Lec 1: 01/18/2012

Introduction:

The principal feature 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-rays and γ-rays than in other spectral regimes.

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

It is an important theoretical discipline, encompassing many other sub-branches of physics. Broadly speaking, it involves the study of:

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

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

3) Interaction of matter and radiation under the extreme conditions of very strong gravity and magnetic fields.

4) Emission of large fluxes of X-rays, γ-rays, and

sometimes UV radiation.

It therefore provides new physical problems and tests of fundamental theories, such as general relativity, under conditions that are totally inaccessible in the laboratory.

Astronomical Wavebands:

- Radio waveband ($3\,MHz \leq \nu \leq 30\,GHz$; $100\,m \geq \lambda \geq 1\,cm$; $10^{-8}\,eV \leq E \leq 10^{-4}\,eV$).
- Millimeter and 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 ($3\times10^{12}\,Hz \leq \nu \leq 3\times10^{14}\,Hz$; $100\,\mu m \geq \lambda \geq 1\,\mu m$; $10^{-2}\,eV \leq E \leq 1\,eV$).
- Optical waveband ($3\times10^{14}\,Hz \leq \nu \leq 10^{15}\,Hz$; $1\,\mu m \geq \lambda \geq 300\,nm$; $1\,eV \leq E \leq 3\,eV$).

- Ultraviolet waveband (10^{15} Hz $\leq \nu \leq 3\times10^{16}$ Hz ; 300 nm $\geq \lambda \geq$ 10 nm; 3 eV $\leq E \leq$ 0.1 keV).
- X-ray waveband (3×10^{16} Hz $\leq \nu \leq 3\times10^{19}$ Hz; 10 nm $\geq \lambda \geq$ 0.01 nm; 0.1 keV $\leq E \leq$ 100 keV).
- γ-ray waveband ($\nu \geq 3\times10^{19}$ Hz; $\lambda \leq$ 0.01 nm, $E \geq$ 100 keV)

Atmospheric Absorption:

Our eyes have developed the greatest sensitivity to light in the ~400 nm - 700 nm range, the "visible" portion of the spectrum. This waveband encompasses most of the sun's spectral output (roughly a blackbody peaking at ~600 nm). Also, it represents one of the few regions in the spectrum where atmospheric absorption is essentially non existent.

Let us briefly discuss the atmospheric absorption in different energy ranges.

Below about 60 keV ($\lambda \gtrsim 200$ nm), the dominant interaction is the photoelectric effect, in which an atomic electron completely absorbs the incident photon. The cross-section for this process increases sharply at the absorption edges. Above ~10 MeV, photons passing through the atmosphere begin to produce electron-positron pairs. Between the two energies ($60\,\mathrm{keV} \lesssim E \lesssim 10\,\mathrm{MeV}$), the dominant interaction is inelastic Compoton scattering of photons off free electrons.

The attenuation suffered by a ray with intensity I is described by:

$$\frac{dI}{ds} = -\nu \rho I$$

Here ν is the absorption coefficient defined as the cross-section per unit mass of the material, and ρ

is the pathlength. For a uniform medium:

$$I_{(d)} = I_0 \exp(-\mu \rho d)$$

Taking into account of different processes, we have:

$\mu = \sigma_c + \tau_a + \kappa$ → pair production

τ_a → photoelectric absorption

σ_c → Compton scattering

At the energies relevant in high-energy astrophysics, the contribution from Rayleigh scattering may be ignored. For photon energies $\gtrsim 0.5$ MeV, we have $\mu \lesssim 0.1\ cm^2 g^{-1}$. This implies that astronomical measurements at these energies must be made at column densities $\rho d \lesssim \frac{1}{\mu} \sim 10\ g\, cm^{-2}$. On Earth, this column density corresponds to a height of ~ 30 km. Therefore, high-energy astrophysics is primarily a high altitude and space-based discipline.

It is important to note that at very high energies ($\gtrsim 100$ GeV) the atmosphere itself becomes part of the detector. At such energies a cascade of electron-positron pairs will be produced. The resulting radiation produces Cherenkov light, which can be detected with air Cherenkov detectors on the ground.