# Astrophysics

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| **Objectives:** | 00UV | **Discipline:** | Physics |
| **Ponderation:** | 3-2-3 | **Course Code:** | 203-BZA-05 |
| **Prerequisite:** | 00UT (*Waves, Optics and Modern Physics*) | **Course Credit:** | 2 2/3 |
| **Corequisite** | | **Semester:** | 4 |

## Introduction

Astronomy and Astrophysics is a Science Option course, designed for fourth semester science students, familiar with elementary classical mechanics, differential and integral calculus, and waves and modern physics. Using these tools, the course will give students a comprehensive introduction to astronomy and astrophysics, from ancient times to the present. Emphasis will be on the logic behind astronomical thinking, rather than on the memorization of facts.

Astronomy once seemed a rather esoteric and irrelevant pursuit. The Greeks believed that the Heavens and the Earth were two entirely separate places, obeying different physical laws. But with the theory of Copernicus, and the work of Kepler, Galileo and Newton, people came to understand that Earth is a tiny part of the Universe and that the same physical laws apply throughout. In the nineteenth century, great progress was made in measuring the properties of the stars. In recent decades there have been enormous advances in our understanding of the structure and evolution of stars, galaxies and the Universe itself. The Universe is a much more violent, complex and exciting place than we realized. We now see that there is a deep and intimate connection between astrophysical events, the chemical composition of Earth, and the very existence of life. These are some of the ideas that Astronomy and Astrophysics will explore.

Some of the learning activities in *Astrophysics* will contribute to the attainment of objective 00UU and are marked **[00UU]**.

In the Science Program, *Astrophysics* contributes to the following program goals described in the *Exit Profile*:

| | Goals of the Science Program | Performance Criteria |
|---|---|---|
| 1. | To master the knowledge and skills of a basic scientific education | 00UV, 00UU |
| 2. | To master the knowledge and skills of a basic general education | |
| 3. | To apply the experimental method | 3.1 –3.5 |
| 4. | To take a systematic approach to problem solving | 4.1 –4.6 |
| 5. | To use the appropriate data-processing technology | |
| 6. | To reason logically | 6.1 –6.4 |
| 7. | To communicate effectively | 7.1, 7.3 – 7.6 |
| 8. | To learn in an autonomous manner | 8.1 –8.3 |
| 9. | To work as members of a team | 9.1 –9.3 |
| 10. | To recognize the links between science, technology and the evolution of society | 10.1, 10.2 |
| 11. | To construct a personal system of values | |
| 12. | To identify the context in which scientific ideas originated and evolved | 12.1 |
| 13. | To display attitudes and behaviour compatible with the scientific spirit and method | 13.1 –13.5 |
| 14. | To apply acquired knowledge and skills to new situations | 14.1 |

# Objectives and Standards for *Astrophysics*

In the following chart, italicized items marked with (*) are optional enrichment items which will not be evaluated in the final exam (these are not the only possible enrichment items — they are the most commonly used ones).

| OBJECTIVE | STANDARD | LEARNING OBJECTIVES |
|---|---|---|
| **Course Objective** | **Achievement Context** | |
| To apply previously acquired knowledge of physical and mathematical concepts to the study of astronomy and astrophysics. | In theoretical situations, individually, to solve numerical problems and answer verbal questions on astronomy and astrophysics, at a level requiring college-level mechanics and waves and optics, and differential and integral calculus<br><br>In experimental settings, in the lab, individually or in a group, with the aid of a laboratory write-up or of scientific documentation, to write lab reports | |
| | **General Performance Criteria** | |
| | 1. Appropriate use of concepts, laws and principles<br>2. Adequate diagrams to represent physical situations<br>3. Use of appropriate terminology and units<br>4. Use of vector techniques where appropriate<br>5. Graphical and mathematical representations of motion<br>6. Justification of the steps taken in analyzing a situation<br>7. Rigorous application of Newton's Laws and the conservation principles<br>8. Critical judgment of results<br>9. Recognition of the limits of a model<br>10. Submission of laboratory reports written in accordance with established norms | |

| Elements of Competency | Specific Performance Criteria | Intermediate Learning Objectives |
|---|---|---|
| 1. To apply previously acquired knowledge of physical and mathematical concepts to the study of astronomy from the ancient Greeks through the 19th century, with particular emphasis on solar system objects | 1.1. Logical analysis of the characteristics of solar system objects, using ideas of ancient Greek astronomers | 1.1.1. Explain the cause of the Moon's phases and the relation between phase and elongation, using diagrams.<br>1.1.2. Explain Aristotle's arguments for the sphericity of the Earth.<br>1.1.3. Calculate the relative Earth-Sun and Earth-Moon distances using Aristarchus' method.<br>1.1.4. Calculate the circumference of the Earth using Eratosthenes' method.<br>1.1.5. Describe Ptolemy's theory of the solar system. Explain how he accounted for the limited elongations of Mercury and Venus and for the retrograde motion of the superior planets.<br>1.1.6. Define parallax and use it to calculate the Earth-Moon distance. |
| | 1.2. Logical analysis of the characteristics of solar system objects using the theory of Copernicus and the observations of Galileo | 1.2.1. Describe Copernicus' theory of the solar system. Explain how he accounted for the limited elongations of Mercury and Venus and for the retrograde motion of the superior planets.<br>1.2.2. Define inferior and superior conjunctions, opposition, quadrature, sidereal period, and synodic period.<br>1.2.3. Derive the relation between the synodic and sidereal periods of a planet, and use it to calculate one of these quantities, given the other.<br>1.2.4. Use Copernicus' method to calculate the orbit sizes (in astronomical units) of the planets.<br>1.2.5. Describe Galileo's telescopic observations and explain how these observations support Copernicus' heliocentric theory. |
| | 1.3. Proper use of Kepler's laws of planetary motion and the properties of an ellipse to calculate the parameters of an elliptical orbit | 1.3.1. State and explain Kepler's three laws of planetary motion.<br>1.3.2. Calculate an object's orbital period given the size of its orbit, and vice versa.<br>1.3.3. Carry out calculations involving the semimajor axis, the eccentricity, the periapsis and apoapsis of an elliptical orbit. |
| | 1.4. Rigorous analysis of orbital motion using Kepler's Laws, Newton's Laws and the conservation of angular momentum and energy | 1.4.1. Derive the inverse square law of planetary accelerations from Kepler's Third Law, assuming circular orbits.<br>1.4.2. Explain Newton's use of the Moon to verify his hypothesis of inverse-square acceleration due to Earth's gravitation, explaining all implicit assumptions made in the calculation.<br>1.4.3. Use Newton's Laws, the conservation of energy and angular momentum, and the formulas that result therefrom, to calculate orbital parameters of planets, satellites, comets and space probes; all conic-section orbits are to be included. |
| | 1.5. Clear explanation of astronomical phenomena of the Earth-Moon-Sun system, including appropriate calculations | 1.5.1. Define precession of the equinoxes and explain this phenomenon in Newtonian terms.<br>1.5.2. Define and explain libration of the Moon. |

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|---|---|---|
| | | 1.5.3. Solve problems involving differential gravitational forces (tidal effects). Explain neap tides, spring tides and the variation of tidal amplitude with location. Discuss tidal effects outside the Earth-Moon system.<br>1.5.4. Describe the different types of eclipses of the Sun and Moon, and explain their cause. Define and explain eclipse seasons and the Saros cycle. |
| | 1.6. Careful analysis of effects resulting from the Earth's orbital revolution | 1.6.1. Explain the aberration of starlight.<br>1.6.2. Define the ecliptic, the equinoxes and the solstices. Explain their significance.<br>1.6.3. Define the Arctic and Antarctic Circles and the Tropics of Cancer and Capricorn. Explain their significance.<br>1.6.4. Explain the causes of the seasons. Draw diagrams and do calculations of the Sun's daily path at any latitude in any season. |
| | 1.7. Careful analysis of effects resulting from Earth's daily rotation | 1.7.1. Using diagrams, explain the daily motion of the stars as seen from different latitudes.<br>1.7.2. Describe the coordinate systems of latitude and longitude, right ascension and declination, hour angle and declination, altitude and azimuth.<br>1.7.3. Define sidereal time. Solve numerical problems involving sidereal time, right ascension and hour angle.<br>1.7.4. Define and explain apparent solar time, mean solar time, the equation of time, standard time, Universal time, terrestrial dynamical time, stepped atomic time. Solve numerical problems involving these types of time measurement.<br>1.7.5. Define and explain the International Date Line.<br>1.7.6. Explain the difficulties of constructing a lunar calendar. Explain the Julian calendar and the subsequent Gregorian reform. |
| 2. To apply previously acquired knowledge of physical and mathematical concepts to the measurement of the properties of stars | 2.1. Quantitative determination of the motions and distances of the stars | 2.1.1. Define the parsec. Explain and use the relation between a star's parallax and its distance in parsecs.<br>2.1.2. Define proper motion. Explain and use the relation between proper motion, distance and tangential velocity.<br>2.1.3. Use the Doppler formula to calculate a star's radial velocity.<br>2.1.4. Define space velocity. Given a star's radial and tangential velocities, calculate its space velocity.<br>2.1.5. Define the solar apex and antapex, the local standard of rest, and peculiar velocity. Explain the implications regarding the orbital velocities of the Sun and other stars in the Galaxy.<br>2.1.6. Use the moving-cluster method to calculate the distances to nearby |

| Elements of Competency | Specific Performance Criteria | Intermediate Learning Objectives |
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| | | star clusters. |
| | 2.2. Accurate determination and description of the magnitudes, colours and spectral types of stars | 2.2.1. Define apparent and absolute magnitude. Make calculations using the relation between apparent magnitude, absolute magnitude and distance. Make calculations using the relation between magnitude and luminosity.<br>2.2.2. Define colour index and bolometric magnitude. Use these quantities in calculations.<br>2.2.3. Describe the spectral classes of stars. Explain the relation between spectral class and temperature.<br>2.2.4. Explain the causes of spectral line broadening.<br>2.2.5. Describe the different characteristics of a star that can be deduced from its spectrum. **[00UU]** |
| | 2.3. Quantitative determination of the masses and diameters of stars that belong to binary systems | 2.3.1. Define visual binary, spectroscopic binary and eclipsing binary. Explain the difference between the true relative orbit and the apparent relative orbit.<br>2.3.2. Calculate the masses of the stars in a binary system given the appropriate observed quantities.<br>2.3.3. Calculate the diameters of stars in an eclipsing binary system given the light curve. |
| | 2.4. Graphical description and appropriate use of relations between different properties of the stars | 2.4.1. Describe the mass-luminosity relation for stars; correctly interpret a graph of this relation. Explain its importance in calculating stellar lifetimes.<br>2.4.2. Describe the luminosity function of the stars.<br>2.4.3. Draw the Hertzsprung-Russell diagram and correctly interpret a typical H-R diagram. Classify the stars at different locations on the diagram. Define the Main Sequence.<br>2.4.4. Calculate stellar distances using spectroscopic parallax. Explain the concept of the "standard candle". Define RR Lyrae and Cepheid variables, and explain their importance. |
| 3. To apply previously acquired knowledge of mathematical and physical concepts to the study of the evolution of stars | 3.1. Precise description of theories of stellar energy, including appropriate calculations | 3.1.1. Describe the Helmholtz-Kelvin theory of stellar energy. Explain its mathematical justification and its importance in modern astrophysics.<br>3.1.2. Describe the nuclear-fusion theory of stellar energy; use it to calculate the Main-Sequence lifetimes of stars of different masses. |
| | 3.2. Coherent explanation of methods for determining the interior structure of a star | 3.2.1. Explain the use of hydrostatic equilibrium and the perfect gas law in calculating the interior structure of a star. **[00UU]** |
| | 3.3. Graphical and verbal description of the formation of stars, including appropriate calculations | 3.3.1. Describe each phase of a star's formation from an interstellar cloud **-** from initial gravitational collapse through quasistatic equilibrium to nuclear ignition.<br>3.3.2. Plot the star's path on an H-R diagram as it evolves. |

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|---|---|---|
| | | 3.3.3. Explain the source of the star's energy at each stage. |
| | 3.4. Graphical and verbal description of the mid-lives of stars, including appropriate calculations | 3.4.1. Describe the evolution of a star on the Main Sequence and the cause of its leaving the Main Sequence.<br>3.4.2. Describe the different types of star clusters, including their star composition, and their frequency and location in the galaxy.<br>3.4.3. Explain the importance of star clusters in studying stellar evolution.<br>3.4.4. Correctly interpret the H-R diagrams of star clusters of different ages. |
| | 3.5. Graphical and verbal description of the ultimate fates of stars, including appropriate calculations | 3.5.1. Describe the evolution of stars from the Main Sequence to their final state (white dwarf, neutron star, black hole). Explain the physical reasons for these different fates.<br>3.5.2. Describe nucleosynthesis in the cores of massive stars; explain the relation between core temperature and the atomic number of the fusing nuclei. **[00UU]**<br>3.5.3. Define and describe white dwarfs. Discuss observational evidence of their existence. Describe Chandrasekhar's mass-radius relation and the Chandrasekhar limit.<br>3.5.4. Define and describe supernovae; explain the cause of the energy release.<br>3.5.5. Discuss nucleosynthesis in supernovae. Discuss the possible relations between supernovae, star formation, and life and evolution on Earth. **[00UU]**<br>3.5.6. Define and describe neutron stars. Define pulsars; explain the reason for the rapid pulse period. Explain the evidence that pulsars are neutron stars. Explain possible mechanisms for the energy release. Calculate the rate of energy release of a pulsar, given its slowdown rate.<br>3.5.7. Define and describe black holes. Calculate the Schwartzchild radius of a black hole given its mass. Explain the evidence for the existence of stellar size black holes and galactic black holes. Discuss black holes as energy sources. |
| 4. To apply previously acquired knowledge of mathematical and physical concepts to the study of cosmology | 4.1. Precise description of the present-day distribution and velocity of matter in the Universe, including appropriate calculations | 4.1.1. Explain the Hubble Law and use it to make calculations. Discuss methods of measuring the Hubble constant. Discuss the uniqueness (or lack thereof) of our galaxy's position in the Universe. **[00UU]**<br>4.1.2. Describe the large-scale distribution of matter in the Universe. |
| | 4.2. Clear explanation of the evolution of the Universe over time, including appropriate calculations | 4.2.1. Define and describe quasars. Explain their importance in the study of the history of the Universe. Define gravitational lensing. Explain how time variation of radiation gives information on the size of the source.<br>4.2.2. Define and explain the scale factor of the Universe, R(t). Describe open, flat and closed models of the Universe in terms of R(t). Relate |

| Elements of Competency | Specific Performance Criteria | Intermediate Learning Objectives |
|---|---|---|
| | | the Hubble time to the age of the Universe.<br>4.2.3. Define the deceleration parameter q.<br>4.2.4. Define critical density and explain its importance. Make calculations using the formula for critical density. Discuss the “missing mass” problem and dark matter candidates.<br>4.2.5. Describe the theory of inflation and explain its importance.<br>4.2.6. Define and discuss the cosmic microwave background radiation.<br>4.2.7. Describe the evolution of the Universe over its first one million years, according to the standard Big Bang model. Describe alternative theories such as the old Steady State theory. Define the cosmological constant. |
| 5. To verify experimentally some of the laws and principles associated with astronomy and astrophysics | 5.1. Careful performance of the laboratory procedures provided | 5.1.1. Work cooperatively in a small group to obtain data.<br>5.1.2. Employ safe procedures and show concern for one’s own safety and the safety of others in the laboratory and while observing.<br>5.1.3. Exercise care in carrying out measurements to obtain the best results possible. |
| | 5.2. Logical analysis of and appropriate mathematical treatment of data | 5.2.1. Choose and apply appropriate mathematical, graphical and logical tools. **[00UU]** |
| | 5.3. Coherent and justifiable conclusions | 5.3.1. Understand and apply the principles involved in each experiment.<br>5.3.2. State clearly the conclusions to be drawn from one’s analysis and justify them. |
| | 5.4. Proper adherence to course norms for submitting laboratory reports | |

## Methodology

Astronomy and Astrophysics is presented in a series of lectures, labs and demonstrations. Emphasis is placed on applying scientific principles and mathematical techniques mastered in previous courses in the science program to the understanding of the historical development of astronomy and to current problems in astrophysics. Students are also required to make some astronomical observations as part of the laboratory component of the course.