PHYS 375 – Final Project Report

Andrew Reeves

20459205

Prof: Avery Broderick

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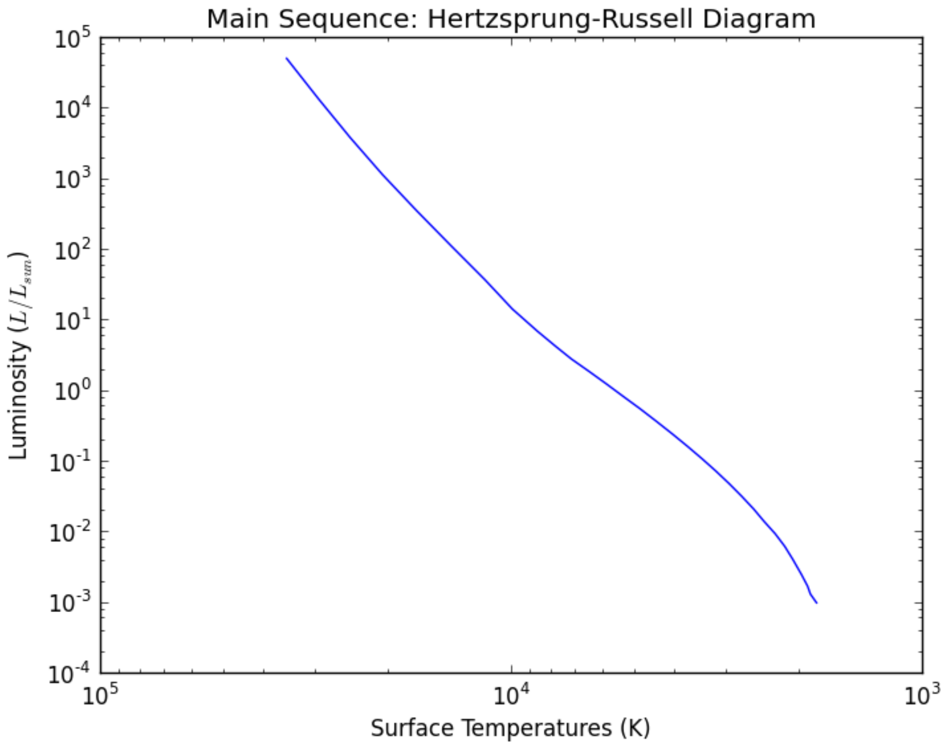
1: Our group chose to solve the stellar structure equations using Python 2.7 and our own adaptive Runge-Kutta method. Our code was written to be quite modular, with relatively small python functions to break the code down into manageable chunks. All of these functions were put in either of two classes to generate a star. Our first class was used for generating a trial star (called "*trialStar*"), given a central density and a central temperature. The *trialStar* class was then iteratively called by our "*Star*" class, which uses the bisection method (it varies the central temperature until we get a star that meets the surface luminosity condition within a certain error tolerance). A more specific breakdown of how the classes work is included below:

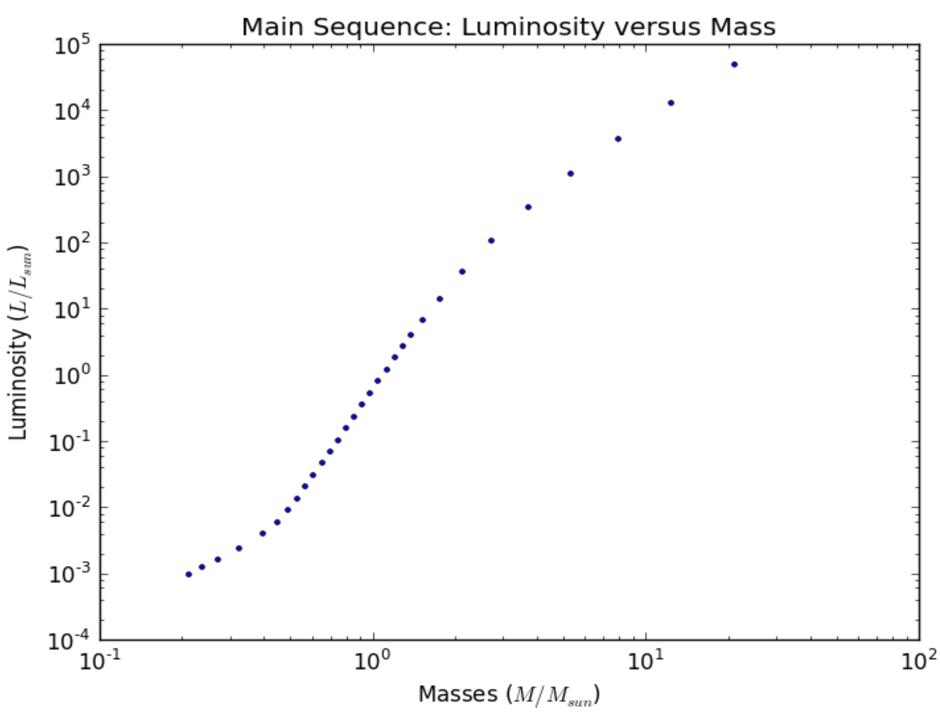
trialStar: All of the functions to make a trial star for a given central temperature and density are included in this class, including the Runge-Kutta method. The init function uses the given initial conditions and initializes all of the relevant arrays and necessary values. Then the Runge-Kutta method is called to integrate the five coupled ODEs. Our particular adaptive Runge-Kutta method employed a maximum and minimum step-size (1000.0m and 1.0x10^7 m, respectively) to make sure our star solutions were accurate with reasonable surface temperatures and so the solutions didn't take as long to compute. All suggestions and boundary conditions from the project pdf were utilized as given, although we also added in maximum radius and mass cutoffs to avoid excessive waste of computation time for the cases when the trial star is highly radiative (ie: not a real star).

Star: This class used the bisection method (as described in the first paragraph) to generate the "correct" star for a given central temperature. We limited our bisection method to 110 iterations, with a tolerance of 1.0x10^-10, since we didn't want it to run forever. In addition, we used a series of checks to make sure that we had converged to a proper star (ie: not highly radiative). Everything else implemented in our bisection method is identical in function to that stated in the project pdf.

2: (a) Main sequence Hertzsprung-Russell Diagram:

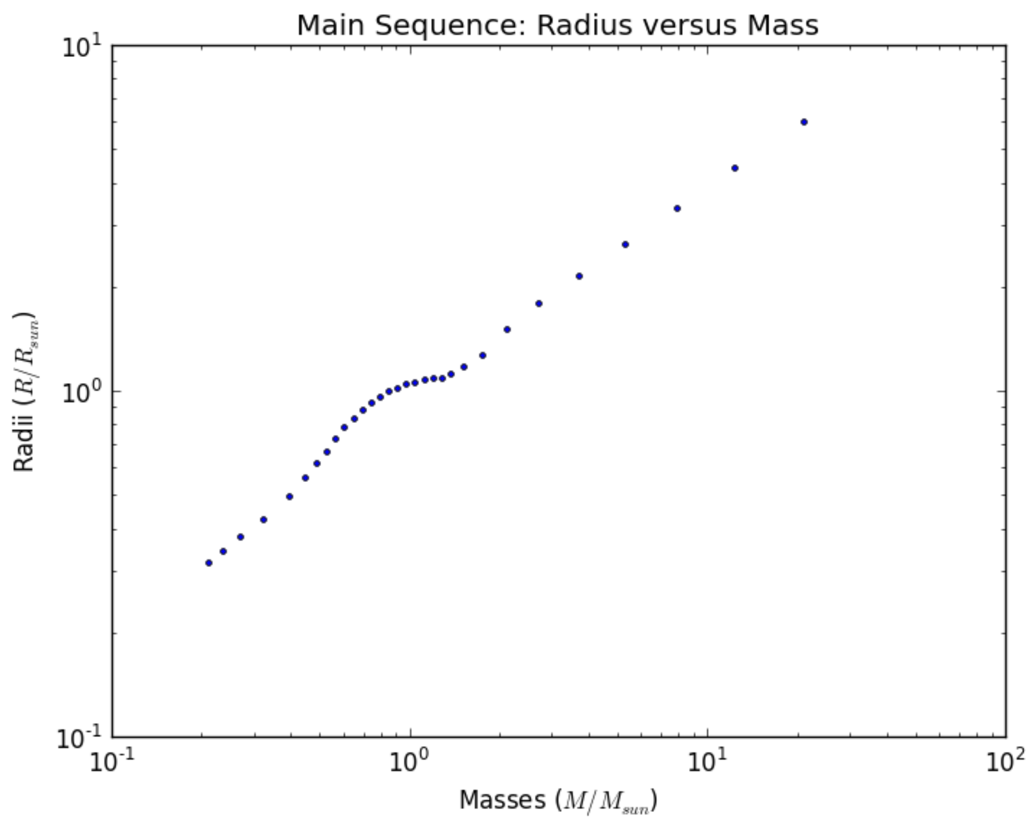


(b) $L/L_\odot$ as a function of $M/M_\odot$:



Qualitatively, for masses lower than about 3 solar masses, this plot is remarkably similar to the corresponding plot in the text. The crook in the curve occurs at a slightly slower mass, but the slope of the line before and after the crook looks very reasonable. Interestingly, for higher mass stars the luminosity deviates from a straight line on this log-log plot, likely because our stellar model only includes the PP-chain and the CNO-chain.

(c) $R/R_\odot$ as a function of $M/M_\odot$:

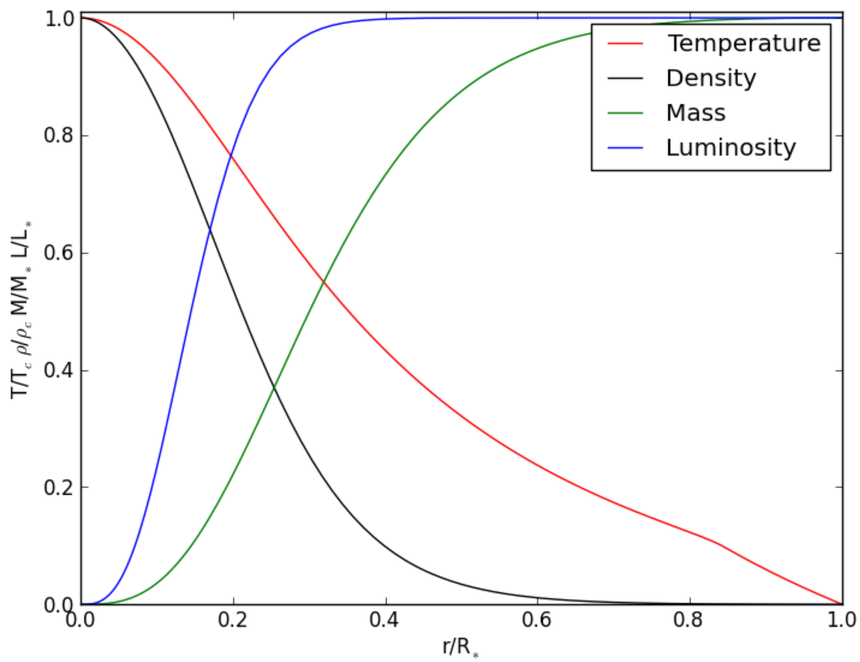


This plot does not match the corresponding plot in the text as closely. There is a strange hump where the crook should occur, although once past the hump, the stars follow a line with a slightly lower slope than before the hump – similar to the plot in the text. Due to the hump, it is difficult to tell exactly where the crook between the two lines would be, but it seems fairly close to where it appears in the plot in the textbook. As well, the slope before the hump seems quite similar, although after the hump it is a bit steep.

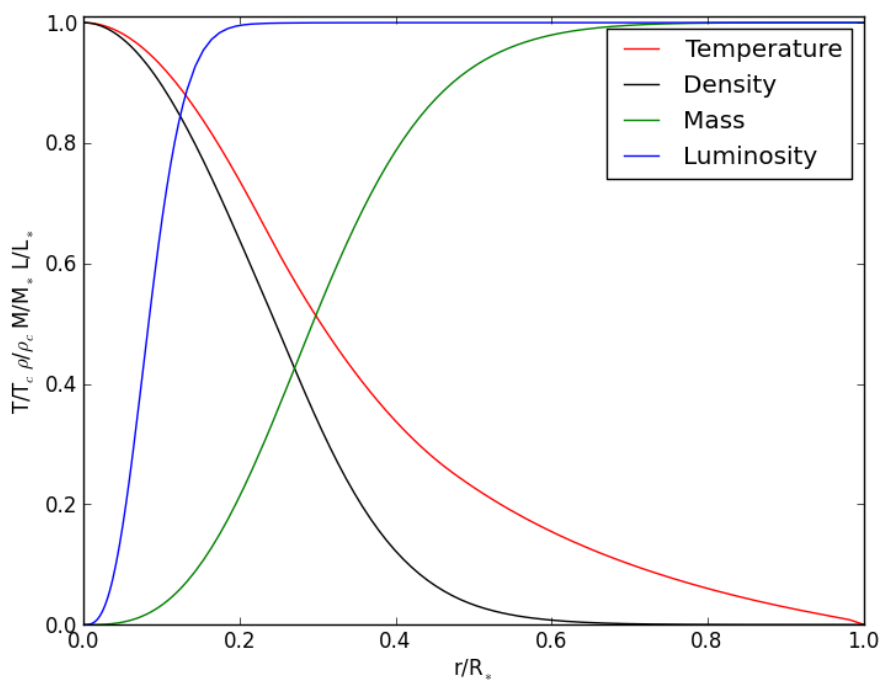
3. Stars chosen: 0.673 solar masses (central temperature: $8.23\text{x}10^{6}$ K) and 5.58 solar masses (central temperature: $2.6\text{x}10^{7}$ K).

(a): Plot of ρ (density), T (temperature), M (mass), L (luminosity):

0.673 M⊙:

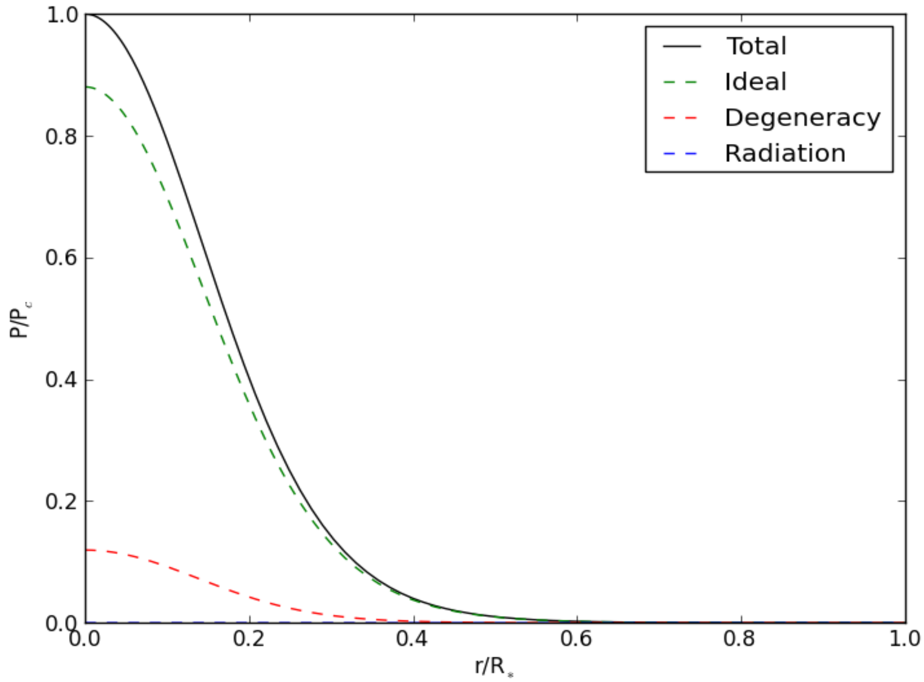


5.58 M⊙:

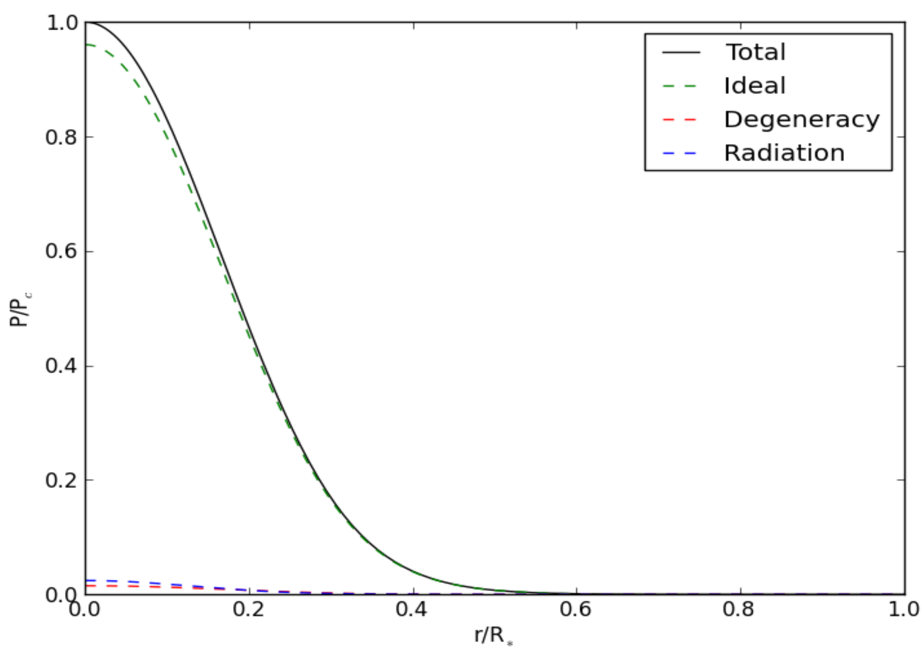


P (pressure):

0.673 M⊙:

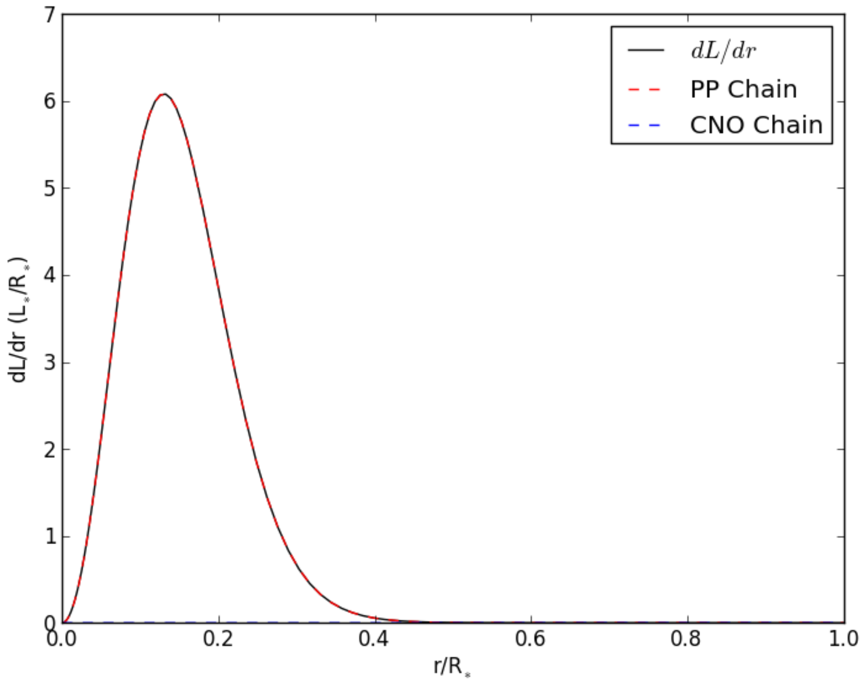


5.58 M⊙:

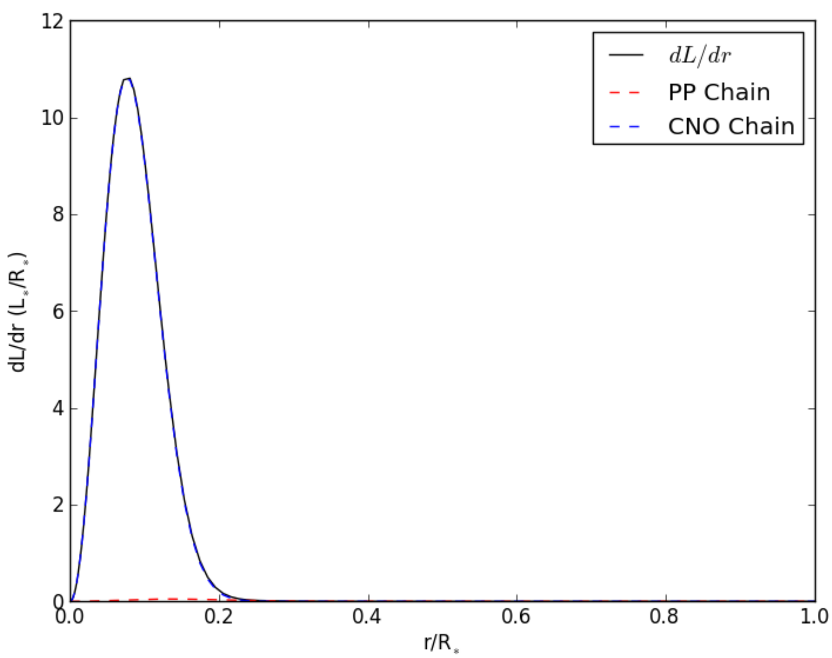


dL/dr :

0.673 M⊙:

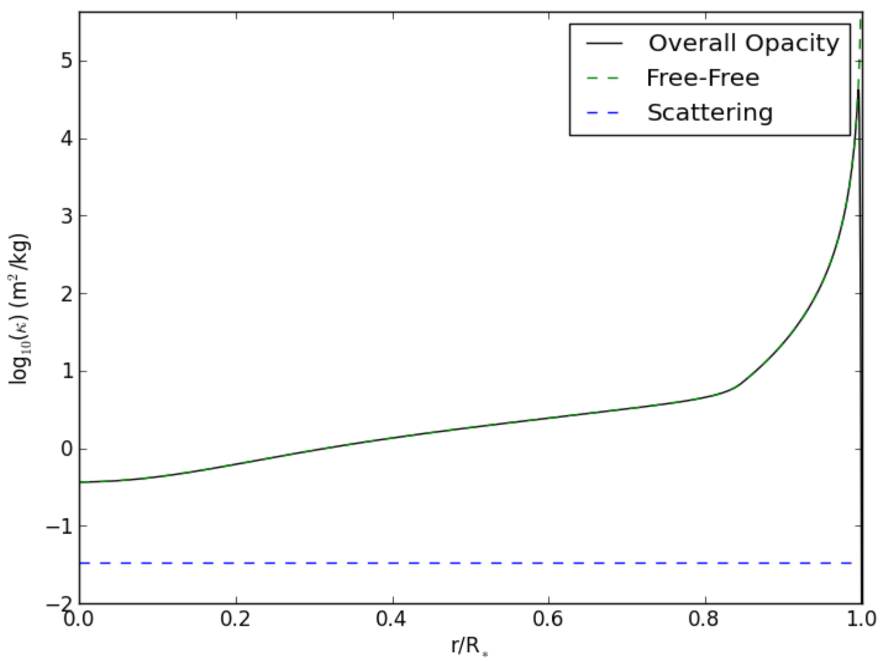


5.58 M⊙:

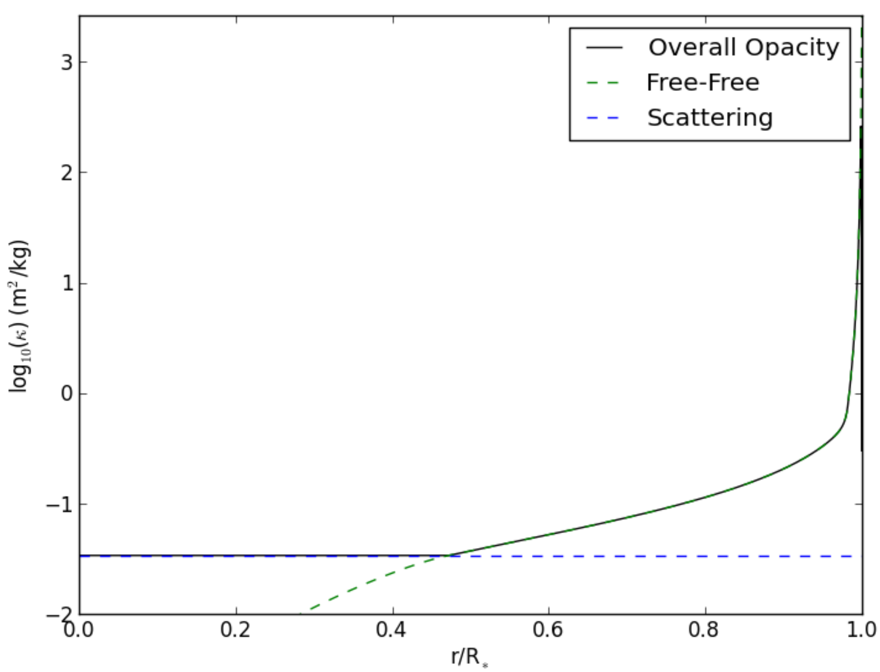


κ (opacity):

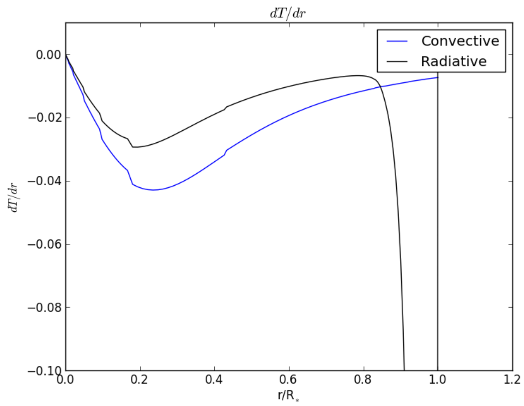
0.673 M⊙:



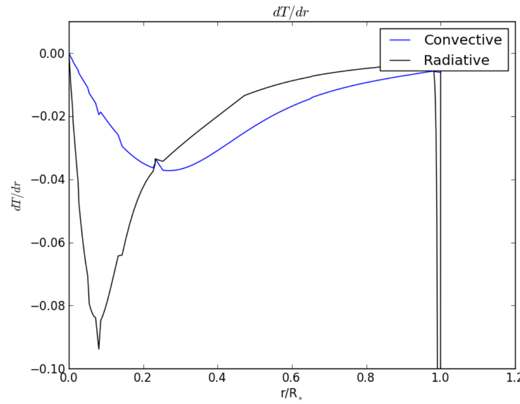
5.58 M⊙:



(b) Convection Zones:



0.673 M⊙



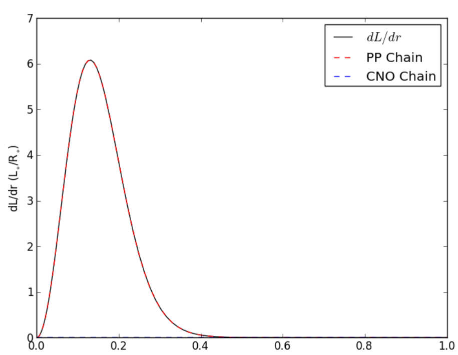
5.58 M⊙

Included above are plots of the convective and radiative dT/dr components for the 0.673 solar mass and the 5.58 solar mass stars, respectively.

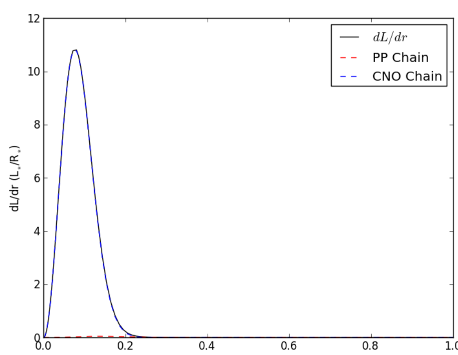
From these plots it is clear that for the 0.673 solar mass star the convection zone starts at 0.9 of the total radius and goes out to the surface of the star. The convection zone starts there because that is where the opacity is beginning quite large. Radiative heat transfer becomes much less effective at dissipating heat and so convection turns on.

For the 5.58 solar mass star the star is convective from 0.0 to 0.2 of its radius and also for a small distance from the surface. Convection occurs near the core because the incredible intensity of the heat being generated cannot be dissipated quickly enough via radiative heat transfer. As well, near the surface, just like the lower mass star, as the opacity increases, forcing convection to turn on, for the same reason as for the lower mass star.

(c) Energy generation:



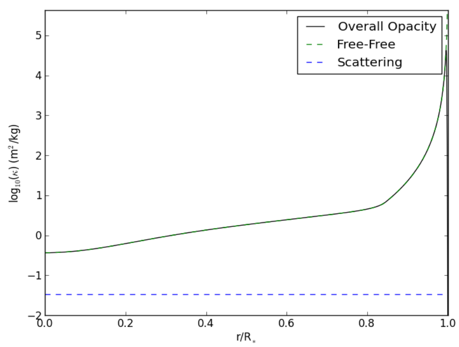
0.673 M⊙

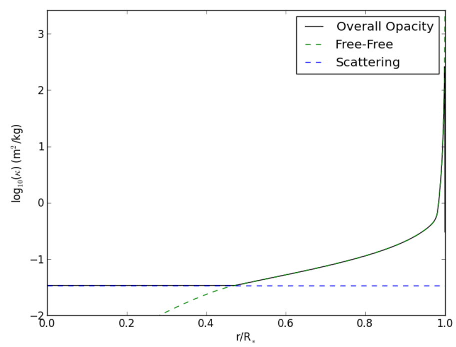


5.58 M⊙

From the dL/dr plots in part (a), it is obvious for the 0.673 solar mass star that the dominant energy generation source is the PP-chain. This makes sense because for stars smaller than our sun, they aren't hot enough for the CNO-chain to contribute significantly as an energy generation mechanism, since the CNO-chain requires much higher temperatures for fusion to occur at an appreciable rate. The 5.58 solar mass star, on the other hand, has the CNO-chain as its dominant energy generation source, as expected for a star significantly more massive than the Sun, with a very high central temperature.

(d) Dominant opacities:





0.673 M⊙ **5.58 M⊙**

For the 0.673 solar mass star the dominant opacity is always the free-free scattering. The opacity situation is a little more interesting for the 5.58 solar mass star. Its dominant opacity from 0.0 to 0.5 of its radius is due to electron scattering and then from 0.5 of its radius to the surface, the dominant opacity is due to free-free scattering. If I were to personally hypothesize why the electron scattering opacity is so high in the interior of the higher mass star, I would say this is happening because of electron-positron pair production from very high energy photons being produced by the extremely high temperatures. (This is probably incorrect, but I thought it would be a fun guess as to what is going on inside this star).

For both stars, near/at/shortly after the surface, the temperature drops below 10^4 K and so the H minus opacity is chosen, although it would not be the dominant opacity if this choice had not been made (an equation was given in the pdf to smooth out this effect, plus it's at the surface so it's not really important for this question, but I thought I would mention it anyway).