Stellar Structure Modelling

Computer exercises for the course in Stellar Structure and Evolution, Fall 2002

Lab report due: Thursday, 17 October 2002

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, 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 about having a pulsation output.) The text files `modin.001` and `modin.015` in the lab directory show examples of the screen input, where numbers like `6.93e10` are entered in exponential notation.

Note that your initial guesses should not lie “too far” off from the solution, or else the numerical algorithm will not 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, recompiling and running 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,
L: 3.4942D+33
T_{eff}: 5.6522D+03,
$\log(T_{eff})$: 3.7522,
$\log(L/L_\odot)$: -.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	$\log(\epsilon)$	$\log(\kappa)$	$\log(\mathcal{L}_r(\mathrm{conv}))$	$\frac{\mathcal{L}_r(\mathrm{conv})}{\mathcal{L}_r(\mathrm{tot})}$	∇	∇_{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 Questions to consider

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 in order to do exercise 8 below, it is important to choose the same stellar masses in each case.)

3. To get converged models, experiment with making initial estimates that are close enough to produce convergent stellar models. Produce models for at least three stars of different masses. Report what kinds of 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. For a given chemical composition, choose three stars of different masses and investigate the different quantities such as mass, radius, density, pressure and temperature 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. Again for a given chemical composition, 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. Again looking at models of the same chemical composition, compare how the following quantities change according to the mass of the star: central temperature, central density, central energy generation rate, and effective temperature. Interpret these results!

7. Use fits to determine the mass-radius and mass-luminosity relations (i.e., how the total stellar radius and the total luminosity depend on the total stellar mass).

8. Now study the effect of chemical composition by comparing the models with different chemical composition. 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 $\log \mathcal{L}$-$\log T_{\rm eff}$ 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

Present your results in a written report that describes what you have been investigating and the results you achieved, both in text and pictures. Please think about the best way to plot interesting quantities in a limited number of diagrams.

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). You can learn more about both of these tools by following the links on

`http://www.astro.uu.se/~mizuno/Teaching/`

The lab directory `/u1/local/lab/stjarnstruktur/zams` contains the IDL routine `readzams.pro` to help you read model output into IDL arrays, as well as `ps_open.pro` and `ps_close.pro` to produce Postscript output. If you have any problems, Michelle is in the office until October 11 and can offer some help with IDL and the other tools.

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 is the version by Michelle Mizuno, October 2002, based on the one written by Nils Ryde on September 15, 1997.