Assignment 3: Degenerate electrons

After finishing the long phase of core hydrogen burning, stars extend their envelopes when they enter the red giant phase. At the same time their core undergoes contraction due to the lack of nuclear burning. At some point the density in the core becomes high enough for quantum effects to play a role in the pressure of the electrons. The increased pressure due to electron degeneracy is what prevents the core from contracting any further.

The notes from lectures 4 and 5 will be helpful in solving the tasks below.

Tasks

a) Start from the work directory for this assignment. It is set to start from a $1\,M_\odot$ star just at the onset of a He flash. Let MESA simulate the flash for half a year of physical time. Use the last profile file to create a log-log plot of all density and temperature values in the star at that particular point in time. Do *not* just use the plot created by MESA during the simulation, but create it yourself using the data from the profile file. State the ρ–T coordinates of the core and the surface of the star.

b) The quantity $1/\mu_e$ is the average number of free electrons per nucleon. What is the value of μ_e in the core and at the surface of the star? You may assume full ionisation.

c) Calculate the number density of electrons n_e in the core.

d) The Fermi momentum is the momentum of highest occupied state at zero temperature. Compute it at the centre of the star.

e) Estimate the core pressure under the assumption of completely degenerate, non-relativistic electrons. What would it be for completely degenerate, relativistic electrons? Compare the values to the pressure you get from MESA and discuss your observations.

f) Now simply assume an ideal gas law and compute the pressure P_{ideal} for the whole stellar profile. Compare it to the actual pressure P_{MESA} by plotting the ratio $P_{\mathrm{ideal}}/P_{\mathrm{MESA}}$ against the mass coordinate. Discuss what this means for the structure of the red giant.

g) Bonus question: Explain why degenerate gases are much more susceptible to explosive nuclear burning than non-degenerate ones. Hint: What is the fundamental mathematical difference in their equations of state? Which quantity influences reactions most strongly?

Report

Prepare a two-page (not including figures) report on this assignment. The bonus question is not needed for a perfect grade, but can be used to make up for a missing task on this or a future assignment.

Every group has to hand in their report at the beginning of the lab class on 13/11/2017.

Resources

- Questions regarding this assignment should be directed to `r.p.ratnasingam2@ncl.ac.uk` or `a.hindle@ncl.ac.uk`.
- The slides and the template work directory can be found on Blackboard.
- All materials are also available on https://www.mas.ncl.ac.uk/~npe27/PHY3033/
- The template work directory is also available via Git.