Homework 4

Due **February 13 at 2pm in class**

Please show all work, writing solutions/explanations clearly, or no credit will be given. You are encouraged to work together, but everyone must turn in independent solutions: do not copy from others or from any other sources.

1. An emission line has been detected in the hard X-ray spectrum of a number of binary X-ray sources in which the X-ray emitting star is a neutron star. The lines have different photon energies in different X-ray sources. For example, in Hercules X–1 this line occurs at a photon energy of about 50 keV. It is thought that these lines are cyclotron lines emitted by electrons.

   (a) Give a very short argument as to why these lines are probably not due to either normal atomic emission lines or to nuclear (gamma–ray) lines.

   (b) Given that the lines are cyclotron lines, calculate the magnetic field strength (in gauss) on the neutron star in Hercules X–1.

2. A low redshift radio galaxy contains relativistic electrons, which can emit radiation either by synchrotron emission or by inverse Compton emission. Assume that the source of the photons which undergo inverse Compton emission is the omnipresent 2.73 K cosmic microwave background.

   (a) How big must the magnetic field in the radio galaxy be such that the synchrotron luminosity exceeds the inverse Compton luminosity?

   (b) Assume that the typical relativistic electron has $\gamma = 3000$. Estimate the typical frequency ν_{IC} of the inverse Compton scattered photons. In what part of the spectrum (radio, infrared, optical, ultraviolet, X-ray, gamma–ray) is this frequency located?

   (c) Assume that the magnetic field is at the limiting value from part (a), and that the typical electron has $\gamma = 3000$. Estimate the typical frequency ν_S of the synchrotron photons. In what part of the spectrum (radio, infrared, optical, ultraviolet, X-ray, gamma–ray) is this frequency located?

3. A low redshift quasar contains a total of 10^{53} ergs (total energy including rest mass) of relativistic electrons, with a power–law distribution with $p = 2.5$ extending from $\gamma = 10$ to $\gamma = 10^5$. The particles are located in a region with a magnetic field of $B = 1$ gauss.

   (a) Estimate the synchrotron luminosity of the quasar, in ergs/s. What is the spectral index of the synchrotron emission?

   (b) Assuming the main source of photons to be inverse Compton scattered is the 2.73 K cosmic background, estimate the inverse Compton luminosity (in ergs/s). What is the spectral index of the inverse Compton emission?

4. A highly relativistic electron initially has an Lorentz factor of γ_o. The electron is in a region of space with a magnetic field with an energy density U_B. The main energy loss mechanism of the electron is synchrotron emission. Use the pitch–angle–averaged emission rate for synchrotron emission.

   (a) How does the electron Lorentz factor vary with time as the electron loses energy? (Assume the electron is always relativistic.)

   (b) Estimate the time (in years) it takes an electron with $\gamma_o = 10^4$ to lose half of its energy in a 10^{-5} gauss magnetic field.