MESA Long Problem #2

This lab concerns the evolution and pulsation of extremely low-mass white dwarfs, the so-called "ELM" white dwarfs. Recently, pulsations were discovered in this class of objects (Hermes et al. 2012), and the total currently known is 3 (Hermes, private communication). These stars have masses far too low to be the result of single star evolution; they must have been higher mass stars that sustained very high mass loss due to binary interactions. A priori, we have little information concerning their initial main-sequence masses.

We will use the models we saved during **Rapid Problem #2** as starter models for these calculations.

1. Since the ELMs that have been observed to pulsate have $T_{\rm eff} \sim 9000$ K, we will save models with this target temperature.

   Using as input the `wd3_0.15Msun.mod` model, edit the `inlist_wd4` file to evolve it down to 9000 K; save the output model from this as the file `wd3_0.15Msun_9000K.mod`.

2. Repeat this using the `wd3_0.20Msun.mod` file, and save the output model as the file `wd3_0.20Msun_9000K.mod`.

3. We now wish to pulsate these models. Detar the file called `pulse_mesa_work.tar.Z`; this will create the directory `pulse_mesa_work`. `cd` into this directory and type `clean` and `mk`.

4. Now copy over the inlist you just used to evolve the ELMs, `inlist_wd4`, into this directory, and copy over the model files `wd3_0.15Msun_9000K.mod` and `wd3_0.20Msun_9000K.mod` as well.

5. Either edit the file `inlist` to point to one of these new inlists or just do, e.g., `cp inlist_wd4 inlist`.

6. **Very important!!** Set `calculate_Brunt_N2=.true.` in the `&controls` section. If you don't do this then the pulsation calculations will be meaningless (perhaps this should be the default...)

7. Type `rn` to pulsate the model `wd3_0.15Msun_9000K.mod`. This will write the file freq.data. Rename this file as `wd3_0.15Msun_9000K.freq`.

8. Repeat for file `wd3_0.20Msun_9000K.mod`; save output as `wd3_0.20Msun_9000K.freq`.

9. Compute the approximate period spacing for the high overtone $\ell = 1$ and $\ell = 2$ modes for each of the sequences. To do this, make a plot of $\Delta P_n \equiv P_{n+1} - P_n$ versus P_n, first for the

$\ell = 1$ modes, and then for the $\ell = 2$ modes. Estimating by eye from your plots, is the ratio $\langle \Delta P_n \rangle_{\ell=1} / \langle \Delta P_n \rangle_{\ell=2}$ within each model close to the theoretically expected ratio for high-n g-modes?

10. Now let's compare the results for the different masses. Which mass model has the higher value of $\langle \Delta P_n \rangle_{\ell=1}$? If we naively say that $\langle \Delta P_n \rangle_{\ell=1} \sim M_\star^s$, where s is an unknown exponent, what value of s would you simplistically derive from the two different values of $\langle \Delta P_n \rangle_{\ell=1}$ as a function of $M_\star$?

11. Now edit the `run_star_extras.f` file in the `src` directory. Find the line which has `!extras_check_model = terminate` and uncomment this line. This will allow the code to continue to evolve while writing out pulsation data (this could be useful for grid-like explorations)? Now recompile with `mk`.

12. Run the code using the model `wd3_0.20Msun_9000K.mod` and let it write out the pulsation results for at least two consecutive models. For the $\ell = 1, n = -28$ mode, write down its period and the age of the model for the first two models. Use this information to compute the rate of change of the mode's period (dP/dt) in sec/sec. What is this value?

REFERENCES

"SDSS J184037.78+642312.3: The First Pulsating Extremely Low Mass White Dwarf," Hermes, J. J., Montgomery, M. H., Winget, D. E., Brown, W. R., Kilic, M., & Kenyon, S. J., 2012, ApJ, 750, L28