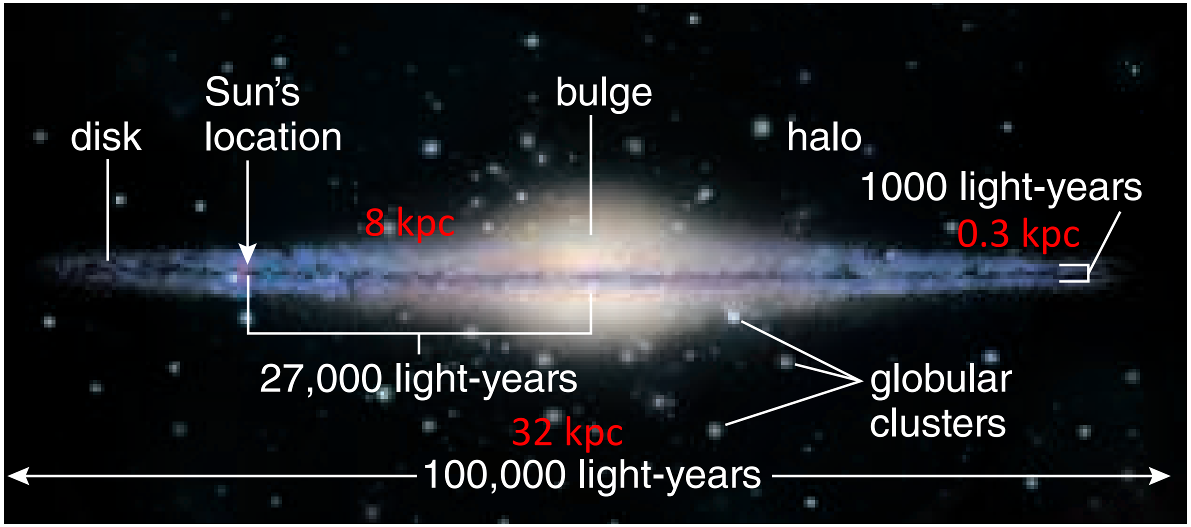
Astronomical measures

Introduction to observational astronomy

Laboratory of Astrophysics

Distance measures

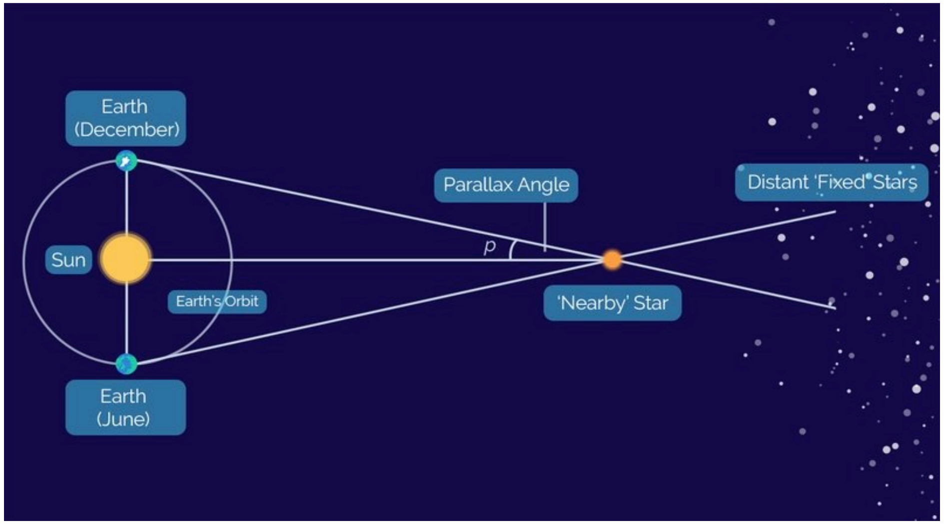
- **Astronomical unit (AU)**: distance between Earth and Sun
- **Light-year (lyr)**: distance of light traveling for a year (9.5×10^{12}km)
- **Parsec (pc)**: 3.26lyr



Distance to Andromeda, closest spiral galaxy: 800 kpc = 0.8 Mpc

Distance measurement

- **Trigonometric Parallax**:



$$\tan p = \frac{1AU}{d}$$

➢ Proxima Centauri (star closest to the Sun)

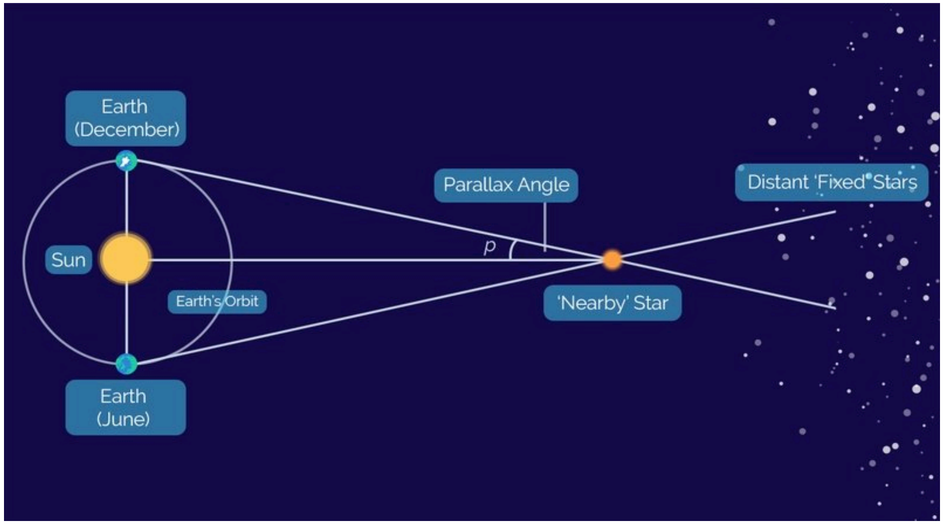
$$p = \frac{1}{d} = 0.77''$$

➢ HD46150 in the cluster NGC 2244 (Rosette Nebula)

$$p = 0.6263 \text{ mas} \qquad d \approx 1600 \text{ pc}$$

Distance measurement

- **Trigonometric Parallax**:



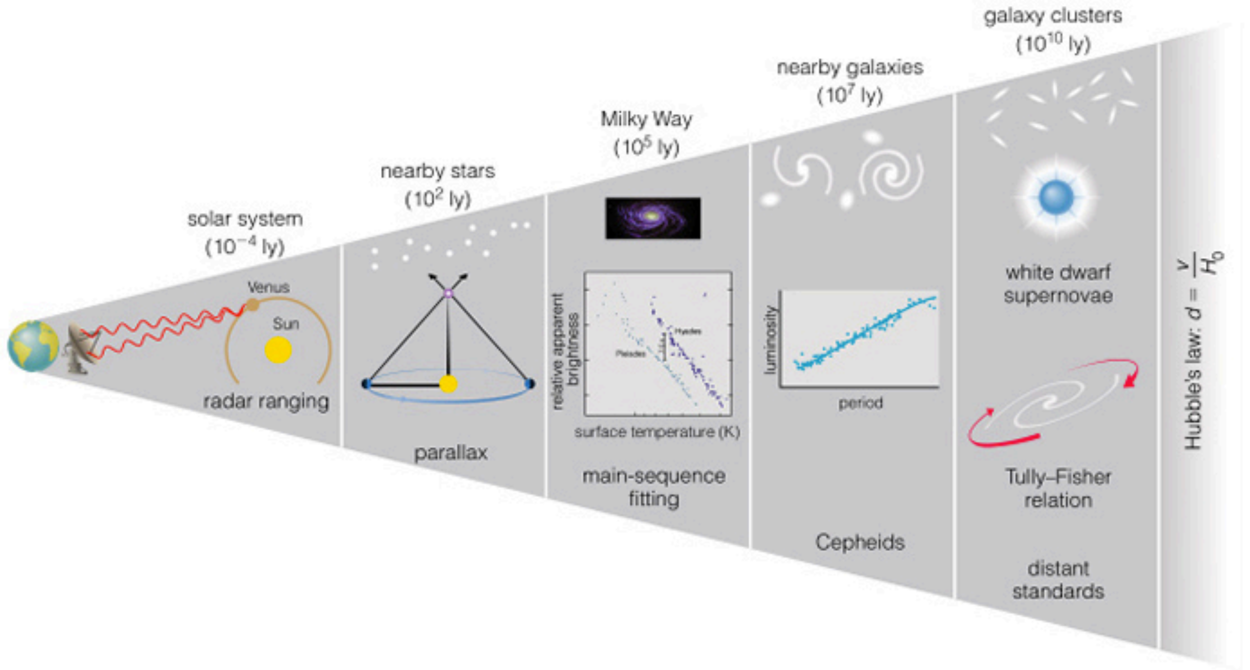
$$\tan p = \frac{1AU}{d}$$

- **Standard candles**: objects with same intrinsic luminosity

Supernovae of type Ia, Variable stars: RR Lyrae, Cepheids….

Distance ladder

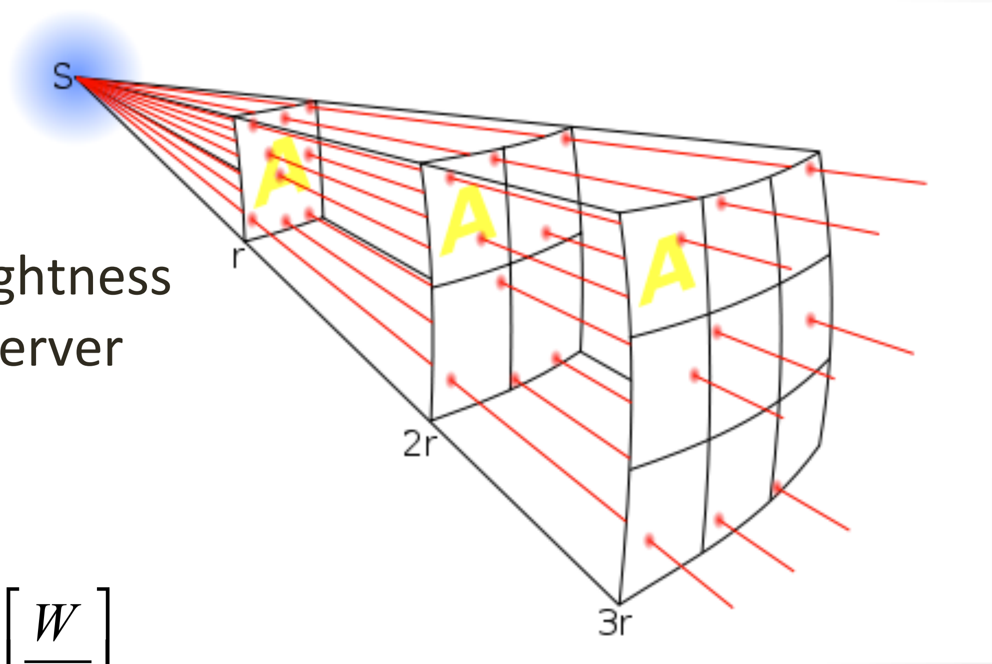
Use of consecutive methods/standard candles calibrated with more nearby ones to reach larger distances



Luminosity & Brightness

- **Luminosity**: radiated electromagnetic power [J/s = W]
- Luminosity of the Sun:

  $L_{\odot} = 3.83 \times 10^{26} W$



- **Apparent brightness**: brightness of object reaching an observer

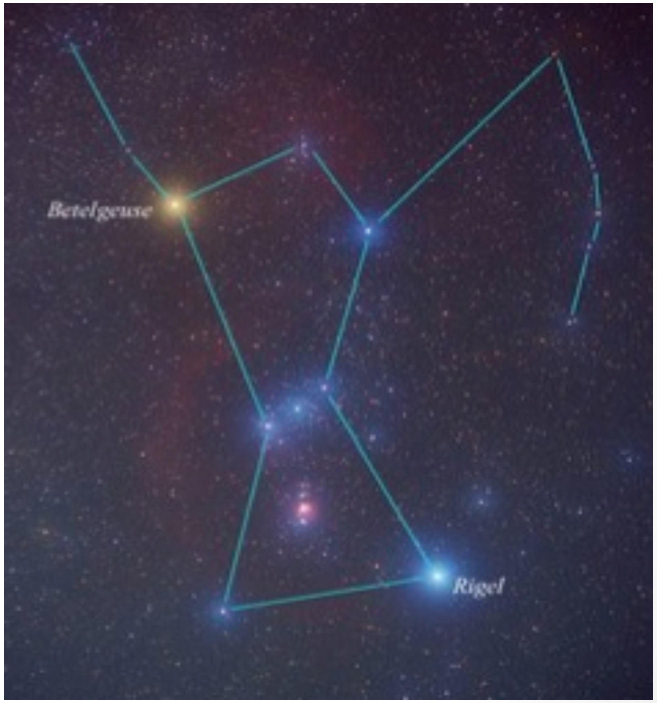
$$F = \frac{L}{4\pi d^2}\left[\frac{W}{m^2}\right]$$

Stellar luminosities

Stars have large luminosity range: $10^{-4} - 10^{6}\,L_{\odot}$

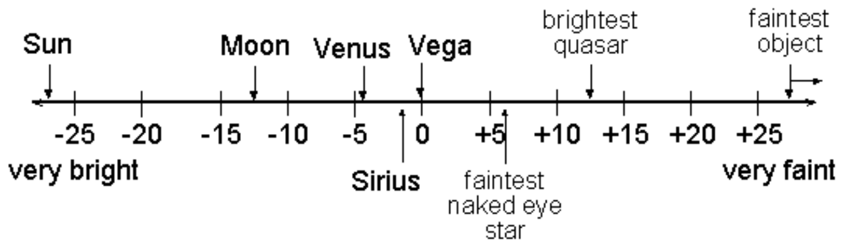
Proxima Centauri
red dwarf
d = 1.3 pc
mass = 0.12 $M_{\odot}$
L = 0.0017 $L_{\odot}$

Betelgeuse (α Orionis)
red supergiant
d = 220 pc
mass ≈ 12 $M_{\odot}$
L ≈ 120,000 $L_{\odot}$



Magnitude scale

- Unit-less measure of brightness
- Inverted Logarithmic scale: brighter have smaller values



$$m_1 - m_2 = -2.5\log_{10}\left(\frac{F_1}{F_2}\right)$$

- Vega has m=0
- **Apparent magnitude (m)**: brightness of object as it appears to us, but this is affected by intrinsic luminosity, distance and extinction
- **Absolute magnitude (M)**: intrinsic luminosity of object defined to be at 10 parsecs

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

Magnitude scale

- **Distance modulus:** $$\mu = m - M = 5\log_{10}\left(\frac{d}{10}\right)$$

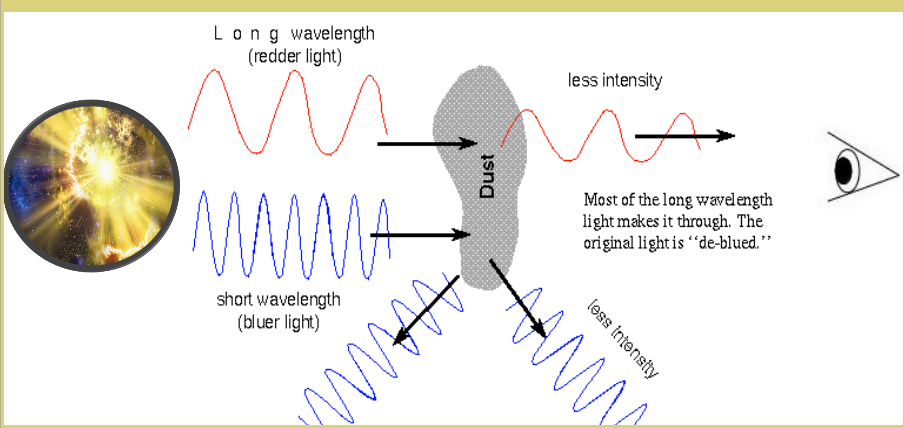
Star	m_V	M_V	Distance (pc)
Sun	-26.81	4.76	4.85e-6
Proxima Cen	11.1	15.6	1.3
Betelgeuse	0.5	-5.85	220
Sirius A	-1.46	1.42	2.6

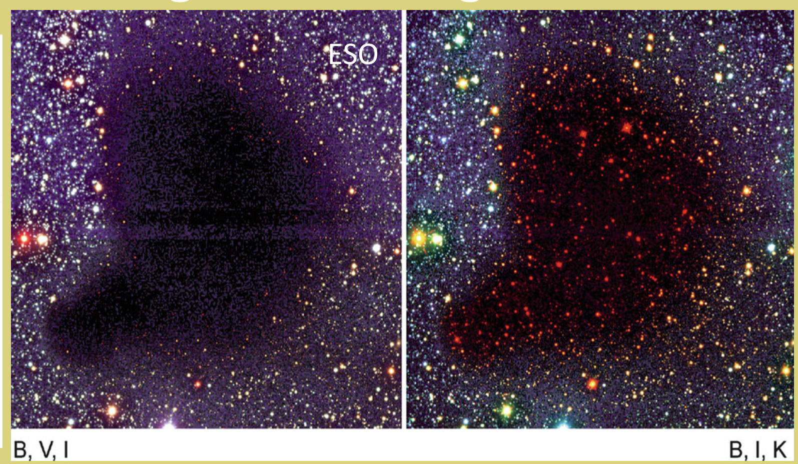
Extinction

- **Extinction**: absorption of light by dust
- Distance modulus corrected by **extinction:**

$$\mu = m - M = 5\log_{10}\left(\frac{d}{10}\right) + A$$

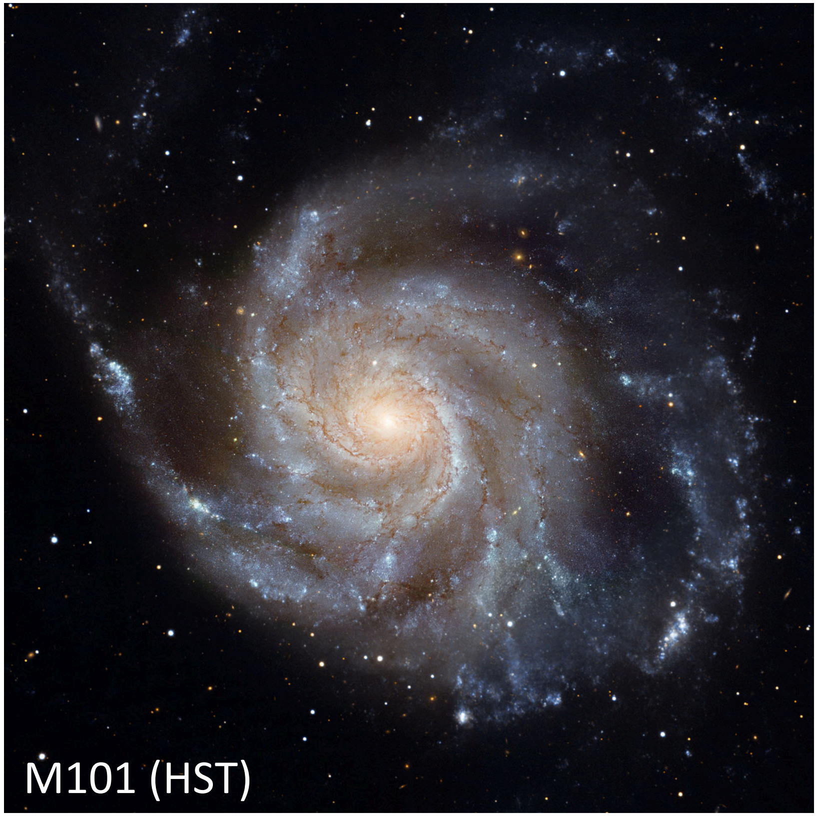
Extinction: absorption of light by dust
Reddening: reemission at longer wavelengths





Surface brightness

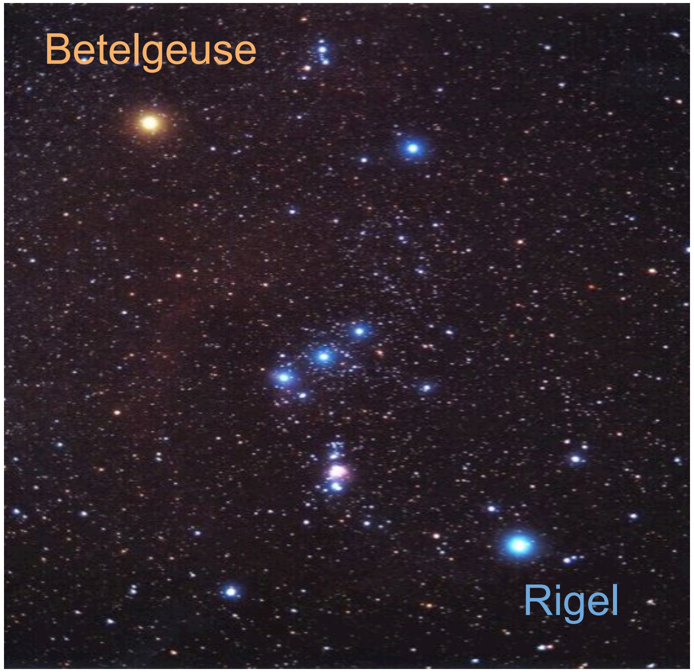
- Important for **extended sources** vs point sources
- **Surface brightness**: brightness (surface) density [mag/arcsec^2]



V-band surface brightness:

- Orion:
  17 mag/arcsec^2
- Andromeda:
  14-18.0 mag/arcsec^2
- M101:
  25.1 mag/arcsec^2

Stellar colors

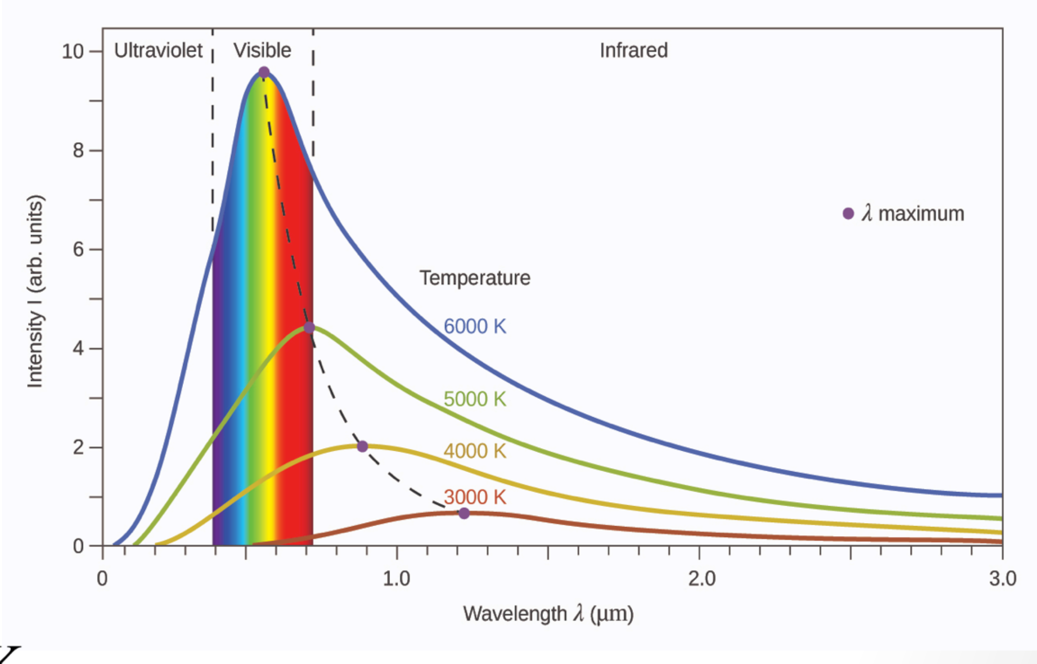


Orion constellation

Central part of the Omega Cen globular cluster (HST)

Stellar colors: surface temperature

- Color is directly related to the surface temperature
- Cool stars are red, hot stars are blue
  - Betelgeuse: 3400K
  - Rigel: 10100 K
- To a first approximation, stars emit as black bodies
- Wien's law



$$\lambda_{max} T = 0.290 \text{ cm K}$$

Stefan-Boltzmann equation

$$L = 4\pi R^2 \sigma T_{eff}^4$$

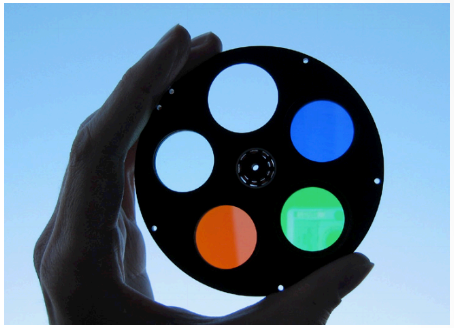
luminosity (L) — radius (R) — effective temperature (T_{eff})

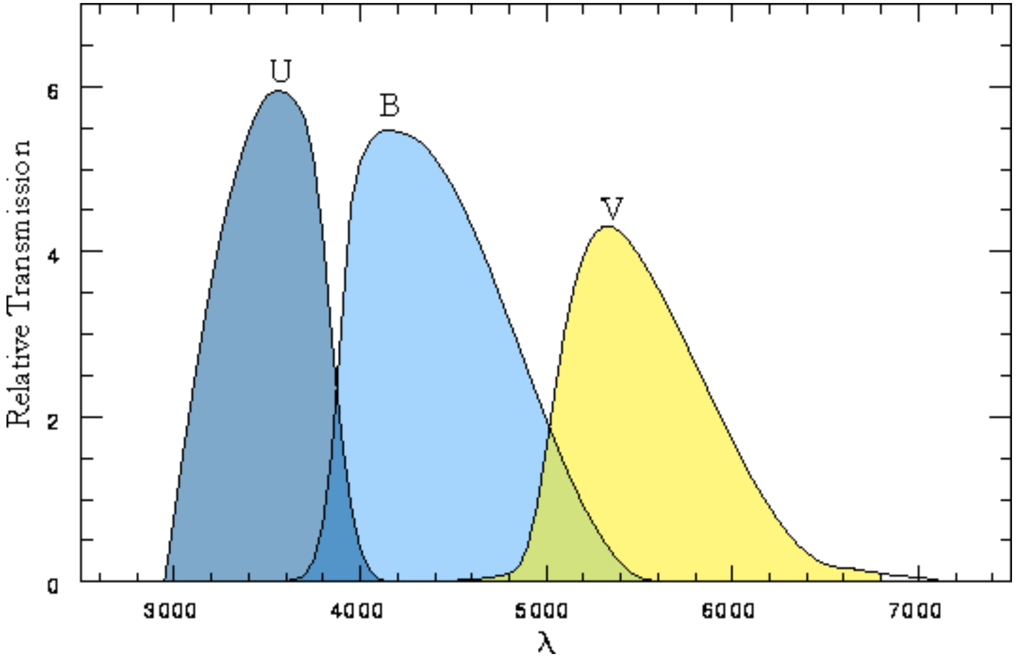
$\sigma = 5.6704 \times 10^{-8} W m^{-2} K^{-4}$ Stefan-Boltzmann constant

- Stars are not perfect black bodies
- Effective temperature (T_{eff}): temperature of blackbody with same integrated surface flux as star
- Sun: $T_{eff} = 5777K$ $\lambda_{max} = 501.6\text{nm}$

Color in astronomy

- In practice, astronomers observe with different **passbands** or **filters**





Color index

U-B = m_U-m_B

B-V = m_B-m_V

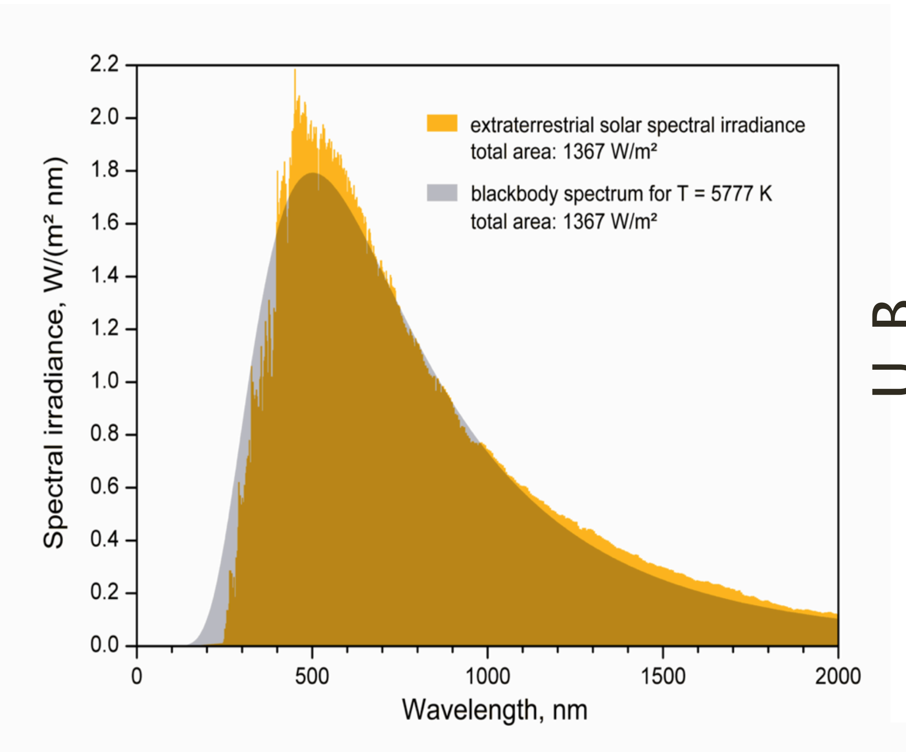
A star with a smaller (B-V) color index is bluer than the one with higher (B-V)

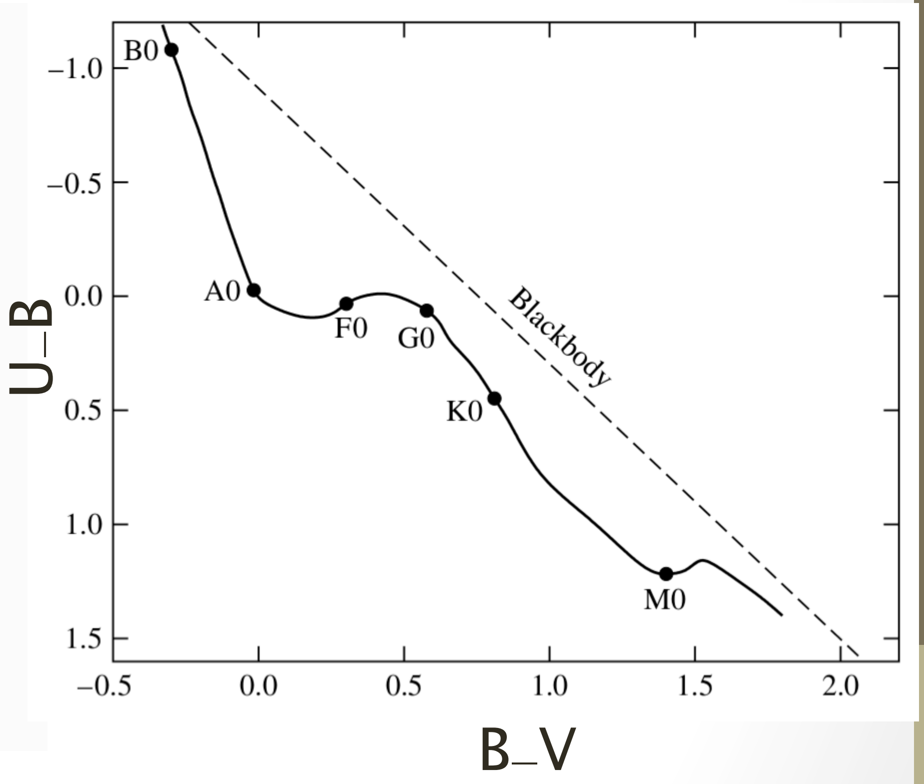
Typical optical filters: UBVRI, ugriz

- **Bolometric magnitude**: magnitudes over all wavelengths

Color in astronomy

- **Stars** are not perfect blackbodies





Hands-on!

Example 1

A. What is the flux that the Earth receives from the Sun?
B. What would be the flux from the Sun if it its distance were 10 pc?

Hands-on!

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$$F = \frac{L}{4\pi r^2} = \frac{3.828 \cdot 10^{33}\,\mathrm{erg\,s^{-1}}}{4\pi (1.496 \cdot 10^{13}\,\mathrm{cm})^2} = $$
$$= 1.36 \cdot 10^{6}\,\mathrm{erg\,cm^{-2}\,s^{-1}}$$

$$\frac{F_{1AU}}{F_{10pc}} = \frac{\frac{L}{4\pi r_1^2}}{\frac{L}{4\pi r_2^2}} = \frac{r_2^2}{r_1^2} =$$

$r_2 \rightarrow 10\,\mathrm{pc}$, $r_1 \rightarrow 1\,\mathrm{AU}$

$$= \left(\frac{2062650\,\mathrm{AU}}{1\,\mathrm{AU}}\right)^2 = 4.25 \cdot 10^{12}$$

$$F_{10pc} = \frac{F_{1AU}}{4.25 \cdot 10^{12}} = \frac{1.36 \cdot 10^{6}}{4.25 \cdot 10^{12}}\,\mathrm{erg\,s^{-1}\,cm^{-2}} =$$
$$= 3.2 \cdot 10^{-7}\,\mathrm{erg\,s^{-1}\,cm^{-2}}$$

Hands-on!

Example 2

The apparent magnitude of the Sun is $m_{\odot} = -26.81$

A. What is its absolute magnitude?

B. What would be the magnitude of the Sun if it were located at the center of the Milky Way?

(Assume the distance to the center is 8 kpc and no extinction).

Example 2

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

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

$$= -26.81 - 5 \cdot \log\left(\frac{4.847 \cdot 10^{-6}}{10}\right) = 4.76$$

$1 AU = 4.847 \cdot 10^{-6}$ pc

$d = 8$ kpc

$$m = M + 5 \log \frac{d}{10\,pc} =$$

$$= 4.76 + 5 \log(800) =$$

$$= 19.3 \text{ mag}$$

Hands-on!

Example 3

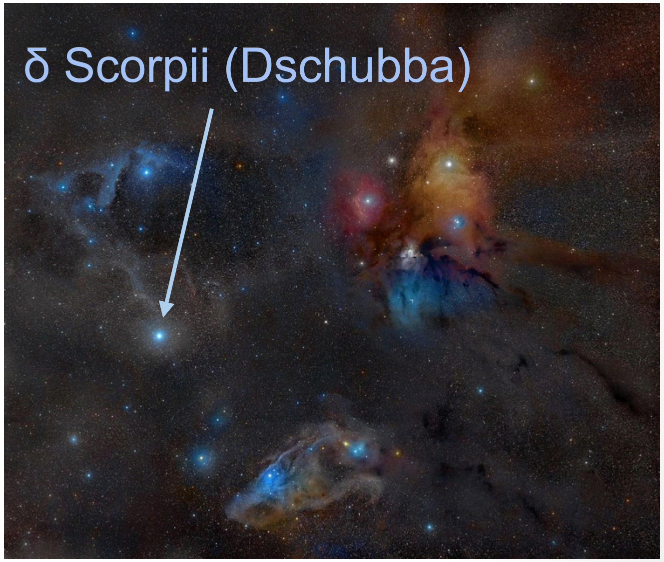
A star consists of a spherical blackbody with the following surface temperature and radius:

$r = 5.6 \times 10^{11}$ cm, $T_{eff} = 28000$ K

The latest measurement of the distance is d = 163pc.

Determine:

a) Luminosity
b) Absolute bolometric magnitude
c) Apparent bolometric magnitude
d) Flux at Earth's surface
e) Flux at star's surface
f) Peak wavelength λ_{max}



Hands-on!

Example 3

r = 5.6x10^{11} cm, T_{eff} = 28000 K, d = 163 pc

a) Luminosity

Stefan-Boltzmann eq.

$1 L_\odot = 3.828 \cdot 10^{26}$ W

$L = 4\pi R^2 \sigma T_{eff}^4 = 1.17 \cdot 10^{31}$ W $= 30564 L_\odot$

$\sigma = 5.6704 \cdot 10^{-8}$ W m^{-2} K^{-4}

Hands-on!

Example 3

$r = 5.6\mathrm{x}10^{11}$ cm, $T_{eff} = 28000$ K, d = 163 pc

b,c) Absolute/apparent magnitude

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

apparent mag.

if we switch to abs. mag:

$$\frac{L_1}{L_2} = 100^{(M_2 - M_1)/5}$$

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

distance (same for abs. mag)

$$\frac{L_1}{L_2} = 10^{\frac{2}{5}(M_2 - M_1)} \Rightarrow M_1 = M_2 - 2.5 \log \frac{L_1}{L_2}$$

M_1: δSco, M_2: Sun

$$M_{\delta Sco} = 4.74 - 2.5 \cdot \log(30564) = -6.47 \text{ mag}$$

$$m_{\delta Sco} = M_{\delta Sco} + 5 \log\left(\frac{d}{10pc}\right) = -6.47 + 5 \log\left(\frac{163}{10}\right) = -0.41 \text{ mag}$$

Hands-on!

Example 3

r = 5.6x10^{11} cm, T_{eff} = 28000 K, d = 163 pc

d,e) Flux at Earth's and star's surface

$$F_E = \frac{L}{4\pi d^2} = \frac{1.17 \cdot 10^{31}\,W}{4\pi \cdot (163 \cdot 3.086 \cdot 10^{16}\,m)^2} = 3.7 \cdot 10^{-8}\,Wm^{-2}$$

$$\left.\begin{array}{l} L = 4\pi R^2 \sigma T_{eff}^4 \\ F = \dfrac{L}{4\pi r^2} \end{array}\right\}$$ at star's surface

$R = r \Rightarrow F = \sigma T^4 = 3.48 \cdot 10^{10}\,Wm^{-2}$

(σ = $5.6704 \cdot 10^{-8}\,Wm^{-2}K^{-4}$)

Hands-on!

Example 3

$r = 5.6 \times 10^{11}$ cm, $T_{eff} = 28000$ K, d = 163 pc

f) Peak wavelength

$$\lambda_{max} = \frac{0.29\ \mathrm{cm\,K}}{28000\ \mathrm{K}} = 1.036 \cdot 10^{-5}\ \mathrm{cm} = 103.6\ \mathrm{nm}$$

UV range