The Light Echo around Supernova 2003gd in Messier 74

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ABSTRACT. We confirm the discovery of a light echo around the Type II-plateau supernova 2003gd in Messier 74 (NGC 628), seen in images obtained with the High Resolution Channel of the Advanced Camera for Surveys on board the Hubble Space Telescope (HST) as part of a larger Snapshot program on the late-time emission from supernovae. The analysis of the echo we present suggests that it is due to the SN light pulse scattered by a sheet of dust grains located \(\sim 113\) pc in front of the SN, and that these grains are not unlike those assumed to be in the diffuse Galactic interstellar medium, both in composition and in size distribution. The echo is less consistent with scattering off carbon-rich grains, and if anything, the grains may be somewhat more silicate rich than the Galactic dust composition. The echo also appears to be more consistent with a SN distance closer to 7 Mpc than to 9 Mpc. This further supports the conclusion we reached elsewhere that the initial mass for the SN progenitor was relatively low \((\sim 8–9 M_\odot)\). The HST should be used to continue to monitor the echo in several bands, particularly in the blue, to better constrain its origin.

1. INTRODUCTION

The scattering of supernova (SN) light by proximate dust in the host galaxy is likely a common occurrence. The presence of light echoes around supernovae (SNe) has been inferred based on infrared excesses (e.g., Dwek 1983; Graham et al. 1983; Graham & Meikle 1986). However, until recently, only five SNe have had echoes unambiguously discovered around them: SN 1987A in the Large Magellanic Cloud, SN 1991T in NGC 4527, SN 1993J in Messier 81 (M81), SN 1998bu in Messier 96 (M96), and SN 1999ev in NGC 4274 (Maund & Smartt 2005). In the cases of the Type Ia SNe 1991T (Schmidt et al. 1994) and 1998bu (Cappellaro et al. 2001), indications of a light echo were evident in ground-based, late-time optical observations. However, the superior angular resolution of the Hubble Space Telescope (HST) was required to visually confirm the existence of the echoes for both SNe (Sparks et al. 1999; Cappellaro et al. 2001). Although for the Type II SN 1987A the interstellar (e.g., Crotts 1988) and circumstellar (e.g., Emmering & Chevalier 1989; Bond et al. 1990) echoes could be discovered from the ground, for the Type IIb SN 1993J the discovery of echoes (Sugerman & Crotts 2002; Liu et al. 2003) is again a result of the high-resolution imaging capabilities of the HST.

These light echoes result as the luminous UV/optical emission pulse from a SN is scattered by dust in dense regions of the SN environment. The UV pulse will tend to photoionize the circumstellar matter and destroy smaller dust grains nearest to the SN, while more distant, larger grains survive the pulse; SNe therefore have the potential to illuminate the most distant interstellar material and the largest structures in the environment (Sugerman 2003). We observe the echo as a ring or arc, but it is actually an ellipsoid, with the SN and the observer at the foci and defined by the light-travel time from the SN (see, e.g., Fig. 1 of Patat 2005). Light echoes provide a means to probe both the circumstellar and interstellar structures around SNe. With a precise distance to the SN and the observed geometry of the echo, we can accurately determine the three-dimensional distribution of dust in the SN environment.

Conversely, as was elegantly shown by Panagia et al. (1991) in the case of SN 1987A, light echoes around a SN provide a means to measure the distance to the SN, based purely on geometric arguments and independent of any distance ladder. The polarized light from the dust echo may facilitate this distance determination (Sparks 1994, 1996). Finally, knowing the SN spectrum, which is what is scattered by the dust echo, we can determine the size distribution and composition of the dust (e.g., Sugerman 2003).
Sugerman (2005) has recently discovered and analyzed a light echo around the Type II-plateau (II-P) SN SN 2003gd in Messier 74 (M74), seen in HST images we obtained when the SN was appreciably fainter. Here we confirm the discovery of the echo and provide a different analysis.

SN 2003gd was discovered by Evans (2003) on 2003 June 12.82 (UT dates are used throughout this paper), and based on the light-curve plateau, Van Dyk et al. (2003) estimate the explosion date at about 2003 March 17. SN 2003gd is a somewhat unusual SN II-P and was recently discussed in detail by Hendry et al. (2005). Of notable interest is that both Van Dyk et al. (2003) and Smartt et al. (2004), using a combination of pre-SN HST and ground-based images, independently determined that the progenitor was an $\sim 8 M_\odot$ red supergiant (RSG), at the lower mass limit of theoretical predictions for core-collapse SNe. The confirmation of the progenitor star was based on late-time HST images obtained by Smartt et al. (2004) at an age of $\sim 137$ days, when the SN was slightly off the plateau but still quite bright in the images (see also Hendry et al. 2005).

2. OBSERVATIONS

In Van Dyk et al. (2003) we presented the early-time $BVRI$ light curves for SN 2003gd, based on monitoring with the Katzman Automatic Imaging Telescope (KAIT). We have continued monitoring the SN with KAIT and therefore update the ground-based light curves in Table 1. We also list the $BR$ late-time magnitudes from our ACS (Advanced Camera for Surveys) Snapshot images in Table 1. In addition, we have attempted to measure the SN brightness in the ACS HRC (High Resolution Channel) images obtained by Smartt et al. (2004) on 2003 August 1; the SN is hopelessly saturated in their F814W image, but we are able to measure $F435W$ and $F555W$ magnitudes for the SN through a 0.5 radius aperture. We include these magnitudes, after correction and photometric transformation, in Table 1.

We observed SN 2003gd on 2004 December 8 with the ACS HRC as part of our larger Cycle 13 Snapshot program on late-time emission from SNe (GO-10272; PI: A. V. F.). These images were obtained when the SN was at an age of $\sim 632$ days (1.73 yr), at significantly later times than the Smartt et al. (2004) images. The bandpasses and exposure times we used were $F435W$ (840 s) and $F625W$ (360 s). All of the data for this program have no proprietary period, and thus we obtained these data from the HST public archive, where standard pipeline procedures had been employed to calibrate the images.

Unfortunately, in the F435W image a cosmic-ray hit or hot pixel sits directly along the echo due west of the SN such that the standard pipeline was unable to reject this pixel from the combination of the cosmic-ray–split observations. We used the IRAF2 tasks fixpix and epix to interpolate the affected pixel as well as we could. In Figure 1 we show the corrected F435W ($\sim B$) and F625W ($\sim R$) images. Although at a relatively low signal-to-noise ratio ($S/N$), the light echo can be readily seen in the HST images. (The echo was not detectable in the earlier images by Smartt et al. [2004] or in the pre-SN HST images.) The relatively bright object within the echo is SN 2003gd.

We measured the SN brightness in both bands, first with a 0.5 radius aperture and then via point-spread function (PSF) fitting (with an equivalent aperture also 0.5 in radius). The model PSFs were constructed from two isolated stars in the ACS HRC images. What is most notable is that the aperture magnitudes for the SN are brighter than the PSF magnitudes, almost certainly because of contamination in the aperture by the echo itself. We adjust the PSF magnitudes to infinite aperture, using the corrections for the HRC in Sirianni et al. (2005), and find $m_{F435W} = 23.76 \pm 0.07$ mag and $m_{F625W} = 22.96 \pm 0.05$ mag. Using the photometric transformations also

\begin{table}[h]
\centering
\caption{Photometry of SN 2003gd in M74}
\begin{tabular}{cccccc}
\hline
UT Date & JD & $B$ (mag) & $V$ (mag) & $R$ (mag) & $I$ (mag) \\
\hline
2003 Aug 1$^*$ & 2,452,853.46 & 19.17(03) & 17.41(03) & ... & ... \\
2003 Aug 25 & 2,452,876.96 & 19.16(08) & 17.70(04) & 16.61(02) & 16.06(03) \\
2003 Aug 31 & 2,452,882.97 & 19.08(12) & 17.66(03) & 16.58(02) & 16.02(03) \\
2003 Sep 6 & 2,452,888.96 & ... & 17.68(04) & 16.62(02) & 16.08(02) \\
2003 Dec 8$^*$ & 2,453,347.95 & 23.73(08) & ... & 22.90(05) & ... \\
\hline
\end{tabular}
\end{table}

$^*$ Transformed using the prescription in Sirianni et al. (2005) from aperture magnitudes (0.5 radius aperture) measured from the ACS HRC images obtained during program GO-9733. The $F435W$ magnitude is 19.23(01) and the $F555W$ magnitude is 17.56(01). The $F814W$ image of the SN is completely saturated and is therefore useless.

2 IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatory, which is operated by AURA, Inc., under cooperative agreement with the National Science Foundation.

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in Sirianni et al., we derive $B = 23.73 \pm 0.08$ mag and $R = 22.90 \pm 0.05$ mag (Table 1). We caution that these transformations are derived from stars with normal photospheres and not for emission, reflected or otherwise, from sources with unusual spectra, such as SNe. The uncertainties in $B$ and $R$ given here are strictly those in the photometric measurements and in the transformation coefficients, and they likely underestimate the actual uncertainties.

The light echo has an asymmetric structure: only an arc of emission, not a complete ring, most noticeably to the northwest, is seen in both the F435W and F625W bands. Some far weaker emission is seen to the south of the SN; the emission to the east is not part of the echo but instead is from the stars C and D noted by Smartt et al. (2004). After all the stars, including the SN, were subtracted using the model PSFs from the images, the surface brightness of the echo was measured in both bands. We used the IRAF task minstatistics with an arc-shaped pixel mask to determine the average count rate per pixel in the echo; i.e., $0.024 \pm 0.013$ s$^{-1}$ pixel$^{-1}$ over 82 pixels in F435W and $0.032 \pm 0.021$ s$^{-1}$ pixel$^{-1}$ over 78 pixels in F625W. After subtracting the average sky-pixel count rate, and with the zero points from Sirianni et al. (2005) and a HRC plate scale of 0.027 pixel$^{-1}$, these translate to average surface brightnesses of $\langle \mu_{F435W} \rangle = 21.5 \pm 0.5$ mag arcsec$^{-2}$ and $\langle \mu_{F625W} \rangle = 21.1 \pm 0.6$ mag arcsec$^{-2}$. Integrating over the echo in each band, we derive $m_{F435W} = 24.5 \pm 0.5$ mag and $m_{F625W} = 24.2 \pm 0.6$ mag, with negligible change in the transformation (again following Sirianni et al.) to $m_B = 24.5 \pm 0.5$ mag and $m_R = 24.2 \pm 0.6$ mag, given the echo’s color (i.e., $B - R = 0.3 \pm 0.8$ mag). Assuming Vega as photometric zero point, the echo has fluxes $(1.1 \pm 0.7) \times 10^{-18}$ and $(4.9 \pm 2.8) \times 10^{-19}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$ at $B$ and $R$, respectively (Table 2). Note that Sugerman (2005) finds somewhat different values for both the surface brightness $(\mu_{F435W} = 20.8 \pm 0.2$ mag arcsec$^{-2}$ and $\mu_{F625W} = 21.4 \pm 0.3$ mag arcsec$^{-2}$) and flux $(m_B = 24.2 \pm 0.1$ mag and $m_R = 23.9 \pm 0.1$ mag), although these values

**TABLE 2**

|          | $F_{\text{coh}}(B)$ | $F_{\text{coh}}(R)$ |
|----------|---------------------|---------------------|
| Observed | 11 ± 7              | 4.9 ± 2.8           |
| $d = 7.2$ Mpc$^b$ |                   |                     |
| C+Si dust, $R_e = 3.1$ | 8.5 ± 4.5           | 3.5 ± 1.9           |
| Pure Si dust, $R_e = 3.1$ | 14 ± 7            | 5.1 ± 2.7           |
| Pure C dust, $R_e = 3.1$ | 3.3 ± 1.8          | 2.0 ± 1.0           |
| C+Si dust, $R_e = 4.0$ | 8.8 ± 4.6          | 4.4 ± 2.3           |
| $d = 9.3$ Mpc$^c$ |                   |                     |
| C+Si dust, $R_e = 3.1$ | 5.3 ± 2.8           | 2.2 ± 1.1           |
| Pure Si dust, $R_e = 3.1$ | 8.5 ± 4.5           | 3.1 ± 1.6           |
| Pure C dust, $R_e = 3.1$ | 2.1 ± 1.1           | 1.2 ± 0.6           |
| C+Si dust, $R_e = 4.0$ | 5.4 ± 2.9           | 2.7 ± 1.4           |

*Note.— Fluxes are in $10^{-19}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$.

$^a$ The standard model for dust in the Galactic diffuse ISM is for grain radii between 5.0 Å and 2.0 μm and $b_e = 6 \times 10^{-5}$ (see Weingartner & Draine 2001).

$^b$ SN distance from Van Dyk et al. (2003).

$^c$ SN distance from Hendry et al. (2003).
agree with ours to within the uncertainties. The larger uncertainties we estimated for the fluxes, relative to those estimated by Sugerman (2005), arise from the standard deviation in the count-rate statistics within the pixel mask. Given the low S/N of the echo in the images in both bands, we consider our uncertainties to be quite conservative.

3. ANALYSIS

Here we provide an analysis of the echo and its origin. We note that this analysis differs from that presented by Sugerman (2005). We have determined that SN 2003gd is at the exact center of the light echo, with an uncertainty of <0.2 pixels (<0.005), from comparisons of our Snapshot images to the ACS F435W images obtained by Smartt et al. (2004), when the SN was significantly brighter. The SN itself must therefore be the source of the echo, which we observe at age \( t \) after explosion and age \( \tau \) after optical maximum. The observed echo is the product of the input SN pulse and scattering by dust in the environment.

Following Liu et al. (2003) and Schaefer (1987), we can approximate the ellipsoid near the SN as a paraboloid. The perpendicular linear distance of the line of sight to the SN from the line of sight of the echo, the so-called impact parameter, is \( b = d \theta \), where \( D \) is the SN’s distance from Earth and \( \theta \) is the angular distance of the two lines of sight. We measure a radius of 11.5 ± 1.0 pixels for the echo, which then corresponds to \( \theta = 0.31 \pm 0.03 \). For the SN distance, we assume \( d = 7.2 \) Mpc (Van Dyk et al. 2003) and \( b = 10.8 \pm 1.1 \) pc. We note that Smartt et al. (2004) assume a SN distance of 9.1 Mpc, and Hendry et al. (2005) have estimated a distance of 9.3 Mpc. For the latter distance, \( b = 14.0 \pm 1.3 \) pc (hereafter, we also provide in parentheses estimates of the various parameters, assuming a distance of 9.3 Mpc). The age \( t \), derived from the assumed explosion date, 2003 March 17 (Van Dyk et al. 2003), is 631 days, or 1.73 yr. However, the echo really appears due to the SN pulse, primarily in the UV and the blue. We assume that the SN 2003gd B light curve is similar to that of SN 1999em (see below), and Leonard et al. (2002) determine that the B maximum for the latter SN occurred about 8 days after explosion. Therefore, \( \tau = 623 \) days, or 1.71 yr. The distance from the SN to the echo, \( r = l + c \tau \), can be derived from \( r^2 = b^2 + l^2 \). For \( c \tau = 0.52 \) pc, we find \( l = 112.0 \pm 24.0 \) pc and \( r = 112.5 \pm 23.5 \) pc (\( l = 188.0 \pm 37.0 \) and \( r = 188.5 \pm 37.0 \) pc for 9.3 Mpc).

Given this distance and the echo’s overall asymmetric structure, the echo is mostly from interstellar, not circumstellar dust: for an RSG phase duration of \( \sim 10^4 \) yr and wind speed of \( \sim 10 \) km s\(^{-1}\), the circumstellar matter would only be \( \sim 0.1 \) pc (0.009) in radius. In addition, much of this dust is likely destroyed by the UV SN pulse (Sugerman 2003). The observed thickness of the echo is \( \sim 2 \) pixels, but the stellar image width (FWHM) is larger than this, so that the echo must be barely resolved, if at all. Therefore, any estimate of the dust sheet’s thickness along the line of sight (Liu et al. 2003) must be an upper limit: for the echo, \( \Delta \theta \) is then \( \geq 0.05 \), or \( \Delta b \geq 1.7 \) pc (\( \geq 2.2 \) pc). The dust sheet thickness is then \( \Delta l = (b/c\tau)\Delta b \geq 35 \) pc (\( \geq 59 \) pc).

As is generally done, we assume that the echo arises from single scattering in a thin sheet of dust between us and the SN, and that the sheet thickness is much smaller than the distance between the SN and the sheet. Following the formalism of Chevalier (1986), Cappellaro et al. (2001), and Patat (2005), the flux \( F \) at time \( t \) from the echo at a given wavelength or bandpass is

\[
F_{\text{echo}}(t) = \int_0^t F_{\text{SN}}(t-t') f(t') dt',
\]

where \( F_{\text{SN}}(t-t') \) is the flux of the SN at time \( t-t' \), and \( f(t) \) (in units of s\(^{-1}\)) determines the fraction of light scattered by the echo toward the observer and depends on the echo geometry and the nature of the dust. The total SN light is effectively treated as a short pulse over which the SN flux is constant.

The term \( f(t) \) is assumed to have the form

\[
f(t) = \frac{cN_{\text{hi}}}{r} \int_0^\infty Q_{\text{sc}}(a) \phi(a) \Phi(\alpha, a) da,
\]

where \( N_{\text{hi}} \) is the H number density, \( Q_{\text{sc}}(a) \) is the scattering coefficient for a given grain radius \( a \), \( \phi(a) = \pi a^2 \) is the dust grain cross section for scattering, and \( \Phi(\alpha) \) is the phase function

\[
\Phi(\alpha, a) = \frac{1 - g(a)^2}{4\pi[1 + g(a)^2 - 2g(a)\cos \alpha]^2},
\]

(Heney & Greenstein 1941), where \( g \) is the scattering angle defined by \( \cos \alpha = [(b/c\tau)^2 - 1]/[(b/c\tau)^2 + 1] \) (e.g., Schaefer 1987). The function \( \Phi(\alpha) \) is applicable for the bandpasses being considered here (see Draine 2003). The term \( g(a) \) measures the degree of forward scattering for a dust grain of radius \( a \). From the geometric parameters for this echo, the scattering angle is then \( \alpha \approx 5.5 \) (4.3). The term \( \phi(a) \) is the grain size distribution for grain radius \( a \). Following Sugerman (2003), we consider the dust grain distributions for (spherical) silicate and carbonaceous grains from Weingartner & Draine (2001), and the \( Q_{\text{sc}}(a) \) and \( g(a) \) values for “smoothed UV astronomical silicate” grains (Draine & Lee 1984; Laor & Draine 1993; Wein-gartner & Draine 2001) and carbonaceous graphite (Draine & Lee 1984; Laor & Draine 1993).

To derive the SN fluence, we must integrate the light curves over time in each band. Unfortunately, SN 2003gd was caught late in its evolution, \(~90\) days after explosion. In Van Dyk et al. (2003) we showed from the initial ground-based BVRI light curves that the agreement with the light curves in the same bands for the Type II-P SN 1999em (Hamuy et al. 2001; Leonard et al. 2002, 2003) is quite good on the plateau. It is after the plateau that SN 2003gd and SN 1999em fail to agree
well. This is because SN 2003gd is among the peculiar, low-luminosity, low $^{56}$Ni yield SNe II-P, which also include SN 1997D (Turatto et al. 1998; Benetti et al. 2001) and SN 1999br (Zampieri et al. 2003; Pastorello et al. 2004). However, these latter SNe all appear to agree relatively well with SN 1999em near maximum and early on the plateau as well.

In Figure 2 we show a more complete set of light curves in the $B$ and $R$ bands for SN 2003gd, which includes the updated ground-based data points and the addition of the HST photometry. The SN 2003gd light curves have been adjusted in time to match the SN 1999em light curves; no adjustment in magnitude was necessary. The relatively good match on the plateau is remarkable to match the SN 1999em light curves; no adjustment in magnitude was necessary. The relatively good match on the plateau phase for both SNe suggests that we can employ the early-time SN 1999em data to extrapolate the SN 2003gd light curves back to the date of explosion. Performing the integration, assuming Vega as the flux zero point, we find $7.26 \times 10^{-8}$ and $8.85 \times 10^{-8}$ ergs cm$^{-2}$ Å$^{-1}$ in $B$ and $R$, respectively (note that these differ from the fluences reported by Sugerman [2005]; i.e., $8.0 \times 10^{-8}$ and $7.0 \times 10^{-8}$ ergs cm$^{-2}$ Å$^{-1}$ in $B$ and $R$, respectively). If the SN 2003gd light curves evolved in a manner similar to SN 1999em at early times, then these fluences (and the color curves for SN 1999em from Leonard et al. 2002) emphasize how red the SN likely became soon after maximum light. That is, the SN pulse resulting in the echo was relatively red in color.

The duration of the SN pulse in each bandpass can be obtained by assuming $F_{\text{SN}} \Delta t_{\text{SN}} = \int F_{\text{SN}}(t) dt$ (Cappellaro et al. 2001; Patat 2005). Here we take $F_{\text{SN}}$ to be the SN maximum flux, which we assume to be the $B$ and $R$ maximum fluxes for SN 1999em (Leonard et al. 2002); i.e., $m = 13.79$ and 13.63 mag in $B$ and $R$, respectively, and $\Delta t_{\text{SN}}$ is the pulse duration (this is actually what is termed the “effective width” of the pulse). We then find $\Delta t_{\text{SN}}$ to be $\sim 45$ days in $B$ and $\sim 138$ days (about 3 times longer) in $R$.

We can estimate the H column density from the extinction toward the echo. We assume that since the echo lies quite close to the line of sight to SN 2003gd, the echo suffers the same amount of extinction as does the SN. For the SN, we estimate a total reddening $E(B-V) = 0.13 \pm 0.03$ mag [Van Dyk et al. 2003; Smartt et al. 2004] derive a consistent estimate of the SN reddening, but with a larger uncertainty, $E(B-V) = 0.11 \pm 0.16$ mag]. Next, we must subtract the Galactic reddening contribution, $E(B-V) = 0.07$ mag (Schlegel et al. 1998). Assuming the ratio of total to selective extinction of $R_V = 3.1$ (e.g., Cardelli et al. 1989), we find $A_V = 0.19$ mag internal to the host galaxy. Bohlin et al. (1978) found a fairly constant empirical relation over the diffuse interstellar medium in the Galaxy, $N_H = 5.8 \times 10^{21}E(B-V)$, which provides a normalization for the extinction curve $A_V/N_H = 5.3 \times 10^{-22}$ cm$^2$/erg (Weingartner & Draine 2001). From this relation, and including our estimated uncertainty in the reddening, we derive $N_H = (3.5 \pm 1.7) \times 10^{20}$ cm$^{-2}$ in the dust sheet.

In Table 2 we present the fluxes $F_{\text{echo}}$ in each band for several echo models, for which we have varied the composition of the dust grains. We have calculated the set of models for both our distance assumption and the Hendry et al. (2005) distance estimate. The first model in the set is the diffuse Galactic dust model from Weingartner & Draine (2001) and Draine (2003); it assumes solar abundances with $R_V = 3.1$ and a total C abundance per H nucleon of $b_C = 56$ parts per million, with comparable contributions of carbonaceous and silicate dust with radii in the 5.0 Å–2.0 μm range. We also consider models with $R_V = 3.1$ and either pure silicates or pure carbonaceous grains. Finally, we consider a model with comparable silicate and carbonaceous grain composition, but assuming $R_V = 4.0$. The results are also shown graphically in Figure 3.

The overall agreement of the models and the observations is remarkably good. With the various assumed model inputs, we are reproducing the observed echo reasonably well, and this further implies that the echo likely arises from the diffuse interstellar dust near the SN. The uncertainties in the model fluxes (arising mostly from the uncertainties in the echo geometric measurements and in our reddening estimate) are rather large but are comparable to the measurement uncertainties in the observed fluxes. What we notice is that the C+Si model agrees quite well with the observations. The value of $R_V$ (3.0 or 4.1) has little bearing on this agreement. The pure Si-rich dust model is also consistent with the observations, the pure
C-rich dust model less so (although it agrees to within the uncertainties for $d = 7.2$ Mpc). In fact, for the larger assumed SN distance ($d = 9.3$ Mpc), the pure carbonaceous dust model is no longer consistent with the observations at either band and can be ruled out.

We note that the remaining models calculated for the larger SN distance generally tend to underestimate the flux, although taking into account the large uncertainties in both the observed and model fluxes, it is impossible to rule them out entirely. However, we tentatively suggest that the observed echo may indicate that the actual SN distance is closer to the smaller value we assumed in Van Dyk et al. (2003) than the larger one determined by Hendry et al. (2005) (and the similarly larger distance assumed by Smartt et al. 2004). This, along with the value of $R_{\nu}$, has implications for the absolute magnitude, and therefore the initial mass, of the SN progenitor. A higher $R_{\nu}$ would imply that the progenitor was at most $\sim 0.1$ mag more luminous than what we estimated in Van Dyk et al. However, the larger distance would require the star to be $\sim 0.6$ mag more luminous, which would increase the mass estimate by $\sim 1 M_{\odot}$ (i.e., it would imply that the initial mass was closer to $\sim 10 M_{\odot}$). The relative agreement between the observed echo and the echo models based on the shorter distance reassures us that our low progenitor mass estimate ($\sim 8-9 M_{\odot}$), although uncomfortably near the theoretical limit for core collapse (Woosley & Weaver 1986), is realistic.

4. CONCLUSIONS

We have confirmed the presence of a scattered-light echo around the nearby Type II-plateau SN 2003gd in M74. This discovery could only have been made in images produced with the superior angular resolution of the HST ACS HRC at sufficiently late times for the SN. We conclude that the echo arises from dust in the interstellar SN environment, and our modeling (within the large uncertainties in the observations, which further propagate into the models) suggests that this dust, both in composition and in grain size distribution, is not unlike dust in the diffuse Galactic interstellar medium, although it is also possible the dust could be more silicate rich than carbon rich. In fact, our echo models tend to disfavor dust in the SN environment that is more abundant in carbonaceous grains than silicates. (We note that Sugerman [2005] found that the echo may arise from small, carbon-rich grains.)

The models are not particularly sensitive to the value of $R_{\nu}$ (but we did not compute models with $R_{\nu} > 4$). However, models based on the shorter distance to the SN that we assumed in Van Dyk et al. (2003; 7.2 Mpc) appear to be somewhat more consistent with the observed echo than those for the longer distance assumed by Smartt et al. (2004; 9.1 Mpc) and Hendry et al. (2005; 9.3 Mpc), although the uncertainties are large. These latter two factors slightly increase our confidence in the relatively low estimate ($\sim 8-9 M_{\odot}$) for the initial mass of the SN progenitor we derived in Van Dyk et al.

From $N_{H}$ and assuming a path length $L = \Delta l \approx 35$ pc for the dust sheet, the H number density would be $n_{H} \approx 7$ cm$^{-3}$. Combined with the extinction to the SN, this is consistent with the expectation that light echoes likely emerge from regions with $n_{H} \approx 10$ cm$^{-3}$ and $A_{V} \approx 1$ mag (Sugerman 2003).

This echo should be further monitored with the HST, including use of additional bands, particularly in the UV, to far better constrain the nature of the scattering dust and the echo geometry, and to reveal further new or evolving structures in the echo.

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