PHYC 581: High Energy Astrophysics
Fall 2014

Lecture 1: 08/18/2014

Introduction:

High energy astrophysics involves the study of exceedingly dynamic and energetic phenomena that occur near the most extreme astrophysical objects such as white dwarfs, neutron stars, supernova remnants and black holes.

It is an important discipline encompassing many other sub-branches of physics. It involves the study of:

(1) Large quantities of energy, usually coupled to matter in relativistic regime.

(2) Rapid release of this energy in events of extreme violence, which sometimes destroy the underlying source completely.

(3) Interaction of matter and radiation under extrem

conditions that include very strong gravitational and magnetic fields.

(4) Emission of large fluxes of X-rays and γ-rays, and sometime UV radiation.

It provides new physical problems and tests fundamental theories, such as general relativity, under conditions that are not accessible in terrestrial labs.

Most of our information in high energy astrophysics, and in general the universe, comes from photons. This has to do with the properties of photons in comparison with other possible messangers, specifically massive particles, neutrinos, and gravitational waves:

(1) Production: All kinds of objects emit photons. Neutrinos are also produced pretty commonly (for example in

Hydrogen fusion to Helium) but not enough to compensate for their weak interaction. In contrast, significant production of gravitational waves requires fast motion of large masses, and production of high energy particles need some acceleration mechanism.

(2) Propagation. Photons have a small cross section, but not too small. Neutrinos and gravitotinal waves propagate with almost no interactions, hence provide very good directional information. But, for the same reason, they are also difficult to detect. Massive particles (electrons, protons, nuclei) are affected by the magnetic fields in the galaxy as a result of which some information is lost. In both cases of the neutrinos and massive particles the best observations come from highly energetic sources.

(3) Detection. Many aspects of photons (energy, direction, time of arrival, polarization) can be measured precisely. Similar measurements are much more difficult to make for neutrinos and gravitational waves.

Astronomical Wavebands:

The frequency ν and wavelength λ of electromagnetic waves are related through the dispersion relation $\lambda\nu = c$. The energy E of a photon with frequency ν is given by the relation $E = h\nu$, where h is the Planck constant ($h = 6.63 \times 10^{-34}\ m^2\,kg\,s^{-1}$).

In terms of ν, λ, E electromagnetic waves are divided into the following astronomical wavebands:

- Radio waveband: $3\,MHz \leq \nu \leq 30\,GHz$

$$100\,m \geq \lambda \geq 1\,cm$$
$$10^{-8}\,eV \leq E \leq 10^{-4}\,eV$$

- Millimiter/sub-millimeter waveband: $30\,GHz \leq \nu \leq 3000\,GHz$
  $10\,mm \geq \lambda \geq 0.1\,mm$
  $10^{-4}\,eV \leq E \leq 10^{-2}\,eV$

- Infrared waveband: $3 \times 10^{12}\,Hz \leq \nu \leq 10^{14}\,Hz$
  $100\,\mu m \geq \lambda \geq 1\,\mu m$
  $10^{-2}\,eV \leq E \leq 1\,eV$

- Optical waveband: $3 \times 10^{14}\,Hz \leq \nu \leq 10^{15}\,Hz$
  $1\,\mu m \geq \lambda \geq 300\,nm$
  $1\,eV \leq E \leq 3\,eV$

- Ultraviolet waveband: $10^{15}\,Hz \leq \nu \leq 3 \times 10^{16}\,Hz$
  $300\,nm \geq \lambda \geq 10\,nm$
  $3\,eV \leq E \leq 0.1\,keV$

- X-ray waveband: $3 \times 10^{16}\,Hz \leq \nu \leq 3 \times 10^{19}\,Hz$
  $10\,nm \geq \lambda \geq 0.01\,nm$
  $0.1\,keV \leq E \leq 100\,keV$

- γ-ray waveband: $\nu \geq 3 \times 10^{19}\,Hz$
  $\lambda \leq 0.01\,nm$
  $E \geq 100\,keV$

High energy astrophysics mainly deals with photons in the X-ray and γ-ray bands. The principal featur that distinguishes high energy astrophysics from other branches of astronomy is the relative paucity of photons in the X-ray and γ-ray bands. There are two reasons for this:

(1) For a given energy budget, it is a lot more difficult to produce high energy γ-ray photons than photons in the optical range.

(2) The sky is far less crowded in the X-ray and γ-ray bands than in other spectral regimes.