Stars and Planets I
AY 220A Winter 2025
Homework 6
Due March 3

Pick one of the following problems. There is no extra credit.

1 (100 points). The first stars formed in the Universe (Population III stars) were composed of only primordial gas. While the hydrogen and helium abundances of these stars are essentially unchanged, the differences in metal content can create some surprising results.

(a) Run a 100 $M_\odot$, zero-metallicity model from pre-main sequence through at least the point when He burning dominates the luminosity of the star. On Canvas, I have provided inlist files and an abundance file that will get you started.

Examine the abundances over time by plotting the H, He, C, N, O, Mg, Ne, and Fe abundance over time by plotting each abundance vs. stellar age. Remark on the behavior of the elements, especially considering the initial conditions and the state of the star when changes occur.

(b) To better understand the above results, plot the luminosity from p-p, CNO, and triple-alpha burning as a function of time. Describe what is physically happening as the star evolves during this time. Explain how the abundances and nuclear reactions are related. Explain how zero-metallicity stars behave differently from those with metals.

(c) Run 10- and 1000-$M_\odot$ zero-metallicity models. Run a 10 $M_\odot$ model at solar metallicity. Make sure all are run until at least when He burning dominates the total luminosity.

Make a Hertzsprung-Russell diagram for these stars with all data from your simulations. Comparing the luminosity from H burning to the overall luminosity, the time when they are first equal is roughly the start of the main sequence. Mark the ZAMS. Similarly, mark TAMS (a central H abundance of 10^{-2} is a good starting point to investigate). Mark the places on the HR diagram where the luminosity is dominated by p-p, CNO, or triple-alpha fusion.

Comment on how the evolutionary tracks differ between solar and zero-metallicity stars. Describe how the evolution of the zero-metallicity stars depends on what kind of burning is happening.

2 (100 points). We want to investigate the white dwarf sequence and particularly how their atmospheres affect observables.

(a) First, using a sample of nearby stars ($d < 100$ pc) with good colors (S/N in the blue and red bands $\geq$5) and excellent parallaxes (S/N > 20), identify the white dwarfs on a color-magnitude diagram. Because you are choosing your sample to be very close, there is generally very little dust. Therefore, you do not need to make reddening/extinction corrections. Include your query.

(b) Once you select the white dwarfs, use the Gaia cross-matches with SDSS to get white dwarfs with SDSS photometry. Plot color-magnitude diagrams in the Gaia bands (M_G vs. BP–RP) and in the blue SDSS bands (M_u vs. $u - g$).

(c) The provided CSV file (`SDSS_WDs.csv`) has a list of SDSS white dwarfs and their associated photometry. Cross-match with Gaia to create a list of spectroscopically classified white dwarfs in Gaia.

DA white dwarfs have hydrogen atmospheres, while DB white dwarfs have helium atmospheres and DQ white dwarfs have carbon atmospheres. With spectra, we can clearly separate these classes. The SDSS CSV file has an entry called "SpecType" that has these classifications.

On a separate plot, remake your color-magnitude diagrams for the Gaia white dwarf sample from (b), including all stars from (b). On top of that, plot the DA, DB, and DQ white dwarfs as distinct colors and label them. How do the stellar classes match up with the structure seen in the CMD? Remark on differences between the Gaia and SDSS CMDs.

(d) The position of a white dwarf on the CMD depends on its mass and age. Reproduce the CMD from (b) and plot the 0.2, 0.6, and 1.0 $M_\odot$ cooling curves. Connect the curves in intervals of 1 Gyr to create a grid for white dwarf cooling that depends on mass and age.

(e) Comparing to the provided cooling curves (there are several more models than used for (d)), determine the mass for each DA WD and plot their mass distribution as a histogram. Explain its shape.