PHYSICS OF STARS & NEBULAE

TUTORIAL 1

PROBLEM 1 – ESTIMATES

(1a) Estimate the mean density and central temperature of the Sun.

(1b) How long would it take the Sun to collapse under its own weight if its internal thermal pressure suddenly vanished?

(1c) Estimate the temperature of the Sun's surface, assuming it radiates as a perfect blackbody. What is the wavelength at the peak of the blackbody spectrum for this temperature? What colour does it correspond to? The Planck function is

$$B_\lambda = \frac{2hc^2}{\lambda^5}[\exp(hc/\lambda k_{\rm B}T) - 1]^{-1}.$$

(1d) Consider instead a Supergiant with a surface temperature of $T_{\rm eff} = 26000$ K and luminosity $L = 2.6 \times 10^5\, L_\odot$. Estimate its radius, assuming it shines as a perfect blackbody.

(1e) If the average density of the Supergiant is the same as that of the Sun, what would its mass be? In fact its mass is only $25\, M_\odot$. How much smaller is its mean density than the Sun's?

You may use the physical constants $m_{\rm H} = 1.67 \times 10^{-27}$ kg (mass of the hydrogen atom), $k_{\rm B} = 1.38 \times 10^{-23}\,{\rm J\,K^{-1}}$ (Boltzmann constant), $h = 6.63 \times 10^{-34}$ J s (Planck's constant), $\sigma_{SB} = 5.67 \times 10^{-8}\,{\rm W\,m^{-2}\,K^{-4}}$ (Stefan–Boltzmann constant), $G = 6.67 \times 10^{-11}\,{\rm N\,m^2\,kg^{-2}}$ (gravitational constant), $c = 3.00 \times 10^8\,{\rm m\,s^{-1}}$ (speed of light).

The mass, radius, and luminosity of the Sun are, respectively, $M_\odot = 1.99 \times 10^{30}$ kg, $R_\odot = 6.96 \times 10^8$ m, and $L_\odot = 3.86 \times 10^{26}$ W.

PROBLEM 2 – RADIATIVE DIFFUSION

(2a) How long would it take a photon to escape from the centre of a Supergiant to the surface if it suffered no collisions?

(2b) Estimate the mean free path of a photon between electron collisions in a Supergiant. Use the mean density from (1e) above. (The mass of an electron is $m_e = 9.11 \times 10^{-31}$ kg and its Thomson cross–section is $\sigma_T = 6.65 \times 10^{-29}\,{\rm m^2}$.)

(2c) How many times will a photon scatter off an electron on its way from the centre to the surface of the Supergiant?

(2d) What then is the actual escape time for the photon?