principles governing the universe and understanding its beginning, to the formation and evolution of stars and galaxies, and the search for habitable extrasolar planets. All courses numbered in the 12000s include labs for engaging in astronomical inquiry through classical experiments, opportunities for telescope observing, and data analysis. Students seeking a more in-depth examination of selected astrophysical topics may take a course numbered in the 18000s as a third course in the physical sciences or as a general elective. While the 12000 and 18000 courses are aimed at students not majoring in the sciences, quantitative analysis is an important part of all courses offered by the Department of Astronomy and Astrophysics. Any tools beyond pre-calculus algebra will be taught as needed.

Study Abroad Program

The Study Abroad program in Paris is another option for completing the general education requirement in the physical sciences. Every Spring Quarter, a three-course Astronomy program is offered at the University of Chicago Center in Paris. This sequence is designed for students not majoring in the sciences, but it also may be of interest to science majors who want to supplement their work in physics and chemistry with a quarter devoted to the cosmos. For details, see the Study Abroad (https://study-abroad.uchicago.edu) page for Paris: Astronomy (http://study-abroad.uchicago.edu/programs/paris-astronomy/).

Major in Astrophysics

The major program in Astrophysics reflects Chicago's tradition of interdisciplinary study and emphasis on mastery of the intellectual processes of inquiry and discovery. The curriculum integrates courses in physics, mathematics, and astrophysics, alongside statistical, computational, and observational training that lead to active involvement in research. Students gain expertise interpreting mathematical models that describe universal physical laws across all scales, from nuclear to cosmological; utilizing quantitative analysis techniques; evaluating scientific literature and research critically; and contributing to astronomical investigations. Upon completion, graduates are equipped with a broad foundation in physics, experience in computational and statistical methods, and hands-on research preparation, enabling them to excel in graduate studies or pursue careers in STEM fields that demand technological and analytical proficiency.

The mathematics requirement for the Astrophysics Major is the sequence MATH 18300-18400-18500-18600 Mathematical Methods in the Physical Sciences I-II-III-IV, starting in the Autumn Quarter of the first year. The Mathematical Methods sequence may also start in Winter Quarter, if additional exposure to calculus is needed. Students interested in a more advanced mathematics track may substitute the MATH 18300-18400-18500-18600 sequence with MATH 20250 and MATH 20300-20400-20500 Analysis in Rn I-II-III or MATH 20250 and MATH 18400-18500. Students invited to take the MATH 20700-20800-20900 Honors Analysis in Rn I-II-III sequence may also use it as a substitution for MATH 18300-18400-18500-18600.

There are two tracks for students interested in the major. The program leading to a BA in Astrophysics consists of sixteen courses beyond the general education requirement. The program leading to a BS in Astrophysicsconsists of eighteen courses beyond the general education requirement. Students considering the major in Astrophysics are strongly encouraged to meet with the Academic Affairs Administrator in the Department of Astronomy and Astrophysics as early as possible to review program requirements.

Grading

Courses must be taken for quality grades (no P/F grading). Students must receive a quality grade of at least C in all of the ASTR-coded courses counted toward their major or minor program. Students in the Astrophysics major must also receive a quality grade of at least C– in required courses offered by other departments. Students who do not meet the grading requirement for a course must retake it before advancing to higher-level courses

in the program. In addition, students are expected to meet the academic performance standards set forth by the Office of College Community Standards (https://college.uchicago.edu/student-services/academic-review/).

Summary of Requirements for the BA in Astrophysics

GENERAL EDUCATION		
PHYS 13100-13200	Mechanics; Electricity and Magnetism (or higher)	200
One of the following sequences:		200
MATH 15100-15200	Calculus I-II *	
MATH 16100-16200	Honors Calculus I-II	
Total Units		400
MAJOR		
ASTR 13300	Introduction to Astrophysics	100
PHYS 13300	Waves, Optics, and Heat (or higher)	100
MATH 18300-18400-18500-18600	Mathematical Methods in the Physical Sciences I-II-III-IV	400
ASTR 21000	Statistical Techniques in Astrophysics	100
ASTR 21100	Computational Techniques in Astrophysics	100
ASTR 21200	Observational Techniques in Astrophysics	100
PHYS 22500	Intermediate Electricity and Magnetism I	100
PHYS 23410	Quantum Mechanics I	100
ASTR 25400	Radiation Processes in Astrophysics	100
ASTR 24100	The Physics of Stars	100
One of the following:		100
ASTR 25800	Astrophysics of Exoplanets	
ASTR 23900	Physics of Galaxies	
ASTR 24300	Cosmological Physics	
Two electives to be selected from list of approved courses		200
Total Units		1600

* Credit may be granted by examination.

Summary of Requirements for the BS in Astrophysics

GENERAL EDUCATION		
PHYS 13100-13200	Mechanics; Electricity and Magnetism (or higher)	200
One of the following sequences:		200
MATH 15100-15200	Calculus I-II *	
MATH 16100-16200	Honors Calculus I-II	
Total Units		400
MAJOR		
ASTR 13300	Introduction to Astrophysics	100
PHYS 13300	Waves, Optics, and Heat (or higher)	100
MATH 18300-18400-18500-18600	Mathematical Methods in the Physical Sciences I-II-III-IV	400
ASTR 21000	Statistical Techniques in Astrophysics	100
ASTR 21100	Computational Techniques in Astrophysics	100
ASTR 21200	Observational Techniques in Astrophysics	100
PHYS 22500	Intermediate Electricity and Magnetism I	100
PHYS 23410	Quantum Mechanics I	100
PHYS 23510	Quantum Mechanics II	100
ASTR 25400	Radiation Processes in Astrophysics	100
ASTR 24100	The Physics of Stars	100
PHYS 27900	Statistical and Thermal Physics	100
One of the following:		100
ASTR 25800	Astrophysics of Exoplanets	

ASTR 23900	Physics of Galaxies	
ASTR 24300	Cosmological Physics	
Two electives to be selected from list of approved courses		200
Total Units		1800

* Credit may be granted by examination.

Curriculum Overview

The following tables illustrate the order in which courses in the Astrophysics major are intended to be taken, with the sequence of courses aligned to prerequisites. Prospective majors typically start course work in their first year; however, it is possible to complete all program requirements in three years. Students are encouraged to contact the Academic Affairs Administrator for assistance in planning individual programs.

First Year

Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 13100	PHYS 13200	ASTR 13300
MATH 18300	MATH 18400	PHYS 13300
		MATH 18500

The technical courses in the second year of the Astrophysics Major require knowledge of scientific Python. Students without prior experience with Python must enroll in ASTR 20500 Introduction to Python Programming with Applications to Astrophysics before taking either ASTR 21000 Statistical Techniques in Astrophysics or ASTR 21100 Computational Techniques in Astrophysics. ASTR 21000 may be deferred to the third year in order to enroll in ASTR 20500 in the Autumn Quarter.

Second Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 21000 (may be deferred to third year)	ASTR 21100	ASTR 21200
MATH 18600	PHYS 22500	

In the third and fourth years, students choose one course from among ASTR 23900 Physics of Galaxies, ASTR 24300 Cosmological Physics, or ASTR 25800 Astrophysics of Exoplanets. Students in the BS track also enroll in PHYS 23510 Quantum Mechanics II and PHYS 27900 Statistical and Thermal Physics. Both the BA and BS require two electives, which may be taken in any quarter (subject to prerequisites).

Third Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 25400	ASTR 24100	PHYS 23510 (BS track only)
	PHYS 23410	ASTR 23900 (option 1)
		ASTR 25800 (option 2)

Fourth Year

Autumn Quarter	Winter Quarter
PHYS 27900 (BS track only)	ASTR 24300 (option 3)

Honors

ASTR 29900 Honors Thesis is an independent research course available to fourth-year students with a GPA of 3.5 or higher in the required courses for the major and 3.0 overall. Eligible students must have a faculty-approved project that will be undertaken over three quarters as their thesis research. Students who wish to be considered for honors must notify the Academic Affairs Administrator as early as possible in the Autumn Quarter and obtain the department's Guidelines for the Honors Thesis Course (https://d3qi0qp55mx5f5.cloudfront.net/astrophysics/docs/Guidelines_for_ASTR_29900_SEPT_2022.pdf?mtime=1663107514). The student and research supervisor complete the Honors Thesis Form (https://d3qi0qp55mx5f5.cloudfront.net/astrophysics/docs/Guidelines_for_ASTR_29900_SEPT_2022.pdf?mtime=1663107514) and return it to the Academic Affairs Administrator before the end of the third week of the Autumn Quarter. The student enrolls in the thesis course by completing the College Reading and Research Course Form (https://d3qi0qp55mx5f5.cloudfront.net/astrophysics/docs/Guidelines_for_ASTR_29900_SEPT_2022.pdf?mtime=1663107514) and returning it to the Academic Affairs Administrator. Students who do not meet the GPA requirements for the thesis course but have a faculty-approved research project may contact the Deputy Chair for Academic Affairs in Astronomy and Astrophysics for consent to enroll.

Electives

ASTR 20500	Introduction to Python Programming with Applications to Astrophysics	100
ASTR 21400	Creative Machines and Innovative Instrumentation	100
ASTR 23900	Physics of Galaxies [§]	100

ASTR 24300	Cosmological Physics §	100
ASTR 24500	The Physics of the Dark Universe (not offered in 2026-2027)	100
ASTR 25800	Astrophysics of Exoplanets §	100
ASTR 28500	Science with Large Astronomical Surveys	100
ASTR 29001 & ASTR 29002	Field Course in Astronomy and Astrophysics I and Field Course in Astronomy and Astrophysics II	200
ASTR 29700	Participation in Research	100
ASTR 29800	Undergraduate Research Seminar	100
GEOS 22000	Origin and Evolution of the Solar System	100
GEOS 22040	Planet Formation in the Galaxy I: From Dust to Planetesimals	100
GEOS 22050	Planet Formation in the Galaxy II: From Planetesimals to Planets	100
GEOS 22060	What Makes a Planet Habitable?	100
PHYS 22600	Electronics	100
PHYS 23510	Quantum Mechanics II (BA only)	100
PHYS 24310	Advanced Quantum Mechanics	100
PHYS 26400	Spacetime and Black Holes	100

§ May be taken as an elective when not fulfilling the requirement.

Other courses may be approved as electives by the Deputy Chair for Academic Affairs. When choosing electives, students should be mindful of any course prerequisites.

Minor in Astronomy and Astrophysics

The grand narrative of astronomy holds wide popular appeal and lends itself to interdisciplinary study: There is a deep history and cultural context, the night sky is profoundly inspiring and accessible to everyone, and the spirit of exploration is communicated in daily media reports of new discoveries. The minor in Astronomy and Astrophysics is designed for students not majoring in the sciences to cultivate understanding of science as a human endeavor across multiple social, historical, and cultural contexts, and to develop comprehension of the quantitative reasoning that supports a deep conceptual understanding of science. Students are allowed flexibility in selecting five courses to compose a rigorous program of study according to individual interest. The selection must include at least two courses numbered in the 12000s and at least one in the 18000s. It is possible for a student pursuing the minor to enroll in select courses numbered in the 20000s; students interested in this option should contact the Academic Affairs Administrator in Astronomy and Astrophysics to discuss course selection. **Please note: courses taken to satisfy the general education requirement in the physical sciences may not be counted towards the minor.**

There are no Physics or Mathematics prerequisites for the minor. Courses must be taken for quality grades (no P/F grading), and students must receive a quality grade of at least C in all courses counting toward program requirements. Students should contact the Academic Affairs Administrator before the end of Spring Quarter of their third year to declare their intention to complete the minor and fill out the College's Consent to Complete a Minor Program (https://humanities-web.s3.us-east-2.amazonaws.com/college-prod/s3fs-public/documents/Consent_Minor_Program.pdf) form.

Astronomy and Astrophysics Courses

ASTR 12600. Matter, Energy, Space, and Time. 100 Units.
A comprehensive survey of how the physical world works, and how matter, energy, space, and time evolved from the beginning to the present. A brief survey of the historical development of mathematics, physics, and astronomy leads to a conceptual survey of the modern theory of the physical universe: space and time in relativity; the quantum theory of matter and energy; and the evolution of cosmic structure and composition. The major theme of this course is the understanding of all nature, from the prosaic to the exotic, using powerful quantitative theory grounded in precise experiments. Although quantitative analysis will be an important part of the course, students will not be expected to employ mathematics beyond algebra. (L)
Instructor(s): Derek Buzasi Terms Offered: Autumn
Equivalent Course(s): PHSC 12600

ASTR 12610. Black Holes. 100 Units.
The past decade has seen the stunning discovery of gravitational waves from black holes merging together, allowing physical theory to be tested in the most exotic and extreme environment in the universe. Black holes are mathematically the most perfectly understood of any physical structure, but their visible effects can be extraordinarily complex. This course will survey the physics of space and time; the nature of black holes, neutron stars, and white dwarf stars; their effects on surrounding matter and light; the astrophysical contexts in which they are observed; and frontier areas of research. The development of Albert Einstein's theory of General Relativity will be placed in historical context, including a review of observational confirmation of predictions of the theory. Experimental work will include use of a robotic telescope to observe circumstances related to extreme

gravity, such as supernovae and the centers of giant galaxies that harbor super-massive black holes. Quantitative analysis will be an important part of the course, but mathematics beyond algebra will not be required. (L)
Instructor(s): Fausto Cattaneo (Summer Quarter); Gordan Krnjaic and Jessica Zebrowski (Winter Quarter) Terms Offered: Summer Winter
Prerequisite(s): PHSC 12600 or PHSC 12700
Equivalent Course(s): PHSC 12610

ASTR 12620. The Big Bang. 100 Units.
The Big Bang model describes the Universe on the largest scales and its evolution from the earliest observationally accessible times through the formation of the complex world we live in today. This powerful framework allows us to interpret a wide range of observations and to make detailed and precise predictions for new experiments. The key motivating observations include the expansion of the Universe and how it has changed with time; the existence of radiation indicating a hot and dense early phase; the abundance of the light elements; and how matter is organized over a wide range of physical scales. The model naturally incorporates dark matter and dark energy, two surprising and poorly understood components that govern the growth of structure over time. The course will explore the history of scientific cosmology and the evidence for the Big Bang model, its consequences for the earliest moments after the Big Bang, and its predictions for the eventual fate of the Universe. Labs will include a hands-on measurement of the relic cosmic microwave background radiation from the early universe and the use of astronomical data to verify key discoveries in the history of Big Bang cosmology. Quantitative analysis will be an important part of the course, but prior experience with mathematics beyond algebra will not be required. (L)
Instructor(s): Jamie Law-Smith Terms Offered: Spring
Prerequisite(s): Must have ASTR/PHSC 12600 Matter, Energy, Space and Time as the pre-requisite for ASTR/PHSC The Big Bang.
Equivalent Course(s): PHSC 12620

ASTR 12700. Stars. 100 Units.
Elements such as carbon and oxygen are created in fusion reactions at high temperatures and pressures in the deep interiors of stars, conditions that naturally arise in stars like the Sun. This course will outline the physical principles at work and the history of the development of the key ideas: how nuclear physics and the theory of stellar interiors account for how stars shine, why they live for such long times, and how the heavy elements in their cores are dispersed to form a new generation of stars. Gravity assembles stars out of more diffuse material, a process that includes the formation of planetary systems. The course shows how, taken together, these physical processes naturally lead to the ingredients necessary for the emergence of life, namely elements like carbon, nitrogen, and oxygen, and planets in stable orbits around long-lived stars. The course features quantitative analysis of data; any tools needed beyond pre-calculus algebra will be taught as part of the course. (L) This course will be offered in the Spring 2027 Study Abroad Paris Astronomy program.
Instructor(s): Fausto Cattaneo (Summer Quarter); Damiano Caprioli (Autumn Quarter). Terms Offered: Autumn Summer
Equivalent Course(s): PHSC 12700

ASTR 12710. Galaxies. 100 Units.
Galaxies have been called island universes, places where stars are concentrated, where they are born, and where they die. The study of galaxies reaches back to the Renaissance; Galileo Galilei first pointed a telescope skyward in 1610 and confirmed a then 2000 year-old Greek conjecture about the nature of our own galaxy -- the Milky Way. This course will use extensive modern observational data from a wide range of telescopes to trace the modern picture for the formation and evolution of galaxies and the stars in them. Galaxies will then be used as markers of yet larger scale structures, in order to explore the influence of gravity over cosmic time. The object of study in this course is galaxies, and the narrative arc traced through that extensive data and understanding will highlight our profound discovery that most of the mass in galaxies (and the Universe as a whole) is in fact an exotic form of matter -- dark matter -- that we cannot directly see. Quantitative analysis will be an important part of the course in both laboratory work and lectures, but mathematics beyond algebra and some geometric understanding will not be required. This course will feature several observationally-oriented labs that will allow students to directly experience how some of the modern understanding of galaxies has arisen. (L) This course will be offered in the Spring 2027 Study Abroad Paris Astronomy program.
Instructor(s): Hsiao-Wen Chen Terms Offered: Winter
Prerequisite(s): PHSC 10800, PHSC 12600 or PHSC 12700. PHSC 12710 can be taken as the first course in a sequence combined with PHSC 12720.
Equivalent Course(s): PHSC 12710

ASTR 12720. Exoplanets. 100 Units.
The discovery of planets in orbit around other stars is one of the newest developments in astronomy, which set off a race to characterize these "exoplanetary" systems. The architectures of planetary systems are set by the formation of the parent star and its protoplanetary disk, but they also encode subsequent evolution. We are now able to place our Solar System into the context of other worlds, and we find some aspects familiar and other aspects quite alien. A challenging next step is to find planets like the Earth in orbit around stars like the Sun. This course will review the techniques for discovery of planets around other stars, what we have learned so far about exoplanetary systems, and the driving questions for the future, including the quest for habitable environments elsewhere. Although quantitative analysis will be an important part of the course, students will not be expected

to employ mathematics beyond algebra. (L) This course will be offered in the Spring 2027 Study Abroad Paris Astronomy program.
Instructor(s): Derek Buzasi (Summer Quarter); Leslie Rogers and Eliza Kempton (Spring Quarter) Terms Offered: Spring Summer
Prerequisite(s): PHSC 10800, PHSC 10100, PHSC 12700 or PHSC 12710.
Equivalent Course(s): PHSC 12720

ASTR 13300. Introduction to Astrophysics. 100 Units.
The course is intended for first-year students intending to major in Astrophysics as an introduction to the range of important physical processes that operate in astrophysical environments, and how these govern structures across a wide range of scales, from planets to superclusters to the Universe. Throughout the course, we will see that similar physical principles (gravity, radiation, particle physics) come in at different stages and systems (planets, stars, galaxies, the Universe). We will also incorporate into each class relevant current active research areas in Astrophysics, especially focusing on connection with research in the department. We anticipate a highly interactive class with a large number of group activities, demos and discussions.
Instructor(s): Chihway Chang Terms Offered: Spring
Prerequisite(s): PHYS 13100-13200

ASTR 18000. The Search for Extraterrestrial Life. 100 Units.
The origin of life is one of the biggest questions of modern science. While substantial progress has been made in understanding how life arose on our planet, such research represents just a single case study in how life originates and evolves. This course covers the search for life beyond Earth from the planets and moons of the Solar System to planets orbiting other stars and intelligent life that may have left its mark on macroscopic scales. The discovery of life beyond Earth would be transformative for our understanding of humanity's place in the universe. A range of ongoing and planned experiments have the potential to detect or put strong constraints on the existence of life during the next few decades. This class will mix traditional lectures with flipped classroom problem-solving sessions.
Instructor(s): Jacob Bean Terms Offered: Spring
Equivalent Course(s): PHSC 18000

ASTR 18100. The Milky Way. 100 Units.
Within a largely empty universe, we live in a vast stellar "island" that we call the Milky Way. As we survey the stellar and interstellar components of the Milky Way-the distribution and motions of stars and interstellar gas, and how these dynamic, ever-changing components interact with each other during their life cycles inside the Milky Way-we will follow the path of ancient astronomers, wonder at their mistakes and prejudices, and form our own understanding.
Instructor(s): Nick Gnedin Terms Offered: Autumn
Prerequisite(s): Any two-course 10000-level general education sequence in chemistry, geophysical sciences, physical sciences, or physics. Can be used as a third course in physical sciences to meet the general education requirement (of six courses total in the biological, physical, and mathematical sciences).
Equivalent Course(s): PHSC 18100

ASTR 18200. The Origin and Evolution of the Universe. 100 Units.
This course provides a comprehensive introduction to modern cosmology. It will discuss how the fundamental laws of physics allow us to understand the origin, evolution, and large-scale structure of the universe. After a brief review of the history of cosmology, the course will cover the expansion of the universe, Newtonian cosmology, Einstein's Special and General Relativity, black holes, dark matter, dark energy, the Cosmic Microwave Background radiation, Big Bang nucleosynthesis, the early universe, primordial inflation, the origin and evolution of large-scale structure in the universe, and cosmic surveys that are probing inflation and cosmic acceleration.
Instructor(s): Austin Joyce Terms Offered: Autumn
Prerequisite(s): No pre-requisites. May not be taken if previous enrollment in ASTR/PHSC 12620 Big Bang.
Equivalent Course(s): PHSC 18200

ASTR 19500. Big Discoveries and Big Problems about the Universe. 100 Units.
In the last 100 years cosmologists have developed a model for the origin, evolution, and present state of the universe, starting 14 billion years ago from a hot, dense initial state (the Big Bang). Our present understanding of the history of the universe involves a rapid early expansion phase (inflation), the formation of neutrons and protons in the primordial soup a microsecond after the bang, the origin of the light elements a minute after the bang, the growth of galaxies and large-scale structures from small seed inhomogeneities, and eventually the formation of stars and planets. Our understanding is based on Einstein's Theory of General Relativity and the action of four fundamental forces. Although the big bang is the most quantitative theory for the origin and evolution of the universe ever imagined, and it is based on our understanding of the quantum world and buttressed by a host of astronomical observations and laboratory experiments, big problems remain, such as: Why is there a universe at all? What is the nature of the mysterious dark matter and dark energy comprising 95% of the present universe? What is the present size and age of the universe? In this seminar course, Wendy Freedman, an observational astronomer, and Rocky Kolb, a theorist, will engage students in discussion about these big discoveries and big problems about the universe.
Instructor(s): Edward Kolb and Wendy Freedman Terms Offered: Winter

Prerequisite(s): No prerequisites. Open to all undergraduates. Complementary, not duplicative, of ASTR 18200 Origin and Evolution of the Universe. Enrollment in both ASTR 18200 and ASTR 19500 is permitted.

ASTR 20500. Introduction to Python Programming with Applications to Astrophysics. 100 Units.
This course is intended for students who are planning to major in Astrophysics to introduce them to programming using Python. It will review basic code elements and data structures commonly used in Python and introduce Python libraries, such as numpy and scipy, and the concepts of vector operations that greatly aid scientific computations with Python. Plotting graphs and data using Matplotlib library will also be introduced.
Instructor(s): Fernanda Correa Horta (Summer); Harley Katz (Autumn) Terms Offered: Autumn Summer

ASTR 21000. Statistical Techniques in Astrophysics. 100 Units.
This course teaches the statistical concepts and techniques that are in common use in astronomical and astrophysical research. It is a computational course: knowledge of scientific Python, including exposure to the NumPy, SciPy, and MatPlotLib libraries, is required for this course.
Instructor(s): Carlo Graziani Terms Offered: Autumn
Prerequisite(s): ASTR 20500 or ASTR 21100 are required prerequisites.

ASTR 21100. Computational Techniques in Astrophysics. 100 Units.
This course will introduce basic computational techniques most often used in astronomical research, such as interpolation, transforms, smoothing, numerical differentiation and integration, integration of ordinary differential equations, and Monte Carlo methods, and elements of basic computer algorithms, data structures, and parallel programming using Python as the main course programming language with heavy use of NumPy, SciPy, and Matplotlib packages. Practical examples where these numerical techniques are applied will be covered via homework and in class exercises using real-world astronomical problems and results of recent papers with emphasis on implementing the algorithms from scratch. The course will cover the access to astronomical archival data, and how to search it efficiently, focusing specifically on the Sloan Digital Sky Survey, but with introduction to other data sets. Machine learning methods will be introduced to illustrate how large data sets can be mined for interesting information.
Instructor(s): Andrey Kravtsov Terms Offered: Winter
Prerequisite(s): ASTR 20500 or ASTR 21000 or CMSC 14100 or consent of the instructor.

ASTR 21200. Observational Techniques in Astrophysics. 100 Units.
This course will prepare students in methods that will be used in their independent research by introducing observation and analysis techniques in a field of astrophysics chosen by the instructor. Students will learn basics of astronomical instrumentation and will apply that knowledge in a practical context (for example, using an on-campus telescope or telescopes controlled robotically from campus). The process of data reduction and calibration will be illustrated, leading to the extraction of scientifically meaningful results.
Instructor(s): Brad Benson Terms Offered: Spring
Prerequisite(s): ASTR 13300 and ASTR 21100.

ASTR 21400. Creative Machines and Innovative Instrumentation. 100 Units.
An understanding of the techniques, tricks, and traps of building creative machines and innovative instrumentation is essential for a range of fields from the physical sciences to the arts. In this hands-on, practical course, you will design and build functional devices as a means to learn the systematic processes of engineering and fundamentals of design and construction. The kinds of things you will learn may include mechanical design and machining, computer-aided design, rapid prototyping, circuitry, electrical measurement methods, and other techniques for resolving real-world design problems. In collaboration with others, you will complete a mini-project and a final project, which will involve the design and fabrication of a functional scientific instrument. The course will be taught at an introductory level; no previous experience is expected. The iterative nature of the design process will require an appreciable amount of time outside of class for completing projects. The course is open to undergraduates in all majors (subject to the pre-requisites), as well as Master's and Ph.D. students.
Instructor(s): Wakely (Autumn Quarter); Juan Estrada (Winter Quarter); Derek Buzasi (Spring Quarter) Terms Offered: Autumn Spring Winter
Prerequisite(s): PHYS 12200 or PHYS 13200 or PHYS 14200; or CMSC 12100 or CMSC 12200 or CMSC 12300; or consent of instructor.
Equivalent Course(s): CMSC 21400, PSMS 31400, ASTR 31400, PHYS 21400

ASTR 23900. Physics of Galaxies. 100 Units.
This course will provide a comprehensive introduction to galaxies, the interstellar and intergalactic mediums. We will examine the basic properties of galaxies and the physical process involved in their structure and evolution. Topics will include the stellar content of galaxies and the dynamics of stars within galaxies, the Milky Way galaxy, the physical state of the interstellar medium, central supermassive black holes and active galactic nuclei, galaxy clusters and the hot intergalactic medium. We will discuss the formation of galaxies and processes that shape the distribution of dark matter and baryonic matter.
Instructor(s): Irina Zhuravleva Terms Offered: Spring
Prerequisite(s): ASTR 24100 for Astrophysics Majors; PHYS 23410 for Physics Majors.

ASTR 24100. The Physics of Stars. 100 Units.
This course develops the physical theory of the internal structure of stars and how their structure changes with time. The material illustrates how to build model stars based on these physical principles and covers

observational constraints on these models, such as the neutrino flux from the core of the Sun. Topics include supernovae and the end states of stars-white dwarfs, neutron stars, and black holes.
Instructor(s): Derek Buzasi Terms Offered: Winter
Prerequisite(s): ASTR 25400 for Astrophysics Majors; PHYS 23410 for Physics Majors.

ASTR 24300. Cosmological Physics. 100 Units.
This course will provide a comprehensive introduction to the principal topics in cosmology, including theoretical and observational foundations. Key topics will include the expansion of the Universe, dark matter and energy, cosmic microwave background, hot Big Bang, and the origin and evolution of structure.
Instructor(s): Wayne Hu Terms Offered: Winter
Prerequisite(s): ASTR 25400 or PHYS 23410. Intended for advanced students in the Physical Sciences.

ASTR 25400. Radiation Processes in Astrophysics. 100 Units.
Most of what we know about the Universe comes from detection of electromagnetic radiation emitted by individual sources or by diffuse media.#Once we understand the processes by which the radiation was created and the processes by which the radiation is scattered or modified as it passes through matter, we can address the physical nature of the sources.#The physics of radiation processes includes electricity and magnetism; quantum mechanics and atomic and nuclear structure; statistical mechanics; and special relativity.
Instructor(s): Fausto Cattaneo Terms Offered: Autumn
Prerequisite(s): PHYS 22500 and MATH 18500.

ASTR 25800. Astrophysics of Exoplanets. 100 Units.
Extrasolar planets, a.k.a. exoplanets, are planets orbiting other stars. First definitively detected in the mid 1990s, the planet count has rapidly expanded and their physical characterization has sharpened with improved observational techniques. Theoretical studies of planetary formation and evolution are now attempting to understand this statistical sample. The field also aspires to address questions about life in the universe. This course emphasizes hands-on activities, like working with real astronomical data to find and characterize exoplanets. Topics are the radial velocity, transit, and other discovery and characterization techniques; statistical distributions of known planets; comparisons among planet structure and planetary system types; formation in a protoplanetary disk and subsequent dynamical evolution; the goal of finding life on an exoplanet; colonization of exoplanets; and the Fermi paradox.
Instructor(s): Diana Powell Terms Offered: Spring
Prerequisite(s): ASTR 25400; PHYS 18500 recommended.
Equivalent Course(s): GEOS 32080

ASTR 28500. Science with Large Astronomical Surveys. 100 Units.
The last several decades have seen a rapid proliferation of novel astronomical survey programs mapping billions of objects across the full sky with extraordinary sensitivity and precision. This course will explore the wide variety of science that can be done with surveys like the Sloan Digital Sky Survey, the Dark Energy Survey, the Gaia satellite, and the Vera C. Rubin Observatory Legacy Survey of Space and Time. Science topics will include our Solar System, our Galaxy, the Local Group, distant galaxies, and cosmological measurements of our Universe. We will familiarize ourselves with the hardware and software components of astronomical surveys, before diving into hands-on analysis of public data sets. Students will learn computational and statistical techniques for analyzing large astronomical data sets. This course aims to equip upper-level undergraduate students with the knowledge and tools needed to begin independent research using astronomical survey data.
Instructor(s): Alex Drlica-Wagner Terms Offered: Spring
Prerequisite(s): ASTR 13300 and ASTR 21100 and ASTR 21200.

ASTR 29001. Field Course in Astronomy and Astrophysics I. 100 Units.
In this two-quarter course students will explore an area of astrophysical research through weekly meetings in preparation for multiple observing nights at a large research telescope. The observing may be a combination of remote observing and in-person, depending on timing, the facility involved. Students will analyze data collected during their observing experiences and will collaborate to produce one or more scientific papers to be published in professional journals. Students must enroll in both ASTR 29001 and ASTR 29002.
Instructor(s): Alex Ji Terms Offered: Winter
Prerequisite(s): Third-year students majoring in Astrophysics who have completed at least four ASTR-coded courses in the Major. Enrollment limited to 10 students.

ASTR 29002. Field Course in Astronomy and Astrophysics II. 100 Units.
In this two-quarter course students will explore an area of astrophysical research through weekly meetings in preparation for multiple observing nights at a large research telescope. The observing may be a combination of remote observing and in-person, depending on timing, the facility involved. Students will analyze data collected during their observing experiences and will collaborate to produce one or more scientific papers to be published in professional journals. Students must enroll in both ASTR 29001 and ASTR 29002.
Instructor(s): Alex Ji Terms Offered: Spring
Prerequisite(s): ASTR 29001

ASTR 29003. Field Course in Astronomy and Astrophysics III. 100 Units.
This course allows students who participated in ASTR 29001-29002 to continue or finish projects that emerged from prior research activity.

Instructor(s): Michael Gladders Terms Offered: Autumn

ASTR 29700. Participation in Research. 100 Units.
Participation in research may take various forms, including independent work on a small project, assisting an advanced graduate student or faculty member in their research, or participating as a member of a research collaboration. Students must arrange for a faculty-approved research project in advance of the start of the term and submit a completed College Reading and Research Course Form to the Academic Affairs Administrator in Astronomy and Astrophysics in order to enroll. Contact the Academic Affairs Administrator for more information.
Instructor(s): Staff Terms Offered: Autumn Spring Summer Winter
Prerequisite(s): Third- or fourth-year standing and consent of instructor.

ASTR 29800. Undergraduate Research Seminar. 100 Units.
In this course students will engage with various scientific practices to prepare them for participation in research. Students will critically analyze research presented in popular and scholarly scientific literature and practice computational, statistical, and observational techniques to explore astrophysical problems. The course will emphasize student-led discussions and interactive presentations to synthesize previous coursework and strengthen scientific thinking and communication skills. Guest lectures by members of research groups will highlight projects undertaken by faculty in Astronomy and Astrophysics to acquaint students with possibilities for research participation.
Instructor(s): Hsiao-Wen Chen Terms Offered: Spring
Prerequisite(s): ASTR 13300 and ASTR 21100.

ASTR 29900. Honors Thesis. 100 Units.
ASTR 29900 Honors Thesis is an independent research course, supervised by a faculty member in the Department of Astronomy and Astrophysics, in which the student either contributes to a faculty research project or engages in an approved independent research project. Eligible students enroll in ASTR 29900 for one quarter during their fourth year. Students intending to complete the Honors Thesis must meet with the Director of Undergraduate Studies in Astronomy and Astrophysics before the third week of Autumn Quarter to obtain Guidelines for the Honors Thesis Course and complete the Honors Thesis Form.
Instructor(s): Staff Terms Offered: Autumn Spring Winter
Prerequisite(s): Open to students who are majoring in Astrophysics with fourth-year standing. The student must earn a GPA of 3.50 or higher in the required courses for the Major and 3.0 overall, or obtain consent from the Deputy Chair for Academic Affairs to be eligible to enroll.