Stellar Structure Modelling

Computer exercises for the course in Stellar Structure and Evolution, Ht2003

Lab report due: Thursday, 9 October 2003 at 10:15 a.m.

1 Introduction

In this computer exercise, you will generate models of stars on the zero-age main sequence (ZAMS) in order to examine and compare their properties. The computer program that you will be using to create the models is called `zams.f` and comes from the book *Stellar Interiors* by C. J. Hansen and S. D. Kawaler. It is worth reading chapter 2.2 of this book, "Single Stars On and Near the Main Sequence," to get an overview for this project. You can also read a bit more about the computer code itself in Appendix C. Finally, if you are interested in more details of stellar modelling (which however are not required), chapter 7 of the book contains information about the numerical methods used to produce such models.

2 Getting started

Copy the program's source code from the lab directory into your own working directory (named, for example, ZAMS). You can do this with UNIX commands in a terminal window, e.g.:

```
mkdir ZAMS
cd ZAMS
cp  /u1/local/lab/stjarnstruktur/zams/zams.f  zams.f
```

Then compile the Fortran 77 program:

```
f77 -o zams zams.f
```

This will give you an executable file called `zams`, which you run by simply typing its name. The program will ask you for the stellar mass and the hydrogen and helium content, as well as your guesses for the central pressure and temperature, the total radius and the total luminosity. (Do not bother with pulsation output.)

The lab directory contains a number of useful files, such as the text files `modin.001` and `modin.015`, which show examples of the screen input. Note that numbers such as 6.93×10^{10} are entered in exponential notation (`6.93e10`).

You will soon notice that your initial guesses should not lie "too far off" from the solution, or else the numerical algorithm will fail to converge and you will get a message complaining about the equation of state (EOS). In that case, you will have to think about how to make better guesses for the starting values. If your guesses are better but not quite good enough for the program to converge within 15 iterations, try changing the value of `NTRY=15` on line 128 of the source code to something larger; then recompile and run the program again.

The generated output file (with whatever name you gave it) will include information such as the following:

****FINAL MODEL*****
P_c: 1.4820D+17,
T_c: 1.4419D+07,
R: 6.9321D+10,
$\mathcal{L}$: 3.4942D+33
$T_{\rm eff}$: 5.6522D+03,
$\log T_{\rm eff}$: 3.7522,
$\log(\mathcal{L}/\mathcal{L}_\odot)$: -.0418

****

depth point	$1-\mathcal{M}_r/\mathcal{M}$	$\log r$	$\log P$	$\log T$	$\log \rho$	$\log \mathcal{L}_r$
2	9.98776351D-01	9.28096	17.1603	7.1551	1.9145	31.6380
3	9.97511452D-01	9.38525	17.1539	7.1528	1.9104	31.9306
4	9.96203968D-01	9.44732	17.1483	7.1507	1.9068	32.1041
5	9.94852527D-01	9.49218	17.1432	7.1489	1.9035	32.2283
6	9.93455716D-01	9.52763	17.1383	7.1471	1.9004	32.3255
7	9.92012082D-01	9.55714	17.1336	7.1454	1.8973	32.4054
8	9.90520130D-01	9.58255	17.1290	7.1438	1.8943	32.4735
9	9.88978322D-01	9.60498	17.1245	7.1422	1.8913	32.5329
10	9.87385079D-01	9.62512	17.1200	7.1406	1.8884	32.5856
...						

depth point	$\log \epsilon$	$\log \kappa$	$\log \mathcal{L}_r$(conv)	$\frac{\mathcal{L}_{\rm r}({\rm conv})}{\mathcal{L}_{\rm r}({\rm tot})}$	∇	∇_{ad}	∇_{rad}
2	1.2278	.1844	.0000	.0000	.37297	.39887	.3730
3	1.2131	.1885	.0000	.0000	.36572	.39887	.3657
4	1.2006	.1920	.0000	.0000	.36252	.39888	.3625
5	1.1891	.1952	.0000	.0000	.36040	.39888	.3604
6	1.1783	.1982	.0000	.0000	.35874	.39888	.3587
7	1.1678	.2010	.0000	.0000	.35733	.39888	.3573
8	1.1577	.2038	.0000	.0000	.35607	.39889	.3561
9	1.1478	.2065	.0000	.0000	.35490	.39889	.3549
10	1.1380	.2092	.0000	.0000	.35380	.39889	.3538
...							

3 Exercises

The idea is to use this lab to explore and get an overview of the properties of main-sequence stars. Below are some questions for you to consider.

1. Read the description in chapter 2.2 of Hansen and Kawaler about the stellar modelling code. What approximations have been made and what would be needed to get more realistic models? What is the range of applicability of the models, i.e., in what range are the models reasonably realistic and when should you be a bit skeptical of the model output?

2. Generate a series of models with solar composition. (Later, in order to compare the effects of chemical composition, do the same for models of more metal-rich or metal-poor stars, in which you will have to decide on reasonable values for the metallicity Z. Note that for exercise 8 below, it is important to choose the same stellar masses in each case.)

3. You undoubtedly had to experiment with making initial estimates that are close enough to produce convergent stellar models. Report what methods and assumptions you tried, what difficulties you may have had, and how you managed to find good initial guesses. Be detailed in explaining the calculations and approximations you made.

4. Choose three stars of different masses and investigate the important quantities as functions of radius and of mass. Plot the quantities so that the structural differences between the stars can be compared easily at a glance.

5. Examine the different temperature gradients and explain how to identify the convective zones in your models. Use plots to get an overview of the different extent of convective zones in models of different masses, and discuss the reasons for those differences.

6. How do the central temperature, density, energy generation rate, and effective temperature change according to the mass of the star? Interpret these results!

7. Use fits to determine the mass-radius and mass-luminosity relations.

8. Now study the effect of metallicity by comparing models with different chemical compositions. For a given mass, which chemical composition has the largest central temperature? The largest central density? The largest energy generation rate at the center? Explain why this is so.

9. Use your data to plot the zero-age main sequence in the traditional $\log \mathcal{L}$ vs. $\log T_{\rm eff}$ diagram. How does the ZAMS differ for stars of different chemical compositions? How do you account for the differences in effective temperature and luminosity between two models of the same mass but different chemical composition?

4 Report

Write up your results in a report that describes your investigations and conclusions, using text and a limited number of educational plots. Be sure to think carefully about what is the best way to present your data.

In addition to whatever programs you may already be using, the computer system at the Observatory has a number of tools for your use. For those of you who would like to write your report in the typesetting language LaTeX, which is widely used by astronomers, you may use the computer file `ZAMS_lab.tex` with these instructions as a template.

Very nice plots can be produced using IDL (Interactive Data Language). The lab directory `/u1/local/lab/stjarnstruktur/zams` contains a few help files (see the `README` file there), including the IDL routine `readzams.pro` to read model output into an IDL array, and a sample batch file `myplot.pro` to produce a Postscript plot.

Finally, if you have comments about how to improve this laboratory exercise, they are very welcome!

The software for this exercise was developed by C. J. Hansen and S. D. Kawaler, in *Stellar Interiors: Physical Principles, Structure and Evolution*, Springer-Verlag, 1994. This computer exercise (version 2003 by M. Mizuno) was based on the one written by Nils Ryde on September 15, 1997.