ET Life

This class (Lecture 8):

Origin of C,O, and N

Next Class:

Star Formation

HW 3 is due Wed.

Music: *Here Comes the Sun* – The Beatles

Website

- The domain uiuc.edu is no longer valid.
- So, the correct class website is:

http://eeyore.astro.illinois.edu/~lwl/classes/astro330/spring10/

Drake Equation

The class's first estimate is

Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	9 stars/yr	systems/star	planets/system	life/planet	intel./life	comm./intel.	yrs/comm.

Outline

- Sneaky little neutrinos (proof of fusion)
- C and O for the first time (1^{st} gen of stars)
- N for the first time (2^{nd} gen of stars)

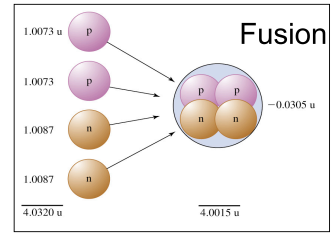
What is Fusion?

$$4p \rightarrow {}^4\mathrm{He}\ (2p, 2n)$$

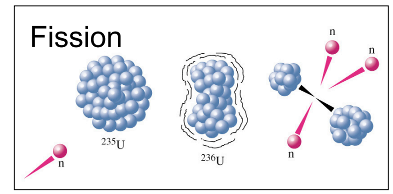
Basic idea is to take 4 protons (ionized hydrogen atoms) and slam them together to make an ionized helium atom.

Fusion vs. Fission

- Light nuclei: fusion
  - Fuse together light atoms to make heavier ones
  - Happens in the Sun
  - H-Bomb

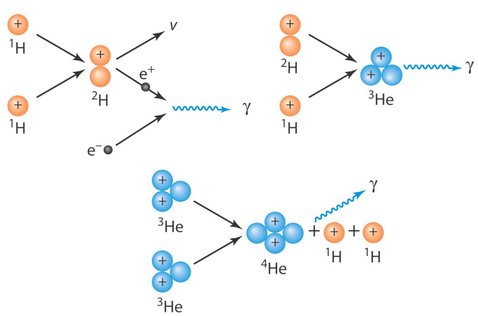


- Heavy nuclei: fission
  - Break apart heavier atoms into lighter ones
  - Used in power plants
  - A-Bomb



Nuclear Fusion in the Sun's Interior

- Proton-Proton Chain
  - 4 hydrogen atoms fuse to make 1 helium atom
  - Requires very high density and temperature (at least 7 million K)

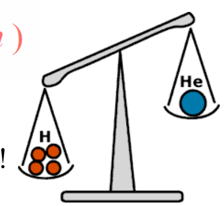


The Proton-Proton (p-p) Chain

Why does fusion release energy?

Fusion: $4p \rightarrow {}^4\mathrm{He}\ (2p, 2n)$

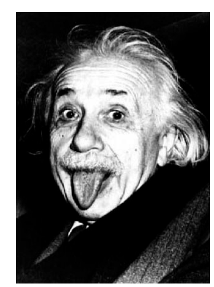
Fact: **4m(*p*) > m(^{4}He)** !
<u>mass of whole < mass of parts</u>!



Einstein says ***E* = *mc*^{2}**:

- Mass is a form of energy!
- Each ^{4}He liberates energy:

$$E_{\mathrm{fusion}} = m_{\mathrm{lost}}c^2 = 4m(p)c^2 - m({}^4\mathrm{He})c^2 > 0!$$

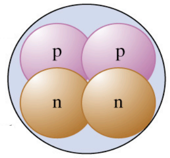


The Nucleus

- Okay, so we know that the nucleus can have numerous protons (+'s) very close.

Helium

- **Something is odd here!**
- **What is it?**

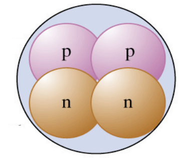


The Nucleus

- **Discuss with neighbor. Click C on your iclicker when done.**

Helium

- **Something is odd here!**
- **What is it?**

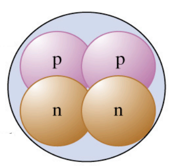


The Nucleus

- **Why doesn't the nucleus of the atom fly apart?**

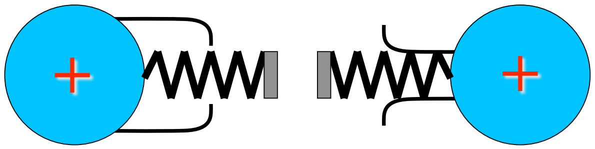
Helium

- **Something is odd here!**
- **What is it?**



4 Fundamental Forces

- Gravity
- Electromagnetic
- **Strong Nuclear**
  - **The strongest of the 4 forces**
  - **The force which holds an atom's nucleus together, in spite of the repulsion between the protons.**
  - **Does not depend on charge**
  - **Not an inverse square law– very short range.**
- Weak Nuclear



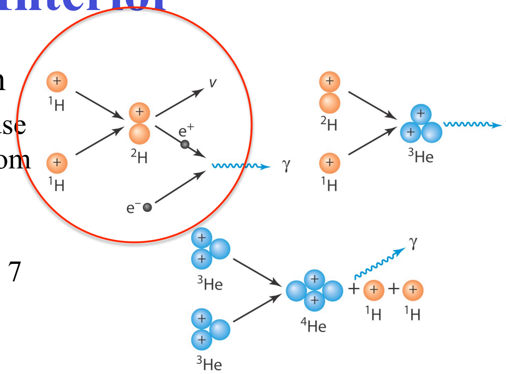
Question

Why does the Sun shine?

a) Nuclear burning.
b) Nuclear burning of helium to carbon.
c) Nuclear burning of dreams to pure energy.
d) Nuclear burning of hydrogen to helium.
e) Nuclear burning of carbon to helium.

Nuclear Fusion in the Sun's Interior

- Proton-Proton Chain
  - 4 hydrogen atoms fuse to make 1 helium atom
  - Requires very high density and temperature (at least 7 million K)



The Proton-Proton (p-p) Chain

http://www.youtube.com/watch?v=Czbh_sdqX84

Nuclear Reactions in the Sun

- Chain: 4 protons helium
- First step in chain (2 protons combine):

$$p + p \rightarrow [np] + e^+ + \nu$$

- Start with 2 particles (protons)
- End up with 4 particles (two of which are glued together)
- Each product is very interesting in its own right....

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^+ + \nu$$

$[np]$ = **deuterium**

- 1 proton + 1 neutron bound together into nucleus of element…
- Hydrogen, but has neutron, so 2 times mass of normal H
  - "Heavy Hydrogen"
- Simplest composite nucleus

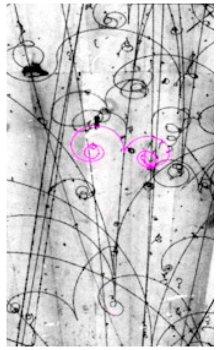
Discovery of D in lab: ***Nobel Prize***
about 0.01% of all H on earth is D
✓ including in your body:
you contain about 10 kilos (20 lbs) of H, and about 2 grams of D
✓ Water (normally H_2O) with D is D_2O : "heavy water"

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^{+} + \nu$$

e^{+} = **positron**

- Exactly the same as electron but charge **+1**
- **Antimatter**
- Combines with normal e^{-}
  - Both are gone, release of energy
  - ***Annihilation***



Discovery of positron in lab: ***Nobel Prize***
Because of this reaction

➢ The Sun contains a small amount of antimatter!

Nuclear Reactions in the Sun

$$p + p \rightarrow [np] + e^{+} + \nu$$

ν (Greek letter "nu") = **neutrino**

- Particle produced in nuclear reactions ***only***
- Tiny mass: $m(\nu) < 10^{-6} m(e)$!
- Moves at nearly the speed of light
- ***Very*** weakly interacting

Discovery of neutrino in lab: ***Nobel Prize***

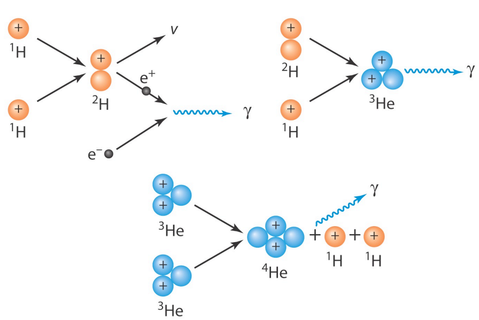
10 billion from Sun go through hand every sec

➢ Reach out!

➢ Go through your body, Earth, but almost never interact

Nuclear Fusion in the Sun's Interior

- Proton-proton in stars like the Sun
  - Hydrogen fused to make helium
  - 0.7% of mass converted to energy



The Proton-Proton Cycle

They Might Be Giants
Why Does The Sun Shine

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot, the Sun is not
A place where we could live
But here on Earth there'd be no life
Without the light it gives

We need its light
We need its heat
The Sun light that we seek
The Sun light comes from our own Sun's atomic energy

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where hydrogen is built into helium
At a temperature of millions of degrees

The Sun is hot

The Sun is so hot that everything on it is a gas: Aluminum, Copper, Iron, and many others

The Sun is large... If the sun were hollow, a million Earth's would fit inside
And yet, it is only a middle-sized star

The Sun is far away... About 93,000,000 miles away
And that's why it looks so small

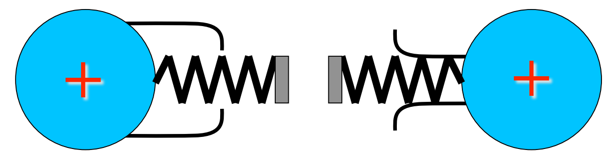
But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

Scientists have found that the Sun is a huge atom smashing machine
The heat and light of the sun are caused by nuclear reactions between Hydrogen, Nitrogen, Carbon, and Helium

The Sun is a mass of incandescent gas
A gigantic nuclear furnace
Where Hydrogen is built into Helium
At a temperature of millions of degrees

Why Nuclear Fusion Doesn't Occur in Your Coffee

- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time



Question

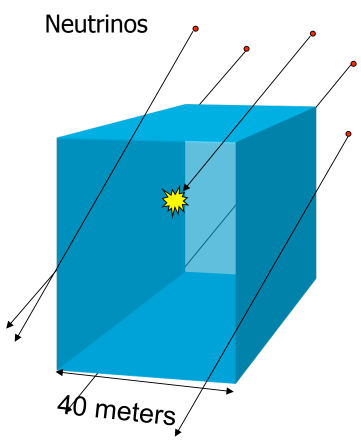
What force allows fusion to work?

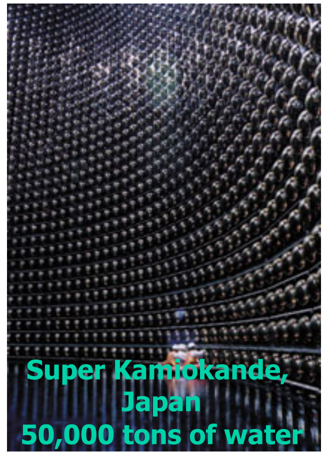
a) The Force.
b) Nuclear Strong Force.
c) Nuclear Weak Force.
d) Fusion Force.
e) Electromagnetic Force

Sneaky Little Neutrinos

- The Sun's nuclear fusion produces a particle called a *neutrino*
- Matter is almost transparent to neutrinos
- On average, it would take a block of lead over a quarter of a light-year long to stop one
- Roughly 1 billion pass through every square centimeter of you every second!

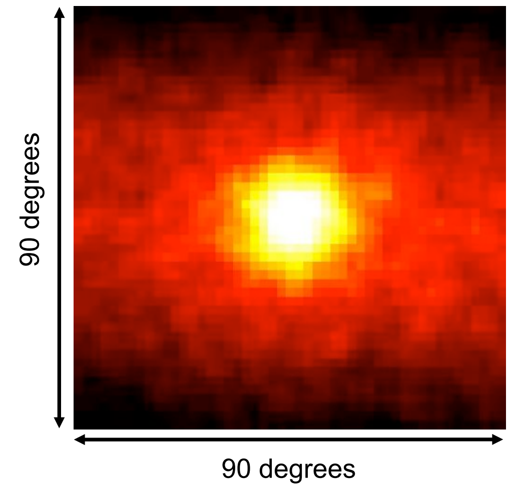
Detecting Neutrinos





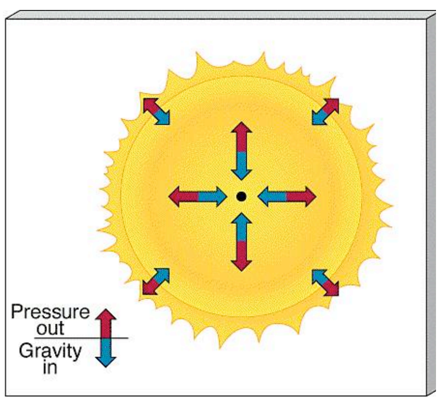
The Sun in Neutrinos

- **Confirmation** that nuclear fusion is happening in the Sun's core
- 500 days of data
- As they can only be produced by nuclear processes, our energy source concept must be fundamental



Why Doesn't The Sun Shrink?

- Sun is currently stable
- Pressure from the radiation created by fusion balances the force of gravity.
- Gravity is balanced by pressure from fusion!



Alf Doesn't Care?

- A star in hydrostatic equilibrium will not shrink or swell.
- It will maintain constant size, density, and temperature for more than a million years!
- At this point, the star is called a main sequence star.
  - MS is when a star burns H into He
- If stars were not constant, what effect would that have on life on orbiting planets. Ultraviolet light variations?

http://alf.disim.com/photos/photoposter.htm

Cosmic Gall

very little

NEUTRINOS, they are very small.
They have ~~no~~ charge and have ~~no~~ mass
hardly
And ~~do not~~ interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold shoulder steel and sounding brass,
Insult the stallion in his stall,
And scorning barriers of class,
Infiltrate you and me! Like tall
and painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
and pierce the lover and his lass
From underneath the bed-you call
It wonderful; I call it crass.

- *Telephone Poles and Other Poems*, John Updike, Knopf, 1960

Think-Pair-Share

If we could sustain fusion in the lab we could meet humankind's energy needs nearly forever! Why is it so difficult to achieve this, when stars do it every day?

Important Questions

The Sun remains stable and on the main sequence as long as it has hydrogen to fuse in the core… it will evolve and will kill all life on Earth after all the fuel is gone.

How long will the fuel last? What happens when the fuel runs out?

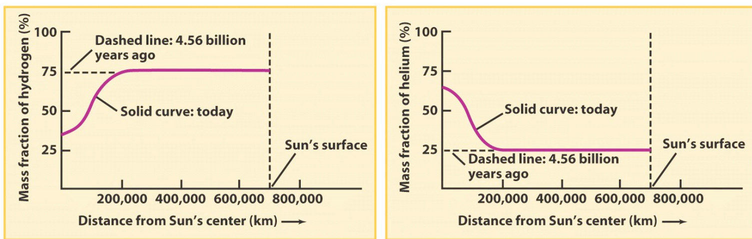
How much Gas do we have left?

- 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

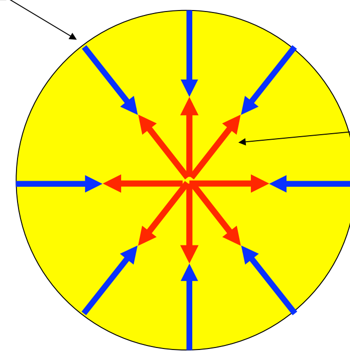
- On the main sequence for ~11 billion years.
- The core is where fusion occurs- H ⇒ He
- Eventually, runs out of hydrogen in the core.
  - Rest of Sun is mostly hydrogen, but not in the core.
- And it's not hot enough to fuse helium!.....yet



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

The Battle between Gravity and Pressure

Gravity pushes in

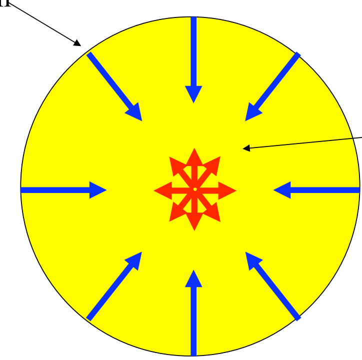


Heat pressure from H→He fusion pushes out.

Hydrostatic equilibrium: Balanced forces

The Battle between Gravity and Pressure

Gravity pushes in



With end of H fusion, gravity thinks it's winning

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 ⇒ brightness increases!
- As the envelope expands, it cools – so it becomes a **red giant**

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

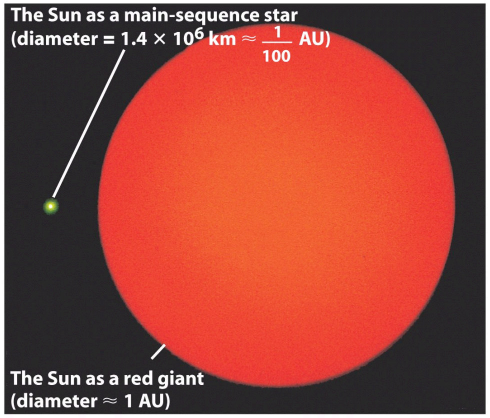
Question

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

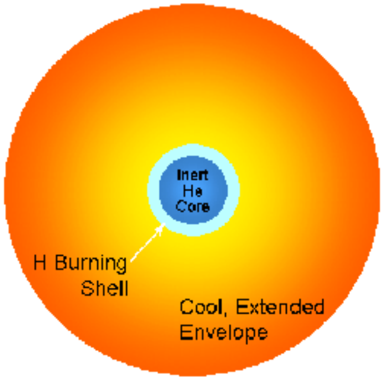
- The Sun will expand to 100-250 times bigger than it is now!
- The same mass but now it's bigger.



The Sun today and as a red giant

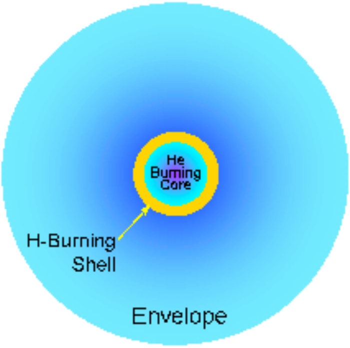
Contraction Junction

- Core gets hotter, and hotter, and hotter until…
- 100 million degrees F
- Core heats ⇒ He fusion ignites
- He ⇒ C & O



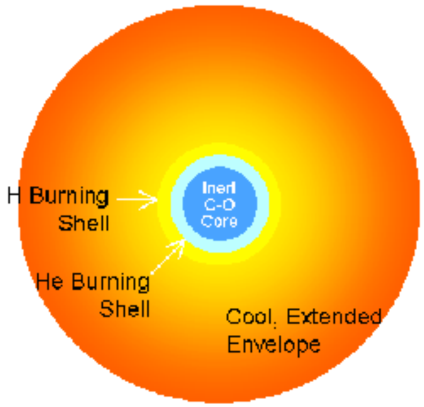
The Horizontal Branch

- 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

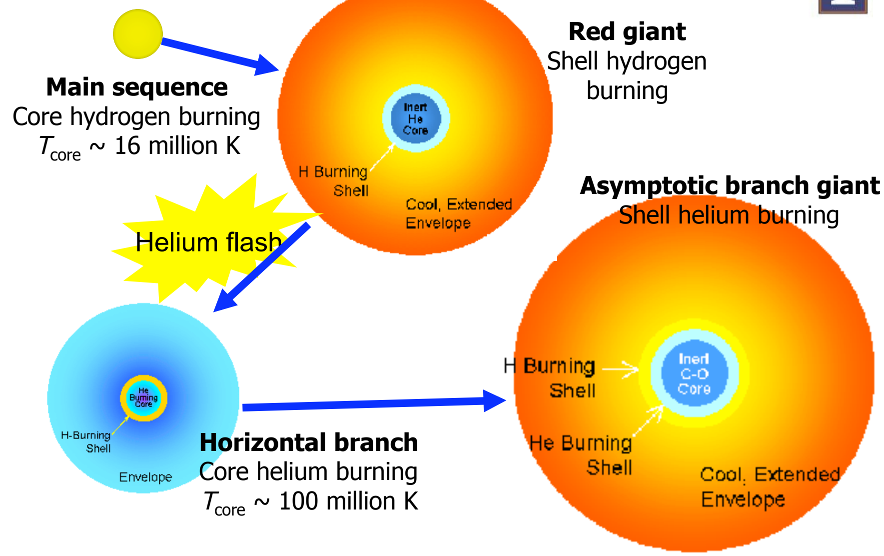


When Helium Runs Out… 7.8 Billion Years

- 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
- Called an ***asymptotic giant branch*** star



Life of a Low Mass Star



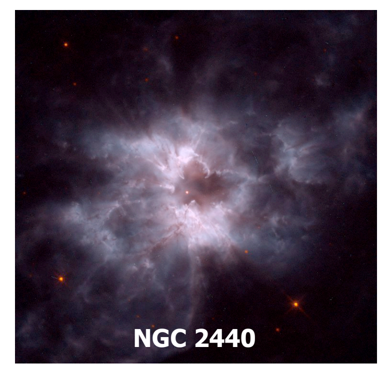
Question

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.

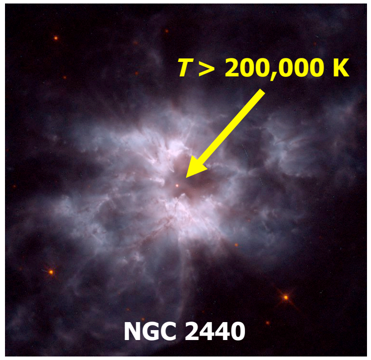
End Game

- 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

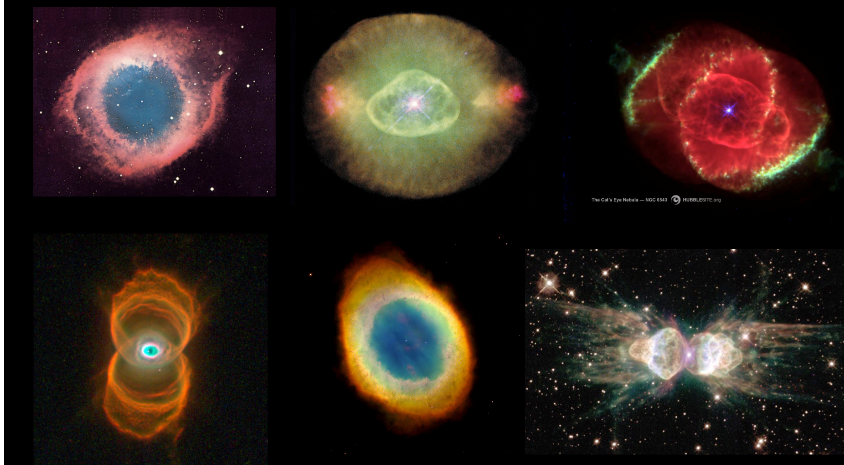


End Game

- "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.*



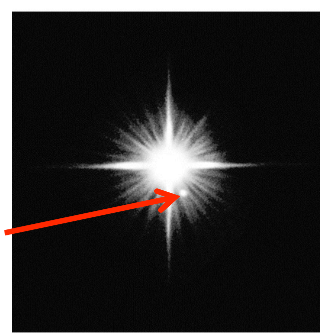
Planetary Nebulae



What About the Core?

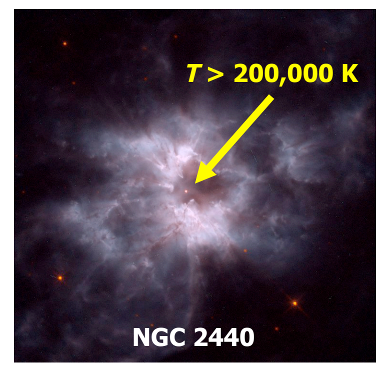
- Final fate - **White dwarf**
  - Slowly cools off over billions of years
  - Just a hot body
  - No fusion
  - Not really a star in some ways
  - Size of the Earth

Sirius B



What Happens to Earth?

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



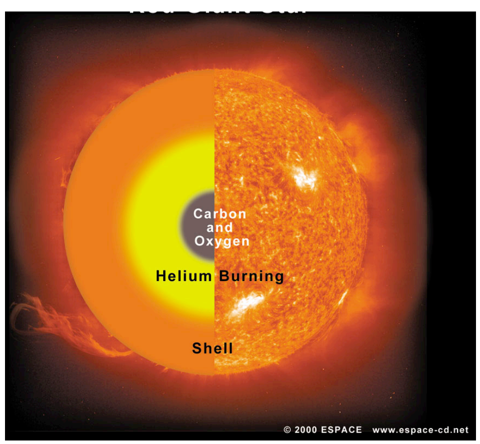
Question

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

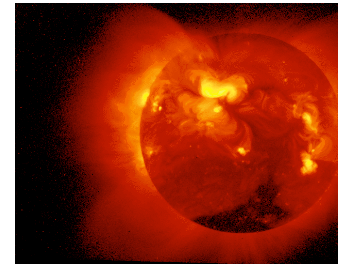
a) whimper; it just cools down over time.
b) supernova blasting heavy elements into space.
c) blackhole.
d) planetary nebula and a white dwarf.
e) a helium flash.

The First Stars

- In the cores of the first stars, it gets hot enough for nuclear fusion.
- In the internal furnace of these first stars is where <u>carbon and oxygen are created for the first time in the Universe</u>.
- Higher density and temperature of the red giant phase allows for the <u>creation of sulfur, phosphorous, silicon, and finally iron</u>.



Nuclear Fusion in the First Stars



- Core $T > 10$ million K
  - Violent collisions
  - e^- stripped from atoms (ionized)
  - Nuclei collide, react
    - They get close enough that the nuclear strong force takes over.
- Thru series (chain) of reactions
- <u>4 protons → helium (2p,2n) nucleus + energy</u>
- **Fusion:** light nuclei combine → heavier nuclei