

## Lecture 13: The stars are suns

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- Connection between the sun and the stars:  
Stars are fusion reactors like our sun, with similar physical properties. Spectroscopes, atomic theory, and especially measurements of stellar distances (1838) made it possible for astronomers to derive properties of stars and establish the Sun-stellar connection.
- Physical properties of stars we want to know:
  1. How much energy do stars emit? Luminosity  $L$  (flux, distance)
  2. How hot are they ? Surface temperature  $T$  (spectroscopic analysis)
  3. How big are they? Radius  $R$  (surf. temp., luminosity)
  4. What are stars made of? Chemical composition (spectroscopic analysis)
  5. How much mass stars contain ? Mass (next lecture)
- How do we find this out ?  
Apart from the Sun, all other stars are normally unresolved – just points of lights. But we can measure: Apparent brightness  $f$  and Spectrum: continuum emission tells us about surface temperature and dark lines tell us about the surface composition.
- Apparent Brightness or Flux ( $f$ )  
is measured in watts per  $\text{m}^2$ . Flux from the Sun (at the Earth) =  $1.4 \text{ kW}/\text{m}^2$ . Flux from Sirius (at the Earth) =  $1/10^7 \text{ W}/\text{m}^2$ . Flux (Sun) = 10 billion x Flux (Sirius).
- Historically astronomers measure the brightness of stars in magnitudes.  
Magnitude system was invented by Hipparchus (190-120 BC) – he ranked stars by their apparent brightness from ‘first magnitude’ (brightest) to ‘sixth magnitude’ (dimpest). Bright stars have low magnitudes (measure of faintness). A difference of 5 magnitudes corresponds to a factor of 100 in brightness - e.g. a 6th magnitude star is 100 times fainter than a 1st magnitude star. Flux and magnitude are related with:

$$\frac{f_A}{f_B} = (2.512)^{(m_B - m_A)}. \quad (1)$$

- Apparent brightness is not a measure of the luminosity (in watts) of a star. Star of given brightness could be: dim but close, or luminous and distant.
- Inverse Square Law for light tell us that the flux is inversely proportional to the distance squared:

$$f = \frac{L}{4\pi d^2} \quad (2)$$

- Therefore, star’s Luminosity can be calculated from:  $L = f \times 4\pi \times d^2$ . But we need distance! Historically, measuring distances to astronomical objects has been one of the toughest tasks in astronomy – for nearby stars it can be done by measuring the parallax.
- Heliocentric or Trigonometric Parallax  
Pencil example: the amount by which the pencil appears to shift when we view it from two different

angles depends on how far the pencil is from our eyes. So, we measure the angular shift (= parallax) and estimate the distance to the pencil or star. When we observe the same star after 6 month, looking from the opposite side of the Earth's orbit around the Sun, the star appears to have moved against the backdrop of distant stars as the Earth orbits the Sun.

$$d(\text{pc}) = \frac{1}{p(\text{arcsec})} \quad (3)$$

- Parallax decreases with distance.
- First stellar parallax was measured in 1838 by Friedrich Bessel. From the Earth we can measure parallax of stars that are less than 300 ly (92 pc) away. Distances to 10,000 stars have been measured this way. 1989-1993: Hipparcos satellite measured parallax for 120,000 stars, maximum distance: a few  $\times 10^3$  pc. In 2011: Gaia will measure parallax for 1 billion stars.
- Back to Stellar Luminosity: we have  $f$  and  $d$  and can calculate  $L$ .  $L = f \times 4\pi \times d^2$ . For example:  $f(\text{Sun}) = 10 \text{ billion} \times f(\text{Sirius})$ , and Distance to Sirius is 2.63 pc = 8.6 ly = 543,000 AU. Therefore,

$$\frac{L(\text{Sirius})}{L(\text{Sun})} = \frac{f(\text{Sirius}) \times 4\pi \times (543,000 \text{AU})^2}{10^{10} f(\text{Sun}) \times 4\pi \times (1 \text{AU})^2} \sim 30. \quad (4)$$

Sirius is 30 times more luminous than the Sun.

- Typical stellar luminosities:  
The range of stellar luminosities is very large. The most luminous stars have  $L = 10^5 \times L(\text{Sun})$ . These are bright supergiants. The least luminous stars have  $L = 10^{-4} \times L(\text{Sun})$ . These are dwarfs (class on Wednesday).
- Surface temperature:  
stars radiate like blackbodies and Wien law tell us that the higher the temperature, the shorter the peak wavelength  $\rightarrow$  we measure  $\lambda_{max}$ , derive  $T$  using:

$$\lambda_{max} = \frac{3 \text{ mm}}{T(\text{K})} \quad (5)$$

- Stefan-Boltzmann law tells us that the total amount of power emitted by every square meter of the blackbody,  $F$ , depends only on the surface temperature  $T$ :

$$F = 5.67 \times 10^{-8} T^4 \text{W/m}^2 \quad (6)$$

Then, the total luminosity (summed up over star's surface area) that star emits, depends on star's radius  $R$  and temperature  $T$ :

$$L = 4\pi R^2 F = \text{const.} \times R^2 T^4. \quad (7)$$

But we don't need to worry about constants if we express everything relative to the Sun:

$$\frac{L}{L(\text{Sun})} = \left( \frac{R}{R(\text{Sun})} \right)^2 \times \left( \frac{T}{T(\text{Sun})} \right)^4. \quad (8)$$

If we know temperature and luminosity we can use this last equation to calculate stellar radius  $R$ .