Physics 435 – Quiz 2 – Radiation Pressure on Matter

Hydrogen, the main material content of the Universe, often falls onto stars in various situations in a process of *accretion*. Typically the hydrogen is at high temperature and therefore ionized. If the luminosity of the star is too high, radiation pressure will prevent hydrogen from falling onto the star. This very important limiting luminosity is called the *Eddington Limit*.

The radiation interacts primarily with the electrons in the plasma. The effective area of the electrons on which the radiation acts is the Thomson cross-section: $\sigma_T = 7 \times 10^{-25}$ cm^2. Each electron, however, effectively has a mass of the *proton* because as it gets pushed by the radiation it pulls a proton, which is oppositely charged, along with it.

a) Derive an expression for the Eddington Limit in terms of M and physical constants. You should find that the Eddington Limit does not depend on distance or stellar radius. Treat the electron as a perfect absorber.

Equate the radiation pressure exerted on an absorber of area σ_T to the gravitational attraction on a proton. The radiation pressure is $P_{\rm rad} = F/c$, where F is the flux. We get

$$\sigma_T \frac{L}{4\pi d^2 c} = G\frac{M m_p}{d^2},$$

where d is the distance from the star (which scales out of the problem) and M is its mass. We get

$$L_{\rm edd} = 4\pi \frac{G c m_p}{\sigma_T} M.$$

b) Numerically evaluate the Eddington Limit in cgs units for the Sun.

Putting in numbers for $M = M_\odot$ gives $L_{\rm edd} \simeq 10^{38}$ erg s^{-1}.

c) Obtain an expression that relates the Eddington limit in units of $L_\odot$ to an arbitrary stellar mass M in units of $M_\odot$.

The luminosity from part (b) is $4 \times 10^4 L_\odot$, hence

$$\frac{L_{\rm edd}}{L_\odot} = 4 \times 10^4 \frac{M}{M_\odot}.$$

In other words, if the Sun had 4×10^4 its current luminosity, the radiation pressure would blow its outer layers away; this will happen later in the Sun's life. Note how the result depends only on the mass.