Supernovae in Galaxy Clusters

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Summary. We present the results of several surveys for supernovae (SNe) in galaxy clusters. SNe discovered in deep, archival *HST* images were used to measure the cluster SN Ia rate to $z = 1$. A search for SNe in nearby ($0.06 \leq z \leq 0.2$) Abell galaxy clusters yielded 15 SNe, 12 of which were spectroscopically confirmed. Of these, 7 are cluster SNe Ia, which we will use to measure the SN Ia rate in nearby clusters. This search has also discovered the first convincing examples of intergalactic SNe. We conclude with a brief description of ongoing and future cluster SN surveys.

1 Introduction

This contribution describes our observational studies of SNe in galaxy clusters. The motivation to search for SNe in the fields of rich galaxy clusters is discussed in a contribution by Maoz et al. (this volume), and more fully by Gal-Yam, Maoz & Sharon [1] and Maoz & Gal-Yam [5].

Observationally, SN searches in galaxy clusters were pioneered in the late 1980's by Norgaard-Nielsen et al. [6], resulting in the first detection of a $z = 0.31$ SN in the galaxy cluster AC118. More recently, low-redshift clusters have been monitored for SNe by the Mount Stromlo Abell Cluster SN Search [7]).

We present below the results from several surveys for SNe in galaxy clusters we have carried out using both ground-based telescopes and the Hubble Space Telescope (*HST*).

2 The SN Rate in High-z Clusters from HST

We have conducted a survey for high redshift SNe in deep *Hubble Space Telescope* archival images of nine galaxy clusters. Six apparent SNe are detected (Fig. 1), with $21.6 \leq I_{814} \leq 28.4$ mag. Two SNe are associated with cluster galaxies (at redshifts $z = 0.18$ and $z = 0.83$), three are probably in galaxies not in the clusters (at $z = 0.49$, $z = 0.60$, and $z = 0.98$), and one is at unknown z. After accounting for observational efficiencies and

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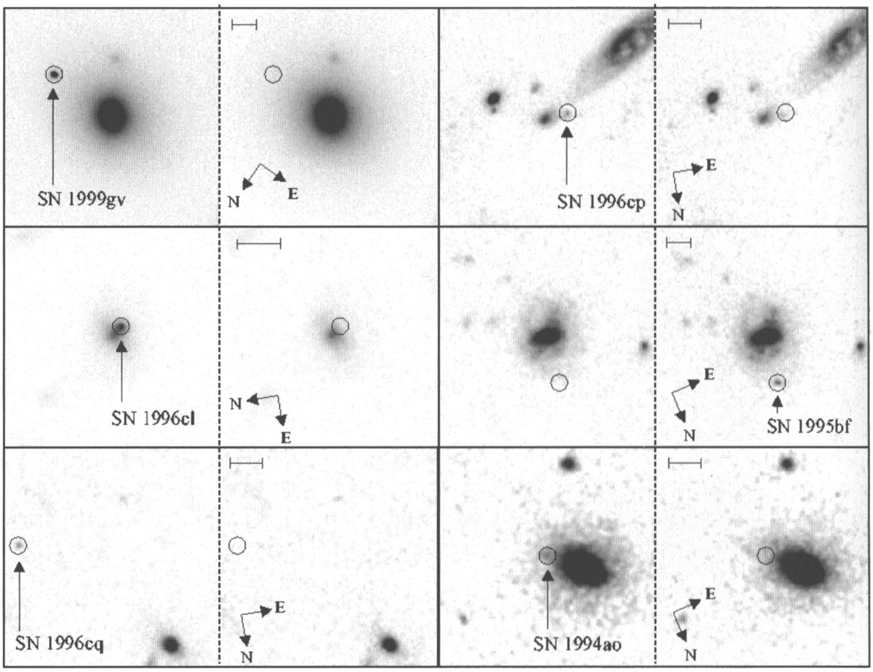

Fig. 1. Sections of the images, at two epochs, for each of the six apparent SNe discovered in our *HST* cluster survey. The scales shown in the upper-left-hand corners correspond to $1''$.

uncertainties (statistical and systematic) we derive the rate of type-Ia SNe within the projected central $500h_{50}^{-1}$ kpc of rich clusters: $R = 0.20^{+0.84}_{-0.19}h^2_{50}$ SNu in $0.18 \leq z \leq 0.37$ clusters, and $R = 0.41^{+1.23}_{-0.39}h^2_{50}$ SNu in clusters at $0.83 \leq z \leq 1.27$ (95 per cent confidence interval; 1 SNu $\equiv$ 1 SN century^{-1} per $10^{10}L_{B\odot}$). Combining the two redshift bins, the mean rate is $R_{\bar{z}=0.41} = 0.30^{+0.58}_{-0.28}h^2_{50}$ SNu.

We also compare our observed counts of field SNe (i.e., non-cluster SNe of all types) to recent model predictions. The observed field count is $N \leq 1$ SN with $I_{814} \leq 26$ mag, and $1 \leq N \leq 3$ SNe with $I_{814} \leq 27$ mag. These counts are about two times lower than some of the predictions. Since the counts at these magnitudes are likely dominated by type-II SNe, our observations may suggest obscuration of distant SNe II, or a SN II luminosity distribution devoid of a large high-luminosity tail. Further details are presented by Gal-Yam, Maoz & Sharon [1]. Additional archival SNe from *HST*, providing significantly stronger constraints on the properties of high-z SNe, are discussed in a contribution by Sharon, Gal-Yam & Maoz (these proceedings).

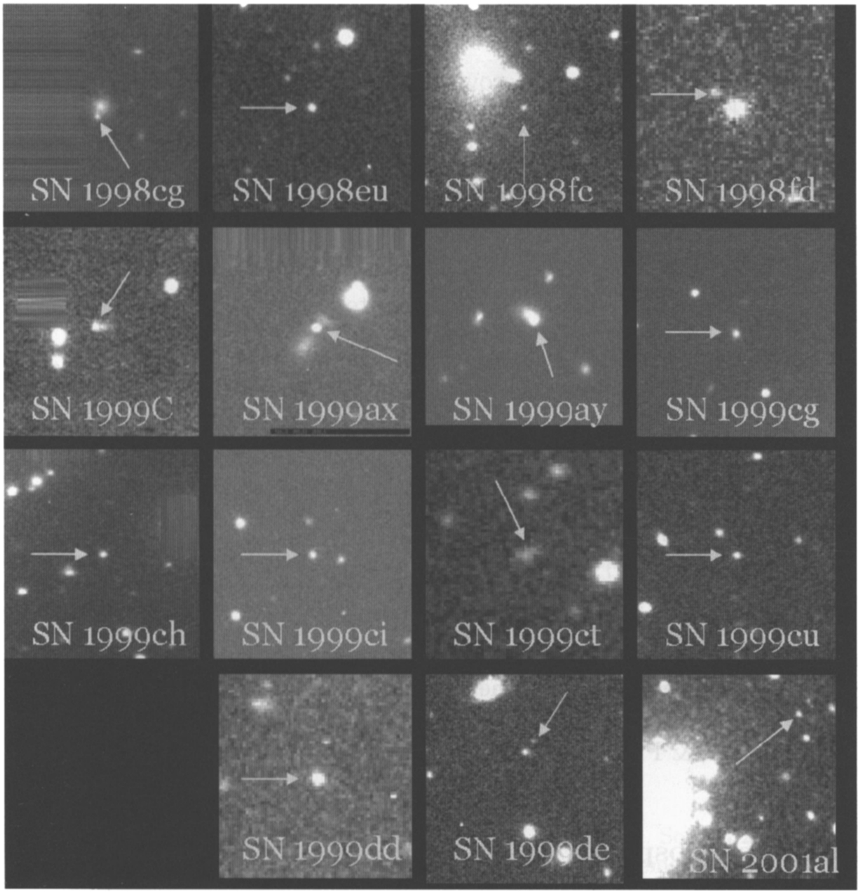

Fig. 2. Images of the 15 supernovae discovered by WOOTS.

3 WOOTS: A Survey for SNe in $0.06 < z < 0.2$ Clusters

3.1 Cluster SN Rates

The Wise Observatory Optical Transient Search (WOOTS) is a survey for SNe in the fields of $0.06 \leq z \leq 0.2$, rich Abell galaxy clusters using the Wise 1 m telescope. 15 SNe were discovered (Fig. 2), and for 12 of these we obtained follow-up spectroscopy. Seven SNe turned out to have occurred in cluster galaxies, while five are field events. 11 of the events (including all cluster SNe) are apparently SNe Ia, and many were discovered near maximum light. The cluster SN sample is suitable for the calculation of the SN rate in clusters (Gal-Yam & Maoz, in preparation).

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3.2 Intergalactic SNe

Of the seven cluster SNe Ia discovered in the course of WOOTS, two SNe, 1998fc in Abell 403 ($z = 0.10$) and 2001al in Abell 2122/4 ($z = 0.066$), have no obvious hosts. Both events appear projected on the halos of the central cD galaxies, but have velocity offsets of 750-2000 km s^{-1} relative to those galaxies, suggesting they are not bound to them. Deep Keck imaging of the locations of the two SNe are used to put upper limits on the luminosities of possible dwarf hosts, $M_R > -14$ mag for SN 1998fc and $M_R > -11.8$ mag for SN 2001al. The fractions of the cluster luminosities in dwarf galaxies fainter than these limits are $< 3 \times 10^{-3}$ and $< 3 \times 10^{-4}$, respectively. Thus, 2/7 of the SNe would be associated with $\leq 3 \times 10^{-3}$ of the luminosity attributed to galaxies. It is argued, instead, that the progenitors of both events were probably members of a diffuse population of intergalactic stars, recently detected in local clusters via planetary nebulae and red giants. Considering the higher detectability of host-less SNe compared to normal SNe, we estimate that 20^{+12}_{-15} percent of the SN Ia parent stellar population in clusters is intergalactic. This fraction is consistent with other measurements of the intergalactic stellar population, and implies that the process that produces intergalactic stars (e.g., tidal disruption of cluster dwarfs) does not disrupt or enhance significantly the SN Ia formation mechanism. Host-less SNe are potentially powerful tracers of the formation of the intergalactic stellar population out to high redshift. Further details can be found in Gal-Yam, Maoz, Guhathakurta, & Filippenko [2].

4 Future Prospects

Measurements of SN rates in clusters out to $z = 1$ provide a powerful and unique tool to probe cluster metal enrichment and the progenitors of SNe Ia (see contribution by Maoz et al., this volume). The results are currently limited by large errors due to small number statistics. It is therefore desirable to obtain additional measurements of SN rates in clusters. The WOOTS cluster SN sample will provide another measured point at $z \sim 0.15$. We have also begun a ground-based survey for SNe in rich, lensing clusters at $z \sim 0.3$, using the 2.5 m NOT telescope at La Palma, Spain. This survey aims to enlarge the number of SNe used to calculate the cluster SN rate in the $z \sim 0.3$ bin (1 SN) by an order of magnitude, and thus to significantly decrease the statistical error. The first results of this survey include the discovery of several cluster SNe (e.g., Fig. 3; Gal-Yam, Maoz, Prada & Guhathakurta [3]) as well as new strong lensing clusters. A similar survey for SNe in high redshift clusters ($z \sim 0.8$) using 4 m class (or larger) telescopes is being planned. With such data, it will be possible to set strong constraints on the origin of iron in the ICM and the characteristic delay time of SNe Ia.

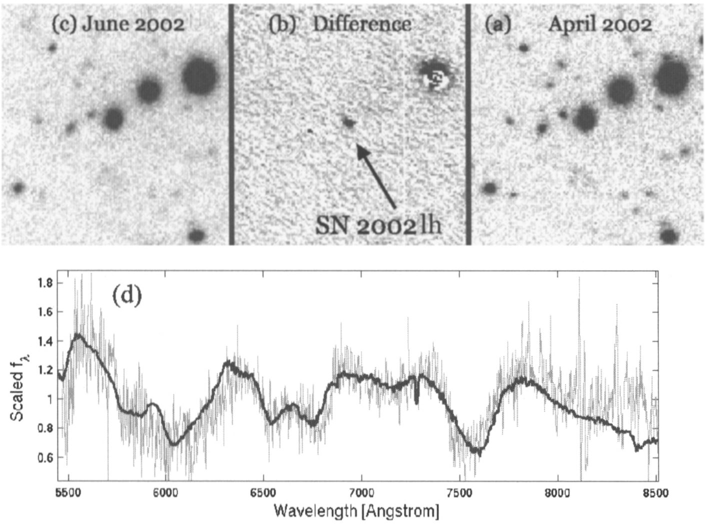

Fig. 3. Subtraction of a NOT image of Abell 1961 (z=0.232) obtained in April 2002 (a) from a similar image obtained in June 2002 (c) reveals SN 2002lh (b). In panel (d) the comparison of the Keck spectrum of this event (light) with a redshifted spectrum of the nearby SN 1999ee near peak magnitude (bold, from Hamuy et al. [4]), reveals this is a SN Ia at z=0.236, i.e., in one of the cluster galaxies.

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