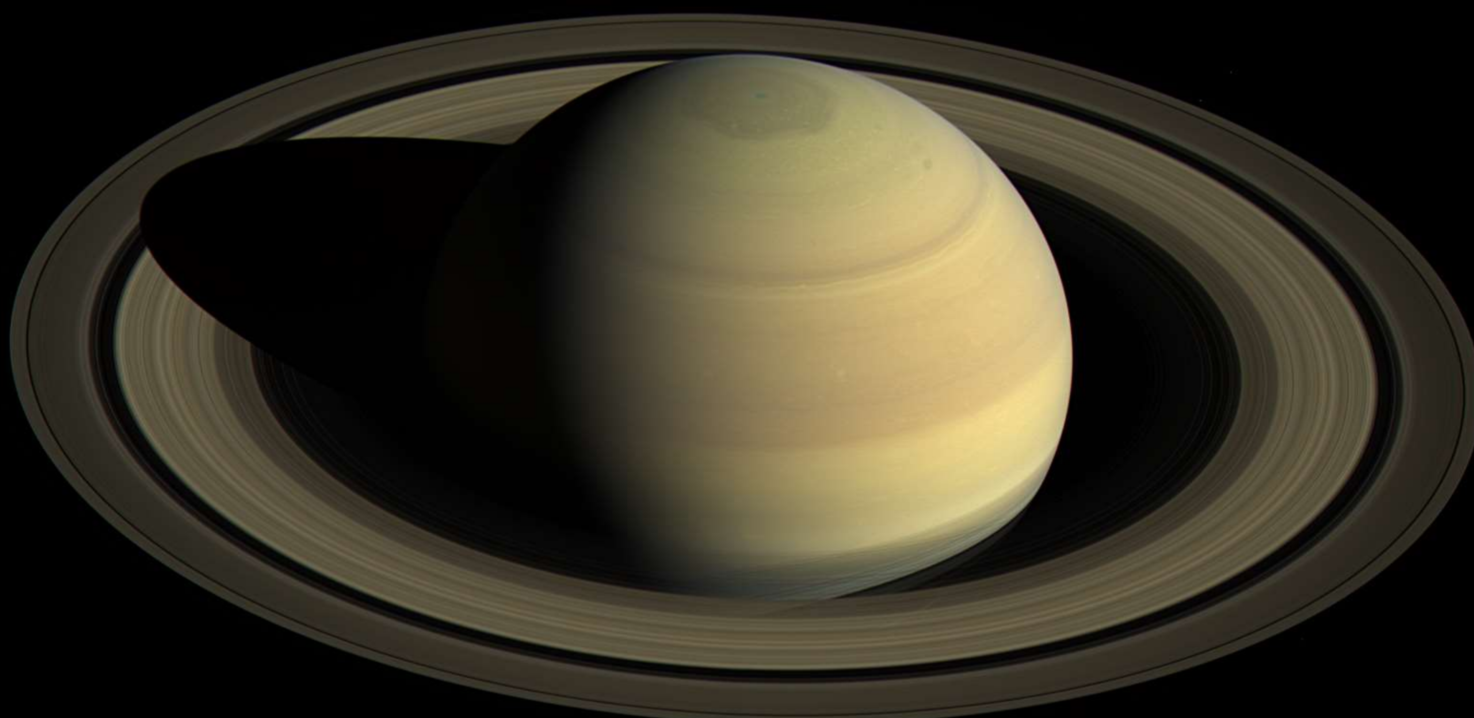
AST 2002
Introduction to Astronomy



A Few Quick Things…

E-mailing me: Must have AST2002 in the subject

Mary Hinkle, Graduate Teaching Assistant:

Office Hours: Mon 1:30-3:00pm. PSB 316

My office hours: Mon 3:00-4:00pm. PSB 308

Tue 3-4 pm. PSB 308

Curved Exam Grades have been Uploaded to Webcourses… this should give a reasonable idea how you are doing in the class… am still uploading extra credit

Scores on Webcourses will not be accurate until near the end of the course. Sorry.

Next Knights Under the Stars Event – Wed 28th Mar 8:30-10:00pm – tonight

Opportunity to make up the 1% extra credit that was offered (if you haven't been yet, worth 2%) – only 2 more opportunities left (and sometimes doesn't happen!)

What have we covered? What is next?

Chapter 12: Surveying the Stars

12.1. Properties of Stars

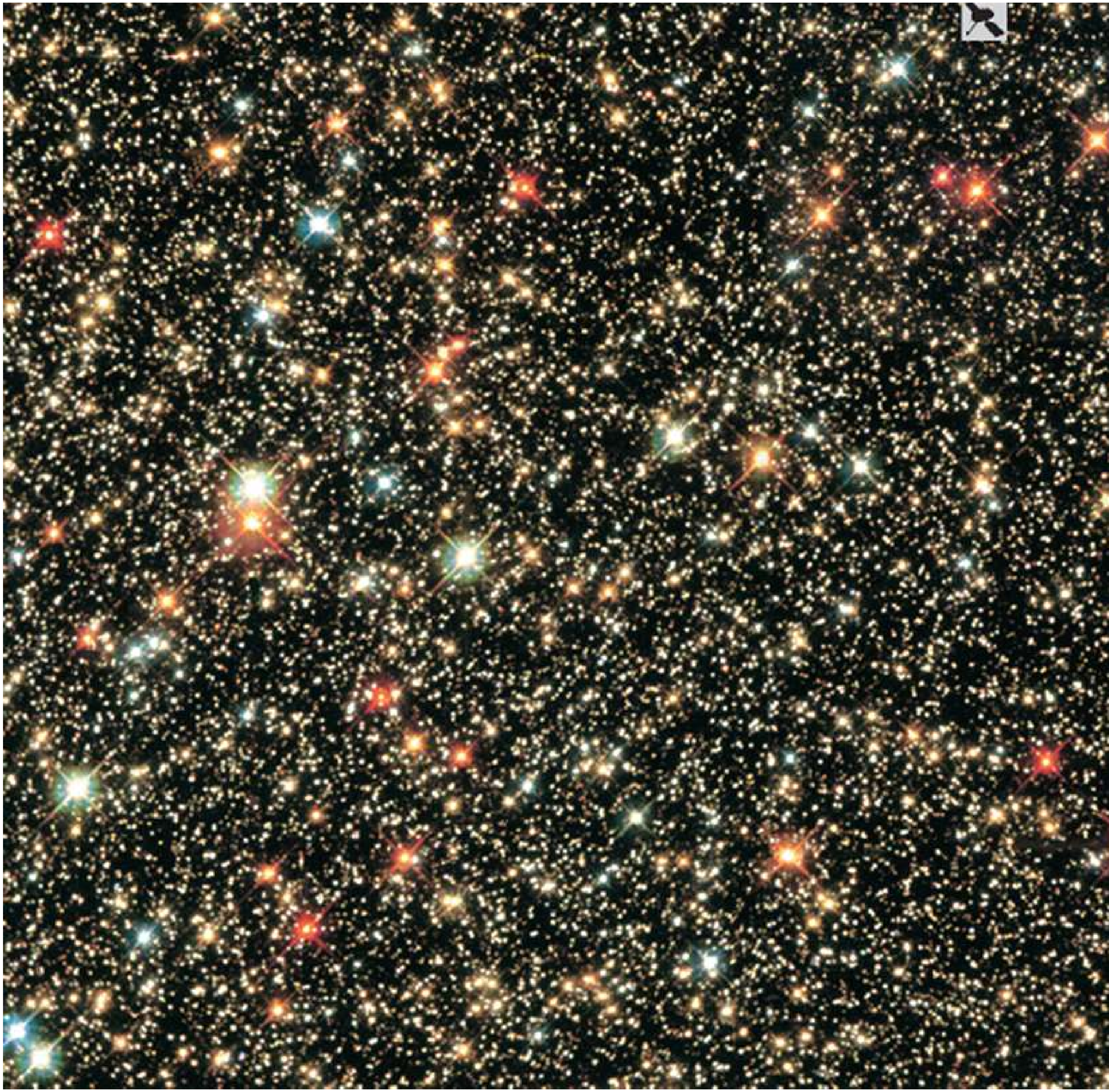
- How do we measure stellar luminosities?
- How do we measure stellar temperatures?
- How do we measure stellar masses?

12.2. Patterns Among Stars

- What is the Hertzsprung-Russel diagram?
- What is the significance of the main sequence?
- What are giants, supergiants, and white dwarfs?

12.3. Star Clusters

- What are the two types of star clusters?
- How doe we measure the age of star clusters?



Stellar Diversity

Hubble Space Telescope image of Baede's window towards the galactic center…

Some stars are:

Blue…
White…
Yellow…
Red…

Some stars are:

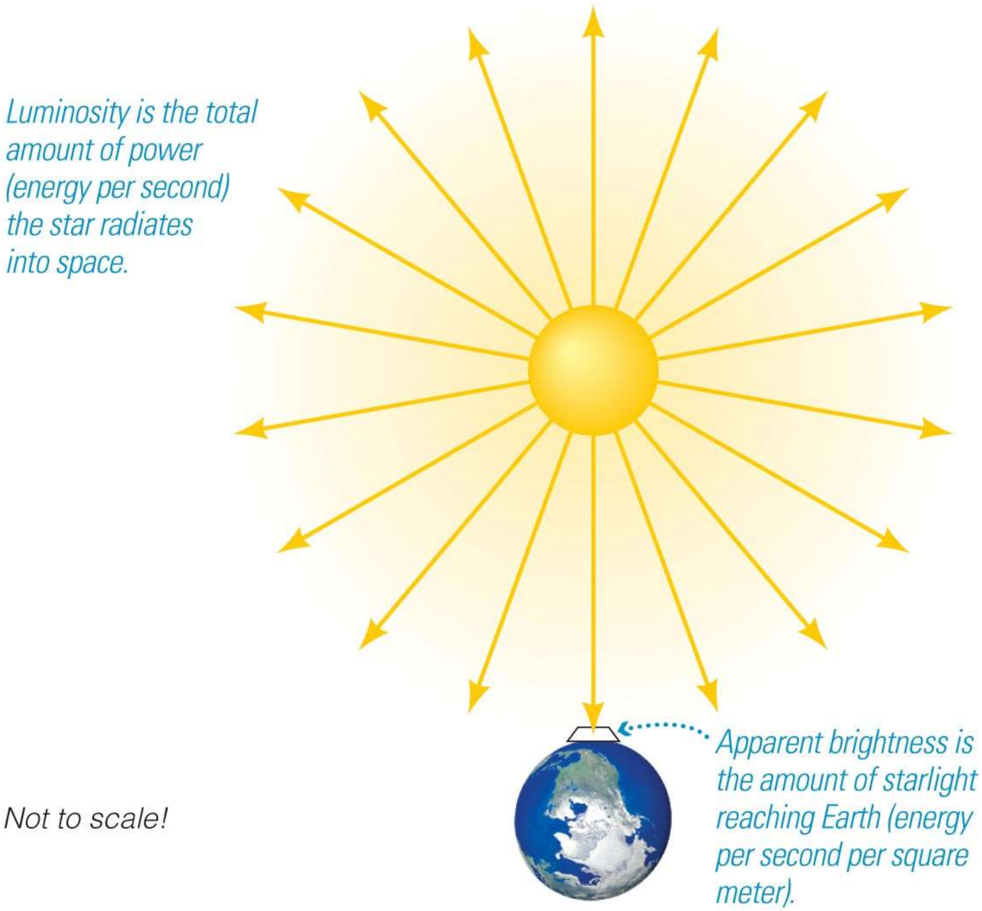
Really bright…
Much dimmer…

Are there more:

- *blue or red stars?*
- *Brighter or dimmer stars?*

Any dim blue stars?

Relationship between Luminosity and Brightness



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)

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

$$Luminosity = 4\pi(distance)^2 \times brightness$$

Absolute & Apparent Magnitudes

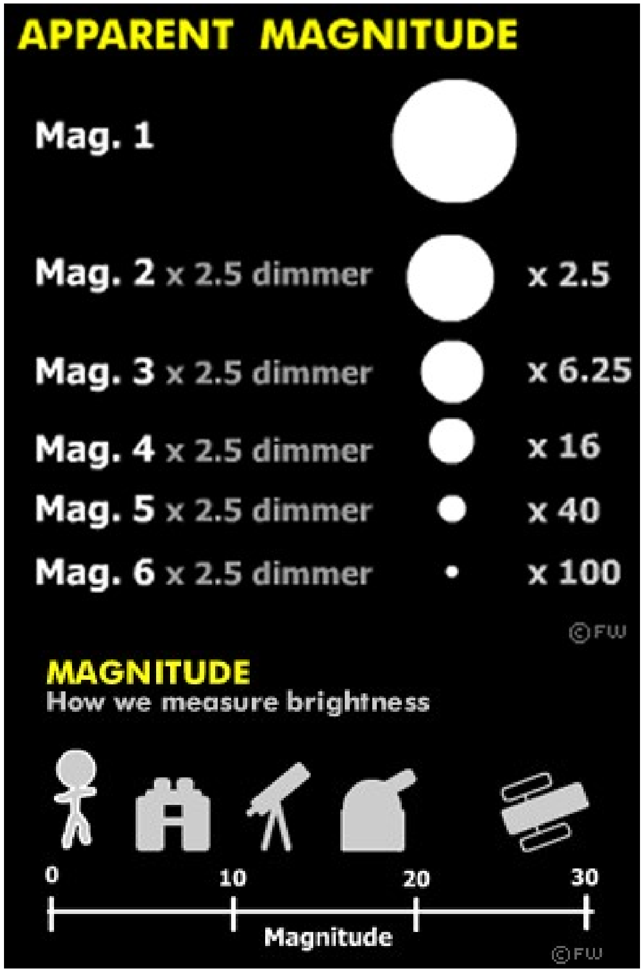
Luminosity ranges of stars:

- **High end:** ~10^6 L_{Sun} (*e.g.*, Betelgeuse is 120,000 L_{Sun})
- **Low end:** ~10^{-4} L_{Sun} *(e.g., Proxima Centauri is 0.0006* L_{Sun}*)*

Apparent Magnitude: (Hipparchus; 1-6 scale)

- *Gets 2.5x dimmer per magnitude…*

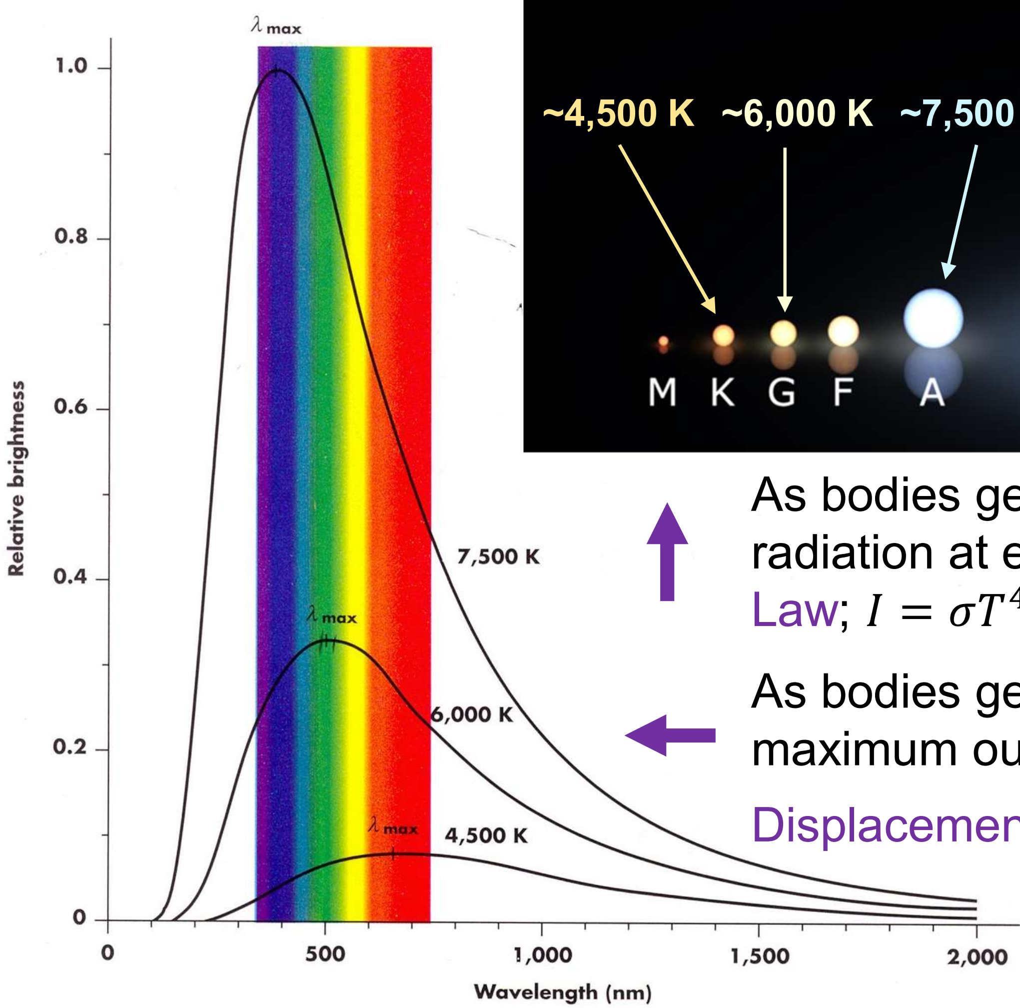
$$\frac{\text{apparent brightness of Star 1}}{\text{apparent brightness of Star 2}} = (100^{1/5})^{m_1 - m_2}$$

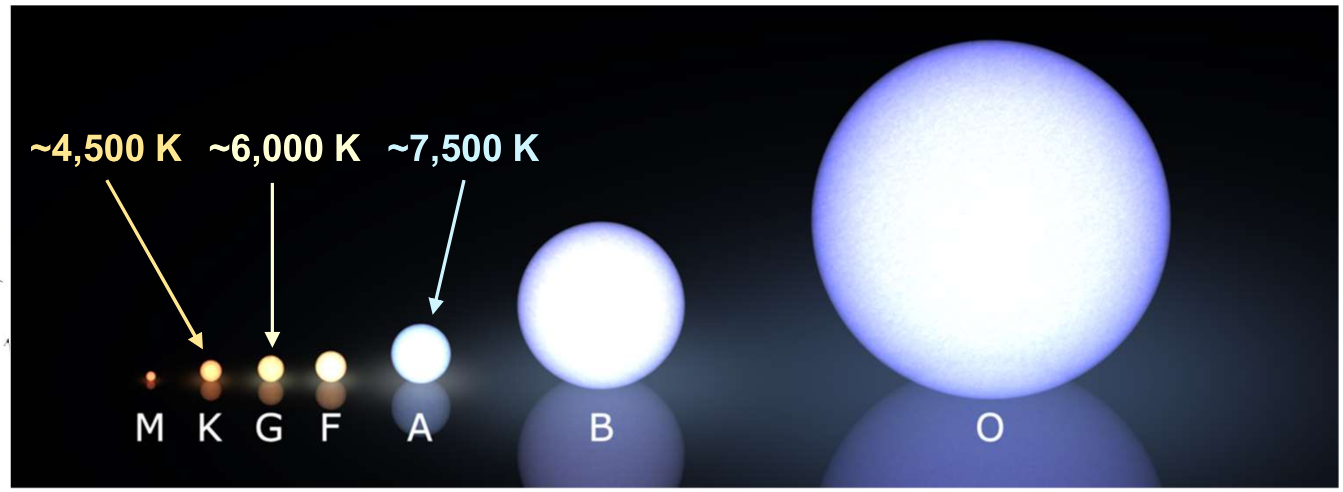


Absolute Magnitude:

- The apparent magnitude that a star would have, if it were at a distance of 10 parsecs (or 32.6 light years).
- For example, our Sun would have an absolute magnitude of 4.8 on this scale

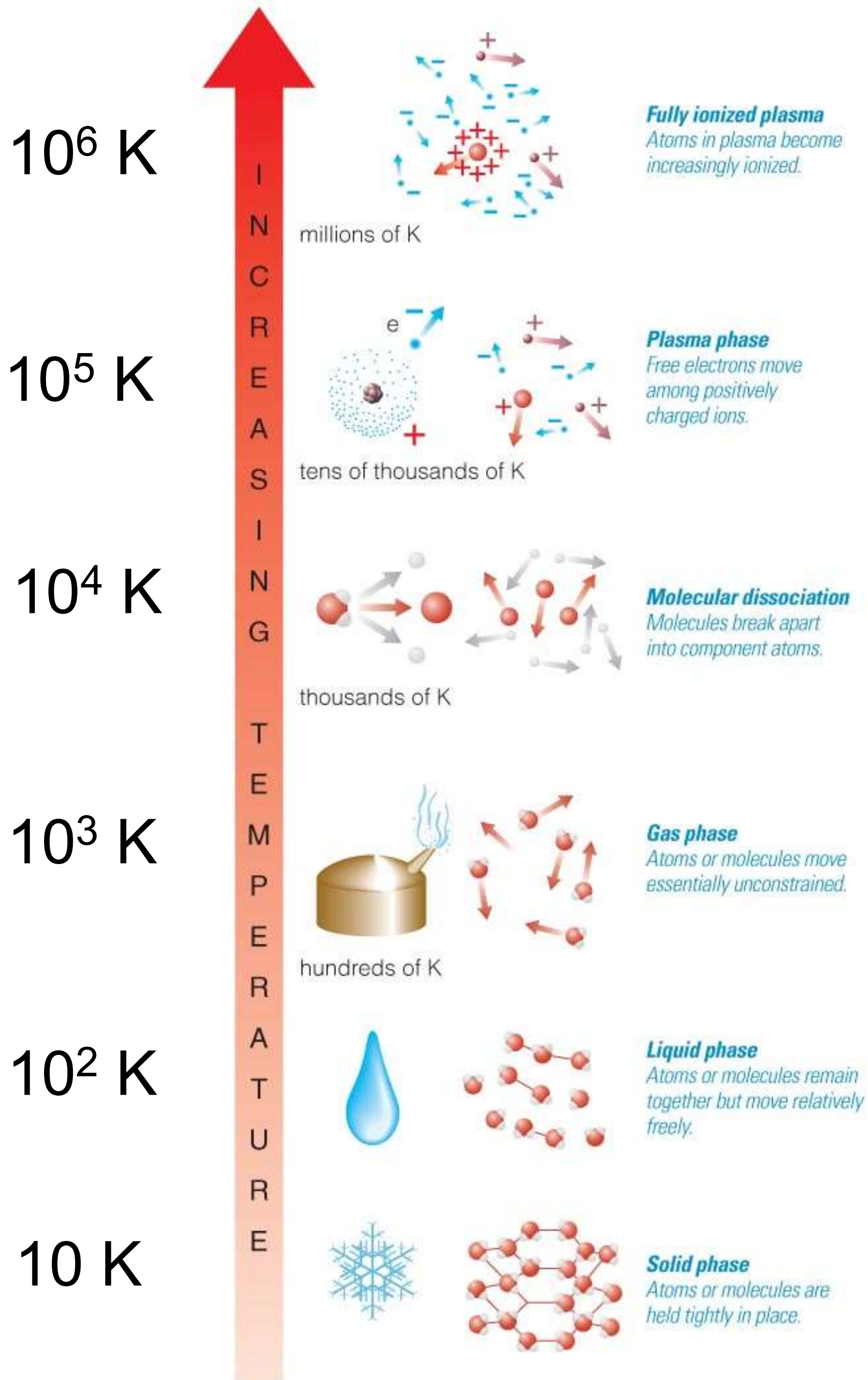
Temperature of Stellar Photospheres: black body radiation revisited





As bodies get warmer, they emit overall more radiation at each wavelength (Stephan-Boltzmann Law; $I = \sigma T^4$ where σ=5.67 × 10[8] J/m[2]K[4])

As bodies get warmer, the wavelength where maximum output is shifts to the left (Wien's Displacement Law; $\lambda_{peak}(T) = \frac{2.898 \times 10^{-3} (m\ K)}{Temperature\ (K)}$



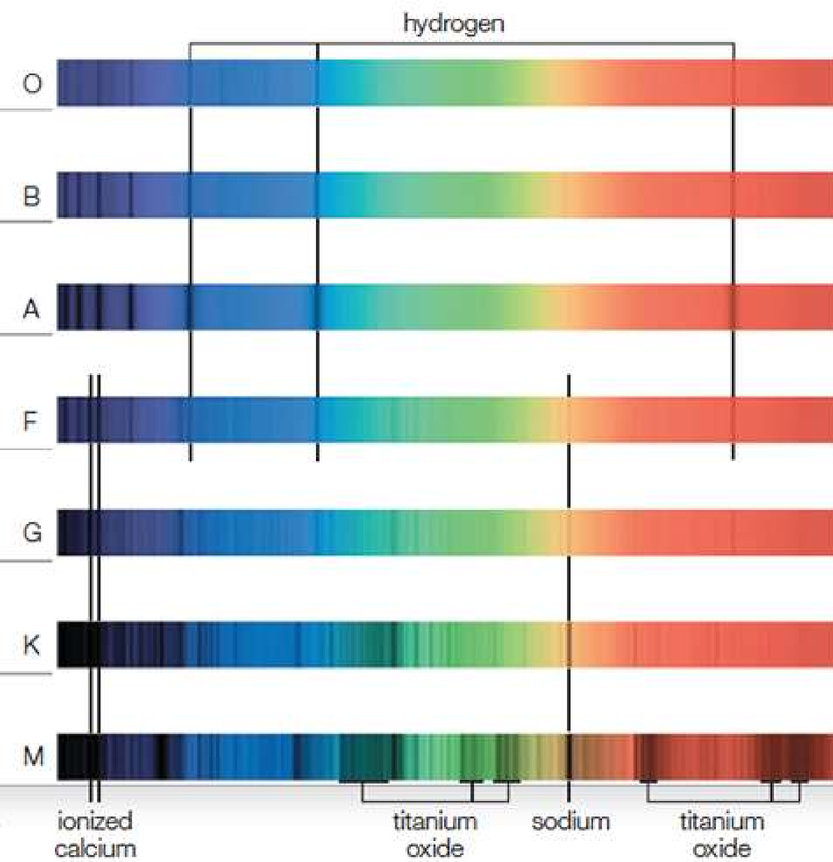
How Does Star Temperature Alter the Spectrum?

Remember 1 eV ~ 10,000 K

- Molecular lines will only be observed in low-temperature stars
- As temperature increases some metals will begin to ionize (e.g., Calcium at 4.4 eV) and bonds will start to break (3-9 eV)
- Ionized Helium requires 24.5 eV so will only become prominent in the hottest stars
- Hydrogen lines are strongest in Stars around 10,000 K… the ionization energy of hydrogen is 13.6 eV… so when stars get too hot hydrogen is completely ionized and no longer visible…

Stars Based on Spectral Type

Spectral Type	Example(s)	Temperature Range	Key Absorption Line Features	Brightest Wavelength (color)	Typical Spectrum (selected lines labeled)
O	Stars of Orion's Belt	>33,000 K	Lines of ionized helium, weak hydrogen lines	< 89 nm (ultraviolet)*	
B	Rigel	33,000 K–10,000 K	Lines of neutral helium, moderate hydrogen lines	89–290 nm (ultraviolet)*	
A	Sirius	10,000 K–7500 K	Very strong hydrogen lines	290–390 nm (violet)*	
F	Polaris	7500 K–6000 K	Moderate hydrogen lines, moderate lines of ionized calcium	390–480 nm (blue)*	
G	Sun, Alpha Centauri A	6000 K–5200 K	Weak hydrogen lines, strong lines of ionized calcium	480–560 nm (yellow)	
K	Arcturus	5200 K–3700 K	Lines of neutral and singly ionized metals, some molecules	560–780 nm (red)	
M	Betelgeuse, Proxima Centauri	<3700 K	Strong molecular lines	>780 nm (infrared)	

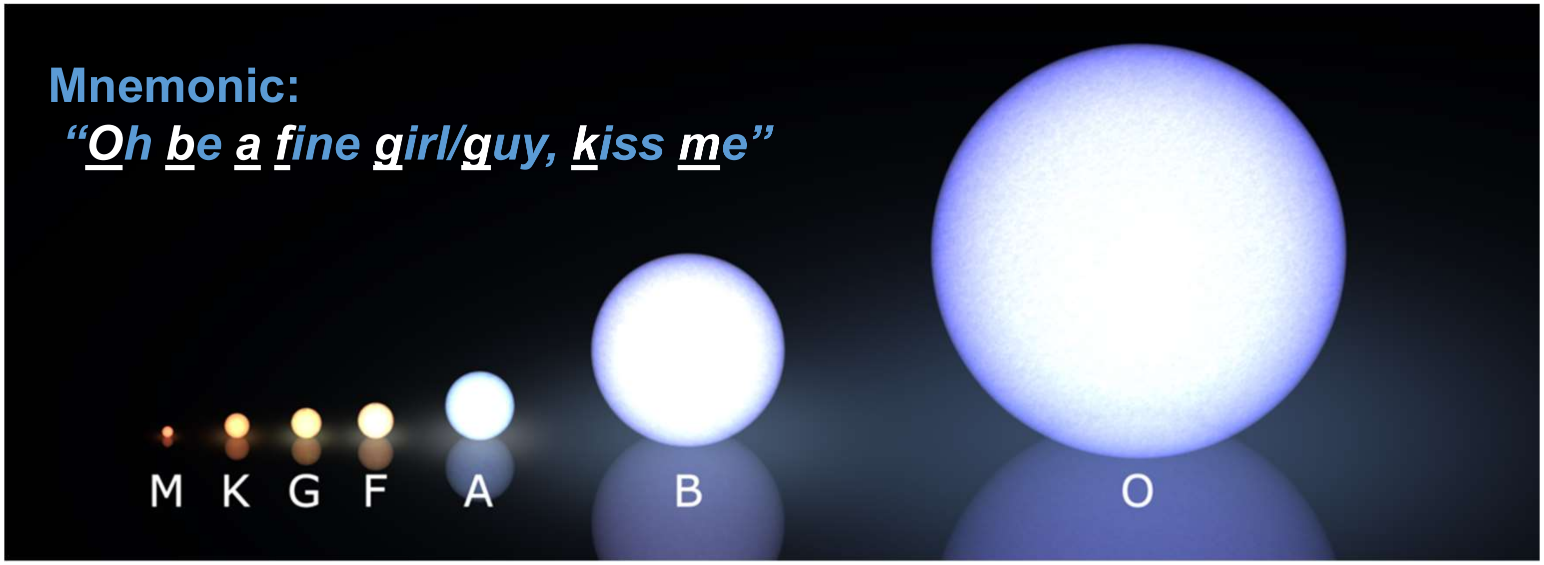


*All stars above 6000 K look more or less white to the human eye because they emit plenty of radiation at all visible wavelengths.

Lines in a star's spectrum correspond to a temperature & ***spectral type:***

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

Stellar Classification System



- Annie Jump Cannon's stellar classification system adopted since 1910
  - Originally classified due to strength of hydrogen lines (A is strongest)
- Subdivided into subclasses from 0-9 (0 being hottest, 9 being coolest)
  - Our Sun is a G2-type star from this classification system.
- There are additional types L, T, and Y which are cooler objects (e.g., red/brown dwarfs … these are failed or dying stars)

Binary Systems and Stellar Masses

If you remember (from Newton's formulation of Kepler's 3rd law), binary systems allow us a method to determine the mass. From the relationship for circular orbits, $v = 2\pi r / p$, *we need two of the following:*

1. Orbital period (p)
2. Orbital separation (a or r = radius)
3. Orbital velocity (v)

→ Fortunately, approximately half of all stars are in binary systems.

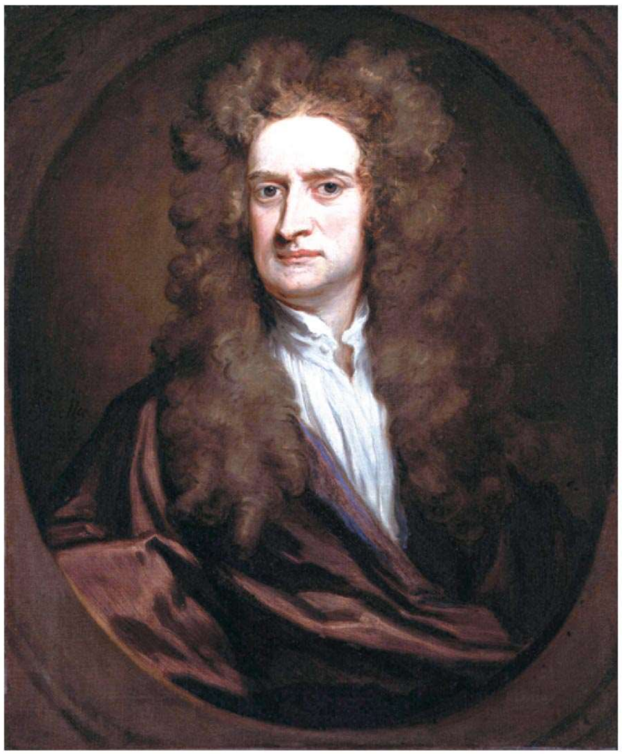
How can we determine these properties?

- Transits…
- Doppler Shifts…
- Astrometry…

i.e. using the same techniques used for detecting exoplanets

Determination of Mass in Binary Systems

http://www.austincc.edu/jheath/Solar/Hand/NVK3L/nvk3l.htm



Isaac Newton

We measure mass using gravity, and Newton's version of Kepler's 3rd law:

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

p = period

a = average separation

G = Universal Gravitational Constant (6.67408×10^{-11} m^3 kg^{-1} s^{-2})

M_1 and M_2 are the masses of the stars in the system

- Direct mass measurements are only possible for stars in binary star systems.
- But they can provide a framework for us to calculate the masses of other stars.

Example – Determining the Mass of a Binary System

From Kepler: $a^3 = p^2$ or $\frac{a^3}{p^2} = 1$ where a = distance, p=orbital period

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

If we do calculations in terms of the mass of our Solar System (~M_{sun}), and use AU for distances we can make the equation a bit easier to handle:

$$\frac{a^3}{p^2} = M_1 + M_2$$

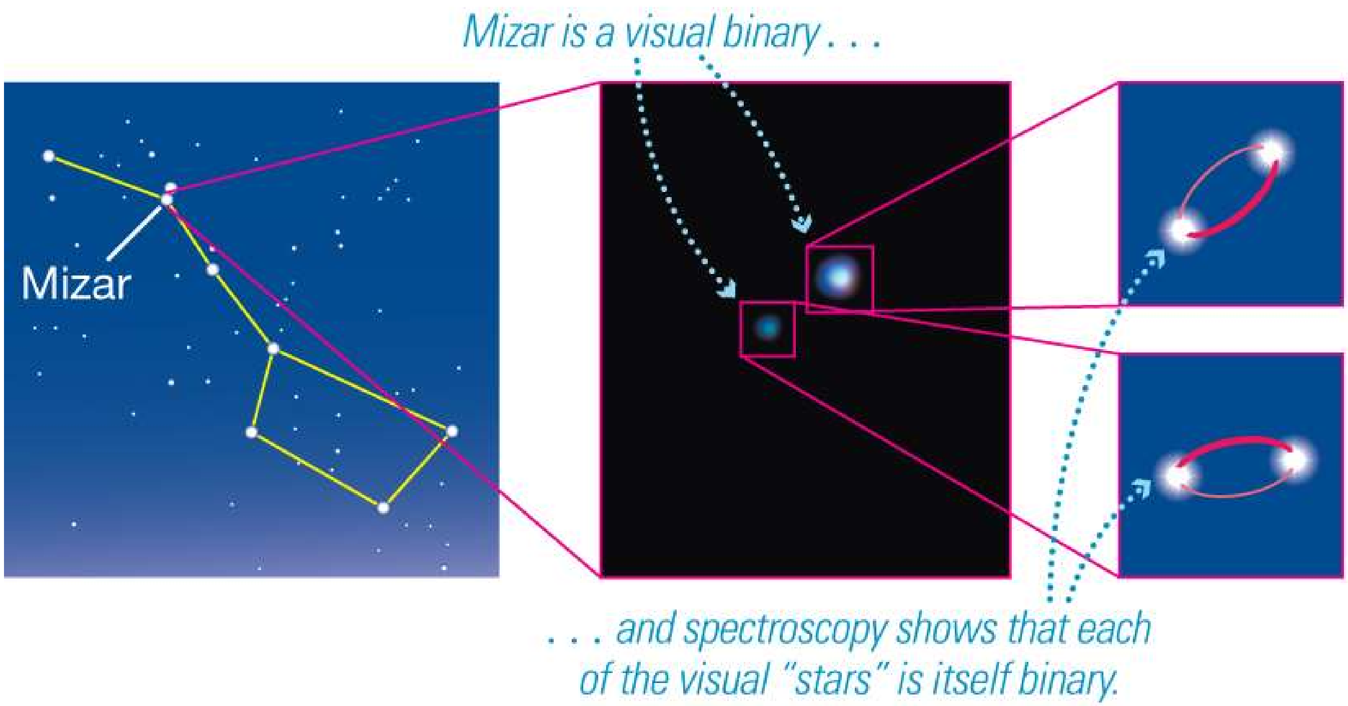
Example: A binary star system is found to have an orbital period of 2 years and an orbital separation of 4 AU.

Solution: Putting these into the equation we get: $\frac{4^3}{2^2} = \frac{64}{4} = 16\ldots$

→ We now know that $M_1 + M_2 = 16\ M_{sun}$

→ But that is as far as we can go. Or is it?

Binary Star Systems are Common!



- If we have a system where there is a binary, and <u>one</u> of those systems is itself a binary, then we can precisely determine the mass of the other star…
- We can then combine this with other information such as spectral properties and distance to learn about star masses/luminosities…

iClicker Question

How does the apparent brightness of a star depend on its distance from Earth?

A. The apparent brightness is independent of distance from Earth

B. The apparent brightness is inversely proportional to distance

C. The apparent brightness is proportional to distance

D. The apparent brightness is inversely proportional to the square of the distance

E. The apparent brightness is proportional to the distance squared

iClicker Question

How does the apparent brightness of a star depend on its distance from Earth?

A. The apparent brightness is independent of distance from Earth

B. The apparent brightness is inversely proportional to distance

C. The apparent brightness is proportional to distance

D. The apparent brightness is inversely proportional to the square of the distance

E. The apparent brightness is proportional to the distance squared

iClicker Question

Which of the following spectral types is the hottest type of star?

A. A-type
B. B-type
C. F-type
D. G-type
E. M-type

iClicker Question

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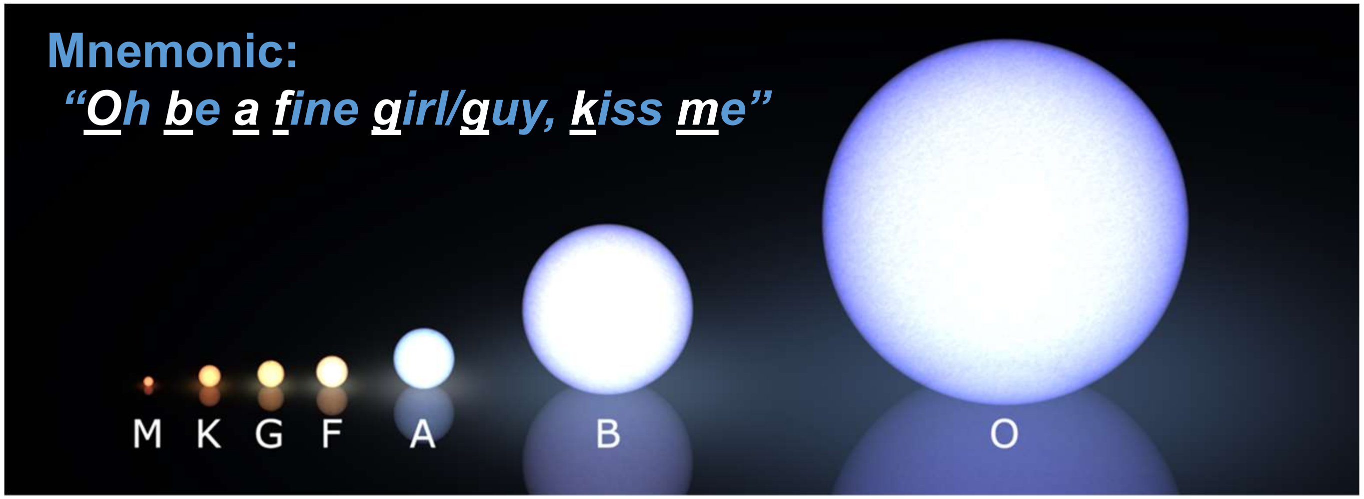
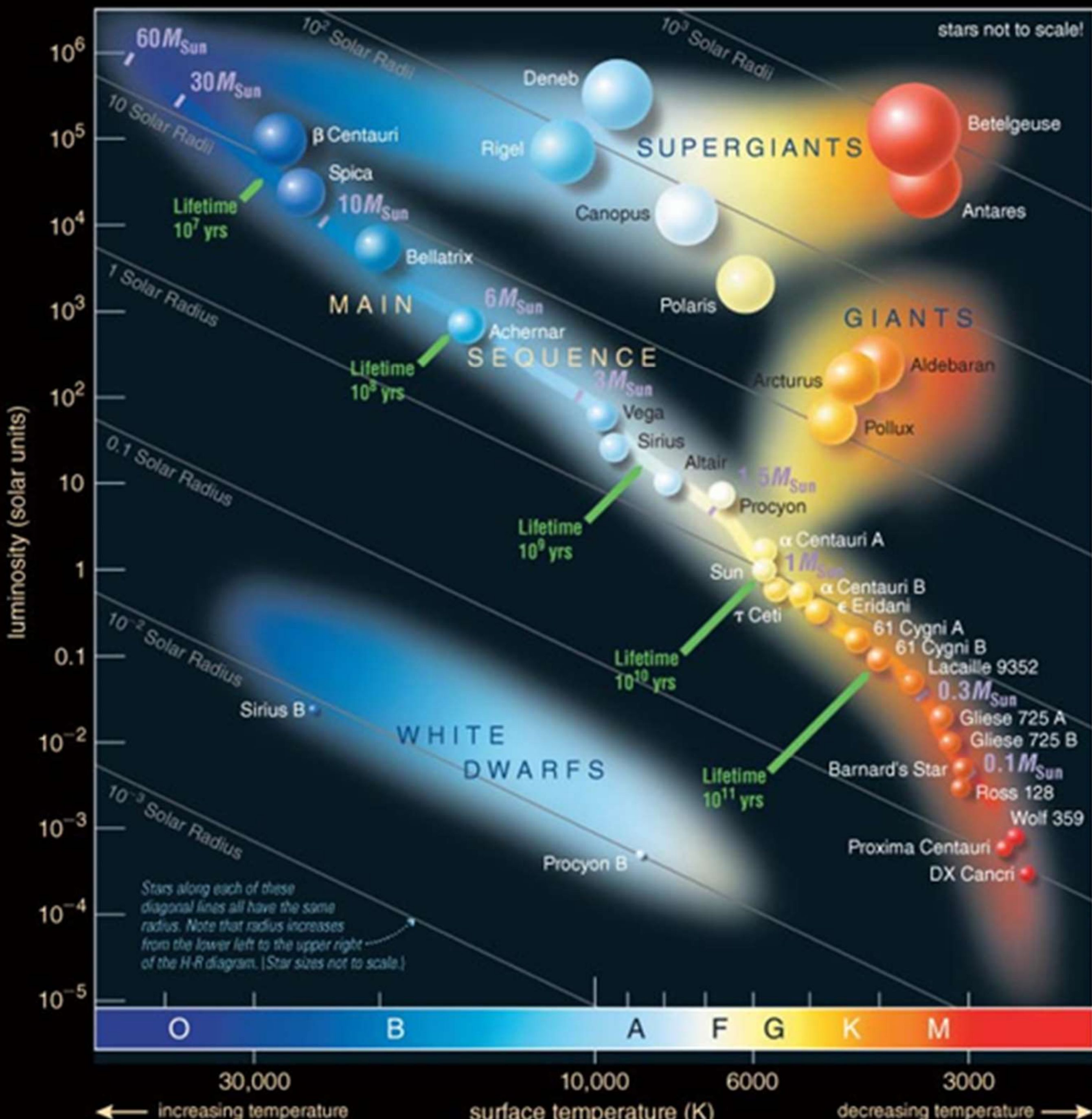




Today …

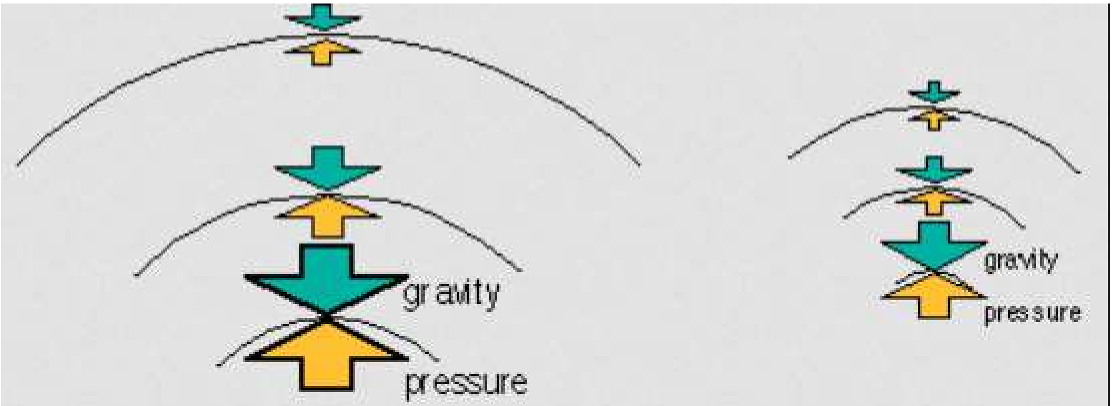
Need to understand:

- Mass-Luminosity relationship
- Main sequence
  - Masses
  - Lifetimes
- Sizes on Main sequence
- Giants & supergiants
- White dwarfs

Hertzsprung-Russel (H-R) Diagrams

Early 20th century astronomers Ejnar Hertzsprung and Henry Russel independently started producing graphs of the spectral type on one axis against the luminosity of the star on the other axis…

- Stars with more mass have more gravity, and more pressure.
- Therefore, their cores are more dense and at higher temperatures
  - Much more efficient for fusion by proton-proton chain reaction
  - Also makes other fusion reactions possible (CNO cycle coming later)
- Small increases in mass can lead to large increases in luminosity



More massive stars have greater gravity compression. They need higher core temperatures to be stable and have very many more nuclear reactions. A slight change in mass produces a large change in luminosity.

Stellar Properties Review

Luminosity: from brightness and distance

(0.08M_{Sun}) $10^{-4}L_{Sun} – 10^{6}L_{Sun}$ **(100M_{Sun})**

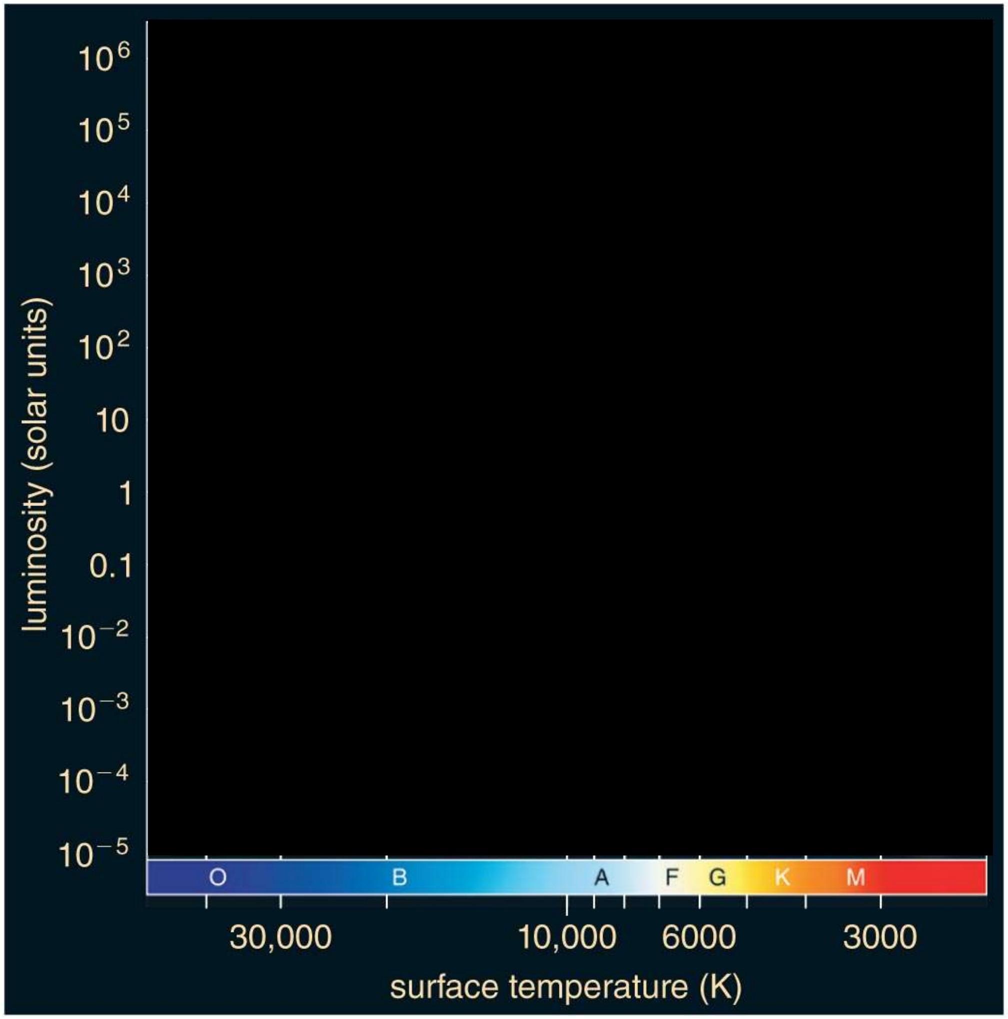
Temperature: from color and spectral type

(0.08M_{Sun}) 3000 K – 50,000 K **(100M_{Sun})**

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

$0.08M_{Sun} – 100M_{Sun}$

Main Sequence of H-R Diagram: Hydrogen-burning phase



- Most stars fall somewhere on the ***main sequence*** of the H-R diagram. (~90%)
- ***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).
- Larger stars have greater density and pressure in their core. More energy production. More Luminosity.
- More radiation pressure (larger radius – *but not giants*)

Relationship between Mass and Lifetime

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

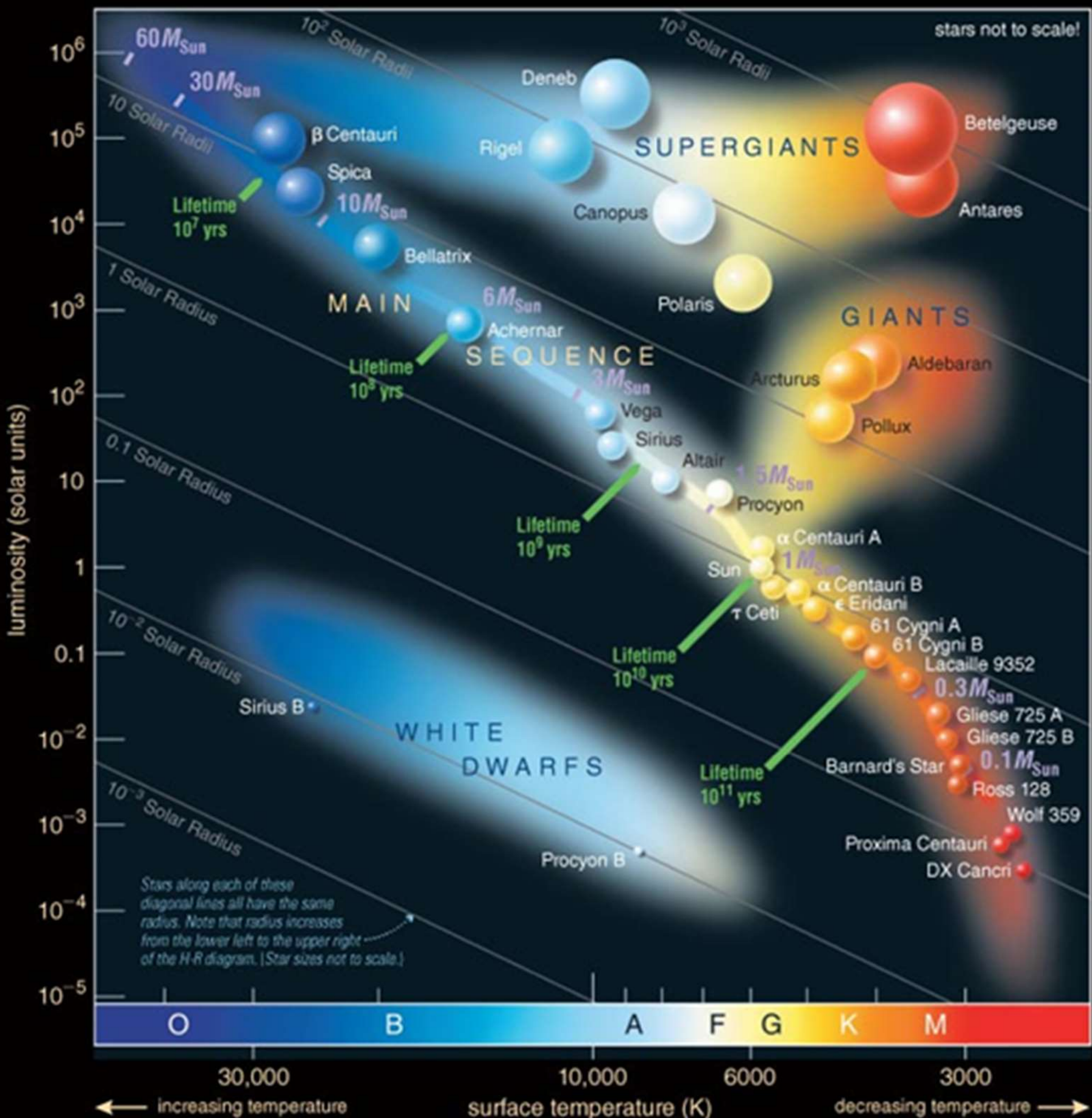
Sun's life expectancy: 10 billion years

Life expectancy of a 10M_{Sun} star:

- 10 times as much fuel, BUT uses it 10^4 times as fast (10^4 L_{sun})
- 10 billion years × 10/10^4 (=1000× shorter) = ~10 million years

Life expectancy of a 0.1M_{Sun} star:

- 0.1 times as much fuel, and uses it only 0.01 times as fast
- 10 billion years × 0.1/0.01 (= 100x longer) = ~100 billion years



Today …

Need to understand:

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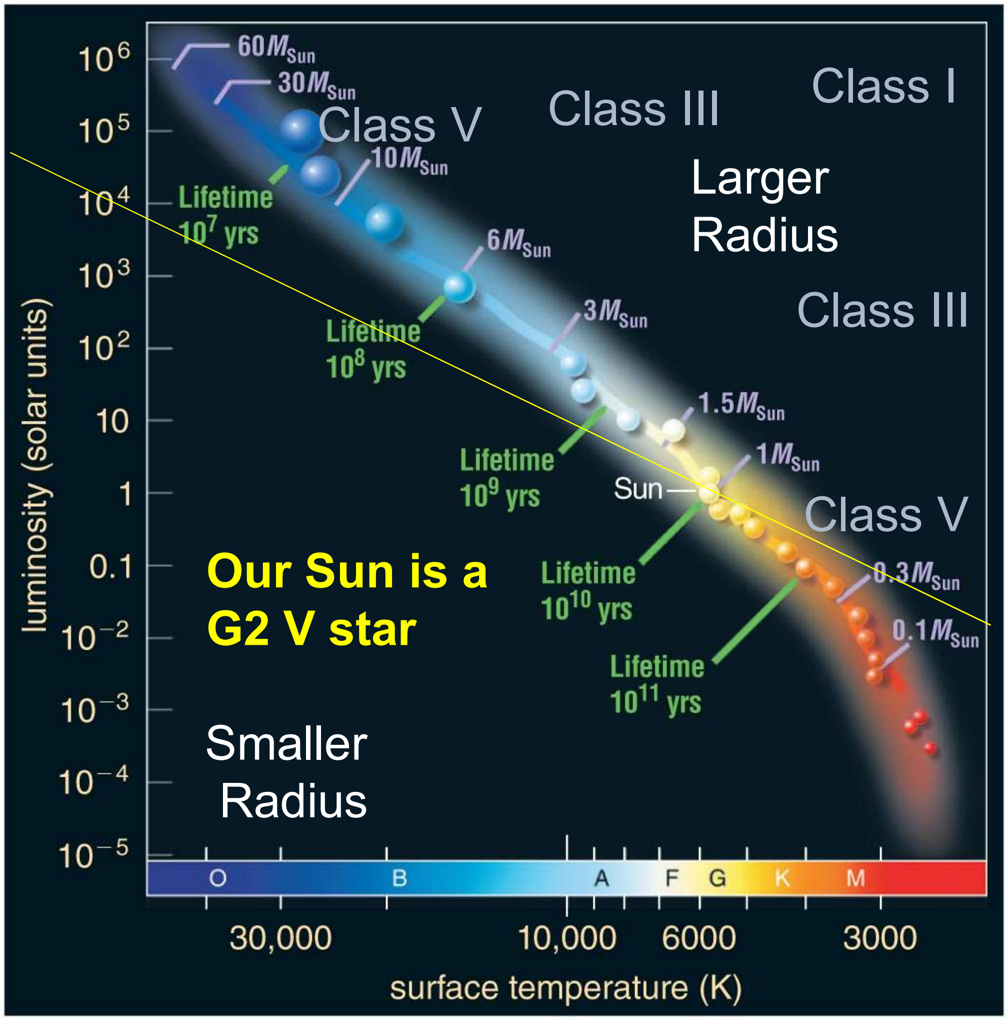
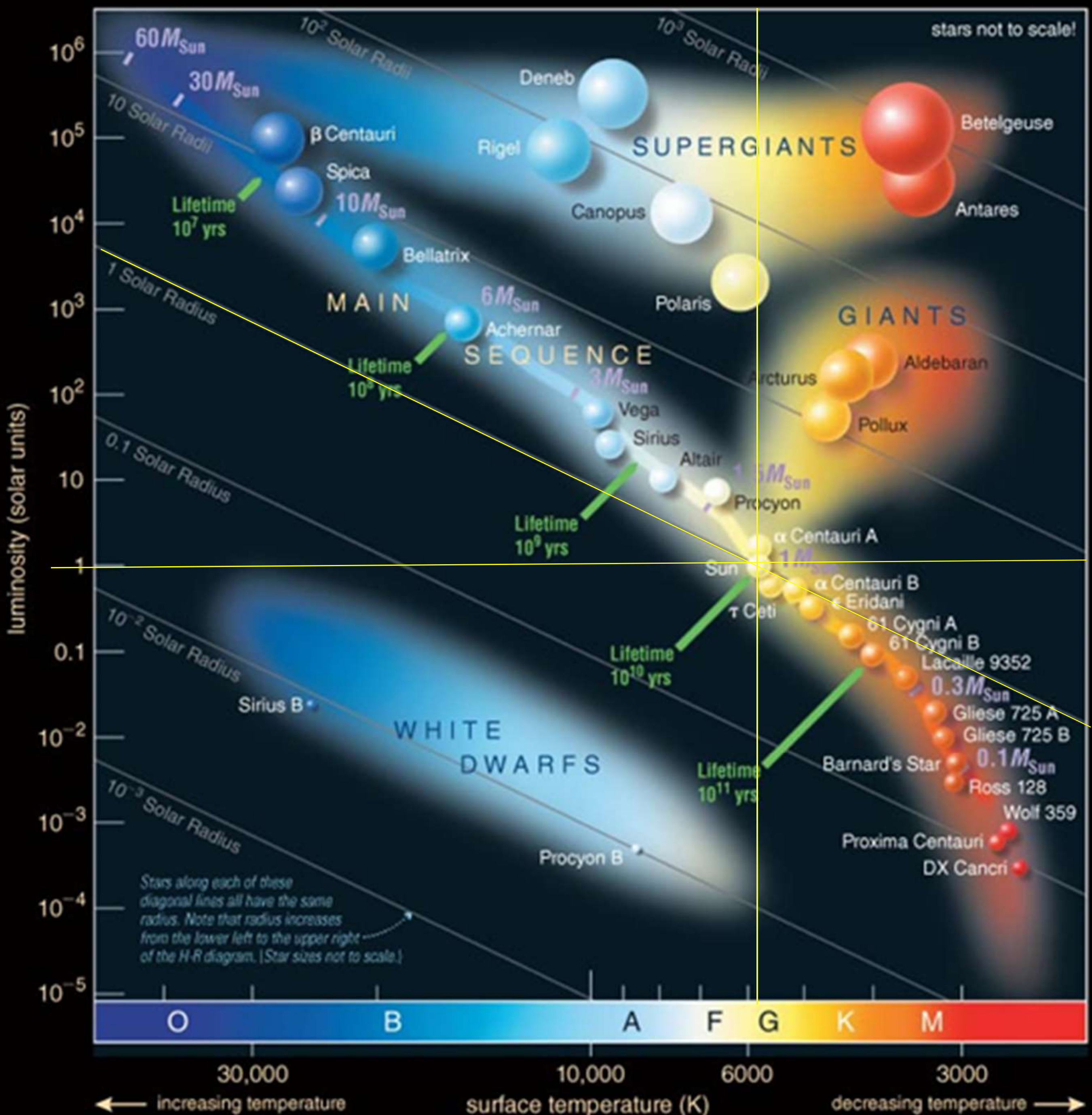
- Main sequence
    - Masses
    - Lifetimes
- Sizes on Main sequence
- Giants & supergiants
- White dwarfs

Star Radii on the H-R diagram



- More massive main sequence stars will naturally be a little bit larger… (up to ~ $10R_{Sun}$)
- The only way for stars to become more luminous for a given temperature is if they are larger… (more surface area is irradiating heat)
- Class I supergiants ~1000 R_{sun}

Class	Description
I	Supergiants
II	Bright giants
III	Giants
IV	Subgiants
V	Main-sequence stars



Today …

Need to understand:

- Mass-Luminosity relationship
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  - Masses
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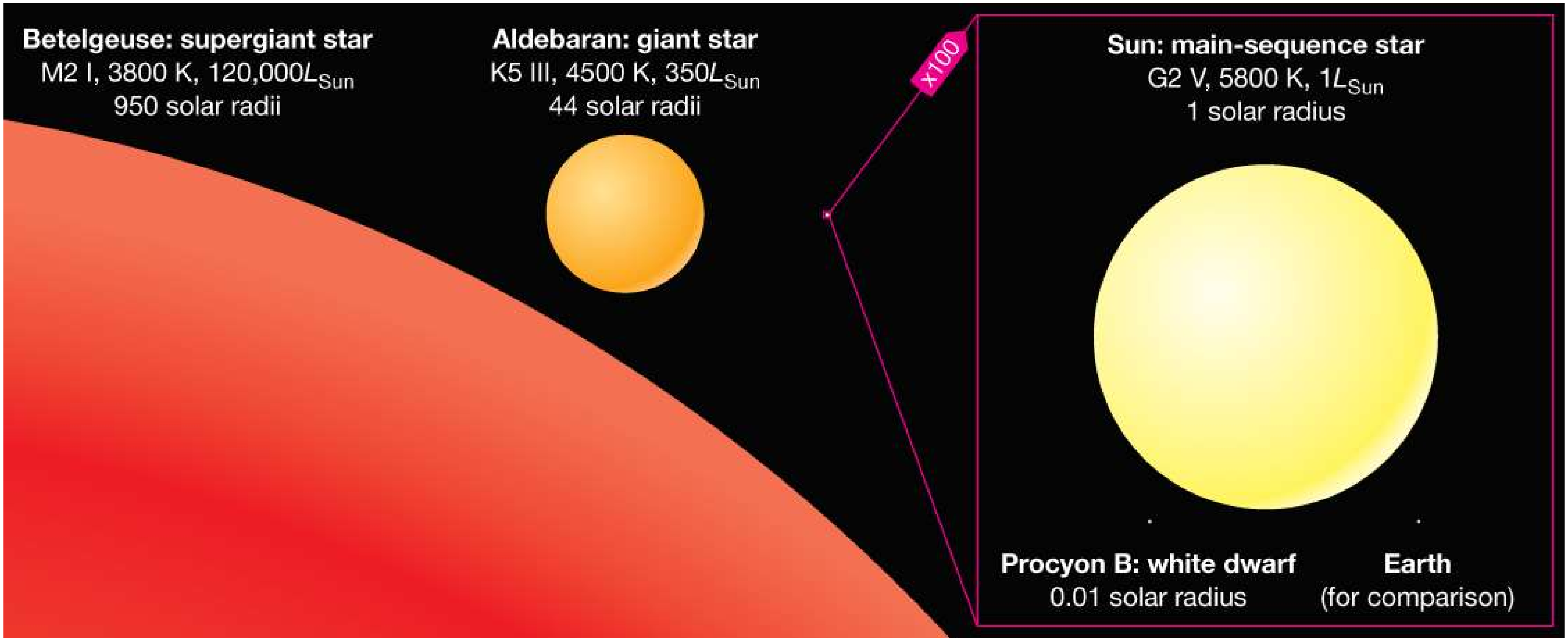
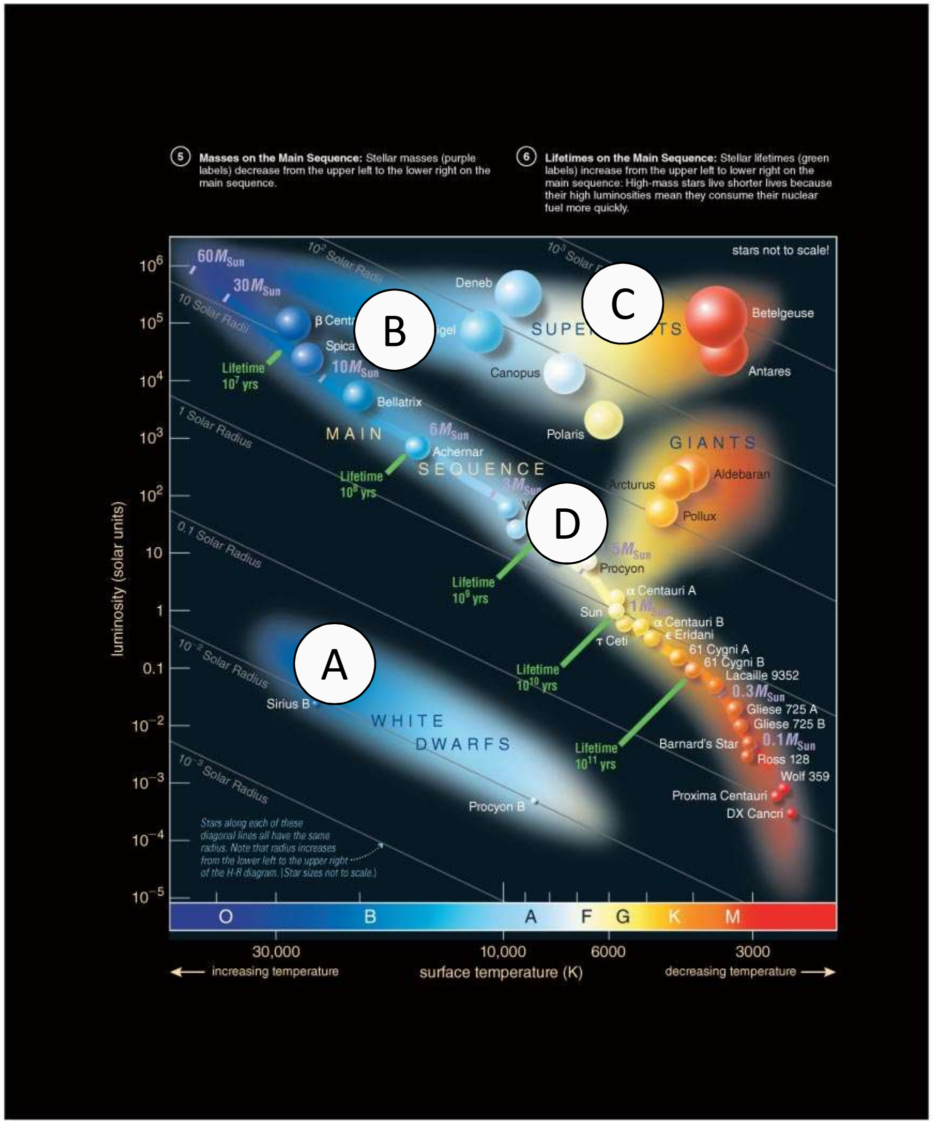
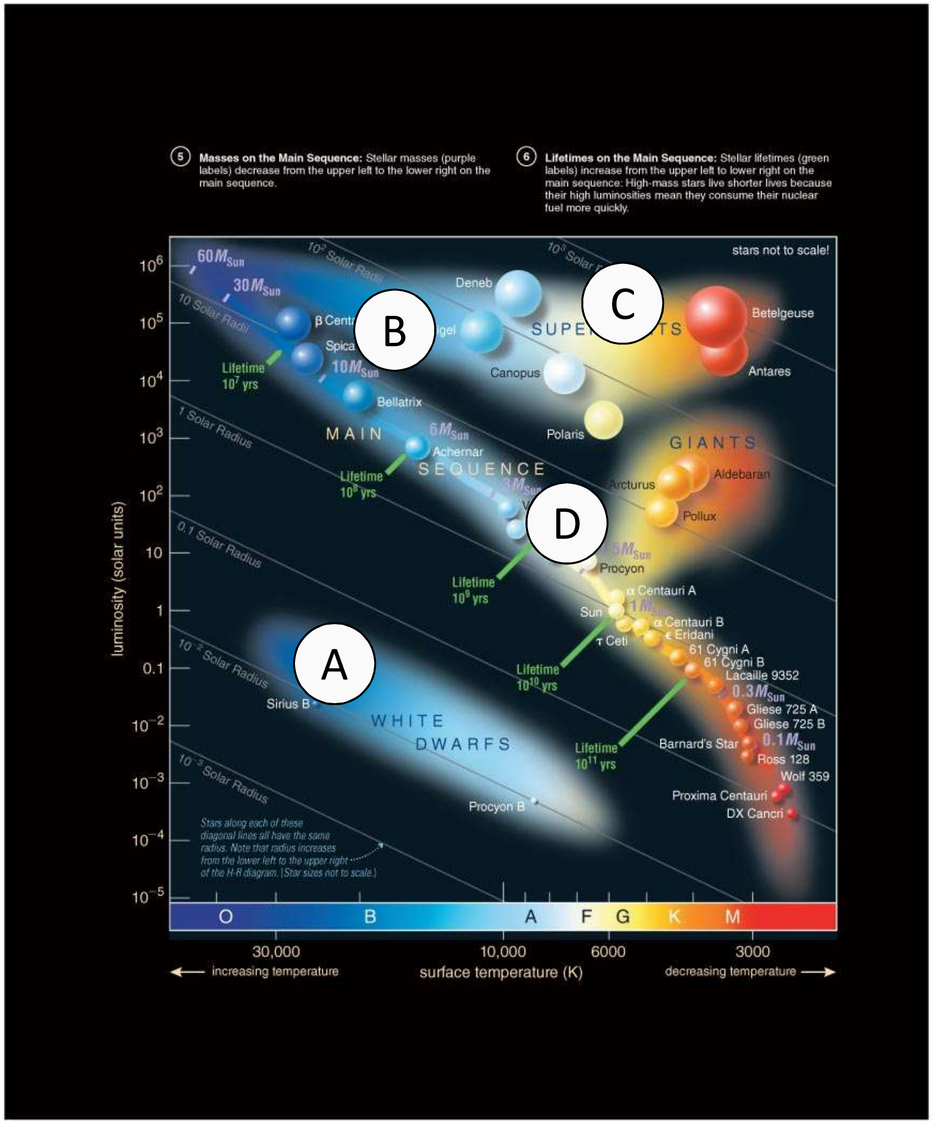
Supergiants & White Dwarfs



- Giants & Supergiants are stars nearing the end of their lives
- At the end of the life of a low-mass star, the outer layers are ejected, and the “dead’ core remains – these are White Dwarfs

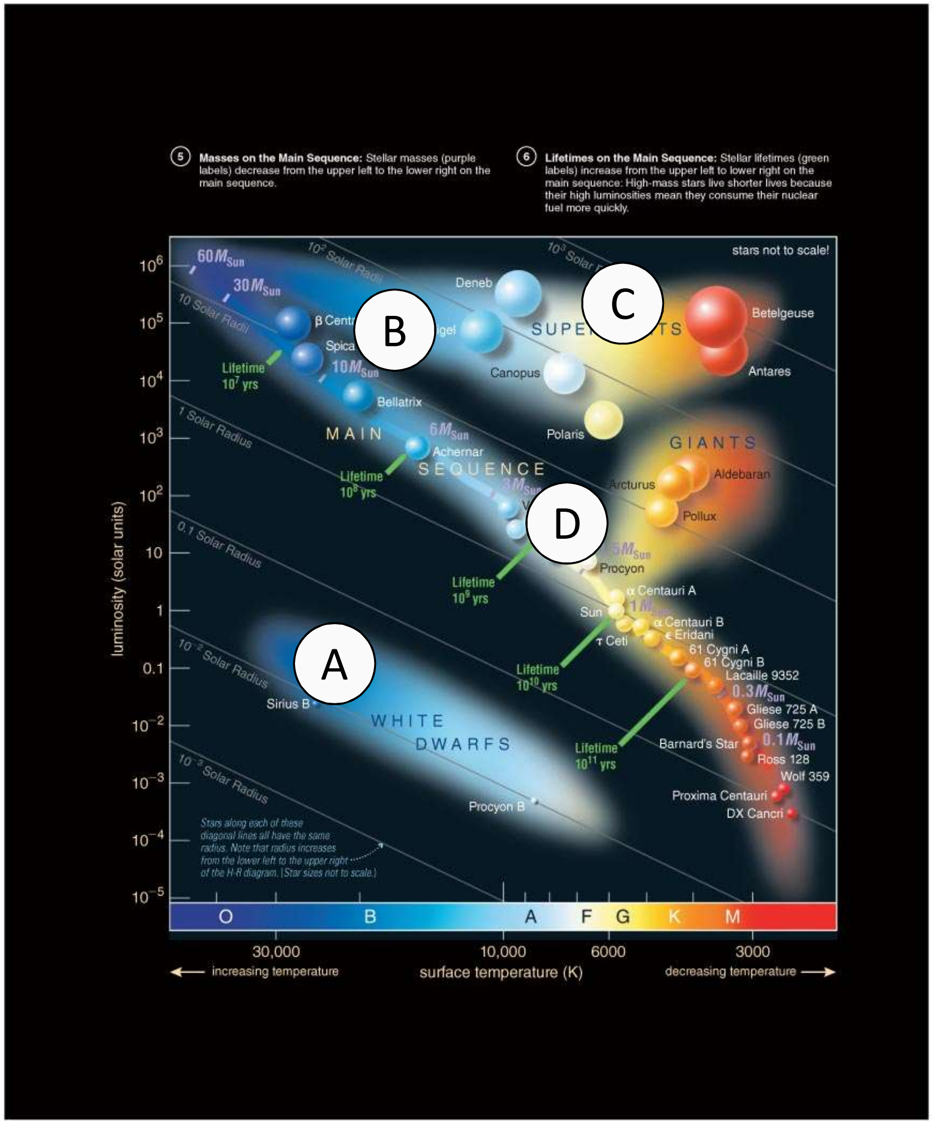


Which star is the hottest?

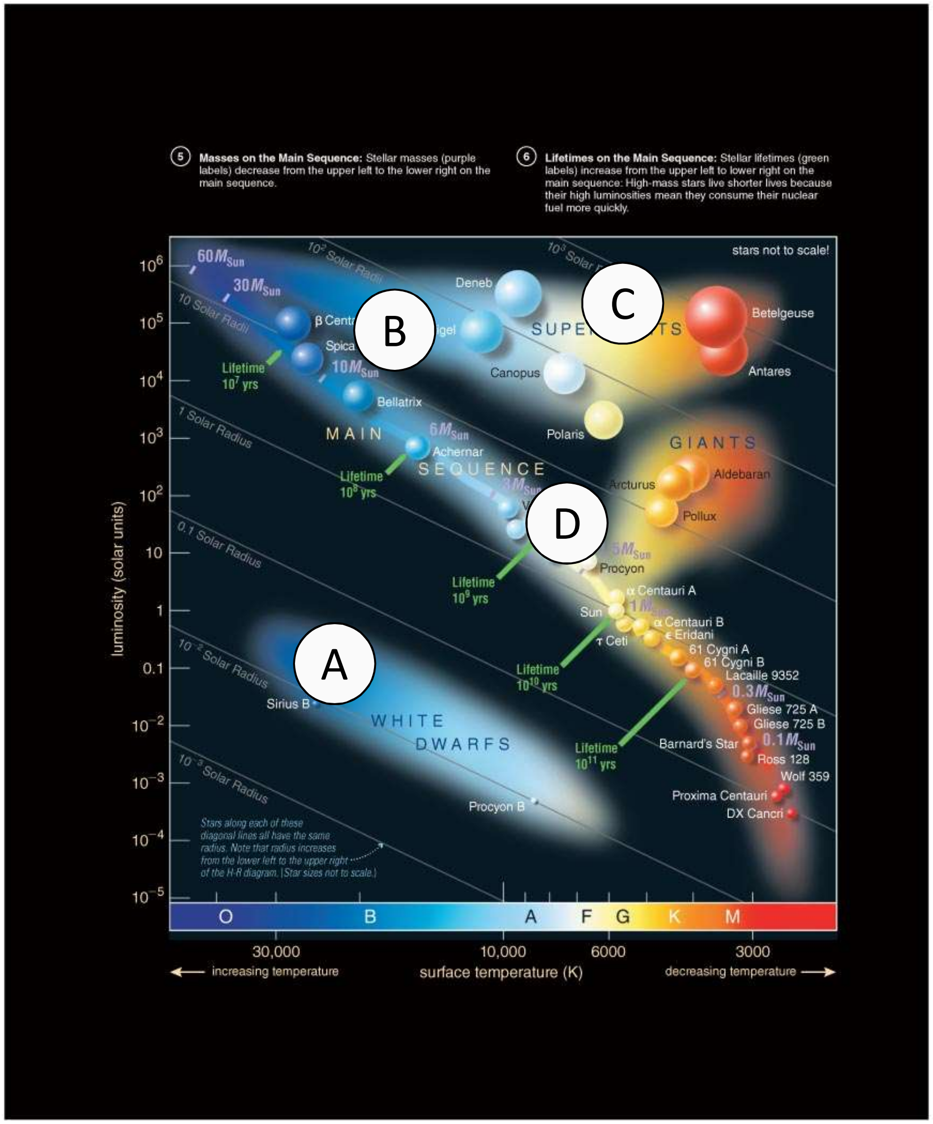


Which star is the hottest?

A

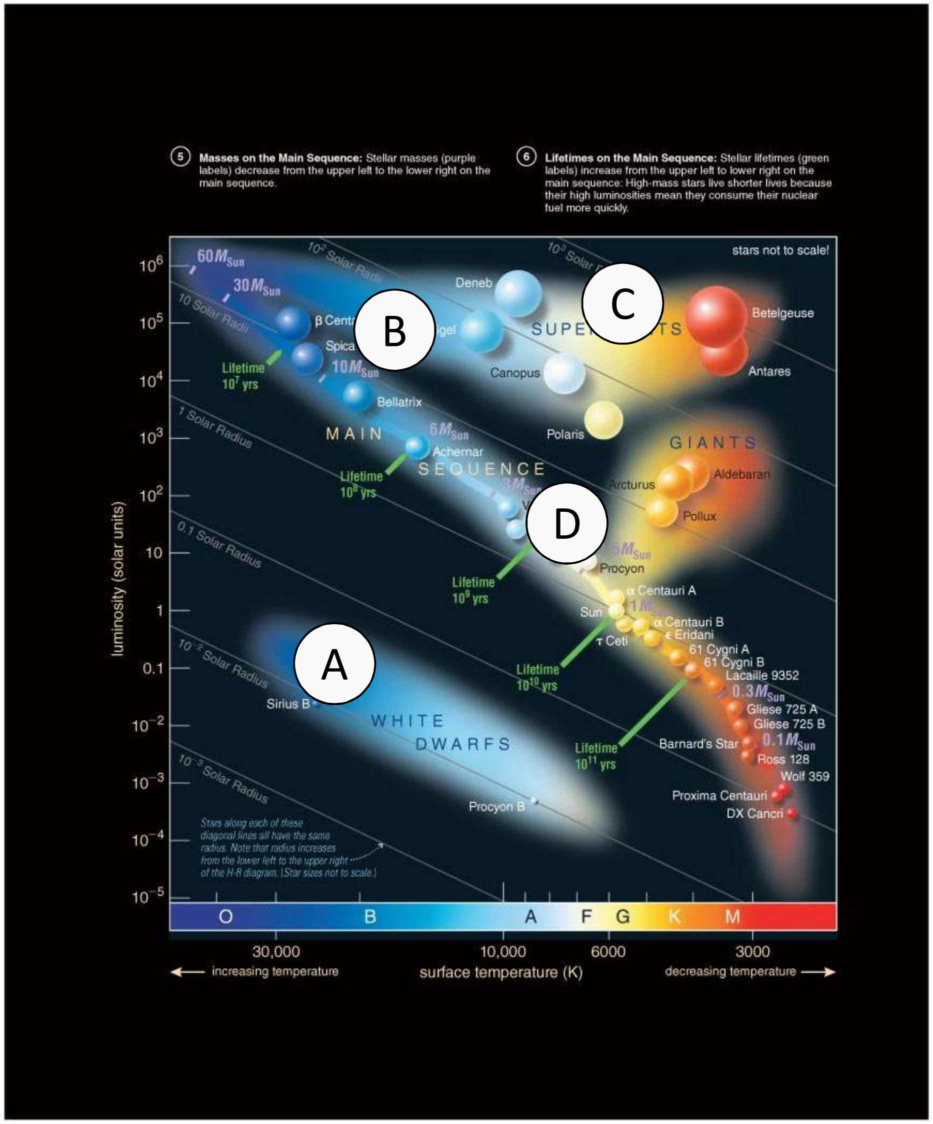


Which star is the most luminous?

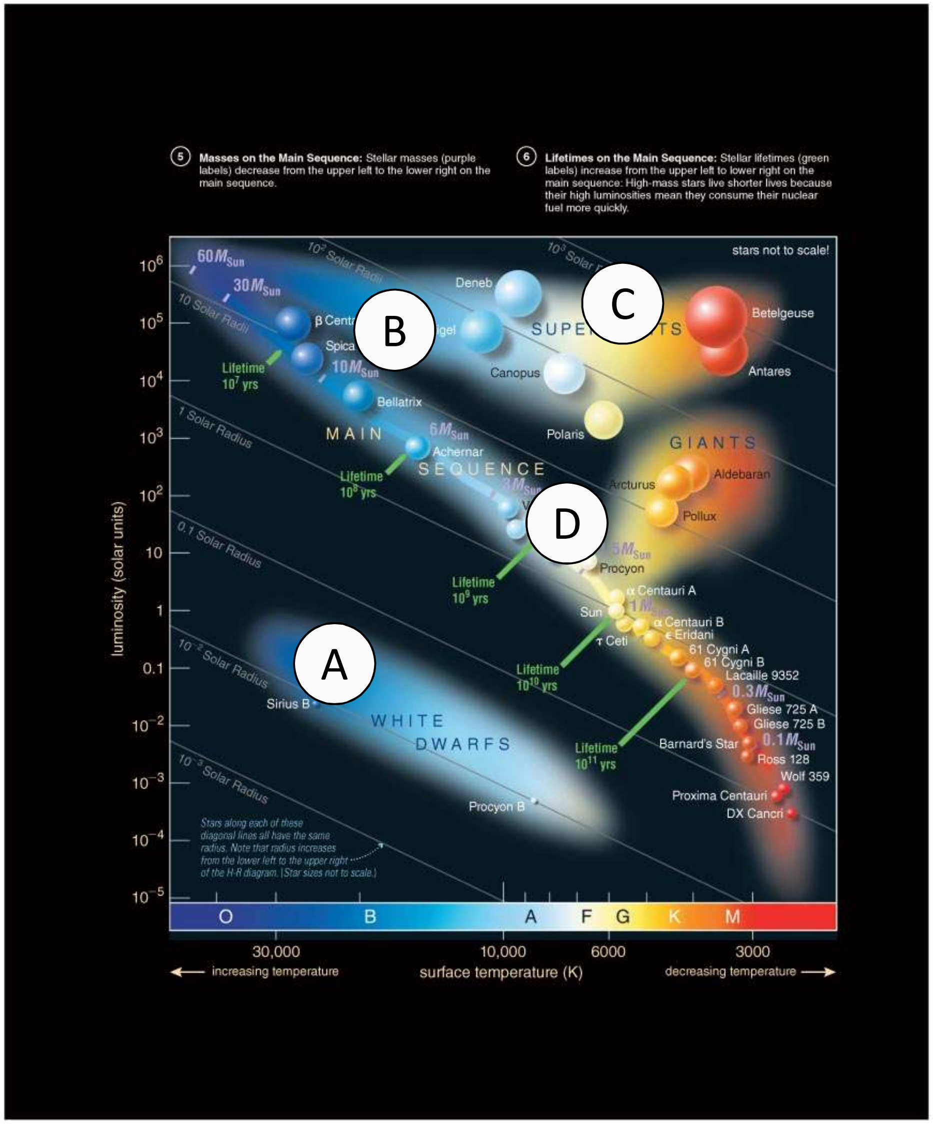


Which star is the most luminous?

C



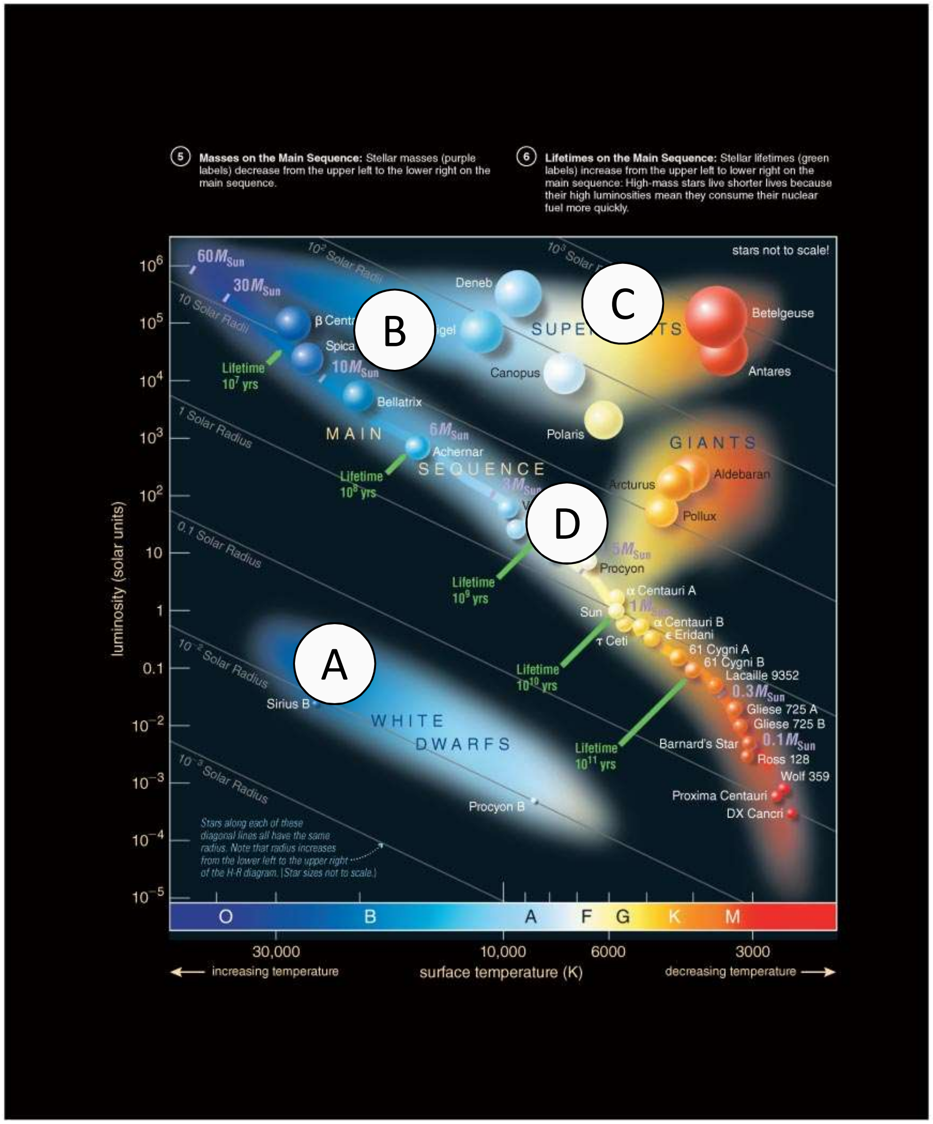
Which star is a main-sequence star?



Which star is a main-sequence star?

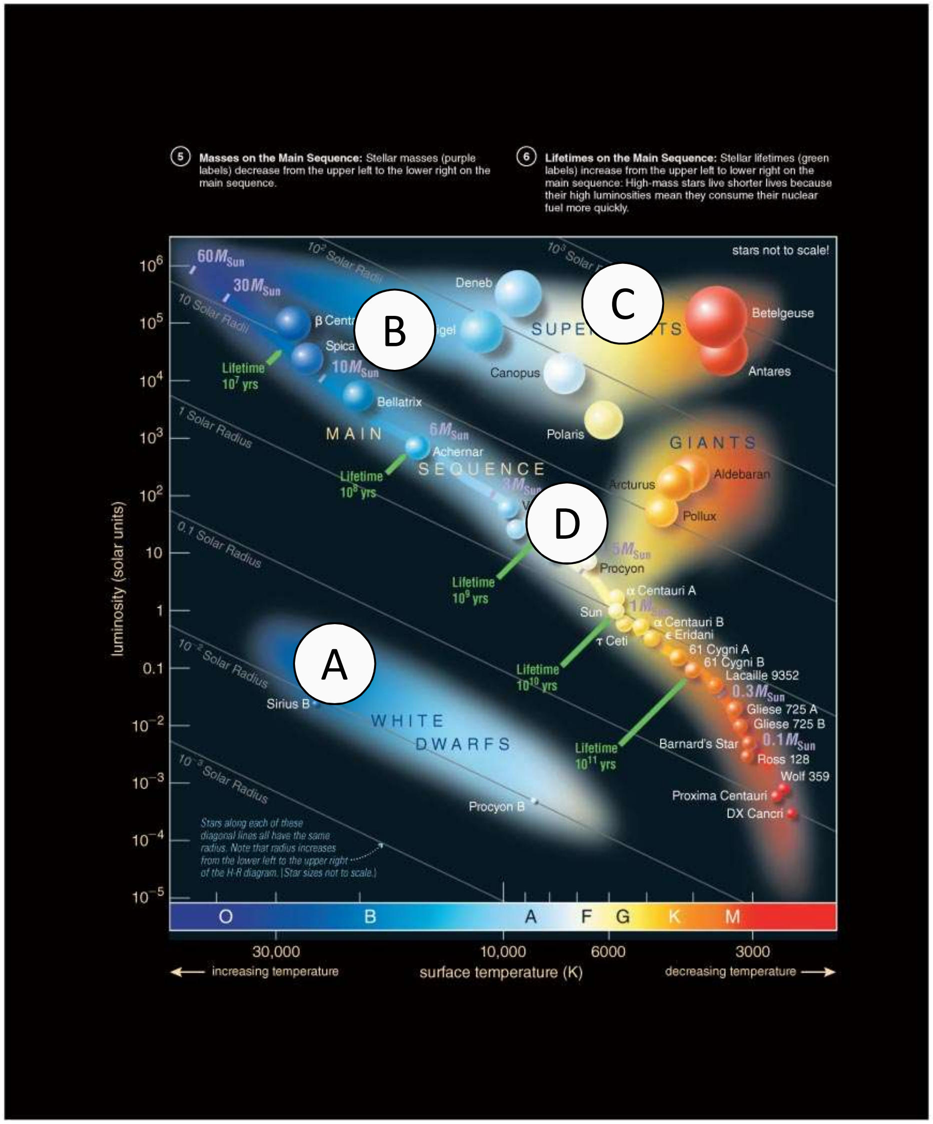
D

iClicker Question



Which star has the largest radius?

iClicker Question



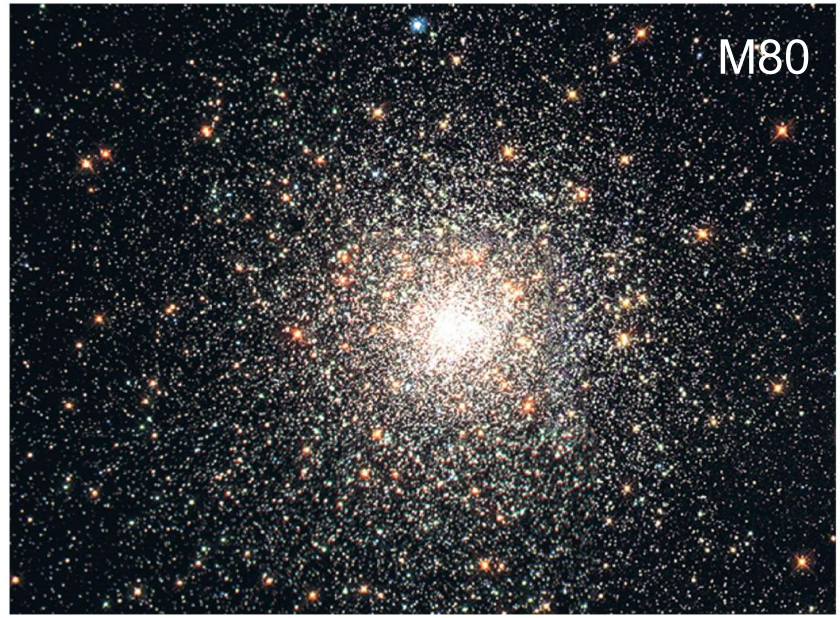
Which star has the largest radius?

C

12.2. 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 are giants, supergiants, and white dwarfs?
  - All stars become larger and redder after core hydrogen is exhausted: **giants** and **supergiants.**
  - Most stars end up as tiny **white dwarfs** after fusion has ceased.

Two types of Star Clusters



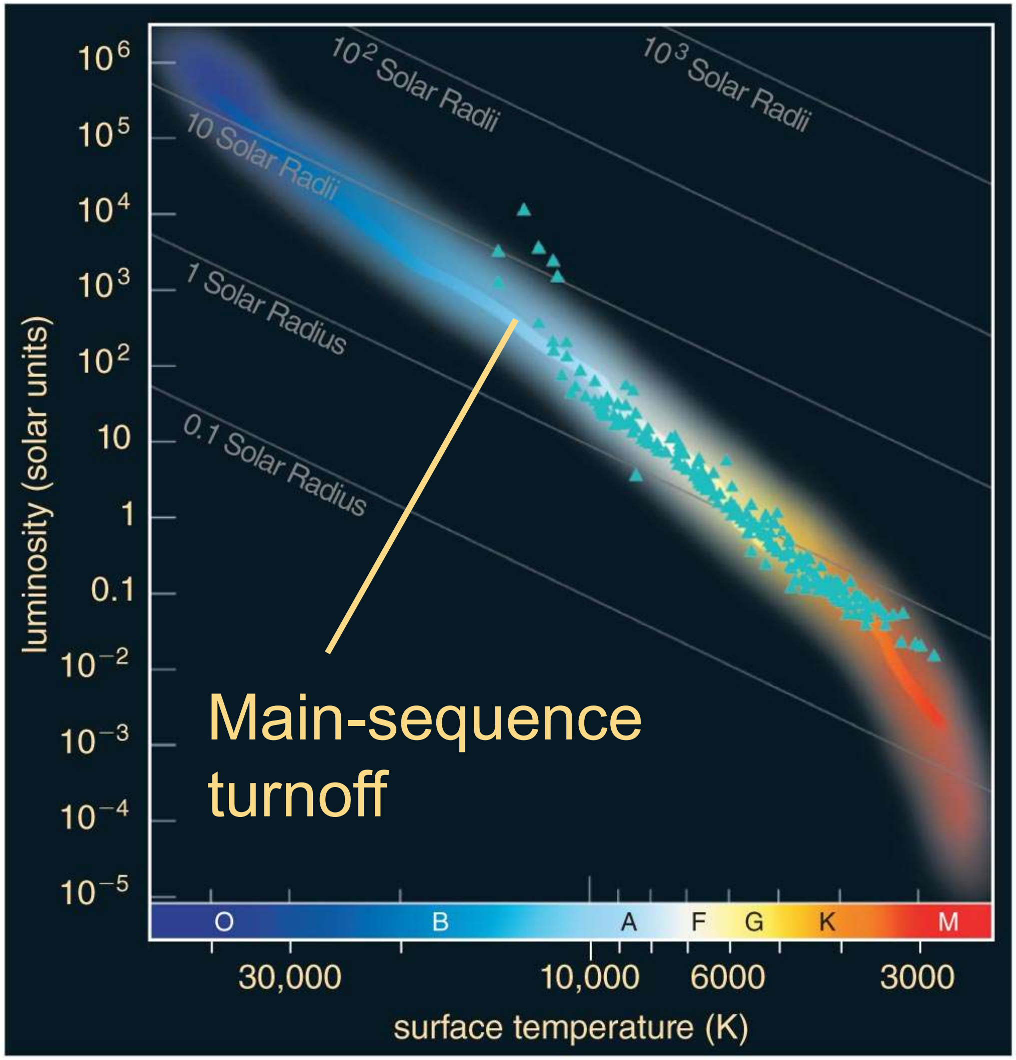
Open Cluster

- A few thousand loosely packed stars
- Young in age
- Located within the disk of the galaxy

Globular Cluster

- Up to millions of stars in dense ball, tightly bound by gravity
- Often much older in age
- Located in the halo region of the galaxy (above and below the disk)

How can we Determine the Age of a Star Cluster?

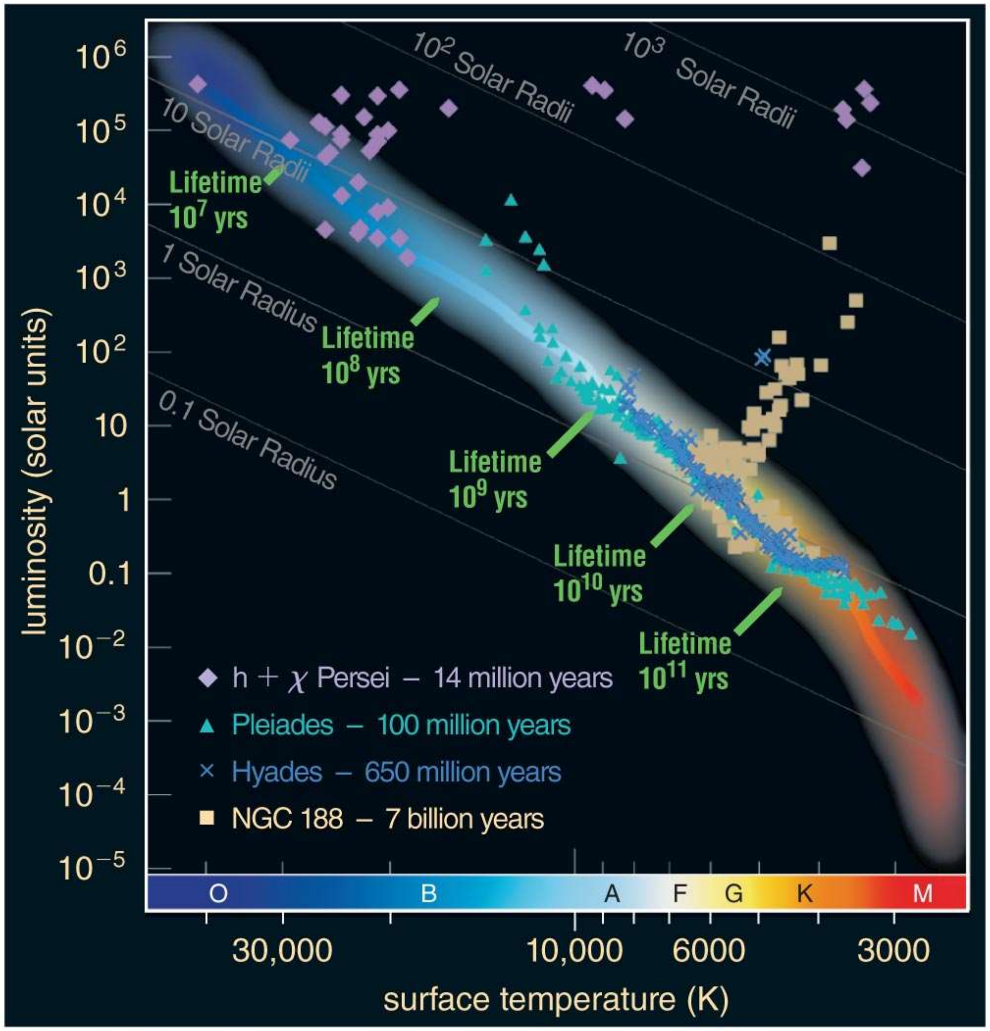


Clusters of stars are thought to have formed around the same time…

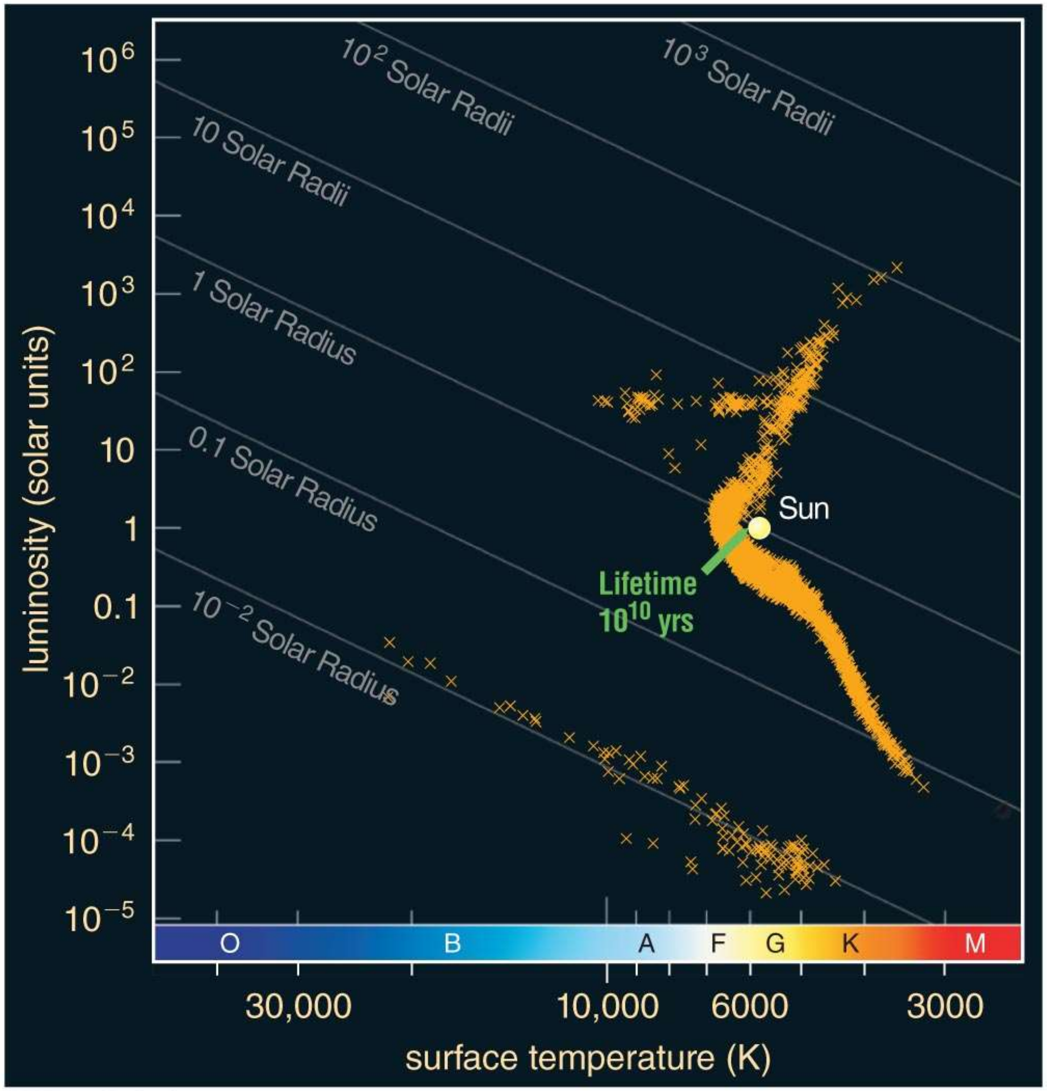
By cataloging the star-types in a cluster we find that the there a ‘turn-off’ point where the larger stars have begun leaving the main sequence…

Pleiades (shown in blue triangles) now has no stars with a life expectancy less than around 100 million years.

We can repeat this for multiple star clusters to determine their ages…



Can we use Star Clusters to Date the Universe? The Galaxy?



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

Here, the stars of M4 point to an age of ~12.2 billion years

Note that the white dwarfs are also shown here…

12.3. 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 roughly equals the life expectancy of its most massive stars still on the main sequence.

End of Todays Lecture