

Stars

Properties of Stars in general

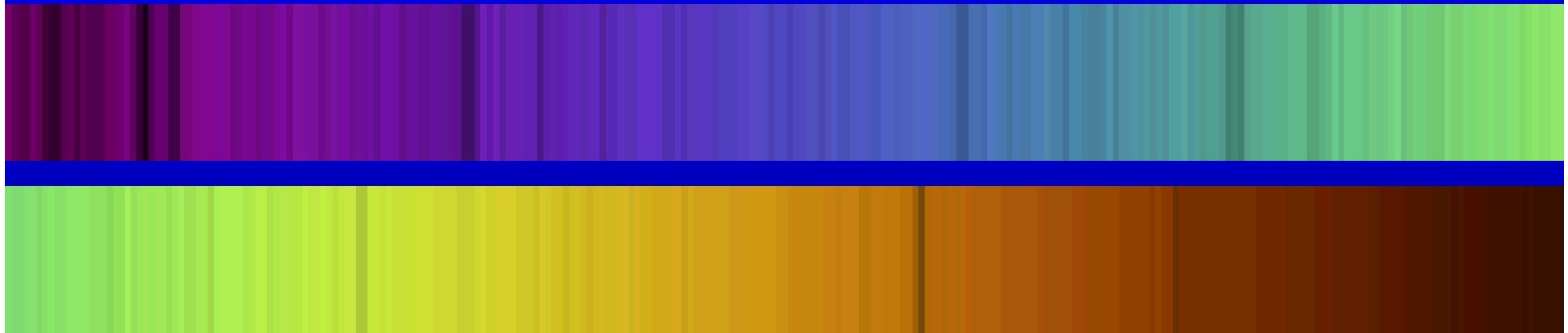
Properties of Stars



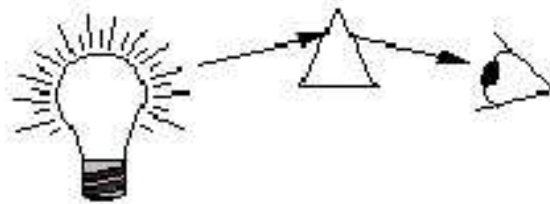
Colour tells us about Temperature

- Blue stars – very hot ~ 20,000K
- White stars - hot ~ 10,000k
- Sun-like stars – yellow ~ 6,000K
- Orange stars ~ 4500k
- Red stars ~ 3000K
- Temperature has a major effect on the spectral lines seen in the atmosphere of a star

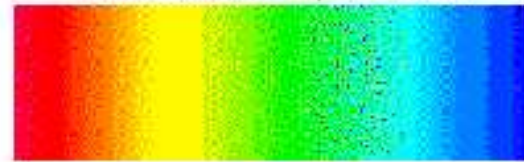
Fraunhofer Lines



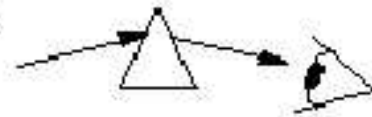
- Joseph Fraunhofer observed the solar spectrum in 1814 and found some 600 dark lines.
- In 1864, Sir William Huggins matched some of these dark lines in spectra from other stars with terrestrial substances, demonstrating that stars are made of the same materials of everyday material rather than exotic substances.



Continuum Spectrum



Hot Gas



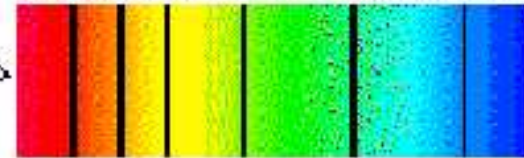
Emission Line Spectrum



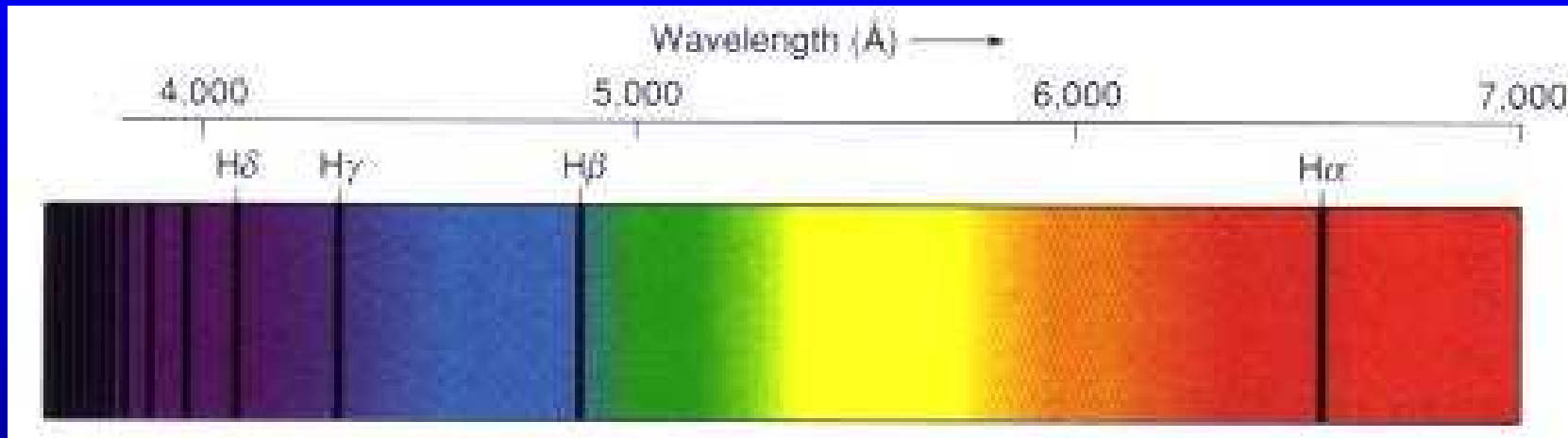
Cold Gas



Absorption Line Spectrum

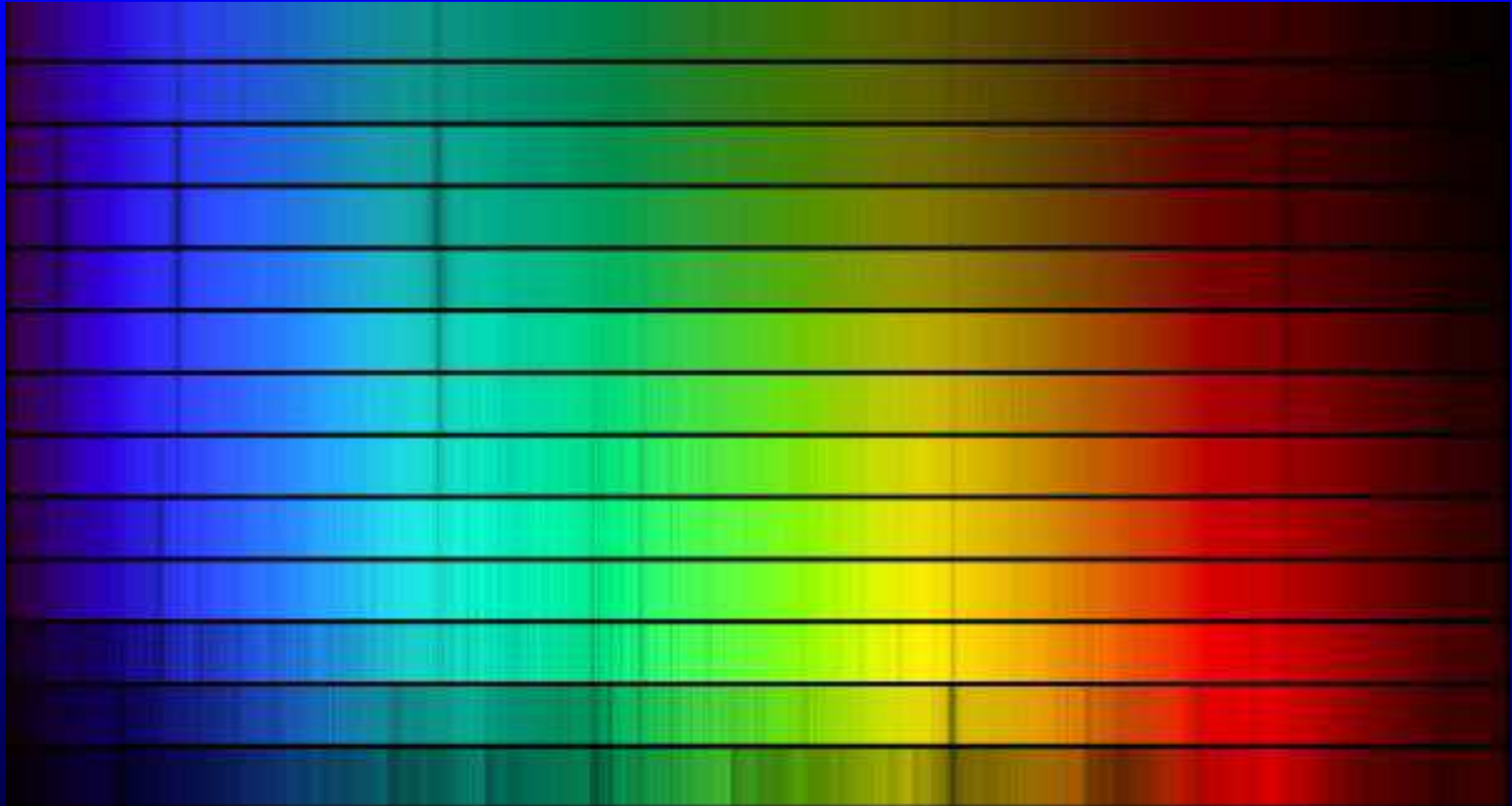


Spectral Lines of Hydrogen



- Another set of lines was discovered that had no Earth counterpart.
- A new element had been discovered in the Sun!
- Helium – (Helios = Sun)

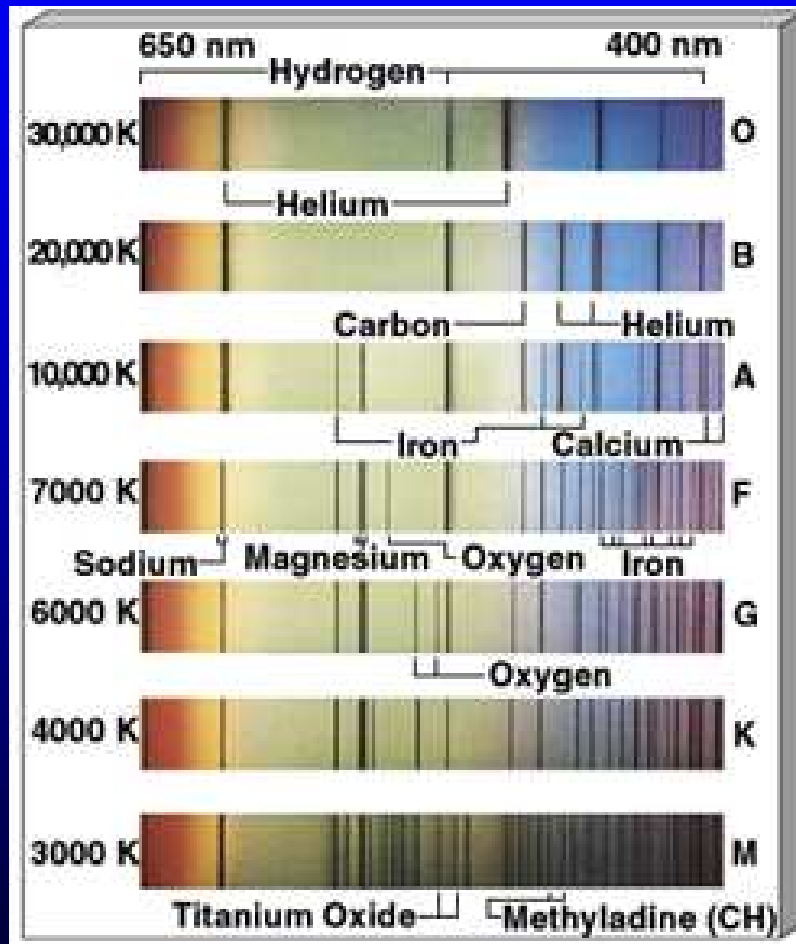
Spectra of different stars



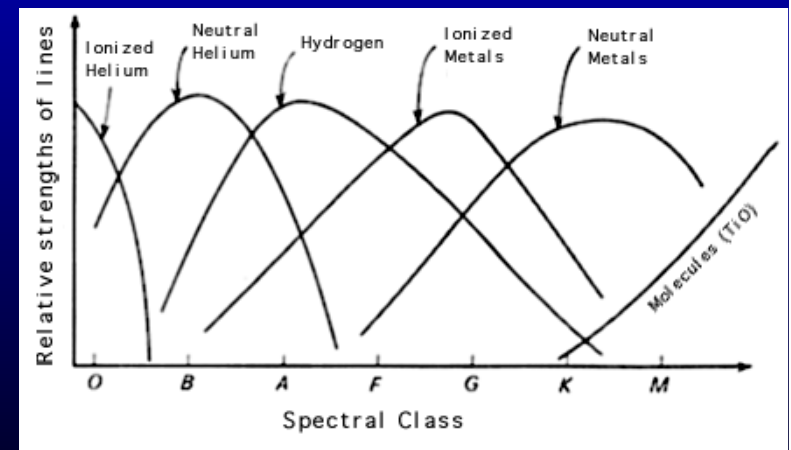
Spectral Classes

- From their temperatures, derived from colour and spectra, we classify stars into groups, each with 10 subdivisions:
- O,B,A,F,G,K,M
- Each class goes from say, G0 (hottest) to G9 (coolest in the group)
- Our Sun is a type G2 star.

Relationship with stellar class.



- The graph shows how the intensity of different lines varies with spectral type (and hence with temperature).



Stellar Luminosity

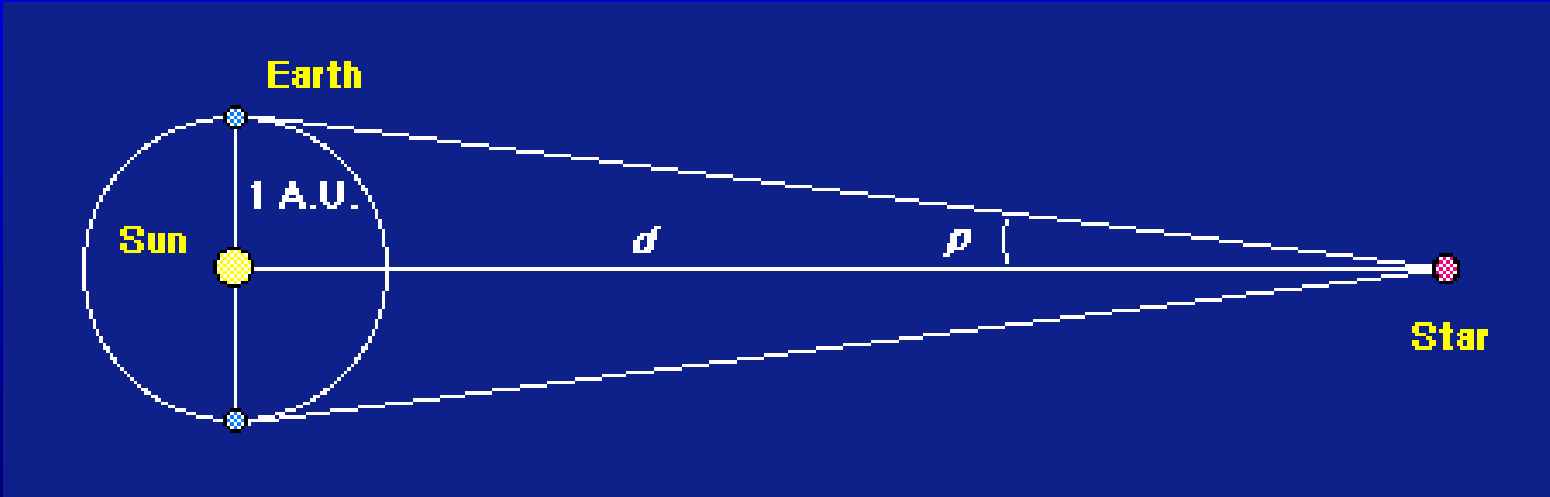
How bright stars really are.

In our mind we line all stars up at a fixed distance from the Sun so stars that appear brighter are actually brighter and vice-versa.

We choose a distance of 10 parsecs * or 32.6 light years.

The star is given an **Absolute Magnitude** which is what its Apparent Magnitude would be if it lay at that distance.

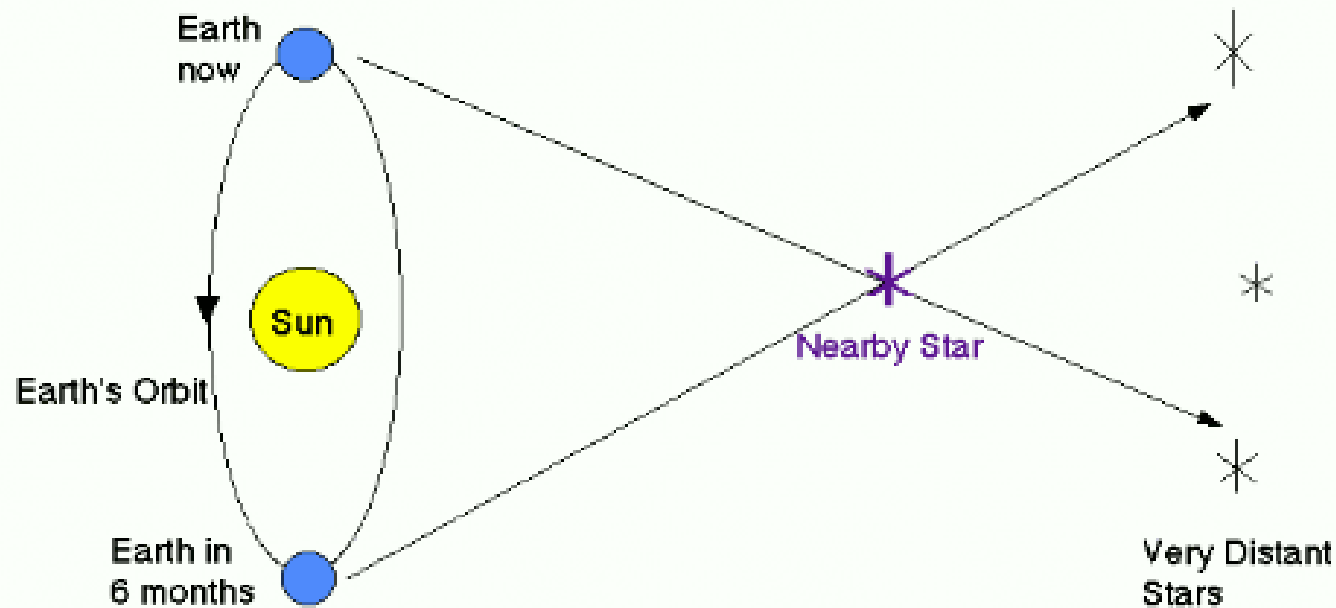
* A parsec is the distance at which the Earth's orbital radius (1 AU) will subtend an angle of 1 arc second.



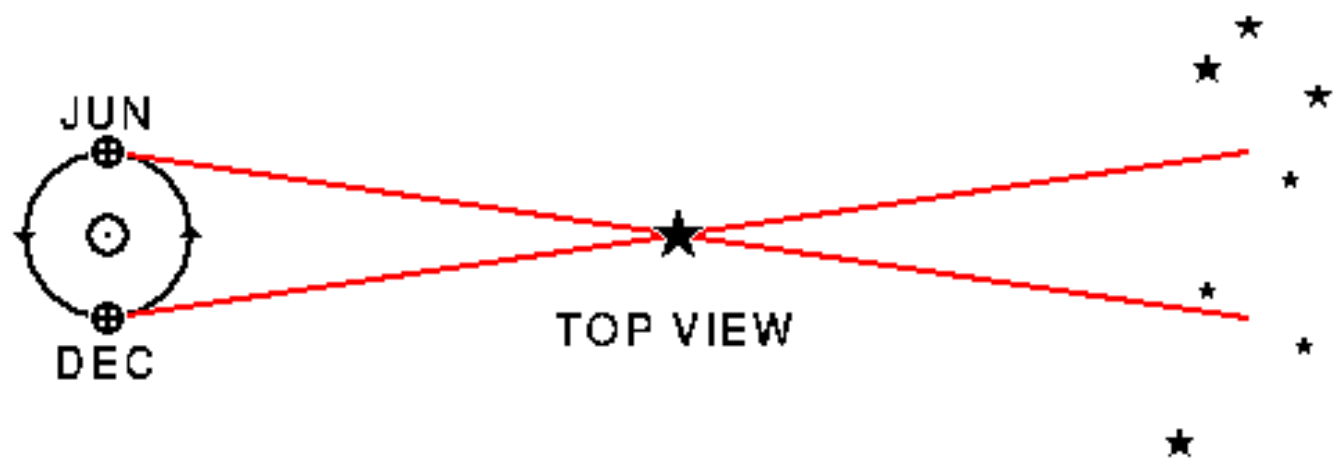
Stellar Parallax

In order to find the Absolute Magnitudes we need to measure the distances to stars.

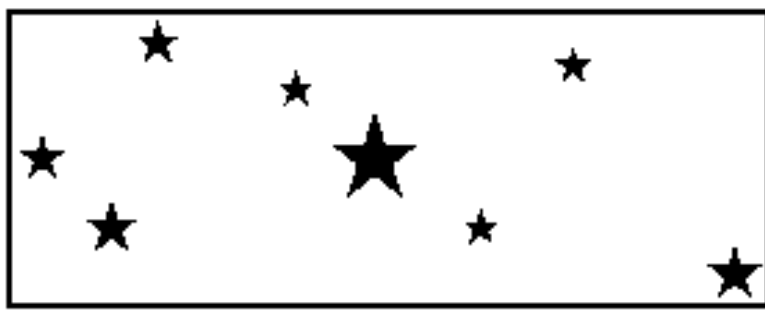
Large Baselines : Earth's Orbit



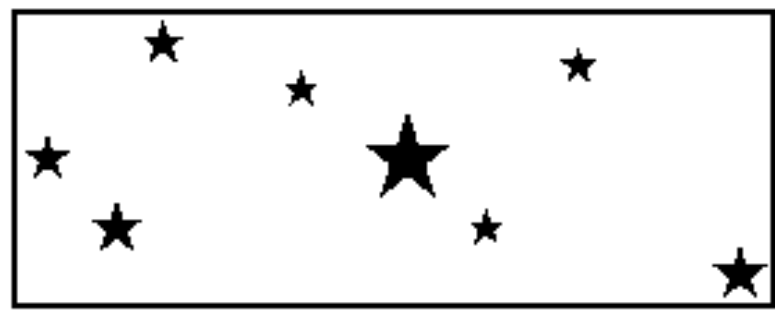
- A very large baseline is need to measure the parallax of stars



TOP VIEW



DEC



JUN

Parallax

$$\text{Distance (in parsecs)} = \frac{1}{\text{parallax (in arcseconds)}}$$

- the formula

Parallax Example

$$\text{Distance} = \frac{1}{\text{Parallax}}$$

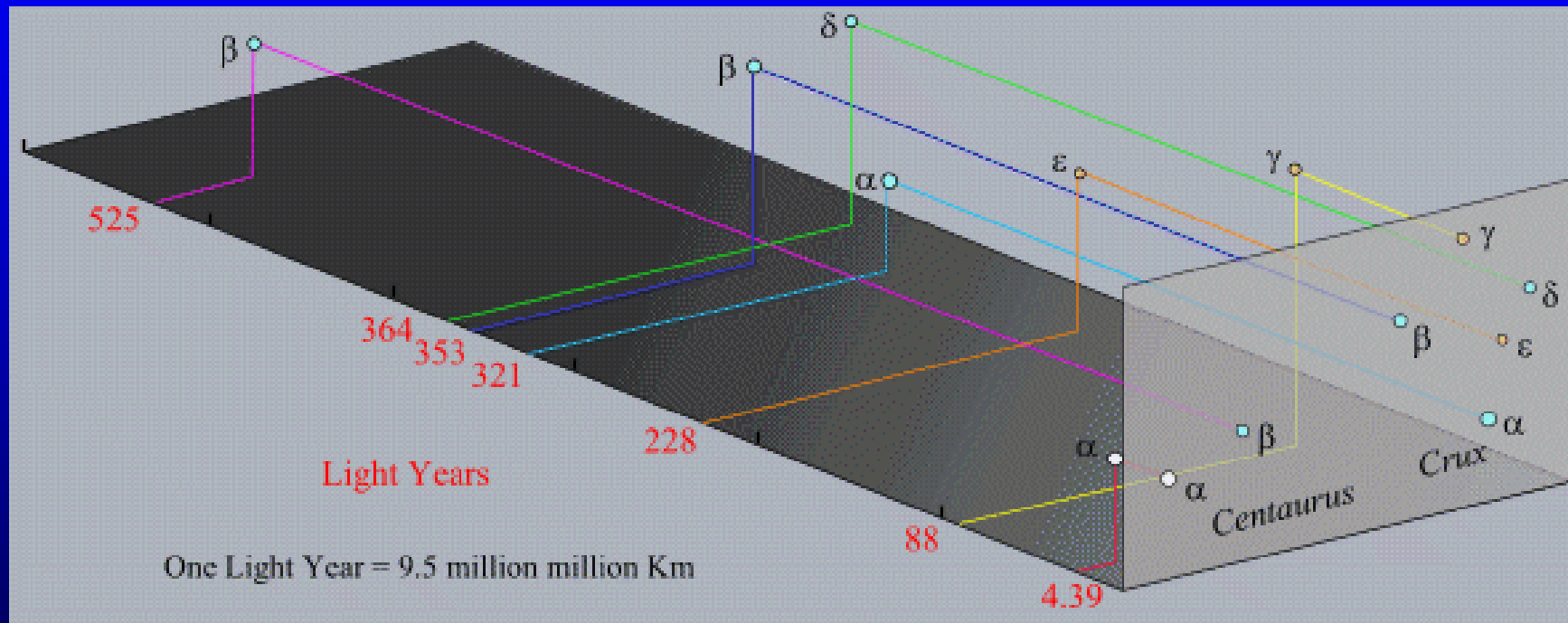
$$\text{Distance} = \frac{1}{(0.2)} = 5 \text{ pc}$$

- What is the distance of a star with a parallax of 0.2 Arcseconds?

A problem

- Stars are moving around the Galactic Centre so, if near, may be seen to move across the sky.
- True motion of a star across the celestial sphere is called **Proper Motion**.
- So observed motion may not all be due to parallax.
- Observe again after 12 months. If no proper motion than the star will return to its original position.
- If the star does not return to its original position, both the parallax and proper motion can be calculated. (Better to observe for a few years!)





Given the distance in parsecs, what is the absolute magnitude M of a star with apparent magnitude m ?

- The brightness ratio will be the square of the ratio of the distances $(d/10)^2 = R$
- This ratio corresponds to a magnitude difference of $2.5 \log_{10} (R)$
- So $M = m - 2.5 \log_{10} (R)$

Example: Sun

$$D = 4.7 \times 10^{-6} \text{ pc } *, \quad m = -26.75$$

- $R = (4.7 \times 10^{-6} / 10)^2$
 $= 2.2 \times 10^{-13}$

$$\begin{aligned} M &= -26.75 - (2.5 \times \text{Log}_{10} 2.2 \times 10^{-13}) \\ &= -26.75 - (2.5 \times (-12.66)) \\ &= -26.75 + 31.65 \\ &= +4.9 \end{aligned}$$

The Sun has an absolute magnitude of +4.9

* $D = (8 \text{ (minutes)} / (365 \times 24 \times 60)) / 3.26 \text{ pc}$

Example: Rigel

$$D = 237 \text{ pc}, \quad m = 0.12$$

- $R = (237/10)^2$
 $= 562$

$$\begin{aligned} M &= 0.12 - (2.5 \times \text{Log}_{10} 562) \\ &= 0.12 - (2.5 \times 2.75) \\ &= -6.7 \end{aligned}$$

Rigel has an absolute magnitude of -6.7

Relative Luminosity

Rigel with respect to Sun

- Difference in Magnitudes is $6.7 + 4.9$
- = 11.6 magnitudes
- $R = 2.512^{11.6}$
= 45,315

So Rigel has a luminosity ~45,000 times that of our Sun

The luminosity of our Sun is taken as the reference luminosity of 1.

Spectroscopic Parallax

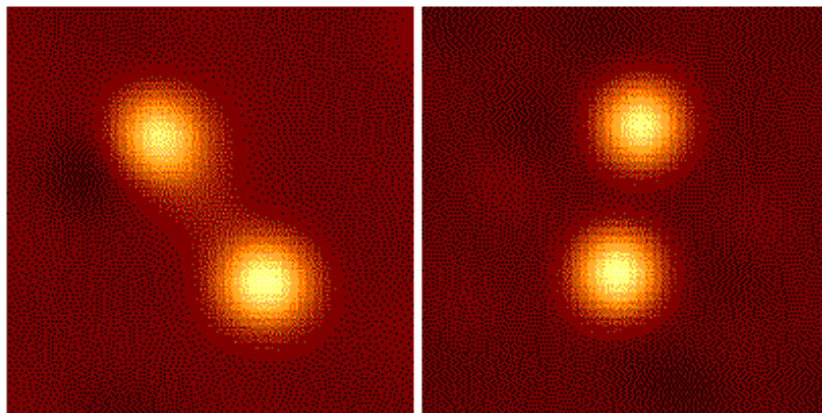
- To estimate the distances to stars further away than the method of parallax will work.
- We assume that stars of the same spectral type – such as a B6 or a F3 – will have the same absolute brightness.
- If we see a B6 star which appears 1/100 times as bright as a B6 star of known distance, say 2 parsecs, we can deduce its distance to be $2 \times 10 = 20$ parsecs, as brightness falls as the inverse square.

Example of Spectroscopic Parallax

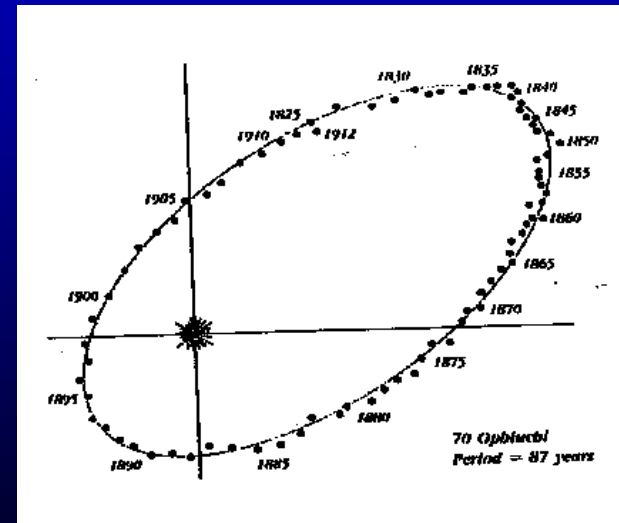
- A G4 type star lies at a distance of 4 parsecs and has an apparent magnitude of 8.
- A second G4 star has an apparent magnitude of 16.
- Brightness ratio is $2.512^8 = 1585$
- The relative distance is given by the square root of the relative brightness.
- Its distance will thus be $4 \times (1585)^{1/2}$
 $= 4 \times 39.8 = 159$ parsecs.

Stellar Masses

- This has been done with a step by step approach.
 - Find a binary system where the period is known and where one of the stars is a type G2 like our Sun. We assume that its mass is the same as our Sun.



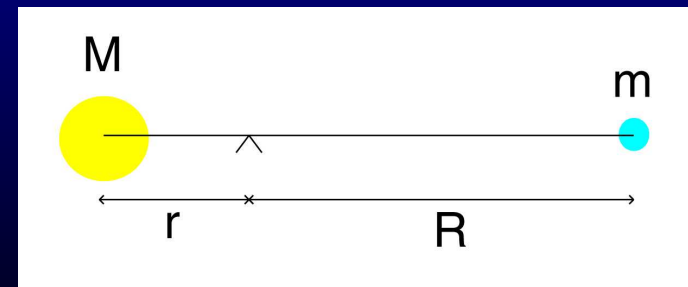
Images of Capella taken on the 13th (left) and 28th (right) September 1995. The separation between the stars is 55 milli-arcsec.



- Using Newton's revised form of Kepler's Third Law we can calculate the radii of the orbits of the two stars about their common centre of gravity.

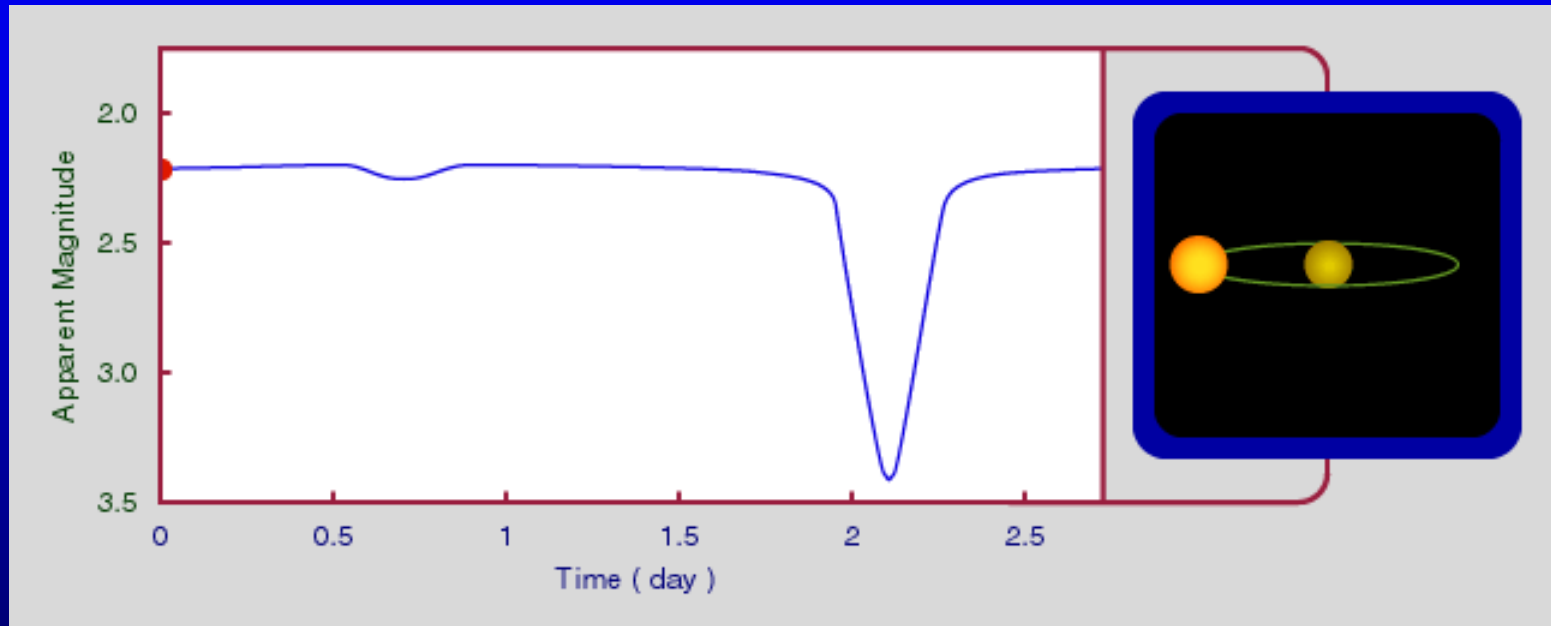
$$p^2 = \text{constant} / (M + m) \times R^3$$

- “balancing” about the centre of mass and assuming that we know M (initially the mass of our Sun)
 - $M r = m R$
 - So $m = 1 \times (r / R)$ Solar Masses.

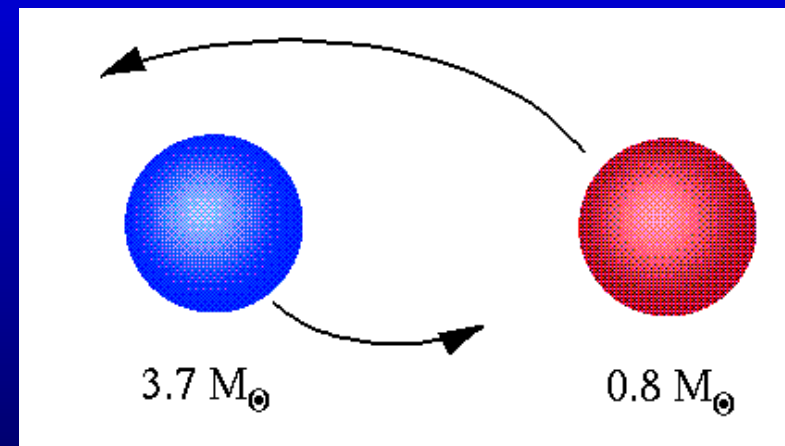
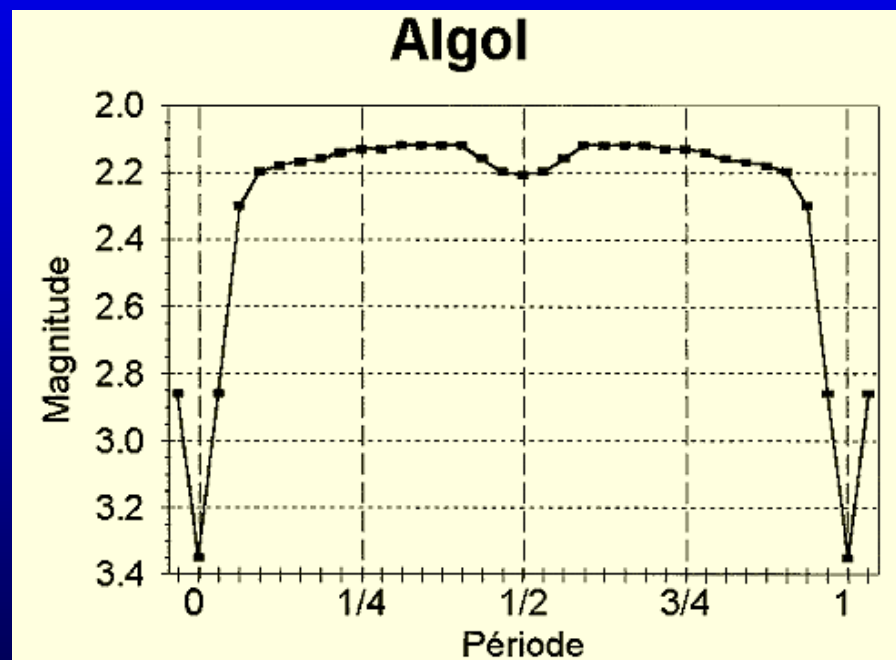


- Now, if we can find a binary system with a star of mass m in orbit around another star of unknown mass, we can deduce its mass too.
- In this way, through observations of stellar binary systems we have been able to find the masses of stars of different types.
- It turns out that the absolute brightness and mass of stars are related – more massive stars being brighter.
- The most massive stars are about 50 Solar Masses
- The least massive are $\sim 7\%$ the Sun's mass.

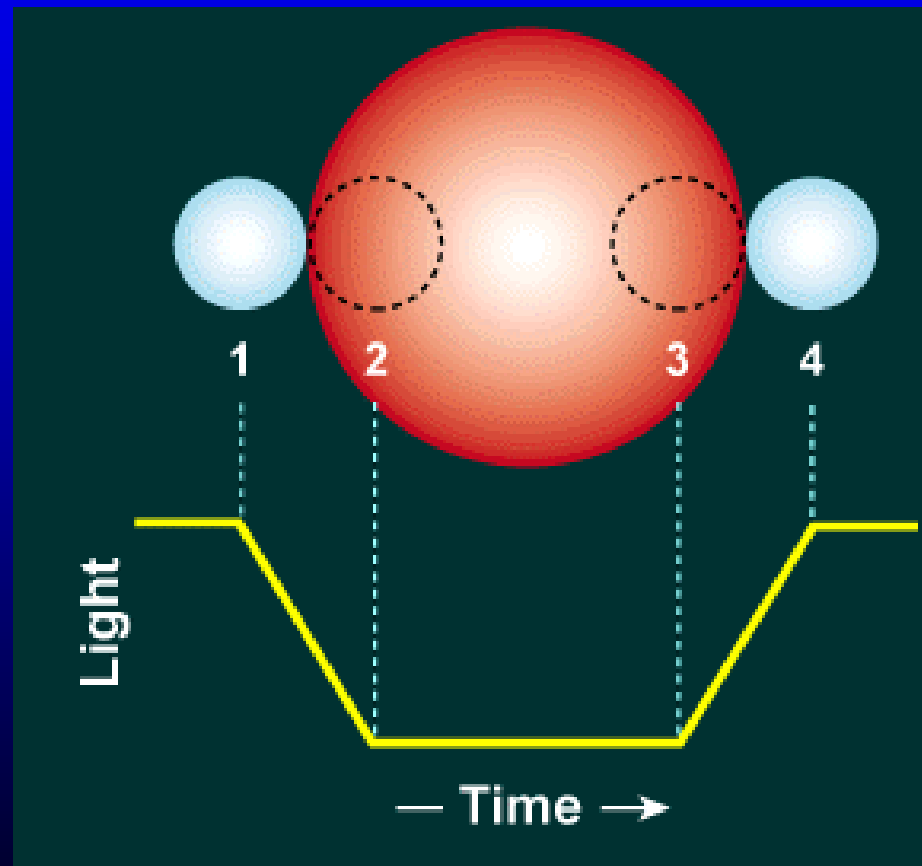
Eclipsing Binaries



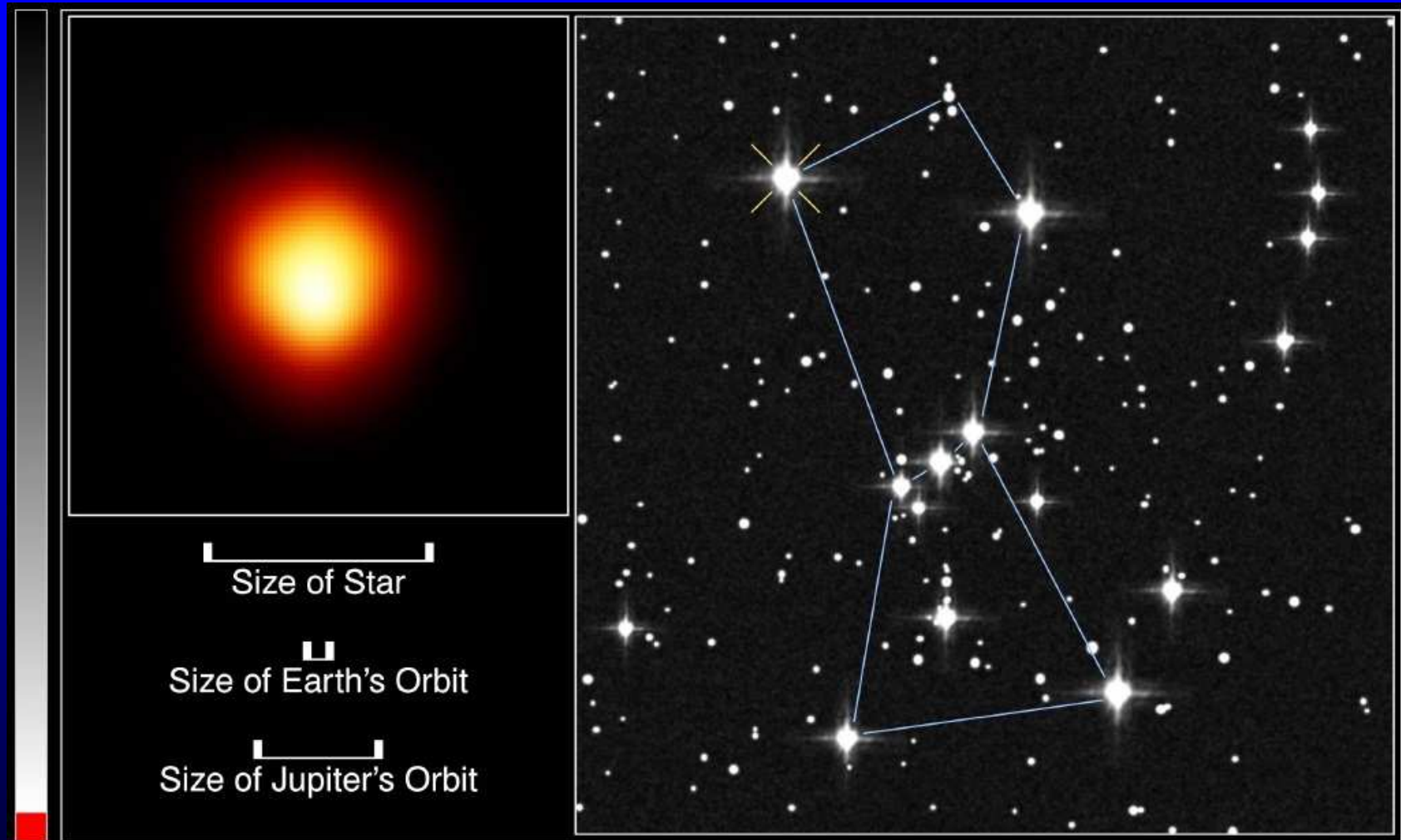
Algol



Can find diameters too



Stellar Sizes

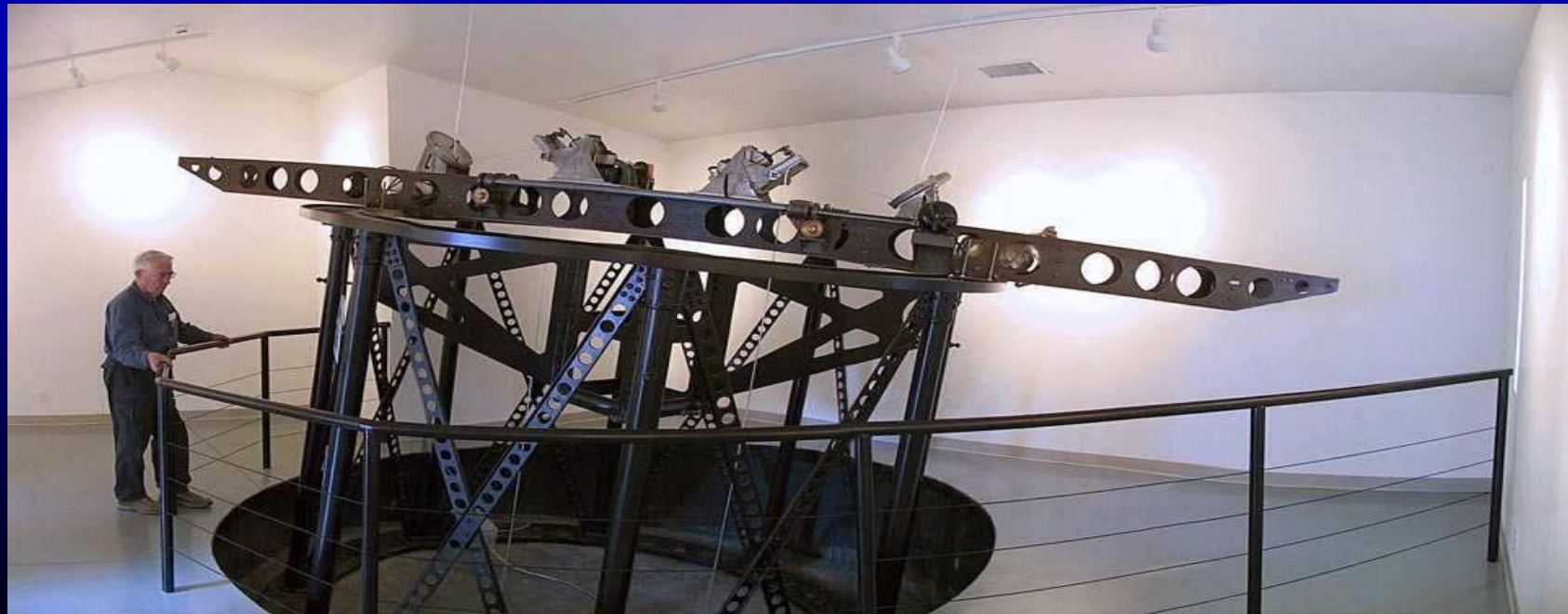


Atmosphere of Betelgeuse · Alpha Orionis

Hubble Space Telescope · Faint Object Camera

Michelson's Stellar Interferometer

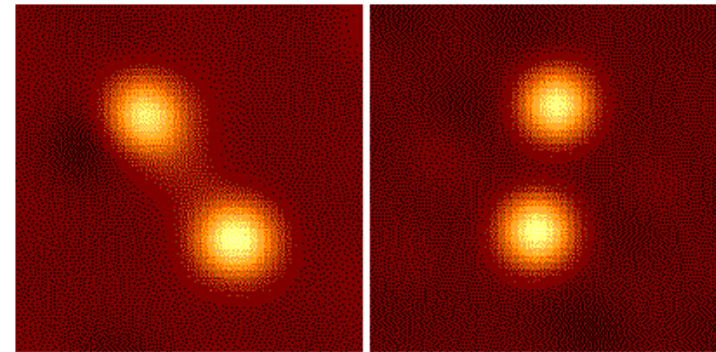
- Interferometers - using two or more separated optical telescopes can find the diameters of many stars.
- Michelson combined the light from 2 small mirrors above the 100" Mt Wilson Telescope.





COAST at Cambridge

- Interferometers can now image stars



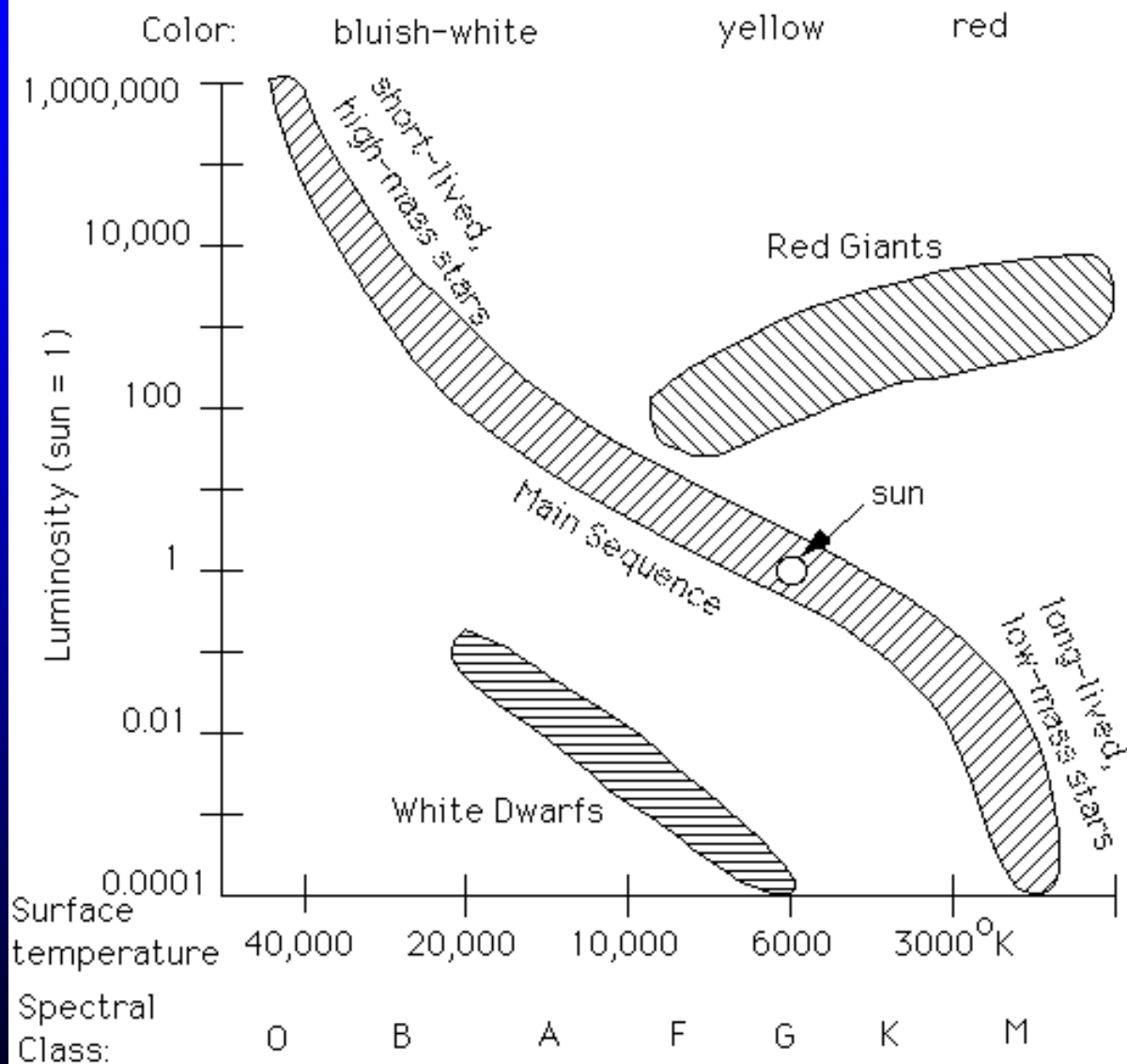
Images of Capella taken on the 13th (left) and 28th (right) September 1995. The separation between the stars is 55 milli-arcsec.

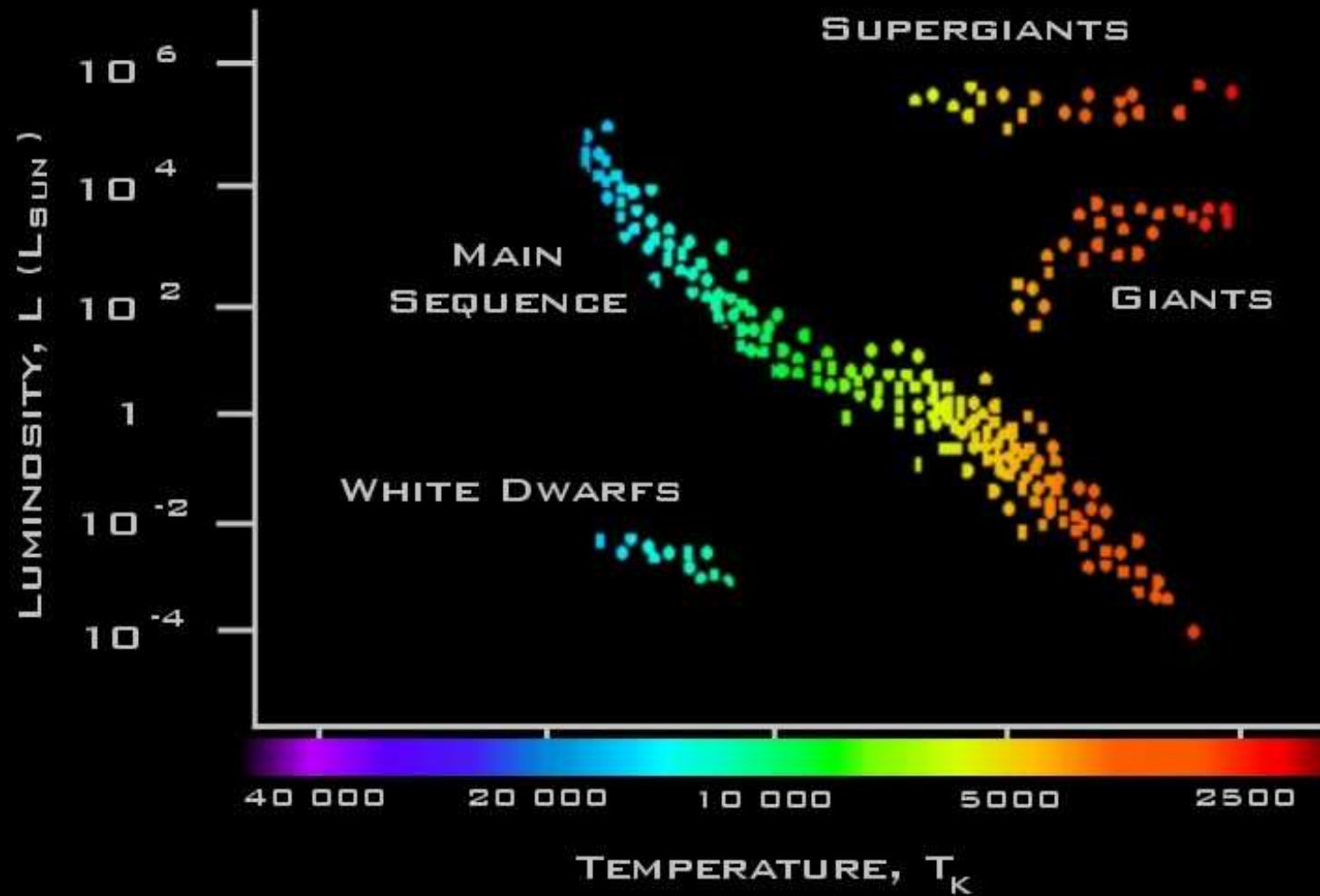
Hertzsprung-Russell Diagram

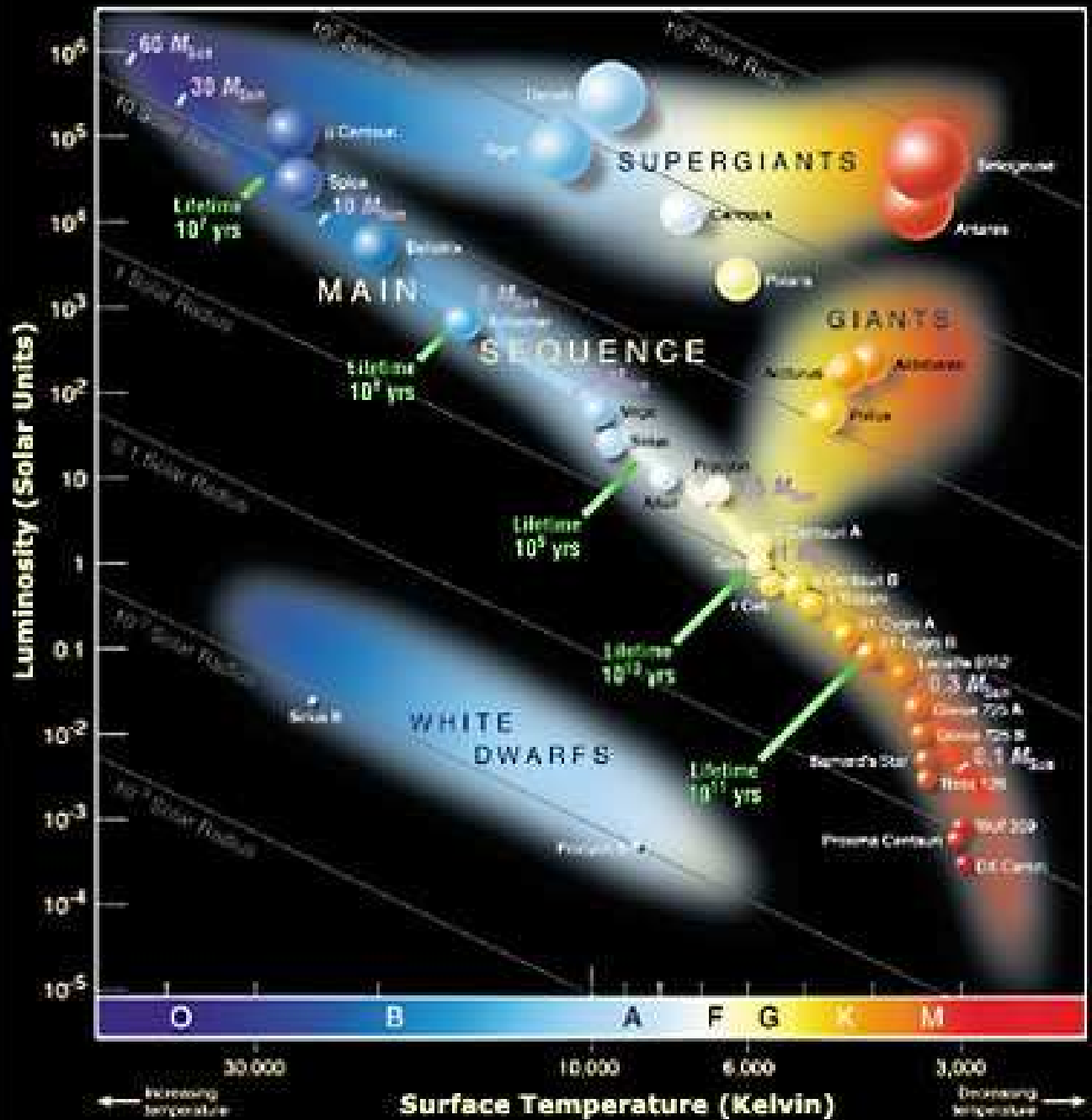
- In ~ 1910, Ejnar Hertzsprung and Henry Russell both independently plotted a new kind of graph :
- Surface Temperature of star (or spectral type) – x axis
- Luminosity of star (or Absolute Magnitude) - y axis

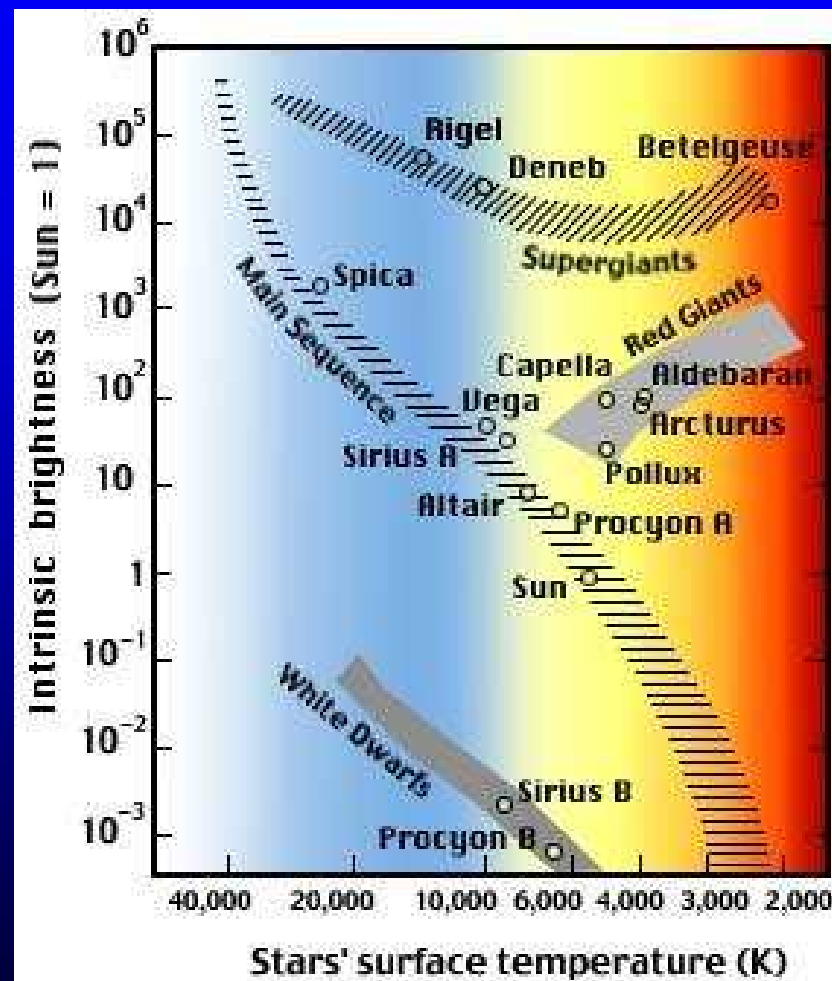
The H-R Diagram

Temperature-Luminosity Diagram









The Main Sequence

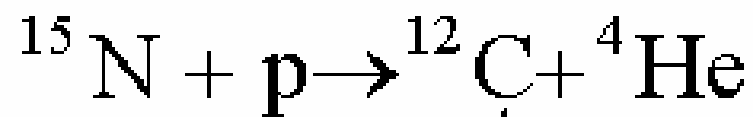
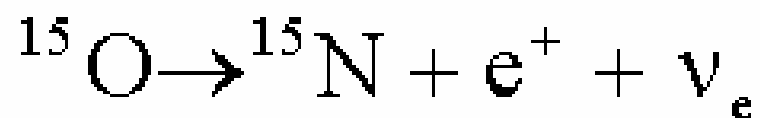
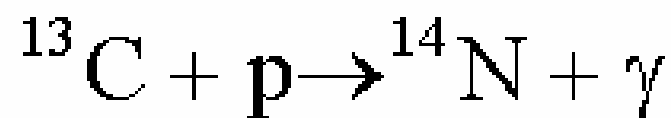
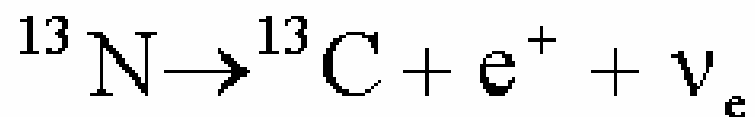
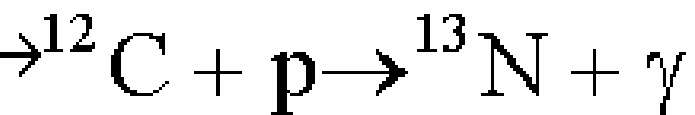
- Most stars lie on an “S” shaped region of the graph called the Main Sequence.
 - Faint, red, low mass, stars lie on the lower right. These are called Red Dwarfs.
 - Bright, yellow, medium mass stars lie in the centre. Called Yellow Dwarfs.
 - Very Bright, blue, high mass stars lie on the upper left called Blue Giants.

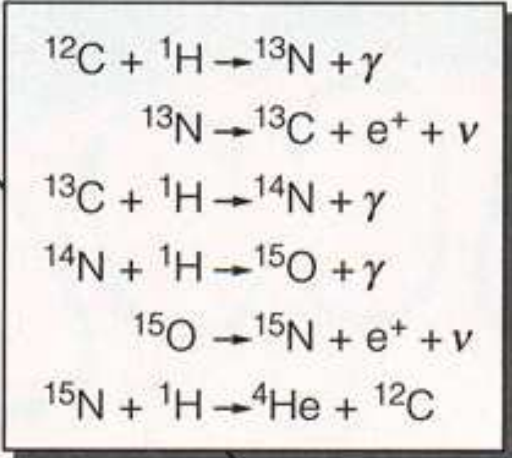
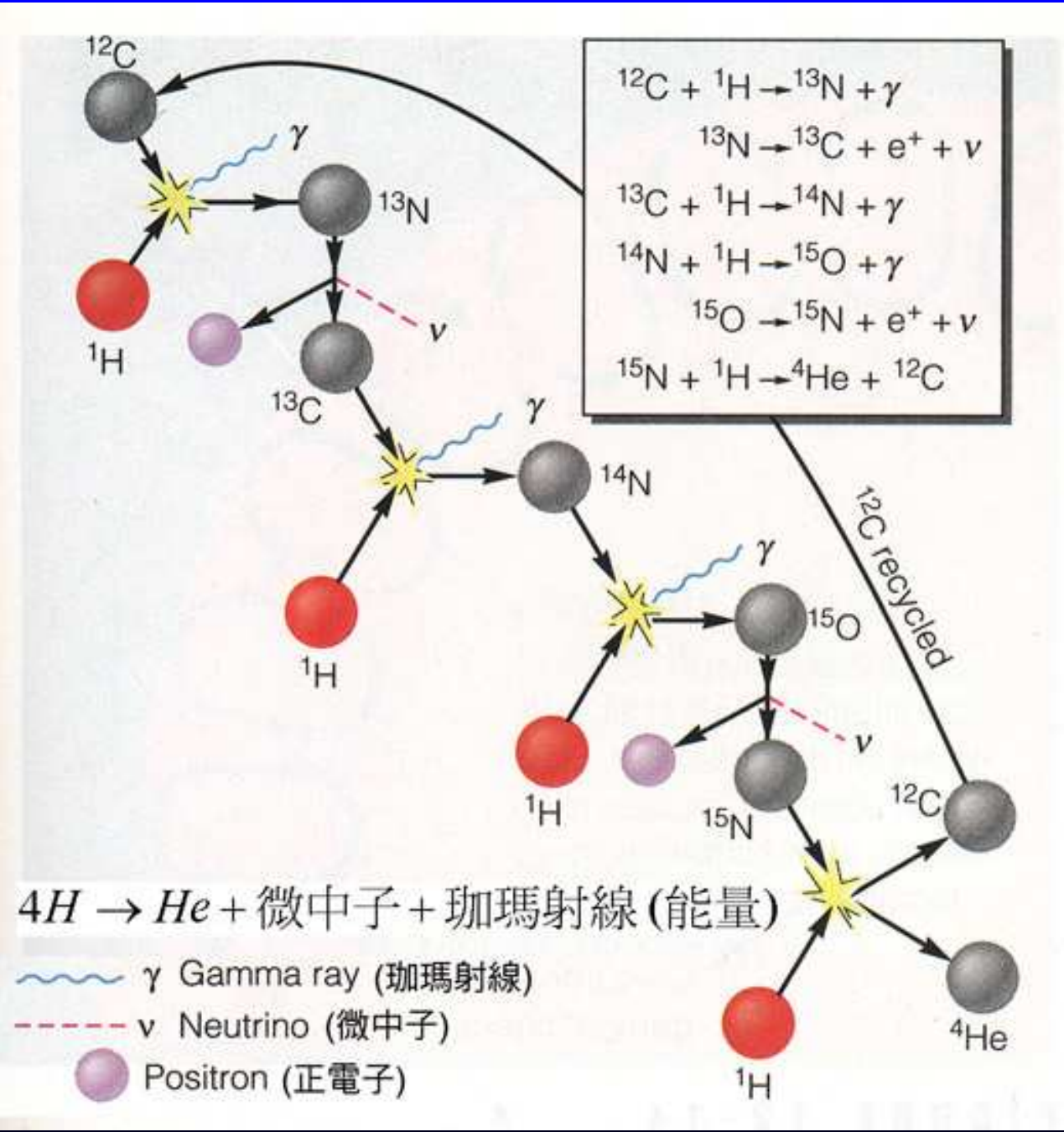
What does this tell us?

- Most stars are seen to lie on the Main Sequence.
 - This is because stars spend the major part of their life in the region of the main sequence
 - During this period they are burning Hydrogen into Helium in their cores.
 - Their position in the main sequence is dependant on their mass (more massive at the upper left).
 - During their life they become somewhat hotter and move up to the left.
 - Our Sun is now ~ 20% hotter than when it first became a main sequence star.




Faster Hydrogen Burning

- The pressure at the centre of massive stars has to be higher to support the extra mass.
- This requiring higher central temperatures.
- The central temperatures can reach 30,000,000K
 - (about twice that of our Sun)
- This higher temperature allows a very efficient process to take place to convert Hydrogen to Helium:
 - The CNO Cycle **Carbon-Nitrogen-Oxygen cycle.**
 - Carbon acts as a catalyst.





$4H \rightarrow He + \text{微中子} + \text{伽瑪射線 (能量)}$

-  γ Gamma ray (伽瑪射線)
-  ν Neutrino (微中子)
-  Positron (正電子)

Their Lifetimes on the Main Sequence

- You have seen that the Luminosity of a star like Rigel is 45,000 times that of our Sun.
 - It thus burns its Hydrogen fuel 45,000 time faster.
 - But its mass (= fuel supply) is only ~ 17 times that of our Sun.
 - So its life cannot be so long:
 - ~ $17/45,000$ that of our Sun *****
 - ~ = $1/1125$
- Thus its life will be ~ $10,000,000,000 / 1125$ yrs
= ~ 9 Million yrs
(The lifetime of a 1 solar mass star is ~10 billion yrs)

Evolution off the Main Sequence

- In the latter stages of their life stars evolve into the upper right part of the diagram to form Red Giants or Red Supergiants (cool surface, so at right, but very large - so very bright).
- The end state of many stars similar to our Sun are white dwarfs which lie in the lower left of the diagram (hot - so at left, small - so faint).
- We will look at this in the next section of the course.