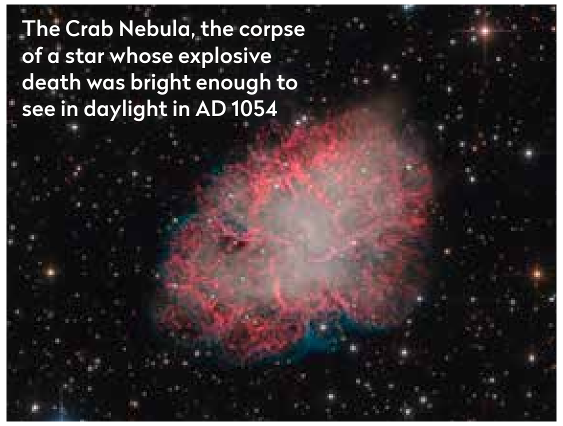
EXPLAINER

Supernovae

Some stars die in a spectacularly powerful and violent fashion. Here's how it happens

▲ While some stars quietly fizzle out at the end of their lives, others go supernova – an explosion so huge that the star briefly outshines its whole galaxy



The Crab Nebula, the corpse of a star whose explosive death was bright enough to see in daylight in AD 1054

A supernova recorded in ancient rock paintings in New Mexico

All stars die. How they die depends in part on their mass, but their deaths can result in titanic and spectacular explosions in space – supernovae – when they briefly outshine their host galaxies and radiate more energy than our Sun will deliver in its lifetime.

The term 'supernova' was first coined in 1934 by Walter Baade and Fritz Zwicky at the Mount Wilson Observatory in California, when they witnessed an explosive event in the Andromeda Galaxy. But supernovae were being observed long before the invention of the telescope, the oldest being RCW 86 spotted by Chinese astronomers in AD 185 as a 'guest star' visible in the sky for eight months. Perhaps the most famous supernova is the Crab Nebula, captured in AD 1054 by Native Americans in the form of rock carvings in Arizona and New Mexico.

Supernovae broadly separate into two main types and result from either a thermonuclear runaway or a core collapse within a star.

Type Ia supernovae are the result of runaway nuclear reactions. They happen in binary star systems where at least one star is a white dwarf – the small, dense, remnant core of a star that has exhausted its fuel and shed its outer layers in the form of a planetary nebula. A white dwarf has tremendous gravity and will accumulate material from its stellar companion until it reaches the Chandrasekhar Limit, or 1.44 times the mass of our Sun. When it exceeds this, its core heats up, resulting in an excessive and unsustainable amount of energy and pressure; a runaway nuclear reaction results and the star explodes.

A **Type II supernova** occurs when a star with a mass greater than eight times that of our Sun runs out of fuel and collapses under its own gravity. Having fused its hydrogen into helium, it sequentially burns carbon, neon, oxygen and silicon. There is an energy balance: gravity pulling in, radiation pushing out. But once silicon supplies are exhausted, the core becomes a hunk of iron and no further energy can be released through nuclear fusion.

Rebound effect

Once this critical core density is reached, gravity has the upper hand. With no internal pressure to support it, the outer shell of the star implodes. The collapsing outer layers rebound and detonate as a supernova, violently ejecting the star's material into space. **Type Ib and Ic supernovas** also undergo core collapse just as Type II supernovae do, but they have lost most of their outer hydrogen layer. There are subtypes of each of these supernovae too, classified by the elements visible in their spectra.

To study these explosions, astronomers use telescopes: the Hubble Space Telescope observes Type Ia supernovae billions of lightyears away for hundreds of days after detonation; NuSTAR uses X-ray vision to observe before, during and after events; and ULTRASAT observes in ultraviolet light, detecting explosions within seconds or minutes. Surveys such as the All-Sky Automated Survey for Supernovae (ASAS-SN) and the Dark Energy Survey provide a continuous stream of data from our Galaxy to identify supernovae.

Astronomers also use Type Ia supernovae as 'standard candles' to measure cosmic distances, since they blaze with equal brightness at their peak.

On average, a supernova occurs every 10 seconds in the Universe. Their remnants (see above) heat up the interstellar medium, distributing elements heavier than iron and providing the ingredients for the next generation of stars – a recycling process vital to the ecology of our Galaxy.

This brilliant supernova in galaxy NGC 2525 was visible for months in 2018

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Zombie stars, beauty queens and black holes

Once a star has gone supernova, it's destined to live on as one of these three types of object...

NEUTRON STARS

When a Type II supernova of a star with 8–20 times the mass of the Sun occurs, the remnant is a super-hot, ultra-dense collapsed core, a neutron star, where gravity has even squeezed the space from between particles in atoms. It is city-sized but with more mass than our Sun and a magnetic field billions of times stronger. Neutron stars can spin rapidly, hundreds of times per second, emitting regular pulses of radio waves detectable by telescopes – pulsars.

SUPERNOVA REMNANTS

These are the ethereal-looking structures left over from supernovae, which you'll have seen in beautiful astrophotos. They consist of hot gas, plasma and interstellar material swept up by the shockwave of the initial detonation. The shockwave heats and ionises the gas surrounding it to extremely high temperatures, emitting light across various wavelengths. They are also a source of cosmic rays, where the shock accelerates particles to high speeds.

STELLAR-MASS BLACK HOLES

When stars with a mass 20–30 times that of our Sun exhaust their fuel, their cores collapse to almost infinite density to create a black hole. The outer layers may blast into space; the star can be so heavy the shockwave can't overcome the black hole's gravity and the entire star is consumed. These explosions can create long gamma-ray bursts; material is spun up around the black hole and blasts away at close to the speed of light.