H-R Diagrams

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

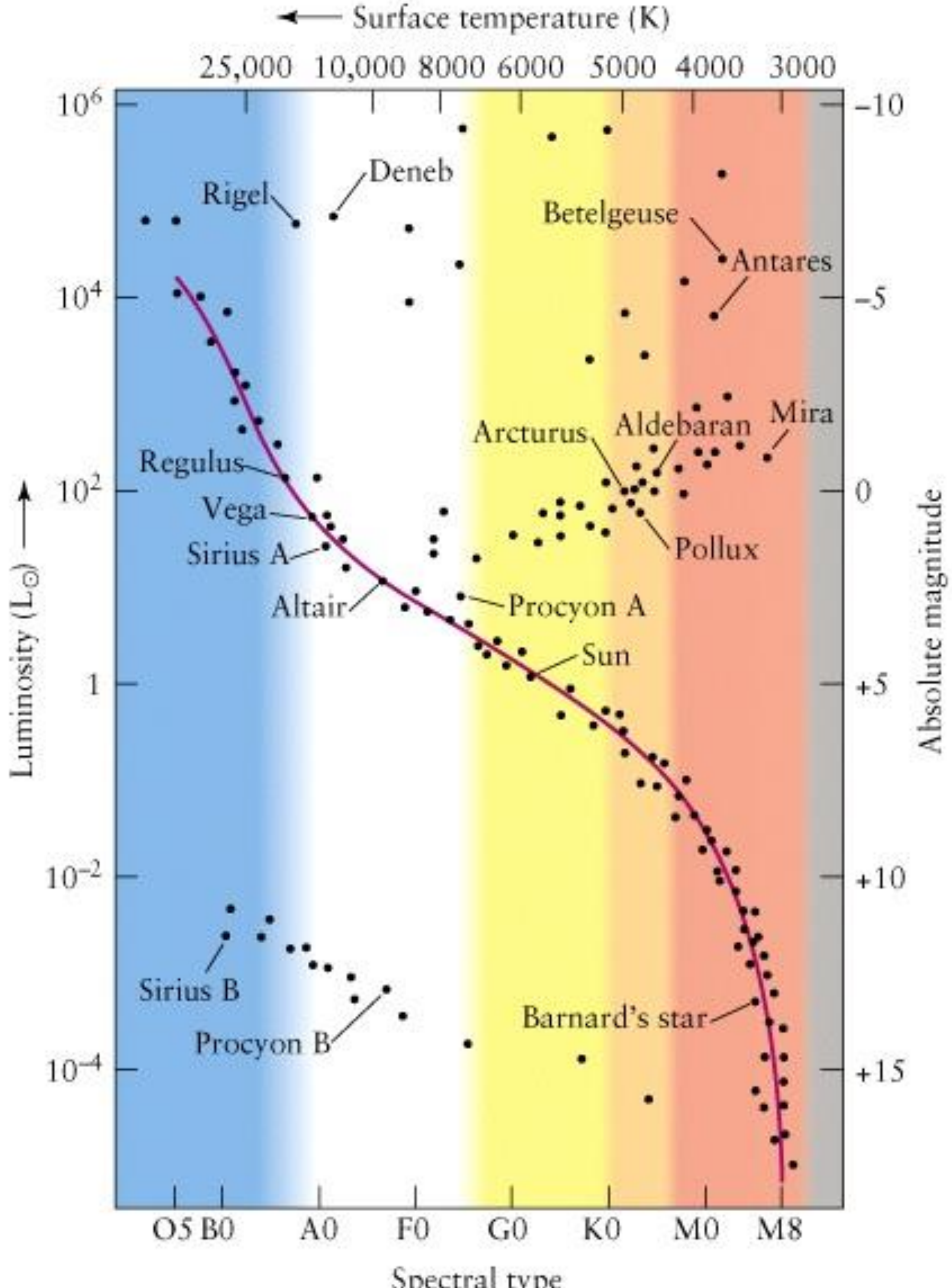
Hertzsprung-Russell Diagrams

- stars plotted on a graph of:

  L versus T_{eff}

  reveal a very distinctive pattern
- these plots are called Hertzsprung-Russell diagrams or H-R diagrams for short

H-R diagram for
some bright stars



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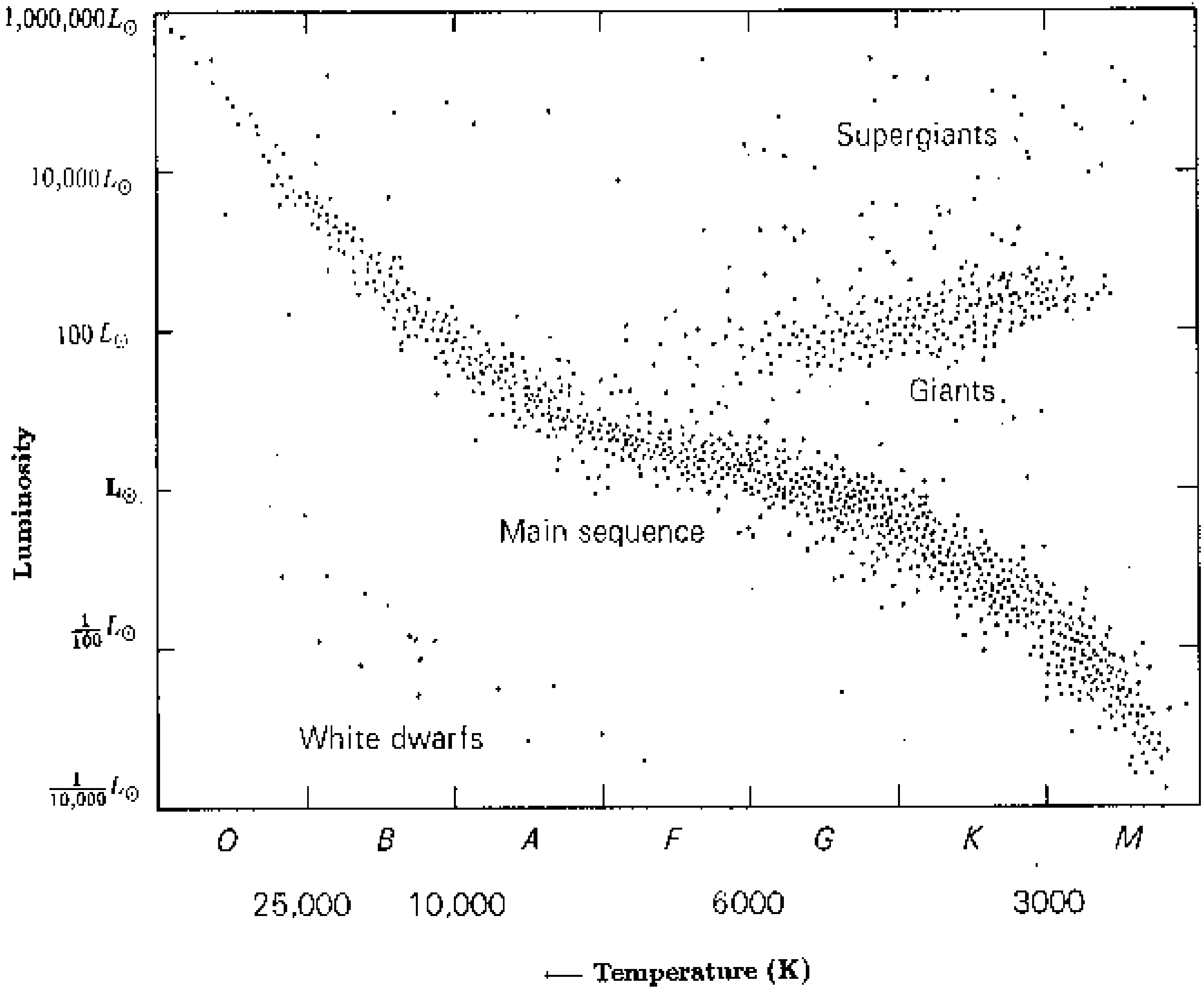
Hertzsprung-Russell Diagram for Stars in the Solar Neighborhood

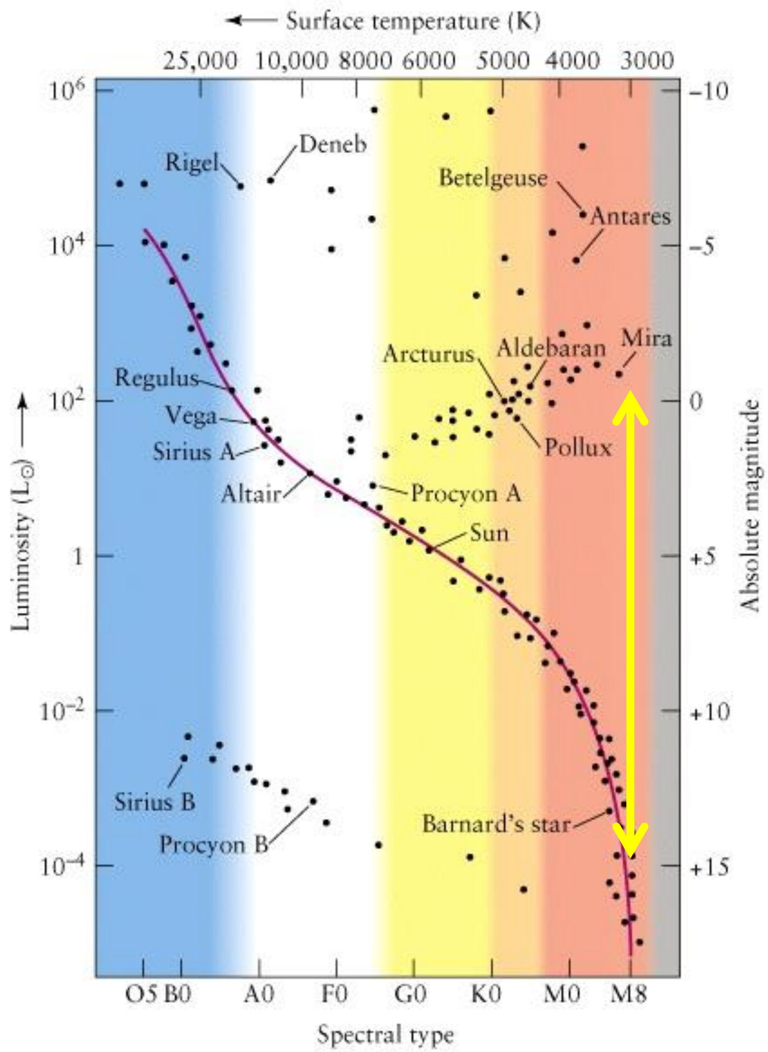


Locations on the H-R diagram

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

Class Example

- How many times larger is a 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}?



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

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

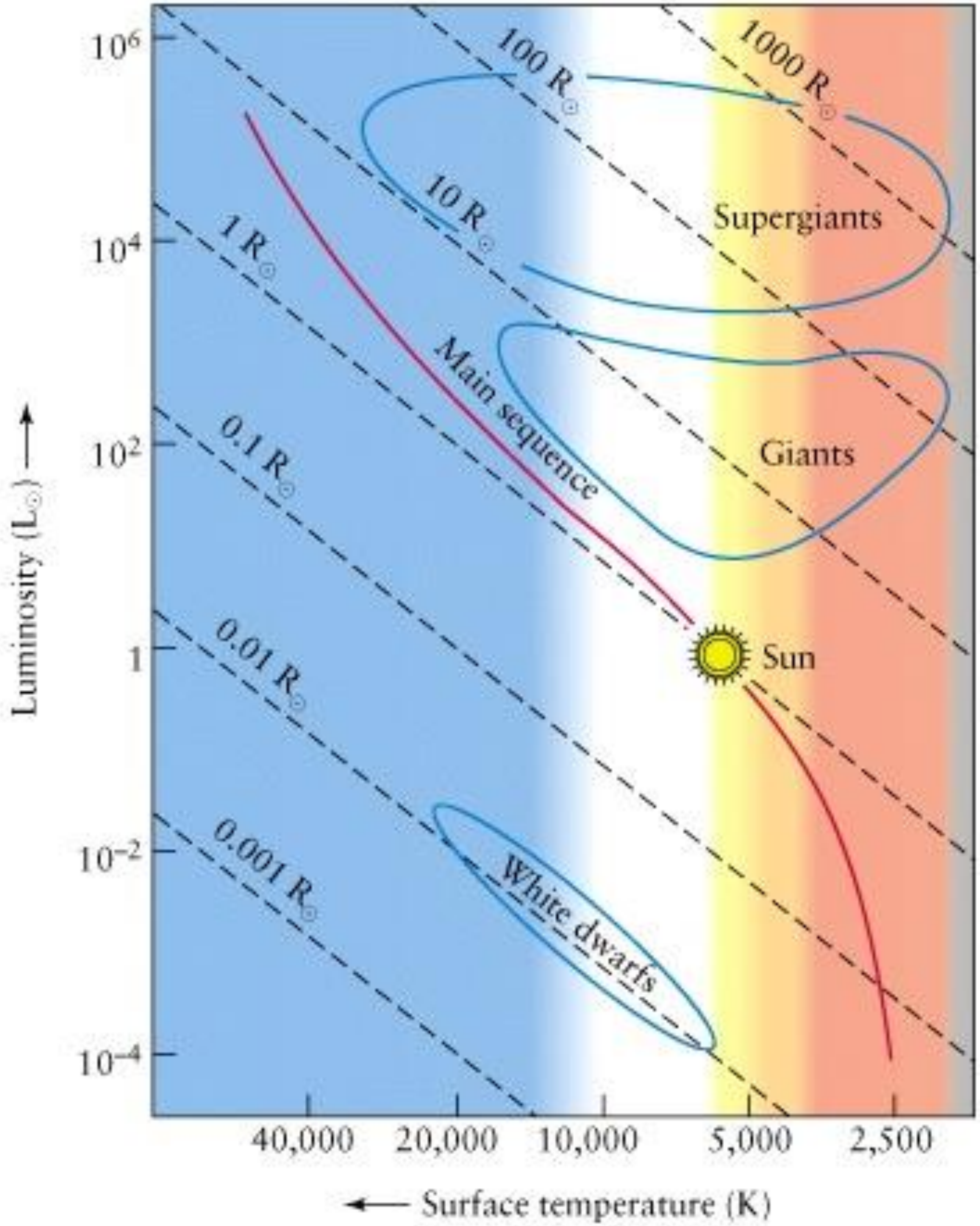
$$\frac{L_{RG}}{L_{RD}} = \left(\frac{R_{RG}}{R_{RD}}\right)^2 \left(\frac{T_{RG}}{T_{RD}}\right)^4$$

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

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

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

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



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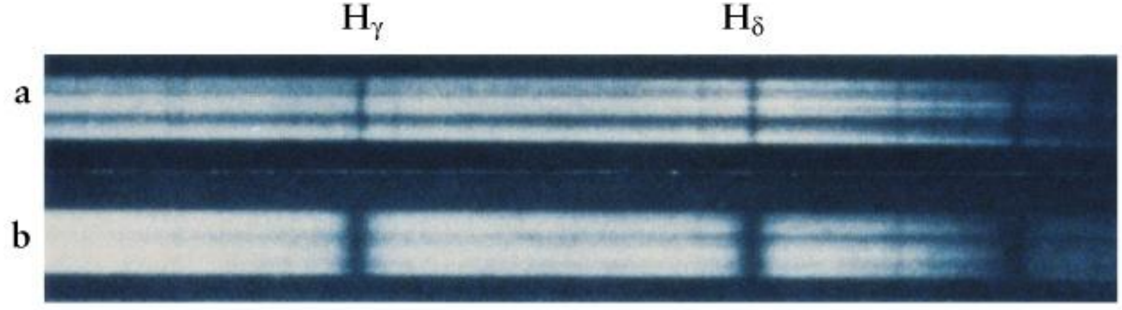
Luminosity Classification

- Larger stars (if also of similar mass) will have a lower average density which means less collisions between atoms
- This produces narrower line widths and this is used for luminosity classification

12 000 K Supergiant

12 000 K Main Sequence



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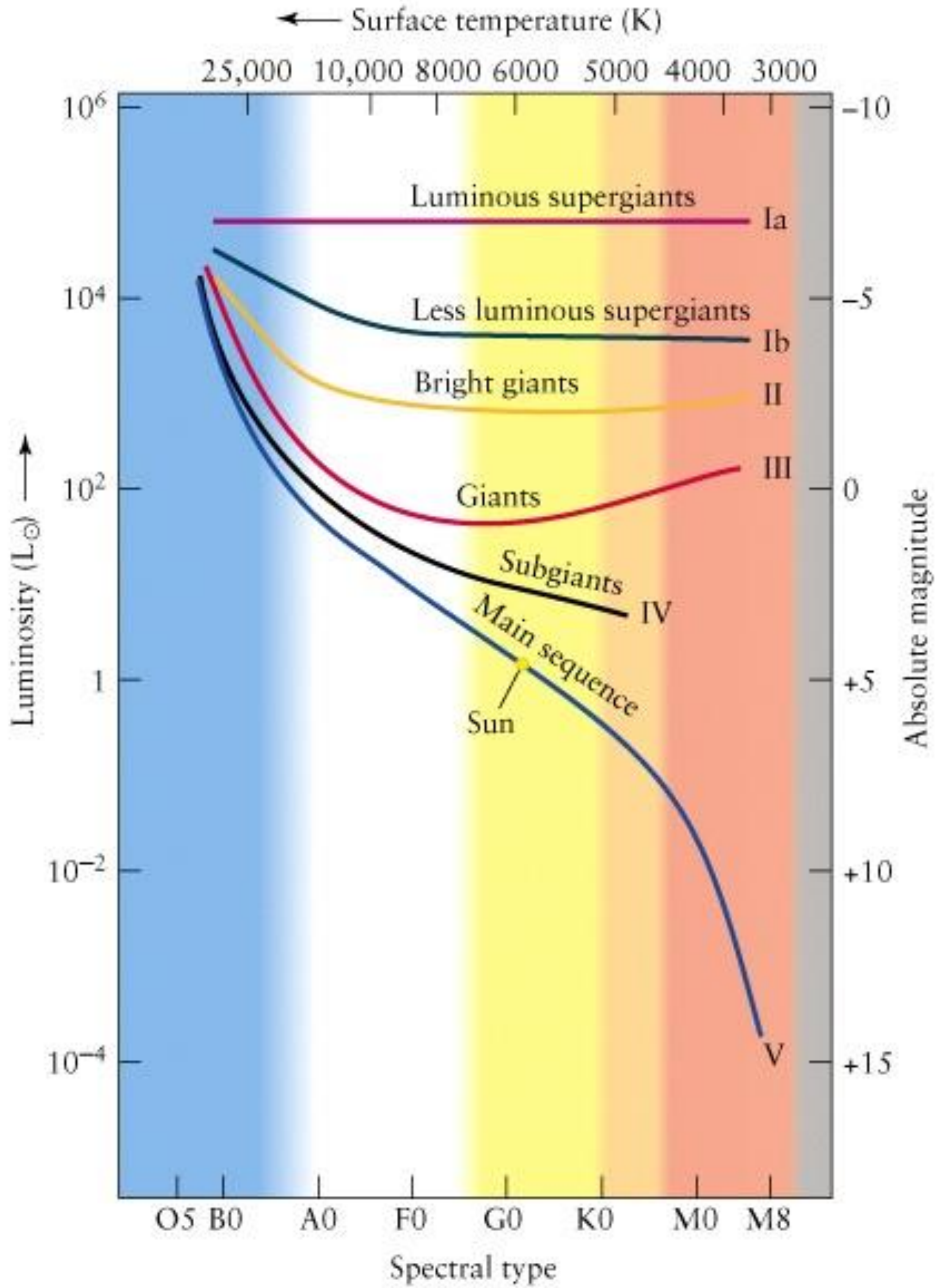

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Mass-Luminosity Relation

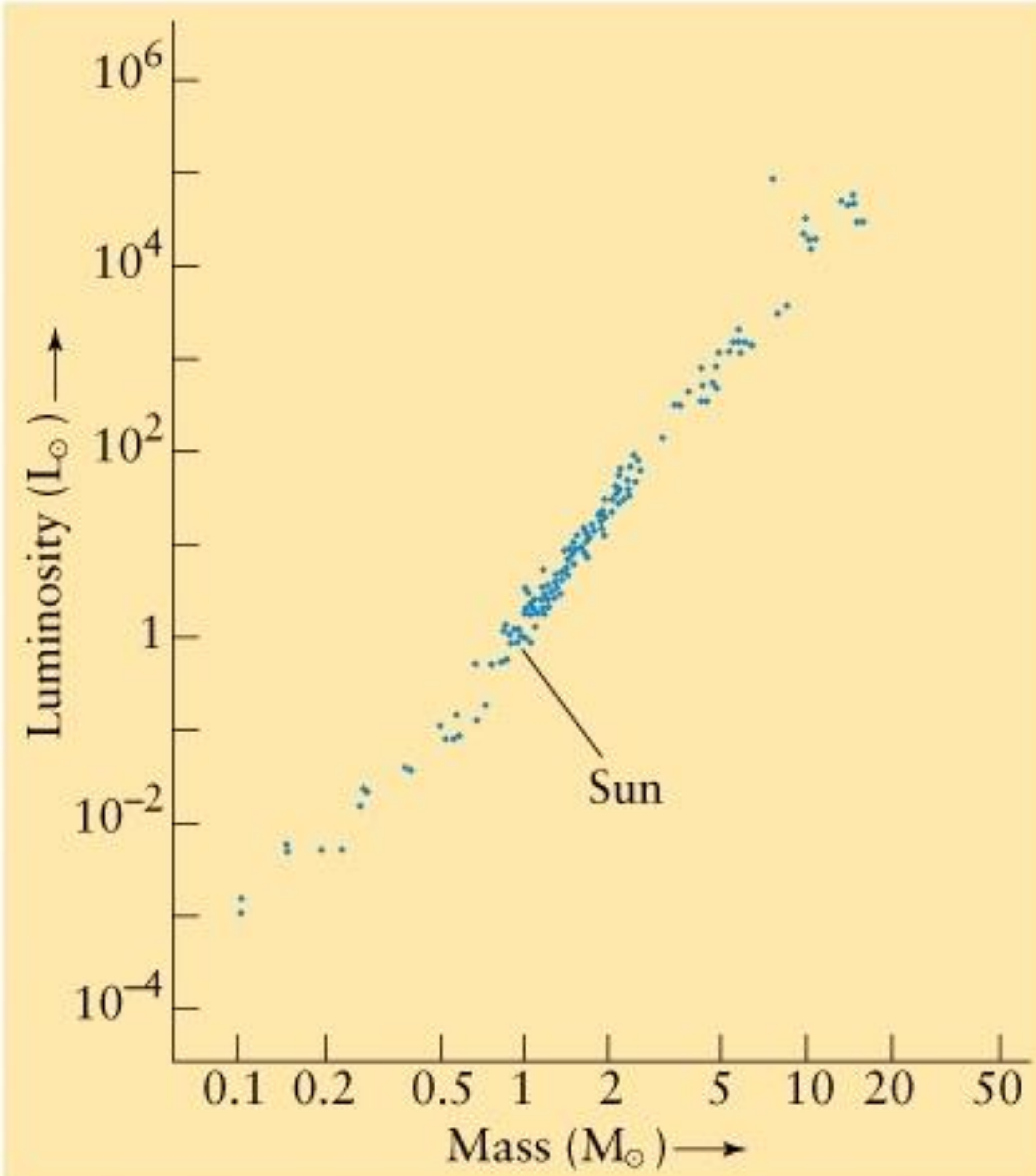
- stellar masses determined from binary stars reveal a relationship between mass and luminosity for <u>main sequence</u> stars of the form

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

  - in solar units

$$\frac{L}{L_{Sun}} \approx \left(\frac{M}{M_{Sun}}\right)^{3.3}$$

Mass-luminosity relation for main sequence stars



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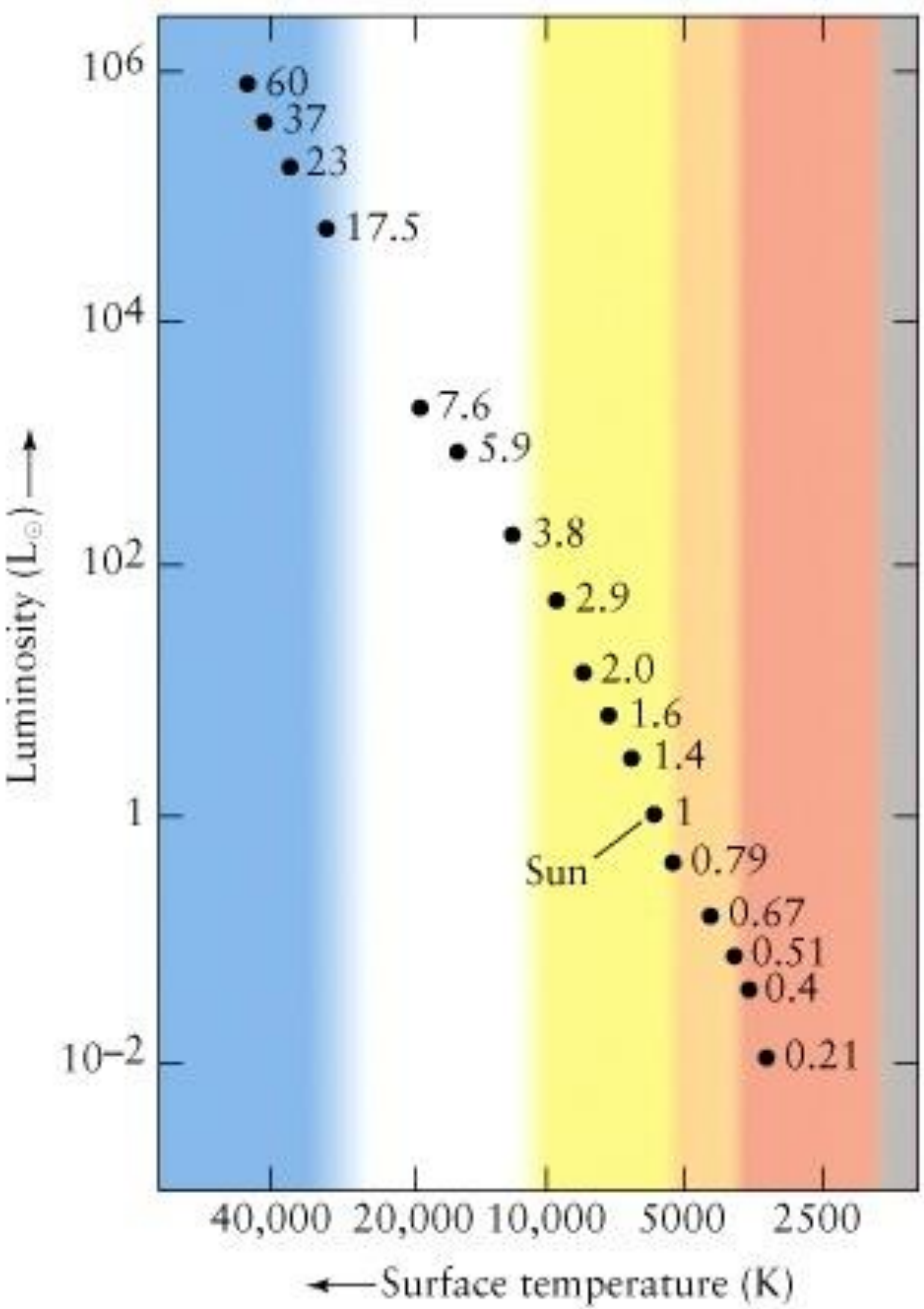
Stellar masses along the main sequence



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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 $t_{MS} = \dfrac{E}{L}$
- amount of energy $= \mathrm{D}mc^2 \propto M$
- rate at which energy is radiated

$L \propto M^{3.3}$

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

- i.e. massive stars spend much less time

on the main sequence than low mass stars.

Class Example

- By scaling from the main sequence lifetime for the Sun ($\tau_{MS}(Sun) = 10^{10}$ years) calculate the main sequence for the minimum and maximum mass stars in years.

Scaling the Sun's MS lifetime

for the most massive MS stars:

$$t_{MS} = t_{MS}(Sun)\left({}^{M}\!\!\diagup_{\mathrm{M}_{Sun}} \right)^{-2.3}$$

$$= 10^{10} \times 100^{-2.3} = 10^{5.4} = 2 \times 10^{5} \text{ years}$$

and for the least massive:

$$t_{MS} = 10^{10} \times 0.08^{-2.3} = 3 \times 10^{12} \text{ years}$$

i.e. much older than the Universe.

Stellar Evolution

- Initial mass of a star determines its fate
- Can divide into two broad categories
  - Low mass stars like the Sun
  - High mass stars that are 10-100 times more massive than the Sun

Low Mass Stars

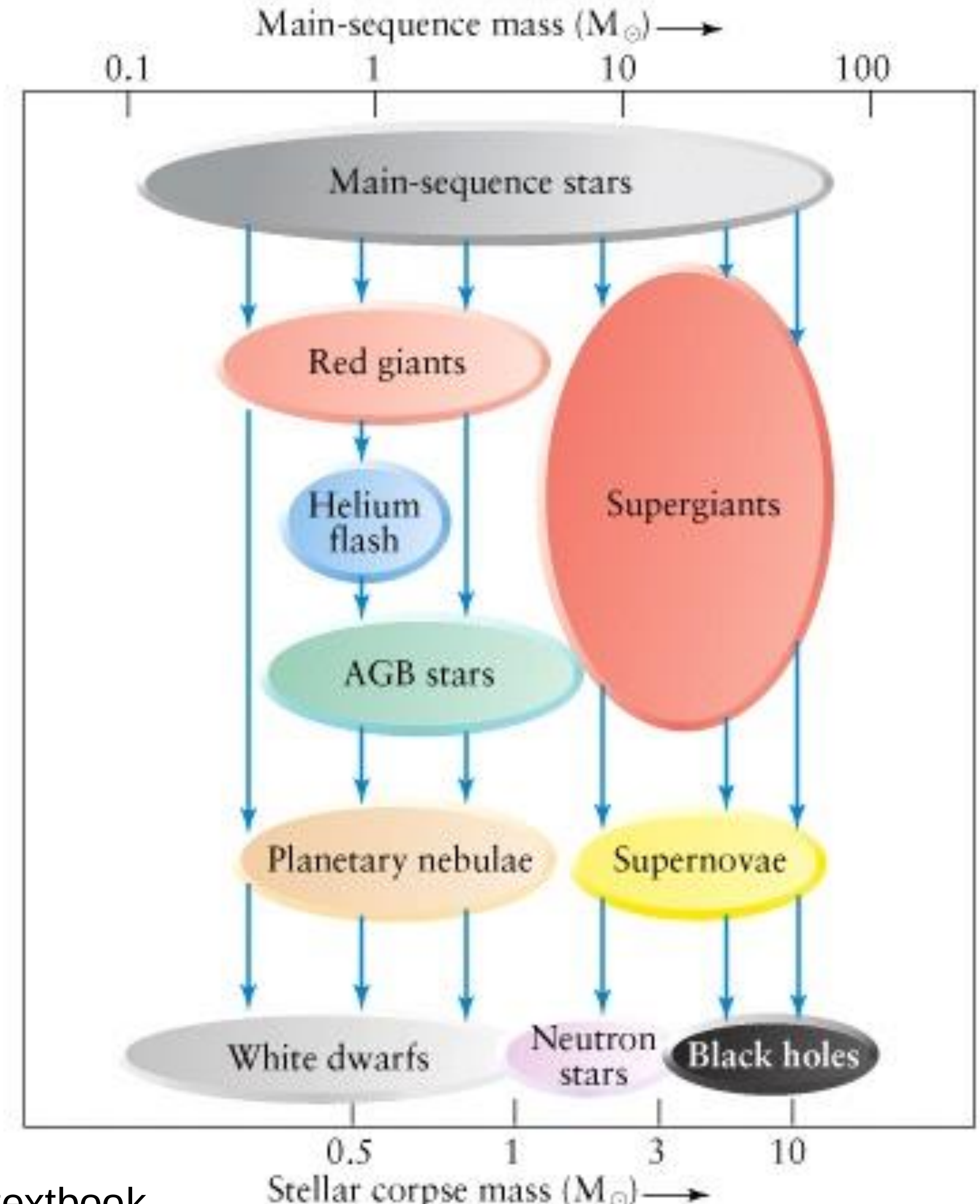
- After hydrogen exhaustion in core, the core shrinks and the envelope expands
- Evolves into a red giant
- Repeats after burning helium
- Ejects envelope as planetary nebulae
- Leaves behind a white dwarf

Planetary nebula

High Mass Stars

- Evolve into super giants
- Successively burn elements up to iron
- Explode as supernovae
- Leave behind either a neutron star or black hole

Supernova 1987A before and just after explosion



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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