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. As stars go, is our Sun especially large or small?
7. What are giant, supergiant, and white dwarf stars?
8. How do we know the distances to remote stars?
9. Why are binary star systems important in astronomy?
10. How can a star’s spectrum show whether it is actually a binary star system?
11. What do astronomers learn from stars that eclipse each other?

Parallax

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
- 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
Barnard’s star has a parallax of 0.54 arcsec

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

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

\[ d = 1 \text{ pc} \times \frac{3.26 \text{ ly}}{1 \text{ pc}} = 3.26 \text{ ly} \]

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 \( \text{W/m}^2 \)
\( L \) = star’s luminosity, in \( \text{W} \)
\( d \) = distance to star, in meters

- 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

The Population of Stars

- Stars of relatively low luminosity are more common than more luminous stars
- Our own Sun is a rather average star of intermediate luminosity

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

Stellar Motions

- \( v \) = the star’s space velocity
- \( v_r \) = the star’s radial velocity
- \( v_\perp \) = the star’s tangential velocity

\( d \) = distance from Earth to the star

This side is also equal to \( v_r \)

This side is also equal to \( v_\perp \)
Astronomers often use the magnitude scale to denote brightness – a scale that was introduced by the ancient Greeks about 300 BC

- 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

A star’s color depends on its surface temperature - recall Wien’s Law

<table>
<thead>
<tr>
<th>Star</th>
<th>Surface temperature (K)</th>
<th>b_V/b_u</th>
<th>b_V/b_B</th>
<th>Apparent color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bellatrix (red)</td>
<td>2,700</td>
<td>0.61</td>
<td>0.61</td>
<td>Red</td>
</tr>
<tr>
<td>Regulus (blue)</td>
<td>12,500</td>
<td>0.90</td>
<td>0.72</td>
<td>Blue</td>
</tr>
<tr>
<td>Sirius (blue)</td>
<td>9,000</td>
<td>1.00</td>
<td>0.96</td>
<td>Blue</td>
</tr>
<tr>
<td>Vega (rojo)</td>
<td>18,000</td>
<td>1.07</td>
<td>1.07</td>
<td>White</td>
</tr>
<tr>
<td>Aldebaran (red)</td>
<td>15,000</td>
<td>1.23</td>
<td>1.39</td>
<td>Yellow-orange</td>
</tr>
<tr>
<td>Antares (red)</td>
<td>15,000</td>
<td>1.87</td>
<td>1.17</td>
<td>Yellow-orange</td>
</tr>
<tr>
<td>Aldebaran (red)</td>
<td>15,000</td>
<td>1.82</td>
<td>1.76</td>
<td>Orange</td>
</tr>
</tbody>
</table>

Photometry and Color Ratios

- Photometry measures the apparent brightness of a star
- 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
- The color ratios are a measure of the star’s surface temperature
The spectra of stars reveal their chemical compositions as well as surface temperatures

- Stars are classified into spectral types
  - divisions of the spectral classes
    - O, B, A, F, G, K, and M
  - Subclasses
    - 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
- The original letter classifications originated from the late 1800s and early 1900s

- The spectral class of a star is directly related to its surface temperature
  - O stars are the hottest
  - M stars are the coolest

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

Full Spectral Typing
Spectral Class and Luminosity Class

- The Sun
  - Classified as a G2 V
- Luminosity classes (use Roman numerals)
  - I – Giant
  - II – Giant
  - III – Giant
  - IV – Sub-giant
  - V – Main Sequence

Relationship between a star’s luminosity, radius, and surface temperature

\[ L = 4\pi R^2\sigma T^4 \]

- \( L \) = star’s luminosity, in watts
- \( R \) = star’s radius, in meters
- \( \sigma \) = Stefan-Boltzmann constant = \( 5.67 \times 10^{-8} \) W m\(^{-2}\) K\(^{-4}\)
- \( T \) = star’s surface temperature, in kelvins

- Stars come in a wide variety of sizes
- Recall Stefan-Boltzmann Law
The Hertzsprung-Russell (H-R) Diagram

- The H-R diagram is a graph plotting the absolute magnitudes of stars against their spectral types—or, equivalently, their luminosities against surface temperatures.
- The positions on the H-R diagram of most stars are along the main sequence, a band that extends from high luminosity and high surface temperature to low luminosity and low surface temperature.

By carefully examining a star’s spectral lines, astronomers can determine whether that star is a main-sequence star, giant, supergiant, or white dwarf.

(a) A supergiant star has a low-density, low-pressure atmosphere: its spectrum has narrow absorption lines.

(b) A main-sequence star has a denser, higher-pressure atmosphere: its spectrum has broad absorption lines.

Using the H-R diagram and the inverse square law, the star’s luminosity and distance can be found without measuring its stellar parallax.

Pathway to Spectroscopic Parallax
Binary Stars

- Binary Stars
  - Two stars held in orbit around each other by their mutual gravitational attraction
    - Surprisingly common
- Visual Binary
  - Those binary star systems that can be resolved into two distinct star images by an Earth-based telescope are called visual binaries
  - Each of the two stars in a binary system moves in an elliptical orbit about the center of mass of the system

Sample Binary Star System

A Binary Star System Analogy

The center of mass of the system of two children is nearer to the more massive child.

Fulcrum

A "binary system" of two children

Binary Star Systems and Stellar Masses

- Binary stars are important because they allow astronomers to determine the masses of the two stars in a binary system
- The masses can be computed from measurements of the orbital period and orbital dimensions of the system

\[ M_1 + M_2 = \frac{a^3}{P^2} \]

\( M_1, M_2 \) = masses of two stars in binary system, in solar masses
\( a \) = semimajor axis of one star's orbit around the other, in AU
\( P \) = orbital period, in years
Mass-Luminosity Relation for Main-Sequence Stars

• Main sequence stars are stars like the Sun but with different masses
• The mass-luminosity relation expresses a direct correlation between mass and luminosity for main-sequence stars
• The greater the mass of a main-sequence star, the greater its luminosity (and also the greater its radius and surface temperature)

Spectroscopy makes it possible to study binary systems in which the two stars are close together

• Some binary star systems can be detected and analyzed even though the system may be so distant, or the two stars so close together, that the two star images cannot be resolved
• A spectroscopic binary appears to be a single star but has a spectrum with the absorption lines for two distinctly different spectral types of stars
• A spectroscopic binary has spectral lines that shift back and forth in wavelength
  – This is caused by the Doppler effect, as the orbits of the stars carry them first toward then away from the Earth
Light curves of eclipsing binaries provide detailed information about the two stars

- An eclipsing binary is a system whose orbits are viewed nearly edge-on from the Earth, so that one star periodically eclipses the other
- Detailed information about the stars in an eclipsing binary can be obtained from a study of the binary’s radial velocity curve and its light curve