Radiative Processes

1. A massive galaxy cluster contains a hot intergalactic medium which emits thermal bremsstrahlung X-rays at a temperature of 5×10^8 K. The total X-ray luminosity is 10^{38} Watts, and the radius of the cluster is approximately 1 Mpc. Assuming a uniform distribution of isothermal hydrogen gas, calculate the total mass of the plasma. You can further take that the total emissivity is given by

$$\varepsilon = 1.4 \cdot 10^{-40} \, n_e^2 \, T^{1/2}$$

(**2 points**)

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2. A quasar shows broad Hα emission lines from the hydrogen Balmer series, centred at 6563 Angstroms, with a width consistent with typical Doppler velocities of 4000 km s^{-1}. Show that thermal broadening cannot explain the width of this hydrogen line. What could explain the origin and width of these emission lines?

(**1 points**)

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3. A new object is discovered 100 Mpc from Earth, with an X-ray luminosity of 10^{36} W. Assuming that all photons are radiated at 1 keV, estimate the number of photons per second that would be detected by the Chandra X-ray telescope, which has an effective collecting area of 0.04 m^2 (at 1 keV).

(**1 points**)

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4. *The Eddington Limit*

(a) Show that the condition that a cloud of material can be ejected by radiation pressure from a nearby luminous object is that the object's mass to luminosity ratio (M/L) is be less than κ/(4πGc), where G = gravitational constant, c = speed of light, κ = mass absorption coefficient of the cloud material (assume isotropy and that κ is independent of frequency).

(b) Show that the maximum luminosity (referred to as Eddington luminosity L_{Edd}) that this object can have and still not be torn apart by radiation pressure is

$$L_{Edd} = 4\pi G M c \frac{m_p}{\sigma_T} = 3.3 \cdot 10^4 \left(\frac{M}{M_\odot}\right) L_\odot$$

The value for κ should be estimated for pure, fully ionized hydrogen as that due to Thomson scattering off free electrons.

(**3 points**)

Radiative Processes

Please also check the calculations marked '**(*exercise*)**' in the lecture notes as we also plan to discuss them. As a reminder, they were as follows (**1 point for each exercise**):

L1) only half of the gravitational energy released during grav. collapse is converted into kinetic energy:

$$\Delta E_{kin} = -\frac{1}{2}\Delta E_{pot}$$

L2) show that – under the assumption of hydrostatic equilibrium – the cumulative total mass profiles of a galaxy cluster follows:

$$M(<r) = -\frac{kTr}{G\mu m_p}\left(\frac{dln\rho_g}{dlnr} + \frac{dlnT}{dlnr}\right)$$

where ρ_g and T are the gas density and temperature, respectively. Assume an ideal gas.

L3) show that galaxy clusters follow the scaling relation:

$$M_{vir} \propto T^{3/2}$$

where M_{vir} is the total mass and T the gas temperature. For the calculation you can use/assume that...

- the cluster is in virial equilibrium,
- the total and gas mass are related via $M_{vir} = f_b M_{gas}$, where f_b is the (constant!) baryon fraction, and
- the total mass relates to the radius via $M_{vir} = D\, R_{vir}^3$, where D is a (cosmology-dependant) constant.