Supernova Explosions

Novae

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

First, mass is transferred from the normal star to the surface of its white dwarf companion.
Novae

This H material piles up on its surface. Gradually, the weight increases, and so does the temperature, until it approaches that of the degenerate interior of the dwarf. 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

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 $10^{16}$ 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
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. These explosions mark the deaths of massive stars. Type II supernovae are enriched in heavier elements.
Types of 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 Supernova

Astronomy Today, Chaisson and McMillan

Type Ia

Universe by Freedman, Geller, and Kaufmann
Extragalactic Supernova

SN 2005cs
Supernovae

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

Principles of Stellar Evolution and Nucleosynthesis, Clayton
Elements in the Human Body

- 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)


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

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
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