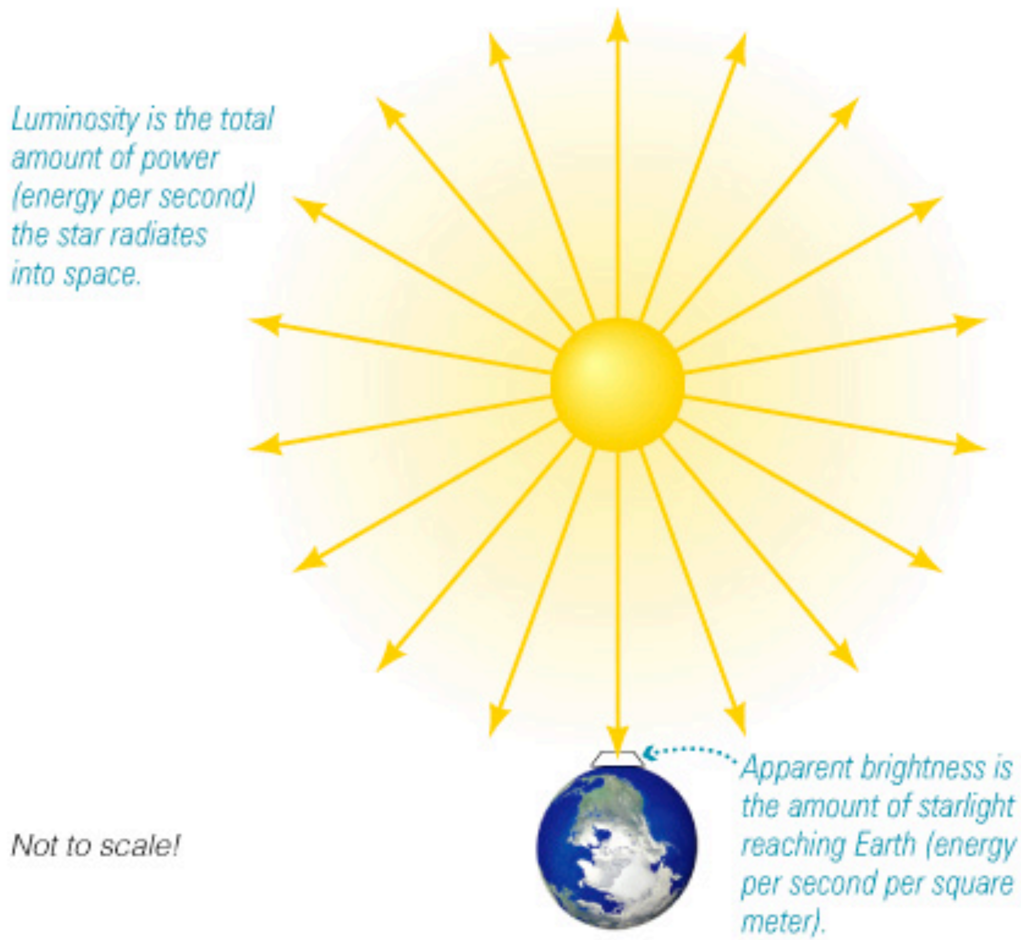
Chapter 11
Surveying the Stars

Brightness of a star depends on both distance and luminosity



Luminosity:

Amount of power a star radiates

(energy per second = watts)

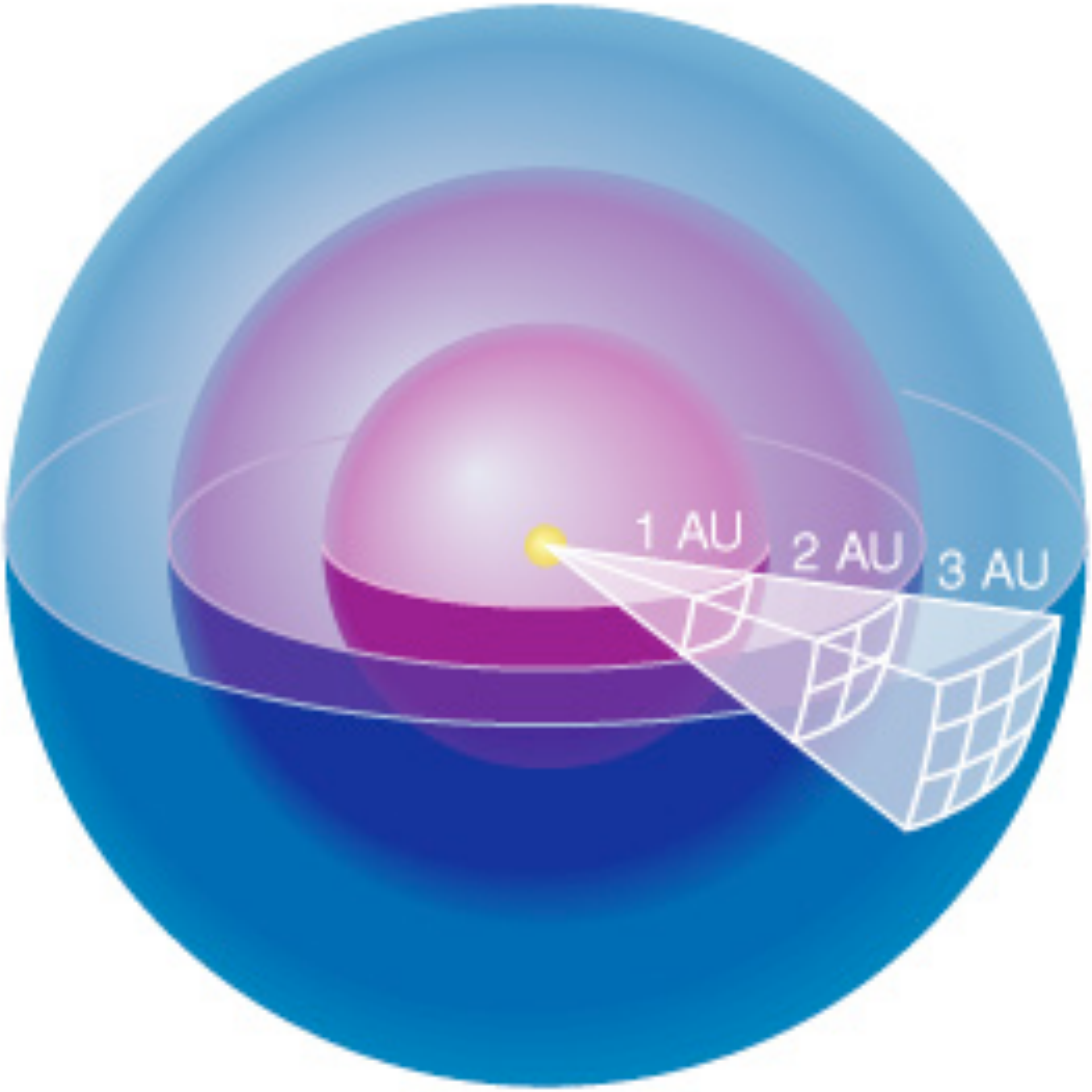
Apparent brightness:

Amount of starlight that reaches Earth

(energy per second per square meter)

These two stars have about the same luminosity— which one appears brighter?

50%	1.	A. Alpha Centauri
50%	2.	B. The Sun



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:

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

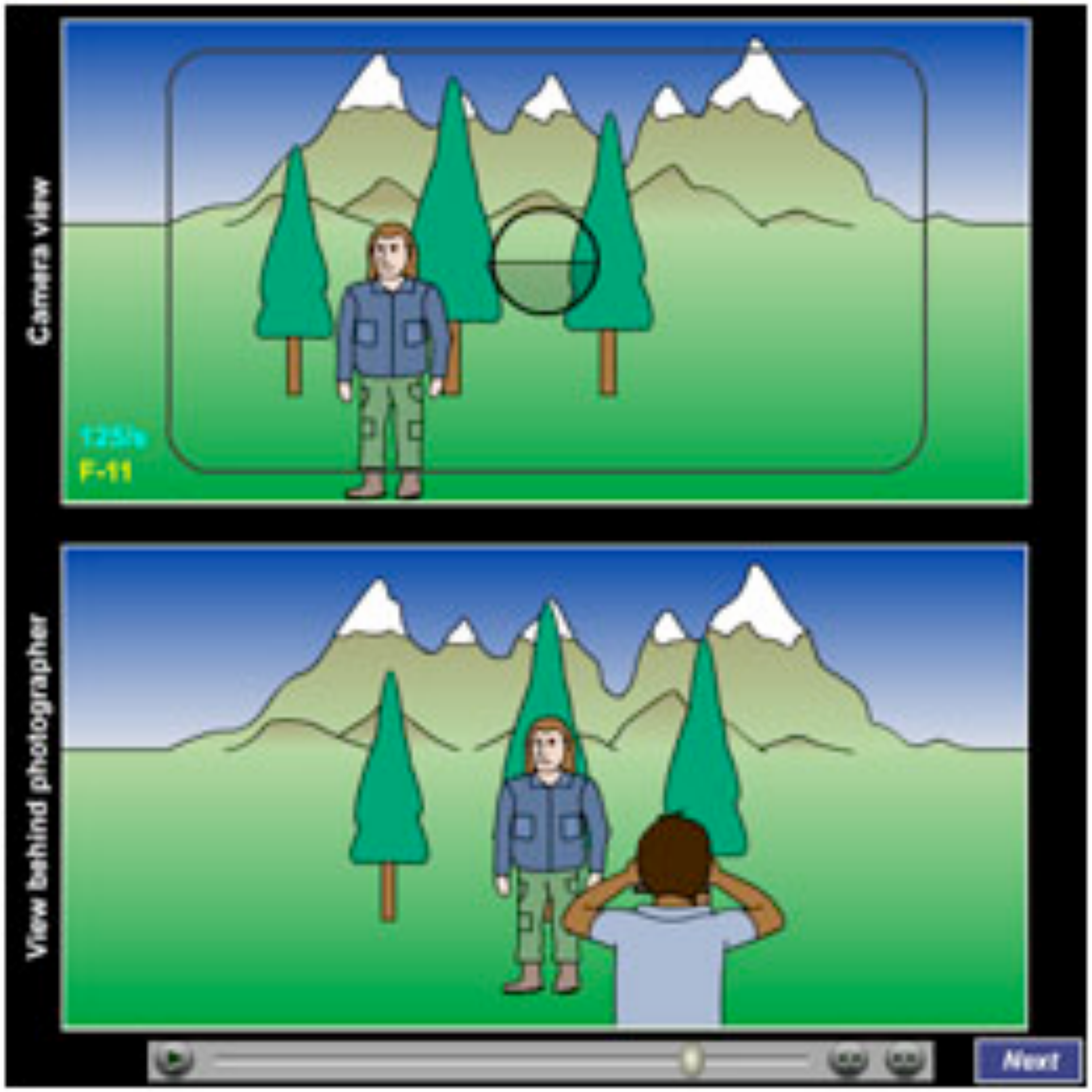
We can determine a star's luminosity if we can measure its distance and apparent brightness:

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

How would the apparent brightness of Alpha Centauri change if it were three times farther away?

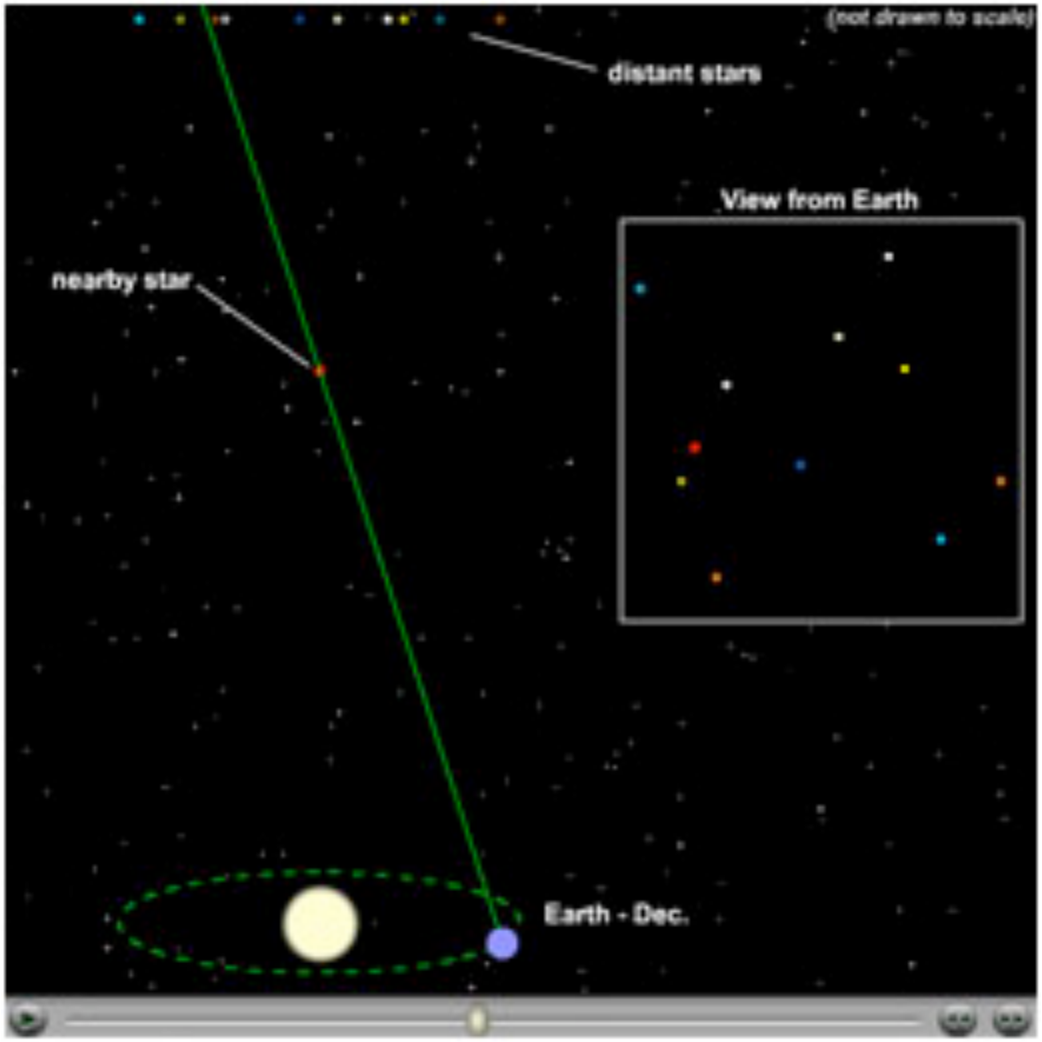
25%	1.	A. It would be only 1/3 as bright.
25%	2.	B. It would be only 1/6 as bright.
25%	3.	C. It would be only 1/9 as bright.
25%	4.	D. It would be three times as bright.

So how far away are these stars?



PLAY Introduction to Parallax

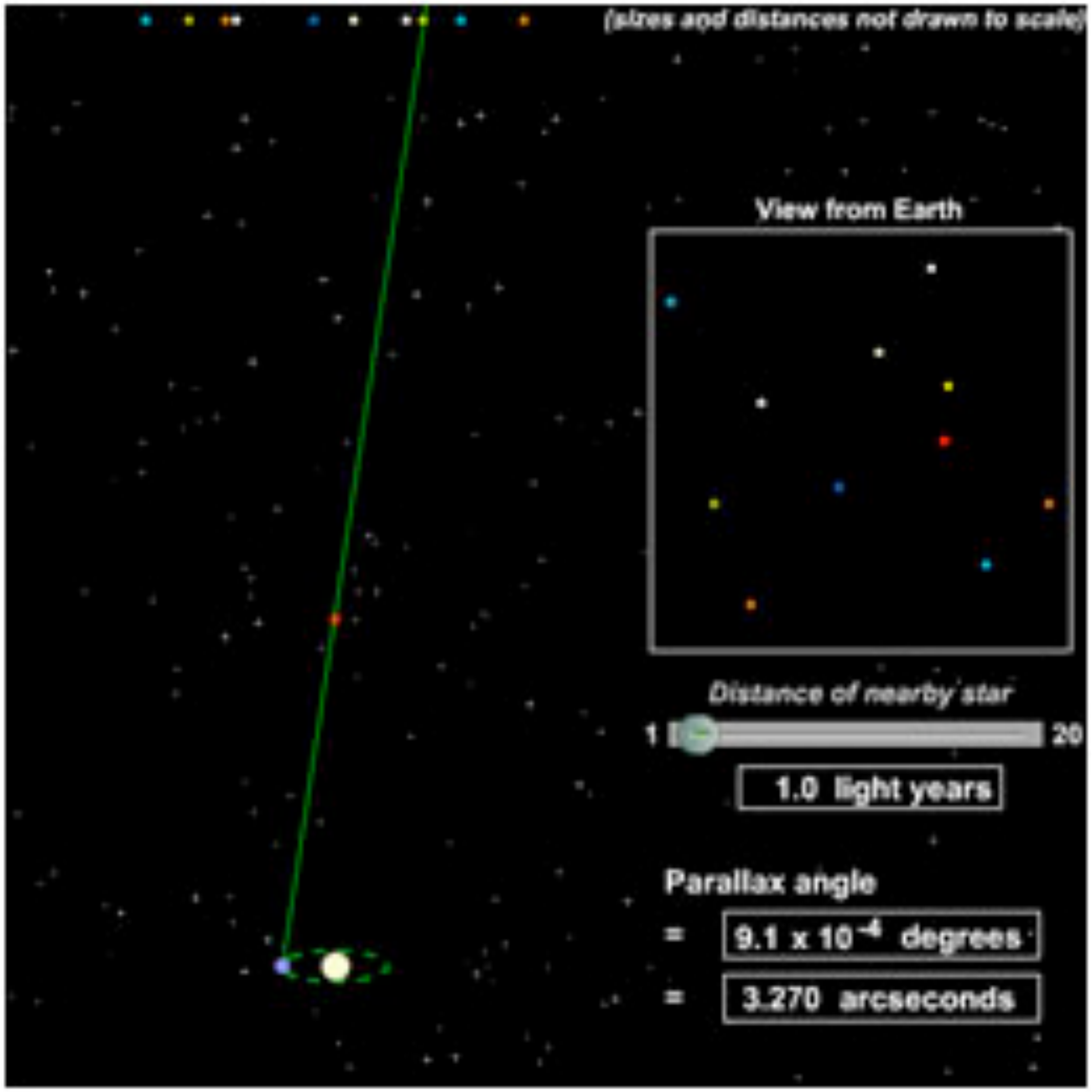
Parallax is the apparent shift in position of a nearby object against a background of more distant objects.



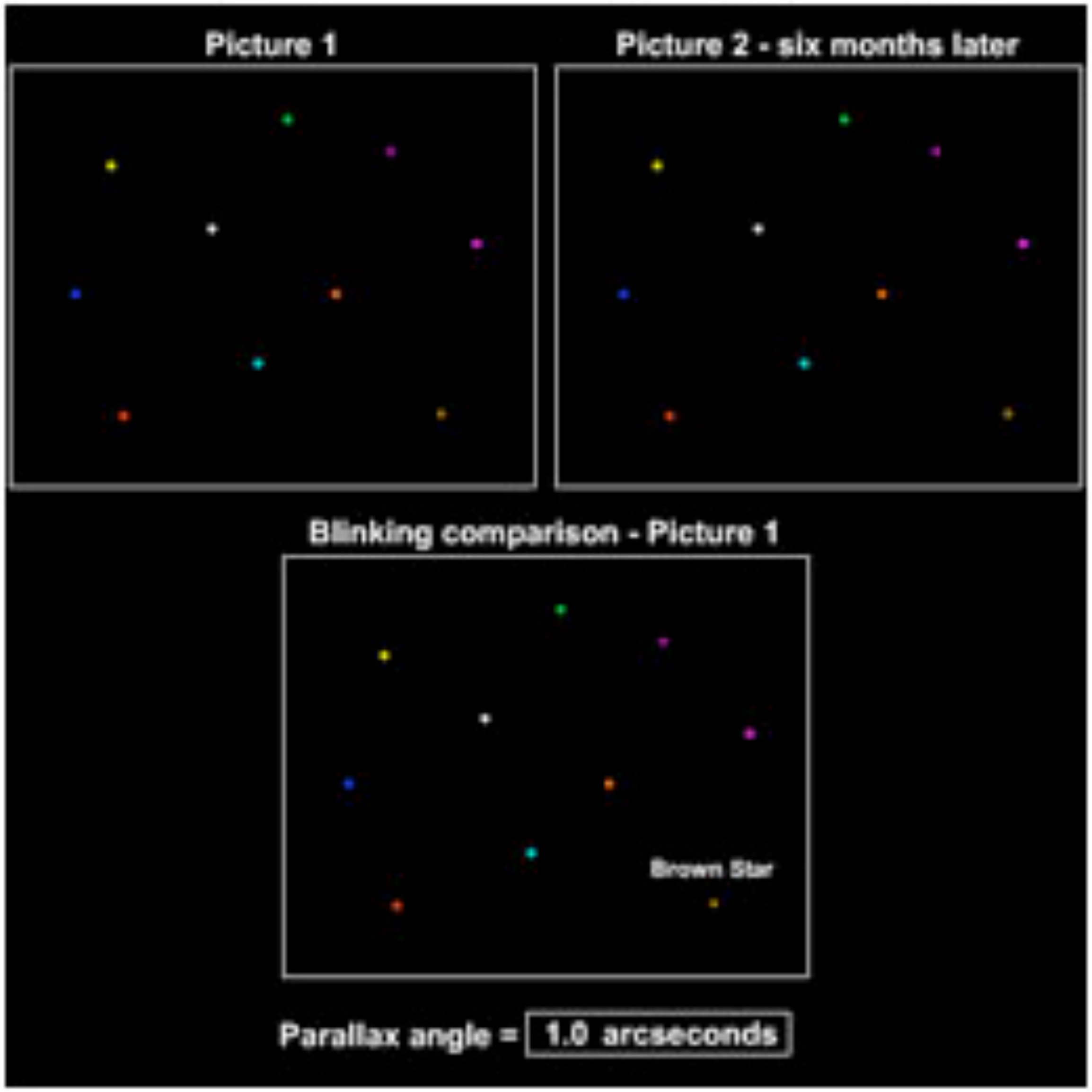
Apparent positions of the nearest stars shift by about an arcsecond as Earth orbits the Sun.

PLAY Parallax of a Nearby Star

The parallax angle depends on distance.

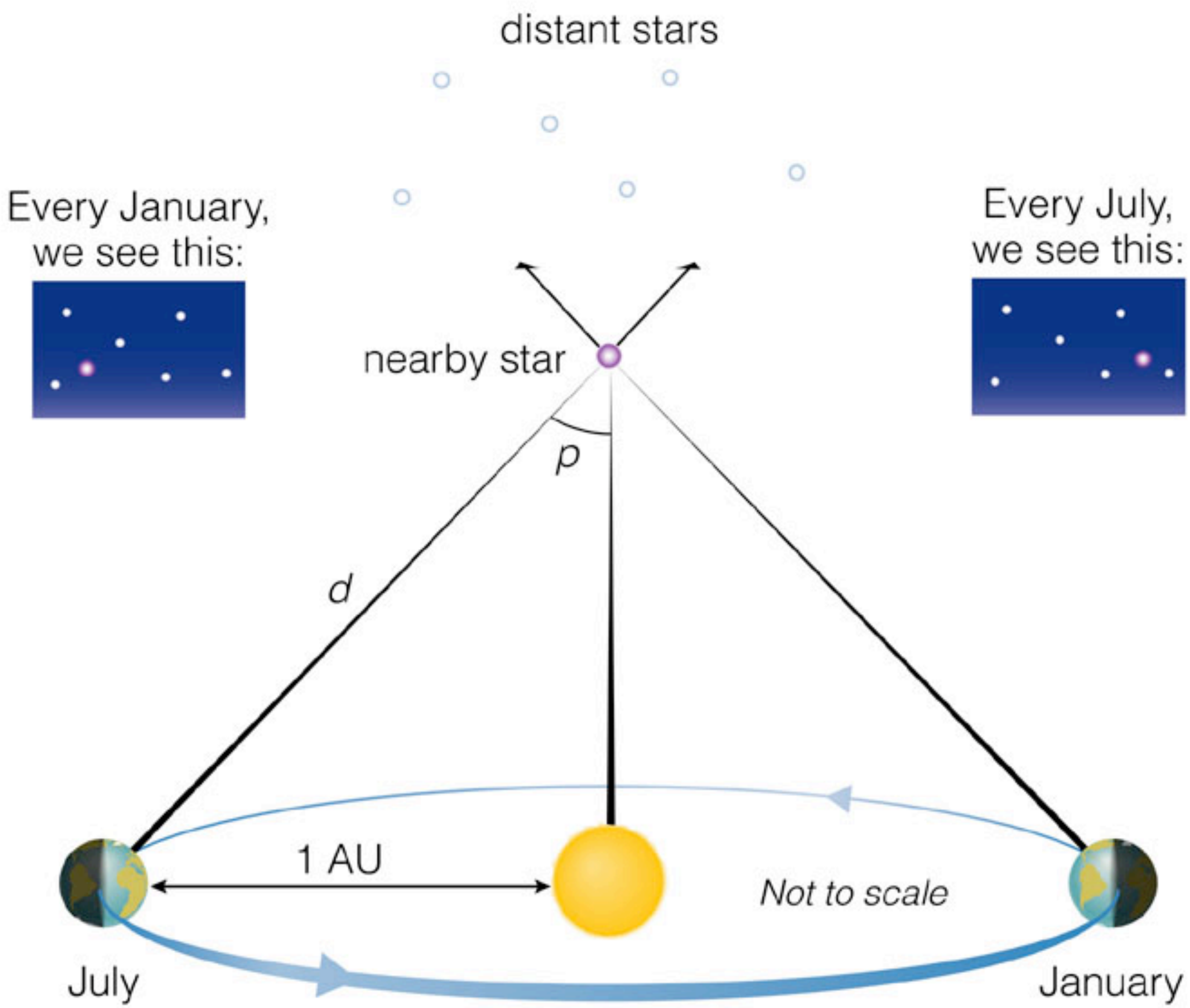


PLAY Parallax Angle as a Function of Distance



Parallax is measured by comparing snapshots taken at different times and measuring the shift in angle to star.

PLAY Measuring Parallax Angle


distant stars
Every January,
we see this:
Every July,
we see this:
nearby star
p
d
1 AU
Not to scale
July
January

Parallax and Distance

$$p = \text{parallax angle}$$

$$d \text{ (in parsecs)} = \frac{1}{p \text{ (in arcseconds)}}$$

$$d \text{ (in light-years)} = 3.26 \times \frac{1}{p \text{ (in arcseconds)}}$$

Most luminous stars:

$10^6 \ L_{Sun}$

Least luminous stars:

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

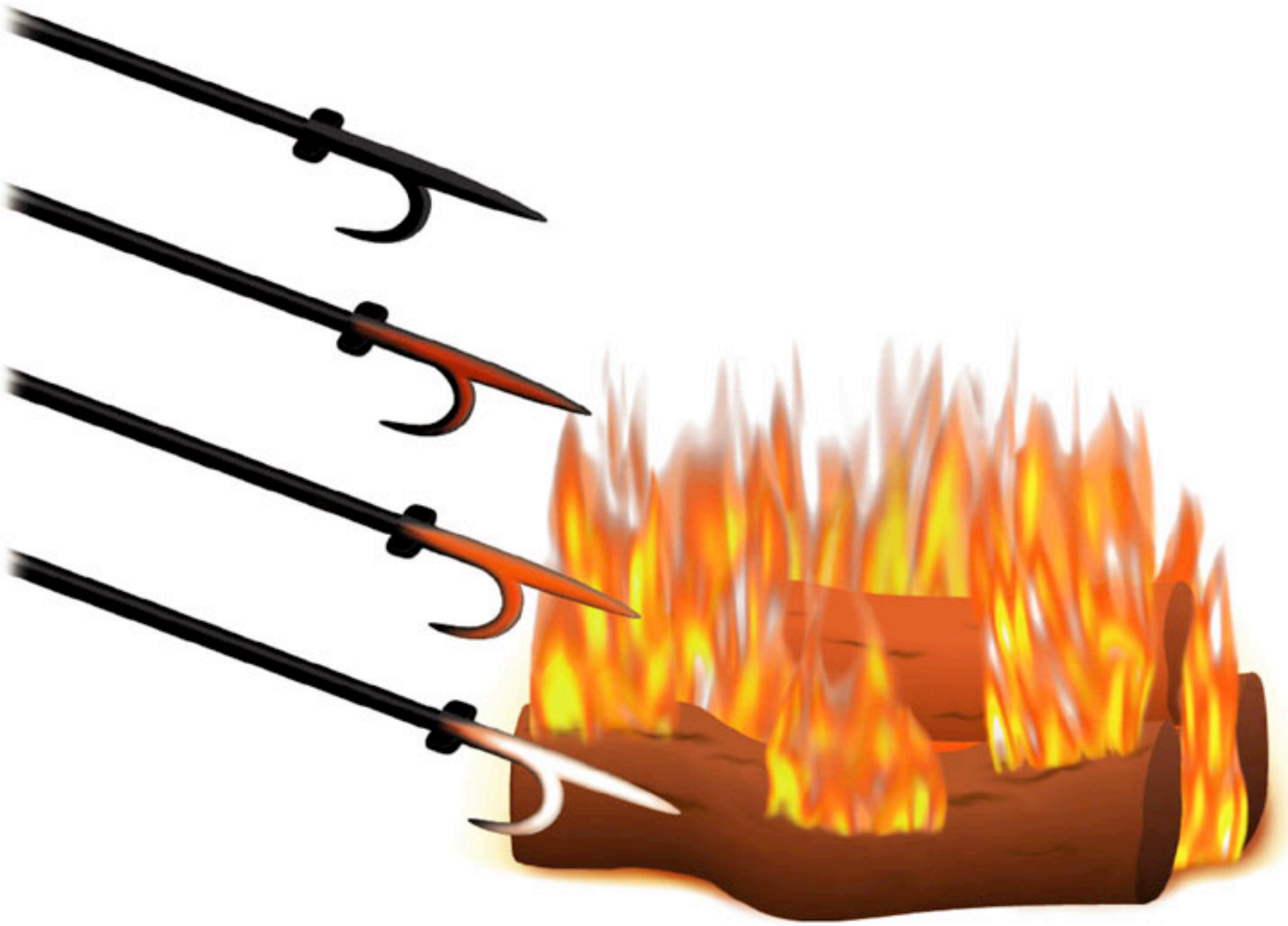
(L_{Sun} is luminosity of Sun)

The Magnitude Scale

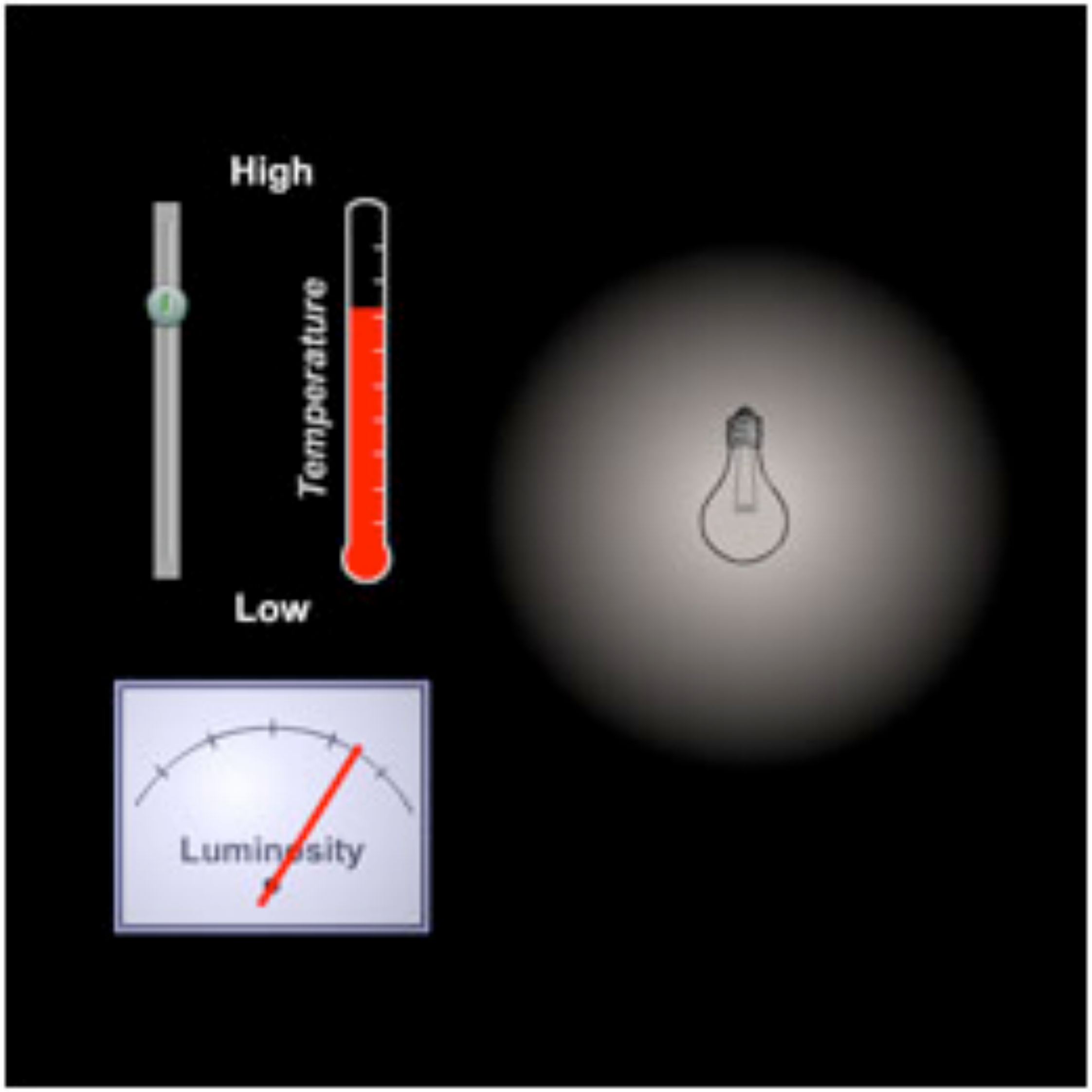
$m =$ apparent magnitude $\qquad M =$ absolute magnitude

$$\frac{\text{apparent brightness of Star 1}}{\text{apparent brightness of Star 2}} = (100^{1/5})^{m_1 - m_2}$$

$$\frac{\text{luminosity of Star 1}}{\text{luminosity of Star 2}} = (100^{1/5})^{M_1 - M_2}$$



Every object emits ***thermal radiation*** with a spectrum that depends on its temperature.

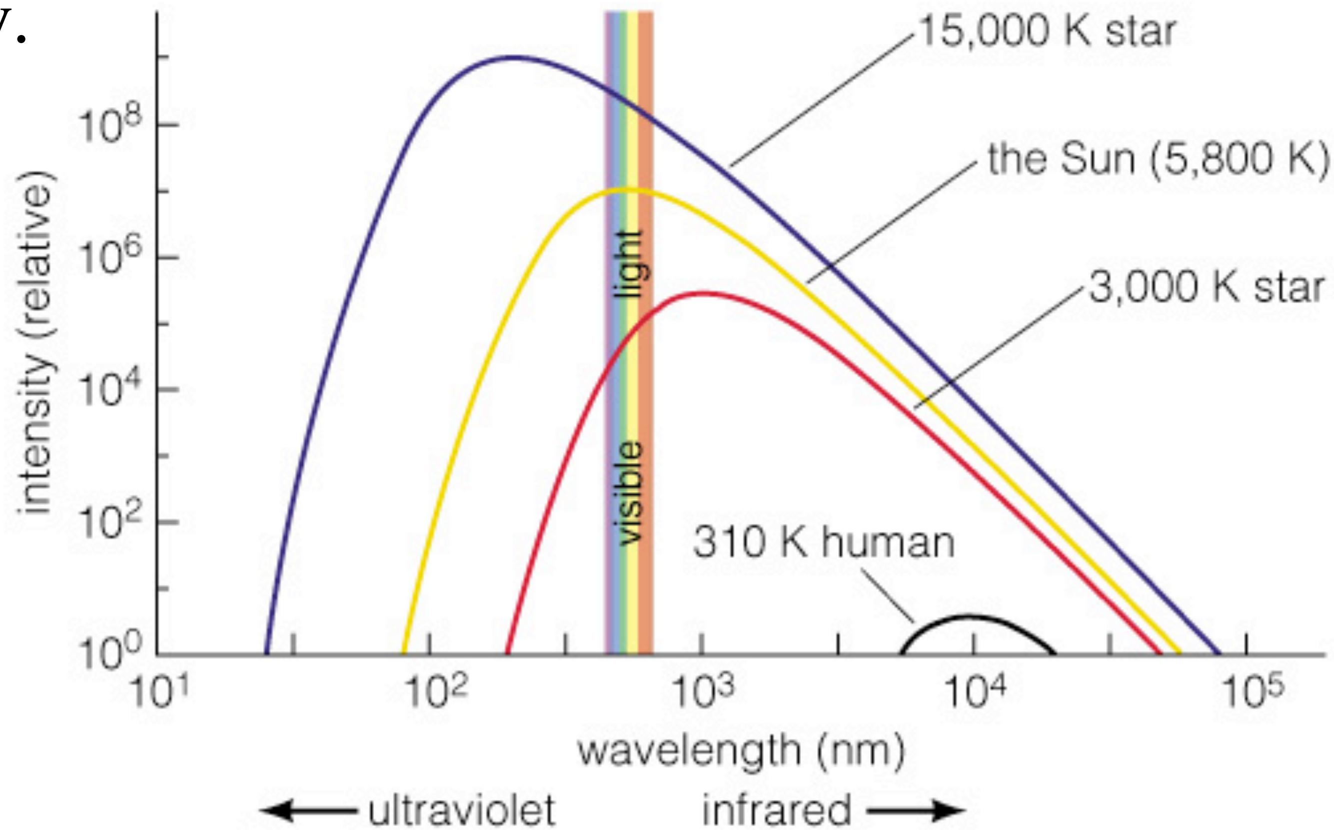


An object of fixed size grows more luminous as its temperature rises.

PLAY Relationship Between Temperature and Luminosity

Properties of Thermal Radiation

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



Hottest stars:

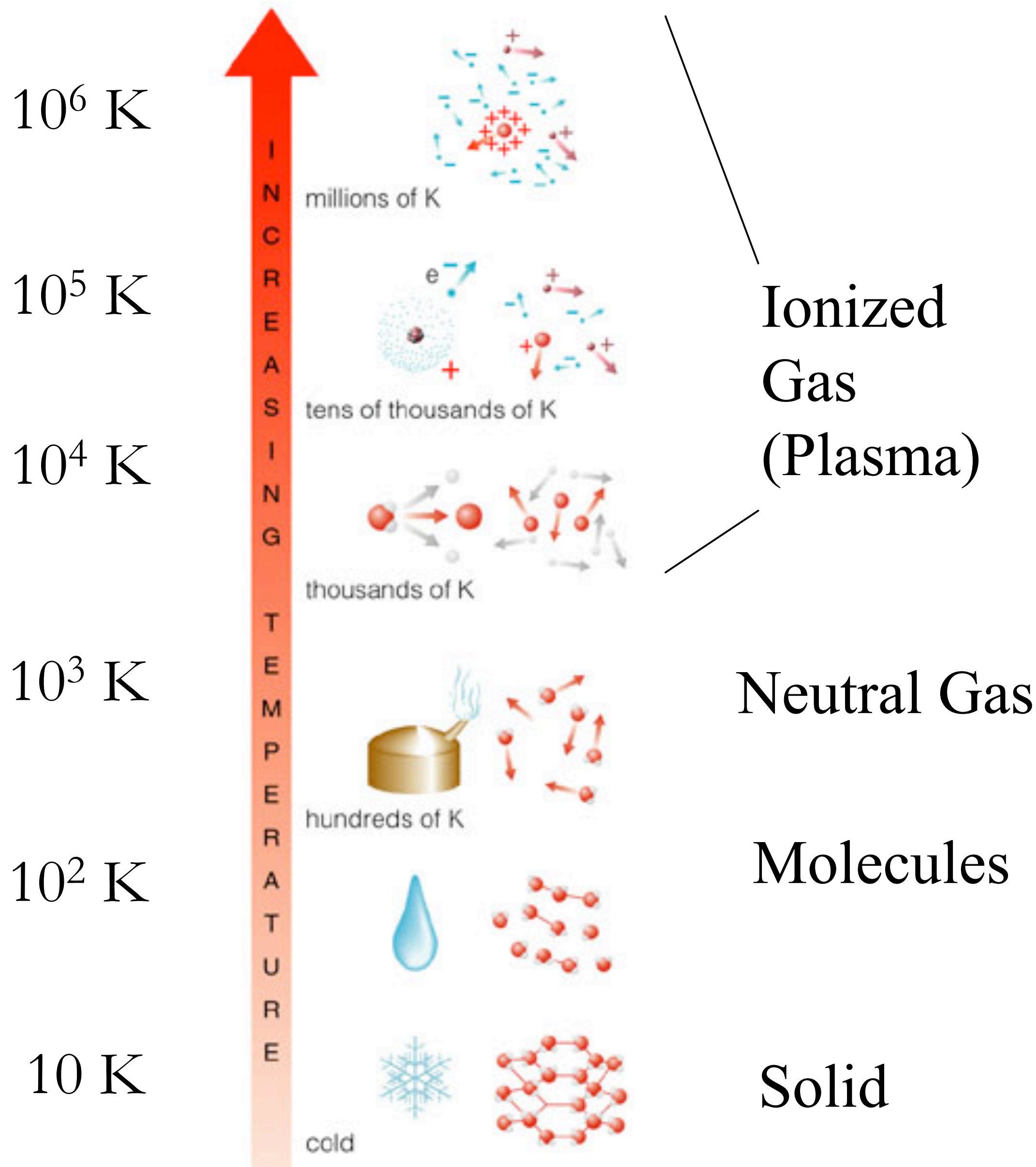
50,000 K

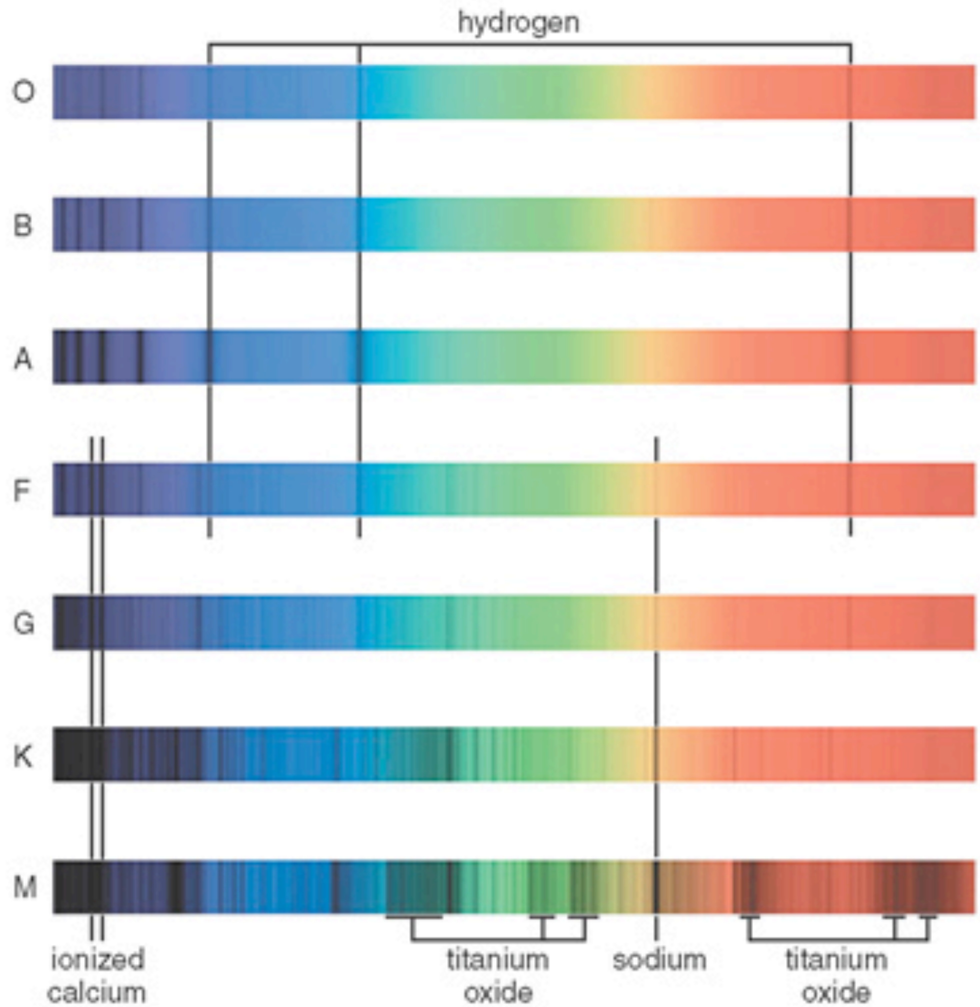
Coolest stars:

3,000 K

(Sun’s surface is 5,800 K)

Level of ionization also reveals a star’s temperature.





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

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

Which of the stars below is hottest?

25%	1.	A. M star
25%	2.	B. F star
25%	3.	C. A star
25%	4.	D. K star

Pioneers of Stellar Classification

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

To measure a star's *true* brightness, or luminosity, you need to know

1. Its temperature and distance
2. Its temperature and color
3. Its apparent brightness and distance
4. Its apparent brightness and color
5. Its distance, apparent brightness, and color or temperature

20%

20%

20%

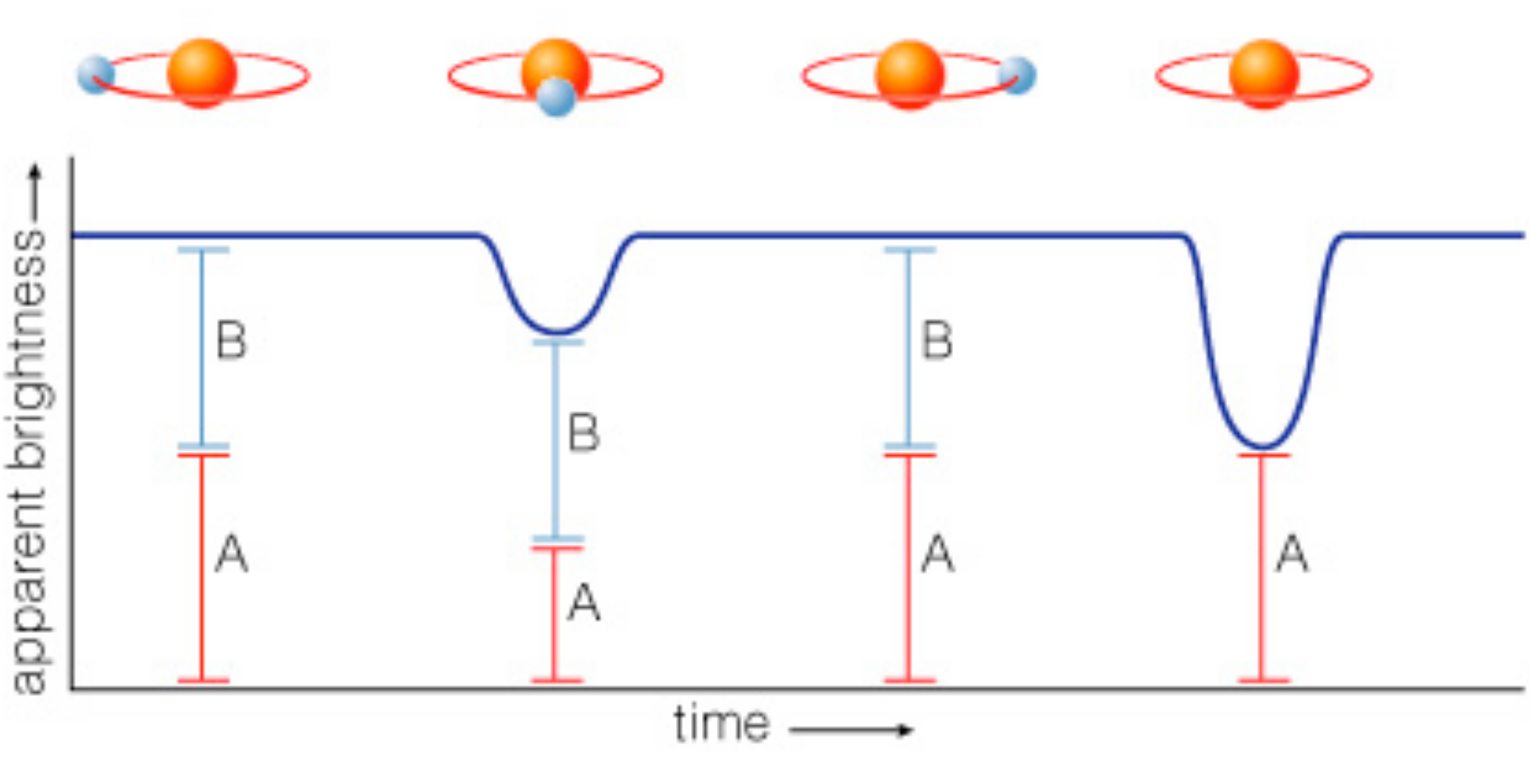
20%

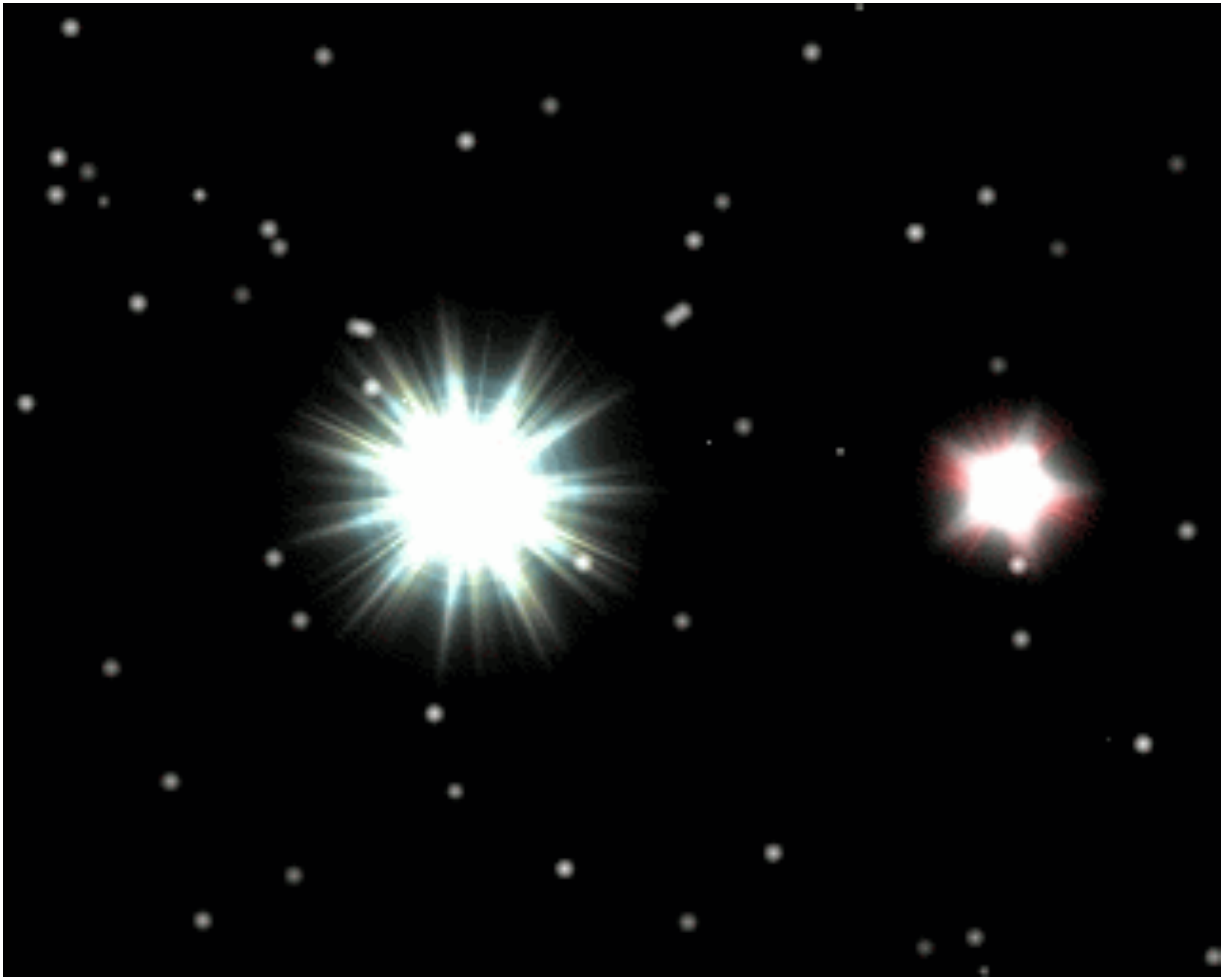
20%

What is the fundamental way of measuring the distance to the stars?

20%	1.	Radar
20%	2.	The H-R diagram
20%	3.	Measuring apparent brightness
20%	4.	Parallax
20%	5.	Doppler shifts

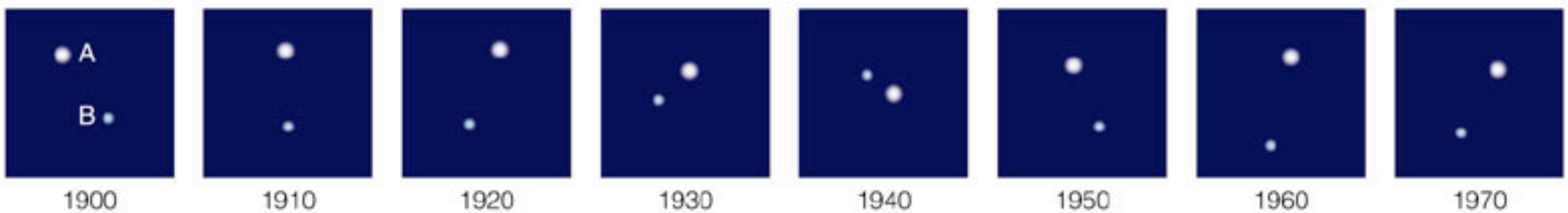
How do we measure stellar masses?





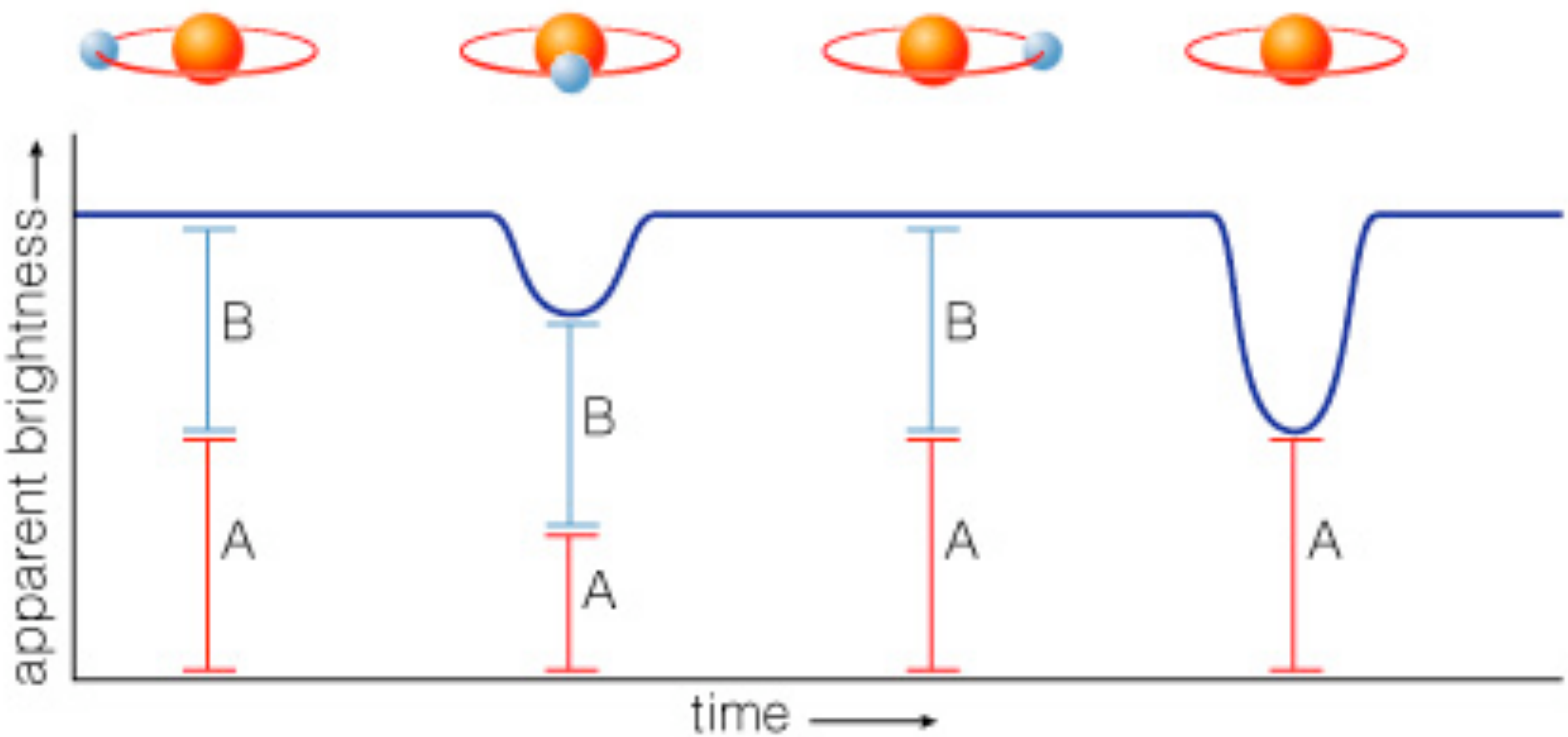
Orbit of a binary star system depends on strength of gravity

Visual Binary



We can directly observe the orbital motions of these stars.

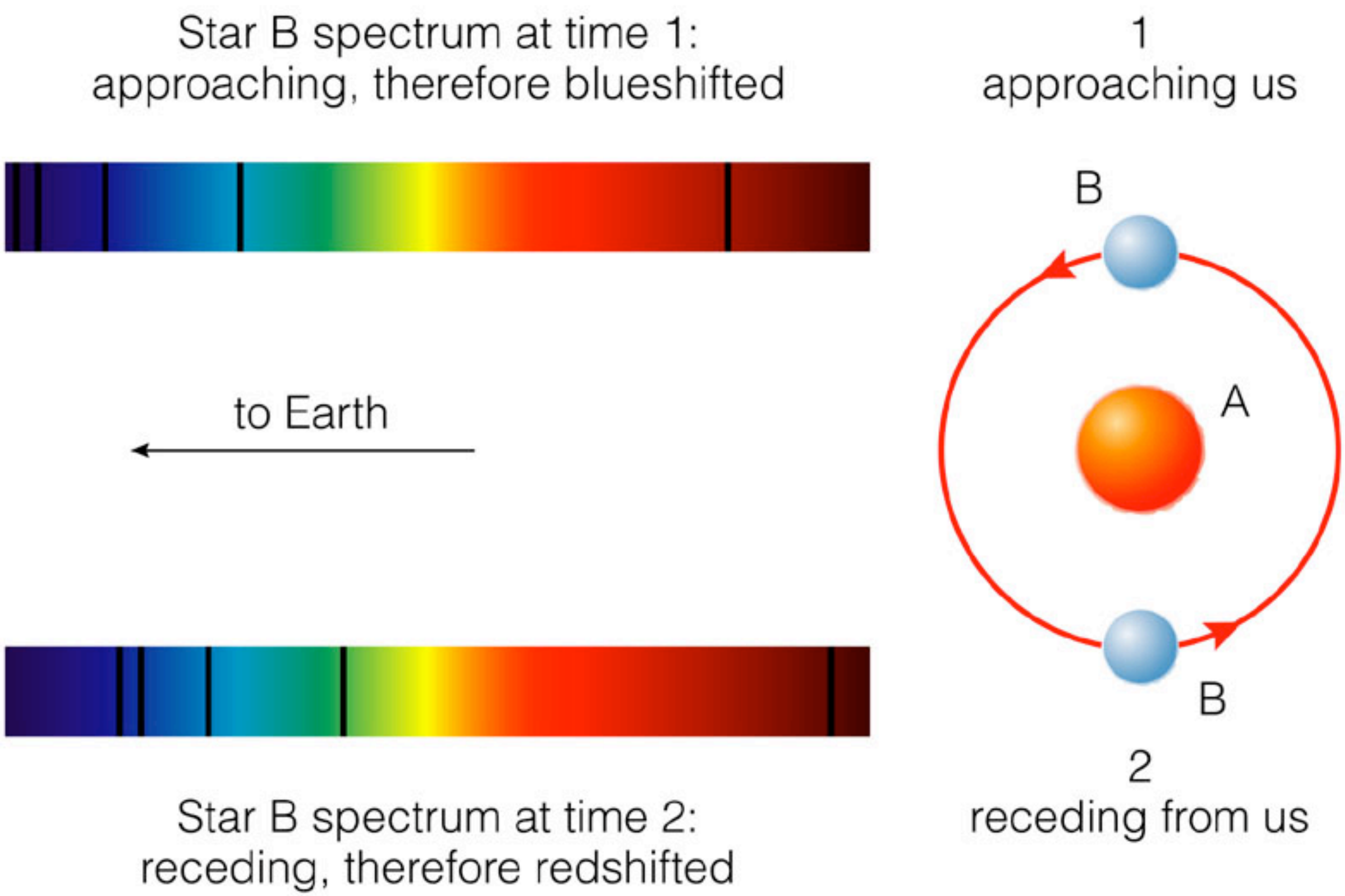
Eclipsing Binary



We can measure periodic eclipses.

PLAY Exploring the Light Curve of an Eclipsing Binary Star System

Spectroscopic Binary



We determine the orbit by measuring Doppler shifts.

Isaac Newton

We measure mass using gravity.

Direct mass measurements are possible only for stars in binary star systems.

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

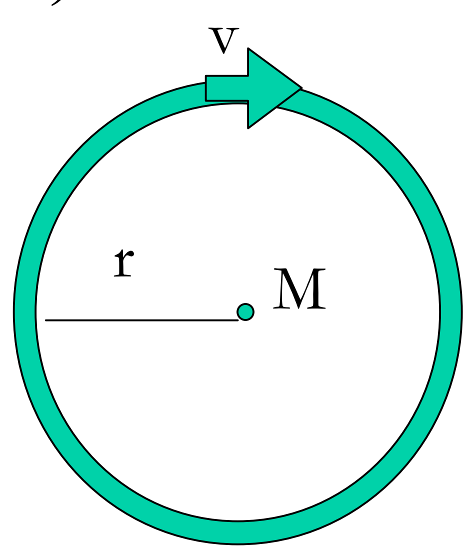
p = period

a = average 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, $v = 2\pi r / p$



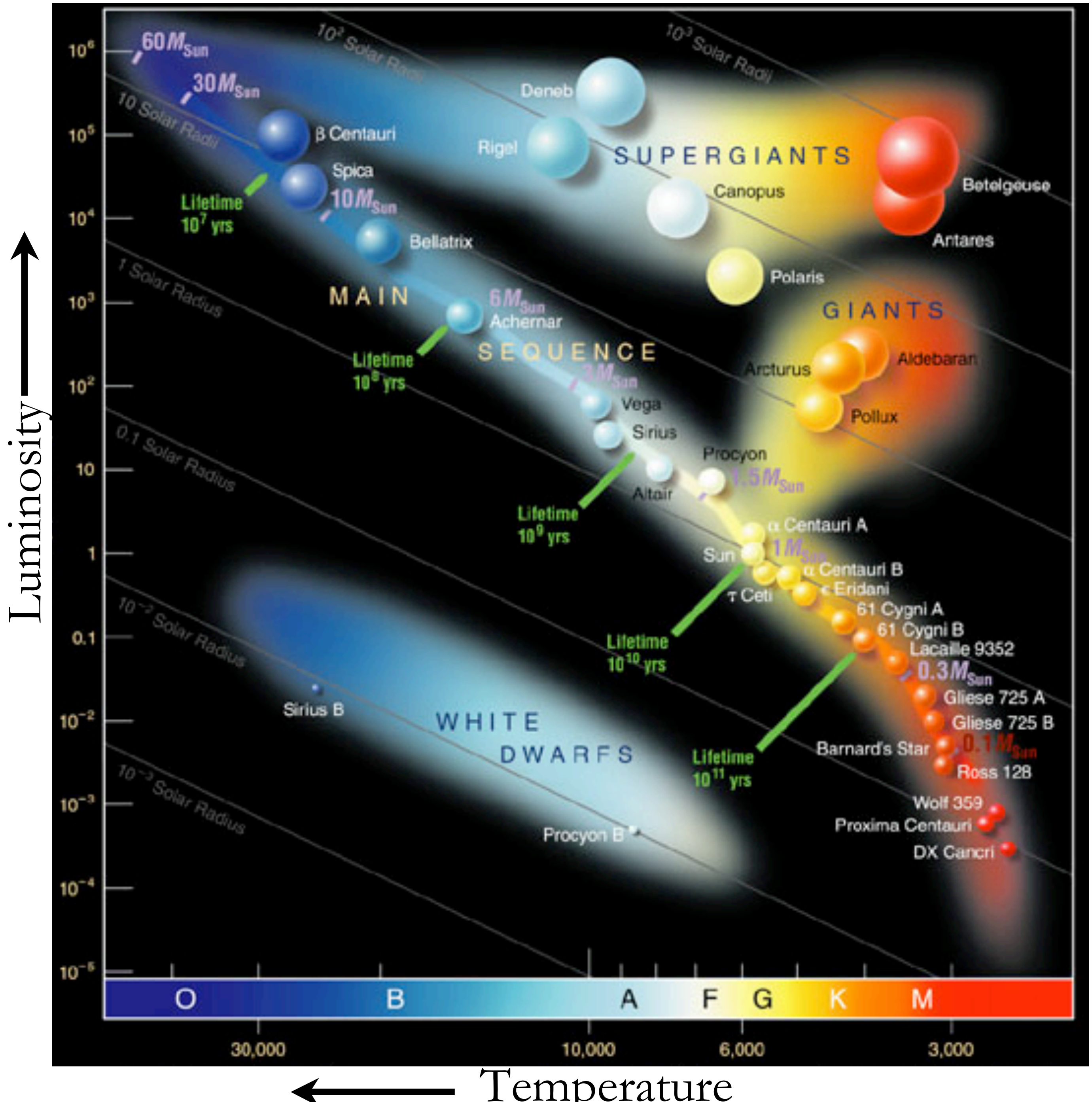
Most massive stars:

$100\ M_{Sun}$

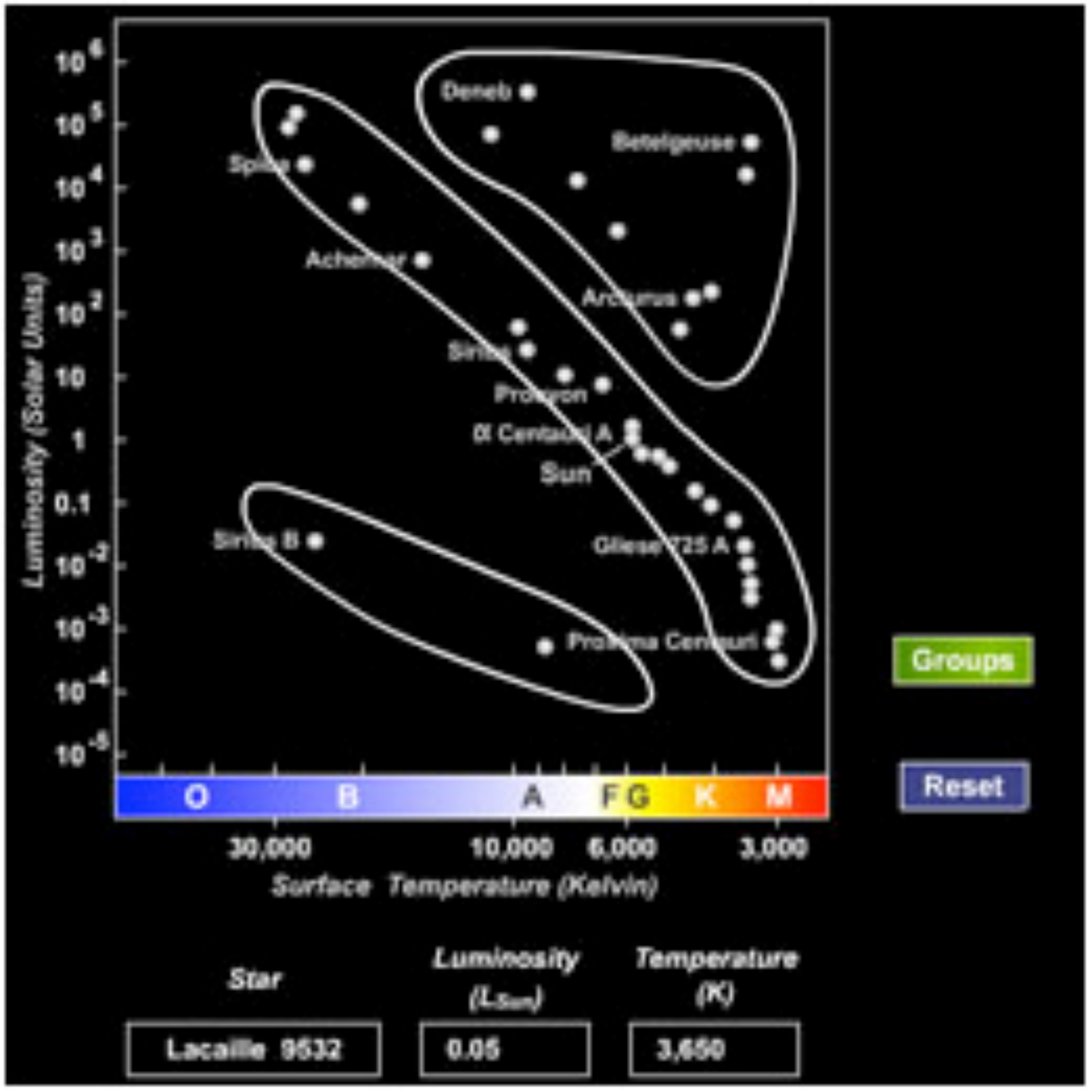
Least massive stars:

$0.08\ M_{Sun}$

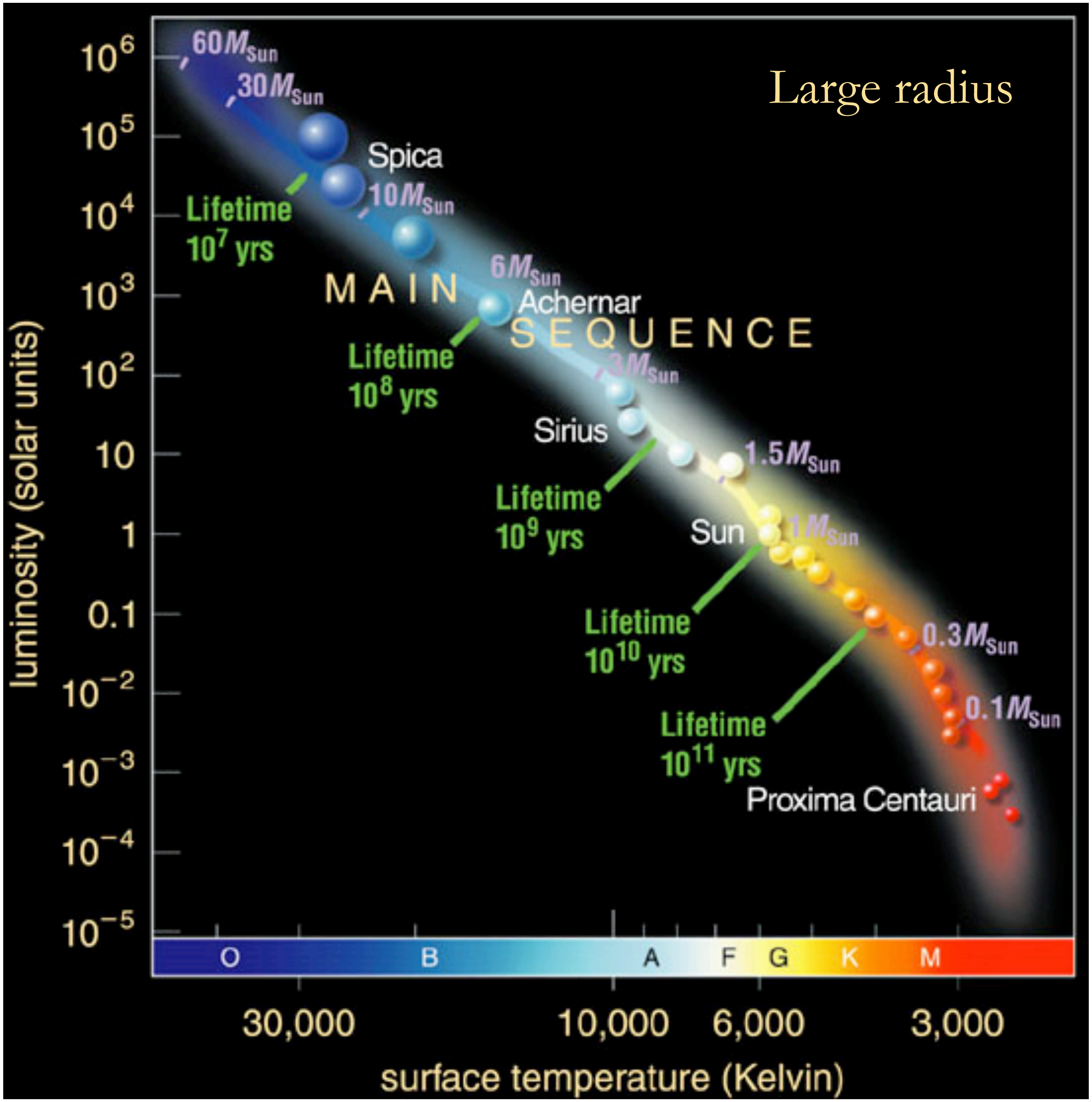
(M_{Sun} is the mass of the Sun.)



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

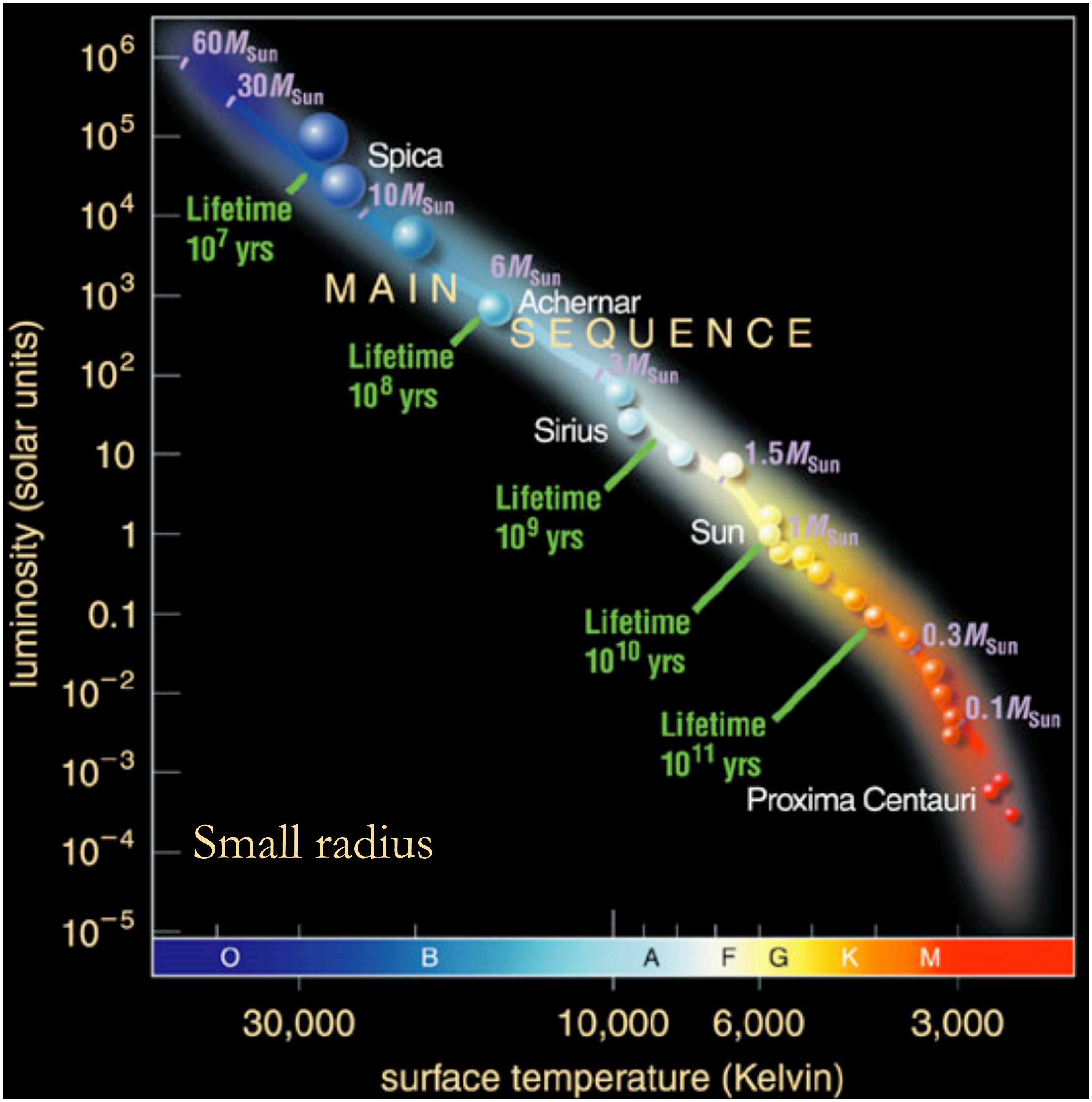


PLAY Generating an H-R Diagram



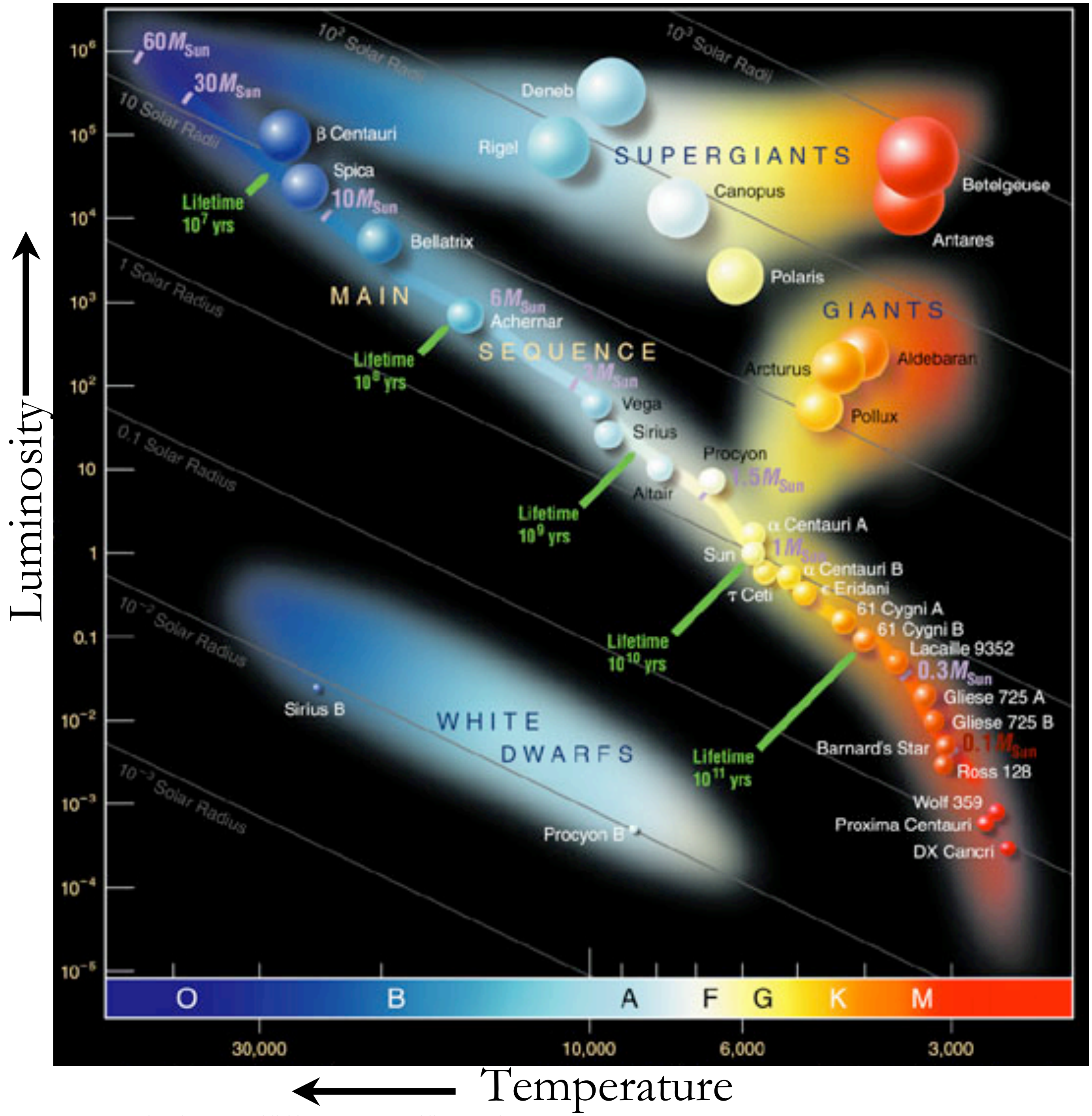
Stars with lower *T* and higher *L* than main-sequence stars must have larger radii:

giants and ***supergiants***



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

white dwarfs



H-R diagram depicts:

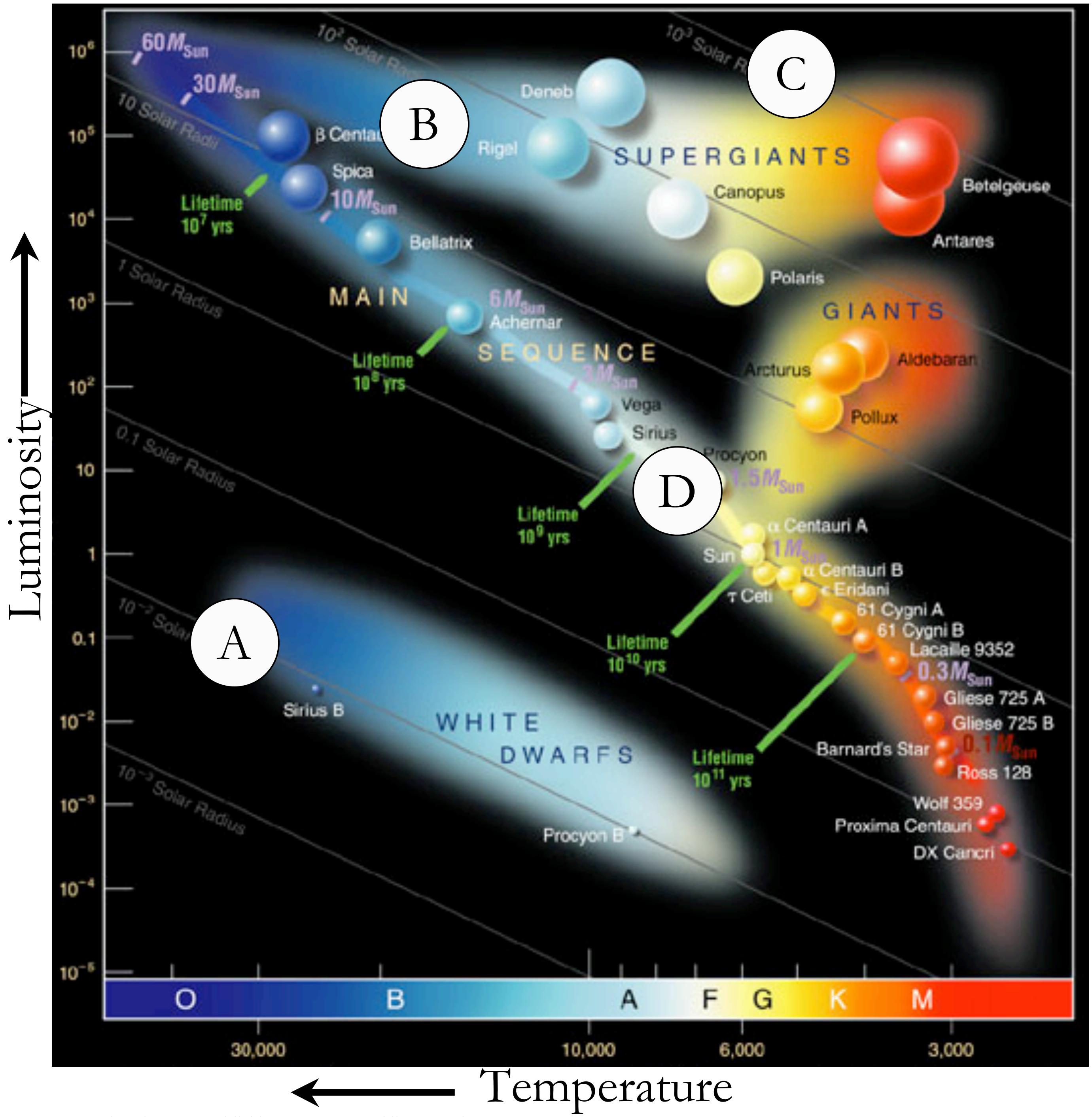
Temperature

Color

Spectral type

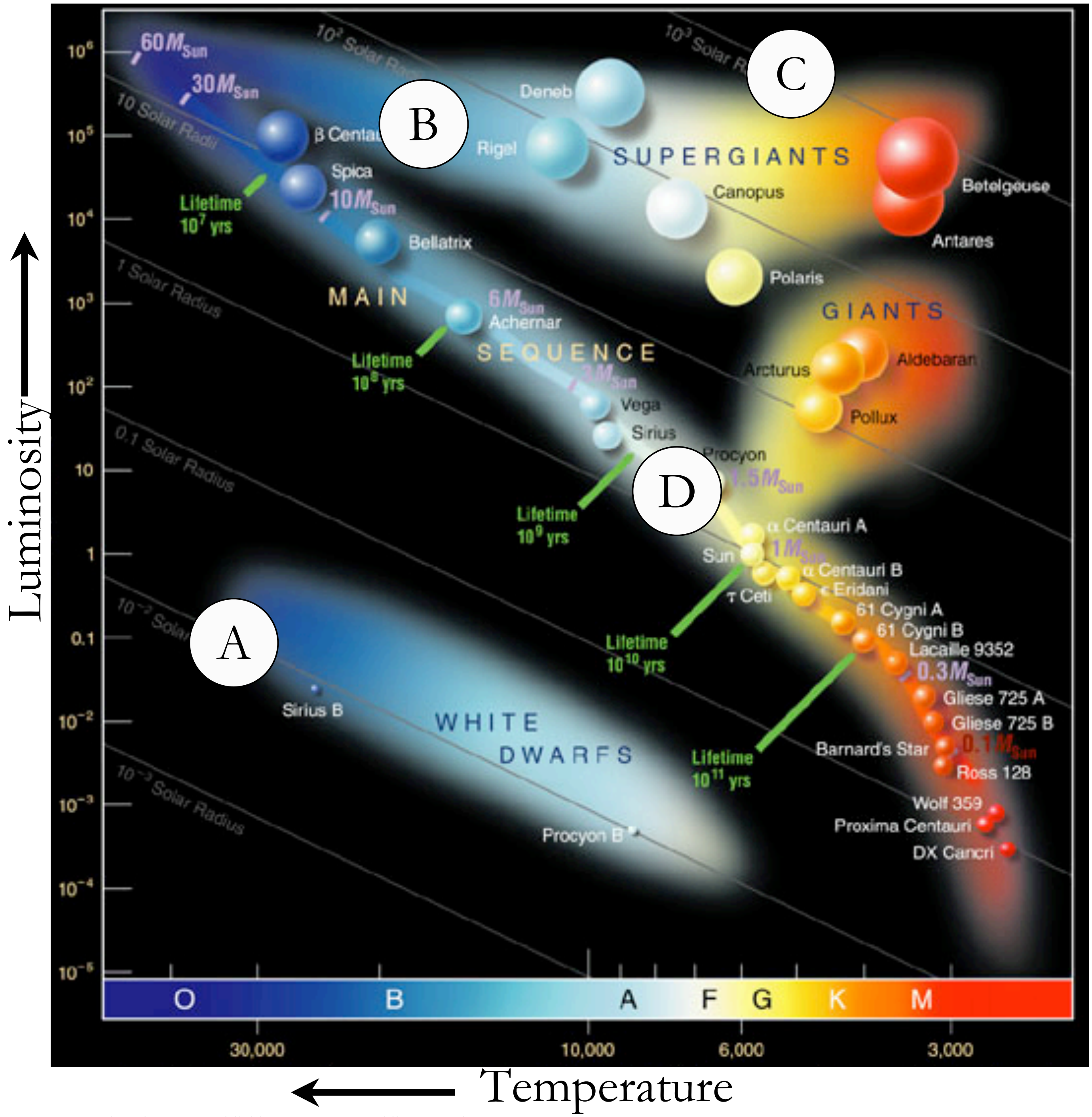
Luminosity

Radius

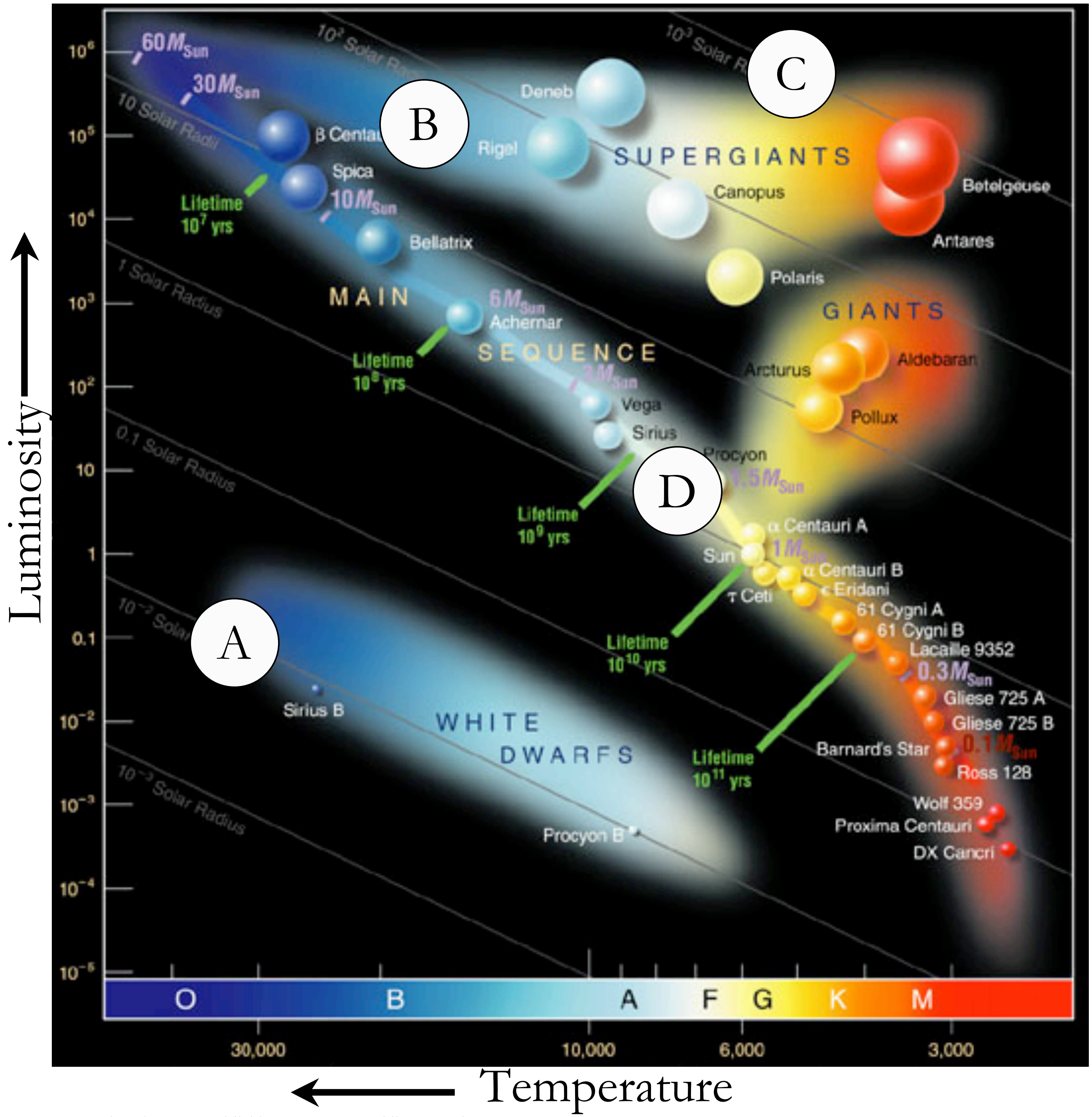


Which star is the hottest?

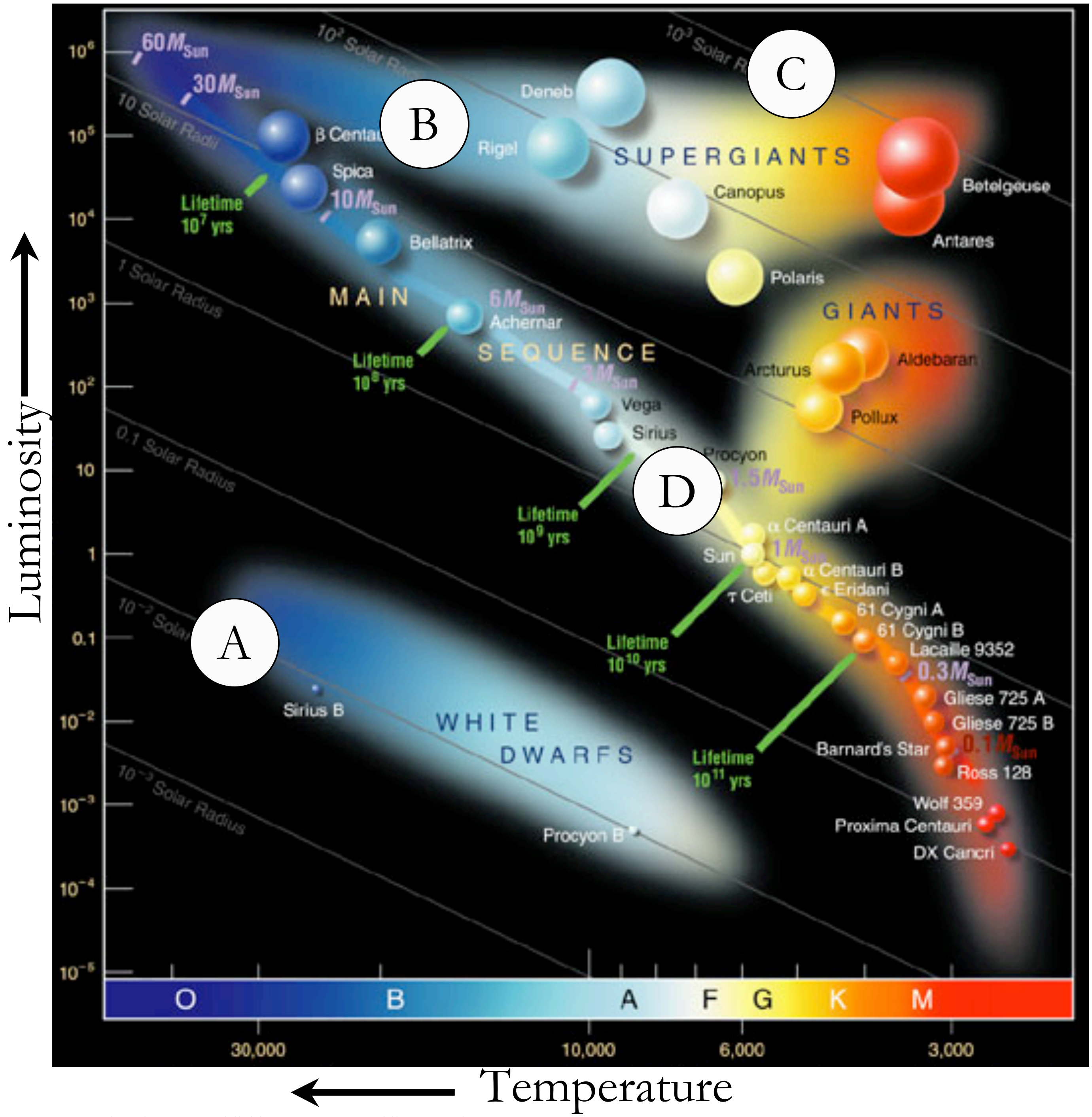
1. A
2. B
3. C
4. D



Which star is the most luminous?

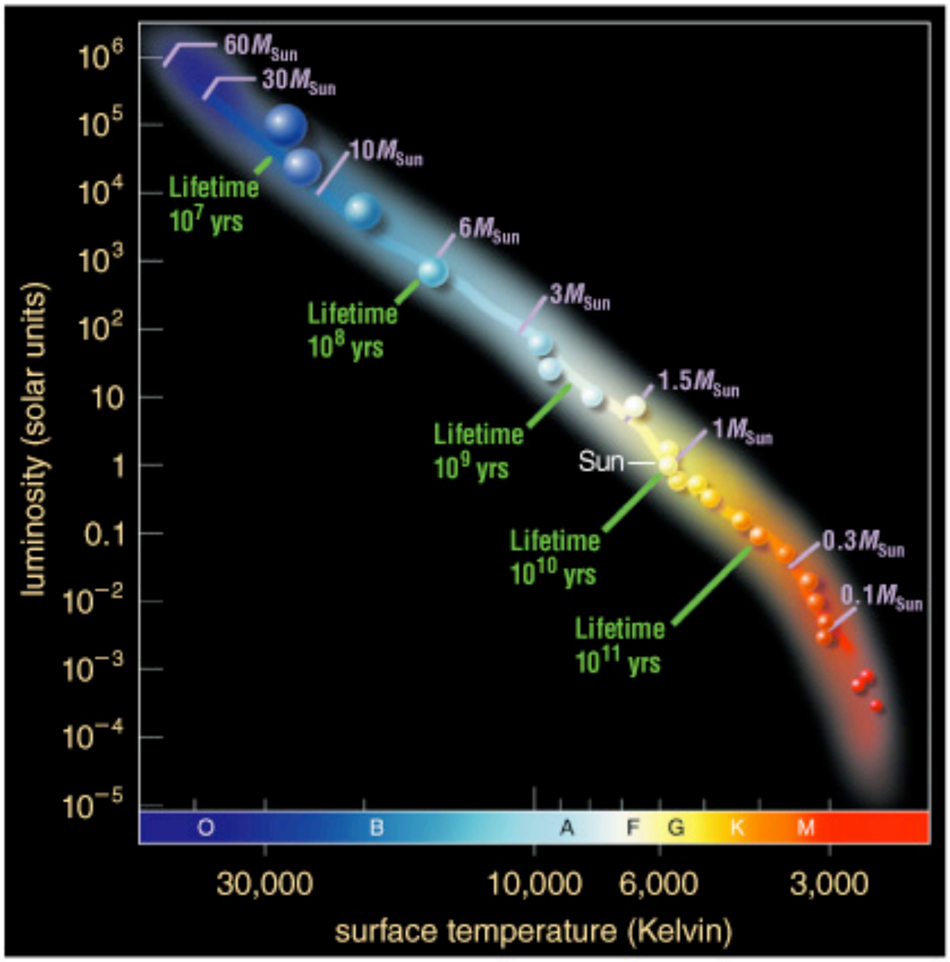


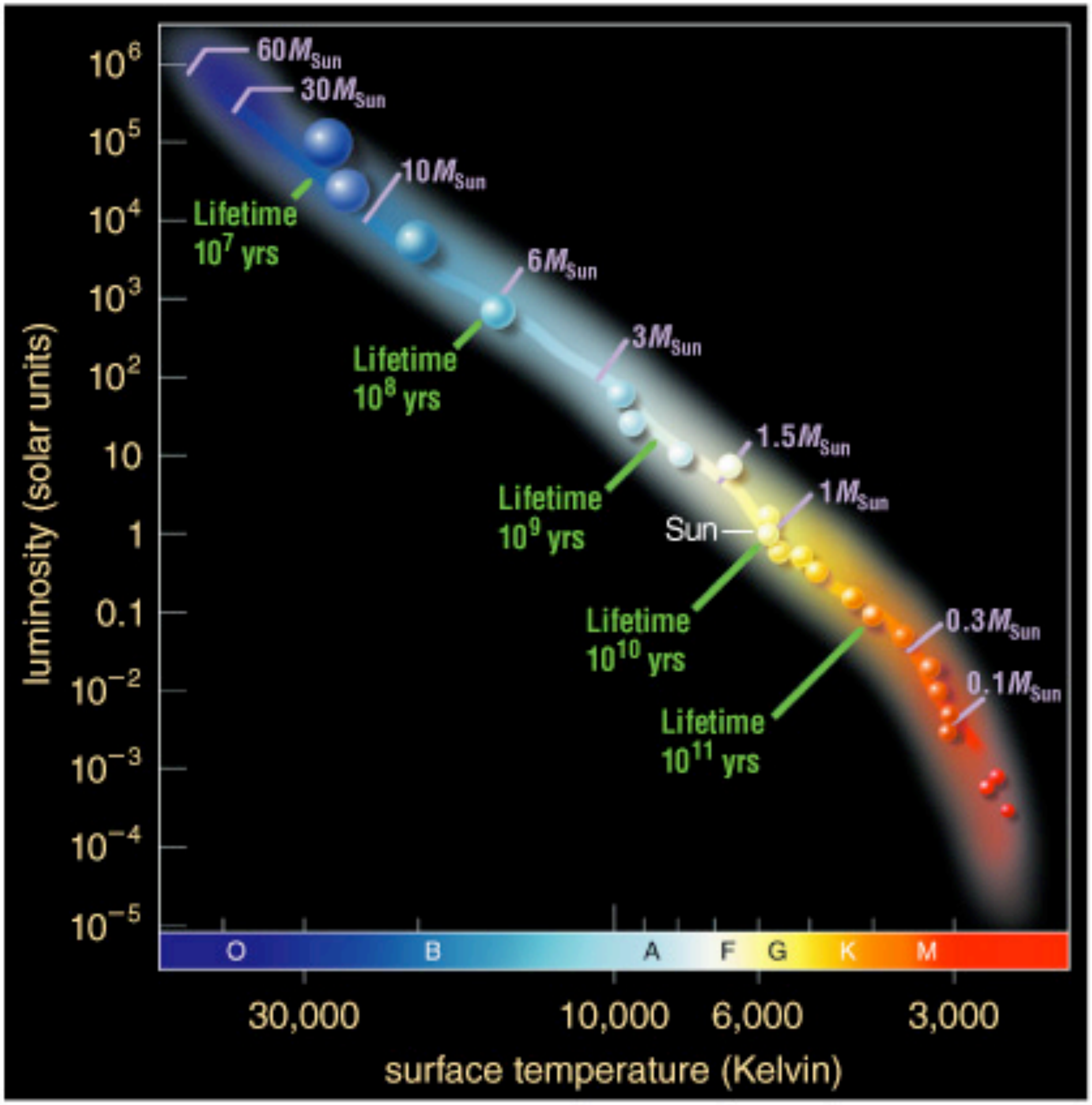
Which star is a main-sequence star?



Which star has the largest radius?

What is the significance of the main sequence?

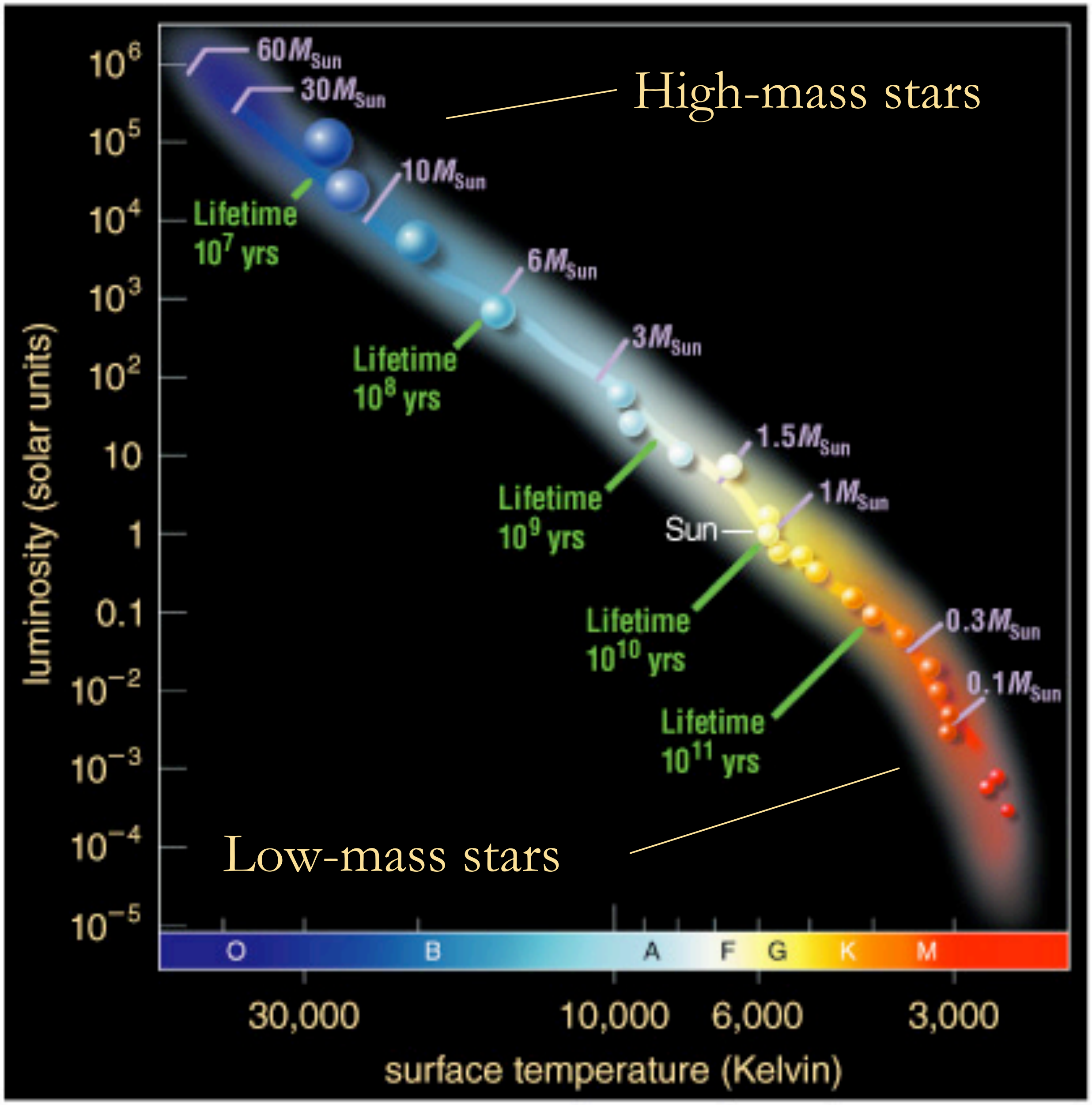




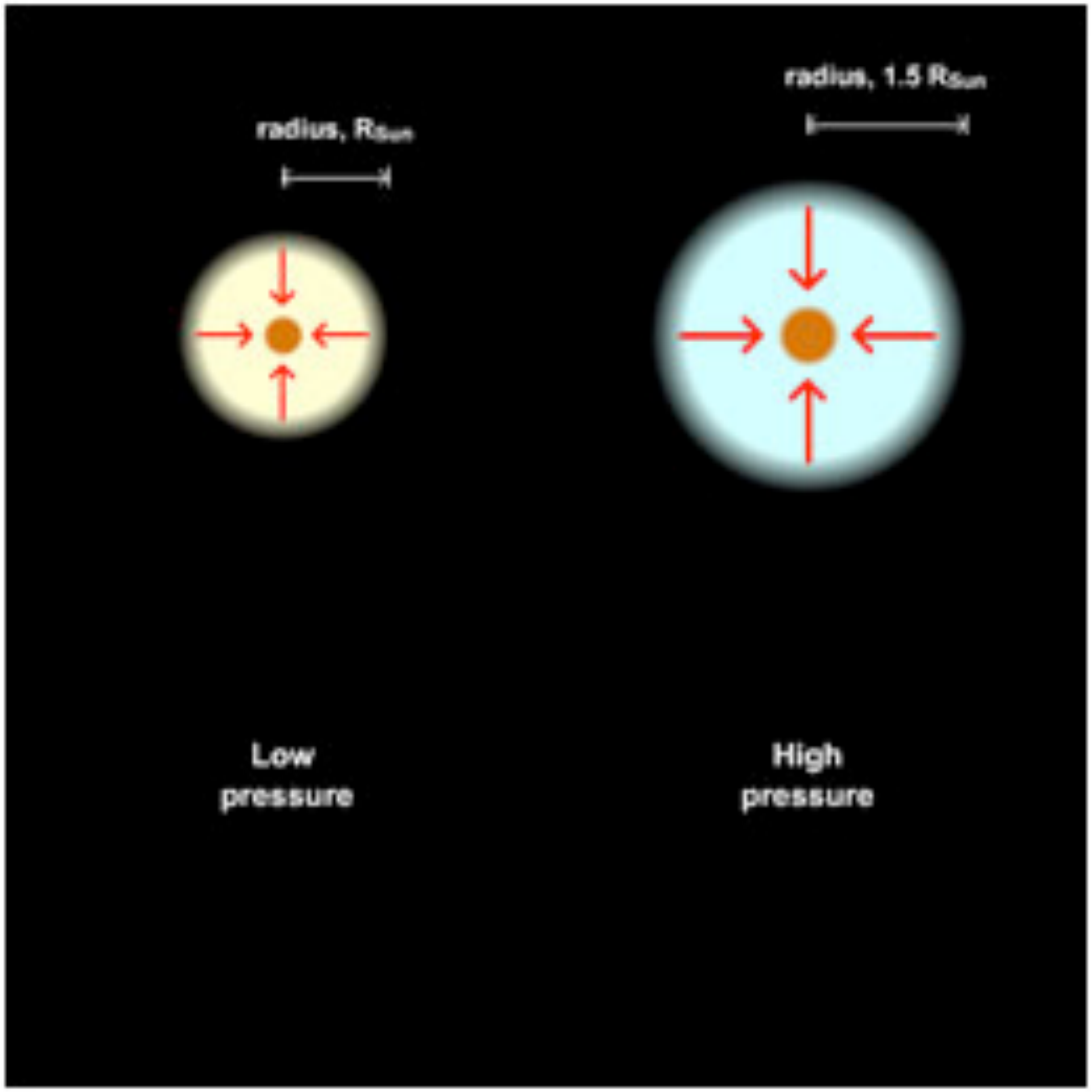
Main-sequence stars are fusing hydrogen into helium in their cores, like the Sun.

Luminous main-sequence stars are hot (blue).

Less luminous ones are cooler (yellow or red).



The mass of a normal, hydrogen-burning star determines its luminosity and spectral type!



PLAY Hydrostatic Equilibrium

The core pressure and temperature of a higher-mass star need to be higher in order to balance gravity.

A higher core temperature boosts the fusion rate, leading to greater luminosity.

Stellar Properties Review

Luminosity: from brightness and distance

$10^{-4}\ L_{\text{Sun}}$–$10^{6}\ L_{\text{Sun}}$

Temperature: from color and spectral type

3,000 K–50,000 K

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

$0.08\ M_{\text{Sun}}$–$100\ M_{\text{Sun}}$

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

$0.08\ M_{Sun}$–$100\ M_{Sun}$

In binary stars, the orbital period depends on the masses of the stars and the sizes of the orbits. Why is this so valuable to know?

33%

1. We can predict how long an orbit will take

33%

2. This is the main way we determine the masses of stars

33%

3. This lets us know if two stars that look close together in the sky really are in orbit

Mass and Lifetime

Until core hydrogen (10% of total) is used up

Sun's life expectancy: 10 billion years

Life expectancy of a 10 M_{Sun} star:

10 times as much fuel, uses it 10^4 times as fast

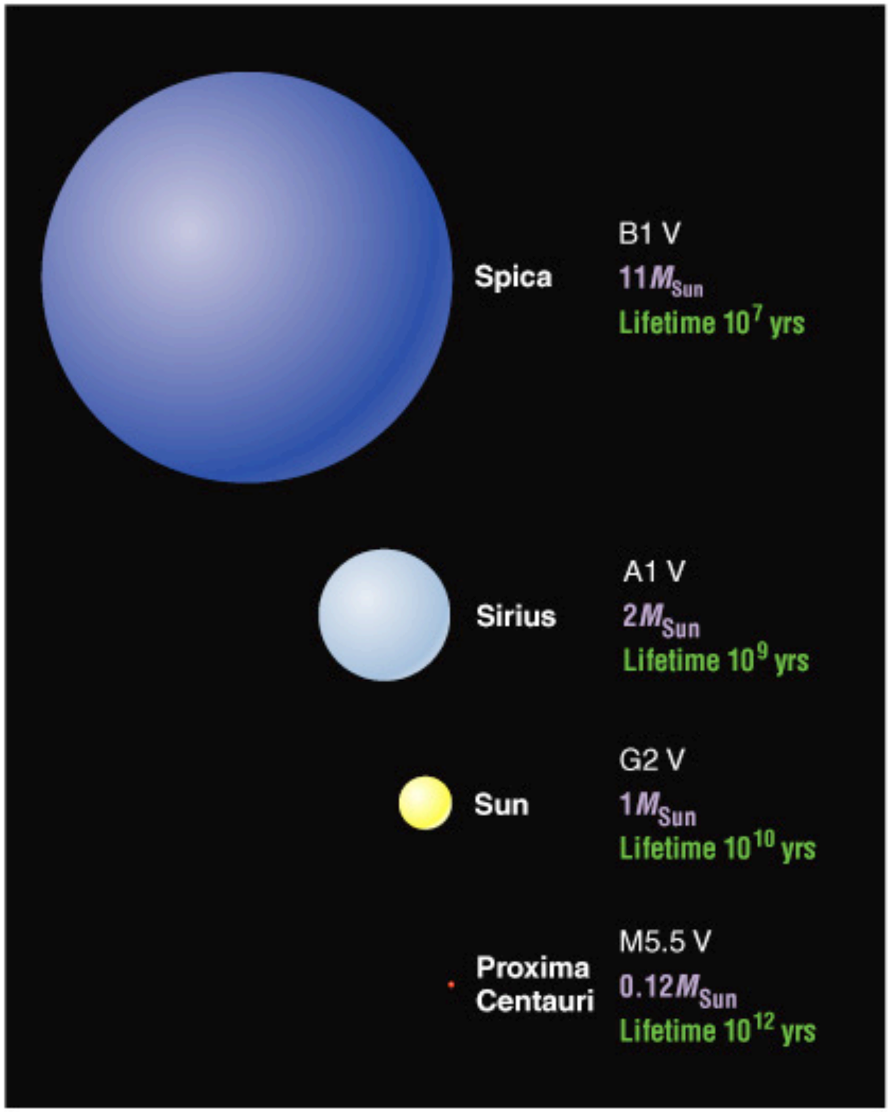
10 million years ~ 10 billion years × $10/10^4$

Life expectancy of a 0.1 M_{Sun} star:

0.1 times as much fuel, uses it 0.01 times as fast

100 billion years ~ 10 billion years × 0.1/0.01

Main-Sequence Star Summary



High-mass:

- High luminosity
- Short-lived
- Large radius
- Blue

Low-mass:

- Low luminosity
- Long-lived
- Small radius
- Red

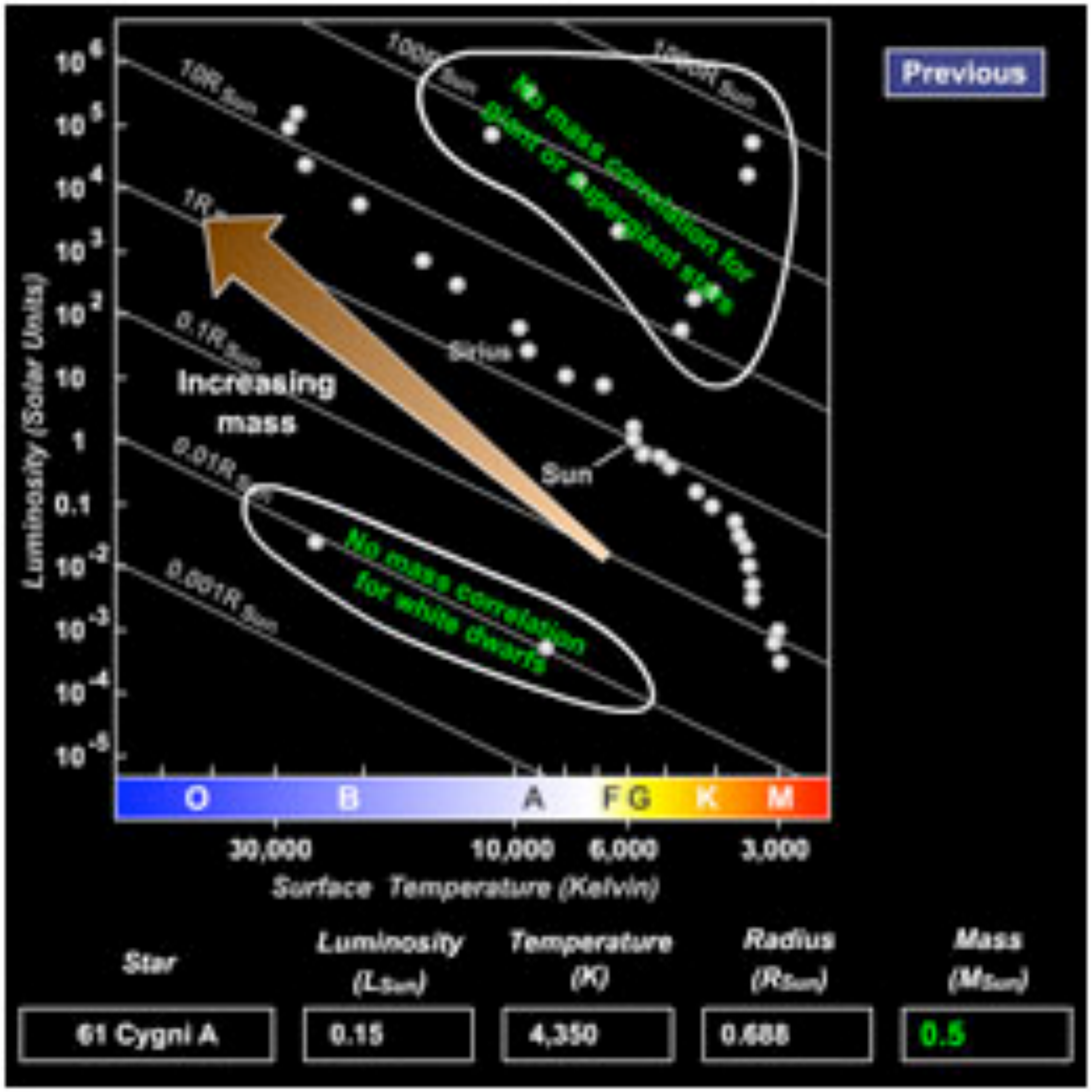
What are giants, supergiants, and white dwarfs?

Off the Main Sequence

- Stellar properties depend on both mass and age: those that have finished fusing H to He in their cores are no longer on the main sequence.

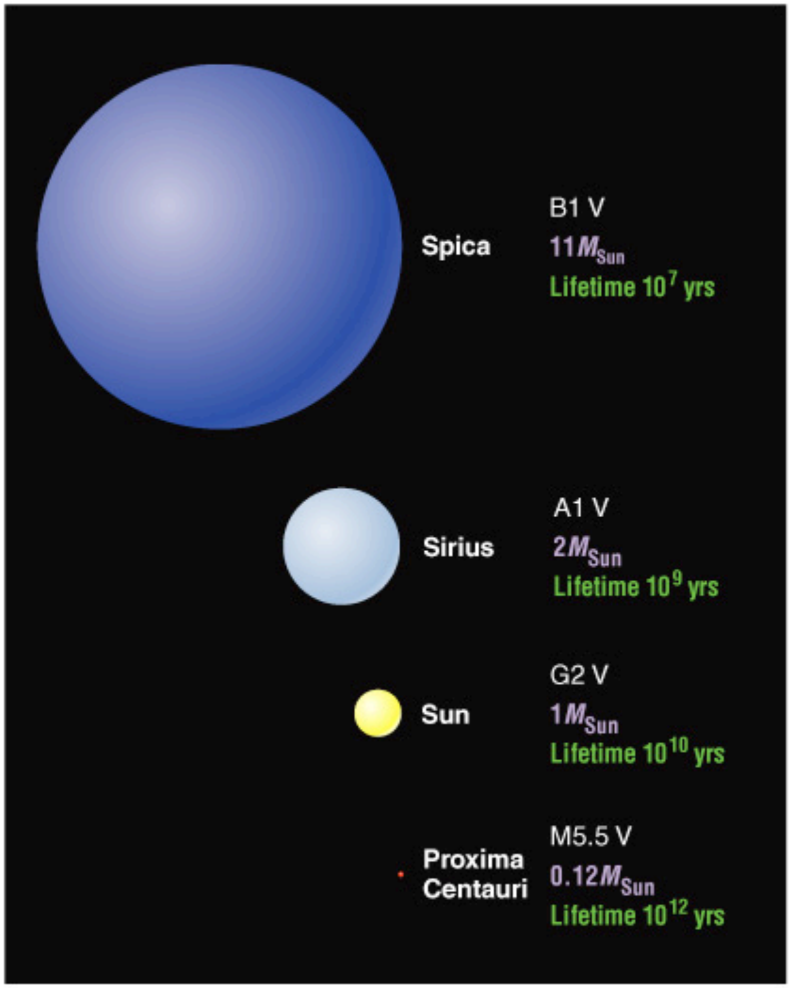
- All stars become larger and redder after exhausting their core hydrogen: **giants** and **supergiants.**

- Most stars end up small and white after fusion has ceased: **white dwarfs.**

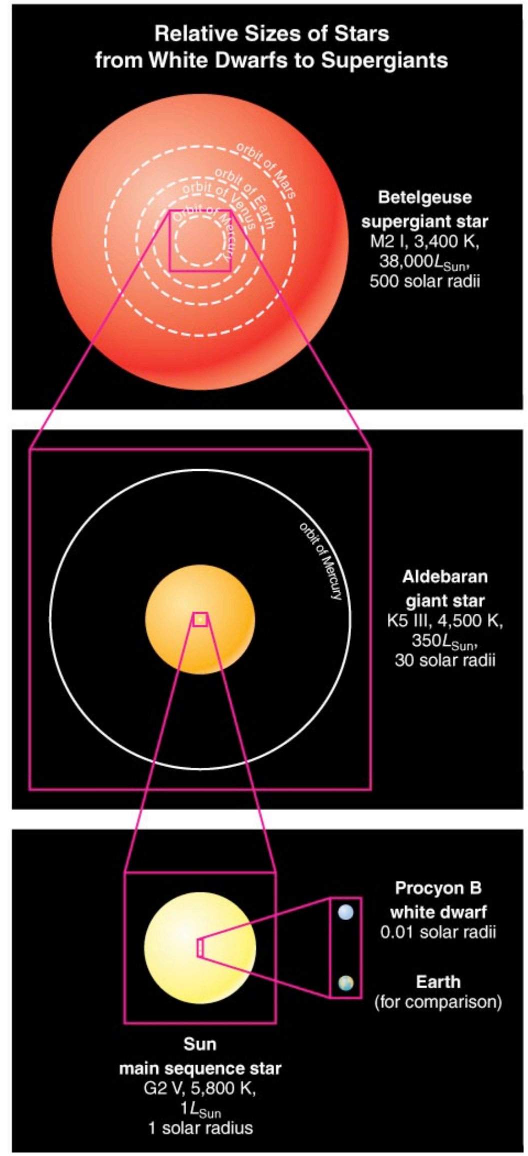


PLAY

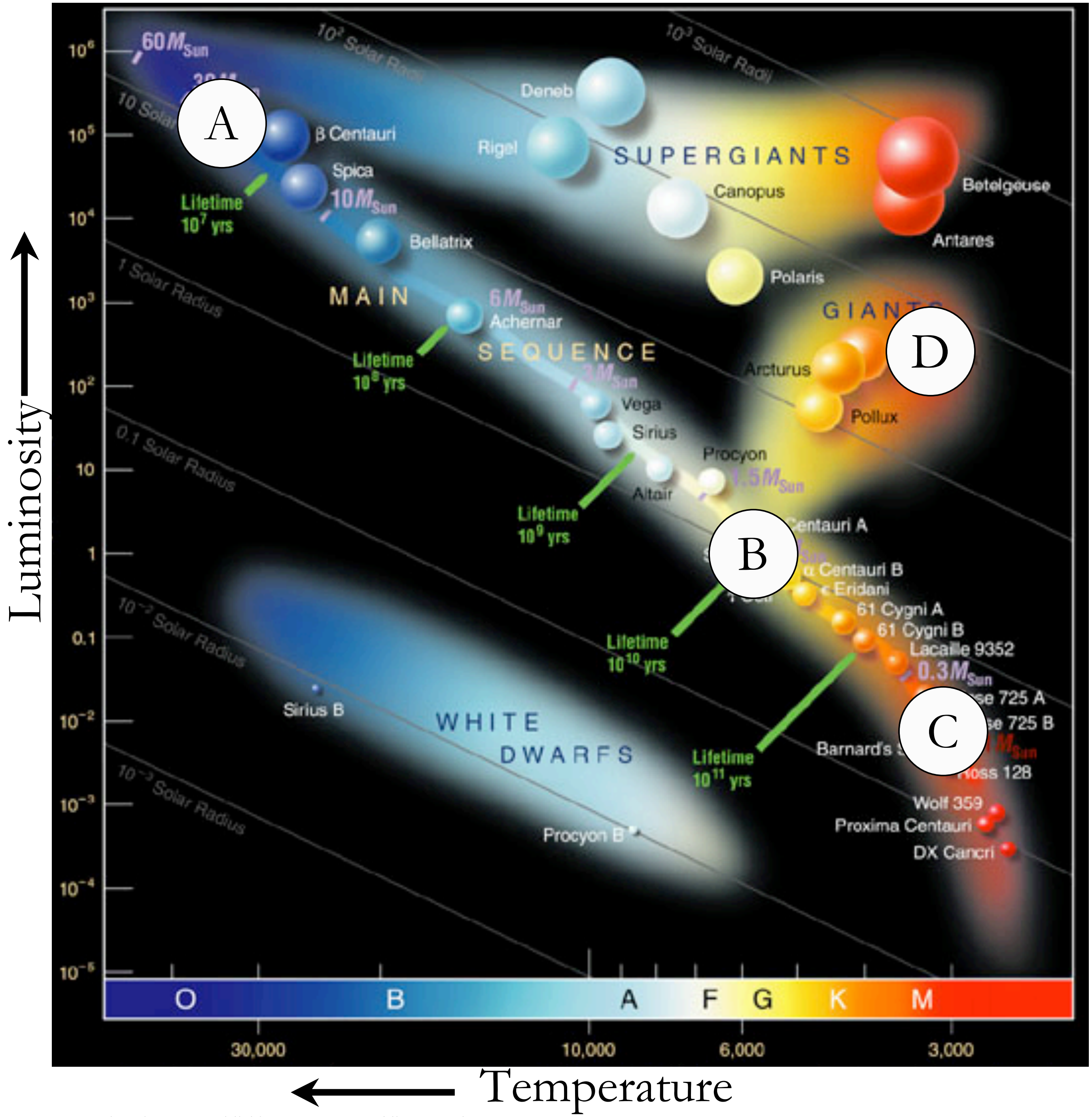
Relationship between Main-Sequence Stellar Masses and Location on H-R Diagram



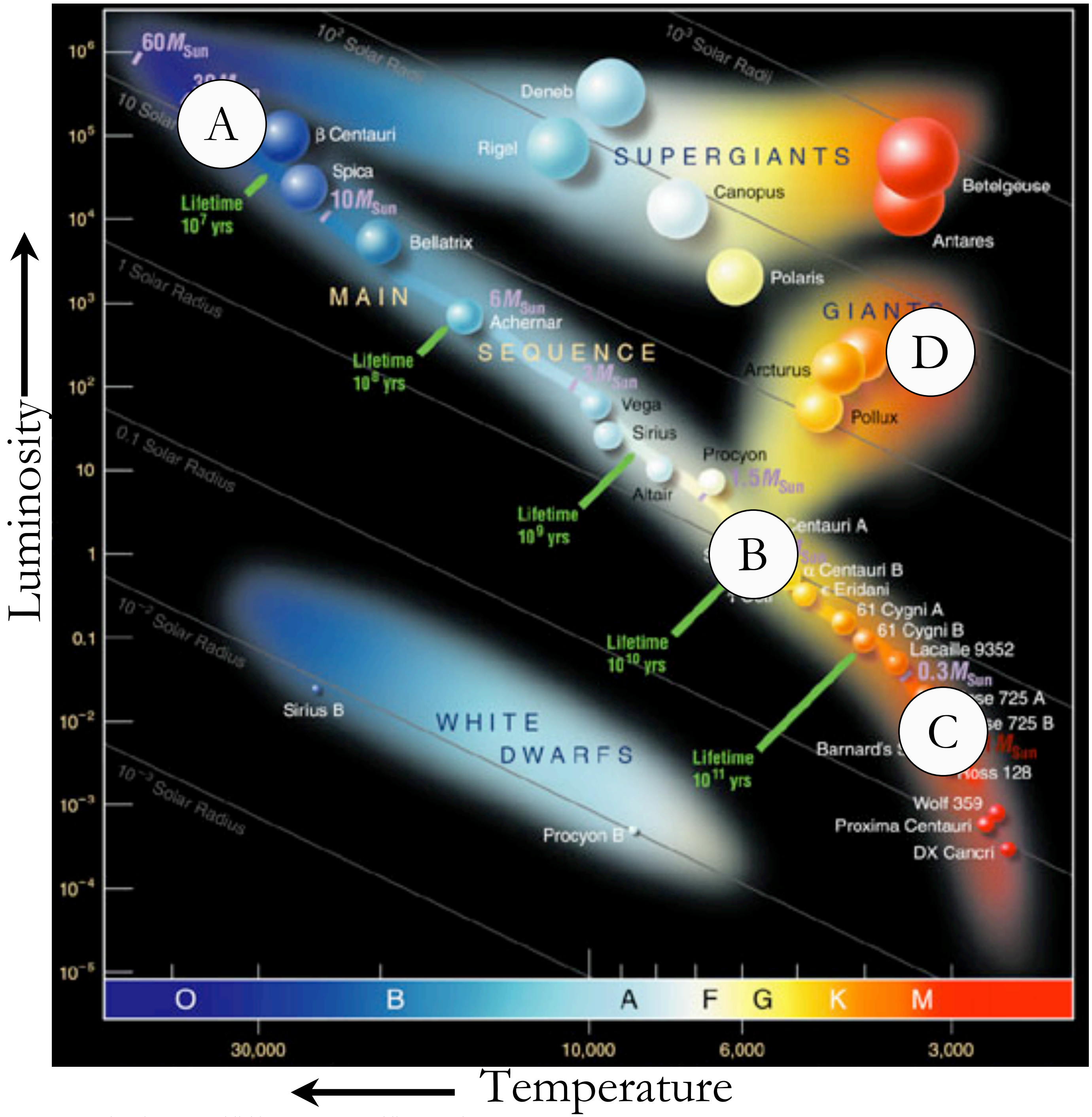
Main-sequence stars (to scale)



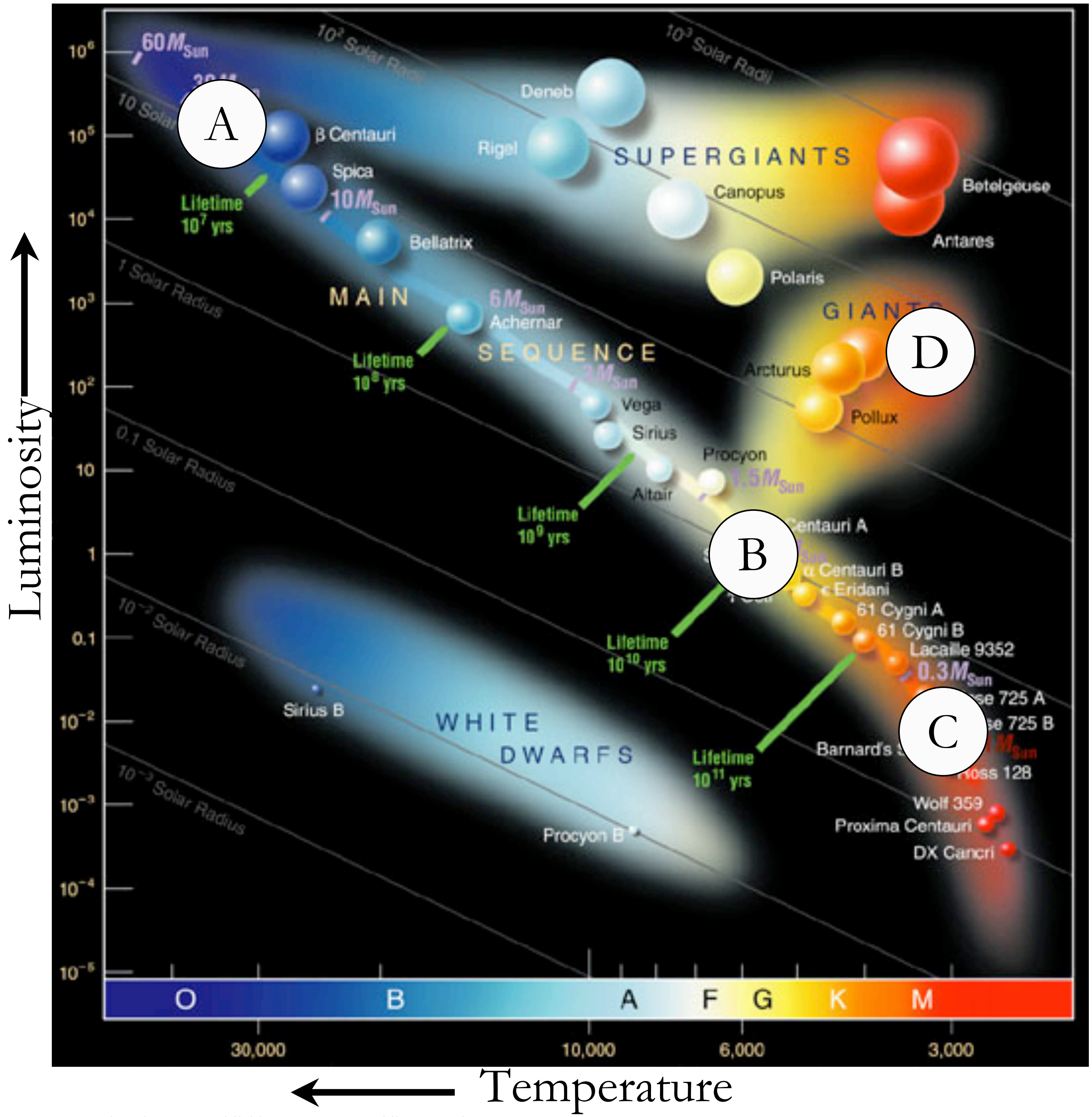
Giants, supergiants, white dwarfs



Which star is most like our Sun?



Which of these stars will have changed the least 10 billion years from now?

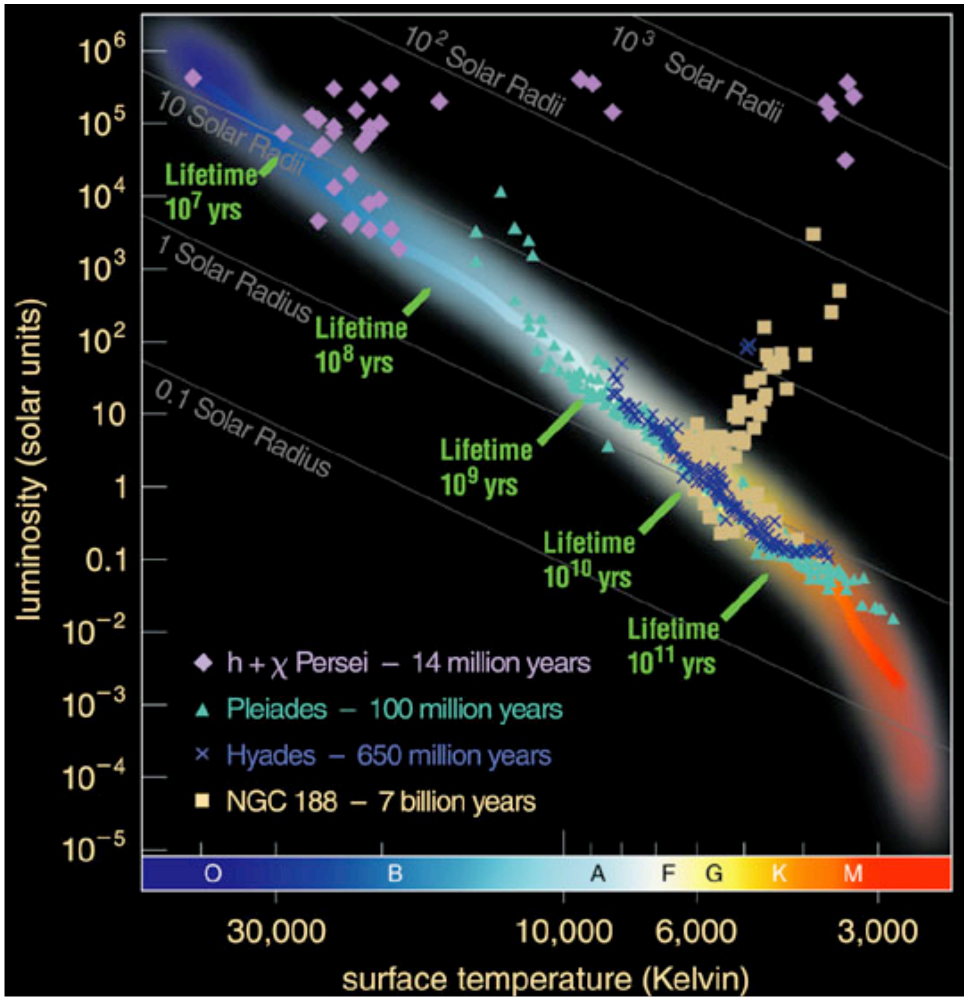


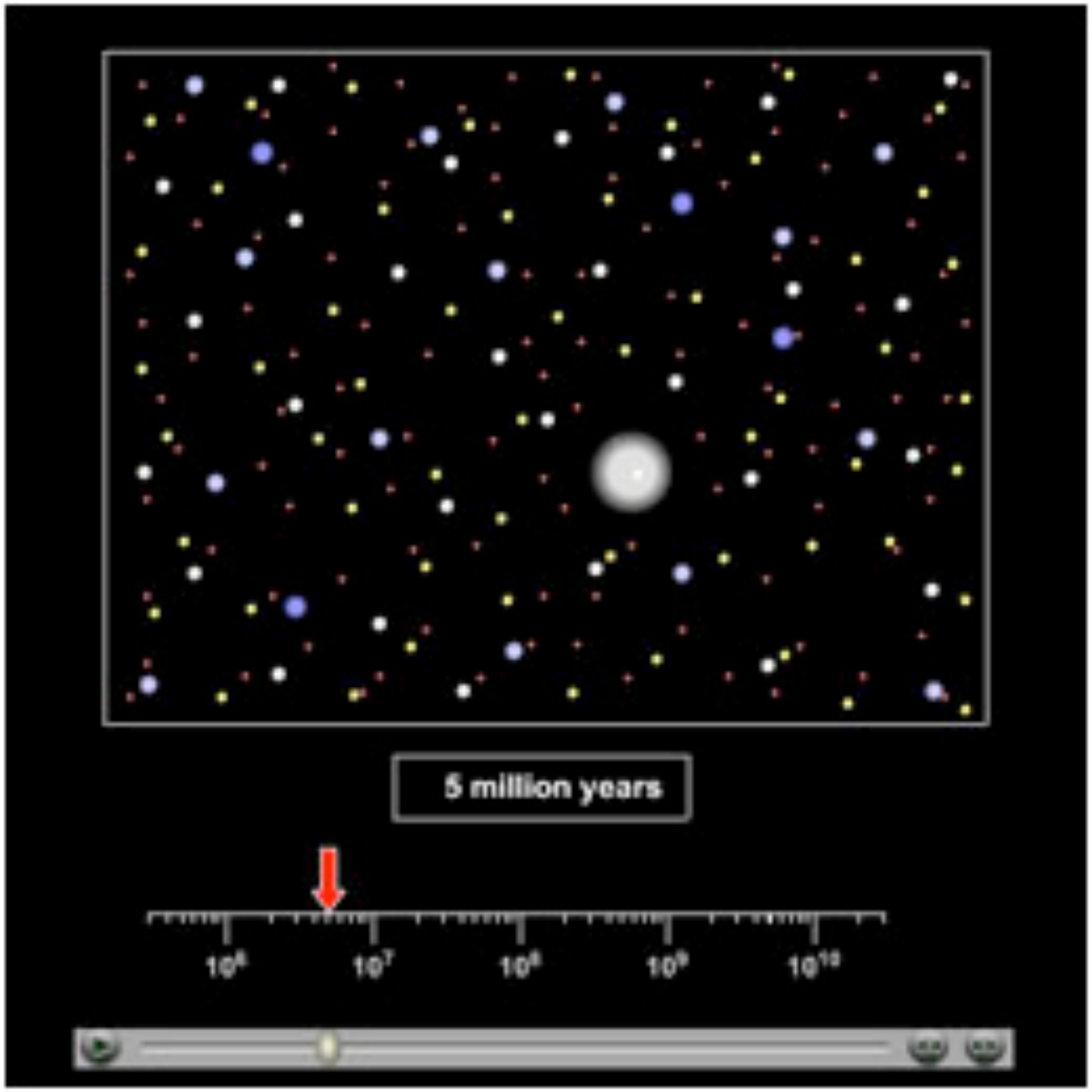
Which of these stars can be no more than 10 million years old?

Open cluster: A few thousand loosely packed stars

Globular cluster: Up to a million or more stars in a dense ball bound together by gravity

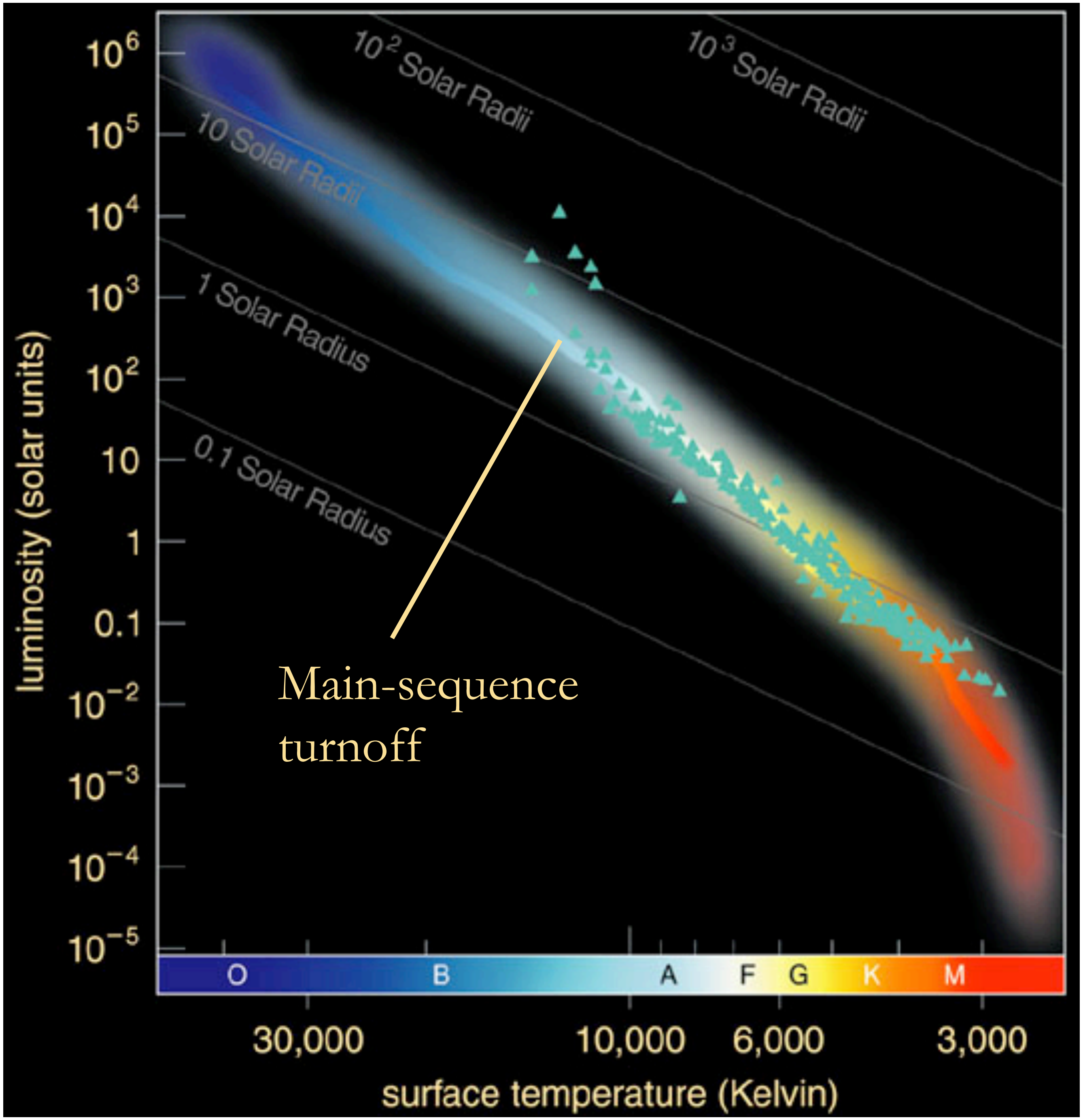
How do we measure the age of a star cluster?



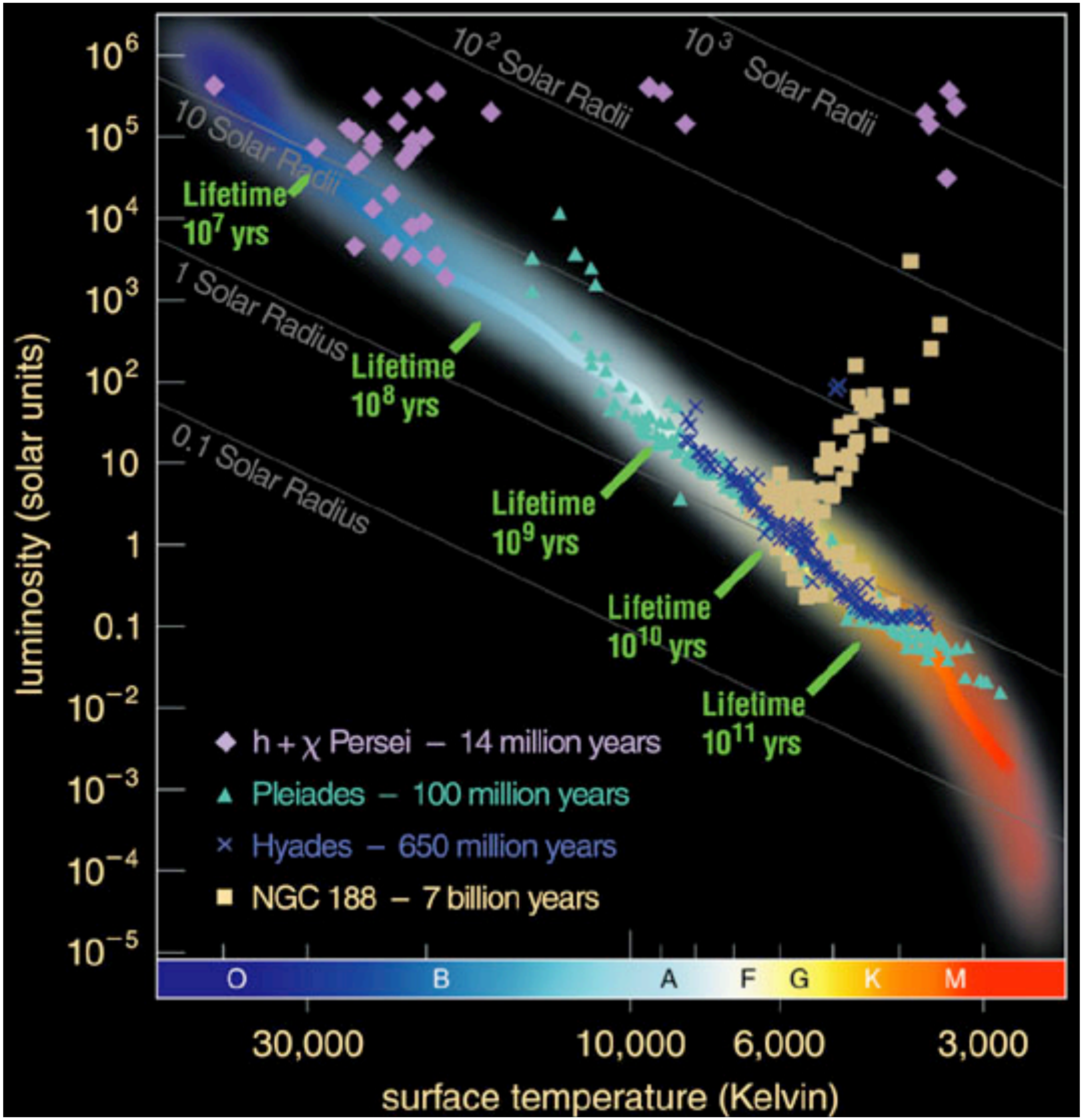


Massive blue stars die first, followed by white, yellow, orange, and red stars.

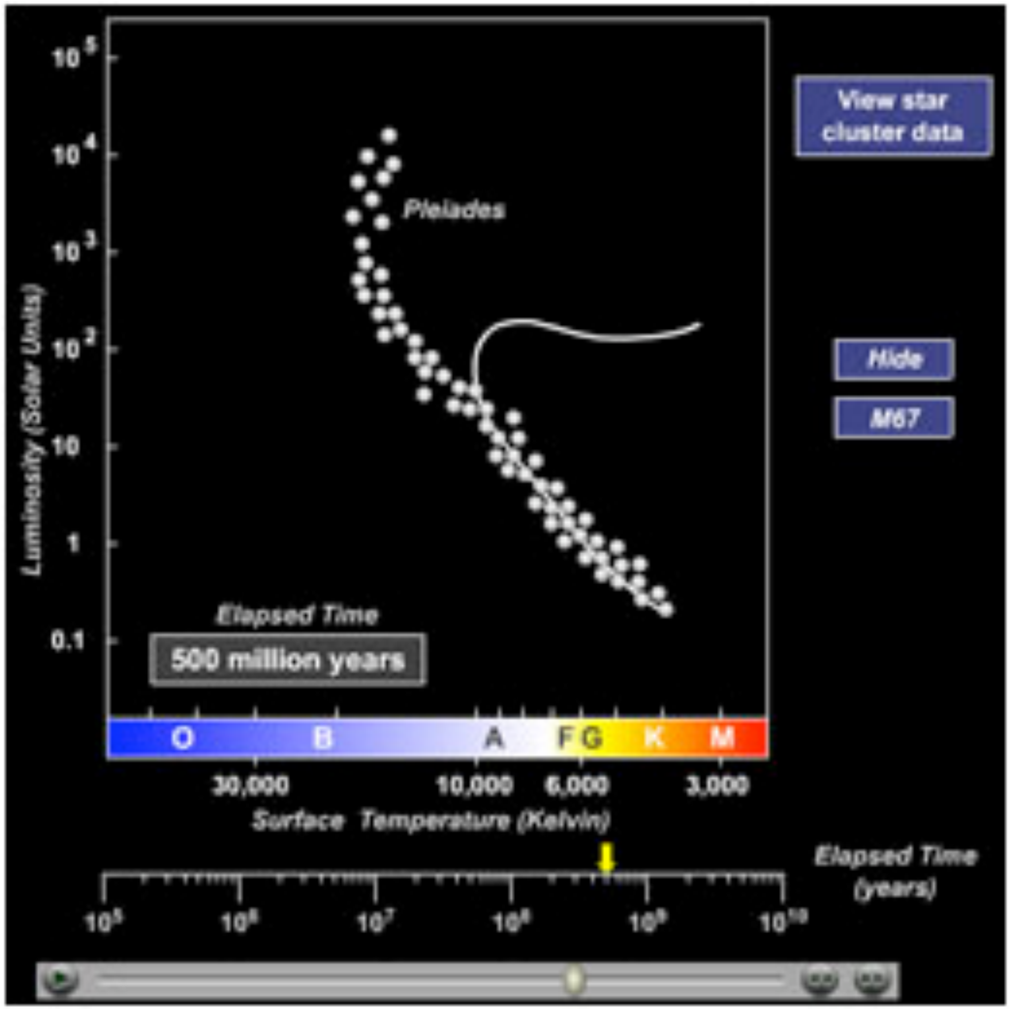
PLAY Visual Representation of a Star Cluster Evolving



Pleiades now has no stars with life expectancy less than around 100 million years.

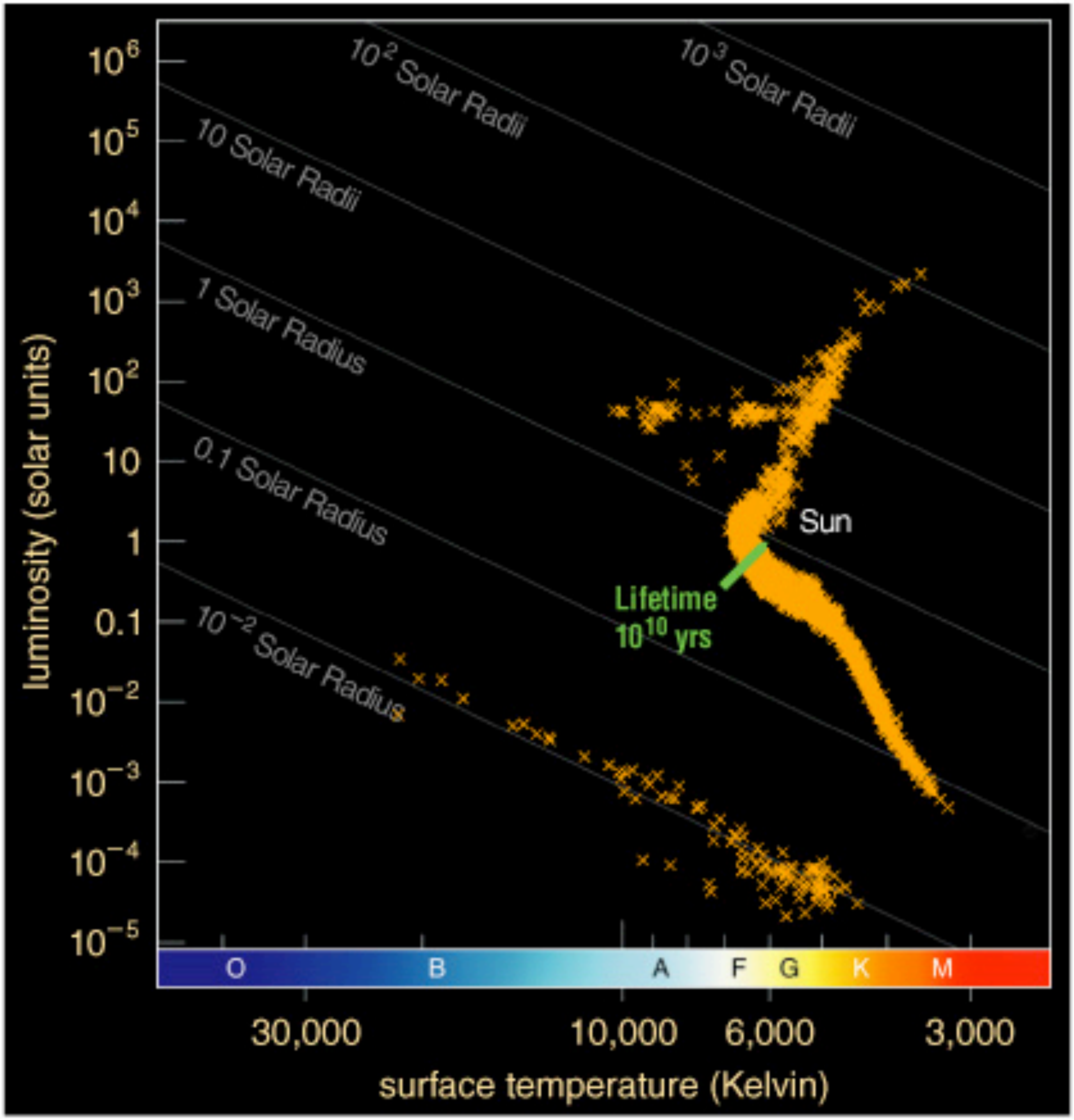


The main-sequence turnoff point of a cluster tells us its age.



To determine accurate ages, we compare models of stellar evolution to the cluster data.

PLAY Using the H-R Diagram to Determine the Age of a Star Cluster



Detailed modeling of the oldest globular clusters reveals that they are about 13 billion years old.

If a star was moved twice as far away, what would happen to it?

20%	1. It would get twice as faint
20%	2. It would get four times fainter
20%	3. It would get fainter and redder
20%	4. It would get fainter and bluer
20%	5. If moved only two times farther, you wouldn't notice much change

How can you tell the temperatures of stars?

20%	1.	Color–the hottest stars are “red hot”
20%	2.	Color–the hottest stars are “bluish white”
20%	3.	Spectral type
20%	4.	1 and 3
20%	5.	2 and 3

Why do the hottest spectra (types O and B) show few absorption lines?

20%	1. Many elements have been used up in these stars
20%	2. These stars are old and were formed before there were many elements in the galaxy
20%	3. Many atoms in these stars are ionized–have lost electrons–so can't absorb
20%	4. Much of their absorption is in the ultraviolet
20%	5. 3 and 4

How would you expect the <u>lifetime</u> of a massive
star near the top of the main sequence
to compare to the Sun's?

25%	1.	Longer
25%	2.	About the same
25%	3.	Shorter
25%	4.	Very, very much shorter

Why does a photograph of a star field (e.g. Figure 11.4) show some stars to be larger than others?

25%

1. Some stars are larger than others and therefore appear larger.

25%

2. Some stars are nearer than others and therefore appear larger.

25%

3. Both (1) and (2).

25%

4. Photographs make brighter stars appear larger than fainter stars, although they should all be points of light.

What do the colors of stars in the Hertzsprung-Russell diagram tell us?

20%	1.	The size of the star.
20%	2.	The luminosity of the star.
20%	3.	The surface temperature of the star.
20%	4.	The core temperature of the star.
20%	5.	The mass of the star.

Two stars that look very different must be made of different kinds of elements.

25%

1. Yes, stars have a wide range of compositions.

25%

2. Yes, stars appear different because of their different composition.

25%

3. No, stars appear different due to their different ages and masses, not composition.

25%

4. No, stars appear different because of their varying dista