H-R Diagrams

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

Hertzsprung-Russell Diagrams

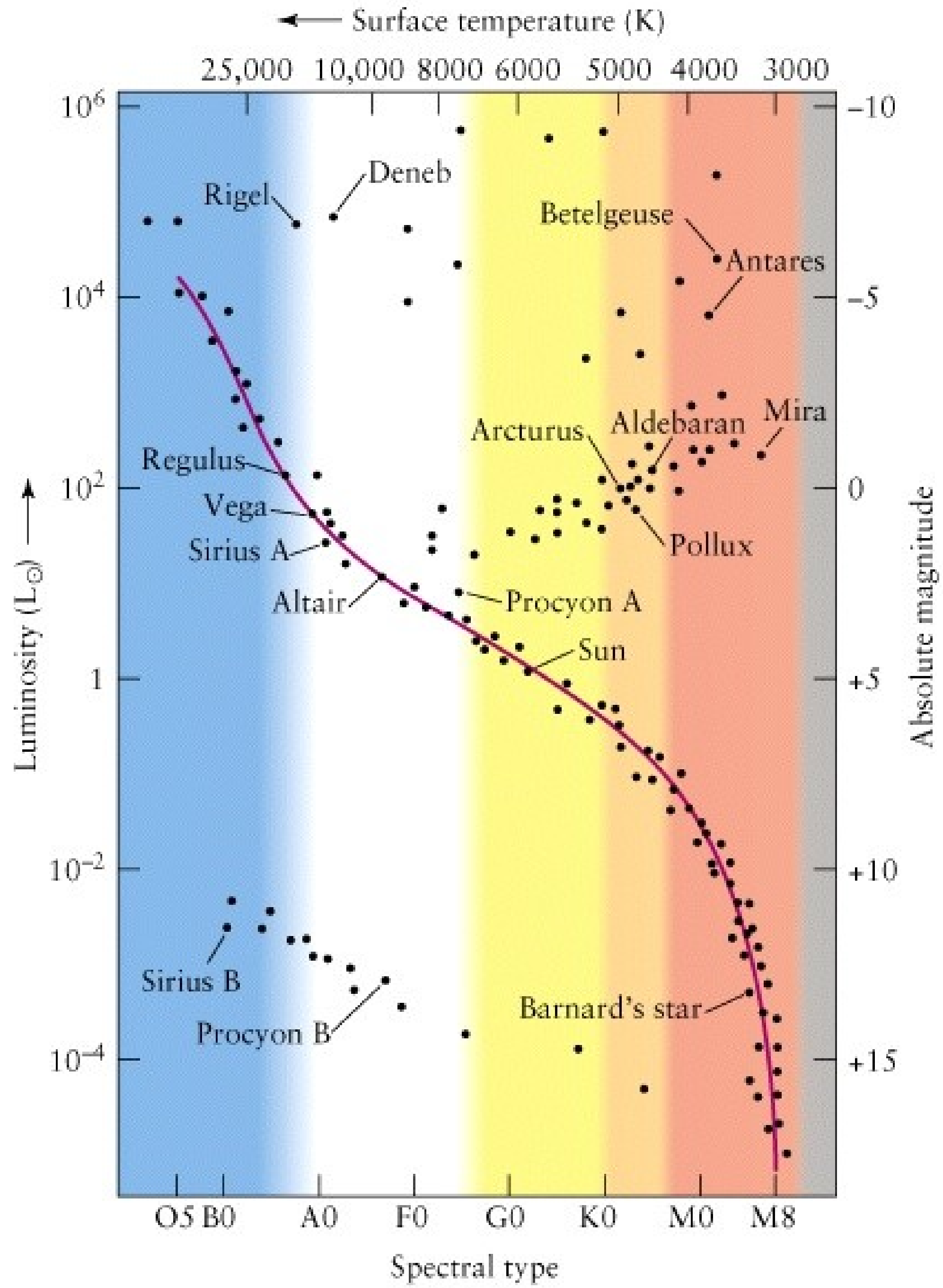
- stars plotted on a graph of either:

  M_V versus Spectral Type

  or

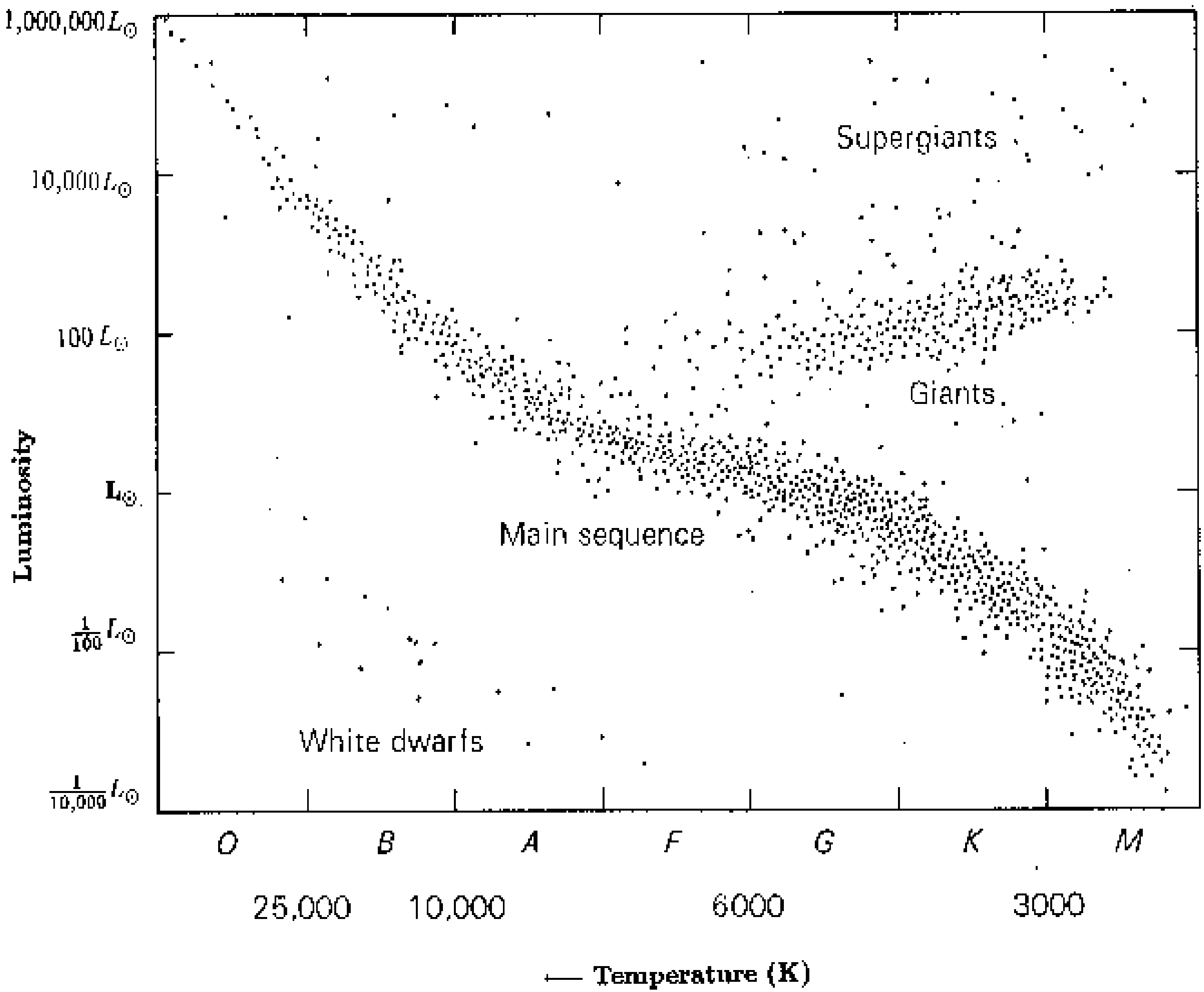
  L versus T_{eff}

  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_{eff}=3000 K) with $L=10^2\ L_\odot$ than a main sequence red dwarf with $L=10^{-4}\ L_\odot$ and the same T_{eff}?

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

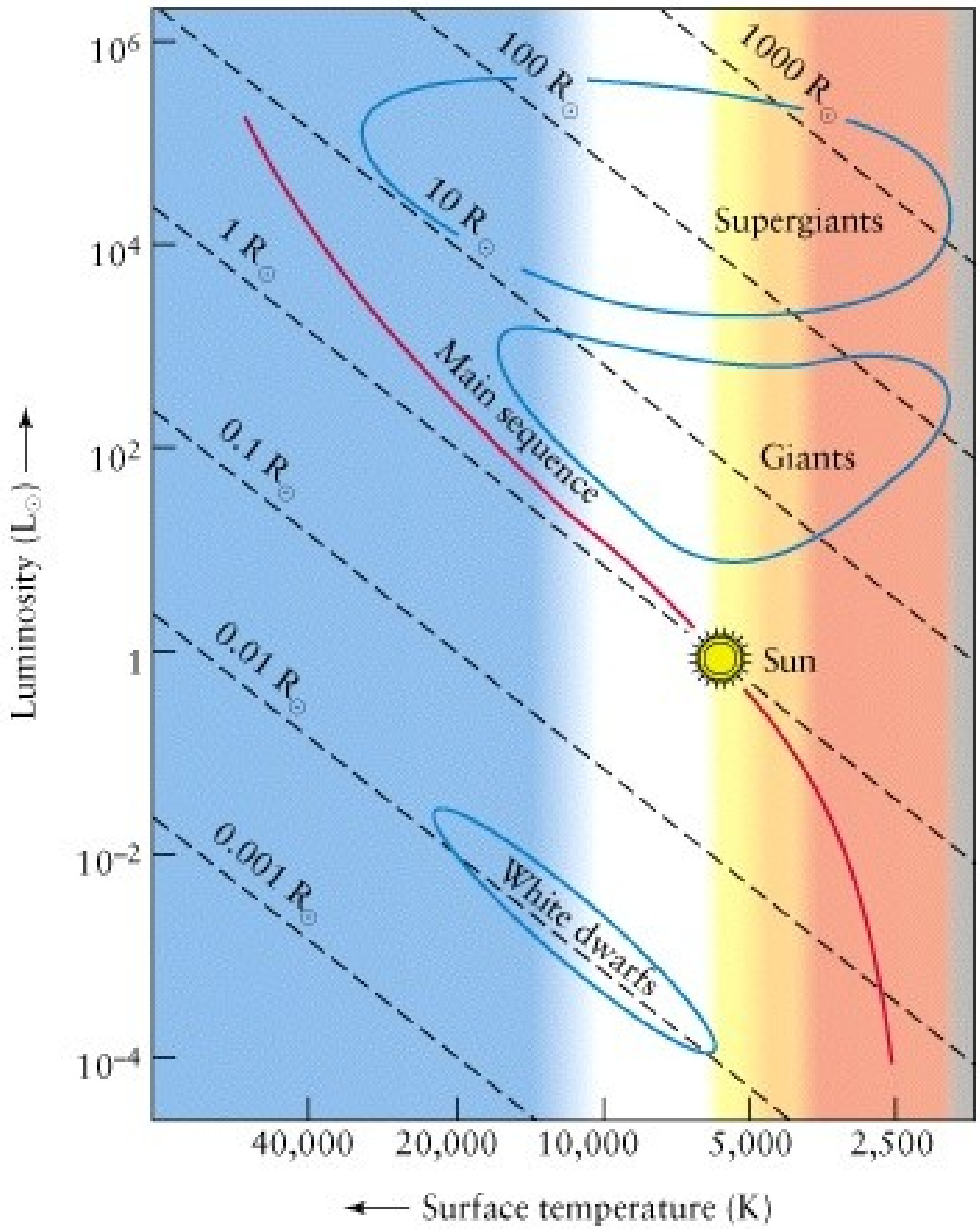
$$L \propto R^2 T_{eff}^4$$

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

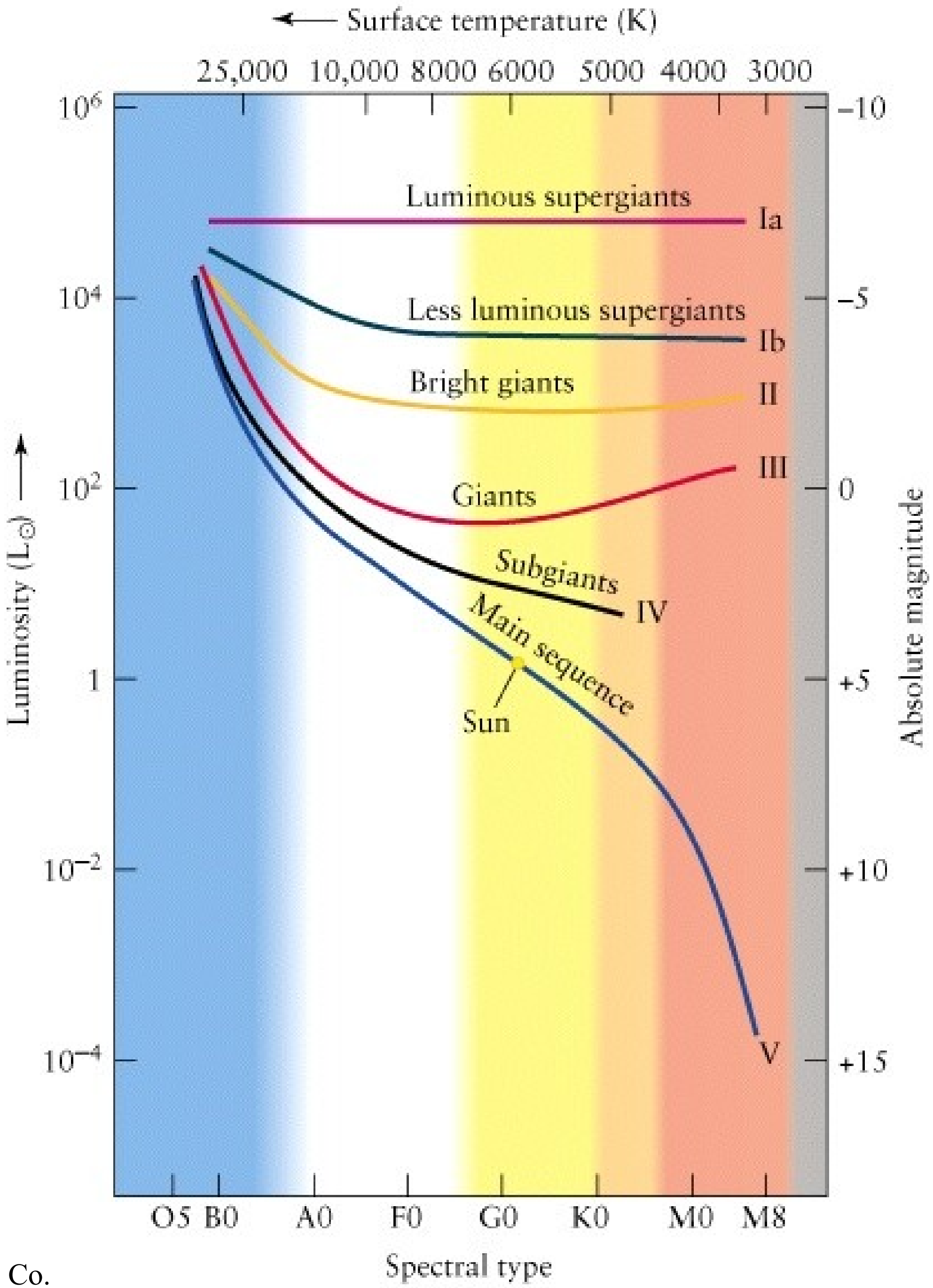
$$T_{RG} \approx T_{RD}$$

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

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



Sizes of stars in different locations on the H-R diagram


← Surface temperature (K)
25,000
10,000
8000
6000
5000
4000
3000
10^6
10^4
10^2
1
10^{-2}
10^{-4}
Luminosity ($L_\odot$)
−10
−5
0
+5
+10
+15
Absolute magnitude
Luminous supergiants
Ia
Less luminous supergiants
Ib
Bright giants
II
III
Giants
Subgiants
IV
Main sequence
Sun
V
O5
B0
A0
F0
G0
K0
M0
M8
Spectral type

Mass-Luminosity Relation

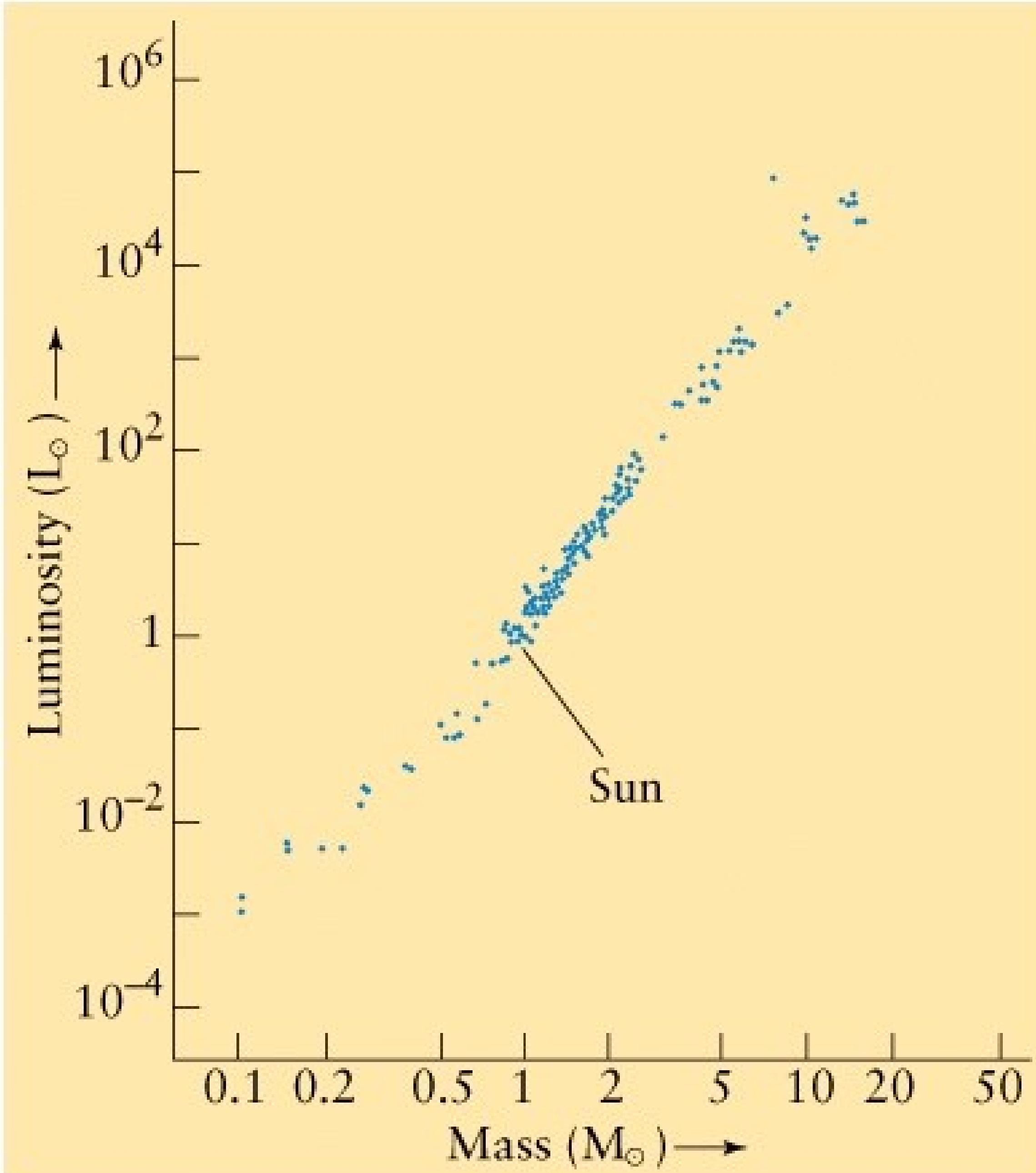
- stellar masses determined from binary stars reveal a relationship between mass and luminosity for <u>main sequence</u> stars of the form

$$L \propto M^{\alpha} \qquad 2 < \alpha < 4$$

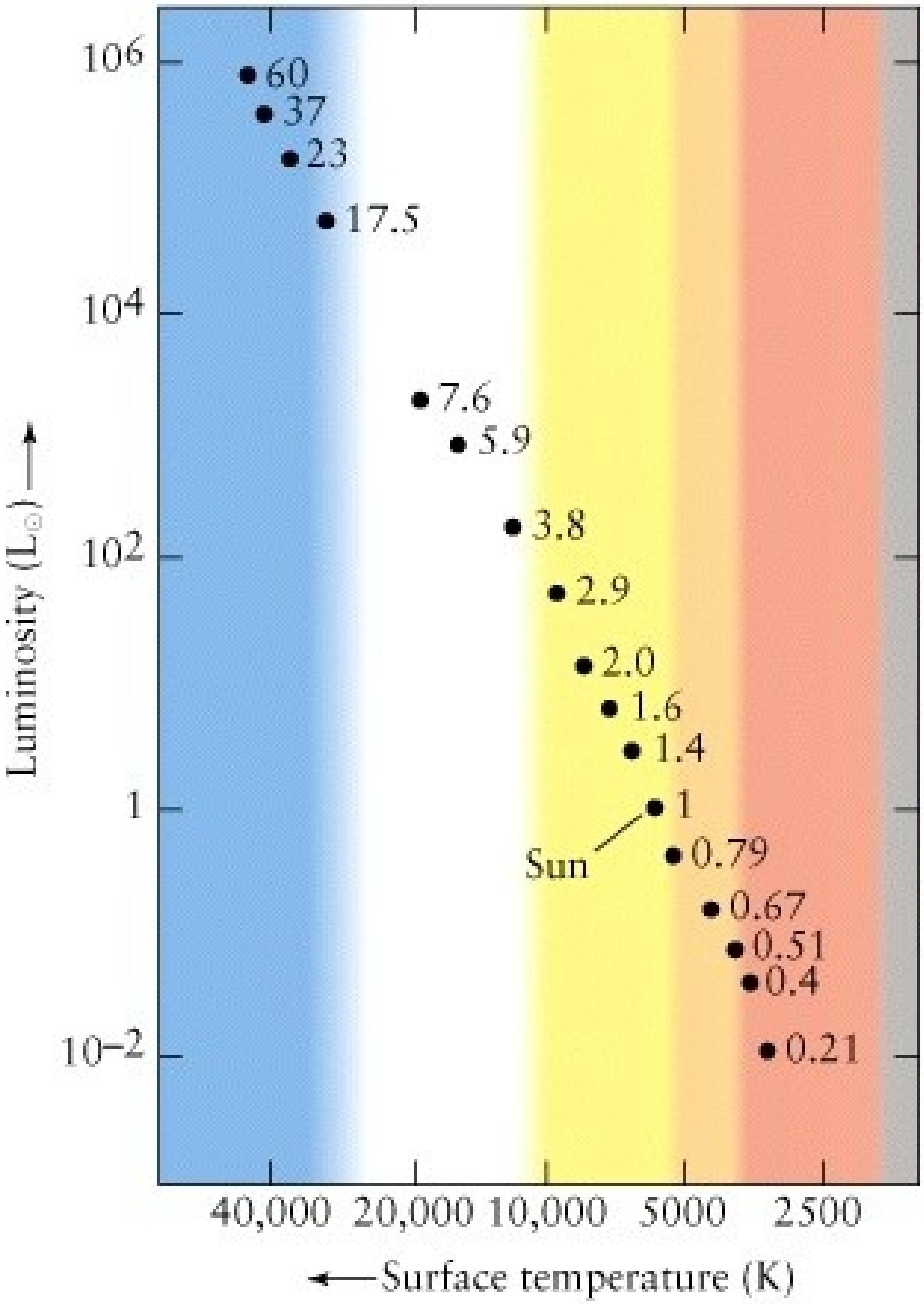
$$\bar{\alpha} \approx 3.3$$

  - in solar units

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



 Mass-luminosity relation for main sequence stars



Stellar masses along the main sequence

Range of Main Sequence Masses

- lower limit ~ 0.08 $M_{\odot}$
- below that stars never hot enough to burn hydrogen - brown dwarfs
- upper limit ~ 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 $\tau_{MS} = \dfrac{E}{L}$
- amount of energy = $\Delta mc^2 \propto M$
- rate at which energy is radiated

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

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

- 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?

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

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

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

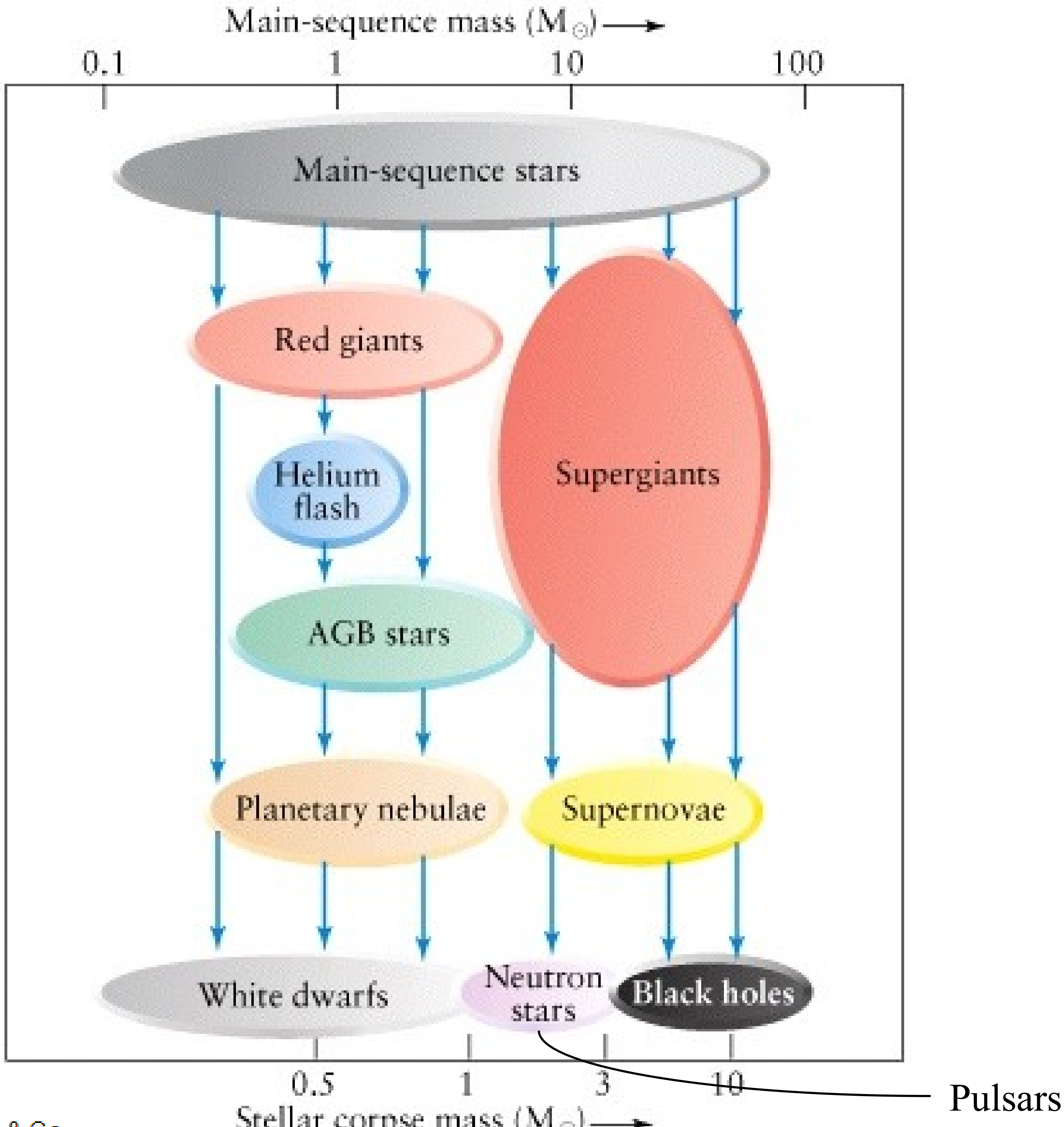
$$= \left(\frac{10}{1}\right)^{-2.3} 10^{10} = 10^{7.7} = 5 \times 10^{7} \text{ years}$$

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

Planetary
nebula

Supernova 1987A before and just after explosion


Main-sequence mass ($M_\odot$)
0.1
1
10
100
Main-sequence stars
Red giants
Supergiants
Helium flash
AGB stars
Planetary nebulae
Supernovae
White dwarfs
Neutron stars
Black holes
0.5
1
3
10
Stellar corpse mass ($M_\odot$)
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.