Astronomy 150:
Killer Skies

This Class (Lecture 15):
The Dying Sun

Next Class:
Computer Labs

HW4 due on Sunday!

Music: *Why Does the Sun Really Shine*– They Might Be Giants

Night Obs

- Dates:
  - Monday, Sept. 21st ✔
  - Tuesday, Sept. 22nd ✗
  - Wednesday, Sept. 23rd ✗
  - Thursday, Sept. 24th ✗
  - Monday, Sept. 28th ✗
  - Tuesday, Sept. 29th ✔
  - Wednesday, Sept. 30th ✔
  - Thursday, Oct. 1st ✗
  - Monday, Oct 5th
  - Tuesday, Oct 6th

Go to assignment page on class website for more info.

You **MUST** download worksheet before you go.

Can be cloudy, so check webpage before you go.

Question

Did you go to the Observatory yet?

a) Yes, it was okay.
b) Yes, it was cool!
c) Yes, it was the highlight of my life so far!
d) Yes, but it was boring.
e) No, but I will do so as soon as I can, I promise. I had other things I had to do, but I really, really want to go and I will make it a **top** priority in my life!

Computer Lab: 15% of Grade!

- Computer labs to look for real killer asteroids.
- Dates:
  - Monday Sept 28th ✔
  - Monday, Oct 5th
  - Monday, Oct 12th
- Places:
  - Nevada Labs
  - Oregon Labs

- Limited space each day, so you ***MUST*** have a reservation for that day and that lab!
- See Assignments webpage for more info and to sign up!
- Lectures are cancelled for those dates.

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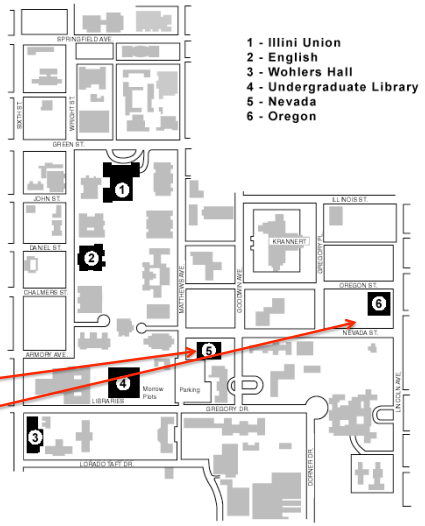


Outline

- The Sun runs out of fuel
  - Red Giant!
  - Horizontal Branch Star
  - Asymptotic Giant Branch
- The dead Sun— White Dwarf

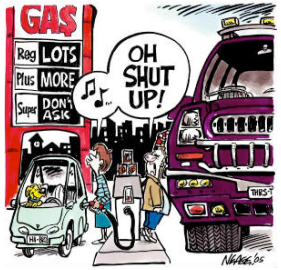
Important Questions

The Sun remains stable and on the main sequence as long as it has hydrogen to fuse in the core… it evolves and will likely kill all life on Earth, but up until now, it has still been on the main sequence.

- **How long will the fuel last?**
- **What happens when the fuel runs out? And how bad will it be for the Earth?**

How much Gas do we have left?

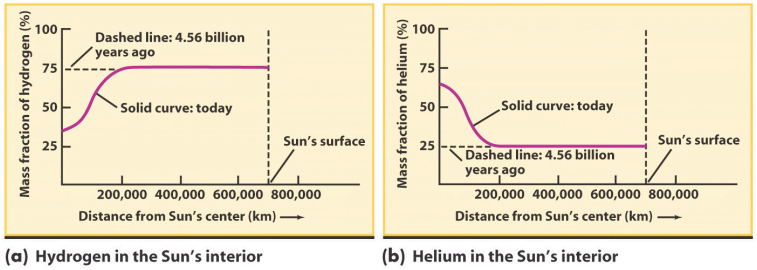
- Total energy available is easily calculated by mass of hydrogen in Sun and energy released by each hydrogen conversion.
- We only have about 6 billion years left!



http://skeptically.org/sitebuildercontent/sitebuilderpictures/.pond/suv-econ-gas-pump.jpg.w300h294.jpg

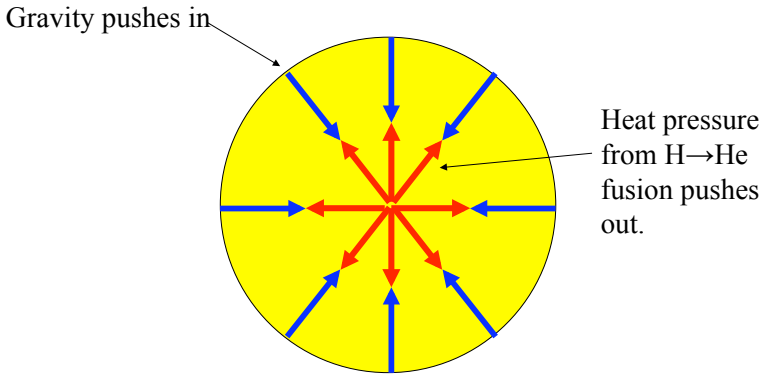
Hungry, Hungry Sun

- On the main sequence for ~11 billion years.
- The core is where fusion occurs- H ⇒ He
- Eventually, runs out of hydrogen in the core.
  - Rest of Sun is mostly hydrogen, but not in the core.
- And it's not hot enough to fuse helium!.....yet



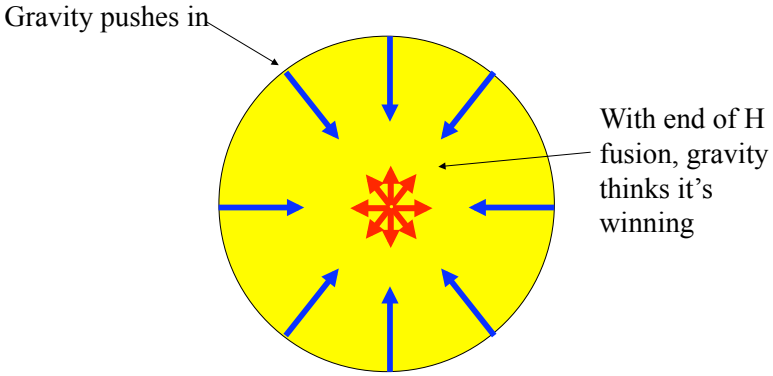
(a) Hydrogen in the Sun's interior (b) Helium in the Sun's interior

The Battle between Gravity and Pressure



Hydrostatic equilibrium: Balanced forces

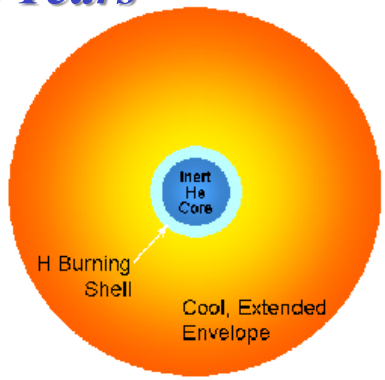
The Battle between Gravity and Pressure



Unbalanced forces

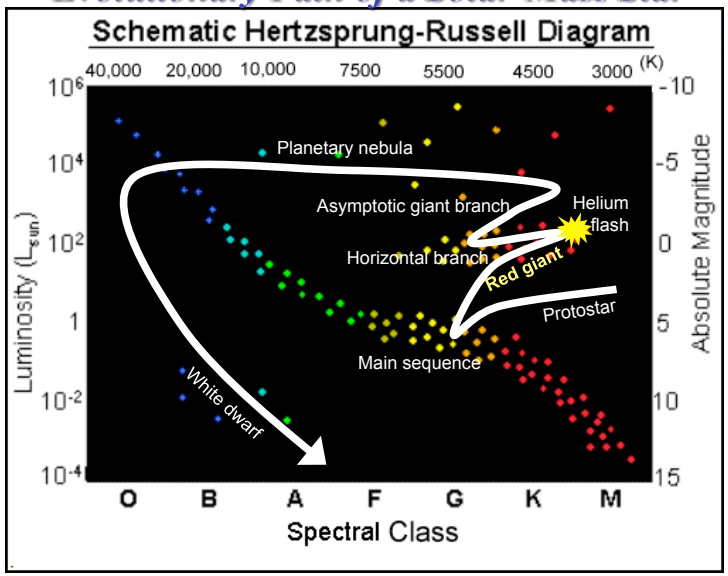
The Red Giant Phase: 6 Billion Years

- When the hydrogen is gone in the core, fusion stops
- Core starts to contract under its own gravity
- This contracting heats the core, and hydrogen fusion starts in a shell around the core
- Energy is released, expands envelope ⇒ Lum increases!
- As the envelope expands, it cools – so it becomes a **red giant**

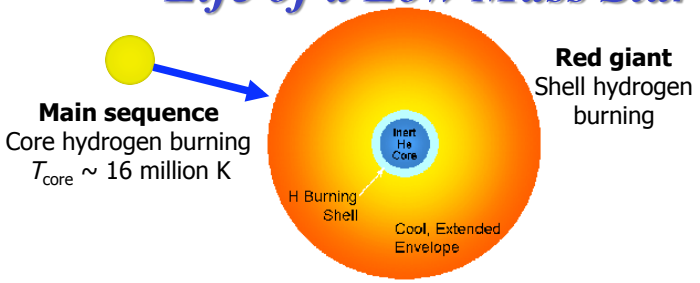


http://www.youtube.com/watch?v=kWY7mS1A_AM&feature=fvw

Evolutionary Path of a Solar-Mass Star



Life of a Low Mass Star



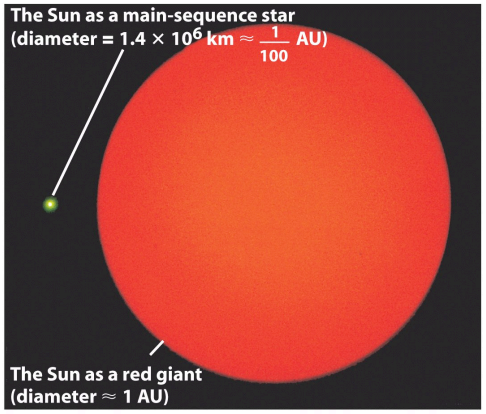
Question

As the Sun moves off the main sequence what happens in the core?

a) Hydrogen burning stops
b) Helium burning stops
c) TNT burning stops
d) We don't know, but it makes the Sun red.

In 6-7 Billion years

- The Sun will expand to 100-250 times bigger than it is now!
- The same mass but now it's bigger.



The Sun today and as a red giant

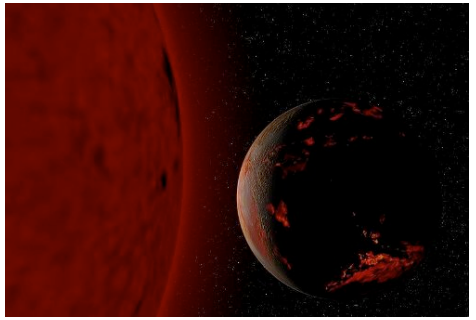
In 6-7 Billion years

- The surface gravity decreases and the Sun has more luminosity.
- The solar wind turns into a stellar wind, and it looses material as it expands, about 10^7 times more than now.
- It's blowing it all away!

http://www.astropix.com/wp/wp-content/uploads/2006/12/2006_02.JPG

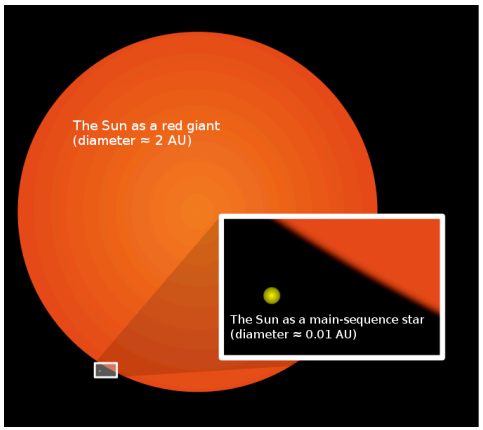
In 6-7 Billion years

- During the time it expands it loses a significant fraction of mass.
- So, the planets move outward.
- Planets race away as the Sun expands.
- Who wins?
- We aren't yet sure.



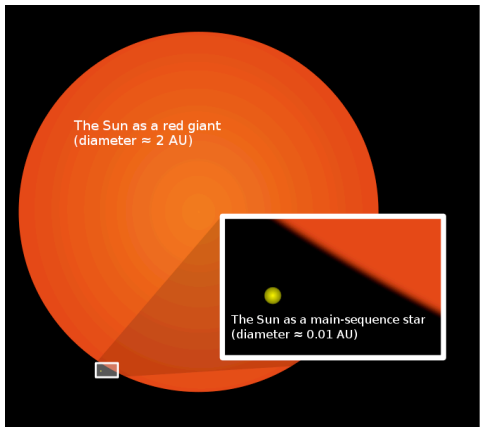
In 6-7 Billion years

- We use to think that the Sun would gobble the Earth.
  - Mercury gone
  - Venus probably gone
  - Earth?
- BUT even if not, with the Earth's oceans and atmosphere gone, crust still melts.
- Not good…



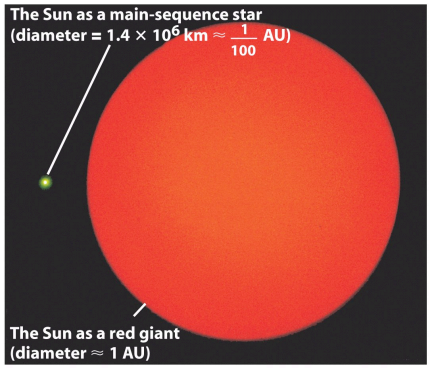
In 6-7 Billion years

- Mars?
  - For sure too hot.
- Jupiter's Moons?
  - Still too hot
  - Europa's water vaporizes
- Even the moons of Uranus and Neptune may be too hot.



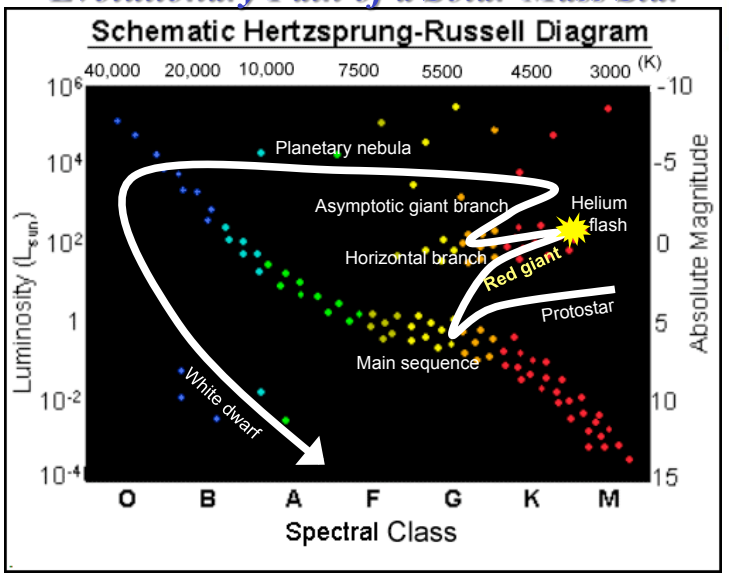
Mitigation

- We would have to move the Earth out to Pluto or further!
- Probably not possible.
  - Interactions with Jupiter may eject us from Solar System
- Even then, Sun no longer in equilibrium, may oscillate in size or brightness.
- BUT, we got billions of years to figure it out!

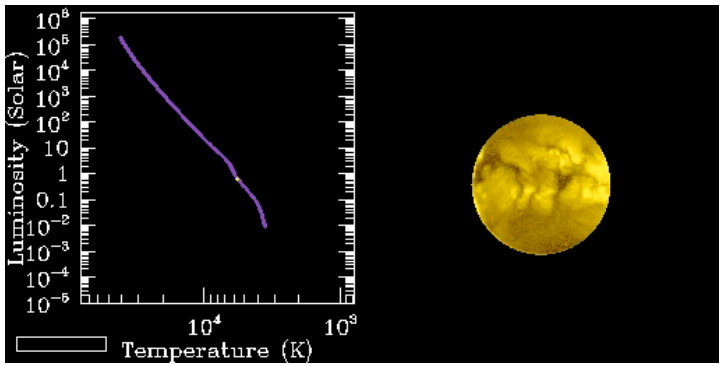


The Sun today and as a red giant

Evolutionary Path of a Solar-Mass Star



Evolutionary Path of the Sun

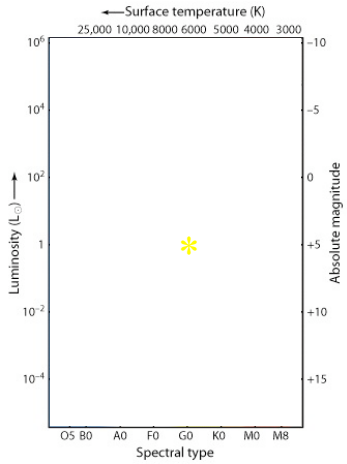


http://rainman.astro.uiuc.edu/ddr/stellar/index.html

Question

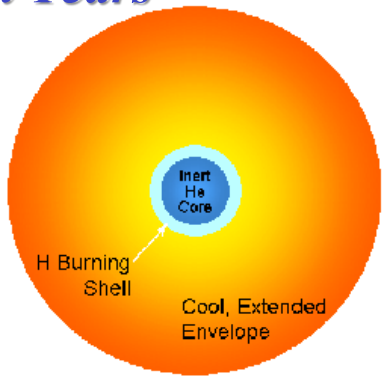
As the Sun evolves into a red giant, its position on the H-R diagram will move…

1. Up and to the left
2. Down and to the right
3. Down and to the left
4. Up and to the right



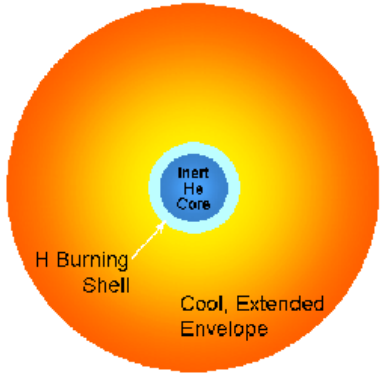
Contraction Junction: 7.7 billion Years

- The Sun is a huge red giant!
- In He core, contraction increases density & temperature
- Contraction slowed by Pauli exclusion principle: can't put two electrons in same state
- Quantum "degeneracy" pressure.



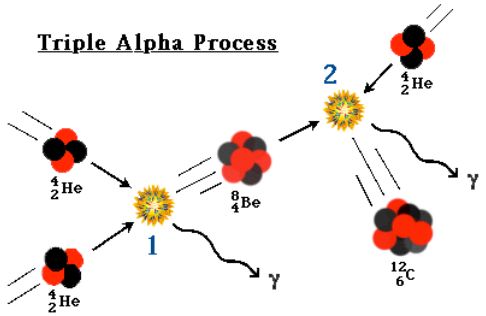
Contraction Junction

- Degenerate core and H burning shell
- Hotter, and hotter, and hotter until…
- 100 million degrees F
- Core heats ⇒ He fusion ignites
- He ⇒ C & O



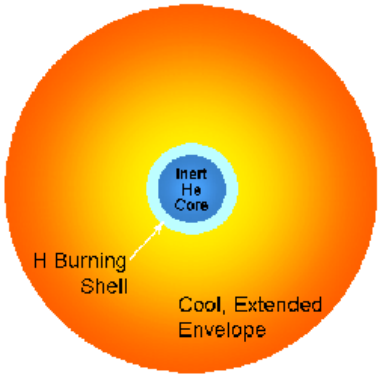
Helium Burning

- When the core of the star reaches 100 million degrees, it can start to fuse helium (the ash of hydrogen burning) into carbon
- Called the Triple-Alpha Process
  - Converts 3 heliums into one carbon + energy



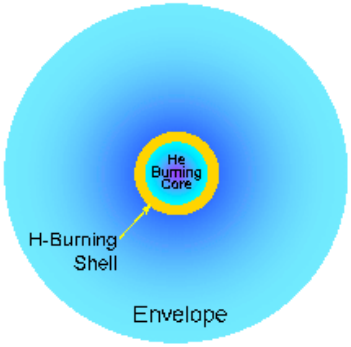
Helium Flash: 7.7 Billion Years

- Helium Flash (~few min)
- Note: explosion energy trapped in outer layers so don't see anything special from the outside
- As much energy released as all of the rest of the stars in the Galaxy.
- Core turns normal and it calms down.



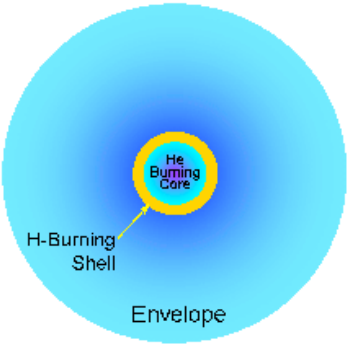
The Horizontal Branch

- Helium burning stabilizes the core
- 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
  - Also He burning is unstable



Mitigation

- If we moved the Earth, we have to move it back.
- Temperatures will drop out by Pluto.
- But our descendents 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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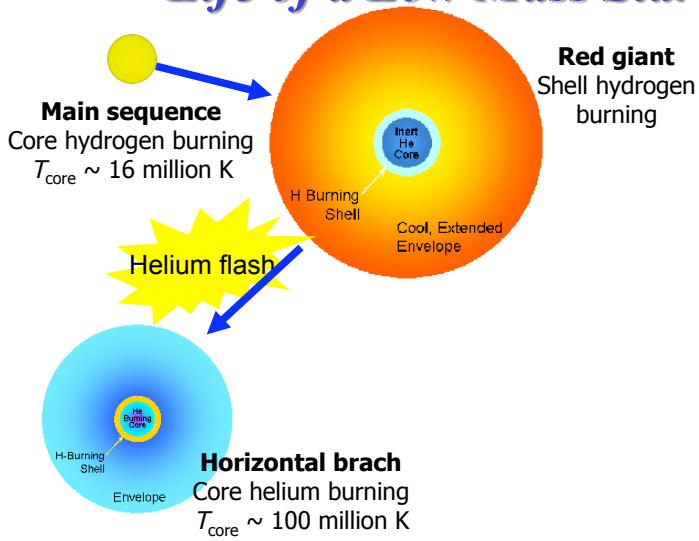
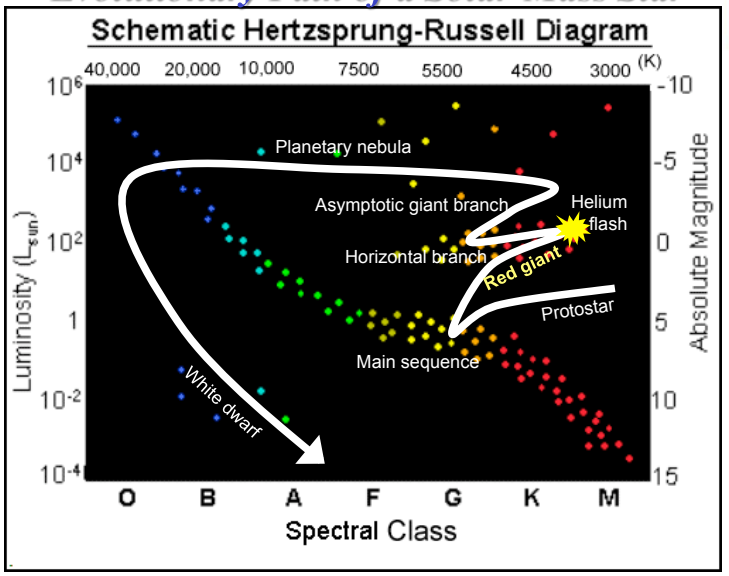
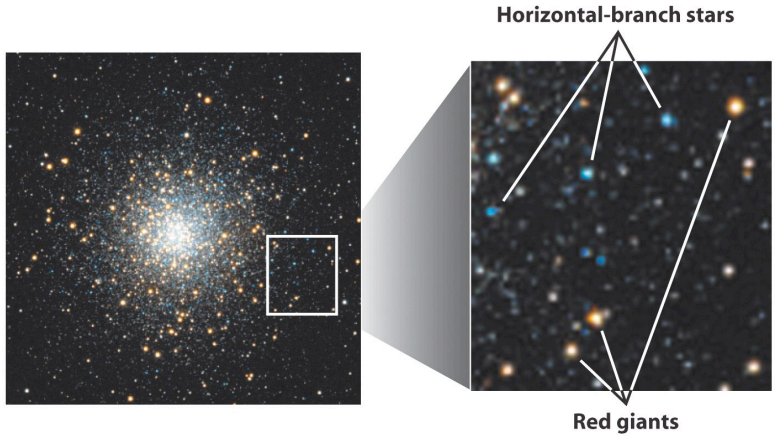


Evolutionary Path of a Solar-Mass Star

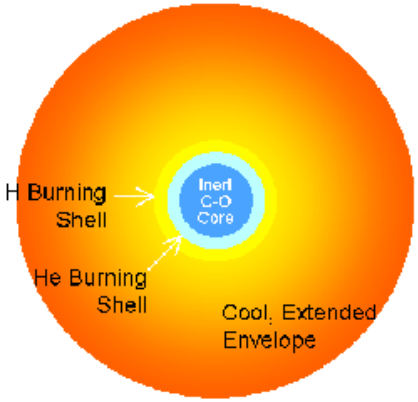


Aging Stars



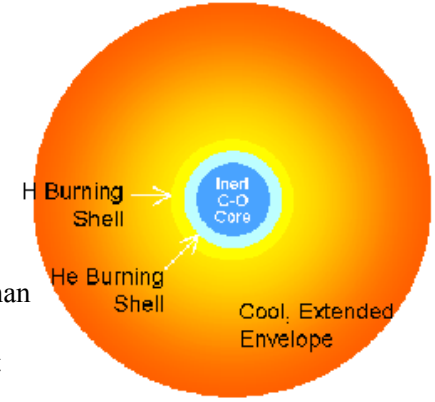
When Helium Runs Out… 7.8 Billion Years

- Fusion in the core stops – the helium has been converted to carbon and oxygen
- Stellar core collapses under its own gravity
- Shell starts fusing helium
- Star starts to grow and cool again



When Helium Runs Out… 7.8 Billion Years

- Called the ***asymptotic giant branch***
- Gets hotter again, have to move Earth back out
- But, expansion is quicker than before, 20 million years.
- Will get more luminous than last time!
- Considering what is about to happen, perhaps best to leave Solar System.



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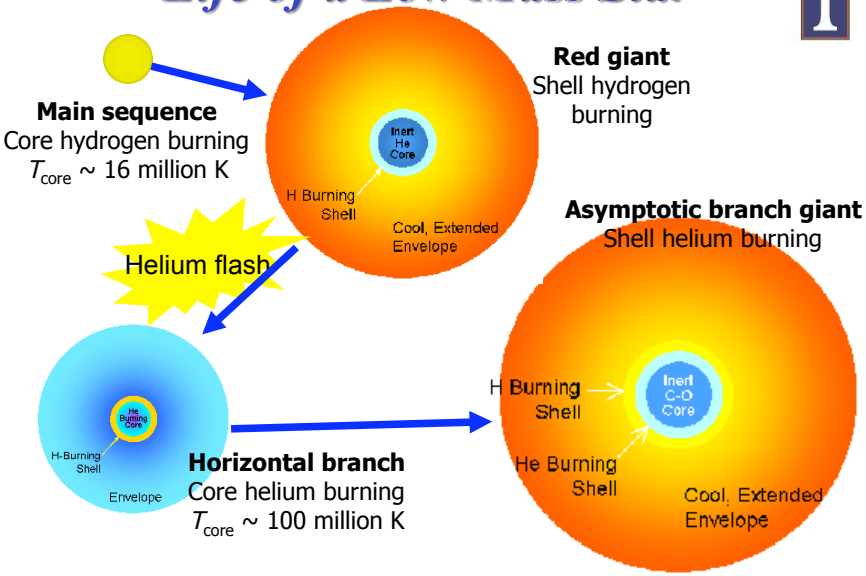
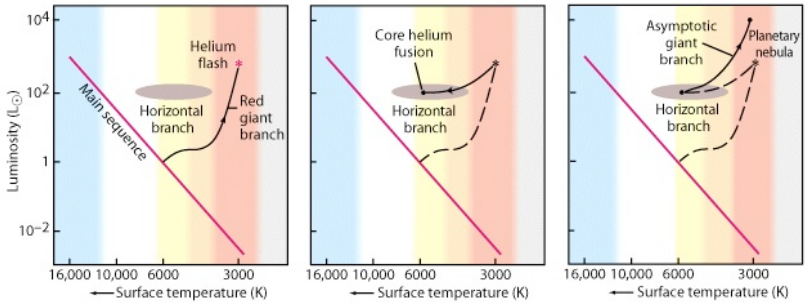


Evolutionary Path of a Solar-Mass Star



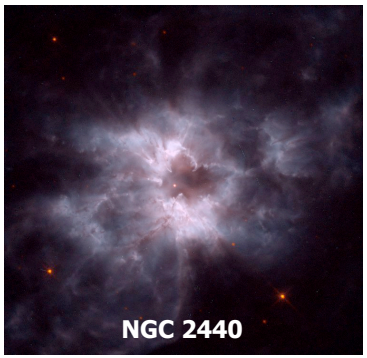
Question

As the Sun becomes an asymptotic giant branch star, what is happening in the central core of the Sun?

a) Hydrogen burning.
b) Helium burning.
c) TNT burning.
d) Nothing is burning, fusion has stopped.
e) We don't know, but it makes the Sun red.

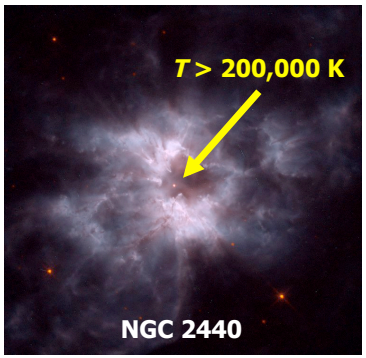
End Game

- At these last stages, the Sun will likely oscillate in size and temperature.
- This is messed up and creates a "Superwind"
- Outer layers of the red giant star are cast off
  - Up to 80% (at least 50%) of the star's original mass

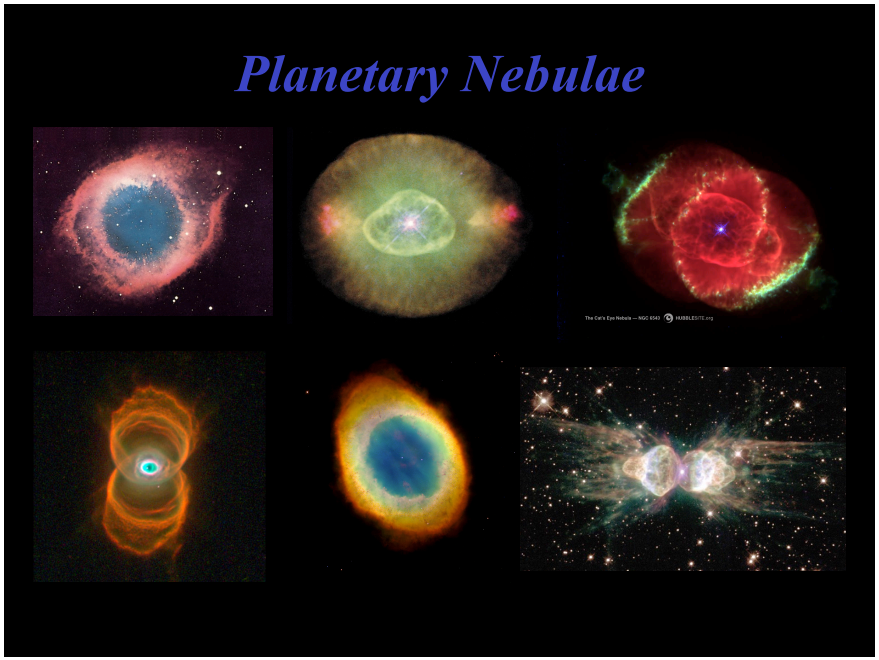


End Game

- "The core remains, made of carbon/oxygen "ash" from helium fusion
  - The core is very hot, above 200,000 K
- Ultraviolet radiation from the core ionizes the cast off outer layers
  - Becomes a *planetary nebula*
  - *Unfortunate name, but some of the most beautiful objects in the sky.*



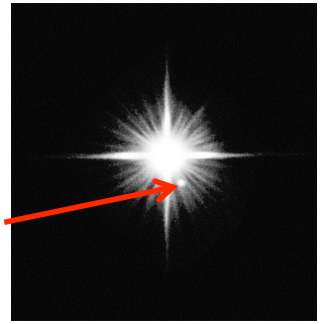
Planetary Nebulae



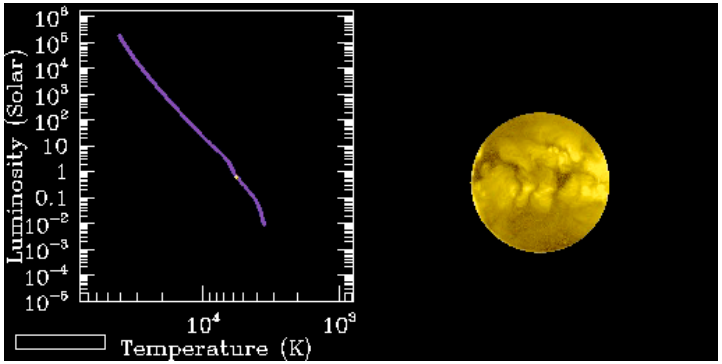
What About the Core?

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

Sirius B



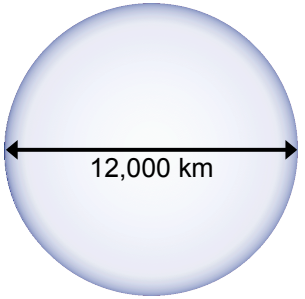
Evolutionary Path of the Sun



http://rainman.astro.uiuc.edu/ddr/stellar/index.html

What About the Sun's Core?

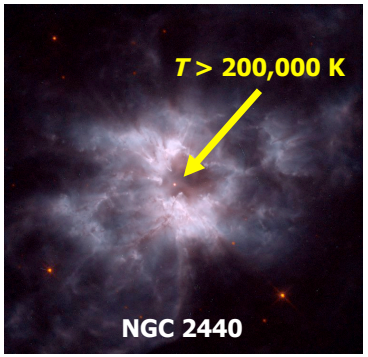
- Nuclear fusion has **stopped**, and gravity begins to win the battle
- Core contracts to the size of the Earth
  - But its about 60% the Sun's mass!
  - Material in the core is compressed to a density of 1,000 kg/cm^3!
  - Very hot, surface temperature >100,000 K



but will usually weigh about 0.6 Solar masses

What Happens to Earth?

- We have detected planets around white dwarfs, but they have presumable have 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.



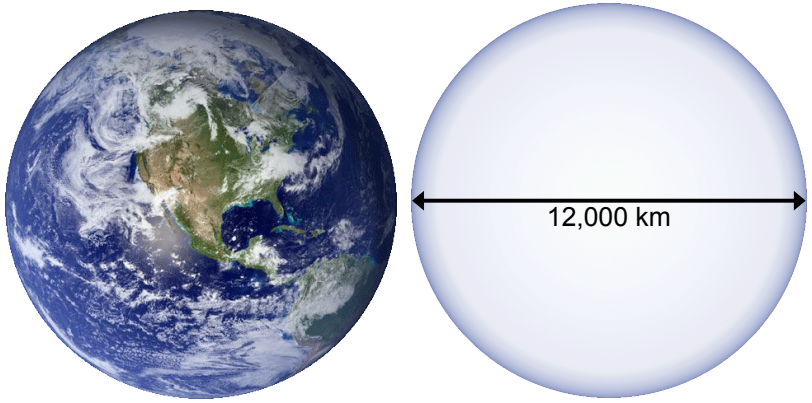
Electron Degeneracy

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

Matter in the core of a normal star

Electron-degenerate matter
1 ton per cubic cm

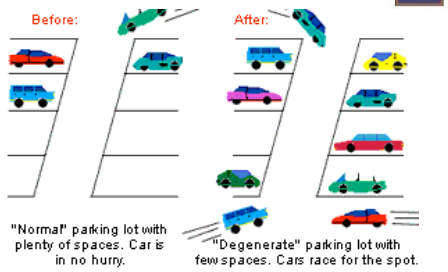
Relative Size of White Dwarf

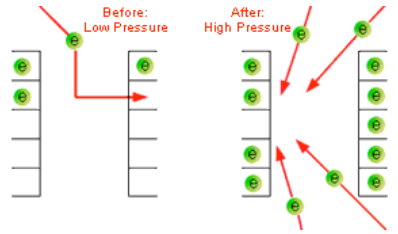


White dwarf– but will usually weigh about 0.6 Solar masses

Degeneracy Pressure

- Electrons are forced into higher energy levels than normal – all of the lower levels are taken
- Effect manifests itself as pressure





NASA

Chandrasekhar limit

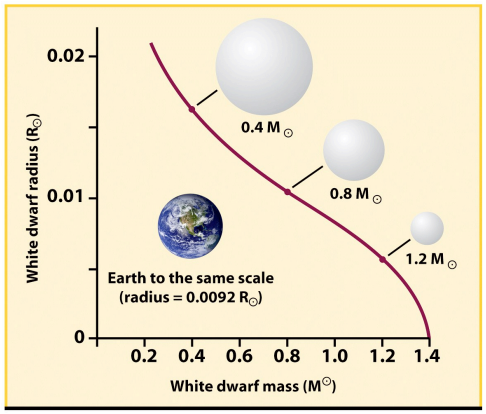
- Maximum mass of a white dwarf.
  - 1.4 solar masses!
- No white dwarf observed is over this.
- If mass is higher, the white dwarf can not support itself with electron degeneracy, and it collapses more!
- Gravity is a harsh mistress!
  - More of this latter.

Subrahmanyan Chandrasekhar 1910-1995

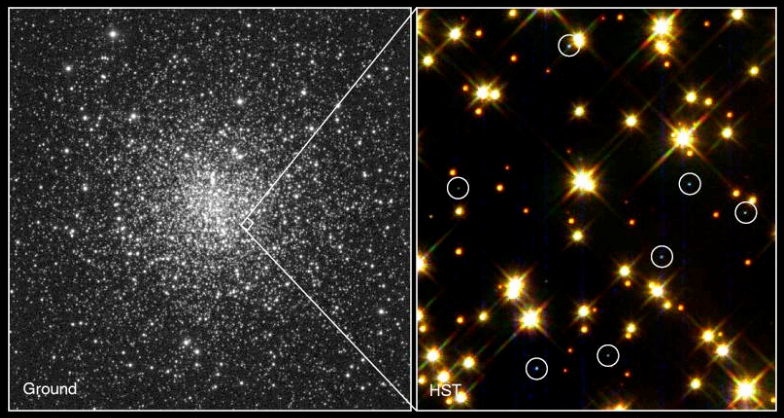
White Dwarfs are Weird

The more massive, the smaller!

Their radius *decreases* with mass!



White Dwarves!

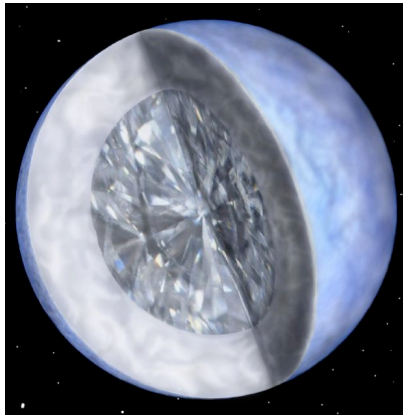


White Dwarf Stars in M4 HST • WFPC2

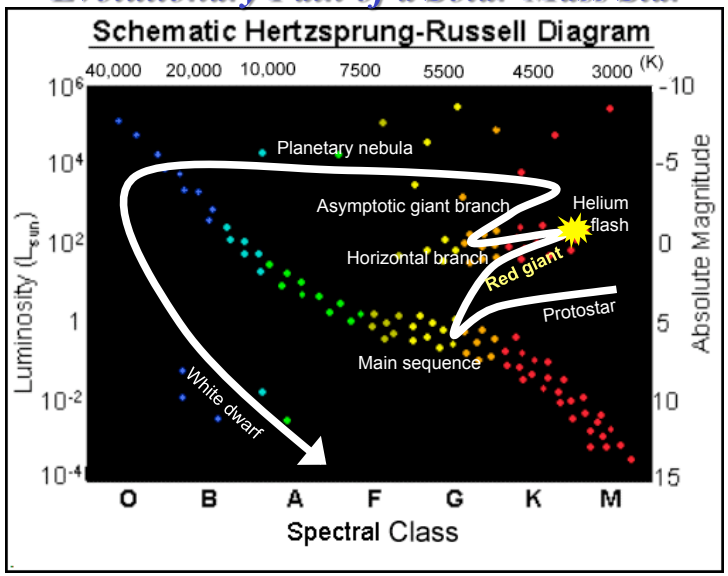
PRC95-32 · ST ScI OPO · August 28, 1995 · H. Bond (ST ScI), NASA

Stellar Diamonds!?!

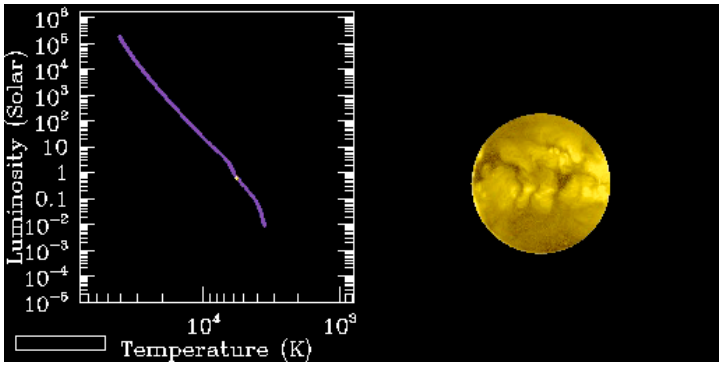
- The interior of the white dwarf crystallizes due to the extreme pressures
- Made mostly of carbon (some oxygen)
- Crystallized carbon = **a diamond**
  - With a blue-green tint from the oxygen
  - 10 billion trillion trillion carats!



Evolutionary Path of a Solar-Mass Star



Evolutionary Path of the Sun



http://rainman.astro.uiuc.edu/ddr/stellar/index.html

Question

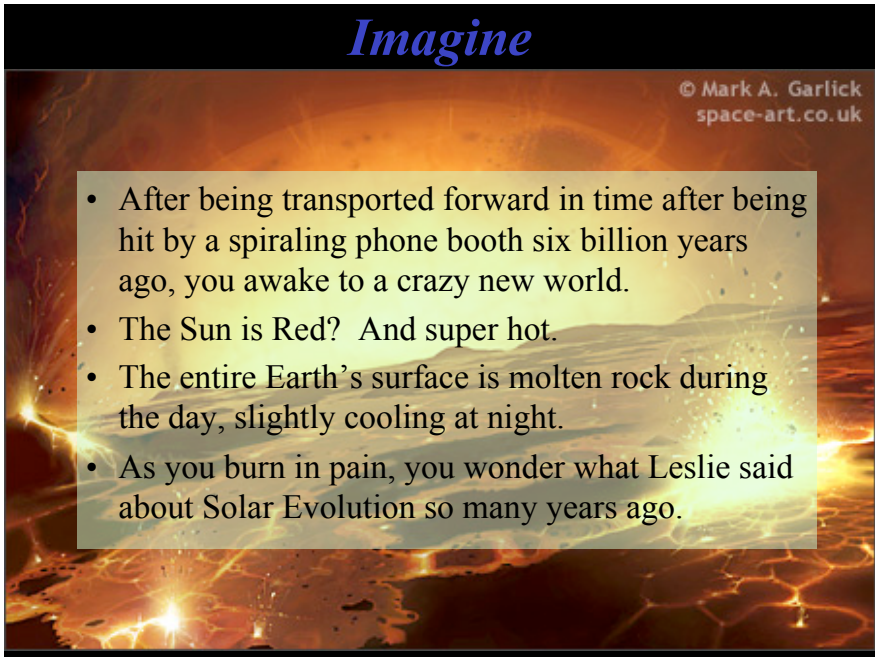
This is the way the Sun ends. This is the way the Sun ends, not with a bang but a

a) whimper; it just cools down over time.
b) supernova blasting heavy elements into space.
c) blackhole.
d) planetary nebula and a white dwarf.
e) a helium flash.

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



- 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.