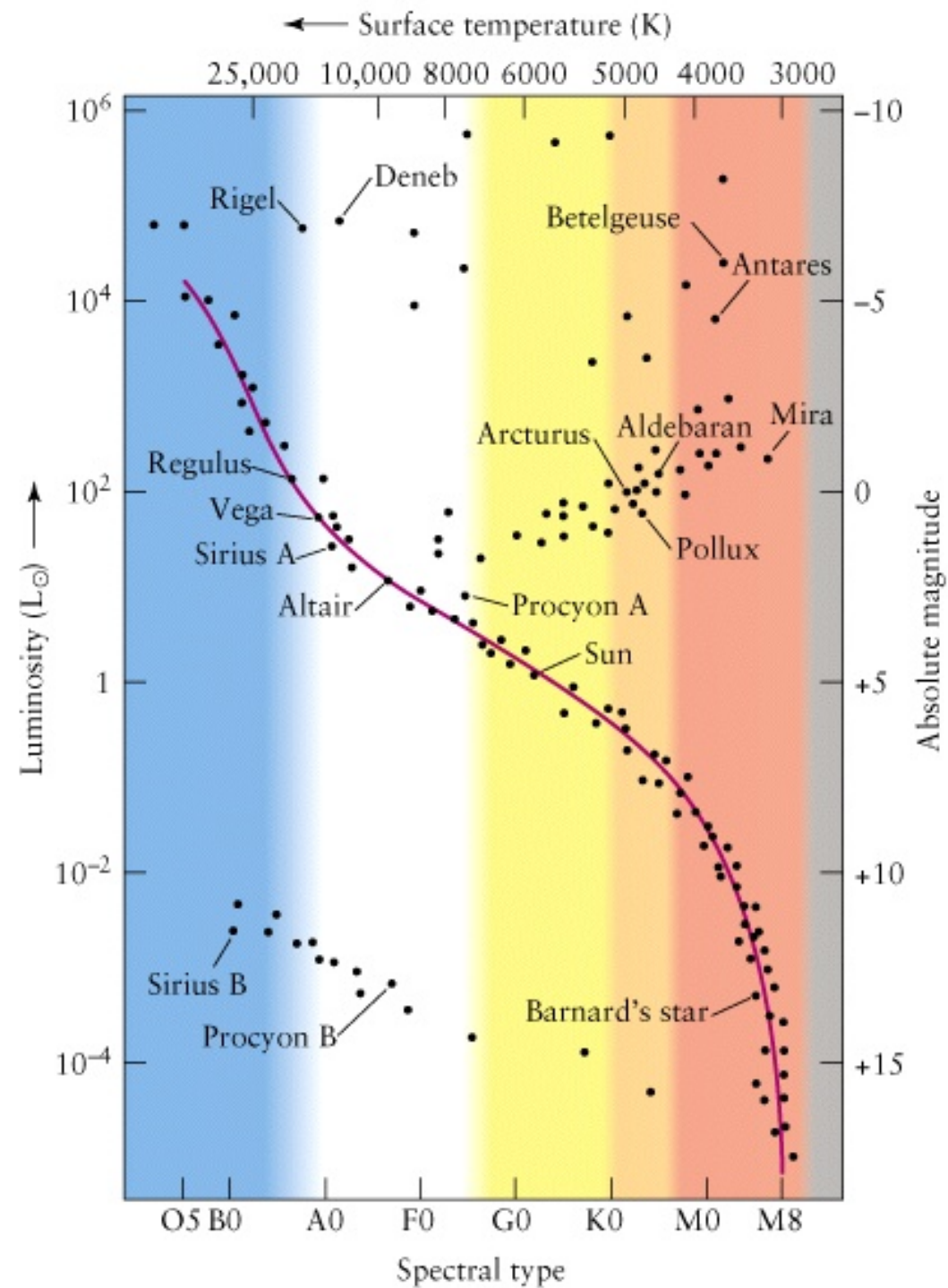


# H-R Diagrams

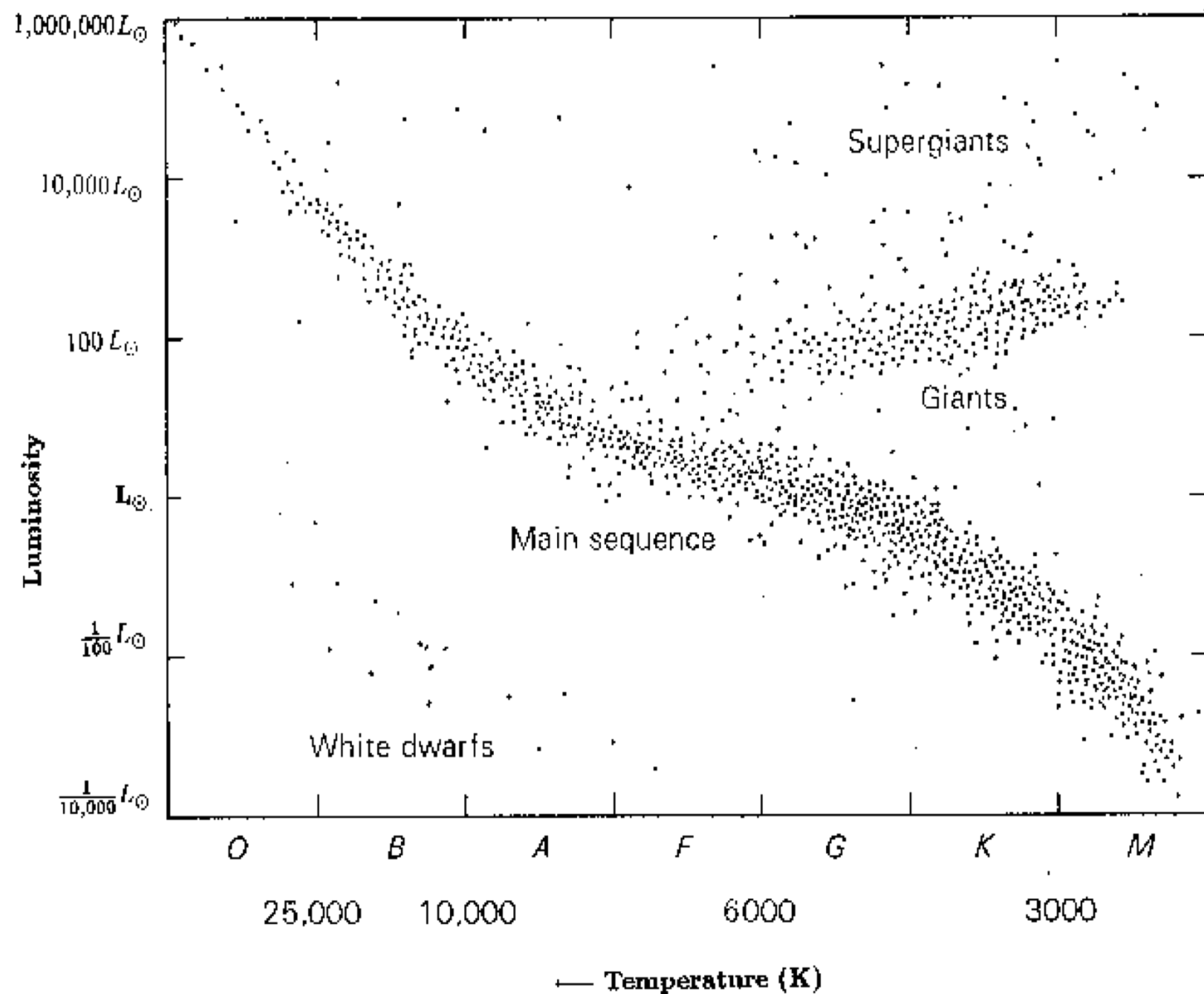
- H-R diagrams
- Stellar masses and range
- Main sequence lifetime
- Stellar evolution

# Hertzsprung-Russell Diagrams

- stars plotted on a graph of either:  
 $M_V$  versus spectral type  
or  
 $L$  versus  $T_{\text{eff}}$   
reveal a distinctive pattern
- (in general need to know distance)
- these plots are called Hertzsprung-Russell diagrams or H-R diagrams for short



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  $T_{\text{eff}}$ ?

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

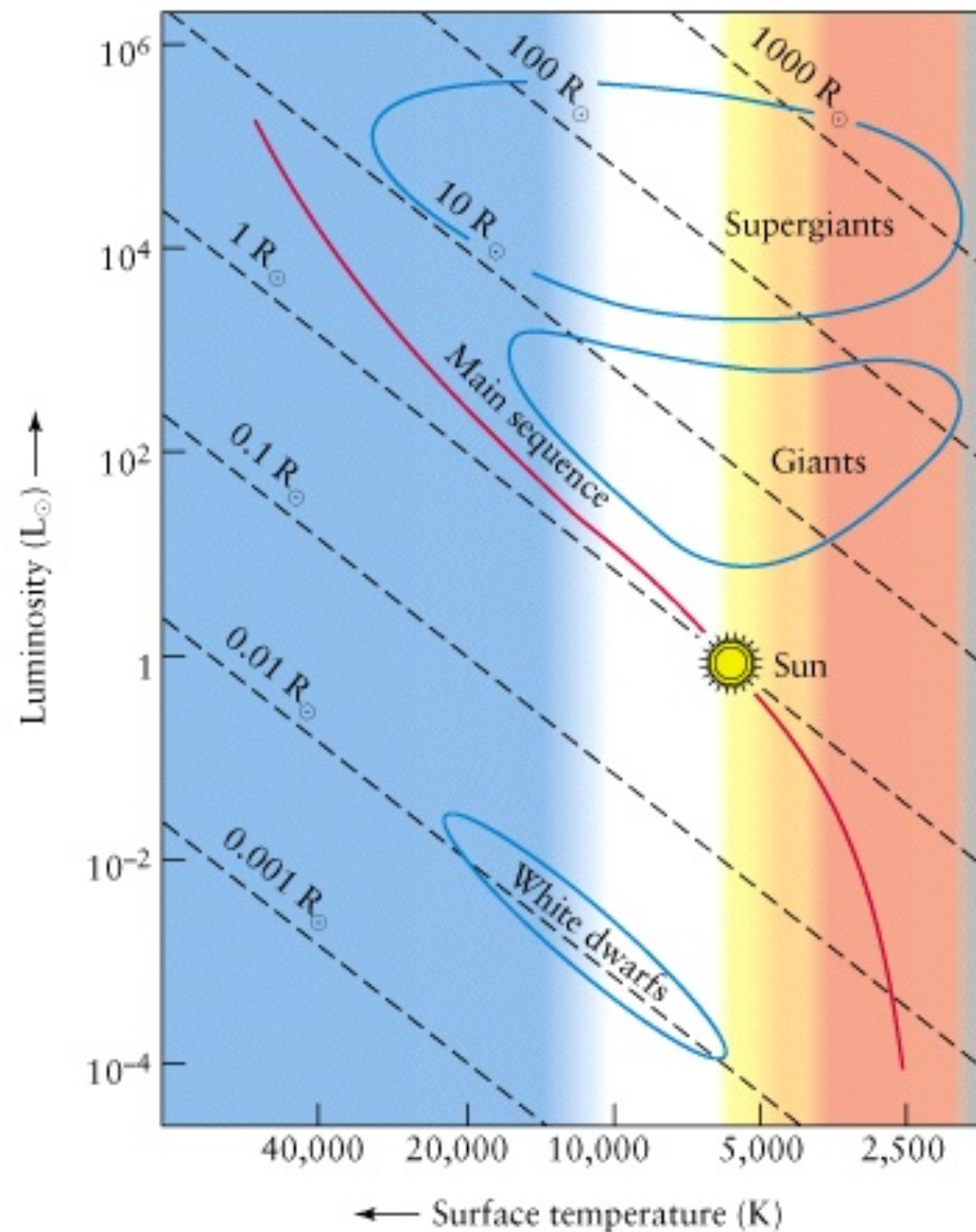
$$L \propto R^2 T_{eff}^4$$

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

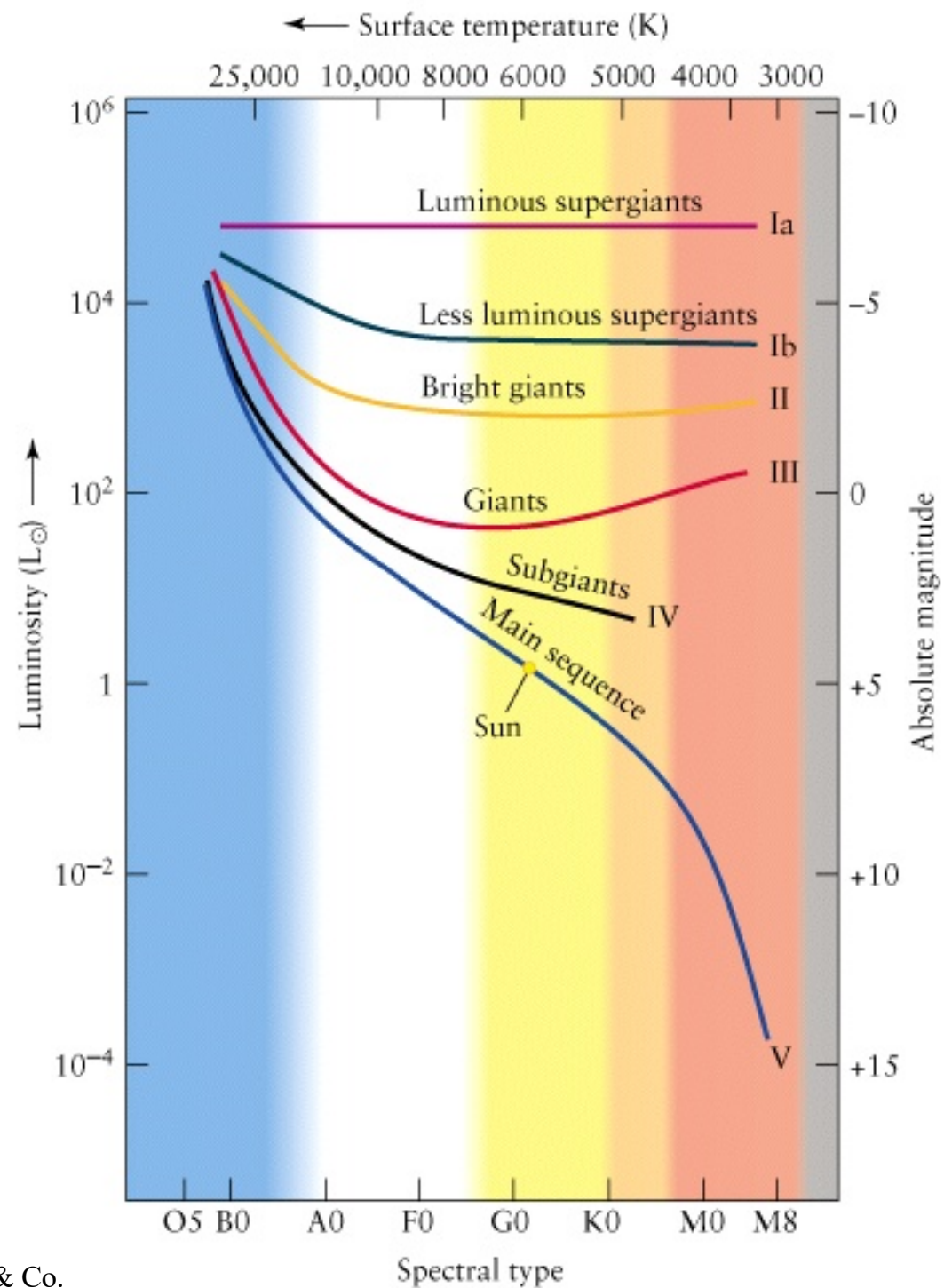
$$T_{RG} \approx T_{RD}$$

$$\frac{R_{RG}}{R_{RD}} = \left( \frac{L_{RG}}{L_{RD}} \right)^{\frac{1}{2}}$$

$$= \left( \frac{10^2}{10^{-4}} \right)^{\frac{1}{2}} = 10^3$$



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



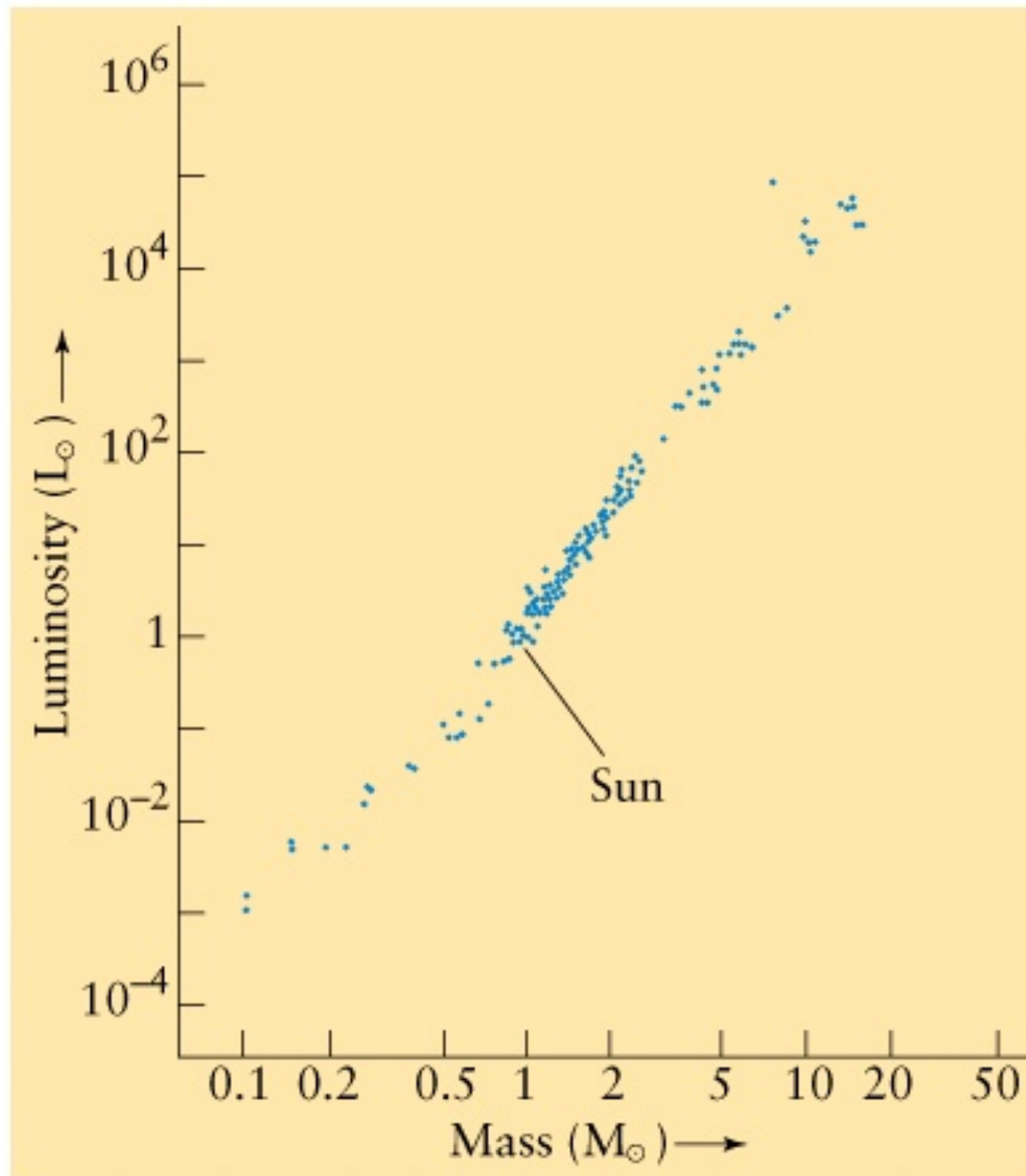
# Mass-Luminosity Relation

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

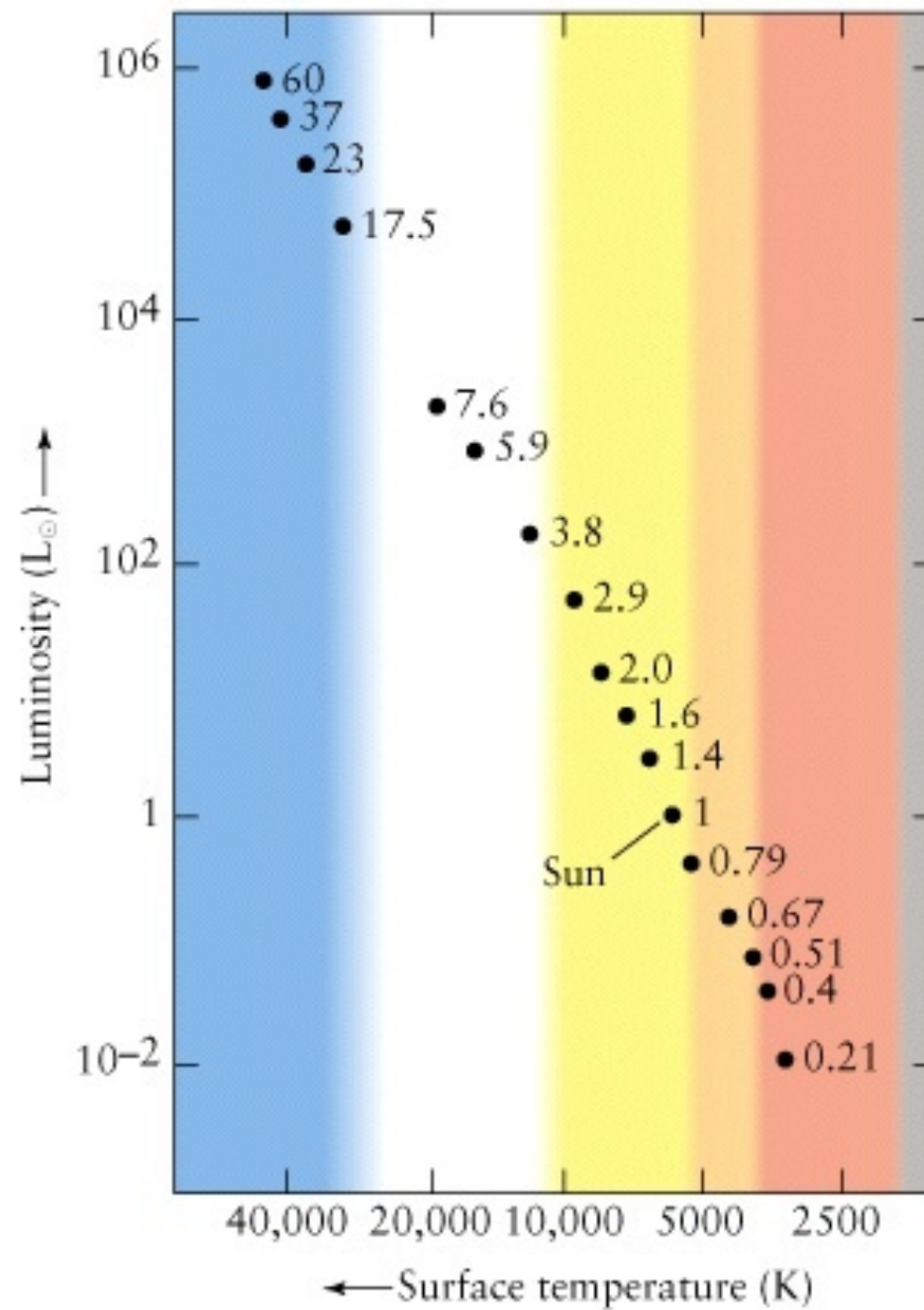
$$L \propto M^{\alpha} \quad 2 < \alpha < 4$$
$$\bar{\alpha} \approx 3.3$$

- 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.

# Class Example

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

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

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

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

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

# 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

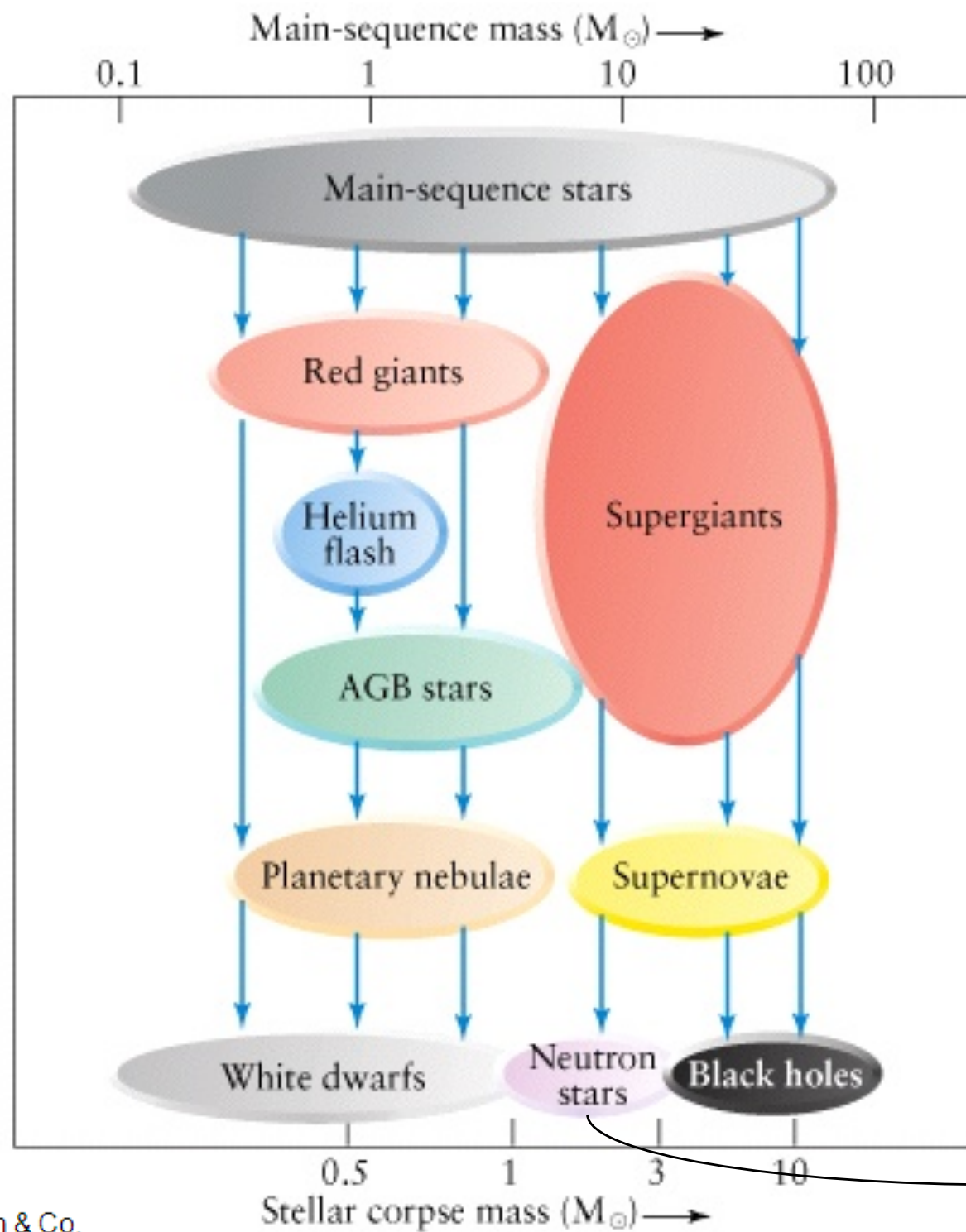


Hubble  
Heritage

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.