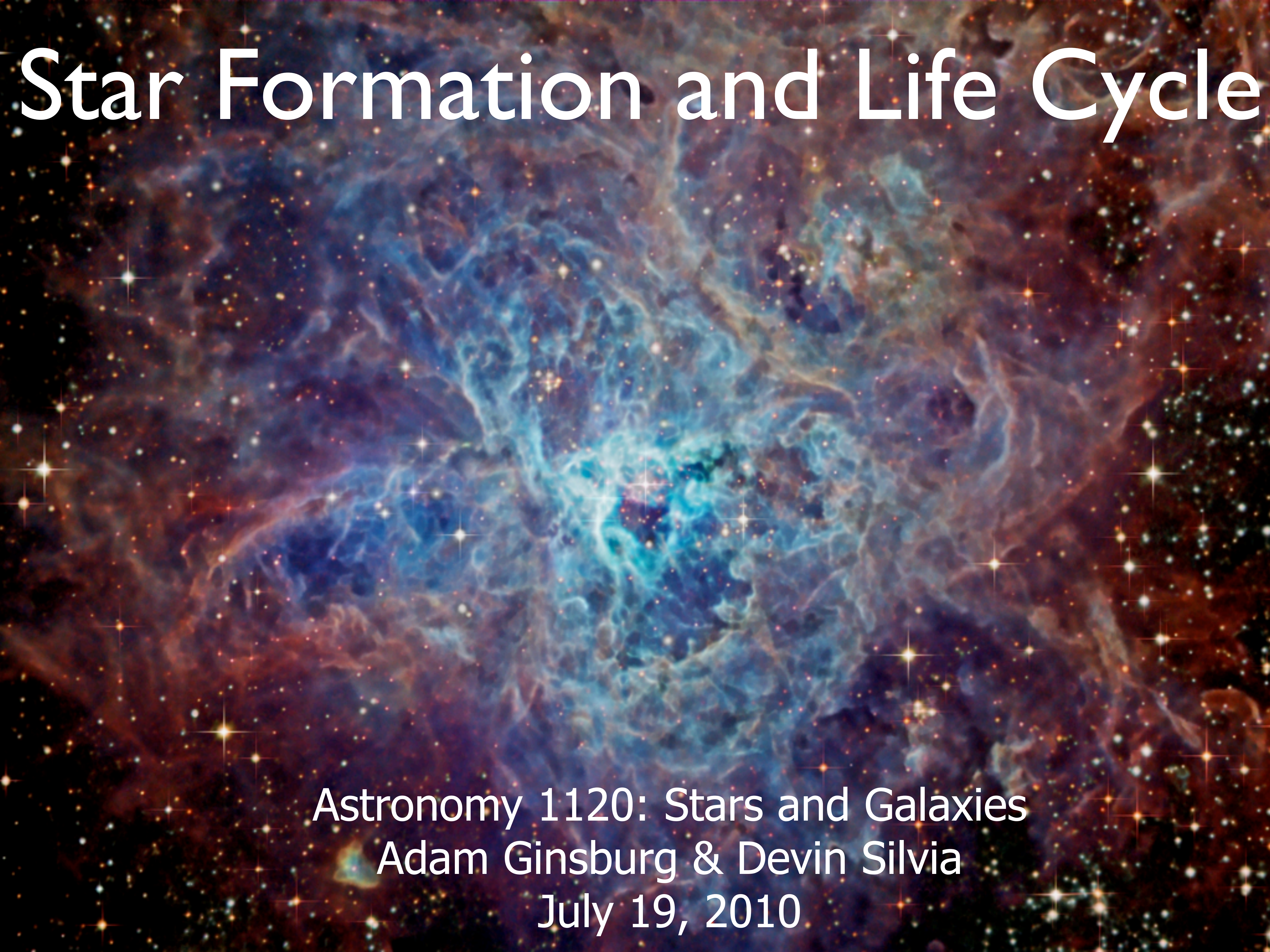
Star Formation and Life Cycle



Astronomy 1120: Stars and Galaxies

Adam Ginsburg & Devin Silvia

July 19, 2010

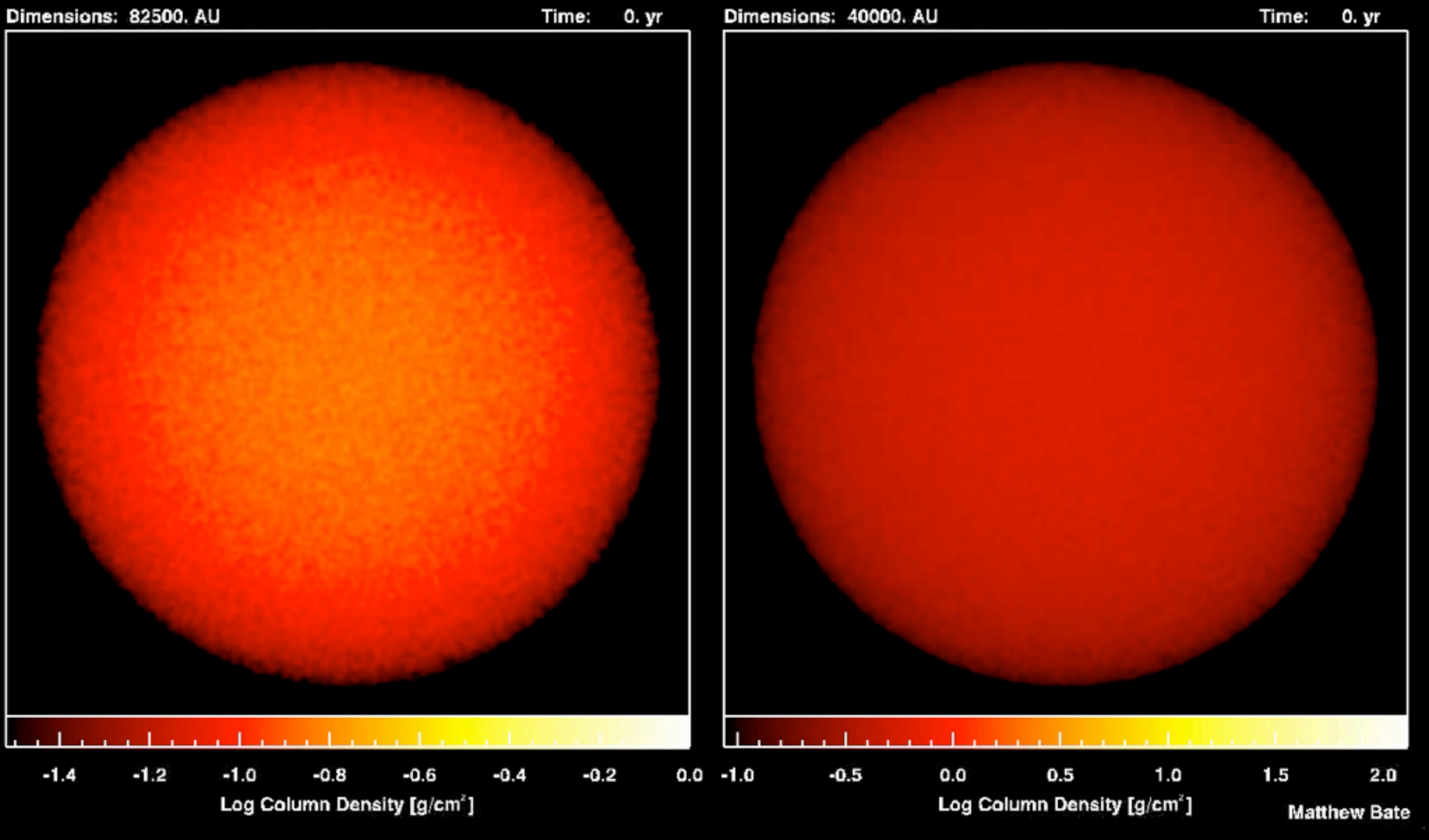
Learning Goals

- How do stars form?
  - Terms: accretion, protostar
- What happens to stars as they age?
  - Terms: Red Giant, Cepheid Variable, Hertzsprung-Russell Diagram, Main Sequence

Birth

Start from dense clouds of gas and dust seen in silhouette against background stars

Collapse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Log Column Density [g/cm²]
Dimensions: 40000. AU
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Log Column Density [g/cm²]
Matthew Bate

Collapse

- What concept is illustrated in protostellar collapse that we discussed in week 1?

A) Conservation of Energy

B) Conservation of Angular Momentum

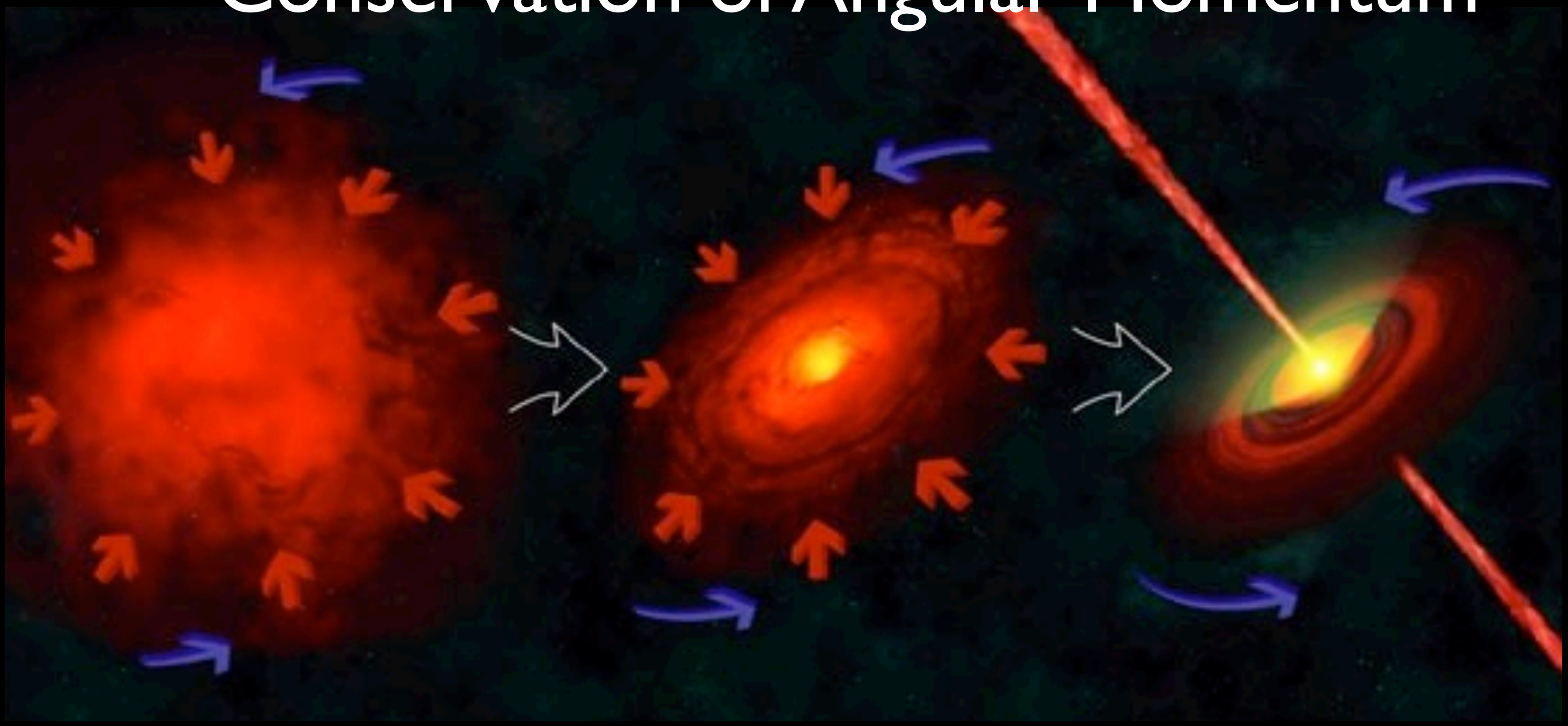
C) Conservation of Momentum

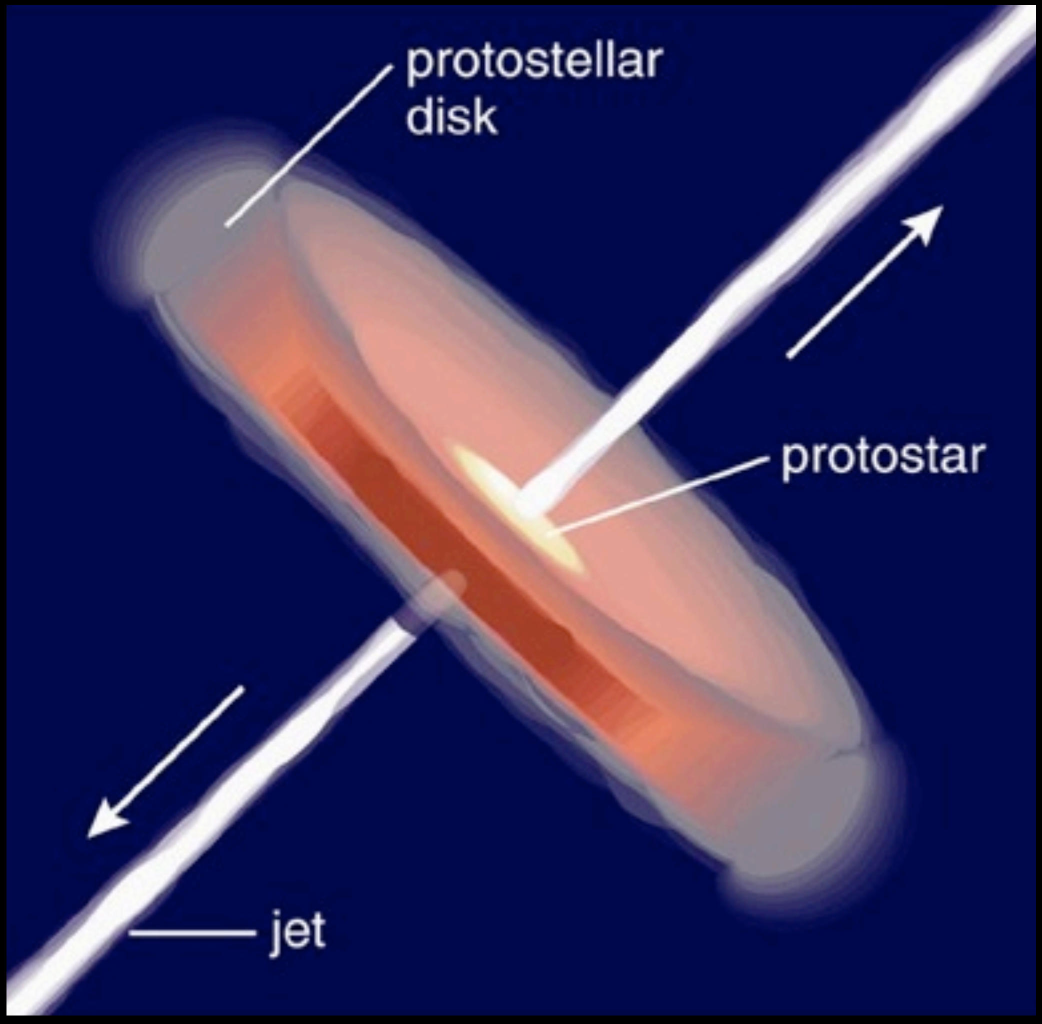
D) $I \propto T^4$

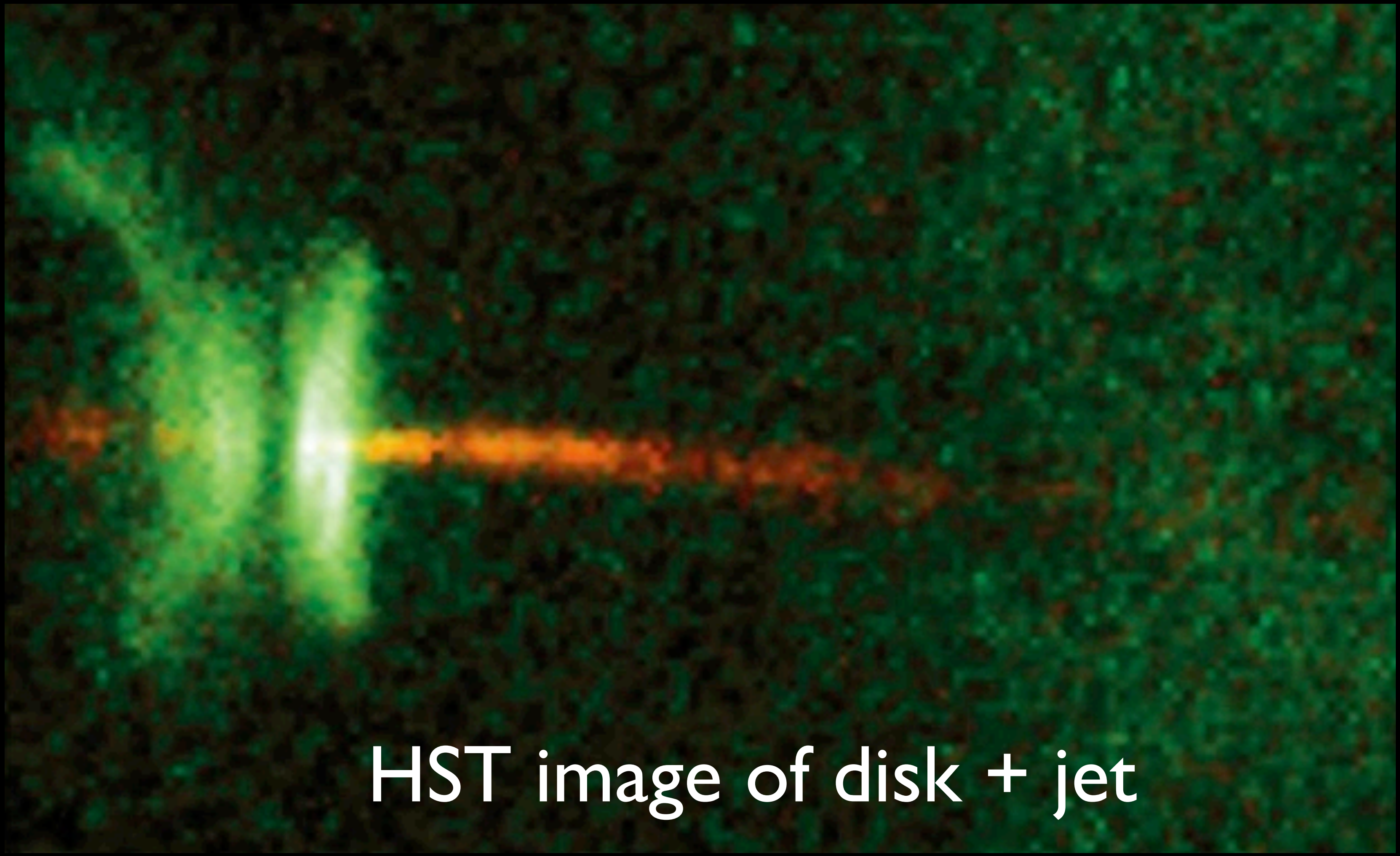
E) F=Ma

Collapse into Disks

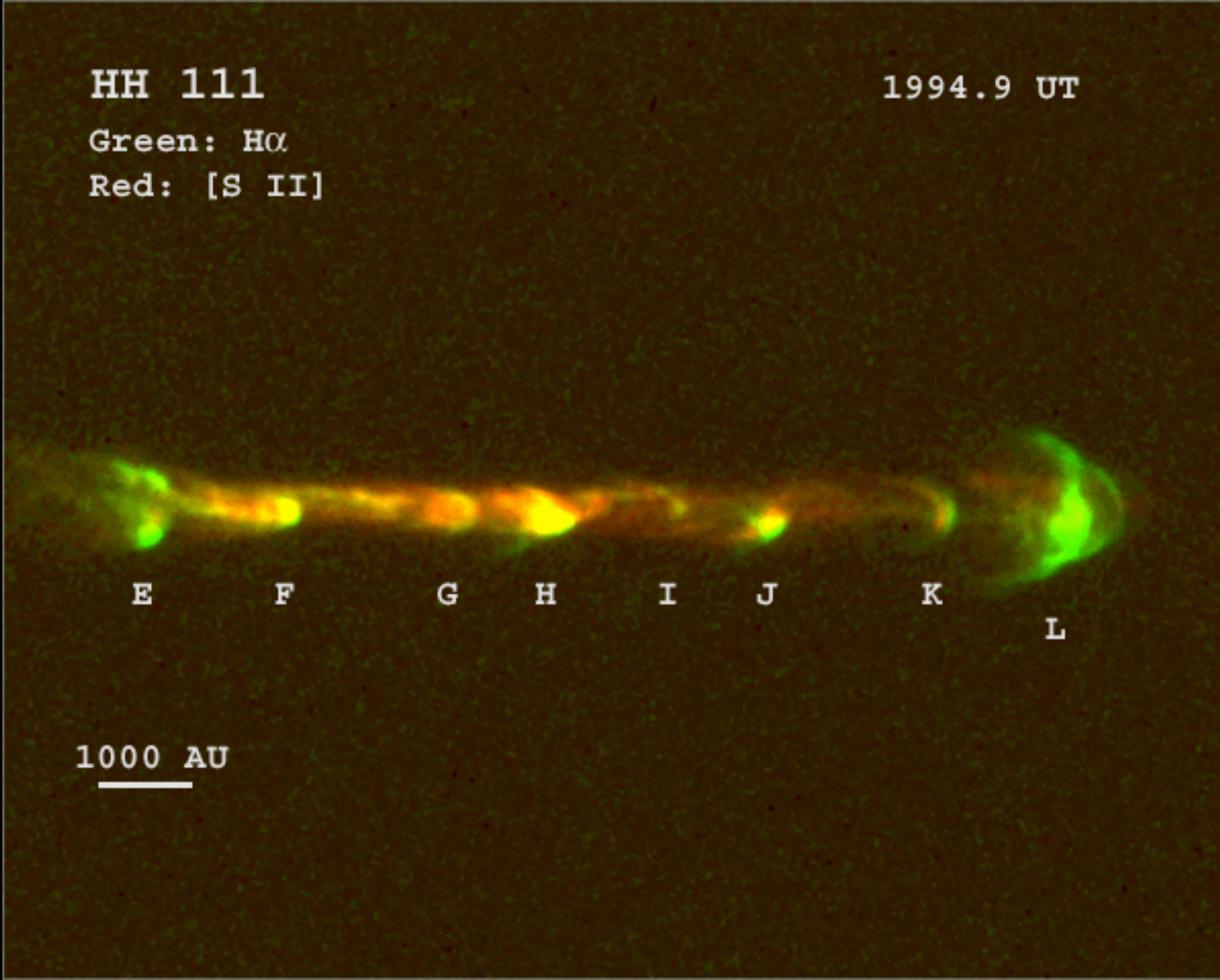
Conservation of Angular Momentum

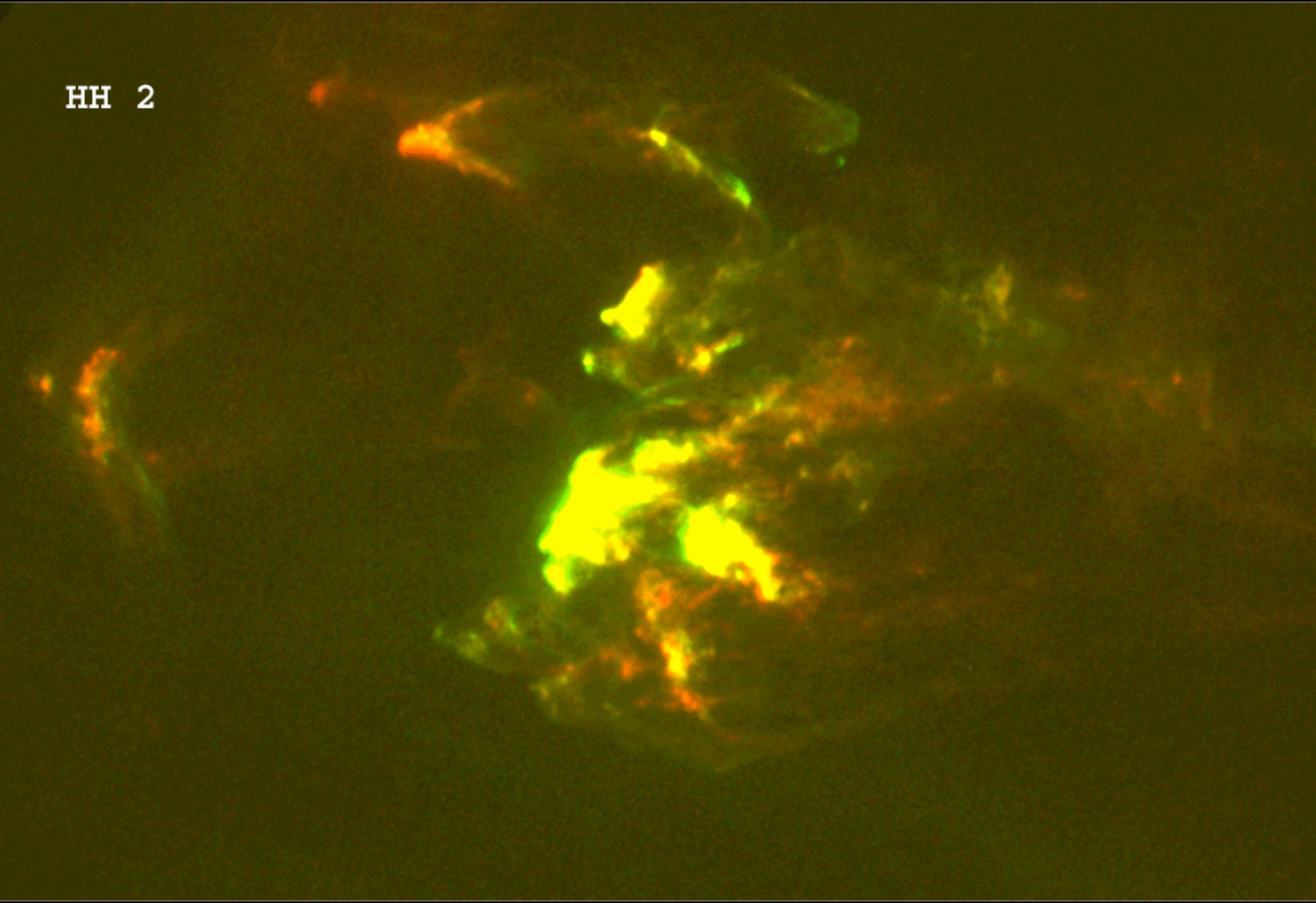


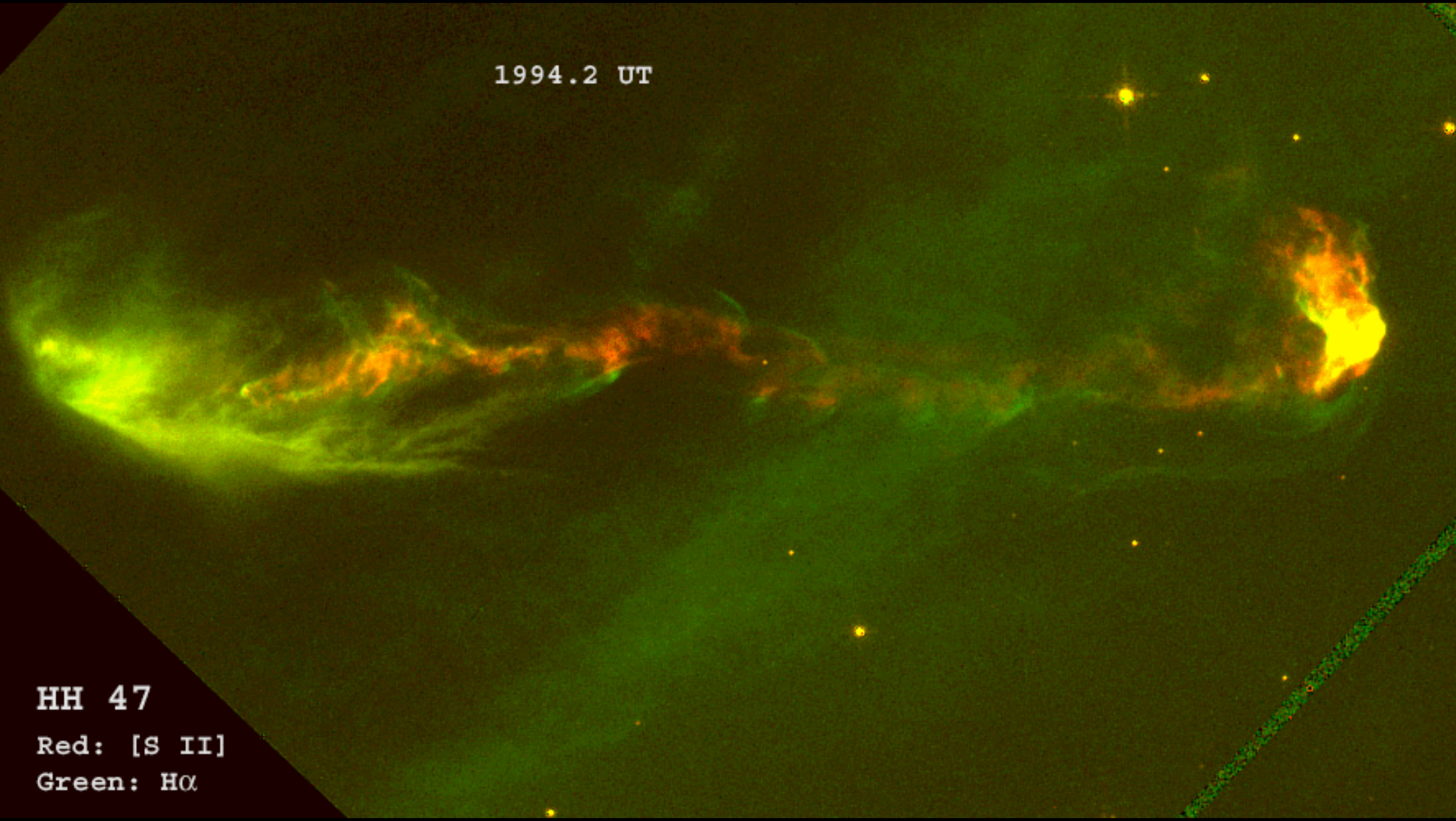




HST image of disk + jet

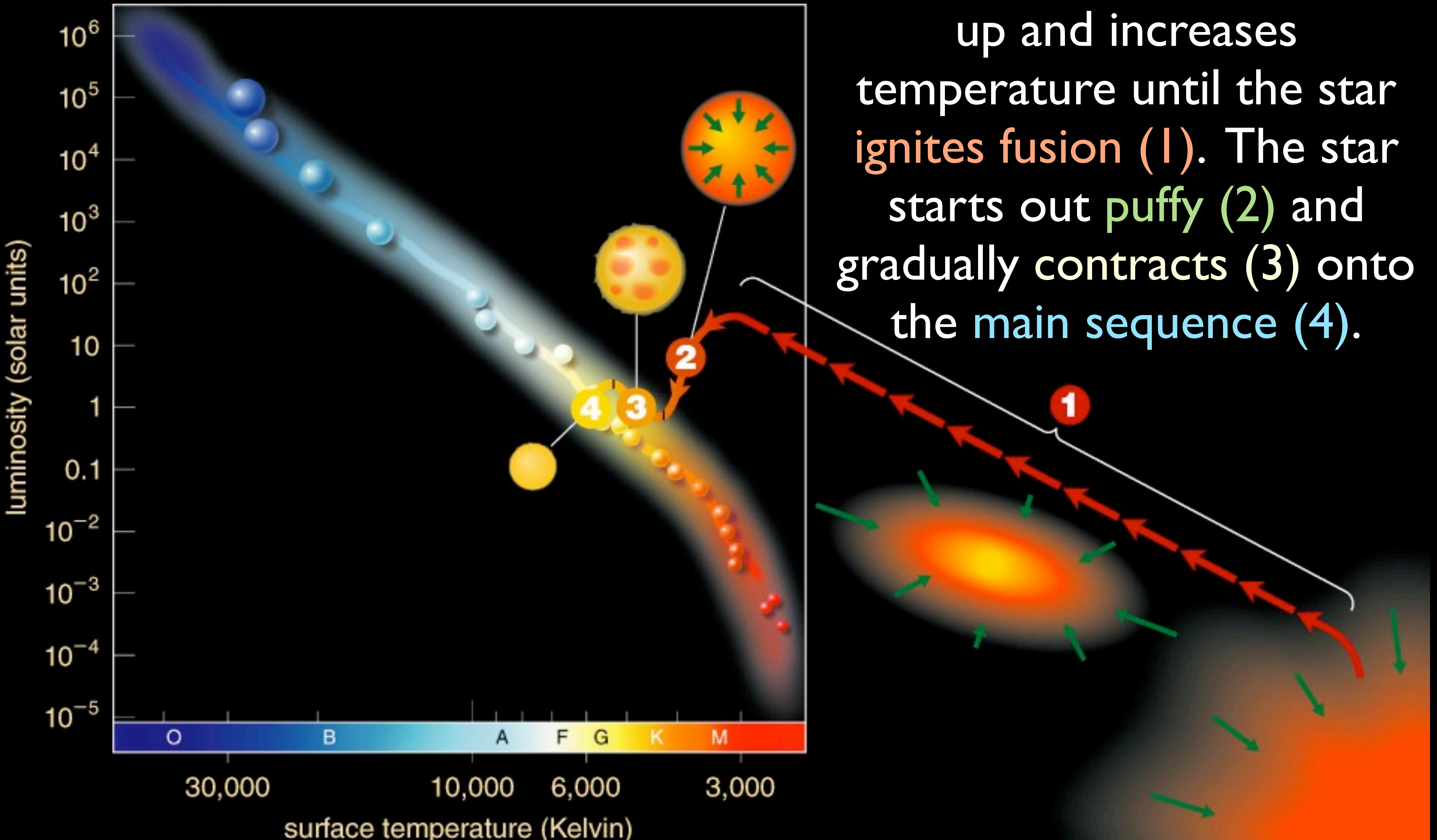

HH 111
1994.9 UT
Green: Hα
Red: [S II]
E
F
G
H
I
J
K
L
1000 AU


HH 2


1994.2 UT
HH 47
Red: [S II]
Green: Hα

Star Formation with Jets

From cloud to star...



Pressure of gravity builds up and increases temperature until the star ignites fusion (1). The star starts out puffy (2) and gradually contracts (3) onto the main sequence (4).

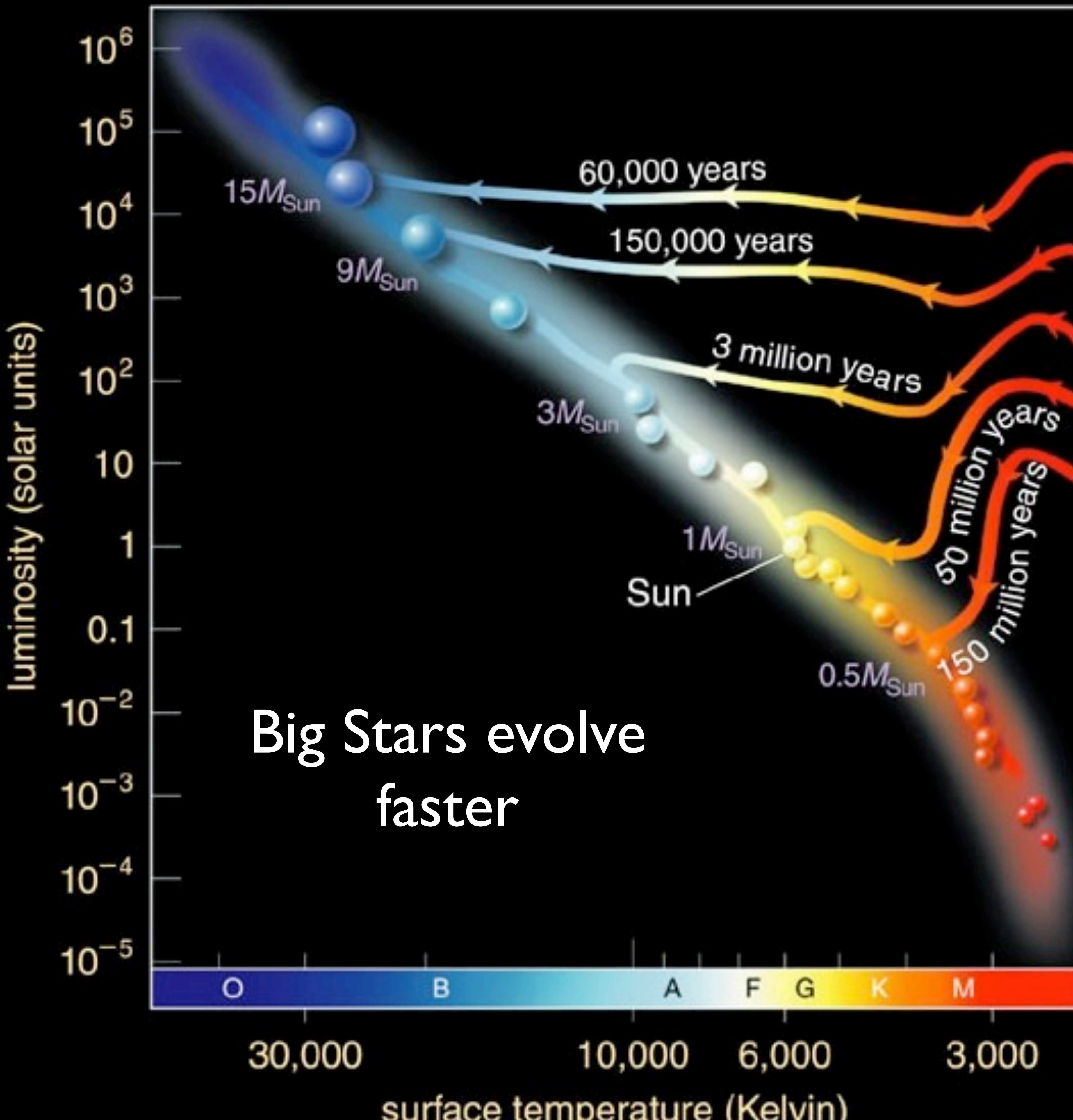
Protostars

- Which is biggest?

A) A young protostar with the same mass as the sun

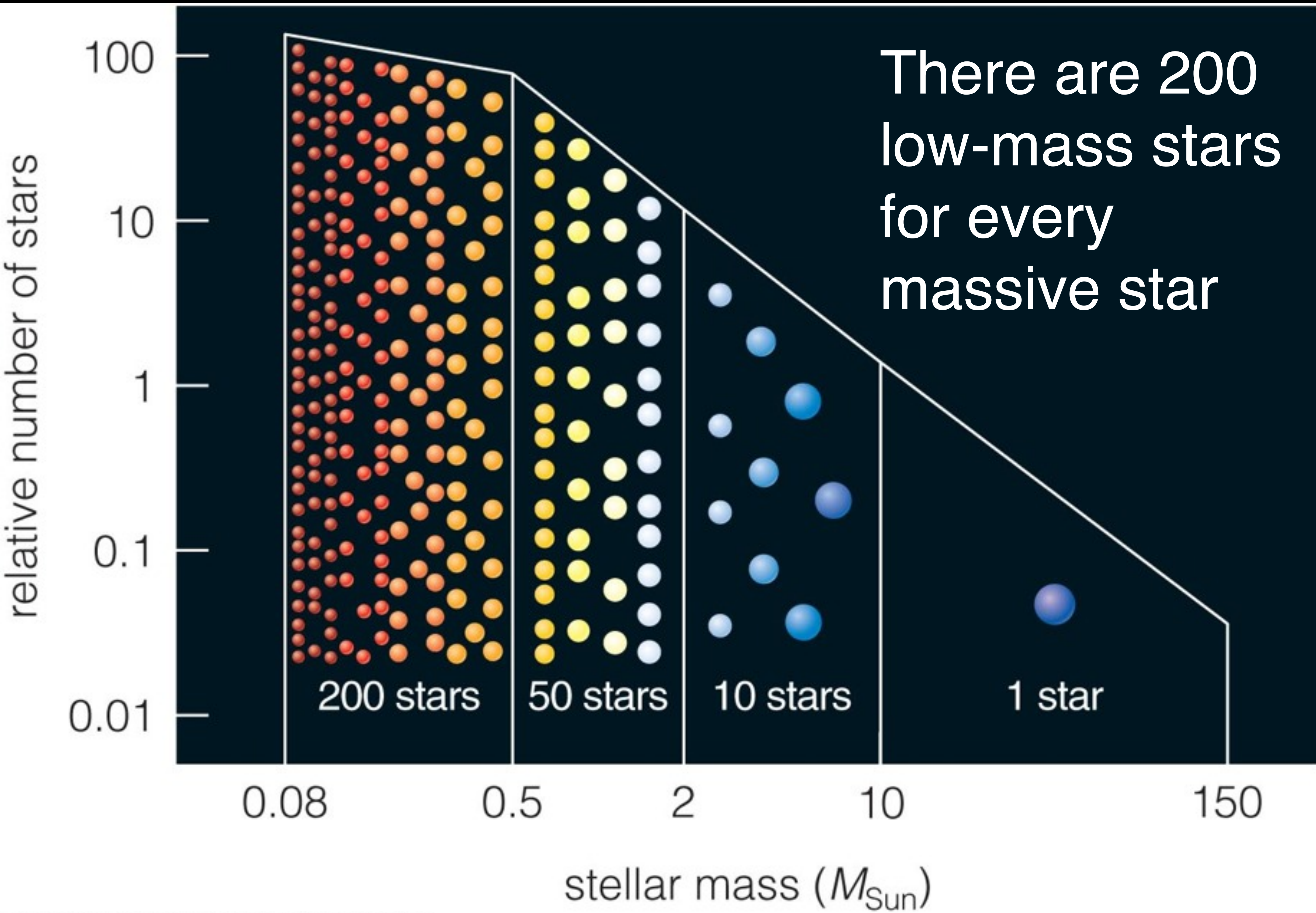
B) The sun

C) Jupiter

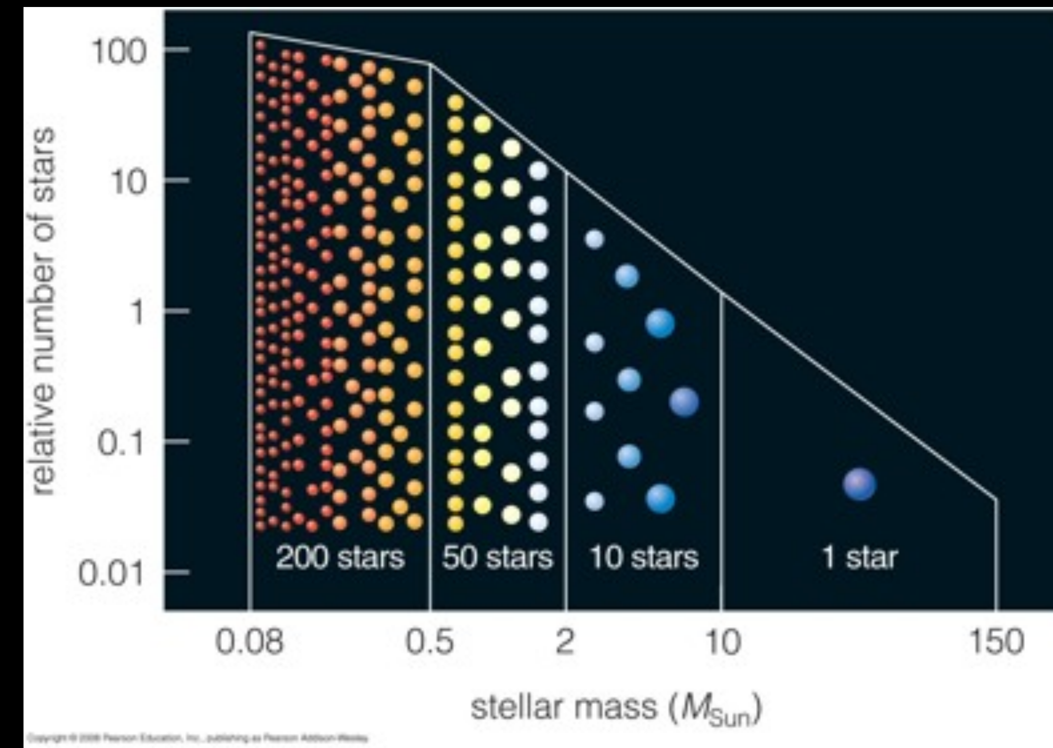


Big Stars evolve faster

Big vs Little



The IMF



- Which are the most common?

A) Massive, blue-white O-stars

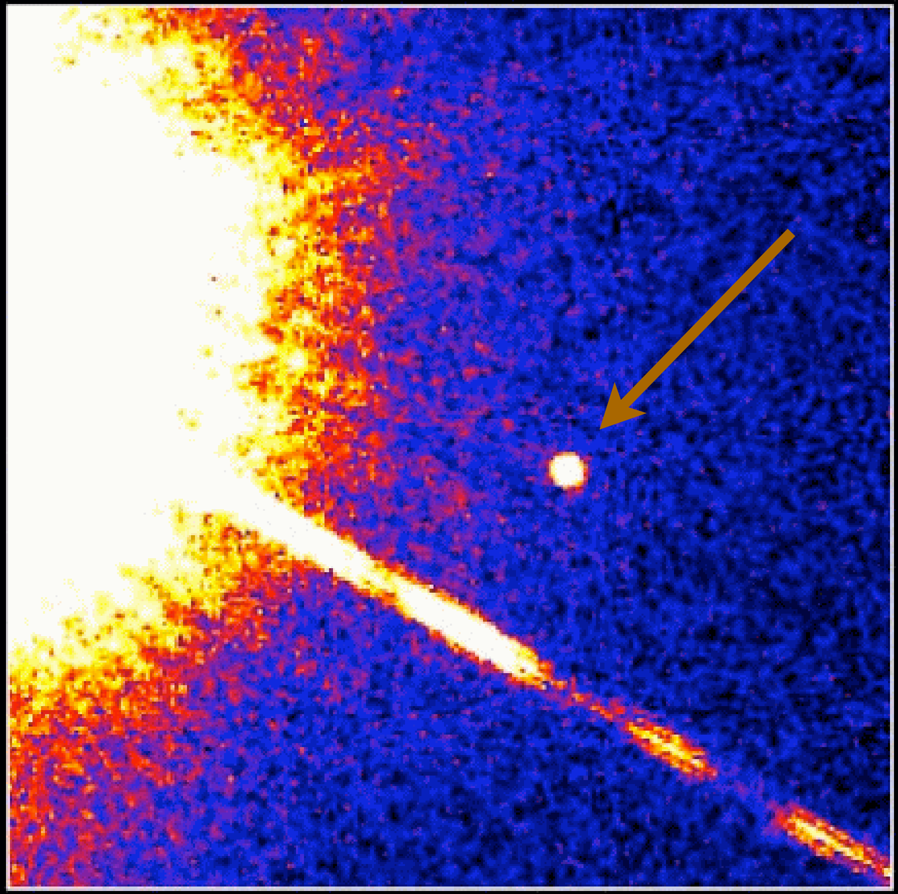
B) Moderate mass stars

C) Yellow sun-like stars

D) Low-mass, cool, red, M-stars

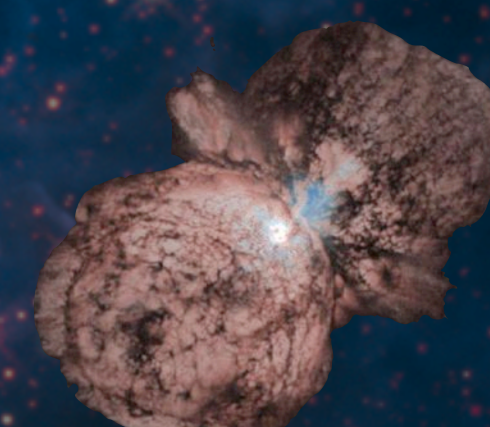
Biggest & Smallest

- Lower limit: Below 0.08 solar masses, gravitational pressure is too weak to ignite fusion.
    - Brown Dwarves are “failed stars” that mark the transition from Jupiter-like objects to stars

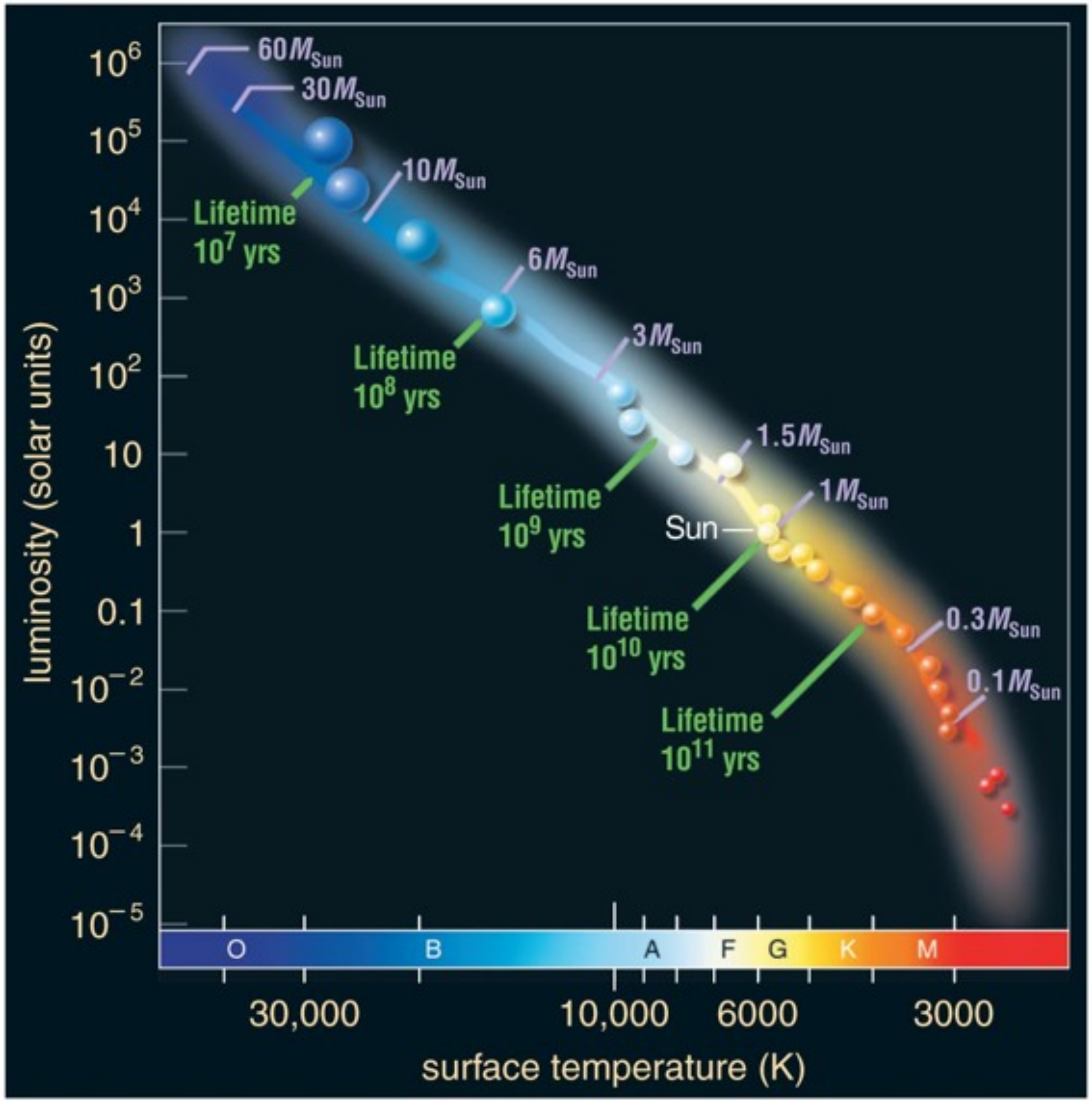


Biggest & Smallest

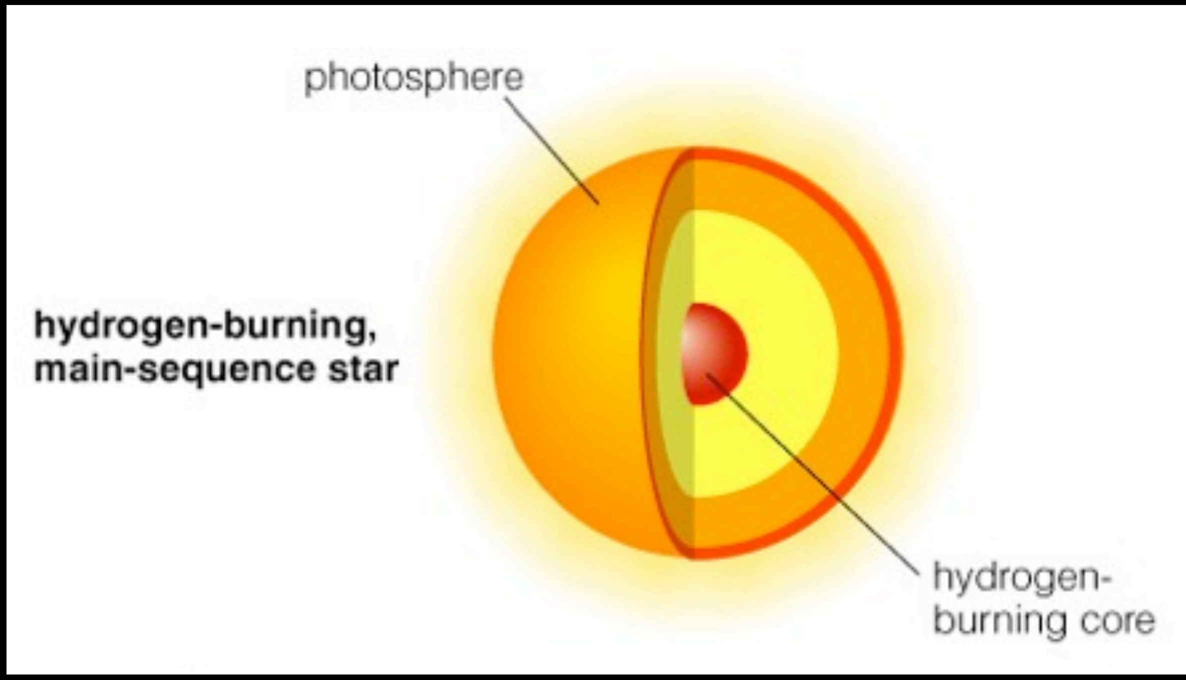
- Upper Limit: For the most massive stars, fusion turns on before all of the gas & dust has accumulated on the star
  - The upper mass limit is not known, but the highest mass stars discovered to date are ~120 solar masses



The Main Sequence



- Stars do their thing (fusion) for millions to tens of billions of years



Brightness

- In a young cluster, which stars provide the most light?

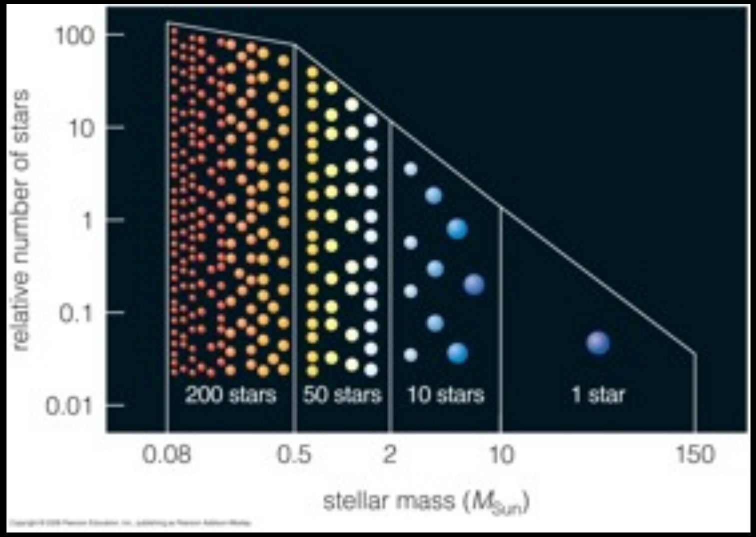
A) Massive, rare blue-white O-stars

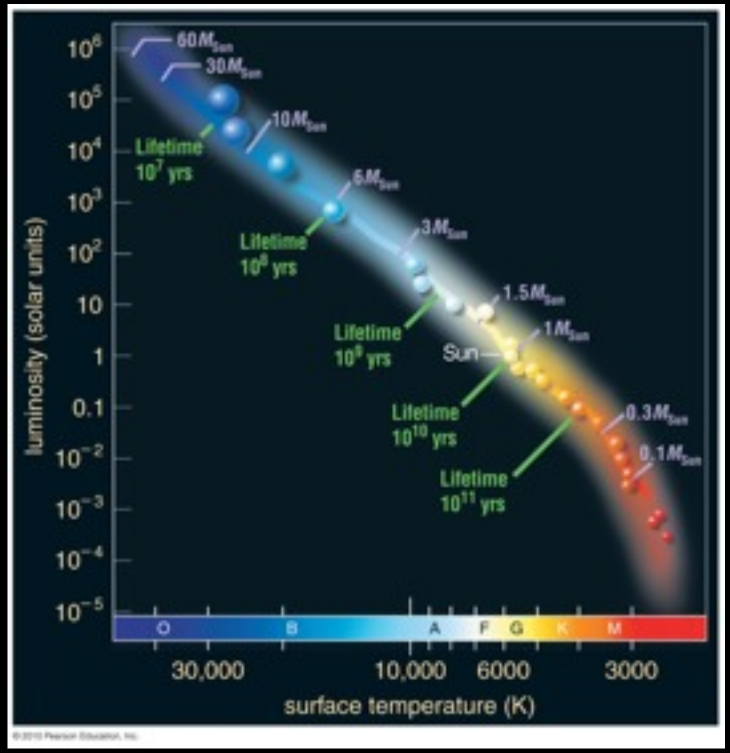
B) Sparse moderate-mass stars

C) Yellow sun-like stars

D) Low-mass, common, cool, red, M-stars

E) Failed stars: Brown Dwarves



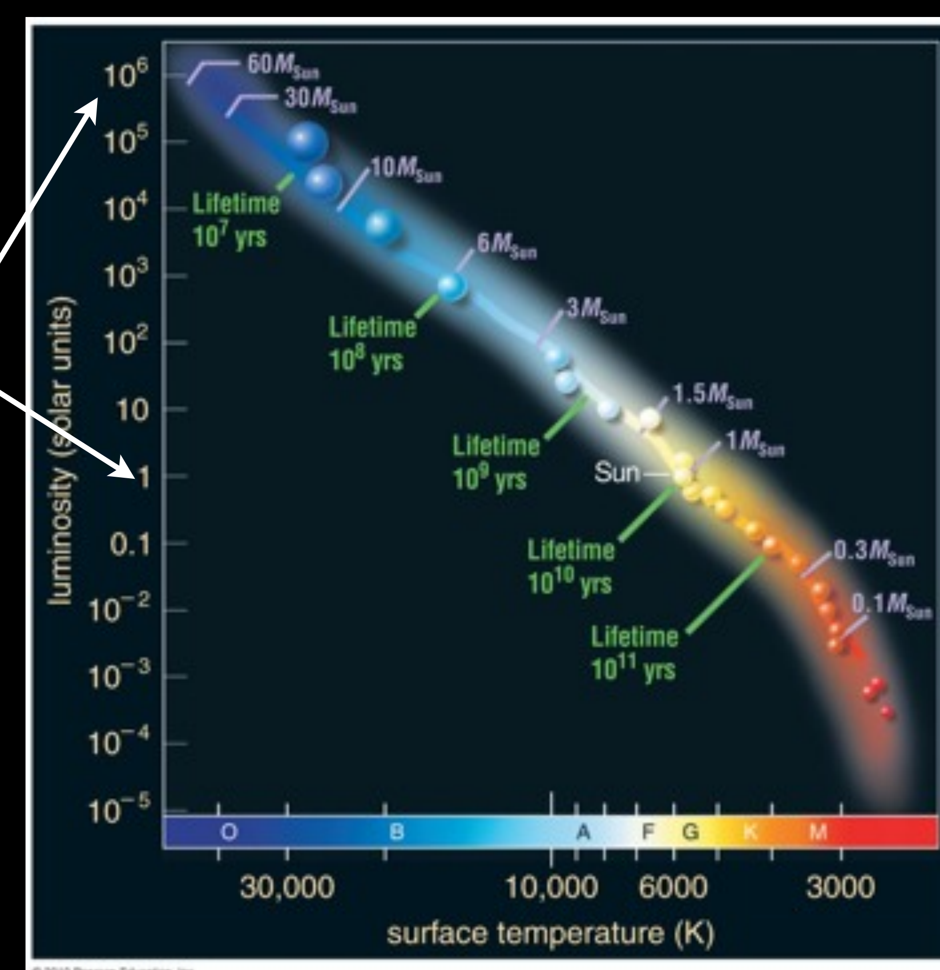


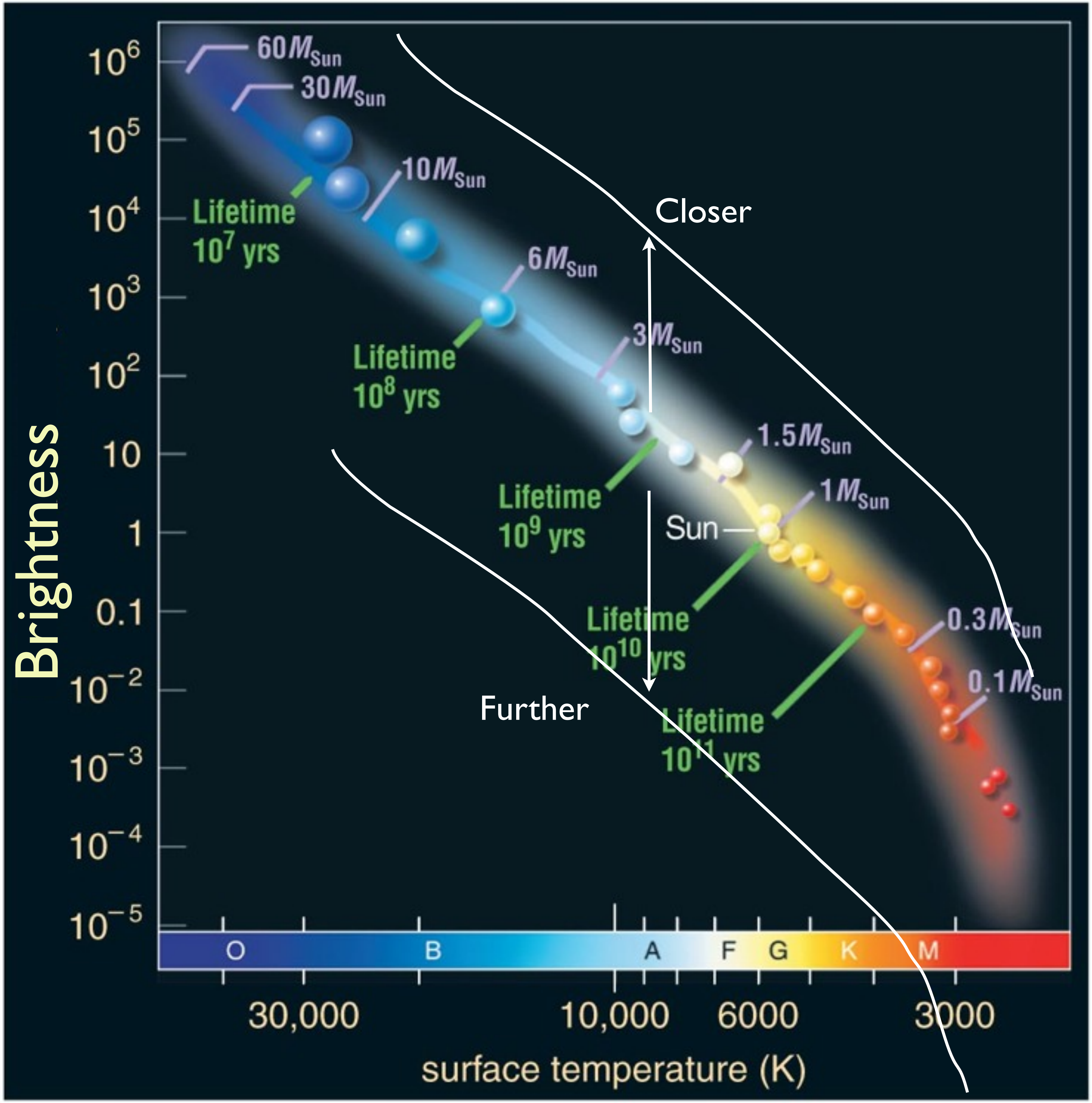
Brightness

- In a young cluster, which stars provide the most light?

A) Massive, rare blue-white O-stars

Even though they're rare, one big O-star is as bright as 1,000,000 Suns!





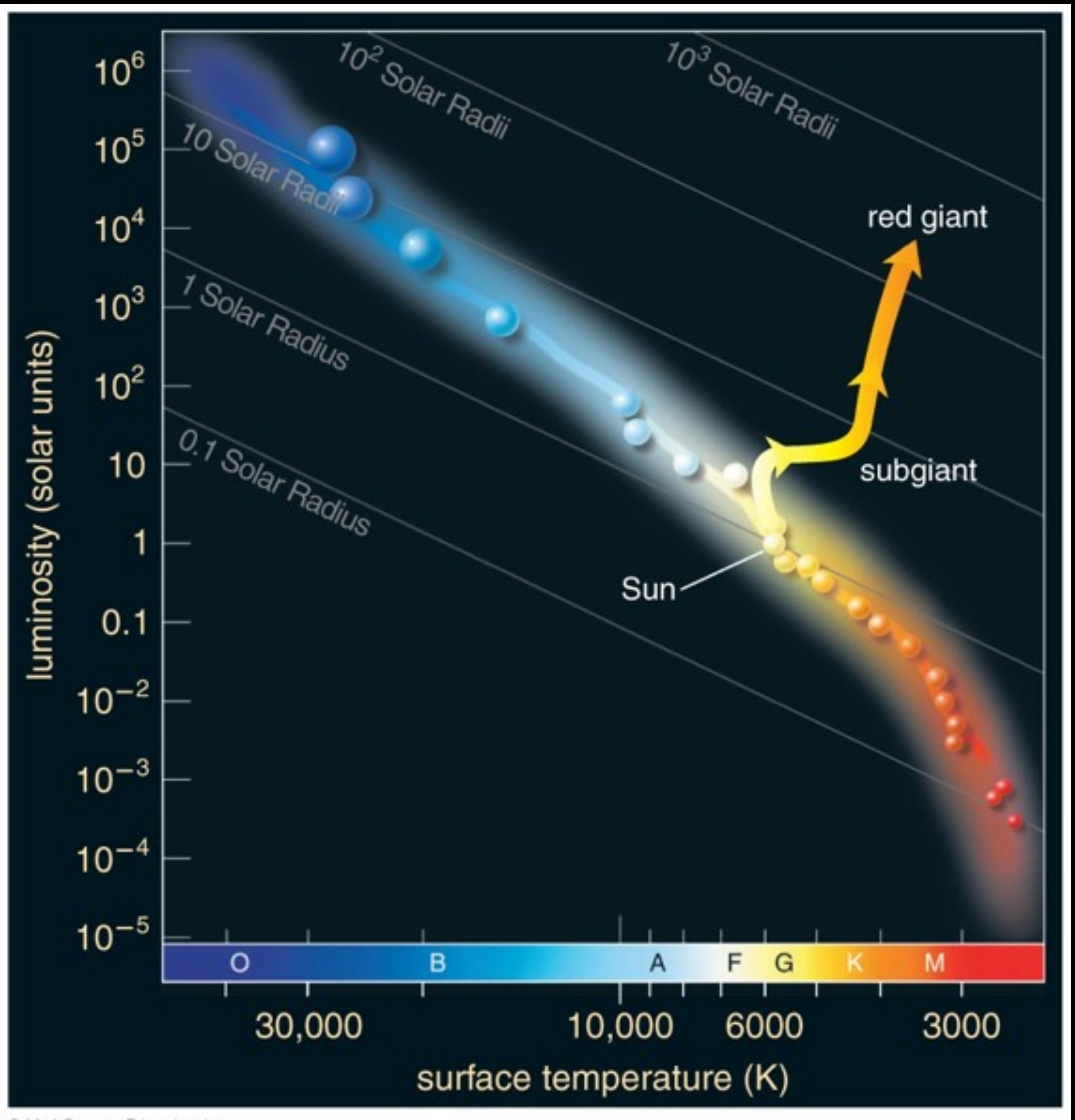
Main sequence fitting:

More distant stars will be fainter, but groups of stars will have the same shape on the temperature-luminosity HR diagram

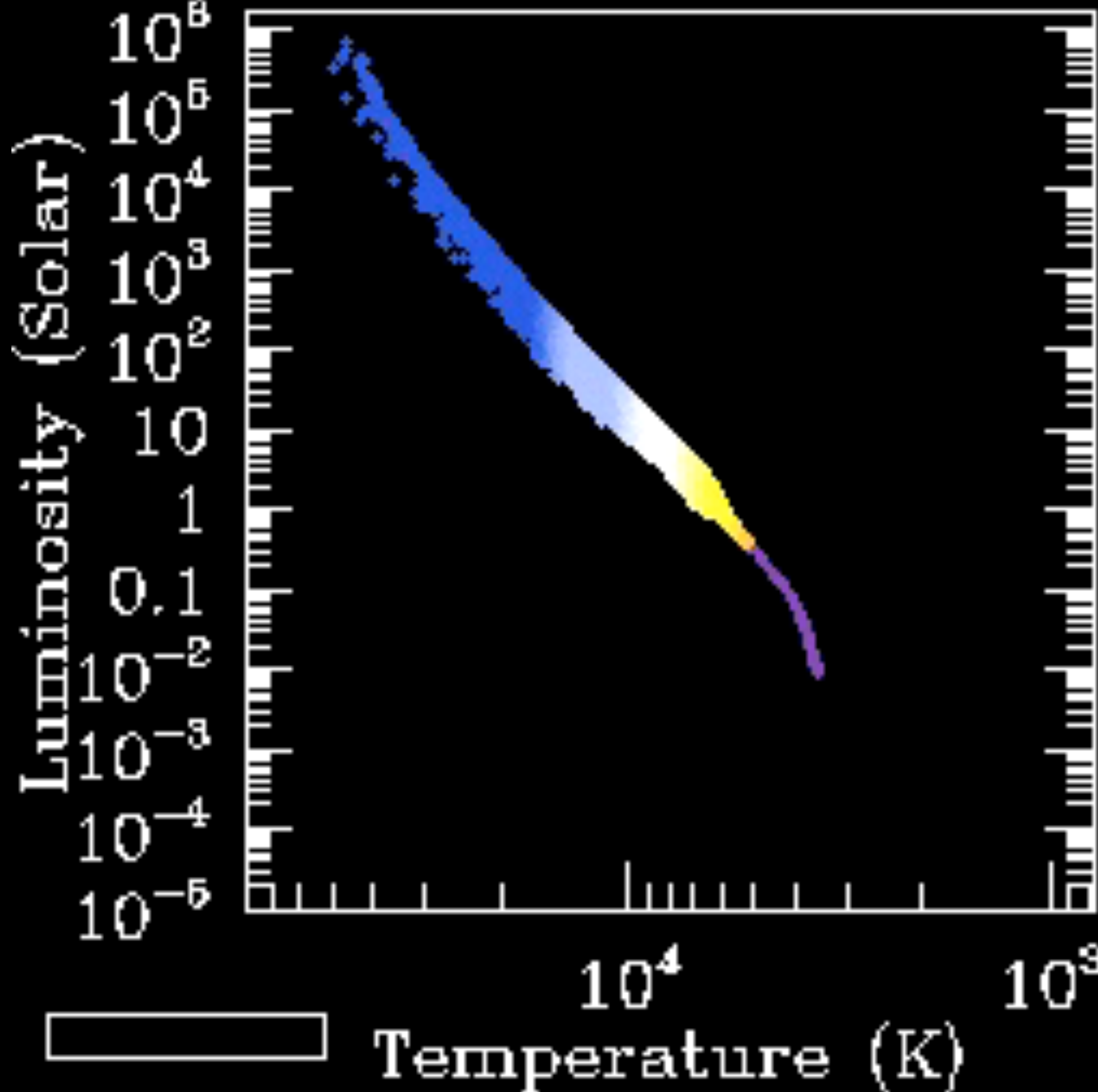
As stars get old...

- Two sequences: Low-mass and High-mass
  - Stars like the sun have a complicated but well-understood aging process
  - Bigger stars (bigger than about 8 times the mass of the sun) do something different
    - we don't know quite as much about these

Stellar Aging



- After 10 billion years or so, the Sun will finish burning hydrogen in its core
- it will start to expand



from http://rainman.astro.illinois.edu/ddr/stellar/beginner.html

Aging

- Which stars start to die first?

A) Massive blue-white O-stars

B) Moderate-mass stars

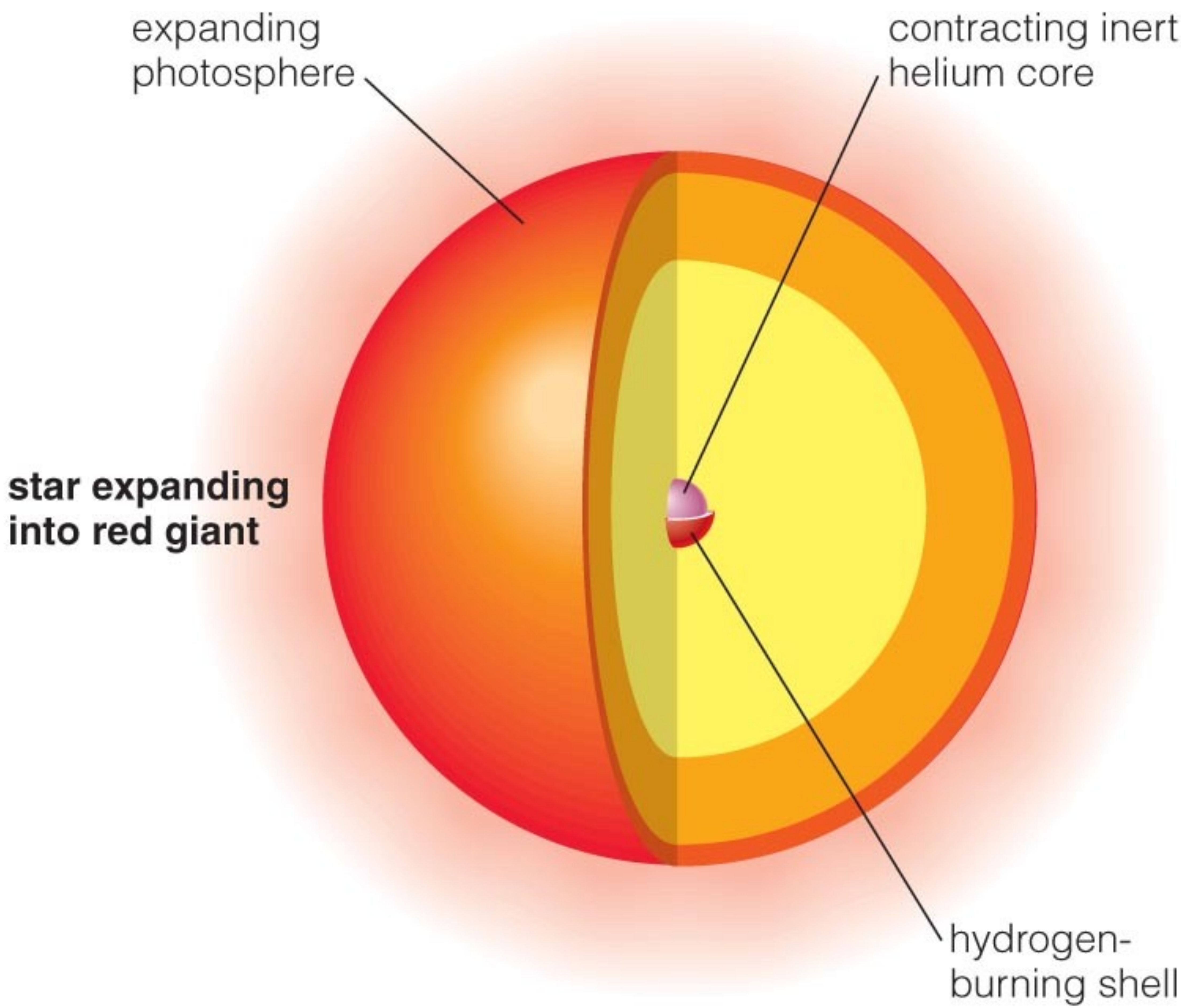
C) Yellow sun-like stars

D) Low-mass, cool, red, M-stars

E) Failed stars: Brown Dwarves

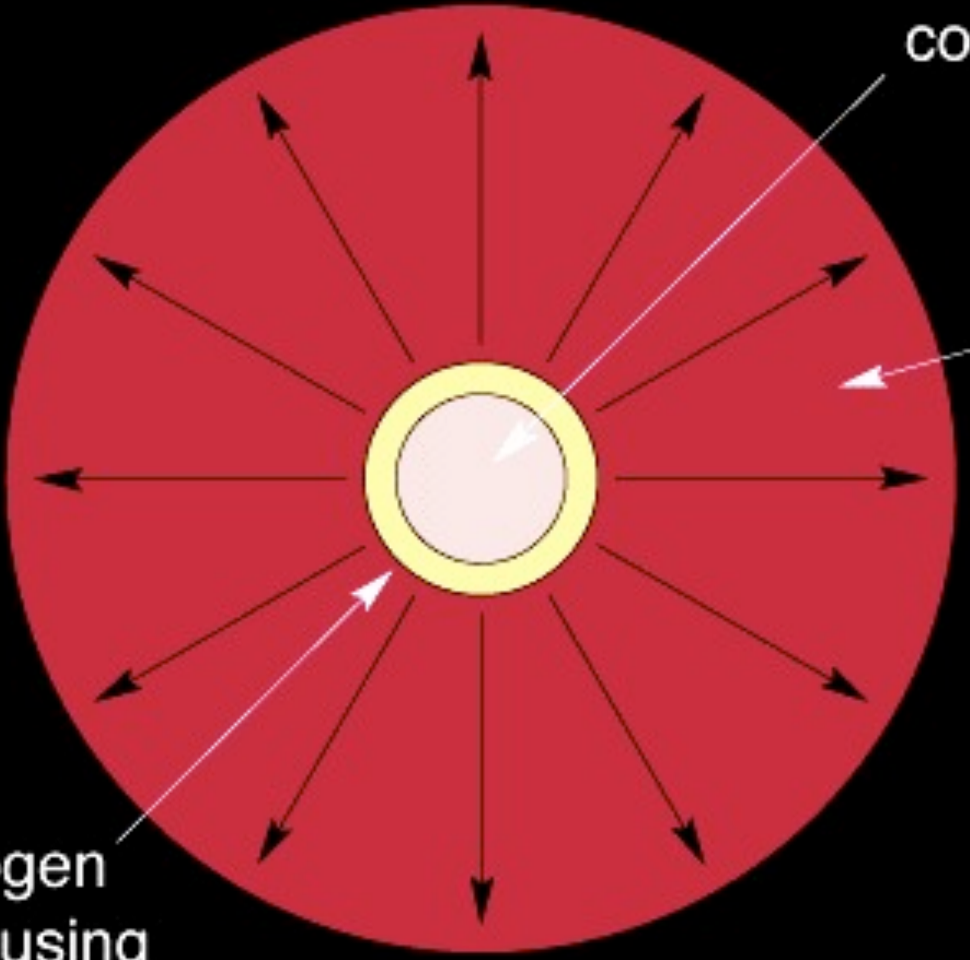
Why do stars leave the Main Sequence?

- They run out of hydrogen and helium builds up in the core instead
  - The core still isn't hot enough to fuse helium (requires 100 million K)
- Fusion stops: there's nothing to support against gravity
  - Gravity collapses the core
  - As it collapses, it heats up
- The area around the core heats up, and it still has hydrogen, so hydrogen shell fusion starts


expanding
photosphere
contracting inert
helium core
star expanding
into red giant
hydrogen-
burning shell

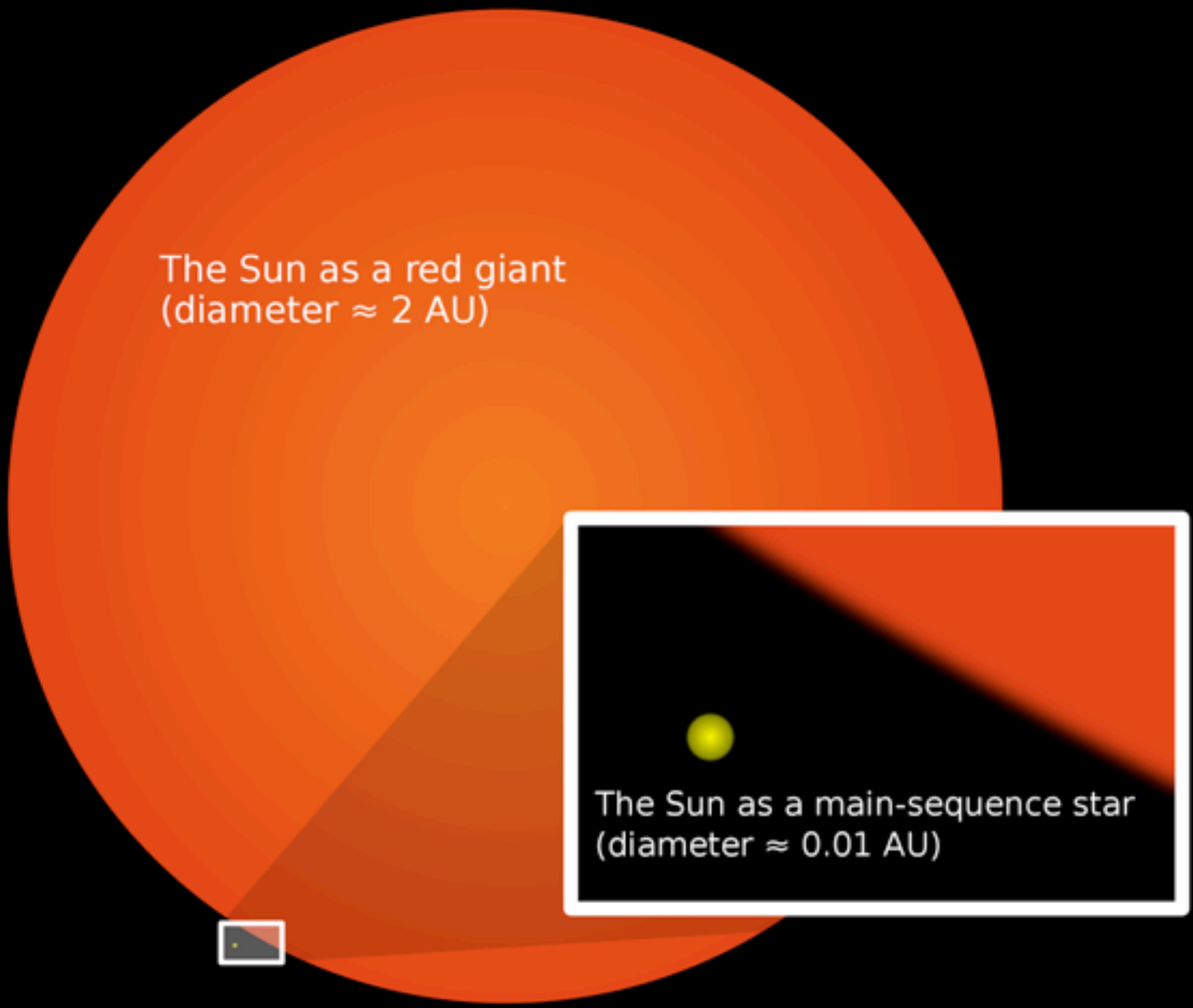
Transition to Red Giant

- The fusing Hydrogen shell is more **luminous** than the old core
  - it forces the outer layers of the star to expand
- As the core slowly collapses more, the shell heats up and burns hydrogen faster
  - The star continues to brighten



Slooow expansion

- In the sun, this process will take ~1 billion years after it spends ~10 billion years on the Main Sequence



Red Giants

- Why are red giants more luminous than their main-sequence predecessors?

A) They're bigger (more surface area)

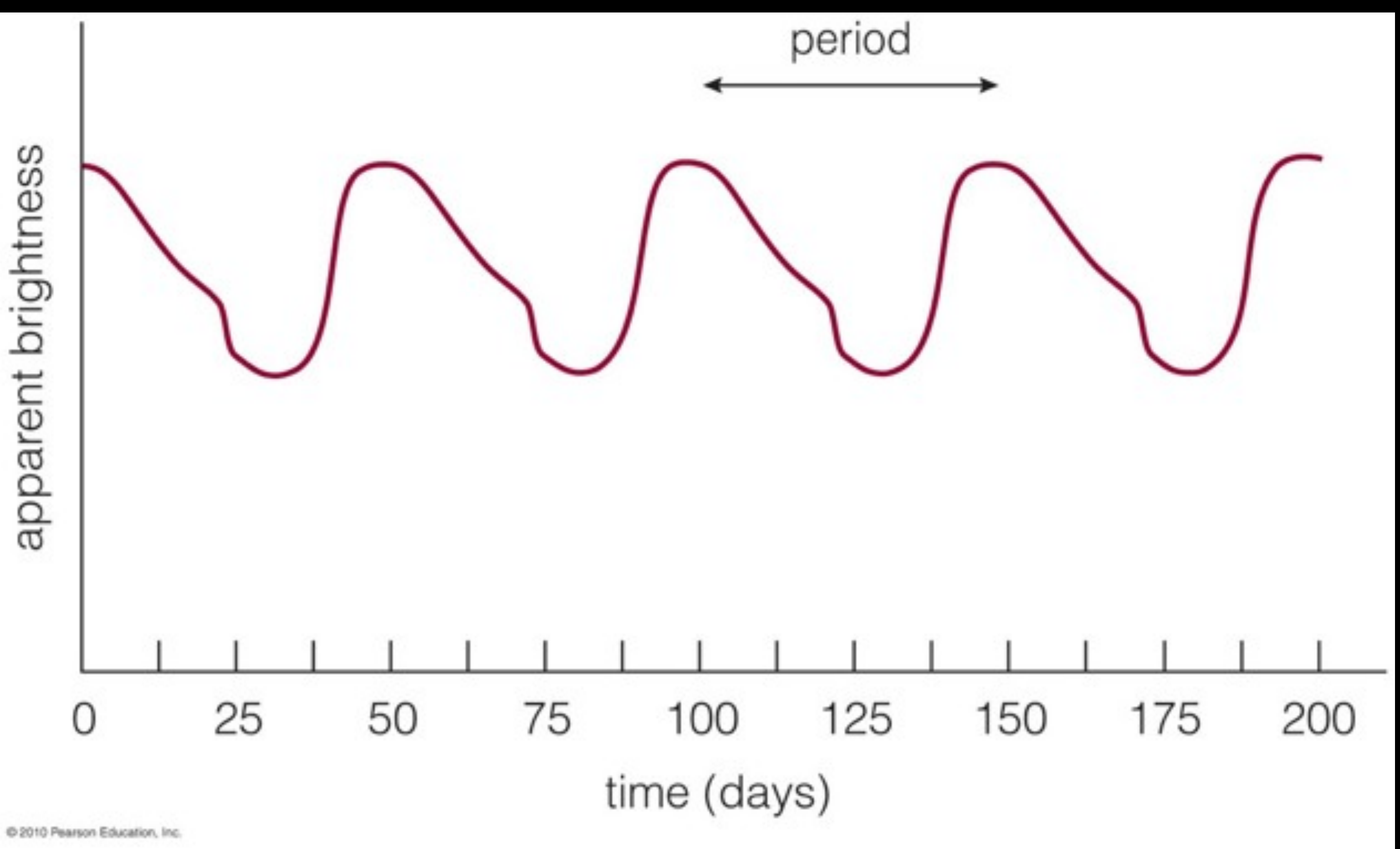
B) They're hotter (hotter photosphere)

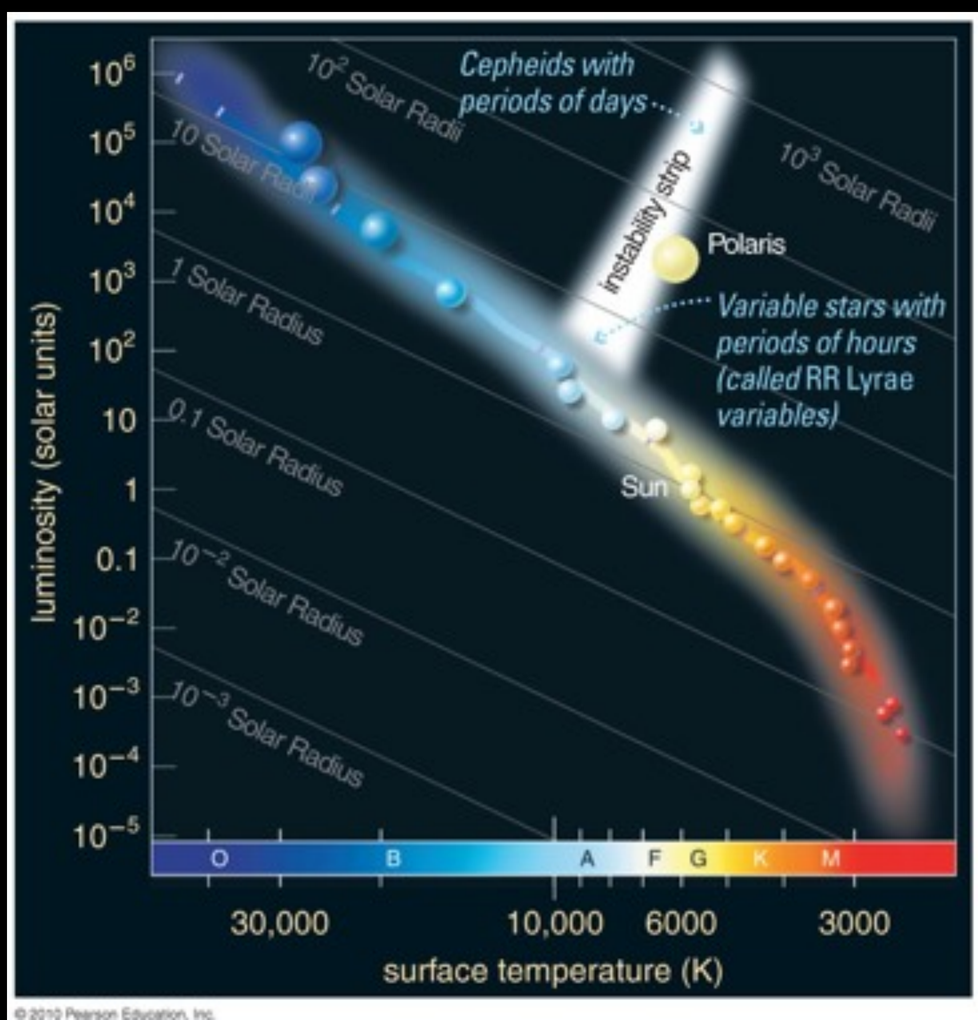
C) They are powered by fission instead of fusion

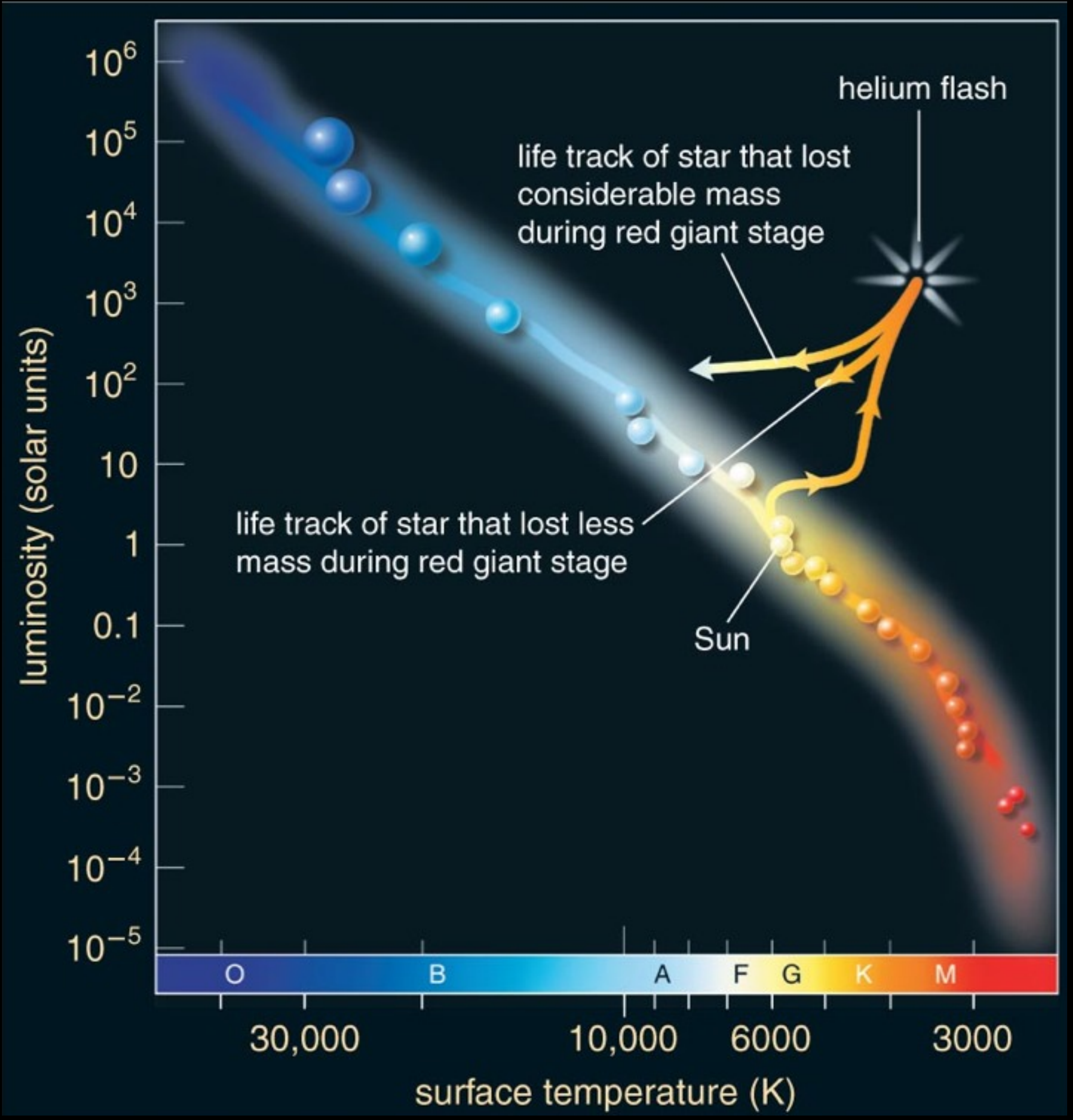
D) They're red, which means they're angry, and everyone knows anger makes you brighter

Cepheids

- Cepheids are the Red Giants that form from 5-20 solar mass stars
- Their pulsation period is directly related to their luminosity





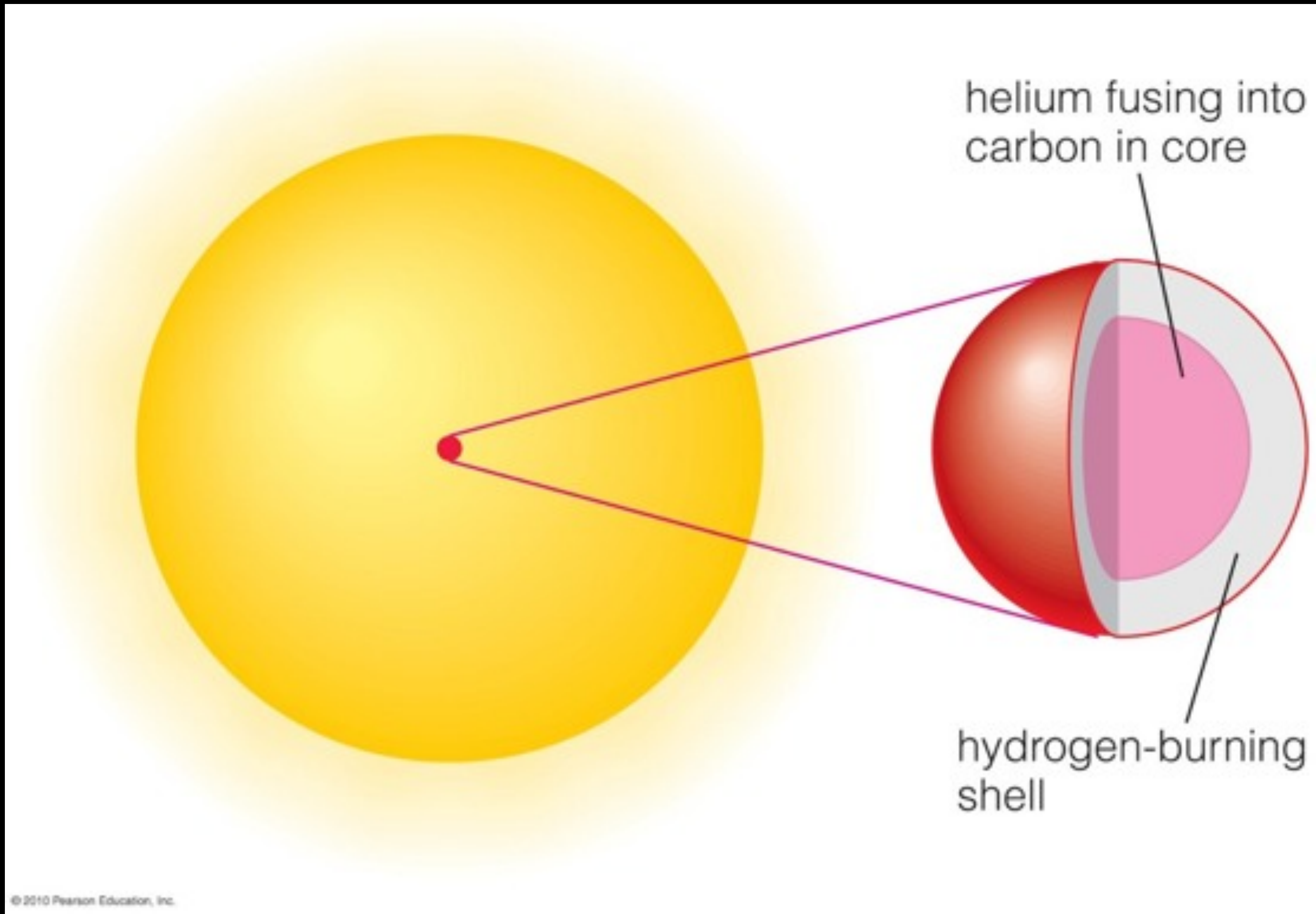


helium flash
life track of star that lost considerable mass during red giant stage
life track of star that lost less mass during red giant stage
Sun
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
O B A F G K M
30,000
10,000
6000
3000
surface temperature (K)

Horizontal Branch

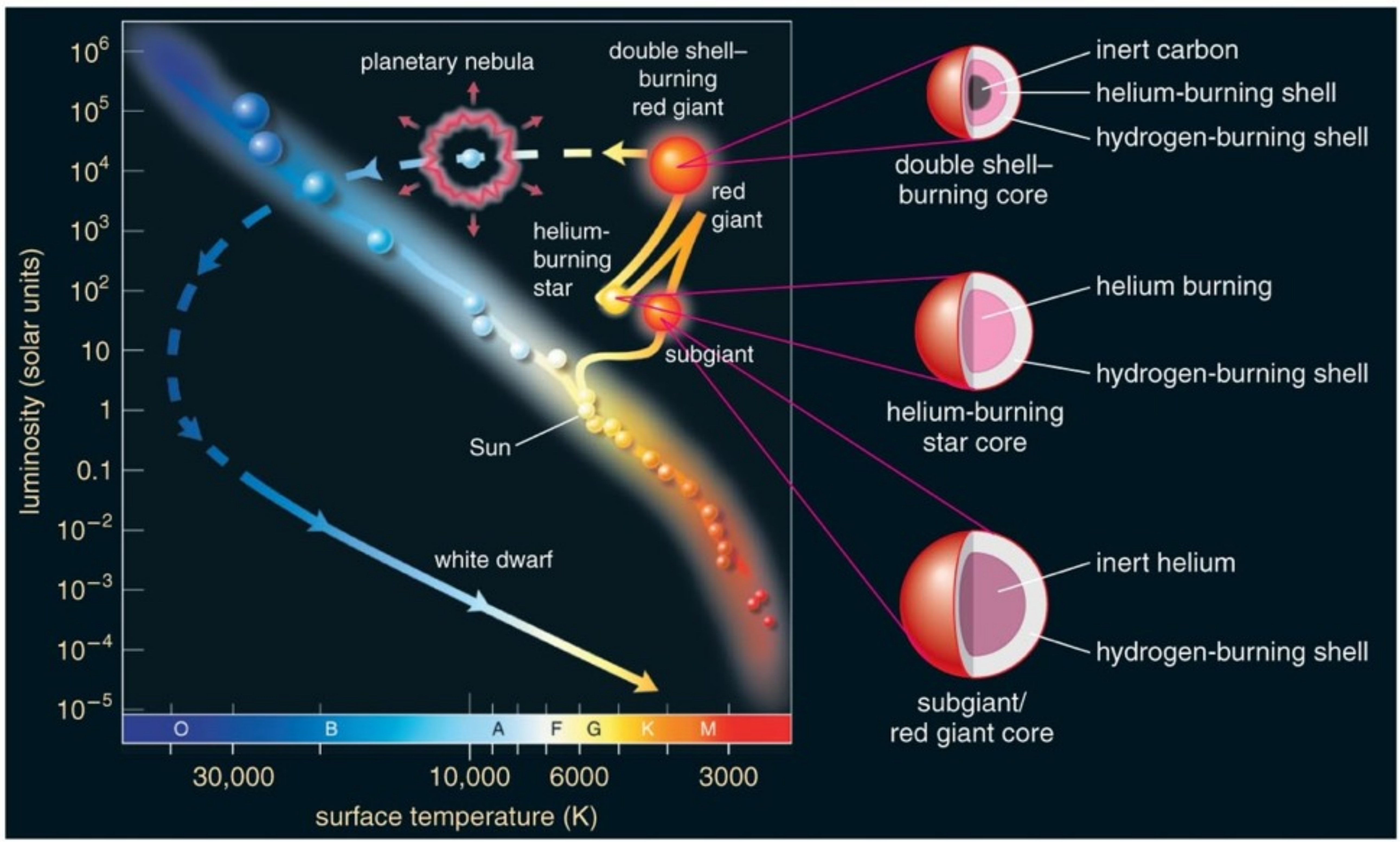
- The core continues to collapse slowly and heat up until eventually it reaches 100 million K, when it can fuse Helium into Carbon

- Helium burning starts with a Helium Flash: the whole core heats up at once
- After the flash, the star's **luminosity** stays constant by burning helium in the core but its radius decreases and the star gets yellower



A complicated track...

Check out page 608 (5th ed) between chapter 18 and 19 –
“Cosmic Context Part V: Balancing Pressure and Gravity”



Brightest?

- When is a Sun-like star brightest (most luminous)?

A) As a yellow main-sequence star

B) As a reddish sub-giant

C) As a Red Giant

D) As a young White Dwarf

Hottest?

- When is a Sun-like star hottest?

A) As a yellow main-sequence star

B) As a reddish sub-giant

C) As a Red Giant

D) As an orange Horizontal Giant Branch star

Longest?

- Which phase lasts longest?

A) yellow main-sequence

B) reddish sub-giant

C) Red Giant

D) orange Horizontal Giant Branch

E) young White Dwarf

One more phase...

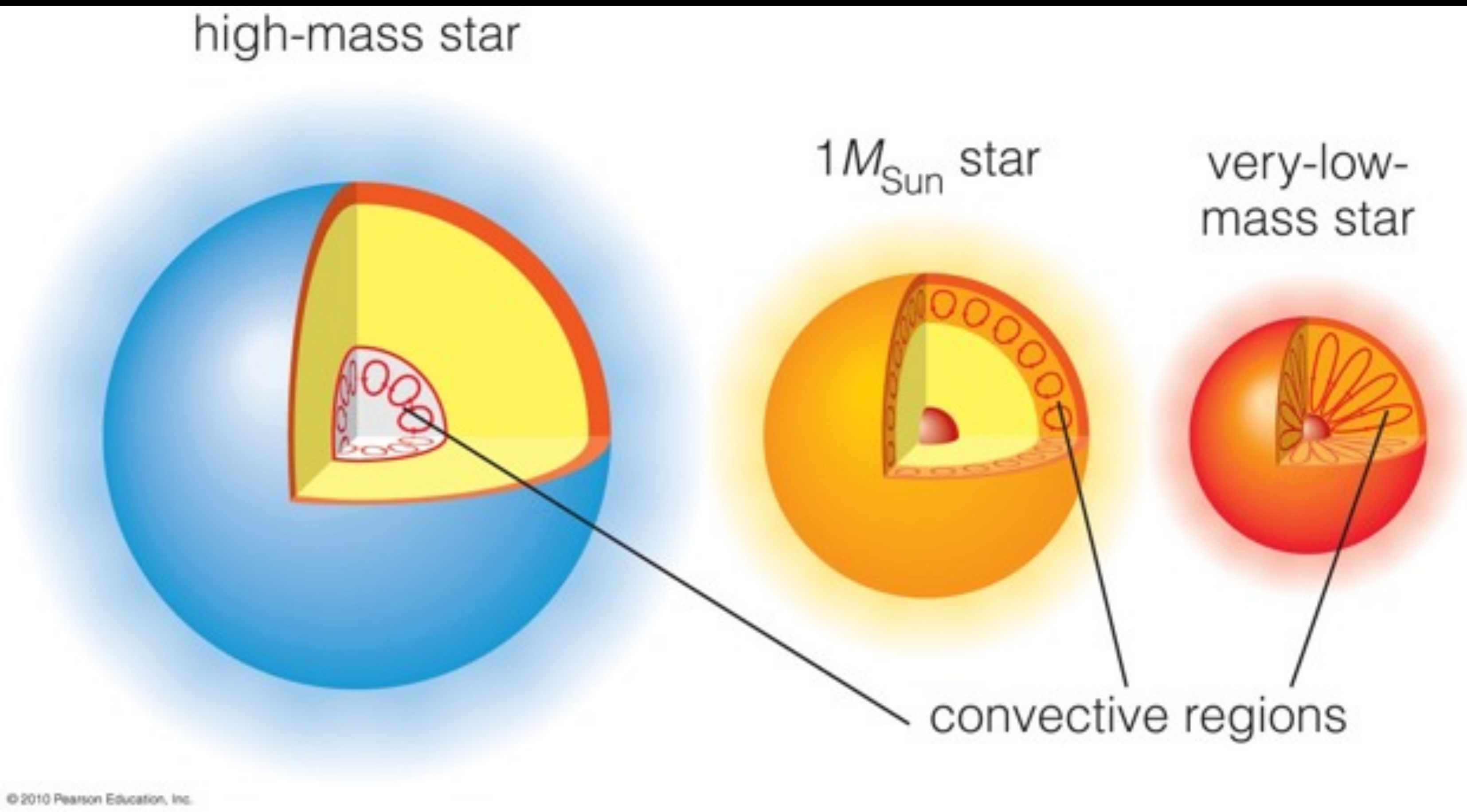
- The last kink is the Asymptotic Giant Branch (AGB)
  - Two shells: One Hydrogen, one Helium
  - Carbon/Oxygen core
- Eventually, Helium shell becomes inert
  - Then Thermal Pulses begin. Over a few million years, a few “bursts” of Helium shell burning ignite
  - These pulses blow off a circumstellar envelope

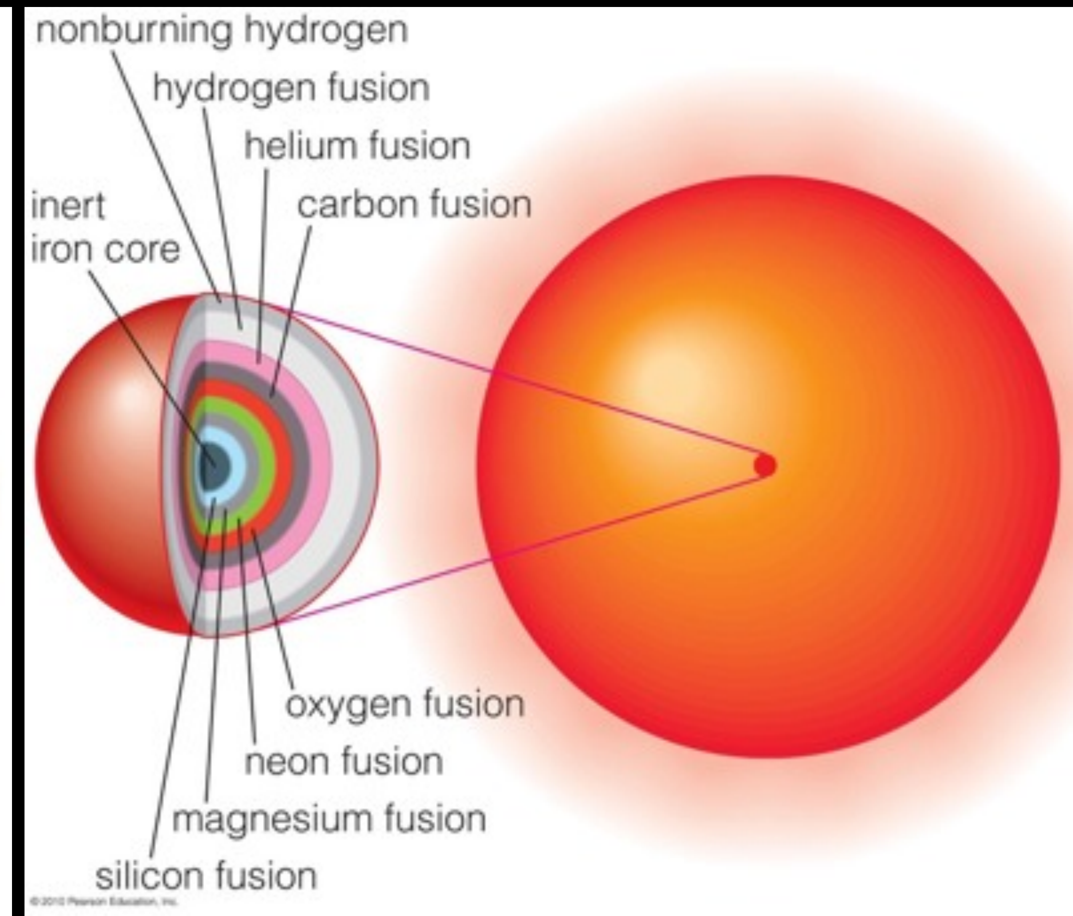
Pre-Planetary Nebulae

- Finally, all of the outer layers are blown off, leaving a white-hot core of Carbon and Oxygen
    - This happens very rapidly: only ~1,000 years (remember, the Sun will live 10,000,000,000 years)
- Very pretty!

Massive Stars

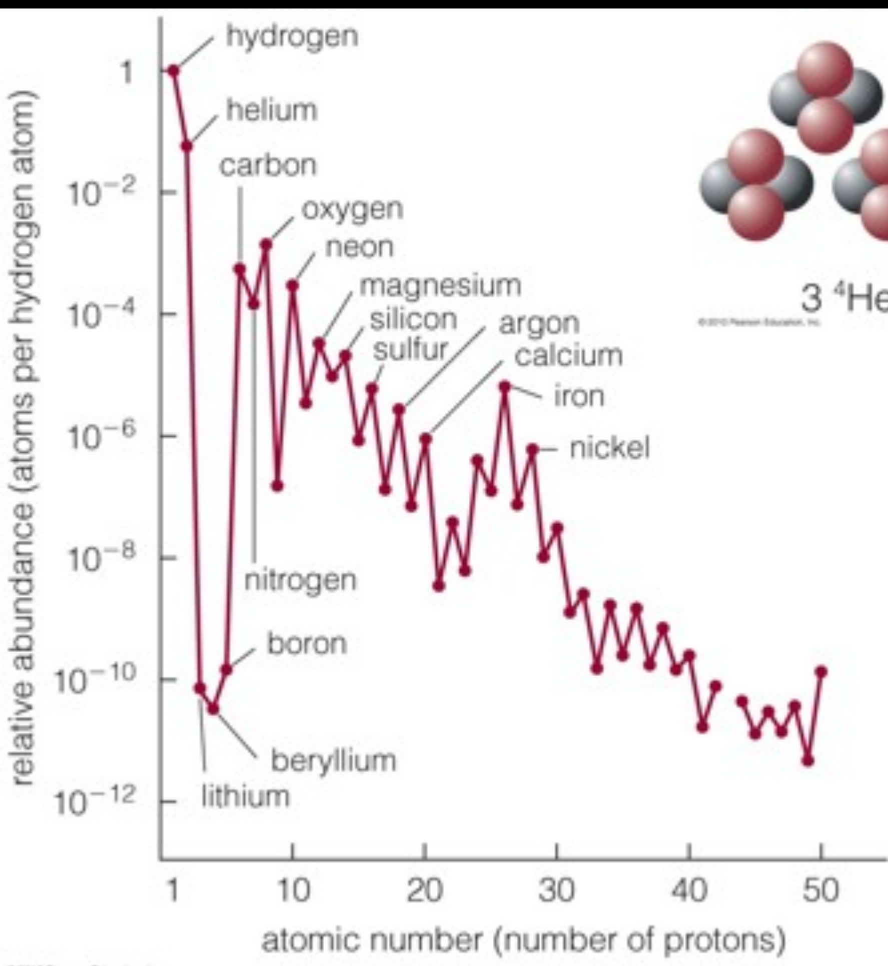
- They're different!
- Convection on the inside, fusion of heavier elements
  - The core burns through H, then He, then Carbon, and so on until Iron is reached

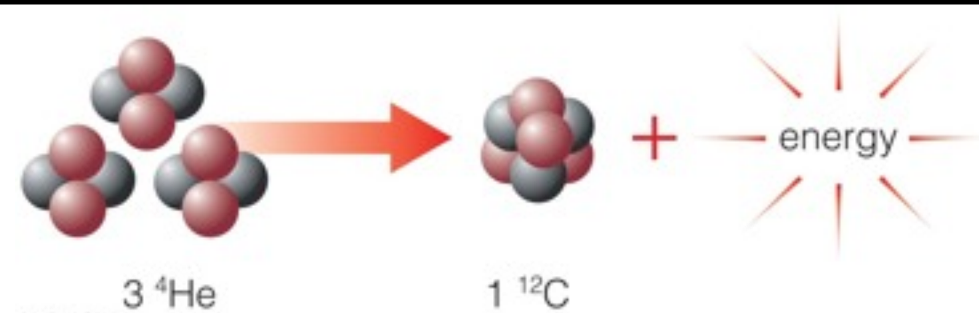


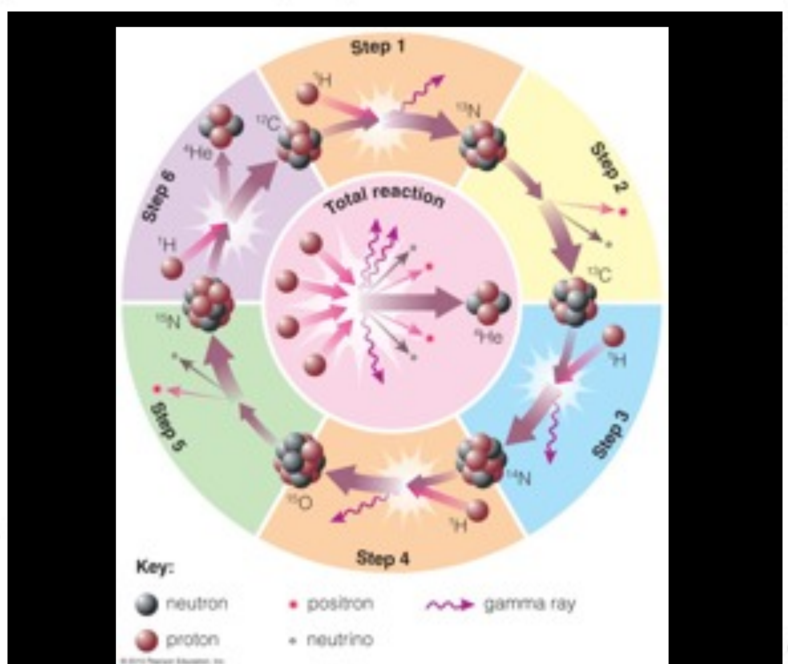


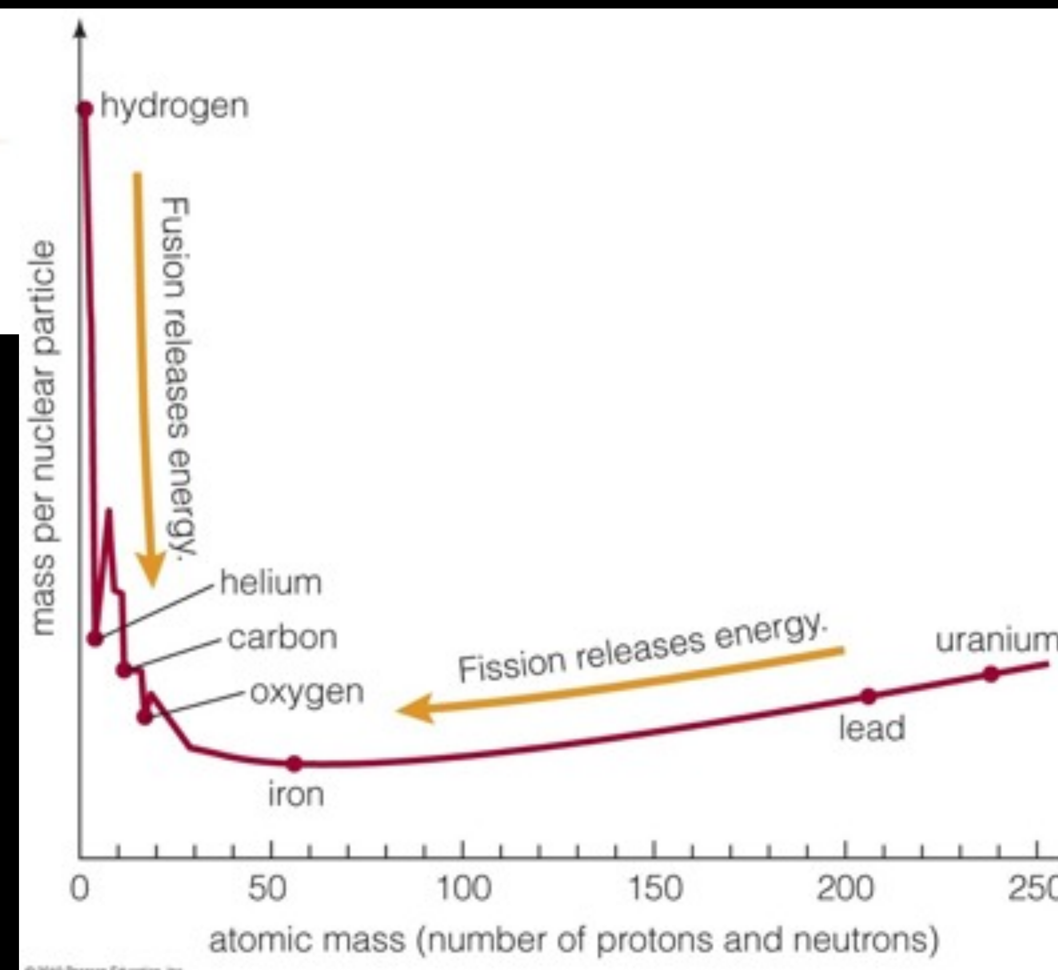
Massive Star Fusion

- Massive stars fuse Hydrogen into Helium via the CNO cycle
  - Much more efficient than PP chain







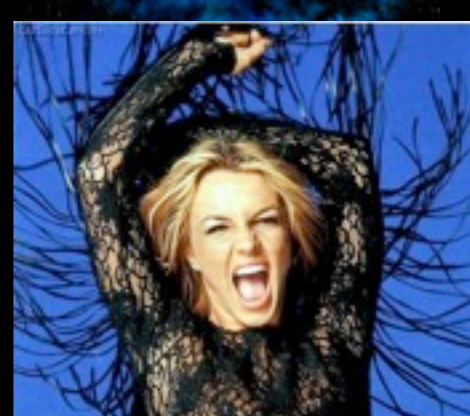


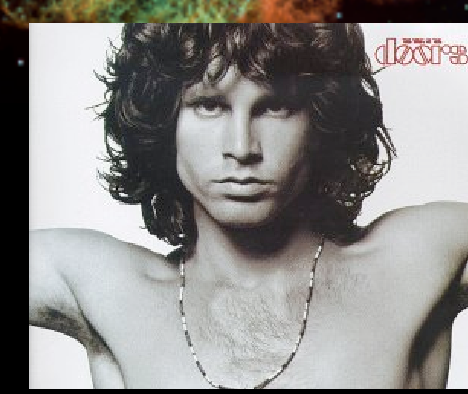
Massive Star = Rock Star

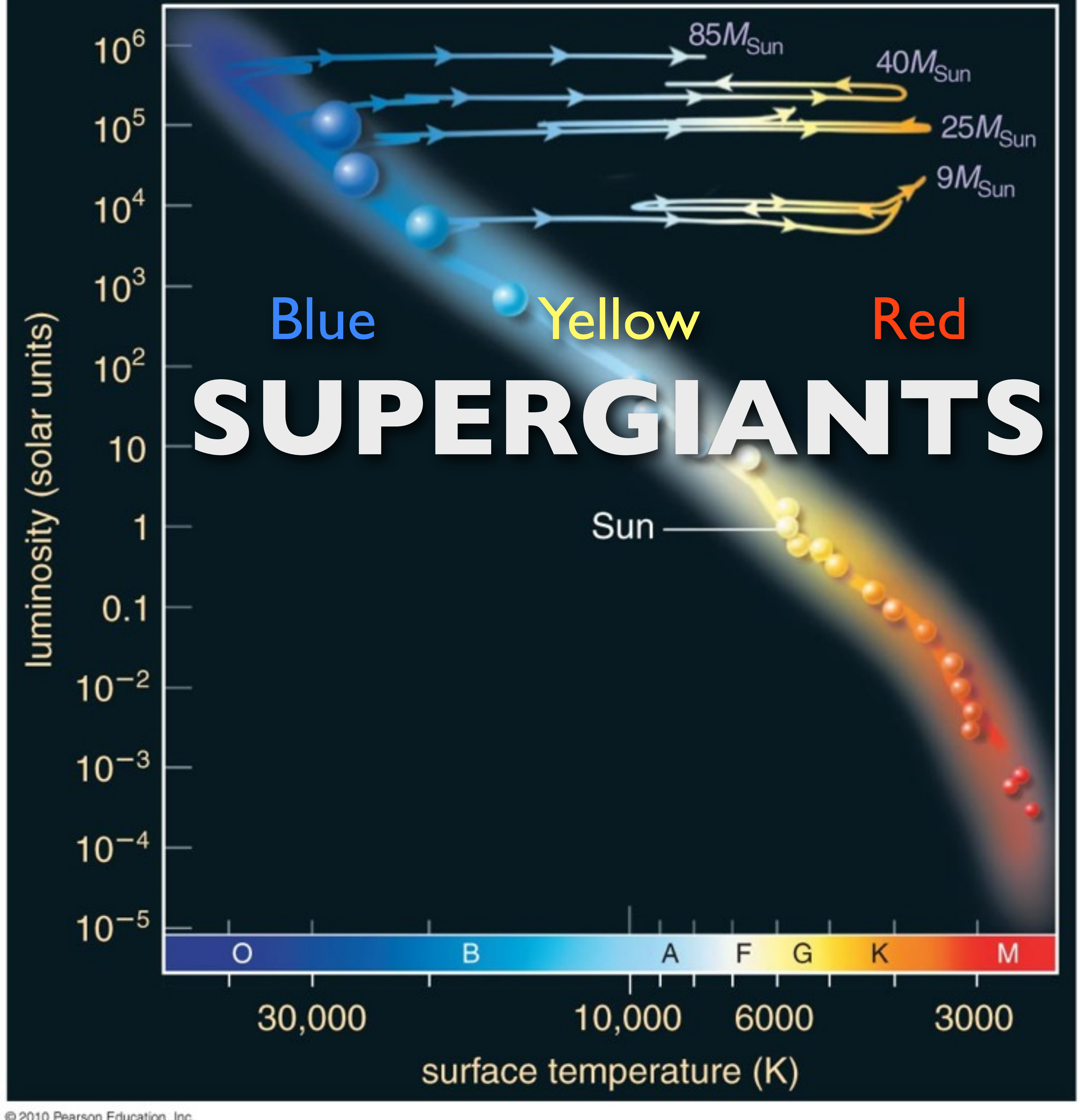
- Short lifetimes
- “The light that burns twice as bright burns half as long.” *-Blade Runner*
    - Not an exact formula, but massive stars do burn through their fuel faster (more than twice as fast)









When massive stars get old...

Rock star analogy continued:

They oscillate between hot and not, but stay just as **luminous**

Luminosity

- Which best explains why supergiants have the same **luminosity** but different color?

A) They are generating the same amount of energy in their cores

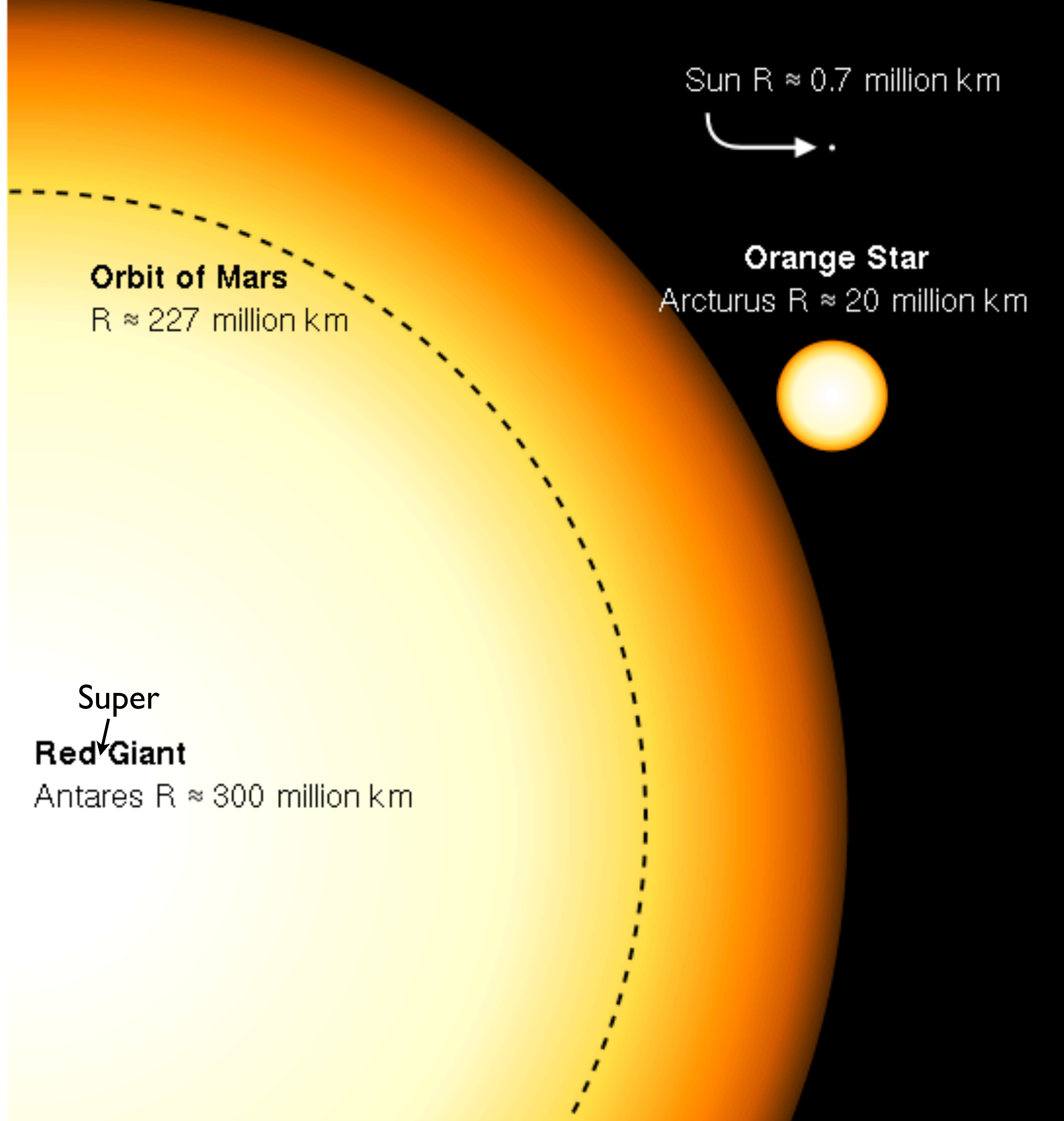
B) They are the same size

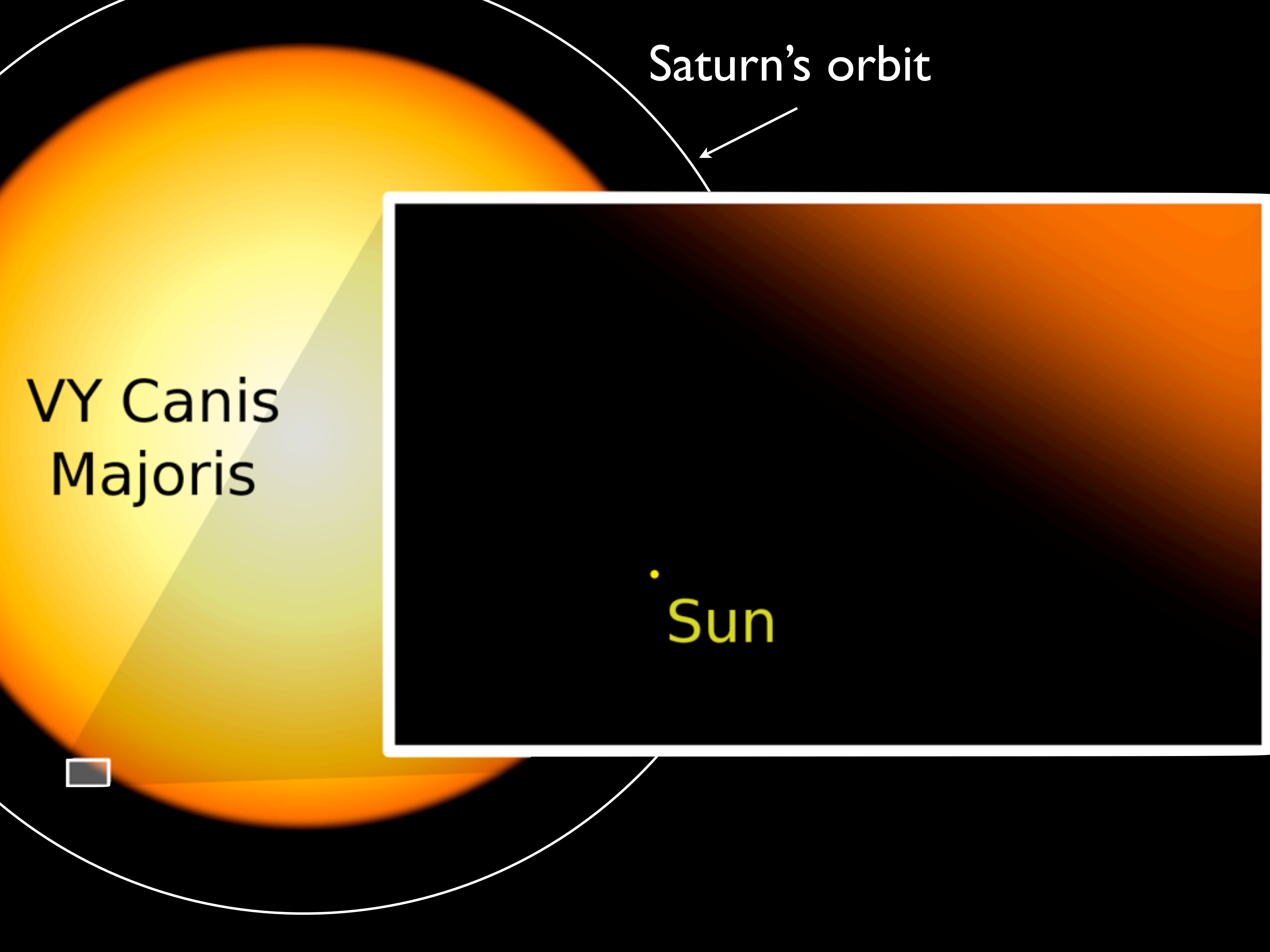
C) They are the same temperature

D) Their cores are the same composition

E) None of these

They get BIG...


Sun R ≈ 0.7 million km
Orange Star
Arcturus R ≈ 20 million km
Orbit of Mars
R ≈ 227 million km
Super
Red Giant
Antares R ≈ 300 million km



Saturn's orbit
VY Canis Majoris
Sun

Bouncing back and forth...

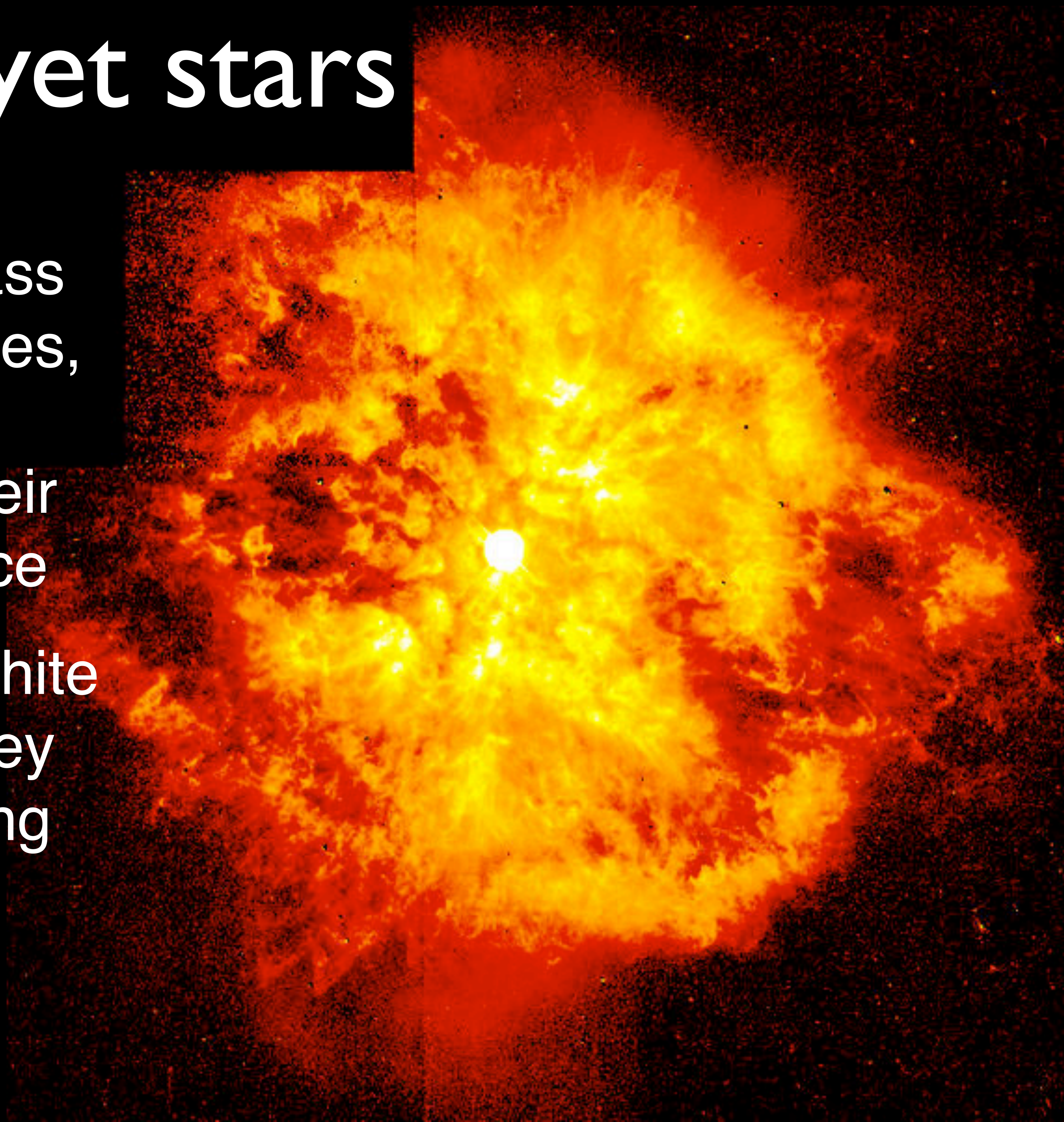
- Massive stars will bounce back and forth between red and blue supergiant phases
    - Some really big ones will be **hypergiants**
- The last phase before death is unknown: May be red supergiants, Luminous Blue Variables, or Wolf-Rayet stars...

LBVs

- My favorite stars....
- They are up to **1 million times** more luminous than the sun
- They sometimes experience enormous blasts of energy during which they become ***100 million times*** more luminous than the sun
  - 100,000,000. Despite being 8000 light-years away, Eta Carinae was the 2nd brightest star in the sky for 10 years!

Wolf-Rayet stars

- Like low-mass white dwarves, they have blown off their entire surface
- but unlike white dwarves, they are still fusing elements in their cores



Massive Stellar Aging

- Which phase lasts longest?

A) blue-white main-sequence

B) Luminous Blue Variable

C) Red Supergiant

D) Wolf-Rayet

E) Can’t tell or they’re equal

Massive Stellar Aging

- Which phase is brightest?

A) blue-white main-sequence

B) Yellow Supergiant

C) Red Supergiant

D) Wolf-Rayet

E) Can’t tell or they’re equal

Massive Stellar Aging

(hint)

- Which phase is awesomest?

A) blue-white main-sequence

B) Yellow Supergiant

C) Red Supergiant

D) Wolf-Rayet

E) **Luminous Blue Variable**

Learning Goals Revisited

- How do stars form?
  - They collapse from molecular clouds into protostars
- What happens to stars as they age?
  - They get **big**
    - Some get **brighter** and cooler
    - Some go crazy

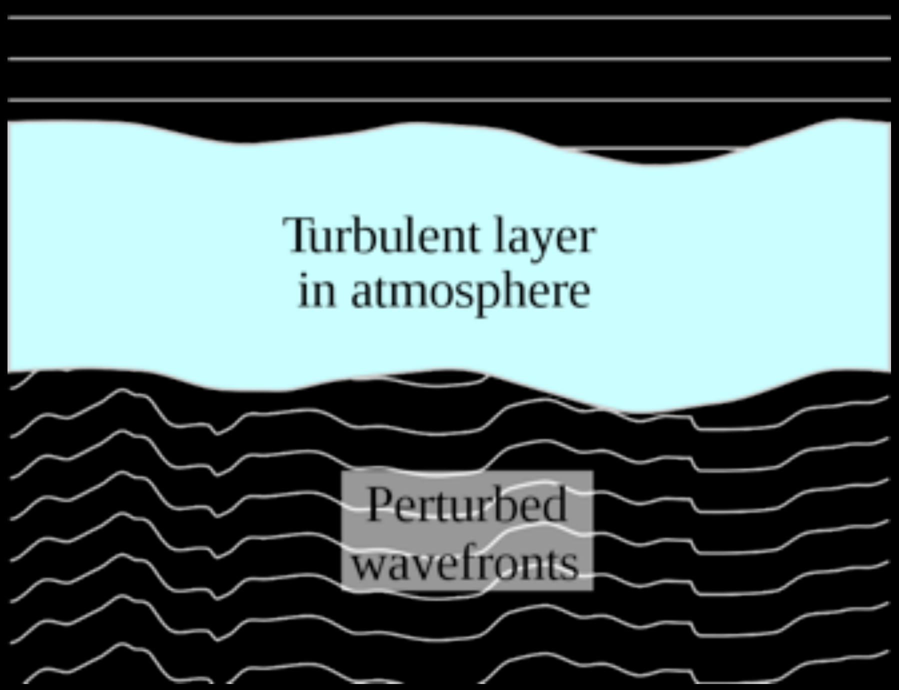
LT, Reading & Homework

- Lecture Tutorial: Star birth & lifetimes, page 111
- Reading: page 608 (5th ed) between chapter 18 and 19 – "Cosmic Context Part V: Balancing Pressure and Gravity"
- Mastering Astronomy
  - Tell us if there continue to be errors. There is a self-led tutorial that may cause problems similar to HW2

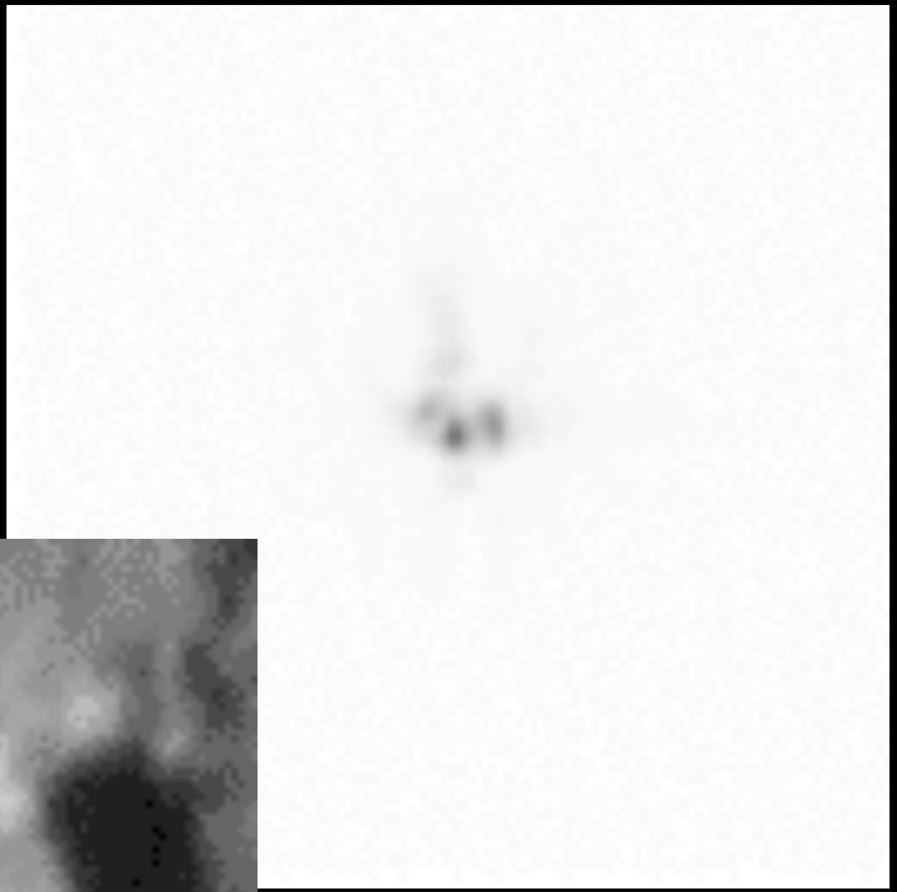
Test 2

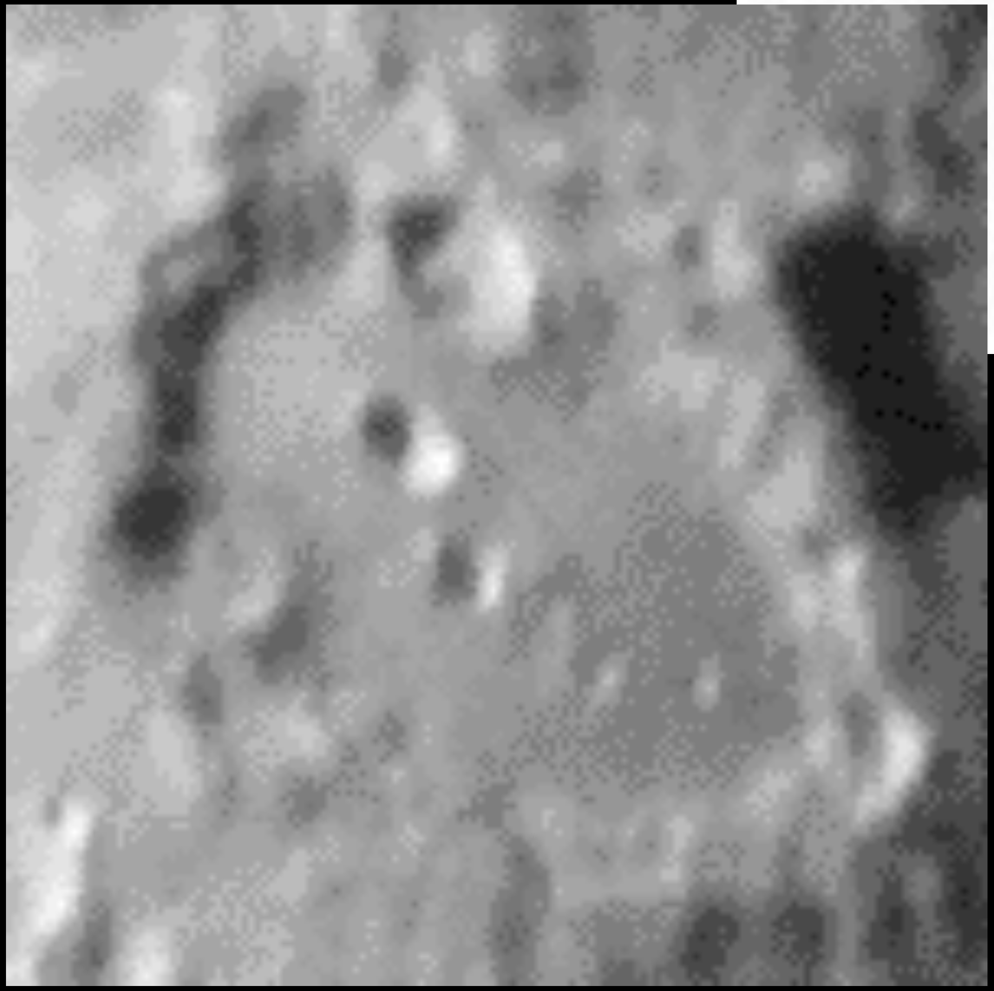
- Question 17 was dropped
- Question 9 was curved to be out of 1 instead of 2 points
- One concept commonly missed: Twinkling

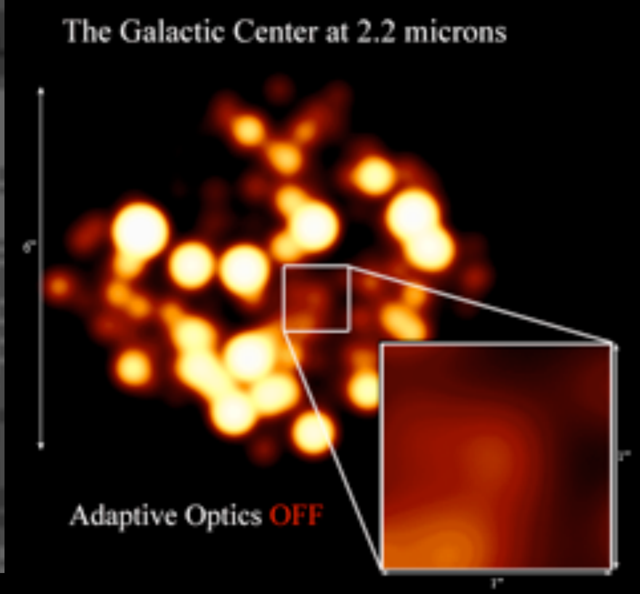
Atmospheric Seeing



Parallel light waves are distorted







Limits the maximum resolution of ground-based telescopes