Stars

- Spectral lines from stars
- Binaries and the masses of stars
- Classifying stars: HR diagram
- Luminosity, radius, and temperature
- “Vogt-Russell” theorem
- Main sequence
- Evolution on the HR diagram

A star is at a distance of 1.3 parsecs, what is its parallax?

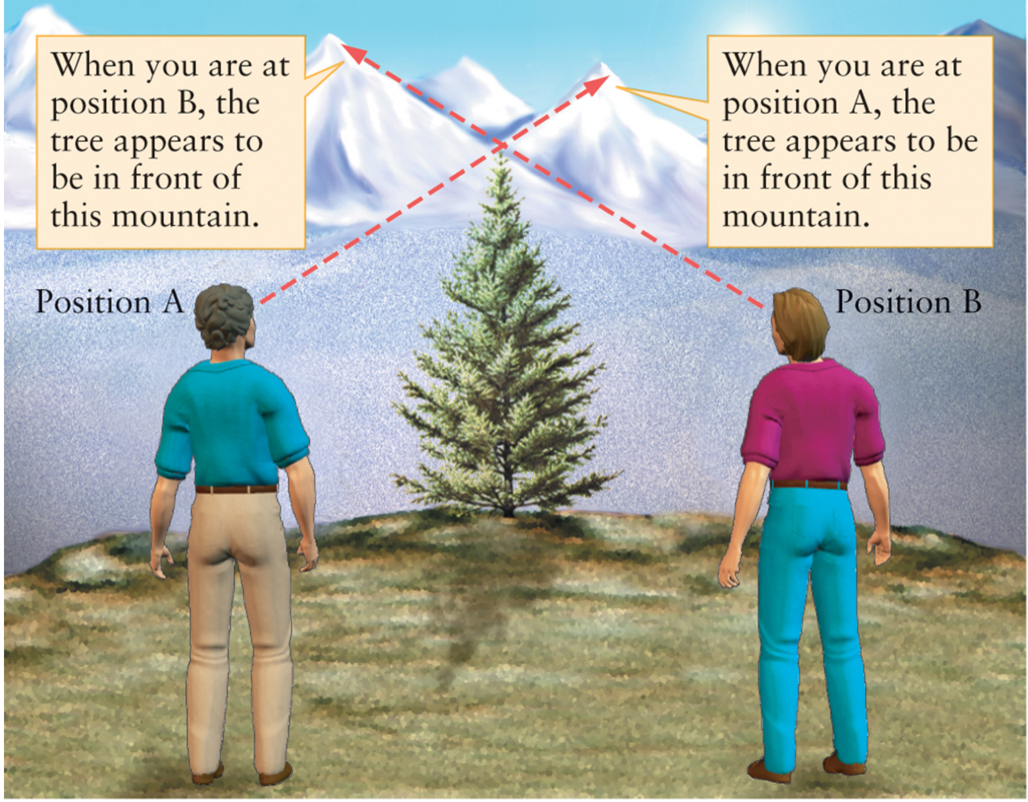
A) About 10 arcseconds
B) About 1 arcsecond
C) About 0.1 arcseconds
D) About 0.01 arcseconds

A star is at a distance of 4×10^{17} meters, what is its parallax?

A) About 10 arcseconds
B) About 1 arcsecond
C) About 0.1 arcseconds
D) About 0.01 arcseconds

Note 1 parsec $\approx 3 \times 10^{16}$ meters

Parallax



- Parallax uses the change in an object's apparent position, compared to the background.
- Imagine looking at some nearby object (a tree) against a distant background (mountains). When you move from one location to another, the nearby object appears to shift with respect to the distant background scenery.

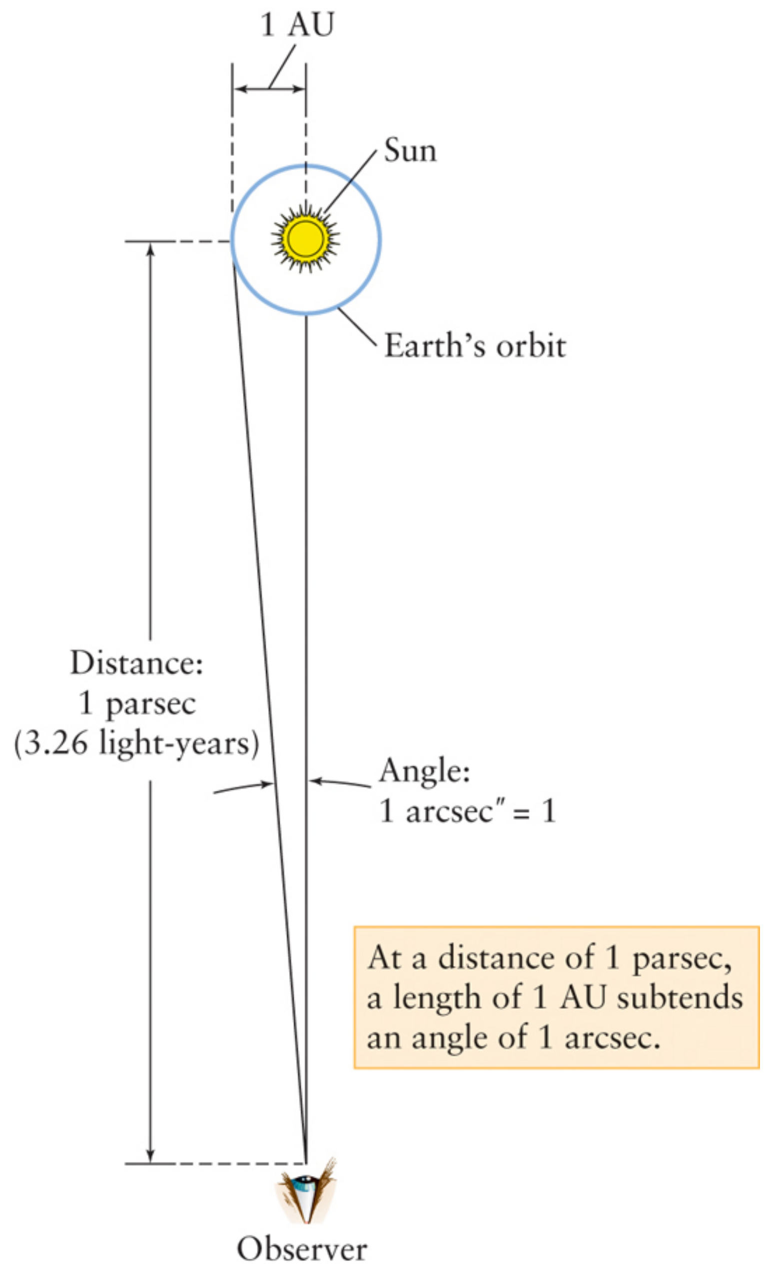
Parallax and the Distances to the Stars

$$d = \frac{1}{p}$$

- d = distance to a star, in parsecs
- p = parallax angle of that star, in arcseconds
- This simple relationship between parallax and distance reveals that the closest stars have the greatest parallax.
- Astronomers often describe distances in parsecs rather than light-years because they use the observed parallax to measure distance.

A “*Parsec*” ?

- The ***parsec***, a unit of length commonly used by astronomers, is equal to 3.26 light-years.
- The parsec is defined as the distance at which 1 AU perpendicular to the observer’s line of sight subtends an angle of 1 arcsec.



Periodic Table

1	2											3	4	5	6	7	8
H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

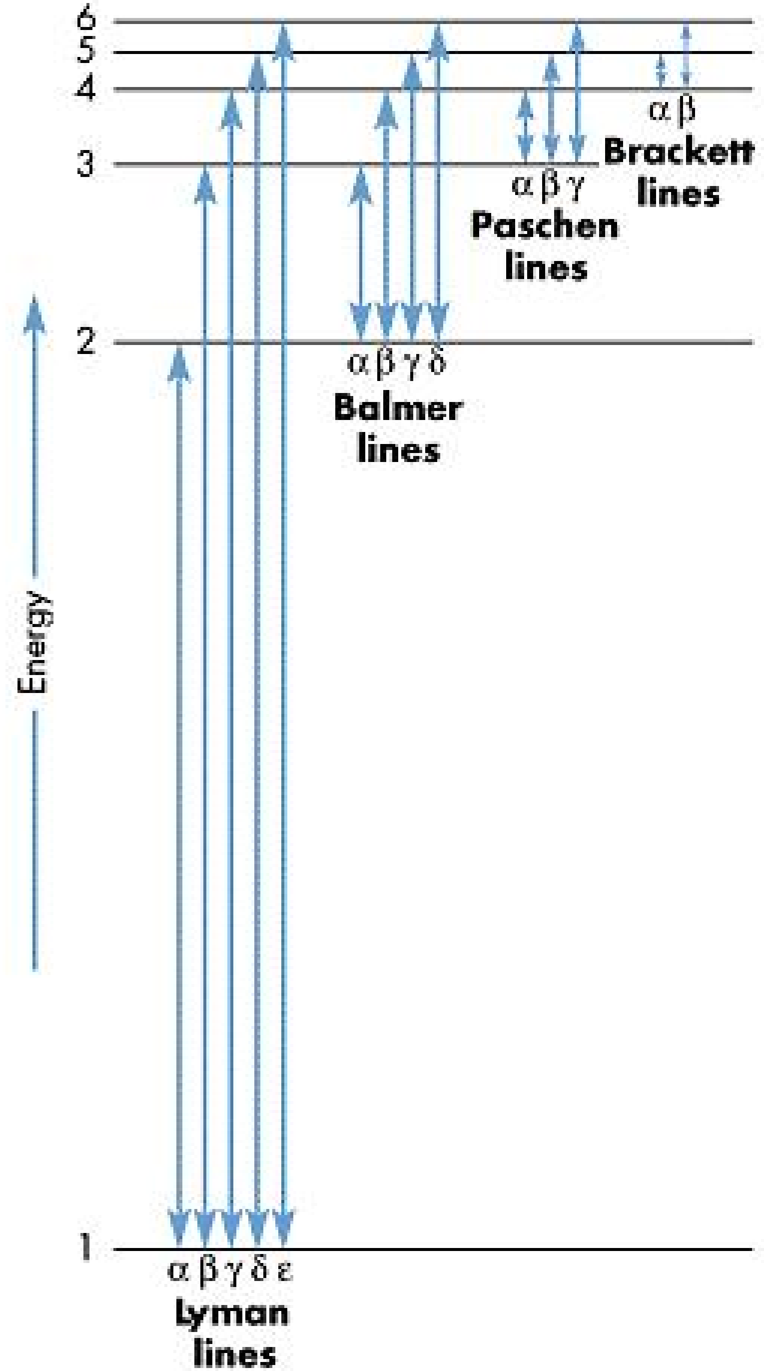
Ordered by number of protons: H=1, He=2, Li=3, …
Columns are determined by chemical properties

When an object is moving towards you, the light it emits is shifted

A) to the left
B) to shorter wavelengths
C) to longer wavelengths
D) the wavelength is unaffected

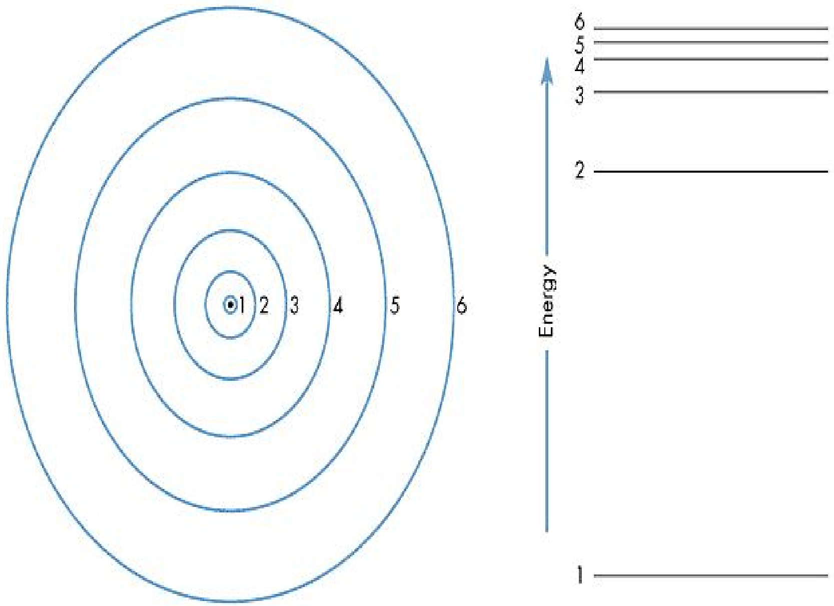
Which of the following types of light has wavelengths shorter than ultraviolet light?

A) visible
B) infrared
C) X-ray
D) radio



Spectral lines of hydrogen

The length of arrow sets energy of emitted photon.



A Possible distances of the electron in a hydrogen atom **B** Energy levels for the hydrogen atom

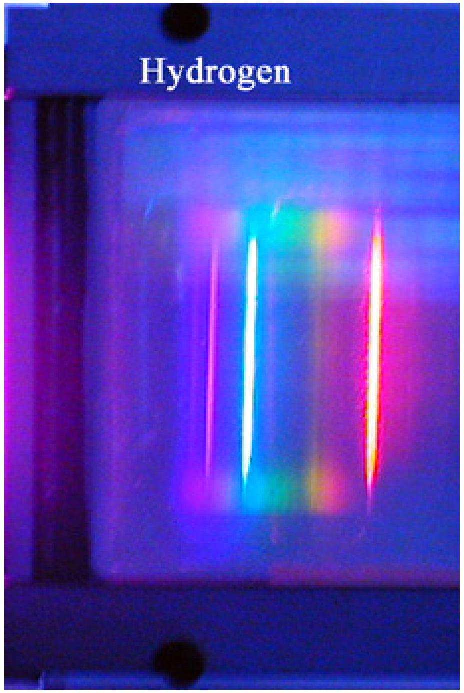
Spectral lines

- Each element (hydrogen, helium, neon, mercury, iron, …) has its own particular set of energy levels and its own set of spectral lines.
- Each element will emit and absorb these lines.

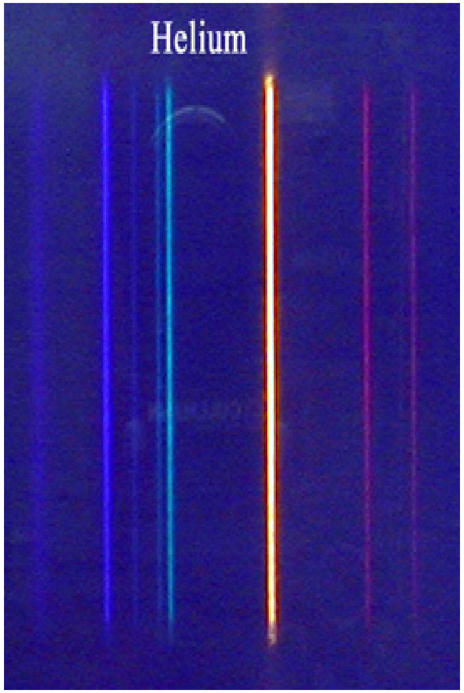
- Do demos (7B10.10, 7B11.15)

Spectra

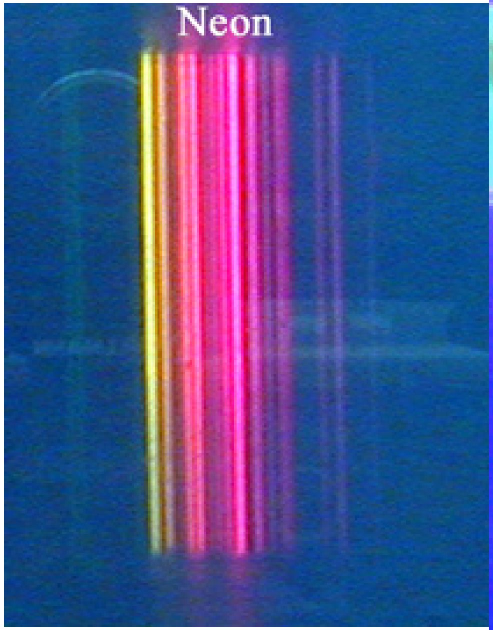
A



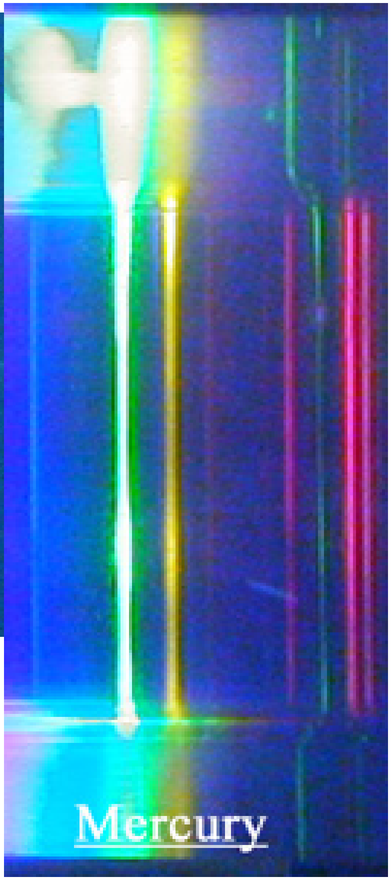
B



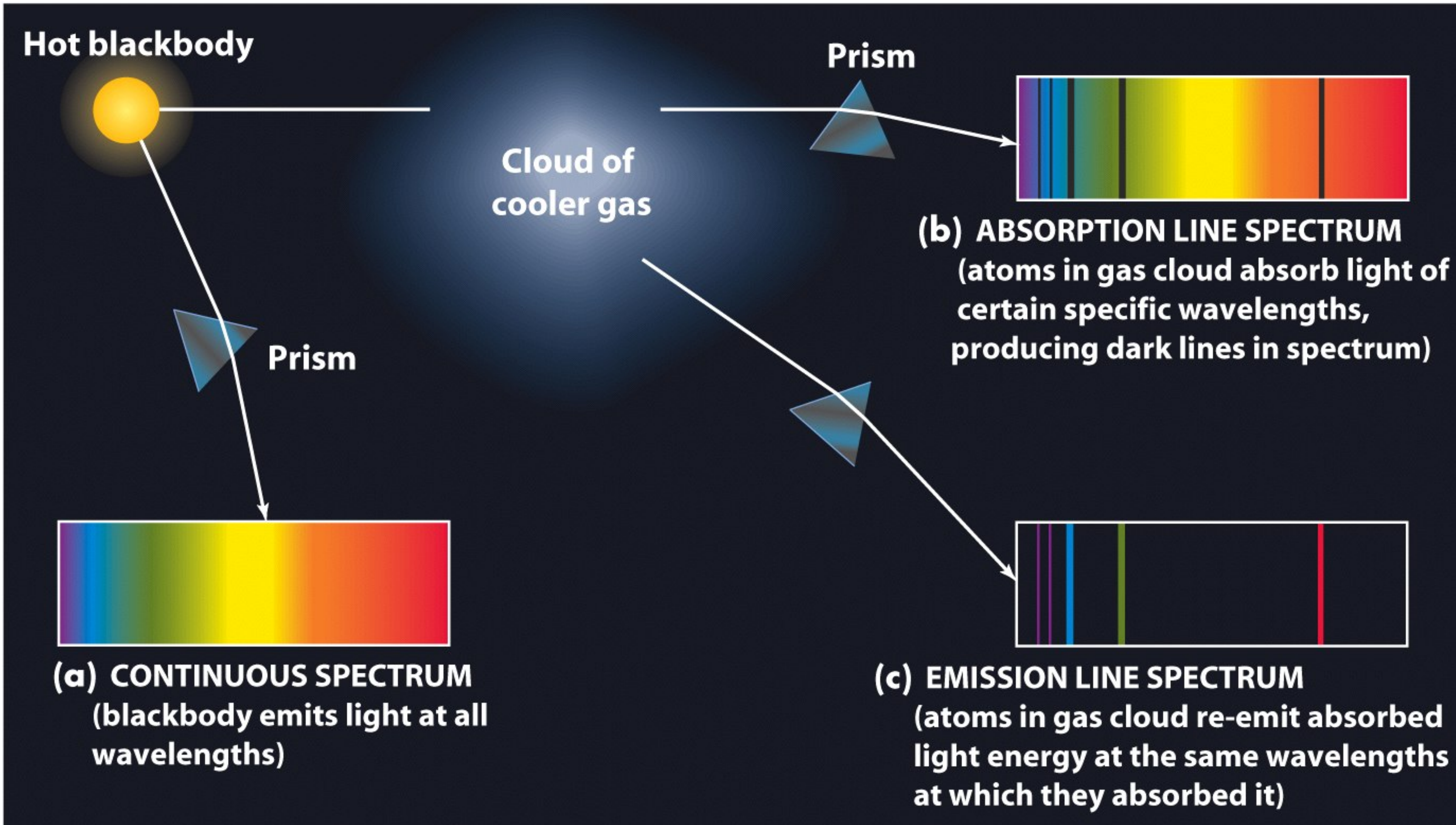
C



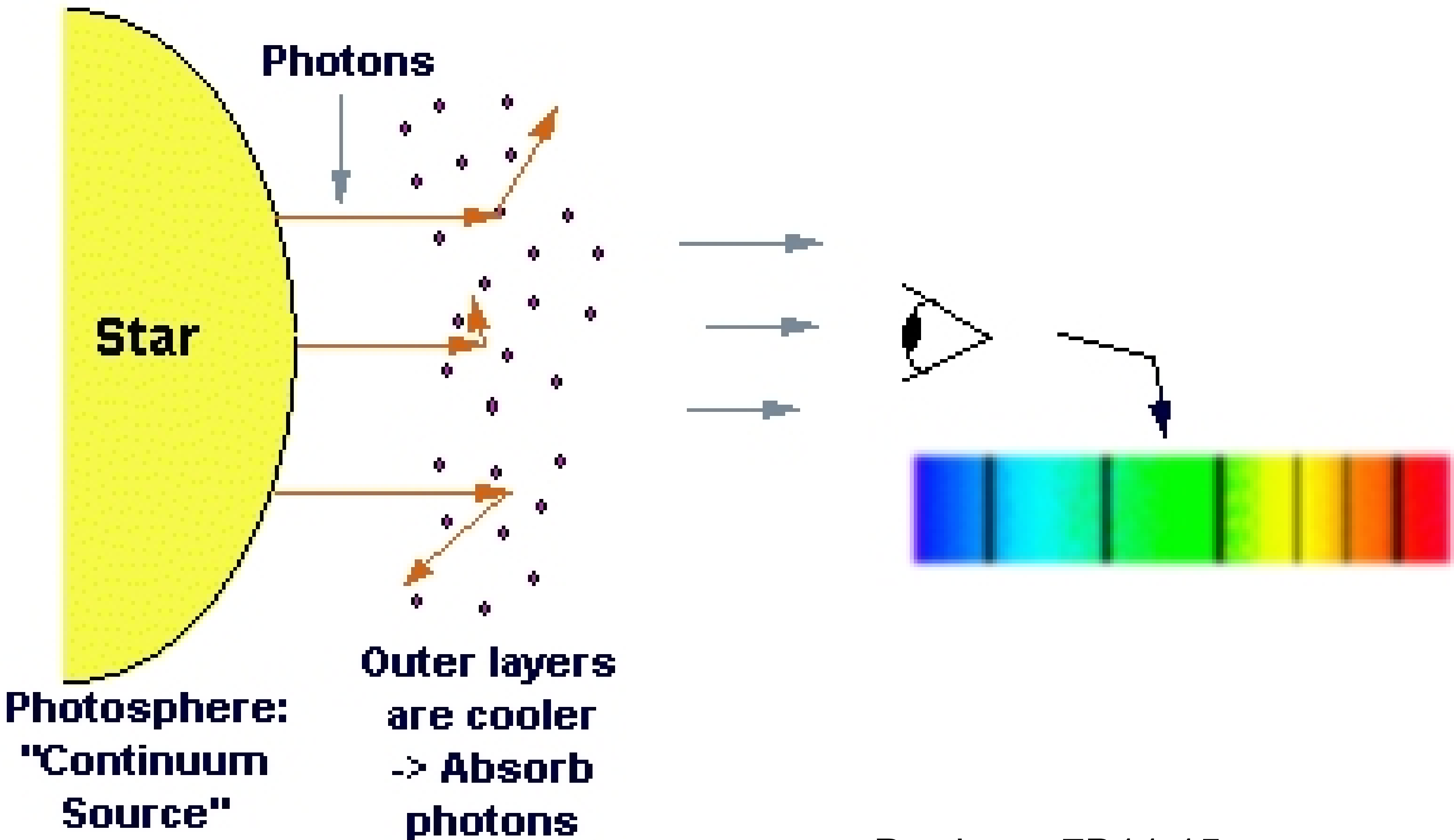
D



Lines can be emitted or absorbed



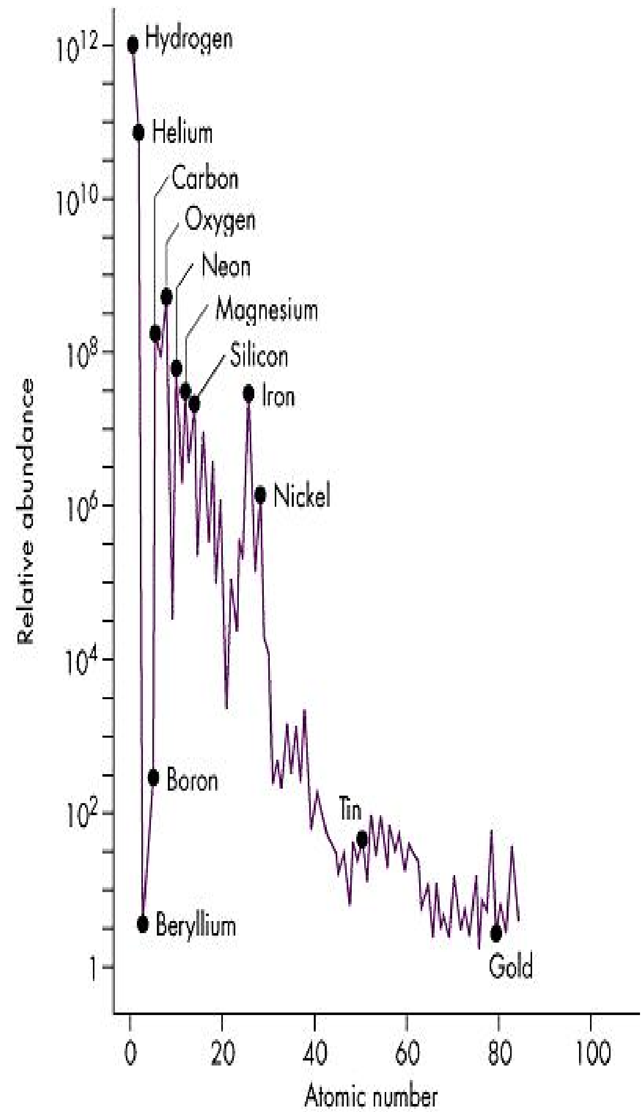
Absorption spectrum of a star



Do demo 7B11.15

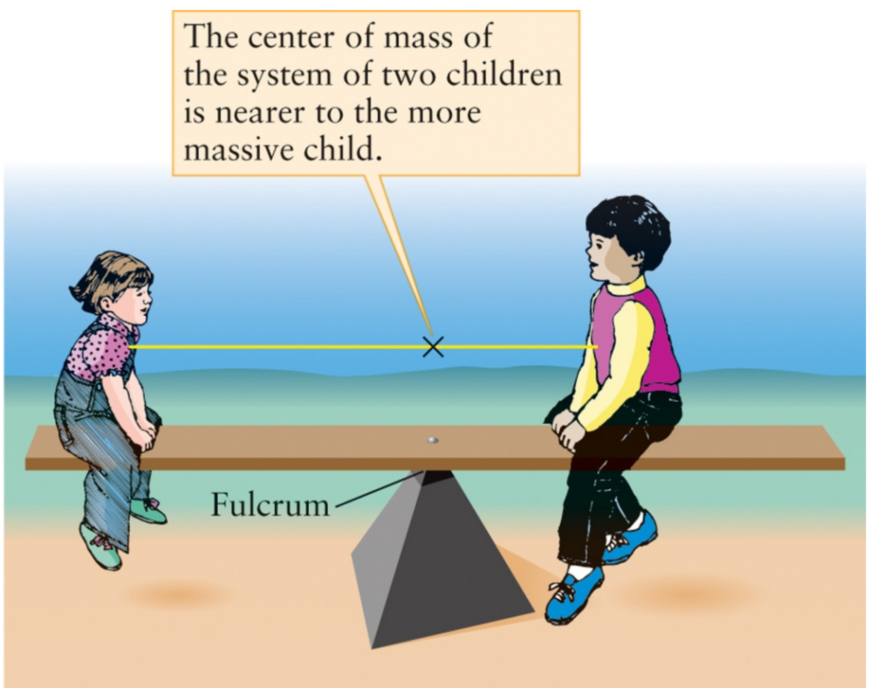
Composition of a typical star

The spectral lines from a star can be used to determine the composition, or the relative number of atoms of each elements, in the star.

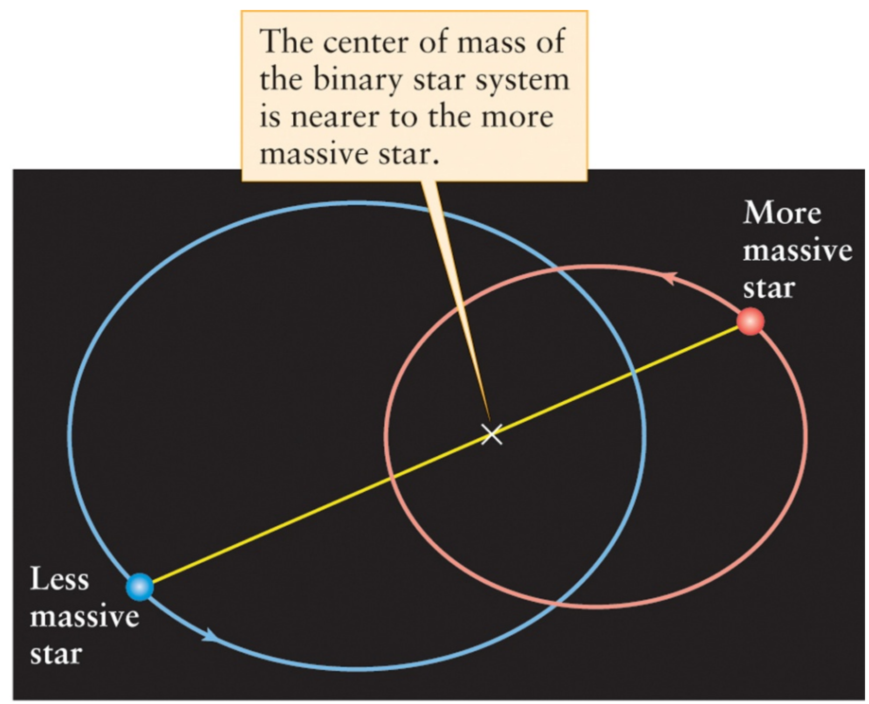


Binary Systems Reveal the Masses of Stars

- There is no direct way to measure the mass of an isolated star.
- ***Binary stars*, or *binaries*,** are pairs of stars that orbit each other.
- Binary stars orbit around their common “center of gravity”.

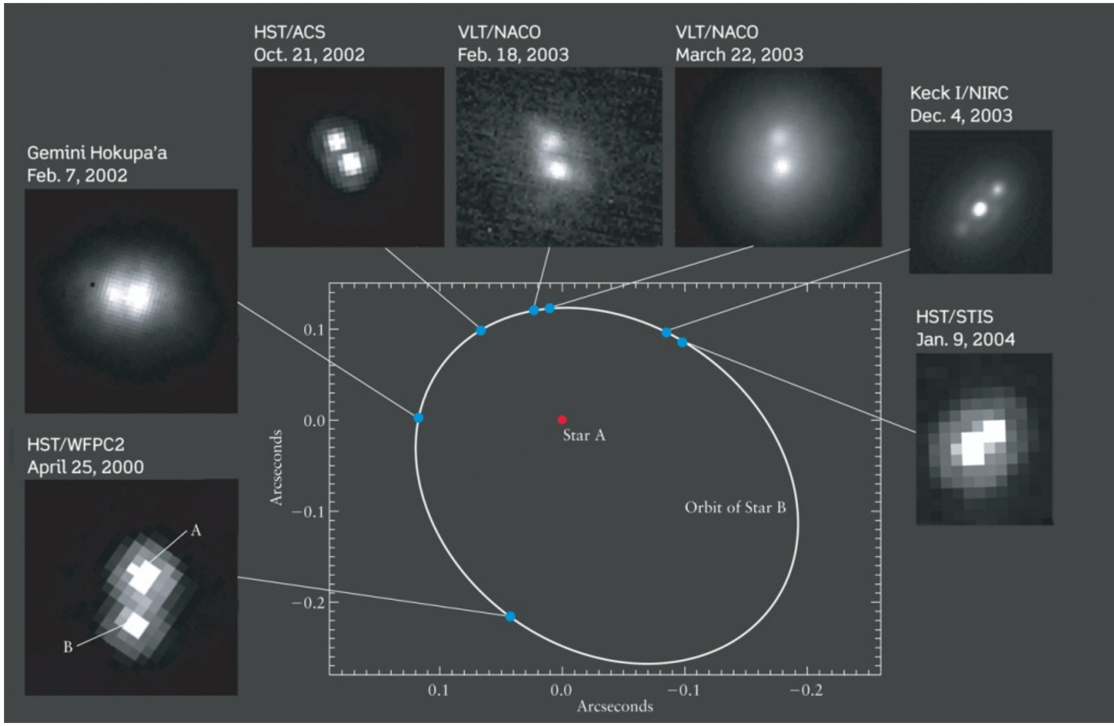


(a) A “binary system” of two children



(b) A binary star system

Binary Systems Reveal the Masses of Stars



- Binary star systems follow Kepler's laws:
  - M_1, M_2 = masses of two stars in solar masses
  - a = semimajor axis of orbit in A.U.
  - P = orbital period in years
- Can use images or Doppler shifts

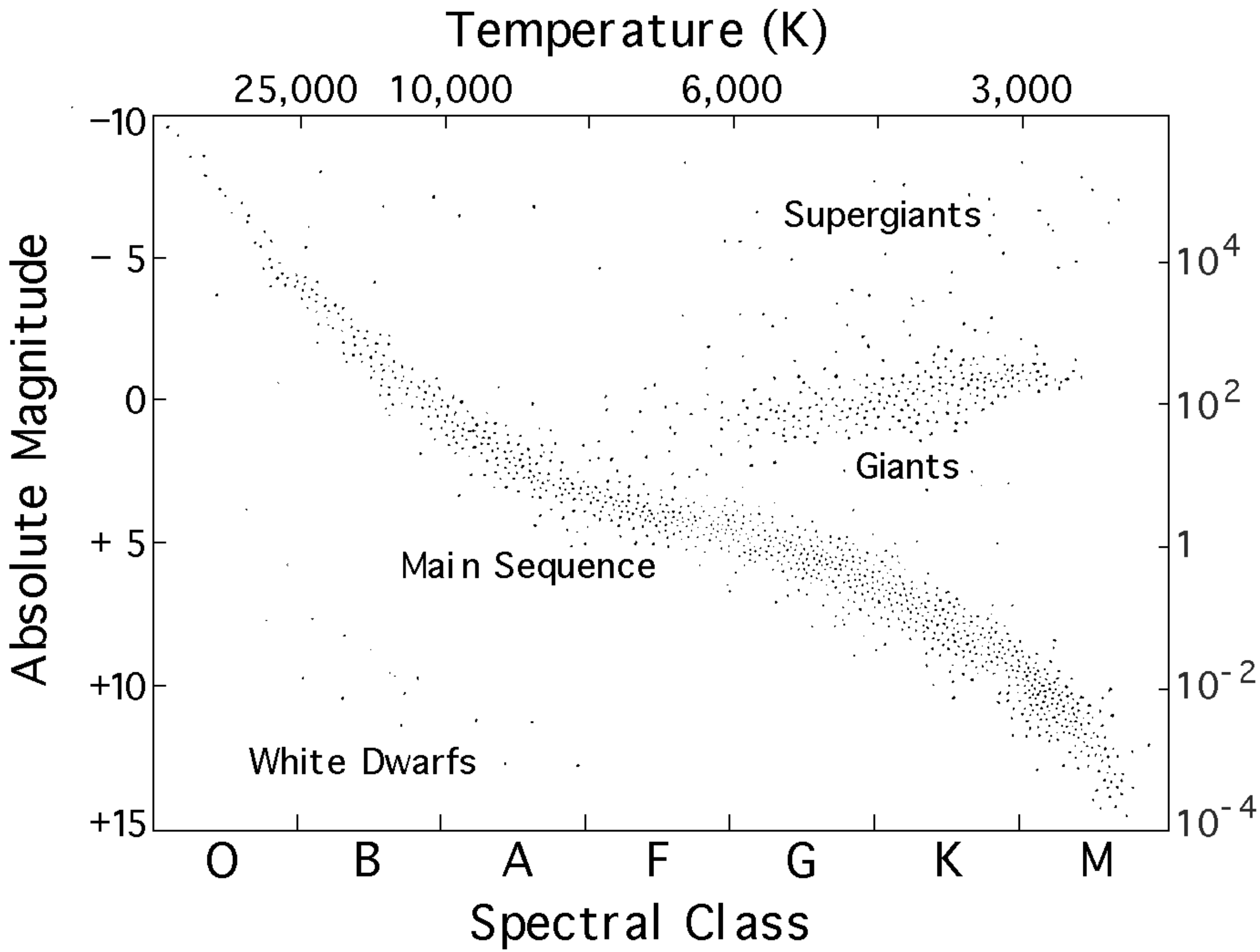
$$M_1 + M_2 = \frac{a^3}{P^2}$$

Classifying stars

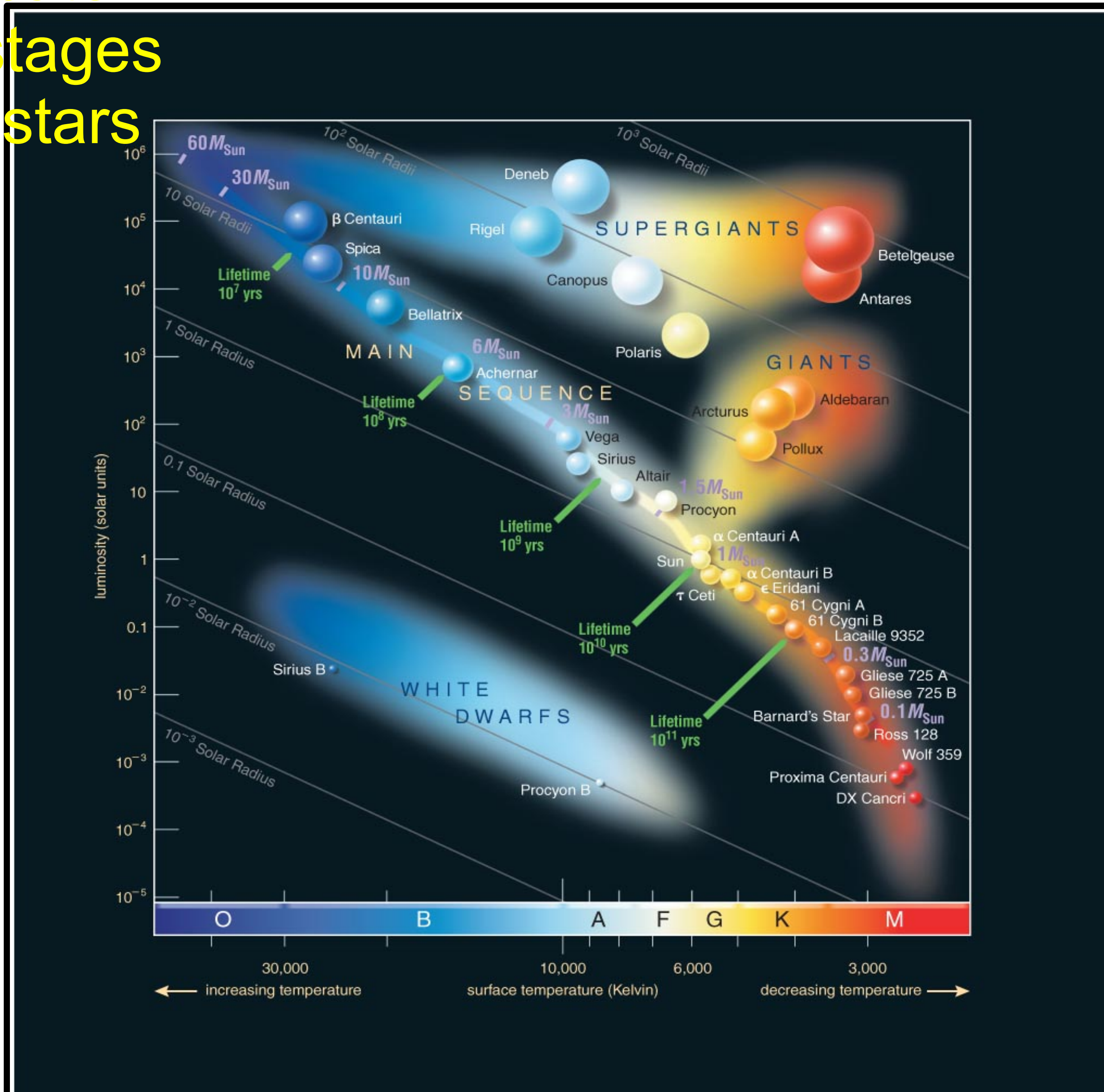
- We now have two properties of stars that we can measure:
  - Luminosity
  - Color/surface temperature

- Using these two characteristics has proved extraordinarily effective in understanding the properties of stars – the Hertzsprung-Russell (HR) diagram

If we plot lots of stars on the HR diagram, they fall into groups



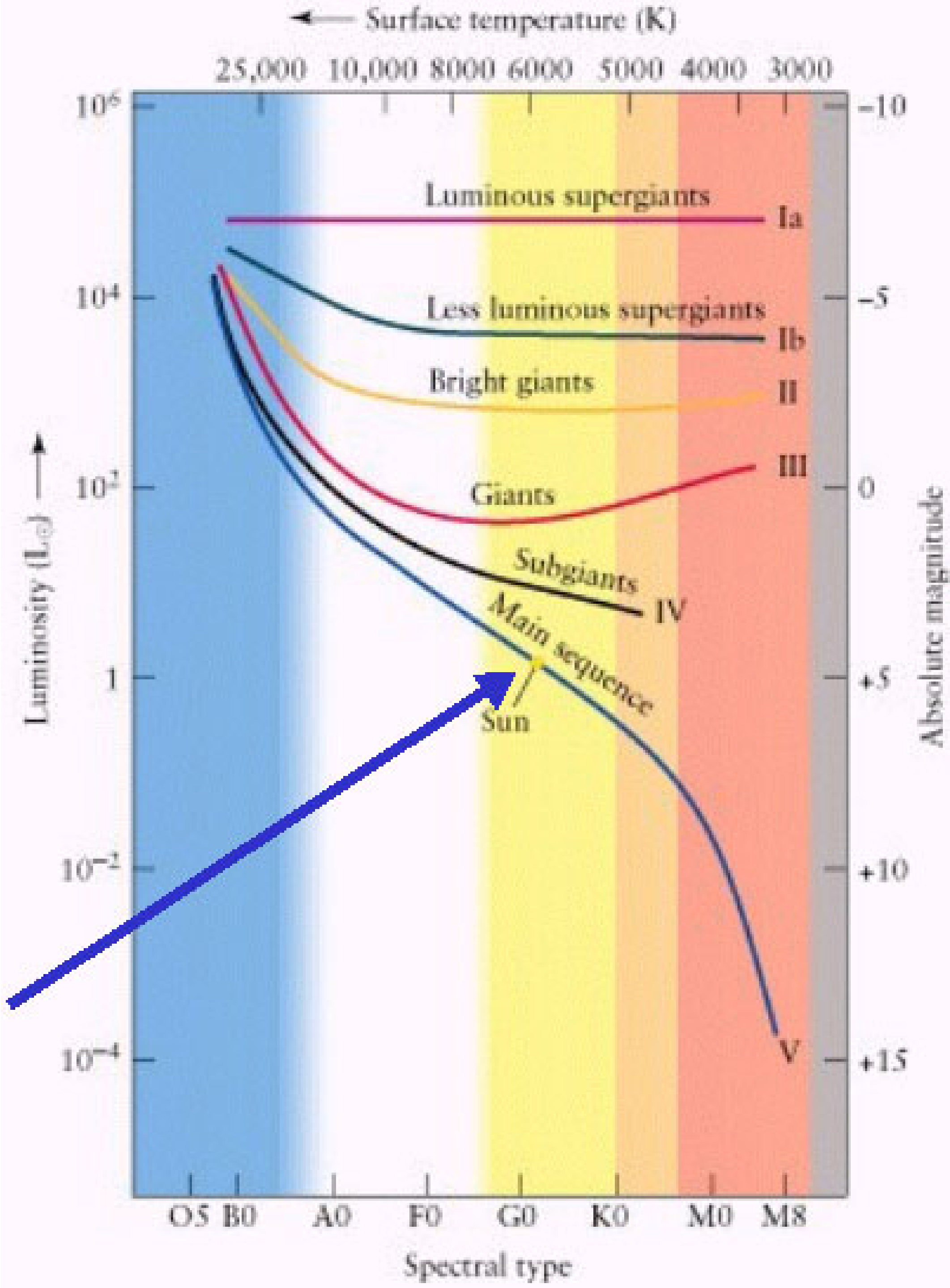
These groups indicate types of stars, or stages in the evolution of stars



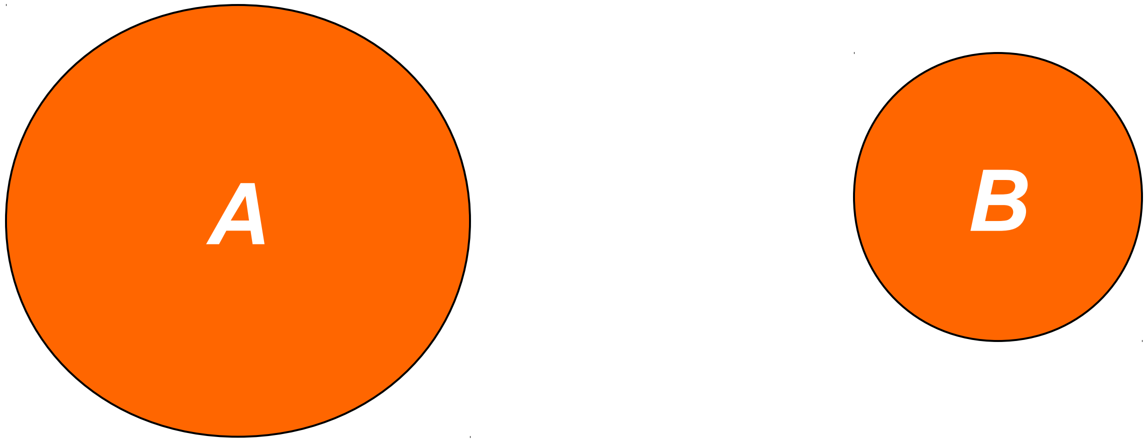
Luminosity classes

- Class Ia,b : Supergiant
- Class II: Bright giant
- Class III: Giant
- Class IV: Sub-giant
- Class V: Dwarf

The Sun is a G2 V star



Luminosity versus radius and temperature



$R = 2\, R_{\mathrm{Sun}}$

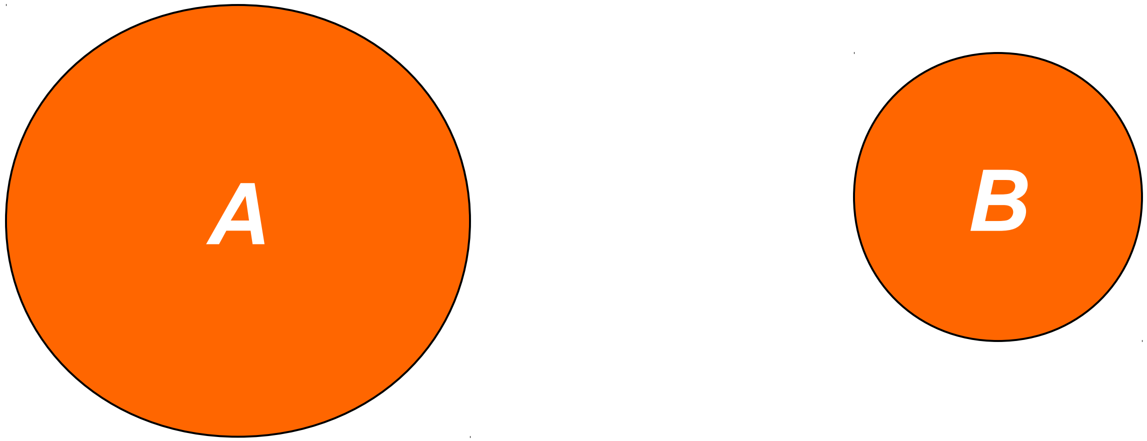
$T = T_{\mathrm{Sun}}$

$R = R_{\mathrm{Sun}}$

$T = T_{\mathrm{Sun}}$

Which star is more luminous?

Luminosity versus radius and temperature



$R = 2\ R_{Sun}$

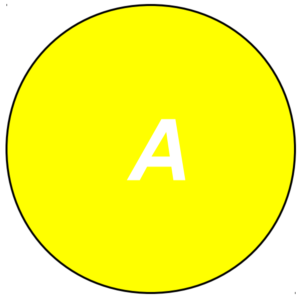
$T = T_{Sun}$

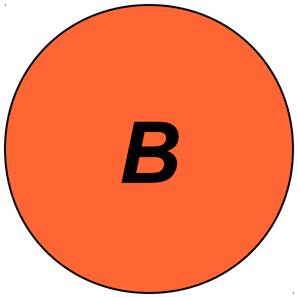
$R = R_{Sun}$

$T = T_{Sun}$

- Each cm^2 of each surface emits the same amount of radiation.
- The larger stars emits more radiation because it has a larger surface, $A = 4\pi R^2$. It emits 4 times as much radiation.

Luminosity versus radius and temperature





$R = R_{Sun}$ $\quad$ $R = R_{Sun}$

$T = 2T_{Sun}$ $\quad$ $T = T_{Sun}$

Which star is more luminous?

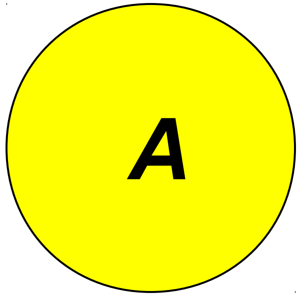
Press A for Star A, B for star B

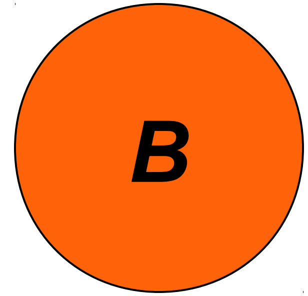
Luminosity Law

$$\frac{L_A}{L_B} = \frac{R_A^2 T_A^4}{R_B^2 T_B^4}$$

If star A is 2 times as hot as star B, and the same radius, then it will be $2^4 = 16$ times as luminous.

Luminosity versus radius and temperature



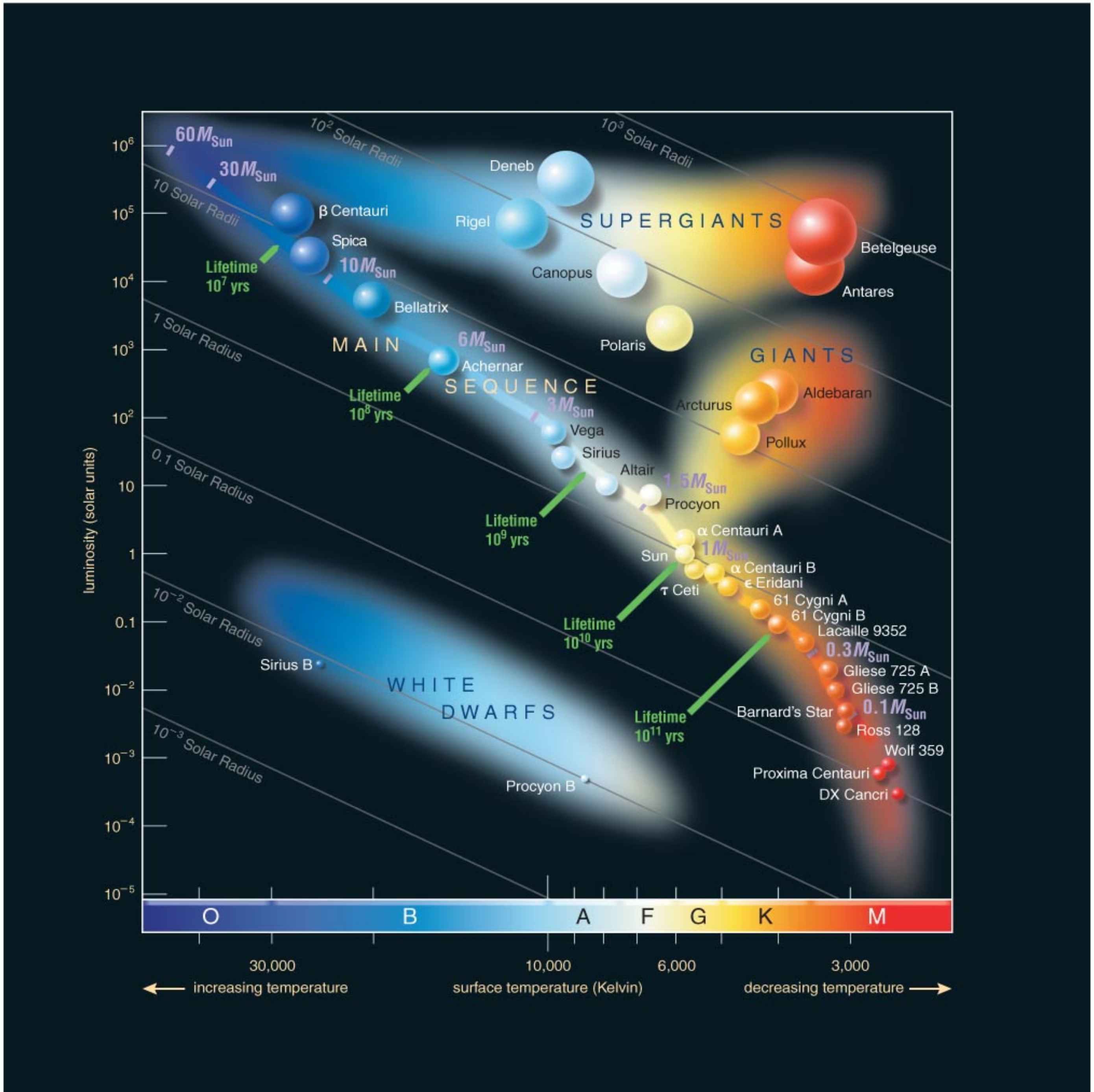


$R = 0.5R_{Sun}$ $\quad$ $R = R_{Sun}$

$T = 2T_{Sun}$ $\quad$ $T = T_{Sun}$

How much more luminous is star A?

A) 2x, B) 4x, C) 8x, D) 16x, E) 32x



From a star's luminosity and temperature, we can calculate the radius.

Properties of Stars

- Stars have many different properties: mass, luminosity, radius, chemical composition, surface temperature, core temperature, core density, …
- However, the entire history of how an isolated star will evolve – meaning how the properties of the star will change with time – is determined by just two properties: **mass** and **chemical composition**.
- This is the “Vogt-Russell” theorem.

“Vogt-Russell” theorem for spheres of water

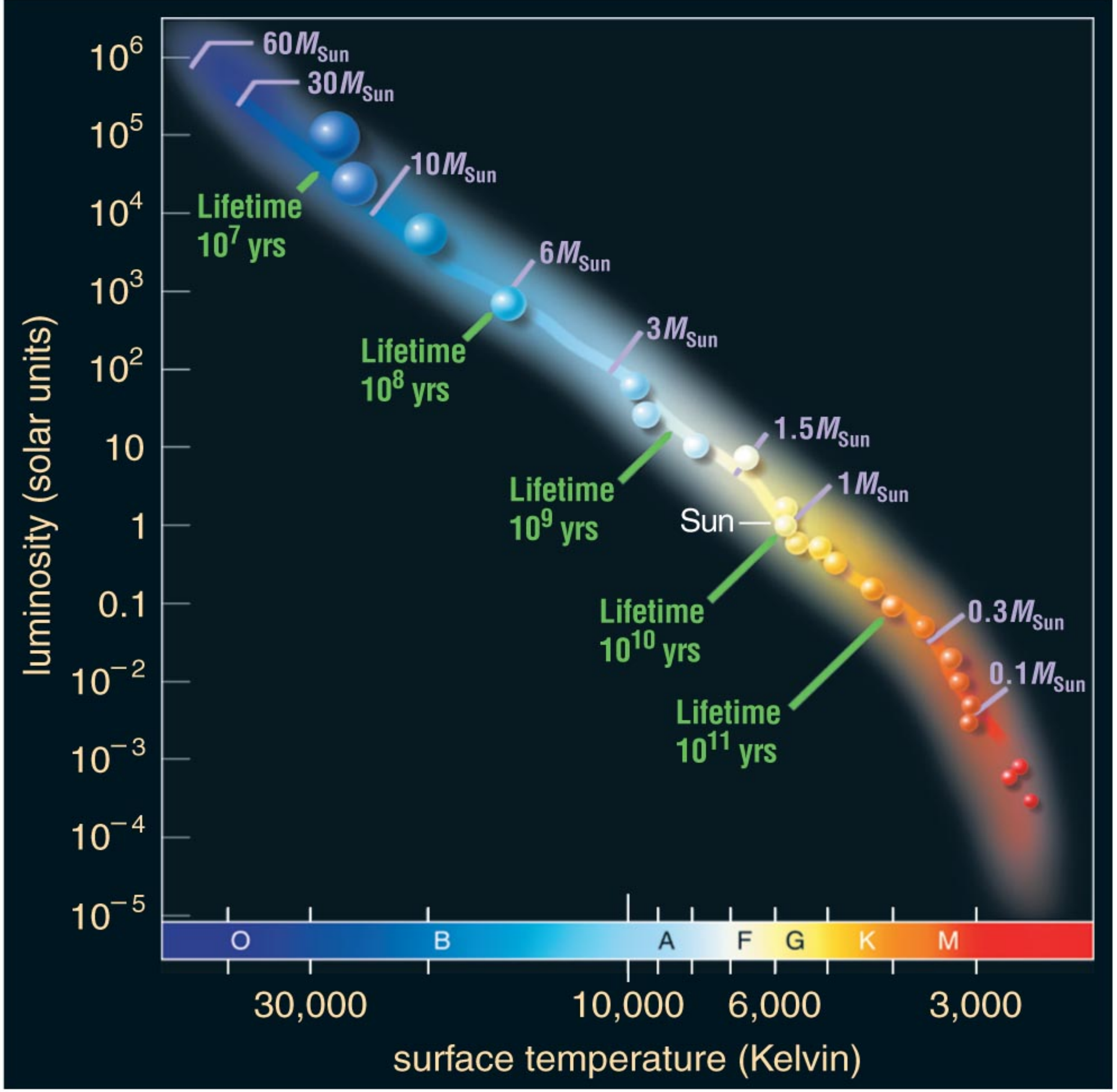
- Spheres of water have several properties: mass, volume, radius, surface area …
- We can make a “Vogt-Russell” theorem for balls of water that says that all of the other properties of a ball of water are determined by just the mass and even write down equations, e.g.
  mass = volume $\times$ density of water.
- The basic idea is that there is only one way to make a sphere of water with a given mass.

“Vogt-Russell” theorem

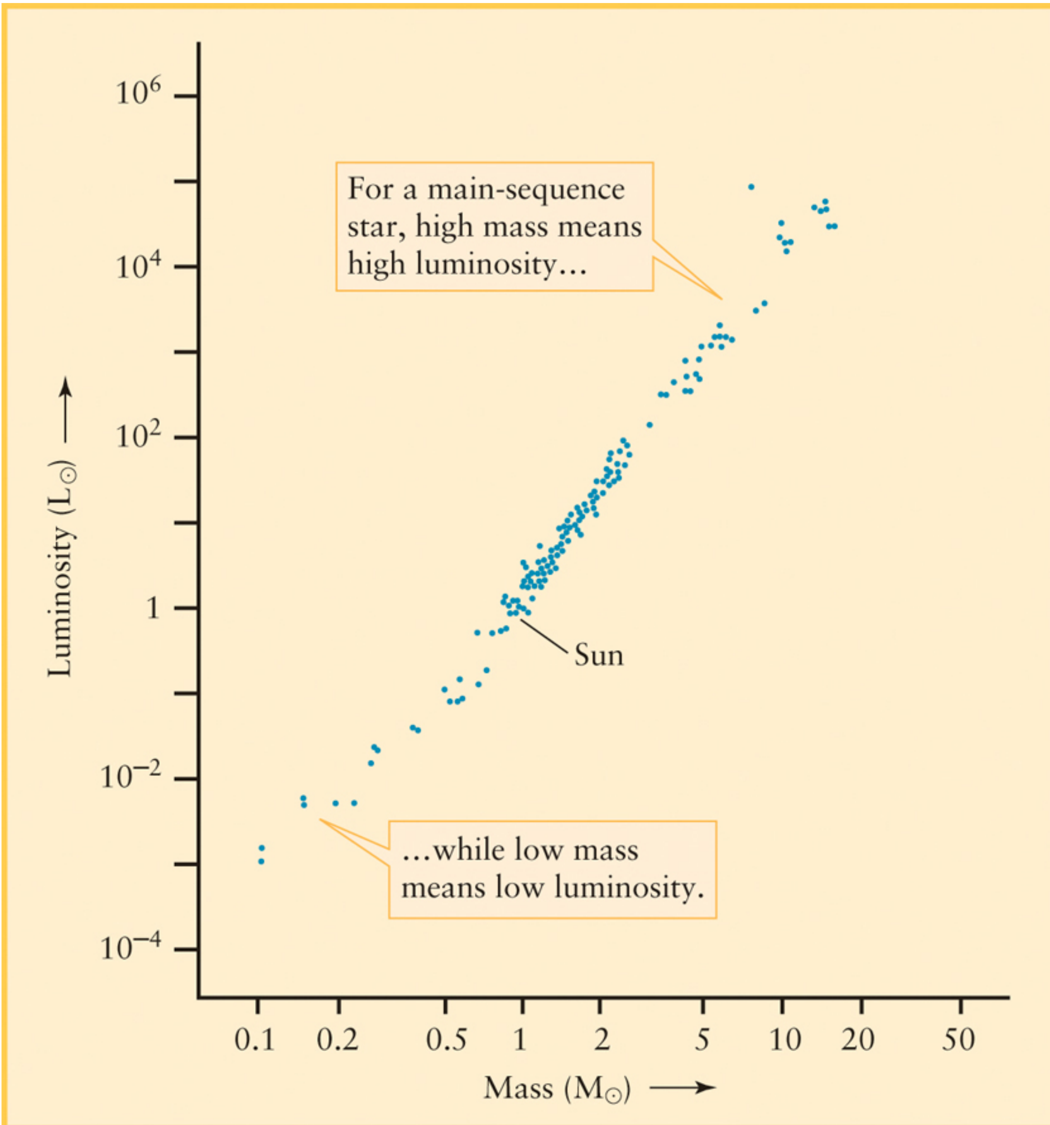
- The idea of the “Vogt-Russell” theorem for stars is that there is only one way to make a star with a given mass and chemical composition – if we start with a just formed protostar of a given mass and chemical composition, we can calculate how that star will evolve over its entire life.
- This is extremely useful because it greatly simplifies the study of stars and is the basic reason why the HR diagram is useful.

HR diagram

Main sequence is when a star is burning hydrogen in its core.
The luminosity and temperature of a main-sequence star are set by its mass.
More massive means brighter and hotter.



Mass-Luminosity relation on the main sequence



$$\frac{L}{L_\Theta} \approx \left(\frac{M}{M_\Theta} \right)^{3.5}$$

Mass-Lifetime relation

- The lifetime of a star (on the main sequence) is longer if more fuel is available and shorter if that fuel is burned more rapidly
- The available fuel is (roughly) proportional to the mass of the star
- From the previous, we known that luminosity is much higher for higher masses
- We conclude that higher mass star live shorter lives

A ten solar mass star has about ten times the sun's supply of nuclear energy. Its luminosity is 3000 times that of the sun. How does the lifetime of the star compare with that of the sun?

A) 10 times as long

B) the same

C) 1/300 as long

D) 1/3000 as long

A ten solar mass star has about ten times the sun's supply of nuclear energy. Its luminosity is 3000 times that of the sun. How does the lifetime of the star compare with that of the sun?

$$\frac{t_A}{t_B} = \frac{M_A}{M_B}\frac{L_B}{L_A} = \frac{10}{1}\frac{1}{3000} = \frac{1}{300}$$

Mass-Lifetime relation

Mass/mass of Sun	Lifetime (years)
60	400,000
10	30,000,000
3	600,000,000
1	10,000,000,000
0.3	200,000,000,000
0.1	3,000,000,000,000

For main-sequence stars, the hottest stars are also the:

A) closest.
B) dimmest.
C) most massive.
D) smallest.

For main-sequence stars, the hottest stars also have:

A) the shortest lives.
B) the longest lives.
C) the largest pay checks.
D) lifetime does not depend on temperature.

Review Questions

- What tool do astronomers use to understand the evolution of stars?
- What is the relation between luminosity, radius, and temperature?
- What parameters determine the evolution of a star?
- How does a star’s mass influence its lifetime?