Supernova Searches

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Abstract Supernovae are extremely bright stellar explosions that sometimes outshine the integrated light of the parent galaxies. The physics of their explosions and the variety of supernova types present fascinating problems in stellar evolution, and their intrinsic luminosity makes them useful probes of cosmology. Searches for supernovae are currently underway by both amateur and professional astronomers using telescopes that range from a few inches' aperture to 10 meters. Of special interest are two groups, the High-z Supernova Search Team and the Supernova Cosmology Project, which discover and study supernovae that exploded when the Universe was half its present age.

1. Introduction

Supernovae are the ultimate variable stars. Type Ia explosions are thermonuclear detonations of lowly white dwarfs. Over two weeks their brightness can rise by more than twenty magnitudes—a factor of ten million. These exploding stars are easily seen in small telescopes as far away as the Virgo cluster of galaxies, and if we were lucky enough to have one go off in our Milky Way, the supernova would be easily visible during the day.

Somewhere in the Universe a supernova explodes every second. While this sounds encouraging to the would-be supernova discoverer, it translates into roughly one supernova per galaxy per century. It has been three hundred years since the last supernova was seen in our Milky Way, so the odds of finding one event are slim unless the equivalent of hundreds of Milky Ways are searched. Yet there are exceptions. Berlind and Garnavich (1997) discovered SN 1997W in NGC 664 less than three arcseconds from a fading SN 1996bw in NGC 664 uncovered two months earlier. While accidental discoveries are fun, it takes the hard work of a systematic search to achieve a scientifically useful result.

2. Local searches

Local supernovae range in distance from inside our Milky Way out to redshifts of a few hundredths ($z < 0.03$). While searching for supernovae in the Milky Way can be as simple as a naked-eye check for new bright stars, there are more sophisticated and thorough methods available. Type II (and Ib, Ic) supernovae are massive stars that have run out of energy in their centers and can no longer support themselves against gravity. When the core collapses, it releases a huge number of neutrinos in a few seconds. Neutrinos are weakly interacting particles which easily pass through the Earth without being stopped, so they are notoriously hard to detect. Yet detectors to search for neutrinos from the nuclear reactions in the Sun have been built, generally underground to prevent other particles from confusing the signal. Some of these experiments detected a handful of neutrinos from the collapsing core of SN 1987A in the Large Magellenic Cloud before the event was discovered at optical wavelengths. Since then, physicists have realized that by combining efforts, their neutrino experiments form a very sensitive core-collapse supernova detector (K. Scholberg 1997, private communication) which may someday announce a Galactic supernova before it becomes visible optically.

There are a number of ongoing systematic searches for supernovae in nearby galaxies. One of the most successful is the Beijing Astronomical Observatory (BAO) search, which discovered a significant number of explosions in 1997. An automated search by a group at Berkeley (and the Katzman Automatic Imaging Telescope, or KAIT) had been out of action for some time, but has begun to produce new events. And there are a large number of dedicated amateurs using CCDs or eyeballs to discover nearby supernovae. R. Evans, W. Johnson, B. Wren, S. Pesci, M. Armstrong, and many others have been very productive in their searches.

The science that can be derived from this work is enormous. Very little is known about supernovae light curves and spectra before maximum. The key is to discover the events early while the flux is still on the rise. This requires constant coverage of many thousands of galaxies. If done carefully, nearby searches can be used to estimate the local supernova rate. But for a rate to be calculated, complete records must be kept of all the galaxies searched and the magnitude limit of the non-detection. Finally, the distances to nearby supernovae can be calibrated using distance indicators such as Cepheid variables. This links the Galactic distance scale to the cosmic scale and allows the estimate of such cosmological parameters as the Hubble constant. Currently there is only a handful of known supernovae in galaxies with measured Cepheids, but searches for local supernovae can fix this problem.

3. Distant searches

Beyond $z \sim 0.03$, even the most energetic supernovae are difficult to spot using a small telescope. Large telescopes have small fields of view, which means few galaxies can be searched in any single CCD exposure. Thus, there are few organized searches for $0.03 < z < 0.3$, and the ones that attempt it use very wide-field instruments. For many years one of the most successful programs was by C. Pollas using a Schmidt telescope and photographic film, but this search ended due to lack of funds. The Mt. Stromlo Abell Cluster Search (Reiss *et al.* 1998) and the European EROS collaboration (http://eros.in2p3.fr) are both using systems designed to find Galactic gravitational lensing events to search for supernovae in this troublesome range. With improved computer technology and the increasing size of CCD detectors, there are plans for additional searches at $0.03 < z < 0.3$.

4. High-redshift searches

At very faint magnitude limits ($m \gtrsim 22$), supernova searches become efficient because many galaxies can be seen in a single deep CCD exposure on a large telescope. Five to ten supernovae per night can be found using a 4-m aperture telescope and a large area detector. Two groups, the High-*z* Supernova Search Team (Garnavich *et al.* 1998) and the Supernova Cosmology Project (Perlmutter *et al.* 1997) have set out to discover events at $z > 0.3$. Their efforts have been very successful, with about 200 supernovae discovered over the past three years, and these high-z searches are the primary reason why there were a record 163 supernovae reported in 1997 (compared to 92 in 1996 and 57 in 1995; see Figure 1). These efforts have also found the most distant supernovae known, with $z \sim 1$.

The High-*z* searches require observing the same fields more than three weeks apart and subtracting the images using sophisticated software that matches seeing, background, and flux levels between the epochs. What should remain after this process are the objects that have changed in some way: asteroids, variable stars, active Galactic nuclei (AGN), and supernovae (Figure 2). Asteroids are very numerous at these magnitude limits, but can be identified by their motion if multiple images of each field are taken on the same night. Distinguishing supernovae from AGNs and other variables is more difficult. Spectra are generally taken to confirm the identification as well as measure a redshift and attempt to figure out the type of supernova.

Why work so hard to find and study these distant events? The Hubble constant describes the current expansion rate of the Universe, but by comparing the brightnesses and redshifts of nearby and distant Type Ia supernovae, it is possible to see if the rate of expansion has changed over cosmic time. At $z \sim 1$, the Universe was half its current age, and between then and now the deceleration of the expansion should be detectable from accurate measurements of the distances and redshifts of supernovae. The deceleration rate is a direct measure of the total matter density of the Universe, since it is the gravitational pull of the matter which is slowing the expansion (Figure 3). Thus, supernovae provide a direct measurement of some of the basic characteristics of the Universe.

Early results suggest very little deceleration over the past seven billion years and therefore insufficient matter in the Universe to reverse the expansion. There is some danger involved in coming to this conclusion, however. If dust or properties of Type Ia supernovae have evolved between $z = 1$ and the present, then the distances measured from the supernovae are unreliable. Currently there is no evidence for evolution in the supernovae or in the dust extinction. But more work on understanding both the High-*z* supernovae and nearby events is needed to place the cosmological observations on firm ground.

5. Conclusions

The number of organized searches for supernovae by professional and amateur astronomers is at an all-time high, resulting in record numbers of reported discoveries. Important scientific problems in stellar astronomy and cosmology can be addressed by the systematic discovery of supernovae at all redshifts. This is a field in which amateur astronomers can make useful contributions.

6. Addendum, 2006

A year after the AAVSO meeting in Sion, the High-z Supernova Search Team and the Supernova Cosmology Project analyzed a larger sample of distant supernovae than shown here. The two groups found that the universe appears to be *accelerating*, rather than decelerating, due to an unknown Dark Energy. Continued high-redshift supernova discoveries and observations of the cosmic microwave background confirm that the universe is dominated by this mysterious Dark Energy component.

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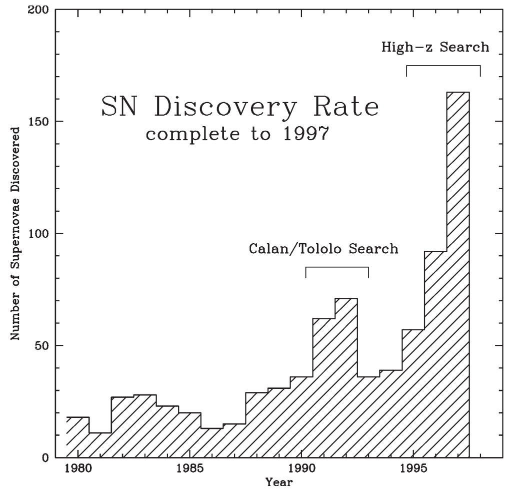

Figure 1. The discovery rate of all supernovae between 1980 and 1997 from the International Supernova Network (http://www.supernovae.net/isn.htm). The average number of events discovered by amateur astronomers is about five per year, but twenty were found in 1996. The Calan/Tololo Survey (Hamuy *et al.* 1996) was a collaboration of Chilean astronomers that was very successful in finding supernovae in the early 1990s.

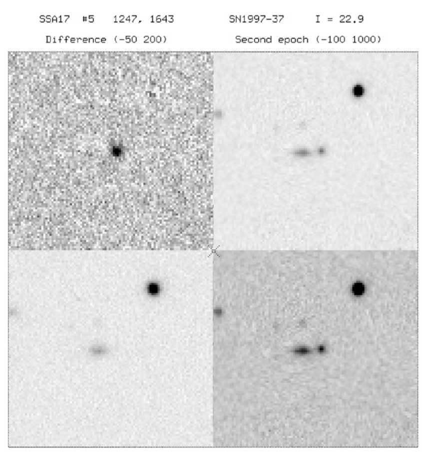

Figure 2. The discovery images of SN 1997cd at a redshift of 0.51. The lower left panel shows the "template" image taken three weeks before discovery. The two panels on the right show the discovery image at two contrast levels. The upper left panel displays the difference between the two epochs, and clearly shows the galaxy and foreground stars subtracted away and the presence of the supernova.

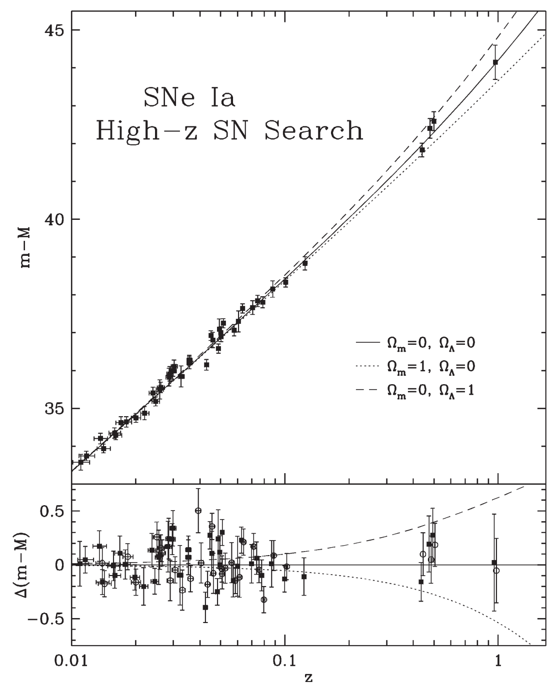

Figure 3. The supernova Ia Hubble diagram (distance as *m–M* versus redshift *z*) extending to nearly $z = 1.0$ from Garnavich *et al.* (1998). The many low-redshift supernovae define the zero point (Hubble constant and Type Ia absolute magnitude), so that measuring the brightness of the High-*z* events provides a direct estimate of how the expansion rate has changed. The lower panel shows the deviation of the supernovae magnitudes from a model Universe with no matter (Ω_m) or vacuum energy (Ω_Λ). The two types of symbols indicate the different magnitudes derived from two methods for correcting for the light curve decline rate in Type Ia events.