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 nucleus 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**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 13100-13200</td>
<td>Mechanics; Electricity and Magnetism (or higher)</td>
<td>200</td>
</tr>
<tr>
<td>One of the following sequences:</td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>MATH 15100-15200</td>
<td>Calculus I-II</td>
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<tr>
<td>MATH 16100-16200</td>
<td>Honors Calculus I-II</td>
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<tr>
<td><strong>Total Units</strong></td>
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**MAJOR**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
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<tbody>
<tr>
<td>ASTR 13300</td>
<td>Introduction to Astrophysics</td>
<td>100</td>
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<tr>
<td>PHYS 13300</td>
<td>Waves, Optics, and Heat (or higher)</td>
<td>100</td>
</tr>
<tr>
<td>MATH 18300-18400-18500-18600</td>
<td>Mathematical Methods in the Physical Sciences I-II-III-IV</td>
<td>400</td>
</tr>
<tr>
<td>ASTR 21000</td>
<td>Statistical Techniques in Astrophysics</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 21100</td>
<td>Computational Techniques in Astrophysics</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 21200</td>
<td>Observational Techniques in Astrophysics</td>
<td>100</td>
</tr>
<tr>
<td>PHYS 22500</td>
<td>Intermediate Electricity and Magnetism I</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 29800</td>
<td>Undergraduate Research Seminar</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 25400</td>
<td>Radiation Processes in Astrophysics</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 24100</td>
<td>The Physics of Stars</td>
<td>100</td>
</tr>
<tr>
<td>One of the following:</td>
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<td>100</td>
</tr>
<tr>
<td>ASTR 25800</td>
<td>Astrophysics of Exoplanets</td>
<td></td>
</tr>
<tr>
<td>ASTR 23900</td>
<td>Physics of Galaxies</td>
<td></td>
</tr>
<tr>
<td>ASTR 24300</td>
<td>Cosmological Physics</td>
<td></td>
</tr>
<tr>
<td>Two electives to be selected from list of approved courses</td>
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<td>200</td>
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<tr>
<td><strong>Total Units</strong></td>
<td></td>
<td>1600</td>
</tr>
</tbody>
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* 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**

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>PHYS 13100-13200</td>
<td>Mechanics; Electricity and Magnetism (or higher)</td>
<td>200</td>
</tr>
<tr>
<td>One of the following sequences:</td>
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<tr>
<td>MATH 15100-15200</td>
<td>Calculus I-II</td>
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<tr>
<td>MATH 16100-16200</td>
<td>Honors Calculus I-II</td>
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</tr>
<tr>
<td><strong>Total Units</strong></td>
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<td>400</td>
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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**

<table>
<thead>
<tr>
<th>First Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 20500 (Elective)</td>
<td></td>
<td>PHYS 13200</td>
<td>ASTR 13300</td>
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<tr>
<td>PHYS 13100</td>
<td>MATH 15200</td>
<td>PHYS 13300</td>
<td></td>
</tr>
<tr>
<td>MATH 15100</td>
<td>MATH 18300</td>
<td></td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Second Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 21000</td>
<td>ASTR 21100</td>
<td>ASTR 21200</td>
<td></td>
</tr>
<tr>
<td>MATH 18400</td>
<td>MATH 18500</td>
<td>MATH 28900</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Third Year</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>PHYS 22500</td>
<td>ASTR 28500 (Elective)</td>
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<table>
<thead>
<tr>
<th>Fourth Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 25400</td>
<td>ASTR 24100</td>
<td>ASTR 23900</td>
<td></td>
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**BA in Astrophysics starting with MATH 18300**

<table>
<thead>
<tr>
<th>First Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
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</thead>
<tbody>
<tr>
<td>PHYS 13100</td>
<td>PHYS 13200</td>
<td>ASTR 13300</td>
<td></td>
</tr>
<tr>
<td>MATH 18300</td>
<td>MATH 18400</td>
<td>PHYS 13300</td>
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<tr>
<td></td>
<td></td>
<td>MATH 18500</td>
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<table>
<thead>
<tr>
<th>Second Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 21000</td>
<td>ASTR 21100</td>
<td>ASTR 21200</td>
<td></td>
</tr>
<tr>
<td>MATH 18600</td>
<td>PHYS 22500</td>
<td>ASTR 29800</td>
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</table>
Third Year
Autumn Quarter Winter Quarter
ASTR 25400 ASTR 24100
PHYS 23410 (Elective)

Fourth Year
Autumn Quarter Winter Quarter
ASTR 25000 (Elective) ASTR 29800

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 PHYS 21100 ASTR 21200
MATH 18400 MATH 18500 ASTR 29800

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

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

Third Year
Winter Quarter
ASTR 25400
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 Field Course in Astronomy and Astrophysics I 200
& ASTR 29002 and Field Course in Astronomy and Astrophysics II
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
Relativity will be placed in historical context, including a review of observational confirmation of predictions of which they are observed; and frontier areas of research. The development of Albert Einstein’s theory of General neutron stars, and white dwarf stars; their effects on surrounding matter and light; the astrophysical contexts in extraordinarily complex. This course will survey the physics of space and time; the nature of black holes, are mathematically the most perfectly understood of any physical structure, but their visible effects can be allowing physical theory to be tested in the most exotic and extreme environment in the universe. Black holes The past decade has seen the stunning discovery of gravitational waves from black holes merging together, ASTR 12610. Black Holes. 100 Units. Equivalent Course(s): PHSC 12600 Instructor(s): Paolo Privitera Terms Offered: Autumn the course, students will not be expected to employ mathematics beyond algebra. (L) quantitative theory grounded in precise experiments. Although quantitative analysis will be an important part of this course in the past have found it beneficial to bring their own laptops to class if they have them. 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 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 10800 or PHSC 12700
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 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 12600
Equivalent Course(s): PHSC 12700

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
This 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

Prerequisite(s): None

Terms Offered: Spring
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 Kratsov 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. Equivalent Course(s): CHEM 21400, CMSC 21400, ASTR 31400, PHYS 21400, PSMS 31400

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): CHEM 21400, CMSC 21400, ASTR 31400, PHYS 21400, PSMS 31400

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, GEOS 32060, ASTR 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 of 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): KNOW 37011, CHSS 37011, GNSE 23162, HIPS 27011, 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.
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): HIST 35305, SALC 39000, CHSS 39001, HIPS 27010, ASTR 39000, KNOW 39000

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 29000.

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.