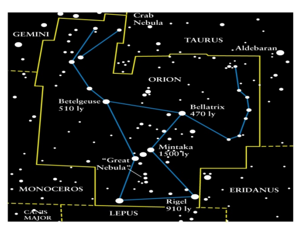
# Photometry

# 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 magnitude 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

$$F_2 / F_1 = 100^{(m_1 - m_2)/5}$$

$$\log (x^n) = n \log (x)$$

$$\log (F_2 / F_1) = (m_1 - m_2) / 5 \ \log (100) = 2 (m_1 - m_2) / 5$$

$$\Delta m = m_1 - m_2 = 2.5 \log ( F_2 / F_1 )$$

## Apparent Magnitudes

$\Delta m = m_1 - m_2 = 2.5 \log ( F_2 / F_1 )$

| **Δm** | **Flux Ratio** |
|---|---|
| 0.0 | 1.0 : 1 |
| 0.5 | 1.6 : 1 |
| 1.0 | 2.5 : 1 |
| 2.0 | 6.3 : 1 |
| 2.5 | 10 : 1 |
| 3.0 | 16 : 1 |
| 4.0 | 40 : 1 |
| 5.0 | 100 : 1 |
| 10.0 | 10,000 : 1 |

## Example

$m_1 - m_2 = 2.5 \log ( F_2 / F_1 )$

Let $m_1 = 4.2^m$ and $F_2 / F_1 = 27$

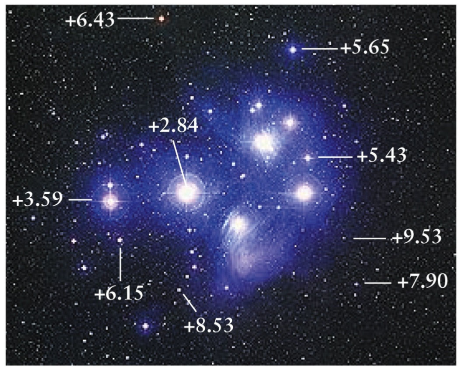
$4.2 - m_2 = 2.5 \log ( 27 )$

$4.2 - m_2 = 3.6$

$m_2 = 4.2 - 3.6$

$m_2 = 0.6^m$

# The Pleiades

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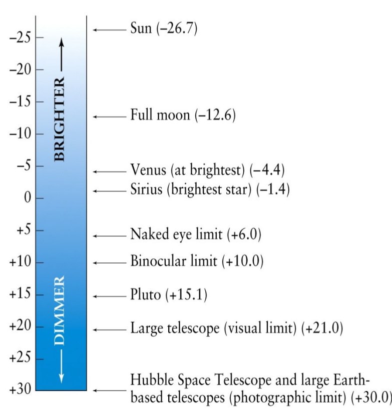
# Magnitude Scale

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| Object | m |
|---|---|
| Sun | -26.7 |
| Full Moon | -12.6 |
| Venus | -4.4 |
| Jupiter | -2.0 |
| Sirius | -1.4 |
| Naked-eye limit | 6.5 |
| Binoculars | 10 |
| 4-m telescope | 26 |
| Hubble | 30 |

# Full Range

$\Delta m = m_1 - m_2 = 2.5 \log ( F_2 / F_1 )$

$\Delta m = 30 - (-26.7) = 56.7$

$56.7 = 2.5 \log ( F_2 / F_1 )$

$\log ( F_2 / F_1 ) = 56.7 / 2.5 = 22.7 \cong 23$

$F_2 / F_1 = 10^{23}$

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.

$L_{sun} = 3.826 \times 10^{26}$ 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.

$F = L / (4 \pi d^2)$

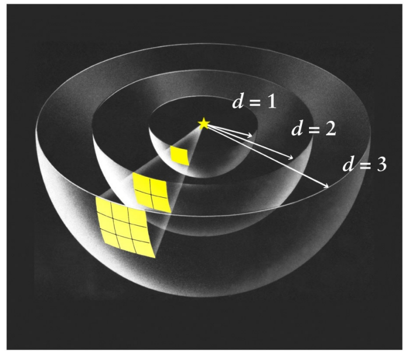
# Propagation of Light

Apparent Brightness

Flux = Luminosity / 4 π $d^2$

Inverse Square Law

$$\frac{Flux_1}{Flux_2} = \frac{4 \pi d_2^2}{4 \pi d_1^2} = \frac{d_2^2}{d_1^2}$$

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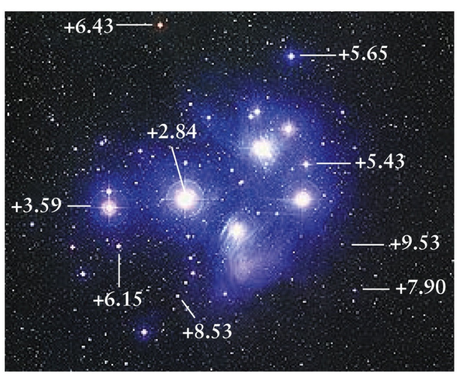
# The Pleiades

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# 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 $(10)^2$ = 100X, or
the Magnitude must **decrease** by 5.0 mag

Therefore, M = 7.5 – 5.0 = 2.5 mag

# Absolute Magnitudes

$$m_1 - m_2 = 2.5 \log ( F_2 / F_1 )$$

$$F = L / 4 \pi d^2$$

$$F(10) / F(d) = ( d / 10 )^2$$

$$\mathbf{m - M = 5 \log ( d / 10 )}$$

# Example

$m - M = 5 \log ( d / 10 )$

Let $m = 6.3^m$ and $d = 38$ pc

$6.3 - M = 5 \log ( 38 / 10 )$

$6.3 - M = 2.9$

$M = 6.3 - 2.9$

$M = 3.4^m$

# The Sun's Absolute Magnitude

$m - M = 5 \log ( d / 10 )$

Let $m = -26.7^m$ and $d = 1/206265$ pc

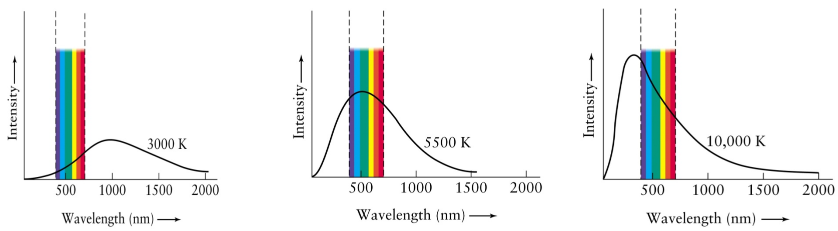
$-26.7 - M = 5 \log (1/206265 / 10 )$

$-26.7 - M = -31.5$

$M = -26.7 + 31.5$

$M = 4.8^m$

# Color and Temperature




a This star looks red

b This star looks yellow-white

c This star looks blue-white

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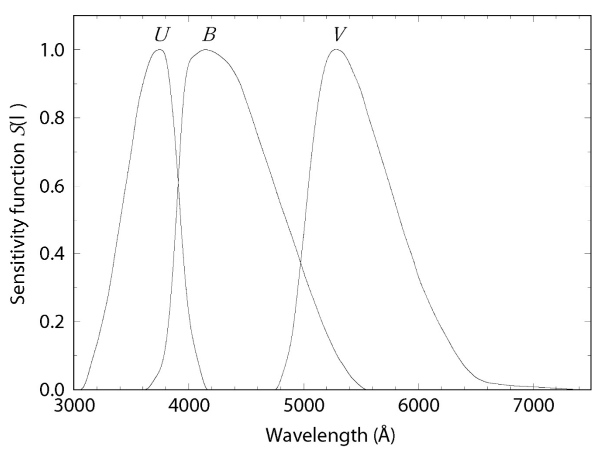
# UBV Filter Bandpasses




*Modern Stellar Astronomy*, Ostlie & Carroll

# Color Indices

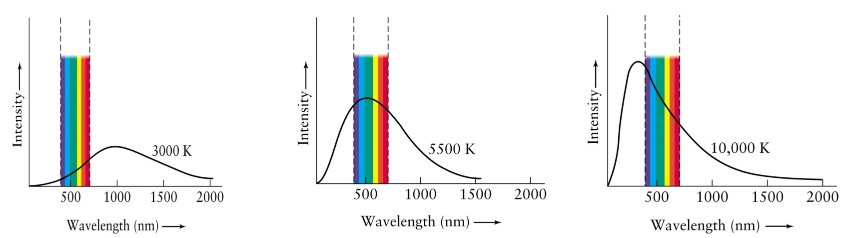
| | | |
|---|---|---|
| Filters | U | Ultraviolet |
| | B | Blue |
| | V | Visual |

( U – B ) and ( B – V ) are color indices

$$B - V = M_B - M_V$$

Ultraviolet, blue, and visual magnitude scales are adjusted to be equal to one another, so that they give a color index of 0 to a star with a temperature of about 10,000 K. The (B – V) index ranges from about -0.4 (bluest, hottest stars) to more than +2.0 (redder, coolest stars).

# Color and Temperature

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# 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:

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

The corresponding magnitude is **$M_{bol}$ = 4.75 mag .**

# Table of Colors

H8 BRIGHT STARS, J1998.5

| Flamsteed/Bayer Designation | | | HR No. | Right Ascension | Declination | Notes | $V$ | $U-B$ | $B-V$ | Spectral Type |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | h m s | ° ′ ″ | | | | | |
| 11 | v1032 | Ori | 1638 | 5 04 29.0 | +15 24 08 | fv | 4.68 | −0.09 | −0.06 | A0p Si |
| | $\eta^2$ | Pic | 1663 | 5 04 55.7 | −49 34 47 | fv | 5.03 | +1.88 | +1.49 | K5 III |
| 2 | $\epsilon$ | Lep | 1654 | 5 05 23.9 | −22 22 23 | fv | 3.19 | +1.78 | +1.46 | K4 III |
| | $\zeta$ | Dor | 1674 | 5 05 29.1 | −57 28 29 | f | 4.72 | −0.04 | +0.52 | F7 V |
| 10 | $\eta$ | Aur | 1641 | 5 06 24.6 | +41 13 57 | fv | 3.17 | −0.67 | −0.18 | B3 V |
| 67 | $\beta$ | Eri | 1666 | 5 07 46.5 | − 5 05 18 | fvd | 2.79 | +0.10 | +0.13 | A3 IVn |
| 69 | $\lambda$ | Eri | 1679 | 5 09 04.5 | − 8 45 21 | fv | 4.27 | −0.90 | −0.19 | B2 IVn |
| 16 | | Ori | 1672 | 5 09 14.7 | + 9 49 40 | fvmd6 | 5.43 | | +0.24 | A9m |
| 3 | $\iota$ | Lep | 1696 | 5 12 13.7 | −11 52 15 | d | 4.45 | −0.40 | −0.10 | B9 V: |
| 5 | $\mu$ | Lep | 1702 | 5 12 51.8 | −16 12 26 | fsv | 3.31 | −0.39 | −0.11 | B9p Hg Mn |
| 4 | $\kappa$ | Lep | 1705 | 5 13 09.7 | −12 56 36 | d7 | 4.36 | −0.37 | −0.10 | B7 V |
| 17 | $\rho$ | Ori | 1698 | 5 13 12.7 | + 2 51 34 | vd67 | 4.46 | +1.16 | +1.19 | K1 III CN 0.5 |
| 11 | $\mu$ | Aur | 1689 | 5 13 19.5 | +38 28 58 | f | 4.86 | +0.09 | +0.18 | A7m |
| | $\theta$ | Dor | 1744 | 5 13 45.5 | −67 11 13 | f | 4.83 | +1.39 | +1.28 | K2.5 IIIa |
| 19 | $\beta$ | Ori | 1713 | 5 14 27.9 | − 8 12 12 | fsvd6 | 0.12 | −0.66 | −0.03 | B8 Ia |
| 13 | $\alpha$ | Aur | 1708 | 5 16 34.7 | +45 59 48 | fcvd67 | 0.08 | +0.44 | +0.80 | G6 III + G2 III |
| | o | Col | 1743 | 5 17 25.8 | −34 53 48 | f | 4.83 | +0.80 | +1.00 | K0/1 III/IV |
| 20 | $\tau$ | Ori | 1735 | 5 17 32.0 | − 6 50 45 | fsd6 | 3.60 | −0.47 | −0.11 | B5 III |
| 15 | $\lambda$ | Aur | 1729 | 5 19 02.1 | +40 05 52 | fd | 4.71 | +0.12 | +0.63 | G1.5 IV–V Fe–1 |
| | $\zeta$ | Pic | 1767 | 5 19 19.9 | −50 36 27 | f | 5.45 | +0.01 | +0.51 | F7 III–IV |