ASTR 4600: High Energy Astrophysics (winter)

Calendar description: This course discusses the astrophysical processes that create high-energy photons (X-rays and γ-rays) as well as the emission created from very energetic electrons (synchrotron and inverse Compton). Topics include gas and radiative processes, high-energy detectors and telescopes, and astrophysical processes from the solar system to black holes and gamma-ray bursts responsible for high-energy emission.

Contents

Overview

This course falls into the realm of astrophysical *theory* and relates to astronomical phenomena ranging from the solar system to the very early universe. Thus this course is well-placed near the end of the undergraduate's programme where their grasp of basic physics and various phenomena in the universe is fairly well developed. It is hoped that in describing the traditional topics in high-energy astrophysics, the instructor will be able to introduce and/or revisit some of the more exotic phenomena in the galaxy and universe such as X-ray binaries, pulsars, white dwarfs, cataclysmic variables, supernovae remnants, galaxy clusters, active galaxies and their AGNs, gamma-ray bursters, *etc.*

This course is intended to be offered every second year, with the honours student enrolling in their 5000-level course requirement in the year when this course is not offered. It should be offered in the winter terms following the fall when ASTR 3400 (Interstellar matter and stellar evolution) is offered to minimise the overlap these courses might otherwise have. While beneficial, this consideration is insufficient to list ASTR 3400 as a formal prerequisite. Indeed, ideas in ASTR 3500 (Galaxies and Cosmology) are also germane to ASTR 4600, and the only way to prevent *all* overlap between ASTR 4600 and the 3000-level courses is to offer ASTR 4600 *every* year which, given the number of students, is probably not justifiable.

Prerequisites

ASTR 2400 Physics of Stars

In discussing mechanism in high energy astrophysics, as appreciation of the basic properties of stars and how they generate and dissipate energy will serve as a starting point in understanding high-energy poccesses in general.

PHYS 2400 Electricity and Magnetism

Students will need to have a reasonable understanding of Maxwell's equations in differential form so that the electromagnetic wave equation may be developed and used to discuss the transmission and polarisation of radiation.

PHYS 3300 Classical Mechanics

ASTR 4600 will depend on PHYS 3300 and, indirectly, PHYS 1500 (Introduction to Modern Physics) for their units on special relativity, since many processes in high-energy astrophysics are relativistic in nature. In addition, the level of physics sophistication required by a student to complete PHYS 3300 will be beneficial in completing this course.

While high-energy processes associated with compact objects invariably lead to a discussion of degenerate matter, it is felt that the introduction to quantum ideas from PHYS 1500 is sufficient background for this. That said, most students entering into ASTR 4600 will have had PHYS 3500 (Quantum Mechanics I) in the previous one to three semesters.

The prerequisite mathematics for PHYS 3300 (MATH 301, 2303, 2311) provide a sufficient mathematical background for this course.

Dependent courses

none

Student Outcomes

The overall aim of ASTR 4600 is to provide students with an understanding of high-energy processes in astrophysics, and what high-energy emission can tell us about the physical environment from which the emission originates. Typical questions student completing ASTR 4500 should be able to answer include:

1. How can one determine the density and temperature of a gas emitting x-rays?
2. What can one infer from a synchrotron spectrum?
3. What are first- and second-order Fermi acceleration?
4. How can one tell the difference between synchrotron and inverse-Compton radiation?

Curriculum

1. gas processes
    - collisions
    - ionisation
    - viscosity
    - shocks
2. radiative processes
    - black body
    - Compton and inverse-Compton
    - synchrotron
    - bremsstrahlung
    - bound transitions
3. instrumentation and detection methods
    - gamma-rays
    - x-rays
    - radio waves
4. examples of high-energy astrophysical phenomena
    - supernovae and remnants
    - neutron stars, pulsars, magnetars
    - x-ray binaries
    - active galaxies
    - gamma-ray bursts

Suggested texts

1. *An Introduction to High-Energy Astrophysics* by Rosswog and Brüggen (ISBN 978-0-521-85769-7) is complete, up-to-date, and at an appropriate level. The book can be covered in its entirety. It introduces the required physics in the first few chapters and then follows with discussion of the traditional astronomical topics (*e.g.*, compact objects, AGN, SNR).

2. *High Energy Astrophysics: Volume 2* by Longair (ISBN 0-521-43584-6) is widely regarded as the bible on the subject of high-energy astrophysics. Volume 2 concentrates on the stars and galaxy while Volume 1 on the processes and detection. Sold as a set, the books would be expensive, though a useful addition to any serious students' library. Selecting only on volume would require supplementary material from the instructor. In addition, the books are dated.

Notes to the instructor

1. The suggested curriculum follows Rosswog and Brüggen for items 1 and 2. Items 3 and 4 in the curriculum are left “open” and may need supplements, depending on the text chosen and whatever other texts the student may already have from previous ASTR courses. The instructor is therefore encouraged to consult with instructors of the 2000 and 3000 level ASTR courses to determine what these texts may be.