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, composed of courses numbered in the 12000s and 18000s that are offered on campus. 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. In Spring Quarter 2024, the Paris program will offer ASTR 12600 Matter, Energy, Space, and Time, ASTR 12610 Black Holes, and ASTR 12620 The Big Bang. For details, see the Study Abroad (https://study-abroad.uchicago.edu) page for Paris: Astronomy (http://study-abroad.uchicago.edu/programs/paris-astronomy/).

Students who have already completed their general education requirement in the physical sciences may count the three courses taken in Paris toward the five required to satisfy the minor in Astronomy and Astrophysics.

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. Students will gain broad knowledge of the universal, physical laws from the nuclear to cosmological; familiarity with computational methods and statistical data analysis; and experience with experimental and observational techniques through participation in research. Graduates of the Astrophysics program will be positioned to pursue advanced degrees in physics, astronomy, or similar fields, or enter government service, science education, or scientific journalism.

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 Astrophysics consists of eighteen courses beyond the general education requirement. The BS track is recommended for students expecting to apply to graduate school in the physical sciences.

The mathematics requirement is the sequence MATH 18300-18400-18500-18600 Mathematical Methods in the Physical Sciences I-II-III-IV. 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.

GRADING

Courses must be taken for quality grades (no P/F grading). Students must receive a quality grade of at least C in all courses counting toward program requirements. In addition, students who are majoring in Astrophysics must receive a quality grade of at least C- in prerequisite courses offered by other departments.

HONORS

ASTR 29900 Honors Thesis is an independent research course, supervised by a faculty member, in which the student may contribute to a faculty research project, or engage in independent research, over the course of the academic year. To be considered for honors, a fourth-year student must have a GPA of 3.5 or higher in the required courses for the major and 3.0 overall, and a faculty-approved research project. Eligible students who wish to be considered for honors must notify the Academic Affairs Administrator as early as possible before the start of 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 may enroll in the thesis course in any quarter by completing the College Reading and Research 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.

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
ASTR 29800	Undergraduate Research Seminar	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.

†   Students with no previous coding experience should take ASTR 20500 before enrolling in ASTR 21000. Students who matriculated prior to Autumn 2022 and who have already completed ASTR 20500 are not required to take ASTR 21000.

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
PHYS 22500	Intermediate Electricity and Magnetism I	100
ASTR 21000	Statistical Techniques in Astrophysics [†]	100
ASTR 21100	Computational Techniques in Astrophysics	100
ASTR 21200	Observational Techniques in Astrophysics	100
PHYS 23410	Quantum Mechanics I	100
ASTR 29800	Undergraduate Research Seminar	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.

[†]   Students with no previous coding experience should take ASTR 20500 before enrolling in ASTR 21000. Students who matriculated prior to Autumn 2022 and who have already completed ASTR 20500 are not required to take ASTR 21000.

The Astrophysics BS Chemistry Variant track has been temporarily suspended. Students who matriculated prior to 2023 with the intention of pursuing this track should contact the Academic Affairs Administrator.

SAMPLE PROGRAMS

The sample programs below illustrate the order in which courses in the Astrophysics major are intended to be taken, with the sequence of courses aligned to prerequisites. Students are encouraged to contact the Academic Affairs Administrator for assistance in planning individual programs.

BA in Astrophysics starting with MATH 15100

First Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 20500 (Elective)	PHYS 13200	ASTR 13300
PHYS 13100	MATH 15200	PHYS 13300
MATH 15100		MATH 18300

Second Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 21000	ASTR 21100	ASTR 21200
MATH 18400	MATH 18500	ASTR 29800
		MATH 18600

Third Year

	Winter Quarter	Spring Quarter
	PHYS 22500	ASTR 28500 (Elective)

Fourth Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 25400	ASTR 24100	ASTR 23900

BA in Astrophysics starting with MATH 18300

First Year

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

Second Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 21000	ASTR 21100	ASTR 21200
MATH 18600	PHYS 22500	ASTR 29800

Third Year

Autumn Quarter	Winter Quarter
ASTR 25400	ASTR 24100
	PHYS 23410 (Elective)

Fourth Year

Autumn Quarter	Winter Quarter
ASTR 25000 (Elective)	ASTR 25800

BS in Astrophysics starting with MATH 15100

First Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 20500 (Elective)	PHYS 13200	ASTR 13300
PHYS 13100	MATH 15200	PHYS 13300
MATH 15100		MATH 18300

Second Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 21000	ASTR 21100	ASTR 21200
MATH 18400	MATH 18500	ASTR 29800
		MATH 18600

Third Year

	Winter Quarter	Spring Quarter
	PHYS 22500	PHYS 23510 (Elective)
	PHYS 23410	

Fourth Year

Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 25400	ASTR 24100	ASTR 23900
PHYS 27900		

BS in Astrophysics starting with MATH 18300

First Year

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

Second Year

Autumn Quarter	Winter Quarter	Spring Quarter
MATH 18600	ASTR 21100	ASTR 21200
ASTR 21000	PHYS 22500	ASTR 29800

Third Year

Autumn Quarter	Winter Quarter
ASTR 25400	ASTR 24100
	PHYS 23410

Fourth Year

Autumn Quarter	Winter Quarter
PHYS 26400 (Elective)	ASTR 24300
PHYS 27900	ASTR 24500 (Elective)

ELECTIVES

ASTR 20500	Introduction to Python Programming with Applications to Astrophysics	100
ASTR 21400	Creative Machines and Innovative Instrumentation	100
ASTR 25000	Order-of-Magnitude Astrophysics	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 30100	Stars	100
ASTR 30300	Interstellar Matter	100
ASTR 30400	Galaxies	100
ASTR 30600	Detection of Radiation	100
ASTR 31000	Cosmology I	100
ASTR 31100	High Energy Astrophysics	100
CMSC 23010	Parallel Computing	100
CMSC 25025	Machine Learning and Large-Scale Data Analysis	100
CMSC 25400	Machine Learning	100

GEOS 22000	Origin and Evolution of the Solar System	100
GEOS 22060	What Makes a Planet Habitable?	100
PHYS 22600	Electronics	100
PHYS 23410	Quantum Mechanics I (BA in Astrophysics only)	100
PHYS 23510	Quantum Mechanics II (BA or BS in Astrophysics)	100
PHYS 24310	Advanced Quantum Mechanics	100
PHYS 26400	Spacetime and Black Holes	100

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 11901. Physics of Stars: An Introduction. 100 Units.
Understanding how stars work - what makes them shine - is one of the great accomplishments of 20th-century science. The theory of stellar structure allows us to investigate the interiors of stars, even though what we observe is radiation from their outer atmospheres. This theory also helps us determine how old stars are, how they create heavier nuclei from lighter nuclei in their centers, and how they evolve from birth to death, ending as a white dwarf, a neutron star, or a black hole. This course introduces you to the concepts behind and applications of this crucial breakthrough. We will review the physical principles - gravity, pressure, radiation, and how radiation interacts with matter - and apply these principles to further our understanding of stellar structure. We will collect our own measurements of stellar properties, such as the temperatures and luminosities of stars, using robotic telescopes controlled via the internet. Using these and other data, we will test the theory of stellar structure and explore what it can tell us about the universe. While it is not required, students who have taken this course in the past have found it beneficial to bring their own laptops to class if they have them.
Instructor(s): Rich Kron Terms Offered: Summer
Prerequisite(s): Open to high school students only.

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): Paolo Privitera 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); Rich Kron (Winter Quarter) Terms Offered: Summer Winter. Summer Quarter instructor is Fausto Cattaneo.
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): John Carlstrom Terms Offered: Spring
Prerequisite(s): PHSC 12600
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)
Instructor(s): Fausto Cattaneo (Summer Quarter); Damiano Caprioli (Autumn Quarter) Terms Offered: Autumn Summer. Summer Quarter instructor is Fausto Cattaneo.
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)
Instructor(s): Jeff McMahon 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)
Instructor(s): Jacob Bean Terms Offered: Winter

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): Joshua Frieman Terms Offered: Spring
Prerequisite(s): PHYS 13300; may be taken concurrently.

ASTR 18200. The Origin and Evolution of the Universe. 100 Units.
This course provides a comprehensive introduction to modern cosmology for students wishing to delve deeper into the subject than PHSC 12620 (which is not a prerequisite) but at a similar mathematical level. 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): Edward Kolb Terms Offered: Winter
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 18200

ASTR 18700. From Fossils to Fermi's Paradox: Origin and Evolution of Intelligent Life. 100 Units.
The course approaches Fermi's question, "Are we alone in the universe?," in the light of recent evidence primarily from three fields: the history and evolution of life on Earth (paleontology), the meaning and evolution of complex signaling and intelligence (cognitive science), and the distribution, composition and conditions on planets and exoplanets (astronomy). We also review the history and parameters governing extrasolar detection and signaling. The aim of the course is to assess the interplay between convergence and contingency in evolution, the selective advantage of intelligence, and the existence and nature of life elsewhere in the universe - in order to better understand the meaning of human existence.
Instructor(s): P. Sereno; L. Rogers; S. London Terms Offered: Winter
Prerequisite(s): Third or fourth-year standing. This course does not meet the requirements of the Biological Sciences major.
Equivalent Course(s): PSYC 28810, BIOS 13142, BPRO 28800

ASTR 18800. Philosophical Problems in Cosmology. 100 Units.
In this course, we will undertake a comparison of the philosophical underpinnings of the Aristotelian and Copernican cosmologies, including a comparison of mechanistic and teleological approaches to the natural world. The epistemological foundations of the scientific method, in particular as applied to cosmology (from Galileo to the modern context) will be examined, as will positivist vs. realistic outlooks on cosmology. (For example, what does science say-or not say-about the inside of a black hole, or the space beyond the Hubble horizon?) We will ponder questions such as: Do the epistemological foundations of science require us to be able to repeat relevant experiments? If so, does this disqualify cosmology as a science? If not, why? Might our universe be part of a computer simulation? What information could possibly convince us that this is true or false?
Instructor(s): Dan Hooper Terms Offered: Spring
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): HIPS 18800, PHSC 18800

ASTR 18850. Interpreting Nature: On the Relation Between Art and Science. 100 Units.
In this course we will investigate the role of art and science in history and contemporary life, and challenge the artificial distinctions between them that we are often taught. We will explore the deeper, abstract connections that unite the two subjects, and through understanding beautiful things in nature as both artistic and scientific, apply this way of thinking to everyday experience. Coursework will be highly interactive and will involve readings, discussions, guest lectures, and field trips. A final project, presented as part of an art exhibit, will highlight the connections between art and science students discovered from daily life that most inspired and excited them.
Instructor(s): Chihway Chang Terms Offered: Spring

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): Andrey Kratsov Terms Offered: Autumn
Note(s): This course is aimed at students planning to major in Astrophysics.

ASTR 21000. Statistical Techniques in Astrophysics. 100 Units.
Python programming techniques will be illustrated and applied to basic statistical concepts that are used in astronomical research. Working knowledge of Python is required for this course.
Instructor(s): Nick Gnedin Terms Offered: Autumn
Prerequisite(s): ASTR 20500 or CMSC 12100 or CMSC 14100 or consent of instructor.

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 CMSC 12100 or CMSC 14100 or consent of instructor.
Equivalent Course(s): ASTR 31200

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 20500 or working knowledge of Python. ASTR 13300 recommended.

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): Autumn Quarter Instructor: Scott Wakely 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): ASTR 31400, CMSC 21400, PHYS 21400, CHEM 21400, PSMS 31400

ASTR 21700. Are we doomed? Confronting the End of the World. 100 Units.
We may be at a pivotal point in human history, with civilization facing unprecedented threats including nuclear Armageddon, climate change, and pandemics. This class will explore our potential for self-inflicted catastrophe, as well as approaches for mitigating these perils. We will consider this through readings and engagement with a range of speakers focused on various imminent perils, from the perspective of a wide range of disciplinary perspectives, including sociology, philosophy, theology, anthropology, statistics, physics, astrophysics, economics, law, business, and the arts.
Instructor(s): D. Holz, J. Evans Terms Offered: Winter
Prerequisite(s): PQ: Third- or fourth-year standing
Equivalent Course(s): SOCI 20531, KNOW 21700, BPRO 25800, SOCI 30531

ASTR 22060. What Makes a Planet Habitable? 100 Units.
This course explores the factors that determine how habitable planets form and evolve. We will discuss a range of topics, from the formation of planets around stars and the delivery of water, to the formation of atmospheres, climate dynamics, and the conditions that allow for the development of life and the evolution of complex life. Students will be responsible for periodically preparing presentations based on papers in peer-reviewed journals and leading the discussion.
Instructor(s): E. Kite Terms Offered: Winter

Equivalent Course(s): GEOS 22060, ASTR 32060, GEOS 32060

ASTR 23700. Histories of Women in Science. 100 Units.
In the mid-1980s, only two female students drew women when asked what a scientist looked like and none of the male students in the study did. Only 8% of STEM workers in 1970 were women; in 2019 that number was still only 27%. This would seem to suggest that the history of women in science is a recent one. Yet historians of science have foregrounded women's involvement in fields ranging from early modern medicine to twentieth century astrophysics. This class introduces students to these histories, investigates how and why science came to be a gendered as male, and asks to what extent gendered values continue to inform modern conceptions scientific achievement or value. In so doing, this course also introduces students to feminist science studies and challenges students to reflect upon their own (gendered) experiences of science. Students are strongly encouraged to develop final research projects that draw upon their own interests, scientific expertise, and linguistic competencies. No prior experience with history is required for this course, although an enthusiasm for history is advised.
Instructor(s): Kristine Palmieri Terms Offered: Winter
Equivalent Course(s): PHSC 27010, HIPS 27011, GNSE 23162, KNOW 37011, CHSS 37011, GNSE 37011, HIST 27806

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): Robert Rosner 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. PHYS 27900 recommended.

ASTR 24500. The Physics of the Dark Universe. 100 Units.
Approximately 85% of the mass in our universe is "dark matter," which is not made of familiar particles in disguise. The evidence for this remarkable fact comes from galactic dynamics, the clustering of matter on cosmological scales, the cosmic microwave background, gravitational lensing, and the yields of light elements formed shortly after the big bang. However, despite this vast body of evidence, the microscopic nature of dark matter is currently unknown and there are many candidate theories which make different predictions about its non-gravitational interactions with visible matter. In this course we will survey the evidence for the existence of dark matter, introduce some of the most commonly studied theories (e.g. WIMPs and axions), and explore their testable implications.
Instructor(s): Gordan Krnjaic Terms Offered: Winter
Prerequisite(s): ASTR 24100 for Astrophysics Majors; PHYS 23410 for Physics Majors. PHYS 27900 recommended.

ASTR 25000. Order-of-Magnitude Astrophysics. 100 Units.
In physics and astrophysics, an approximate answer is often just as (if not more) useful than an exact answer. Making order-of-magnitude estimates is helpful to develop physical intuition, to verify numerical solutions, and to evaluate whether a research problem is worth pursuing. In this course, students will receive coaching and practice in physics-based reasoning, back-of-the envelope estimation, and thinking on their feet. Students will be encouraged to take a broad perspective, to think critically, and to have fun using physics to understand the universe around them.
Instructor(s): Leslie Rogers Terms Offered: Autumn
Note(s): Open to 3rd and 4th year undergraduates in the Physical Sciences by instructor consent.
Equivalent Course(s): ASTR 35000

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 28500. Science with Large Astronomical Surveys. 100 Units.
The last several years have seen a veritable explosion of novel astronomical survey programs covering large areas of sky with unprecedented sensitivity. 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. Students will learn computational and statistical techniques for analyzing large astronomical data sets.
Instructor(s): Alex Drlica-Wagner Terms Offered: Spring
Prerequisite(s): ASTR 13300 and ASTR 21100 and ASTR 21200.

ASTR 29000. Counterhistories of Mathematics and Astronomy. 100 Units.
Mathematics and astronomy are often taught as packaged universal truths, independent of time and context. Their history is assumed to be one of revelations and discoveries, beginning with the Greeks and reaching final maturity in modern Europe. This narrative has been roundly critiqued for decades, but the work of rewriting these histories has only just begun. This course is designed to familiarize students with a growing literature on the history of mathematics and astronomy in regions which now make up the global south. It is structured as a loosely chronological patchwork of counterexamples to colonial histories of mathematics and astronomy. Thematic questions include: How were mathematical and astronomical knowledge conjoined? How were they embedded in political contexts, cultural practices, and forms of labor? How did European scientific modernity compose itself out of the knowledges of others? Where necessary, we will engage with older historiographies of mathematics and astronomy, but for the most part we will move beyond them. No mathematics more advanced than highschool geometry and algebra will be assumed. However, those with more mathematical preparation may find the course especially useful.
Instructor(s): Prashant Kumar Terms Offered: Autumn
Equivalent Course(s): ASTR 39000, HIST 35305, KNOW 39000, HIPS 27010, SALC 39000, CHSS 39001

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. Winter Quarter is graded P/F only; a quality grade is issued in Spring Quarter.
Instructor(s): Michael Gladders Terms Offered: Winter. Winter Quarter grade is P/F only.
Prerequisite(s): Open to third-year students majoring in Astrophysics who have completed ASTR 29800.
Note(s): Winter Quarter grade is P/F only.

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): Michael Gladders Terms Offered: Spring
Prerequisite(s): ASTR 29001

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.
Terms Offered: Autumn Spring Summer Winter
Prerequisite(s): Third- or fourth-year standing and consent of instructor.
Note(s): Students may register for multiple quarters of independent research and may work with different faculty members each quarter.

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): Clarence Chang Terms Offered: Spring
Prerequisite(s): ASTR 13300 and ASTR 21200.
Note(s): Intended for students in the Astrophysics Major program.

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.
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. Before the third week of Autumn Quarter students intending to complete the Honors Thesis must have an approved research project that will be supervised by a faculty member, and meet with the Academic Affairs Administrator to obtain Guidelines for the Honors Thesis Course and complete the Department of Astronomy and Astrophysics Honors Thesis Form. Students are required to submit the College Reading and Research Course Form to the Academic Affairs Administrator in the quarter in which they enroll in the course.

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