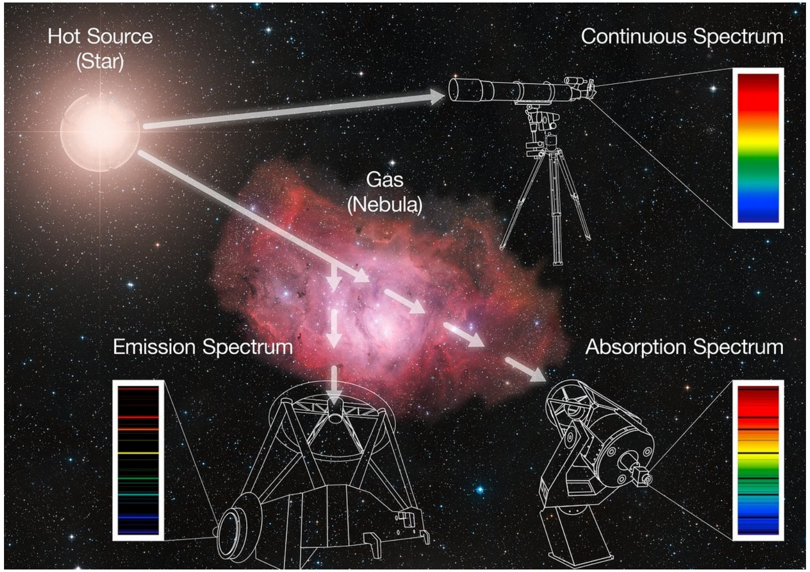
Essentials of Astronomy 2



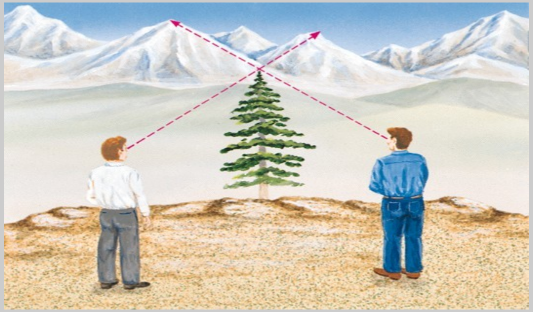
Dr Priya Hasan
Asst Professor in Physics
Maulana Azad National Urdu University
Hyderabad
priya.hasan@gmail.com

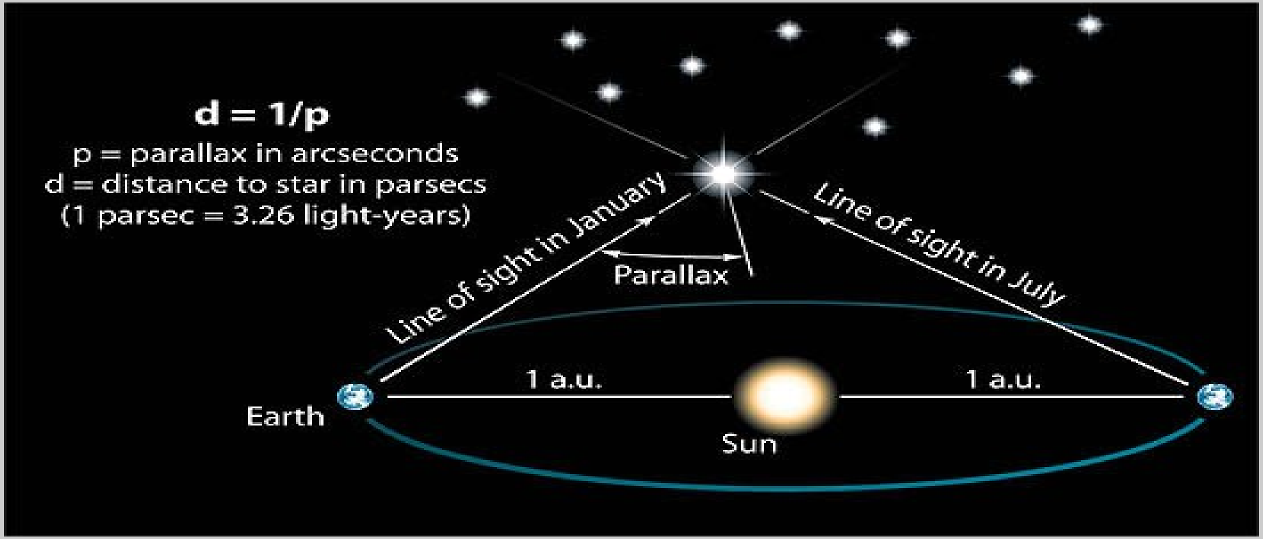
In this lecture....

- Parallax
- Magnitude scale
- Photometry
- Spectroscopy

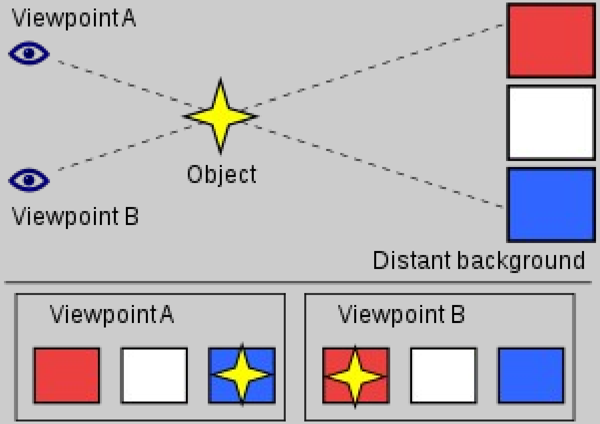
What do we observe in stars?

Parallax

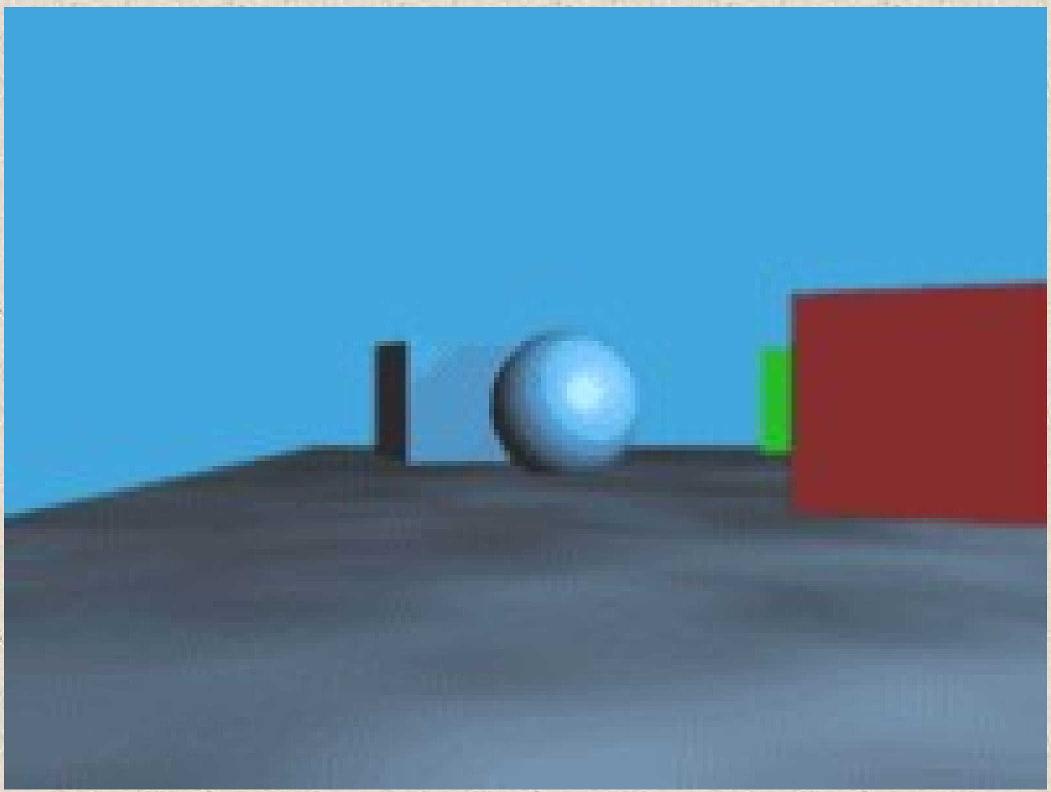




d = 1/p
p = parallax in arcseconds
d = distance to star in parsecs
(1 parsec = 3.26 light-years)
Line of sight in January
Line of sight in July
Parallax
1 a.u.
1 a.u.
Earth
Sun



Viewpoint A
Viewpoint B
Object
Distant background
Viewpoint A
Viewpoint B



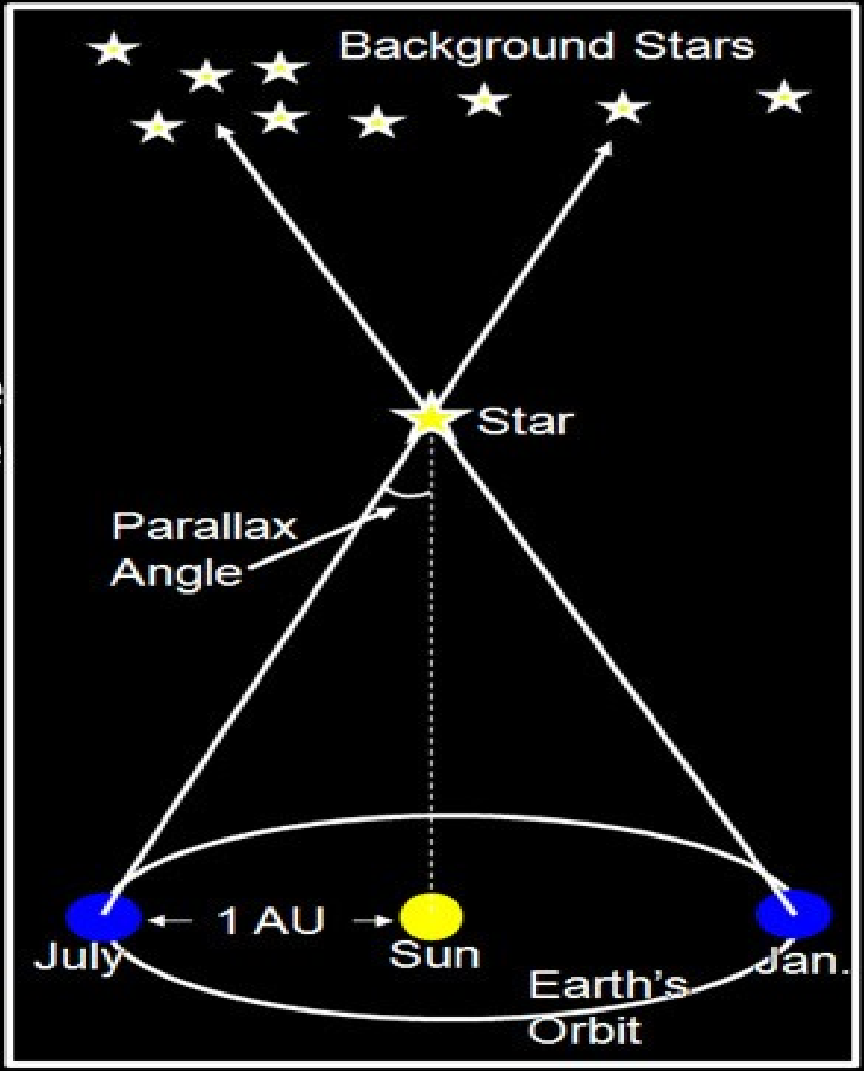
Parallax

(a method for obtaining the distance to nearby objects)

Parallax is the apparent change in position of nearby objects relative to more background objects as the observer changes position. As the earth revolves around the sun, the apparent positions of nearby stars change relative to background objects.

$$d = \frac{1}{\pi} \quad \text{or} \quad \pi = \frac{1}{d}$$

Where d is the distance in parsecs and π is the parallax in arc seconds.



Parallax measurements

Proxima Centauri (a member of the triple system of **Alpha Centauri**), has a **parallax** of 0.76813″
d= 1/0.76813, or 1.302 pc
Barnard's star p= 0.54831″, d=1/0.54831 ~ 2 pc
Errors in parallaxes were 0.001″
Hipparcos satellite has measured only about 100,000 to an accuracy of 0.001″

Now comes Gaia!!

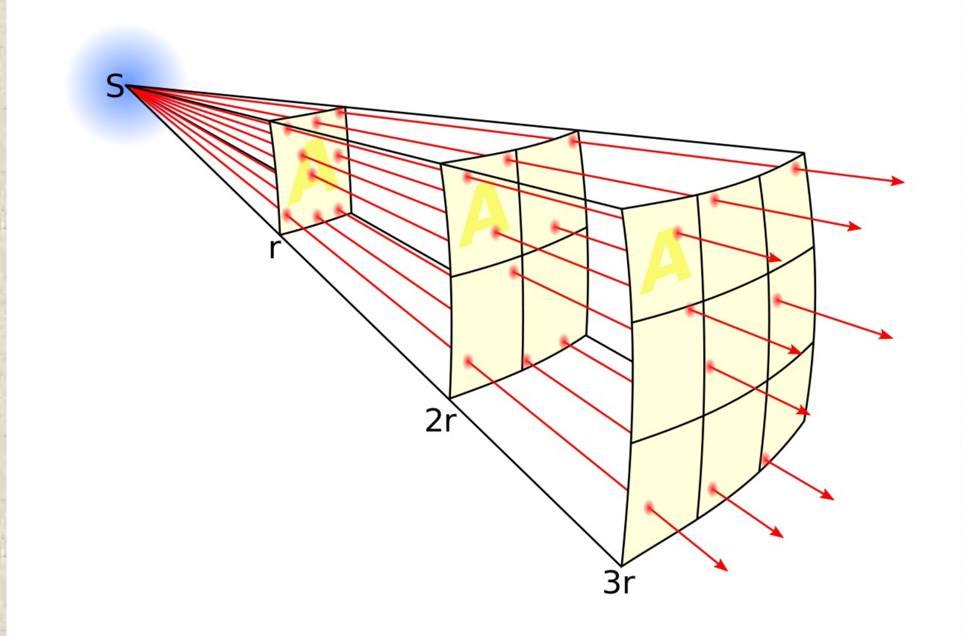
Luminosity and Flux

Luminosity - A star produces light – the total amount of energy that a star emits per second is called its Luminosity.

For the Sun:

3.846×10^{26} watts (3.846×10^{33} ergs per second)

Flux –If we have a light detector (eye, camera, telescope) we measure the light emitted by the star – the total amount of energy intercepted by the detector divided by the area of the detector– called the Flux.



Luminosity does'nt depend on distance!!

Flux Depends!!!

Luminosity

(the total energy that a star produces each second)

Luminosity depends on both the radius of a star and its surface temperature. It is the product of ...

- Flux - the total energy produced each second by each square meter of a blackbody radiator. Given by the Stefan-Boltzmann Law in units of J/s-m^2 where temperatures in Kelvin.

$$f = \sigma T^4$$

- Area - the total surface area of the star (area of a sphere in m^2).

$$A = 4\pi R^2$$

Thus, the Luminosity in units of J/s is given by:

$$L = 4\pi R^2 \sigma T^4$$

Flux and luminosity

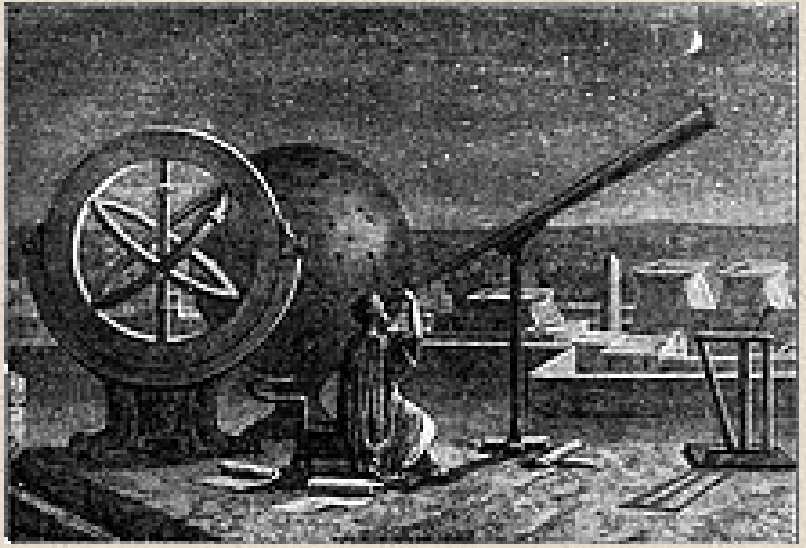
Flux varies as 1/distance^2

Mathematically, if we have two stars A and B

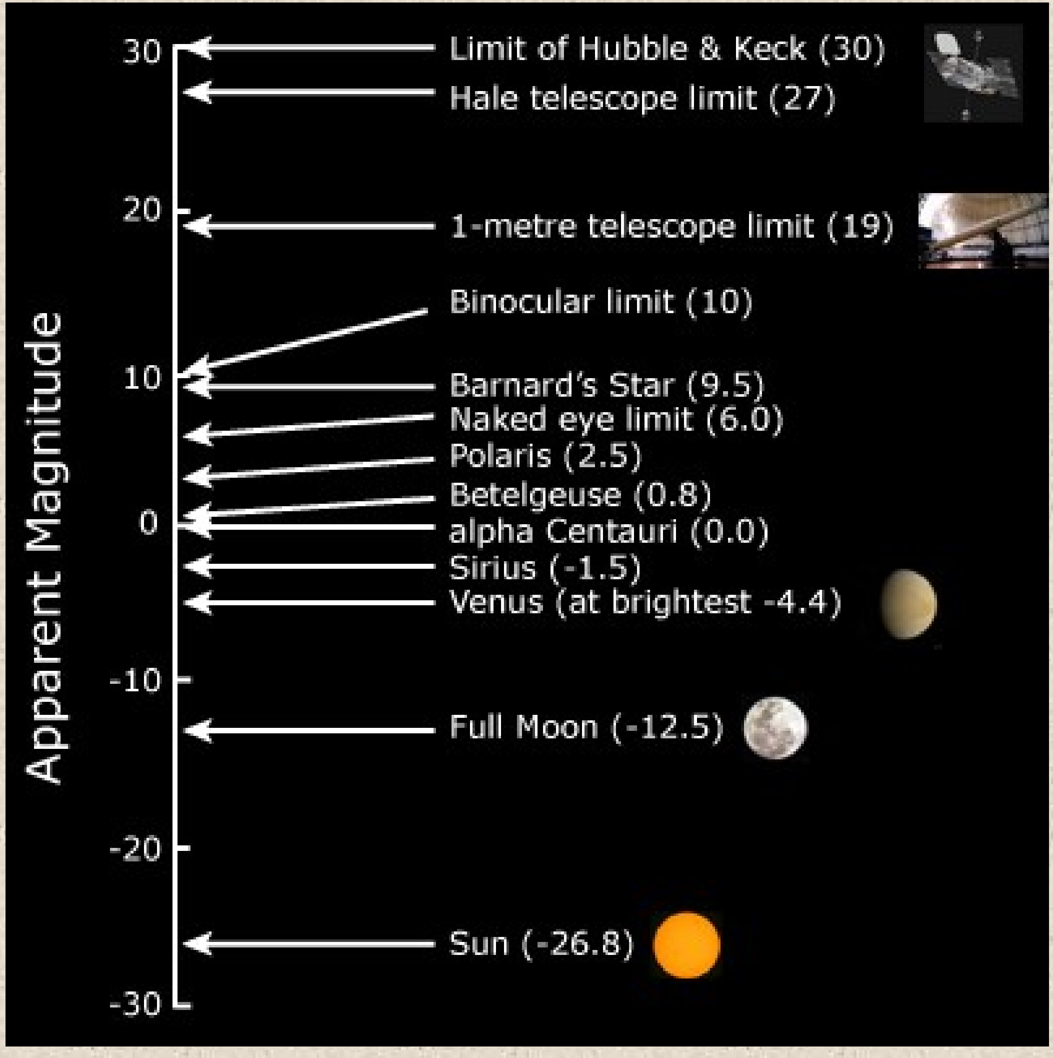
$$\frac{\text{Flux}_A}{\text{Flux}_B} = \frac{\text{Luminosity}_A}{\text{Luminosity}_B}\left(\frac{\text{Distance}_B}{\text{Distance}_A}\right)^2$$

Brightness of a star ~ flux, not its luminosity.

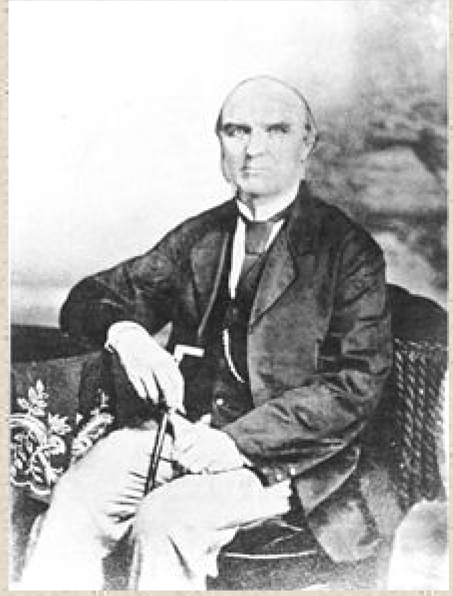
Brightness = Flux.



Hipparchus of Nicaea (c. 190 – c. 120 BC) Founder of trigonometry, discovery of precession of the equinoxes.



Magnitude Scale



m_1-m_2	F_2/F_1
0.0	1
1.0	2.512
2.0	6.309
3.0	15.849
4.0	39.811
5.0	100.00

1856 Norman Pogson of Oxford proposed that a logarithmic scale of $5\sqrt{100} \approx 2.512$

For two stars which differ by 5 magnitudes, the flux differs by a factor of 100

Smaller magnitudes are brighter!
Magnitude is a logarithmic scale!

Intensity and Magnitude

(the magnitude system is a logarithmic expression of intensity or flux)

Five magnitudes corresponds to 100 factors of intensity. Thus, each magnitude corresponds to 2.5 factors of intensity.

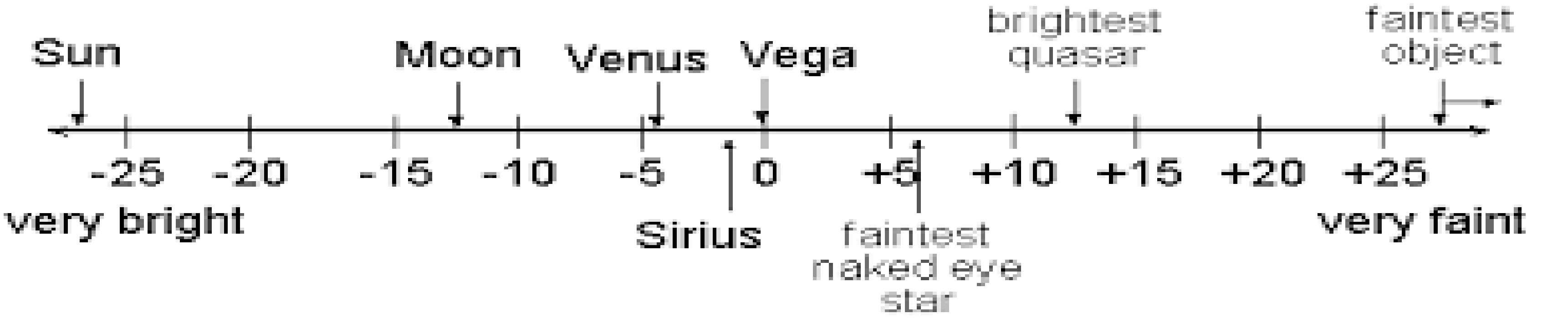
$$(100)^{\frac{1}{5}} = 2.512$$

Thus, we can compare the intensities (fluxes) of stars and A and B by forming a ratio and calculate their magnitude difference.

$$\frac{I_A}{I_B} = (2.512)^{(m_B - m_A)}$$

Magnitude scale (Apparent)

$$m_B - m_A = 2.5 \log \frac{\ell_A}{\ell_B}.$$



Apparent brightnesses of some objects in the magnitude system.

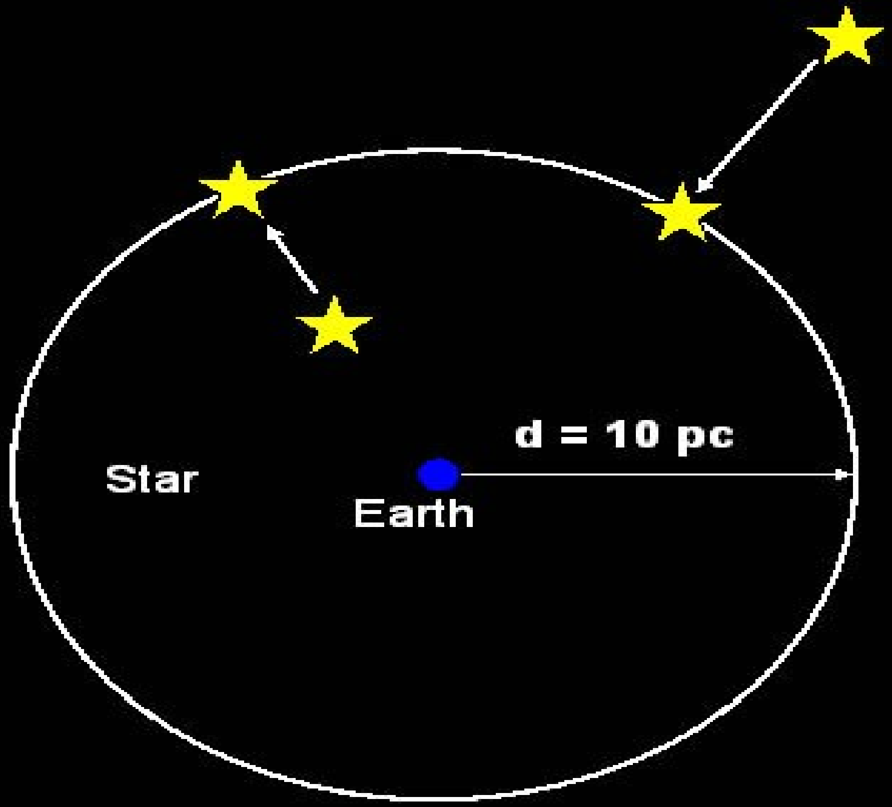
Absolute Magnitude

(useful for describing how intrinsically luminous objects are)

Absolute magnitude is described as the apparent magnitude an object would have at a distance of 10 parsecs.

Imagine moving all of the stars in the sky so that they reside on a sphere of radius 10 parsecs that is centered on the Earth. The apparent magnitude that these stars would have at that time is their absolute magnitude. Thus, it is a theoretical quantity.

Absolute magnitudes for stars ranges from about -8 for the most energetic stars to about 15 for the least energetic.



Distance Modulus

(a useful quantity for determining distances)

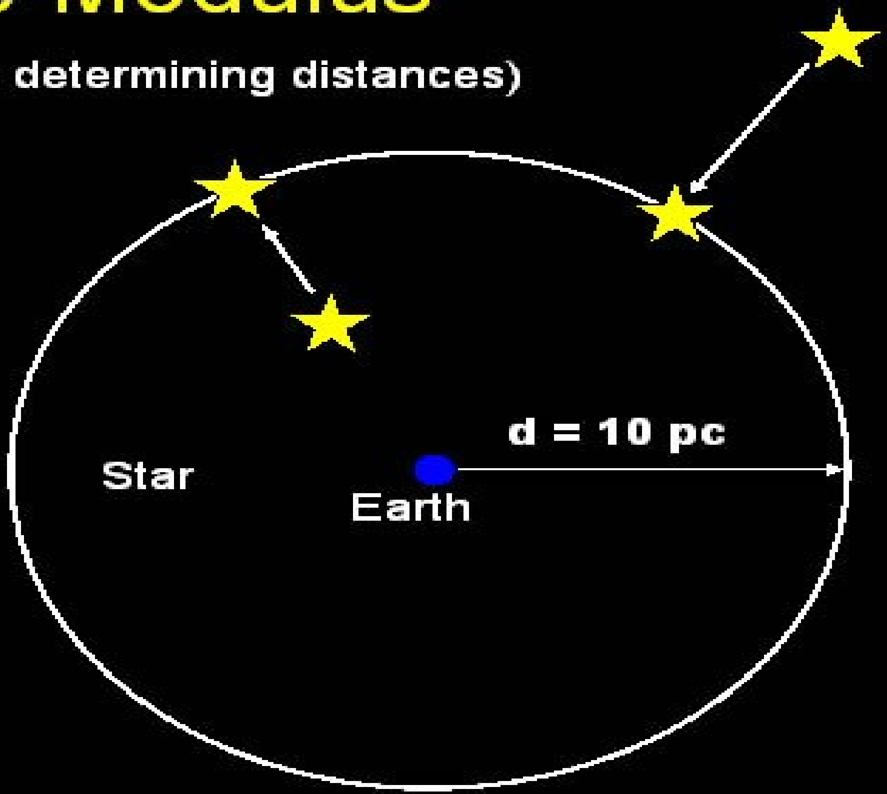
The distance modulus is the difference between apparent magnitude m and absolute magnitude M for an object.

$$m - M = -5 + 5\log_{10} d$$

m < M $\rightarrow$ d < 10 pc

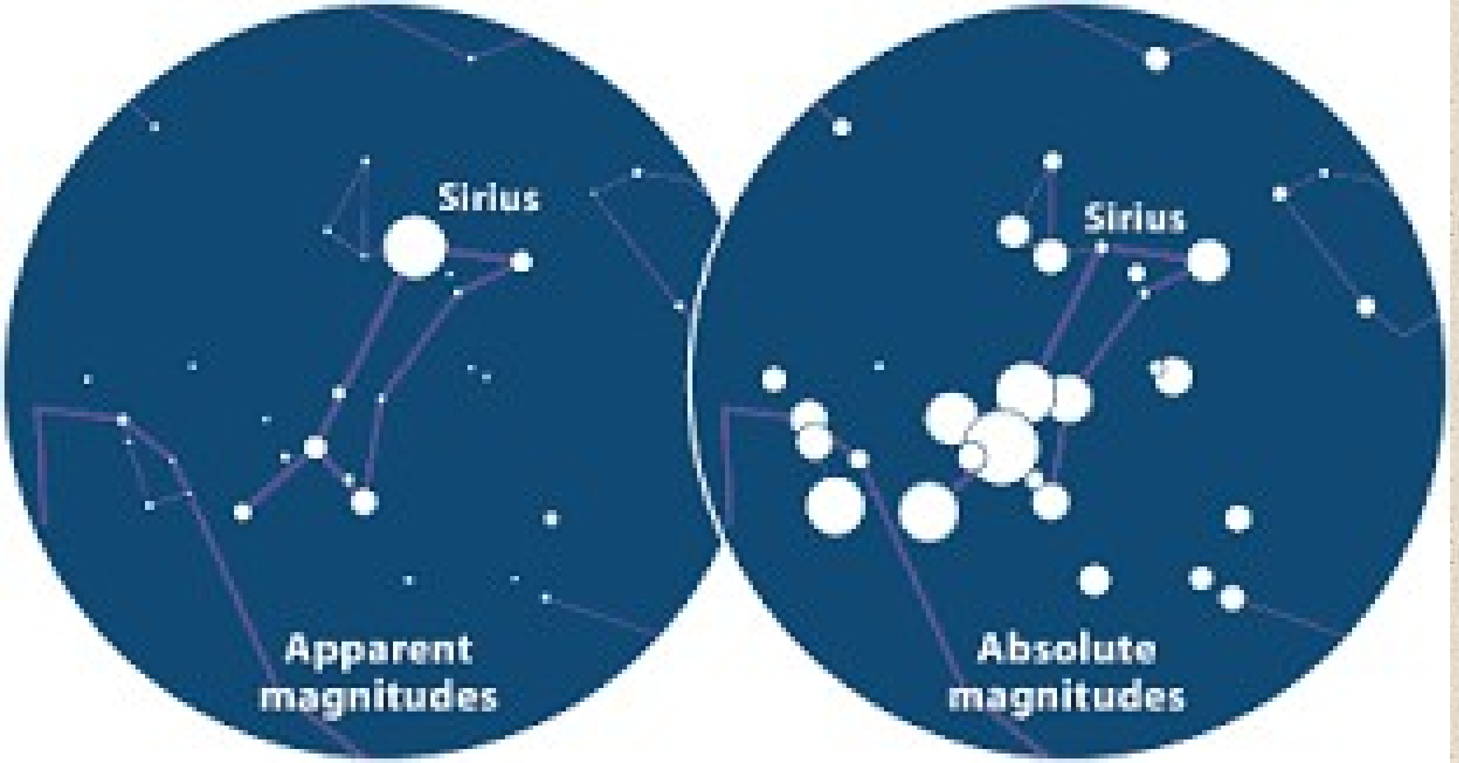
m >M $\rightarrow$ d > 10 pc

$$d = (10\,pc) \times 10^{\frac{m-M}{5}}$$



Rule: A distance modulus of 5 corresponds to a distance of 100 pc

The Absolute world!!!



Bolometric Magnitudes

Flux varies with wavelength.

We need to observe at all wavelengths of EMR, from gamma rays to the longest radio waves.

Quantities integrated over all wavelengths are called bolometric quantities

When we do multiwavelength astro, we are extrapolating/ interpolating bolometric mags!

Photometry: Measuring Photons

See lecture on Telescopes.....

Magnitude limits for detectors:

Human eye 2mm	6
6″	12.9
18″	15.3

Photometry: Measuring Photons

Magnitude limits for detectors:
In general $m=2+5\log D$
(D in mm)

Human eye 2mm	6	
6″	12.9	log(152 mm)=2.18
18″	15.3	log(457 mm)=2.65

Photometric systems

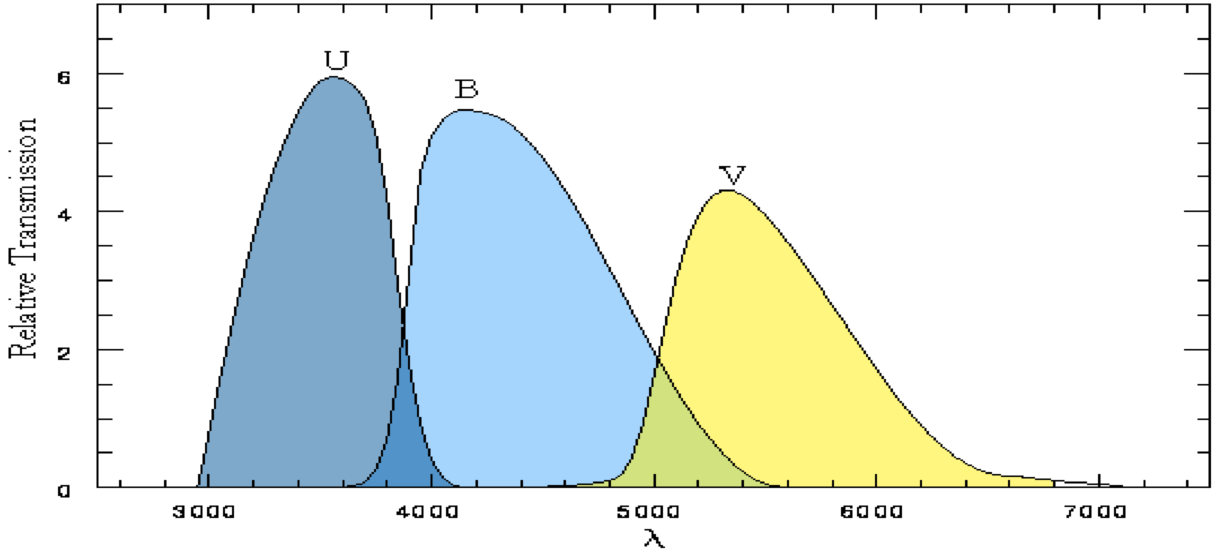
Three rough categories based on the size of the wavelength intervals transmitted by their filters.

Wide-band systems (such as the UBV system) have filter widths ~ 900 A

Intermediate-band filter widths ~ 200 A.

Narrow-band systems are used to isolate and measure a single spectral line and may have widths of 30 A or less.

UBV system

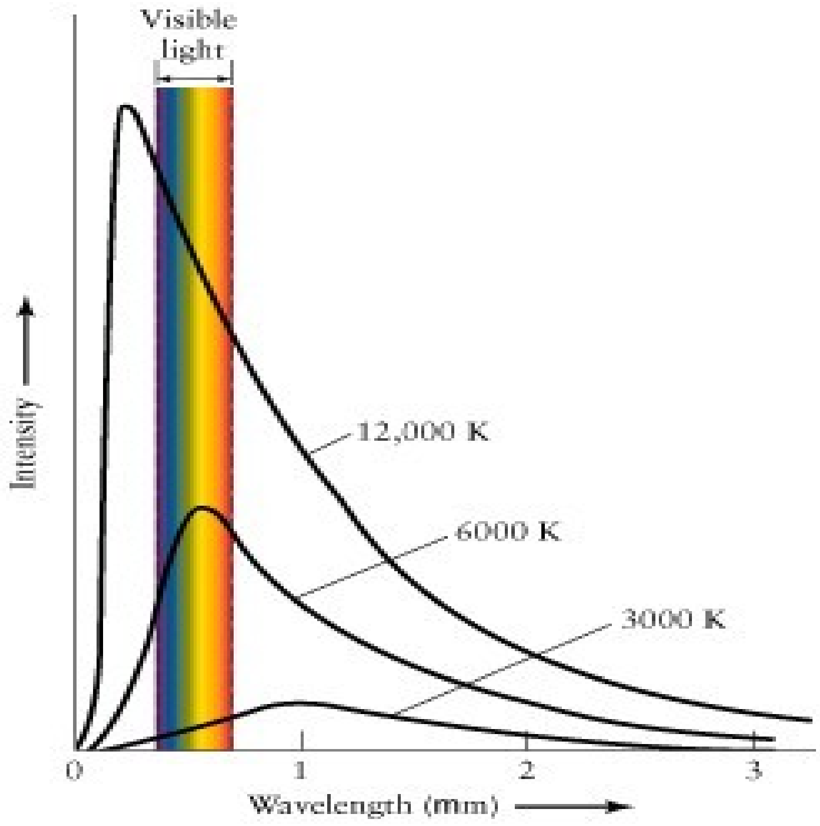


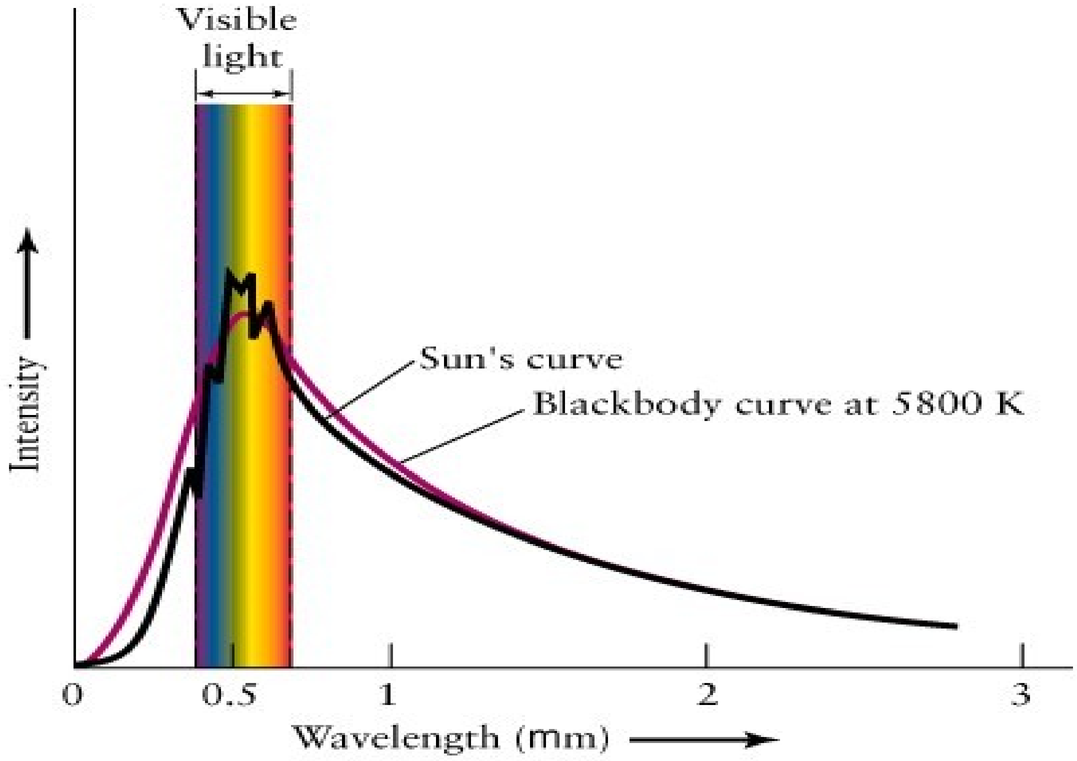
U for ultraviolet, B for blue, and V for visual.

Central wavelengths : U - 3600 A; B - 4400 A, V -5500 A

Width: 1000 ˚, B filter (3900 A - 4900 A)

Temperature

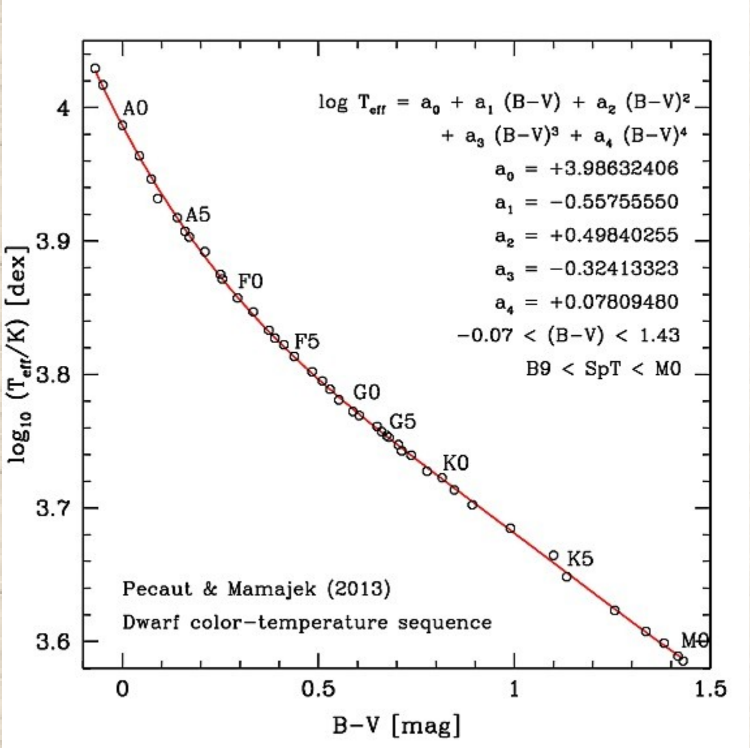




Colors

$$B - V = m_B - m_V$$

$$B - V = m_B - m_V = -2.5\log(f_B/f_V) + \text{constant}$$

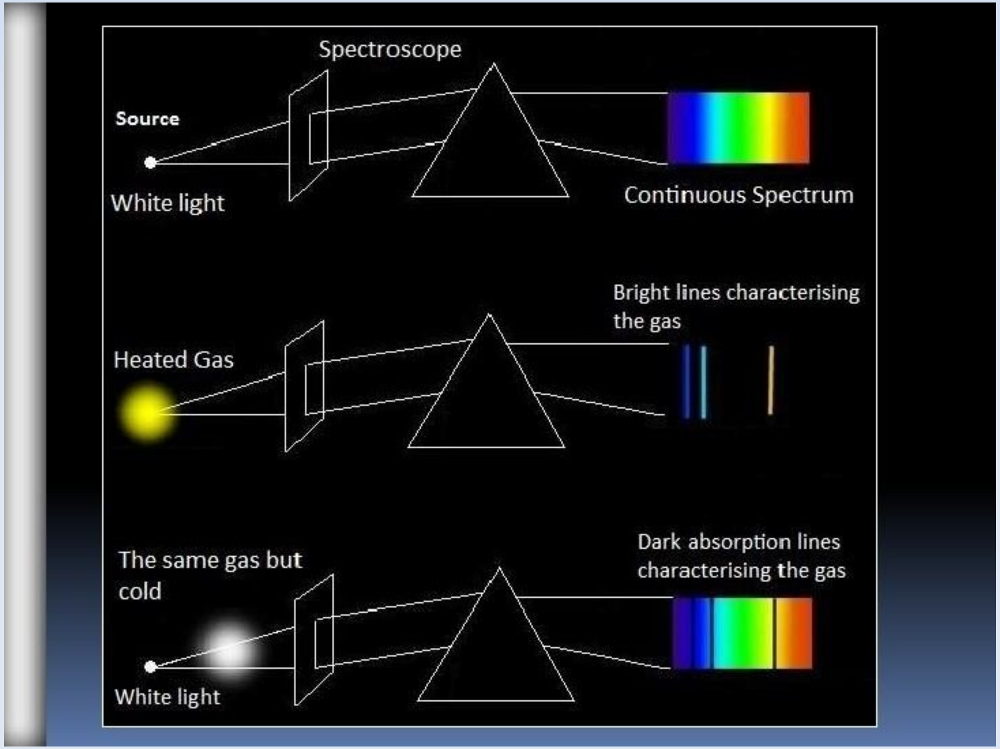


Spectral Type, Color and Effective Temperature for Main-Sequence Stars (continued)

Main-Sequence Stars (Luminosity Class V)

Sp. Type	T_e (K)	$L/L_\odot$	$R/R_\odot$	$M/M_\odot$	M_{bol}	BC	M_V	$U-B$	$B-V$
G0	5940	1.25	1.06	1.05	+4.50	−0.18	+4.7	+0.06	+0.58
G2	5790	1.07	1.03	—	+4.66	−0.20	+4.9	+0.12	+0.63
Sun[a]	5777	1.00	1.00	1.00	+4.74	−0.08	+4.82	+0.195	+0.650
G8	5310	0.656	0.96	—	+5.20	−0.40	+5.6	+0.30	+0.74
K0	5150	0.552	0.93	0.79	+5.39	−0.31	+5.7	+0.45	+0.81
K1	4990	0.461	0.91	—	+5.58	−0.37	+6.0	+0.54	+0.86
K3	4690	0.318	0.86	—	+5.98	−0.50	+6.5	+0.80	+0.96
K4	4540	0.263	0.83	—	+6.19	−0.55	+6.7	—	+1.05
K5	4410	0.216	0.80	0.67	+6.40	−0.72	+7.1	+0.98	+1.15
K7	4150	0.145	0.74	—	+6.84	−1.01	+7.8	+1.21	+1.33
M0	3840	0.077	0.63	0.51	+7.52	−1.38	+8.9	+1.22	+1.40
M1	3660	0.050	0.56	—	+7.99	−1.62	+9.6	+1.21	+1.46
M2	3520	0.032	0.48	0.40	+8.47	−1.89	+10.4	+1.18	+1.49
M3	3400	0.020	0.41	—	+8.97	−2.15	+11.1	+1.16	+1.51
M4	3290	0.013	0.35	—	+9.49	−2.38	+11.9	+1.15	+1.54
M5	3170	0.0076	0.29	0.21	+10.1	−2.73	+12.8	+1.24	+1.64
M6	3030	0.0044	0.24	—	+10.6	−3.21	+13.8	+1.32	+1.73
M7	2860	0.0025	0.20	—	+11.3	−3.46	+14.7	+1.40	+1.80

Spectroscopy

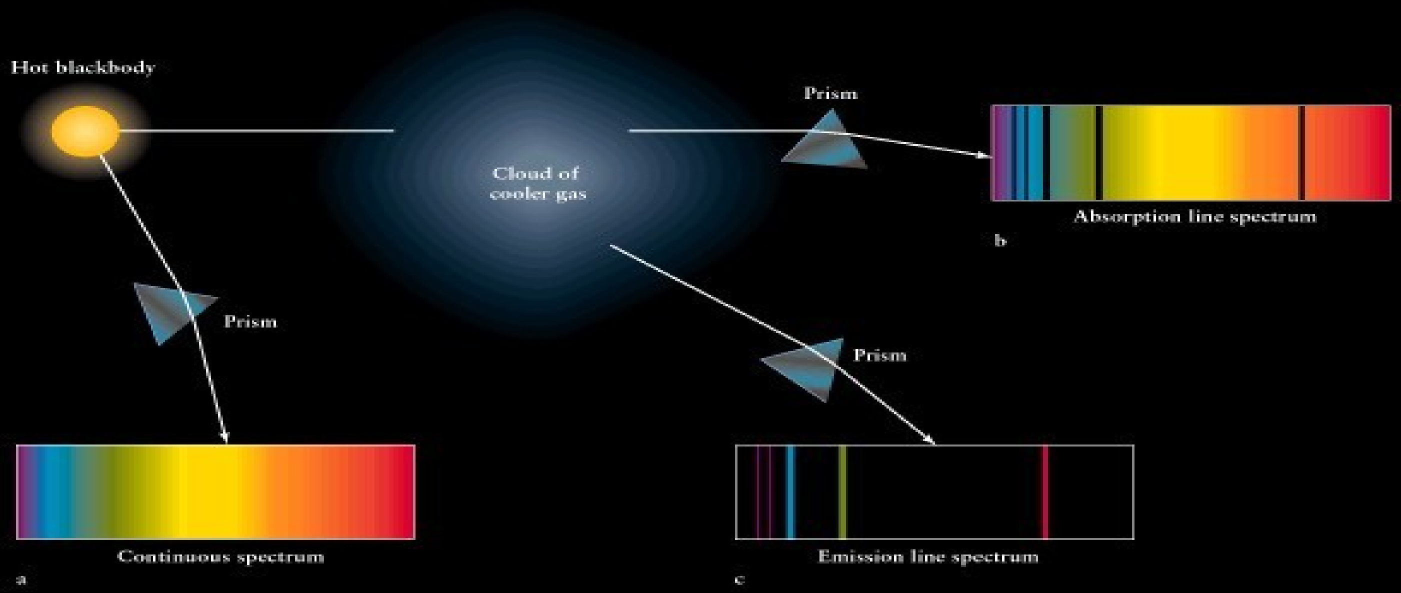


How to find the Temperature?

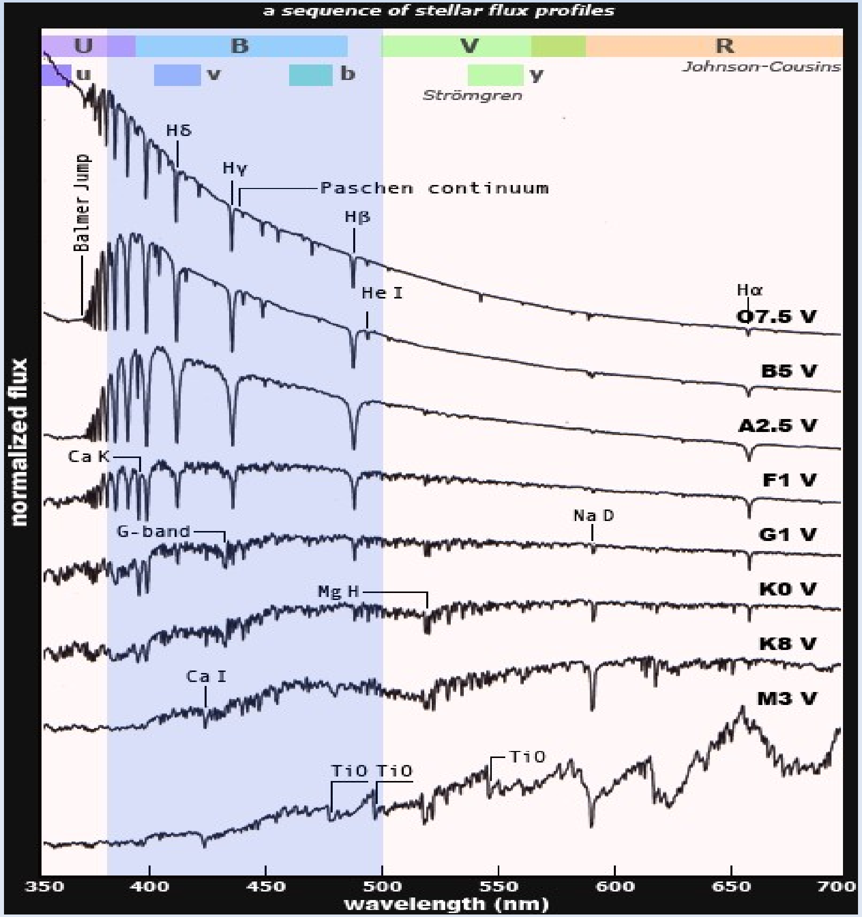
- To measure the temperature of a star we use must measure the spectrum of the star and then apply more physics
- We assume the star is a “black body radiator” and then we can compute the temperature from the spectral shape.

Temperature

Looking at individual spectral lines in a star's spectrum defines thl the ***spectral class*** of the star ~ temperature



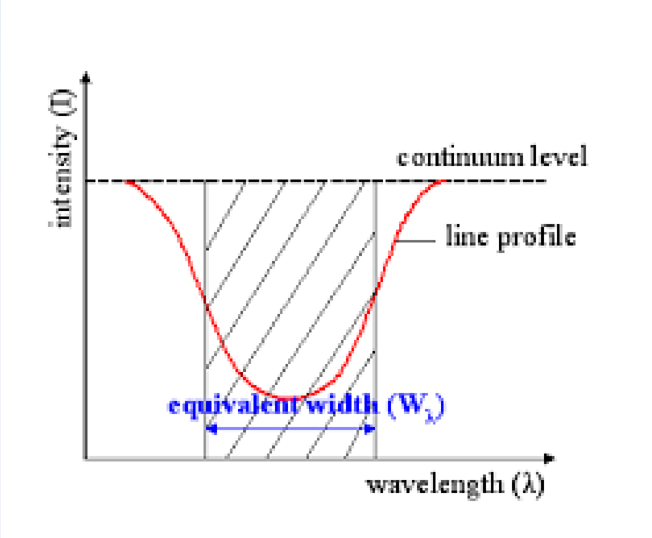
Stellar Spectra



Definition of Spectral Resolution

- **Spectral Resolution** $= \mathbf{R} = \boldsymbol{\lambda/\delta\lambda}$
  where λ is the operating wavelength and $\delta\lambda$ is the smallest wavelength interval that can be resolved
- **Photometry** $R < 10$ for $\delta\lambda \sim 1000\text{Å}$
- **Low Resolution Spectroscopy** (or Narrow Band Photometry) $R < 100$
- **Medium Resolution Spectroscopy** $100 < R < 10{,}000$
- **High Resolution Spectroscopy** $R > 10{,}000$

Equivalent width



Doppler Shifts

Thermal/Pressure Broadening

Chemical composition....

Quiz 2....

Intensity

The monochromatic intensity is the brightness of a beam of radiation.

$dE_\nu = I_\nu \, dA \, dT \, d\nu \, d\omega$

where dE_ν is the amount of energy passing through an area dA in time dT, over a frequency interval $d\nu$, into a solid angle $d\omega$.

The units of I_ν are ergs cm^{-2} s^{-1} Hz^{-1} sr^{-1}.

Simply, I_ν is the brightness of a photon. Since photons do not decay, I_ν must not depend on distance. This is implicit in the definition that I_ν is per steradian (the beam spreads out - but it doesn't lose energy).

The total intensity I is the monochromatic intensity I_ν integrated over all frequencies.

The units of I are ergs cm^{-2} s^{-1} sr^{-1}.

Flux and Intensity

The monochromatic flux $F\nu$ is the integral of the product $I_\nu \cos(\theta)$ over all solid angles.

This is the net flow of energy perpendicular to some surface dA whose normal makes an angle θ with respect to the observer.

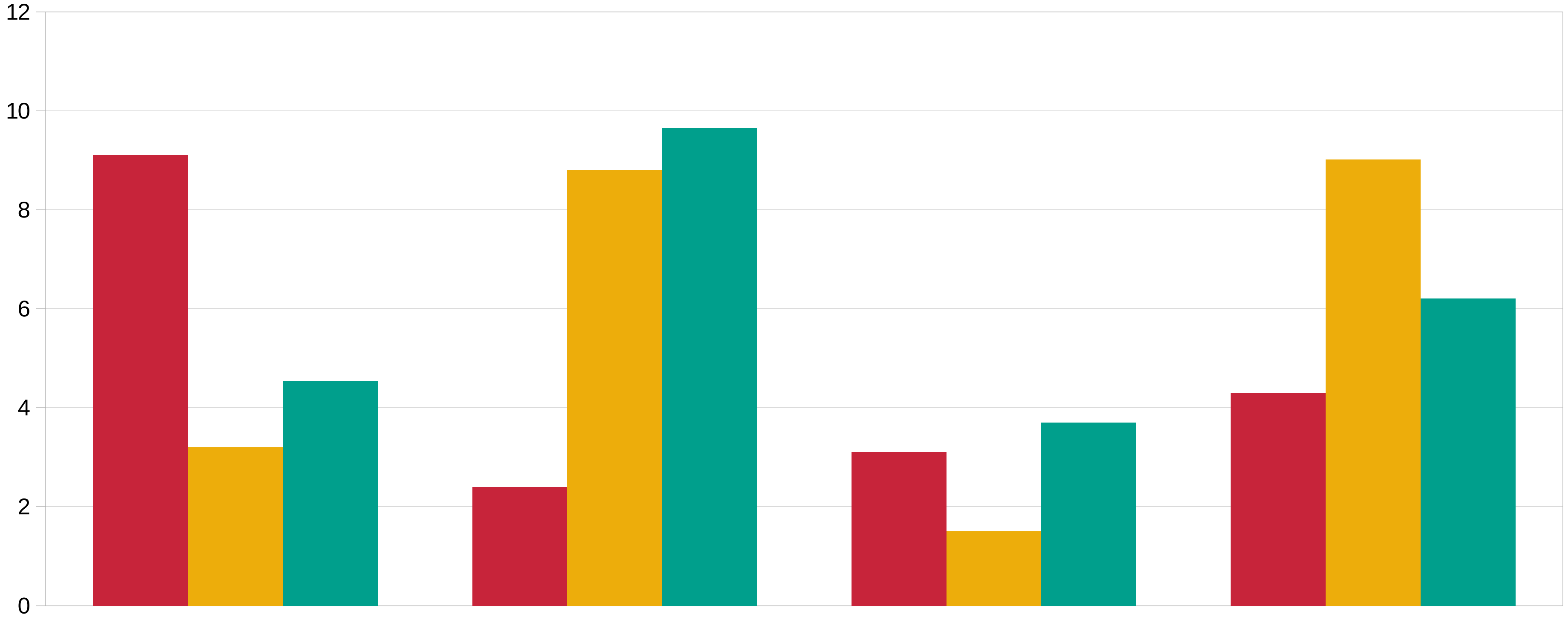
Note that flux is a vector. It depends on θ. Intensity is a scalar. We often separate the flux into two parts, an ingoing and an outgoing part. $F=F^+-F^-$. In the case of stellar atmospheres, F^-, the incoming part, is negligable. The units of $F\nu$ are ergs cm^{-2} s^{-1} Hz^{-1}.

For an intensity $I\nu$, the flux emitted by a stellar disk $F_\nu=\pi I_\nu$.

Often in astronomy, we define flux = F/π, such that the numerical values of I and F are the same.

The luminosity L is the brightness integrated over all angles and wavelengths.

The units are energy/time. $L = 4\pi d^2 F$.


12
10
8
6
4
2
0