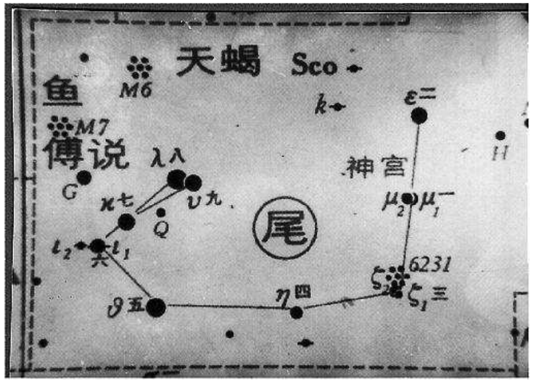
Supernovae

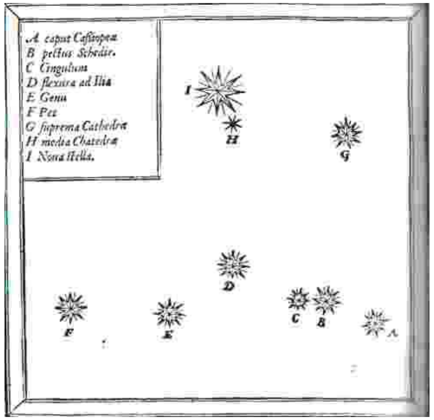
Historical Supernovae

Supernovae (term coined by Baade & Zwicky, 1934) increase in magnitude by 20 mag

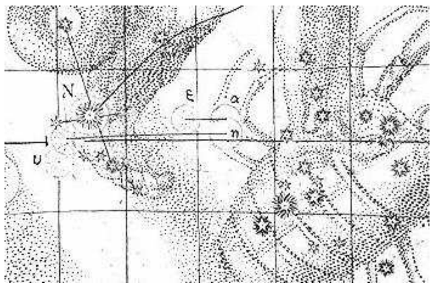


The guest star of AD 393, Wang, Yu & Chen (1997, A&A 318, L59)

Historical Supernovae



Tycho Brahe's Supernova 1572

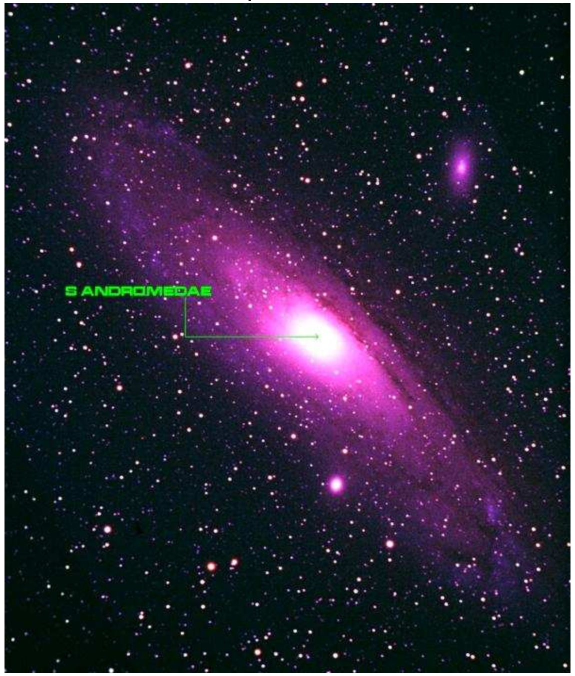


Johannes Kepler's Supernova 1604

Galactic supernovae

Year of appearance	constellation	magnitude	visibility months
185	Centaurus	−8	6?
386	Sagitarius	+1.5	
393	Scorpius	0	
1006	Lupus	−7.5	24
1054	Taurus	−6	24
1181	Cassiopeia	0	6
1572	Cassiopeia	−6	16
1604	Ophiuchus	−3	12
1667	Cassiopeia	obscured	-
∼1850	G1.9+0.3	obscured	–

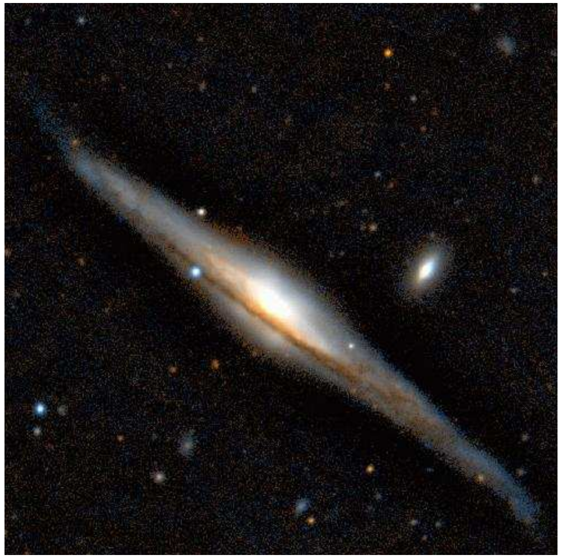
S Andromedae = Supernova 1885 in the Andromeda galaxy



Ernst Hartwig

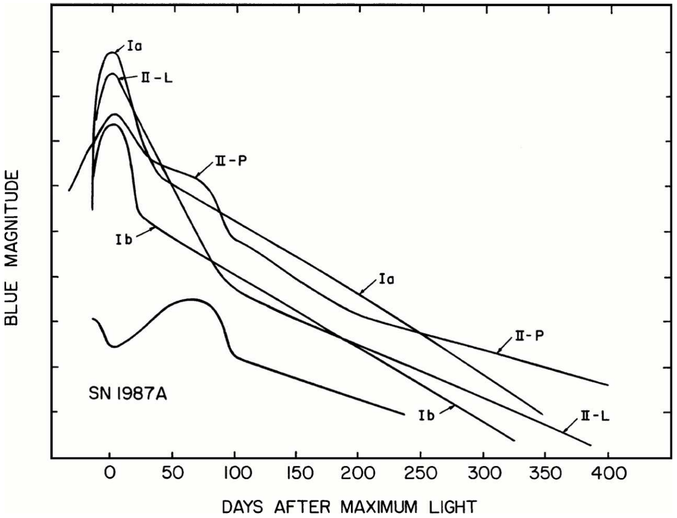
20.08.1885: discovery of S And

SN1994d (HST WFPC)



Type II SN2001cm in NGC5965 (2.56 m NOT, Håkon Dahle; NORDITA)

Extragalactic Supernovae

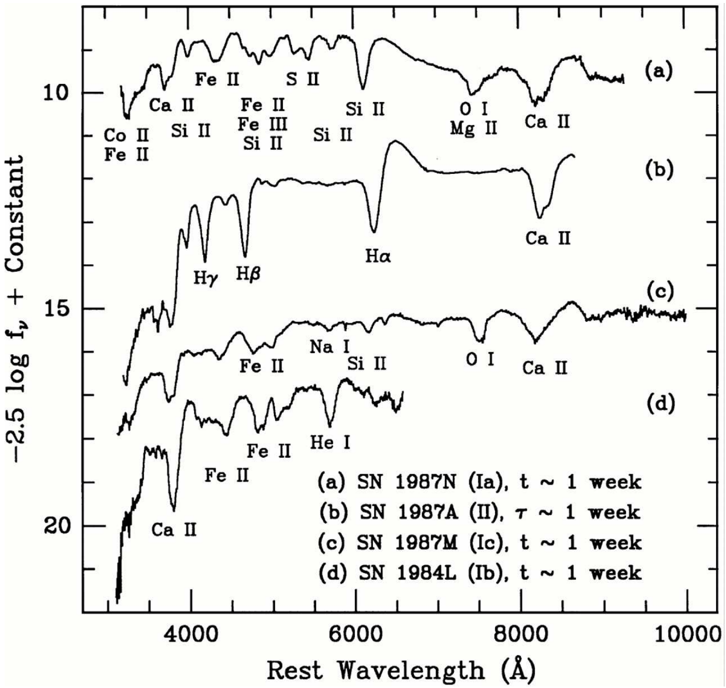


(Filippenko, 1997, ARAA Fig. 1)

Light curves of SNe I all very similar, SNe II have much more scatter.

SNe II-L ("linear") resemble SNe I

SNe II-P ("plateau") have const. brightness to within 1 mag for extended period of time.



(Filippenko et al., 1997, Fig. 1); t: time after maximum light; τ: time after explosion; P Cyg profiles give $v \sim 10000\,\mathrm{km\,s^{-1}}$

Rough classification (Minkowski, 1941):

Type I: no hydrogen in spectra; subtypes Ia, Ib, Ic

Type II: hydrogen present, subtypes II-L, II-P

Note: pre 1985 subtypes Ia, Ib had different definition than today $\Longrightarrow$ beware when reading older texts.

Supernova Statistics

Clue on origin from supernova statistics:

- SNe II, Ib, Ic: never seen in elliptical galaxies, which are void of gas and have no new star formation; generally associated with spiral arms and H II regions in spiral galaxies, i.e., with star forming regions

$\Longrightarrow$ progenitor of SNe II, Ib, Ic: massive stars ($\gtrsim 8\,M_\odot$)

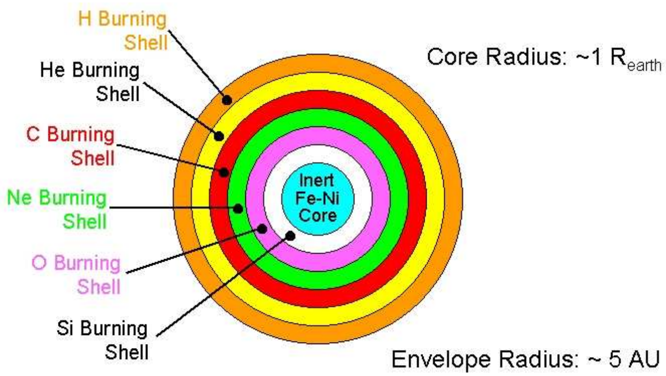
$\Longrightarrow$ “core collapse supernova”

- SNe Ia: all types of galaxies, coming from both young and old stellar populations.

$\Longrightarrow$ stellar progenitors of SNe Ia can not be massive stars, because such stars do no longer exist in old stellar populations.

common model: accreting carbon-oxygen white dwarfs undergoing thermonuclear runaway

Core Collapse Supernovae



Successive stages of nuclear burning in a massive star:

1. H burning, ash: He
2. He burning, ashes: C, O, Ne, Mg
3. C burning, ashes: Ne, Na, Mg
4. Ne burning, ashes: O, Mg ...
5. O burning, ashes: Si, P, S, ...
6. Si burning, ashes: Fe, Ni

Final state: “onion-shell”

Core Collapse Supernovae

Standard core-collapse supernova model:

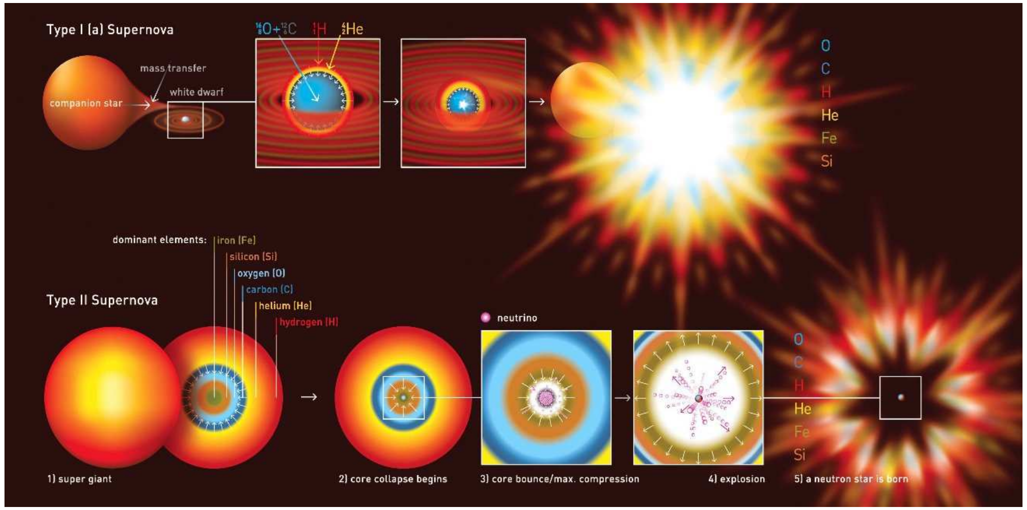
$t = 0$ **s:** Collapse of Fe core of star with main sequence mass $>10\,M_\odot$, triggered by electron capture and photodisintegration of Fe ($T \sim 10^{10}\,\mathrm{K}$, $\rho \sim 10^{10}\,\mathrm{g\,cm^{-3}}$).

rebound: outer material rebounds off core, looses velocity because of photodisintegration and neutrino loss

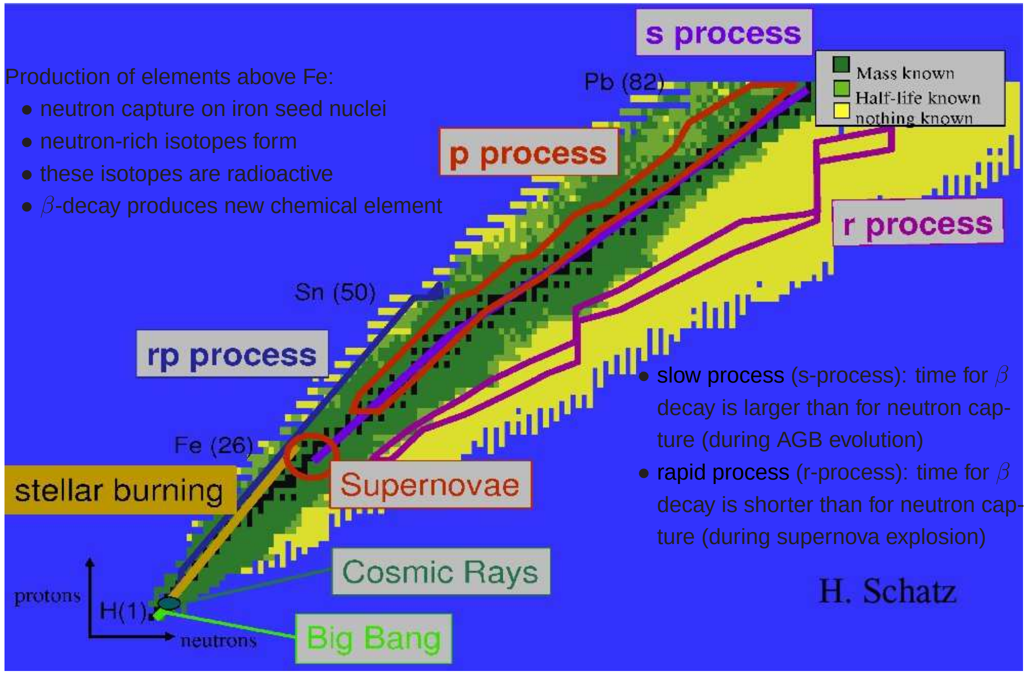
$t = 0.1$ **s:** proto-neutron star formed with $R \sim 30\,\mathrm{km}$, $M = 1.4\,M_\odot$, standing shock $\sim$150 km above neutron star

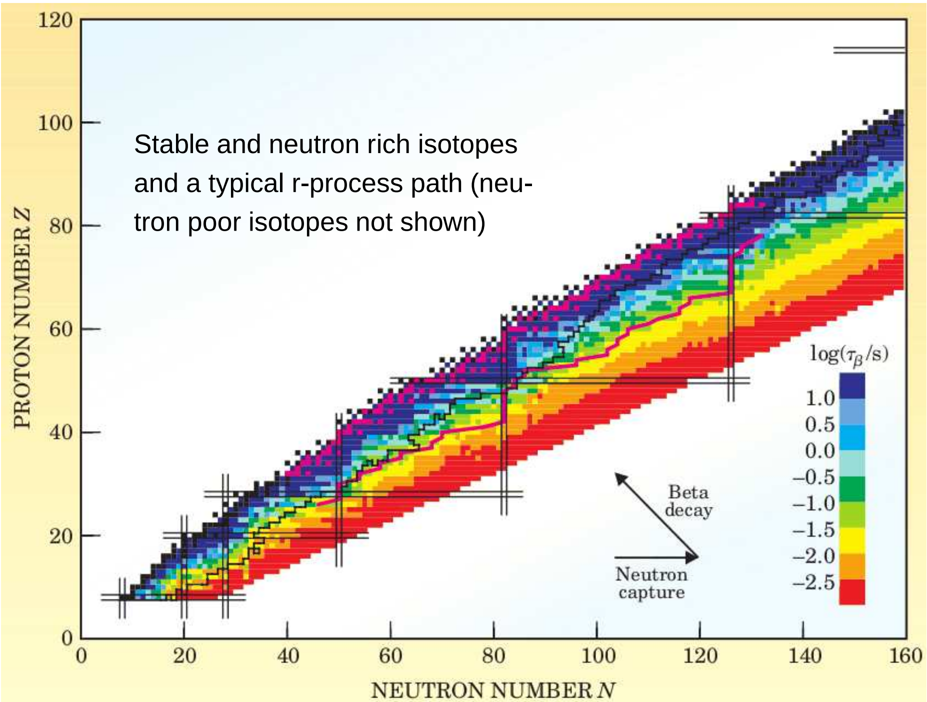
$t = 0.1$ **s until** $t = 0.2$ **s:** start to radiate $\sim 10^{53}\,\mathrm{erg\,s^{-1}}$ as neutrinos, triggers convection, heats material by depositing 10^{51} erg ($\longrightarrow$ convection)

$t = 0.2$ **s:** SN explosion is triggered



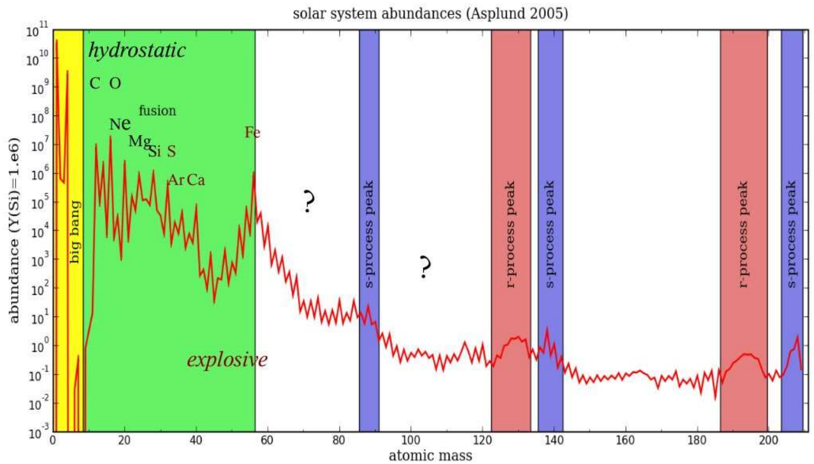
F.K. Thielemann





(Cowan & Thielemann, 2004, Physics Today, 46; after P. Möller)

Nucleosynthesis



With SN calculations and fusion mechanisms in stars, it is possible to explain the observed elemental abundance pattern of the solar system.

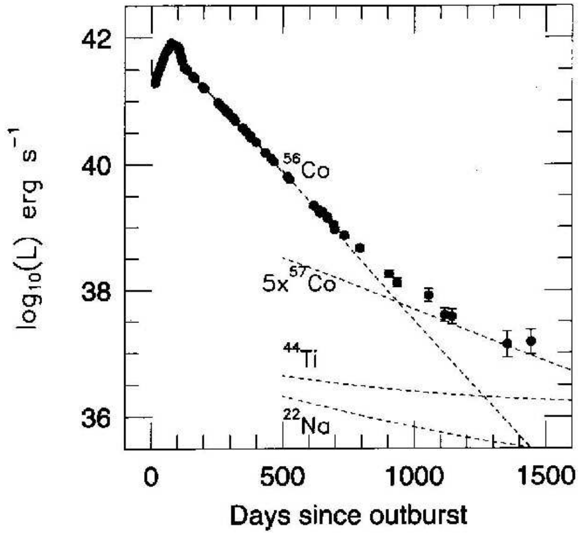
First work on these processes: Burbidge, Burbidge, Fowler, Hoyle, 1957 (B^2FH)

SN1987a

SN1987A in the Large Magellanic Cloud, 1987 February 23

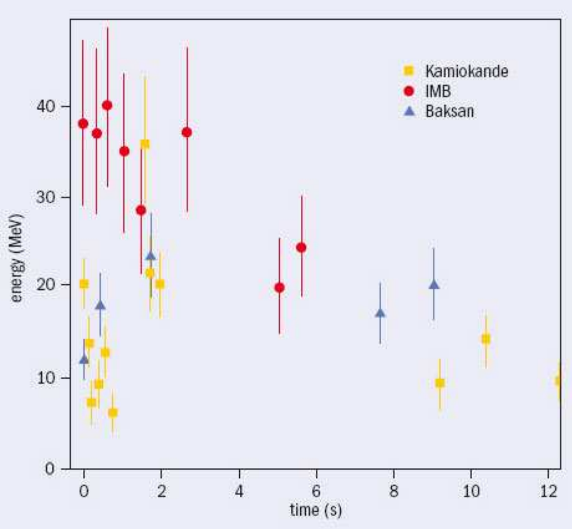
- distance well known = 50 kpc
- visible to the naked eye ($V_{max} = 4.5$ mag), first after 300 yrs
- for the first time it was possible to identify the progenitor star
- progenitor Sanduleak -69 202 = massive star, i.e., blue supergiant
- supports core collapse model
- light curve has been measured over 25 yrs, presently $V = 21$ mag
- spectral changes have been monitored over many years

SN1987a



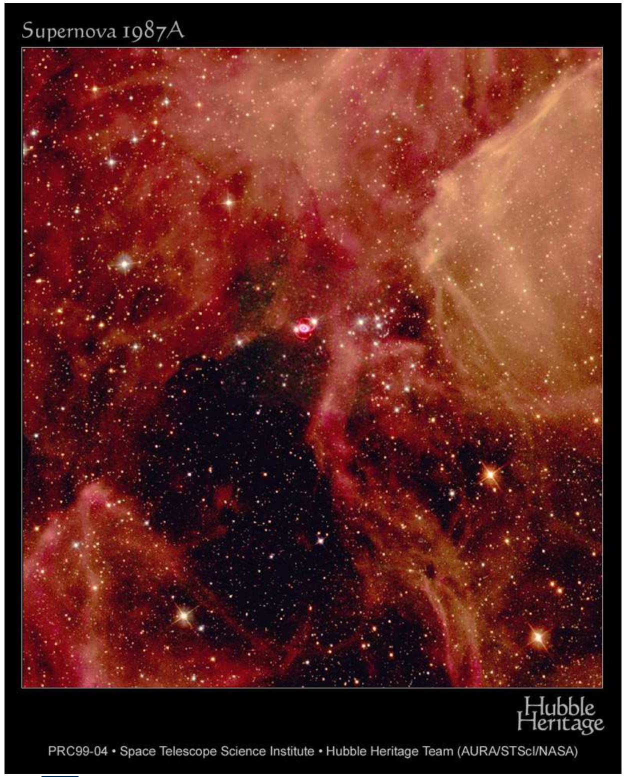
Expanding envelope powered by radioactive decay of short lived isotopes created in the core collapse

SN1987a



Neutrinos detected as predicted by core collapse model

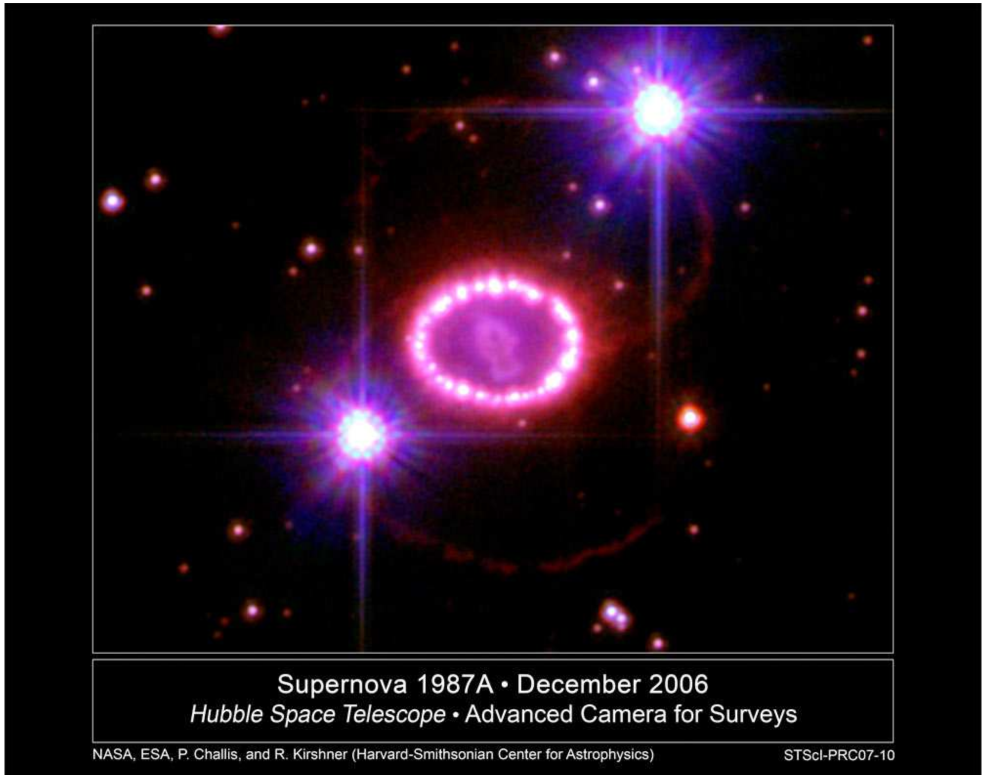
Cern Courier



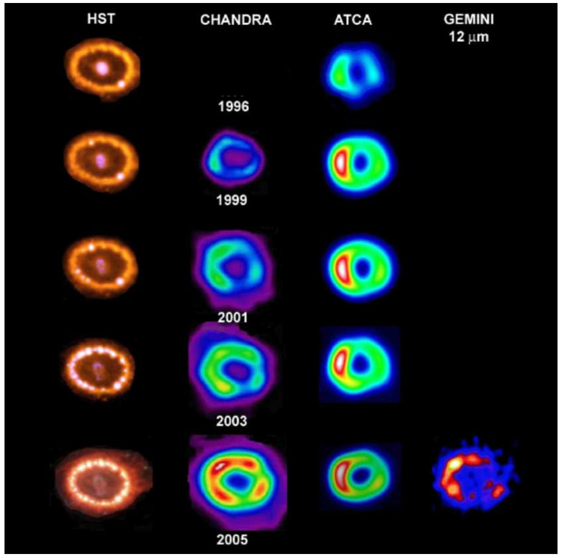
Additional features:

The mysterious rings

- central ring, light year across due to impact of a shock wave on circumstellar material, ejected from progenitor star; started to glow after more than 15 years.
- outer rings, possibly due to ionization of material illuminated by SN light. Material possibly from bipolar outflow during blue supergiant phase (fast blue SG wind colliding with slower RG wind); material ejected $\sim$20000 years before explosion.



SN1987a

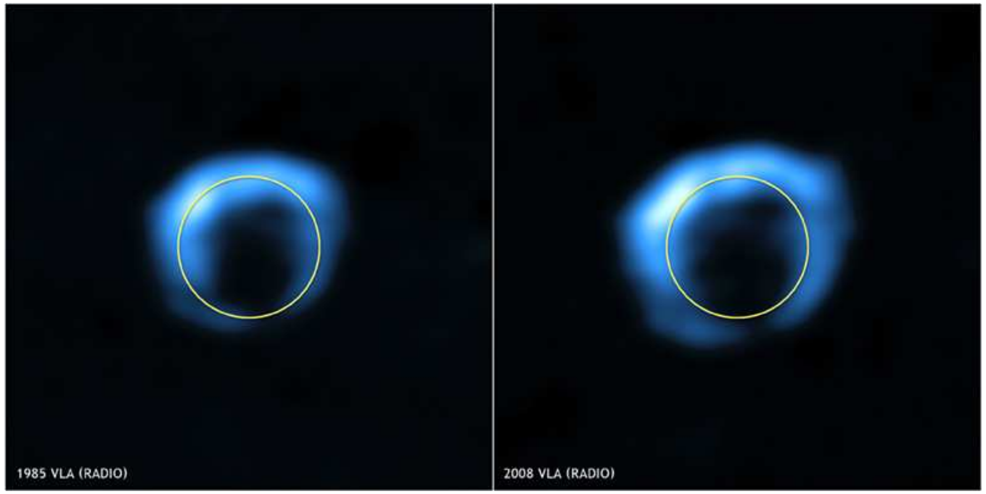


McCray 2007, Fig. 6

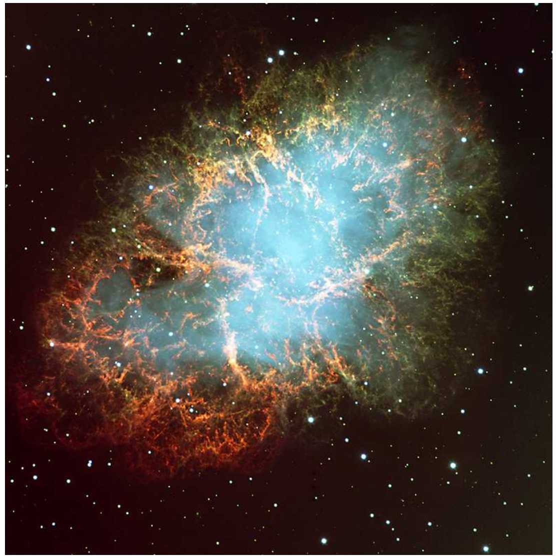
Late time light curve due to radioactive decay of Cobalt.

- Day 125–1100: dominated by decay of ^{56}Co
- After $\sim$ 3 years: radioactive decays of long-lived ^{57}Co and later of ^{44}Ti start to heat the system
- Today: Light curve almost flat and $\sim 10^{-7}$ fainter than at maximum! Ring still brightening!

SN 1987A has made the transition to a young Supernova Remnant!

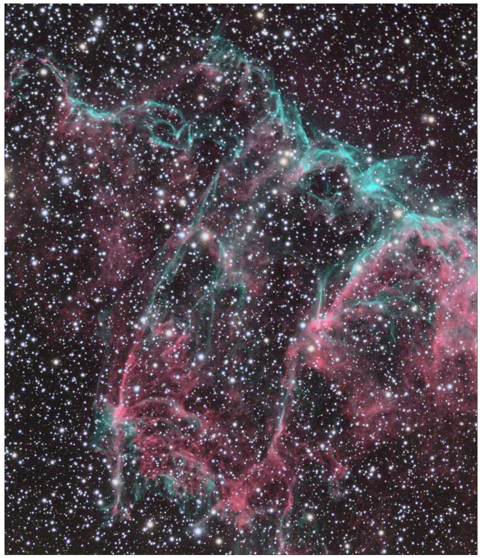


G1.9+0.3: Youngest Galactic SN remnant. While known since long time, it was only in 2008 that the fast expansion was noted $\Longrightarrow$ age: 140 ± 30 years
Due to strong extinction by dust in MW, explosion was not observed.



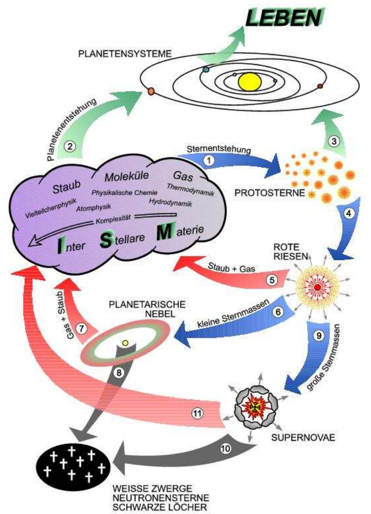
(ESO VLT/FORS 2)

Crab nebula: young remnant of SN of 1054, observed light due to synchrotron radiation (radiation emitted by electrons accelerated in magnetic field)



5000–10000 year old IC 1340/Veil Nebula/Cygnus Loop (ⓒLoke Kun Tan)

Older supernova remnants: "wispy structure" due to interaction with interstellar medium, radiation (line emission) mainly caused by heating due to shocks.



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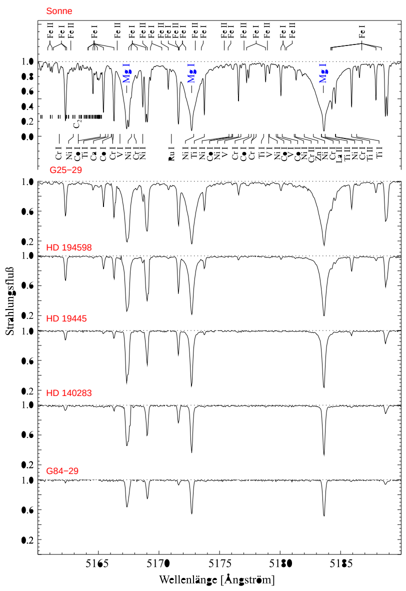
Galactic circuit of matter

- stars and planets form from gas & dust (interstellar medium ISM)
- stars return material to the ISM mostly during their late phases of evolution
- low mass stars loose mass through winds and envelope ejection
- high mass stars loose mass through winds and explosions
- binary stars loose mass through common envelope ejection and explosions
- end stages extract material from the circuit
- circuit stops when supply of gas & dust used up



Chemical evolution

- Hydrogen and helium formed in the Big Bang (see later)
- first generation of stars contain hydrogen and helium only
- stars produce heavier chemical elemnts in their interior
- newly produced elements are dredged-up to the surface in the course of stellar evolution
- stellar winds inject heavier elements to the ISM
- stellar explosions inject heavier elements to the ISM
- next generation of stars is enriched in heavier elements