Senior astrophysics Lab 2: Evolution of a 1 $M_\odot$ star

Name:

Checkpoints due: Friday 13 April 2018

1 Introduction

This is the first of two computer labs using existing software to investigate the internal structure and evolution of stars.

In this lab, we will follow the evolution of a $1 M_\odot$ star from the birth of the star (time $t = 0$), through the main-sequence phase and toward the giant branch.

As discussed in lectures, this software calculates a sequence of static models, describing the changes in the internal structure of the star as a function of time. Each model is a description of the state of the star (pressure, density, temperature, etc.) for a single time; a stellar model *sequence* is a series of such models for many consecutive times $t, t + \Delta t, \ldots$.

2 Window to the Stars

You will be using a program called *Window To The Stars* (WTTS)[1] to make your own stellar model sequences.

This program is installed on a Linux server in the School of Physics, so you need to connect to it using the NoMachine remote desktop. In order to do this, you will need to set up the connection. This only needs to be done once; in future weeks, you can just connect to the server and start working.

To set up the connection:

- From the Windows menu, go to `All programs` and run `NoMachine`.
- Click `Continue` on the opening screen (you might want to select `Don't show this message again` on all the help screens).
- In the orange bar, select `New`. Then on the next few screens, select
  Protocol: NX
  Host: skyscape.physics.usyd.edu.au, **port**: 4000
  Authentication method: password
  Don't use proxy
  Name for connection: astro

[1] WTTS is a free user interface to a stellar evolution code called TWIN. You can find details of the code, installation instructions and a manual at the website www.astro.uni-bonn.de/∼izzard/window.html.

This completes the set-up of the connection, and you should now be back in the `Recent connections` screen. When you next open `NX`, you will see an icon called `astro`, so you can skip straight to the next step.

2.1 Connecting to the Linux server

If you haven't already done so, expand the window to the whole screen with the left button at the bottom. Double-click the `astro` icon to start the session. (If asked to verify the host authenticity, click `Yes`). Then enter the username and password given to you. Choose `Create a new virtual desktop` on the next screen, and you're logged in.

(You will see a whole series of help screens the first time you run the program. You may want to check the `Don't show this message again` button on the lower left).

2.2 Running WTTS

You are now on a Linux desktop. Right-click on the desktop background and select `Open terminal`. It is probably a good idea to create a new subdirectory for your work, as WTTS creates a lot of files while running; e.g.

```
mkdir WTTS
cd WTTS
```

You can now start WTTS by typing

```
wtts &
```

in the terminal window (the ampersand starts the program in the background, so you can still use the terminal window).

2.3 Evolving a sun-like model

Start WTTS, then load the Zero-Age Main Sequence (ZAMS) model of a star like the Sun: On the main *Options* page, do *Reset from defaults*. Select the button *From ZAMS Library*. To the right of this are three menus for Z (choose 0.02), M1 (choose 1) and M2 (choose anything: WTTS allows the evolution of two stars, but we're only interested in one).

In the *Operations Mode* tab, check that INIT_RUN.ISB is set to 1 (single star operation) and INIT_RUN.KTW is set to 1, and set INIT_RUN.KPT to 750 (originally 1).

In the *Evolve* tab, click on *Clear Log Window*, then click *Evolve*.

After a few seconds, you should see lots of text appearing. Click on *Follow Log* to see the latest messages. The program will stop when the evolution is finished, or when it reaches 750 models. The last line of the log file should read *Evolution done*[2]. (This will take several minutes, so get it started as soon as possible).

Save your model sequence by going to the *Load/Save Tab*, then clicking on *Save Model Set*. Give it a sensible name like `sun`, since it is a model for the Sun. This will save a file called `sun.zip` in the directory where you're running `wtts`. If the program crashes, or you want to come back to it later, you can re-load this model instead of calculating it again from scratch. You will also want this model again for the following lab.

[2]Sometimes you get an error, but the sequence has been made anyway, so just continue.

2.4 Loading an existing model sequence

You can use the *Load/Save Tab* to load a model sequence that is already calculated; for instance, there is one on the eLearning site called `sun1.zip`. If you need to load a model, copy it to your directory, then start WTTS and load it in the *Load/Save Tab*.

3 Exercise 1: Solar model

Now we are going to explore this model.

The primary tool of stellar evolution is the *Hertzsprung-Russell diagram* (HRD). This is a graph with the effective temperature (T_{eff}) on the x axis and stellar luminosity on the y axis. Click on the HRD tab: you should see the HRD of your model sequence.

Q1 Sketch the HR diagram for your star.

Q2 What are the effective temperature and luminosity of the starting model? What are the units?

Q3 What are the maximum temperature and luminosity the model eventually reaches?

You can zoom in and out by manually setting the *X Range* and *Y Range* boxes. To have the ranges set automatically set the boxes to * (asterisk). You can label the curve in the

HRD with one of many variables. The default is the *Age*, which is just the age of the star (in years). Note the labels along the curve. You can try selecting something else from the *Label With* drop-down menu. If you have too many/not enough labels, simply reduce/increase the *Label Spacing*.

Q4 Switch between *Age* and *Model number* as labels. Which direction does the star travel, i.e. at which end of the curve does it start and end?

Locate the point in the HRD corresponding to the same luminosity as our Sun has now.

Q5 What is the approximate age (to 2 significant figures)? What is the effective temperature? Is this a good model for the Sun?

▶ **CP1** Tutor's initials

4 Exercise 2: Internal structure

Go to the *Structure* tab.

You will see some options on the left and an image panel on the right. By selecting some of the options you can display information about various stellar structure variables, such as the central temperature, chemical composition etc. as a function of (usually) time. Set the x axis variable to *Age*; the buttons below govern whether you plot linear, log or 10^x for both x and y axes. You can enter ranges manually, or use * to autoscale.

There is a long list of variables you can plot on the y axis. Start with *Log Luminosity* and check the age when the star passes through the Sun's current luminosity. By plotting *Model Number* on the x axis you can find the model number corresponding to the model with the current solar luminosity.

Q1 Which model has the Sun's luminosity? What is its age?

Q2 Now plot *log Central Temperature* on the y axis. Sketch the graph below.

Q3 How hot is the centre of the star at age zero? What is the final temperature?

Q4 What is the central temperature in the model most like our Sun?

Q5 At what age does the central temperature level off?

Now choose *Central abundance of H* for the y axis.

Q6 How long does it take for the star to exhaust its central H supply? How and why does this affect the central temperature?

Now choose *Central abundance of He* but do *not* deselect the hydrogen abundance.

Q7 What is the initial helium abundance? Why does the helium abundance increase as a function of time?

Q8 What is the final helium abundance? Has helium burning started at the end of your model set? Why or why not?

Now go to the *Internals* tab. Select pressure P for the y-axis and `X axis: shell#`, in order to plot the central pressure as a function of shell number. This changes as a function of time (model number), so choose just the model most like our Sun (from CP2 Q1), using the grey bars at the bottom left.

Q9 What is the central pressure for this model? How does this compare to the value we estimated in lecture 5? (Note that WTTS is working in cgs units, so the units of pressure are dyn/cm^2 = 0.1 Pa).

▶ **CP2** Tutor's initials

5 Exercise 3: Stellar radius

Q1 Going back to the *Structure* tab: plot the radius of your star as a function of time.

Q2 When does the star pass through the current solar radius?

Q3 Is this a good model for the Sun? How close is it to your answer in question 2? Comment.

▶ **CP3**

Tutor's initials