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High Energy Astrophysics II: Example Sheet 3

This example sheet contains a mixture of numerical and algebraic problems, drawing upon material from both HEA1 and HEA2.

1. The eclipsing binary X-ray source SMC X-1 lies in the Small Magellanic Cloud (at a distance of 50 kpc). It is an X-ray pulsar. A detector with an aperture of $0.04\,\mathrm{m}^2$ detects ~50 X-rays, of typical energy 5 keV, per second from SMC X-1. Estimate the X-ray luminosity of SMC X-1.

2. The Coma cluster of galaxies contains hot intracluster gas which emits thermal bremsstrahlung X-rays at a temperature of $10^8\,\mathrm{K}$. The luminosity of the Coma cluster, between 0.5 and 10 keV, is $5\times10^{37}\,\mathrm{W}$ and the cluster radius is about $600\,\mathrm{kpc}$. Use the bremsstrahlung formulae from your lecture notes, for a homogeneous isothermal source, to estimate the number density and total mass of intracluster gas, its thermal energy and (from its luminosity) its cooling time in years.

3. Assuming equipartition of energy density for optical starlight and magnetic fields in the galaxy, and if the energy density for starlight is $U_{opt} = 10^6$ eV/m^3, estimate the typical value of the galactic magnetic field. How many starlight photons m^{-3} does U_{opt} correspond to assuming that a typical visible light wavelength is 600nm? Using the value of the galactic magnetic field obtained above, calculate the value of γ^2 required for electrons to produce X-ray photons of frequency $\nu_m = 10^{18}$ Hz

4. If the number density of hydrogen nuclei in space is ~ 10^6m^{-3} and the energy density of microwave background photons is ~ 5×10^{-14} Jm^{-3}, each with a typical energy of 3×10^{-4} eV, calculate the ratio of the number density of microwave background photons to the number density of hydrogen nuclei.

5. Circinus X-1 is a bright X-ray source in our Galaxy. By analysing its spectrum, we deduce a hydrogen column density of $2\times10^{26}\,\mathrm{Hm}^{-2}$ in the direction of the source. If the average density of gas towards Circinus X-1 is $3\times10^{-21}\,\mathrm{kg\,m}^{-3}$, estimate the distance (in kpc) to Circinus X-1. If the measured

column density were $2\times10^{28}\,\mathrm{Hm^{-2}}$ instead of $2\times10^{26}\,\mathrm{Hm^{-2}}$, would you believe your distance estimate?

6. A large solar flare can be roughly modelled as a cylindrical region $5\times10^{7}\,\mathrm{m}$ in diameter and about $5\times10^{7}\,\mathrm{m}$ high, emitting thermal bremsstrahlung radiation at a temperature of $10^{7}\,\mathrm{K}$. The flux from the flare, integrated over all energies, is equal to $10^{-4}\,\mathrm{Wm^{-2}}$. Estimate the electron density in the flare, stating clearly any assumption that you make. Compute the thermal energy density of the flare region. If the magnetic field in the flaring region is equal to 0.2T, compute the magnetic energy density of the flare and compare it to the thermal energy density.

7. Consider a spherical cloud of ionised hydrogen near a supermassive black hole with $n_e = n_P = 10^{14}\,\mathrm{m^{-3}}$. Take the temperature and radius of this cloud to be $2\times10^{7}\,\mathrm{K}$ and $10^{8}\,\mathrm{m}$ respectively, and assume that it radiates only via thermal bremsstrahlung. Using the bremsstrahlung formulae from your notes for a uniform isothermal plasma, calculate the total X-ray luminosity in the range 0.1 keV – 100 keV. Suppose now that the ionised hydrogen is divided equally into 4 spherical clumps, each of radius $10^{7}\,\mathrm{m}$ and of constant number density. Compute the number density of each clump if the total mass of plasma remains the same. Assuming that each lump retains a temperature of $2\times10^{7}\,\mathrm{K}$, compute the combined bremsstrahlung luminosity from the 4 clumps. Has the luminosity increased, decreased or remained the same compared with the unclumped case?

8. (Not examinable material, but perhaps of interest to get you thinking). Estimate roughly how many X-ray photons (i.e. in the range 0.1 – 100 keV) a human will emit in their lifetime.

9. In the supernova SN1987A, in the Large Magellanic Cloud (at a distance of 50 kpc), it is estimated that $10^{46}\,\mathrm{J}$ of energy was released in neutrinos (each of mean energy 10 MeV). Estimate roughly how many neutrinos from SN1987A passed through each person on Earth.

10. Use the formula for the scale height for an isothermal atmosphere, from section 2.1 of your notes, to estimate the scale height of the (iron) atmosphere of a 1.4 solar mass neutron star of radius 10km and surface temperature $10^{6}\,\mathrm{K}$