MESA tutorial: Session 3

Late Evolution of Massive Stars

Hand in your answers to all the numbered questions (i.e. 1 a, b, c etc.), they will make up your grade for the MESA practicum part of the course.

→ Download the MESA inlists needed for this tutorial from Brightspace (`session3.zop`). `hw3_inlist_to_C_exhaust` will be used for problem 1, while `hw3_inlist_problem2` is for problem 2 (and 3).

Pro Tip

Some of the models you will run in this practicum may take a long time (5-10 min) to complete. There is no need to wait for models to finish before starting on the analysis and plotting code!

1 Luminosity of Massive Stars at late stages

We have learned how stars spend their life balancing the energy they loose from their surface (aka Luminosity) with nuclear reactions from their core. Let's explore the contributions of various nuclear reaction chains to the photon luminosity, and compare this to neutrino losses during the life of massive stars.

- For this problem set, make a new copy of the `$MESA_DIR/star/work` directory and place `hw3_inlist_to_C_exhaust` and `history_columns.list` in your new working directory. In the `inlist` file, change `inlist_project` to point to `hw3_inlist_to_C_exhaust`. (for good measure you may want to remove `inlist_project`)
- ./clean; ./mk the directory, and ./rn MESA models at $M = 20, 30, 40 M_\odot$ through central C exhaustion. That is, change in the `&controls` section in `hw3_inlist`:

```
    xa_central_lower_limit_species(1) = 'c12'
    xa_central_lower_limit(1) = 5d-5
```

  Note the setting `log_directory = 'M20_HW3'`: will redirect your output to a new directory with this name, so you don't have to copy the whole work directory each time you want to run a new model.

Pro Tip

You will be making quite a few HR diagrams in this exercise. Consider creating a reusable Python function to streamline the plotting process.

(a) Plot the evolutionary tracks of the three massive stars on a single HR diagram as scatter plots, each colored by a different luminosity component: $\log(L_i/L)$ for i = H, He, and Z. (3p)

Clip the pre-main sequence evolution from your plot for clarity. For example, start from the first step with central hydrogen abundance < 0.69:

```
# find index of MS
start = np.flatnonzero(np.asarray(hist.center_h1) < 0.69)[0]
# select range of interest
print(hist.star_age[start:])
```

(b) Create a fourth plot. This will again be an HR diagram, but instead of phothon luminosity on the y-axis, use the luminosity emitted in neutrinos (`log_Lneu`) Color this plot by `np.log10(center_c12)`. (2p)

(c) Interpret your results. It might be helpful to compare your results to Figure 2 from Farag et al. 2020 (2p)

2 Radius evolution of massive stars

You need `hw3_inlist_problem2` for this exercise. This inlist results in more properly resolved stars (note the difference in HR diagram). Because of this it will take much longer run the late evolution, which is why we will only run the stars until core He exhaustion.

- Choose a mass between 15 $M_\odot$ and 40 $M_\odot$, and change the inlist accordingly. Don't forget to point the master inlist to `hw3_inlist_problem2` instead of `hw3_inlist_to_C_exhaust`
- As before, *change the* `log_directory = 'X'` for each new model you evolve! (Otherwise the data from the previous models will be overwritten.)

(a) Make a plot of the radius of the star versus the age. (1p)

- What are the fast and slow phases of evolution? When does the star expand, and when does it contract? By how much does the star expand during its evolution?
- Find the values of the radius of this star that delimit Case A, Case B and Case C of mass transfer. (See p. 225 in Chapter 15 of the lecture notes for a definition of these different cases.)

(b) If the star is in a binary system, in which phase in its evolution is it most likely that the star fills its Roche lobe?
Note: Observations show that the distribution of the orbits of binary stars is roughly uniform in $\log(a)$. For example, the number of binary stars with separations in the range 10–100 $R_\odot$ is similar to that in the range 100–1000 $R_\odot$. (2p)