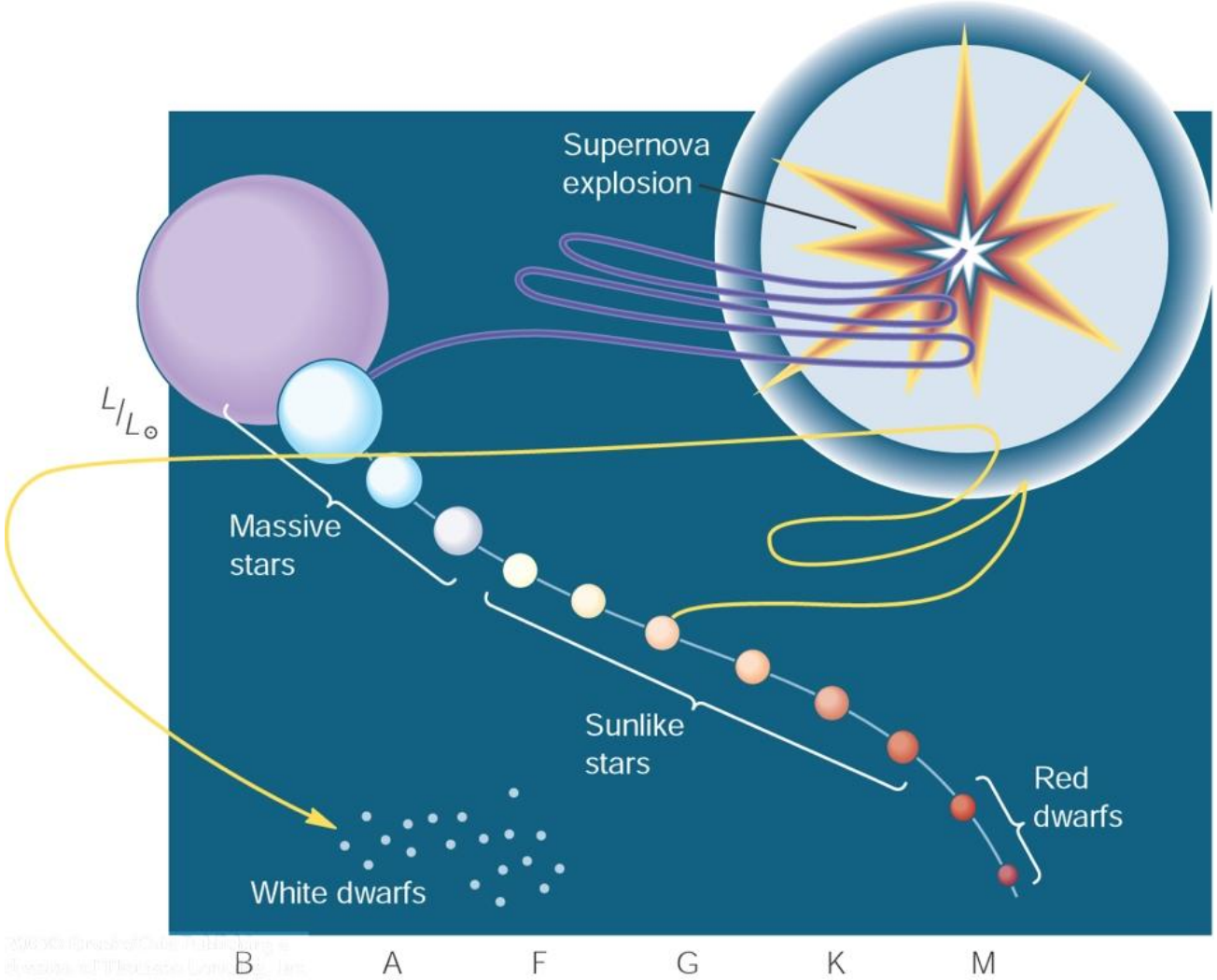
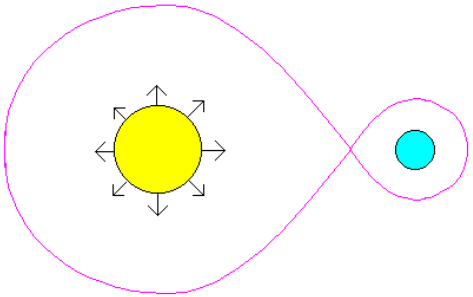
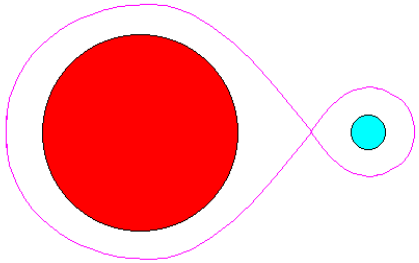
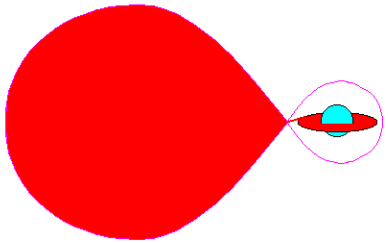
# Review – Stellar Evolution

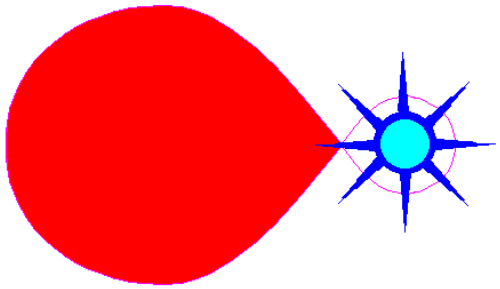
- Main Sequence - star burns hydrogen to helium in core
- Red Giant – hydrogen burns in shell leaving helium
- Horizontal Branch – helium burns in core leaving carbon









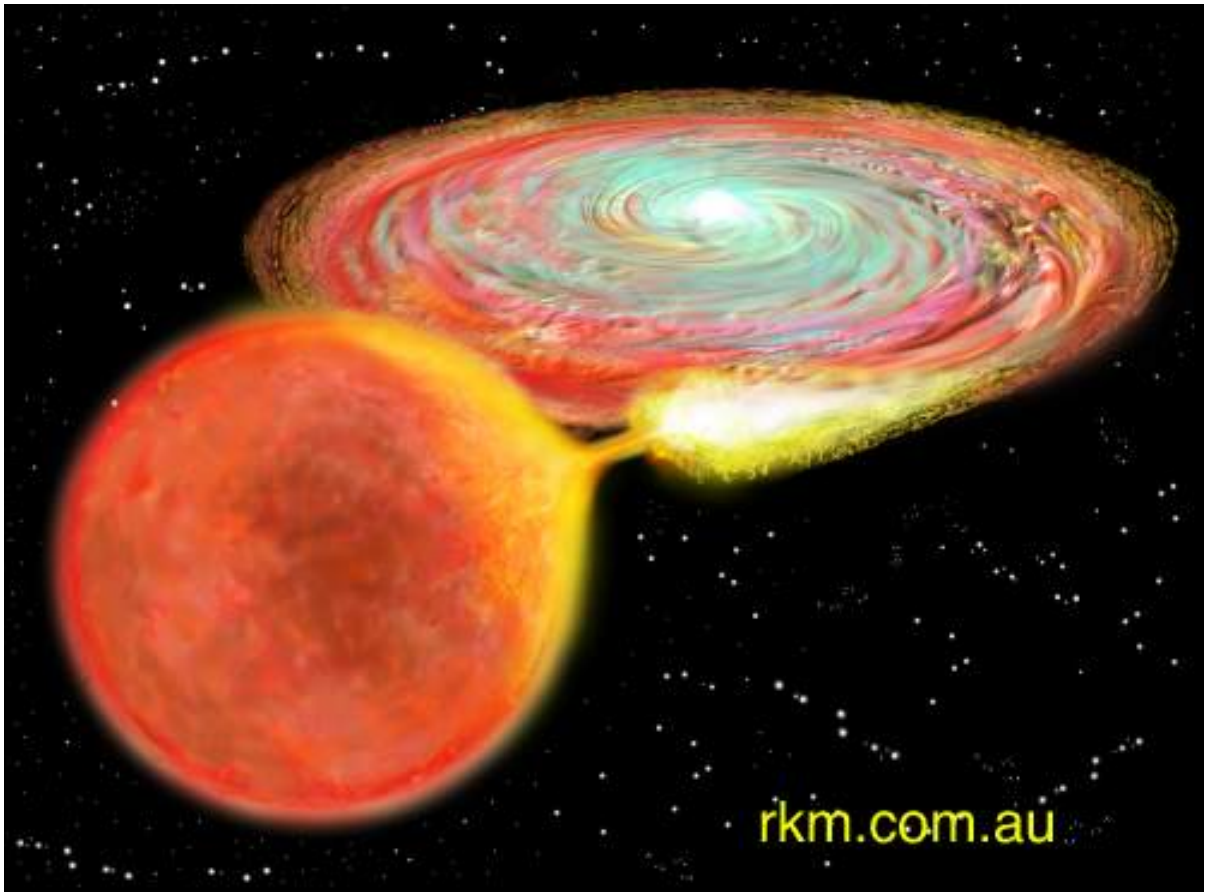


# Binary Star Evolution

- Higher mass star evolves first
- Forming white dwarf
- Companion star becomes a red giant
- Overflows its Roche Lobe
- Dumping Hydrogen onto white dwarf

# Accretion Disk

- Hydrogen gas flows from Roche Lobe through Lagrange point L1
- The gas forms an accretion disk then falls on star

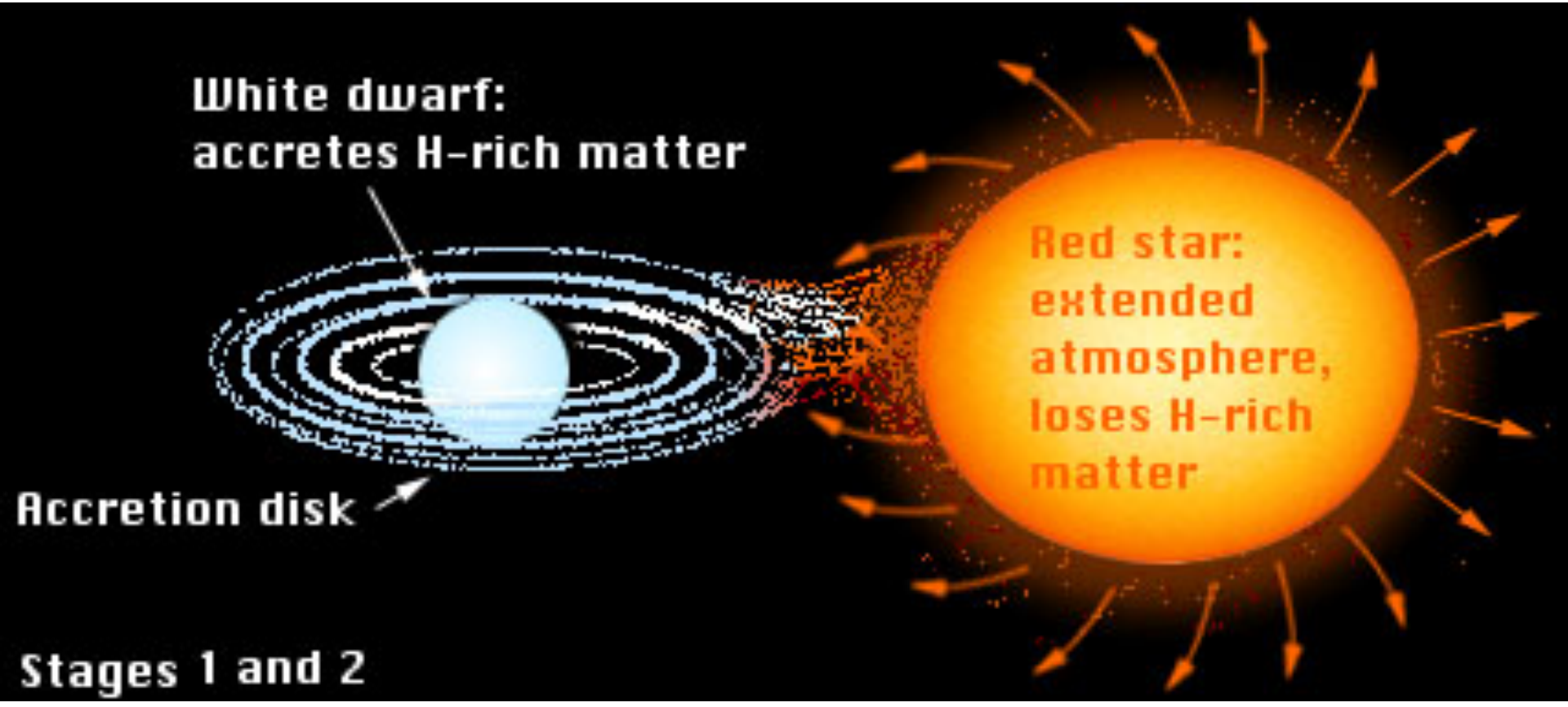


# Hot Spot

- Hot spot forms where stream hits accretion disk
- Friction in accretion disk heats gas up to ~million K
- Emitting UV & X-rays

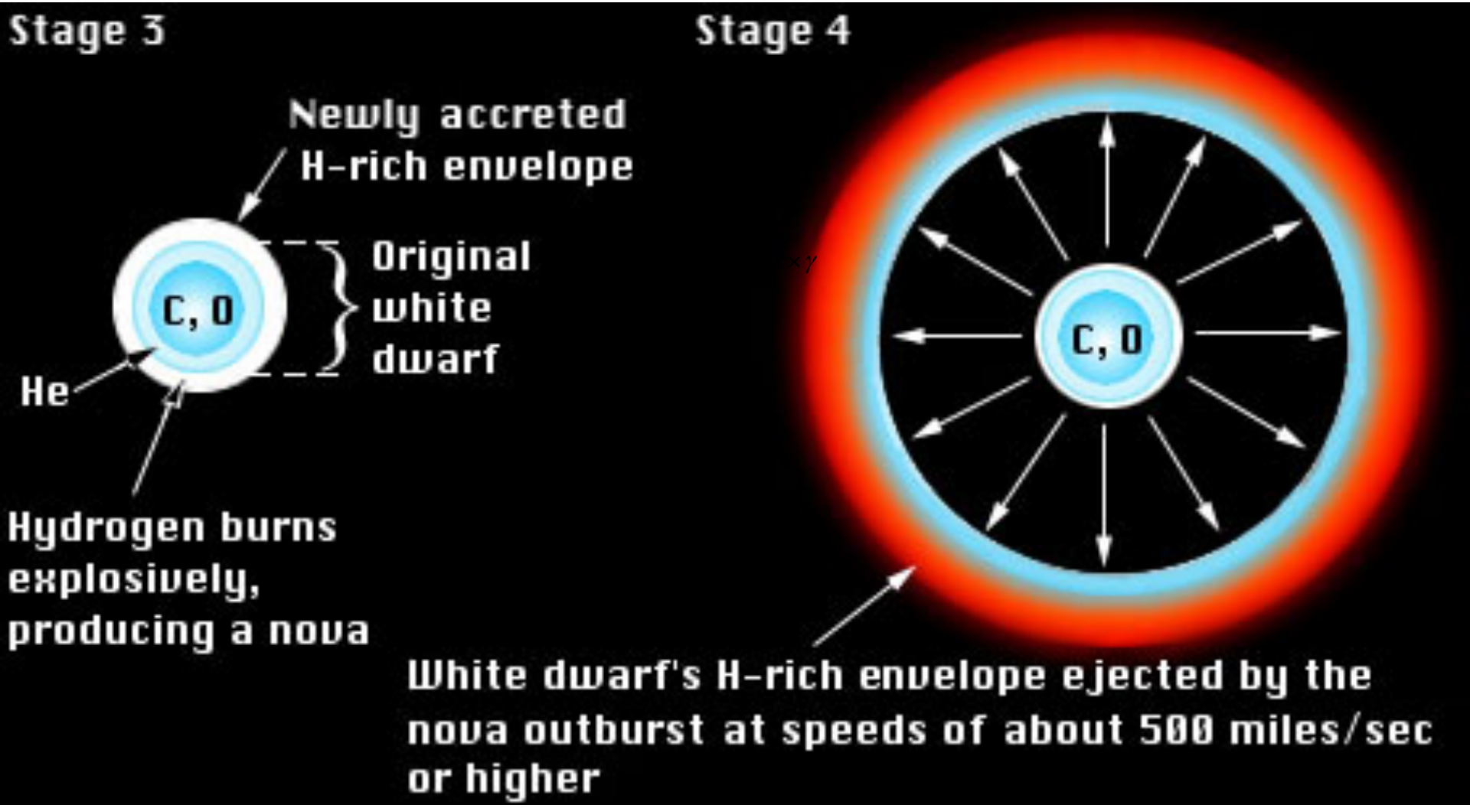
# Nova

- What happens to the Hydrogen which falls on an electron degenerate white dwarf??



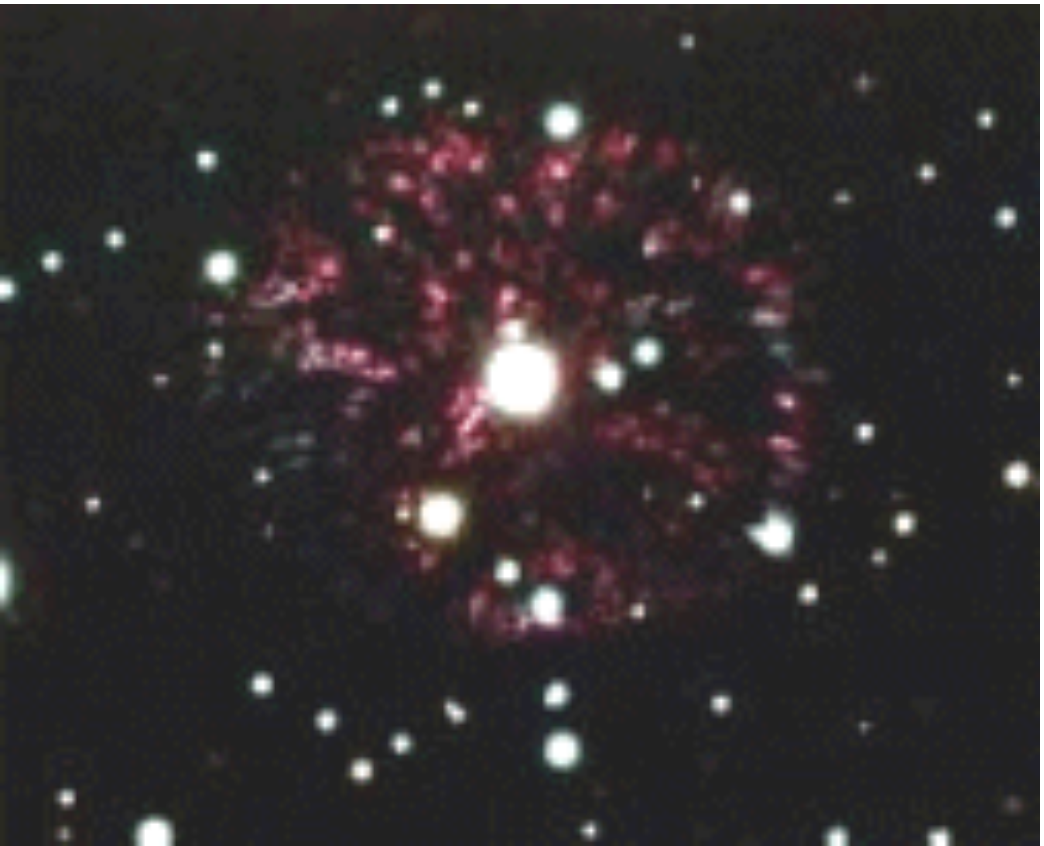
# Nova 2

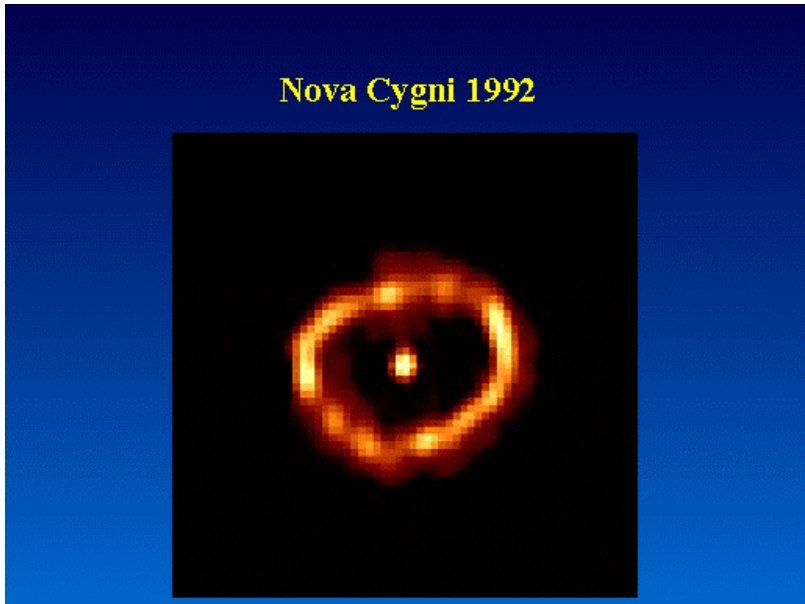
- Do not throw gasoline on hot coals!



# GK Persi

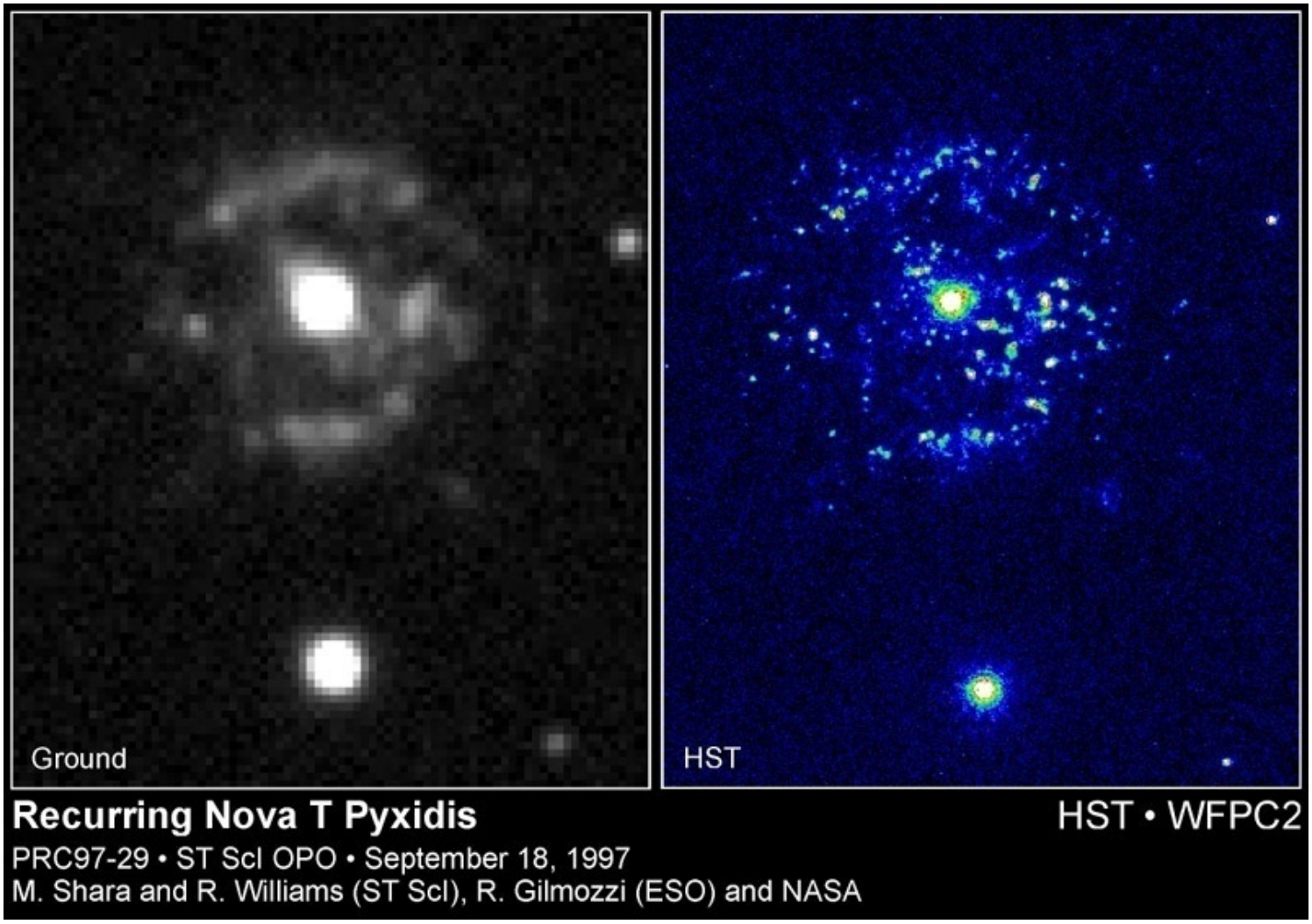
- After ~100 earth masses, burns hydrogen to helium
- 10,000 times brighter
- Nebula ejected at ~600km/sec
- 0.001 solar mass ejected so white dwarf is not destroyed
- We observe a few novae per year in our galaxy

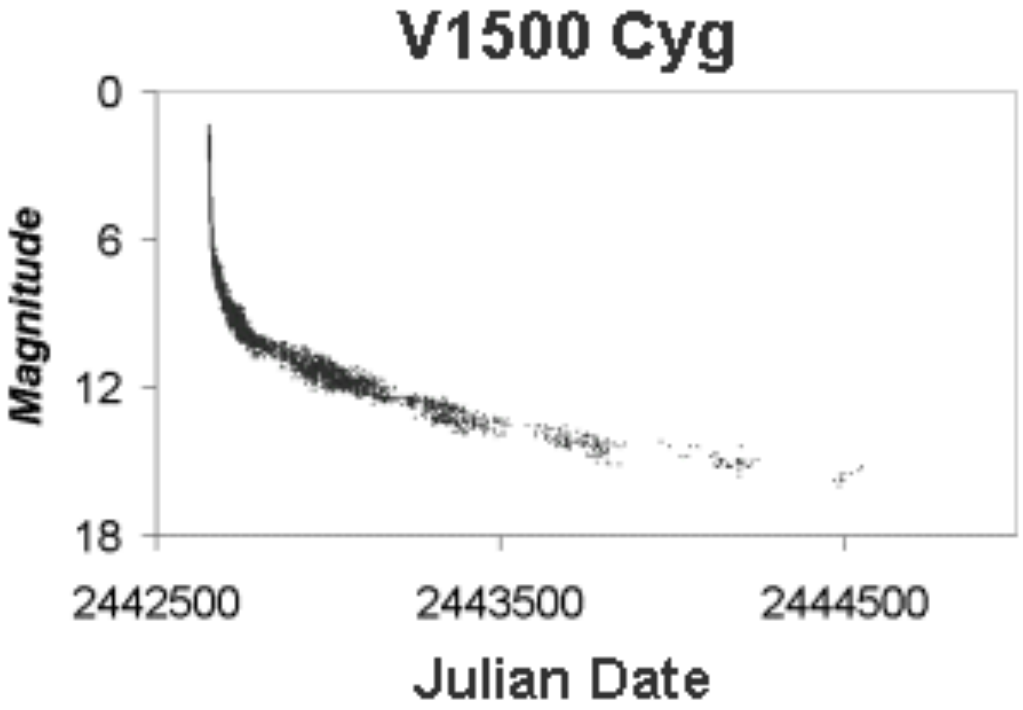




# Recurrent Nova T Pyx

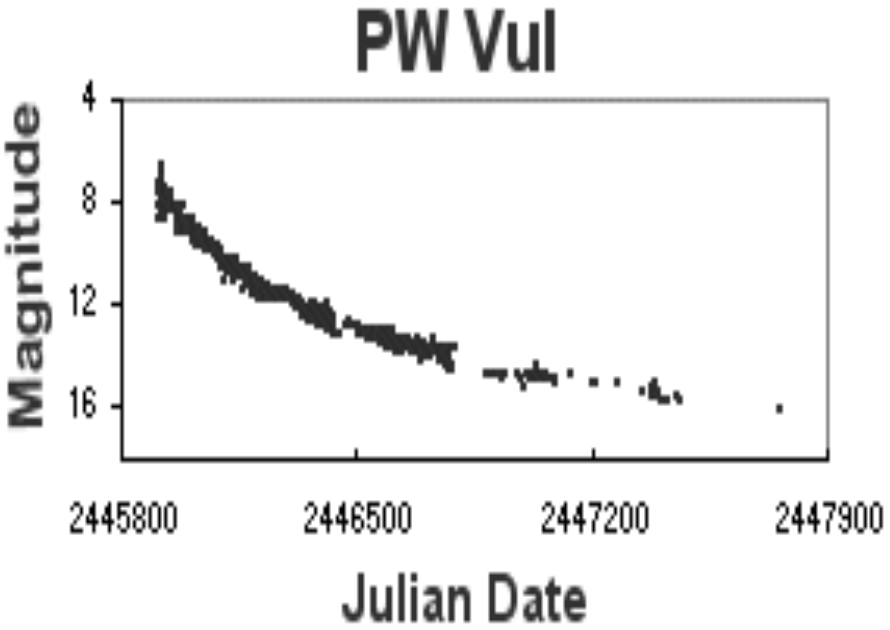
- Nova can happen again every few to thousands of years





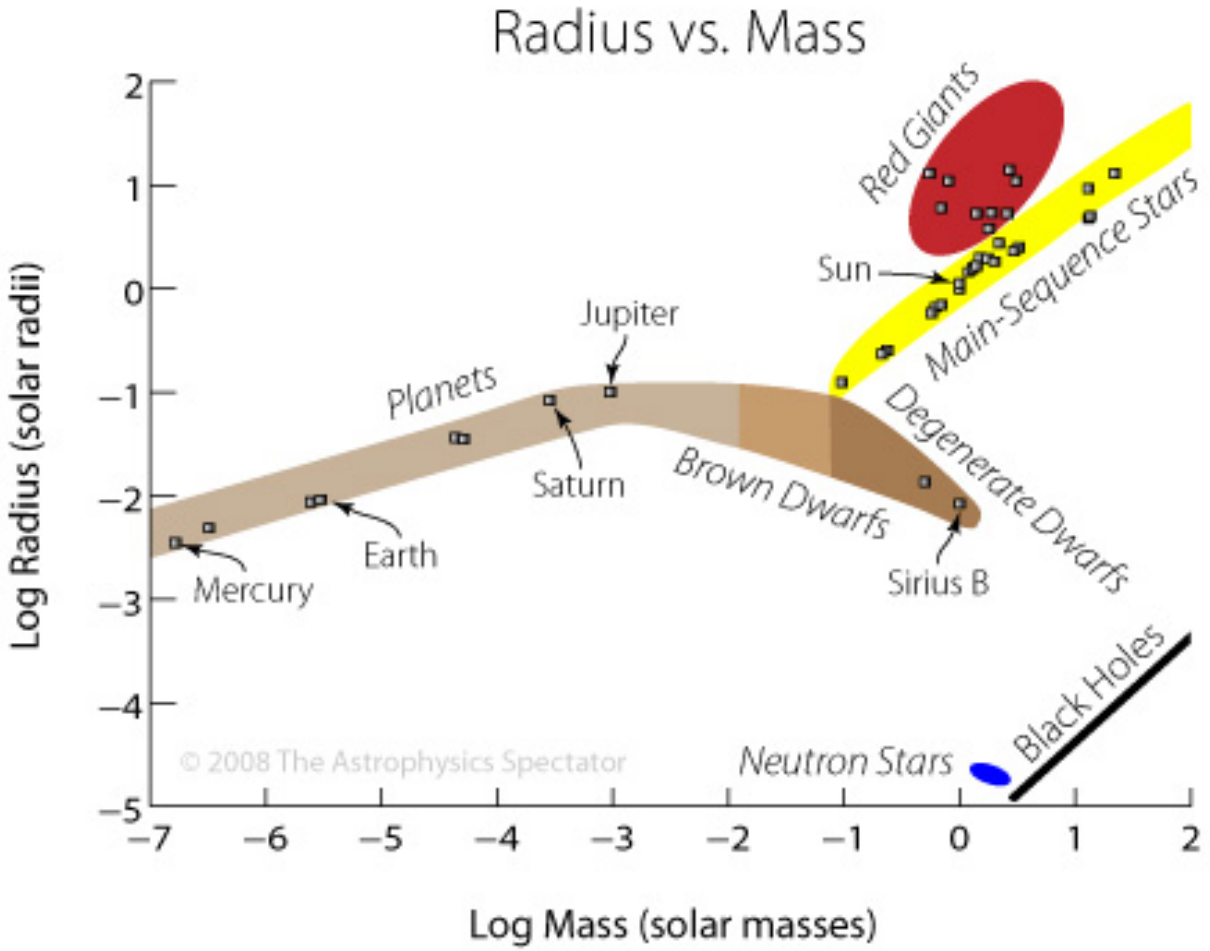

# Novae Light Curves

- Distance Indicators
- Depending on rate of decline- absolute magnitudes ~-4

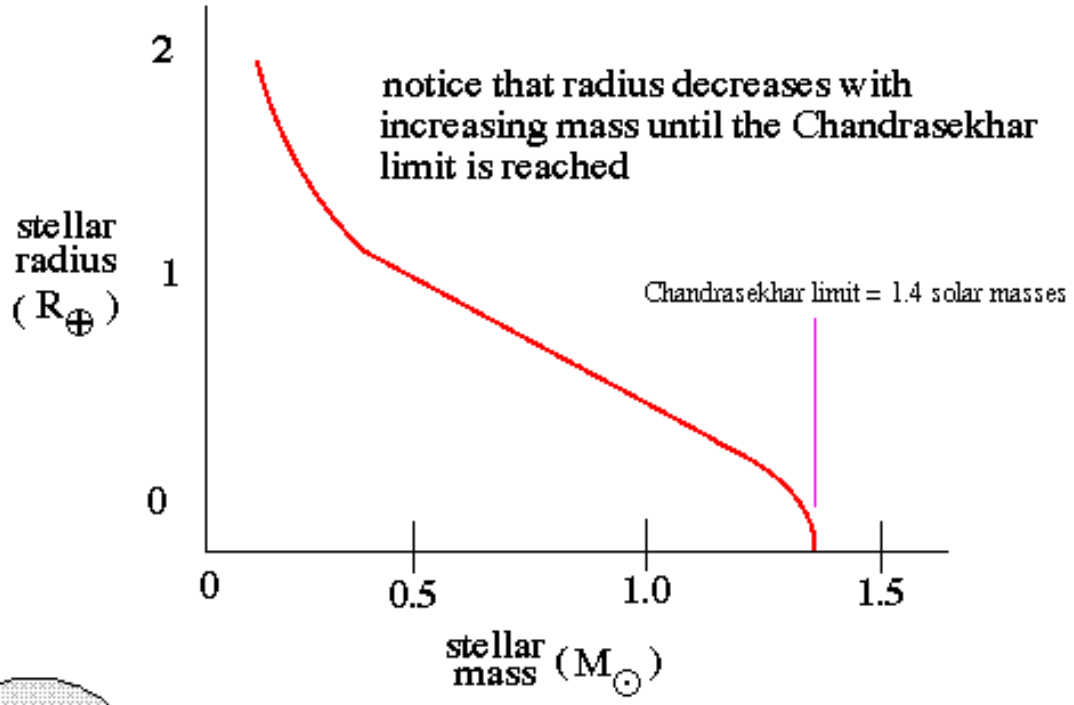


# Compact Objects / Stars

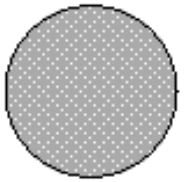
- Small radius & Large mass =High density
- White Dwarfs: more mass – smaller radius



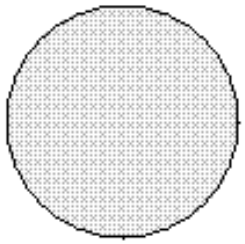
# Mass-Radius Relation for White Dwarf Stars




Regular star:
More mass => larger size.

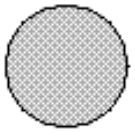


M = 0.5 solar mass



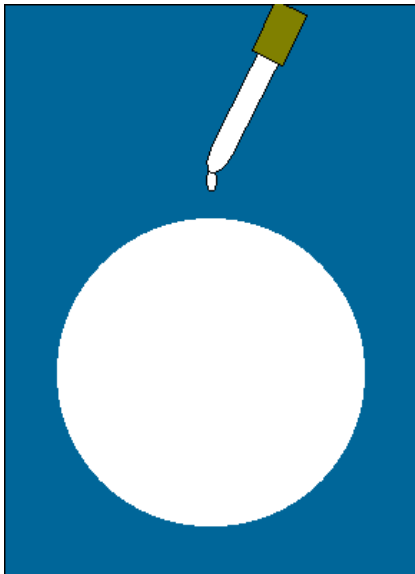
M = 1.0 solar mass

Degenerate star:
More mass => *smaller* size.



M = 0.5 solar mass

M = 1.0 solar mass

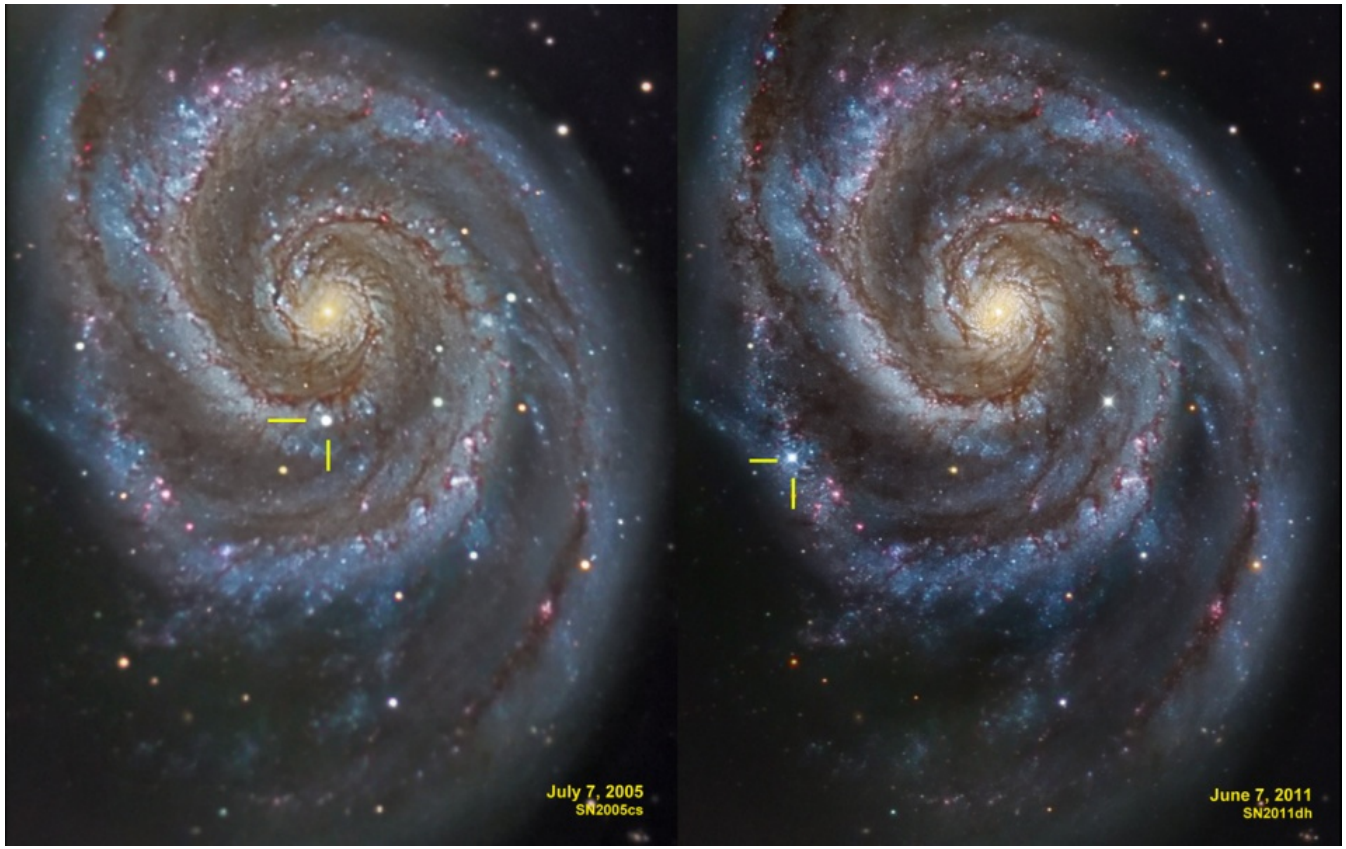


# Chandrasekhar Mass/Limit

- An electron degenerate star can not be more massive than 1.4 solar masses
- Mass loss can be so large that even 7 or 8 solar mass stars may become this small
- But what about bigger stars?

# Novae / Supernovae

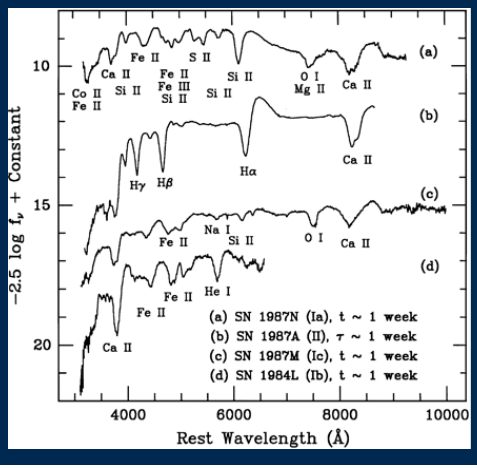
- Nova = thousands of Suns
- Supernova = Billion of Suns
- Bright as galaxy: TypeIa@6500ly=Venus @500ly=Moon, @1 light year =Sun



# Supernovae Types

- **Type Ia – Carbon-detonation** = White dwarf explodes destroying star
- **Type II – core-collapse** of massive star leaving neutron star/black hole
- Equal brightness & equal number observed

## Spectra Comparison

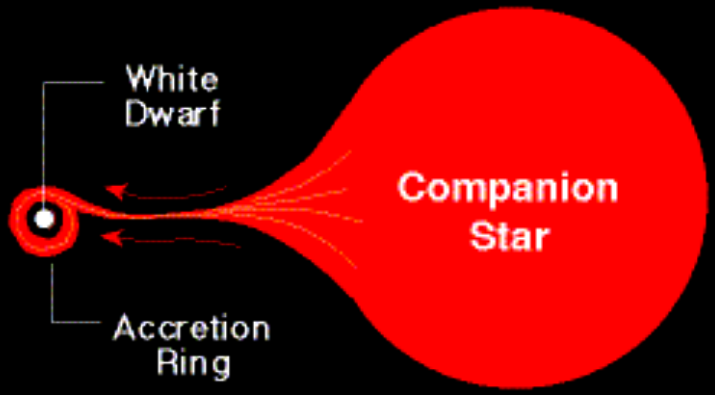



## Types of Supernovae

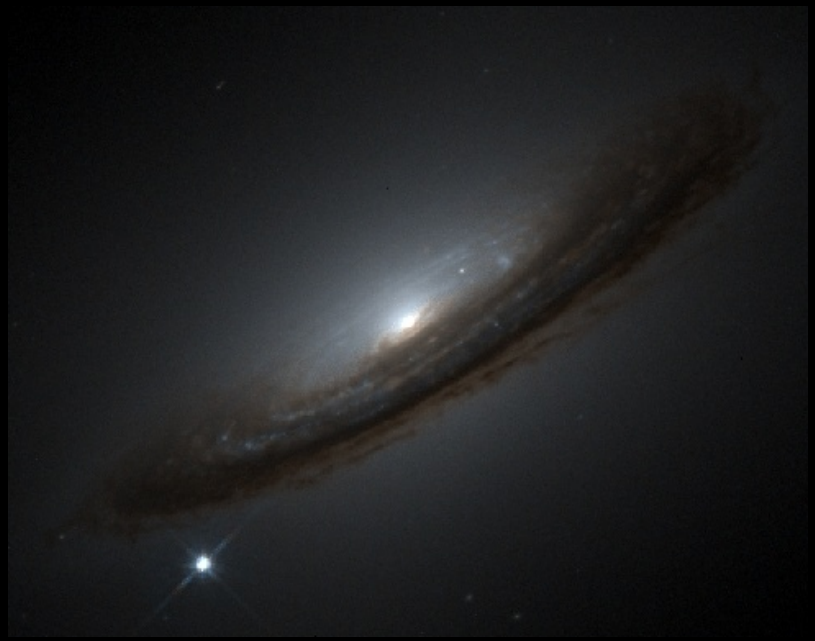
- *Type I – No Hydrogen*
- *Type II – Have Hydrogen*
- *Type III – SN 1961I*

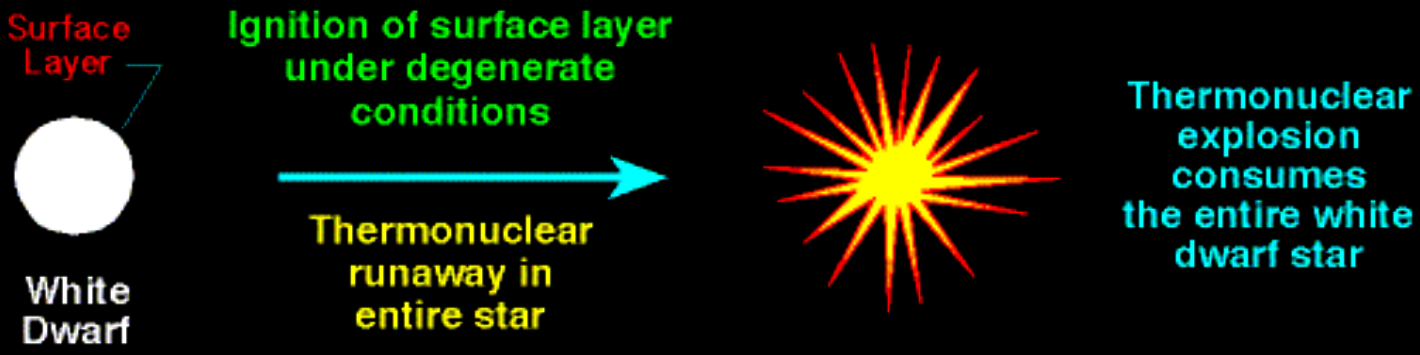
# Carbon-Detonation Supernova

- Mass transfer forces white dwarf to exceed (Chandrasekhar?) limit & collapse triggers carbon deflagration=Type Ia



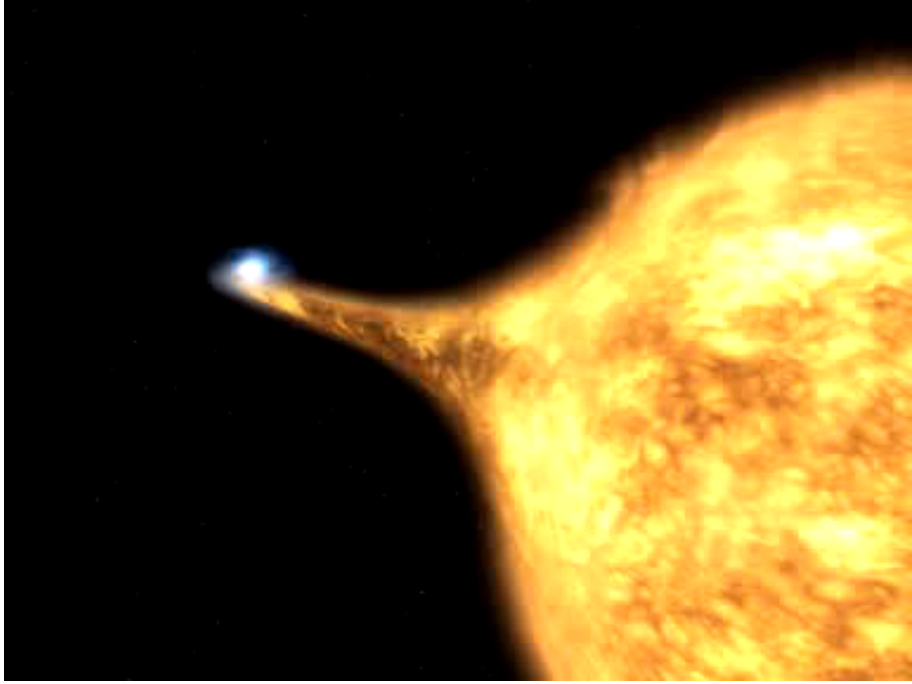

Thin hydrogen surface layer accumulated on white dwarf through accretion ring

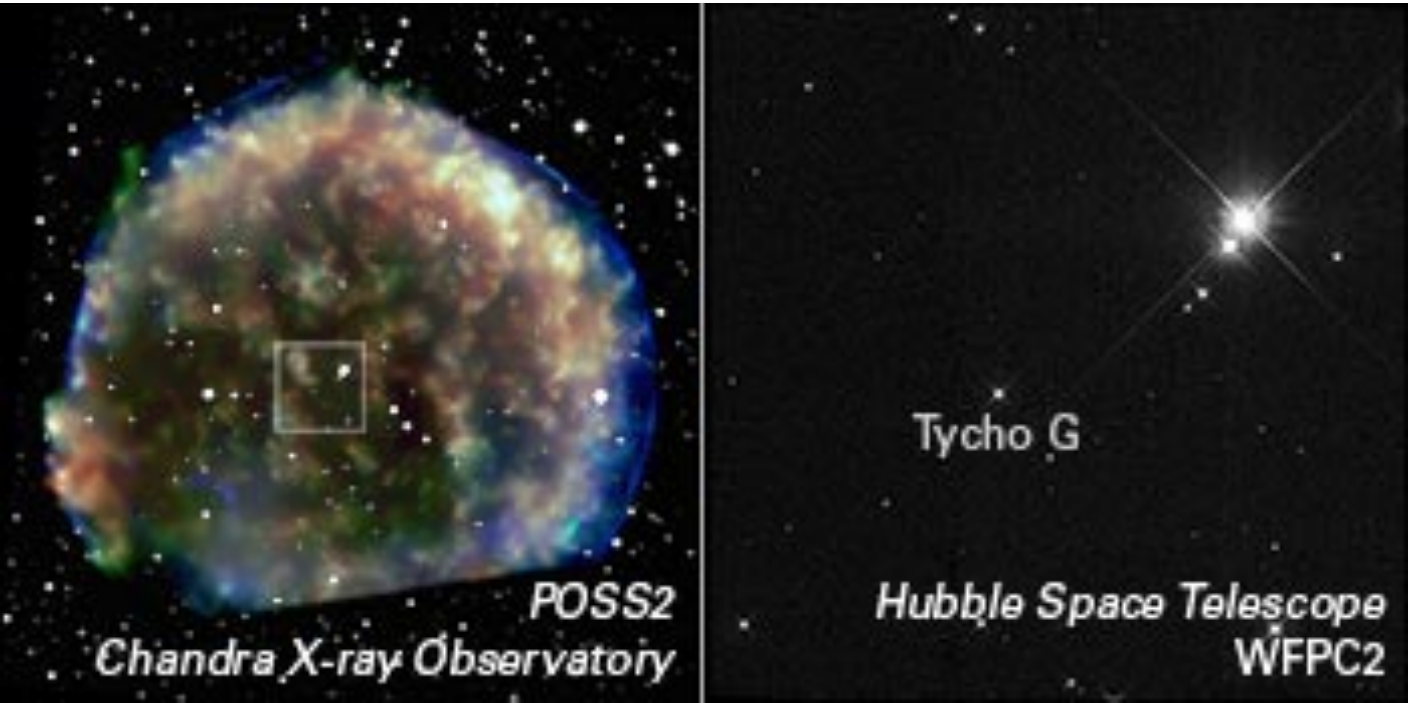


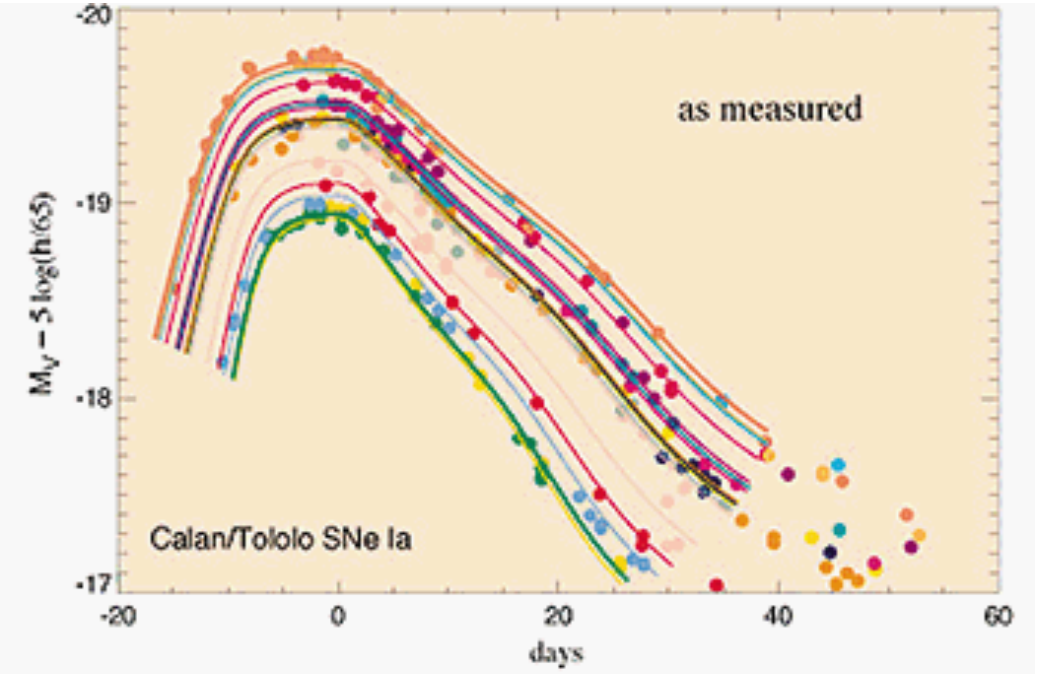


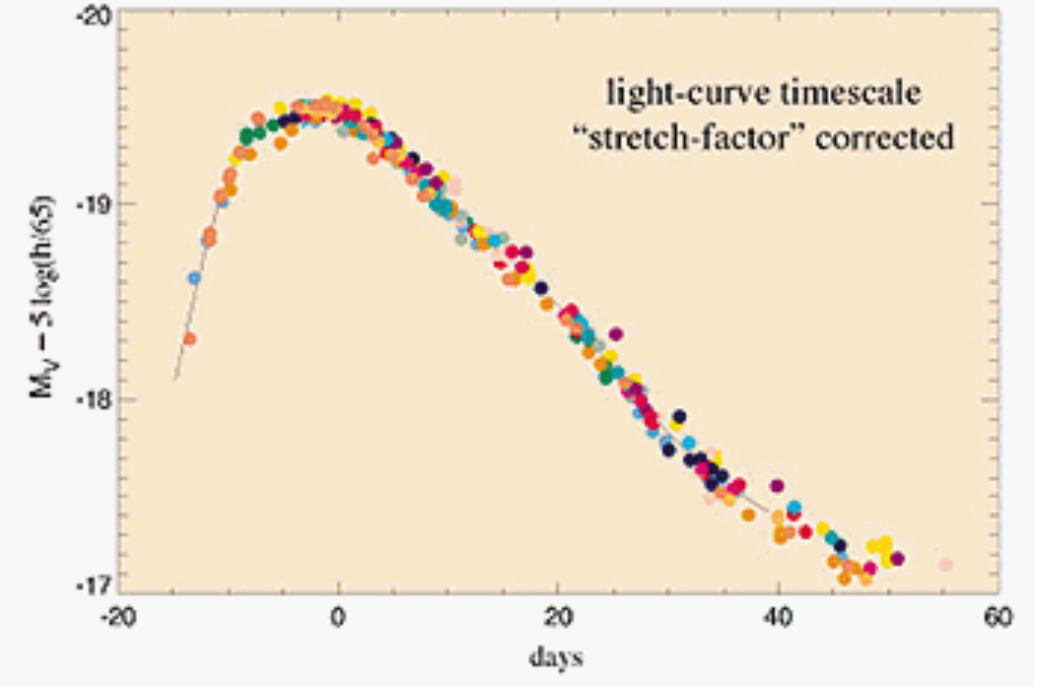
# Animation of Tycho's Supernova

- "Runaway star" is found moving away from center of nebula at 3 times speed of other stars ~ 140km/sec





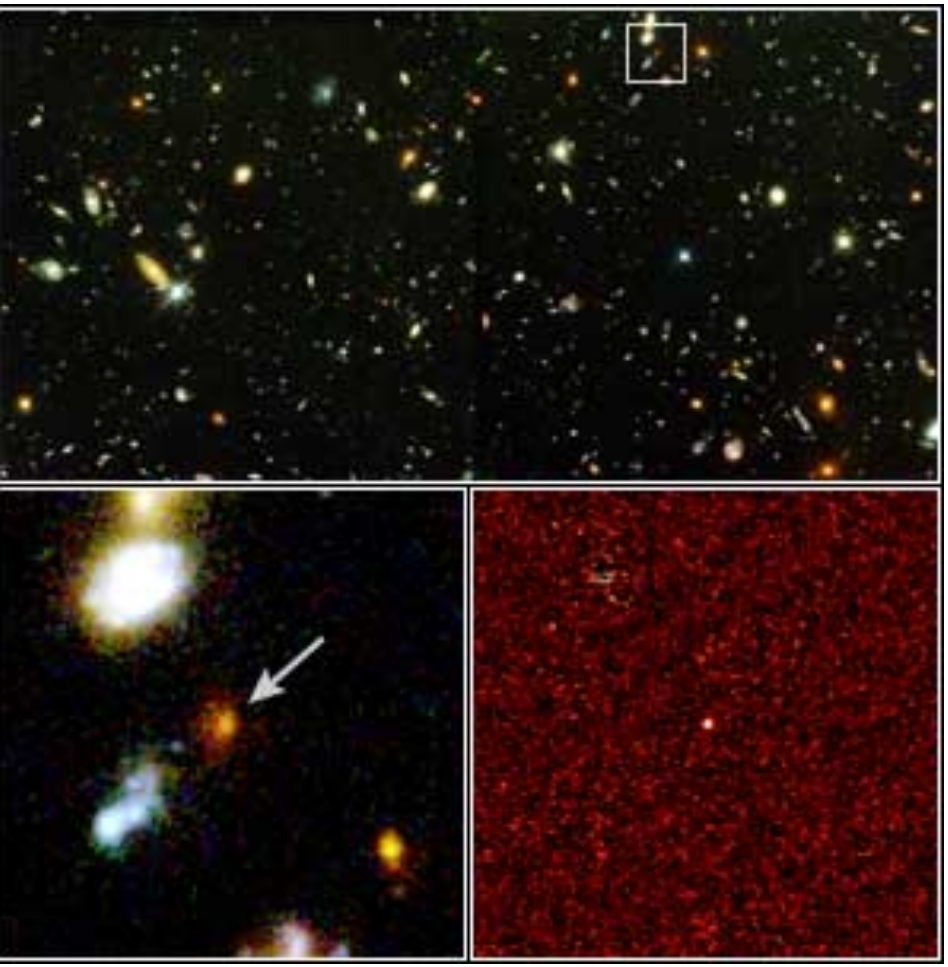



# Type Ia Supernovae Light Curves

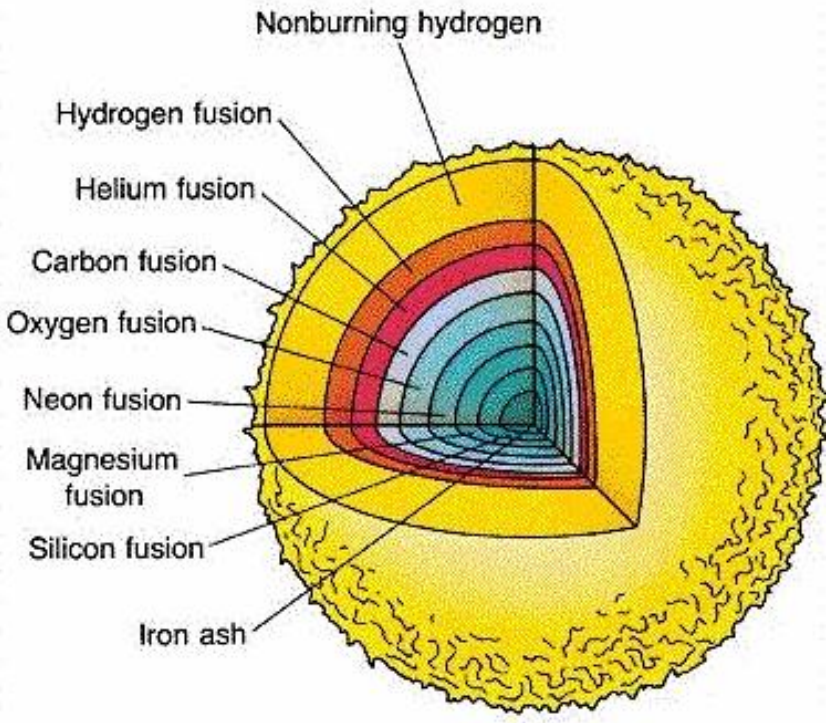
- After correcting for the stretch/width
- All Type Ia supernovae have the same intrinsic brightness
- Same absolute magnitude

# Most Distant Supernova

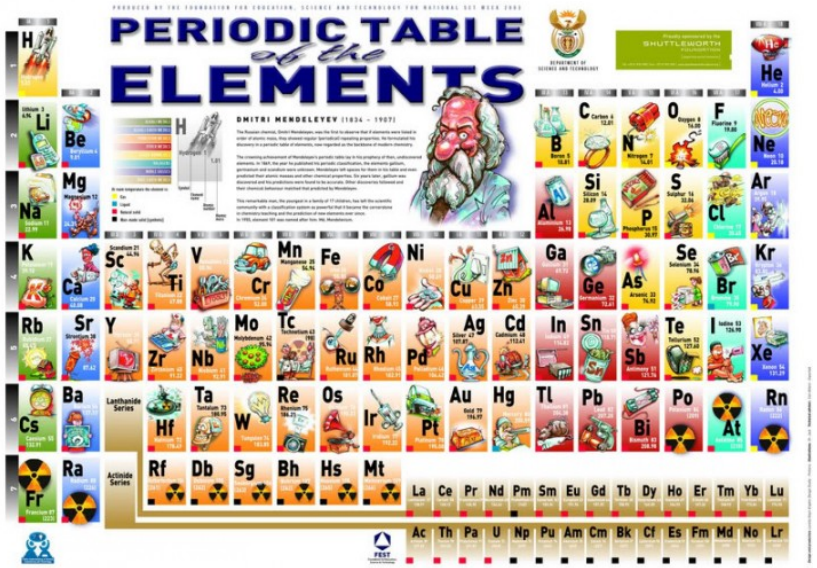


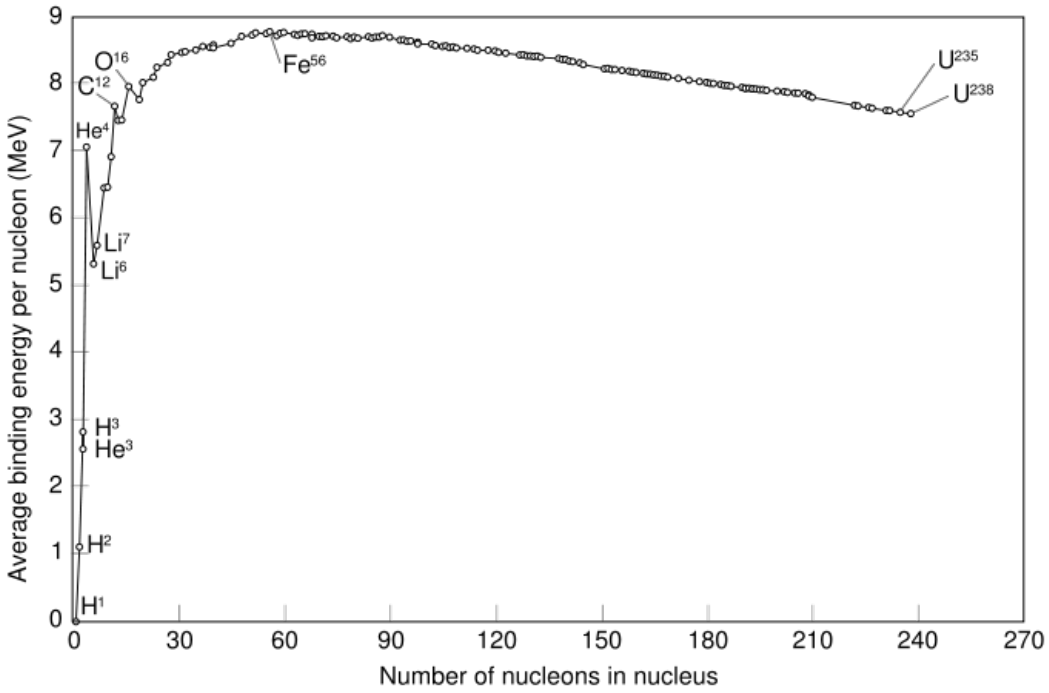
- Because they can become as bright as a whole galaxy of stars
- We know their absolute magnitude so we can find their distance
- Even when they are on the other side of the universe

# Larger than 8 Solar Mass Star



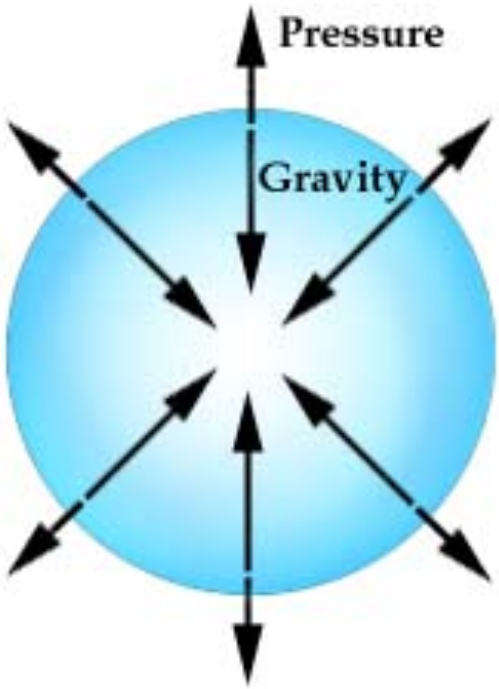

- Lighter elements burn in cooler shells farther from iron core
- Star larger than 8 $M_{sun}$ can't lose enough mass to become a white dwarf

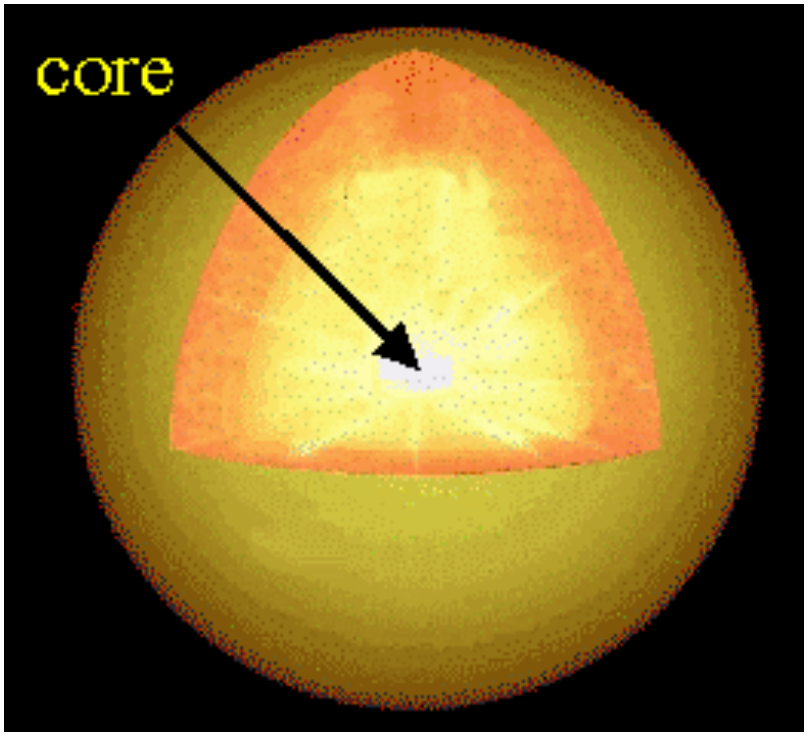


# Type II Supernova

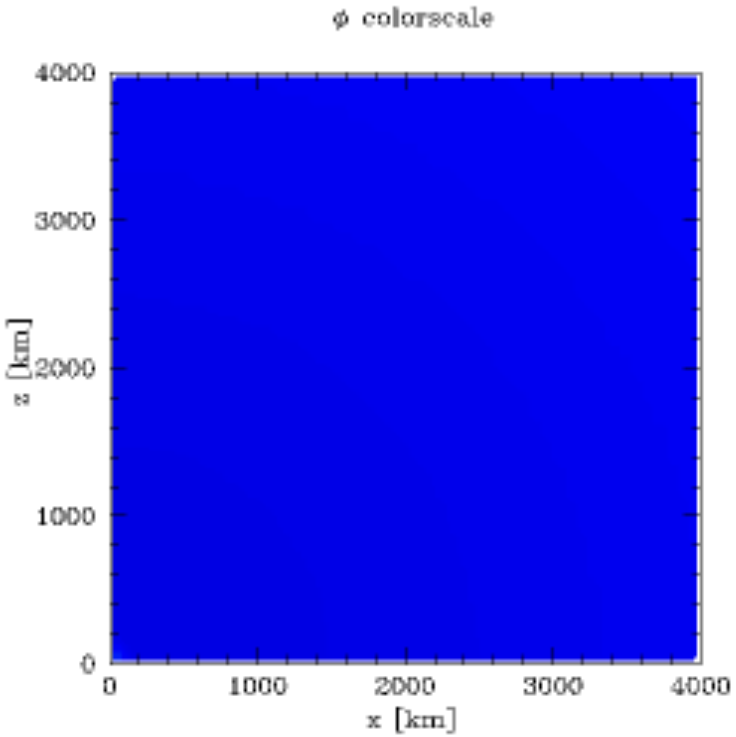
- When iron core reaches a few solar masses – dense core collapses
- Innermost 500km in a few millisconds (0.25c)
- So hot photons **photodisintegrate** Iron - absorbing energy
- Electron +Proton ⇒ Neutron + Neutrino & Neutrinos escape
- 99% of energy comes out as neutrinos, 1% shock wave, 0.01% light

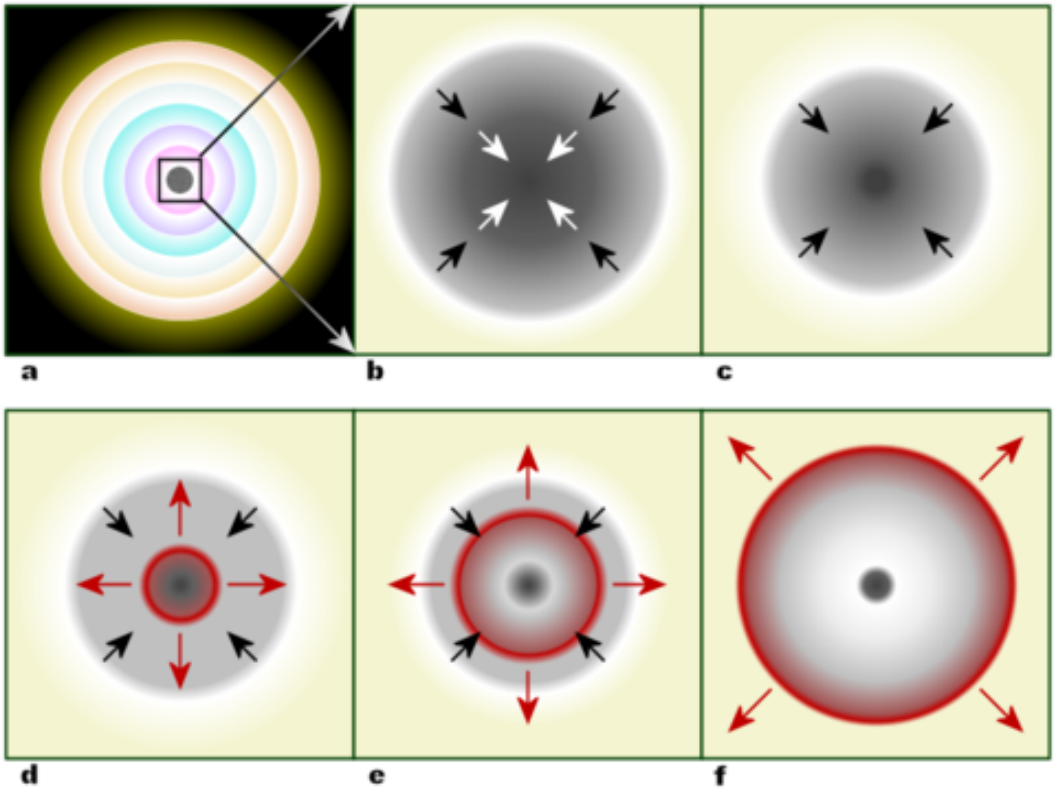


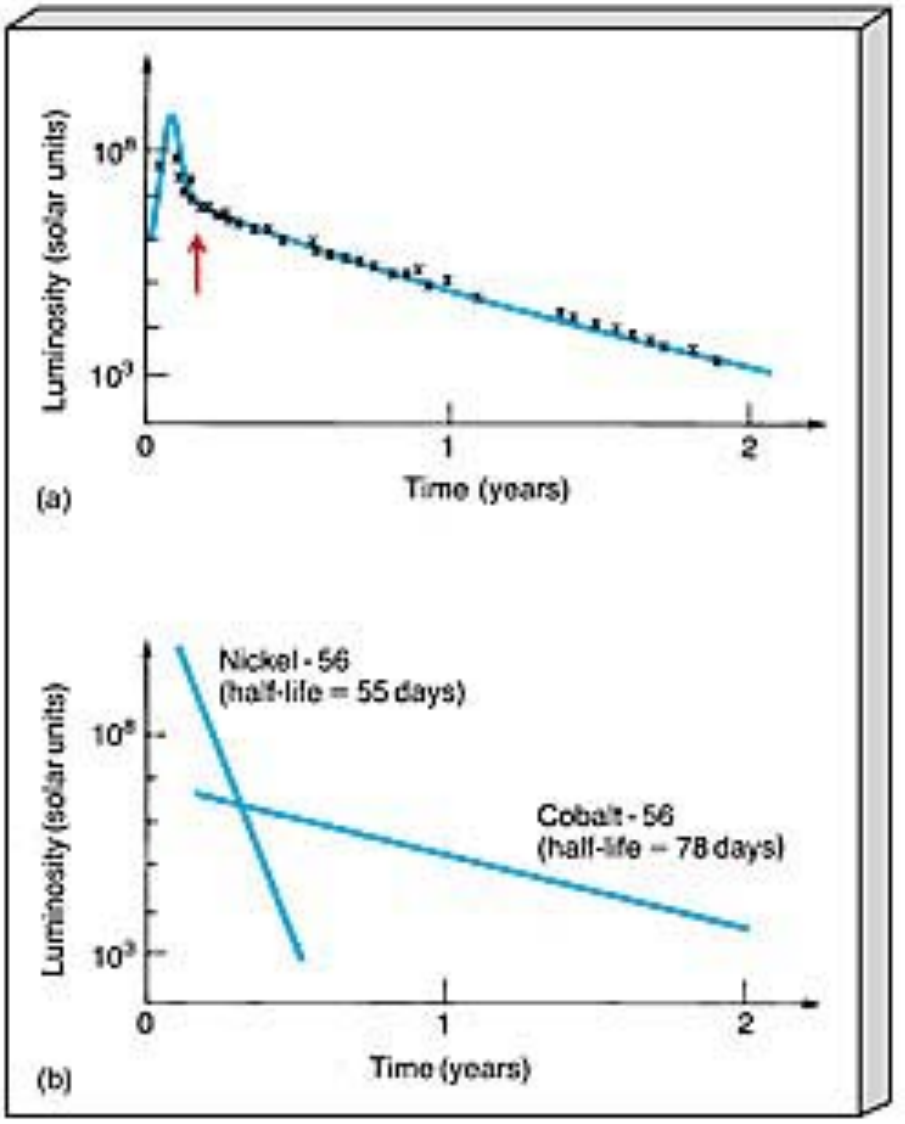



# Core-Collapse Supernova

- Neutron degeneracy stops collapse => rebounds
- Rebound forms shock wave but it stalls
- Density ~$10^{12}$ gm/cm$^3$ so even neutrinos push shock
- Plus turbulence and star explodes



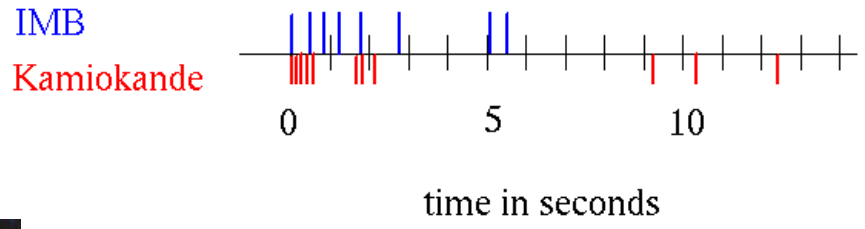



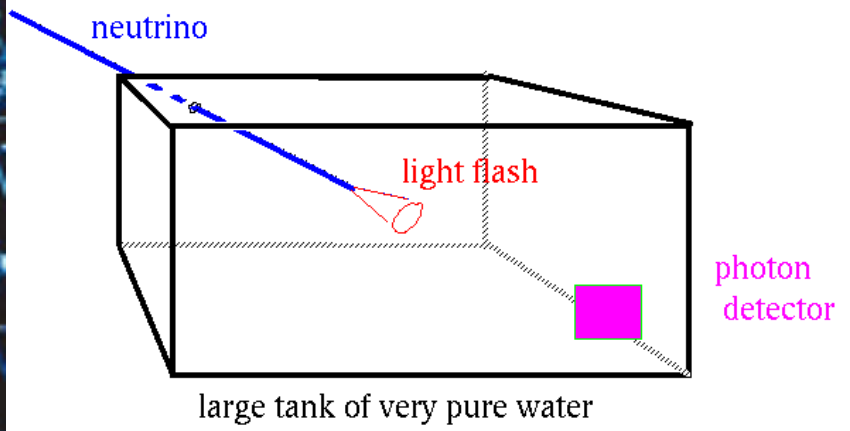

# SN1987A

- Type II Supernova in LMC
- Discovered by Ian Shelton
- 169,000 light years V=4
- Light curve powered by Decay of radioactive Nickel & Cobalt agrees with stellar nucleosynthesis theory

# Neutrinos Detected

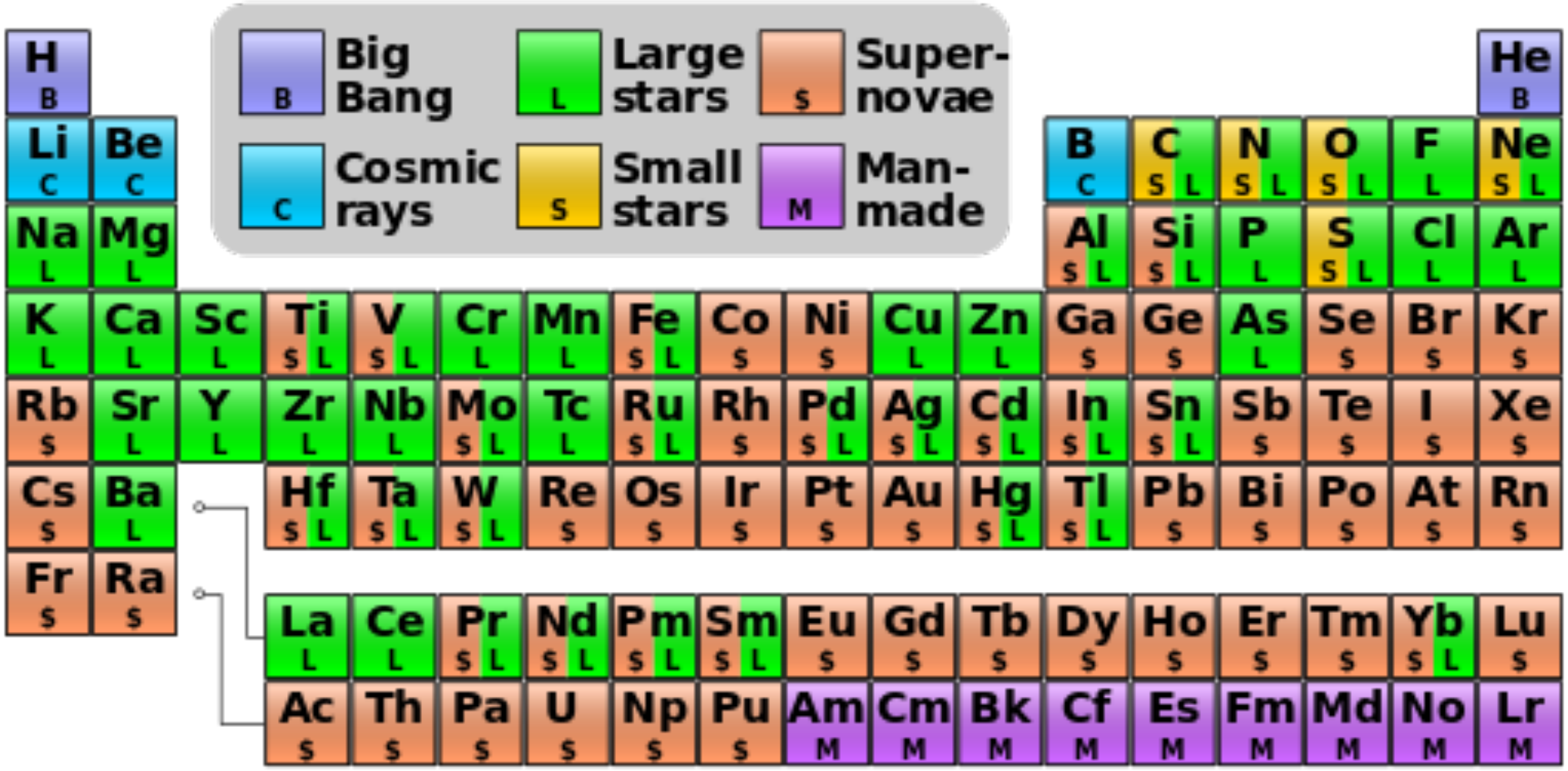
- 10 trillion/sec pass through you
- 20 Neutrinos from SN1987A detected - agrees with theory
- Neutrinos arrived hours before light so neutrino's speed~=light
- IceCube @ South Pole



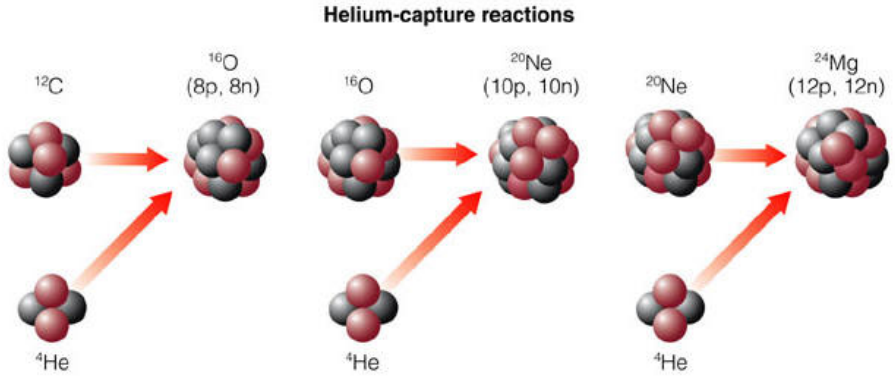
# Stellar Nucleosynthesis

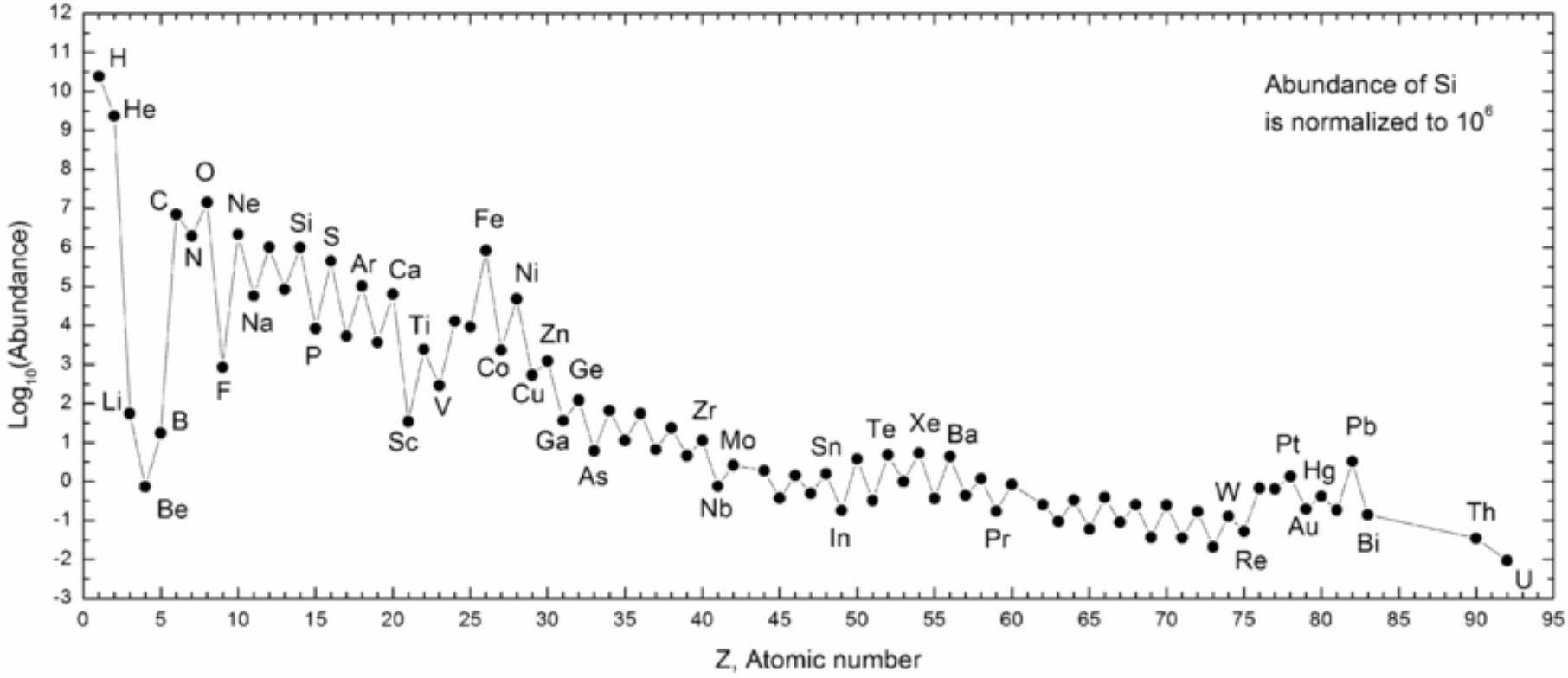
- Stars form all elements heavier than Helium



# Helium Capture

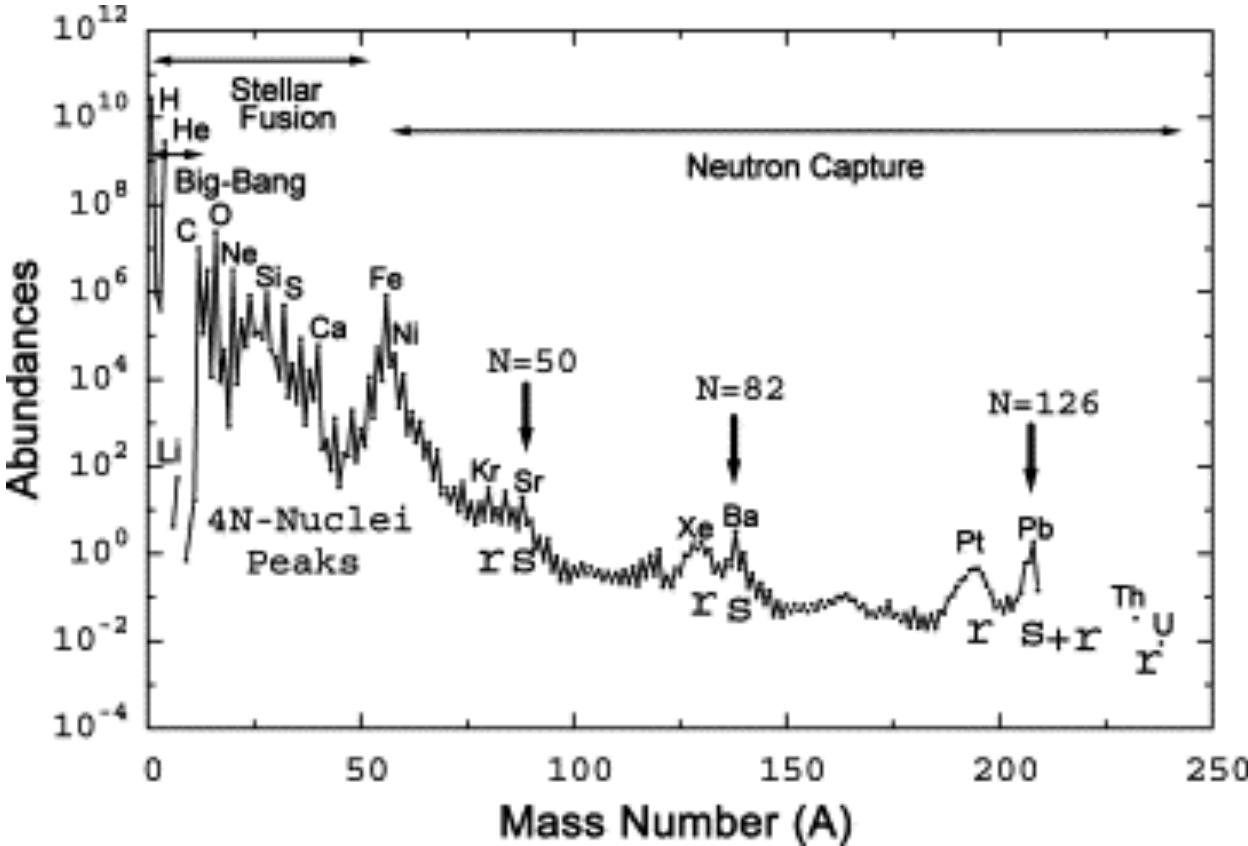
- Makes even numbered elements heavier than carbon
- Takes place in AGB stars



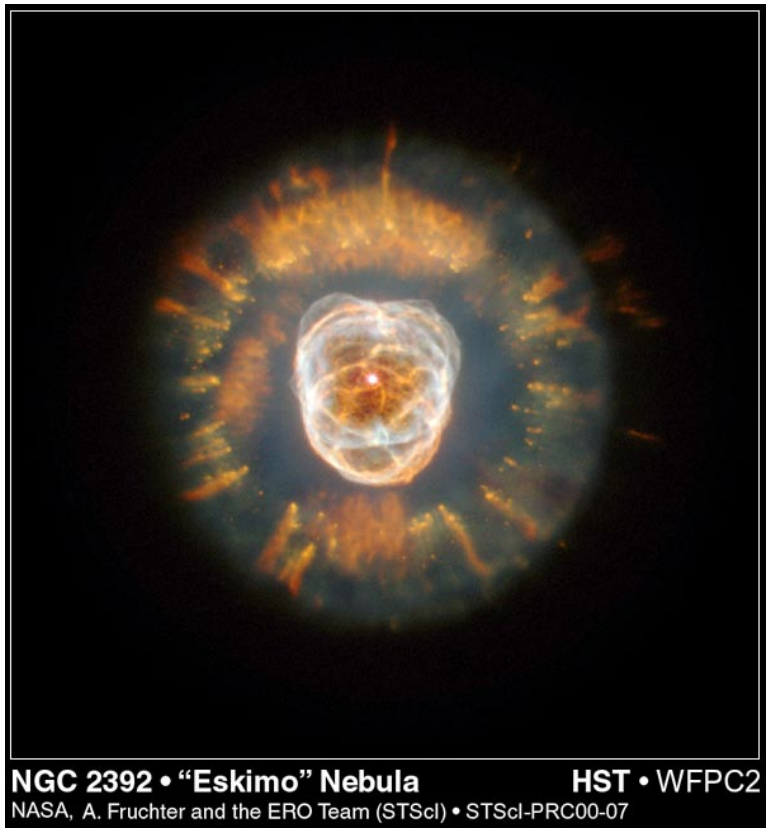
# Slow Neutron Capture

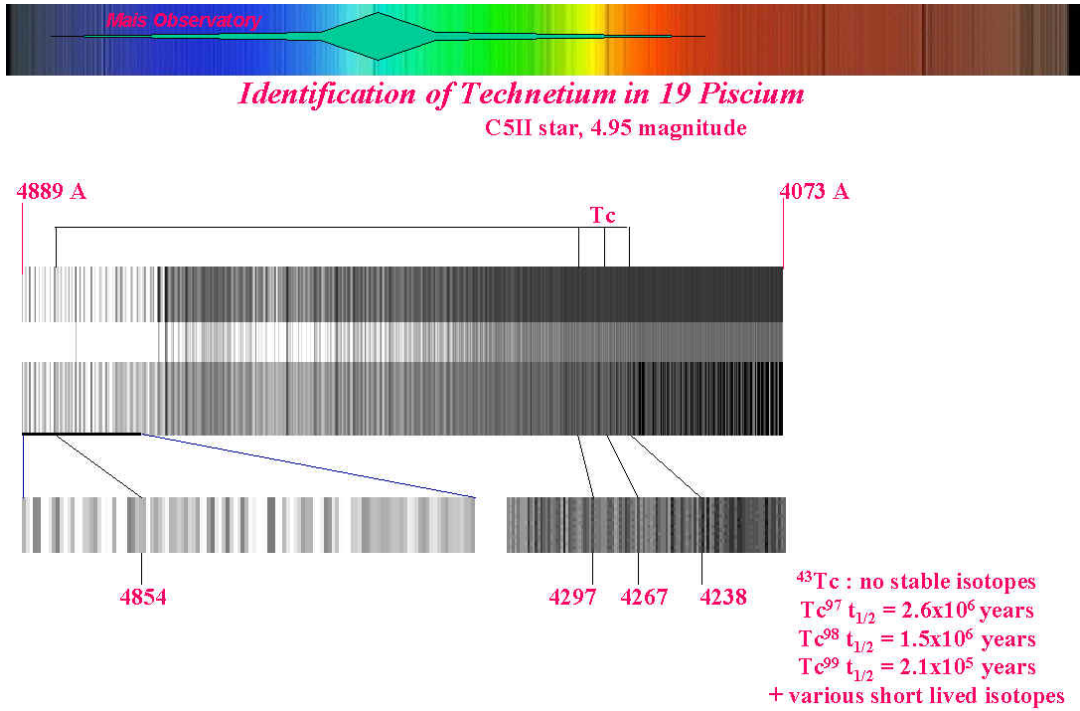
- S-process occurs in AGB stars
- Produces elements heavier than iron, but not Ur&Th
- Neutrons captured & element decays producing heavier element



# Evidence of Stellar Nucleosynthesis: Technetium

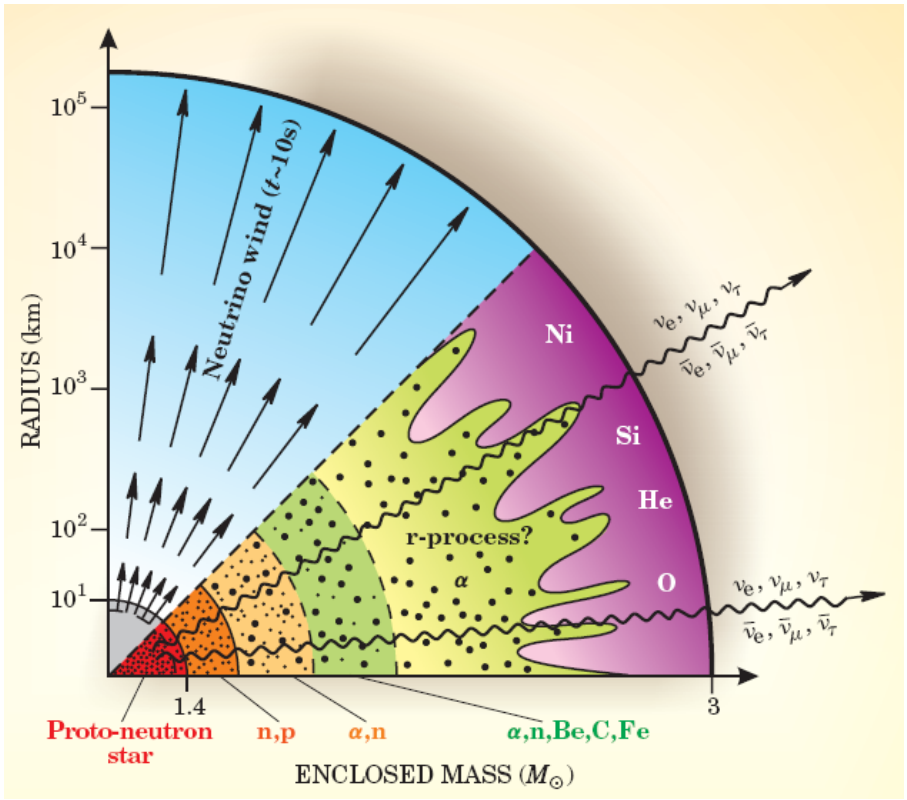
- Technetium radioactively decays ~million years
- But observed in AGB stars so
- Must be produced in AGB stars

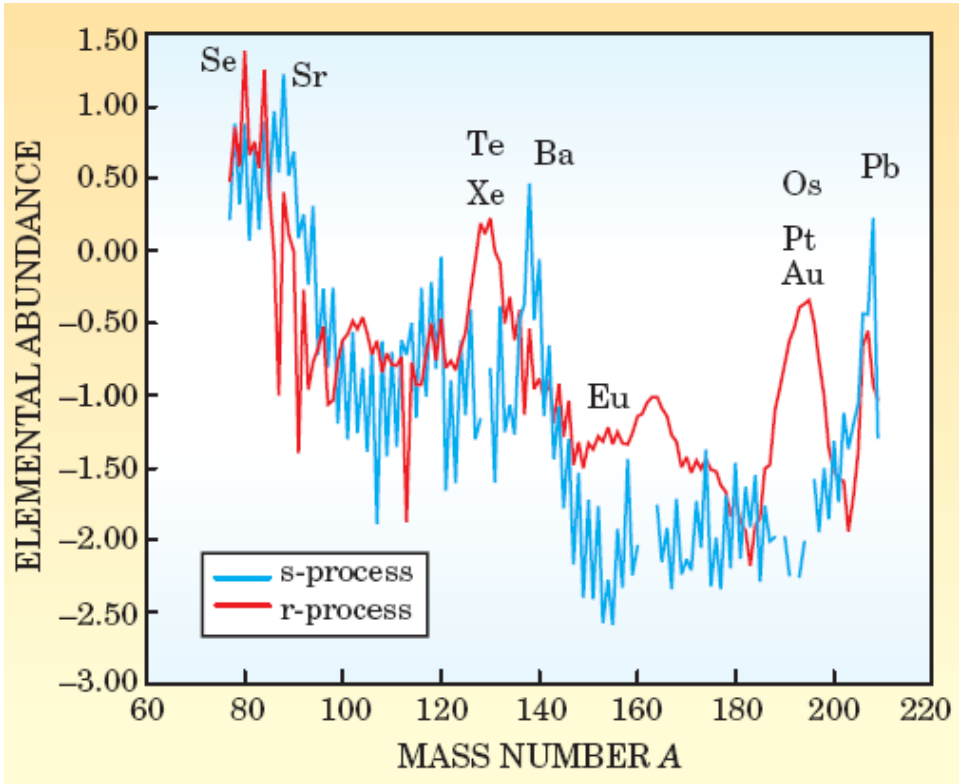


# Rapid r-process **Neutron Capture**

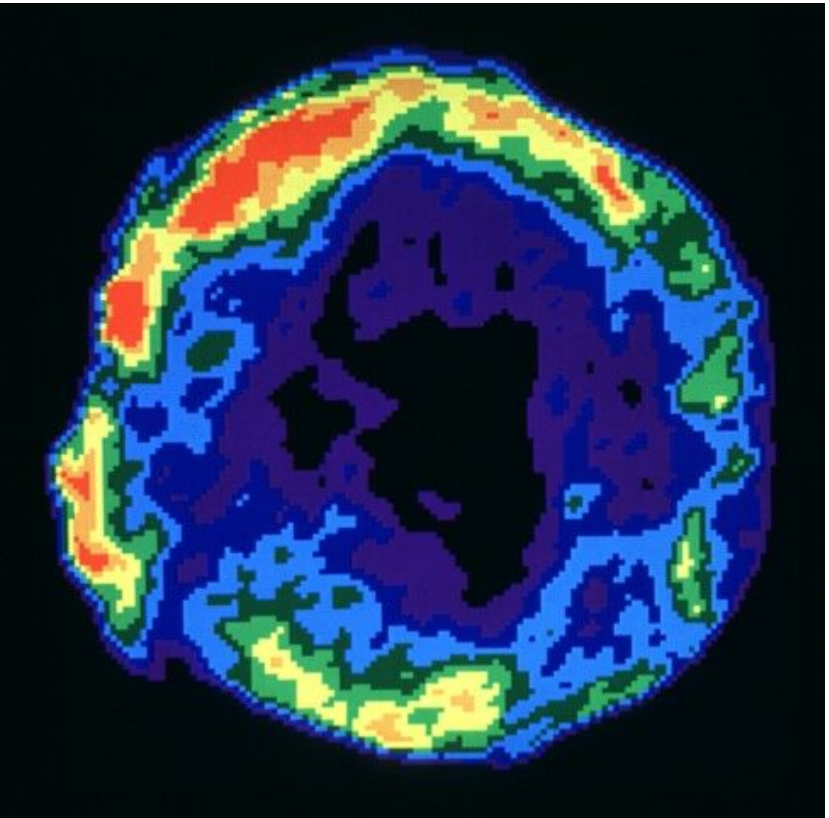
- Elements beyond iron formed by r-process during Type II Supernova collapse
- Producing Gold & Uranium & Thorium
- Abundances agrees with theory

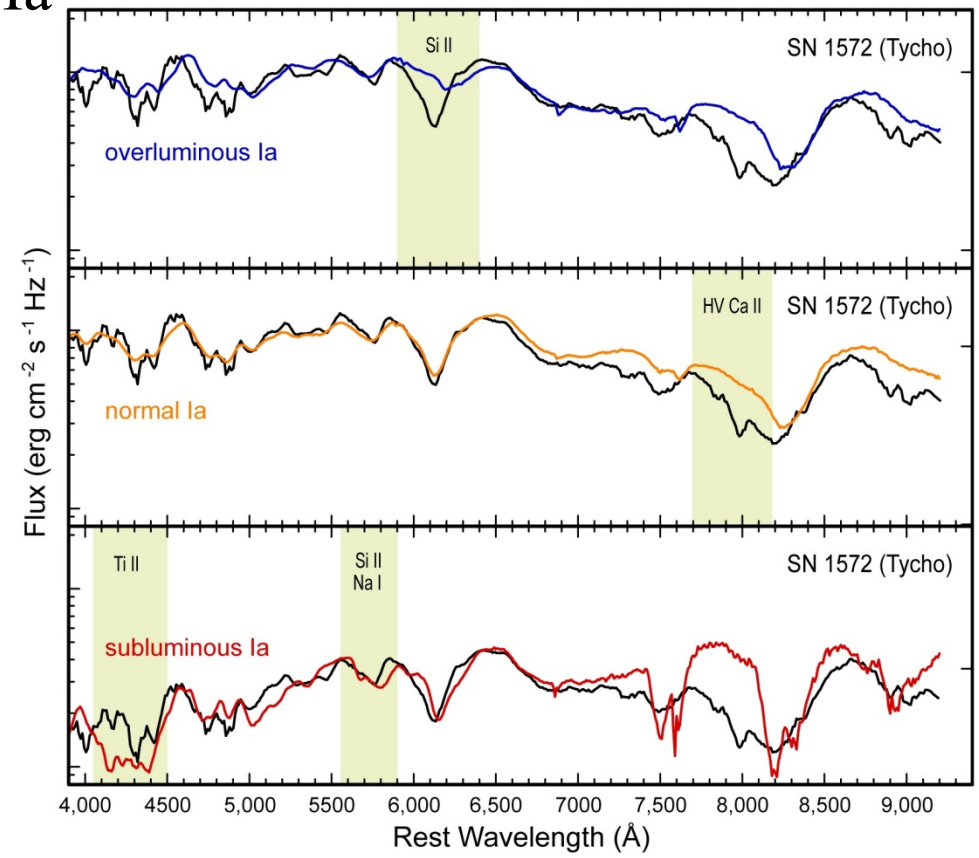


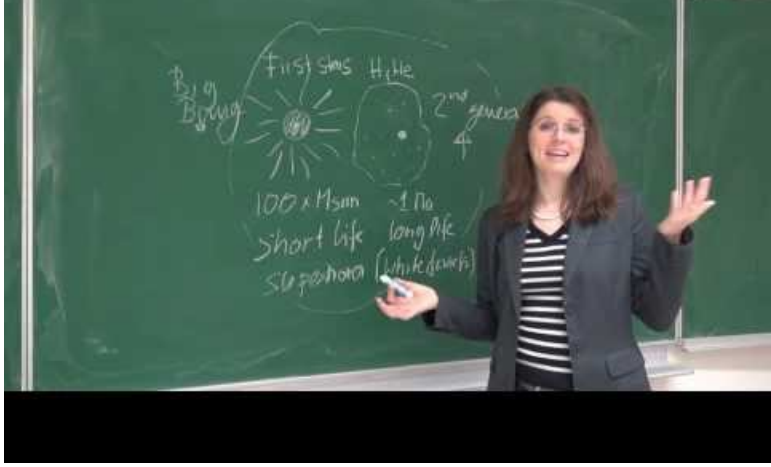
# Debris Enrich Next Generation

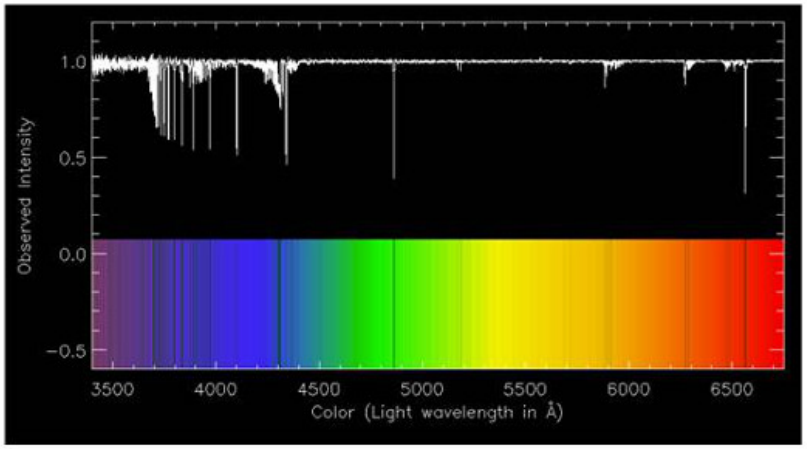
- Tycho's SNR 1572
- High, medium and low energy x-rays are blue, green and red
- Debris are red yellow green at~10Million K
- Material ejected at ~15,000 km/sec creates shock wave
- Spectra of light echo gives Type Ia

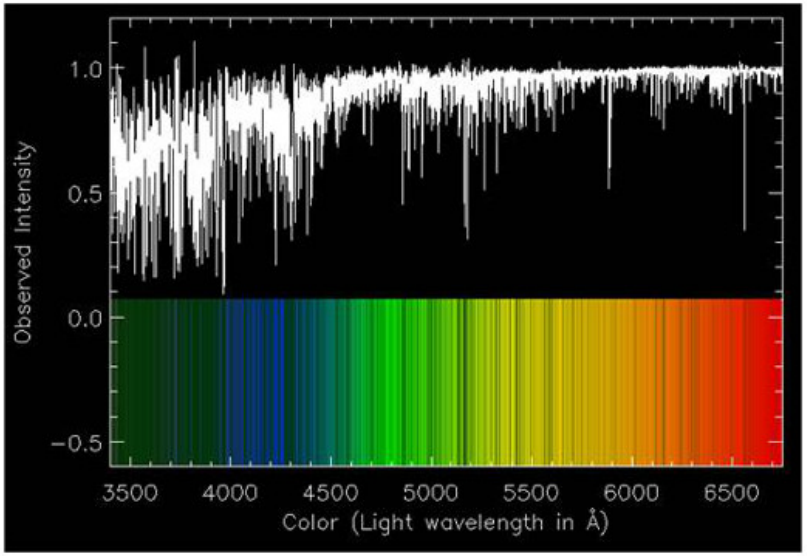




# Most metal poor star



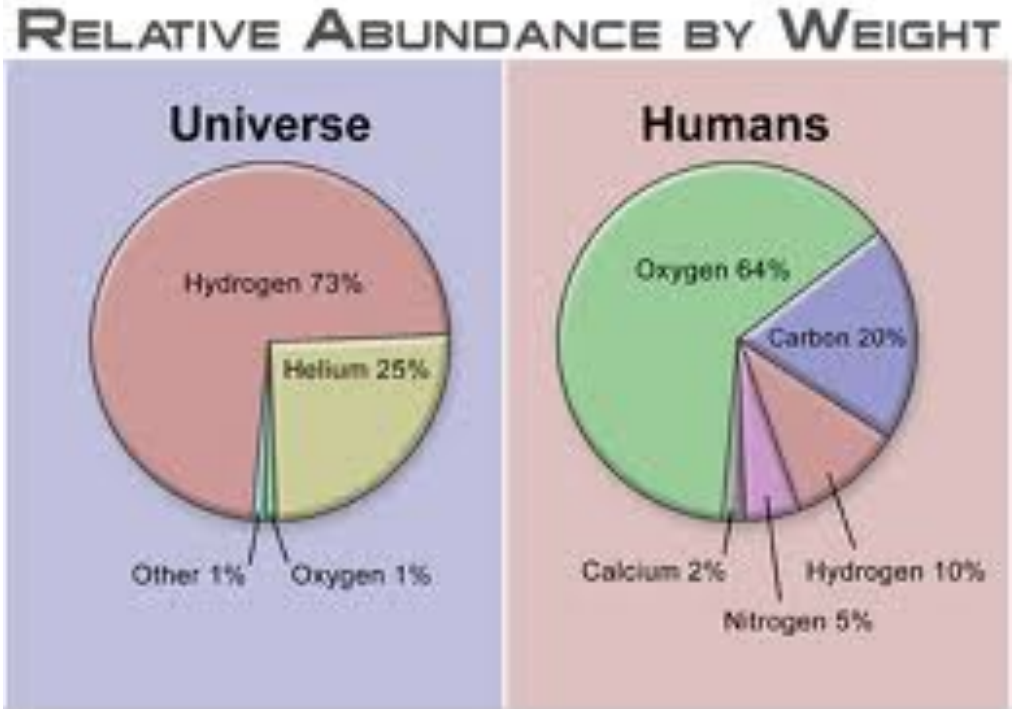




- First stars formed had no elements heavier than Hydrogen and helium
- Second generation had few heavy elements
- SM0313 has 15million times less heavy elements than the sun

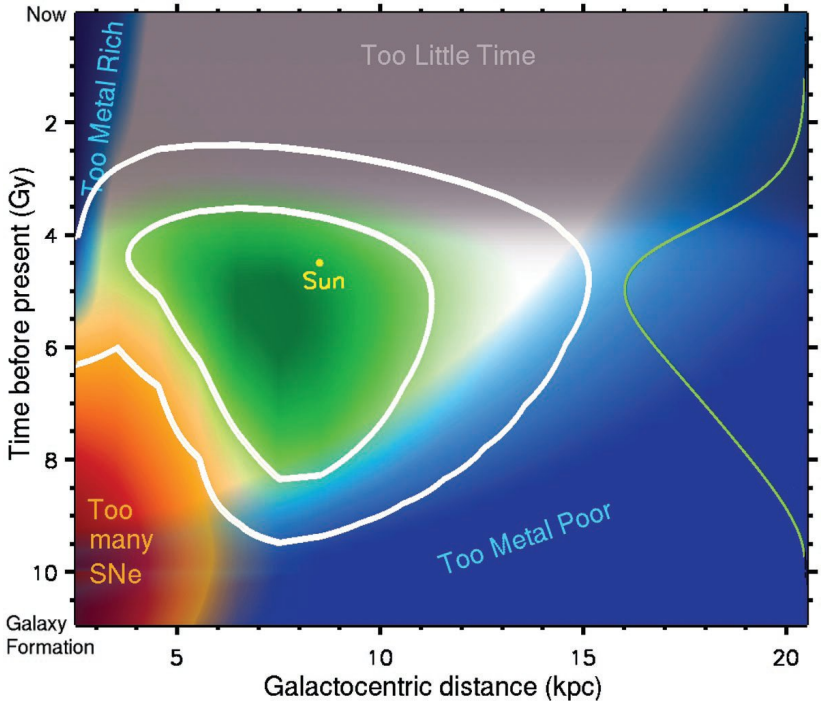
# Stellar Nucleosynthesis

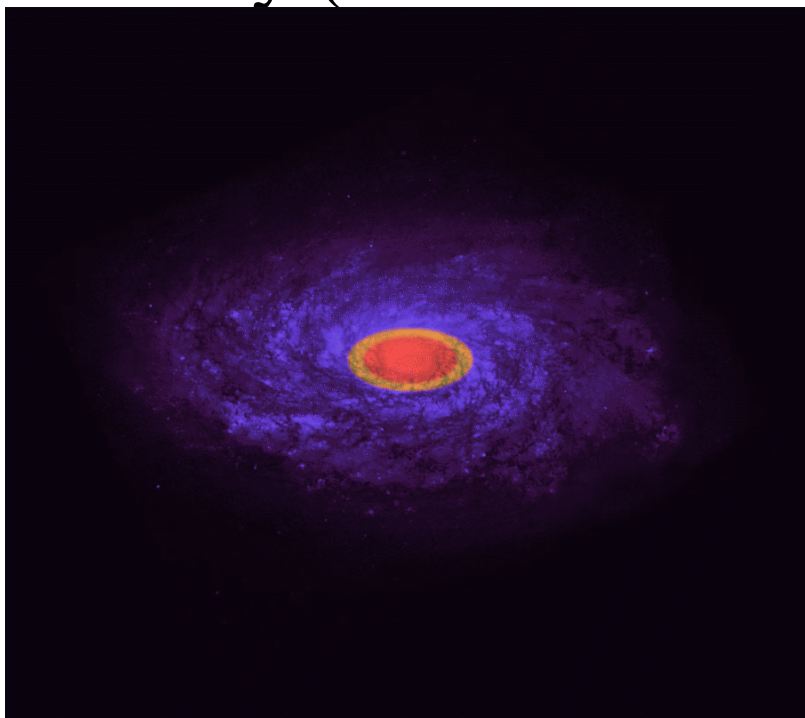
- We are all made of star dust
- We are ashes of nuclear furnaces
- We are nuclear waste




# Galactic Habitable Zone

- Red zone has too many supernovae
- Blue- too few supernovae/too few heavy elements
- Green is just right
- Each time step is 600 million years from beginning of Milky Way until today (12Billion

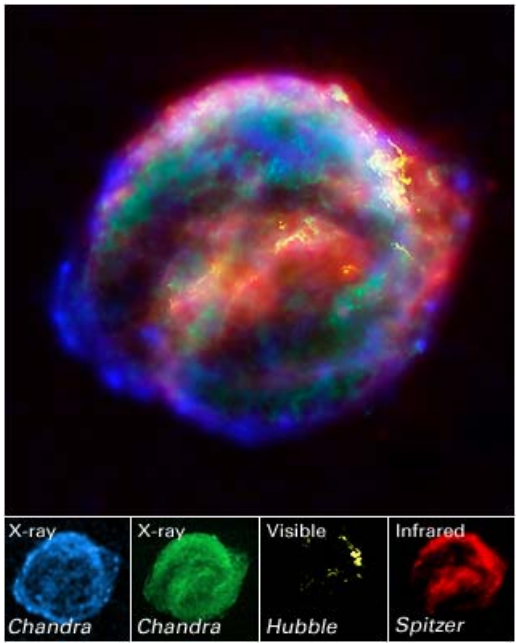


# Historical Supernovae

| Year | Date | Con | mag | Remnant | Observed/Comments |
|---|---|---|---|---|---|
| 1006 | Apr 30 | Lup | -9 | | Arabic; also Chinese, Japanese, European |
| 1054 | Jul 4 | Tau | -6 | M1 Crab | Chinese, North American(?) Arab, Japan |
| 1181 | | Cas | -1 | 3C 58 | Chinese and Japanese |
| 1203 | ? | Sco | 0 | 1230? Aql | |
| 1572 | Nov 6 | Cas | –4 | Tycho SNR | Tycho Brahe's SN |
| 1604 | Oct 9 | Oph | –3 | Kepler SNR | Johannes Kepler's SN |
| 1680?1667? | | Cas | ? | Cas A | Not seen ? Radio remnant 1950 |

1 supernova per galaxy per 100 years BUT Not all observed !



# Crab Nebula

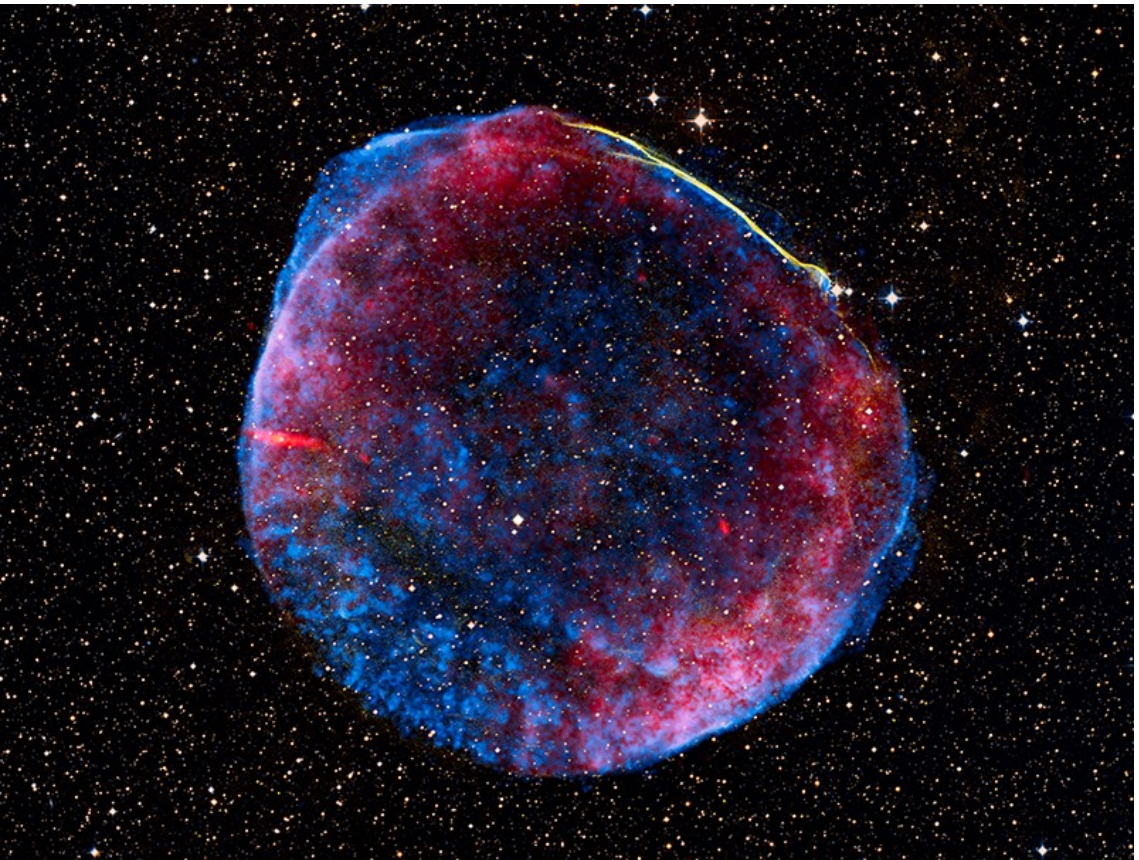
- Guest star appeared 4 July 1054
- Seen by Chinese in daytime; distance=6500ly
- Red is emission nebula =supernova remnant
- Blue is synchrotron emission
- Powered by compact object

# Synchrotron Radiation

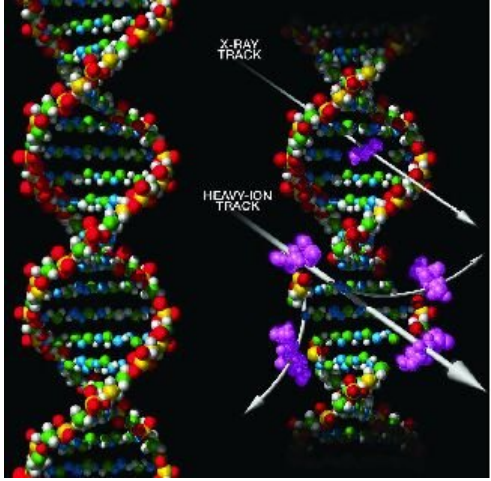
- Electron Spirals in Magnetic field
- Acceleration causes emission of photon
- Polarized light


# Supernova Remnants

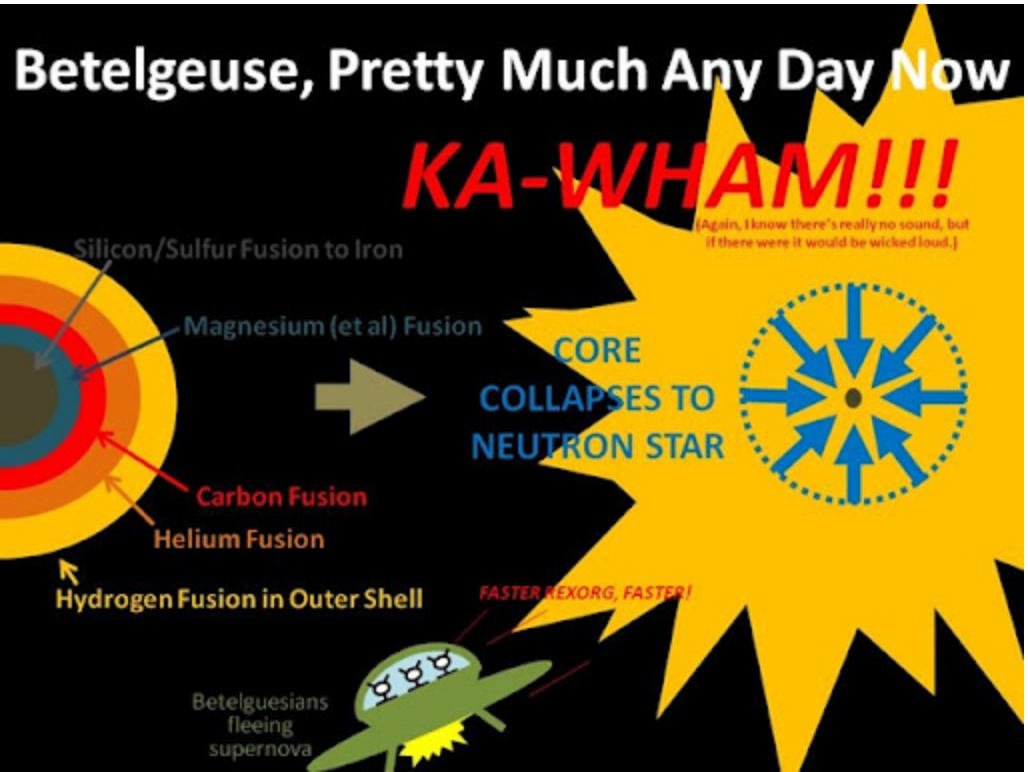
- Expanding shell enriches interstellar medium with heavy elements
- Debris from Crab=100tons, hits Earth in 100,000years




# Are Supernovae Dangerous?

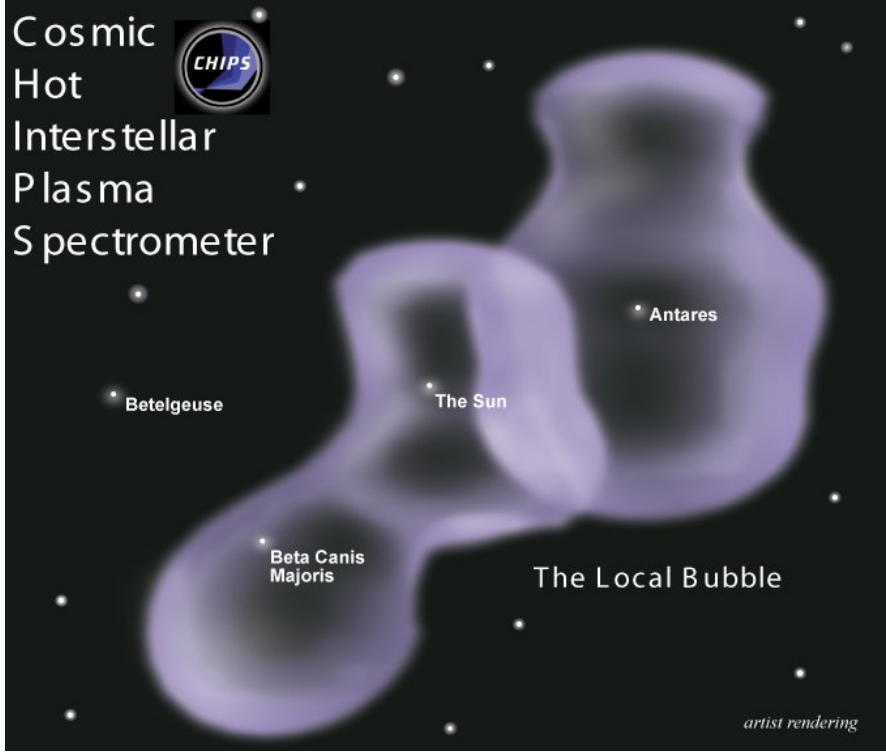


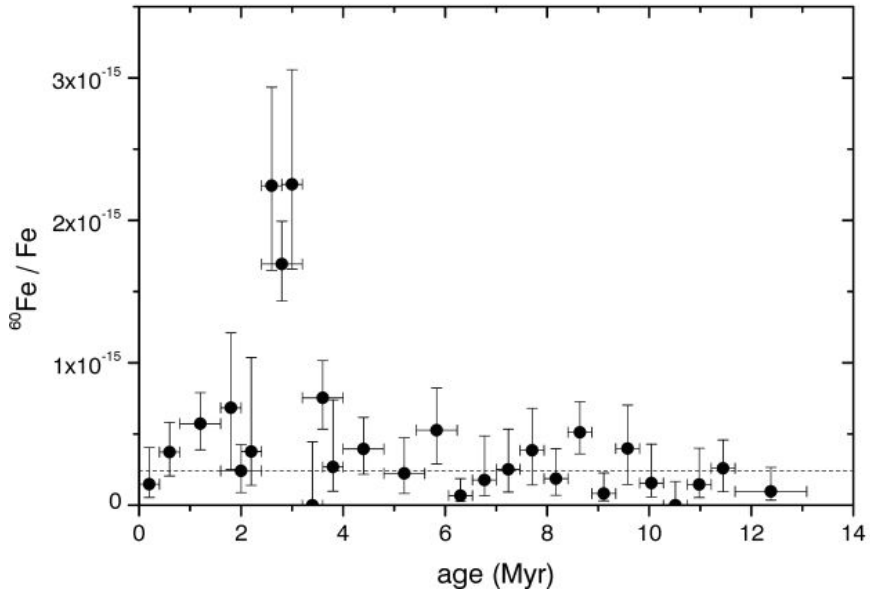

- Type II=Spica, Rigel, Betelguese not close
- IK Peg Type Ia **progenitor**
- Initial burst of light, neutrinos, okay but
- X-rays & Gamma-rays=ozone layer destruction
- Dangerous within ~10 pc




# Past Extinctions

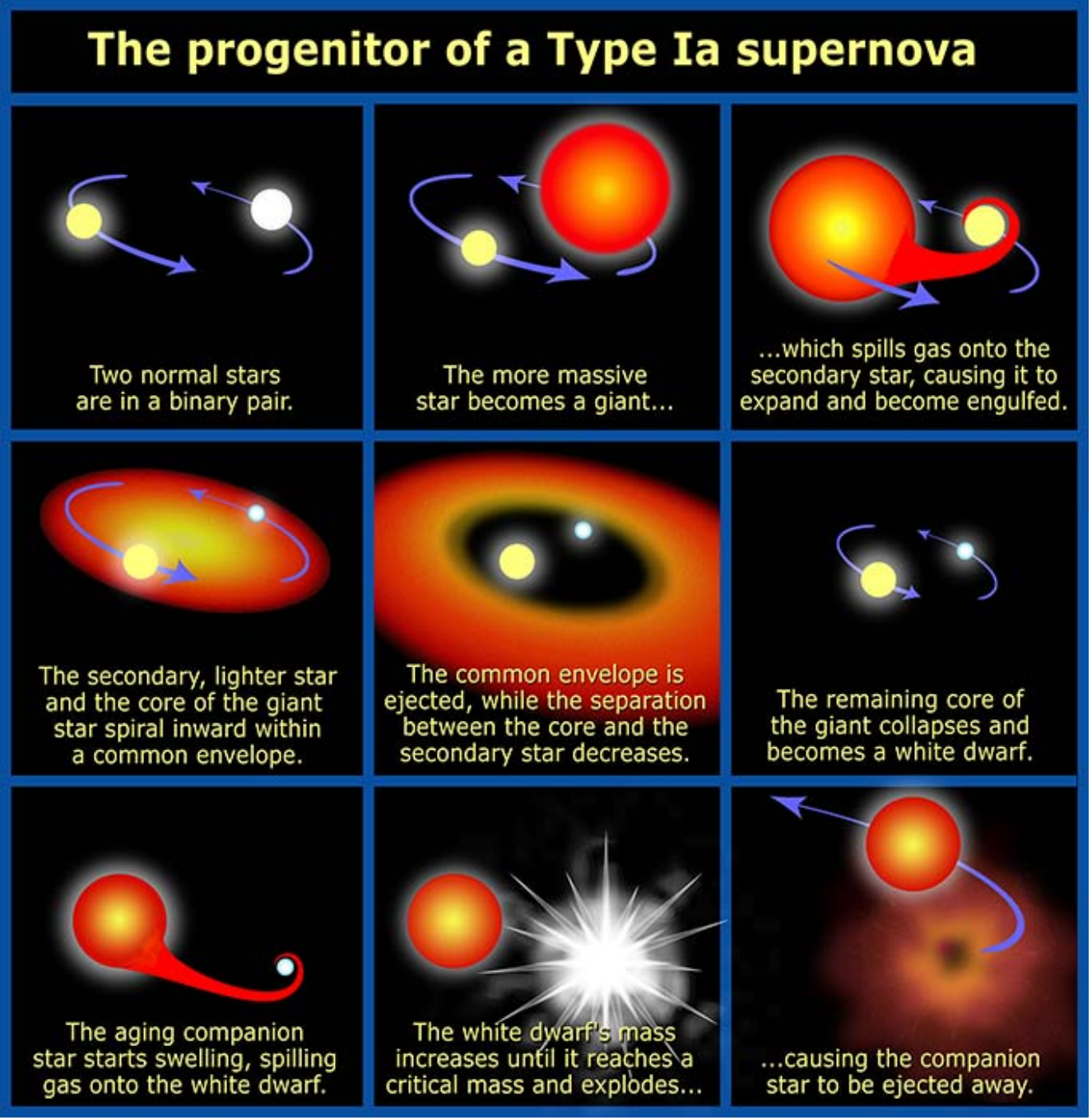
- Extinction every 100? Million years
- Past extinctions? – maybe evidence from sea floor&ice caps




# Which of the following statements is False:

a. Nova: an explosion on the surface of a white dwarf
b. Type Ia supernova: explosion of whole white dwarf
c. Type II supernova: explosion of a high mass star
d. Stellar nucleosynthesis produces the high mass elements in the periodic table
e. All of these are true

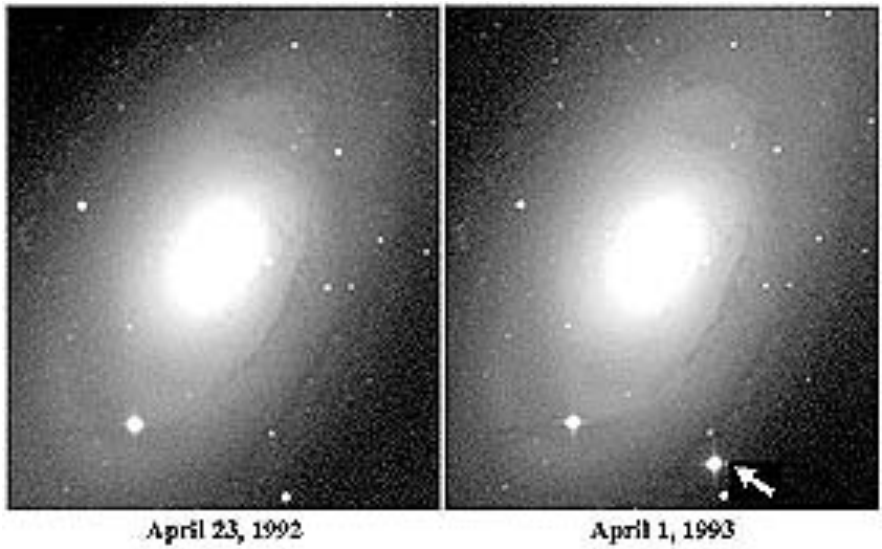


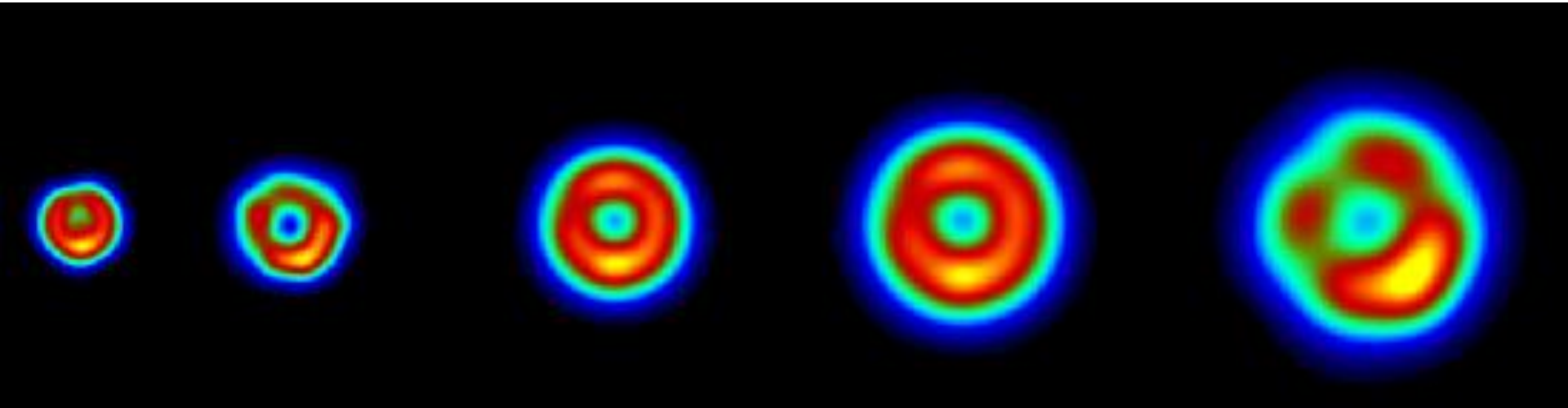

# Type Ia Supernova

- White dwarf in a binary system
- Which is heated to ignition by mass transfer from secondary
- Heat ignites carbon deflagration
- Producing Iron, silicon etc.

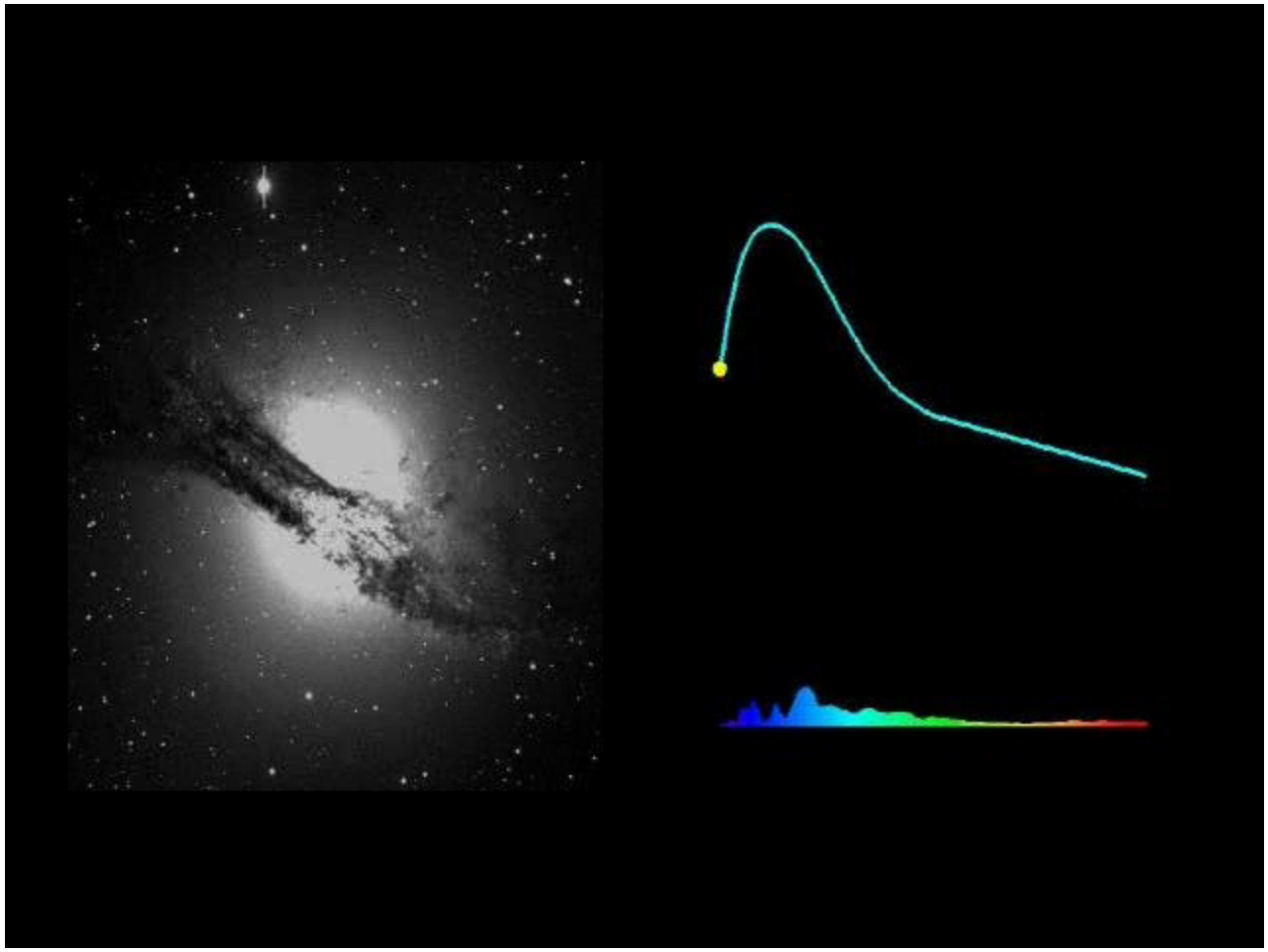
# SN1993J in M81in Visible and Radio

- 11 Million ly distant Type IIb
- Reached V=10 so Absolute Magnitude is ~-18
- Equals a galaxy of stars
- Expansion of nebula and size give estimate of age ~1000's years
- Velocity of expansion (10,000 km/ sec) & proper motion gives distance



# Supernova Cosmology Project



# Nova Herculis 1934

- Hydrogen accretes onto white dwarf = degenerate gas
- After ~100 earth masses
- PP then CNO cycles burn hydrogen to helium