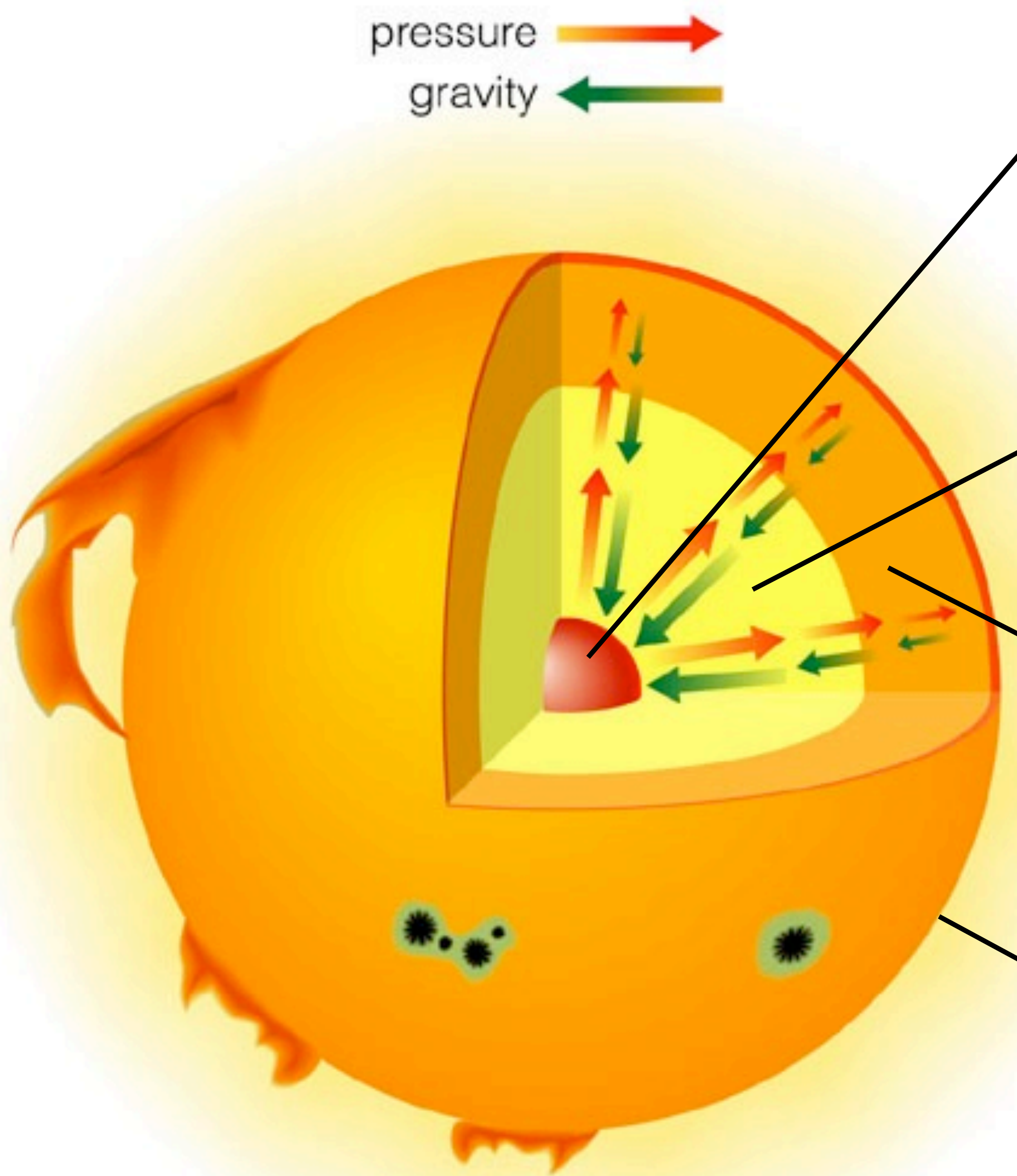
Today

- Stars
  - distances
  - spectral types
  - the HR diagram



Core:

Energy generated by nuclear fusion

~ 15 million K

Radiation zone:

Energy transported upward by photons

Convection zone:

Energy transported upward by rising hot gas

Photosphere:

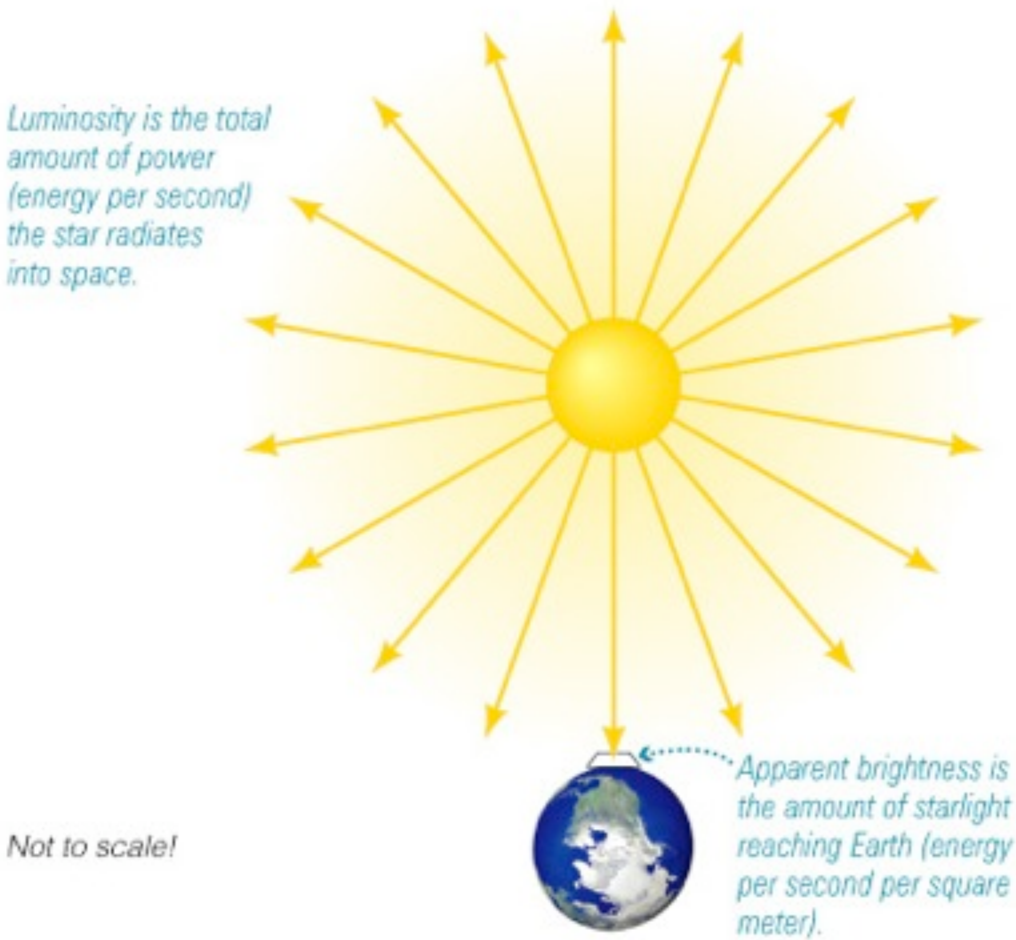
Visible surface

~5,800 K

10_01StructSun

Energy transport

- Energy generated by fusion deep in the core
- Energy transported outwards through sun by
  - radiation (photons), or
  - convection (churning gas motion)
- Energy radiated from surface into space as light



Luminosity: L

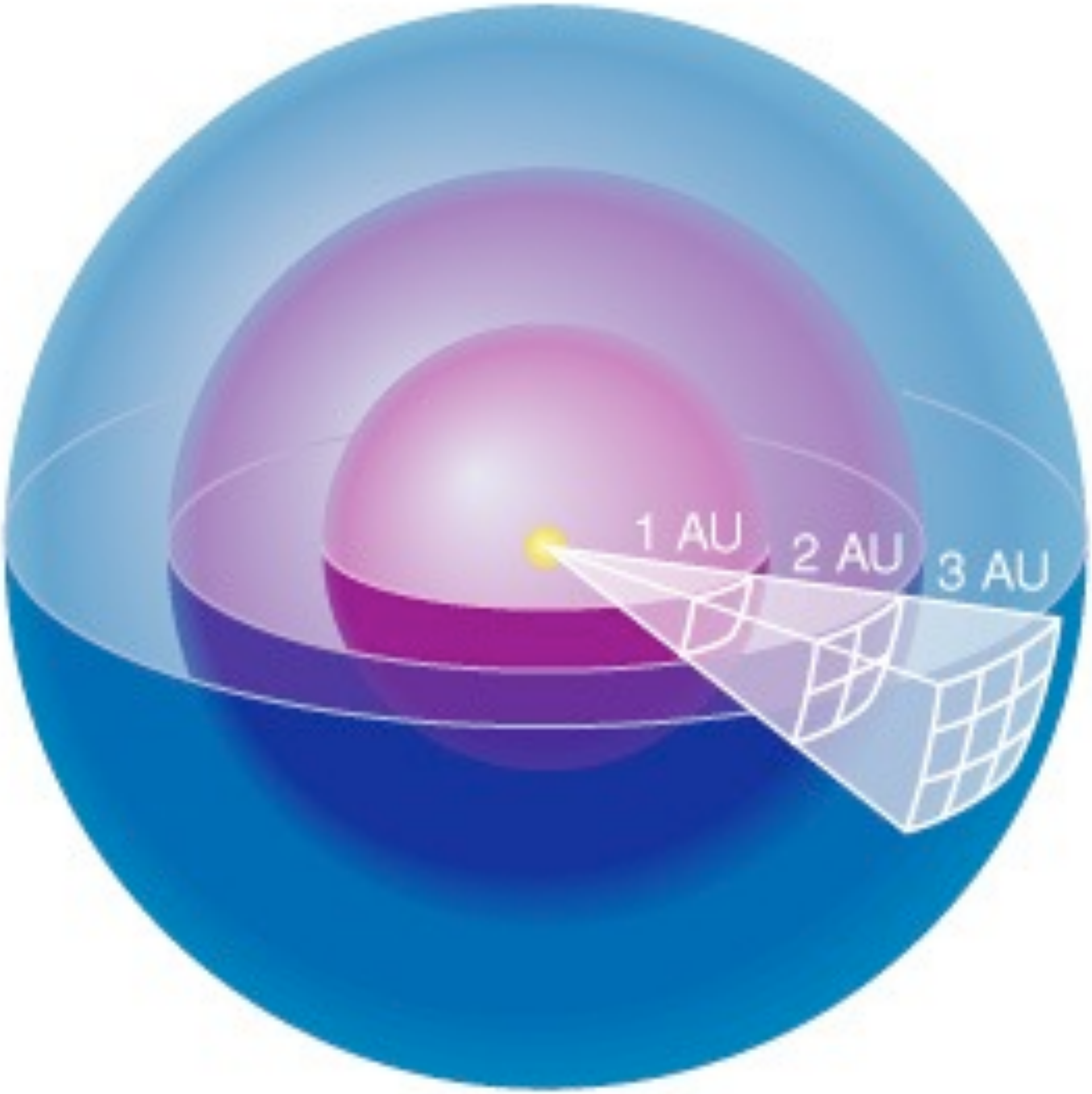
Amount of power a star radiates

(energy per second = watts)

Apparent brightness: b

Amount of starlight that reaches Earth

(energy per second per square meter)



Luminosity passing through each sphere is the same

Area of sphere:

$$4\pi\ (\text{radius})^2$$

Divide luminosity by area to get brightness.

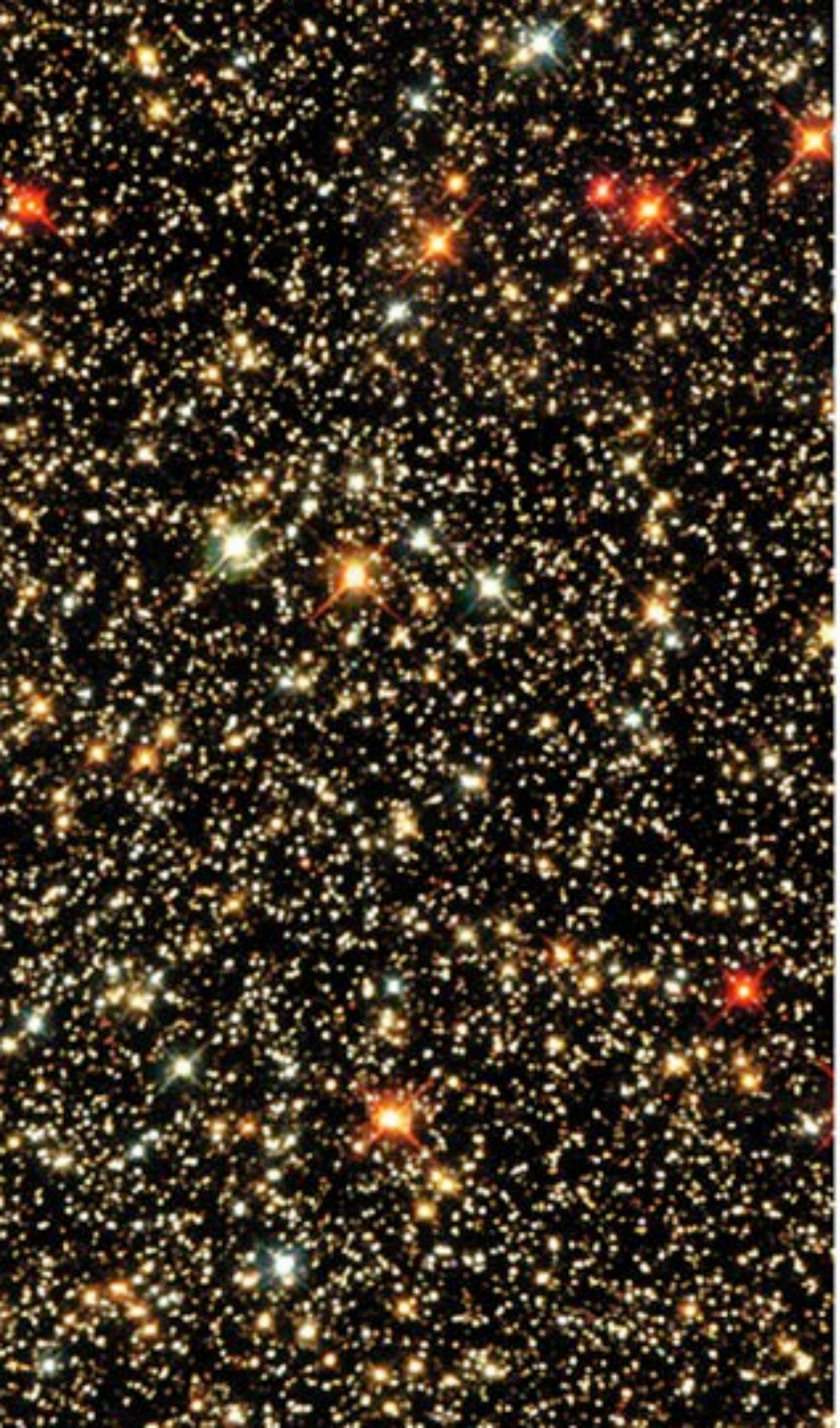
The relationship between apparent brightness and luminosity depends on distance:

$$\text{Brightness} = \frac{\text{Luminosity}}{4\pi\,(\text{distance})^2}$$

$$b = \frac{L}{4\pi d^2}$$

intrinsic property

measurable quantities



So how far away are the stars?

Start with a crude guess:
all stars are like the sun
with the same luminosity:

$$d = \sqrt{\frac{L}{4\pi b}}$$

With this crude approximation,
the brighter stars in the sky would
be about a light-year away.

Parallax and Distance

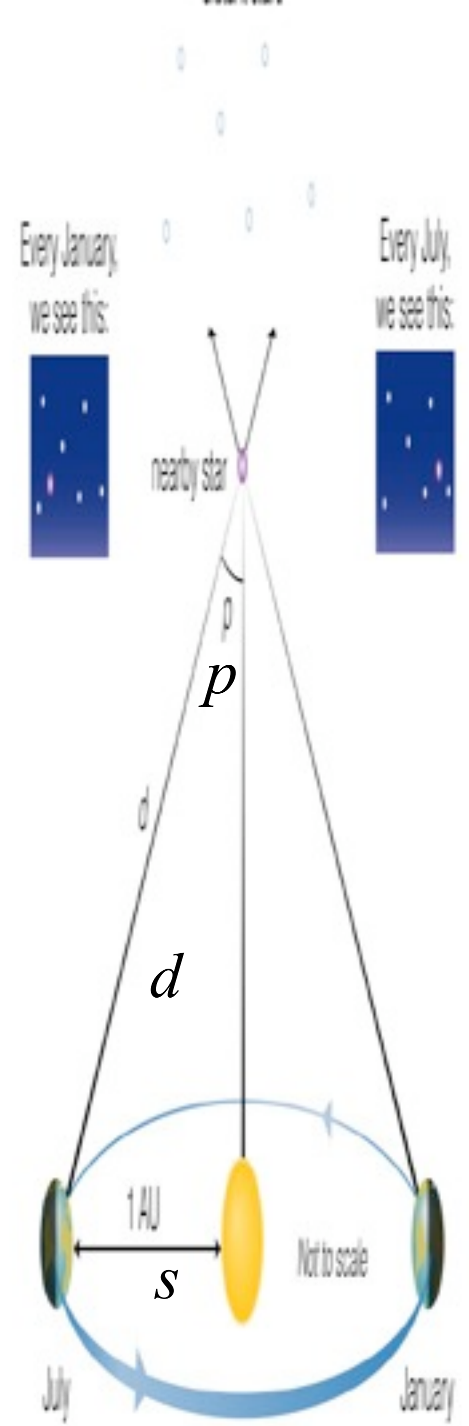
$$d = \frac{s}{p}$$

The natural units for the parallax angle *p* are radians.
Then distance *d* and separation *s* are in the same units.

For the special case of *s* = 1 AU
and *p* measured in arcseconds,
d comes out in parsecs (pc).

1 pc = 3.26 light-years

The *closest* star (Proxima Centauri) is
4.2 light-years away, so $p < 1''$
- no wonder the Ancients couldn't detect parallax!



Most luminous stars:

$10^6 \; L_{Sun}$

Least luminous stars:

$10^{-4} \; L_{Sun}$

(L_{Sun} is luminosity of the Sun)

Hottest stars:

50,000 K

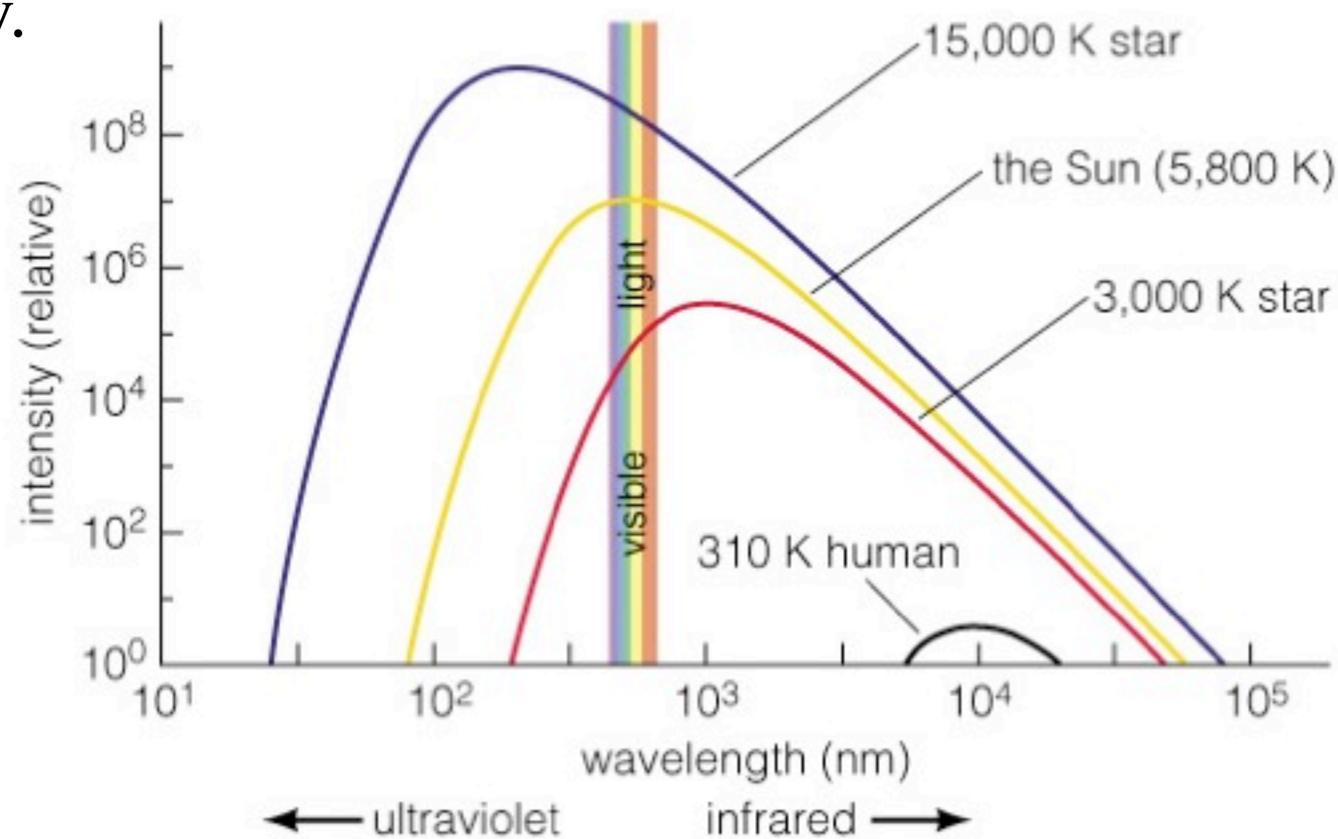
Coolest stars:

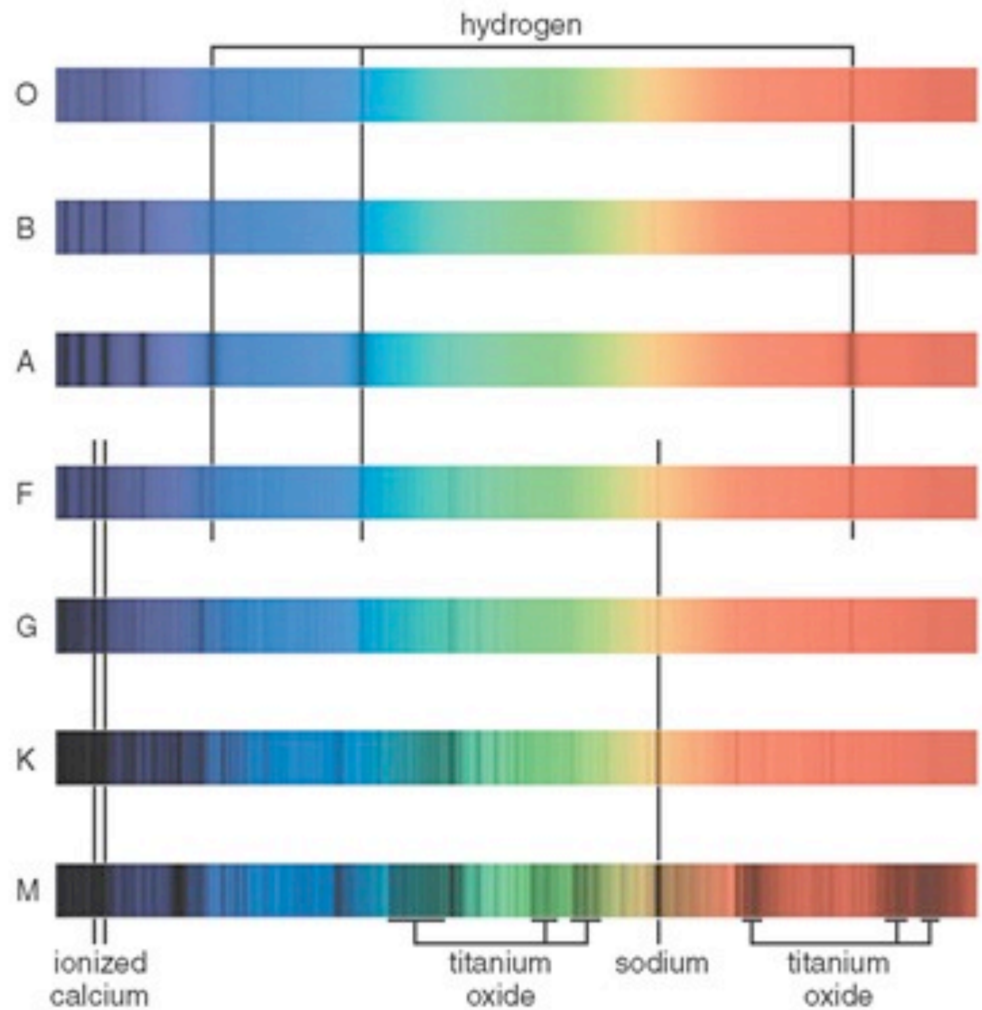
3,000 K

(Sun's surface is 5,800 K)

Properties of Thermal Radiation

1. Hotter objects emit more light per unit area at all frequencies.
2. Hotter objects emit photons with a higher average energy.





Lines in a star's spectrum correspond to a ***spectral type*** that reveals its temperature:

(Hottest) O B A F G K M (Coolest)

Remembering Spectral Types

(Hottest) O B A F G K M (Coolest)

- Oh, Be A Fine Girl/Guy, Kiss Me
- Only Boys Accepting Feminism Get Kissed Meaningfully
- Oh Boy, An F Grade Kills Me

Pioneers of Stellar Classification

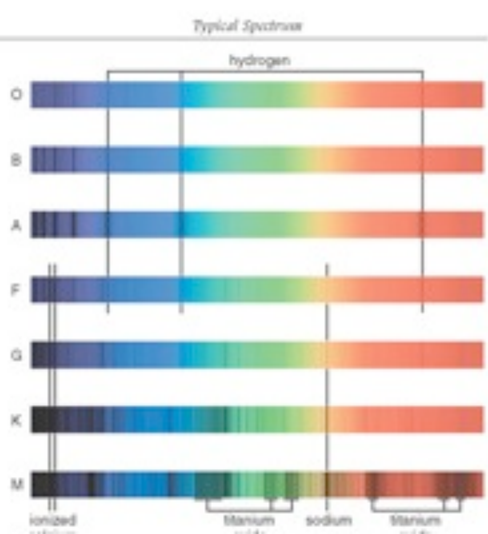
- Annie Jump Cannon and the "calculators" at Harvard laid the foundation of modern stellar classification.

Spectral Types are a sequence in Temperature

Hot ⟷ Cool

O B A F G K M

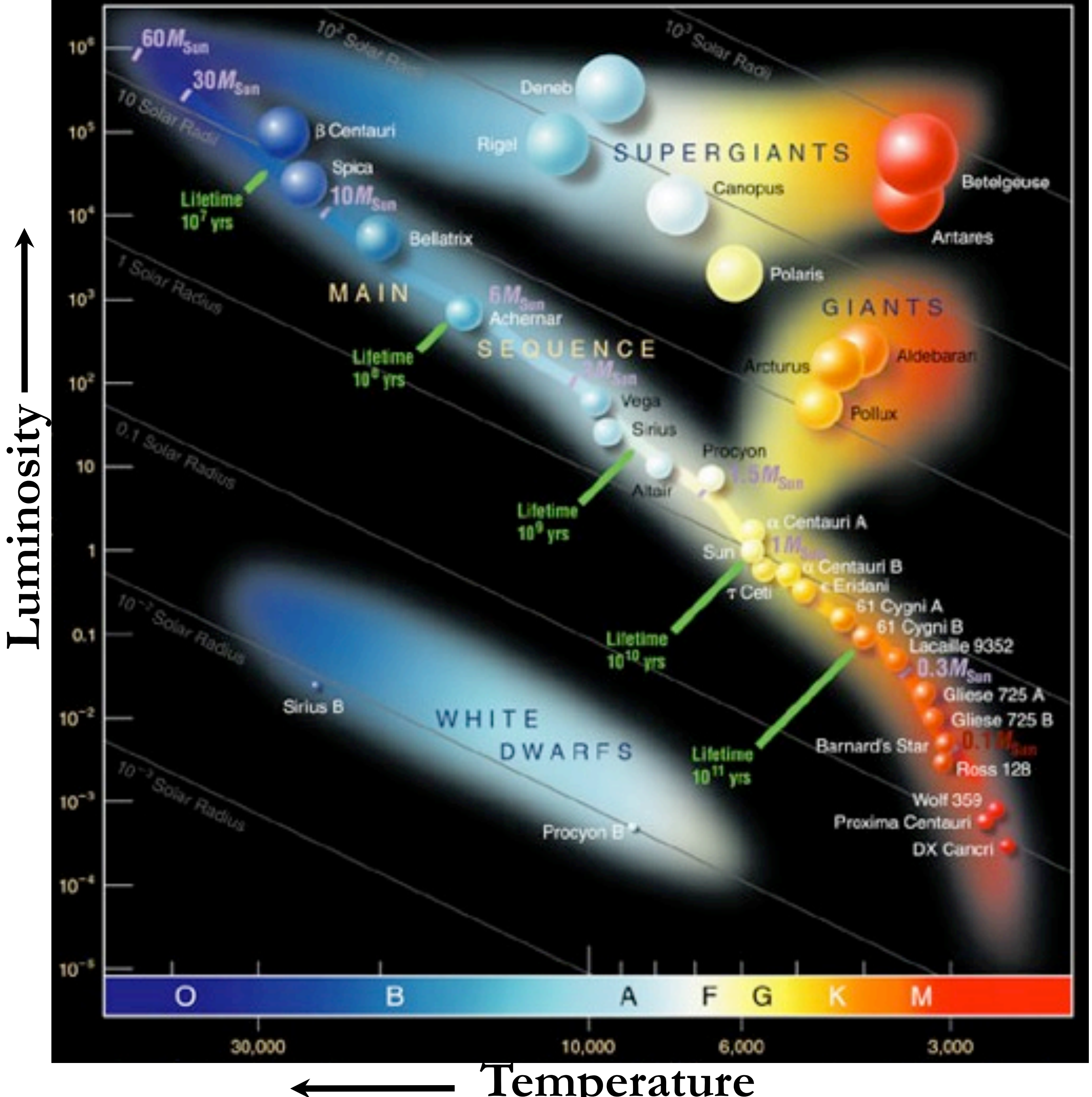
...F8 F9 G0 G1 G2 ... G8 G9 K0 K1...



The Sun is type G2

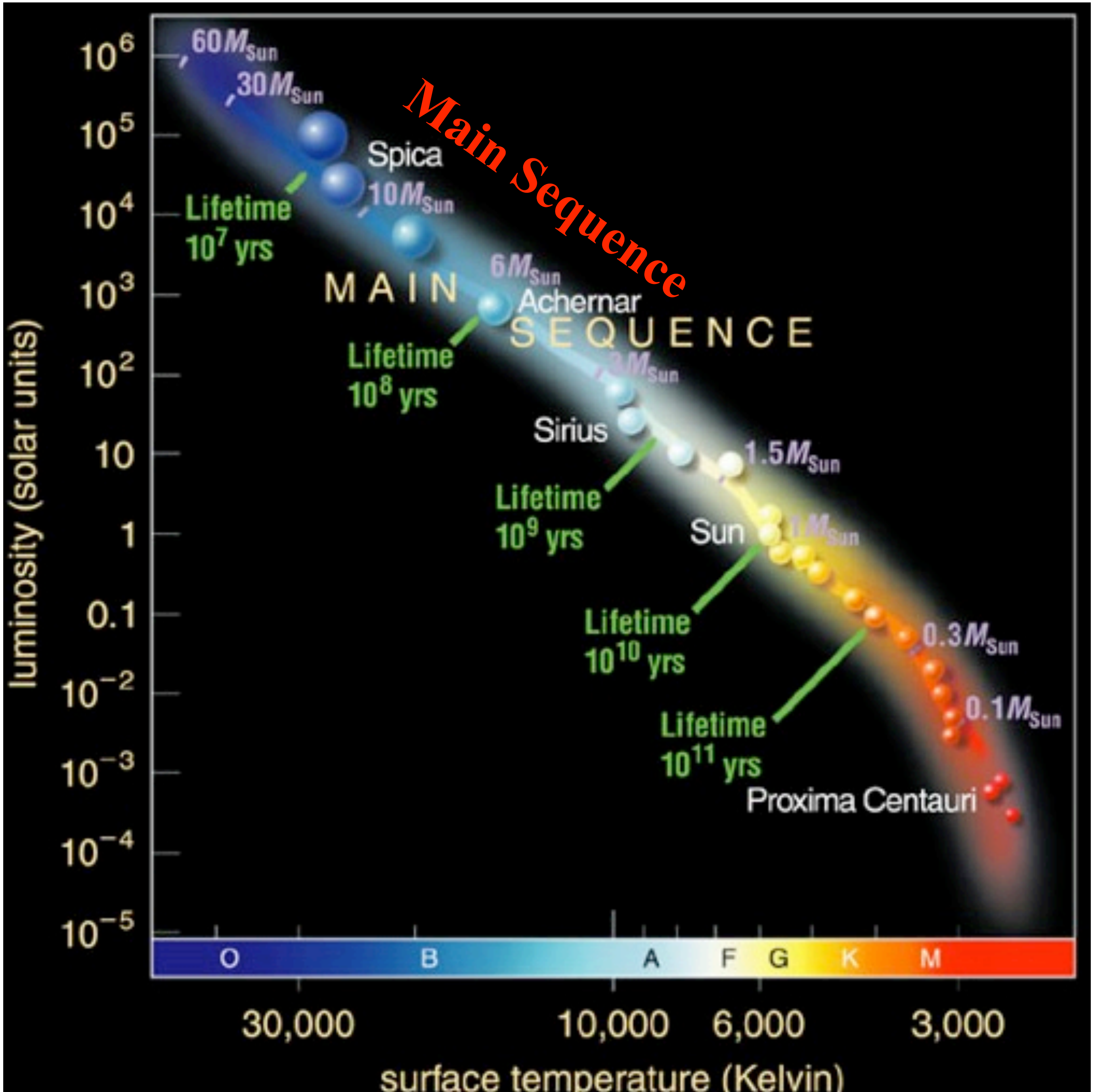
Hertzsprung-Russell (HR) Diagram

- Plots Luminosity vs Temperature
- Luminosity requires measurement of
  - brightness
  - distance
- Temperature from
  - Wien's Law (color) or
  - Spectral Type



An H-R diagram plots the **luminosities** and **temperatures** of stars.

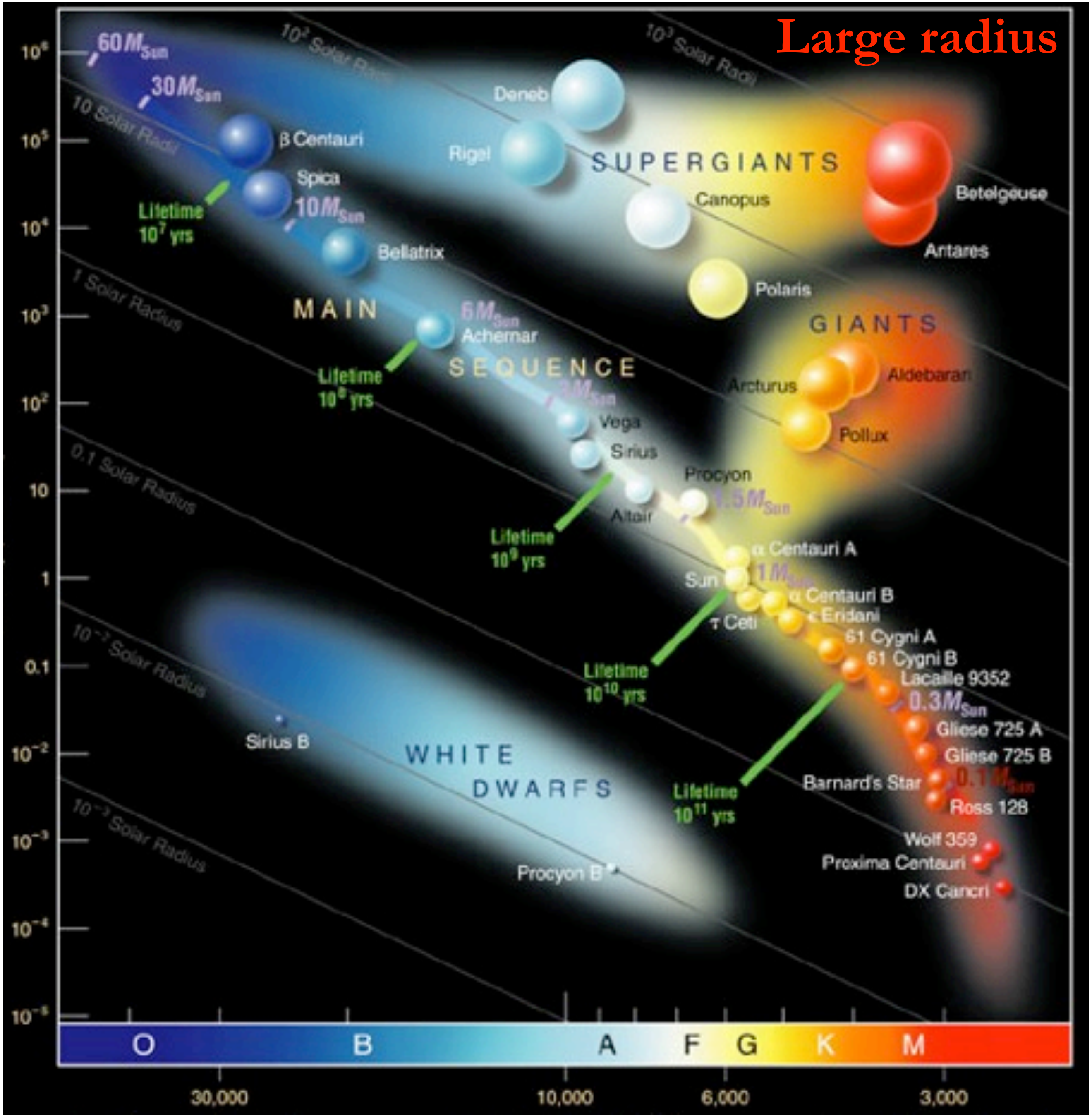
Each star is on point on this diagram.



Most stars fall somewhere on the ***main sequence*** of the H-R diagram.

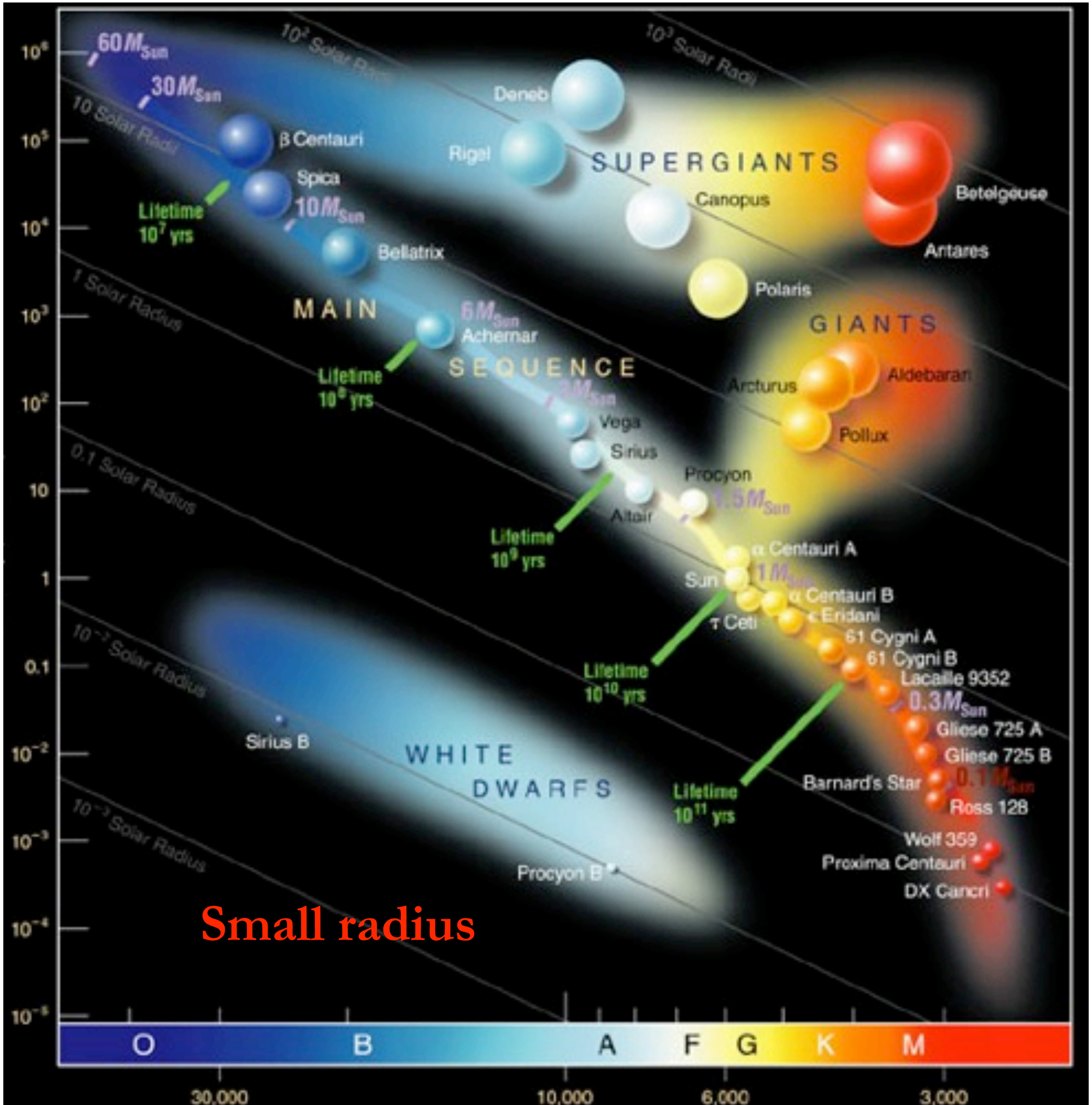
Hot stars tend to be brighter. Remember the Stefan-Boltzmann Law:

$$L \propto R^2 T^4$$



Stars with lower *T* and higher *L* than main-sequence stars must have larger radii:

giants and ***supergiants***



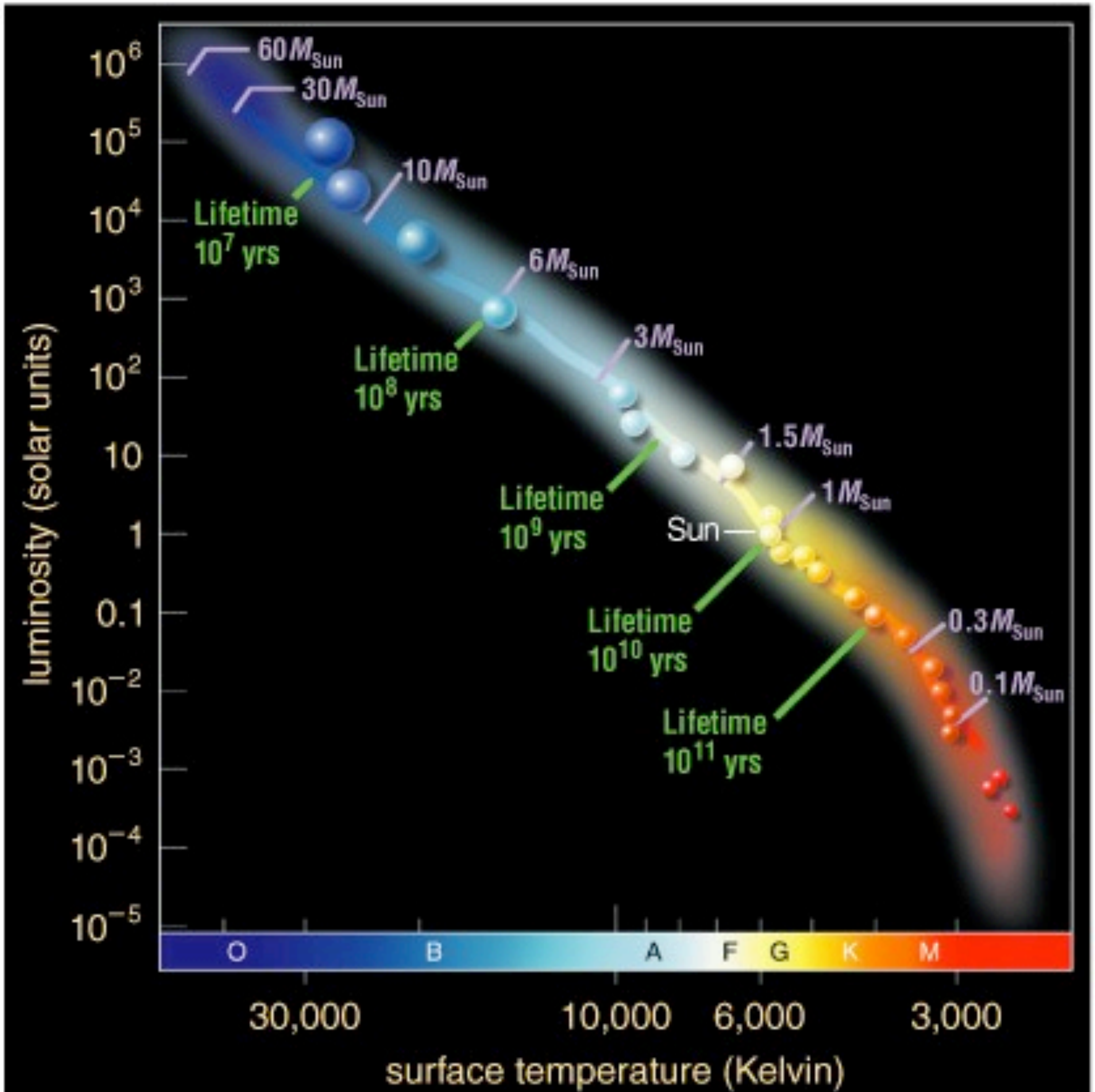
Stars with higher T and lower L than main-sequence stars must have smaller radii:

white dwarfs

A star's full classification includes spectral type (OBAFGKM) and luminosity class (related to the size of the star - bigger is brighter):

I — supergiant
II — bright giant
III — giant
IV — subgiant
V — main sequence

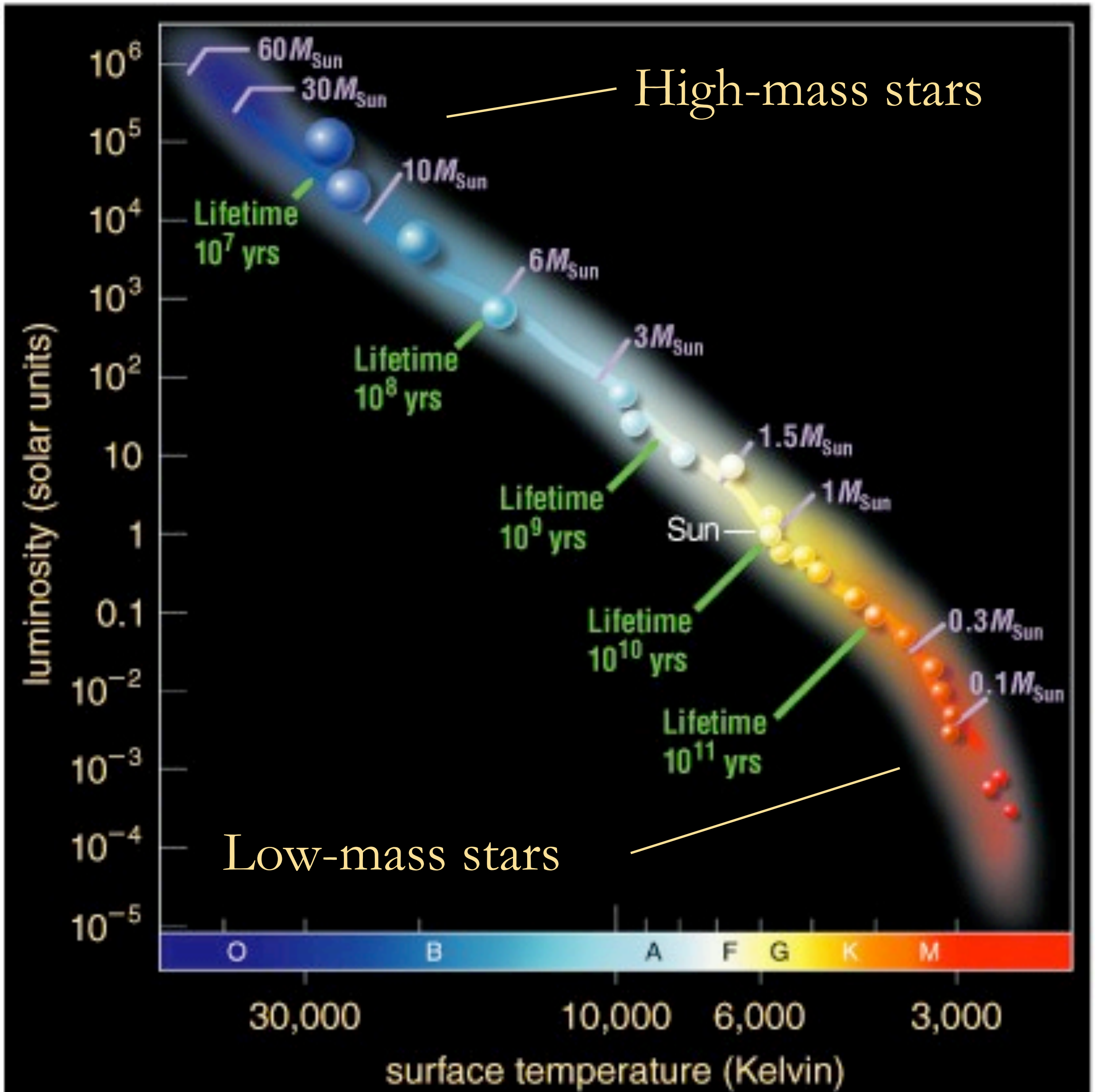
Examples: Sun — G2 V
Sirius — A1 V
Proxima Centauri — M5.5 V
Betelgeuse — M2 I



Main-sequence stars are fusing hydrogen into helium in their cores, like the Sun.

Luminous main-sequence stars are hot (blue).

Less luminous ones are cooler (yellow or red).



Mass measurements of main-sequence stars show that the hot, blue stars are much more massive than the cool, red ones.

The mass of a main sequence star determines its luminosity and spectral type!

For stars, mass is destiny

Stellar Properties Review

Luminosity: from brightness and distance

$(0.08\ M_{Sun})$ $10^{-4}\ L_{Sun}$–$10^{6}\ L_{Sun}$ $(100\ M_{Sun})$

Temperature: from color and spectral type

$(0.08\ M_{Sun})$ 3,000 K–50,000 K $(100\ M_{Sun})$

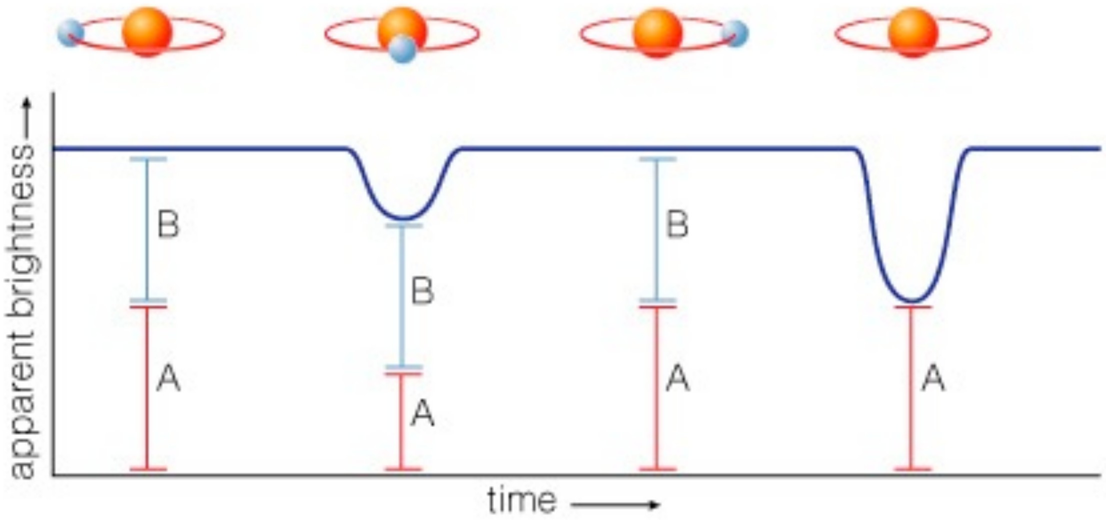
Mass: from period (P) and average separation (a) of binary-star orbit

$0.08\ M_{Sun}$–$100\ M_{Sun}$

The lowest mass star

- main sequence stars are "hydrogen burning"
- 0.08 solar masses
  - lowest mass star
  - not arbitrary:
  - This is the limit for hydrogen fusion
    - objects with less mass can not ignite fusion
    - such sub-stellar objects are called "brown dwarfs"

How do we measure stellar masses?



© 2006 Pearson Education, Inc., publishing as Addison Wesley

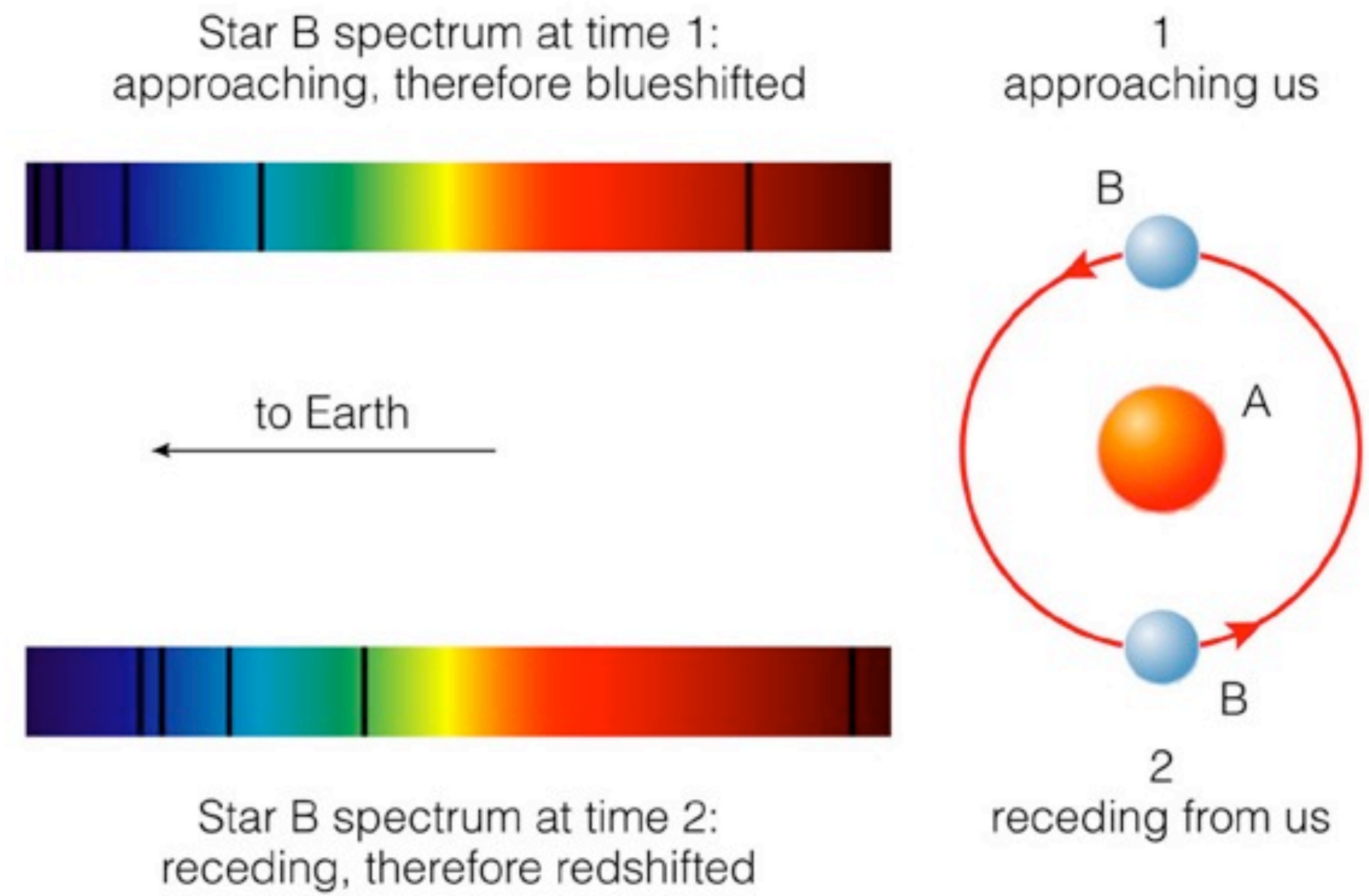
with binary stars!

Types of Binary Star Systems

- Visual binary - can see individual stars orbit one another
- Eclipsing binary - see individual stars eclipse one another
- Spectroscopic binary - see two spectral types

About half of all stars are in binary systems.

Spectroscopic Binary



We determine the orbit by measuring Doppler shifts.

Isaac Newton

Direct mass measurements are possible for stars in binary star systems using Netwon's generalization of Kepler's third law:

$$P^2 = \frac{4\pi^2}{G\,(M_1 + M_2)}\,a^3$$

P = period

a = separation

Need two out of three observables to measure mass:

1. Orbital period (*P*)
2. Orbital separation (*a* or *r* = radius)
3. Orbital velocity (*v*)

For circular orbits, $v = 2\pi r / p$