Properties of Stars

- For such huge objects, stars have comparatively simple properties when seen from a long way off
  - apparent magnitude
  - distance – and direction in space
  - luminosity - absolute magnitude
  - temperature - spectral class
  - diameter
  - single, binary or multiple
  - mass
  - motion (*covered in a later section of the course*)

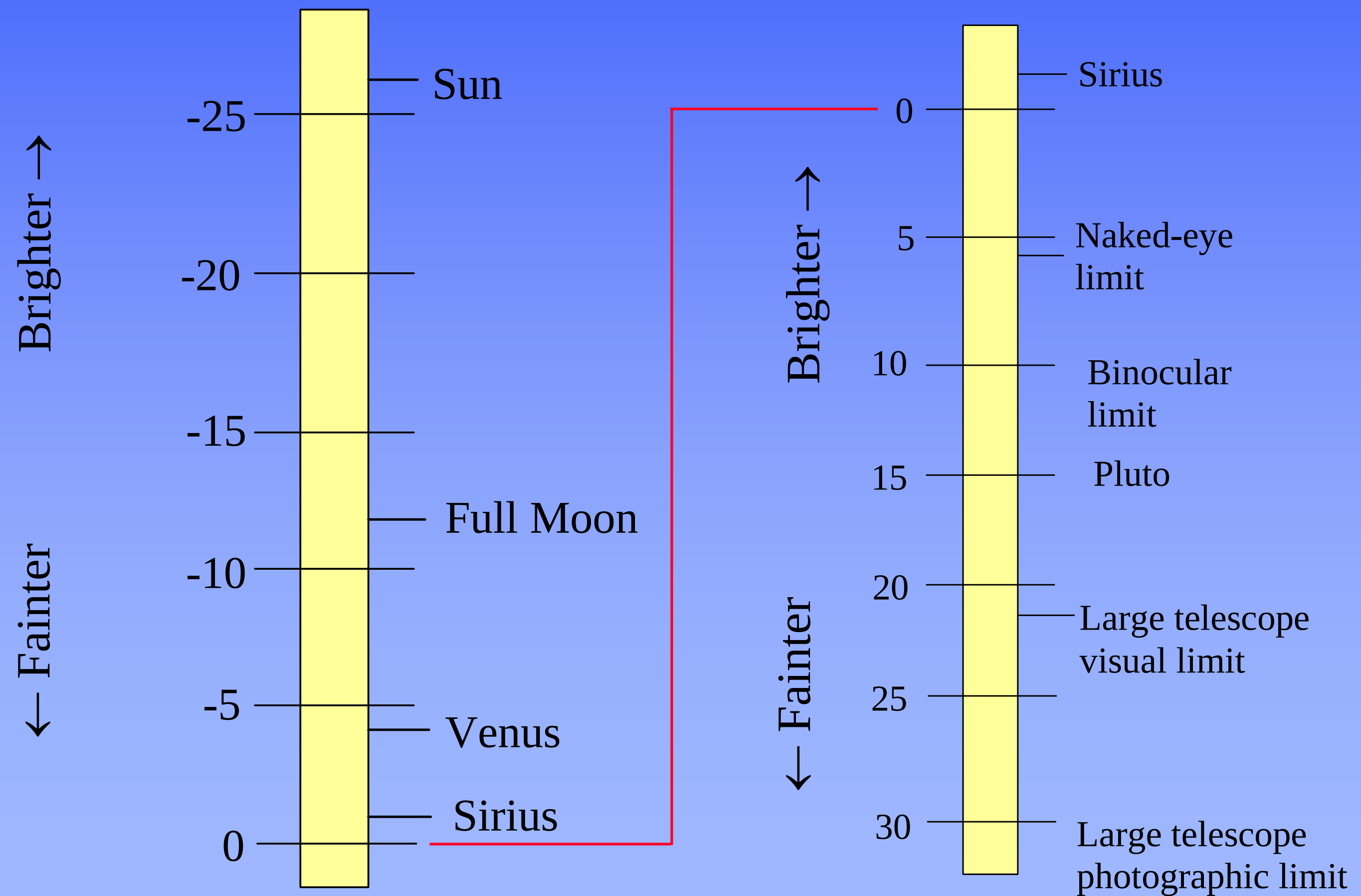
Measuring Stars

- *Luminosity* - total power output of star in **watts**
- *Apparent Magnitude* - brightness observed. This depends on:
  - luminosity of the star
  - distance of the star
  - presence of absorbing interstellar matter between us and the star
- Hipparchus (about 150 BC) originated the division of stars into classes, from first magnitude to sixth magnitude

Apparent Magnitude, m

- The modern magnitude scale is based on measurements of the amount of light received from a star (or object)
- One step in the scale involves a change in amount of light of 2.512. 5 steps involve a change of exactly 100 (i.e. 2.512^5)
  - magnitude 0 is one step brighter than first magnitude; magnitude -1 is one step brighter than magnitude 0. Brightest star, *Sirius*, has magnitude -1.47; weakest telescopic object, approximately magnitude 34

Range of Apparent Magnitudes

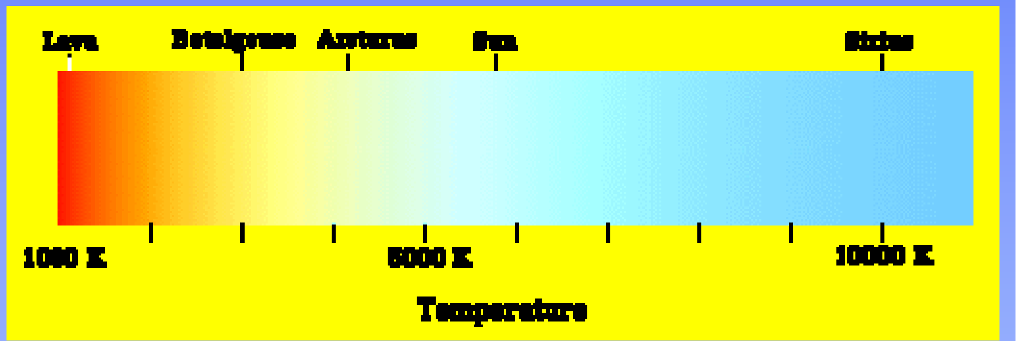


Magnitude Comparisons

- e.g. *Procyon*, is a double star. One component is a white dwarf of magnitude 10.5; the main component has magnitude 0.5. *What is the ratio of light received from the 2 components?*
  - number of brightness steps = 10.5 - 0.5 = 10
  - ratio of brightness = $2.512^{10} = 100^{2} = 1\times10^{4}$
- *Regulus* has an apparent magnitude of 1.36. *How much more light from Sirius reaches us?*
  - number of brightness steps = 1.36 - (-1.47) = 2.83
  - ratio of light received = $2.512^{2.83} = 13.55$

Stellar Temperatures

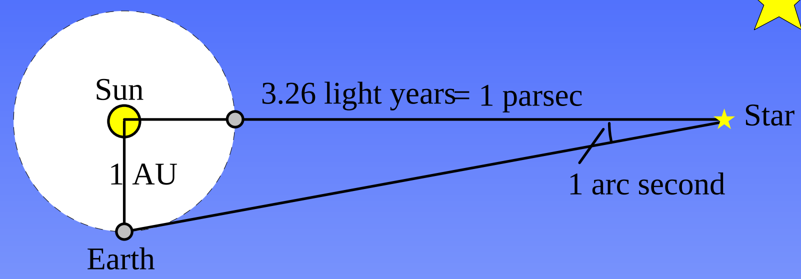
- Hot stars emit more in the blue than in the rest of the spectrum. Cool stars emit less in the blue
  - measure the apparent magnitude through a blue filter and call it **B**
  - measure the apparent magnitude through a yellow filter, representing what our eyes see; call it **V** (visible)

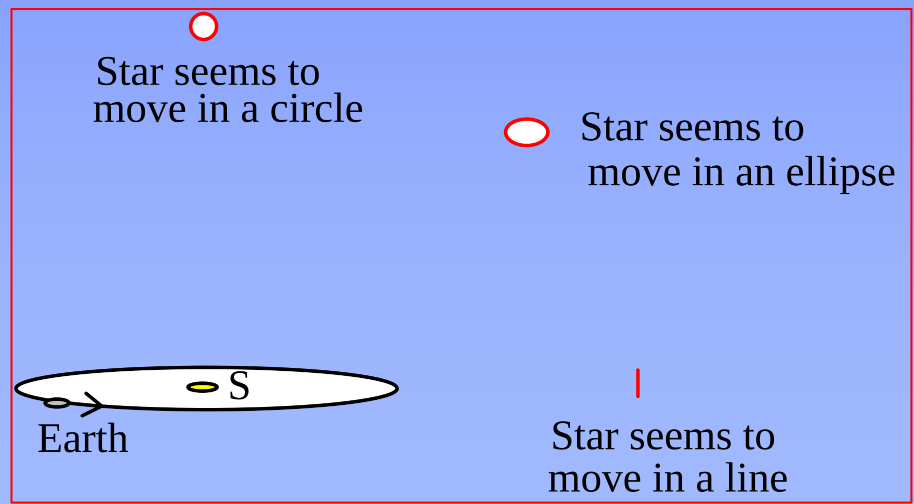


- **B - V** is called the *colour index* and is a measure of the temperature of the star. **B - V** = - 0.3 for a hot star; **B - V** = +1.2 for a cool star

Stellar Parallax

- The *parallax angle* is the maximum difference in angle you sight on a star when your position changes by 1 AU
- When the parallax angle is one arc second, the star is *1 parsec* distant. *Parsec*, abbreviated *pc* ≡ 3.26 LY





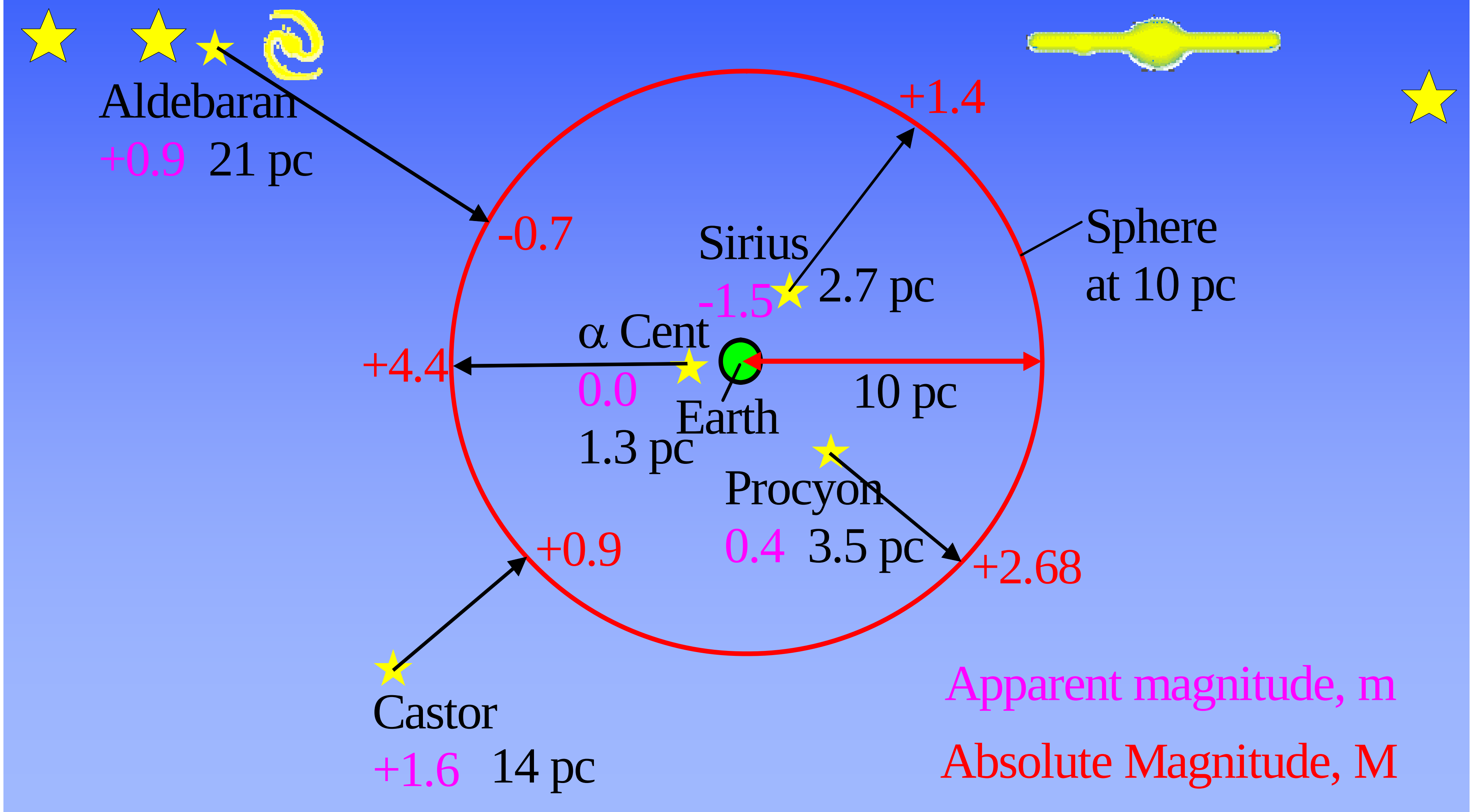
Stellar Distances

- Measuring stellar parallax is the most accurate method of finding the distance of stars
  - if you can measure parallax to 0.01" arc, you can measure distances to 100 *pc*
- The *Hipparcos* satellite measured parallax to 0.001" and has measured the distance of 120,000 stars. (0.001" is the angular size of a golf ball at the other side of the Atlantic)

Absolute Magnitude, M

- The amount of light from a star decreases as the square of its distance from us (the inverse square law of radiation – more on this later)
- *Distance*, *apparent magnitude* and *luminosity* are therefore related. If you know any two, you can calculate the third
- Astronomers use as a measure of the luminosity the magnitude of the star *if it were at 10 pc*. This is called the **absolute magnitude**, denoted M

Absolute Magnitude Sketch

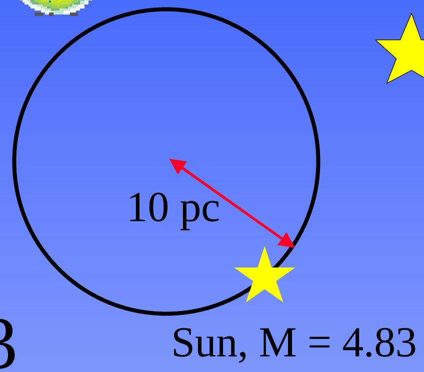


Absolute Magnitude Example

- *Procyon* is 11.4 LY (light years) distant and has an apparent magnitude of 0.4. *What is its absolute magnitude?*
- 11.4 LY = 11.4/3.26 *pc* = 3.50 *pc*
  - at 10 *pc* distance, light would be reduced by a factor $(10/3.50)^2 = 8.163$
  - hence magnitude would change by x, where $2.512^x = 8.163$ or $x = \log(8.163)/\log(2.512) = 2.28$
  - therefore absolute magnitude M is 0.4 + 2.28 = 2.68

Luminosity & Absolute Magnitude

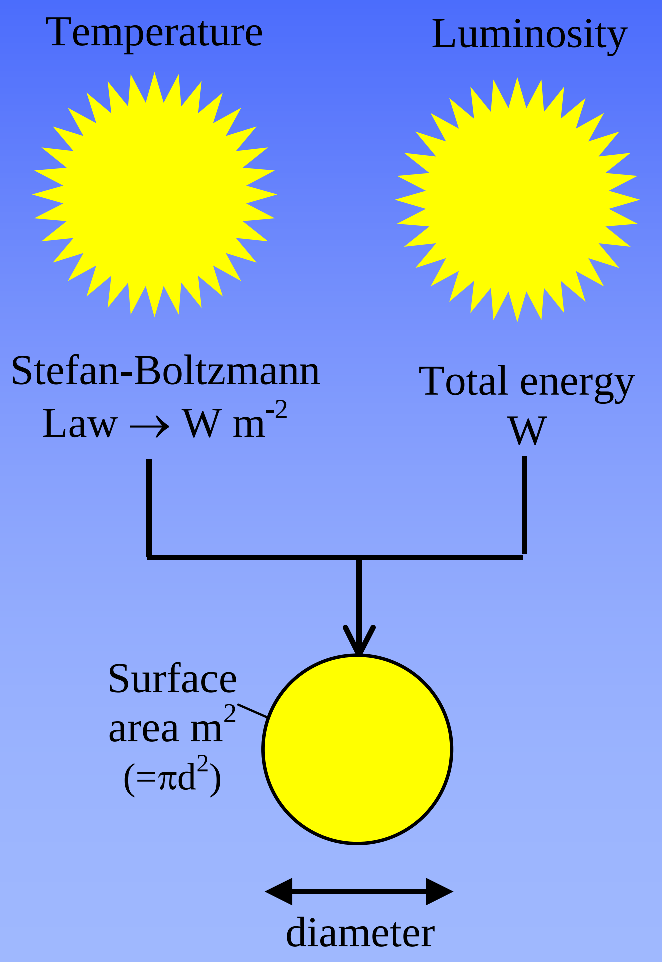
- The Sun provides the link between luminosity and absolute magnitude
  - the absolute magnitude of the Sun is 4.83
  - its luminosity is 3.9×10^{26} W



- Absolute magnitude (M) $\rightarrow$ Luminosity (L)
  - e.g. Aldebaran has M = -0.7, what is its luminosity?
    - Magnitude difference from Sun = 4.83 – (-0.7) = 5.53
    - Hence extra light compared with Sun = $2.512^{5.53}$ =163
    - $\therefore$ luminosity of Aldebaran = $163 \times 3.9 \times 10^{26} = 6.4 \times 10^{28}$ W

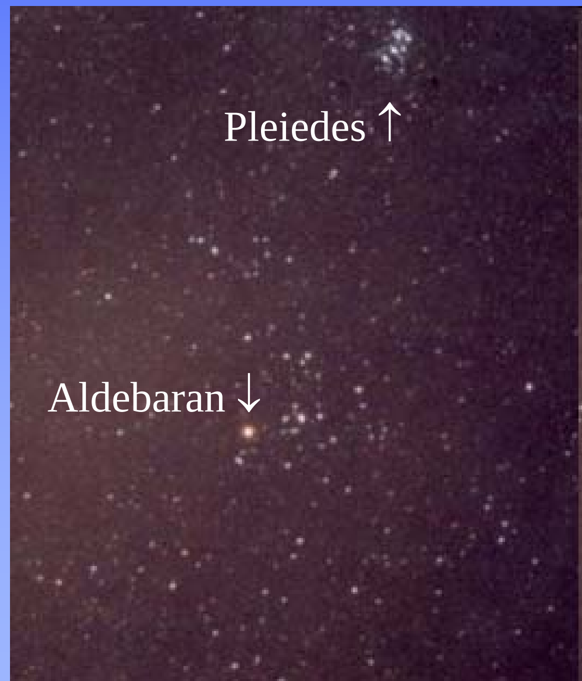
Temperature & Luminosity → Stellar Diameter

- From **temperature** and **luminosity**, a star’s diameter can be deduced
- A correction for the fraction of the total radiation that is visible light needs to be made.



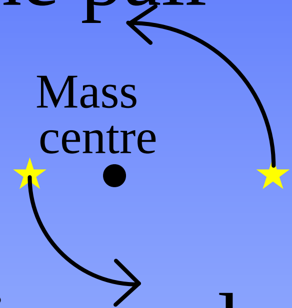
Stellar Diameter Calculation

- Aldebaran: T = 3950 K; L = 6.4×10^{28} W
- Stefan-Boltzmann law
  - $\sigma \times 3950^4 = 13.8 \times 10^6$ W m^{-2}
- Hence area, A
  - $(6.4\times10^{28}/13.8\times10^{6}) = 4.64\times10^{21}$ m^2
- Diameter from $A = \pi d^2$
  - $d = 3.84\times10^{10}$ m
- A correction needs to be made because for a cooler star a smaller fraction of the radiation is light



Binary Stars

- A binary star is a pair of stars that orbit each other about a common centre of mass. The pair obey Kepler's laws



- *Visual binaries* can be seen in motion
- For visual binaries, the period of revolution and size of orbit gives the total stellar *mass* from Kepler's 3rd law. From the ratio of distances of the two stars from their centre of mass, the individual masses can be deduced

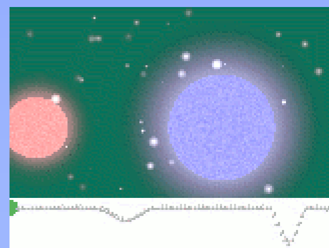
Motion of 61 Cyg

- This animated gif shows the motion (down and right) of the binary pair 61 Cyg relative to background stars and the slight rotation of the pair over a time-span of 35 years
  - their period is 653 years
  - separation ~85 AU

Courtesy:
http://www.solstation.com/stars/61cygni2.gif

Eclipsing Binaries

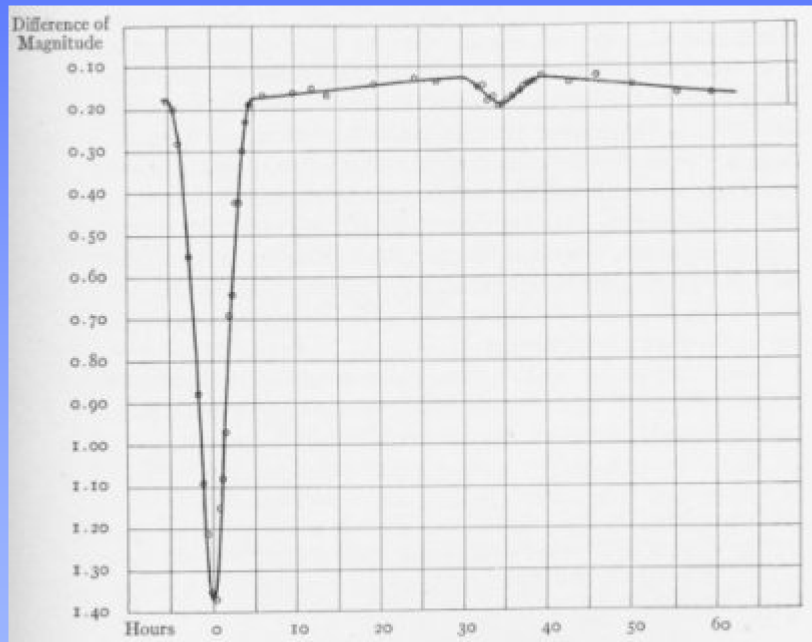
- Binary groupings can be deduced even when the individual stars cannot be separated
- An *eclipsing binary* is a pair of stars where one passes in front of the other in our line of sight. From the time taken for each eclipse, the *diameters* of the stars can be deduced
  - if the stars are too close together to visually separate, then you see one star winking
    - Algol is a famous example



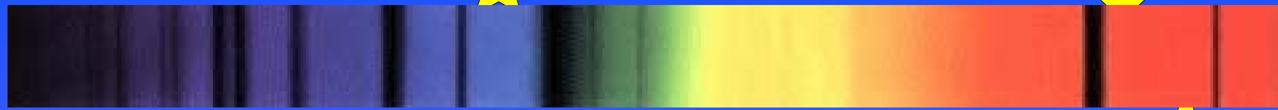
Animation courtesy: http://commons.wikimedia.org/wiki/Image:Eclipsing_binary_star_animation_2.gif

Algol (the eye of Medusa's head in Perseus)

- Algol eclipses every 2.87 days
- The Earth is in the same plane as the orbiting stars
- A small bright star orbits a large dull star
- The main eclipse is when the bright star goes behind the dull star

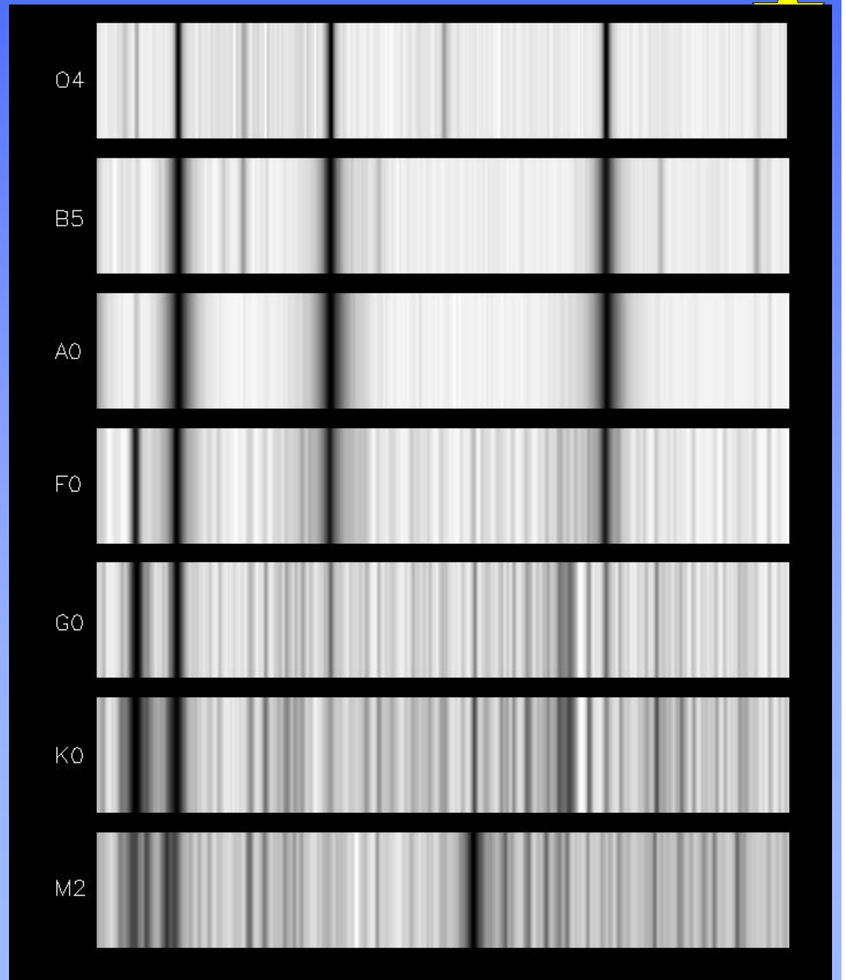


Courtesy:
http://www.astro.uiuc.edu/~kaler/sow/algol.html



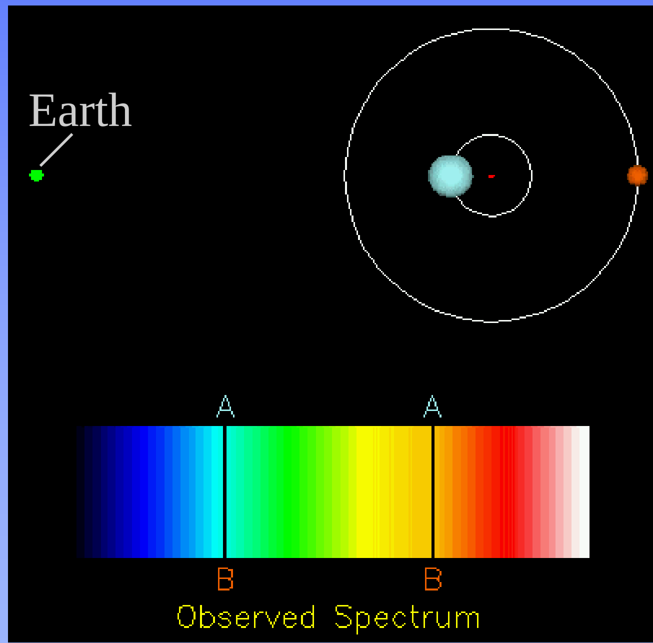
Stellar Spectra

- The light spectrum of a star shows characteristic bright and **dark** spectral lines
  - the dark lines are due to absorption by chemical elements in the photosphere
  - the bright lines are due to emission in the outer layers



Spectroscopic Binaries

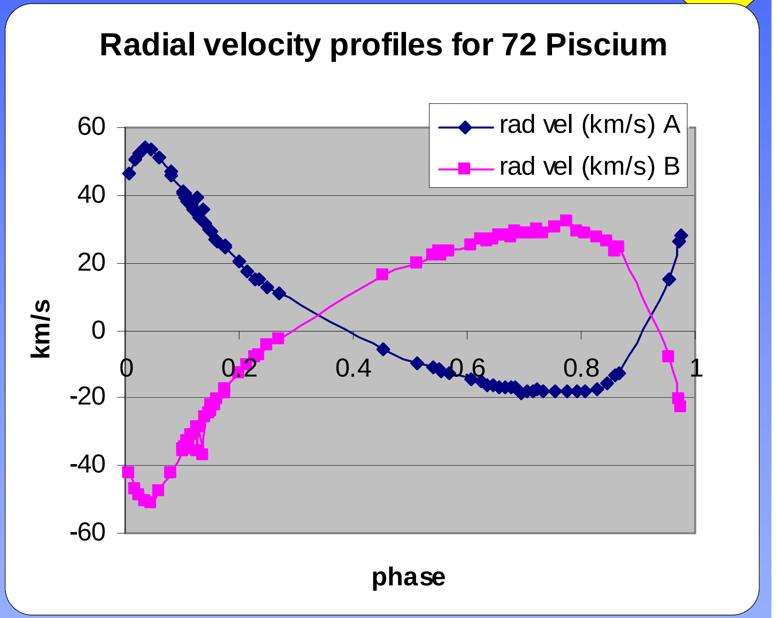
- *Spectroscopic binaries* can be detected at any distance
- Spectral lines shift in position with radial velocity of the star
  - *red shift* takes place when a star moves away, *blue shift* when it approaches
- Binary stars can show double lines



Animation courtesy Ohio-State Univ

Deductions from Spectroscopic Binary Stars

- Unless the two components are of comparable magnitude, only the brightest is seen
  - the motion of the spectral lines shows the presence of an unseen binary component
- The radial velocity curve(s) can be plotted. From these and the period:
  - the orbital eccentricity
  - the ratio of the masses
  - the sum of the masses and orbital sizes, within an inclination factor



Period 50.4 days; mass ratio 1.1; e = 0.5

Spectral Classes

- The spectra of many stars ranked in order of temperature fall into distinctive classes
- These are labelled **O B A F G K M**
- Each class is subdivided into 10. Our Sun is a **G2** star