Life of stars, formation of elements

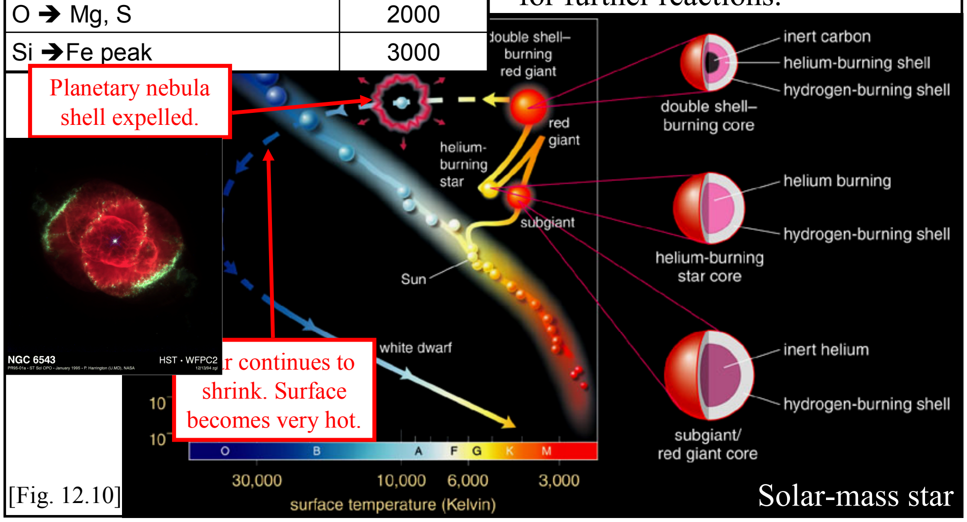
- Recap life of sun
- Life of massive stars
- Creation of elements
- Formation of stars

- Profs. Jack Baldwin & Horace Smith will teach course for the remainder of the term to allow me time to finish the Spartan IR Camera
  - baldwin@pa.msu.edu
  - smith@pa.msu.edu
  - E-mail Loh@msu.edu to contact me.
- Homework 5 is due 6:30am on Friday, 23 March.
- Extra-Credit for best OBAFGKM mnemonic.
  - Enter in Angel before 31 March.
- Astronomical Horizons
  - E Loh, Spartan Infrared Camera
  - Planetarium, 7:30, Thurs.

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 → O, Mg	1500
O → Mg, S	2000
Si → Fe peak	3000

Stars with < 2 $M_\odot$

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



[Fig. 12.10]
Solar-mass star

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 ➔ 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.
  - 0.7% of mass turns into energy.
- 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.

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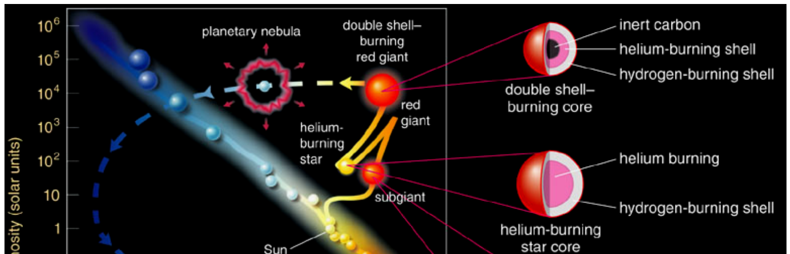
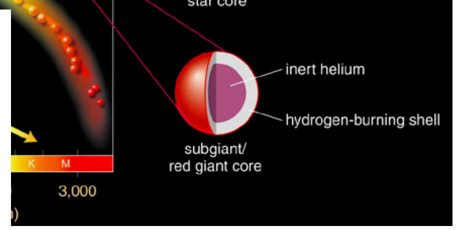
Sun becomes a giant

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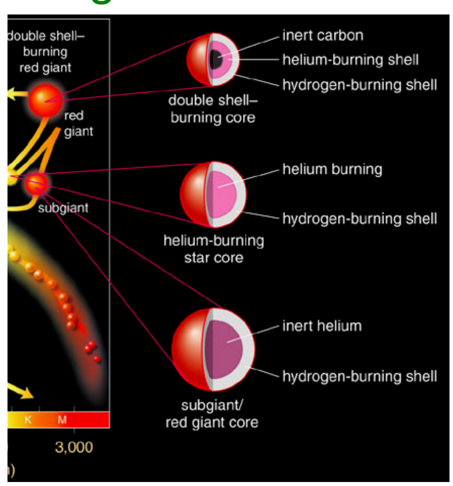
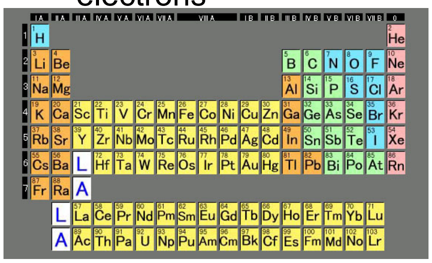
- When sun uses up the He in the core, it contracts & gets hotter. NO, it does not.
  - New physics: At sufficiently high density, quantum mechanical pressure comes in. It is independent of temperature.
  - Will discuss this next class.
  - No more fusion means sun becomes inert. White dwarf.



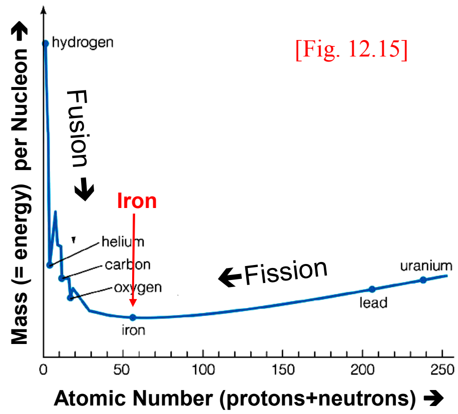
Nucleosynthesis: where we came from.

- 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



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

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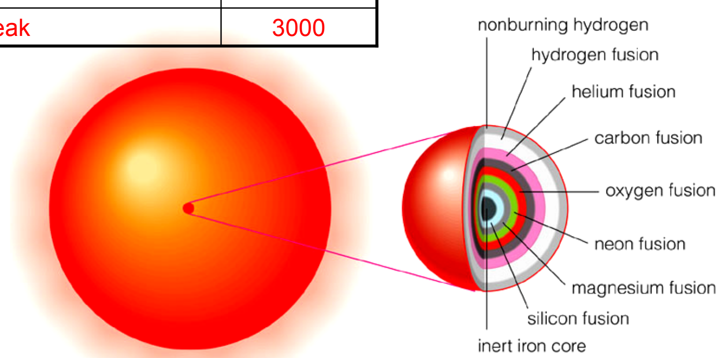
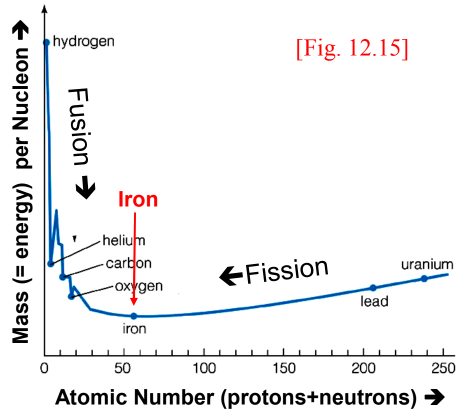
- "Onion skin" model
  - Central core is iron
  - Outer layers correspond to each previous step in nuclear burning chain.

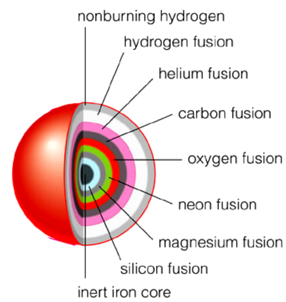


Supernovae

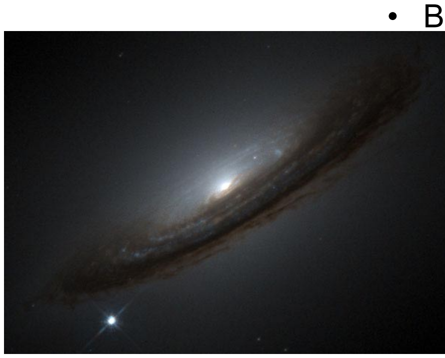
- For M > 7-8 $M_{\odot}$, stars cannot "gracefully" lose mass and become white dwarfs.
- Massive stars end up with iron cores

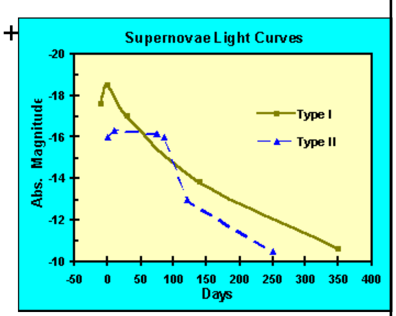
  ➔ No further nuclear burning possible
- Core eventually becomes too massive to be held up by degenerate electron pressure:
  - $e^{-} + p \rightarrow n$
  - Sudden core collapse: 10^4 km ➔ 20 km
  - Then core rebounds
  - Outer layers fall in, then get hit by rebounding core.





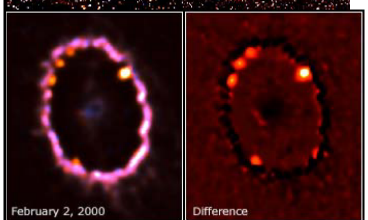
- Explosion releases huge kinetic energy
  - ➔ heating ➔ lots of photons
- Luminosity in photons temporarily exceeds that of whole galaxy full (10^{11}) of stars.
- But far greater luminosity neutrinos
  - e^{-} +



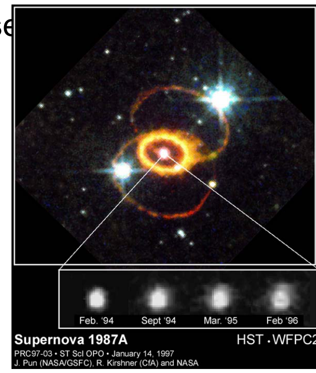


Supernova 1987A

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

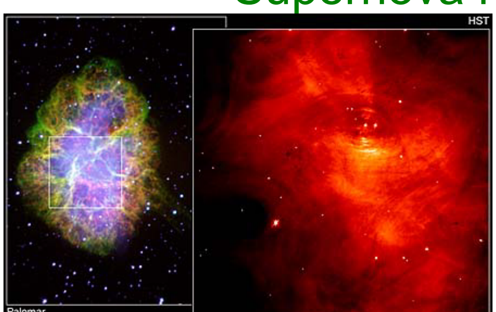


Pre-existing circumstellar ring lit up first by photons from SN, now by blast wave from SN.

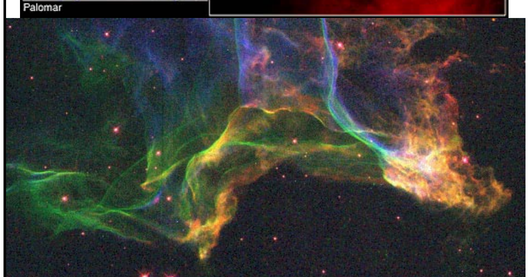


Supernova remnants

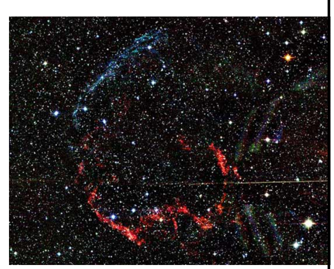
We expect one supernova in Milky Way every 25-100 yrs.



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



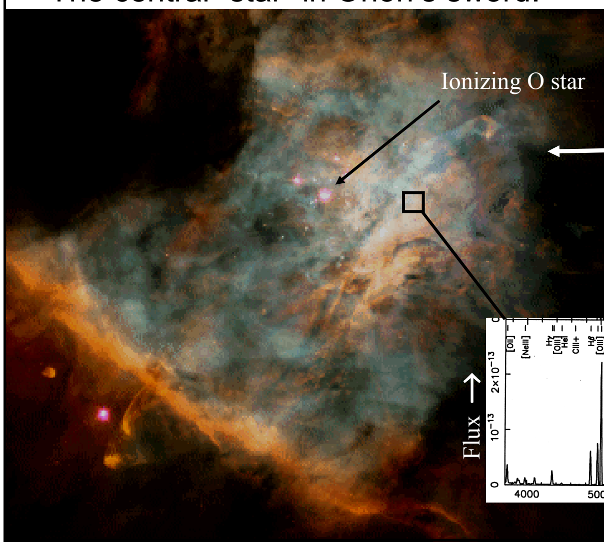
Cygnus Loop
20,000 yrs old.
2500 LY away.

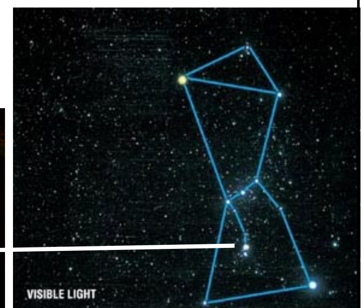


IC 443
8000 yrs old

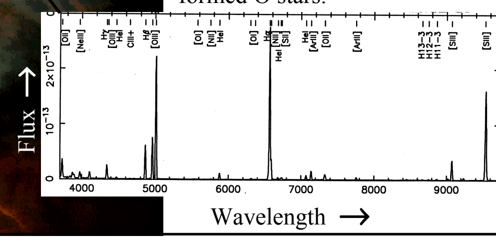
Formation of Stars: The Orion Nebula

- 1500 LY away from us
- The central "star" in Orion's sword.

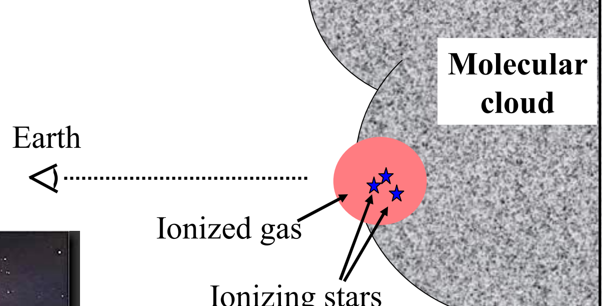




An "H II" region:
ionized gas excited by recently-formed O stars.

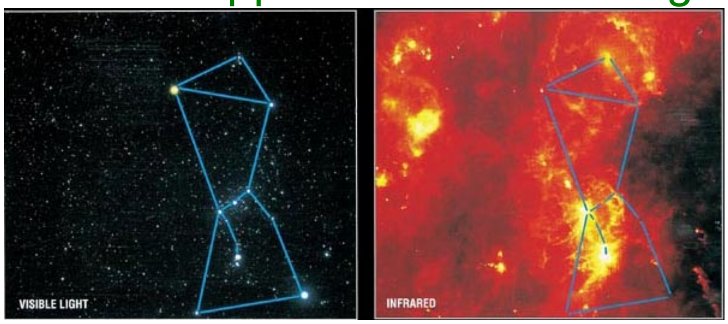


HII region is small cavity at edge of much bigger molecular cloud



- Ionized region has "blown out" of near side of dense cloud.
- Many more similar star-formation regions buried deep inside cloud.

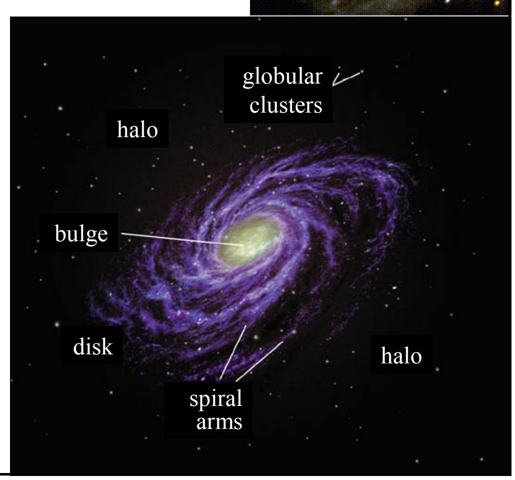
Full extent of star-formation region becomes apparent in infra-red light.



- 100 LY across
- 200,000 $M_\odot$
- Only a few of its stars close to the near edge can be seen in visible light.
  - Infrared light penetrates dust & shows many more stars.

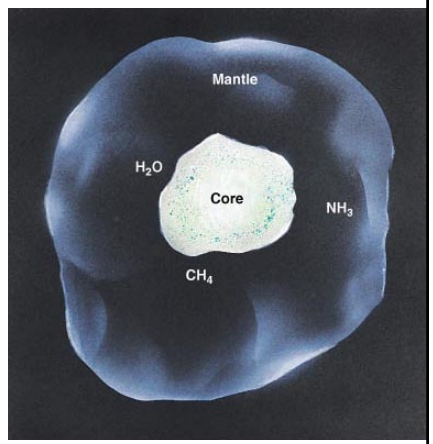
Interstellar Gas and Dust [14.2]

- Space between stars is not empty.
- *Interstellar medium:*
  - Gas
  - Dust
  - Molecular clouds
- More concentrated in spiral arms of Galaxy
- Stars form from this material



Dust

- Tiny grains
  - 10^{-8} to 10^{-7} m.
- Built up of molecules of most common elements after hydrogen and helium
  - Core: Silicates or Graphite (Si, O, C)
  - Mantle: C,N,O combined with H
- Absorb light
  - Absorb strongest in blue, less in red.
  - Blocks view through disk of our Galaxy
    - except in infrared
    - and (better yet) radio

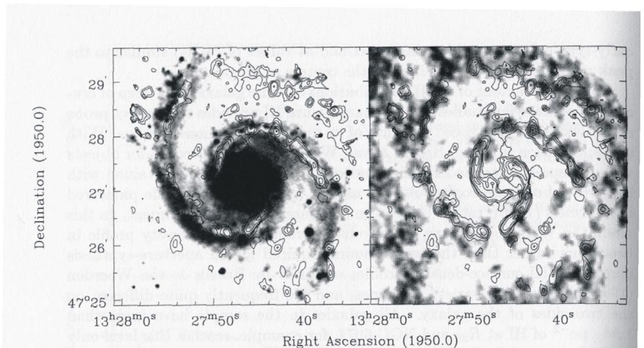


Molecular clouds

- Massive interstellar gas clouds
  - Up to ~10^5 $M_\odot$
  - 100's of LY in diameter.
- High density by interstellar medium standards
  - Up to 10^5 atoms per cm^3
- Shielded from UV radiation by dust ➔ atoms are combined into molecules.
  - H_2 …and also H_2O, NH_3, CO plus much more complex molecules.
- Preferred place for stars to form.

Giant Molecular Clouds

Dense concentrations of H_2, CO and other molecules, + dust.

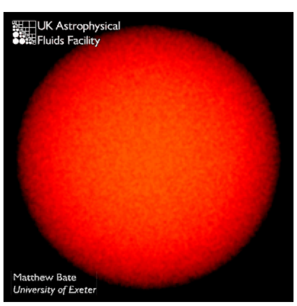


CO contours over image from starlight.

CO contours over radio image.

M51 – a nearby spiral galaxy

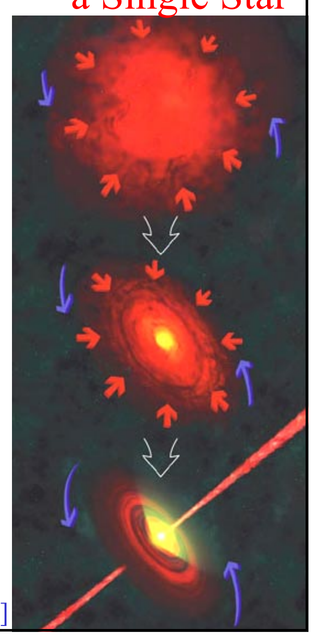
Computer simulation: Star Formation in a Molecular Cloud



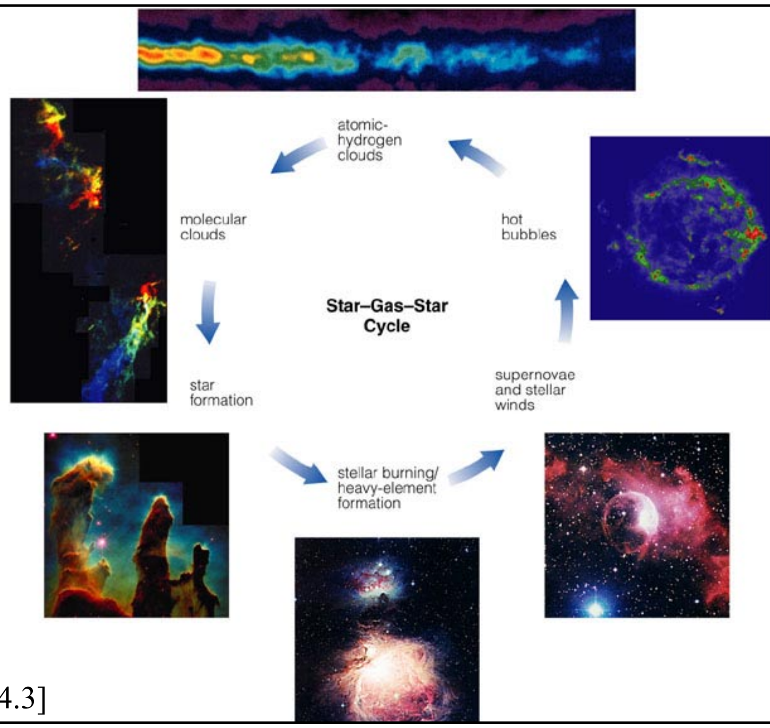
Collapse and fragmentation of 50 solar-mass cloud.

- Initially 1 light-year in diameter.

Final Collapse of a Single Star



[Fig 12.3]


atomic-
hydrogen
clouds
molecular
clouds
hot
bubbles
Star–Gas–Star
Cycle
star
formation
supernovae
and stellar
winds
stellar burning/
heavy-element
formation
[Fig. 14.3]