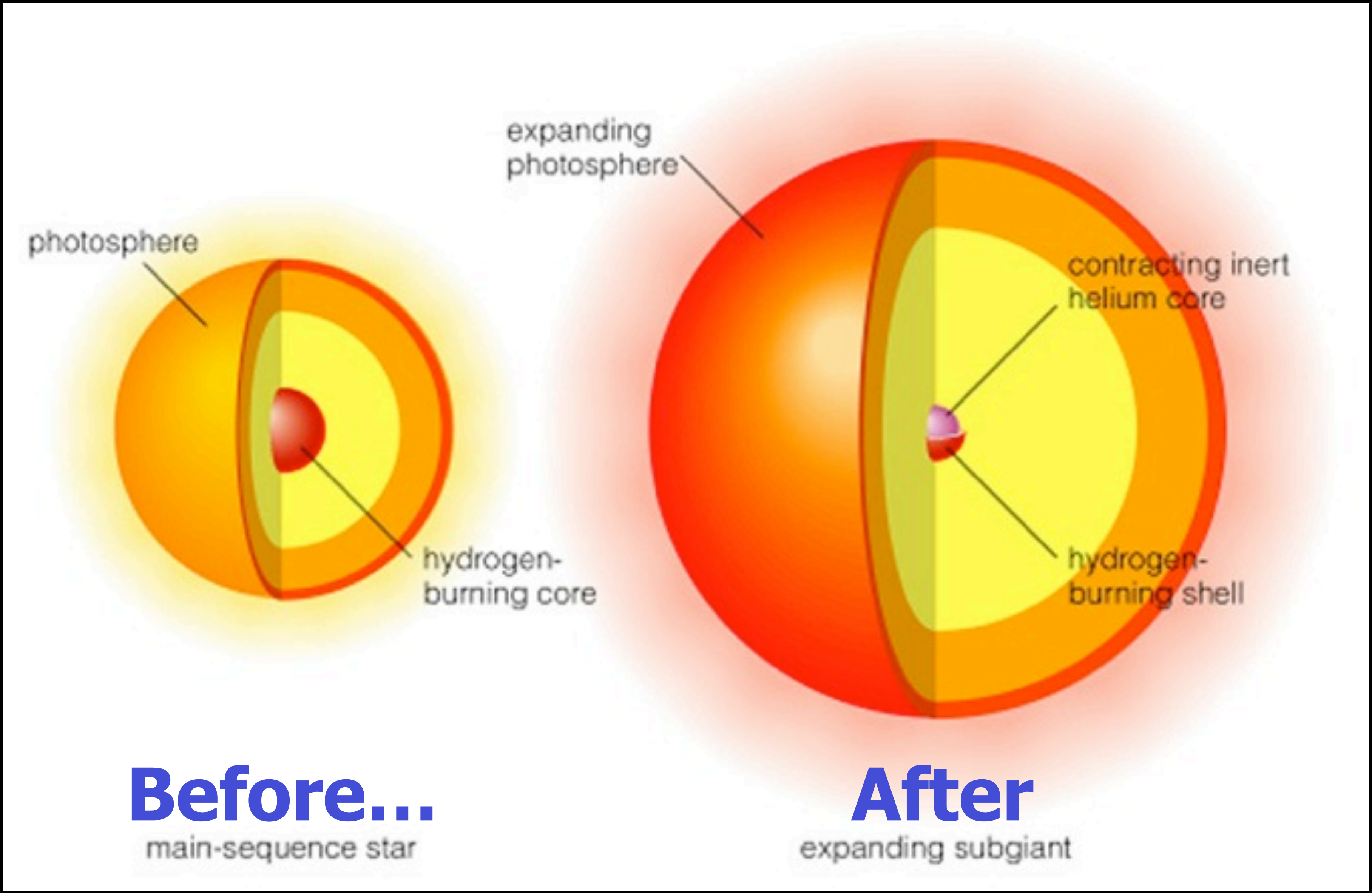
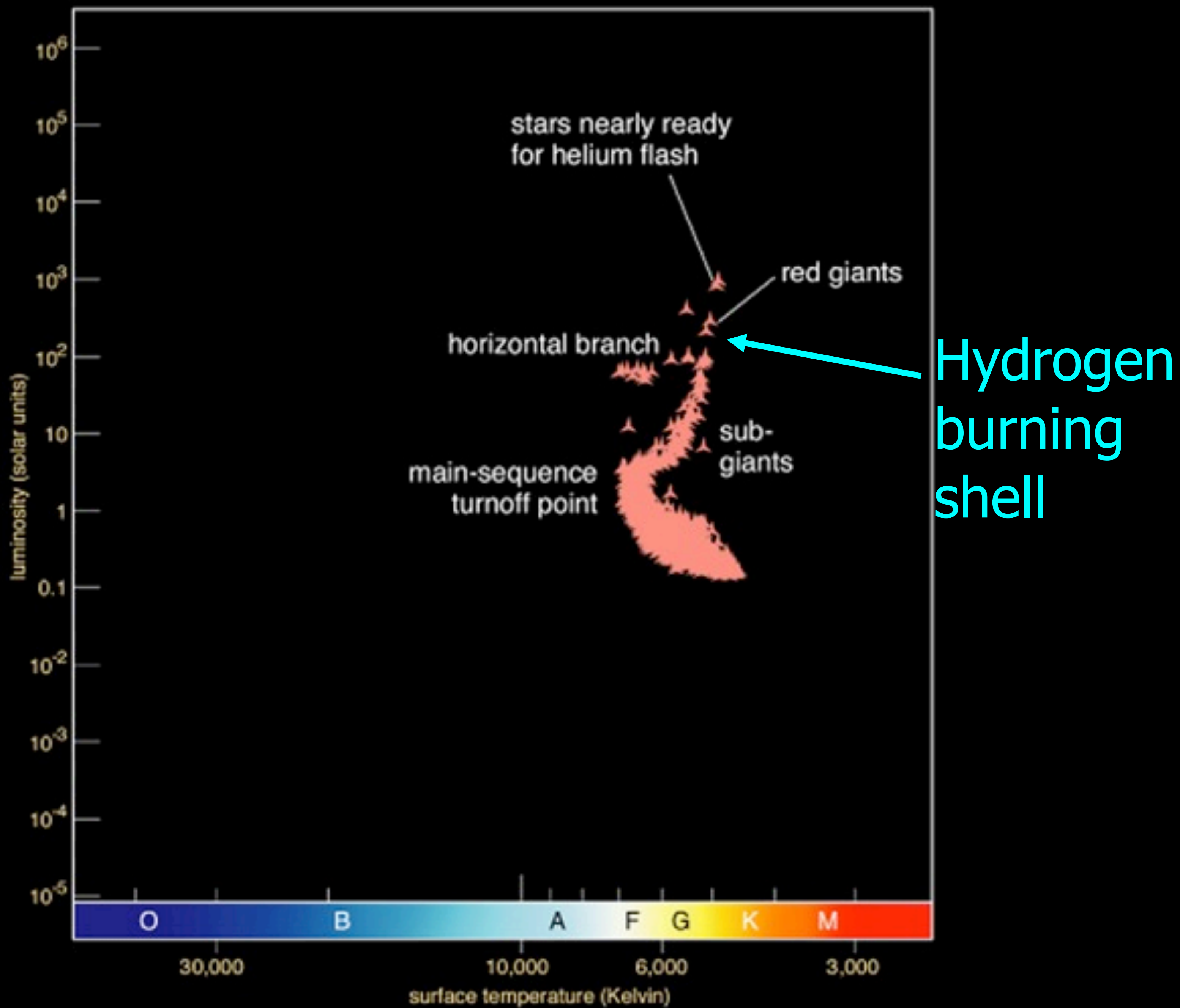
Astr 102

Lec 9: Stellar Evolution and Death

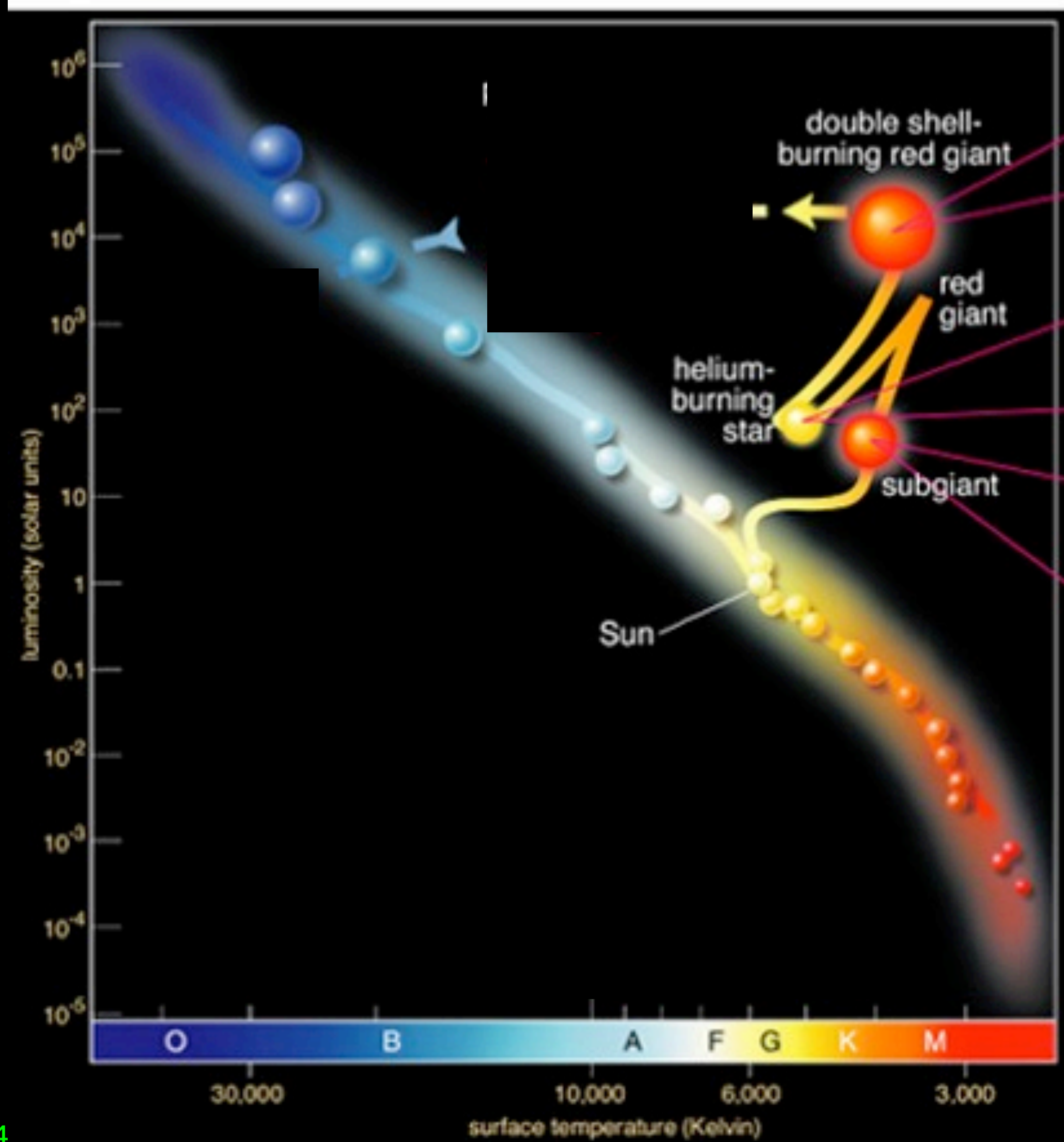
- Why do stars leave main sequence?
- What conditions are required for elements besides Hydrogen to fuse, and why?
- How do stars die: white dwarfs, neutron stars, black holes.

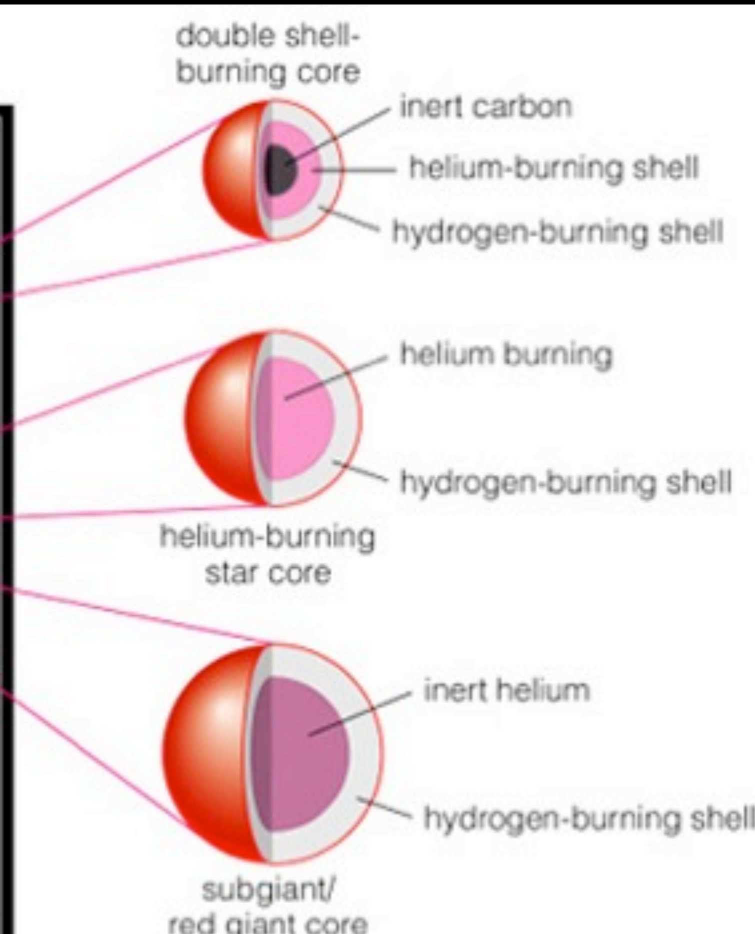
Helium core, Hydrogen burning shell.




stars nearly ready
for helium flash
red giants
horizontal branch
sub-
giants
main-sequence
turnoff point
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
6,000
3,000
surface temperature (Kelvin)
Hydrogen
burning
shell

The "evolutionary track" of a $1M_\odot$ star





Track shows where a <u>single star</u> is in the HR diagram at different points in its lifetime.

Why you should care…

The Sun is going to do this!!!!

(Uh oh…)

Swelling is HUGE!

- Sun's photosphere will extend past the Earth's orbit.

Not Good.

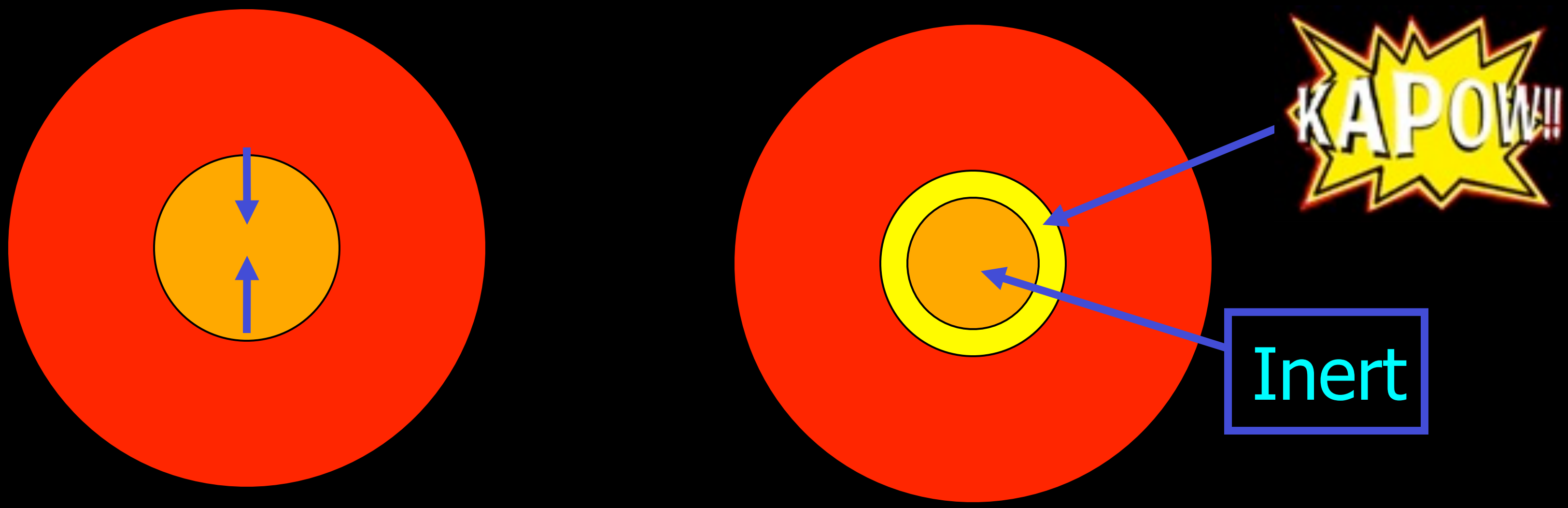
- But don't worry, it'll already be way too hot to live here.

So what's next for a Red Giant?

Like everything for stars, depends almost entirely on MASS!

The Thought Process of a Desperate Star…

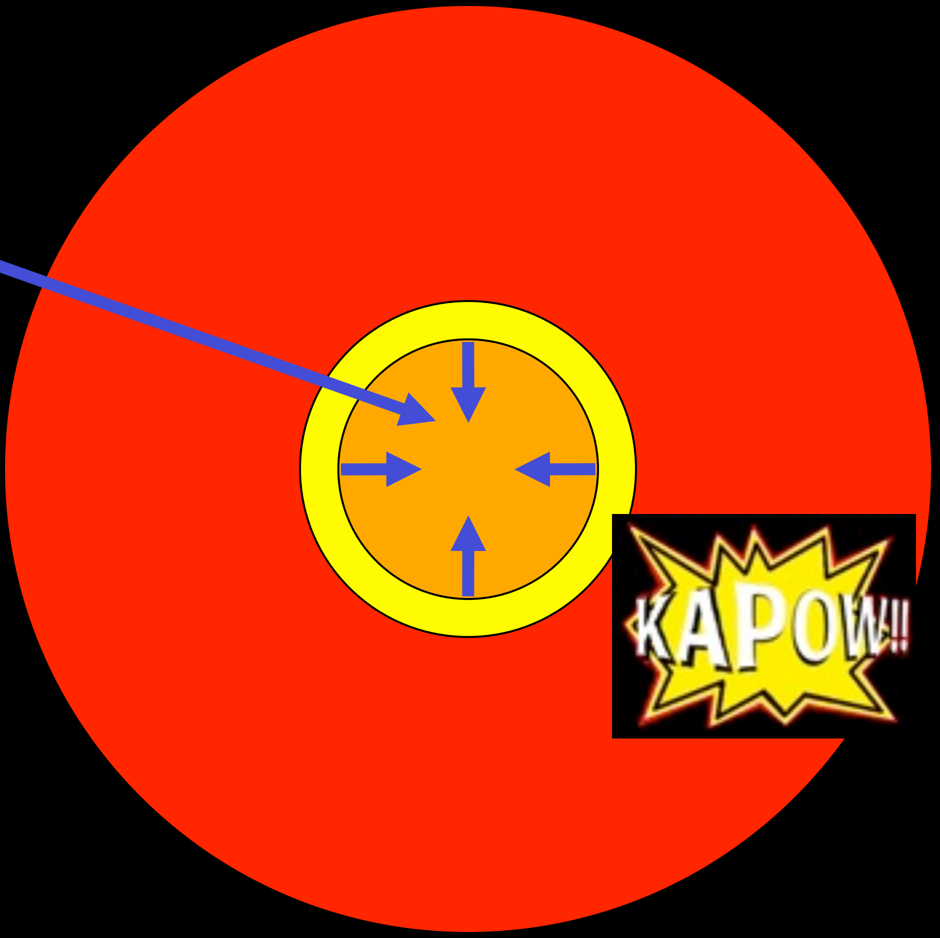
- Oh oh, I'm out of fuel.
- There goes my pressure support, I'd better collapse my core.
- Oh wait, now I can start burning my old fuel just outside the core. Whew.



The inert core <u>still</u> keeps collapsing!

Shell burning can't heat up the core effectively.

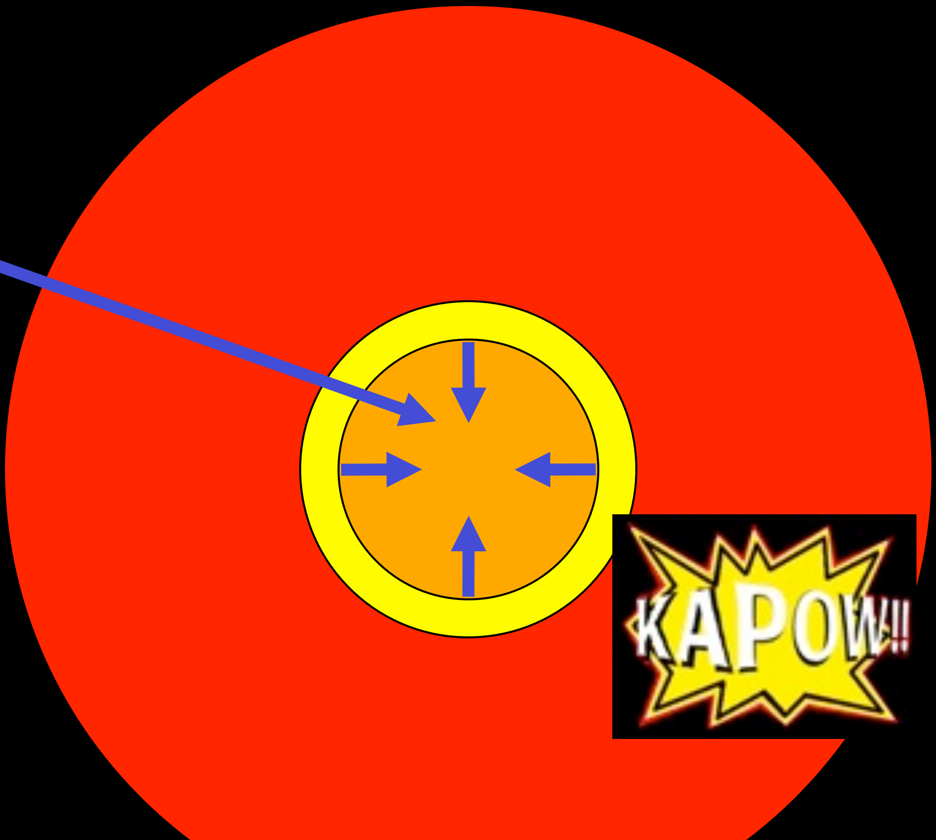
The core still doesn't have enough pressure support!

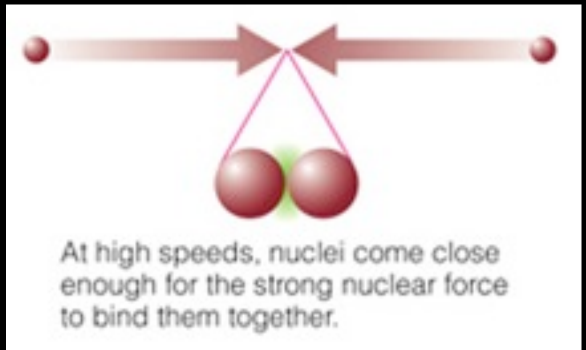


He burning:

But, as the core collapses, it heats up!

It also gets denser!

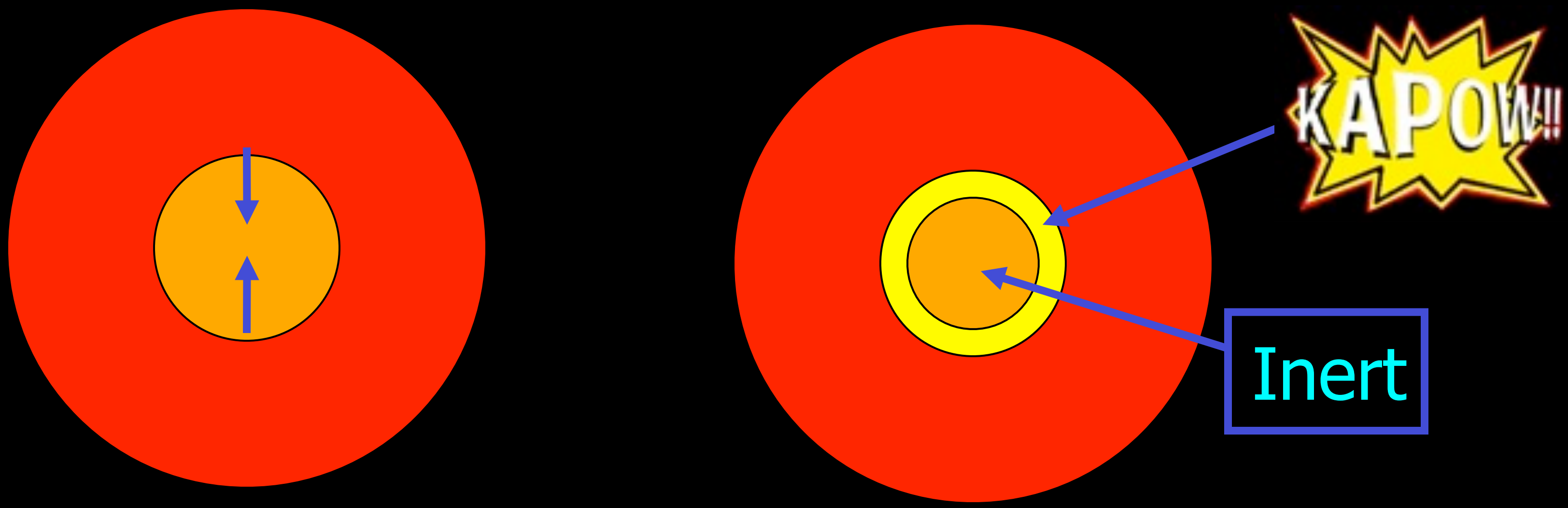




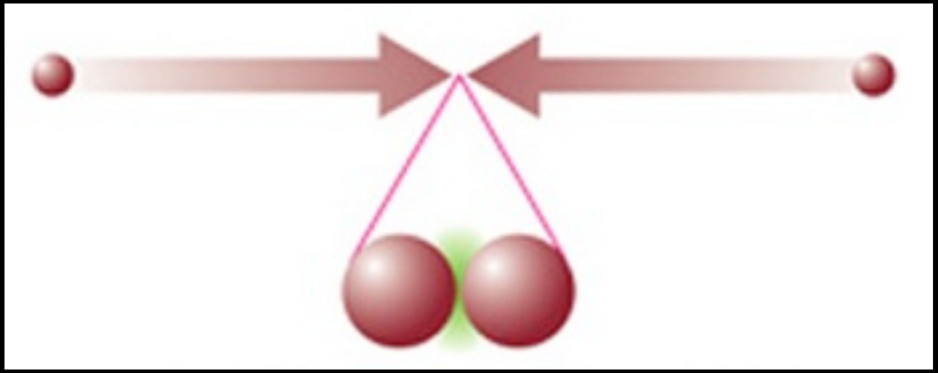
Maybe it gets hot & dense enough for this?
(with He, not H)

This process works no matter what the original fuel was

- Oh oh, I'm out of ~~Hydrogen~~ ~~Helium~~ Carbon.
- There goes my pressure support, I'd better collapse my core.
- Oh wait, now I can start burning my old fuel just outside the core. Whew.



Where the cycle ends depends upon mass.

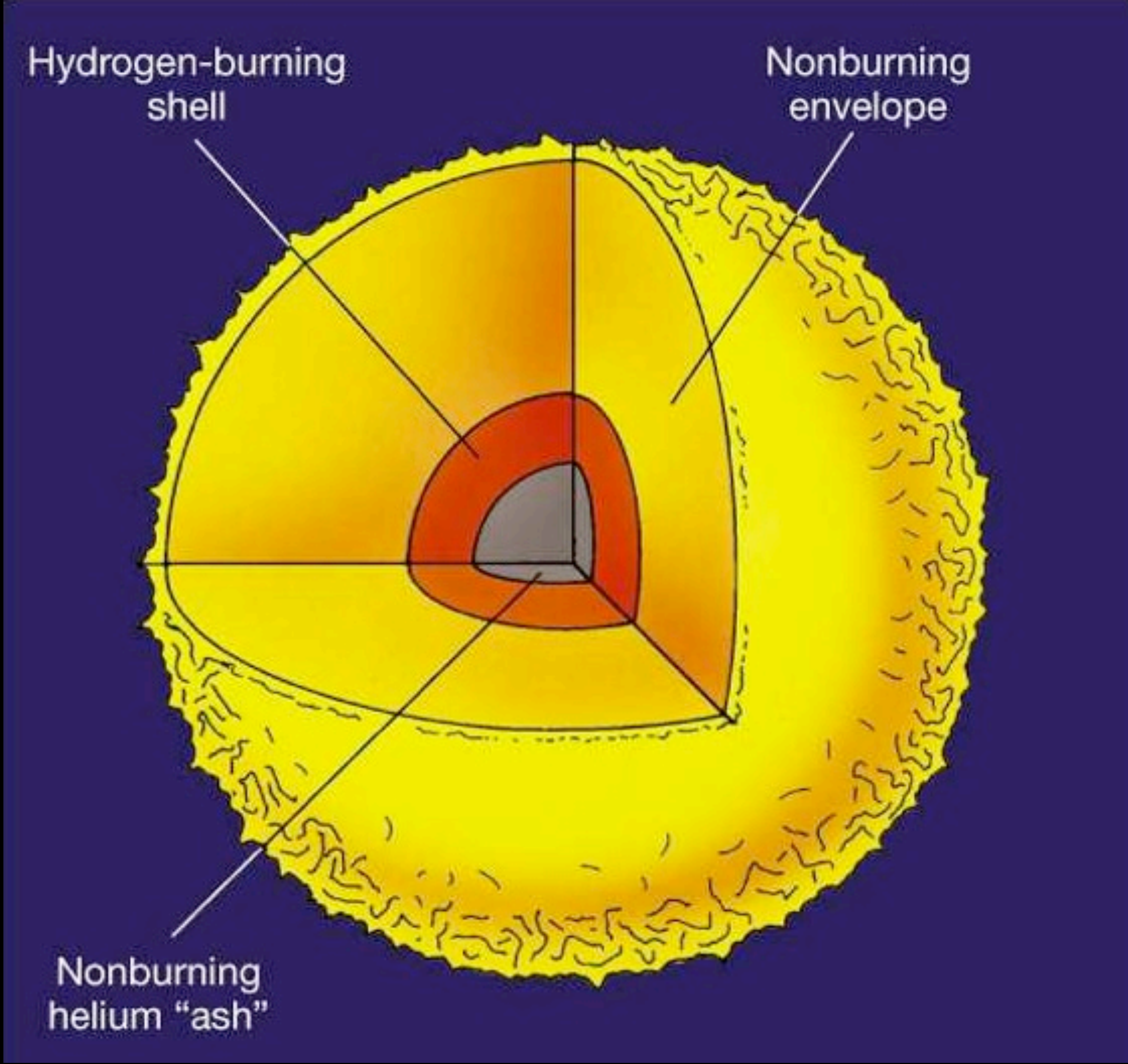


Very Low Mass: Can't burn anything by H.

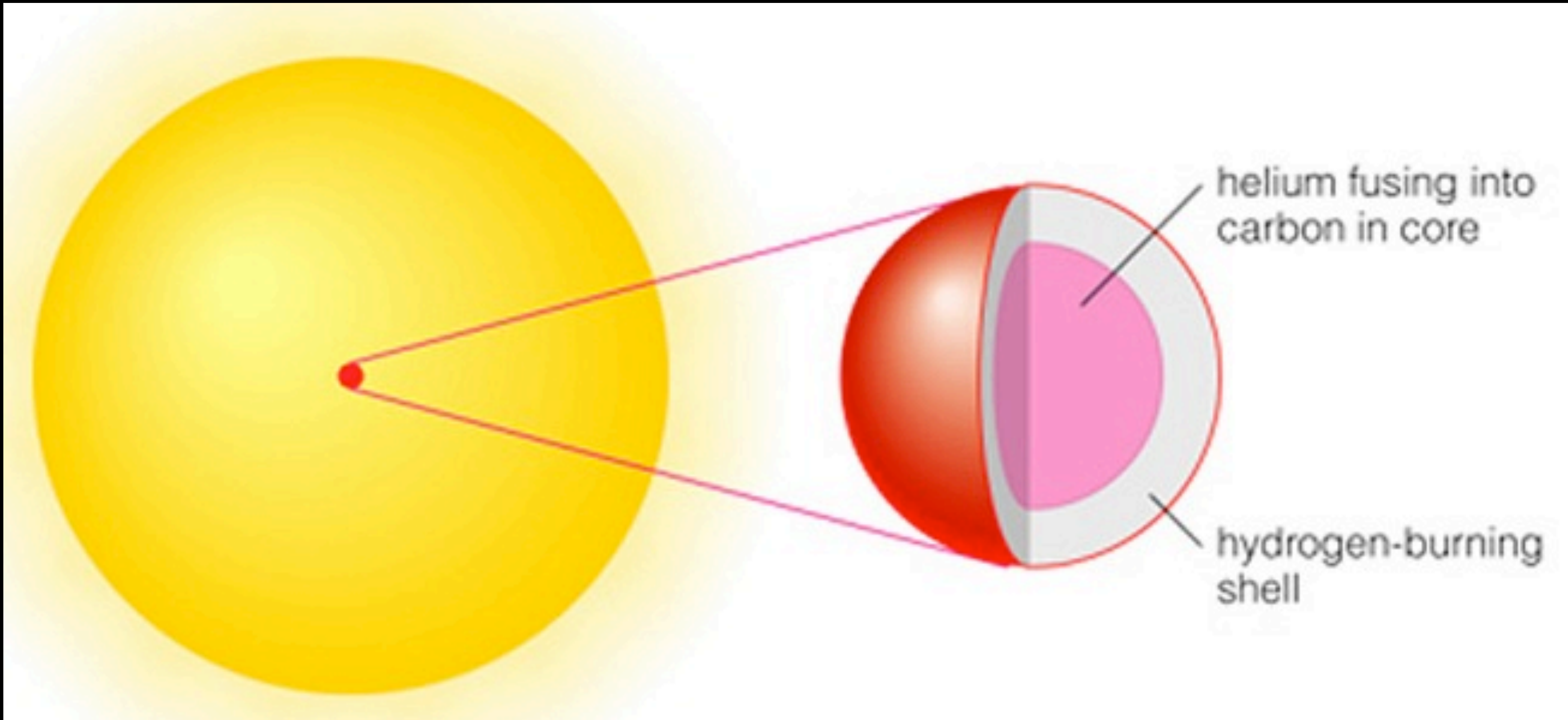
Solar Mass: Can burn He, but nothing else.

Very High Mass: Can burn anything!

Low Mass Stars ($<1M_{\odot}$) Stop



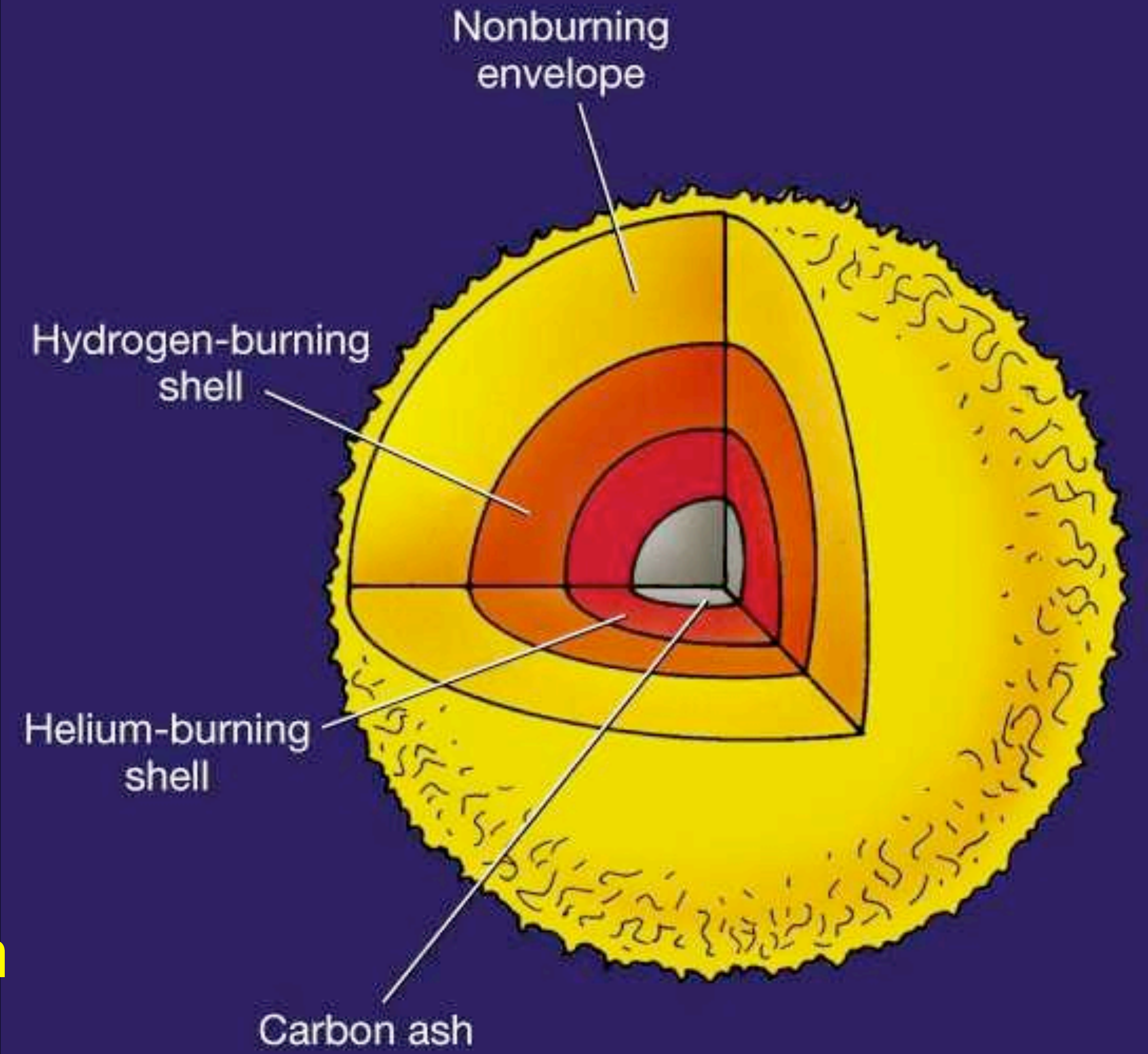
Stars like the Sun can burn He when the core shrinks and heats enough…



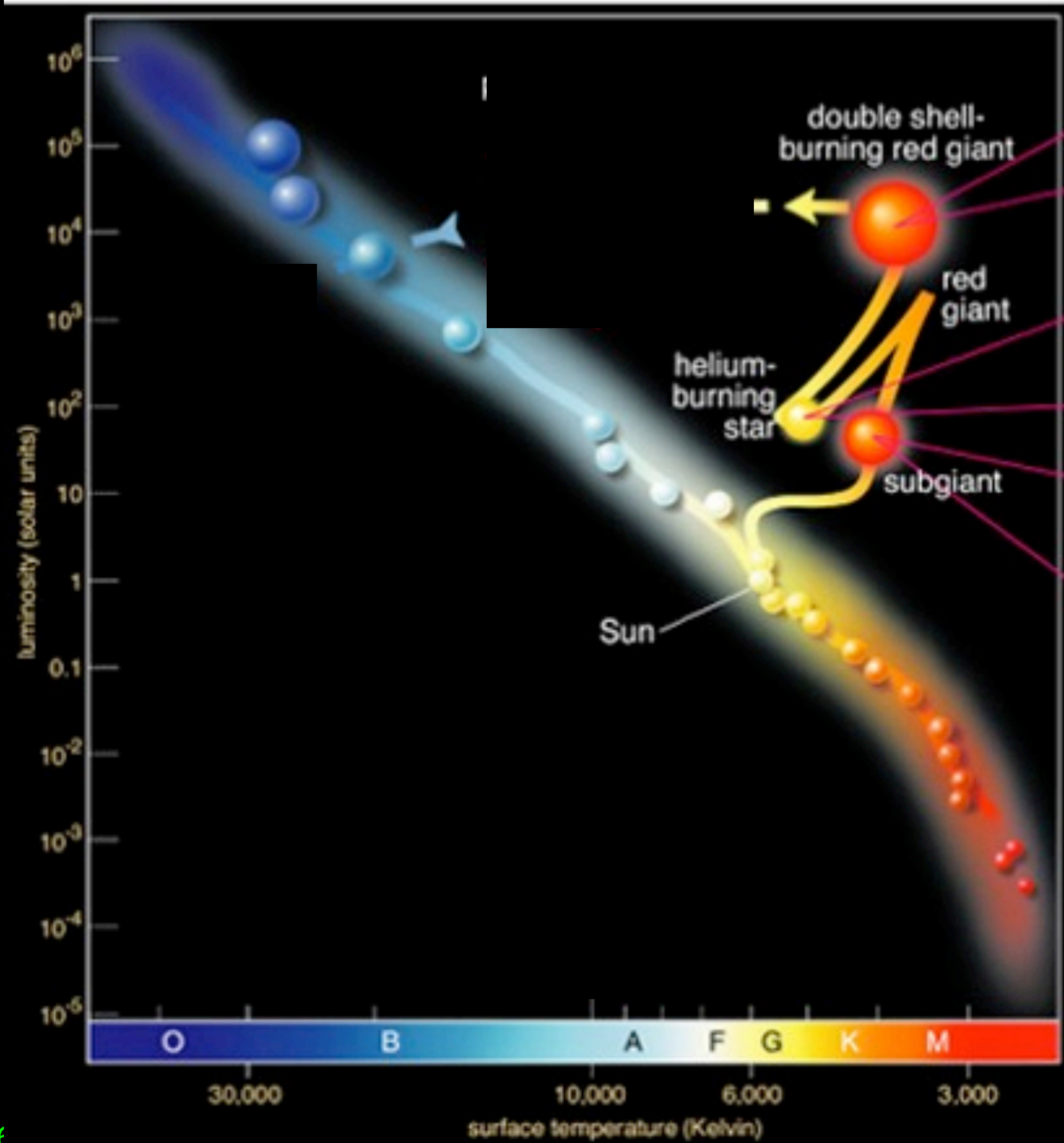
3 Helium nuclei → 1 Carbon nucleus

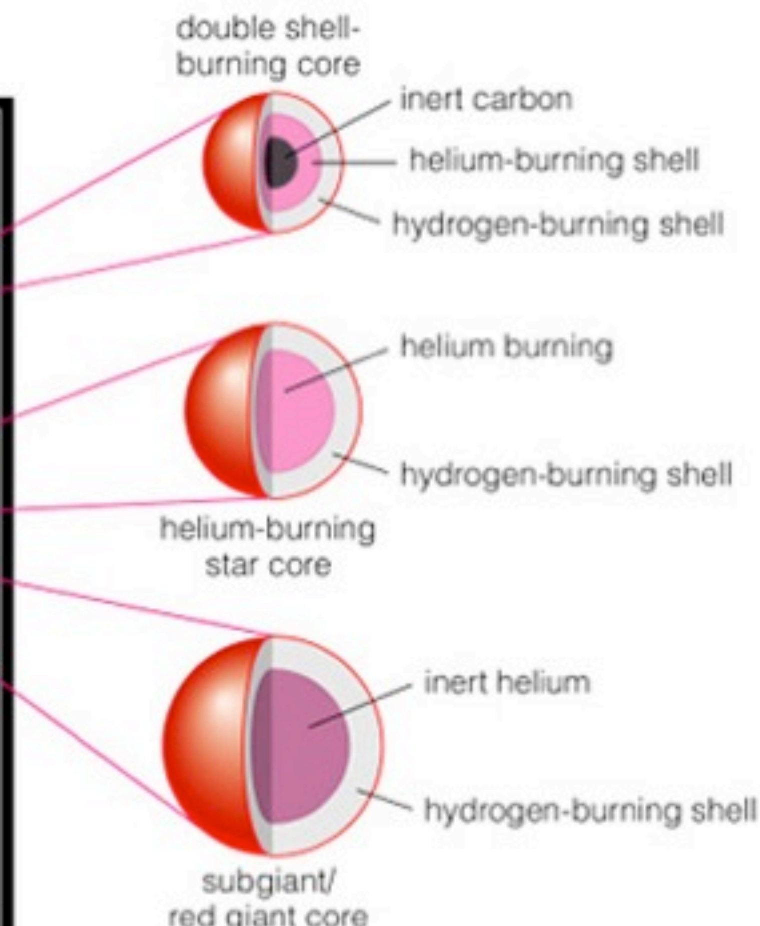
Stars like the Sun stop Fusion here…

Note that there are now two shells! Extra luminous!



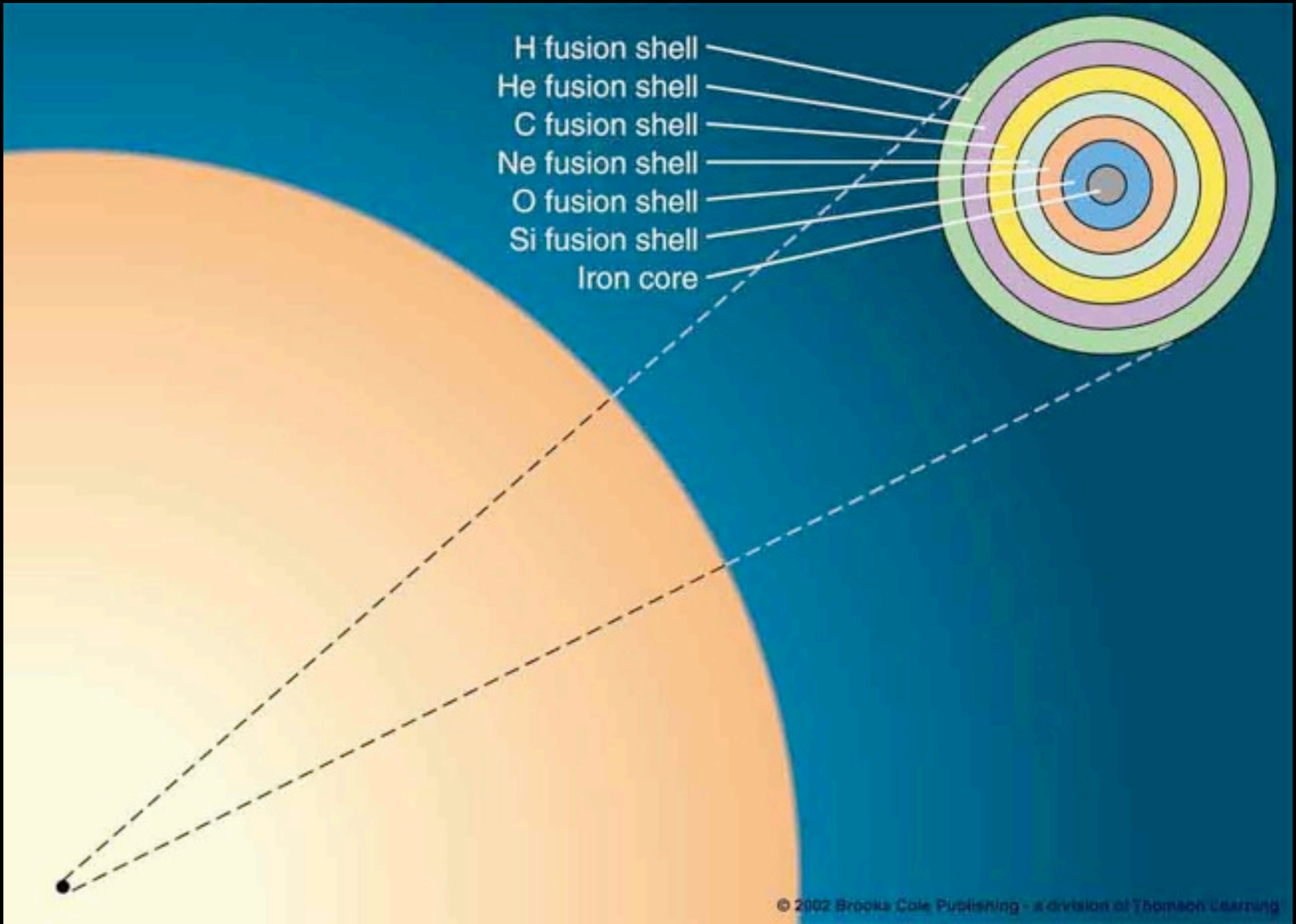
The "evolutionary track" of a $1M_\odot$ star





Track shows where a <u>single star</u> is in the HR diagram at different points in its lifetime.

High mass stars keep right on going!



Each stage is energetically less successful than the first:

- Core is hotter and hotter each time.
- Burn rate is faster and faster…
- …but less and less energy is released per fusion reaction (i.e. energy difference between H and He is particularly large).

Each Cycle is shorter than the one before!

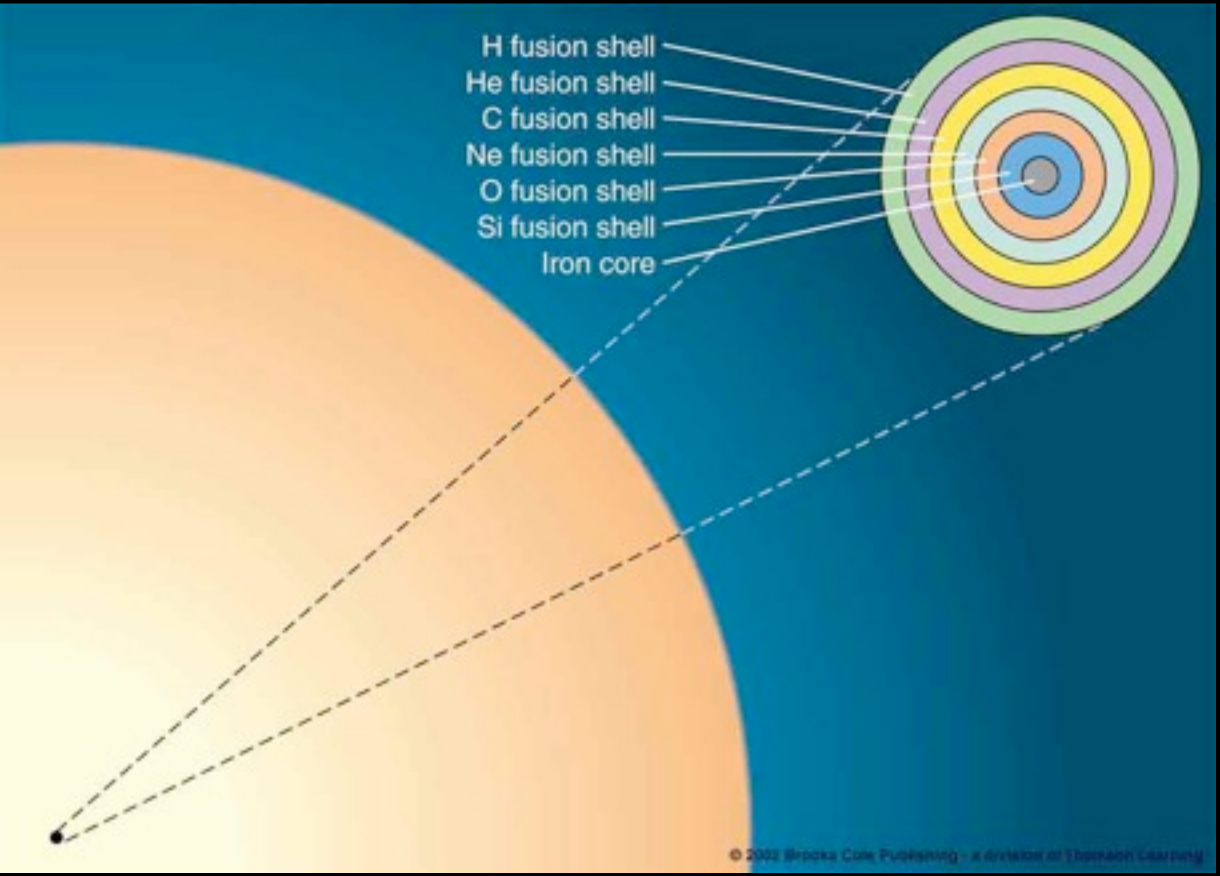
For a massive star…

- H-burning: 7 million years (10^7 K)
- He-burning: 500,000 years (10^9 K)
- C-burning: 600 years (10^{11} K)
- Ne-burning: 1 year (10^{12} K)
- O-burning: 6 months (10^{13} K)
- Si-burning: 1 day! (10^{14} K)

"Nucleosynthesis"

- We're made of all that stuff made while powering desperate stars!!!!

This process is where most iron and carbon come from



Astronomers refer to all the elements heavier than Helium as "metals"

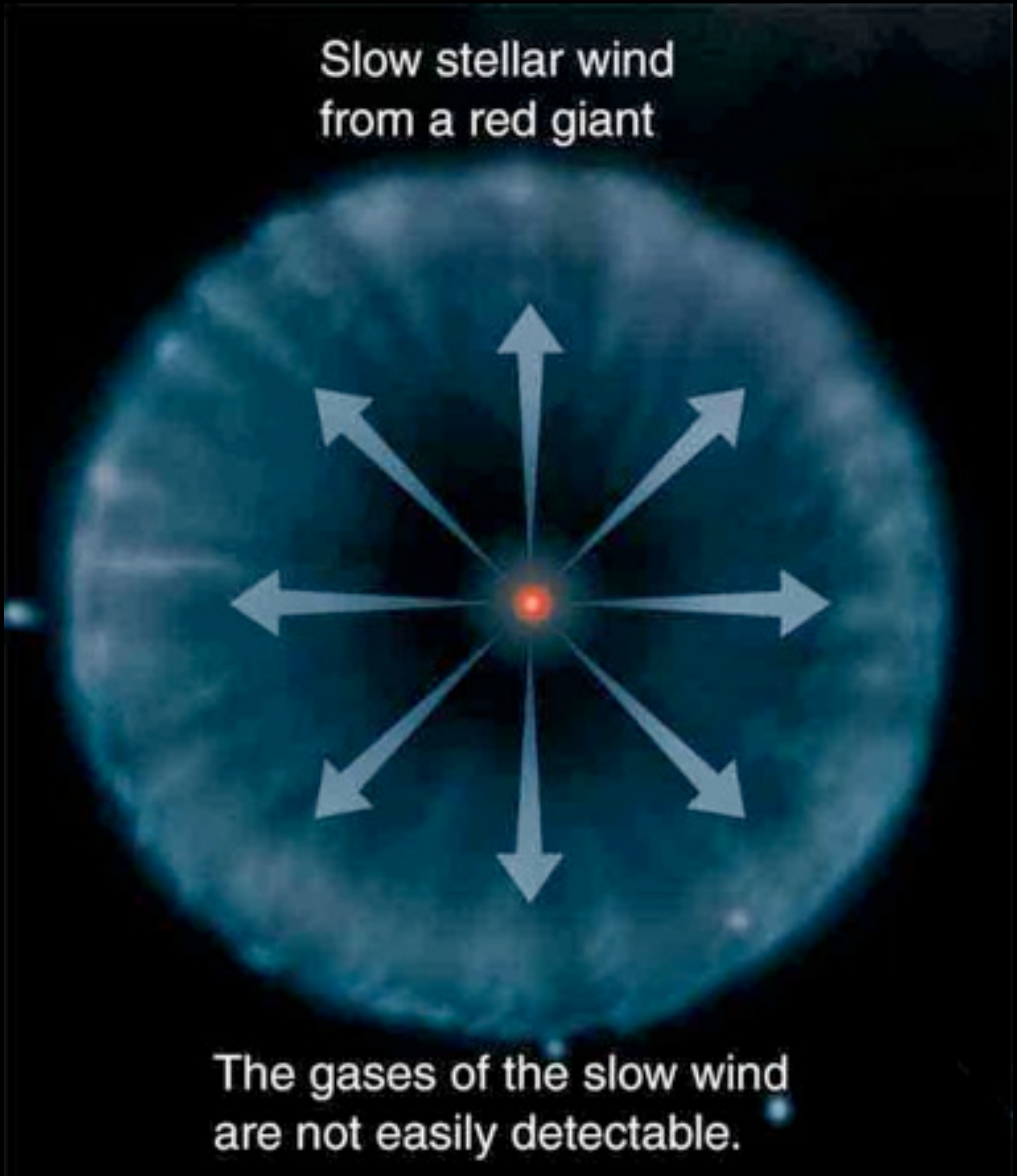
We see metals everywhere we look in the Universe. How did they get out of stars?

One way is through “stellar winds”

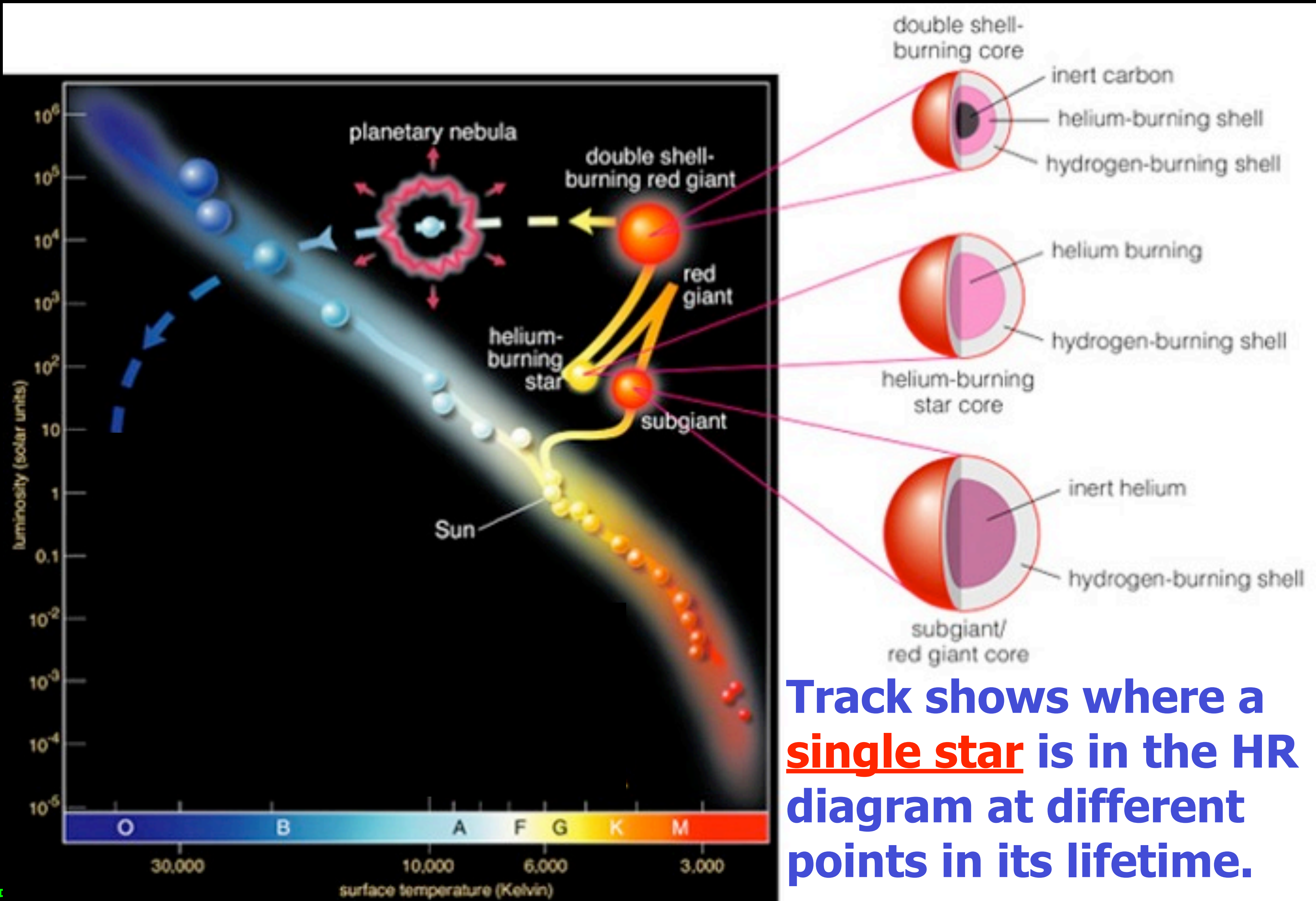
The star V838 Monocerotis

The swollen outer layers get pushed off! "Stellar Wind"

- ~20% of the star's mass is returned to the galaxy!

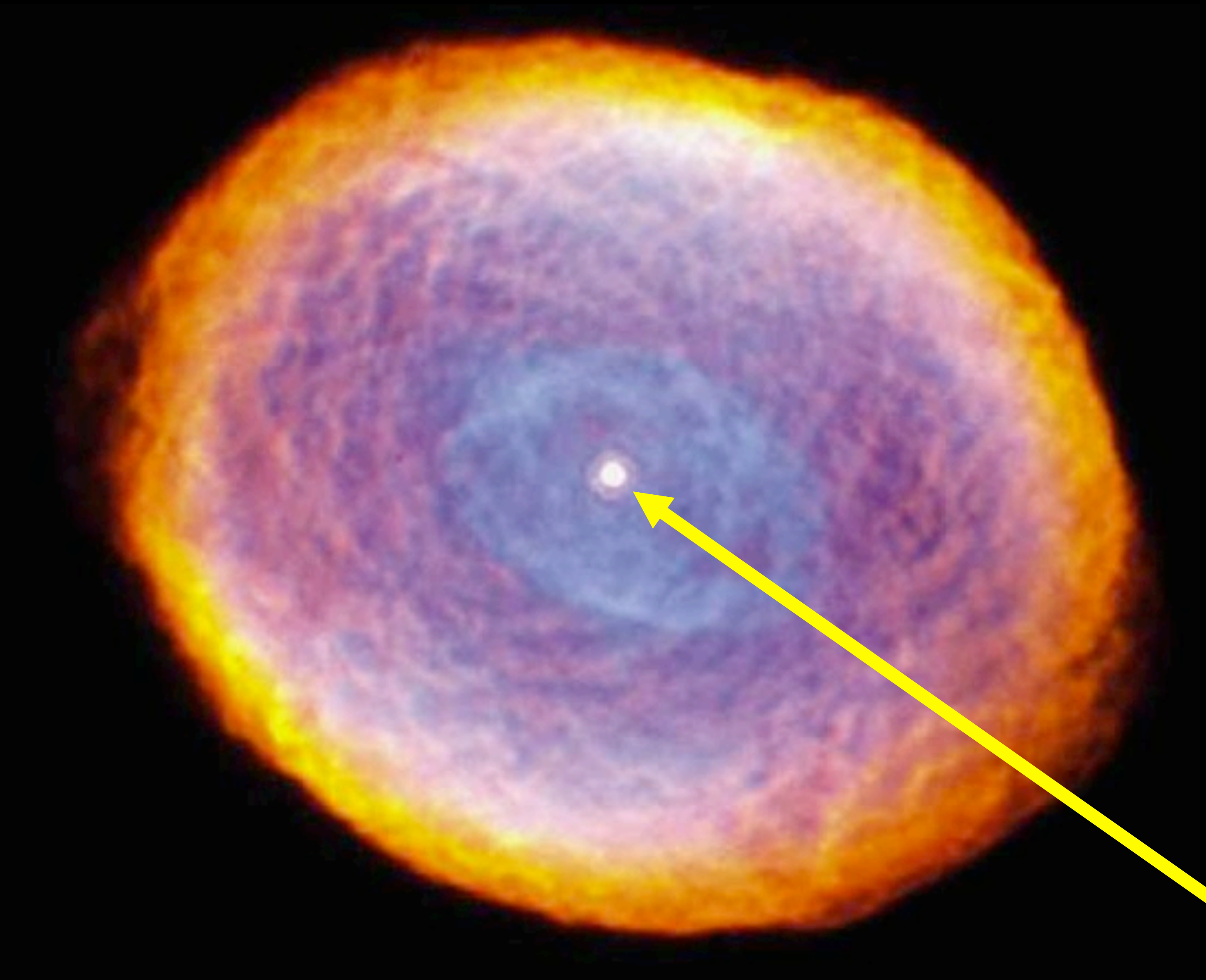


The "evolutionary track" of a $1M_\odot$ star

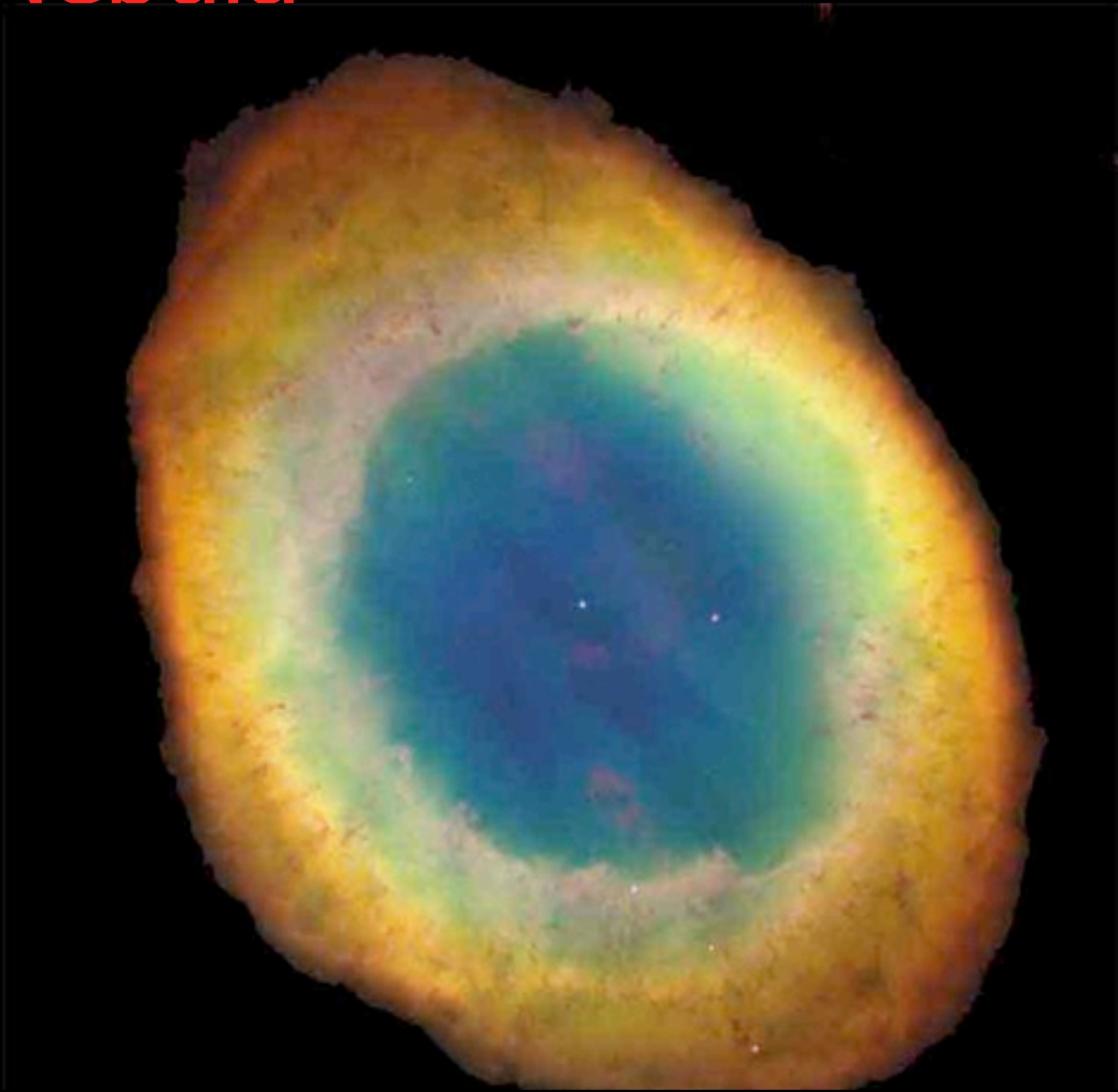


Track shows where a <u>single star</u> is in the HR diagram at different points in its lifetime.

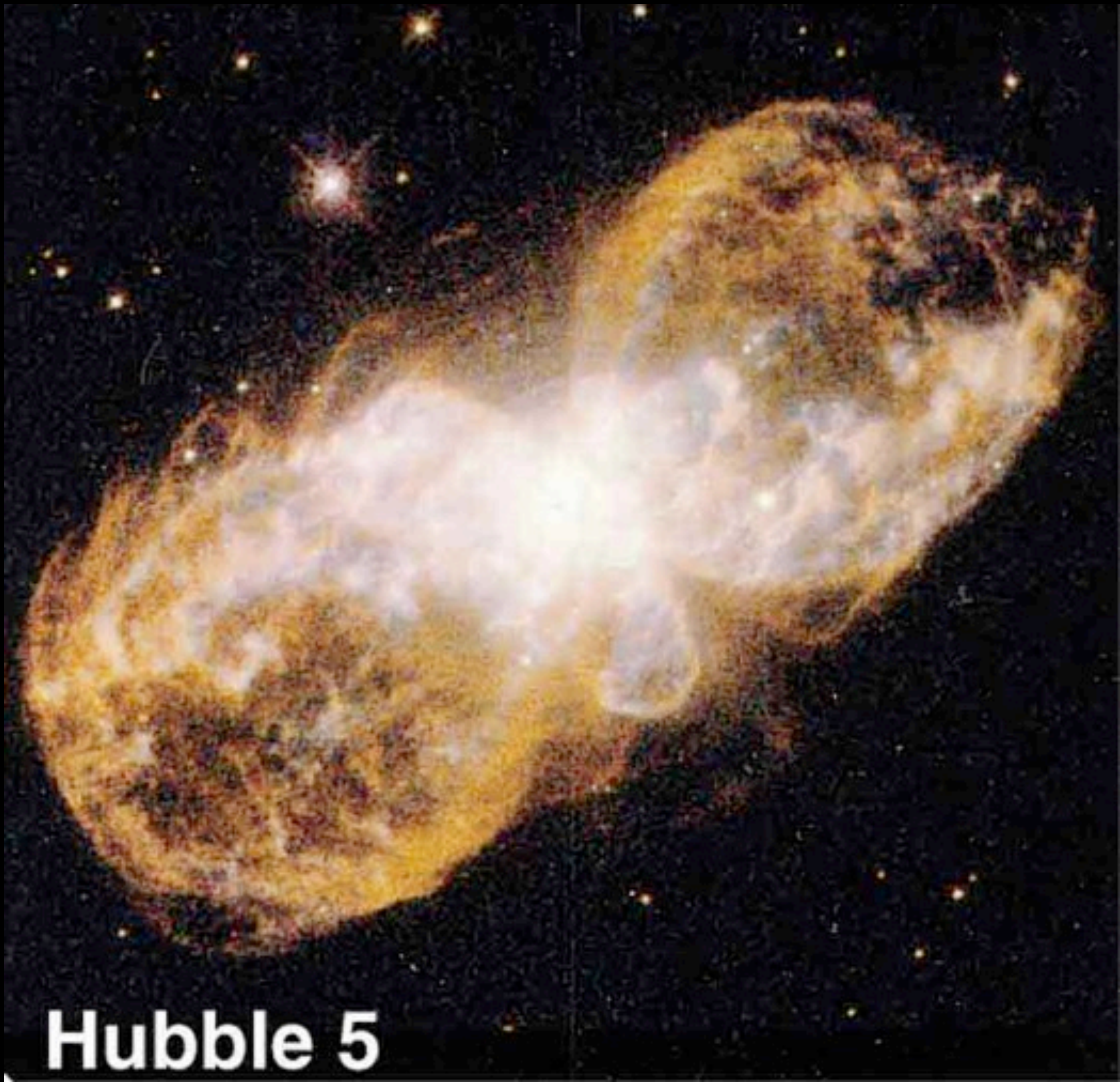
A "Planetary Nebula"!



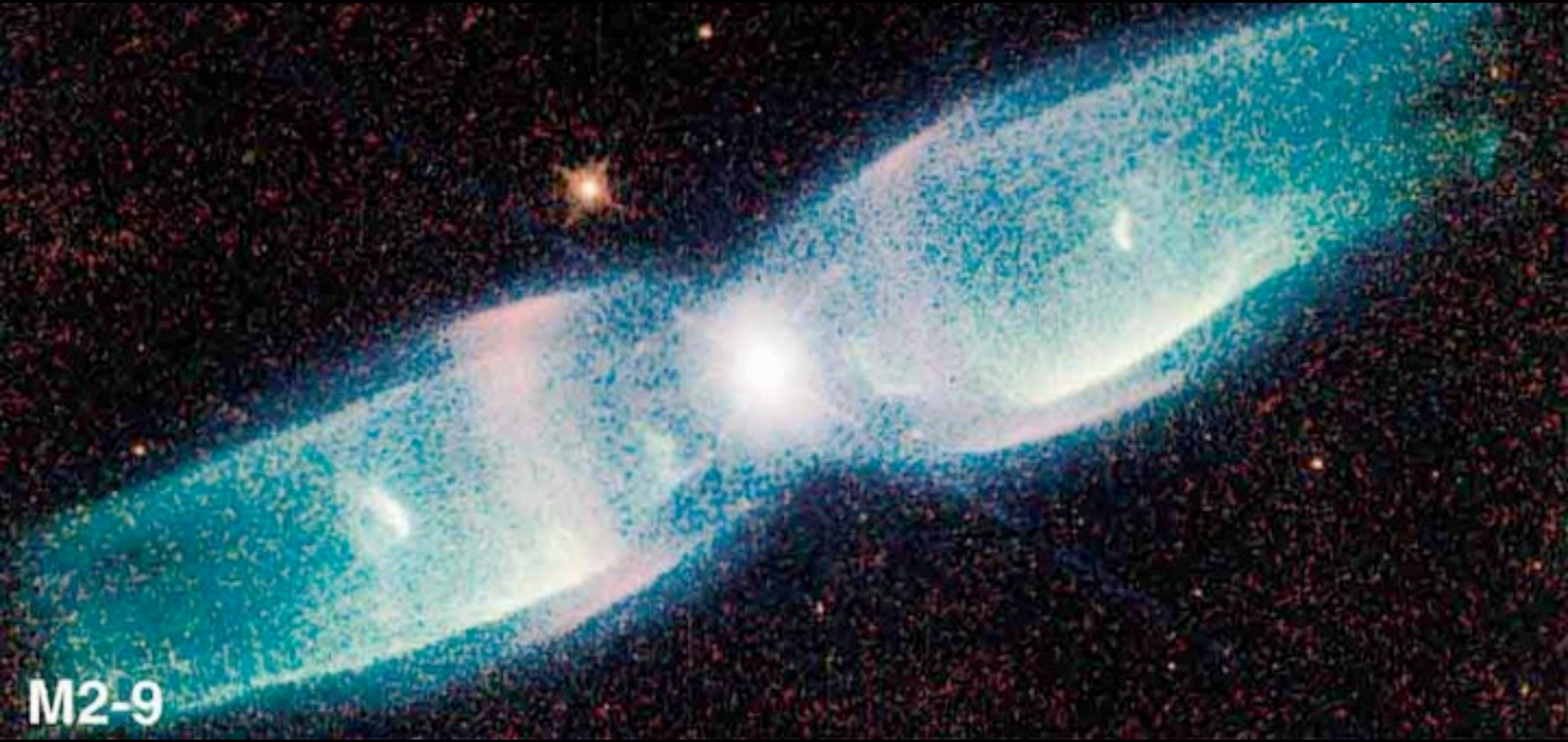
The Ring Nebula



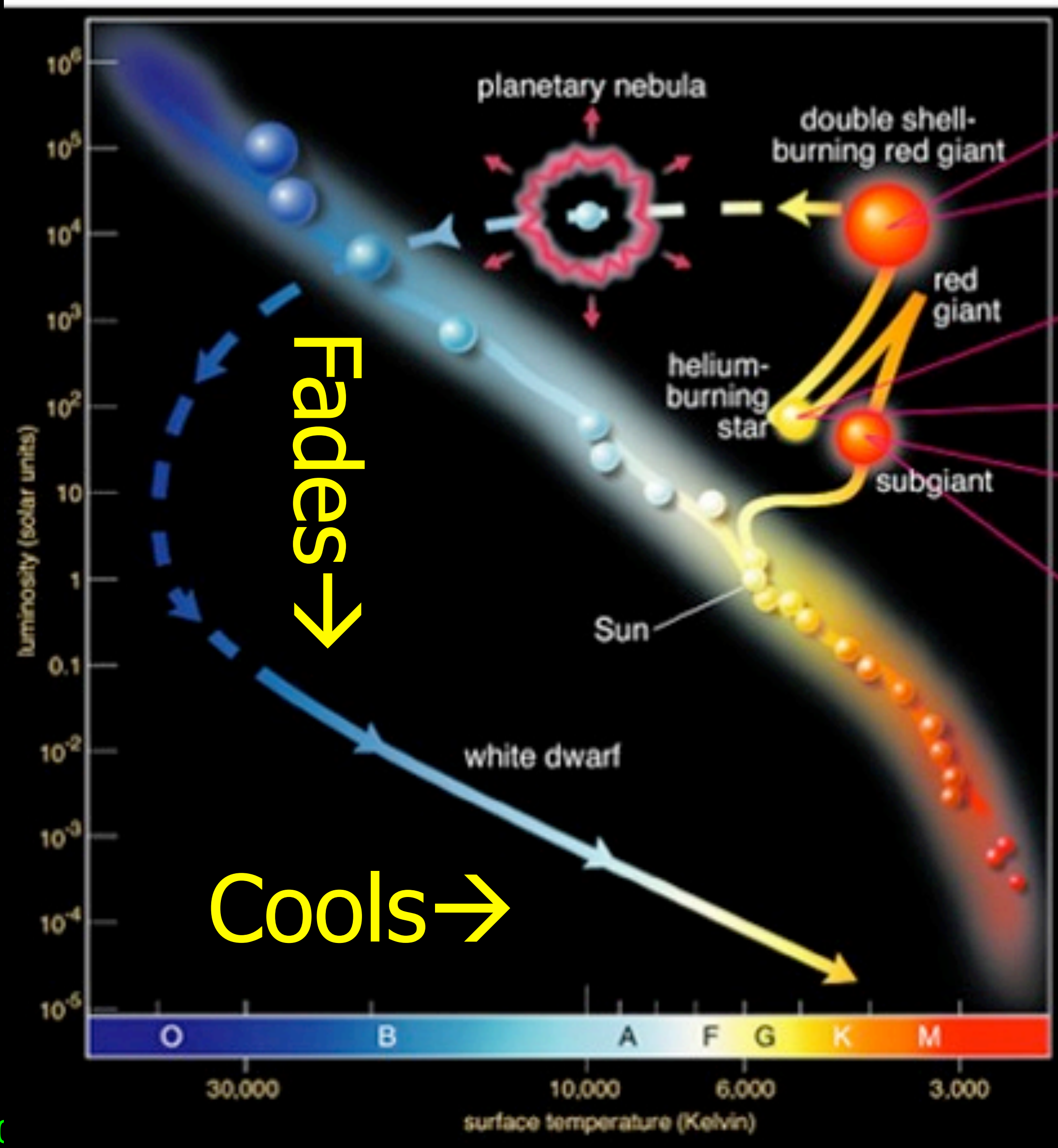
“Bipolar”

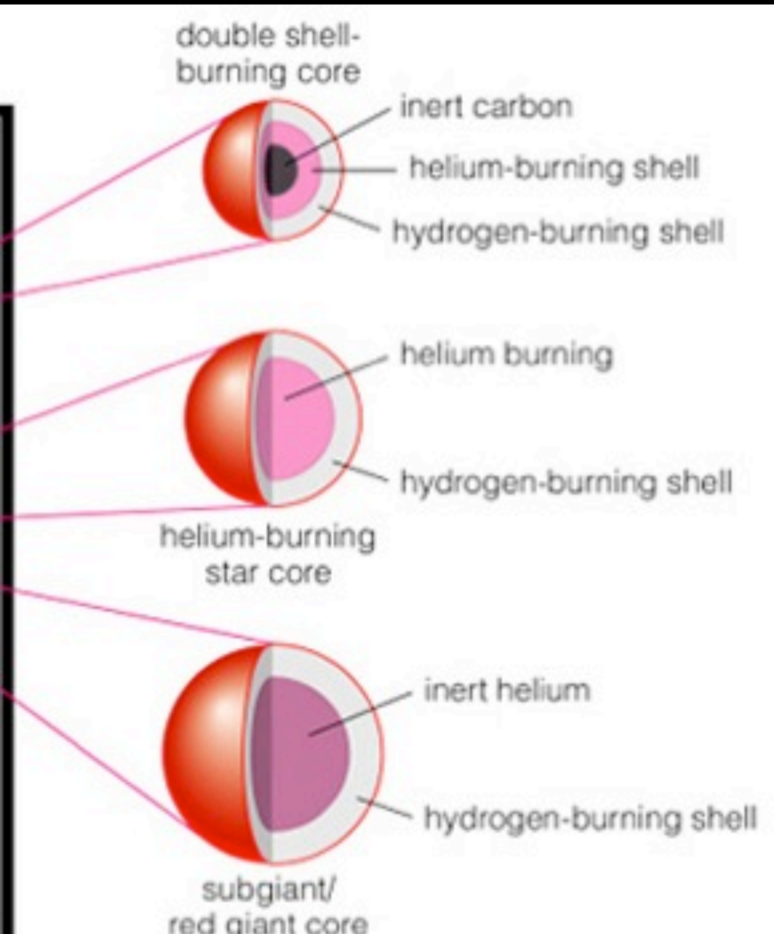


The Siamese Squid Nebula



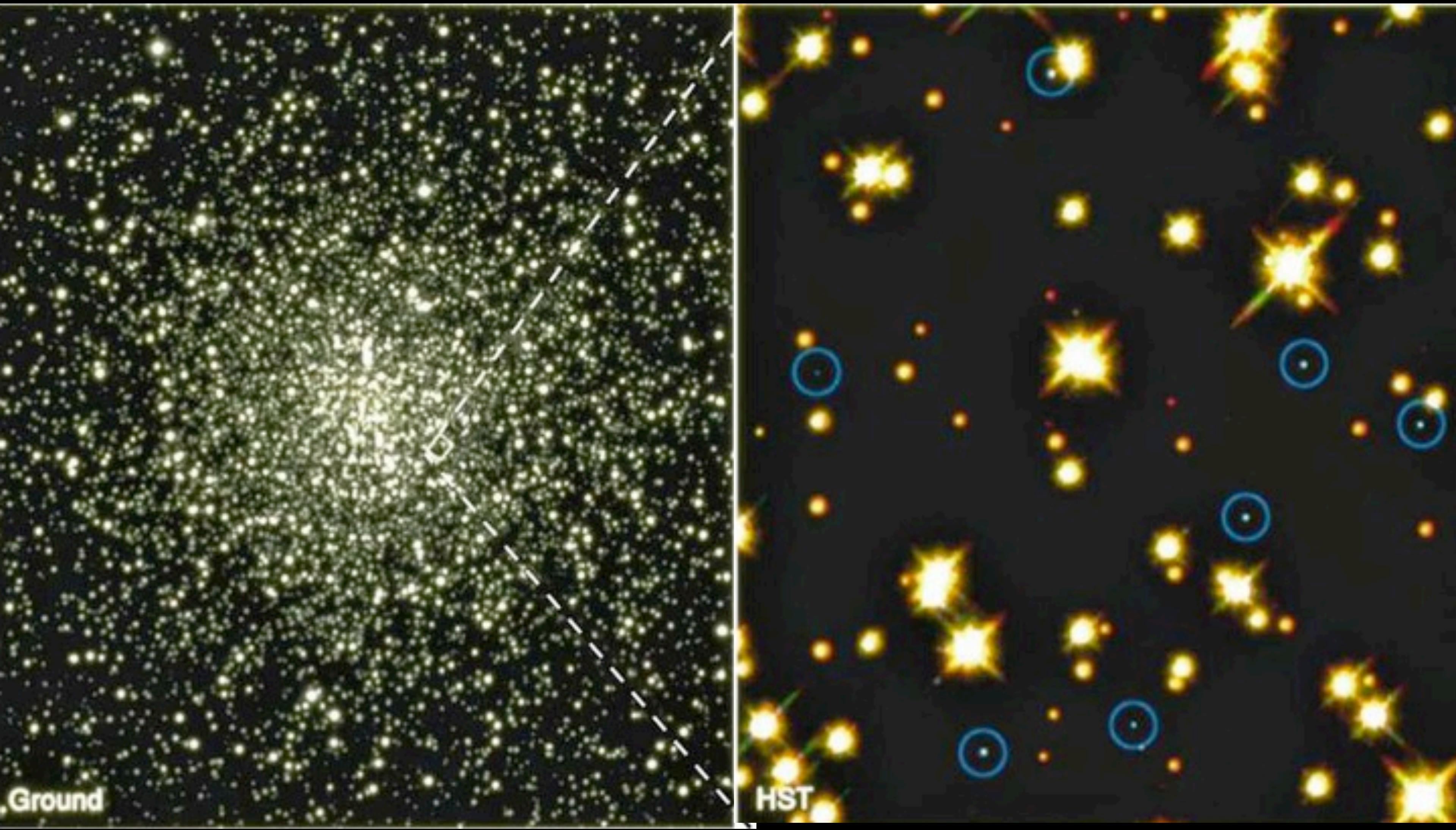
The "evolutionary track" of a $1M_{\odot}$ star





Track shows where a <u>single star</u> is in the HR diagram at different points in its lifetime.

White dwarfs in distant globulars



White Dwarfs are bizarre.

- They're **really** dense.

Most of the mass of the star is now in a sphere the size of the Earth!

~2000 kg/cm^3

How did they get so dense?

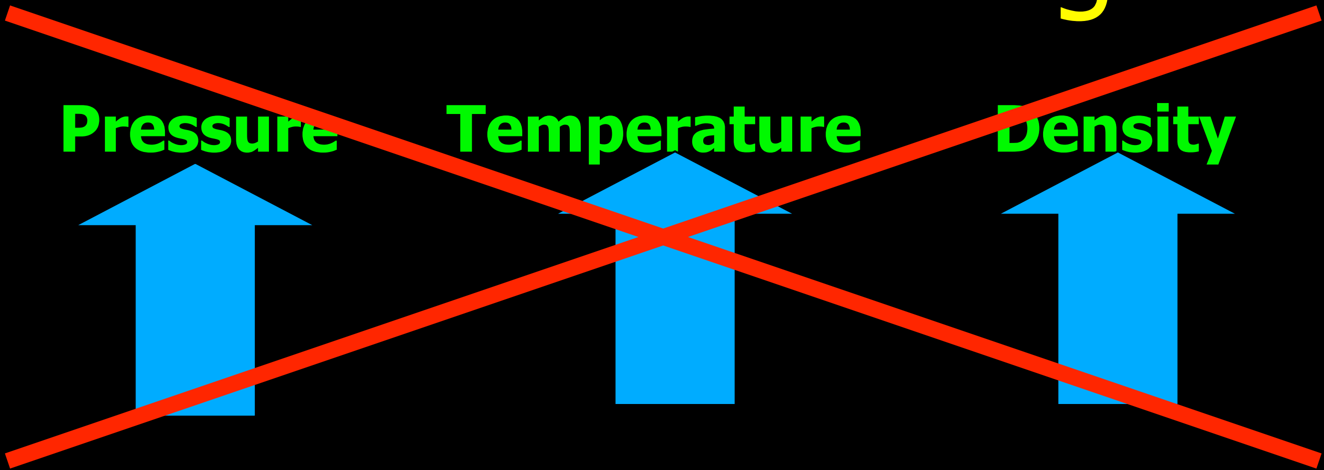
1. Fusion stopped
2. Temperature dropped
3. Pressure dropped
4. Gravity won!
5. Collapse!

But what stopped the collapse?

Normal gas pressure has failed, so it has to be something else.

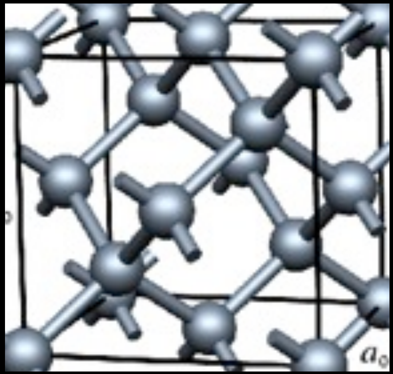
Why aren't white dwarfs infinitely

- At these densities, the gas in the star is no longer normal.

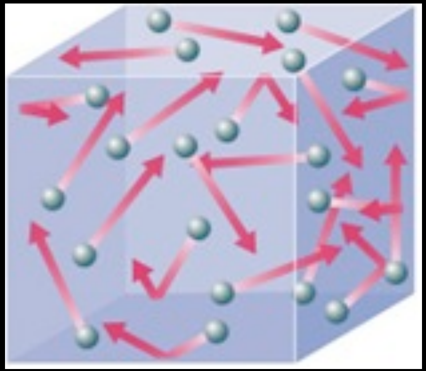


- Pressure is produced by quantum mechanical effects!

- <u>Nuclei</u> are locked into a crystal “lattice”

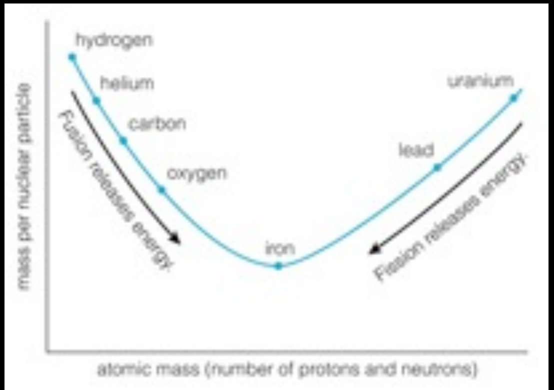


- <u>Electrons</u> are rushing about at very high speeds.

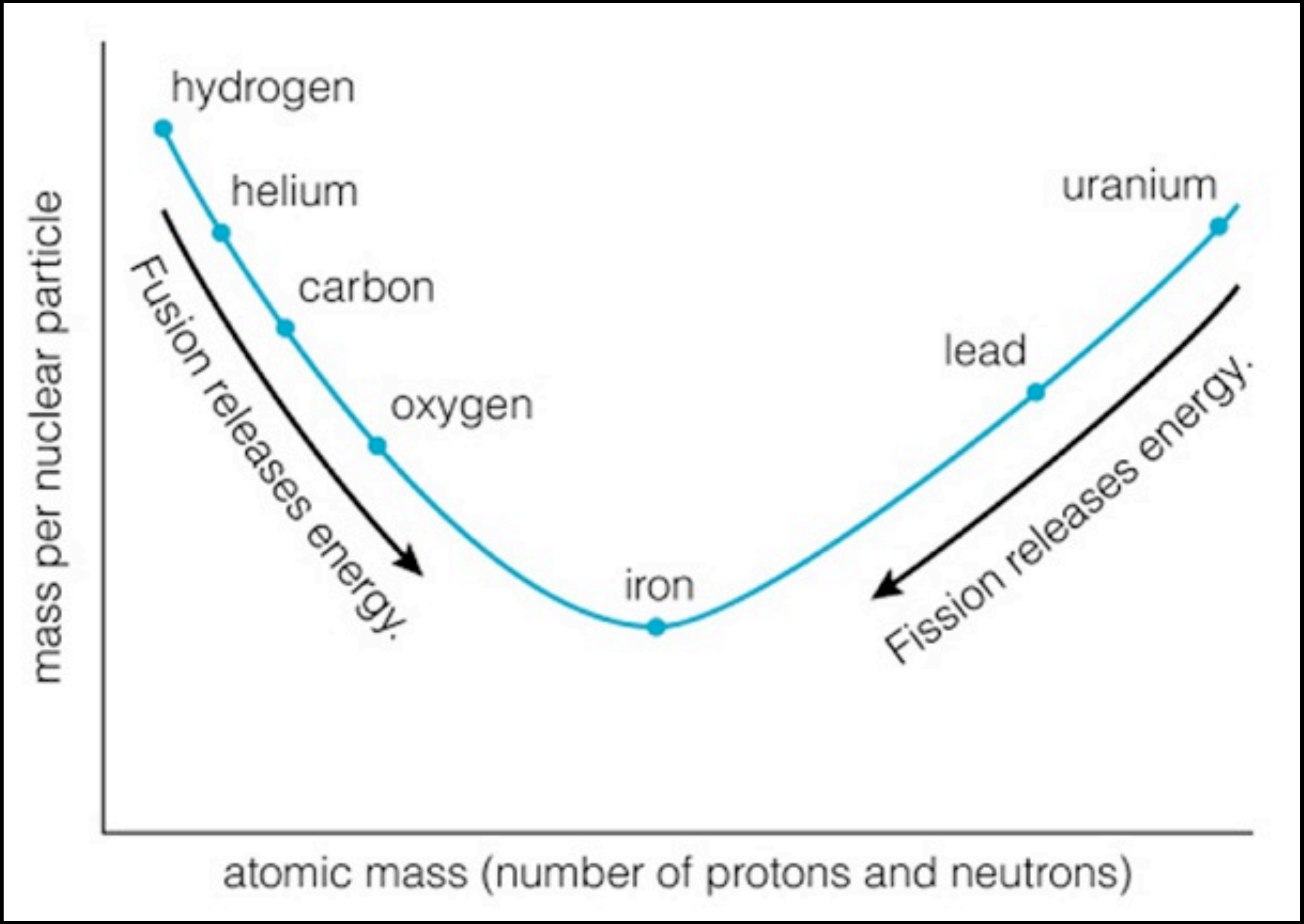


The Death Throes of a High Mass Star

- It really really really runs out of fuel.
  - Low mass stars run out because they don't get hot enough to burn what they have left.
  - High mass stars run out because they've burned everything! Can't burn iron!

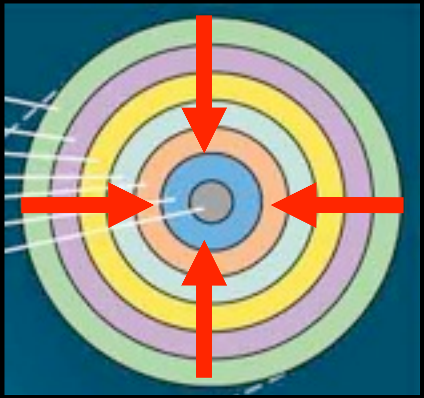


Iron has the least mass per nuclear particle.



When fusion stops:

- Core cools.
- Pressure drops
- Star collapses!



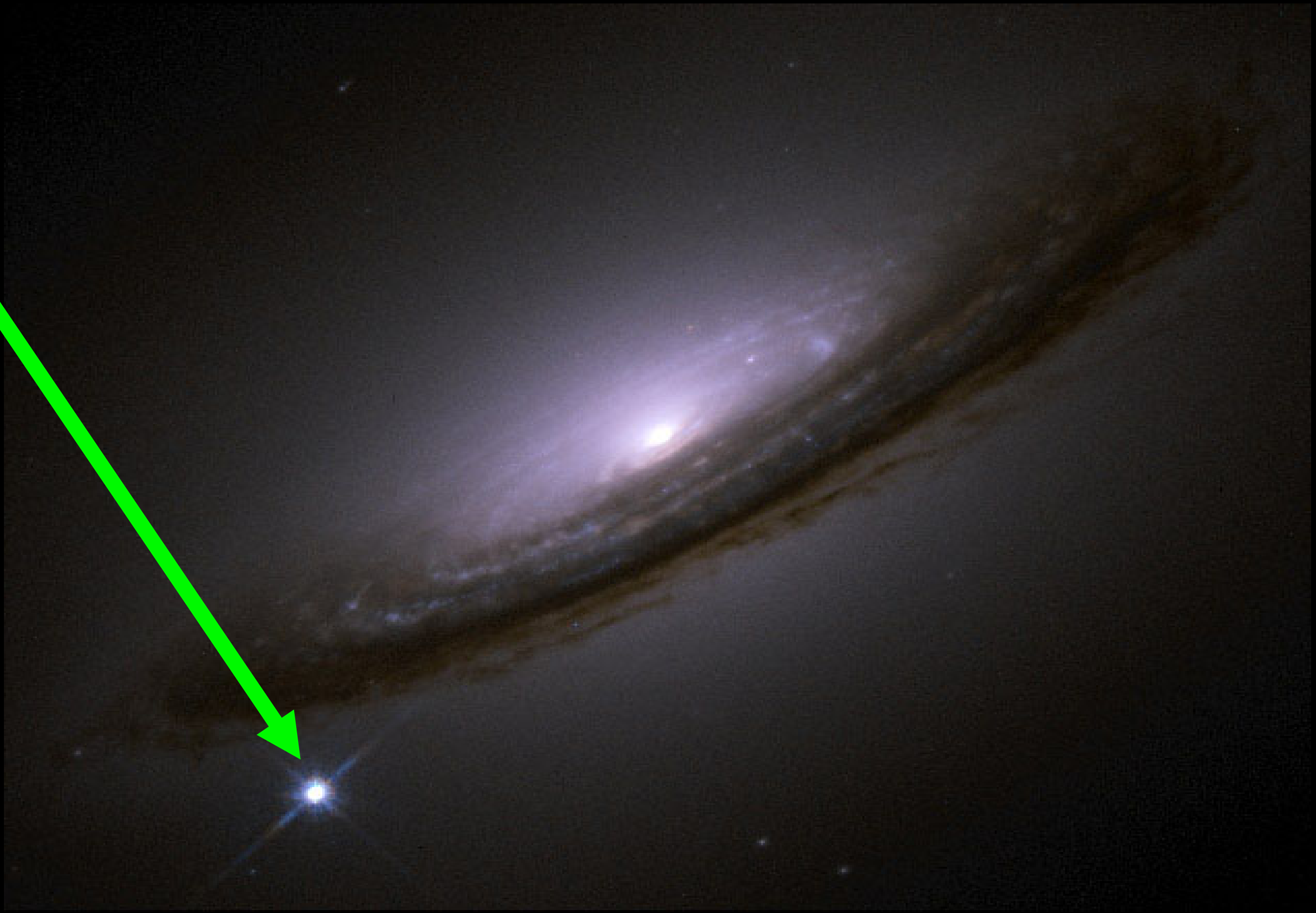
This releases a huge amount of the star's gravitational potential energy!

- Used to be Massive & Big!
- Now it's Massive & Tiny!

Supernova explosion: gravitational collapse of core releases more than 100 times the energy released by the Sun over it's whole lifetime!!!

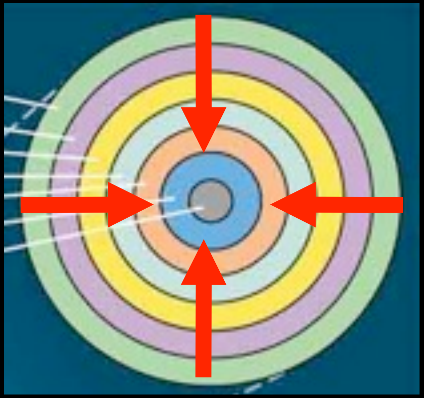
Luminosity is 10^{10} $L_{\odot}$!

(for a week or so)



What happens to the core when fusion stops:

- Core cools.
- Pressure drops
- Star collapses!



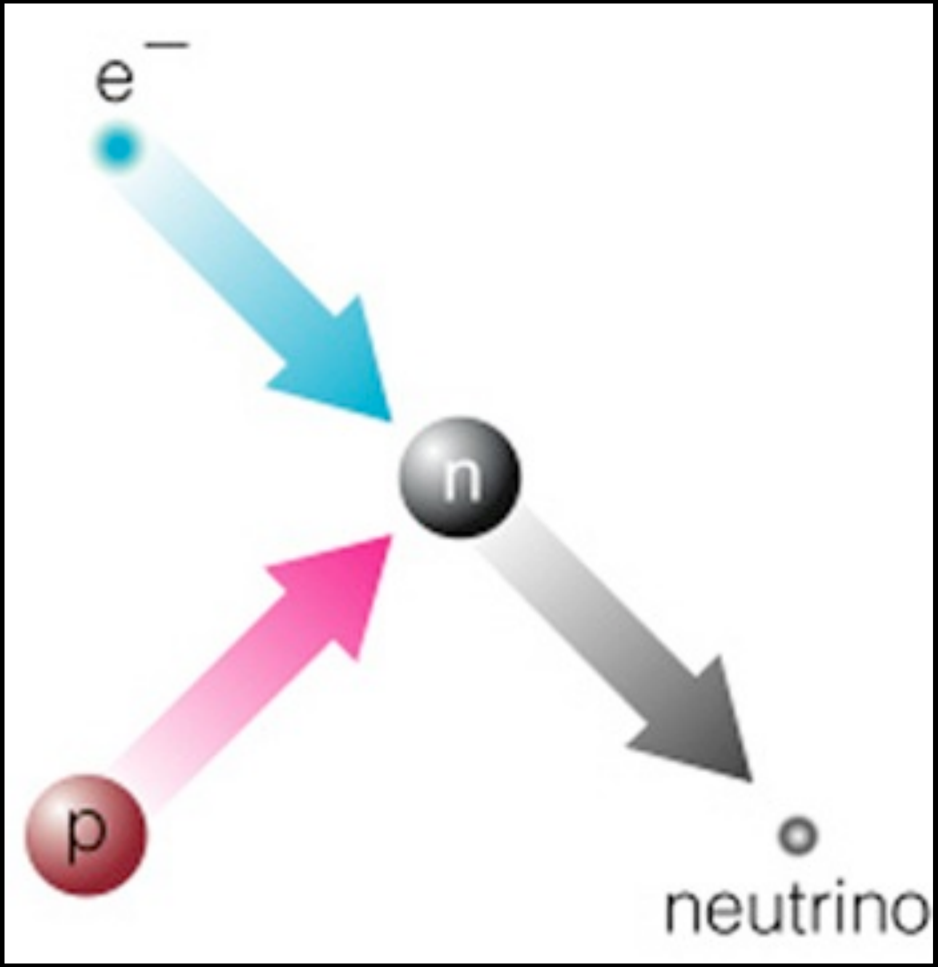
It tries to support itself with electron degeneracy pressure…

But, $M > 1.4M_{\odot}$!!!! Collapses more!

It's hot and dense…

But it can't detonate, since **iron can't burn…**

Electrons just can't handle it!



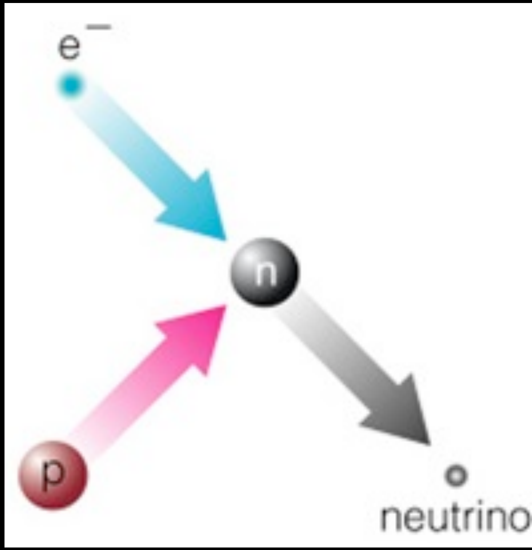
The whole core becomes solid **NEUTRONS**!!!

- Dense as the nucleus of an atom!
- Held together by gravity though, not the strong force.

"NEUTRON STAR"

Let's review:

- Massive Star collapses!
- But, M > 1.4$M_\odot$!!!! Can't be supported by electron degeneracy pressure
- Electrons combine with protons.
- Star becomes solid neutrons!



Neutron Degeneracy Pressure Supports the "**Neutron Star**"

Can neutron degeneracy pressure fail too?

G: Yes   B: No

What happens if neutron degeneracy pressure can't support the core either?

- Collapses some more! (M > $3M_{\odot}$ or so?)
- Nothing (we know of) can stop it!

BLACK HOLE!

<u>Any</u> mass smaller than a particular size becomes a black hole!

All objects have an “Escape Velocity”

- Depends on **mass** & **size**

$$V_{escape}^2 = \frac{2GM}{R_s}$$

Escape velocity depends on mass and size!

$$V_{escape}^2 = \frac{2GM}{R_s}$$

- Moon: 2 km/s
- Earth: 11 km/s
- Sun: 620 km/s
- White Dwarf: 7,600 km/s
- Neutron Star: 160,000 km/s

When the escape velocity is larger than the speed of light, NOTHING CAN GET OUT!

c≈300,000 km/s

So how smooshed do you have to get to be a black hole?

$$V_{escape}^2 = \frac{2GM}{R_s} = c^2 \Rightarrow R_s = \frac{2GM}{c^2}$$

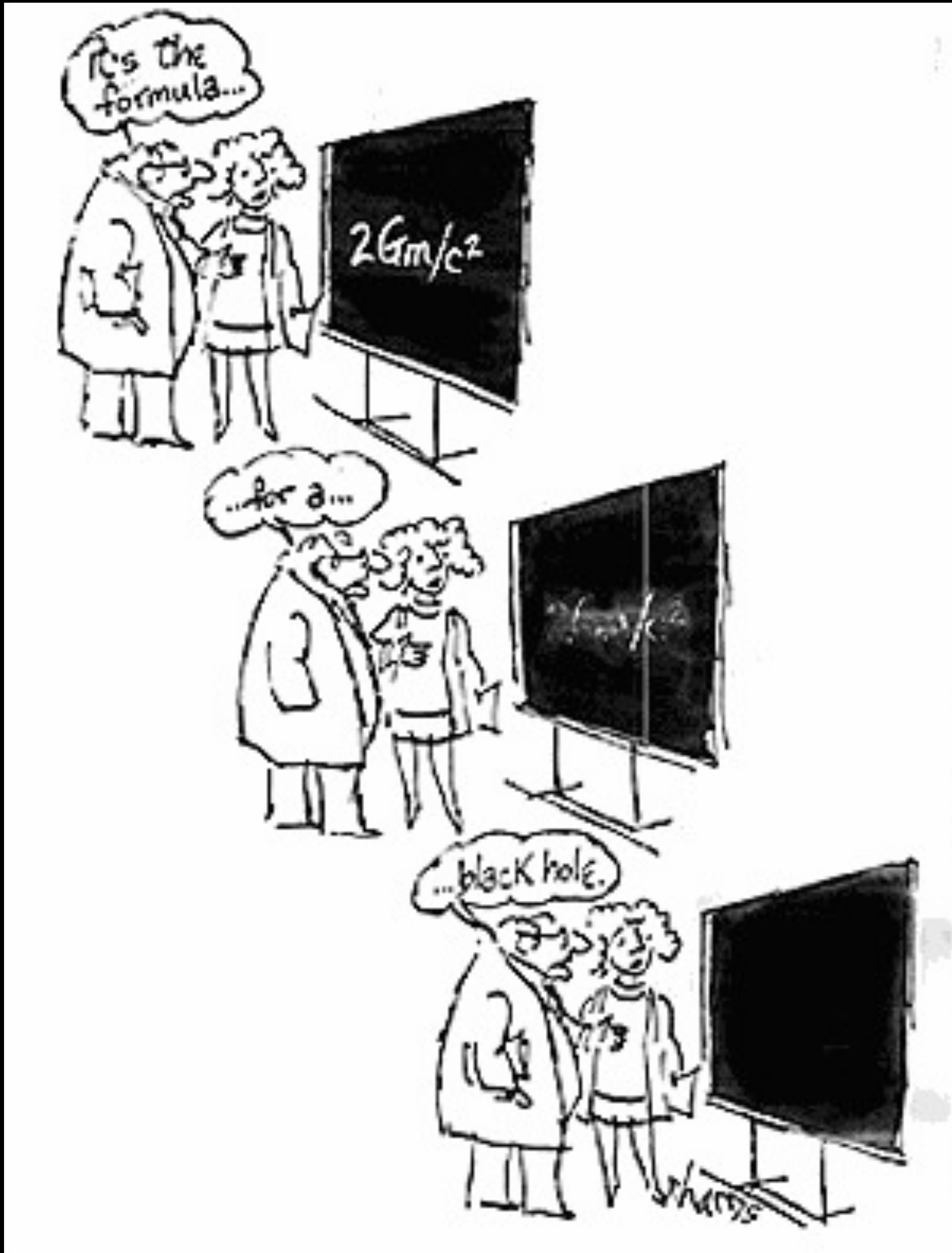
- "R_s" = "Schwarzschild Radius"

What's **Your** Schwarzschild Radius?

$$R_s = \frac{2GM}{c^2}$$

- $M \sim 70$ kg
- $R_s \sim 10^{-25}$ m!

Smaller than a nucleus!

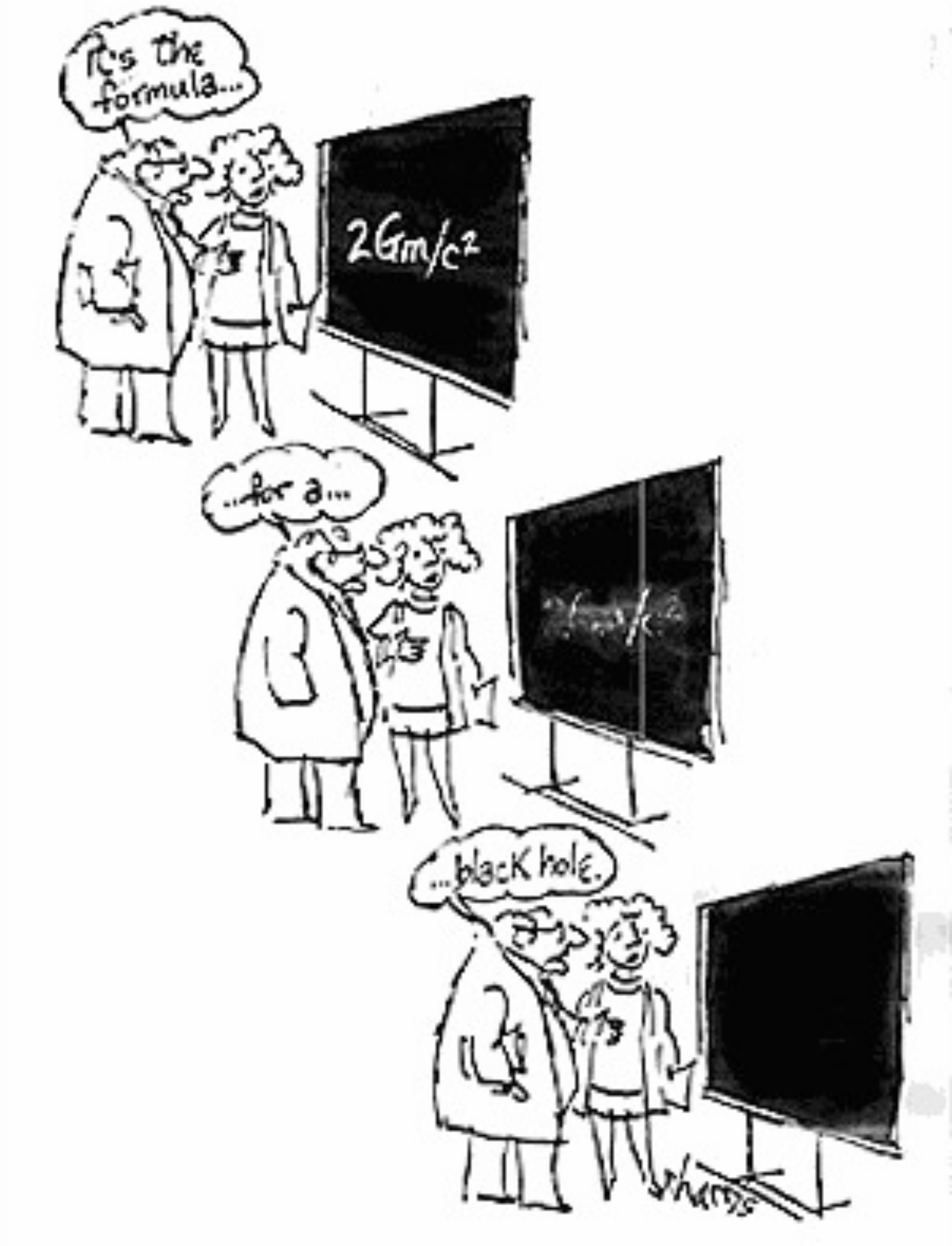


What about the Sun?

$$R_s = \frac{2GM}{c^2}$$

- $M \sim 2 \times 10^{30}$ kg
- $R_s \sim 3$ km!

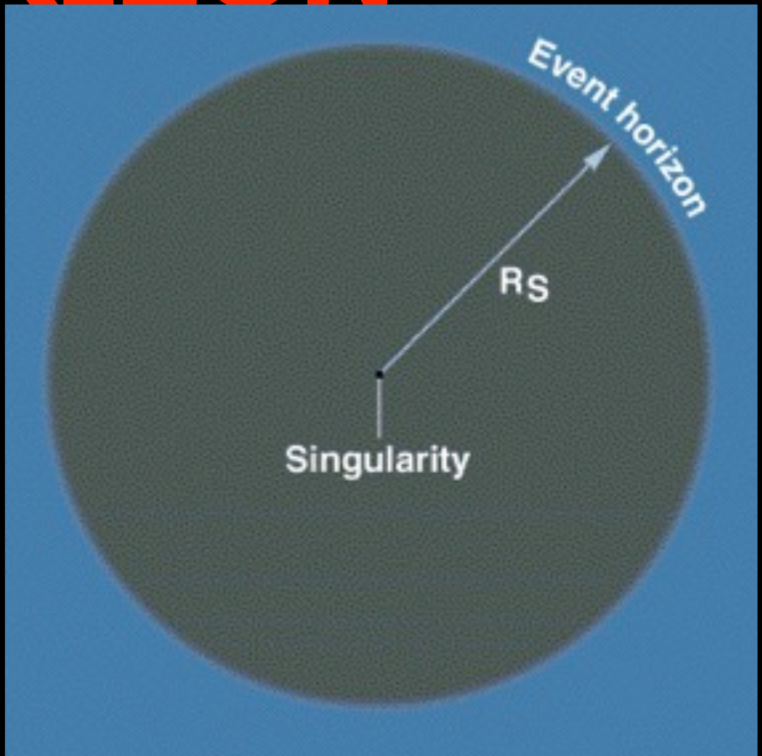
Still tiny! Smaller than a neutron star!



What does the Schwarzschild radius mean?

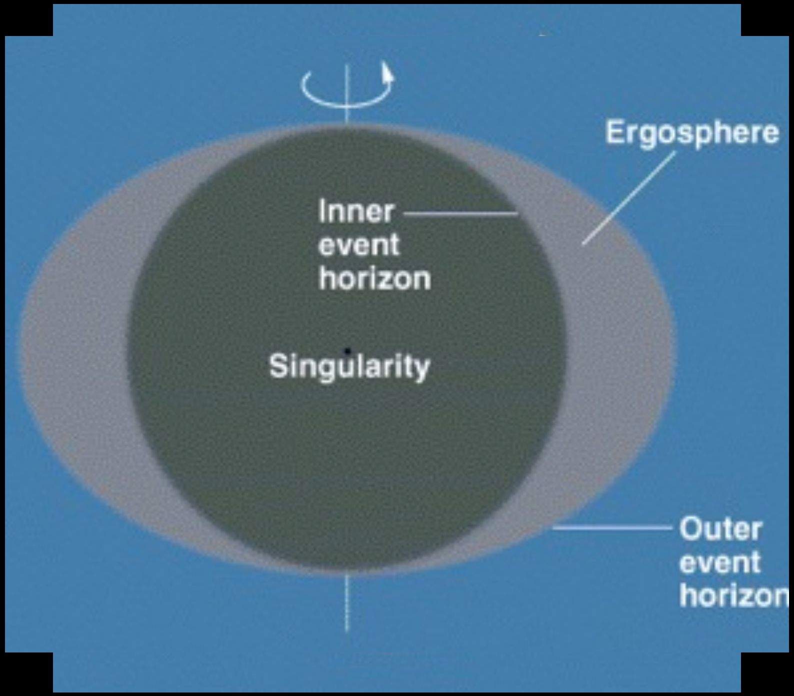
- If you're inside R_s, you can never leave!

"EVENT HORIZON"



- It doesn’t matter what’s inside the event horizon.

Only things that matter are the mass, electrical charge, and rotation speed of the black hole.



- If you're well outside R_s, the black hole acts like any other mass.

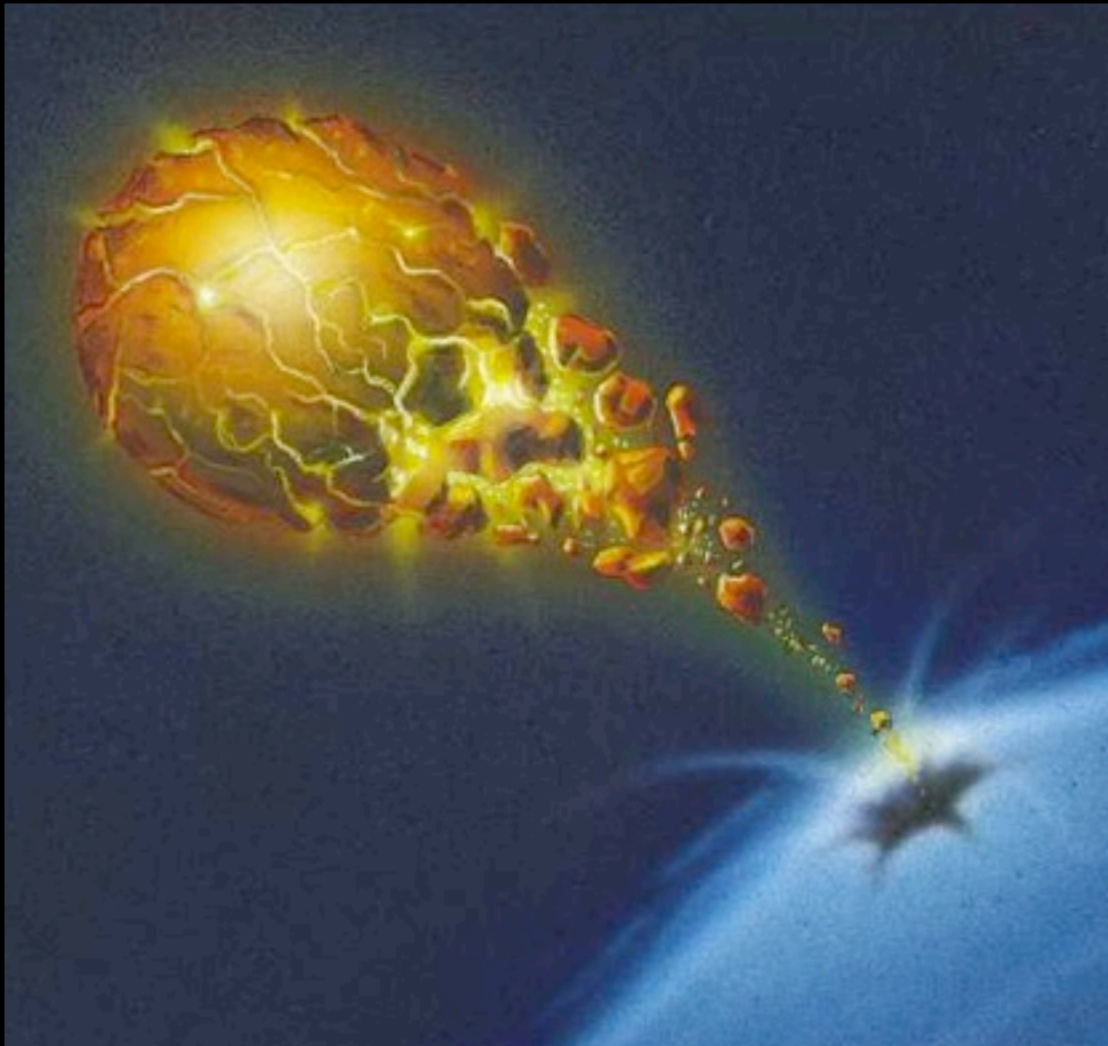
Q: If the Sun turns into black hole tomorrow, what will happen to the Earth?

Yellow: The Earth will be sucked in.
Pink: Nothing.

If you see a black hole,

DON'T JUMP!!!

Both sides of your body fall straight towards the black hole, stretching **and** smooshing you.



Black holes are rarely black!

Black holes can be some of the brightest objects in the universe!

1. X-ray binaries
2. Quasars & Active Galactic Nuclei