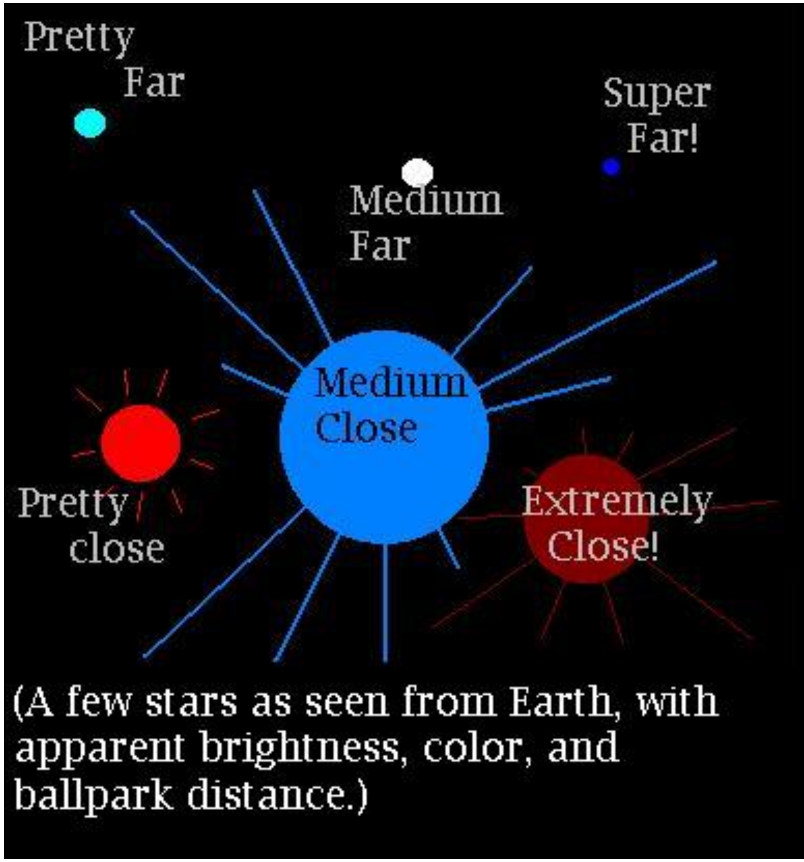
Gaia—Launched in Dec 2013

- 3D map of the stars near Sun = 10% of Galaxy
- Measure the positions of a billion stars to brightness V=20
- Precise to 0.000024 arcseconds = hair at 1000km
- Accurate parallax/distances? → absolute magnitudes? = luminosities

Properties of the Stars

Star' s distance is critical to understanding:

- **Luminosity=**intrinsic brightness =total energy emitted
- Diameter and Mass
- And to define a typical star

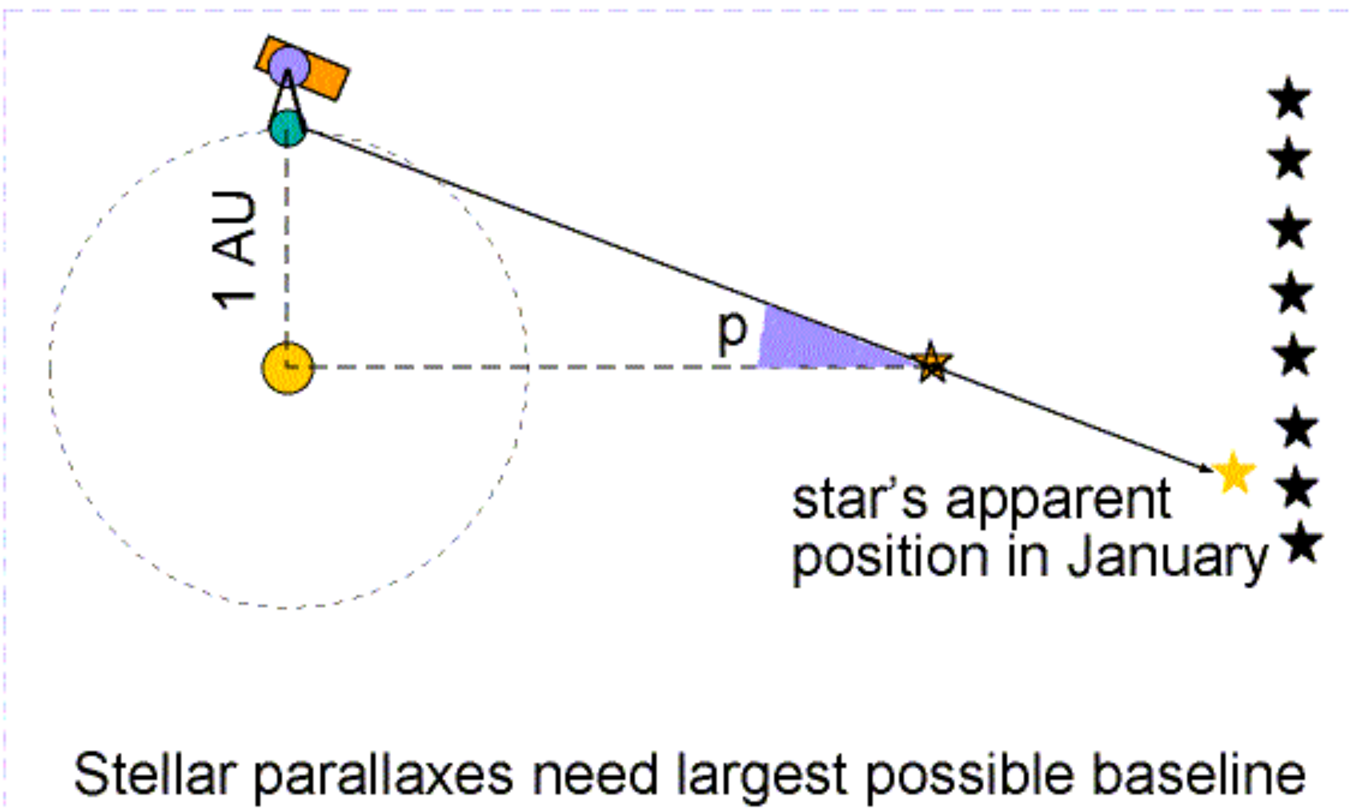


Distance Can Be Measured by:

- Superposition – stars beyond planets
- Angular/Linear Size
- *Galileo had a thread covering Vega comparing to Sun's size*
- Apparent/Intrinsic Brightness
- *Huygens tried a hole in a tube reducing Sun to = Sirius*
- *Newton/Gregory compared Saturn to Sirius => within factor of 5 times*

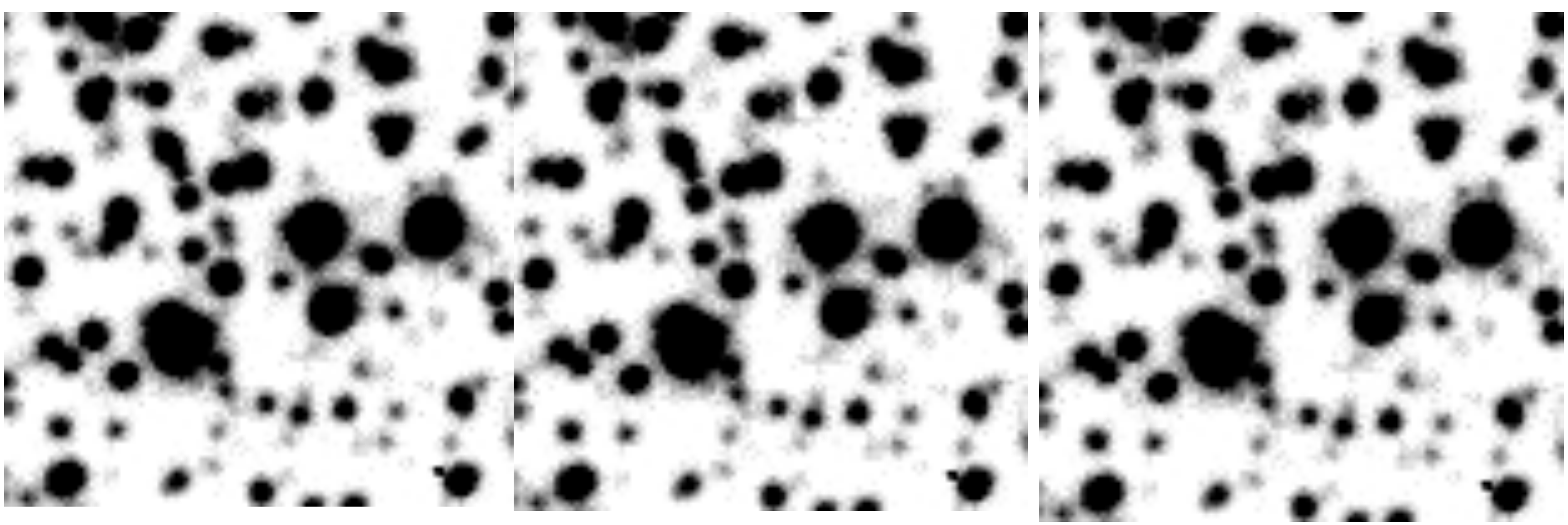
Stellar Parallax

- **Parallax** is the apparent motion of an object due to the motion of the observer
- Star seen from two sites separated by 1 AU with a parallax of 1 arc second is at 1 **parsec** ~ 3 **light years**
- Distance in parsecs=1/Parallax in arc seconds



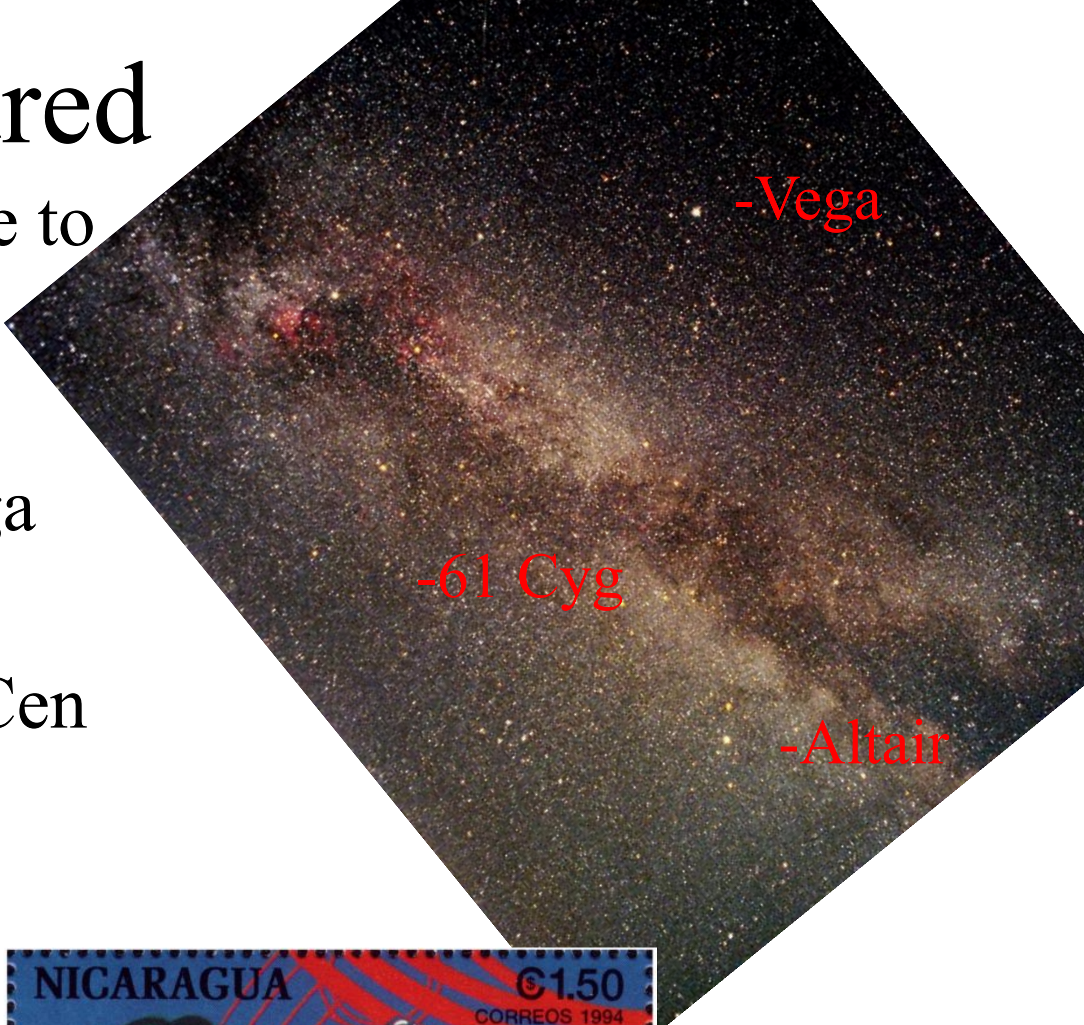
Stellar Parallax

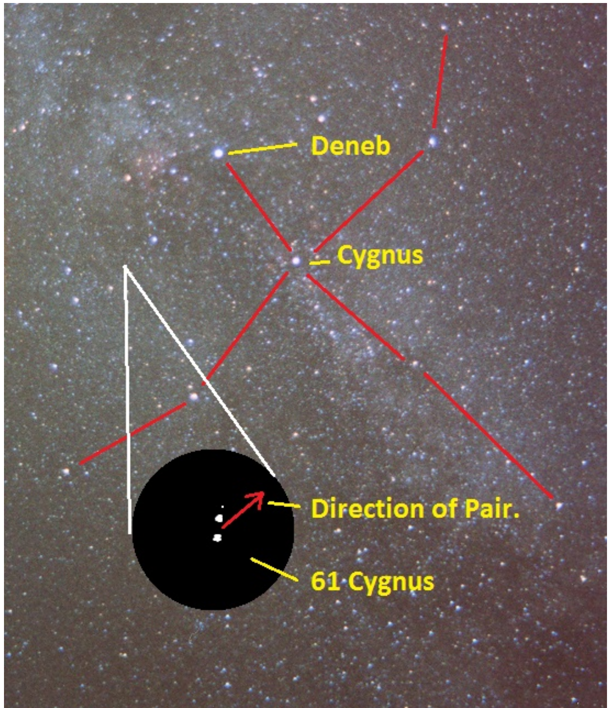
- *Take a picture from one side of the Earth's orbit*
- *Take a picture from the other side of the Earth's orbit*
- *Blink the pictures*
- Star's image ~ 1” (arc second)
- Blurring of atmosphere restricts ground based to ±o.oo2”
- *One arc second is a typewriter period at 100 meters*
- *10,000 stars from ground; 120,000 Hipparcos; 1 Billion Gaia*



Parallax Measured

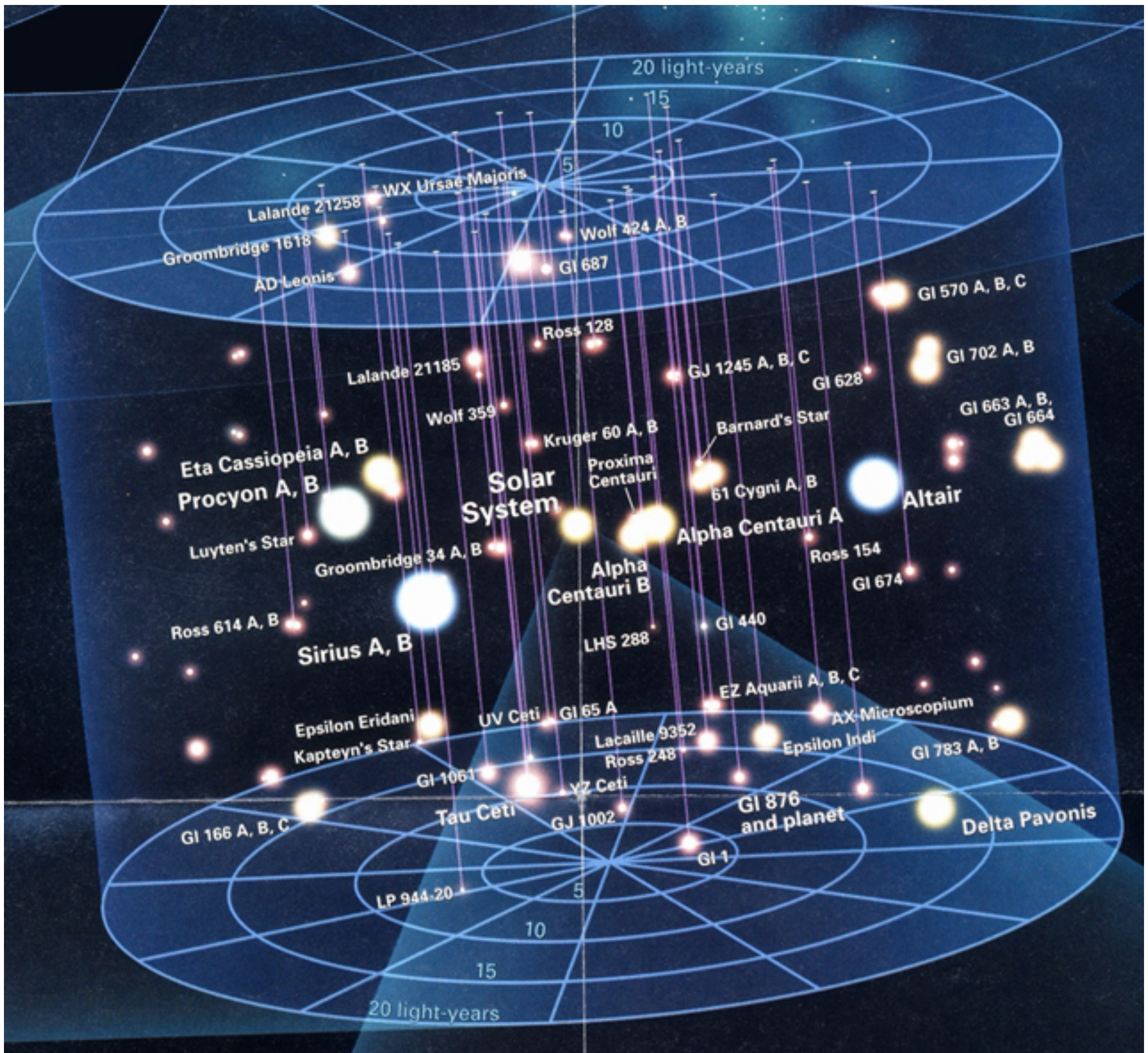
- Bessel measured distance to 61 Cygni in 1838
- Struve measured parallax=distance to Vega
- Henderson measured parallax=distance of α Cen





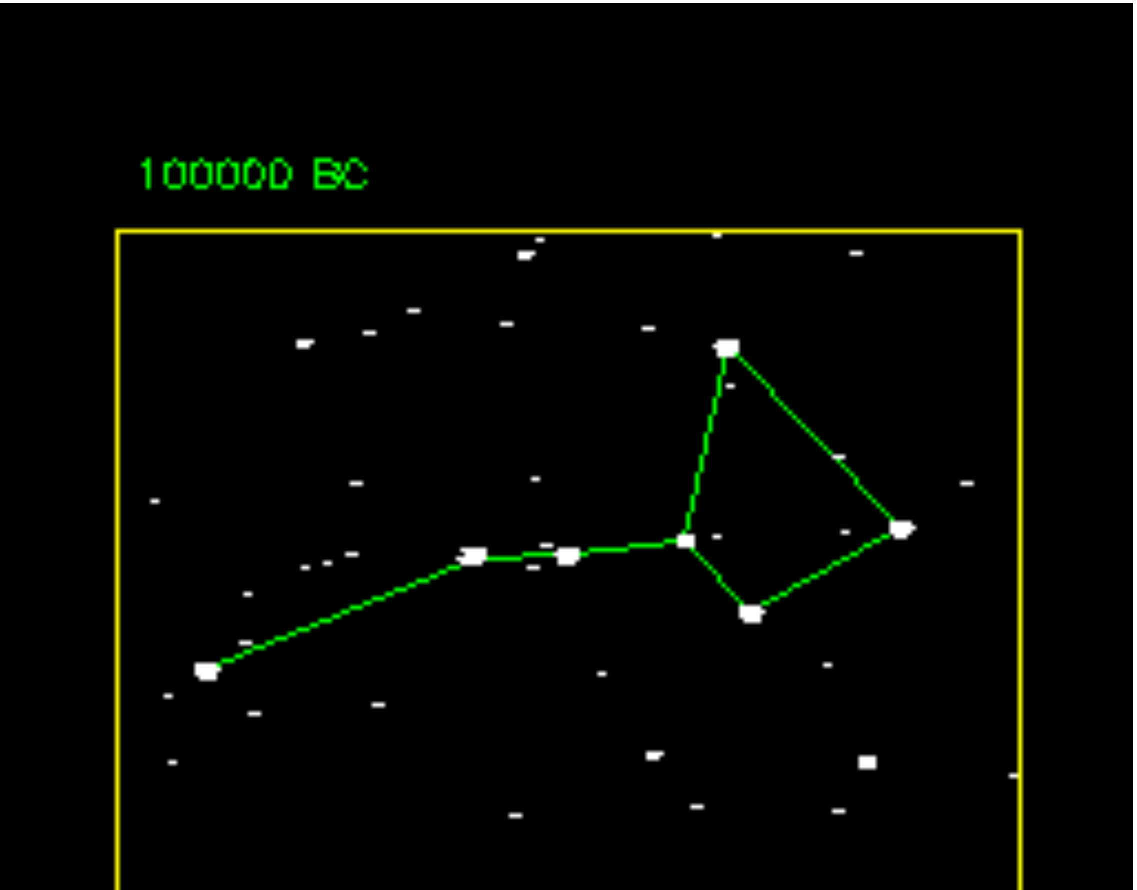
The Nearest Stars

- If the sun were a golf ball the nearest star would be in Comox
- αCentauri is nearest star at 4light years then Barnard's star



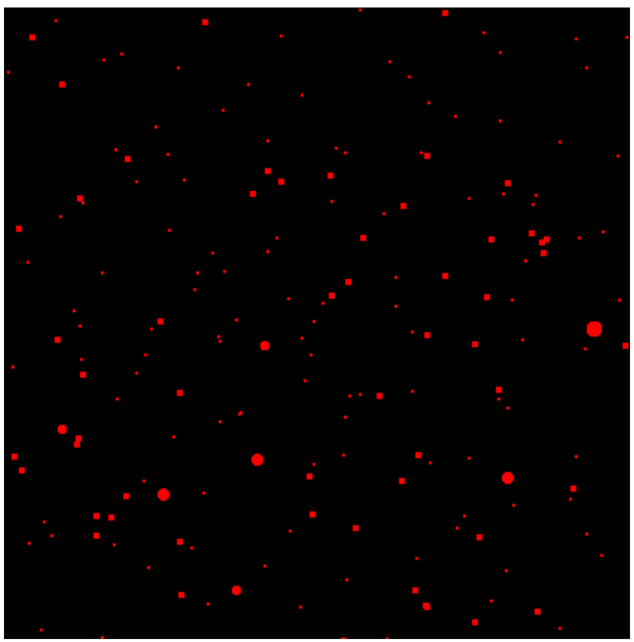
Proper Motion

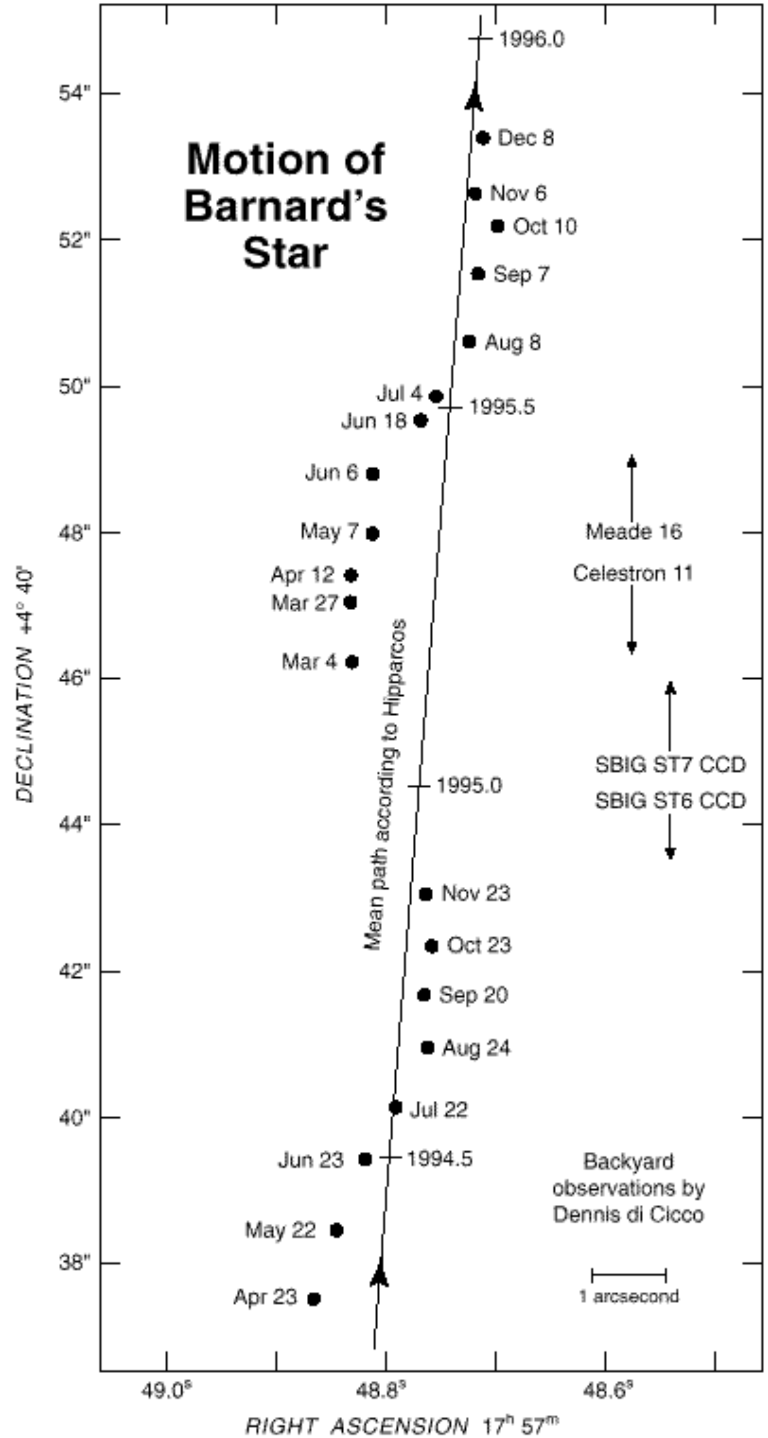
- Angular motion of a star across sky in arc seconds per year
- Edmund Halley discovered proper motion of Arcturus (2.3”/year), Sirius and Aldebaran in 1718, by comparing his star positions to Ptolemy’s ~100AD



Barnard's Star

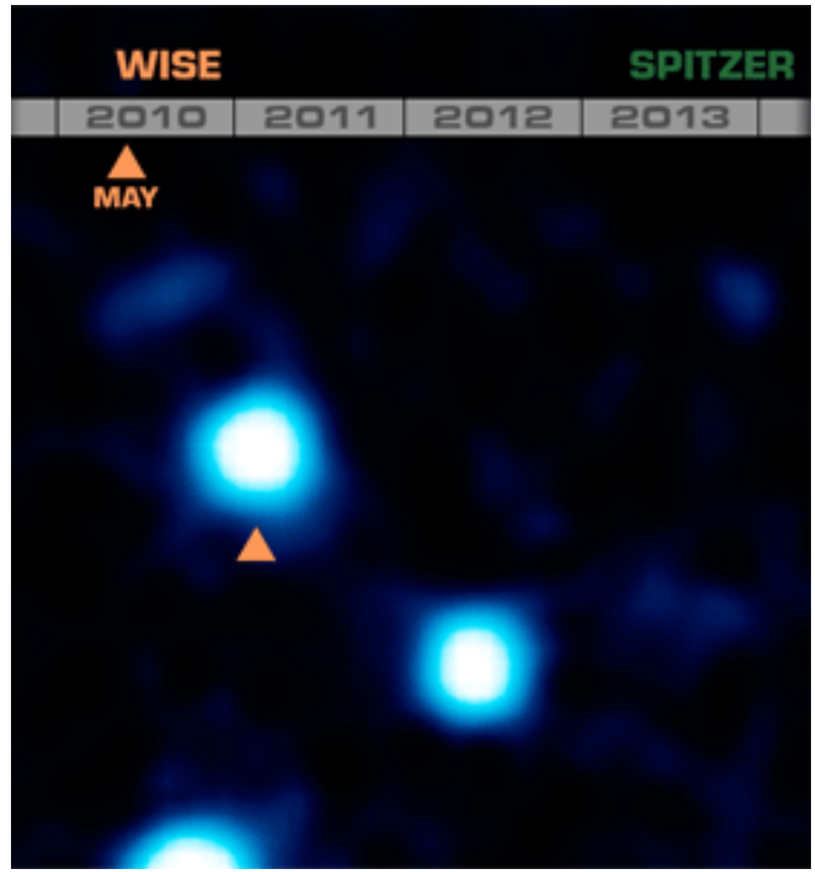
- As Barnard's Star moves across the sky (Largest Proper Motion)
- Parallax makes it seem to wobble back and forth
- Second nearest star
- Discovered in 1916



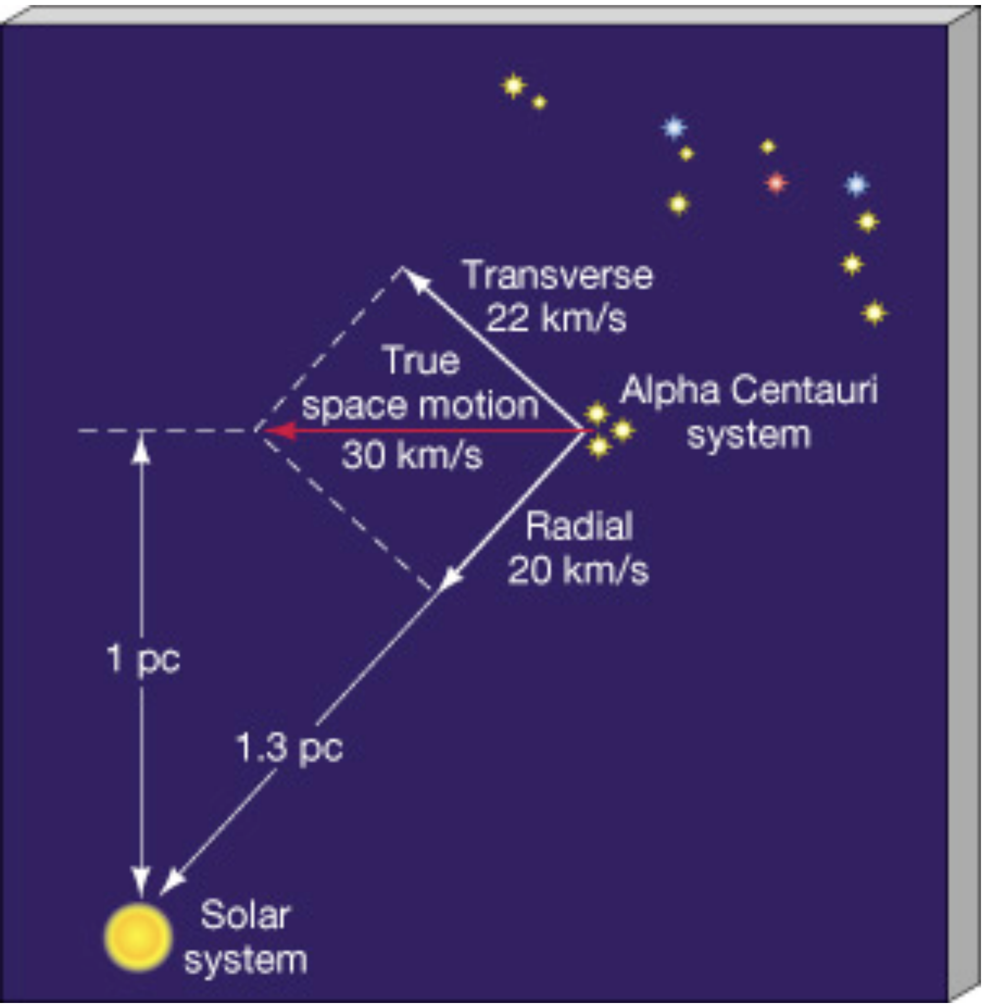


Brown Dwarf WISE 0855

- Coolest brown dwarf ~250K
- 4th closest system ~7light years
- 3rd largest proper motion
- Announced May 2014



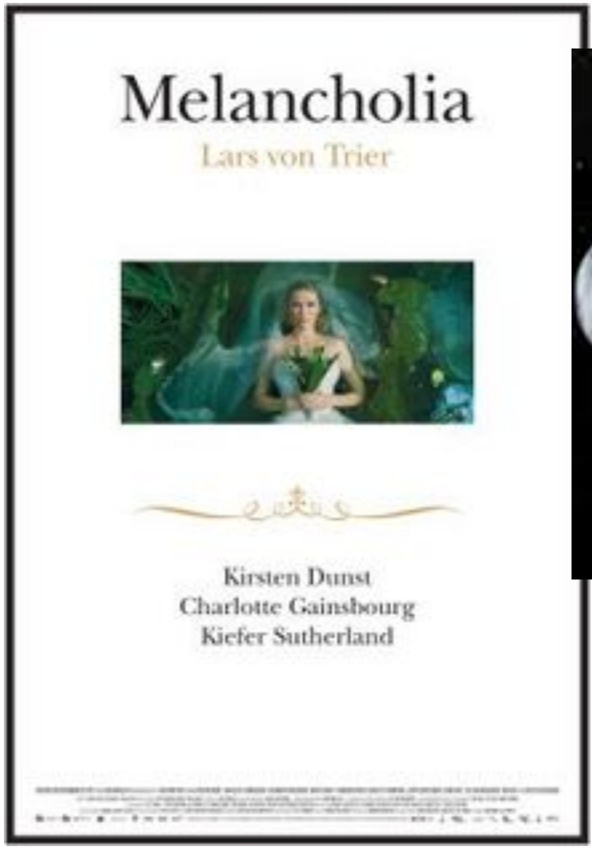
Space Motion



- Sum of Radial Velocity + Tangential Velocity is the Space Velocity/ Motion
- Stars with Blue shift are coming towards us
- Could they hit us?

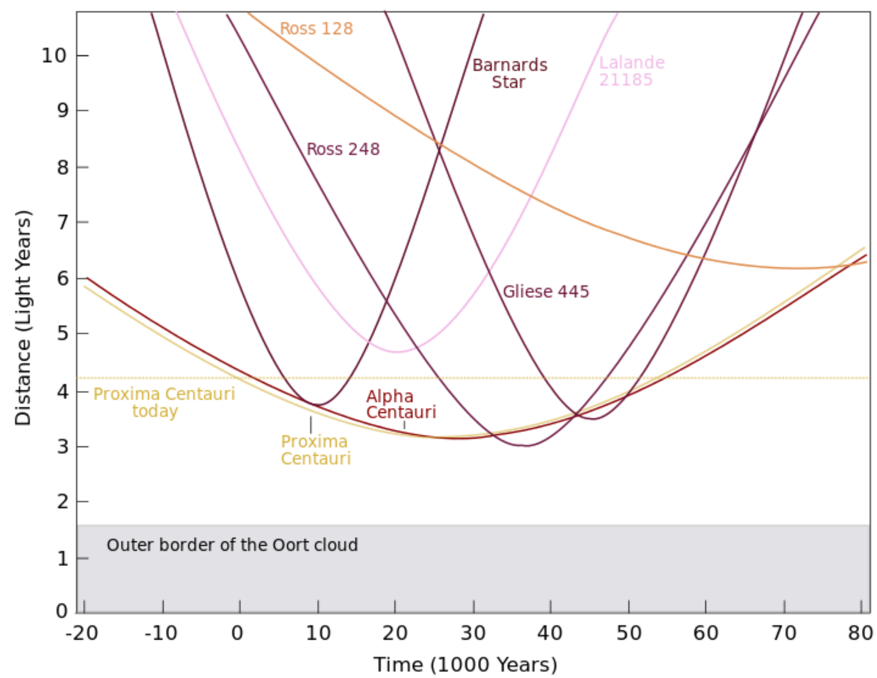
Doomsday

- Popular theme in Hollywood productions



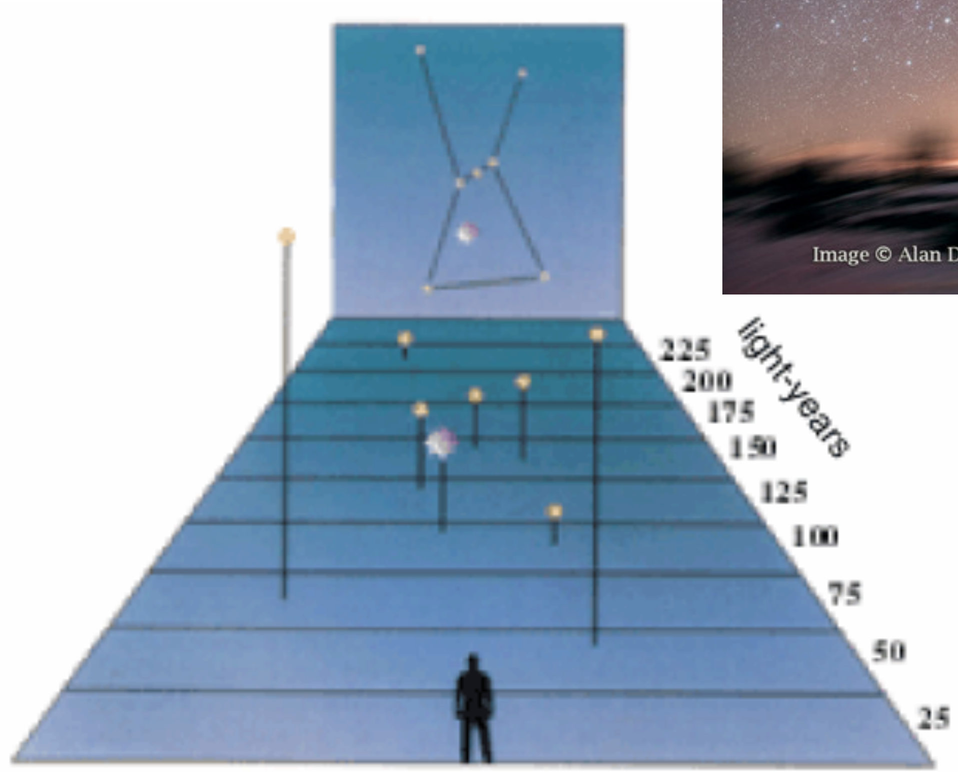
Gliese 710

- Distance =63 light years
- Close approach in 1.5 million years
- Close enough to disrupt Oort cloud?
- Comet showers??

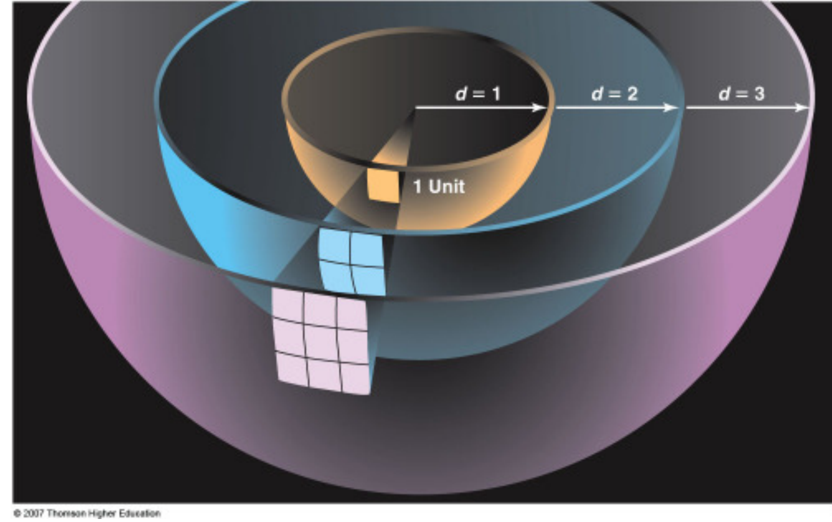


Apparent Brightness

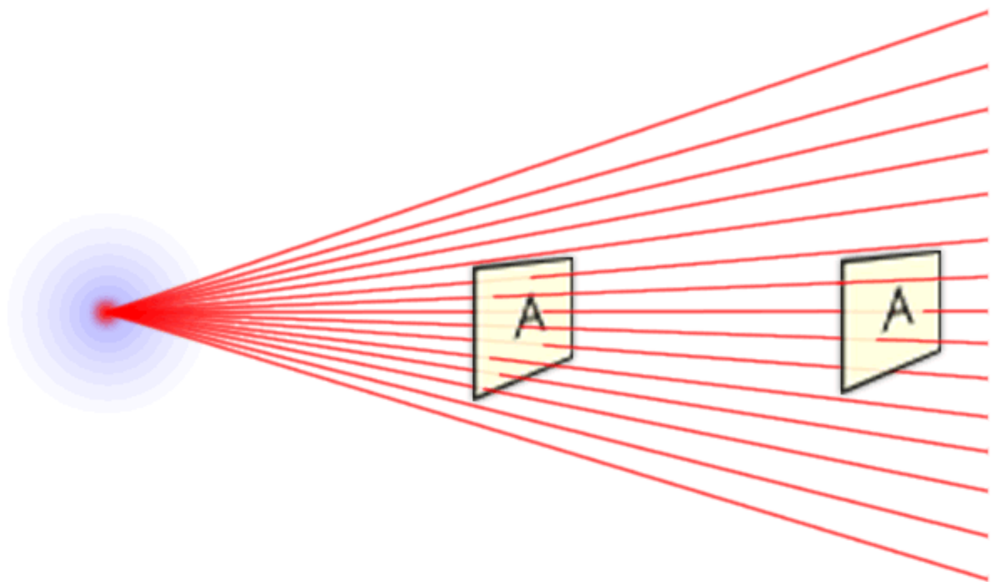
- Apparent Brightness measured by number of photons per second/cm^2
- Apparent Brightness of a star depends on its distance and luminosity

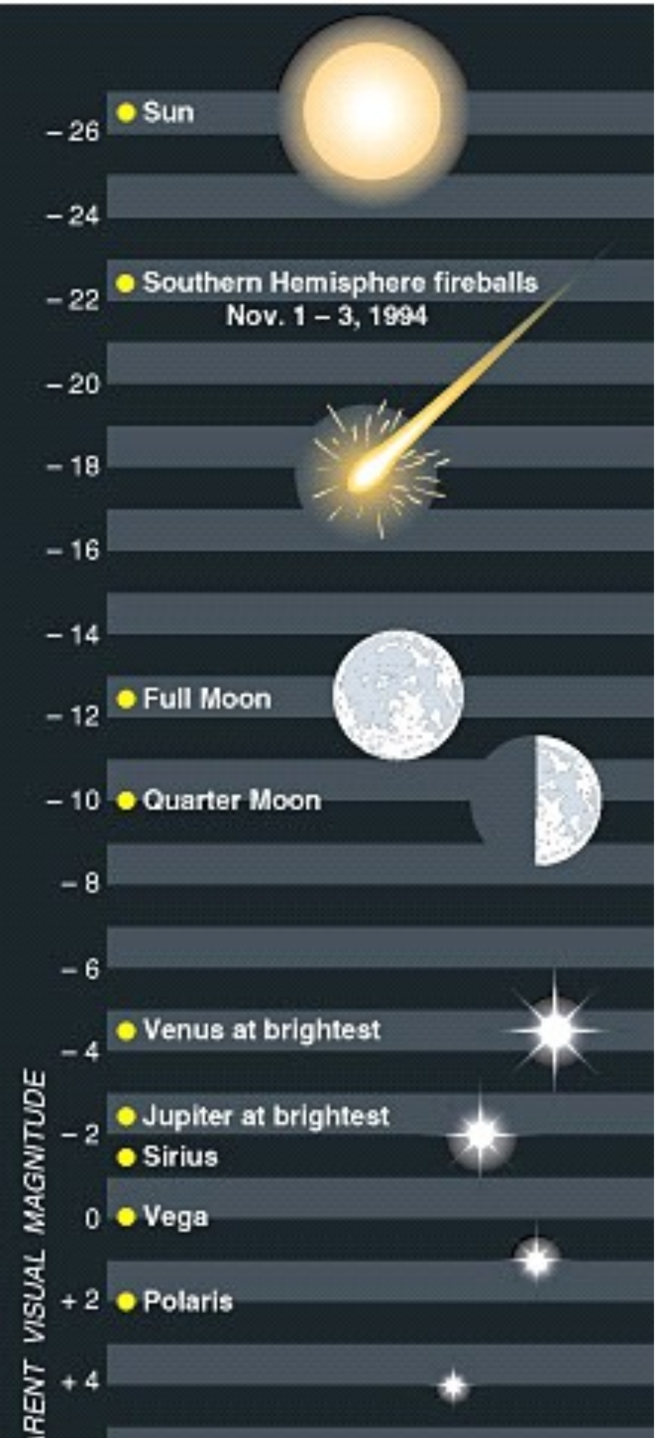


Inverse-Square Law



- Fainter means farther:
- At a greater distance photons spread over greater area
- If 1st square=36photons then 2nd=9photons & 3rd=4photons



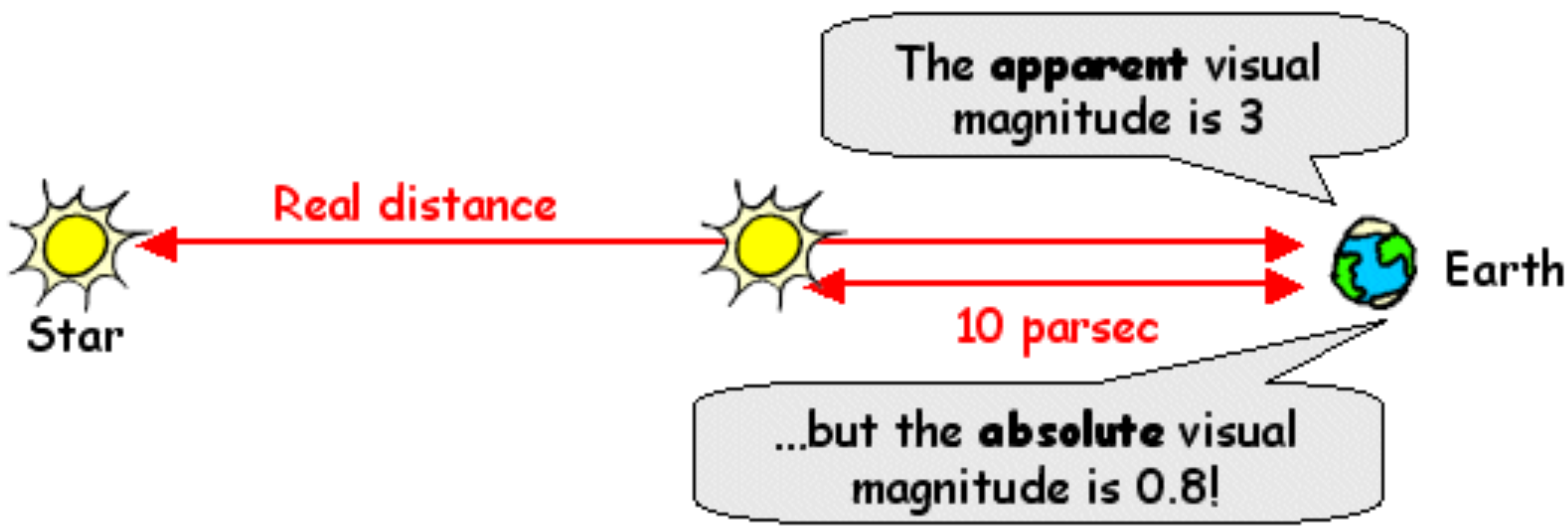


Magnitude Scale

- Hipparcos rated naked eye stars from brightest to faintest; from 1-6 magnitudes
- Each magnitude is 2.5 times as much light
- Like decibels

Apparent and **Absolute Magnitudes**

- **Apparent magnitude** is the brightness of the star as seen from the Earth
- **Absolute Magnitude** is the brightness a star would have at a distance of 10 parsecs
- **Absolute Magnitude** measures intrinsic brightness or Luminosity of the star



Distance Modulus

(a useful quantity for determining distances)

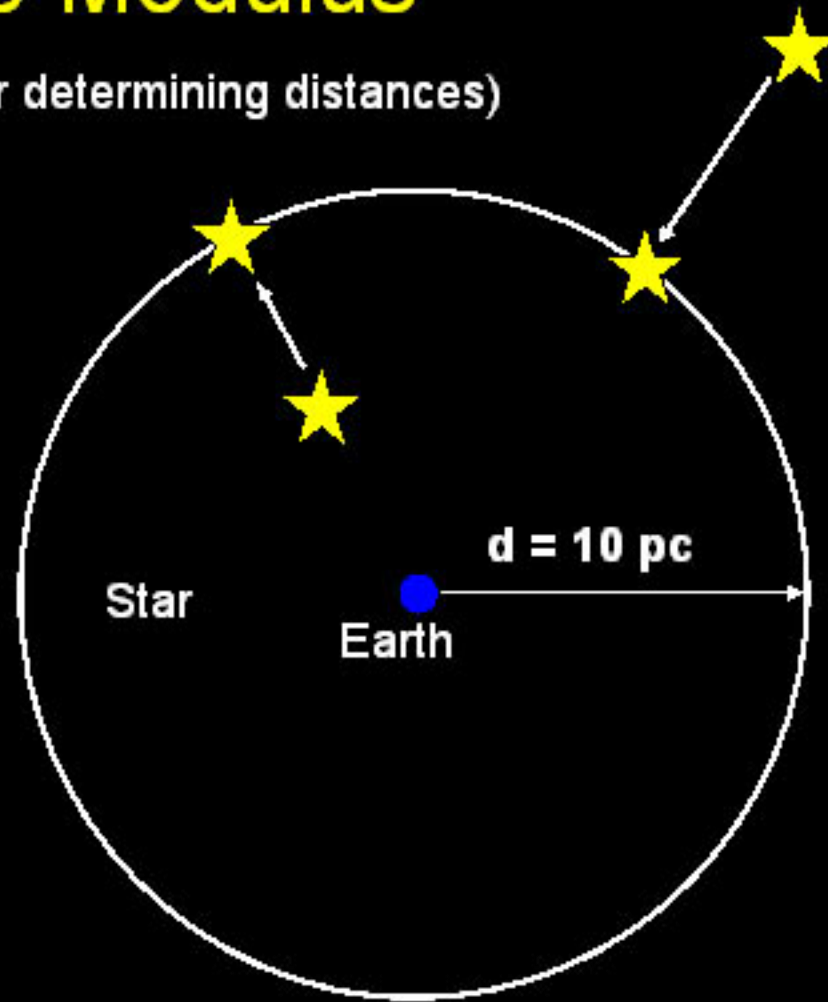
The distance modulus is the difference between apparent magnitude m and absolute magnitude M for an object.

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

$m < M \rightarrow d < 10$ pc

$m > M \rightarrow d > 10$ pc

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

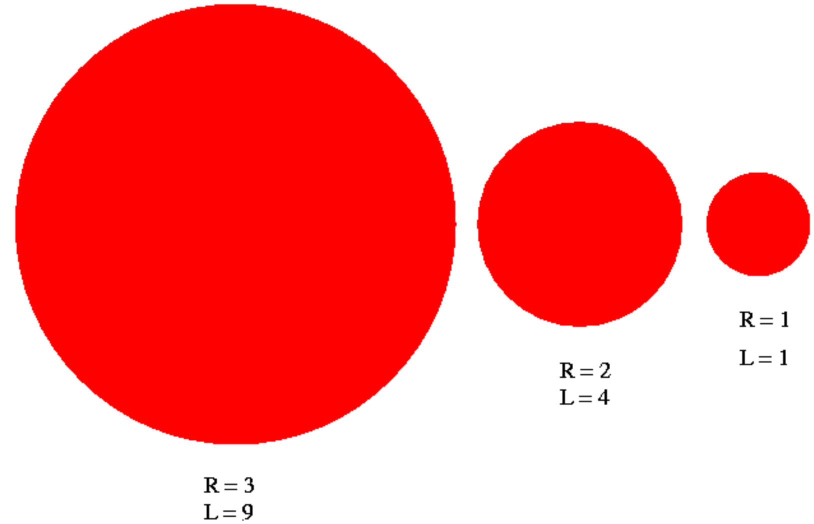


Rule: A distance modulus of 5 corresponds to a distance of 100 pc

Range of Stellar Luminosity

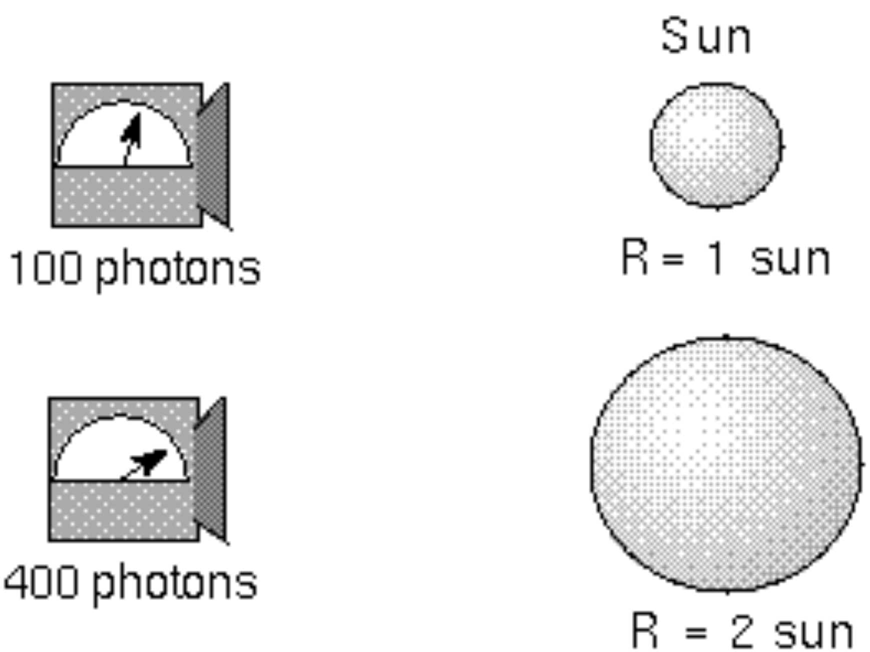
- If the sun was a 100 watt light bulb
- Then brightest stars are ~ equal to the Empire State building (1,000,000 times Luminosity of sun)
- The faintest stars are like a small flashlight (0.001 Luminosity of sun)

Luminosity Depends on Area $A = 4\pi R^2$



A bigger star is a brighter star

Luminosity is also proportional to the surface area.

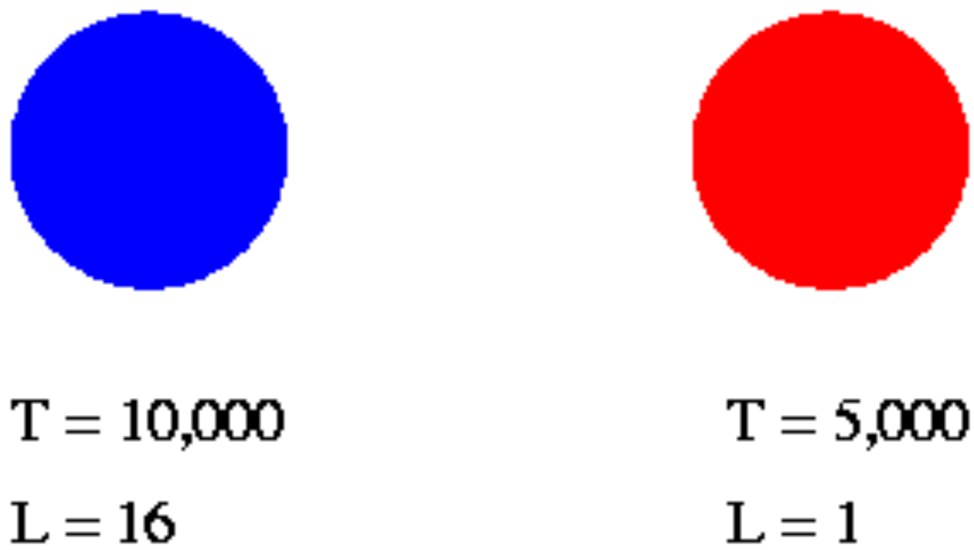


surface area = $4\pi R^2$

$$\frac{\text{star surface area}}{\text{Sun surface area}} = \left(\frac{2}{1}\right)^2$$

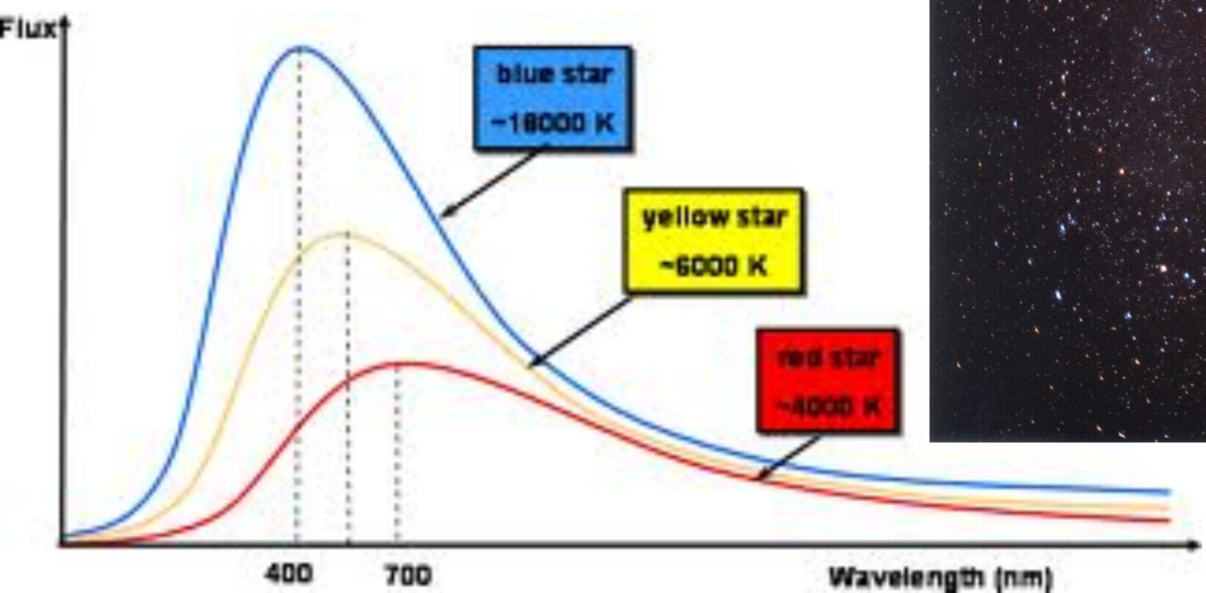
Luminosity depends on (Temperature)^4

- A hotter area is a brighter area (per square meter)



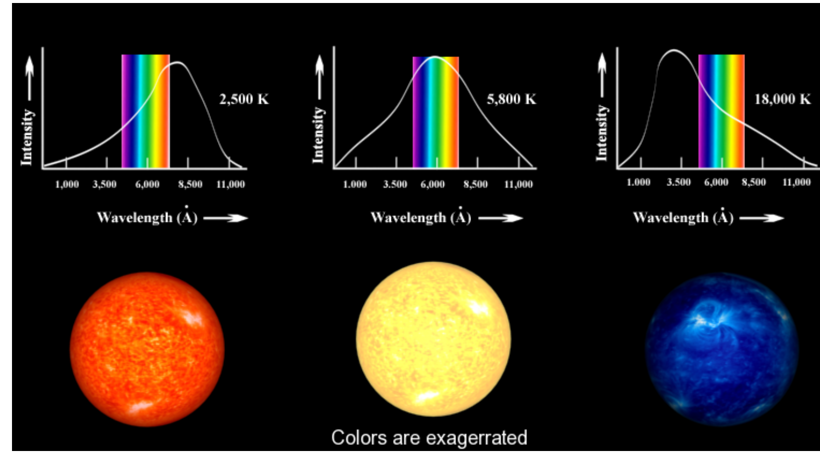
How Hot are the Stars?
Blackbody Spectra

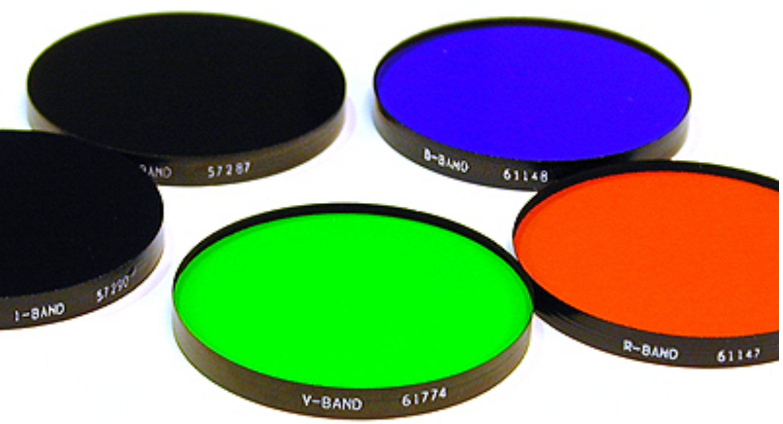
- As the temperature goes up there are more collisions & more violent
- So more photons AND more energetic photons (=blue)
- Higher temperature shorter **wavelength of peak emission**=
- Higher temperature bluer color

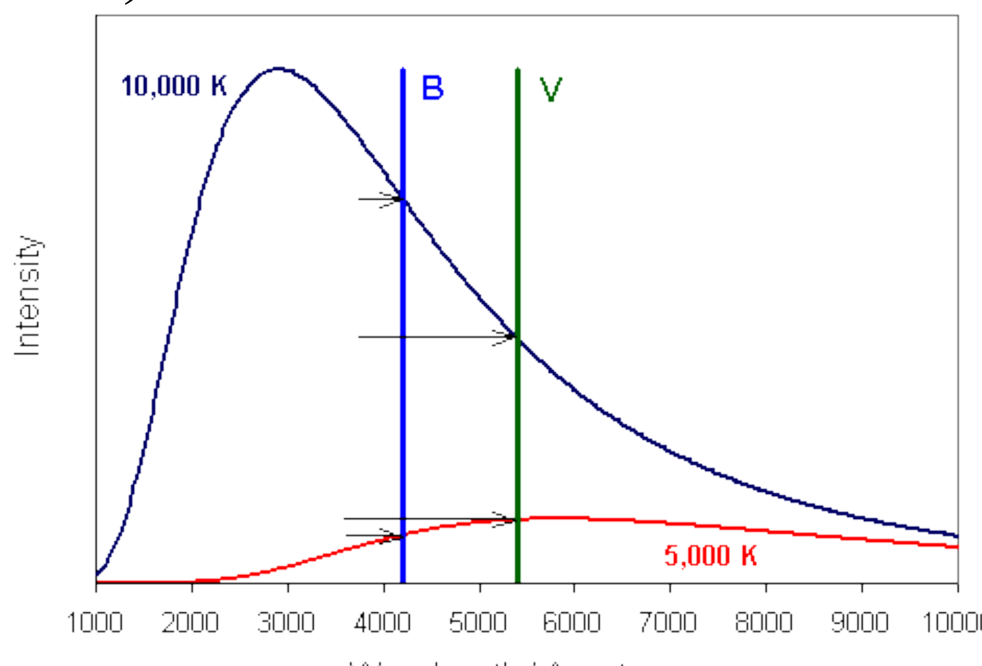


Red Stars are Cool&Blue Stars are Hot

- Color of star depends on star's surface temperature
- **Photometry** is observing thru standard V & B filters to find the color index (B-V) & thus the temperature

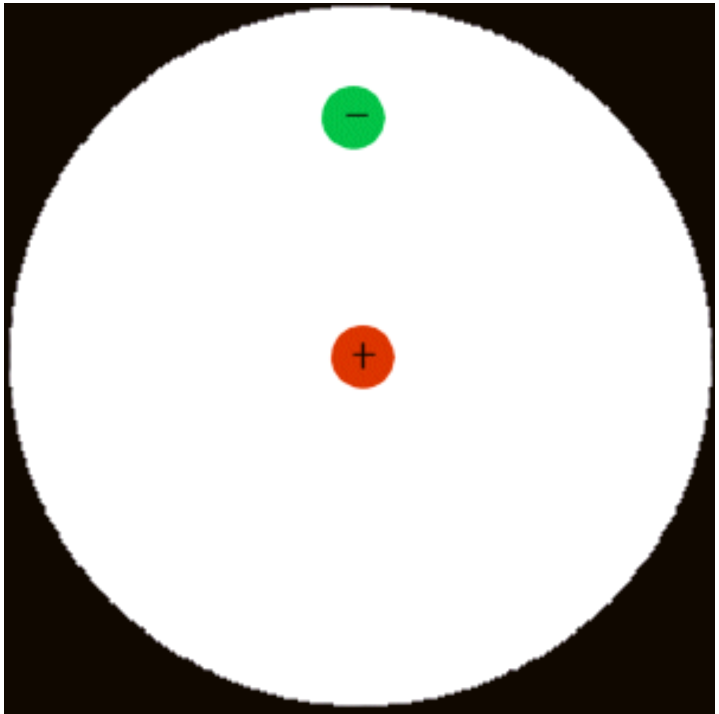


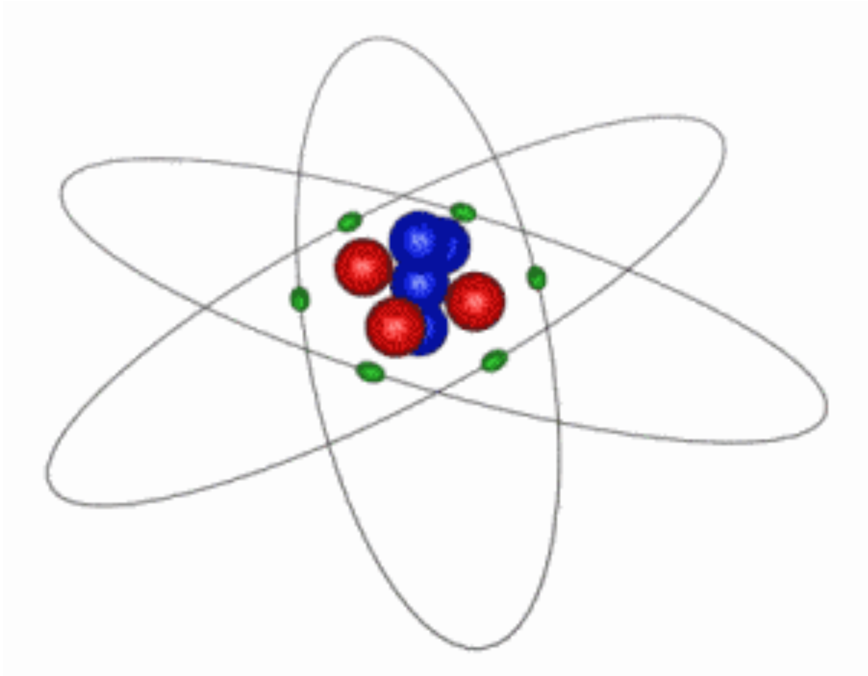




Niels Bohr's Atom

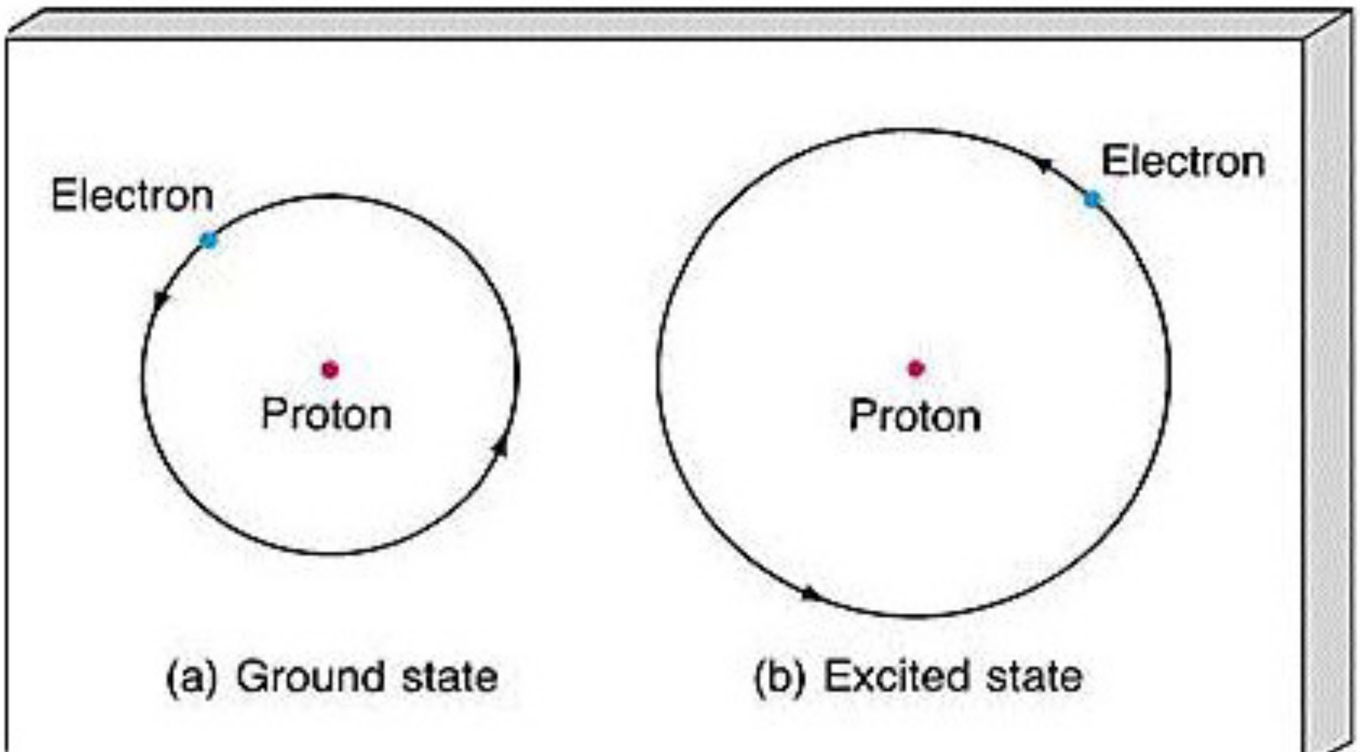
- Tiny positive nucleus contains most of mass
- "Orbited" by negatively charged electron(s)
- Different elements: different number of protons = electrons
- Different **isotopes** have number of neutrons



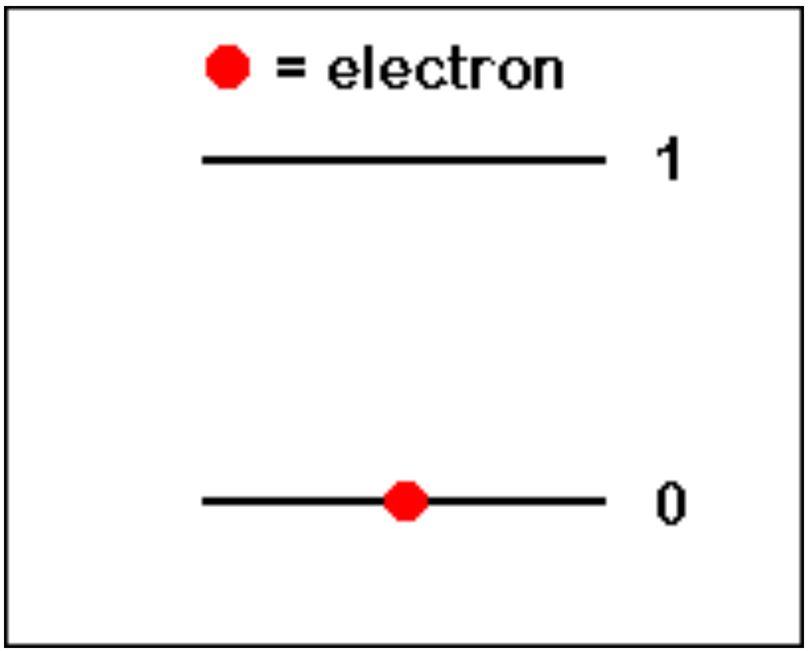


Quantum Mechanics

- Energy is **quantized** so only certain **orbitals**/energies allowed (just like stairs, piano keys, bookshelf)
- Electron can be in lowest energy (=**ground state**) can raised to higher energy (=**excited state**)



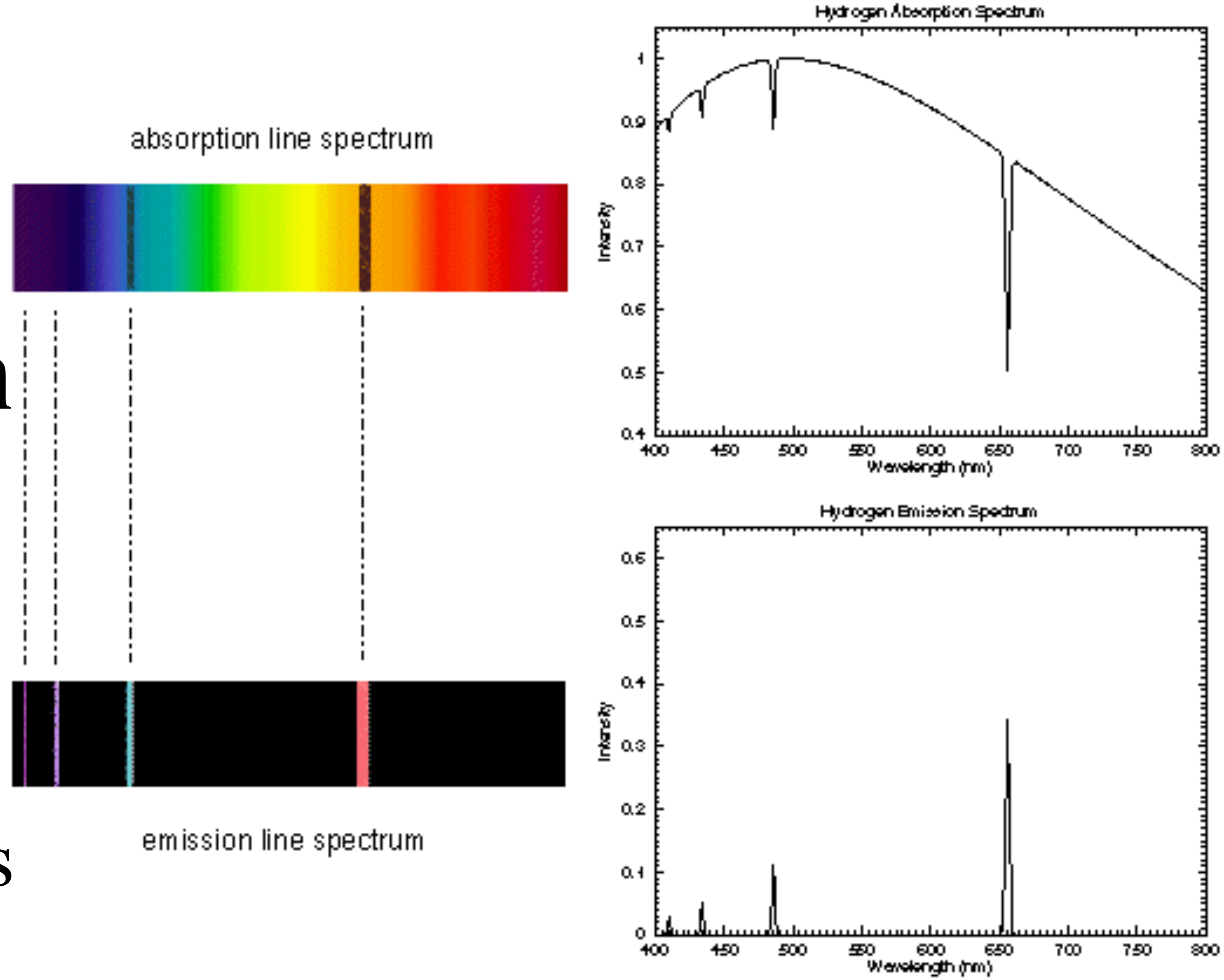
Photon Emission/Absorption



- The electron jumps to a higher **energy level** when a photon is absorbed = absorption
- **Excited state**
- The electron jumps to a lower energy when it emits a photon = emission
- **Ground state**

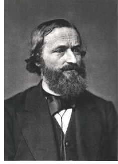
Emission Matches **Absorption Spectrum**

- Energy difference between states determines color of photon

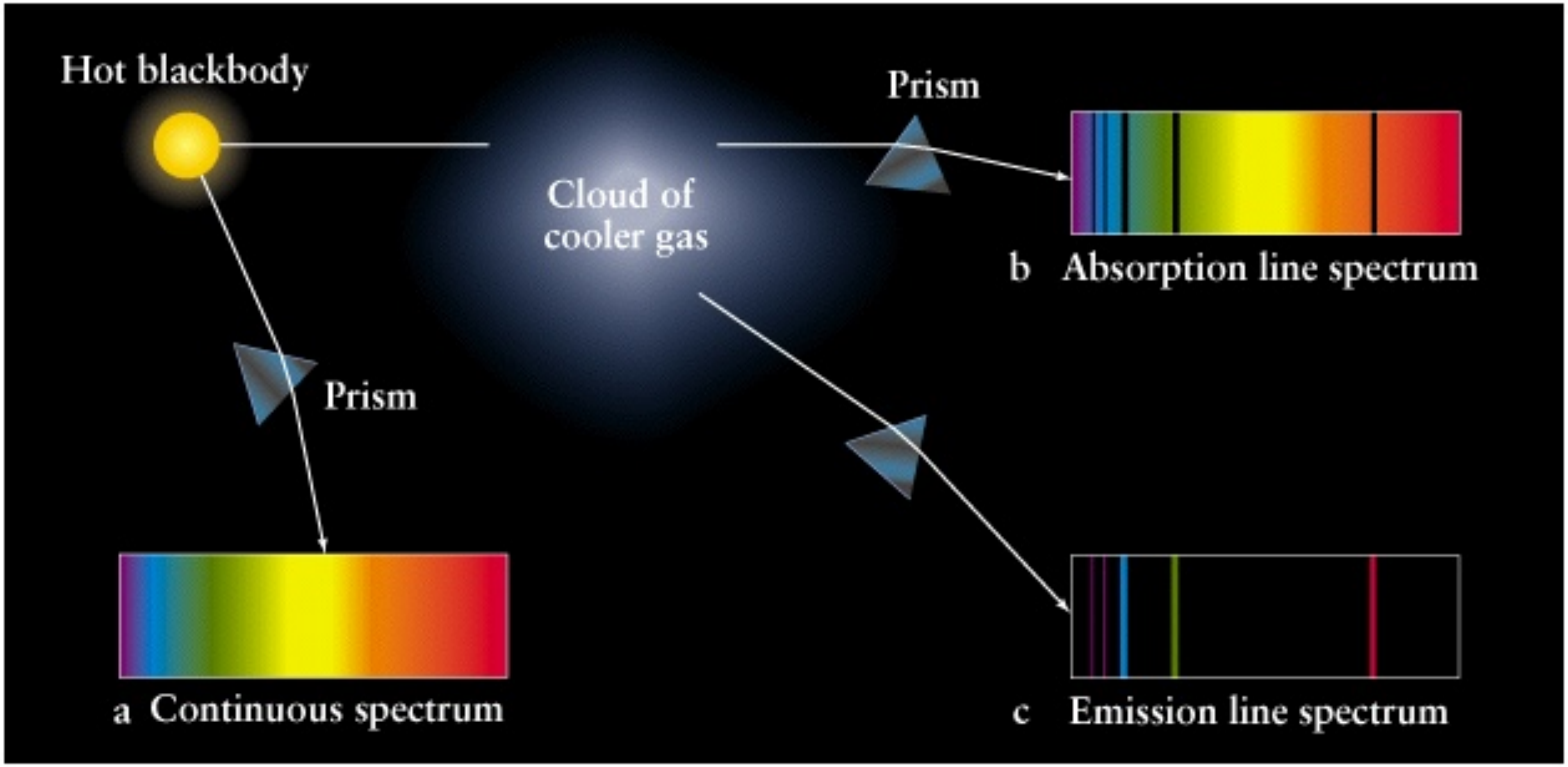


Two ways of showing the same spectra: on the **left** are pictures of the dispersed light and on the **right** are plots of the intensity vs. wavelength. Notice that the pattern of spectral lines in the absorption and emission line spectra are the **same** since the gas is the same.

Kirchhoff's Laws 1861

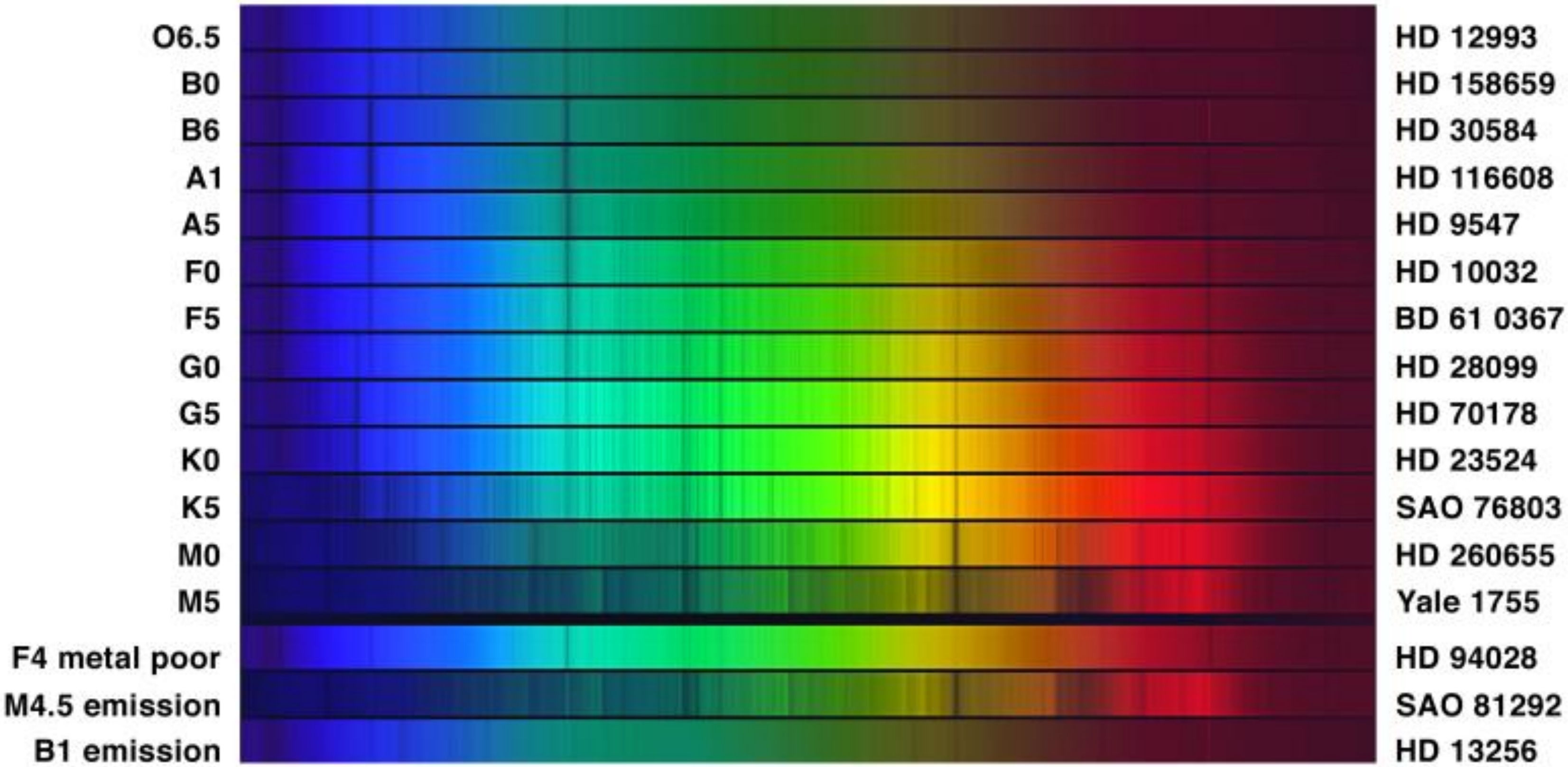


- **Continuous** – solid, liquid or dense gas will radiate at all wavelengths
- **Emission** - a low density gas will emit light at specific wavelengths
- **Absorption** - results from a continuous spectrum passing through a low density gas resulting in dark spectral lines



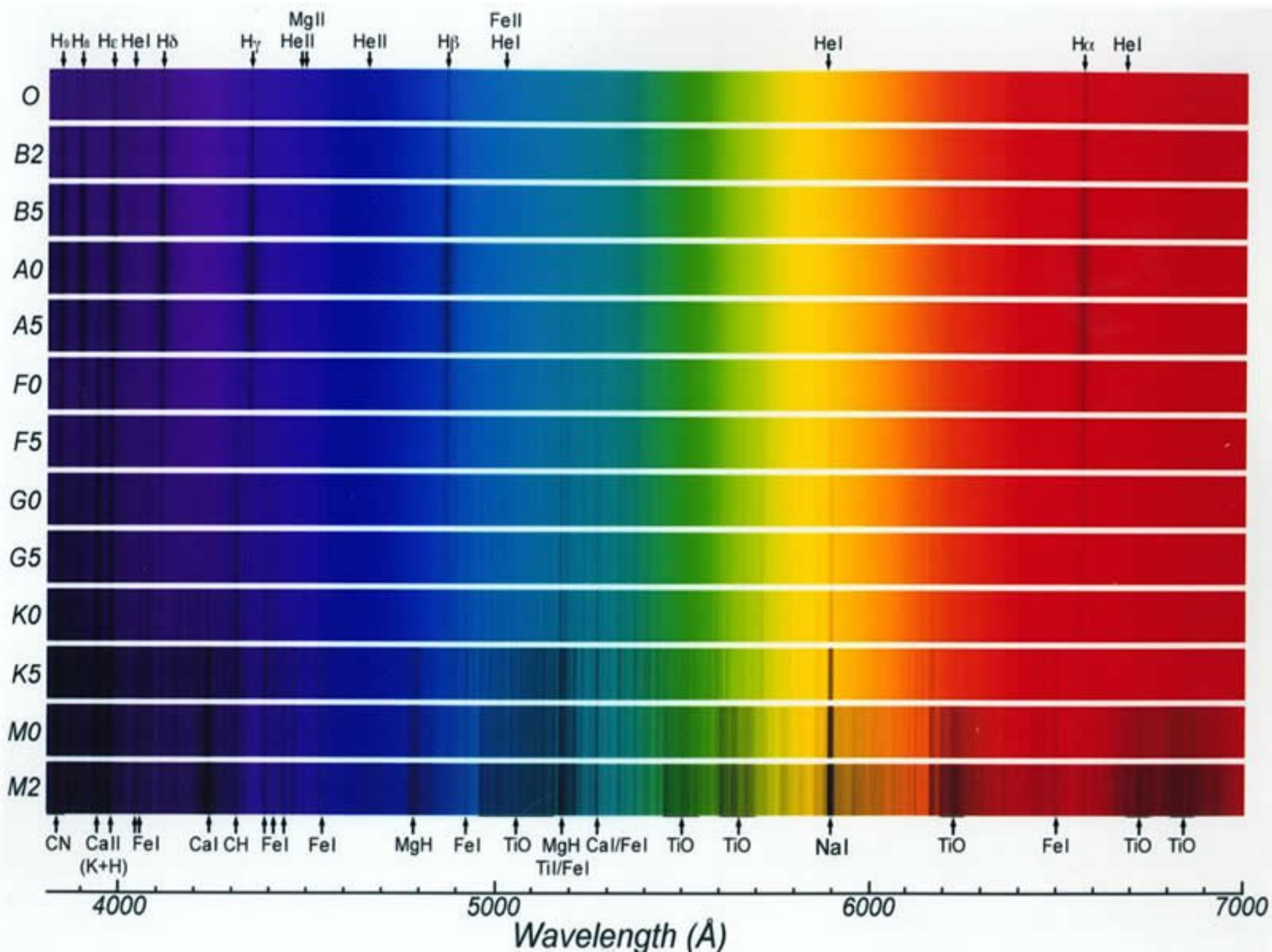
Spectral Class/Type

- Annie Jump Cannon classified the stars
- **OBAFGKM**
- Oh Be A Fine Girl/Guy Kiss Me



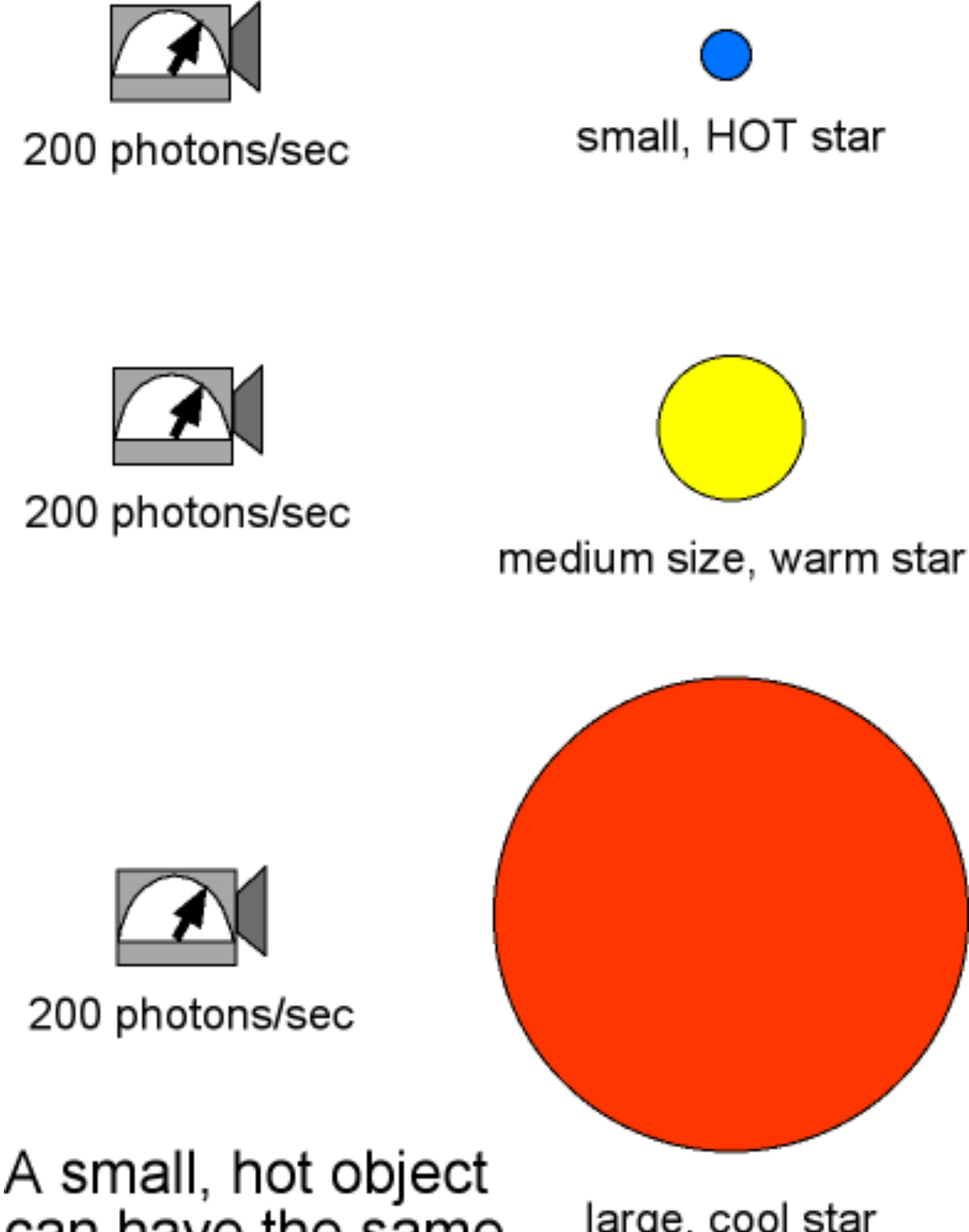
Spectral Class is a Temperature Scale

- Temperatures of 30,000K to 3,000Kelvin



Radius-Luminosity-Temperature Relation

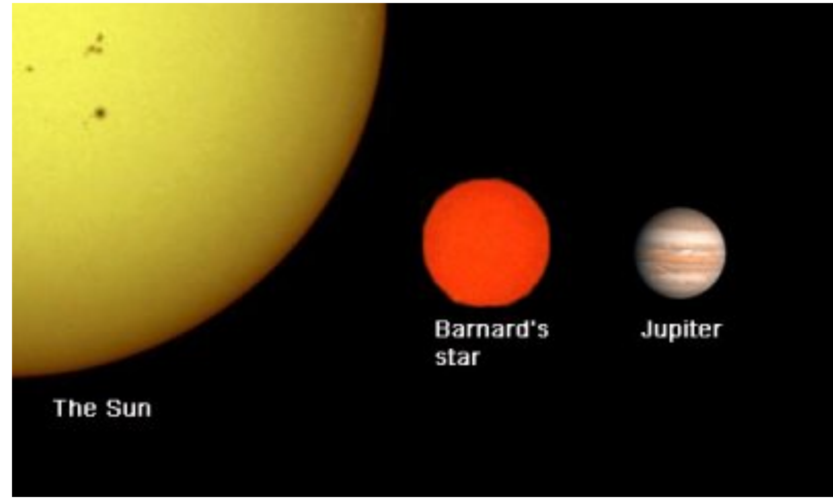
- $L = 4\pi R^2 \sigma T^4$
- Apparent magnitude & distance gives absolute magnitude = luminosity=L
- Color gives temperature=T
- $L_{sun} = R_{sun}^2 T_{sun}^4$ gives Radius=R_{sun}

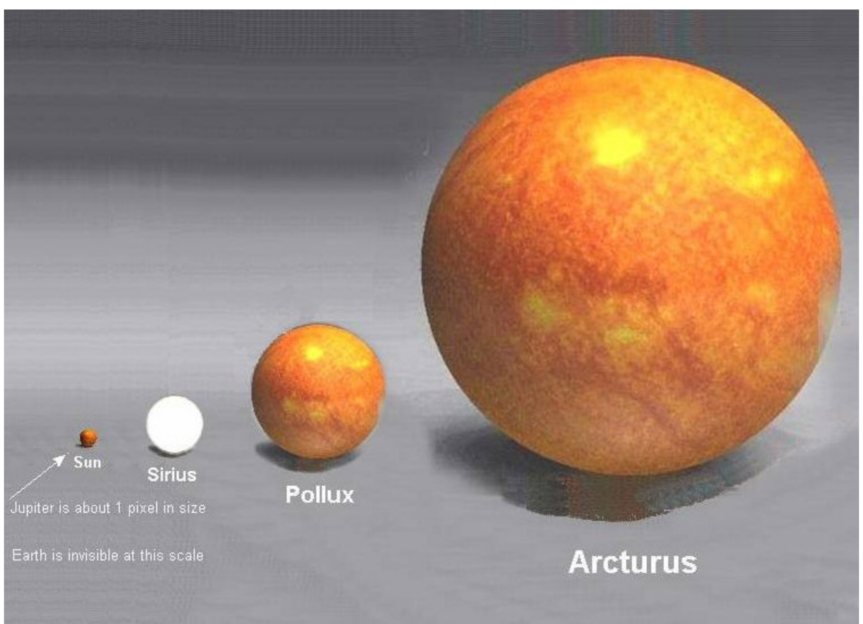


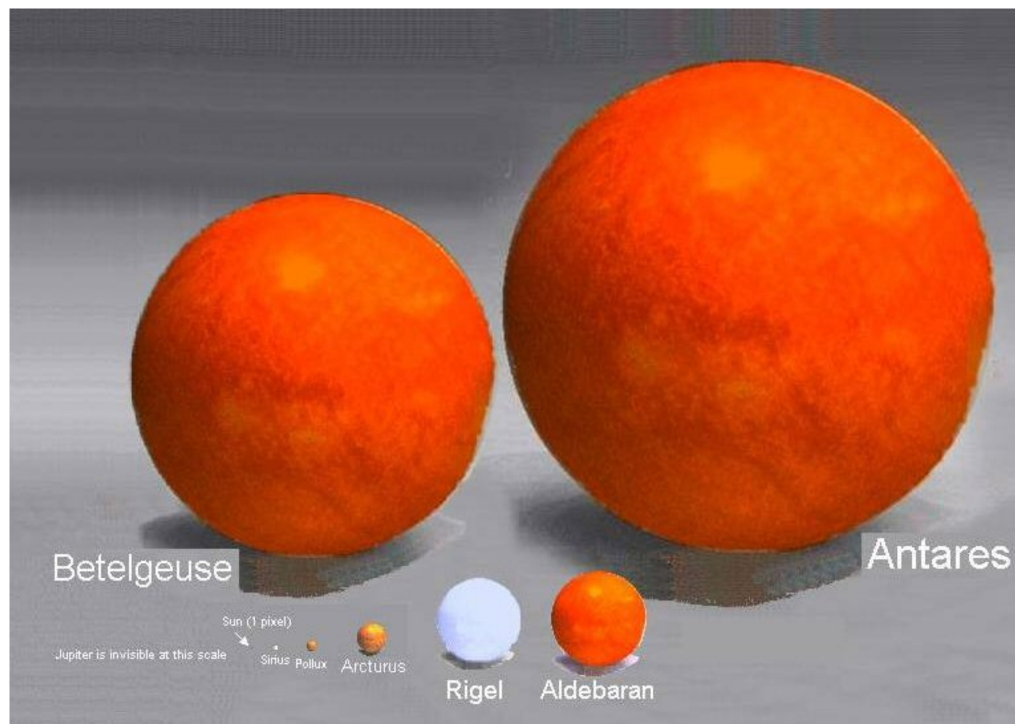
A small, hot object can have the same luminosity as a large, cool object

Radii of Stars

- **White Dwarfs** the size of Earth
- **Main Sequence** stars are the size of the sun
- **Giants** are the size of Earth's orbit
- **Supergiants** are the size of Jupiter's orbit





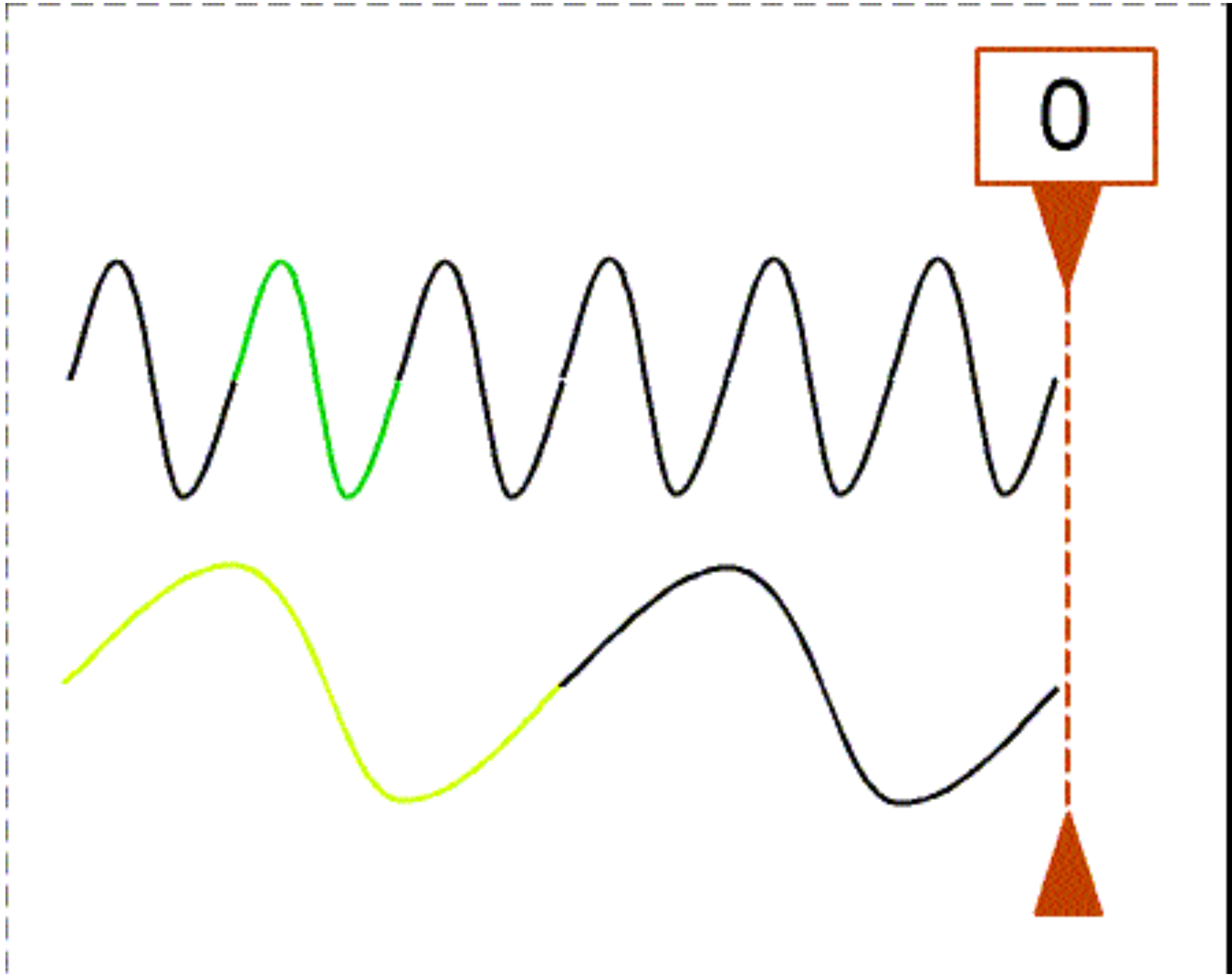


The absolute magnitude (=Luminosity) of a star:

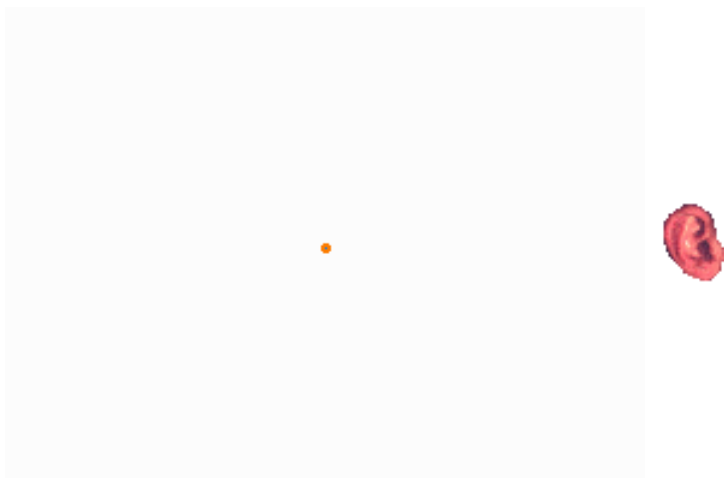
a) Depends on the star’s radius
b) Depends on the star’s temperature
c) Can be found from its apparent magnitude & distance
d) Is the brightness a star would have at 10 parsecs
e) All of these are correct

Light Waves Have a **Frequency** f, **Velocity** c, **Wavelength** λ (lambda)

- **Frequency** counts number of waves
- Frequency = 3 cycles/ sec or 3 Hertz
- Frequency of 1 cycle/ sec= 1 Hertz
- Has three times wavelength λ
- Velocity $c = f\lambda$

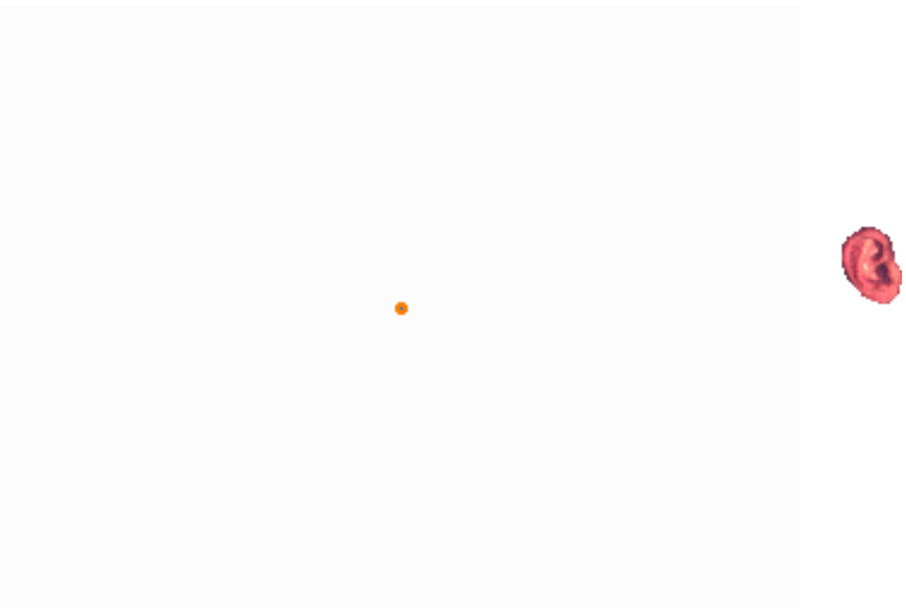


Stationary Source



- Speed of waves equals the wavelength λ times the frequency f
- $C=\lambda f$

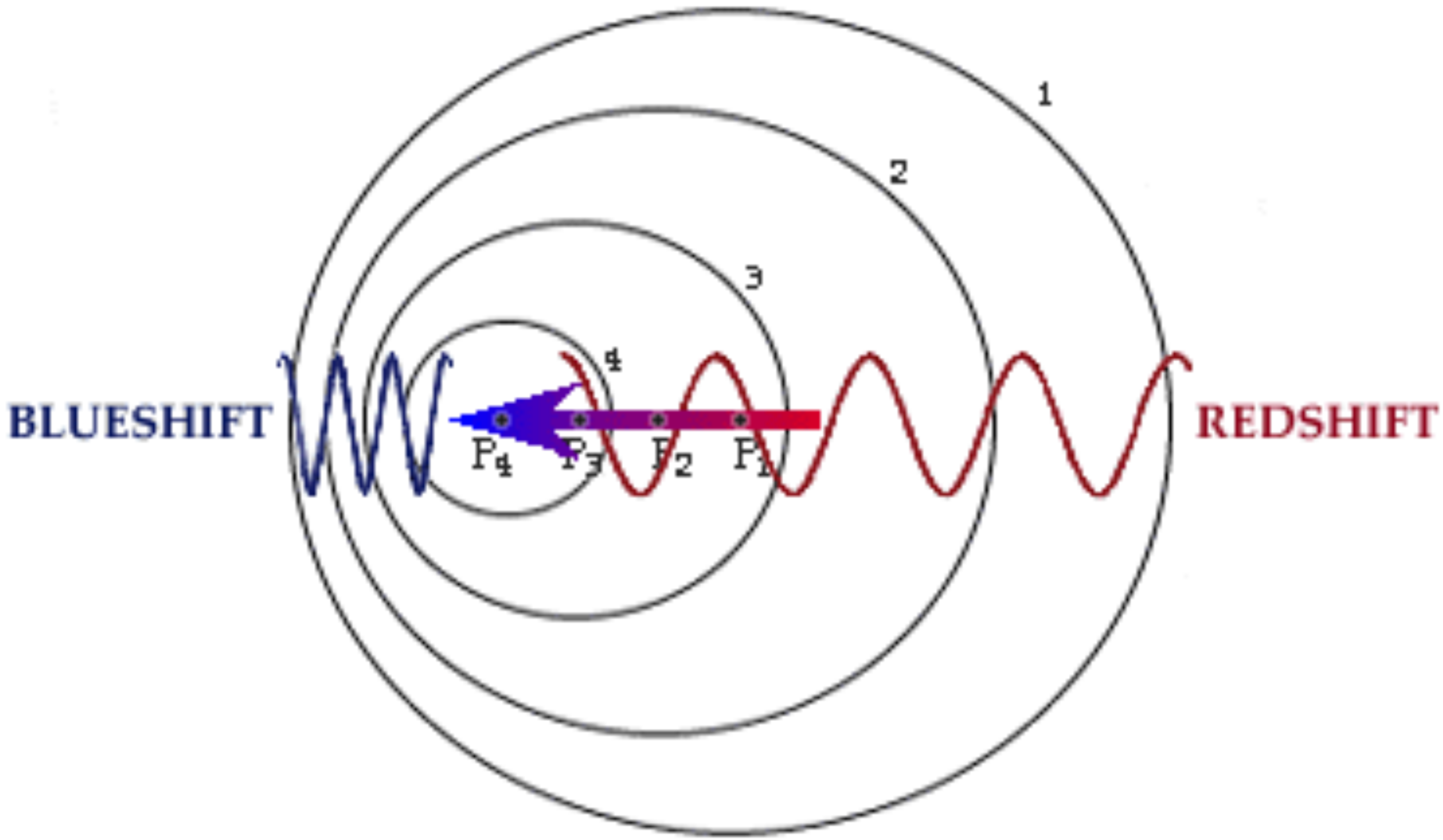
Moving Source



- Wavelengths in direction of motion are compressed
- Wavelengths when source is moving away from observer are stretched
- Speed of source determines how much stretching

Doppler Effect

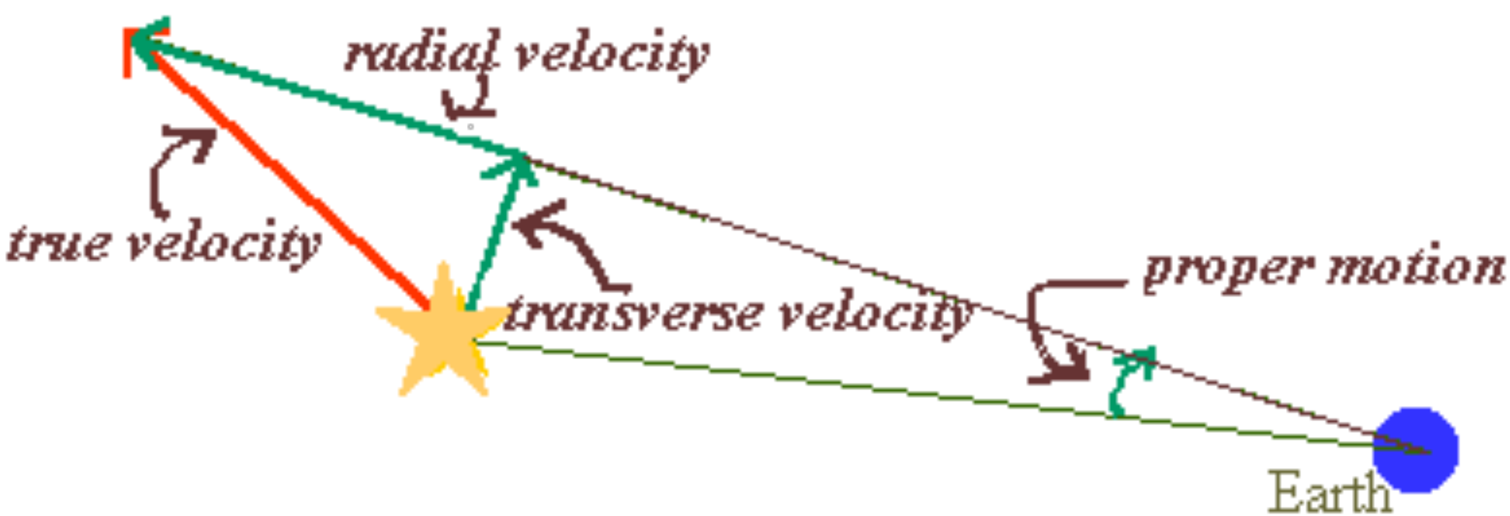
- $V_r / C = (\lambda - \lambda_o) / \lambda_o = \Delta \lambda/\lambda_o$
- If the source is receding (moving away) then it is a redshift
- If the source is approaching then the light is blueshifted



Space Velocity

- Depends on distance to star and **tangential**/transverse **velocity**
- Combine with **radial velocity** to find **space**/true **velocity**

Figure 1

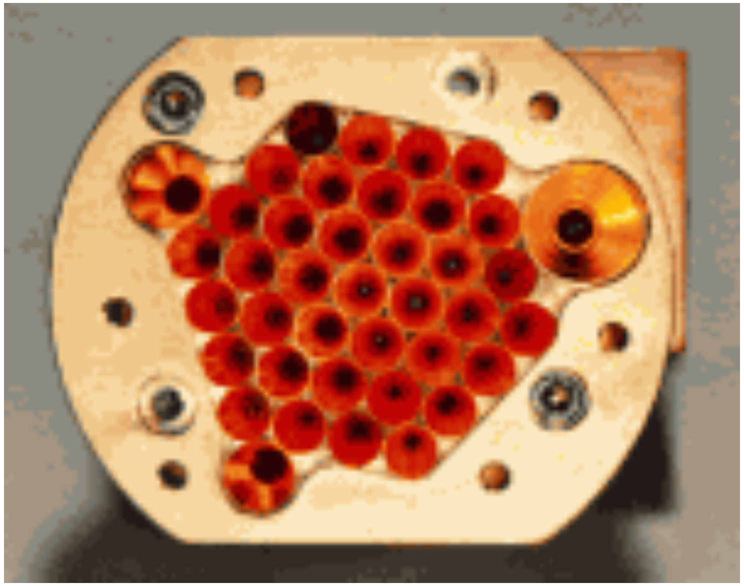


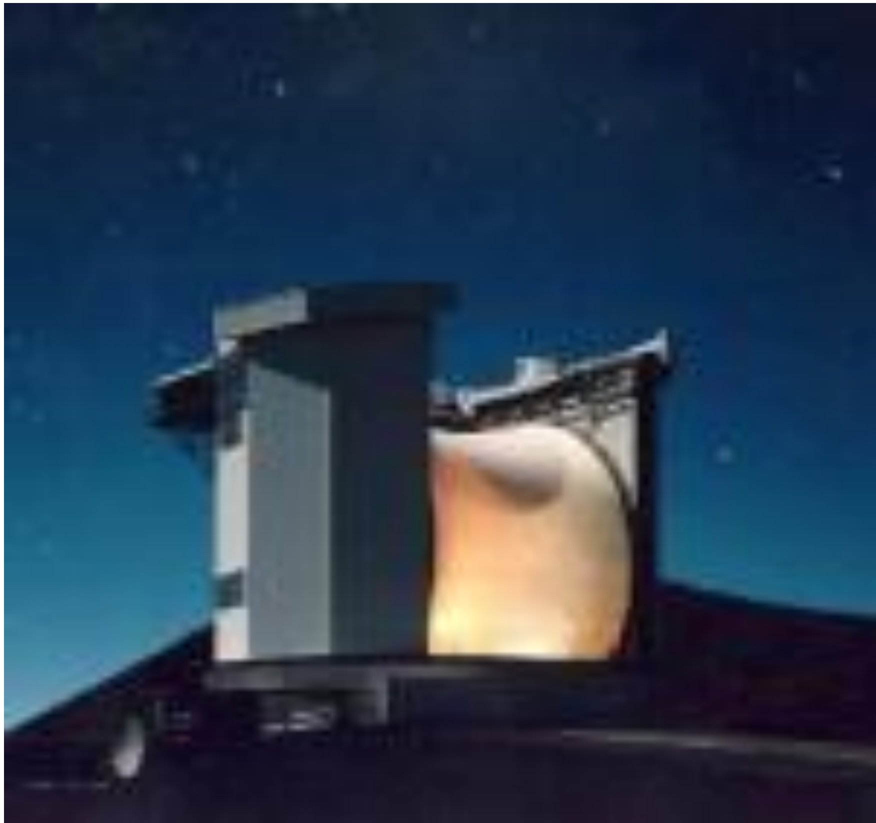
Nearby Stars = Large Proper Motion

The Bolometer

- *The absolute bolometric magnitude of the sun is $M_{bol} = 4.7$*
- *The sun's luminosity is $4X10^{26}$watts*

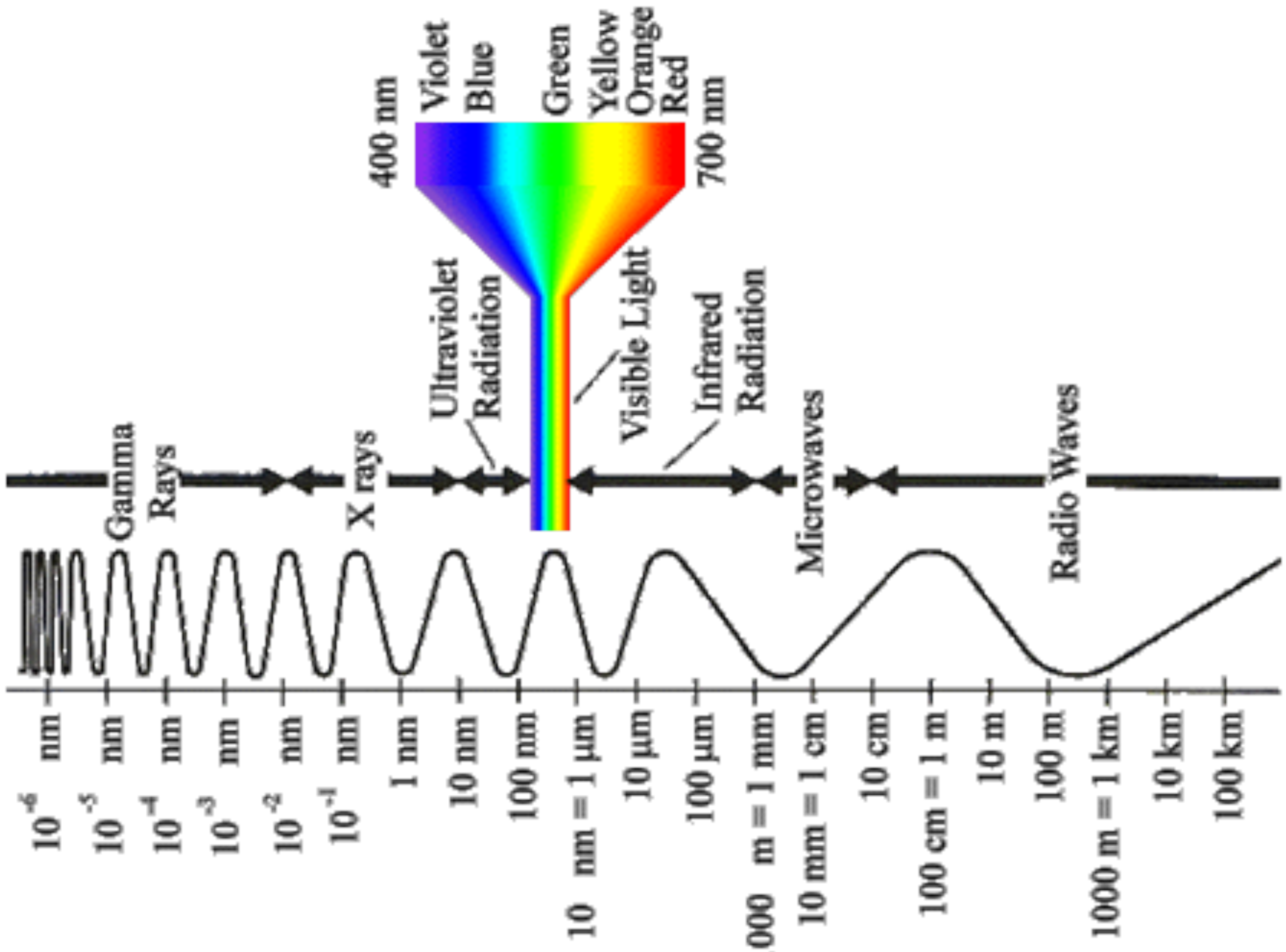
- *SCUBA & JCMT*



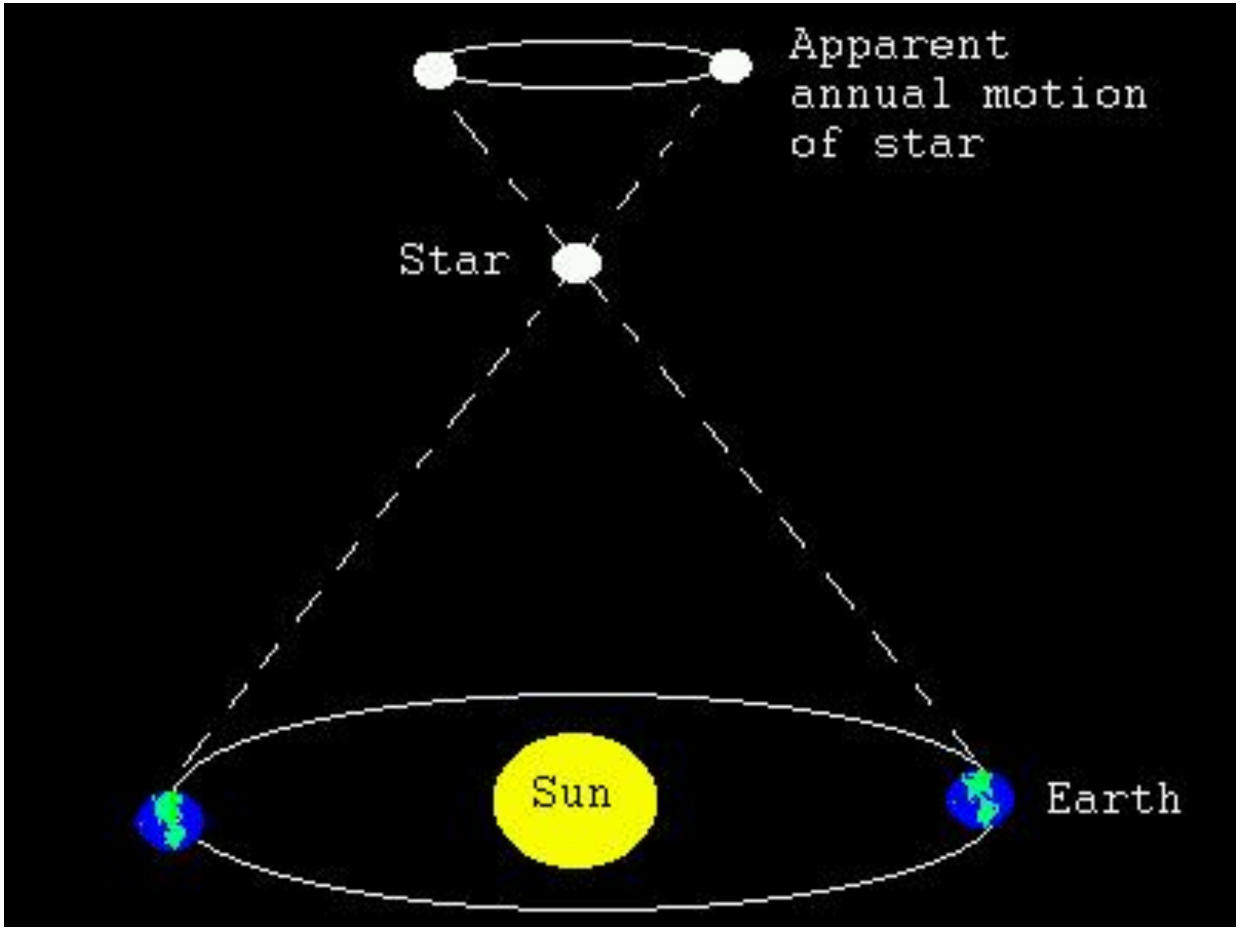


Bolometric Magnitude M_{bol}

- *M_v is absolute visual magnitude and M_B is blue etc*
- Luminosity is the total amount of energy = bolometric
- *Need to make a correction M_v+BolCorrect=M_{bol}*



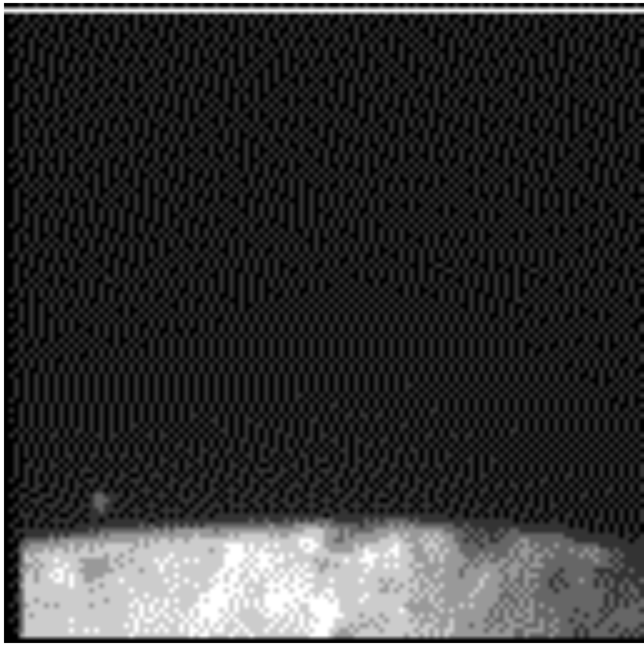
Stellar Parallax

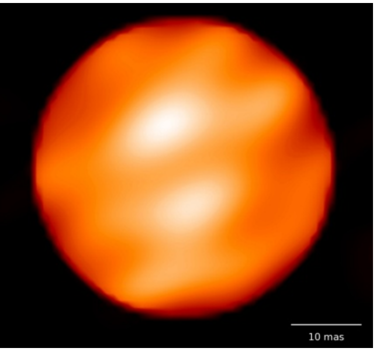


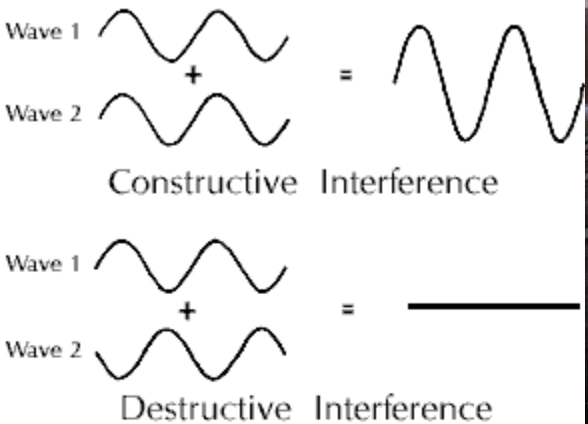
- Distance in parsecs = 1 / parallax in arc seconds
- 1 parsec = 206265 AU = 3.26 light years

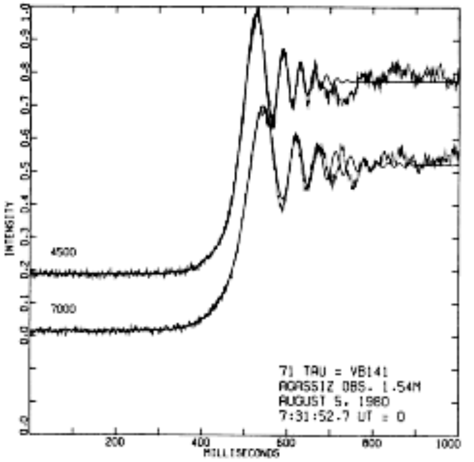
Other Methods of Measuring Radii

- *Eclipsing binaries later*
- *As Aldebaran disappears behind the moon the light diffracts around the edge and we can find its diameter*
- Interferometry allows radius measurements of Betelgeuse









Magnitude-Distance: Astro Today Box 17-1 (Universe=17-3)

- $\mu = m - M$ $D = 10^{((\mu+5)/5)}$ $m_v - M_v = -5 + 5 \log_{10}(D)$

Star	**Name**	**m**	**M**	**Spectra**	**Dist D**
α Boo	Arcturus	-0.2	-0.2	K2	
α Ori	Betelgeuse	0.4		M2	160pc
	Barnard's		13.2	M5	1.6pc
m-M	**D parsecs**	**m-M**	**D**	**m-M**	**D**
-4	1.6pc	1	16pc	6	160pc
-3	2.5pc	2	25pc	7	250pc
-2	4pc	3	40pc	8	400pc
-1	6.3pc	4	63pc	9	630pc
0	10pc	5	100pc	10	1000pc