ASTROPHYSICS

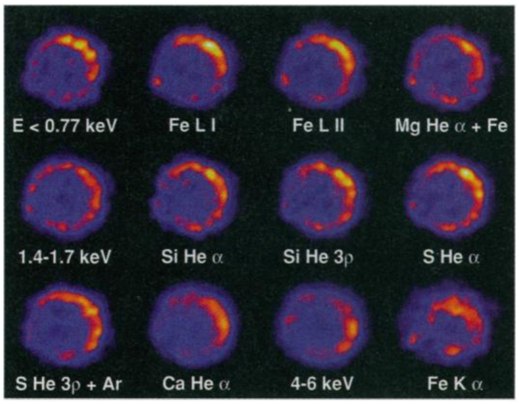
The Quest for a Supernova Companion

Pilar Ruiz-Lapuente

In their seminal work on supernova explosions, Hoyle and Fowler (*1*) described how a white dwarf, a common endpoint in the evolution of low- and intermediate-mass stars, could become a powerful fusion bomb if its interior temperature rose to about 2×10^8 to 5×10^8 K. They anticipated that this type of explosion could well correspond to the class of objects identified by Minkowski (*2*), called supernovae of type I and much later renamed type Ia. These supernovae are characterized by their spectral signatures (*3*) and are the brightest observable stellar explosions. The supernova of the millennium, the Lupus supernova (also designated SN 1006 after the year of its appearance) was a supernova of this type. The supernova discovered by Tycho Brahe (*4*), SN 1572, was also of this type. Both are the only unambiguous type Ia supernovae observed in our galaxy during the last thousand years. Although considerable progress in hydrodynamic calculations in the explanation of the observed spectra and light curves has been achieved, puzzles remain about the evolutionary path toward explosion.

The first question is how such high temperatures ($>10^8$ K) can be attained in the usually cold degenerate cores of white dwarfs. A natural way to heat white dwarfs up is by the accretion of material from a stellar companion. If the white dwarf grows in mass by taking material from a donor star, its central density and temperature rise, and it can achieve the critical condition near 1.4 solar masses ($M_\odot$), the so-called Chandrasekhar mass. Ideas on what the companion could be and about the evolutionary path to explosion have been outlined, and various possible types of binary systems have been proposed (*5*). Despite the strong inference that thermonuclear supernovae arise in binary systems, there has not yet been any direct evidence of the companion star, and its nature is still unknown. The binary path was nevertheless found to be the easiest physical way to give rise to bare white dwarfs exploding in large enough numbers to account for those supernovae. The single-star models were both physically and statistically unsuccessful. Recently, new momentum has been given to the study of possible evolutionary paths to explosion (*3*, *6*). Observational efforts with specific goals have been set up to clarify the issue by contrasting the models with empirical evidence.

What is the nature of the companion star? Which ways of feeding the white dwarf with either C, H, or He succeed in making the white dwarf reach explosive conditions? The general idea of H or He transfer from a companion that is not a white dwarf is called the "single-degenerate scenario." In this picture, the companion star might be a giant, a subgiant, a He star, or a main-sequence star. As pointed out by Nomoto (*7*), not all rates of transfer of mass to a white dwarf are favorable to its growth and an explosive end as a supernova. Low accretion rates favor a much less violent explosion: a nova, which differs from a supernova in that the white dwarf remains intact, and there is opportunity for further recurrent outbursts. Whereas a nova is a skin-depth explosion, a supernova affects the whole star. Hachisu, Kato, and Nomoto (*6*) have reestimated the favorable rates of accretion of H to burn it into He and to eventually grow C. The accretion rates can be larger than estimated before and might produce phenomena that can be detected. These authors suggest that periods of mass transfer rates of H larger than 10^{-6} $M_\odot$ year^{-1} might be involved in the transfer of mass to the white dwarf from companions such as low-mass red giants or subgiants of 0.8 to 1.5 $M_\odot$. The transfer will also produce strong winds originated in the mass-accreting white dwarf. Burning of the accreted H into He and of the He into C can lead to the growth in mass and increase of the central temperature of the star, which would finally explode.



Tycho's supernova. False color montage of SN1572 taken at different x-ray energies showing the distribution of chemical elements. [Courtesy of E. Gotthelf, NASA]

A number of tests have been undertaken to reveal whether such a picture involving a H- or He-donor companion is correct. (i) With a very high transfer rate, traces of circumstellar H might be seen in the spectra of the supernova in the days immediately after the explosion. A project to set up limits through observations of early spectra has set constraints in one case, SN 1994D (*8*). (ii) A further limit is obtained from radio observations: The H-rich circumstellar envelope surrounding the system could end up emitting in radio wavelengths if the transfer rate of H before the explosion was very large (*9*). (iii) Any material stripped from the companion in the interaction of the ejecta with the nearby less dense star could give signatures of emission, as the supernova gets dimmer. The limits on the x-ray emission coming from the interaction of the expanding shell of the supernova with the circumstellar material and the measurement of the density of neutral hydrogen in the circumstellar region of the supernova can also inform us about the rates of mass transfer from the companion (*10*). So far, those projects have just dealt with a few cases and disfavor high rates of mass transfer (larger than 10^{-6} $M_\odot$ year^{-1}), but firm conclusions require the study of a larger sample of supernovae. Further actions (*11*, *12*) concentrate on dating the explosion from the chemical enrichment history of iron or from the position of the supernovae in their host galaxies, or from inspection of the sites and environments where type Ia supernovae explode. The region of SN 1006 shows no sign of any surviving companion core at the position of the explosion, and neither do the sites of more recent extragalactic type Ia supernovae (*12*). In this last project, the high spatial resolution of the images taken by the Hubble Space Telescope of fields in nearby galaxies, accumulated from other projects, were used to compare images of supernova fields before and after the explosion. The lack of detection of any object up to magnitude 23 to 24 at the sites of those extragalactic type Ia supernovae would exclude the possibility of bright cores of the companion star surviving the explosion. The lack of any source detected in the region of the historical type 1a supernovae, at a distance of a few kiloparsecs, is most compelling, because it excludes not only bright remnant companions, but fairly in-

The author is in the Department of Astronomy, Faculty of Physics, University of Barcelona, Barcelona, Spain. E-mail: pilar@mizar.am.ub.es

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trinsically dim ones. A program scheduled for the Hubble Space Telescope will obtain color photometry of the stars in the center of both remnants (*13*), and strong constraints will be placed on the companion properties, even if nothing is detected.

If the material accreted by the white dwarf is neither H nor He, C + O from a disrupted C + O white-dwarf companion is another possibility. This alternative, known as the double-degenerate scenario, involves the progressive approach of two white dwarfs orbiting around the center of mass of the system while they emit gravitational wave radiation. The less massive white dwarf is disrupted in the process, forming a torus of material around the most massive one. The accretion of this mass by the surviving white dwarf could cause its explosion. The lack of detection of any surviving companion could eventually confirm that it is destroyed in the course of the binary evolution, as expected in the merging of C + O white dwarfs. Such a confirmation would establish this scenario as the right evolutionary path. Some objections have been raised, however: fine tuning in the accretion process might be required to avoid the burning of C into Ne and Mg, which would lead to a collapse event instead of an explosion (*14*). The final accretion resulting from merging still needs careful numerical evaluation to ascertain the final result of the double-degenerate scenario.

Transfer of H or He to the white dwarfs in the single-degenerate scenario differs from the C + O transfer in that it opens up more possibilities of explosion: if the H-accreting white dwarfs were the right evolutionary path to type Ia supernovae, they could undergo explosions starting at the edge and propagating toward the center well before the white dwarf could reach the Chandrasekhar mass. The explosion of Chandrasekhar-mass white dwarfs gives a successful account for the common type Ia supernovae, as shown by a model proposed by Nomoto, Thielemann, and Yokoi (*15*). But explosions that happen before reaching such a mass are found in the calculations where a He detonation is triggered in the external layers (*16*). Although they might not respond to the common type Ia phenomenon, they could correspond to very dim ones (*17*). A mixture of almost standard Chandrasekhar explosions with some very faint "peculiar" sub-Chandrasekhar explosions could exist. A few extremely faint type Ia explosions have been identified, in any case: The last supernova of type Ia that exploded in the Andromeda galaxy, in 1885, was of such a type. On the other hand, the evolutionary path toward explosion will not be directly reflected in the spectrum of the exploded white dwarf itself.

Whatever the companions to those supernovae might be, their emission has been obscured by the overwhelming luminosity of the exploded white dwarf. Despite the difficulties, however, important physical understanding will eventually arise: Pairs of white dwarfs should be merging in the universe, and one wonders what kind of object results. If compact objects can arise in this way (*13*), they should contribute to the population of neutron stars. If an explosion is obtained, many things will be explained to the satisfaction of those who searched and saw nothing: The merging of two white dwarfs will not give any H signatures nor a strong radio or x-ray emission after the explosion. It will not leave behind any star that can be observed afterward. These reasons tempt people to bet on them for type Ia supernovae. On the other hand, there are many loose ends that need tying up, and the outcome of the single-degenerate pairs and their possible relation with type Ia supernovae will also eventually be clarified. Perhaps nature chooses more than a single evolutionary path toward stellar explosions.

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NUCLEAR TRANSPORT

Whose Finger Is on the Switch?

David S. Goldfarb

Having successfully infected a cell, viruses co-opt the cell's own intracellular processes to replicate. Often key cellular reactions, these co-opted functions are also of interest to molecular biologists. One such process is nuclear transport—the mechanism by which cells move macromolecules into and out of the nucleus. In a report on page 1842 of this issue, Richards *et al.* (*1*) illuminate the mechanism of nuclear transport, describing its control by the small guanosine triphosphatase (GTPase) Ran. And in a related paper on page 1845, Her *et al.* (*2*) report that vesicular stomatitis virus (VSV) shuts off host transport with a flick of the Ran switch. Ironically, an efficient switching mechanism, evolved to control nuclear transport, creates an Achilles' heal susceptible to viral attack.

The author is in the Department of Biology, University of Rochester, Rochester, NY 14627, USA. E-mail: Goldfarb@nucleus.biology.rochester.edu

Pores arrayed in the nuclear membrane form multiple gateways in and out of the nucleus. Various cargo are delivered from the nucleoplasm and cytoplasm to the nuclear pore complex by distinct targeting pathways (*3*). The best understood targeting pathway is nuclear localization signal (NLS)–directed protein import (see the figure). Cargo with NLSs is targeted to the nucleus by soluble factors (α and β) that promote docking at sites adjacent to the pore complex and subsequent translocation through the pore. Targeting pathways for different classes of cargo use both common and distinct transport factors (*4*). Export from the nucleus is also mediated by multiple pathways. Nuclear export signal (NES)–directed protein export is distinct from the export of mRNA (as heterogeneous nuclear ribonucleoprotein), tRNA, and rRNA (as ribosomes), each of which apparently occurs by a distinct pathway (*3*). Few components of any export apparatus are