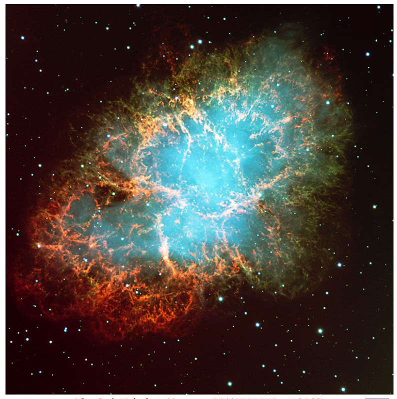
Supernova Explosions



The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

ESO PR Photo 40f/99 (17 November 1999)

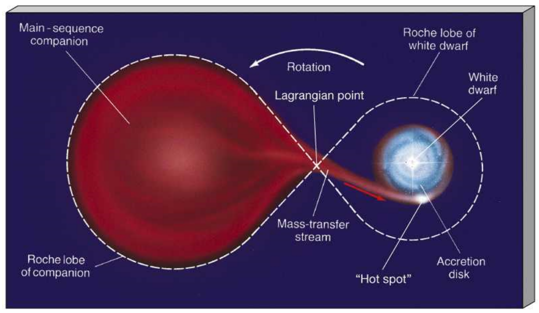
Novae

Novae occur in close binary-star systems in which one member is a white dwarf.

First, due to the second star's evolution, its size is increasing.

Second, some of its mass is transferred to the surface of its white dwarf companion.

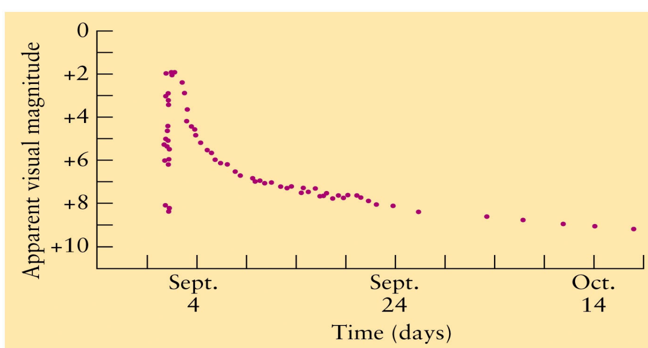
Novae



Astronomy Today, Chaisson and McMillan

This H material piles up on the white dwarf's surface. Gradually, the mass increases, and so does the temperature. Then, explosively, hydrogen burning ignites and blows off the outer layer of matter. Velocities of ejection up to 1000 km/s are observed. The mass ejected is from 10^{-5} to 10^{-4} solar masses.

Novae Light Curves



Universe by Freedman, Geller, and Kaufmann

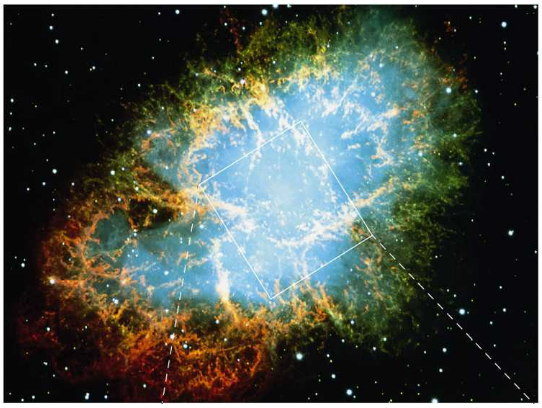
Novae remain bright for only a few days or weeks and then they gradually fade. The typical increase in magnitude is about 5 mags.

Supernovae

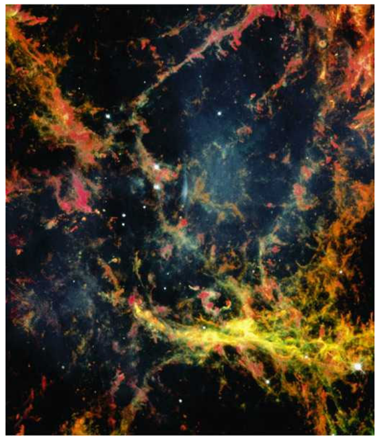
The light curve of a supernovae is similar to that of an ordinary nova, except that it is far brighter and lasts longer. At maximum light, supernovae reach 10^{10} solar luminosities (i.e., up to 25 magnitudes).

Bright emission lines in their spectra indicate ejected material is there. The velocities are as high as 10,000 km/s. A large fraction of the ordinary star may be given off in the explosion.

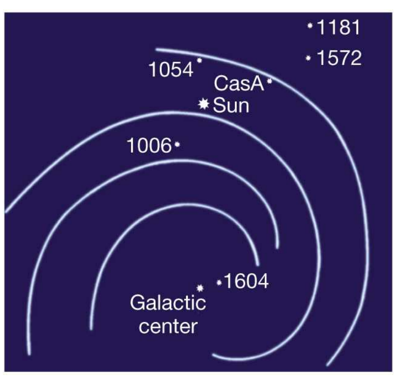
Crab Nebula



Crab Nebula Insert



Supernovae



Five supernovae have been observed in our galaxy during the past 1000 years.

Chinese reported supernovae (“guest stars”) in AD 1006, 1054, and 1181.

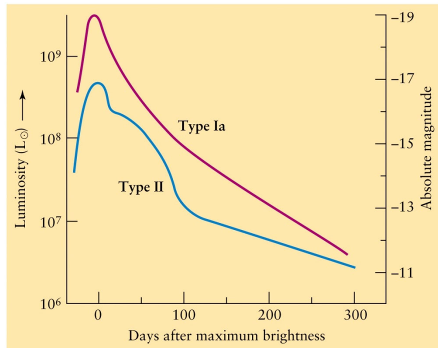
The other two were in 1572 (Tycho’s) and 1604 (Kepler’s).

Although not observed when it exploded, Cas A is recognized as a SN remnant.

Types of Supernovae

Observational studies indicate there are two general kinds of supernovae light curves, and hence there must be two different mechanisms for the explosion.

Type II supernovae appear in regions where there are young, massive stars (e.g., spiral arms). **These explosions mark the deaths of massive stars.**
Type II supernovae are enriched in heavier elements.



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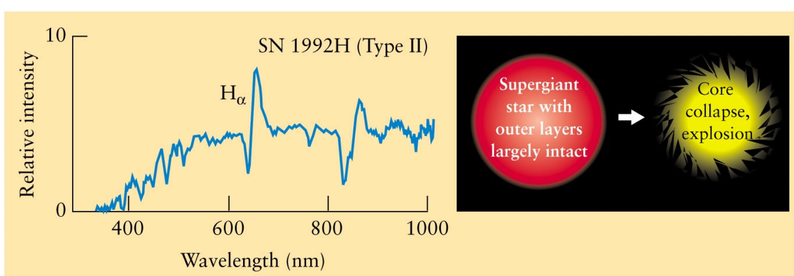
Type II Supernova



Universe by Freedman, Geller, and Kaufmann

Type II Light Curves

The light curves of Type II supernovae can be classified as either Type II-L (linear) or Type II-P (plateau). A temporary plateau exists between about 30 and 80 days after maximum light; no such detectable plateau exists for Type II-L objects.

The source of the plateau is the radioactive decay of the large amount of ^{56}Ni that was produced by the shock front during its march through the star. Other radioactive isotopes were produced, too. If the isotopes are present in sufficient quantities, each in turn may contribute to the overall light curve, causing the slope of the curve to change.

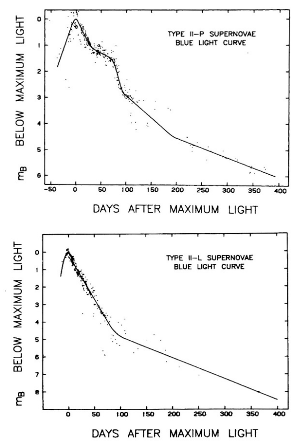
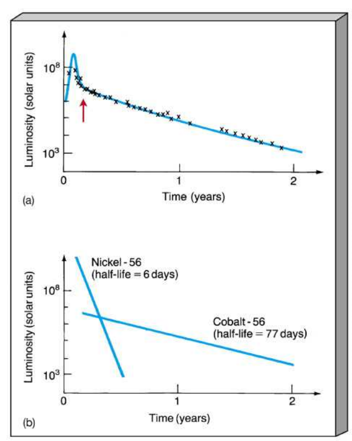


Figure 13.16 The characteristic shapes of Type II-P and Type II-L light curves. These are composite light curves, based on the observations of many supernovae. (Figures from Doggett and Branch, *Astron. J.*, *90*, 2303, 1985.)

Radioactive Decay

The ^{56}Ni is transformed into ^{56}Co through beta-decay.

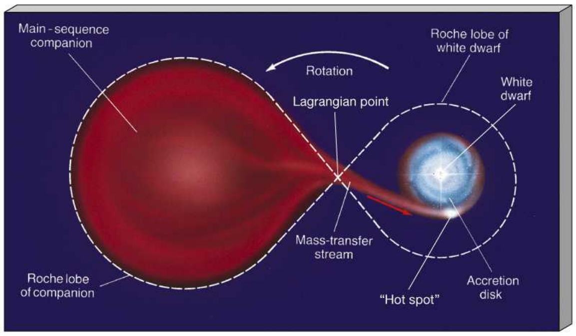
The energy released by the decay is deposited into the optically thick expanding shell, which is then radiated away from the supernova remnant’s photosphere. This “holds up” the light curve for a time, resulting in the observed plateau.



Astronomy Today, Chaisson and McMillan

Type Ia Supernovae

Type Ia are thought to occur **in binary systems that contain a white dwarf** and a nearby companion. Mass transfer causes the mass of the white dwarf to **exceed 1.4 solar masses**.



Astronomy Today, Chaisson and McMillan

Type Ia Supernovae

Type Ia are thought to occur **in binary systems that contain a white dwarf** and a nearby companion. Mass transfer causes the mass of the white dwarf to **exceed 1.4 solar masses**.

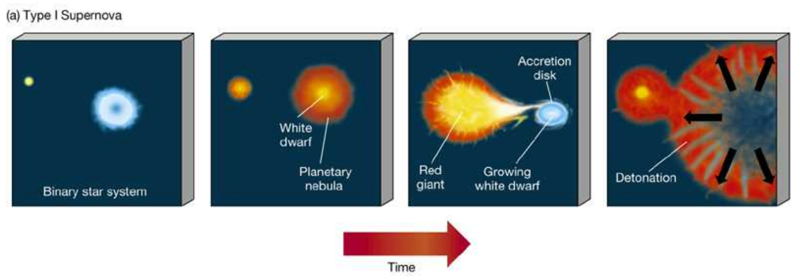
The star collapses because the electron degeneracy cannot hold up this weight. Nuclear reactions begin (basically a "CO Flash"), and the energy released destroys the star.

No central star remains behind.

Typically, these supernovae are associated in elliptical galaxies or in regions of galaxies where there are large numbers of old, low-mass stars.

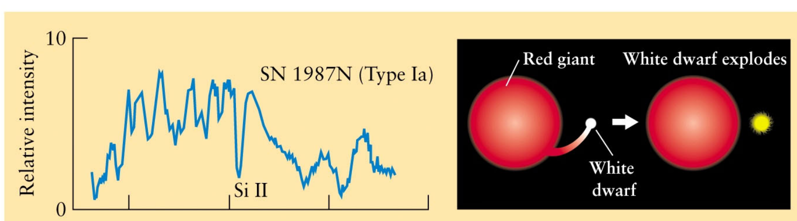
Hydrogen is not seen in their spectra.

Type Ia



Astronomy Today, Chaisson and McMillan

Type Ia

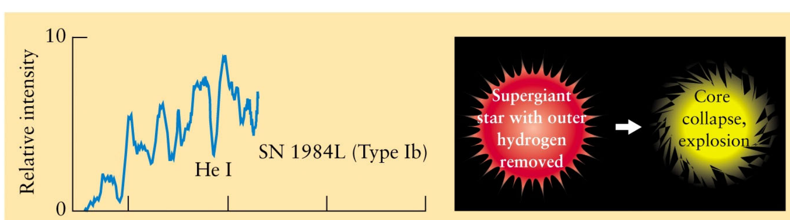


Universe by Freedman, Geller, and Kaufmann

Types of Supernovae

Type Ib and **Type Ic** supernovae are more like the Type II supernovae.

Type Ib



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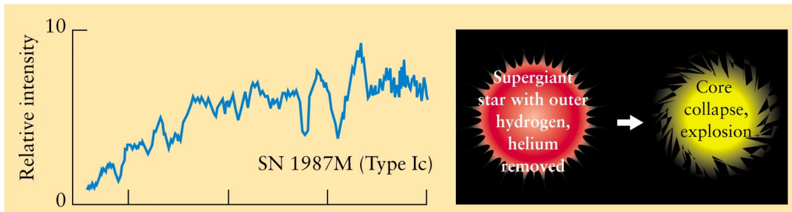
Type Ic



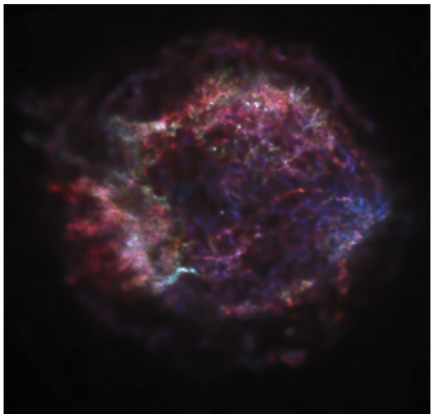
Universe by Freedman, Geller, and Kaufmann

Veil Nebula

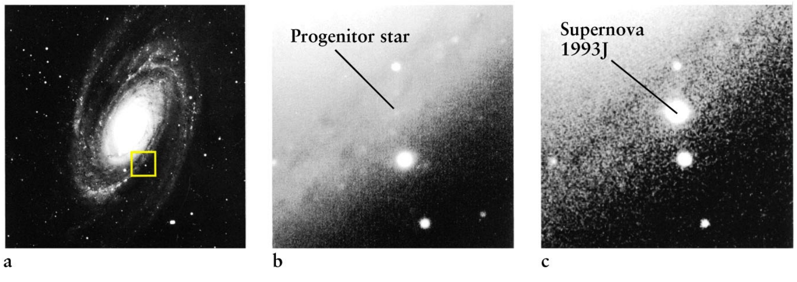
Vela Nebula

Gum Nebula

Cassiopeia A

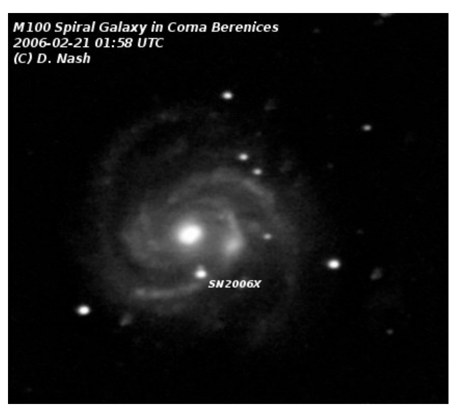


Extragalactic Supernova

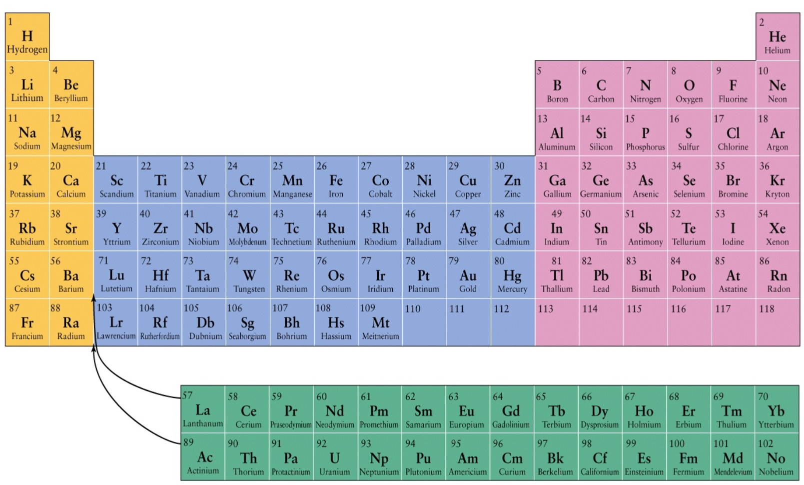


SN 2005cs

Supernovae



Periodic Table



Heavy Elements

The term ***heavy elements*** is generally taken to designate those nuclei more massive than the iron-group nuclei. Their natural abundances are far greater than can be produced in nuclear equilibrium reactions.

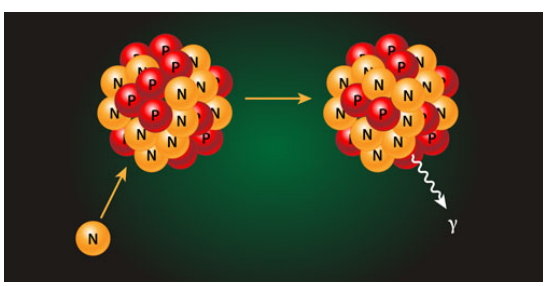
There is no way to make these nuclei using ***charged*** particle reactions.

But capturing neutrons – that have no charge – is easy. There is a huge quantity of neutrons mixed with the supernova remnant's material.

This is how the elements heavier than iron are created.

Neutron Capture

With no Coulomb barrier to overcome, heavy elements capture neutrons easily even at extremely low energies. Neutron cross sections generally *increase* with decreasing energy. One concludes that heavy elements could be synthesized at relatively moderate temperatures by exposing lighter nuclei to a flux of neutrons.



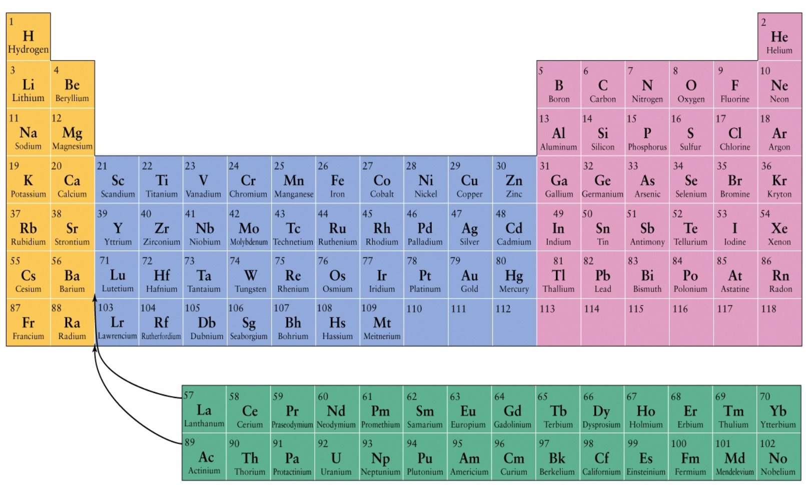
Free Neutrons

The difficulty with the idea is that free neutrons are not normally thought to be abundant in the major phases of nuclear burning.

The main line of nuclear energy generation does not involve the liberation of neutrons until the carbon-energy generation is reached.

Neutrons are liberated to some extent by secondary reactions during He burning in red giants, **but they are primarily produced in Type II supernovae explosions.**

Periodic Table



Elemental Abundances

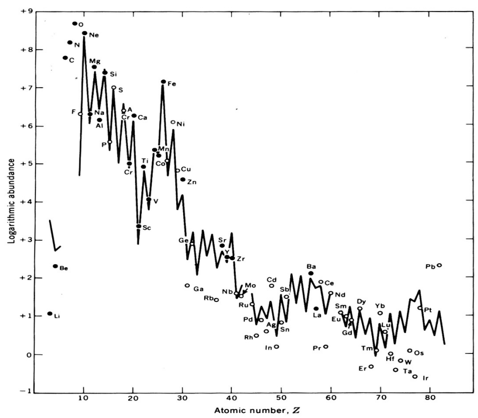


Fig. 1-22 The abundances of the elements in the solar system. The dots represent values obtained from the strengths of absorption lines in the spectrum of the sun, whereas the line represents the historic compilation of Suess and Urey, which was based mainly on chemical evidence from the earth and meteorites. Many of the estimates from both techniques have been improved since 1956, but the general features remain the same. It has been these abundance features which have inspired the nuclear physicists to seek the sets of thermonuclear circumstances that will reproduce this figure in a natural way.

Principles of Stellar Evolution and Nucleosynthesis, Clayton

Elements in the Human Body

http://www.hopechannelsouthern.org/family

23	Vanadium (V)
25	Manganese (Mn)
26	Iron (Fe)
27	Cobalt (Co)
29	Copper (Cu)
30	Zinc (Zn)
34	Selenium (Se)
42	Molybdenum (Mo)
50	Tin (Sn)
53	Iodine (I)

https://en.wikipedia.org/wiki/Composition_of_the_human_body

LMC SN 87A

This supernova occurred in the nearby (southern-sky) galaxy known as the Large Magellanic Cloud (LMC) in 1987.

This supernova was different because it was not nearly as bright as traditional ones.

LMC SN 87A

LMC SN 87A

a

b

Australian Astronomical Observatory / David Malin Images

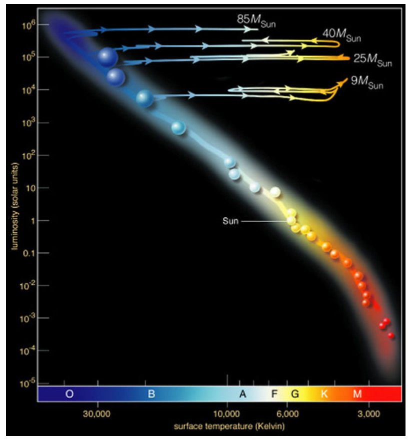
LMC SN 87A

Why was this supernova not nearly as bright as traditional ones?

Ultimate explanation: The Fe core collapse occurred when the star was a blue supergiant – not a red one – as all theories had assumed.

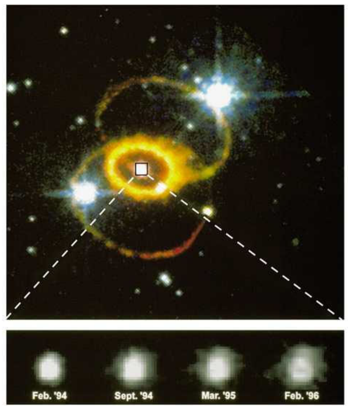
Additional data: A high flux of neutrinos was detected over a 10-second interval during the time the star began to brighten.

Movement on the HR Diagram

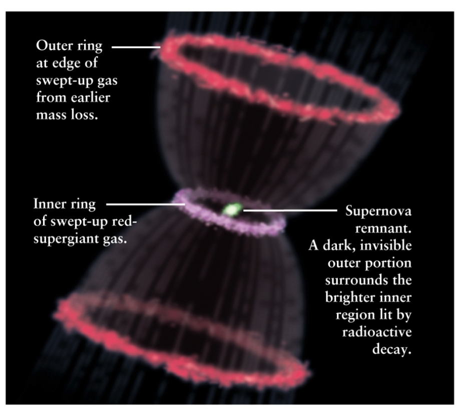


LMC SN 87A

LMC SN 87A



LMC SN 87A



R. Kirshner and P. Chalis, Harvard-Smithsonian Center for Astrophysics; STScI

Neutron Star Remnant?

SN 1987A appears to be a core-collapse supernova, which should result in a neutron star. The neutrino data indicate that a compact object did form at the star's core. However, since it first became visible, astronomers have been searching for the collapsed core but have not detected it.

The Hubble Space Telescope has taken images of the supernova regularly since August 1990, but, so far, the images have shown no evidence of a neutron star.

Evolutionary Paths