SUPERNova 2003ie WAS LIKELY A FAINT type iIP event

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Received 2012 October 26; accepted 2013 February 3; published 2013 March 6

ABSTRACT

We present new photometric observations of supernova (SN) 2003ie starting one month before discovery, obtained serendipitously while observing its host galaxy. With only a weak upper limit derived on the mass of its progenitor (<25 M⊙) from previous pre-explosion studies, this event could be a potential exception to the “red supergiant (RSG) problem” (the lack of high-mass RSGs exploding as Type IIP SNe). However, this is true only if SN2003ie was a Type IIP event, something which has never been determined. Using recently derived core-collapse SN light-curve templates, as well as by comparison to other known SNe, we find that SN2003ie was indeed a likely Type IIP event. However, with a plateau magnitude of ∼−15.5 mag, it is found to be a member of the faint Type IIP class. Previous members of this class have been shown to arise from relatively low-mass progenitors (<12 M⊙). It therefore seems unlikely that this SN had a massive RSG progenitor. The use of core-collapse SN light-curve templates is shown to be helpful in classifying SNe with sparse coverage. These templates are likely to become more robust as large homogeneous samples of core-collapse events are collected.

Key word: supernovae: individual (SN2003ie)

Online-only material: color figures

1. INTRODUCTION

Core-collapse supernovae (SNe) mark the end stage of massive (M > 8 M⊙) stars. They are largely divided into two groups: H-poor explosions (Type I SNe) and H-rich explosions (Type II SNe; see Filippenko 1997 for a review). Several additional subclasses have been identified, including interacting SNe IIn (see, e.g., Schlegel 1990; Kiewe et al. 2012, and references therein), linearly declining SNe III, plateau light-curve SNe IIP, H-deficient SNe IIn, and events displaying long rise times similar to SN1987A. Arcavi et al. (2012) find a distinct subdivision in the R-band light curves of the IIP, IIL, and IIn subtypes.

A large spread of plateau luminosities has been observed for SNe IIP, with some as bright as MR ∼−17.5 during the plateau (Arcavi et al. 2012), the “canonical” Type IIP SN1999em at MR ∼−16.5, and several low-luminosity events at MR ∼−15 (Pastorello et al. 2004), perhaps extending down even to MR ∼−12 (Pastorello et al. 2007).

SNe IIP have been robustly associated with the explosions of red supergiants (RSGs) using direct pre-explosion imaging of the SN sites (see Smartt 2009; Leonard 2011 for reviews; Van Dyk et al. 2012; Fraser et al. 2012 for recent results), with faint SNe IIP arising from the lower mass progenitors (see Fraser et al. 2011 and references therein).

However, while RSGs in the local group have masses up to ∼30 M⊙ (Levesque et al. 2005), Smartt et al. (2009) find that none of the observed progenitors of confirmed SNe IIP are more massive than ∼17 M⊙. It is unclear why no RSG with a mass in the range of 17–30 M⊙ has been observed to explode as a Type IIP event, and this discrepancy has been dubbed the “RSG problem.”

Assuming a Salpeter initial mass function (IMF), Smartt et al. (2009) find that the probability of their sample not including any SN from a massive RSG by chance is very low (1.8%). The IMF alone is therefore not enough to resolve this problem. Massive RSGs might explode as SNe IIn, IIn, or IIn, but so far these SNe were found to arise from lower mass progenitors (Smartt et al. 2003), binaries (Podsiadlowski et al. 1993; Woosley et al. 1994; Maund et al. 2004), and luminous blue variables (Gal-Yam & Leonard 2009), respectively. Other options could be that massive RSGs are enshrouded by thick dust, making their explosions difficult to detect, or that they collapse directly to black holes.

One possible exception to the RSG problem is SN2003ie, for which only a loose progenitor mass upper limit (25 M⊙; Smartt et al. 2009) could be derived from pre-explosion non-detections. However, due to the sparse data available for this SN, its subclass could not be determined. Determining whether SN2003ie was a Type IIP event or not could have implications for the RSG problem, thus motivating this study.

SN2003ie was discovered on 2003 September 19 (Arbour & Boles 2003; UT times used throughout). A spectrum taken by Benetti et al. (2003) revealed that it was a Type II SN. Harutyunyan et al. (2008) find that the spectrum was similar to that of SN1998A. Both SN2003ie and SN1998A show a significant (∼2100 km s−1) blueshift in their Hα emission line (Harutyunyan et al. 2008). This prompted the suggestion that SN2003ie, like SN1998A, is a member of the slowly rising SN1987A-class (Smartt et al. 2009). These events are thought to arise from blue supergiants (BSGs; Kleiser et al. 2011; Pastorello et al. 2012; Taddia et al. 2012). Indeed SN1987A had a massive BSG progenitor (16–22 M⊙; Arnett et al. 1989). If this were the case, SN2003ie would not be of any relevance to the RSG problem. However, Pastorello et al. (2005) note that blueshifted Hα emission has also been observed in the Type IIP SN1999em. It is therefore not clear which subclass of Type II events SN2003ie belongs to.

Here we present BVRI photometry of SN2003ie obtained serendipitously during observations of its host galaxy, NGC 4051. Our data cover approximately 130 days starting one month prior to discovery. We compare the light curve of this event to those of other SNe in order to better constrain its subtype.
2. OBSERVATIONS

We used the \textit{BVRI} photometer with the AP7p CCD camera mounted on the AZT-8 70 cm Crimean Reflector to observe the galaxy NGC 4051 during the months of July to 2004 January. Several observations captured SN2003ie, starting from 2003 August 18 (approximately one month before discovery; Figure 1). We employ the \textsc{mkdifflc} routine (Gal-Yam et al. 2003 August 18 (approximately one month before discovery; January. Several observations captured SN2003ie, starting from the galaxy NGC 4051 during the months of 2003 July to 2004 August. Our photometry and the Benetti et al. (2003) spectrum are digitally released via WISeREP\(^5\) (Yaron & Gal-Yam 2012). We constrain the explosion time to be between 2003 July 19 and 2003 August 18. Our photometry and the Benetti et al. (2003) spectrum are digitally released via WISeREP\(^5\) (Yaron & Gal-Yam 2012).

\(^3\) IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under cooperative agreement with the National Science Foundation.

\(^4\) NED is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

\(^5\) http://www.weizmann.ac.il/astrophysics/wiserep

\(^6\) Derived from the Benetti et al. (2003) spectrum. The magnitudes depend on the (highly uncertain) flux calibration applied to that spectrum and are presented here for completeness only.

Figure 1. \textit{R}-band image of SN2003ie in the galaxy NGC 4051, taken with the 70 cm Crimean Reflector on 2003 August 18.

\begin{table}[h]
\centering
\begin{tabular}{cccccc}
\hline
\textbf{MJD} & \textbf{B} & \textbf{V} & \textbf{R} & \textbf{I} \\
\hline
52870.282 & 15.83 (0.07) & 15.19 (0.06) & 15.25 (0.08) & 15.02 (0.09) \\
52870.285 & 15.27 (0.07) & 15.18 (0.07) & 15.35 (0.08) & 15.11 (0.10) \\
52870.288 & 15.32 (0.06) & 15.24 (0.07) & 15.28 (0.08) & 15.05 (0.09) \\
52870.291 & 15.33 (0.06) & 15.26 (0.07) & 15.31 (0.08) & 15.00 (0.09) \\
52904.781a & >17.40 & 15.89 & >15.25 \\
52965.642 & 18.15 (0.15) & 16.71 (0.11) & 16.05 (0.08) & 15.56 (0.10) \\
52965.644 & 18.10 (0.12) & 16.82 (0.09) & 16.01 (0.07) & 15.62 (0.10) \\
52965.646 & 18.09 (0.18) & 16.77 (0.09) & 16.05 (0.07) & 15.61 (0.09) \\
52965.648 & 18.35 (0.13) & 16.75 (0.09) & 16.07 (0.08) & 15.66 (0.10) \\
52966.602 & 18.32 (0.13) & 16.59 (0.11) & 15.98 (0.11) & 15.66 (0.10) \\
52966.604 & 18.26 (0.14) & 16.66 (0.10) & 16.02 (0.09) & 15.62 (0.12) \\
52966.605 & 18.33 (0.13) & 16.83 (0.10) & 16.03 (0.08) & 15.71 (0.12) \\
52966.606 & 18.44 (0.15) & 16.69 (0.09) & 16.05 (0.08) & 15.59 (0.12) \\
52967.617 & 18.01 (0.17) & 16.89 (0.09) & 16.09 (0.08) & 15.67 (0.10) \\
52967.619 & 18.13 (0.11) & 16.71 (0.11) & 16.10 (0.08) & 15.73 (0.10) \\
52967.621 & 18.29 (0.17) & 16.59 (0.10) & 16.06 (0.08) & 15.59 (0.09) \\
52967.623 & 18.42 (0.19) & 16.75 (0.11) & 16.04 (0.08) & 15.72 (0.10) \\
52968.647 & 18.08 (0.19) & 16.72 (0.10) & 16.03 (0.08) & 15.63 (0.09) \\
52968.649 & 18.61 (0.42) & 16.65 (0.09) & 16.08 (0.08) & 15.67 (0.10) \\
52968.651 & 18.17 (0.18) & 16.66 (0.10) & 16.04 (0.08) & 15.70 (0.11) \\
52968.653 & 18.29 (0.21) & 16.74 (0.11) & 16.04 (0.08) & 15.77 (0.10) \\
52983.589 & 17.11 (0.15) & 16.33 (0.12) & 16.13 (0.11) & 15.81 (0.12) \\
52983.591 & 17.16 (0.15) & 16.31 (0.13) & 15.95 (0.12) & 15.81 (0.12) \\
52983.592 & 17.24 (0.14) & 16.32 (0.13) & 15.98 (0.11) & 15.81 (0.12) \\
52983.594 & 17.10 (0.22) & 16.36 (0.13) & 15.99 (0.13) & 15.98 (0.11) \\
52996.630 & 17.42 (0.14) & 16.94 (0.09) & 16.41 (0.19) \\
52996.632 & 17.62 (0.16) & 16.87 (0.13) & 16.18 (0.15) \\
52996.634 & 17.66 (0.20) & 16.88 (0.09) & 16.43 (0.21) \\
52996.636 & 17.59 (0.13) & 16.84 (0.09) & 16.32 (0.15) \\
52997.629 & 17.66 (0.16) & 17.04 (0.17) & 16.56 (0.31) \\
52997.631 & 17.45 (0.14) & 17.01 (0.15) & 16.30 (0.25) \\
52997.634 & 17.68 (0.14) & 16.78 (0.14) & 16.42 (0.25) \\
52997.636 & 17.55 (0.15) & 17.08 (0.17) & 16.25 (0.14) \\
\hline
\end{tabular}
\caption{Photometry of SN2003ie}
\end{table}

\textbf{Table 1}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{\textit{BVRI} light curves of SN2003ie. Observations taken on the same day are averaged. The circles denote our photometry, the square denotes synthetic photometry derived from the Benetti et al. (2003) spectrum, and the triangles denote lower limits for the synthetic photometry derived using this spectrum (which only partially covered the \textit{B} and \textit{R} bands). (A color version of this figure is available in the online journal.)}
\end{figure}
3. DISCUSSION

We compare the $R$-band light curve of SN2003ie with those of SN1998A (the best spectroscopic fit to SN2003ie found by Harutyunyan et al. 2008), SN1999em (considered a “typical” SN IIP), and SN2005cs (a well-observed faint SN IIP) in the top panel of Figure 3 (a broader comparison to SN templates is also presented, see below). It is clear that photometrically, SN2003ie is not a member of the 87A-class, especially when considering the drop in brightness approximately 100 days after our first detection. This behavior, together with the observed $B$-band decline (Figure 2), is typical of Type IIP events. The possibility of a massive BSG progenitor for SN2003ie is therefore disfavored.

While the drop from the plateau for SN2003ie is more gradual than some other SNe IIP, it is still far from the Type III and Type IIf light-curve templates derived from the Caltech Core-Collapse Program sample by Arcavi et al. (2012; bottom panel of our Figure 3).

SN2003ie is thus a Type IIP SN, likely arising from an RSG progenitor which cannot be constrained to a mass $<17 M_\odot$ (Smartt et al. 2009).

However, the absolute plateau magnitude of SN2003ie ($\sim-15.5$; Figure 2), being similar to that of SN2005cs (Figure 3), puts it in the faint SN IIP category. We note that the expansion velocities of SN2003ie and SN2005cs at day $\sim 40$ are also similar ($\sim 3400$ km s$^{-1}$; measured as the blueshift of the H$\alpha$ absorption compared to the emission peak). Several other faint Type IIP SNe had relatively low-mass progenitors ($\sim 12 M_\odot$; Fraser et al. 2011). Therefore, we conclude that this event is not likely to have been the explosion of a high-mass RSG.

4. SUMMARY

We have presented new photometric observations of SN2003ie, which strongly suggest that it was a faint Type IIP event. Despite the spectroscopic similarities to SN1998A (Harutyunyan et al. 2008), we show that these two events are not similar photometrically. We use the templates derived by Arcavi et al. (2012) to also rule out a IIL or IIf classification.

With only an upper limit of $25 M_\odot$ on its progenitor mass, SN2003ie could thus have been the exception to the RSG problem. However, as a member of the faint Type IIP subclass, this option is not likely.

Our work demonstrates that using core-collapse SN light-curve templates could prove useful for transient identification when only sparse photometric and spectroscopic data are available.
available. Constructing robust templates, however, requires a large homogeneous sample of well-classified events. Such a sample will likely be produced using current and future wide field transient surveys, such as the Palomar Transient Factory (Law et al. 2009; Rau et al. 2009).

A.G. and I.A. acknowledge support by the Israeli and German-Israeli Science Foundations, and an EU/FP7/ERC grant.

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