Analyzing Starlight

1) Blackbody radiation
2) Properties of Stars
3) Measuring the Properties of Stars
4) H-R diagram
Review

- Properties of waves
  - wavelength, frequency, period, speed
- Light is an electromagnetic wave
- Atoms/energy levels
  - absorption and emission of photons
- Doppler effect
- Temperature and light
  - all objects emit light
  - hotter = bluer & brighter
Temperature and Light

- Hot objects give off light
- Temperature is a measure of how fast the atoms/molecules are moving
  - hot atoms move faster than cooler atoms
    - faster movement means more collisions
- Collisions of atoms can convert energy to light
  - This is how an incandescent light bulb glows
Temperature and Light

- Hotter objects give off more light
  - luminosity is proportional to temperature raised to the fourth power
    \[ L \propto T^4 \]
  - e.g. if you double an object’s temperature, the luminosity goes up by a factor of 16 (2^4)

- Hotter objects give off bluer light
  - the wavelength is proportional to the inverse temperature
    \[ \lambda \propto \frac{1}{T} \]
  - e.g. if you double an object’s temperature, the wavelength drops in half
Intensity and Luminosity

- Luminosity is the total amount of light given off by an object.
- Intensity is how much light we observe.
  - if an object radiates light evenly in all directions...
  - the intensity goes as $1/r^2$
    (r = distance from the source)
    \[ I = \frac{L}{4\pi r^2} \]
  - think of a sphere
- We can use the observed intensity to measure the distance if we know the luminosity.
Blackbody Radiation

- Light radiated due to temperature, follows a pattern
  - blackbody radiation
  - all objects radiate light
- This can be used to measure the surface temperature of an object
  - this is how we can measure the temperature of the Sun
We learned that \( \lambda \propto \frac{1}{T} \)

Really, it is \( \lambda = \frac{(2900 \ \mu m \ K)}{T} \)

we can rewrite as \( T = \frac{(2900 \ \mu m \ K)}{\lambda} \)

- \( \mu m = \) micron = \( 1 \times 10^{-6} \) m
- \( K = \) Kelvin (a measure of temperature
  - \( K = 0 \) is absolute zero, the coldest temperature possible
  - \( K = 273 \) is the freezing point of water (32 °F)
  - \( K = 373 \) is the boiling point of water (212 °F)
- the Sun’s light peaks at \( \lambda = 0.5 \ \mu m \)

So, \( T = \frac{(2900 \ \mu m \ K)}{0.5 \ \mu m} = 5,800 \ \text{K} \)

So the surface temperature of the Sun is 5,800 K
Sources of Light

- Several primary sources of light
  - reflection of light from another source
    - how we see most objects in this room
    - how we see planets, the Moon, asteroids, etc
  - creation of light from energy
    - glow of hot materials or from fusion
    - how the Sun glows
    - how we see comets
  - atomic emission of photons
    - could be from absorption
    - how we identify gases on a remote body
Observing Stars

- We study stars by observing their light
- What can we learn about stars?
  - Brightness/luminosity
  - Distance from us
  - Velocity (has fast/what direction)
  - Mass
  - Size
  - Composition
- Ultimately, we would like to find common characteristics between stars and learn the how and why of them
Stereoscopic Viewing

- To determine distance to an object, we view it from 2 different places
  - see how it moves with respect to far background
  - this is how our eyes work
- In astronomy, we view stars from different parts of the Sun’s orbit
  - close stars will move a lot, far stars will move a little
Measuring Distance

By measuring the angle by which the star “moves”, we can determine the distance.

**Angles**
- 1 degree = 60 arcminutes
- 1 arcminute = 60 arcseconds
- 1 arcsecond = 1/360th degree

**Distance**
- 1 parsec = 3.26 lightyears

$$\text{distance (parsecs)} = \frac{1}{\text{angle (arcsecs)}}$$
Measuring Luminosity

- We measure a star’s brightness by how much light we see.
- We have just measured its distance.
- Therefore, we can measure luminosity:
  \[
  \text{brightness} = \frac{\text{luminosity}}{4\pi r^2} \quad (r = \text{distance to star})
  \]
  \[
  \text{luminosity} = \text{brightness} \times 4\pi r^2
  \]

- We have measured the luminosity of many nearby stars:
  - Our Sun is more luminous than most.
  - Least luminous is 0.0001 times our Sun.
  - Most luminous is \(10^6\) times our Sun.
Measuring Temperature

- We use the colors of light to determine temperature
  - measure light through a blue filter and a yellow-green filter
  - ratio of amount of light allows us to measure the temperature
    - like we did for the Sun
  - most stars are cooler than our Sun
Measuring Size

- Once we know the luminosity and temperature, we can measure the size

  \[ \text{luminosity} = \text{surface area} \times \text{constant} \times T^4 \]

  \[ \text{surface area} = 4\pi r^2 \ (r = \text{radius of star}) \]

  \[ \text{luminosity} = 4 \pi r^2 \times \text{constant} \times T^4 \]

- We can solve for radius and calculate it

- Most stars are smaller than the Sun

- Smallest stars are 0.01 times the size of the Sun

- Largest stars are at several thousand times the size of the Sun
Classification of Stars

- Classify stars by temperature
- Classes: O, B, A, F, G, K, M
  - Oh, Be A Fine Guy/Gal, Kiss Me

- O is the hottest stars
- M are the coolest stars
- The Sun is a G class
Determining the Mass

- Determine the mass from the effects of gravity
- Use binary star systems
  - two stars orbiting each other
  - they follow ellipses with a shared focal point (Kepler’s Laws)
  - measure velocities
- Visual measurement
  - see both stars, use Doppler shift
- Eclipsing binary
  - one passes in front of the other and brightness changes
Stellar Composition

- Stars are primarily composed of hydrogen and helium
  - some other trace elements
- Here's a sampling of composition

<table>
<thead>
<tr>
<th>Element</th>
<th>Percent by Number</th>
<th>Percent by Mass</th>
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<tbody>
<tr>
<td>Hydrogen</td>
<td>92.5%</td>
<td>74.5%</td>
</tr>
<tr>
<td>Helium</td>
<td>7.4%</td>
<td>23.7%</td>
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<tr>
<td>Oxygen</td>
<td>0.064%</td>
<td>0.82%</td>
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<tr>
<td>Carbon</td>
<td>0.039%</td>
<td>0.37%</td>
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<tr>
<td>Neon</td>
<td>0.012%</td>
<td>0.19%</td>
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<tr>
<td>Nitrogen</td>
<td>0.008%</td>
<td>0.09%</td>
</tr>
<tr>
<td>Iron</td>
<td>0.003%</td>
<td>0.13%</td>
</tr>
</tbody>
</table>
H-R Diagram

- Einar Hertzsprung
- Henry Russell
- Compiled data on stars
- Plotted luminosity vs temperature
- Astronomers consider this the most important plot