ASTRONOMY 1195: OBSERVATIONAL ASTRONOMY

HOMEWORK ASSIGNMENT #8

DUE: November 17, 2016

Problem 1. Evolution of the sun.

a) What tells the sun to leave the main sequence and become a red giant star?
   
   When the H in the core's core is depleted, the core contracts and heats up, igniting the shell of H outside the core. The pressure generated from the increasing luminosity expands the envelope of the star outward, creating the size of giant. The surface then cools to 3000 to 3500K and is maintained by H ion feedback.

b) Why does helium fusion begin with a flash in low mass stars?
   
   In degenerate core, the pressure is independent of T, so when the T of the core heats up to 10^8K, He burning begins. This further heats the core, rapidly increasing the burn rate and creating the runaway explosion that is the Helium Flash.

c) The structure of an evolved solar mass star changes dramatically from just before to just after the helium flash. What happens to the stellar parameters below after the helium flash.

<table>
<thead>
<tr>
<th>Radius of the core (bigger, or smaller)?</th>
<th>Bigger</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radius of the star (bigger, or smaller)?</td>
<td>Smaller</td>
<td>✓</td>
</tr>
<tr>
<td>Source of energy generation (what, and where)?</td>
<td>No fusion in the core</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>H burning in a shell</td>
<td>✓</td>
</tr>
<tr>
<td>Luminosity of the star (bigger, or smaller)?</td>
<td>Smaller</td>
<td>✓</td>
</tr>
</tbody>
</table>

d) The sun will ascend the red giant branch twice. What is the core's composition, and what is happening at the core of the sun to cause the second ascent?

The core's composition is depleted of H and He, and is instead made up of carbon. He shell burning begins and joins existing H shell burning, causing expansion of the envelope and contraction of the core.
Problem 2. Horizontal branch stars are about 100 times more luminous than the sun, and are fusing helium into carbon at their cores by the triple alpha reaction:

\[ 3 \cdot ^4\text{He} \rightarrow ^{12}\text{C} + 2\gamma \]

The mass of each \(^4\text{He}\) nuclei is \(6.6499 \times 10^{-27}\) kg, while that of \(^{12}\text{C}\) is \(1.9937 \times 10^{-26}\) kg.

a) How much energy is released per triple alpha reaction?
\[ E = (3 \cdot 6.6499 \times 10^{-27} \text{kg}) \cdot (1.9937 \times 10^{-26} \text{kg}) \cdot (1.6 \times 10^{13} \text{eV}) \]
\[ = 1.443 \times 10^{10} \text{J} \]

b) A solar mass star might burn its entire helium core (0.1 \(M_\odot\)) into carbon while on the horizontal branch. How much energy is released converting the core into carbon? (Hint: first calculate how many reactions could occur)
\[ \frac{1.9937 \times 10^{-26} \text{kg}}{6.6499 \times 10^{-27} \text{kg}} \cdot \frac{1.443 \times 10^{10} \text{J}}{3.6 \times 10^{13} \text{eV}} = 1.440 \times 10^{15} \text{J} \]

Given your answer to part b), how long would you expect a solar mass star to remain on the horizontal branch?

\[ \frac{1.440 \times 10^{15} \text{J}}{10^{-24} \text{J}/\text{sec}} \cdot \left( \frac{1 \text{ hour}}{3600 \text{ sec}} \cdot \frac{1 \text{ day}}{24 \text{ hr}} \cdot \frac{1 \text{ year}}{365 \text{ day}} \right) = 9.98 \times 10^6 \text{ years} \]


a) When a massive star goes supernova, about \(10^{46}\) joules of energy are released in a few seconds. How much mass is destroyed at this instant?
\[ E = m \cdot (2.0 \cdot 10^{-24} \text{J/kg})^2 = 10^{46} \text{J} \]
\[ m = \frac{1.11 \times 10^{-26} \text{kg}}{1.4 \times 10^{-12} \text{J/kg}} \]
b) How does the mass in a) compare with the mass of the earth (6 × 10^{24} \text{ kg})?

\[
\frac{1.1 \times 10^{34} \text{ kg}}{6 \times 10^{24} \text{ kg}} = 18000 \text{ times the mass of the earth.}
\]

\checkmark

c) Assume that the O star progenitor has a luminosity of 1.0 × 10^{32} \text{ Joules/second, and stays on the main sequence for 3 million years. How does the energy released in the supernovae compare with the total energy released by the star during its main sequence lifetime?}

\[
\begin{align*}
3 \times 10^6 \text{ years} & \times 3.6 \times 10^{36} \text{ Joules/second} \times 3 \times 10^6 \text{ years} \times 1.0 \times 10^{32} \text{ J/s} \\
& = 9.5 \times 10^{66} \text{ J} \\
& \approx 1 \text{ times the same amount of energy}
\end{align*}
\]

\checkmark

d) In three sentences or less, what is the difference between Type I and Type II supernovae?

A Type II supernova is a neutrino-driven blast wave that occurs by the core collapse of a red supergiant, driving off the outer layers of the star. A Type I supernova occurs by the collapse of a white dwarf that is pushed over the Chandrasekhar limit by mass transfer from its binary star.

\checkmark

Problem 4. Stellar endstates.

a) What are the relative radii of a red-supergiant star, a red-giant star, the sun, a white dwarf, and a neutron star?

\[
\begin{array}{ccc}
\text{1000} \text{ R}_\odot & \text{10} \text{ R}_\odot & \text{1} \text{ R}_\odot \\
\text{1000} \text{ R}_\odot & \text{10} \text{ R}_\odot & \text{1} \text{ R}_\odot \\
\end{array}
\]

\checkmark

b) What supports a main sequence star against gravity? What supports a white dwarf? What supports a neutron star?

Nuclear fusion supports a main sequence star.
Electron degeneracy pressure supports the white dwarf.
Electron degeneracy pressure supports a neutron star.

\[
\begin{array}{c}
\text{Nuclear fusion supports a main sequence star.} \\
\text{Electron degeneracy pressure supports the white dwarf.} \\
\text{Electron degeneracy pressure supports a neutron star.}
\end{array}
\]

\[
\begin{array}{c}
\text{16} \\
\text{18}
\end{array}
\]

\checkmark

\checkmark

c) Which has a larger radius, a 0.3 \text{ M}_\odot or a 1.3 \text{ M}_\odot white dwarf?

A 0.3 \text{ M}_\odot white dwarf.

\checkmark

d) What is the largest mass that a white dwarf can have? Why, physically, does this limit exist?

1.4 M_\odot, the electrons become relativistic such that degeneracy pressure can no longer support the cell.

\checkmark