Lab 1: The Mass-Radius Discrepancy Amongst Low-Mass Stars

1 Starting with the `1M_pre_ms_to_wd` test_suite

For this set of labs we will use the `1M_pre_ms_to_wd` test_suite as our starting point. So lets begin by creating a working directory by copying this test_suite anywhere you like. Then cd into this working directory. As always, when you use a test suite outside of the test suite folder, you have to delete the line "`MESA_DIR = ../../../..`" from the makefile and the line "`mesa_dir = '../../..'`" from the main inlist.

Lets begin by making some changes to the default inlist file. We'll want to re-compute pre-MS models each time, so set (in star_job):
`create_pre_main_sequence_model = .true.`
`pre_ms_T_c = 7d5`
The second line above helps the initial models relax to an initial solution.
In controls, set:
`initial_Z = 0.020d0`
which sets the metallicity to "solar". Lets also start with photosphere atmosphere tables:
`which_atm_option = 'photosphere_tables'`
and a mixing length:
`mixing_length_alpha = 1.75d0`
Finally, lets turn off the rotation-related controls in `star_job`.
We want these models to terminate before they evolve off the main sequence. To do that we can specify a maximum age: `max_age = 1.0d10`
However, the higher mass models will evolve off the main sequence before 10 Gyr, so lets set another stopping condition:
`xa_central_lower_limit_species(1) = 'h1'`
`xa_central_lower_limit(1) = 0.1`
this will stop a star when its central H mass fraction drops below 0.1.
Hint: Some of these conditions will be already set in the inlist; make sure you don't have the same condition set twice.

2 Mass-Radius Relations

Go to the google spreadsheet for today (here). Select one of the masses by typing in your initials in the "student initials" column. Run models for each of the permutations listed in the spreadsheet. These include metallicity variations (Z =0.01, 0.02, 0.035), varying the surface boundary condition (between simple and τ = 100), and varying the $a_{\rm MLT}$ parameter. The default settings should be Z = 0.02, photo BCs, and $a_{\rm MLT} = 1.75$.

If you try running one of the low masses, the run will stop before reaching the main sequence. Why? Which setting do you have to change? The test suite is optimized for evolving a 1 $M_\odot$ star; which settings should be changed for a low mass star?

Once the spreadsheet has been filled in we will make plots of the results, comparing the models to the data.

Bonus (if you finish early):
Lets now explore the sensitivity of your default results to several assumptions. The parameter `max_years_for_timestep` controls the maximum timestep allowed by MESA. Try changing this to '1d8' or even shorter. Now try changing the nuclear reaction network to `basic.net`. Finally, try implementing the PTEH EOS (see L5488-5491 in controls.defaults). Record the percent change to your default radius in the google doc. Which if any of these changes influence the results? Why?

Lab 2: Detailed Modeling of a Binary System

1 The UV Psc binary system

Lets now focus on a single well-studied binary system, UV Psc, with key parameters listed in Table 1.

Figure 1 shows an example from Feiden & Chaboyer (2013) of attempting to fit this system in both radius-age and radius-T_{eff} diagrams, for "canonical" models. The shaded regions show the observational constraints.

For this lab, lets try to simultaneously fit the radius and T_{eff} for this binary pair. Lets assume the stars have a common age and metallicity, and we have the freedom to vary age, metallicity, α_{MLT}, and, as a bonus (if you have time), the initial helium abundance (`initial_y`).

To do this we are going to use `pgstar`. See here for how to plot R vs. T_{eff} and here for how to plot R vs. age. You will want to use the `R_Teff_target*` parameters to define the "target" box set by the observational constraints, and you'll probably want to define fixed axes as well. Try getting both of these plots in a single window using the `Grid1*` feature. You'll probably want to enable the option to save png files. See `star/defaults/` for the gory details. Note that you will need to modify the default `history_columns.list`.

Consider pairing up with someone so that each of you can be running one of the two masses required for this lab. Run the various permutations in tandem to more easily see which model parameters, if any, are able to reproduce the data.

Mass	Radius	T_{eff}
0.9829 ± 0.0077	1.110 ± 0.023	5780 ± 100
0.76440 ± 0.00450	0.8350 ± 0.0180	4750 ± 80

Table 1: data for UV Psc

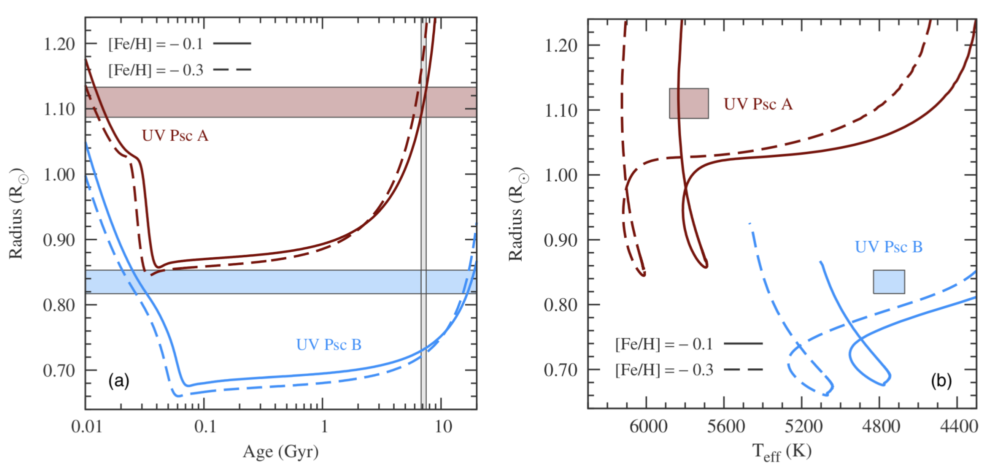

Figure 1: Reproduction of Fig. 1 from Feiden & Chaboyer (2013) showing their attempt to fit the UV Psc binary system with the Dartmouth stellar evolution model, considering variation in age and metallicity.

Lab 3: Inhibition of Convection with Magnetic Fields

1 Modifying MLT within `MESA`

As discussed in the lecture, there are good reasons to believe that the presence of magnetic fields will inhibit the onset and efficiency of convection. There are several models in the literature for incorporating the effect of magnetic fields. Here we will consider the model of Mullan & McDonald (2001, 2010; MM) in part because it is very simple to implement. The basic idea is as follows:

The usual Schwarzschild criterion for convection is defined according to:

$$\nabla_{\rm rad} > \nabla_{\rm ad}, \tag{1}$$

where $\nabla \equiv {\rm dln}T/{\rm dln}P$ and $\nabla_{\rm ad}$ and $\nabla_{\rm rad}$ and the adiabatic and radiative gradients, respectively. The MM prescription, which is based on earlier work by Gough & Tayler (1966), makes the following modification to the usual criterion:

$$\nabla_{\rm rad} > \nabla_{\rm ad} + \delta \tag{2}$$

where

$$\delta = \frac{B^2}{B^2 + 4\pi\gamma\, P_{\rm gas}}, \tag{3}$$

where B is the (vertical component of the) magnetic field (in Gauss), γ is the ratio of specific heats, and $P_{\rm gas}$ is the gas pressure (cgs units).

In this lab you will modify the treatment of MLT within `MESA` using `run_star_extras.f`. You will need to pass the input magnetic field from the inlist to `run_star_extras.f`, and you will need to define a new subroutine, e.g., `my_other_mlt` within `run_star_extras.f`, in which you compute δ and a modified adiabatic gradient, and then execute a normal call to the `mlt_eval` subroutine. Note that because we are modifying `run_star_extras.f` you will need to recompile `MESA` before running.

Use this new feature to try fitting the stellar parameters of the UV Psc system with a non-zero magnetic field. Consider experimenting with both constant δ and constant B models.

Hint: Take a look at `star/other/other_mlt.f90` for step-by-step instructions for implementing an alternative MLT prescription.
Hint: Consider magnetic field values of the order of a kG.