# Stellar Structure Project

AST 3Y03 Winter 2017
Due March 23, 2017

In this project, you will write a computer code which solves the equations of stellar structure, and investigate some properties of your stellar models. You may use any programming language you would like. However, you must make your code understandable to me, so use lots of comments and reasonable variable names.

Procedure:

1. Use the time-independent equations of stellar structure, as derived in class, and assume radiative equilibrium throughout the interior of the star. Assume the solar abundance is X=0.70, Z=0.02.

2. Use the following constitutive equations:
   - Kramer's opacity: $\kappa = 4.34 \times 10^{25} Z(1+X)\, \rho\, T^{-3.5}$
   - Energy generation from the p-p chain: $\varepsilon = 10^{-29}\ \rho\, X^2\, T^4$
   - Ideal gas equation of state: $P = R\, \rho\, T/\mu$, where R is the gas constant $8.31 \times 10^7$ erg/K/g

3. Following the method from M. Schwarzschild (see accompanying file) and the Runge-Kutta or equivalent integration method, integrate the equations of stellar structure from the centre. At each point, calculate the homology invariants U, V and n+1. I suggest you use an initial value of $p_C$ of 0.712, and you will find that you need to determine $p_C$ to at least 9-10 decimal places to have solution curves in the acceptable part of the UV plane. The results are a **very** sensitive function of $p_C$. In the Schwarzschild units, you will need to make sure that you reach a value of x~10-15 where n+1 ~ 2.5. Changing the value of $p_C$ will allow you to increase the range of x; do this first before you try to refine the exact value to ~10 decimal places.

4. The envelope solutions for convective envelopes can be found in /1/home/asills/3Y03_W2017/structure/uvintegrations.dat on phys-ugrad. Fit the core and envelope solutions together where n+1 = 2.5 in the core integration. Small values of E, less than about 10, should be used for realistic models. Evaluate $x_0$, $q_0$, $f_0$, $t_0$, and $p_0$ using the solutions from the 1955 paper by Harm & Schwarzschild. The PDF file of this paper is available on Avenue. Evaluate the constants C and D. Use these values to convert your stellar model to physical units for a 1 $M_\odot$ star with a luminosity of 1 $L_\odot$.

5. Plot the density, temperature, and pressure as a function of mass fraction $(m/M_*)$ for your model.

6. Assuming that all stars have the same dependence of their structure variables on mass in dimensionless units as for the solar model, calculate L, $T_{eff}$, $T_C$, $P_C$, and R for models with masses of 0.7, 0.8, 0.9, 1, 2, 3, 4 and 5 $M_\odot$.

7. Plot the models on the theoretical HR diagram to give a zero age main sequence. Compare with the observed main sequence (table in /1/home/asills/3Y03_W2017/structure/HRDiagram.dat). Briefly discuss the reasons for any disagreement.

## Things to include in your write-up

1. A short description of what you did. Do not go into detail, especially where I have outlined the procedure above. Describe what you had to do in a way that your mother (i.e. an intelligent non-astronomer) would understand.

2. The plots mentioned above, and your values of the relevant quantities.

3. A statement about who collaborated with you on this project, what they worked on with you, and an estimate of what fraction of the work they did. Also estimate how long this project took you, and assess its relevance, interest level, and appropriateness for an undergraduate project worth 15% of your final mark.

4. Your computer code. Please send it to me by email (asills@mcmaster.ca). I will compile and run it, so make sure that all necessary files are included, the code is commented, and the output is in a reasonable form. If there are any parameters that the user should input, tell me what values I should use.