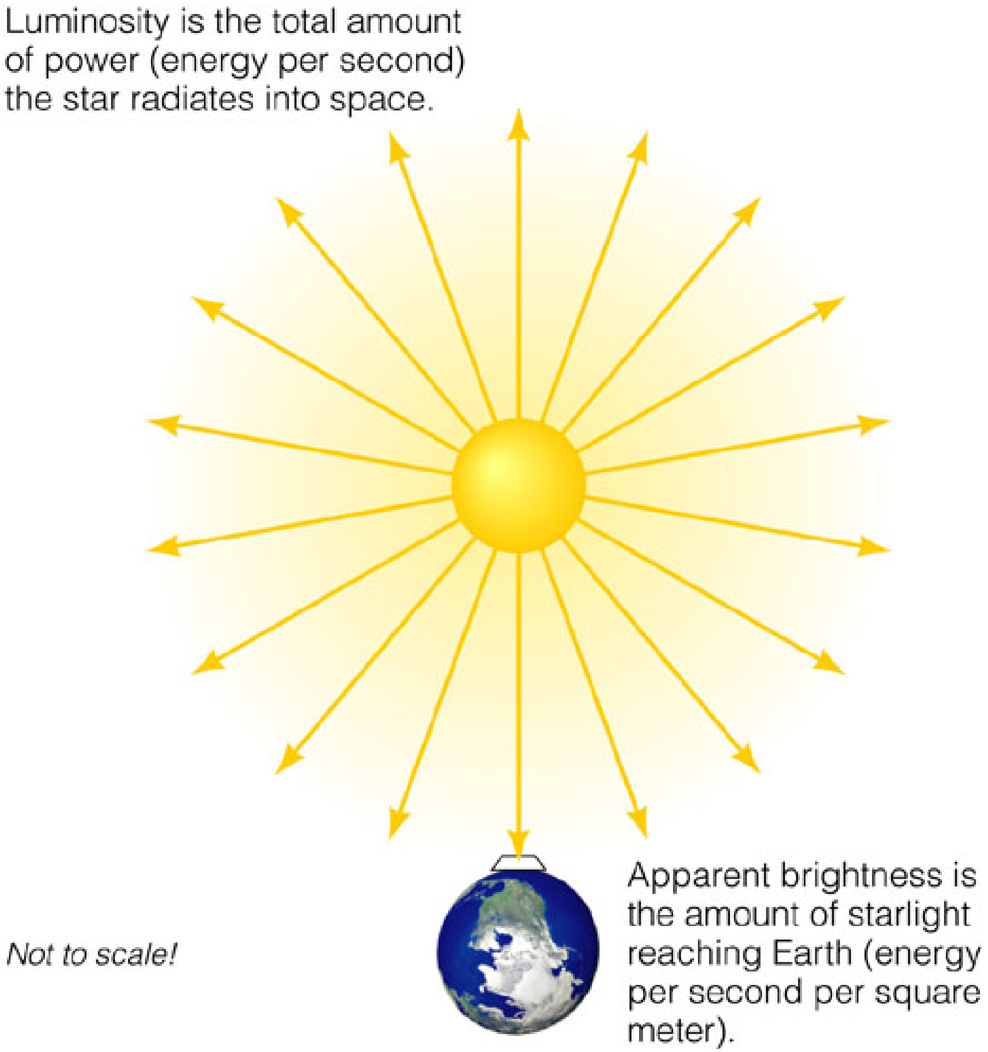
Surveying the Stars

Properties of Stars

- **Our Goals for Learning**
- **How luminous are stars?**
- **How hot are stars?**
- **How massive are stars?**

How luminous are stars?

The 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)

Thought Question

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

A. Alpha Centauri
B. The Sun

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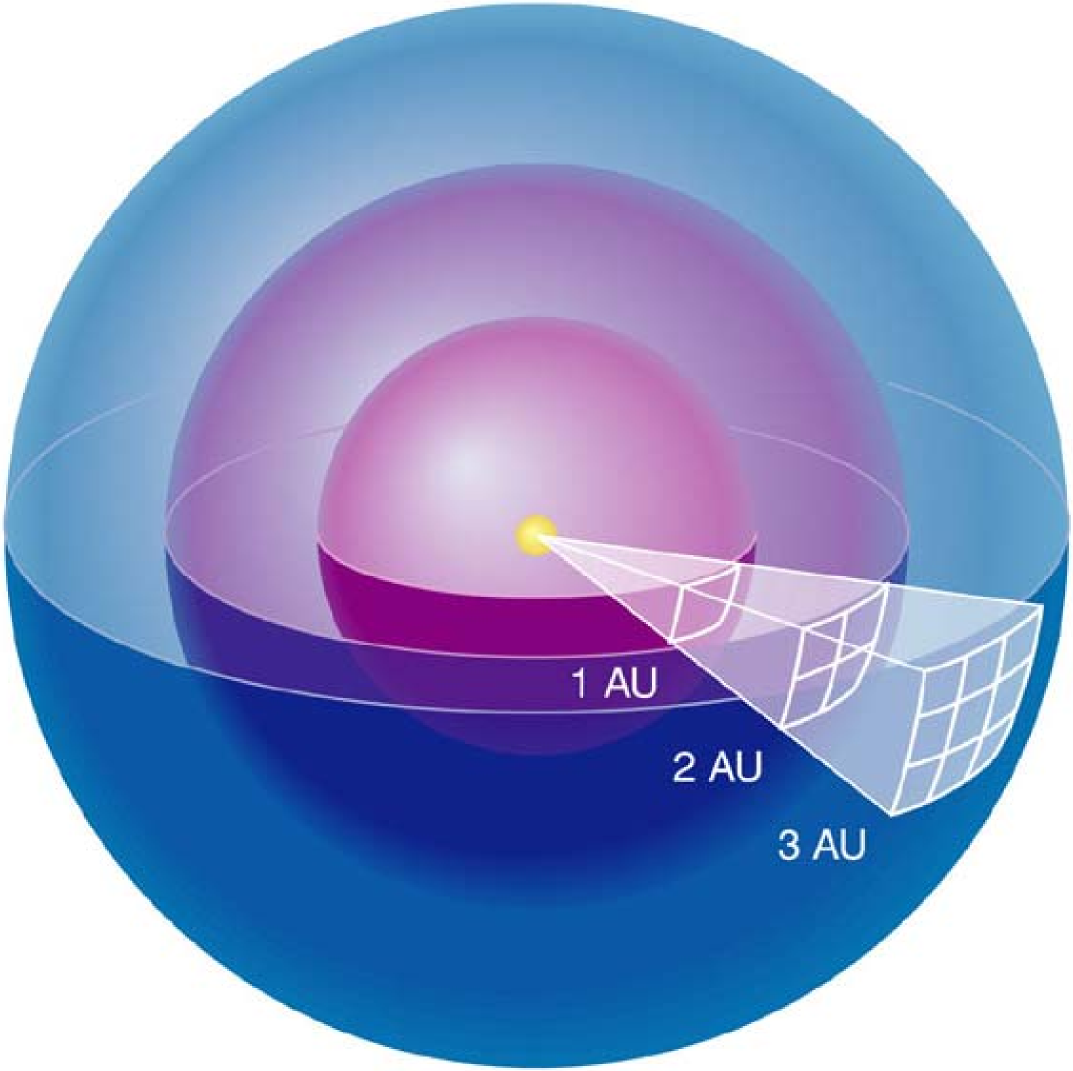

Luminosity passing through each sphere is the same

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:

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

Thought Question

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

A. It would be only 1/3 as bright
B. It would be only 1/6 as bright
C. It would be only 1/9 as bright
D. It would be three times brighter

Thought Question

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

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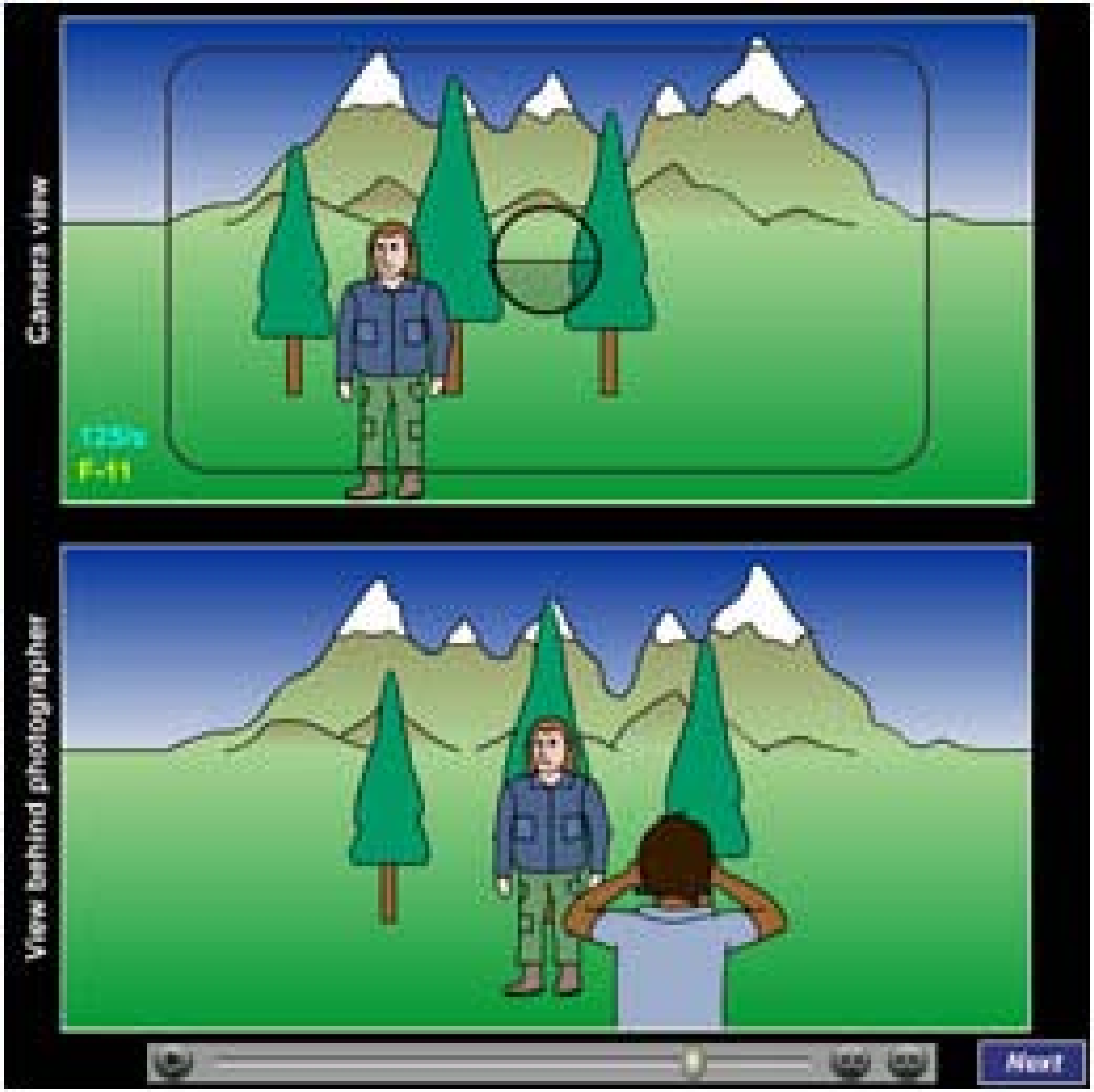
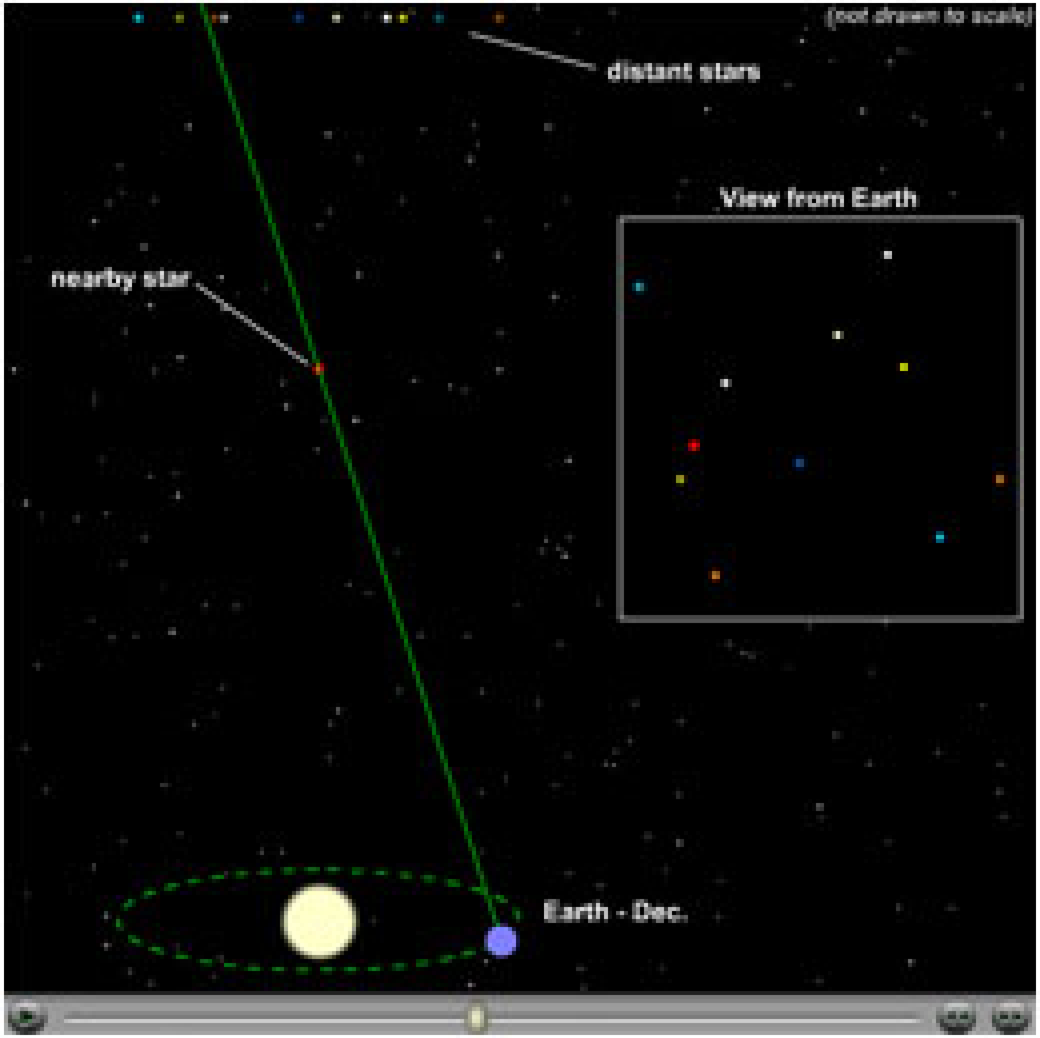
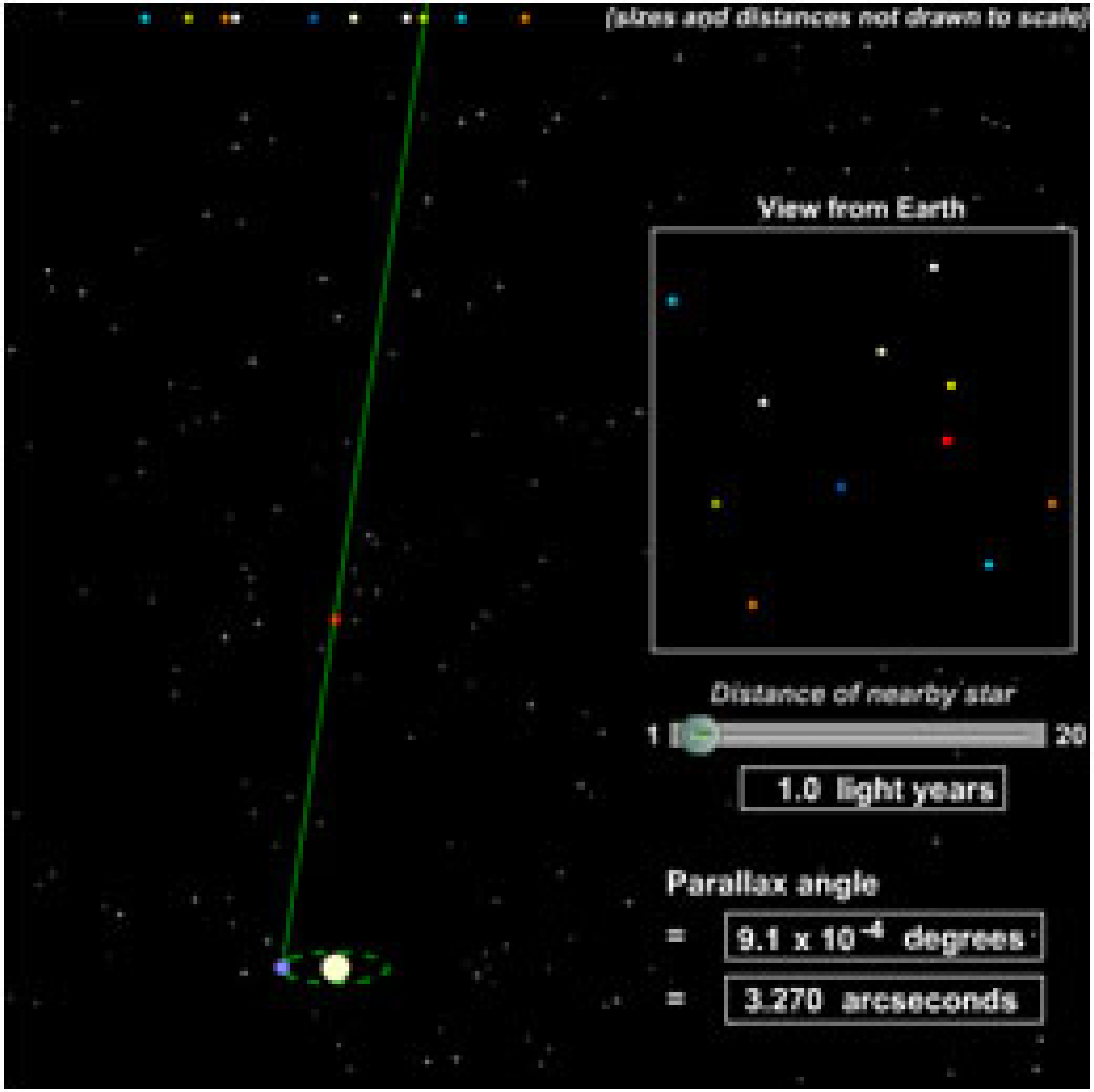
So how far are these stars?



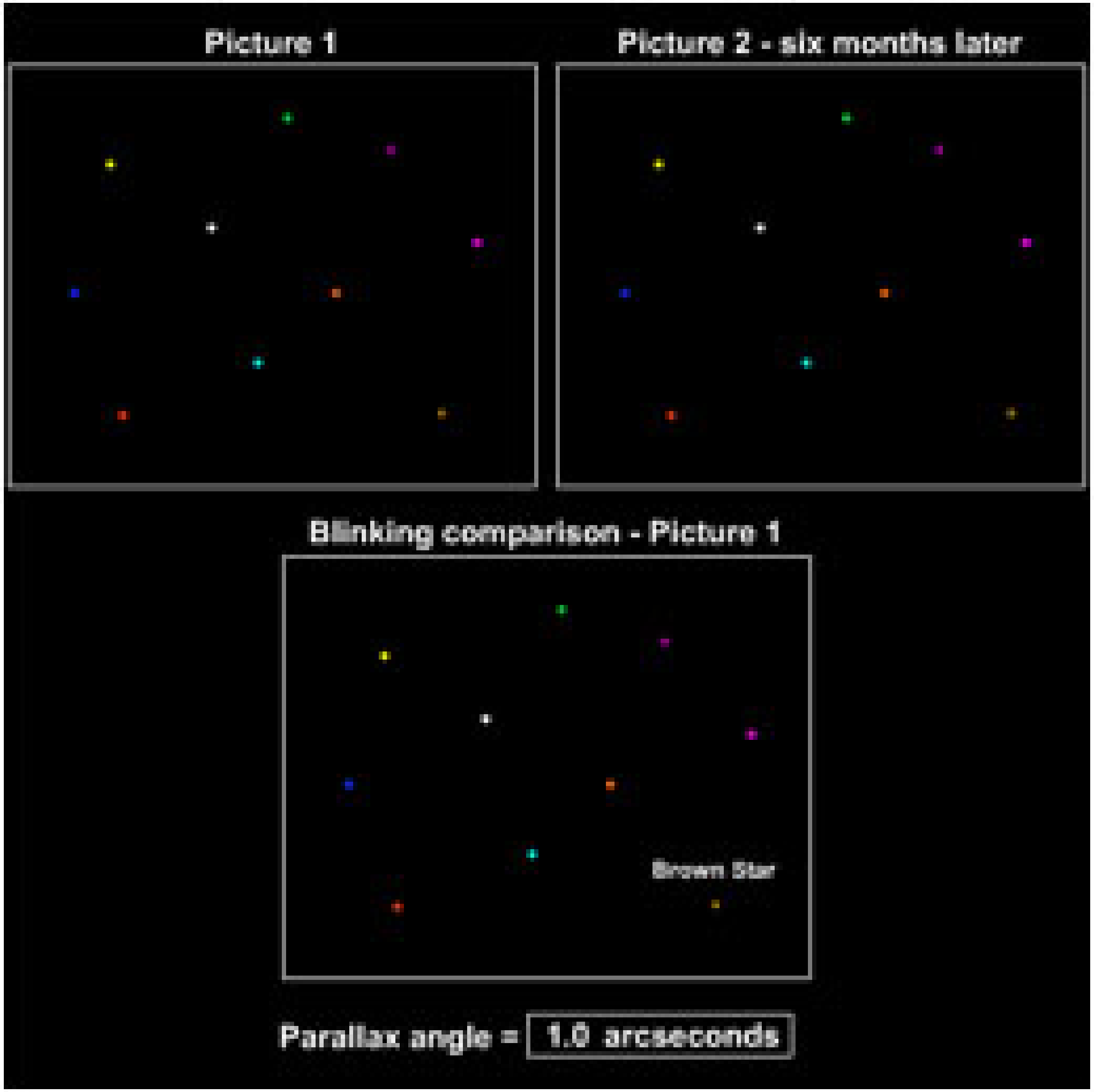
Parallax is the apparent shift in position of a nearby object against a background of more distant objects



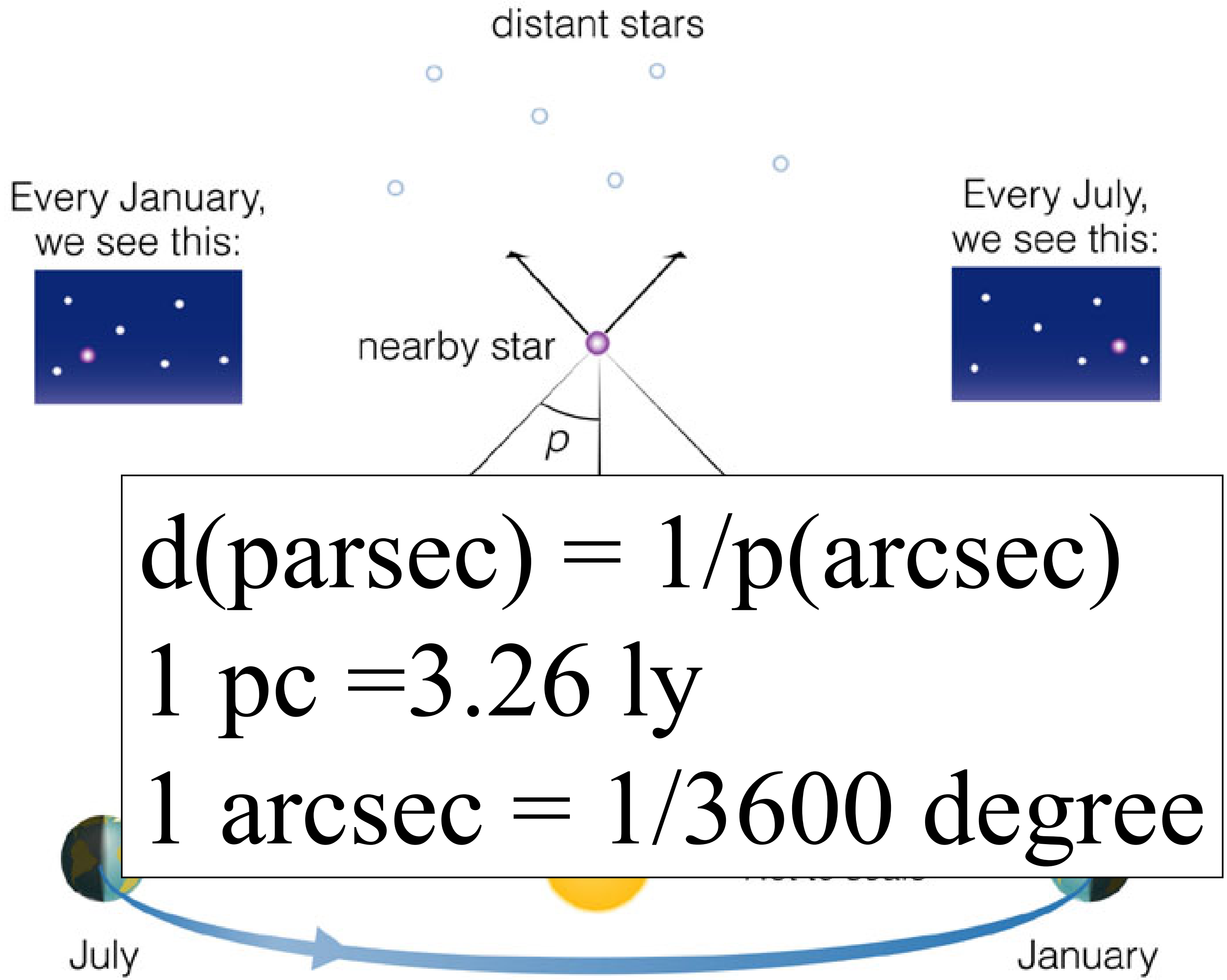
Apparent positions of nearest stars shift by about an arcsecond as Earth orbits Sun



Parallax angle depends on distance



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



d(parsec) = 1/p(arcsec)

1 pc =3.26 ly

1 arcsec = 1/3600 degree

Σ 2398
Lalande 21185
Grm 34
Ross 248
61 Cygni
G51-15
Wolf 359
Ross128
3 pc
Procyon
2 pc
1 pc
SUN
Barnard
BD+5° 1668
Sirius
Epsilon
Eridani
Alpha
Centauri
Ross 154
UV Ceti
Tau Ceti
Luyten
789-6
Lacaille 8760
Lacaille 9352
Epsilon Indi

Most luminous stars:

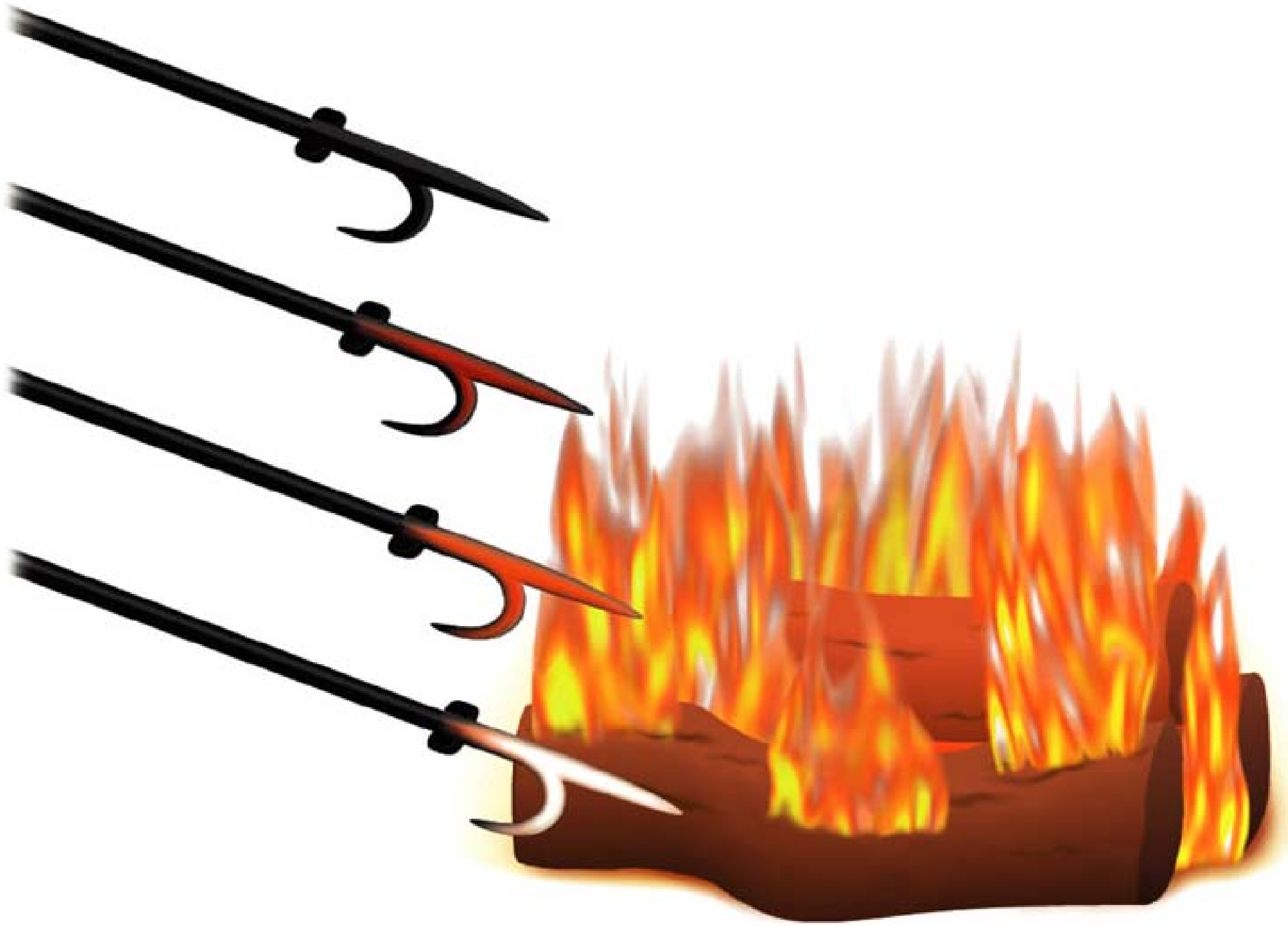
10^6 L_{Sun}

Least luminous stars:

10^{-4} L_{Sun}

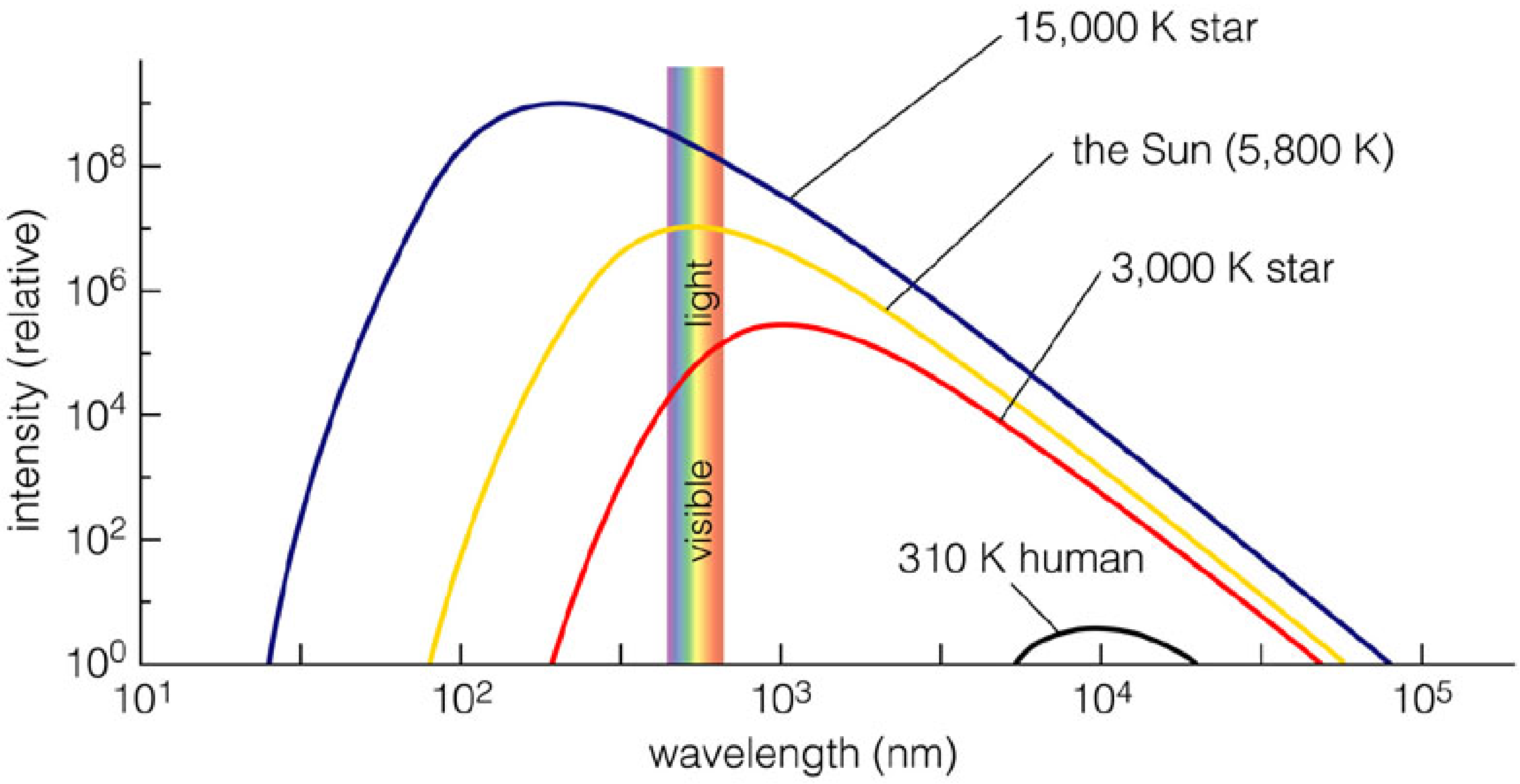
(L_{Sun} is luminosity of Sun)

How hot are stars?



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

Laws of Thermal Radiation



1) Hotter objects emit more light at all wavelengths

2) Hotter objects tend to emit light at shorter wavelengths and higher frequencies

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

10^6 K

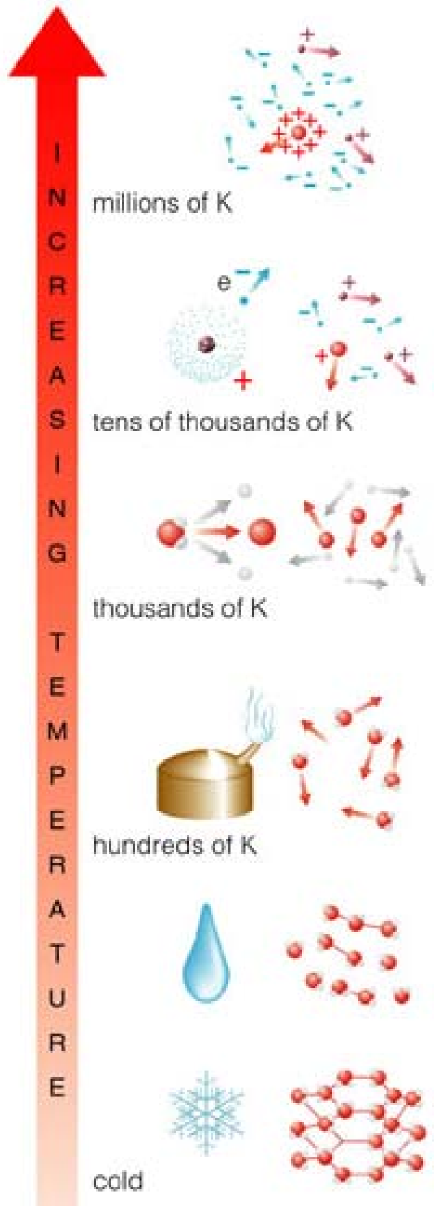
10^5 K

10^4 K

10^3 K

10^2 K

10 K

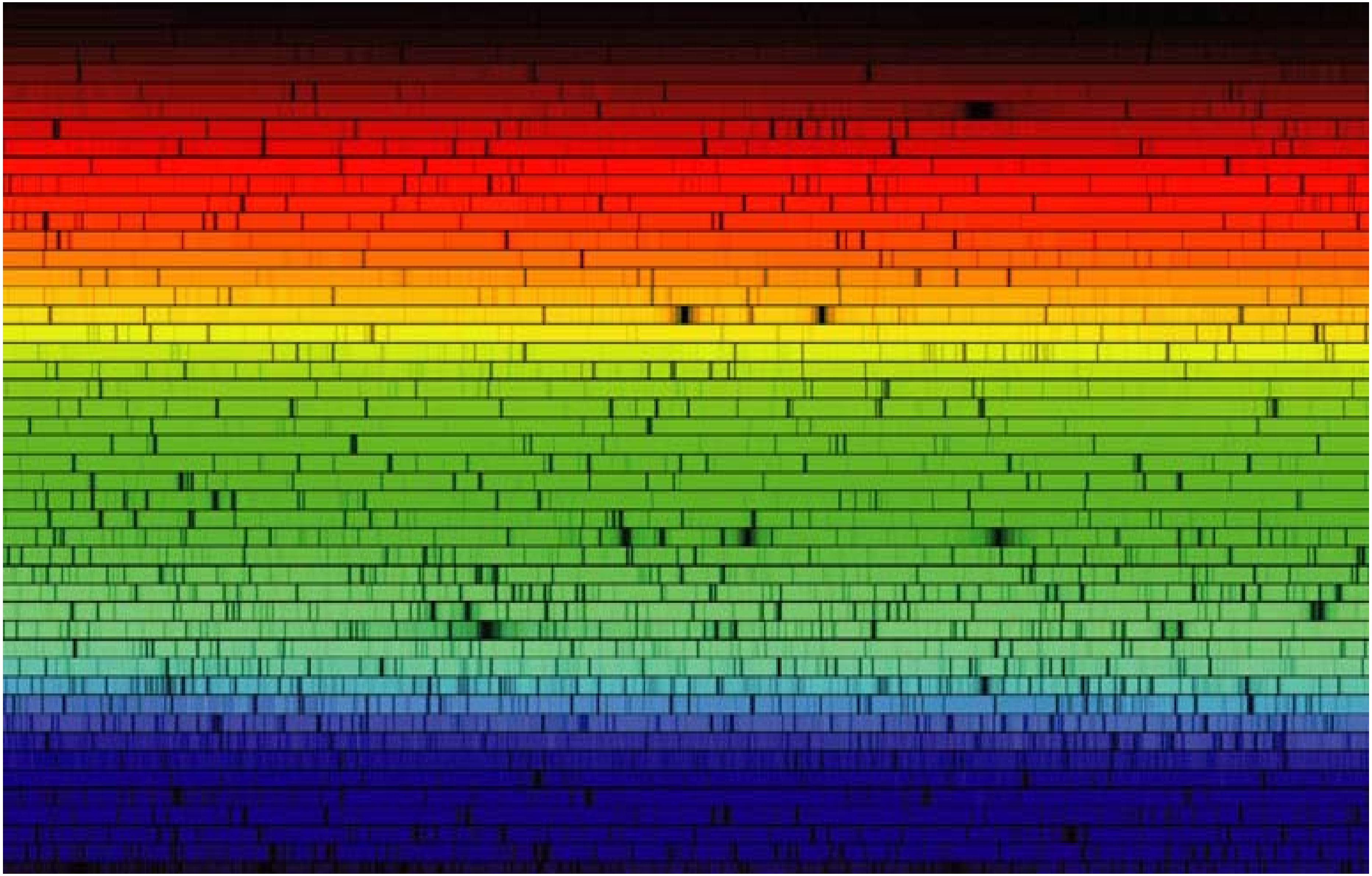


Ionized Gas (Plasma)

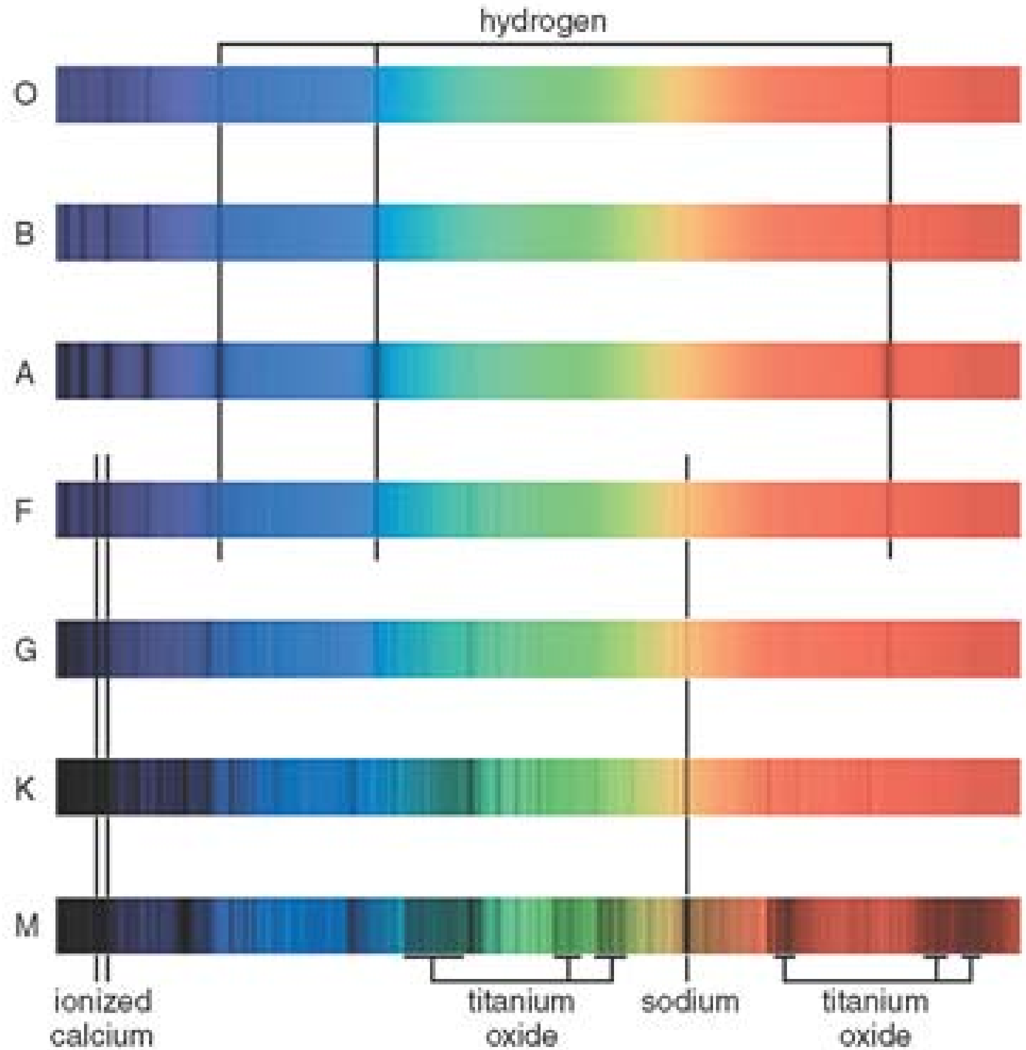
Neutral Gas

Molecules

Solid



Absorption lines in star's spectrum tell us ionization level



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, Kiss Me (ca. 1920)
- Only Boys Accepting Feminism Get Kissed Meaningfully (today)

Thought Question

Which kind of star is hottest?

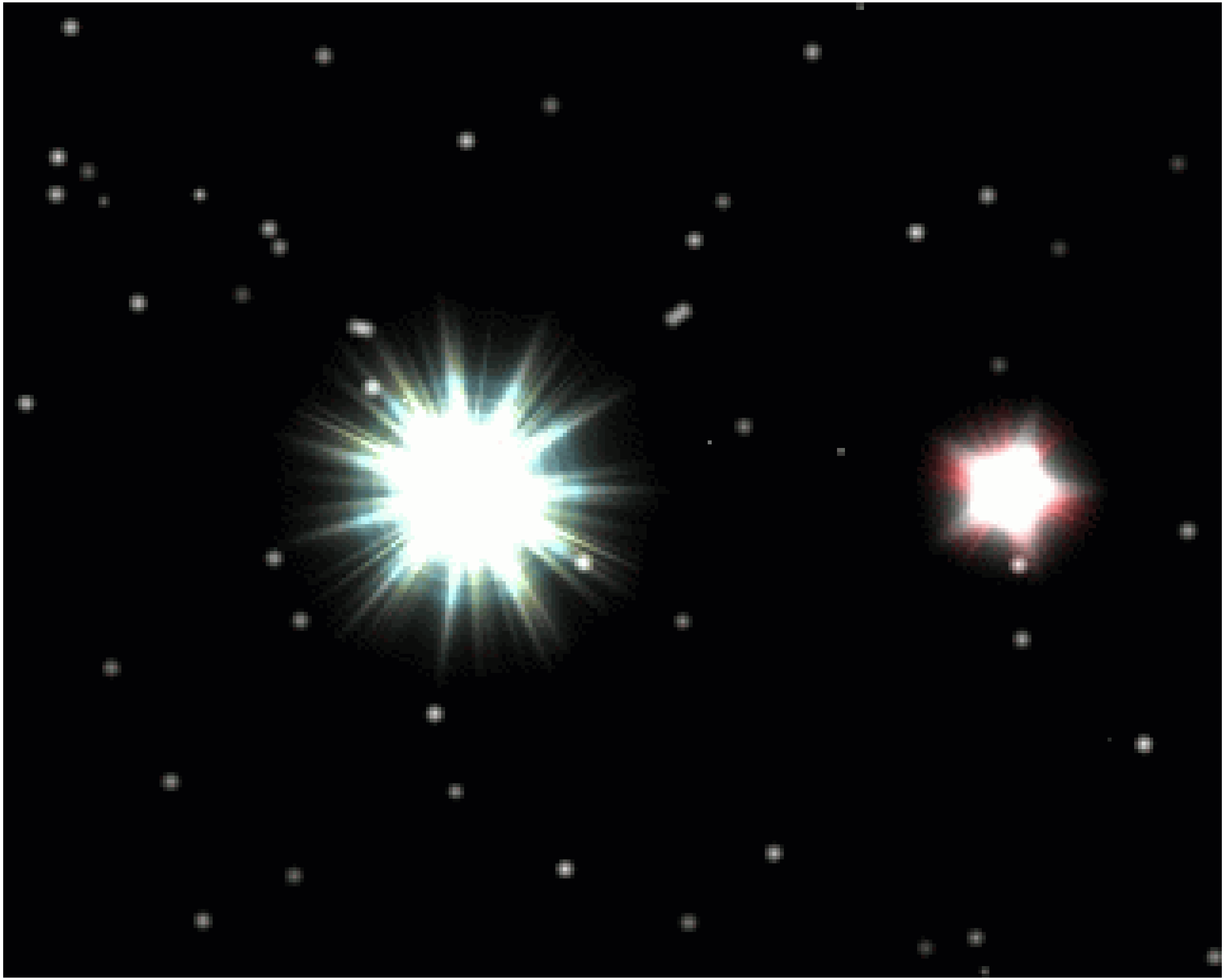
A. M star
B. F star
C. A star
D. K star

Thought Question

Which kind of star is hottest?

A. M star
B. F star
C. A star
D. K star

How massive are stars?



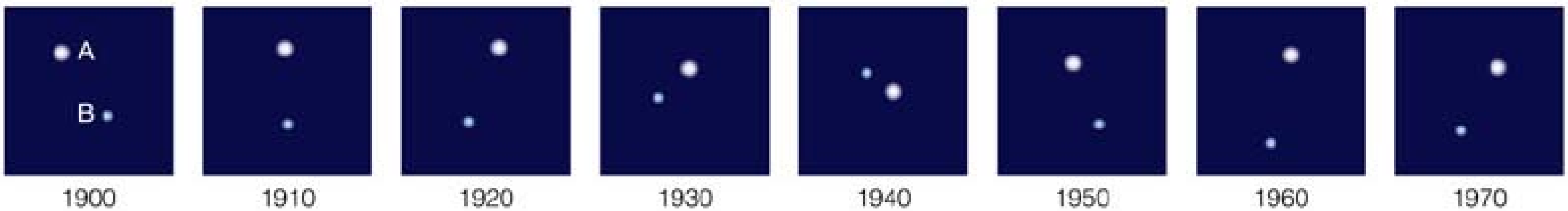
The orbit of a binary star system depends on strength of gravity

Types of Binary Star Systems

- Visual Binary
- Eclipsing Binary
- Spectroscopic Binary

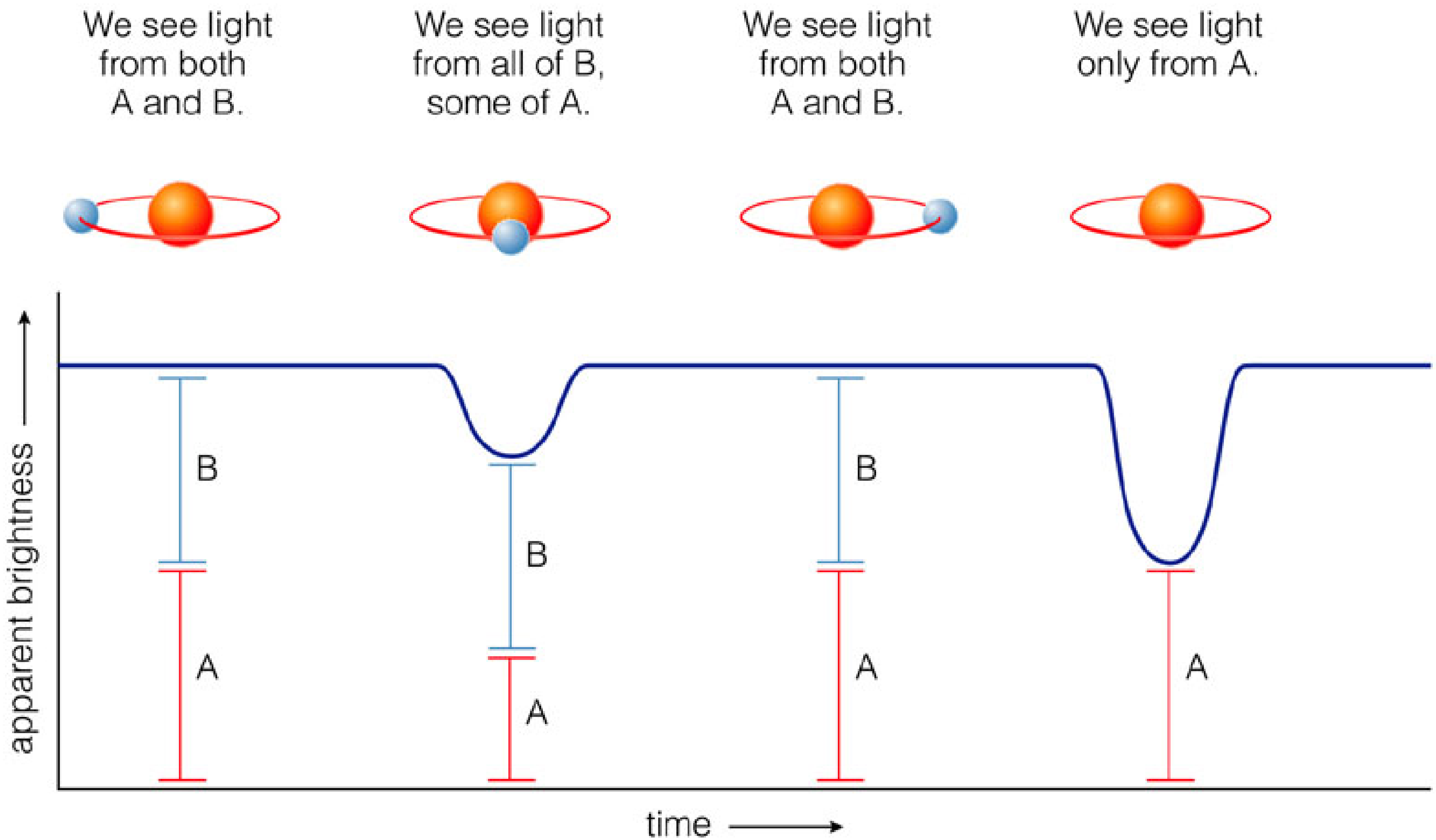
About half of all stars are in binary systems

Visual Binary



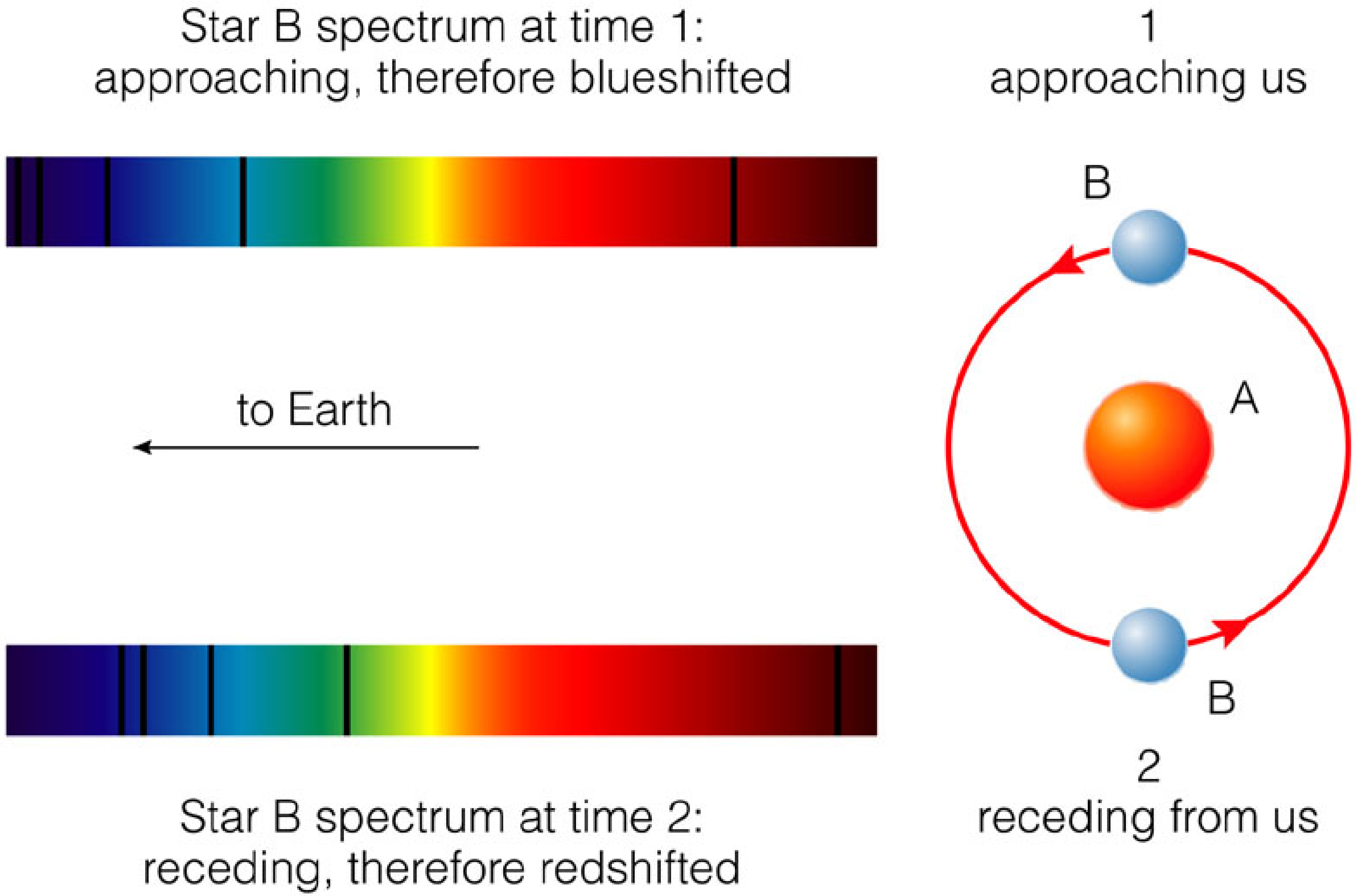
We can directly observe the orbital motions of these stars

Eclipsing Binary



We can measure periodic eclipses

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

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

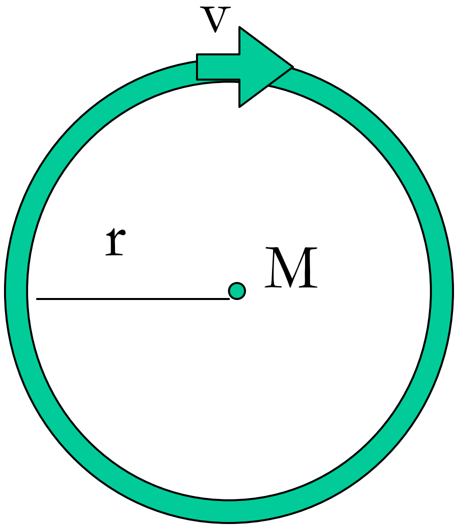
p = period

a = average separation

Need 2 out of 3 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:

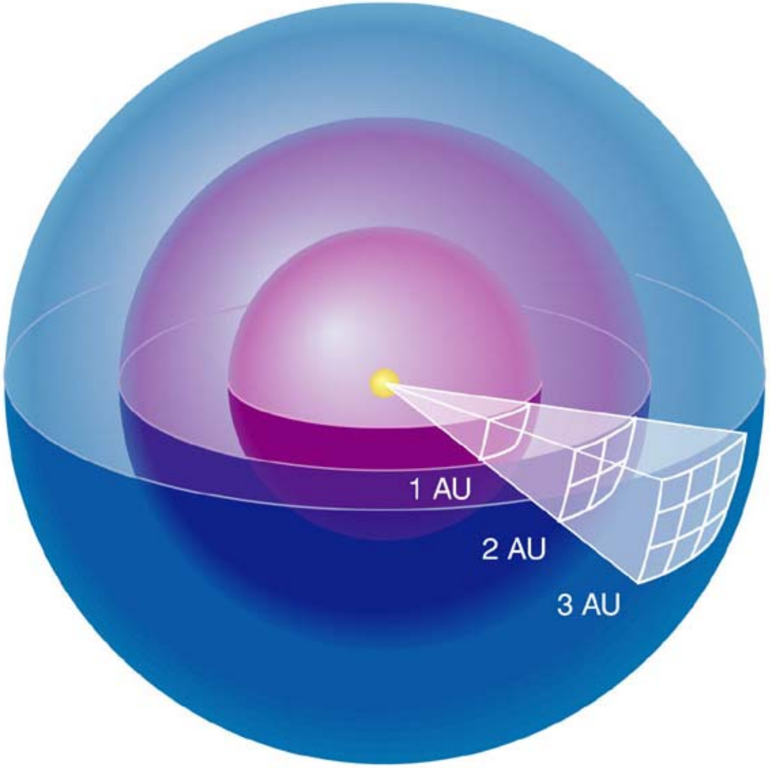
$0.08\ M_{Sun}$

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

What have we learned?

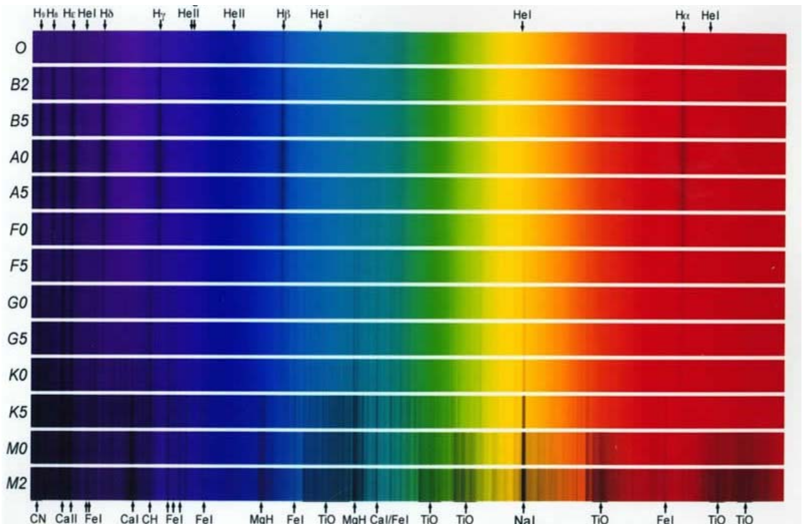
How luminous are stars?

- The **apparent brightness** of a star in our sky depends on both its **luminosity** —the total amount of light it emits into space—and its distance from Earth, as expressed by the **inverse square law for light**.



What have we learned?

- **How hot are stars?**
- The surface temperatures of the hottest stars exceed 40,000 K and those of the coolest stars are less than 3,000 K. We measure a star's surface temperature from its color or spectrum, and we classify spectra according to the sequence of **spectral types** OBAFGKM, which runs from hottest to coolest.



What have we learned?

- **How massive are stars?**
- The overall range of stellar masses runs from 0.08 times the mass of the Sun to about 100 times the mass of the Sun.

Classifying Stars

Our Goals for Learning

- **How do we classify stars?**
- **Why is a star's mass its most important property?**
- **What is a Hertzsprung–Russell diagram?**

How do we classify stars?

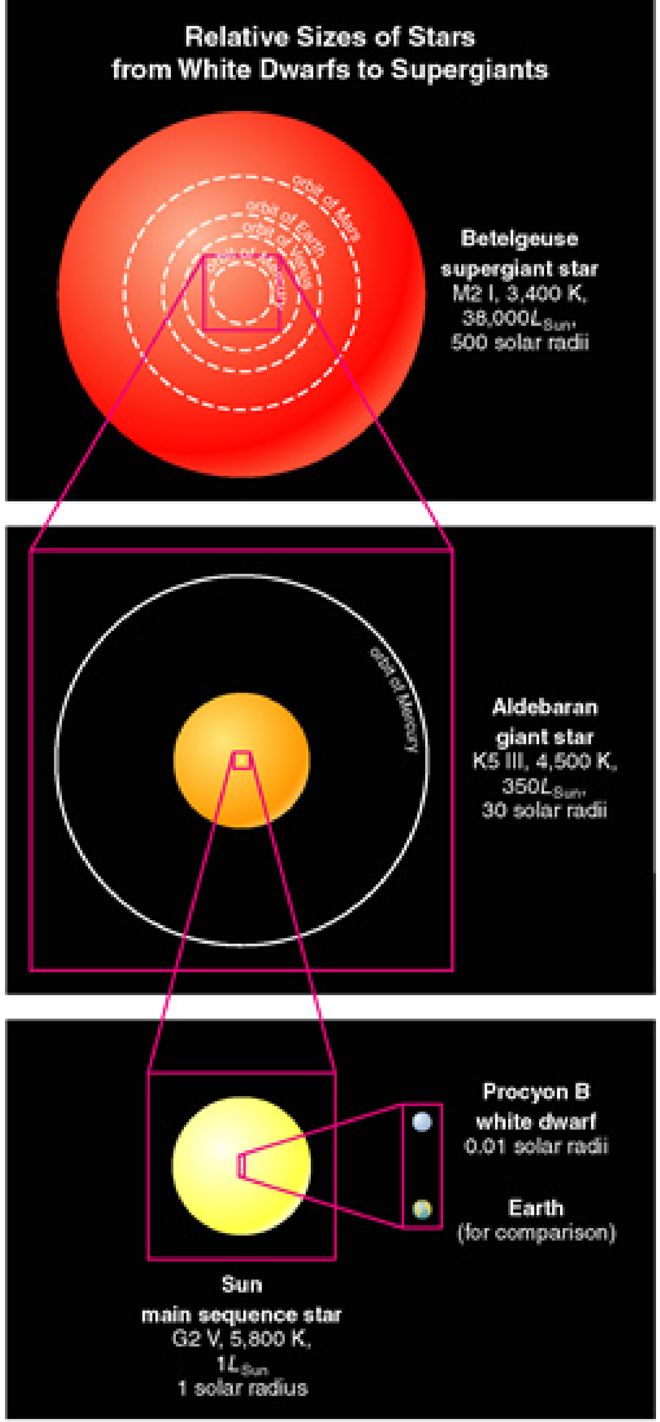
Most of the brightest stars are reddish in color

Color and luminosity are closely related among the remaining "normal" stars

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)



Why are some red stars so much more luminous?

They're bigger!

Biggest red stars:

$1000\ R_{sun}$

Smallest red stars:

$0.1\ R_{Sun}$

A star's full classification includes spectral type (line identities) and luminosity class (line shapes, related to the size of the star):

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

Why is a star's mass its most important property?

Each star's properties depend mostly on mass and age

Stellar Properties Review

Luminosity: from brightness and distance

10^{-4} L_{Sun} - 10^{6} L_{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_{Sun} - 100 M_{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

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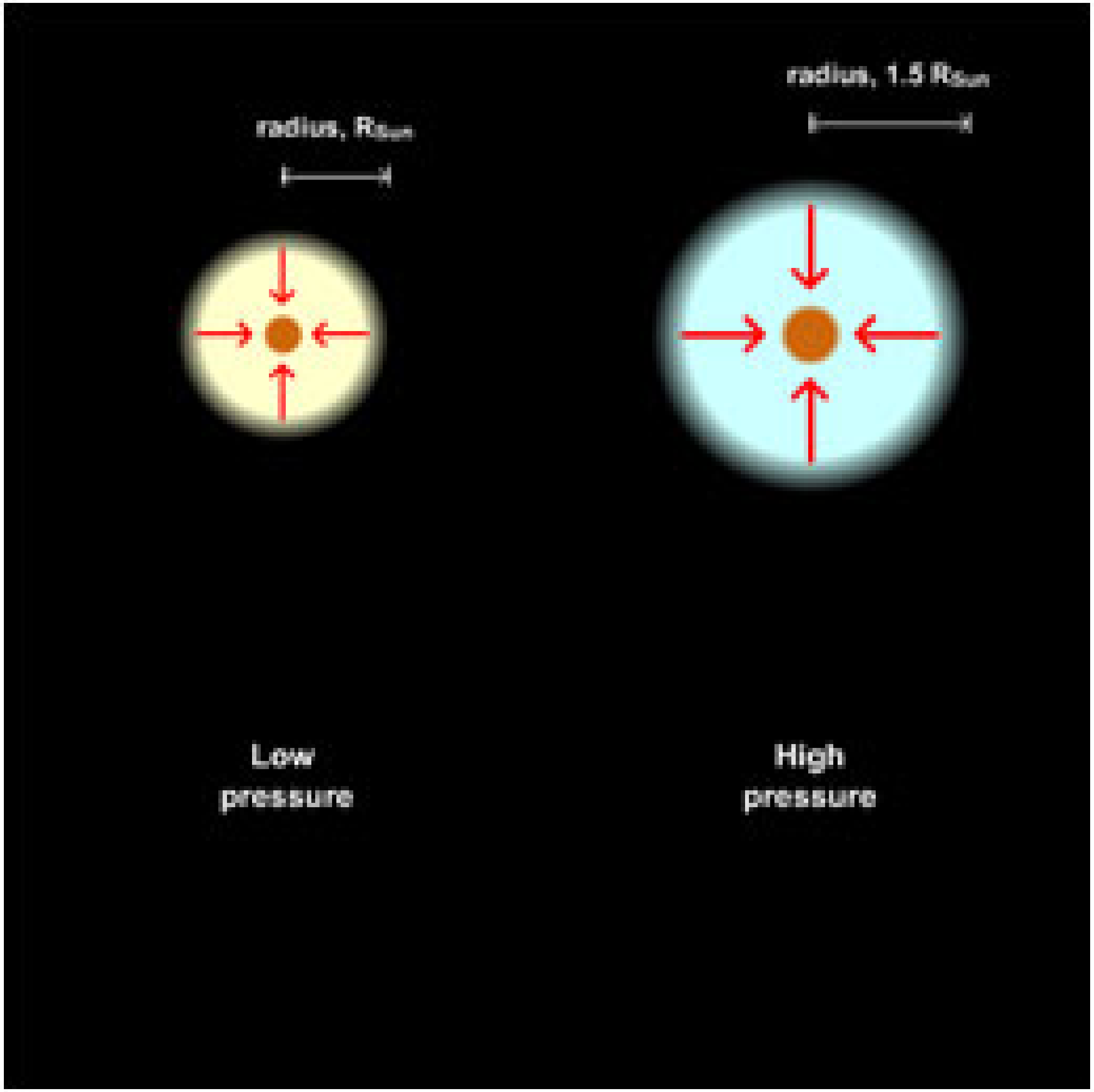


Core pressure and temperature of a higher-mass star need to be larger in order to balance gravity

Higher core temperature boosts fusion rate, leading to larger luminosity

Mass & Lifetime

Sun's life expectancy: 10 billion years

Mass & Lifetime

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

Sun's life expectancy: 10 billion years

Mass & Lifetime

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

Sun's life expectancy: 10 billion years

Life expectancy of 10 M_{Sun} star:

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

10 million years ~ 10 billion years x 10 / 10^4

Mass & Lifetime

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

Sun's life expectancy: 10 billion years

Life expectancy of 10 M_{Sun} star:

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

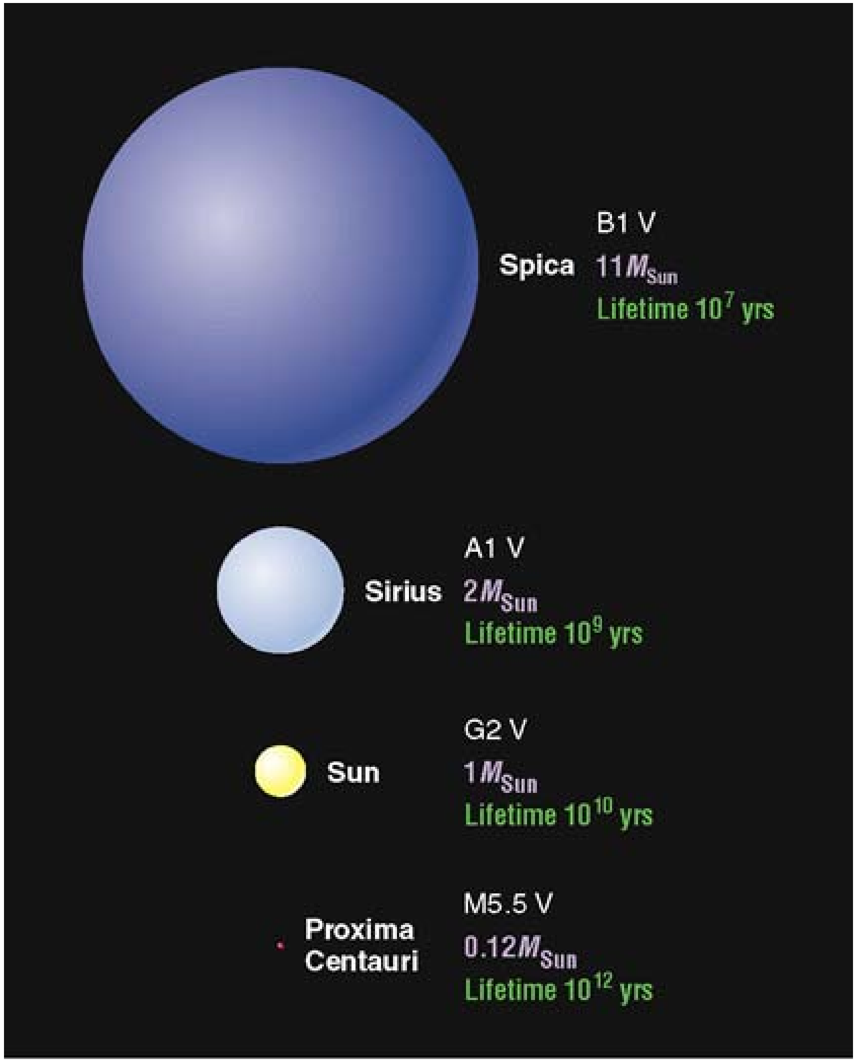
10 million years ~ 10 billion years x 10 / 10^4

Life expectancy of 0.1 M_{Sun} star:

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

100 billion years ~ 10 billion years x 0.1 / 0.01

Main-Sequence Star Summary



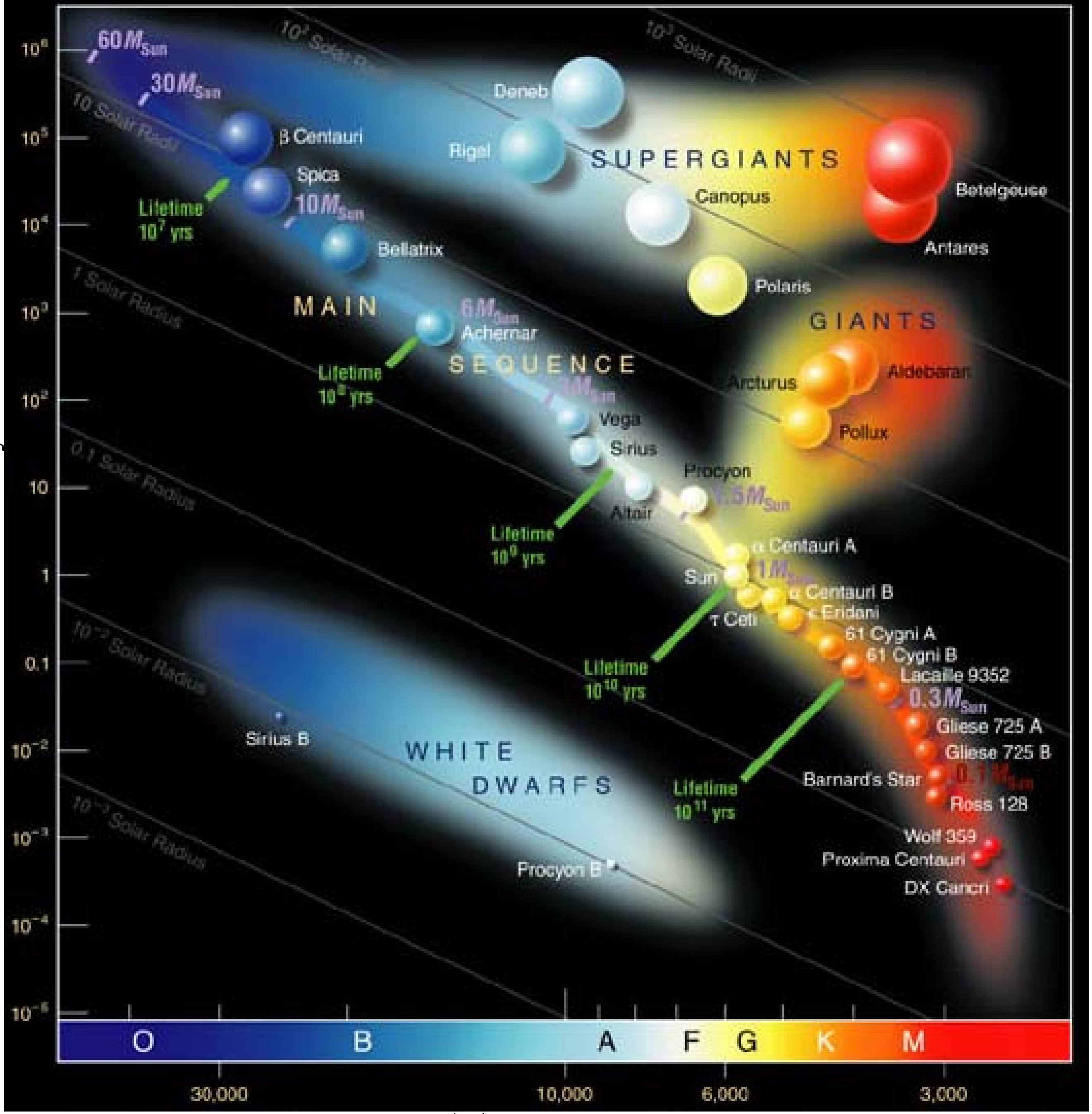
High Mass:

- High Luminosity
- Short-Lived
- Large Radius
- Blue

Low Mass:

- Low Luminosity
- Long-Lived
- Small Radius
- Red

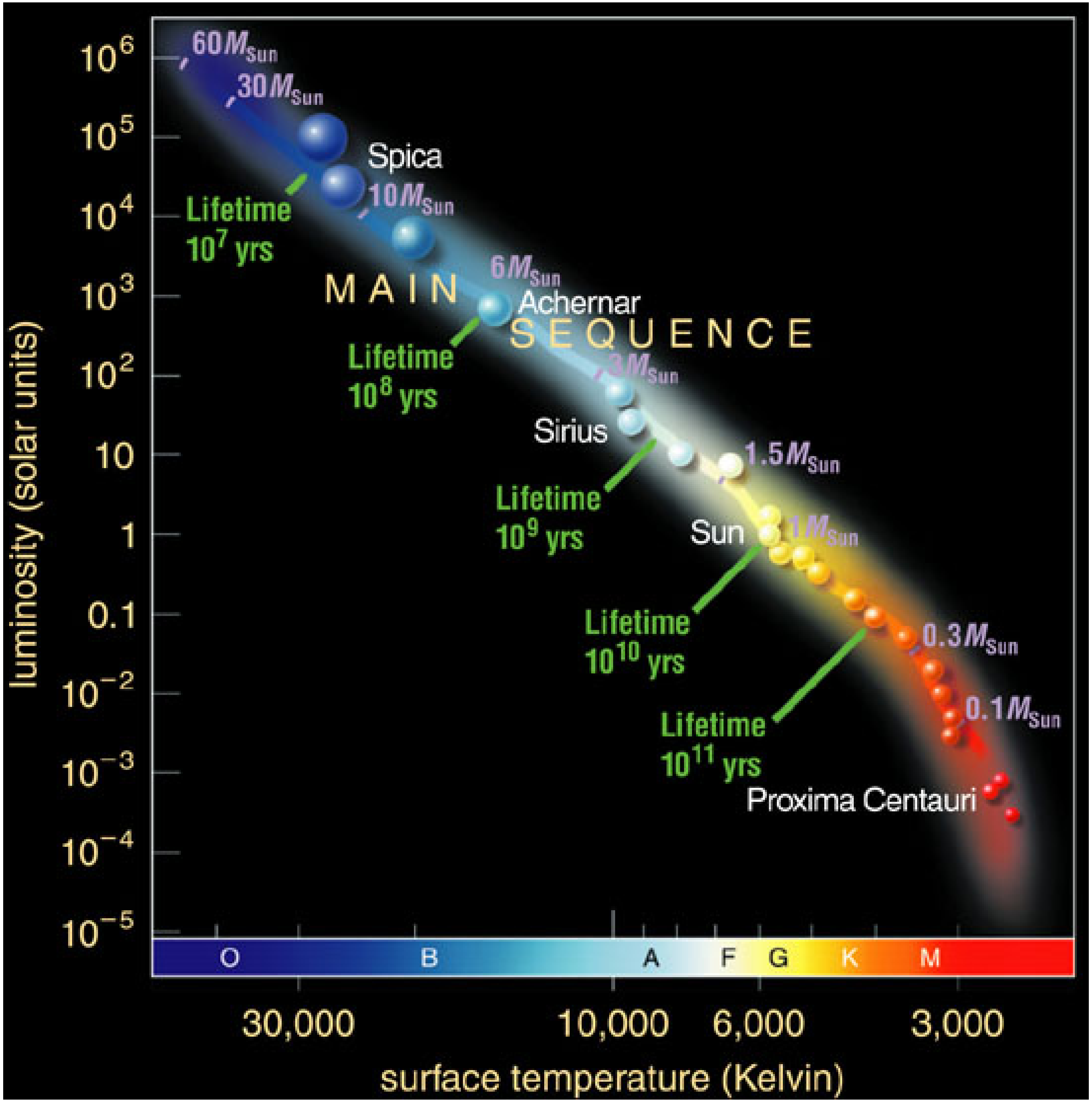
What is a Hertzsprung-Russell Diagram?



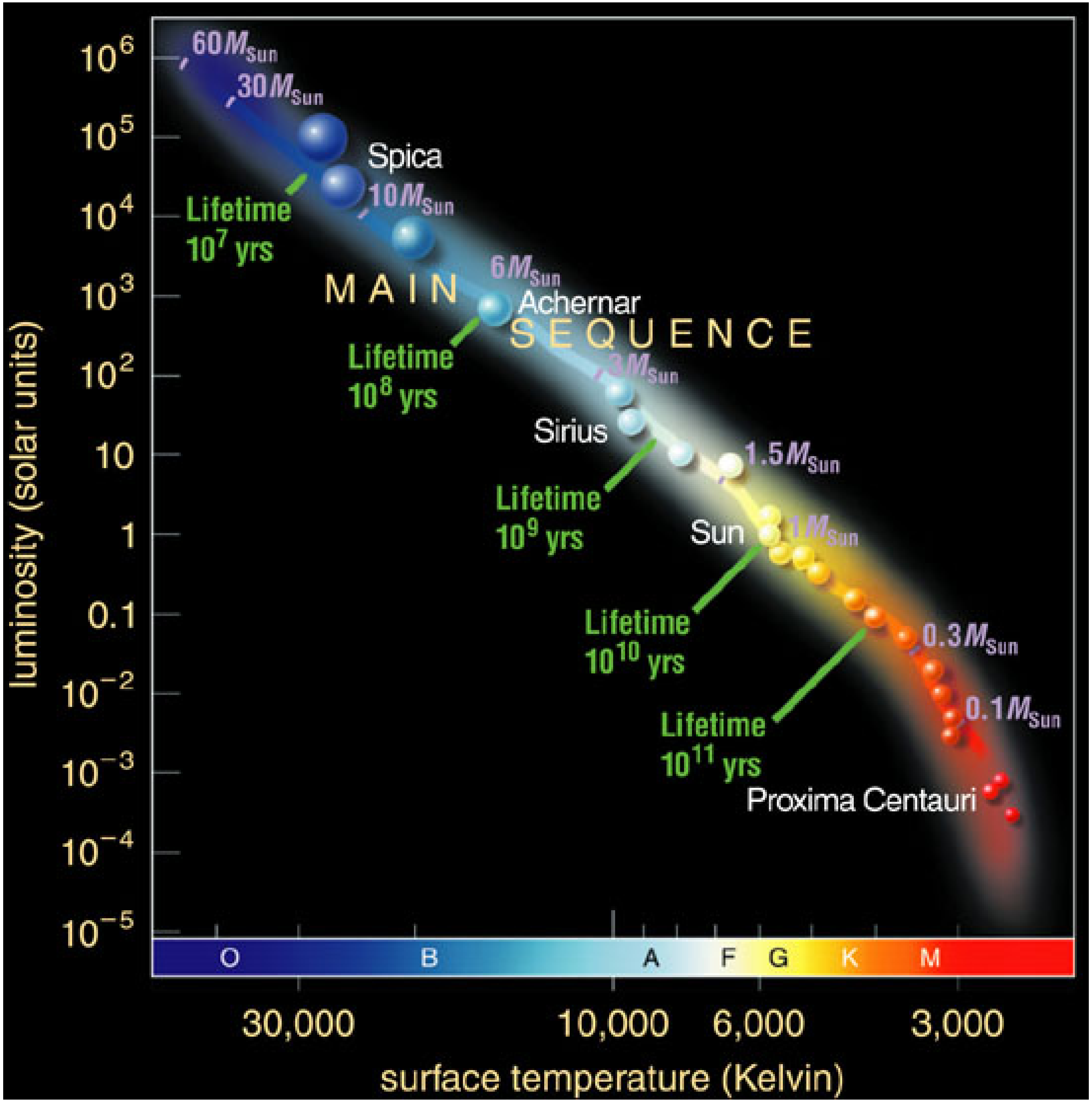
Luminosity

Temperature

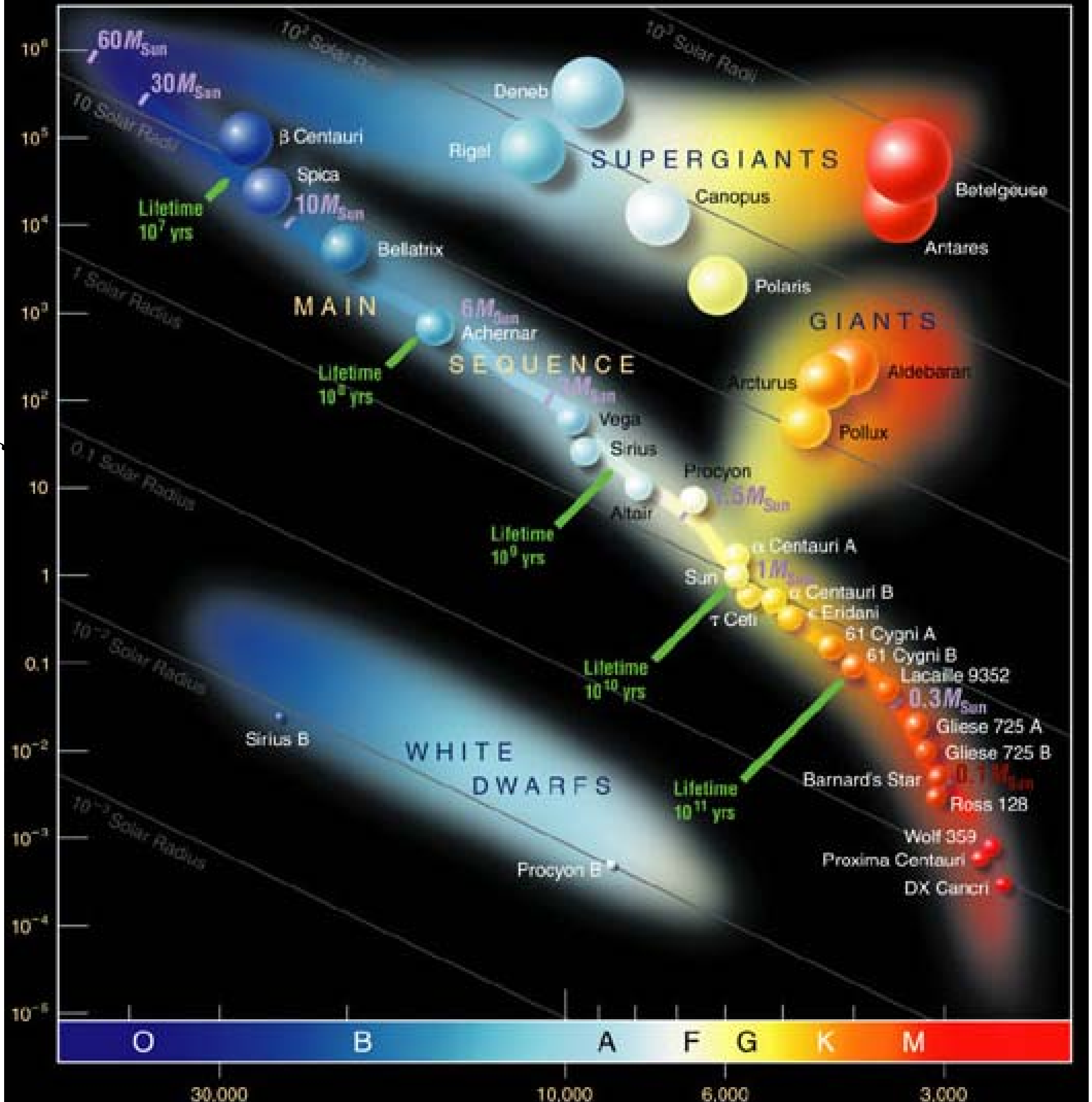
An H-R diagram plots the luminosity and temperature of stars



Normal hydrogen-burning stars reside on the ***main sequence*** of the H-R diagram



Stars with low temperature and high luminosity must have large radius



Luminosity →

← Temperature

H-R diagram depicts:

Temperature

Color

Spectral Type

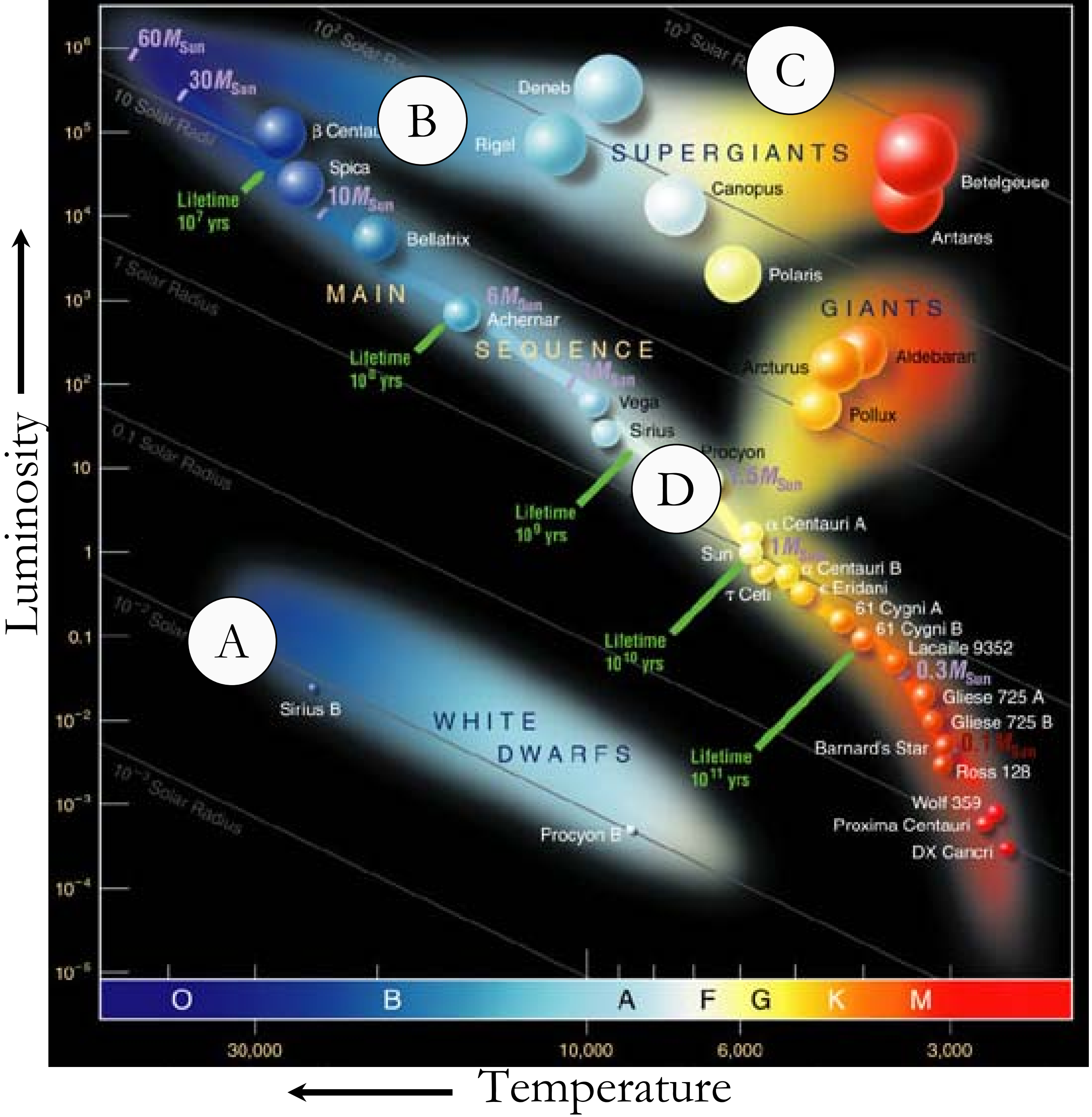
Luminosity

Radius

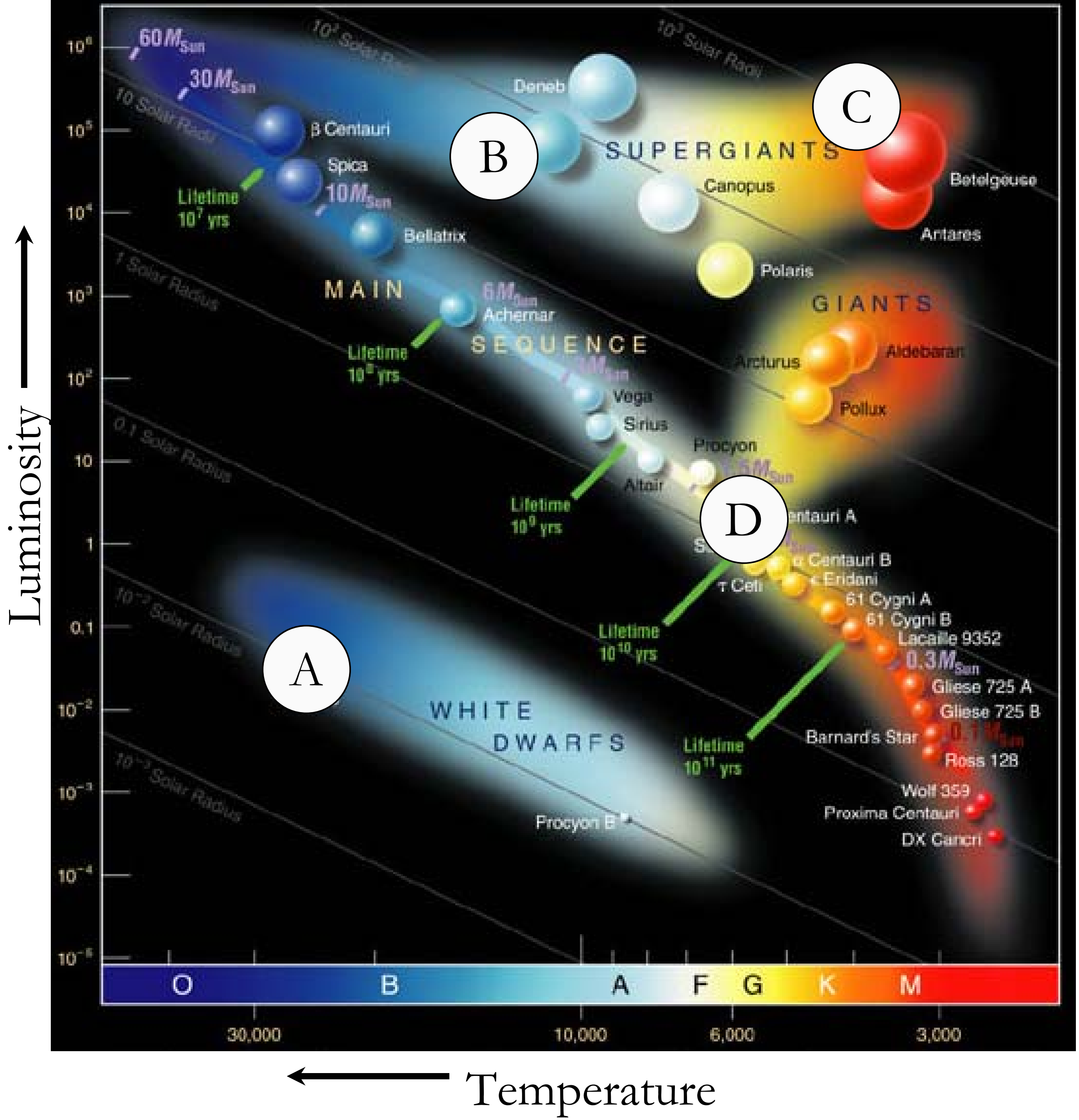
*Mass

*Lifespan

*Age

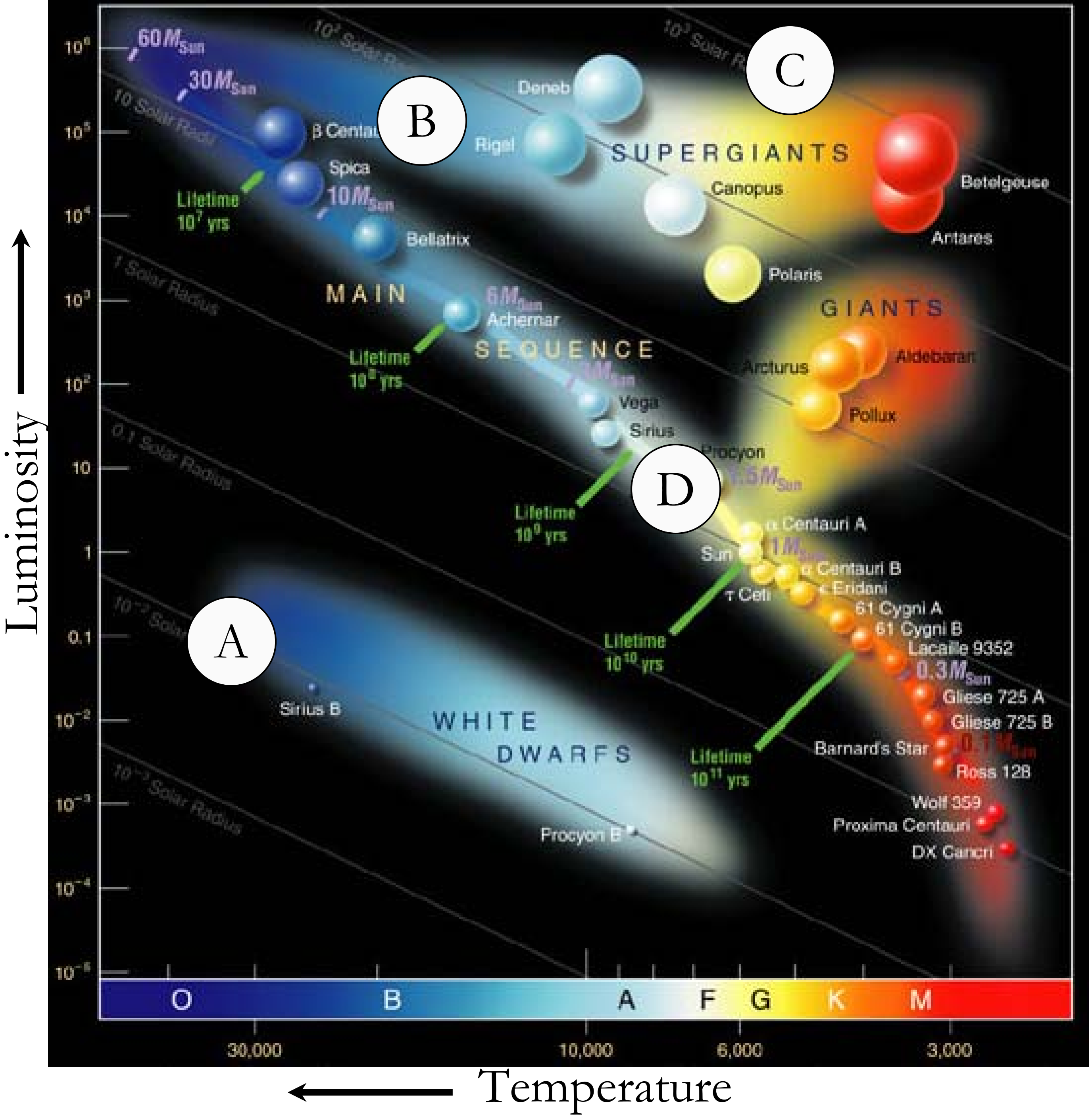


Which star is the hottest?

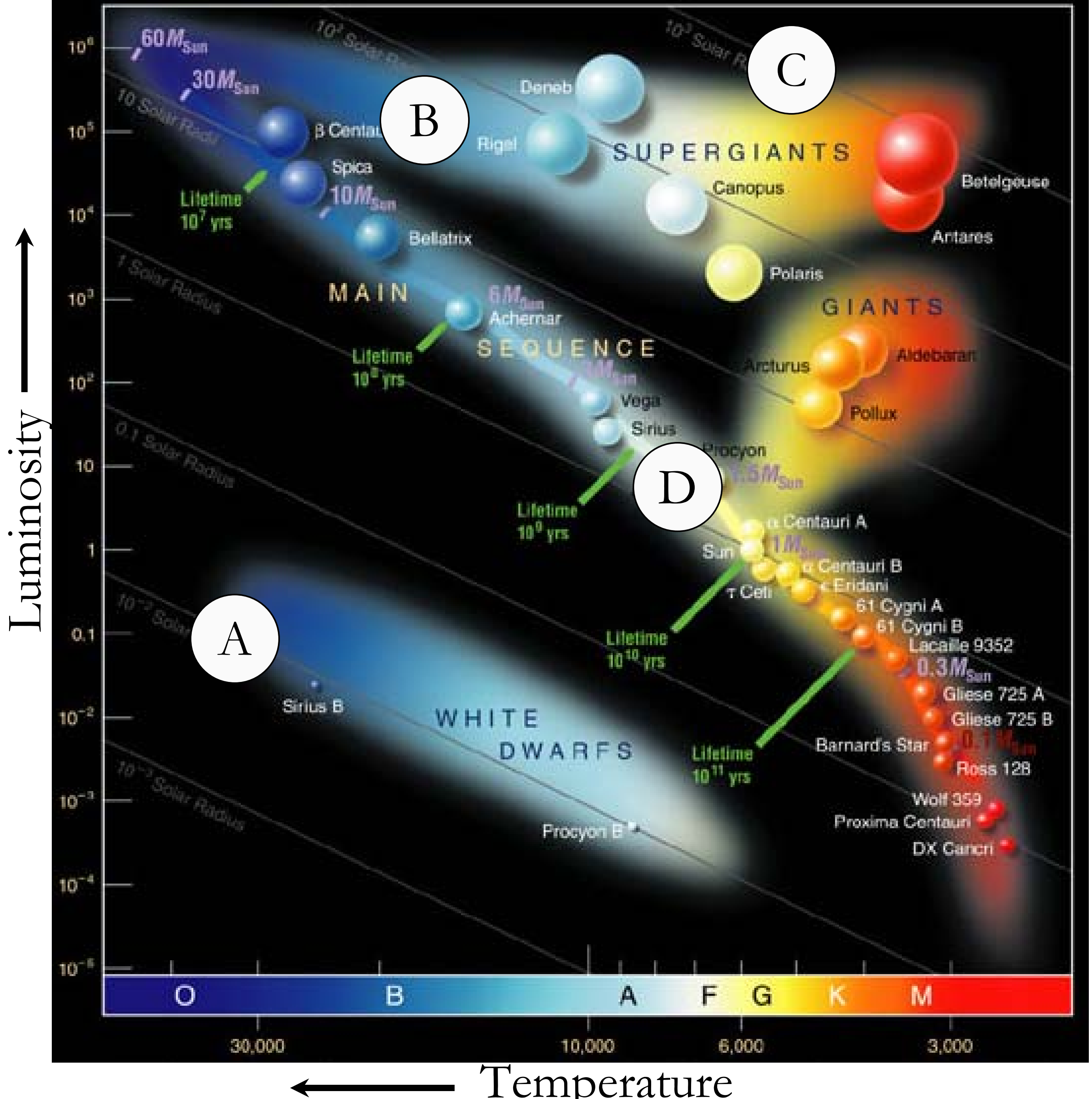


Which star is the hottest?

A

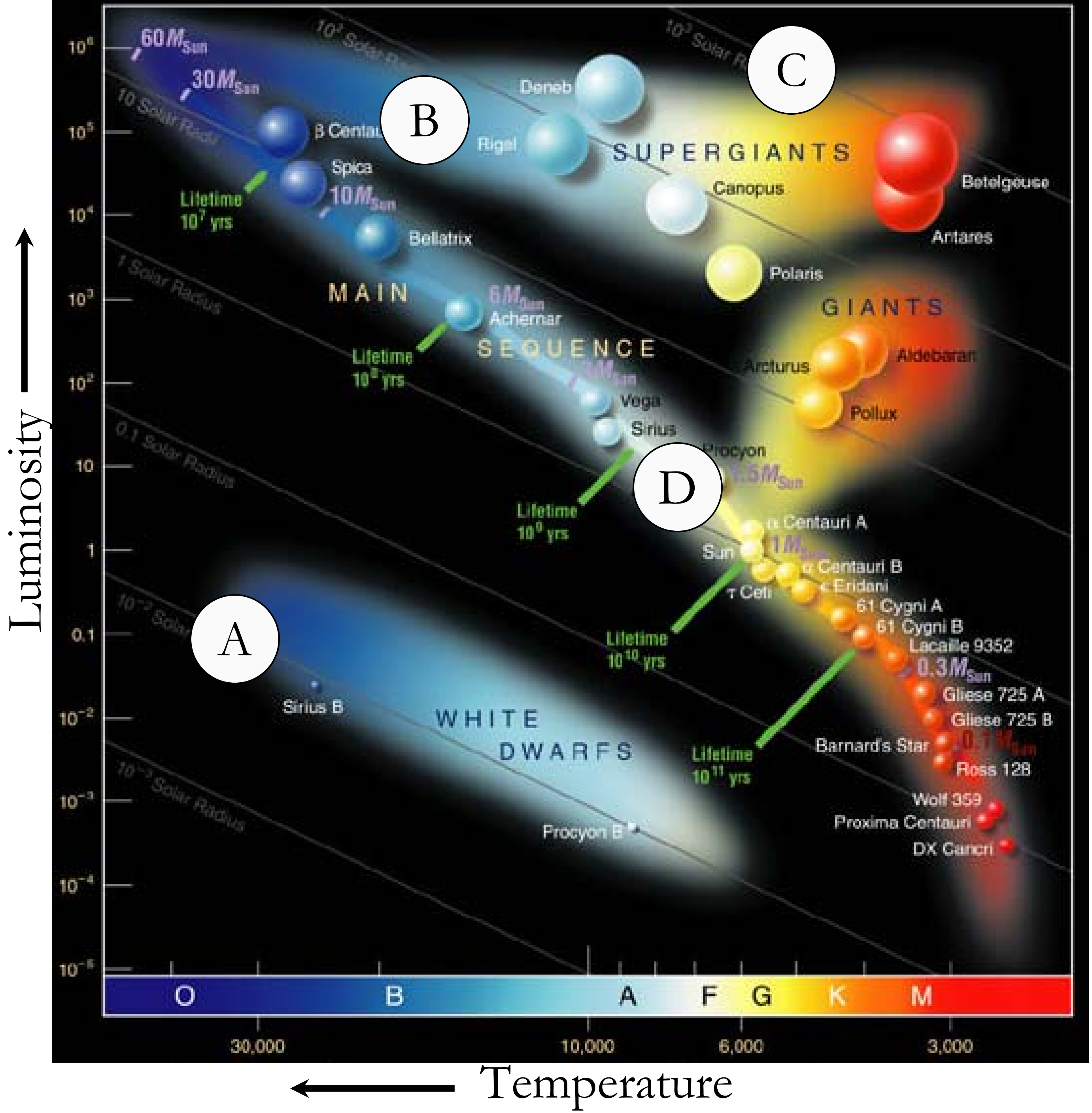


Which star is the most luminous?

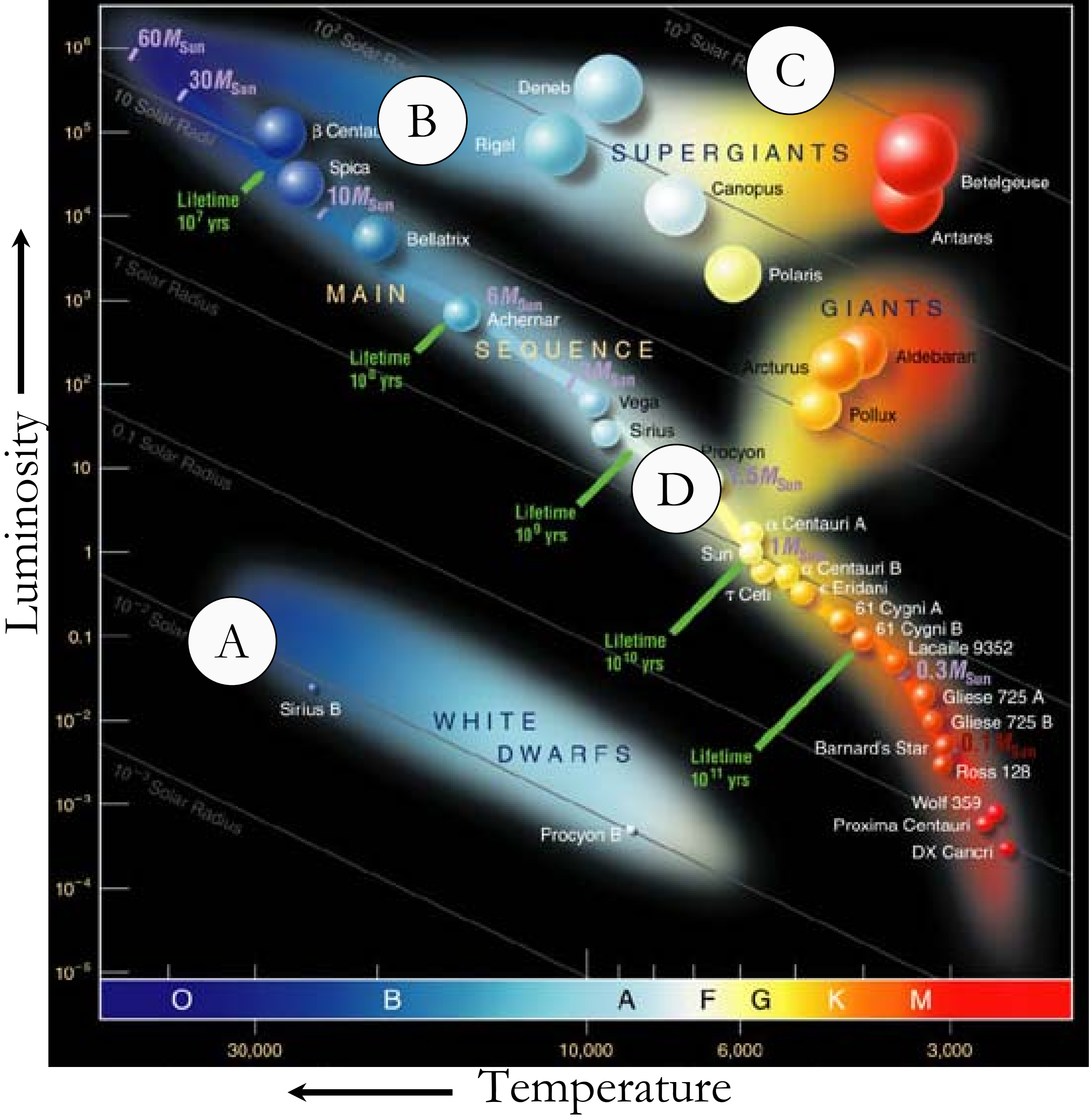


Which star is the most luminous?

C

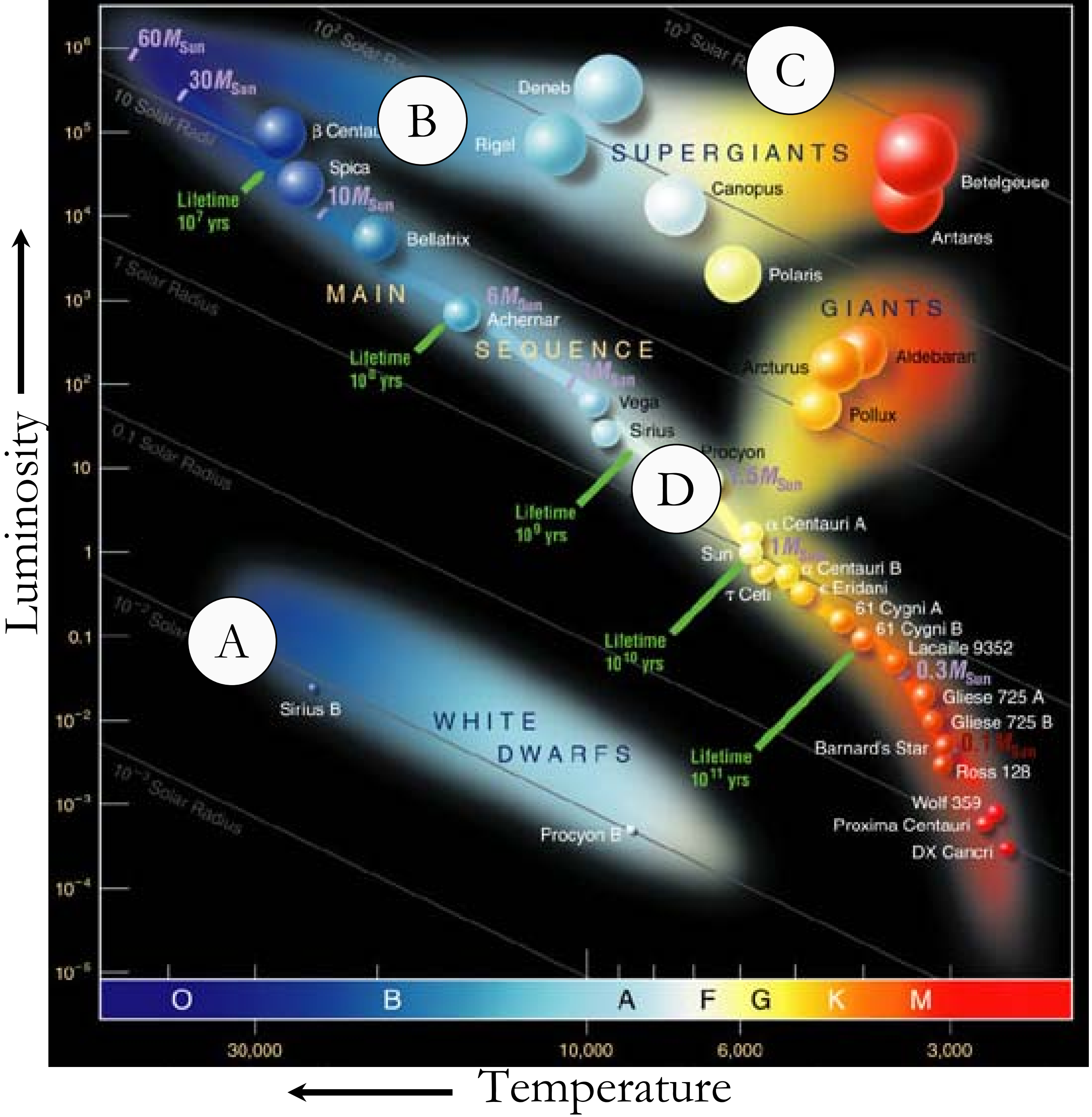


Which star is a main-sequence star?

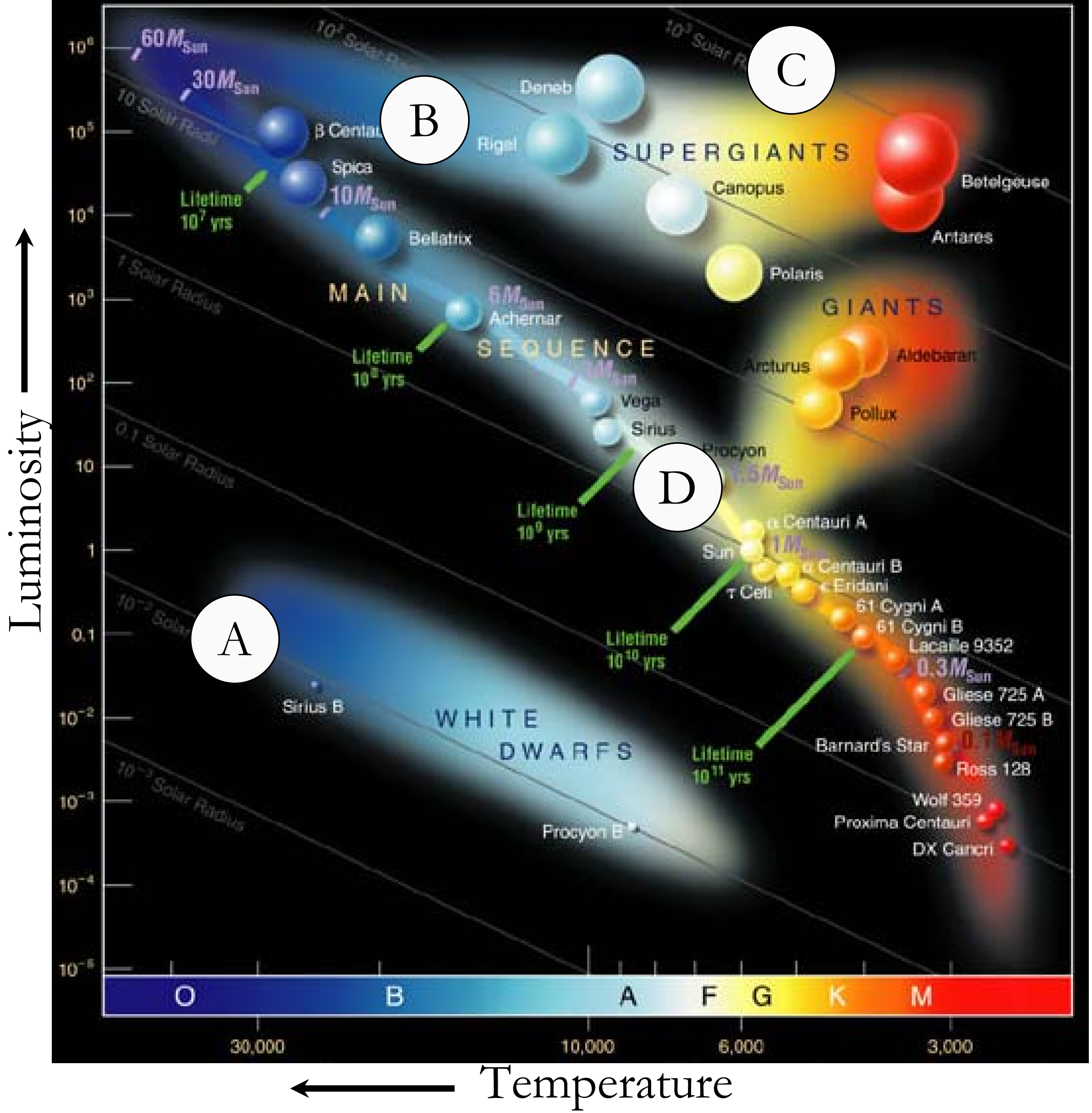


Which star is a main-sequence star?

D

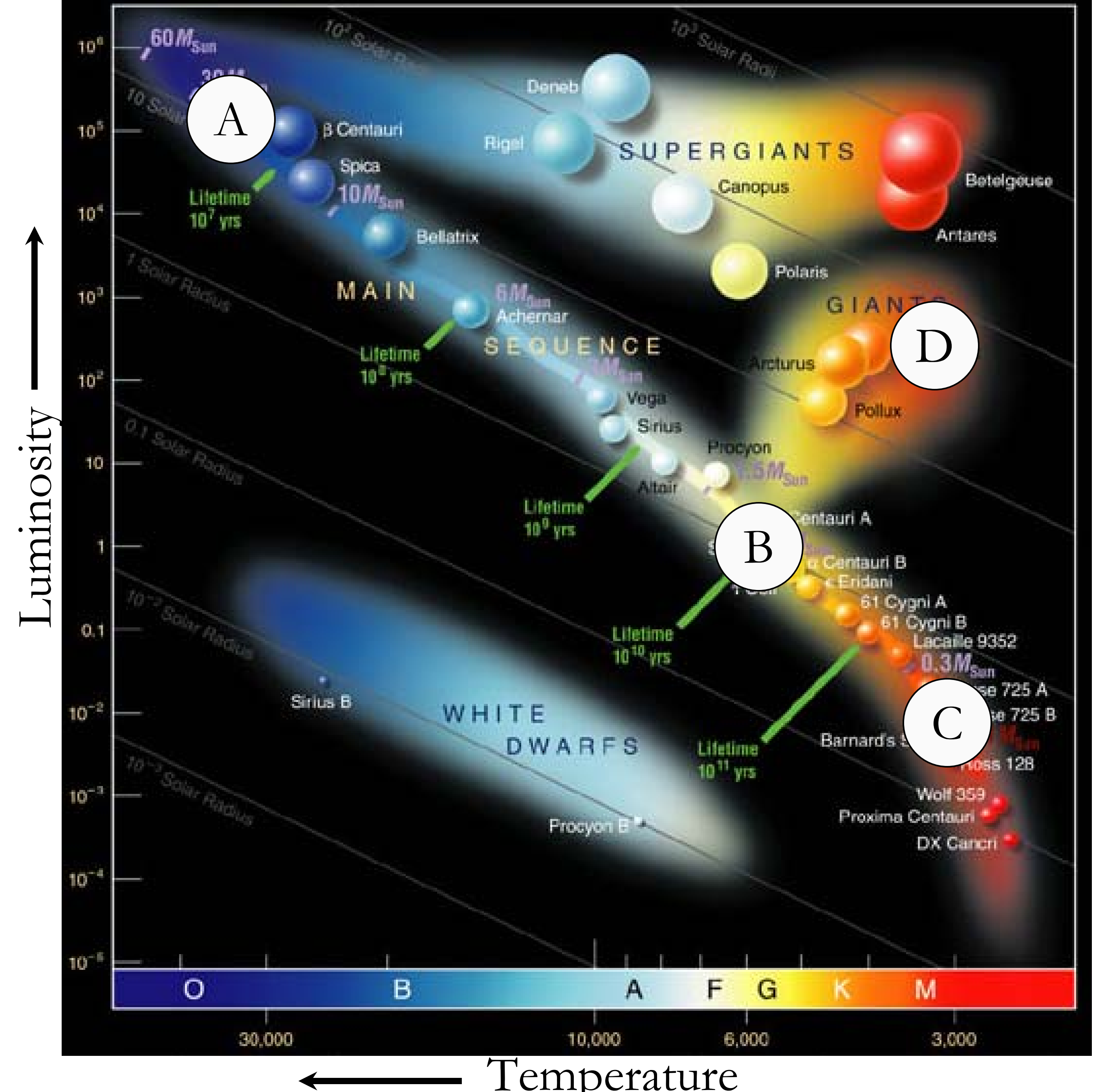


Which star has the largest radius?

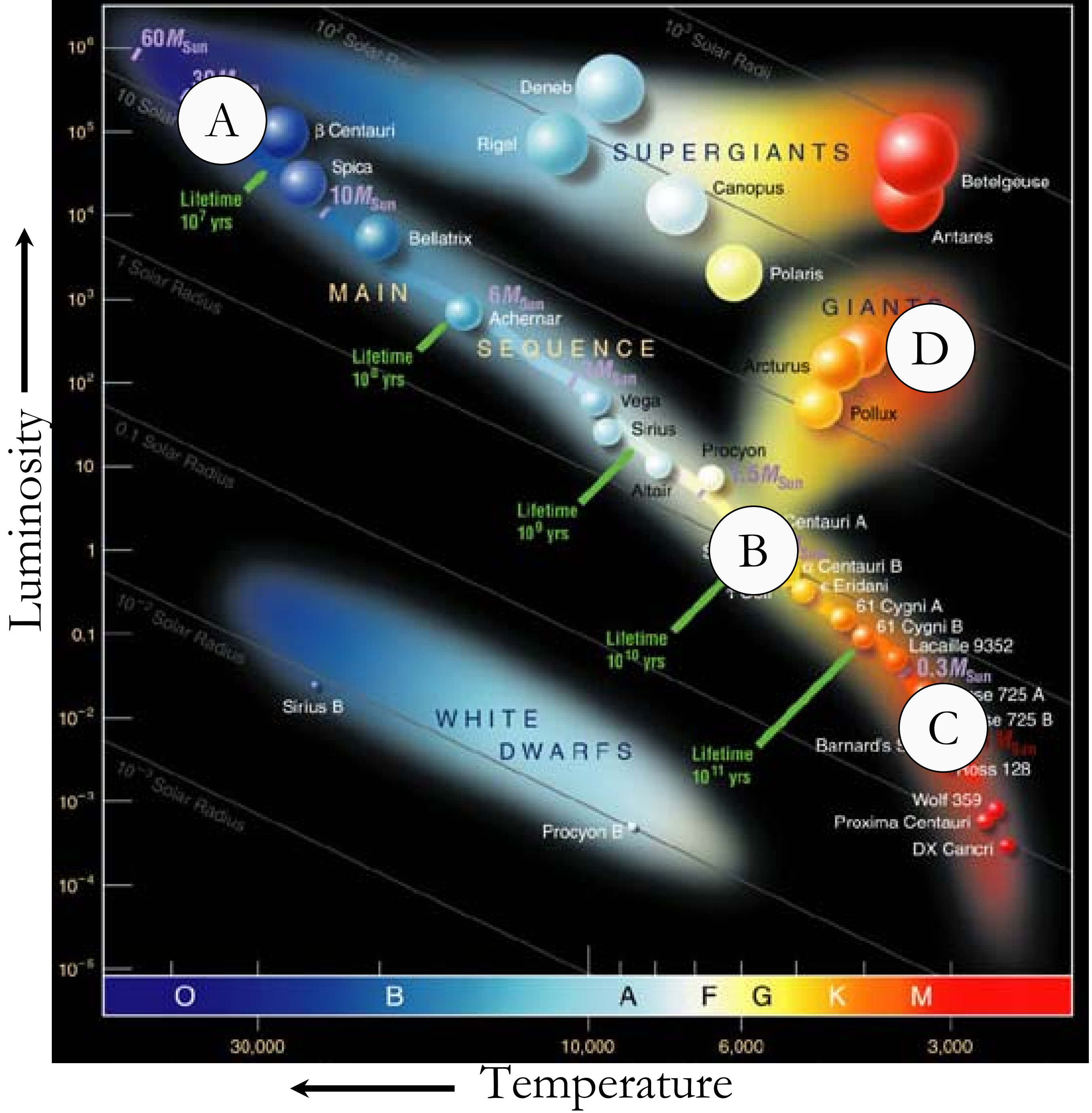


Which star has the largest radius?

C

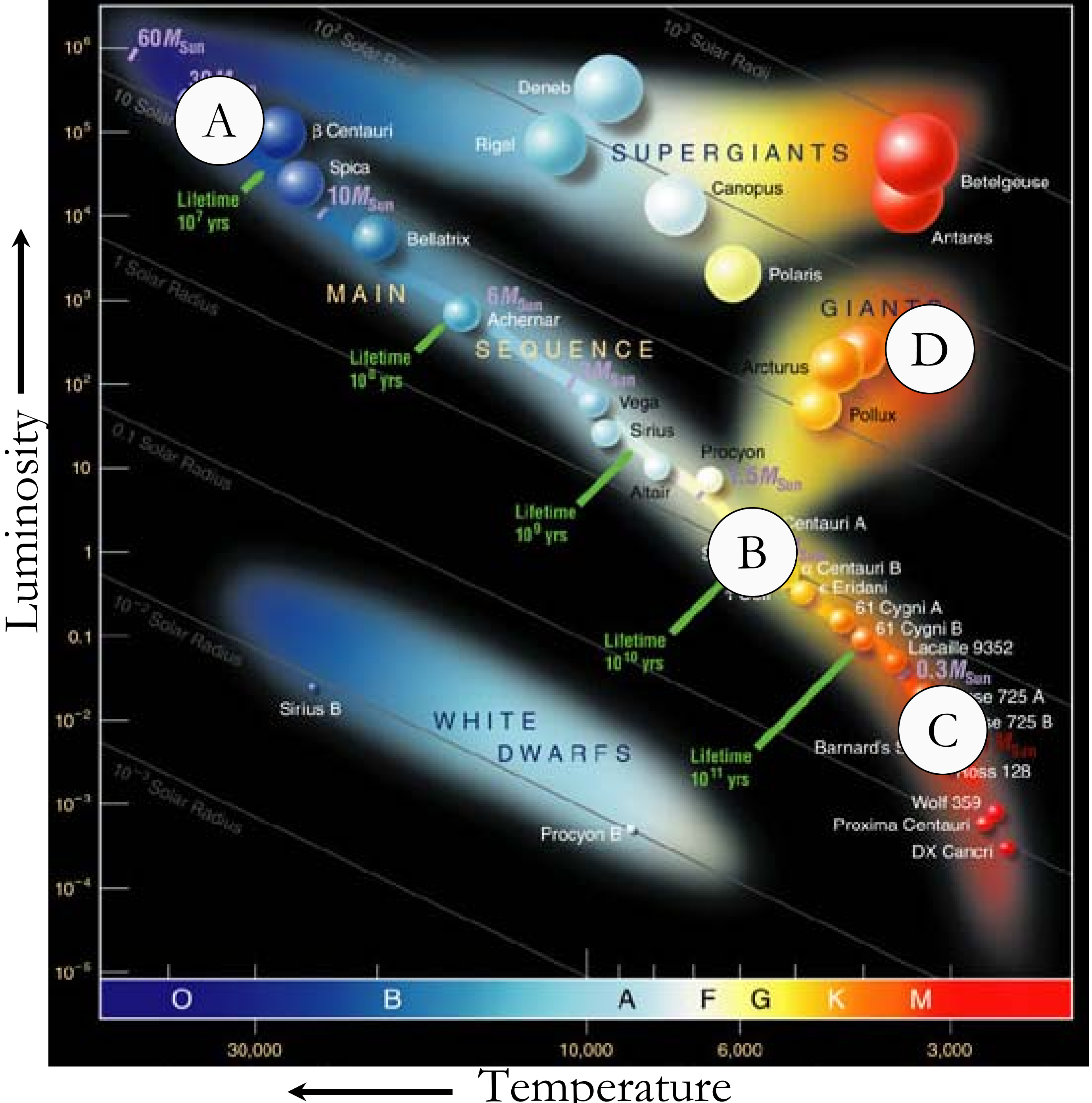


Which star is most like our Sun?

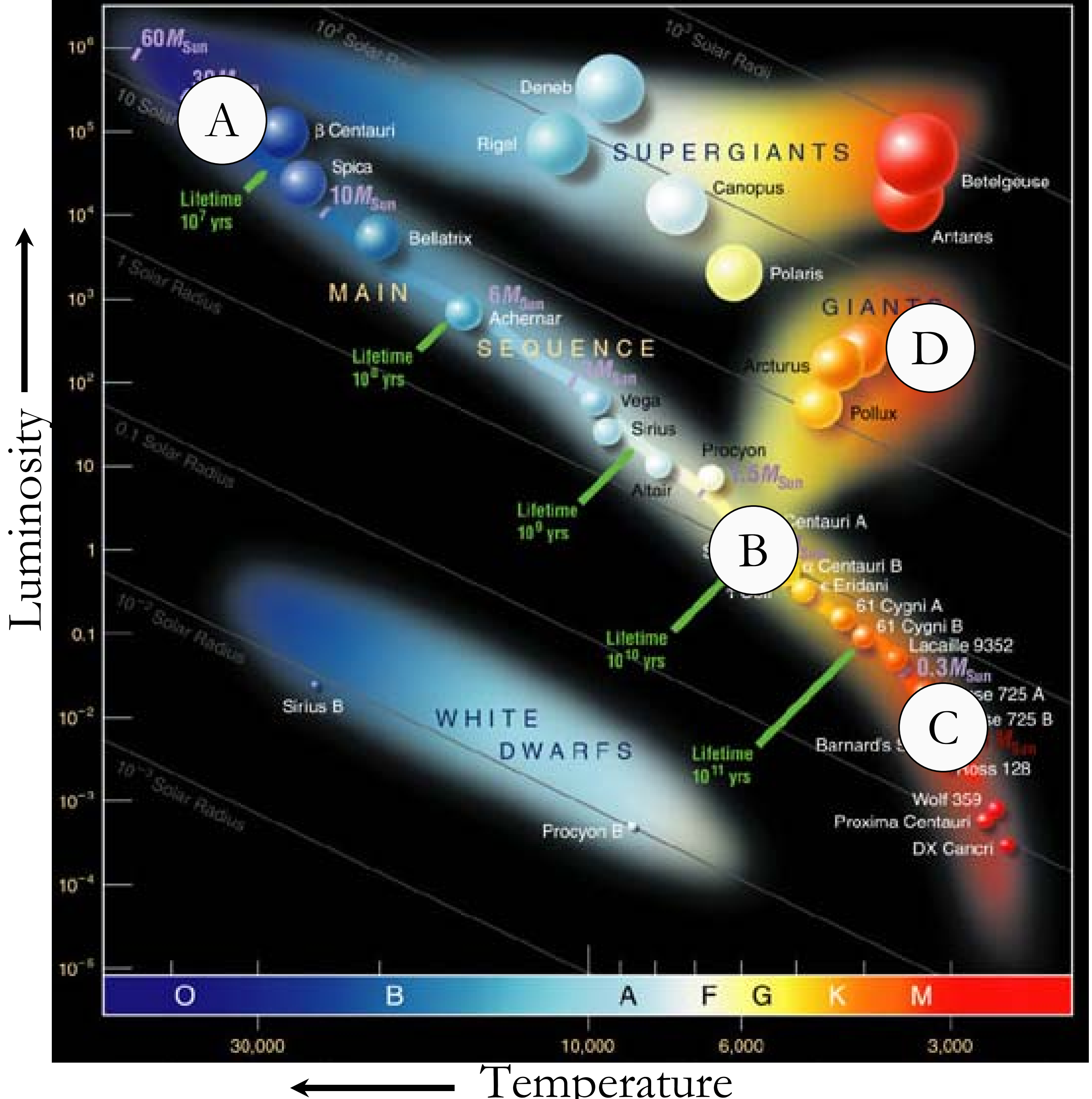


Which star is most like our Sun?

B

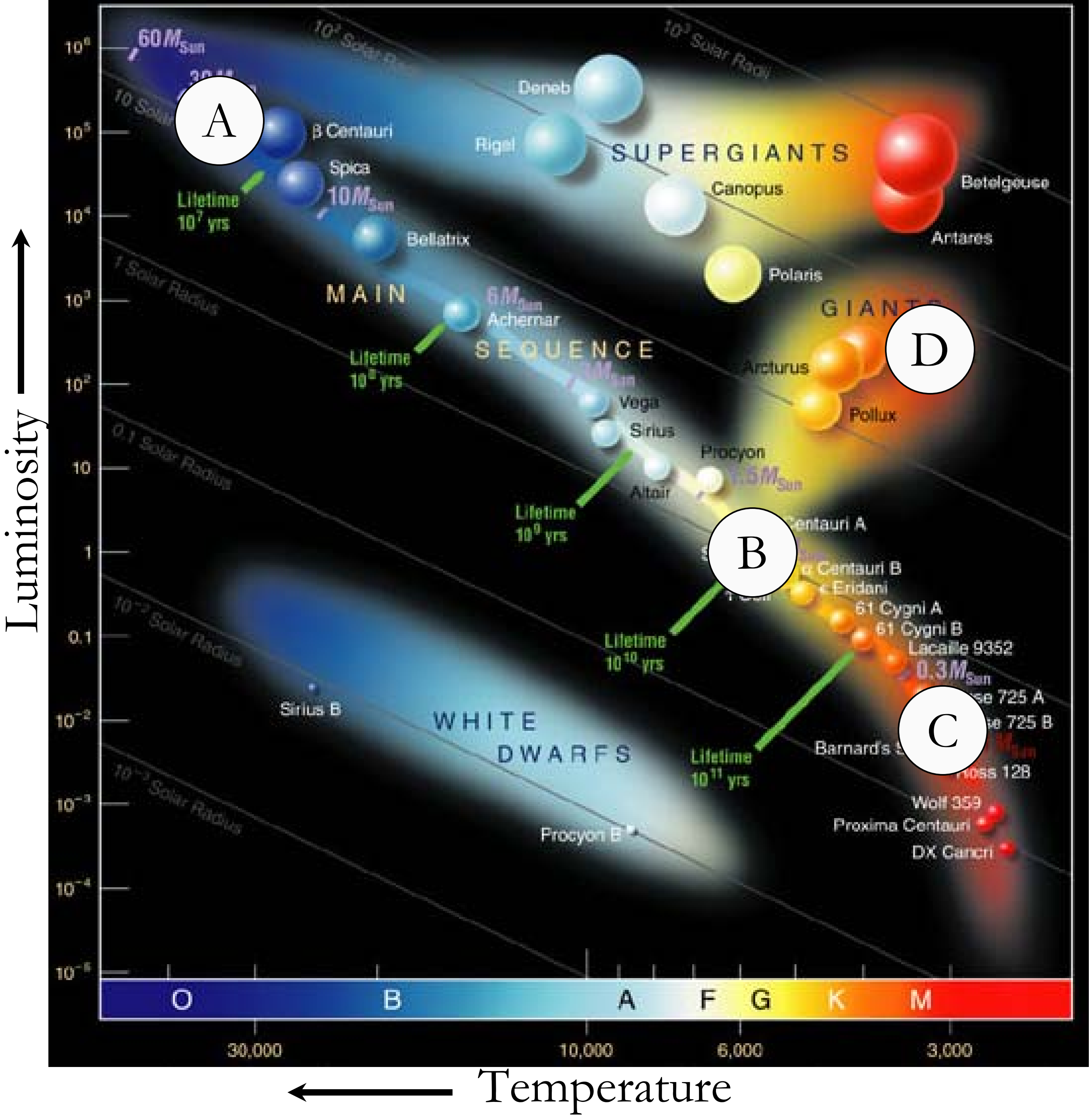


Which of these stars will have changed the least 10 billion years from now?

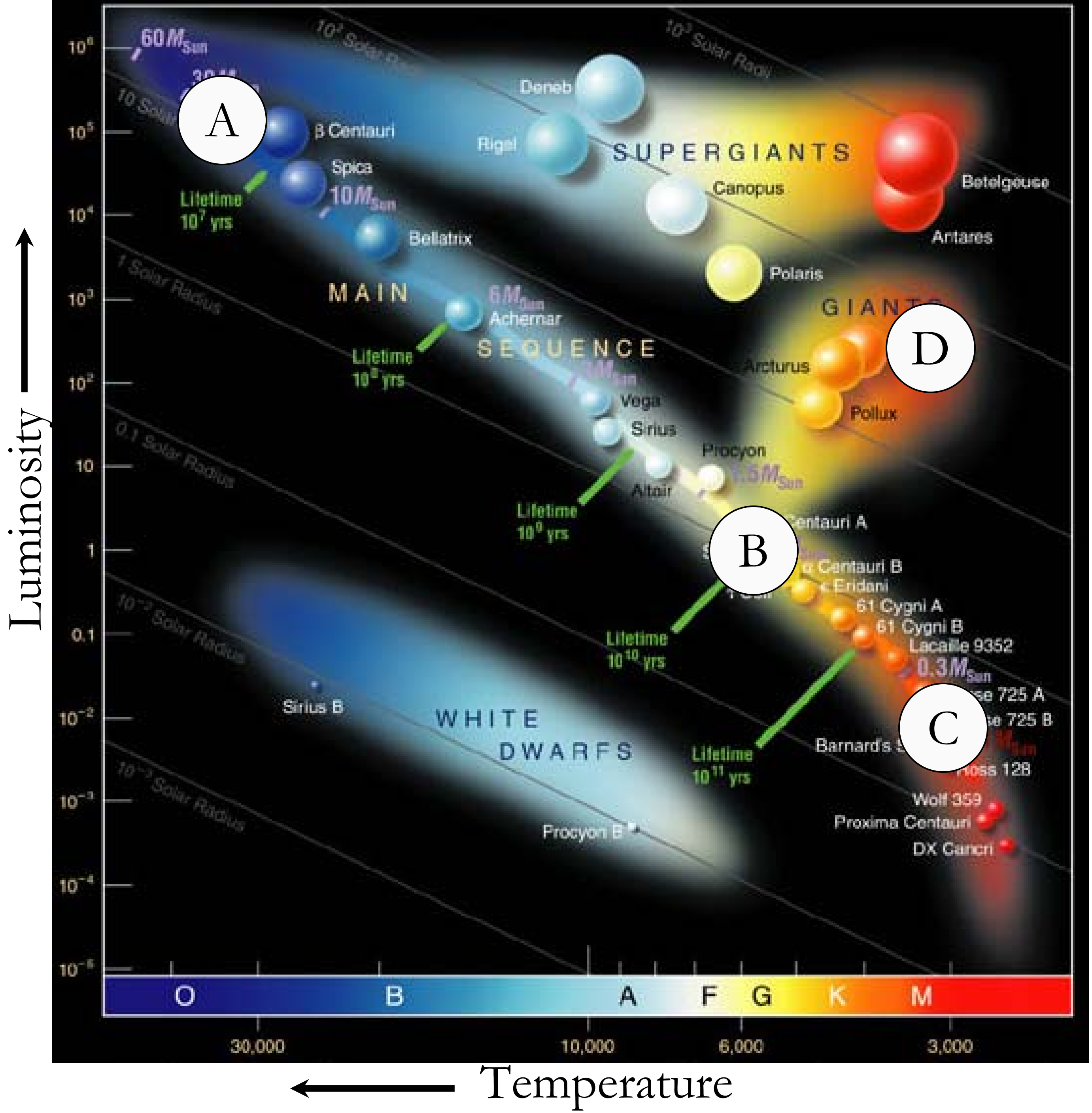


Which of these stars will have changed the least 10 billion years from now?

C



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



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

A

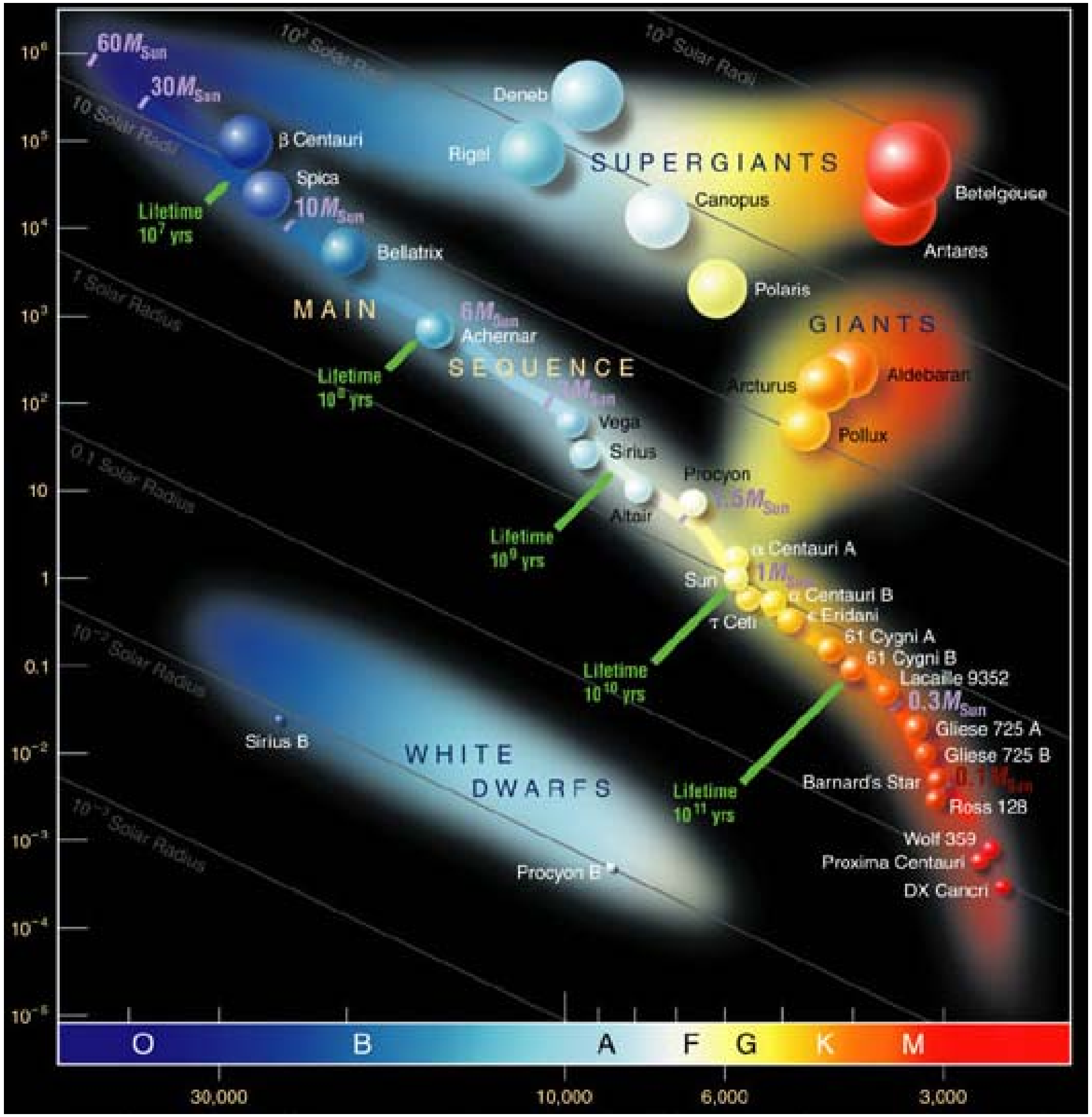
What have we learned?

- **How do we classify stars?**
- We classify stars according to their **spectral type** and **luminosity class**.
- The spectral type tells us the star's surface temperature
- The luminosity class how much light it puts out.

- **Why is a star's mass its most important property?**
- A star's mass at birth determines virtually everything that happens to it throughout its life.

What have we learned?

- **What is a Hertzsprung-Russell diagram?**
- An **H–R diagram** plots stars according to their surface temperatures and luminosities.



11.3 Star Clusters

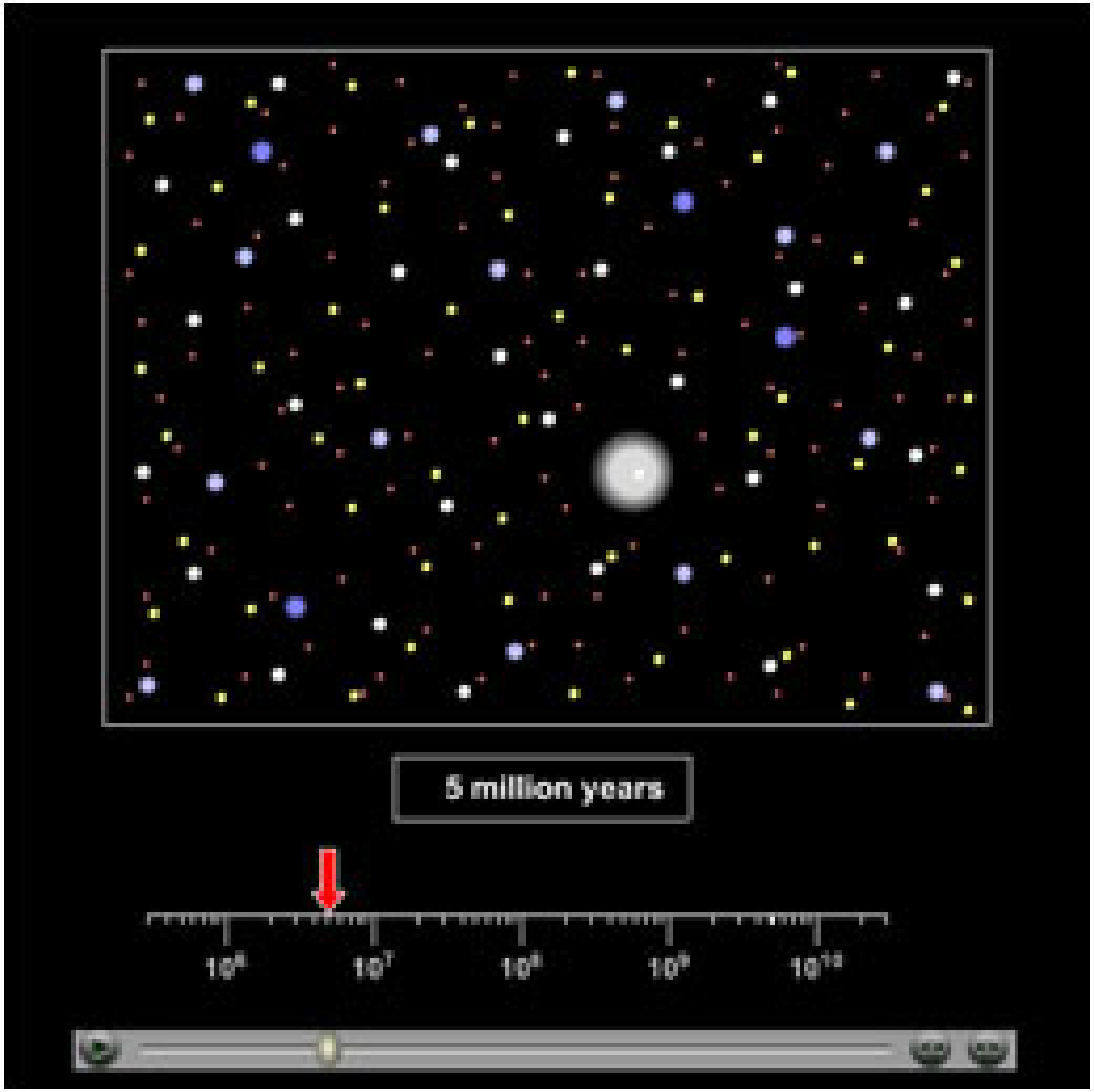
- **Our Goals for Learning**
- **What are the two types of star clusters?**
- **How do we measure the age of a star cluster?**

What are the two types of star clusters?

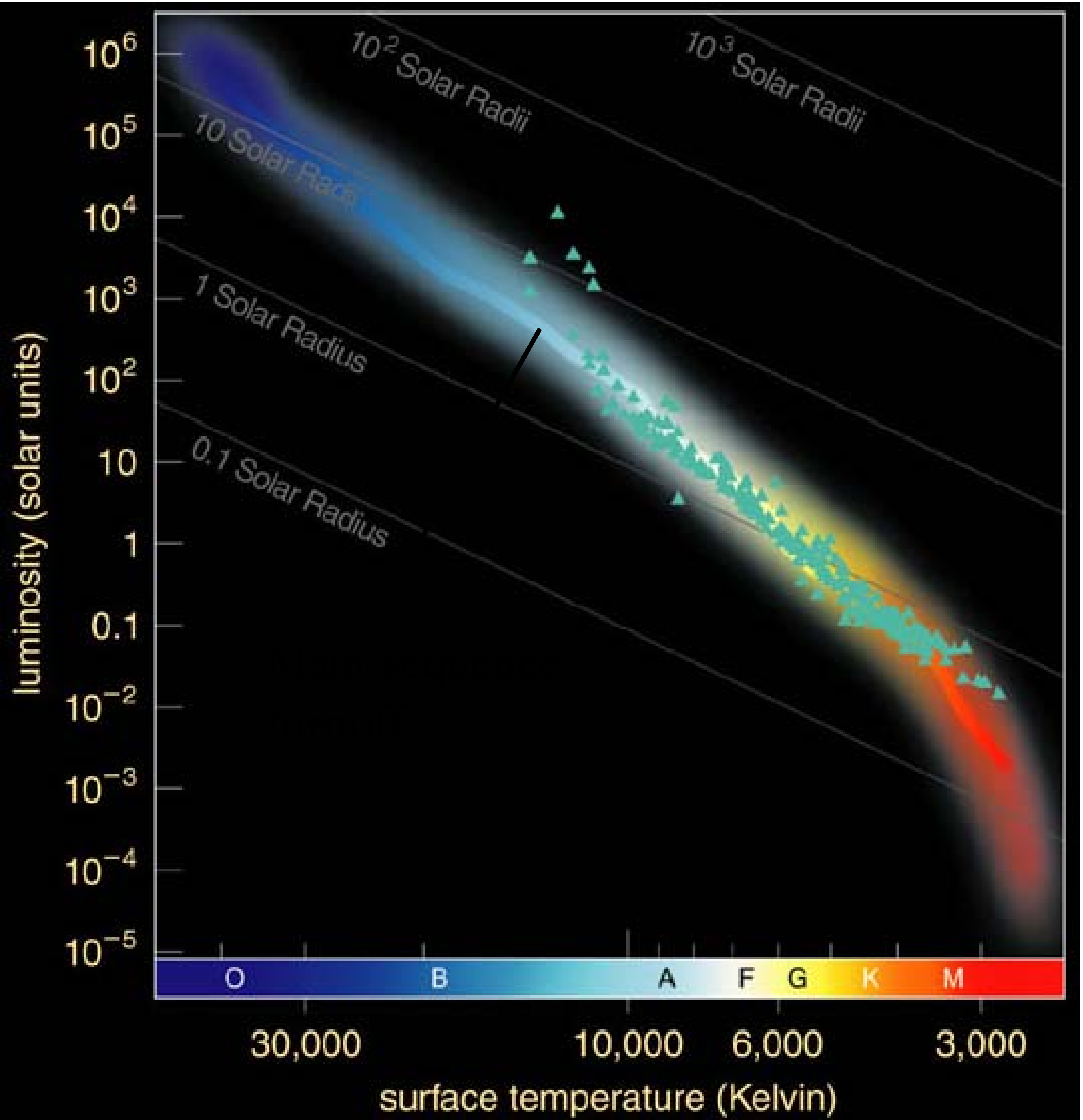
Open cluster: A few thousand loosely packed stars

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

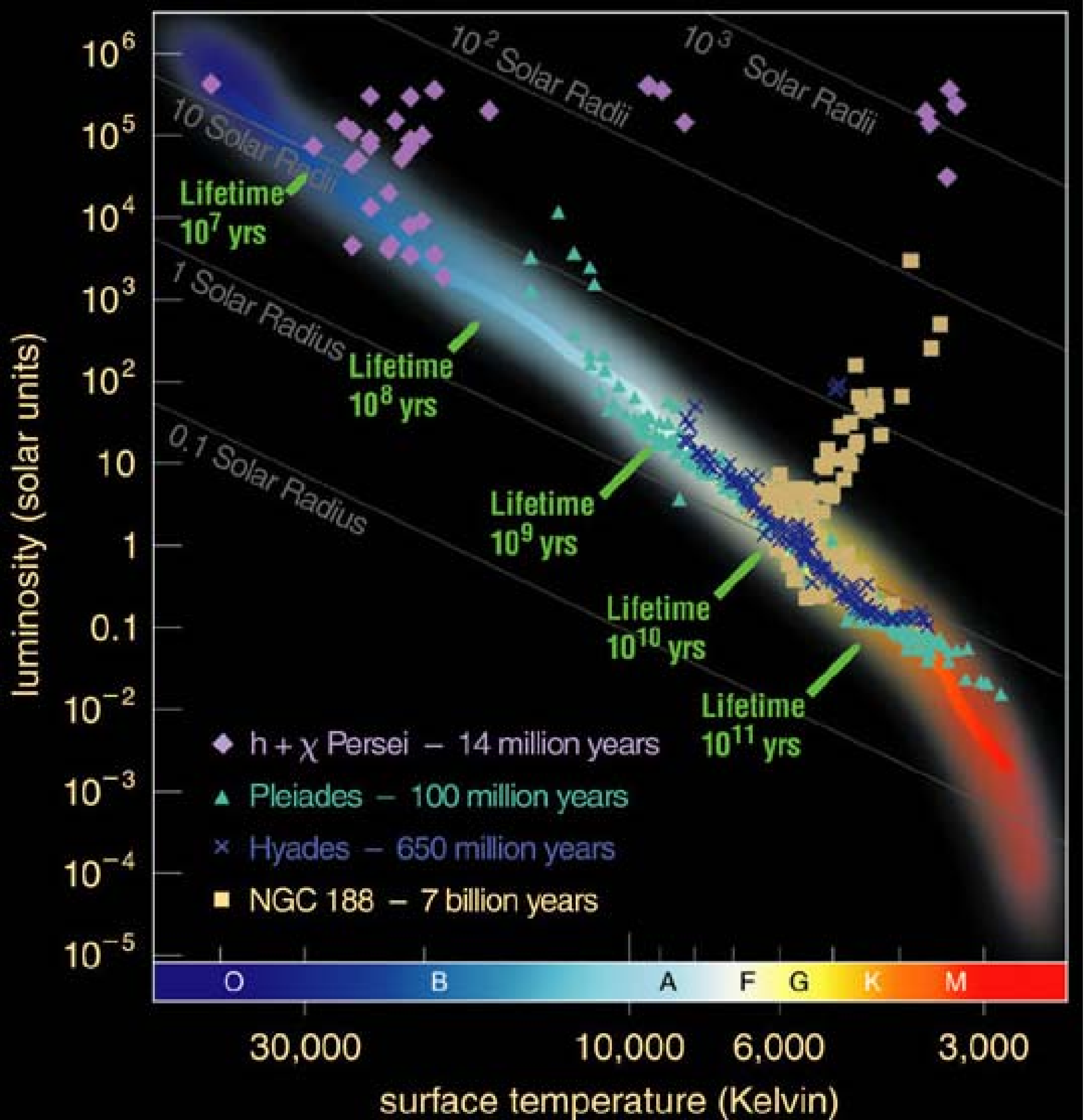
How do we measure the age of a star cluster?



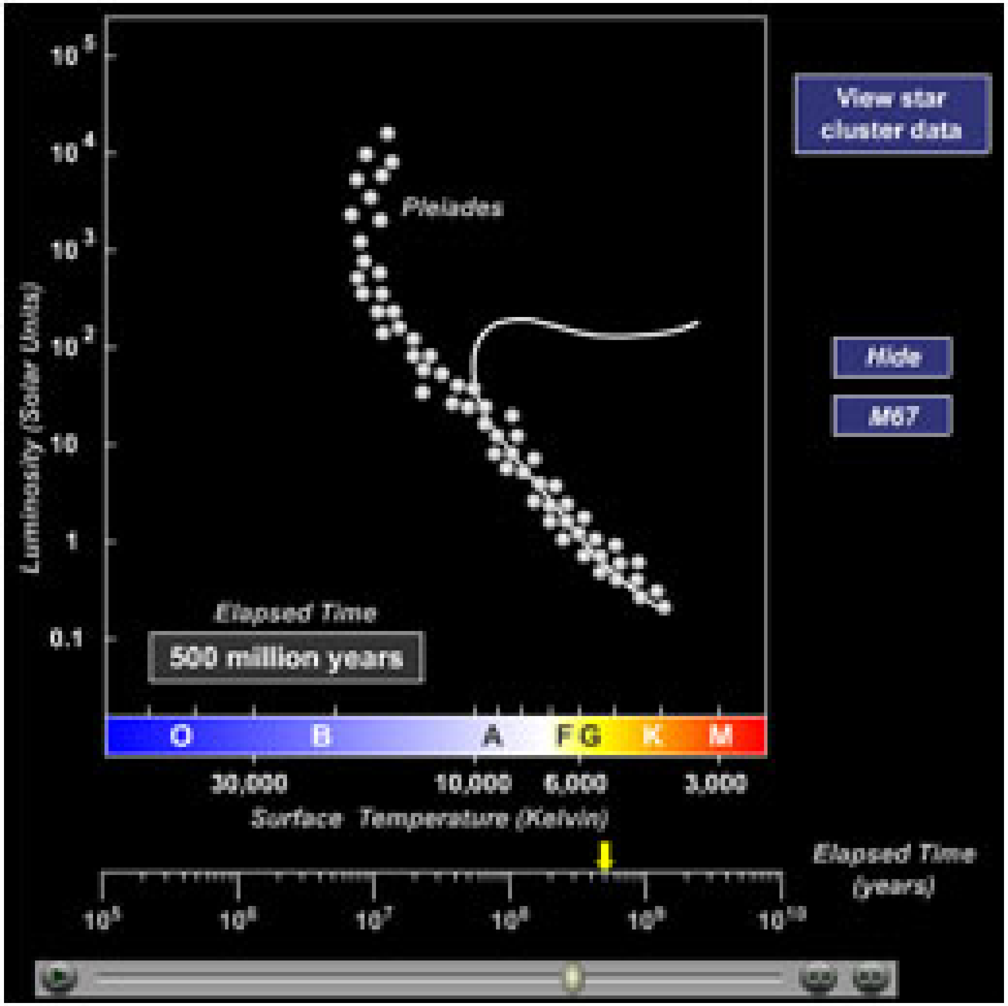
Massive blue stars die first, followed by white, yellow, orange, and red stars



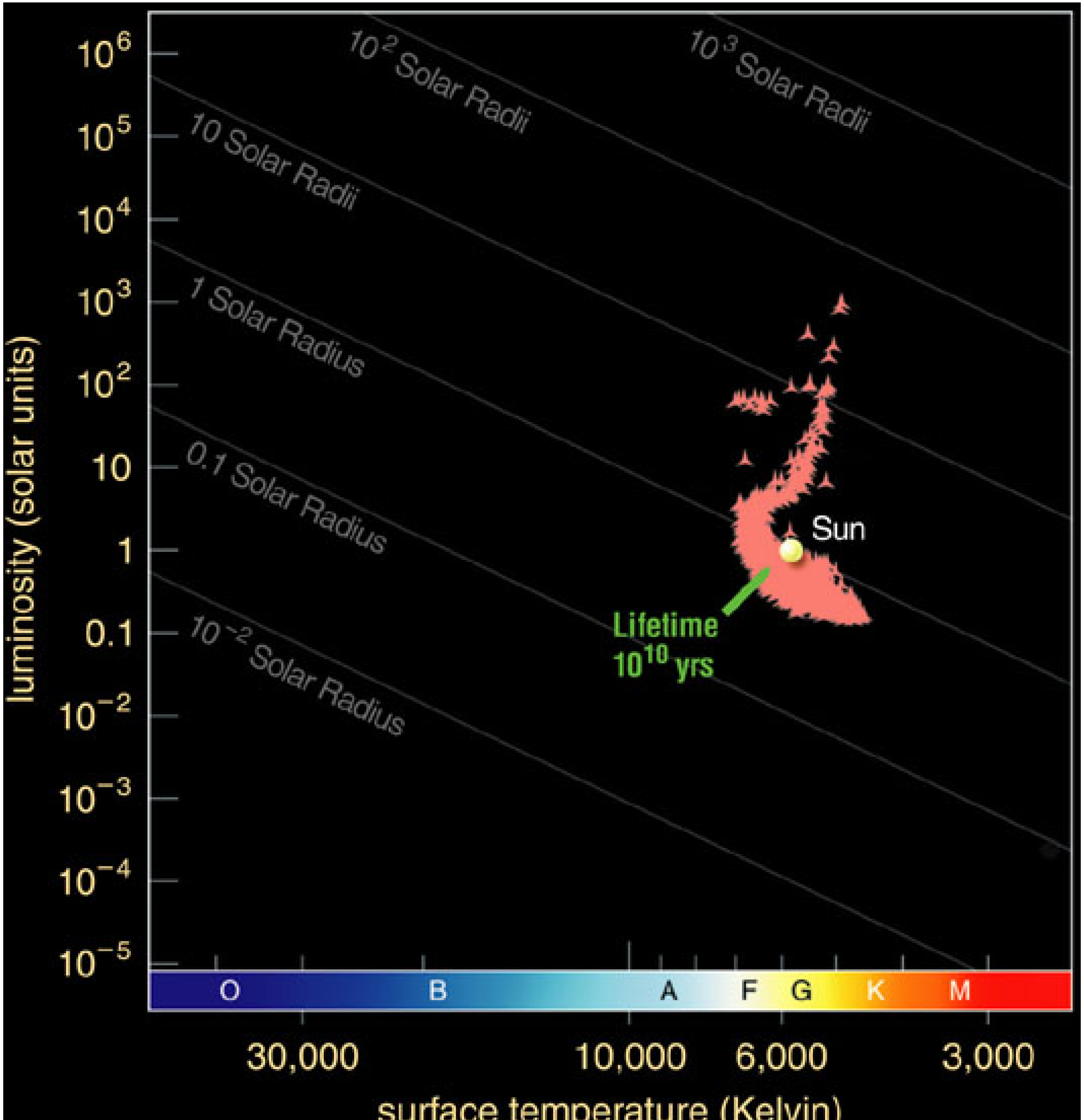
Pleiades now has no stars with life expectancy less than around 100 million years



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



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

What have we learned?

- **What are the two types of star clusters?**
- **Open clusters** contain up to several thousand stars and are found in the disk of the galaxy.
- **Globular clusters** contain hundreds of thousands of stars, all closely packed together. They are found mainly in the halo of the galaxy.

What have we learned?

- **How do we measure the age of a star cluster?**
- Because all of a cluster's stars we born at the same time, we can measure a cluster's age by finding the **main sequence turnoff** point on an H–R diagram of its stars. The cluster's age is equal to the hydrogen-burning lifetime of the hottest, most luminous stars that remain on the main sequence.