Stars I

Chapter 17

Distance and Magnitude

Why doesn't comparison work?

Distances

• The nearest star (Alpha Centauri) is 40 trillion kilometers away (4 ly)

• Distance is one of the most important quantities we need to measure in astronomy

How Does One Measure Distance?

• The first method uses some simple geometry
  – Parallax
  • Have you ever notice that as you change positions the background of a given object changes?
  • Now we let the Earth move in its orbit
  • Because of the Earth’s motion some stars appear to move with respect to the more distant stars

• Using the apparent motion of stars gives us the method called...

Stellar Parallax

• \( p = \frac{r}{d} \)
  – if \( r = 1 \) A.U. and we rearrange...

• We get: \( d = \frac{1}{p} \)

• Definition:
  – if \( p = 1'' \) then \( d = 1 \) parsec
    • 1 parsec = 206,265 A.U.
    • 1 parsec = 3.69 x 1013 km
    • 1 parsec = 3.26 lightyears
  – So Alpha Centauri is 1.3 pc away
  – 40 trillion km, 24.85 trillion mi, and 4 ly

Distance Equation—some examples!

• Our distance equation is: \( d = \frac{1}{p''} \)

• Example 1:
  – \( p = 0.1'' \) and \( d = \frac{1}{p} \)
  – \( d = \frac{1}{0.1''} = 10 \) parsecs

• Example 2 Barnard’s Star:
  – \( p = 0.545 \) arcsec
  – \( d = \frac{1}{0.545} = 1.83 \) parsecs

• Example 3 Proxima Centauri (closest star):
  – \( p = 0.772 \) arcsec
  – \( d = \frac{1}{0.772} = 1.30 \) parsecs
Difficulties with Parallax

• The very best measurements are 0.01"
• This is a distance of 100 pc or 326 ly (not very far)

Improved Distances

• Space!
• In 1989 ESA launched HIPPARCOS
  – This could measure angles of 0.001 arcsec
  – This moves us out to about 1000 parsecs or 3260 lightyears
  – HIPPARCOS has measured the distances of about 118,000 nearby stars
• The U.S. Naval Observatory Interferometer can come close to this level from the ground

How do we measure distances beyond 1000 pc?

• Indirectly!
  – We will now discuss a system that will reappear throughout the semester and it is very critical that you understand how it works.

Luminosity, Apparent brightness, and the Inverse square law

• Luminosity = total amount of power (energy per sec)
  – Measured in L or Watts
• Apparent brightness = power per area (power per square meter)
  – Measured in W/m², symbol = b

Brightness

• \[ b = \frac{L}{4\pi d^2} \]
• \[ b_s = 3.9 \times 10^{26} W/4\pi (1.5 \times 10^{11} m)^2 \]
  \[ = 1370 \text{ W/m}^2 \]
• We measure brightness using a CCD. This method is called photometry.

Apparent Magnitudes

How bright do the stars appear?
Apparent Magnitude Scale

- It is symbolized by \( m \)
  - Brightest Stars in the sky are 1st magnitude
  - Faintest stars visible to the naked-eye are 6th magnitude
  - each step in magnitude is 2.512 times brighter

<table>
<thead>
<tr>
<th>Magnitude Difference</th>
<th>Brightness Ratio</th>
<th>Brightness Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.512^1</td>
<td>2.512</td>
</tr>
<tr>
<td>2</td>
<td>2.512^2</td>
<td>6.31</td>
</tr>
<tr>
<td>3</td>
<td>2.512^3</td>
<td>15.85</td>
</tr>
<tr>
<td>4</td>
<td>2.512^4</td>
<td>39.82</td>
</tr>
<tr>
<td>5</td>
<td>2.512^5</td>
<td>100.00</td>
</tr>
<tr>
<td>10</td>
<td>2.512^10</td>
<td>10,000</td>
</tr>
</tbody>
</table>

A Modern Magnitude System

- Now we know some stars are brighter than 1st magnitude
  - Sirius A: -1.46
  - Canopus: -0.72
  - Arcturus: -0.06
  - Alpha Centauri: -0.01
  - Vega: 0.04
  - Capella: 0.08
  - Rigel: 0.14

What Effects Apparent Magnitude?

- Intrinsic brightness of the object
- Distance to the object
- Examples

<table>
<thead>
<tr>
<th>Star</th>
<th>Magnitude</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sirius A</td>
<td>-1.46</td>
<td>8.61 ly</td>
</tr>
<tr>
<td>Canopus</td>
<td>-0.72</td>
<td>313 ly</td>
</tr>
<tr>
<td>Alpha Centauri</td>
<td>-0.01</td>
<td>4.4 ly</td>
</tr>
<tr>
<td>Rigel</td>
<td>0.14</td>
<td>773 ly</td>
</tr>
</tbody>
</table>

Distance and Brightness

- For nearby stars we know
  - Distance from parallax
  - Apparent magnitude
  - Ratio of apparent brightness when compared to the sun
- We can calculate the luminosity using that information.

Absolute Magnitude

- \( M \) represents absolute magnitude
- \( M \) is the magnitude a star would have if placed at a distance of 10 pc from Earth
- Now back to the question of distances...
How do we measure distances beyond 1000 pc?

• Indirectly!
  – Here is how it works

That looks complicated lets make it simpler

• \[ m_1 - m_2 = (2.5)^*(\log(b_1) - \log(b_2)) \]
• \[ b = l/4\pi d^2 \text{ and } B = L/4\pi D^2 \]
• \[ m - M = (2.5)^*(\log(L/4\pi D^2) - \log(L/4\pi d^2)) \]
• \[ m - M = 5 \times \log(d/D) \]
  – Remember the absolute magnitude is the magnitude if the object was at 10 parsecs
• This gives us: \[ m - M = 5 \log(d/10) \]
  or \[ m - M = 5 \log(d) - 5 \]

Absolute Magnitude

• Remember this is the brightness of an object if it appeared at 10 parsecs
• Examples of Absolute Magnitudes
  – Sun = +4.8
  – Faintest Stars = +20.0
  – Giant Elliptical Galaxies = -23.0
  – Supernova 1987 A = -15.5
• Example of Distance Modulus
• The Sun:
  – \[ m - M = 5\log(d) - 5 \]
  – \[ m = -26.7, M = ?, d = 5.011*10^{-6} \text{ pc} \]

Distances

• If we know the apparent magnitude and the absolute magnitude we can find the distance
  – To do this we must have a known absolute magnitude
  – Objects which have a known absolute magnitude are called Standard Candles

Absolute Magnitude

• Remember: \[ m - M = 5 \log(d) - 5 \]
  – Solve for \( \log(d) \):
    • \[ \log(d) = [(m - M) + 5] / 5 \]
  – We will use this equation several times during this semester when discussing distance to astronomical objects.
• \( m - M \) is also called the distance modulus
  – \( (m - M) \) is (-) then object closer than 10 pc
  – \( (m - M) \) is (+) then object farther than 10 pc
  – \( (m - M) \) is zero then object is exactly 10 pc away

Refinement of the Magnitude Scales

• We must refine our definition of magnitudes
• To really understand magnitude we have to talk about filters
• There are many filter systems used in astronomy
  – Johnson-Cousins
  – Stromgren
  – Infrared
  – Washington
  – Johnson UBV Filters
Representation of Magnitudes

• Apparent magnitude
  – $m_V$ is the magnitude in the V filter
  – this is sometimes just V
• Absolute magnitude
  – $M_V$ is the magnitude in the V filter
  – this is also sometimes just V

Colors

• Let’s define color in the Astronomical Context
• Color Indices or a Color Index
  • The difference between two magnitudes taken in two different filters
• Examples:
  – $(B-V)$
  – $(U-B)$
  – $(b-y)$

Example Stars

<table>
<thead>
<tr>
<th>Star</th>
<th>B-V</th>
<th>U-B</th>
<th>Temp</th>
<th>appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bellatrix</td>
<td>-0.23</td>
<td>-0.87</td>
<td>21,500 K</td>
<td>Blue</td>
</tr>
<tr>
<td>Regulus</td>
<td>-0.12</td>
<td>-0.38</td>
<td>12,000 K</td>
<td>Blue-White</td>
</tr>
<tr>
<td>Sirius</td>
<td>+0.01</td>
<td>-0.05</td>
<td>9,400 K</td>
<td>Blue-White</td>
</tr>
<tr>
<td>Megrez</td>
<td>+0.08</td>
<td>+0.07</td>
<td>8,800 K</td>
<td>White</td>
</tr>
<tr>
<td>Altair</td>
<td>+0.22</td>
<td>+0.08</td>
<td>7,400 K</td>
<td>Yellow</td>
</tr>
<tr>
<td>Sun</td>
<td>+0.62</td>
<td>+0.10</td>
<td>5,800 K</td>
<td>Yellow</td>
</tr>
<tr>
<td>Aldebaran</td>
<td>+1.54</td>
<td>+1.90</td>
<td>3,700 K</td>
<td>Orange</td>
</tr>
<tr>
<td>Betelgeuse</td>
<td>+1.85</td>
<td>+2.06</td>
<td>2,400 K</td>
<td>Red</td>
</tr>
</tbody>
</table>