Stellar Evolution

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Star Clusters: stellar nurseries

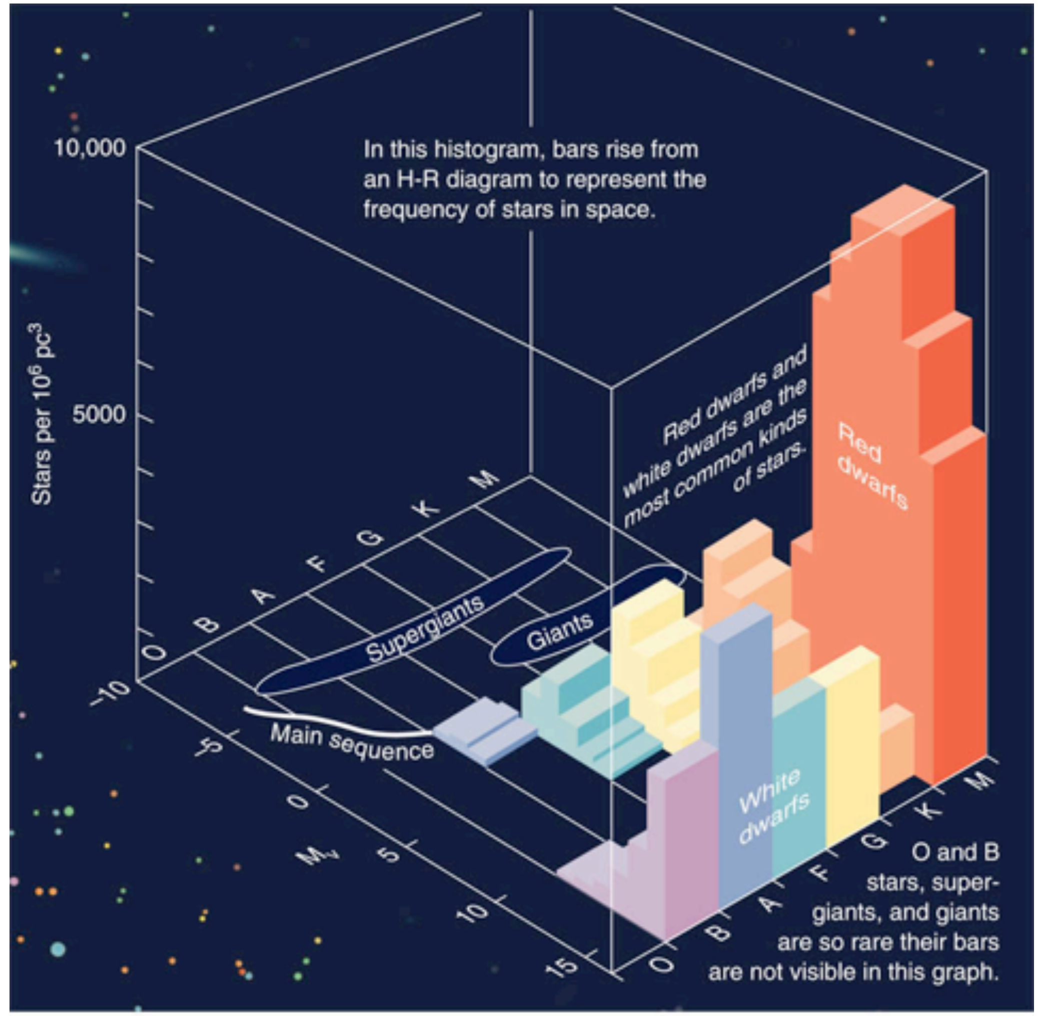
- As we saw in Orion and in the simulations, **stars form in clusters.**
- Young clusters (right) are still forming stars and remain surrounded by hot gas and dust.
- This gas is an example of a *emission nebula*. It is red from ionized hydrogen (hydrogen that has lost its electron).

Star Clusters

- As we saw in Orion and in the simulations, **stars form in clusters.**
- The Pleiades (right) are 100 million years old and only have a little gas and dust remaining.
- This gas is an example of a *reflection nebula*. It is blue for the same reason that the sky is.

How common are different stars?

- Low mass stars are very common. (K and M stars)
- Sun-like stars are rarer (G stars)
- High mass (O and B stars) are very rare.



Implication of Mass-Luminosity Relation

More mass = More Luminosity = faster rate of fusion

= Shorter lifetime on Main Sequence!

Table 7-2 | Main-Sequence Stars

Spectral Type	Mass (Sun = 1)	Luminosity (Sun = 1)	Approximate Years on Main Sequence
O5	40	405,000	1×10^6
B0	15	13,000	11×10^6
A0	3.5	80	440×10^6
F0	1.7	6.4	3×10^9
G0	1.1	1.4	8×10^9
K0	0.8	0.46	17×10^9
M0	0.5	0.08	56×10^9

O Stars have 40x mass of Sun, live 10,000x shorter.

A stars have 3x mass of Sun, live 20x shorter.

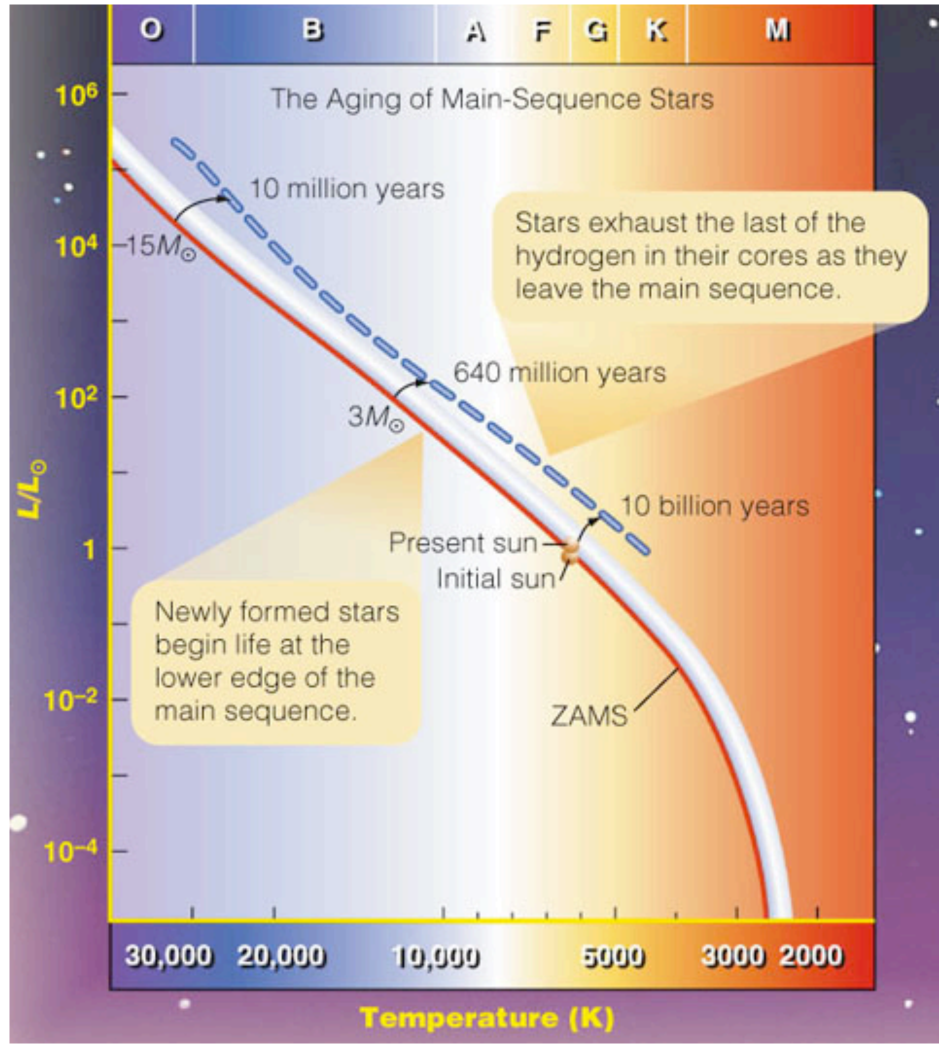
M stars have half the mass of Sun, and live 7x longer.

Stellar Evolution

What happens after the main sequence?

Evolution on the Main Sequence

As main sequence stars consume their hydrogen, the cores have to heat up to continue fusion. Therefore the stars get bigger over time on the main sequence.



What happens after the Main Sequence?

Stars spend 90% of their lifetime on the main sequence fusing hydrogen into helium in their cores.

What happens when the hydrogen runs out?

What happens after the Main Sequence?

What happens when the hydrogen runs out?

It depends on the **mass** of the star.

1. Very low mass stars (M < 0.8 solar masses)
2. Low mass stars (M < 8 solar masses)
3. Low mass stars with companions (binary stars)
4. High mass stars (M > 8 solar masses)
5. Very high mass stars (much greater than 8 solar masses)

Very low mass stars

?

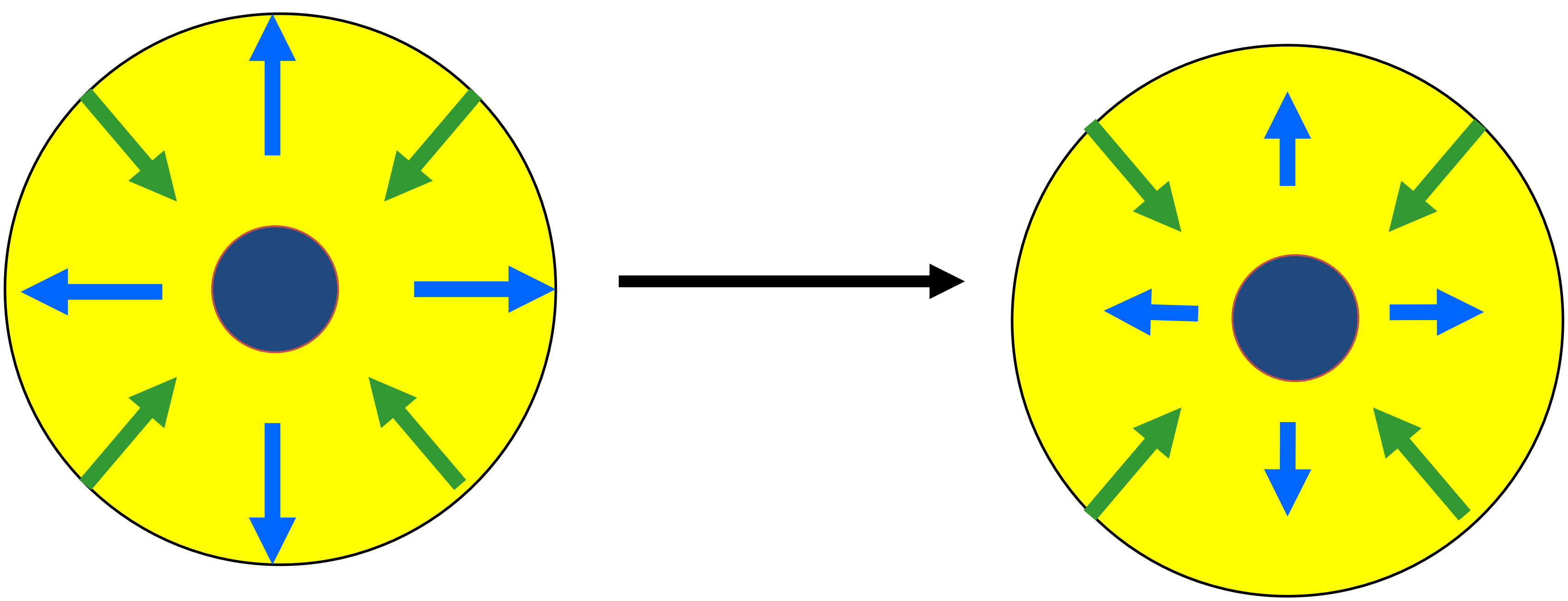
Every one of them is still on the main sequence.

Low mass stars (< 8 solar masses)

- When a star like the Sun starts to run out of hydrogen in the core, fusion slows down.
- The star is no longer in hydrostatic equilibrium, and is **out of balance**.
- Something has to happen to keep the star from collapsing.

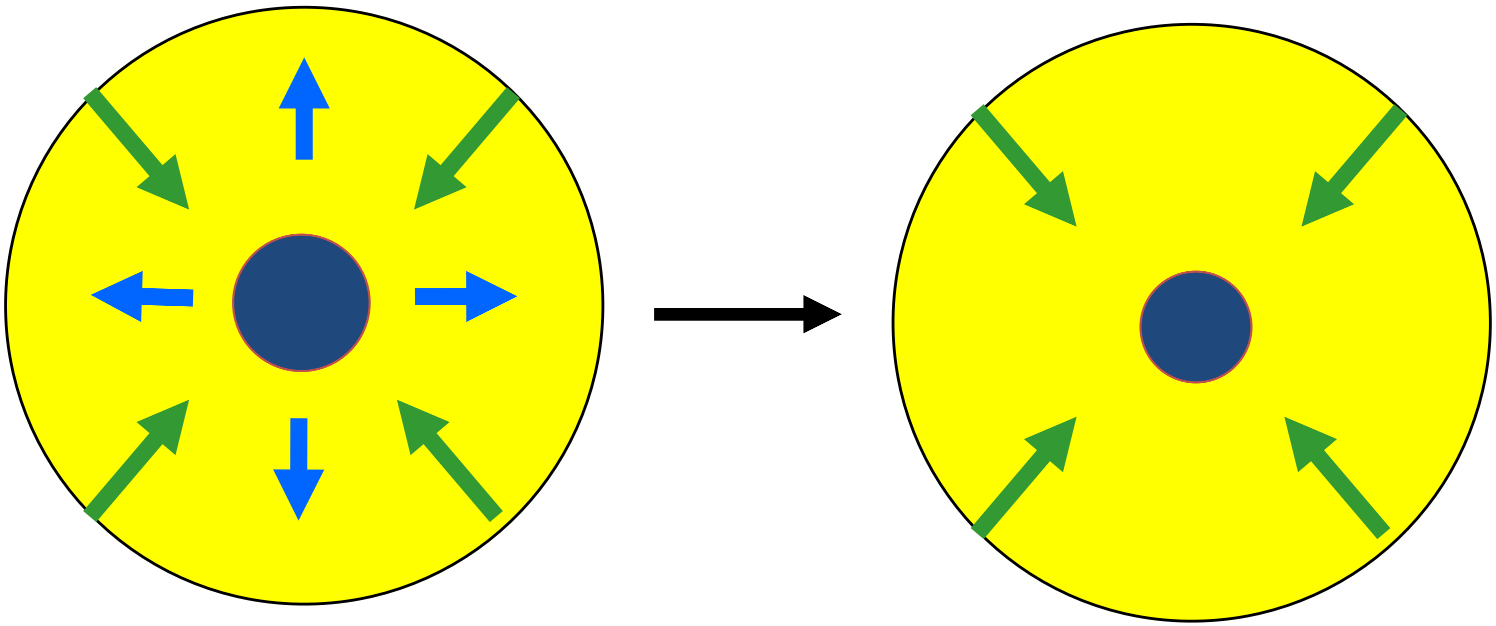
Out of balance

- Start running out of hydrogen in the core, now the outward pressure is less than the gravitational collapse



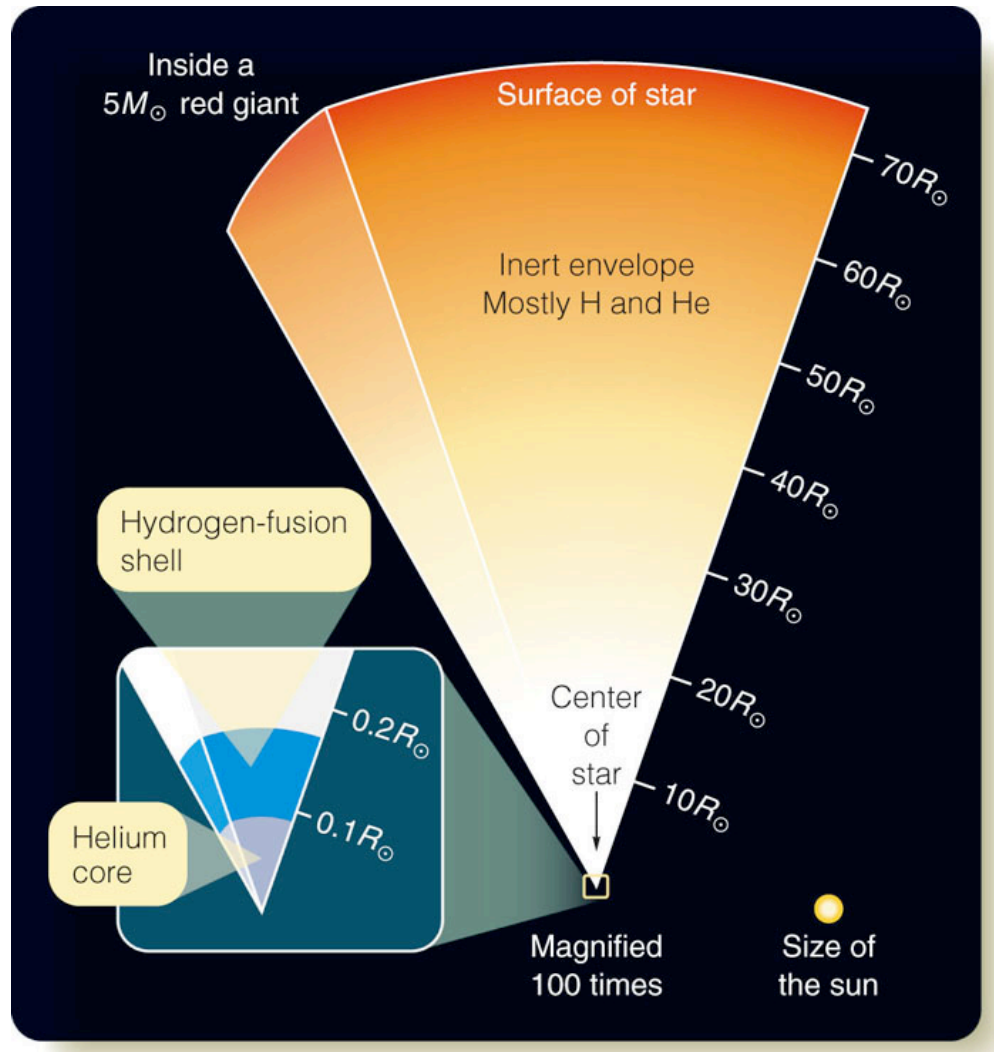
Out of balance

- What will happen to the core?



Main Sequence Star becomes a Red Giant

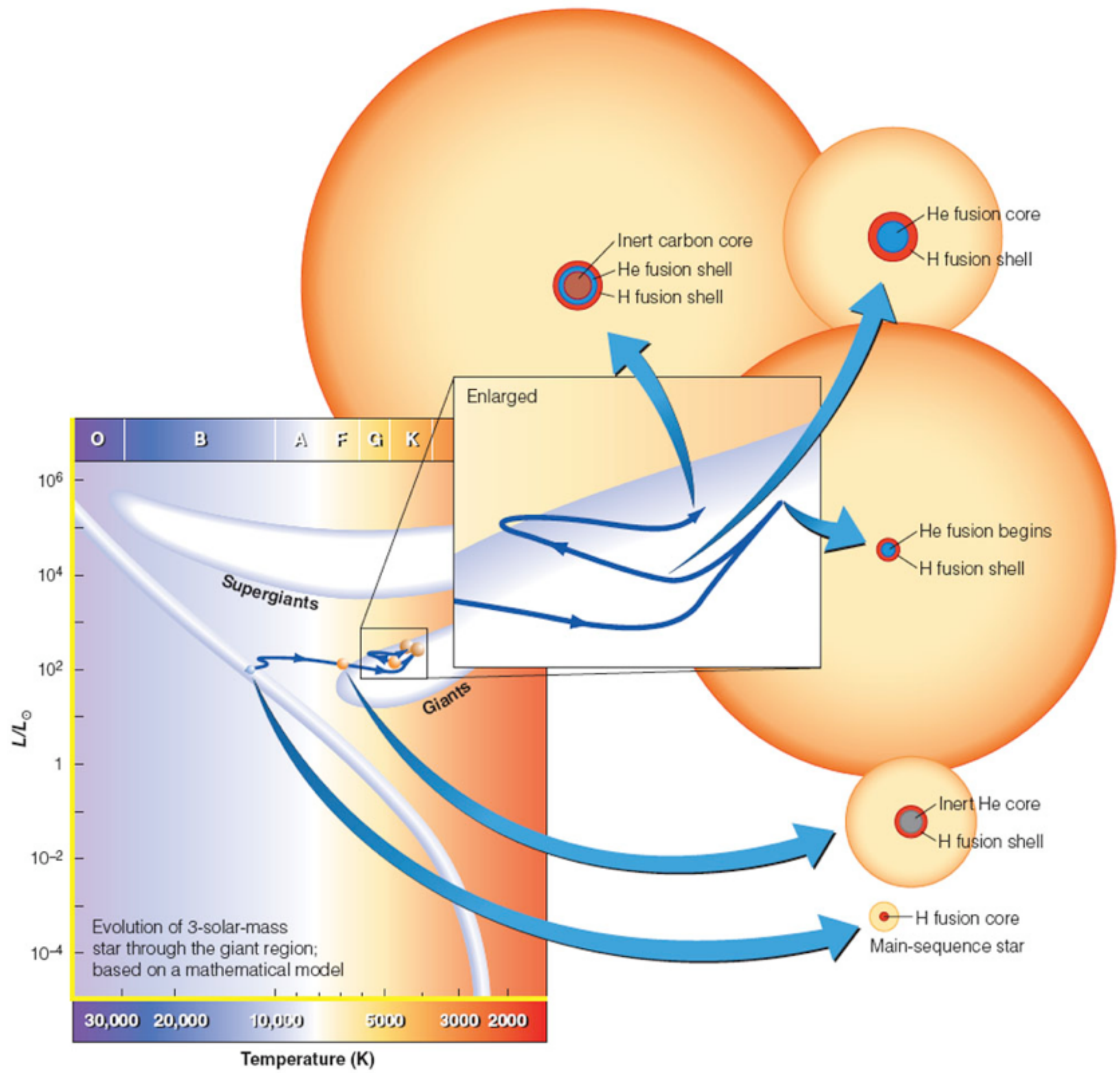
- Star starts to collapse, heating up central regions until a ***shell*** around the core is hot enough for hydrogen fusion.
- The energy from this shell is enough to cause the rest of the star to expand into a red giant.
- A stellar burp!



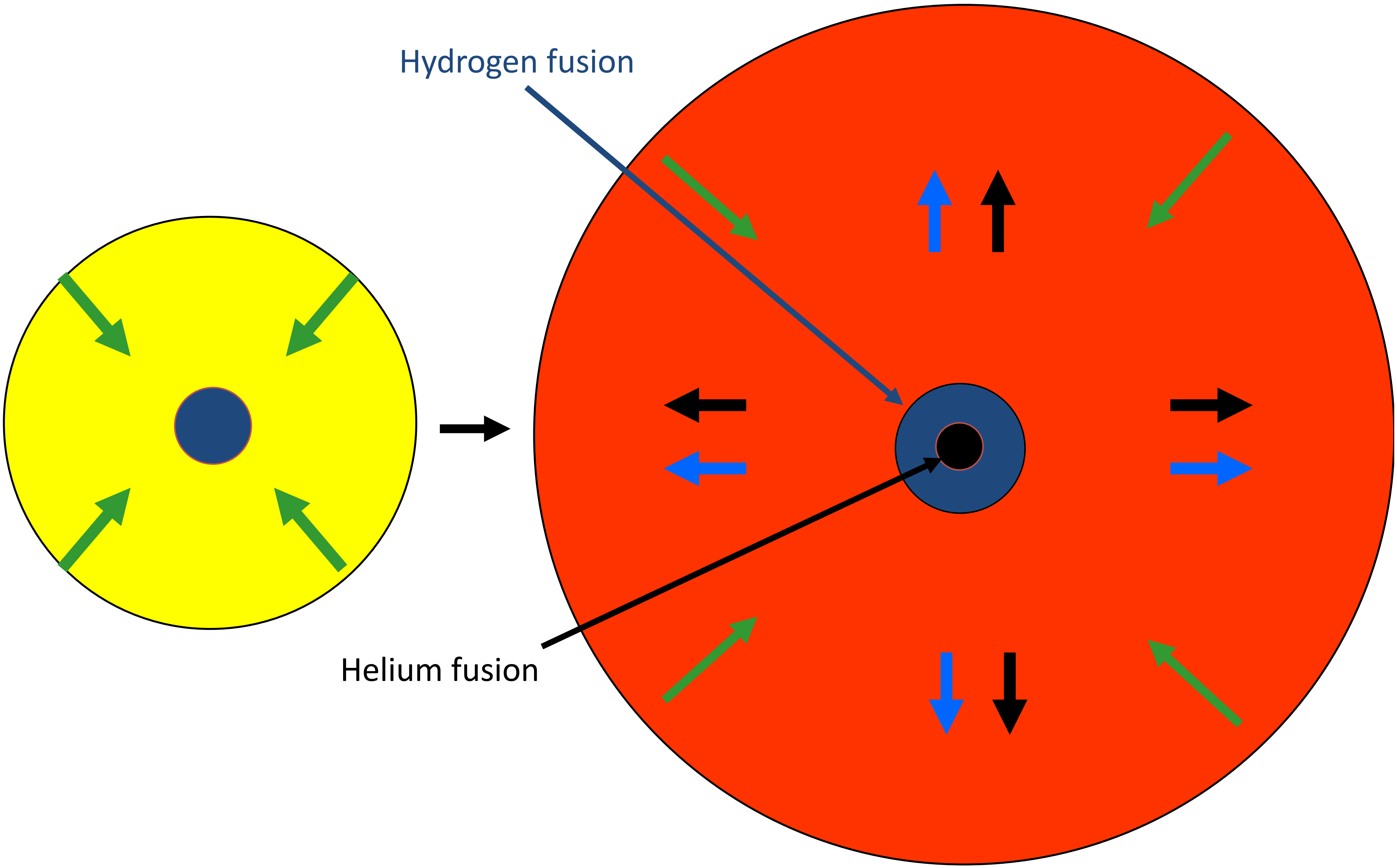
Helium fusion begins at the core of a giant

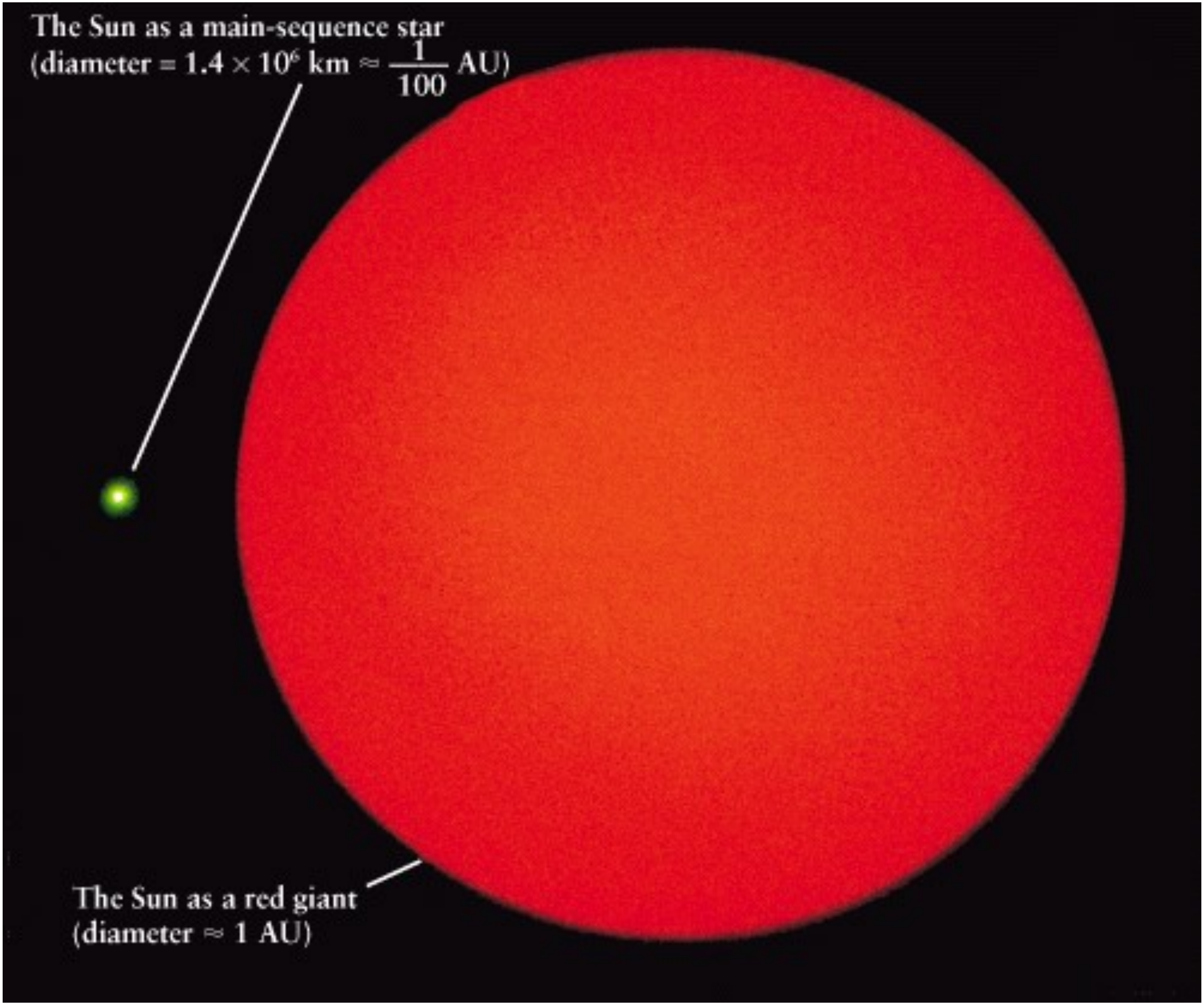
While the exterior layers expand, the helium core continues to contract and eventually becomes hot enough (100 million Kelvin) helium to begin to fuse into carbon and oxygen

- core helium fusion
- 3 He $\Rightarrow$ C + energy *and* C + He $\Rightarrow$ O + energy

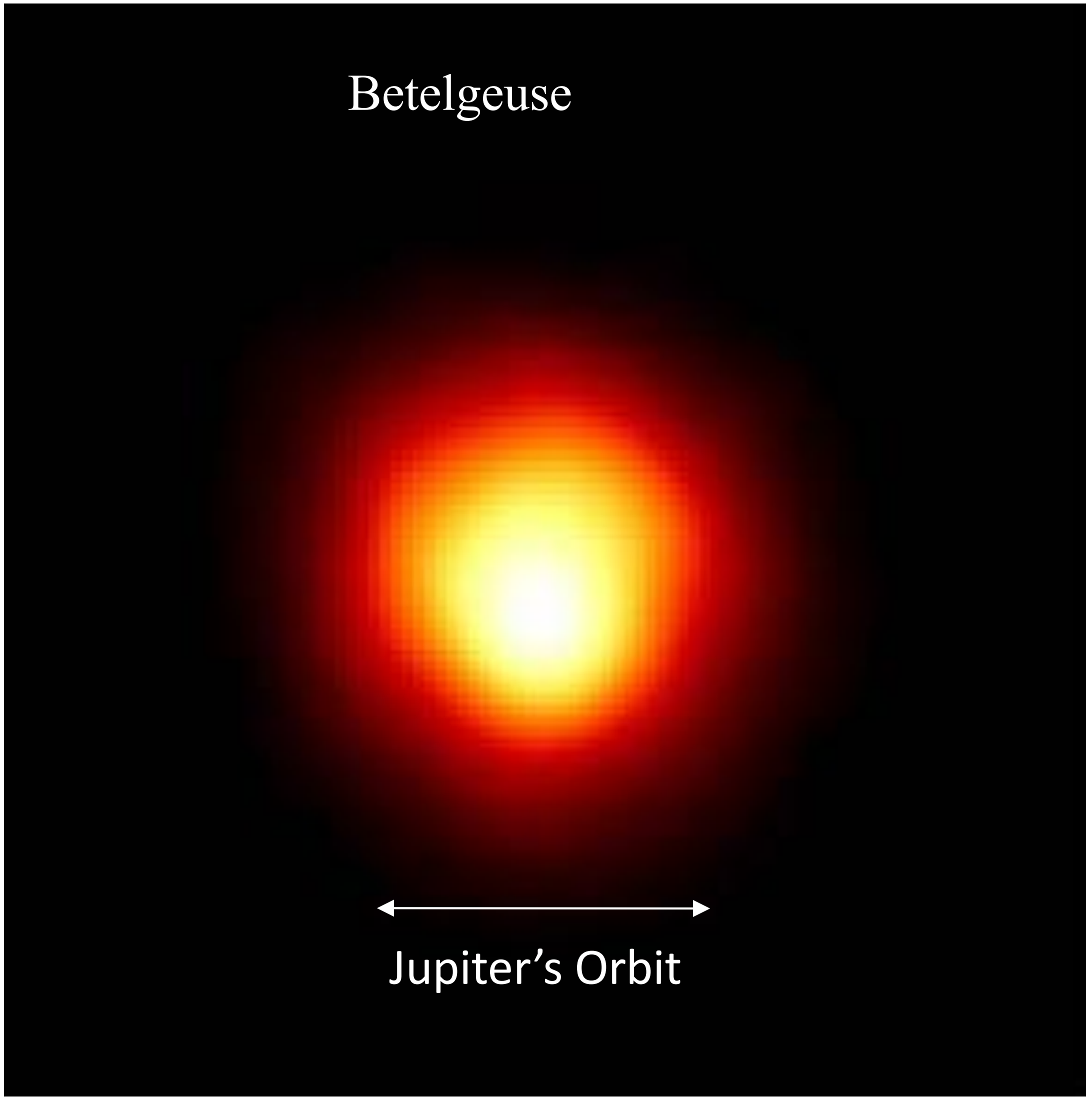


Main Sequence Stars become Red Giants

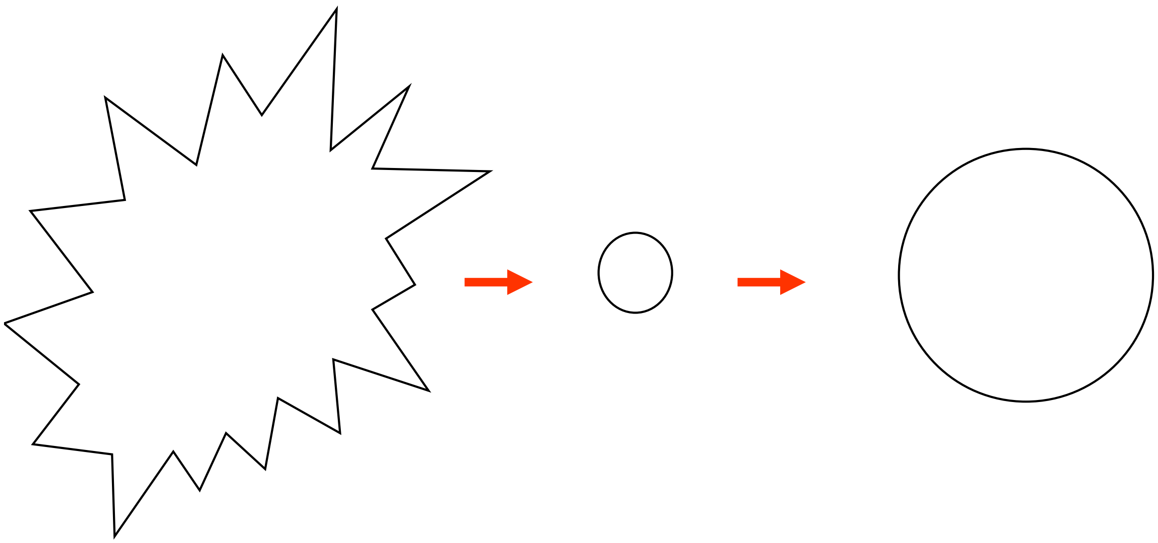



The Sun as a main-sequence star
(diameter = 1.4×10^6 km $\approx \frac{1}{100}$ AU)
The Sun as a red giant
(diameter $\approx$ 1 AU)

Red Giants



The Life of a Star



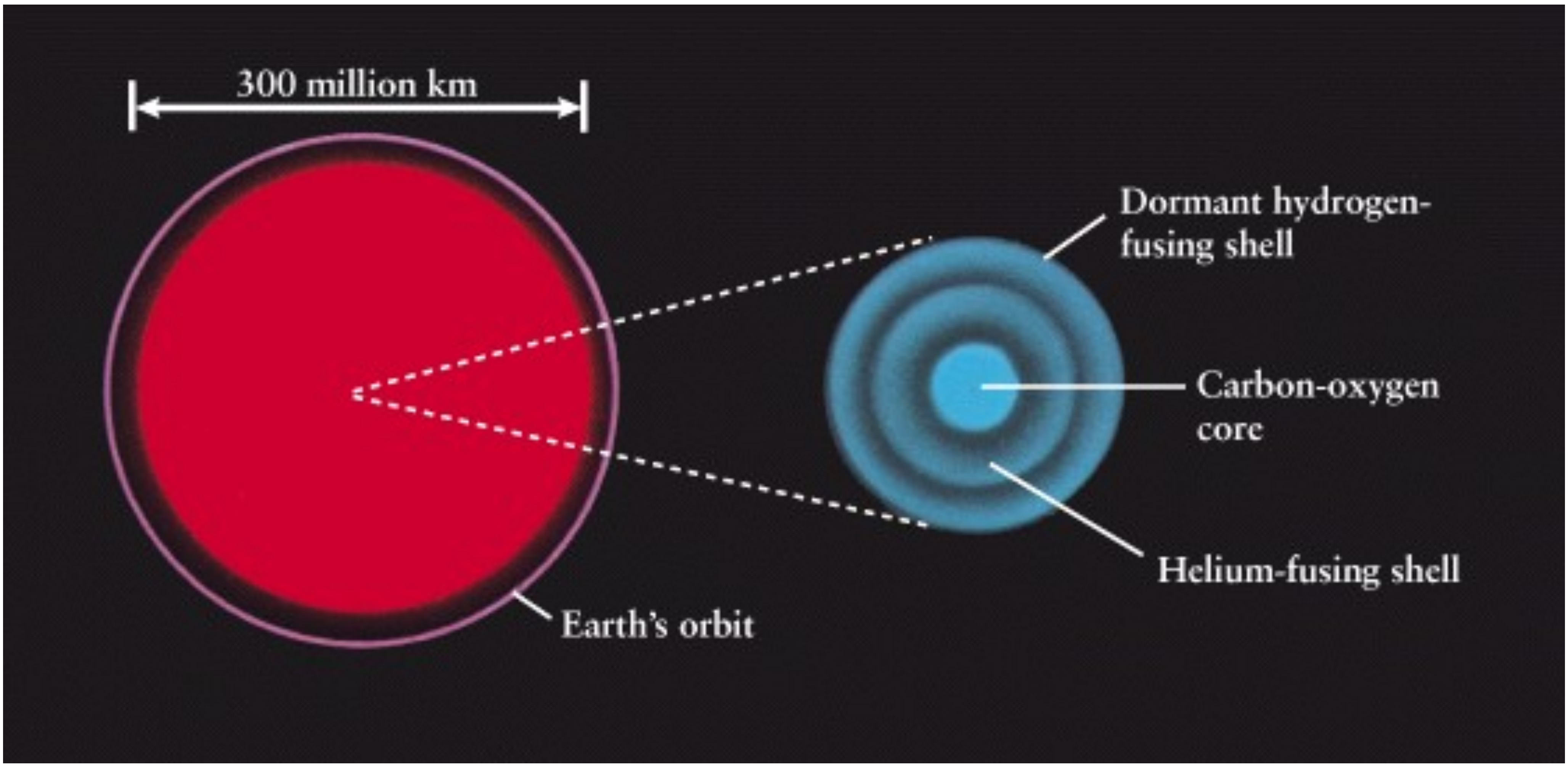
Interstellar Cloud (gas and dust)

Main Sequence Star

Red Giant

What happens when the star runs out of helium?

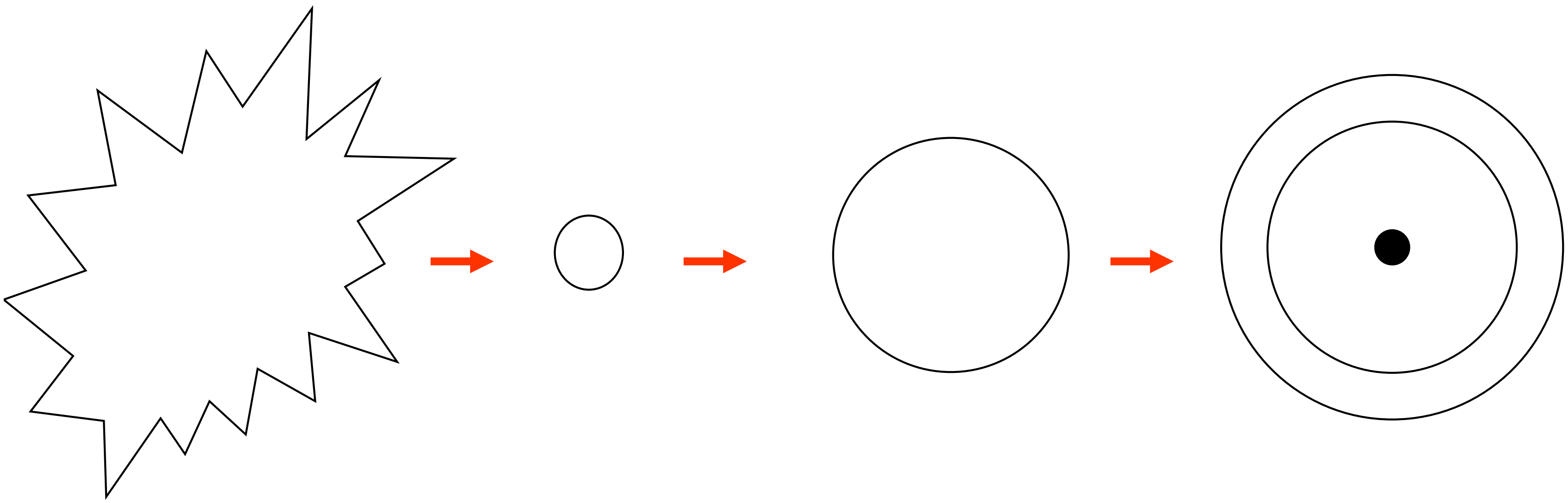
- The core runs out of fuel!
- Shell fusion of helium begins outside the core.



Low Mass stars (< 8 $M_{\odot}$)

- The core runs out of fuel!
- Shell fusion begins outside the core.
- Eventually the shell fusion creates too much outward pressure and energy which explosively push out the outer layers of the star and produce a ***planetary nebula***.

Low mass stars ($< 8\ M_{\odot}$)



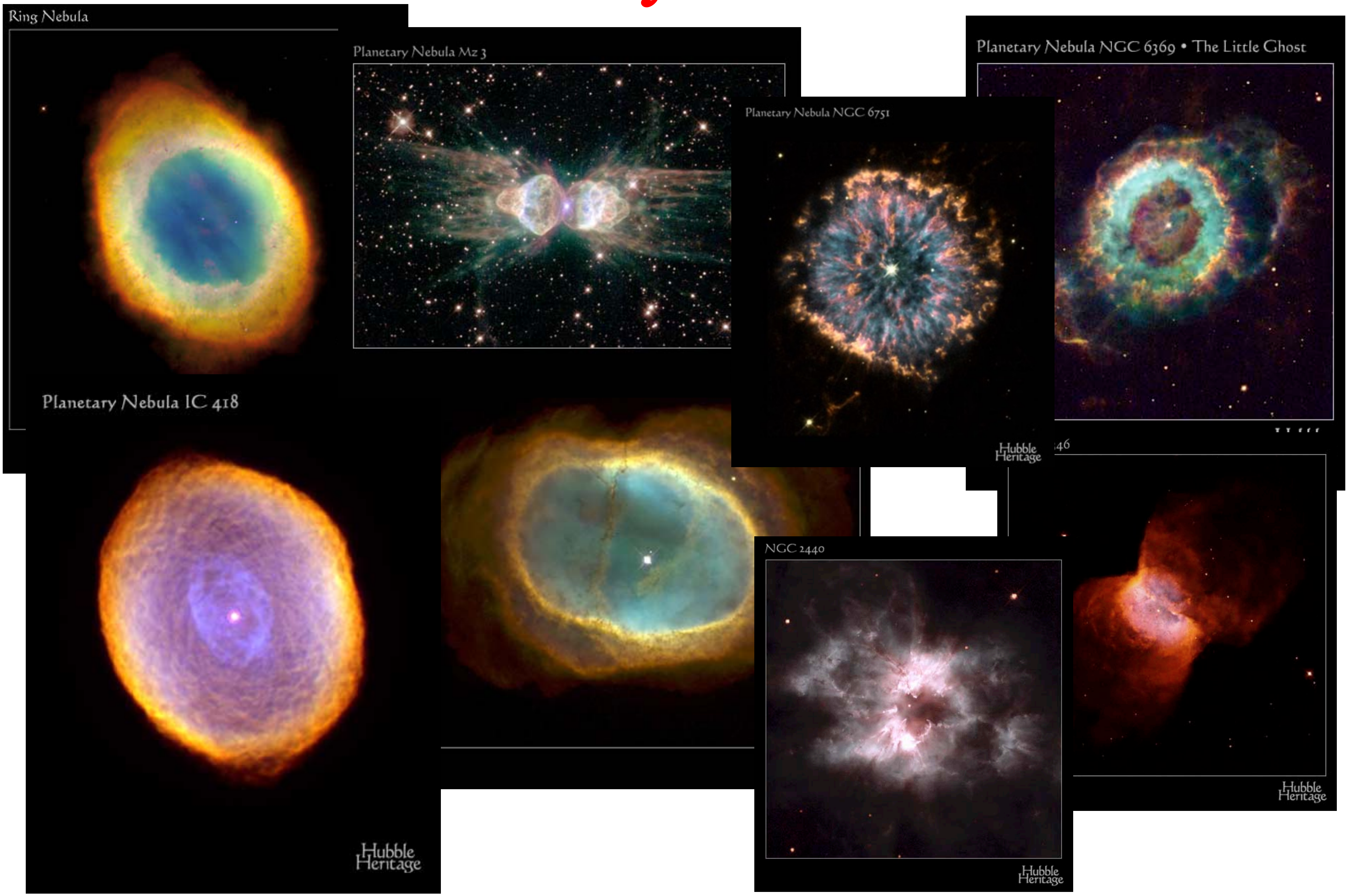
Interstellar Cloud (gas and dust)

Main Sequence Star

Red Giant

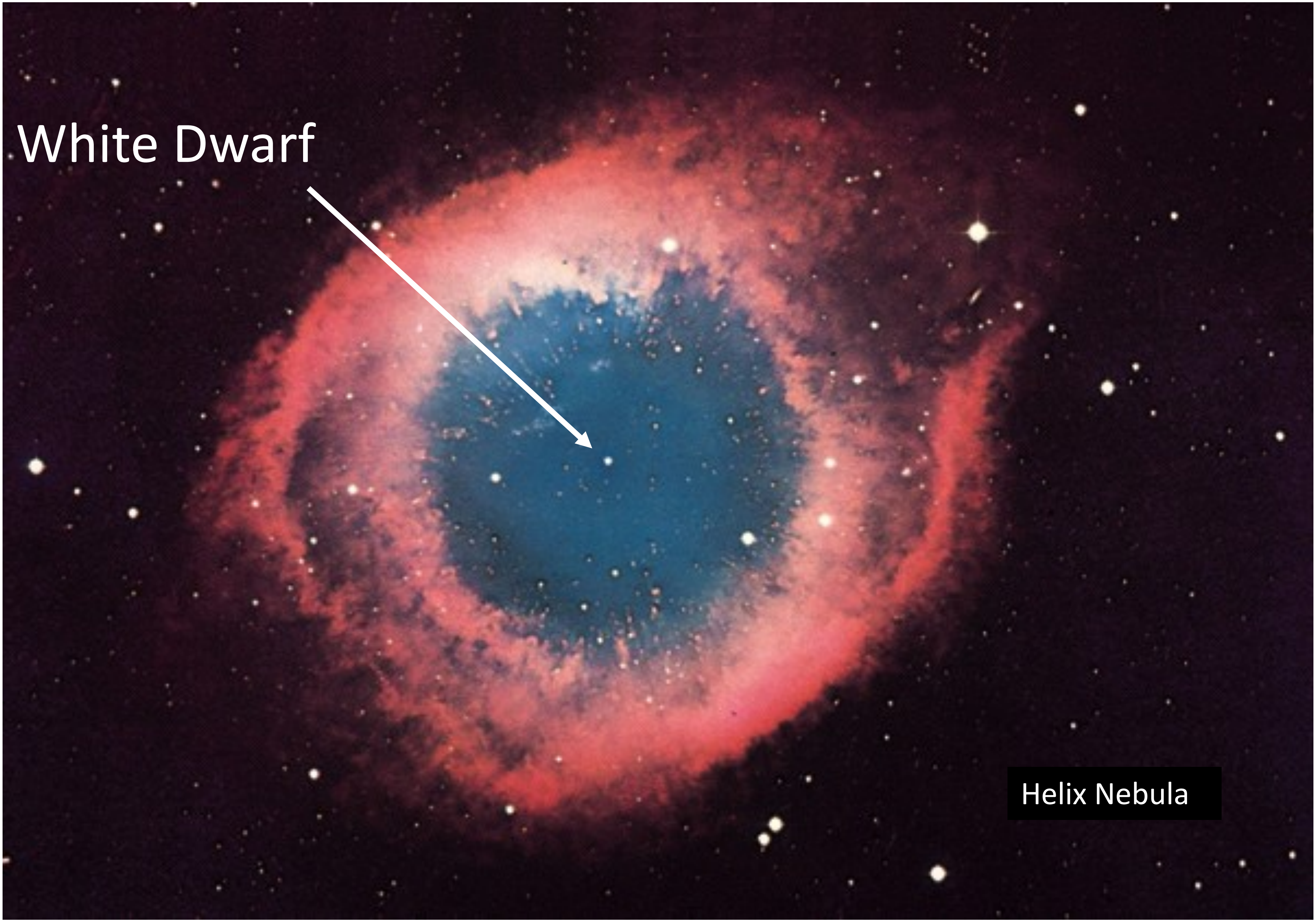
Planetary Nebula

Planetary Nebulae

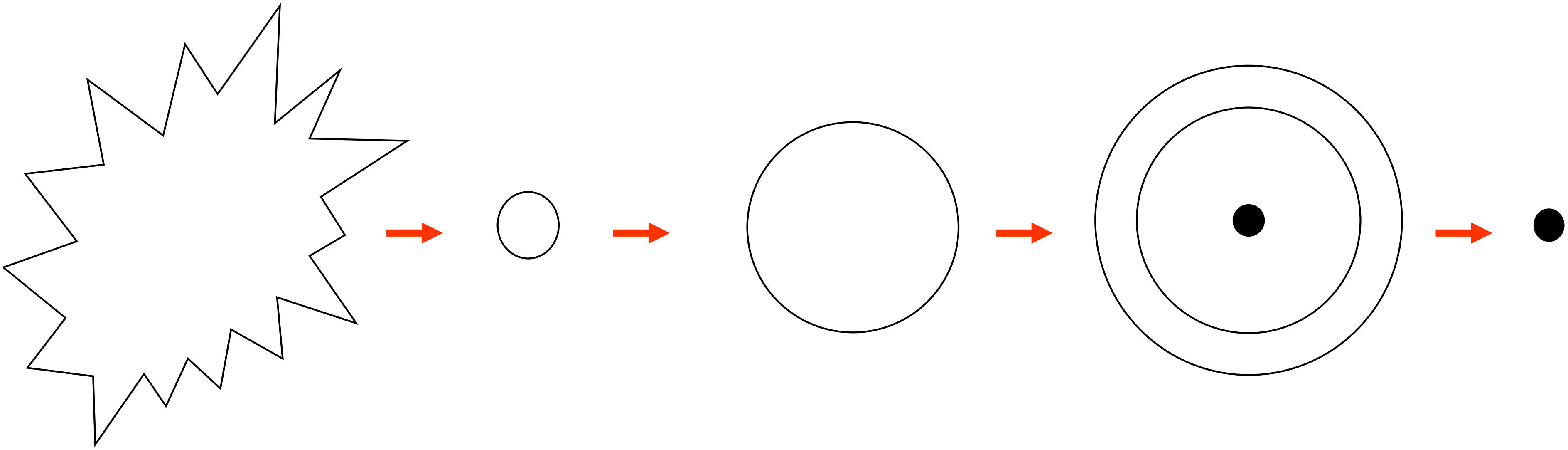


The burned-out core of a low-mass star becomes a white dwarf

- When the planetary nebula disperses, all that is left behind is the burned-out, hot core of the star, called a **white dwarf**.
- A core with remaining mass less than 1.4 $M_{\odot}$.
- These tiny star remnants are approximately the size of planet Earth
- One cubic centimeter (like a sugar cube) of a white dwarf star would weigh several tons.


White Dwarf
Helix Nebula

Low mass stars ($< 8\ M_{\odot}$)



Interstellar Cloud (gas and dust)

Main Sequence Star

Red Giant

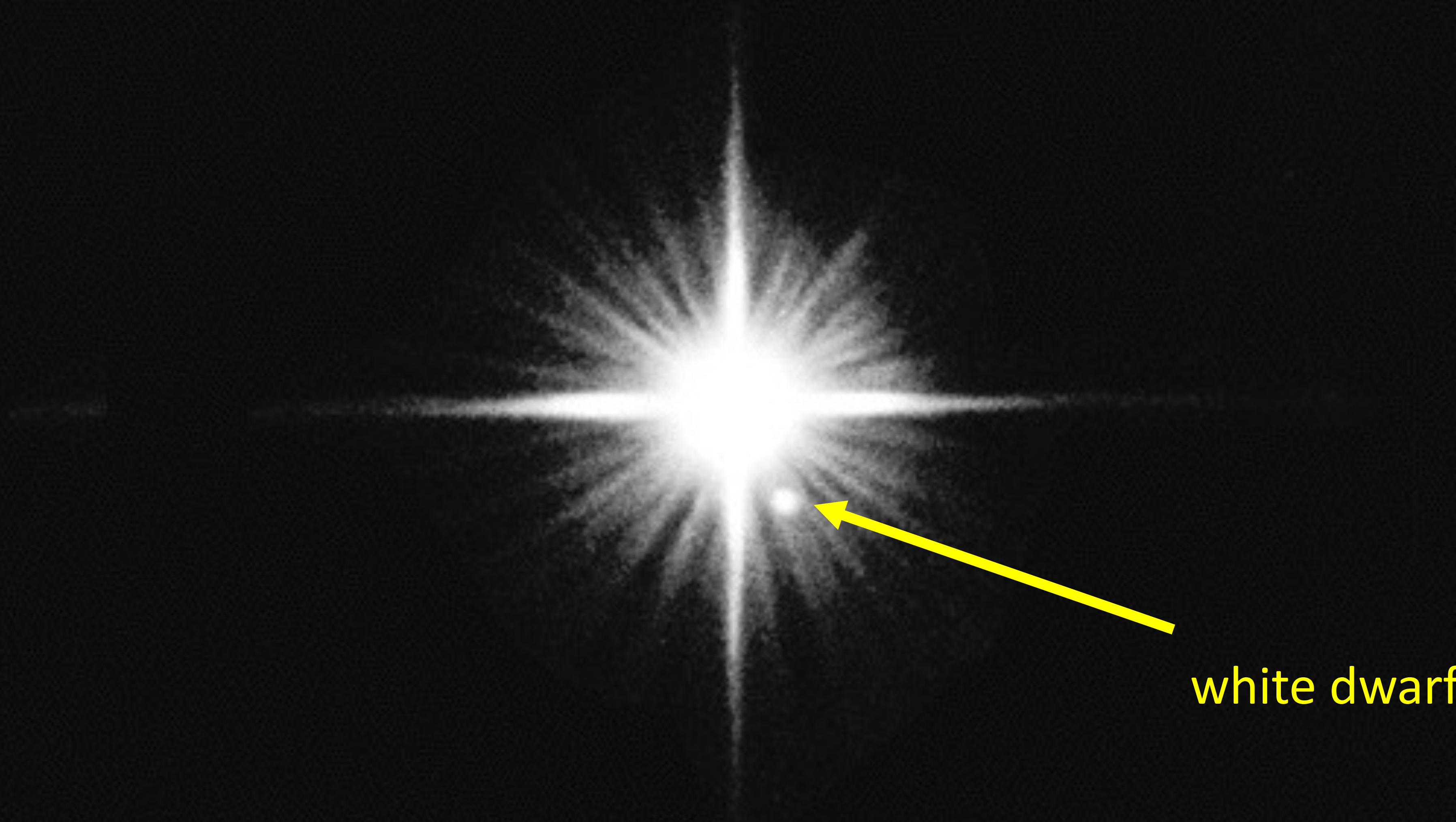
Planetary Nebula

White Dwarf

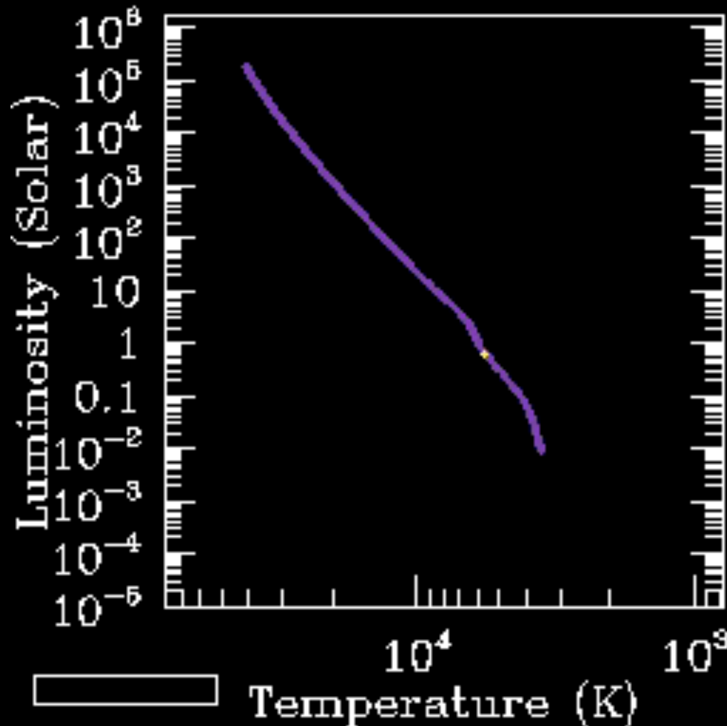
What happens to white dwarfs? Do they just sit there??

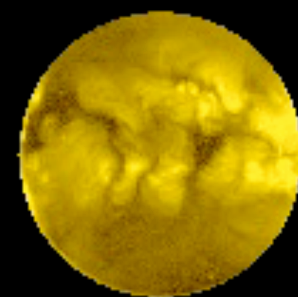
If the white dwarfs are isolated, yes. They will cool down and become BLACK DWARFS.

Sirius and its White Dwarf companion



Evolution of a Low Mass Star



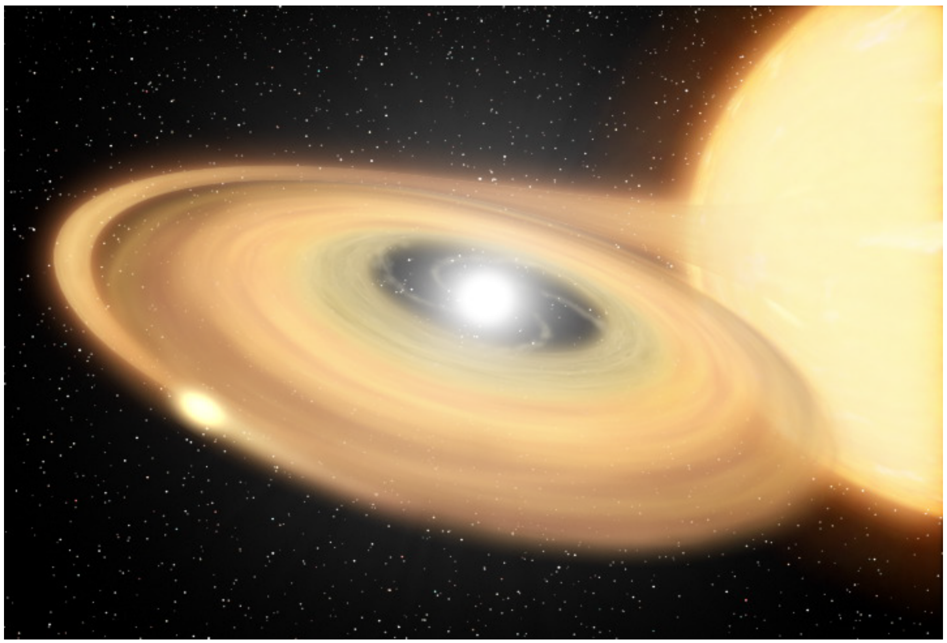


Low mass stars with companions

If a low mass star is a binary star (if it has a companion), it will evolve in the same way, except....

As its companion evolves and gets bigger, the white dwarf can steal mass from it. The stolen matter forms an external layer which can quickly ignite and shine brightly creating a ***nova***.

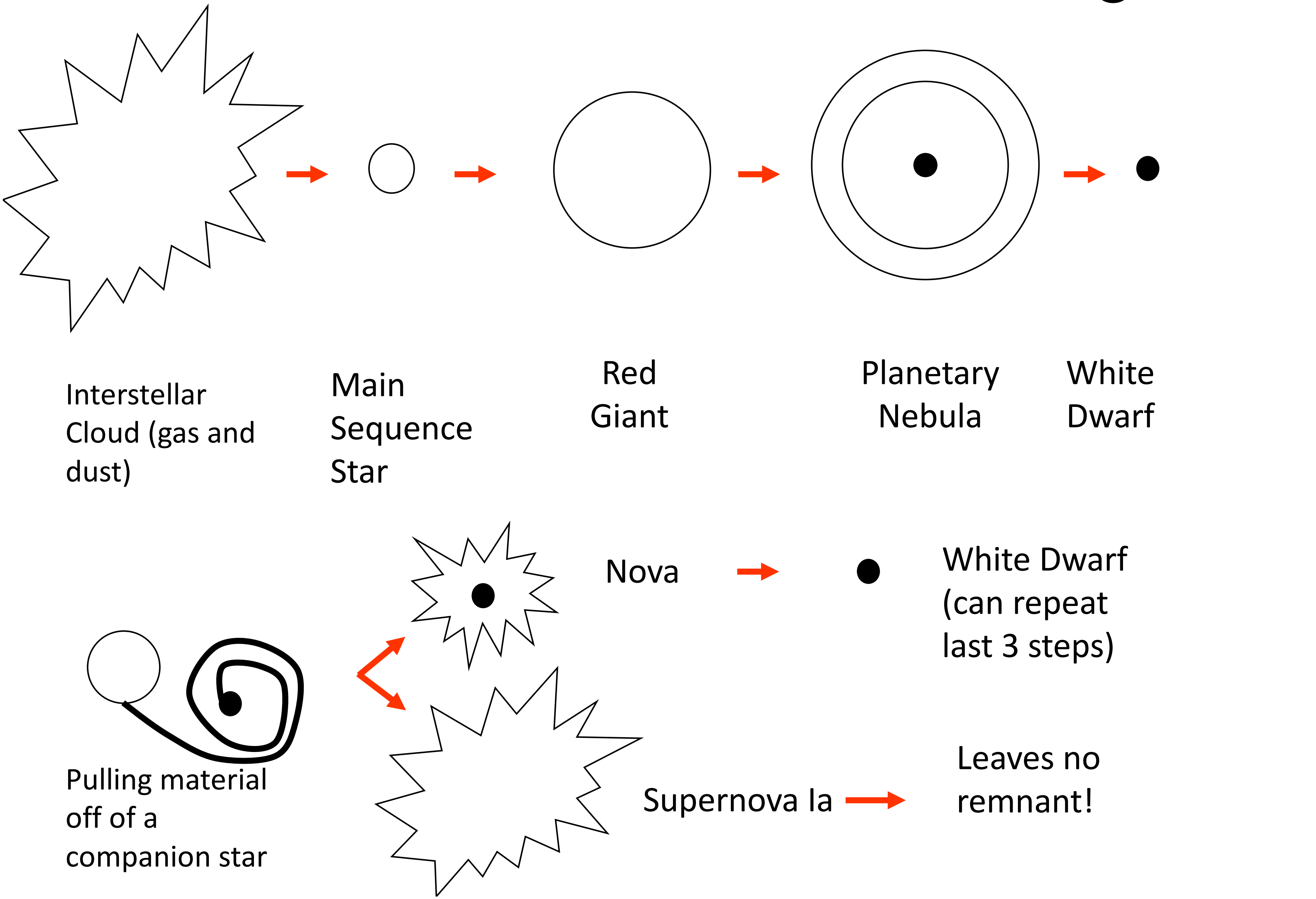
What's a Nova?



- A nova occurs in binary systems where a white dwarf is pulling mass from its companion.
- A nova is a relatively gentle explosion of hydrogen gas on the surface of a white dwarf in a binary star system.
- This process does not damage the white dwarf and it can repeat.

Sometimes the mass transfer can be *excessive*. So excessive that the white dwarf will not be able to support the mass it gains. So, what would have been a nova becomes a **SUPERNOVA**!

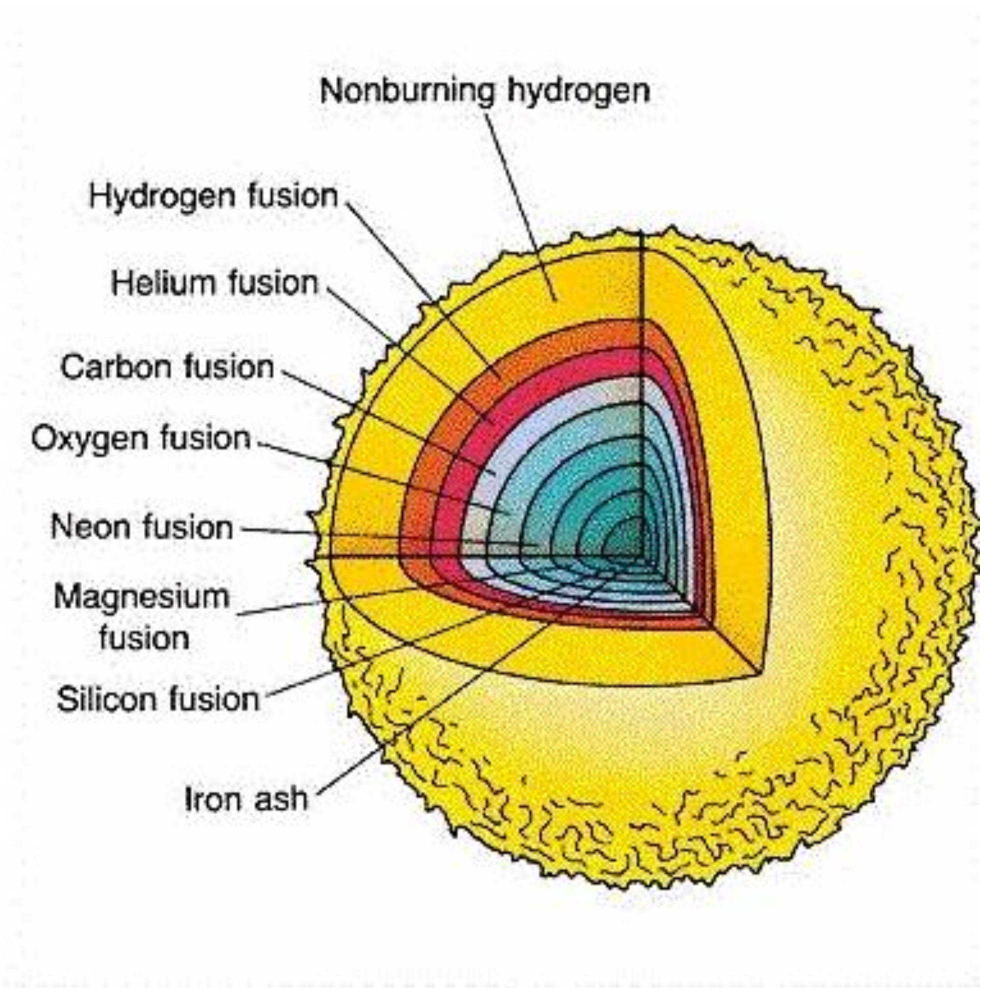
Low mass stars ($< 8\, M_\odot$)



High mass stars (> 8 solar masses)

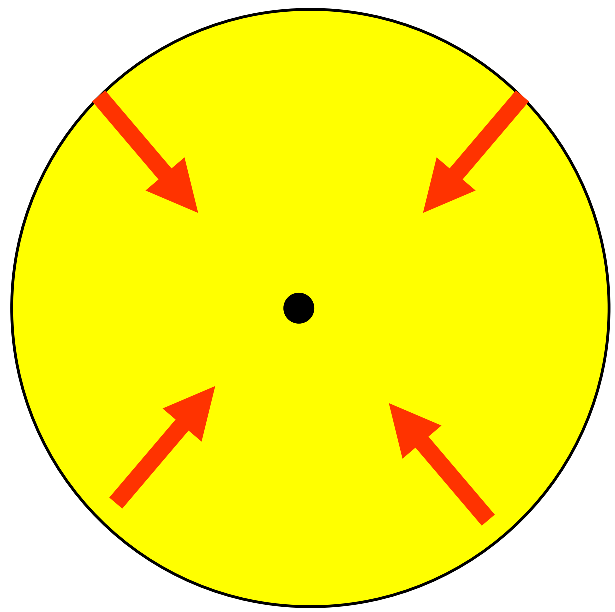
- Like low mass stars, they will become red giants when they finish hydrogen fusion, but they will not become white dwarfs with planetary nebulae.
- Fusion in the core continues through many more stages than for low mass stars. Each stage is shorter than the next.
- Heavier elements are produced:
  - carbon, (over 500,000 years)
  - oxygen, (over 600 years)
  - neon,
  - silicon, (over 6 months)
  - and so on up to iron (over 1 day)

A series of different types of fusion reactions occur in high-mass stars



Core runs out of fuel!

Gravity ( ) wants to collapse the star!



High-Mass Stars (> 8 $M_\odot$)

- The core and outer layers run out of fuel.
- The star then collapses, due to gravity.
- The mass, however, is high enough that nothing can balance the gravitational collapse and…..

Supernovae -Type II

- The collapsing outer layers of the star will collapse against and bounce outward off the compact collapsed core in an explosive event sending out a shockwave. This explosive event is called a Type II Supernova!!!
- During the Supernova, heavier elements are created from fusion events, like magnesium, lead, or gold.

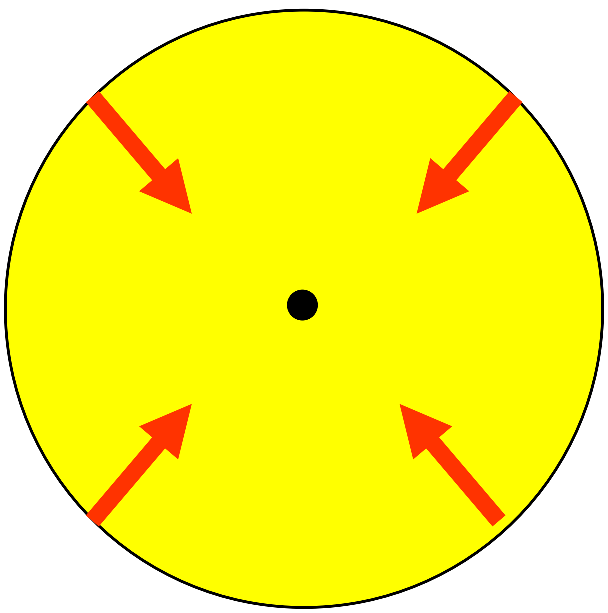
A Supernova Type II occurred here before we did.

- The atoms that created our world and solar system come from nuclear fusion in stars and from supernovae events!
- We are all made of star stuff!

High-Mass Stars (> 8 $M_\odot$)

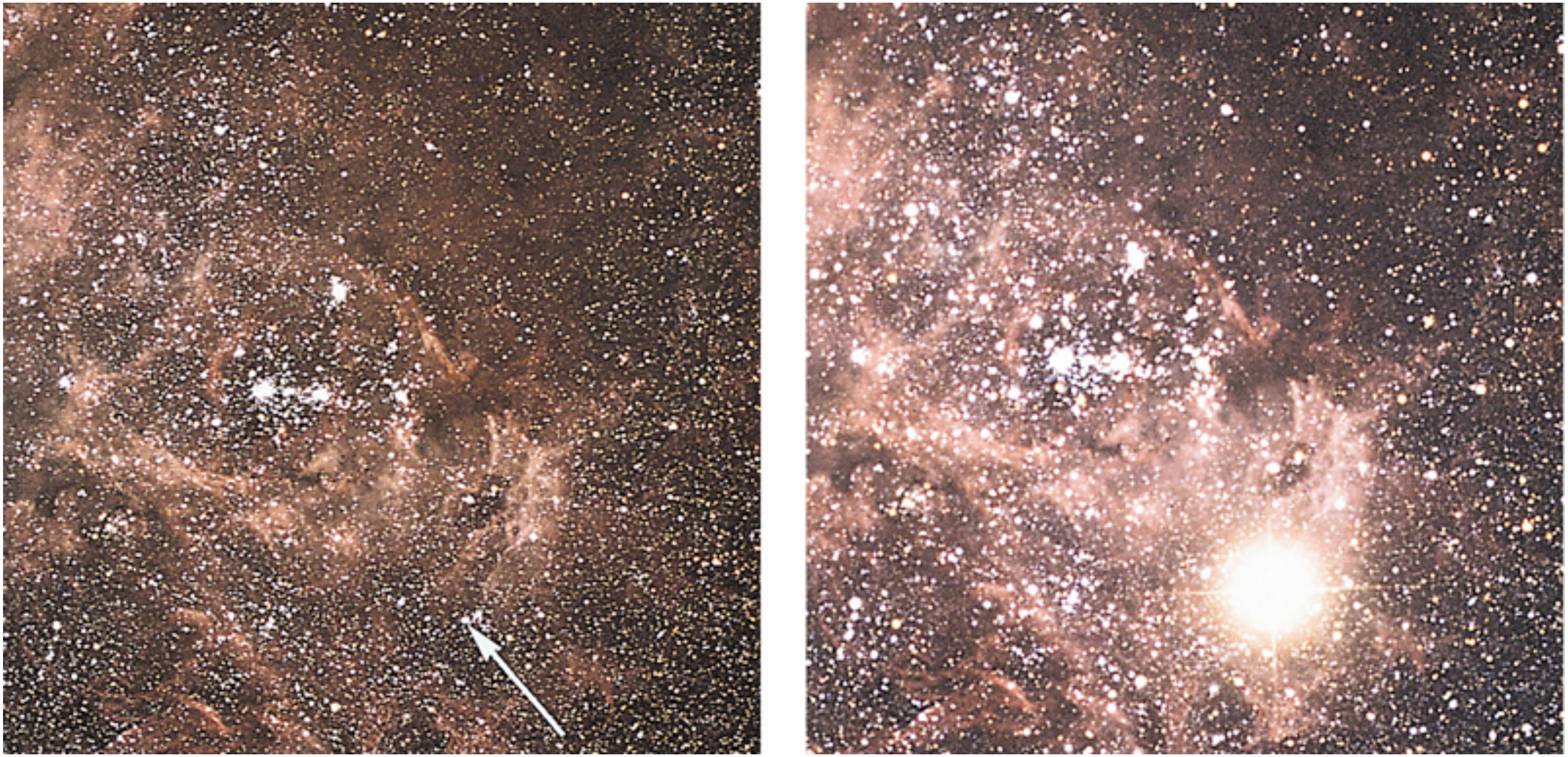
Gravity (←) wants to collapse the star

No outward pressure = implosion



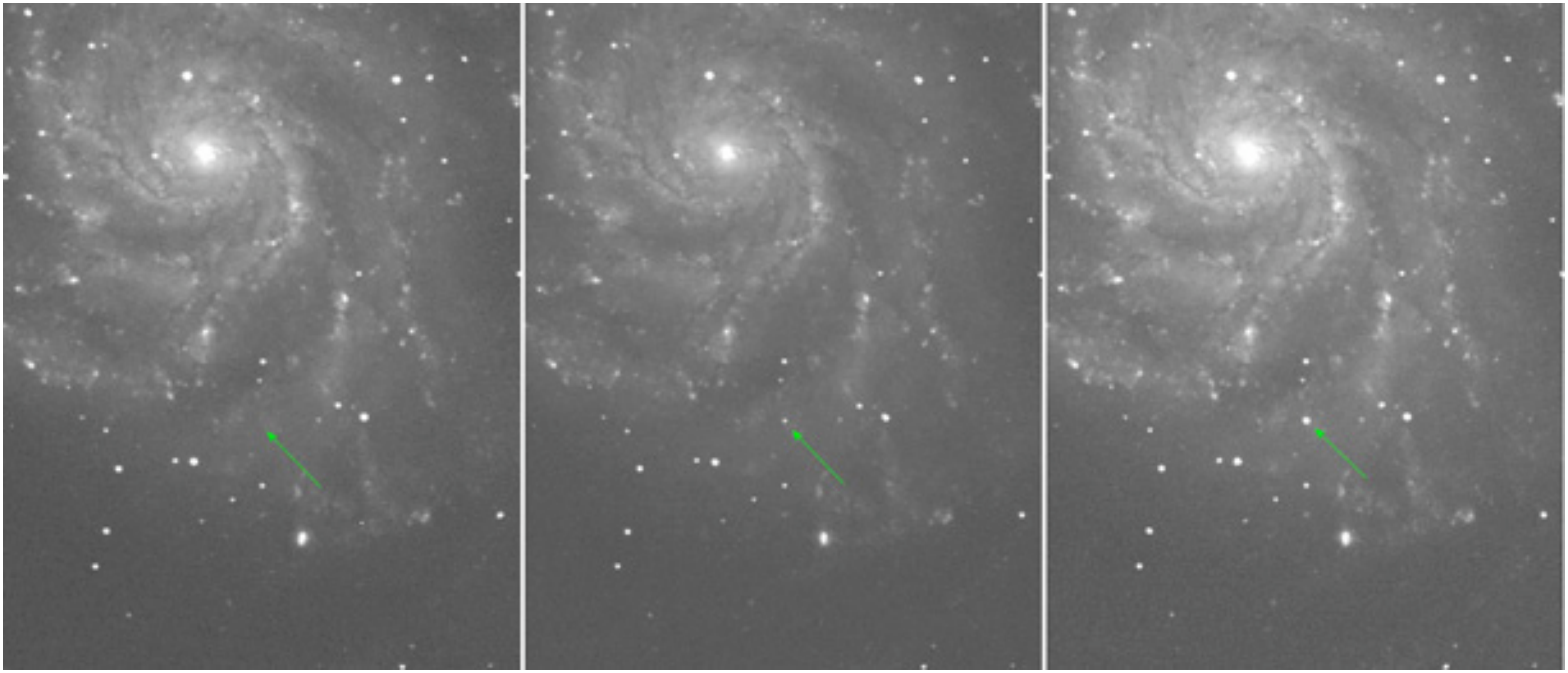
Rebound of outer layers against the core = supernova

Supernovae



SN 1987A

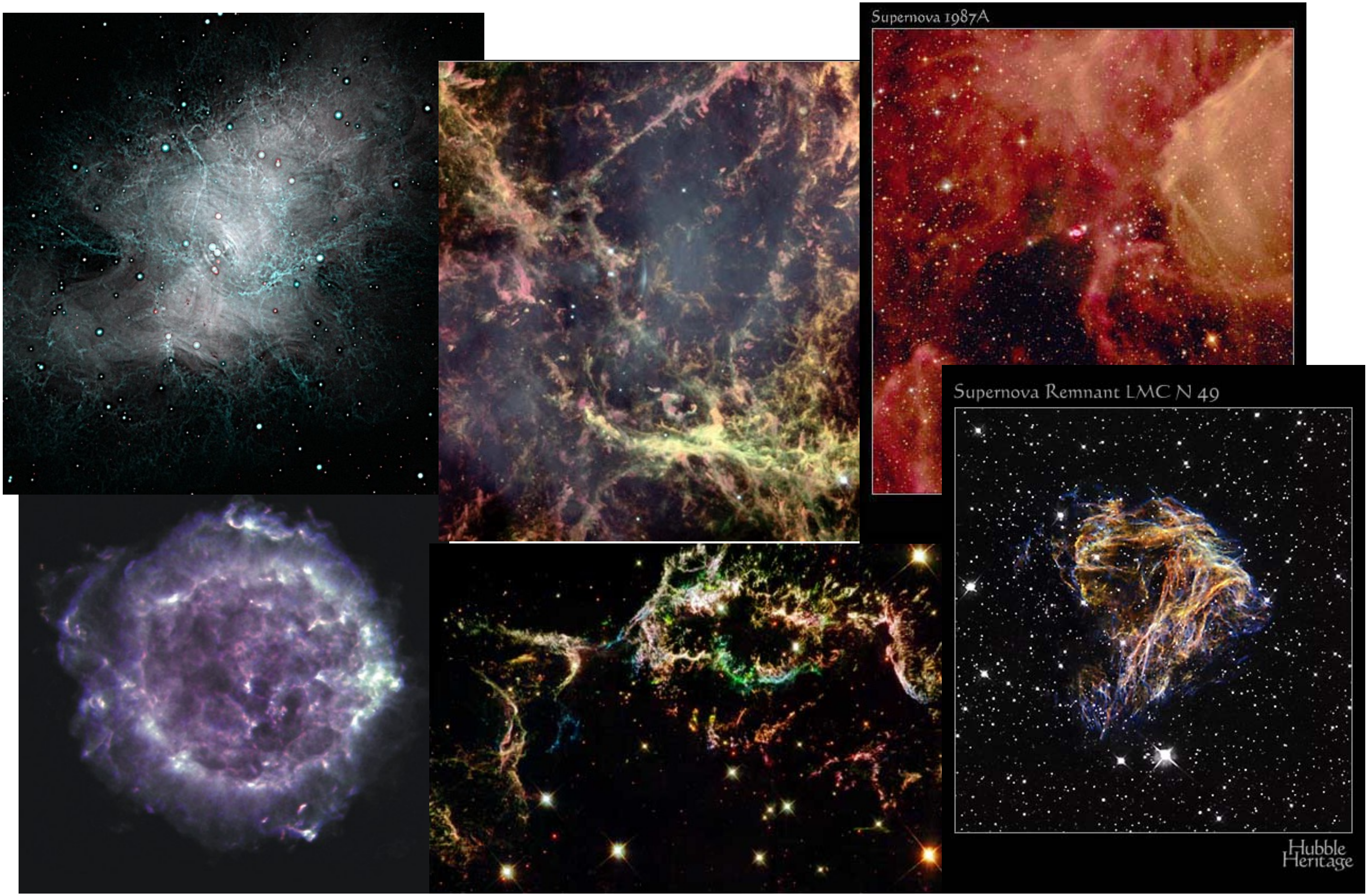
Supernovae



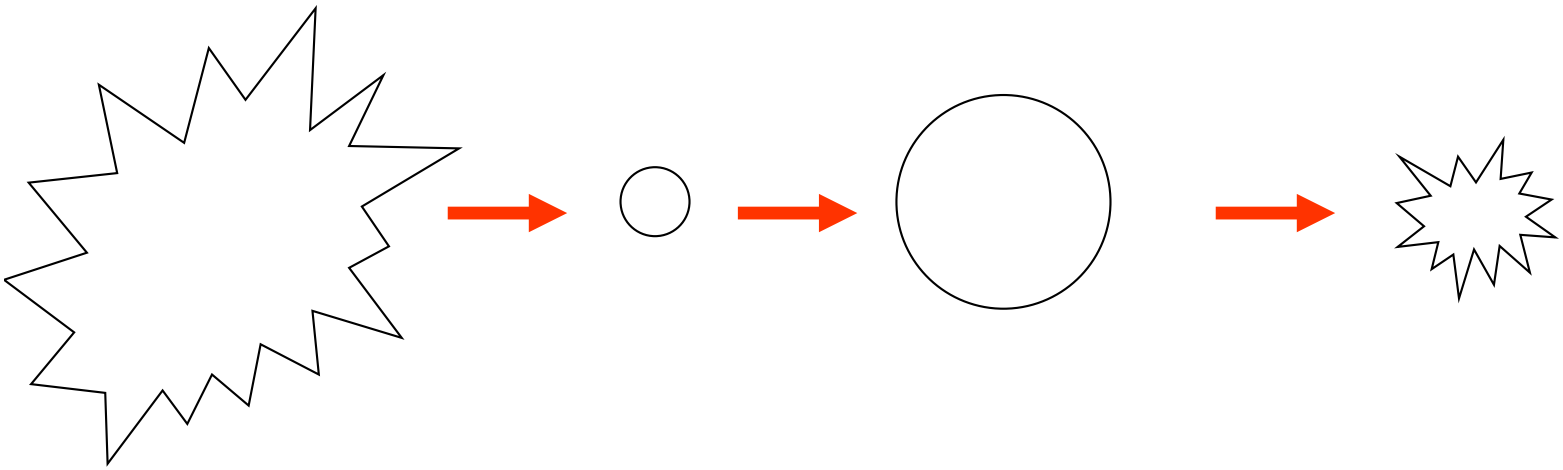
August 22, 2011 August 23, 2011 August 24, 2011

SN 2011fe in M101

Supernova Remnants



High-Mass Stars (> 8 $M_\odot$)



Interstellar Cloud (gas and dust)

Big Main Sequence Star

Red Giant

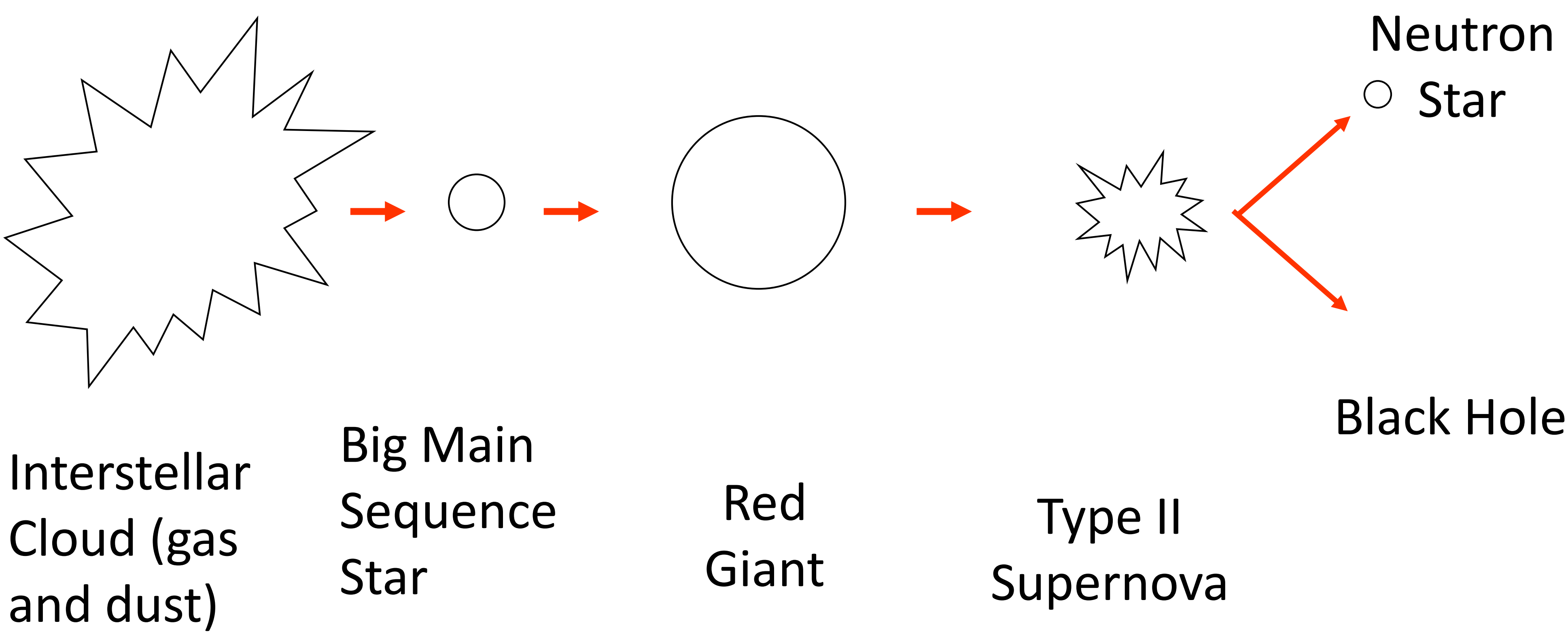
Type II Supernova

Very high mass stars

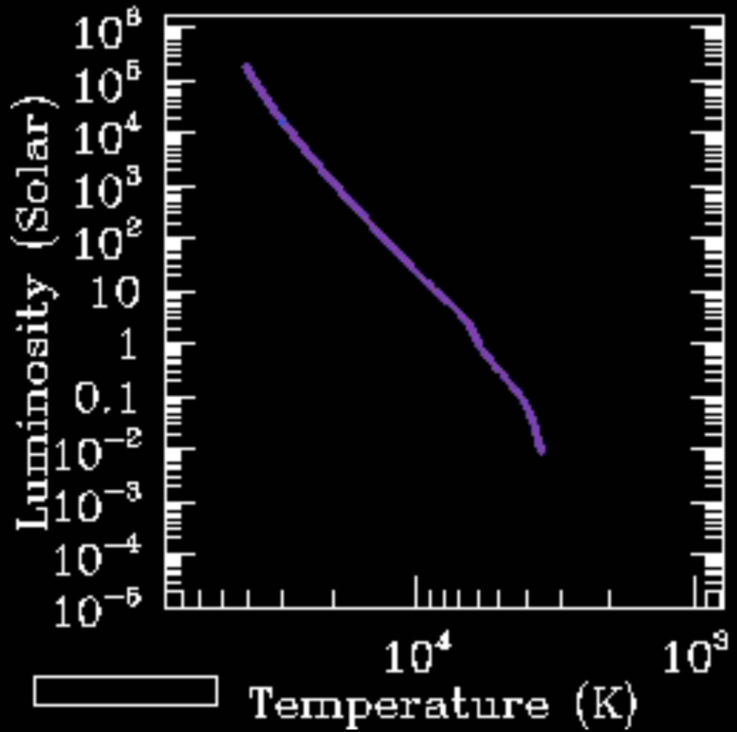
- Depending on the exact mass of the star, the remnant of a high mass or a very high mass star differ.
- neutron star
  – the really big ones: remaining mass of 1.4 to about 3 $M_{\odot}$
- black hole
  – the **really really big ones**: remaining mass greater than 3 $M_{\odot}$

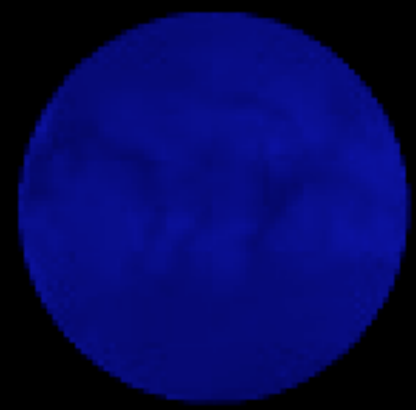
We will discuss these objects in more detail next class.

High-Mass Stars (> 8 $M_{\odot}$)



Evolution of a High Mass Star





Which of the following lists, in the correct order, is a possible evolutionary path for a star?

A. Red Giant, Neutron Star, White Dwarf, nothing
B. Red Giant, Type I Supernova, Black Hole
C. Red Giant, Type II Supernova, Planetary Nebula, Neutron Star
D. Red Giant, Planetary Nebula, White Dwarf
E. Red Giant, Planetary Nebula, Black Hole

For a white dwarf to become a nova it is necessary for it to

A. have a binary companion
B. become a black hole
C. have begun life as a high-mass star
D. rejoin the main sequence

How did astronomers figure all of this out???

Star Clusters

- Since stars form in clusters, you get a snapshot of stellar evolution at a moment of time for all masses of stars.
- We can observe stars of different masses at different stages of their evolution.

Example HR Diagrams

- The HR diagrams look different for star clusters of different ages.
- Young clusters have massive stars already evolving off the main sequence while low mass stars have yet to reach it.
- Old Clusters only have low mass stars still on the main sequence.