Reminder: no class on Thursday

• Still no iClickers on the bookstore…very soon!

• Also: Please review Chapter 05-BLACKBODY
Questions from last class (iClicker format)

• 1. Sunspots are
   A. areas obscured by higher layers of clouds
   B. ashes of nuclear burning brought to the surface by convection
   C. holes in the photosphere that allow us to see deeper regions
   D. regions which are cooler and darker than surrounding material
   E. causing global warming
More questions…

• 2. What are the most energetic eruptive events to occur on the Sun?
  A. thermonuclear explosions
  B. erupting prominences
  C. coronal mass ejections
  D. solar flares
More…

• 3. **Spicules on the solar surface are**
  
  A. streams of solar coronal material, usually seen only during a total solar eclipse.
  
  B. curtain-like structures hanging over sunspot regions.
  
  C. intense eruptions from sunspot groups and active regions, associated with solar flares.
  
  D. jets of gas surging out of the photosphere of the Sun into the chromosphere, usually at supergranule boundaries.
More questions…

• 4. Which of the following is most likely to get to Earth from the core of the Sun, before any of the others?
  A. protons
  B. electrons
  C. photons
  D. neutrinos
5. During the sunspot cycle the position of new sunspots on the Sun
   A. changes from mid-latitudes to the equator
   B. changes from mid-latitudes to the poles
   C. changes from the equator to the mid-latitudes
   D. changes from the equator to the poles
   E. does not change in any predictable manner
6. Sunspot cycles are, on the average, what length?
   A. 22 years
   B. 11 years
   C. 5.5 years
   D. 1 year
   E. 3 years
TODAY: From the Sun to the Stars!
We have $10^{11}$ stars in our MW alone!

• How can we know the nature of stars?
• Stars are as luminous or more than the Sun ->
thermonuclear reactions *must* be occurring within them as well!
• How we calculate their distances?
Star Maps

[Image of a star map]

[Image of a man holding a sign]

[Image of a book cover]

The Original Guide to Celebrity Homes, Hangouts and Hideaways.
Light is electromagnetic radiation and is characterized by its wavelength ($\lambda$).
Wavelength and Frequency

Frequency and wavelength of an electromagnetic wave

\[ v = \frac{c}{\lambda} \]

- \( v \) = frequency of an electromagnetic wave (in Hz)
- \( c \) = speed of light = \( 3 \times 10^8 \) m/s
- \( \lambda \) = wavelength of the wave (in meters)
Because of its electric and magnetic properties, light is also called **electromagnetic radiation**

- Visible light falls in the 400 to 700 nm range
- Stars, galaxies and other objects emit light in all wavelengths
An opaque object emits electromagnetic radiation according to its temperature.
Wien’s law and the Stefan-Boltzmann law are useful tools for analyzing glowing objects like stars

- A blackbody is a hypothetical object that is a perfect absorber of electromagnetic radiation at all wavelengths
- Stars closely approximate the behavior of blackbodies, as do other hot, dense objects
- The intensities of radiation emitted at various wavelengths by a blackbody at a given temperature are shown by a blackbody curve
Wien’s Law

\[ \lambda_{\text{max}} = \frac{0.0029 \text{ K m}}{T} \]

\[ \lambda_{\text{max}} = \text{wavelength of maximum emission of the object (in meters)} \]

\[ T = \text{temperature of the object (in kelvins)} \]

Wien’s law states that the dominant wavelength at which a blackbody emits electromagnetic radiation is inversely proportional to the Kelvin temperature of the object.
1. Add a chemical substance to a flame

2. Send light from the flame through a narrow slit, then through a prism

3. Bright lines in the spectrum show that the substance emits light at specific wavelengths only
Kirchhoff’s Laws

(a) CONTINUOUS SPECTRUM (blackbody emits light at all wavelengths)

(b) ABSORPTION LINE SPECTRUM (atoms in gas cloud absorb light of certain specific wavelengths, producing dark lines in spectrum)

(c) EMISSION LINE SPECTRUM (atoms in gas cloud re-emit absorbed light energy at the same wavelengths at which they absorbed it)

MOVIE….see http://bcs.whfreeman.com/universe7e/
Absorption spectrum of the Sun

Emission spectrum of iron (in the laboratory on Earth)

For each emission line of iron, there is a corresponding absorption line in the solar spectrum; hence there must be iron in the Sun’s atmosphere.
Guiding Questions

1. How far away are the stars?
2. What evidence do astronomers have that the Sun is a typical star?
3. What is meant by a “first-magnitude” or “second magnitude” star?
4. Why are some stars red and others blue?
5. What are the stars made of?
6. How do we know the distances to remote stars?
Parallax

When you are at position B, the tree appears to be in front of this mountain.

When you are at position A, the tree appears to be in front of this mountain.
Stellar Parallax

In January, the nearby star appears to be here.

In July, the nearby star appears to be here.

Parallax of a nearby star
The closer the star, the more its apparent position shifts as seen from Earth.

Parallax of an even closer star

MOBILE...see http://bcourses.whfreeman.com/universe7e/
Careful measurements of the parallaxes of stars reveal their distances

Relation between a star’s distance and its parallax

\[ d = \frac{1}{p} \]

- \( d \) = distance to a star, in parsecs
- \( p \) = parallax angle of that star, in arcseconds

- Distances to the nearer stars can be determined by parallax, the apparent shift of a star against the background stars observed as the Earth moves along its orbit
• Parsecs: a star with a parallax angle of 1 second of arc (p=1 arcsec) is at a distance of 1 parsec.
• 1 parsec=3.26 light-years (3.09x10^{13} \text{ km}=206,265 \text{ AU})
Barnard’s star has a parallax of 0.54 arcsec

\[ d = \frac{1}{p} = \frac{1}{0.547} = 1.83 \text{ pc} \]

Because 1 parsec is 3.26 light-years, this can also be expressed as

\[ d = 1.83 \text{ pc} \times \frac{3.26 \text{ ly}}{1 \text{ pc}} = 5.96 \text{ ly} \]
• Parallax measurements made from orbit, above the blurring effects of the atmosphere, are much more accurate than those made with Earth-based telescopes
• Stellar parallaxes can only be measured for stars within a few hundred parsecs

Parallax measurements are the cornerstone for all other Methods of finding the distances to remote objects
Luminosity of a star falls with distance!

With greater distance from the star, its light is spread over a larger area and its apparent brightness is less.

MOVIE....see http://bcsw.mhhe.com/universe7e/
If a star’s distance is known, its luminosity can be determined from its brightness

Inverse-square law relating apparent brightness and luminosity

\[ b = \frac{L}{4\pi d^2} \]

- \( b \) = apparent brightness of a star’s light, in W/m²
- \( L \) = star’s luminosity, in W
- \( d \) = distance to star, in meters

**Inverse-square law \( b \) is proportional to \( 1/d^2 \)**

- A star’s luminosity (total light output), apparent brightness, and distance from the Earth are related by the inverse-square law
- If any two of these quantities are known, the third can be calculated
Measuring a star’s apparent brightness is called *photometry*. 

\[ L = 4\pi d^2 b \Rightarrow \]

Determining a star’s luminosity from its apparent brightness:

\[ \frac{L}{L_\odot} = \left( \frac{d}{d_\odot} \right)^2 \frac{b}{b_\odot} \]

- \( L/L_\odot \) = ratio of the star’s luminosity to the Sun’s luminosity
- \( d/d_\odot \) = ratio of the star’s distance to the Earth-Sun distance
- \( b/b_\odot \) = ratio of the star’s apparent brightness to the Sun’s apparent brightness

For a given distance, the brighter the star, the more luminous that star must be. For a given apparent brightness, the more distant the star, the more luminous.
Stars comes in a variety of different luminosities: 
$10^6 \, L_{\text{sun}}$ to $10^{-4} \, L_{\text{sun}}$

(Of more than 30 stars within 4pc of the Sun only three have greater luminosity than the Sun)
The Luminosity Function

Stars of relatively low luminosity are more common than more luminous stars.

The exact shape of the curve only applies to the vicinity of the Sun and similar regions in the MW. (but in general low luminosity stars are much common than high-luminosity ones).

Our own Sun is a rather average star of intermediate luminosity.
Astronomers often use the magnitude scale to denote brightness

Apparent magnitude: how bright an object appears from Earth

The greater the apparent magnitude, the dimmer the star.

- The apparent magnitude scale is an alternative way to measure a star’s apparent brightness.
- The absolute magnitude of a star is the apparent magnitude it would have if viewed from a distance of 10 parsecs.

Some apparent magnitudes:
- Sun (-26.7)
- Full moon (-12.6)
- Venus (at brightest) (-4.4)
- Sirius (brightest star) (-1.4)
- Naked eye limit (+6.0)
- Binocular limit (+10.0)
- Pluto (+15.1)
- Large telescope (visual limit) (+21.0)
- Hubble Space Telescope and large Earth-based telescopes (photographic limit) (+30.0)
Apparent magnitudes of stars in the Pleiades
A star’s color depends on its surface temperature

Red stars are relatively cold, with low temperatures; blue stars are relatively hot, with high surface temperatures.
Photometry measures the apparent brightness of a star $b_u$, $b_B$, $b_V$.

The color ratios of a star are the ratios of brightness values obtained through different standard filters, such as the U, B, and V filters.

These ratios are a measure of the star’s surface temperature.
<table>
<thead>
<tr>
<th>Star</th>
<th>Surface temperature (K)</th>
<th>$b_V/b_B$</th>
<th>$b_B/b_U$</th>
<th>Apparent color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bellatrix (γ Orionis)</td>
<td>21,500</td>
<td>0.81</td>
<td>0.45</td>
<td>Blue</td>
</tr>
<tr>
<td>Regulus (α Leonis)</td>
<td>12,000</td>
<td>0.90</td>
<td>0.72</td>
<td>Blue-white</td>
</tr>
<tr>
<td>Sirius (α Canis Majoris)</td>
<td>9400</td>
<td>1.00</td>
<td>0.96</td>
<td>Blue-white</td>
</tr>
<tr>
<td>Megrez (δ Ursae Majoris)</td>
<td>8630</td>
<td>1.07</td>
<td>1.07</td>
<td>White</td>
</tr>
<tr>
<td>Altair (α Aquilae)</td>
<td>7800</td>
<td>1.23</td>
<td>1.08</td>
<td>Yellow-white</td>
</tr>
<tr>
<td>Sun</td>
<td>5800</td>
<td>1.87</td>
<td>1.17</td>
<td>Yellow-white</td>
</tr>
<tr>
<td>Aldebaran (α Tauri)</td>
<td>4000</td>
<td>4.12</td>
<td>5.76</td>
<td>Orange</td>
</tr>
<tr>
<td>Betelgeuse (α Orionis)</td>
<td>3500</td>
<td>5.55</td>
<td>6.66</td>
<td>Red</td>
</tr>
</tbody>
</table>

Source: J.-C. Mermilliod, B. Hauck, and M. Mermilliod, University of Lausanne.
Guiding Questions

1. How far away are the stars?
2. What evidence do astronomers have that the Sun is a typical star?
3. What is meant by a “first-magnitude” or “second magnitude” star?
4. Why are some stars red and others blue?
The spectra of stars reveal their chemical compositions as well as surface temperatures.

- Stars are classified into spectral types (subdivisions of the spectral classes O, B, A, F, G, K, and M), based on the major patterns of spectral lines in their spectra (“Oh Be A Fine Girl/Guy Kiss Me”)
The Sun whose spectrum is dominated by calcium and iron is a G2 star
The spectral class and type of a star is directly related to its surface temperature: O stars are the hottest and M stars are the coolest.
### Table 19-2: The Spectral Sequence

<table>
<thead>
<tr>
<th>Spectral class</th>
<th>Color</th>
<th>Temperature (K)</th>
<th>Spectral lines</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Blue-violet</td>
<td>30,000–50,000</td>
<td>Ionized atoms, especially helium</td>
<td>Naos (ζ Puppis),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mintaka (δ Orionis)</td>
</tr>
<tr>
<td>B</td>
<td>Blue-white</td>
<td>11,000–30,000</td>
<td>Neutral helium, some hydrogen</td>
<td>Spica (α Virginis),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rigel (β Orionis)</td>
</tr>
<tr>
<td>A</td>
<td>White</td>
<td>7500–11,000</td>
<td>Strong hydrogen, some ionized metals</td>
<td>Sirius (α Canis Majoris),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vega (α Lyrae)</td>
</tr>
<tr>
<td>F</td>
<td>Yellow-white</td>
<td>5900–7500</td>
<td>Hydrogen and ionized metals such as calcium and iron</td>
<td>Canopus (α Carinae),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Procyon (α Canis Minoris)</td>
</tr>
<tr>
<td>G</td>
<td>Yellow</td>
<td>5200–5900</td>
<td>Both neutral and ionized metals, especially ionized calcium</td>
<td>Sun, Capella</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(α Aurigae)</td>
</tr>
<tr>
<td>K</td>
<td>Orange</td>
<td>3900–5200</td>
<td>Neutral metals</td>
<td>Arcturus (α Boötis),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Aldebaran (α Tauri)</td>
</tr>
<tr>
<td>M</td>
<td>Red-orange</td>
<td>2500–3900</td>
<td>Strong titanium oxide and some neutral calcium</td>
<td>Antares (α Scorpii),</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Betelgeuse (α Orionis)</td>
</tr>
<tr>
<td>L</td>
<td>Red</td>
<td>1300–2500</td>
<td>Neutral potassium, rubidium, and cesium, and metal hydrides</td>
<td>Brown dwarf Teide 1</td>
</tr>
<tr>
<td>T</td>
<td>Red</td>
<td>below 1300</td>
<td>Strong neutral potassium and some water (H₂O)</td>
<td>Brown dwarf Gliese 229B</td>
</tr>
</tbody>
</table>

- Most brown dwarfs are in even cooler spectral classes called L and T
- Unlike true stars, brown dwarfs are too small to sustain thermonuclear fusion
Key Words

- absolute magnitude
- apparent brightness
- apparent magnitude
- color ratio
- distance modulus
- double star
- inverse-square law
- light curve
- luminosity
- magnitude scale

- OBAFGKM
- parallax
- parsec
- photometry
- spectral classes
- spectral types
- stellar parallax