Surveying the Stars

Chapter 11


Betelgeuse
Stars
Eclipsing Binary
Inverse Square Law for Light
Main-Sequence
luminosity
brighter
hydrogen
luminous
fusion
thermal radiation
10-4 LSun
mass
Absorption lines
cluster
Orbital Period
surface temperatures
main-sequence
Sirius
0.08 RSun
Spectral Type
luminosities
Radius
G2
4 trillion years
Mass
radius
MSun
Centauri
solar
Luminosity
0.08 MSun
stars
surface temperature
1000 RSun
Globular
O B A F G K M
orbit
cooler
H-R
2x106 LSun
million
White
brightness
distance
LSun
bright
apparent brightness
red
Snapshot
spectrum
massive
Hertzsprung-Russell Diagram
hottest
Cluster
stellar parallax
color
100 thousand years
temperature
sequence
star clusters
150 MSun

Properties of Stars

* Stars live too long for us to follow one from its birth to its death
* To analyze star properties, we look at many many stars, all at different points in their lifespans
* We then draw hypotheses from what we observe - followed up by computer models

Properties of Stars...

* We know that stars were formed from great clouds of gas & dust
* Most stars are born with a similar chemical composition as our Sun (73% H, 25% He, 2% heavier elements)
* Yet stars differ in size, age, brightness and temperature

The Fox Fur Nebula

This interstellar beast is formed of cosmic dust and gas interacting with the energetic light and winds from hot young stars

Credit & Copyright: Jean-Charles Cuillandre (CFHT) & Giovanni Anselmi (Coelum Astronomia), Hawaiian Starlight

Properties of Stars...

* Astronomers have concluded that stars have three really fundamental properties:

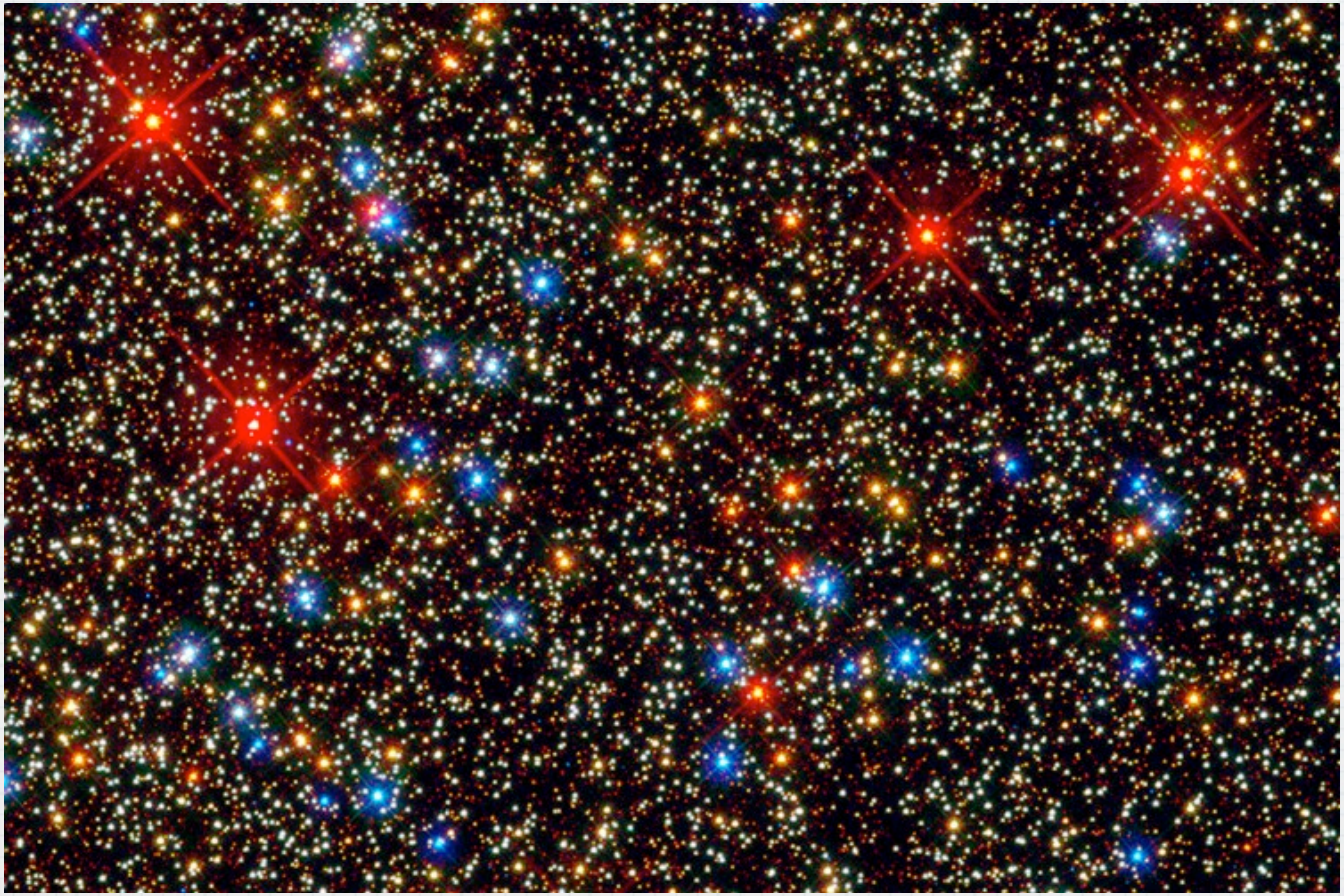
1. luminosity
2. surface temperature
3. mass

1. How luminous are stars?

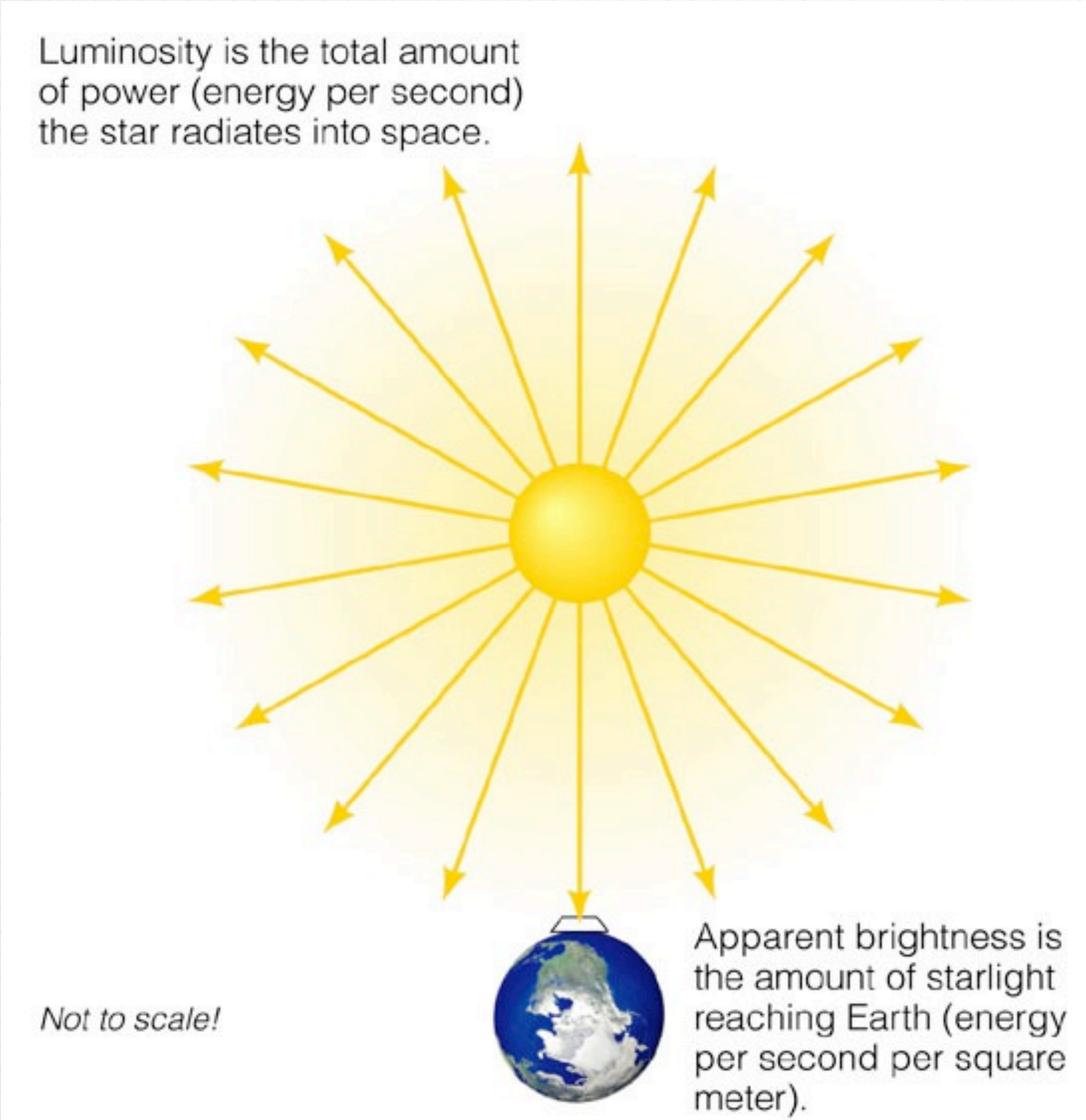
* On a clear and dark night, away from a city, one can immediately see that stars vary in brightness
* Constellations were drawn using the brightest ones
* Yet, a star's luminosity we see on Earth is dependent on its distance as well as its true (or intrinsic) brightness

The brightness of a star depends on both distance and luminosity

This picture cannot tell us which stars are closer and which are truly brighter



The Center of Globular Cluster Omega Centauri
Credit: NASA, ESA, and the Hubble SM4 ERO Team



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)

Luminosity

* 2 stars, Betelgeuse and Procyon, appears equally as bright to us
* Their **apparent brightness** is the same
* But Betelgeuse is 5,000 times brighter than Procyon
* Betelgeuse **luminosity** is greater than Procyon

Luminosity...

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

A. Alpha Centauri

B. The Sun

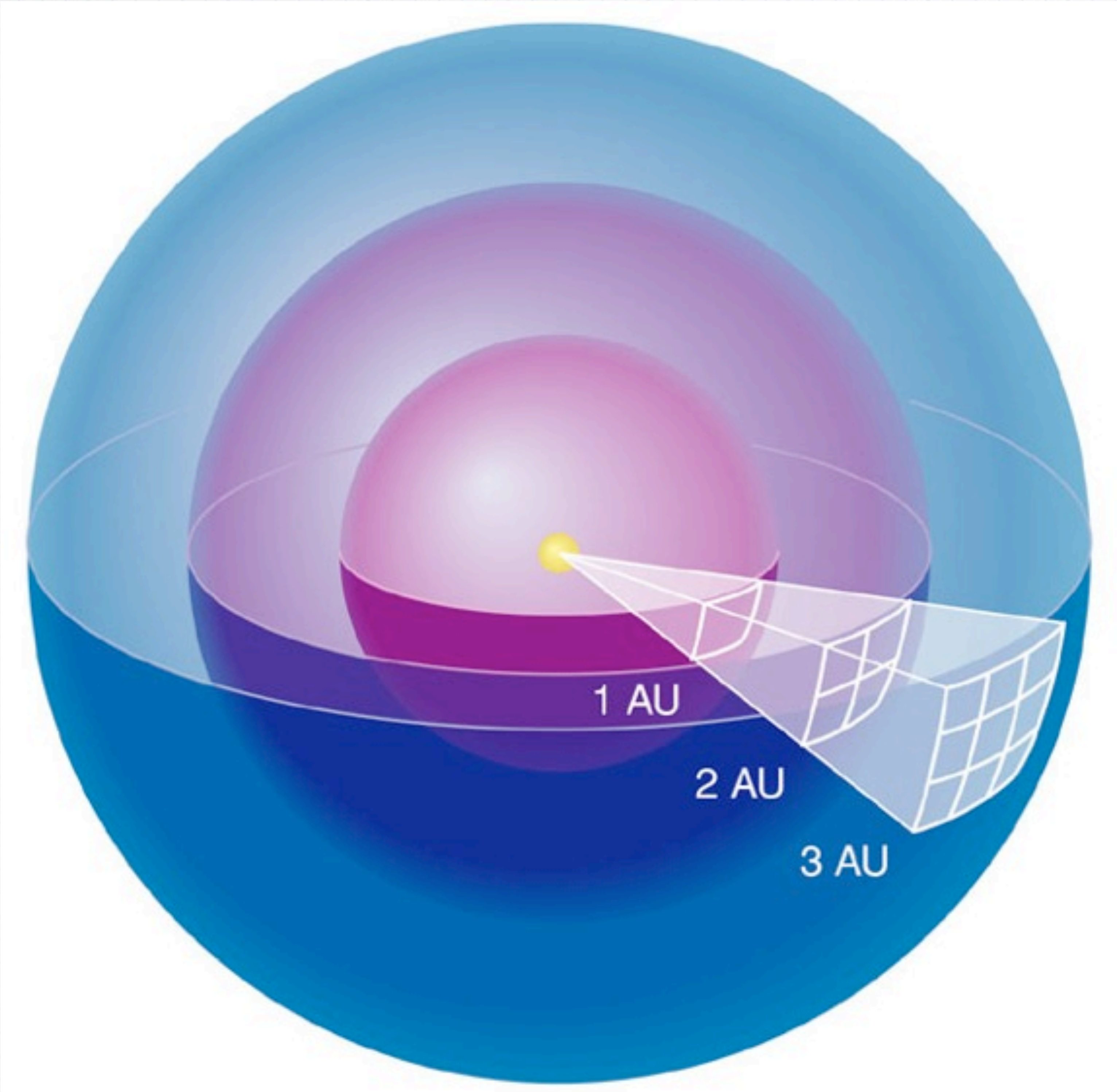
Luminosity...

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

A. Alpha Centauri

B. The Sun (!)

The Inverse Square Law for Light



Luminosity passing through each sphere is the same

The energy twice as far from the source is spread over 4 times the area, hence the one-fourth the intensity at that distance

The relationship between apparent brightness and luminosity depends on distance:

It is an inverse distance square relationship

$$\text{Brightness} = \frac{\text{Luminosity}}{4\pi\,(\text{distance})^2} \asymp \frac{1}{d^2}$$

To determine a star's luminosity we need to measure its distance and apparent brightness

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

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

Question

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

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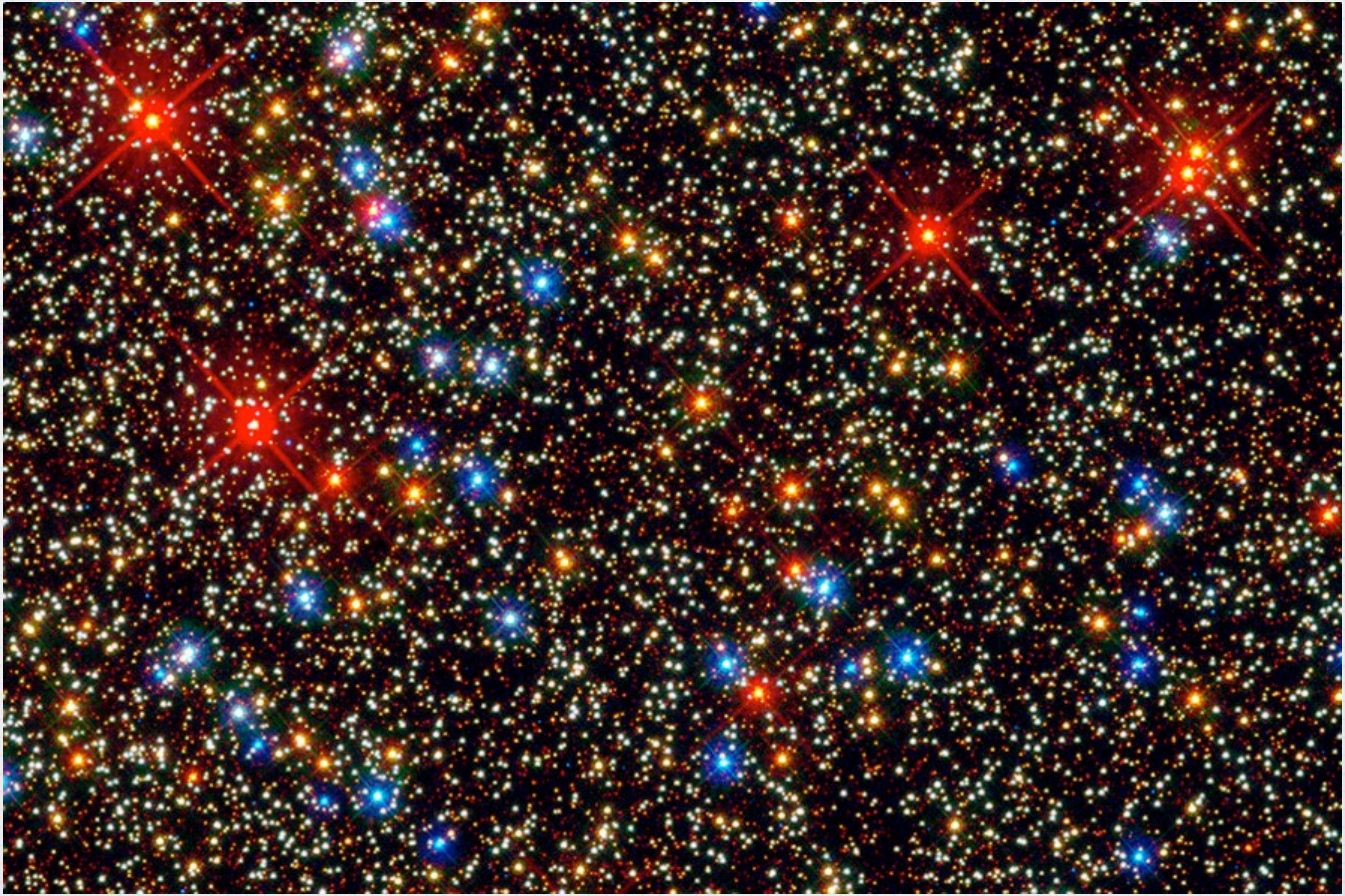
So now the problem has shifted to that of finding distances

How far are these stars?

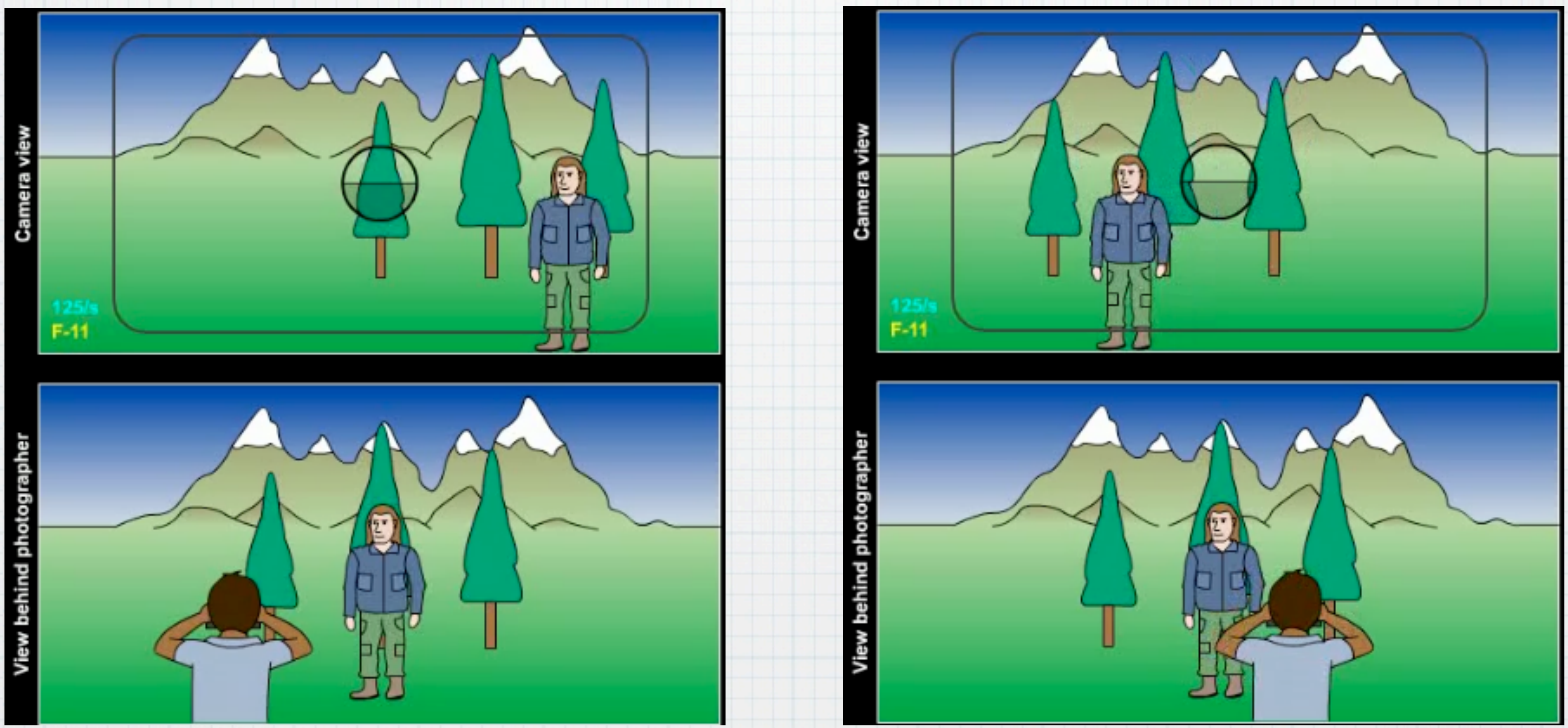
The Center of Globular Cluster Omega Centauri
Credit: NASA, ESA, and the Hubble SM4 ERO Team

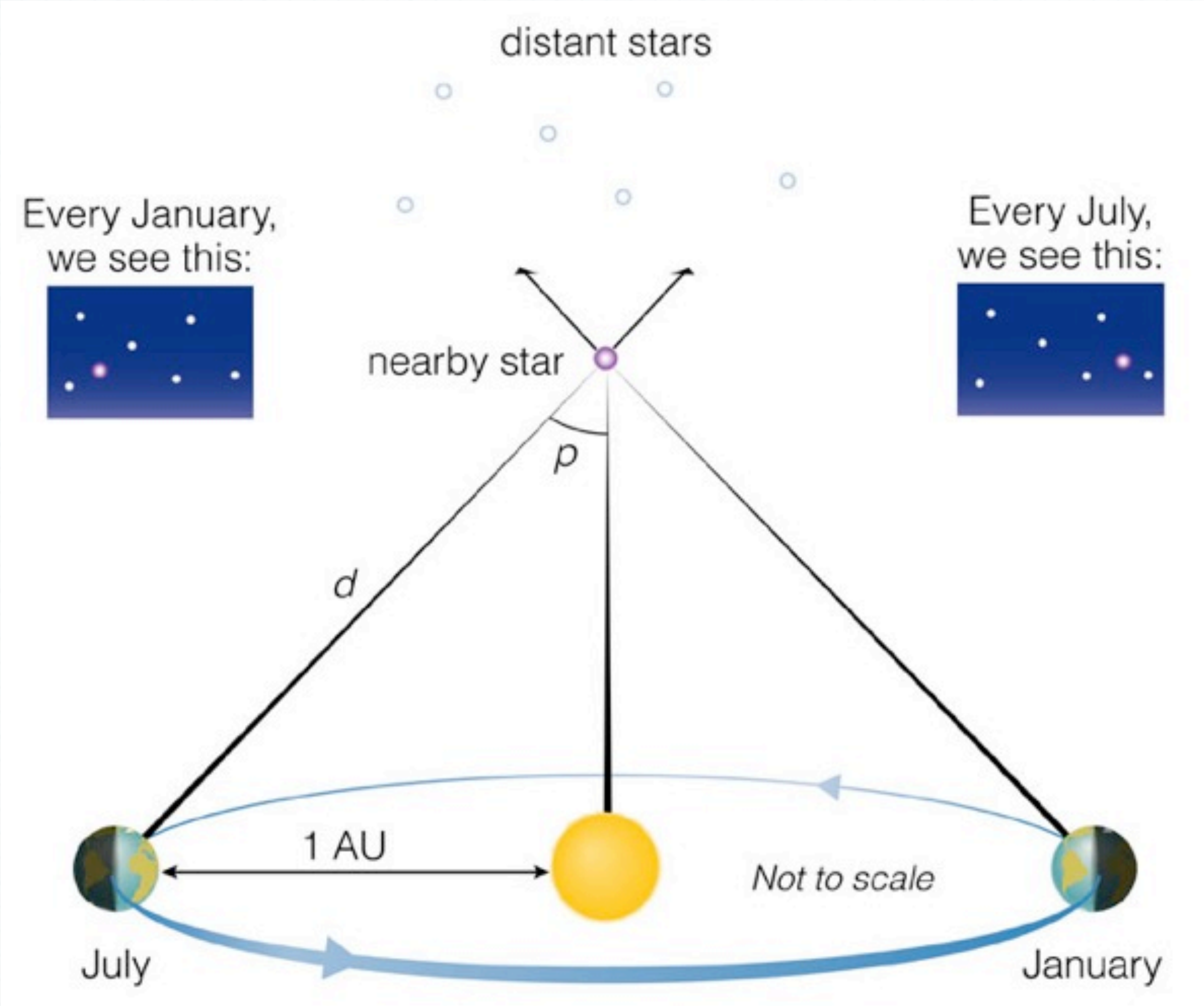


The most direct way to measure a star's distance is to measure its stellar parallax

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

The Greeks had no chance of measuring a stellar parallax...

We can accurately measure stellar parallax for stars within a few hundred light-years - the local solar neighborhood

Luminosity

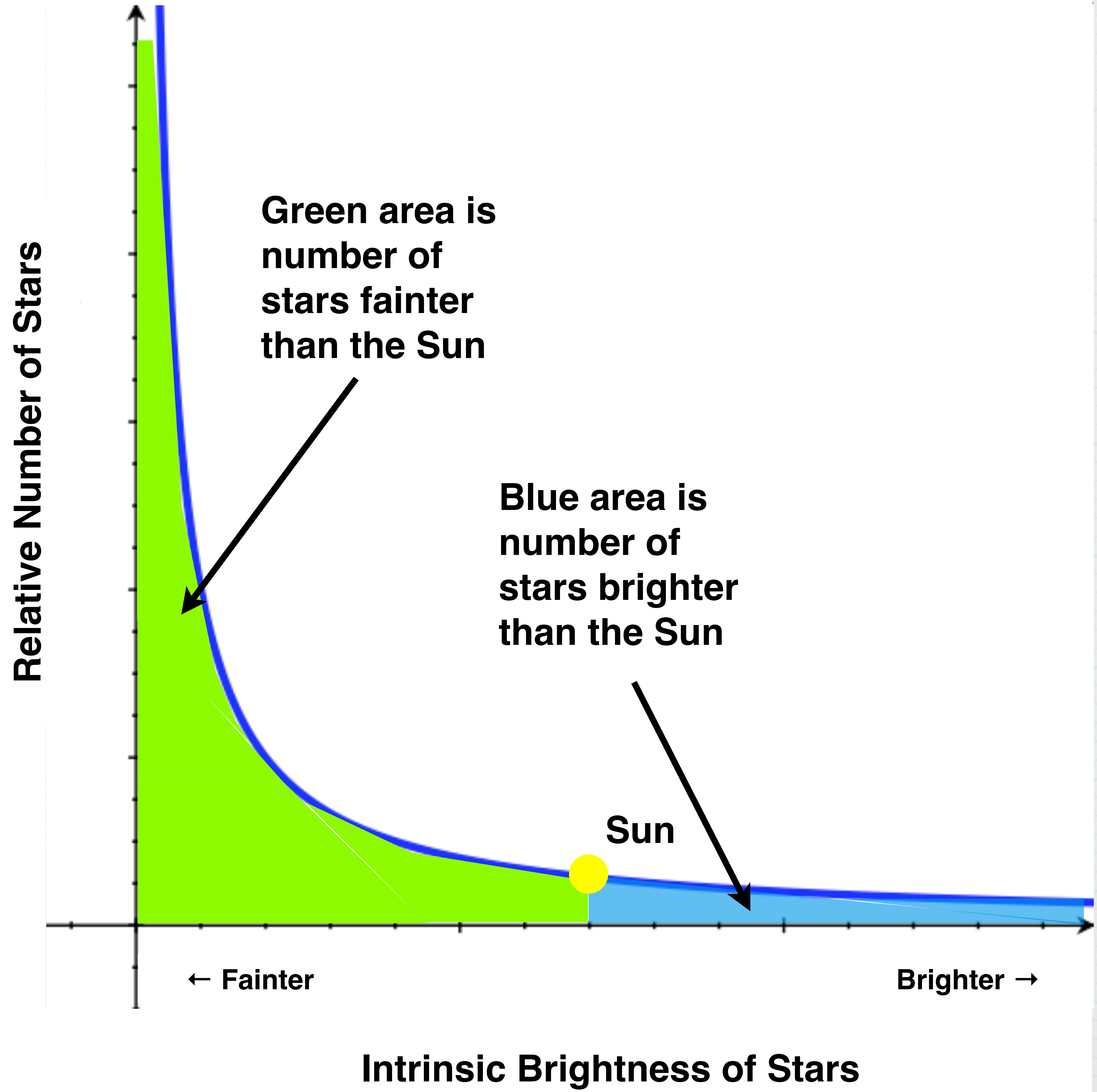
* Stellar parallax is the only technique which tells us a star's distance directly without any other assumption
* Once we have measured its apparent brightness and we have measured its distance via stellar parallax we can then calculate its luminosity (true brightness)
* We have done this for about several thousands of stars. Enough to draw some conclusions

The True Luminosity of Stars

- The **dimmest stars** are **1/10,000 dimmer** than our Sun, or $10^{-4}\ L_{Sun}$
- The **brightest stars** are **2 million times brighter** than our Sun, or $2 \times 10^{6}\ L_{Sun}$
- **Dim stars are far more common than bright ones**
- **Our Sun** is in the middle of the range, meaning it **is brighter than most stars**

The Sun is a relatively bright star

Most stars are fainter



Some examples

The Center of Globular Cluster Omega Centauri
Credit: NASA, ESA, and the Hubble SM4 ERO Team

Proxima Centauri (nearest star to Sun) has a luminosity of 0.0006 L_{Sun})

(The Sun is about 1667 times brighter than Proxima Centauri)

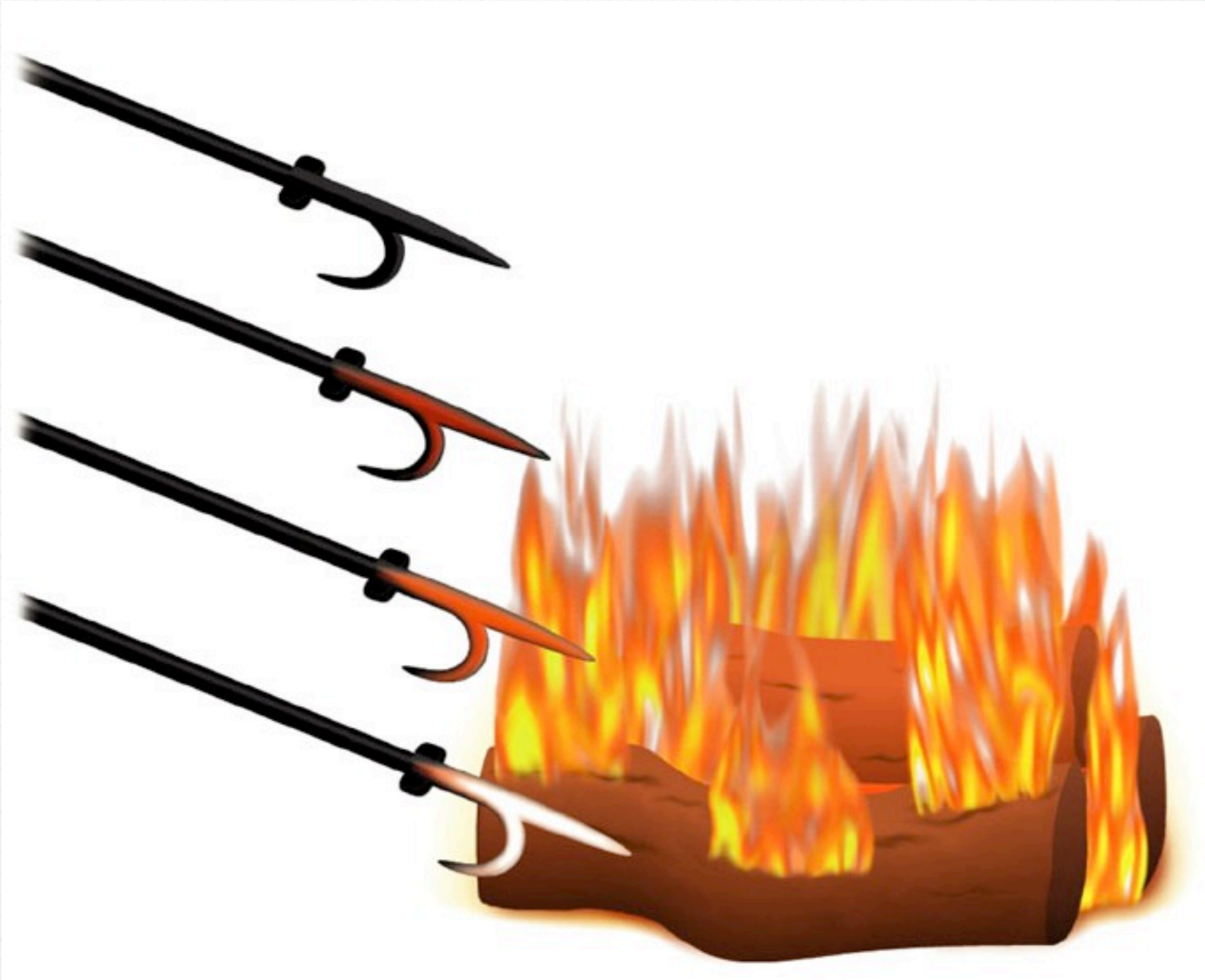
Betelgeuse (in Orion) has a luminosity of 38,000 L_{Sun}

(The Sun is about 0.00003 times brighter than Betelgeuse)

2. How hot are stars?

* The second most fundamental property of a star is its surface temperature
* We can determine surface temperature directly from
  * the star's color, or
  * its spectrum

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

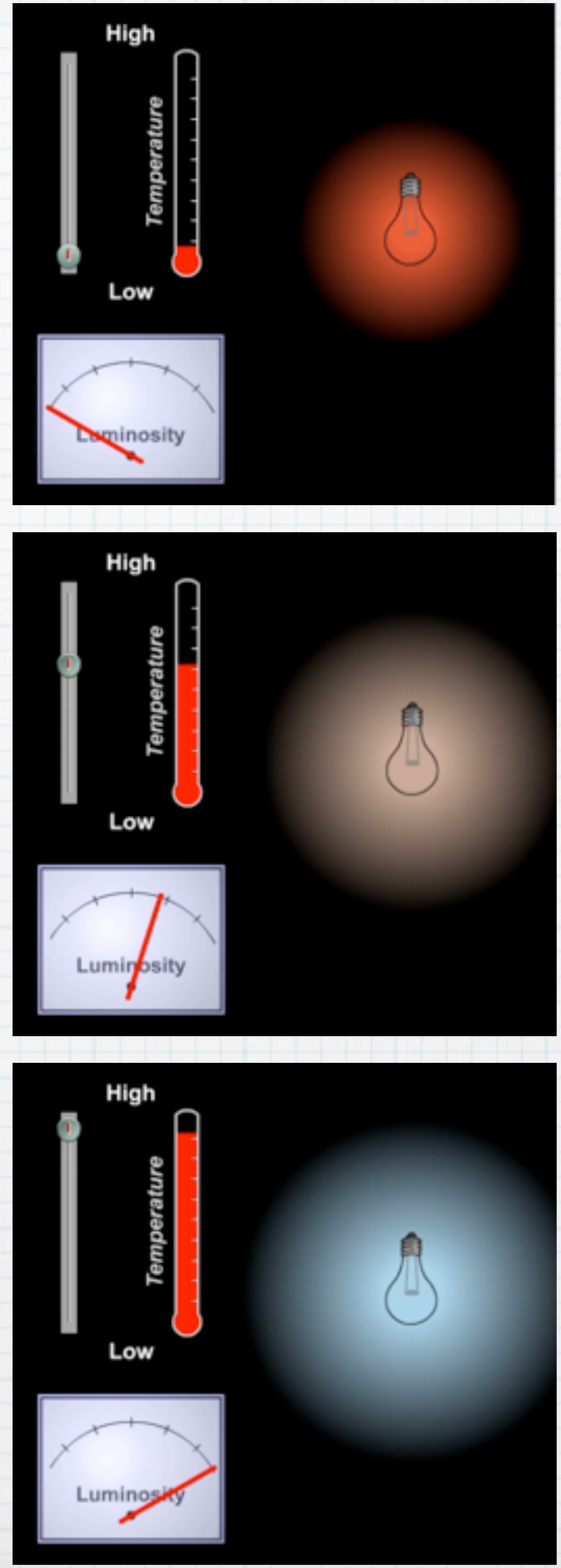


An object of fixed size grows more luminous as its temperature rises

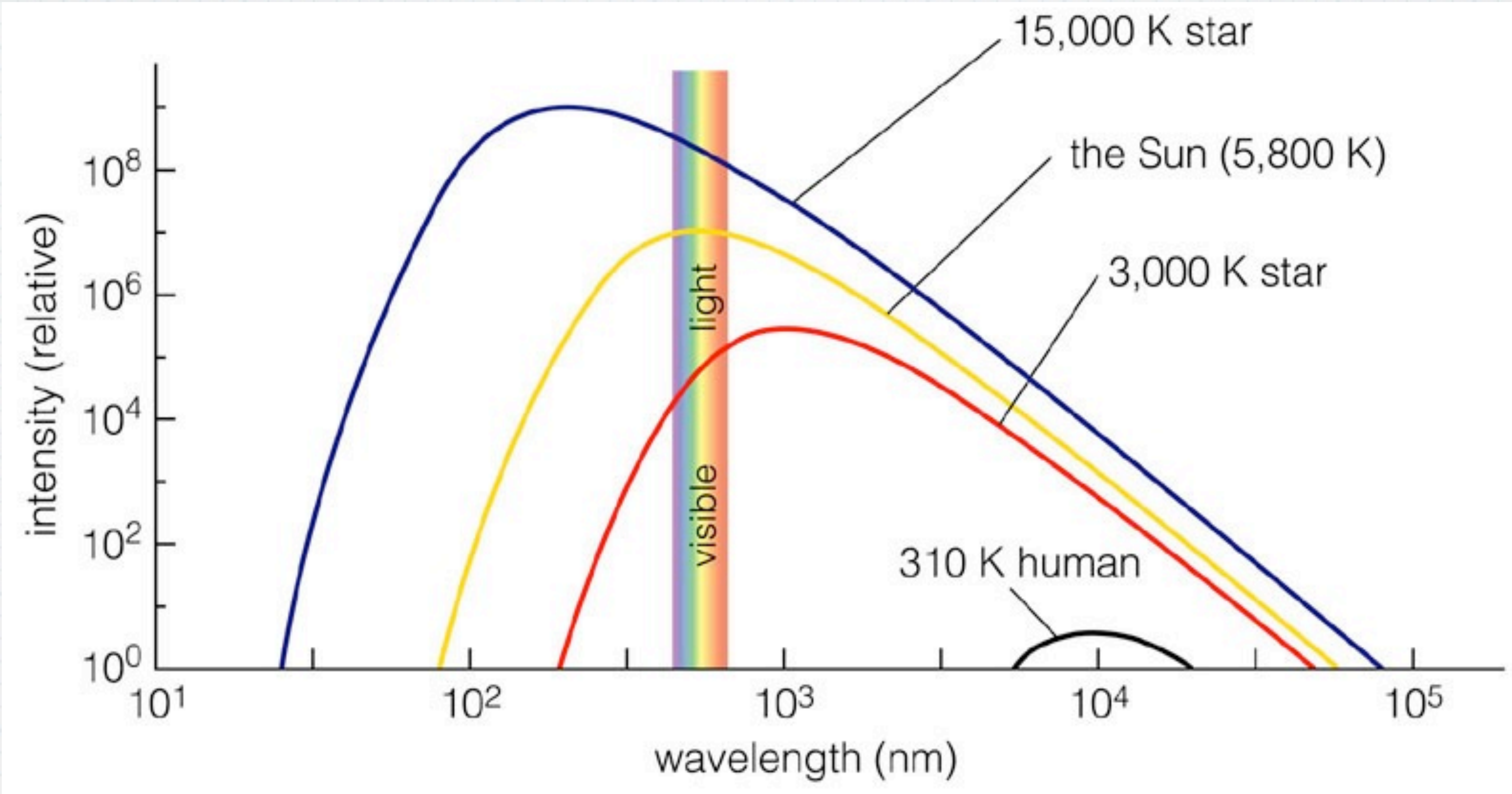
Betelgeuse is a cool star
surface T = 3,400 K... red

The Sun is warmer
surface T = 5,800 K... yellow

Sirius is hot
surface T = 9,400 K... blue

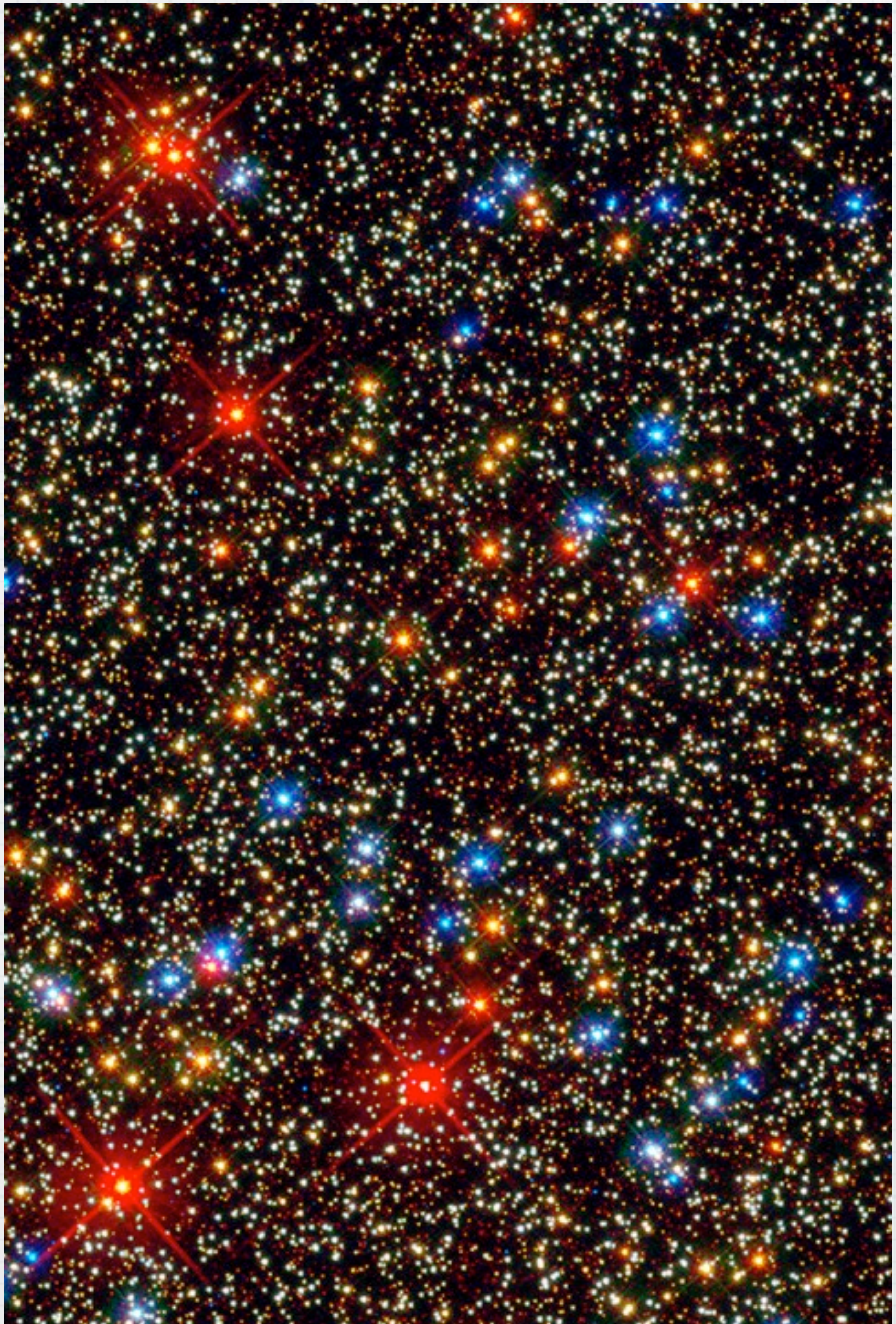


Laws of Thermal Radiation



1) Hotter objects emit more light (energy) at all wavelengths

2) Hotter objects emit more light at shorter wavelengths (higher frequencies)



Hottest stars: 55,000 K

Coolest stars: 3,000 K

Sun's surface: 5,800 K

The Center of Globular Cluster Omega Centauri
Credit: NASA, ESA, and the Hubble SM4 ERO Team

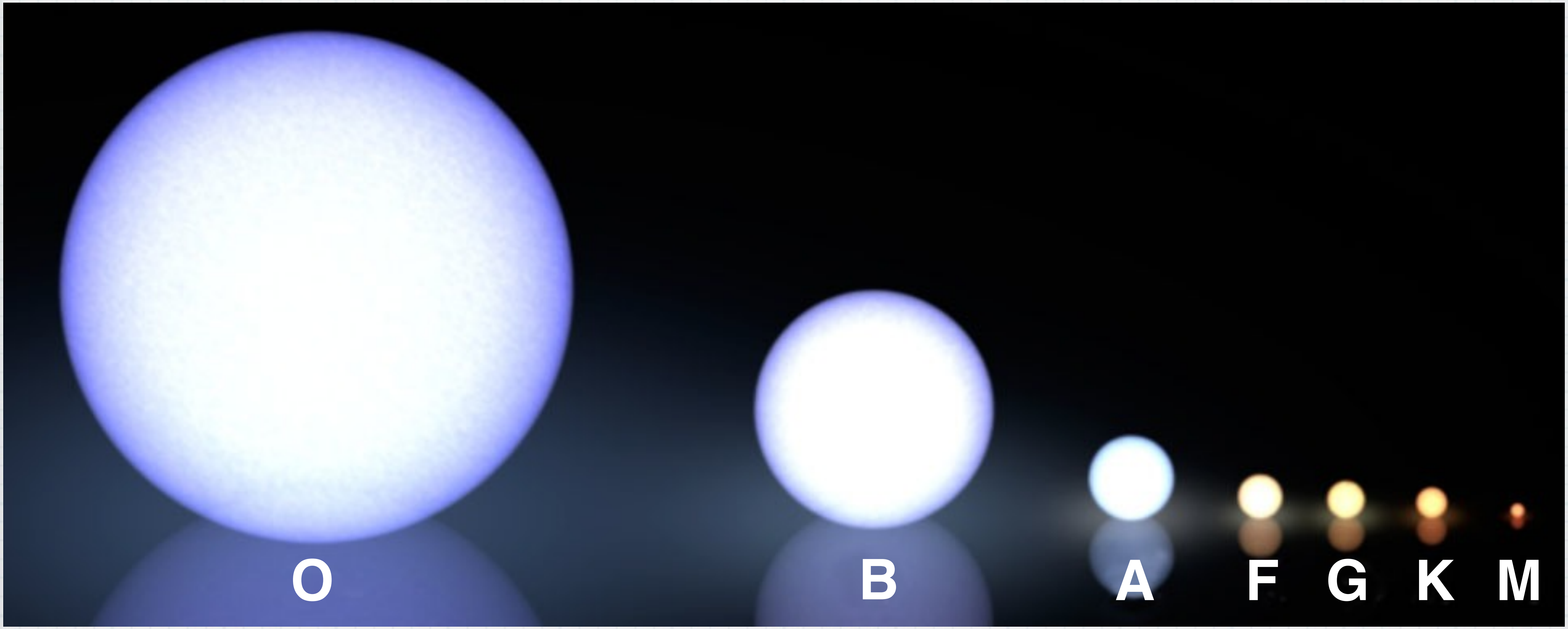
Spectral Type

* Most stars are currently classified using the letters O, B, A, F, G, K and M, where O stars are the hottest and the letter sequence indicates successively cooler stars up to the coolest M class
* The original classification (A, B, C,...) was based on the strength of the Hydrogen line. However it was realized (1910) that a temperature-based classification made more sense

O B A F G K M
(the spectral types)

* (hottest) O B A F G K M (coolest)
* Oh, Be A Fine Girl/Guy Kiss Me

Spectral Types & Colors



few of these ---------------------- increasingly more of these

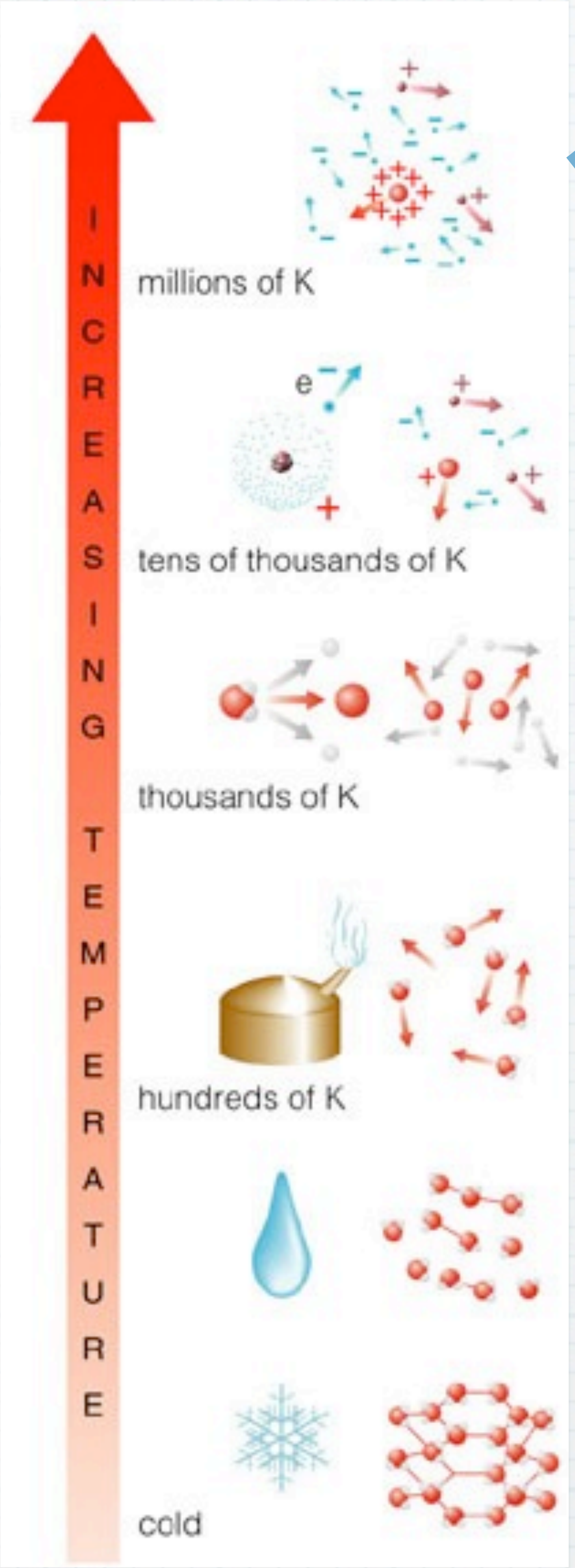
O Stars

* O-type stars make up just a fraction of a percent of the stars in the Universe, but the violent phenomena associated with them mean they have a disproportionate effect on their surroundings:
* their winds and shocks waves can both trigger and stop star formation
* their radiation powers the glow of bright nebulae, their supernovae enrich galaxies with the heavy elements crucial for life, and they emit gamma-ray bursts, which are among the most energetic phenomena in the Universe
* O-type stars are therefore implicated in many of the mechanisms that drive the evolution of galaxies

Spectral Type & Temperature

* High temperatures ionizes atoms
* A star's spectral lines provides another way to measure its surface temperature
* It is a more accurate method
    * (we also get more information about the star such as its magnetism)

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

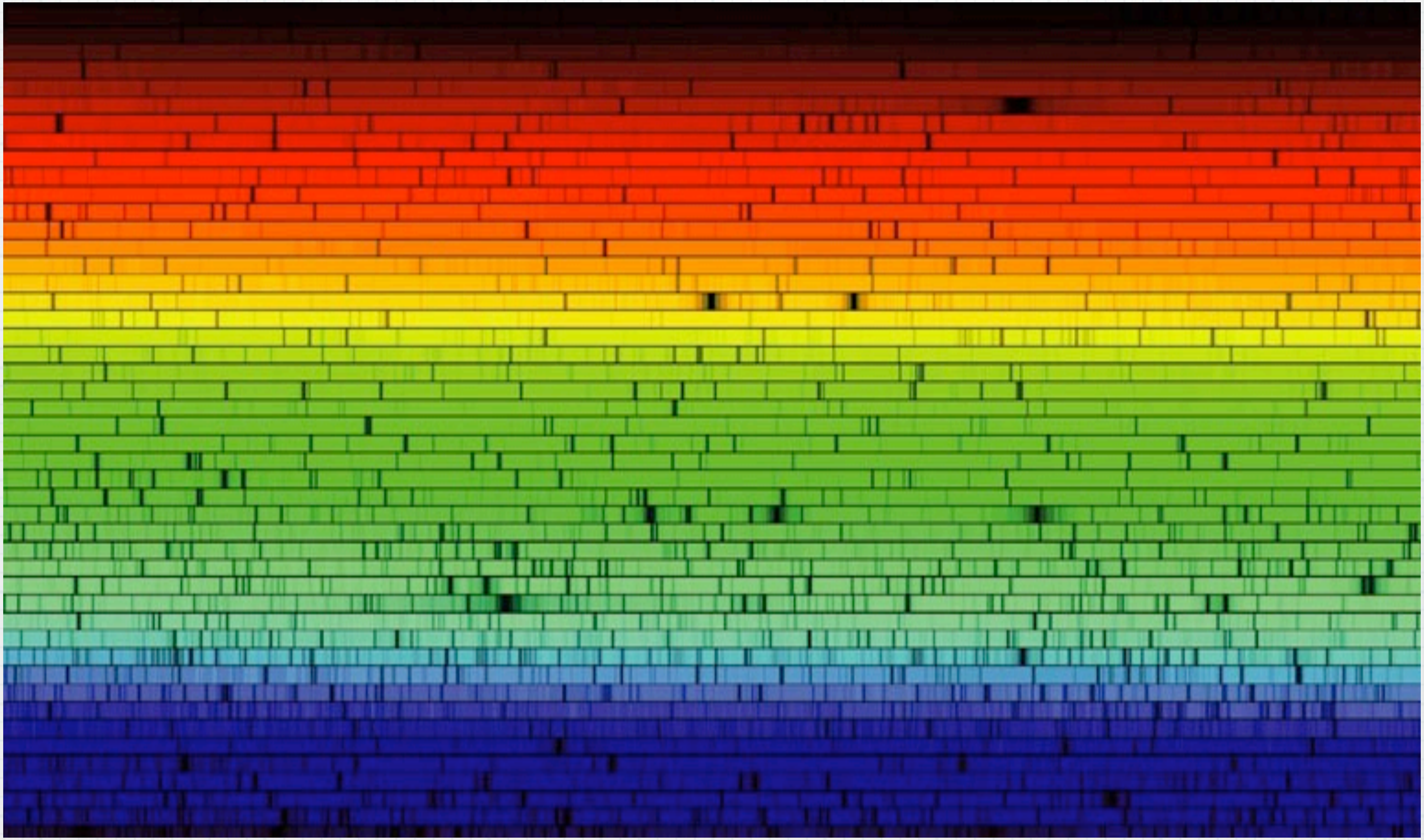
Ionized Gas (Plasma)

Neutral Gas

Molecules

Solid

Absorption lines in star's spectrum tell us ionization level

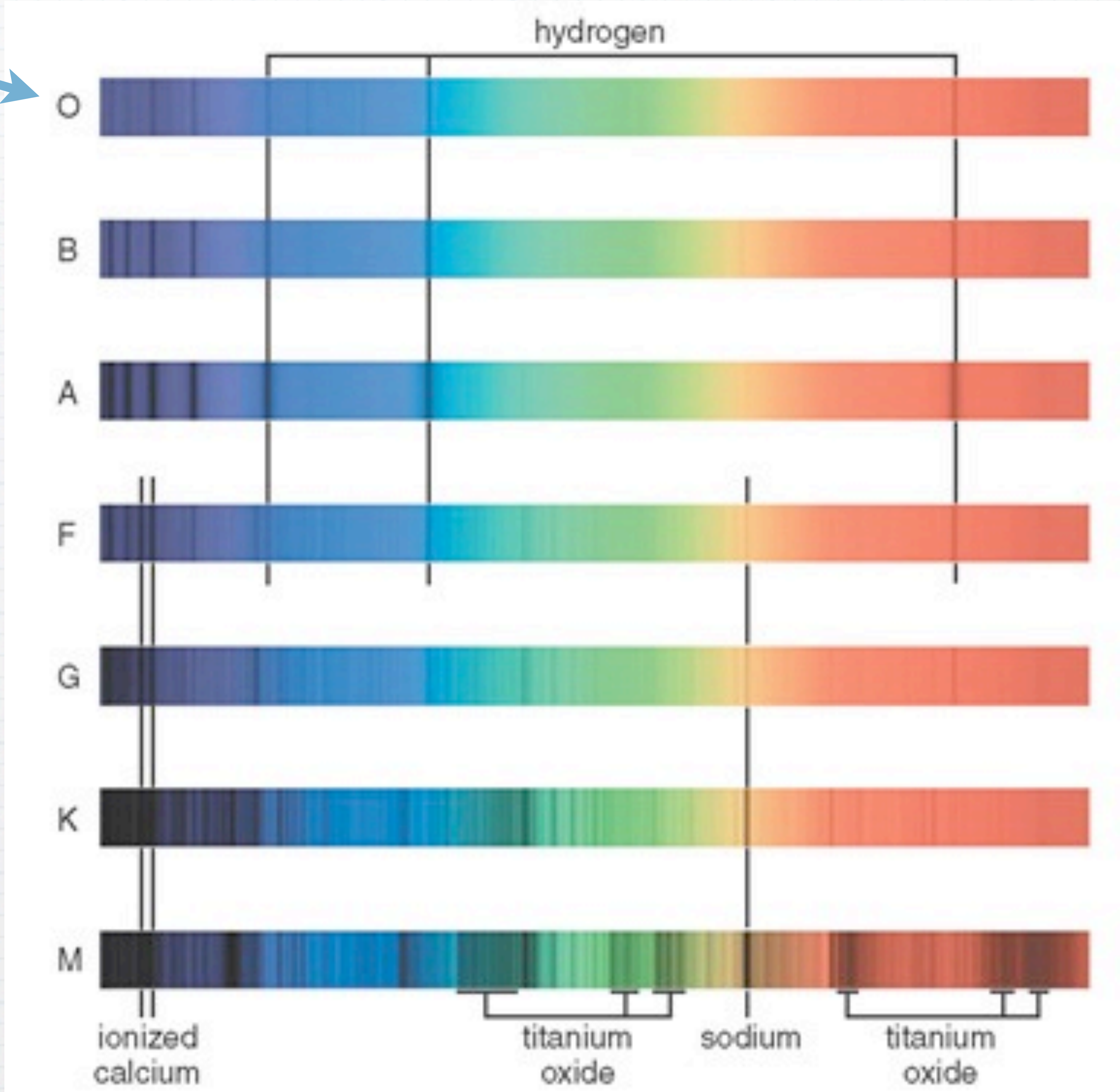


Absorption lines in a star's spectrum correspond to a spectral type that reveals its temperature

(Hottest)

O	30,000–60,000 K
B	10,000–30,000 K
A	7,500–10,000 K
F	6,000–7,500 K
G	5,000–6,000 K
K	3,500–5,000 K
M	2,000–3,500 K

(Coolest)



Question

Which kind of star is hottest?

A. M star

B. F star

C. A star

D. K star

Question

Which kind of star is hottest?

A. M star

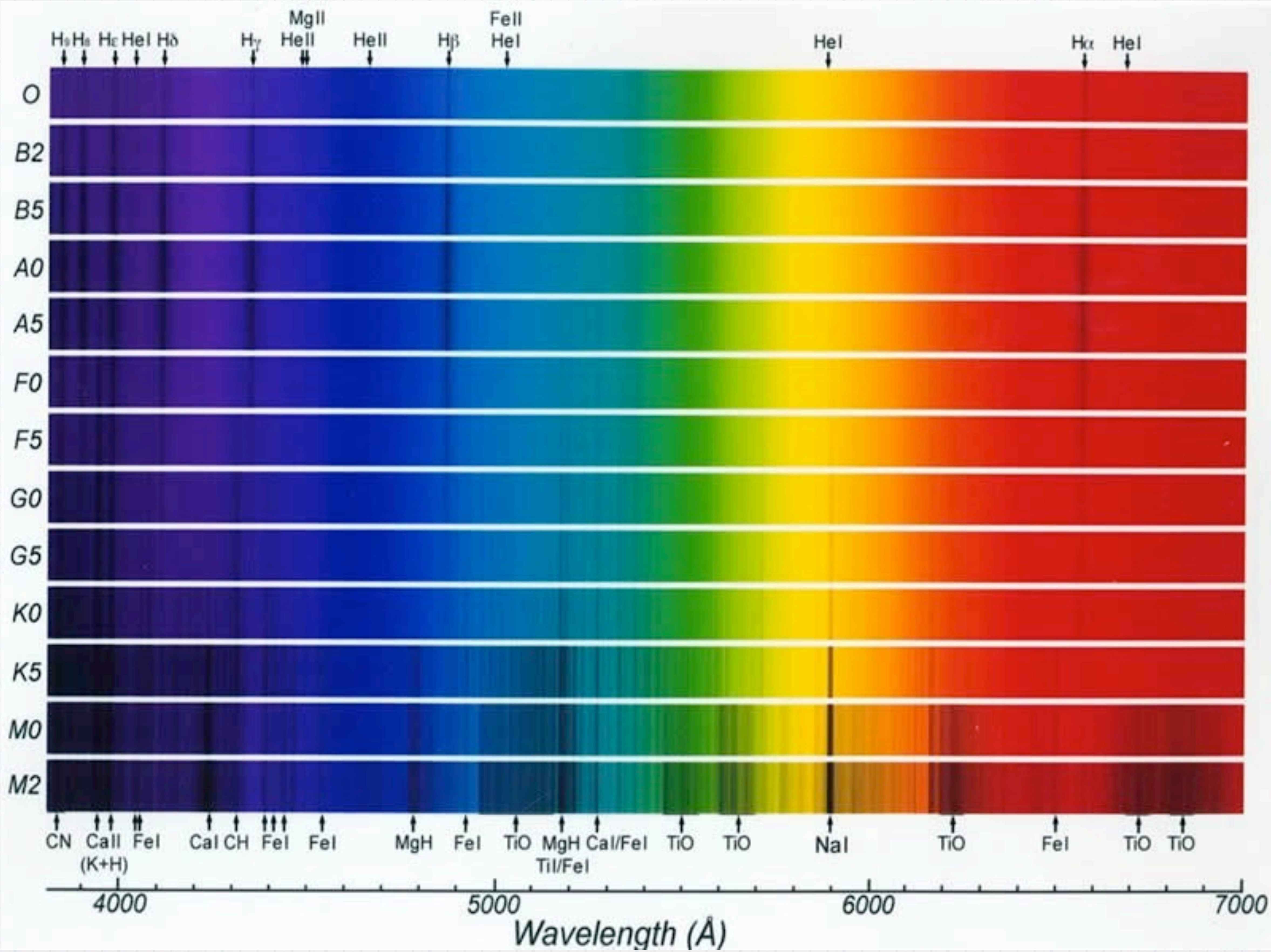
B. F star

C. A star

D. K star

O B A F G K M
0 1 2 3 4 5 6 7 8 9

* Each spectral type is subdivided even further
* B0, B1, B2, ..., B9
* The larger the number, the cooler the star
* The Sun's spectral type is G2
* Warmer than a G3, cooler than a G1 star


MgII
HeII
FeII
HeI
H9 H8 Hε HeI Hδ Hγ HeII Hβ HeI Hα HeI
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN CaII (K+H) FeI CaI CH FeI FeI MgH FeI TiO MgH TiI/FeI CaI/FeI TiO TiO NaI TiO FeI TiO TiO
4000
5000
6000
7000
Wavelength (Å)

Question

Which kind of star is hottest?

A. M0 star
B. F2 star
C. O6 star
D. K5 star
E. O5 star

Question

Which kind of star is hottest?

A. M0 star

B. F2 star

C. O6 star

D. K5 star

E. O5 star

3. How Massive Are Stars?

* The third most fundamental property of a star is its **mass**
* It is difficult to get an accurate value
* Yet, as we will find out later, a **star's mass is its most important property**

Kepler's 3rd Law (via Newton)

* The most dependable method for measuring a star's mass relies on Kepler's third law
* We need to **observe** both the **orbital period** and the **average orbital distance** of a star orbiting another one
* That is called a **binary star system**

Types of Binary Star Systems

1. Visual Binary
2. Eclipsing Binary
3. Spectroscopic Binary

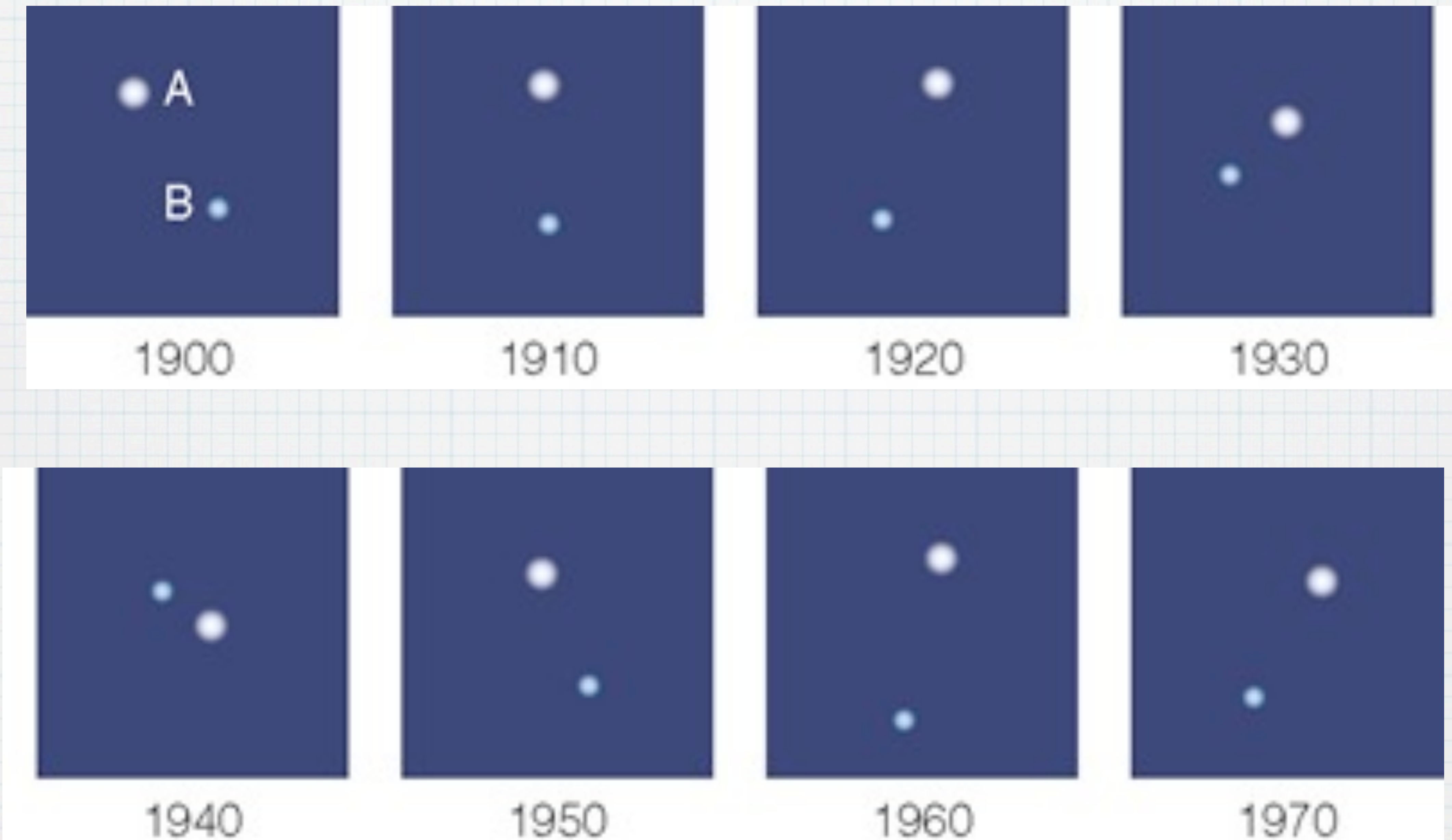
About half of all stars are in binary systems

1. Visual Binary

* So called because we directly observe the orbital motions of these stars
* Sometimes one of these two stars is so faint we can't see it, yet we can observe the wobbling, or shifting, position of the brighter one

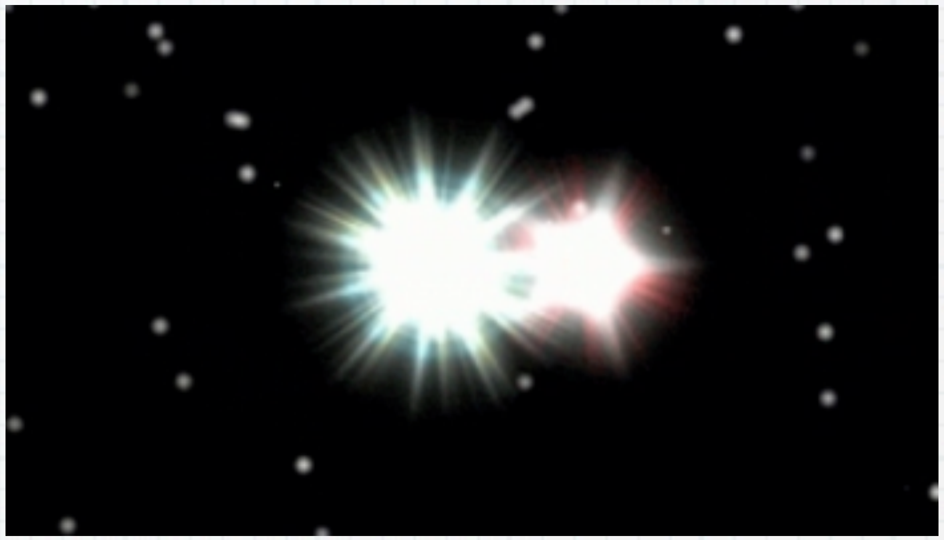
Sirius A and Sirius B, a visual binary star system

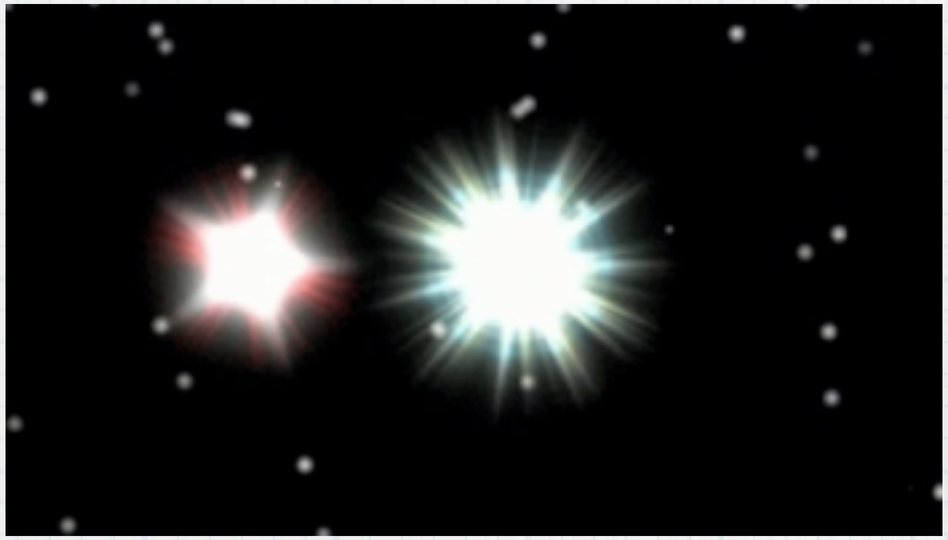
Sirius A and Sirius B at 10-year interval



2. Eclipsing Binary

1


2


3


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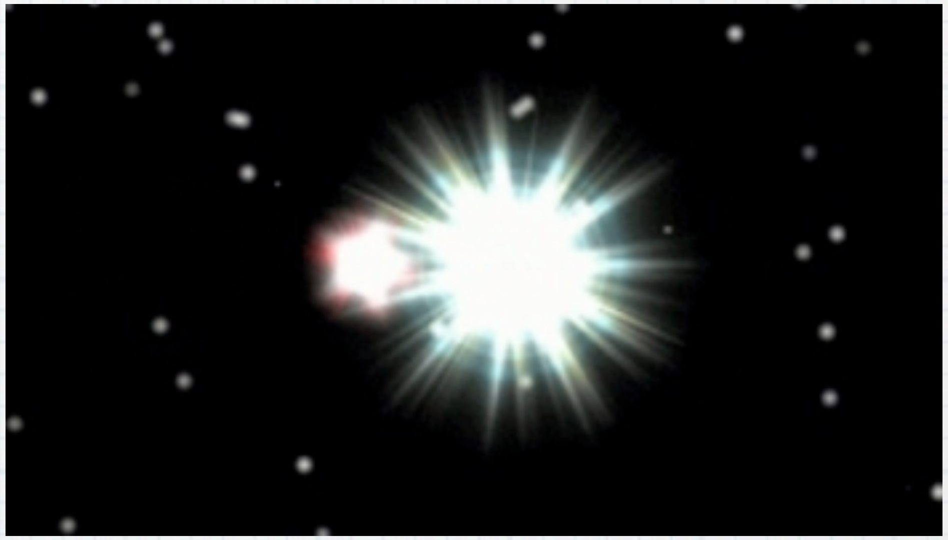
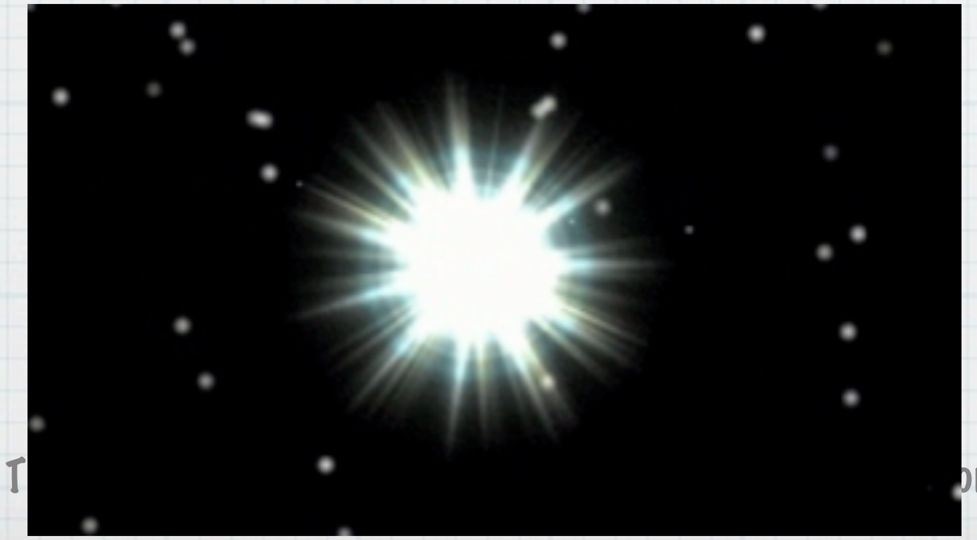
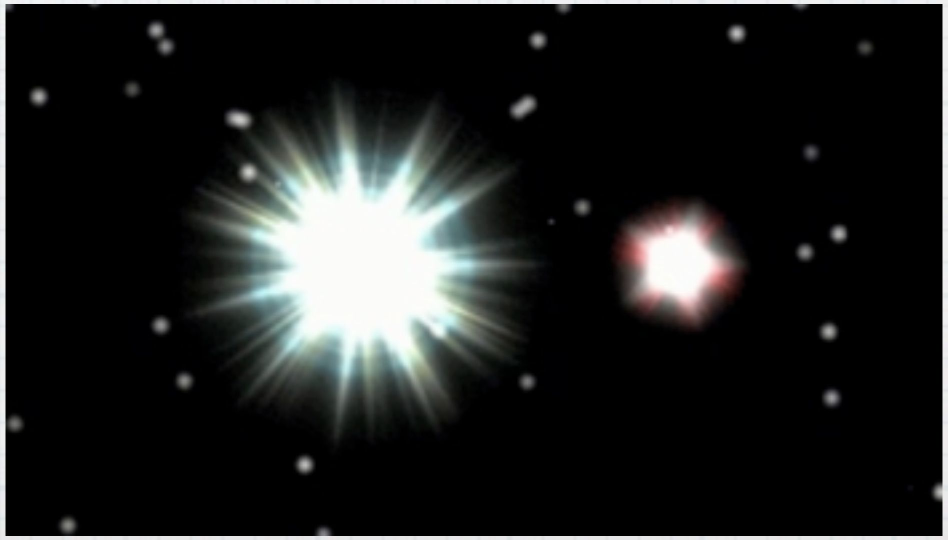


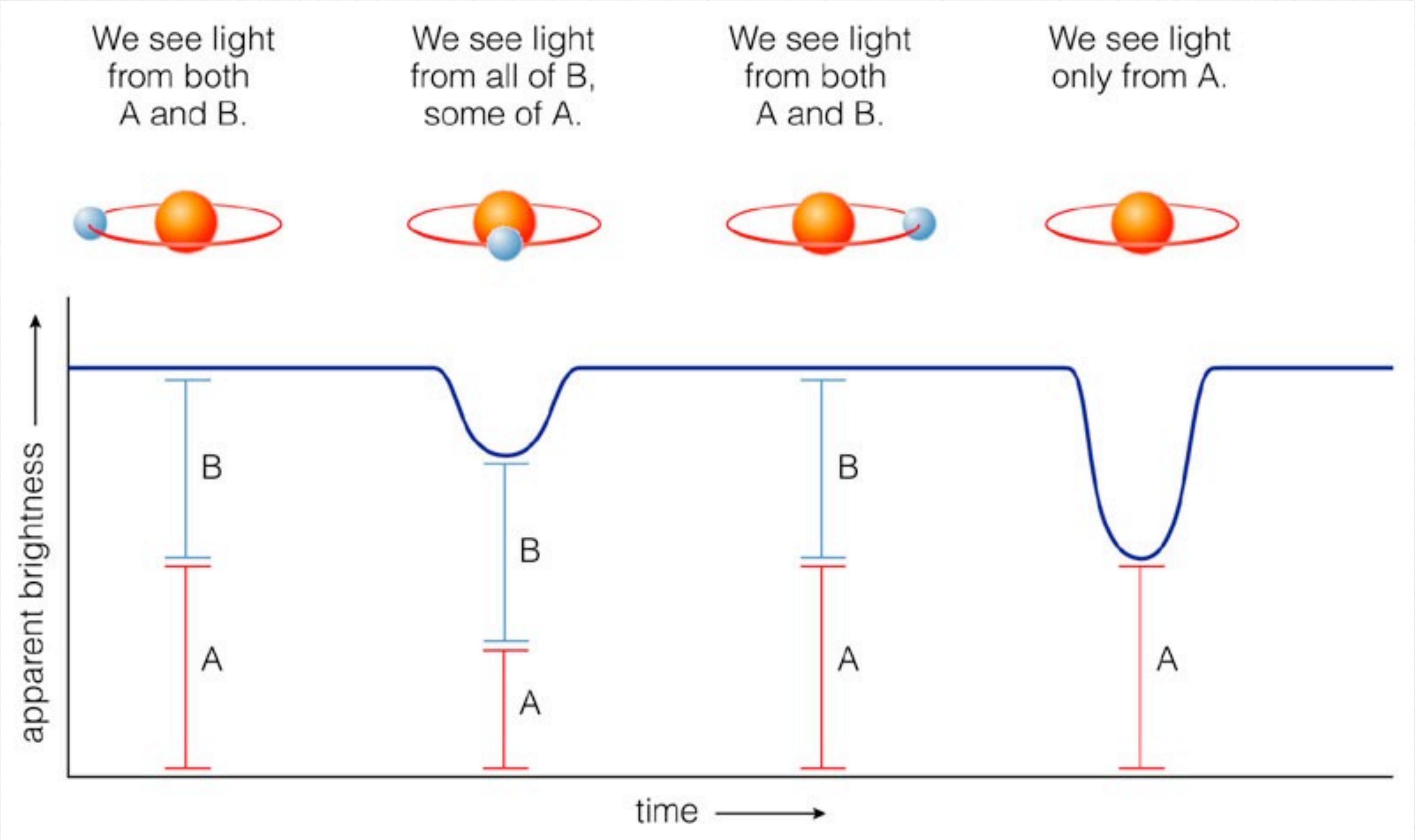
5


6


Eclipsing Binary...

* So called because the orbital plane of the pair of stars is in our line of sight
* When one star eclipses the other, the apparent brightness of the system drops
* We can measure and plot the light curve

Apparent brightness of the light curve versus time

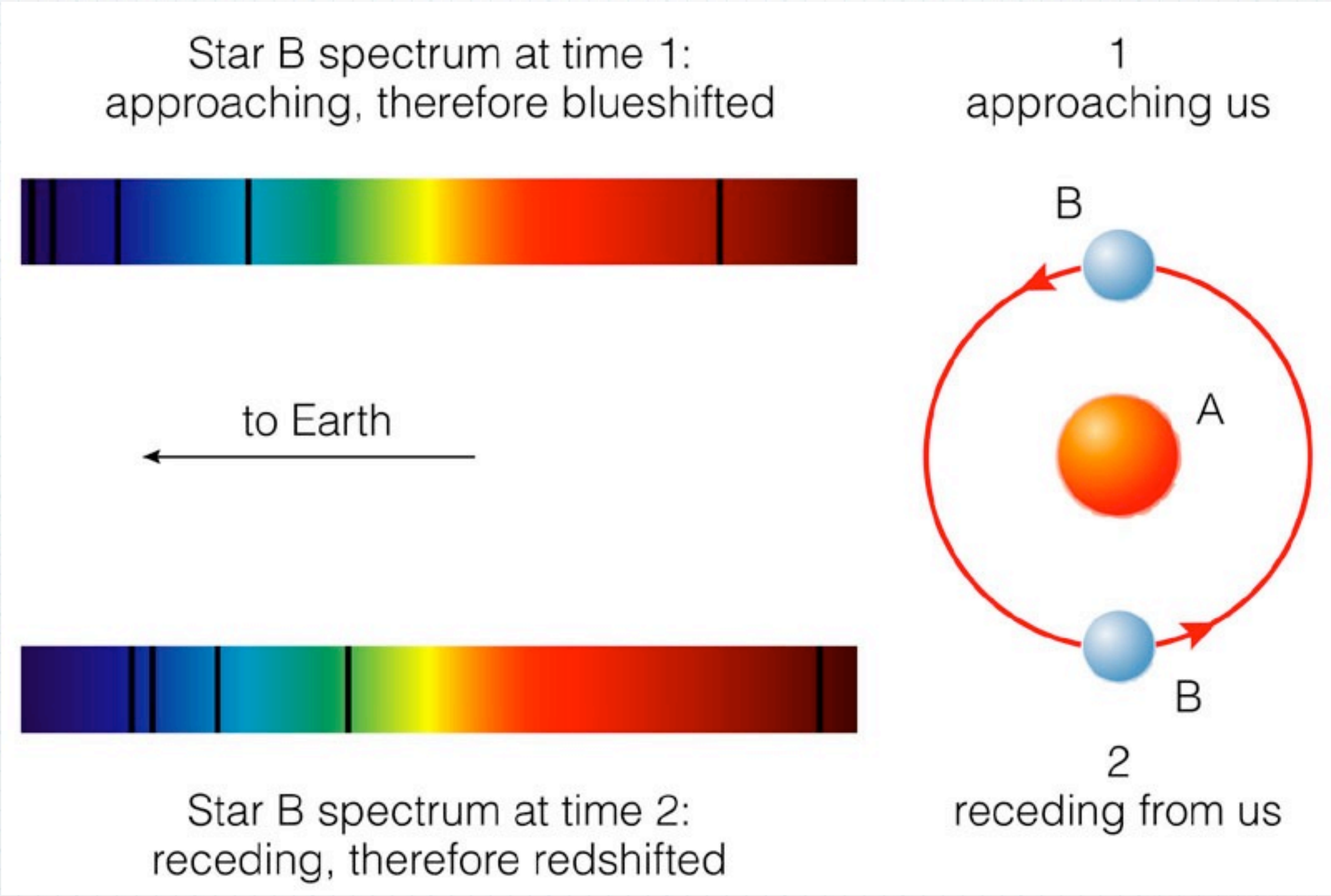


3. Spectroscopic Binary

* Where spectral line shifts are due to the Doppler shift
* As one star orbits another, it periodically moves toward us and away from us

➡ Hence we see a tiny blueshift followed by a redshift

We determine the orbit by measuring Doppler shifts



Measuring Orbital Period

1. Visual binary
   * how long an orbit takes
2. Eclipsing binary
   * how long between eclipses
3. Spectroscopic binary
   * how long for the spectral lines to shift back & forth

Measuring Average Star Separation

* In rare cases this can be measured directly
* Else we need to find the stars' actual orbital speeds as an intermediate step
* This can be done without bias using **eclipsing binary stars** (line of sight!) and the Doppler shifts

Measuring Average Star Separation...

* Eclipsing binaries also allow us to measure the stellar radii directly (by timing how long each eclipse lasts)
* Hence eclipsing binaries are quite important to the study of stellar masses

Back to Measuring Stellar Masses

Isaac Newton

We measure mass using gravity

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

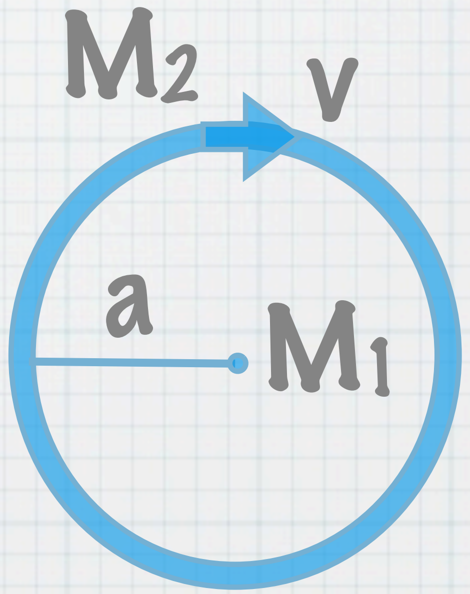
$$P^2 = \frac{4\pi^2}{G(M_1 + M_2)} a^3$$

P = period

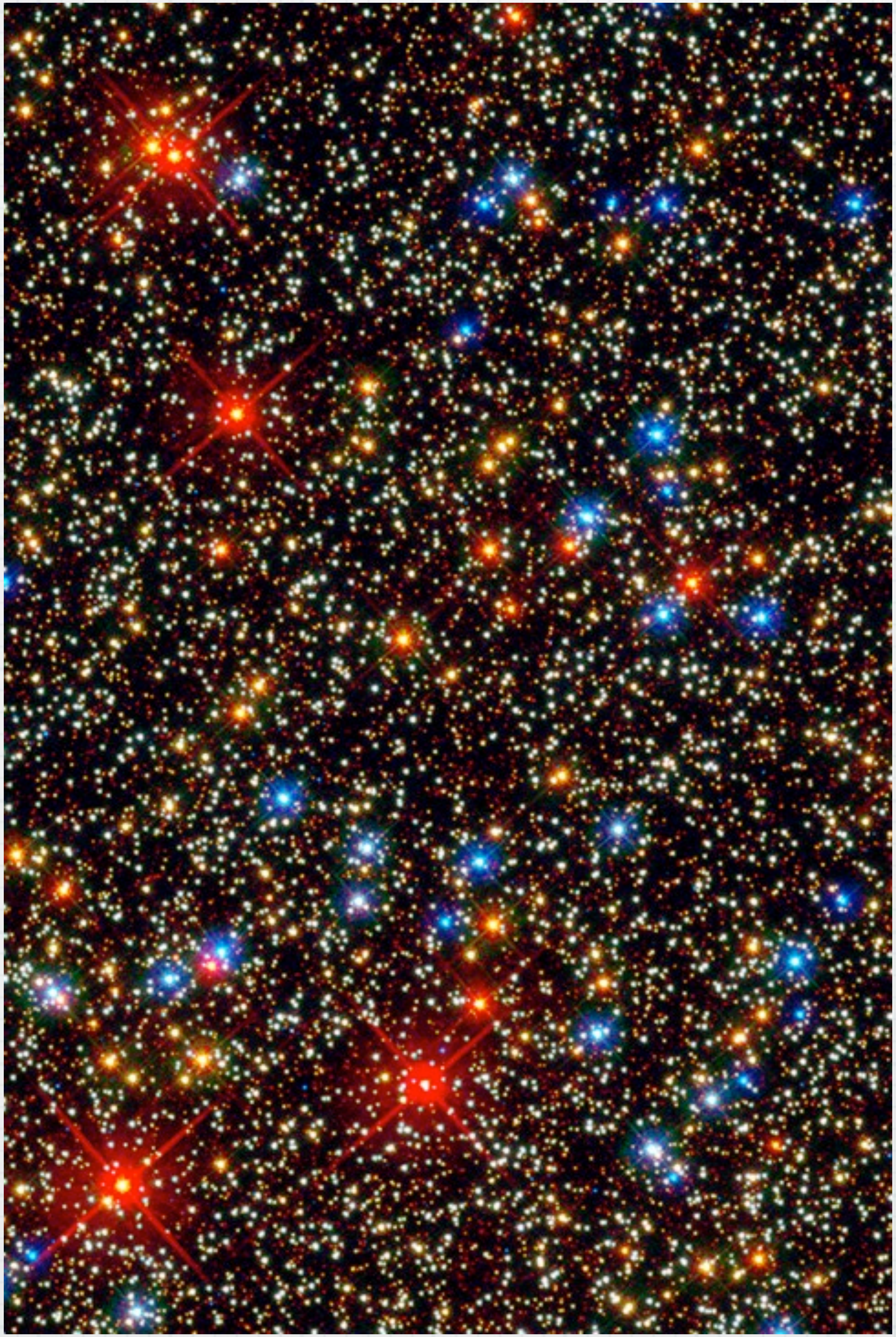
a = average separation

We need 2 out of 3 of these observables to measure mass:

* Orbital Period (p)
* Orbital Separation (radius a)
* Orbital Velocity (v)



* For circular orbits, $v = 2\pi a / p$



The Center of Globular Cluster Omega Centauri
Credit: NASA, ESA, and the Hubble SM4 ERO Team

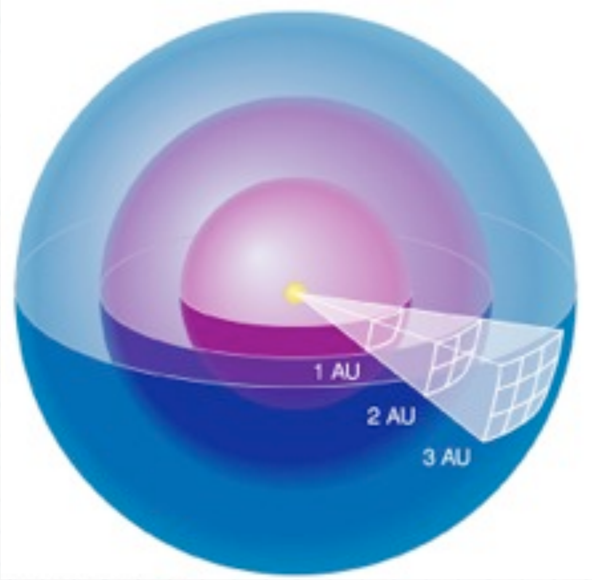
Most massive stars:

150+ M_{Sun}

Least massive stars:

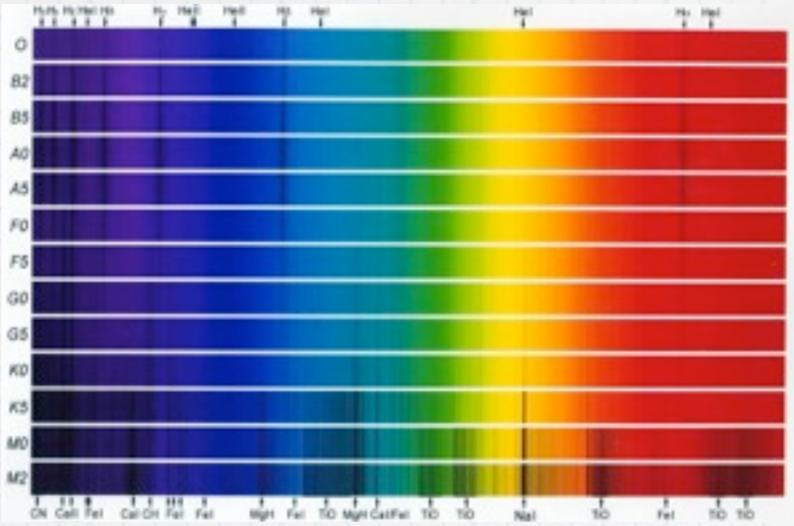
0.08 M_{Sun}

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



Snapshot

* 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



Snapshot...

* 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.

Snapshot...

- How massive are stars?
- The overall range of stellar masses runs from 0.08 times the mass of the Sun to about 150 times the mass of the Sun
- or $0.08\ M_{Sun} \lesssim M_{star} \lesssim 150\ M_{Sun}$

Classifying Stars

- Stars come with a wide range of
  - luminosities
  - surface temperatures
  - masses
- Are these related to one another?
- Can we detect patterns to help classify them?

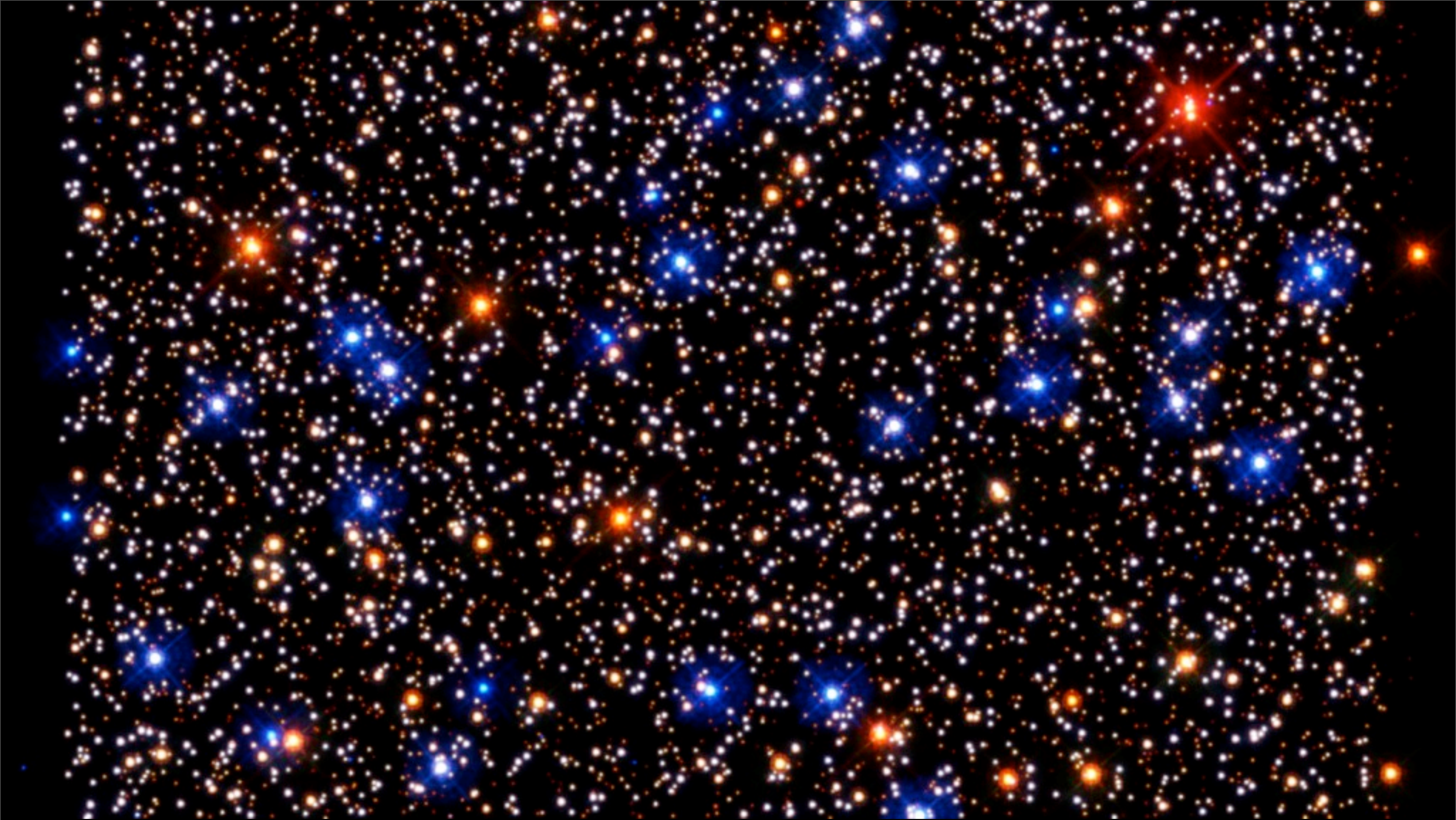
These stars are found in the center of a globular cluster

As a group, we can compare their true luminosities and colors

Astronomers like to study the colors of stars in a quantitative way.

They like to sort the stars by color, putting the blue stars on the left and the red stars on the right.

13a



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13e

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13f

They like to sort the stars by color,
putting the blue stars on the left and
the red stars on the right.

13g

They like to sort the stars by color, putting the blue stars on the left and the red stars on the right.

13h

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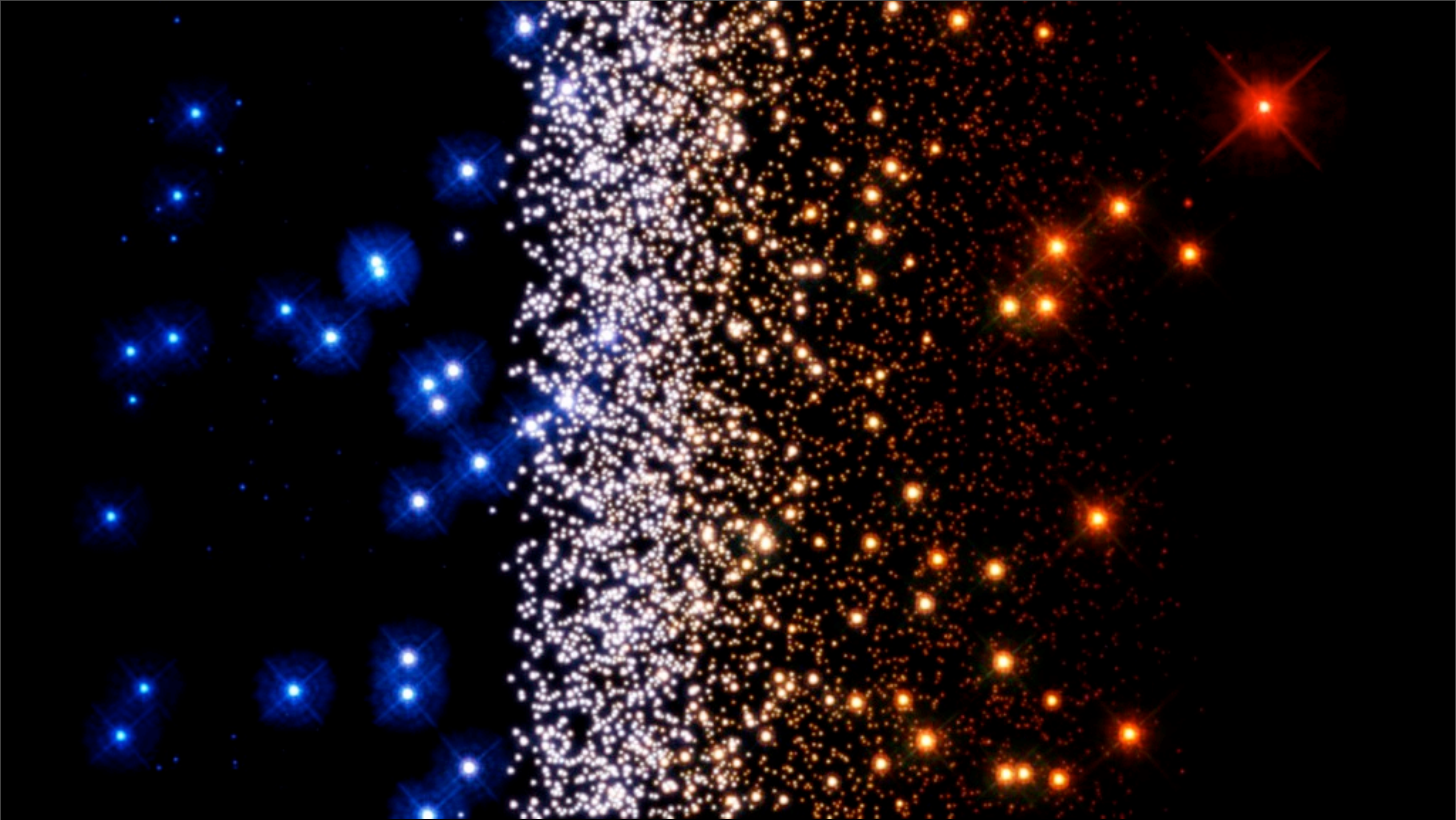

They like to sort the stars by color, putting the blue stars on the left and the red stars on the right.

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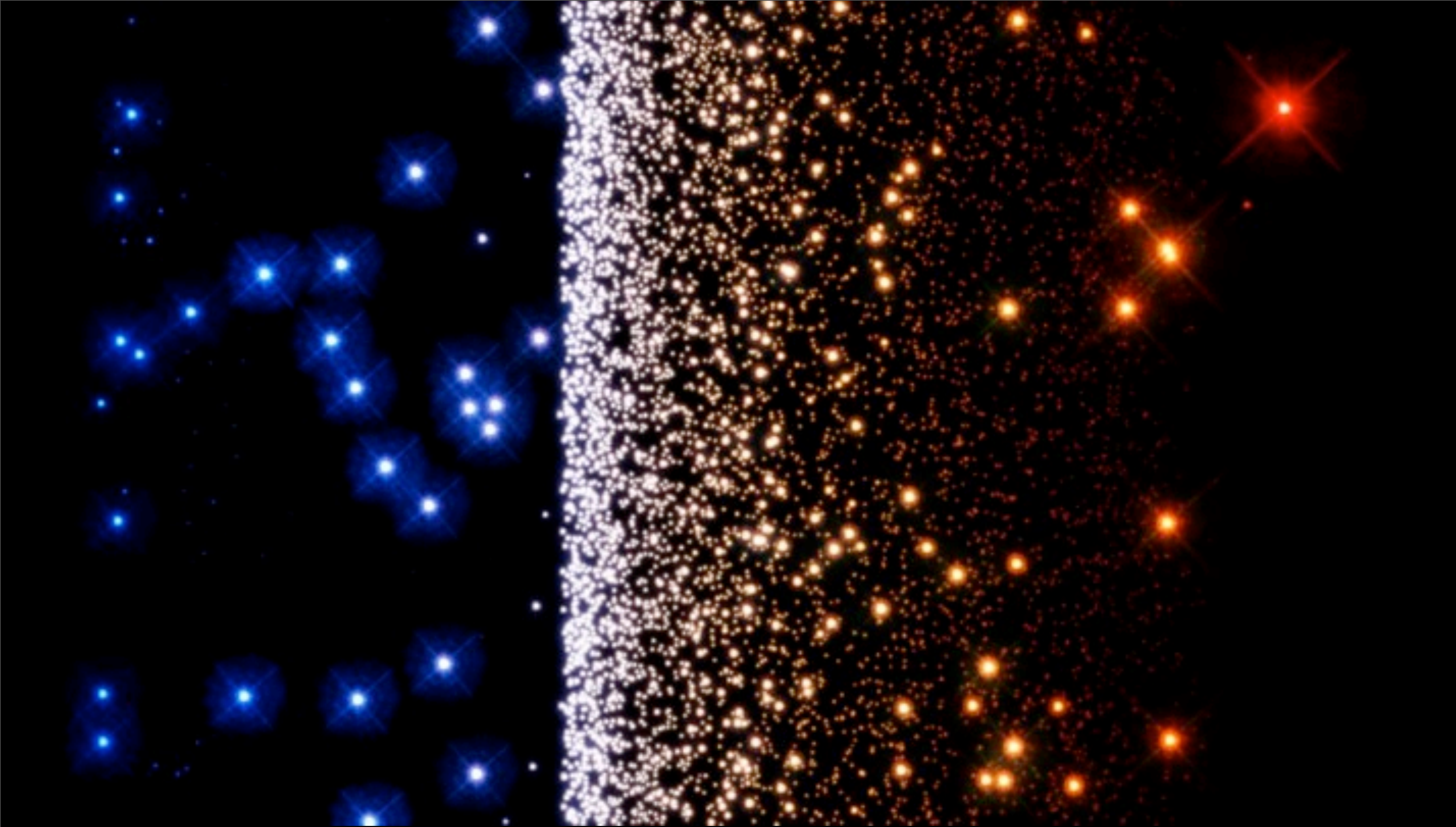
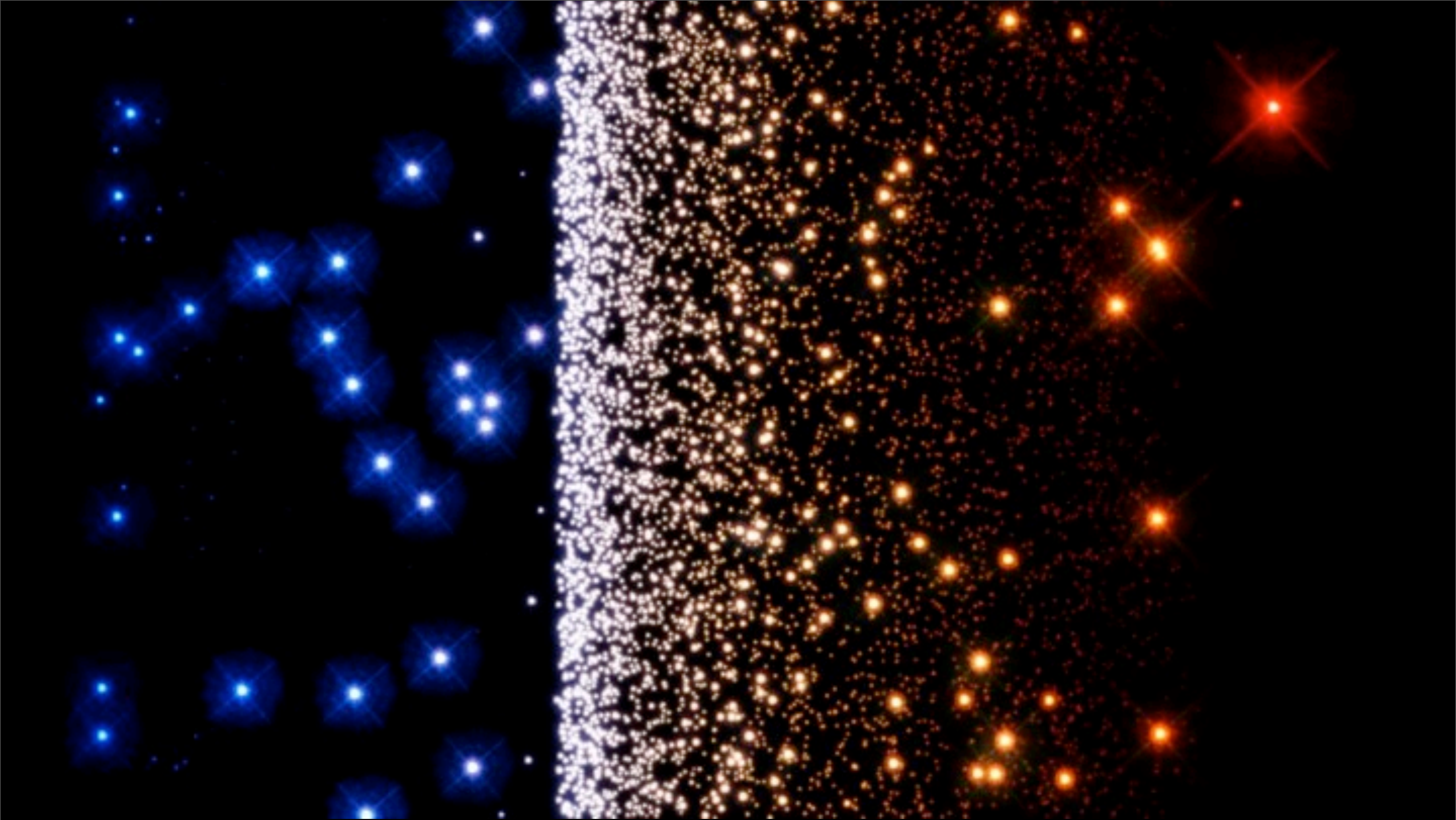
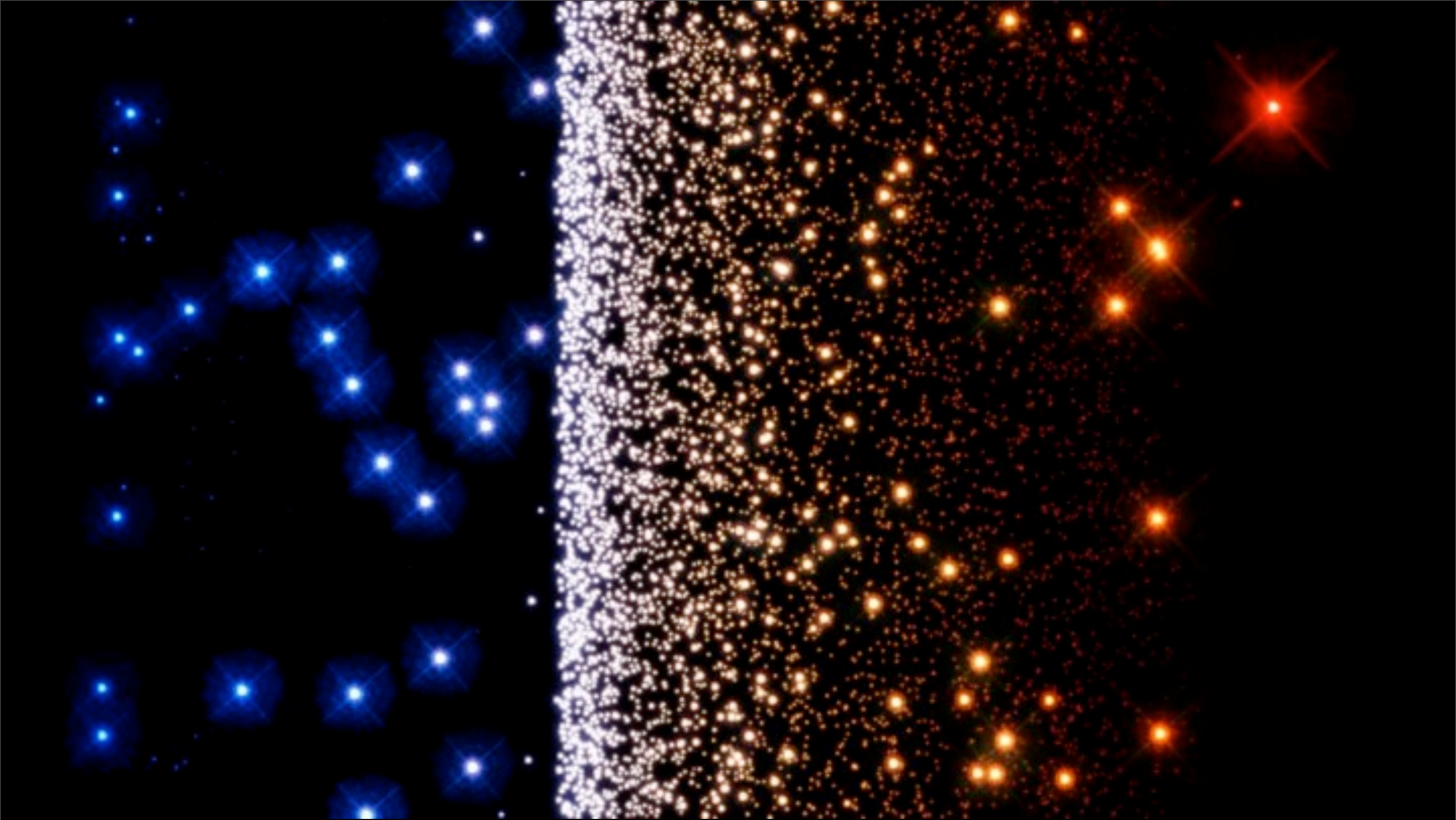


They like to sort the stars by color, putting the blue stars on the left and the red stars on the right.

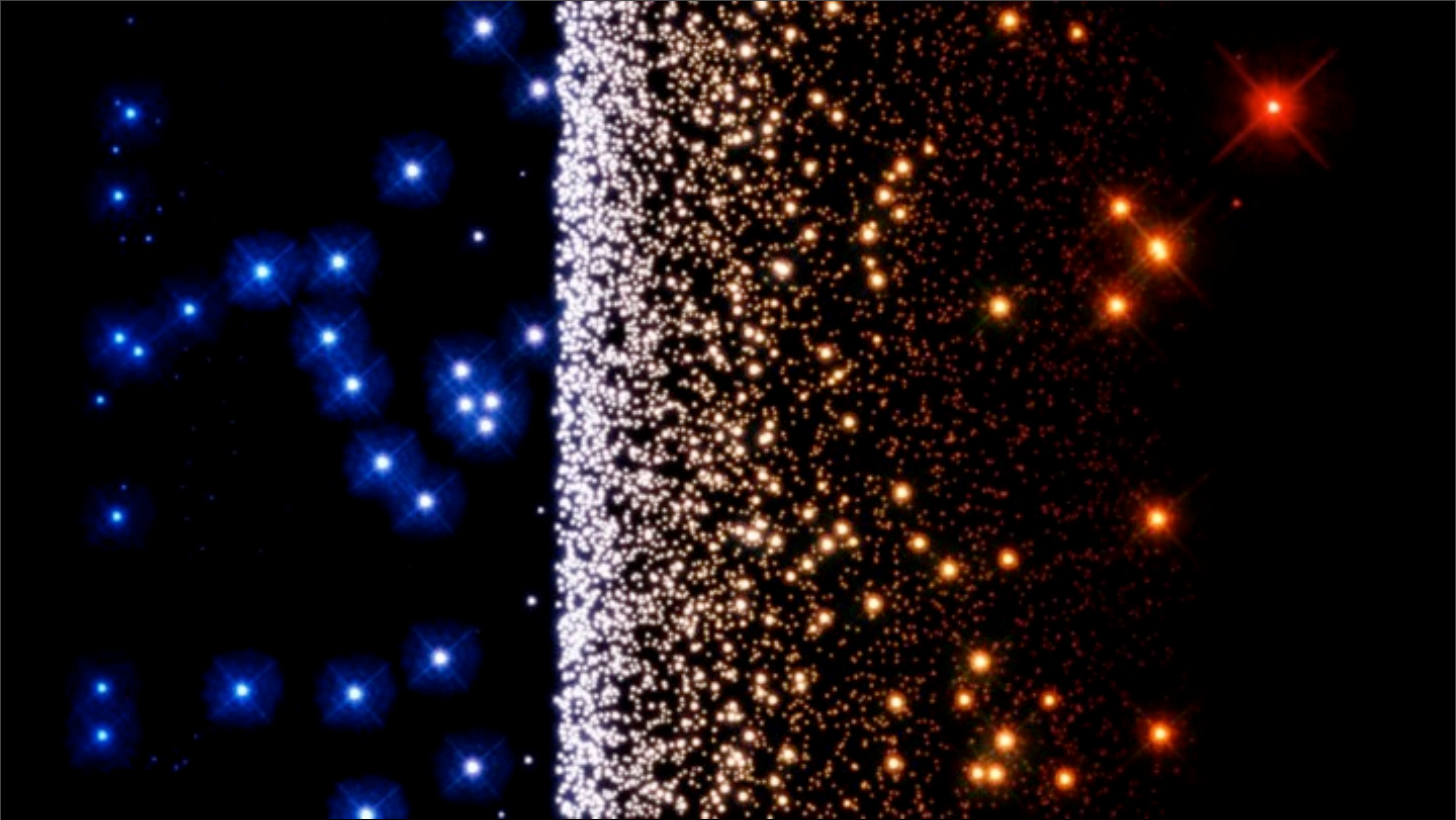
13k



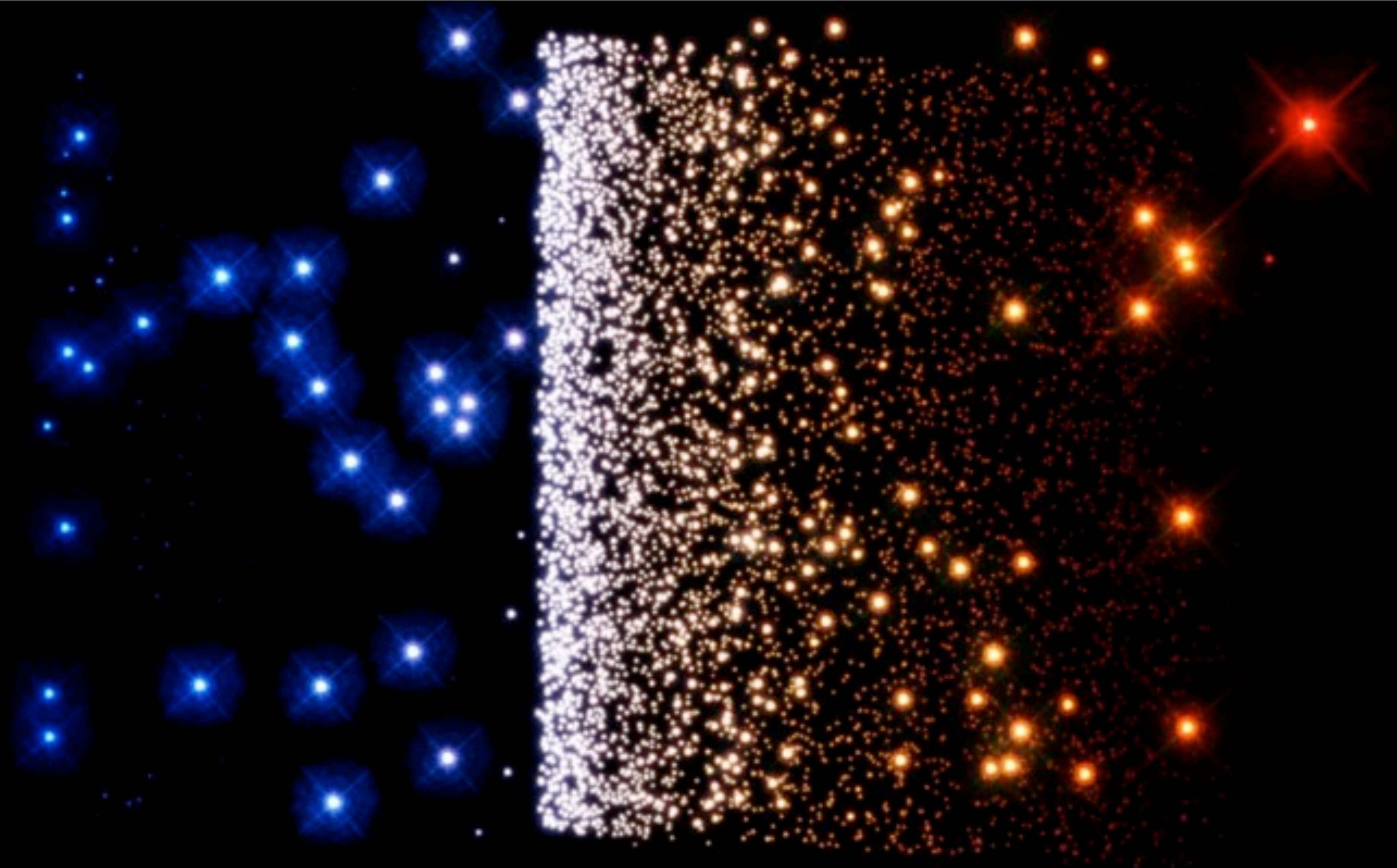
Note that there are very few extreme stars; most bright stars are **white**, meaning they have a balanced spectrum.



Astronomers also like to characterize the stars in terms of brightness.



They like to sort the stars,
putting the **bright** stars on top,
and the faint stars on the bottom.



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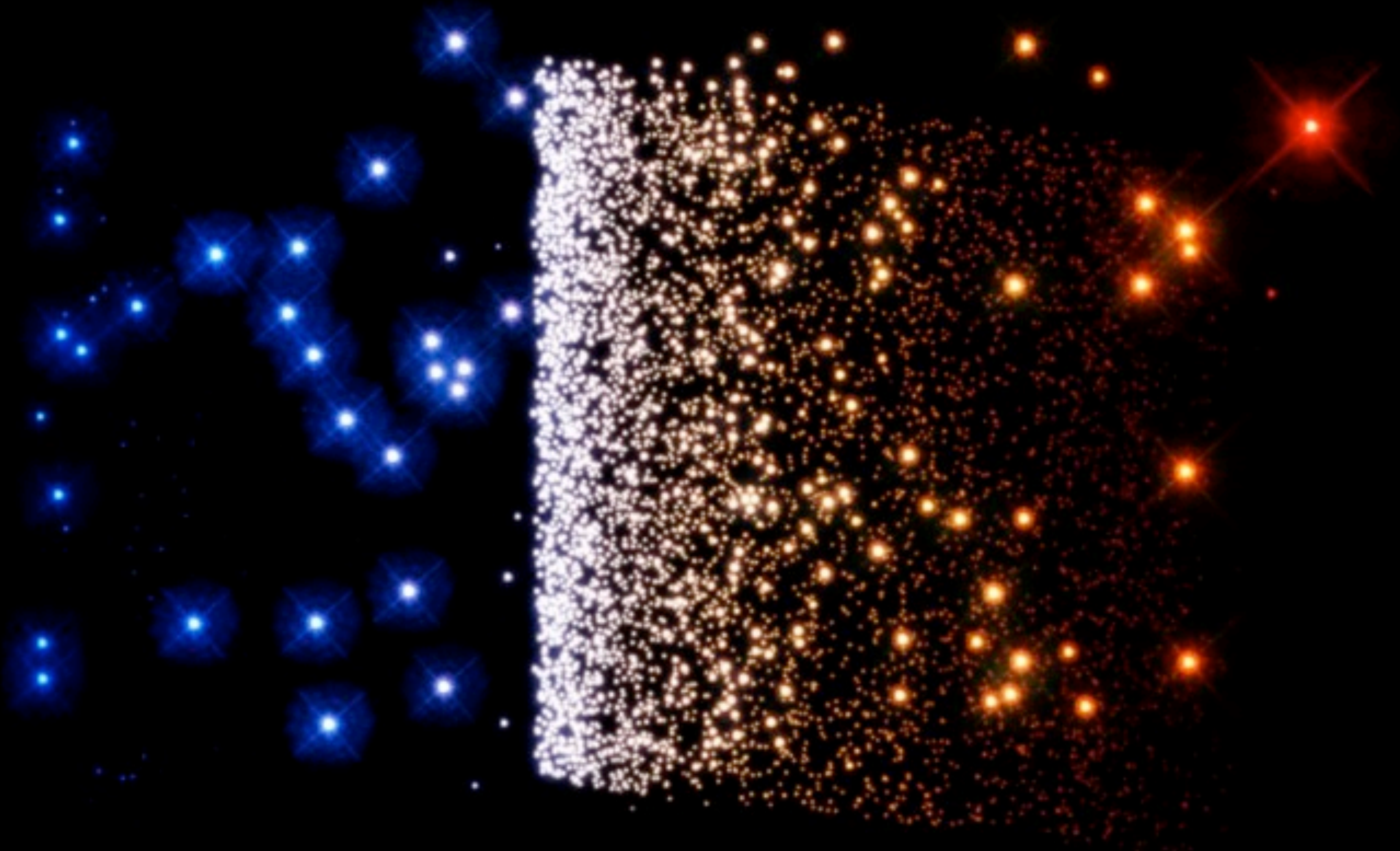

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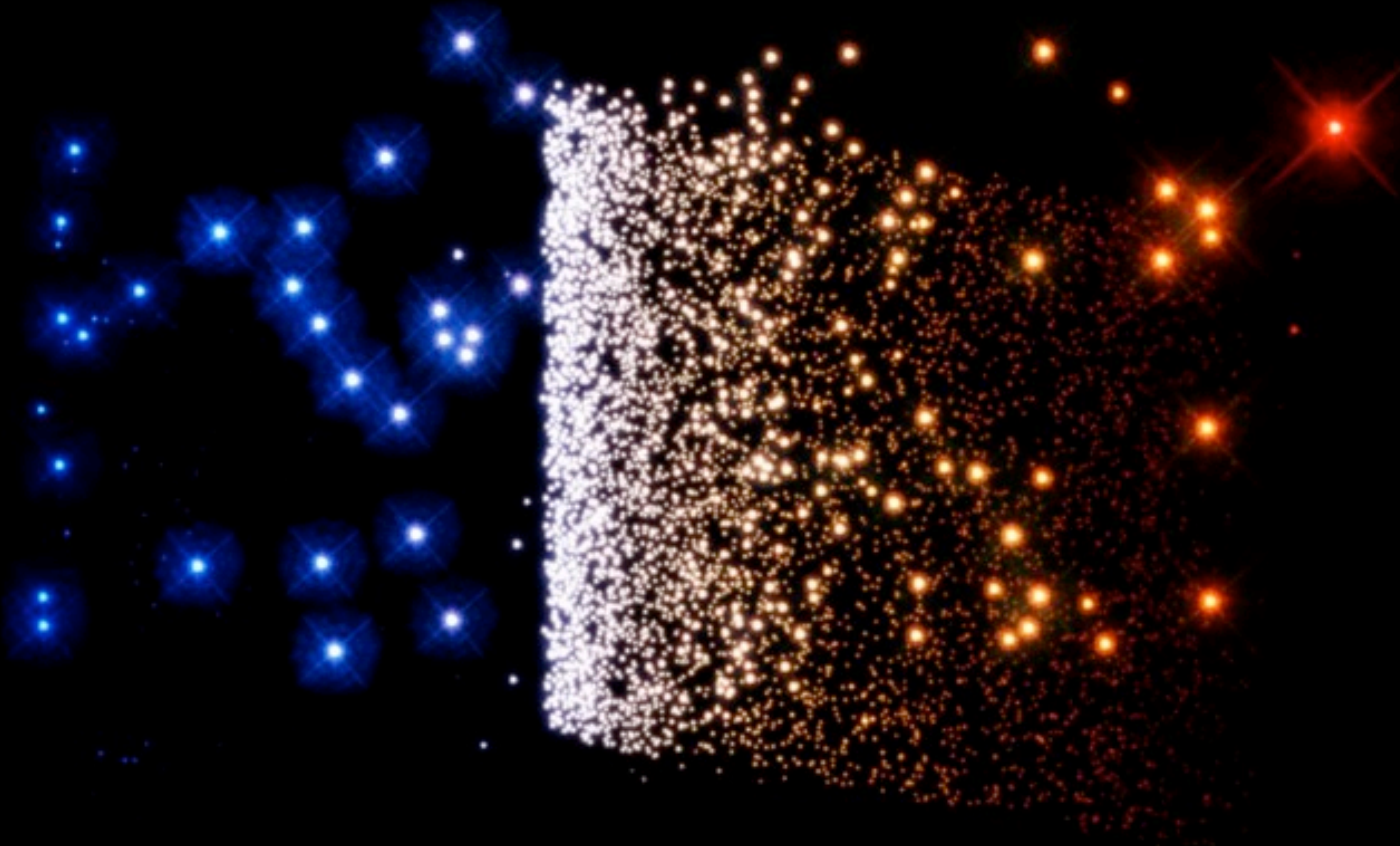

They like to sort the stars,
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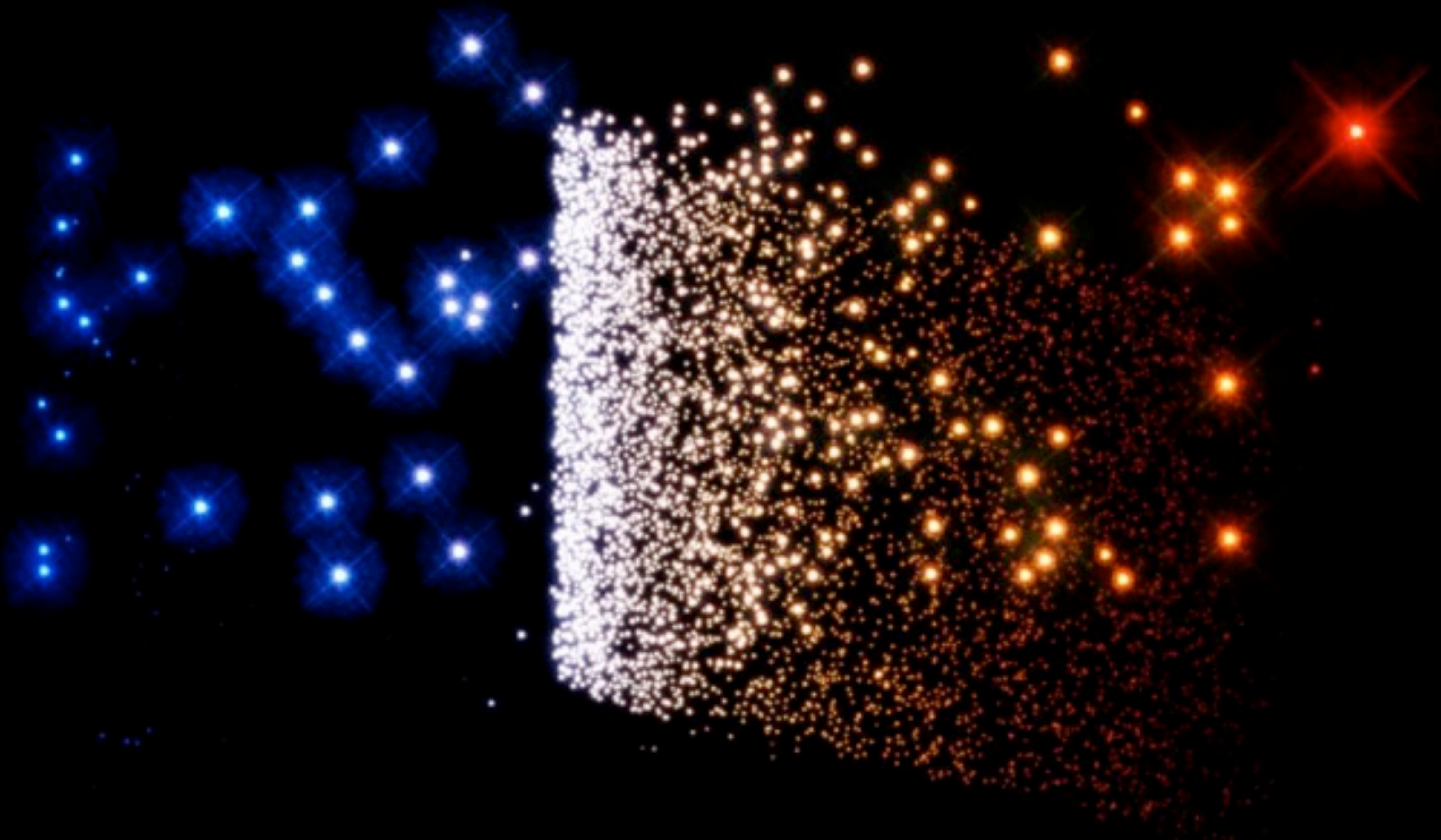

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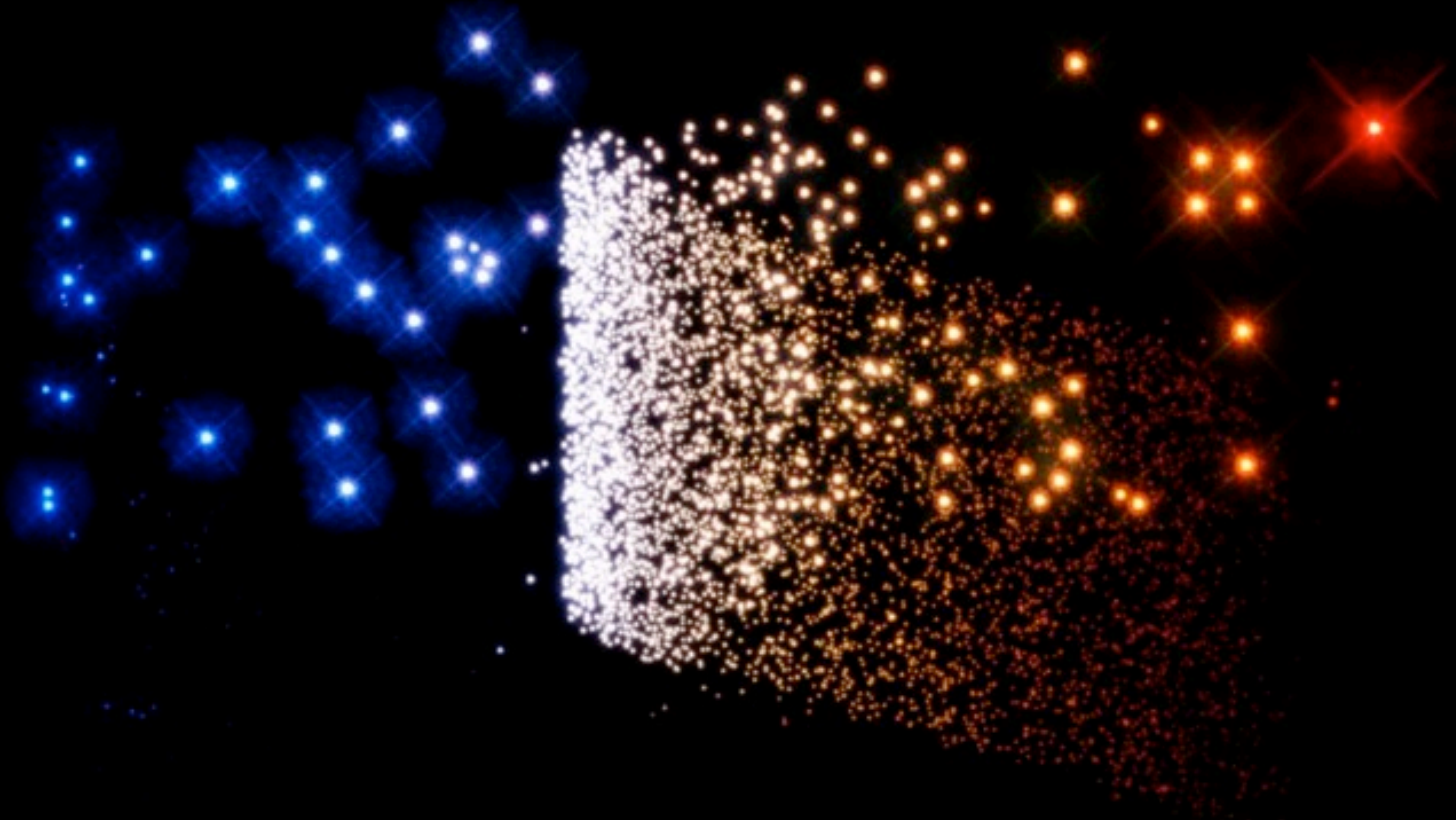

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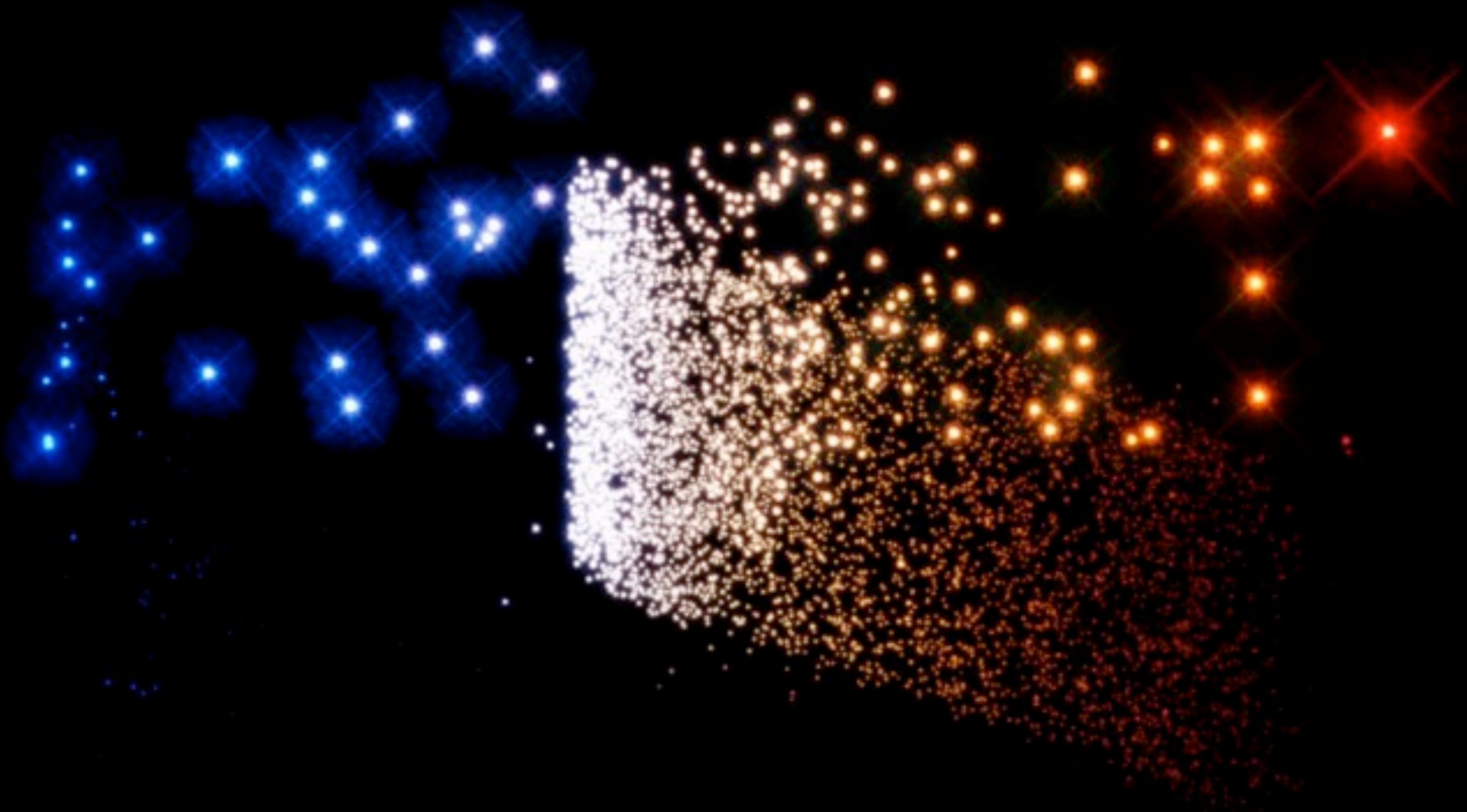

They like to sort the stars,
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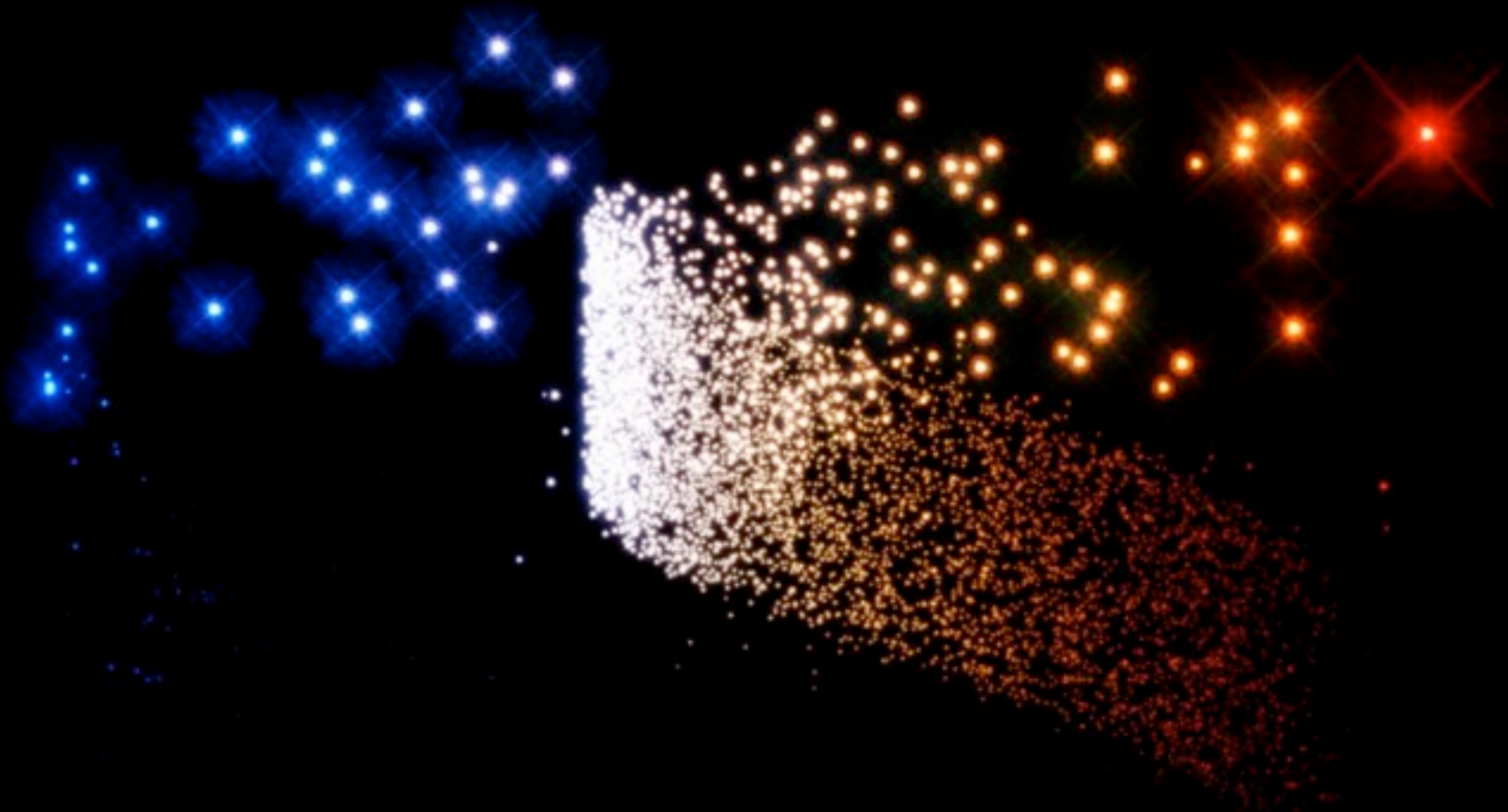
15g



They like to sort the stars,
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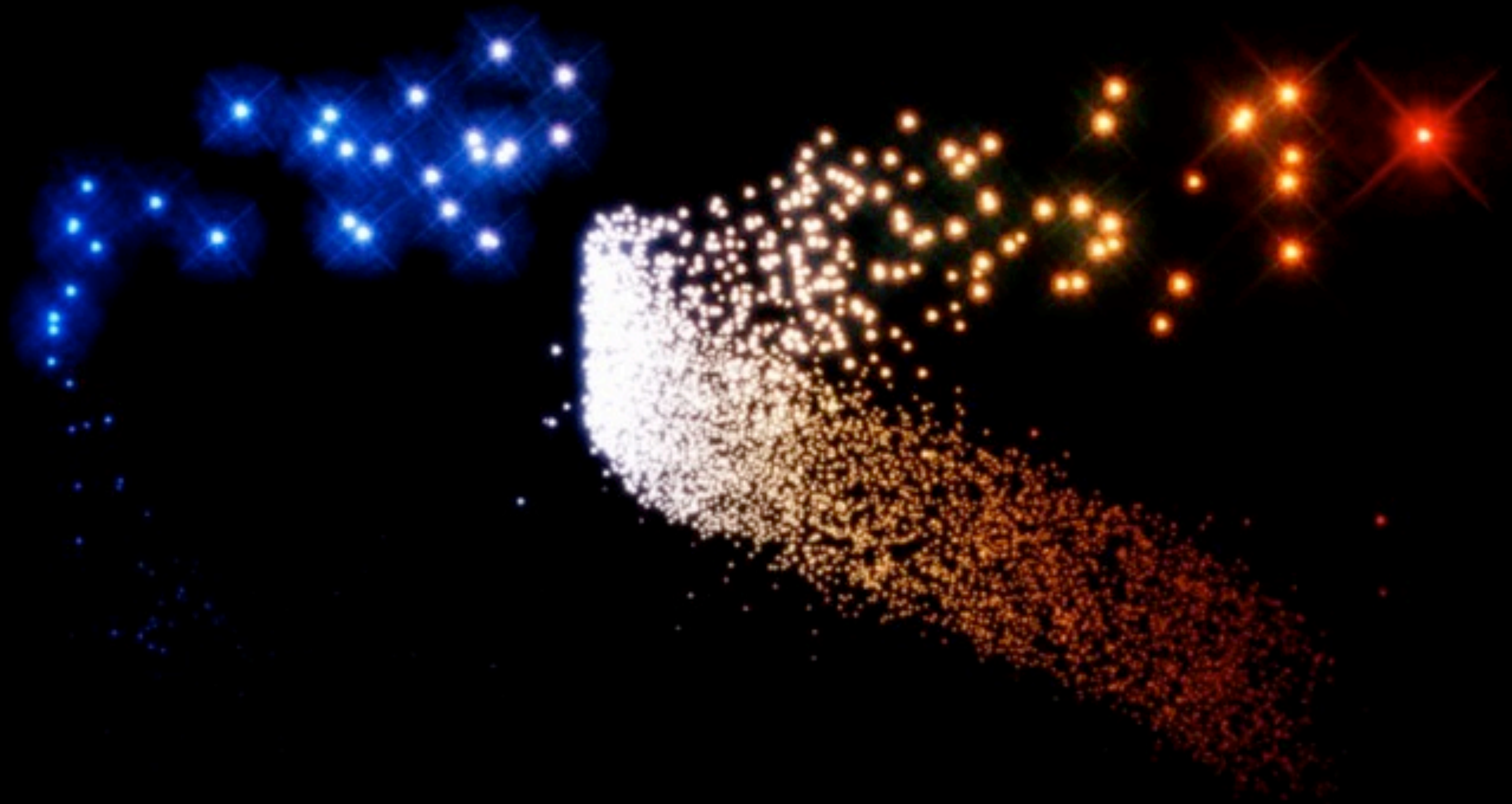
and the faint stars on the bottom.

15h



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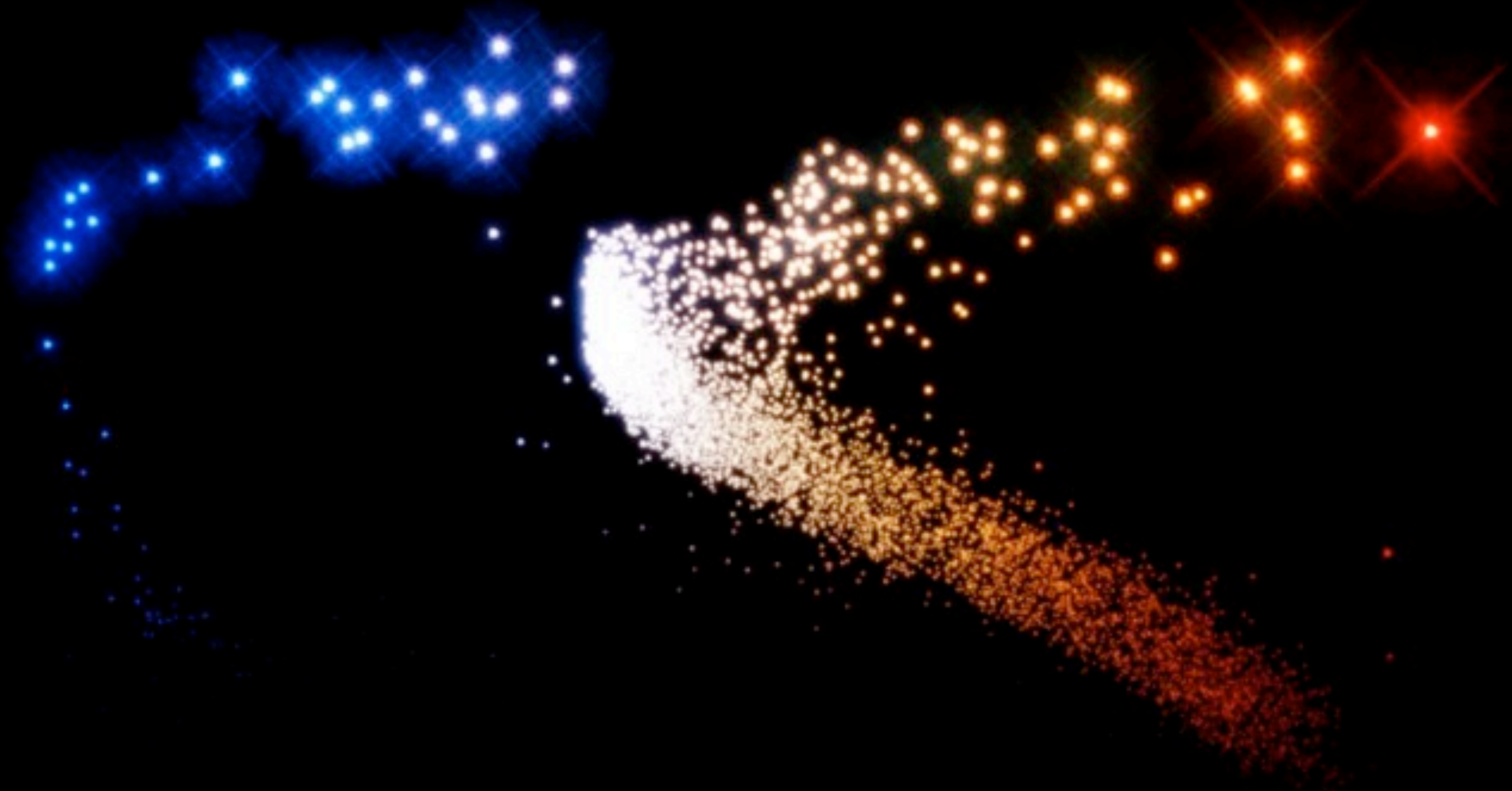

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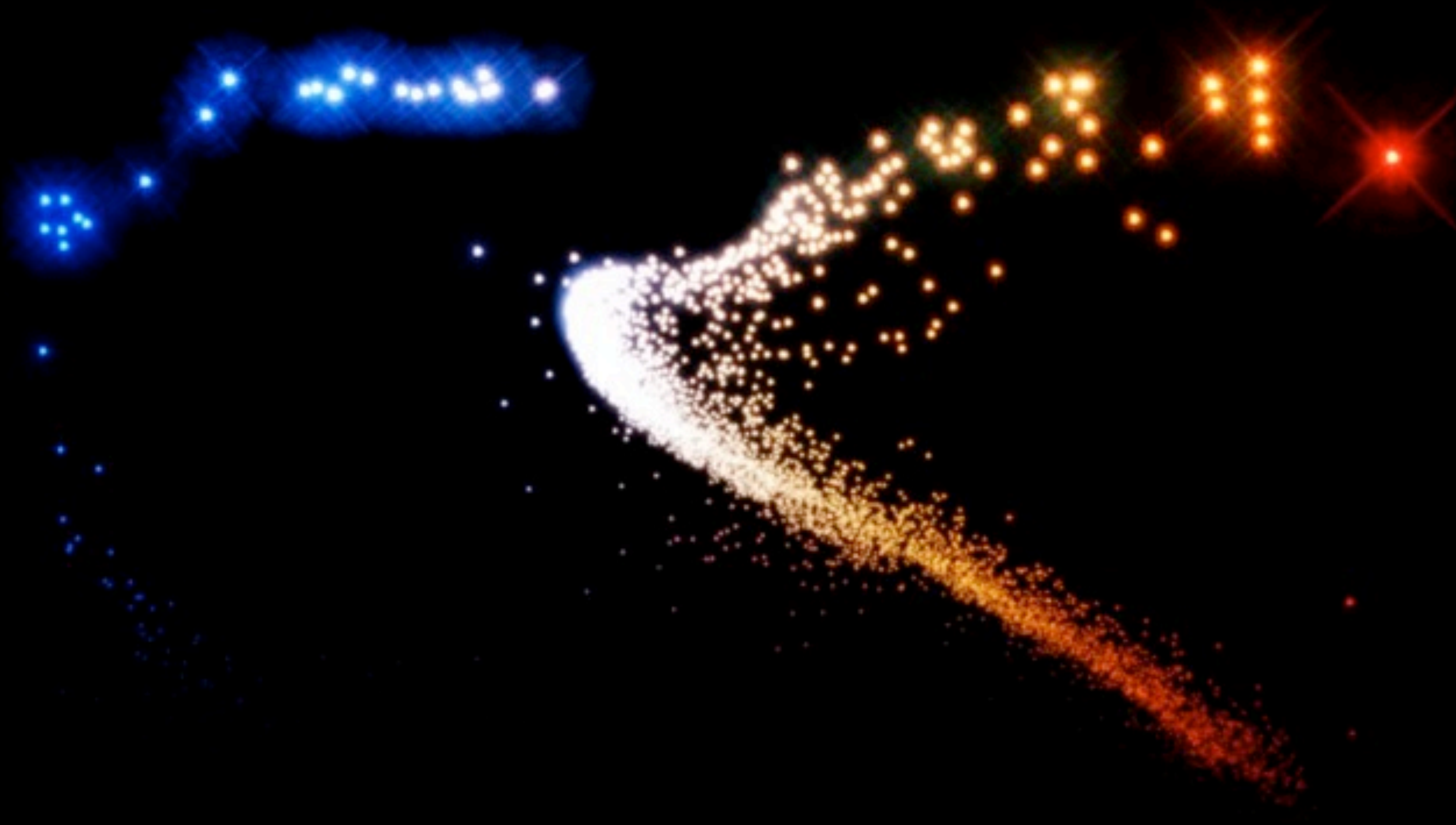
15j



They like to sort the stars,
putting the **bright** stars on top,
and the faint stars on the bottom.

15k

This is called a Color-Magnitude Diagram (CMD).

Main-Sequence Stars

* Stars that follow the color-magnitude trend fuse hydrogen into helium in their cores
* Definition: a main-sequence star fuses hydrogen into helium in its core
* Our Sun is a G2 main-sequence star
* All main-sequence G type stars are similar to our Sun in both luminosity and surface temperature

Main-Sequence Stars...

* Main-sequence stars with cooler surface temperature (K and M) are much less luminous than the Sun
* A K-type star has a surface temperature of about 4,000 K, yet its luminosity is about a tenth that of the Sun (0.1 L_{Sun})
* A M-type star's surface temperature is about 3,500 K, its luminosity is 0.001 L_{Sun}

Main-Sequence Stars...

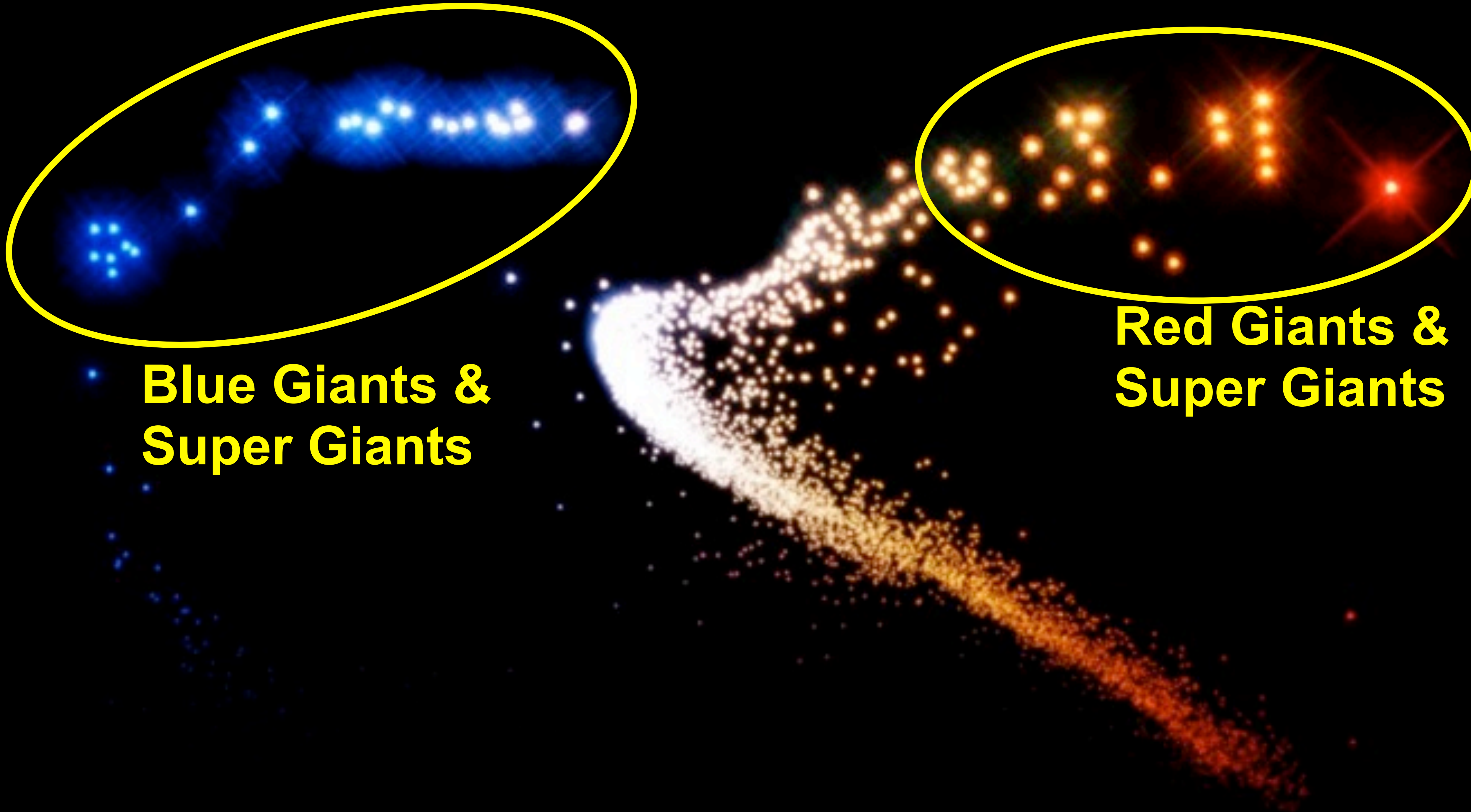
* On the other end, **blue main-sequence stars produce much more light than the Sun**
* An O-type star has a surface temperature of about 30,000 K, and its luminosity is about 100,000 times that of the Sun (100,000 L_{Sun})
* We also observed that there are very few bright stars and many more dim ones
* OBAFGKM (few Os, many more Ms)

Giants & Supergiants

* Going back at the very few bright stars that were very red
* Red means low surface temperature
* Bright means they are very luminous

➡ They cannot be main-sequence stars

To be so bright, they must be **enormous** in size

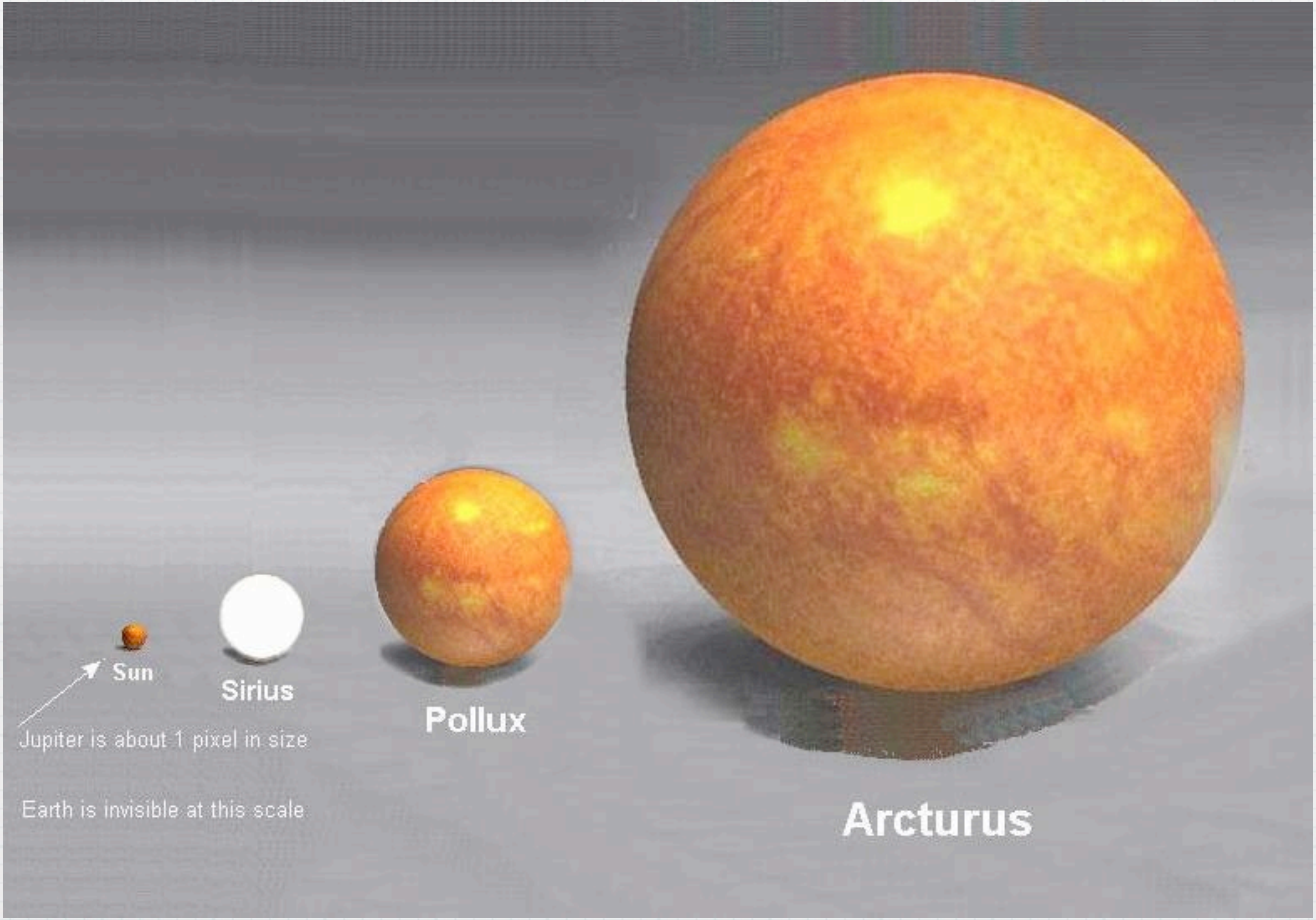


This is called a Color-Magnitude Diagram (CMD).

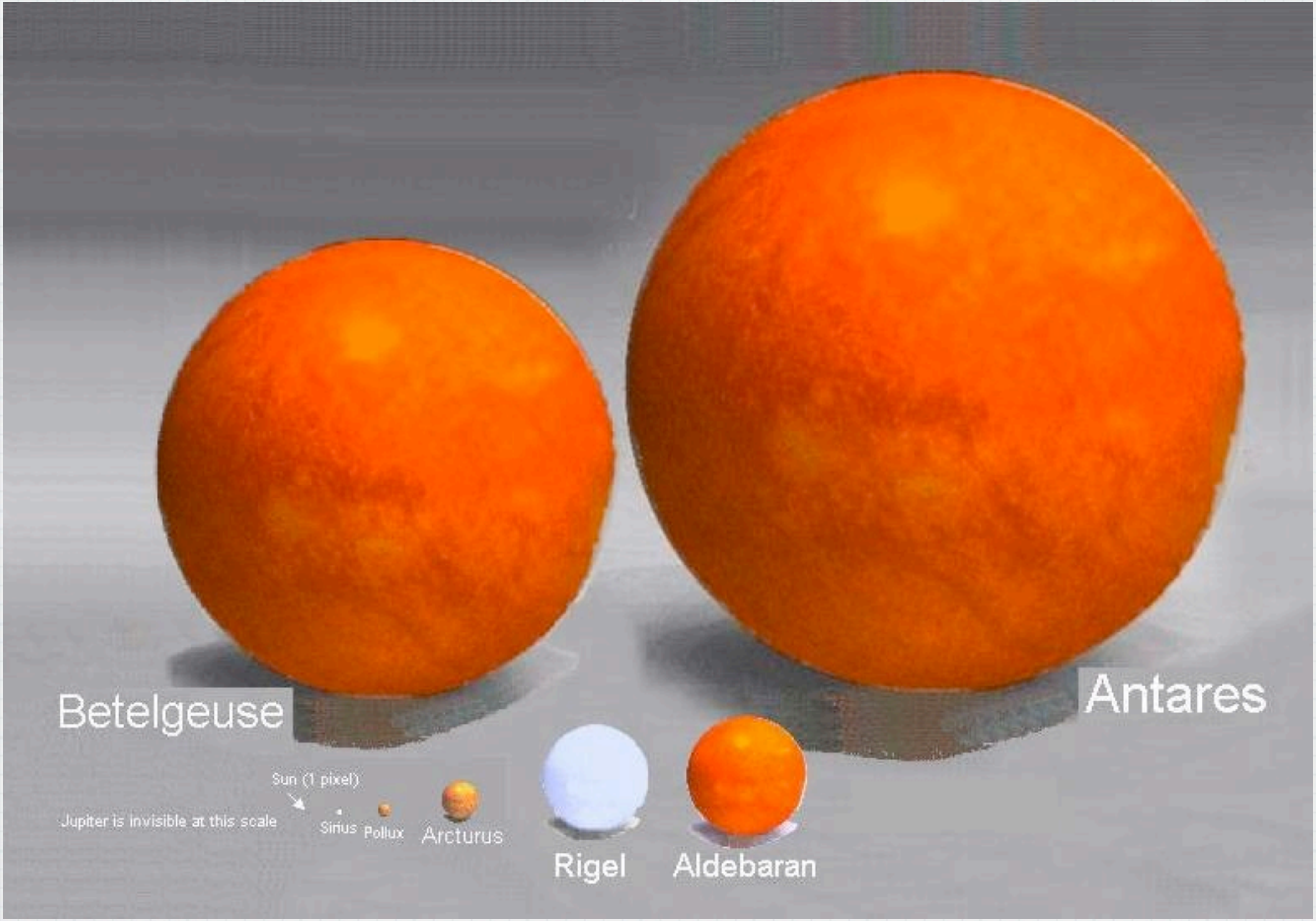
Giants & Supergiants...

* Astronomers divide these gigantic stars into two groups
  * Giants
    * radii: 10 to 100 solar radius
  * Supergiants
    * radii: up to 1,000 solar radius

Giants Stars



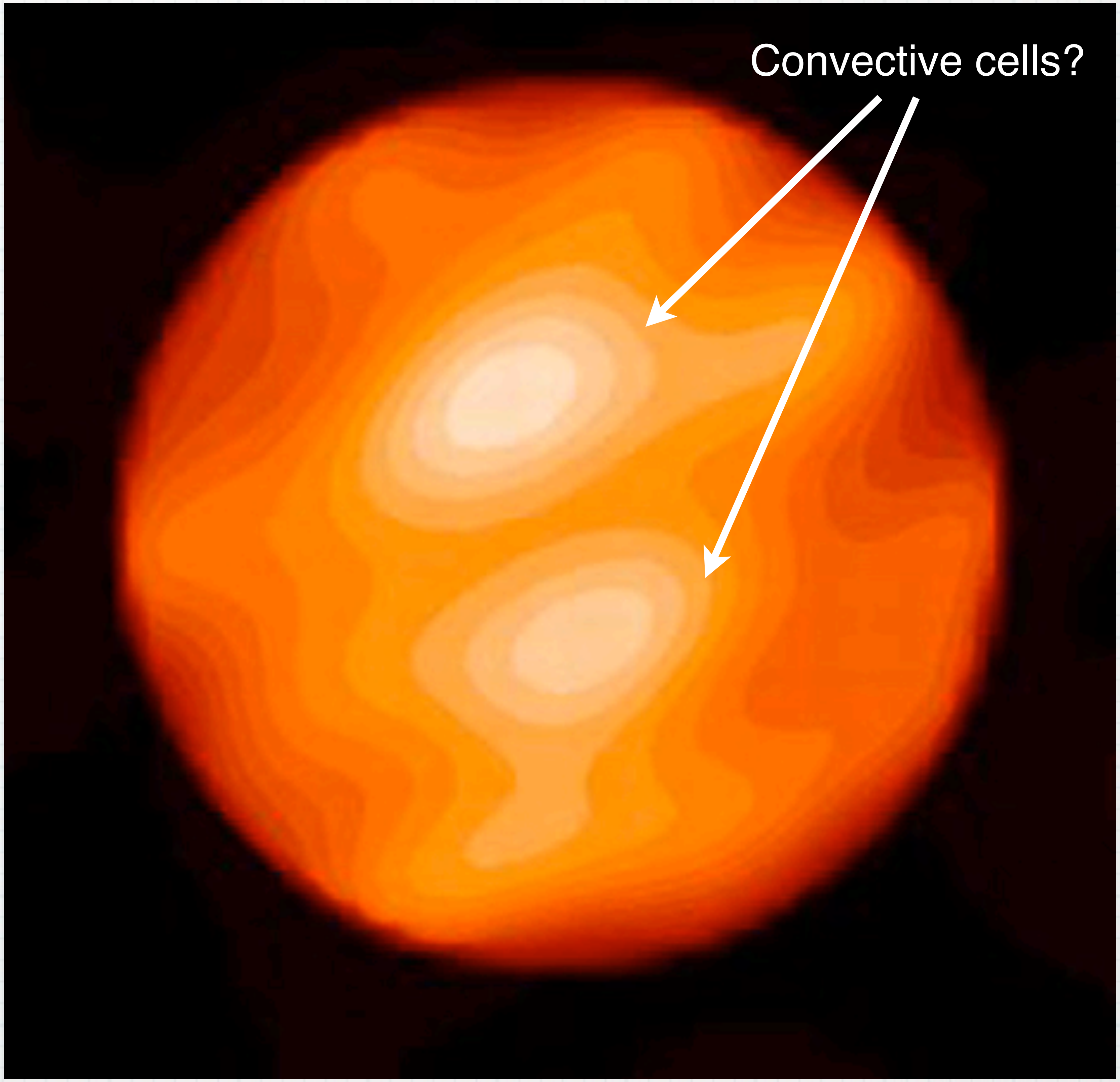
Supergiants Stars



Imaging Stars ... is now possible!

By using infrared interferometry, Betelgeuse can now be resolved

Betelgeuse (a red supergiant star: 600 R_{Sun}) extends to the orbit of Jupiter



Credit: Xavier Haubois (Observatoire de Paris) et al.

Why are there giants & supergiants?

* Clearly these stars do not follow the surface temperature-luminosity relationship of main-sequence stars

* They are near or past the end of their hydrogen to helium fusion cycle in the core

* Fusing hydrogen around the core is not being auto regulated and the fuse rate is increasing, which expands the star to an enormous size

White Dwarfs

* White dwarfs are another general class of stars
* Their surface temperatures can be very hot
* But their luminosities are very low
    * typically 0.1 L_{Sun} to 0.0001 L_{Sun}

White Dwarfs...

* To have such small luminosities, yet having high surface temperatures, the radii must be very small
* Typically, they have the radius of the Earth, or 0.01 R_{Sun}
* Yet, their masses are similar to the Sun

➡ They have very high densities:

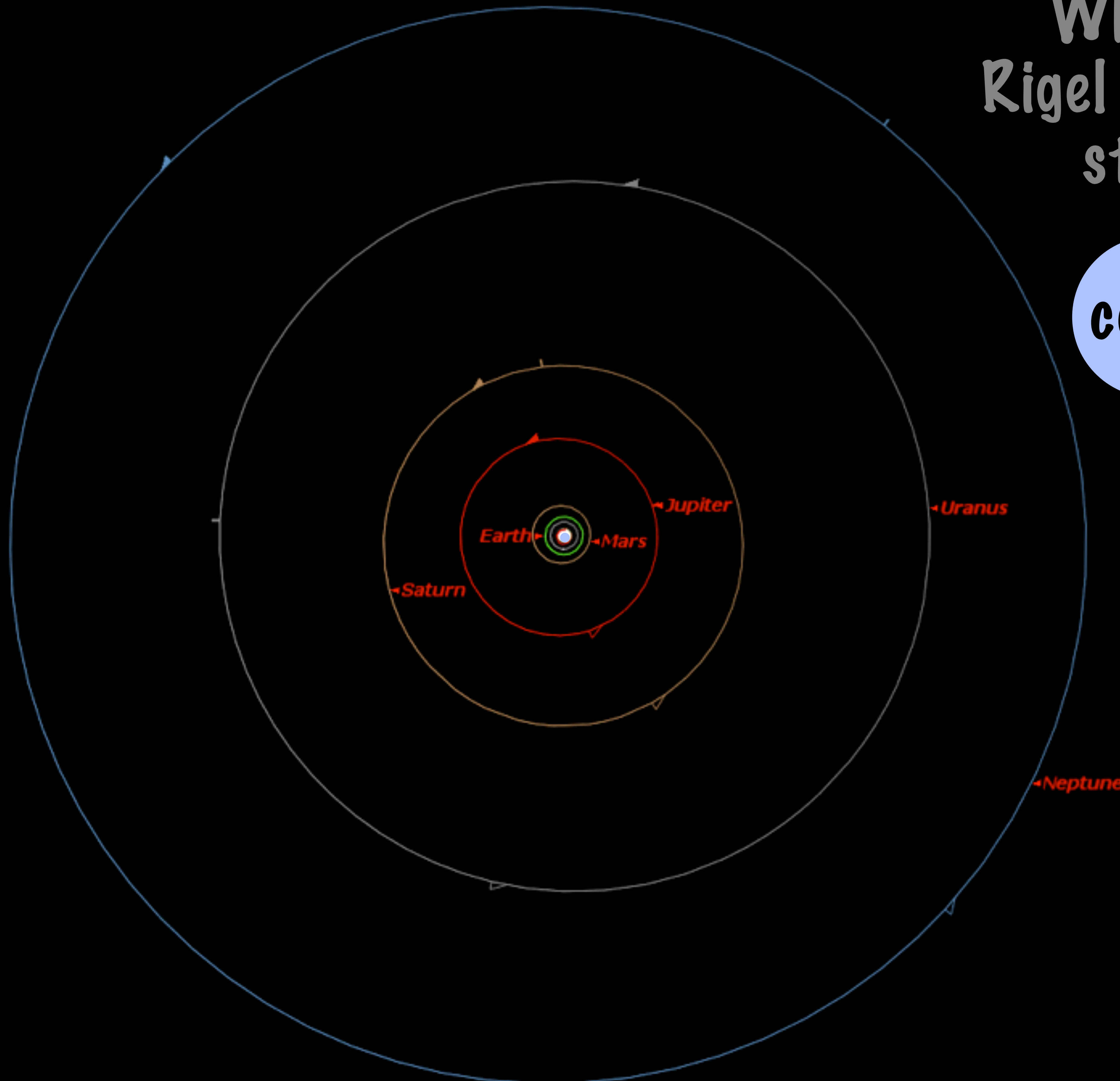
One "teaspoon" of white dwarf matter weighs several tons!

This is called a
Color-Magnitude Diagram
(CMD).

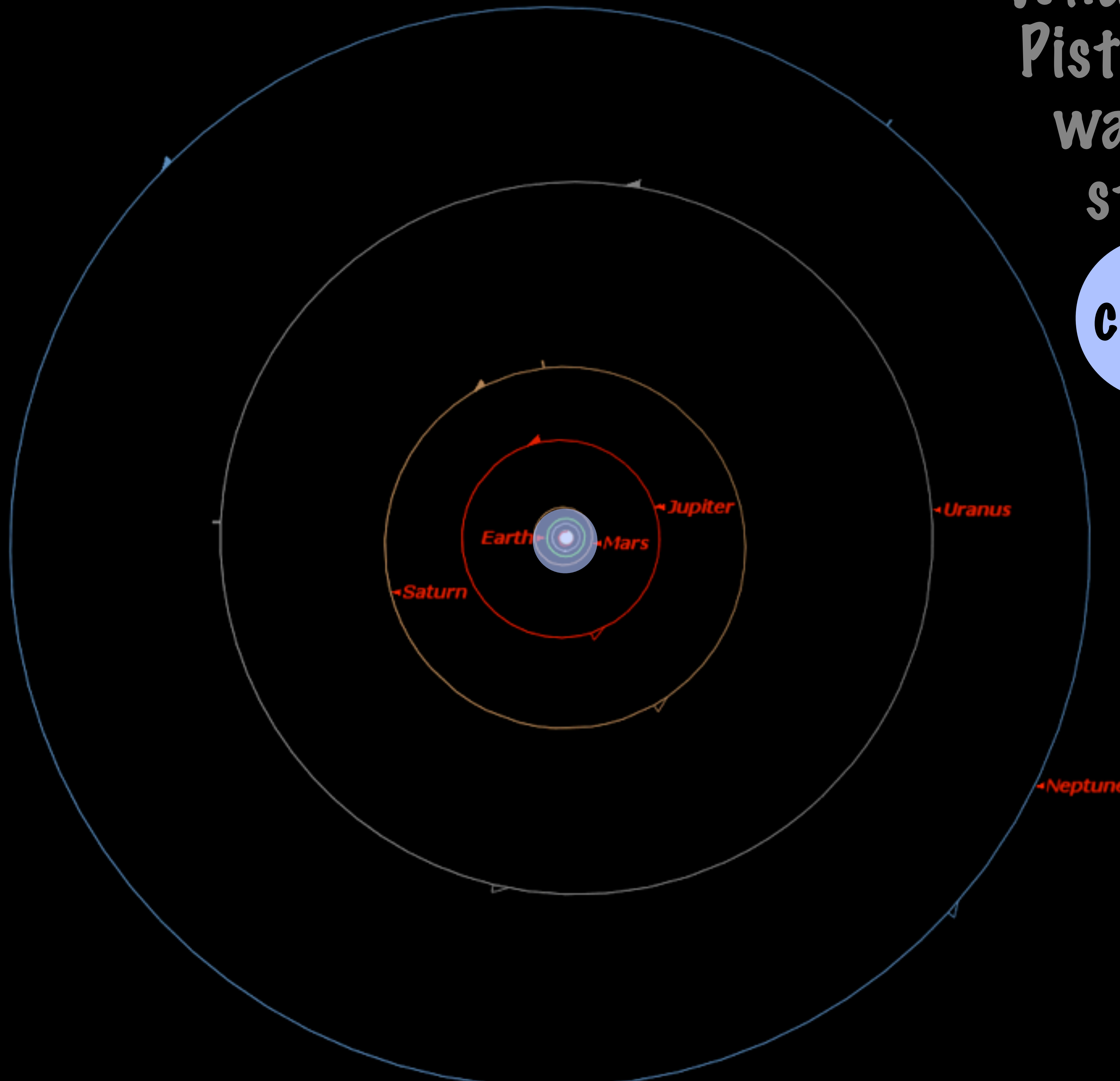
White Dwarfs...

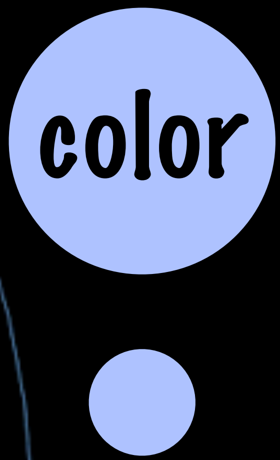
* What are they?
* They are the **remnants of stars which have exhausted their nuclear fuel in their cores**
* They slowly cool with time, becoming dimmer

What if Rigel was our star?



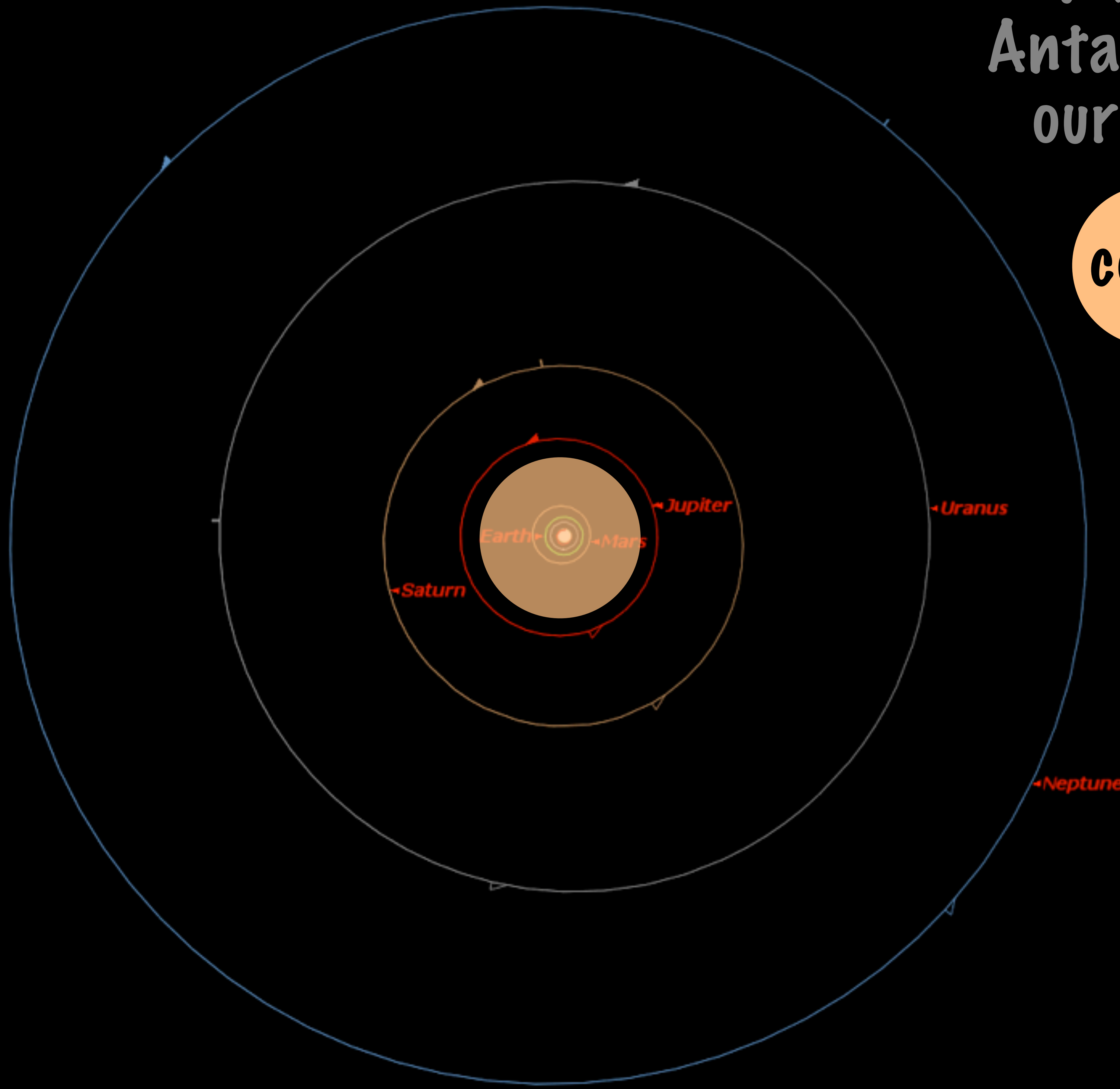
What if the Pistol Star was our star?



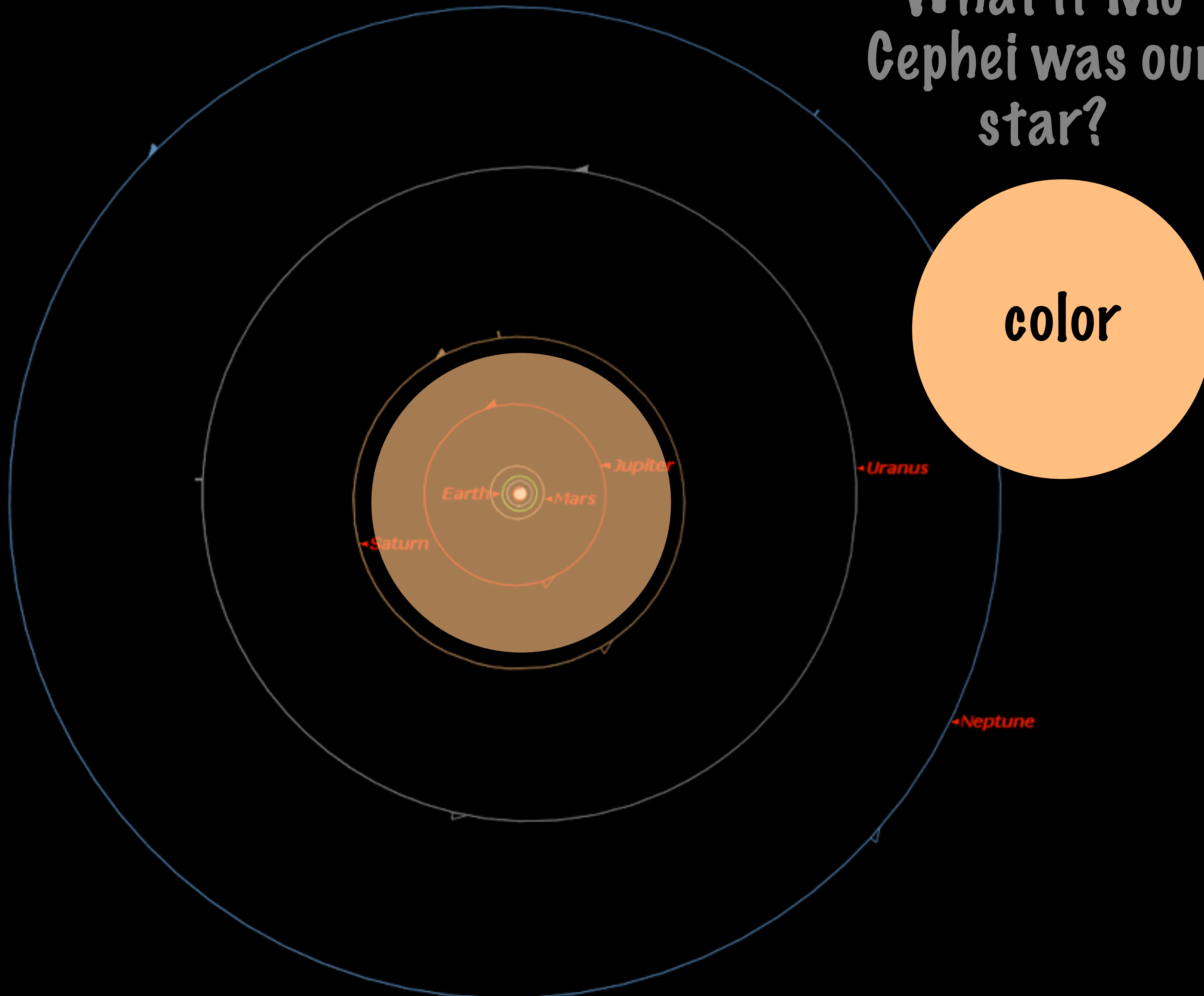


What if Antares was our star?

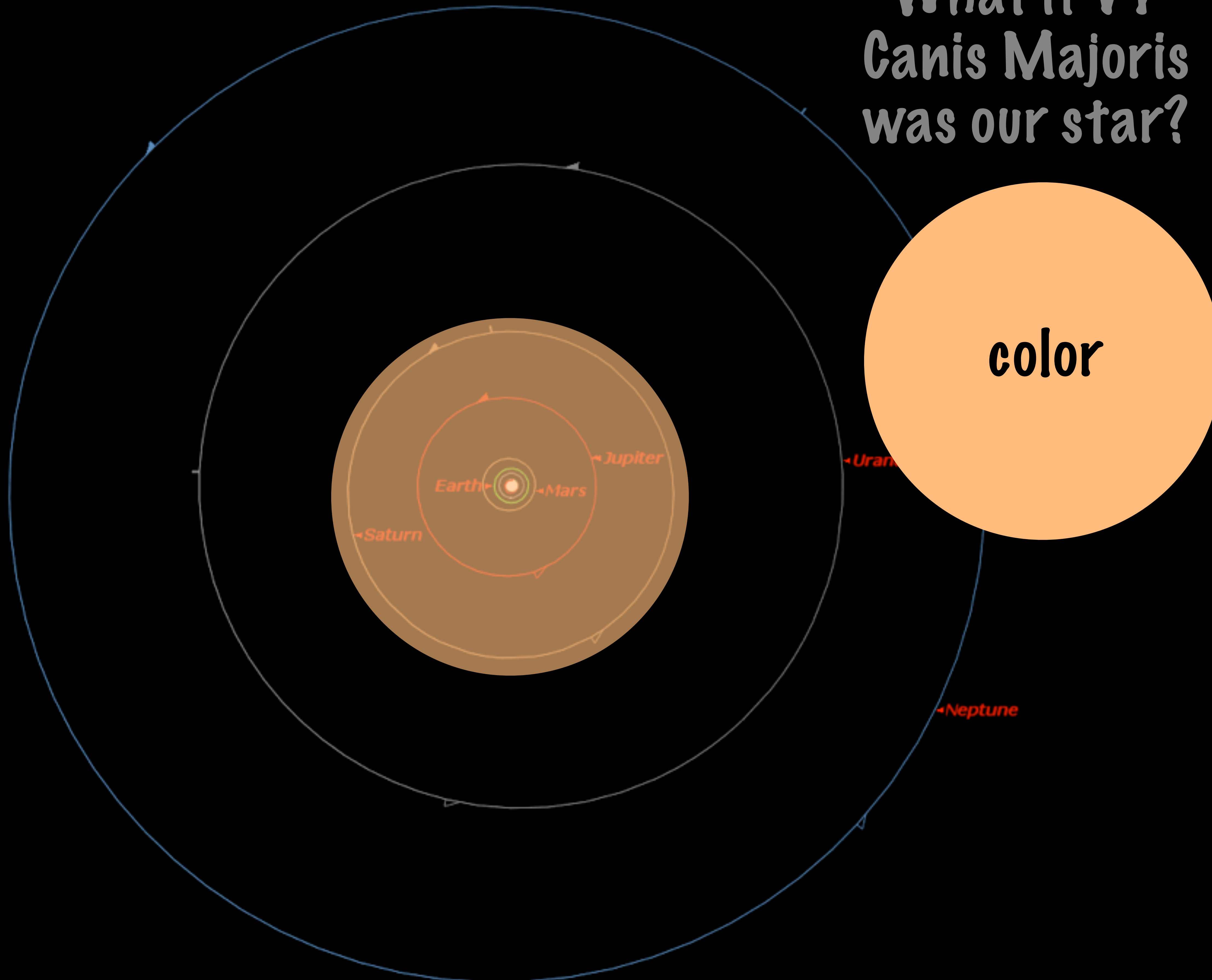
color



What if Mu Cephei was our star?



What if VY Canis Majoris was our star?



Snapshot

* Why are some red stars so much more luminous than other red stars?
* They are bigger!
    * Biggest red stars: 1,000 R_{Sun}
    * Smallest red stars: 0.1 R_{Sun}
* They are not main-sequence stars

Snapshot

* Why are some blue stars so much less luminous than other blue stars?
* They are smaller!
    * White dwarfs: 0.01 R_{Sun} (Earth size)
* They are stars that have already died

Luminosity Class

Stars still generating energy via fusion are assigned a luminosity class

- 0. - hypergiant
- ➔ I. - supergiant
- II. - bright giant
- ➔ III. - giant
- IV. - subgiant
- ➔ V. - main-sequence
- VI. - subdwarfs
- ➔ VII. - white dwarfs

A main-sequence star is officially classified as a dwarf

Full Stellar Classification

* A star full classification includes a spectral type and a luminosity class
* For example
  * Sun - G2 V
  * Sirius - A1 V
  * Proxima Centauri - M5.5 V
  * Betelgeuse - M2 I

A star's mass is its most important property. Why?

* Back then, astronomers classified stars by their spectral types and luminosities
* Today, we know that **the most fundamental property of any star is its mass (and its composition)**
* Let's see why

Main-Sequence Stars

* In observed binary stellar systems the main-sequence stars with the larger mass are always hot & bright, while
* the less massive ones are always cool & dim

Mass and Fusion Burn Rate

* The more massive a main-sequence star, the more gravity to compress the core
    ➡ Higher compression means higher core temperature and greater fusion rate
    ➡ Higher fusion rate means a more luminous star

Mass and Fusion Burn Rate...

* We already saw that the nuclear fusion rate is **very** sensitive to temperature

➡ So **the fusion rate is very sensitive to mass**

Mass and Fusion Burn Rate...

* For example, a 10 M_{Sun} main-sequence star will fuse hydrogen at a rate 10,000 times that of the Sun

➡ That star is about 10,000 more luminous than the Sun

Mass and Surface Temperature

* Since a 10 M_{Sun} main-sequence star is 10,000 times brighter than the Sun, then its surface temperature has to be significantly hotter than the Sun's to account for that luminosity
* Hence, **a main sequence star's mass determine its luminosity and its surface temperature**

Mass and Surface Temperature...

* We can estimate a main-sequence star's mass just by knowing its spectral type
* We know that any hydrogen-burning main-sequence star that has a G2 spectral type must have the same luminosity and mass as the Sun

Mass and Stellar Lifespans

* A star is born with a **limited** supply of hydrogen

* **Since a 10 M_{Sun} main-sequence star is 10,000 times brighter than the Sun, it is burning the hydrogen 10,000 times faster than the Sun**

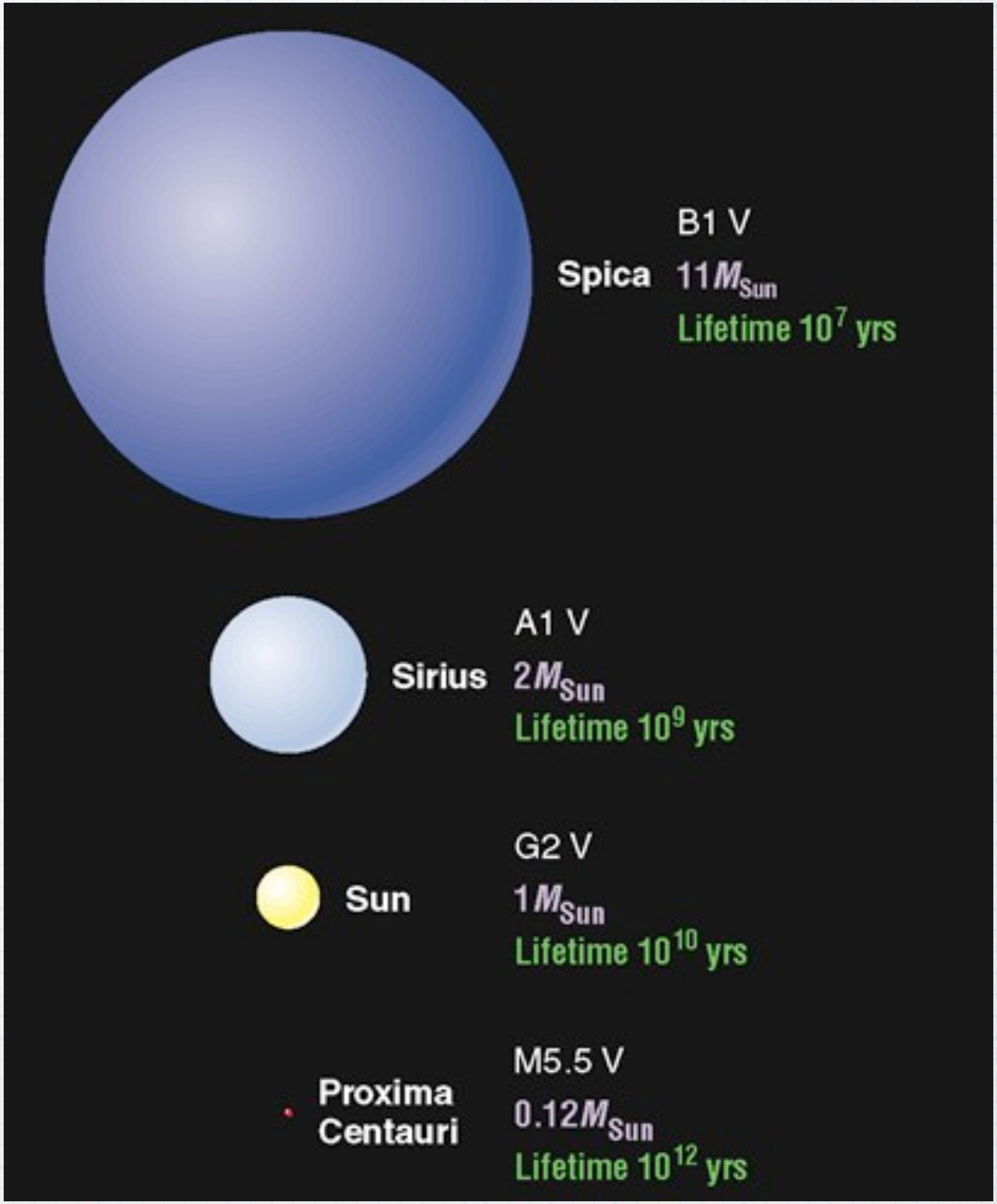
➡ Its lifetime is then 10/10,000 = **1/1,000 as long as the Sun's lifetime**

The Mass Factor

* A 0.3 M_{Sun} main-sequence star is 0.01 L_{Sun}. It will live 0.3/0.01 = 30 times longer than the Sun (or 300 billion years!)
* We can conclude by stating that a main-sequence star's mass will determine its luminosity, its spectral type and its lifetime

Four main-sequence stars

Heavier main-sequence stars are hotter and brighter than the lighter ones but they also have much shorter lifetimes



Stellar Properties Review

Luminosity: from brightness and distance

$10^{-4}\ L_{Sun} \Leftrightarrow 2 \times 10^{6}\ L_{Sun}$

Temperature: from color and spectral type

3,000 K ⇔ 55,000 K

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

$0.08\ M_{Sun} \Leftrightarrow 150\ M_{Sun}$

Main-Sequence Star Summary

Class	Mass (solar units)	Luminosity (solar units)	Surface Temperature (K)	Radius (solar units)	Main Sequence lifespan (yrs)
M6	0.10	0.003	2,900	0.16	2 trillion
M1	0.50	0.03	3,800	0.6	200 billion
K1	0.75	0.3	5,000	0.8	30 billion
G0	1.0	1	6,000	1.0	10 billion
F2	1.5	5	7,000	1.4	2 billion
A0	3	60	11,000	2.5	200 million
B4	5	600	17,000	3.8	70 million
B2	10	10,000	22,000	5.6	20 million
B0	15	17,000	28,000	6.8	10 million
O8-9	25	80,000	35,000	8.7	7 million
O3-4	60	790,000	44,500	15	3.4 million

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

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

Mass, Luminosity and Radius: **Solar units**

Temperature: **Kelvin**
Lifetime: **Years**

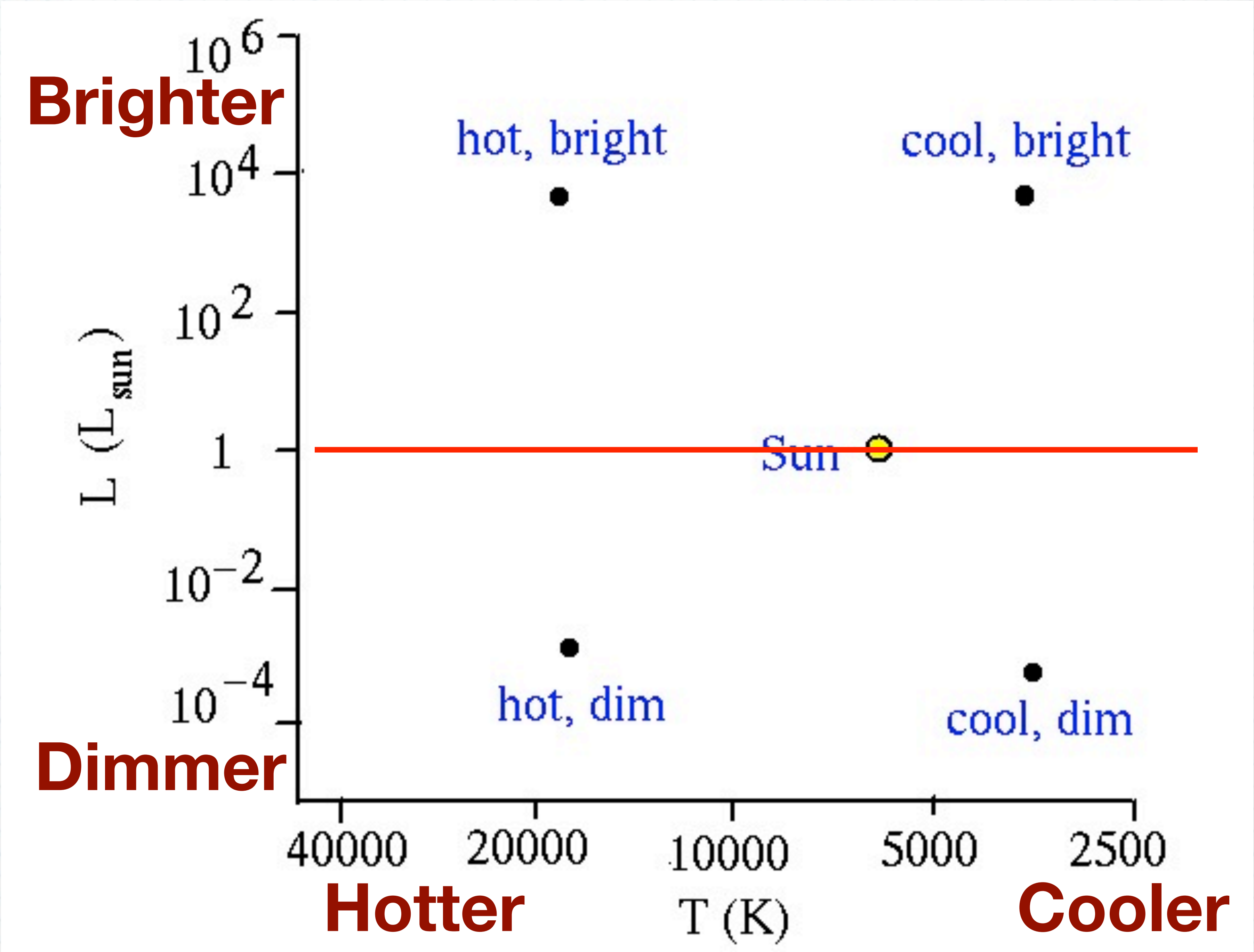
The Hertzsprung-Russell Diagram

* The relationships between stellar mass, luminosity, temperature and lifetime can be visualized in a diagram called the **Hertzsprung-Russell diagram**
* It is named after 2 astronomers
* Named the **H-R diagram** thereafter

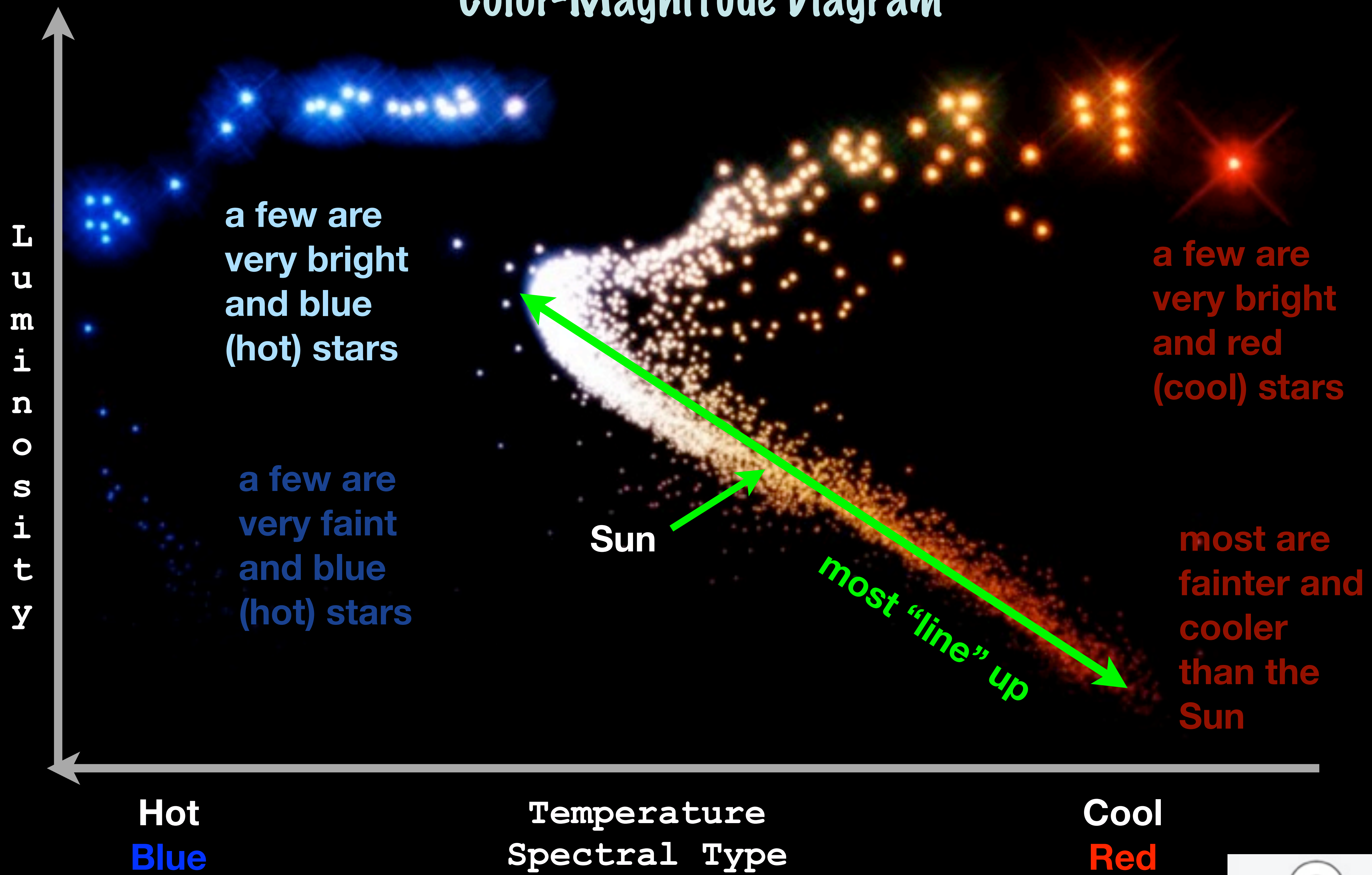
The Hertzsprung-Russell Diagram...

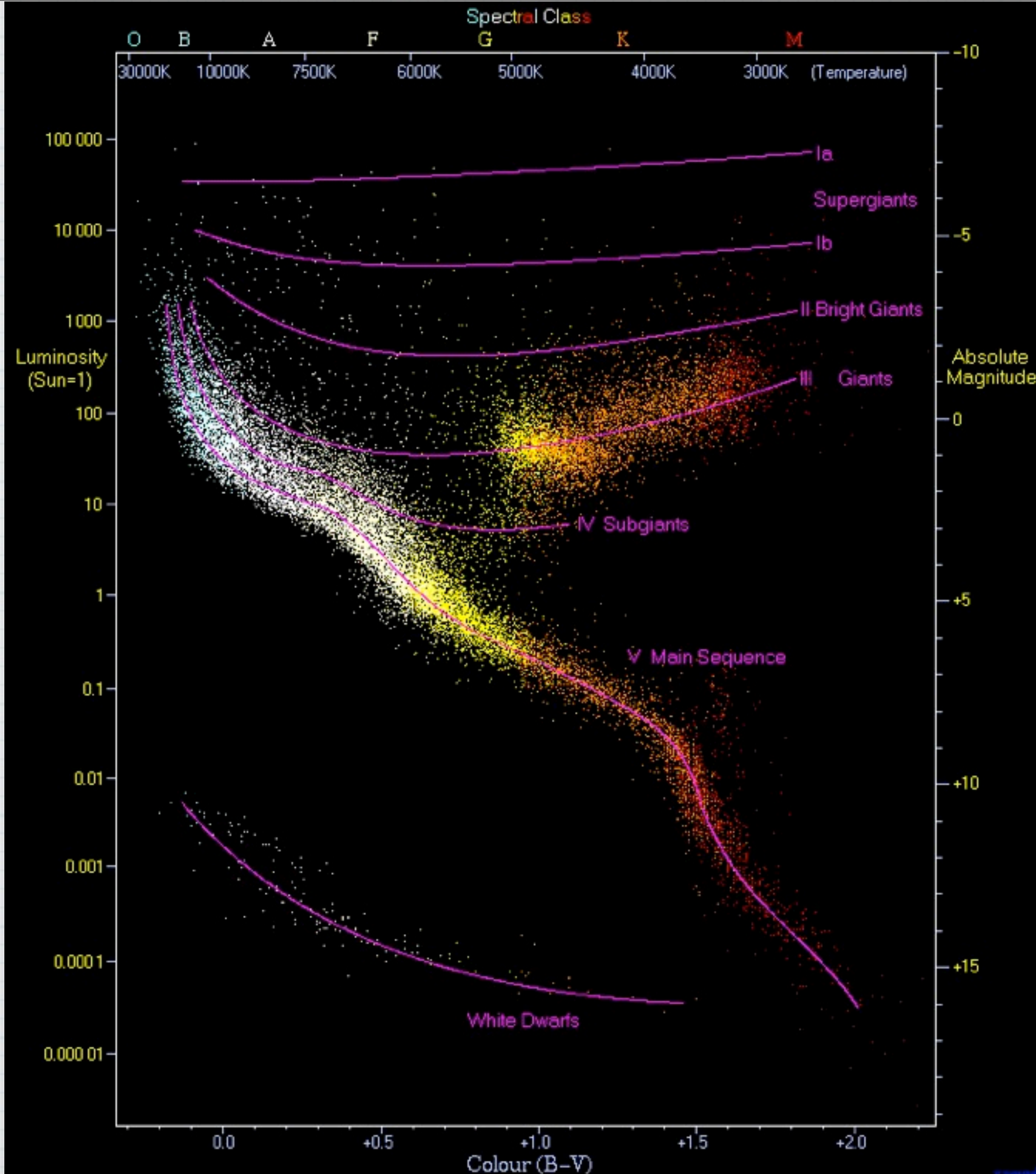
This diagram plot luminosity in solar units on the Y axis and stellar temperature on the X axis

Notice that the scales are not linear

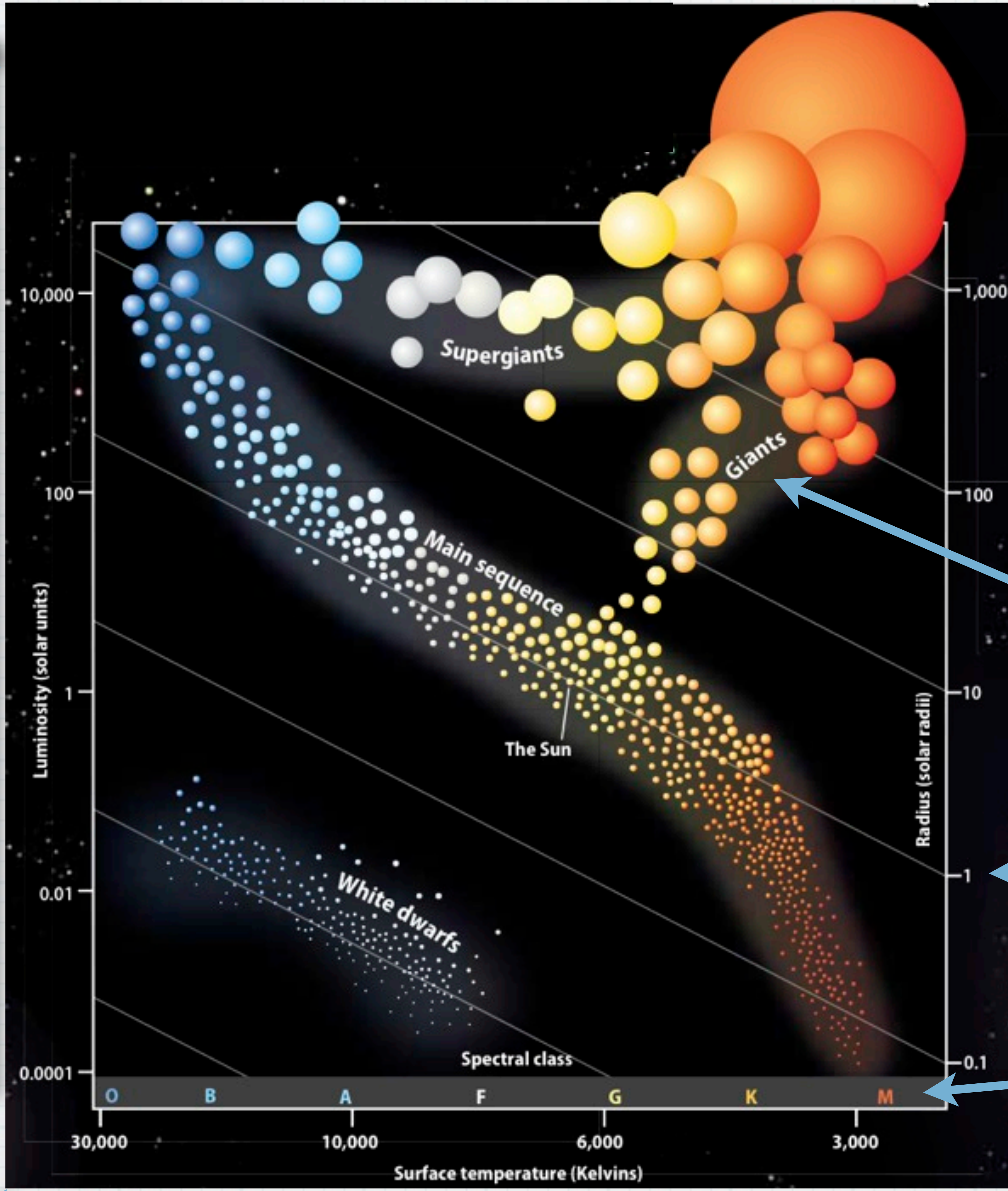


Star Distribution
Color-Magnitude Diagram





Hertzsprung-Russell diagram



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

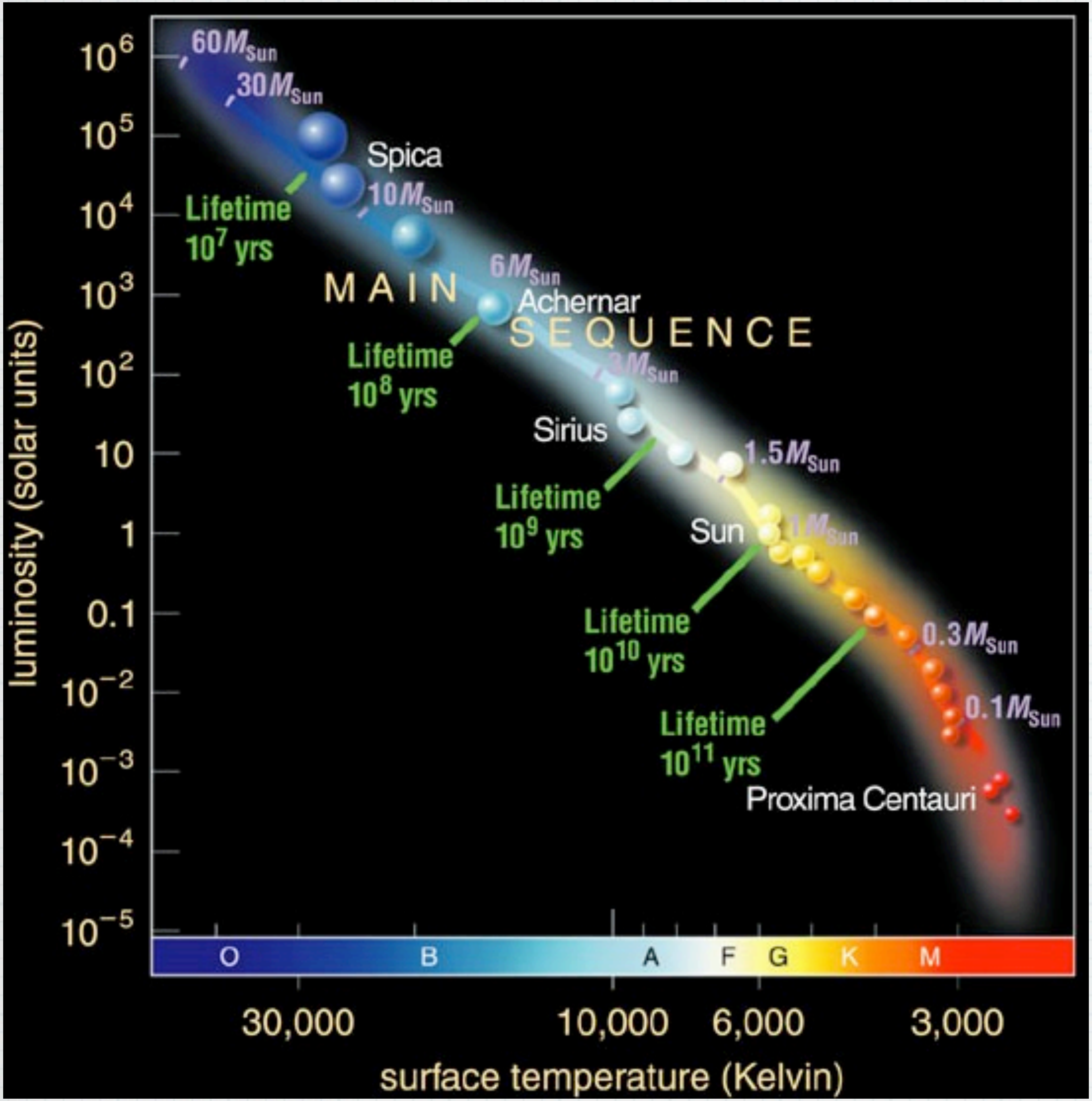
Luminosity

Temperature

Group

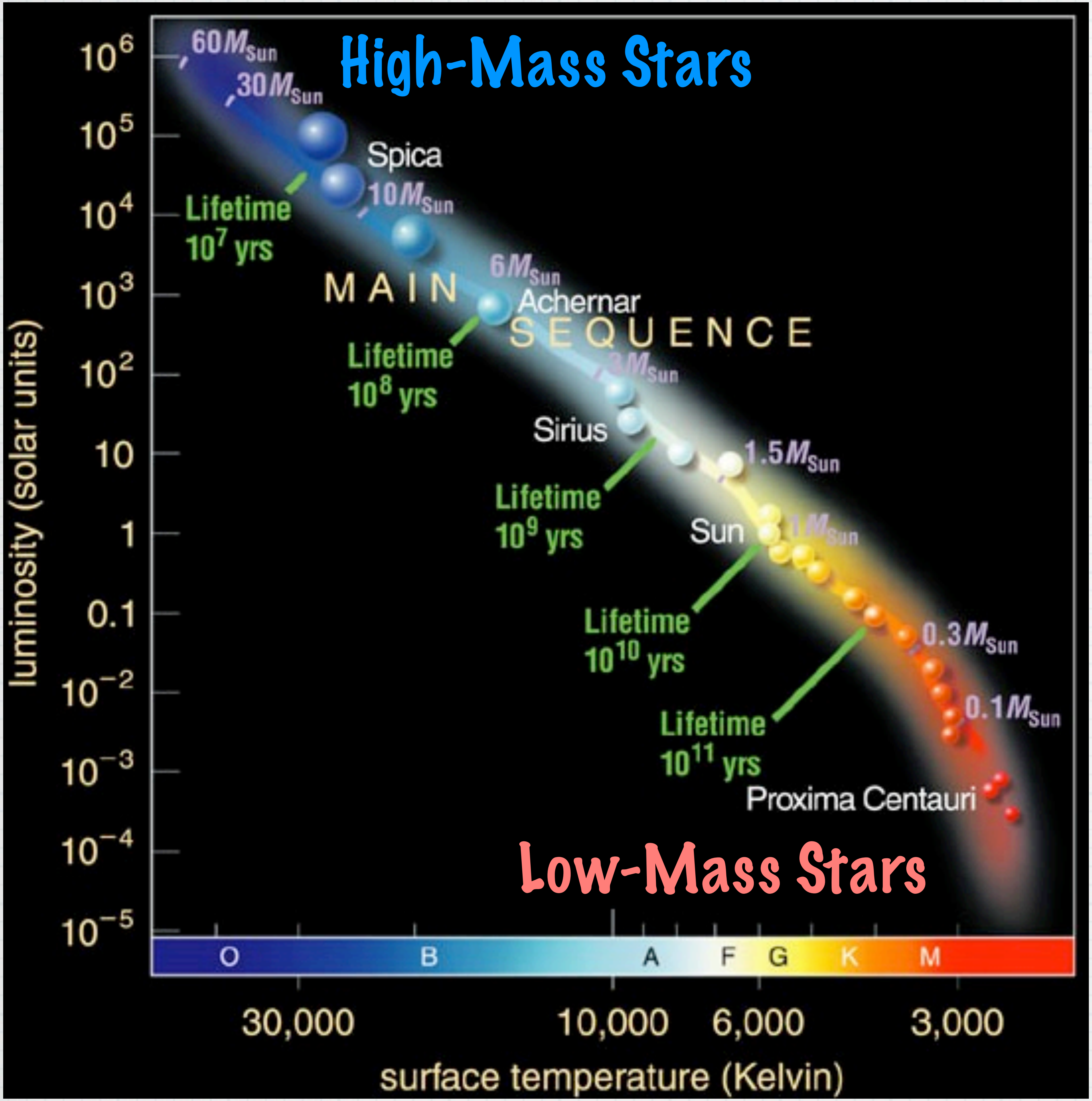
Solar Radius

Spectral Type

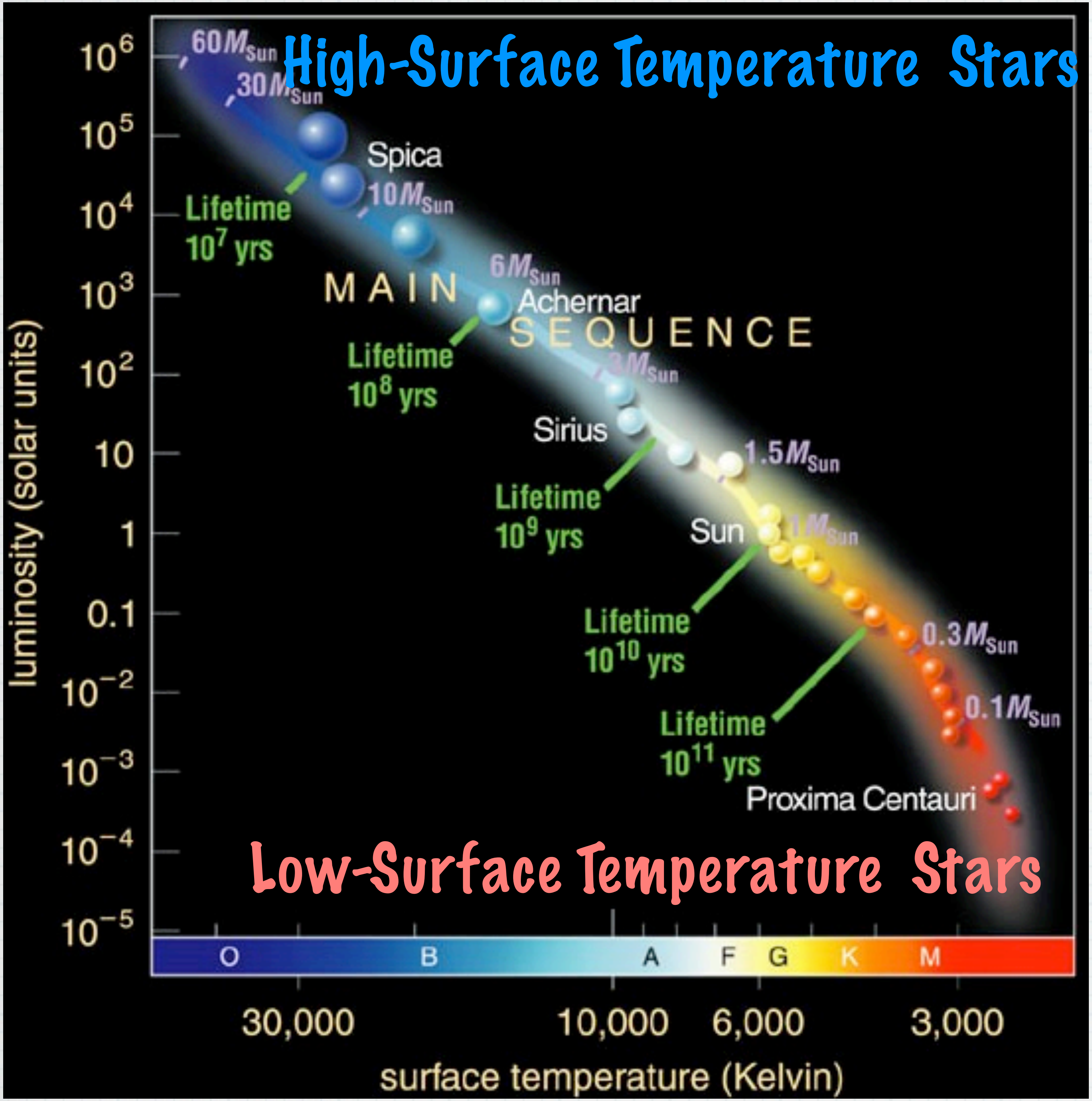


Hydrogen-burning stars reside on the main sequence of the H-R diagram

For stars located on the main-sequence, their lifetime can be deduced



Hydrogen-burning stars reside on the main sequence of the H-R diagram



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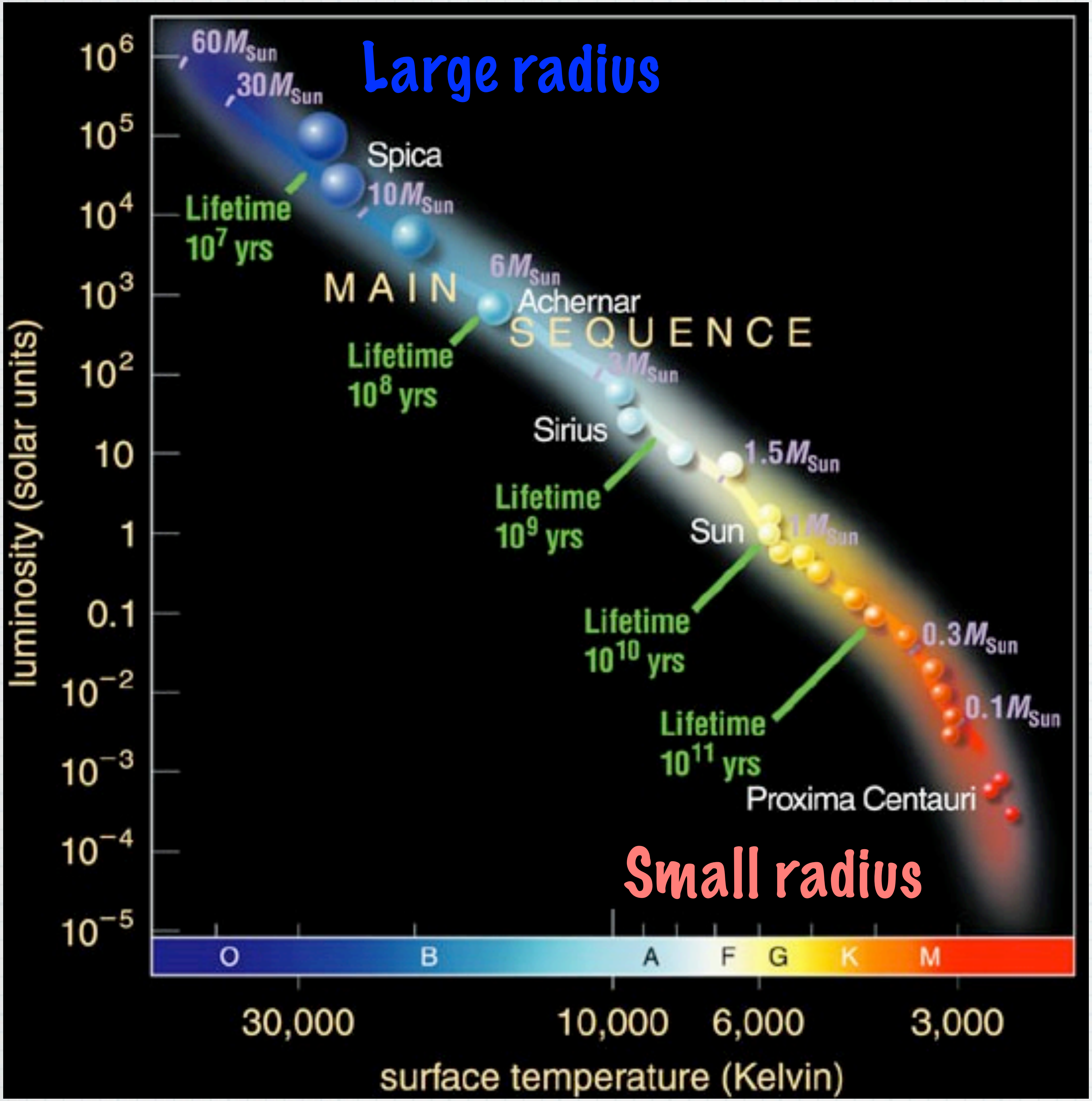
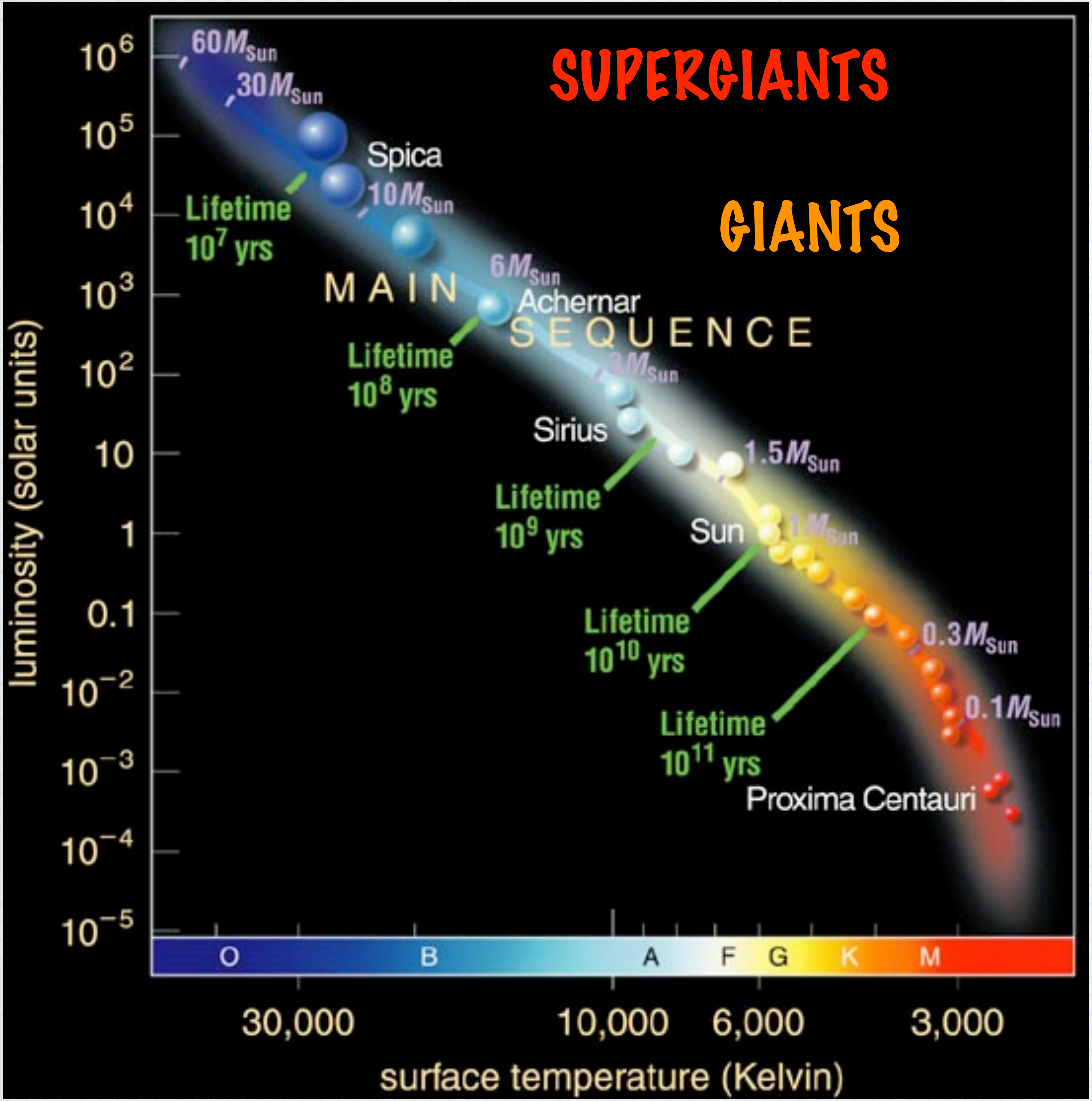
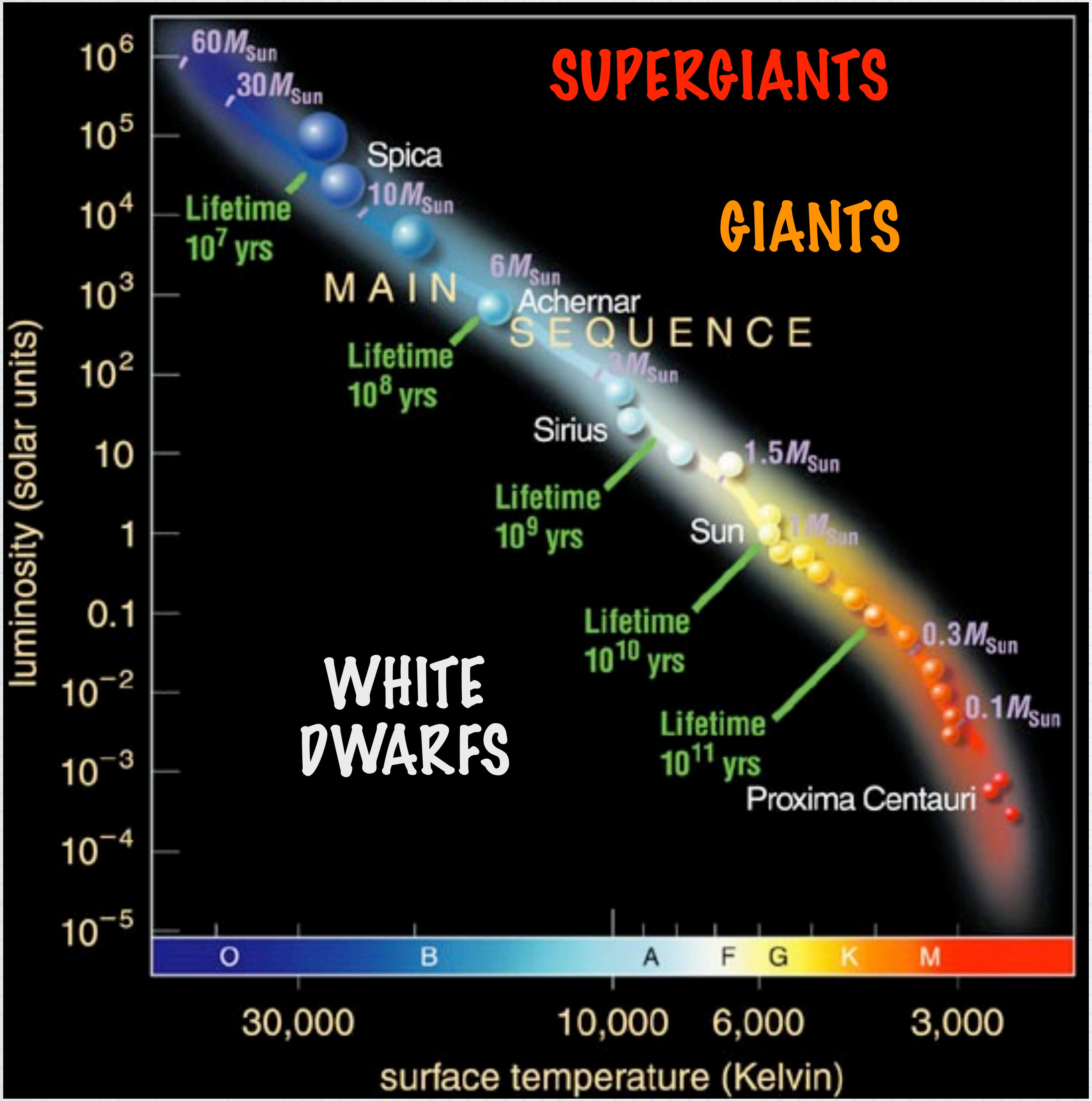


Hydrogen-burning stars reside on the main sequence of the H-R diagram



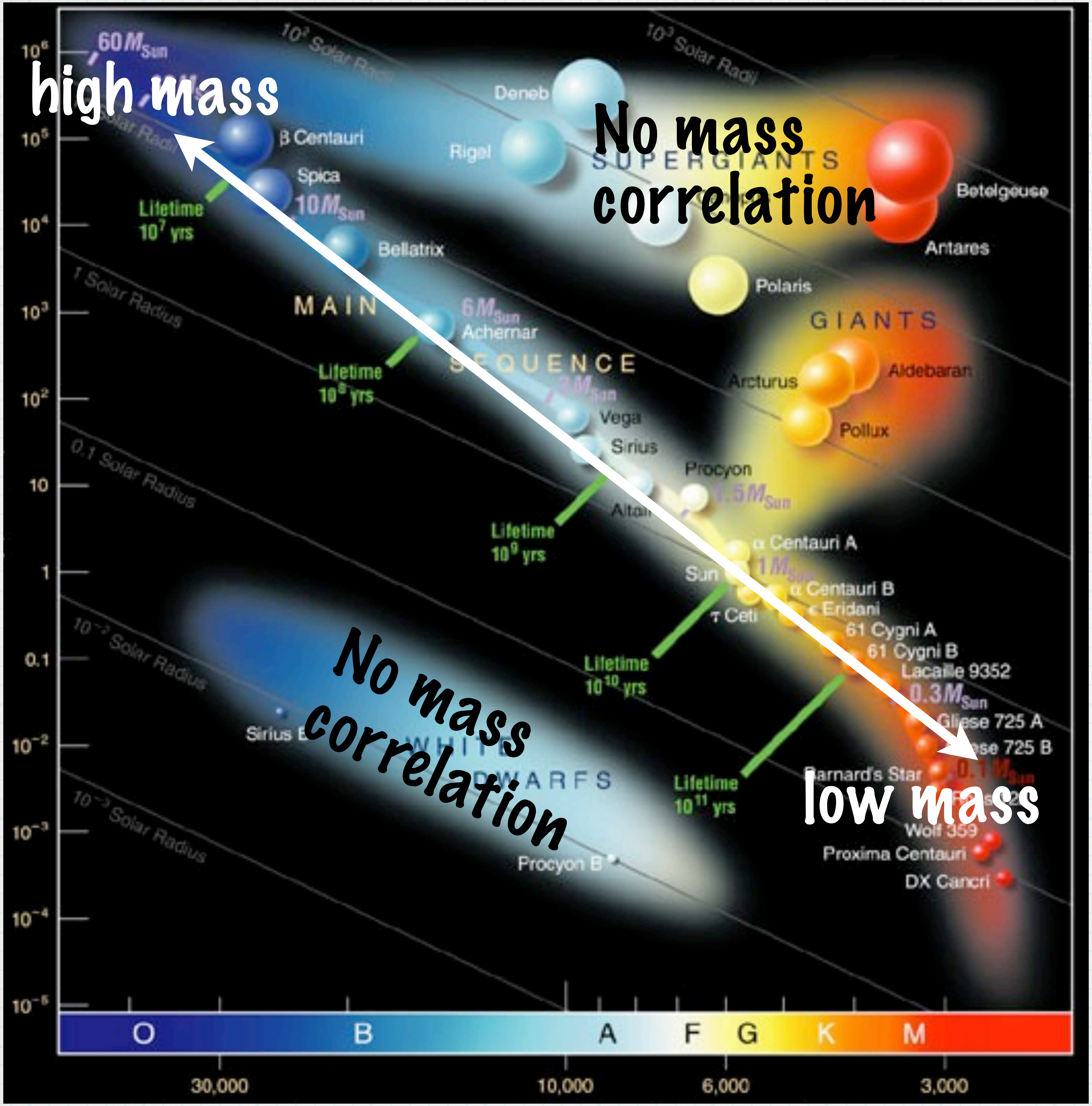
Stars with low temperature and high luminosity must have large radii



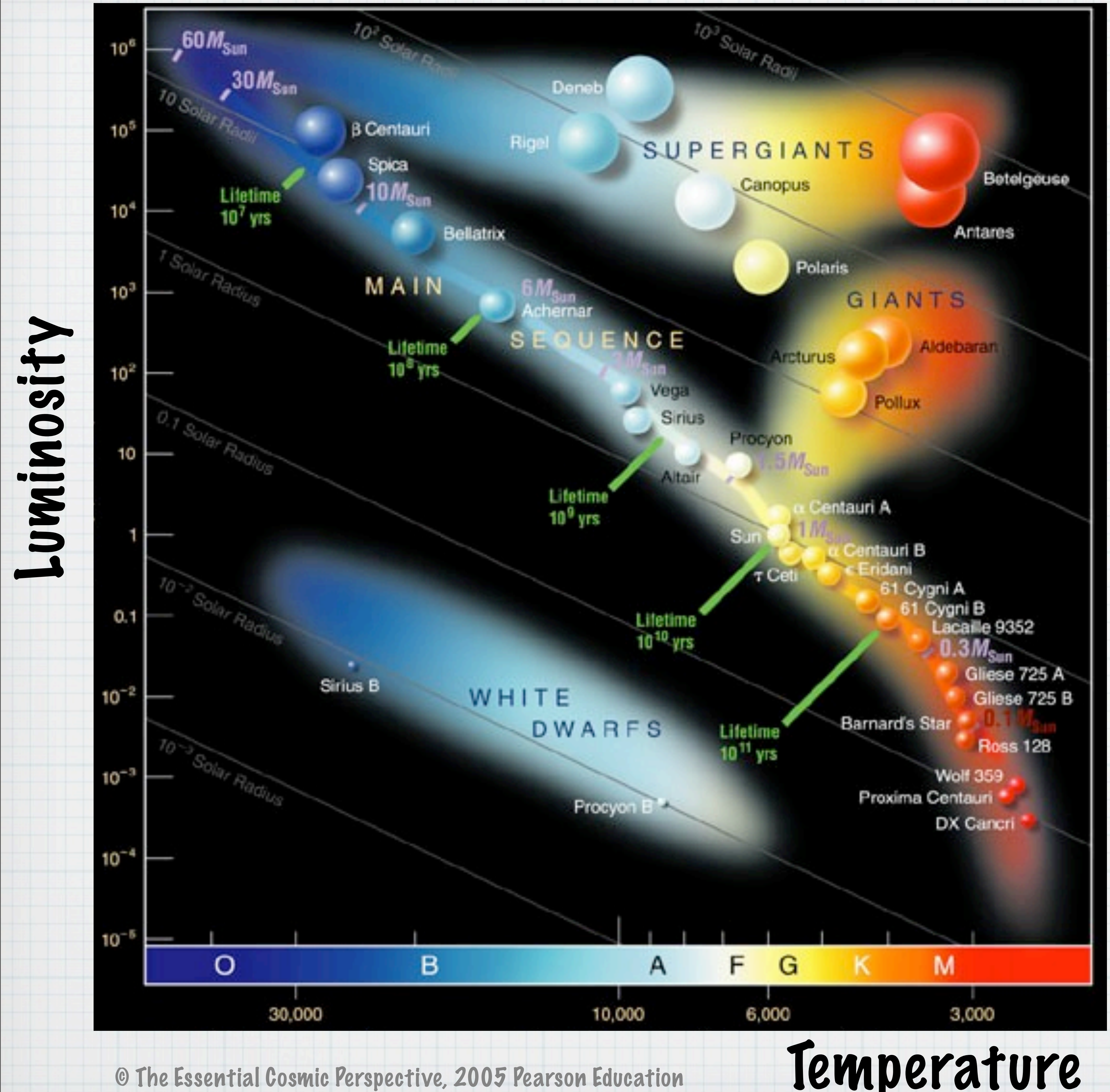
Stars with high temperature and low luminosity must have small radii

Main-sequence mass correlation

Luminosity



Temperature

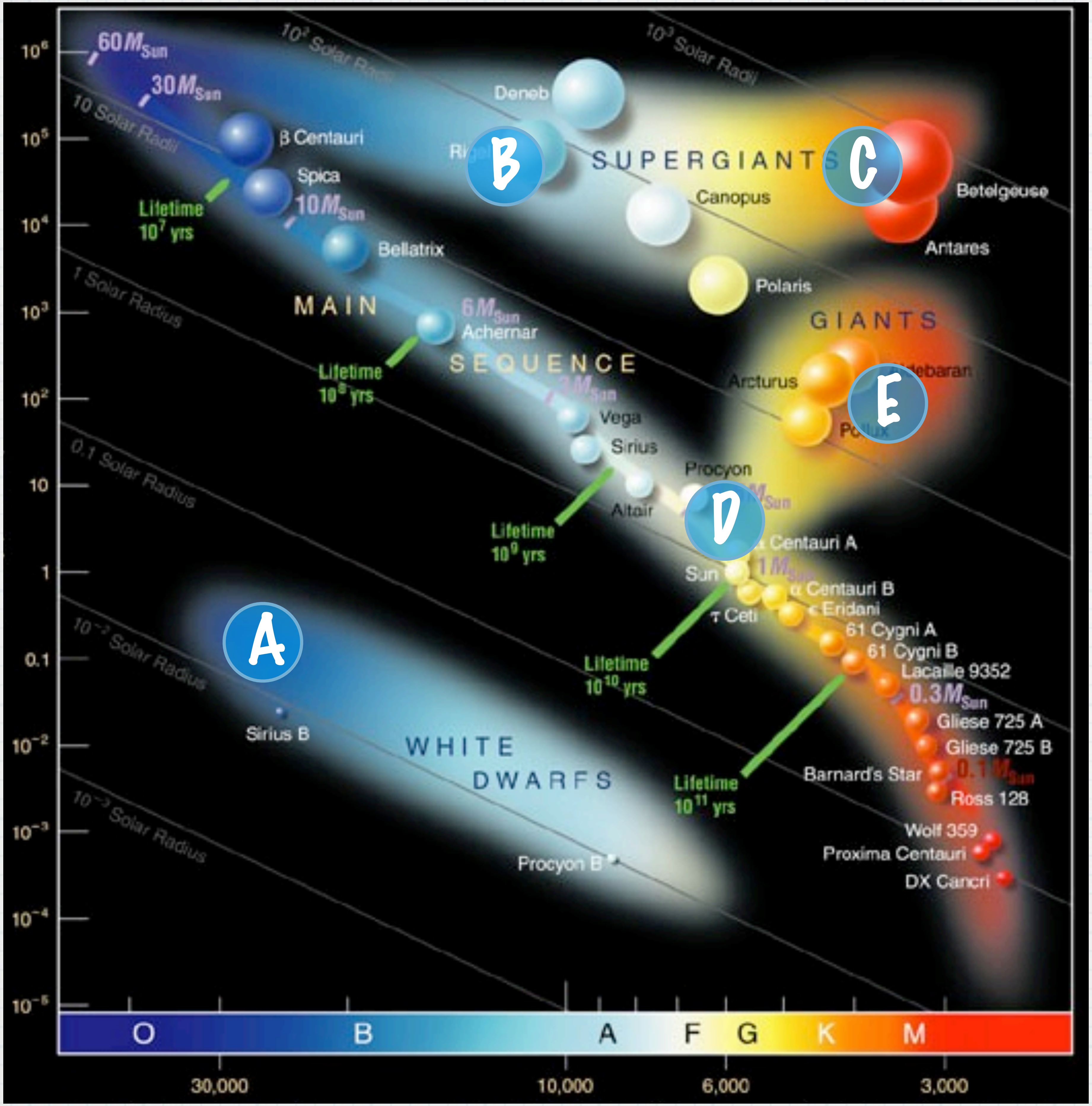


H-R diagram depicts:

Temperature
Color
Spectral Type
Luminosity
Radius
*Mass
*Lifespan
*Age

Which star is the hottest?

Luminosity

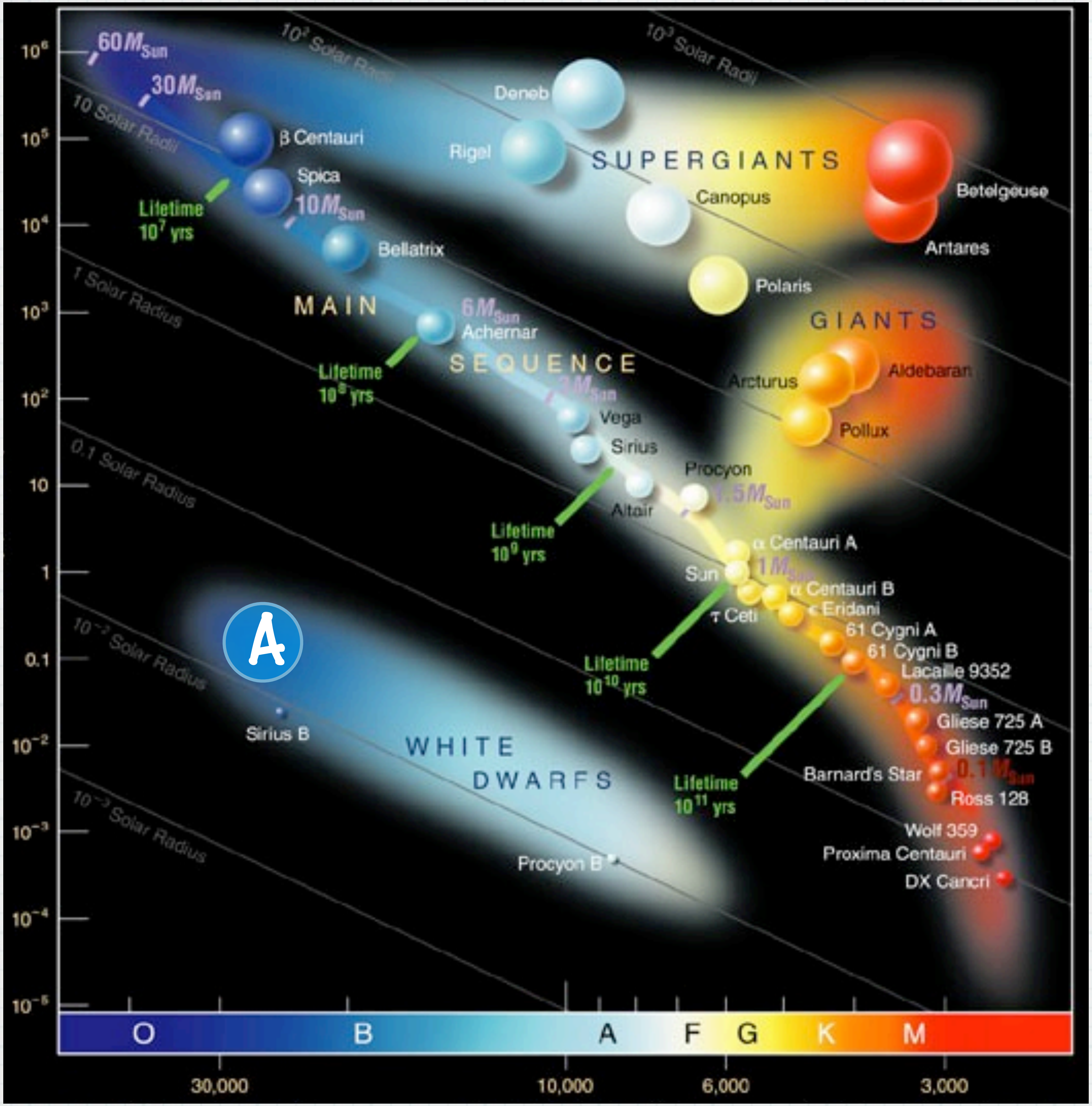


Temperature

Which star is the hottest?

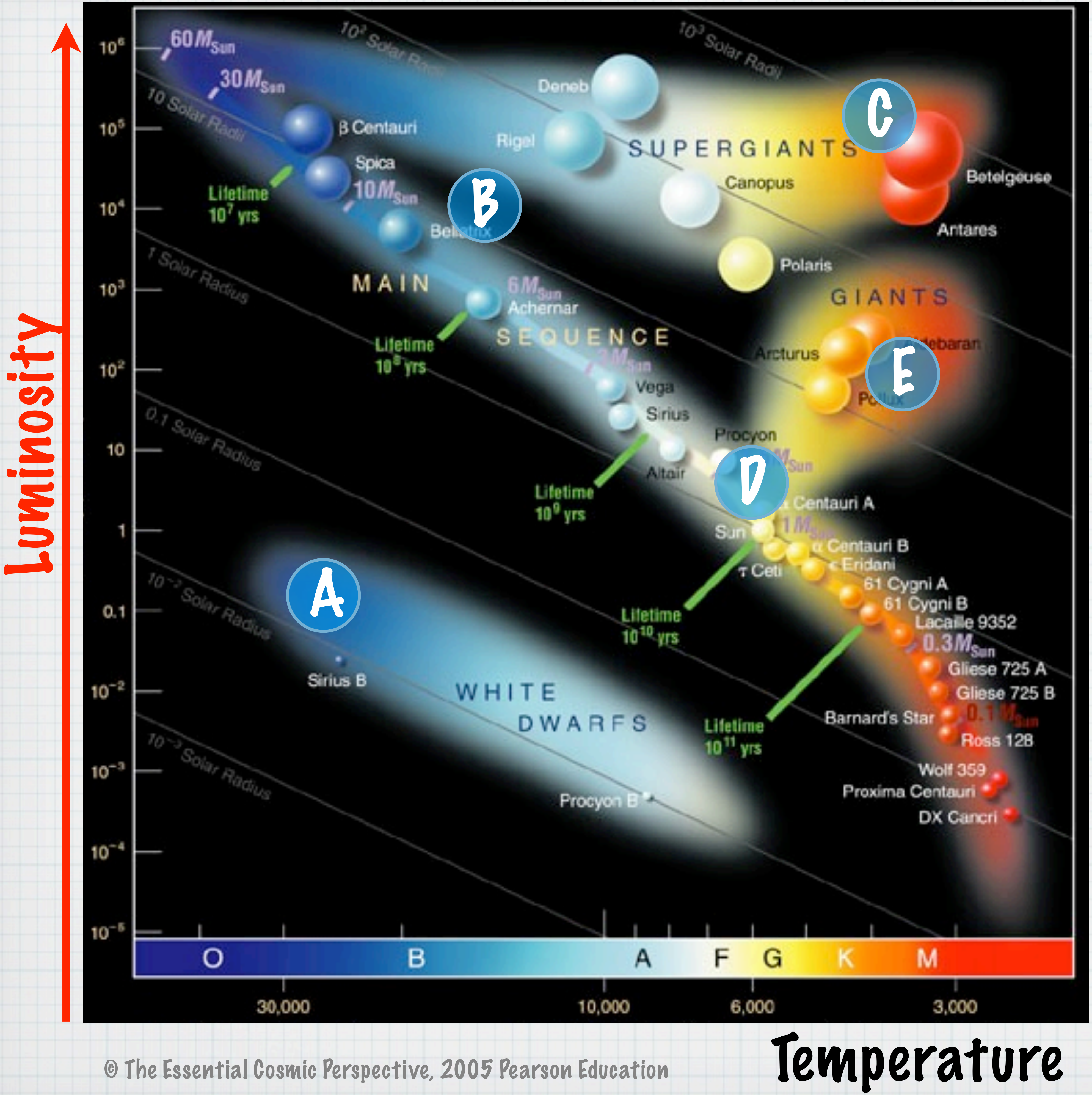
A

Luminosity



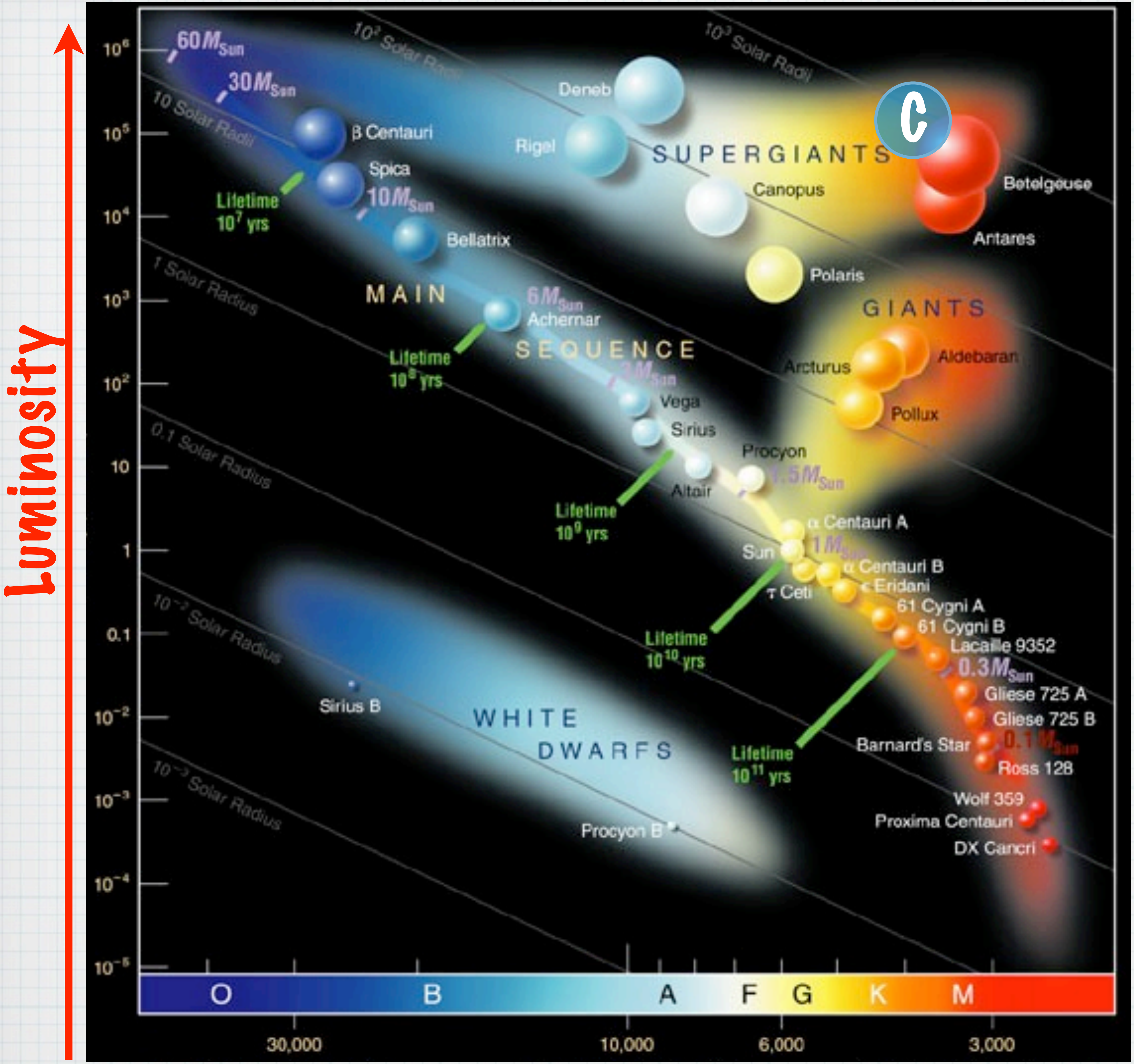
Temperature

Which star is the most luminous?



Which star is the most luminous?

C



Temperature

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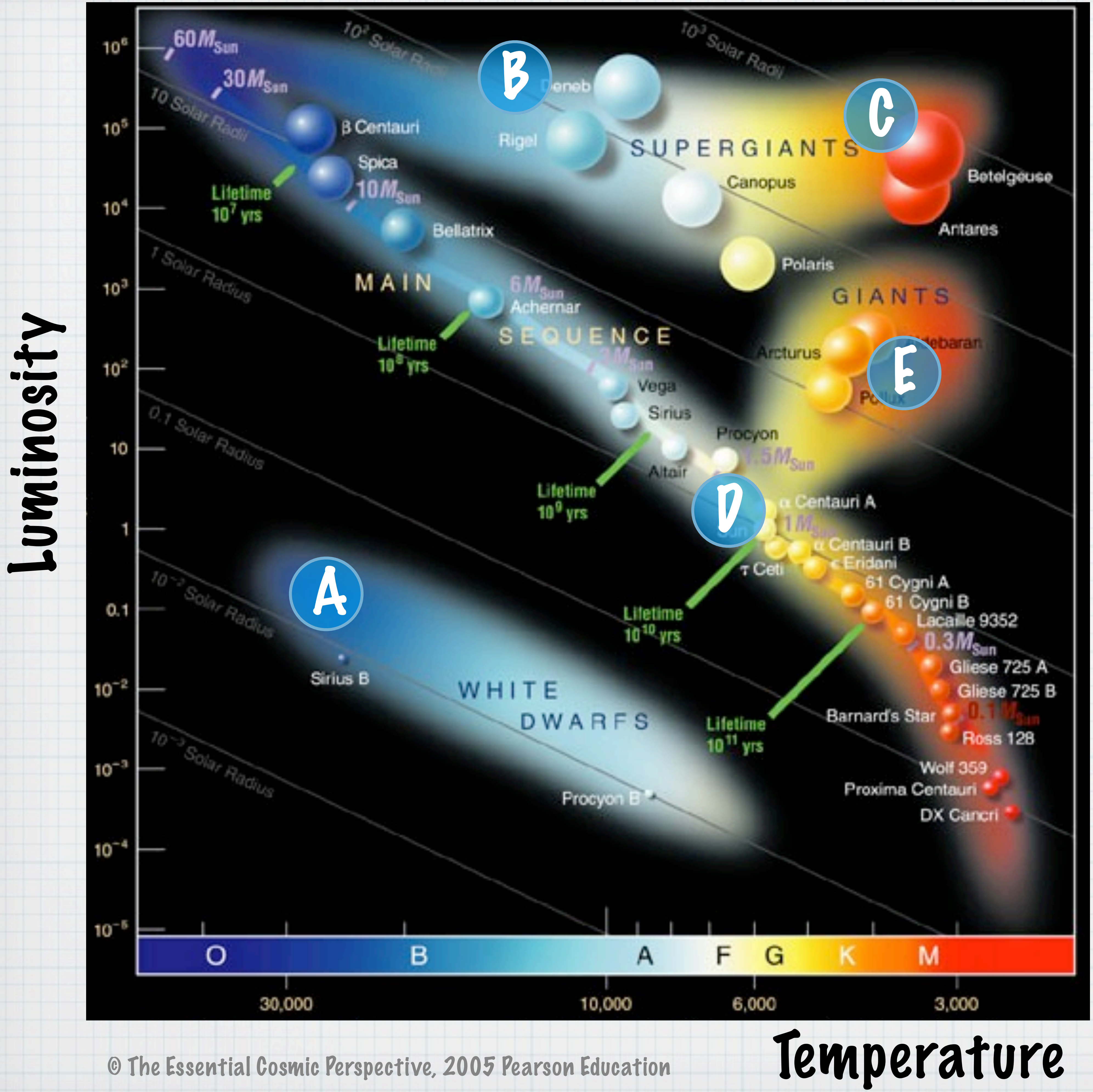
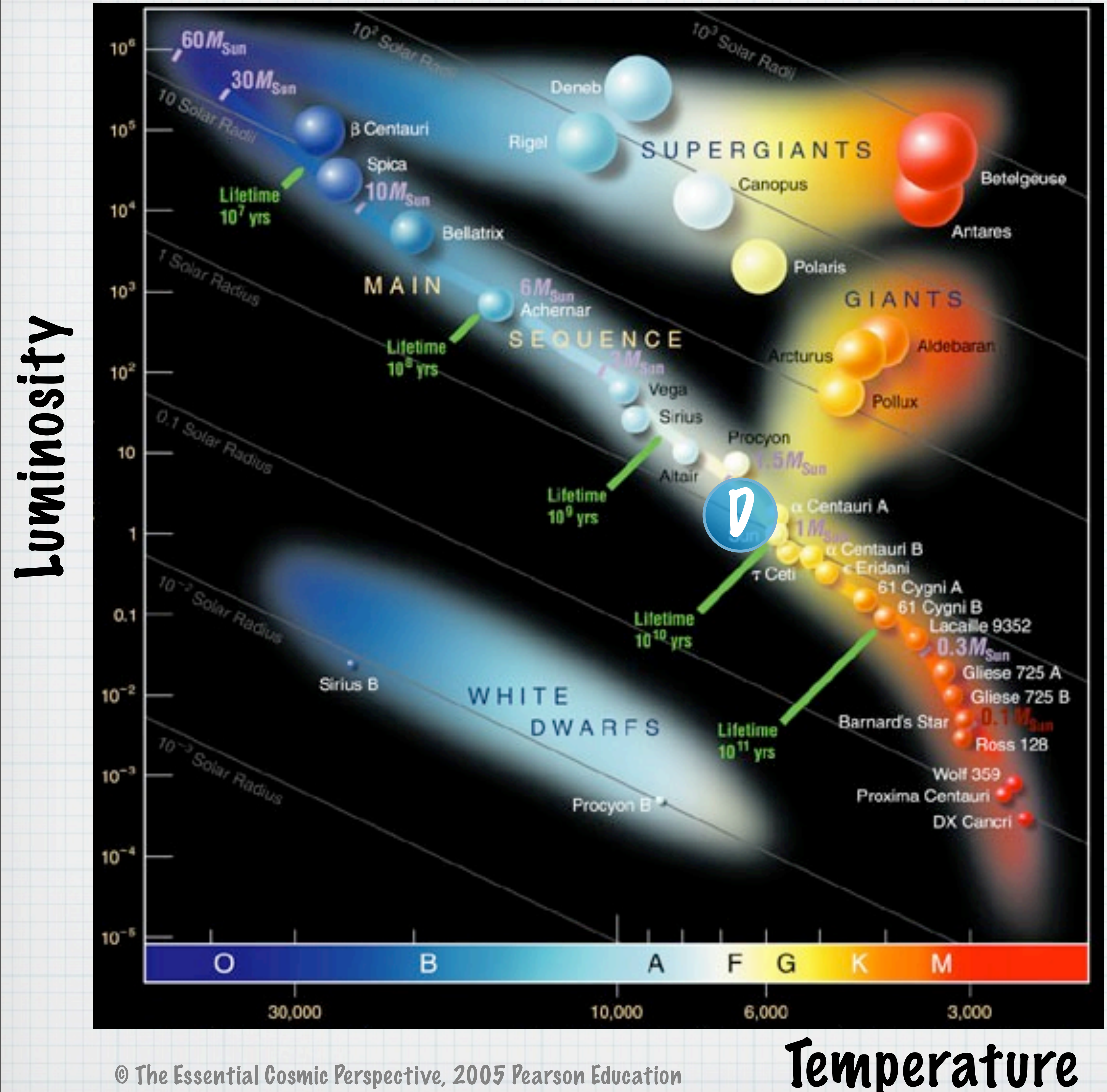
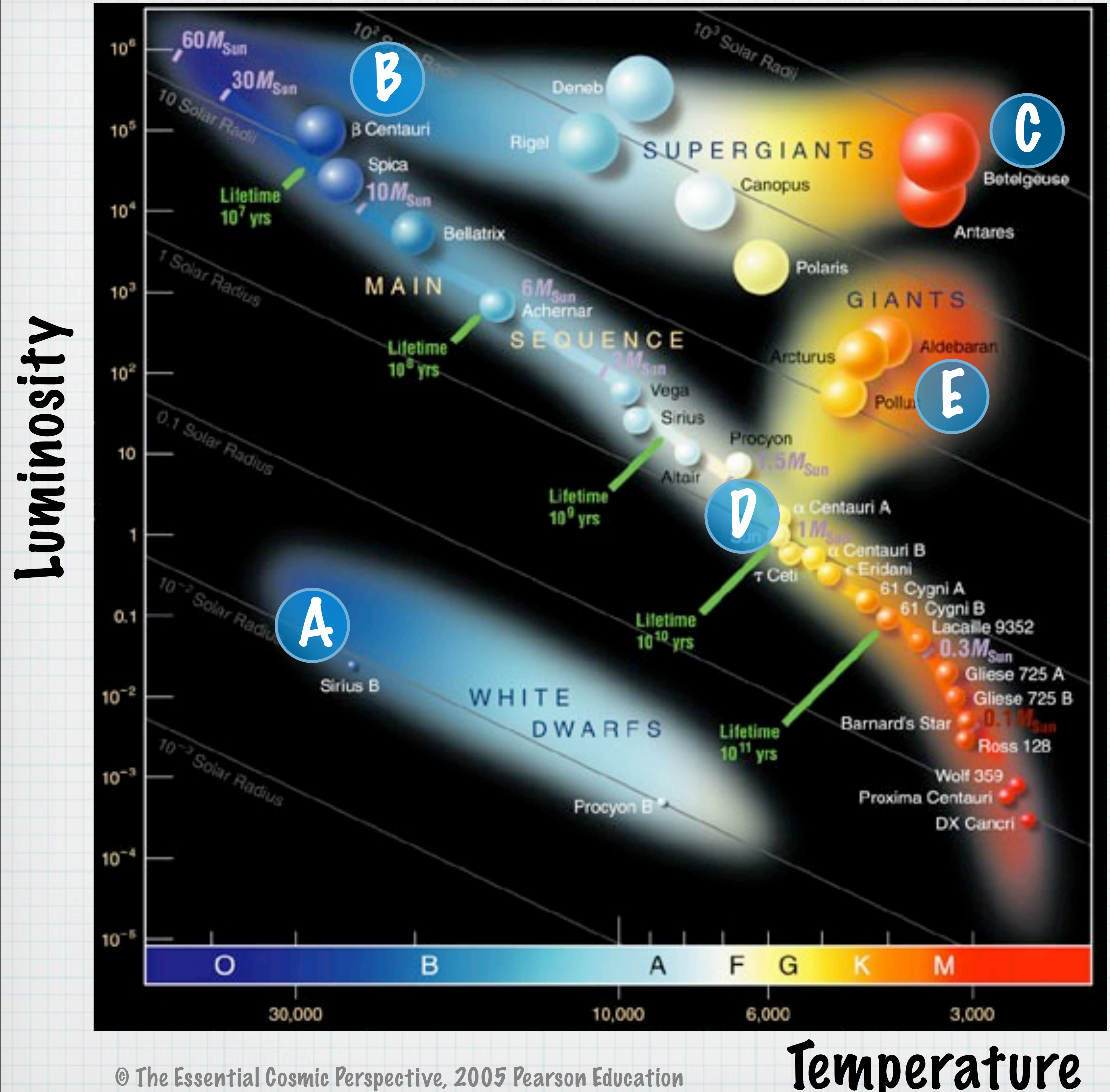


Which star is a main-sequence star?



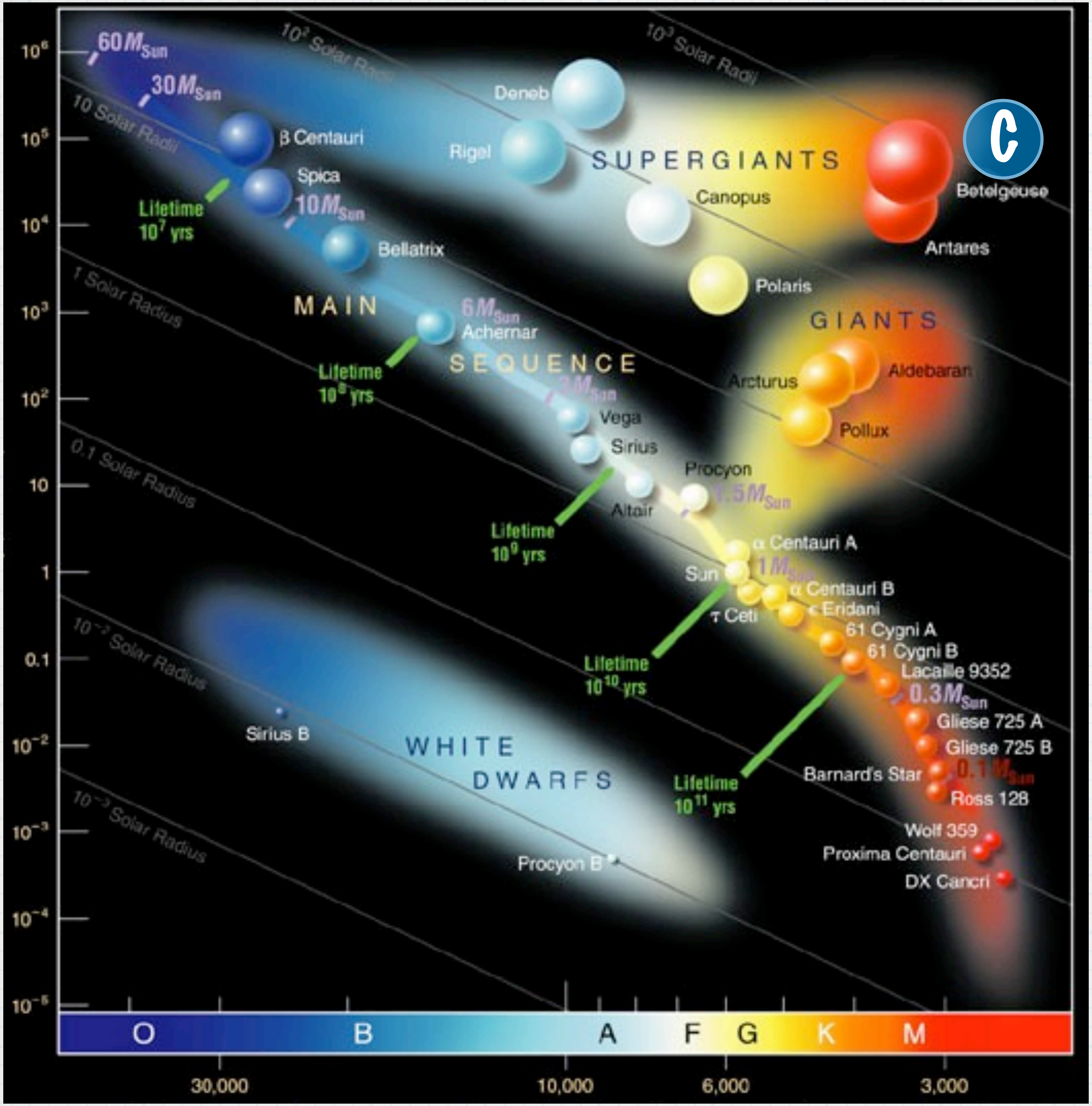
Which star is a main-sequence star?

D



Which star has the largest radius?

Which star has the largest radius?

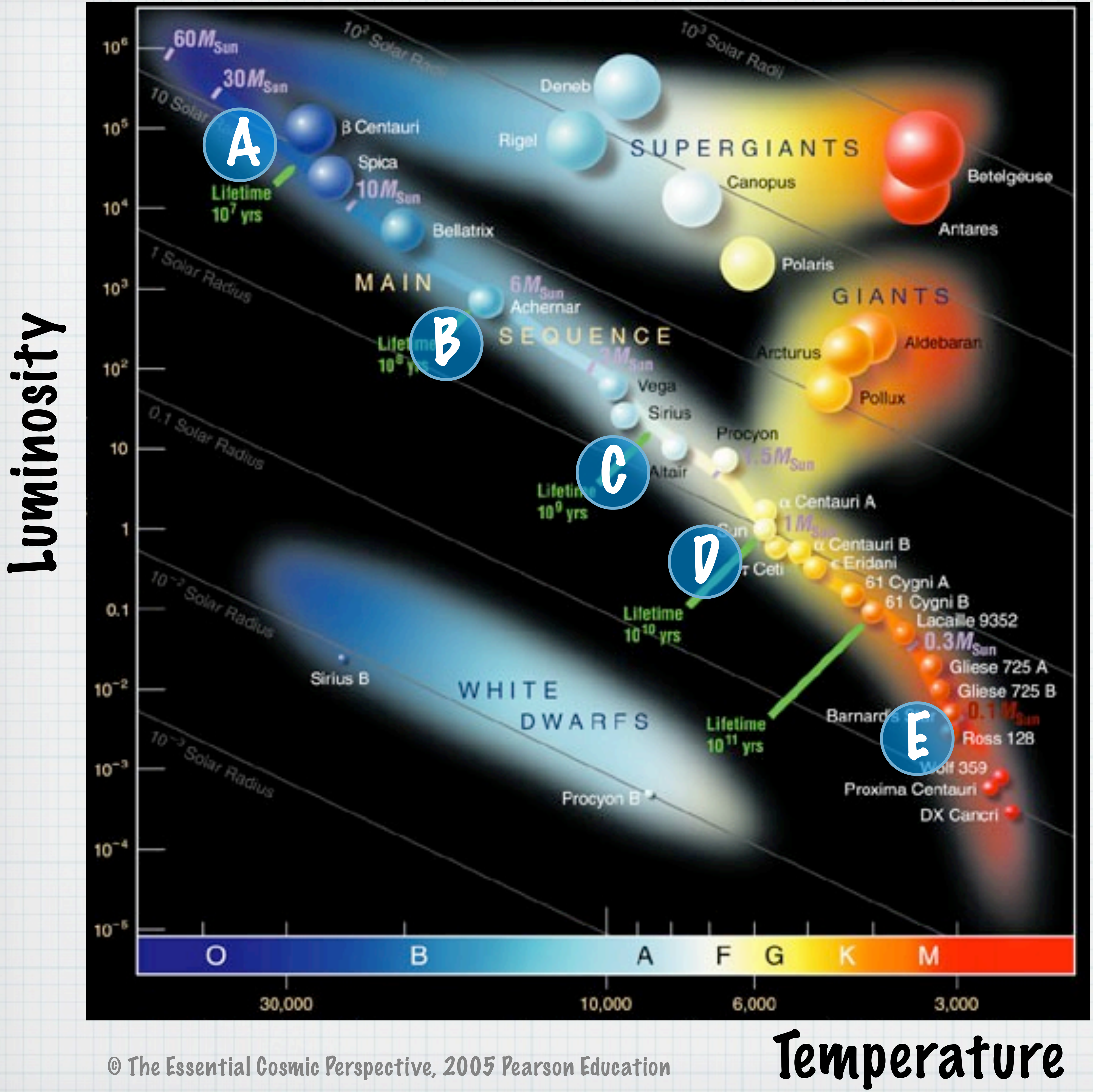


Luminosity

Temperature

C

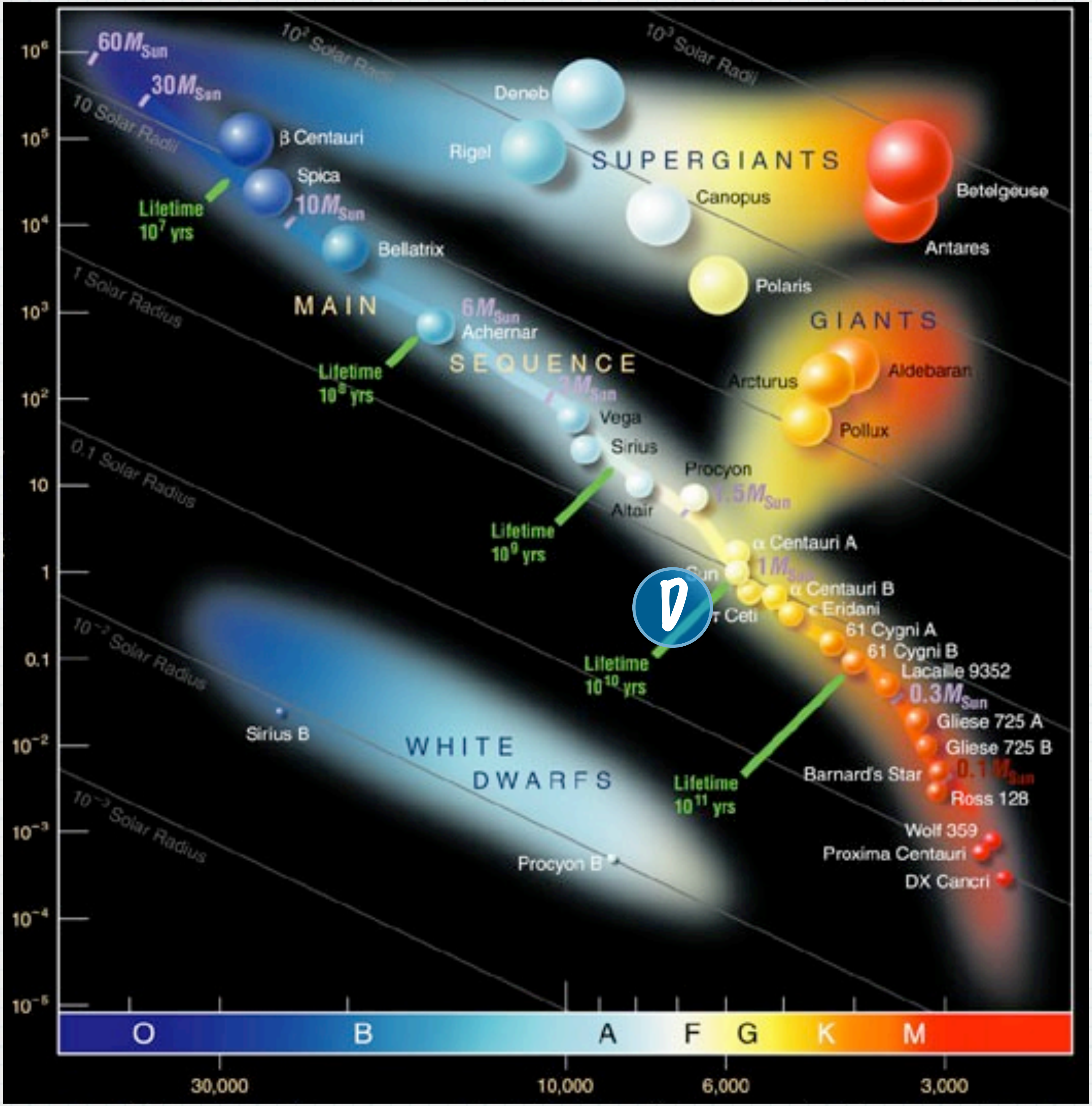
Which star is most like our Sun?



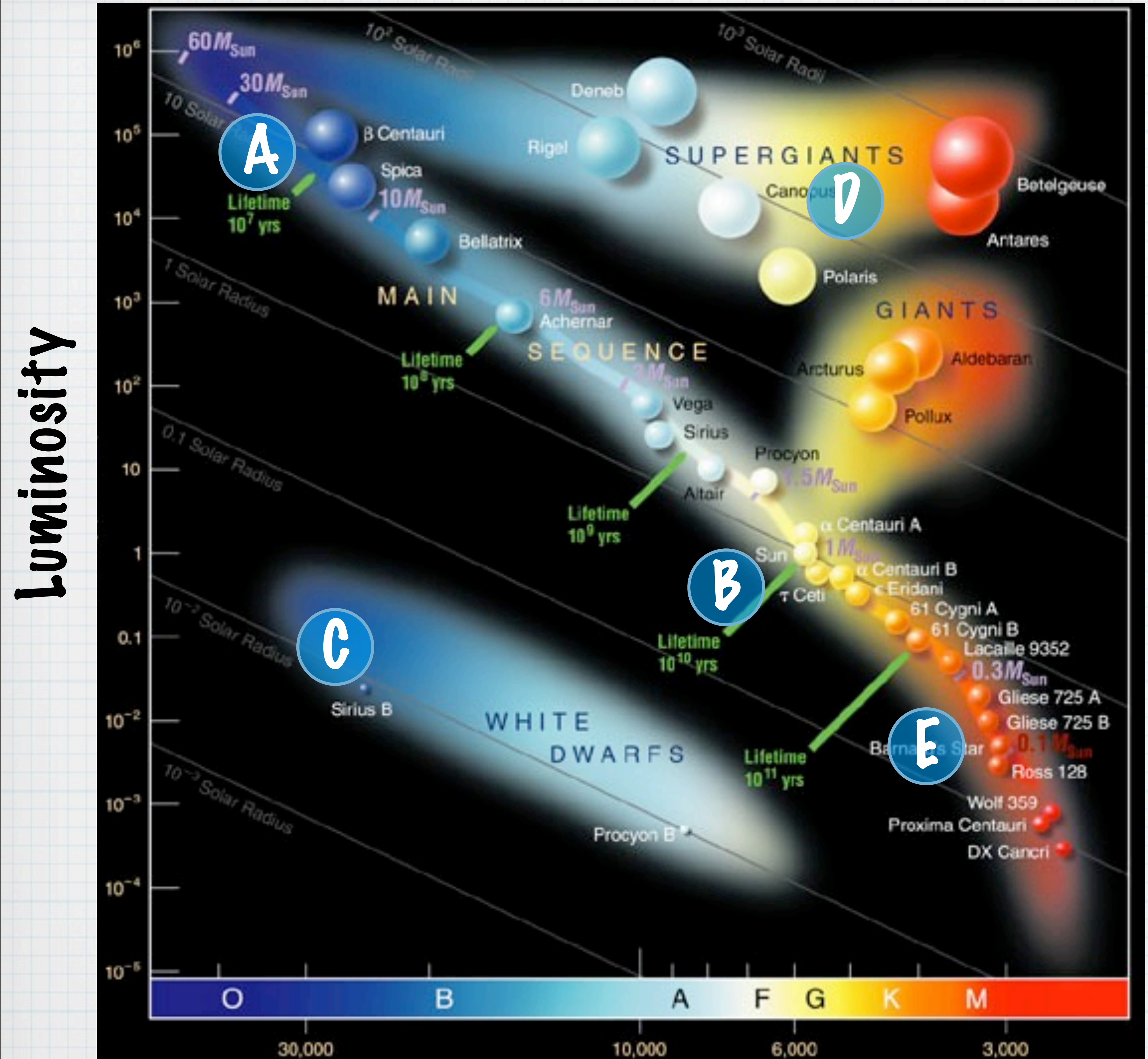
Which star is most like our Sun?

D

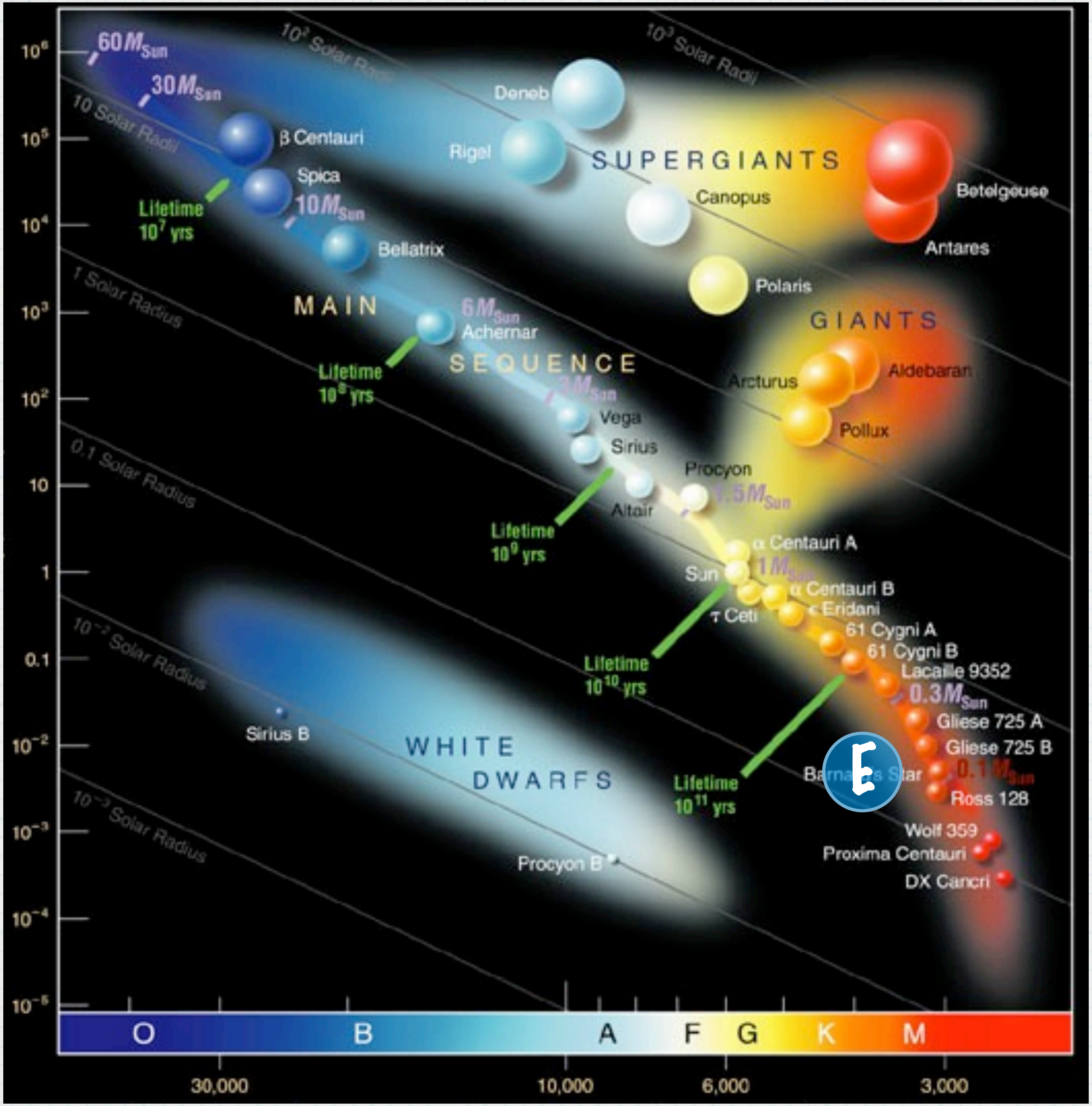
Luminosity



Temperature



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

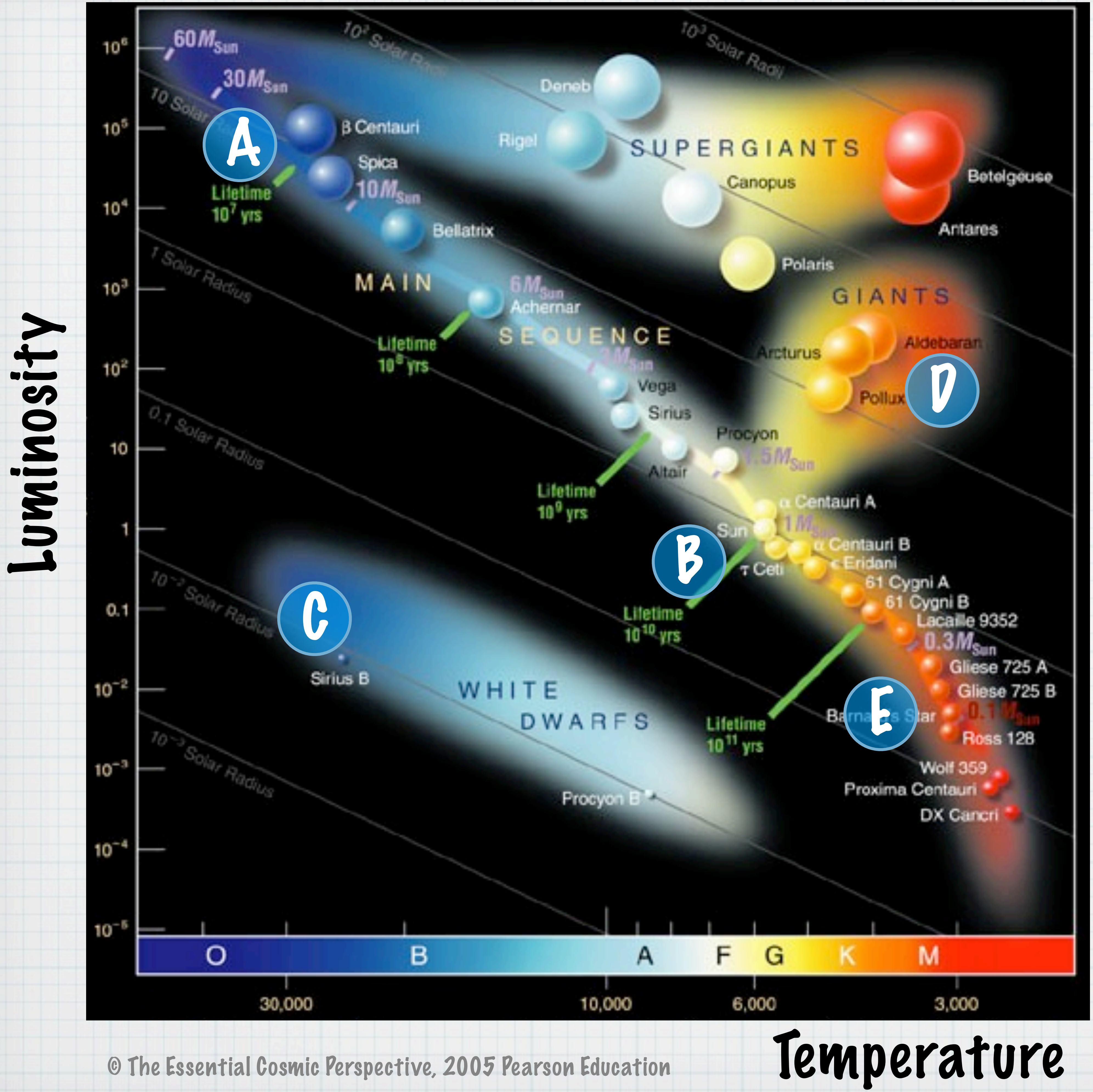


Luminosity

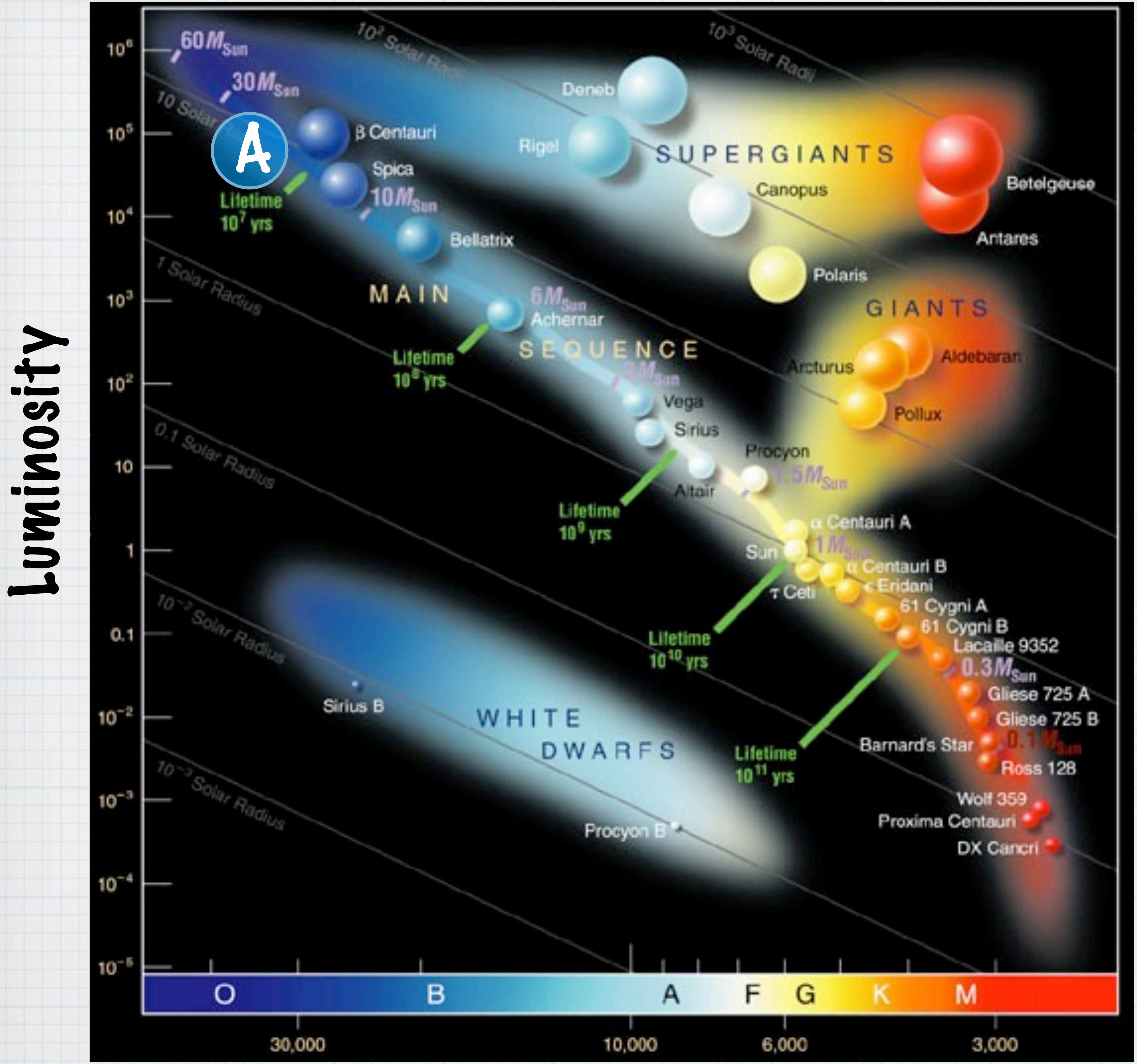
Temperature

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

E



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

Snapshot

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

A star's mass (and composition) at birth determines virtually everything that happens to it throughout its life

Snapshot

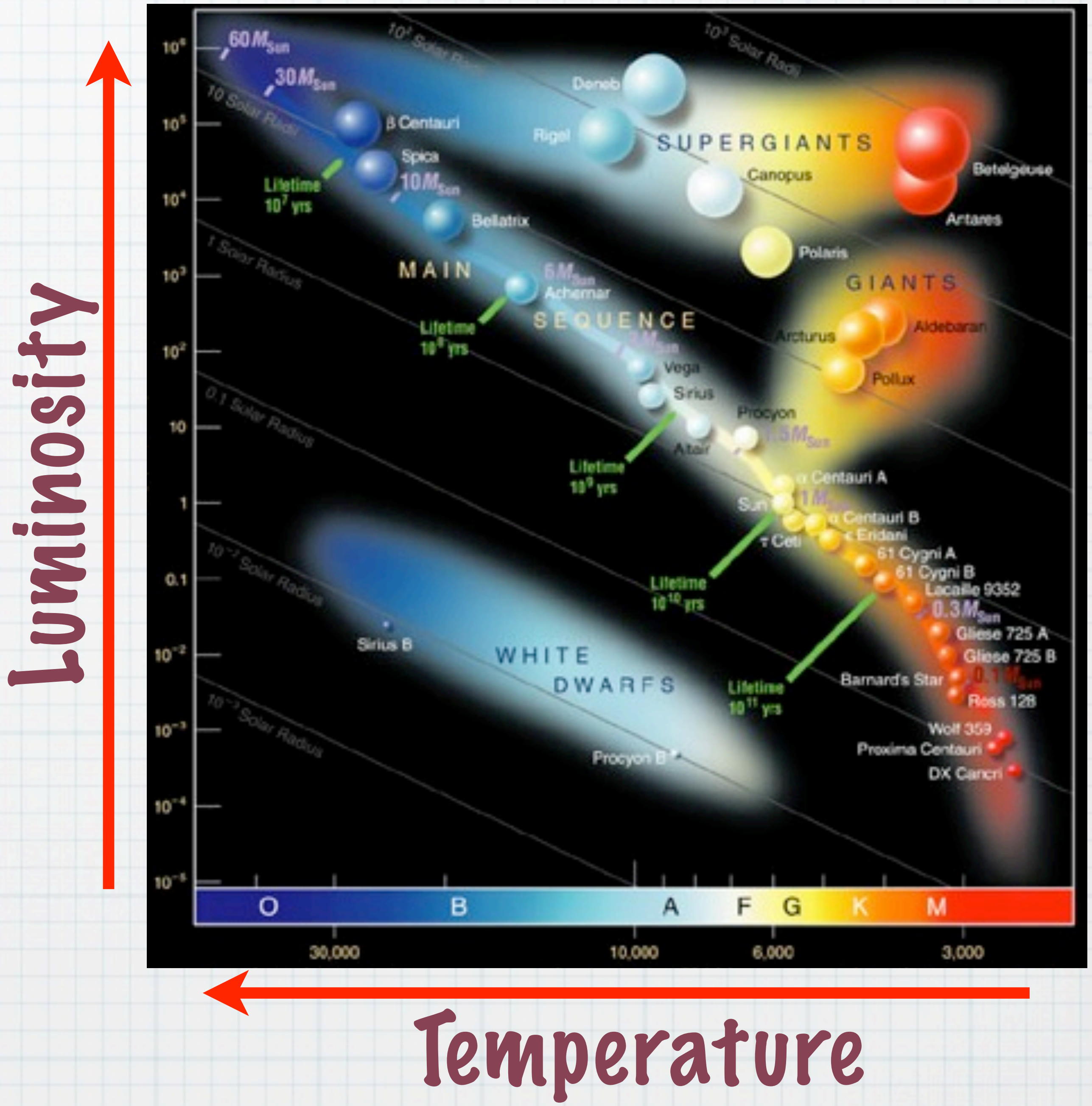
* How do we classify stars?
* We classify stars according to their spectral type and luminosity class

1. The spectral type tells us the star's surface temperature

2. The luminosity class tells us how much light it puts out

Snapshot...

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



Star Clusters

* Most stars are born in groups because the giant gas clouds that form stars make many stars at once
* A single interstellar gas cloud contains enough material to form thousands of stars
* These groups of stars are called star clusters

Star Clusters...

* Star clusters are very important:
  1. All stars in a cluster lie at the same distance from us
  2. All stars in a cluster formed at about the same time ± a few million years
* There are two types of star clusters

Star Clusters...

1. The open clusters

* contain up to several thousands stars
* up to 30 light-years across
* found in the **disk** of the galaxy
* are mostly young (a few hundred million years at most)

Star Clusters...

2. The globular clusters

* contain up to ten million stars
* from 60 to 150 light-years across
* mostly found above and below the **disk** of the galaxy in the region we call the **halo**
* are old: they were formed at the same time their mother galaxy was formed, so around 10 billion years old

Open clusters: A few thousand loosely packed stars

The Pleiades
M44

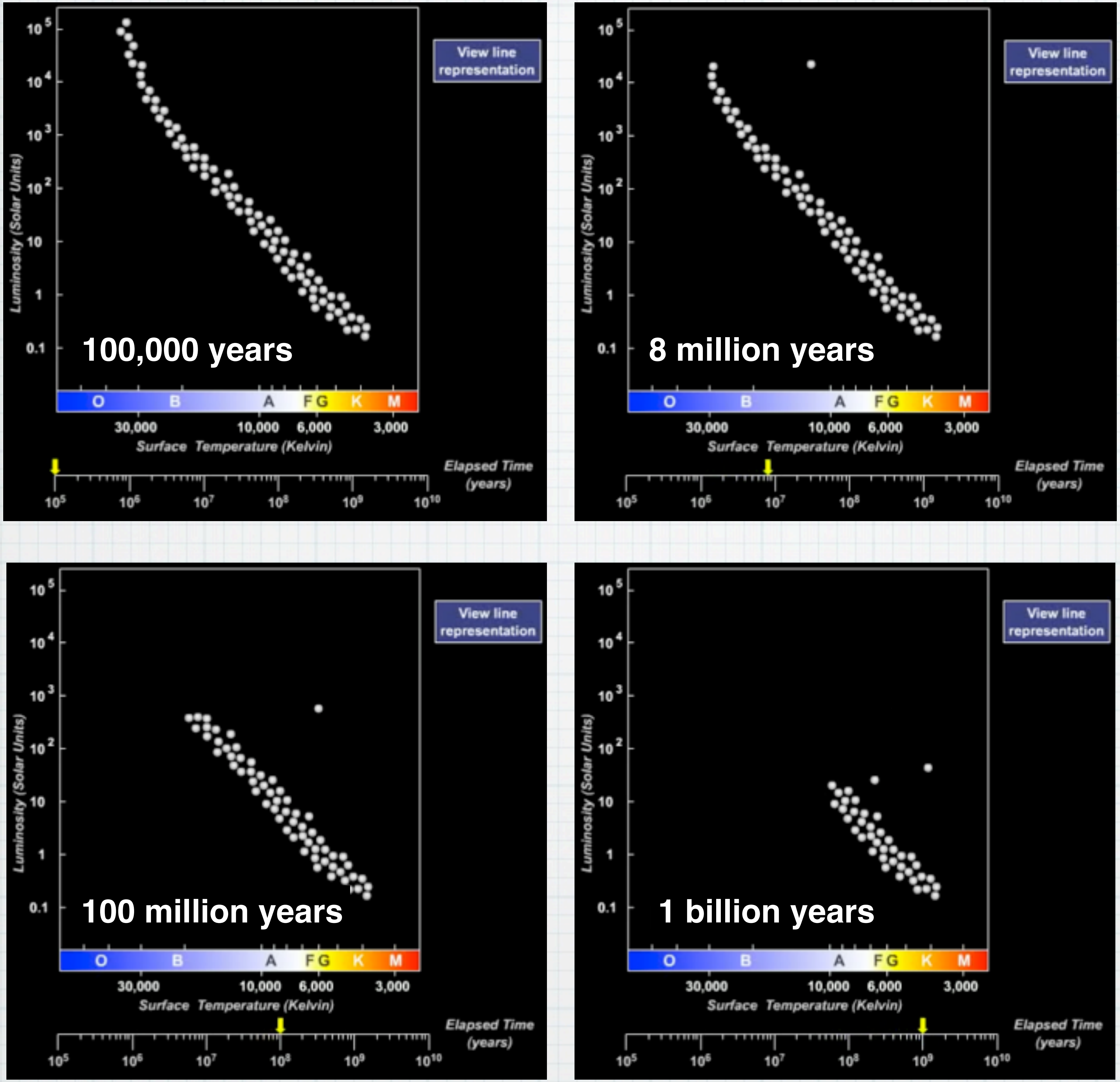
Globular clusters: Hundreds of thousands or more stars in a dense ball bound together by gravity

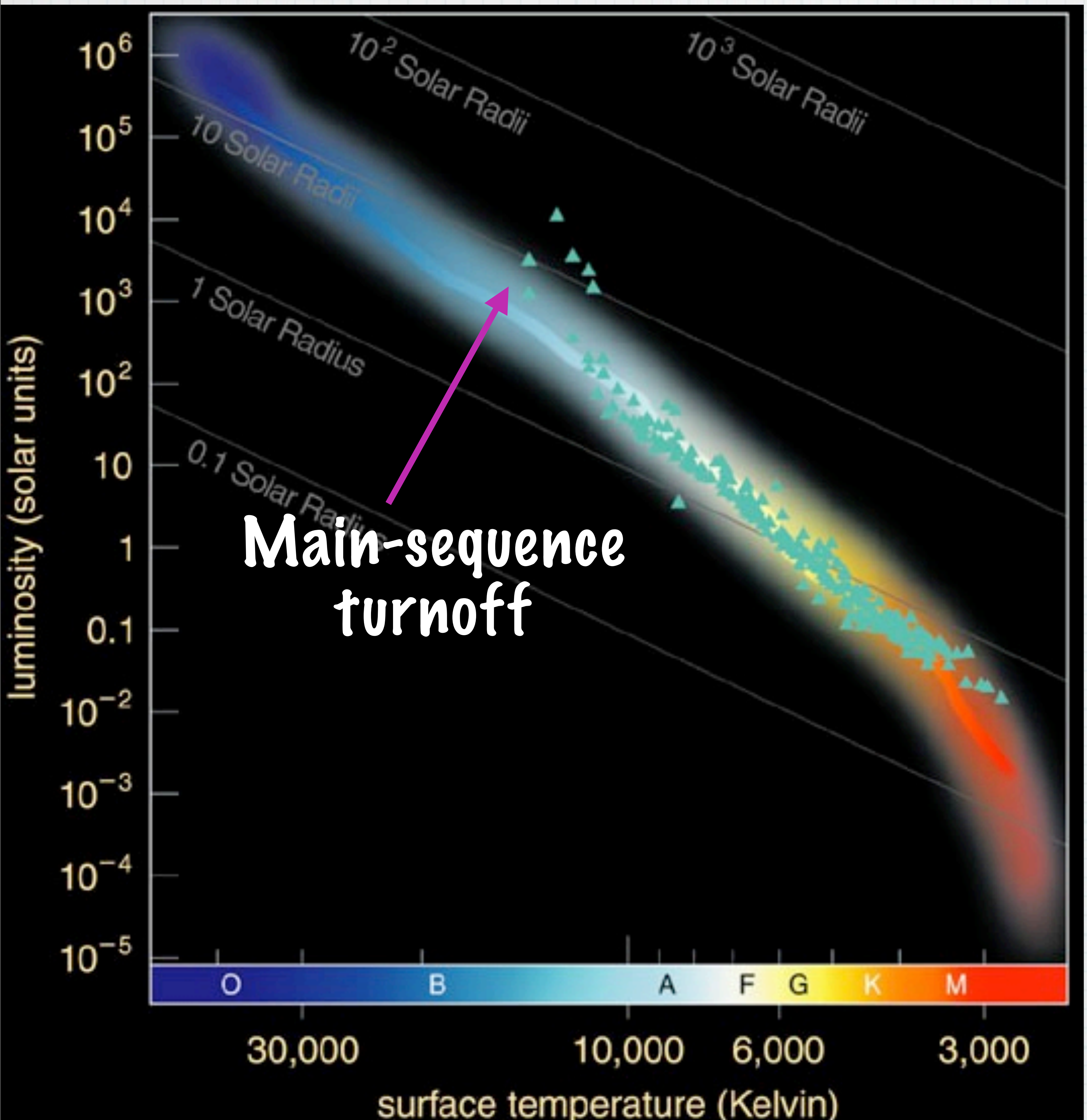
M 13 - Hercules Cluster - about 1 million stars - 150 ly ∅

How do we measure the age of a star cluster?

* Massive blue stars die first, followed by white, yellow, orange, and red stars
* By plotting the cluster's stars in an H-R diagram, we look for stars that are moving out of the main-sequence branch
* The precise point where stars diverge from the main-sequence is called the **main-sequence turnoff point**

Using the H-R diagram to determine the age of a star cluster

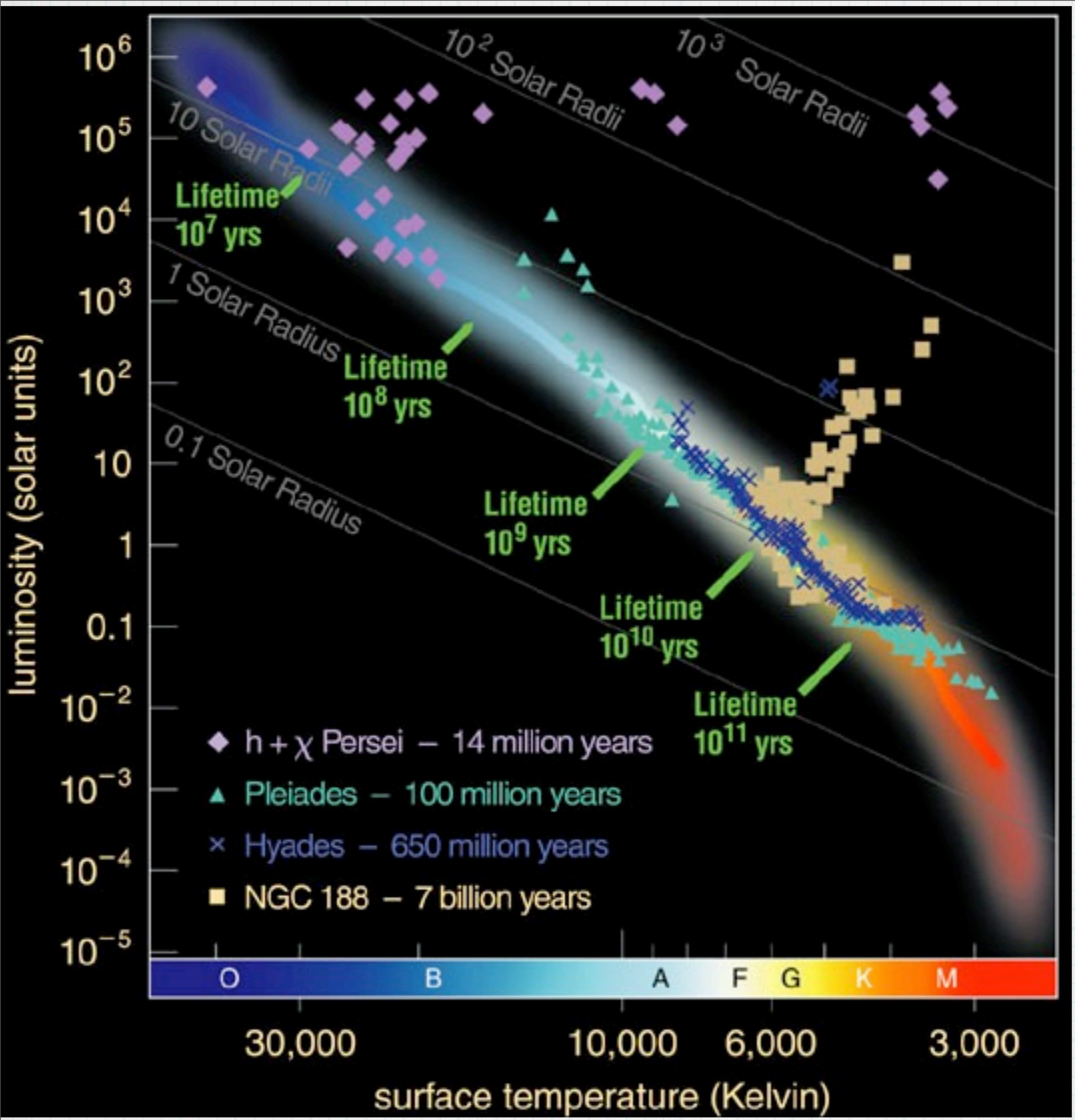




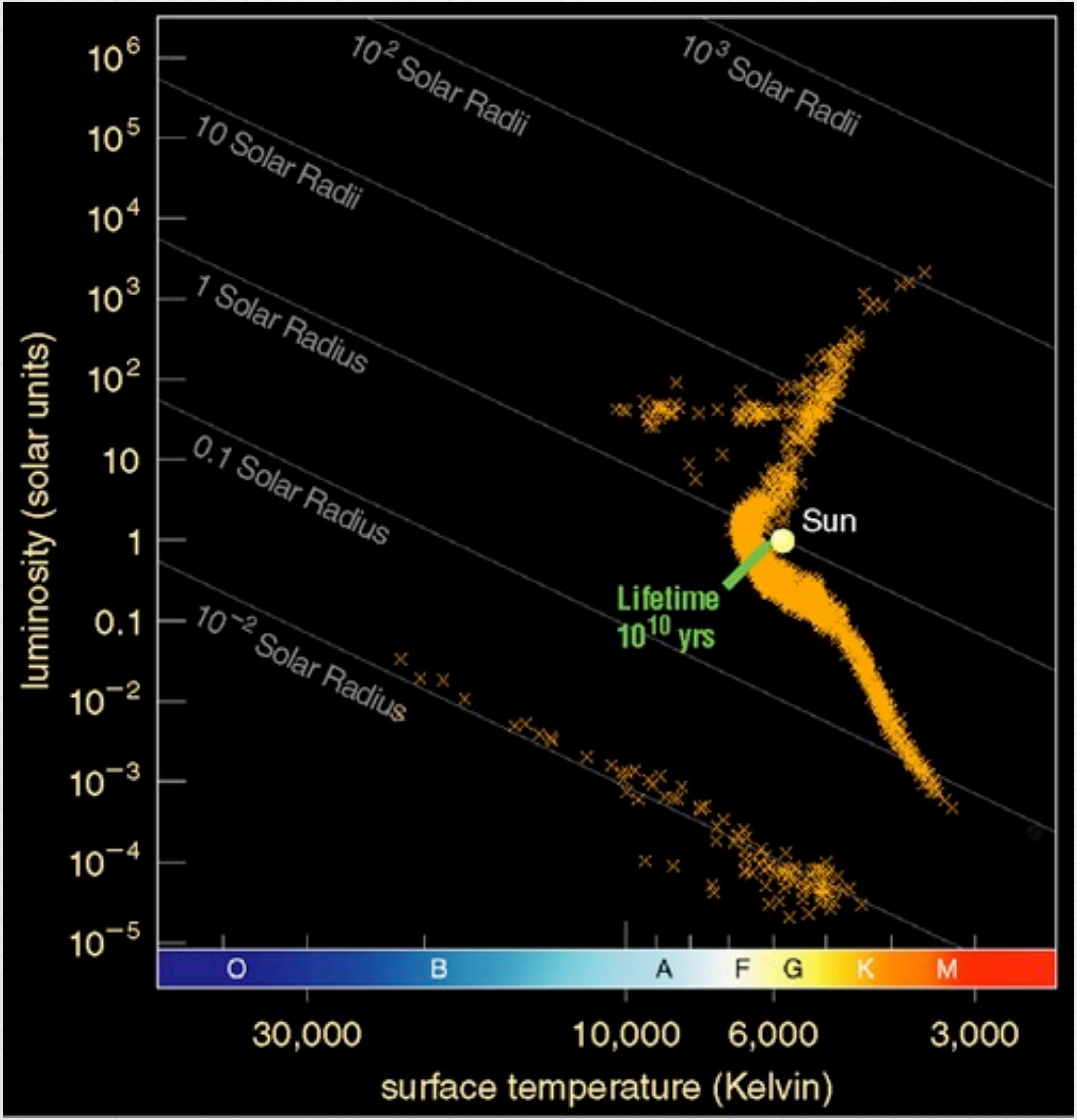
The Pleiades cluster is missing its upper main-sequence stars

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

Hence it is about 100 million years old



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



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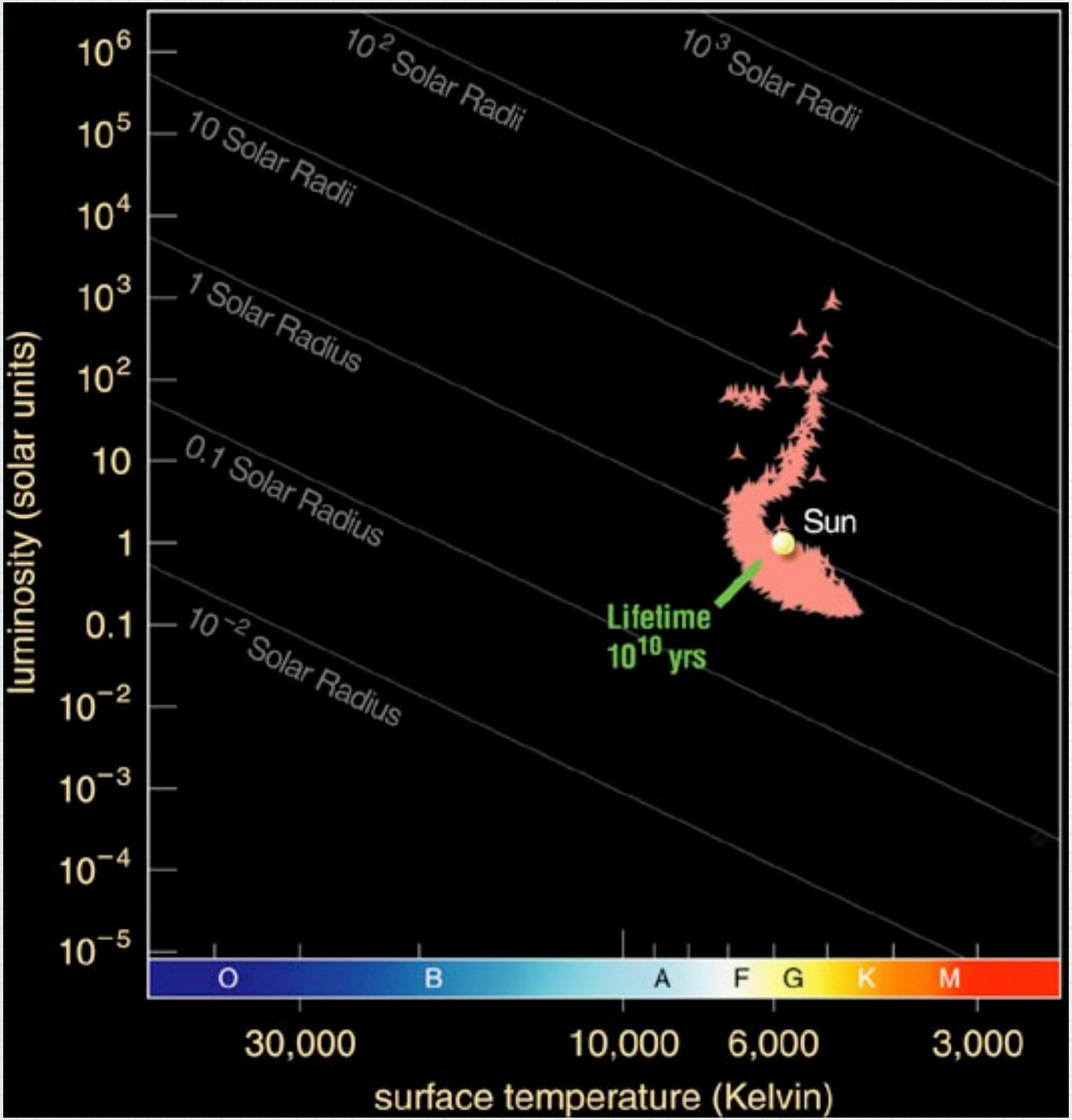
Stars from the globular cluster M4

Main-sequence turnoff point is near stars like our Sun

The cluster is around 10 billion years old



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

So the Universe must be at least that old

Good stuff

* http://www.youtube.com/watch?v=HEheh1BH34Q
* http://www.youtube.com/watch?v=Kqe6F-Qf9Tk
* http://www.youtube.com/watch?v=g4iD-9GSW-0
* http://demonstrations.wolfram.com/RadiusAndTemperatureOfMainSequenceStars/
* http://www.uni.edu/morgans/ajjar/Astrophysics/blackbody3.html