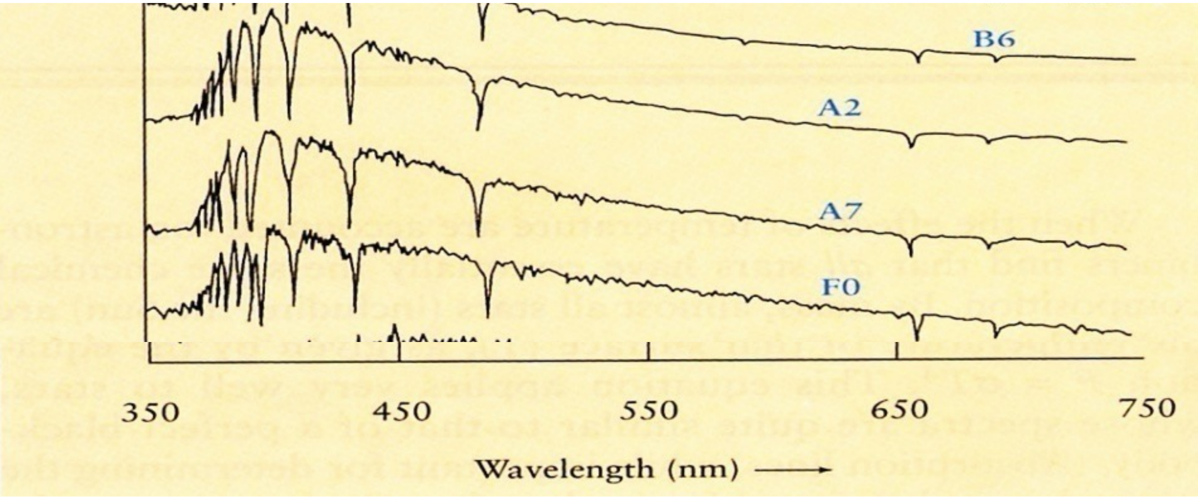
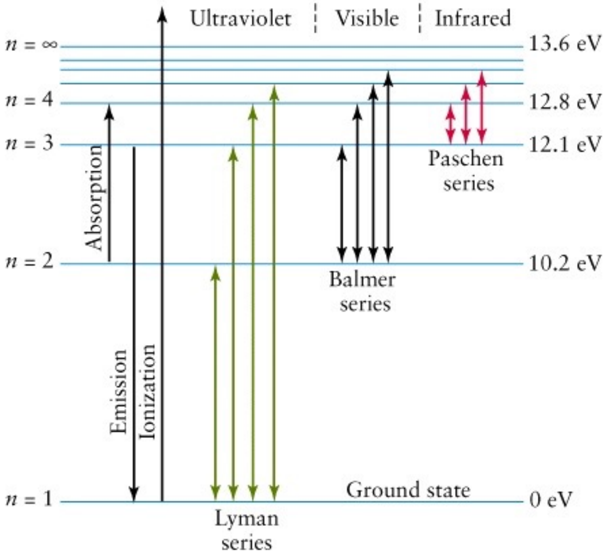
- Why is there a drop in the continuum level below 360 nm in A type stars?





- The continuum radiation with λ<360 nm is ionizing hydrogen atoms in the n=2 level

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:

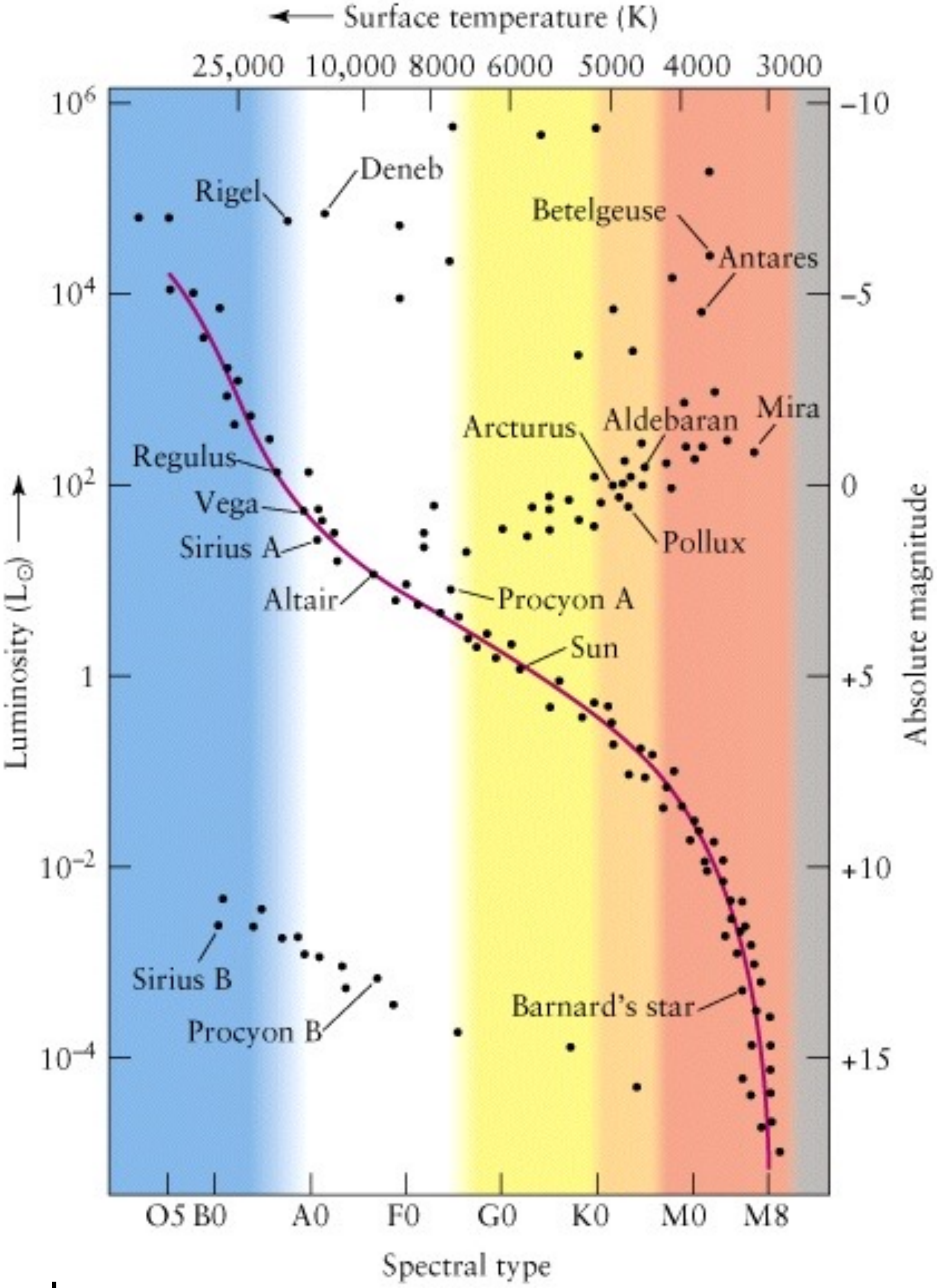
  M_V versus Sp. Type

  or

  L versus T_{eff}

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

H-R diagram for some bright stars



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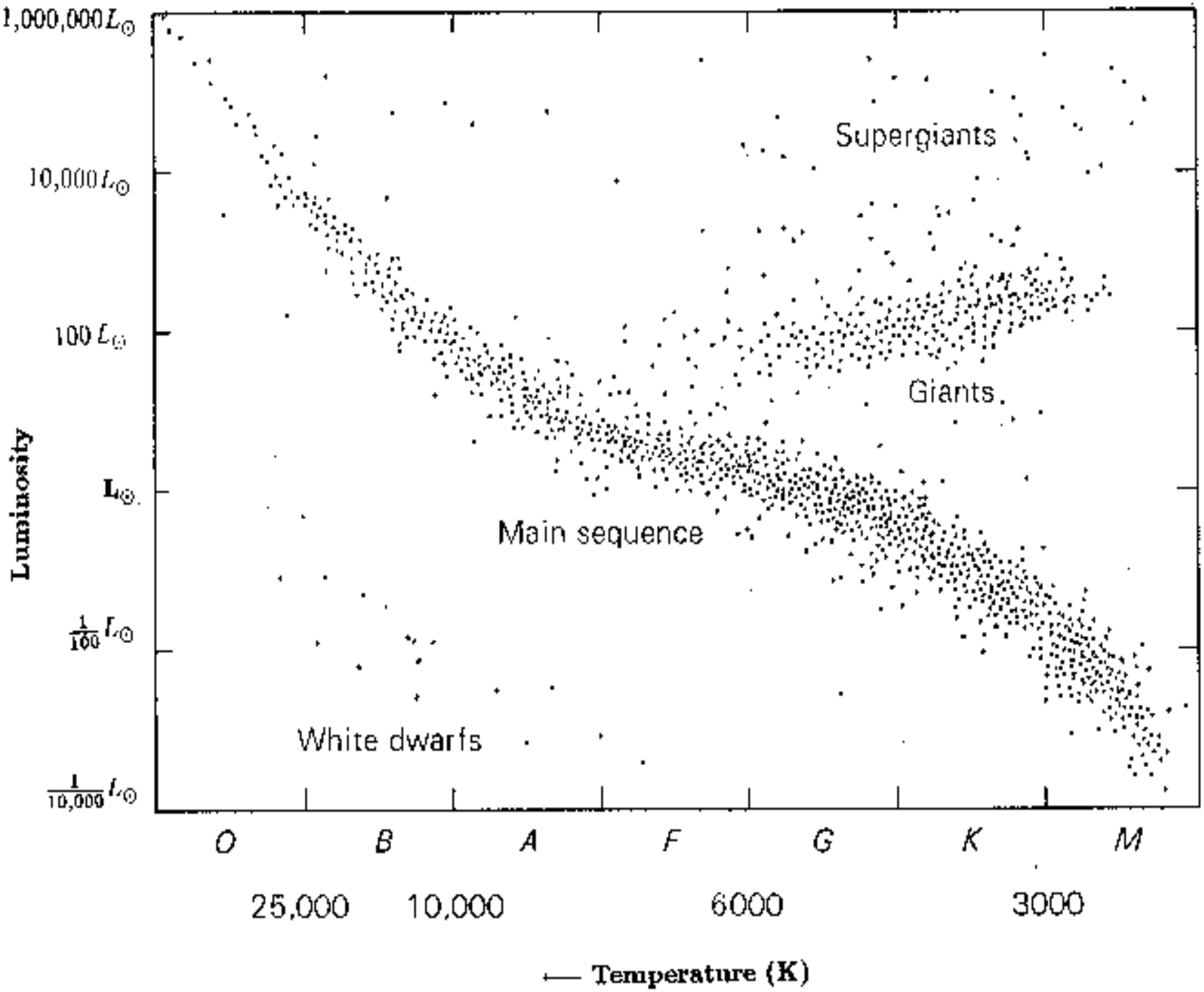


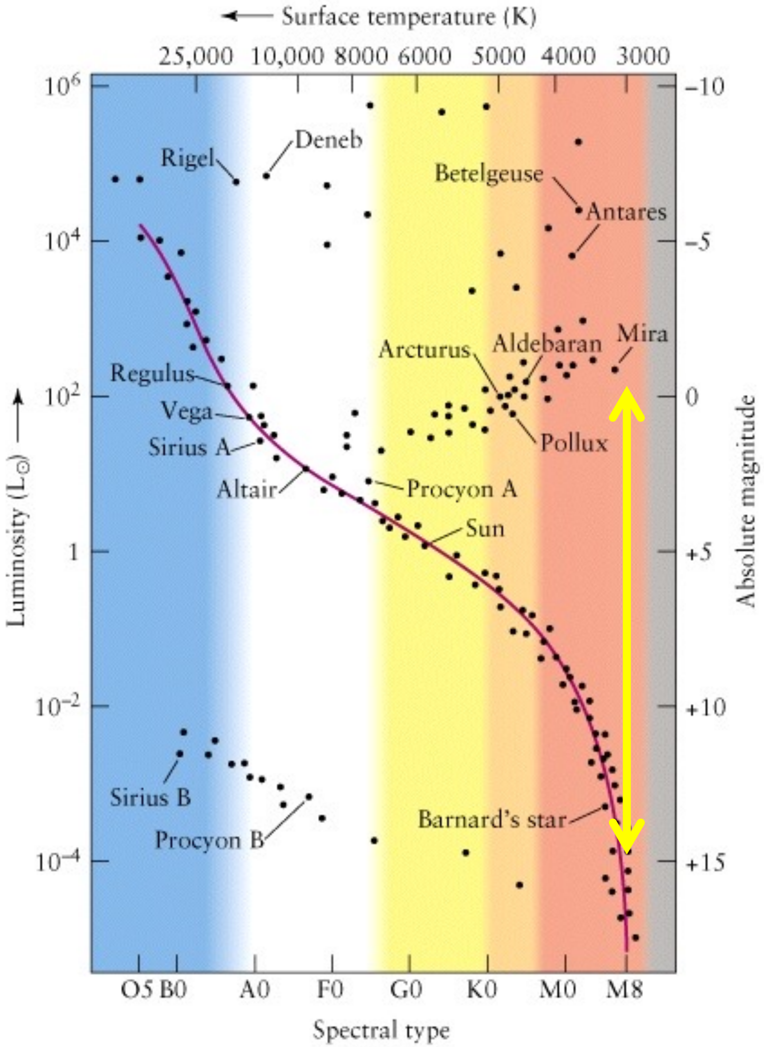
Hertzsprung-Russell Diagram for Stars in the Solar Neighborhood

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 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}?



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

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

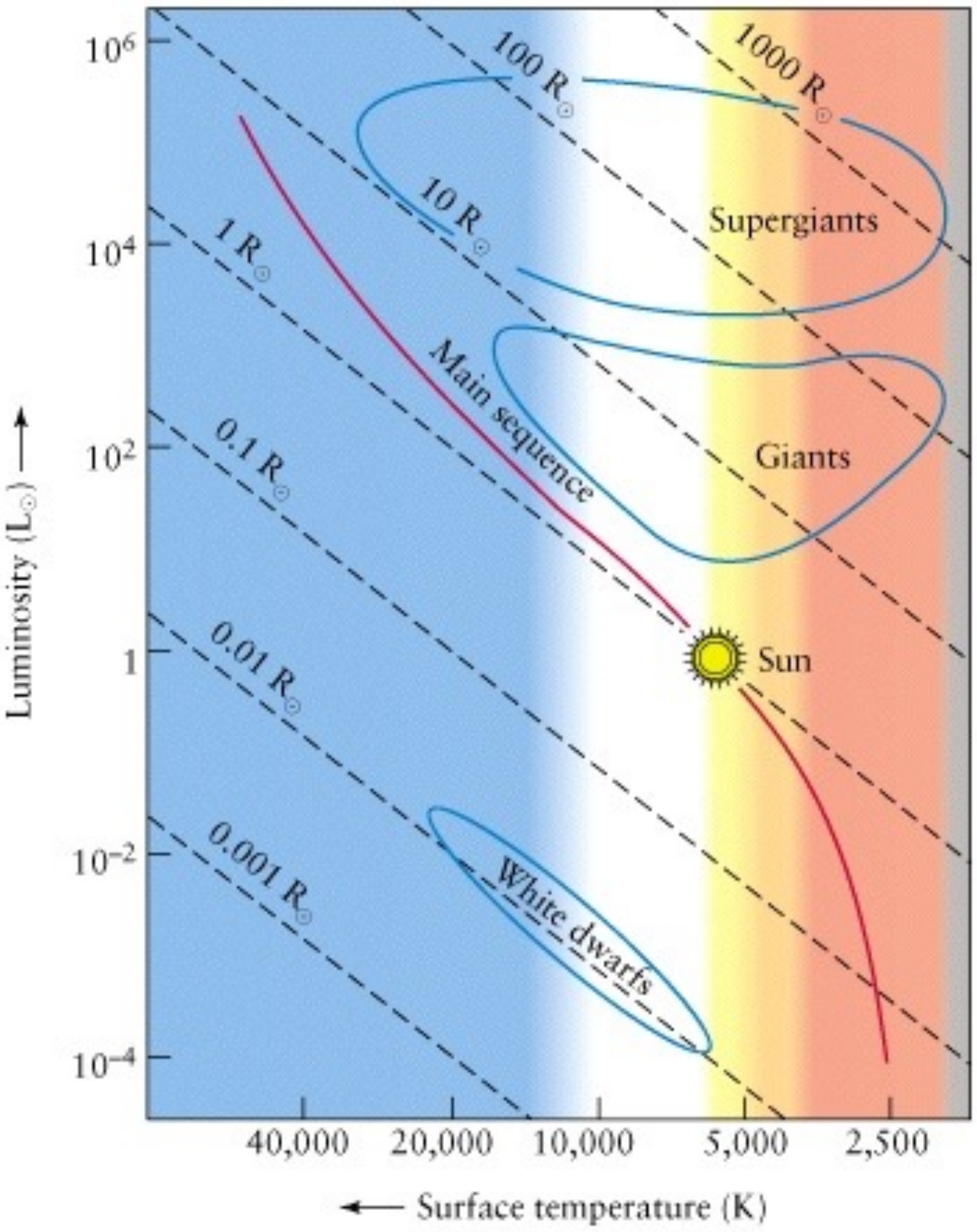
$$\frac{L_{RG}}{L_{RD}} = \left(\frac{R_{RG}}{R_{RD}}\right)^2 \left(\frac{T_{RG}}{T_{RD}}\right)^4$$

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

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

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

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



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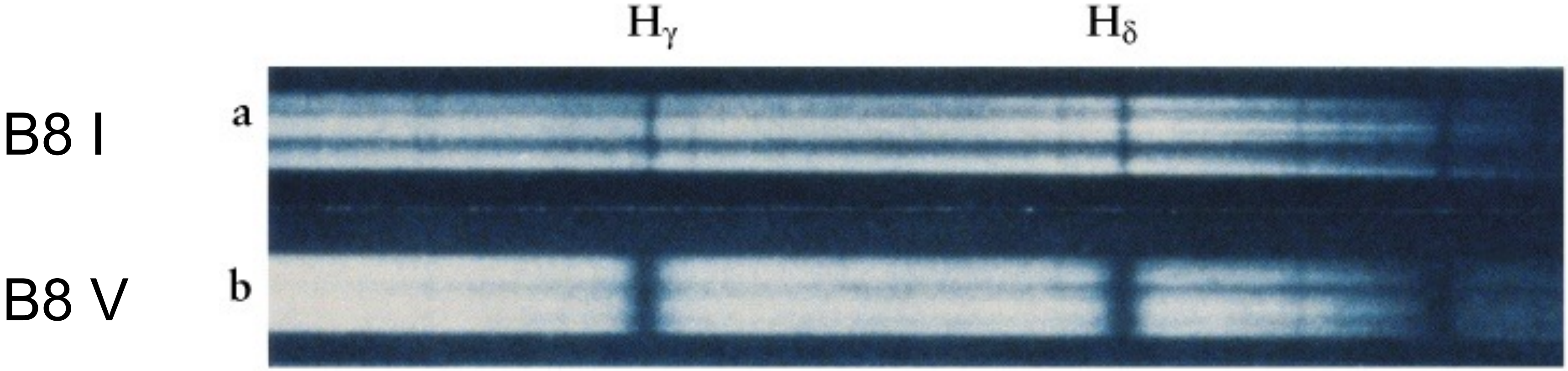
Luminosity Classification

- 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



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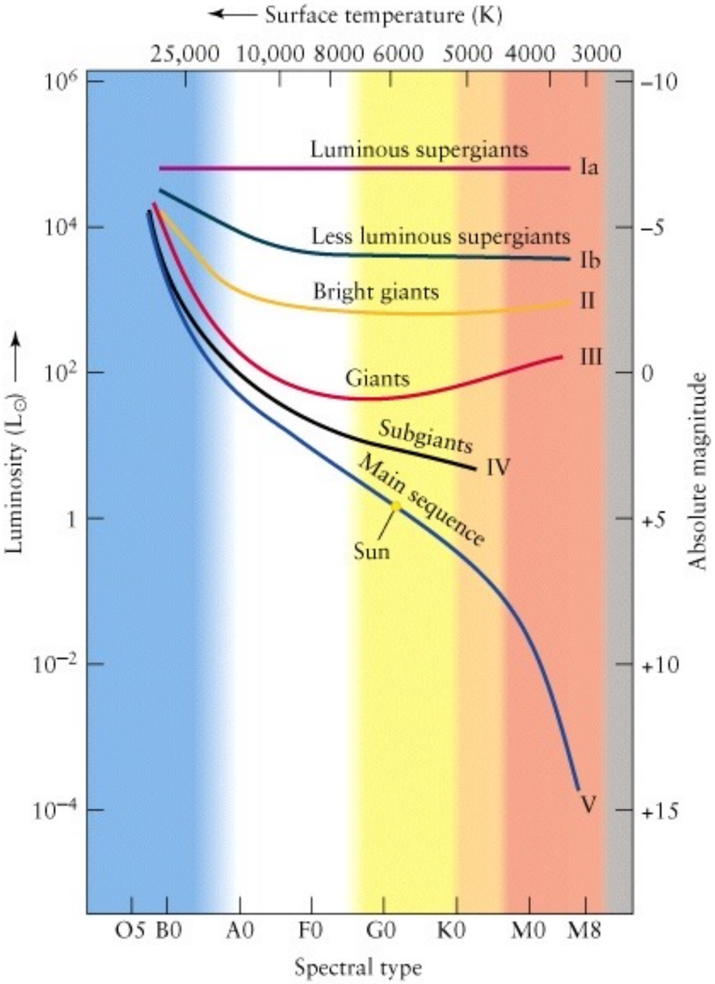
I	II	III	IV	V	VI
super-giants	bright giants	giants	sub-giants	MS (dwarfs)	sub-dwarfs



e.g. The Sun is G2 V

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Mass-Luminosity Relation

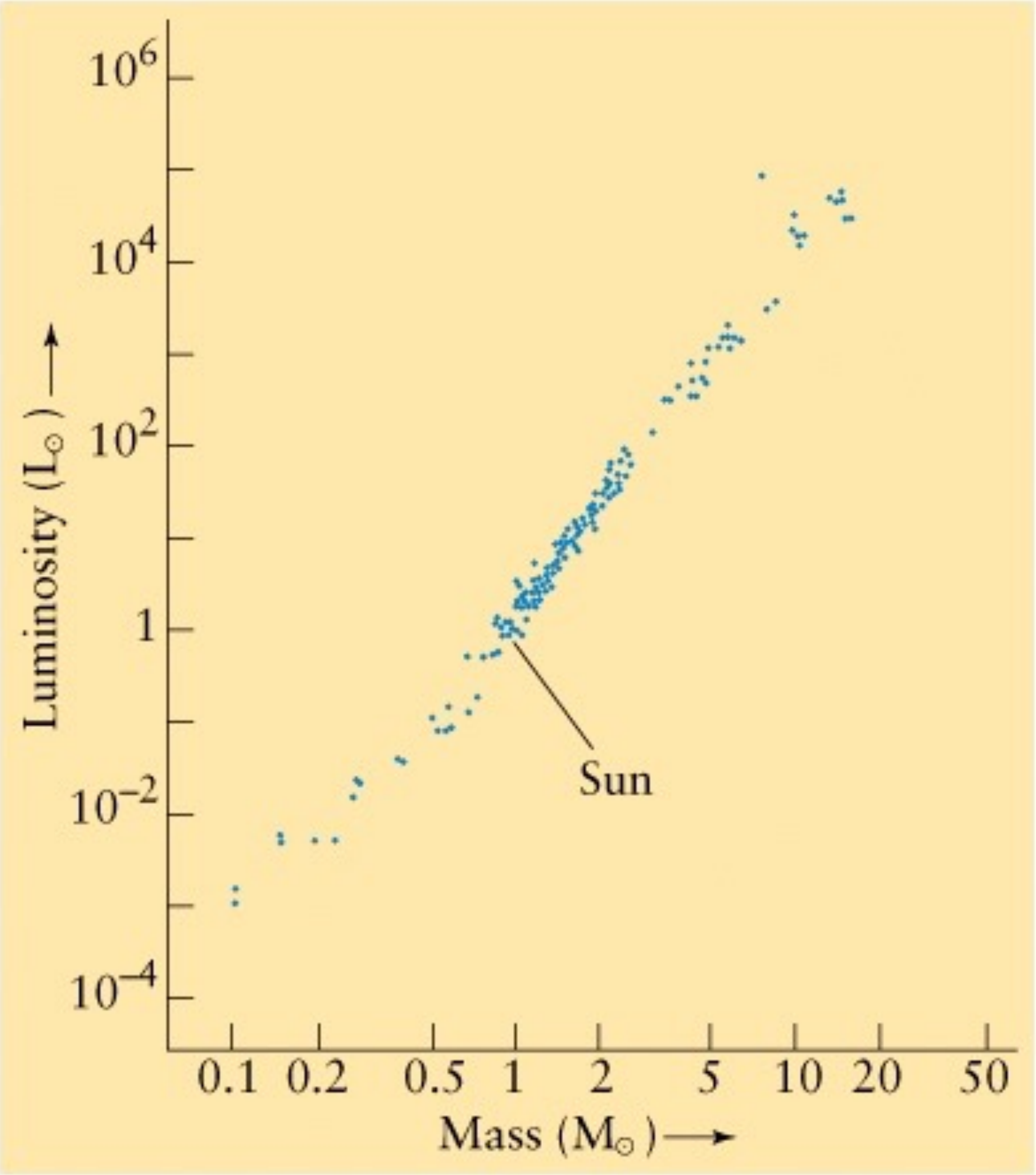
- stellar masses determined from binary stars reveal a relationship between mass and luminosity for main sequence stars of the form

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

- 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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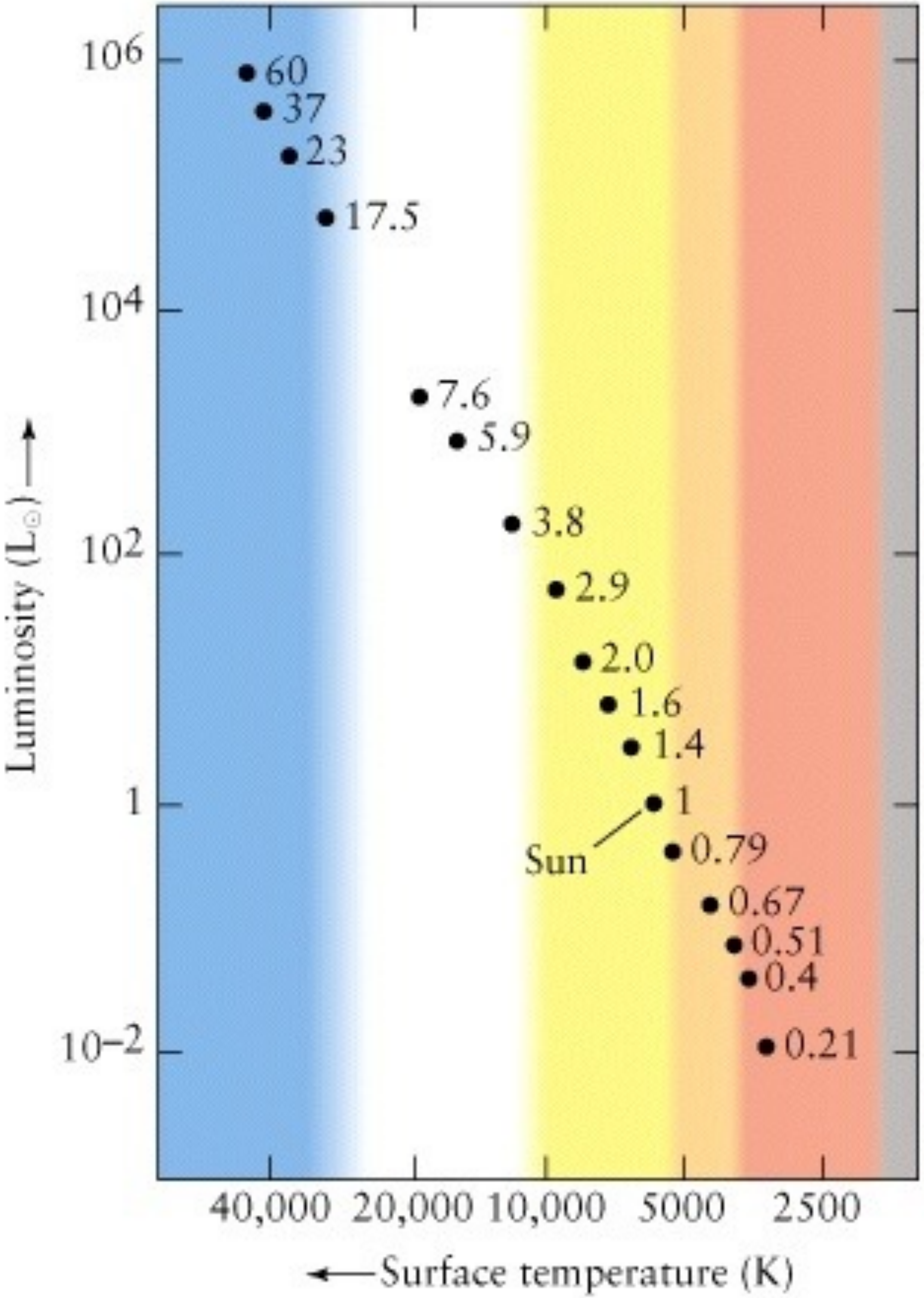
Stellar masses along the main sequence



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

$L \propto M^{3.3}$

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

- 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 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:

$$\tau_{MS} = \tau_{MS}(Sun)\left(M / M_{Sun} \right)^{-2.3}$$

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

and for the least massive:

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

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


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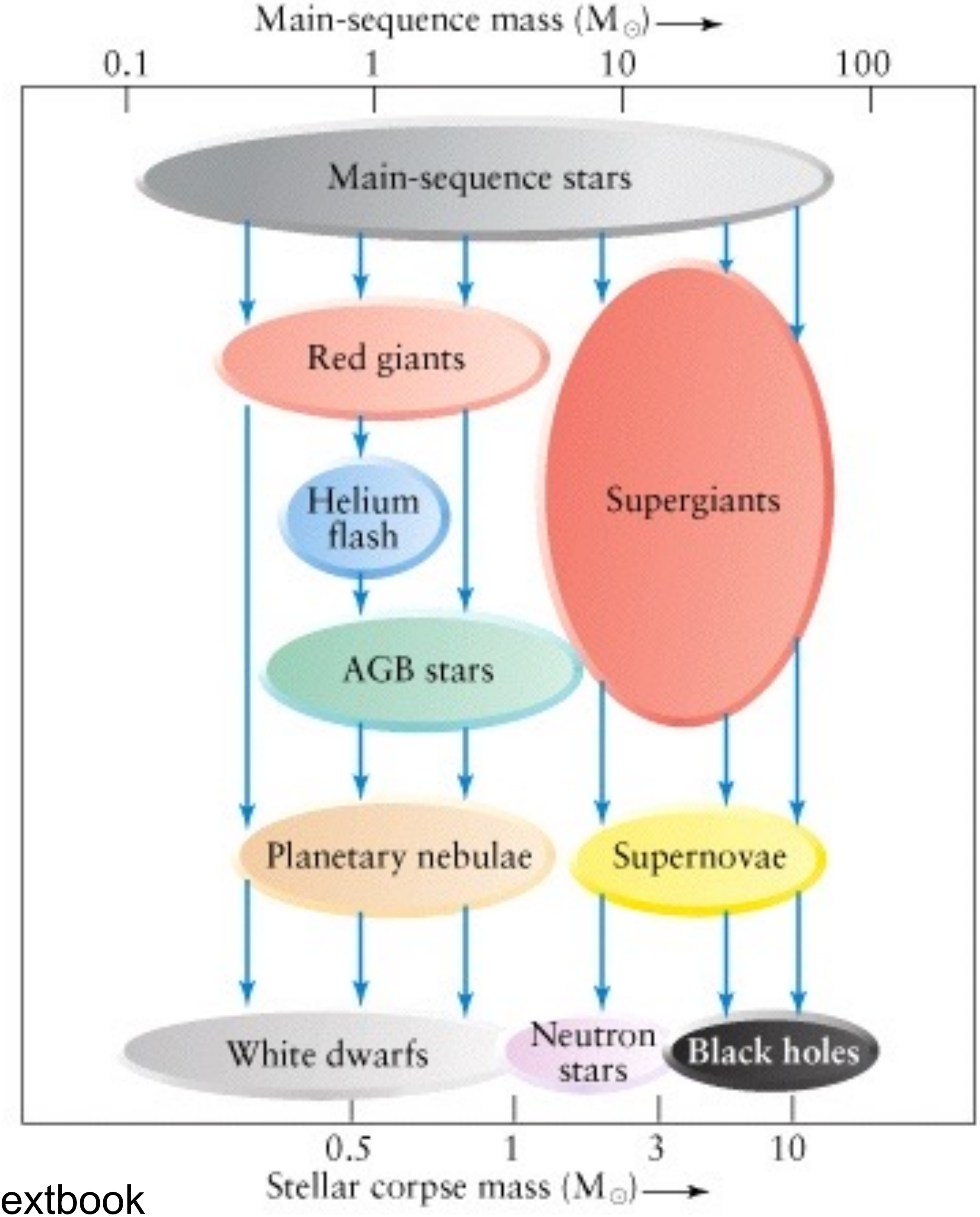
Supernova 1987A before and just after explosion



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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

Class Example

- White dwarf stars have a mass of about 0.6 $M_{\odot}$ and a radius similar to the Earth. What is their average density?