Astronomy 100
Tuesday, Thursday 2:30 - 3:45 pm

Tom Burbine
tburbine@mtholyoke.edu

www.xanga.com/astronomy100
Thing some people are having trouble with

• The Sun is believed to be ~5 billion years old (like 4.6 billion years)
• This age is from radioactive dating of elements in meteorites
• The Sun is believed to be able to burn Helium for another ~5 billion years
• Its billions not millions!!!!!!!!!!!!!
HW (due today)

• I want you to draw me a Hertzsprung-Russell Diagram
• Label the axes
• Label the regions with different types of stars
  • O, B A, F, G, K, M
• Tell me the phrase people use to remember the order
Homework Assignment
(Due March 31)

• Make up a test question
• Multiple Choice
• A-E possible answers
• 1 point for handing it in
• 1 point for me using it on test
• The question needs to be on material that will be on the 3rd exam
• 15 people got extra HW credit for me using their question (or inspiring a question)
There will be an OWL assignment due on Thursday March 31 at 11:59 pm. There are 15 questions and a perfect score will give you 2 homework points.
Classification of Stars

• Stars are classified according to luminosity and surface temperature
• Luminosity is the amount of power it radiates into space
• Surface temperature is the temperature of the surface
Luminosity is the total amount of power (energy per second) the star radiates into space.

Apparent brightness is the amount of starlight reaching Earth (energy per second per square meter).

Not to scale!
Inverse Square Law

• The apparent brightness varies inversely by the square of the distance \((1/d^2)\)
• If the Earth was moved to 10 Astronomical Units away, the Sun would be \(1/100\) times dimmer
• If the Earth was moved to 100 Astronomical Units away, the Sun would be \(1/10000\) times dimmer
If the Earth was moved to $1 \times 10^8$ Astronomical Units away, the Sun would be ...

A) $1 \times 10^{-12}$ times dimmer
B) $1 \times 10^{-14}$ times dimmer
C) $1 \times 10^{-16}$ times dimmer
D) $1 \times 10^{-18}$ times dimmer
E) $1 \times 10^{-20}$ times dimmer
If the Earth was moved to $1 \times 10^8$ Astronomical Units away, the Sun would be …

A) $1 \times 10^{-12}$ times dimmer
B) $1 \times 10^{-14}$ times dimmer
C) $1 \times 10^{-16}$ times dimmer
D) $1 \times 10^{-18}$ times dimmer
E) $1 \times 10^{-20}$ times dimmer
Luminosity-Distance Formula

• Apparent brightness = Luminosity
  \[ 4\pi \times (\text{distance})^2 \]

Usually use units of Solar Luminosity

\[ L_{\text{Sun}} = 3.8 \times 10^{26} \text{ Watts} \]
Measuring Distance to Stars

• Measuring distances to stars is much harder to measure than brightness
• But to determine the Luminosity of the star, we need to know the distance to it
Every January, we see this: near star.

Every July, we see this: near star.

1 AU
Parallax

- Sine angle = length of opposite side / length of hypotenuse
- Sine p = 1 AU/(distance)
- Distance = 1 AU/sin p
Stretch out your arm as shown here.
parsec

• Definition:
• 1 parsec is the distance to an object with a parallax angle of 1 arc second
• $1 \text{ pc} = \frac{1 \text{ AU}}{\sin(1 \text{ arc second})}$
• $1 \text{ pc} = \frac{1 \text{ AU}}{4.84814 \times 10^{-6}} = 206,265 \text{ AU}$
• Equals 3.26 light years
Remember

• 1 degree = 60 arc minutes (symbol ‘)
• 1 arc minute = 60 arc seconds (symbol ″)
What formula do we use

- \( d \) (in parsecs) = \( \frac{1}{p} \) (in arc seconds)
- For small angles, the change in angle is approximately equal to the change in sine of the angle
Calculations

• For example, a star with a parallax angle of $\frac{1}{2}$ arc seconds is 2 parsecs away
• For example, a star with a parallax angle of $\frac{1}{20}$ arc seconds is 20 parsecs away
PRS question

A star with a parallax angle of .01 arc seconds is
A) 10 parsecs away
B) 100 parsecs away
C) 1,000 parsecs away
D) 10,000 parsecs away
E) 100,000 parsecs away
PRS question

A star with a parallax angle of .01 arc seconds is
A) 10 parsecs away
B) 100 parsecs away
C) 1,000 parsecs away
D) 10,000 parsecs away
E) 100,000 parsecs away
Note

- We can only measure parallax for stars within a few hundred light years from Earth.
Luminosity-Distance Formula

- Luminosity = Apparent brightness \times 4\pi \times (\text{distance})^2
Surface Temperature

- Determine surface temperature by determining the wavelength where a star emits the maximum amount of radiation.
- Surface temperature does not vary according to distance, so it is easier to measure.
Who were these people?

• These were the women (called computers) who recorded, classified, and catalogued stellar spectra
• Willamina Fleming (1857-1911) classified stellar spectra according to the strength of their hydrogen lines
• Classified over 10,000 stars
Fleming’s classification

- A - strongest hydrogen emission lines
- B - slighter weaker emission lines
- C, D, E, … L, M, N
- O - weakest hydrogen lines emission lines
Annie Jump Cannon (1863-1941)

• Cannon reordered the classification sequence by temperature and tossed out most of the classes
• She devised OBAFGKM
Each spectral type had 10 subclasses, e.g., A0, A1, A2, ..., A9 in the order from the hottest to the coolest.

Cannon classified over 400,000 stars.
OBAFGKM

- Oh Be A Fine Girl/Gal Kiss Me
- Play song
<table>
<thead>
<tr>
<th>Spectral Type</th>
<th>Example(s)</th>
<th>Temperature Range</th>
<th>Key Absorption Line Features</th>
<th>Brightest Wavelength (color)</th>
<th>Typical Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Stars of Orion’s Belt</td>
<td>&gt;30,000 K</td>
<td>Lines of ionized helium, weak hydrogen lines</td>
<td>&lt;97 nm (ultraviolet)*</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Rigel</td>
<td>30,000 K–10,000 K</td>
<td>Lines of neutral helium, moderate hydrogen lines</td>
<td>97–290 nm (ultraviolet)*</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Sirius</td>
<td>10,000 K–7,500 K</td>
<td>Very strong hydrogen lines</td>
<td>290–390 nm (violet)*</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Polaris</td>
<td>7,500 K–6,000 K</td>
<td>Moderate hydrogen lines, moderate lines of ionized calcium</td>
<td>390–480 nm (blue)*</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Sun, Alpha Centauri A</td>
<td>6,000 K–5,000 K</td>
<td>Weak hydrogen lines, strong lines of ionized calcium</td>
<td>480–580 nm (yellow)</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Arcturus</td>
<td>5,000 K–3,500 K</td>
<td>Lines of neutral and singly ionized metals, some molecules</td>
<td>580–830 nm (red)</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Betelgeuse, Proxima Centauri</td>
<td>&lt;3,500 K</td>
<td>Molecular lines strong</td>
<td>&gt;830 nm (infrared)</td>
<td></td>
</tr>
</tbody>
</table>

*All stars above 6,000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.

Copyright © 2004 Pearson Education, publishing as Addison Wesley.
Cecilia Payne-Gaposchkin (1900-1979)

• Payne argued that the great variation in stellar absorption lines was due to differing amounts of ionization (due to differing temperatures), not different abundances of elements
Cecilia Payne-Gaposchkin (1900-1979)

• She proposed that most stars were made up of Hydrogen and Helium
• Her 1925 PhD Harvard thesis on these topics was voted best Astronomy thesis of the 20th century
Continuum for free electrons

$\text{Balmer Lines}$

$\text{Lyman Lines}$

Ground State = Lowest Energy Level

$n=1$

$\alpha \rightarrow H\gamma$

$\beta$
It takes progressively more energy to remove successive electrons from an atom. That is, it is much harder to ionize electrons of He II than He I.
Hertzsprung-Russell Diagram

- Both plotted spectral type (temperature) versus stellar luminosity
- Saw trends in the plots
- Did not plot randomly
Remember

- Temperature on x-axis (vertical) does from higher to lower temperature
- O – hottest
- M - coldest
Hertzsprung-Russell Diagram

- Most stars fall along the main sequence
- Stars at the top above the main sequence are called Supergiants
- Stars between the Supergiants and main sequence are called Giants
- Stars below the Main Sequence are called White Dwarfs
### Table 16.2 Stellar Luminosity Classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Supergiants</td>
</tr>
<tr>
<td>II</td>
<td>Bright giants</td>
</tr>
<tr>
<td>III</td>
<td>Giants</td>
</tr>
<tr>
<td>IV</td>
<td>Subgiants</td>
</tr>
<tr>
<td>V</td>
<td>Main sequence</td>
</tr>
<tr>
<td>wd</td>
<td>white dwarfs</td>
</tr>
</tbody>
</table>
Classifications

• Sun is a G2 V
• Betelgeuse is a M2 I
Radius

- Smallest stars on the main sequence fall on the bottom right
- Largest stars on main sequence fall on the top left
- At the same size, hotter stars are more luminous than cooler ones
- At the same temperature, larger stars are more luminous than smaller ones
• What do Main Sequence Stars have in common?
  – A) Similar Masses
  – B) Similar Diameters
  – C) Tend to fuse Hydrogen to Helium for Energy
  – D) Similar Surface Temperatures
  – E) Similar Stellar Luminosities
What do Main Sequence Stars have in common?

- A) Similar Masses
- B) Similar Diameters
- C) Tend to fuse Hydrogen to Helium for Energy
- D) Similar Surface Temperatures
- E) Similar Stellar Luminosities
Main Sequence Stars

• Fuse Hydrogen into Helium for energy
• On main sequence, mass tends to decrease with decreasing temperature
What does this tell us

• The star’s mass is directionally proportional to how luminous it is
• More massive, the star must have a higher nuclear burning rate to maintain gravitational equilibrium
• So more energy is produced
Main Sequence Lifetimes

- The more massive a star on the main sequence, the shorter its lifetime
- More massive stars do contain more hydrogen than smaller stars
- However, the more massive stars have higher luminosities so they are using up their fuel at a much quicker rate than smaller stars
Ages

- Universe is thought to be about 14 billion years old
- So less massive stars have lifetimes longer than the age of the universe
- More massive stars have ages much younger
- So stars must be continually forming
Questions