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 (http://collegecatalog.uchicago.edu/thecollege/physicalsciences/) 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. 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.

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 or MATH 20250 and MATH 18400-18500. Students invited to take the MATH 20700-20800-20900 sequence may also use it as a substitution for MATH 18300-18400-18500-18600.

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:

MATH 15100-15200 Calculus I-II 200
MATH 16100-16200 Honors Calculus I-II

Total Units 400

MAJOR

ASTR 13300 Introduction to Astrophysics § 100

MATH 18300-18400-18500-18600 Mathematical Methods in the Physical Sciences I-II-III-IV 400
<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>ASTR 20500</td>
<td>Introduction to Python Programming with Applications to Astro Statistics</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>One of the following:</td>
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<td>100</td>
</tr>
<tr>
<td>PHYS 22500</td>
<td>Intermediate Electricity and Magnetism I</td>
<td></td>
</tr>
<tr>
<td>PHYS 23410</td>
<td>Quantum Mechanics I</td>
<td></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>
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<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>
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<tr>
<td>ASTR 25800</td>
<td>Astrophysics of Exoplanets</td>
<td></td>
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<tr>
<td>ASTR 23900</td>
<td>Physics of Galaxies</td>
<td></td>
</tr>
<tr>
<td>ASTR 24300</td>
<td>Cosmological Physics</td>
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</tr>
<tr>
<td>Two electives to be selected from list of approved courses</td>
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</table>

Total Units 1600

* Credit may be granted by examination.

‡ Students who matriculated prior to Autumn 2018 may substitute any 20000-level ASTR course for ASTR 13300.

SUMMARY OF REQUIREMENTS FOR THE BS IN ASTROPHYSICS (PHYSICS VARIANT)

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>
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<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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Total Units 400

MAJOR

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Units</th>
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</thead>
<tbody>
<tr>
<td>ASTR 13300</td>
<td>Introduction to Astrophysics §</td>
<td>100</td>
</tr>
<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 20500</td>
<td>Introduction to Python Programming with Applications to Astro Statistics</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 23410 &amp; PHYS 23510</td>
<td>Quantum Mechanics I and Quantum Mechanics II †</td>
<td>200</td>
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<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>PHYS 27900</td>
<td>Statistical and Thermal Physics</td>
<td>100</td>
</tr>
<tr>
<td>One of the following:</td>
<td></td>
<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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</tbody>
</table>

Total Units 1800

* Credit may be granted by examination.

‡ Students who matriculated prior to Autumn 2018 may substitute any 20000-level ASTR course for ASTR 13300.
† Students in the BS in Astrophysics (Physics Variant) who matriculated prior to Autumn 2020 and who have already completed PHYS 15400 Modern Physics and PHYS 23400 Quantum Mechanics I are not required to take PHYS 23510 Quantum Mechanics II.

**SUMMARY OF REQUIREMENTS FOR THE BS IN ASTROPHYSICS (CHEMISTRY VARIANT)**

**GENERAL EDUCATION**

CHEM 11100-11200 Comprehensive General Chemistry I-II (or equivalent) ††

One of the following sequences:

- 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**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>ASTR 13300</td>
<td>Introduction to Astrophysics</td>
<td>100</td>
</tr>
<tr>
<td>PHYS 13100-13200-13300</td>
<td>Mechanics; Electricity and Magnetism; Waves, Optics, and Heat (or higher)</td>
<td>300</td>
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<tr>
<td>MATH 18300-18400-18500</td>
<td>Mathematical Methods in the Physical Sciences I-II-III</td>
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<tr>
<td>CHEM 11300</td>
<td>Comprehensive General Chemistry III</td>
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<tr>
<td>ASTR 20500</td>
<td>Introduction to Python Programming with Applications to Astro Statistics</td>
<td>100</td>
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<tr>
<td>ASTR 21100</td>
<td>Computational Techniques in Astrophysics</td>
<td>100</td>
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<tr>
<td>ASTR 21200</td>
<td>Observational Techniques in Astrophysics</td>
<td>100</td>
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<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>
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<tr>
<td>ASTR 24100</td>
<td>The Physics of Stars</td>
<td>100</td>
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<tr>
<td>CHEM 26100</td>
<td>Quantum Mechanics</td>
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<tr>
<td>CHEM 26200</td>
<td>Thermodynamics</td>
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</table>

One of the following:

- ASTR 25800 | Astrophysics of Exoplanets | 100 |
- ASTR 23900 | Physics of Galaxies | 100 |
- ASTR 24300 | Cosmological Physics | 100 |

One elective to be selected from list of approved courses: 100

Total Units: 1800

† Credit may be granted by examination.

†† CHEM 10100-10200 Introductory General Chemistry I-II and CHEM 12100-12200 Honors General Chemistry I-II also satisfy this requirement. Enrollment into a particular sequence is based on chemistry placement or AP score. Students should consult with the Department of Chemistry regarding Advanced Placement and Accreditation Examinations.

**SAMPLE PROGRAMS**

The sample programs below illustrate different paths for fulfilling requirements for the Astrophysics major. Students starting in mathematics courses other than MATH 15100 and MATH 18300 should consult with the Academic Affairs Administrator in Astronomy and Astrophysics regarding the best path through the major.

**BA in Astrophysics starting with MATH 15100**

<table>
<thead>
<tr>
<th>First Year</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
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<tbody>
<tr>
<td>Autumn Quarter</td>
<td>PHYS 13100</td>
<td>ASTR 13300</td>
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<tr>
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<table>
<thead>
<tr>
<th>Second Year</th>
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<tbody>
<tr>
<td>Autumn Quarter</td>
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<td>ASTR 21100</td>
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<tr>
<td>MATH 18400</td>
<td>MATH 18500</td>
<td>MATH 18600</td>
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<table>
<thead>
<tr>
<th>Third Year</th>
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<tbody>
<tr>
<td>PHYS 22500</td>
<td>Elective</td>
<td>Elective</td>
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</table>
Fourth Year
Autumn Quarter
ASTR 25400
Winter Quarter
ASTR 24100
ASTR 25800

BA in Astrophysics starting with MATH 18300

First Year
Autumn Quarter
PHYS 14100
PHYS 18300
Winter Quarter
PHYS 14200
MATH 18400
Spring Quarter
ASTR 13300
ASTR 14300
MATH 18500

Second Year
Autumn Quarter
ASTR 20500
MATH 18600
Winter Quarter
ASTR 21200
PHYS 23410
Spring Quarter
ASTR 21100
ASTR 29800

Third Year
Autumn Quarter
ASTR 25400
Winter Quarter
ASTR 24100
Spring Quarter
Elective

Fourth Year
Winter Quarter
Elective

BS in Astrophysics (Physics Variant) starting with MATH 15100

First Year
Autumn Quarter
PHYS 13100
PHYS 18300
Winter Quarter
PHYS 13200
MATH 15200
Spring Quarter
ASTR 13300
ASTR 13300
MATH 18300

Second Year
Autumn Quarter
ASTR 20500
MATH 18600
Winter Quarter
ASTR 21200
PHYS 23410
Spring Quarter
ASTR 21100
ASTR 29800
MATH 18600

Third Year
Winter Quarter
PHYS 23410
Elective
Spring Quarter
PHYS 23510
Elective

Fourth Year
Autumn Quarter
ASTR 25400
Winter Quarter
ASTR 24100
Spring Quarter
ASTR 24300

BS in Astrophysics (Physics Variant) starting with MATH 18300

First Year
Autumn Quarter
PHYS 13100
PHYS 18300
Winter Quarter
PHYS 13200
MATH 18400
Spring Quarter
ASTR 13300
ASTR 14300
MATH 18500

Second Year
Autumn Quarter
ASTR 20500
MATH 18600
Winter Quarter
ASTR 21200
PHYS 23410
Spring Quarter
ASTR 21100
ASTR 29800
PHYS 23510

Third Year
Autumn Quarter
ASTR 25400
Winter Quarter
ASTR 24100
Spring Quarter
Elective

Fourth Year
Winter Quarter
Elective
Spring Quarter

BS in Astrophysics (Chemistry Variant) starting with MATH 15100

First Year
Autumn Quarter
CHEM 11100
MATH 15100
Winter Quarter
CHEM 11200
MATH 15200
Spring Quarter
ASTR 13300
CHEM 11300
MATH 18300
### BS in Astrophysics (Chemistry Variant) starting with MATH 18300

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<tbody>
<tr>
<td>CHEM 11100</td>
<td>CHEM 11200</td>
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<td>MATH 18500</td>
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<tr>
<td>MATH 18300</td>
<td>MATH 18400</td>
<td>CHEM 11300</td>
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<table>
<thead>
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<th>Second Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
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<tbody>
<tr>
<td>PHYS 14100</td>
<td>PHYS 14200</td>
<td>PHYS 14300</td>
<td></td>
</tr>
<tr>
<td>ASTR 20500</td>
<td>ASTR 21200</td>
<td>ASTR 29800</td>
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<table>
<thead>
<tr>
<th>Third Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 25400</td>
<td></td>
<td>ASTR 24100</td>
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<table>
<thead>
<tr>
<th>Fourth Year</th>
<th>Autumn Quarter</th>
<th>Winter Quarter</th>
<th>Spring Quarter</th>
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<tbody>
<tr>
<td>CHEM 26100</td>
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<tr>
<td>ASTR 29800</td>
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#### ELECTIVES

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<thead>
<tr>
<th>Course</th>
<th>Title</th>
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<tbody>
<tr>
<td>ASTR 21300</td>
<td>Origin and Evolution of the Solar System</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 21400</td>
<td>Creative Machines and Innovative Instrumentation</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 25000</td>
<td>Order-of-Magnitude Astrophysics</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 28500</td>
<td>Science with Large Astronomical Surveys</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 29001</td>
<td>Field Course in Astronomy and Astrophysics I</td>
<td>100</td>
</tr>
<tr>
<td>&amp; ASTR 29002</td>
<td>Field Course in Astronomy and Astrophysics II</td>
<td>200</td>
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<tr>
<td>ASTR 30100</td>
<td>Stars</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 30300</td>
<td>Interstellar Matter</td>
<td>100</td>
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<tr>
<td>ASTR 30400</td>
<td>Galaxies</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 30600</td>
<td>Detection of Radiation</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 31000</td>
<td>Cosmology I</td>
<td>100</td>
</tr>
<tr>
<td>ASTR 31100</td>
<td>High Energy Astrophysics</td>
<td>100</td>
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<tr>
<td>GEOS 22040</td>
<td>Planet Formation in the Galaxy I: From Dust to Planetesimals</td>
<td>100</td>
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<tr>
<td>GEOS 22050</td>
<td>Planet Formation in the Galaxy II: From Planetesimals to Planets</td>
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<tr>
<td>GEOS 22060</td>
<td>What Makes a Planet Habitable?</td>
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<tr>
<td>PHYS 22600</td>
<td>Electronics</td>
<td>100</td>
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<tr>
<td>PHYS 23410</td>
<td>Quantum Mechanics I (BA in Astrophysics students who take PHYS 22500 may use PHYS 23410 as an elective.)</td>
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<tr>
<td>PHYS 23510</td>
<td>Quantum Mechanics II (Only BA in Astrophysics students may use PHYS 23510 as an elective.)</td>
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<tr>
<td>PHYS 26000</td>
<td>Fluid Dynamics</td>
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<tr>
<td>PHYS 26400</td>
<td>Spacetime and Black Holes</td>
<td>100</td>
</tr>
<tr>
<td>PHYS 26500</td>
<td>Topics in General Relativity and Cosmology</td>
<td>100</td>
</tr>
</tbody>
</table>

Other courses may be approved as electives by the Deputy Chair for Academic Affairs in Astronomy and Astrophysics.
Instructor(s): TBD Terms Offered: Summer

This course in the past have found it beneficial to bring their own laptops to class if they have them.

We will collect our own measurements of stellar properties, such as the temperatures and luminosities of stars, radiation interacts with matter - and apply these principles to further our understanding of stellar structure.

Of this crucial breakthrough. We will review the physical principles - gravity, pressure, radiation, and how a white dwarf, a neutron star, or a black hole. This course introduces you to the concepts behind and applications they create heavier nuclei from lighter nuclei in their centers, and how they evolve from birth to death, ending as observe is radiation from their outer atmospheres. This theory also helps us determine how old stars are, how

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): TBD 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.**  
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): Fausto Cattaneo (Summer Quarter); Craig Hogan (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): Dan Hooper  
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): Jeffrey McMahon (Winter Quarter); Paolo Privitera (Paris Astronomy Program, Spring Quarter)

Terms Offered: Spring Winter. Paris Astronomy Program, Spring 2023

Prerequisite(s): PHYS 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 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. Students intending to pursue the BS in Astrophysics Chemistry Variant may enroll without PHYS 13300.

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

Note(s): 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). Not recommended for students who have taken ASTR/PHSC 12720 Exoplanets.

Equivalent Course(s): PHSC 18000

ASTR 18100. The Milky Way. 100 Units.

Within a largely empty universe, we live in a vast stellar “island” that we call the Milky Way. As we survey the stellar and interstellar components of the Milky Way—the distribution and motions of stars and interstellar gas, and how these dynamic, ever-changing components interact with each other during their life cycles inside the Milky Way—we will follow the path of ancient astronomers, wonder at their mistakes and prejudices, and form our own understanding.

Instructor(s): Nick Gnedin Terms Offered: 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): PHSC 18100
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 are often taught. We will explore the deeper, abstract connections that
unite the two subjects, and through understanding beautiful things in nature as both scientific and artistic, 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 18900. Mapping the Heavens: Early Astronomical Surveys. 100 Units.
The science of astronomy has been characterized as establishing "our place in the Universe." The stars we see in
the night sky seem to extend indefinitely. Are they organized in some kind of structure? How far out do they go?
What lies beyond the stars? Questions like these motivated much of the work at observatories in the years from
1890 to 1920. Thanks to technological advances in telescopes and photography during this period, significant
progress was made in constructing maps that located the Solar System with respect to the surrounding "system
of the stars." In this class we will explore the historical development of understanding the arrangement of things
in space using resources that were available to the practitioners at the time: original photographic glass plates
(mostly digitized files); star catalogs and maps; and scientific publications. To the extent possible, we will try to
understand how the science looked from the perspective of astronomers a hundred years ago. Along the way we
will study aspects that confounded astronomers then, most importantly the nature of the "spiral nebulae" (spiral
galaxies), and how the "nebular system" (large-scale structure in the galaxy distribution) related to the "sidereal
system" (the Milky Way).
Instructor(s): Rich Kron Terms Offered: Spring. Paris Astronomy Program, Spring 2023
Prerequisite(s): 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 18900, HIPS 18900

ASTR 20500. Introduction to Python Programming with Applications to Astro Statistics. 100 Units.
The course will introduce students to programming using Python language and will review basic code elements
and data structures commonly used in Python. It will introduce Python libraries, such as numpy and scipy and
the concepts of vector operations that greatly aid scientific computations with Python. Plotting of graphs and
data using Matplotlib library will also be introduced. Programming techniques will be illustrated and applied to
basic statistical concepts that are used in astronomical research.
Instructor(s): Andrey Kratsov Terms Offered: Autumn
Prerequisite(s): Placement into MATH 15100 or higher, or by consent.

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: Spring
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: Winter
Prerequisite(s): ASTR 13300 or consent of instructor. ASTR 20500 or CMSC 12100 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): PHYH 12200 or PHYH 13200 or PHYH 14200; or CMSC 12100 or CMSC 12200 or CMSC 12300; or consent of instructor.
Equivalent Course(s): CHEM 21400, ASTR 31400, PSMS 31400, CMSC 21400, PHYH 21400

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: TBD
Prerequisite(s): PQ: Third- or fourth-year standing
Equivalent Course(s): BPRO 25800, SOCI 30531, ASTR 31700, SOCI 20531, KNOW 21700

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): Edwin Kite Terms Offered: Winter
Equivalent Course(s): GEOS 32060, GEOS 22060, ASTR 32060

ASTR 23500. Historical Highlights in Astronomy from Hipparcos to Hubble. 100 Units.
This course will focus on important developments in our understanding of the universe from ancient Greeks to modern Geeks, taught from the perspective of a scientist. Even more interesting than the advances were the missteps and false assumptions that impeded progress. The course grade will be based on a 45-minute presentation about a relevant person or historical discovery. Instructor(s): Edward Kolb Terms Offered: Winter
Equivalent Course(s): ASTR 33500

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: Autumn
Prerequisite(s): ASTR 24100 and PHYH 23400 or PHYH 23410 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): Daniel Fabrycky Terms Offered: Winter
Prerequisite(s): ASTR 25400 or PHYH 23400 or PHYH 23410 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 and PHYH 23400 or PHYH 23410 or consent of instructor. PHYH 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 and PHYS 23400 or PHYS 23410, or consent of instructor. 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): MATH 18400 or MATH 18500 (recommended) and PHYS 22500 or PHYS 23400 or PHYS 23410 or consent of instructor.

ASTR 25800. Astrophysics of Exoplanets. 100 Units.
Extrasolar planets, a.k.a. exoplanets, are planets orbiting other stars. First definitively detected in the mid 1990s, the planet count has rapidly expanded and their physical characterization has sharpened with improved observational techniques. Theoretical studies of planetary formation and evolution are now attempting to understand this statistical sample. The field also aspires to address questions about life in the universe. This course emphasizes hands-on activities, like working with real astronomical data to find and characterize exoplanets. Topics are the radial velocity, transit, and other discovery and characterization techniques; statistical distributions of known planets; comparisons among planet structure and planetary system types; formation in a protoplanetary disk and subsequent dynamical evolution; the goal of finding life on an exoplanet; colonization of exoplanets; and the Fermi paradox.
Instructor(s): Jacob Bean Terms Offered: Spring
Prerequisite(s): ASTR 24100 and PHYS 23400 or PHYS 23410 or consent of instructor.
Equivalent Course(s): GEOS 32080

ASTR 25000. 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
Prerequisite(s): ASTR 13300 and (ASTR 20500 or CMSC 12100); ASTR 21100 and ASTR 21200 recommended; third- or fourth-year standing in the College or by consent of instructor.

ASTR 28700. Cosmic Evolution of Information. 100 Units.
The course will assemble a concise narrative of how physics and cosmology explain ubiquitous cosmic structure, complexity, and arrows of time. The cosmic evolution of macroscopic and microscopic information will be reviewed, including the distinct and unique roles of quantum mechanics and gravity. Readings will be chosen first to address what is explained by well-established thermodynamics, quantum theory, general relativity, and inflationary cosmology, and then turn to still-unresolved foundational tensions among theories, such as the relationship of gravity and causal structure with quantum nonlocality and indeterminacy, and to physical constraints on future evolution. The course will be conducted as a seminar, with significant student participation in discussion and presentation. It is designed as a graduate elective, but is open to undergraduates with adequate preparation in thermodynamics, quantum mechanics, and relativity.
Instructor(s): Craig Hogan Terms Offered: Winter
Prerequisite(s): Open to undergraduates with adequate preparation in thermodynamics, quantum mechanics, and relativity.
Equivalent Course(s): ASTR 38700

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.
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 with an instructor in advance of the start of the term before enrolling. Contact the Academic Affairs Administrator in Astronomy and Astrophysics for more information.
Terms Offered: Autumn Spring Summer Winter
Prerequisite(s): Third- or fourth-year standing and consent of instructor. Students must submit a completed Reading and Research Course Form to the Academic Affairs Administrator in Astronomy and Astrophysics before instructor consent will be given.
Note(s): 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 Astronomy and Astrophysics to acquaint students with possibilities for research participation.
Instructor(s): Clarence Chang Terms Offered: Spring
Prerequisite(s): ASTR 13300 and (ASTR 20500 or CMSC 12100) and ASTR 21200; or consent of instructor.
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.