Astronomy 150: Killer Skies
Lecture 17, February 27

Assignments:

- HW5 due Friday at start of class
- Night Observing continues this week
- Computer Lab 1 due next Friday

Guest Lecturer: Prof. Athol Kemball

Last time: the Future Sun: Part I

Today: the Future Sun: Death Throes

Night Observing

Night Observing continues next week

- if you do it, need to go one night
- allow about 1 hour

When: Mon-Thurs, 7-9pm

3 observing stations:

- Large telescope in observatory dome
- 2 outdoor telescopes
- Night sky constellation tour

Subscribe to Night Observing Status Blog

http://illinois.edu/blog/view/413

Get weather cancellation updates

Assignment details on class website

Report form required!

- download and print out before you go
- Complete report due on or before Mar. 16

Astrometry of Asteroids Lab

A chance to work with real data

Software:

- Installed on ICS lab computers (Windows)
- Or download to your PC

Manual & worksheet on class website

Work in groups up to 3

The lab is more mathematical than anything else in the course

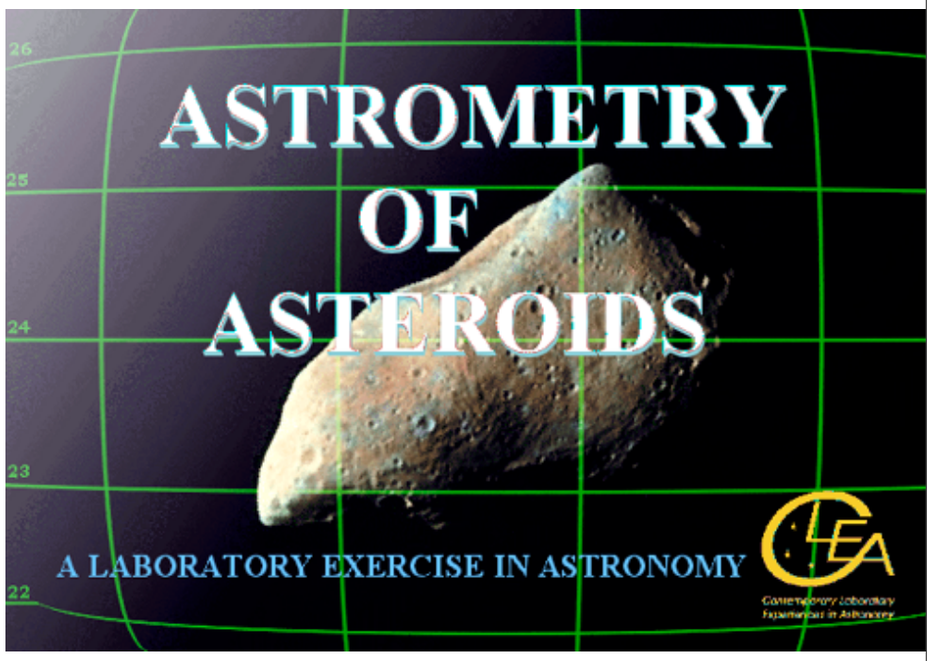
- but instructions explain everything step-by step, so:
- allow yourself time! can take 2 hours or more
- don't wait till the last minute!

to give you time:

- no class next Wednesday Feb 29--work on lab instead!

Completed worksheet due by Fri., March 2

Help session: 3/1, 5-7pm, Oregon ICS lab



just so we are totally clear...

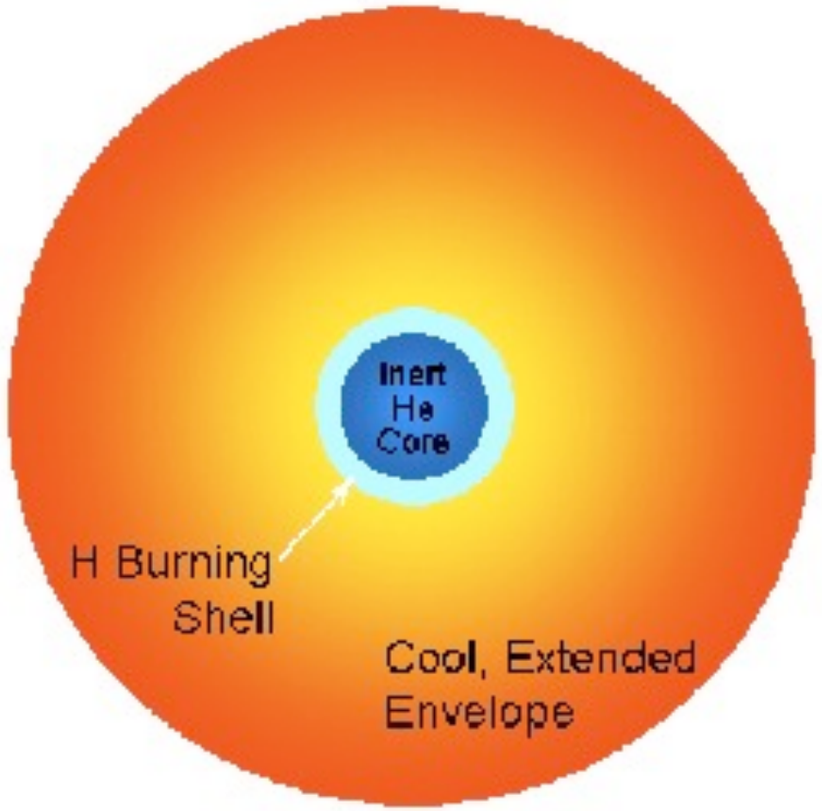
No lecture Wednesday!

Work on Computer Lab!

See you this Friday when the lab is due.

Life of a Sunlike Star

Main sequence
Core hydrogen burning
T_{core} ~ 16 million K



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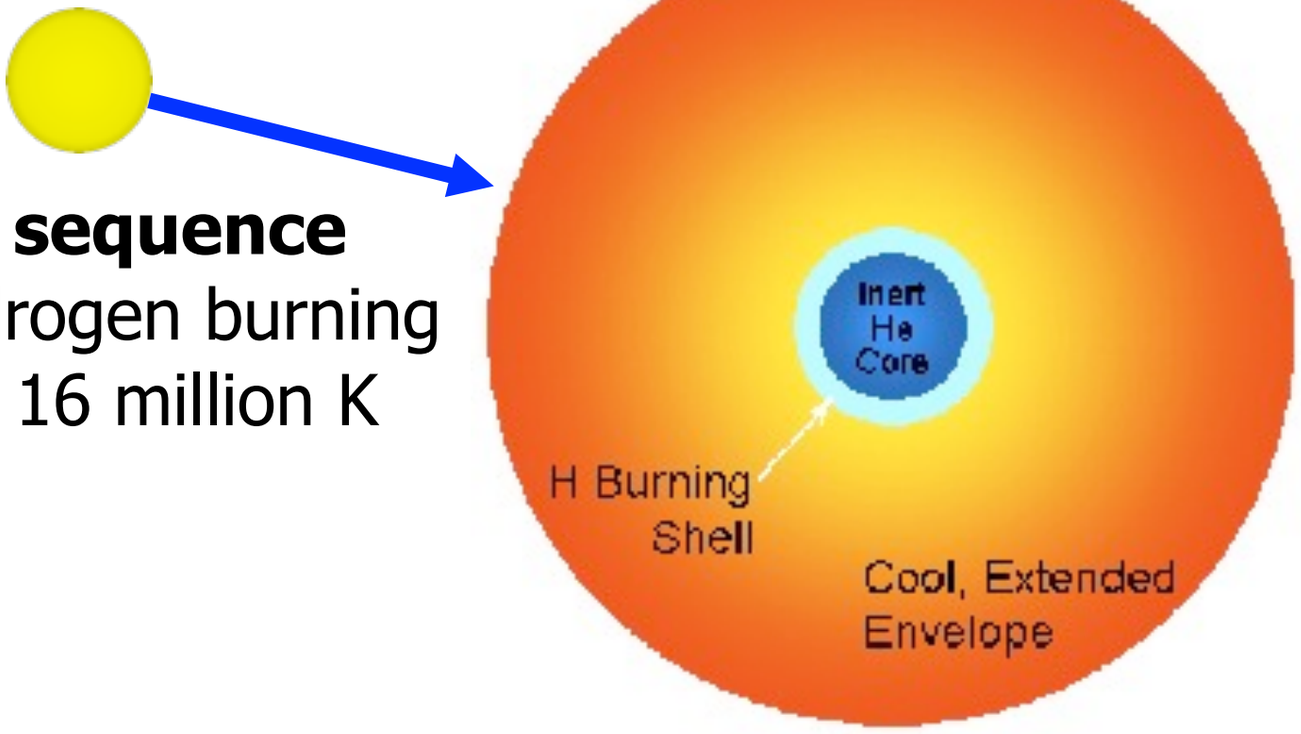

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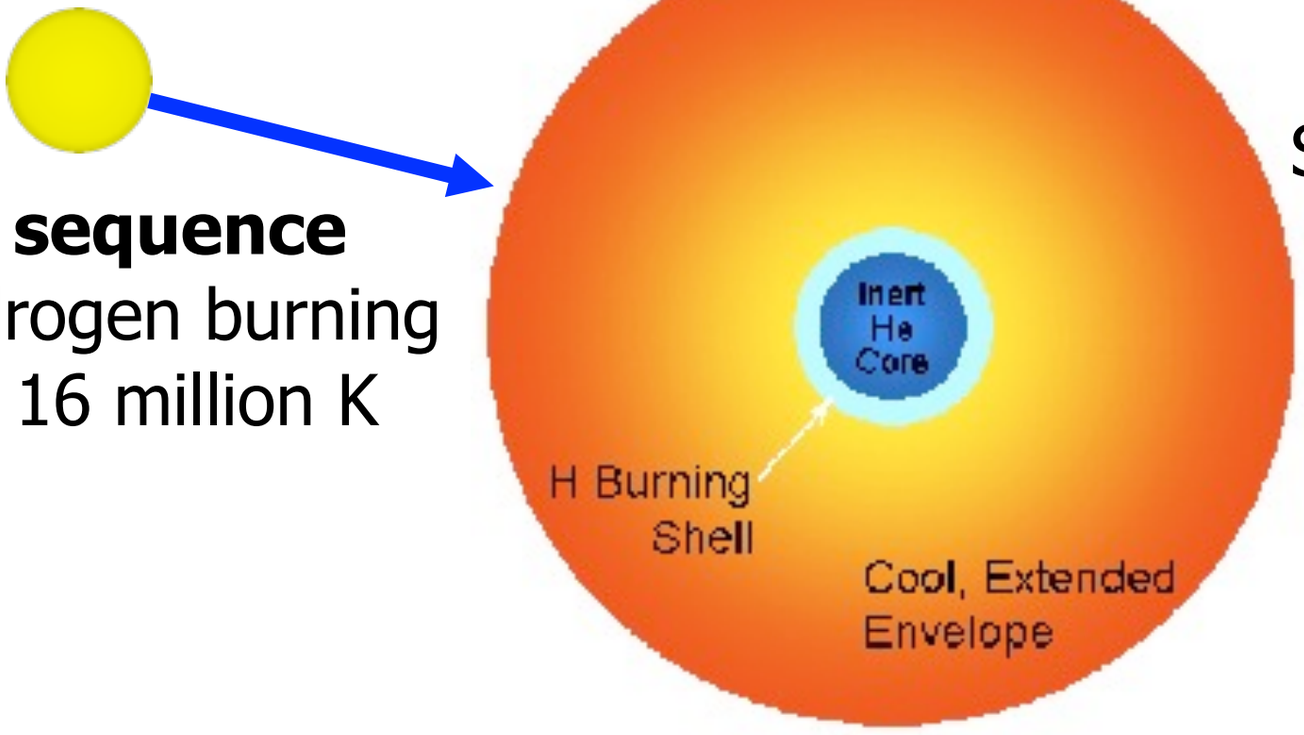
Red giant

Life of a Sunlike Star



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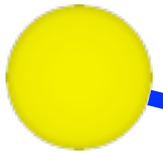
Red giant
Shell hydrogen burning

Life of a Sunlike Star



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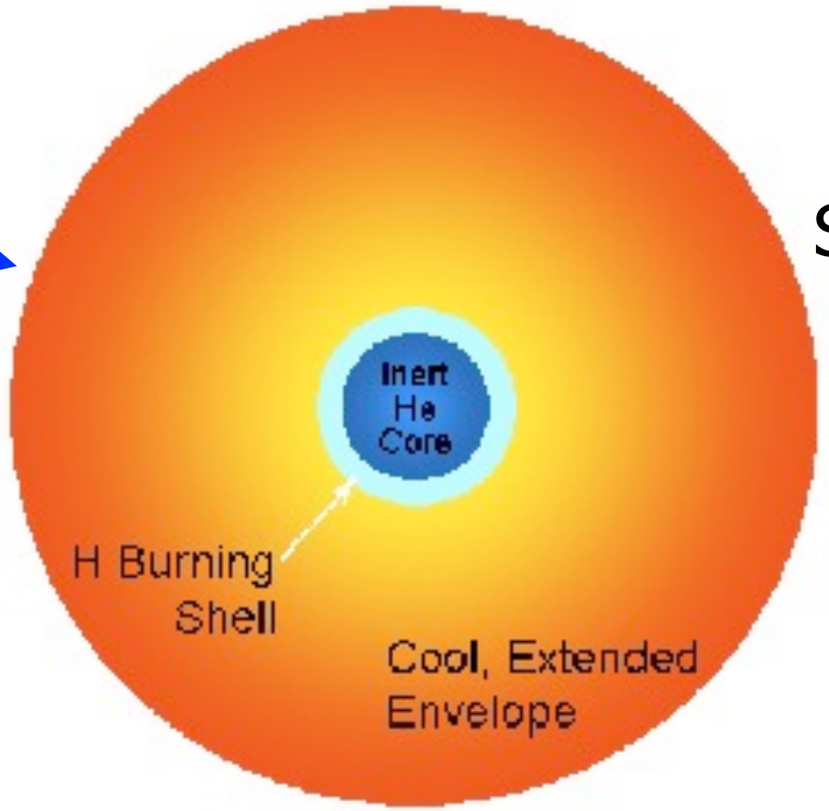
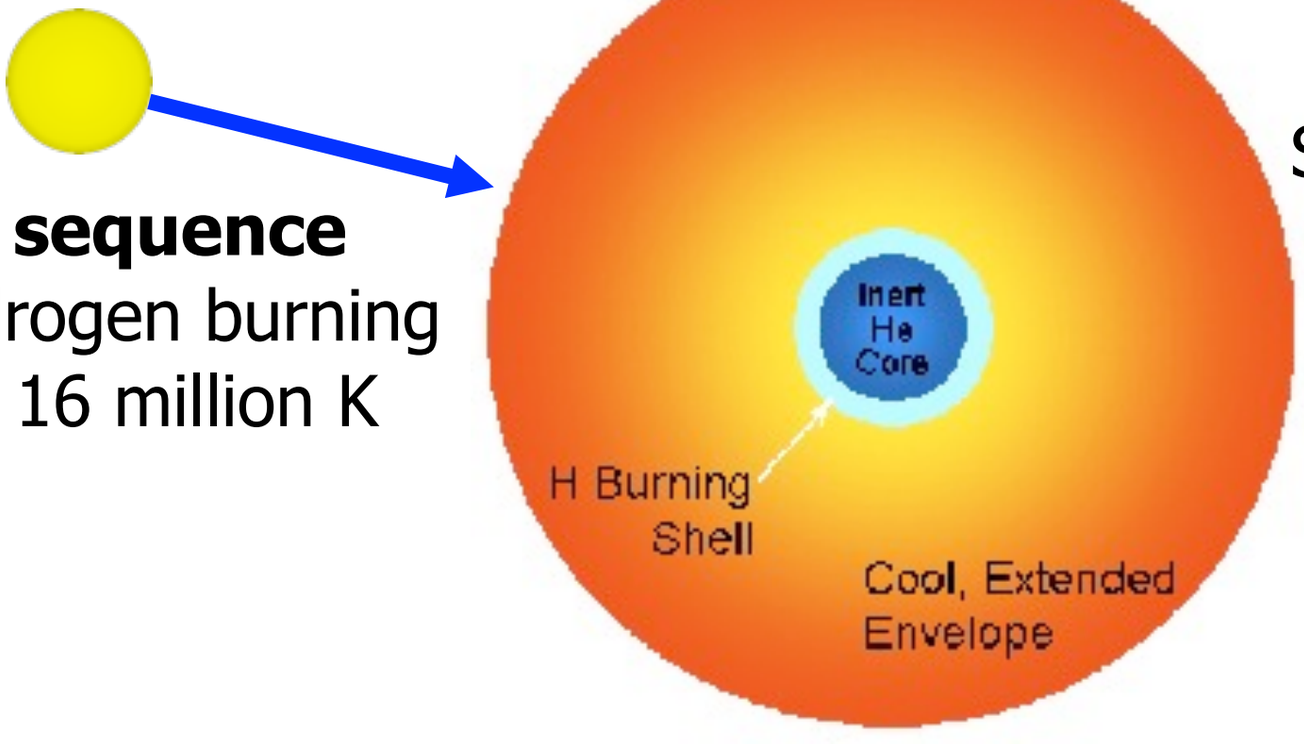


Red giant
Shell hydrogen
burning

When we left off on Friday:

Life of a Sunlike Star



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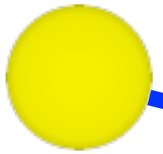
When we left off on Friday:

✓ **Sun hydrogen exhausted**

Life of a Sunlike Star



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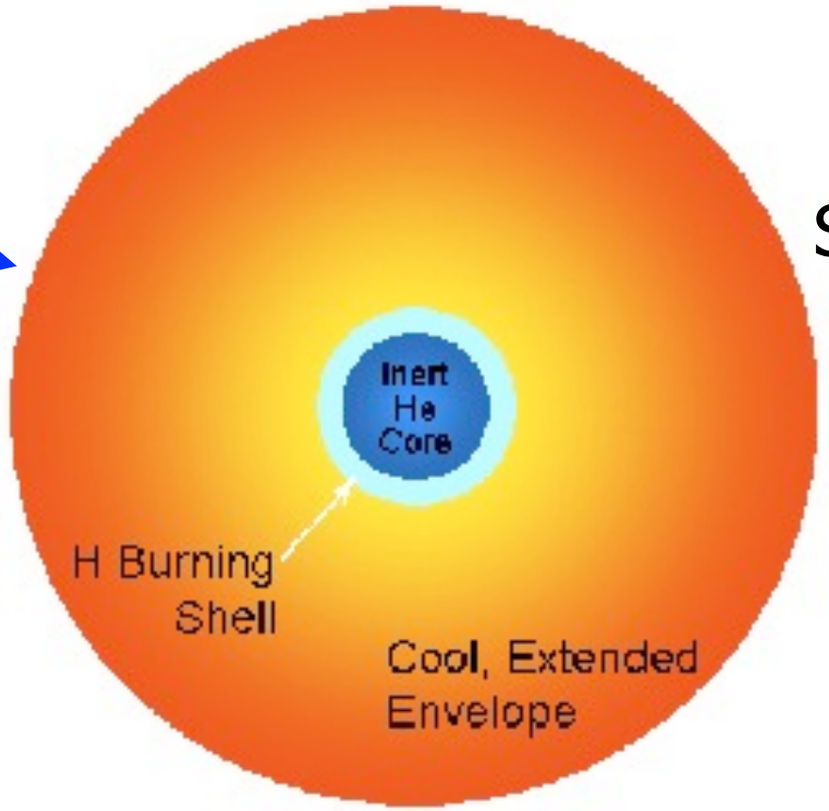

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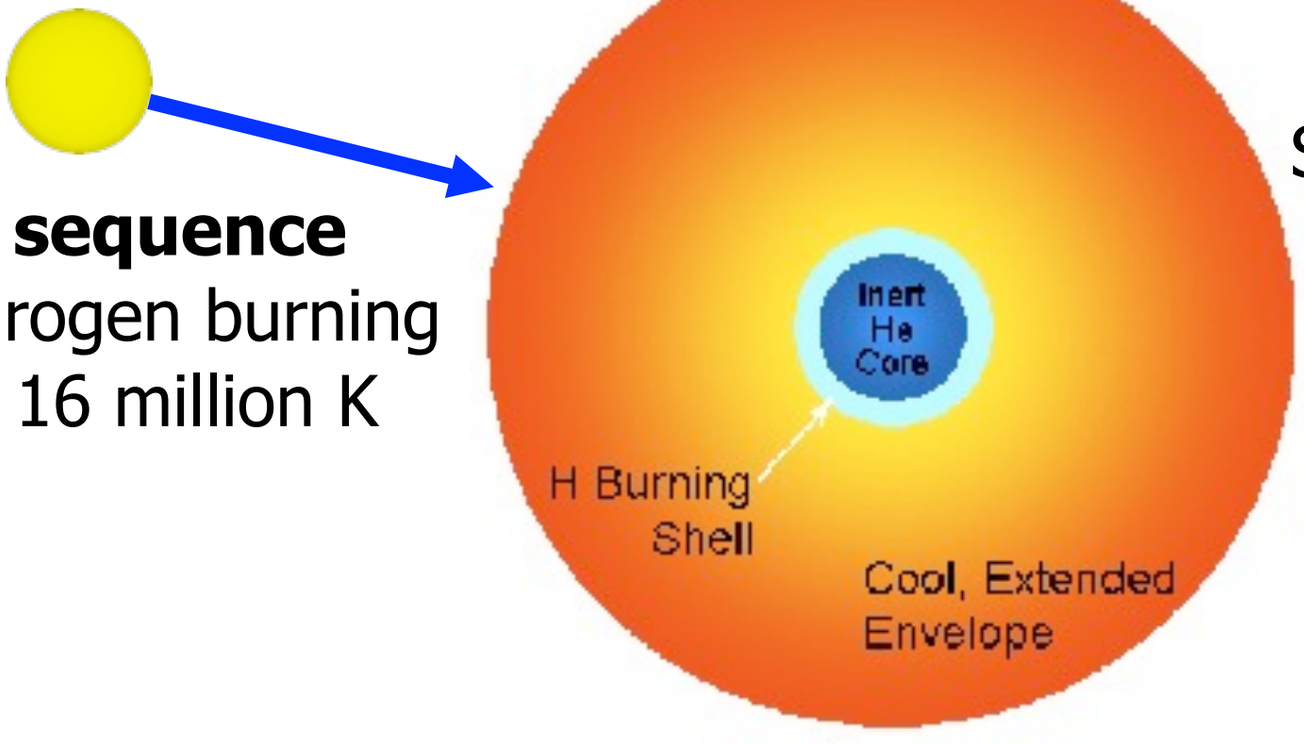
When we left off on Friday:

- ✓ **Sun hydrogen exhausted**
- ✓ **Core filled with inert (for now) helium**

Life of a Sunlike Star



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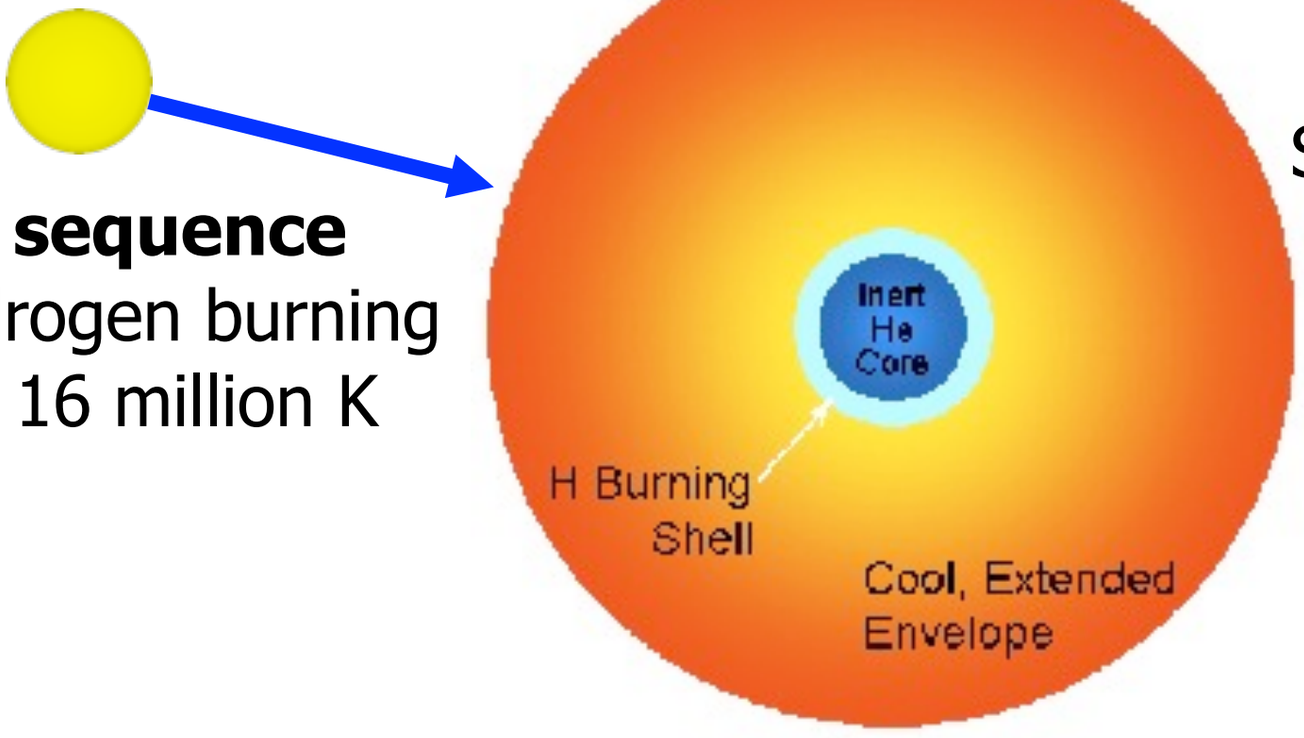

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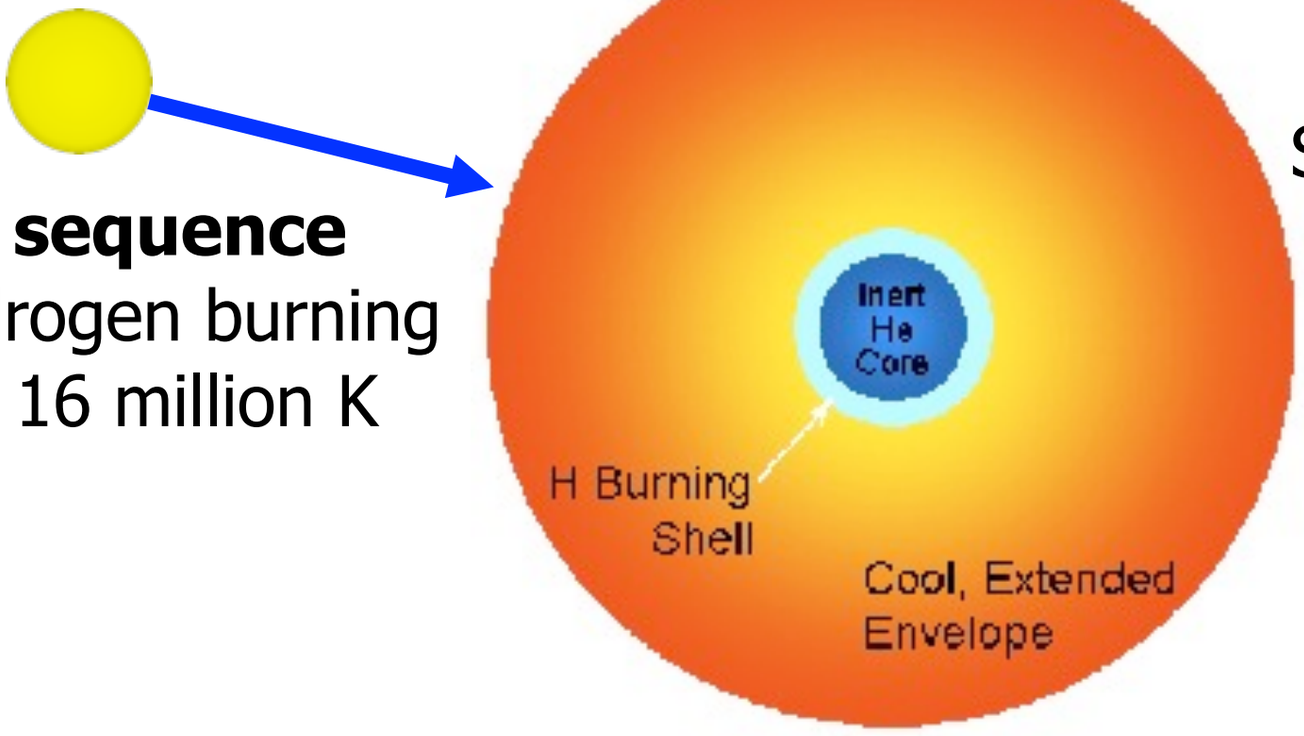

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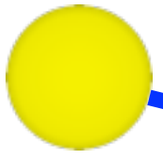

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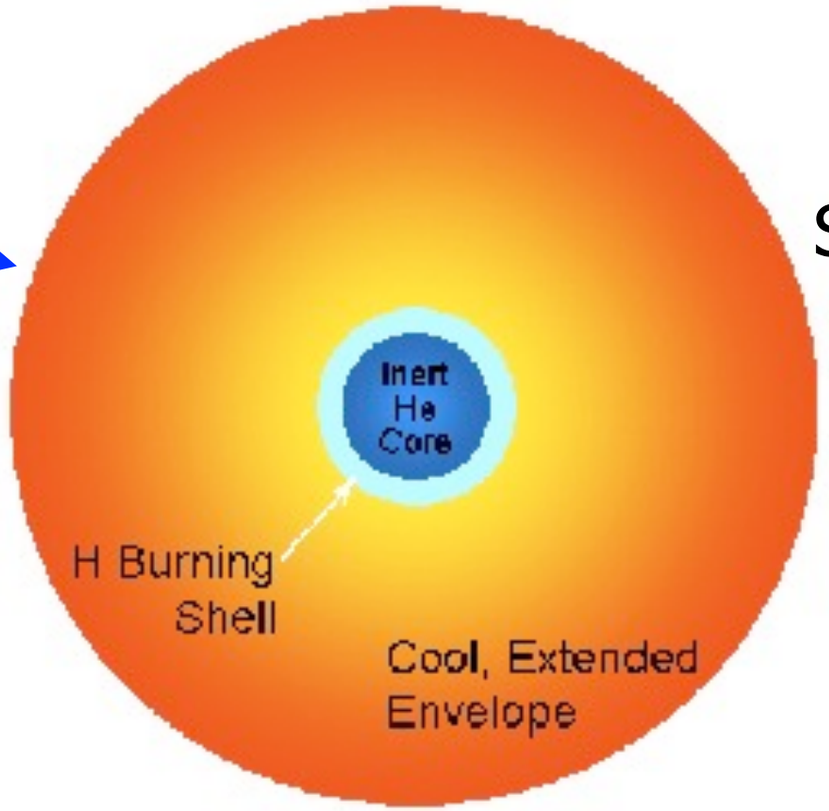

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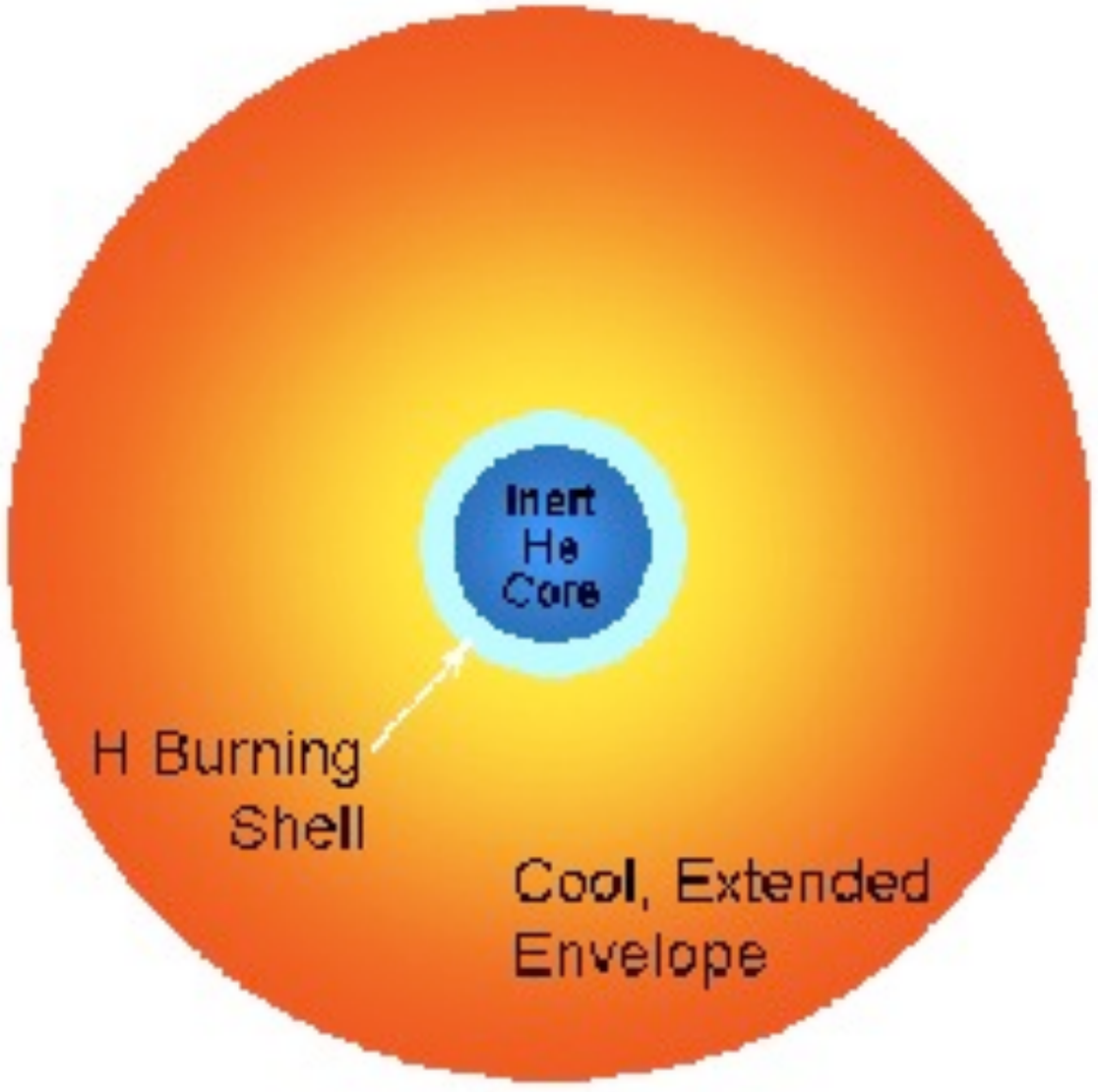
- ✓ **Sun bloated to red giant**
- ✓ **Mercury & Venus gone**
- ✓ **Pluto looking like attractive real estate**

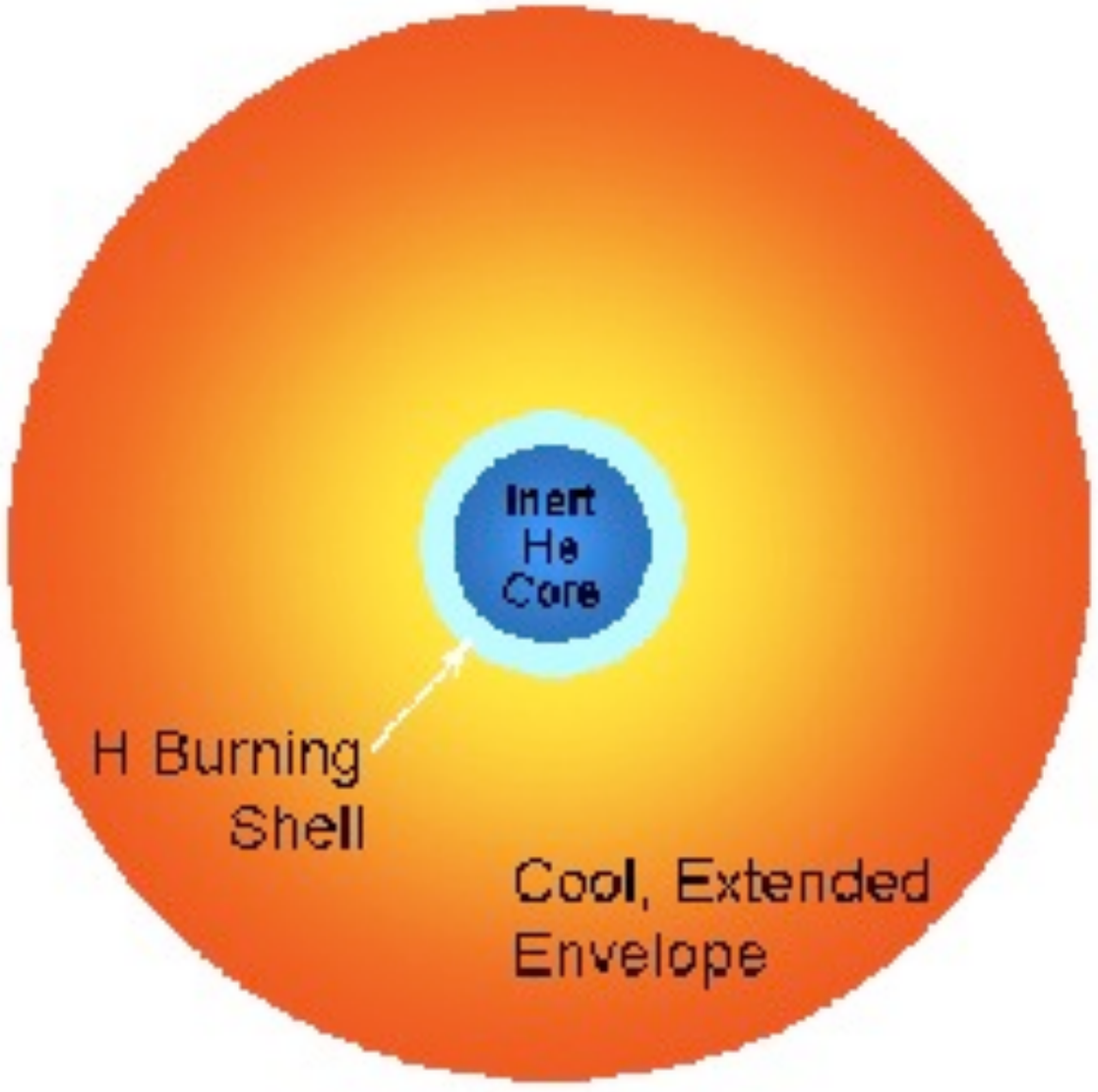
Contraction Junction

- In core, contraction increases density
- Hotter, and hotter, and hotter until…



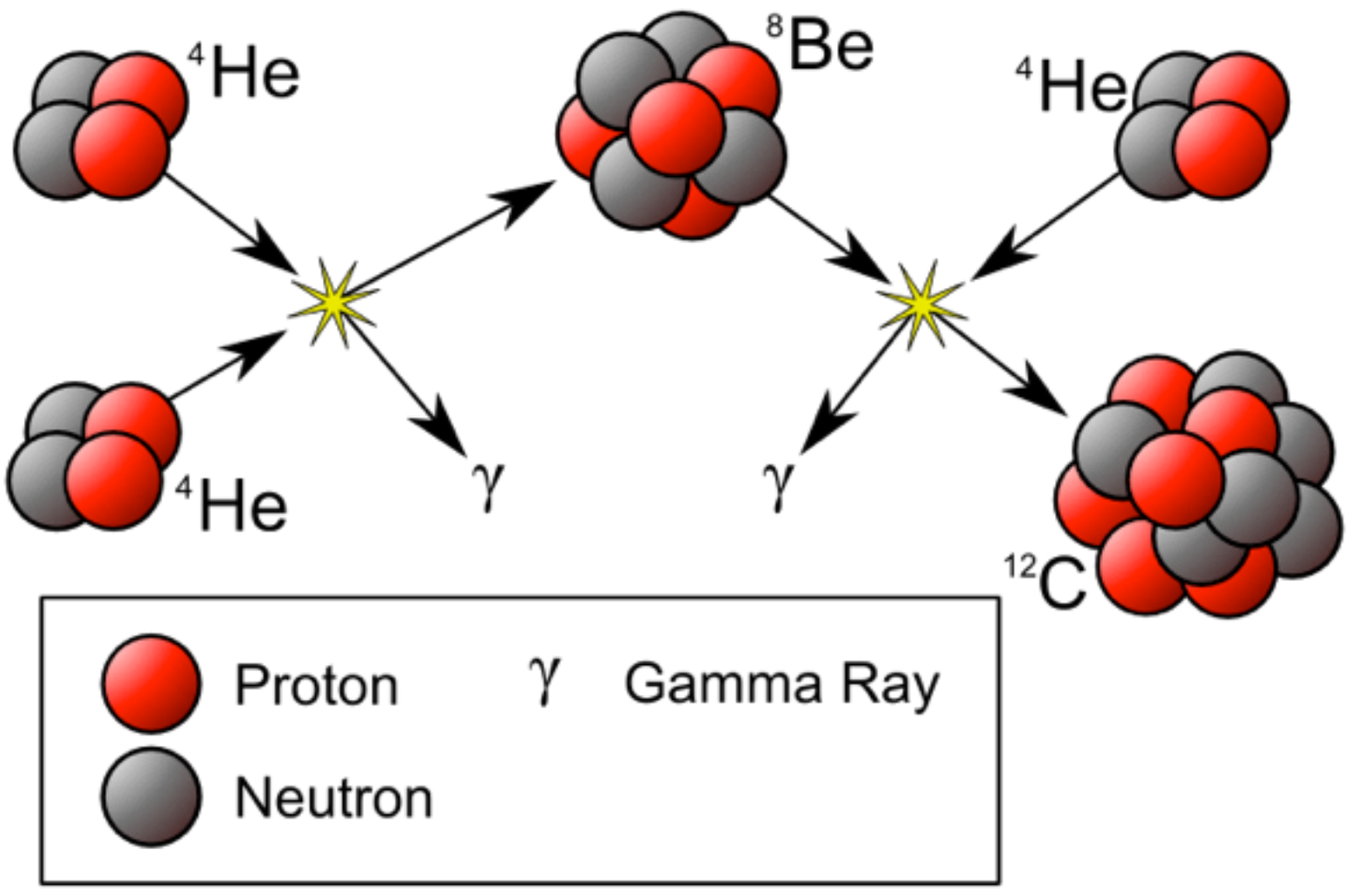
Contraction Junction

- 100 million degrees F
- Core heats ⇒ He fusion ignite
- He ⇒ C & O



Helium Burning

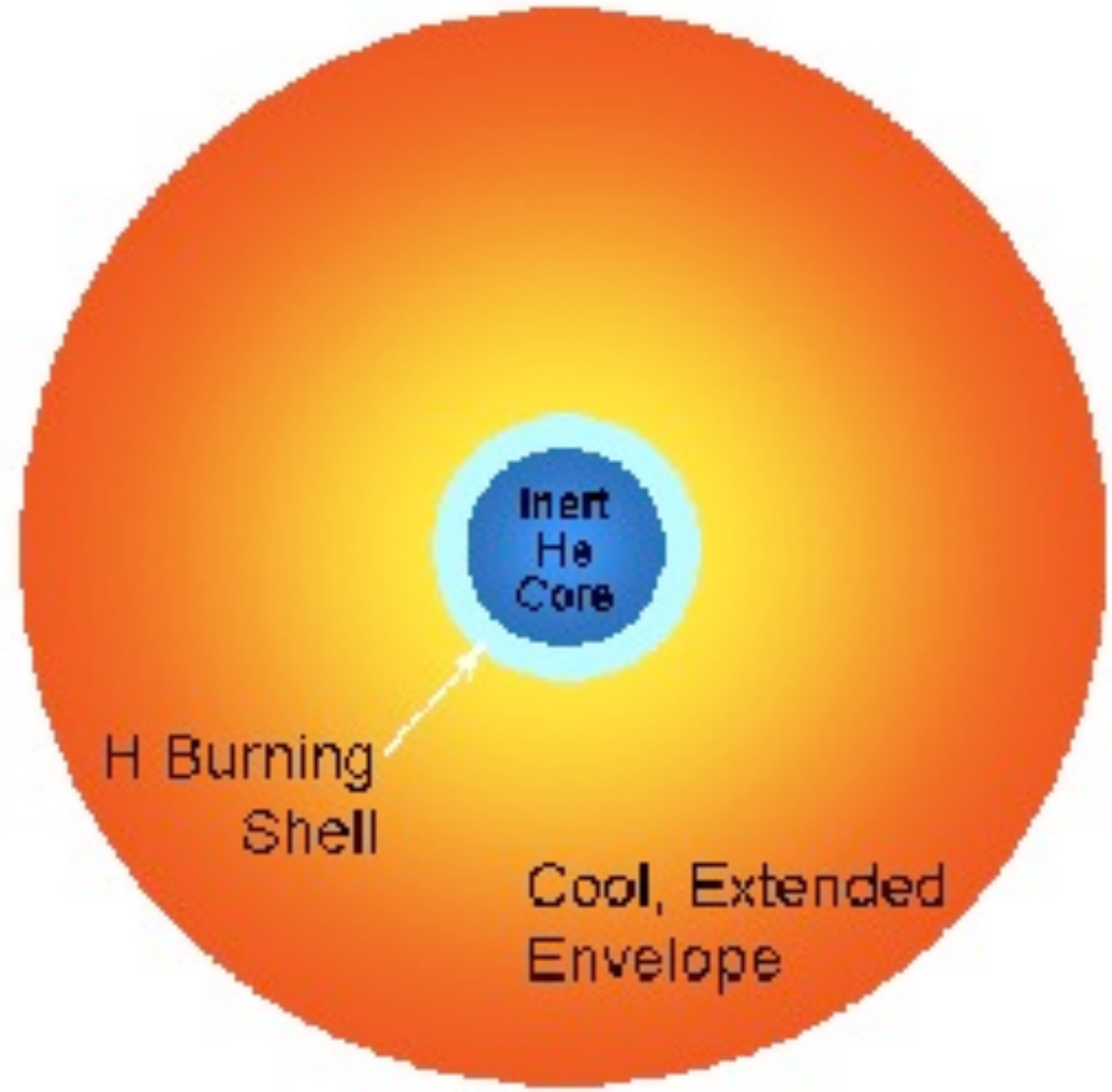
- When the core of the star reaches 100 million degrees, particle collisions very violent, can then fuse helium (the ash of hydrogen burning) into carbon
- helium "ash" now becomes "fuel" -- the Sun recycles!
- Called the Triple-Alpha Process
  - Converts 3 heliums into one carbon + energy



Helium Burning

- As helium fuses into carbon, carbon slowly accumulates in the core.
- Collisions between carbon-12 and a helium nucleus can create the stable nucleus of oxygen-16, which increases with the carbon concentration.
- So process of burning helium creates C and O “ash”.

Helium Flash: 7.7 Billion Years



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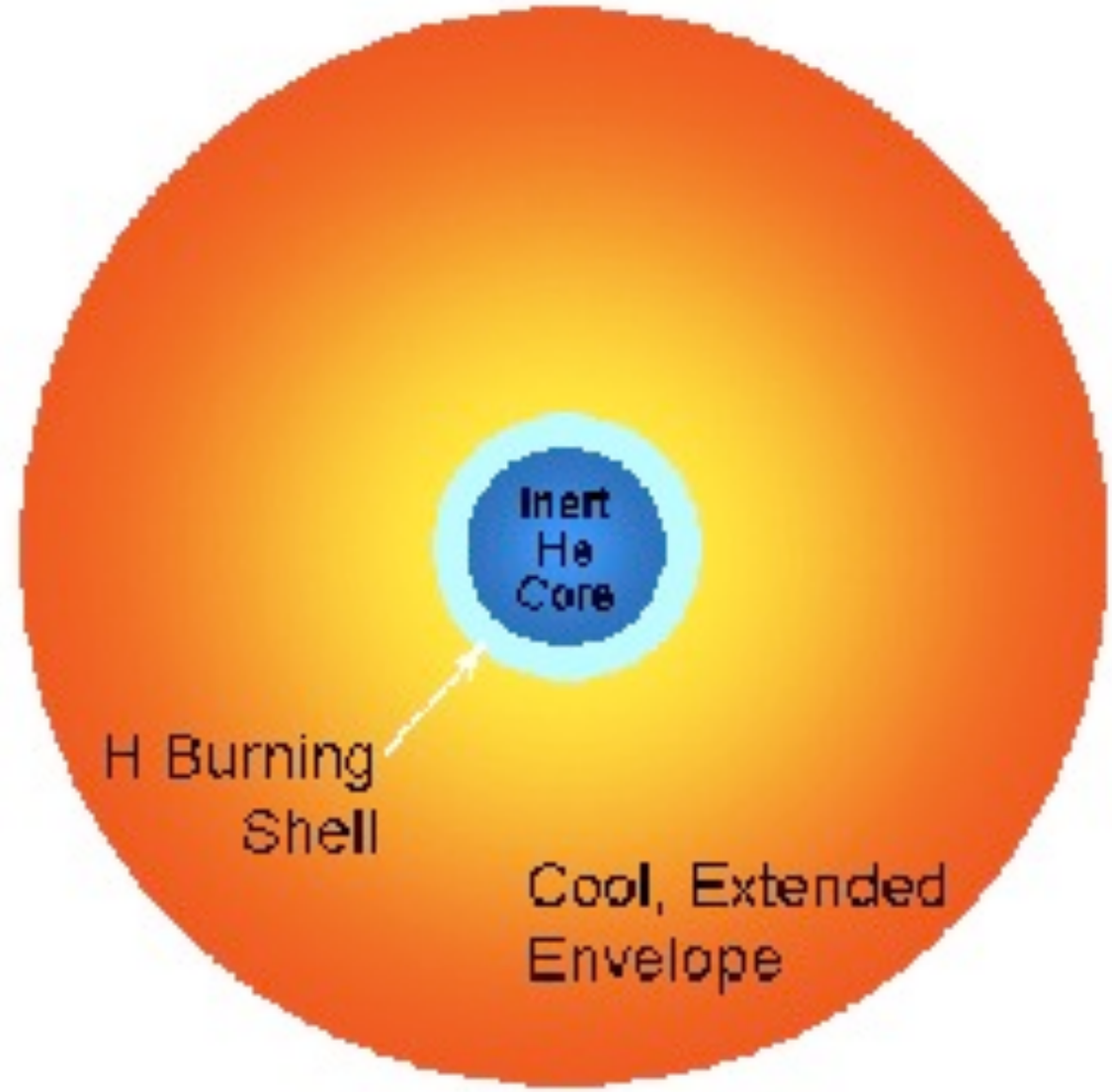
- Helium Flash: explosion at core of Sun when helium finally ignites all at once



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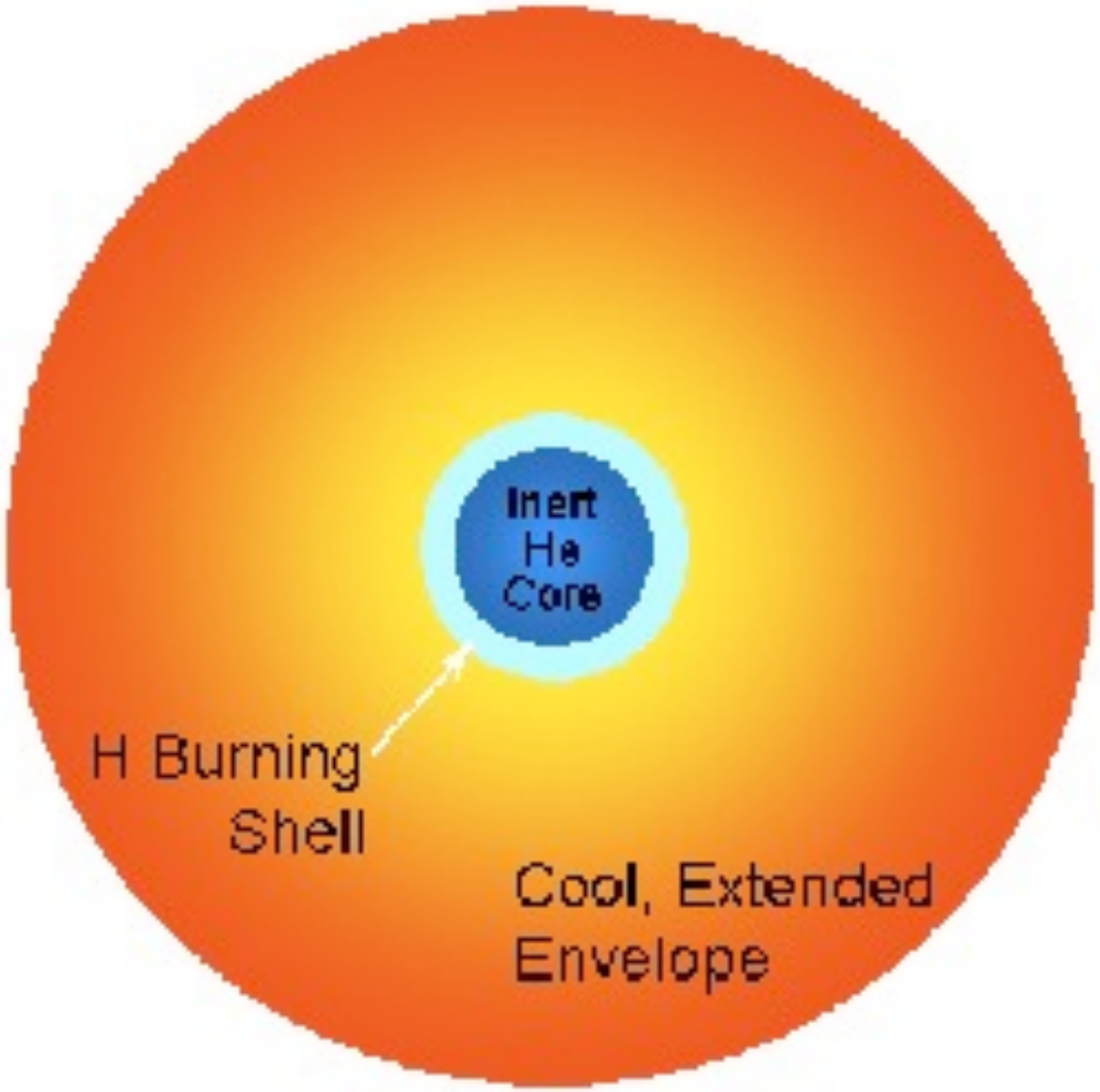
- very rapid: ignites in ~few min



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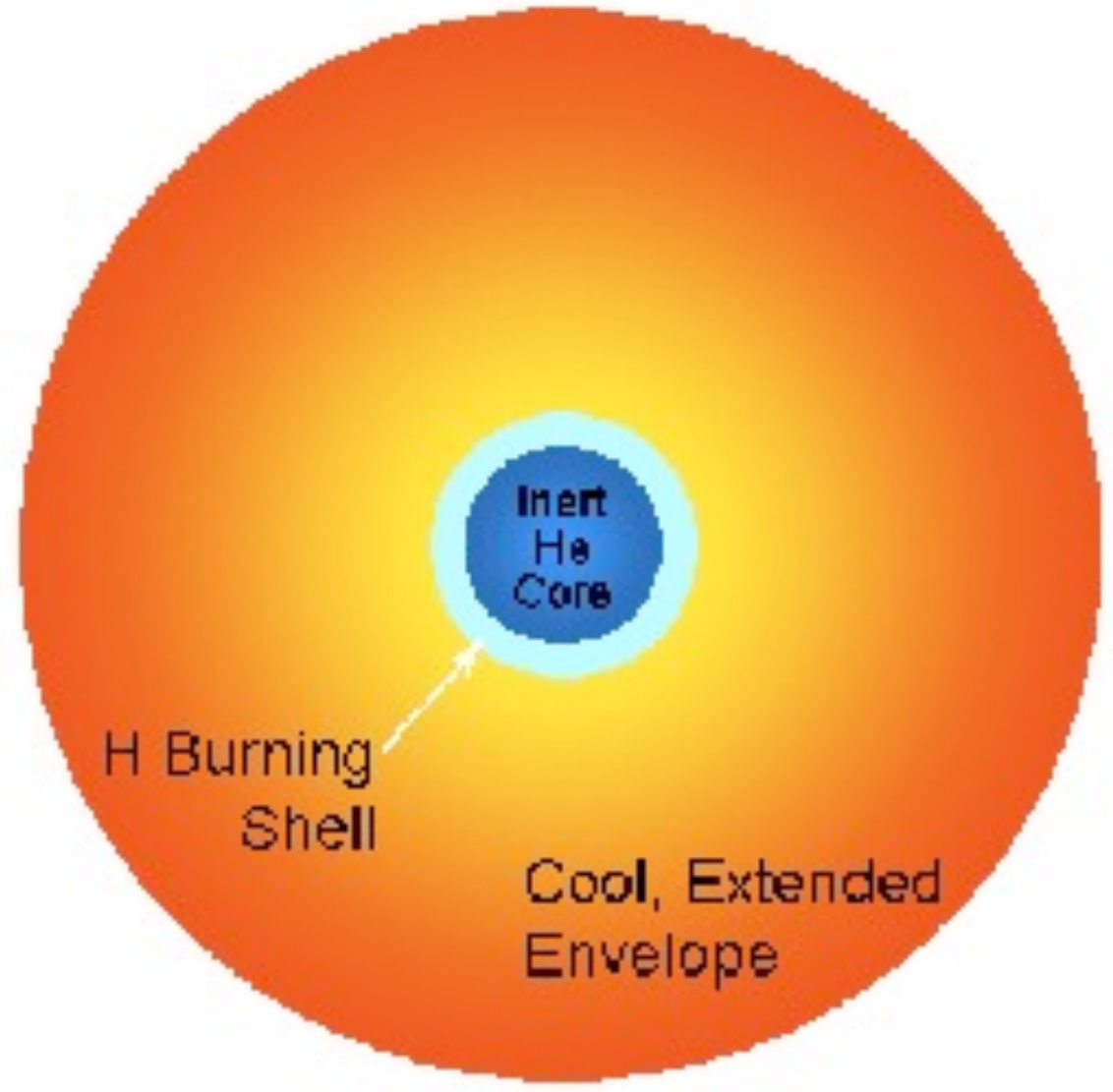

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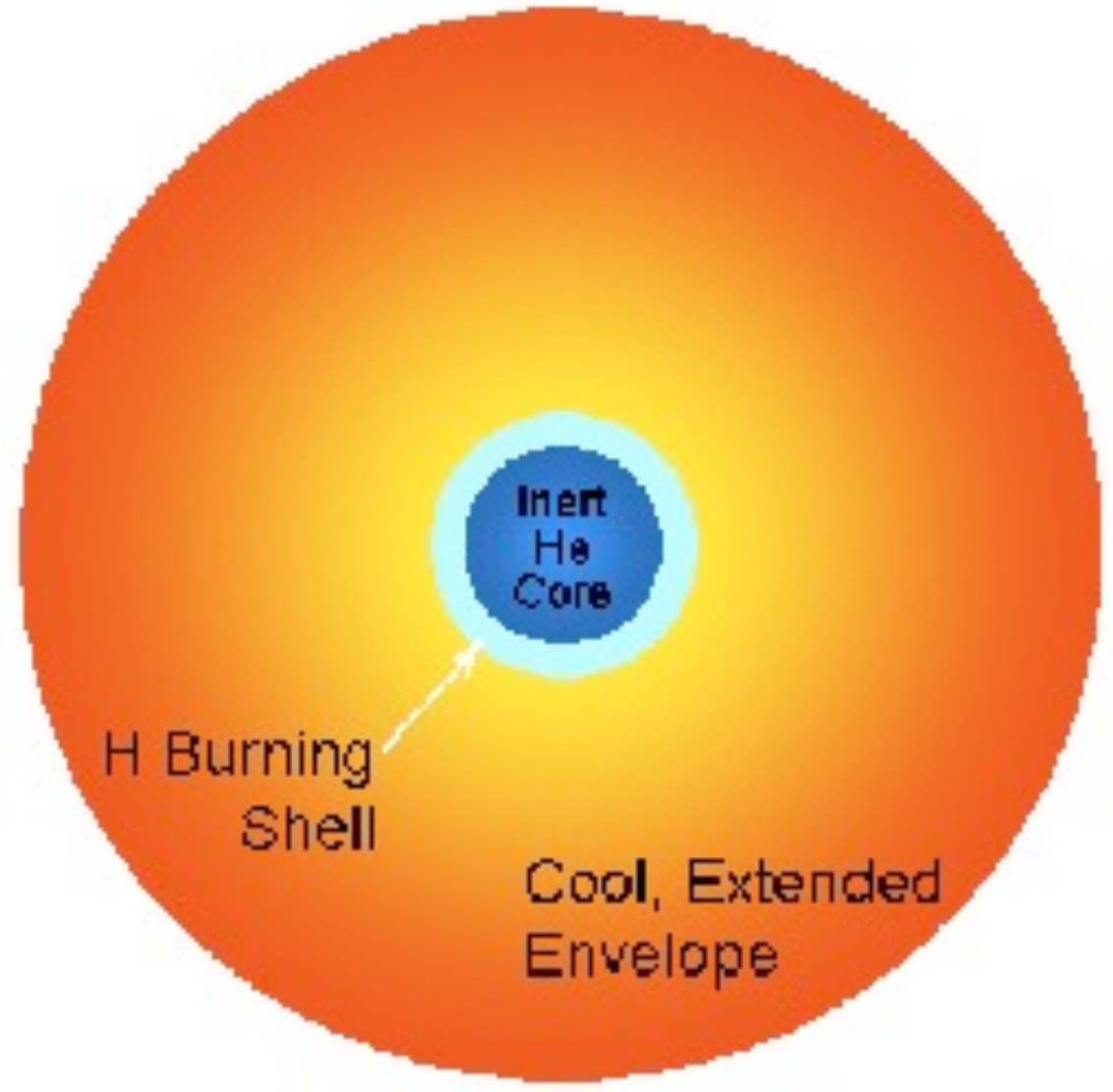

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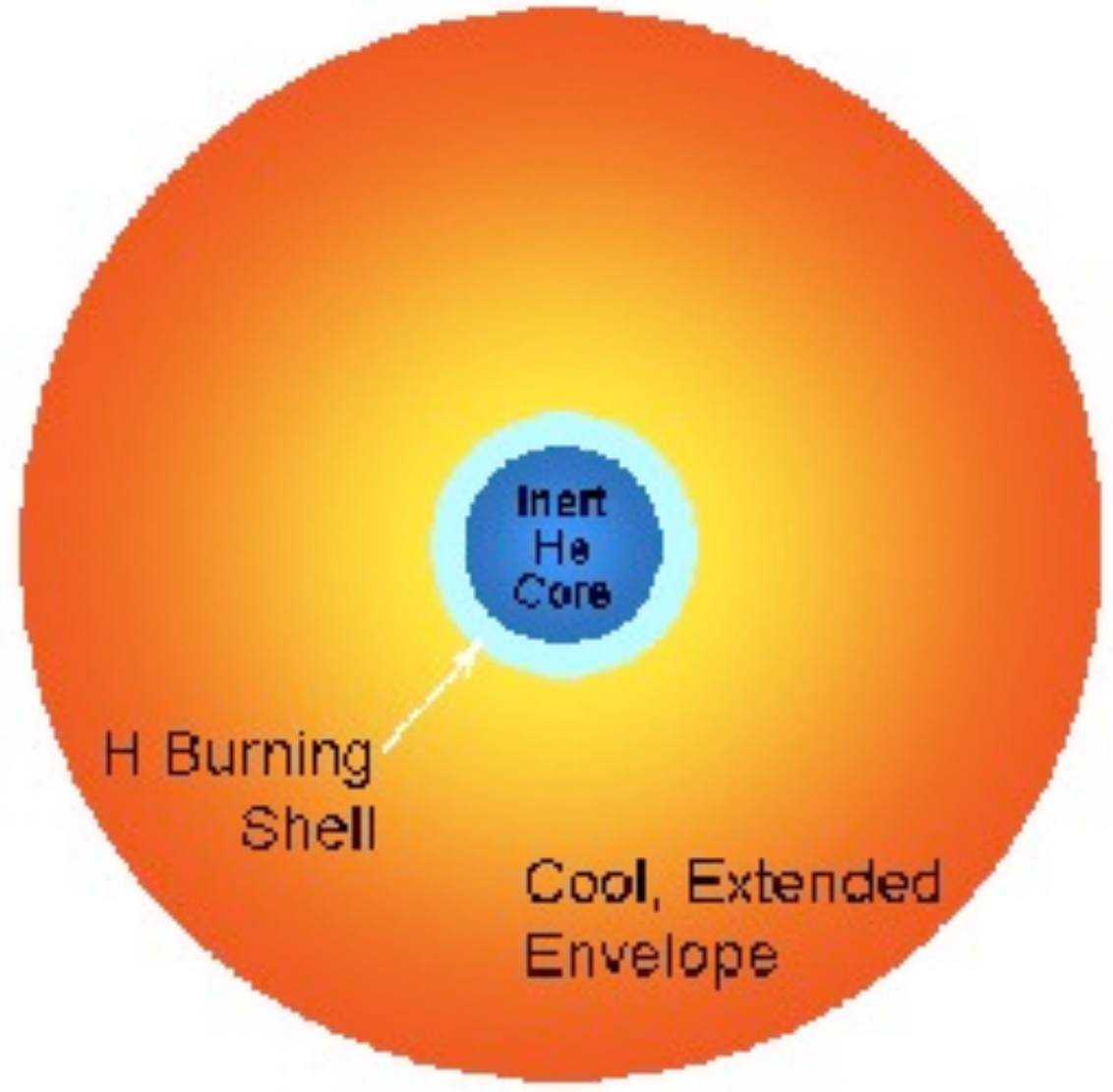
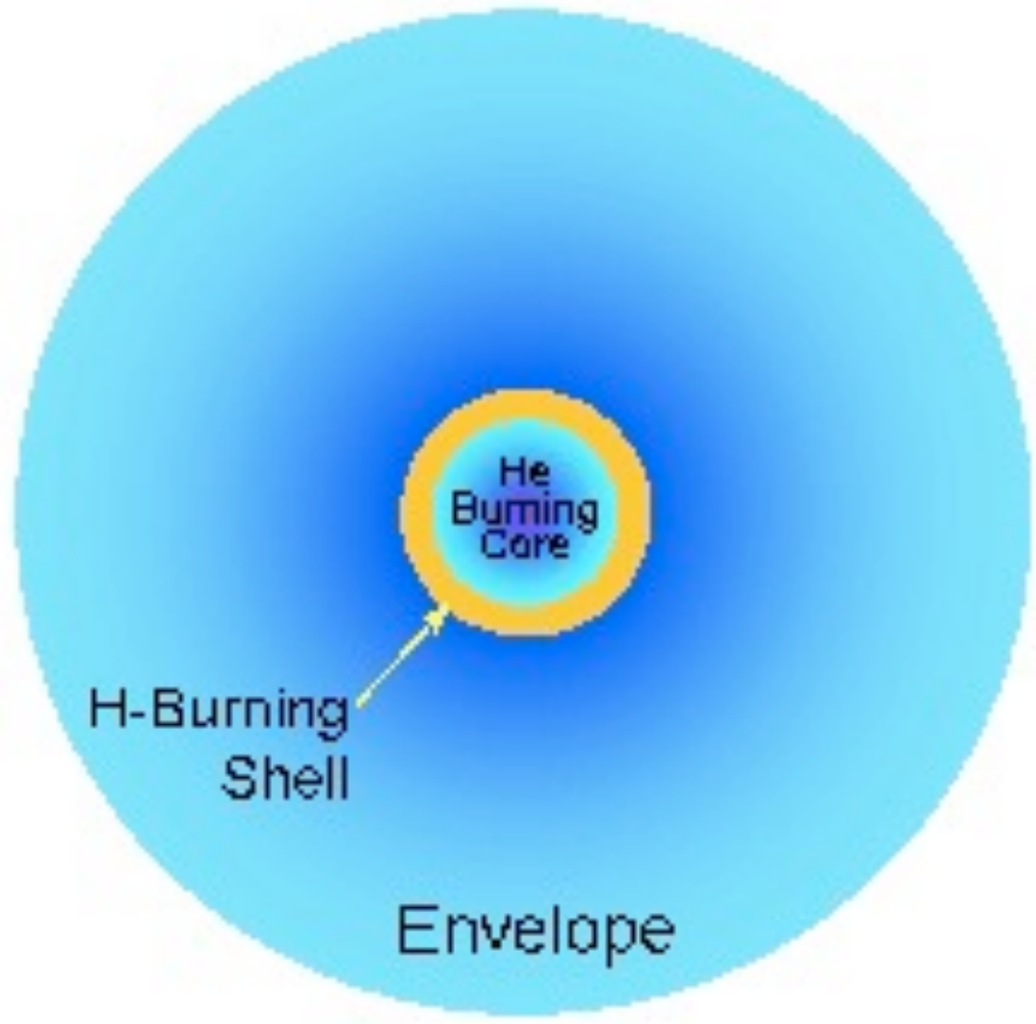
- During time of explosion, as much energy released as all of the rest of the stars in the Galaxy.
- Core turns normal and it calms

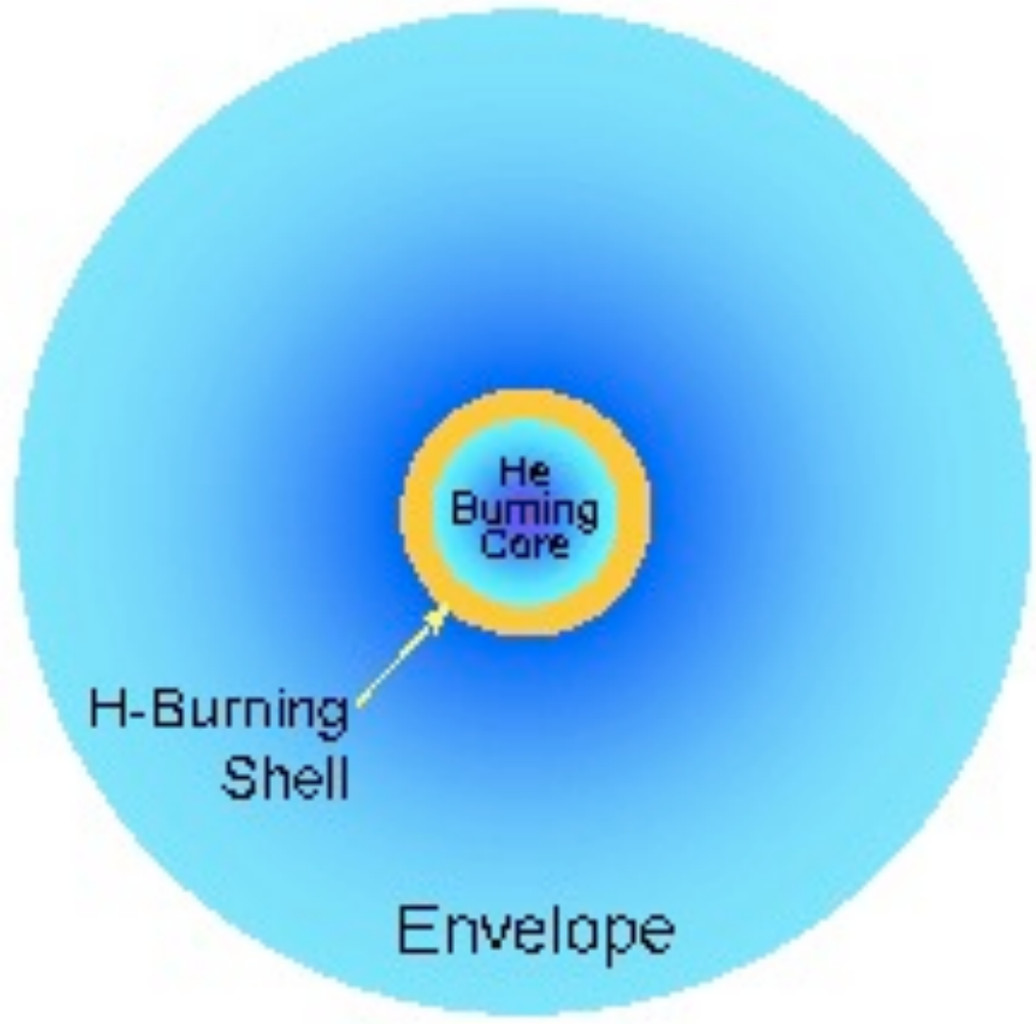


The Horizontal Branch



The Horizontal Branch

- Stars in helium burning phase:
  - "horizontal branch"



The Horizontal Branch

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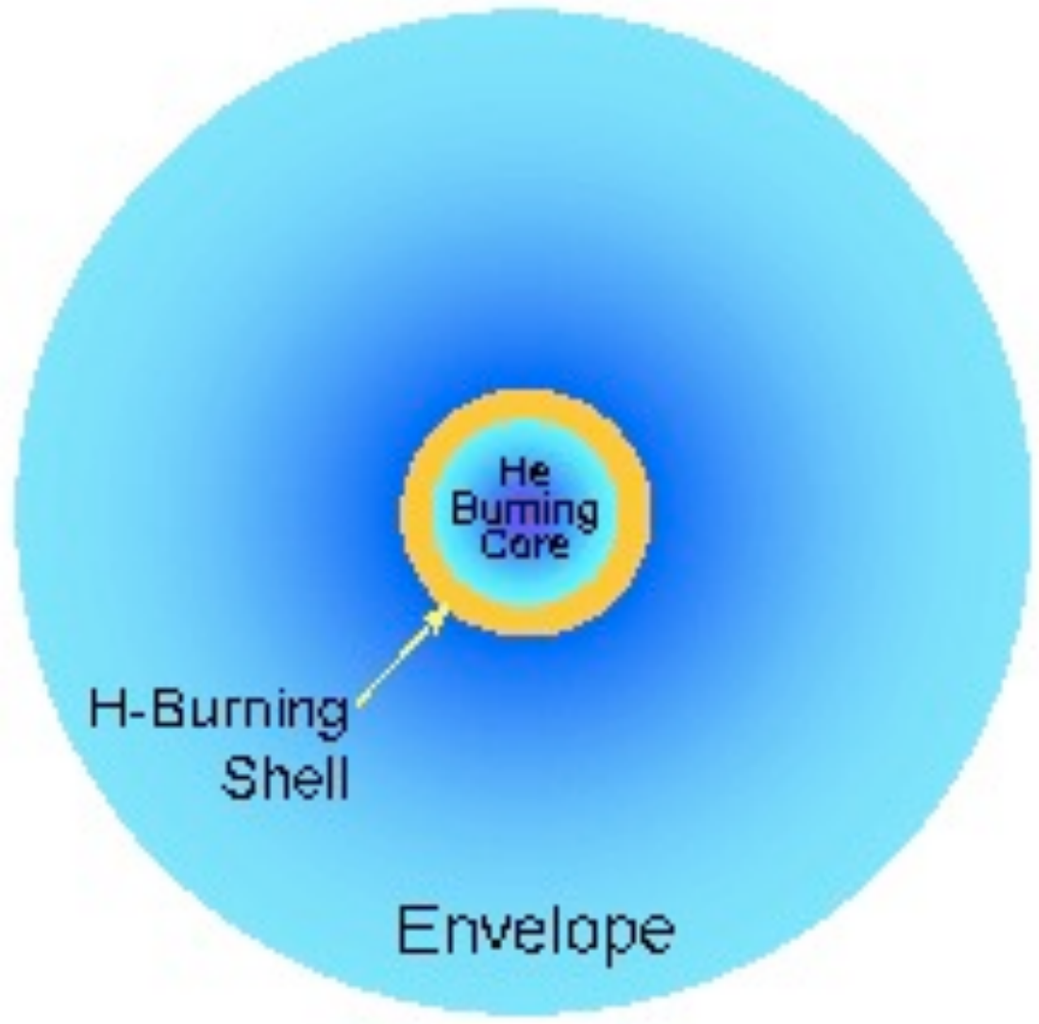
  - but destabilizes outer layers!



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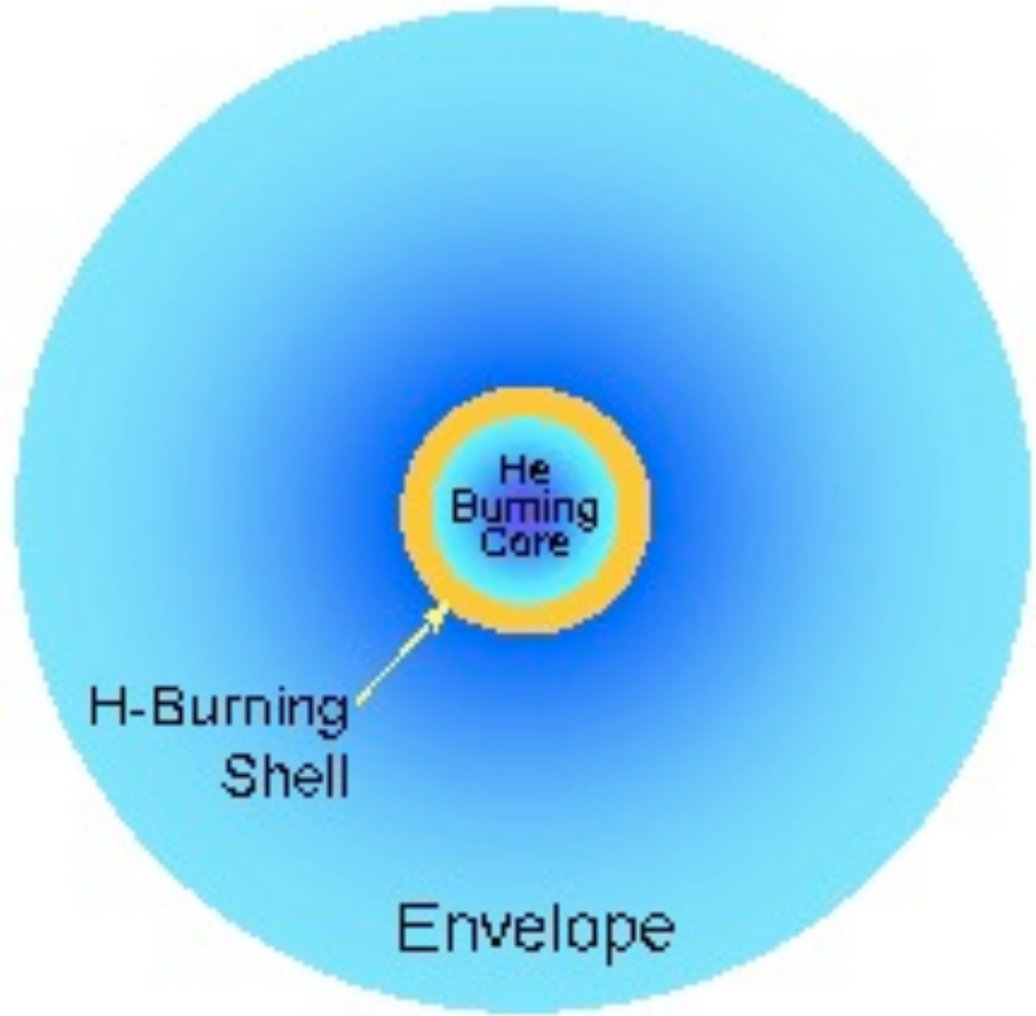
- The outer envelope shrinks, heats up, and dims slightly



The Horizontal Branch

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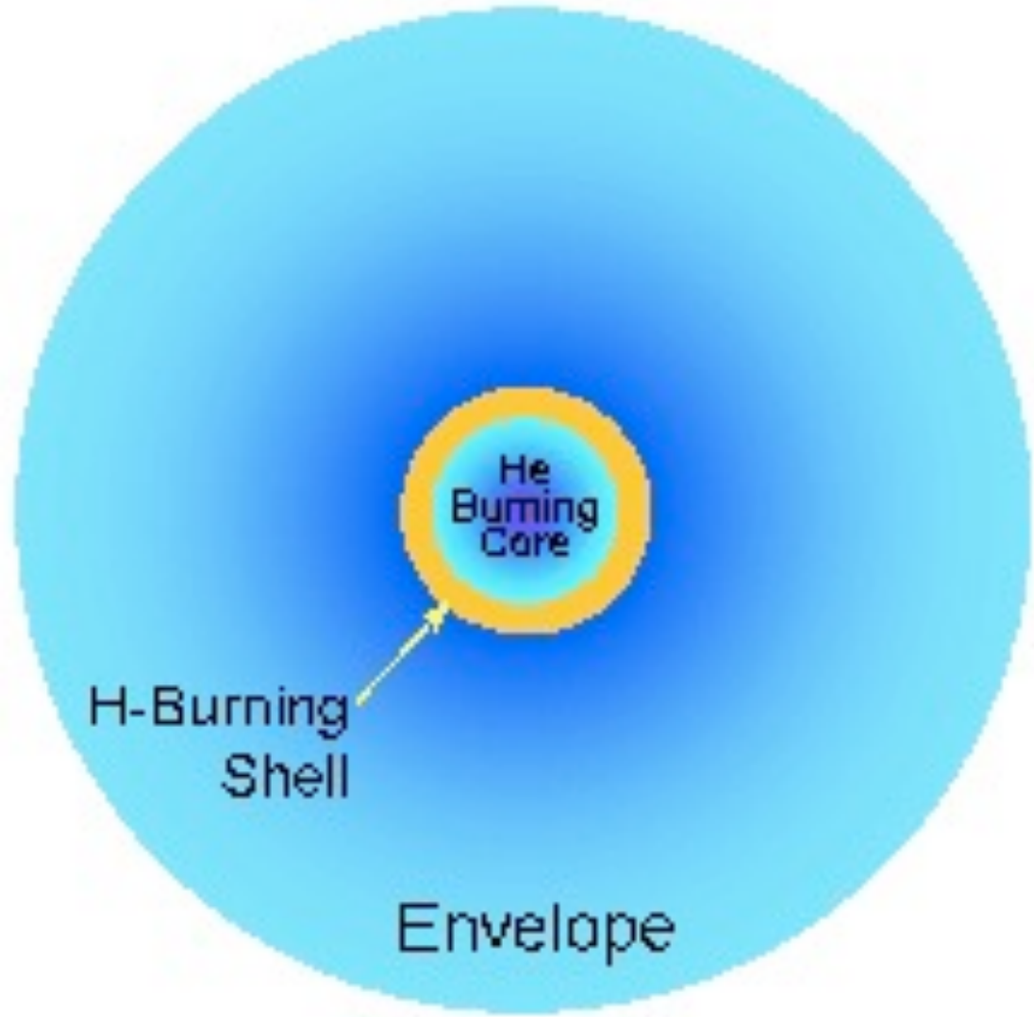
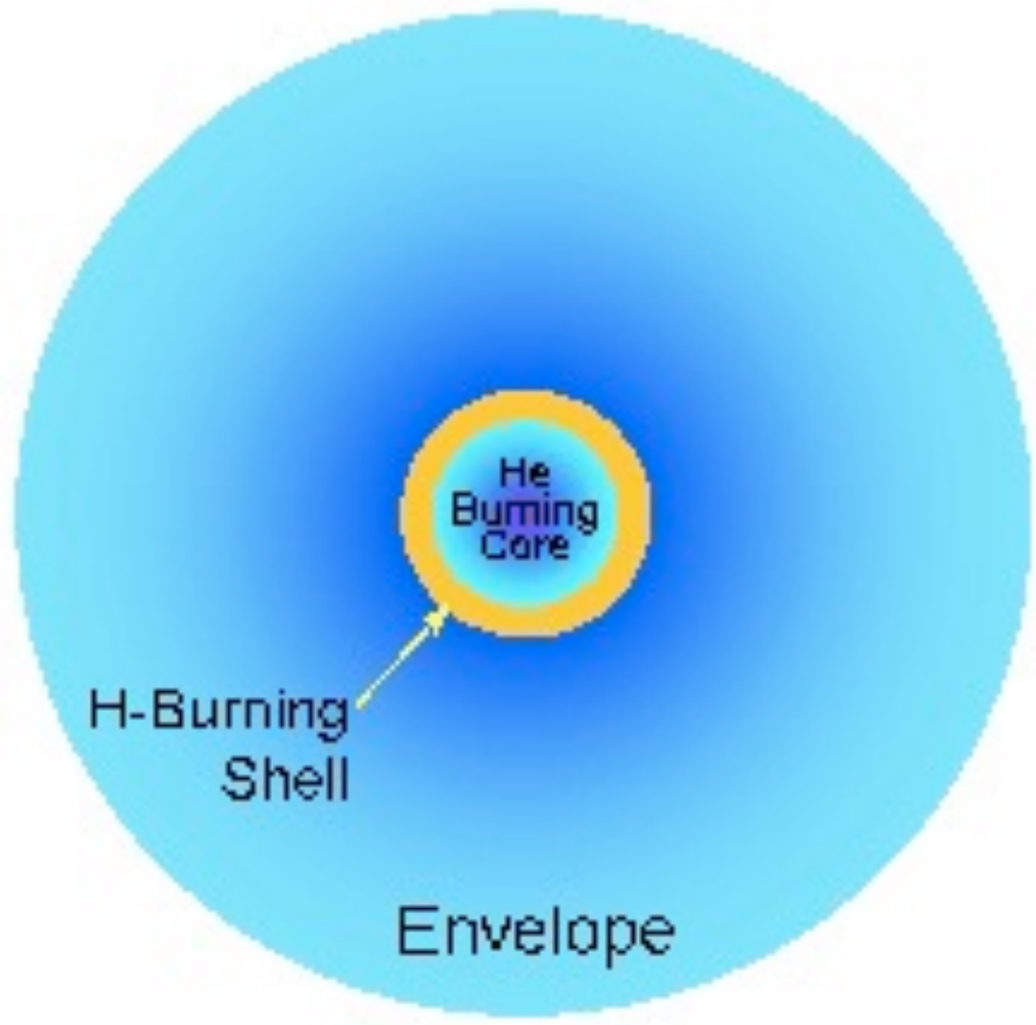
  - "horizontal branch"
- Helium burning stabilizes the core
  - but destabilizes outer layers!
- The outer envelope shrinks, heats up, and dims slightly
- But helium doesn't last very long as a fuel
  - Horizontal branch lifetime is only about 10% that of a star's main sequence lifetime
  - Our Sun will burn helium for about a billion years

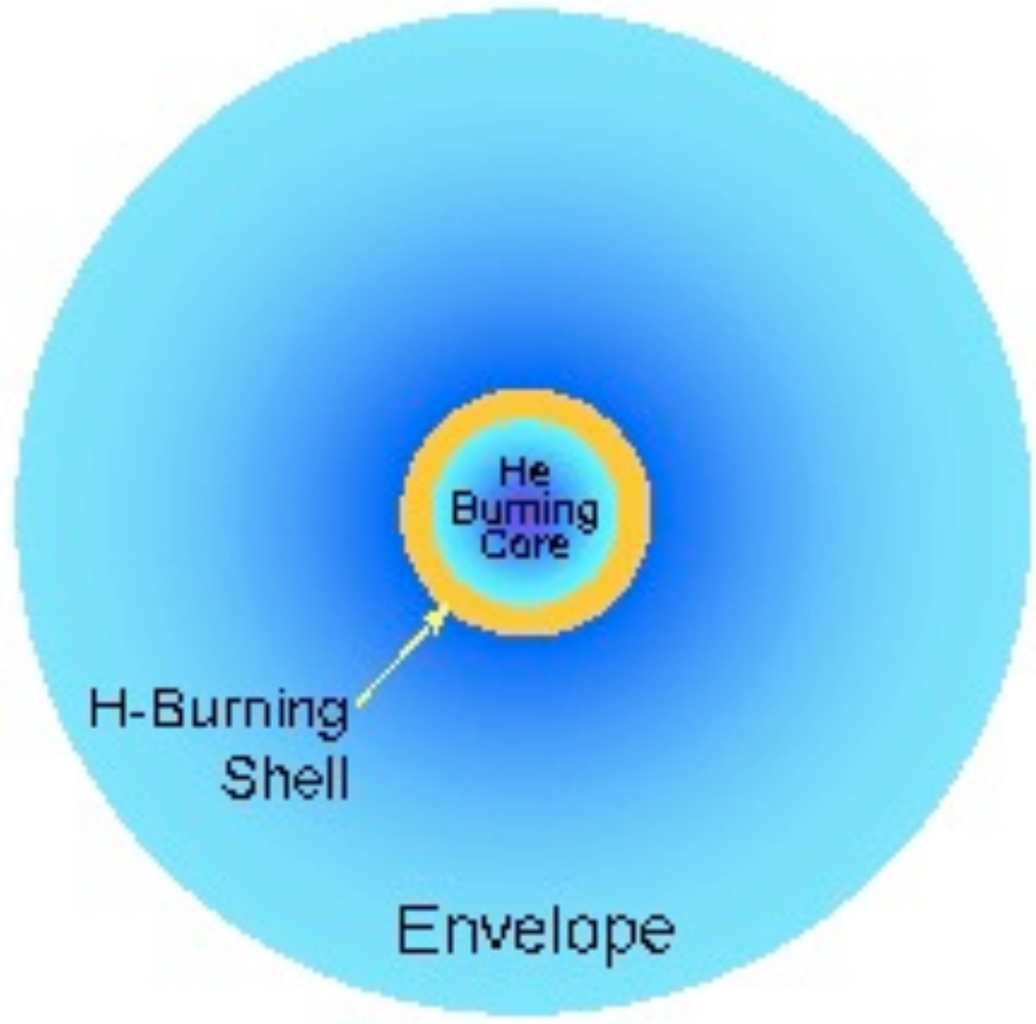


Mitigation



Mitigation

- Horizontal branch luminosity lower
  - solar system temperatures drop
  - habitable zone moves inward again



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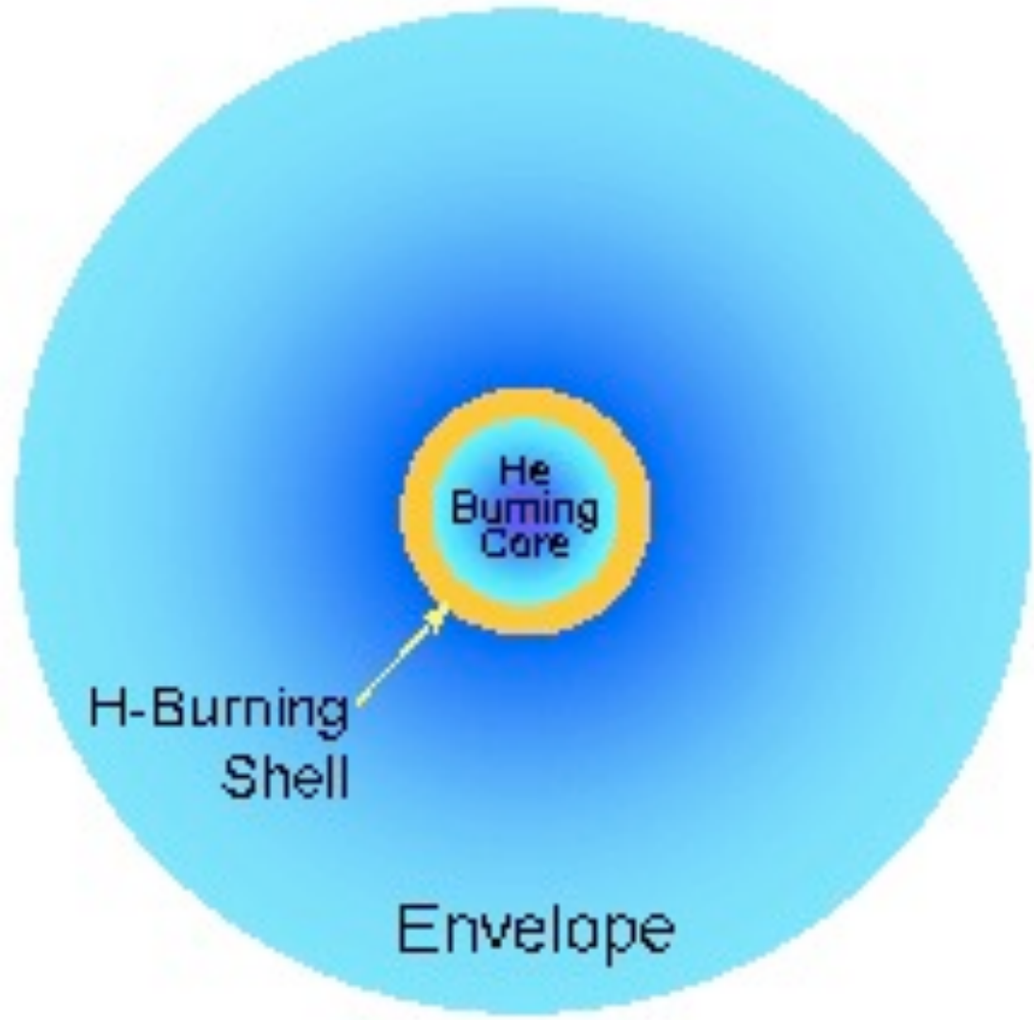

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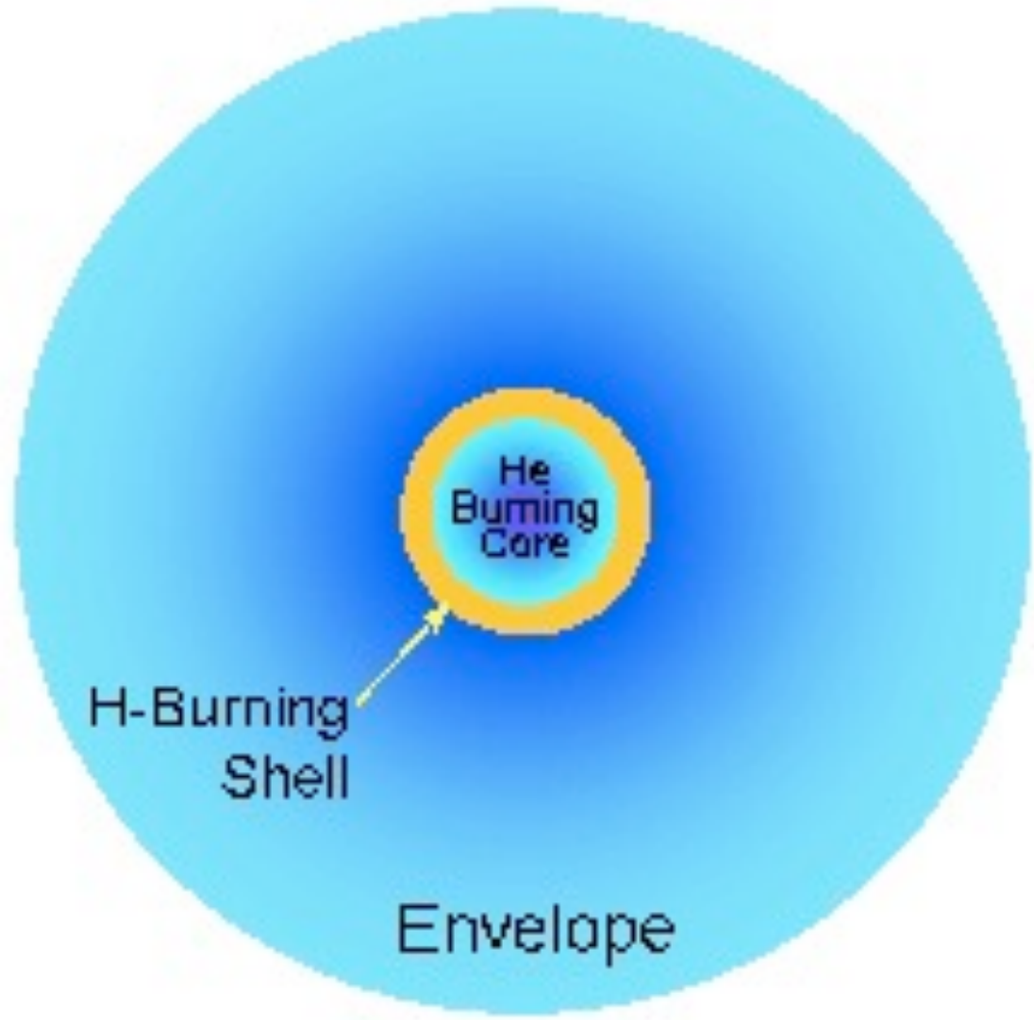

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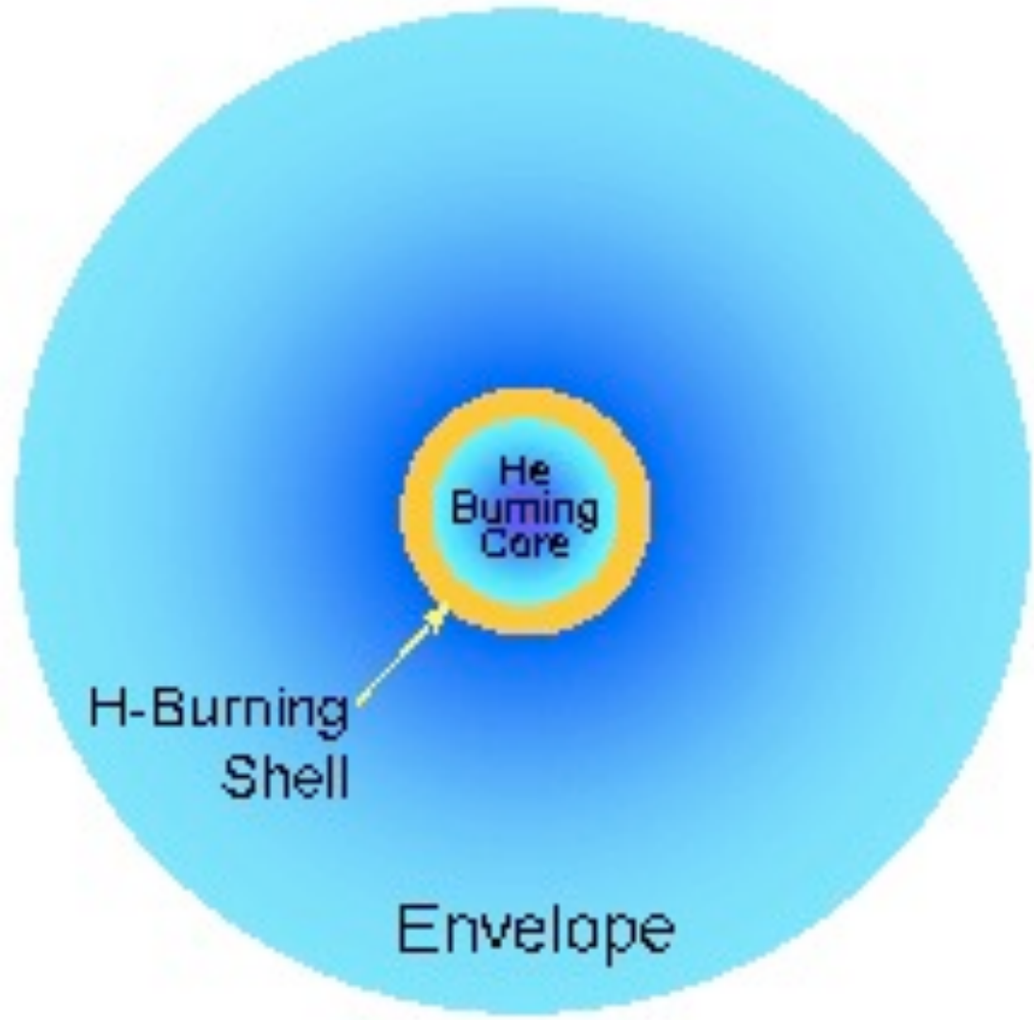

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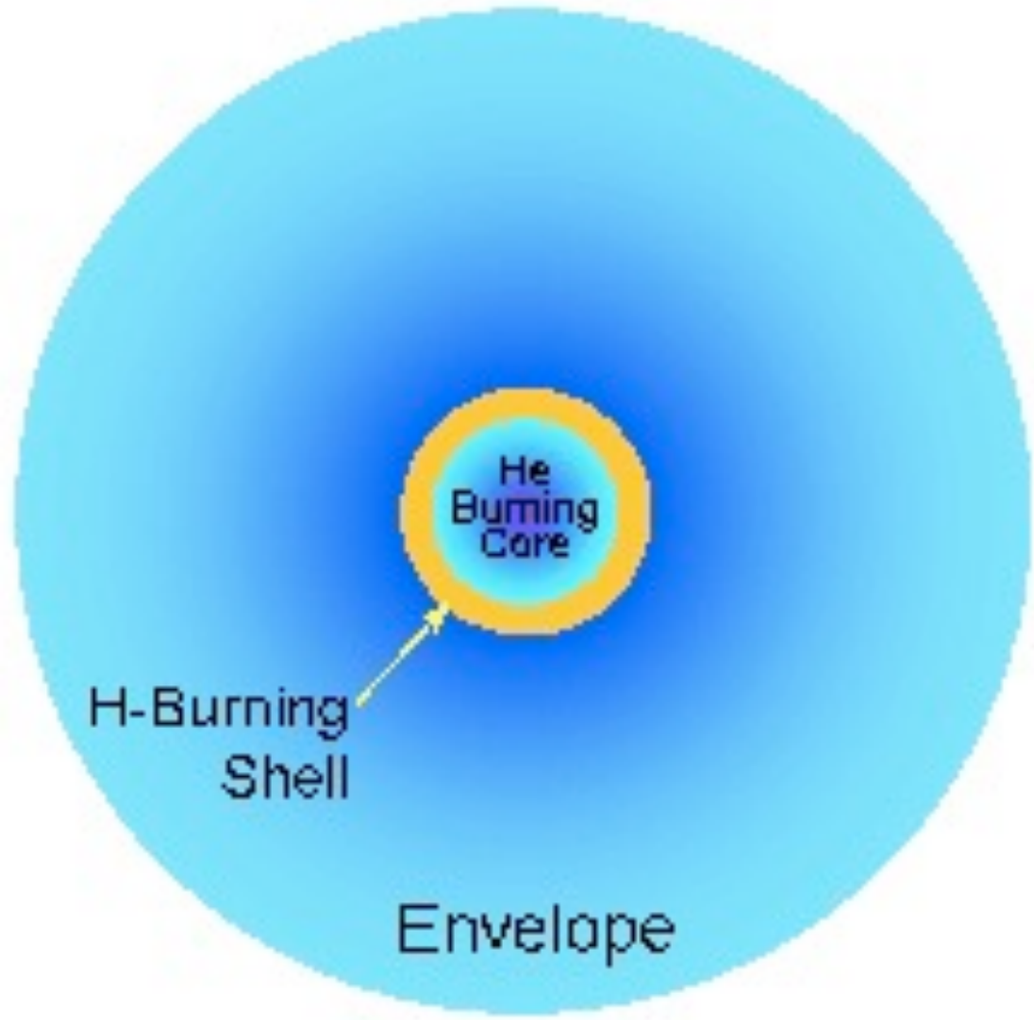
- But our descendants have less time to figure this out, as the change is faster.
- Need to move back in a few million years.



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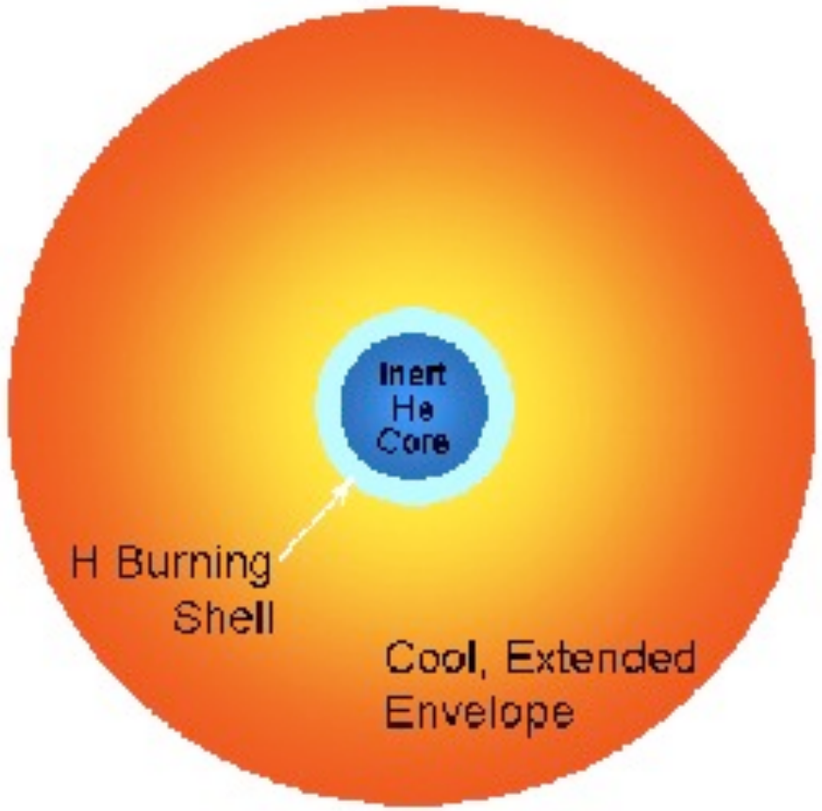

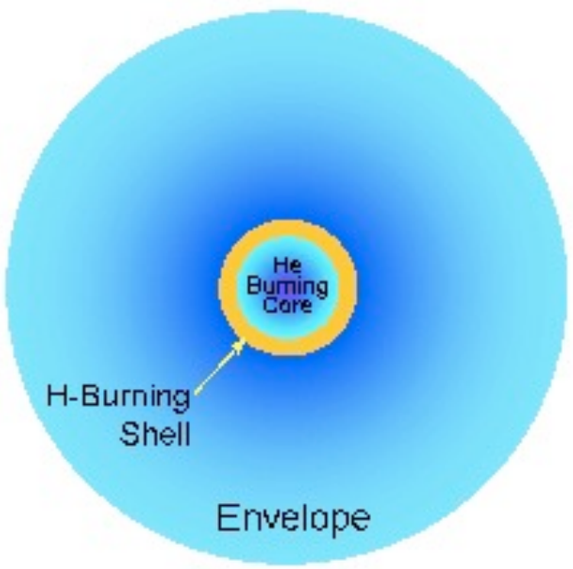

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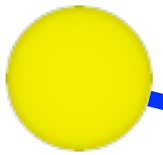

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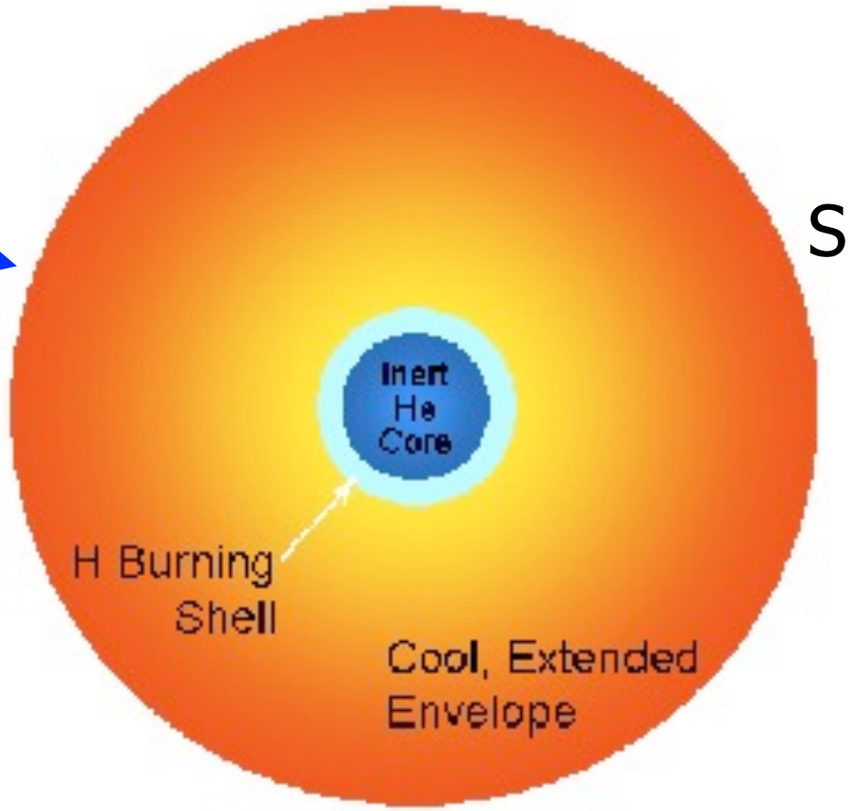

Red giant
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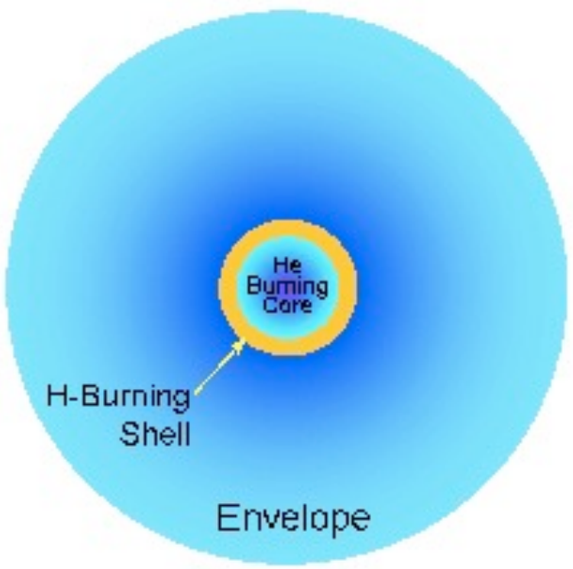

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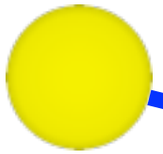

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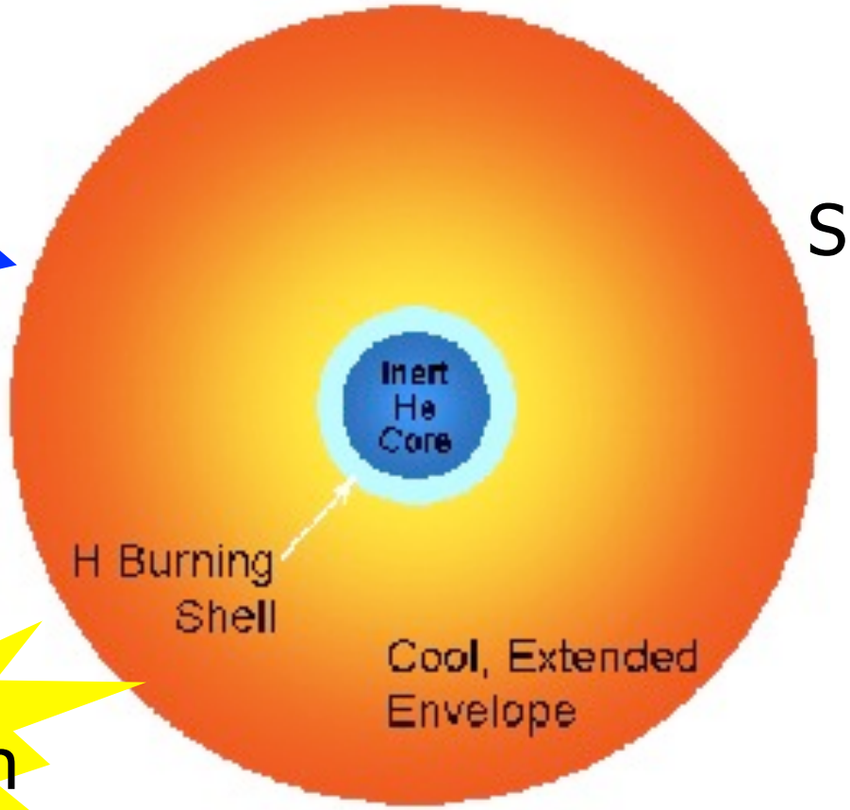

Red giant
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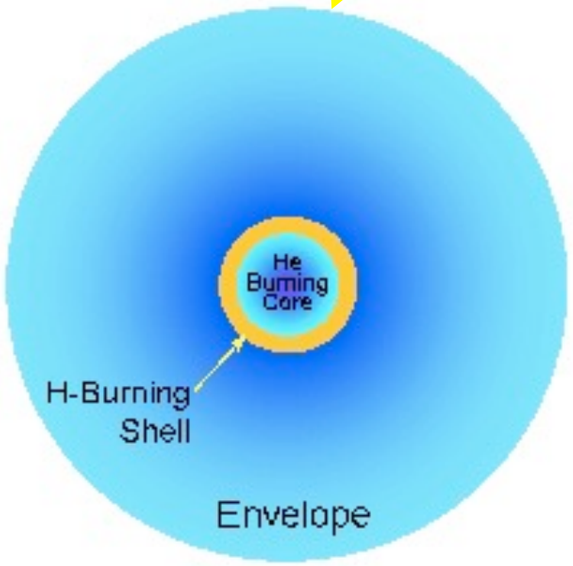
Helium flash



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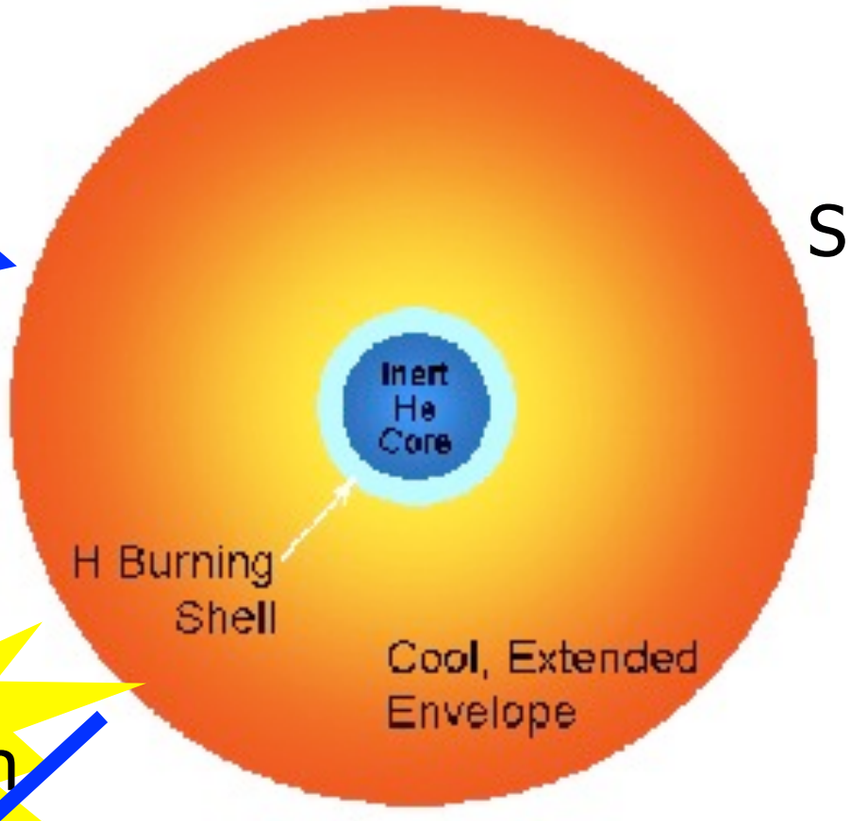
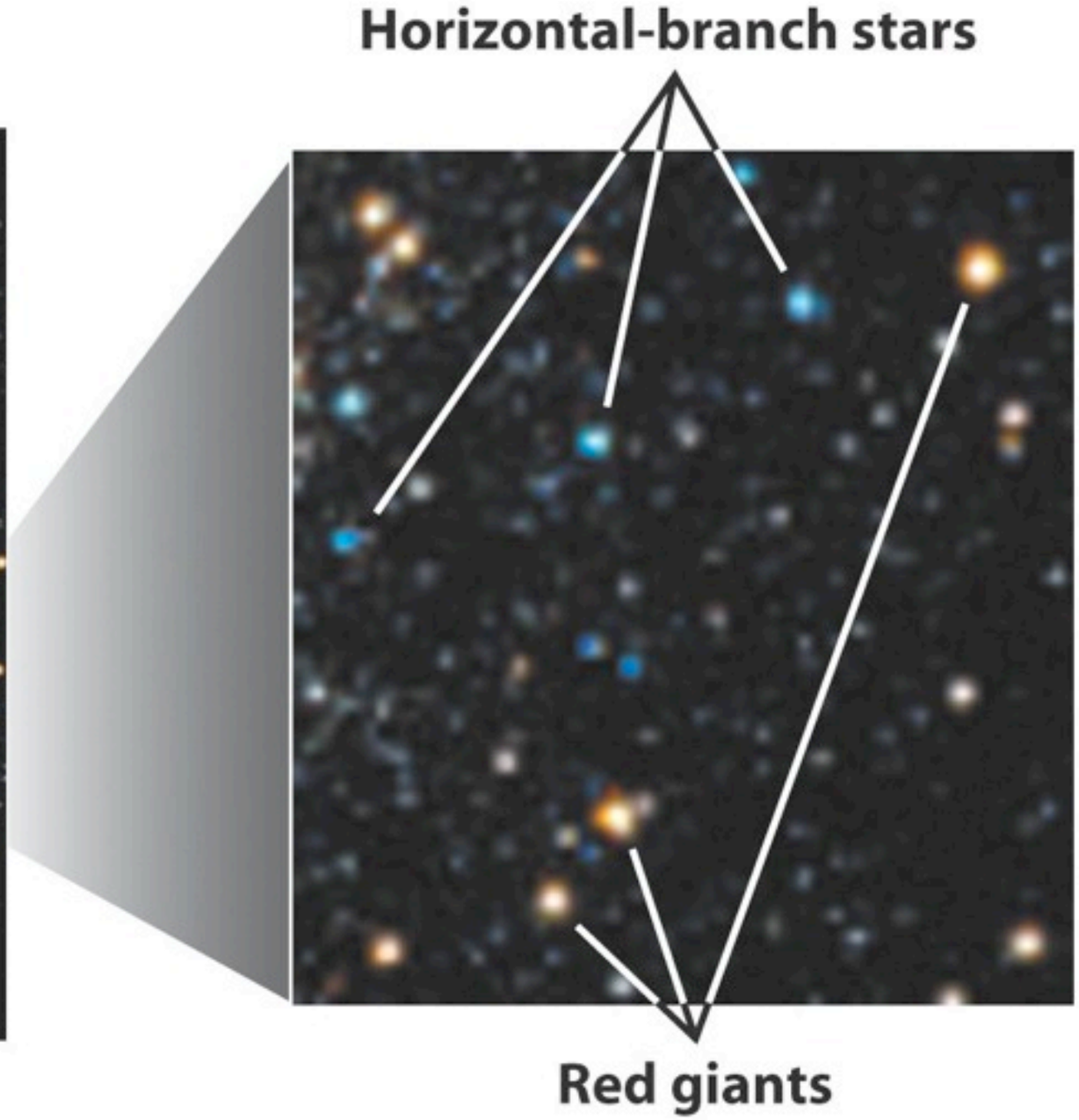


Red giant
Shell hydrogen
burning

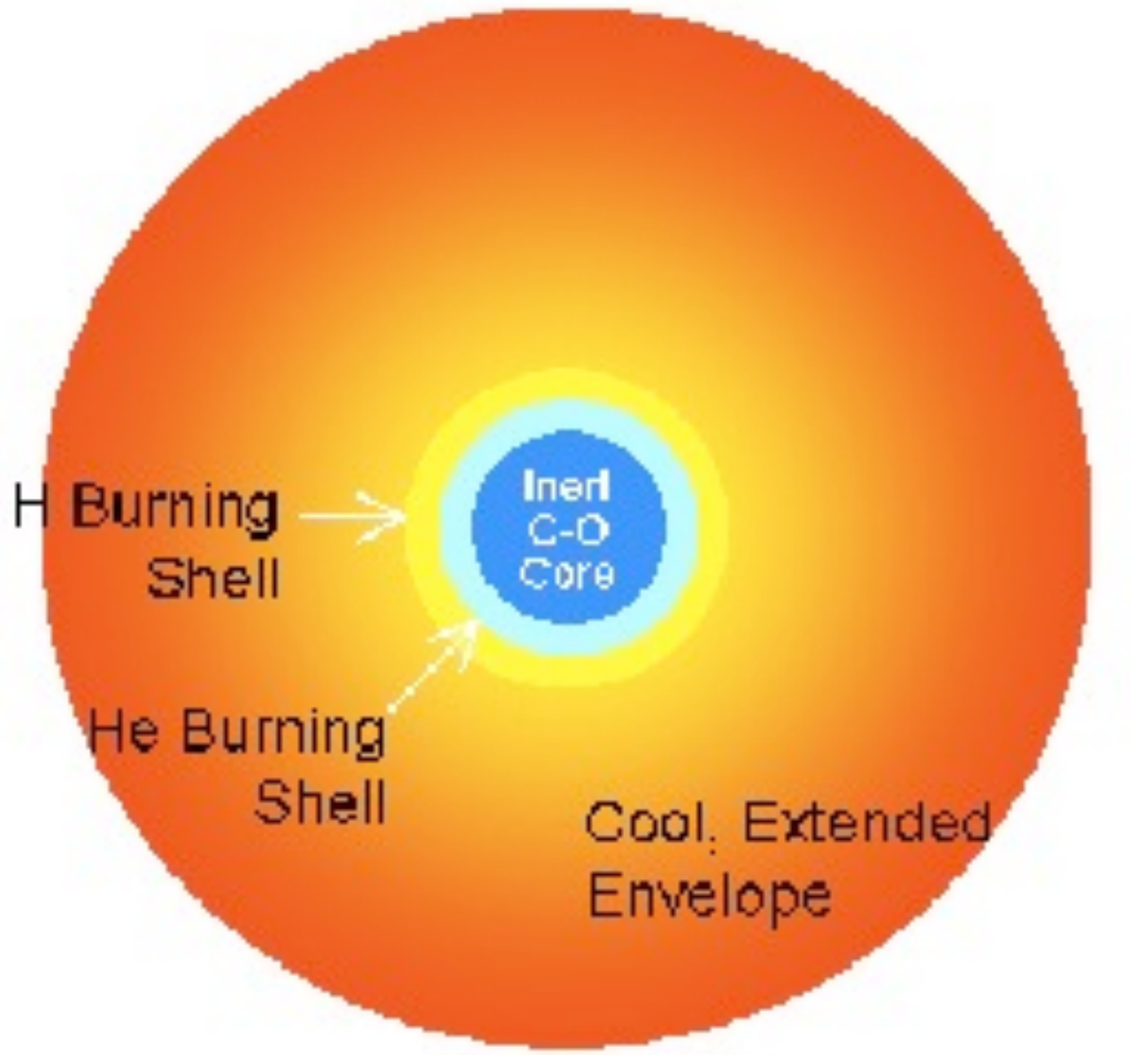
Helium flash

Horizontal brach
Core helium burning
T_{core} ~ 100 million K

Aging Stars



When Helium Runs Out…
7.8 Billion Years from Now



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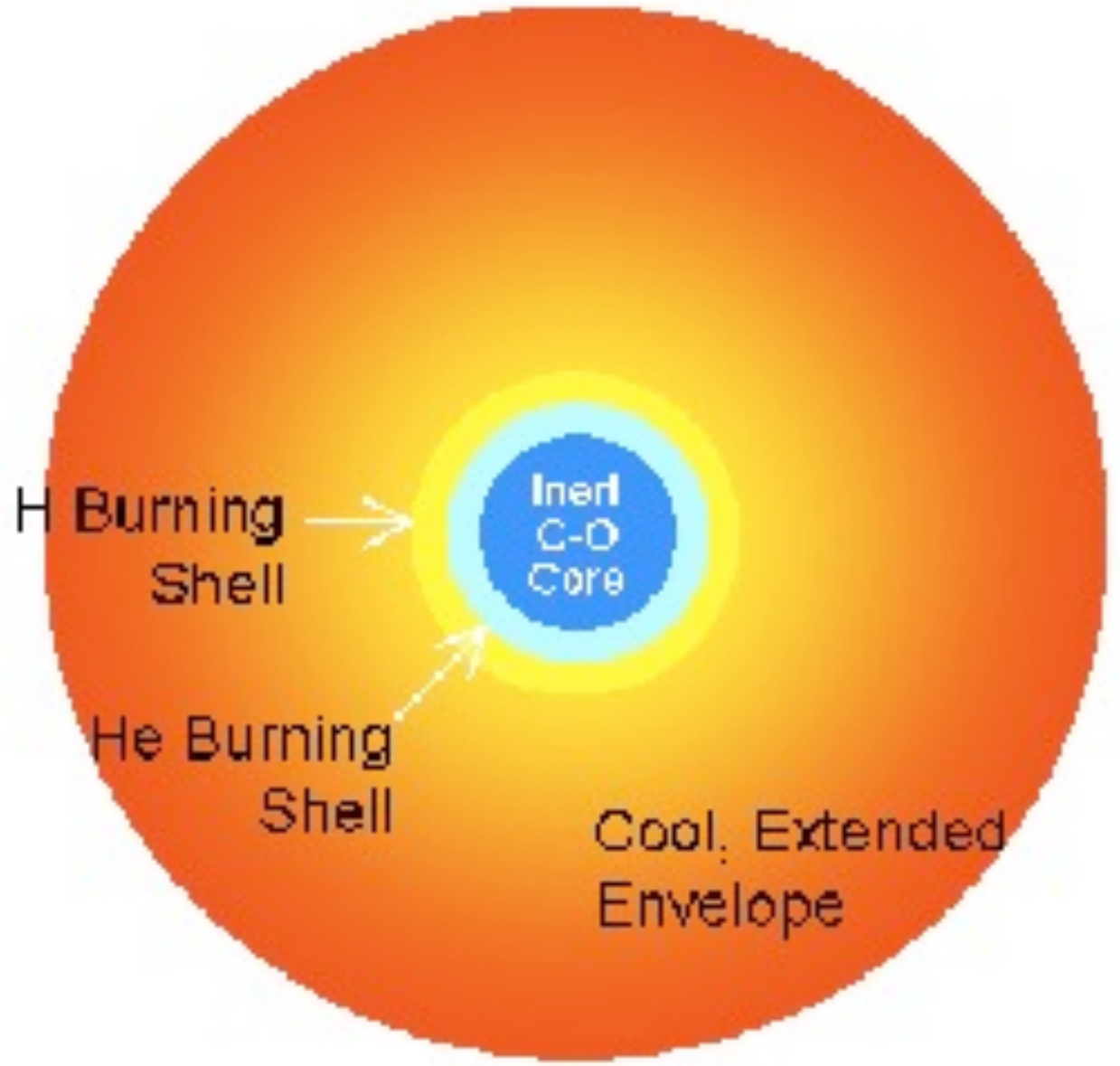

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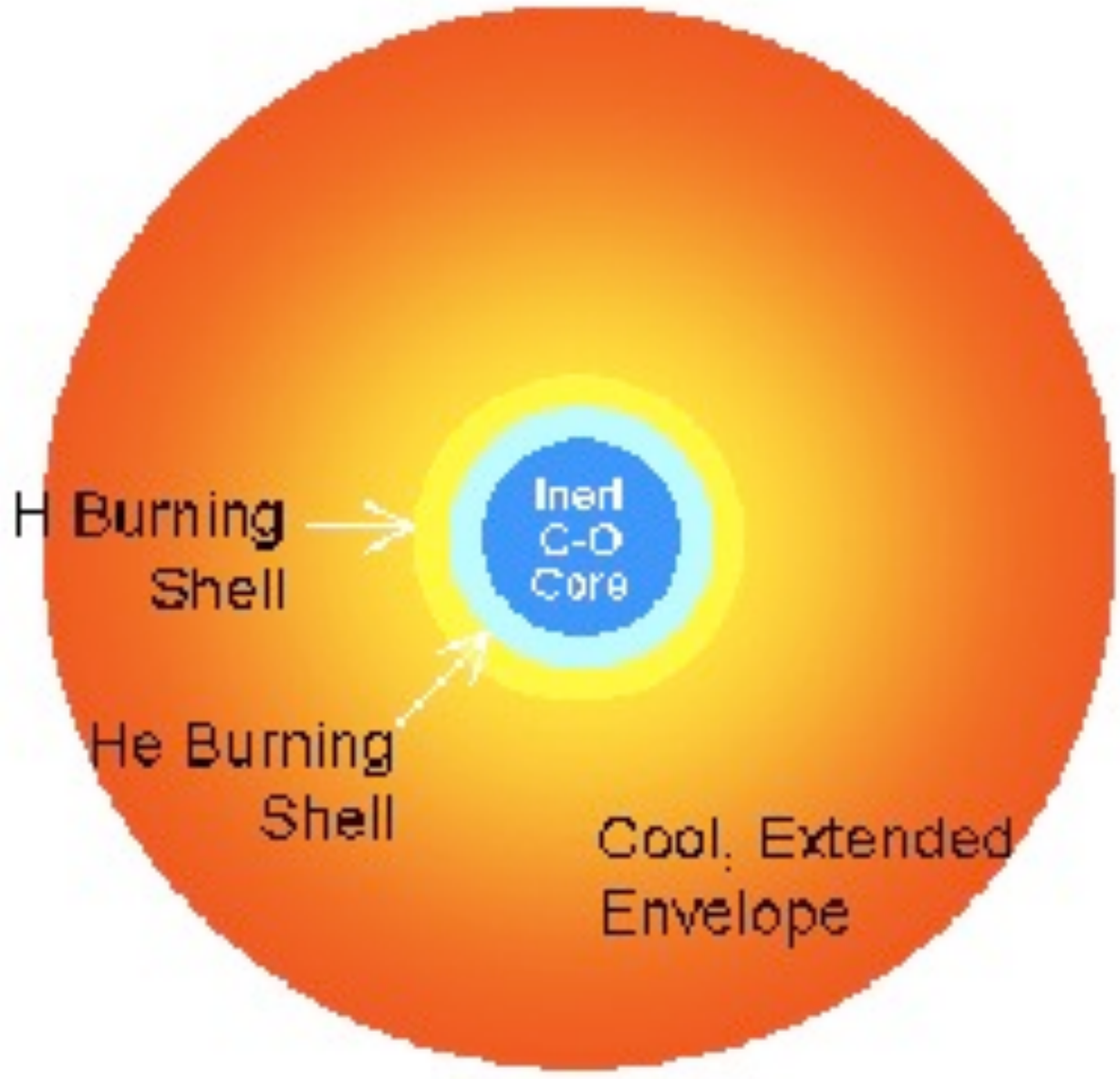

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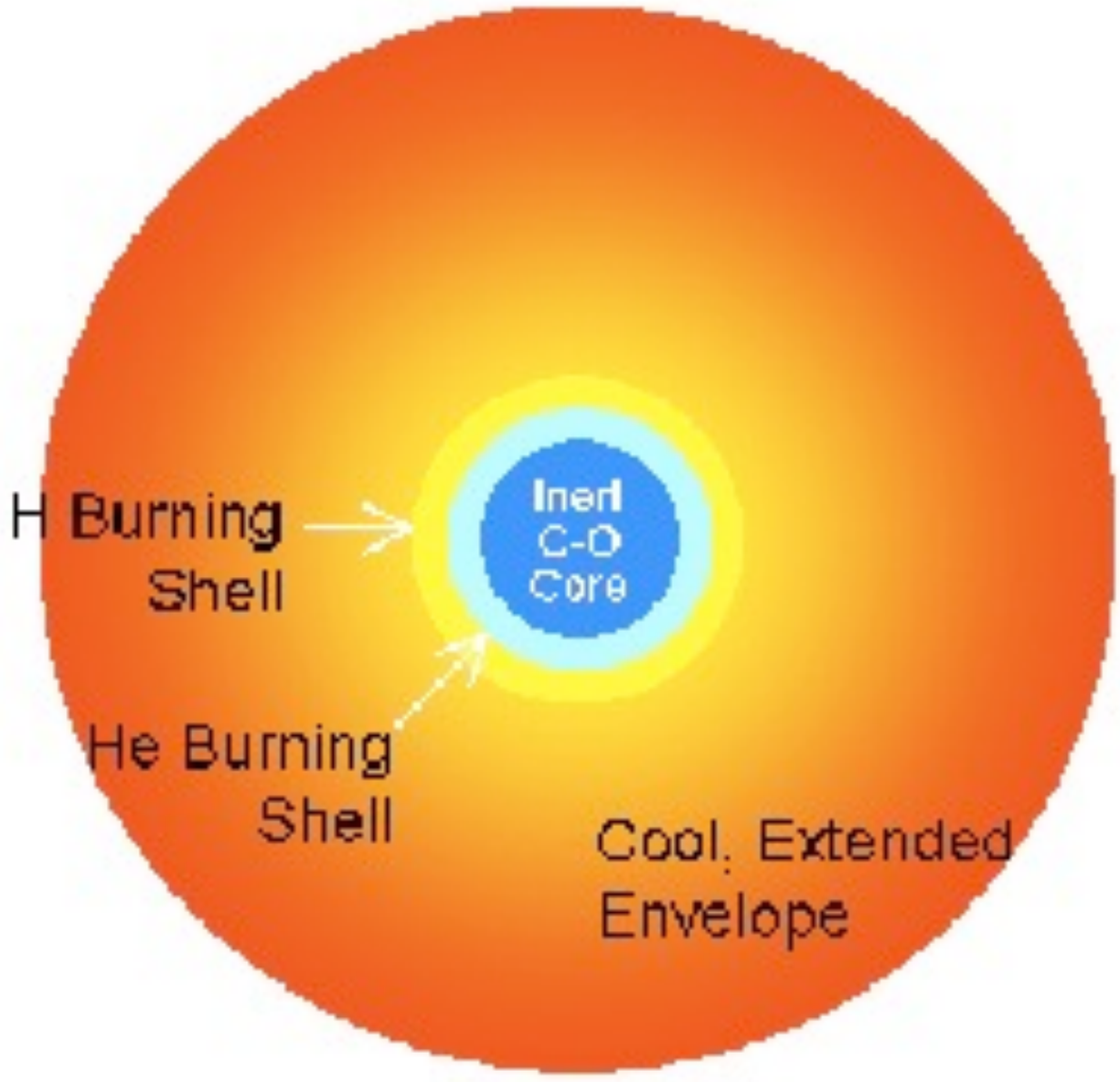

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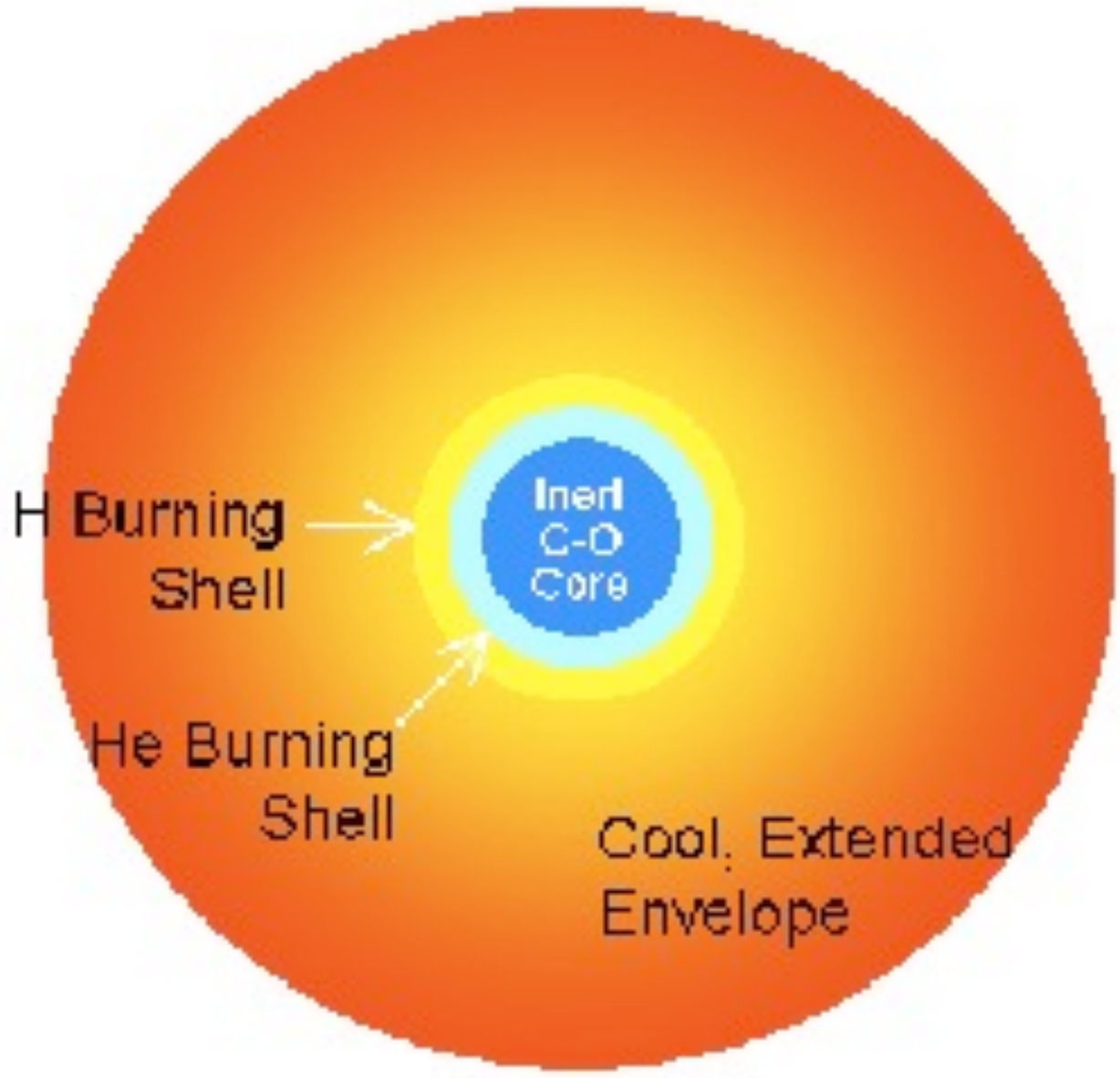

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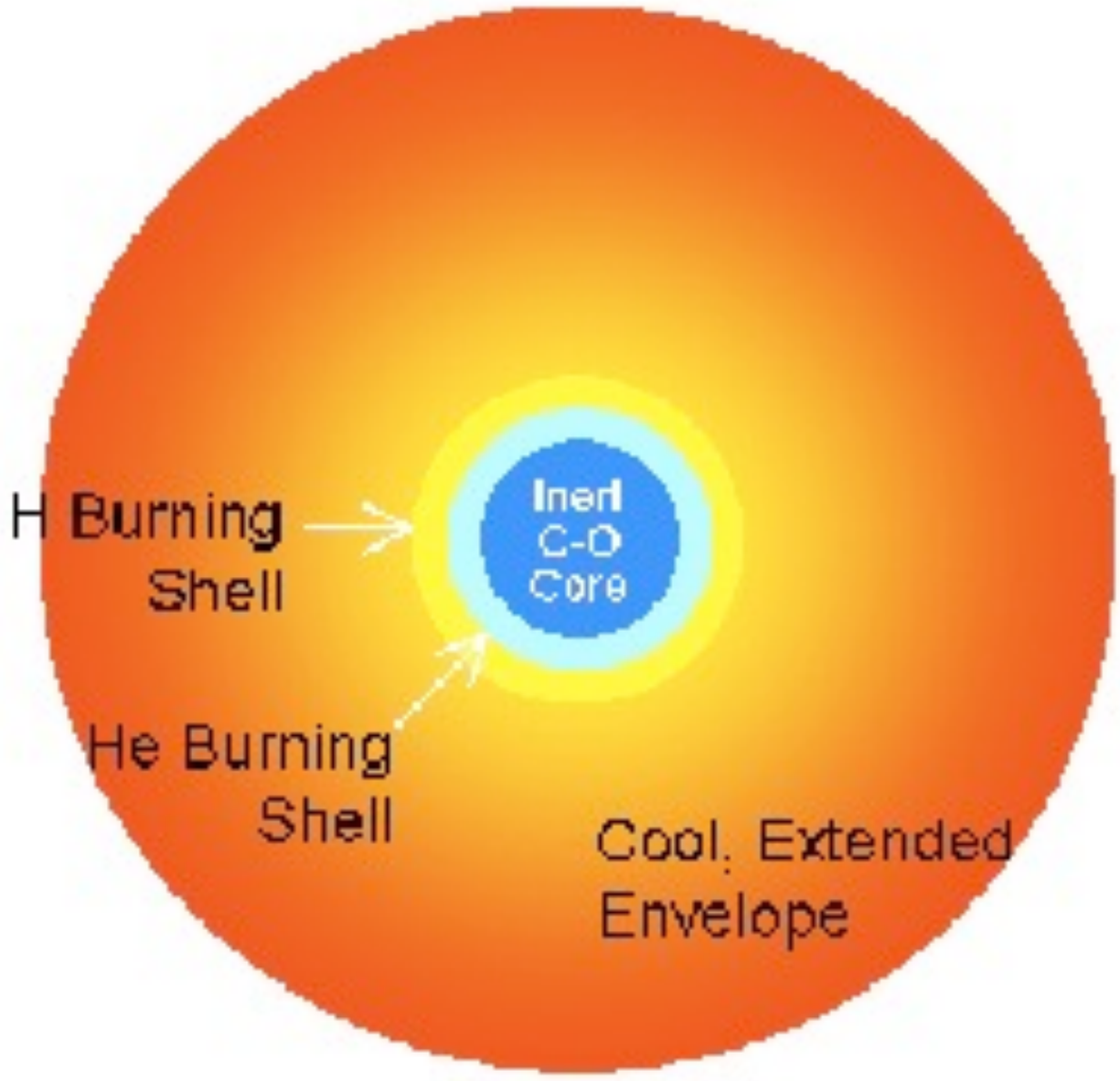

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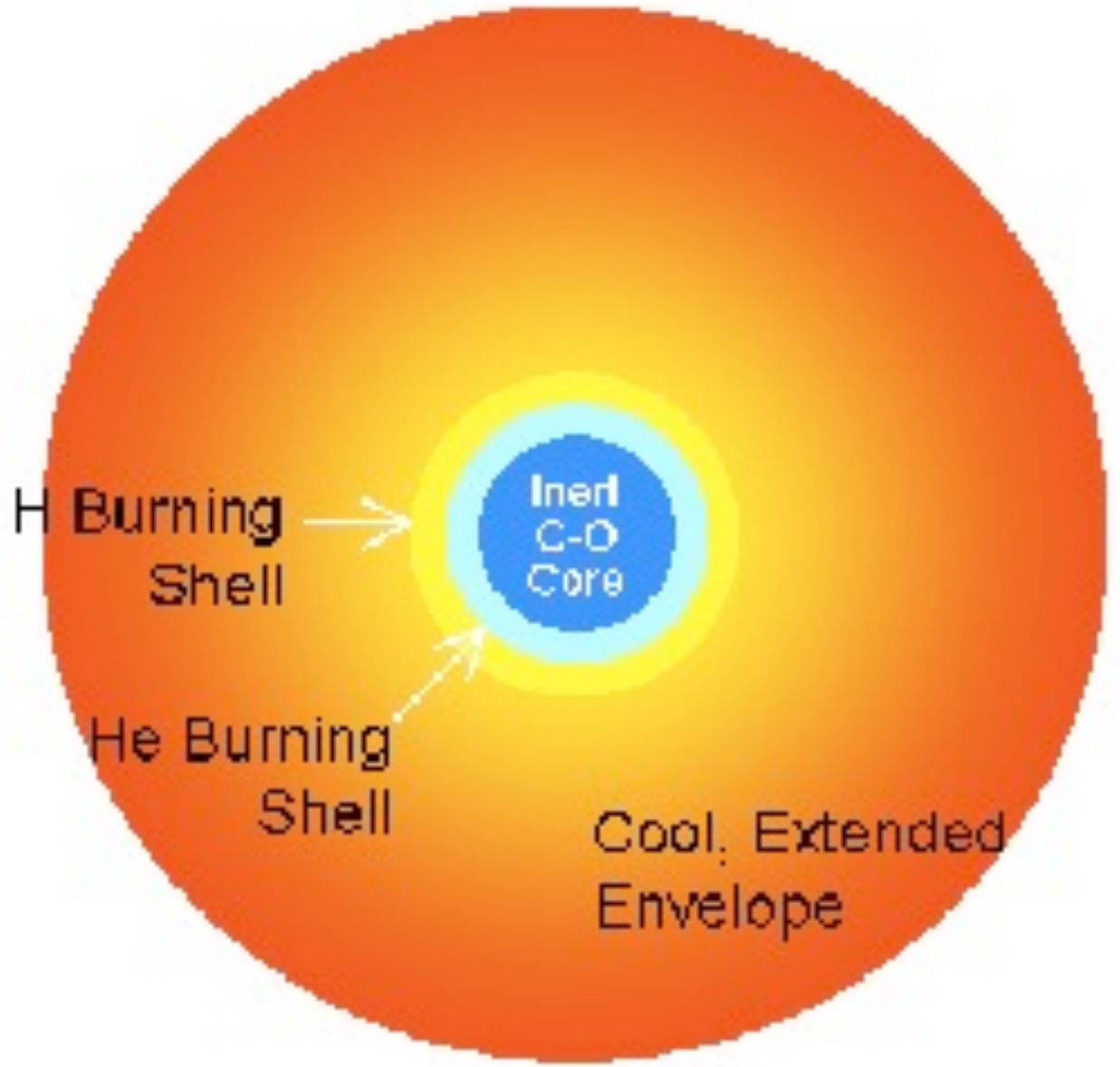

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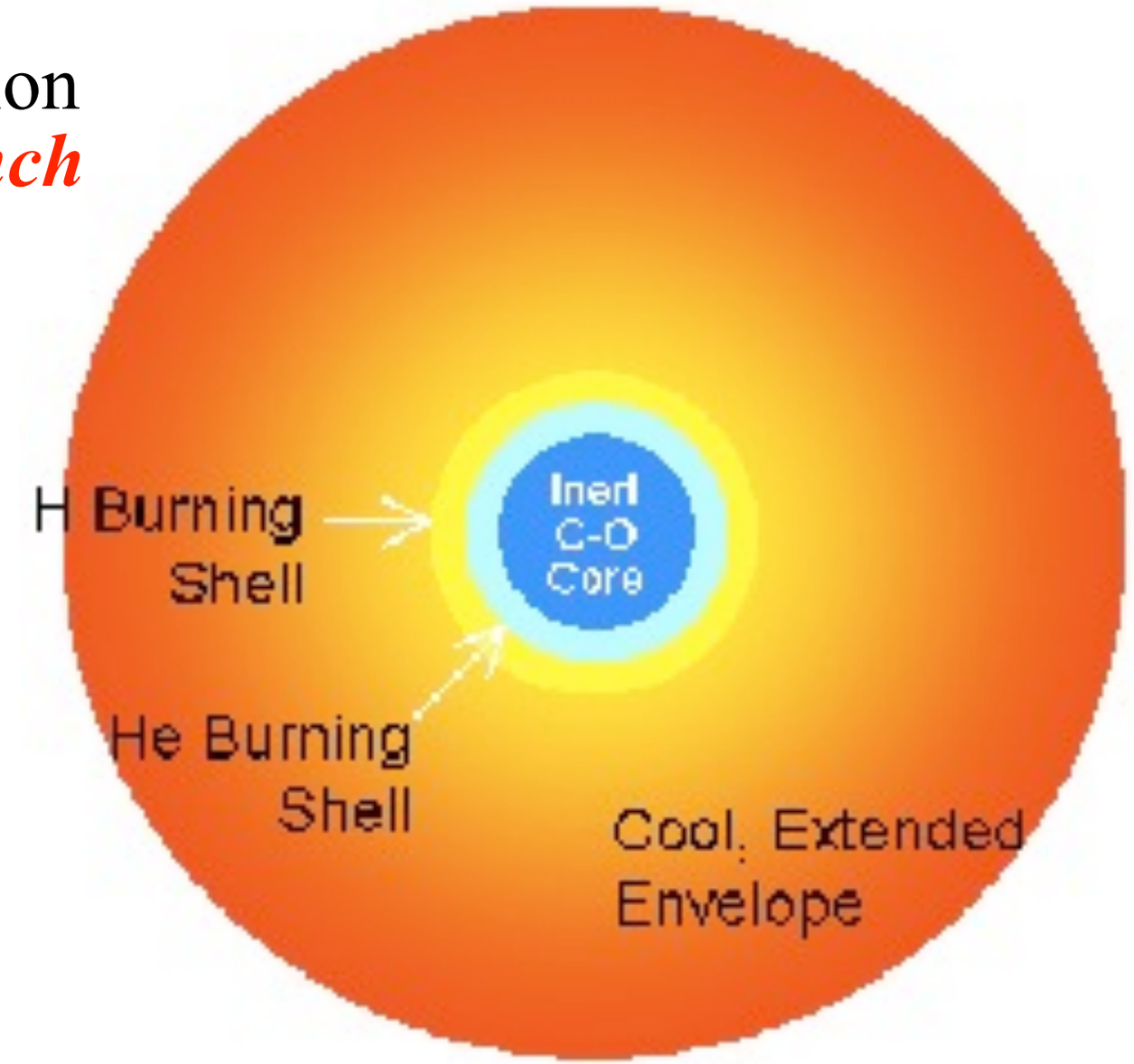
- Phase after core helium exhaustion called the ***asymptotic giant branch***



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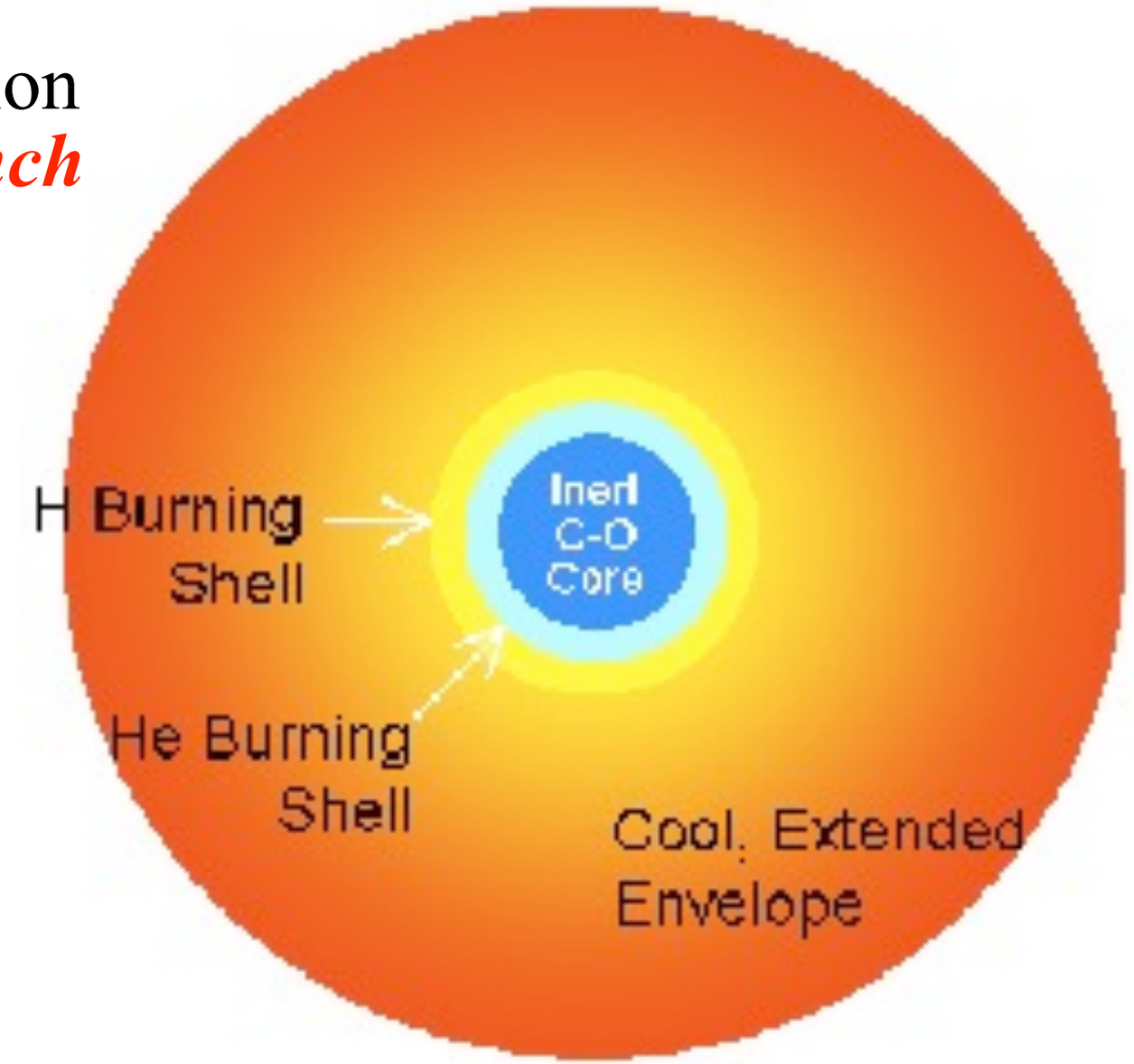

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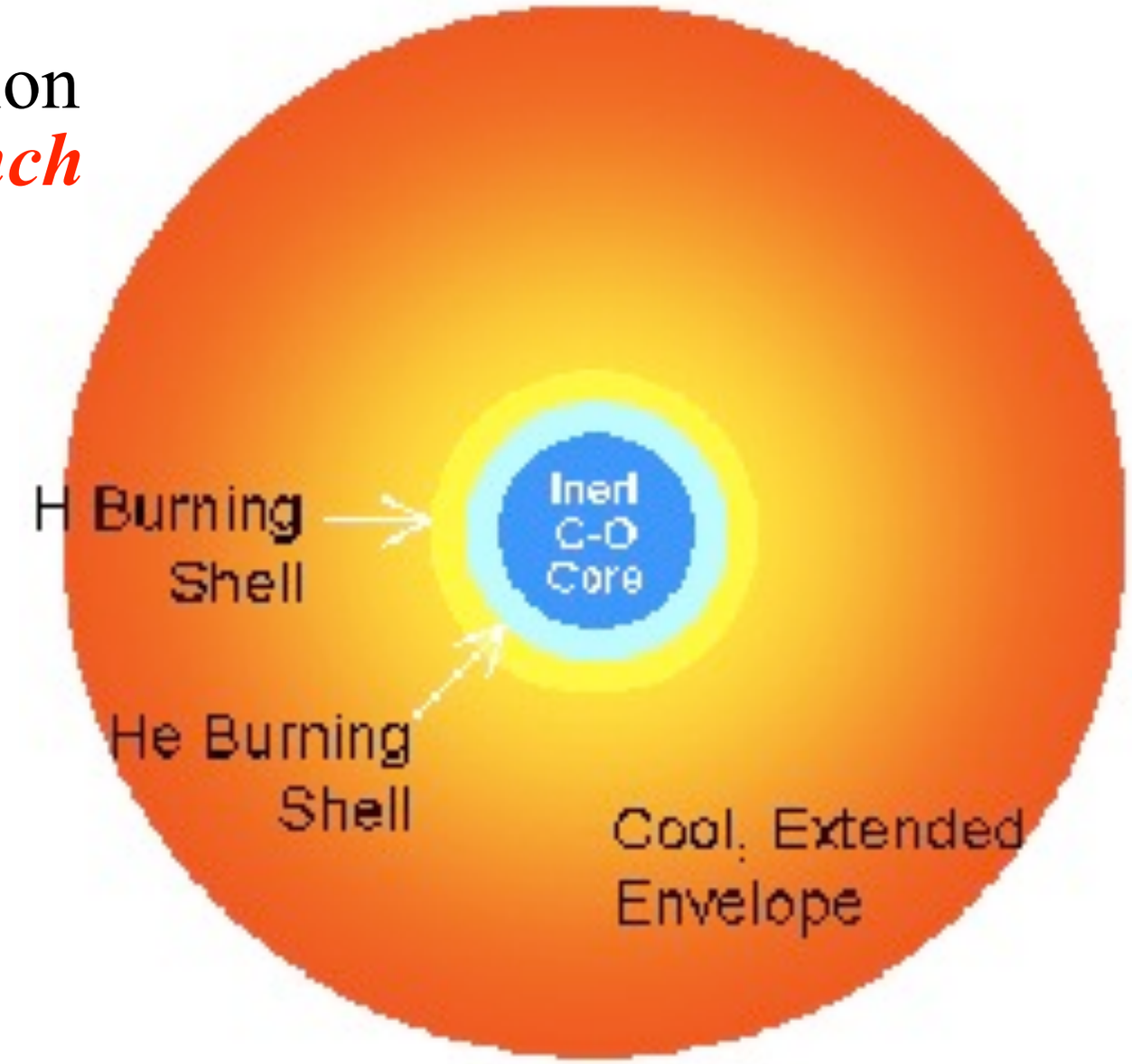

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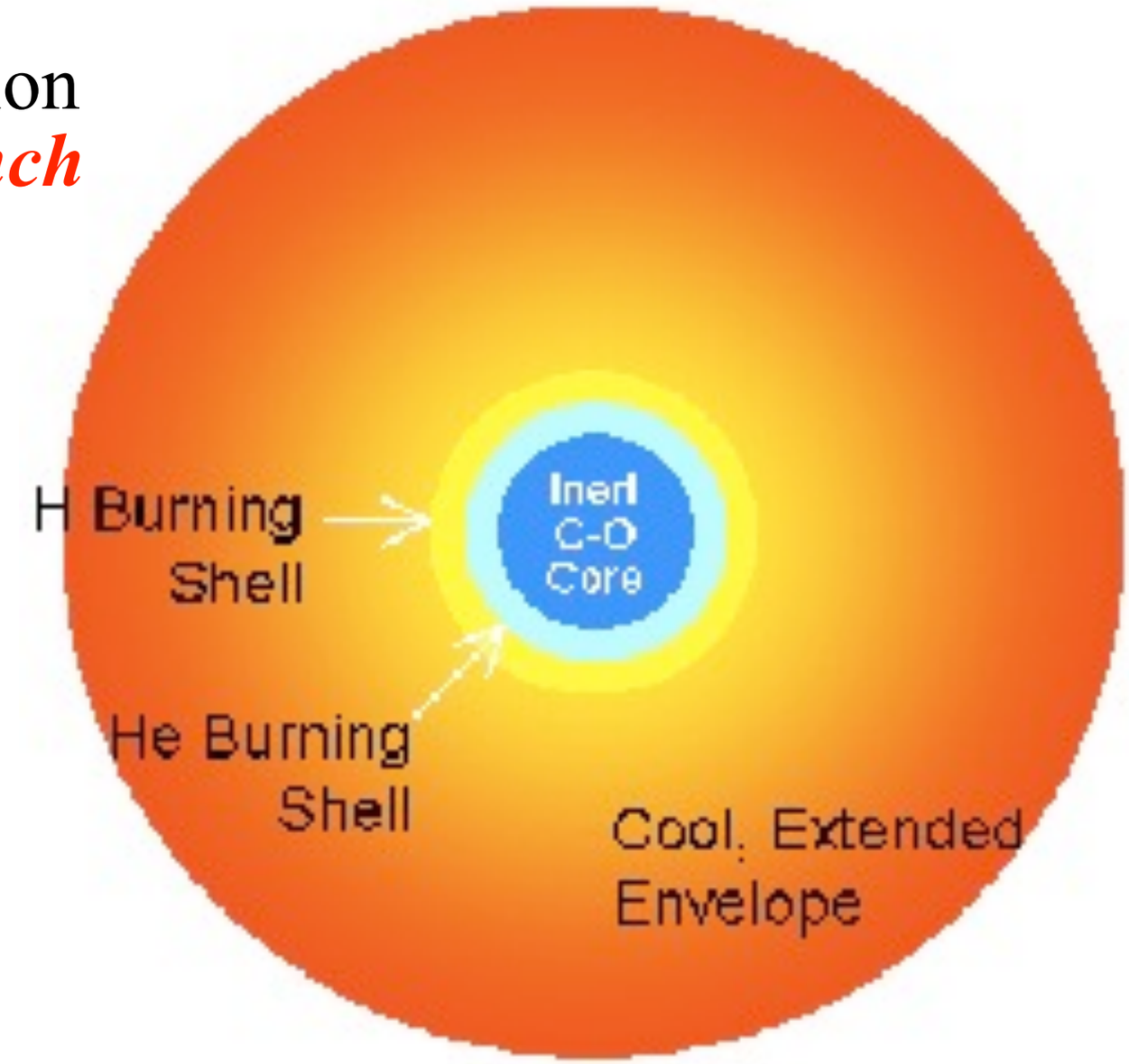

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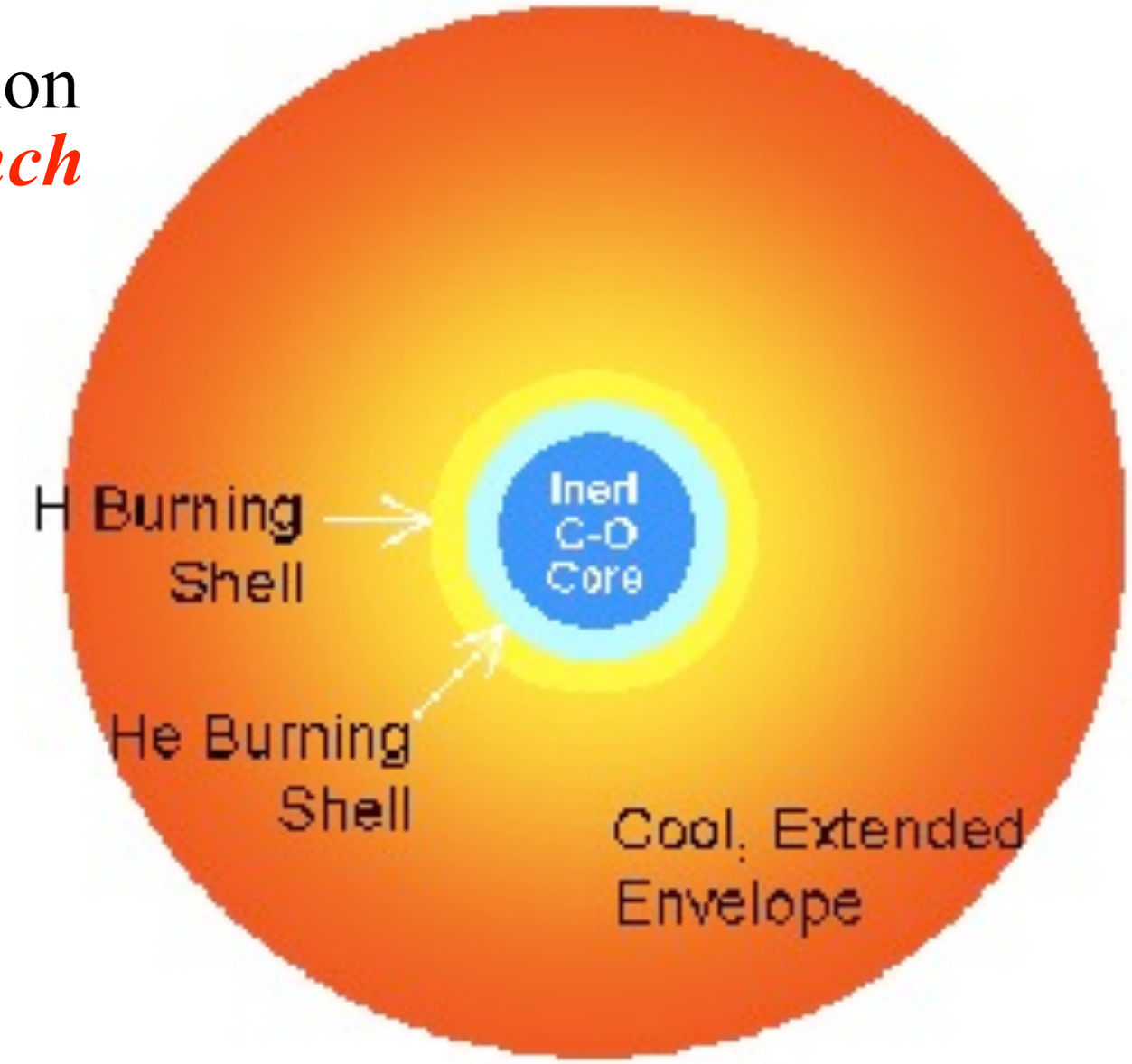
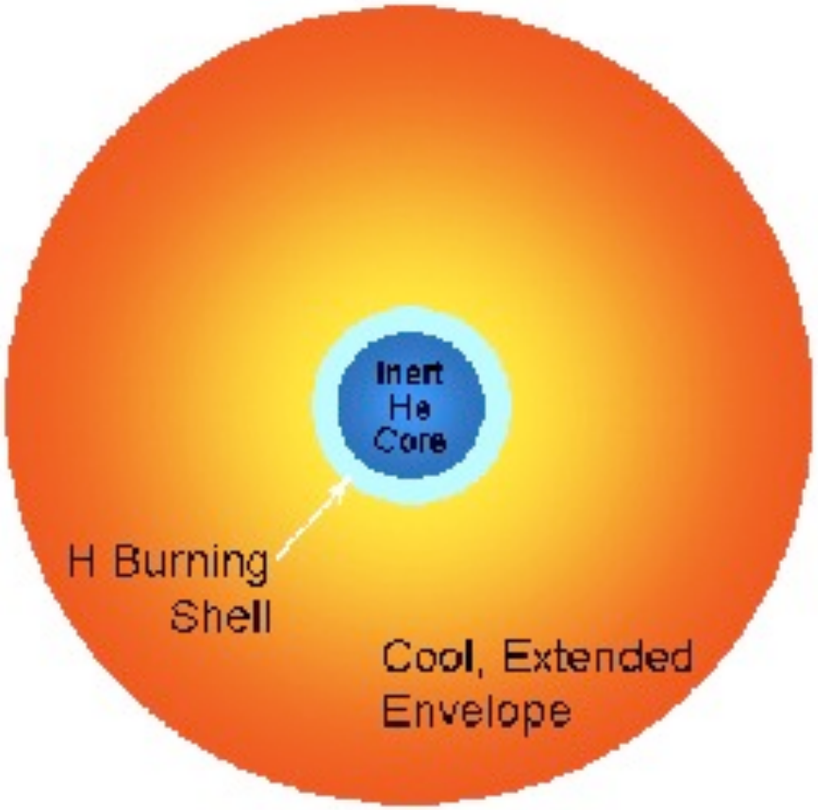
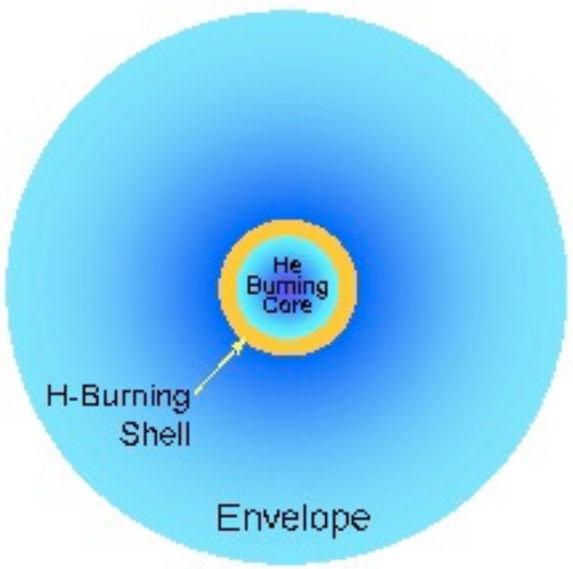
- Will get more luminous than last time!
- Considering what is about to happen, perhaps best to leave Solar System at this point.

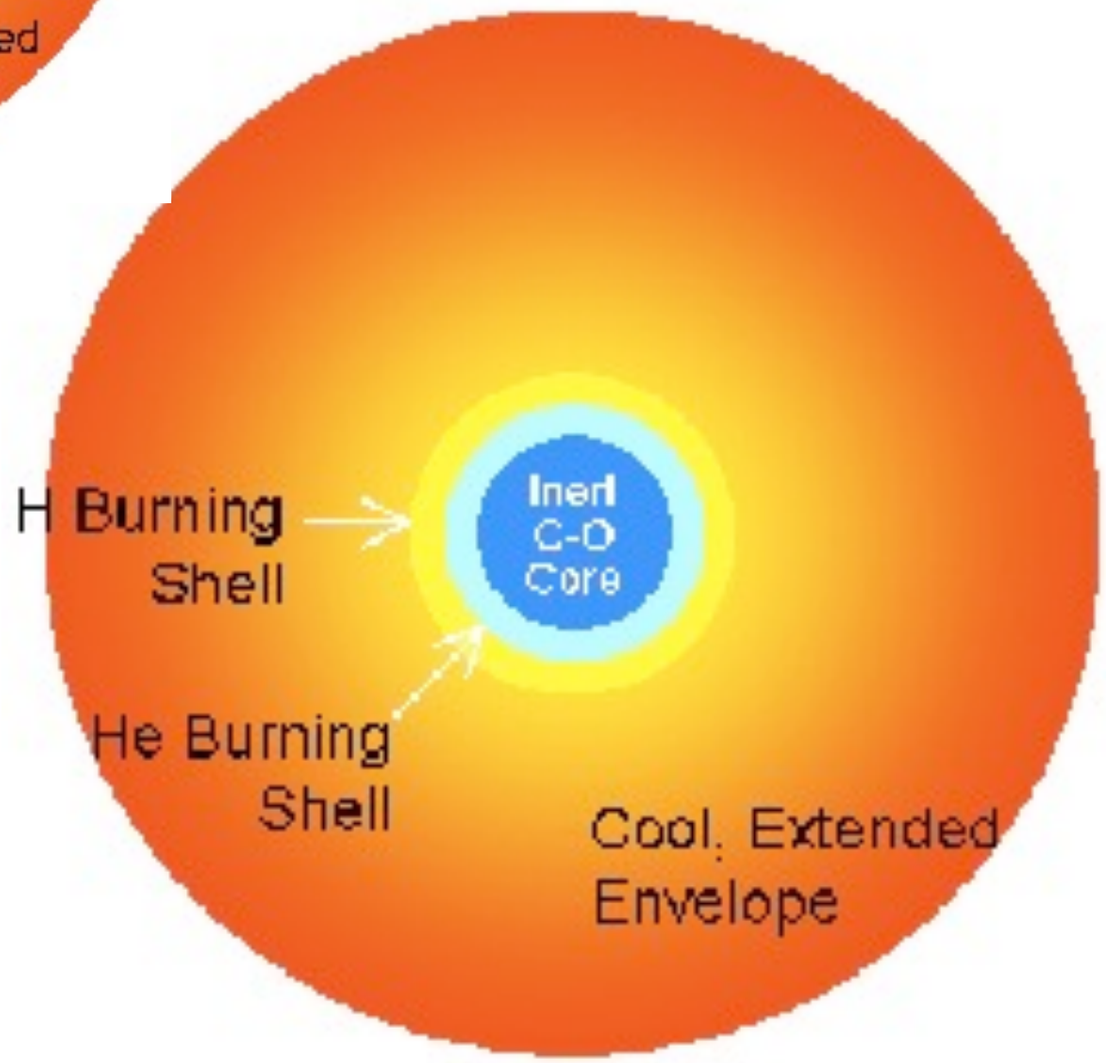


Life of a Low Mass Star

Main sequence
Core hydrogen burning
T_{core} ~ 16 million K







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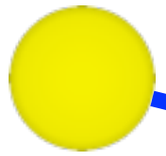

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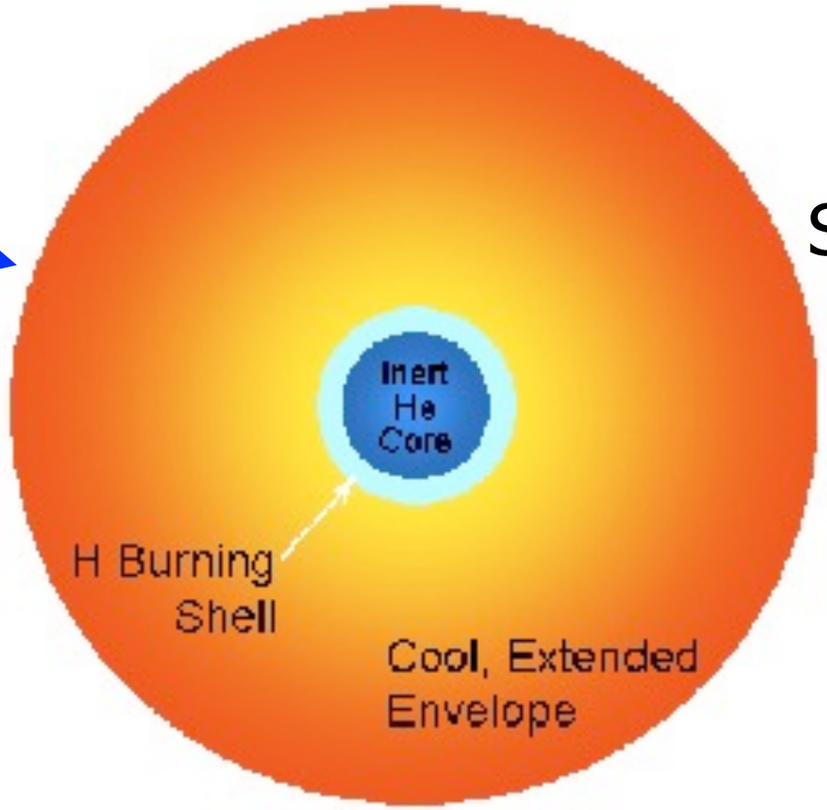
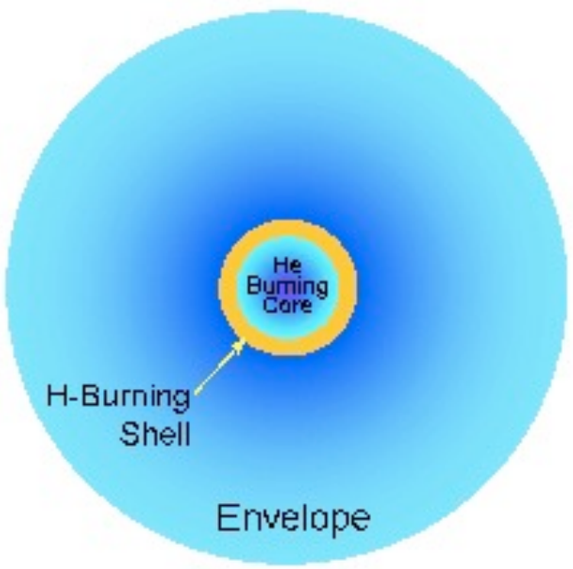
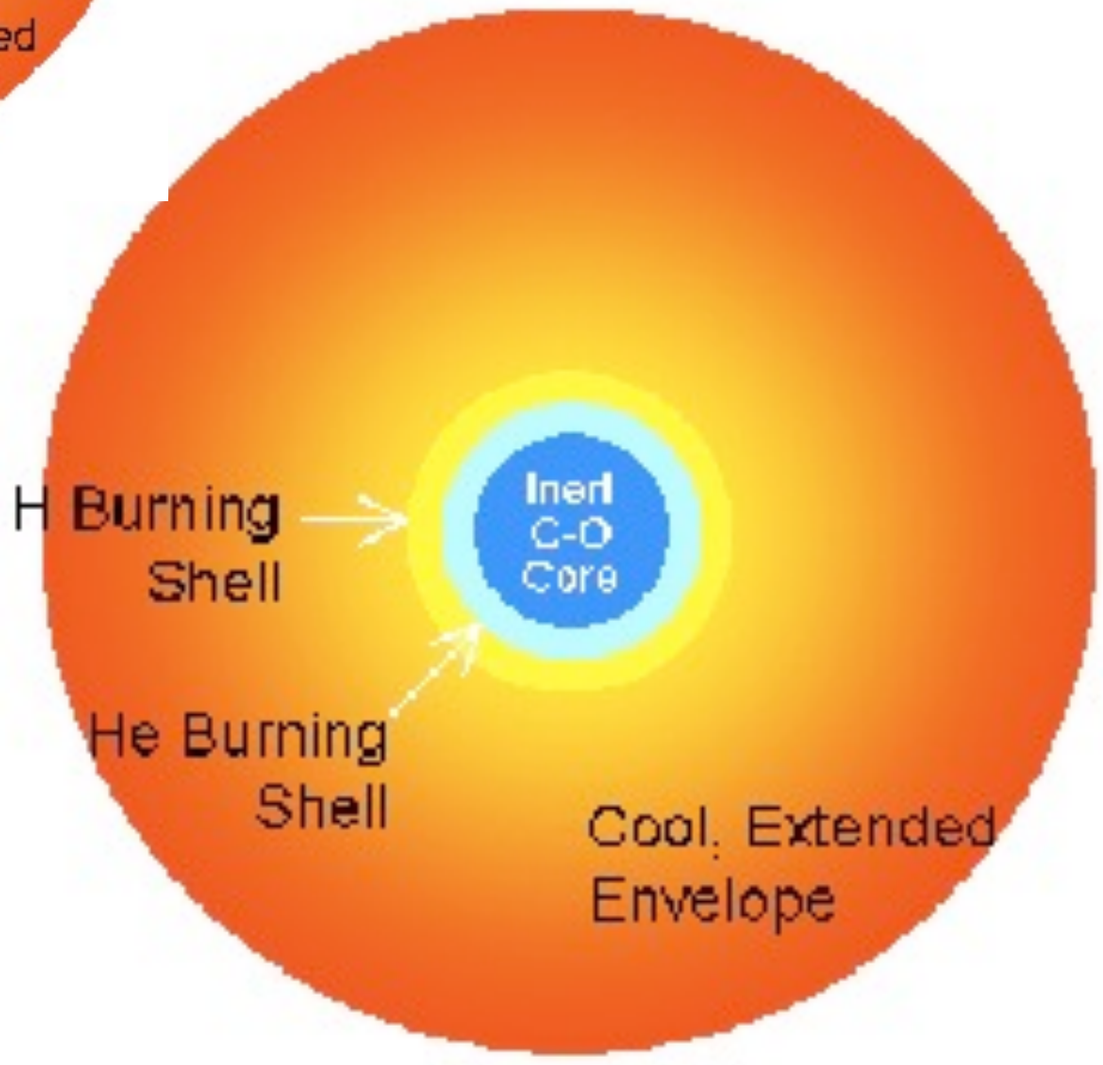


Red giant
Shell hydrogen
burning





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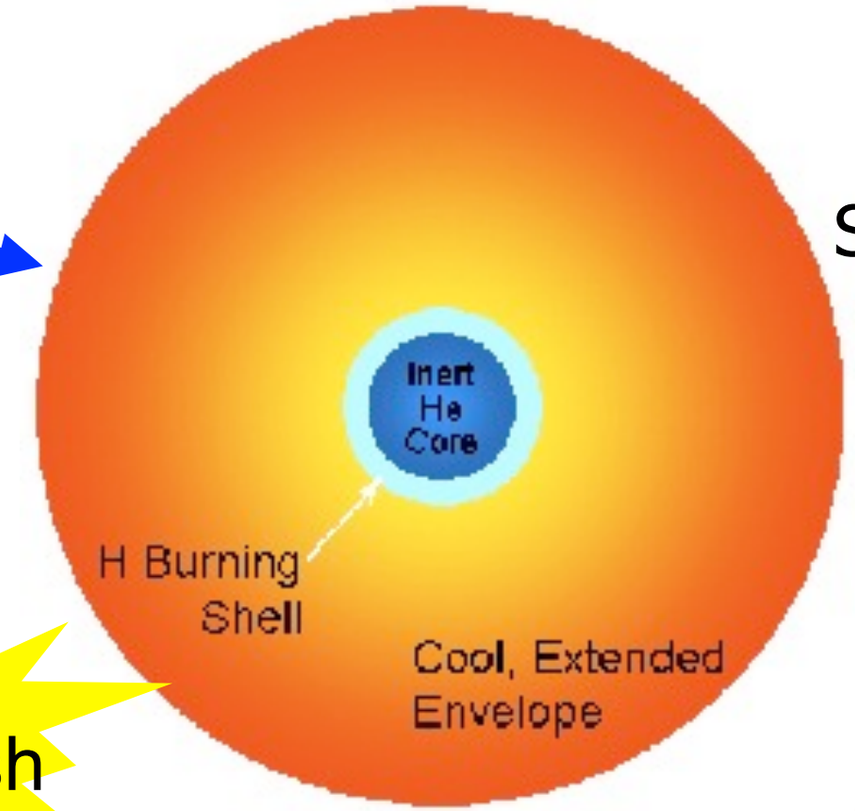
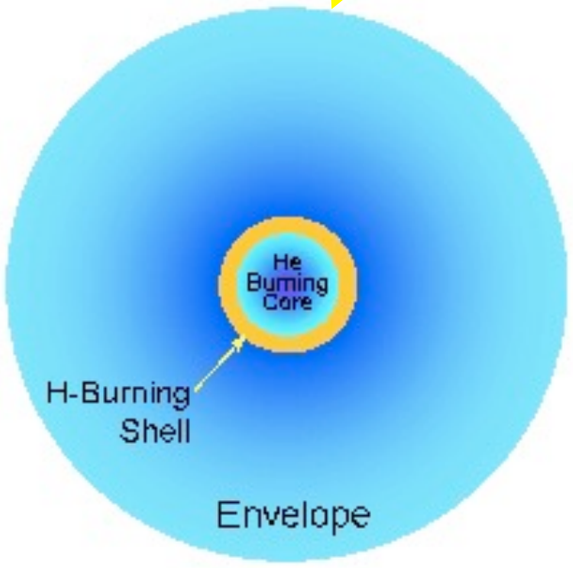
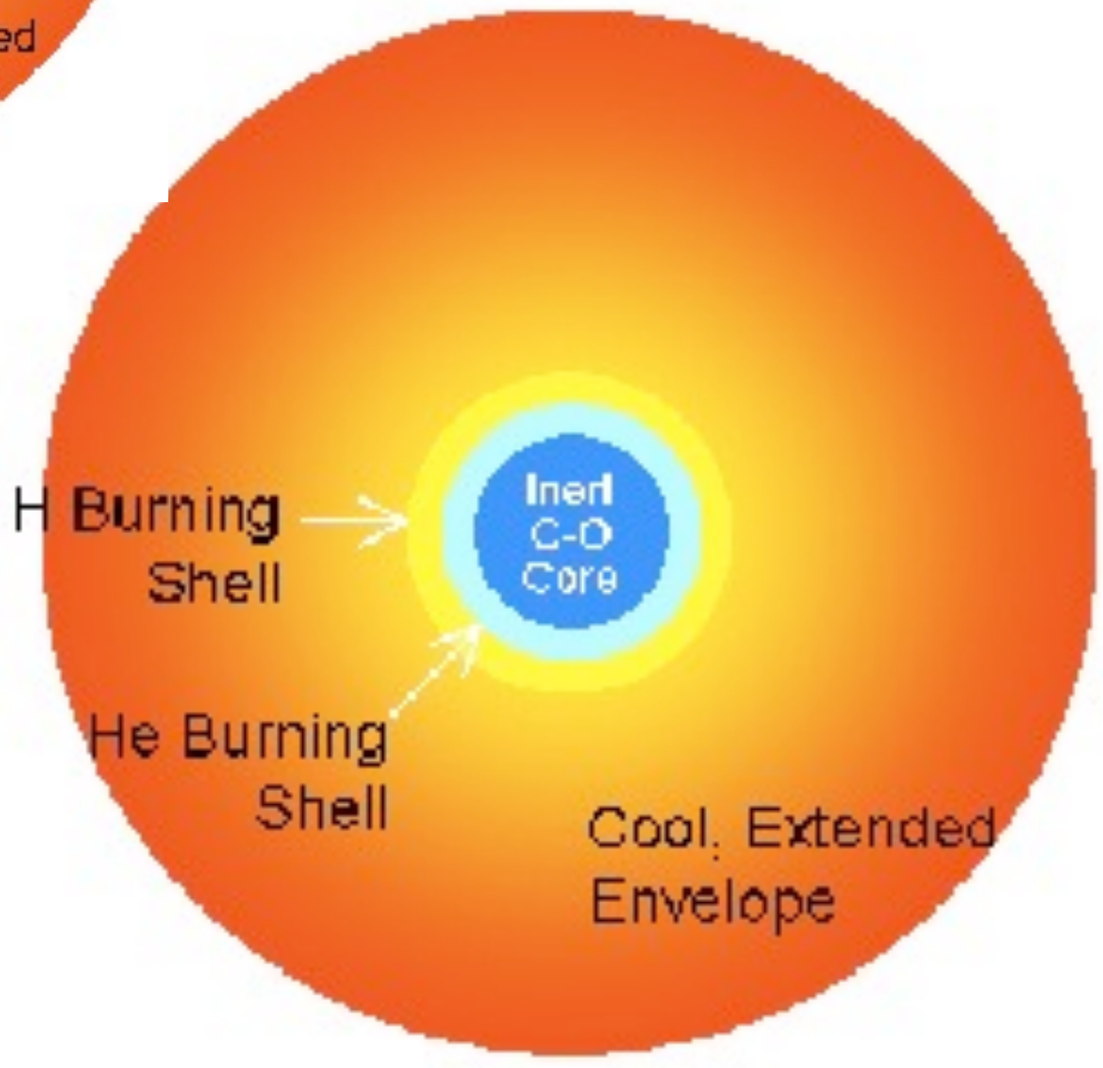
Helium flash







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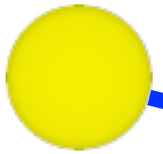

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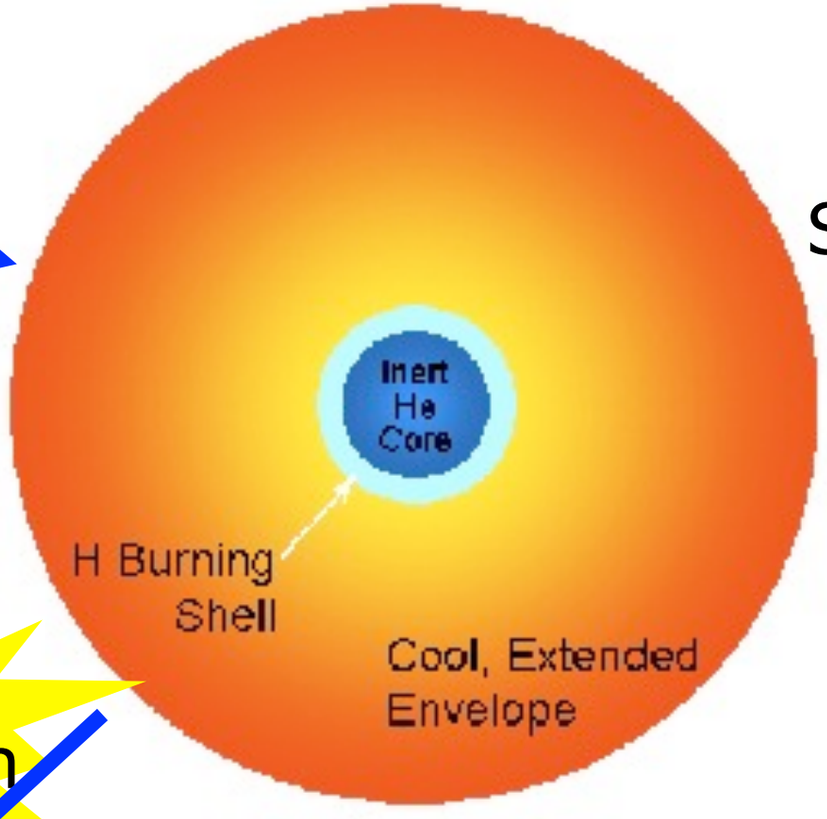

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Shell hydrogen
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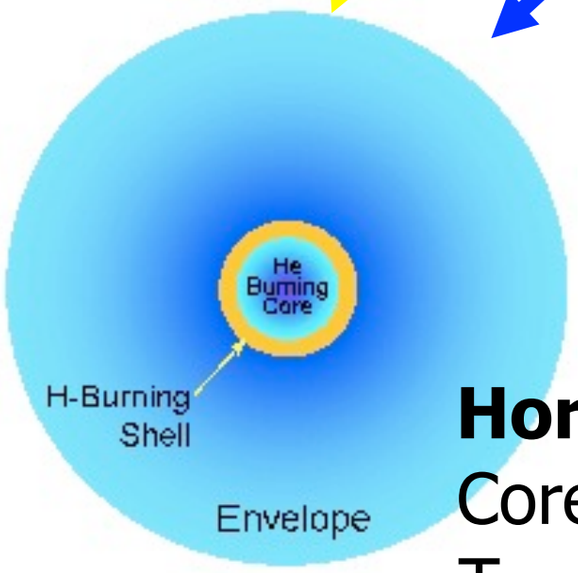
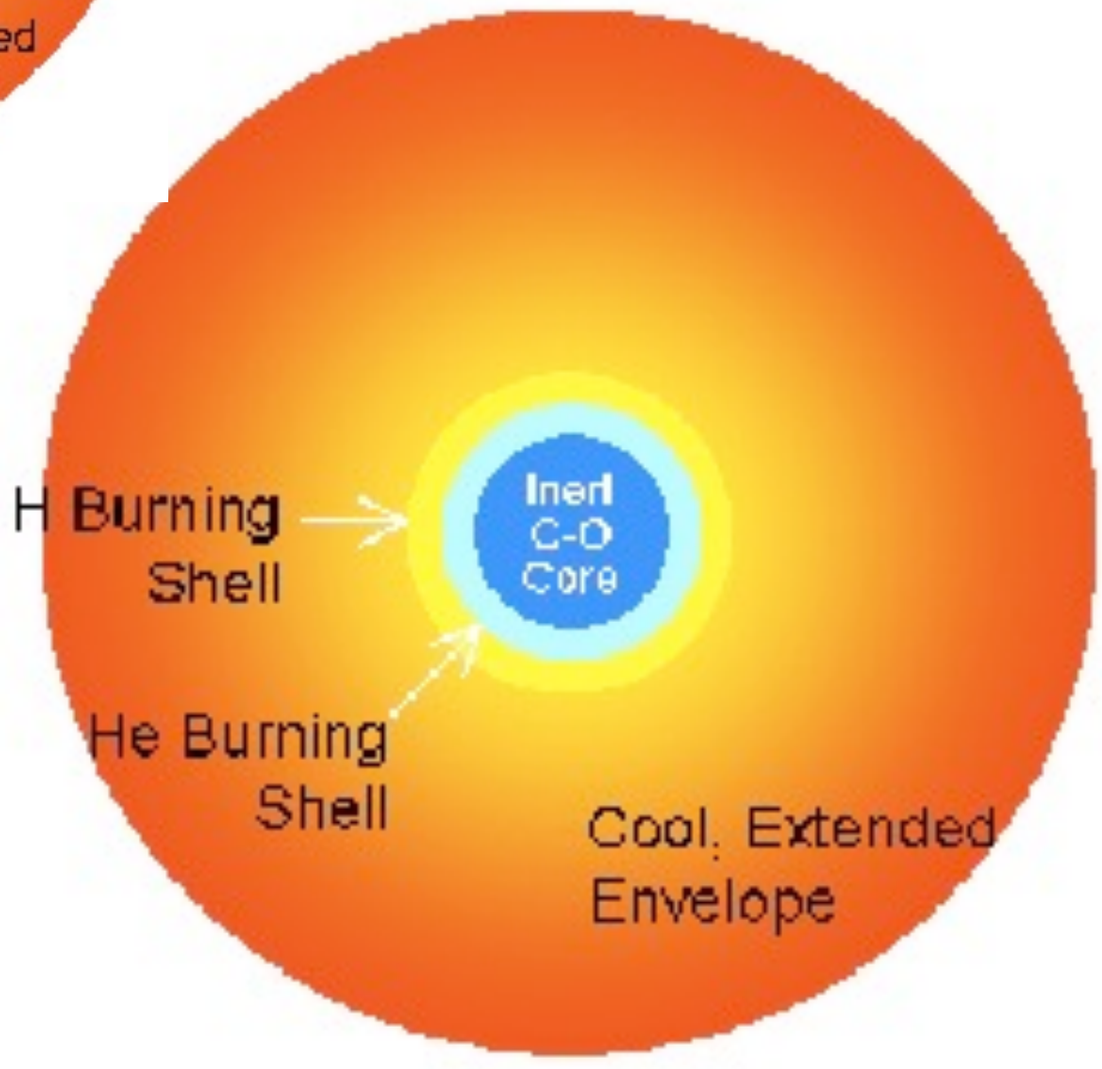
Helium flash



Horizontal branch
Core helium burning
T_{core} ~ 100 million K



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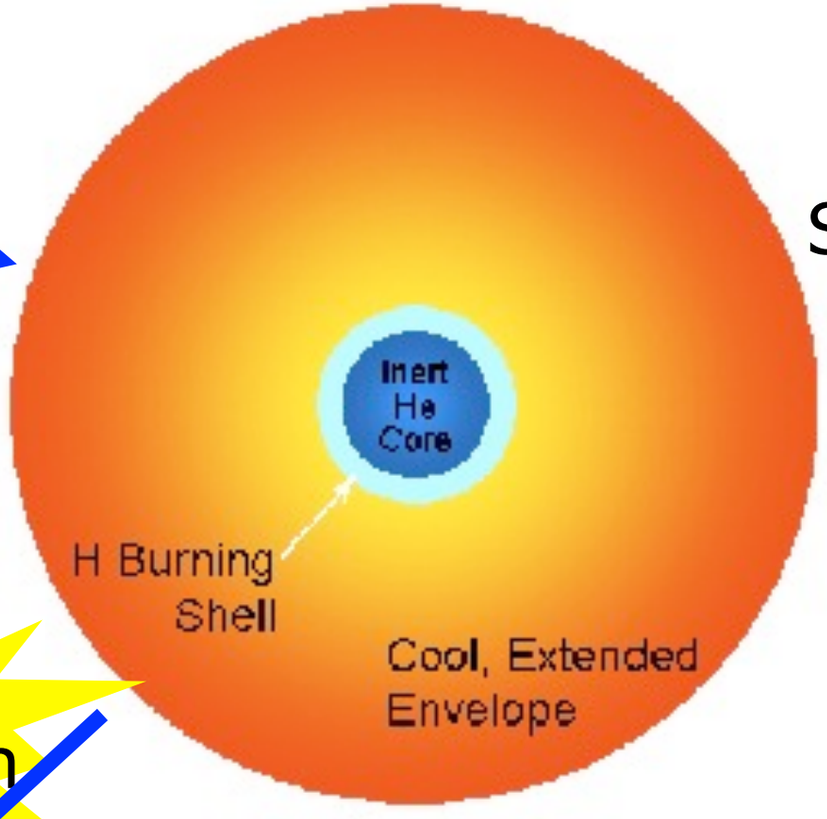

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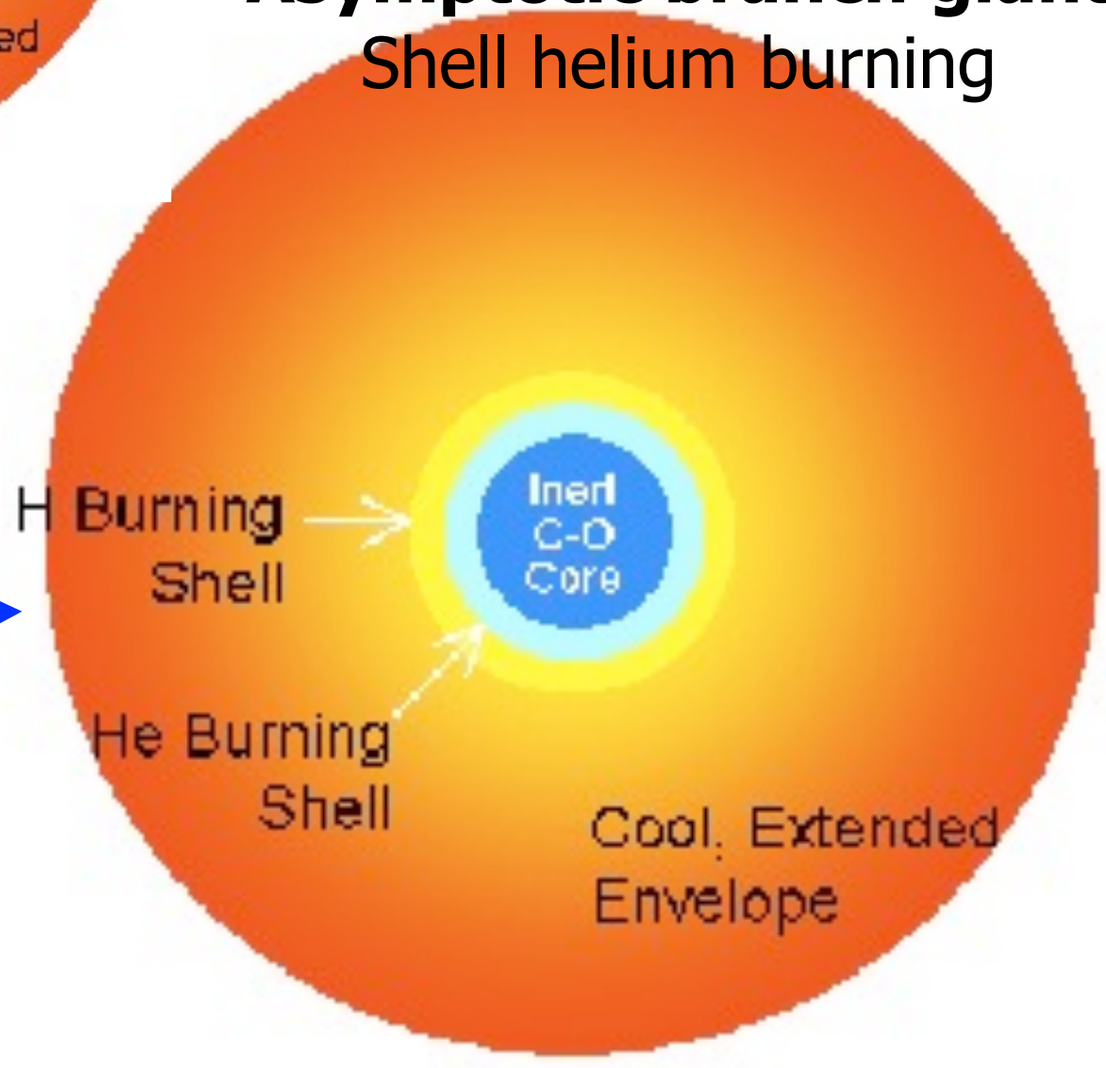
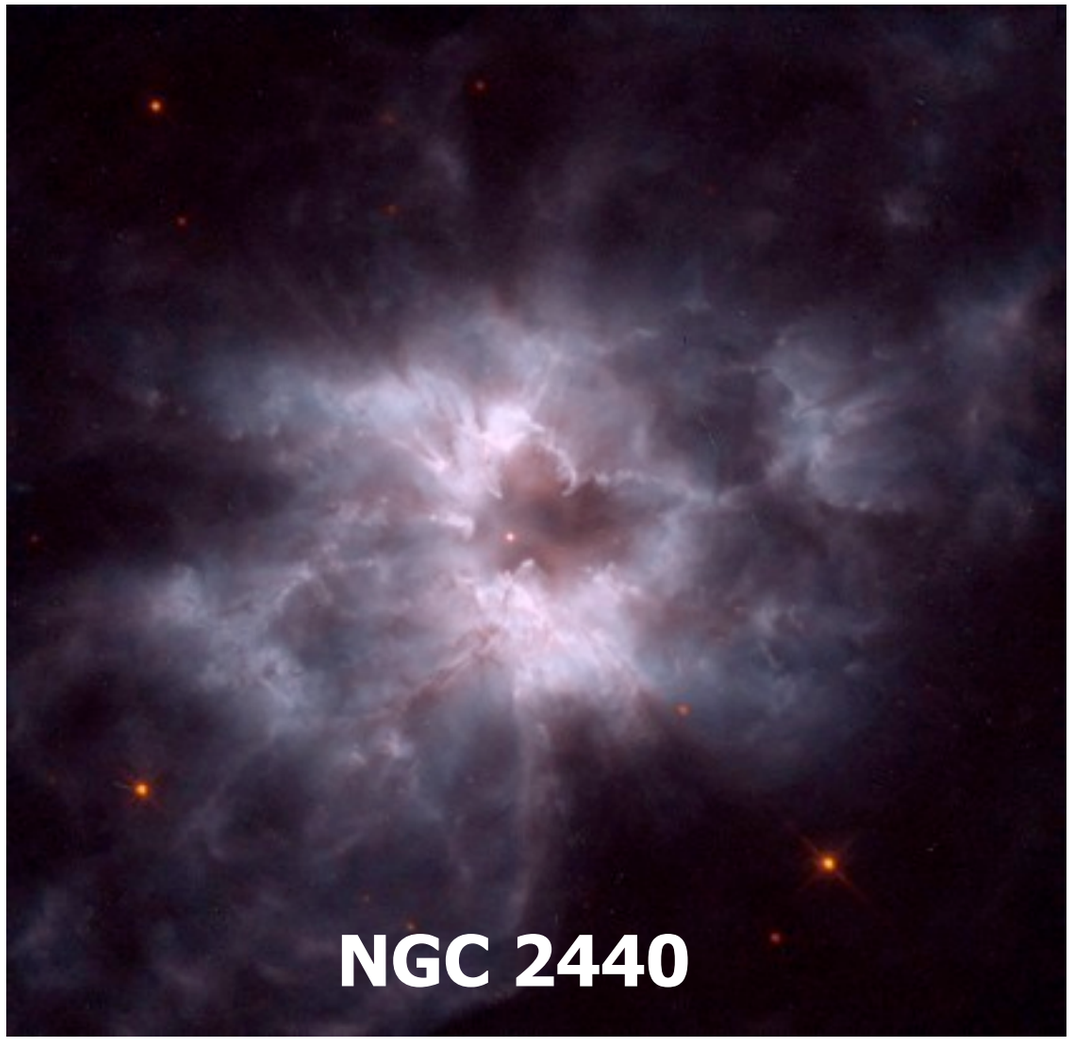
Asymptotic branch giant
Shell helium burning



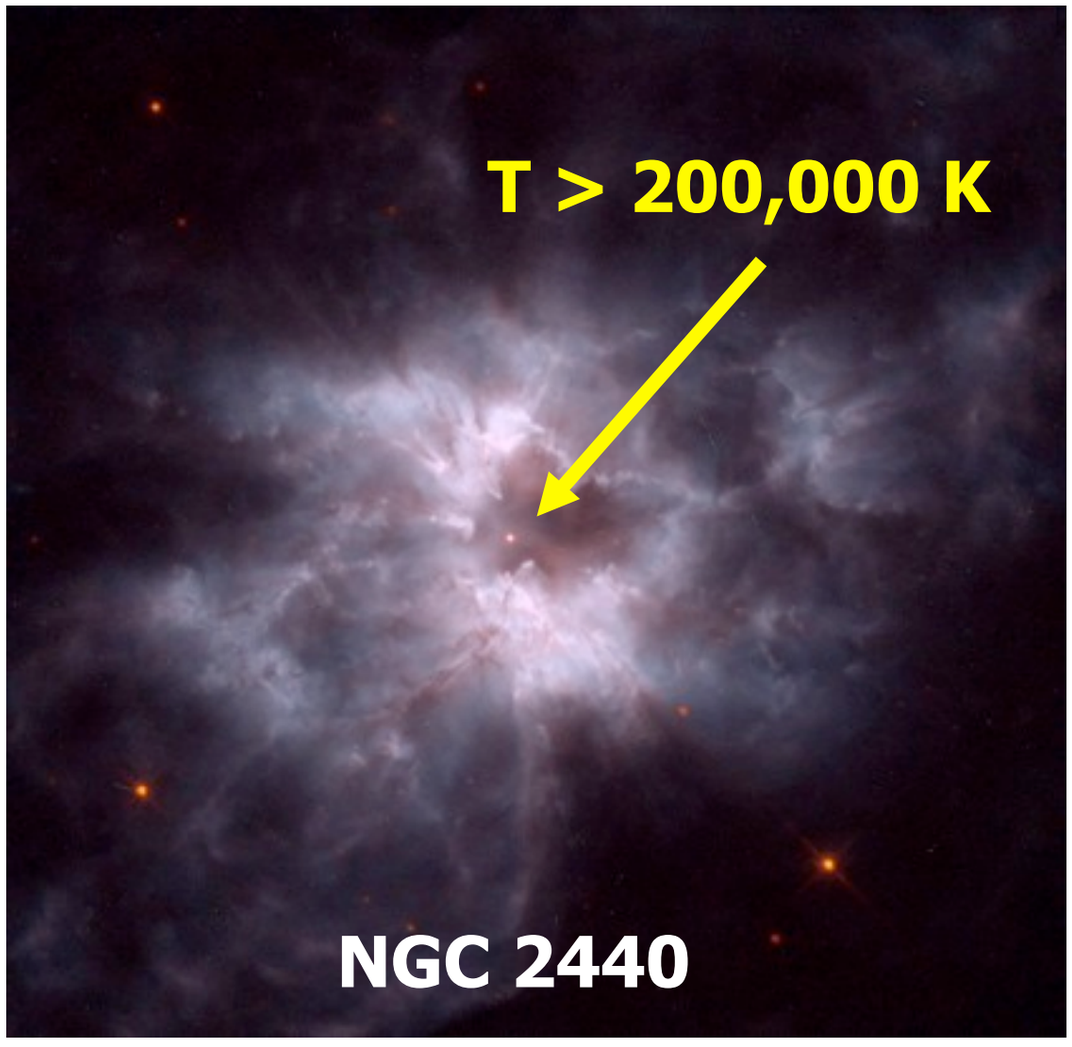
End Game

- At these last stages, the Sun will likely oscillate in size and temperature.
- The two burning shells are unstable and their oscillations lead to a “Superwind”
- Outer layers of the red giant star are cast off
  - Up to 80% (at least 50%) of the star’s original mass
  - carries away all but the innermost material of the star
  - including all of the new elements created there: helium, carbon

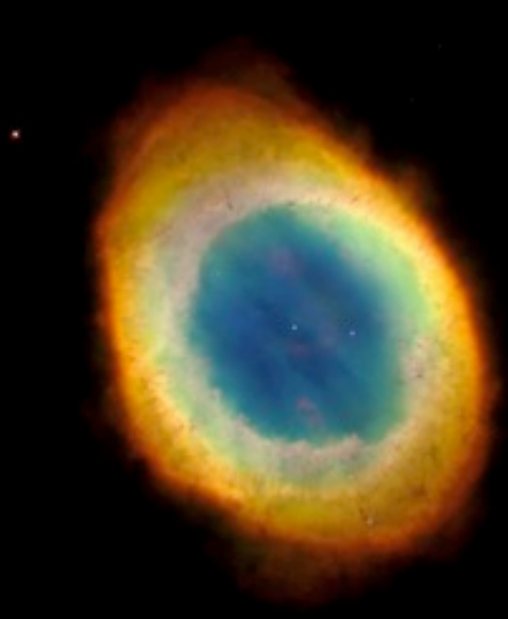


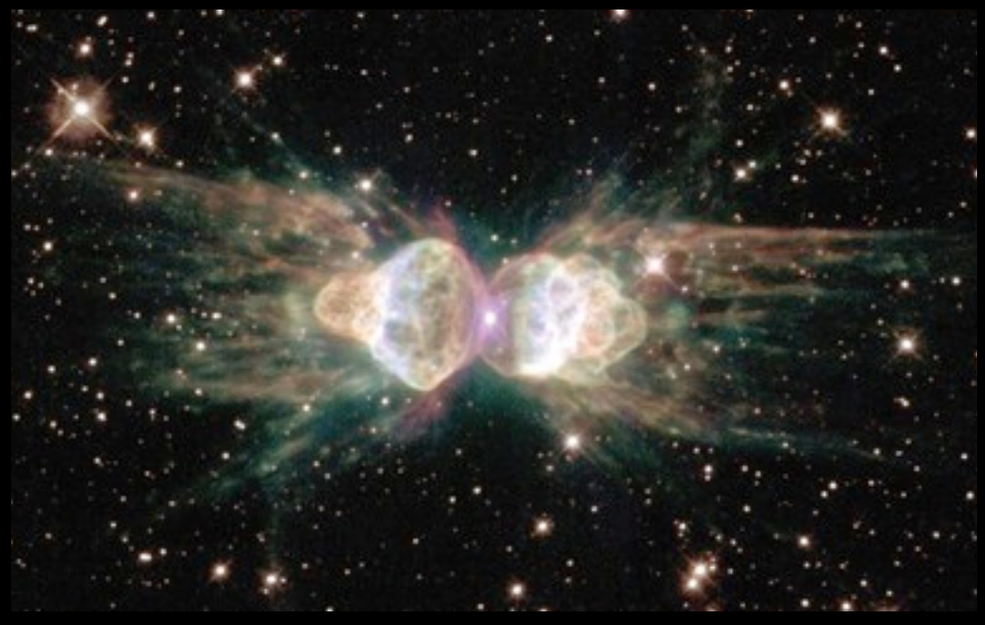
End Game

- The lcore remains, made of carbon/oxygen "ash" from helium fusion
  - The core is very hot, above 200,000 K
  - laid bare, and seen as "white hot"
- Ultraviolet radiation from the core ionizes the cast off outer layers
  - Becomes a *planetary nebul*
  - *Unfortunate name (nothing to do with planets), but some of the most beautiful objects in the sky.*



Planetary Nebulae





What About the Core?

- Final fate - **White dwarf**
  - "cinder" of burnt out core of sunlike star
  - Slowly cools off over billions of years
  - Just a hot body
  - No fusion
  - Not really a star in some ways

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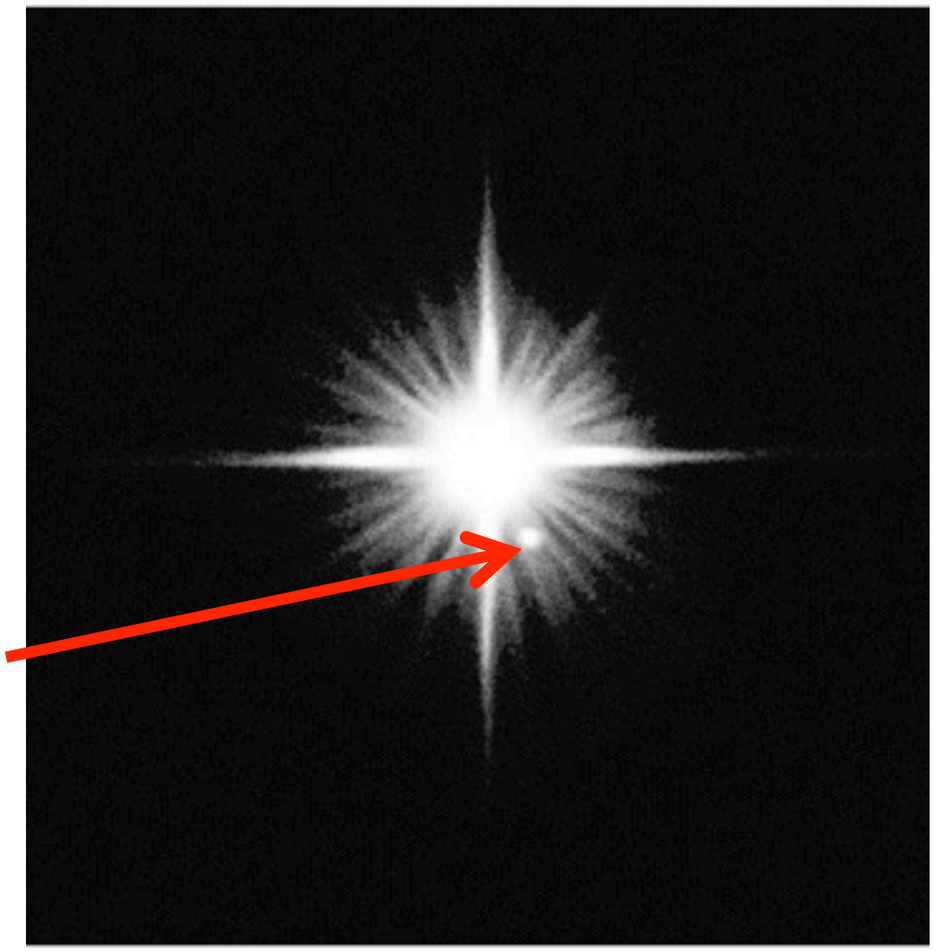
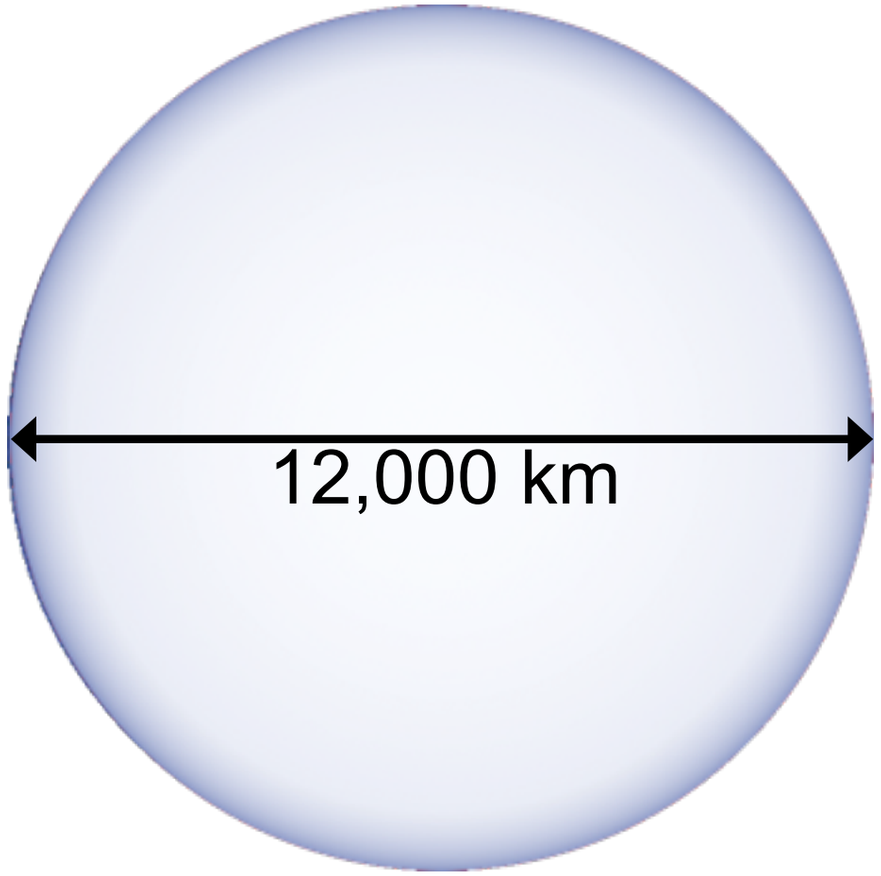


Sirius B

What About the Sun's Core?

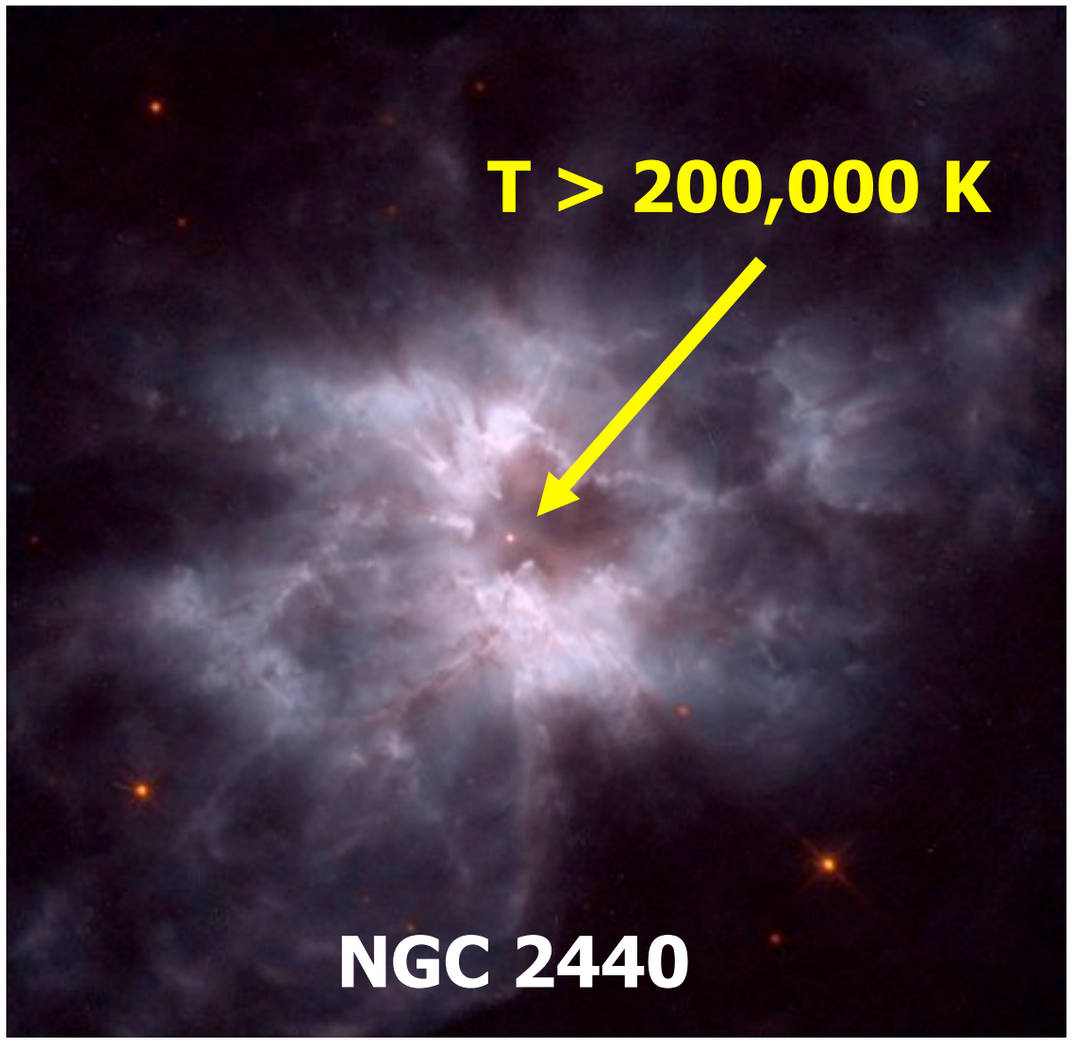
- Nuclear fusion has **stopped**, and gravity begins to win the battle
- Core contracts to the size of the Earth
  - But its about 60% the Sun's mass!
  - Material in the core is compressed to a density of 1,000 kg/cm^3
  - 10^6 times denser than you!
  - Very hot, surface temperature >100,000 K



but will usually weigh about 0.6 Solar masses

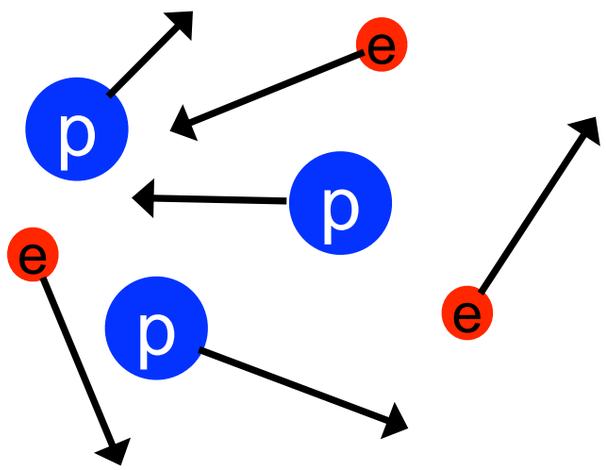
What Happens to Earth?

- We have detected planets around white dwarfs, but they have presumable had a hard time.
- If you were to visit the wasteland of Earth, the Sun would only be a very bright point of light.
- Not sufficient for life.



Electron Degeneracy

- The electrons get so squashed together that they get pushed into *degenerate states*
  - packed into ultradense quantum solid
  - This creates **pressure** to counteract gravity (Pauli exclusion)
  - Stops contraction



Matter in the core of a normal star

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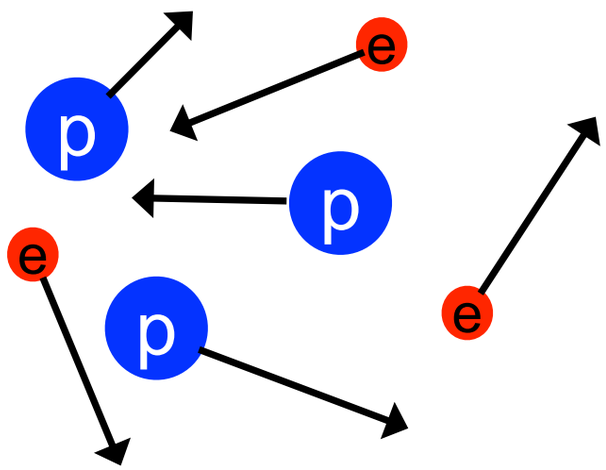

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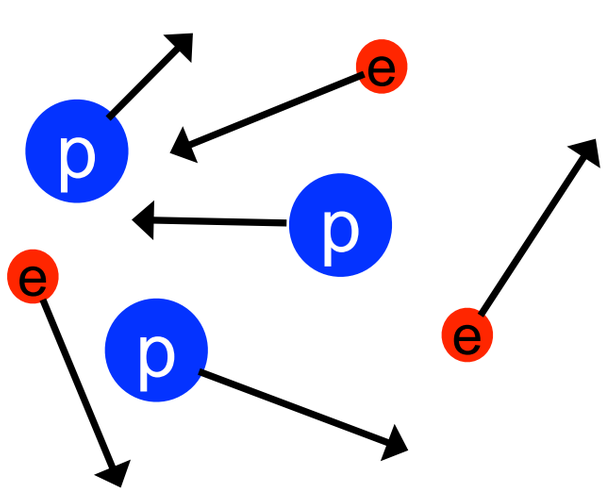

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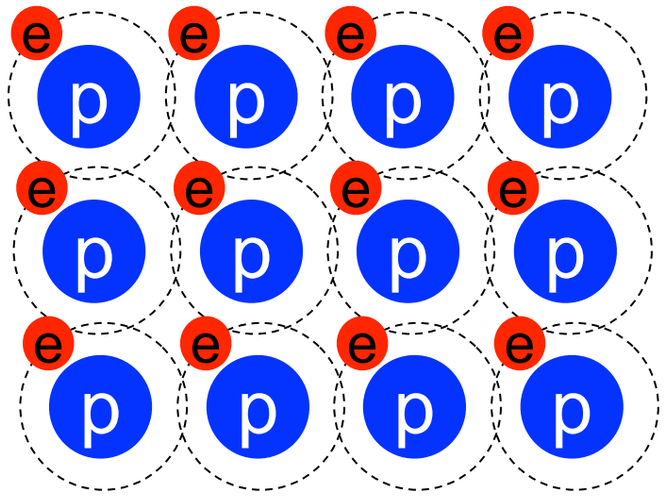
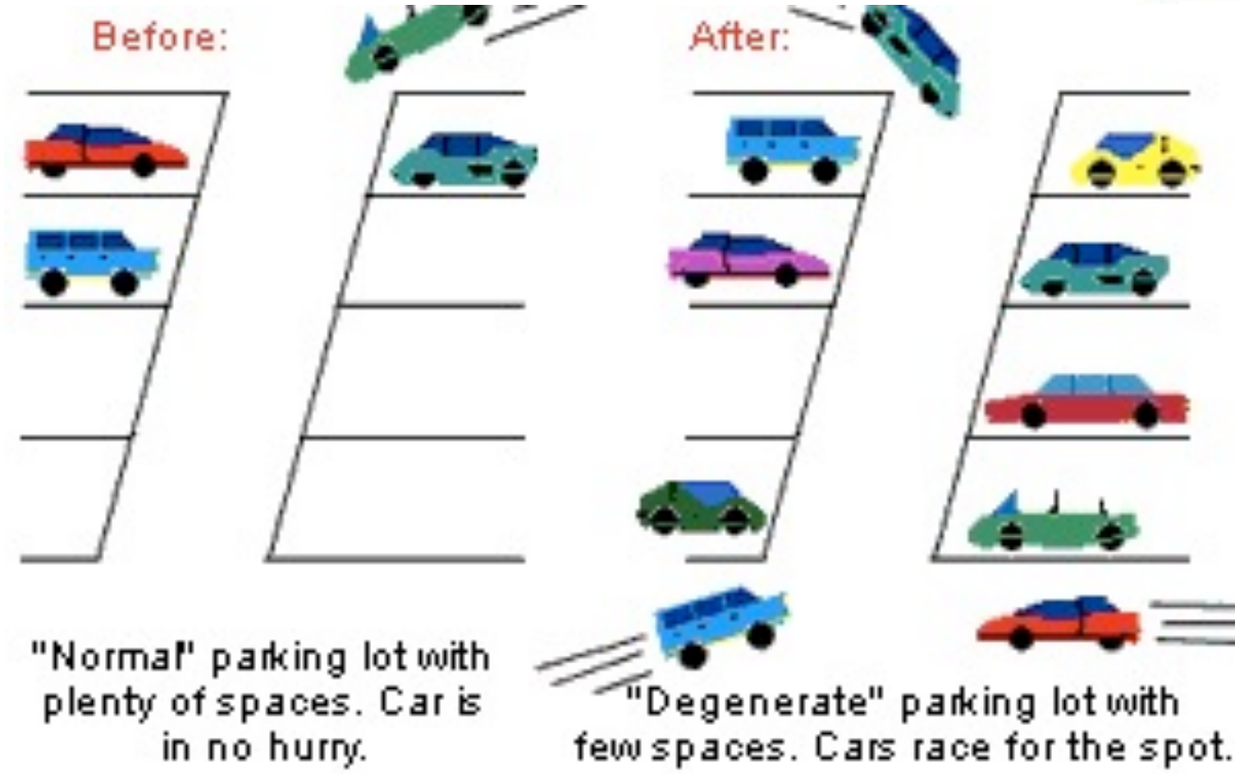


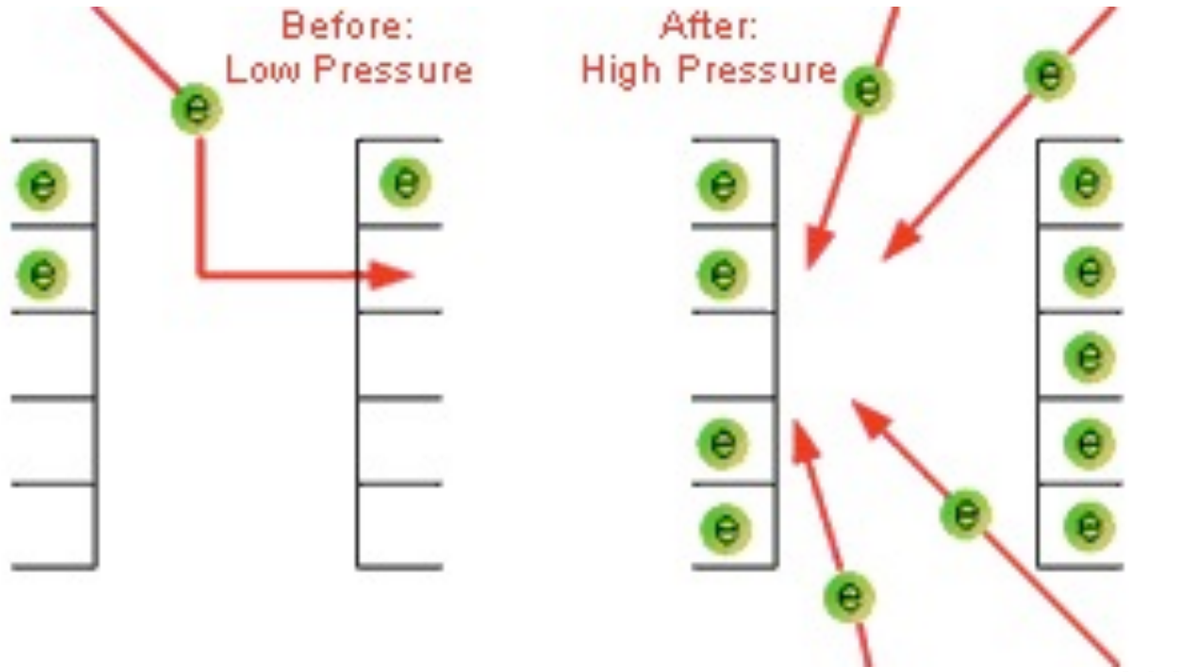
Electron-degenerate matter
1 ton per cubic cm

Degeneracy Pressure

- Electrons are forced into higher energy levels than normal – all of the lower levels are taken

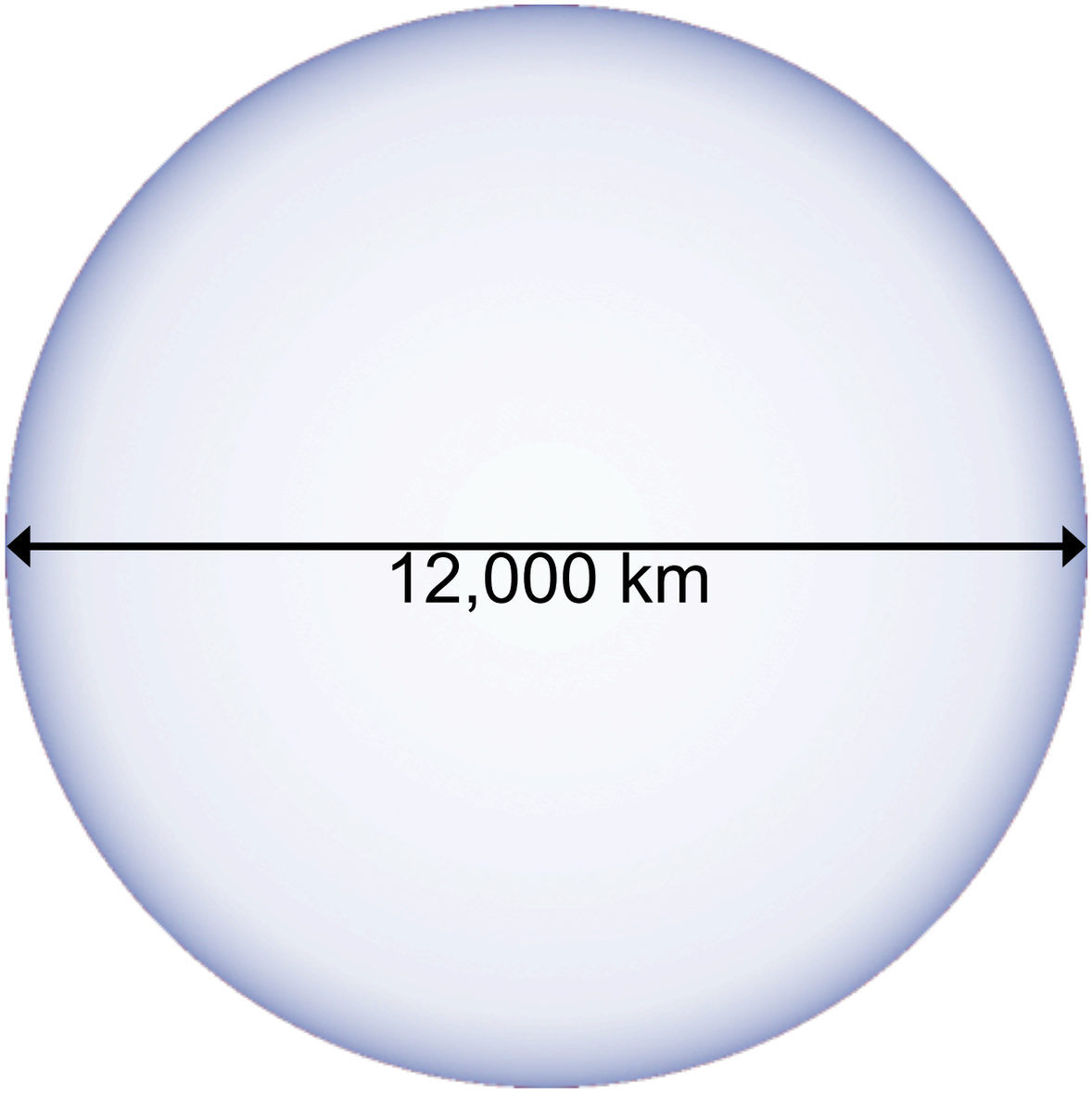
- Effect manifests itself as pressure





NASA

Relative Size of White Dwarf



White dwarf– but will usually weigh about 0.6 Solar masses

Chandrasekhar limit

Subrahmanyan Chandrasekhar 1910-1995

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- Maximum mass of a white dwarf.
  - 1.4 solar masses!

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Subrahmanyan Chandrasekhar 1910-1995

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Subrahmanyan Chandrasekhar 1910-1995

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- Gravity is a harsh mistress!
  - More of this latter.
- But Sun already has less mass
  - and will have less still as white dwarf
  - so the Sun's white dwarf corpse will be stable, able to support its own gravity
  - and will simply cool off forever

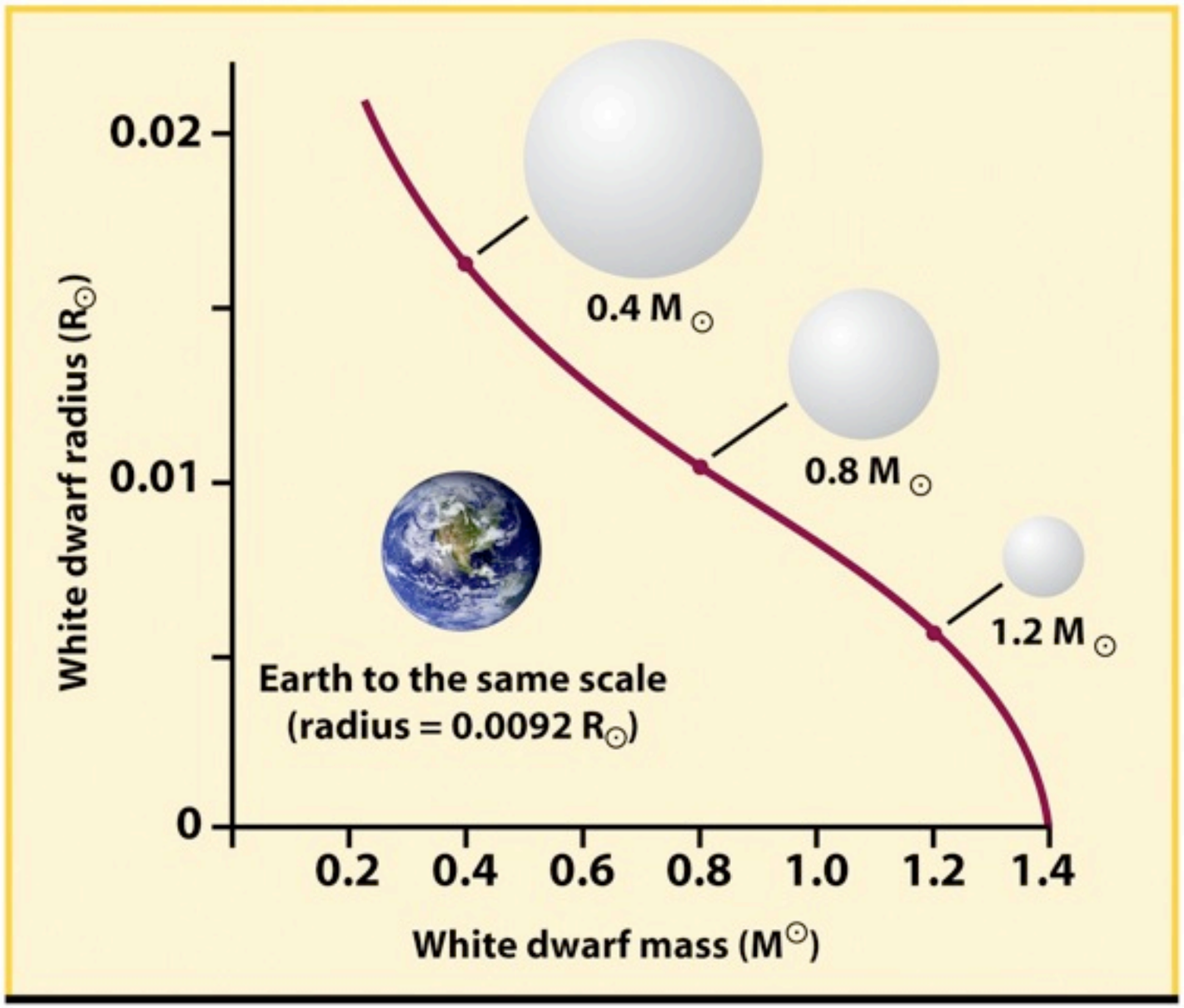
Subrahmanyan Chandrasekhar 1910-1995

White Dwarfs are Weird

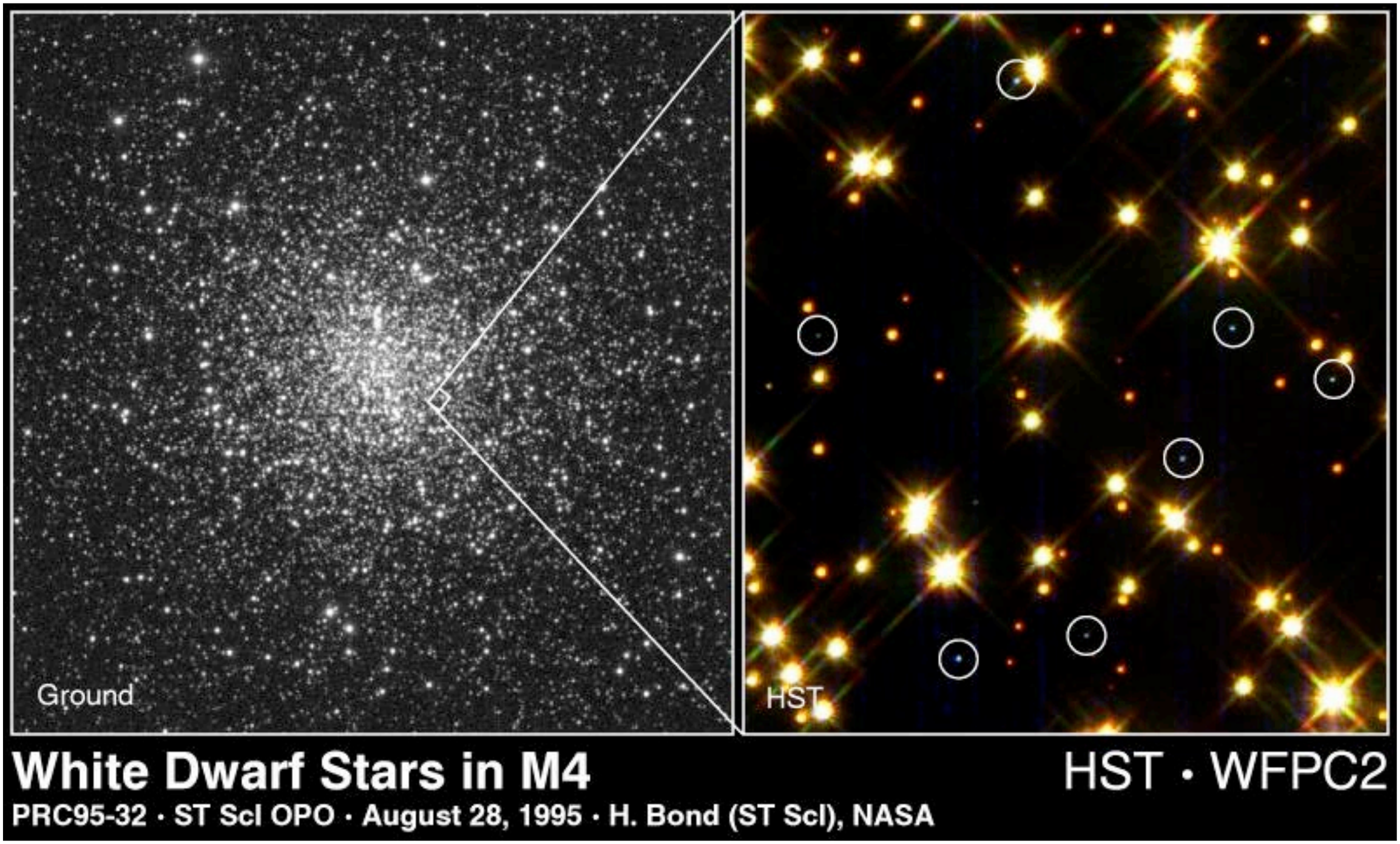
The more massive, the smaller!

Their radius *decreases* with mass!

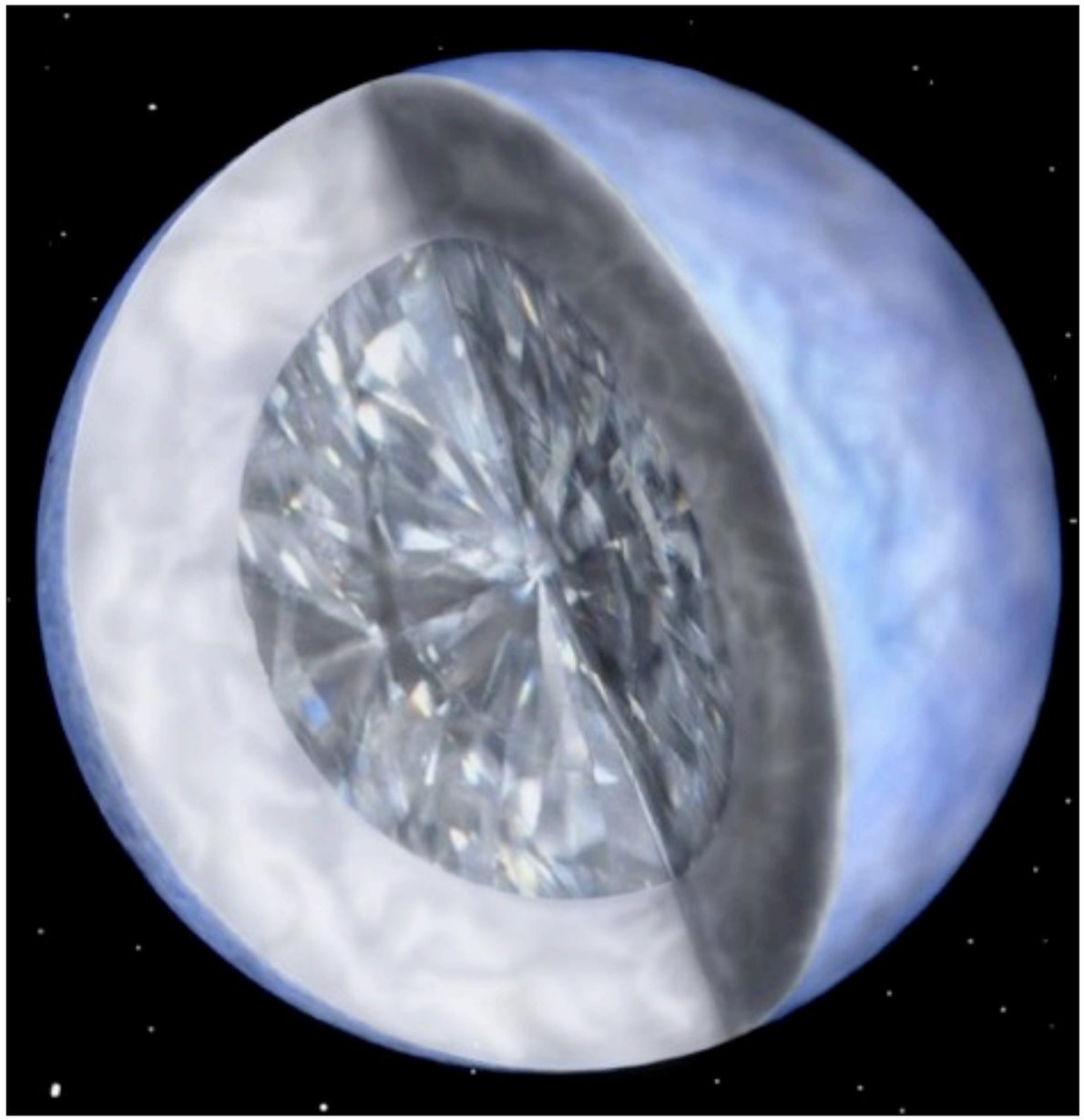
Why? More mass=more gravity, star compressed more



White Dwarves!

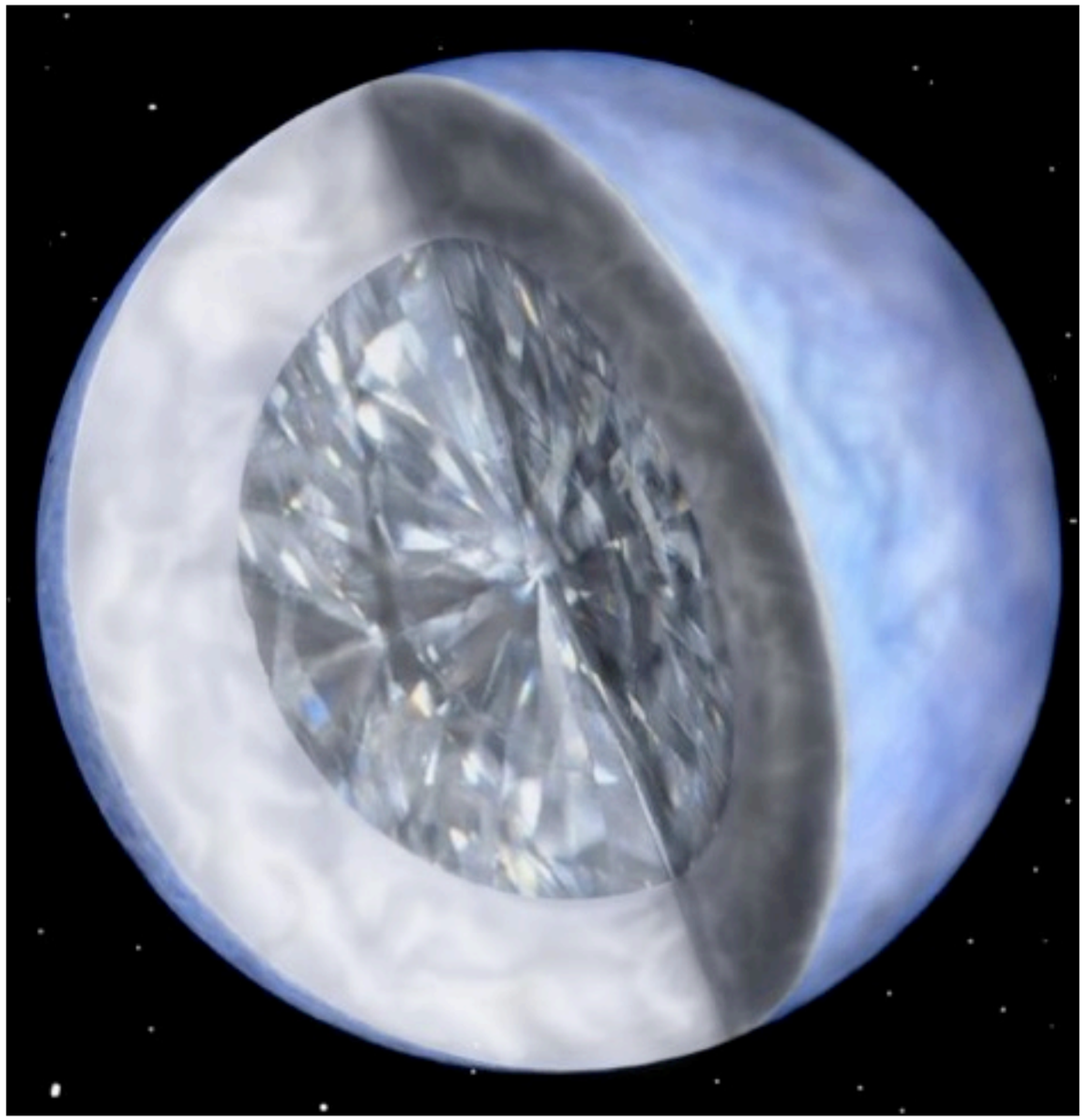


Stellar Diamonds!?!



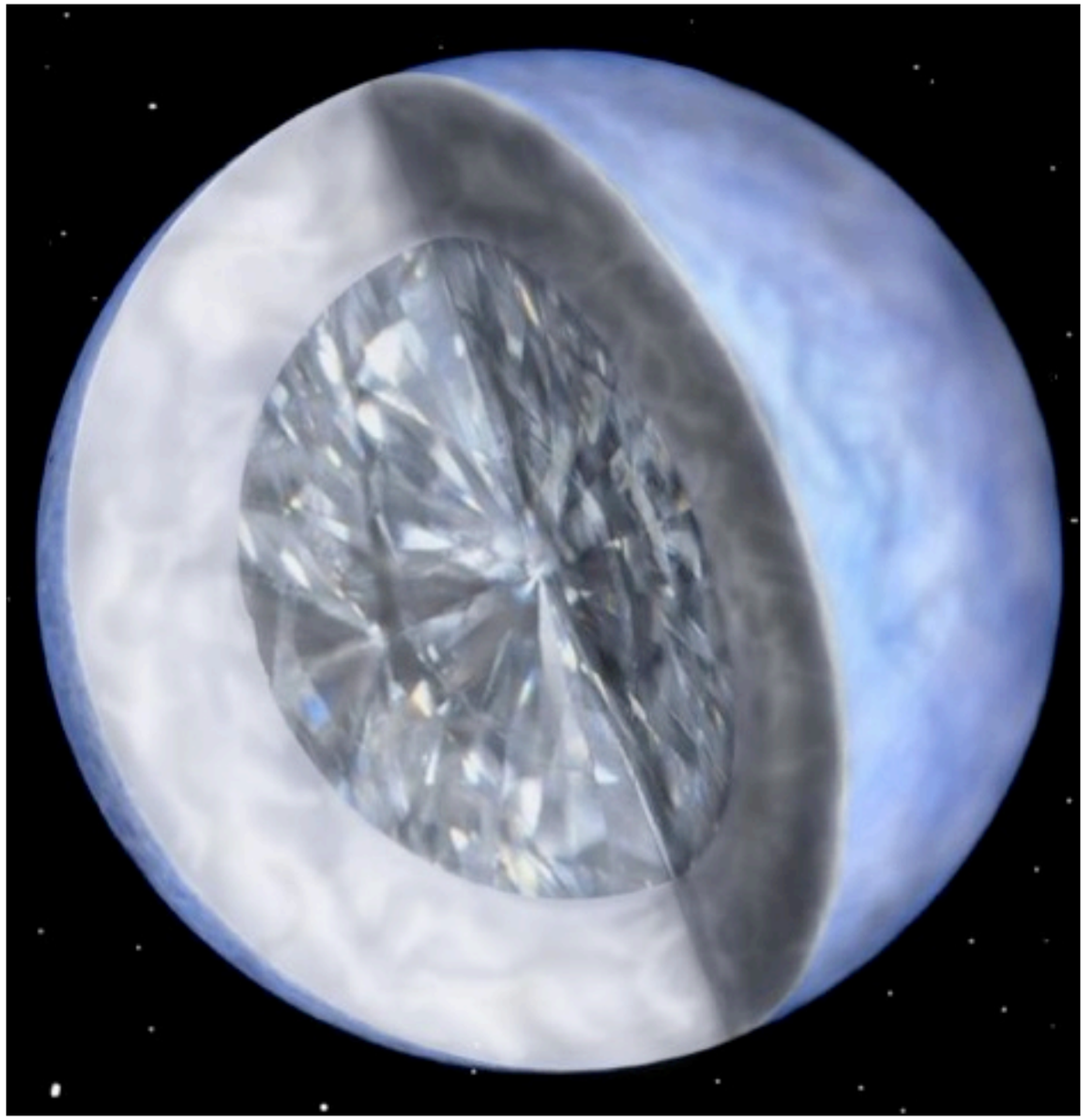
Stellar Diamonds!?!

- The interior of the white dwarf crystallizes due to the extreme pressures



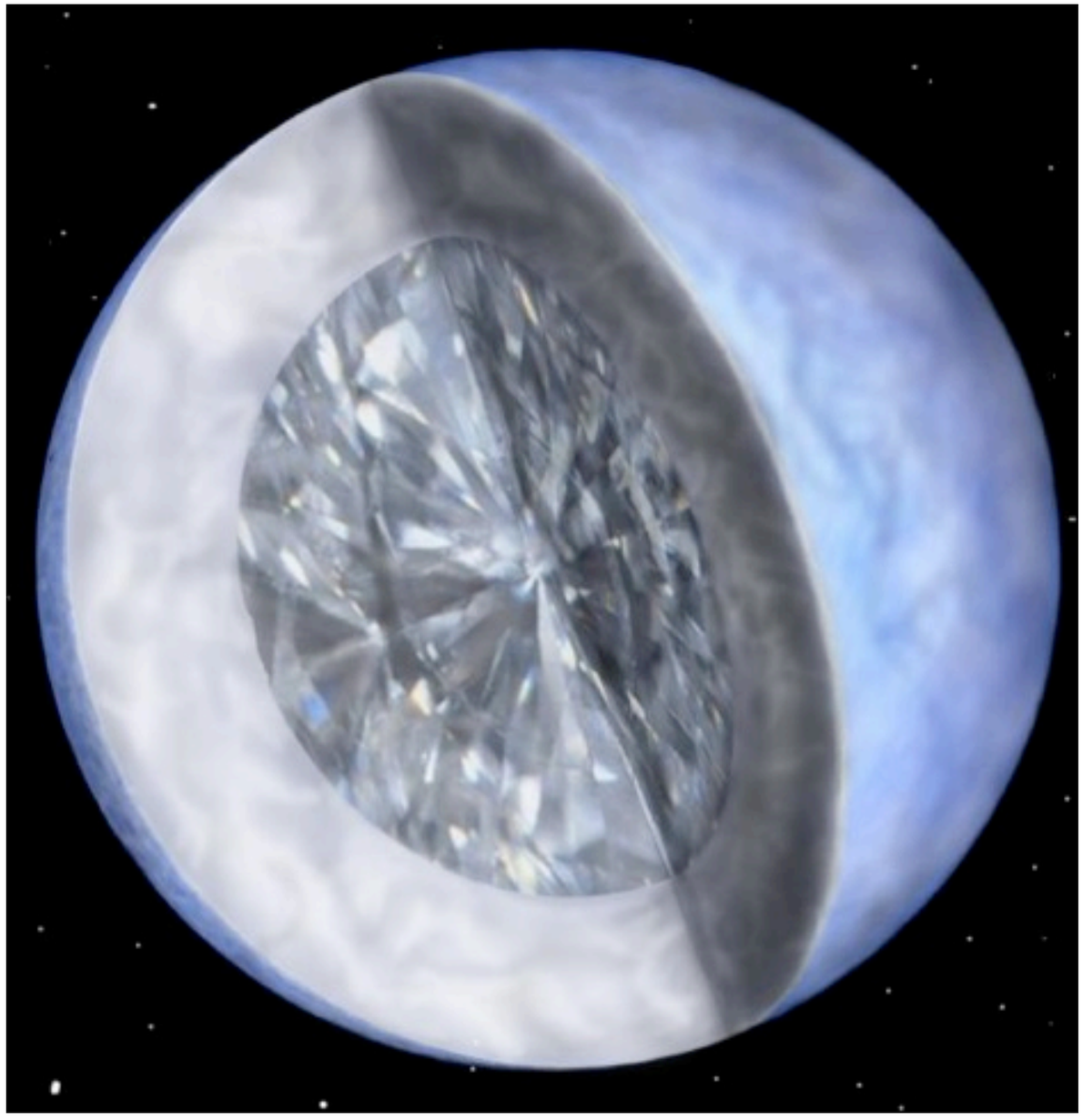
Stellar Diamonds!?!

- The interior of the white dwarf crystallizes due to the extreme pressures
- Made mostly of carbon (some oxygen)



Stellar Diamonds!?!

- The interior of the white dwarf crystallizes due to the extreme pressures
- Made mostly of carbon (some oxygen)
- Crystallized carbon = **a diamond**
  - With a blue-green tint from the oxygen
  - 10 billion trillion trillion carats!



Question

This is the way the Sun ends. This is the way the Sun ends, not with a bang but a

a) whimper; it just cools down over time.

b) supernova blasting heavy elements into space.

c) blackhole.

d) planetary nebula and a white dwarf that cools with time.

e) a helium flash.

Imagine

Imagine

- After being dropped into suspended animation in a Pizza accident a billion years ago, you awake to a crazy new world.
- Disregarding the signs warning people to stay underground, you wander outside and see that the Sun is only about 10% more luminous, but it is crazy hot and the oceans are shrinking.
- As you quickly succumb to heat stroke, you wonder what Leslie said about Solar Evolution so many years ago.

Imagine

Imagine

- After being transported forward in time after being hit by a spiraling phone booth six billion years ago, you awake to a crazy new world.
- The Sun is Red? And super hot.
- The entire Earth's surface is molten rock during the day, slightly cooling at night.
- As you burn in pain, you wonder what Leslie said about Solar Evolution so many years ago.