



DARA Basic Training

NAMIBIA-BOTSWANA 2019

UNIT 1: INTRODUCTION TO ASTROPHYSICS

Windhoek, 7 –18 January 2019

H-R Diagrams

- H-R diagrams
- Stellar masses and range
- Main sequence lifetime
- Stellar evolution

Hertzsprung-Russell Diagrams

- stars plotted on a graph of either:

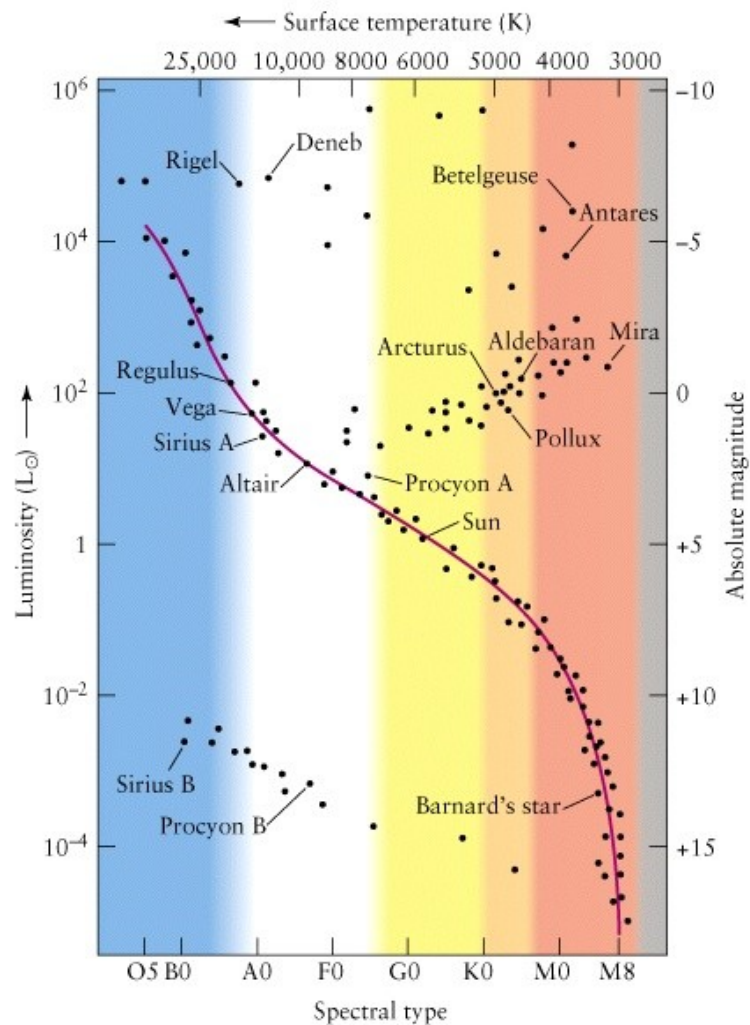
M_v versus Sp. Type

or

L versus T_{eff}

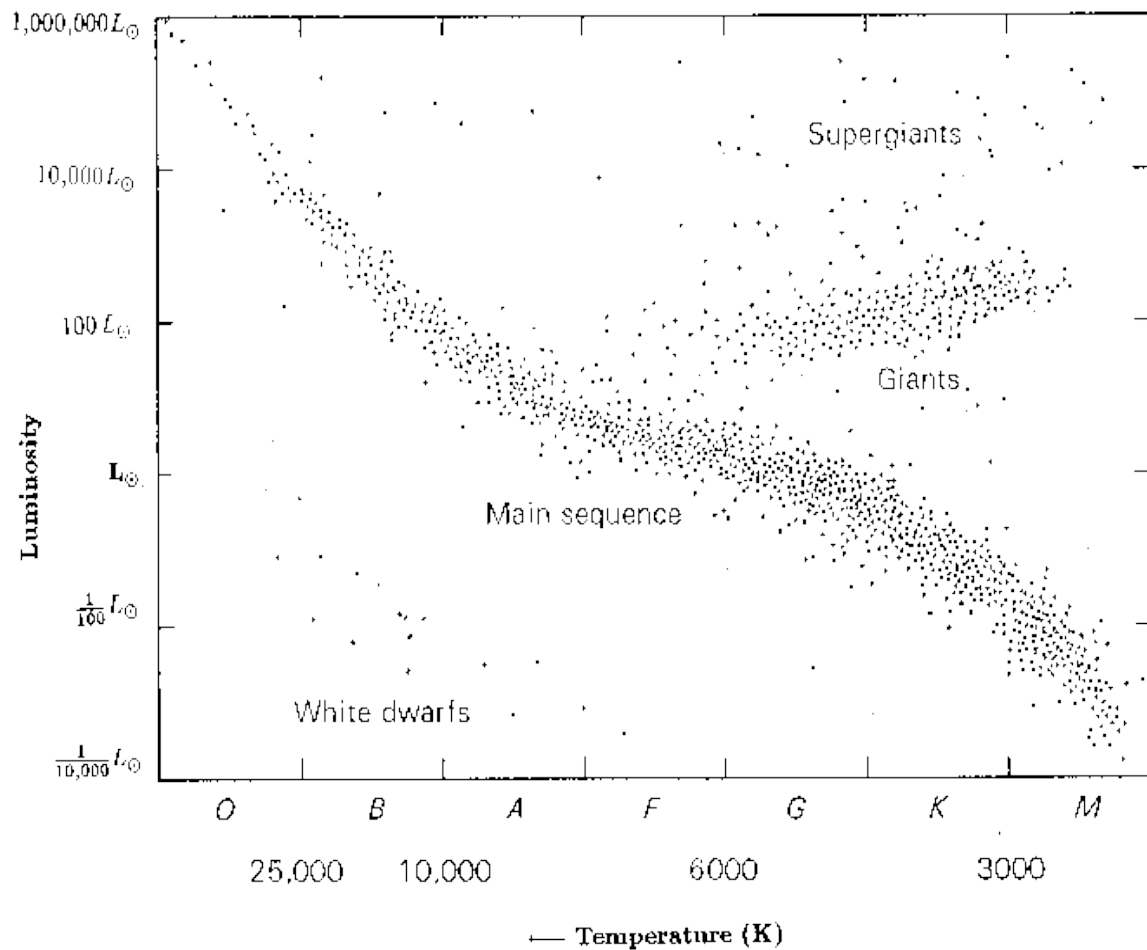
reveal a very distinctive pattern

- (in general need to know distance)
- these plots are called Hertzsprung-Russell diagrams or H-R diagrams for short



H-R diagram for some bright stars

Hertzsprung-Russell Diagram for Stars in the Solar Neighborhood



Locations on the H-R diagram

- most stars lie on a locus called the main sequence (MS)
- others are red (cool) and lie above the MS and are called red giants (RGs)
- a band of stars lie across the top called supergiants (SGs)
- others are blue (hot) and lie below the MS and are called white dwarfs (WDs)

Class Example

- How many times larger is a late M type red giant ($T_{\text{eff}}=3000\text{ K}$) with $L=10^2 L_{\odot}$ than a main sequence red dwarf with $L=10^{-4} L_{\odot}$ and the same T_{eff} ?

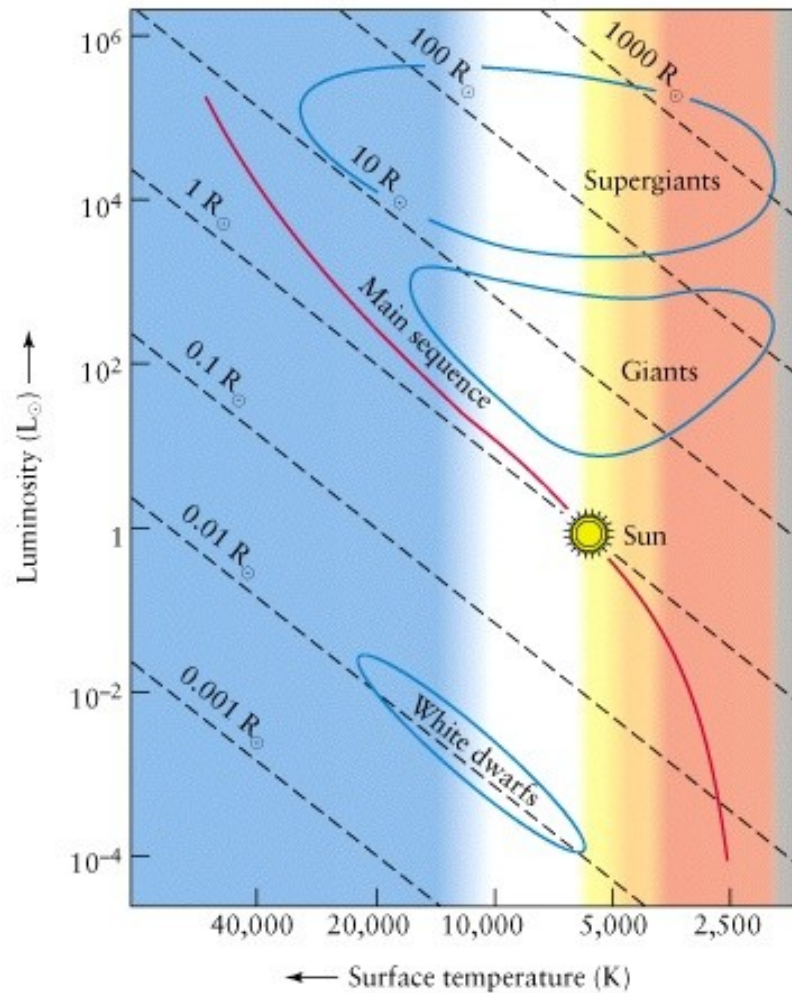
$$L = 4\pi R^2 \sigma T_{eff}^4$$

$$L \propto R^2 T_{eff}^4$$

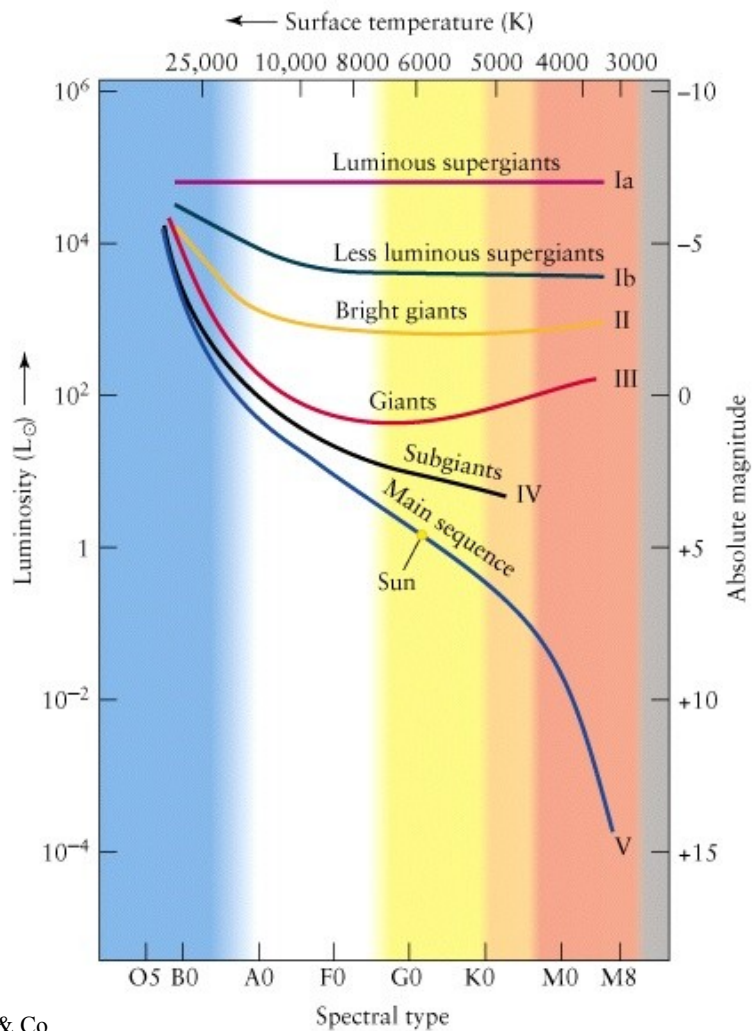
$$\frac{L_{RG}}{L_{RD}} = \left(\frac{R_{RG}}{R_{RD}} \right)^2 \left(\frac{T_{RG}}{T_{RD}} \right)^4$$

$$T_{RG} \approx T_{RD}$$

$$\begin{aligned} \frac{R_{RG}}{R_{RD}} &= \left(\frac{L_{RG}}{L_{RD}} \right)^{\frac{1}{2}} \\ &= \left(\frac{10^2}{10^{-4}} \right)^{\frac{1}{2}} = 10^3 \end{aligned}$$



© Universe, W H Freeman & Co. Sizes of stars in different locations on the H-R diagram



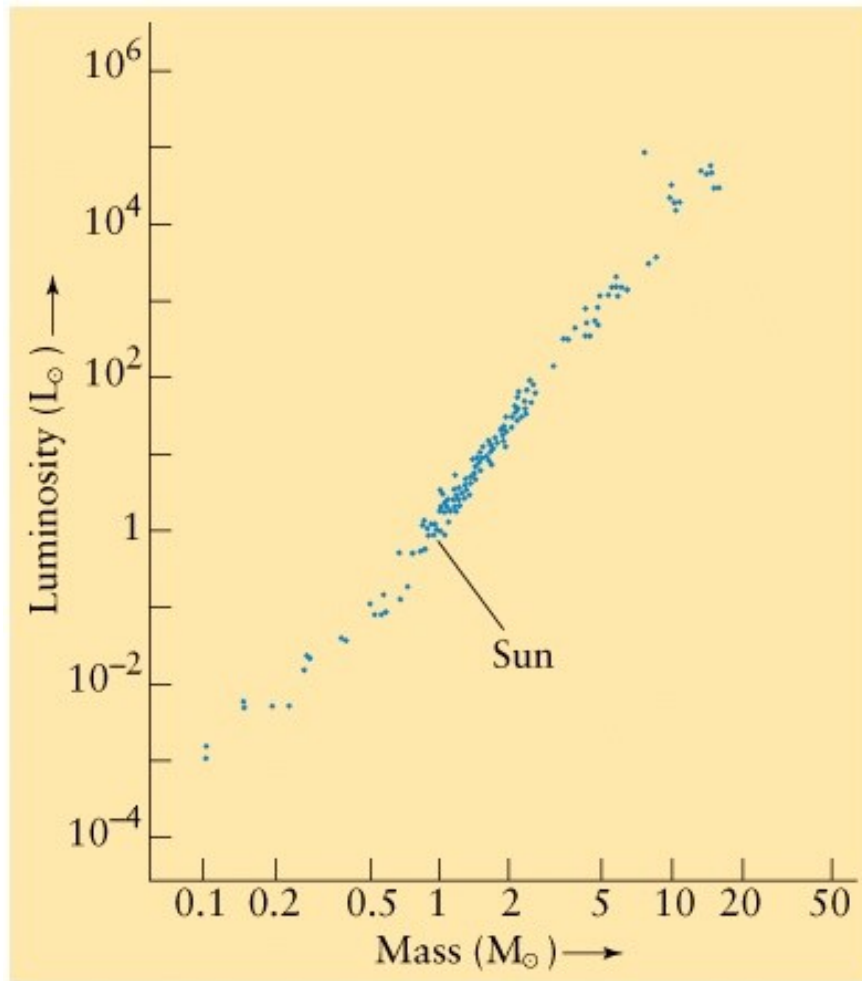
Mass-Luminosity Relation

- stellar masses determined from binary stars reveal a relationship between mass and luminosity for main sequence stars of the form

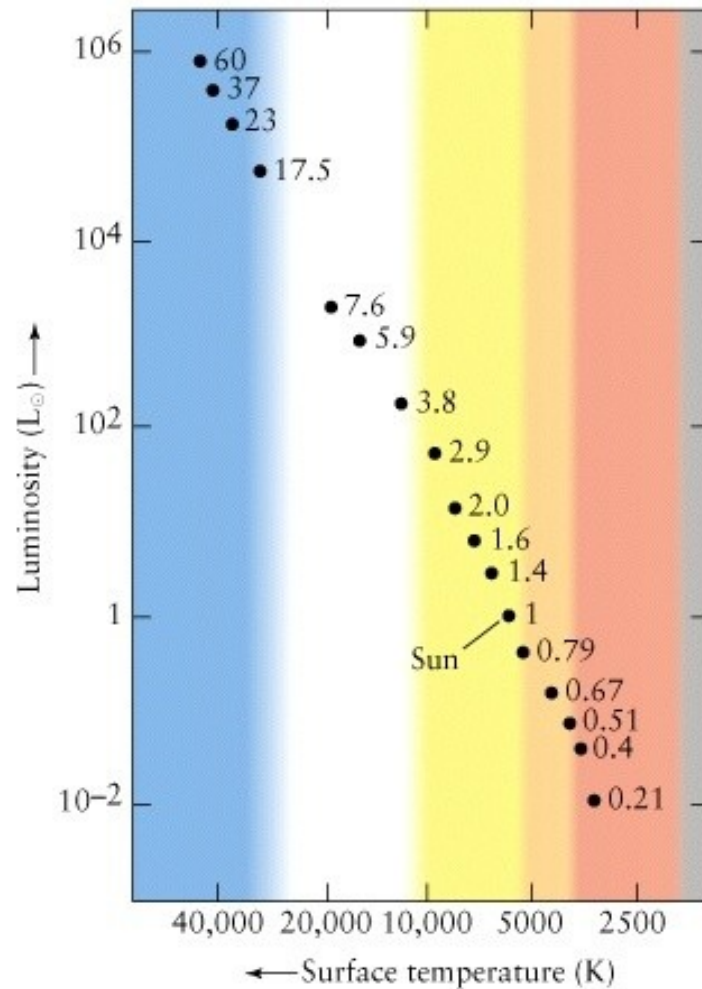
$$L \propto M^\alpha \quad 2 < \alpha < 4$$
$$\bar{\alpha} \approx 3.3$$

- in solar units

$$\frac{L}{L_\odot} \approx \left(\frac{M}{M_\odot} \right)^\alpha$$



© Universe, W H Freeman & Co. Mass-luminosity relation for main sequence stars



Range of Main Sequence Masses

- lower limit $\sim 0.08 M_{\odot}$
- below that stars never hot enough to burn hydrogen - brown dwarfs
- upper limit $\sim 100 M_{\odot}$
- above this star is blown apart by radiation pressure
- many more low mass than high mass main sequence stars

Main Sequence Lifetime

- MS lifetime $\tau_{MS} = \frac{E}{L}$
- amount of energy = $\Delta mc^2 \propto M$
- rate at which energy is radiated

$$L \propto M^{3.3}$$

$$\therefore \tau_{MS} \propto \frac{M}{L} \propto \frac{M}{M^{3.3}} \propto M^{-2.3}$$

- i.e. massive stars spend much less time on the main sequence than low mass stars.

Example

- What is the main sequence lifetime of a $10 M_{\odot}$ star given that for the Sun it is 10^{10} years?

$$\tau_{MS} \propto M^{-2.3}$$

$$\frac{\tau_*}{\tau_{\Theta}} = \left(\frac{M_*}{M_{\Theta}} \right)^{-2.3}$$

$$\tau_* = \left(\frac{M_*}{M_{\Theta}} \right)^{-2.3} \tau_{\Theta}$$

$$= \left(\frac{10}{1} \right)^{-2.3} 10^{10} = 10^{7.7} = 5 \times 10^7 \text{ years}$$

Stellar Evolution

- Initial mass of a star determines its fate
- Low mass stars like the Sun evolve into red giants and then eject their outer layers as planetary nebulae leaving behind a white dwarf
- High mass evolve into supergiants and then explode as supernovae leaving behind a neutron star or black hole

Cat's Eye Nebula • NGC 6543

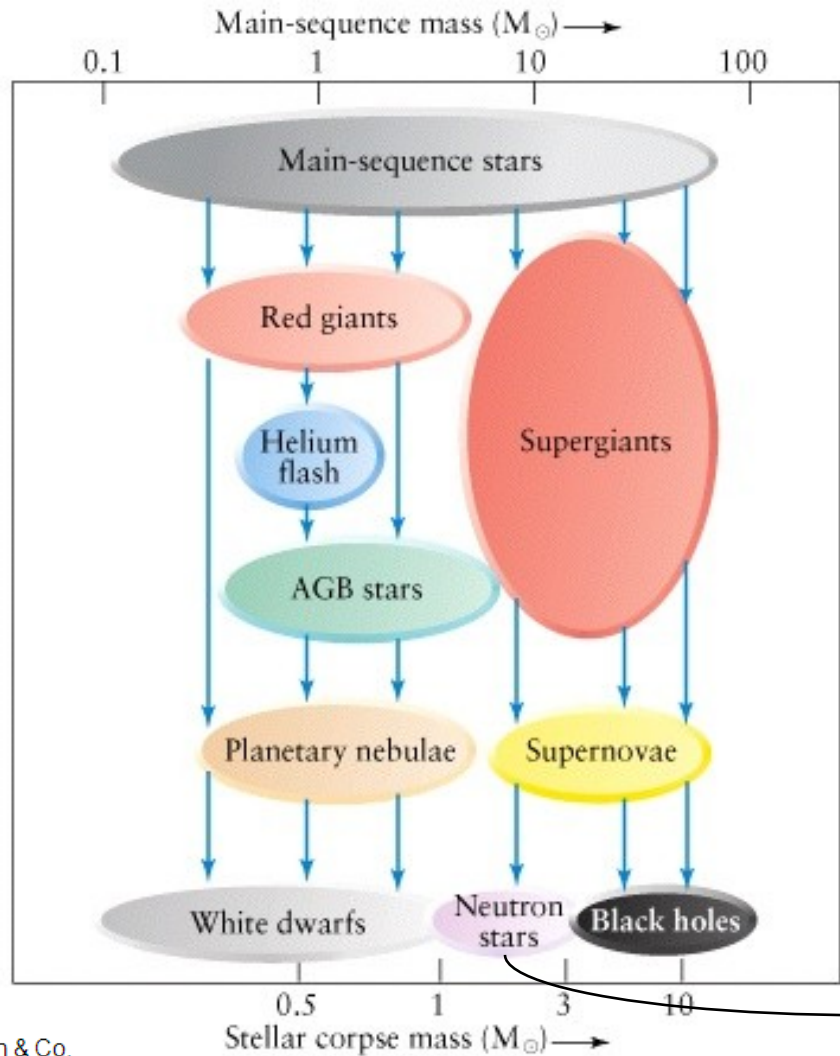


Hubble
Heritage

Planetary
nebula



Supernova 1987A before and just after explosion



Pulsars

Summary

- An H-R diagram reveals distinctly different types of star
- Massive main sequence stars are much more luminous and much rarer than lower mass ones
- The mass of a star determines its position on the main sequence, its lifetime, its evolutionary path and its endpoint.