Minilab 1: Massive Stars Approaching the Main Sequence

For this first part of our work, we will build a massive star on the Hydrogen Burning Zero Age Main Sequence (ZAMS). All students will each have a unique mass star to explore during this whole lab this afternoon. You will pick a mass from a table in the Summer School Spreadsheet; we do this so that we fairly cover the mass ranges we wish to explore.

1 Starting in a blank work directory

Navigate to wherever you want to do your work, and copy a default work directory there.

```
cp -r $MESA_DIR/star/work minilab1
cd minilab1
```

Copy `history_columns.list`, and `profile_columns.list` from `$MESA_DIR/star/defaults/` into your new work directory.

2 Setting up your massive star model at ZAMS

Check the `&star_job` section of your `inlist_project` and make sure it tells the model to start on the pre-main sequence.

```
create_pre_main_sequence_model = .true.
save_model_when_terminate = .true.
save_model_filename = '<your selected mass between 3 and 100>ZAMS.mod'
```

Because we also want to be able to stare at pgstar plots at the end of the run, add the following to the `&star_job` section of your `inlist_project`:

```
pause_before_terminate = .true.
```

Open the MESA Summer School Spreadsheet to the Bildsten tab. Select and put your name next to one of the (unclaimed) masses between 3 and $100\mathcal{M}_{\odot}$. In `inlist_project`, change the initial mass from `initial_mass = 15` to

```
initial_mass = <your selected mass between 3 and 100>
```

To avoid numerical problems at the stellar surface due to the Fe opacity peak, we will be running models at low metallicity. This needs to be reflected in both the `&kap` and `&controls` sections of the inlist. In `inlist_project`, change the opacity base metallicity from `Zbase = 0.02` to

```
Zbase = 1d-4
```

and change the initial metallicity from `initial_z = 0.02` to

```
initial_z = 1d-4.
```

Also check the `&controls` section of your `inlist_project` and make sure that the model stops when the model reaches its ZAMS as typically defined:

```
Lnuc_div_L_zams_limit = 0.99d0
stop_near_zams = .true.
```

3 Reporting on the ZAMS Properties of your Star

In order to eventually test the Eddington standard model, and observe how stellar properties vary with increasing mass, we turn to crowd-sourcing! ***Read the following before executing*** `./mk && ./rn` ***to ensure that you are saving all the required output.***

In the MESA Summer School Spreadsheet, you will record the the **surface luminosity** (L, `luminosity`) in units of $\mathcal{L}_\odot$, **stellar radius** (R, `radius`) in units of $\mathcal{R}_\odot$, **central temperature** (T_c, `center_T`) in K, **central density** (ρ_c, `center_Rho`) in g/cm^3, and **mass of the convective core** (M_c, `mass_conv_core`) in $\mathcal{M}_\odot$, for your selected mass model **at the ZAMS**.

To save to the `LOGS/history.data` file, add or uncomment all the above quantities in the local `minilab1/history_columns.list` file copied from `$MESA_DIR/star/defaults`.

Finally, using `run_star_extras`, calculate and report the **ratio of the radiation pressure to the total pressure ($P_{\rm rad}/P$) at the half-mass coordinate** in the `MESA` model at ZAMS. E.g., if your model is $15\mathcal{M}_\odot$, you want to report $P_{\rm rad}/P$ at the $7.5\mathcal{M}_\odot$ coordinate. You can calculate $P_{\rm rad} = 1/3aT^4$ where a is the radiation constant $a = 7.5657 \times 10^{-15} \mathrm{erg} \cdot \mathrm{cm}^{-3} \cdot \mathrm{K}^{-4}$, or use the value stored in `MESA` as `s% prad`.

To do this, first edit the `minilab1/src/run_star_extras.f90` file in your work directory, and replace the line `include 'standard_run_star_extras.inc'` with the contents of `$MESA_DIR/include/standard_run_star_extras.inc`.

You can then make `MESA` print $P_{\rm rad}/P$ at the half-mass coordinate to the terminal (see the documentation surrounding `num_trace_history_values` in `controls.defaults`), and/or you can inspect LOGS/history.data at the end of the simulation run. Doing both is recommended2.34e4!

We encourage you to try to think of how you'd implement this yourself, following what you learned in the `run_star_extras` lab run by Josiah. However, if you need more inspiration, see the suggested pseudocode structure in the next page. If you're really stuck, see the solutions provided in the Dropbox. Once this is implemented, you're ready to run (`./mk && ./rn`)!

While the star is evolving, stare at the T-rho profile and chat with the people at your virtual table about what you see for your mass and how some properties appear to be different for people who ran different masses. Any trends of interest?

3.1 Hints:

Pseudo-code suggestion for calculating and reporting $P_{\rm rad}/P$ at the half-mass coordinate in your `run_star_extras`:

! In the `how_many_extra_history_columns` subroutine, set
`how_many_extra_history_columns=1`

! In the `data_for_extra_history_columns` subroutine,
! Find the half-mass coordinate:
!!! **COMMON PITFALL: make sure units of mass coordinate & star mass are the same**

```
do k=surface to center
    if mass coordinate <= star mass/2:
        set khalf = k
        exit (so it only stores once!!!)
    end if
end do
```

! Store $P_{\rm rad}/P$ at the half-mass coordinate:
! In the `data_for_extra_history_columns` subroutine, set
`vals(1)=s% prad(khalf)/s% P(khalf)`
! Also set
`names(1)='prad_div_p_half_mass'`.

If you want to be really fancy (and earn those ever-valuable `MESA` bonus points), you could interpolate across the cells bounding the half-mass coordinate, rather than using a single cell as suggested above, but for our purposes this should certainly suffice.