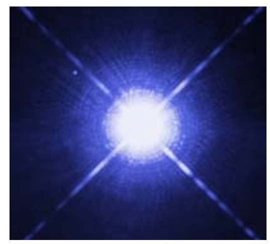
The dying sun/ creation of elements

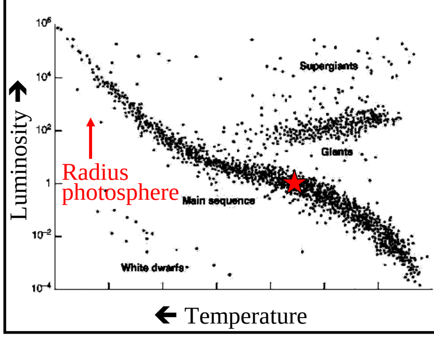
- Homework 6 is due Thurs, 2 April at 6:00am
- OBAFGKM extra credit
  - Angel: Lessons>Extra Credit
  - Due 11:55pm, 31 March
- Final exam (new, later time)
  - 6 May, **3:00-5:00**, BPS 1410

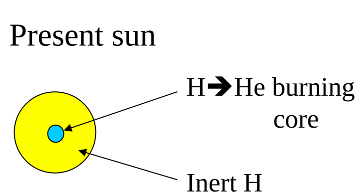
- Why does the sun die?
- Life of massive stars
- Creation of elements. Where are uranium & gold created?



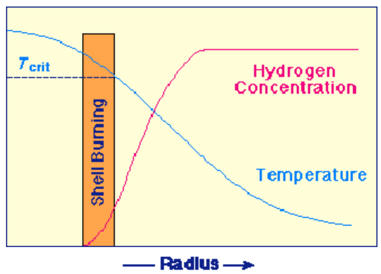
Life of the sun: Present sun

- Hydrogen is fusing to produce helium in the core
- Temperature is 10MK



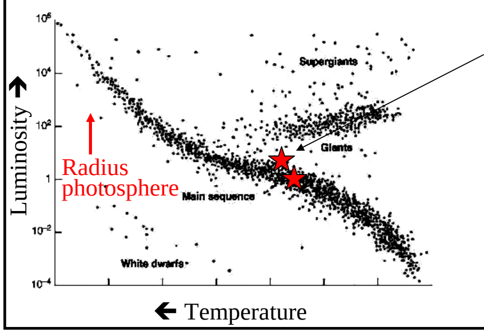


Life of the sun: red giant

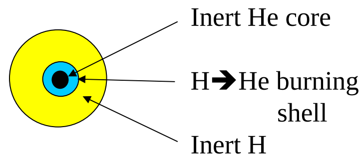


- Hydrogen in the core is used up.
- Hydrogen burns in a shell.
- Star becomes larger
- Surface becomes cooler

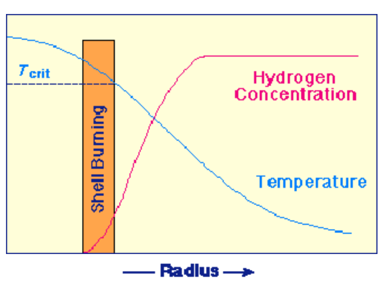
➔ *Red giant.*



5 Byr from now

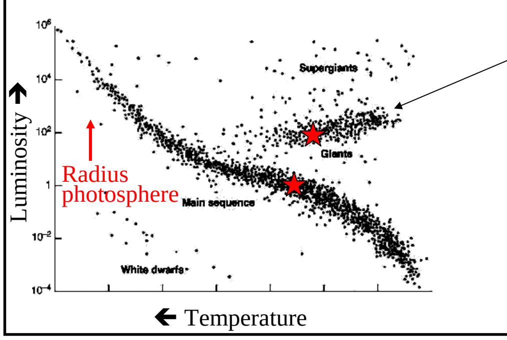


Life of the sun: red giant

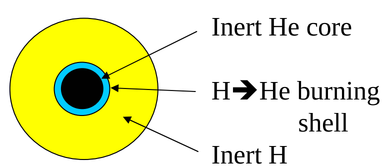


- Heat source moves closer to surface.
- Layers below surface swell up.
- Star becomes larger
- Surface becomes cooler

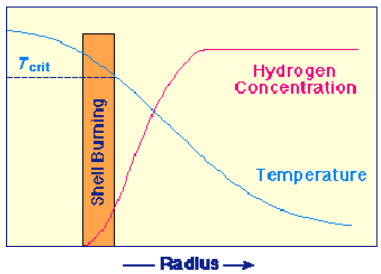
➔ *Red giant.*



Few 100 Myr later



Life of the sun: red giant



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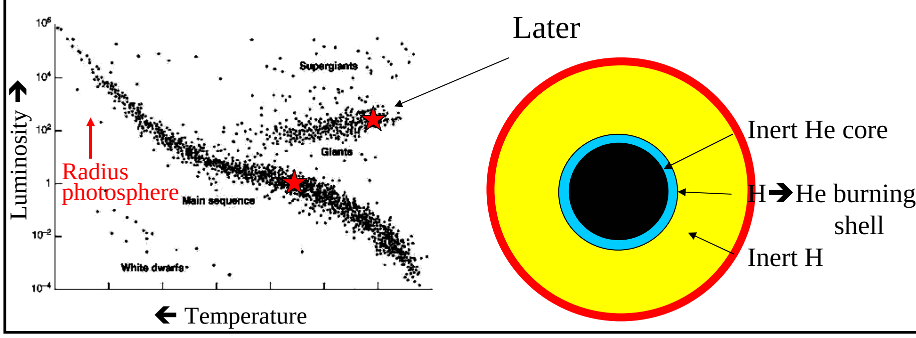
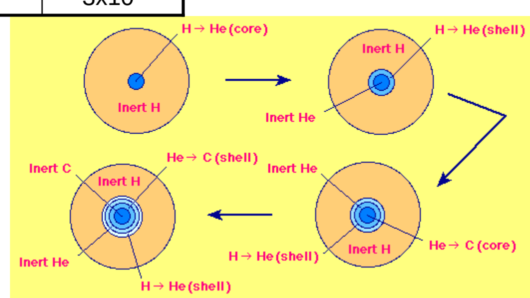


After helium is used up

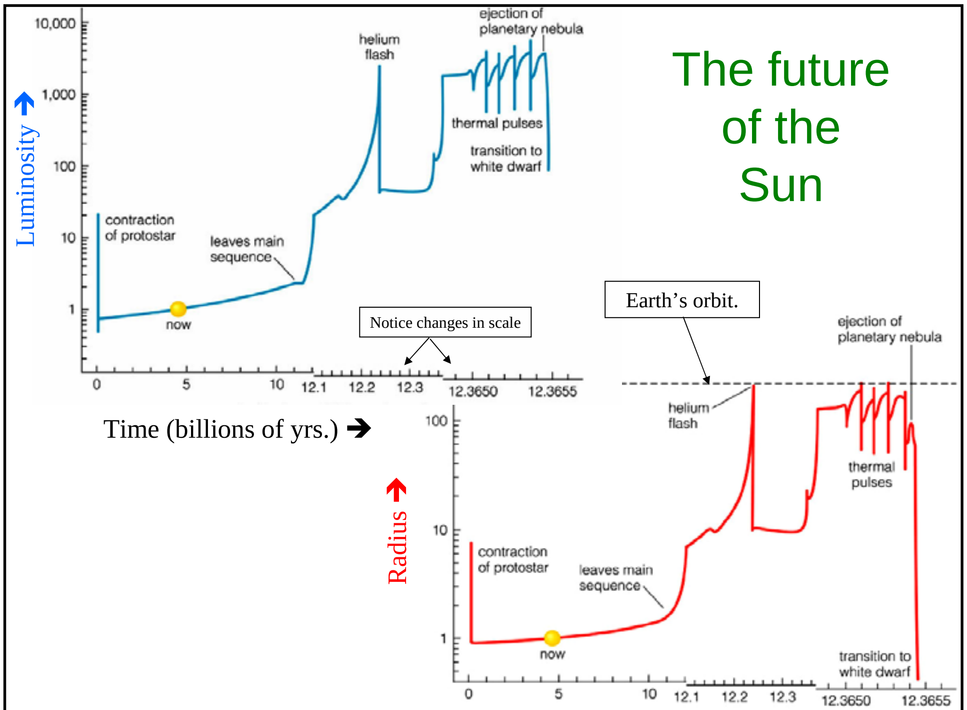
Reaction	Min. Temp.
4 ^{1}H ➔ ^{4}He	10^{7} ° K
3 ^{4}He ➔ ^{12}C	2×10^{8}
^{12}C + ^{4}He ➔ ^{16}O, Ne, Na, Mg	8×10^{8}
Ne ➔ O, Mg	1.5×10^{9}
O ➔ Mg, S	2×10^{9}
Si ➔Fe peak	3×10^{9}

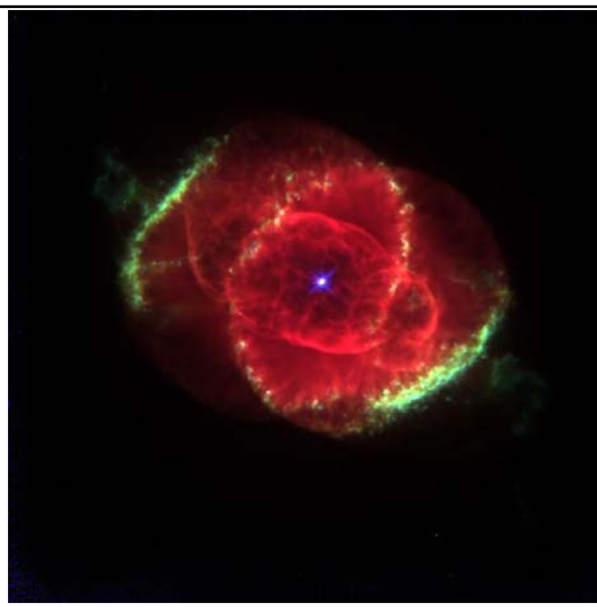
Triple-alpha process

- Contraction heats center
- Helium starts to burn.



The future of the Sun





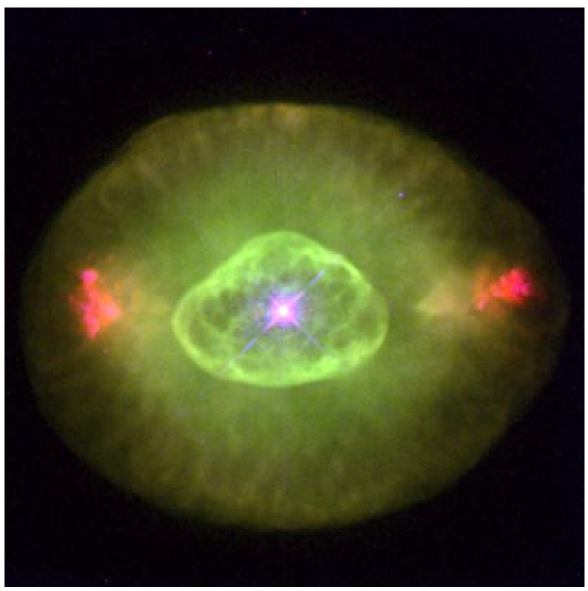
- Cat's Eye.

Harrington & Borkowski, (UMd) & NASA

- Helix nebula
- Gas & dust ejected by star in the middle.
- Ejection occurred several times.
- Wind blows gas into previous ejecta.
- Colors
  - Blue: O
  - Red: H & N

NASA, NOAO, ESA, Hubble Helix Nebula Team, M. Meixner (STScI), and T.A. Rector (NRAO).

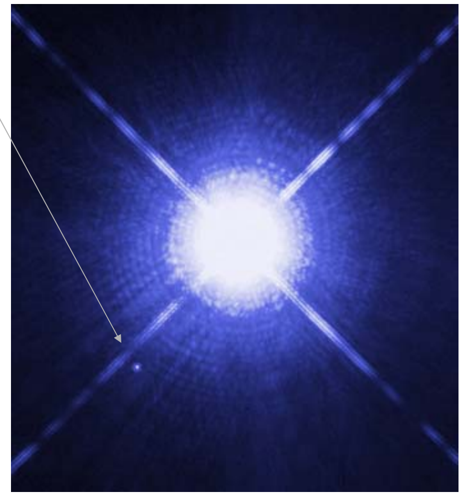
- NGC 6826
- Wind from hot star blows on material expelled by pulses.
- When pulses stop, there is no more nuclear fusion.
- The central star is a white dwarf. It cools gradually



Balick (U Wash), et al & NASA

The dead sun

- White dwarf Sirius B
- White dwarf is initially very hot.
- As it cools, the white dwarf grows redder and fainter.
- Q Put these in order: MS, WD, giant, PN
  a. MS, WD, G, PN
  b. MS, WD, PN, G
  c. MS, PN, G, WD
  d. MS, G, PN, WD

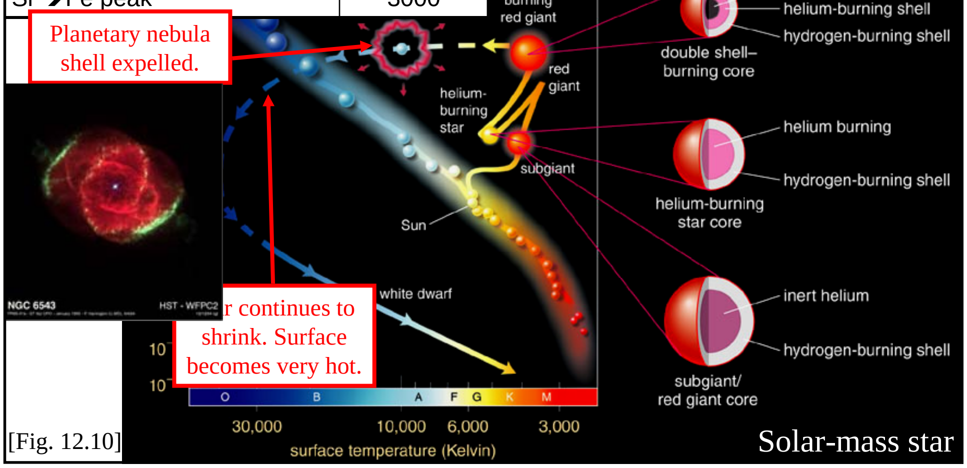


NASA, H E Bond (STSCI) et al.

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

Stars with < 2 $M_\odot$

- End is He $\rightarrow$ C, O burning.
- Core never gets hot enough for further reactions.



[Fig. 12.10]

What stars do

- Gravity: Center of star always trying to contract and become more dense and hotter.
- Nuclear burning interrupts this from time to time
  - High temperature makes high pressure
  - *Pressure* is what halts gravitational contraction.

Fusion

- Fusing two H nuclei
  - Two protons, both positively charged, repel.
  - Requires high speed to overcome repulsion.
- Q Why does fusing He require a higher minimum temperature, 200MK rather than 10MK?
  a. He is heavier
  b. He nucleus has twice as much charge.
  c. He is harder to ionize.
- Model how to answer questions that require more than recall of facts.
  - Does mass affect ability of nuclei to fuse?
  - Does charge affect…
  - Is ionization (removing electrons) part of fusion of nuclei?

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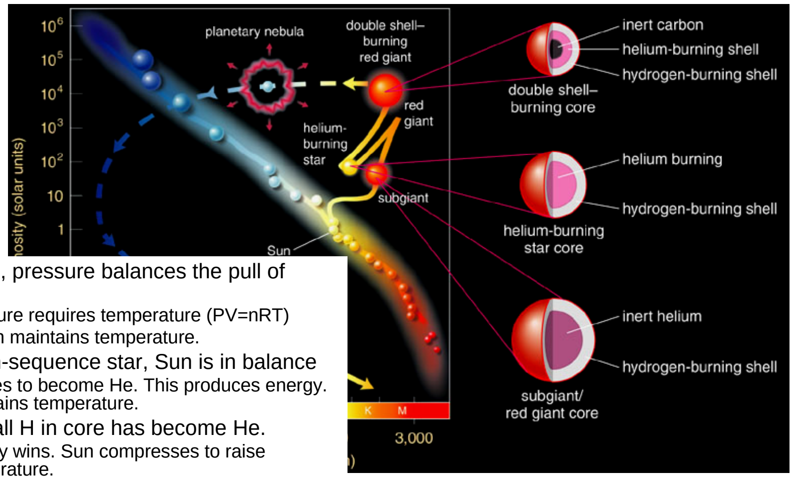
Sun becomes a giant



- In the sun, pressure balances the pull of gravity.
  - Pressure requires temperature (PV=nRT)
  - Fusion maintains temperature.
- As a main-sequence star, Sun is in balance
  - H fuses to become He. This produces energy. Maintains temperature.
- In 5 Byr, all H in core has become He.
  - Gravity wins. Sun compresses to raise temperature.
  - Now shell is hot enough to fuse H.
- Sun will eventually get hot enough to burn He
  - 3He becomes C.

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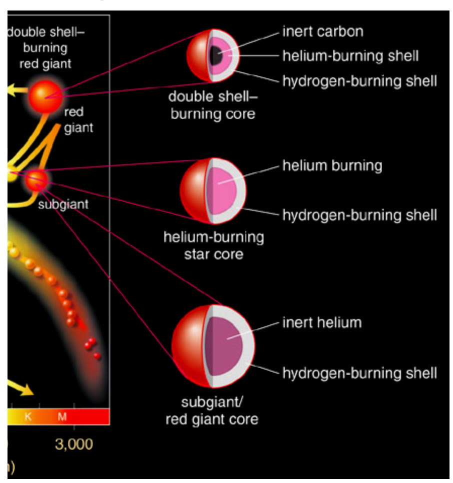
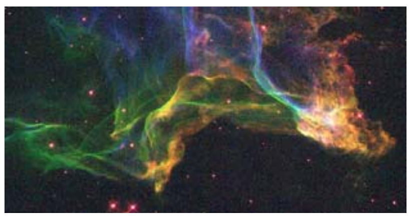
- Sun will eventually get hot enough to burn He
  - 3He becomes C.
- When sun uses up the He in the core, it contracts & gets hotter. NO, it does not.
  - New physics: At sufficiently high density, quantum mechanical pressure comes in. It is independent of temperature.
  - Will discuss this next class.
  - No more fusion means sun becomes inert. White dwarf.



Creation of elements

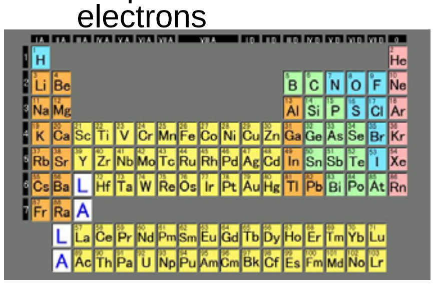


Cygnus Loop
Supernova 20,000 yr ago

- 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

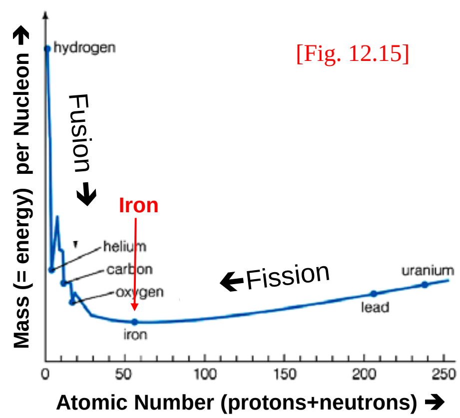
Nucleosynthesis: where we came from.

- H, He, Li are only elements formed in initial formation of universe
  - simplest stable combinations of protons, neutrons and electrons



Periodic Table is in order of complexity

Element	Protons	Neutrons	Total
H	1	0	1
He	2	2	4
Li	3	4	7
C	6	6	12
N	7	7	14
O	8	8	16
Fe	26	30	56



[Fig. 12.15]

Fusion in stars → increasingly more complicated, but more stable nuclei.
- Up until iron (Fe).

In more massive stars (>2 $M_\odot$) nuclear burning in successive shells

Reaction	Min. Temp.
4 $^{1}H \rightarrow {}^{4}He$	10 MK
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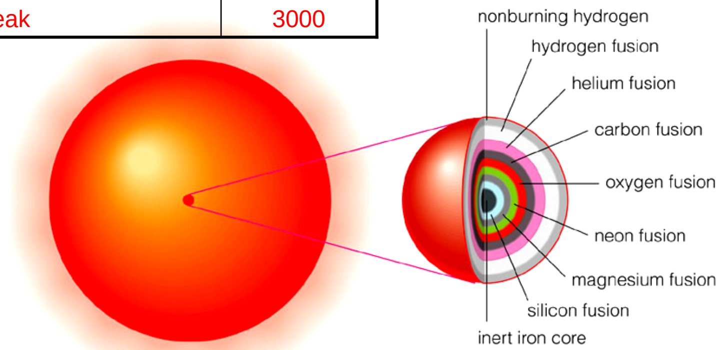
- "Onion skin" model
  - Central core is iron
  - Outer layers correspond to each previous step in nuclear burning chain.

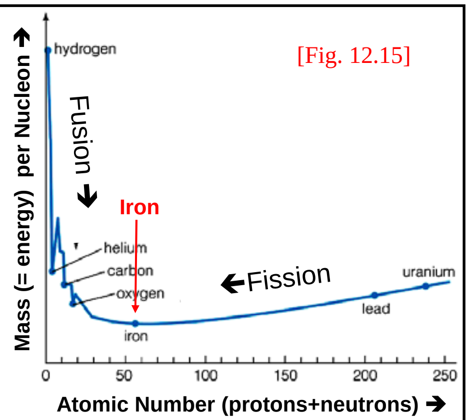


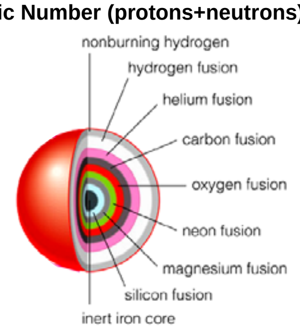
Supernovae

- For M > 7-8 $M_\odot$, stars cannot "gracefully" lose mass and become white dwarfs.
- Massive stars end up with iron cores

  → No further nuclear burning possible
- Core eventually becomes too massive to be held up by degenerate electron pressure:
  - $e^- + p \rightarrow n$
  - Sudden core collapse: 10^4 km → 20 km
  - Then core rebounds
  - Outer layers fall in, then get hit by rebounding core.

[Fig. 12.15]



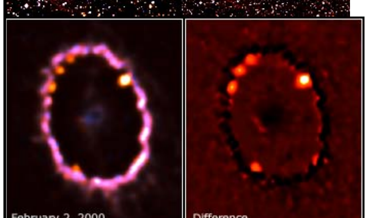


Kapow!

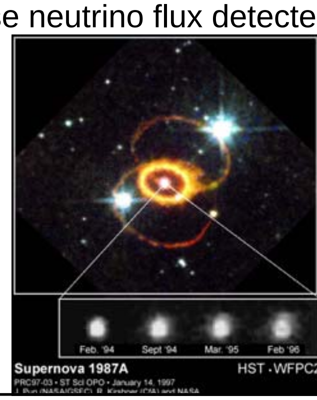
- Explosion releases huge kinetic energy
  - ➔ heating ➔ lots of photons
- Luminosity in photons temporarily exceeds that of whole galaxy full (10^{11}) of stars.
- But far greater luminosity in neutrinos
  - $e^- + p$ ➔ n + neutrino

Supernova 1987A

- Exploded in Large Magellanic Cloud
  - Small spiral galaxy that orbits our own Galaxy.
- Caught in act of exploding and intensively studied.
- Intense neutrino flux detected.



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

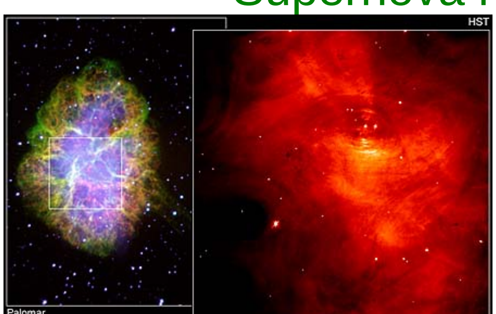


Neutron capture

- 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

Supernova remnants

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



Crab Nebula.
1054 AD.
Ripples are due to energy being dumped into gas by beam from pulsar.

IC 443
8000 yrs old

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