Supernovae, like Gamma-ray Bursts, their even higher-energy cousins, are a nearly perfect match for Gemini’s capabilities and queue-based operational approach. Access to a broad swath of the infrared/optical spectrum, and the ability to provide rapid-response follow-up observations, make Gemini an excellent supernova science machine. Rapid response was critical for observations of SN 2008D in NGC 2770, which produced bright X-ray/ultraviolet emissions detected by NASA’s Swift satellite in early March 2008. Within 1.7 days, Gemini initiated a sequence of events to obtain optical spectra chronicling the birth of a supernova in real time (Modjaz et al.). However, it was one of the initial commissioning datasets from the Gemini Multi-Object Spectrograph (GMOS) at Gemini North in late 2001 that delivered one of Gemini’s first major results in the study of exploding stars.

The supernova, designated SN 2003gd, came to the attention of Australian amateur astronomer and supernova hunter Rev. Robert Evans when he noticed a new star as he visually scanned the nearby galaxy M74 (NGC 628) through his 31-centimeter (12-inch) telescope in June 2003. Shortly after this discovery, a team led by Stephen Smartt and Justyn Maund (University of Cambridge, UK) found that the Gemini GMOS commissioning images of the galaxy (see Figure 1), clearly recorded the progenitor star. The science-grade data they found in the Gemini Science Archive (GSA) included g-, r-, and i-band images taken under excellent seeing conditions. From the Gemini (and additional Hubble Space Telescope) data, the team identified and characterized the progenitor star’s temperature, luminosity, radius, and mass. From this, the team concluded that the star was a normal, massive, red supergiant, much like the closer and well-known star Betelgeuse, which will likely meet a similar fate relatively soon. Additional observations by Smartt’s team confirmed that SN 2003gd was a normal Type II supernova, making this the first time that a red supergiant progenitor star had been identified “on its deathbed” prior to going supernova. In September 2008, Maund and Smartt also led another HST/Gemini program to look for the progenitor. However, it was gone, providing verification of its pre-explosion identity.

SN 2003gd was also scrutinized by a large international team of scientists, this time to look for evidence of dust. In August 2004, team-members Doug Welch (McMaster University) and Geoff Clayton (Louisiana State University) used GMOS again to take deep optical spectra of SN 2003gd and look for the effect of extinction by dust via its impact on the Hα emission peak. The team’s detection made it clear that large quantities of dust (on the order of 0.02 solar mass) could be produced in a very short period of time after a supernova explosion of this type.

About two years earlier, another team led by Patrice Bouchet (CTIO), this time using the mid-infrared instrument T-ReCS on Gemini South, announced the detection of lesser amounts of dust around the more evolved (as well as closer and more famous) supernova remnant SN 1987A (see Figure 2, page 34). The closest observed supernova of the past 400 years, SN 1987A allowed the team to resolve a well-defined dust ring with the T-ReCS data. Augmenting the Gemini
Figure 1: Gemini GMOS image of M-74 (NGC 628) with inset (left) showing pre-explosion star (enhanced) from Gemini image. Right inset image shows the supernova six months after it exploded (right inset image from Isaac Newton Telescope).
data with X-ray observations from the Chandra Space Telescope and radio data from the Australian National Telescope Facility, the researchers found strong confirmation that dust is a key product of supernova explosions.

Another type of supernova, Type Ia (SNe Ia, thought to be the result of a white dwarf amassing material from a companion until the white dwarf becomes unstable and explodes) is the subject of a multi-observatory program, including Gemini, called the Supernova Legacy Survey (SNLS). Concurrent with the SNLS, Gemini also participated in a smaller, similar survey called ESSENCE (Equation of State: SupErNovae trace Cosmic Expansion). The primary goal of the SNLS (and to a large extent ESSENCE) is to better understand the nature of “dark energy” and, by assembling a large sample size (over 500 SNe Ia), to determine dark energy’s average equation of state parameter ($w$) and ultimately determine (to $3\sigma$) if dark energy is something other than a manifestation of Einstein’s “cosmological constant.” Dark energy is the force that is accelerating the expansion of the universe and is thought to encompass about 70 percent of the energy budget of the universe.

The SNLS targeted SNe Ia in the redshift range of $z = 0.3-0.9$ from wide-field Canada-France-Hawai`i Telescope (CFHT) images, which revealed an average of 40 candidates per month. In addition to Gemini and CFHT, the W.M. Keck Observatory and the Very Large Telescope (VLT) were the key partners in the SNLS effort. During the five-year life of the survey, from 2003-2008, the Gemini Multi-Object Spectrograph (GMOS) observed almost 300 targets, of which almost 200 were SNe Ia supernovae. Many of the fainter, more challenging observations were assigned to Gemini due to the extreme sensitivity and high signal-to-noise ratio made possible by the use of the Nod & Shuffle technique on GMOS to obtain optical spectra (see sample in Figure 3 and a full description of the Nod & Shuffle technique on page 58).

The SNLS survey continues to have a long and prosperous legacy. As of early 2010, about 20 refereed papers based on its data have entered the astronomical literature. These papers cover topics such as dark energy, rates of supernovae, and a 2010 paper (Sullivan et al., in press) which found that the intrinsic brightness of Type Ia supernovae are even more dependent upon galaxy type than previously suspected; this will have profound implications for future SNe Ia cosmological analysis.

While Gemini excels at supernova research by adjusting quickly to transient events, at the other extreme is the study of supernova light echoes. By their very nature, supernova light echoes can be seen hundreds or even thousands of years after the explosion, but they offer astronomers a chance to literally look back in time and, like a detective, unravel the nature of a supernova whose light has long faded. The principle is easy: as the light from a supernova travels through space, it encounters gas clouds that reflect the light in all directions, including toward us. By expanding the light from the echo into...
a spectrum, astronomers can identify characteristic spectral features and identify what type of supernova occurred. Results from the more recent SN 1987A provide a "control" as seen in Figure 4. A more dramatic result came by using the Nod & Shuffle technique with GMOS on Gemini South, which produced a spectrum from light echoes still resonating over 400 years after a star exploded and creating what is now known as SNR 0509-67.5 in the Large Magellanic Cloud. The spectrum (Figure 5) revealed beyond any reasonable doubt that this was a Type Ia event.

The study of supernovae has proven extremely well-matched to Gemini's capabilities. Demand for Target of Opportunity observations of newly exploded stars continues to run high, as these data help answer questions about how and why they explode. The study of supernovae might someday even lead to an understanding of the mysterious dark energy and even the ultimate fate of our universe.

References:

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