

# 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, the minor program in Astronomy and Astrophysics (aimed at students not majoring in the sciences), 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 will satisfy the general education requirement in the physical sciences from among six courses numbered in the 12000s. These courses are designed for students not majoring in the sciences and 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. The Study Abroad program in Paris is another option for completing the general education requirement in the physical sciences.

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.

## 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. Courses in Computer Science and Statistics complement a foundational program in Physics, reflecting the essential relationships among the physical sciences. 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 fifteen 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.

Please note that courses counted toward the major must be taken for quality grades (no P/F grading).

## 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 13100-13200	Elementary Functions and Calculus I-II *	
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
One of the following:		100
MATH 13300	Elementary Functions and Calculus III	
MATH 15300	Calculus III	
MATH 16300	Honors Calculus III	
PHYS 22000	Introduction to Mathematical Methods in Physics	

PHYS 15400	Modern Physics	100
One of the following:		100
PHYS 22100	Mathematical Methods in Physics	
MATH 20100	Mathematical Methods for Physical Sciences II	
One of the following:		100
CMSC 12100	Computer Science with Applications I	
CMSC 15100	Introduction to Computer Science I	
CMSC 16100	Honors Introduction to Computer Science I	
One of the following:		100
STAT 22000	Statistical Methods and Applications *	
STAT 23400	Statistical Models and Methods	
STAT 24400	Statistical Theory and Methods I	
STAT 24410	Statistical Theory and Methods Ia	
ASTR 21100	Computational Techniques in Astrophysics	100
ASTR 21200	Observational Techniques in Astrophysics	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 23900	Physics of Galaxies	
ASTR 24300	Cosmological Physics	
Two electives to be selected from list of approved courses		200
Total Units		1500

\* Credit may be granted by examination.

% Students who matriculated prior to Autumn 2018 may substitute any 200-level ASTR course for ASTR 13300.

### Summary of Requirements for the BS in Astrophysics (Physics Variant)

#### GENERAL EDUCATION

PHYS 13100-13200	Mechanics; Electricity and Magnetism *	200
One of the following sequences:		200
MATH 13100-13200	Elementary Functions and Calculus I-II *	
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
One of the following:		100
MATH 13300	Elementary Functions and Calculus III	
MATH 15300	Calculus III	
MATH 16300	Honors Calculus III	
PHYS 22000	Introduction to Mathematical Methods in Physics	
PHYS 15400	Modern Physics	100
One of the following:		100
PHYS 22100	Mathematical Methods in Physics	
MATH 20100	Mathematical Methods for Physical Sciences II	
One of the following:		100
CMSC 12100	Computer Science with Applications I	
CMSC 15100	Introduction to Computer Science I	
CMSC 16100	Honors Introduction to Computer Science I	
One of the following:		100
STAT 22000	Statistical Methods and Applications *	
STAT 23400	Statistical Models and Methods	

STAT 24400	Statistical Theory and Methods I	
STAT 24410	Statistical Theory and Methods Ia	
ASTR 21100	Computational Techniques in Astrophysics	100
ASTR 21200	Observational Techniques in Astrophysics	100
ASTR 29800	Undergraduate Research Seminar	100
PHYS 23400	Quantum Mechanics I	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 23900	Physics of Galaxies	
ASTR 24300	Cosmological Physics	
Three electives to be selected from list of approved courses		300
Total Units		1800

\* Credit may be granted by examination.

### Summary of Requirements for the BS in Astrophysics (Chemistry Variant)

#### GENERAL EDUCATION

CHEM 11100-11200	Comprehensive General Chemistry I-II (or equivalent) *	200
One of the following sequences:		200
MATH 13100-13200	Elementary Functions and Calculus I-II	
MATH 15100-15200	Calculus I-II *	
MATH 16100-16200	Honors Calculus I-II	
Total Units		400

#### MAJOR

PHYS 13100-13200-13300	Mechanics; Electricity and Magnetism; Waves, Optics, and Heat (or higher)	300
ASTR 13300	Introduction to Astrophysics	100
One of the following:		100
MATH 13300	Elementary Functions and Calculus III	
MATH 15300	Calculus III	
MATH 16300	Honors Calculus III	
MATH 20000	Mathematical Methods for Physical Sciences I	
PHYS 22000	Introduction to Mathematical Methods in Physics	
One of the following:		100
PHYS 22100	Mathematical Methods in Physics	
MATH 20100	Mathematical Methods for Physical Sciences II	
One of the following:		100
CMSC 12100	Computer Science with Applications I	
CMSC 15100	Introduction to Computer Science I	
CMSC 16100	Honors Introduction to Computer Science I	
One of the following:		100
STAT 22000	Statistical Methods and Applications *	
STAT 23400	Statistical Models and Methods	
STAT 24400	Statistical Theory and Methods I	
STAT 24410	Statistical Theory and Methods Ia	
CHEM 11300	Comprehensive General Chemistry III	100
ASTR 21100	Computational Techniques in Astrophysics	100
ASTR 21200	Observational Techniques in Astrophysics	100
ASTR 29800	Undergraduate Research Seminar	100
ASTR 25400	Radiation Processes in Astrophysics	100
ASTR 24100	The Physics of Stars	100
CHEM 26100	Quantum Mechanics	100
CHEM 26200	Thermodynamics	100

One of the following:	100
ASTR 23900            Physics of Galaxies	
ASTR 24300            Cosmological Physics	
One elective to be selected from list of approved courses	100
Total Units	1800

\* Credit may be granted by examination

### Sample Programs

The sample programs below illustrate different paths for fulfilling requirements for the Astrophysics major. The first example shows a path for the BS in Astrophysics with the introductory sequence in Physics.

First Year		
Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 13100	PHYS 13200	ASTR 13300
MATH 15100	MATH 15200	PHYS 13300
		MATH 15300
Second Year		
Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 15400	ASTR 21100	ASTR 21200
PHYS 22100	STAT 23400	ASTR 29800
CMSC 12100		PHYS 23400
Third Year		
Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 25400	ASTR 24100	Elective
	Elective	
Fourth Year		
Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 27900	Elective	ASTR 24300

This sample shows a path for the BS in Astrophysics with the introductory sequence in Chemistry.

First Year		
Autumn Quarter	Winter Quarter	Spring Quarter
CHEM 11100	CHEM 11200	ASTR 13300
MATH 16100	MATH 16200	CHEM 11300
		MATH 20000
Second Year		
Autumn Quarter	Winter Quarter	Spring Quarter
PHYS 13100	PHYS 13200	PHYS 13300
	STAT 22000	MATH 20100
Third Year		
Autumn Quarter	Winter Quarter	Spring Quarter
ASTR 25400	ASTR 24100	ASTR 21200
CMSC 12100	ASTR 21100	ASTR 29800
Fourth Year		
Autumn Quarter	Winter Quarter	Spring Quarter
CHEM 26100	CHEM 26200	ASTR 23900
	Elective	

### Electives

ASTR 25800	Astrophysics of Exoplanets	100
ASTR 28200	Current Topics in Astrophysics	100
ASTR 30100	Stars	100
ASTR 30300	Interstellar Matter	100
ASTR 30400	Galaxies	100
ASTR 33000	Computational Physics and Astrophysics	100
CMSC 15200	Introduction to Computer Science II	100
CMSC 15400	Introduction to Computer Systems	100
CMSC 23500	Introduction to Database Systems	100
CMSC 23900	Data Visualization	100
CMSC 28510	Introduction to Scientific Computing	100
GEOS 21200	Physics of the Earth	100
GEOS 22040	Planet Formation in the Galaxy I: From Dust to Planetesimals	100

GEOS 22050	Plant Formation in the Galaxy II: From Planetesimals to Planets	100
GEOS 22060	What Makes a Planet Habitable?	100
GEOS 22200	Geochronology	100
MATH 20250	Abstract Linear Algebra (or higher)	100
PHYS 18500	Intermediate Mechanics	100
PHYS 22500	Intermediate Electricity and Magnetism I	100
PHYS 22600	Electronics	100
PHYS 22700	Intermediate Electricity and Magnetism II	100
PHYS 23400	Quantum Mechanics I (BA only)	100
PHYS 23500	Quantum Mechanics II	100
PHYS 26000	Fluid Dynamics	100
PHYS 26400	Spacetime and Black Holes	100
STAT 22200	Linear Models and Experimental Design	100
STAT 22400	Applied Regression Analysis	100
STAT 24500	Statistical Theory and Methods II	100
STAT 24510	Statistical Theory and Methods IIa	100
STAT 25100	Introduction to Mathematical Probability	100
STAT 25300	Introduction to Probability Models	100
STAT 27400	Nonparametric Inference	100
STAT 27850	Multiple Testing, Modern Inference, and Replicability	100

### Grading

Students in the major or minor programs offered by the Department of Astronomy and Astrophysics must receive a quality grade of at least C in all courses counting toward major/minor 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

Students who have completed the requirements for the BA or BS in Astrophysics are encouraged to prepare an honors thesis based on their work. To be considered for honors, a student must earn a GPA of 3.5 or higher in the required courses for the major and 3.0 overall (or obtain consent from the assistant chair for academic affairs), and have an approved research project that will be supervised by a faculty member.

Eligible students who wish to be considered for honors will first meet with the academic affairs administrator to obtain guidelines and requirements for this option, followed by a meeting with their research mentor resulting in a plan for the supervision of the research. The student enrolls in ASTR 29900 Honors Thesis in any quarter of their graduation year. A goal of the honors track is to mentor students through the process of preparing research and submitting it for publication. Along the way, students present their research to various groups, including Astronomy and Astrophysics faculty, for feedback and discussion.

### 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 was 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 substitute a course numbered in the 20000s for one of the 18000 courses. Students interested in exploring this option must meet with the academic affairs administrator 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.** Students who satisfy their general education requirement in the physical sciences in Astronomy and Astrophysics may pursue the minor through completing the remaining courses numbered in the 12000s and at least one in the 18000s.

There are no Physics or Mathematics prerequisites for the minor. Courses must be taken for quality grades (no P/F grading). Students must meet with 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](https://humanities-web.s3.us-east-2.amazonaws.com/college-prod/s3fs-public/documents/Consent_Minor_Program.pdf)) form.

### Study Abroad Program

Every Spring Quarter a three-course Astronomy program is offered in Paris, composed from the courses numbered in the 12000s that are offered on campus. This sequence was designed for students not majoring in the sciences but may also

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 2020, the Paris program will offer ASTR 12700 Stars, ASTR 12710 Galaxies, and ASTR 12720 Exoplanets.

The Astronomy program in Paris satisfies the general education requirement in the physical sciences. 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. For details, see the Study Abroad (<https://study-abroad.uchicago.edu>) page for Paris: Astronomy (<http://study-abroad.uchicago.edu/programs/paris-astronomy>).

#### 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): Erik Shirokoff Terms Offered: Autumn

Equivalent Course(s): PHSC 12600

##### **ASTR 12610. Black Holes. 100 Units.**

Black Holes are the most exotic, extreme and paradoxical systems in the universe. They are the densest concentrations of energy, yet they convert all matter that falls in to pure space-time curvature; they radiate more power than anything else, even though most of their radiation is not even made of light; they are mathematically the most perfectly understood of any physical structure, but their enigmatic behavior is still the subject of a violent disagreement among experts that highlights our ignorance of how quantum physics relates to gravity. This course will survey the physics of space and time, the nature of black holes, their effects on surrounding matter and light, the astrophysical contexts in which they are observed, frontier areas of research as quantum gravity and gravitational waves, and the importance of space-time physics to everyday needs such as navigation and energy. The modern theory of space and time, as well as black holes, will be placed in historical context, with special attention to the work of Albert Einstein. Experimental exercises will include direct measurement of the speed of light and gravitational mass, and experience with interferometry. Quantitative analysis will be an important part of the course, but mathematics beyond algebra will not be required. (L)

Instructor(s): Nick Gnedin Terms Offered: 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): Rocky Kolb 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): Daniel Fabrycky Terms Offered: Autumn

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): Alex Drlica-Wagner Terms Offered: Winter

Prerequisite(s): 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 past two decades have witnessed the discovery of planets in orbit around other stars and the characterization of extra-Solar (exo-) planetary systems. We are now able to place our Solar System into the context of other worlds and a surprising conclusion that most planetary systems look nothing like our own. A challenging next step is to find planets as small as the Earth in orbit around stars like the Sun. The architecture of planetary systems reflects the formation of the parent star and its protoplanetary disk, and how these have changed with time. 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: Spring

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 13300; may be taken concurrently.

**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: Autumn

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): TBD Terms Offered: Spring. Not offered in 2019-2020

Prerequisite(s): Any two-course 10000-level general education sequence in chemistry, geophysical sciences, physical sciences, or physics.

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 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): TBD Terms Offered: Not offered in 2019-2020.

Prerequisite(s): Any two-course 10000-level general education sequence in chemistry, geophysical sciences, physical sciences, or physics.

Note(s): Not offered in 2019-2020.

Equivalent Course(s): PHSC 18200

**ASTR 18300. Searching Between the Stars. 100 Units.**

With the advent of modern observational techniques (e.g., radio, satellite astronomy), it has become possible to study free atoms, molecules, and dust in the vast space between the stars. The observation of interstellar matter provides information on the physical and chemical conditions of space and on the formation and evolution of stars.

Instructor(s): Al Harper Terms Offered: Winter

Prerequisite(s): Any two-course 10000-level general education sequence in chemistry, geophysical sciences, physical sciences, or physics.

Equivalent Course(s): PHSC 18300

**ASTR 18400. Origins: From the Big Bang to Human Consciousness. 100 Units.**

In this course we will look at the approaches to, data for, and theories of the big transitions in the evolution of the physical universe and the living world.

Instructor(s): Wendy Freedman and Neil Shubin Terms Offered: Spring

Prerequisite(s): Any two-course 10000-level general education sequence in chemistry, geophysical sciences, physical sciences, or physics.

**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: TBD. Not offered in 2019-2020

Prerequisite(s): Any two-course 10000-level general education sequence in chemistry, geophysical sciences, physical sciences, or physics.

Equivalent Course(s): PHSC 18800, HIPS 18800

**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. 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): CMSC 12100 or CMSC 15100 or CMSC 16100 with a grade of C- or better, plus working knowledge of Python.

**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): Al Harper Terms Offered: Spring

Prerequisite(s): ASTR 13300 or consent of instructor.



**ASTR 23900. Physics of Galaxies. 100 Units.**

This course will provide a comprehensive introduction to galaxies and the interstellar medium and will examine the physical processes involved in their structure and evolution. Topics will include the stellar content of galaxies and the dynamics of stars within galaxies, the physical state of the interstellar medium, central supermassive black holes and power generation in active galactic nuclei, what can be learned about the distribution of mass from gravitational lensing, and processes that shape the relative distributions of dark matter and baryonic matter.

Instructor(s): Hsiao-Wen Chen Terms Offered: Spring

Prerequisite(s): ASTR 24100 or consent of instructor.

**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 or PHYS 23400 or consent of instructor.

**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: Spring

Prerequisite(s): ASTR 24100 or consent of instructor.

**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): Damiano Caprioli Terms Offered: Autumn

Prerequisite(s): PHYS 15400; ASTR 13300 and PHYS 15400 required for students majoring in Astrophysics.

Equivalent Course(s): ASTR 30500

**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 upcoming Large Synoptic Survey Telescope. 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.

Instructor(s): Alex Drlica-Wagner Terms Offered: Spring. Not offered in 2019-2020.

Prerequisite(s): Third- or fourth-year standing in the College and completion of intermediate-level courses in the Physical Sciences; or by consent of instructor.

Note(s): This course is aimed at undergraduate and graduate students in the Physical Sciences. Not offered in 2019-2020.

Equivalent Course(s): ASTR 41200

**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 seminars in preparation for a four-night visit to an observatory during the spring break. In the second quarter of the course students will analyze data collected during their observing experience and will collaborate to produce a single paper similar in format to scientific papers published in professional journals. Students must enroll in both ASTR 29001 and ASTR 29002.

Instructor(s): Michael Gladders Terms Offered: Winter

Prerequisite(s): Open to third-year students majoring in Astrophysics who have completed ASTR 13300, ASTR 21200 and ASTR 29800.

**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 seminars in preparation for a four-night visit to an observatory during the spring break. In the second quarter of the course students will analyze data collected during their observing experience and will collaborate to produce a single paper similar in format to scientific papers 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.**

Students are assigned to work in the research group of a member of the faculty. Participation in research may take the form of independent work on a small project or assistance to an advanced graduate student or faculty member in his or her research.

Instructor(s): Rich Kron Terms Offered: Autumn Spring Summer Winter

Prerequisite(s): Third- or fourth-year standing and consent of instructor.

Note(s): Students must arrange with instructor in advance of the start of the term. Students are required to submit the College Reading and Research Course Form. Available for either quality grades or for P/F grading. Students may register for this course for as many quarters as they wish; they need not work with the same faculty member each time.

**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 the Astronomy and Astrophysics Department to acquaint students with possibilities for research participation.

Instructor(s): Clarence Chang Terms Offered: Spring

Prerequisite(s): CMSC 12100, CMSC 15100 or CMSC 16100; STAT 22000, STAT 23400, STAT 24400 or STAT 24410; and ASTR 21100 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 must notify the Academic Affairs Administrator in the Department of Astronomy and Astrophysics of their intention to complete an Honors Thesis by the 3rd week of Autumn Quarter of their fourth year.

Instructor(s): Rich Kron 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 Assistant Chair for Academic Affairs—and have an approved research project that will be supervised by a faculty member. Students are required to submit the College Reading and Research Course form in the quarter in which they enroll in the course.





### Font Notice

This document should contain certain fonts with restrictive licenses. For this draft, substitutions were made using less legally restrictive fonts. Specifically:

Times was used instead of Trajan.

Times was used instead of Palatino.

The editor may contact Leepfrog for a draft with the correct fonts in place.