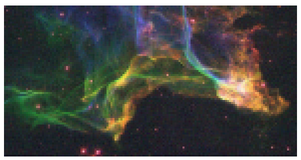
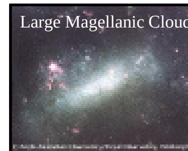
Supernovae–Oct 19



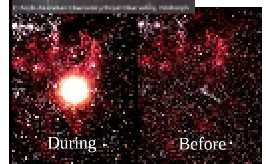
Cygnus Loop
Supernova 20,000 yr ago

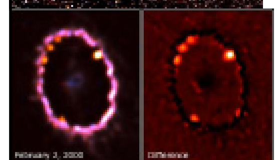
- Where were the elements in the baby made?
  - Carbon was made and expelled by giants
  - Iron was made in massive stars and expelled by supernovae
  - Heavier elements were made in supernovae & in giants by the R & S processes

Supernova 1987A

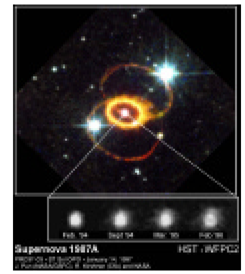


- Exploded in Large Magellanic Cloud
  - LMC is small galaxy that orbits our own Milky Way Galaxy.



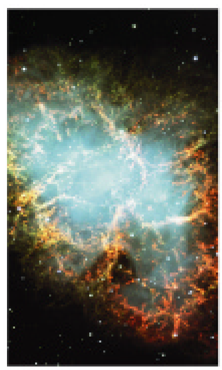


Pre-existing circumstellar ring lit up first by photons from SN, now by blast wave from SN.



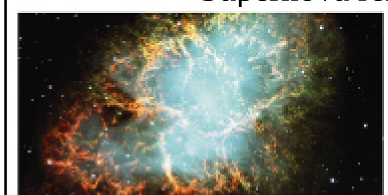
Guest star of 1054

- 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.–p564.
- Gas expelled in 1054AD, still glowing
- Other SN
  - 1572 Tycho
  - 1604 Kepler

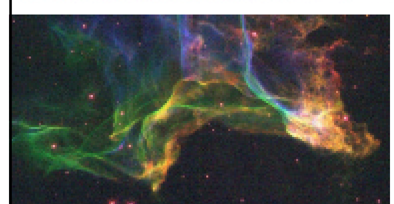


Supernova remnants

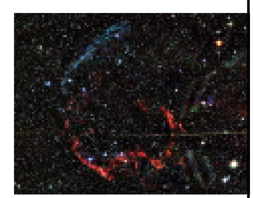
We expect one supernova in Milky Way every 25-100 yrs.



Crab
1,000 yrs old



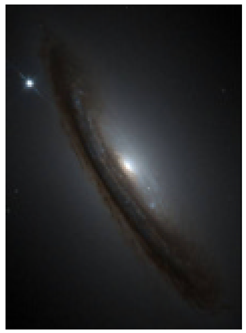
Cygnus Loop
20,000 yrs old.
2500 LY away.



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
  $3\,{}^{4}He \rightarrow {}^{12}C$
- When He exhausted, gravity wins, and core contracts.
- Temperature rises.
- 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.
$4\,{}^{1}H \rightarrow {}^{4}He$	10^{7} ° K
$3\,{}^{4}He \rightarrow {}^{12}C$	2×10^{8}
${}^{12}C + {}^{4}He \rightarrow {}^{16}O$, 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

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

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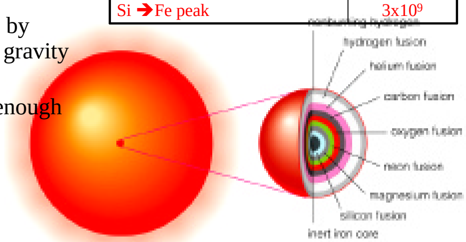

What is a supernova? Why massive star becomes a supernova

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

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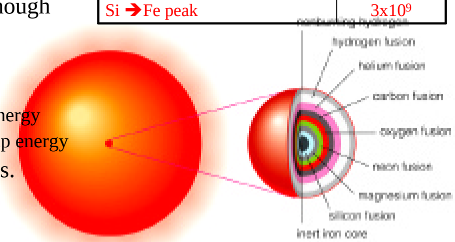

What is a supernova? Why massive star becomes a supernova

- 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
3 $^{4}He \rightarrow {}^{12}C$	2×10^8
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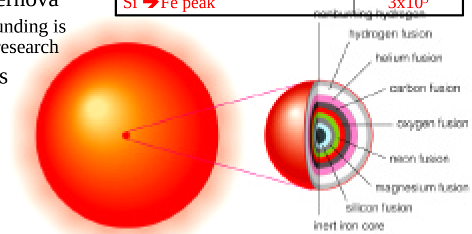
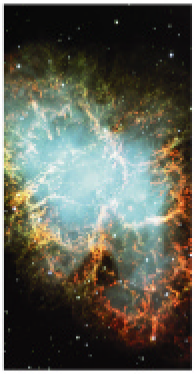


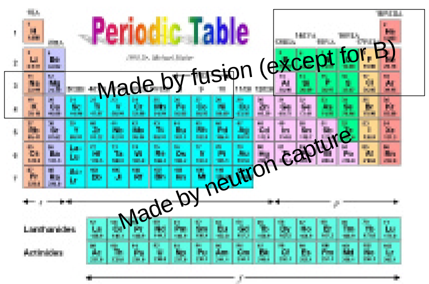
What is left?

- Outer layers expelled into space. New stars may form.
- Core becomes
  - Neutron star. One in Crab. Pulses every 1/30 s.
  - Black hole
- Neutron star
  - Normally neutron→proton+electron+neutrino+energy
  - Pressure is so high that proton+electron+energy→neutron+neutrino
  - Whole star is like a big nucleus of neutrons.
  - Neutrons are degenerate
  - Star is size of Lansing

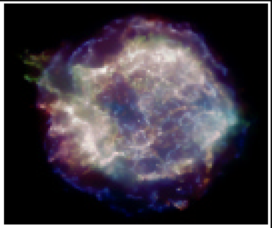


Making elements heavier than iron

- 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.
- Nucleus may decay into a more stable one.
- 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

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