The Hunt For Missing Supernovae

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Astronomers are using adaptive optics to help solve a supernova puzzle.

By Stuart Ryder and Seppo Mattila

THE RATE at which massive stars exhaust their nuclear fuel, undergo core collapse, and then end their lives in colossal supernova explosions, has a huge influence on the evolution of their host galaxies. Supernovae drive the enrichment of gas by releasing the products of nuclear burning in their core out to the interstellar medium, which then triggers the next round of star formation. In dwarf galaxies undergoing a burst of star formation, supernovae may even expel some of this gas out of the galaxy entirely as a *superwind*.

Stellar evolution theory, combined with recent identifications of actual supernova progenitor (precursor) stars, indicates that only stars more massive than ~ 8 times that of the Sun will end their lives as core-collapse supernovae. Assuming that the ratio of such massive stars to less-massive stars (the so-called Initial Mass Function) is the same everywhere in the universe, then the observed supernova rate provides a measure of the star formation rate. This can potentially be employed across a vast range of cosmic distances.

Above: This infrared image of IRAS 17138-1017 was made by combining images from Gemini's Near-Infrared Imager (NIRI) with the adaptive optics system Altair in June 2008. The red colour of SN 2008cs is due to the large amount of intervening dust.

Despite the efforts of dedicated amateur supernova hunters such as Australia's Bob Evans, and robotic searches such as the Lick Observatory's Katzman Automatic Imaging Telescope, the only thing we know for certain is that the current rate of supernova discoveries is less than the actual rate of supernova events.

But just how many supernovae are we missing? Let's examine the types of galaxies where supernovae ought to be occurring at the highest rates, namely those undergoing a starburst episode in which massive-star supernova progenitors are being born at the highest rates. The class of starburst galaxies known as Luminous Infrared Galaxies (LIRGs), whose total infrared luminosity exceeds 10^{11} solar luminosities, and their more extreme cousins the Ultra-Luminous Infrared Galaxies (ULIRGs), that emit more than 10^{12} solar luminosities at infrared wavelengths, ought to be the ideal hunting grounds for supernovae. Yet, barely a handful of the more than 4,500 catalogued supernova discoveries thus far have been found in LIRGs and ULIRGs.

GEMINI OBSERVATORY

The Gemini North Laser Guide Star system in use, as seen from the catwalk of the nearby Canada-France-Hawaii Telescope.

Why is this? There are two main reasons. First, LIRGs and ULIRGs are incredibly dusty. Indeed, it is the action of the dust – which absorbs nearly all the optical radiation emitted by the young stars or supernovae, and re-radiates it at longer wavelengths – that gives rise to their prodigious infrared luminosities. Therefore, to detect such supernovae we must work at near-infrared wavelengths, where dust obscuration is significantly reduced. Secondly, both this dust and the tendency of stars to form in clusters result in LIRGs and ULIRGs appearing extremely clumpy, with star formation tightly concentrated within the galactic nuclear regions. As most of the LIRGs are at least 150 million light-years away, spotting a new point source against such a bright and complex background in natural seeing conditions is extremely challenging. The availability of adaptive optics systems like "Altair" on the 8.1-metre Gemini North telescope on Mauna Kea, Hawaii, which can deliver image quality of 0.1 arc-second resolution at near-infrared wavelengths (the size of a one dollar coin seen from 50 km away!), enables us to overcome both of these handicaps at one stroke.

Searching with Adaptive Optics

In September 2004, we used the Nasmyth Adaptive Optics System Near-Infrared Imager and Spectrograph on one of the European Southern Observatory's four 8.2-metre Very Large Telescopes in Chile to discover a supernova in the LIRG IRAS 18293-3413. This was subsequently confirmed with our detection of a radio counterpart using the Very Large Array (VLA) radio telescope in New Mexico, and designated SN 2004ip by the IAU's Central Bureau for Astronomical Telegrams (CBAT).

SN 2004ip was the first supernova discovered using natural guide star adaptive optics. Encouraged by this success, and wanting to extend our supernova search to LIRGs that don't have a bright enough natural guide star within reach, we initiated a program to use Altair's laser guide star to image nine LIRGs at intervals of three to six months over four observing semesters. Our simulations have indicated that this is the optimum interval to detect supernovae. Any longer, and we risk allowing a supernova to rise to maximum and decline again without ever being caught, while more frequent observations would restrict the sample of galaxies we can monitor, and actually lower our chances of a discovery.

Remarkably, with just our third target observation, we hit pay dirt. The LIRG IRAS 17138-1017 had previously been observed with the Hubble Space Telescope's NICMOS infrared camera in September 2004. A simple visual comparison of our image taken on April 21 last year with this Hubble image revealed in fact not just one new supernova, but also one "historical" candidate from 2004 which is no longer visible but has since been designated SN 2004iq.

Subsequent re-observations, together with some observations from the Nordic Optical Telescope (NOT), enabled us to compile light curves. VLA detection of a radio counterpart last May put the core-collapse supernova nature of this object beyond doubt, and it was designated SN 2008cs.

The near-infrared light curves of core-collapse supernovae fall into two classes: the so-called "ordinary," and the "slowly declining" events which are almost 1.5 magnitudes brighter at maximum. SN 2008cs is of the latter type, discovered seven weeks prior to reaching its maximum brightness. The inferred visual extinction is a whopping 17.2 - 18.8 magnitudes, meaning that fewer than one in a million photons escapes the dust – little wonder that so few supernovae have so far been found in LIRGs by optical searches! Nevertheless, SN 2008cs marks the first of what we anticipate will be a significant number of highly obscured and previously uncounted supernovae to be discovered with the aid of laser guide star adaptive optics. ✦

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GEMINI OBSERVATORY

The Gemini North Observatory at sunset.

Gemini Observatory

Gemini consists of two twin 8.1-metre telescopes, one (Gemini North) atop Mauna Kea in Hawaii, and the other (Gemini South) on Cerro Pachon in Chile. Australia is one of seven countries in partnership that operate the telescopes (the others being Argentina, Brazil, Canada, Chile, the United Kingdom, and the United States). Gemini North saw first light in 1999 and Gemini South in 2000.

– Greg Bryant