Astronomy is, at once, the oldest science and one of the most vibrant fields of modern research. Its goal is to construct testable, quantitative, coherent models of the universe (the UNIty of the diVERSE) and its contents—galaxies, stars, and planets. The department offers two majors, both of which require a solid grounding in the mathematics and physics necessary for the pursuit of the discipline.

The astrophysics major is designed as preparation for graduate study and consists of a standard physics major sequence; a yearlong introduction to astrophysics (typically taken in the sophomore year, but open to first-years with adequate preparation in calculus and physics); and two required courses covering advanced topics in astronomy. Research, in the form of summer internships and/or term-time independent projects, which can lead to a senior thesis, is strongly encouraged. For a research thesis, students should enroll in the parallel, two-semester sequence \textit{ASTR UN3997-ASTR UN3998 INDEPENDENT RESEARCH}, preferably in their senior year. Students begin the research project in the fall and complete the written thesis in the spring.

The astronomy major provides a basis for further study in the field, but is also designed to be compatible with liberal arts students who pursue other careers and those wishing to combine astronomy with related sciences other than physics, such as chemistry or geology. It requires only two physics courses beyond the introductory sequence and can be completed easily if begun in the sophomore year.

The department offers numerous introductory astronomy courses at the 1000-level that do not have prerequisites. The calculus-based \textit{ASTR UN2001 INTRO TO ASTROPHYSICS I - ASTR UN2002 INTRO TO ASTROPHYSICS II} sequence is recommended for astronomy majors and concentrators and is required for astrophysics majors. Most 3000-level courses, as well as \textit{ASTR GU4260 MODELING THE UNIVERSE}, are offered every other year. Students should inquire with the director of undergraduate studies if they have specific questions on the course schedule. \textit{ASTR UN3996 Current Research in Astrophysics} is a one-point course offered in the fall, designed to introduce majors to research methods and topics. It requires students to attend the department colloquia and a seminar designed to help students understand the colloquium topic. The 3000-level courses need not be taken in any particular order.

### Professors
James Applegate  
Greg Bryan (Chair)  
Zoltan Haiman  
Jules P. Halpern (emeritus)  
David J. Helfand  
Kathryn Johnston  
Laura Kay (Barnard)  
Jeremiah P. Ostriker  
Frederik B. S. Paerels  
Joseph Patterson  
Mary E. Putman  
David Schiminovich  
Jacqueline van Gorkom (emeritus)

### Associate Professor
Marcel Aguiers  
David Kipping  
Lorenzo Sironi

### Assistant Professors
Melissa K. Ness  
Jane Huang

### Adjunct Professor
Michael Allison (GISS)  
Mordecai-Mark MacLow (Hayden Planetarium)  
Rebecca Oppenheimer (Hayden Planetarium)  
Michael Shara (Hayden Planetarium)  
Ruth Angus (Hayden Planetarium)

### Senior Lecturer

### On Leave
Profs. Patterson, Schiminovich, Zoltan (Fall 2022)

### Guidelines for all Astronomy Majors, Concentrators, and Interdepartmental Majors
Courses in which the grade of D has been received do not count toward the major or concentration requirements.

### Major in Astronomy
The major requirements, to be planned with the director of undergraduate studies, are as follows:

**Mathematics**
- Calculus sequence through MATH UN1202 Calculus IV or MATH UN1208 Honors Mathematics IV

**Astronomy**
- Select one of the following options:
  - **Option 1:**
    - Two 3-point 1000-level astronomy courses
    - 12 points in astronomy at the 2000-level or above
  - **Option 2:**
    - \textit{ASTR UN2001 INTRO TO ASTROPHYSICS I - ASTR UN2002 INTRO TO ASTROPHYSICS II}
    - 9 points in astronomy at the 3000-level or above

**Physics**
- Select one of the following physics sequences:
  - **Sequence 1:**
PHYS UN1401  - PHYS UN1402  - PHYS UN1403  
INTRO TO MECHANICS # THERMO 
and INTRO ELEC/MAGNETSM # OPTCS 
and INTRO-CLASSCL # QUANTUM WAVES

Sequence 2:
PHYS UN1601  - PHYS UN1602  - PHYS UN2601  
PHYSICS I:MECHANICS/RELATIVITY 
and PHYSICS II: THERMO, ELEC # MAG 
and PHYSICS III:CLASS/QUANTUM WAVE

Sequence 3:
PHYS UN2801  - PHYS UN2802  
ACCELERATED PHYSICS I 
and ACCELERATED PHYSICS II

Additional Physics Courses  
Two physics courses at the 3000-level or above

Students contemplating graduate study are advised to include at least two of these physics courses:

PHYS UN3003  MECHANICS
PHYS UN3007  ELECTRICITY-MAGNETISM
PHYS GU4021  QUANTUM MECHANICS I 
- PHYS GU4022  QUANTUM MECHANICS II

One of these may be substituted for 3 points of astronomy.

Major in Astrophysics

Students considering an Astrophysics major are encouraged to meet with the director of undergraduate studies. If possible, it is useful to start the physics sequence in the first year.

Mathematics
Calculus sequence through MATH UN1202 Calculus IV or MATH UN1208 Honors Mathematics IV

Astronomy
ASTR UN2001  - ASTR UN2002  
INTRO TO ASTROPHYSICS I 
and INTRO TO ASTROPHYSICS II

6 points in astronomy at the 3000-level or above

Physics
Select one of the following physics sequences:

Sequence 1:
PHYS UN1401  - PHYS UN1402  - PHYS UN1403  
INTRO TO MECHANICS # THERMO 
and INTRO ELEC/MAGNETSM # OPTCS 
and INTRO-CLASSCL # QUANTUM WAVES

Sequence 2:
PHYS UN1601  - PHYS UN1602  - PHYS UN2601  
PHYSICS I:MECHANICS/RELATIVITY 
and PHYSICS II: THERMO, ELEC # MAG 
and PHYSICS III:CLASS/QUANTUM WAVE

Sequence 3:
PHYS UN2801  - PHYS UN2802  
ACCELERATED PHYSICS I 
and ACCELERATED PHYSICS II

Additional Physics Courses  
PHYS UN3003  MECHANICS
PHYS UN3007  ELECTRICITY-MAGNETISM
PHYS UN3008  ELECTROMAGNETIC WAVES # OPTICS
PHYS GU4021  QUANTUM MECHANICS I 
- PHYS GU4022  QUANTUM MECHANICS II

Or

PHYS BC3006  QUANTUM PHYSICS 
- PHYS GU4023  and THERMAL # STATISTICAL PHYSICS

Concentration in Astronomy

An extra 3 points of physics can substitute for 3 points of astronomy, as long as the course submitted is at the equivalent or higher level. The concentration requirements are as follows:

Mathematics
9 points of mathematics

Astronomy
15 points of astronomy, nine of which must be at or above the 2000-level

Physics
9 points of physics

Fall 2023

ASTR UN1403 EARTH, MOON, AND PLANETS.  3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: recommended preparation: a working knowledge of high school algebra.
Prerequisites: recommended preparation: a working knowledge of high school algebra. The overall architecture of the solar system. Motions of the celestial sphere. Time and the calendar. Major planets, the earth-moon system, minor planets, comets. Life in the solar system and beyond. This course is similar to ASTR BC 1753. You cannot enroll in both courses and receive credit for both.

Spring 2023: ASTR UN1403

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<tbody>
<tr>
<td>ASTR 1403</td>
<td>001/11866</td>
<td>M W 8:40am - 9:55am</td>
<td>David Helfand</td>
<td>3.00</td>
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Fall 2023: ASTR UN1403

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</table>

ASTR UN1420 Galaxies and Cosmology.  3 points.
CC/GS: Partial Fulfillment of Science Requirement

Galaxies contain stars, gas dust, and (usually) super-massive black holes. They are found throughout the Universe, traveling through space and occasionally crashing into each other. This course will look at how these magnificent systems form and evolve, and what they can tell us about the formation and evolution of the Universe itself. You cannot enroll in ASTR UN1420 in addition to ASTR BC 1754 or ASTR UN1404 and receive credit for both.

Fall 2023: ASTR UN1420

<table>
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<tr>
<th>Course Number</th>
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<th>Instructor</th>
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<td>Mary Putman</td>
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</table>
ASTR UN1453 ANOTHER EARTH. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
This course cannot be taken for credit if BC1753 has been taken.

This course will explore the unique properties of Earth, compared to other planets in the Solar System, and the possibility of Earth-like planets around other stars. The basics of the Solar System, gravity, and light will be covered, as well as the geology and atmospheres of the terrestrial planets. The properties of Earth that allowed life to develop and whether life can develop on other planets will be discussed. Finally, the discovery of planets beyond our Solar System and the likelihood of another Earth will be a key component of the course.

Spring 2023: ASTR UN1903
Course Number  Section/Call  Times/Location  Instructor  Points  Enrollment
ASTR 1903  001/12452  T Th 10:10am - 11:25am  601 Fairchild Life Sciences Bldg  David Kipping  3.00  39/60

ASTR UN1836 STARS AND ATOMS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: recommended preparation: a working knowledge of high school algebra.

Prerequisites: recommended preparation: a working knowledge of high school algebra. What is the origin of the chemical elements? This course addresses this question, starting from understanding atoms, and then going on to look at how atoms make stars and how stars make atoms. The grand finale is a history of the evolution of the chemical elements throughout time, starting from the Big Bang and ending with YOU. You cannot enroll in ASTR UN1836 in addition to ASTR BC1754 or ASTR UN1404 and receive credit for both.

Spring 2023: ASTR UN1836
Course Number  Section/Call  Times/Location  Instructor  Points  Enrollment
ASTR 1836  001/11571  T Th 8:40am - 9:55am  517 Hamilton Hall  Kathryn Johnston  3.00  71/80

ASTR UN1904 ASTRONOMY LAB II. 1.00 point.
Laboratory for ASTR UN1404. Projects include use of telescopes, laboratory experiments in the nature of light, spectroscopy, and the analysis of astronomical data. Lab 2 ASTR UN1904 - goes with ASTR BC1754 or ASTR UN1404 (or ASTR UN1836 or ASTR UN1420)

Spring 2023: ASTR UN1904
Course Number  Section/Call  Times/Location  Instructor  Points  Enrollment
ASTR 1904  002/00444  T 7:00pm - 10:00pm  Room TBA  Laura Kay, Ryan Golant, Jennifer Mead  1.00  11/16

ASTR UN2001 INTRO TO ASTROPHYSICS I. 3.00 points.
Prerequisites: a working knowledge of calculus. Corequisites: a course in calculus-based general physics. First term of a two-term calculus-based introduction to astronomy and astrophysics. Topics include the physics of stellar interiors, stellar atmospheres and spectral classifications, stellar energy generation and nucleosynthesis, supernovae, neutron stars, white dwarfs, and interacting binary stars.

Spring 2023: ASTR UN2001
Course Number  Section/Call  Times/Location  Instructor  Points  Enrollment
ASTR 2001  001/12456  M W 2:40pm - 3:55pm  333 Uris Hall  Marcel Agueros  3.00  29/40

ASTR UN2900 FRONTIERS OF ASTROPHYSICS. 1.00 point.
Several members of the faculty each offer a brief series of talks providing context for a current research topic in the field and then present results of their ongoing research. Opportunities for future student research collaboration are offered. Grading is Pass/Fail

Spring 2023: ASTR UN2900
Course Number  Section/Call  Times/Location  Instructor  Points  Enrollment
ASTR 2900  001/12454  F 10:10am - 11:25am  330 Uris Hall  David Helfand  1.00  53/60

ASTR UN3273 HIGH ENERGY ASTROPHYSICS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics. No previous, Astronomy background required.

A survey of the most energetic and explosive objects in the Universe and their radiation. Topics include: techniques of X-ray and gamma-ray astronomy; observations of neutron stars (pulsars) and black holes; accretion disks and relativistic jets; supernovae, supernova remnants, gamma-ray bursts, quasars and active galactic nuclei; clusters of galaxies; cosmic rays and neutrinos.

Spring 2023: ASTR UN3273
Course Number  Section/Call  Times/Location  Instructor  Points  Enrollment
ASTR 3273  001/12458  M W 2:40pm - 3:55pm  825 Seeley W. Mudd Building  Lorenzo Sironi  3.00  16/30

ASTR 3273  001/19016  M W 2:40pm - 3:55pm  825 Seeley W. Mudd Building  Lorenzo Sironi  3.00  5/5
ASTR UN3602 PHYSICAL COSMOLOGY. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics.
Prerequisites: one year of calculus-based general physics. The standard hot big bang cosmological model and modern observational results that test it. Topics include the Friedmann equations and the expansion of the universe, dark matter, dark energy, inflation, primordial nucleosynthesis, the cosmic microwave background, the formation of large-scale cosmic structures, and modern cosmological observations.

Fall 2023: ASTR UN3602

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<th>Course Number</th>
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<th>Instructor</th>
<th>Points</th>
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<td>ASTR 3602</td>
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<td>T Th 2:40pm - 3:55pm</td>
<td>Greg Bryan</td>
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<td>ASTR 3602 AU1</td>
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<td>Greg Bryan</td>
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ASTR UN3997 INDEPENDENT RESEARCH. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: the instructor’s permission. For an independent research project or independent study, a brief description of the proposed project or reading, with the supervising faculty member’s endorsement, is required for registration.
Prerequisites: the instructor’s permission. For an independent research project or independent study, a brief description of the proposed project or reading, with the supervising faculty member’s endorsement, is required for registration. A variety of research projects conducted under the supervision of members of the faculty. Observational, theoretical, and experimental work in galactic and extragalactic astronomy and cosmology. The topic and scope of the work must be arranged with a faculty member in advance; a written paper describing the results of the project is required at its completion (note that a two-term project can be designed such that the grade YC is given after the first term). Senior majors in astronomy or astrophysics wishing to do a senior thesis should make arrangements in May of their junior year and sign up for a total of 6 points over their final two terms. Both a substantial written document and an oral presentation of thesis results are required.

Fall 2023: ASTR UN3997

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<th>Course Number</th>
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<td>ASTR 3997</td>
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<td>M W 8:40am - 9:55am</td>
<td>Melissa Ness</td>
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<td>333 Uris Hall</td>
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ASTR GU4260 MODELING THE UNIVERSE. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics.
Prerequisites: one year of calculus-based general physics. The goal of this course is to provide a basic hands-on introduction to the practice and theory of scientific computing with applications in astronomy and astrophysics. The course will include an introduction to programming, as well as a sampling of methods and tools from the field of scientific computing. The course will include a hands-on project in which students use numerical methods to solve a research problem. Students who are interested in participating in research projects are strongly encouraged to take the course in their sophomore or junior year.

Fall 2023: ASTR GU4260

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<th>Course Number</th>
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<tr>
<td>ASTR 4260</td>
<td>001/12470</td>
<td>T Th 10:10am - 11:25am</td>
<td>Mordecai-Mark</td>
<td>3.00</td>
<td>33/30</td>
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<td>233 Seeley W. Mudd Building</td>
<td>Mac Low</td>
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</table>

ASTR GR6001 RADIATIVE PROCESSES. 3.00 points.
Prerequisites: 3000-level electromagnetic theory and quantum mechanics.
Prerequisites: 3000-level electromagnetic theory and quantum mechanics. Radiation mechanisms and interaction of radiation with matter. Applications of classical and semiclassical radiation theory and atomic physics to astrophysical settings. Radiative transfer, polarization, scattering, line radiation, special relativity, bremsstrahlung, synchrotron radiation, inverse compton scattering, ionization losses, shocks and particle acceleration, plasma processes, atomic structure and spectroscopic terms, radiative transitions and oscillator strengths, curve of growth, molecular spectra.

Fall 2023: ASTR GR6001

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<th>Course Number</th>
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<td>M W 1:10pm - 2:25pm</td>
<td>Frederik Paerels</td>
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ASTR GR9003 RESEARCH SEMINAR I. 3.00 points.
Fall 2023: ASTR GR9003

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<th>Course Number</th>
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<td>ASTR 9003</td>
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<td>M 4:00pm - 5:15pm</td>
<td>Jane Huang</td>
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<td>12/15</td>
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<td>1322 Pupin Laboratories</td>
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Spring 2023

ASTR UN1403 EARTH, MOON, AND PLANETS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: recommended preparation: a working knowledge of high school algebra.
Prerequisites: recommended preparation: a working knowledge of high school algebra. The overall architecture of the solar system. Motions of the celestial sphere. Time and the calendar. Major planets, the earth-moon system, minor planets, comets. Life in the solar system and beyond. This course is similar to ASTR BC 1753. You cannot enroll in both courses and receive credit for both.

Spring 2023: ASTR UN1403

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<th>Course Number</th>
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<th>Instructor</th>
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<tr>
<td>ASTR 1403</td>
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<td>M W 8:40am - 9:55am</td>
<td>David Helfand</td>
<td>3.00</td>
<td>38/60</td>
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ASTR UN1404 STARS, GALAXIES  & COSMOLOGY. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Distances to, and fundamental properties of, nearby stars; nucleosynthesis and stellar evolution; novae and supernovae; galaxies; the structure of the universe and theories concerning its origin, evolution, and ultimate fate. You can only receive credit for ASTR UN1404 if you have not taken ASTR BC1754, ASTR UN1420 or ASTR UN1836.

Spring 2023: ASTR UN1404

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<tr>
<th>Course Number</th>
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<td>James Applegate</td>
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</table>
ASTR UN1610 THEOR-UNIVERS: BABYLON-BIG BANG. 3.00 points.  
CC/GS: Partial Fulfillment of Science Requirement

Milestones in the science of cosmology over the past 6000 years. Skylore and observation in ancient cultures. The twin revolutions of the Greeks: Pythagoras and Ptolemy; and Aristotle, Aquinas, and the Great Chain of Being. The scientific revolution: the impersonal and deterministic world-order of Newton, Laplace, and Kelvin. The erosion of that world-order by mathematics and experiment in the 20th century (relativity, quantum physics, dark matter, and the expanding universe). Todays searches for a new grand order in the Universe, which can cope - or maybe not - with these blows to yesterdays comfortable wisdom.

Spring 2023: ASTR UN1610

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<th>Course Number</th>
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<td>ASTR 1610</td>
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<td>Joseph Patterson</td>
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ASTR BC1753 LIFE IN THE UNIVERSE. 3.00 points.

An introductory course intended primarily for nonscience majors. This interdisciplinary course focuses on the subject of Life in the Universe. We will study historical astronomy, gravitation and planetary orbits, the origin of the chemical elements, the discoveries of extrasolar planets, the origin of life on Earth, the evolution and exploration of the Solar System, global climate change on Venus, Mars and Earth, and the Search for Extraterrestrial Life (SETI). You cannot receive credit for this course and for ASTR UN1403 or ASTR UN1453. Can be paired with the optional Lab class ASTR UN1903.

Spring 2023: ASTR BC1753

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<th>Course Number</th>
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<th>Times/Location</th>
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<td>ASTR 1753</td>
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<td>Laura Kay</td>
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ASTR UN1836 STARS AND ATOMS. 3.00 points.  
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: recommended preparation: a working knowledge of high school algebra.  
Prerequisites: recommended preparation: a working knowledge of high school algebra.  
What is the origin of the chemical elements? This course addresses this question, starting from understanding atoms, and then going on to look at how atoms make stars and how stars make atoms. The grand finale is a history of the evolution of the chemical elements throughout time, starting from the Big Bang and ending with YOU. You cannot enroll in ASTR UN1836 in addition to ASTR BC1754 or ASTR UN1404 and receive credit for both.

Spring 2023: ASTR UN1836

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<th>Course Number</th>
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<th>Times/Location</th>
<th>Instructor</th>
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<th>Enrollment</th>
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<tr>
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<td>001/11571</td>
<td>T Th 8:40am - 9:55am</td>
<td>Kathryn Johnston</td>
<td>3.00</td>
<td>71/80</td>
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Fall 2023: ASTR UN1836

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1836</td>
<td>001/12453</td>
<td>T Th 8:40am - 9:55am</td>
<td>Kathryn Johnston</td>
<td>3.00</td>
<td>42/80</td>
</tr>
</tbody>
</table>

ASTR UN1903 ASTRONOMY LAB I. 1.00 point.  
Laboratory for ASTR UN1403. Projects include observations with the departments telescopes, computer simulation, laboratory experiments in spectroscopy, and the analysis of astronomical data. Lab 1 ASTR UN1903 - goes with ASTR BC1753, ASTR UN1403 or ASTR UN1453

Spring 2023: ASTR UN1903

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 1903</td>
<td>001/00441</td>
<td>M 7:00pm - 10:00pm</td>
<td>Laura Kay, Matthew Scoogins</td>
<td>1.00</td>
<td>16/16</td>
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<tr>
<td>ASTR 1903</td>
<td>002/00442</td>
<td>W 6:00pm - 9:00pm</td>
<td>Laura Kay, Shifra Mandel</td>
<td>1.00</td>
<td>10/16</td>
</tr>
<tr>
<td>ASTR 1903</td>
<td>003/00804</td>
<td>M 6:00pm - 9:00pm</td>
<td>Laura Kay, Soichiro Hattori</td>
<td>1.00</td>
<td>14/16</td>
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Fall 2023: ASTR UN1903

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tbody>
<tr>
<td>ASTR 1903</td>
<td>001/00612</td>
<td>M 6:00pm - 9:00pm</td>
<td>Laura Kay, James Sullivan</td>
<td>1.00</td>
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</tr>
<tr>
<td>ASTR 1903</td>
<td>002/00613</td>
<td>T 7:00pm - 10:00pm</td>
<td>Laura Kay, Michael Messere</td>
<td>1.00</td>
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</table>

ASTR UN1904 ASTRONOMY LAB II. 1.00 point.  
Laboratory for ASTR UN1404. Projects include use of telescopes, laboratory experiments in the nature of light, spectroscopy, and the analysis of astronomical data. Lab 2 ASTR UN1904 - goes with ASTR BC1754 or ASTR UN1404 (or ASTR UN1836 or ASTR UN1420)

Spring 2023: ASTR UN1904

<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<th>Enrollment</th>
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<tbody>
<tr>
<td>ASTR 1904</td>
<td>002/00444</td>
<td>T 7:00pm - 10:00pm</td>
<td>Laura Kay, Ryan Golant, Jennifer Mead</td>
<td>1.00</td>
<td>11/16</td>
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Fall 2023: ASTR UN1904

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
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<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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</thead>
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<tr>
<td>ASTR 1904</td>
<td>001/00614</td>
<td>W 6:00pm - 9:00pm</td>
<td>Laura Kay, Max Lee</td>
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</table>

ASTR UN2002 INTRO TO ASTROPHYSICS II. 3.00 points.

Prerequisites: a working knowledge of calculus. Corequisites: the second term of a course in calculus-based general physics. Continuation of ASTR UN2001; these two courses constitute a full year of calculus-based introduction to astrophysics. Topics include the structure of our galaxy, the interstellar medium, star clusters, properties of external galaxies, clusters of galaxies, active galactic nuclei, and cosmology

Spring 2023: ASTR UN2002

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTR 2002</td>
<td>001/11573</td>
<td>T Th 10:10am - 11:25am</td>
<td>Mary Putman</td>
<td>3.00</td>
<td>23/40</td>
</tr>
</tbody>
</table>
### ASTR UN3101 MODERN STELLAR ASTROPHYSICS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics. Introductory astronomy is not required, but some exposure to astronomy is preferable. In the first half of the course, we will examine the physics of stellar interiors in detail, leading us to develop models of stellar structure and consider how stars evolve. In the second half of the course, we will discuss special topics, such as pre-main sequence evolution, the late stages of stellar evolution, and supernovae and compact objects.

<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tbody>
<tr>
<td>ASTR 3101</td>
<td>001/11574</td>
<td>M W 10:10am - 11:25am</td>
<td>Melissa Ness</td>
<td>3.00</td>
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<tr>
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<td>644 Seeley W. Mudd</td>
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### ASTR UN3646 OBSERVATIONAL ASTRONOMY. 3.00 points.

Prerequisites: one year of general astronomy

Topics include the physics of stellar structure, stellar atmospheres, radiation transport, nucleosynthesis, stellar evolution, star formation, pulsation, interacting binary stars, white dwarfs, and neutron stars.

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<tbody>
<tr>
<td>ASTR 3646</td>
<td>001/11576</td>
<td>Th 7:00pm - 9:30pm</td>
<td>David Schiminovich</td>
<td>3.00</td>
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### ASTR UN3998 INDEPENDENT RESEARCH. 3.00 points.

Prerequisites: the instructor’s permission. For an independent research project or independent study, a brief description of the proposed project or reading, with the supervising faculty member’s endorsement, is required for registration.

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tbody>
<tr>
<td>ASTR 3998</td>
<td>001/11578</td>
<td>M 4:00pm - 5:15pm</td>
<td>Frederik Paerels</td>
<td>3.00</td>
<td>11/15</td>
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### ASTR GU4303 ASTROSTATISTICS. 3.00 points.

Astronomers live in era of “big data”. Whilst astronomers of a century ago collected a handful of photographic plates each night, modern astronomers collect thousands of images encoded by millions of pixels in the same time. Both the volume of data and the ever present desire to dig deeper into data sets has led to a growing interest in the use of statistical methods to interpret observations. This class will provide an introduction to the methods commonly used in understanding astronomical data sets, both in terms of theory and application. It is one six classes the department offers every fourth semester.

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
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<tbody>
<tr>
<td>ASTR 4303</td>
<td>001/11579</td>
<td>T Th 10:10am - 11:25am</td>
<td>David Kipping</td>
<td>3.00</td>
<td>31/40</td>
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<td>644 Seeley W. Mudd</td>
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### ASTR GR6004 STELLAR STRUCTURE & EVOLUTION. 3.00 points.

Topics include the physics of stellar structure, stellar atmospheres, radiation transport, nucleosynthesis, stellar evolution, star formation, pulsation, interacting binary stars, white dwarfs, and neutron stars.

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
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<tbody>
<tr>
<td>ASTR 6004</td>
<td>001/11581</td>
<td>M W 10:00am - 11:25am</td>
<td>Greg Bryan</td>
<td>3.00</td>
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### ASTR GR6005 PHYSICAL COSMOLOGY LEC. 3.00 points.

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tbody>
<tr>
<td>ASTR 6005</td>
<td>001/11583</td>
<td>M W 2:40pm - 3:55pm</td>
<td>Zoltan Haiman</td>
<td>3.00</td>
<td>13/25</td>
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### ASTR GR9004 RESEARCH SEMINAR II. 3.00 points.

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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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<tbody>
<tr>
<td>ASTR 9004</td>
<td>001/11584</td>
<td>M 4:00pm - 5:15pm</td>
<td>Frederik Paerels</td>
<td>3.00</td>
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**All Courses (including those not offered in academic year 2023-2024)**

### ASTR UN1234 UNIVERSAL TIMEKEEPER. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: high school algebra and latent curiosity are assumed. The goal of the course is to illustrate — and perhaps even inculcate — quantitative and scientific reasoning skills. The subject material employed in this task is the study of atoms and their nuclei which, through a wide variety of physical and chemical techniques, can be used to reconstruct quantitatively the past. Following an introduction to atoms, light, and energy, we will explore topics including the detection of art forgeries, the precise dating of archeological sites, a reconstruction of the development of agriculture and the history of the human diet, the history of past climate (and its implications for the future), the history and age of the Earth, and the history of the Universe. The course has no required text. Readings of relevant articles and use of on-line simulations will be required.
ASTR S1403D Earth, Moon, and Planets. 3 points.
Prerequisites: Recommended preparation: a working knowledge of high school algebra.
May be counted toward the science requirement for most Columbia University undergraduate students. The overall architecture of the solar system. Motions of the celestial sphere. Time and the calendar. Major planets, the earth-moon system, minor planets, comets. Life in the solar system and beyond.

ASTR UN1403 EARTH, MOON, AND PLANETS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: recommended preparation: a working knowledge of high school algebra.
Prerequisites: recommended preparation: a working knowledge of high school algebra. The overall architecture of the solar system. Motions of the celestial sphere. Time and the calendar. Major planets, the earth-moon system, minor planets, comets. Life in the solar system and beyond. This course is similar to ASTR BC 1753. You cannot enroll in both courses and receive credit for both

Spring 2023: ASTR UN1403
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1403 001/11866 M W 8:40am - 9:55am 333 Uris Hall David Helfand 3.00 38/60
Fall 2023: ASTR UN1403
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1403 001/12449 T Th 1:10pm - 2:25pm 141 Uris Hall James Applegate 3.00 58/75

ASTR UN1404 STARS, GALAXIES # COSMOLOGY. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Distances to, and fundamental properties of, nearby stars; nucleosynthesis and stellar evolution; novae and supernovae; galaxies; the structure of the universe and theories concerning its origin, evolution, and ultimate fate. You can only receive credit for ASTR UN1404 if you have not taken ASTR BC1754, ASTR UN1420 or ASTR UN1836

Spring 2023: ASTR UN1404
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1404 001/11569 T Th 1:10pm - 2:25pm 330 Uris Hall James Applegate 3.00 52/75

ASTR UN1453 ANOTHER EARTH. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
This course cannot be taken for credit if BC1753 has been taken.

This course will explore the unique properties of Earth, compared to other planets in the Solar System, and the possibility of Earth-like planets around other stars. The basics of the Solar System, gravity, and light will be covered, as well as the geology and atmospheres of the terrestrial planets. The properties of Earth that allowed life to develop and whether life can develop on other planets will be discussed. Finally, the discovery of planets beyond our Solar System and the likelihood of another Earth will be a key component of the course

Fall 2023: ASTR UN1453
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1453 001/12452 T Th 10:10am - 11:25am 601 Fairchild Life Sciences Bldg David Kipping 3.00 39/60

ASTR UN1420 Galaxies and Cosmology. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Galaxies contain stars, gas dust, and (usually) super-massive black holes. They are found throughout the Universe, traveling through space and occasionally crashing into each other. This course will look at how these magnificent systems form and evolve, and what they can tell us about the formation and evolution of the Universe itself. You cannot enroll in ASTR UN1420 in addition to ASTR BC1754 or ASTR UN1404 and receive credit for both

Fall 2023: ASTR UN1420
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1420 001/12451 M W 10:10am - 11:25am 602 Hamilton Hall Mary Putnam 3 64/80

ASTR UN1610 THEOR-UNIVERS:BABYLON-BIG BANG. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Milestones in the science of cosmology over the past 6000 years. Skylore and observation in ancient cultures. The twin revolutions of the Greeks: Pythagoras and Polymny; and Aristotle, Aquinas, and the Great Chain of Being. The scientific revolution: the impersonal and deterministic world-order of Newton, Laplace, and Kelvin. The erosion of that world-order by mathematics and experiment in the 20th century (relativity, quantum physics, dark matter, and the expanding universe). Today’s searches for a new grand order in the Universe, which can cope - or maybe not - with these blows to yesterdays comfortable wisdom

Spring 2023: ASTR UN1610
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1610 001/11570 M W 6:10pm - 7:25pm 329 Pupin Laboratories Joseph Patterson 3.00 60/75

ASTR BC1753 LIFE IN THE UNIVERSE. 3.00 points.
An introductory course intended primarily for non-science majors. This interdisciplinary course focuses on the subject of Life in the Universe. We will study historical astronomy, gravitation and planetary orbits, the origin of the chemical elements, the discoveries of extrasolar planets, the origin of life on Earth, the evolution and exploration of the Solar System, global climate change on Venus, Mars and Earth, and the Search for Extraterrestrial Life (SETI). You cannot receive credit for this course and for ASTR UN1403 or ASTR UN1453. Can be paired with the optional lab class ASTR UN1903

Spring 2023: ASTR BC1753
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1753 001/00095 T Th 2:40pm - 3:55pm 202 Altschul Hall Laura Kay 3.00 98/120

ASTR BC1754 Stars, Galaxies, and Cosmology. 3 points.
Prerequisites: Recommended preparation: A working knowledge of high school algebra.
Corequisites: Suggested parallel laboratory course: ASTR C 1904y. Examines the properties of stars, star formation, stellar evolution and nucleosynthesis, the Milky Way and other galaxies, and the cosmological origin and evolution of the universe. Students may not receive credit for both ASTR BC 1754 and ASTR C1404.
ASTR UN1836 STARS AND ATOMS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: recommended preparation: a working knowledge of high school algebra.
Prerequisites: recommended preparation: a working knowledge of high school algebra. What is the origin of the chemical elements? This course addresses this question, starting from understanding atoms, and then going on to look at how atoms make stars and how stars make atoms. The grand finale is a history of the evolution of the chemical elements throughout time, starting from the Big Bang and ending with YOU. You cannot enroll in ASTR UN1836 in addition to ASTR BC1754 or ASTR UN1404 and receive credit for both

Spring 2023: ASTR UN1836
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1836 001/11571 T Th 8:40am - 9:55am 517 Hamilton Hall Kathryn Johnston 3.00 71/80
Fall 2023: ASTR UN1836
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1836 001/12453 T Th 8:40am - 9:55am 702 Hamilton Hall Kathryn Johnston 3.00 42/80

ASTR UN1903 ASTRONOMY LAB I. 1.00 point.
Laboratory for ASTR UN1403. Projects include observations with the departments telescopes, computer simulation, laboratory experiments in spectroscopy, and the analysis of astronomical data. Lab 1 ASTR UN1903 - goes with ASTR BC1753, ASTR UN1403 or ASTR UN1453

Spring 2023: ASTR UN1903
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1903 001/00441 M 7:00pm - 10:00pm Room TBA Laura Kay Matthew Scoggins 1.00 16/16
ASTR 1903 002/00442 W 6:00pm - 9:00pm Room TBA Laura Kay Shifra Mandel 1.00 10/16
ASTR 1903 003/00804 M 6:00pm - 9:00pm Room TBA Laura Kay Soichiro Hattori 1.00 14/16

Fall 2023: ASTR UN1903
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1903 001/00612 M 6:00pm - 9:00pm 1402 Pupin Laboratories Laura Kay James Sullivan 1.00 12/15
ASTR 1903 002/00613 T 7:00pm - 10:00pm 1402 Pupin Laboratories Laura Kay Michael Messare 1.00 7/15

ASTR UN1904 ASTRONOMY LAB II. 1.00 point.
Laboratory for ASTR UN1404. Projects include use of telescopes, laboratory experiments in the nature of light, spectroscopy, and the analysis of astronomical data. Lab 2 ASTR UN1904 - goes with ASTR BC1754 or ASTR UN1404 (or ASTR UN1836 or ASTR UN1420)

Spring 2023: ASTR UN1904
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1904 002/00444 T 7:00pm - 10:00pm Room TBA Laura Kay Ryan Golant Jennifer Mead 1.00 11/16

Fall 2023: ASTR UN1904
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 1904 001/00614 W 6:00pm - 9:00pm 1402 Pupin Laboratories Laura Kay Max Lee 1.00 13/15

ASTR UN2001 INTRO TO ASTROPHYSICS I. 3.00 points.
Prerequisites: a working knowledge of calculus. Corequisites: a course in calculus-based general physics. First term of a two-term calculus-based introduction to astronomy and astrophysics. Topics include the physics of stellar interiors, stellar atmospheres and spectral classifications, stellar energy generation and nucleosynthesis, supernovae, neutron stars, white dwarfs, and interacting binary stars

Fall 2023: ASTR UN2001
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 2001 001/12456 M W 2:40pm - 3:55pm 333 Uris Hall Marcel Agueros 3.00 29/40

ASTR UN2002 INTRO TO ASTROPHYSICS II. 3.00 points.
Prerequisites: a working knowledge of calculus. Corequisites: the second term of a course in calculus-based general physics. Continuation of ASTR UN2001; these two courses constitute a full year of calculus-based introduction to astrophysics. Topics include the structure of our galaxy, the interstellar medium, star clusters, properties of external galaxies, clusters of galaxies, active galactic nuclei, and cosmology

Spring 2023: ASTR UN2002
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 2002 001/11573 T Th 10:10am - 11:25am 415 Schapiro Cepser Mary Putman 3.00 23/40

ASTR UN2900 FRONTIERS OF ASTROPHYSICS. 1.00 point.
Several members of the faculty each offer a brief series of talks providing context for a current research topic in the field and then present results of their ongoing research. Opportunities for future student research collaboration are offered. Grading is Pass/Fail

Fall 2023: ASTR UN2900
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 2900 001/12454 F 10:10am - 11:25am 330 Uris Hall David Helfand 1.00 53/60
ASTR 2900 AU1/18954 F 10:10am - 11:25am Other Other David Helfand 1.00 6/5

ASTR UN3101 MODERN STELLAR ASTROPHYSICS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics. Introductory astronomy is not required, but some exposure to astronomy is preferable. In the first half of the course, we will examine the physics of stellar interiors in detail, leading us to develop models of stellar structure and consider how stars evolve. In the second half of the course, we will discuss special topics, such as pre-main sequence evolution, the late stages of stellar evolution, and supernovae and compact objects.

Spring 2023: ASTR UN3101
Course Number Section/Call Times/Location Instructor Points Enrollment
ASTR 3101 001/11574 M W 10:10am - 11:25am 644 Seeley W. Mudd Building Melissa Ness 3.00 20/40
ASTR UN3102 Planetary Dynamics and Physics of the Solar System. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based Physics.

ASTR UN3103 GALAXIES. 3.00 points.
Prerequisites: one year of calculus-based general physics.
Prerequisites: one year of calculus-based general physics. Galaxies fill the universe with structure. They are bound objects that harbor stars, gas, dust and dark matter. This course will discuss the content and structure of galaxies. It will start with the Milky Way, a rotating spiral galaxy, with a particular emphasis on the properties of the interstellar medium. Dwarf galaxies, the building blocks of larger galaxies, will subsequently be discussed, followed by spiral, elliptical and irregular galaxies. The formation and evolution of different galaxy types will be an important focus of the course, as well as the environment in which the galaxies reside. We will intersperse reviews of current papers on galaxies throughout the semester

ASTR UN3105 EXTRASOLAR PLANETS # ASTROBIOL. 3.00 points.
Prerequisites: One year of calculus-based physics.
The emerging field of extrasolar planets and astrobiology will be covered at a quantitative level, with a major emphasis on astrophysical phenomena and techniques. The subject will be introduced through an investigation of current planetary formation theories and approaches to planet detection, including what we currently know about extrasolar planets and detailed reference to state-of-the-art studies. An astronomer’s view of the origin of life and extreme biology will be developed and applied to questions of cosmo-chemistry, observable life-signatures, habitable zones and other astrophysical constraints on the development of organisms.

ASTR UN3106 The Science of Space Exploration. 3 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one semester course in introductory astronomy or astrophysics (e.g., ASTR UN1403, ASTR UN1404, ASTR UN1420, ASTR UN1836, ASTR UN2001, ASTR UN2002, ASTR BC1753, ASTR BC1754). Ability in mathematics up to and including calculus is strongly urged. How and why do humans explore space? Why does it require such extraordinary effort? What have we found by exploring our Solar System? We investigate the physics and biological basis of space exploration, and the technologies and science issues that determine what we can accomplish. What has been accomplished in the past, what is being explored now, and what can we expect in the future? How do space scientists explore the Solar System and answer science questions in practice? What do we know about solar systems beyond our own?

ASTR UN3273 HIGH ENERGY ASTROPHYSICS. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics. No previous, astronomy background required.
A survey of the most energetic and explosive objects in the Universe and their radiation. Topics include: techniques of X-ray and gamma-ray astronomy; observations of neutron stars (pulsars) and black holes; accretion disks and relativistic jets; supernovae, supernova remnants, gamma-ray bursts, quasars and active galactic nuclei; clusters of galaxies; cosmic rays and neutrinos.

ASTR UN3602 PHYSICAL COSMOLOGY. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics.
Prerequisites: one year of calculus-based general physics. The standard hot big bang cosmological model and modern observational results that test it. Topics include the Friedmann equations and the expansion of the universe, dark matter, dark energy, inflation, primordial nucleosynthesis, the cosmic microwave background, the formation of large-scale cosmic structures, and modern cosmological observations.

ASTR UN3646 OBSERVATIONAL ASTRONOMY. 3.00 points.
Prerequisites: one year of general astronomy
Prerequisites: one year of general astronomy Introduction to the basic techniques used in obtaining and analysing astronomical data. Focus on ground-based methods at optical, infrared, and radio wavelengths. Regular use of the telescope facilities atop the roof of the Pupin Labs and at Harriman Observatory. The radio-astronomy portion consists mostly of computer labs, In research projects, students also work on the analysis of data obtained at National Observatories.

Spring 2022: ASTR UN3646

<table>
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<tr>
<th>Course Number</th>
<th>Section/Call Number</th>
<th>Times/Location</th>
<th>Instructor</th>
<th>Points</th>
<th>Enrollment</th>
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</thead>
<tbody>
<tr>
<td>ASTR 3646</td>
<td>001/11576</td>
<td>M W 7:00pm - 9:30pm 1402 Pupin Laboratories</td>
<td>David Schiminovich</td>
<td>3.00</td>
<td>26/25</td>
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</table>

ASTR UN3985 Statistics and the Universe (Seminar). 3 points.
Prerequisites: First year calculus required, introductory physics or astronomy
Essential statistical methods will be applied in a series of case studies and research projects taken from the latest advances in cosmology, astronomy and physics. Statistics of measurement and detection, fundamentals of hypothesis testing, classifications, data modeling, time-series analysis, correlation and clustering will be explored through hands-on investigation using data from recent experiments and surveys.
ASTR UN3996 Current Research in Astrophysics. 1 point.
Prerequisites: two semesters of astronomy classes and two semesters of physics classes.
The goal of this course is to introduce astronomy and astrophysics majors to the methods and topics of current astronomical research. The course will also help with the development of critical thinking skills. Each week, the topic of the course will be centered on the subject of the Astronomy department colloquium; this may include research on planets, stars, galaxies or cosmology. There will be two required meetings per week: the first will be to discuss papers related to the colloquium (time TBD), and the second will be the colloquium itself (at 4:15 pm each Wednesday). Grading is Pass/Fail.

ASTR UN3997 INDEPENDENT RESEARCH. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: the instructor’s permission. For an independent research project or independent study, a brief description of the proposed project or reading, with the supervising faculty member’s endorsement, is required for registration.
Prerequisites: the instructor’s permission. For an independent research project or independent study, a brief description of the proposed project or reading, with the supervising faculty member’s endorsement, is required for registration. A variety of research projects conducted under the supervision of members of the faculty. Observational, theoretical, and experimental work in galactic and extragalactic astronomy and cosmology. The topic and scope of the work must be arranged with a faculty member in advance; a written paper describing the results of the project is required at its completion (note that a two-term project can be designed such that the grade YC is given after the first term). Senior majors in astronomy or astrophysics wishing to do a senior thesis should make arrangements in May of their junior year and sign up for a total of 6 points over their final two terms. Both a substantial written document and an oral presentation of thesis results are required.

Spring 2023: ASTR UN3997

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<tr>
<td>ASTR 3997</td>
<td>001/12461</td>
<td>T Th 10:10am - 11:25am</td>
<td>Melissa Ness</td>
<td>3.00</td>
<td>9/15</td>
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</table>

ASTR UN3998 INDEPENDENT RESEARCH. 3.00 points.
Prerequisites: the instructor’s permission. For an independent research project or independent study, a brief description of the proposed project or reading, with the supervising faculty member’s endorsement, is required for registration.
Prerequisites: the instructors permission. For an independent research project or independent study, a brief description of the proposed project or reading, with the supervising faculty member’s endorsement, is required for registration. A variety of research projects conducted under the supervision of members of the faculty. Observational, theoretical, and experimental work in galactic and extragalactic astronomy and cosmology. The topic and scope of the work must be arranged with a faculty member in advance; a written paper describing the results of the project is required at its completion (note that a two-term project can be designed such that the grade YC is given after the first term). Senior majors in astronomy or astrophysics wishing to do a senior thesis should make arrangements in May of their junior year and sign up for a total of 6 points over their final two terms. Both a substantial written document and an oral presentation of thesis results are required.

Spring 2023: ASTR UN3998

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<tr>
<td>ASTR 3998</td>
<td>001/11578</td>
<td>T Th 10:10am - 11:25am</td>
<td>Frederik Paerels</td>
<td>3.00</td>
<td>11/15</td>
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ASTR GU4260 MODELING THE UNIVERSE. 3.00 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: one year of calculus-based general physics. Prerequisites: one year of calculus-based general physics. The goal of this course is to provide a basic hands-on introduction to the practice and theory of scientific computing with applications in astronomy and astrophysics. The course will include an introduction to programming, as well as a sampling of methods and tools from the field of scientific computing. The course will include a hands-on project in which students use numerical methods to solve a research problem. Students who are interested in participating in research projects are strongly encouraged to take the course in their sophomore or junior year.

Fall 2023: ASTR GU4260

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<td>ASTR 4268</td>
<td>001/12470</td>
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<td>Mordecai-Mark 3.00</td>
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</table>

ASTR GU4302 General Relativity, Black Holes, and Cosmology. 3 points.
CC/GS: Partial Fulfillment of Science Requirement
Prerequisites: one year of calculus-based general physics. Einstein’s General Theory of Relativity replaced Newtonian gravity with an elegant theory of curved spacetime. Einstein’s theory led to unforeseen and unnerving predictions of singularities and cosmological instabilities. Nearly a century later, these mathematical oddities have been confirmed astrophysically in the existence of black holes, an expanding universe, and a big bang. The course will cover Einstein’s General Theory, beginning with special relativity, with an emphasis on black holes and the big bang.

ASTR GU4303 ASTROSTATISTICS. 3.00 points.
Astronomers live in era of “big data”. Whilst astronomers of a century ago collected a handful of photographic plates each night, modern astronomers collect thousands of images encoded by millions of pixels in the same time. Both the volume of data and the ever present desire to dig deeper into data sets has led to a growing interest in the use of statistical methods to interpret observations. This class will provide an introduction to the methods commonly used in understanding astronomical data sets, both in terms of theory and application. It is one six classes the department offers every fourth semester.

Spring 2023: ASTR GU4303

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<td>ASTR 4303</td>
<td>001/11579</td>
<td>T Th 10:10am - 11:25am</td>
<td>David Kipping</td>
<td>3.00</td>
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Spring 2023: ASTR UN3998

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<tbody>
<tr>
<td>ASTR 3997</td>
<td>001/12461</td>
<td>T Th 10:10am - 11:25am</td>
<td>Melissa Ness</td>
<td>3.00</td>
<td>9/15</td>
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</table>
ASTR GR6001 RADIATIVE PROCESSES. 3.00 points.
Prerequisites: 3000-level electromagnetic theory and quantum mechanics.
Radiation mechanisms and interaction of radiation with matter. Applications of classical and semiclassical radiation theory and atomic physics to astrophysical settings. Radiative transfer, polarization, scattering, line radiation, special relativity, bremsstrahlung, synchrotron radiation, inverse compton scattering, ionization losses, shocks and particle acceleration, plasma processes, atomic structure and spectroscopic terms, radiative transitions and oscillator strengths, curve of growth, molecular spectra

### Fall 2023: ASTR GR6001

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<tr>
<td>ASTR 6001</td>
<td>001/12471</td>
<td>M W 1:10pm - 2:25pm</td>
<td>Frederik Paerels</td>
<td>3.00</td>
<td>20/15</td>
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<td>503 Hamilton Hall</td>
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ASTR GR6003 GALAXIES. 3.00 points.
An introduction to the study of galaxies, from both observational and theoretical perspectives The course will review our current understanding of the formation and evolution of galaxies through descriptions of: their structure and dynamics; the gas and stellar populations they contain; and what we know about the distribution of dark matter within them.

### Spring 2023: ASTR GR6005

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<td>001/11583</td>
<td>M W 2:40pm - 3:55pm</td>
<td>Zoltan Haiman</td>
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<td>13/25</td>
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<td>414 Pupin Laboratories</td>
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**Of Related Interest**

Physics and Astronomy (Barnard)

<table>
<thead>
<tr>
<th>Course</th>
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<tbody>
<tr>
<td>ASTR BC1753</td>
<td>LIFE IN THE UNIVERSE</td>
</tr>
<tr>
<td>ASTR BC1754</td>
<td>Stars, Galaxies, and Cosmology</td>
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Physics

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<tbody>
<tr>
<td>PHYS UN3002</td>
<td>From Quarks To the Cosmos: Applications of Modern Physics</td>
</tr>
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