# Astronomy 330

<u>This class (Lecture 7):</u>

Making C,O, and N

<u>Next Class:</u>

Star Formation

**HW 3 due Wednesday.**

Music: *Sonne*– Rammstein

# Drake Equation HW #1 Result

**= 5840**

N =

# of advanced civilizations we can contact in our Galaxy today

# Grouped

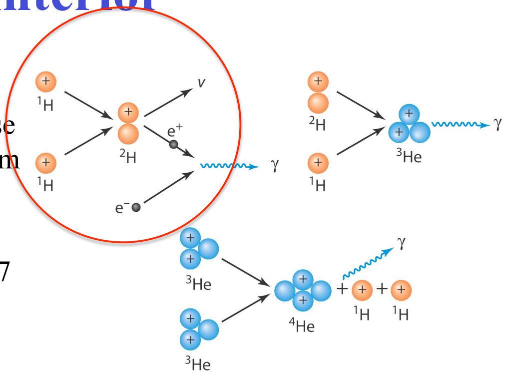
- We spent last week discussing the End of the Universe.
- In groups of 3-4, try to write a 3-4 sentence discussion of the End of the Universe for a non-science major friend.

# 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)
- Molecules are for lovers!

# 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

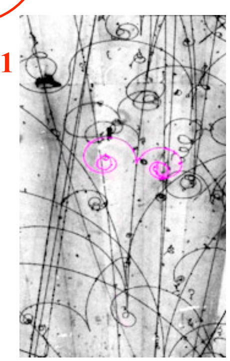
Discovery of D in lab: ***Nobel Prize***
about 0.01% of all H on earth is D
✓ including in your body:
you contain about 10 kilos (20 lbs) of H, and about 2 grams of D
✓ Water (normally $H_2O$) with D is $D_2O$ : "heavy water"

# 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

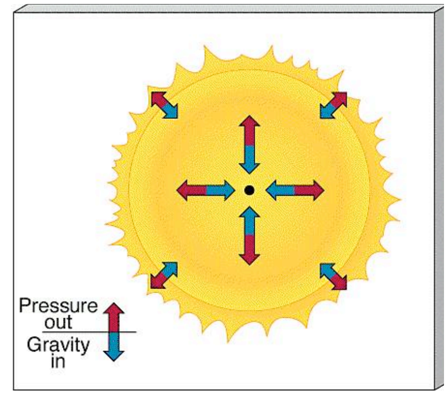
Discovery of neutrino in lab: ***Nobel Prize***

10 billion from Sun go through hand every sec

- Reach out!
- Go through your body, Earth, but almost never interact

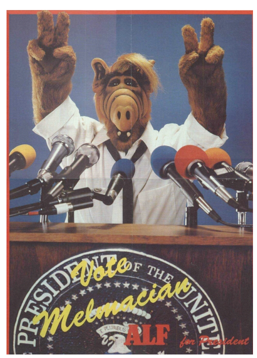
# Why Doesn't The Sun Shrink?

- 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?

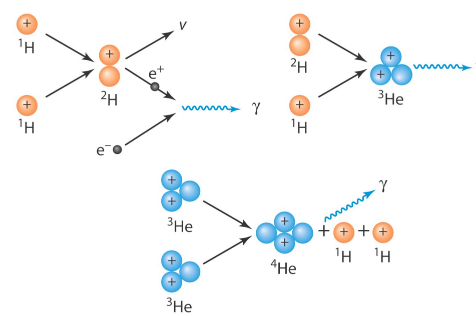
- A star in hydrostatic equilibrium will not shrink or swell.
- It will maintain constant size, density, and temperature for more than a million years!
- At this point, the star is called a main sequence star.
  - MS is when a star burns H into He
- If stars were not constant, what effect would that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




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

# 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

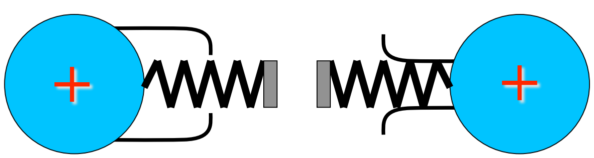
But even when it's out of sight
The Sun shines night and day
We need its heat, we need its light
The Sun light that we seek
The Sun light comes from our own sun's atomic energy

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

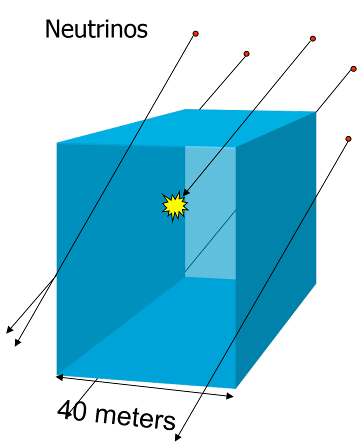
- Fusion requires:
  - High enough temperature (> 5 million K)
  - High enough density
  - Enough time



# 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!

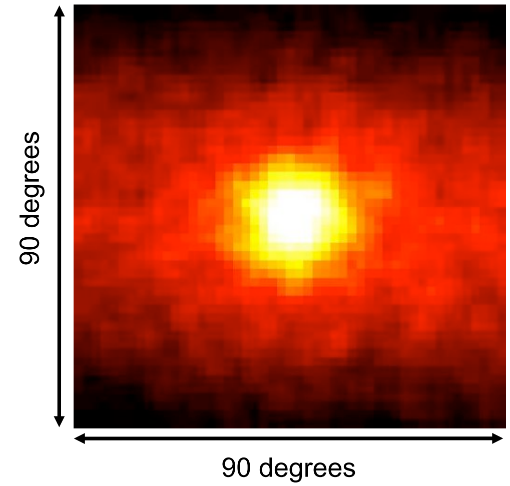
# Detecting Neutrinos





# 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




# Cosmic Gall

very little

hardly

**NEUTRINOS, they are very small.**
**They have no charge and have no mass**
**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?**

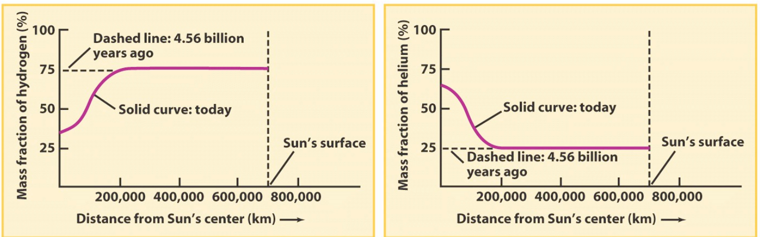
# How much Gas do we have left?

- 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

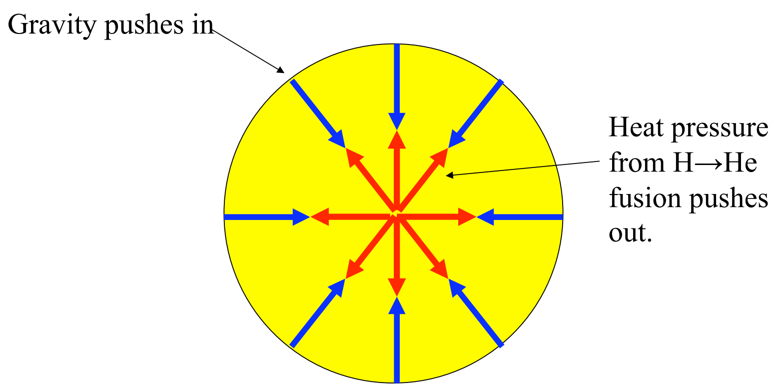
# Hungry, Hungry Sun

- 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



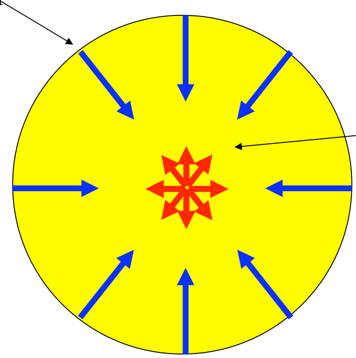

**(a)** Hydrogen in the Sun's interior **(b)** Helium in the Sun's interior

## The Battle between Gravity and Pressure




Hydrostatic equilibrium: Balanced forces

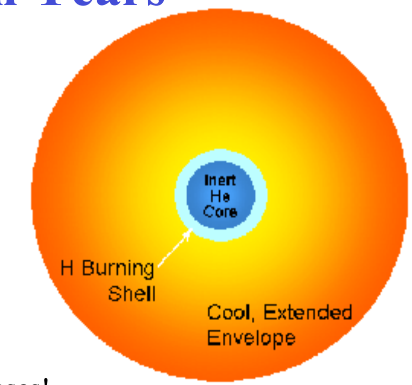
## The Battle between Gravity and Pressure




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




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

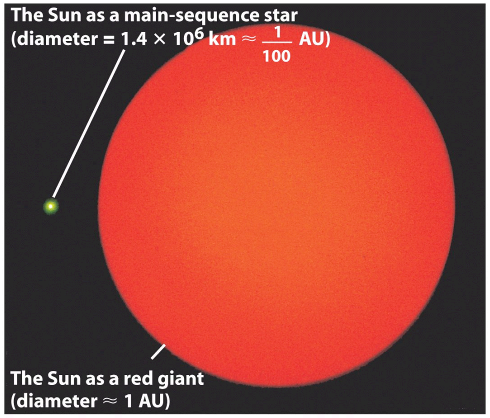
## Question

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

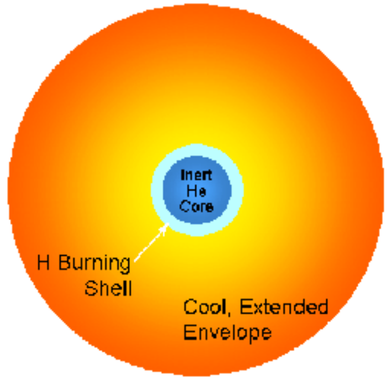
- The Sun will expand to 100-250 times bigger than it is now!
- The same mass but now it's bigger.




The Sun today and as a red giant

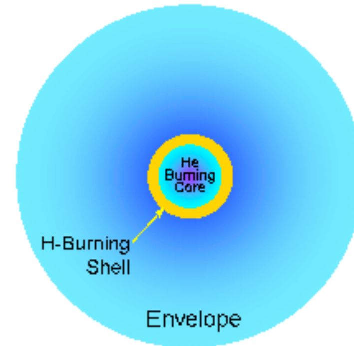
# Contraction Junction

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



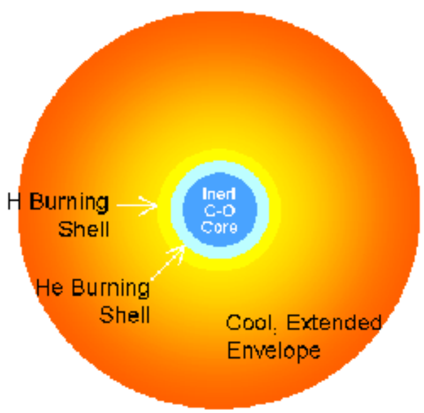

# The Horizontal Branch

- 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

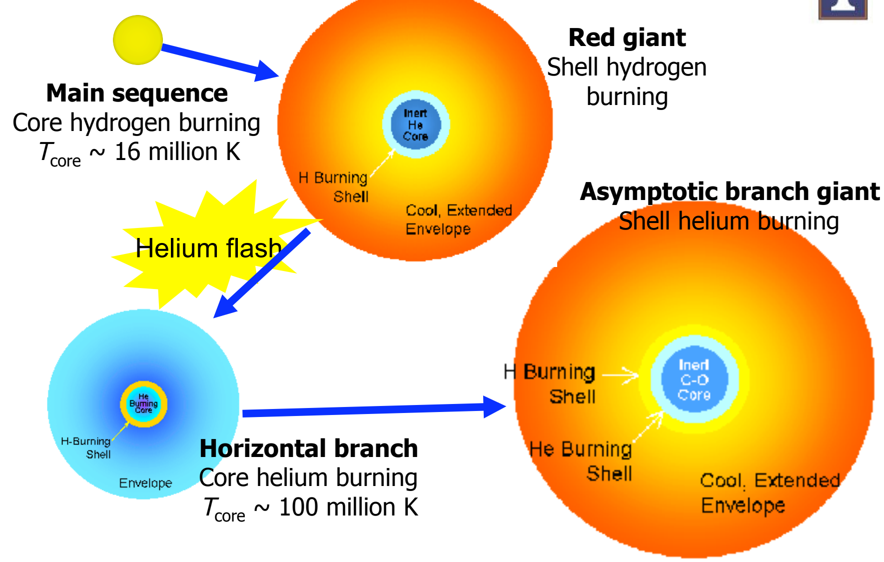



# When Helium Runs Out… 7.8 Billion Years

- 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



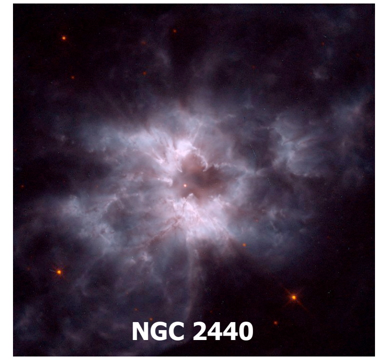
# Question

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.

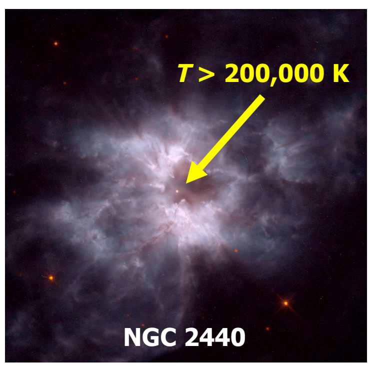
# End Game

- 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

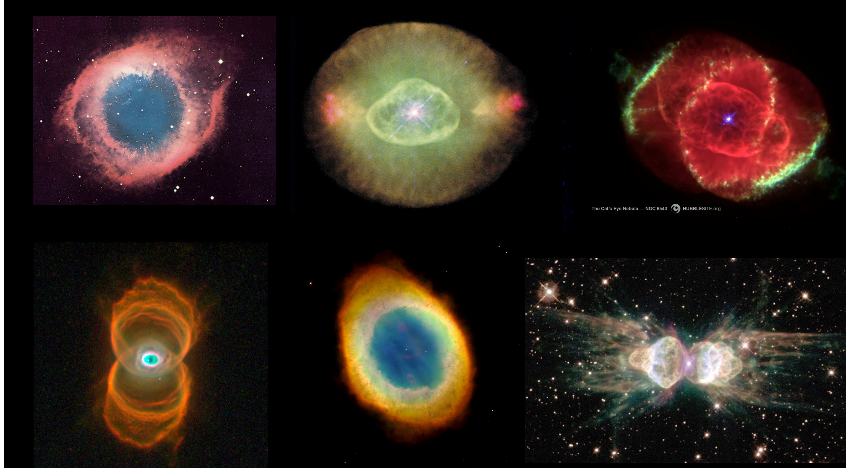



# End Game

- "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.*



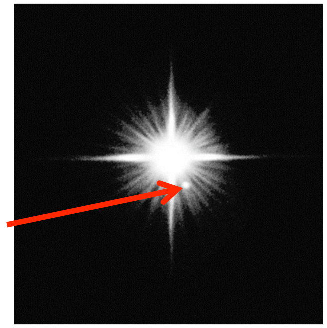

# Planetary Nebulae



# What About the Core?

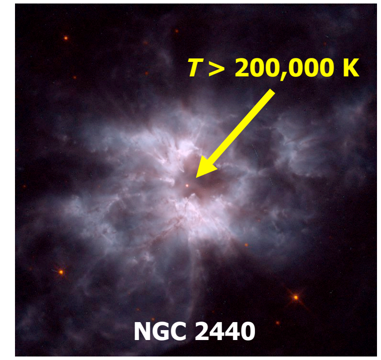
- Final fate - **White dwarf**
  - Slowly cools off over billions of years
  - Just a hot body
  - No fusion
  - Not really a star in some ways
  - Size of the Earth

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.



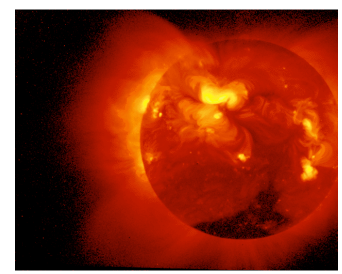

# Question

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.

# Nuclear Fusion in the First Stars

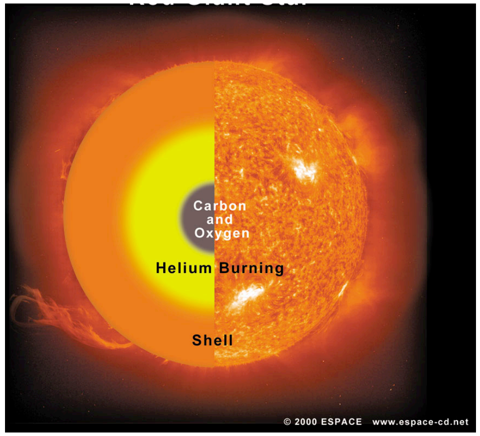
- Core $T$ > 10 million K
  - Violent collisions
  - $e^-$ stripped from atoms (ionized)
  - Nuclei collide, react
    - They get close enough that the nuclear strong force takes over.



- Thru series (chain) of reactions
- 4 protons ⟹ helium (2p,2n) nucleus + energy
- **Fusion:** light nuclei combine ⟹ heavier nuclei

# 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 carbon and oxygen are created for the first time in the Universe.
- Higher density and temperature of the red giant phase allows for the creation of sulfur, phosphorous, silicon, and finally iron.




# Question

The rocky planets that formed around the first stars would have been?

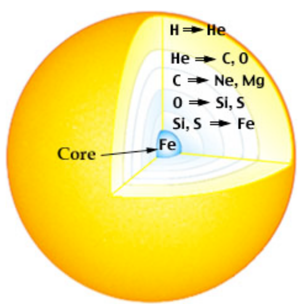
a) A perfect place to raise a family.
b) Devoid of the molecules necessary for life .
c) Too close to the massive star to have life.
d) Inhabited by truly alien creatures.
e) Trick question. There would not have been any rocky planets.

# Iron – The End of the Road

- "Burning" heavier and heavier atoms in the fusion process
- Each stage faster than the last
- After iron - no fuel left!
  - It requires energy to produce heavier atoms

| Stage | Temperature | Duration |
|---|---|---|
| H fusion | 40 million K | 7 million yr |
| He fusion | 200 million K | 500,000 yr |
| C fusion | 600 million K | 600 yr |
| Ne fusion | 1.2 billion K | 1 yr |
| O fusion | 1.5 billion K | 6 mo |
| Si fusion | 2.7 billion K | 1 day |

Values for a $25M_{Sun}$ star

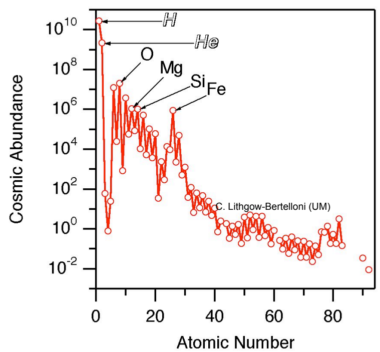



# Supernova!

http://www.spacetelescope.org/images/screen/heic0609c.jpg

# Making Heavy Elements

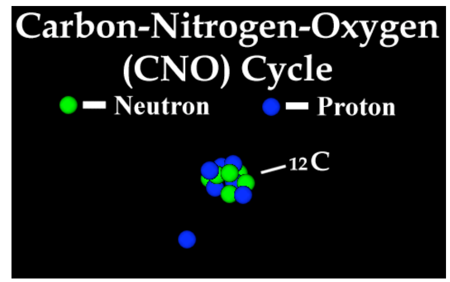
- The star goes <u>supernova</u> and explodes. Some of <u>C, O</u>, P, S, Si, and Fe get carried away. At this point, even heavier elements can be made.
- During the explosion, energy-consuming fusion reactions are possible
- These by-products are *blasted* into space (>90% of star)
- Supernovae provide much of the building blocks for planets… and us!
- **We are recycled supernova debris!**
- **We are Star stuff.**



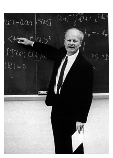

Delenn, B5

# CNO-ing

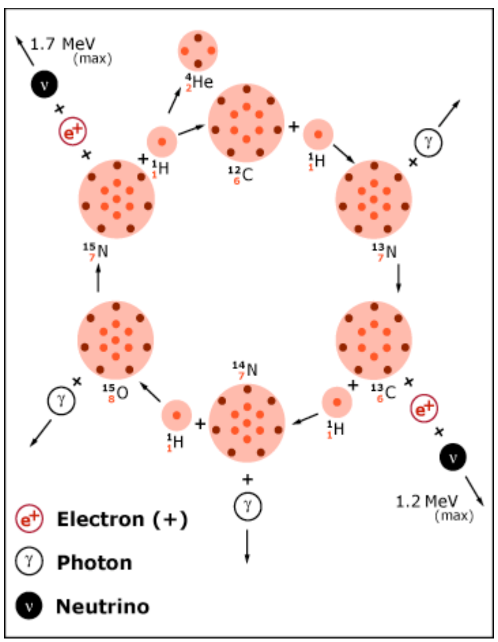
- Now the Universe has some C and O laying around; it can use it.
- In the next generation of stars, the CNO cycle can be used in the fusion process.
- It is more efficient in stars slightly more massive than the Sun.
- Remember the Sun mostly uses proton-proton fusion.




# The CNO Cycle



Hans Bethe



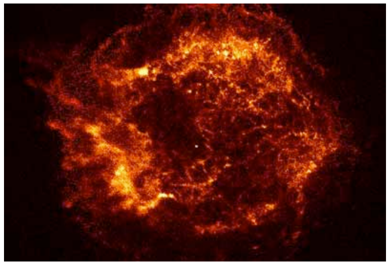

# The Second Generation

- The first stars blew up their new elements into the proto-galaxy.
- Now, the second stars form in the ashes of the first.
- With C and N, the 2nd generation can form helium through the CNO cycle, in which <u>most of the Universe's nitrogen is created</u>.
- The 2nd generation also eventually explodes blowing nitrogen and the other elements into the galaxy.

A supernova in a nearby galaxy. A single star exploding can be brighter than millions of stars in the nucleus.

# The Next Stars

- The new atomic elements from the 1st and 2nd stars are spread out into the galaxy.
- The Sun must be at least a 3rd generation star as we have **nitrogen** in abundance.
- Indeed, the percentage of heavier elements is larger toward the center of the galaxy, where the first generation of stars probably formed. (Seen in ours and other galaxies.)
- **Again, we are star stuff.**
- Keep in mind that this is all from the nuclear strong force– fusion.



The Chandra x-ray observatory has shown that the CasA supernova has flung calcium, iron, and silicon into space.

# Question

HONC is important for life. In which order did these elements first appear in the Universe?

a) H, O, N, C
b) All at once
c) H, C, O, N
d) N, O, H, C
e) C, O, N, H