High-Energy Astrophysics II

Assignment 1

Due: Monday, May 5, 2014, 14:00

1) **On pair production by γ-ray photons:**
   1) Show that a single photon can not produce an electron-positron pair without interacting with another photon because energy and momentum can not be simultaneously conserved if a single photon would be converted into an electron-positron pair.
   b) Verify the expression for the energy threshold of pair production in Spectral energy distribution of 3C66Athe field of the nucleus:

$$E_{\rm thr} = 2\, m_e c^2 \left(1 + \frac{m_e}{m_p}\right). \tag{1}$$

   For this, treat the problem as the collision of a photon with a proton at rest, $p + \gamma \rightarrow p + e^+ + e^-$. Hint: Consider energy and momentum conservation, together with the invariant four-vector scalar product, and keep in mind that at threshold the produced particles are at rest, i.e., the spatial (velocity) components of the momenta of the produced particles are zero.

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2) Gamma-ray bursts (GRBs) are short, extremely luminous bursts of gamma-rays, whose spectra often extend to GeV energies without signes of gamma-gamma absorption. Therefore, the compactness parameter of these objects has to be $\ell < 1$ in the frame of the emission region. Based on this argument, one can find a minimum Lorentz factor (and, hence, Doppler factor), with which the emission region has to move towards Earth so that this condition ($\ell < 1$) is fulfilled.
   a) Find the appropriate correction factors between $L_{\rm obs}$ and L' (in the co-moving frame of the emission region), between $\Delta t_{\rm obs}$ and $\Delta t'$, and between $\langle \epsilon_{\rm obs} \rangle$ and $\langle \epsilon' \rangle$ to find a relation between the compactness parameter inferred from the directly observed flux/luminosity and duration, $\ell_{\rm obs}$ and the intrinsic compactness parameter ℓ'.
   b) For a typical GRB with a γ-ray flux of $F = 3.5 \times 10^{-6}$ erg/(cm^2 s) at a luminosity distance of $d_L = 5$ Gpc, peak photon energy $\langle E_{\rm obs} \rangle = 1$ MeV and a duration of $\Delta t_{\rm obs} = 10$ s, find the minimum Doppler factor $\delta_{\rm min}$ for which $\ell' < 1$.

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3) **GRB Blast Waves:** Consider a GRB produced by the death of a $25\, M_\odot$ star. The GRB produces a blast wave with a total kinetic energy of $\sim 10^{54}$ erg, which moves with an initial Lorentz factor of $\Gamma = 300$ into the surrounding medium.

a) What fraction of the progenitor's mass has been ejected into the blast wave?

b) If this material expands into a homogeneous external medium of density $\rho_{\rm ext} = 5 \times 10^{-21}$ g cm^{-3}, how long (as seen by a stationary observer towards whom the blast wave is expanding) will it take for this blast wave to have swept up the same amount of relativistic mass that was originally ejected? (This determines the duration of the prompt GRB, after which the blast wave will begin to slow down appreciably, initiating the afterglow phase.)

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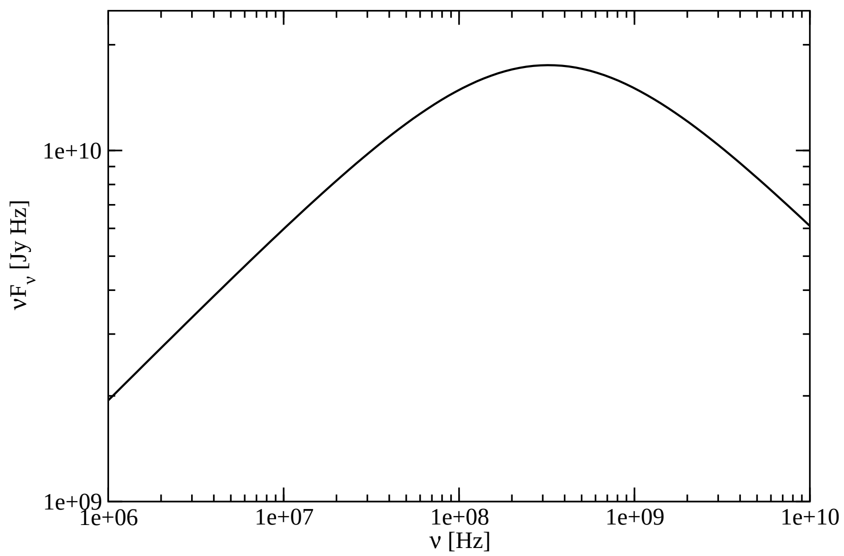

Figure 1: Synchrotron spectrum (νF_ν representation) of a supernova remnant.

4) **Supernova Remnants:** Figure 1 above shows the synchrotron spectrum of a supernova remnant (SNR). Assume that, from independent measurements, we know the strength of magnetic field to be $B = 3.5$ mG.

a) Estimate the age of the SNR.

b) Estimate the expected peak flux and peak frequency of high-energy emission due to inverse-Compton scattering of the CMB. In which frequency range (UV/X-rays/γ-rays?) does this emission peak? Judge whether such a flux might be detectable.

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