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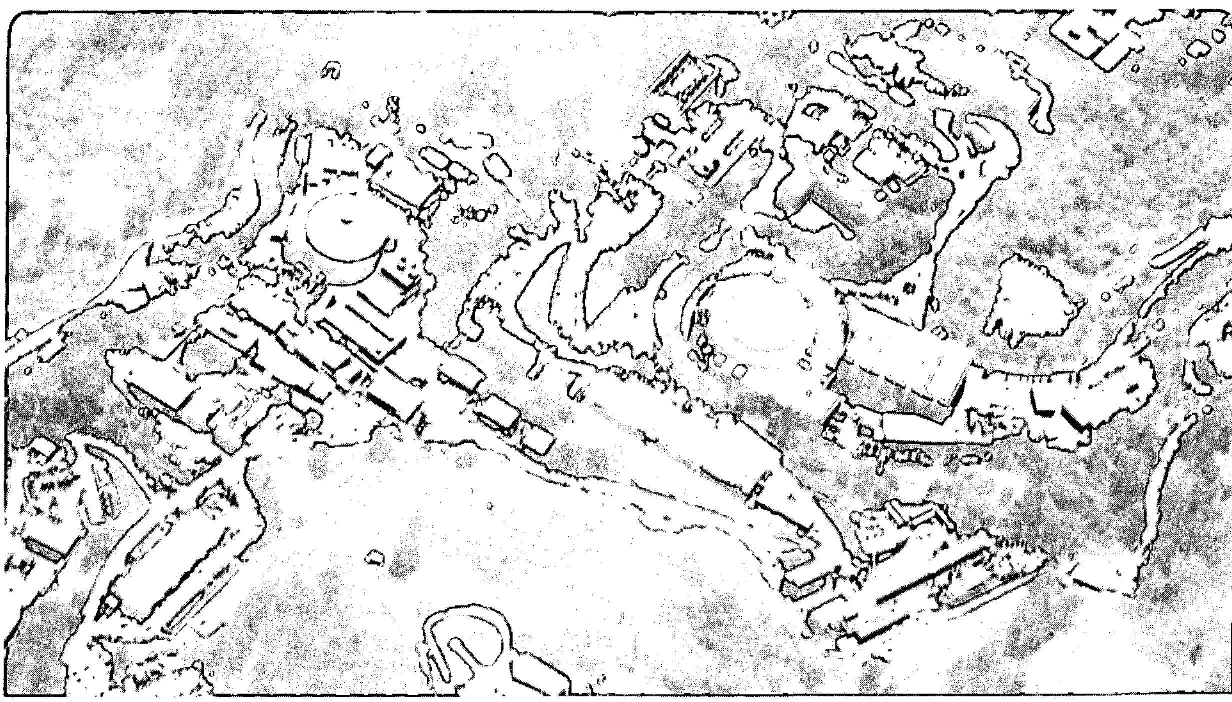

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Preliminary Estimates of Core-Collapse Supernova Rates from the Berkeley Automated Supernova Search

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Abstract

Over the last few years, the Berkeley Automated Supernova Search has discovered 19 supernova. We present here preliminary measurements of supernova rates from a subset of these supernovæ, which were found from a sample of well-monitored galaxies. Two effects are apparent: a surprising number of the supernovæ are Type Ic supernovæ, and most (17 out of 19) of the supernovæ are in late spiral galaxies. Less luminous supernovæ may still be escaping our attention. If the Milky Way galaxy is a late spiral, the core-collapse supernova rate (i.e. for supernovae of types II, Ib, and Ic) should be at least one supernova every 44 ± 9 years (assuming H = 75 km/sec/Mpc). A crude estimate of the core collapse supernova rate in Sc and Sbc galaxies within 5 Mpc would be one supernova every 7 years. These rates have important implications for the design of supernova neutrino, gamma-ray, and gravity-wave detectors. Plans have been developed to extend our search to a better site with more sensitivity to understand the true core-collapse supernova rate in nearby galaxies.

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I. The Experiment

Over the last decade, based on ideas of Stirling Colgate (see Colgate, et al., 1975), we have developed the capability to search over 600 galaxies per night for supernovæ. Our limiting magnitude in the present prototype site is between 16th and 17th visual magnitude. The automated search system is described elsewhere (see Kare et. al., Pennypacker et. al, and Perlmutter et al.) and consists of an computer-controlled telescope, a Charge-Coupled-Device Camera (CCD), and computers for real-time image analysis. About thirty person-years of software development have gone into bringing this system to its present state, five miles from the Berkeley campus. This system has continuously evolved in the degree of automation since its inception, and now functions without an operator at the telescope. Candidate images are shipped over a network back to the lab, and inspected by a physicist in the morning.

One of the strengths of our system is that we can find relatively dim supernovæ, at any phase of the moon, often obscured by the background galaxy light. We have found 19 supernovæ since 1986, but in the rates discussed in this paper are only from the supernovæ found since 1988, when the automated system with a data-base came on line. We take exposures of about one minute. This exposure length is a compromise between different goals of the experiment: we want to discover under-luminous nearby events; we want to find bright, distant Type Ia supernovæ (easily seen at 7500 km/sec); and we want to come back to galaxies as quickly as possible to catch the supernova and watch its evolution. As discussed in the next section, the evolution of the spectrum of these events has made an important change in our understanding of supernova classifications. A more detailed exposition of the results of the search will be presented in a forthcoming paper (Muller et al.).

II. Background

Historically, research has identified Type II supernovæ (classified by the presence of hydrogen in the optical spectra) as core collapse supernovæ, and Type I supernovæ as thermonuclear-driven supernovæ. This simple description has been greatly complicated by the identification of sub-classes of Type I's (Ib's and Ic's), which may be core-collapses. Type Ib's and Ic's (which we shall collectively refer to as type Ibc) are characterized by forbidden oxygen and calcium lines. For example, one supernova discovered by our group (SN1987K) was observed by Alex Filippenko to transform from a Type II (with hydrogen lines) to a Type Ic. The general belief in the community is that Type Ic supernovæ are core collapse events. It has long been known (e.g, see Baade, 1941) that Sc galaxies have more supernovæ.

Supernova	galaxy	galaxy class	IAU circular	date	type	m_{CCD}
1986I	NGC 4254	Sc	4219	5/17	II	14
1986N	NGC 1667	Sc	4287	12/11	Ia	15
1986O	NGC 2227	Scd	4298	12/24	Ia	14
1987K	NGC 4651	Sc	4426	7/28	II→Ic	15
1988H	NGC 5878	Sb	4560	3/3	II	15.5
1988L	NGC 5480	Sc	4590	5/3	Ic	16.5
1989A	NGC 3687	Sbc	4721	1/19	Ia	15.3
1989B	NGC 3627	Sb	4726	1/30	Ia	12
1989L	NGC 7339	Sbc	4791	6/1	II	16
1990B	NGC 4568	Sbc	4949	1/20	Ic	16.0
1990E	NGC 1035	Sc	4965	2/15	II	16.7
1990H	NGC 3294	Sc	4992	4/9	II	16.5
1990U	NGC 7479	Sc	5063	7/28	Ic	16
1990aa	UGC 540	Sc	5087	9/4	Ic	17
1991A	UGC 6872	Sc	5153	1/2	Ic	17
1991B	NGC 5426	Sc	5163	1/12	Ia	16
1991G	NGC 4088	Sbc	5188	3/11	II	17
1991M	IC 1151	Sc	5207	3/13	Ia	16.7
1991N	NGC 3310	Sc	5227	3/30	?	15

Table I

Table caption: Supernova discovered by the Berkeley team. (SN1989B and 1991G were first found by other groups, but were discovered independently by our system.) The first column lists the supernova designation; the second column the parent galaxy, the third column the galaxy Hubble classification, the fourth column the IAU circular where the supernova discovery was announced, the fifth column the discovery date, the sixth column the type of supernova, the seventh column the observed apparent "CCD" magnitude (m_{CCD} is an uncalibrated combination of V and R photometric bands) at discovery (not peak magnitude).

III. The Discoveries

Every clear night we observe galaxies from our reference galaxy list. Although our search list includes galaxies out to recession velocity of 7500 km/sec (=100 Mpc for H=75), we begin to lose our sensitivity to Type Ic supernovæ at a distance of about 12 Mpc. The discovered supernovæ, the galaxy information, and other parameters are shown in Table I. The absolute (intrinsic) magnitude of the supernova plays an important role of how distant we would see it. For example, a Type Ia supernova in the nearby Virgo cluster of galaxies of absolute magnitude –19 yields about 12.5 apparent magnitude supernova at earth. However, we have found Type Ic supernova closer than Virgo 100 times fainter than this, which are near our magnitude limit of about 16th to 17th magnitude. We believe this indicates we are beginning to sample a previously unmeasured part of the supernova luminosity function.

IV. Preliminary Lower Limit on the Supernova Rate

The calculation of the supernova rate depends on the survey period of galaxies and the number of supernova detected. We are in the process of carefully calculating the the exact survey period for our sample of galaxies, and regard our rates as preliminary Given our current estimate of survey period, and the fact we have seen three Type II supernovæ in the Sc/Sbc galaxies, and five Ib-c supernovæ, we find there is one core-collapse supernova per every (42 ± 9) years x h^2 per 10^{10} L_{sun}. This number is different than that in Muller et al., since Type Ia's have been subtracted from the rate. We may be missing dimmer Type II's and Type Ic's, because of the Type Ic and Type II low luminosity. Hence this rate is a lower limit, and the true core-collapse supernova rate may be higher.

V. Interpretation

As initially pointed out by Becklin (1991), nearby bright infrared galaxies, produce many of the nearby, albeit cloaked in dust, supernovæ. As mentioned previously, we do not yet have sufficient data to understand the distribution in absolute luminosities of our supernovæ, but we have some evidence that there are low luminosity Type Ic events. For example, one of our events, SN1990B, had its apparent magnitude measured by Sturch, et. al, (1990), and when combined with the Tully-Fisher distance to that galaxy, is found to have an absolute magnitude of -13.3 (This supernova's magnitude was photometrically measured within a week of estimated maximum light.) This is about a factor of one-hundred times dimmer than the "standard" Type Ia supernova, and is barely detected at 12 Mpc.

Given our results on external galaxies, with an assumption of the morphological type and luminosity of the Milky Way, we can compute a Milky Way core collapse rate. The morphological type of the Milky Way galaxy is either Sbc (Hodge, 1983) or Sb (King, 1990). Assuming a luminosity of 1.7×10^{10} L_{sun}, (King, 1990), and assuming the Milky Way is an Sbc galaxy, we calculate one core-collapse supernova at least every 44 ± 9 years. Using luminosities for nearby galaxies from the Tully-Fisher galaxy catalog, we find for late spirals within 5 Mpc about 13 L_{10} blue luminosities. Using our rate and h = 0.75, we expect one supernova about every 7 years or so, although we emphasize that there are substantial uncertainties in this value. Most of the supernovae that we discover are near our limiting magnitude, and so there is a possibility that the rate is substantially higher. The supernova rate in these nearby galaxies is important for other detectors (neutrino and gravity wave) that have some chance of detecting supernovae. A new telescope has has been designed and partially completed by our group at Berkeley for installation at an improved site. This system can extend our sensitivity by several magnitudes, and determine whether there are additional supernovae beyond our present threshold.

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