Photometry

Hipparchus [160 - 127 BC]

Hipparchus compiled a catalog of about a thousand stars in the second century, BC. He classified them into six categories of brightness, now called magnitudes.
Magnitudes

Recognizing that (a) the response of the human eye is basically logarithmic and (b) the average flux difference between first and sixth magnitudes stars is about 100, Norman Robert Pogson (1856) proposed that:

5 magnitudes exactly corresponds to a ratio of 100 : 1, or

1 magnitude corresponds to a flux ratio of 2.512 : 1.

\[(2.512)^5 = 100.0\]

Note that numerically smaller numbers correspond to brighter stars.

Apparent Magnitudes

\[
\frac{F_2}{F_1} = 100^{(m_1 - m_2)/5}
\]

\[
\log(x^n) = n \log(x)
\]

\[
\log\left(\frac{F_2}{F_1}\right) = \frac{(m_1 - m_2)}{5} \log(100) = 2 \frac{(m_1 - m_2)}{5}
\]

\[
\Delta m = m_1 - m_2 = 2.5 \log\left(\frac{F_2}{F_1}\right)
\]
Apparent Magnitudes

\[ \Delta m = m_1 - m_2 = 2.5 \log \left( \frac{F_2}{F_1} \right) \]

<table>
<thead>
<tr>
<th>( \Delta m )</th>
<th>Flux Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1.0 : 1</td>
</tr>
<tr>
<td>0.5</td>
<td>1.6 : 1</td>
</tr>
<tr>
<td>1.0</td>
<td>2.5 : 1</td>
</tr>
<tr>
<td>2.0</td>
<td>6.3 : 1</td>
</tr>
<tr>
<td>2.5</td>
<td>10 : 1</td>
</tr>
<tr>
<td>3.0</td>
<td>16 : 1</td>
</tr>
<tr>
<td>4.0</td>
<td>40 : 1</td>
</tr>
<tr>
<td>5.0</td>
<td>100 : 1</td>
</tr>
<tr>
<td>10.0</td>
<td>10,000 : 1</td>
</tr>
</tbody>
</table>

Example

\[ m_1 - m_2 = 2.5 \log \left( \frac{F_2}{F_1} \right) \]

Let \( m_1 = 4.2^m \) and \( F_2 / F_1 = 27 \)

\[ 4.2 - m_2 = 2.5 \log (27) \]

\[ 4.2 - m_2 = 3.6 \]

\[ m_2 = 4.2 - 3.6 \]

\[ m_2 = 0.6^m \]
The Pleiades

Magnitude Scale

<table>
<thead>
<tr>
<th>Object</th>
<th>m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>-26.7</td>
</tr>
<tr>
<td>Full Moon</td>
<td>-12.6</td>
</tr>
<tr>
<td>Venus</td>
<td>-4.4</td>
</tr>
<tr>
<td>Jupiter</td>
<td>-2.0</td>
</tr>
<tr>
<td>Sirius</td>
<td>-1.4</td>
</tr>
<tr>
<td>Naked-eye limit</td>
<td>6.5</td>
</tr>
<tr>
<td>Binoculars</td>
<td>10</td>
</tr>
<tr>
<td>4-m telescope</td>
<td>26</td>
</tr>
<tr>
<td>Hubble</td>
<td>30</td>
</tr>
</tbody>
</table>
Full Range

\[ \Delta m = m_1 - m_2 = 2.5 \log \left( \frac{F_2}{F_1} \right) \]

\[ \Delta m = 30 - (-26.7) = 56.7 \]

\[ 56.7 = 2.5 \log \left( \frac{F_2}{F_1} \right) \]

\[ \log \left( \frac{F_2}{F_1} \right) = \frac{56.7}{2.5} = 22.7 \approx 23 \]

\[ F_2 / F_1 = 10^{23} \]

\[ 100,000,000,000,000,000,000,000 : 1 \]

Luminosity and Flux

Luminosity (power) is the rate at which electromagnetic energy is radiated into space by an astronomical object.

\[ L_{\text{sun}} = 3.826 \times 10^{26} \text{ J/s} \]

“Brightness” of a star is radiant flux \( F \) – The total amount of light energy of all wavelengths that crosses a unit area perpendicular to the direction of the light’s travel in unit time. The flux is the number of joules per second at 1 cm\(^2\) of a detector aimed at the star.

\[ F = \frac{L}{(4 \pi d^2)} \]
Propagation of Light

**Apparent Brightness**

\[ \text{Flux} = \frac{\text{Luminosity}}{4 \pi d^2} \]

**Inverse Square Law**

\[ \frac{\text{Flux}_1}{4 \pi d_2^2} = \frac{\text{Flux}_2}{4 \pi d_1^2} = \frac{d_2^2}{d_1^2} \]

The Pleiades
How to Compare Magnitudes

The way to compare the intrinsic brightness is to compare the magnitudes for a given distance, which is 10 pc.

Example:
Suppose a star has $m = 7.5$ mag and is at $d = 100$ pc
Change $d$ to 10 pc
Distance has been reduced by 10X, so the Brightness has increased by $(10)^2 = 100$X, or the Magnitude must decrease by 5.0 mag
Therefore, $M = 7.5 - 5.0 = 2.5$ mag

Absolute Magnitudes

$m_1 - m_2 = 2.5 \log \left( \frac{F_2}{F_1} \right)$

$F = \frac{L}{4 \pi d^2}$

$\frac{F(10)}{F(d)} = \left( \frac{d}{10} \right)^2$

$m - M = 5 \log \left( \frac{d}{10} \right)$
Example

\[ m - M = 5 \log \left( \frac{d}{10} \right) \]

Let \( m = 6.3 \) \( m \) and \( d = 38 \) pc

\[ 6.3 - M = 5 \log \left( \frac{38}{10} \right) \]

\[ 6.3 - M = 2.9 \]

\[ M = 6.3 - 2.9 \]

\[ M = 3.4 \]

The Sun’s Absolute Magnitude

\[ m - M = 5 \log \left( \frac{d}{10} \right) \]

Let \( m = -26.7 \) \( m \) and \( d = 1/206265 \) pc

\[ -26.7 - M = 5 \log \left( \frac{1}{206265} / 10 \right) \]

\[ -26.7 - M = -31.5 \]

\[ M = -26.7 + 31.5 \]

\[ M = 4.8 \]
Color and Temperature

Image of three graphs showing intensity vs. wavelength for stars at different temperatures:

- a. This star looks red
- b. This star looks yellow-white
- c. This star looks blue-white

UBV Filter Bandpasses

Image of a graph showing the sensitivity function for U, B, and V filters across different wavelengths (in Angstroms).
Bolometric Magnitudes

Occasionally, astronomers do discuss the magnitudes of stars based on their entire luminosity. In other words, no filter is used. The Bolometric Magnitude covers the entire electromagnetic spectrum.

Instead of using Flux, one uses the Luminosity of the Sun:

\[ L_{\text{sun}} = 3.826 \times 10^{26} \text{ J/s} \]

The corresponding magnitude is \( M_{\text{bol}} = 4.75 \text{ mag} \).