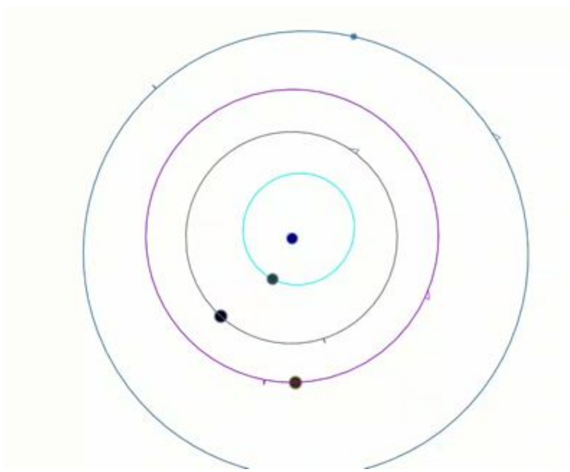
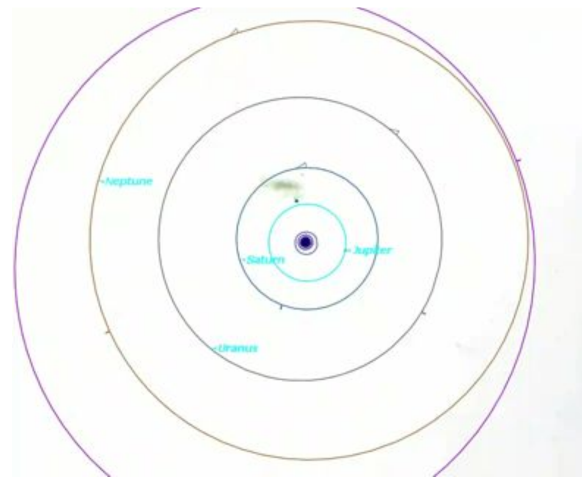
Stars – General Properties

16.1 Physical Properties of Sun

Some basic points about the sun:

1. The sun is the centre of solar system.

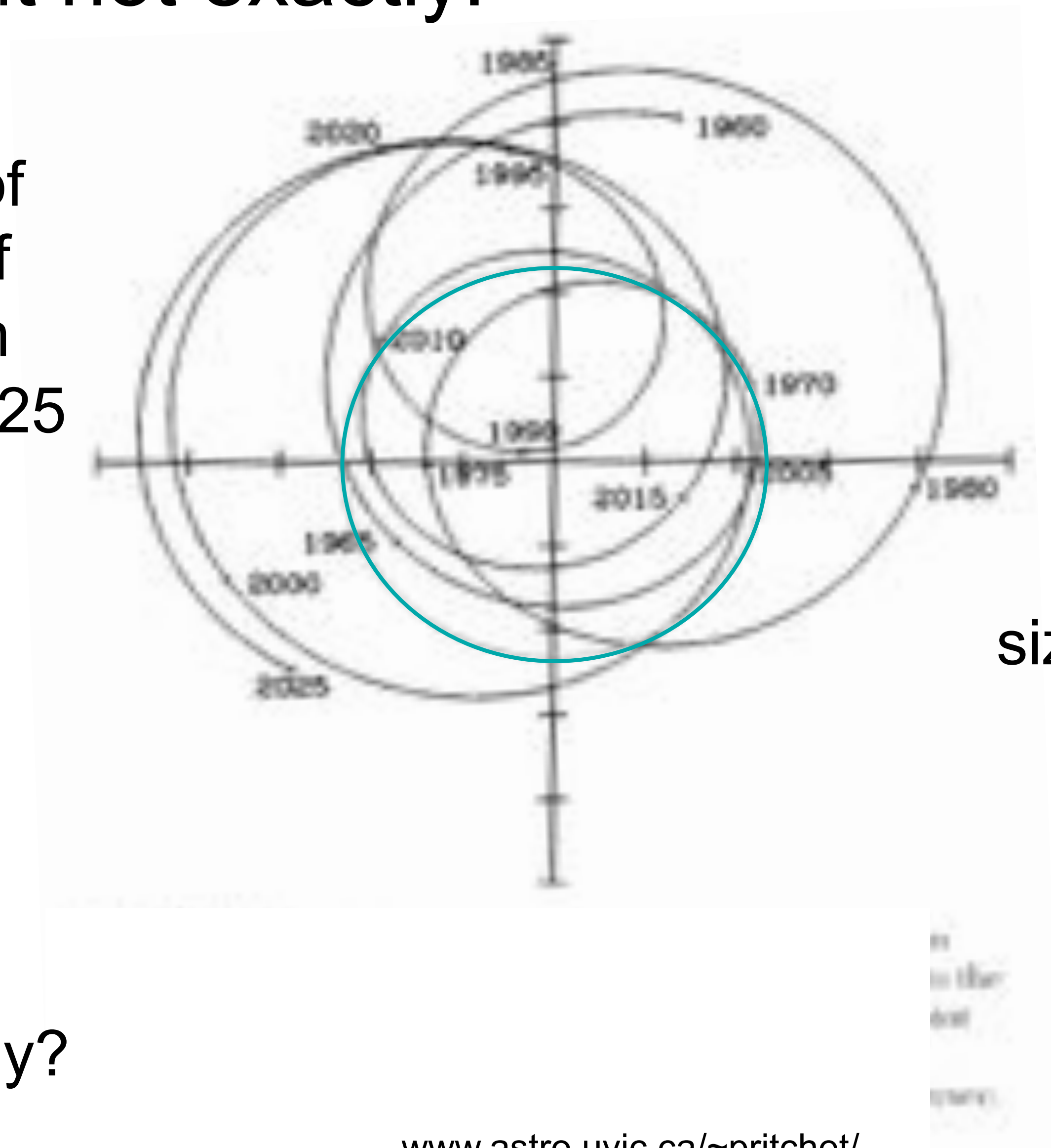




inner planets outer planets

… but not exactly!

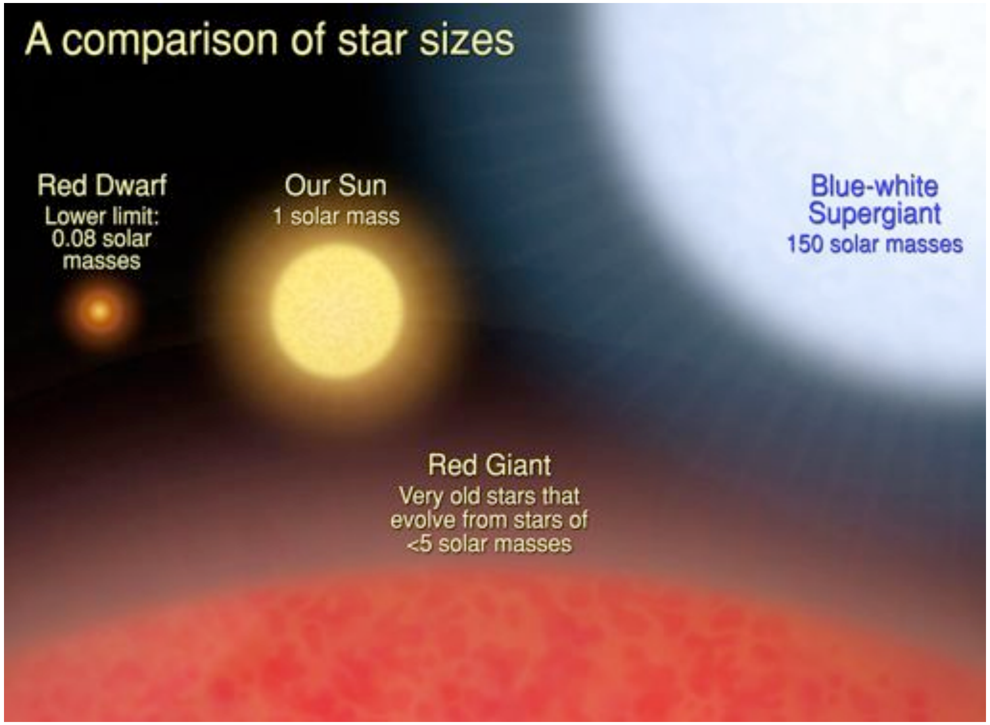
motion of centre of sun from 1960-2025



size of sun

why?

2. The sun is a star, one of billions in the Milky Way



also white dwarfs (size of earth!)

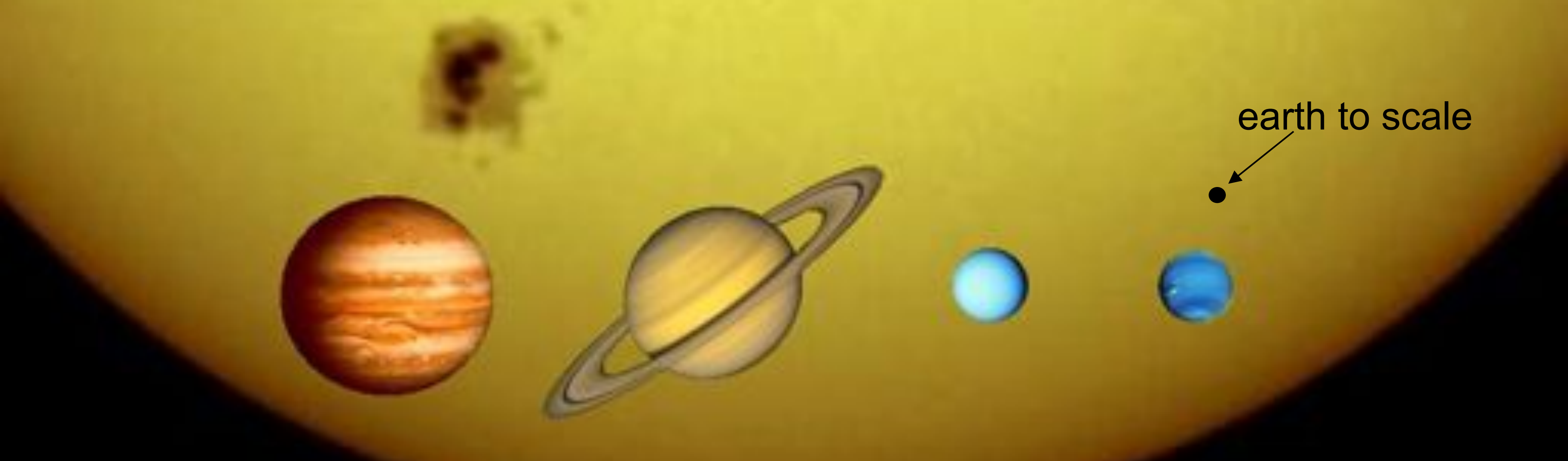
3. The sun is made of gas.

4. The sun is “more or less” unchanging on time scales of billions of years.

5. The energy of the sun comes from …

16.1 Physical Properties of Sun

Radius: 700,000 km, diameter=1,400,000 km
Mass: 2.0×10^{30} kg
Density: 1400 kg/m^3 [compare with water …]
Rotation: Differential; period about a month
"Surface" temperature: 5800 K
Apparent "surface" of Sun is photosphere



17.1 The Solar Neighborhood

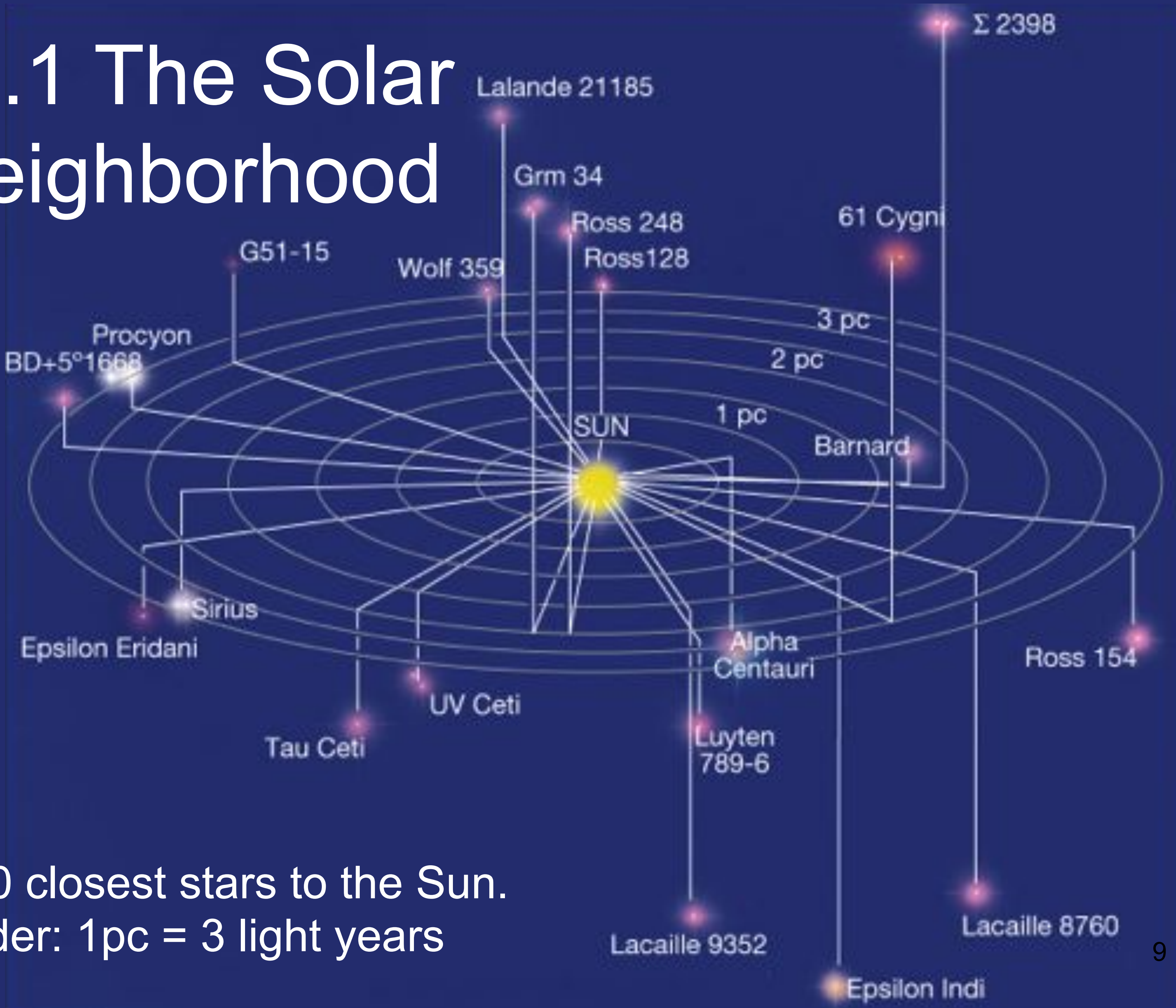
Nearest star to the Sun: Proxima Centauri, which is a member of the three-star system Alpha Centauri complex – distance 4 light years = 1.4 parsecs

17.1 The Solar Neighborhood

Model of distances:

- Sun is a marble, Earth is a grain of sand orbiting 1 m away
- Solar system extends about 50 m from Sun; rest of distance to nearest star is basically empty.
- **Nearest star is another marble 270 km away!**

17.1 The Solar Neighborhood



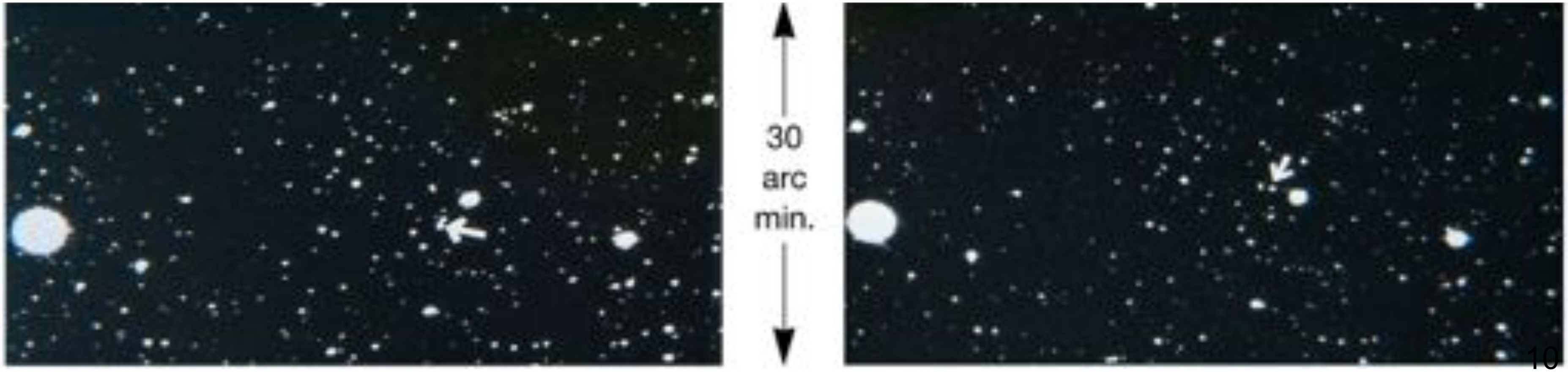
The 30 closest stars to the Sun.
reminder: 1pc = 3 light years

17.1 The Solar Neighborhood

Next nearest neighbor: Barnard's star

- largest proper motion of any star
- ***proper motion*** is the actual observed shift of the star in the sky, after correcting for parallax.

These pictures were taken 22 years apart!



Proper motion - the movies

5° x 4° field in UMa, 100000 yr of proper motion

Barnard's star, 4° x 3° field, 300yr

17.3 Stellar Temperatures

The color of a star is indicative of its temperature. Red stars are relatively cool, whereas blue ones are hotter.

Wien's Law!

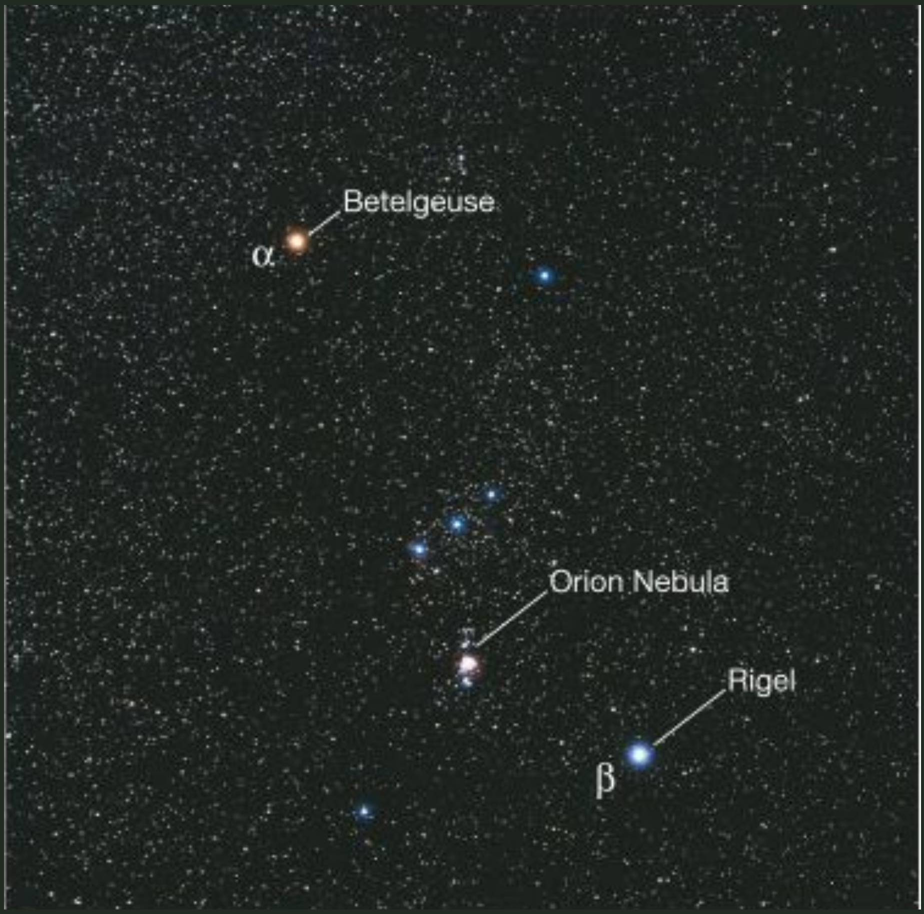


TABLE 17.1 Stellar Colors and Temperatures

Wien's Law!

Approximate Surface Temperature (K)	Color	Familiar Examples
30,000	Blue-violet	Mintaka (δ Orionis)
20,000	Blue	Rigel
10,000	White	Vega, Sirius
7000	Yellow-white	Canopus
6000	Yellow	Sun, Alpha Centauri
4000	Orange	Arcturus, Aldebaran
3000	Red	Betelgeuse, Barnard's star

17.3 Stellar Temperatures

Annie Jump Cannon 1863-1941

Stellar spectra are NOT perfect blackbodies – they are much more informative than the blackbody curves.

There are seven general categories of stellar spectra, corresponding to different temperatures.

From highest to lowest, those categories are

O B A F G K M (R N S)

Oh be a fine girl kiss me right now sweetie.

TABLE 17.1 Stellar Colors and Temperatures

Wien's Law!

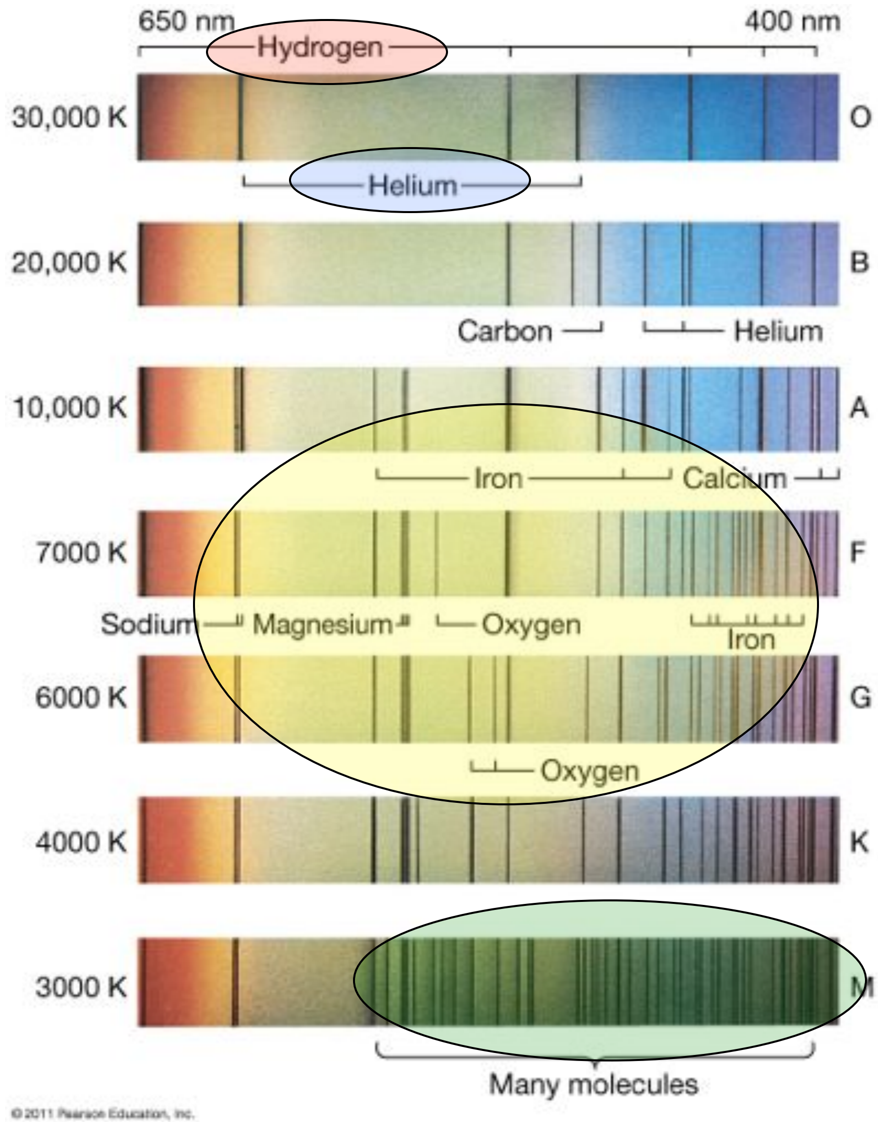
Approximate Surface Temperature (K)		Color	Familiar Examples
30,000	O	Blue-violet	Mintaka (δ Orionis)
20,000	B	Blue	Rigel
10,000	A	White	Vega, Sirius
7000	F	Yellow-white	Canopus
6000	G	Yellow	Sun, Alpha Centauri
4000	K	Orange	Arcturus, Aldebaran
3000	M	Red	Betelgeuse, Barnard's star

17.3 Stellar Temperatures

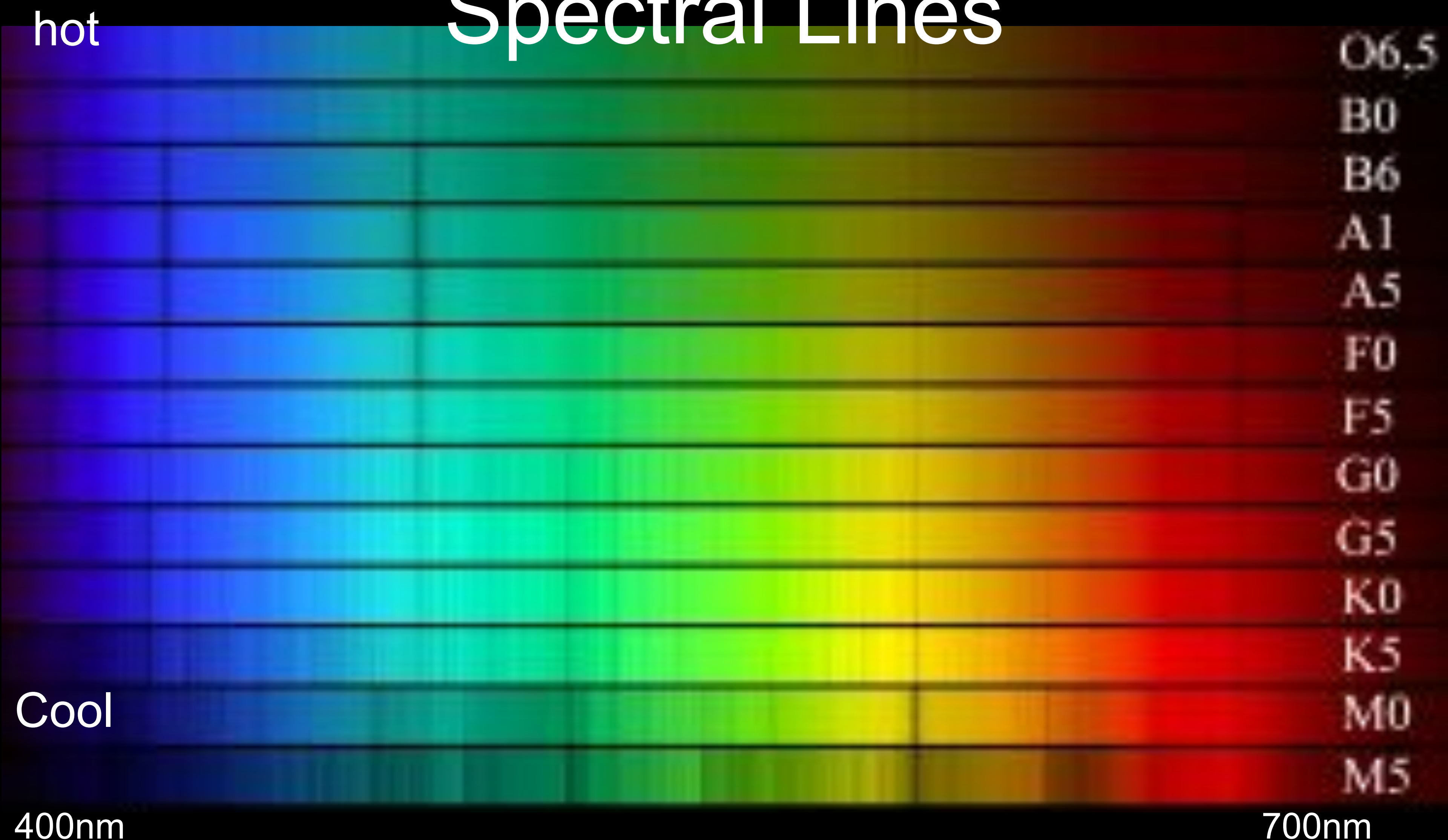
Spectra …

Regardless of what the spectra look like, most "normal" stars are 98% H and He!

Cecilia Payne-Gaposhkin 1900-1979



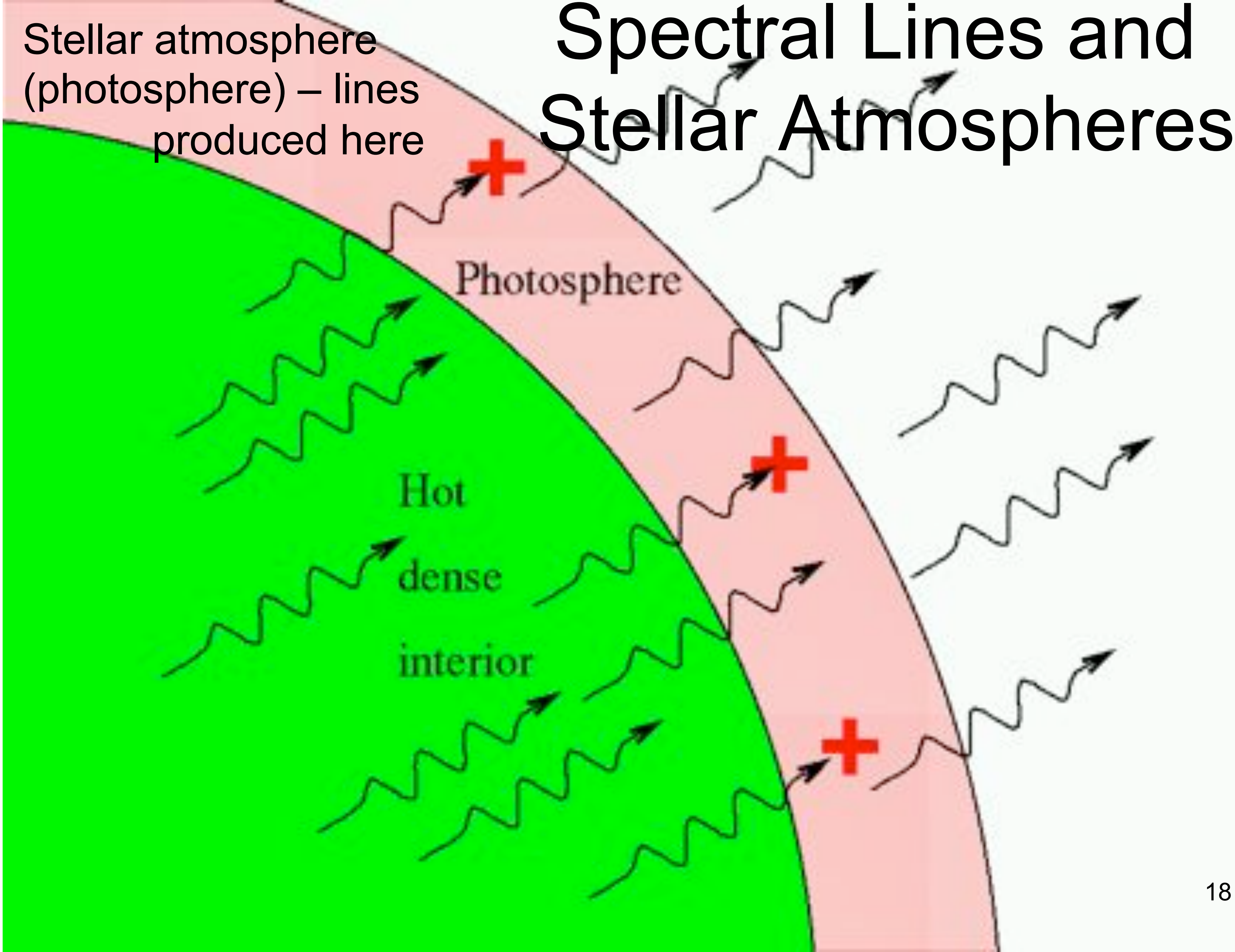
Spectral Lines



continuum: black-body radiation
dark lines: absorption by different elements

Spectral Lines and Stellar Atmospheres

Stellar atmosphere (photosphere) – lines produced here



Spectral Lines and Stellar Atmospheres

Sun during eclipse

17.3 Stellar Temperatures

Characteristics of the spectral classifications

TABLE 17.2 Stellar Spectral Classes

Spectral Class	Approximate Surface Temperature (K)	Noteworthy Absorption Lines	Familiar Examples
O	30,000	Ionized helium strong; multiply ionized heavy elements; hydrogen faint	Mintaka (O9)
B	20,000	Neutral helium moderate; singly ionized heavy elements; hydrogen moderate	Rigel (B8)
A	10,000	Neutral helium very faint; singly ionized heavy elements; hydrogen strong	Vega (A0), Sirius (A1)
F	7000	Singly ionized heavy elements; neutral metals; hydrogen moderate	Canopus (F0)
G	6000	Singly ionized heavy elements; neutral metals; hydrogen relatively faint	Sun (G2), Alpha Centauri (G2)
K	4000	Singly ionized heavy elements; neutral metals strong; hydrogen faint	Arcturus (K2), Aldebaran (K5)
M	3000	Neutral atoms strong; molecules moderate; hydrogen very faint	Betelgeuse (M2), Barnard's star (M5)

huge amount of detail but it's simple …

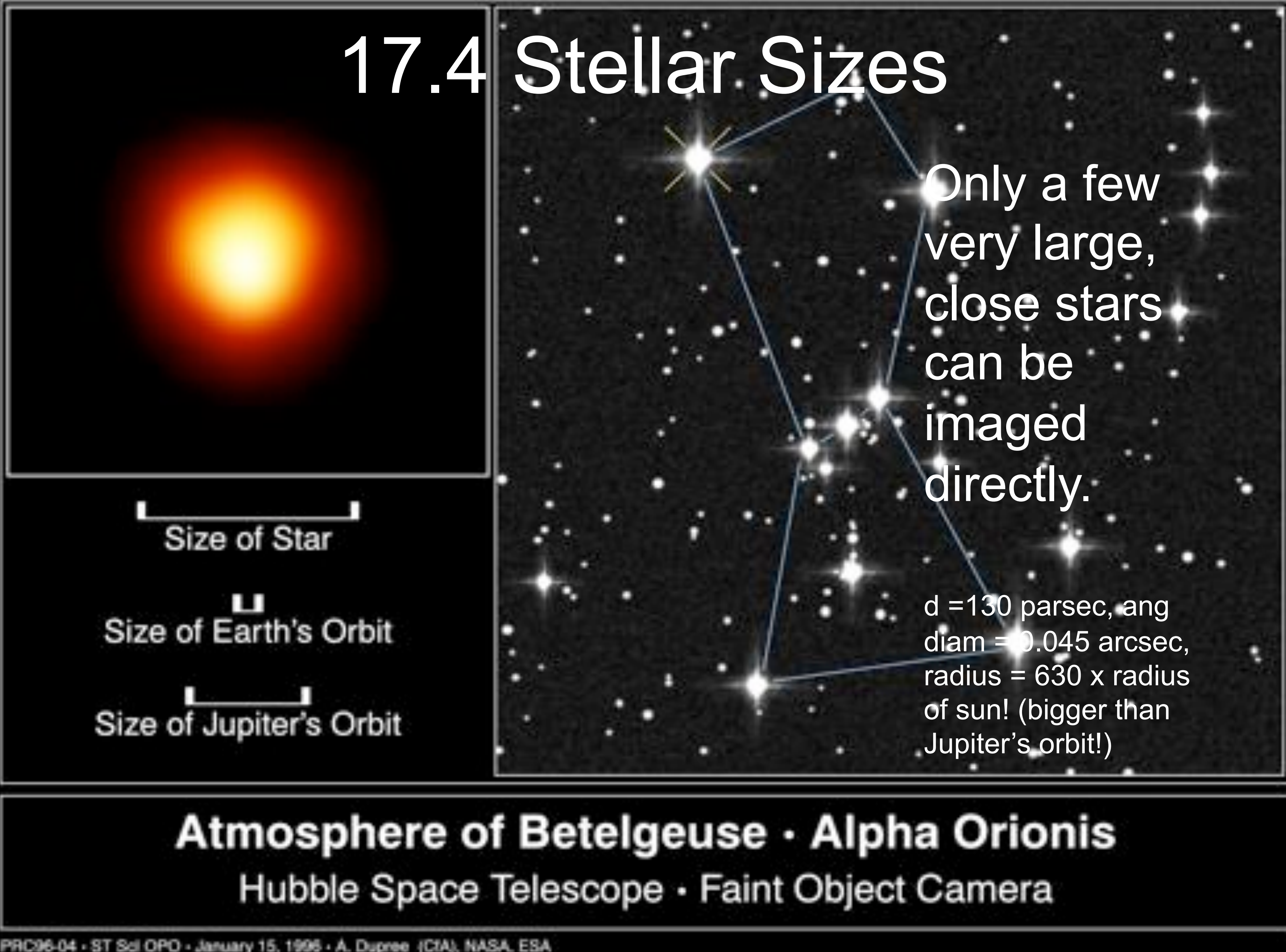
The appearance of the spectrum of a star depends on the temperature of:

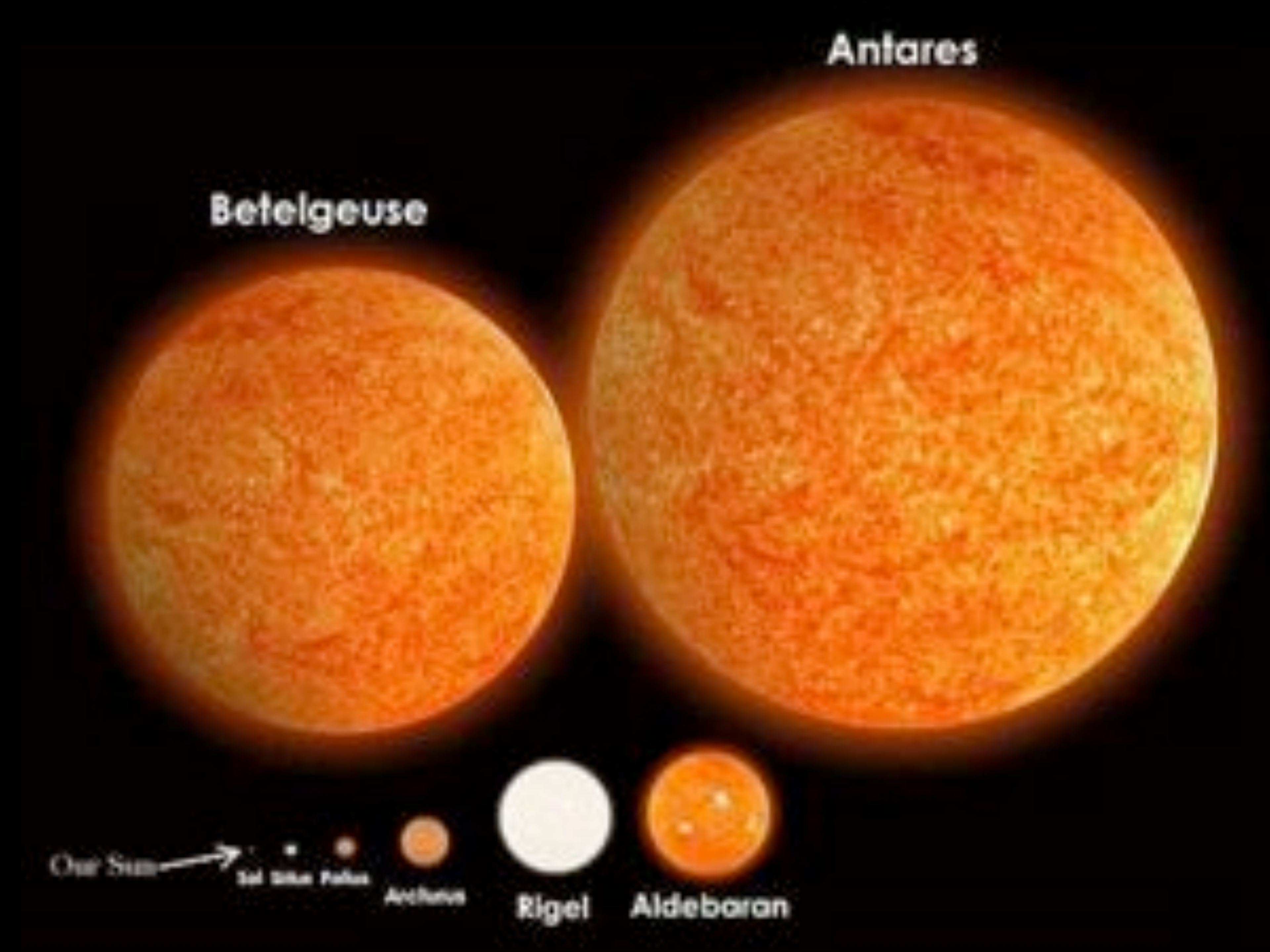
A. The core of the star
B. The middle regions of a star
C. The outermost layer of a star
D. An average of the entire star
E. The interstellar medium

17.4 Stellar Sizes

Only a few very large, close stars can be imaged directly.

d =130 parsec, ang diam = 0.045 arcsec, radius = 630 x radius of sun! (bigger than Jupiter's orbit!)




Antares
Betelgeuse
Our Sun
Sol
Arcturus
Rigel
Aldebaran

17.4 Stellar Sizes

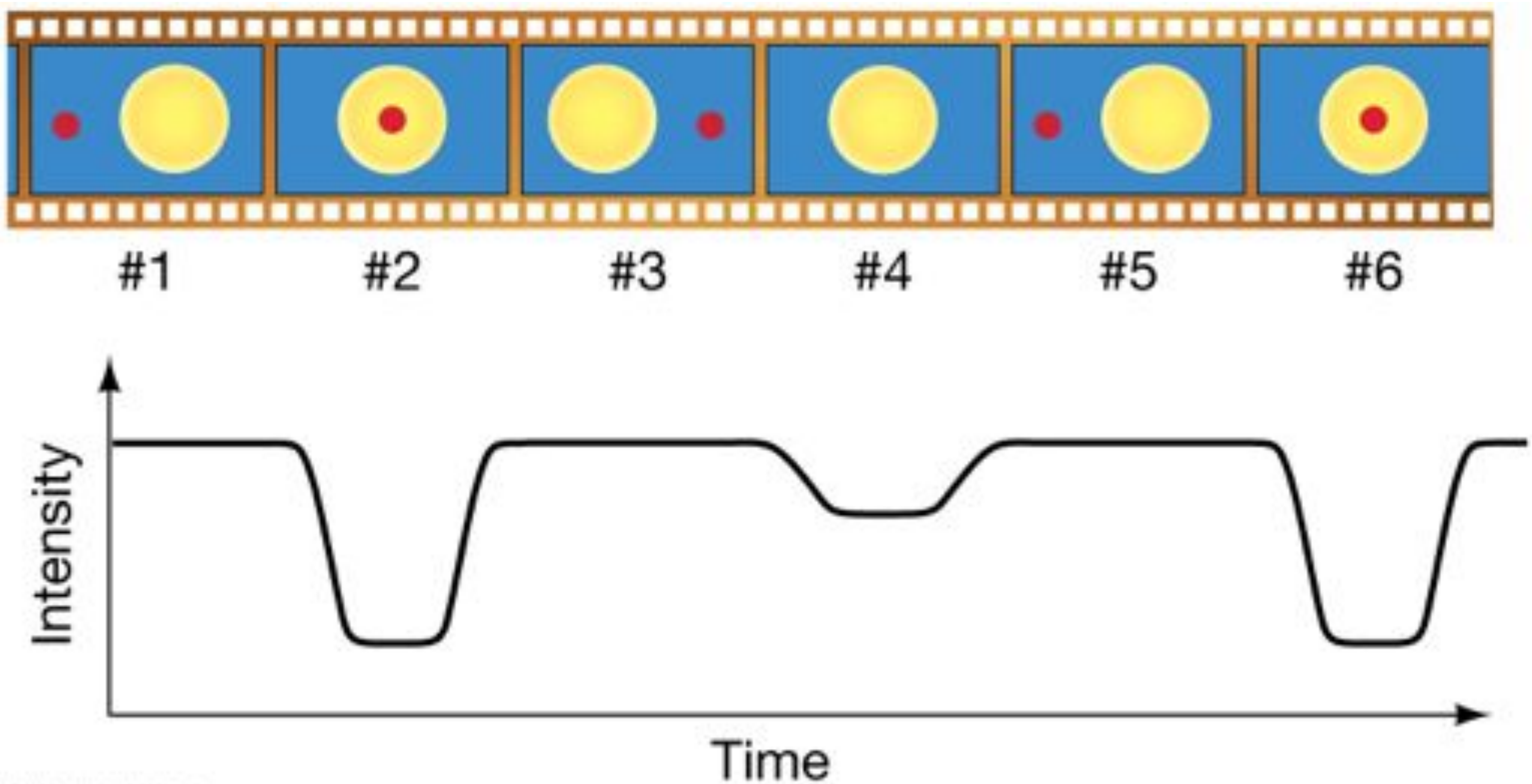
The vast majority of stars cannot be imaged directly; size must be calculated knowing the luminosity and temperature (Stefan-Boltzmann Law).

$$\text{luminosity} \propto \text{radius}^2 \times \text{temperature}^4.$$

- Dwarf stars have radii about 0.1 to 10 x the Sun's
- Giant stars have radii between 10 and 100 times the Sun's
- Supergiant stars have radii more than 100 times the Sun's
- also: white dwarfs (size of earth, about 1/100 Sun), neutron stars (size of Victoria)

17.4 Stellar Sizes

Eclipsing binaries can be measured using the changes in luminosity – gives info on size and “inclination”



http://www.youtube.com/watch?v=qr81dVV1_OE

ESO

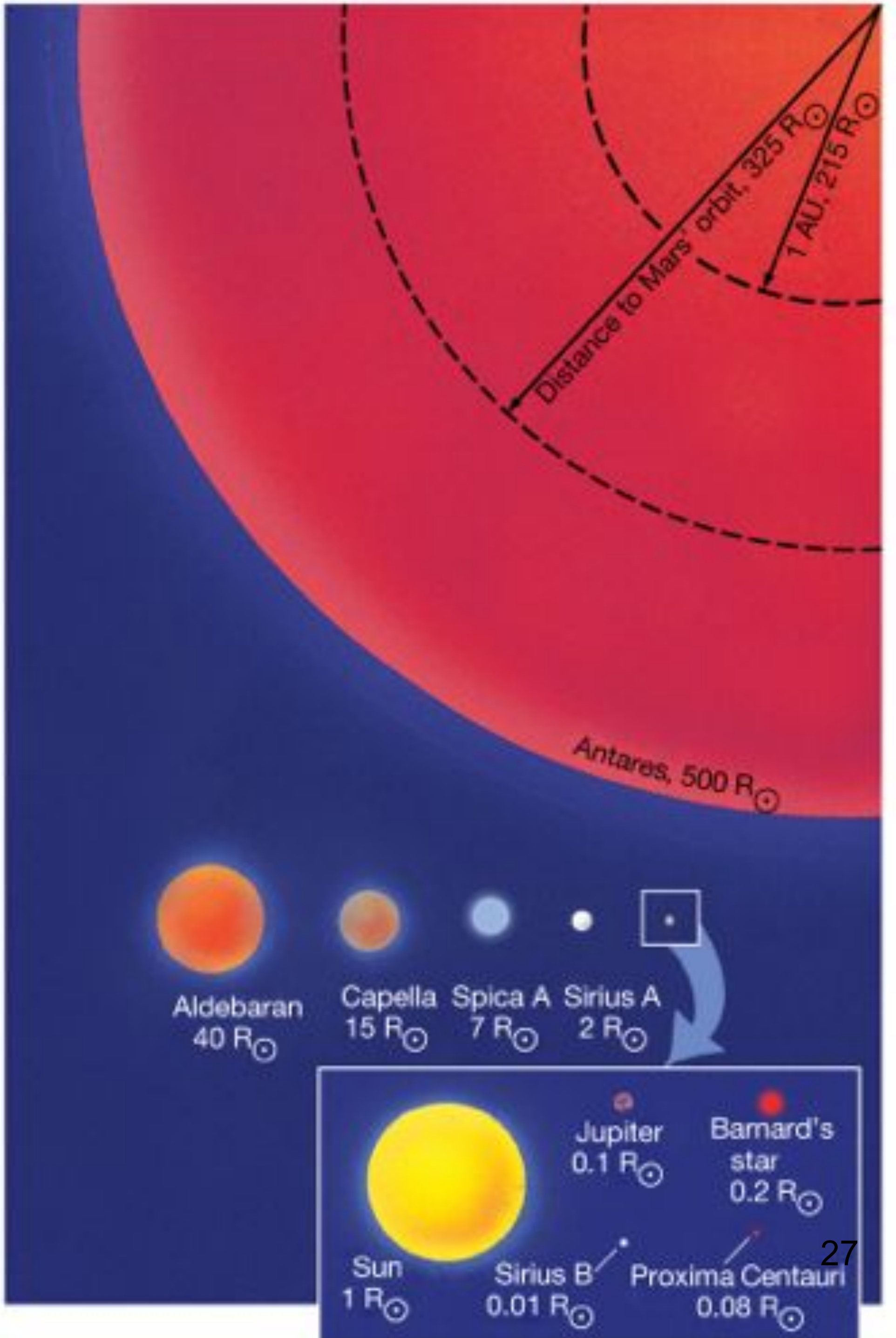
www.eso.org

17.4 Stellar Sizes

Stellar radii vary **widely!**

A great video illustrating this:

http://www.youtube.com/watch?v=HEheh1BH34Q&feature=related



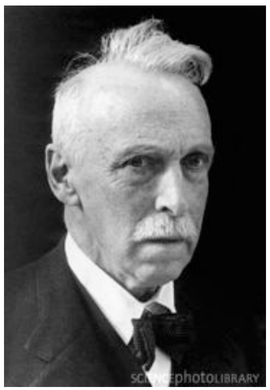
http://www.youtube.com/watch?v=HEheh1BH34Q&feature=related

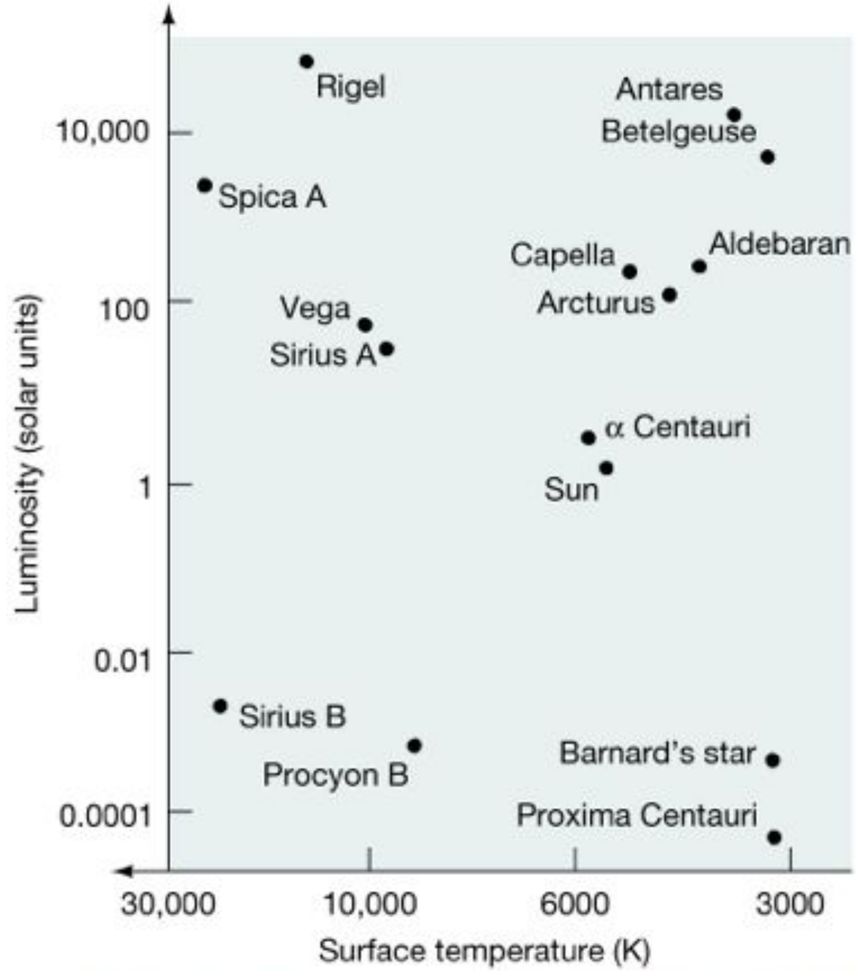
Which technique is used to give sizes of the largest numbers of stars?

A. Eclipsing binaries
B. Direct measurement – take a picture at high magnification
C. Stefan-Boltzmann Law
D. Parallax
E. Proper motion

17.5 Hertzsprung–Russell Diagram

Aka “**colour magnitude diagram**”





or

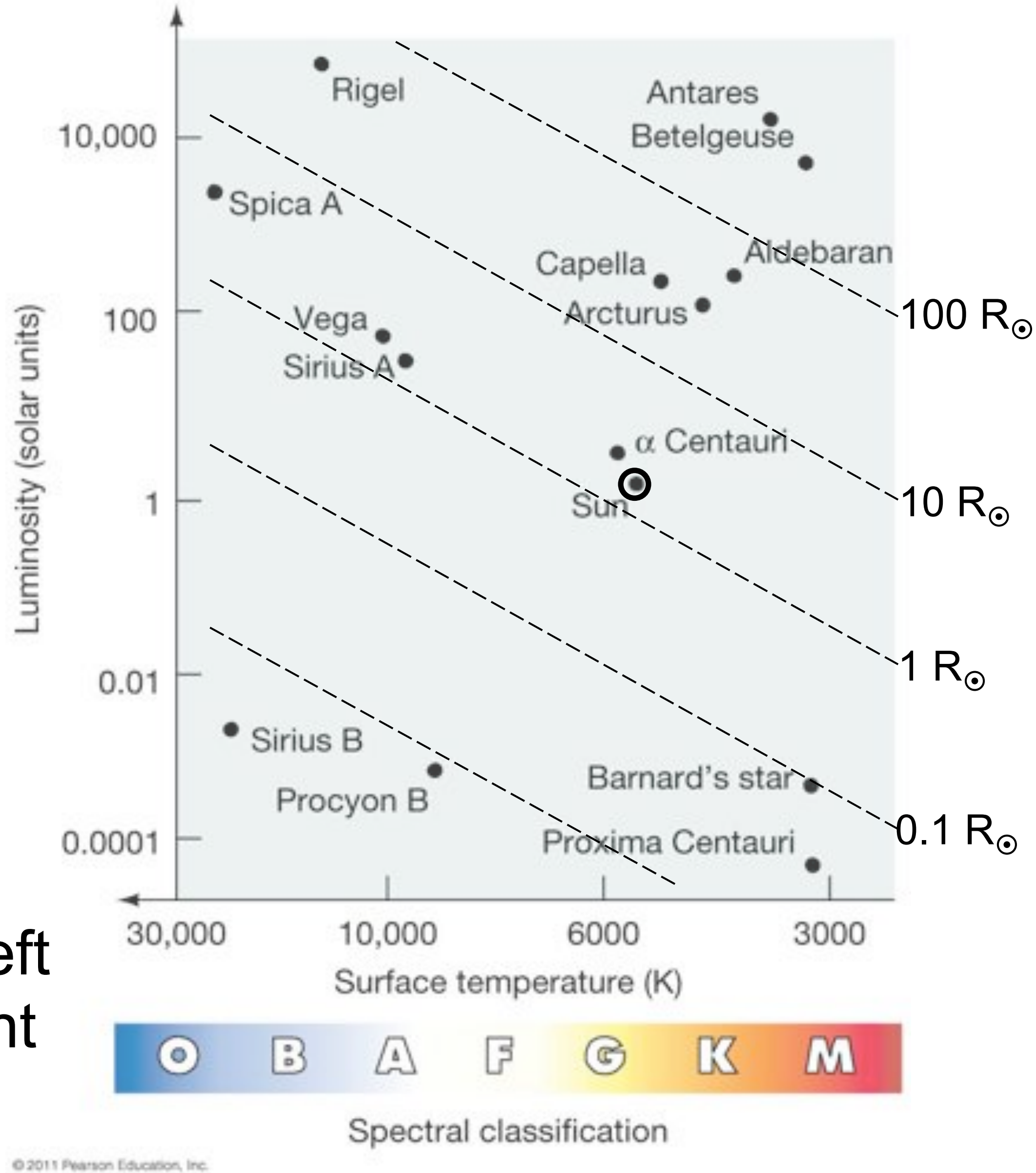
The H–R diagram plots stellar luminosity against surface temperature.

This is an H–R diagram of a few well-known stars.

or colour

H-R Diagram in more Detail

Why?



⊙=sun

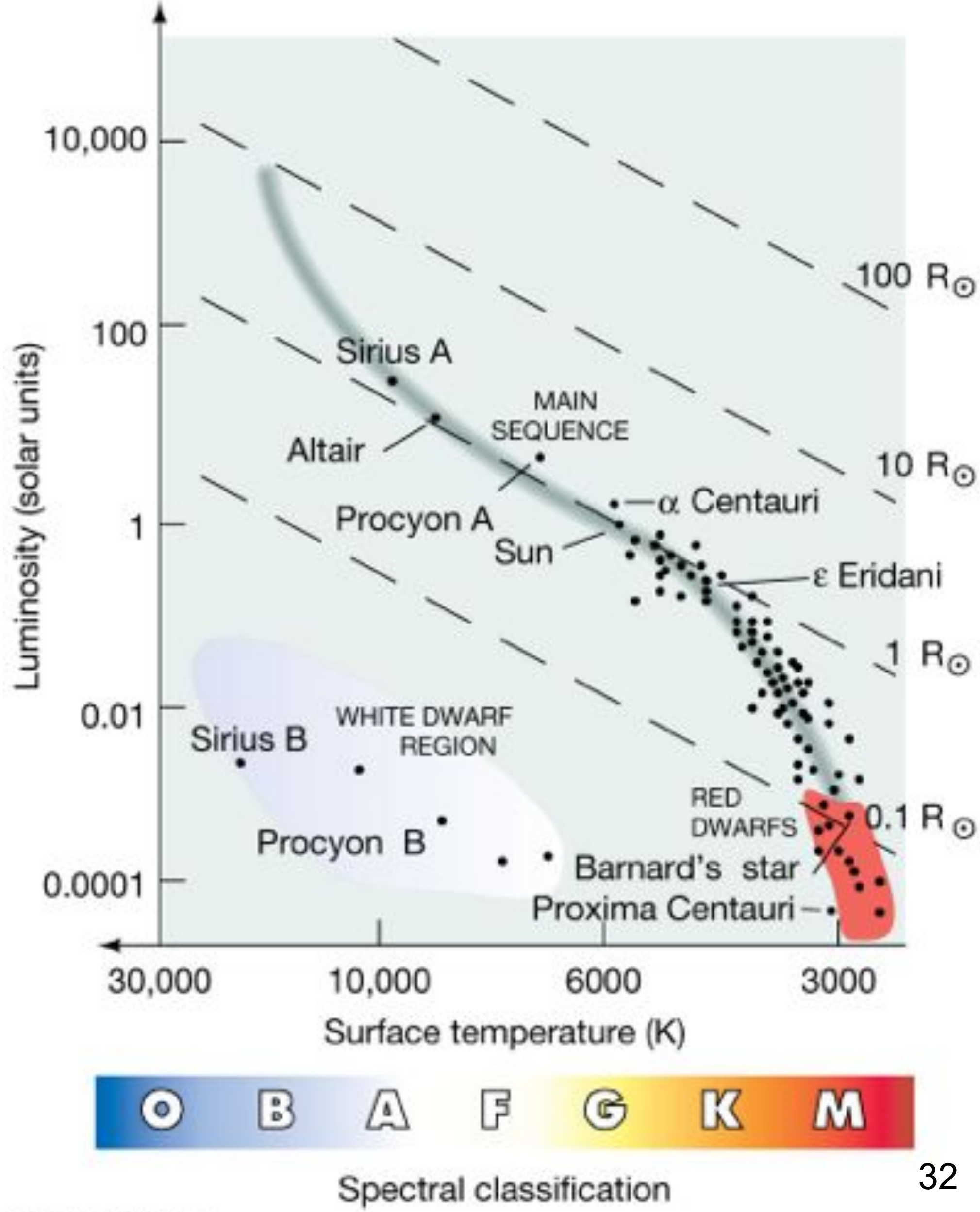
small=lower left
big=upper right

17.5 The H-R Diagram – the Main Sequence

Main sequence - where most stars are.

white dwarf region - these stars are hot but not very luminous, as they are quite small.

80 closest stars to sun

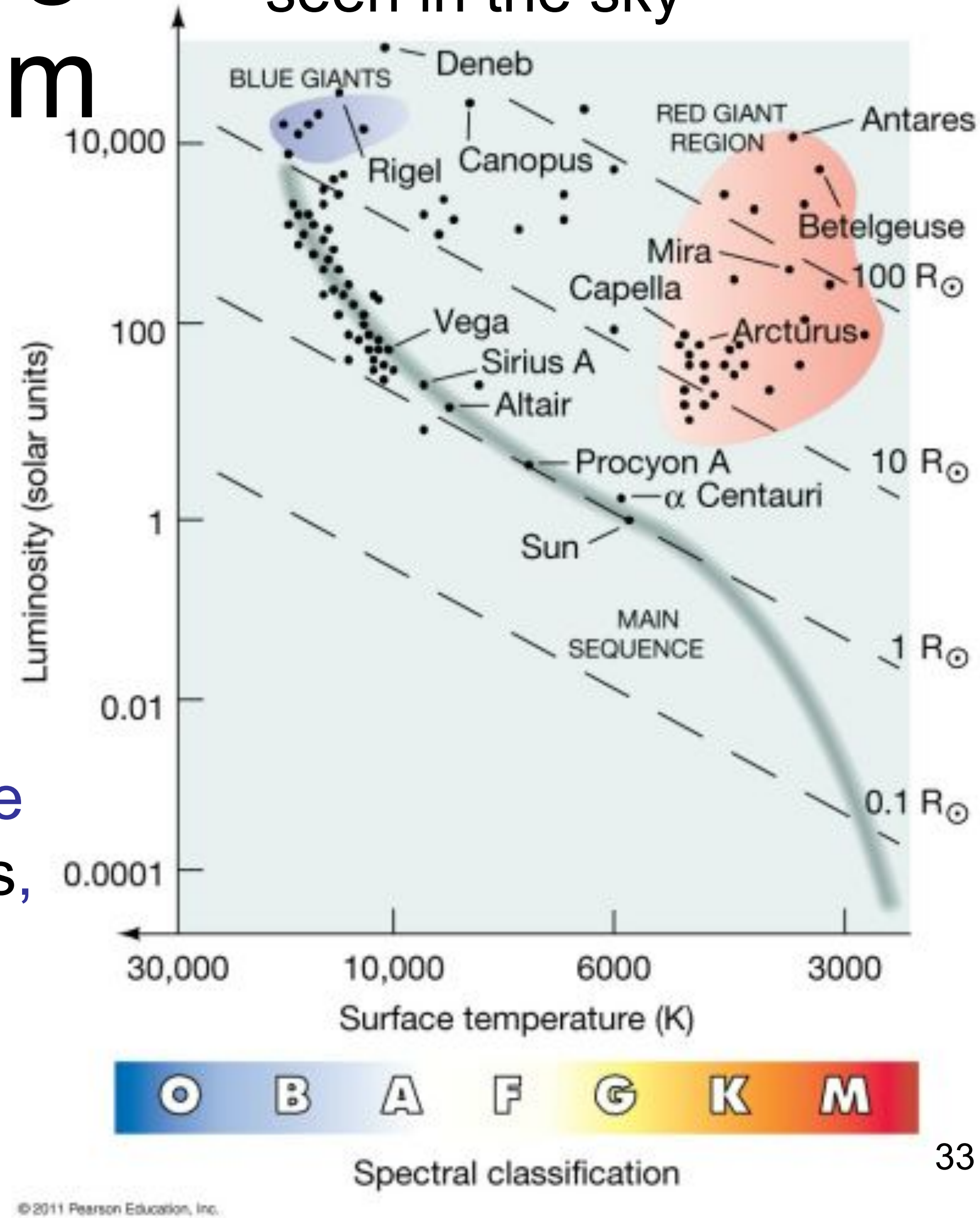


17.5 Hertzsprung–Russell Diagram

100 brightest stars as seen in the sky

These stars are all more luminous than the Sun. Two new categories appear here - the red giants and the blue giants.

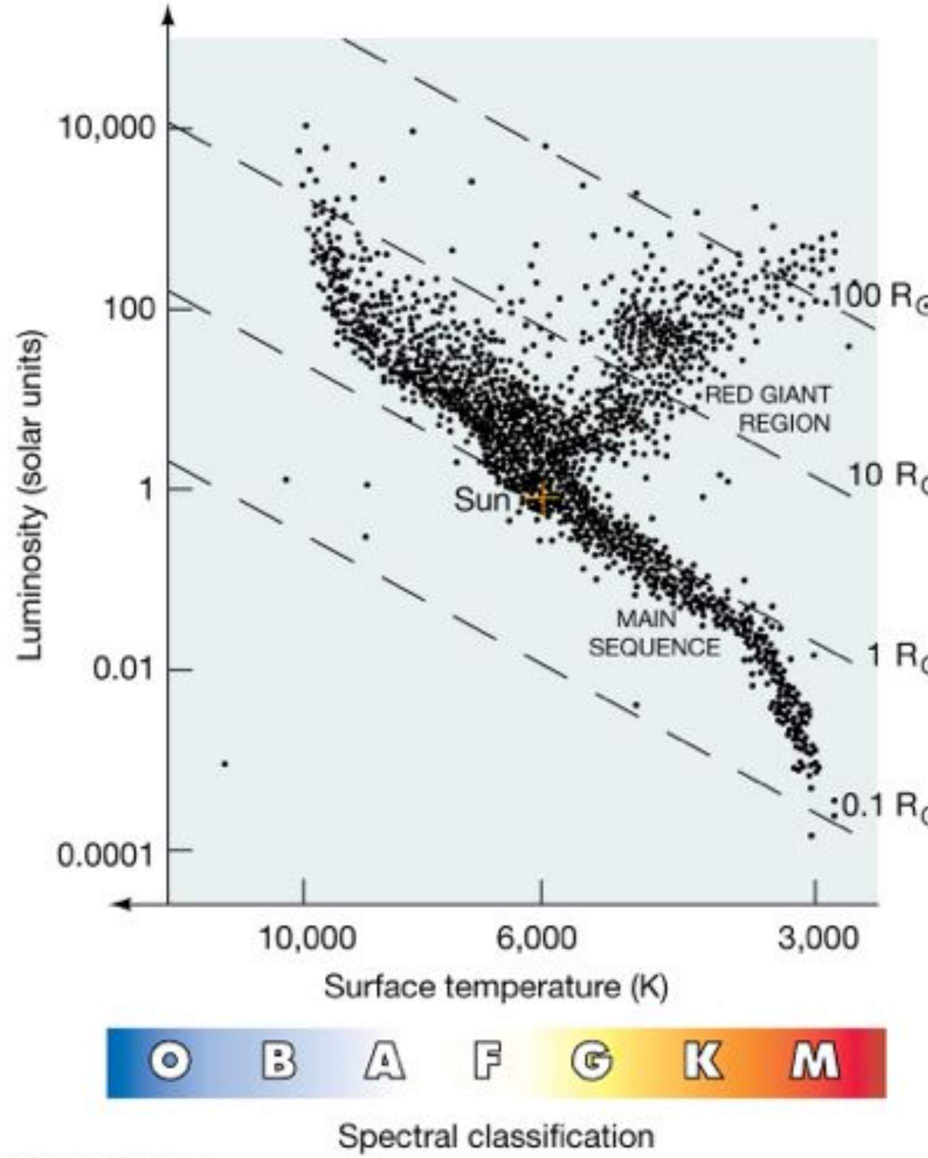
Clearly, the brightest stars in the sky appear bright because of their enormous luminosities, not their proximity. They are very rare and mostly distant.



17.5 Hertzsprung–Russell Diagram

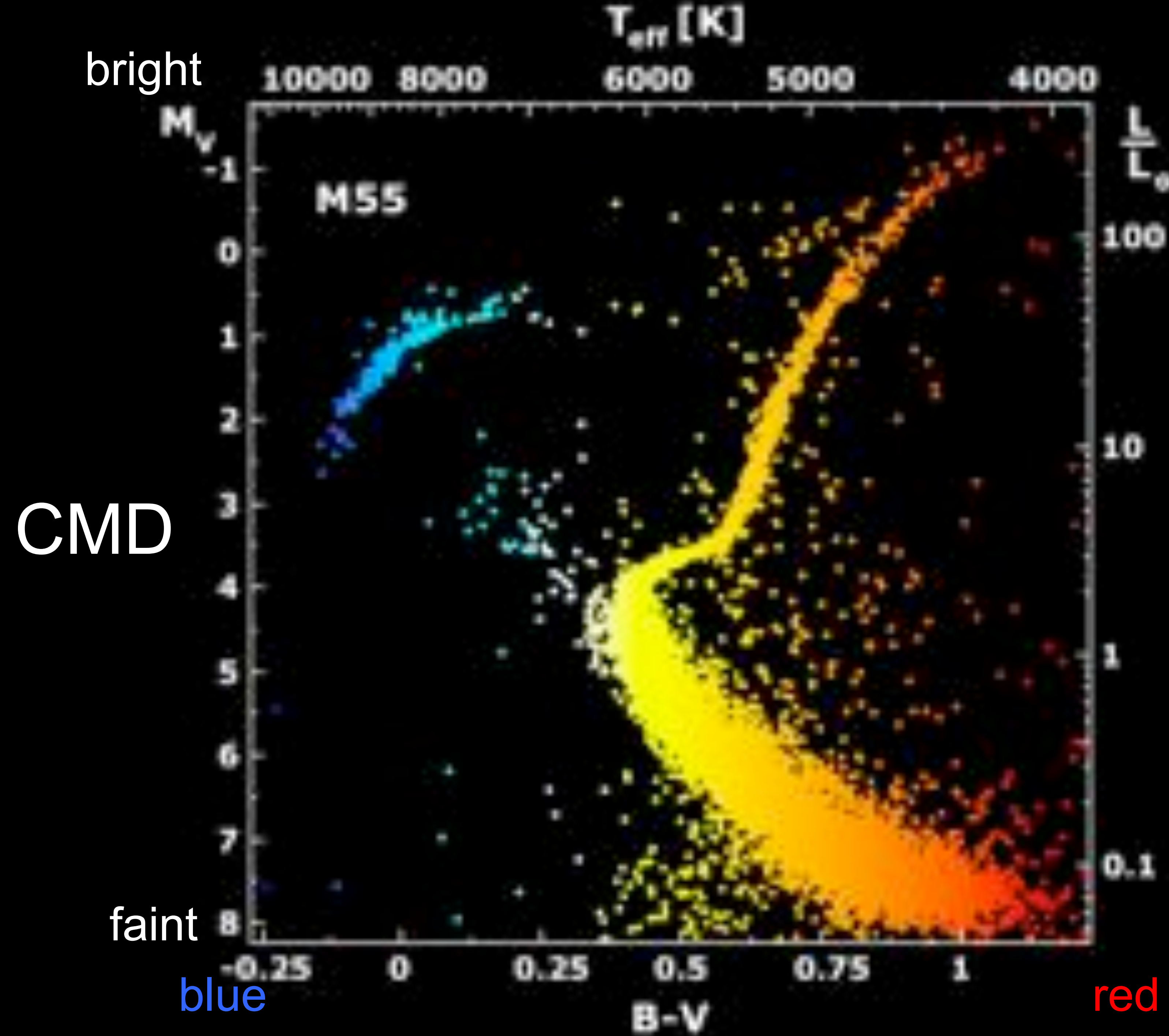
This is an H–R plot of about 20,000 stars. The main sequence is clear, as is the red giant region.

About 90% of these stars lie on the main sequence; 9% are red giants and 1% are white dwarfs.

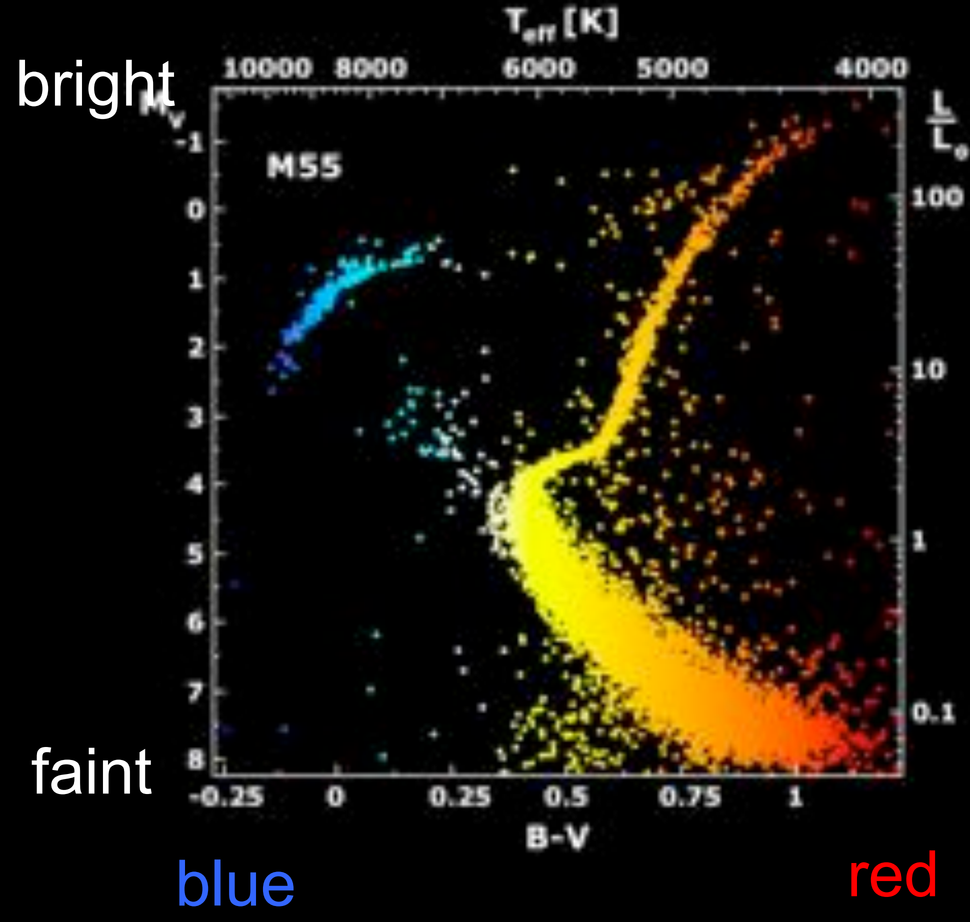


Question: what is the difference between a “Hertzsprung-Russell Diagram” and a “Colour-Magnitude Diagram”?

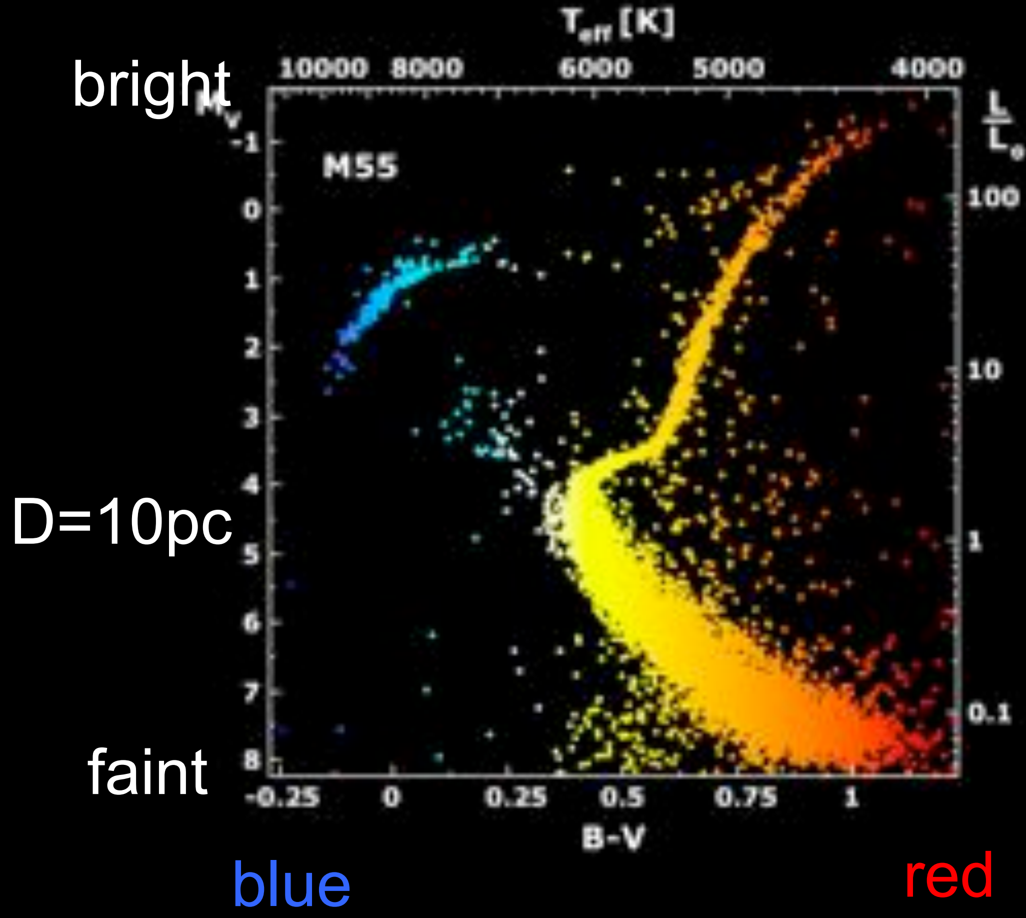
Answer: units!


bright
CMD
faint
blue
red
T_eff [K]
10000
8000
6000
5000
4000
M_V
-1
0
1
2
3
4
5
6
7
8
M55
L/L_⊙
100
10
1
0.1
-0.25
0
0.25
0.5
0.75
1
B-V

Colour Magnitude Diagram



- Luminosity in magnitudes
- Temperature expressed as “B-V colour”
  - Blue light vs visual light, in magnitudes
- Above is for a “standard” distance of 10 pc



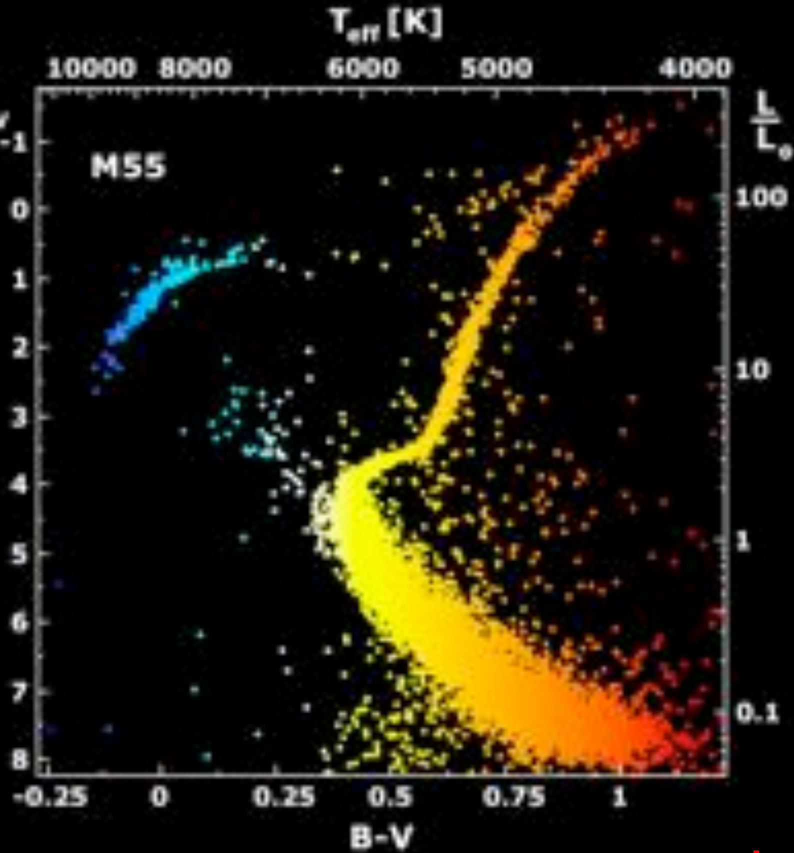
Colour Magnitude Diagram

What is the effect of distance?

bright

D=10pc

faint



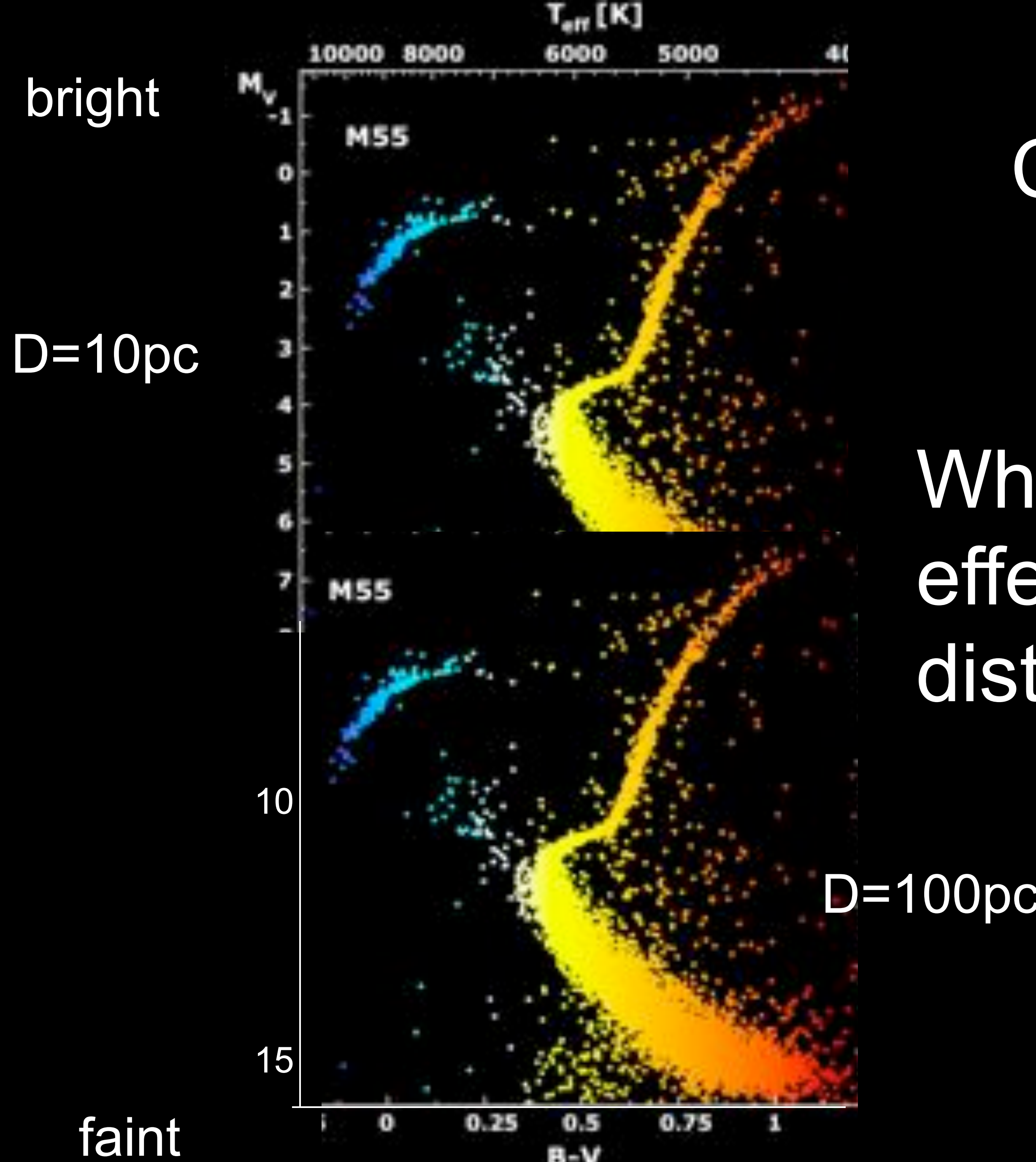
blue

red

Colour Magnitude Diagram

What is the effect of distance?

CMD



What is the effect of distance?

Q: What is the main sequence?

Q: What is the main sequence?

Answer: The main sequence is the location in the HR diagram of hydrogen burning stars.

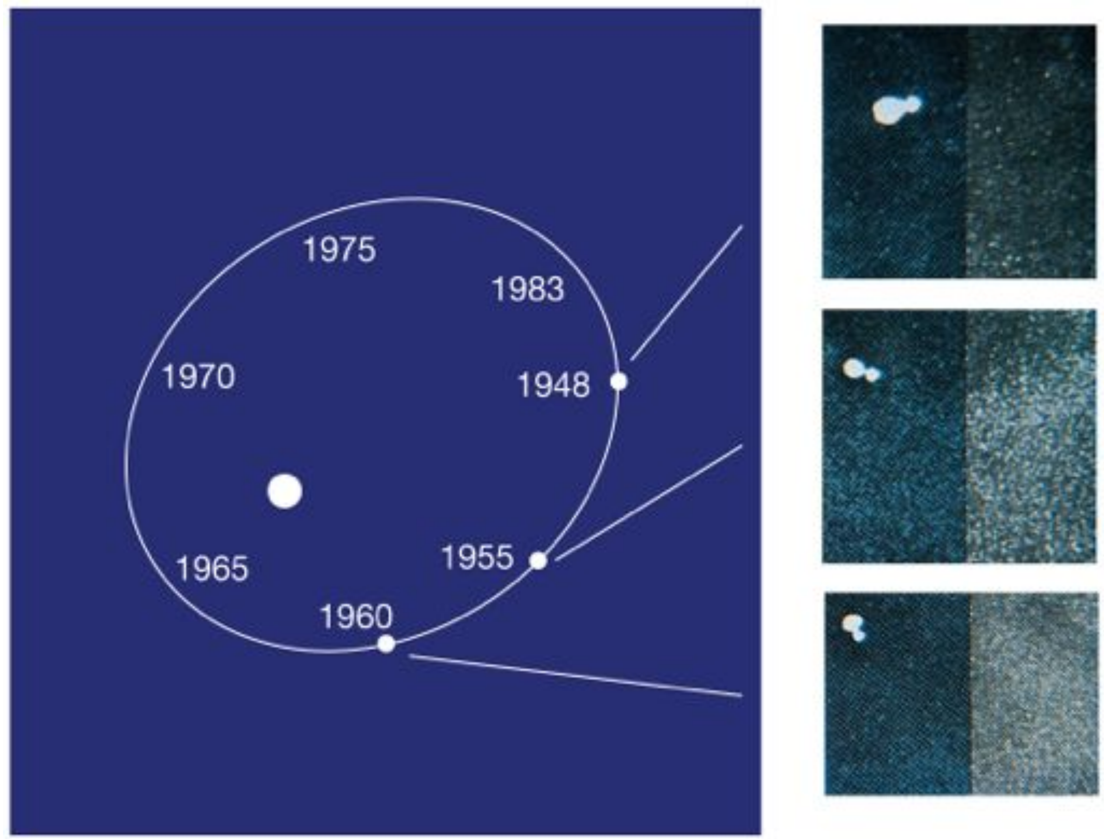
Nuclear reactions: 4H → He

Mass lost, $E=mc^2$

17.7 Stellar Masses

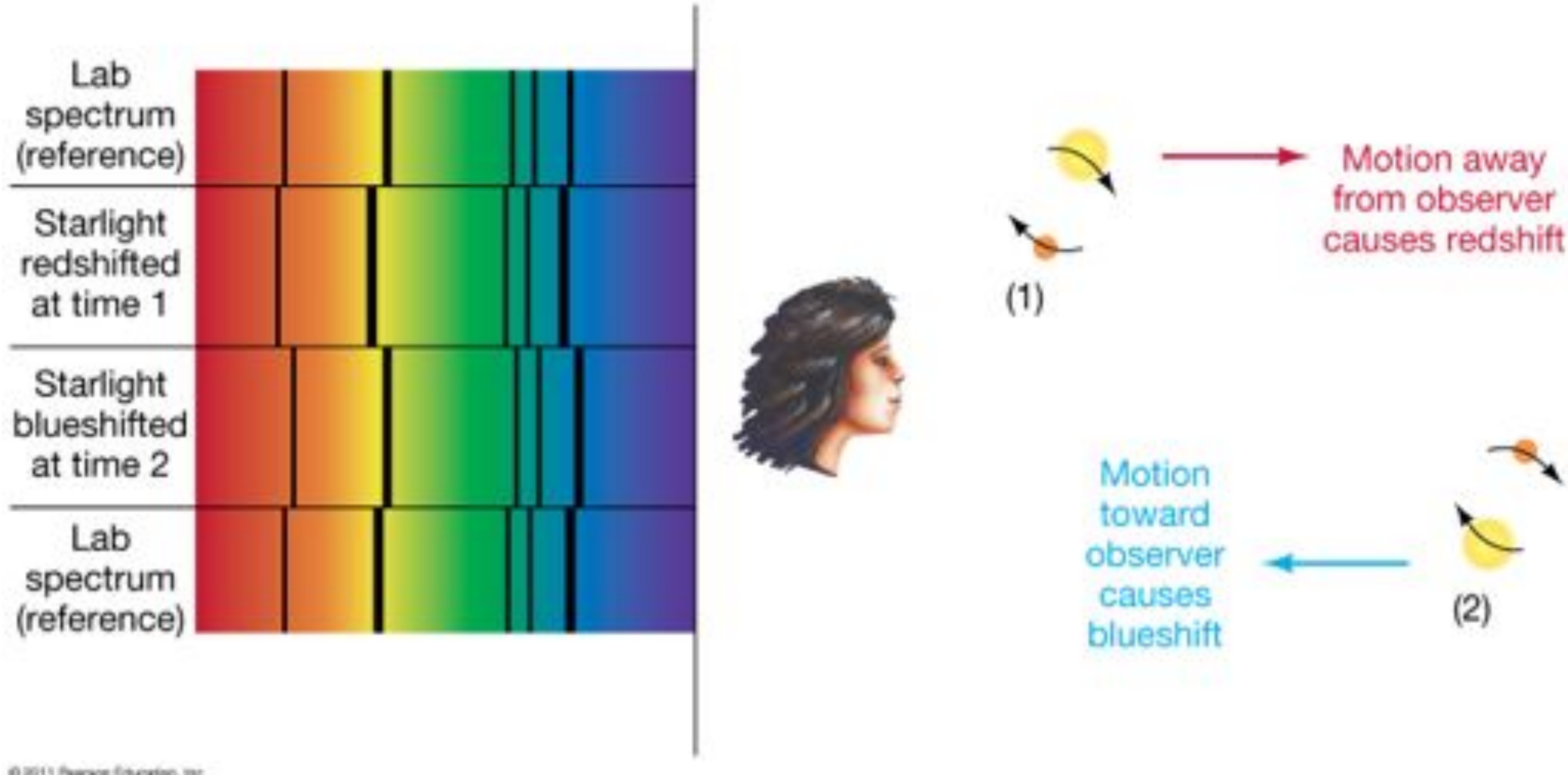
Many stars (50% or more!) are in binary pairs; measurement of their orbital motion allows determination of the masses of the stars.

Visual binaries can be measured directly. This is Krüger 60.



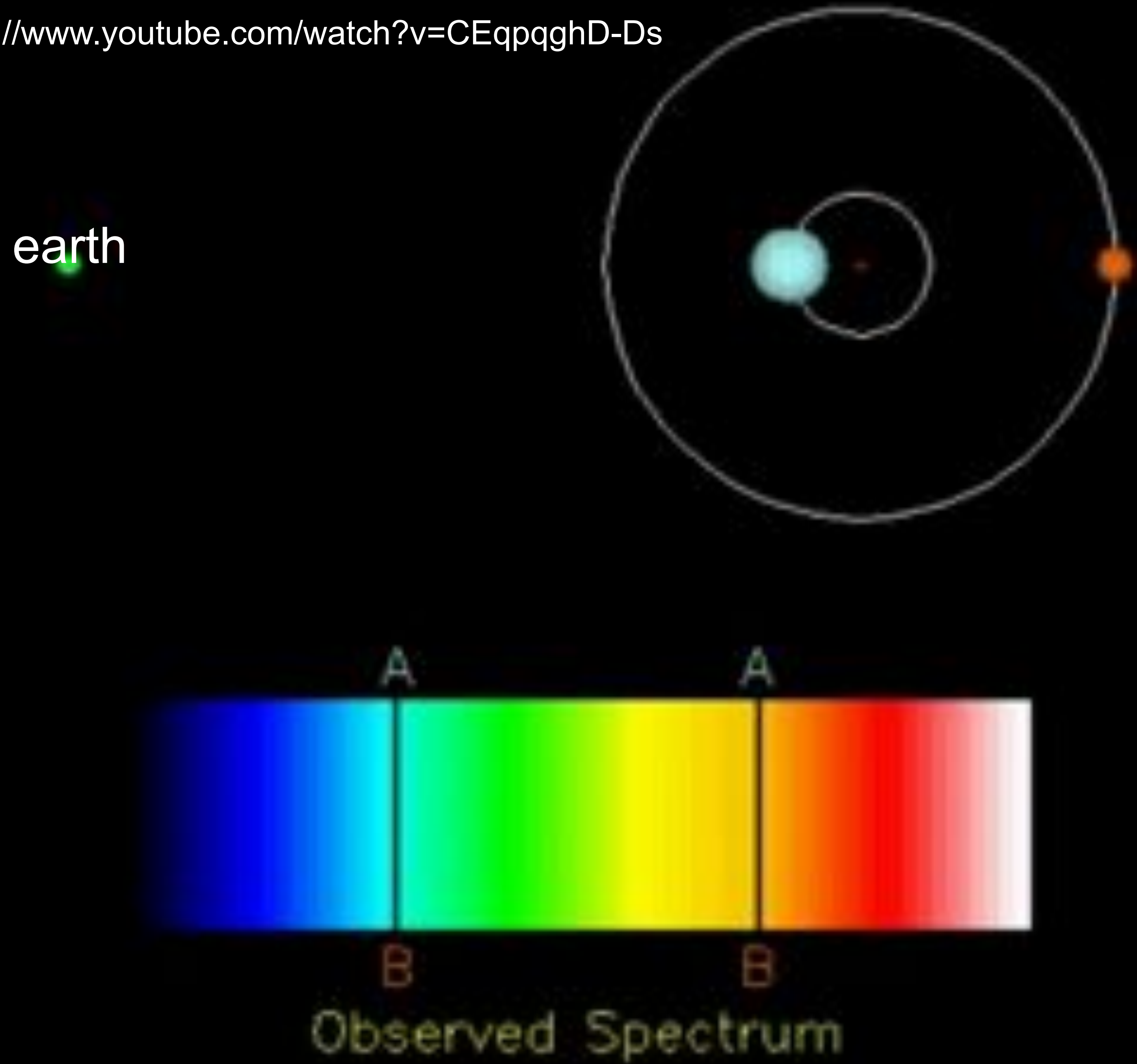
17.7 Stellar Masses

Spectroscopic binaries can be measured using their Doppler shifts



$M = v^2 R/G$ (Kepler, Newton)

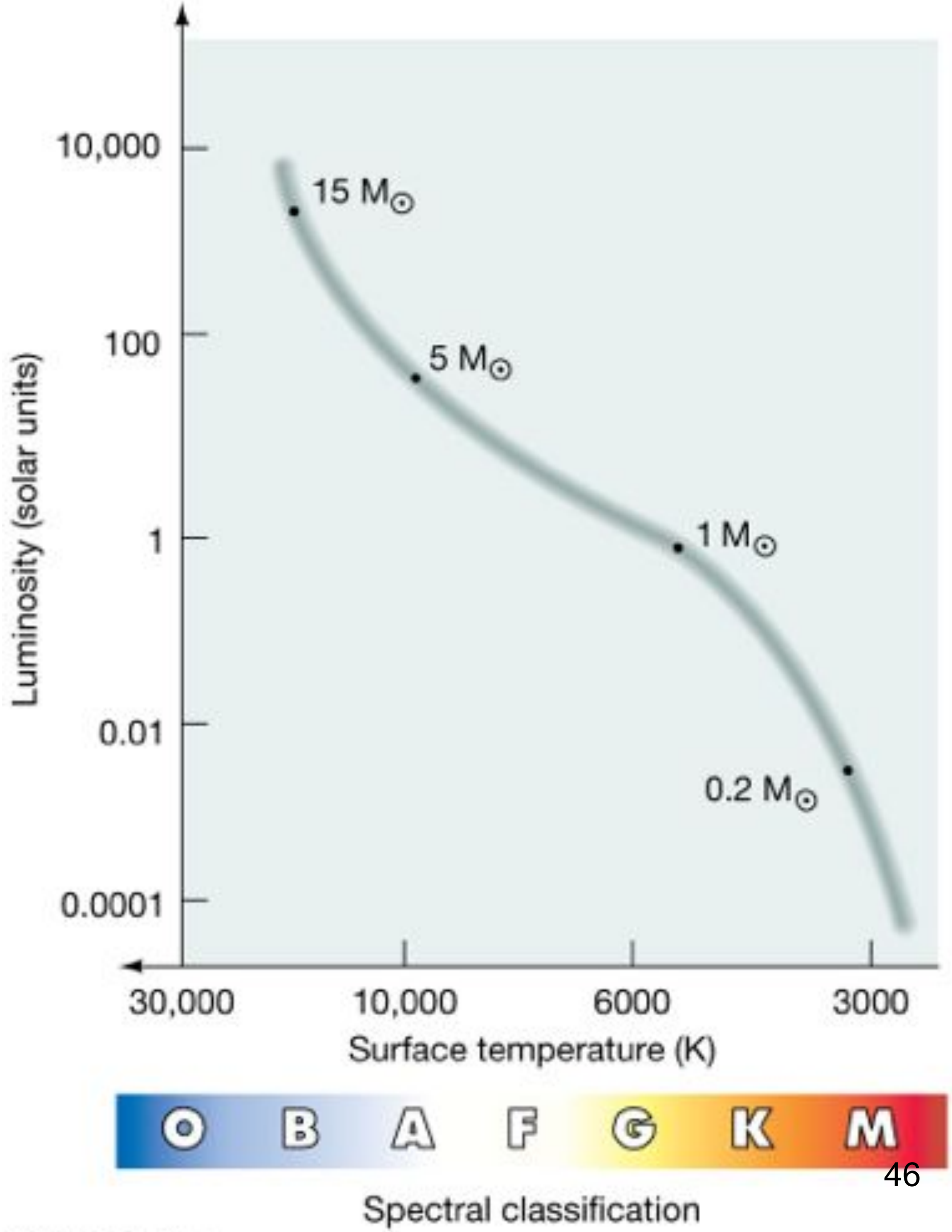
http://www.youtube.com/watch?v=CEqpqghD-Ds



17.7 Stellar Masses

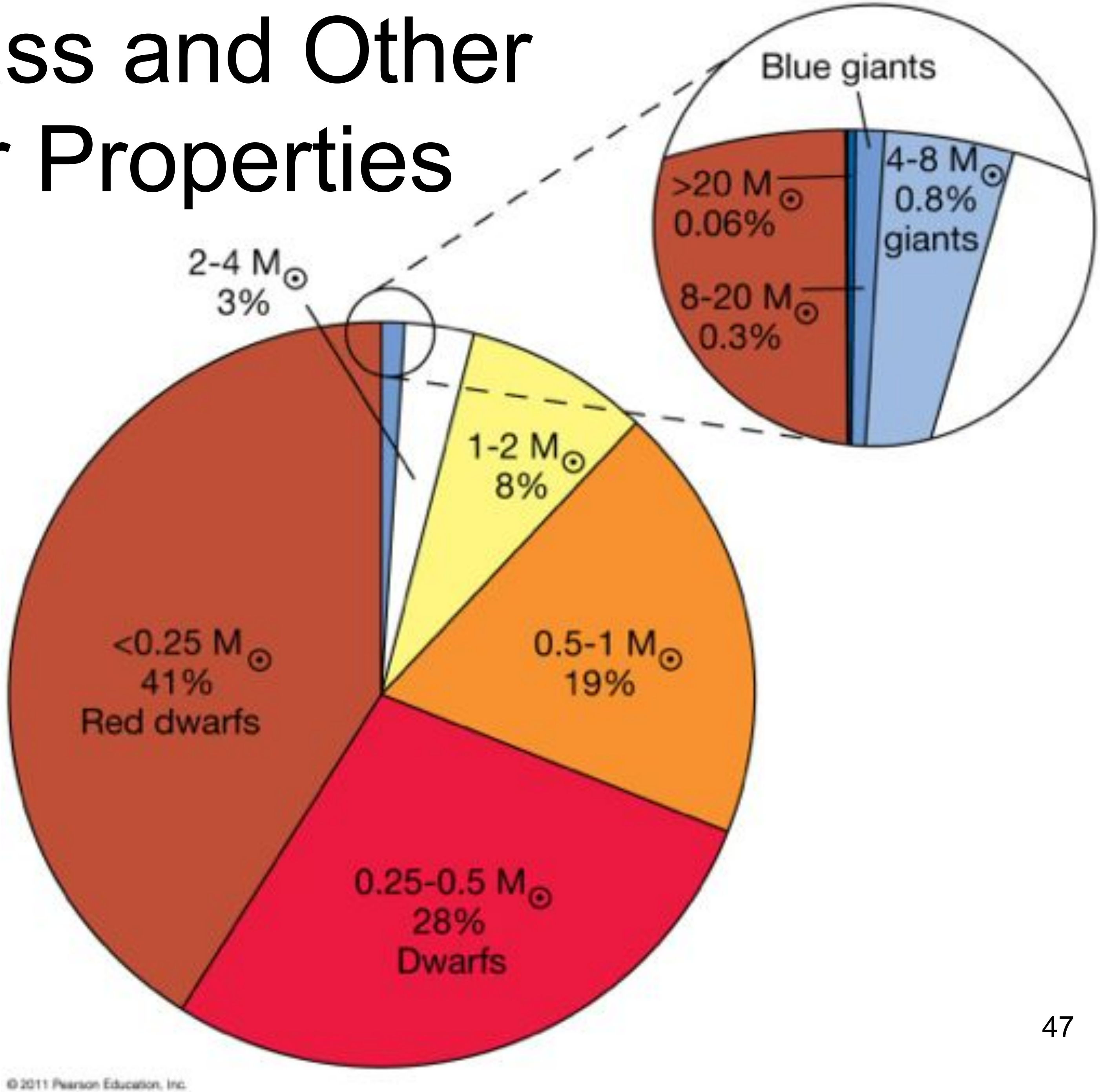
Mass is the main determinant of where a star will be on the main sequence .

- *but <u>only</u> for main sequence stars*



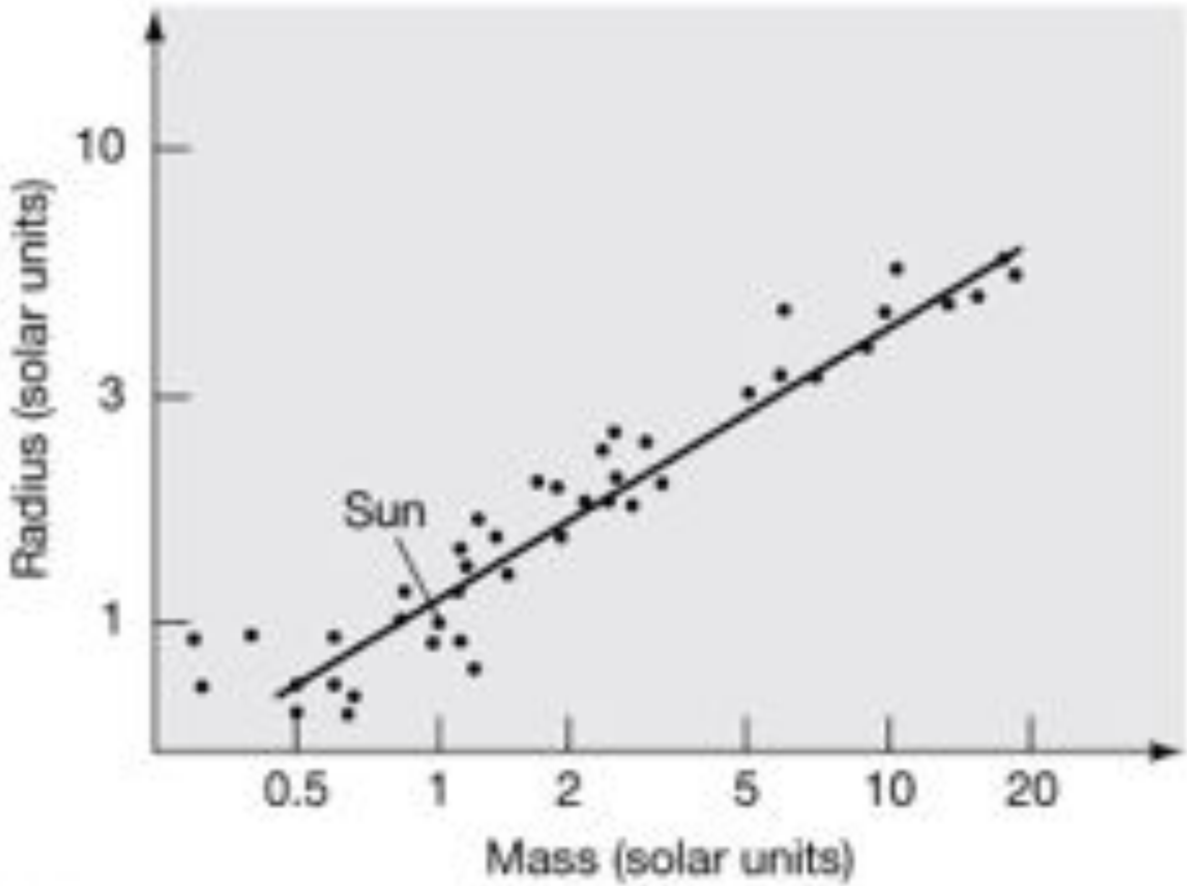
17.8 Mass and Other Stellar Properties

Massive stars are <u>much</u> rarer than the least massive.

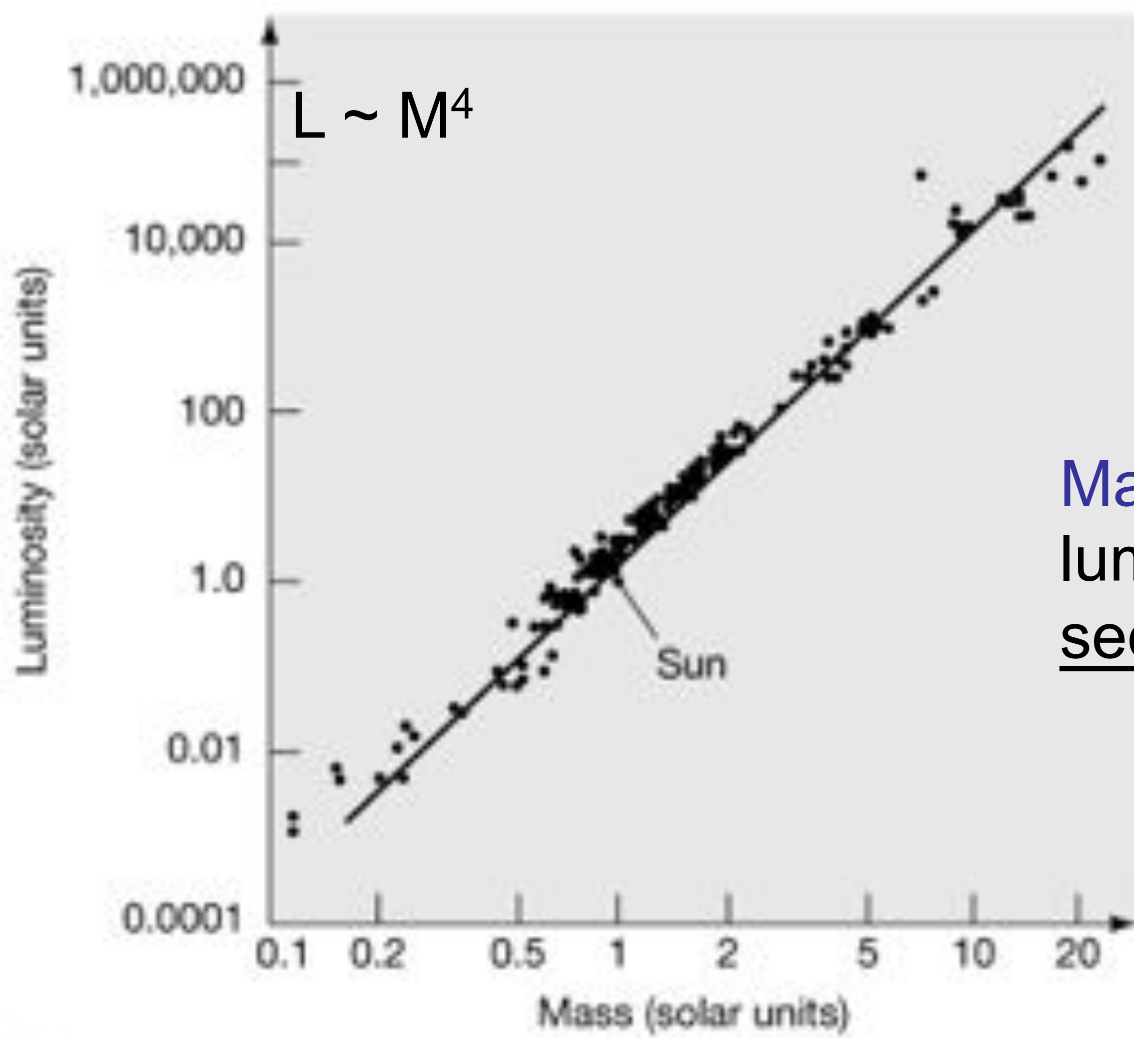


17.8 Mass and Other Stellar Properties for the Main Sequence

Mass is correlated with radius. (but only for main sequence)



17.8 Mass and Other Stellar Properties for the Main Sequence

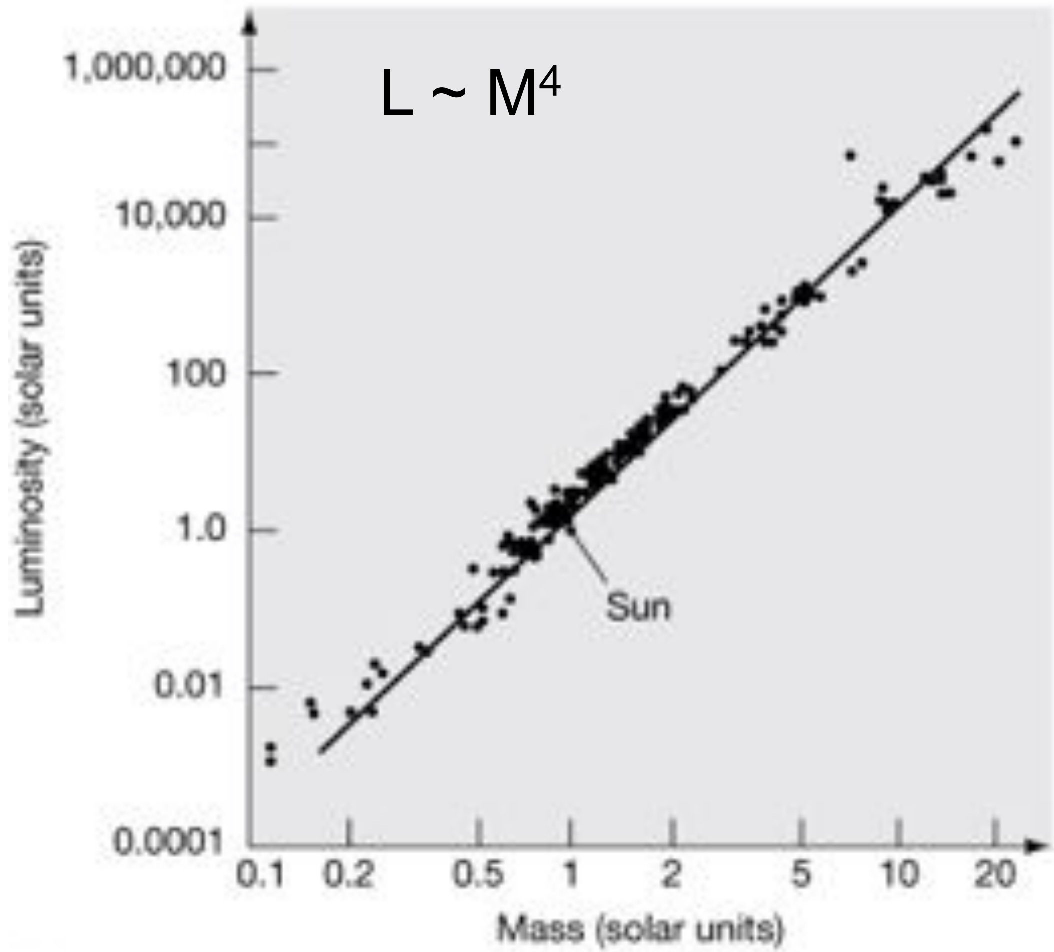


Mass is correlated with luminosity. <u>(only for main sequence)</u>

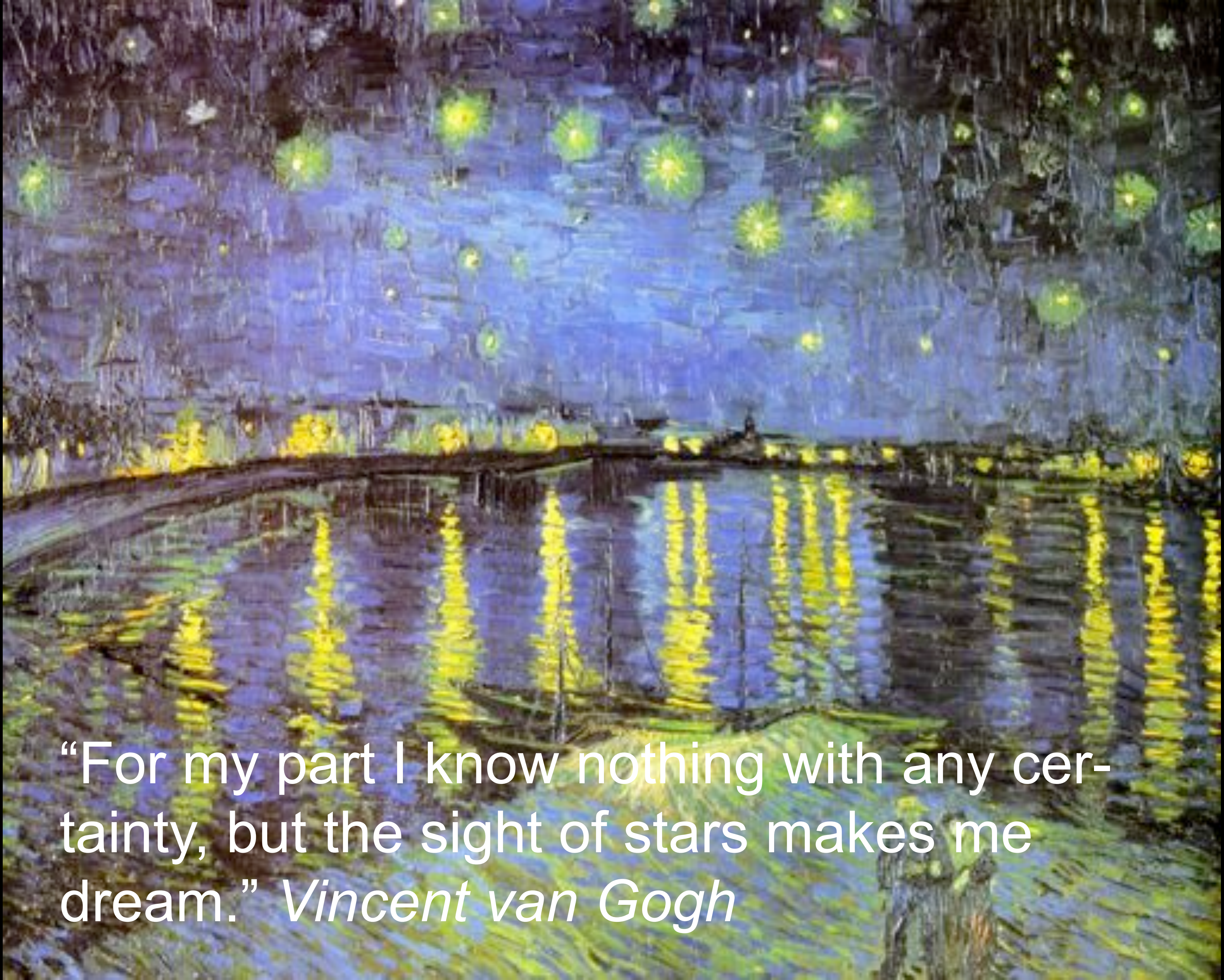
17.8 Mass and Other Stellar Properties

The most massive main sequence stars have the shortest lifetimes—they have a lot of fuel but burn it at a very rapid pace.

On the other hand, small red dwarfs burn their fuel extremely slowly and can have lifetimes of a trillion years or more.



(b)


“For my part I know nothing with any cer-
tainty, but the sight of stars makes me
dream.” *Vincent van Gogh*

What is the main sequence?

A. The place in the Milky Way where most stars are found.
B. The place in the HR diagram where the oldest stars are found
C. The place in the HR diagram where hydrogen burning stars are found
D. The place in the HR diagram where helium burning stars are found