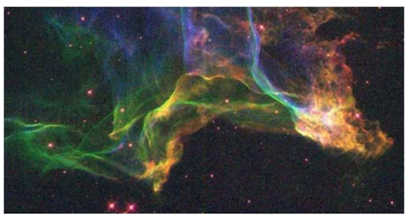
Supernovae — Oct 18

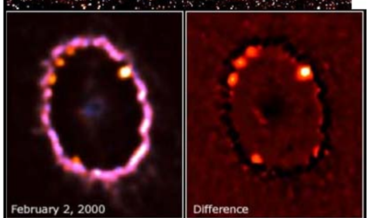


Cygnus Loop
Supernova 20,000 yr ago

- Where were the elements in the baby made?
  - Carbon was made and expelled by giants
  - Iron was made in massive stars and expelled by supernovae
  - Heavier elements were made in supernovae & in giants, where there are free neutrons. Nuclei capture neutrons.
- A massive star ($M > 8M_{\text{sun}}$) ends as supernova
- Elements produced in massive stars

Announcements

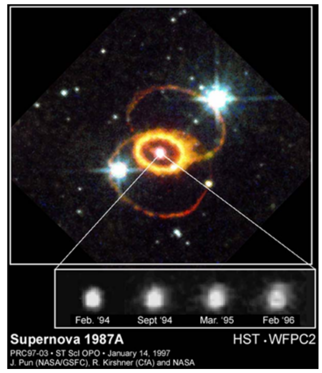
- Test 2 is Wed, Oct 20.
  - Covers material though HR diagram of star clusters (11 Oct). Does not cover energy production.
  - Covers homework 5.
  - Mostly on material since first test.
  - One cheat sheet.
  - See practice test on angel.
  - Missouri “Show me” Club
    - Tues, Oct 19, 7:40-8:40pm
    - BPS 1420
- Homework 5 is due at start of class today, Oct 18. No late papers.



Supernova 1987A

- Exploded in Large Magellanic Cloud
  - LMC is small galaxy that orbits our own Milky Way Galaxy.

Pre-existing circumstellar ring lit up first by photons from SN, now by blast wave from SN.

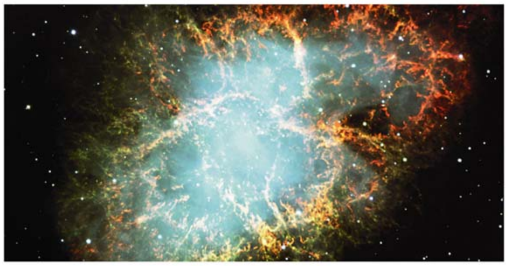


Guest star of 1054, Crab nebula

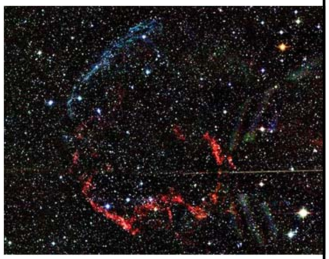
- Records of Sung Dynasty
  - In the first year of the period Chih-ho, …, a guest star appeared several degrees SE of Thien-kuan. After more than a year it gradually became invisible.–p550.
- Gas expelled in 1054AD, still glowing, still moving.
- Other SN
  - 1572 Tycho
  - 1604 Kepler

Supernova remnants

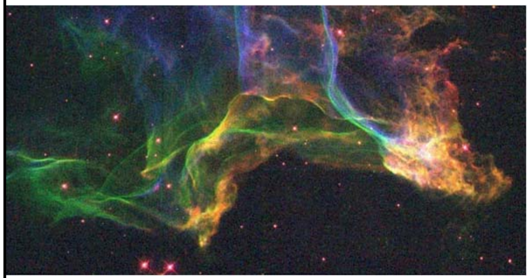
We expect one supernova in Milky Way every 25-100 yrs.



Crab
1,000 yrs old



IC 443
8000 yrs old



Cygnus Loop
20,000 yrs old.
2500 LY away.

Supernovae

- Explosion releases enormous energy
- Luminosity in photons temporarily exceeds that of whole galaxy full (100 billion) of stars.

What is a supernova? Why sun becomes a white dwarf, not a supernova

- In future double-shell burning sun, hot enough to burn
  - $3\,^4He \rightarrow {}^{12}C$
- When He exhausted, gravity wins, and core contracts.
- Electrons are so tight that they become degenerate.
- New source of pressure to resist gravity.
- Temperature not hot enough to burn carbon.

Reaction	Min. Temp.
$4\,^1H \rightarrow {}^4He$	10^7 °K
$3\,^4He \rightarrow {}^{12}C$	$2\text{x}10^8$
$^{12}C + {}^4He \rightarrow {}^{16}O$, Ne, Na, Mg	$8\text{x}10^8$
Ne $\rightarrow$ O, Mg	$1.5\text{x}10^9$
O $\rightarrow$ Mg, S	$2\text{x}10^9$
Si $\rightarrow$ Fe peak	$3\text{x}10^9$

What is a supernova? Why sun becomes a white dwarf, not a supernova

- Sun has one more trick after He is exhausted in core.
  - Burn He in a shell
- Sun is not massive enough to shrink further and get hot enough to burn carbon.
  - $T = M/R$
  - Core is supported by pressure of degenerate electrons.
  - Temperature does not rise to burn anything else.
- End of the road: planetary nebula & white dwarf core

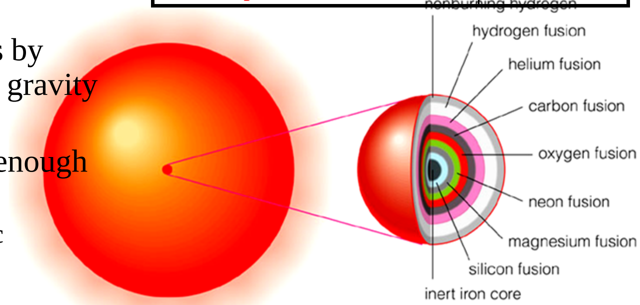
iple-alpha process

Reaction	Min. Temp
$4\,^1H \rightarrow {}^4He$	10 MK
$3\,^4He \rightarrow {}^{12}C$	200 MK
$^{12}C + {}^4He \rightarrow {}^{16}O$, Ne, Na, Mg	800 MK
Ne $\rightarrow$ O, Mg	1500MK
O $\rightarrow$ Mg, S	2000MK
Si $\rightarrow$ Fe peak	3000MK

What is a supernova? Why massive star becomes a supernova

- History of a massive star
- During double-shell burning phase, hot enough to burn
  $3\,^4He \rightarrow ^{12}C$
- When He exhausted, gravity wins, and core contracts.
- Temperature rises by larger amount b/c gravity is stronger.
- Temperature hot enough to burn carbon.
  $^4He + ^{12}C \rightarrow ^{16}O$, etc

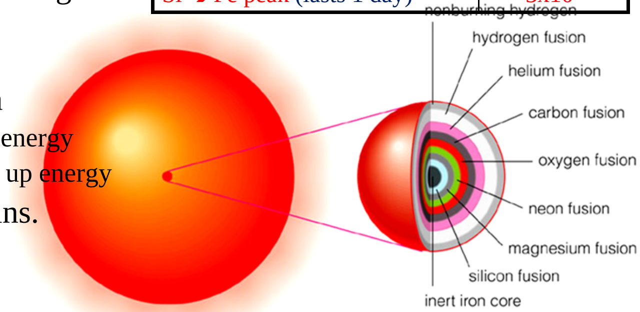
Reaction	Min. Temp.
$4\,^1H \rightarrow ^4He$	10^7 ° K
$3\,^4He \rightarrow ^{12}C$	2×10^8
$^{12}C + ^4He \rightarrow ^{16}O$, Ne, Na, Mg	8×10^8
Ne → O, Mg	1.5×10^9
O → Mg, S	2×10^9
Si → Fe peak	3×10^9



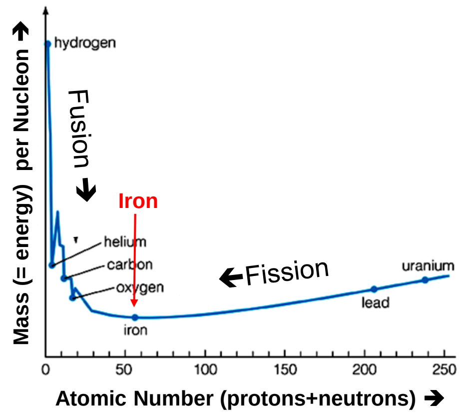
What is a supernova? Why massive star becomes a supernova

- Hot enough to burn
  $^4He + ^{12}C \rightarrow ^{16}O$, etc
- When C exhausted, gravity wins, and core contracts.
- Temperature rises.
- Temperature hot enough to burn neon.
  $^{20}Ne + ^4He \rightarrow ^{24}Mg$
- Disaster with iron
  - Burning releases energy
  - Fusing iron takes up energy
- Gravity finally wins.

Reaction	Min. Temp.
$4\,^1H \rightarrow ^4He$	10^7 ° K
$3\,^4He \rightarrow ^{12}C$	2×10^8
$^{12}C + ^4He \rightarrow ^{16}O$, Ne, Na, Mg	8×10^8
Ne → O, Mg	1.5×10^9
O → Mg, S	2×10^9
Si → Fe peak (lasts 1 day)	3×10^9



- Fusion of stable nuclei less massive than iron releases energy
- Fusion of stable nuclei more massive than iron requires input of energy and therefore cannot occur.



What is a supernova? Why massive star becomes a supernova

- Disaster with iron
  - Burning releases energy
  - Fusing iron takes up energy
- Gravity finally wins.
- Star collapses in few seconds
- Rebounds as supernova
  - Reason for rebounding is topic of current research
- Expel outer layers.

Reaction	Min. Temp.
4 $^{1}H \rightarrow {}^{4}He$	10^{7} ° K
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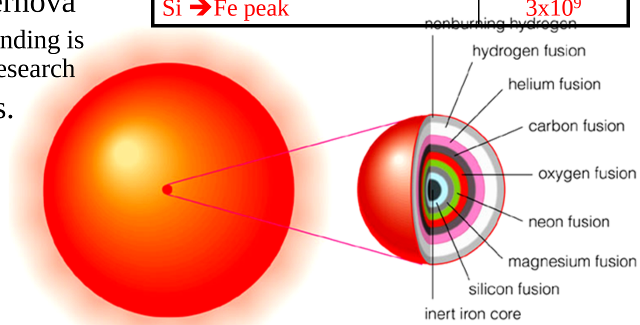


After a supernova, what is left?

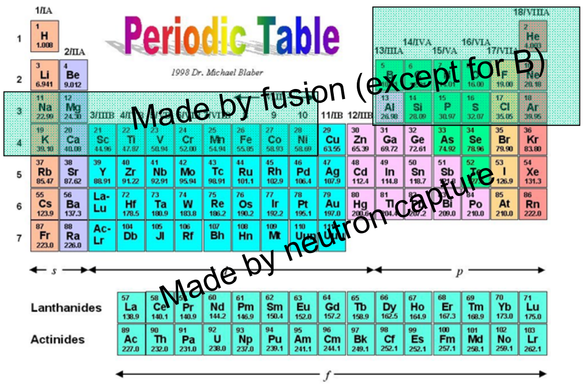
- Outer layers expelled into space. New stars may form.
- Core becomes either
  - a neutron star (Neutron stars in Crab pulses every 1/30 s.)
  - or a black hole.
- Neutron star
  - Normally neutron decays into proton, electron, & neutrino

    $n \rightarrow p + e^{-} + \nu + \text{energy}$
  - Pressure is so high that it is better to have fewer particles

    $p + e^{-} + \text{energy} \rightarrow n + \nu$
  - Whole star is like a big nucleus of neutrons.
  - Neutrons are degenerate
  - Star is size of Lansing
- Black hole: So compact that light cannot escape.

Making elements heavier than iron

- Lighter elements (He, O, C, Ne, Mg, etc) are made by fusion with a release of energy
  - 4H → He + energy
  - 3He → C + energy
- Fe+He→ (heavier element) requires energy. No go.



Neutron capture

- In a supernova, there are free neutrons made by destroying nuclei.
- Nucleus captures neutrons and turns into a heavier nucleus. Inside a nucleus,

  nucleus + n → heavier nucleus
- Nucleus may decay into a more stable one.

  $n \to p + e^- + \upsilon$
- Nucleus may capture more neutrons.
- Eventually unstable nuclei decay into stable ones. Some heavy as uranium.

1. If ^{197}Au captures a neutron, it becomes ___. (Au has 79p. Hg has 80p. Pt has 78p.)
   A. ^{197}Hg
   B. ^{198}Au
   C. ^{198}Hg
   D. ^{198}Pt
2. If a neutron in ^{198}Au decays, it becomes ___. (Au has 79p. Hg has 80p. Pt has 78p.)
   A. ^{198}Hg
   B. ^{198}Au
   C. ^{198}Pt

- The net effect is to turn gold ^{197}Au into mercury ^{198}Hg

Neutron capture

- In a supernova, there are free neutrons made by destroying nuclei.
- Nucleus captures neutrons and turns into a heavier nucleus. Inside a nucleus,

  nucleus + n → heavier nucleus
- Nucleus may decay into a more stable one.

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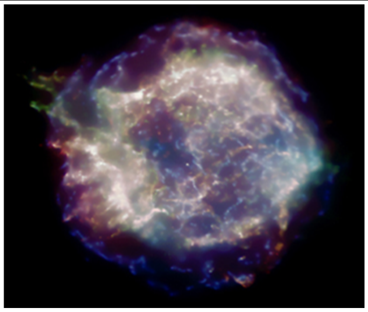
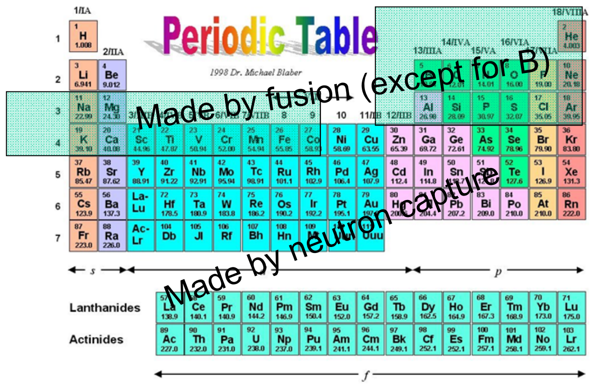


- Calculation of nuclear reactions in a supernova.
- Start with iron and add neutrons
- Look at gold
  - 79 protons, 197-79=118 neutrons

Where were the elements in the baby made?

- Lighter elements (He, O, C, Ne, Mg, etc) are made by fusion with a release of energy
  - 4H → He + energy
  - 3He → C + energy
- Elements heavier than iron are made in supernovae and in giant stars.



Questions on the Supernova Movie

1. What is the only element at the start? How many neutrons does it have?
2. At what time did some gold form? Gold has 79 protons. Is this gold stable?
3. At the end of the calculation, how many protons does the nucleus with the most protons have?
4. What is the time at the end of the calculation?
5. Are the end products stable?

- "R process movie" at www.jinaweb.org/html/gallery3 .html