Assignment 1 — due Monday February 7$^{\text{th}}$ [$Revision$: 1.1]

Question 1

In this question, we will explore the reason why the Sun exhibits a global, pressure-driven outflow from its surface – that is, the *solar wind*.

(i). Derive an expressions for the pressure as a function of radius, $P(r)$, throughout the Sun's corona (the hot, low-density region extending from $r \approx R_\odot$ outwards), under the following assumptions:

   (a) The corona is in hydrostatic equilibrium.

   (b) The corona contains a negligible fraction of the Sun's mass, and therefore you may set $M_r = M_\odot = \text{const.}$ when evaluating the gravitational acceleration g.

   (c) The corona is isothermal, and obeys the ideal-gas equation of state

$$P = \frac{\rho k T}{\mu u}$$

   (here, μ is the mean molecular weight — the particle mass in atomic mass units u).

(ii). Using your expression, find the relationship between the pressure at the base of the corona ($r = R_\odot$) and the pressure far from the Sun ($r \to \infty$).

(iii). At the base of the corona, the number density of particles is $n \approx 10^{14}\,\mathrm{cm}^{-3}$ and the temperature is $T \approx 10^6\,\mathrm{K}$. With a mean molecular weight $\mu = 0.62$, find the pressure far from the Sun.

(iv). By comparing this far-from-the-Sun pressure with the pressure of the ambient Local Interstellar Cloud (where $n \approx 0.1\,\mathrm{cm}^{-3}$ and $T \approx 6,000\,\mathrm{K}$), explain why hydrostatic equilibrium cannot hold, and a wind outflow must ensue.

(v). How do your results change if you assume that the corona is adiabatic rather than isothermal, with

$$P = K\rho^{5/3}$$

   (here, K is a constant which can be determined from the pressure and density at the base of the corona)? Is there still a wind? Can you explain, in physical terms, why the adiabatic and isothermal cases differ (hint: what must be added to the wind to keep it isothermal)?

Question 2

OK, so I said I wasn't going to be setting any problems from *Stellar Interiors*. But then I read through some of the problems, and they're really rather good. So, please answer the following from Chapter 1:

(i). 1.1 — this will require a little bit of research

(ii). 1.6 — note the author of this one!

(iii). 1.10 — a quickie.

Question 3

This question is aimed at getting you familiar with using *EZ-Web* and manipulating the data it produces.

(i). Use a web browser to visit the *EZ-Web* page (`http://www.astro.wisc.edu/~townsend/static.php?ref=ez-web`).

(ii). Read through the documentation on the page.

(iii). Construct an evolutionary sequence of stellar models covering the lifetime of the Sun, by submitting a calculation with the following parameters:

Initial mass: 1.0

Metallicity: 0.02

Maximum Age: 0 (i.e., unlimited)

Maximum Number of Steps: 0 (i.e., unlimited)

Create Detailed Structure Files: no (i.e., unchecked)

Email Address: Your email address

(iv). You will receive an email telling you how to download a zip file containing the calculation results.

(v). Unpack this zip file, to obtain a file `summary.txt` detailing how the Sun's various parameters change during the evolutionary sequence. This summary file is formatted as a table, with each row corresponding to a single time step in the sequence. The columns are defined on the *EZ-Web* page (see the 'Summary Files' subsection in the 'Output File Formats' section); so, column 1 is the step number, column 2 the age, column 3 the stellar mass, and so on.

(vi). With the aid of a plotting program of your choice[1], use the summary file to plot the *evolutionary track* of the Sun in the Hertzsprung-Russell diagram — that is, the $(\log T_{\rm eff}, \log L)$ curve followed by the evolving Sun. Note that the summary file does not list the effective temperature $T_{\rm eff}$; you'll have to calculate it from the stellar radius and luminosity.

(vii). On your plot, mark the ZAMS, TAMS (Terminal Age Main Sequence – where the central hydrogen mass fraction drops to zero), red giant branch and asymptotic giant branch. (You may want to review Chapter 2 of *Stellar Interiors*, esp. Fig 2.7).

[1] I *highly* recommend using IDL to do this. If you're not yet familiar with IDL, now's the time to learn — and I'll be happy to help out.