High-Energy Astrophysics (Ay125), Spring 2009

Final Exam

Due: 8 June 2010

Please find three contiguous hours to take the test. You can use class notes, old homeworks, and solutions, but not books or the internet. Calculator is OK.

I'm looking in these questions for *estimates*, not detailed calculations. In many cases, I do not provide numbers (e.g., for the total energy released in AGN); that is part of the problem/question. In such cases make your assumptions clear (e.g., about the values you use for certain quantities or parameters), and then note clearly how your final result depends on those assumptions.

Choose SIX of the ten problems below.

1. Gamma rays with an energy $E_\gamma \gtrsim 100$ GeV have been reportedly observed from supernova remnants in the Milky Way. What are the possible physical mechanisms for producing such photons?
2. Suppose that AGN are somehow responsible for accelerating ultra-high-energy cosmic rays (UHECRs). What fraction (*roughly*) of the total energy released in AGN goes into UHECRs.
3. Stellar-population models suggest that there should be roughly 10^8 stellar-mass (let's say 3 $M_\odot$) black holes in the Galaxy. *Estimate* the flux of x-ray radiation from accretion of matter from the interstellar medium onto the nearest such black hole. Is this within the range of detectability of any current x-ray telescope?
4. A gamma-ray burst goes off at a cosmological distance. What angular resolution would a radio telescope require to resolve the afterglow after three months?
5. Consider the internal-shock model for gamma-ray bursts: Two shells of similar mass and Lorentz factor γ_1 and γ_2 collide. Use conservation of energy and momentum to find the fraction of energy that will thermalize.
6. Write the expression for the synchrotron self-absorption frequency ν_a as a function of time t, fireball energy E, ISM particle density n, and the fractions ϵ_e and ϵ_B of the fireball energy converted to electron energy and magnetic fields. Separate two cases of fast and slow cooling to determine the effective temperature of the radiating electrons.

7. The cosmic-ray energy density in the Milky Way has an energy density comparable to that in the $\sim \mu$G magnetic field. Use this fact and the fact that the cosmic-ray energy spectrum is $dN/dE \propto E^{-p}$ (with $p \simeq 2.7$) to estimate the differential energy spectrum of gamma rays from decay of neutral pions produce by collisions of cosmic-ray protons with ISM protons. Use the Galactic center as your line of sight.

8. In an interacting binary, the more massive star accretes matter from a less massive companion. Assume angular-momentum–conserving mass transfer. Does the distance between the stars increase or decrease? Give a simple physical explanation for why. How does the result change if angular momentum is lost from the system?

9. If a gamma ray has a sufficiently large energy, it can scatter from a cosmic-infrared-background (CIB) photon to produce an electron-positron pair. Calculate the energy E_γ required of a gamma ray if it is to pair produce by scattering from a CIB photon; use a wavelength of one micron for the CIB photon. Estimate *roughly* the energy density $\rho_{\rm CIB}$ in the CIB; make your assumptions clear. Estimate the mean-free path for gamma rays above the pair-production threshold to pair produce as they travel through the CIB. Write your answer in terms of $\rho_{\rm CIB}$ and evaluate it.

10. In class (the GRB lectures), it was claimed that the radius R of an ultrarelativistic blast wave of energy E expands with time t into a medium of density n as $R \propto (Et/n)^{1/4}$. Derive the t, n, and E dependence for a *non*-relativistic blast wave.