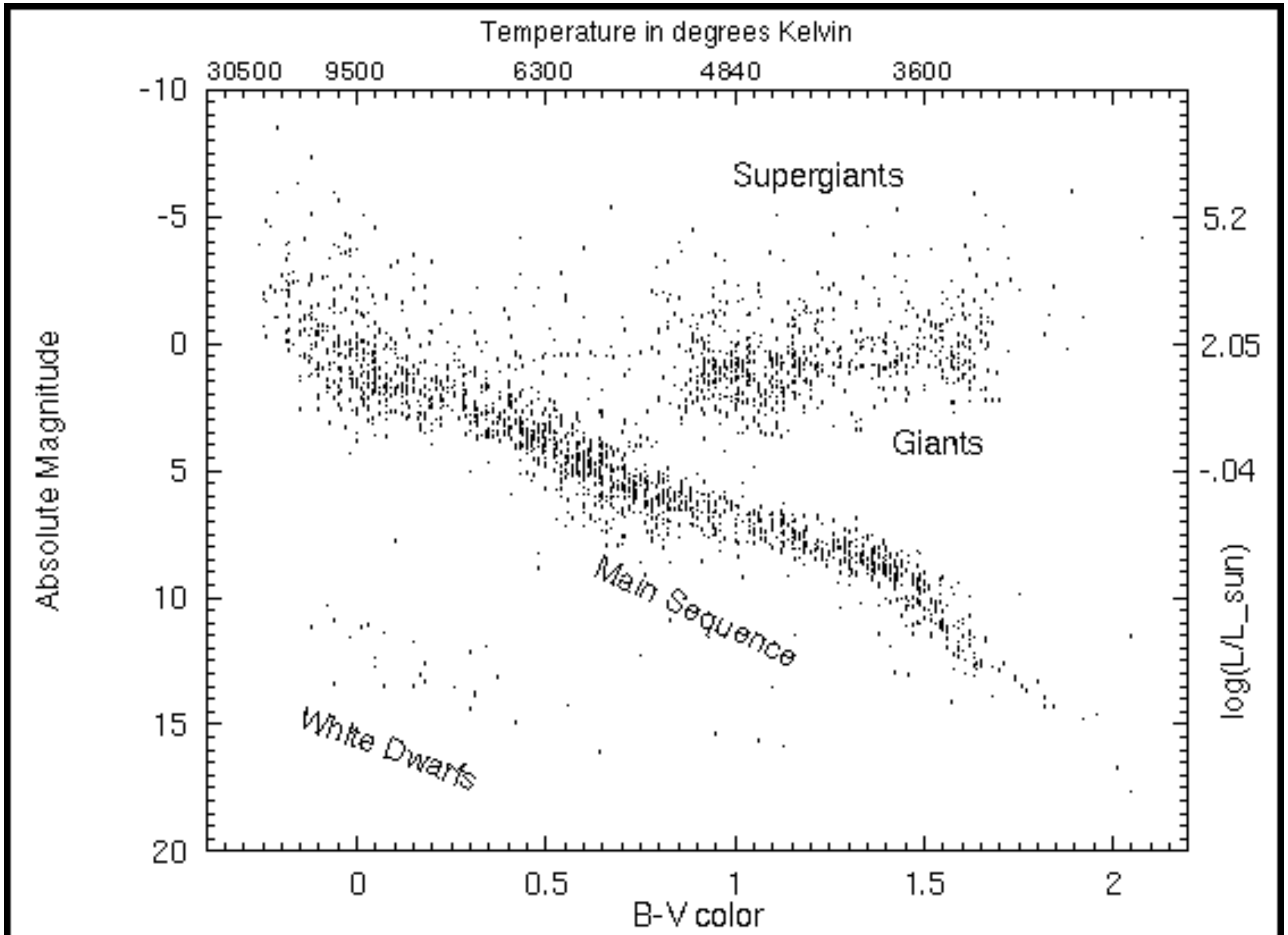
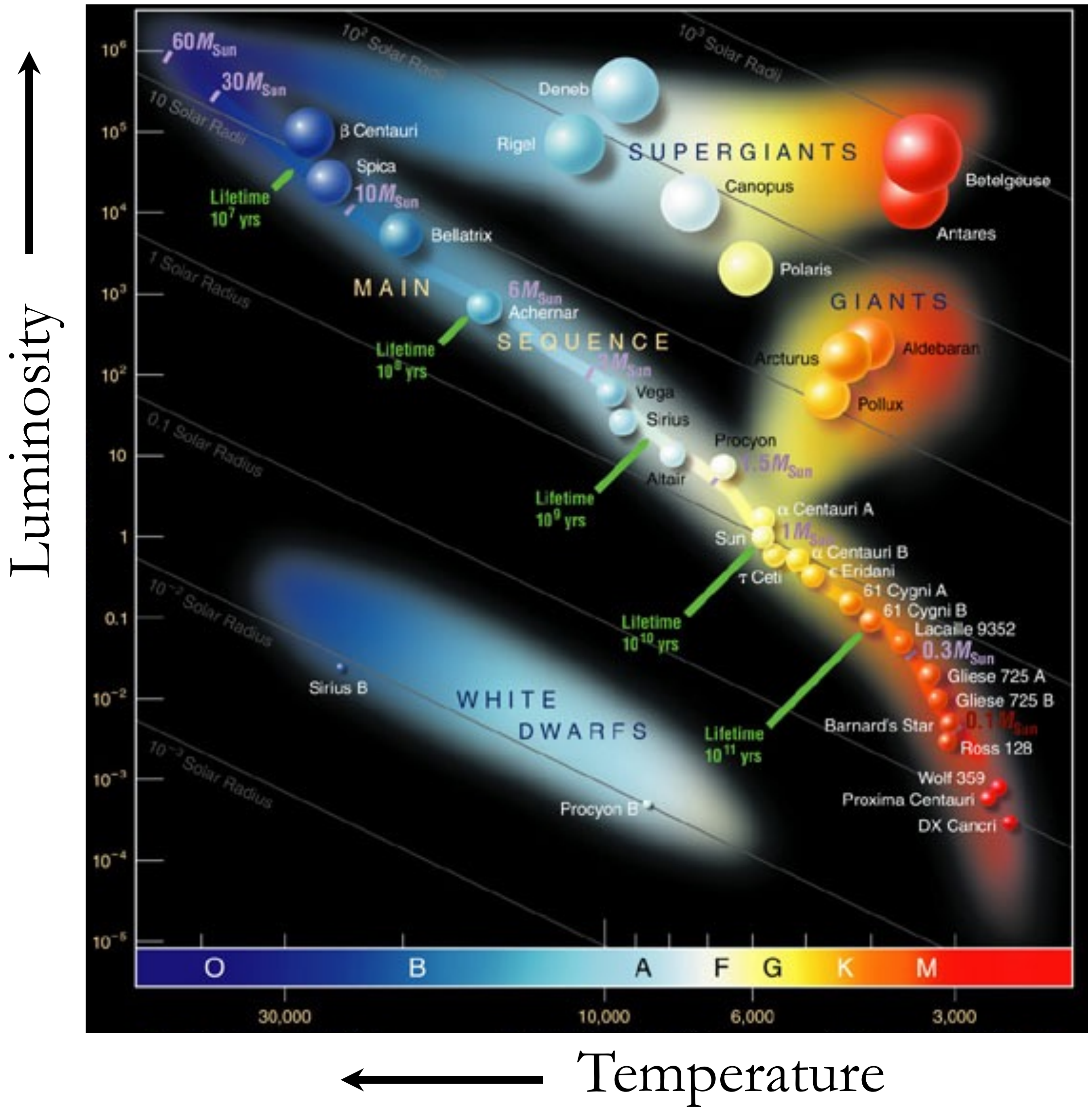
Lecture 15
The Hertzsprung–Russell diagram

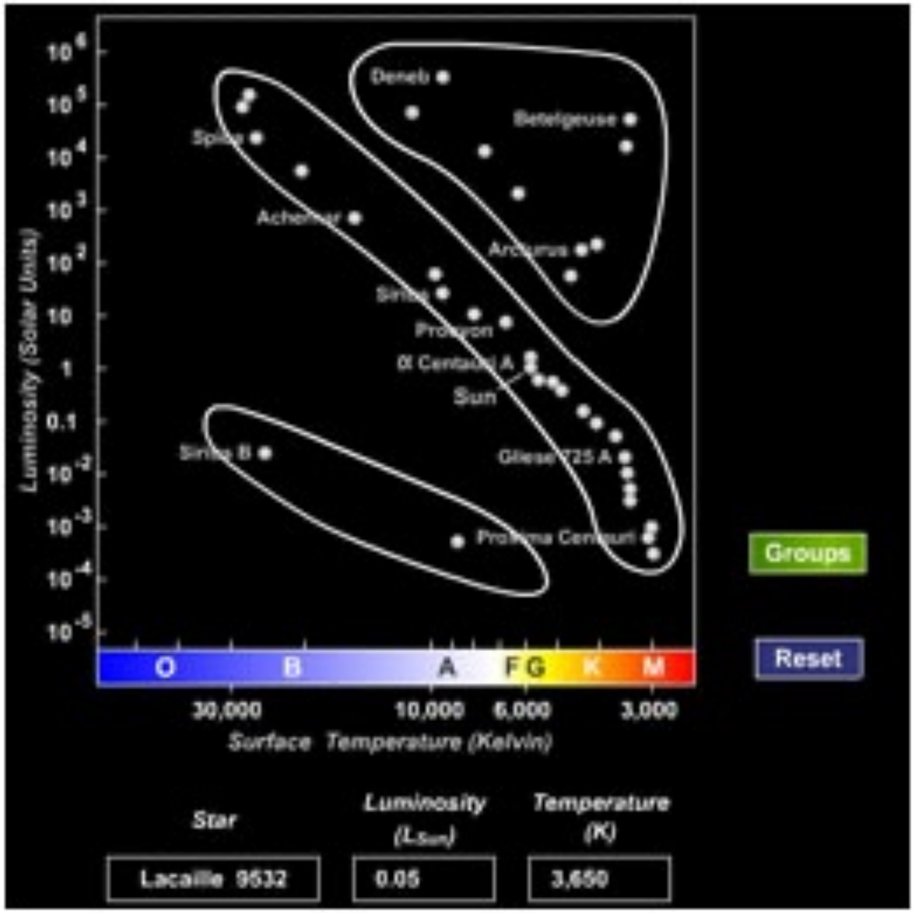


The Hertzsprung–Russell diagram

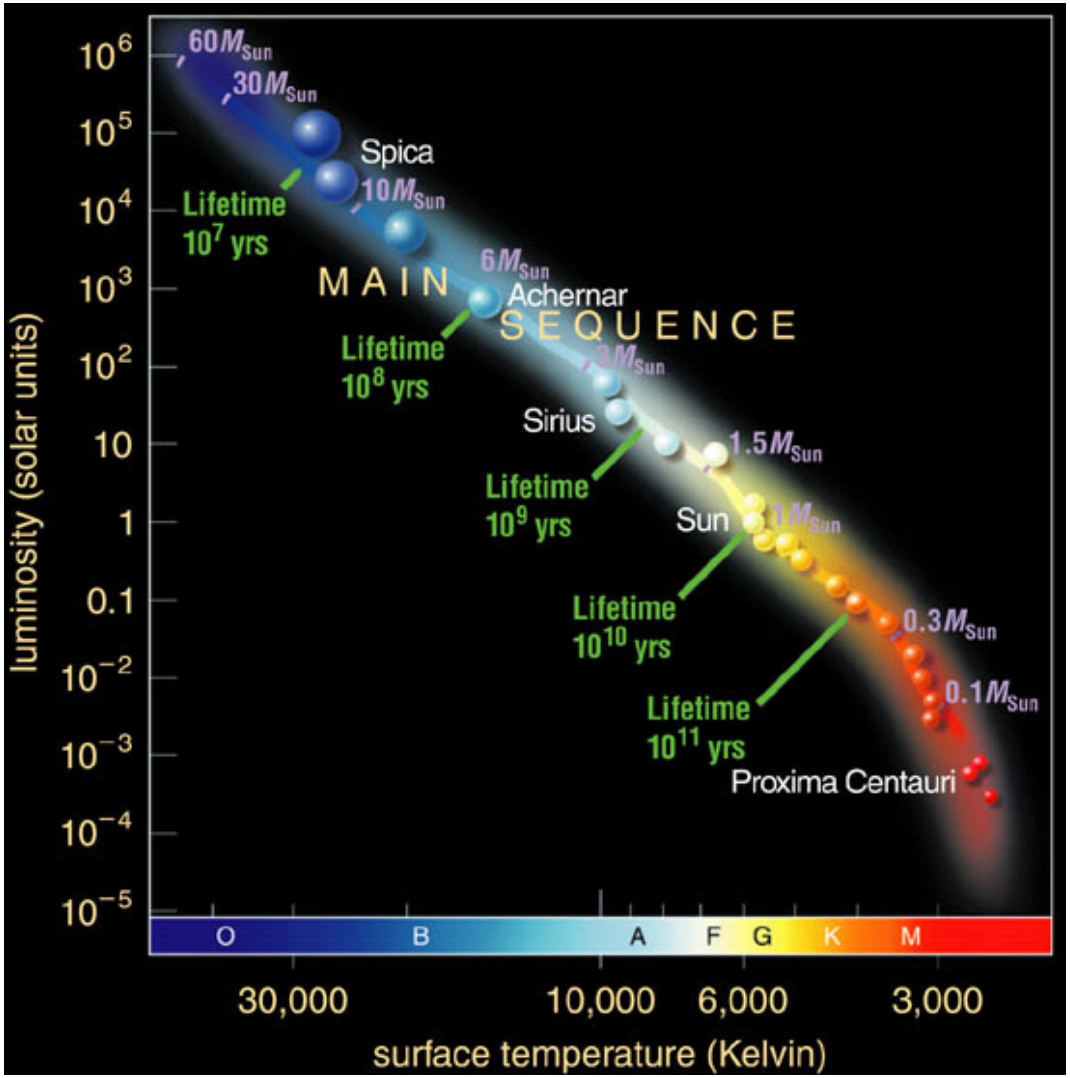


An H-R diagram plots *properties* of stars: the **luminosities** versus **temperatures**.

The Hertzsprung–Russell diagram

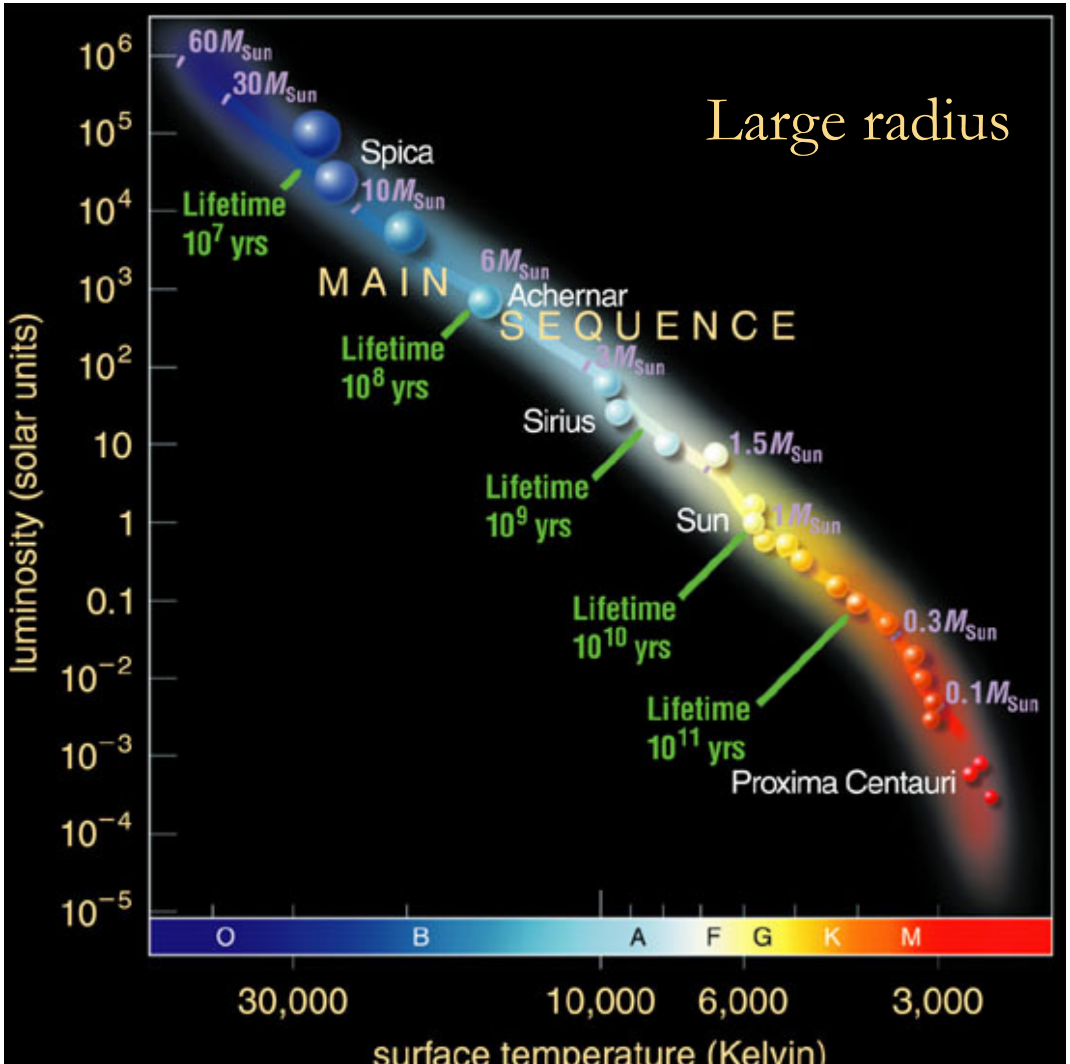


The Hertzsprung–Russell diagram



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

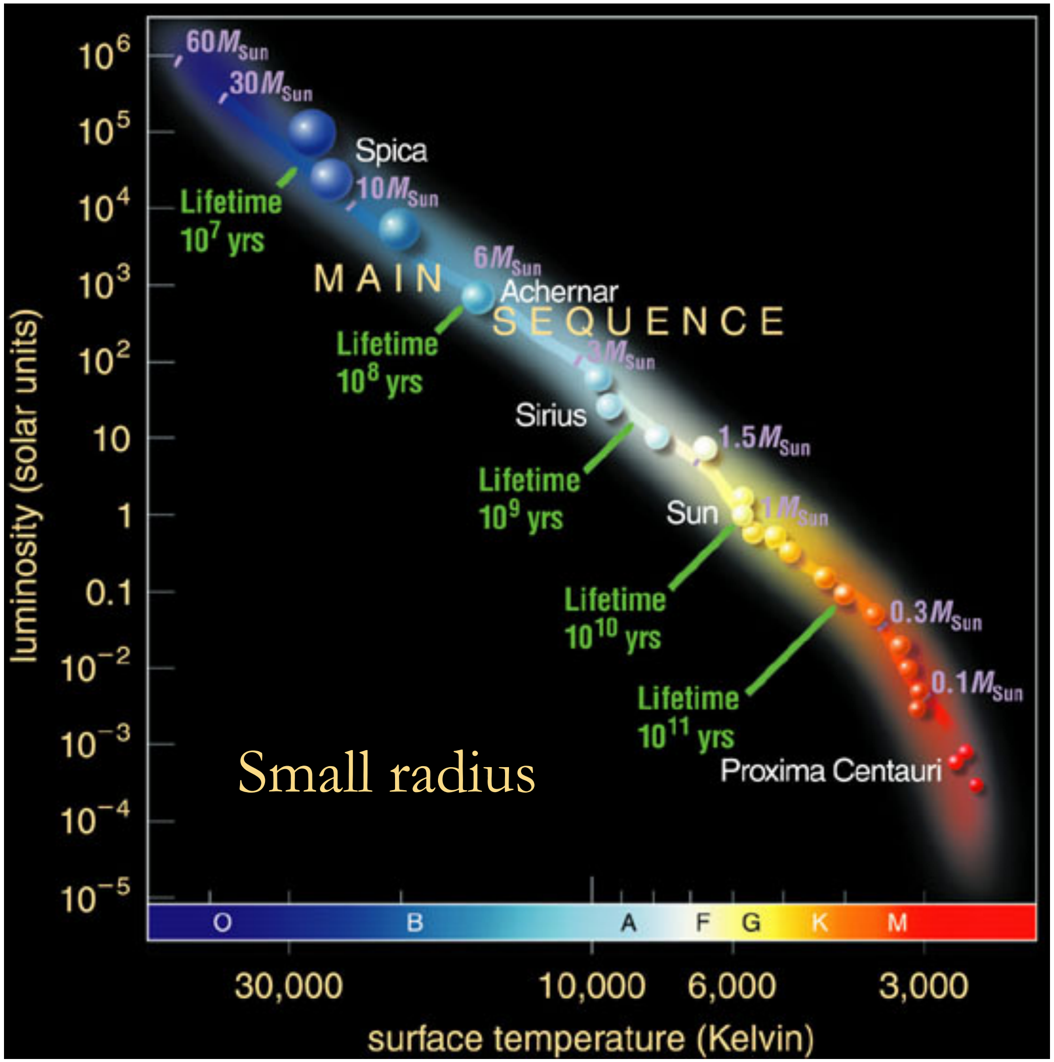
The Hertzsprung–Russell diagram



2. ***Giants*** and ***Supergiants***

Stars with lower *Temp* and higher *Luminosity* than main-sequence stars must have **larger** radii.

The Hertzsprung–Russell diagram



3. ***White dwarfs***

Stars with higher *Temp* and lower *Luminosity* than main-sequence stars must have **smaller** radii.

Spectral classification

A star's full classification includes **spectral type:**

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

(each class is subdivided from 0-9; the *higher* number is *cooler*)

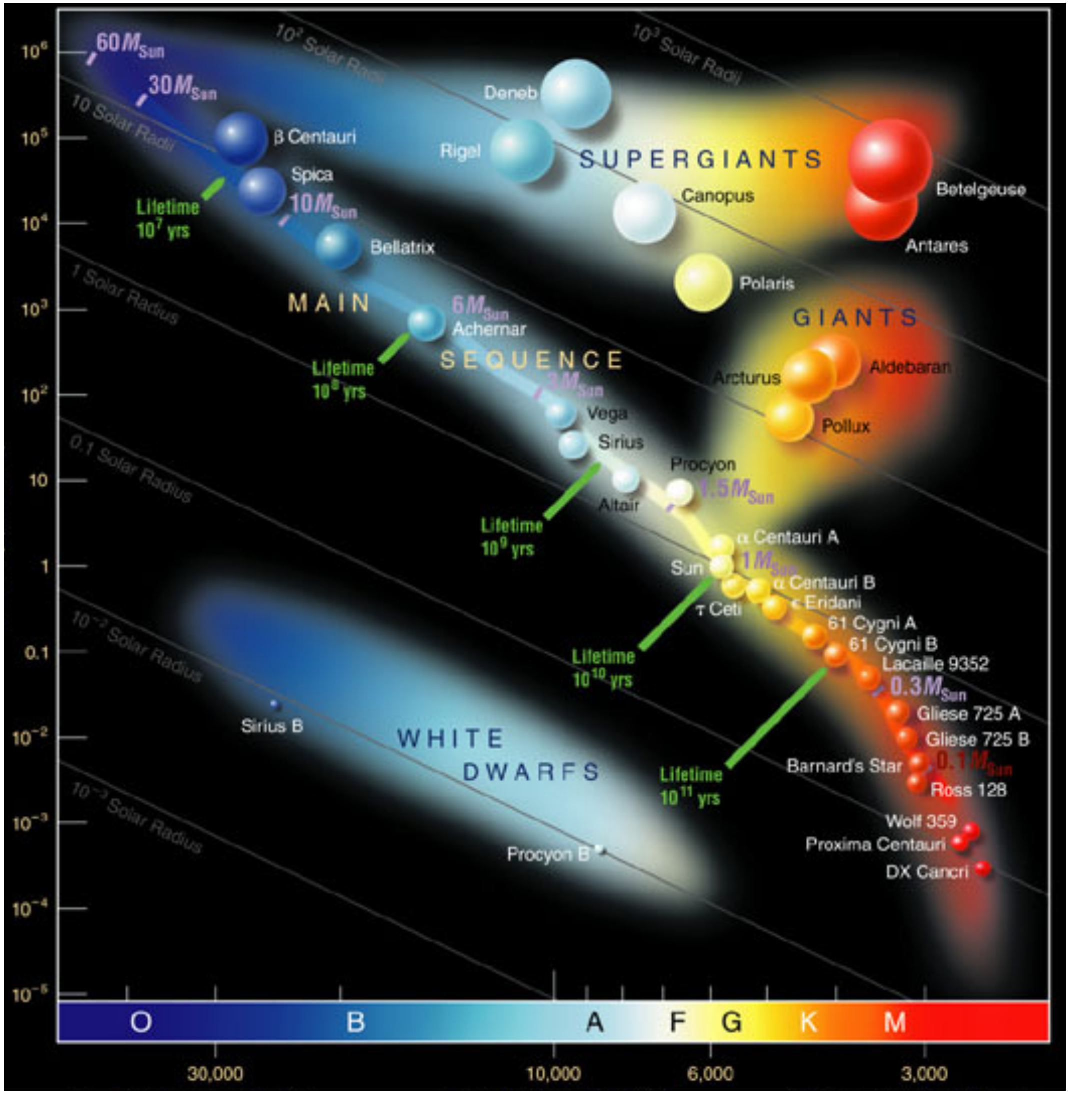
and **luminosity class** (related to the size of the star):

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

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

The Hertzsprung–Russell diagram

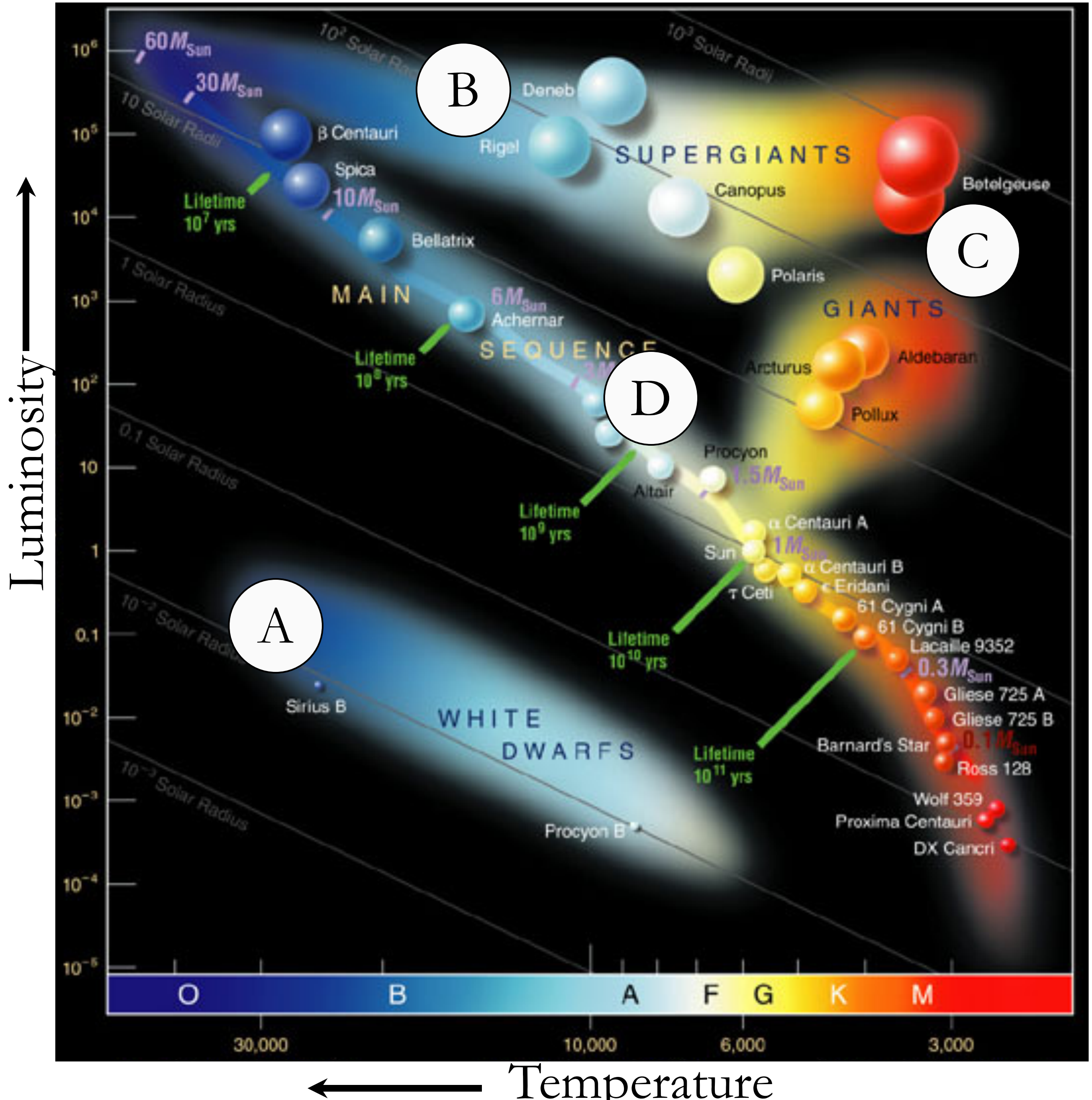
Luminosity



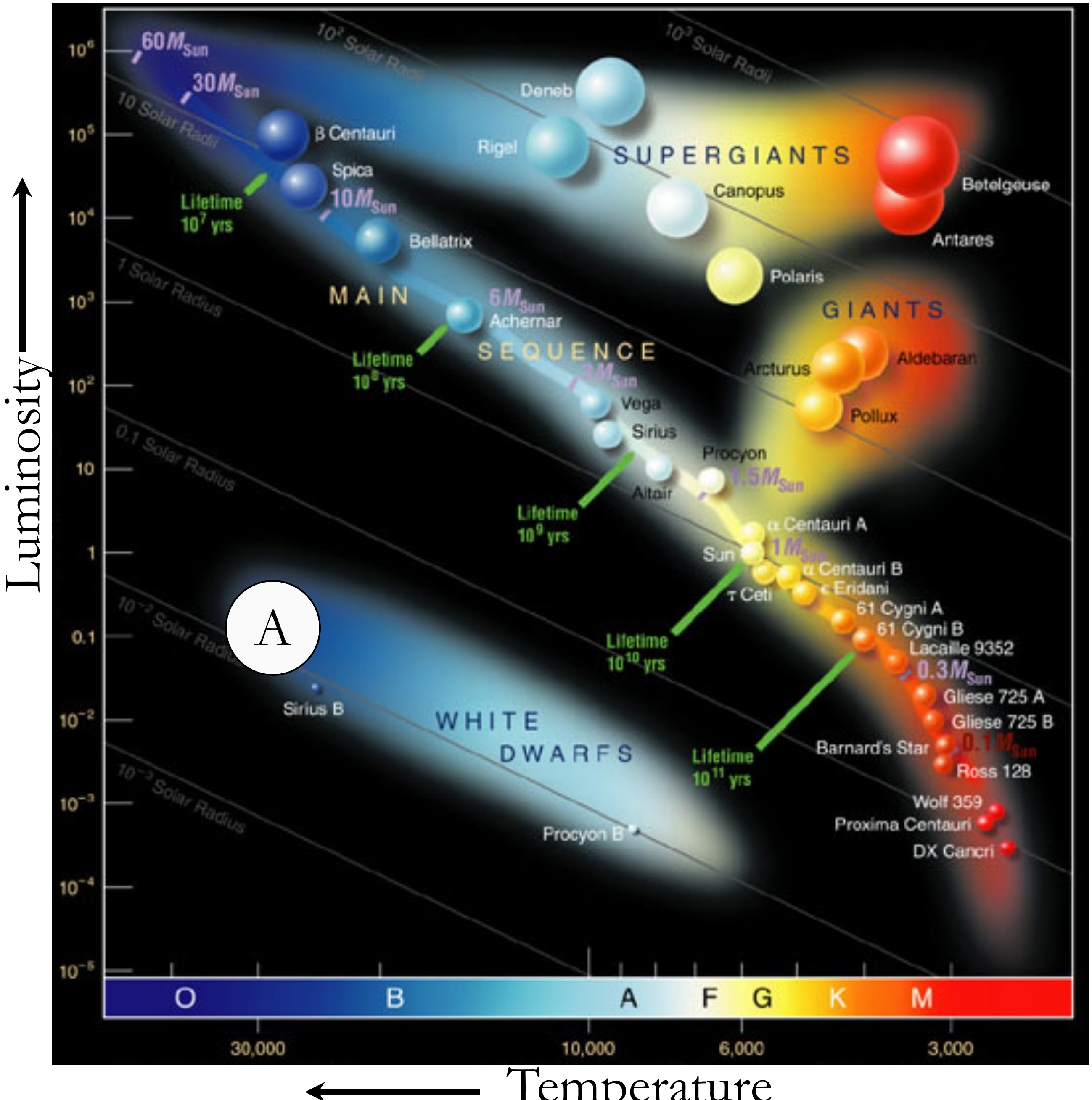
Temperature

HR diagram depicts:

- Temperature
- Color
- Spectral type
- Luminosity
- Radius

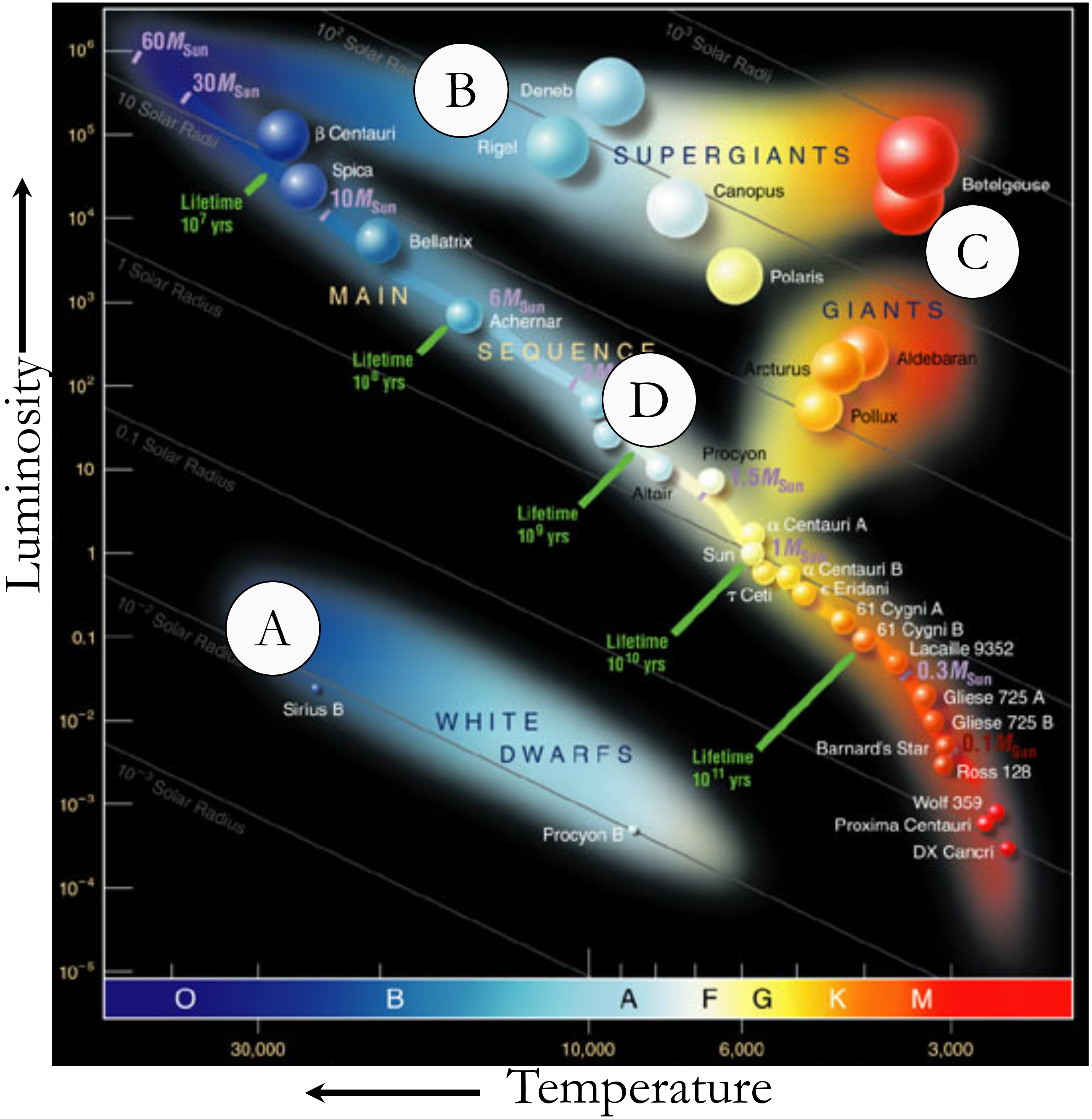


Which star is the hottest?

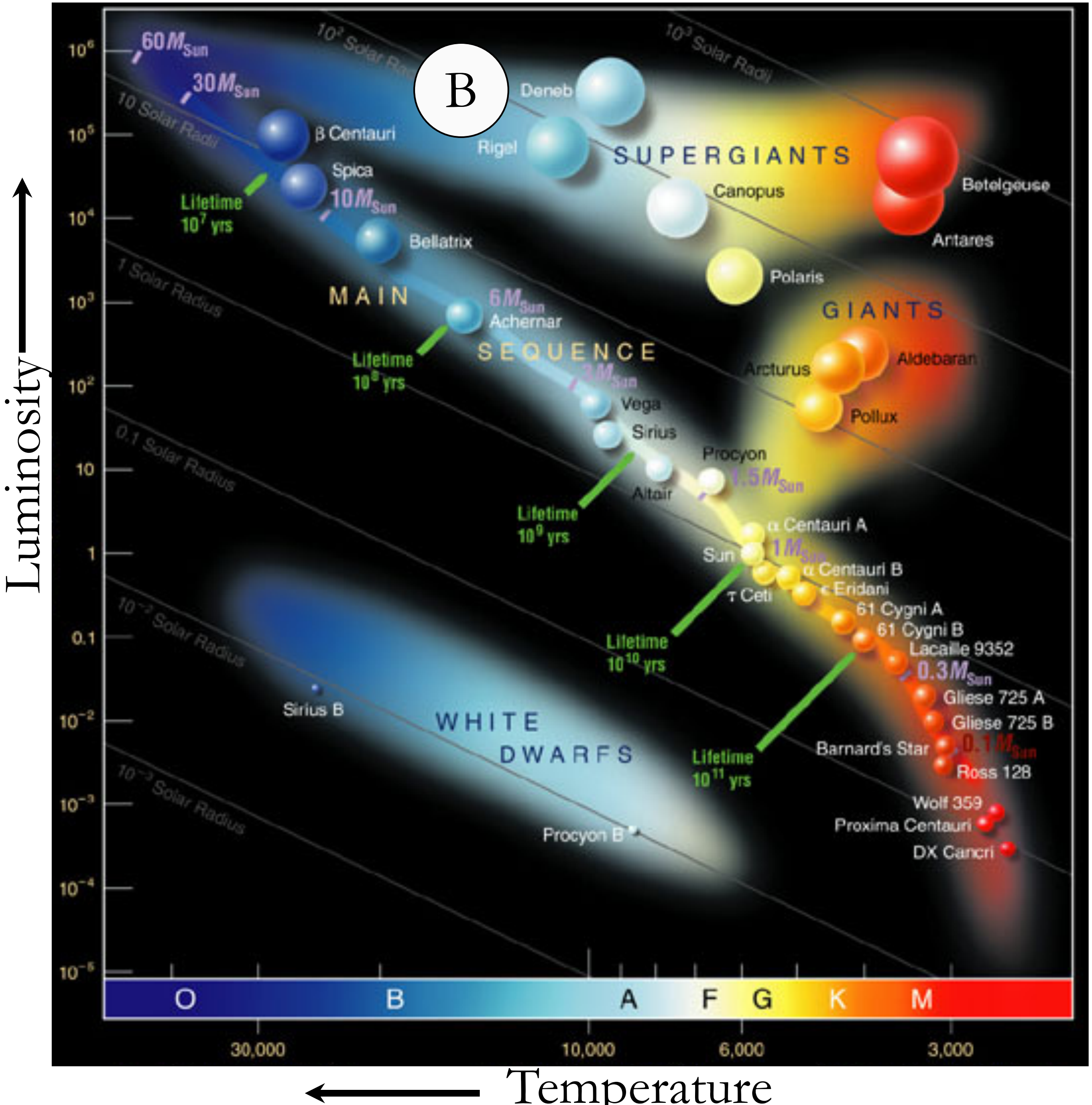


Which star is the hottest?

A

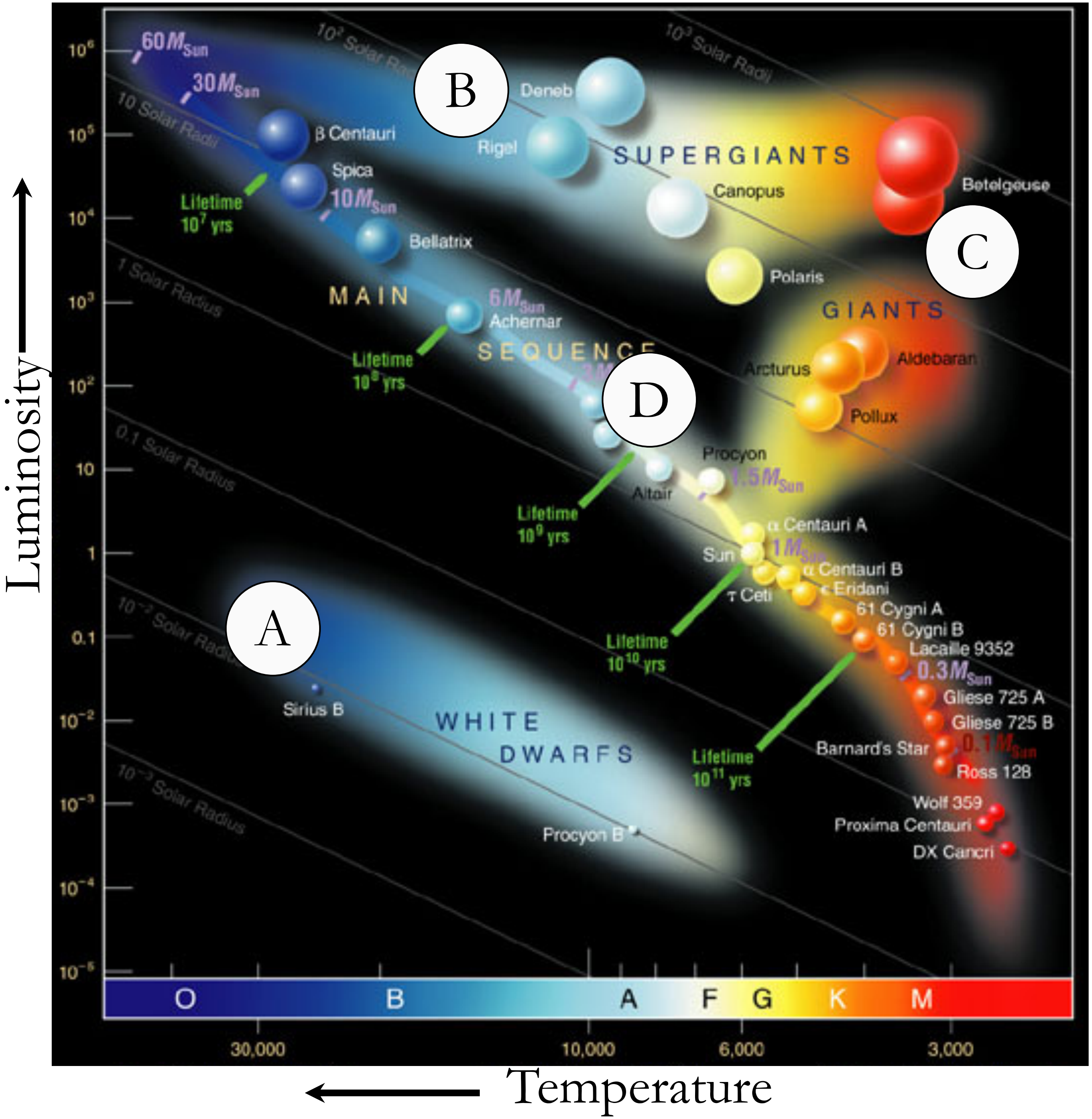


Which star is the most luminous?

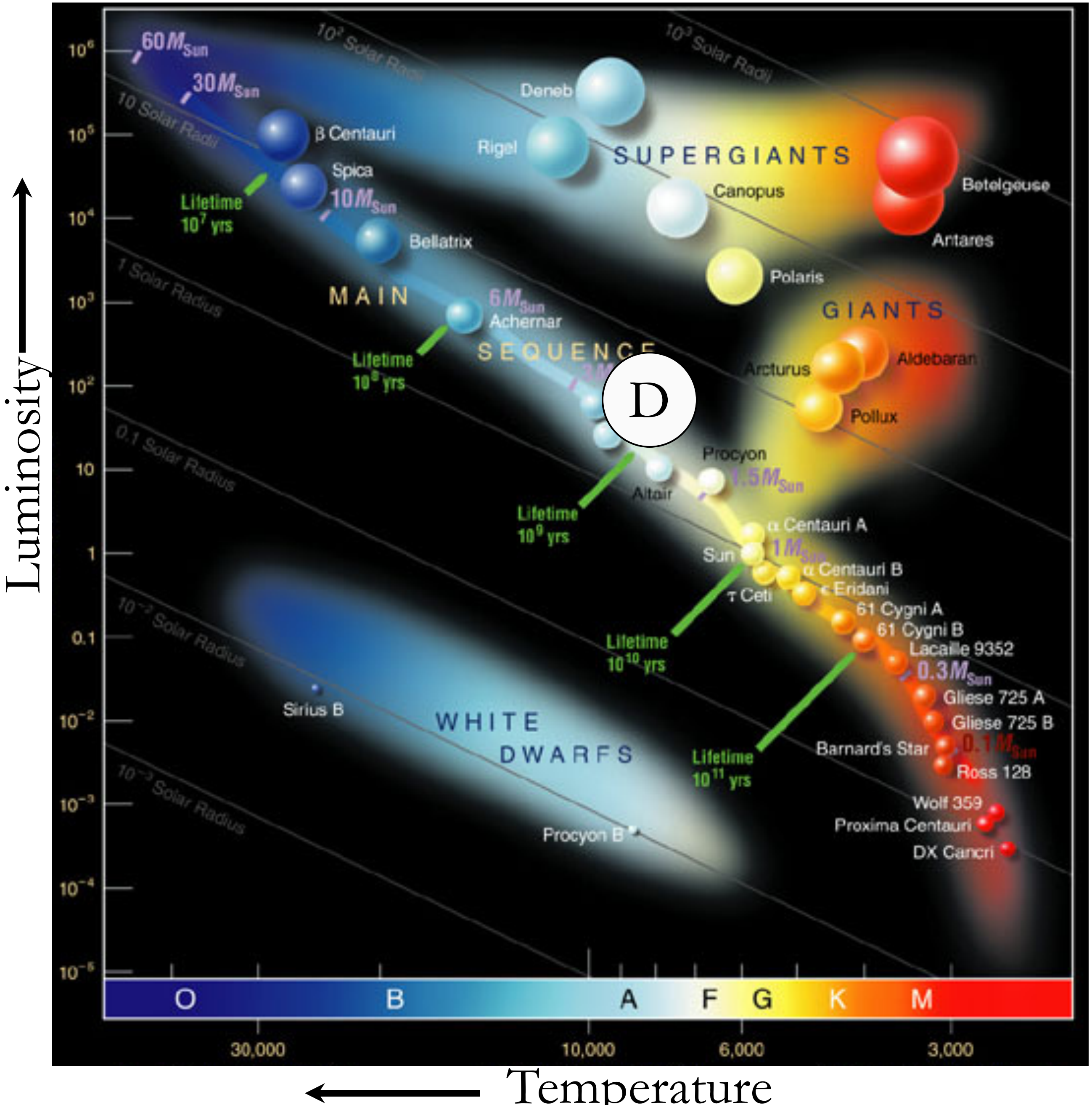


Which star is the most luminous?

B

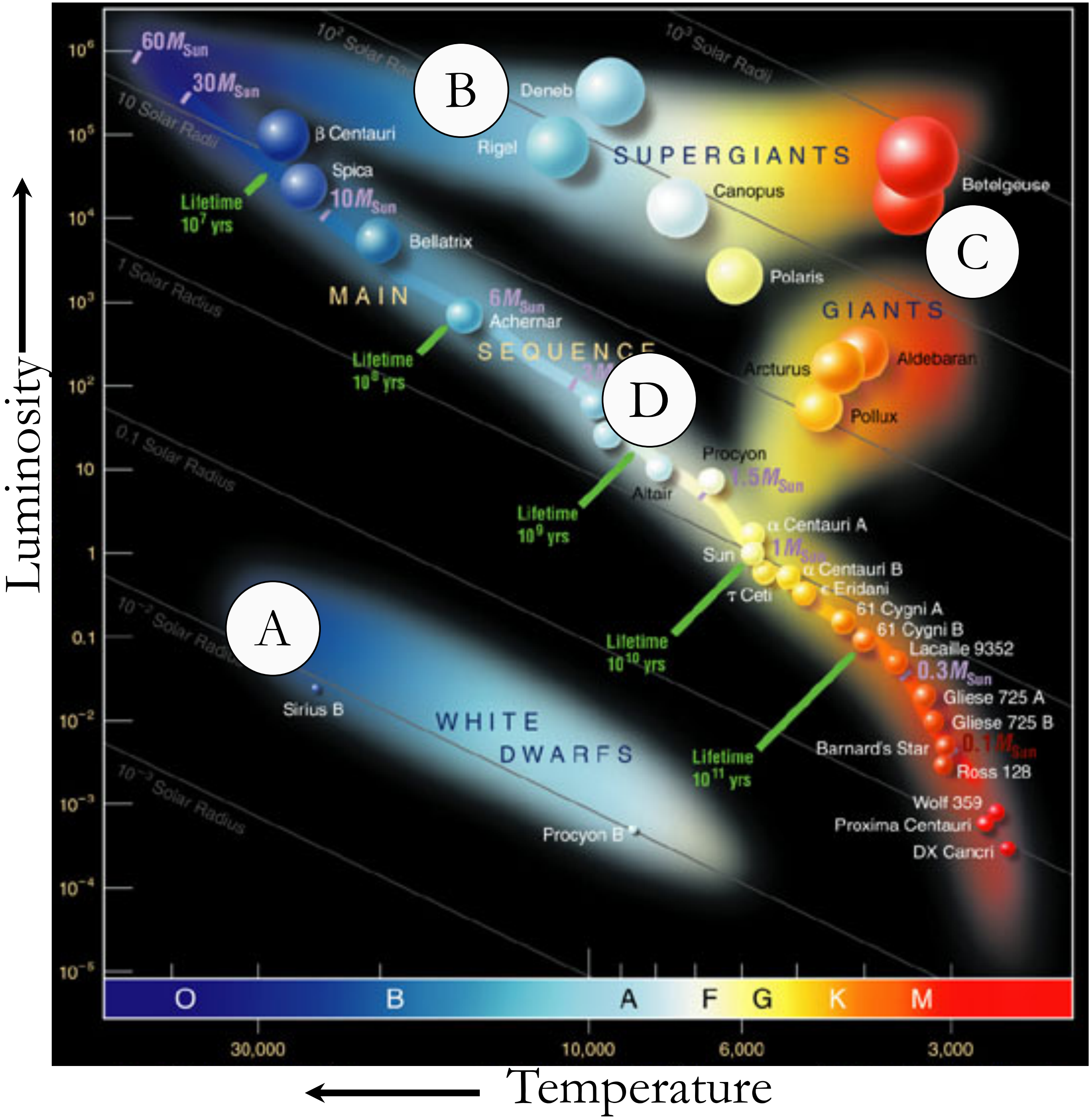


Which star is a main-sequence star?

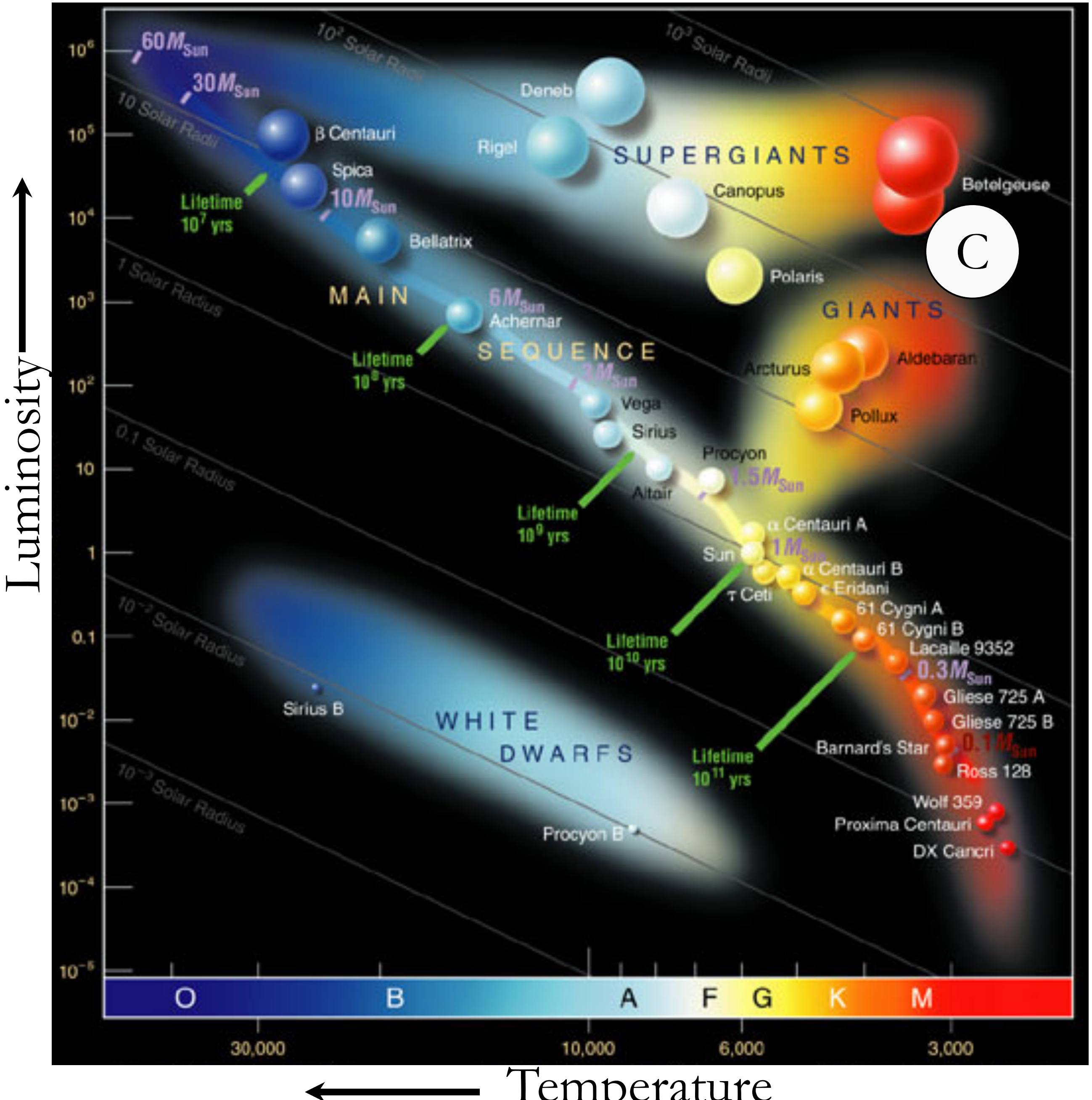


Which star is a main-sequence star?

D



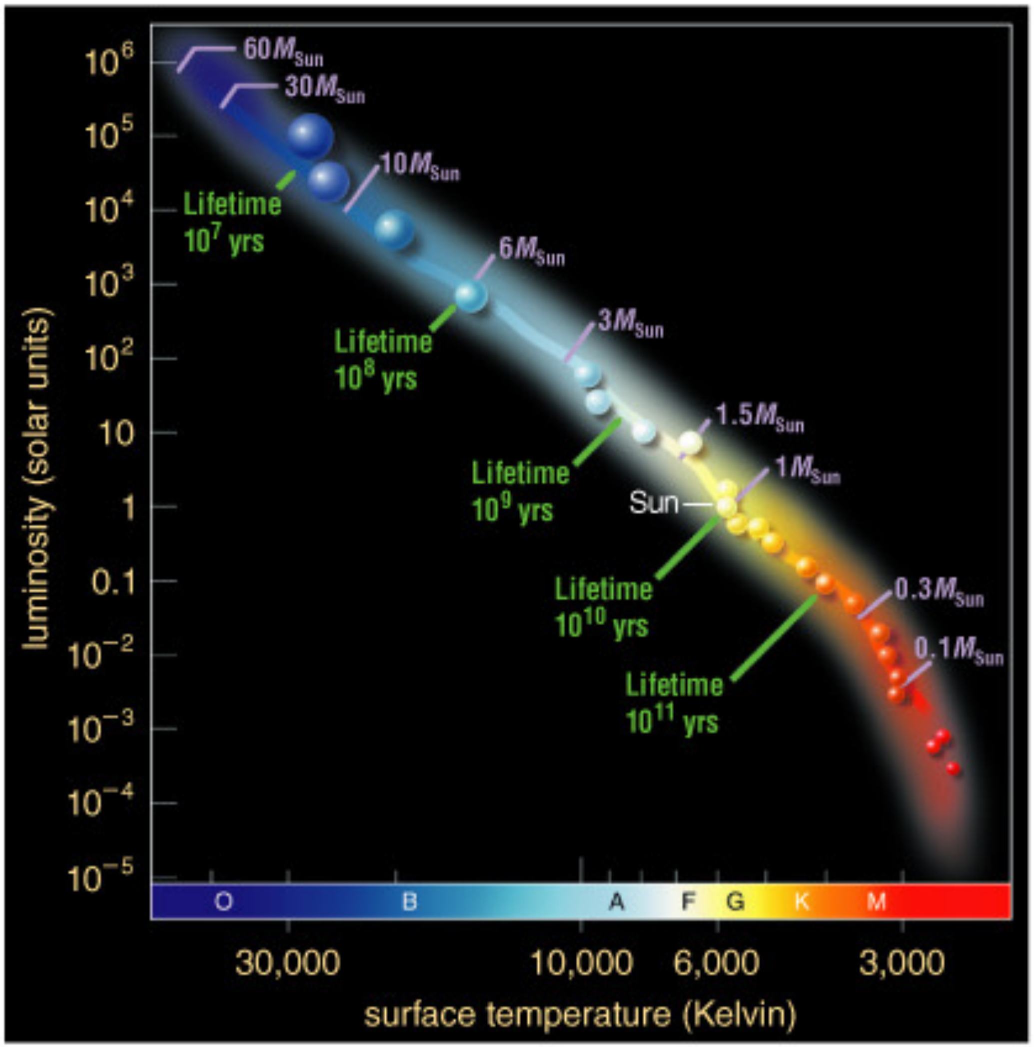
Which star has the largest radius?



Which star has the largest radius?

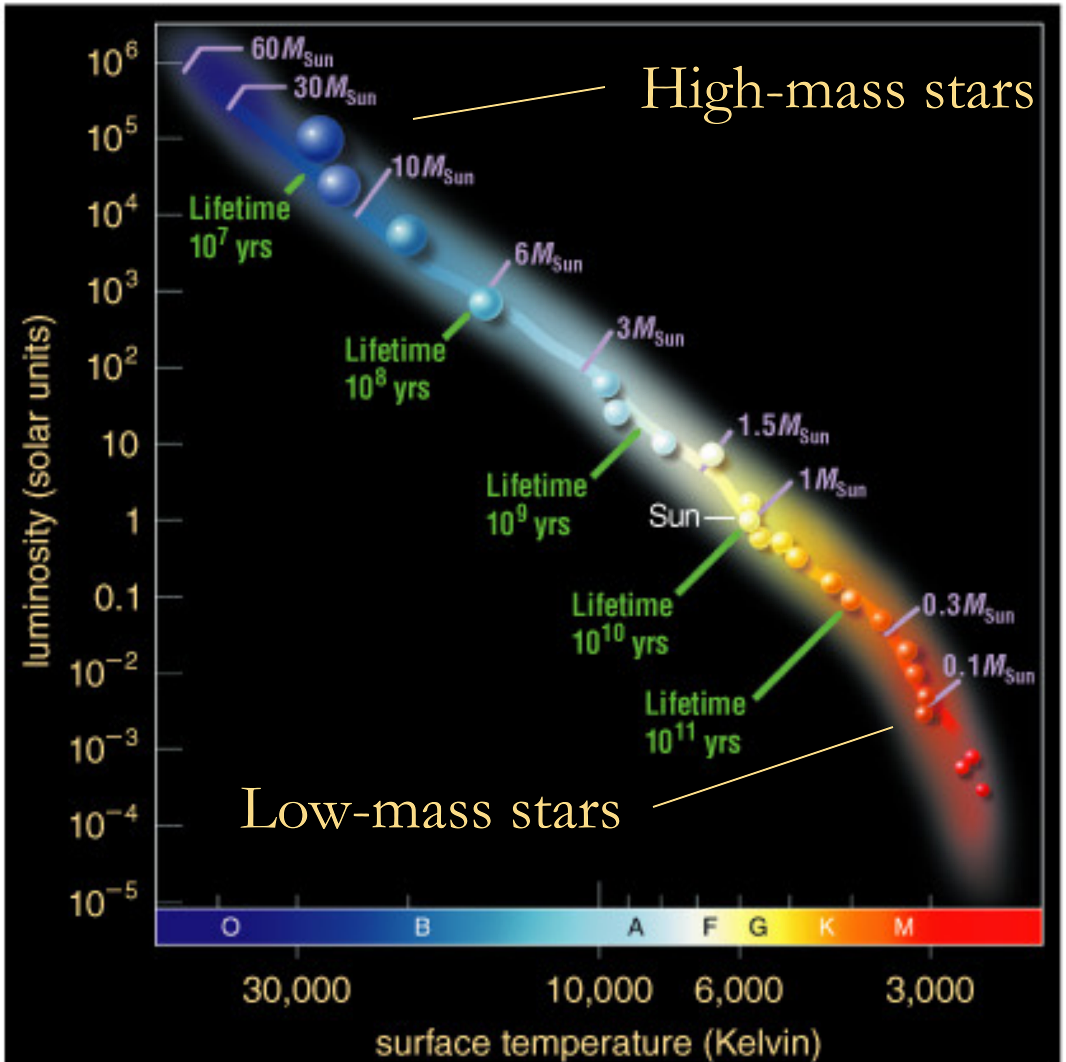
C

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).

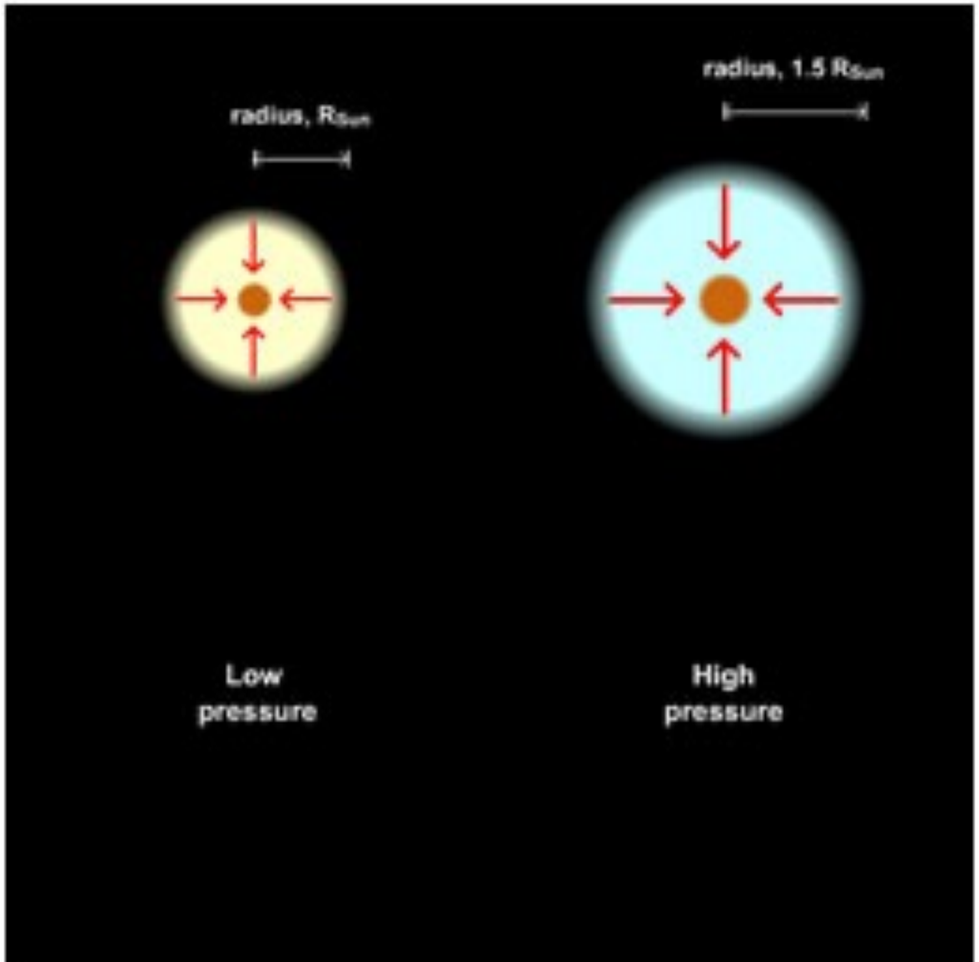
What is the significance of the main sequence?



- *Position along MS is related to mass*
- Hot, blue stars are much more **massive** than the cool, red ones.
- Mass *decreases* as you go down and right on the main sequence.
- Range:

  0.08 M_{Sun} - 150 M_{Sun}

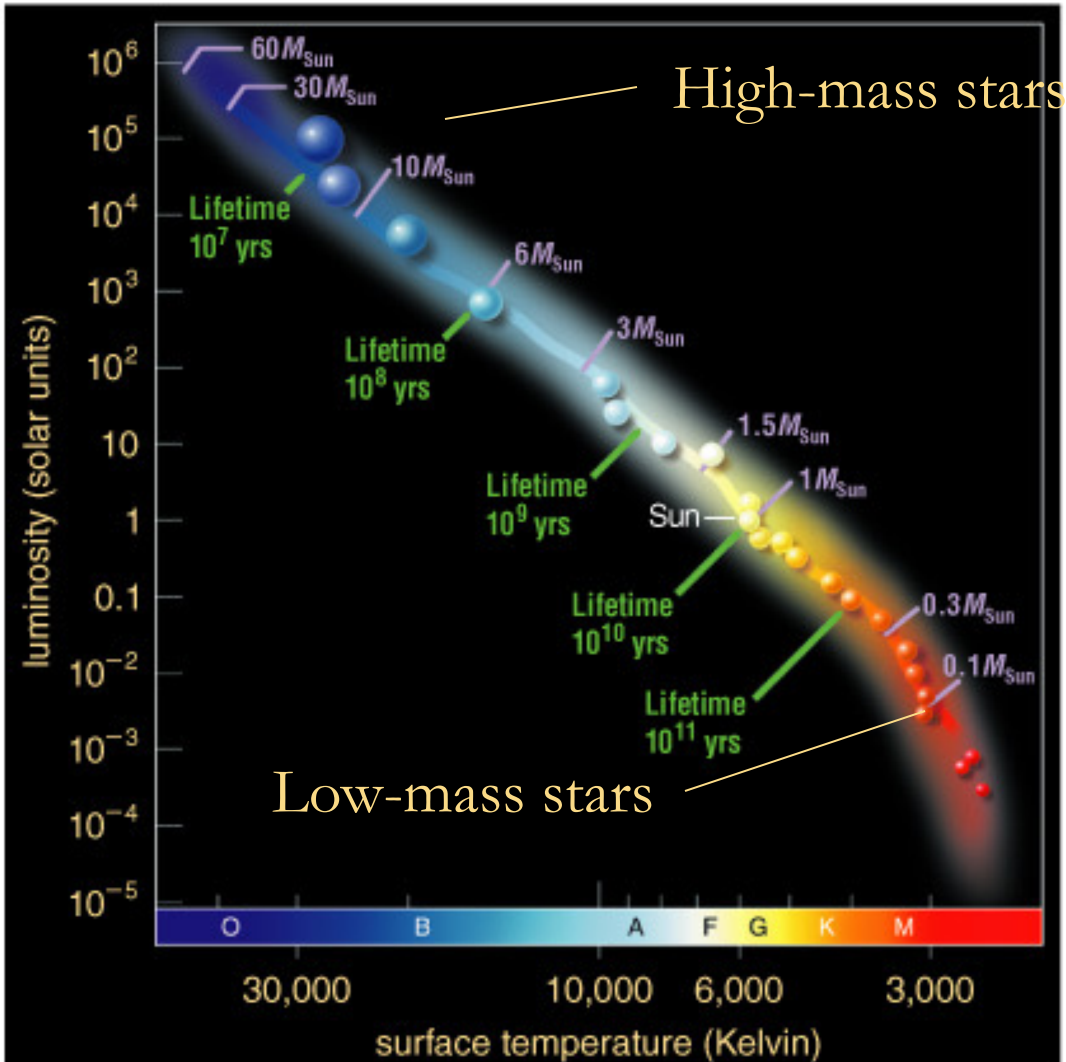
Pressure vs gravity



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.

What is the significance of the main sequence?



1) The **mass** of a normal, hydrogen-burning star determines its fusion rate.
2) Fusion rate determines the star's luminosity and spectral type (temperature).
3) Fusion rate and thus luminosity are very sensitive to mass.
4) Fusion rate has great effect on lifetime!

***Mass** is most important stellar property*

Stellar Properties Review

Luminosity: found from brightness and distance

(0.08 M_{Sun}) $10^{-4} L_{Sun} - 10^{6} L_{Sun}$ (150 M_{Sun})

Temperature: found from color and spectral type

(0.08 M_{Sun}) 3,000 K – 50,000 K (150 M_{Sun})

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

$0.08 M_{Sun} - 150 M_{Sun}$

Mass and Lifetime

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

Life expectancy of a 0.1 M_{Sun} star:

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

10 billion years × 0.1/0.01 ~ 100 billion years

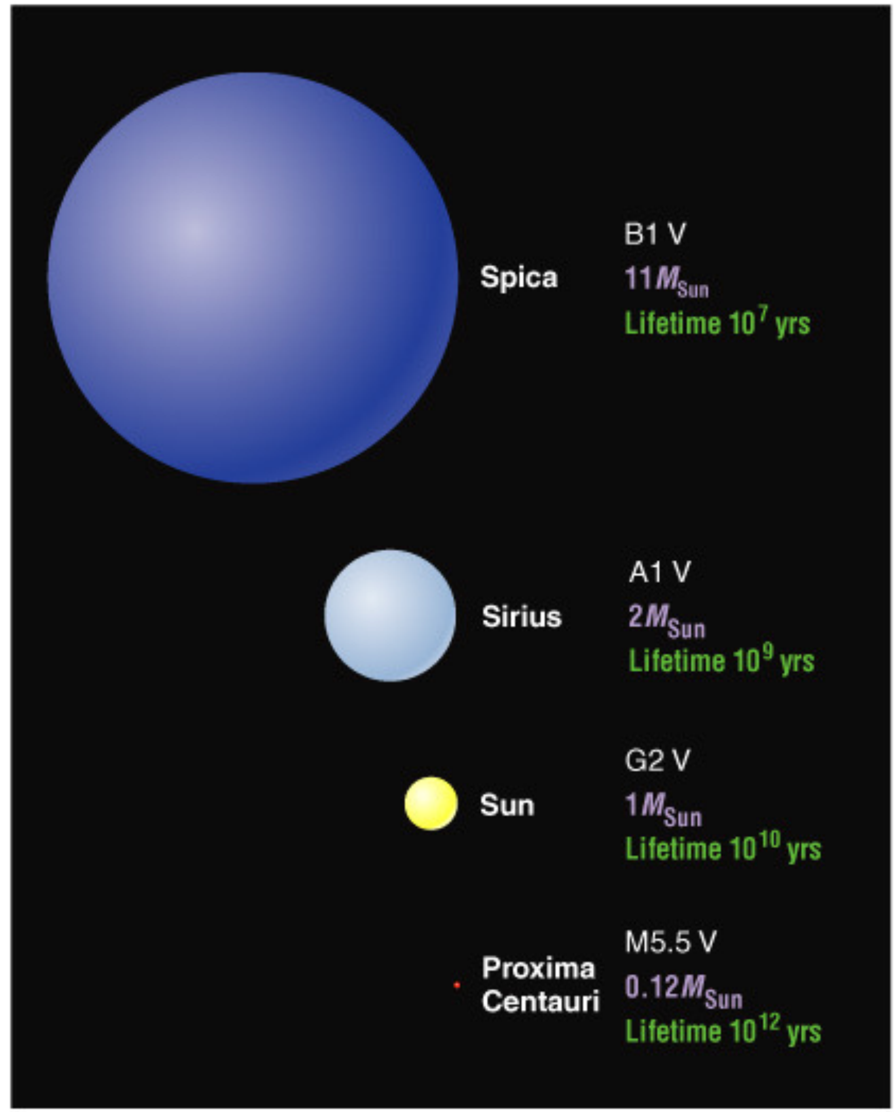
Main-Sequence Star Summary

High-mass:

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

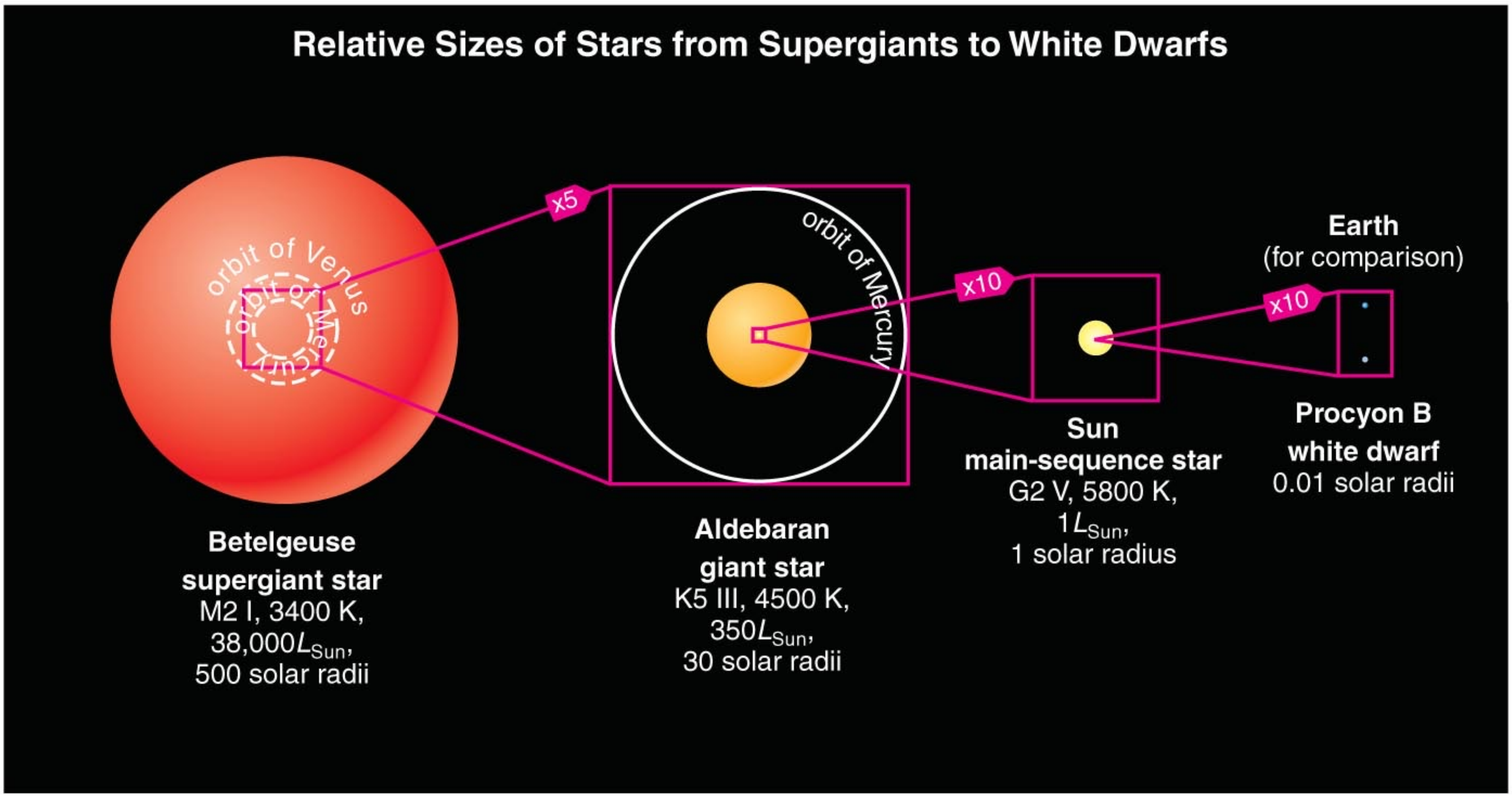
Low-mass:

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

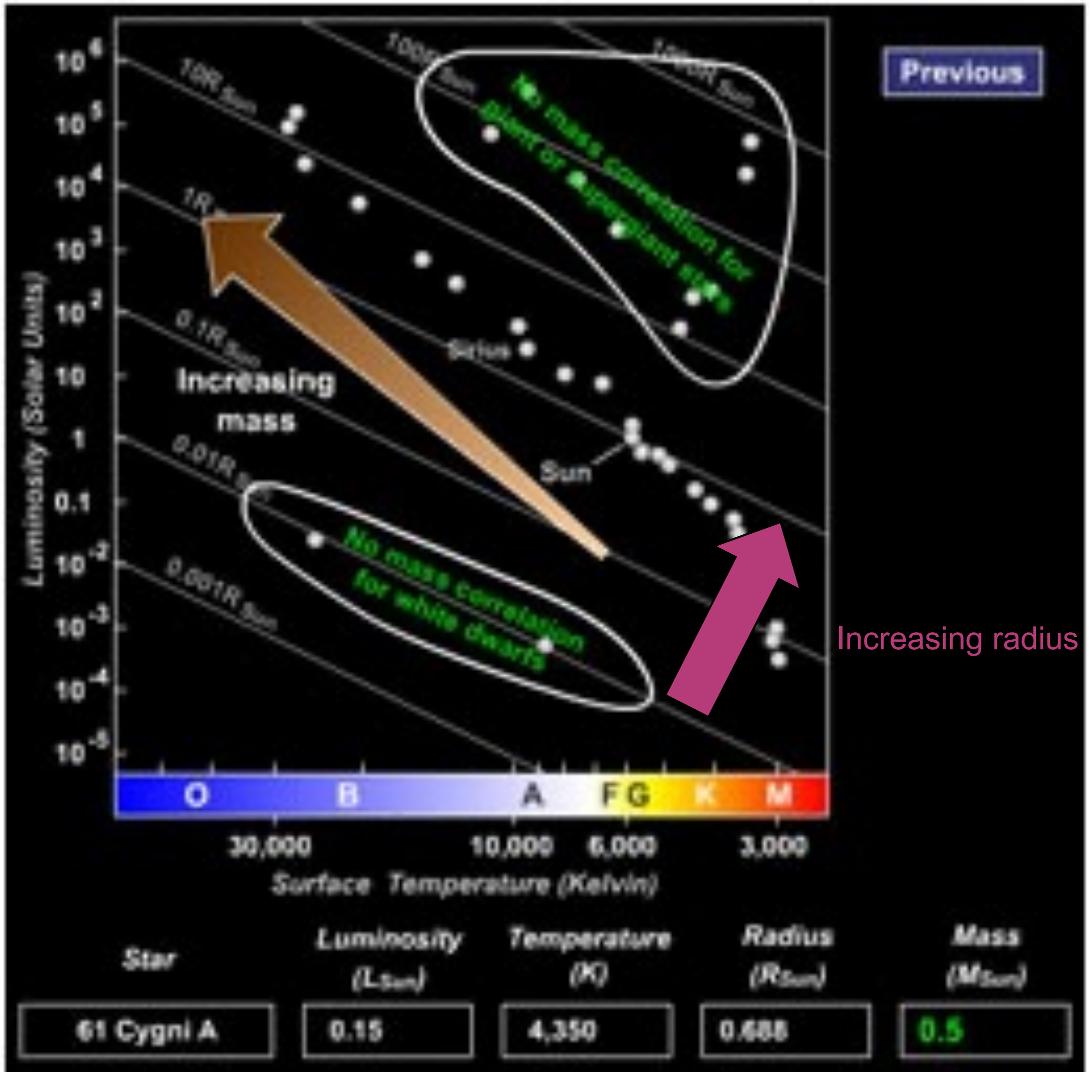


What are giants, supergiants, and white dwarfs?

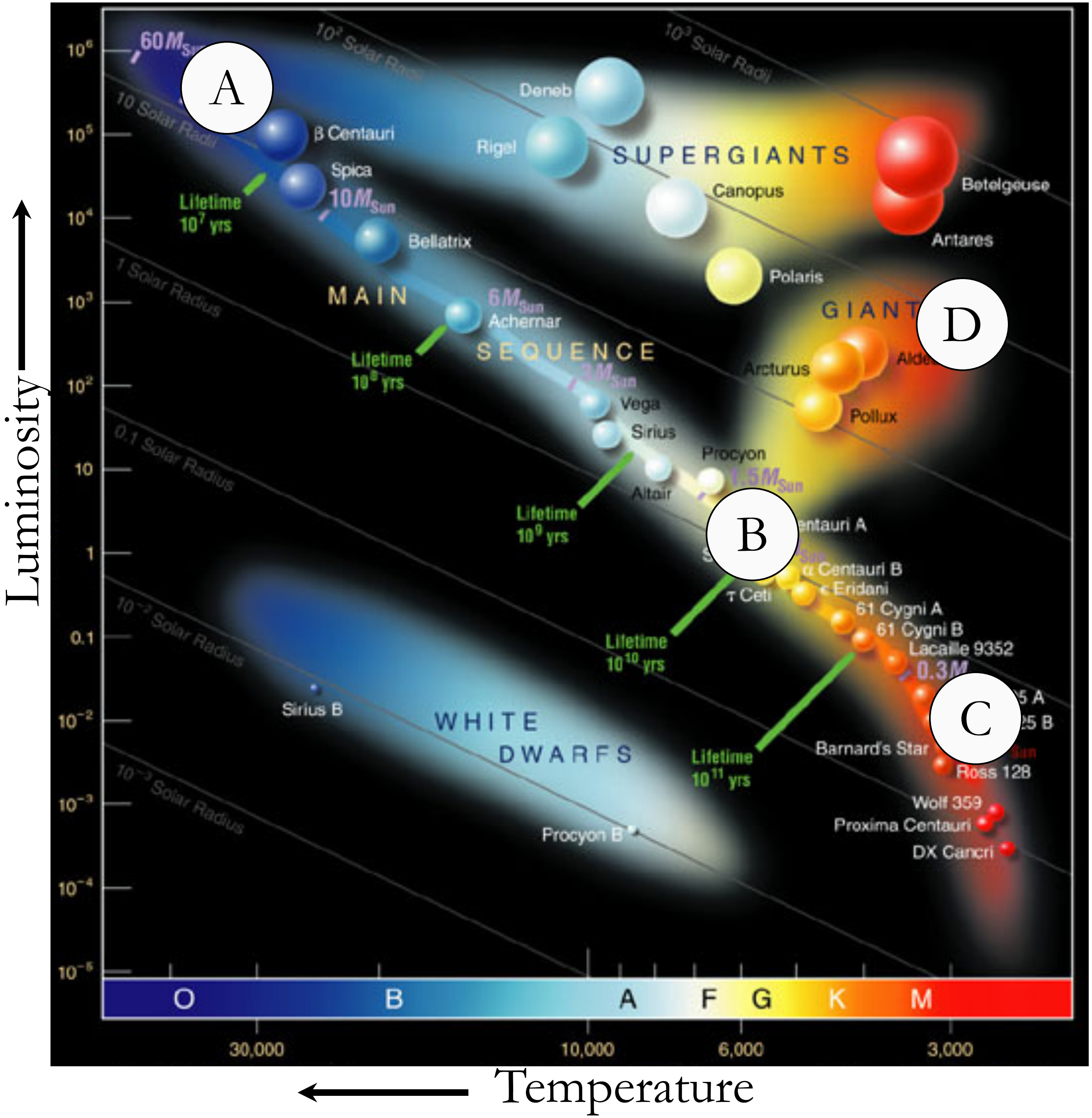
Sizes of Giants and Supergiants



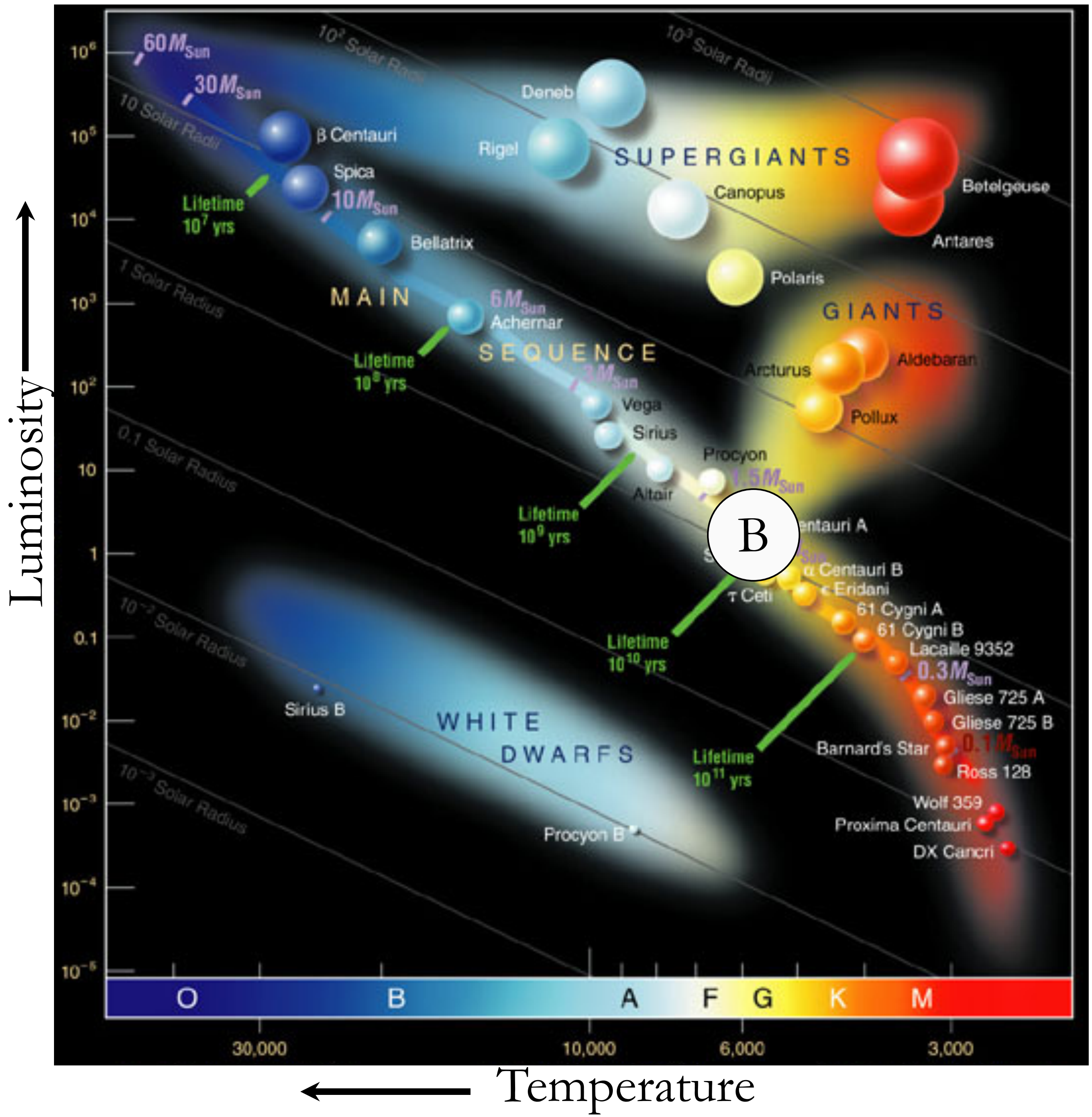
Relationship between Main-Sequence Stellar Masses, Radii, and Location on H-R Diagram



- **Mass** increases to the upper left *on the Main Sequence*
- **Radius** increases to the upper right

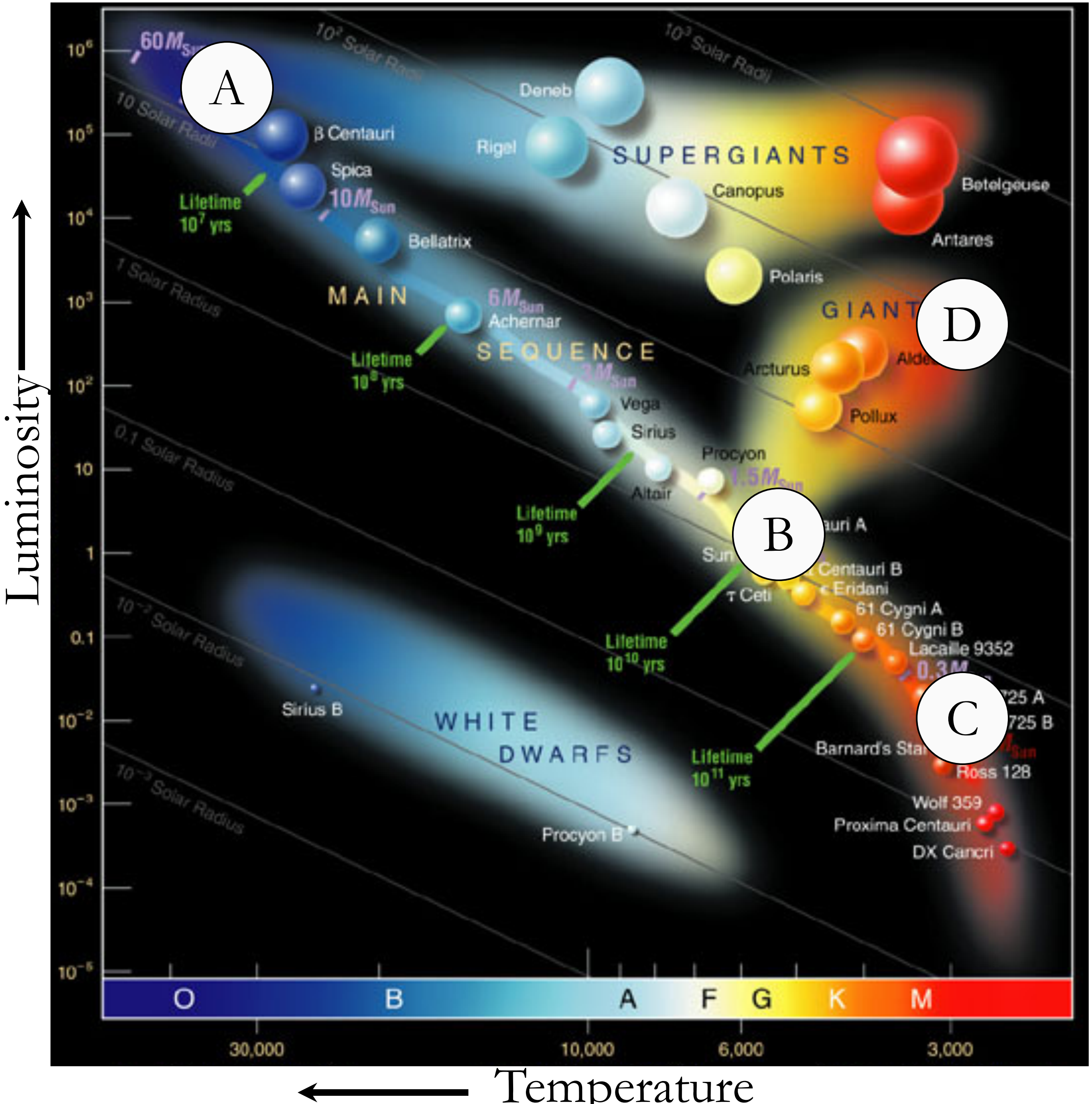


Which star is most like our Sun?

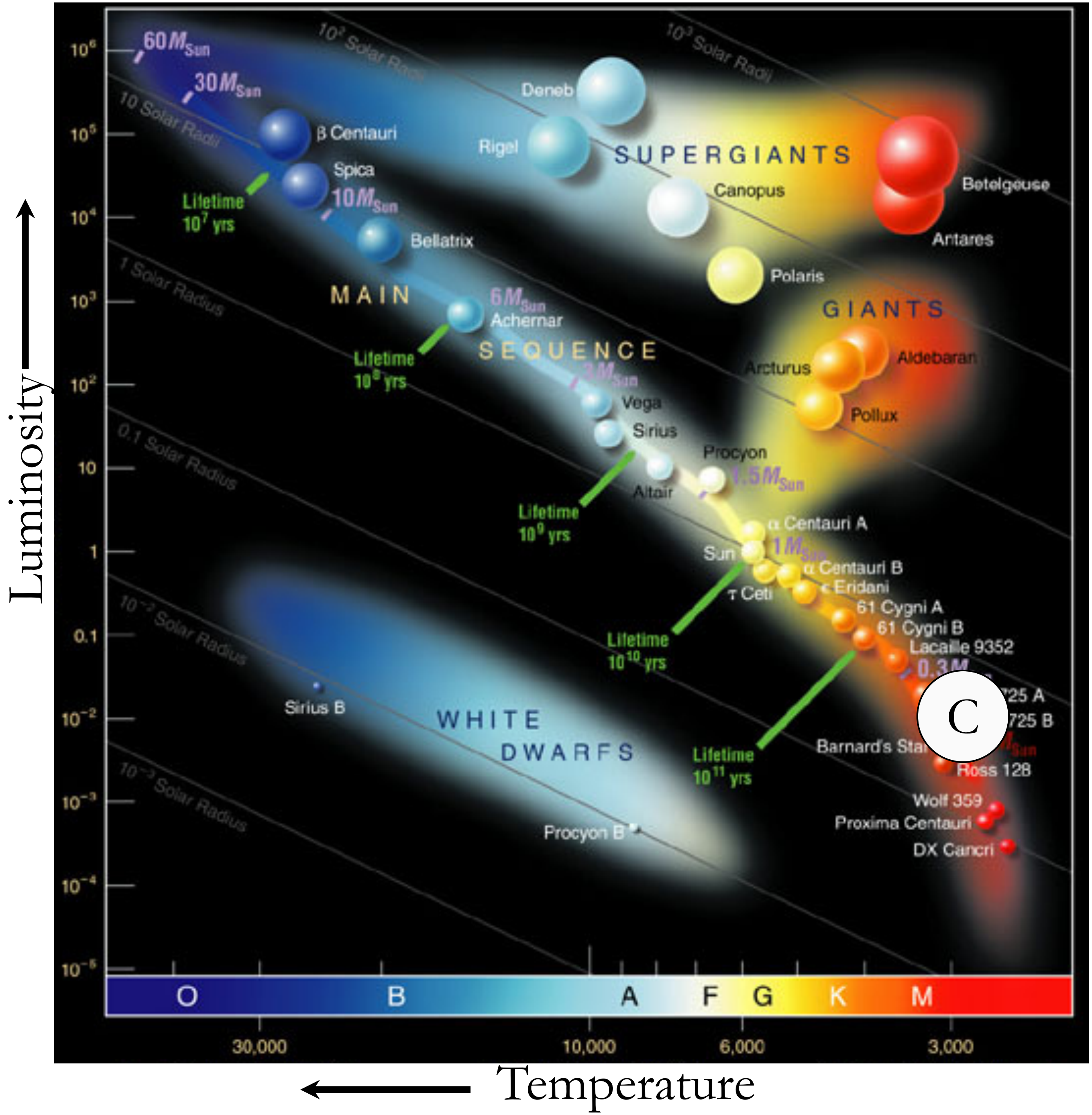


Which star is most like our Sun?

B

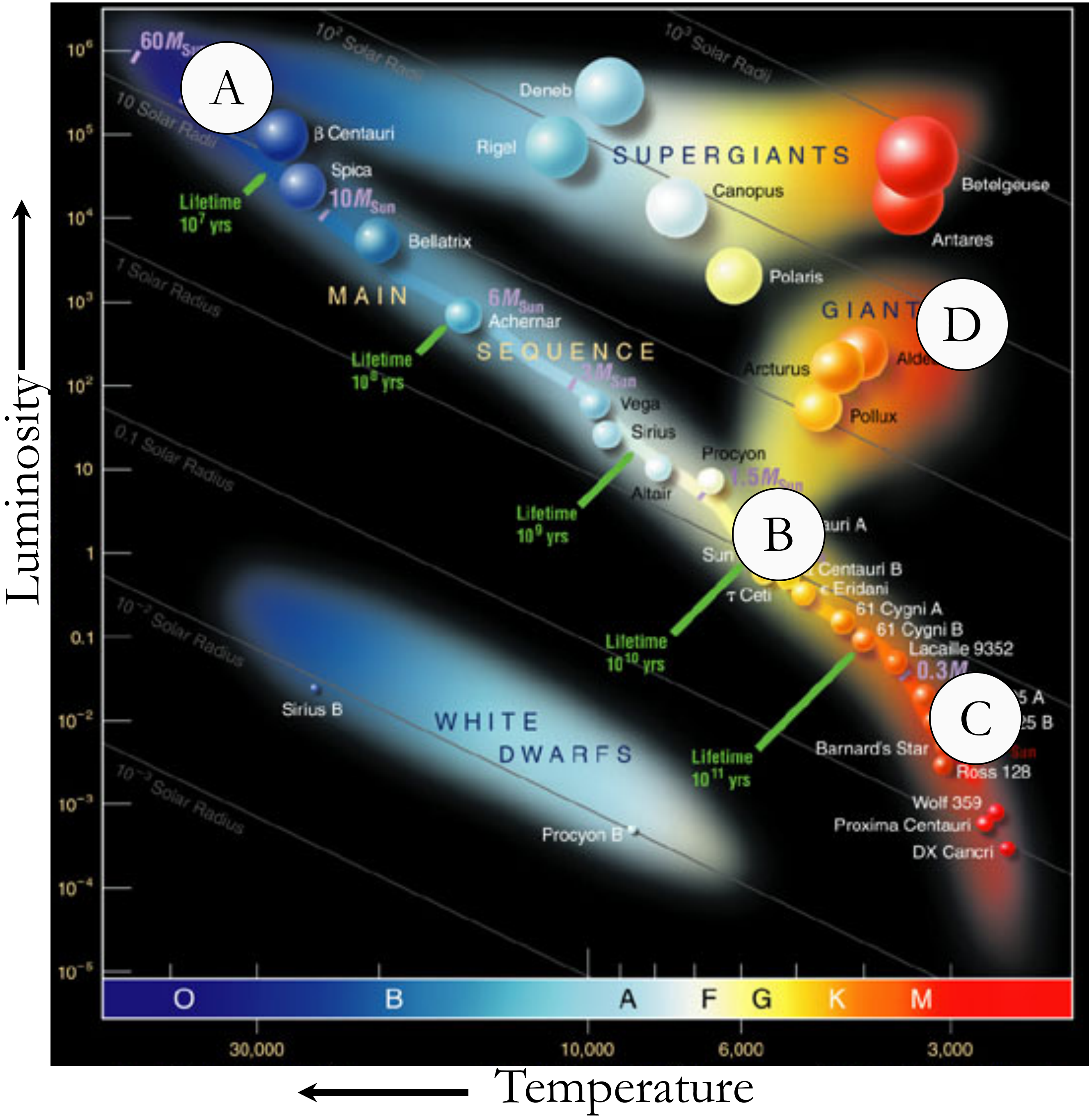


Which of these stars will have changed the least 10 billion years from now?

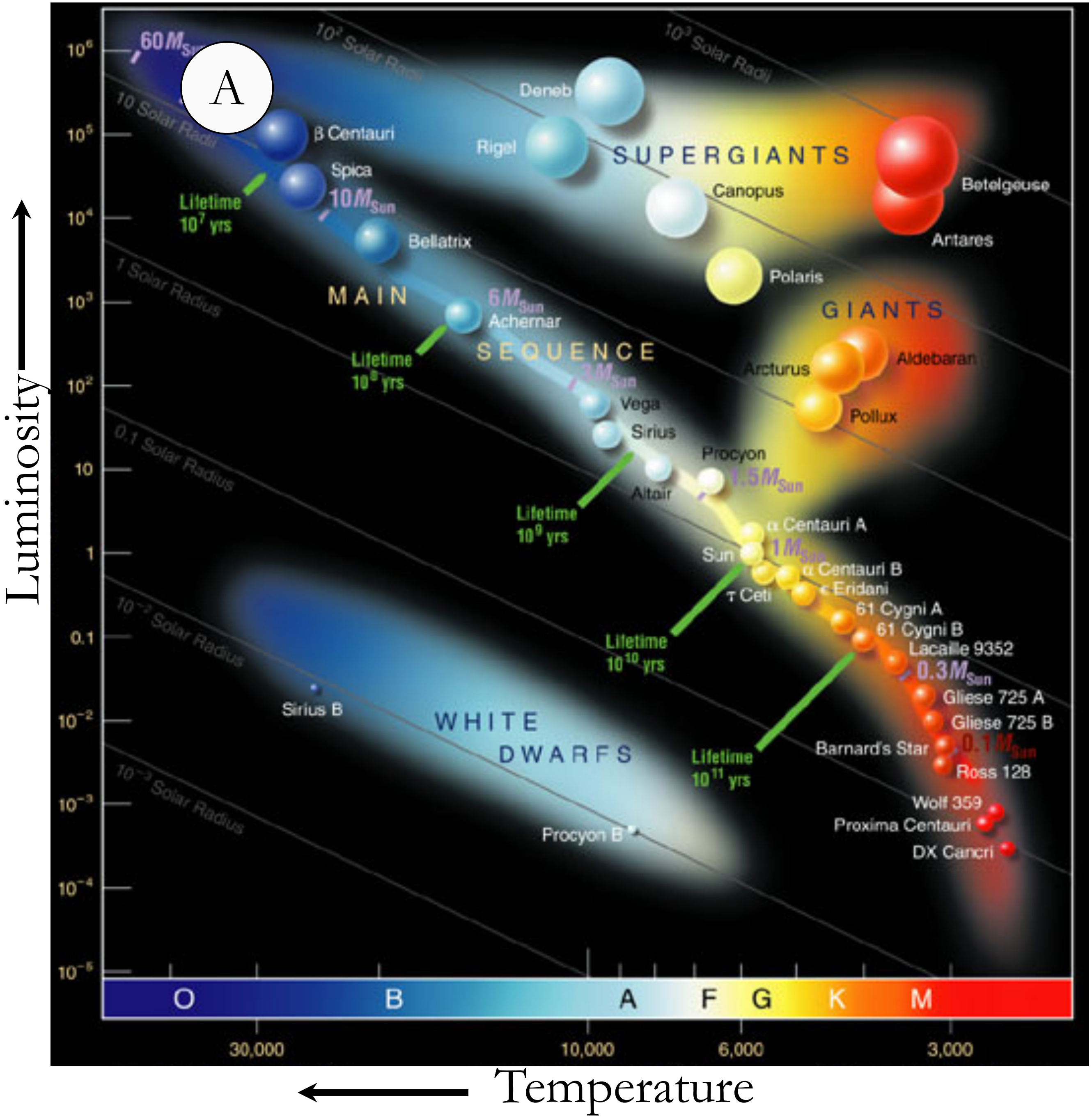


Which of these stars will have changed the least 10 billion years from now?

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?

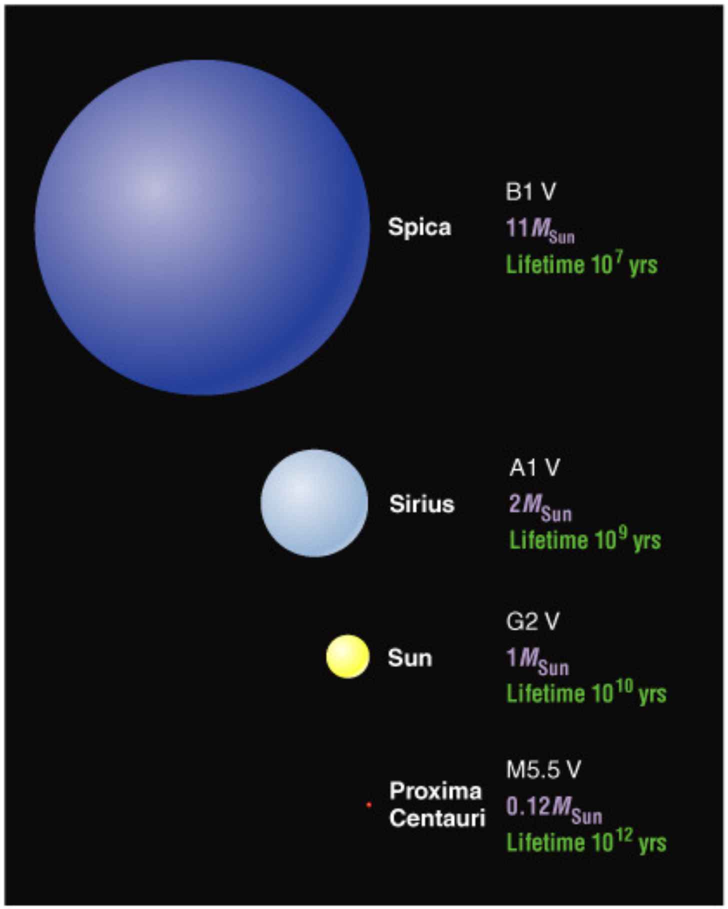
A

Off the Main Sequence

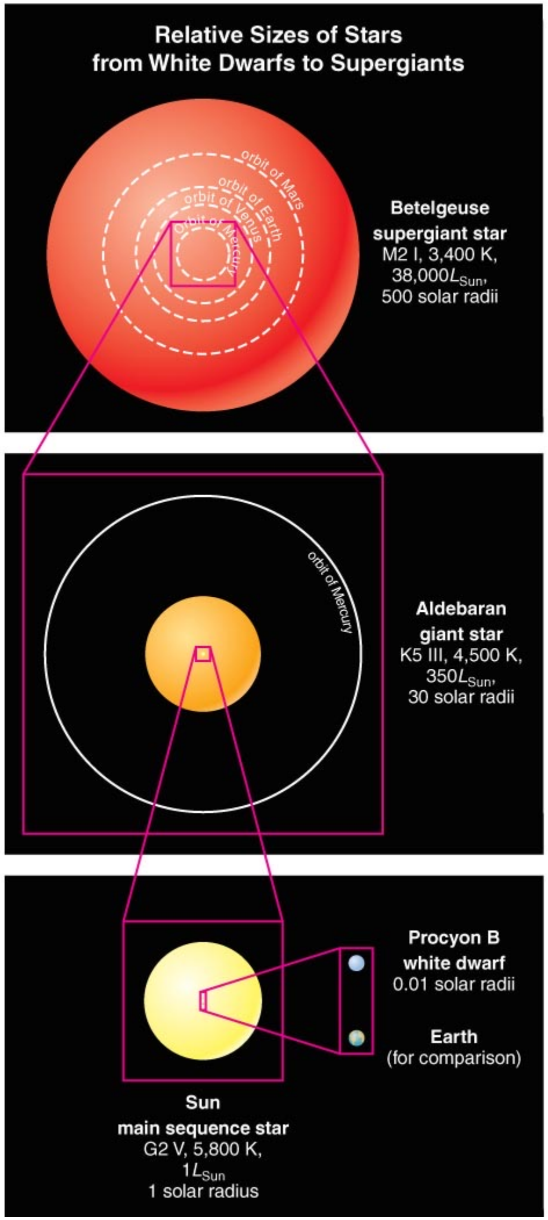
- Stellar properties depend on both **mass** and **age**: *those that have finished fusing H to He in their cores are no longer on the main sequence.*
- *All* stars become larger and redder after exhausting their core hydrogen and become **giants** and **supergiants.** These are cooler but more luminous than MS stars, larger in radius.
- Low mass stars end up small after fusion has ceased. They eject their outer layers and become **white dwarfs.**

Off the Main Sequence

As stars use up their hydrogen fuel, *they leave the main sequence* to become giants, supergiants, and white dwarfs



Main-sequence stars (to scale)



Giants, supergiants, white dwarfs

What have we learned?

Begin 3 minute review

What have we learned?

What is a Hertzsprung–Russell diagram?

An H-R diagram plots the stellar **luminosity** of stars versus surface **temperature** (or color or spectral type).

What is the significance of the main sequence?

Normal stars that fuse H to He in their cores fall on the **main sequence** of an H-R diagram.

A star's **mass** determines its position along the main sequence (high mass: luminous and blue; low mass: faint and red).

What have we learned?

What are giants, supergiants, and white dwarfs?

All stars become larger and redder after core hydrogen burning is exhausted: **giants** and **supergiants.**

Most stars end up as tiny **white dwarfs** after fusion has ceased.

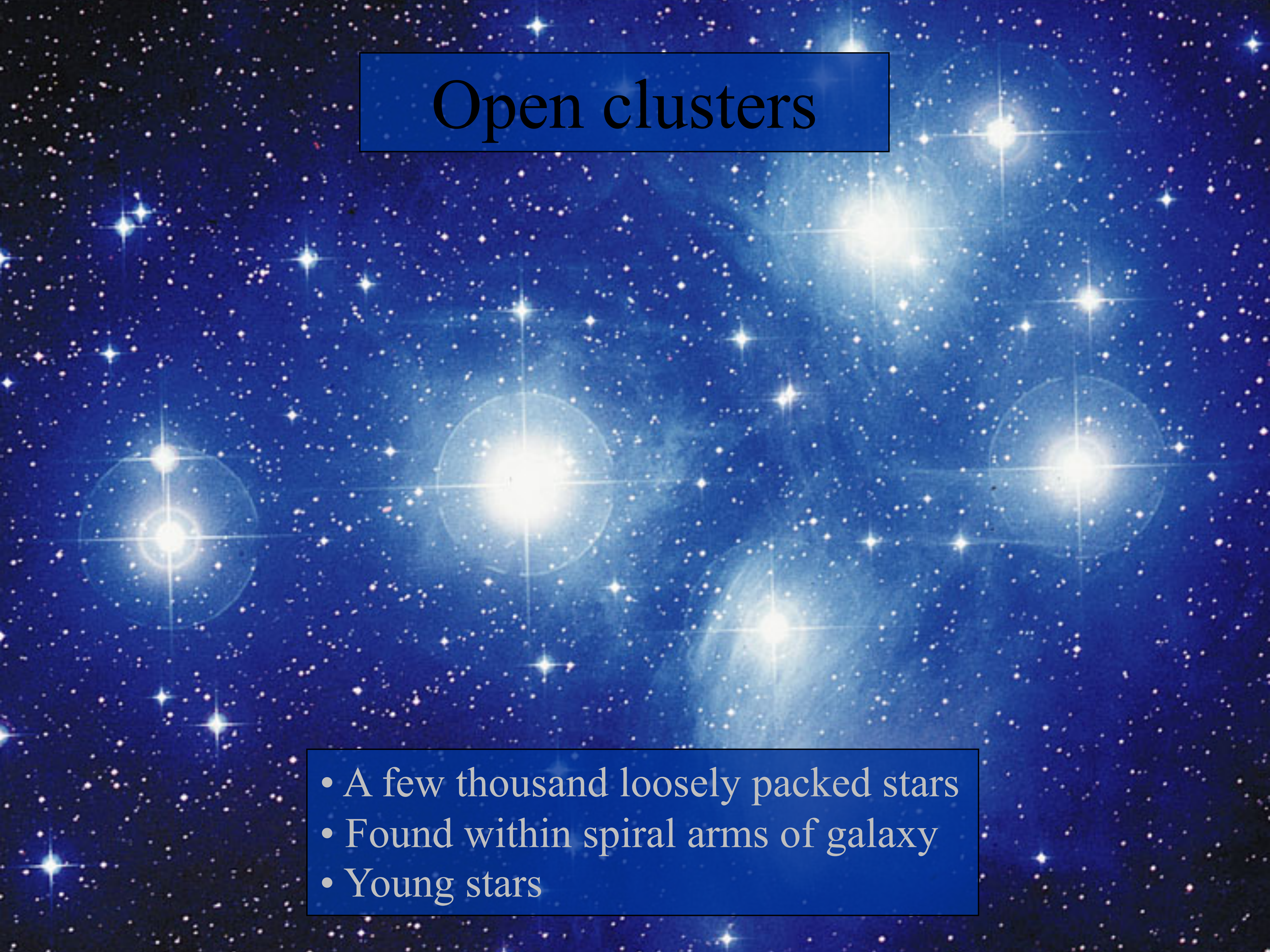
What are the two types of star clusters?

• Stars usually form in groups or clusters.

• They are extremely useful to study because (1) they are at the same **distance** and (2) they are the same **age**, (3) they have the same **composition**.

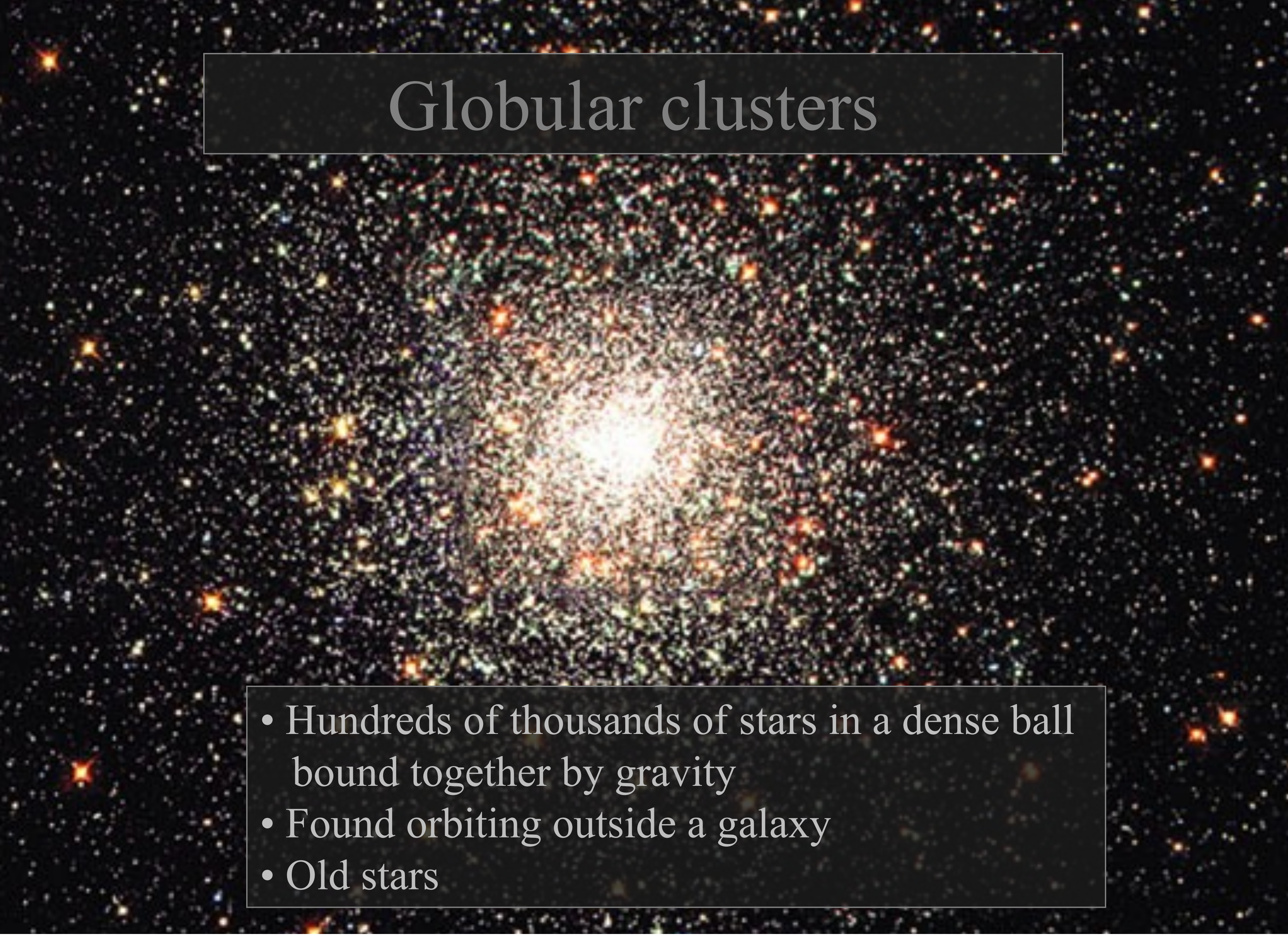
• This allows us to compare them easily and accurately.

Open clusters



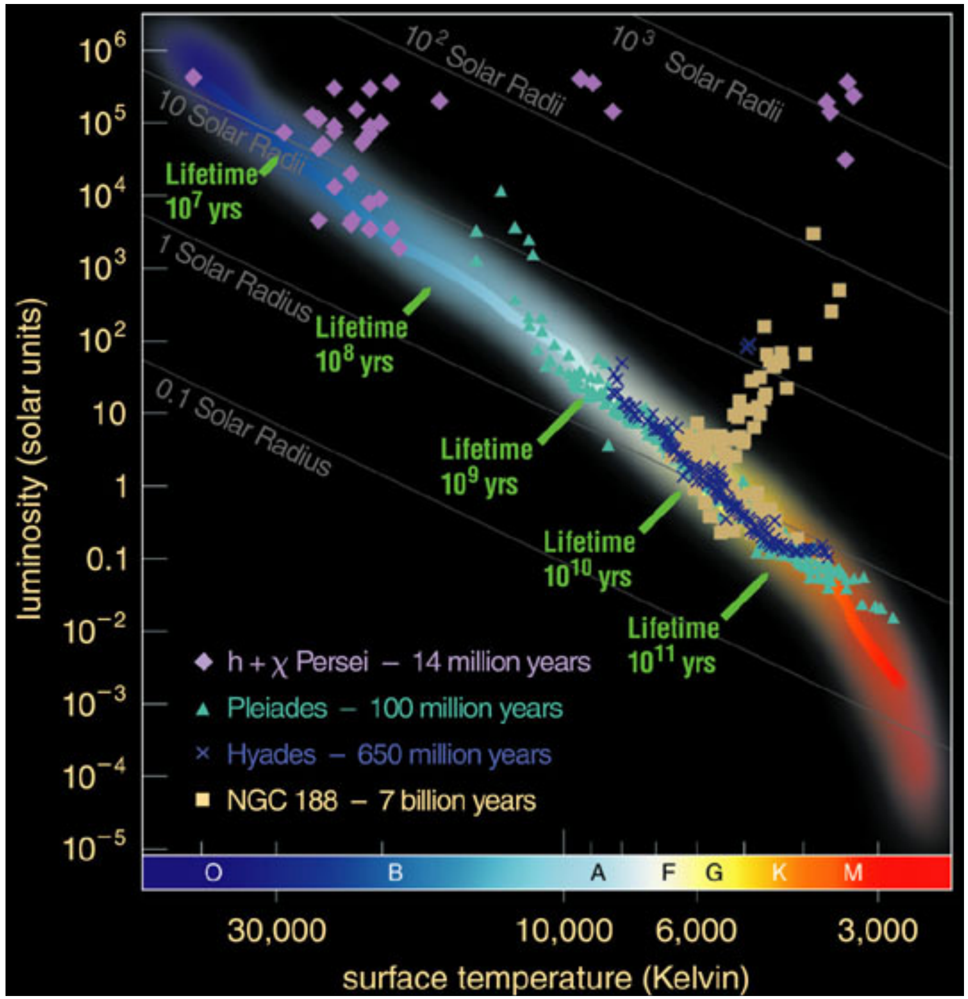
- A few thousand loosely packed stars
- Found within spiral arms of galaxy
- Young stars

Globular clusters

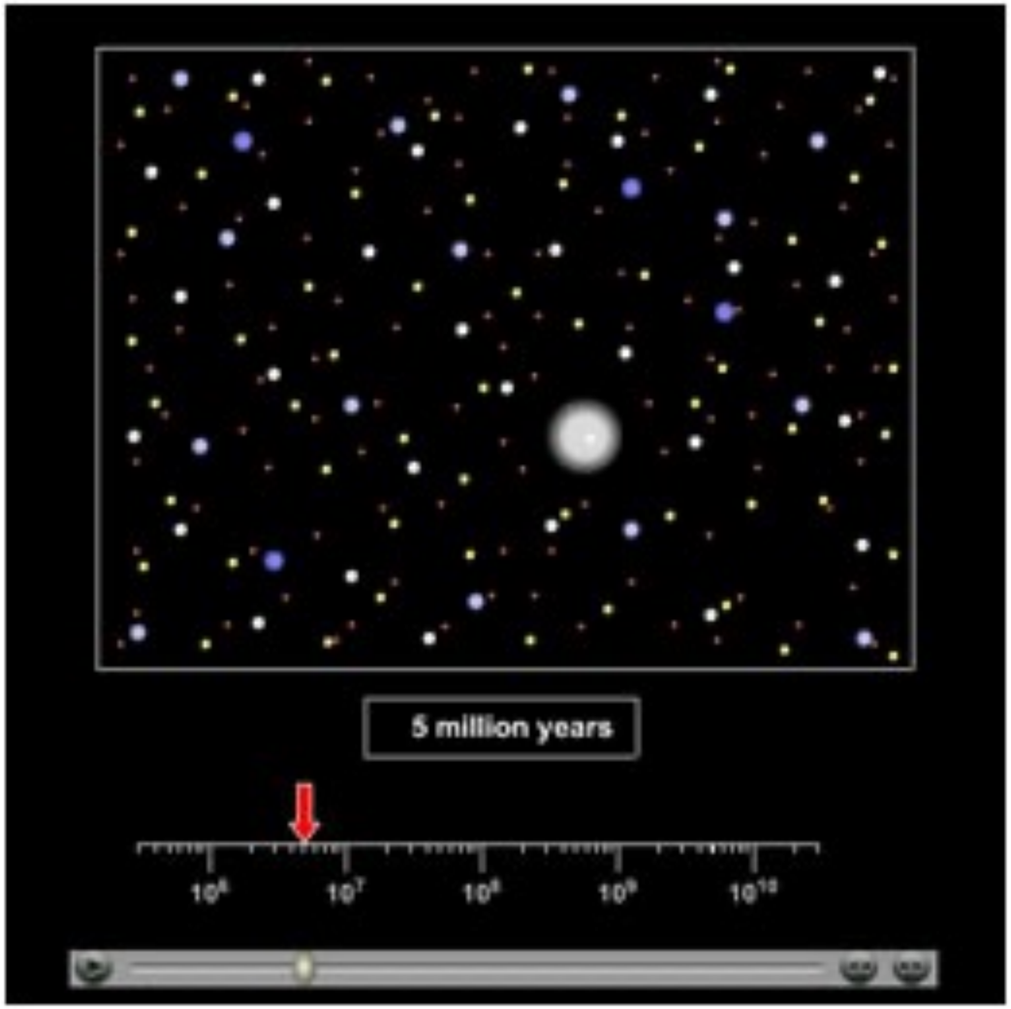


- Hundreds of thousands of stars in a dense ball bound together by gravity
- Found orbiting outside a galaxy
- Old stars

How do we measure the age of a star cluster?



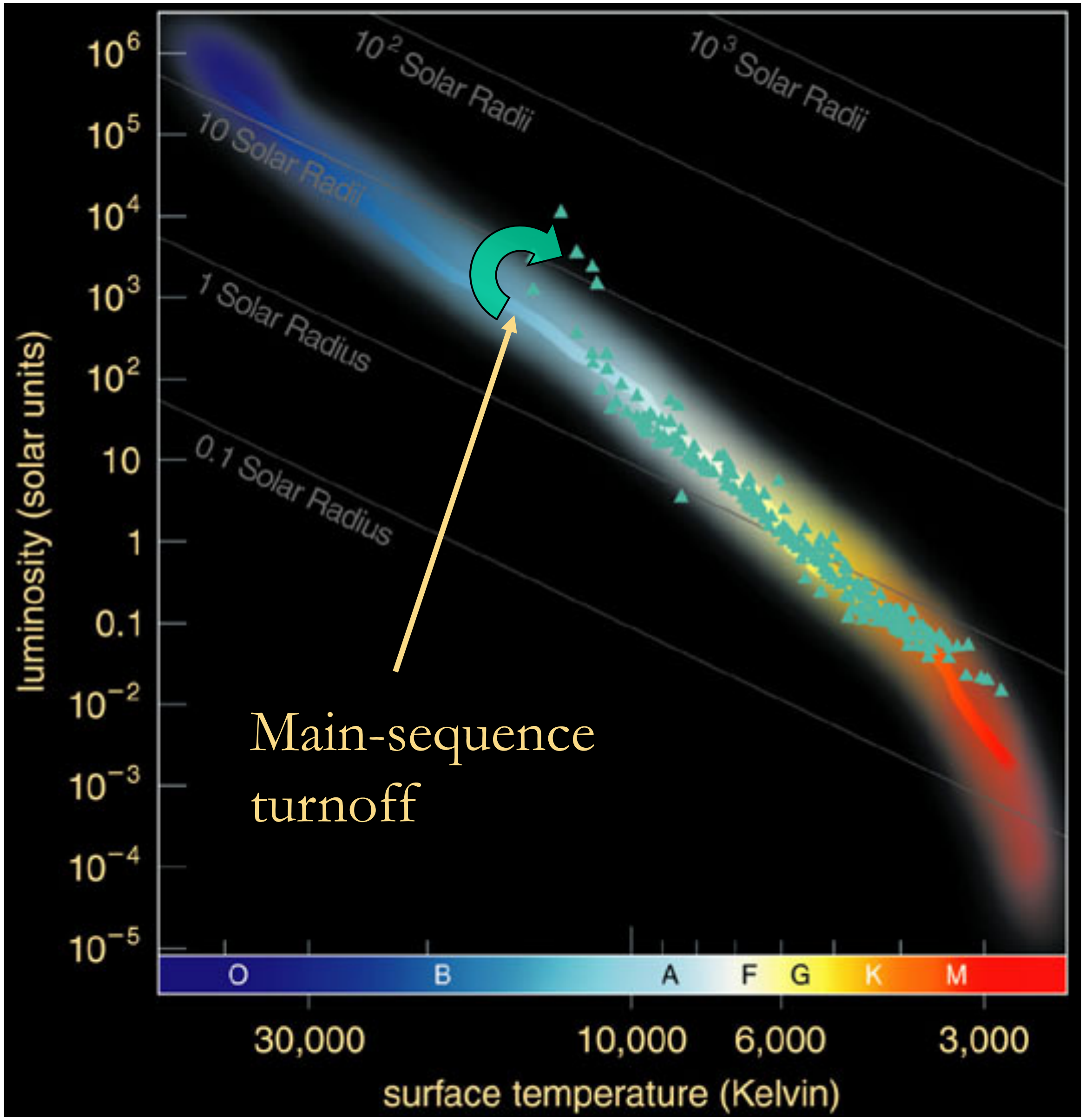
Stellar evolution



- Stars evolve by mass:
- Massive blue stars die first, followed by white, yellow, orange, and then red stars.
- Current remaining stars give us age of cluster!

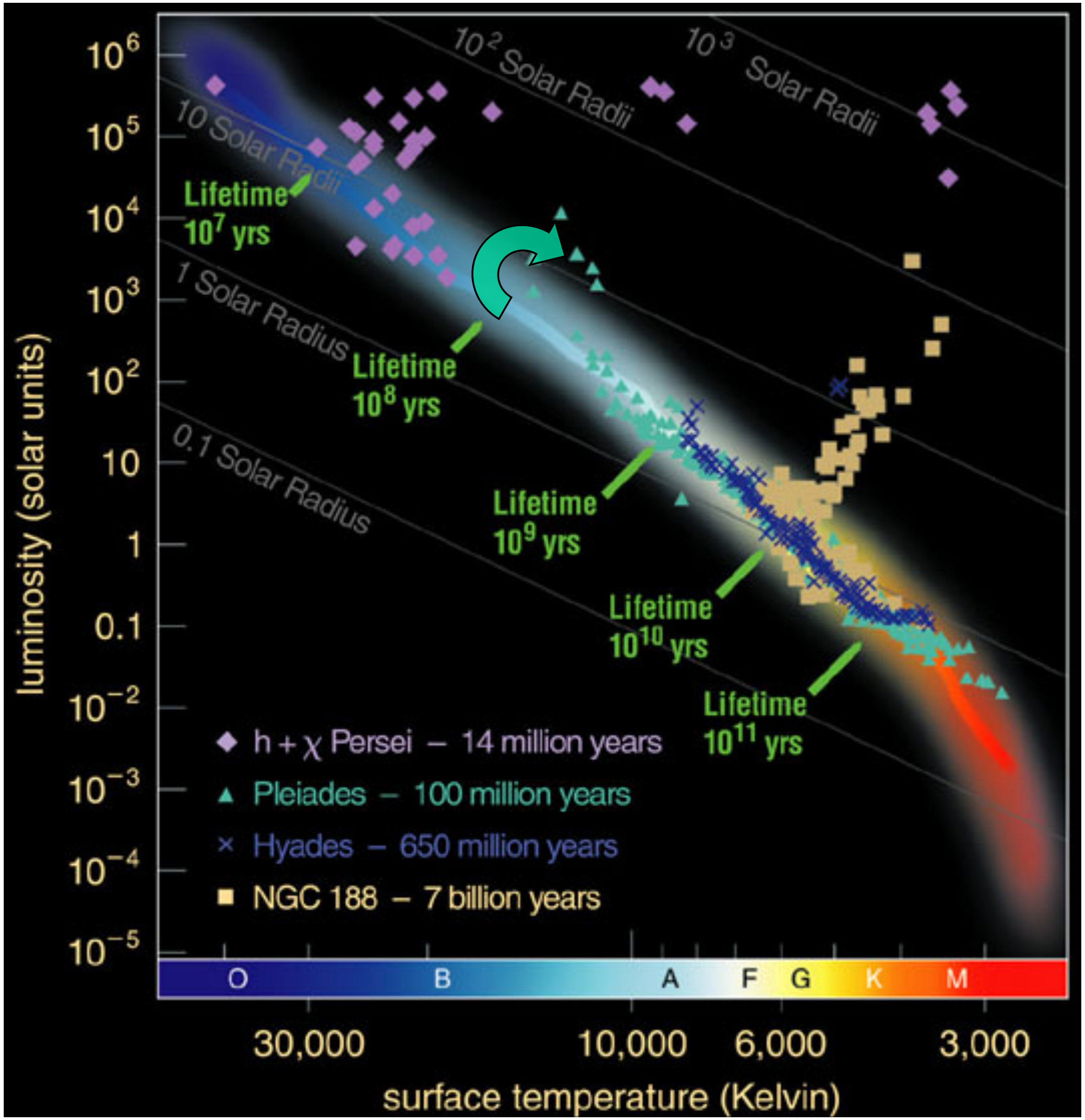
Visual Representation of a Star Cluster Evolving

The turn-off point



- We can plot a HR diagram *just for a cluster* and note the main sequence.
- As cluster stars use up hydrogen, they evolve off the main sequence towards the upper right and become giants or supergiants

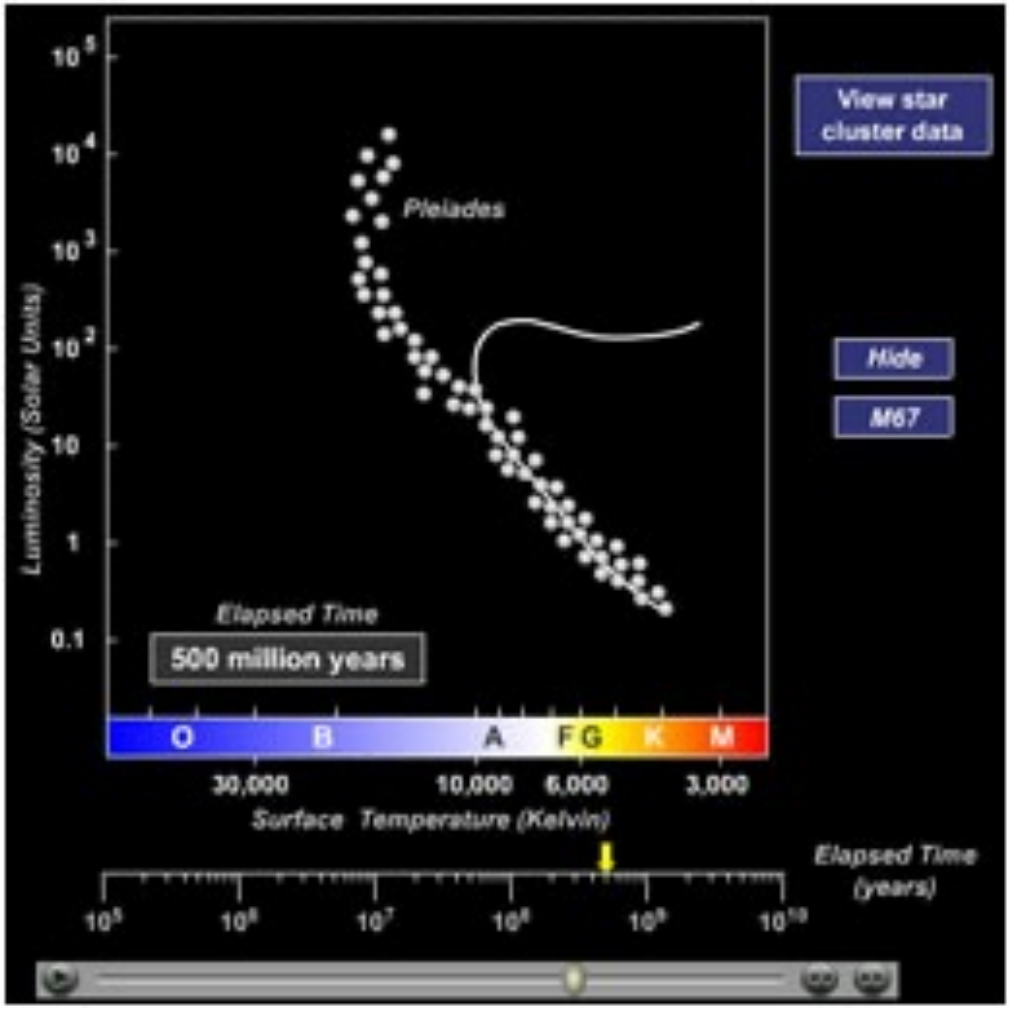
The turn-off point



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

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

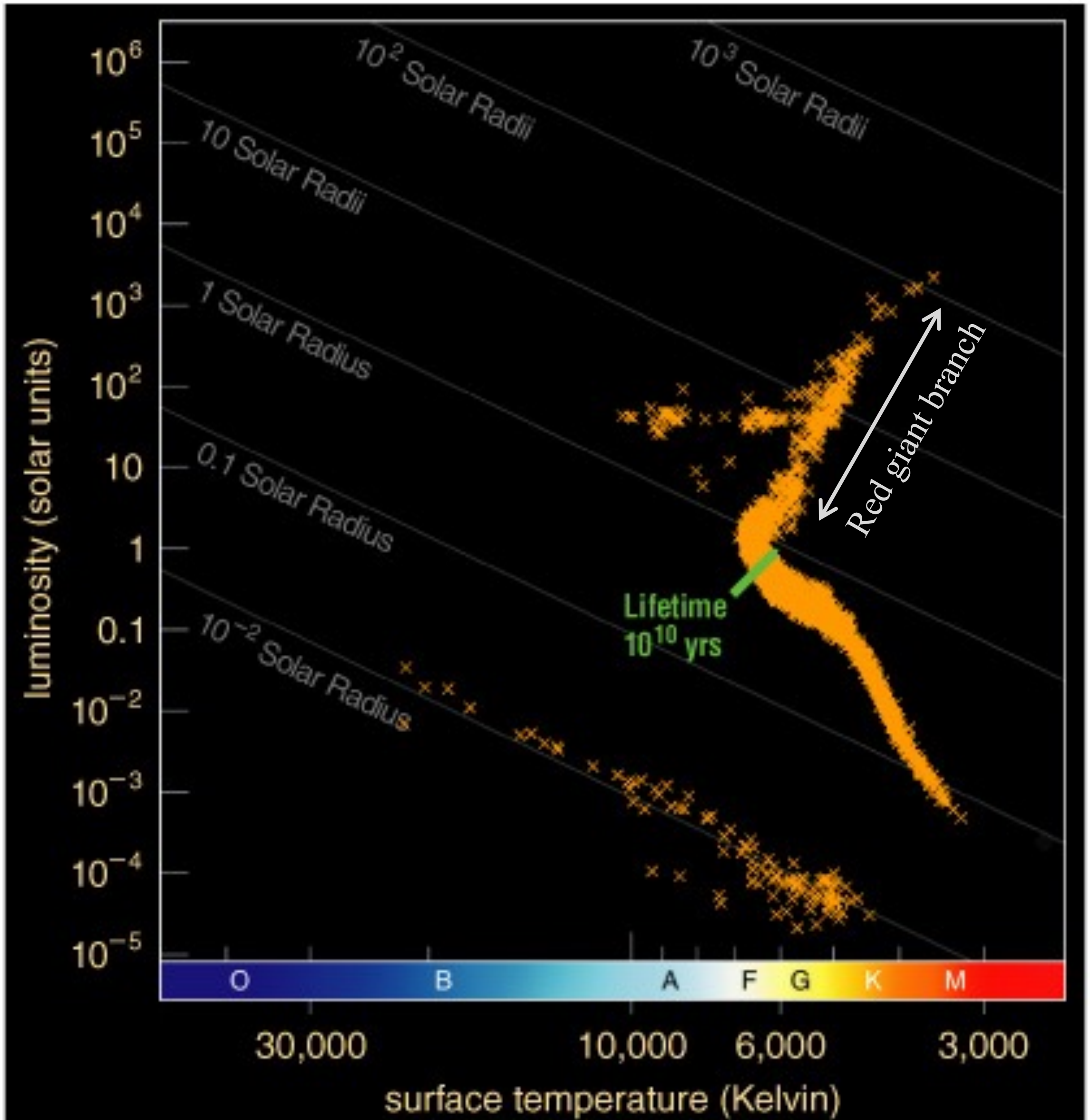
The turn-off point



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

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

The turn-off point



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

Think/Pair/Share

Why do astronomers use the HR diagram so extensively?

A. By plotting radius vs. core temperature, they can understand stellar properties and composition
B. By plotting luminosity vs. surface temperature they can understand stellar types and evolution
C. By plotting mass vs. luminosity, they can understand stellar formation and ages
D. By plotting core temperature vs. luminosity they can understand stellar composition and evolution

Think/Pair/Share

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B. By plotting luminosity vs. surface temperature they can understand stellar types and evolution
C. By plotting mass vs. luminosity, they can understand stellar formation and ages
D. By plotting core temperature vs. luminosity they can understand stellar composition and evolution

What have we learned?

Begin 3 minute review

What have we learned?

What are the two types of star clusters?

Open clusters are loosely packed and contain up to a few thousand stars.

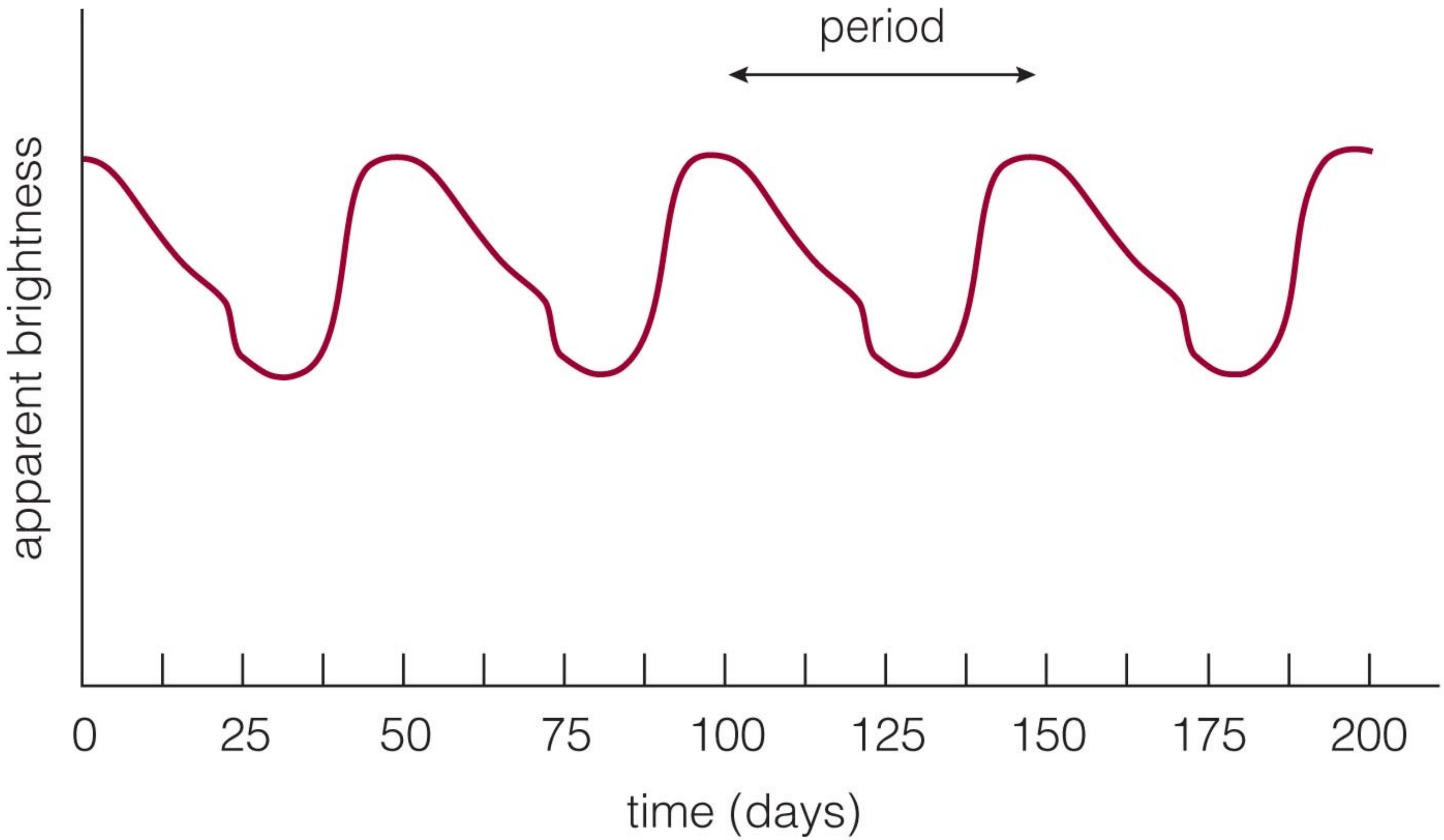
Globular clusters are densely packed and contain hundreds of thousands of stars.

How do we measure the age of a star cluster?

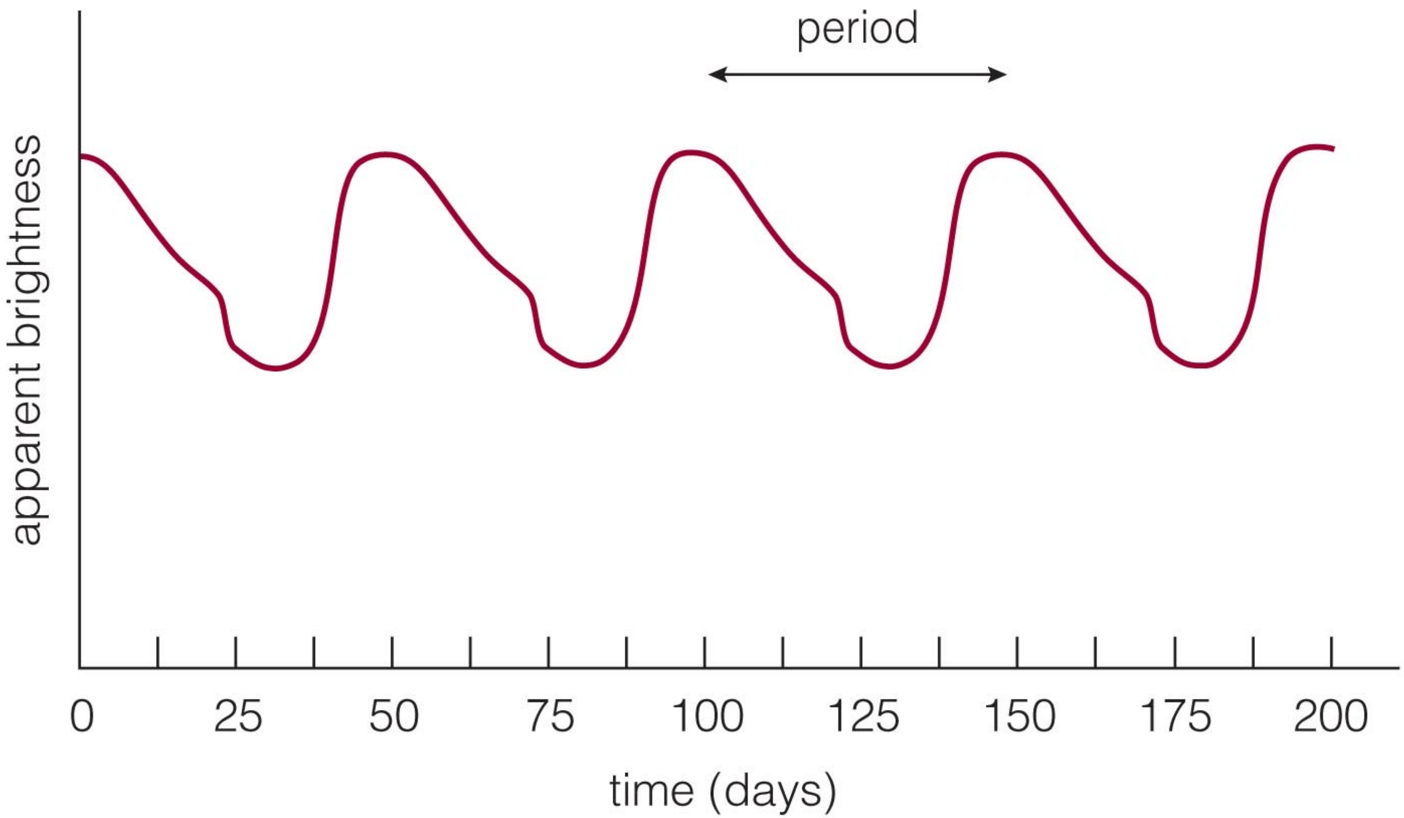
A star cluster's age equals the life expectancy of its most massive stars still on the main sequence.

Exercise: HR diagram

Why do the properties of some stars vary?



Pulsating Variable Stars

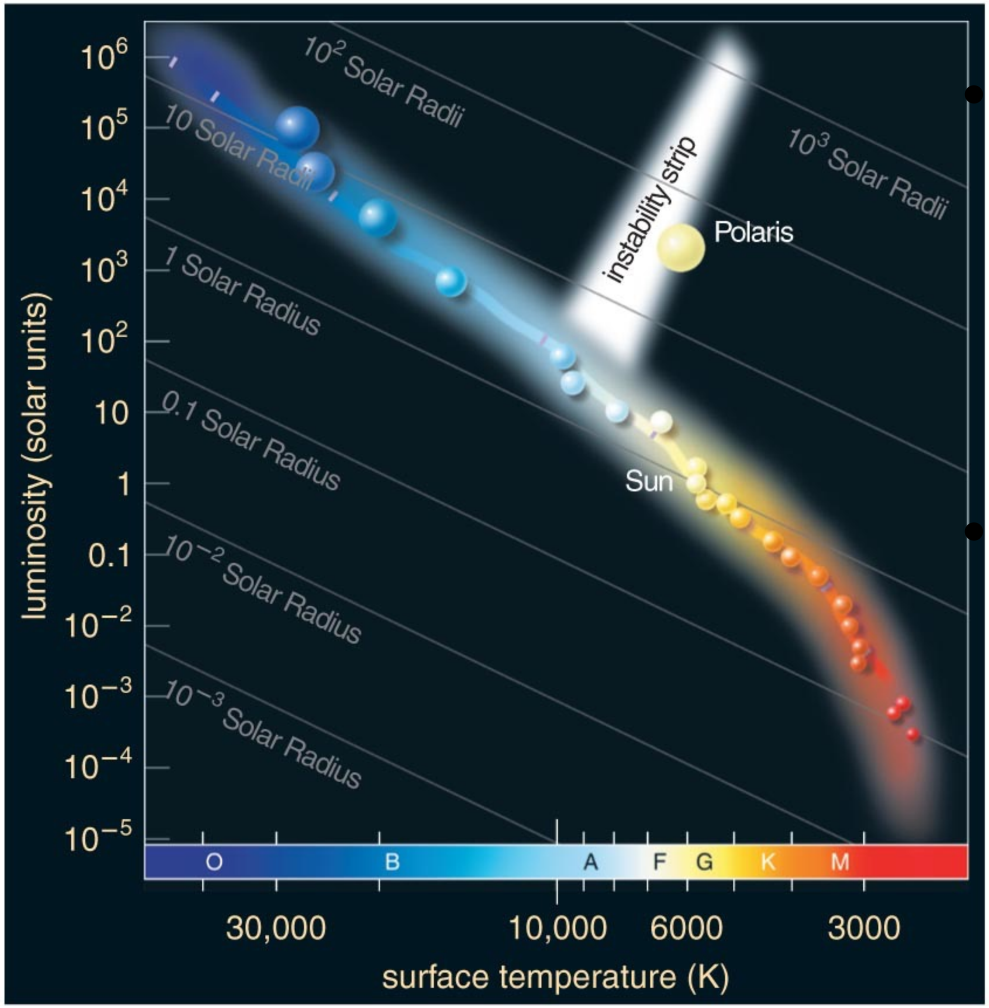


- The light curve of this *pulsating variable star* shows that its brightness alternately rises and falls over a 50-day period.

Variable Stars

- Any star that varies significantly in brightness with time is called a *variable star*.
- Some stars vary in brightness because they cannot achieve proper balance between power radiating coming from the core and power radiated from the surface.
- Such a star alternately expands and contracts, varying in brightness as it tries to find a balance.

Cepheid Variable Stars



- Most pulsating variable stars inhabit an *instability strip* on the H-R diagram.
- The most luminous ones are known as *Cepheid variables*.