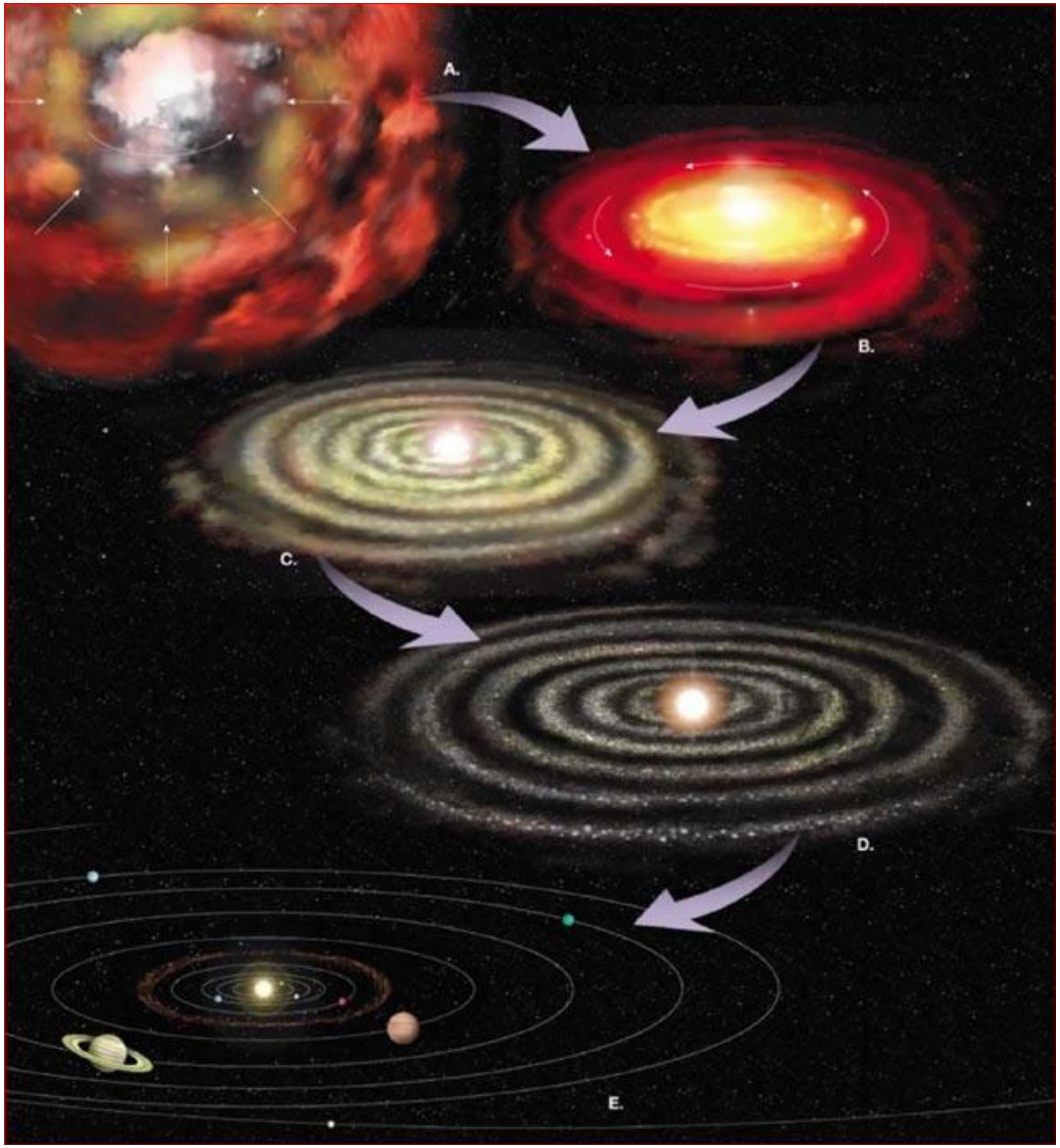


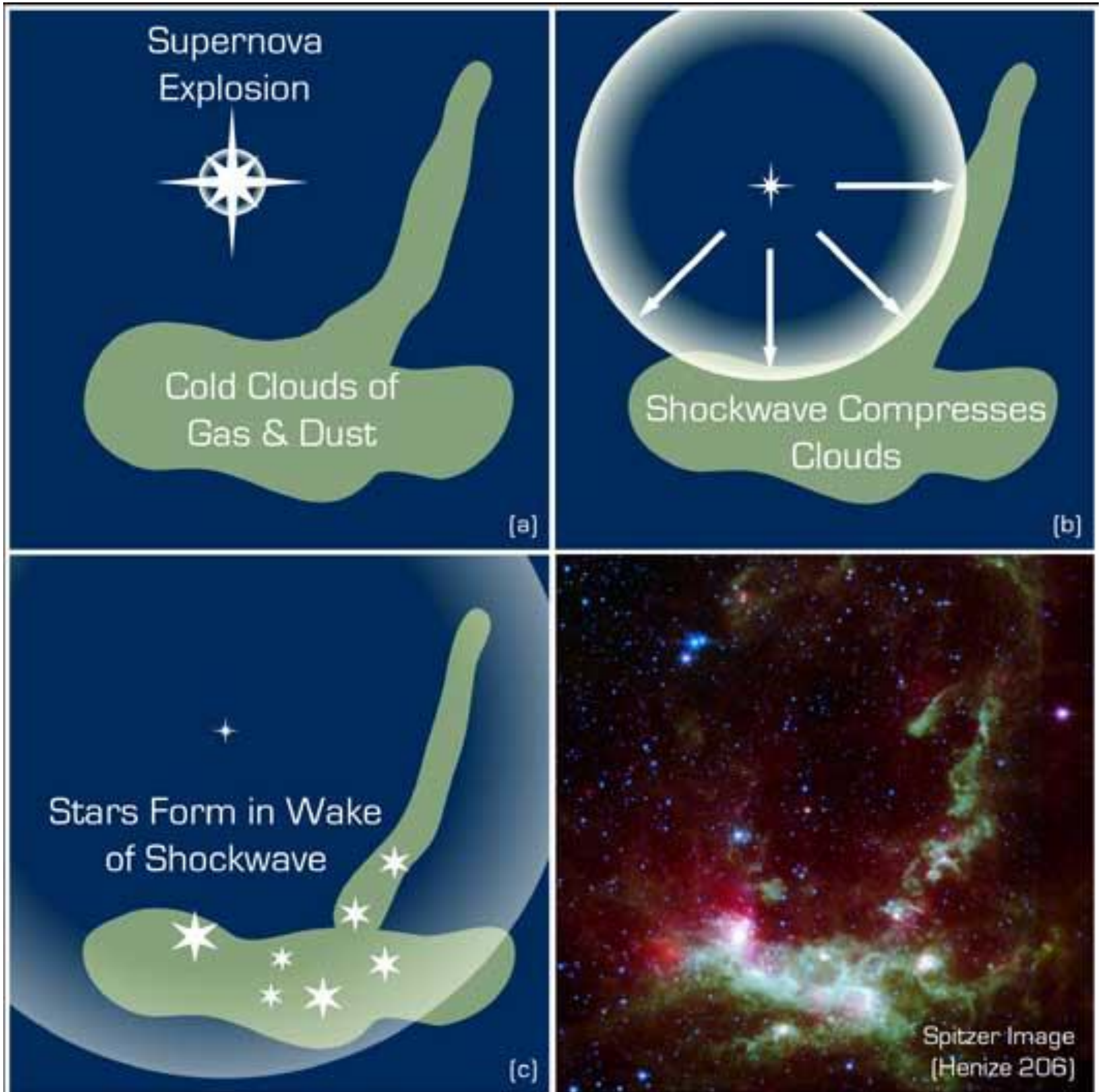
Stars and solar systems form by the modern **Nebular Theory.**

Large clouds of dust and gas collapse into new stars and perhaps make solar system.

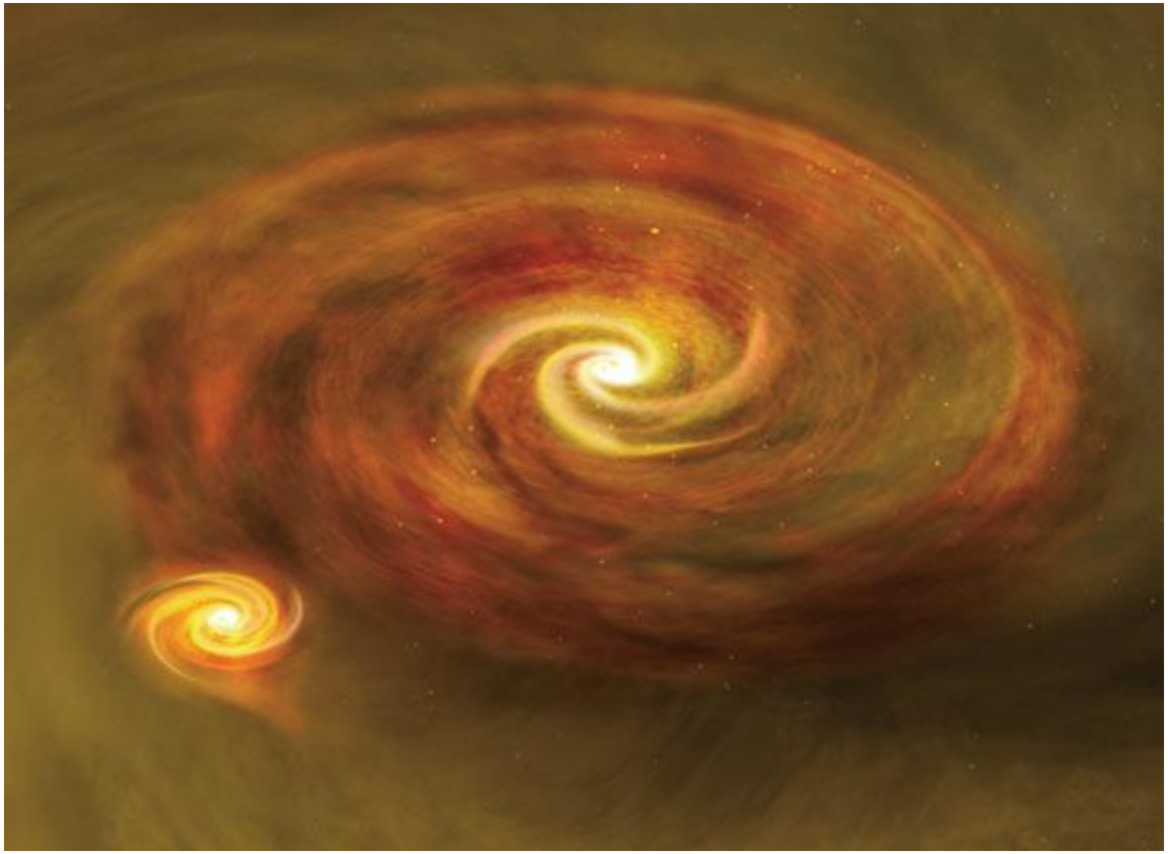
If the nebula (cloud of gas and dust) is large enough, it can become a **stellar nursery**.

Stellar nurseries are large clouds of gas and dust that are actively collapsing under gravity to form many new hot and young stars.

The gravitational collapse of the nebula to form stellar nurseries is most likely initiated by a shockwave from a nearby supernova 10-100 LY away from the nebula.


Supernova
Explosion
Cold Clouds of
Gas & Dust
(a)
Shockwave Compresses
Clouds
(b)
Stars Form in Wake
of Shockwave
(c)
Spitzer Image
(Henize 206)

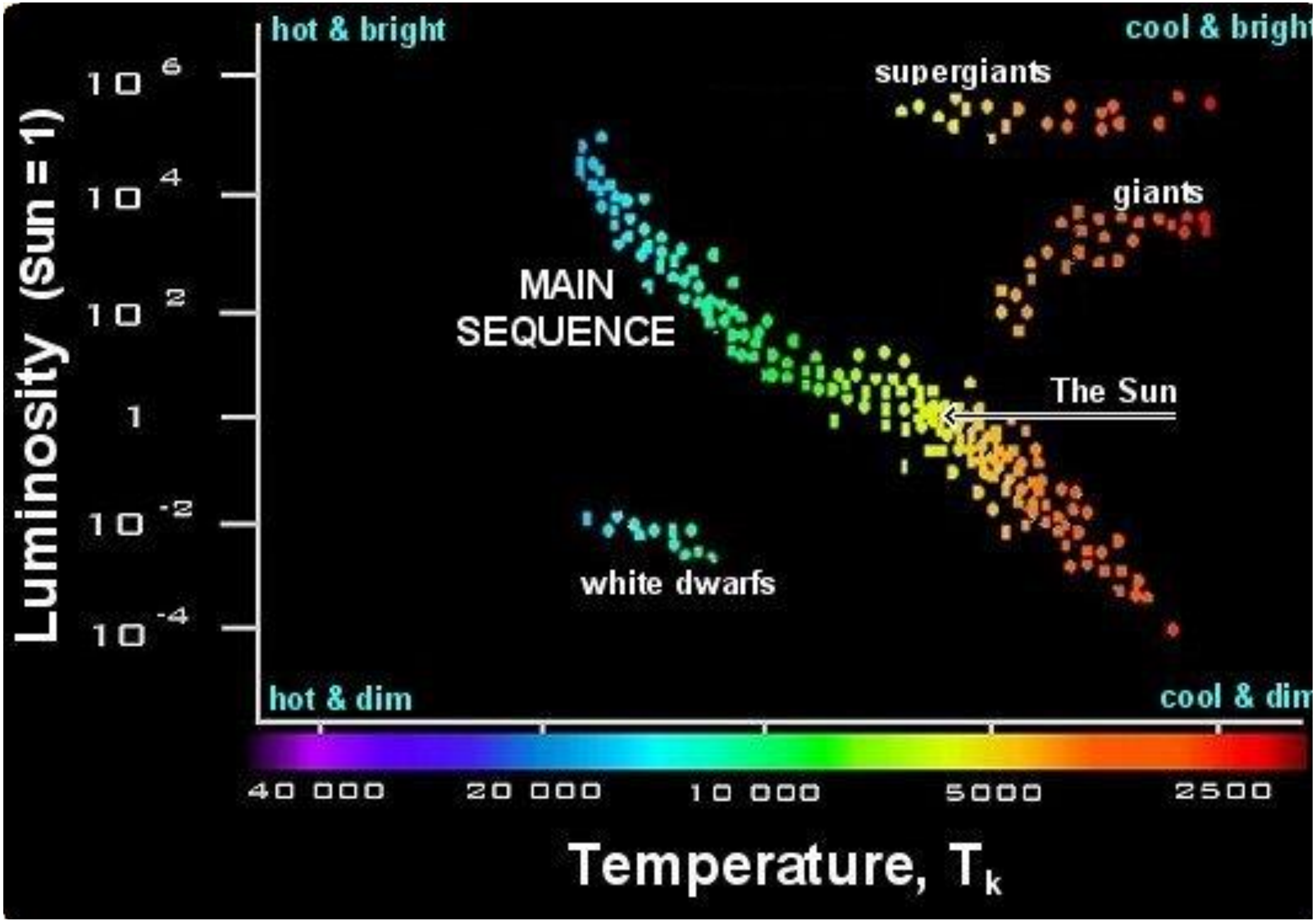
Inside the stellar nursery, many new stars of different sizes form at the same time in different areas of the collapsing gas cloud.



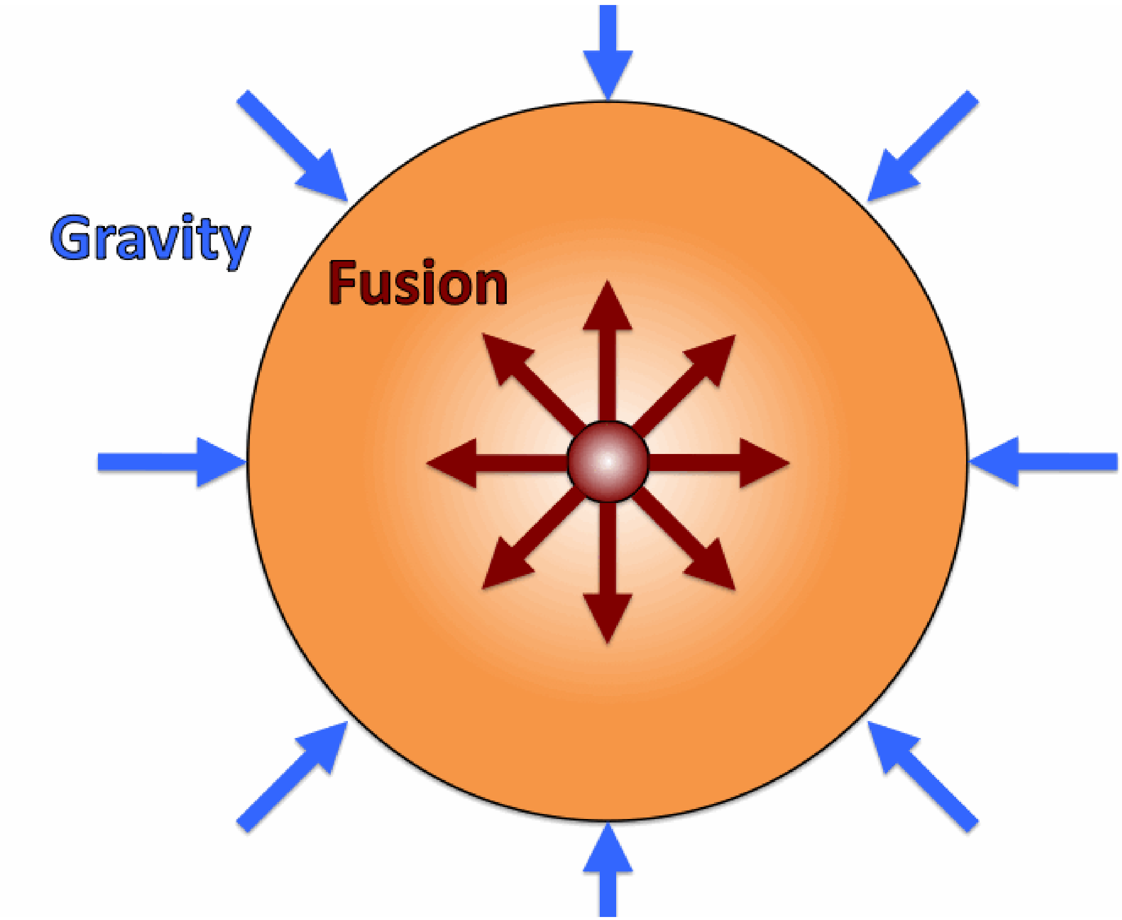
Most stars will form light years apart, and some will form binary star systems.

When the new protostar gains a threshold of mass, the temperature in the core exceeds 1-million K and the pressure in the core is strong enough to start fusion, the protostar achieves ***ignition*** to become a true star.

Once the new star stabilizes after ignition, it will spend the majority of its lifecycle as a **Main Sequence** star.



Hydrostatic equilibrium: The stable "balanced" state when the outward push force through a liquid or gas is equal in magnitude and opposite in direction to the inward pull force.



Main sequence stars keep a stable volume and radius when they are at a state of hydrostatic equilibrium.

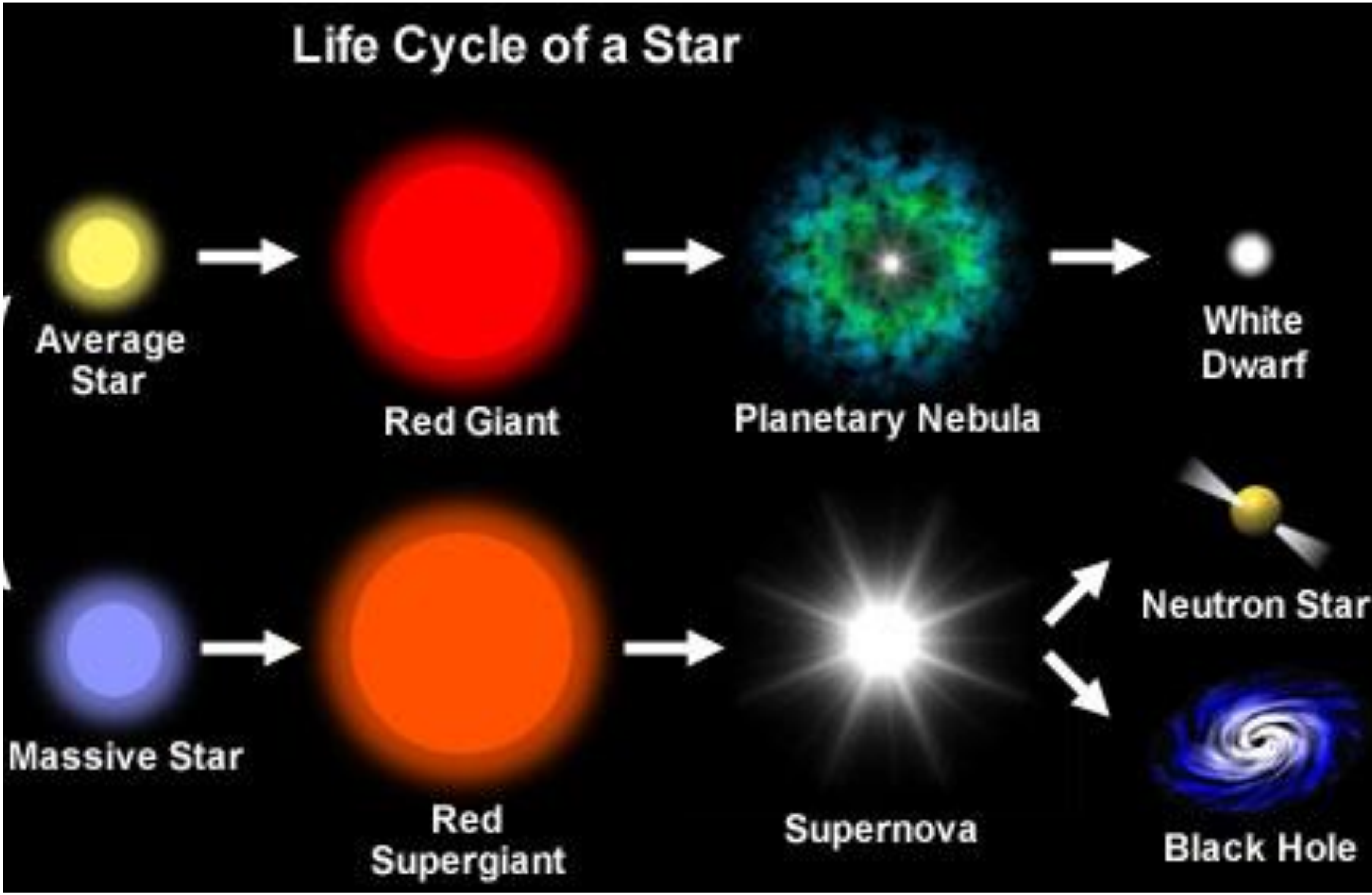
Lifespan of Main Sequence stars

Red dwarfs	M: 100 BY-1 TY
Orange dwarfs	K: 10 BY to 100 BY
Yellow & White	F-G: ~1 BY to 10 BY
Whitish giants	A: ~100 MY to 1 BY
Blue giants	B: ~10 MY to 100 MY
Blue supergiants	O: ~1 MY to 10 MY

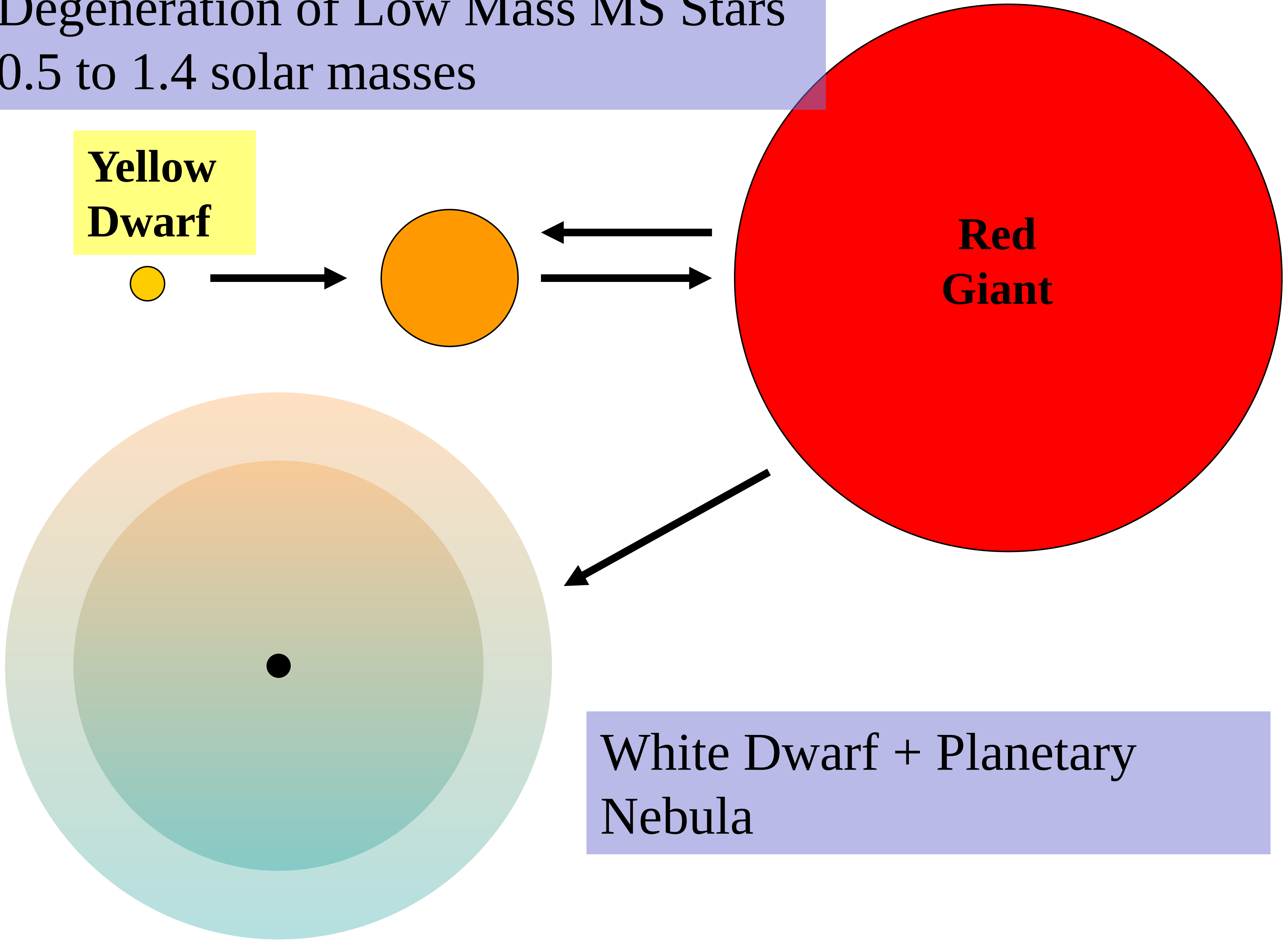
The amount of time the star remains as a Main Sequence star depends on the stars' masses. Large mass stars have shorter lifespans; smaller mass stars have longer lifespans.

More mass → More gravity → Faster fusion → quicker depletion of hydrogen.

The way the star evolves depends on mass.



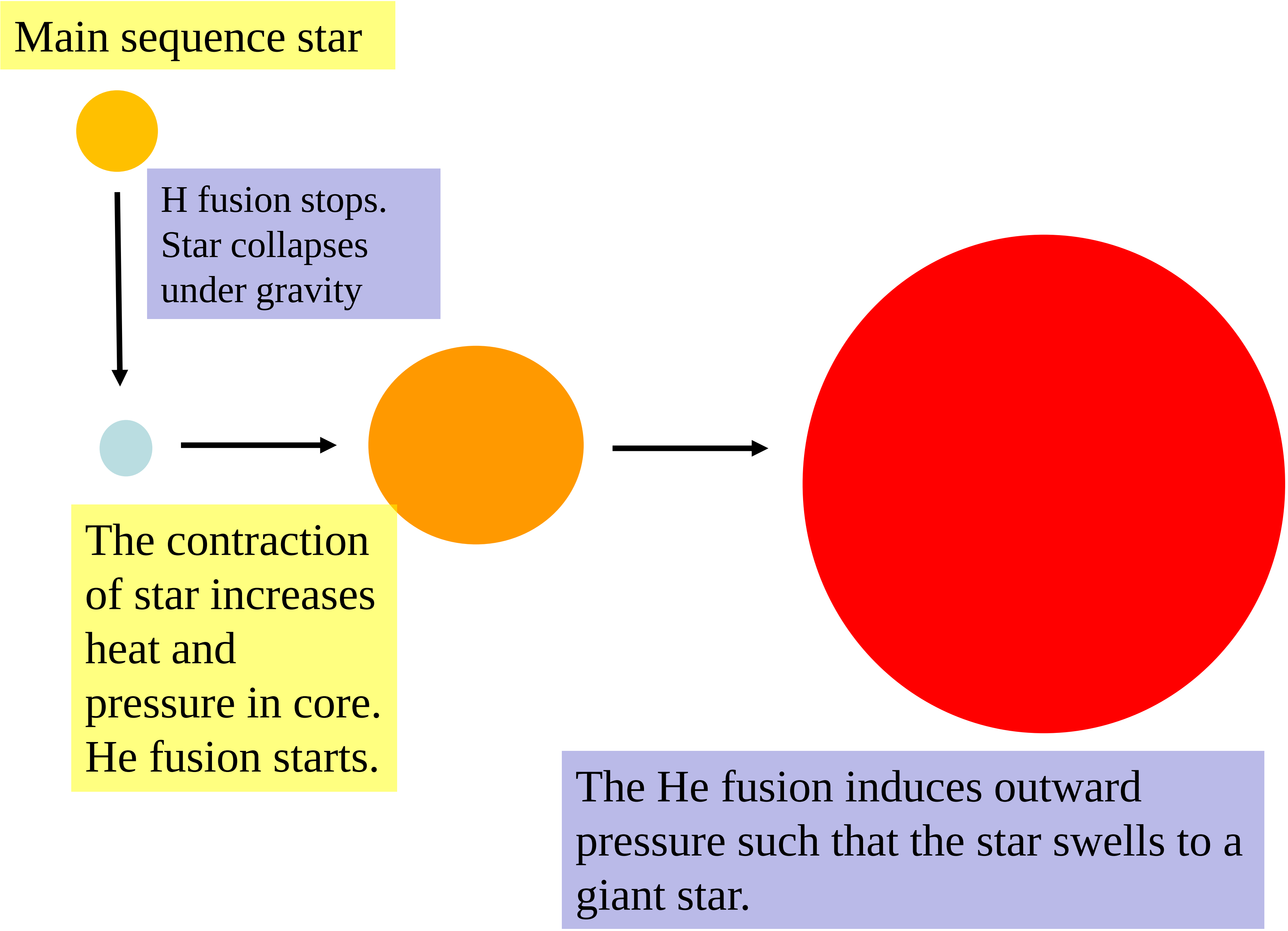
Degeneration of Low Mass MS Stars
0.5 to 1.4 solar masses



Evolution of a Low Mass Star

1. The low mass star will in the main sequence until it has **fused ~90% of H** in core.

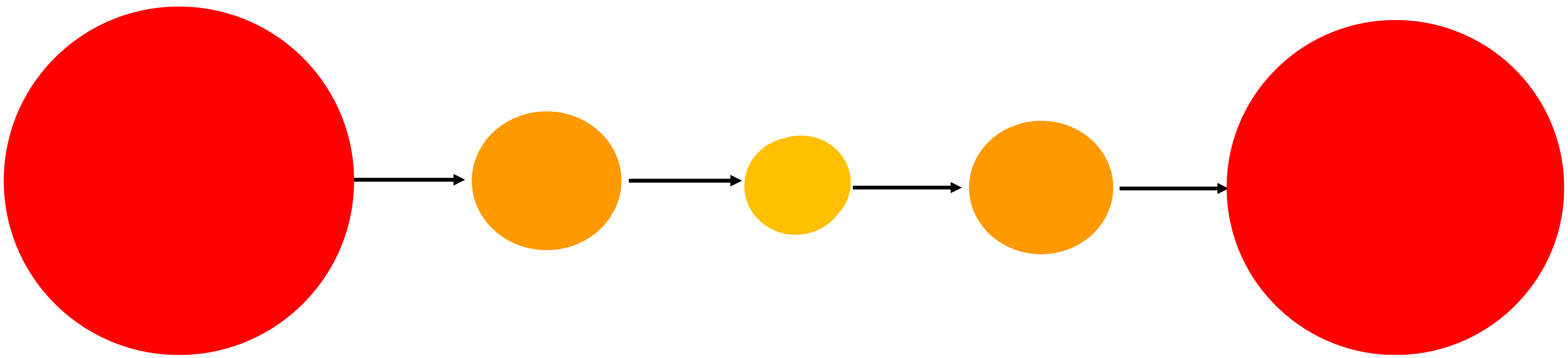
- Fusion rate slows—outward pressure from the core weakens and inward gravity force is greater.
- The star's mass collapses inward onto the core.
- The sudden collapse under gravity creates astronomical heat and "jump starts" fusion of Helium atoms.
- The faster fusion pushes the layers of the star outward, causing the star to swell in diameter and get cooler (turns into a red giant star).


Main sequence star
H fusion stops.
Star collapses
under gravity
The contraction
of star increases
heat and
pressure in core.
He fusion starts.
The He fusion induces outward
pressure such that the star swells to a
giant star.

2. Helium fusion reactions slow again because of the star's expanding radius and cooler temperatures.

- Gravity causes star to collapse again.
- Red giant star contracts back to a yellow giant or orange star.
- The increased gravitational squeezing of gases in the core "jump starts" fusion of 3He → C.
- The faster fusion pushes the layers of the star outward, causing the star to swell in diameter and get cooler.

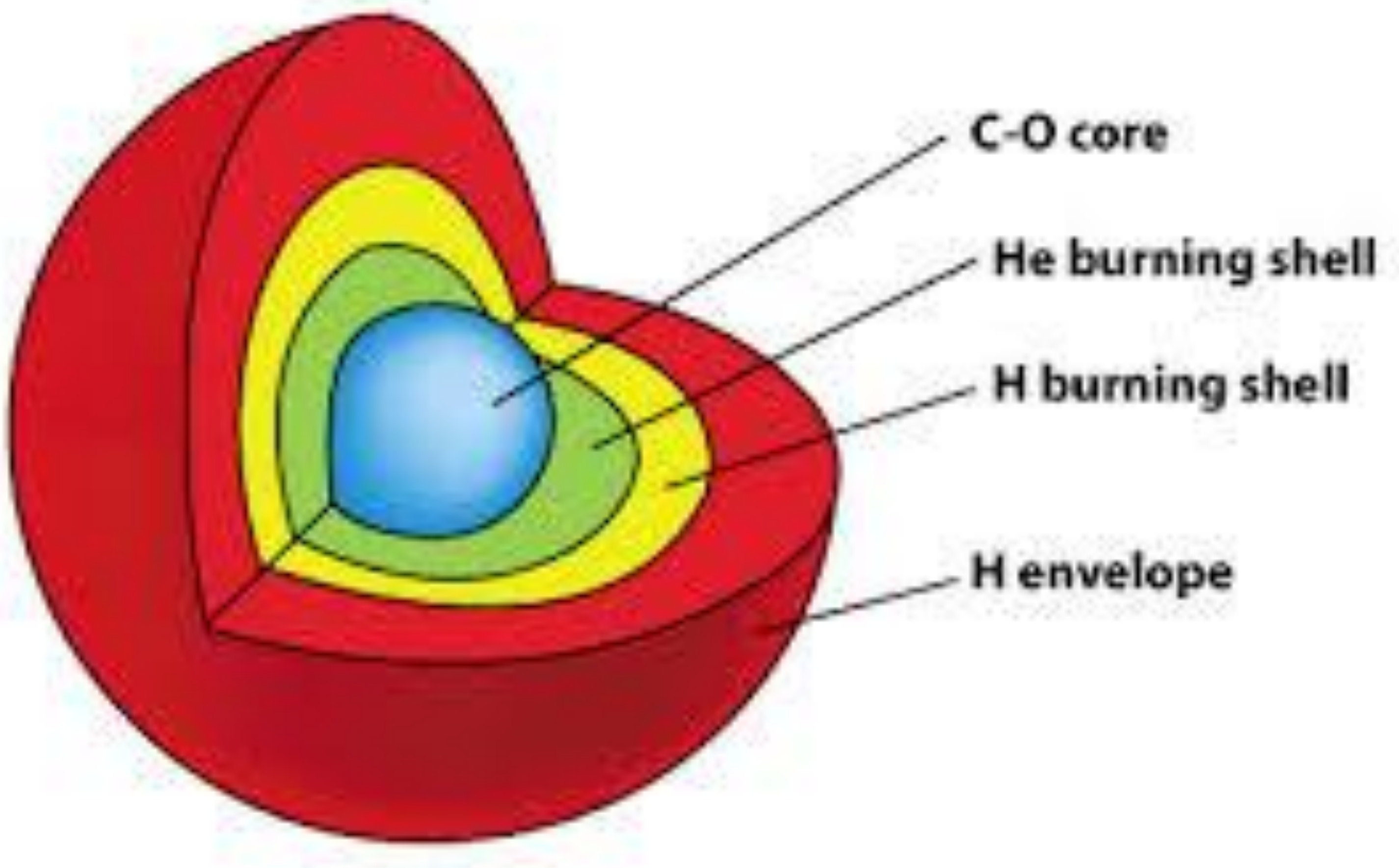
The contraction causes heat and pressure in the core. Carbon in the core begins to fuse



3He $\rightarrow$ C fusion slows as He is depleted. The outward pressure from core decreases. Gravity causes the red giant star to contract to a smaller star.

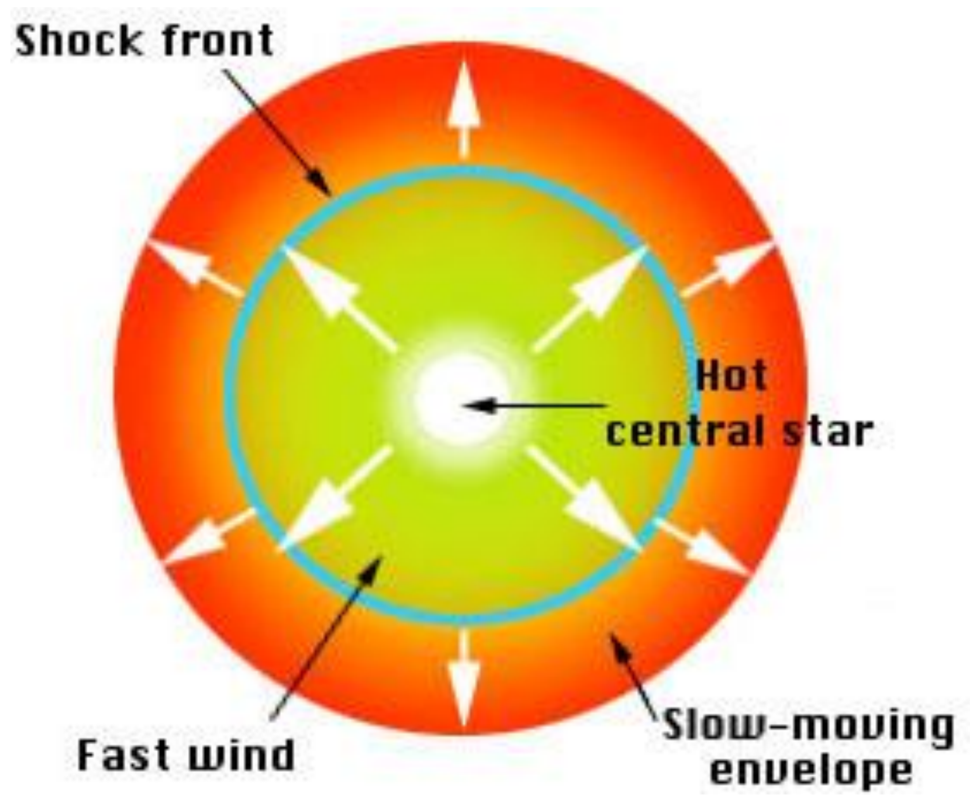
The fusion of C + He $\rightarrow$ O causes the outward pressure in the core to increase. The star violently expands again to a red giant.

Interior of a red giant star near the final years of the star's life cycle. Cooler H and He are in the outer cooler layers of the star. Carbon and helium are fusing to make oxygen.



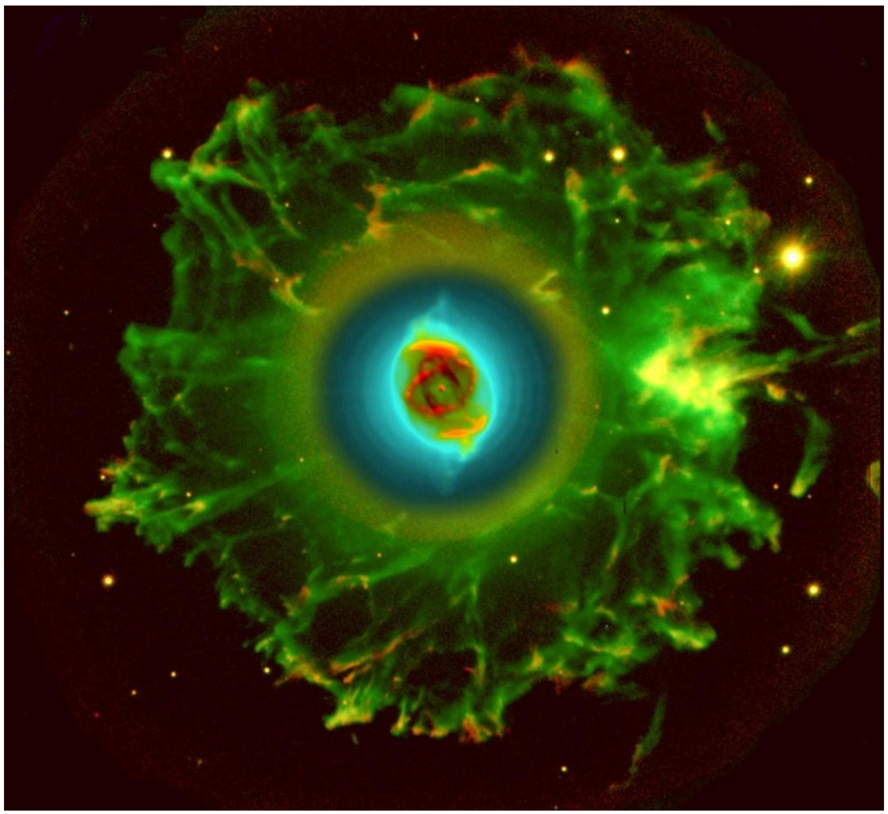
3. The last shock (at carbon fusion) and expansion will cause the outer shell of the star's gases to be thrown outward into space.

- The ring of gases (leftover hydrogen & helium) form the planetary nebula
- The compacted carbon-oxygen core will form the new white dwarf star.



Planetary nebula: an expanding envelope of hot gas emitted from low-mass stars undergoing degeneration at end of their life cycle. *White dwarf* star in the center.

Cat's Eye nebula



Eskimo nebula

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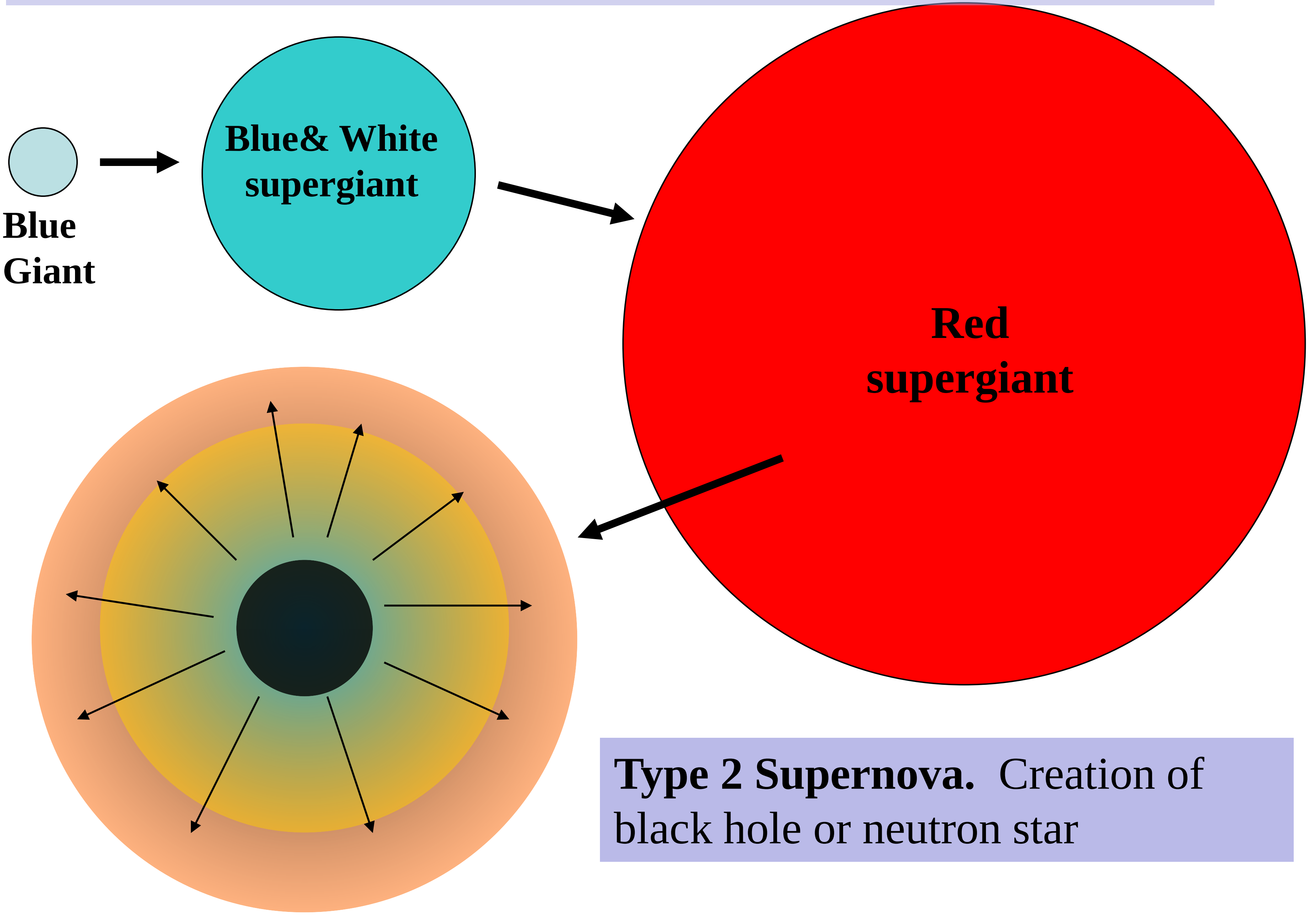
Degeneration of High Mass Stars: > 1.4 solar masses



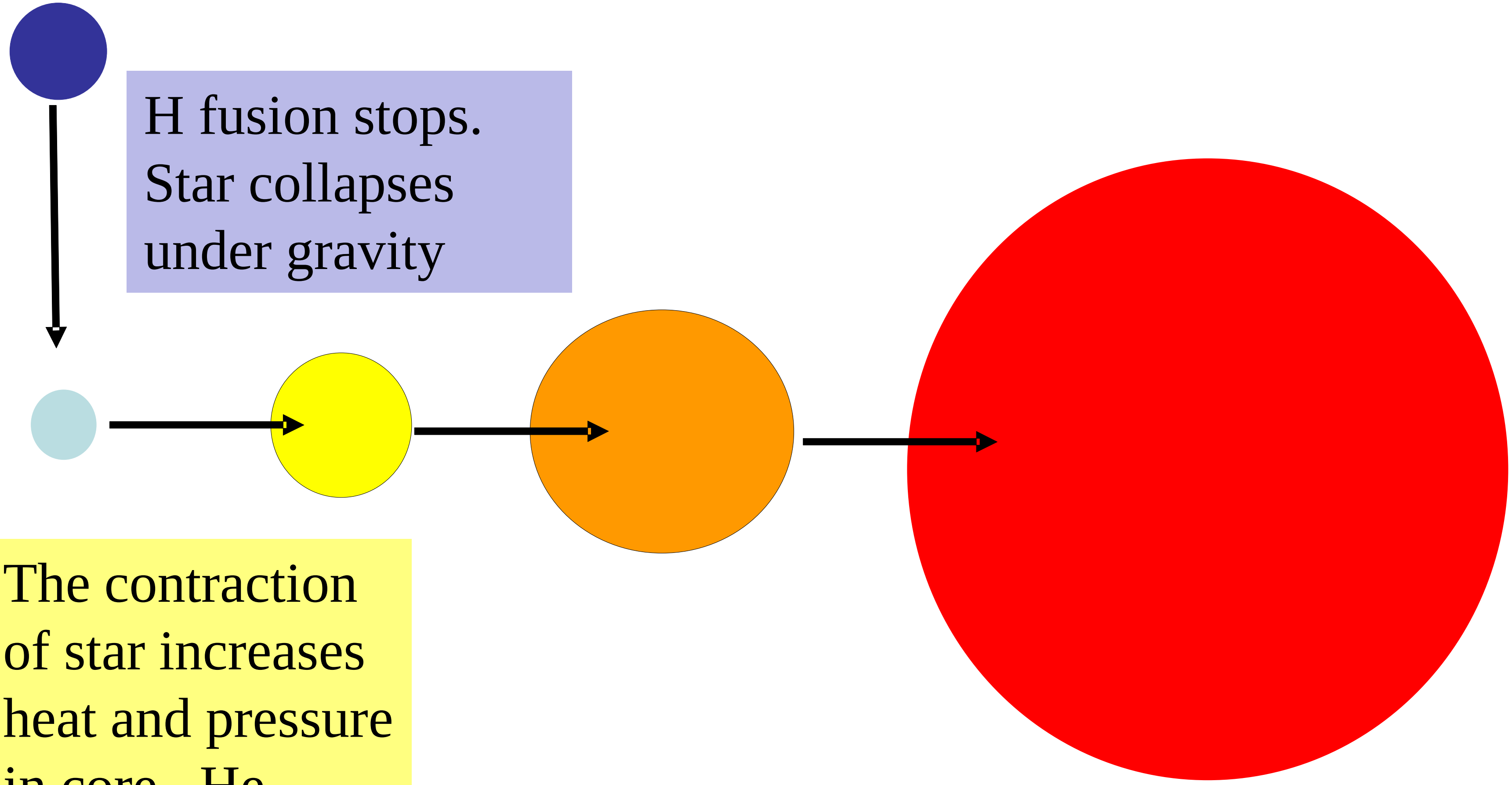
Type 2 Supernova. Creation of black hole or neutron star

Evolution of High Mass Stars

1. The high mass star will in the main sequence until it has **fused ~90% of H** in core.

- Fusion rate slows—outward pressure from the core weakens and inward gravity force is greater.
- The star's mass collapses inward onto the core.
- The sudden collapse under gravity creates astronomical heat and "jump starts" fusion of Helium atoms.
- the layers of the star outward, causing the star to swell in diameter and get cooler (turns into a red supergiant star).

Main sequence blue giant star



H fusion stops. Star collapses under gravity

The contraction of star increases heat and pressure in core. He fusion starts.

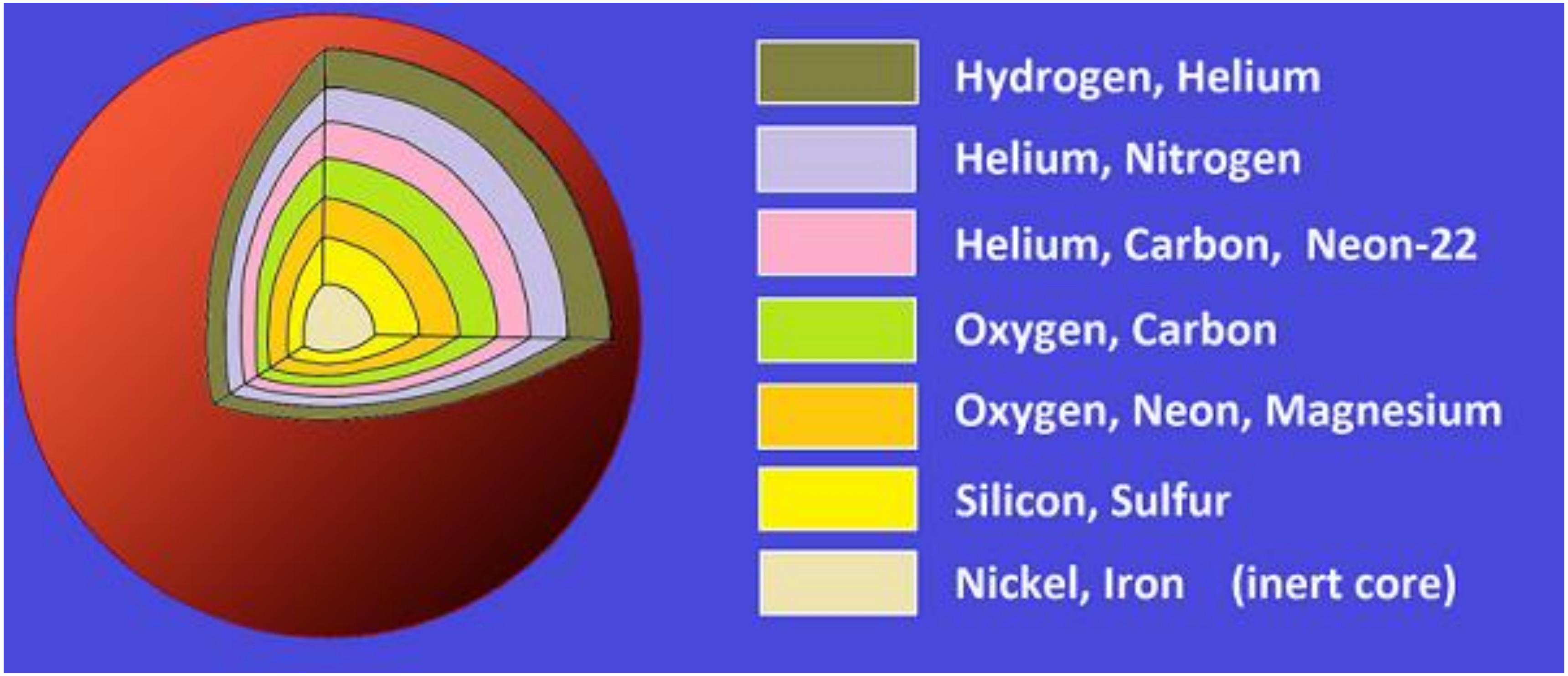
The He fusion induces outward pressure such that the star swells to a blue SG, then yellow SG, then orange SG, to a red SG star.

2. Helium fusion to the element carbon continues until the accumulation of carbon in the core overtakes the helium. Helium fusion slows.

- The outward pressure of the core weakens. The inward gravity force of mass squeezing in on the core overwhelms the star.
- The huge pressure and temperature on the core "jump starts" fusion of carbon atoms to the element oxygen, and Oxygen atoms to the element Neon.

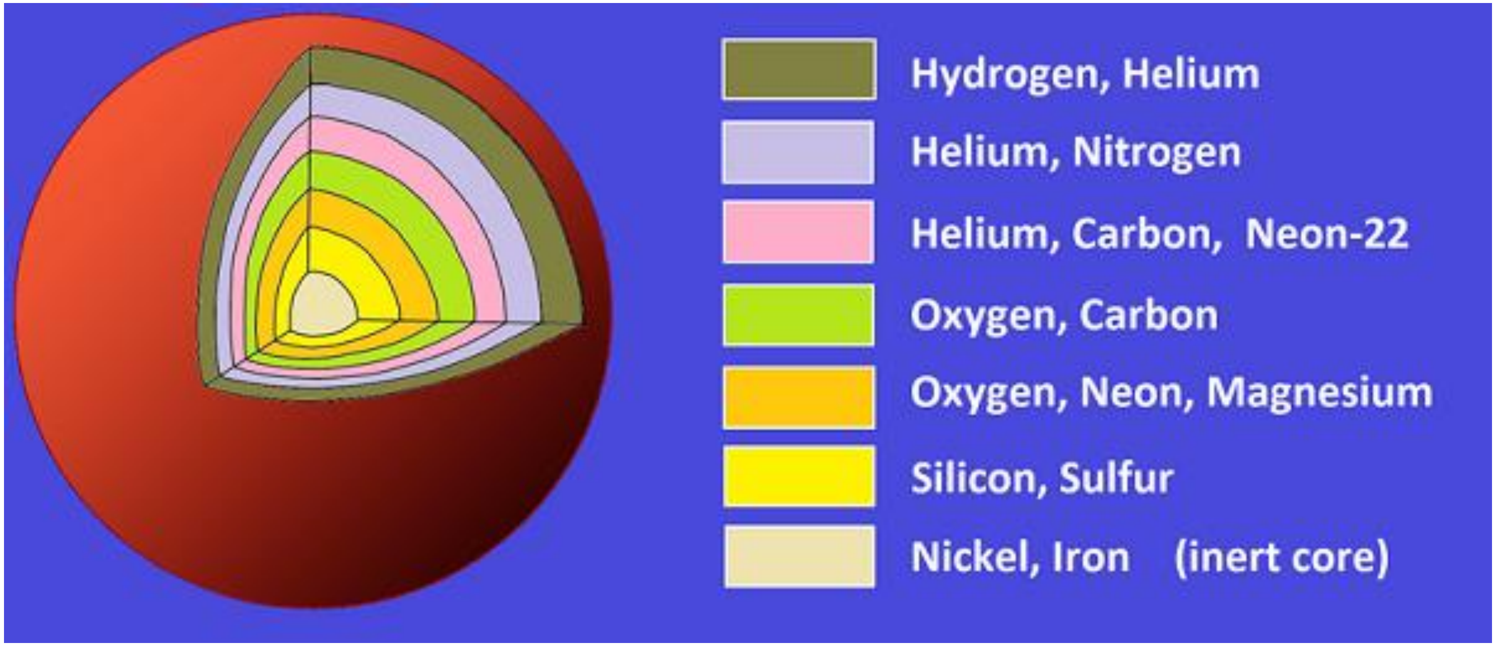
He + C $\rightarrow$ O
He + O $\rightarrow$ Ne

Nucleosynthesis: “Atom making” Creating of progressively heavier elements by fusion reactions in stars and by stellar processes.



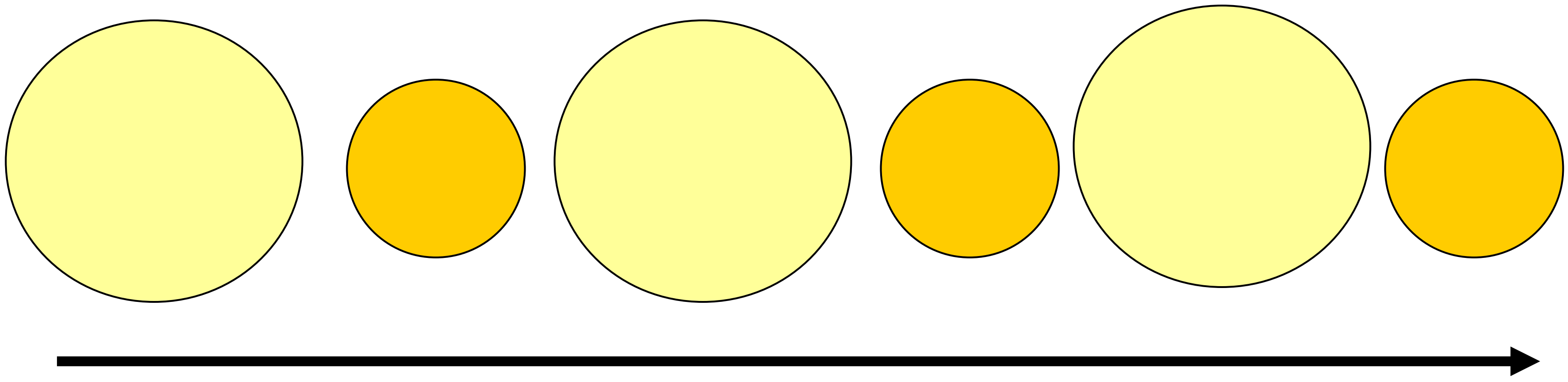
In the red supergiant stars, the condition is “runaway fusion”. As soon as one element is very low in abundance, the next heavier element starts fusing.

As each new element is made, it is heavier than the element atoms that made it. Over time, more elements that are heavier are made and sink inward to the core of the star. When they get into the core, they start fusing to create the next heavier element.



3. The star will swell and contract many, many times as fusion of one element's atoms slows/stops and the next heavier element begins to fuse.

The star will pulsate bright to dim to bright over time. Variable stars—luminosity increases and decreases with time.



Order of the Runaway fusion reactions in red supergiant stars

He + He + He → carbon (C)

C + He → oxygen (O)

O + He → neon (Ne)

C + C → magnesium (Mg)

C + C → oxygen (O) + helium (HE)

Mg + He → silicon (Si)

Si + He → sulfur (S)

S + He → argon (Ar)

Ar + He →calcium (Ca)

Si + Si → iron (Fe) THE END!

4. The last stage of is the runaway fusion reaction is the production of Fe (element 26).

Iron cannot fuse.

- Because the element iron, the heaviest element created by nucleosynthesis, accumulated in the core, all fusion stops.
- No fusion = no outward pressure from the core to counteract the inward force of gravity.

In under 24 hours, the entire mass of the star collapses inward by gravity then explodes.

- The massive inward collapse of the star crushes the core.
- Atoms of elements 1-26 are crushed together where nuclei are crushed against nuclei. Electrons are annihilated.
- The build-up of heat and potential energy by the crushing of elements and atoms together in the core and is released as the massive explosion.
- The crushing of the core and the subsequent massive explosion create **elements 27-92.**

As the star explodes, what happens the core of the star that is not blown outward during the supernova.

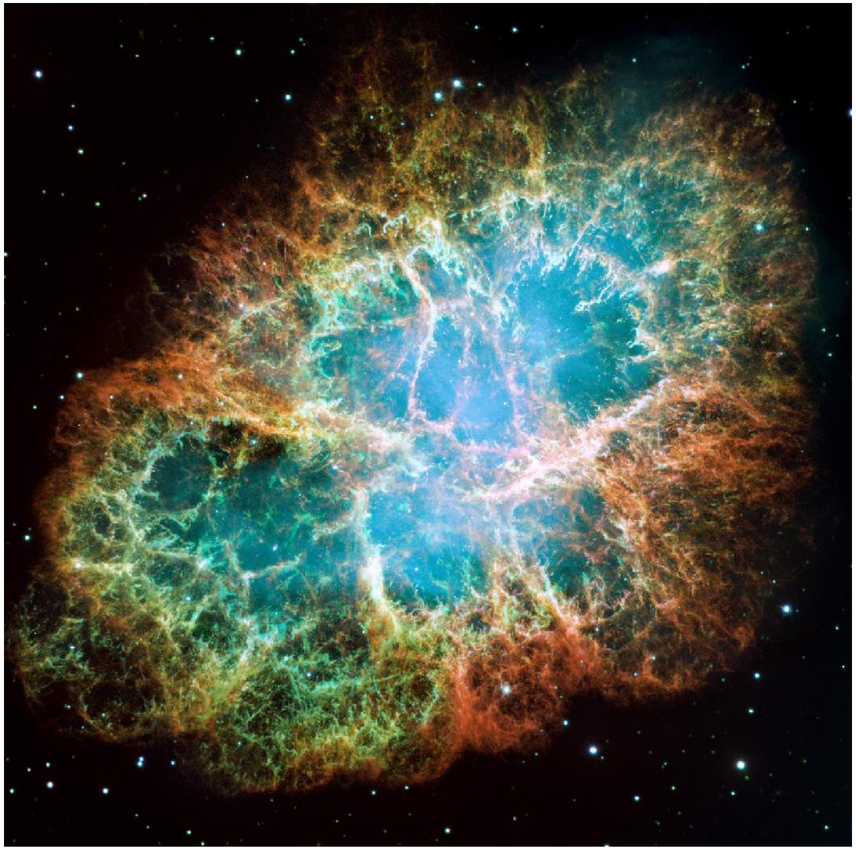
One of two objects remain.

- 1.4-10 solar masses will yield a **neutron star**.
- > 10 solar masses will yield a **black hole**.

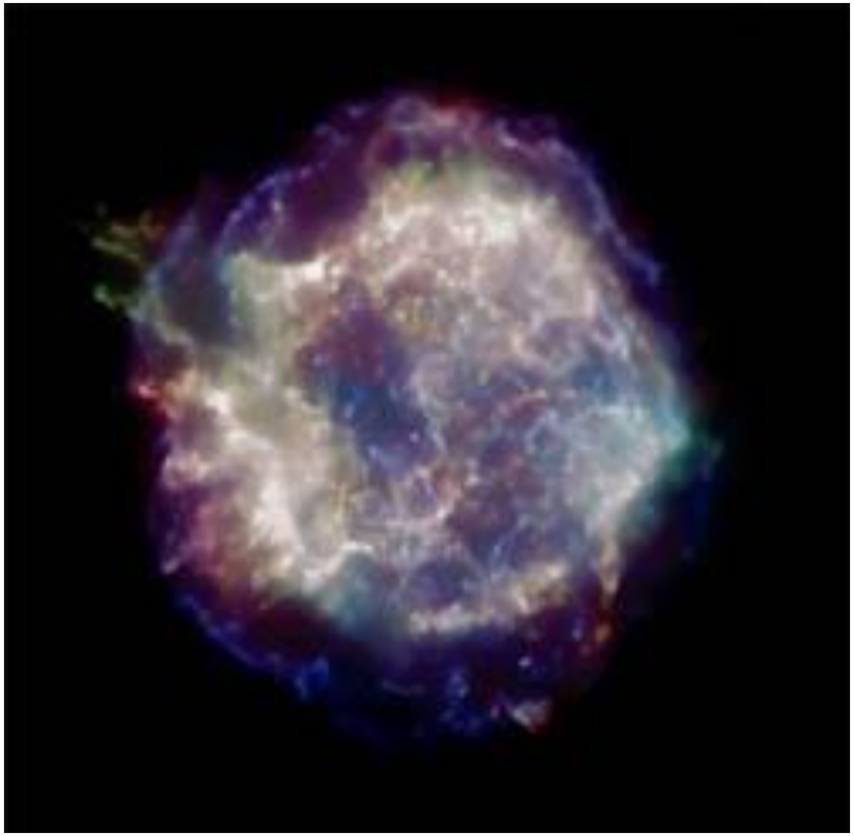
The explanding **supernova remnant nebula** will scatter all the elements into space.

Supernova remnant nebula: a rapidly expanding envelope of hot gas, dust, atoms, and ions violently ejected from exploding red supergiant stars.

Crab nebula



Cassiopeia nebula



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Star going supernova