Lecture 21

Stellar Mass;
The Main Sequence

Visual and Spectroscopic Binaries
Mass and the Main Sequence
Explaining the Main Sequence

Stellar Size

- Taking ratios to the sun (surface temp of sun = 5800 K),
  \[(R/R_\text{sun})^2 = L/L_\text{sun} / (\text{Temp}/5800)^4\]
  - So if we measure luminosity and surface temperature, we have size, without even resolving star as an image!
  - HR diagram groups from top right (cool, luminous) to bottom left (underluminous and hot), are in order of decreasing size.
- To completely specify star class, add "Luminosity class" (I-V) to spectral type, specifying where in HR diagram a star is.
Summarizing Stellar Classes

<table>
<thead>
<tr>
<th>Name</th>
<th>Radius ($R_{\odot}$)</th>
<th>Lum Class</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supergiants</td>
<td>30 - 1000</td>
<td>I–II</td>
<td>Betelgeuse, M2I</td>
</tr>
<tr>
<td>Giants</td>
<td>3 – 100</td>
<td>III–IV</td>
<td>Aldebaran, K5III</td>
</tr>
<tr>
<td>Main Sequence</td>
<td>0.1 - 5</td>
<td>V</td>
<td>Sun, G2V</td>
</tr>
<tr>
<td>White dwarfs</td>
<td>0.01</td>
<td>D</td>
<td>Sirius B</td>
</tr>
</tbody>
</table>

- Notice that both Main Sequence and White Dwarf stars fall near lines of constant radius. This is major hint for models of stellar structure.

Stellar Census

- Get a good idea of how common each type of star is in solar neighborhood, where we can study the faintest stars
- Most stars are Main Sequence, fainter than Sun (KV, MV red dwarfs)
Stellar Mass

The final basic piece of data:

• The only way we can measure the mass is if the star is orbiting another (binary star). Maybe 50% of stars are in binary systems (the sun is an exception here!), but most are not suitable for mass measurement.

• Use (Newton's version of) Kepler's Third Law for sum of masses of two stars $M_1$ and $M_2$ in terms of semi-major axis of orbit ($A$, in AU) and period ($P$, in years)

\[
\frac{(M_1 + M_2)}{M_{\text{sun}}} = A(\text{AU})^3 / P(\text{yr})^2
\]

Binary Orbits

• To get the individual masses, use another fact derived by Newton:
  – The two orbiting objects not only orbit each other in an ellipse (this is the "relative orbit"),
  – each orbits a stationary point in the system, the “center of mass”, in ellipses of size $A_1$ and $A_2$, with $M_1/M_2 = A_2/A_1$.
  – these are the "absolute orbits"


• Works for two kinds of binaries
  – visual binaries
  – spectroscopic binaries:
Visual Binaries

**Visual binary:** stars far enough apart so that their images are separate, not so far apart that $P > 200$ years. Several hundred of these known.
Period $P =$ time for orbit to complete
Semi-major axis $A$ from angular orbital size $\times$ Distance
Location of center of mass by tracing motion of stars relative to distant stars.

- Example: **Sirius A and B:**

Spectroscopic Binaries

**Spectroscopic binary:**
- stars quite close to each other; their images are merged,
- spectra are different since rapid orbital motion plus the Doppler Effect causes the absorption lines in each to be shifted by different amount during orbit.
Mass from Spectroscopic Binaries

Nice applet:
http://instruct1.cit.cornell.edu/courses/astro101/java/binary/binary.htm

- Period $P =$ time for spectroscopic shifts to repeat.
- Orbital Speeds from largest Doppler Shift. Speed =
  \[ \text{Speed} = \frac{\text{wavelength shift}}{\lambda} \times c \]
- Speeds $\times$ Period $= 2 \pi A$, $A_1$ and $A_2$ (for circular orbits -
  ellipses a bit more complicated)
- This has been done for 100's of stars. Works at any
distance, but stars must be really close for orbital velocity
to be detectable

Main Sequence Mass

One important result: Properties of the Main Sequence

- For Main Sequence stars (90% of observed stars), there is a
  unique relationship among Mass, Luminosity, and Radius
  (Surface Temperature):

<table>
<thead>
<tr>
<th>Mass</th>
<th>Lum</th>
<th>Radius</th>
<th>Temp</th>
<th>Spec</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>$5 \times 10^5$</td>
<td>18</td>
<td>40,000</td>
<td>O5</td>
<td>Zeta Pup</td>
</tr>
<tr>
<td>3.2</td>
<td>80</td>
<td>2.5</td>
<td>9,900</td>
<td>A0</td>
<td>Vega</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5,800</td>
<td>G2</td>
<td>Sun</td>
</tr>
<tr>
<td>0.1</td>
<td>$8 \times 10^{-4}$</td>
<td>.13</td>
<td>2,400</td>
<td>M7</td>
<td>Wolf 359</td>
</tr>
</tbody>
</table>
Bottom Line

So the most massive Main Sequence Stars are the most luminous (by a lot) and the largest.

• Recall that the least luminous, and thus the least massive main sequence stars, are the most common.
• For Supergiants, Giants, and White dwarfs, there is no obvious relation between mass and position on the HR diagram.

Next: What does this all mean?

Off the Main sequence

• What are the stars not on the main sequence? They must be stars using some other fuel and/or supported in some other way.
• Theory of Stellar Evolution tries to explain them as stages of star lifetime before and after a main sequence stage.
• Bottom line: each stage lasts as long as the fuel lasts. Gravity wins eventually, resulting in the partial disruption of the star and a collapsed remnant.
Spectral “Luminosity Class”

![Luminosity Class Diagram]

Betelgeuse

![Betelgeuse Image]
Sirius A and B

Sirius B Apparent Orbit
Sirius A and B Absolute Orbit

Main Sequence Mass Luminosity

Figure 6.19, p202, Arny