Class Project Sheet 2

Due: December 2, 2008, *before class*

Reaction Rate
Look reaction rate comments in `ez_nuclear_data.f` and the rate computation in `ez_nuclear.f` and the general settings in `star_controls.f`.

The $^{12}\mathsf{C}(\alpha,\gamma)^{16}\mathsf{O}$ reaction rate is one of the key nuclear physics uncertainties in stellar modeling.

Use low-metalicity stars ($Z = 0.0001$) of 15, 25, and 40 $\mathsf{M}_\odot$.

1. **Write down the equations for the change rates of $^{4}\mathsf{He}$, $^{12}\mathsf{C}$, and $^{16}\mathsf{O}$ due to the $^{12}\mathsf{C}(\alpha,\gamma)^{16}\mathsf{O}$ and triple alpha reaction rates.**
   Please give
   $$\frac{\mathsf{d}Y_{^4\mathsf{He}}}{\mathsf{d}t}\,, \quad \frac{\mathsf{d}Y_{^{12}\mathsf{C}}}{\mathsf{d}t}\,, \text{ and } \quad \frac{\mathsf{d}Y_{^{16}\mathsf{O}}}{\mathsf{d}t}\,.$$
   as a function of the reaction rates λ and the abundances $Y_{^4\mathsf{He}}$, $Y_{^{12}\mathsf{C}}$, and $Y_{^{16}\mathsf{O}}$.

2. **What ratios of $^{12}\mathsf{C}$ to ^{16}do you obtain at the end of central helium burning in the center of the star?**
   Assume central helium burning has come to an end when the central helium fraction has dropped below 10^{-5} or the central temperature has reached $5\times10^{8}\,\mathsf{K}$.

3. **During central helium burning, what is the maximum mass fraction of $^{12}\mathsf{C}$ reached and at what is the mass fraction of $^{4}\mathsf{He}$ at this point?**

4. **Explain: What is the reason for this kind of behavior of the $^{12}\mathsf{C}$ mass fraction?**
   Consider the competition of the $^{12}\mathsf{C}(\alpha,\gamma)^{16}\mathsf{O}$ and triple alpha reaction rates and their dependence on the $^{4}\mathsf{He}$ mass fraction.

5. **How does the central carbon mass fraction at the end of central helium burning change if you increase or decrease the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ by a factor 2?**
   Change the ratio of the $^{12}\mathsf{C}(\alpha,\gamma)^{16}\mathsf{O}$ reaction rate relative to that of the triple alpha reaction rate by changing the $^{12}\mathrm{C}(\alpha,\gamma)^{16}\mathrm{O}$ reaction rate.
   (multiply the rate by factors 2 and 0.5)

6. Compare your results with Figure 4 of `http://arxiv.org/pdf/0705.4404`

For each case, please explain what happens and why.

Best would be if you could document your results using plots.

NOTE: If your model "crash" (program terminates abnormally, as I have found for some masses and some metallicities on some platforms/computer architectures and compiler combinations, try to explore different masses and metallicities.