HTML ABSTRACT

Supernova Environments in Hubble Space Telescope Images

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Abstract. The locations of supernovae in the local stellar and gaseous environment in galaxies contain important clues to their progenitor stars. Access to this information, however, has been hampered by the limited resolution achieved by ground-based observations. High spatial resolution *Hubble Space Telescope (HST)* images of galaxy fields in which supernovae had been observed can improve the situation considerably. We have examined the immediate environments of a few dozen supernovae using archival post-refurbishment *HST* images. Although our analysis is limited due to signal-to-noise ratio and filter bandpass considerations, the images allow us for the first time to resolve individual stars in, and to derive detailed color-magnitude diagrams for, several environments. We are able to place more rigorous constraints on the masses of these supernovae. A search was made for late-time emission from supernovae in the archival images, and for the progenitor stars in presupernova images of the host galaxies. In particular, we highlight the results for the Type II SN 1979C in M100. In addition, we have identified the progenitor of the Type IIn SN 1997bs in NGC 3627. We also add to the statistical inferences that can be made from studying the association of SNe with recent star-forming regions.

INTRODUCTION

A primary goal of supernova (SN) research is an understanding of the progenitor stars and explosion mechanisms of the different SN types. Unfortunately, a SN leaves few traces of the star that underwent the catastrophic event. Unambiguous information can be derived if the progenitors can be directly identified in pre-explosion images, but to date this has been possible only for SNe 1987A, 1961V, 1978K, and 1993J. In the absence of direct information about the progenitors, scrutiny of the host galaxies and local stellar and gaseous SN environments, in favorable cases, yields useful constraints on progenitor ages and masses. However, previous studies have been hampered by the limited spatial resolution of ground-

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based observations. The superior angular resolution of the *Hubble Space Telescope* (*HST*) offers the potential for greater understanding of SN environments.

ARCHIVAL DATA AND PHOTOMETRY

An investigation using *HST* archival data was begun, to (1) study the stellar populations in the immediate SN environments in cases where individual stars or clusters are resolved, and to use this information to help constrain the progenitor star age and mass; (2) search for progenitor stars in images taken prior to SN explosions; (3) search for old visible SNe; (4) augment ground-based data on the statistical association of the different SN types with star-forming regions; and (5) measure magnitudes for SNe observed "accidentally" while still bright.

Van Dyk et al. [1,2] report on WFPC2 results for the environments of 12 SNe II, 5 SNe Ib/c, and 16 SNe Ia. Although *HST* images offer the tremendous advantage of higher angular resolution over similar ground-based data, the images were almost exclusively obtained for other purposes. Limitations include small field of view, images underexposed at the SN sites, and images made through only one filter.

When possible, we employed PSF-fitting DAOPHOT photometry, using Tiny Tim PSFs [3]. To determine uncertainties, we tested with artificial stars of known brightnesses. Count rates were converted to magnitudes using either the synthetic photometric zeropoints from [4] or [5]. We analyze resulting color-magnitude diagrams with theoretical isochrones for solar metallicity from [6]. Where no resolved stars are apparent, we performed aperture photometry, providing a larger-scale measurement of magnitude, and where possible, color.

The problem of overall uncertainty in SN positions is particularly severe for *HST* images. We performed careful verification of the image astrometry, which, in "coarse" or "gyro" mode, can be grossly in error. Despite $\leq 1''$ SN position accuracy, *HST* astrometry is good to $\lesssim 1''\!.5$–$2''$. We assign an estimated error centered on the nominal SN position and regard the error circle as the SN environment. Even with the relative lack of precision, the fine image detail afforded by *HST* in many SN environments provides unprecedented information about SN progenitors.

RESULTS AND CONCLUSIONS

For the first time, through deep multicolor imaging, undertaken, in particular, by the *HST* Cepheid projects, we have been able to produce color-color and color-magnitude diagrams for several SN environments, providing constraints on the ages and masses of stellar populations associated with the SNe, and allowing us to indirectly infer the ages and masses of the SN progenitors, for, e.g., SNe 1940B, 1983V, 1987K, and, 1988M. From archival and GO images of the Type II SN 1979C environment in M100 (Figure 1), Van Dyk et al. [2] were able to rigorously constrain the SN progenitor initial mass, to $M \approx 17$–$18\ M_{\odot}$.

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We may have identified the stellar progenitor of SN 1997bs, clearly visible on a pre-SN *HST* image of NGC 3627 (Figure 2), as a luminous supergiant star with $M_V \simeq -7.4$ mag. (However, SN 1997bs may be an η Car-like superoutburst, like SN 1961V.) This would be only the fifth SN progenitor to ever be identified in pre-explosion images.

We have recovered the old Type II SNe 1979C, 1986J, and possibly 1981K, as expected, since these have shown evidence of interaction with circumstellar gas. From GO multi-band imaging obtained 17 years after explosion, we recover SN 1979C at, e.g., $m_{\mathrm{F439W}} = 23.37$ ($m_B[\mathrm{max}] = 11.6$ mag). Additionally, the Type Ia SN 1994D was caught "by accident" in *HST* images, adding to its existing ground-based light curves.

The colors of the diffuse emission in Type Ia SNe environments indicate that the stellar populations are generally old and red, consistent with red giants, although four SN environments contained bright clusters and H II regions.

The five Type Ib/c SNe appear more closely associated with brighter, more massive stellar regions than do the Type II SNe, contrary to the ground-based results [7], suggesting that the Type Ib/c SN progenitors may be more massive, in general, than Type II SN progenitors.

We will continue to acquire images of SN environments and will build on the current study in future papers.

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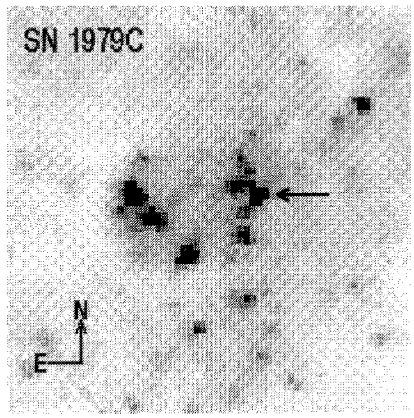

FIGURE 1. *HST* WFPC2 F555W image of the stellar environment of SN 1979C in M100. The arrow points to the SN.

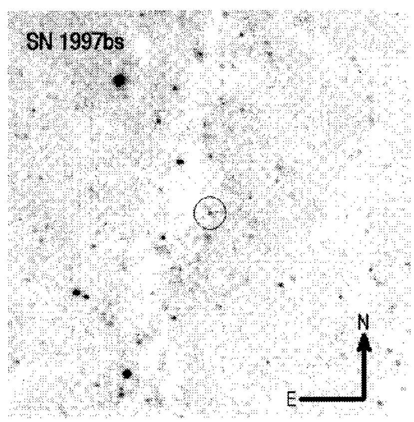

FIGURE 2. *HST* WFPC2 F606W image of the stellar progenitor of SN 1997bs in NGC 3627 (within circle).

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