

# ASTROPHYSICS

**Departmental Office:** 1328 Pupin; 212-854-3278  
<http://www.astro.columbia.edu>

**Director of Undergraduate Studies:**  
 Prof. Frederik B.S. Paerels, 1022 Pupin;  
 212-854-0181; [frits@astro.columbia.edu](mailto:frits@astro.columbia.edu)

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 UNlty 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 *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. *ASTR UN3997* and *ASTR UN3998* cannot be repeated for credit.

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 *ASTR UN2001 Introduction 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 *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. *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  
 Zoltan Haiman  
 Jules P. Halpern  
 David J. Helfand  
 Kathryn Johnston  
 Laura Kay (Barnard)  
 Jeremiah P. Ostriker  
 Frederik B. S. Paerels

Joseph Patterson  
 Mary E. Putman  
 David Schiminovich (Chair)  
 Jacqueline van Gorkom

## Associate Professor

Marcel Agüeros

## Assistant Professors

David Kipping  
 Melissa K. Ness  
 Lorenzo Sironi

## Adjunct Professor

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

## Senior Lecturer

Caleb Scharf

## On Leave

Profs. Halpern, Ness, Van Gorkom (*Fall 2020*)

## 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:

ASTR UN2001 Introduction To Astrophysics, I  
 - ASTR UN2002 and 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 Introduction To Mechanics and  
 - PHYS UN1402 Thermodynamics  
 - PHYS UN1403 and INTRO ELEC/MAGNETISM # OPTCS  
 and Introduction to Classical and  
 Quantum Waves

**Sequence 2:**

PHYS UN1601 - PHYS UN1602 - PHYS UN2601	Physics, I: Mechanics and Relativity and Physics, II: Thermodynamics, Electricity, and Magnetism and Physics, III: Classical and Quantum Waves
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**Sequence 3:**

PHYS UN2801 - PHYS UN2802	Accelerated Physics I and Accelerated Physics II
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**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 and Magnetism
PHYS GU4021 - PHYS GU4022	Quantum Mechanics I and Quantum Mechanics II

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

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## 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	Introduction To Astrophysics, I and INTRO TO ASTROPHYSICS II
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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	Introduction To Mechanics and Thermodynamics and INTRO ELEC/MAGNETISM # OPTCS and Introduction to Classical and Quantum Waves
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**Sequence 2:**

PHYS UN1601 - PHYS UN1602 - PHYS UN2601	Physics, I: Mechanics and Relativity and Physics, II: Thermodynamics, Electricity, and Magnetism and Physics, III: Classical and Quantum Waves
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**Sequence 3:**

PHYS UN2801 - PHYS UN2802	Accelerated Physics I and Accelerated Physics II
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**Additional Physics Courses**

PHYS UN3003	Mechanics
PHYS UN3007	Electricity and Magnetism
PHYS UN3008	Electromagnetic Waves and Optics
PHYS GU4021 - PHYS GU4022	Quantum Mechanics I and Quantum Mechanics II

OR

PHYS BC3006 - PHYS GU4023	Quantum Physics and Thermal and Statistical Physics
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## 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

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## Fall 2021

**ASTR UN1403 Earth, Moon and Planets (Lecture). 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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 2021: ASTR UN1403**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1403	001/11739	T Th 1:10pm - 2:25pm Online Only	James Applegate	3	68/75

**Fall 2021: ASTR UN1403**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1403	001/12831	T Th 10:10am - 11:25am Room TBA	David Helfand	3	73/75

**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

**Fall 2021: ASTR UN1404**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1404	001/12832	T Th 1:10pm - 2:25pm Online Only	James Applegate	3.00	40/75

**ASTR UN1453 Another Earth. 3 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 2021: ASTR UN1453**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1453	001/11740	M W 2:40pm - 3:55pm Online Only	Mary Putman	3	68/75

**Fall 2021: ASTR UN1453**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1453	001/12833	T Th 1:10pm - 2:25pm Room TBA	Caleb Scharf	3	75/75

**ASTR UN1836 Stars and Atoms. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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.

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 W1836 in addition to ASTR BC1754 or ASTR W1404 and receive credit for both.

**Spring 2021: ASTR UN1836**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1836	001/11741	M W 1:10pm - 2:25pm Online Only	Marcel Agueros	3	34/40

**Fall 2021: ASTR UN1836**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1836	001/12834	M W 1:10pm - 2:25pm Room TBA	Kathryn Johnston	3	48/75

**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 2021: ASTR UN1903**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1903	001/12738	T 6:00pm - 9:00pm Online Only	David Schiminovich, Yuxi Lu	1.00	9/12
ASTR 1903	002/12739	M 6:00pm - 9:00pm Online Only	David Schiminovich, Christopher Carr	1.00	7/12

**Fall 2021: ASTR UN1903**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1903	001/00150	M 6:00pm - 9:00pm Room TBA	Laura Kay	1.00	12/12
ASTR 1903	002/00151	T 6:00pm - 9:00pm Room TBA	Laura Kay	1.00	8/12

**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 2021: ASTR UN1904**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1904	001/12740	W 7:00pm - 10:00pm Online Only	David Schiminovich, Karen Perez	1.00	12/14

**Fall 2021: ASTR UN1904**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1904	001/00146	W 7:00pm - 10:00pm Room TBA	Laura Kay	1.00	6/12

**ASTR UN2001 Introduction To Astrophysics, I. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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 2021: ASTR UN2001**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 2001	001/12835	M W 1:10pm - 2:25pm Room TBA	Greg Bryan	3	36/35

**ASTR UN2900 Frontiers of Astrophysics. 1 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 2021: ASTR UN2900**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 2900	001/12836	F 10:10am - 11:25am Room TBA	Caleb Scharf	1	23/50

**ASTR UN3105 Extrasolar Planets and Astrobiology. 3 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.

Fall 2021: ASTR UN3105

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3105	001/12837	T Th 10:10am - 11:25am Room TBA	David Kipping	3	15/20

**ASTR UN3602 Physical Cosmology and Extragalactic Astronomy. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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 2021: ASTR UN3602

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3602	001/12838	M W 10:10am - 11:25am Room TBA	Zoltan Haiman	3	16/25

**ASTR UN3997 Independent Research. 3 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.

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 2021: ASTR UN3997

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3997	001/13263			3	1/10

**ASTR GR6001 Radiative Processes. 3 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 2021: ASTR GR6001

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 6001	001/13264			3	1/20

**ASTR GR8003 Astrophysical fluid Dynamics (Lecture). 3 points. Not offered during 2021-22 academic year.**

An introduction to the fundamental concepts of fluid dynamics with focus on standard applications of the theory to a variety of important astrophysical situations and objects. A brief introduction to several key numerical concepts. A brief description of the complications that arise when a fluid is magnetized.

Fall 2021: ASTR GR8003

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 8003	001/13265	M W 10:10am - 11:25am Room TBA	Lorenzo Sironi	3	1/10

**ASTR GR9003 Graduate Research Seminar I. 3 points.**

Fall 2021: ASTR GR9003

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 9003	001/13266			3	1/10

## Spring 2021

**ASTR UN1403 Earth, Moon and Planets (Lecture). 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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 2021: ASTR UN1403

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1403	001/11739	T Th 1:10pm - 2:25pm Online Only	James Applegate	3	68/75

Fall 2021: ASTR UN1403

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1403	001/12831	T Th 10:10am - 11:25am Room TBA	David Helfand	3	73/75

**ASTR UN1453 Another Earth. 3 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 2021: ASTR UN1453**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1453	001/11740	M W 2:40pm - 3:55pm Online Only	Mary Putman	3	68/75

**Fall 2021: ASTR UN1453**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1453	001/12833	T Th 1:10pm - 2:25pm Room TBA	Caleb Scharf	3	75/75

**ASTR BC1754 Stars, Galaxies, and Cosmology. 3 points.**

BC: Fulfillment of General Education Requirement: Quantitative and Deductive Reasoning (QUA).

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.

**Spring 2021: ASTR BC1754**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1754	001/00484	M W 10:10am - 11:25am 903 Altschul Hall	David Helfand	3	55

**ASTR UN1836 Stars and Atoms. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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.

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 W1836 in addition to ASTR BC1754 or ASTR W1404 and receive credit for both.

**Spring 2021: ASTR UN1836**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1836	001/11741	M W 1:10pm - 2:25pm Online Only	Marcel Agueros	3	34/40

**Fall 2021: ASTR UN1836**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1836	001/12834	M W 1:10pm - 2:25pm Room TBA	Kathryn Johnston	3	48/75

**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 2021: ASTR UN1903**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1903	001/12738	T 6:00pm - 9:00pm Online Only	David Schiminovich, Yuxi Lu	1.00	9/12
ASTR 1903	002/12739	M 6:00pm - 9:00pm Online Only	David Schiminovich, Christopher Carr	1.00	7/12

**Fall 2021: ASTR UN1903**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1903	001/00150	M 6:00pm - 9:00pm Room TBA	Laura Kay	1.00	12/12
ASTR 1903	002/00151	T 6:00pm - 9:00pm Room TBA	Laura Kay	1.00	8/12

**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 2021: ASTR UN1904**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1904	001/12740	W 7:00pm - 10:00pm Online Only	David Schiminovich, Karen Perez	1.00	12/14

**Fall 2021: ASTR UN1904**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1904	001/00146	W 7:00pm - 10:00pm Room TBA	Laura Kay	1.00	6/12

**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.

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 2021: ASTR UN2002**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 2002	001/11742	M W 8:40am - 9:55am Online Only	Frederik Paerels	3.00	30/45

**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 these 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

**Spring 2021: ASTR UN3103**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3103	001/11743	T Th 1:10pm - 2:25pm 307 Pupin Laboratories	David Schiminovich	3.00	21/25

**ASTR UN3998 Independent Research. 3 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.

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 2021: ASTR UN3998**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3998	001/11744		Frederik Paerels	3	5/10

**ASTR GU4242 Order of Magnitude Astrophysics. 3 points.**

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

Estimation is an essential skill for astronomy and life in general. This course will introduce to order of magnitude calculations, the practice of solving problems approximately, within a factor of 10. The course will cover examples from planets, stars, compact objects, galaxies and cosmology.

**Spring 2021: ASTR GU4242**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 4242	001/11745	T Th 10:10am - 11:25am 307 Pupin Laboratories	Lorenzo Sironi	3	12/25

**ASTR GU4303 Astrostatistics. 3 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 2021: ASTR GU4303**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 4303	001/11746	M W 2:40pm - 3:55pm 214 Pupin Laboratories	David Kipping	3	22/25

**ASTR GR6004 Stellar Structure and Evolution. 3 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.

**Spring 2021: ASTR GR6004**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 6004	001/11747	T Th 2:40pm - 3:55pm 420 Pupin Laboratories	Greg Bryan	3	15/20

**ASTR GR9002 Graduate Seminar. 3 points.**

Spring 2021: ASTR GR9002

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 9002	001/11748	Th 12:00pm - 2:15pm 717 Hamilton Hall	Zoltan Haiman	3	11/20

**ASTR GR9004 Graduate Research Seminar II. 3 points.**

Spring 2021: ASTR GR9004

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 9004	001/11749	F 11:00am - 12:00pm 307 Pupin Laboratories	Jacqueline van Gorkom	3	12/15

**All Courses (including those not offered in academic year 2020-2021)****ASTR UN1234 The Universal Timekeeper: Reconstructing History Atom by Atom. 3 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 (Lecture). 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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 2021: ASTR UN1403

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1403	001/11739	T Th 1:10pm - 2:25pm Online Only	James Applegate	3	68/75

Fall 2021: ASTR UN1403

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1403	001/12831	T Th 10:10am - 11:25am Room TBA	David Helfand	3	73/75

**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

Fall 2021: ASTR UN1404

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1404	001/12832	T Th 1:10pm - 2:25pm Online Only	James Applegate	3.00	40/75

**ASTR UN1453 Another Earth. 3 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 2021: ASTR UN1453

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1453	001/11740	M W 2:40pm - 3:55pm Online Only	Mary Putman	3	68/75

Fall 2021: ASTR UN1453

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1453	001/12833	T Th 1:10pm - 2:25pm Room TBA	Caleb Scharf	3	75/75

**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.

**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). Today's searches for a new grand order in the Universe, which can cope - or maybe not - with these blows to yesterdays comfortable wisdom

**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

**ASTR BC1754 Stars, Galaxies, and Cosmology. 3 points.**

BC: Fulfillment of General Education Requirement: Quantitative and Deductive Reasoning (QUA).

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.

**Spring 2021: ASTR BC1754**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1754	001/00484	M W 10:10am - 11:25am 903 Altschul Hall	David Helfand	3	55

**ASTR UN1836 Stars and Atoms. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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.

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 W1836 in addition to ASTR BC1754 or ASTR W1404 and receive credit for both.

**Spring 2021: ASTR UN1836**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1836	001/11741	M W 1:10pm - 2:25pm Online Only	Marcel Agueros	3	34/40

**Fall 2021: ASTR UN1836**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1836	001/12834	M W 1:10pm - 2:25pm Room TBA	Kathryn Johnston	3	48/75

**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 2021: ASTR UN1903**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1903	001/12738	T 6:00pm - 9:00pm Online Only	David Schiminovich, Yuxi Lu	1.00	9/12
ASTR 1903	002/12739	M 6:00pm - 9:00pm Online Only	David Schiminovich, Christopher Carr	1.00	7/12

**Fall 2021: ASTR UN1903**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1903	001/00150	M 6:00pm - 9:00pm Room TBA	Laura Kay	1.00	12/12
ASTR 1903	002/00151	T 6:00pm - 9:00pm Room TBA	Laura Kay	1.00	8/12

**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 2021: ASTR UN1904**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1904	001/12740	W 7:00pm - 10:00pm Online Only	David Schiminovich, Karen Perez	1.00	12/14

**Fall 2021: ASTR UN1904**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 1904	001/00146	W 7:00pm - 10:00pm Room TBA	Laura Kay	1.00	6/12

**ASTR UN2001 Introduction To Astrophysics, I. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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 2021: ASTR UN2001**

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 2001	001/12835	M W 1:10pm - 2:25pm Room TBA	Greg Bryan	3	36/35



**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.

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 2021: ASTR UN2002

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 2002	001/11742	M W 8:40am - 9:55am Online Only	Frederik Paerels	3.00	30/45

**ASTR UN2900 Frontiers of Astrophysics. 1 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 2021: ASTR UN2900

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 2900	001/12836	F 10:10am - 11:25am Room TBA	Caleb Scharf	1	23/50

**ASTR UN3101 Modern Stellar Astrophysics II. 3 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.

**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.

The physics and astrophysics of planets, comets, asteroids, natural and artificial satellites, and pretty much anything in the Solar System - including the Sun. Detailed study of the Earth's atmosphere and oceans: circulations, climate, and weather. Orbital dynamics. The emerging science of extrasolar planets. The origin, evolution, and eventual fate of planets.

**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 these 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

Spring 2021: ASTR UN3103

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3103	001/11743	T Th 1:10pm - 2:25pm 307 Pupin Laboratories	David Schiminovich	3.00	21/25

**ASTR UN3105 Extrasolar Planets and Astrobiology. 3 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.

Fall 2021: ASTR UN3105

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3105	001/12837	T Th 10:10am - 11:25am Room TBA	David Kipping	3	15/20

**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 points.**

CC/GS: Partial Fulfillment of Science Requirement

Prerequisites: one year of calculus-based general physics. No previous, \nastronomy 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 and Extragalactic Astronomy. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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 2021: ASTR UN3602

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3602	001/12838	M W 10:10am - 11:25am Room TBA	Zoltan Haiman	3	16/25

**ASTR UN3646 Observational Astronomy. 3 points.**

Prerequisites: one year of general astronomy

Introduction to the basic techniques used in obtaining and analyzing 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. In research projects, students also work on the analysis of data obtained at National Observatories.

**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 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.

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 these results are required.

Fall 2021: ASTR UN3997

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3997	001/13263			3	1/10

**ASTR UN3998 Independent Research. 3 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.

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 2021: ASTR UN3998

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 3998	001/11744		Frederik Paerels	3	5/10

**ASTR GU4260 Modeling the Universe. 3 points.**

CC/GS: Partial Fulfillment of Science Requirement

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.

**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 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 2021: ASTR GU4303

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 4303	001/11746	M W 2:40pm - 3:55pm 214 Pupin Laboratories	David Kipping	3	22/25

**ASTR GR6001 Radiative Processes. 3 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 2021: ASTR GR6001

Course Number	Section/Call Number	Times/Location	Instructor	Points	Enrollment
ASTR 6001	001/13264			3	1/20

**ASTR GR6003 Galaxies. 3 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.

**ASTR GR6005 PHYSICAL COSMOLOGY. 3 points.**

## Of Related Interest

**Physics and Astronomy (Barnard)**

ASTR BC1753	LIFE IN THE UNIVERSE
ASTR BC1754	Stars, Galaxies, and Cosmology
<b>Physics</b>	
PHYS UN3002	From Quarks To the Cosmos: Applications of Modern Physics