**Hubble Space Telescope WFPC2 Imaging** of SN 1979C and Its Environment

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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. As part of a program to study the environments of supernovae using *Hubble Space Telescope* imaging data, we have examined the environment of the Type II-L supernova SN 1979C in NGC 4321 (M100). We place rigorous constraints on the mass of the SN progenitor, based on photometry of the stellar populations in its environment. The progenitor may have had an initial mass $M \approx 17-18(\pm 3) M_\odot$. Moreover, 17 years after explosion we have recovered and measured the brightness of SN 1979C in several bands, e.g., $m = 23.37$ in F439W [$\sim B$; for comparison, $m_{B}(\text{max}) = 11.6$].

**1. INTRODUCTION**

A primary goal of supernova research is an understanding of the progenitor stars and explosion mechanisms of the different types of supernovae (SNe). In the absence of direct information about the progenitor stars, scrutiny of the host galaxies and local environments of SNe continues to yield valuable clues to their nature. Previous ground-based studies of SN host galaxies and environments have primarily concentrated on statistical results. Investigation of the local stellar and gaseous environments of SNe can, in favorable cases, yield useful constraints on the ages and masses of progenitor stars. However, most studies of this kind have been hampered by the limited spatial resolution of ground-based observations. The superior angular resolution of the *Hubble Space Telescope (HST)* offers the potential for a greater understanding of SN environments.

Presumably caused by the core collapse of massive stars, Type II SNe (SNe II) have been associated with a young stellar population (see, e.g., Van Dyk 1992). SNe II all exhibit hydrogen in their optical spectra, but the strength and profile of the H$_\alpha$ line vary widely among these objects (see, e.g., Schlegel 1996). At late times, SNe II are dominated by the strong H$_\alpha$ emission line. Photometrically, SNe II are subclassified into “plateau” (SNe II-P) and “linear” (SNe II-L), based on the shape of their light curves (Barbon, Ciatti, & Rosino 1979; Doggett & Branch 1985; Patat et al. 1994). As part of a larger survey of SNe environments using...
SN 1979C was discovered on 1979 April 19 by Johnson (1979) at around magnitude 12. Optical spectra first showed a featureless continuum, which later evolved to exhibit strong Hz emission, but with weak or no P Cygni absorption (Panagia et al. 1980; Branch et al. 1981; Barbon et al. 1982; Schlegel 1996). Photometrically, SN 1979C was quite blue near maximum [Patat et al. 1994; maximum occurred on or about 1979 April 15, at \( m_\text{B}(\text{max}) = 11.6 \); de Vaucouleurs et al. 1981] and declined in brightness in a way characteristic of SNe II-L (see, e.g., Barbon et al. 1982). The SN was also extraordinarily luminous, at \( M_\text{B}(\text{max}) \approx -20 \) (see, e.g., Young & Branch 1989), making it the brightest SN II yet observed.

SN 1979C is also a bright late-time radio source (Weiler et al. 1986, 1991). The radio sphere of the SN was resolved by VLBI observations (Bartel et al. 1985). Weiler et al. (1991) showed that its radio emission is consistent with a red supergiant progenitor star that initially had a mass \( \gtrsim 13 M_\odot \). Periodic undulations in the evolution of the radio emission led Weiler et al. (1992) to model the progenitor as possibly being in a detached eccentric binary system with a less massive companion, similar to the VV Cepheii systems. Hydrodynamical simulations by Schwarz & Pringle (1996) confirm that this binary system model is feasible for SN 1979C. The radio emission has been declining in a relatively normal fashion, until, after almost two decades, it has ceased declining and may be rising again at all radio frequencies (Montes et al. 1999).

According to the Chevalier (1982) scenario, the radio emission is best modeled as the interaction of the SN shock wave with relatively high density circumstellar matter, set up by a constant mass-loss rate, constant velocity wind from the red supergiant progenitor. Chevalier & Fransson (1994) have shown from hydrodynamical considerations for SN 1979C that X-ray radiation from the SN shock front can be absorbed by a shell formed via radiative cooling at the reverse shock. This gives rise to a low-ionization optical spectrum in the ejecta and in the shocked shell, while high-ionization lines are formed in the freely expanding SN ejecta. This implies late-time optical emission at Hz, [O I], [O III], and other lines. Fesen & Matonick (1993) from the ground, and Fesen et al. (1999) with \( HST \), have indeed observed strong late-time line emission in the optical and UV and interpret this as the result of the SN shock–circumstellar gas interaction.

The site of SN 1979C was imaged on two sets of \( HST \) data we have analyzed, with details of the separate analyses provided below. Based on its radio position (Weiler et al. 1991), Van Dyk et al. (1996) found this SN to be associated with a faint H II region of radius 1.5\', situated below the bright southern spiral arm in M100 (see also Fesen & Matonick 1993). From the \( HST \) images, the SN is seen to have occurred in or near a small cluster of stars, some of which presumably contribute to the ionization of that H II region. We have also recovered and measured the brightness of the SN in both the broadband and narrowband \( HST \) images obtained in 1996 July, 17 years after explosion.

### 2. ANALYSIS

For the first time, a number of resolved stars are seen in the SN 1979C environment on both sets of \( HST \) images discussed below. We employed point-spread function (PSF) fitting photometry of these stars performed by DAO PHOT (Stetson 1987) and ALLSTAR within IRAF.\(^5\) Stars were located on the images using DAOFIND, with a detection threshold of 3 \( \sigma \), determined by the gain and read-noise parameters for the image. Because of the lack of isolated stars of sufficient signal-to-noise ratio on the images we analyzed, it was impossible to build a good model PSF from field stars on these images. Instead, we employed the Tiny Tim routine (Krist 1995) to produce an artificial PSF. The PSF-fitting photometry resulted in color-magnitude diagrams (CMDs) for the stars in the SN environment.

Throughout this paper we express the magnitudes and colors in the WFPC2 flight magnitude system. To analyze these diagrams, we used the theoretical isochrones for solar metallicity from Bertelli et al. (1994), in order to constrain the ages and masses of the stars. (We have converted the Johnson-Cousins \(UBVRI\) magnitudes and colors for the isochrones into WFPC2 flight system magnitudes and colors, using the transformations given in Table 2 of Van Dyk et al. 1999.) We have assumed the distance modulus to M100 \( (m-M=31.04, \text{ or } d=16.1 \text{ Mpc}) \) measured using Cepheids by Ferrarese et al. (1996).

#### 2.1. \( HST \) Extragalactic Distance Scale Key Project Images

The data obtained from the \( HST \) archive, consisting of 12 F555W and four F814W cosmic-ray–split pairs of images, were originally part of the Extragalactic Distance Scale Key Project (Ferrarese et al. 1996). Details of these observations are given in Table 1.

To take advantage of the very high signal-to-noise ratio made possible by the long exposures, we created images combined in each band from all the individual image sets. Before combining, we first registered the individual images using the cross-correlation method XREGISTER in IRAF, as well as using positions of the brightest stars in each.

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\(^5\) IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
The environment of SN 1979C in NGC 4321 (M100), as seen in a F555W WFPC2 image, summed from the individual images obtained by the HST Key Project. The position of the SN is at the center of the circle, which represents the 1″ radius uncertainty in position. The bright star within the circle is most likely SN 1979C itself (see Fig. 3). Orientation of the image is north up, east to the left.

![Image of SN 1979C](image)

**Fig. 1.** — The environment of SN 1979C in NGC 4321 (M100), as seen in a F555W WFPC2 image, summed from the individual images obtained by the HST Key Project. The position of the SN is at the center of the circle, which represents the 1″ radius uncertainty in position. The bright star within the circle is most likely SN 1979C itself (see Fig. 3). Orientation of the image is north up, east to the left.

**TABLE 1**

Summary of Data for the SN 1979C Environment

| Filter   | Exposure (s) |
|----------|--------------|
| F555W    | 21600        |
| F814W    | 7200         |
| WFPC2-PC1: |             |
| F336W    | 2600         |
| F439W    | 2400         |
| F555W    | 800          |
| F675W    | 1000         |
| F814W    | 1200         |
| F658N    | 3900         |

*a* These data were obtained from the HST Archive.

*b* These images were taken as part of HST program GO 6584.
stars not found on the individual images. The brightest star on the diagram is most likely SN 1979C itself (see § 2.2). We cannot accurately estimate the reddening for this environment from this diagram, but it may be appreciable. Reddening estimates to SN 1979C are $E(B-V) \approx 0.10-0.18$ mag (Panagia et al. 1980; Branch et al. 1981; de Vaucouleurs et al. 1981) and, more recently, $E(B-V) \approx 0.23-0.34$ mag (Fesen et al. 1998; the latter value including possible internal dust absorption). We show in Figure 2 the isochrones from Bertelli et al. (1994) with solar metallicity, reddened by $E(B-V) = 0.15$ mag and adjusted by the distance modulus $m-M = 31.04$, after transforming the isochrones to the WFPC2 flight system colors.

22. HST GO Project 6584 Images

In addition to the Key Project images, the environment of SN 1979C was observed as part of GO Project 6584, whose aim was to study the interaction of SNe with their circumstellar environments. Table 1 lists the details of these observations, which were not nearly as deep as the combined Key Project images, but covered a wider range in wavelength, including the F658N (Hα) narrow band, and also were centered on the PC1 chip, affording higher spatial resolution than the Key Project images. In Figure 3 we show the F555W and F658N images. The arrow in each figure points to what is very likely SN 1979C, which was still optically bright in 1996 July, especially at Hα, consistent with the results of Fesen & Matonick (1993) for 1991 and 1992. The numbering in Figure 3a corresponds to the stars listed in Table 2, for which we provide a comparison with our photometry of the Key Project images discussed above. (The errors for the magnitudes given in Table 2 are the formal errors provided by ALLSTAR.) One can see that the photometry for the two data sets agrees reasonably well; slight discrepancies can be explained in terms of the higher spatial resolution of the GO 6584 images versus the higher signal-to-noise ratio of the Key Project images.

We can measure the Hα line flux from our F658N image in Figure 3b. Using equation (11) in Holtzman et al. (1995) to convert a point-source count rate into flux, we find that the total Hα flux on 1996 July 29 UT for SN 1979C through the F658N filter was $4.7 \times 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$. Fesen & Matonick (1993; see also Fesen et al. 1998) detect a broad-line and narrow-line spectral components at Hα. It is thought that the broad-line flux is produced by the interaction of the SN shock with the presupernova circumstellar matter (Chevalier & Fransson 1994), which is also the source for the radio emission from SN 1979C (Weiler et al. 1991). The unresolved narrow-line component is from the associated H II region, seen by Van Dyk et al. (1996). In the WFPC2-PC1 image the H II emission from this region is seen mostly to the east of the SN (Fig. 3b), and therefore likely contributes very little to the F658N flux. However,
Fig. 3.—The environment of SN 1979C in NGC 4321 (M100), as seen in WFPC2 images obtained as part of GO 6584, in the (a) F555W band and (b) F658N band. The arrow in each figure points to what is likely the SN itself. The numbering on (a) indicates the stars listed in Table 2. Orientation of the image is north up, east to the left.
the broad-line component is broader than the F658N bandpass by a factor \( \sim 5 \). Taking this into account, the flux we derive here agrees with the \( 2.5 \times 10^{-15} \) ergs cm\(^{-2}\) s\(^{-1}\) measured by Fesen & Matonick (1993). Recently, Montes et al. (1998) have found that the radio emission has ceased declining and is possibly rising again. This could lead to an increase in the optical emission-line flux as well.

The photometry was conducted, as above, using an appropriate Tiny Tim PSF in ALLSTAR. For SN 1979C, we find the following filter magnitudes: \( m_{\text{F336W}} = 23.24 \pm 0.09 \), \( m_{\text{F439W}} = 23.37 \pm 0.04 \), \( m_{\text{F555W}} = 22.15 \pm 0.02 \), \( m_{\text{F675W}} = 20.88 \pm 0.03 \), and \( m_{\text{F814W}} = 21.05 \pm 0.04 \); also,
We conclude from both data sets that a noncoeval mixture of young populations exists in the environment of SN 1979C, with very young (~4–6 Myr) blue stars to older (~20 Myr) red supergiants. Most of the stars immediately surrounding the SN appear to be massive main-sequence turnoff stars and a red supergiant star with ages ~10 Myr. If the progenitor of SN 1979C was a member of this population, then its age was also ~10 Myr. Based on the SN’s radio emission (Weiler et al. 1986, 1991), as well as its optical light curve, it is likely that the progenitor was a red supergiant star. Assuming solar metallicity for the models in Bertelli et al. (1994), this implies a mass for the progenitor of ~17–18 $M_\odot$.

We can estimate the error in the mass for the progenitor, resulting from uncertainties in extinction, distance, and in the metallicity of stars in the SN’s environment. We estimate that the extinction uncertainty affects our age estimate by ±2 Myr. The error in the distance modulus to M100 (±0.17 mag; Ferrarese et al. 1996) has a very small effect, at most ±1 Myr. Zaritsky, Kennicutt, & Huchra (1994) show that in M100 the O/H ratio, a measure of metallicity, decreases at large galactocentric radius. An uncertainty in metallicity affects our age estimate the most, by ±4 Myr. All told, we determine that a conservative error in our mass estimate for the SN progenitor, based on the error in the age of the coeval stellar population, is ±3 $M_\odot$.

Nonetheless, our mass estimate is consistent with the constraint on the mass ($\geq 13 M_\odot$) made by Weiler et al. (1991), based on an estimate of the amount of presupernova mass loss. Constraints have been placed on the masses of SN progenitors for other SNe, including 1987A, 1980K, and 1968L, based on the properties of their stellar environments. For SN 1987A in the Large Magellanic Cloud, Romaniello et al. (1999) and Van Dyk, Hamuy, & Mateo (1999) find that the most luminous blue stars in the SN’s environment have ages 10–12 Myr, coeval with the SN progenitor (if the progenitor had mass 19 ± 3 $M_\odot$; Arnett et al. 1989). For the SN II-L 1980K in NGC 6946, Thompson (1982) placed an upper limit of 18 $M_\odot$ on the progenitor mass from a plate taken before explosion. However, this result could be affected by the progenitor being enshrouded in dust and by the large uncertainty in the distance to NGC 6946. For the SN II-P 1968L in M83, Barth et al. (1996) find, based on HST archive data, that its progenitor may have had an initial mass of $\geq 25–30 M_\odot$, if it were coeval with the star clusters in its environment.

This is the first time, however, other than for SN 1987A (Romaniello et al. 1998), that the mass of a SN progenitor has been estimated via the photometry of individual stars in HST images of the SN environment.

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