Chapter 12: Evolution of Low Mass Stars

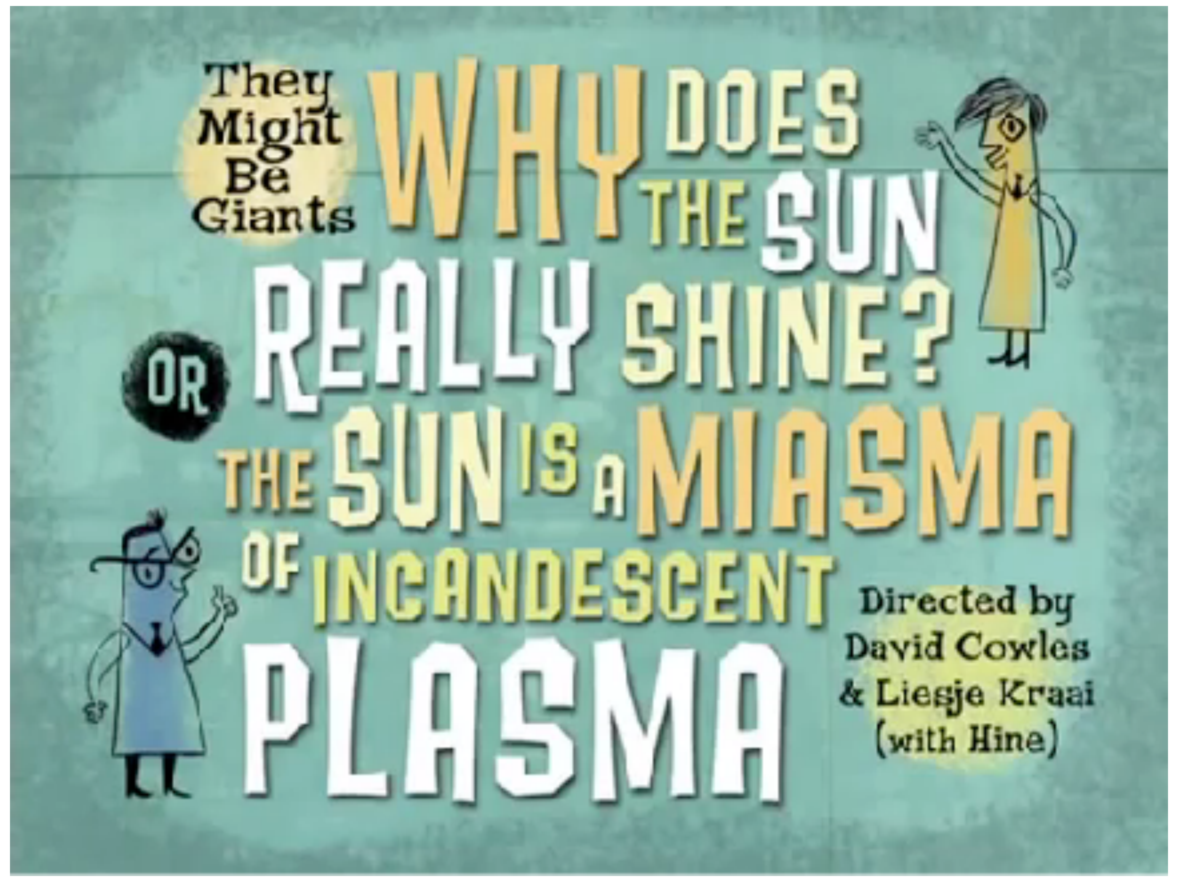
Chapter 12 Reading Assignment due now

In-class/HW Assignment due now!

Turn in extra credit planetarium/observing reports up front (no due date for them, but if you've gone, write them up soon and turn them in!)

Are your grades in Canvas correct???

Midterms available up front



Stellar Properties

Age

Color

Luminosity

Spectral Type

Mass

Temperature

Size

Which of these is most important?

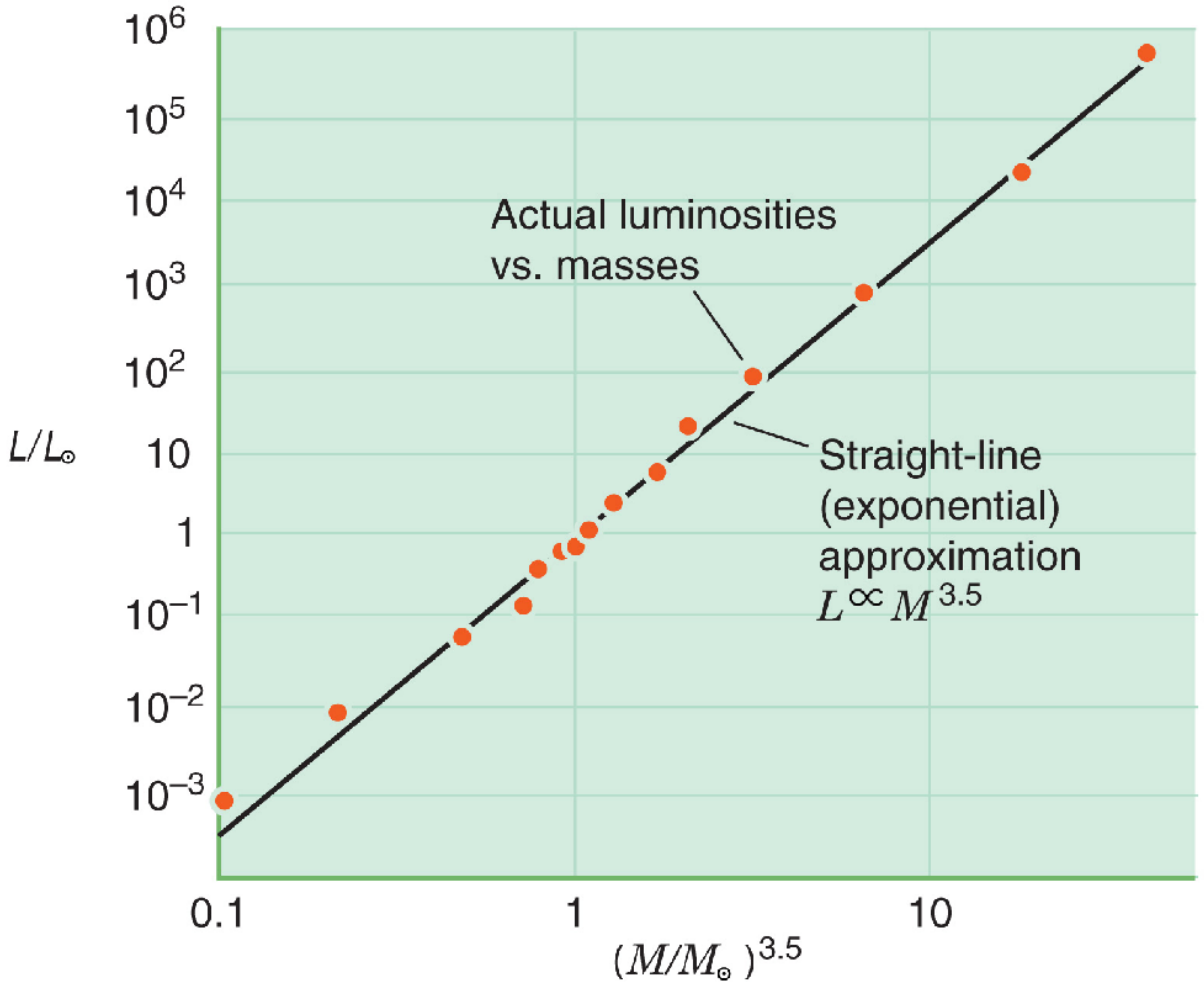
Stellar Properties

Mass

Age

- Color
- Luminosity
- Spectral Type
- Temperature
- Size

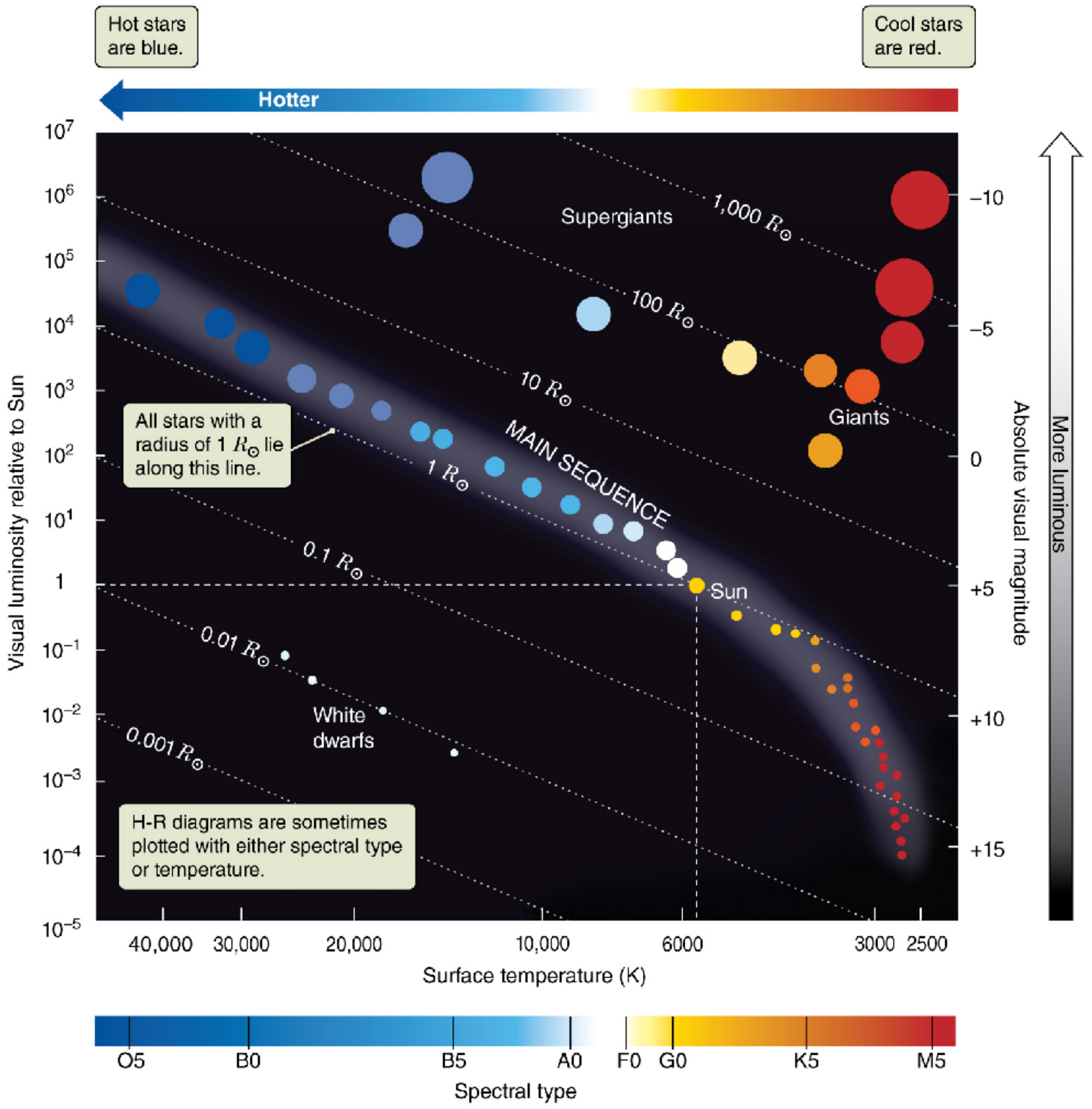
Luminosity depends on mass

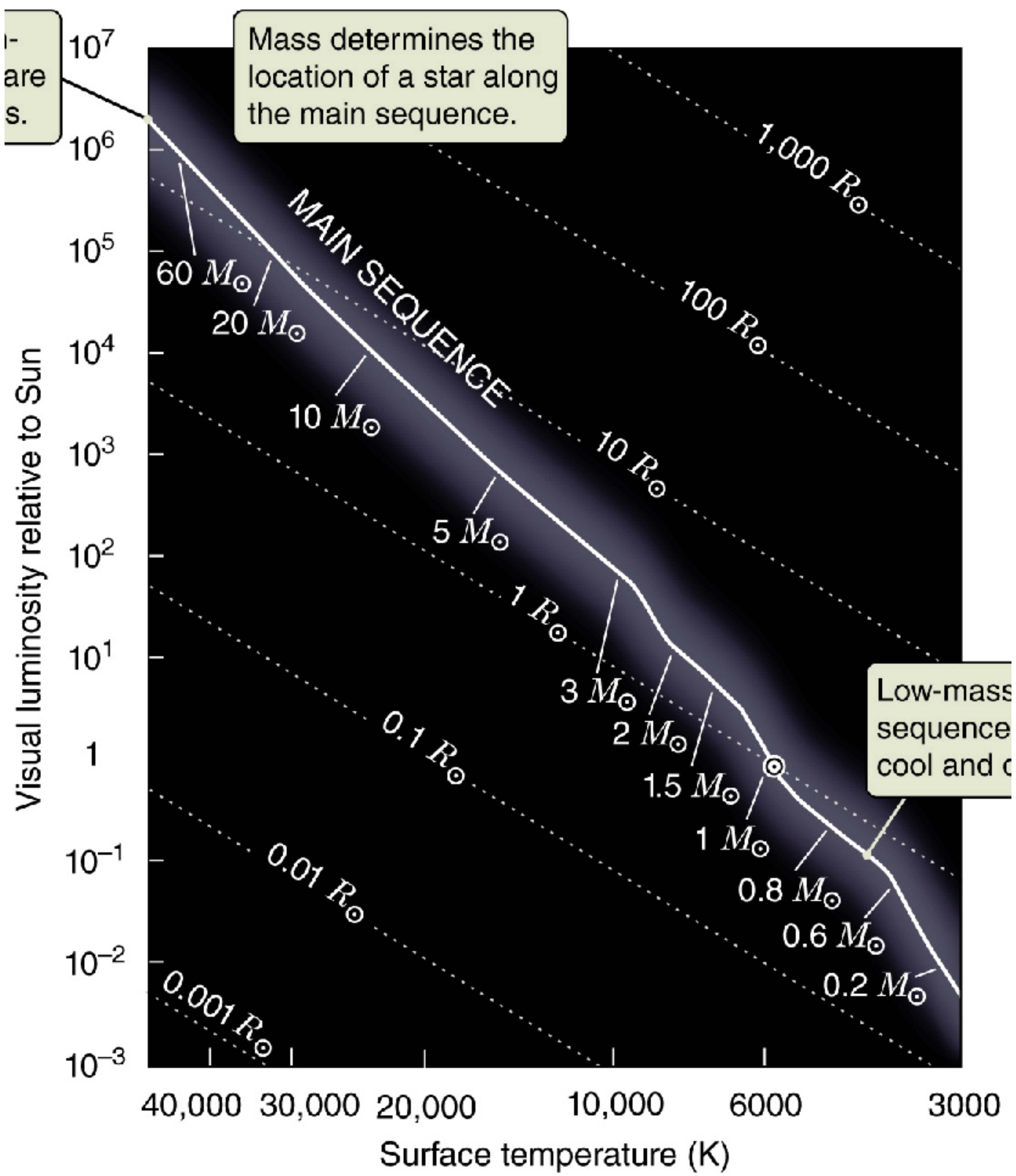


$$\frac{L_{\rm MS}}{L_\odot} = \left(\frac{M_{\rm MS}}{M_\odot}\right)^{3.5}$$

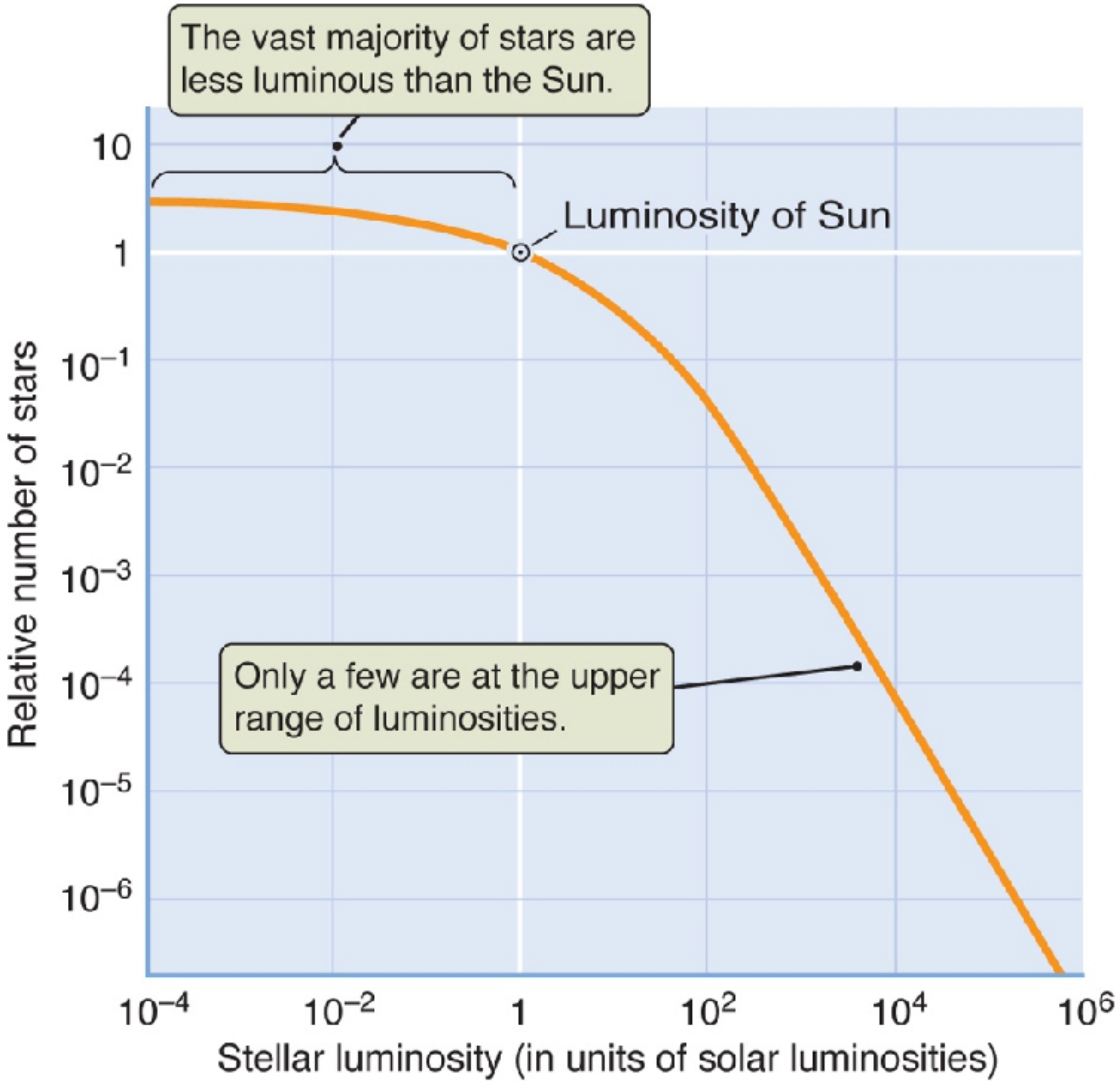

Low
Mass
M K G F A B O
High
Mass
130


Low
Mass
M
K
G
F
A
B
O
High
Mass


Hot stars are blue.
Cool stars are red.
Hotter
Supergiants
1,000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
1 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
0.001 $R_\odot$
Giants
MAIN SEQUENCE
Sun
White dwarfs
All stars with a radius of 1 $R_\odot$ lie along this line.
H-R diagrams are sometimes plotted with either spectral type or temperature.
Visual luminosity relative to Sun
Absolute visual magnitude
More luminous
Surface temperature (K)
40,000 30,000 20,000 10,000 6000 3000 2500
O5 B0 B5 A0 F0 G0 K5 M5
Spectral type


Mass determines the location of a star along the main sequence.
MAIN SEQUENCE
60 $M_\odot$
20 $M_\odot$
10 $M_\odot$
5 $M_\odot$
3 $M_\odot$
2 $M_\odot$
1.5 $M_\odot$
1 $M_\odot$
0.8 $M_\odot$
0.6 $M_\odot$
0.2 $M_\odot$
1,000 $R_\odot$
100 $R_\odot$
10 $R_\odot$
1 $R_\odot$
0.1 $R_\odot$
0.01 $R_\odot$
0.001 $R_\odot$
Low-mass sequence cool and
Visual luminosity relative to Sun
Surface temperature (K)
40,000 30,000 20,000 10,000 6000 3000

Why are fainter (and less massive) stars more common than brighter ones?



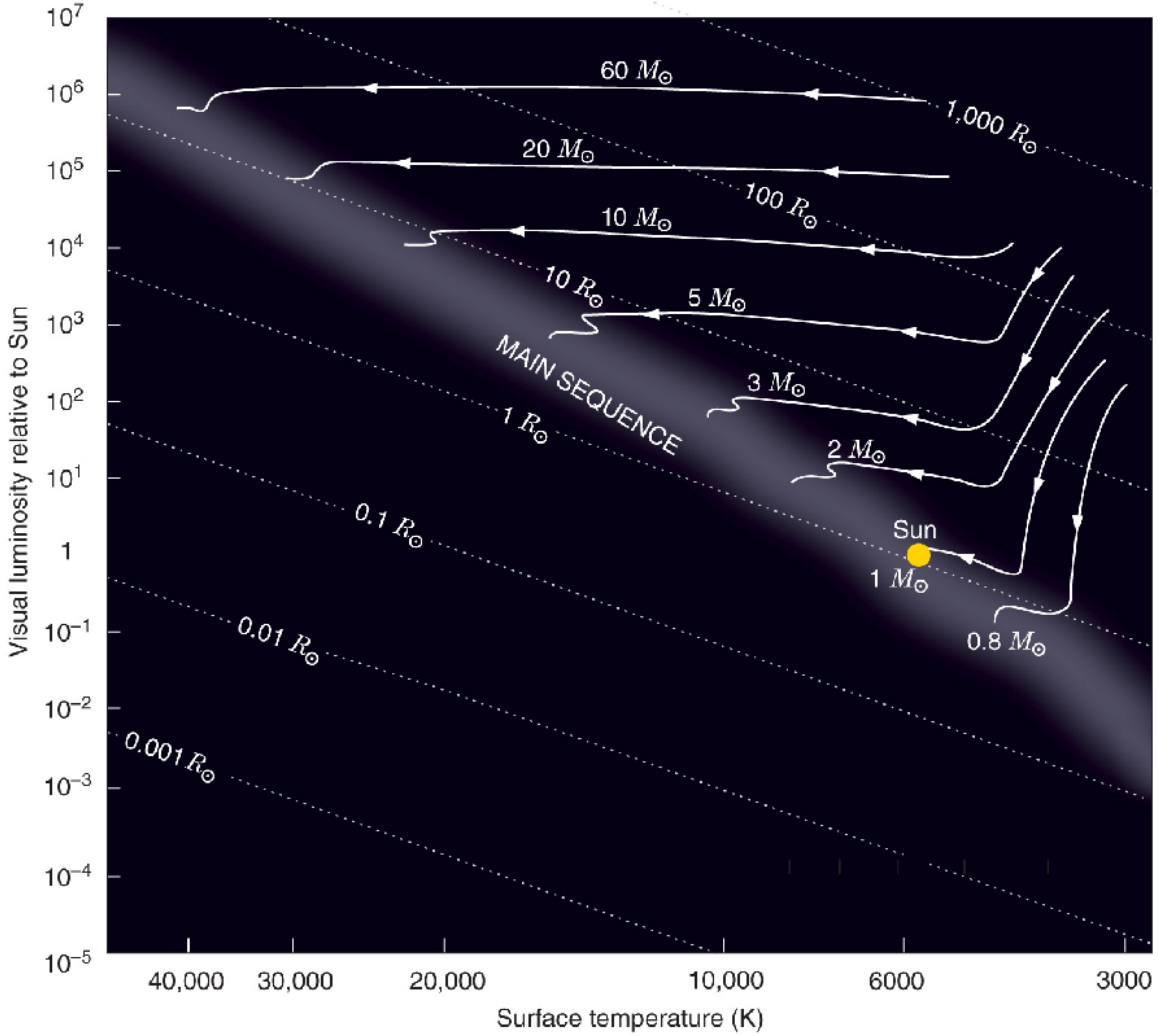
A) They live longer

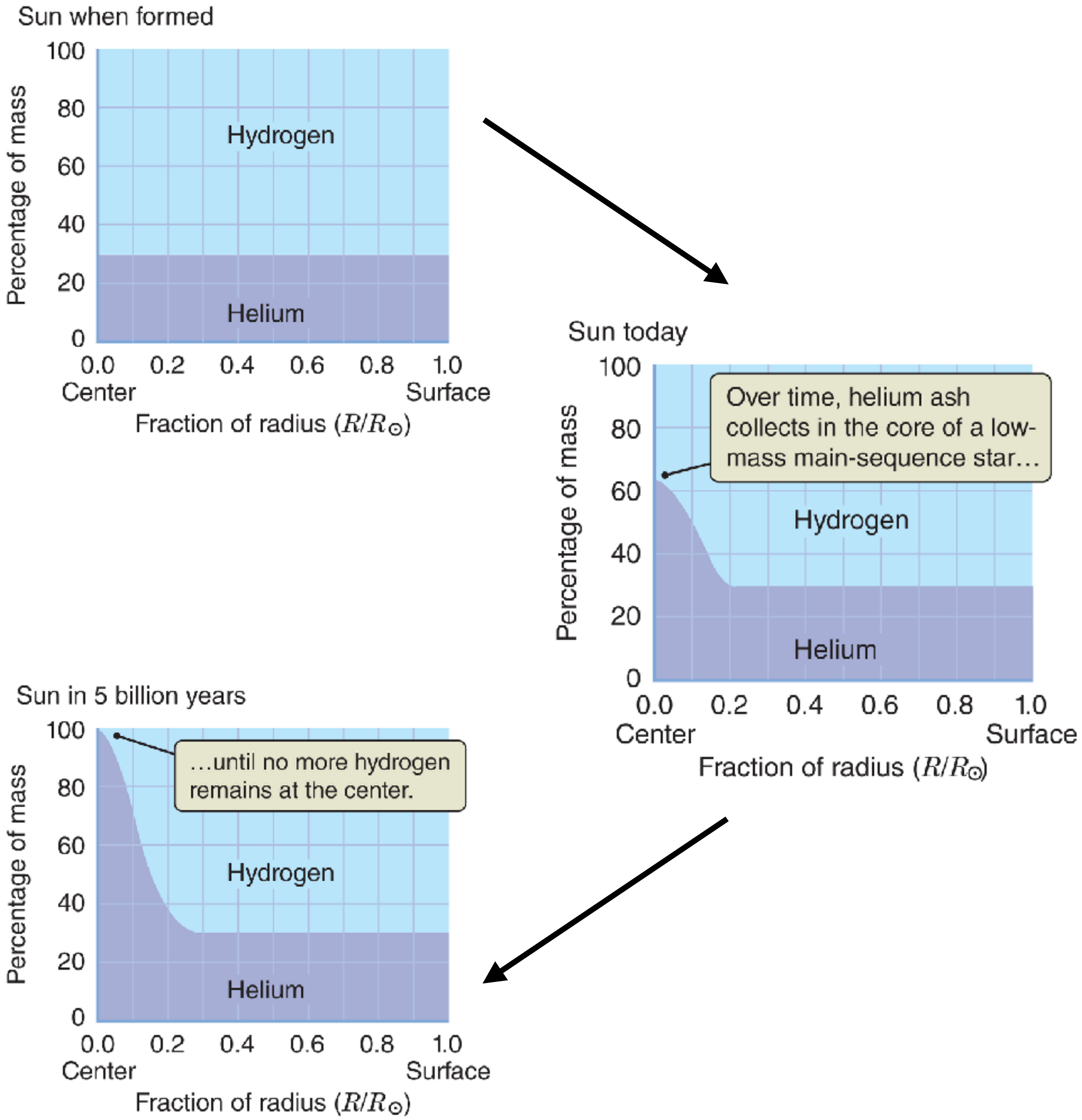
B) They form more frequently

C) They aren't more common, we just see them more easily

The future of our Sun and the evolution of low-mass stars

Protostars to Stars





Lifetime as a function of mass

$$\text{Main Sequence Lifetime} = 1 \times 10^{10} \; \frac{\text{Mass}\,[\text{M}_\odot]}{\text{Luminosity}\,[\text{L}_\odot]} \; \text{years}$$

$$\frac{L_{\text{MS}}}{L_\odot} = \left(\frac{M_{\text{MS}}}{M_\odot}\right)^{3.5}$$

$$\text{Main Sequence Lifetime} = 10^{10} \, \frac{M_{\text{MS}}/M_\odot}{(M_{\text{MS}}/M_\odot)^{3.5}} \; \text{years}$$

$$\text{Main Sequence Lifetime} = 10^{10} \left(\frac{M_{\text{MS}}}{M_\odot}\right)^{-2.5} \; \text{years}$$

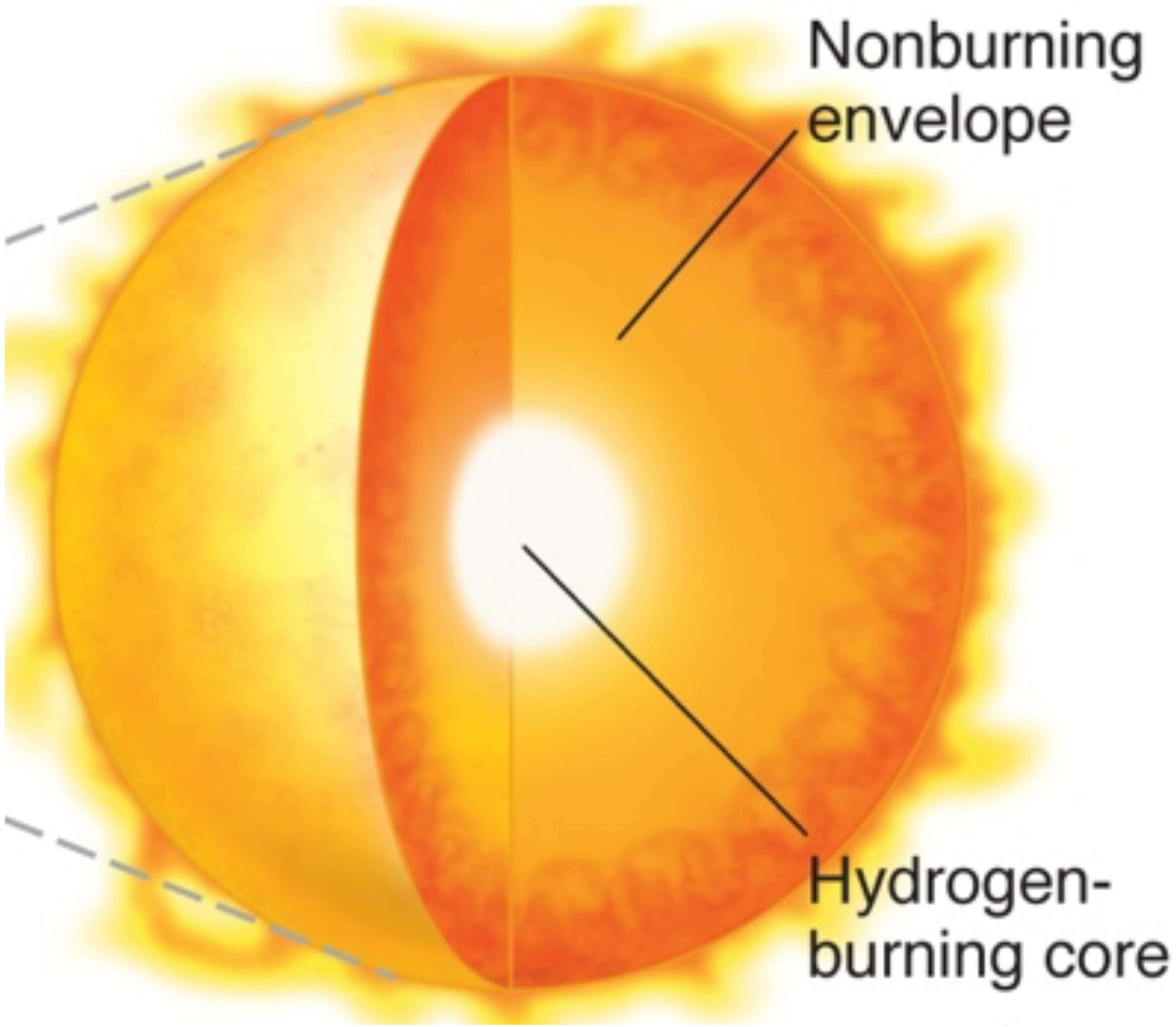
Main Sequence

Power: Hydrogen Core Burning

Temperature = 5800 K

Luminosity = 1 L_{Sun}

Lifetime = 10 billion years



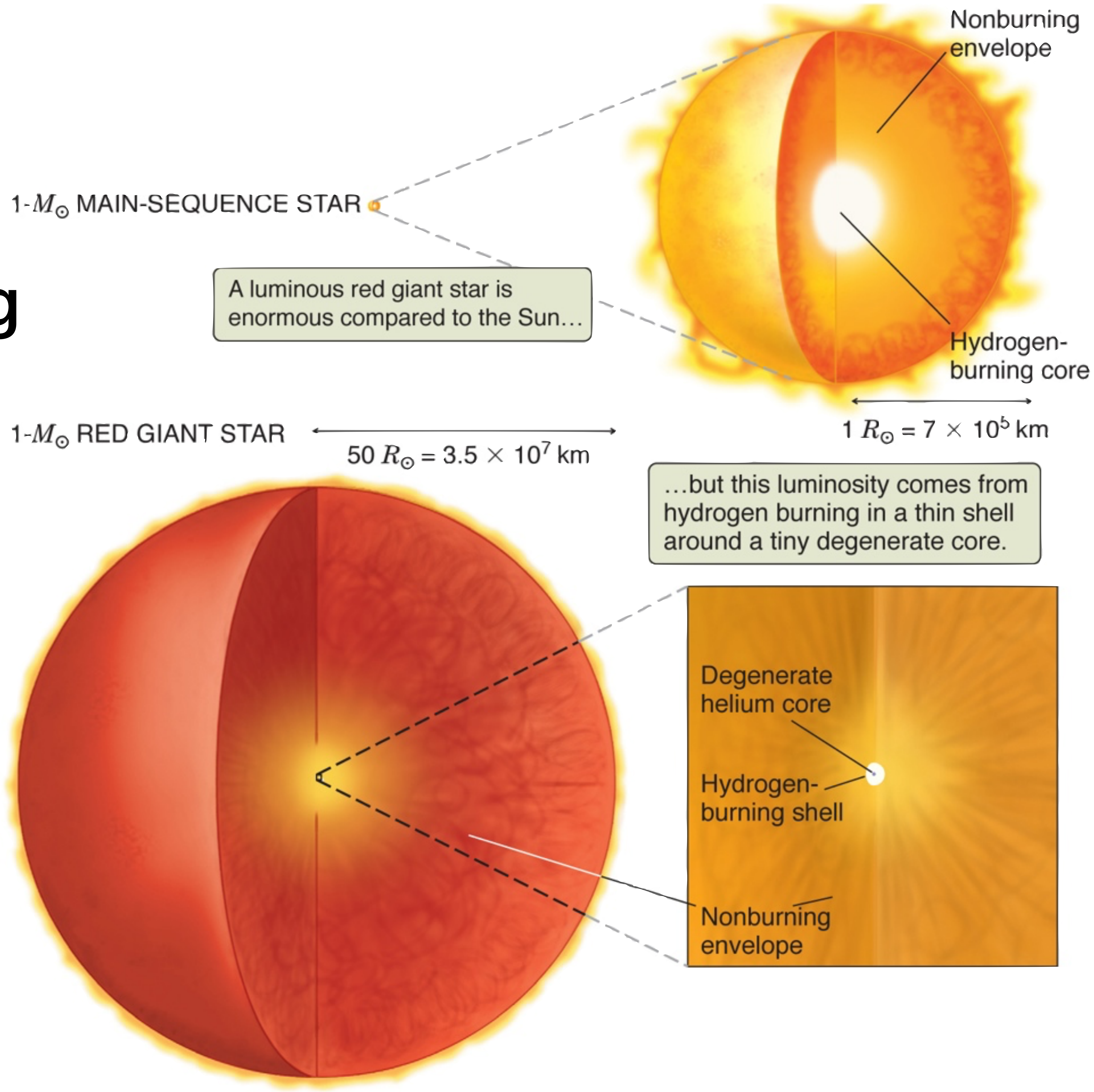
Red Giant Branch

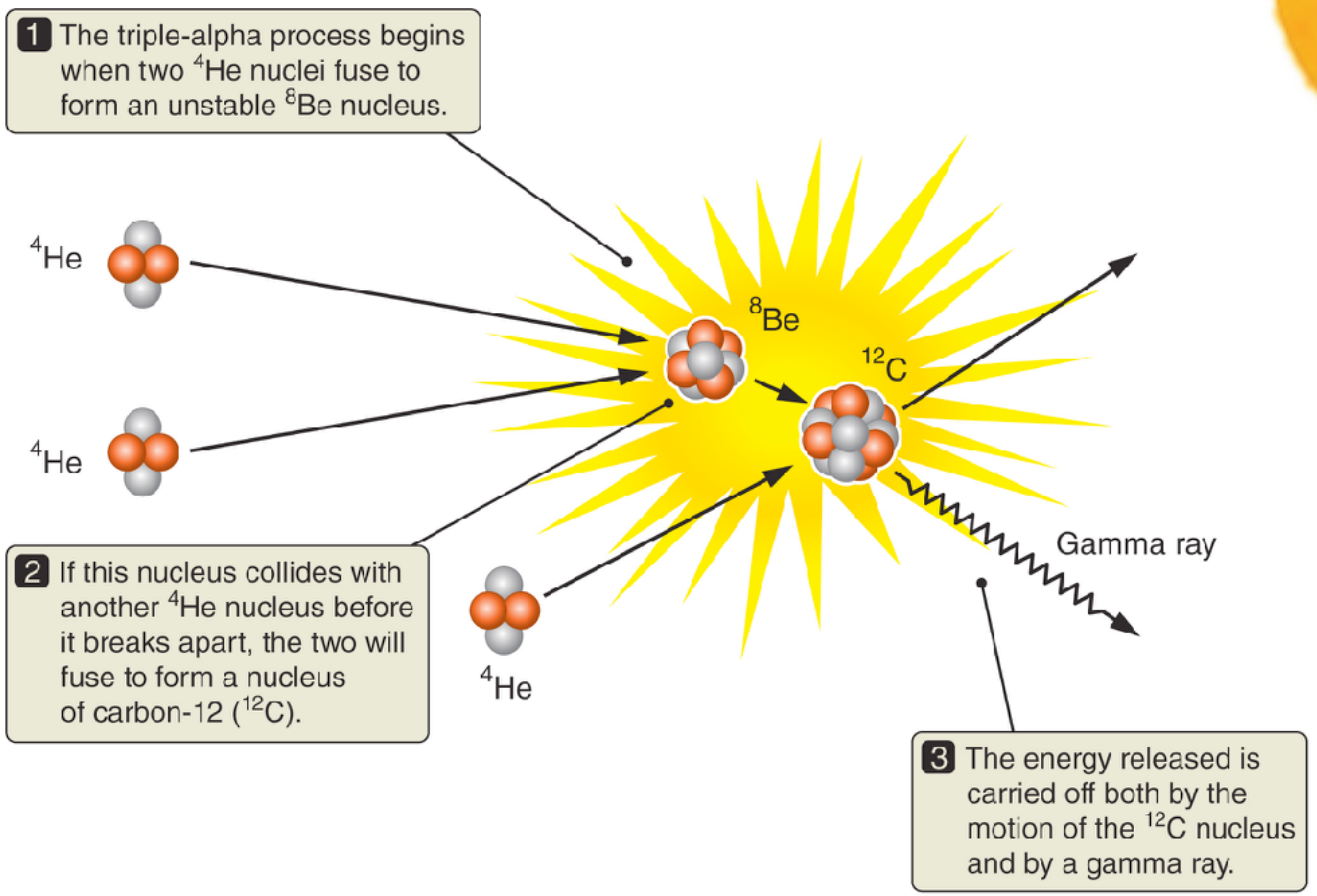
Power: Hydrogen Shell Burning

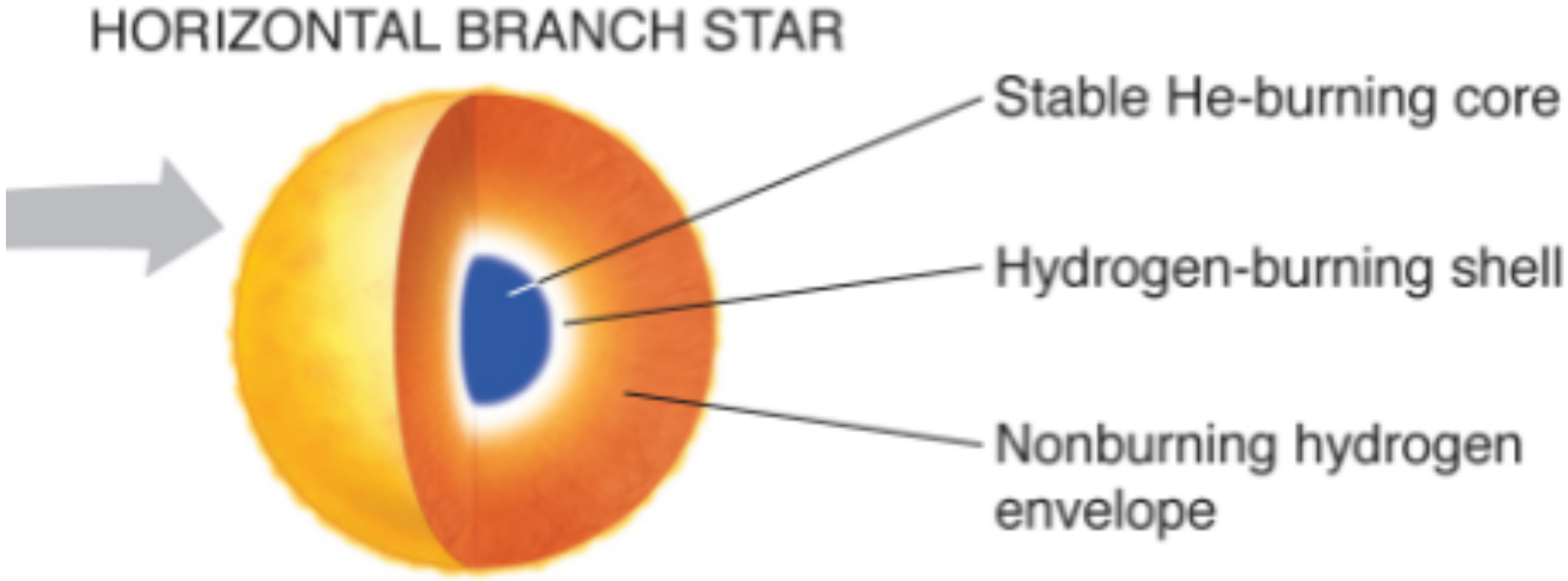
Final Temperature = 3200 K

Final Luminosity = 1000 L_{Sun}

Lifetime = 200 million years







Helium Burning or Horizontal Branch

Power: Helium (into Carbon) Core Burning
+ Hydrogen shell burning
Temperature = 4500 K
Luminosity = 100 L_{Sun}
Lifetime = 100 million years

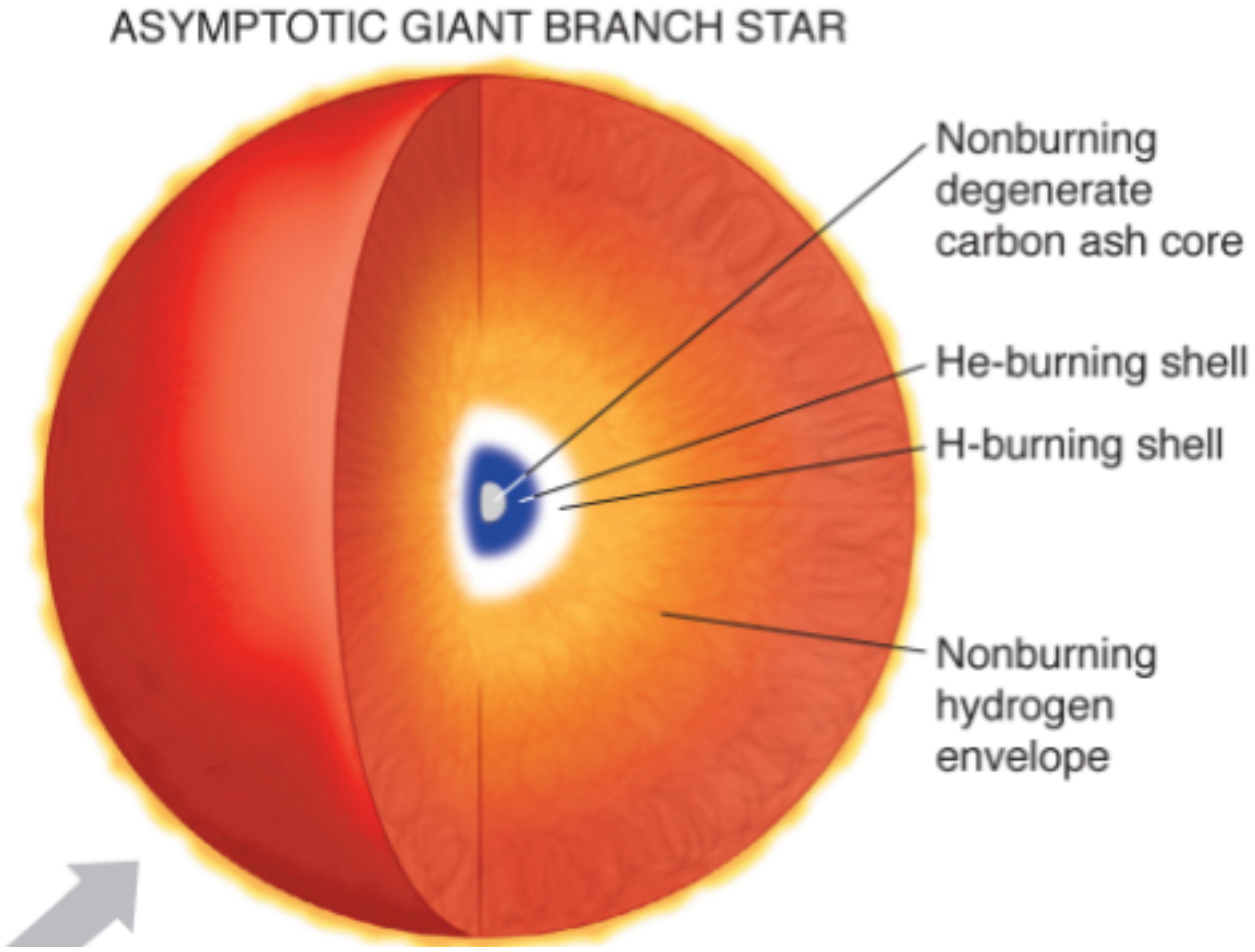
Asymptotic Giant Branch

Power: Helium shell burning
+ Hydrogen shell burning

Final Temperature = 3000 K

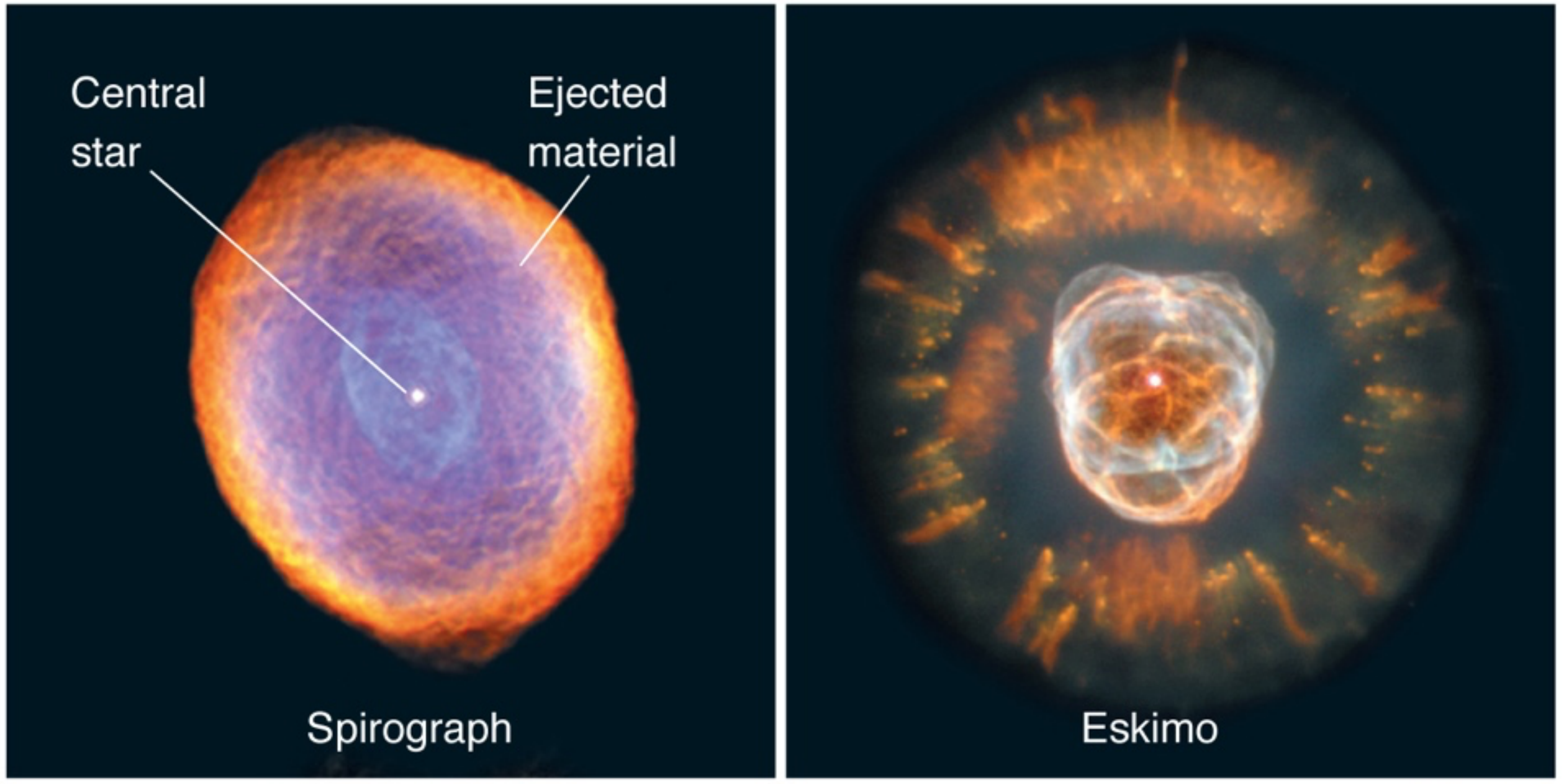
Final Luminosity = 5000 L_{Sun}

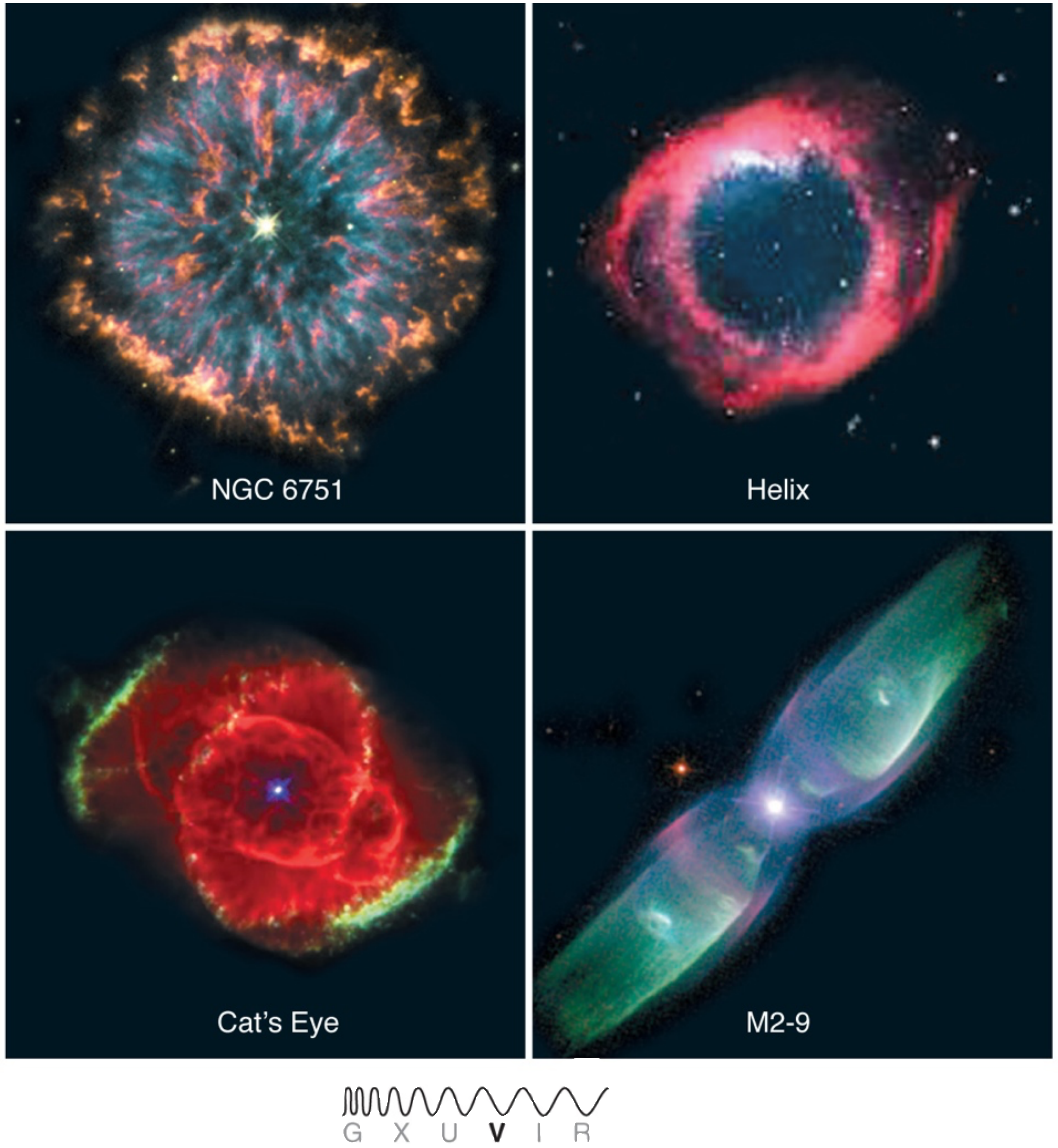
Lifetime = 1 million years



Planetary Nebulae

outer atmosphere ejected by radiation from the core





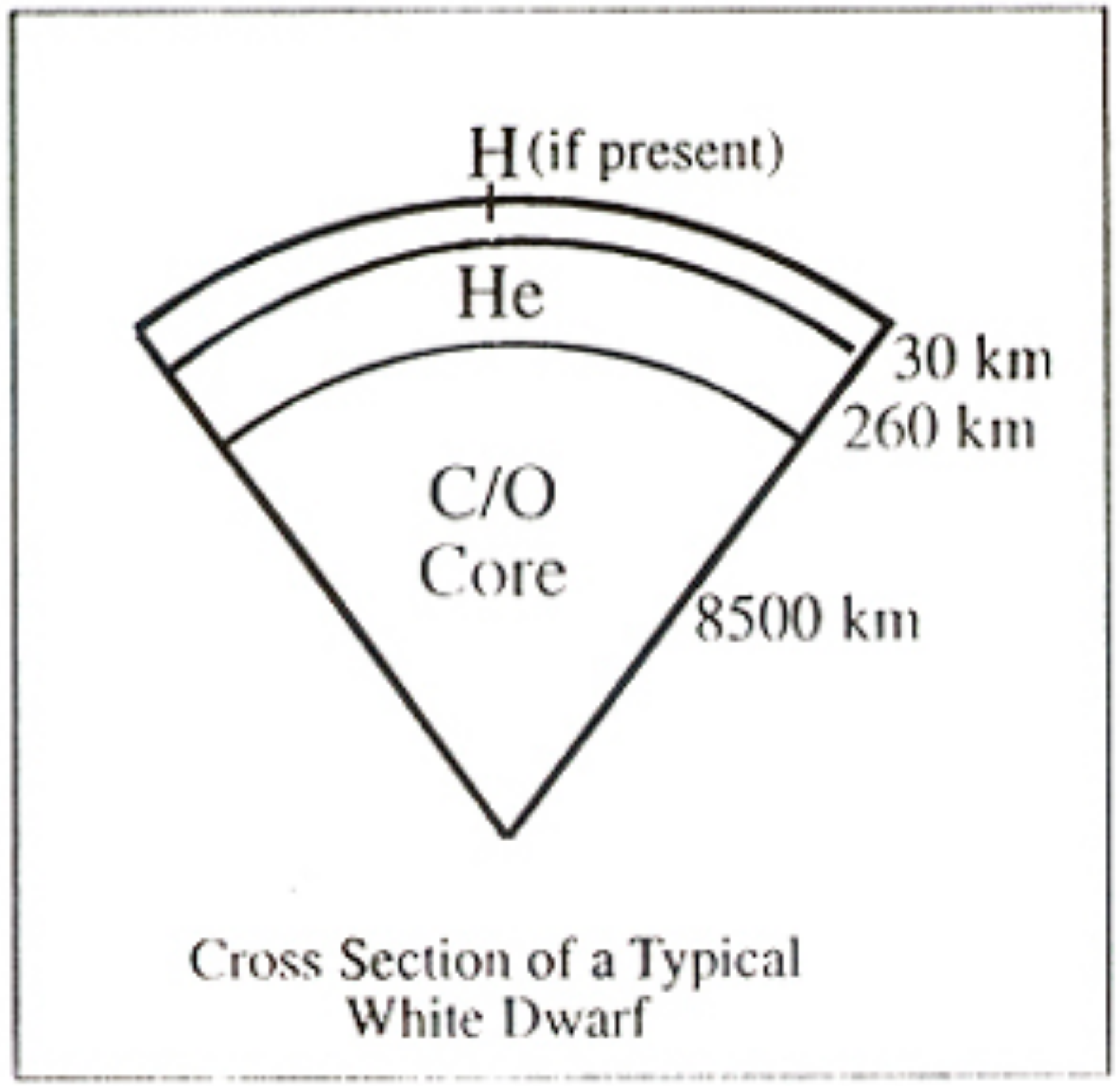
White Dwarf

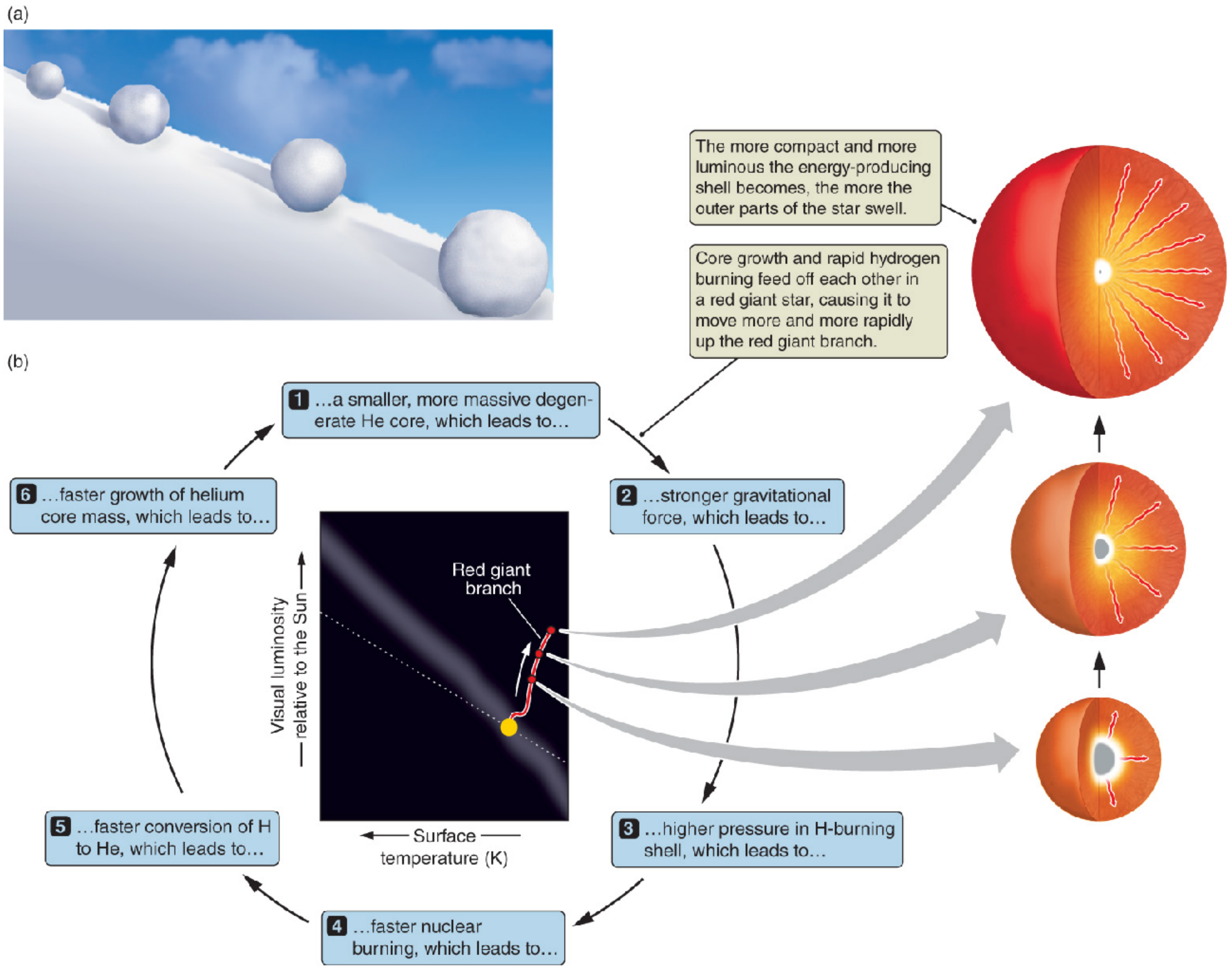
Power: None

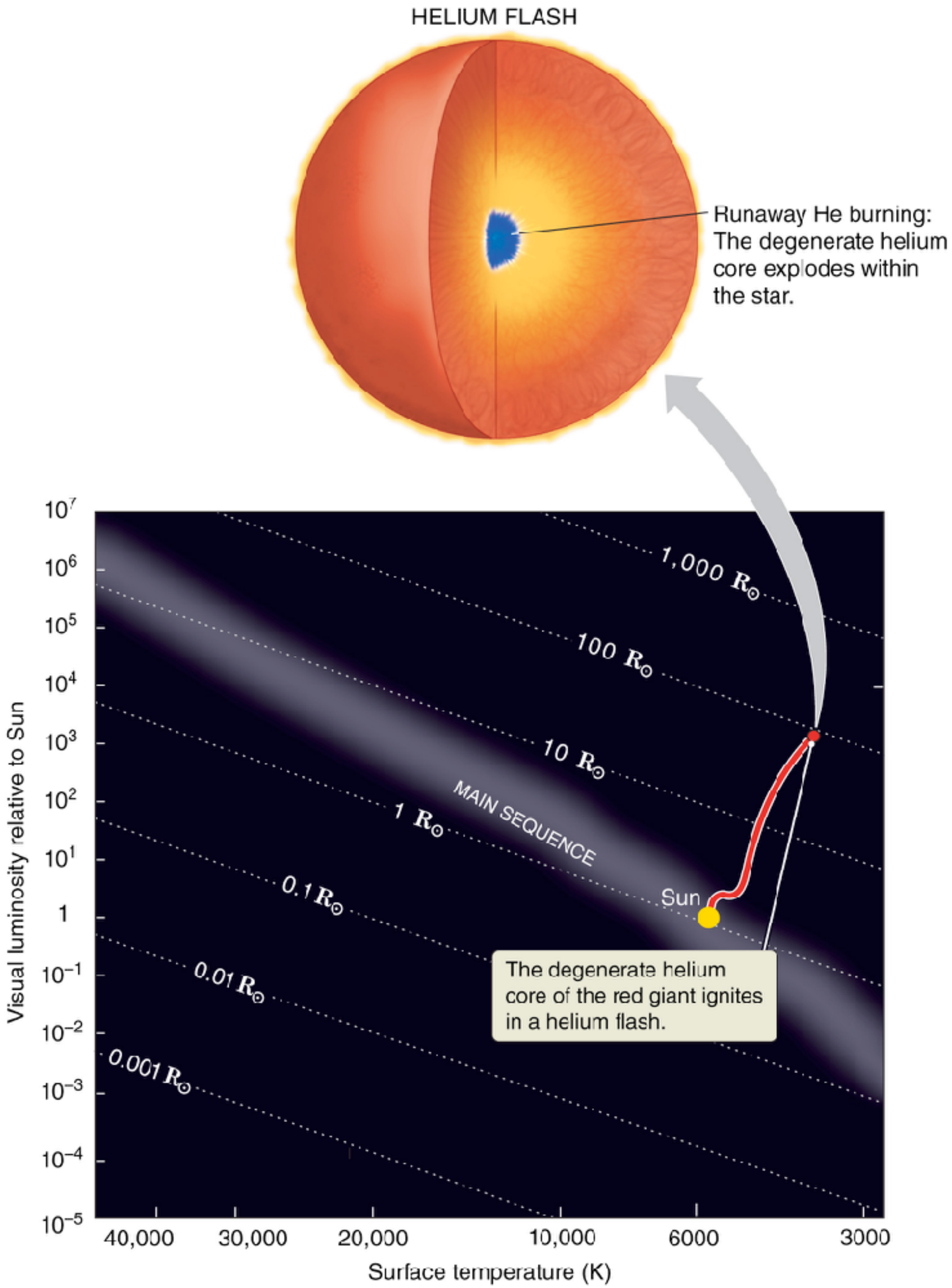
Temperature = 15000 K

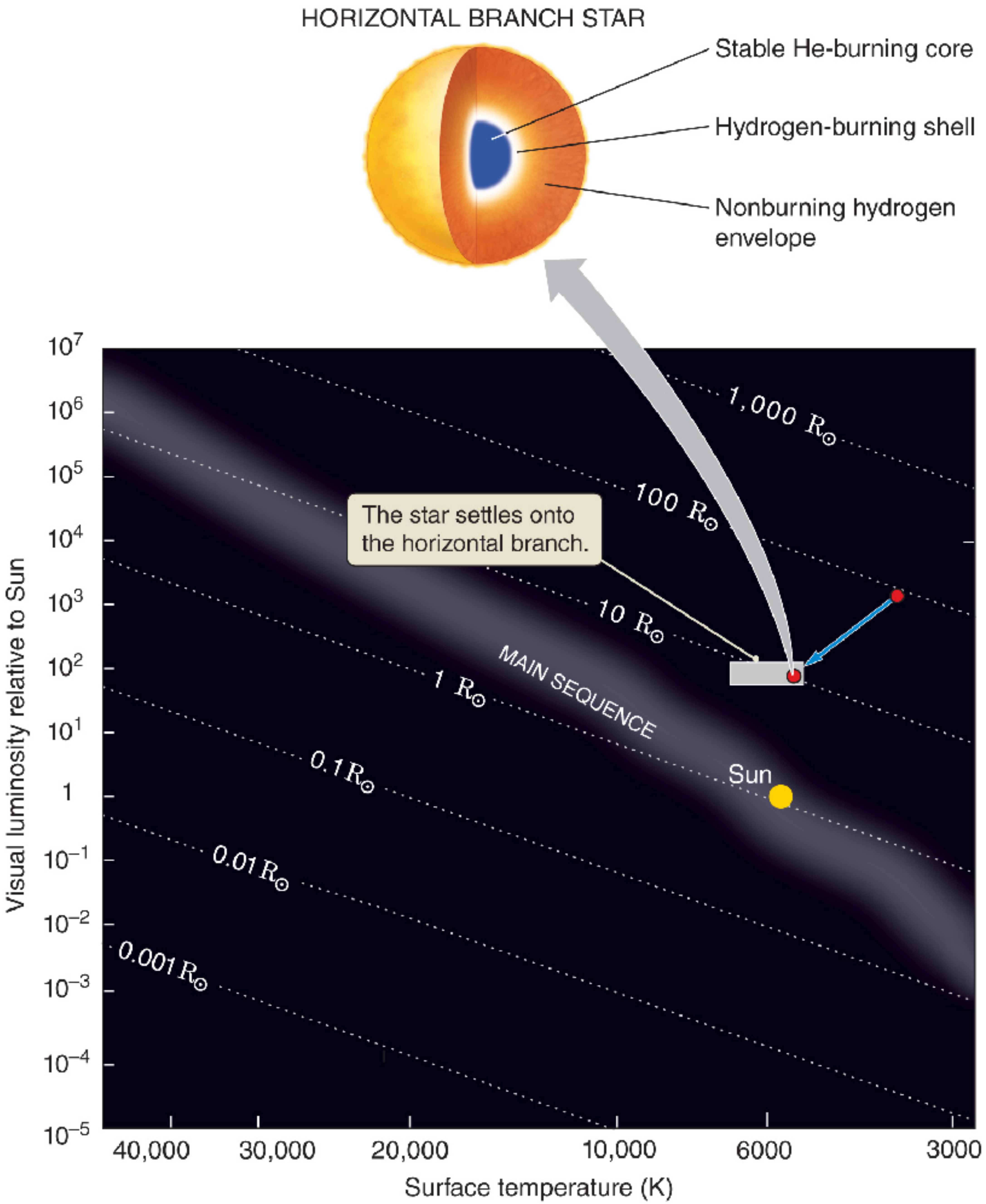
Luminosity = 0.001 L_{Sun}

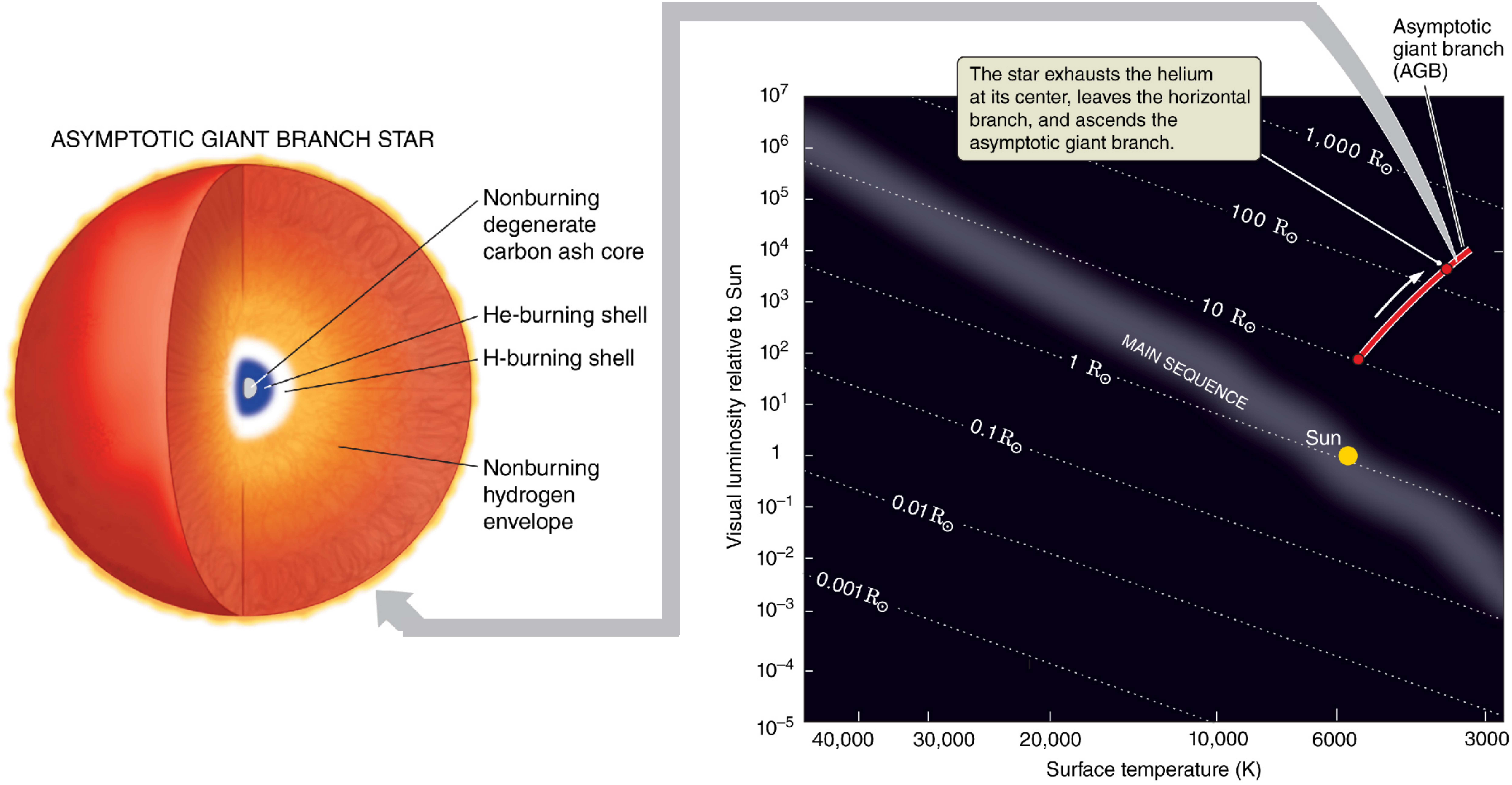
Lifetime = 1 billion years
(to cool down to ~7000 K)

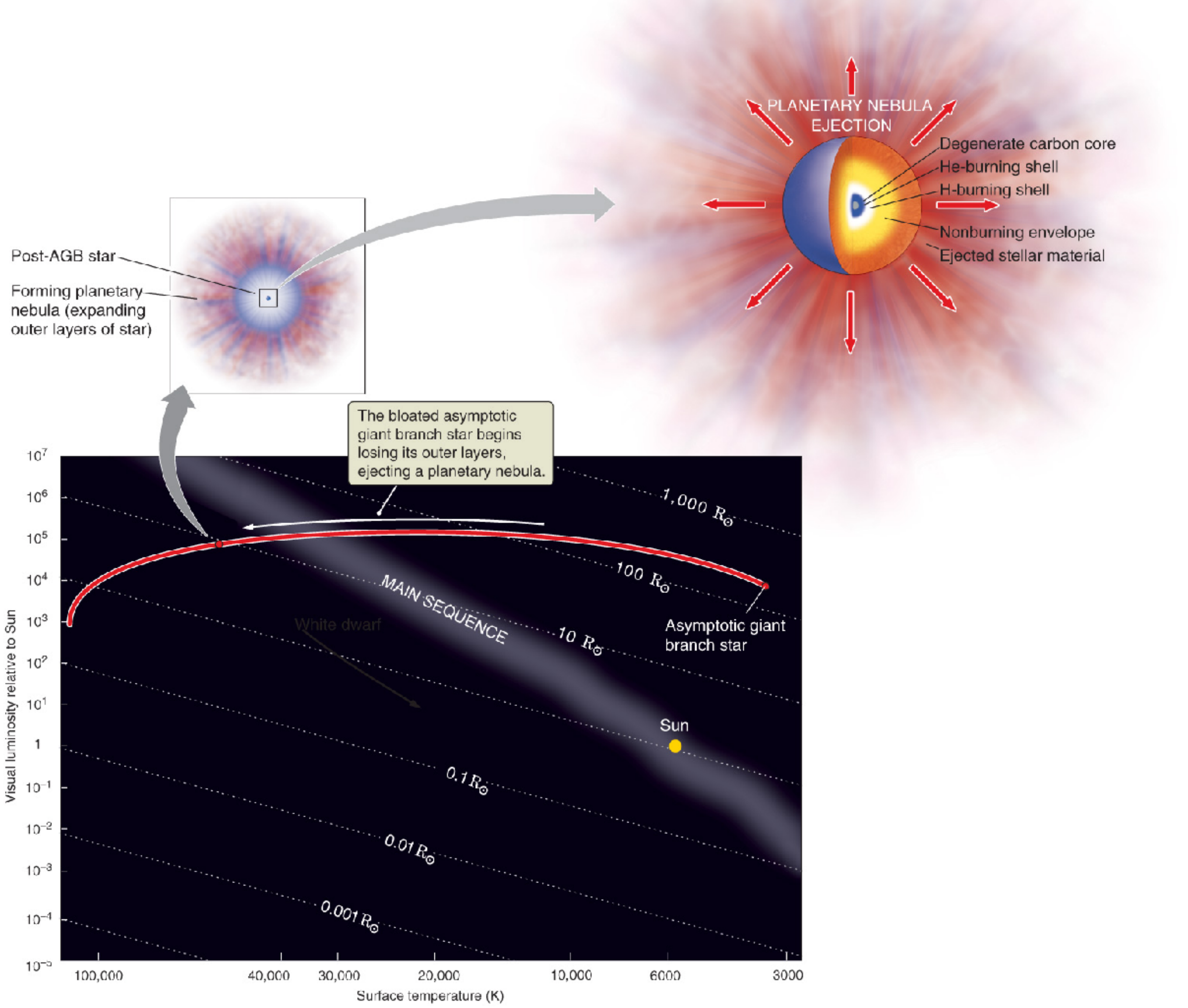


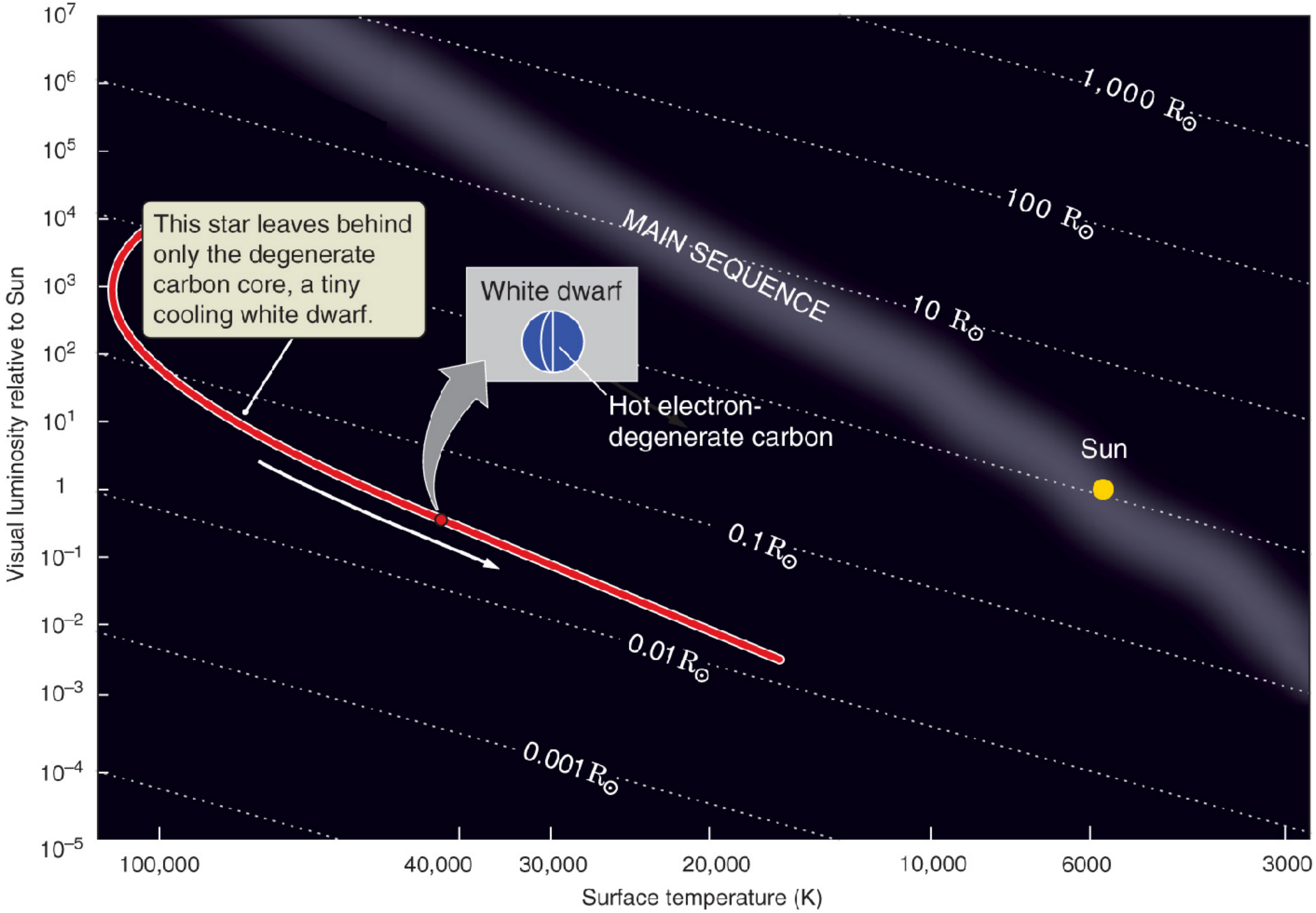

(a)
(b)
The more compact and more luminous the energy-producing shell becomes, the more the outer parts of the star swell.
Core growth and rapid hydrogen burning feed off each other in a red giant star, causing it to move more and more rapidly up the red giant branch.
1 ...a smaller, more massive degenerate He core, which leads to...
2 ...stronger gravitational force, which leads to...
3 ...higher pressure in H-burning shell, which leads to...
4 ...faster nuclear burning, which leads to...
5 ...faster conversion of H to He, which leads to...
6 ...faster growth of helium core mass, which leads to...
Red giant branch
Visual luminosity relative to the Sun
Surface temperature (K)


HELIUM FLASH
Runaway He burning: The degenerate helium core explodes within the star.
The degenerate helium core of the red giant ignites in a helium flash.
1,000 R⊙
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
0.001 R⊙
MAIN SEQUENCE
Sun
Visual luminosity relative to Sun
Surface temperature (K)
40,000
30,000
20,000
10,000
6000
3000


HORIZONTAL BRANCH STAR
Stable He-burning core
Hydrogen-burning shell
Nonburning hydrogen envelope
The star settles onto the horizontal branch.
1,000 R⊙
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
0.001 R⊙
MAIN SEQUENCE
Sun
Visual luminosity relative to Sun
Surface temperature (K)
40,000
30,000
20,000
10,000
6000
3000


ASYMPTOTIC GIANT BRANCH STAR
Nonburning degenerate carbon ash core
He-burning shell
H-burning shell
Nonburning hydrogen envelope
The star exhausts the helium at its center, leaves the horizontal branch, and ascends the asymptotic giant branch.
Asymptotic giant branch (AGB)
1,000 R⊙
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
0.01 R⊙
0.001 R⊙
MAIN SEQUENCE
Sun
Visual luminosity relative to Sun
Surface temperature (K)
40,000
30,000
20,000
10,000
6000
3000

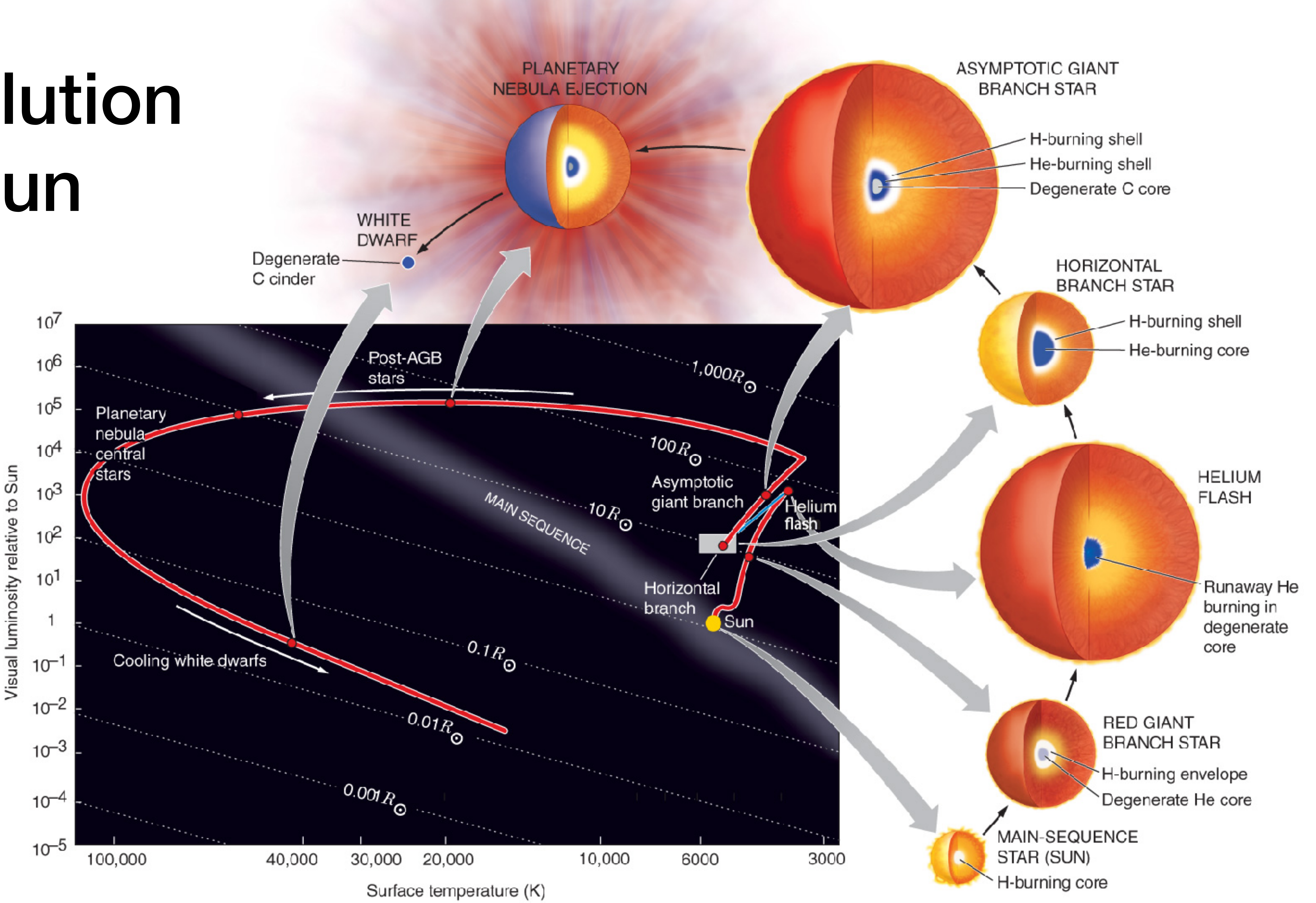

PLANETARY NEBULA EJECTION
Degenerate carbon core
He-burning shell
H-burning shell
Nonburning envelope
Ejected stellar material
Post-AGB star
Forming planetary nebula (expanding outer layers of star)
The bloated asymptotic giant branch star begins losing its outer layers, ejecting a planetary nebula.
1,000 R☉
100 R☉
10 R☉
0.1 R☉
0.01 R☉
0.001 R☉
MAIN SEQUENCE
White dwarf
Asymptotic giant branch star
Sun
Visual luminosity relative to Sun
Surface temperature (K)



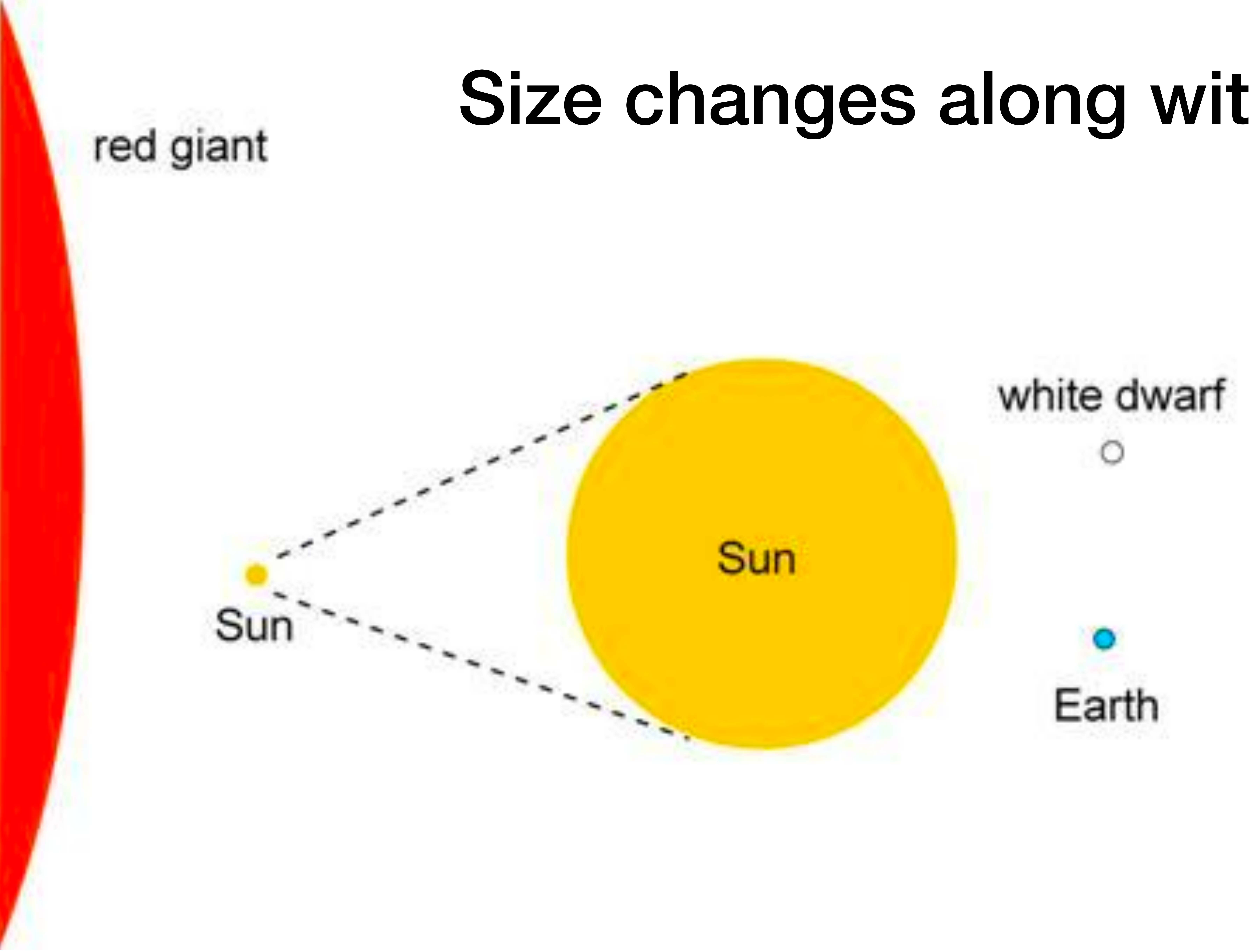
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
10^−1
10^−2
10^−3
10^−4
10^−5
Visual luminosity relative to Sun
100,000
40,000
30,000
20,000
10,000
6000
3000
Surface temperature (K)
1,000 R☉
100 R☉
10 R☉
0.1 R☉
0.01 R☉
0.001 R☉
MAIN SEQUENCE
Sun
This star leaves behind only the degenerate carbon core, a tiny cooling white dwarf.
White dwarf
Hot electron-degenerate carbon

Future Evolution of the Sun

Again, this time with feeling!



Size changes along with temperature



The universe is about 13 billion years old. If I see a 0.7 solar mass star, what phase of evolution will it be in?

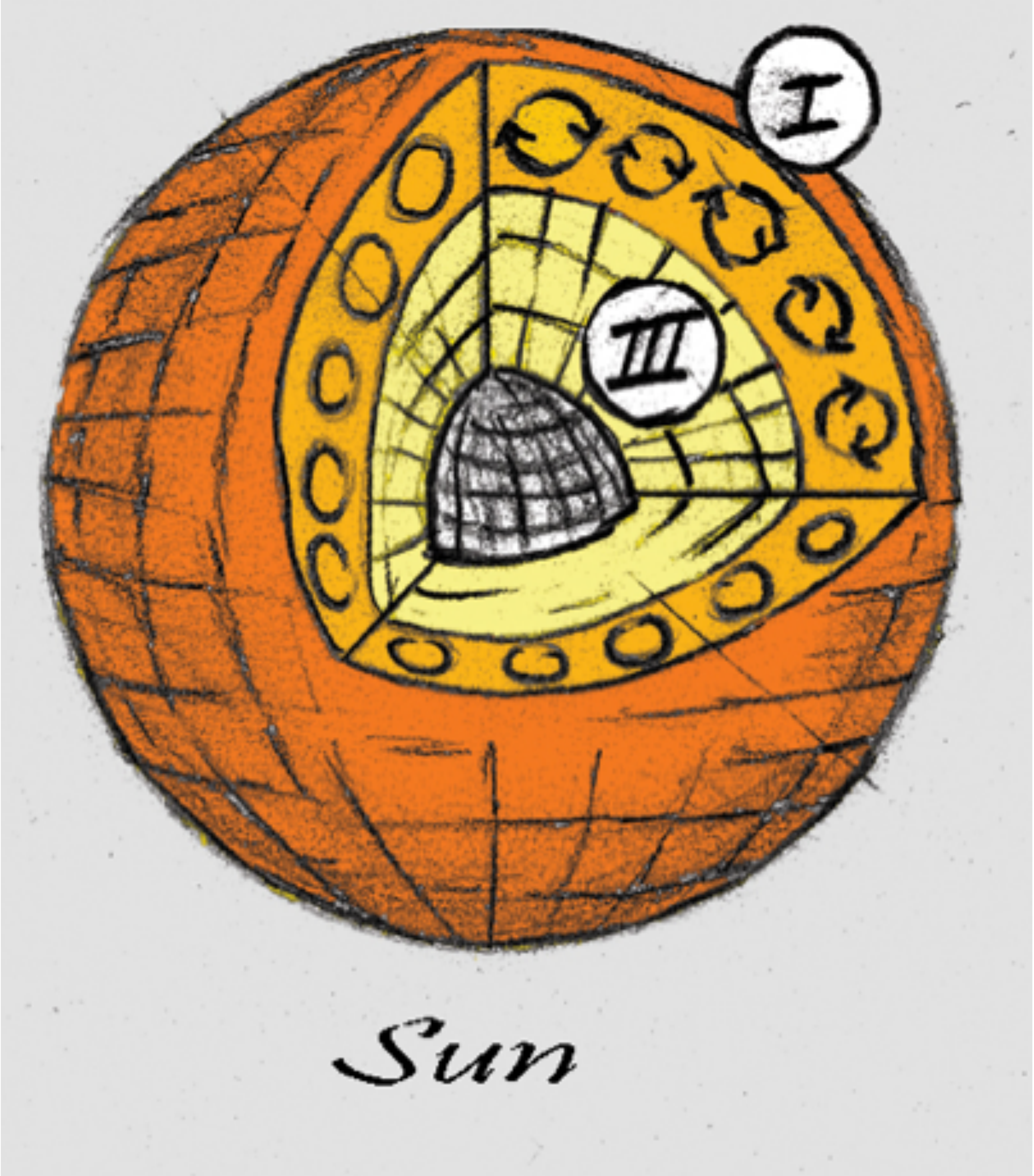
A) Main Sequence

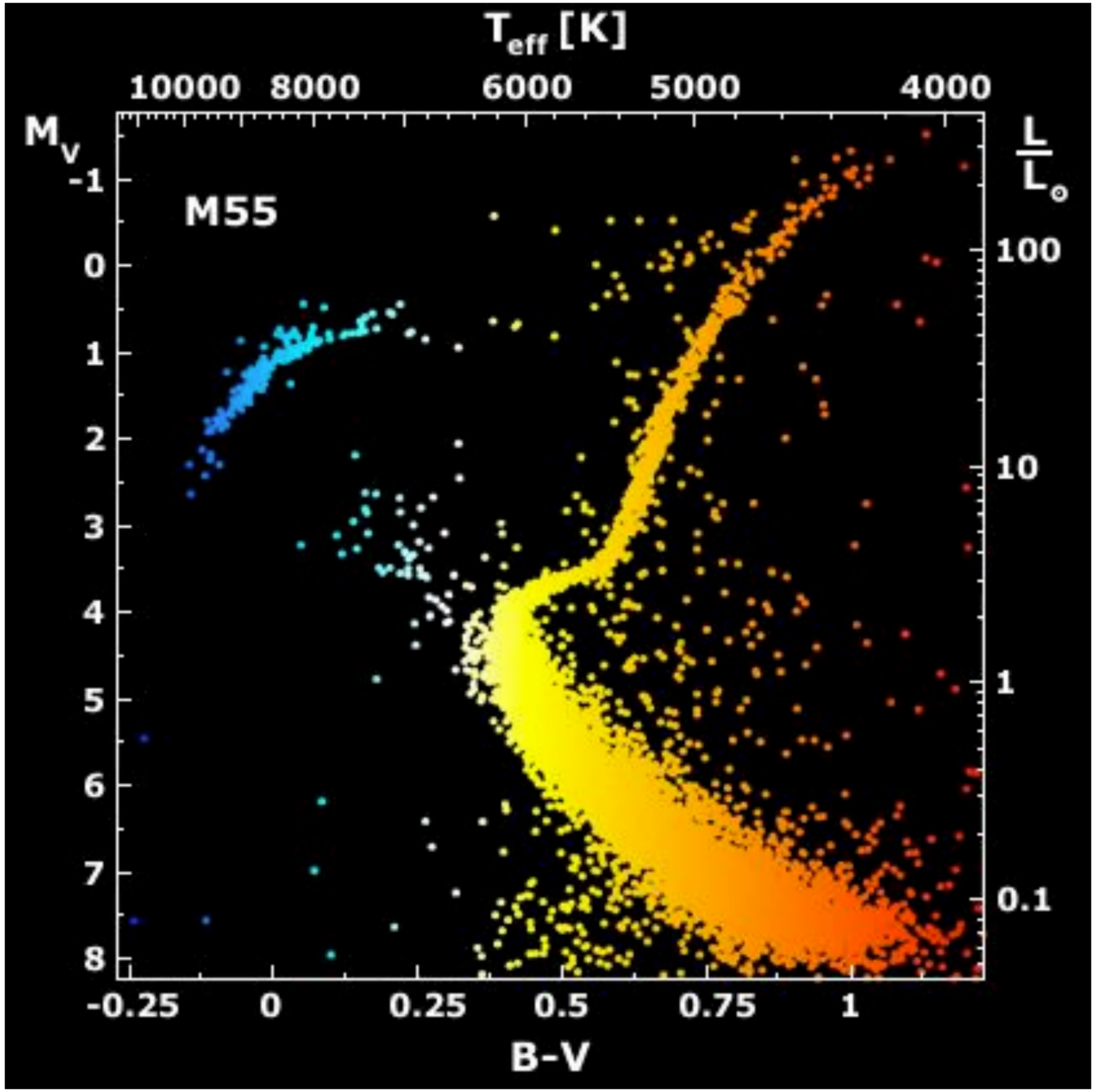
B) Red Giant Branch

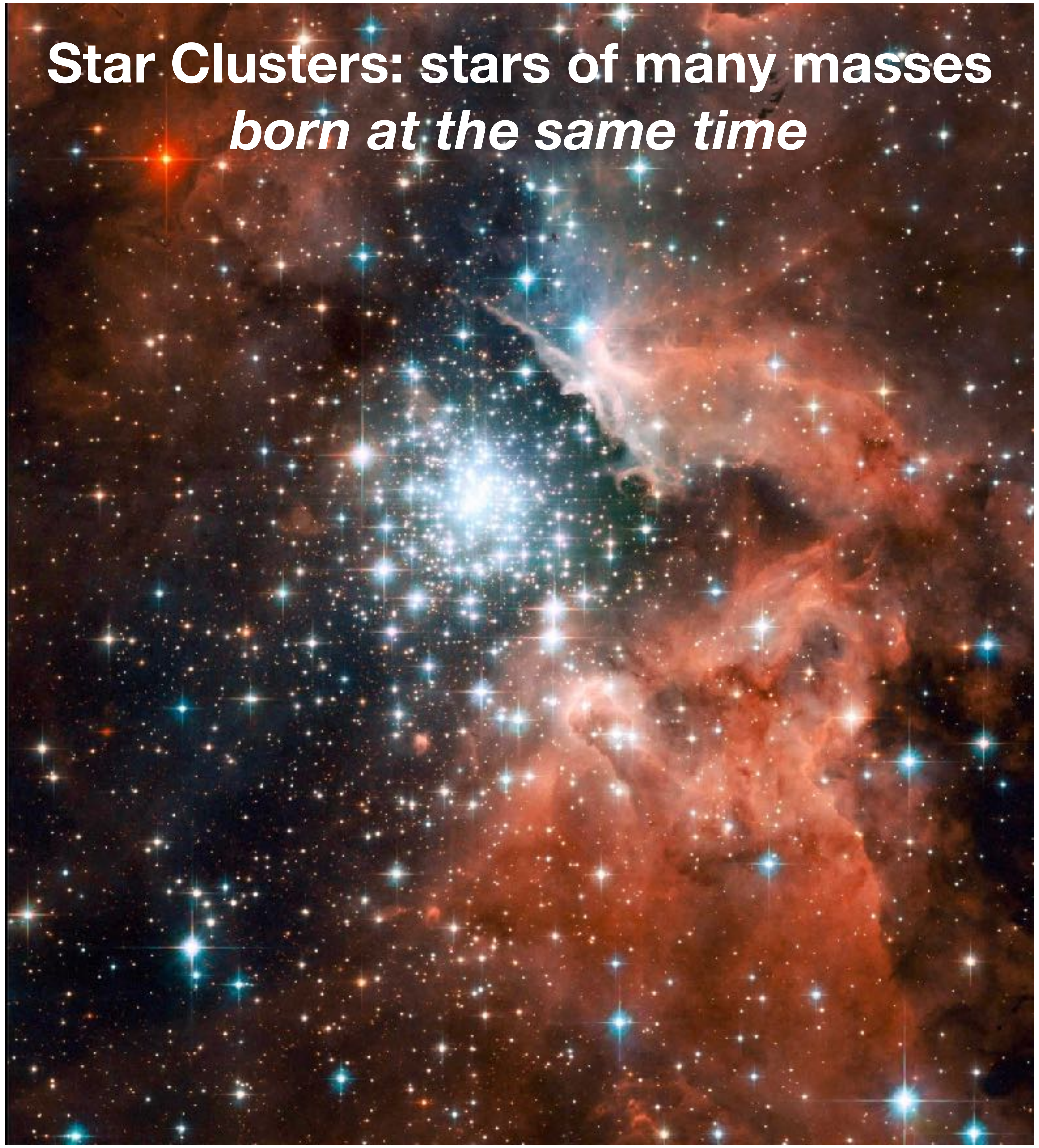
C) Helium Burning

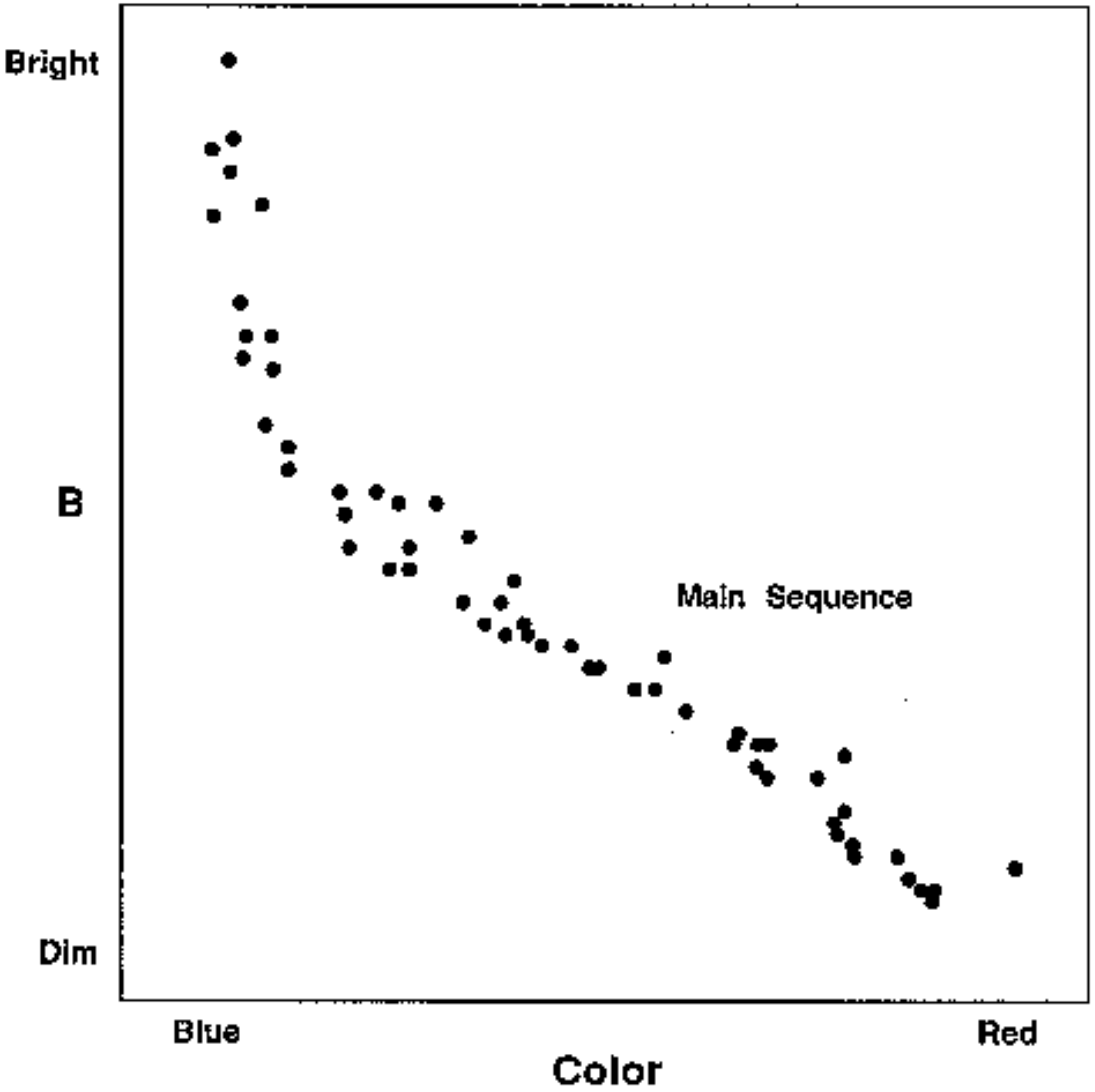
D) Asymptotic Giant Branch

How do we know the different stages of a star's life? We obviously have not been observing stars for long enough to see it go through all the stages.



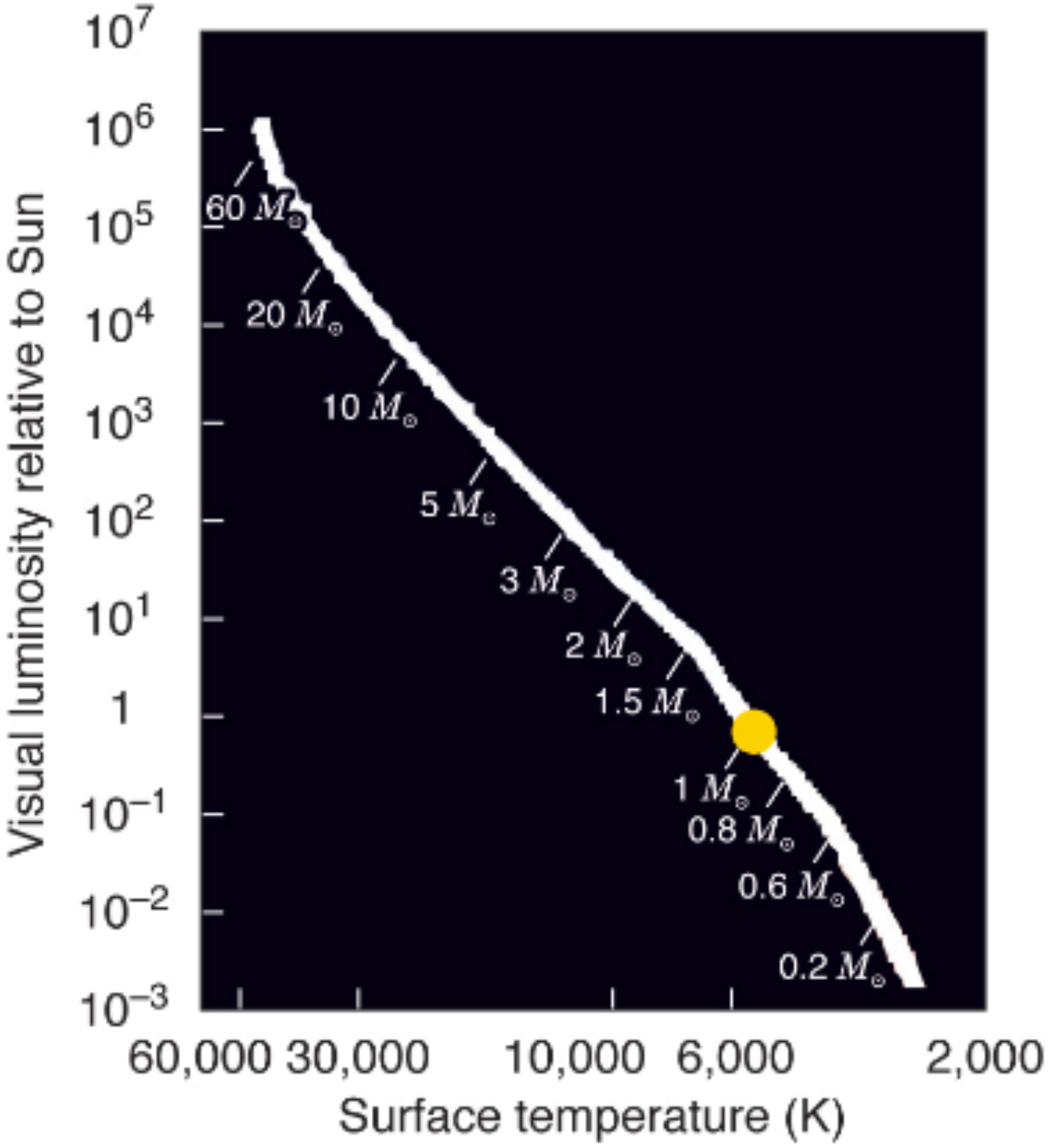



Star Clusters: stars of many masses
born at the same time

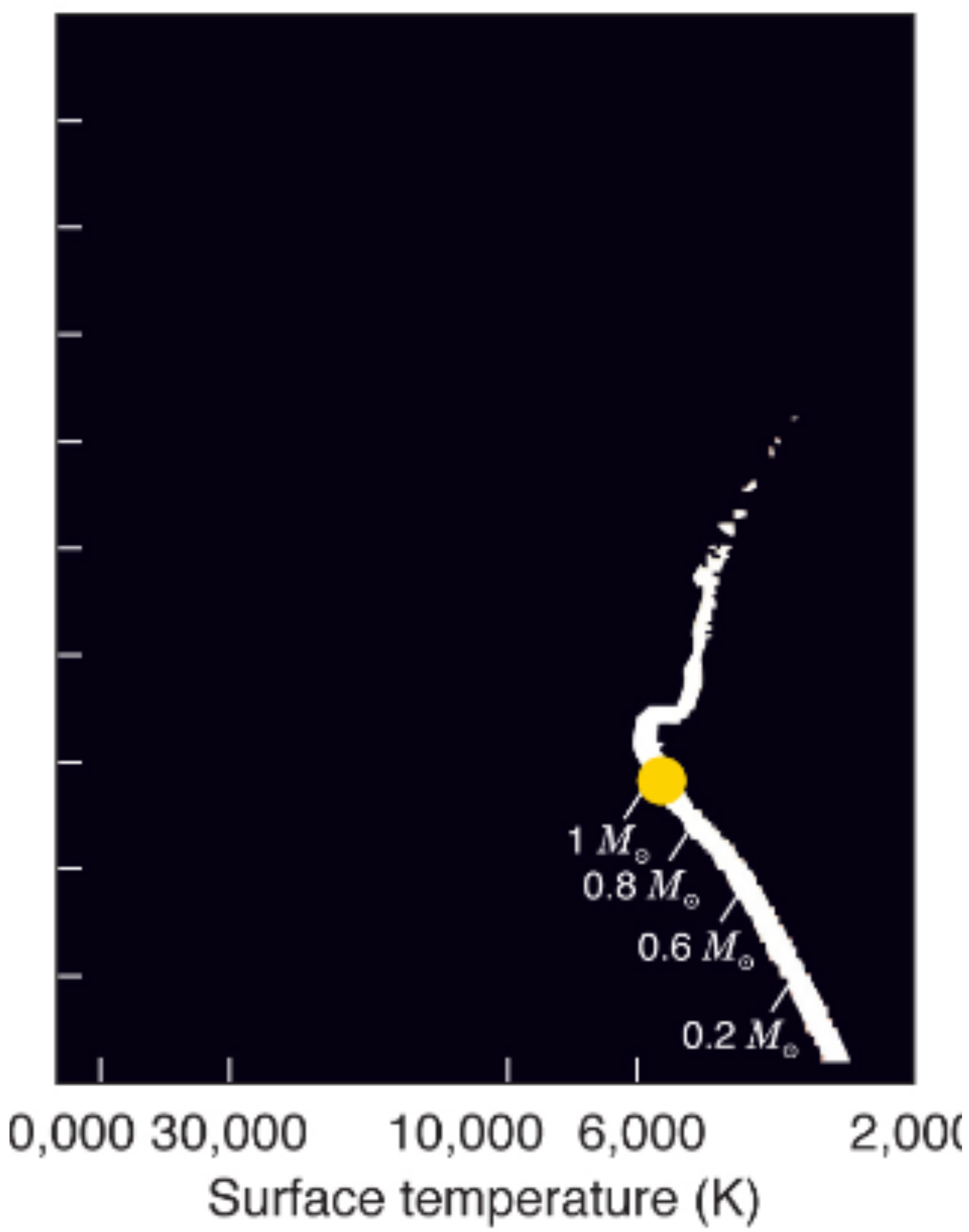

Bright
B
Dim
Main Sequence
Blue
Red
Color

Which of these star clusters is the oldest?

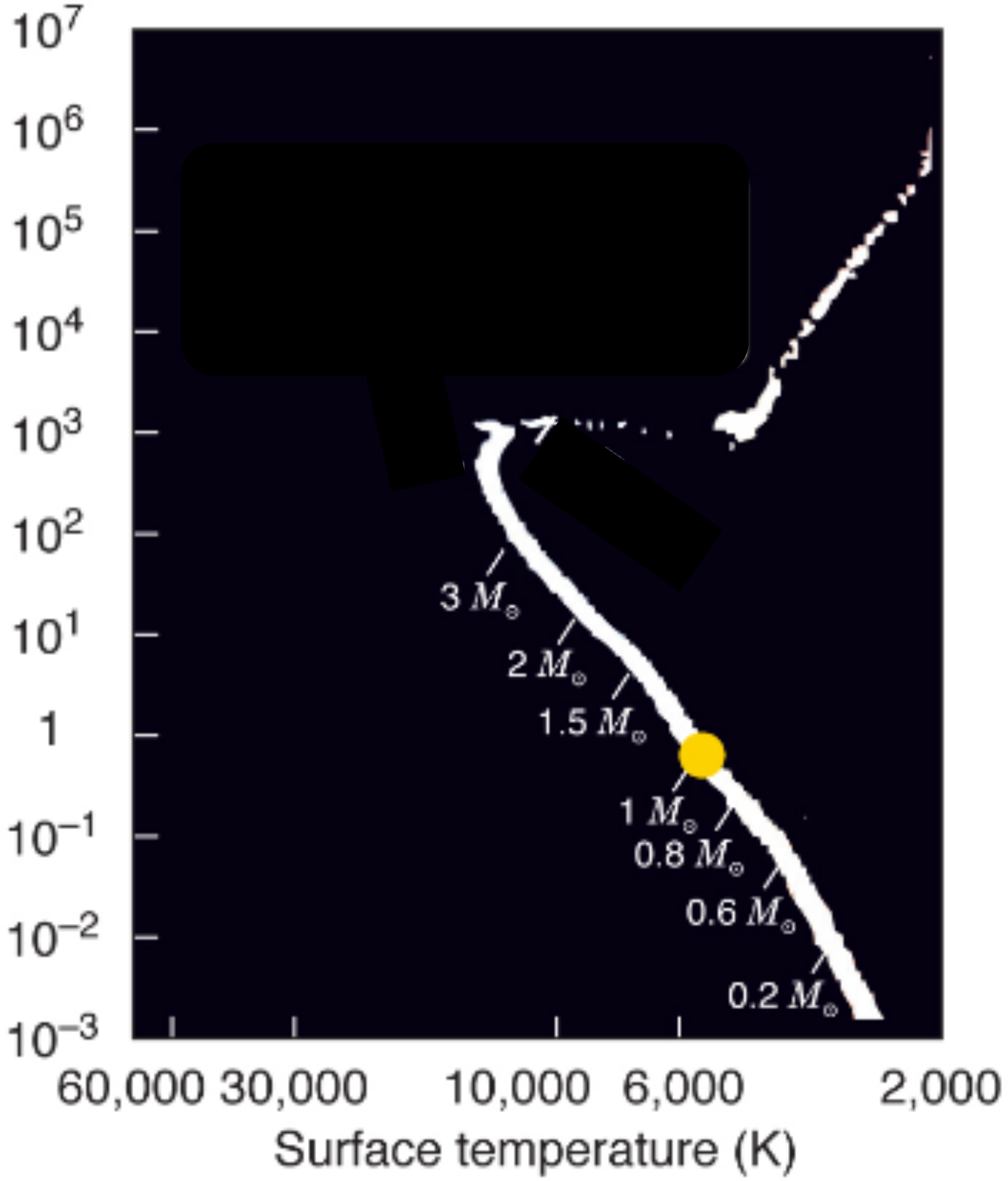
A



B

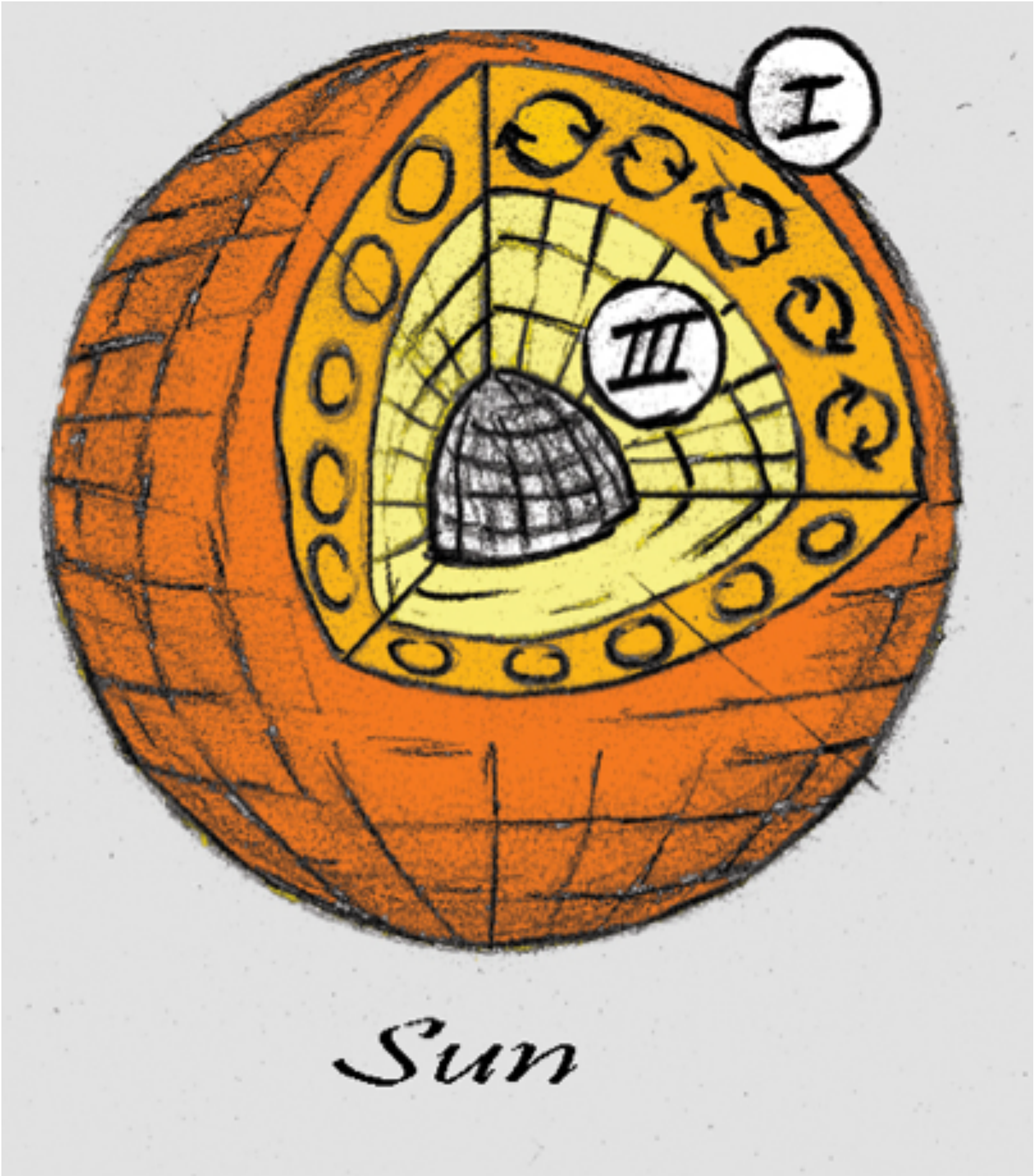


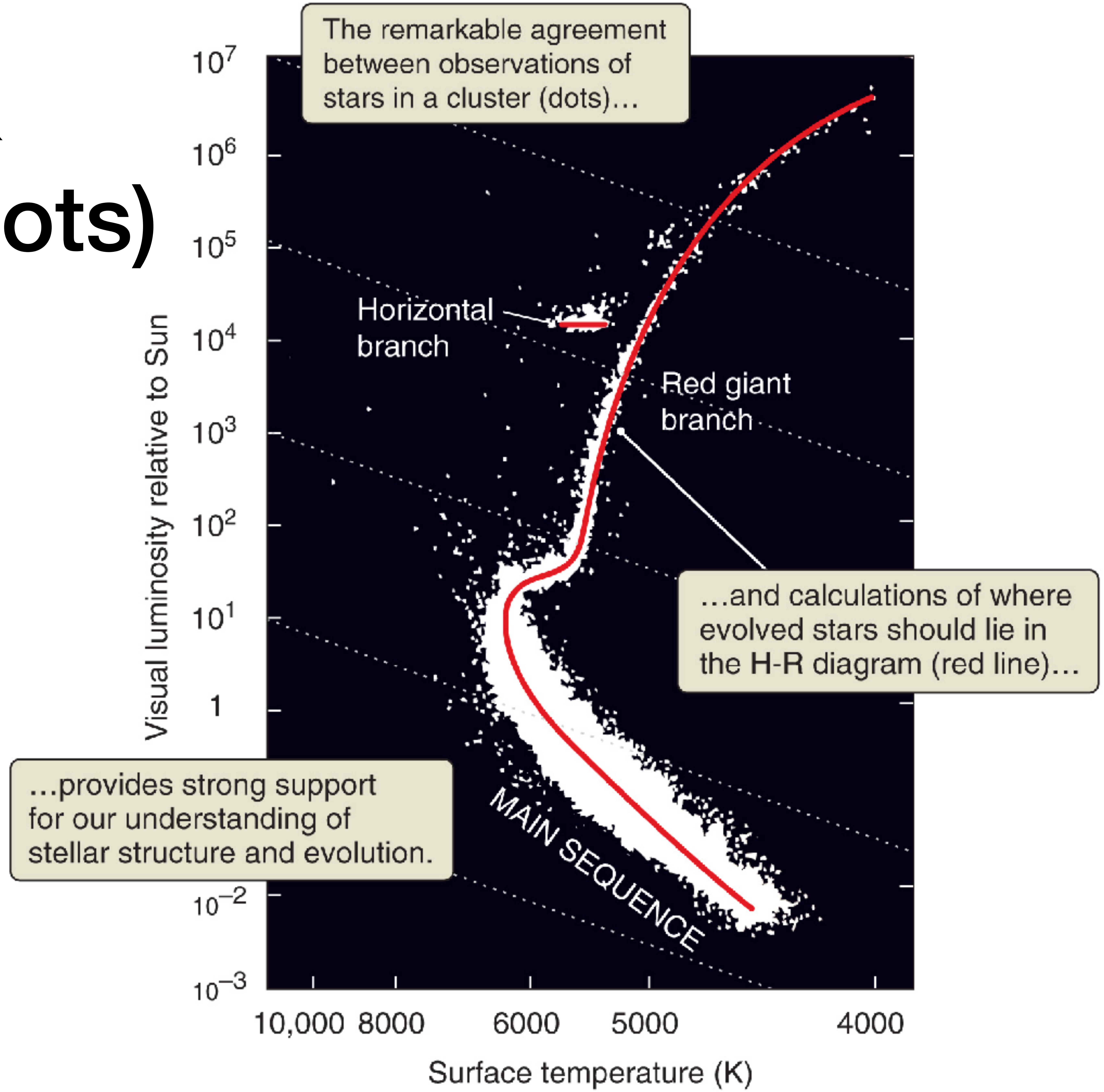
C



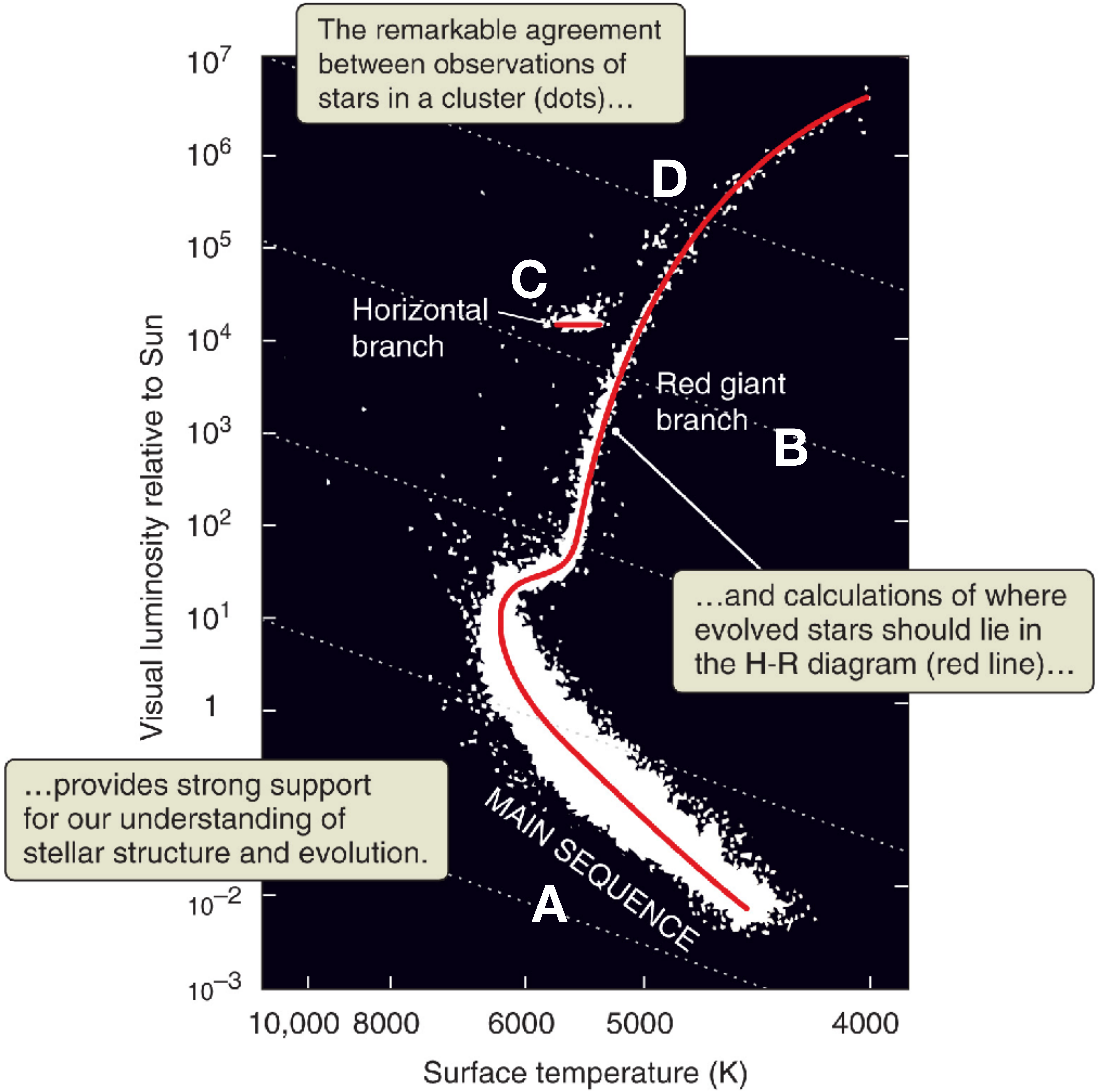
Theory (red line) & Observations (white dots)

We can make a model of any star based on its mass and age

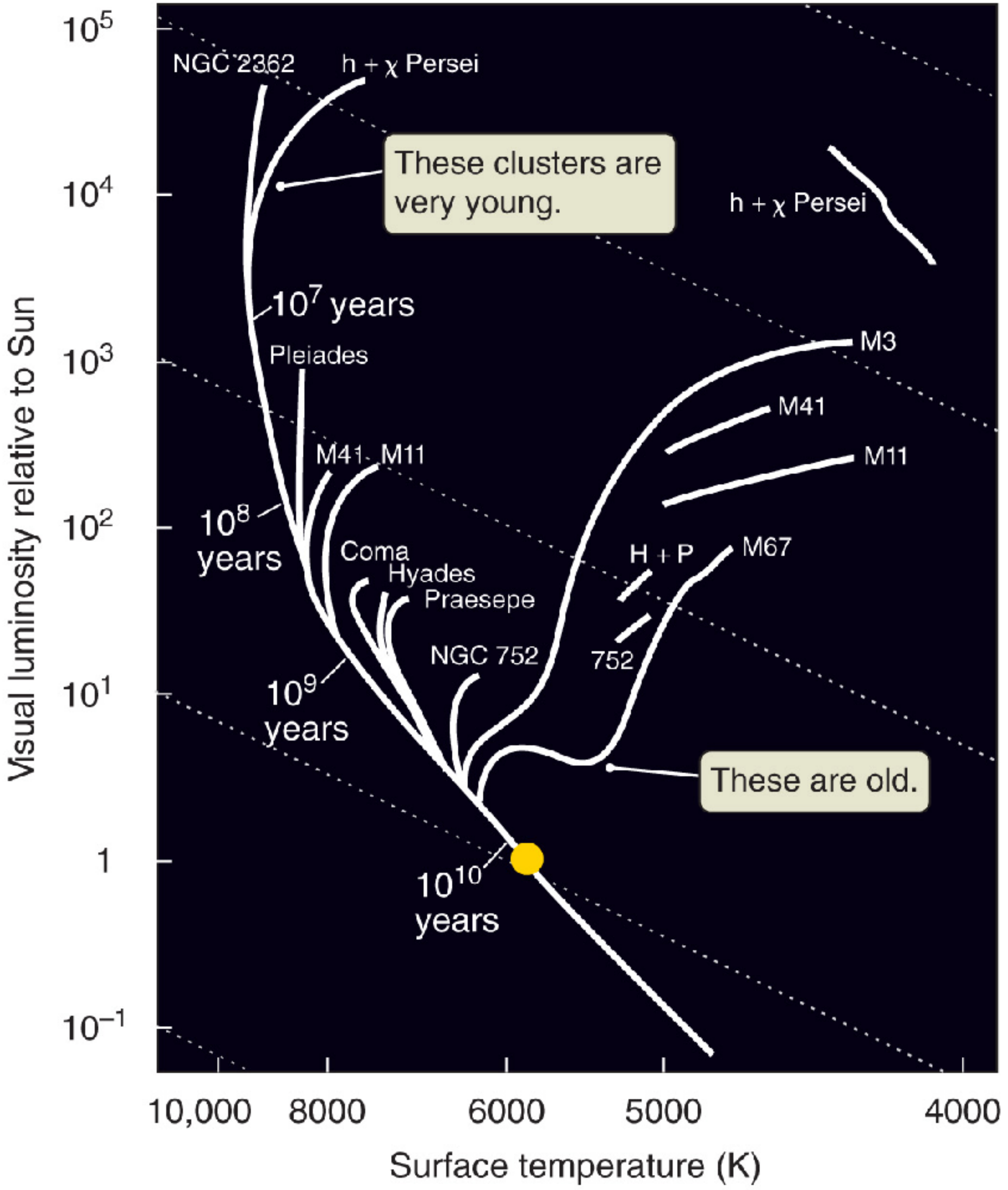




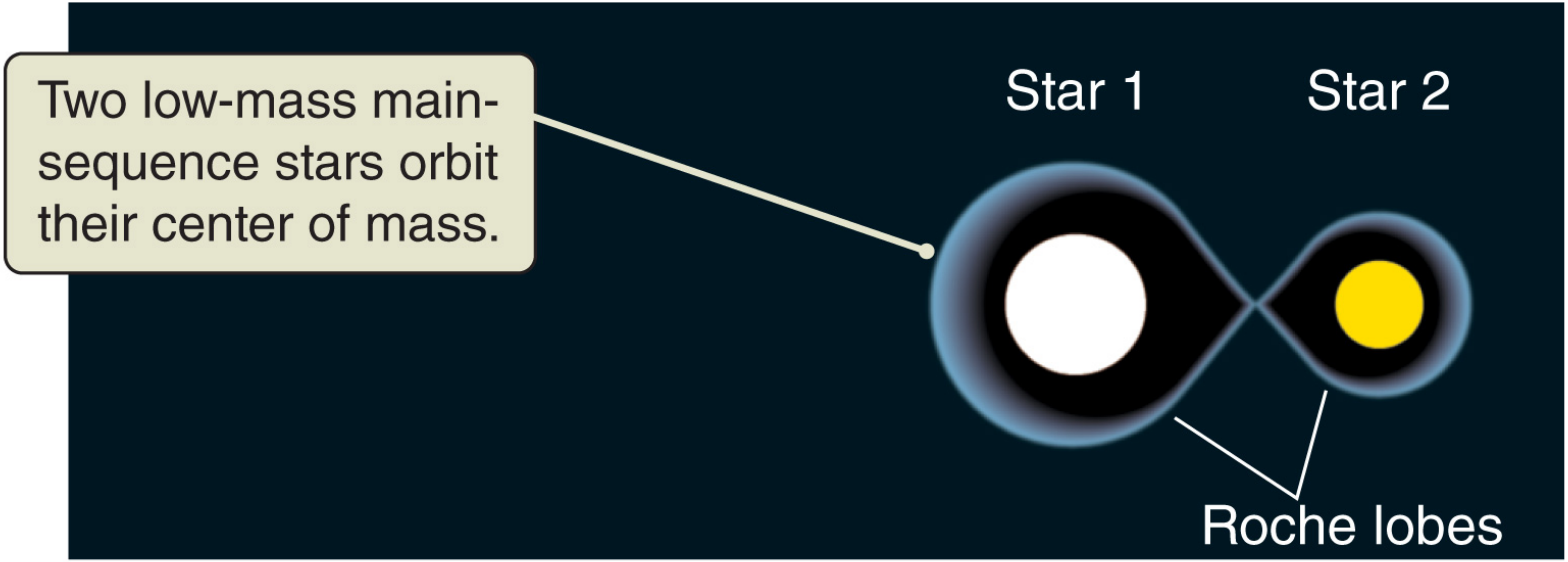
Which stars in this cluster are the most massive?



Because stars in clusters form at the same time, and a star's evolution is determined primarily by its mass, we can observe many clusters and figure out how stars evolve

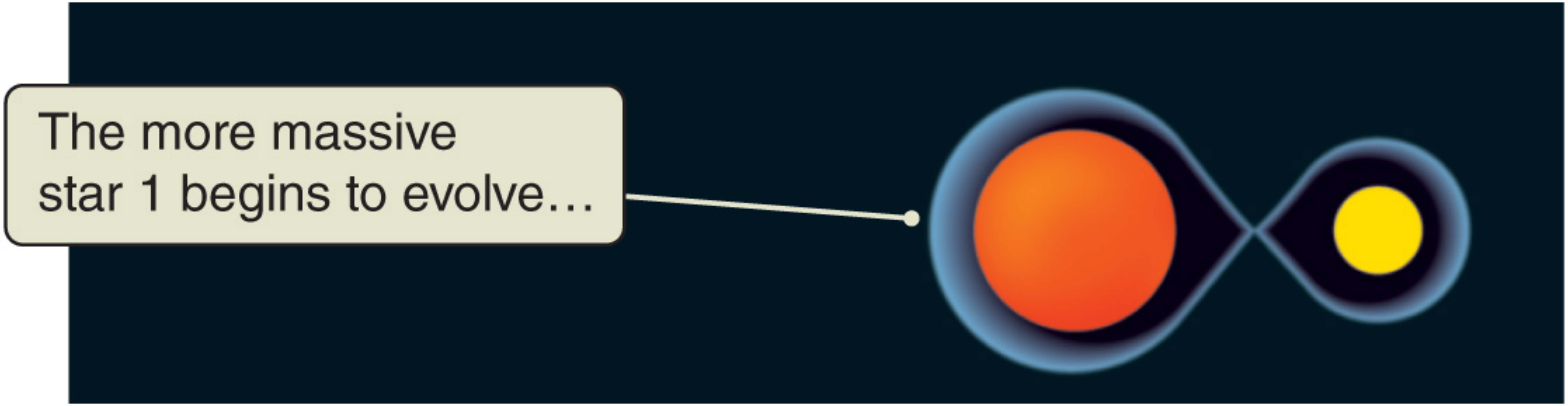


What happens when close binary stars evolve?



What is this???

What happens when close binary stars evolve?



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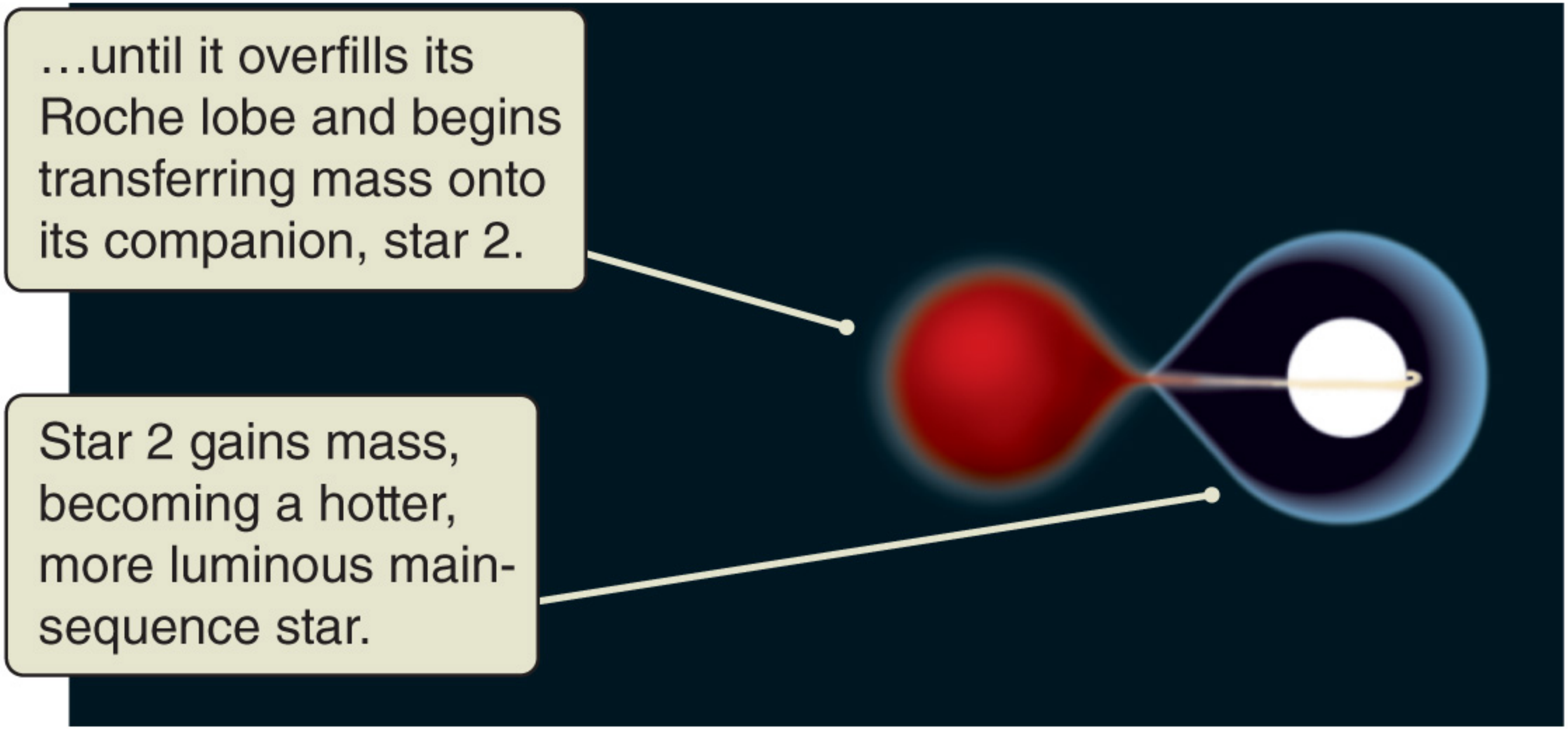

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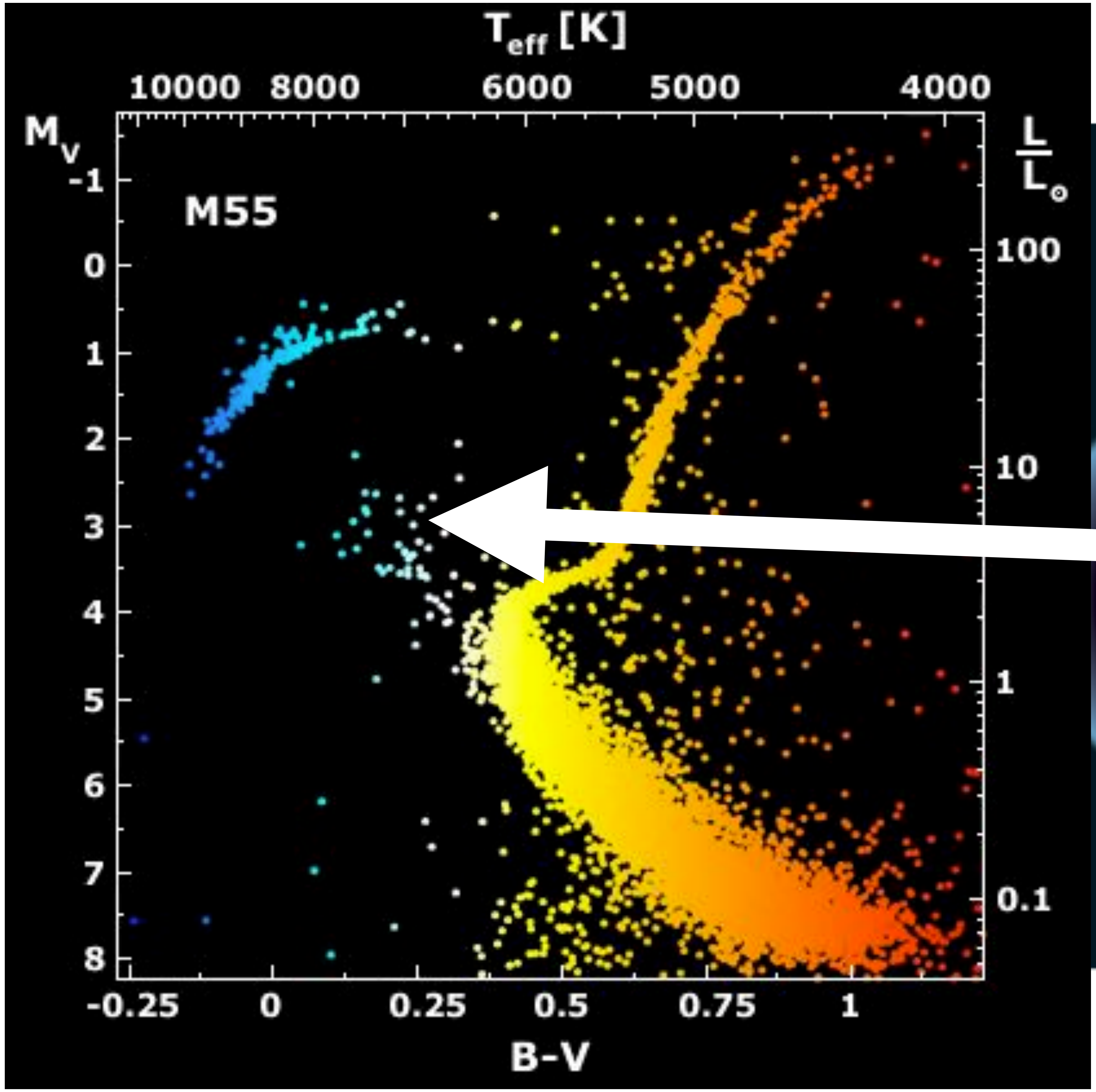
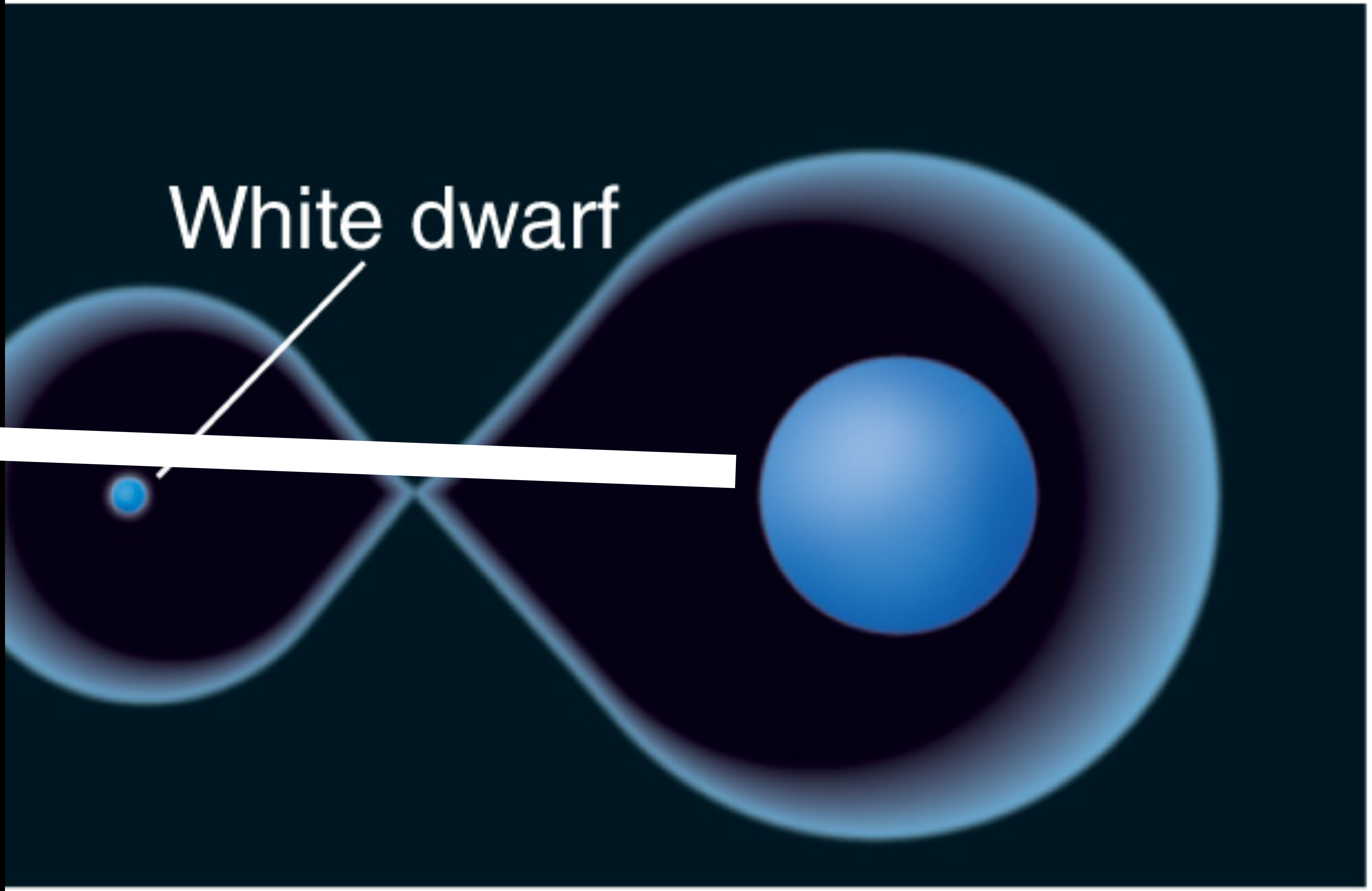
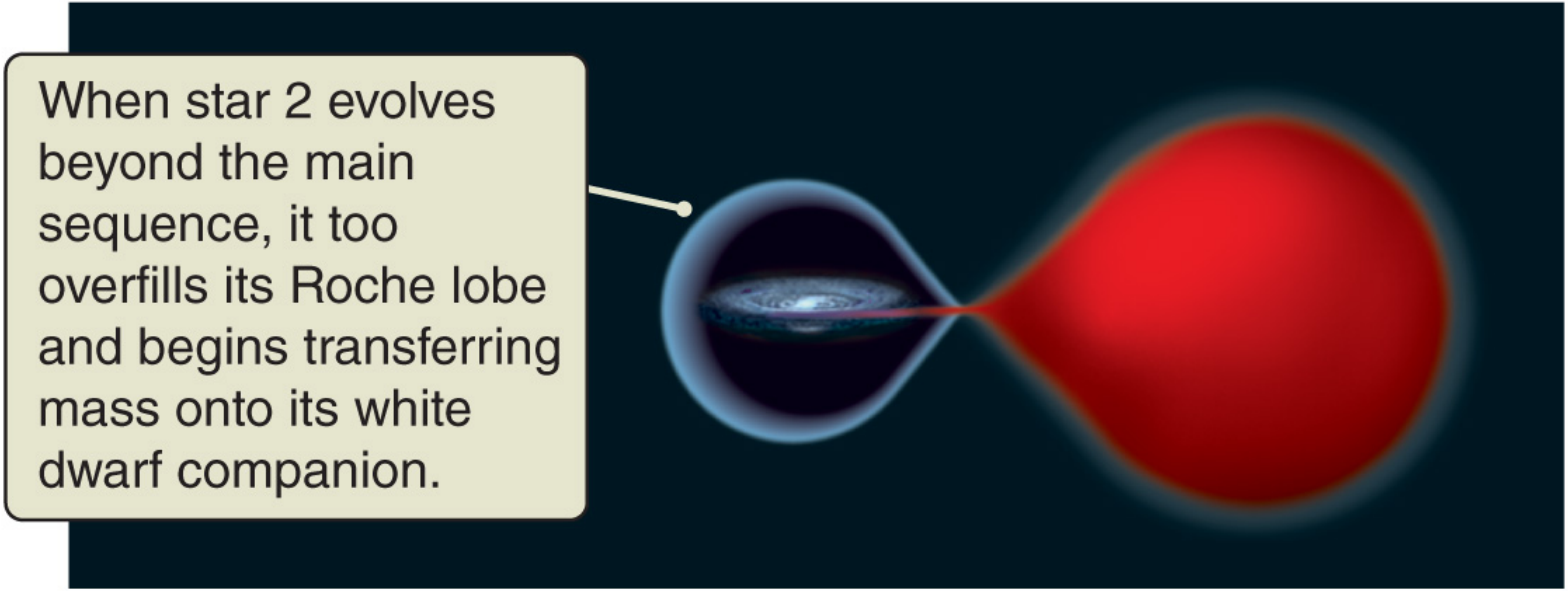




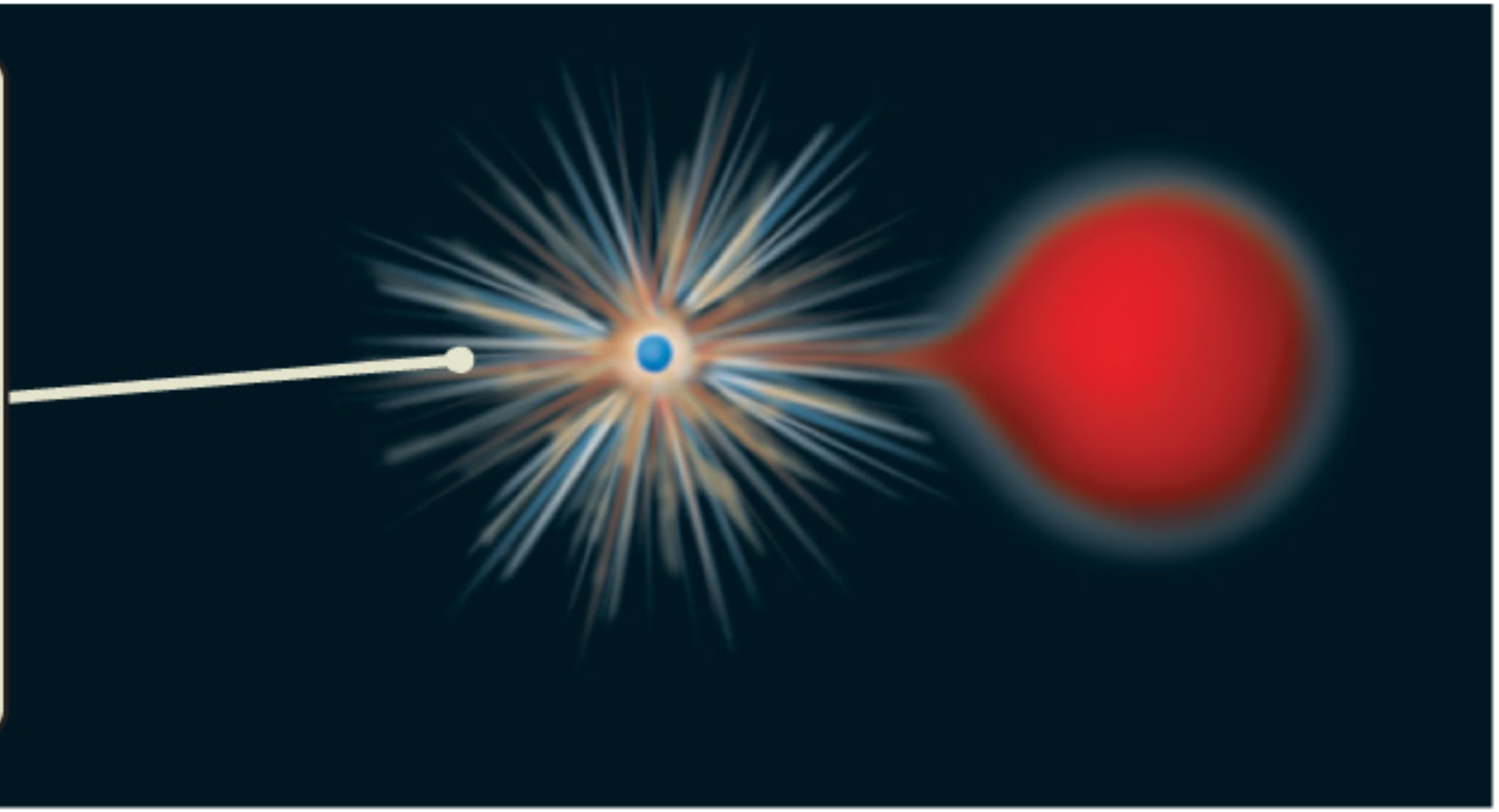
What happens when close binary stars evolve?



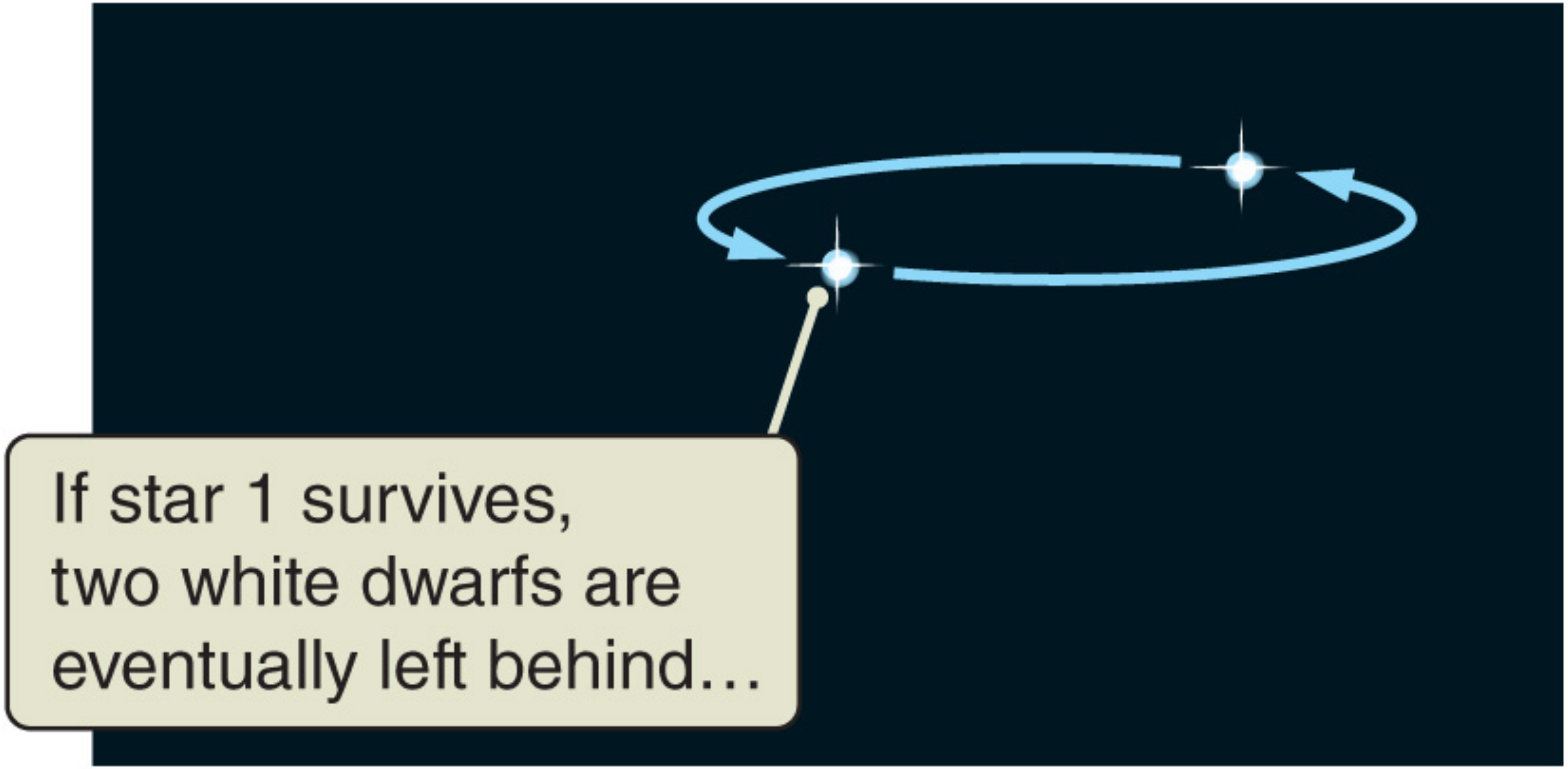
What happens when close binary stars evolve?

A “nova” is what?

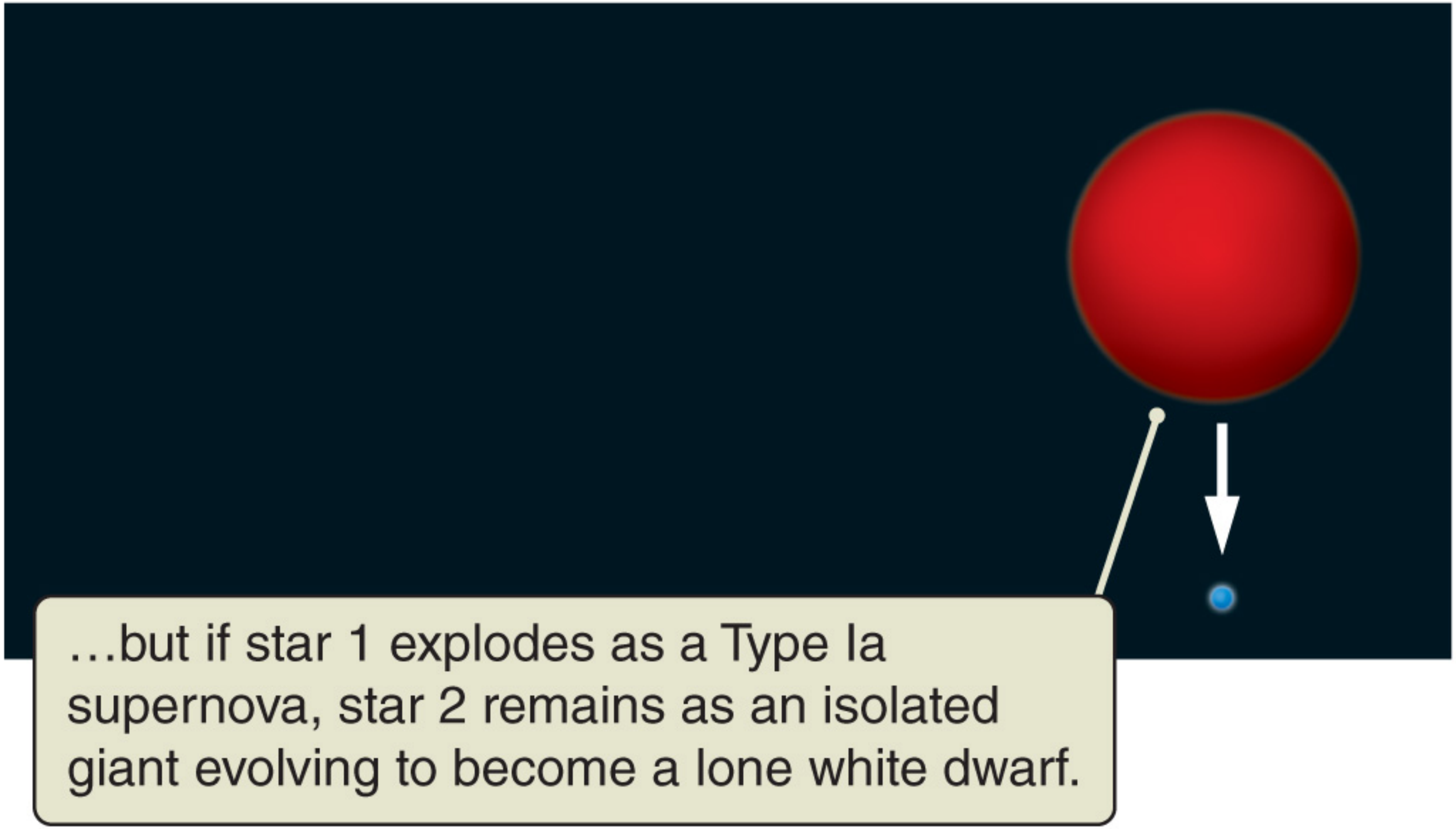
A) Material from Star 2 hits the surface of the white dwarf, causing it to heat up
B) Material from Star 2 accumulates on the surface until it’s hot enough to burn (fuse H -> He)
C) Enough material falls on the white dwarf to cause the entire star to explode



What happens when close binary stars evolve?

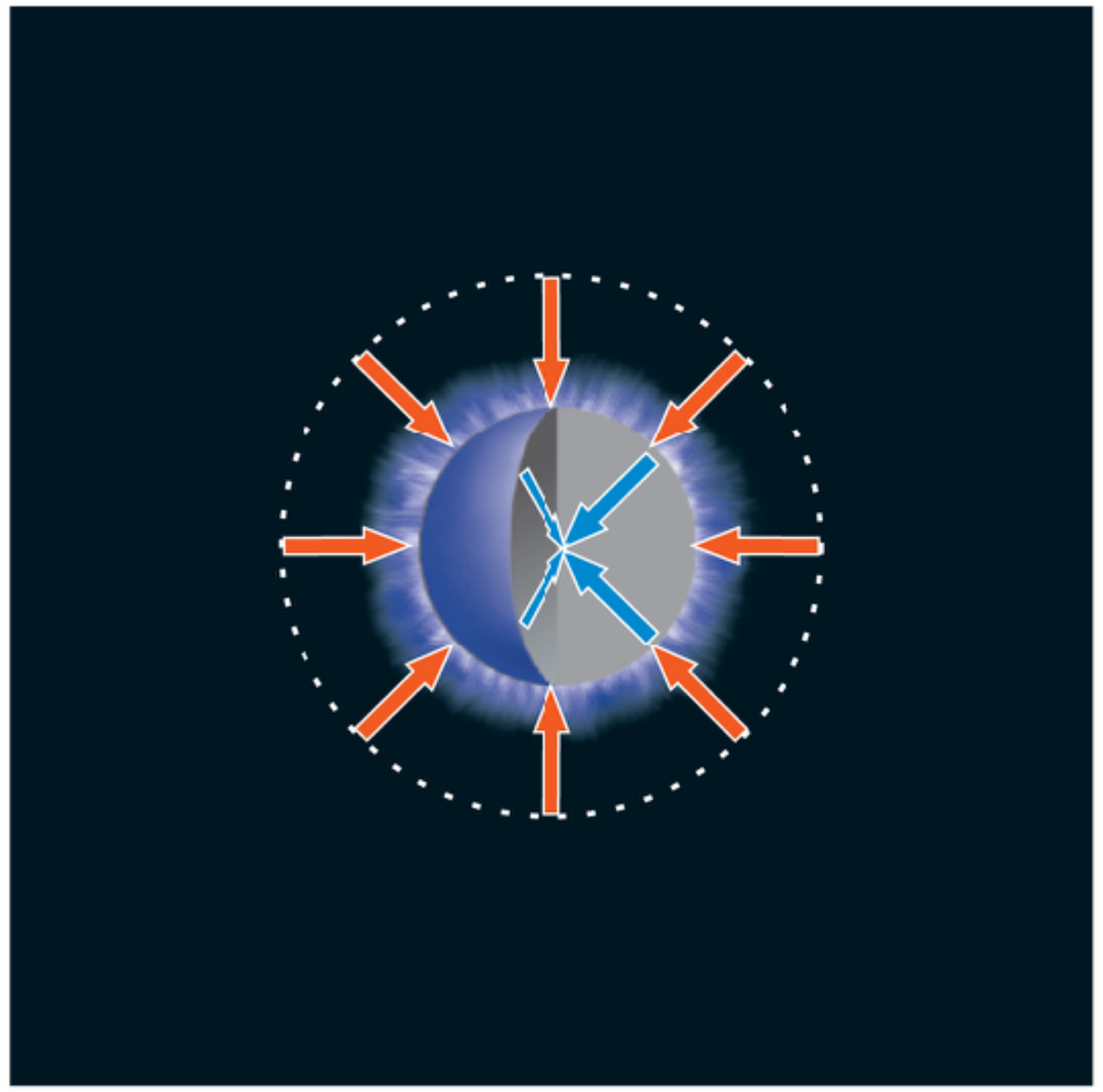


What happens when close binary stars evolve?

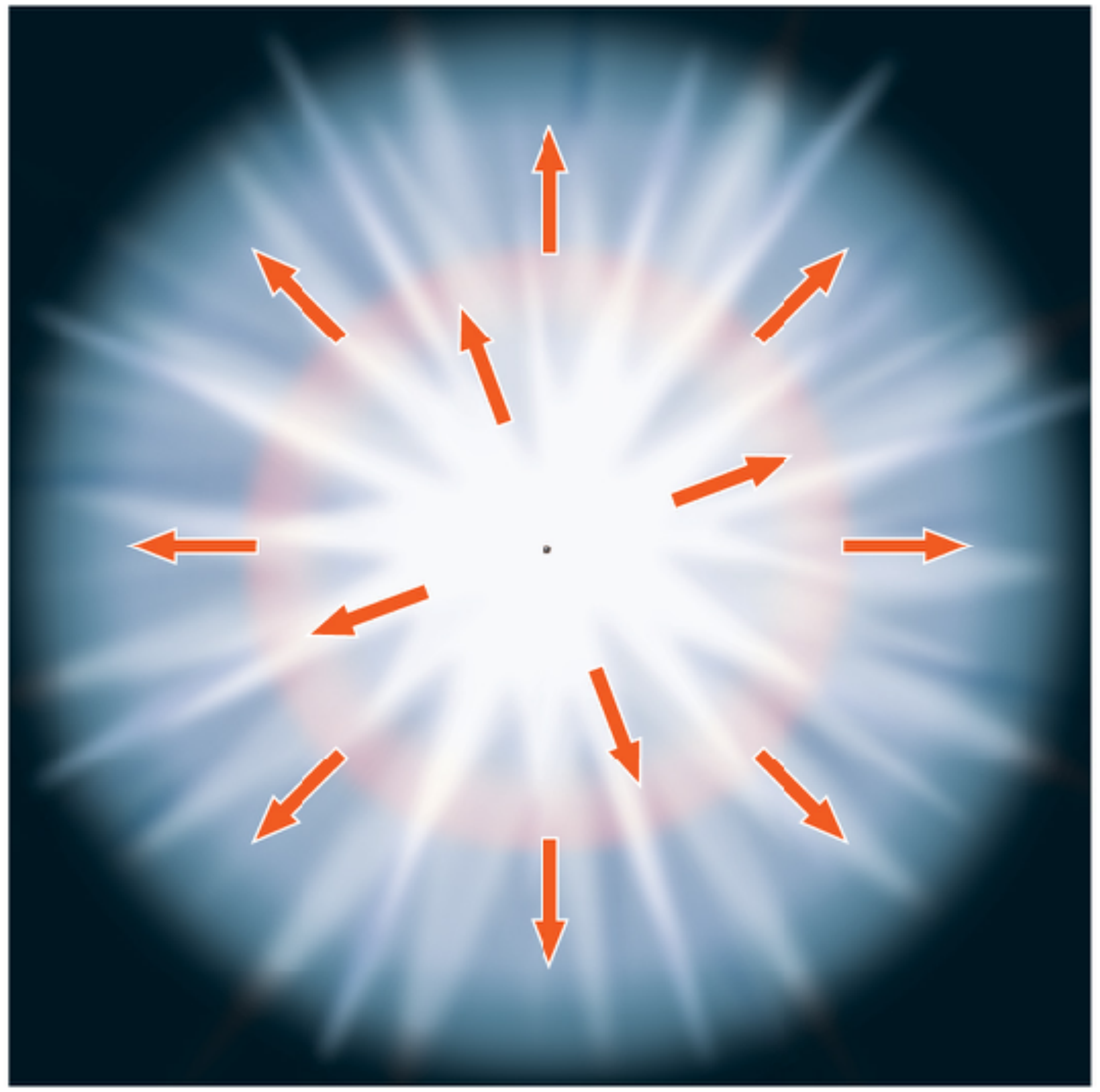


Type Ia Supernovae

If the white dwarf mass exceeds the Chandrasekhar limit, it begins to collapse…



…pushing up the temperature until carbon ignites and burns explosively.



The Type Ia supernova consumes the white dwarf completely.