Stellar Structure and Evolution 2023

Lab Assignment

1.Introduction

The goal of this assignment is to study the evolution of a 1.0 Msun star compare to the evolution a 2.0 Msun star of solar composition from pre-main sequence to white dwarf. This study will be performed via a numerical simulation using the module MESA Star of the code MESA.

You will already have received instructions on how to set MESA up.

2. Running the MESA star

Now that MESA is set up, you will run the simulation corresponding to the assignment which consists in studying and comparing the evolution of a 1.0 Msun star and of a 2.0 Msun star of solar composition from pre-main sequence to white dwarf.

The 1.5M_prems_to_wd folder contains the input information required for the run. The below instructions will allow you to download this file in a zipped form and will show you how to unzip it.

Download in your working directory the folder 1.5M.zip through the following link:

https://surfdrive.surf.nl/files/index.php/s/0BKR0dt9zFsmdjB

```
cd  your_location/your_working_directory
unzip 1.5M.zip
```

Before compiling and running the code, you will have to change the initial mass of the simulation (setting it to 1.0Msun or 2.0 Msun).
This can be done changing the initial mass parameter in the file 1.5M_prems_to_wd. Note that you will also have to change the inlist file if you remane 1.5M_prems_to_wd file.
You can create two directories: e.g. 1.0M_prems_to_wd and 2.0M_prems_to_wd.

Once you have set the initial correct mass, enter the folder, compile and run the code.

```
cd 1.5M_prems_to_wd
source $MESASDK_ROOT/bin/mesasdk_init.csh
./mk
./rn
```

If you experience an error in the above four steps, please try ‘source ~/.cshrc’ and retry.

It should run for a about an hour. In the meantime, you can start analysing the output files created during the simulation.

3. MESA output

The output files that you need to complete the assignment are in the LOGS folder (the whole content of the LOGS folder is overwritten when a new simulation is launched. Therefore, the codes written for the analysis of the output files should not be put in this folder). They consist of a collection of files profile#.data. Each of these files contains information on the star at a given time.
They all have the following structure:

column numbers for the global properties of the star
column names for the global properties of the star
current values of the global properties of the star
blank line
column numbers of the zone properties of the star
column names for the zone properties of the star
current values of the zone properties of the star (1 line per zone)

The zones are ordered from the surface to the core, zone 1 corresponding to the surface and the last zone corresponding to the core.

The global properties of interest for the assignment are:
- star_age – age of the star in yr,
- num_zones – numbers of zones,
- Teff – effective temperature in K,
- photosphere_L – luminosity at the photosphere in Lsun.

The zone properties of interest for the assignment are:
- zone – zone number,
- logT – logT where T is the temperature in the zone in K,
- logRho – logRho where Rho is the density in the zone in g cm^-3
- logR – logR where R is the radius of the zone in R,
- grada – adiabatic gradient
- gradr – radiative gradient

The instructions provided to Mesa Star to run the simulation are contained in the file inlist_1.5M_prems_to_wd. This file contains numerous parameters which can be varied. However you should only modify those concerning the output files (and the initial mass). These parameters, located under the line &controls, are the following:
- profile_interval - frequency in terms of tImesteps at which profile#.data files are written. Mesa Star computes the structure of the star at each timestep and these timesteps can be very short.

Therefore, creating a profile#.data file at each timestep is unnecessary and consumes a lot of disk space. The frequency in terms of timesteps at which profile#.data files are written is set by the parameter profile_interval. It is set to 50 by default which means that a profile#.data file is written every 50 timesteps. You need to adjust this value depending on how many points you want in your plots and what is sensible in terms of disk space. Note that the timesteps vary during the simulation. Therefore, even though the profile#.data files are written at even intervals in terms of timesteps, they are not necessarily written at even intervals in time. Furthermore, during important events of the evolution, profile#.data files can be written more frequently than specified by profile_interval.

- max_num_profile_models - maximum number of profile#.data files that can be written. It is set by default to 150. This value should be increased if more than 150 profile#.data files are created during the simulatioon. Otherwise, when profile150.data is reached, the previous files will be overwritten starting from profile1.data.

4.The assignment

The assignment for this computer lab is composed of running the above simulations, making eight plots (four for each stellar mass) using the output files and writing an essay. The plots and the essay can be produced with any program you want. You need to create four plots to analyse the evolution of a 1.0Msun star (and four plots for the evolution of the 2.0Msun star) of solar composition from pre-main sequence to white dwarf. The plots and the instructions to produce them are the following:

Evolution of the core in the log T_c – log ρ_c plane

- Using the output files created during the simulation, plot the evolution of the core in the log Tc − log ρc plane where Tc and ρc are the temperature and density of the core respectvely. Use log Tc as the horizontal axis and log ρc as the vertical axis.
- Label the evolutionary stages.
- Indicate the age of the star at different places.
- Indicate the regions of the log Tc − log ρc plane corresponding to the four different equations of states. Derive the equations delimiting these different zones.
- Add the theoretical evolutionary track of a 1.0Msun (and 2.0Msun) star in the log Tc − logρc plane.
- Mark the current position of the solar core.

Hertzsprung-Russell diagram

- Using the output files created during the simulation, plot the evolution of the star in the Hertzsprung-Russell diagram, that is in the log Teff − log L plane where Teff is the effective temperature and L the luminosity of the star.
- Label the evolutionary stages.

- Indicate the age of the star at different places.

Convection in the pre-main sequence phase

- Plot the adiabatic and radiative gradients as a function of radius when the star is in the pre-main sequence phase. You only need to make use of a single profile#.data file. However, this file has to correspond to the pre-main sequence phase.
- Label the regions where convection occurs.

Convection in the main sequence phase

- Plot the adiabatic and radiative gradients as a function of radius when the star is in the main sequence phase. You only need to make use of a single profile#.data file. However, this file has to correspond to the main sequence phase.
- Label the regions where convection occurs.

Finally, you need to write an essay about the evolution of the stars. The essay must be written according to the following structure:

1. Introduction

2. Methods: This section must only contain one paragraph. A precise description of the code is not required.

3. Results: In this section, you must present the eight plots and describe them without interpretation.

4. Discussion: This section is the most important. It must contain one subsection for each evolutionary stage of the star. In each subsection, you must explain physically and in detail the evolution of the star based on the four plots, and compare the evolution of 1.0Msun star to the evolution of 2.0Msun.

5. Conclusion

The lectures and the reading materials must be enough for you to complete this assignment successfully. However, you can use other sources if you want. If you do, cite these sources in an appropriate manner. **The essay should not exceed 6 pages of A4 size, including figures. The figures should not be larger than half of an A4 and the 6 pages are to be counted in Times New Roman font of size 12.** Please do indicate your student number(s) on the assignment.

5. Important information

The deadline to hand in the essay is 4th of May at 9am. Please send your essay in PDF format to rota@strw.leidenuniv.nl, ychen@strw.leidenuniv.nl, and cordun@strw.leidenuniv.nl

The will be graded by May 12th. **The essay can be written in pairs. This is preferred but doing it on your own is also allowed.**