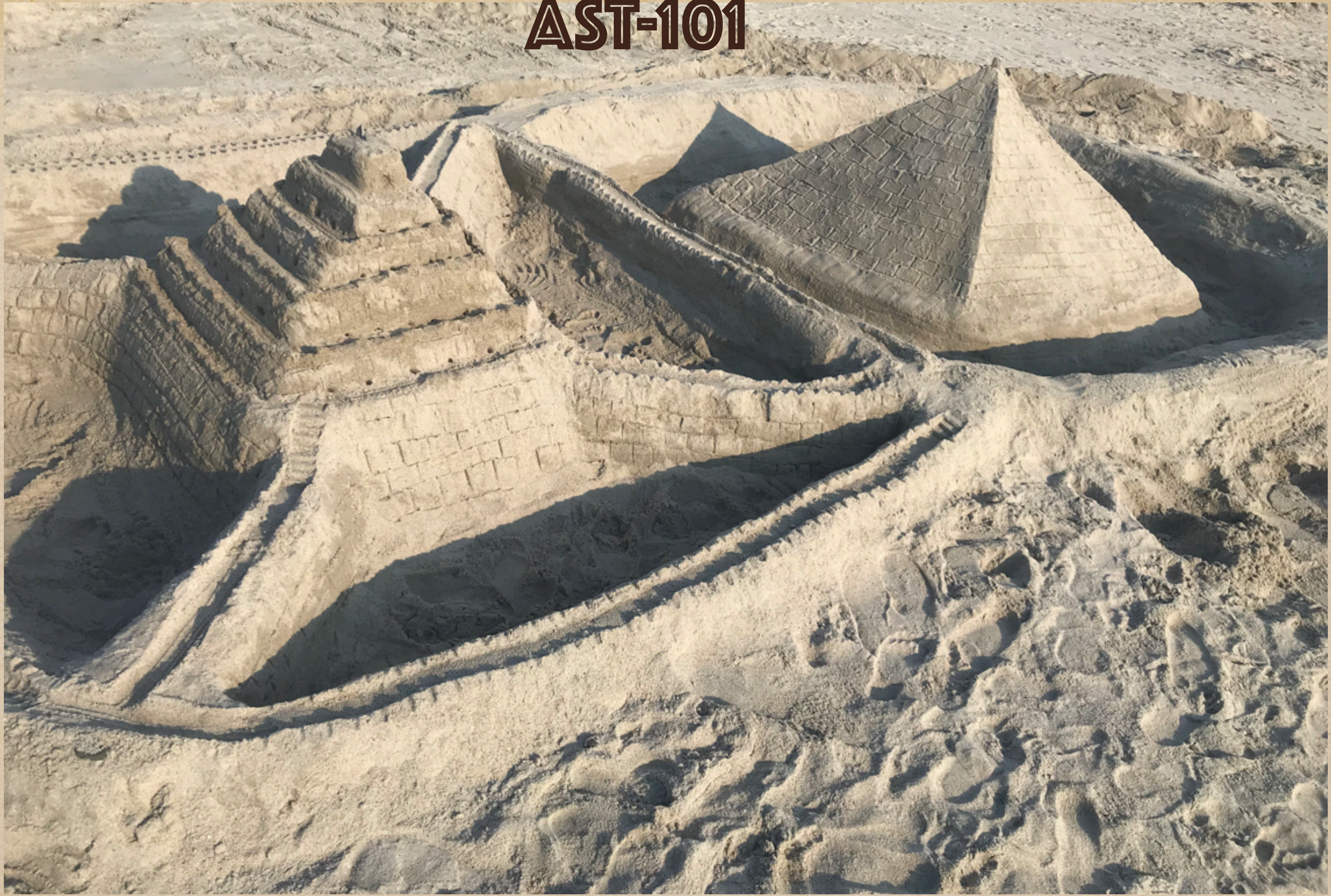
AST-101



Classifying stars: The HR digram

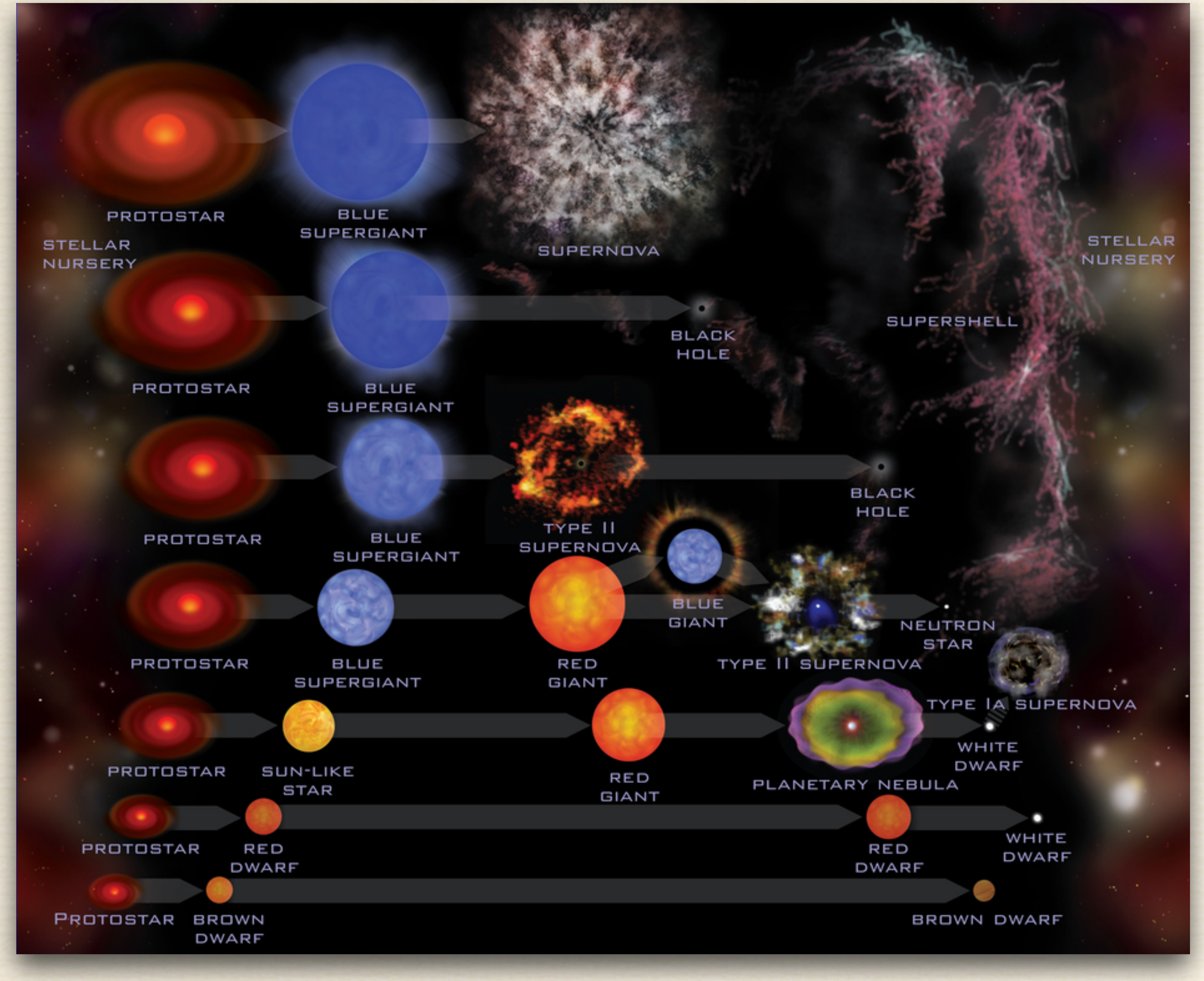
Luis Anchordoqui

Often Only Seeing a Point of Light

Stars are so small compared to their distance to us that we almost never have the resolution to see their sizes and details directly ☛ **point sources**

We deduce everything by measuring the amount of light **(brightness)** at different wavelengths **(color, spectra)**

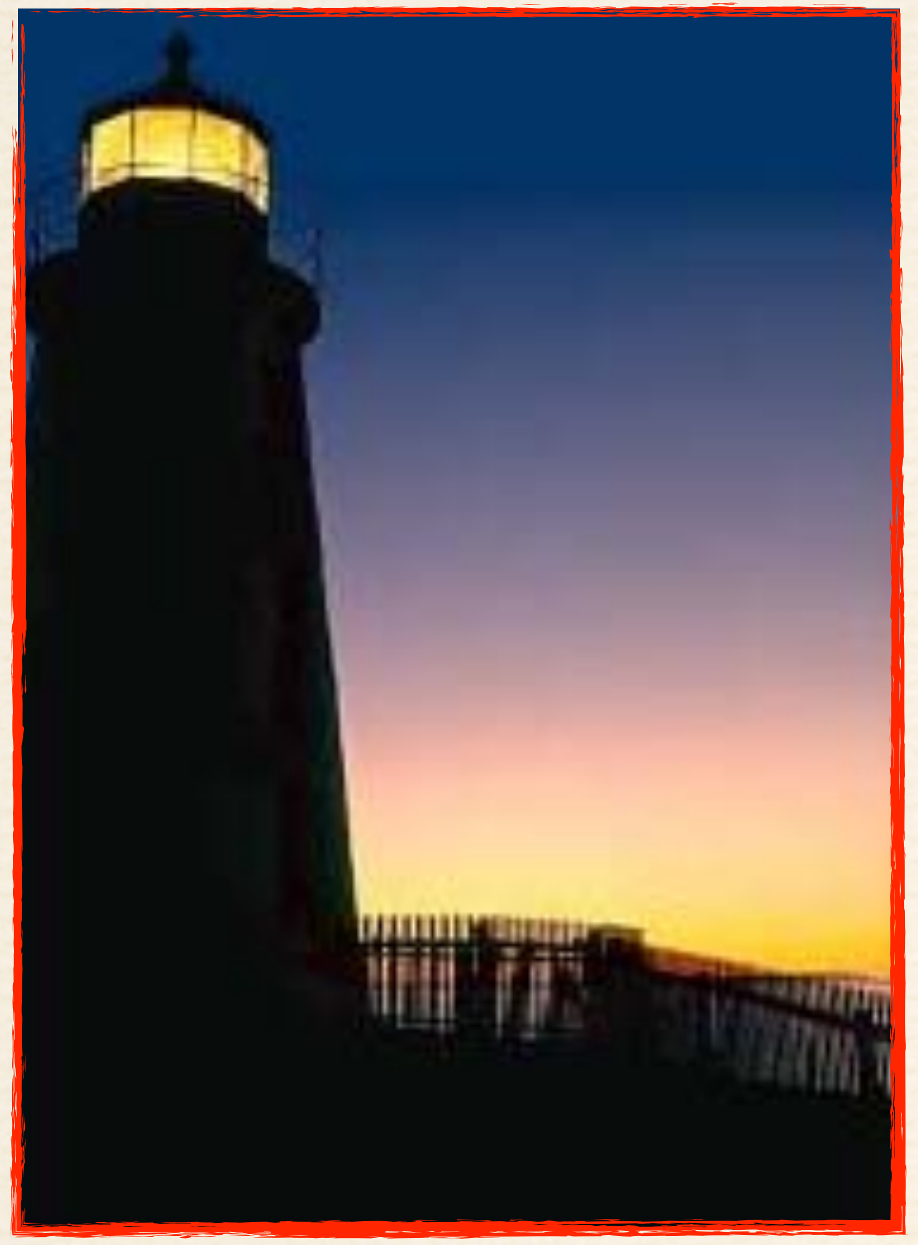
Angular size of Alpha Centauri = .004 arcsec



Stars take millions or even billions of years to go through their life stages but we rarely see a single star change

Observing many different stars lets us figure out the sequence of a single stars life

One of the Most Basic Problems in Astronomy



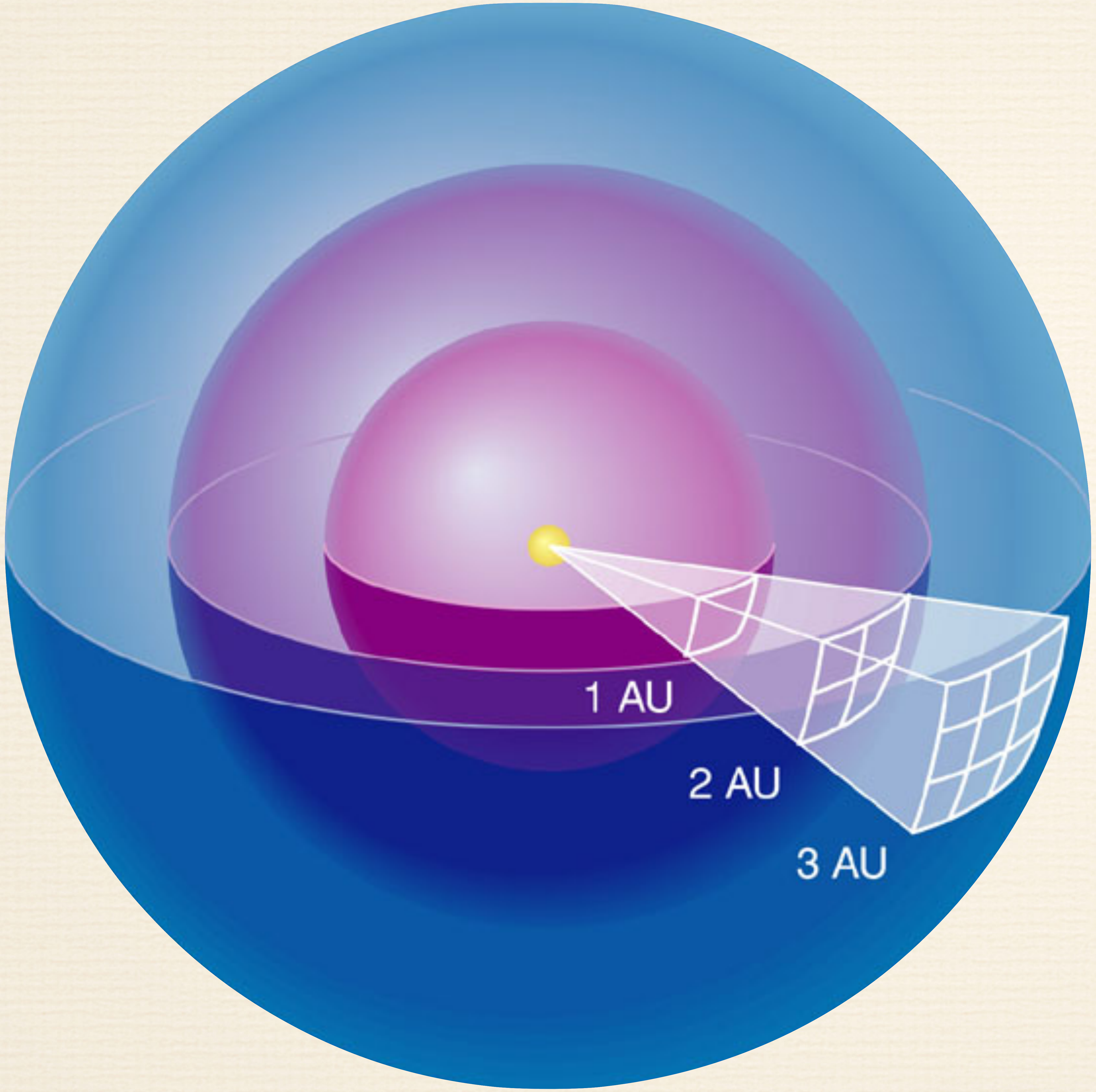
Star of given APPARENT BRIGHTNESS could be either

A. very luminous star far away

B. low luminosity star closer by

DISTANCE to the star matters!

Inverse Square Law of Brightness



Apparent Brightness

$L_0 / 4 \pi (\text{distance})^2$

If you quadruple (x4) your distance to a light source and look again, how much dimmer does it appear?

A. one-half as bright as originally

B. one-fourth as bright

C. one-sixteenth as bright

D. unchanged, since really same light

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What is parallax?

A. The total amount of power that a star emits into space

B. A measurement of the separation of two stars in a visual binary

C. A classification of a star based on its temperature

D. The shift of a stars apparent position due to the motion of the Earth

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The biggest ground-based telescopes with adaptive optics can measure stars positions to accuracies of about 0.1 arcseconds.

How far away can they map the positions of stars via parallax?

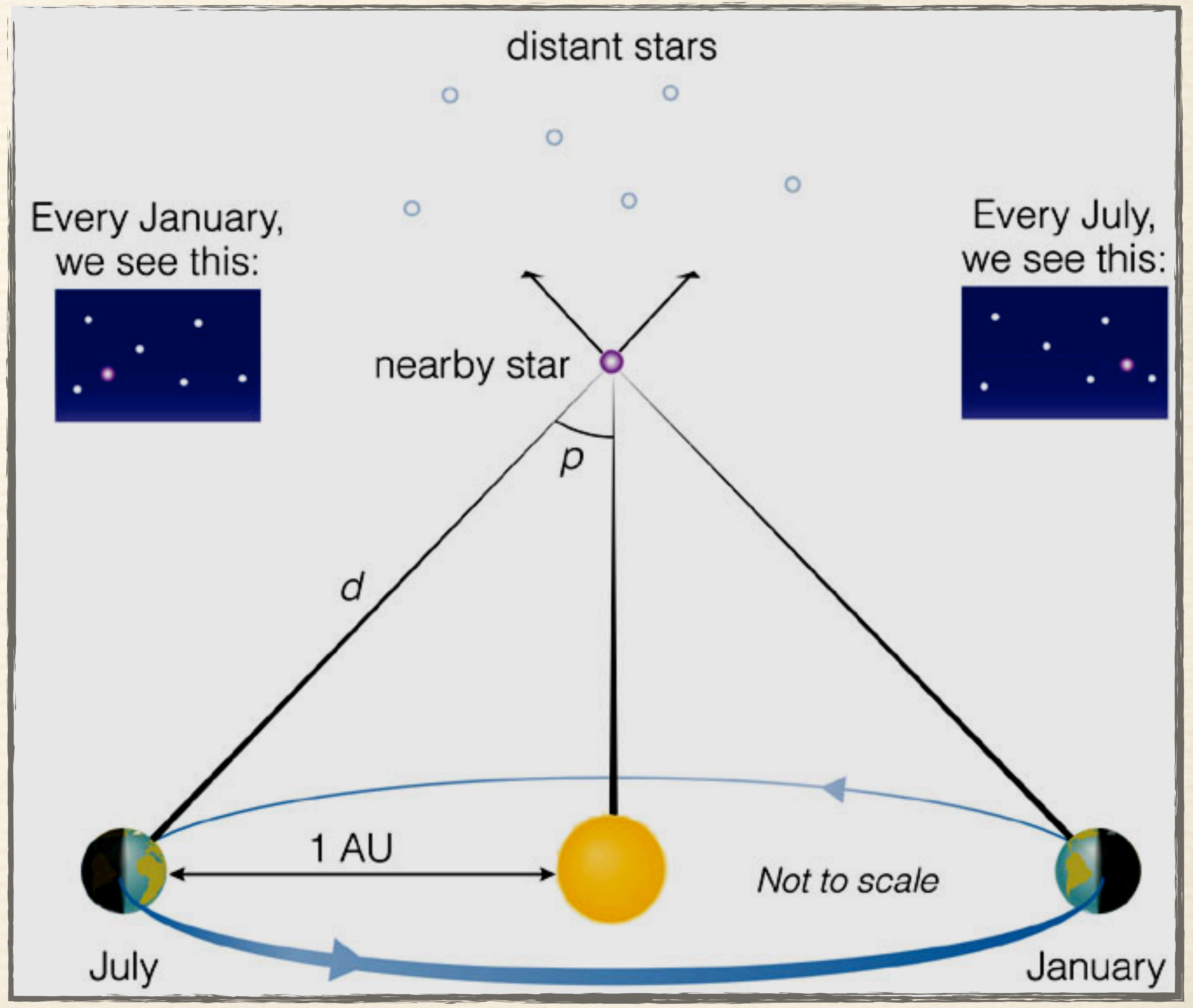
A. 1 pc
B. 10 pc
C. 100 pc
D. 1000 pc

Parallax

B. maximum distance is set by the accuracy with which you can measure positions in the sky (space does better than ground)

Distance (pc) = 1/0.1 arsec = 10 pc = 32.6 ly

d (in parsecs) = 1/p (in arsec)



Brad an Angelina are two stars that have the same apparent brightness

Brad has a larger parallax angle than Angelina

Wich star is more luminous?

A. Brad

B. Angelina

C. Not enough information to know

- Brad has a larger parallax angle
  ☛ he is closer to us

- If they both have the same APPARENT BRIGHTNESS, but Brad is closer...

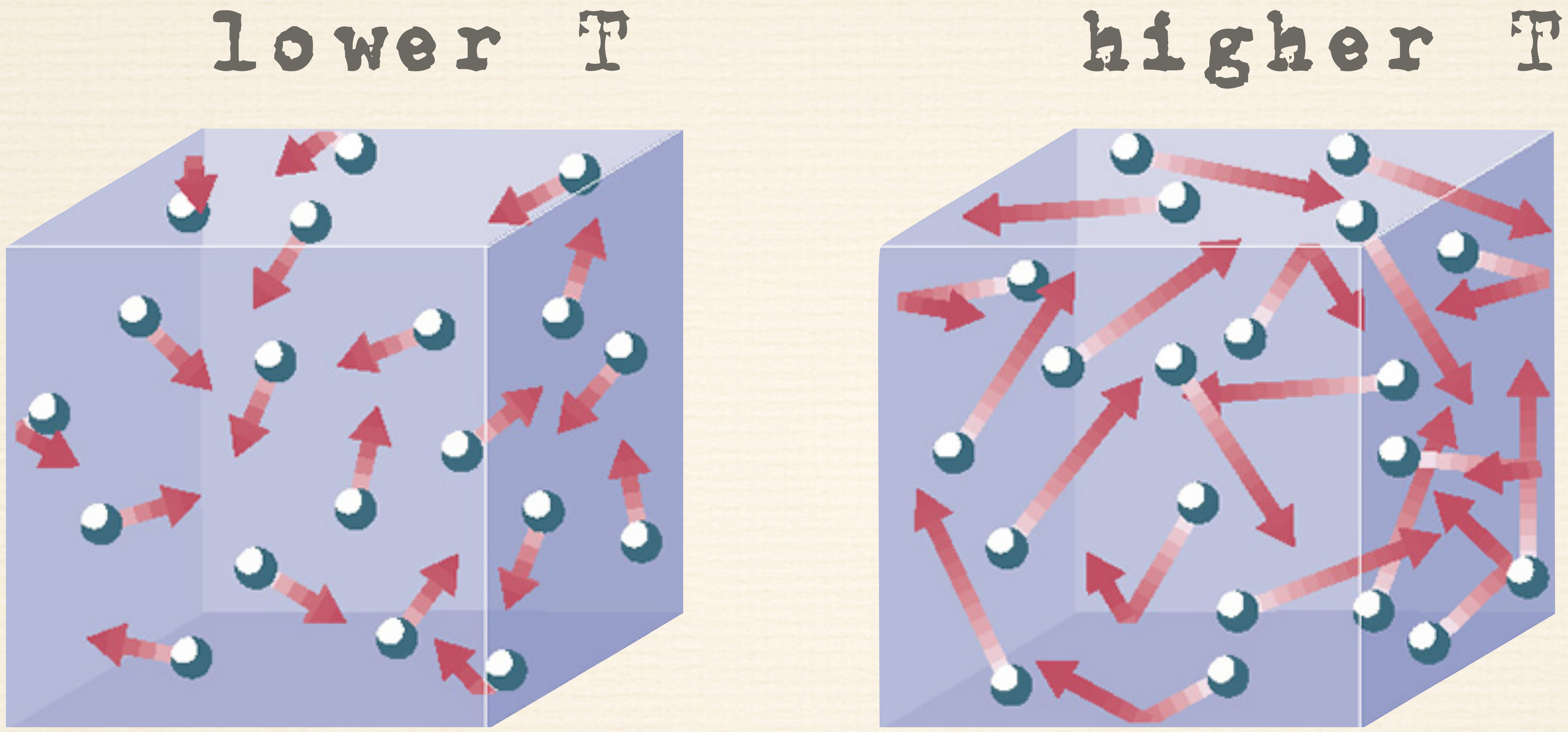
B. Angelina must be more luminous

Stars: Temperature and Color

- Temperature vs heat
- Temperature vs color
- Colors/spectra of stars

Temperature

Longer arrows mean higher average speed



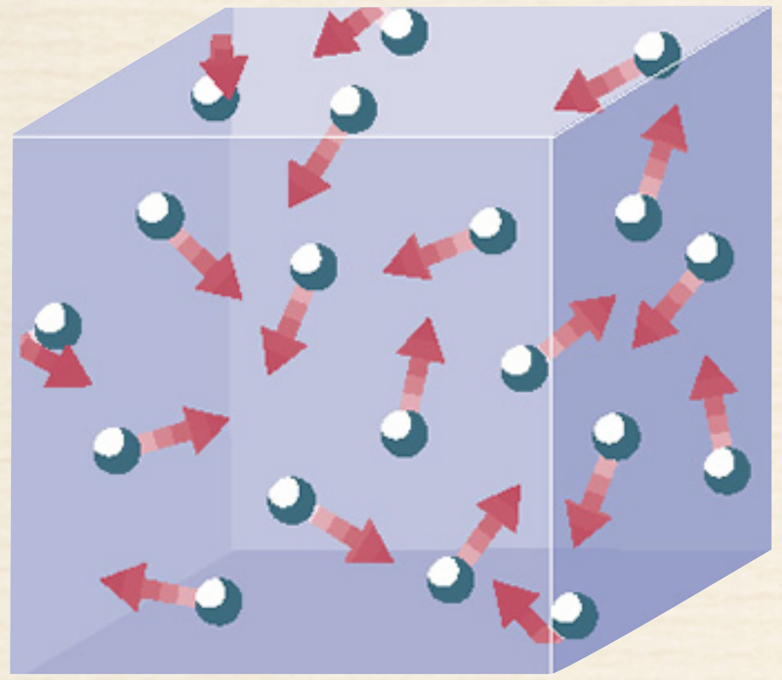
Temperature is proportional to the average kinetic energy per molecule

$$K = \frac{1}{2}mv^2 = \frac{3}{2}kT$$

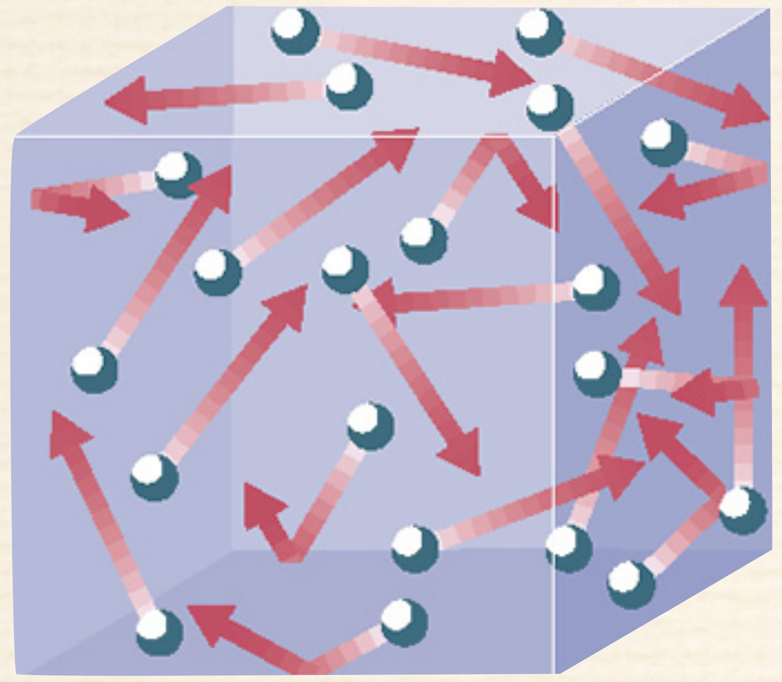
k = Boltzmann constant = 1.38 x 10^{-23} J/K = 8.62 X 10^{-5} eV/K

Temperature vs. Heat

Lower T



Higher T

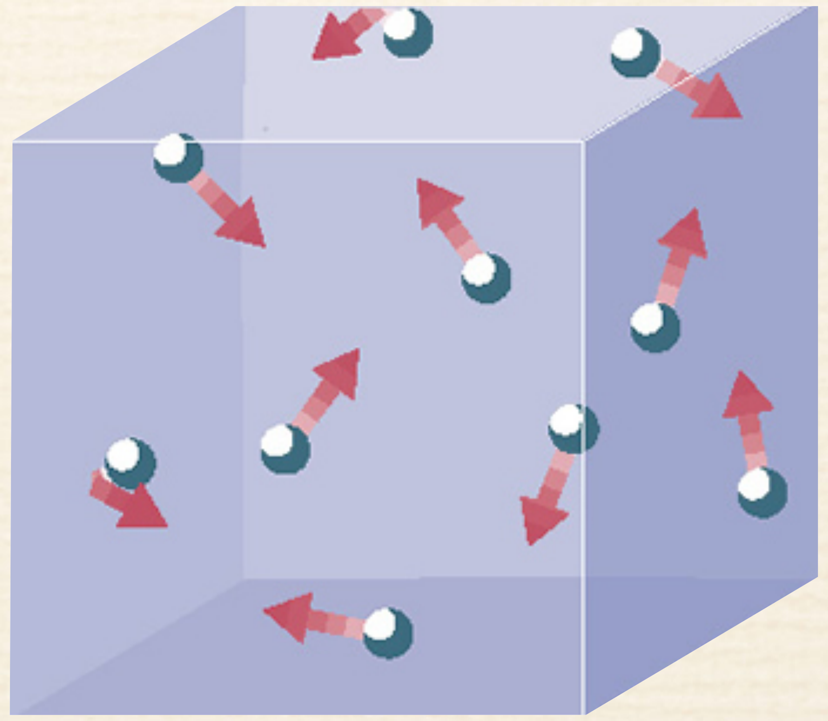


Longer arrows mean higher average speed

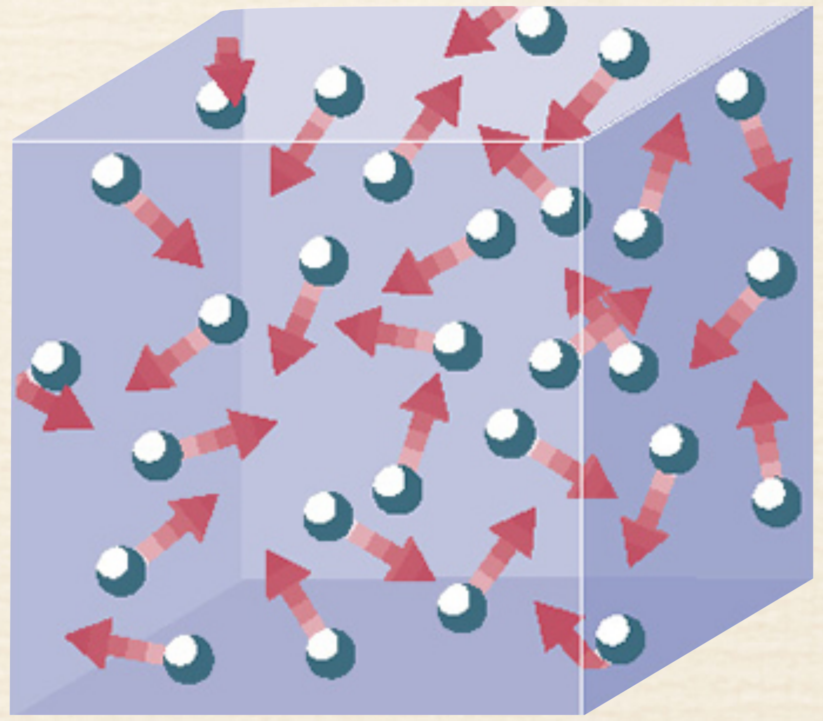
Temperature is proportional to the average kinetic energy per molecule

Heat (thermal energy) is proportional to the total kinetic energy in box

Less heat



More heat



same T

Luminosity of a Black Body Radiator

For the spherical object, the total power radiated = the total luminosity is:

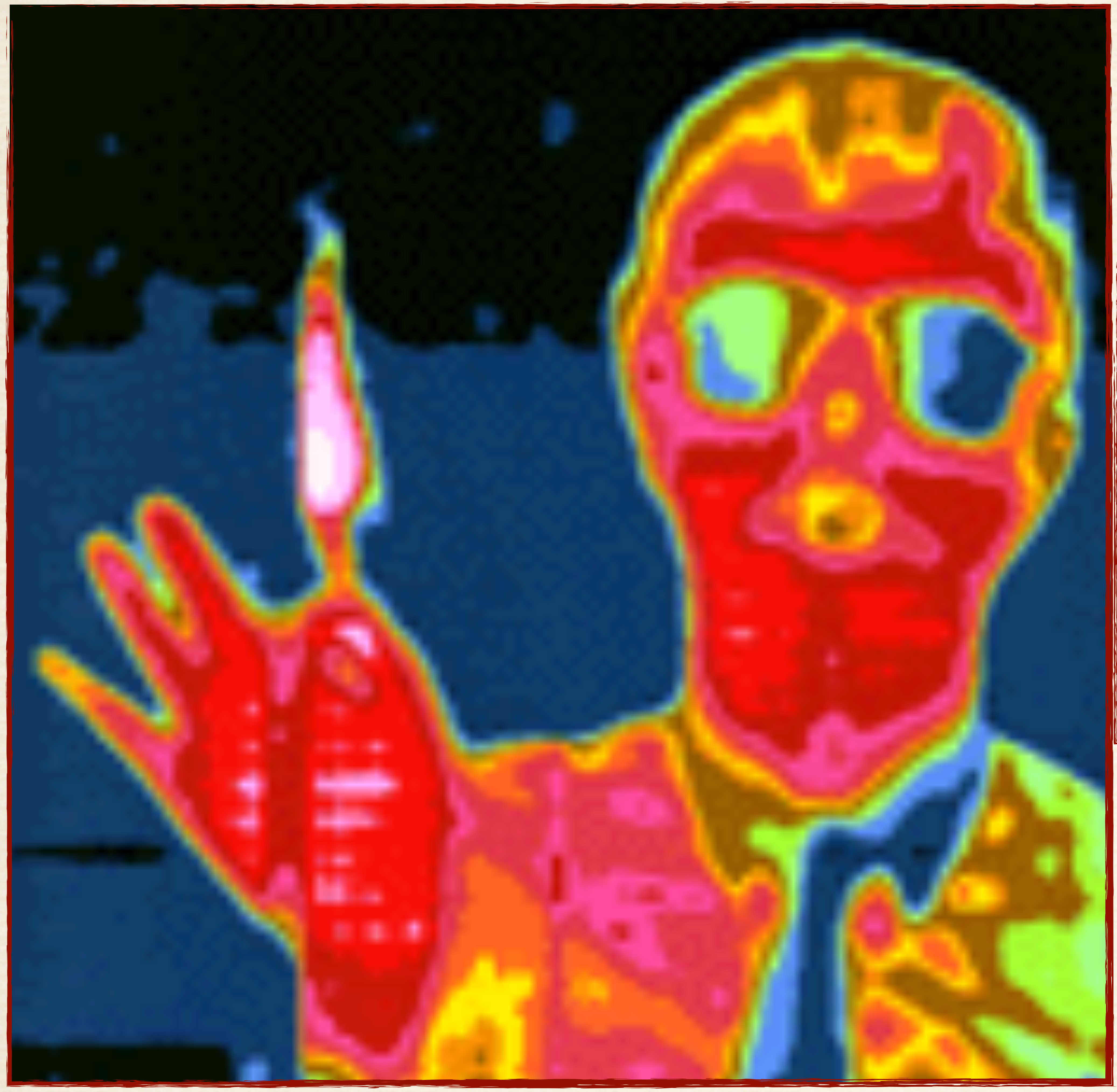
$$L = 4\pi R^2 \sigma T^4$$

T = temperature

σ = Stephan-Boltzman constant = 5.67×10^{-8} W/m$^2\cdot$K^4

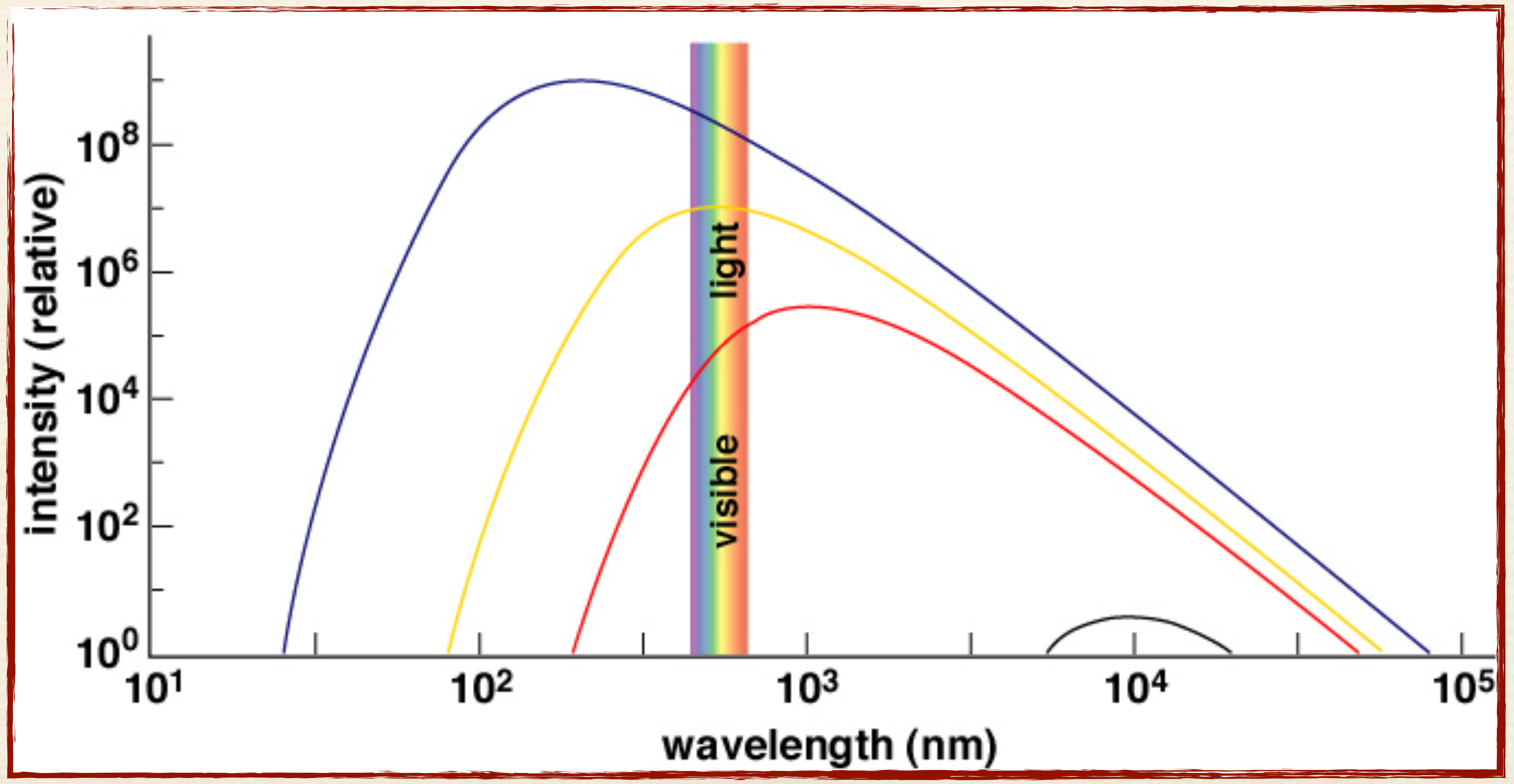
R = radius

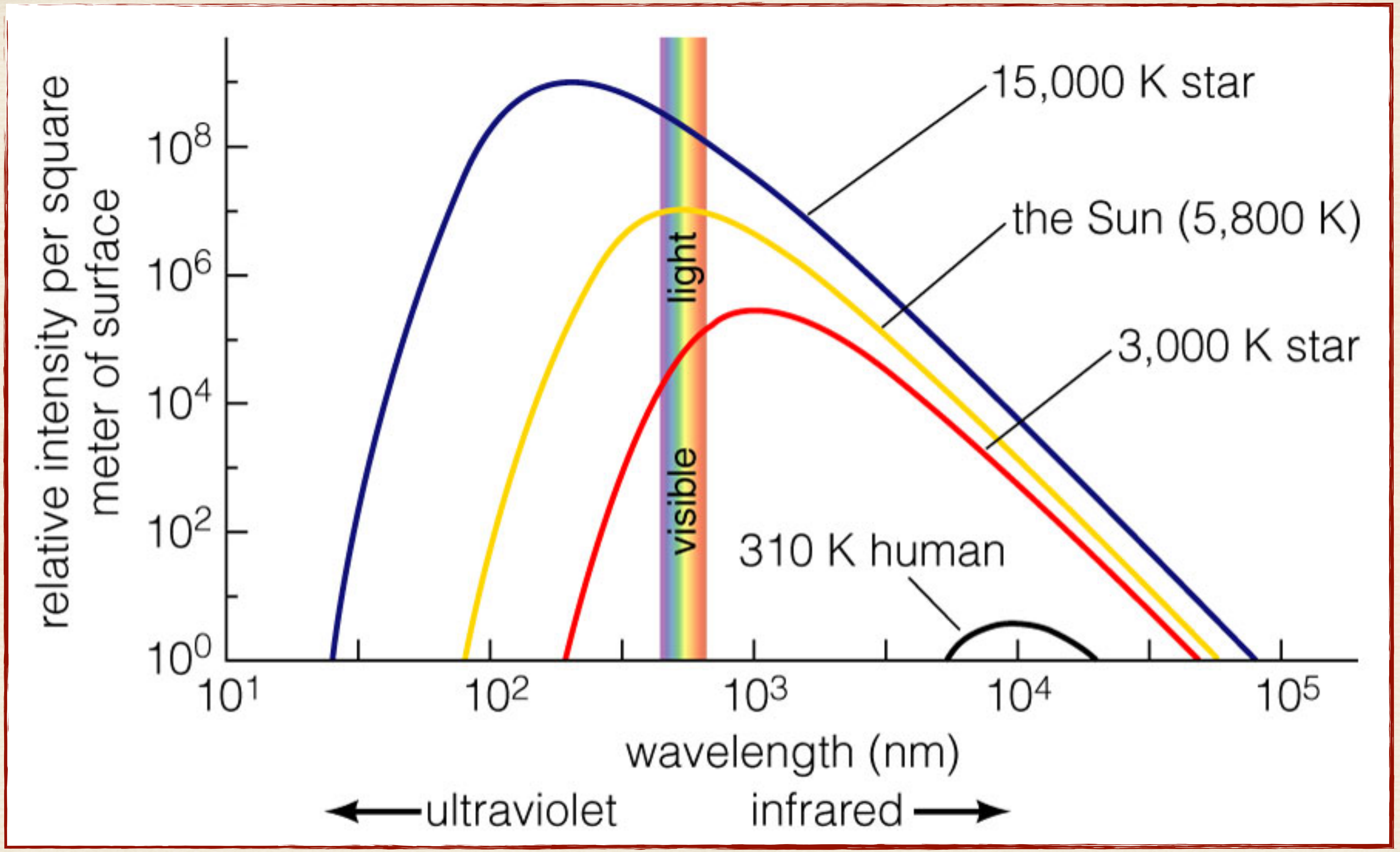
Humans emit blackbody radiaton in the infrared



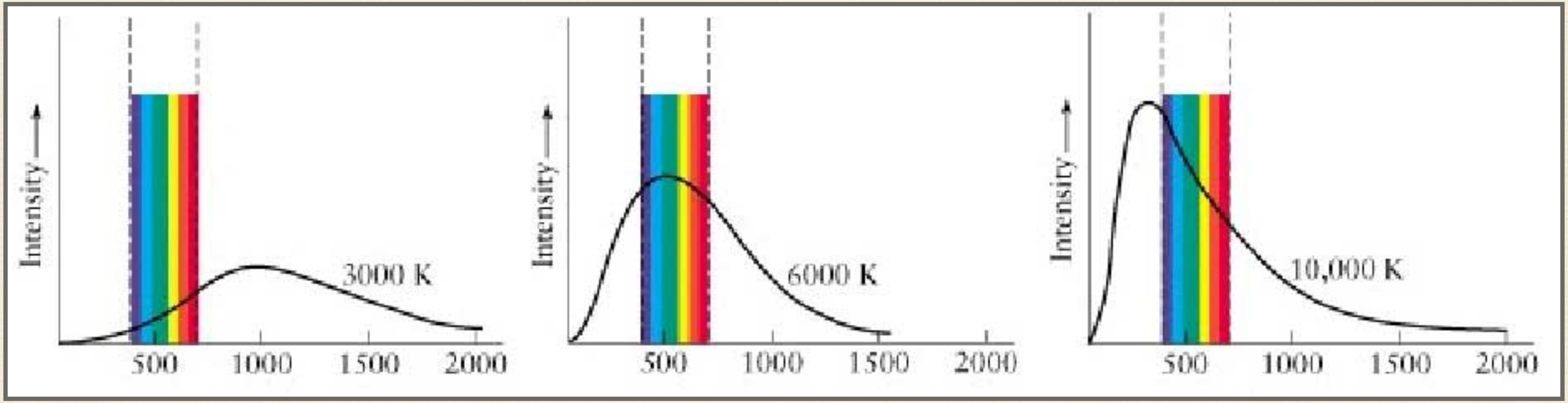
Wien's law

- Cooler objects produce radiation which peaks at lower energies = longer wavelengths = redder colors
- Hotter objects produce radiation which peaks at higher energies = shorter wavelengths = bluer colors
- Wavelength of peak radiation: Wien Law $\lambda_{max} = 2.9 \times 10^6 / T(K)$ [nm]




15,000 K star
the Sun (5,800 K)
3,000 K star
310 K human
visible light
relative intensity per square meter of surface
10^0
10^2
10^4
10^6
10^8
10^1
10^2
10^3
10^4
10^5
wavelength (nm)
← ultraviolet
infrared →

A objects color depends on its surface temperature



Wavelength (nm) →
This star looks red

Wavelength (nm) →
This star looks yellow-white

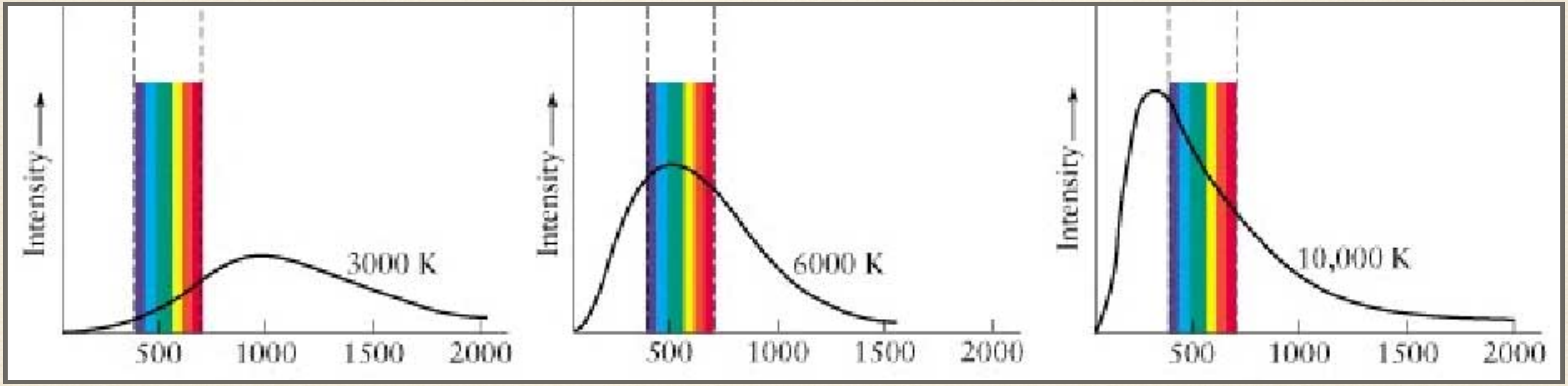
Wavelength (nm) →
This star looks blue-white

Wavelength of peak radiation:

Wien Law $\lambda_{max} = 2.9 \text{ x } 10^6 / T(K)$ [nm]

What can we learn from a stars color?

The color indicates the temperature of the surface of the star

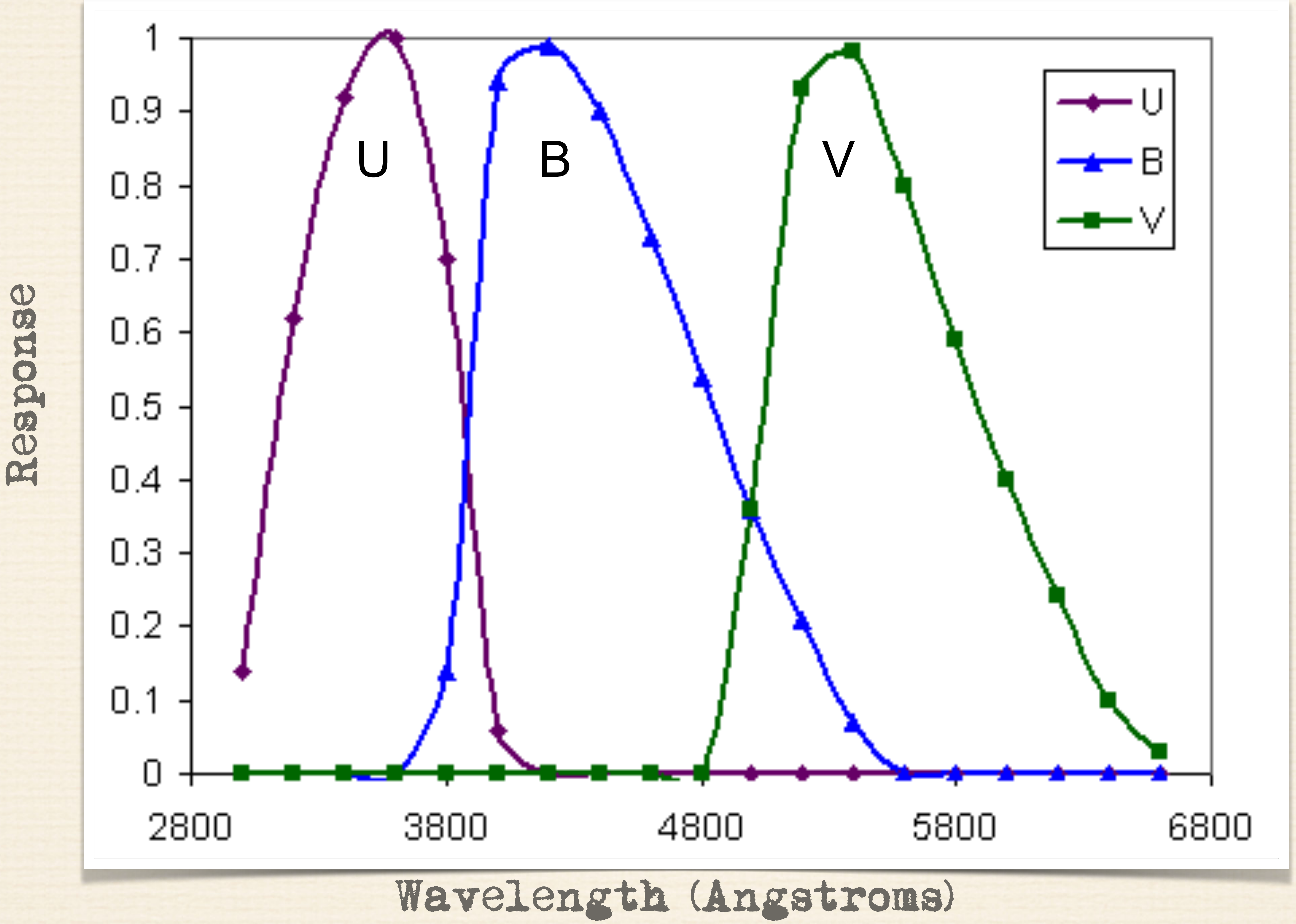


Wavelength (nm) ⟶
This star looks red

Wavelength (nm) ⟶
This star looks yellow-white

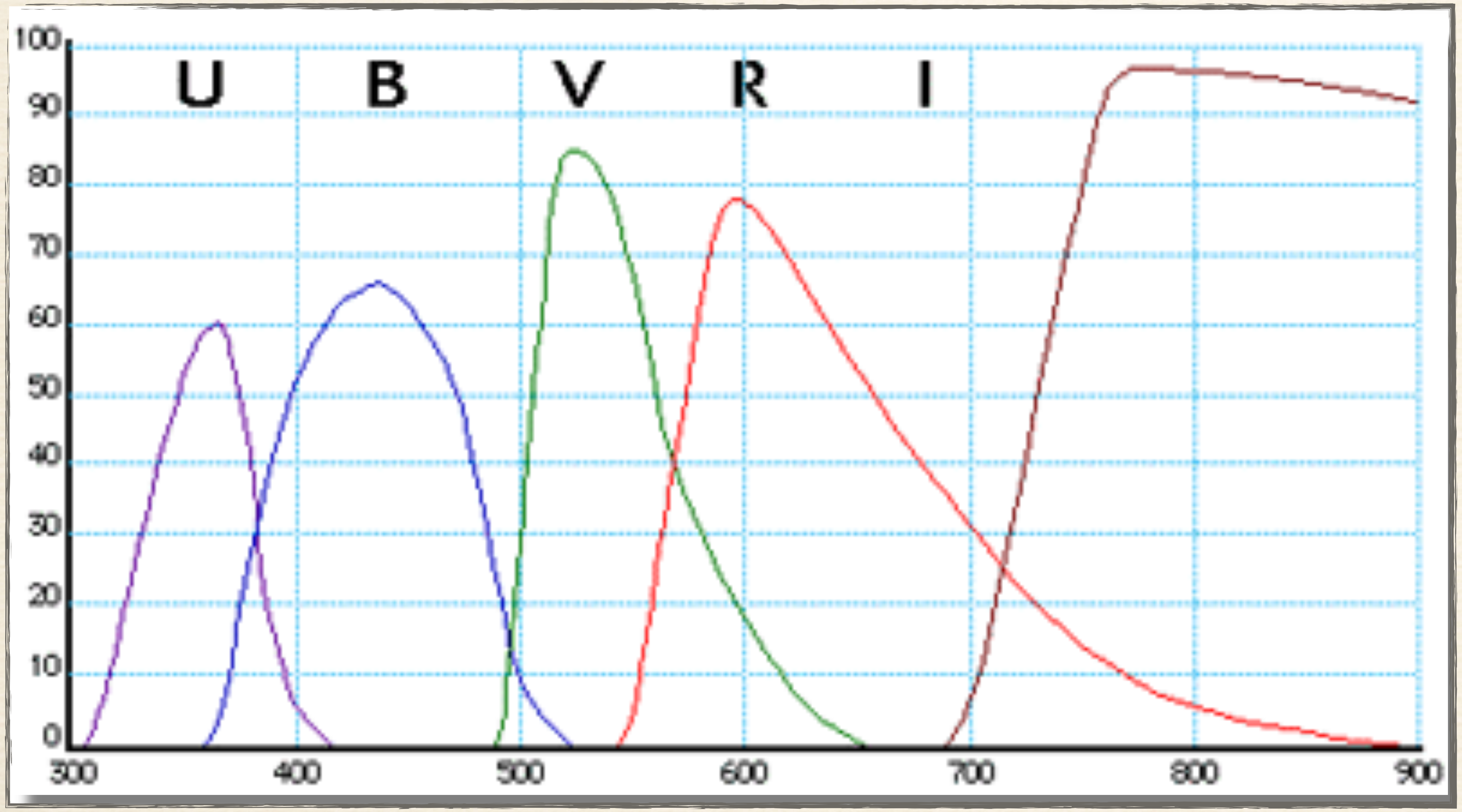
Wavelength (nm) ⟶
This star looks blue-white

Observationally, we measure colors by comparing the brightness of the star in two (or more) wavelength bands



This is the same way your eye determines color, but the bands are different

Use UVRI filters to determine apparent magnitude at each color



The spectrum of a star is primarily determined by

A. The temperature of the star's surface

B. The star's distance from Earth

C. The density of the star's core

D. The luminosity of the star

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Stars are assigned a spectral type based on their spectra

- The spectral classification essentially sorts stars according to their surface temperature

- The spectral classification can also use spectral lines

Spectral Classification: O B A F G K M

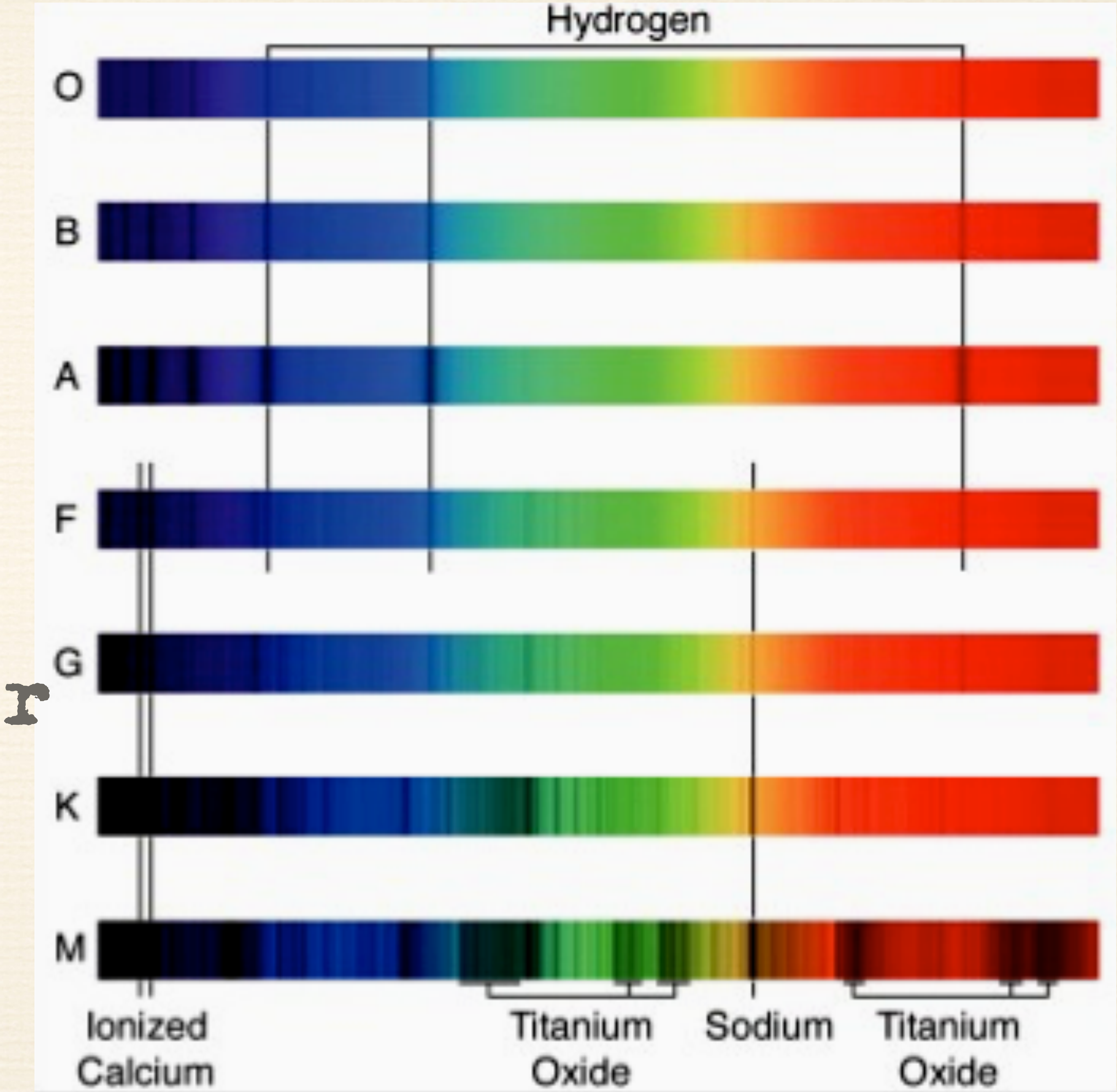
Hottest stars: **O B** mostly helium lines, few hydrogen lines

Hot stars: **A F** helium, hydrogen lines

Cooler stars: **G** hydrogen, heavier atoms

Coolest stars: **M** molecules, (complex absorption bands)

Typical spectrum



OBAFGKM

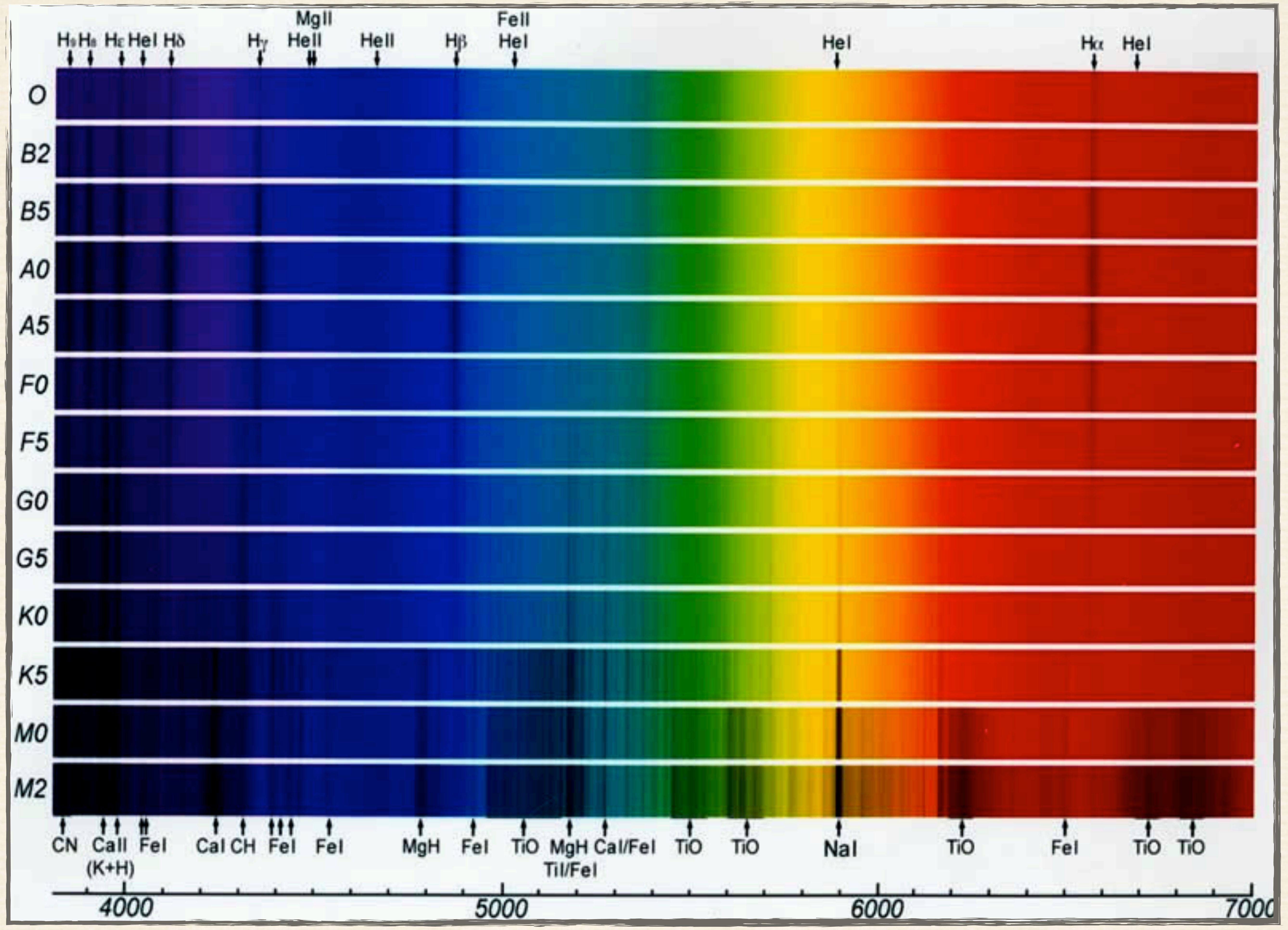
How to remember the sequence?

OBAFGKM

How to remember the sequence?

Oh Be A Fine Girl/Guy, Kiss Me

Spectra help classify stars



Wavelength (A)

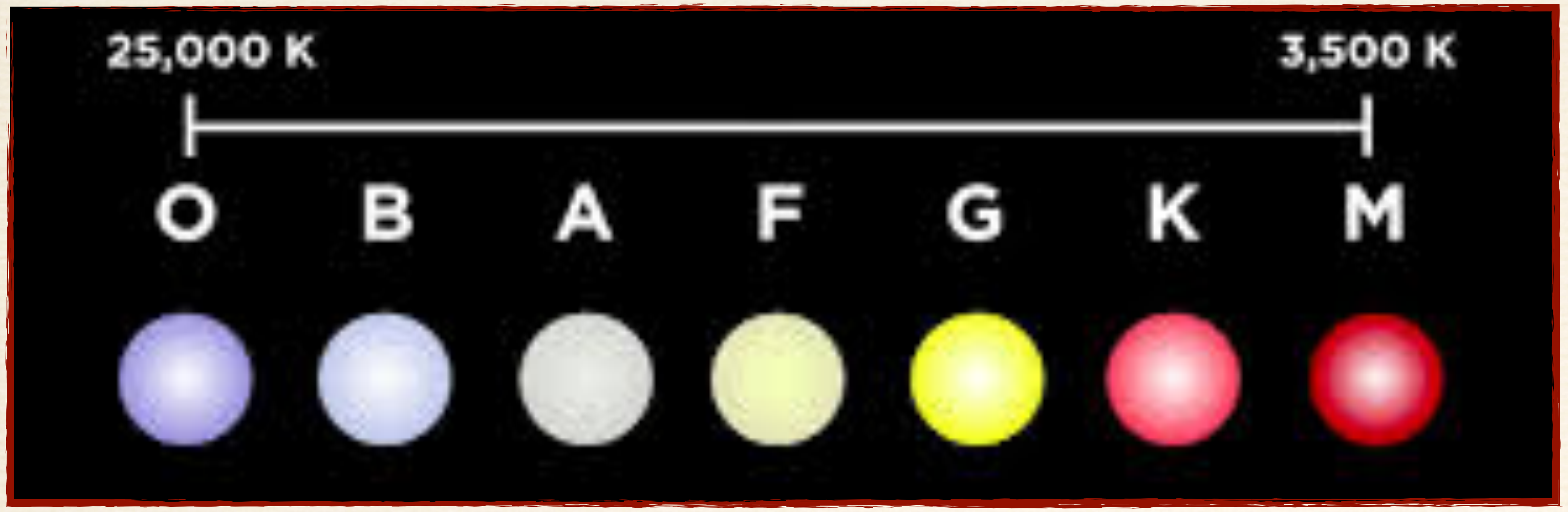
Sequence subdivided by attaching one numerical digit, for example: F0, F1, F2, F3 … F9 where F1 is hotter than F3 . Sequence is O … O9, B0, B1, …., B9, A0, A1, … A9, F0, …

Which is cooler?

A. a star with spectral type G2?

B. a star with spectral type A6?

surface temperature



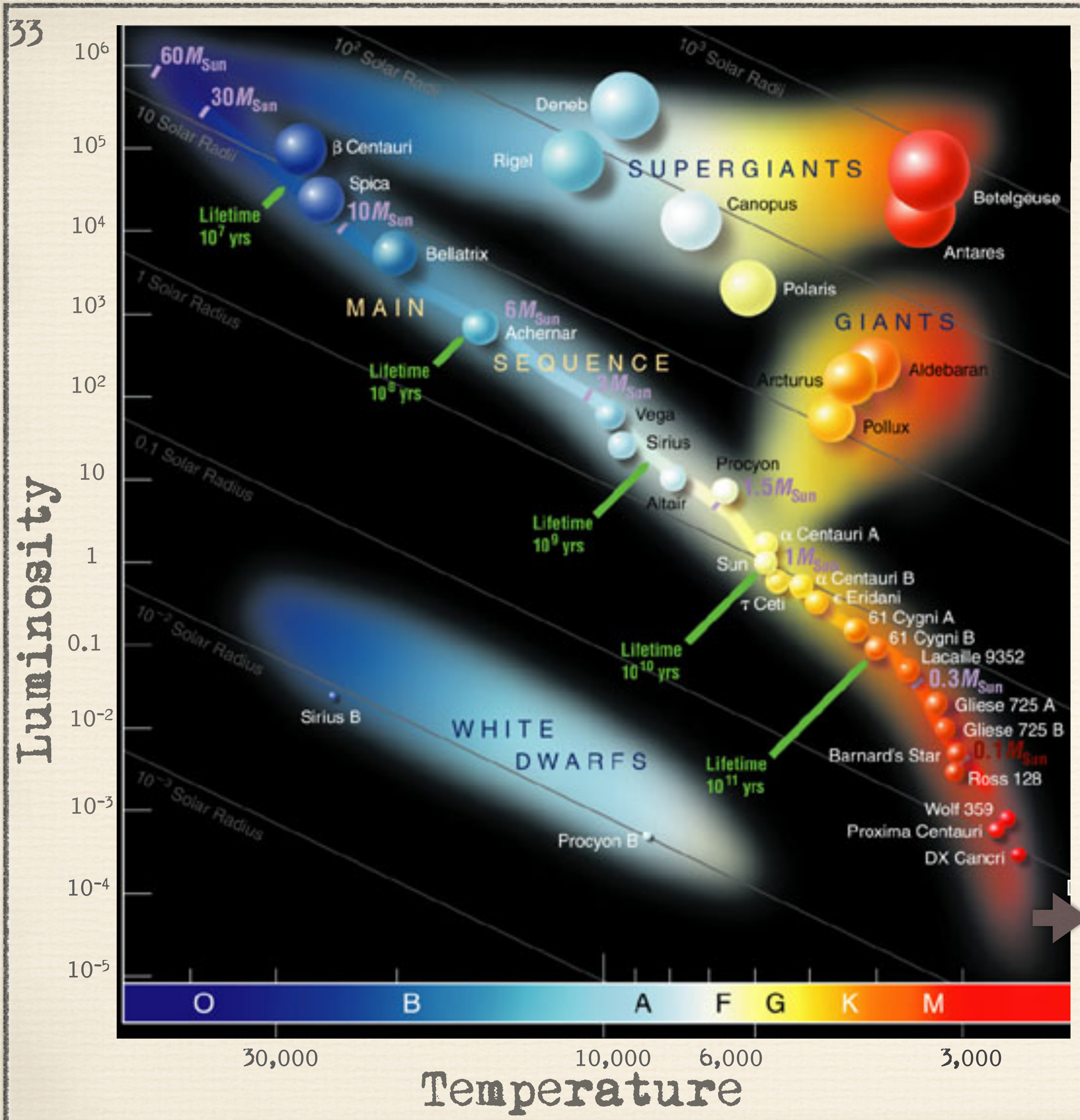
This correlates with the color of the star

A. type G2

Yellow Dwarf Orange Dwarf Red Dwarf

G-Type K-Type M-Type

H-R diagram



Emitted power per unit area= σT^4

$\sigma = 5.67\text{x}10^{-5}$ ergK^{-4}cm^{-2}s^{-1}

Total luminosity from a star of radius R:

$$L=4\pi R^2\sigma T^4$$

For the same temperature, more luminous stars have larger radii

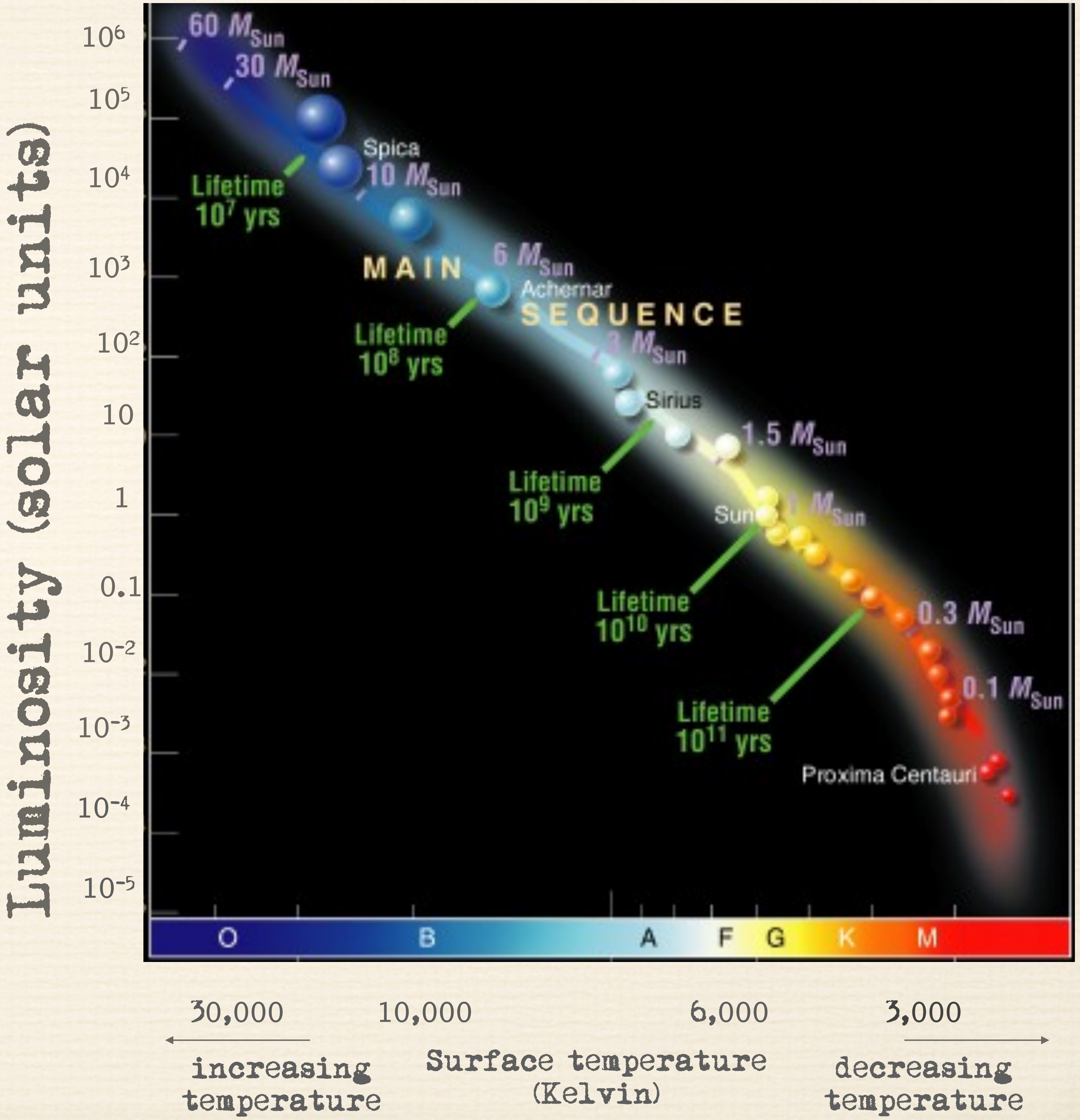
Main sequence stars

Burning **hydrogen** in their cores

Stellar masses decrease downward

Temperatures are **hotter** for more massive stars (more gravitational pressure → higher T, remember Equation of State: $PV = nkT$)

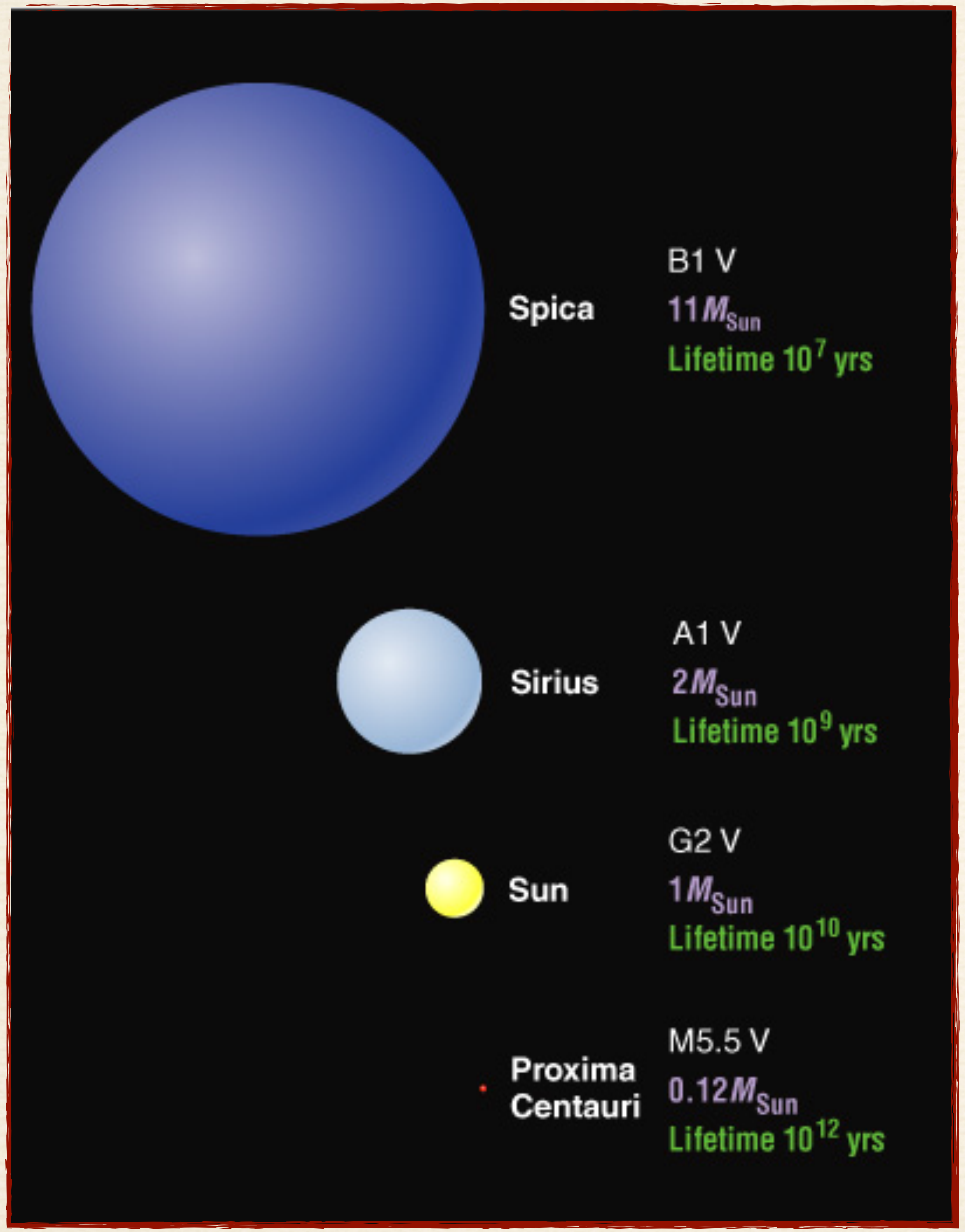
More **luminous** (higher T → much higher emitted power)



Lifetimes on Main Sequence (MS)

- Stars spend 90% of their lives on MS
- Lifetime on MS = amount of time star fuses hydrogen (gradually) in its core
- For Sun (G), this is about 10 billion years
- For more massive stars (OBAF), lifetime is (much) shorter
- For less massive stars (KM), lifetime is longer

Main-Sequence Star Summary



High Mass:

High Luminosity

Short-Lived

Large Radius

Hot

Blue

Low Mass:

Low Luminosity

Long-Lived

Small Radius

Cool

Red

George and Abe are two main sequence stars;

George is an M star and Abe is a B star

Which is more massive?

Which is redder in color?

A. George is more massive and redder

B. Abe is more massive and redder

C. George is more massive; Abe is redder

D. Abe is more massive; George is redder

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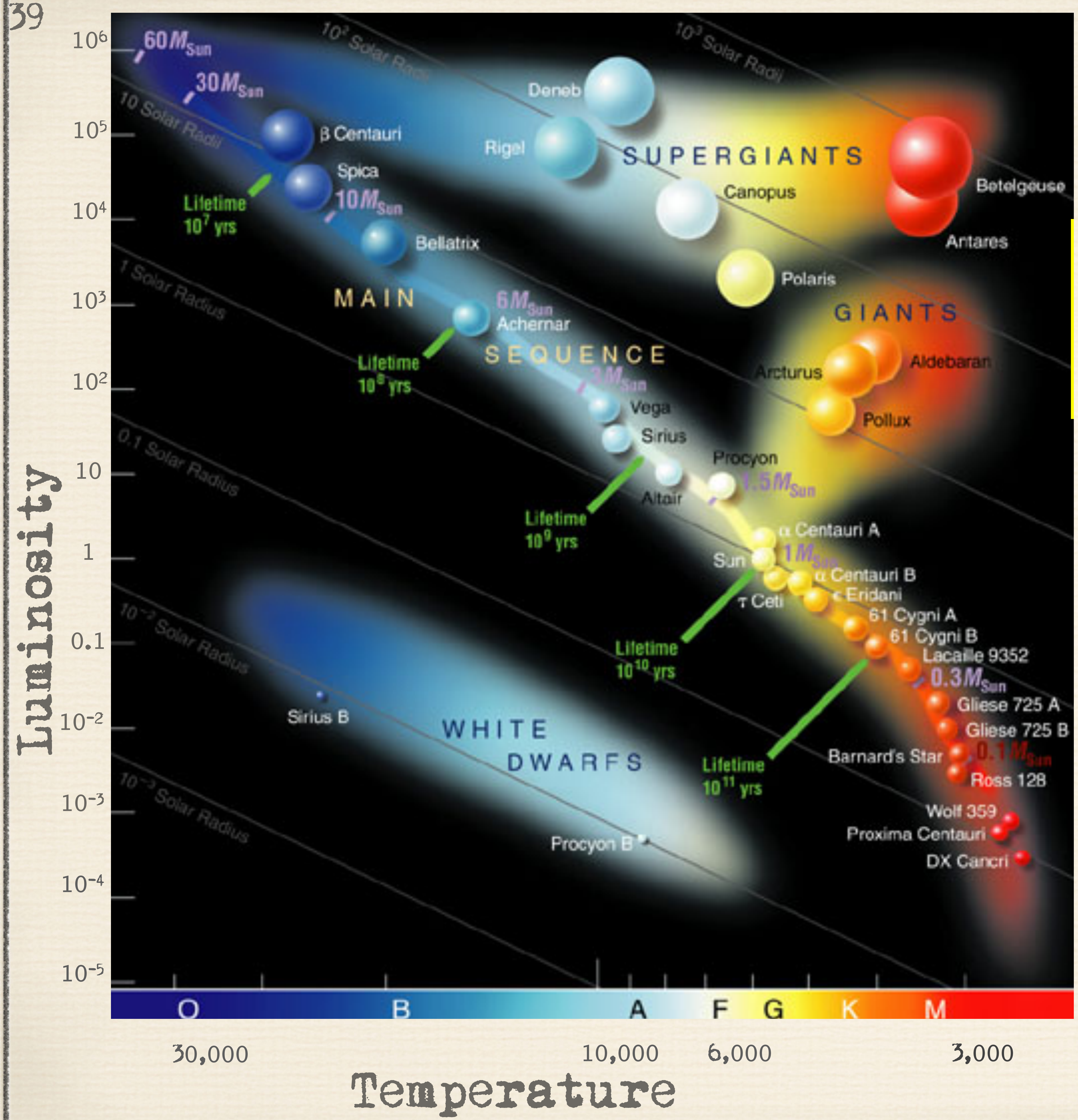
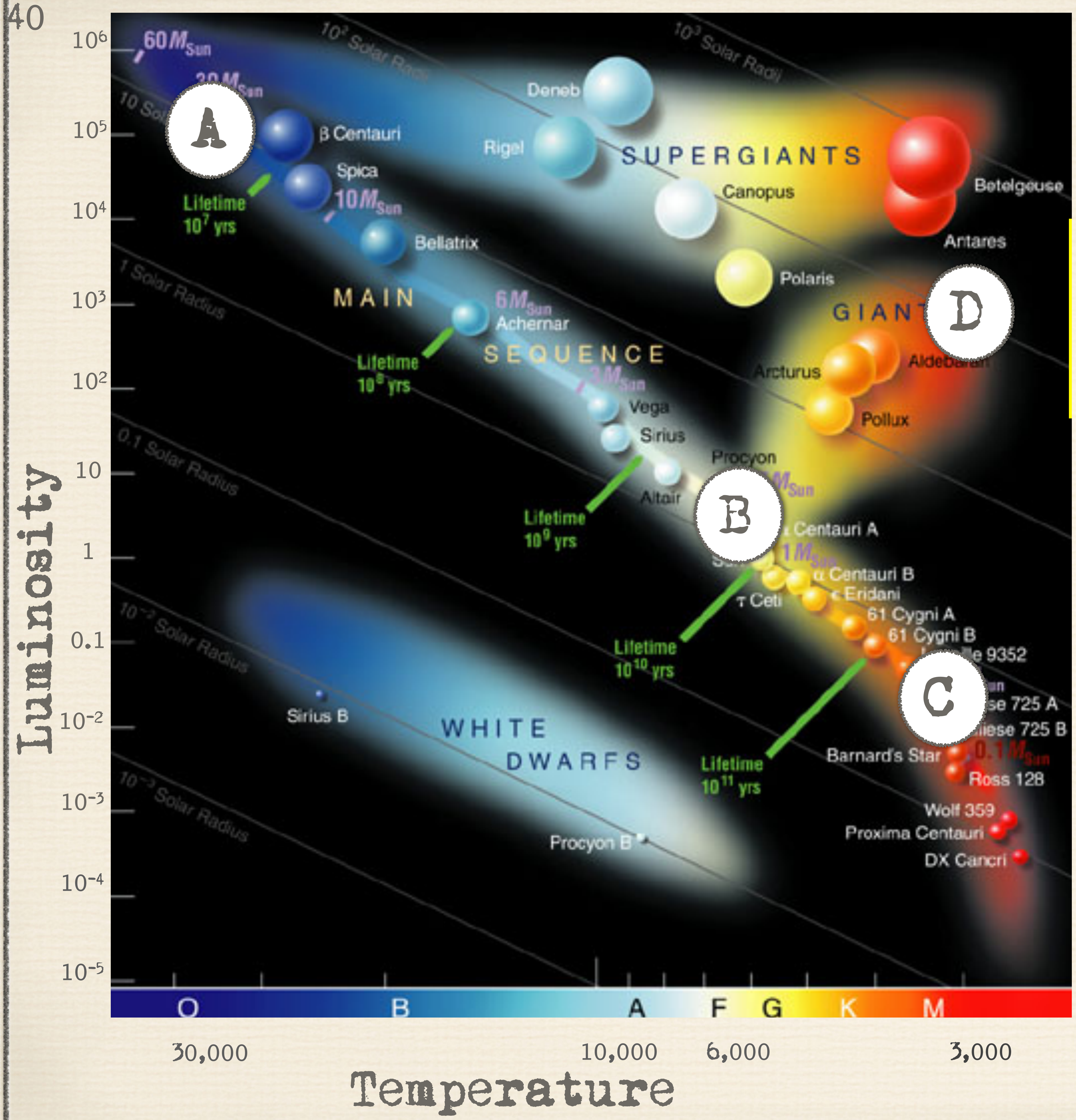
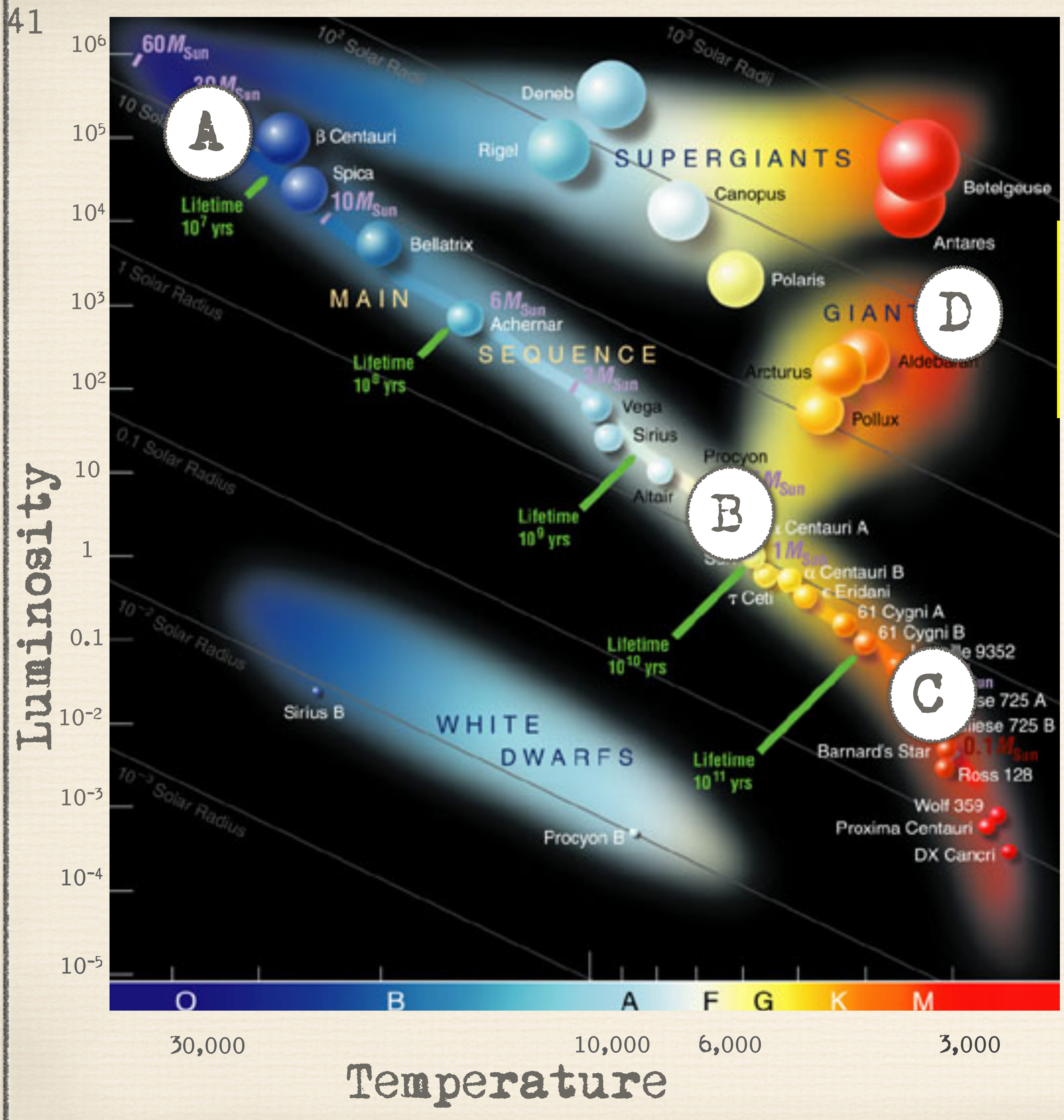


What about the other objects on the H-R diagram?

As stars run out of hydrogen fuel their properties change (generally they turn into red giants- more on why later)

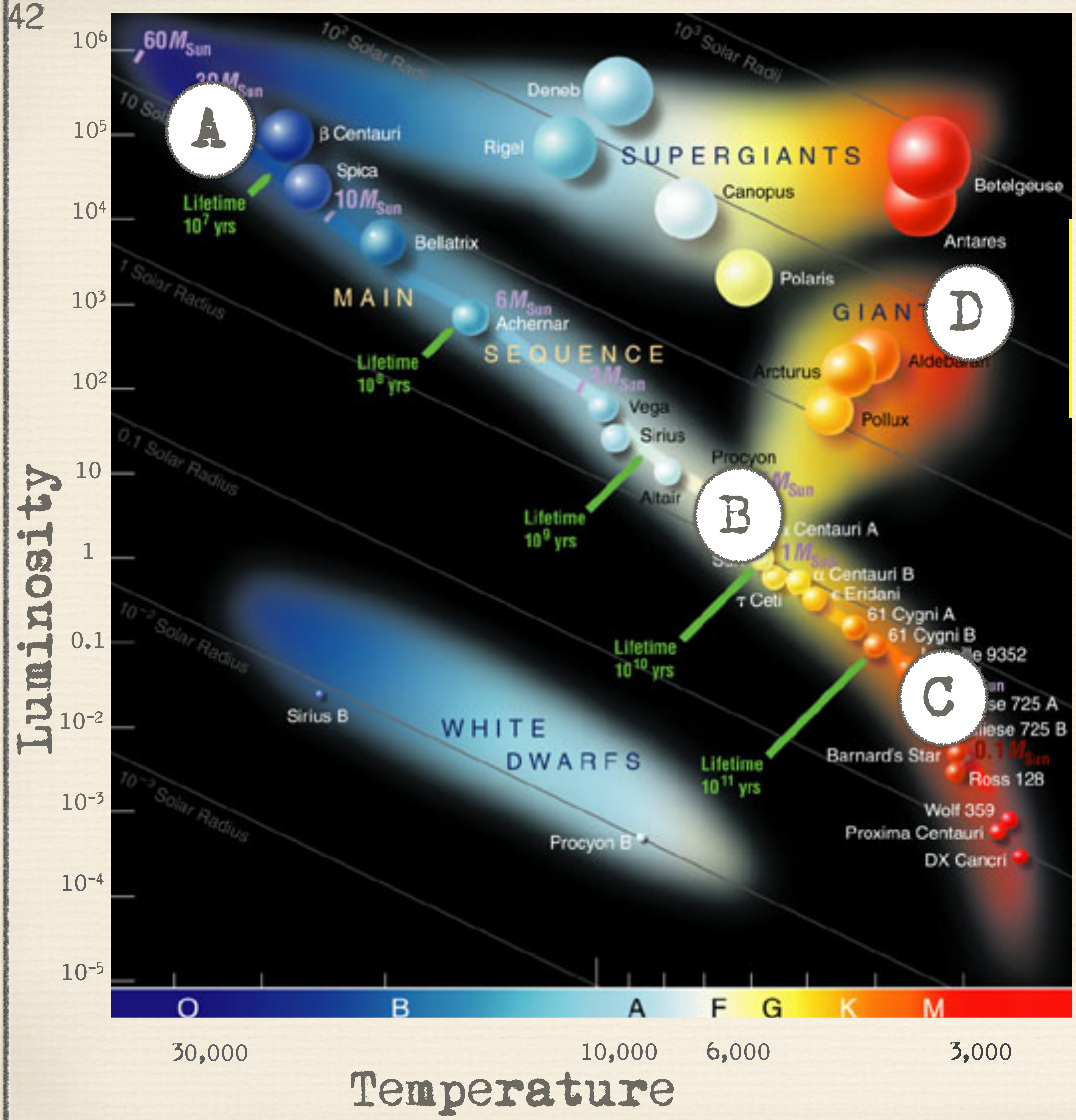


Which star is most like our Sun?

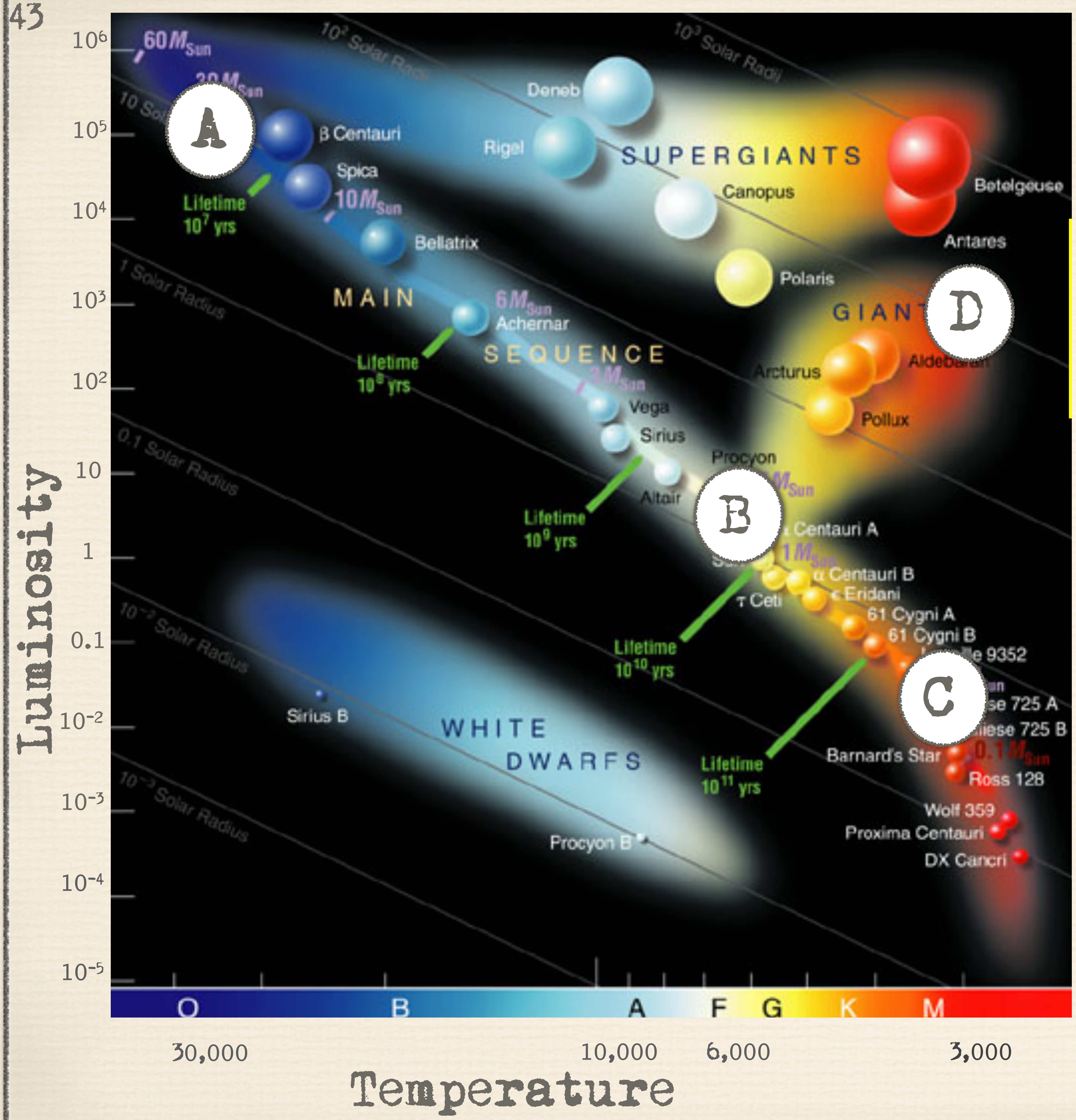


Which star is most like our Sun?

B

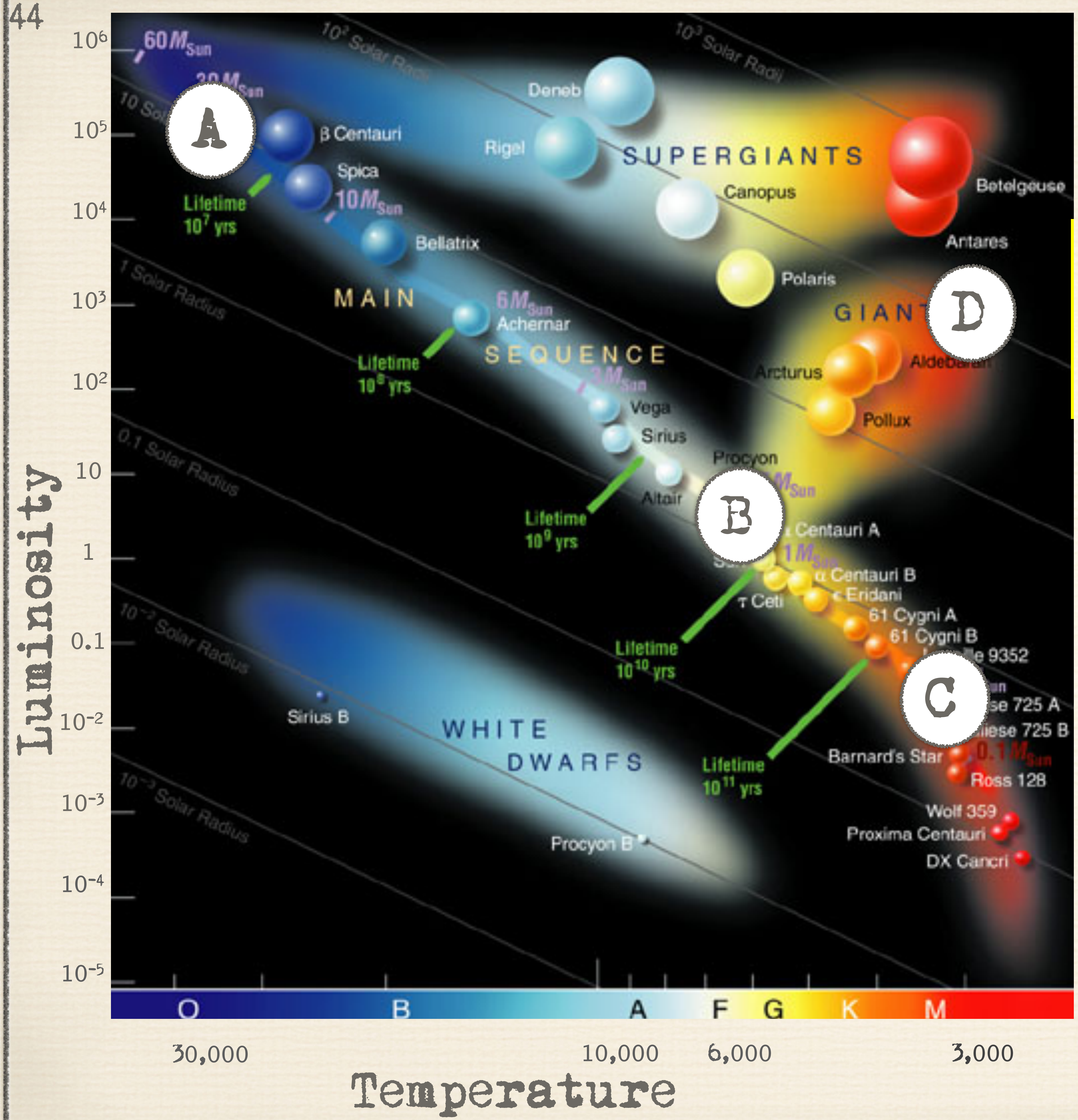


Which of these stars will have changed the least 10 billion years from now?

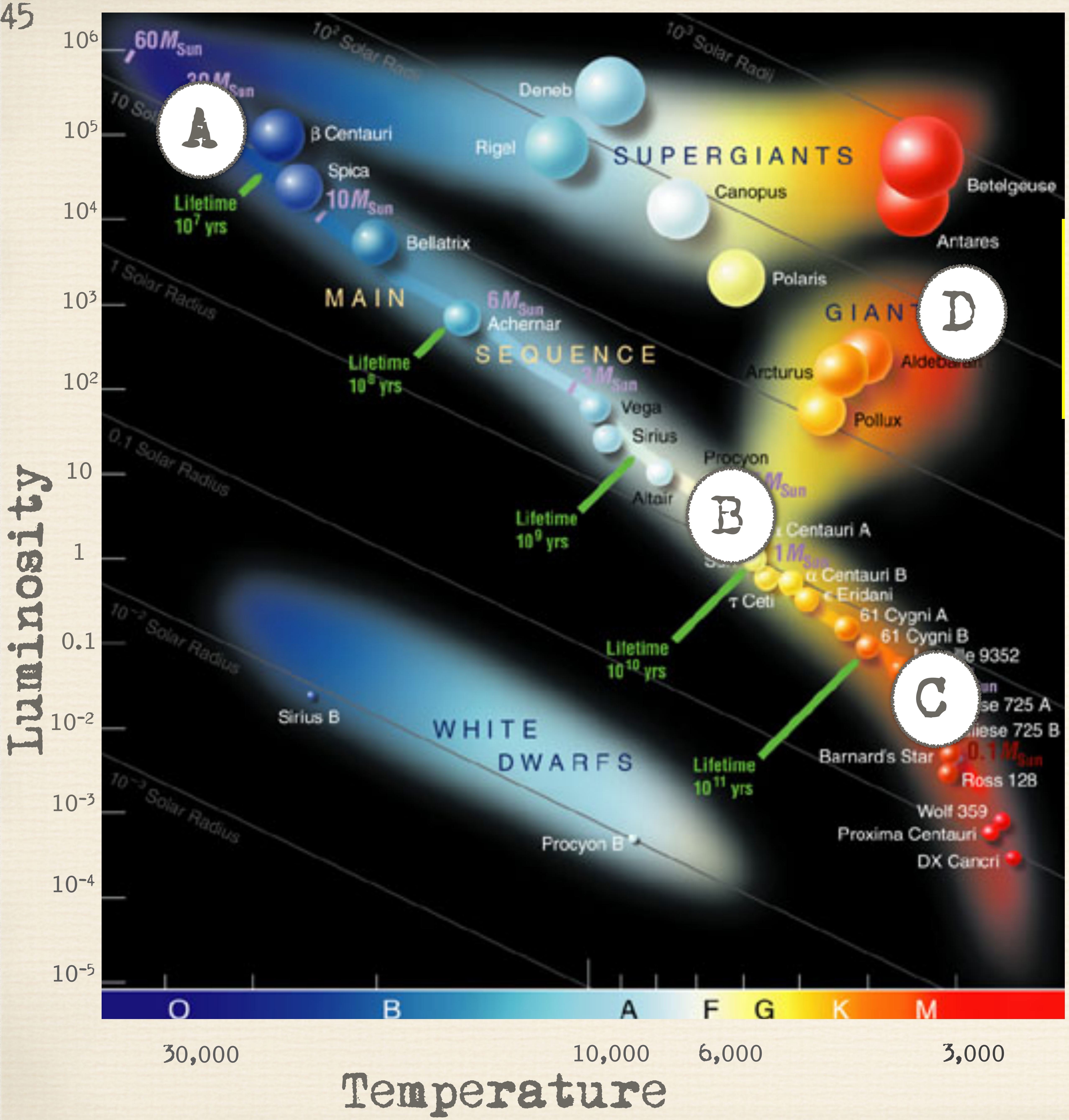


Which of these stars will have changed the least 10 billion years from now?

C



Which of these stars will have no more than 10 million years old?



Which of these stars will have no more than 10 million years old?

A

QUERY 17

Suppose that you have used a Cepheid variable star as a "standard candle" to compute the distance to a particular galaxy

The distance computed is d = 35 Mpc. Much to your embarrassment, you find that the Cepheid variable star has a luminosity L that is actually twice the luminosity you assumed when making your calculation

Is the galaxy closer or farther than you originally calculated?

What is the true distance to the galaxy?

QUERY 17

For a standard candle of assumed luminosity L and measured flux F , the distance is

$$d = \sqrt{\frac{L}{4\pi F}} \qquad \text{(a)}$$

When you increase your assumed luminosity L, you increase the computed distance; thus, the galaxy is farther than you originally calculated

Originally, using a false luminosity L_{false}, you computed

$$\text{(b)} \qquad d_{\text{false}} = \sqrt{\frac{L_{\text{false}}}{4\pi F}} = 35\,\text{Mpc}$$

However, the true distance, using the correct luminosity $L_{\text{true}} = 2L_{\text{false}}$, is

$$d_{\text{true}} = \sqrt{\frac{L_{\text{true}}}{4\pi F}} = \sqrt{\frac{2L_{\text{false}}}{4\pi F}} = \sqrt{2} \times \sqrt{\frac{L_{\text{false}}}{4\pi F}}\,. \qquad \text{(c)}$$

Comparing equation (c) with equation (b), we find that

$$d_{\text{true}} = \sqrt{2} \times d_{\text{false}} = \sqrt{2} \times 35\,\text{Mpc} = 49.5\,\text{Mpc} \qquad \text{(d)}$$

QUERY 18

The "lifespan" of the Sun is 10 billion years; that is, at the time it formed, it contained enough hydrogen to power nuclear fusion for 10 billion years

The star Altair, like the Sun, is powered by the fusion of hydrogen to helium

The mass of Altair is $M_{Altair} = 1.7\ M_\odot$

The luminosity of Altair is $L_{Altair} = 10.7\ L_\odot$

Is the lifespan of Altair shorter or longer than that of the Sun?

What is the approximate lifespan of Altair, in billions of years?

QUERY 18

The lifespan of a star is directly proportional to its mass;

The mass of a star represents its fuel supply, so doubling the mass, all other things being equal, will double its lifespan

In addition, the lifespan of a star is inversely proportional to its luminosity

The luminosity of a star tells you how fast it is using its fuel supply, so doubling the luminosity, all other things being equal, will have its lifespan

If we scale everything by the Sun's properties, we can write a star's lifespan t_{star} as

$$t_{\text{star}} = t_{\text{sun}} \left(\frac{M_{\text{star}}}{M_{\text{sun}}} \right) \left(\frac{L_{\text{sun}}}{L_{\text{star}}} \right)$$

with t_{sun} = 10 billion years, as given in the problem

Since Altair's luminosity is more than 10 times the Sun's luminosity, while its mass is only 70% greater than the Sun's mass, the lifespan of Altair will be shorter than that of the Sun

Thus, Altair's lifespan will be

$$t_{\text{altair}} = 10 \text{ billion years} (1.7) \left(\frac{1}{10.7} \right) = 1.6 \text{ billion years}$$

QUERY 19

The surface of the Sun acts like a fairly good black body (even though it hardly looks black)

If the surface temperature of the Sun is 5, 800 K, find the peak wavelength of the black body radiation

QUERY 19

The surface of the Sun acts like a fairly good black body (even though it hardly looks black)

If the surface temperature of the Sun is 5, 800 K, find the peak wavelength of the black body radiation

The effective temperature of the Sun is 5778 K

Using Wien's law,

$$\lambda_{max} = 2.9 \times 10^6 / T(K)\ [nm]$$

one finds a peak emission per nanometer (of wavelength) at a wavelength of about 500 nm, in the green portion of the spectrum near the peak sensitivity of the human eye