PHYC 581: High Energy Astrophysics

Fall 2018

Homework Assignment #3

(Due October 24, 2018)

1- Energetic electrons in the intergalactic space lose energy by inverse Compton scattering with the Cosmic Microwave Background (CMB) photons, which have a temperature $T = 2.73$ K. Find the energy density of the CMB radiation. What is the lifetime of a 100 GeV electron in the intergalactic space? For simplicity, use the average photon energy in the CMB instead of integrating over the blackbody spectrum and ignore the effects of angle.

The CMB photons are also present within the galaxy, but the radiation field now includes a contribution from stars. The radiative energy density in the interstellar medium is roughly 1 eV cm^{-3}, with a typical photon energy ~ 6 eV. What is the lifetime of a 100 GeV electron in the galaxy? What must the total production rate of energetic electrons within the galaxy be in order to maintain an equilibrium population?

2- A sphere of ionized plasma undergoes gravitational collapse. The sphere is isothermal with temperature T_0, of uniform density, and constant mass M_0 throughout the collapse, which may be described in terms of a decreasing radius $R(t)$. In order to maintain its isothermal structure, the gas cools initially by the emission of optically-thin bremsstrahlung radiation in its interior. However, the sphere eventually becomes optically thick.

(a) What is the total luminosity of the sphere as a function of M_0, $R(t)$, and T_0 while the sphere is optically thin?

(b) What is the luminosity of the sphere as a function of time after it becomes optically thick?

(c) Give an implicit relation, in terms of $R(t)$, for the time t_{thick}, when the sphere becomes optically thick.

3- Centaurus A is an extended source of synchrotron radio emission. The 1-100 MHz radio data can be fit to a curve of the form

$$F_{\rm radio}(\nu) \approx K_{\rm radio}\ \nu^{-0.9}\ {\rm erg\ cm^{-2}\ s^{-1}\ Hz^{-1}}\,,$$

with $K_{\rm radio} \approx 1 \times 10^{-12}$. The upper limit on the 1-10 keV X-ray emission from the extended source implies that the frequency-integrated flux due to the Compton spectrum produced by scattering the CMB radiation off the synchrotron electrons is

$$F_{\rm X-ray} \approx 7 \times 10^{-13}\ {\rm erg\ cm^{-2}\ s^{-1}}\,.$$

Estimate the magnetic field in the source.

4- When a synchrotron source is sufficiently compact, the photons produced via synchrotron radiation are inverse Compton scattered by the relativistic electrons, and the emergent spectrum is known as synchrotron-self Compton radiation. Suppose the electron distribution in such a source may be written as

$$N(\gamma)d\gamma = N_0\gamma^{-x}d\gamma \qquad \gamma_1 \leq \gamma \leq \gamma_2\,.$$

What will the observed spectral index be in this source? For simplicity, ignore angles in the scattering process.

5- A distant object detected with an X-ray satellite has a Rayleigh-Jeans spectrum in the 2-3 keV range, i.e., its intensity may be described as $I_\nu = (2\nu^2/c^2)kT$. This is quite puzzling at first, given that a very similar object seen nearby is known to produce a blackbody spectrum with an effective temperature $kT = 9$ eV. Naively, one would expect its spectrum in the 2-3 keV range to obey the Wien law (i.e., the exponential tail of the Planck function). This apparent contradiction can be resolved if the distant object moves at a very high speed. Explain whether it is moving toward us or away from us, and estimate its speed.