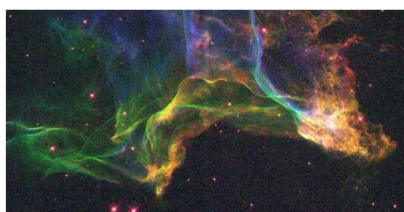


## Supernovae — Oct 18



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.

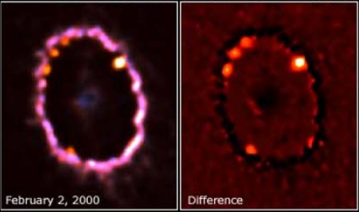


Large Magellanic Cloud



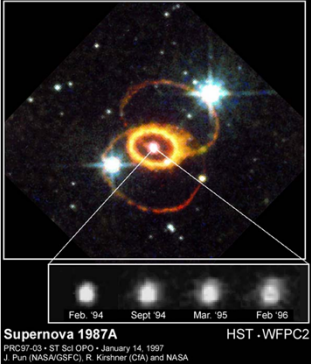
© Anglo-Australian Observatory/Royal Observatory, Edinburgh.

During Before



February 2, 2000 Difference

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



Supernova 1987A HST - WFPC2

PRC87-03 - ST ScI OPO - January 14, 1997  
J. Pui (NASA/GSFC), R. Krushner (CIA) and NASA

Feb '94 Sept '94 Mar '95 Feb '96

## Guest star of 1054, Crab nebula



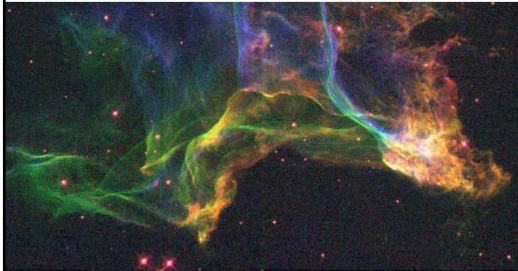
- Records of Sung Dynasty
  - In the first year of the period Chih-ho, ..., a guest star appeared several degrees SE of Thien-kuan. After more than a year it gradually became invisible. -p550.
- Gas expelled in 1054AD, still glowing, still moving.
- Other SN
  - 1572 Tycho
  - 1604 Kepler

## Supernova remnants

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



Crab  
1,000 yrs old



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



IC 443  
8000 yrs old

## 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  
 $3\ ^4\text{He} \rightarrow\ ^{12}\text{C}$
- 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.

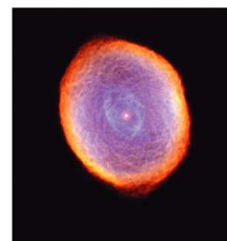
Reaction	Min. Temp.
$4\ ^1\text{H} \rightarrow\ ^4\text{He}$	$10^7\ ^\circ\text{K}$
$3\ ^4\text{He} \rightarrow\ ^{12}\text{C}$	$2 \times 10^8$
$^{12}\text{C} +\ ^4\text{He} \rightarrow\ ^{16}\text{O},\ \text{Ne},\ \text{Na},\ \text{Mg}$	$8 \times 10^8$
$\text{Ne} \rightarrow\ \text{O},\ \text{Mg}$	$1.5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

## 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

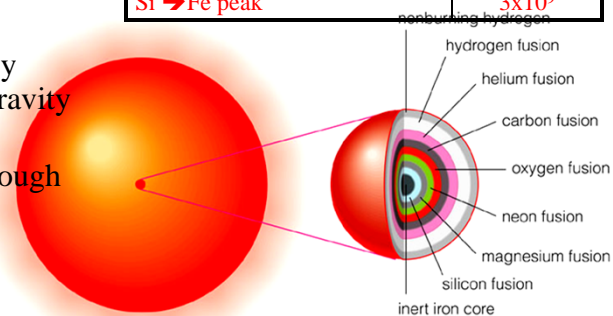


Reaction	Min. Temp.
$4\ ^1\text{H} \rightarrow\ ^4\text{He}$	10 MK
$3\ ^4\text{He} \rightarrow\ ^{12}\text{C}$	200 MK
$^{12}\text{C} +\ ^4\text{He} \rightarrow\ ^{16}\text{O},\ \text{Ne},\ \text{Na},\ \text{Mg}$	800 MK
$\text{Ne} \rightarrow\ \text{O},\ \text{Mg}$	1500MK
$\text{O} \rightarrow\ \text{Mg},\ \text{S}$	2000MK
$\text{Si} \rightarrow\ \text{Fe peak}$	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  
 $3^4\text{He} \rightarrow ^{12}\text{C}$
- When He exhausted, gravity wins, and core contracts.
- Temperature rises by larger amount b/c gravity is stronger.
- Temperature hot enough to burn carbon.  
 $4^4\text{He} + ^{12}\text{C} \rightarrow ^{16}\text{O}$ , etc

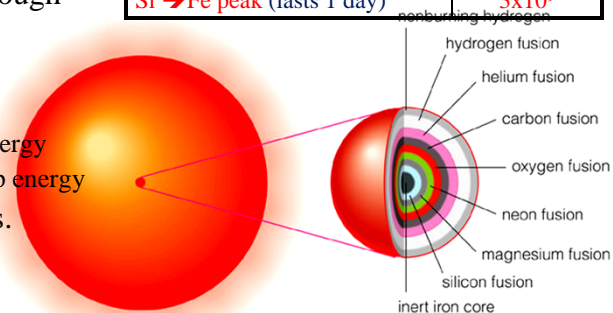
Reaction	Min. Temp.
$4\ ^1\text{H} \rightarrow\ ^4\text{He}$	$10^7\ ^\circ\text{K}$
$3\ ^4\text{He} \rightarrow\ ^{12}\text{C}$	$2 \times 10^8$
$^{12}\text{C} +\ ^4\text{He} \rightarrow\ ^{16}\text{O}, \text{Ne}, \text{Na}, \text{Mg}$	$8 \times 10^8$
$\text{Ne} \rightarrow\ \text{O}, \text{Mg}$	$1.5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



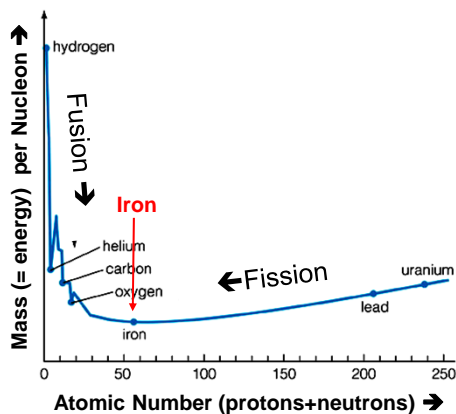
## What is a supernova? Why massive star becomes a supernova

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

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



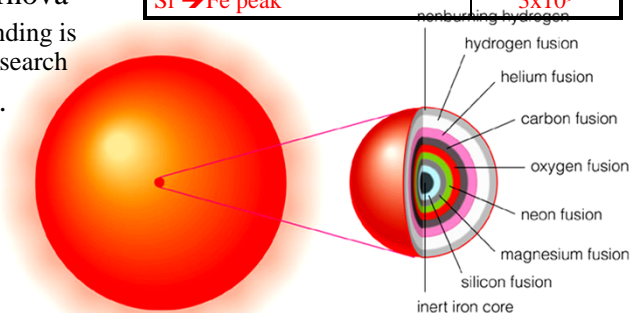
- Fusion of stable nuclei less massive than iron releases energy
- Fusion of stable nuclei more massive than iron requires input of energy and therefore cannot occur.



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



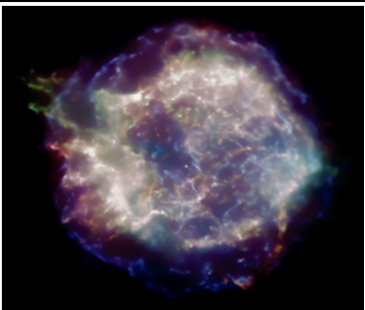




## Neutron capture

- In a supernova, there are free neutrons made by destroying nuclei.
  - Nucleus captures neutrons and turns into a heavier nucleus.  
Inside a nucleus,  
$$\text{nucleus} + n \rightarrow \text{heavier nucleus}$$
  - Nucleus may decay into a more stable one.  
$$n \rightarrow p + e^- + \nu$$
  - Nucleus may capture more neutrons.
  - Eventually unstable nuclei decay into stable ones. Some heavy as uranium.
1. If  $^{197}\text{Au}$  captures a neutron, it becomes \_\_\_\_\_. (Au has 79p. Hg has 80p. Pt has 78p.)
    - A.  $^{197}\text{Hg}$
    - B.  $^{198}\text{Au}$
    - C.  $^{198}\text{Hg}$
    - D.  $^{198}\text{Pt}$
  2. If a neutron in  $^{198}\text{Au}$  decays, it becomes \_\_\_\_\_. (Au has 79p. Hg has 80p. Pt has 78p.)
    - A.  $^{198}\text{Hg}$
    - B.  $^{198}\text{Au}$
    - C.  $^{198}\text{Pt}$
- The net effect is to turn gold  $^{197}\text{Au}$  into mercury  $^{198}\text{Hg}$

## 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,  
$$\text{nucleus} + n \rightarrow \text{heavier nucleus}$$
  - Nucleus may decay into a more stable one.  
$$n \rightarrow p + e^- + \nu$$
  - Nucleus may capture more neutrons.
  - Eventually unstable nuclei decay into stable ones. Some heavy as uranium.
- 
- 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
  - $4\text{H} \rightarrow \text{He} + \text{energy}$
  - $3\text{He} \rightarrow \text{C} + \text{energy}$
- Elements heavier than iron are made in supernovae and in giant stars.

**Periodic Table**  
1999 Dr. Michael Blaber

Made by fusion (except for Bi)

Made by neutron capture

1	H	1.008	1	118	He	4.002	118
2	Li	6.941	3	2	He	4.002	2
3	Li	6.941	3	10	Ne	20.180	10
4	Be	9.012	4	18	Ar	39.948	18
5	B	10.811	5	36	Kr	83.801	36
6	C	12.011	6	54	Xe	131.29	54
7	N	14.007	7	86	Rn	222	86
8	O	15.999	8	118	Og	294	118
9	F	18.998	9	118	Og	294	118
10	Ne	20.180	10	118	Og	294	118
11	Na	22.990	11	118	Og	294	118
12	Mg	24.305	12	118	Og	294	118
13	Al	26.982	13	118	Og	294	118
14	Si	28.086	14	118	Og	294	118
15	P	30.974	15	118	Og	294	118
16	S	32.06	16	118	Og	294	118
17	Cl	35.45	17	118	Og	294	118
18	Ar	39.948	18	118	Og	294	118
19	K	39.098	19	118	Og	294	118
20	Ca	40.078	20	118	Og	294	118
21	Sc	44.956	21	118	Og	294	118
22	Ti	47.88	22	118	Og	294	118
23	V	50.942	23	118	Og	294	118
24	Cr	51.996	24	118	Og	294	118
25	Mn	54.938	25	118	Og	294	118
26	Fe	55.845	26	118	Og	294	118
27	Co	58.933	27	118	Og	294	118
28	Ni	58.693	28	118	Og	294	118
29	Cu	63.546	29	118	Og	294	118
30	Zn	65.38	30	118	Og	294	118
31	Ga	69.723	31	118	Og	294	118
32	Ge	72.64	32	118	Og	294	118
33	As	74.922	33	118	Og	294	118
34	Se	78.96	34	118	Og	294	118
35	Br	79.904	35	118	Og	294	118
36	Kr	83.801	36	118	Og	294	118
37	Rb	85.468	37	118	Og	294	118
38	Sr	87.62	38	118	Og	294	118
39	Y	88.906	39	118	Og	294	118
40	Zr	91.224	40	118	Og	294	118
41	Nb	92.906	41	118	Og	294	118
42	Mo	95.94	42	118	Og	294	118
43	Tc	98.906	43	118	Og	294	118
44	Ru	101.07	44	118	Og	294	118
45	Rh	102.91	45	118	Og	294	118
46	Pd	106.42	46	118	Og	294	118
47	Ag	107.87	47	118	Og	294	118
48	Cd	112.41	48	118	Og	294	118
49	In	114.82	49	118	Og	294	118
50	Sn	118.71	50	118	Og	294	118
51	Sb	121.76	51	118	Og	294	118
52	Te	127.6	52	118	Og	294	118
53	I	126.90	53	118	Og	294	118
54	Xe	131.29	54	118	Og	294	118
55	Cs	132.91	55	118	Og	294	118
56	Ba	137.33	56	118	Og	294	118
57	La	138.905	57	118	Og	294	118
58	Ce	140.12	58	118	Og	294	118
59	Pr	140.908	59	118	Og	294	118
60	Nd	144.24	60	118	Og	294	118
61	Pm	144.913	61	118	Og	294	118
62	Sm	150.36	62	118	Og	294	118
63	Eu	151.964	63	118	Og	294	118
64	Gd	157.25	64	118	Og	294	118
65	Tb	158.925	65	118	Og	294	118
66	Dy	162.50	66	118	Og	294	118
67	Ho	164.930	67	118	Og	294	118
68	Er	167.259	68	118	Og	294	118
69	Tm	168.930	69	118	Og	294	118
70	Yb	173.054	70	118	Og	294	118
71	Lu	174.967	71	118	Og	294	118
72	Hf	178.49	72	118	Og	294	118
73	Ta	180.948	73	118	Og	294	118
74	W	183.84	74	118	Og	294	118
75	Re	186.207	75	118	Og	294	118
76	Os	190.23	76	118	Og	294	118
77	Ir	192.222	77	118	Og	294	118
78	Pt	195.084	78	118	Og	294	118
79	Au	196.967	79	118	Og	294	118
80	Hg	200.59	80	118	Og	294	118
81	Tl	204.38	81	118	Og	294	118
82	Pb	207.2	82	118	Og	294	118
83	Bi	208.980	83	118	Og	294	118
84	Po	209	84	118	Og	294	118
85	At	210	85	118	Og	294	118
86	Rn	222	86	118	Og	294	118
87	Fr	223	87	118	Og	294	118
88	Ra	226	88	118	Og	294	118
89	Ac	227	89	118	Og	294	118
90	Th	232.038	90	118	Og	294	118
91	Pa	231.036	91	118	Og	294	118
92	U	238.029	92	118	Og	294	118
93	Np	237.048	93	118	Og	294	118
94	Pu	244.064	94	118	Og	294	118
95	Am	243.061	95	118	Og	294	118
96	Cm	247.070	96	118	Og	294	118
97	Bk	247.070	97	118	Og	294	118
98	Cf	251.083	98	118	Og	294	118
99	Es	252.083	99	118	Og	294	118
100	Fm	257.105	100	118	Og	294	118
101	Md	258.105	101	118	Og	294	118
102	No	259.105	102	118	Og	294	118
103	Lr	260.105	103	118	Og	294	118

## Questions on the Supernova Movie

1. What is the only element at the start? How many neutrons does it have?
  - “R process movie” at [www.jinaweb.org/html/gallery3.html](http://www.jinaweb.org/html/gallery3.html)
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?