Problem Set 9

Parts A-B Due Monday, December 3 in class

Part C Due via Moodle by Friday, November 30 at 10am

Part A - Conceptual

1. Describe the mechanisms of the "Internal Stellar Thermostat". How does it work and why is it important?
2. Describe qualitatively each stage in the evolution of a <8Msun star from gravitational contraction to the white dwarf stage. For each stage, make sure to address:
    a. What fuel is it burning and where?
    b. Which way does it move on the H-R diagram and why?
    c. How does its surface and core temperature change?
    d. How does its size and density change?
    e. How long does it spend here as a proportion of its total lifetime?
3. Describe how the Heisenberg Uncertainty Principle and the Pauli Exclusion Principle are applied in understanding the conditions in a white dwarf.

Part B - Quantitative

1. Maoz 4.1
2. Maoz 4.3

Part C – Computational – Install and Test MESA Stellar Evolution Code

In lab this week we will be using the MESA (Modules for Experiments in Stellar Astrophysics) code, which is an open source code with lots of complex physics in it. It allows you to visualize all kinds of things that are going on inside stars as they evolve. You should do and submit all of the following before lab on Friday, November 30.

1. Install MESA on either your own computer or one of the classroom computers (note – only works on Mac or Unix machines). I outline the steps below. As always with computational things, every computer will be a bit different here, so please try this early in the week in case you run into trouble.
    a. Download a binary file with all of the MESA dependencies (called MesaSDK) from this website: http://www.astro.wisc.edu/~townsend/static.php?ref=mesasdk. Make sure to download the binary for your version of MacOS (if you're not sure, click on the apple icon in the upper left corner and select "About this Mac" to get your version).
    b. Double click the binary file that you downloaded and drag and drop the MesaSDK folder into the /Applications directory on your Mac.
    c. Open a terminal window. Type `emacs .bashrc` to open a terminal-based text editor. Add the following lines to your .bashrc file:

```
export MESASDK_ROOT=/Applications/mesasdk
source $MESASDK_ROOT/bin/mesasdk_init.sh
export MESA_DIR=/Applications/mesa-r10398
```

`export OMP_NUM_THREADS=4`
Double check that you actually have 4 cores on your machine (specified with `OMP_NUM_THREADS` above) by clicking the Apple → "About this Mac" → "System Report". If you have a different number, change the value for `OMP_NUM_THREADS`

d. To save the file in emacs, type control + X then control + S. To exit emacs, type control + X then control + C.
e. In your terminal, type `source ~/.bashrc`

2. Install command line tools
   a. Open a terminal and type `xcode-select –install`. You may receive a notification that it is already installed.
3. Install Mesa from here: https://sourceforge.net/projects/mesa/files/releases/mesa-r10398.zip/download. This will download a zip file, which you should unzip and drag to the /Applications folder. If you have any trouble, see the Mesa installation instructions for help: http://mesa.sourceforge.net/prereqs.html
4. Follow the Mesa "getting started" instructions here: http://mesa.sourceforge.net/starting.html
   a. Note that ./mk may return **warning** messages about your version of OSX, but these are fine to ignore
5. Test your installation. Note that you should do this in the application XQuartz and not with Terminal.
   a. After copying over the tutorial file per the instructions, run it! It is set up to show you the Pre-main sequence evolutionary track for a 15 solar mass star, and the model should run pretty quickly (just a minute or two).
   b. Note that when you run a MESA file with ./rn, there will be some output to the terminal and two new plot windows will pop up. These will close automatically when the run finishes.

A few notable things about MESA:

1. The timesteps made in the code are not necessarily equal. They get shorter when interesting things are happening and sometimes it is necessary to iterate on a model to get a self-consistent solution for a given timestep. Watch the "age" in the upper left corner of the plots. Sometimes when things in the plot seem to change rapidly you'll note that the age isn't changing even though the models are. This is the code iterating until a self-consistent solution is reached.
2. You may wish to change or swap out certain variables in the inlist_project and inlist_pgplot files. On the MESA homepage, the "controls_defaults" and "pgstar_defaults" menus may prove useful. In particular, you may wish to investigate:
   a. "timestep" controls (search the controls defaults webpage for "timestep")
   b. "stop" controls (search the controls defaults webpage for "stop")
   c. Plot window limits for the H-R diagram at the top of inlist_pgplot

Questions to answer and submit via Moodle:

1) For the original tutorial model (15 Msun star evolution onto main sequence):

   a. Explain the evolution on the HR diagram in the pre-main sequence phase for this star. Include a screenshot of the H-R diagram (you'll have to capture it before it closes)
   b. Explain what the TRho_Profile plot shows. What changes there as the star evolves? How might this information be useful in building intuition about the star

2) Do the first steps of the "Hands-On Tutorial" under "using pgstar" (stop after the third black box, where it says "when you're finished admiring these beauties…"). List the different types of plots that MESA can generate and give a brief description of each and what you think it's showing. Don't try to understand all of the details of every plot, but highlight the ones that you think will be the most useful or intuitive and note what they might be useful for understanding. When you're done, follow the instructions in the "Output to files" section to write out the HR Diagram evolutionary track (HR_win) to a file. Allow the model to finish running (it will take a while!) and include the last H-R diagram plot in your writeup.
   A few other tips:
   a. Note that the tutorial can all be done while a single model is running. It has you change the types and details of the plots that MESA + pgplot can generate, and they should update at the next timestep as the model is running.
   b. The code will read from the inlist and inlist_1.0 files, which are just text files that you can edit in any text editor. You shouldn't touch the inlist_1.0 file except to go in initially and delete all of the content in between the line `&pg star` and the line `/ ! end of pgstar namelist`. All other changes should be made to the file called simply inlist.
   c. Make sure that the line `pgstar_flag = .true.` is in the inlist file under the `&star_job` section before you start the model running
   d. Note that any content that you add needs to be indented for the code to "see" it.
   e. When you save the inlist file, if pgstar needs to close a window, it will stop running the model and give you a prompt in the terminal (the window where you did your ./rn). You just need to hit enter there
   f. Make sure to watch each plot for a few minutes as the model runs to understand what is changing.

3) Edit the inlist file from the pgstar tutorial exercise or the inlist_project file from the original tutorial to do the following. In each case describe what parameter(s) you changed and describe any differences in the H-R diagram evolutionary tracks relative to earlier models and/or what we learned in class. Follow what you did in (2) to save a plot of the final H-R diagram evolutionary track and include it with your explanation.
   a. Evolve a 1 solar mass star to the main sequence.
   b. Evolve a 5 solar mass star to 10Gyr.