ASTRONOMY

Champagne supernova

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Thermonuclear supernovae were thought to occur only when white-dwarf stars of a certain mass explode. The discovery of a supernova that is way over the mass limit might require a reworking of the model.

According to the conventional view, thermonuclear, or type Ia, supernova explosions occur when a white-dwarf star — a star that has exhausted its nuclear fuel and is composed entirely of carbon and oxygen — accretes matter from a close companion star. At the same time, the white dwarf contracts, and so its density and temperature increase. This goes on until its mass approaches the maximum that a white dwarf can have — the Chandrasekhar mass, 1.4 times that of the Sun. At this point, a violent thermonuclear instability releases enough energy from nuclear fusion to blast the white dwarf apart at speeds of a few per cent of the speed of light. The nuclear fusion burns about 0.6 solar masses of the white dwarf to a single isotope, radioactive nickel-56. The decay of this isotope, through cobalt-56 to stable iron-56, provides a delayed source of energy that keeps the ejected matter hot, causing the supernova to attain a peak luminosity (defined as energy radiated per unit time) greater than that of a billion Suns.

On page 308 of this issue, Howell *et al.*[1] throw a spanner in the works. They report observations of a supernova that was too luminous to have been produced by a mere 1.4 solar masses of ejecta. This is the first conclusive evidence for a 'super-Chandra' supernova.

Type Ia supernovae are of great interest to astronomers because they are used to investigate the expansion history of the Universe. Their high luminosities mean they can be seen far away (and therefore far back in time), and their relative brightness can be used to infer their distance. An empirical relation between the rate at which the supernova's luminosity rises and falls, known as the 'stretch'[2], and its peak luminosity allows the latter value, and so the distance, to be inferred with great precision.

In the past decade, type Ia supernovae have been used to show that the expansion of the Universe must be accelerating. This process, working against the pull of gravity, must be driven by some mysterious 'dark energy', possibly supplied by the phenomenon represented by Einstein's cosmological constant. Astronomers are planning to observe large numbers of type Ia supernovae to study the nature of this dark energy[3–6], and are thus eager to know more about the physical features of these titanic nuclear-powered stellar explosions.

The supernova discovered by Howell *et al.*[1] — called SNLS-03D3bb, and also known as SN 2003fg — has a spectrum of emissions and absorptions at optical wavelengths that establishes it as being of type Ia. This means that it is powered by a runaway thermonuclear reaction as described above, rather than by the gravitational processes that power other supernova types. But the peak luminosity of the supernova was 2.2 times higher than that of a typical type Ia event. This luminosity depends on the mass of nickel-56 present; in this case, about 1.3 solar masses of nickel would be needed to produce such luminosity.

That amount of nickel requires far more than the 1.4 solar masses of initial ejecta allowed by the Chandrasekhar limit. This is because fusion reactions produce not just nickel, but also stable iron-group isotopes, and the optical spectrum of SN 2003fg reveals the presence of lighter elements such as silicon, sulphur and calcium. There may also be unburnt oxygen and carbon. Taking all this together, Howell *et al.* estimate that the mass of the ejecta must have been 2.1 solar masses.

How can a white dwarf be so massive? One way would be if two white dwarfs were to spiral together and eventually coalesce. Such an event could occur through loss of a star's angular momentum, caused by ripples in space-time known as gravitational waves. But such an object would probably collapse to a neutron star[7,8] rather than explode as a supernova. A more likely explanation is that matter accumulated by a white dwarf from a normal companion star adds extra angular momentum, causing the white dwarf to rotate more rapidly. This rapid rotation would provide additional support against gravity and allow the white dwarf to become overmassive before it exploded.

The maximum mass a white dwarf might achieve in this way depends on how the angular momentum is distributed within the star; that is, whether it rotates as a single, rigid body, or whether different parts of it rotate at different rates. Differential rotation might be able to support as much as four solar masses, although limitations on how much mass the companion star can transfer may constrain white-dwarf masses to not much more than two solar masses[9].

As a result of the Doppler effect — in which the radiation emitted by an object moving away is stretched or 'redshifted' — features in the spectrum of SN 2003fg are broadened, but by an amount that shows that the ejection velocity was lower than is typical of type Ia supernovae[1]. That is consistent with a super-Chandra white dwarf, because although more nuclear energy is released by fusion in such a body, a higher binding energy is also required to break it up against its self-gravity. Higher binding energy can lead to lower ejection velocity.

To further our understanding of type Ia supernovae, it will be crucial to determine the distribution of masses that they eject. For example, are type Ia supernovae generally super-Chandra, with a smooth distribution between 1.4 and 2.1 solar masses? Howell *et al.*[1] present an analysis of a supernova sample hinting that this may be so. The present data, however, are compatible with the typical type Ia supernova being near the Chandra mass, with SN 2003fg as a special case. This interpretation is suggested by the supernova's distinct overluminosity compared with its peers, and by its violation of the luminosity–stretch relation: despite its extreme brightness, its stretch is typical.

That need not mean that SN 2003fg raises a problem for the use of type Ia supernovae as cosmic distance indicators. If one assumed that SN 2003fg conformed to the luminosity–stretch relation, one would severely underestimate its luminosity, and thus its distance. But it is such a blatant outlier that it has already been excluded from consideration in one cosmology study[10]. The luminosity–stretch relation is empirical and does not entail assumptions about the mass distribution of type Ia supernovae. So it may already be able to accommodate some deviations from the Chandra mass — although not for the exceptional SN 2003fg. ■

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