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The Early Detection and Follow-up of the Highly Obscured Type II Supernova 2016ija/DLT16am*


1 Department of Astronomy and Steward Observatory, University of Arizona, 933 N Cherry Avenue, Tucson, AZ 85719, USA; ltartaglia@ucdavis.edu
2 Department of Physics, University of California, 1 Shields Avenue, Davis, CA 95616, USA
3 European Southern Observatory, Alonso de Córdova 3107, Casilla 19, Santiago, Chile
4 Department of Physics, University of California, Santa Barbara, CA 93106-9530, USA
5 Las Cumbres Observatory, 6740 Cortona Drive, Suite 102, Goleta, CA 93117, USA
6 Astrophysics Research Institute, Liverpool John Moores University, IC2, Liverpool Science Park, 146 Brownlow Hill, Liverpool L3 5RF, UK
7 INAF—Osservatorio Astronomico di Capodimonte, Salita Moiariello 16, Napoli, I-80131 Italy
8 School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, UK
9 Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstraße 1, D-85748, Garching, Germany
10 European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching b. München, Germany
11 Department of Astronomy and Astrophysics, University of California, Santa Cruz, CA 95064, USA
12 Benoziyo Center for Astrophysics, Faculty of Physics, Weizmann Institute of Science, Rehovot 76100, Israel
13 PTIT PACC, Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, PA 15260, USA
14 Dark Cosmology Centre, Niels Bohr Institute, University of Copenhagen, Juliane Maries Vej, 30, DK-2100 Copenhagen, Denmark
15 Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA
16 Tuorla Observatory, Department of Physics and Astronomy, University of Turku, Väisäläntie 20, FI-21500 Piikkiö, Finland
17 Department of Physics, University of California, Santa Barbara, CA 93106, USA
18 Department of Physics and Astronomy, Rutgers, the State University of New Jersey, 136 Frelinghuysen Road, Piscataway, NJ 08854, USA
19 Department of Physics, School of Mathematics and Physics, Queen’s University Belfast, Belfast BT7 1NN, UK
20 Finnish Centre for Astronomy with ESO (FINCA), University of Turku, Väisäläntie 20, 21500 Piikkiö, Finland
21 Department of Physics, Texas Tech University, Box 41051, Lubbock, TX 79409-1051, USA
22 Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, D-85748 Garching bei München, Germany
23 INAF—Osservatorio Astronomico di Brera, via E. Bianchi 36, I-23807 Merate (LC), Italy
24 Carnegie Observatories, Las Campanas Observatory, Casilla 601, La Serena, Chile
25 Departamento de Ciencias Fisicas, Universidad Andres Bello, Avda. Republica 252, Santiago, Chile
26 Millenium Institute of Astrophysics (MAS), Nuncio Monseor Stero Sanz 100, Providencia, Santiago, Chile
27 The Observatories of the Carnegie Institution for Science, 813 Santa Barbara Street, Pasadena, CA 91101, USA
28 Department of Astronomy and The Oskar Klein Centre, AlbaNova University Center, Stockholm University, SE-106 91 Stockholm, Sweden
29 Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark

Received 2017 October 6; revised 2017 December 3; accepted 2017 December 5; published 2018 January 23

Abstract

We present our analysis of the Type II supernova DLT16am (SN 2016ija). The object was discovered during the ongoing $D < 40$ Mpc (DLT40) one-day cadence supernova search at $r \sim 20.1$ mag in the “edge-on” nearby ($D = 20.0 \pm 0.4$ Mpc) galaxy NGC 1532. The subsequent prompt and high-cadenced spectroscopic and photometric follow-up revealed a highly extinguished transient, with $E(B-V) = 1.95 \pm 0.15$ mag, consistent with a standard extinction law with $R_V = 3.1$ and a bright ($M_V = -18.48 \pm 0.77$ mag) absolute peak magnitude. A comparison of the photometric features with those of large samples of SNe II reveals a fast rise for the derived luminosity and a relatively short plateau phase, with a slope of $S_{\text{ave}} = 0.84 \pm 0.04$ mag/50 days, consistent with the extinction properties typical of those of fast-declining SNe II. Despite the large uncertainties on the distance and the extinction in the direction of DLT16am, the measured photospheric expansion velocity and the derived absolute $V$-band magnitude at $\sim 50$ days after the explosion match the existing luminosity–velocity relation for SNe II.

Key words: galaxies: individual (NGC 1532) – supernovae: general – supernovae: individual (SN 2016ija, DLT16am)

Supporting material: data behind figure, machine-readable tables

1. Introduction

The study of cosmic explosions continues to flourish, with innovative experiments exploring new regions of discovery space. Many of these programs are focusing on wide-field imaging and relatively short cadences; see, e.g., the Palomar Transient Factory (PTF; Law et al. 2009), the Asteroid Terrestrial-impact Last Alert System (Tonry 2011), the All Sky Automated Survey for SuperNovae (Shappee et al. 2014; Kochanek et al. 2017), and the PANoramic Survey Telescope And Rapid Response System (Pan-STARRS1; Chambers et al. 2016) among others. These programs discover hundreds
of new supernovae (SNe) every year. This revolution will certainly continue in the era of the Zwicky Transient Facility (Bellm 2014), BlackGEM\(^{31}\) (Bloemen et al. 2015), and the Large Synoptic Survey Telescope (Ivezic et al. 2008). It is still the case, however, that the nearest SNe are not always caught soon after explosion, relinquishing the opportunity for detailed study of the most observable events—a recent prominent example was the type Ia SN 2014J in M82 \((D \sim 3.5\text{ Mpc})\), which was discovered \(~8\text{ days after explosion (Fossey et al. 2014; Goobar et al. 2015).}\)

It is in the hours to days after explosions where clues about the SN progenitors and explosion physics are accessible, and where the fewest observational constraints are present. Early discovery and prompt multi-wavelength follow-up of nearby SNe are essential to fully characterize the physical properties of stellar explosions. Except for a few cases where deep archival Hubble Space Telescope (HST) images are available (Smartt 2009), one of the best ways to gain insight into a SN progenitor and its explosion mechanism is through the analysis of very early-phase data, when the spectra still show the imprint from the outer layers of the progenitor, the explosion energy is still the dominant heat source, and the circumstellar medium (CSM) has not yet been overtaken by the SN ejecta.

In SNe Ia, the very early light curves and spectra can help to constrain the white dwarf (WD) progenitor radius \((\text{e.g., Nugent et al. 2011; Bloom et al. 2012; Zheng et al. 2013, its }^{56}\text{Ni distribution (from the early light curve shape; see Mazzali et al. 2014; Piro & Nakar 2014; Miller et al. 2017), to infer the presence of a normal companion star (via direct shocking of the SN Ia ejecta against the normal companion Kasen 2010; Cao et al. 2015; Marion et al. 2016; Hosseinzadeh et al. 2017), and to probe SN Ia explosion mechanisms. While it is commonly accepted that SNe Ia arise from thermonuclear explosions of carbon-oxygen WDs, it is still unclear by which mechanism(s) the WD accretes the necessary mass (the single or double degenerate scenario; see, \text{e.g., Maoz & Mannucci 2012 for a review}). The detection and strength of Cu \((6580\text{Å})\) in early spectra may also point to viable explosion mechanisms (see, \text{e.g., Mazzali 2001; Höflich & Stein 2002; Röpke et al. 2007; Kasen et al. 2009; Fryer et al. 2010}).

Early light curves of core-collapse (CC) SN shock-cooling tails can constrain the progenitor star radius and give useful information about the envelope structure (see, \text{e.g., Rabinak & Waxman 2011; Bersen et al. 2012; Arcavi et al. 2017; Barbarino et al. 2017; Piro et al. 2017; Sapir & Waxman 2017, for selected theoretical and observational results}). Alternatively, “flash spectroscopy” at very early phases can probe the physical properties of the CSM as well as the mass-loss history of the progenitor star prior to its explosion (\text{e.g., Gal-Yam et al. 2014; Smith et al. 2015; Khazov et al. 2016; Yaron et al. 2017}). Even when archival HST data are available, radius estimates through the analysis of very early data can give important results, since the progenitor field might be contaminated by the presence of binary companions (\text{e.g., Tartaglia et al. 2017a}).

Motivated by the science described above, and by the need for multi-wavelength observations at very early phases, we have begun a pointed, one-day cadence SN search for very young transients in the nearby \((D < 40\text{ Mpc}; \text{ DLT40})\) universe. Given the survey depth of \(r \sim 19\text{ mag and the proximity of the DLT40 galaxy sample (see Section 2), this}}

\(^{31}\) https://astro.ru.nl/blackgem/

\(^{32}\) https://wis-tns.weizmann.ac.il/object/2016ija
and integram slit. This setup yields continuous wavelength coverage. Our nightly schedule is 2017 Nordic Optical Telescope as a report the main results of our photometric and 2017d from explosion. Fully operational telescope 6 a year 2016a 3 Faulkes north and south telescopes with FLOYDS 11 Mpc is suf 2017a 2017b, Milky Way 2015 2017i 40 Mpc of explosion. PROMPT5 DLT40 pre-reduced images A 23 we. The data 2010 10 arcmin 6 grating and the ( ∼ Ia, and recessional velocity curve features that can shed light on the progenitor SN the region above the black solid line. Also noted is the absolute magnitude of ∼ AT 2017gfo Valenti et al. 2017a). The goal of DLT40 is not to fi 2011 2015 or nearby galaxies DLT40 results are in preparation.

3. Observations and Data Reduction

3.1. Spectra

The spectral sequence of DLT16am is shown in Figure 3, while the log of the spectroscopic observations in the optical and NIR domains is reported in Table 1. Optical spectra were mainly provided by Public ESO Spectroscopic Survey for Transient Objects (PESSTO) using the ESO 3.58 m New Technology Telescope (NTT) with the ESO Faint Object Spectrograph and Camera (ν.2, EFOSC2; Buzzoni et al. 1984), and the Las Cumbres Observatory network of telescopes, using the 2 m Faulkes north and south telescopes with FLOYDS (reduced as in Valenti et al. 2014). Early-phase spectra were also provided using the 10 m South African Large Telescope (SALT) with the Robert Stobie Spectrograph (RSS), and the 2.56 m Nordic Optical Telescope (NOT) with Andalucia Faint Object Spectrograph and Camera (ALFOSC). NOT spectra were reduced using FOSCGUI, while the SALT spectrum was reduced using a dedicated pipeline (PySALT; Crawford et al. 2010).

NIR spectra were obtained using the standard “ABBA” technique and an AOV telluric standard was observed at a similar airmass in order to simultaneously correct for telluric absorption and to flux-calibrate the main science data. Most NIR spectra were provided by PESSTO using the NTT with the SOFI spectrograph (all reduced as in Smartt et al. 2015). Two NIR spectra were obtained using the Gemini NIR Spectrograph (GNIRS) at Gemini North (Elias et al. 2006) in cross-dispersed mode, using the 321 mm−1 grating and the 0.675 slit. This setup yields continuous wavelength coverage from 0.8 to 2.5 µm with a resolution of R ∼ 1000. The data were taken with the slit along the parallactic angle, and were reduced with the XDGNIRS PyRAF-based pipeline provided by Gemini Observatory. Flux calibration and telluric correction were performed following the methodology of Vacca et al. (2003). An NIR spectrum was also obtained using the 6.5 m Magellan Baade Telescope with the Folded-port InfraRed Echellette (FIRE). The spectrum was taken in the long slit prism mode, 0.6 slit width, and was a combination of 8 exposures of 126.8 s each. The reduction was done using the standard “firehose” IDL package (Simcoe et al. 2013).
Multi-wavelength (300–2500 nm) intermediate resolution spectra were obtained using the ESO Very Large Telescope (VLT) with X-shooter (Vernet et al. 2011), mounted at the Cassegrain focus of the 8m VLT UT2 telescope. UVB, VIS, and NIR arm data (covering the 300–559.5, 559.5–1024 and 1024–2480 nm wavelength ranges, respectively) were reduced using the X-shooter dedicated pipeline through the ESOREFLEX environment (Freudling et al. 2013). Optical and NIR spectra will be released through the Weizmann Interactive Supernova data REPository (WISEREP33; Yaron & Gal-Yam 2012).

3.2. Light Curves

Photometric data are shown in Figure 4 and reported in Tables 2–4, including publicly available early-time photometry (Chen et al. 2016; Smith et al. 2016).

The griz data were mainly provided by the Las Cumbres Observatory (Brown et al. 2013). Additional griz data were obtained using the MPG/ESO 2.2 m telescope at the La Silla Observatory with the Gamma-ray Burst Optical/Near-infrared Detector (GROND; Greiner et al. 2008), which also provided early-phase photometric data at near-infrared (NIR) wavelengths; the 2 m Liverpool Telescope with the optical imaging component of the Infrared-Optical camera (IO:O); the 2.56 m NOT with the ALFOSC, and the Las Campanas Observatory 1 m Swope Telescope with an E2V camera (Bowen & Vaughan 1973). Pre-reduction steps (including bias, flat-field corrections, image-stacking, and astrometry calibration) for GROND frames were performed as in Krühler et al. (2008), while the final magnitudes for the GROND, IO:O, ALFOSC, and Swope frames were obtained using the reduction pipeline SNOOPY.34 All these images were template-subtracted and photometry was calibrated to the AAVSO Photometric All-Sky Survey (APASS35) catalog.

DLT16am was also observed in the framework of the CHilean Automatic Supernova sEarch survey (Pignata et al. 2009) in Johnson-Cousins R filters using the PROMPT1 telescope (Reichart et al. 2005). All images were reduced following standard procedures, including dark (with the same exposure time) and flat-field corrections, and then they were template-subtracted. The computed photometry is relative to a local sequence calibrated in the field of NGC 1532. The PROMPT1 Johnson-Cousins R-band magnitudes were transformed to the Sloan r-band following the procedure reported in Pignata et al. (2008).

Unfiltered data were provided by the DLT40 (see Section 2) SN search using the 0.4 m PROMPT5 telescope (Reichart et al. 2005), template-subtracted, and calibrated to the APASS r-band.

DLT16am exploded in the same host and ~2 weeks after the Type Ic SN 2016iae (Jha et al. 2016), and pre-SN V-band

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33 https://wiserep.weizmann.ac.il/
34 http://sngroup.oapd.inaf.it/snoopy.html
35 https://www.aavso.org/apass
acquisition images of the field were obtained during its PESSTO spectroscopic campaign. These data were used to constrain the explosion epoch and are included in the V-band light curve of DLT16am (see Smith et al. 2016 and Section 5).

JHK data were also provided by PESSTO36 using the 3.58 m NTT with the Son Of ISAAC camera (SOFI; Moorwood et al. 1998) and reduced using their dedicated pipeline (see Smartt et al. 2015). Further NIR photometry was provided by the NOT Unbiased Transient Survey (NUTS37) with the NOT near-infrared Camera and spectrograph (NOTCam). Pre-reduction steps for NOTCam data were obtained with a modified version of the external IRAF package NOTCAM (v.2.5).38 In addition to differential flat-fielding and median sky level correction, a bad pixel masking and distortion correction were applied before stacking dithered images. Magnitudes were obtained from pre-reduced images using a dedicated pipeline (FOSCGUI).39 NIR photometry was calibrated to the Two Micron All-Sky Survey40 catalog, through point-spread-function (PSF) fitting techniques.

DLT16am was also observed with Swift/XRT on 2016 November 25 (for 2889.4 s), November 26 (for 2966.8 s), November 28 (for 1023.9 s), and December 1 (for 2936.8 s). A previous Swift/XRT exposure of SN 2016iae (which is in the same galaxy) was used to extract the background in the region of DLT16am. Due to this complicated background, we obtained a limiting count rate (assuming an 18” radius) of 1.67 × 10⁻³ counts s⁻¹. Assuming a power-law model with a photon index of 2 and a Galactic absorption A_V = 0.35 m, we find the X-ray luminosity to be 1.67 × 10⁻³ erg cm⁻² s⁻¹.

Table 1
Log of the Spectroscopical Observations

<table>
<thead>
<tr>
<th>Date (UT)</th>
<th>JD</th>
<th>Phase (day)</th>
<th>Instrumental Setup</th>
<th>Grism/Grating</th>
<th>Spectral Range (Å)</th>
<th>Exposure Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20161122</td>
<td>2457715.144</td>
<td>+2</td>
<td>FTS+FLOYDS</td>
<td>2351/mm</td>
<td>5000 – 9200</td>
<td>3600</td>
</tr>
<tr>
<td>20161123</td>
<td>2457716.557</td>
<td>+4</td>
<td>NOT+ALFOSC</td>
<td>Gr4</td>
<td>4000–9700</td>
<td>2400</td>
</tr>
<tr>
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<td>SALT+RSS</td>
<td>PG0300</td>
<td>3200–9200</td>
<td>2250</td>
</tr>
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<td>GB+GR</td>
<td>9000–22000</td>
<td>6 × 270 + 450</td>
</tr>
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<td>+11</td>
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<td>Gr16</td>
<td>6000–10000</td>
<td>2700</td>
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<td>Gr4</td>
<td>4000–9700</td>
<td>2400</td>
</tr>
<tr>
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<td>ESO NTT+EFOSC2</td>
<td>Gr16</td>
<td>6000–10000</td>
<td>2700</td>
</tr>
<tr>
<td>20161222</td>
<td>2457744.517</td>
<td>+32</td>
<td>ESO VLT+X-shooter</td>
<td>UVB+VIS+NIR</td>
<td>3500–25000</td>
<td>700 + 600 + 600</td>
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<td>2457744.881</td>
<td>+32</td>
<td>FTN+FLOYDS</td>
<td>2351/mm</td>
<td>5000–9200</td>
<td>3600</td>
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<td>Gemini+GNIRS</td>
<td>ShortXD</td>
<td>8800–2400</td>
<td>3000</td>
</tr>
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<td>3600</td>
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<td>2351/mm</td>
<td>5000–9200</td>
<td>3600</td>
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<tr>
<td>20170102</td>
<td>2457755.671</td>
<td>+43</td>
<td>Baade+FLR</td>
<td>LDPism</td>
<td>8800–20000</td>
<td>8 × 126.8</td>
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<td>8 × 270 + 4 × 450</td>
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<td>2351/mm</td>
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<td>ShortXD</td>
<td>8800–2400</td>
<td>3000</td>
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<td>6000–10000</td>
<td>2400</td>
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<td>+60</td>
<td>ESO NTT+SOFI</td>
<td>GB+GR</td>
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<td>8 × 270 + 4 × 450</td>
</tr>
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<td>2457779.635</td>
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<td>2400</td>
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<td>ESO NTT+EFOSC2</td>
<td>Gr16</td>
<td>6000–10000</td>
<td>2700</td>
</tr>
</tbody>
</table>

Note. FTN: 2 m Faulkes Telescope North, Las Cumbres Observatory node at the Haleakala Observatory, Hawaii; FTS: 2 m Faulkes Telescope South, Las Cumbres Observatory node at the Siding Spring Observatory, Australia; NOT: 2.56 m Nordic Optical Telescope, located at Roque de los Muchachos, La Palma, Spain; ESO VLT: 8.2 m Very Large Telescope, located at the ESO Cerro Paranal Observatory, Chile; ESO NTT: 3.58 m New Technology Telescope, located at the ESO La Silla Observatory, Chile; Baade: 6.5 m Magellan (Walter Baade) Telescope at the Las Campanas Observatory, Chile; Gemini: 8.19 m Gemini North Telescope at the Mauna Kea Observatories, Hawaii.

NGC 1532, the host of DLT16am, is a SB(s)b edge-on galaxy (de Vaucouleurs et al. 1991), located at R.A. = 04:12:04.3, decl. = −32:52:27 (J2000), with an apparent total magnitude of B = 10.65 ± 0.09 mag (Laubert et al. 1989), showing prominent dust lanes close to the position of DLT16am. From our X-shooter spectrum obtained on 2016 December 22, we infer a heliocentric velocity of 1367 km s⁻¹ (z = 0.00456, see Section 6.1), estimated from the average positions of the Balmer emission lines. Throughout

### 4. The Host Galaxy

NGC 1532 is a SB(s)b edge-on galaxy (de Vaucouleurs et al. 1991), located at R.A. = 04:12:04.3, decl. = −32:52:27 (J2000), with an apparent total magnitude of B = 10.65 ± 0.09 mag (Laubert et al. 1989), showing prominent dust lanes close to the position of DLT16am. From our X-shooter spectrum obtained on 2016 December 22, we infer a heliocentric velocity of 1367 km s⁻¹ (z = 0.00456, see Section 4.1).
are the errors, until the to match the available colors BV and through the H4.1V, for BV). A comparable value r and 5) from the center of the host for DLT16am BV Å2012 grri V, where E Vi rir i 43x751 The Astrophysical Journal, details calibrated to the Vega and to the AB photometric system, respectively. The red ticks mark those of the NIR spectra. The blue ticks mark the epochs at which optical spectra were obtained, while Figure 4. Section 8.4 kpc. While for the foreground Galactic extinction we assumed While for the foreground Galactic extinction we assumed AV = 0.042 mag, as derived from the Schlafly & Finkbeiner (2011) IR-based dust map, the determination of the host-reddening in the direction of DLT16am proved to be more complicated. Early spectra of DLT16am exhibit a very red continuum, with low or almost no signal at wavelengths <6000 Å (with the exception of very early phases, T ≲ 5 days; see Section 6.1), a signature of very high reddening in the direction of the transient.

In order to get an estimate of the host-galaxy-reddening, we measured the equivalent widths (EWs) of the Na i D doublet in our X-shooter spectrum (see Figure 5), on the basis of the correlation between the strength of the Na iD λ5890, 5896 absorption and the color excess (see Poznanski et al. 2012; Phillips et al. 2013).

The estimated values (EW1 ≈ 1.7 Å, EW2 ≈ 2.5 Å) are significantly larger than the saturation limit, where the relation flattens (EW ≳ 0.2 Å; see Poznanski et al. 2012). We therefore estimated the reddening by matching the colors of DLT16am, during the plateau phase, with those of other SNe II (i.e., SNe 2013ej, 2013ab, 2013by and 2014cx; Valenti et al. 2014, 2015; Bose et al. 2015; Huang et al. 2016, respectively; see Figure 6). These transients were selected among those with similar plateau lengths and observed using similar filters, and for the same reasons, are used throughout the paper as comparison objects.

During the plateau phase, the outer hydrogen layer starts to recombine as its temperature decreases to ~6000 K, until the recombination front reaches its base and the plateau ends. This recombination temperature of hydrogen is relatively insensitive to density and metallicity and hence during the plateau SNe II typically share similar physical conditions (see, e.g., Schmidt et al. 1992). A scatter in their colors may therefore be attributed to extinction rather than other intrinsic behaviors (see, e.g., Faran et al. 2014b, and references therein). We therefore fitted the color excess E(B - V) to match the available colors (g - r, r - i, V - r, and V - i) of the comparison objects (hereafter “references”) within the plateau phase, after correcting the observed colors of the references for the corresponding total extinction. A set of values was obtained comparing the colors of DLT16am to those of each reference, taking the minima of the χ2 distributions obtained for each color (i.e., χ2 = ∑ (colr,ref - colr,DLT16am)2, where σ2 col are the errors on the colors of DLT16am, and k = g - r, r - i, V - r, V - i). We also accounted for the uncertainties on the photometry of the references through Monte Carlo simulations, randomly shifting the colors within their errors.

Different extinction laws were recently proposed after analyzing heavily extinguished objects (see, e.g., the case of the obscured Type Ia SN 2002cv Elias-Rosa et al. 2008). Following Calzetti et al. (2000), we also tested their proposed extinction law with RV = 4.05 ± 0.80, getting a reasonable fit to the colors of the references, but unusual bright absolute peak magnitudes for DLT16am (MV = −18.84 ± 0.77 mag), although still within the combined errors on the reddening and distance. For this reason, we cannot rule out a different extinction law for the environment of DLT16am, although we remark that changing RV did not significantly improve the result of the fit. Hereafter, we will therefore adopt a standard value (RV = 3.1; Cardelli et al. 1989). Averaging the best-fit values obtained using the different references we find E(B - V) = 1.95 ± 0.15 mag. A comparable value was obtained measuring the Balmer decrement (i.e., E(B - V) ≈ 2.0 mag through the Hα/Hβ flux ratio) from our X-shooter spectrum, assuming a case B recombination ratio and a standard extinction law with RV = 3.1 (see, e.g., Botticella et al. 2012).

In Figure 6 we show the resulting color evolution and absolute magnitudes of DLT16am, compared with those of the references. We find color evolutions comparable with those of the models, while DLT16am shows brighter absolute magnitudes than those displayed by other objects (but similar to those observed in SN 2013by). In Section 7 we will show that the derived absolute magnitude is consistent with the photospheric
expansion velocity derived from the spectroscopic analysis, matching the existing luminosity–velocity relation for SNe II.

### 4.2. Metallicity and Star Formation Rate

After correcting our X-shooter UVB and VIS spectra for the foreground Galactic extinction, redshift (using the values reported above), and host galaxy extinction, we estimated the local metallicity and SFR of NGC 1532 at the position of DLT16am. An identification of the host galaxy lines commonly used in the literature is reported in Figure 7.

Using the calibration of Pilyugin & Mattsson (2011), based on the strong emission lines of O$^{++}$, N$,^+$, and S$^+$ (the NS calibration), we estimate a local metallicity of 12 + log(O/H) = 8.45 dex or 12 + log(N/H) = 7.46 dex, while following Pettini & Pagel (2004) we obtain

![Figure 5. Zoomed-in view of the region of the Na I D doublet in our X-shooter spectrum. The positions of the host and Galactic Na I D lines are marked with black dashed and blue solid lines, respectively. The best-fit Gaussian models for the Galactic Na I D lines are overplotted using orange solid lines.](image-url)
and their redefinition of the $O_{N_2}$ indices (Alloin et al. 1979) respectively. Assuming a solar value of $12 \log O/H = 8.67$ dex (Asplund et al. 2009), these correspond to $Z \sim \varepsilon$, which is larger than the mean value found by Andresson et al. (2016) for a sample of SNe II, and might be even higher, since metallicity values estimated through line diagnostic are believed to underestimate local abundances (see, e.g., López-Sánchez et al. 2012).

Following Rosa-González et al. (2002), we derive the local SFR from the luminosities of H$_\alpha$, using the relation given by Kennicutt et al. (1994):

$$ML_{\text{SFR}} H_\alpha \, \text{yr}^{-1} = 7.9 \times 10^{-44} L_{H\alpha} \, \text{erg s}^{-1}.$$  \hspace{1cm} (1)

Accounting for the derived distance of NGC 1532, we obtain a local SFR of $1.64 \times 10^{-1} M_\odot \, \text{yr}^{-1}$. This is considerably lower than the SFR of NGC 1532, inferred from its far-infrared (FIR) luminosity. The FIR luminosity for NGC 1532 was derived from its 60 $\mu$m integrated flux density ($9.63 \pm 0.034$ Jy; Sanders et al. 2003), assuming $L_{\text{FIR}} \approx 1.7 L_{60\mu m}$ (Chapman et al. 2000) and a distance of 20 Mpc. Using the relation given by Kennicutt (1998),

$$\text{SFR}(\text{FIR}) (M_\odot \, \text{yr}^{-1}) \approx 4.5 \times 10^{-44} L_{\text{FIR}} \, \text{erg s}^{-1}.$$  \hspace{1cm} (2)

we obtain a global SFR of $\approx 2.2 M_\odot \, \text{yr}^{-1}$, in agreement with the results obtained by Botticella et al. (2012) for the hosts of a sample of nearby ($D < 11$ Mpc) SNe II, corresponding to a specific SFR (sSFR, the SFR per unit of stellar mass) of log sSFR $\approx 10.8$ dex, assuming a stellar mass of $10^{11.14} M_\odot$ (Muñoz-Mateos et al. 2015).

Figure 6. Absolute $g$, $V$, $r$, and $i$-band light curves (left) and $g - r$, $r - i$, $V - r$, $V - i$ color curves (right) of DLT16am, adopting a contribution of $E(B - V) = 1.95 \pm 0.15$ mag from the host galaxy to the total extinction. The absolute light and color curves of the references adopted to infer the host extinction (see the text for more details) are also shown for comparison. The representative error bar at +200 days and +16 mag in the absolute curve panels corresponds to the uncertainty on the derived extinction in the direction of DLT16am, while the green error bar corresponds to the uncertainty on the distance modulus. The dashed black vertical lines in the color curves delimit the region where the colors of DLT16am are fitted to the references (see the text for additional details).

Figure 7. UVB and VIS X-shooter spectra obtained on 2016 December 22. The narrow lines emitted by the host galaxy are identified. The insets in the top and bottom panels show zoomed-in views around the main spectral features.

The early evolution ($\lesssim 10$ days) of the $g - r$, $r - i$, $V - r$, and $V - i$ colors is fast, suggesting a rapid temperature evolution (see also Section 6), supporting our claim that DLT16am was discovered soon after the explosion.

The pseudo-bolometric light curve of DLT16am was computed converting the available magnitudes to flux densities at the corresponding effective wavelengths, which were subsequently integrated using Simpson’s rule. The resulting light curve is shown in Figure 8, along with those of other SNe computed following the same prescriptions and using similar filters. From the analysis of the bolometric light curve of DLT16am, we infer a peak luminosity of $\log L \approx 43$ dex, which has to be considered a lower limit, since the contribution of the UV flux is, in general, important in early SN light curves. On the other hand, at later times (e.g., on the radioactive-decay tail), UV bands give a minor contribution to the total flux. We can therefore use the pseudo-bolometric light curve to infer the $^{56}$Ni mass produced during the SN explosion. This quantity is generally estimated using the method described in Spiro et al. (2014), taking the bolometric luminosity of SN 1987A during the nebular phase as a reference.

We therefore extrapolated the pseudo-bolometric light curve of DLT16am assuming a complete trapping of the $\gamma$-rays produced by the $^{56}$Co decay ($\approx 1$ mag/100 days). Starting from the last observed point (which is likely a few days after the onset of the radioactive tail), we compared the extrapolated luminosity at $\approx +150$ days with that of SN 1987A computed using the same integration limits and at the same phase, to get a rough estimate of the mass of radioactive $^{56}$Ni deposited in the SN ejecta. Using the relation

$$M^{^{56}\text{Ni}} = 0.075 M_\odot \times \frac{L_{\text{SN}}(t)}{L_{\text{STA}}(t)},$$

we infer a relatively high $^{56}$Ni mass of $0.21 \pm 0.09 M_\odot$. A similar amount of radioactive $^{56}$Ni was derived for the Type II-P SN 1992am (Schmidt et al. 1994), while a larger limit was given for SN 2009kf ($M^{^{56}\text{Ni}} < 0.4 M_\odot$; see Botticella et al. 2010). Although the derived luminosity might be significantly affected by the large uncertainty in the estimated extinction and distance modulus, we remark that the photospheric expansion velocity inferred from the spectroscopic analysis is in agreement with the derived bright absolute $i$-band magnitude (and hence the derived total reddening) for DLT16am, according to the existing luminosity–velocity relation (Hamuy & Pinto 2002) for SNe II (see Section 7). In addition, the derived $^{56}$Ni also mass seems to be in agreement with the trend followed by SNe II, with comparable photospheric velocities and absolute magnitudes (see Hamuy 2003a).

### 6. Spectroscopy

Our spectroscopic follow-up campaign started on 2016 November 22.64 UT (2 days after the explosion), lasting up to 2017 March, 7.01 UT (at $\approx 110$ days). NIR spectra were obtained within the same period, with a lower cadence. The flux calibration was checked using photometric information obtained during the closest nights, scaled using low-order polynomials.

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**Figure 8.** Pseudo-bolometric light curve of DLT16am compared to light curves of other SNe II. The luminosities were obtained using similar filters and integration limits. A representative error bar is also shown, corresponding to the uncertainty on the derived extinction in the direction of DLT16am.

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### 5. Photometry

Roughly 2 weeks before the discovery of DLT16am, the Type Ic SN 2016iae exploded in NGC 1532 (Tonry et al. 2016). Pre-SN images of DLT16am were collected during the photometric follow-up campaign of SN 2016iae carried out with the Las Cumbres Observatory 1 m telescope network, and these images provided the template images used in our photometric analysis. GROND data and NTT acquisition images of SN 2016iae were used as templates for frames obtained with the same instrumental setup.

Prior to the discovery on 2016 November 21.19 UT (Tartaglia et al. 2016b), the last DLT40 non-detection was on 2016 November 19.19 UT ($R > 20.7$ mag), suggesting JD = 2457712.7 $\pm$ 1.0 days as the explosion epoch for DLT16am. On the other hand, after the initial discovery, Smith et al. (2016) reported previous detections of the transient on PESSTO V-band acquisition images of SN 2016iae. Although they report a marginal detection on 2016 November 20.10 UT (JD = 2457712.6), when analyzing these archival images we could not find any point source within $\approx 3''$ from the position of DLT16am, while we clearly detected the transient on 2016 November 21.10 UT (JD = 2457713.6). Since the detection limit in the frame obtained on November 20.10 UT is not deep enough to rule out the presence of the transient at this time ($V > 20.2$ mag), we will assume 2457712.6 $\pm$ 1.0 days as the explosion epoch, and refer to this date in computing the phases in both our photometric and spectroscopic analysis.

The final apparent light curves are shown in Figure 4, while Figure 6 shows the absolute and color curves obtained after correcting for the host galaxy extinction (see Section 4.1). Due to the high extinction ($E(B-V) = 1.95 \pm 0.15$ mag see Section 4.1), DLT4016am was never detected in the $B$-band during the first $\approx 60$ days after the explosion, while early detections covering the rise to the light curve maximum at redder wavelengths were available. At early phases, the light curves show relatively fast rises to the maximum in all bands, after which they set on a plateau-like phase with roughly constant magnitudes up to $\approx +80$ days.
6.1. Optical Spectra

Early optical spectra are dominated by a nearly featureless and very red continuum (before reddening correction), with narrow Hα and [S II] lines from the host and little or no flux at wavelengths shorter than 5000 Å. After correcting for the foreground Galactic extinction ($A_V = 0.042$ mag), redshift ($z = 0.00456$, inferred from the X-shooter spectrum; see Section 4) and host extinction ($A_V \approx 6.12$ mag), we estimated the temperature of the ejecta at early phases using a blackbody function to fit the spectral continuum through the CURVE_FIT tool available in the SciPy41 package (Jones et al. 2001; Van Der Walt et al. 2011). We find a rapid decrease, from $16300 \pm 6600$ K at +2 days to $10600 \pm 3200$ K at +5 days, in agreement with the fast color evolution within the early phases (see Section 5), although the large uncertainties might suggest a lack of clear evolution in temperature. The errors on the derived temperatures were estimated by applying different extinction values, within the range of the derived uncertainty on the reddening (see Section 4.1). At later phases ($t > +5$ days), we could not determine the temperatures, since no contribution from the SN to the spectral continuum at $\lambda < 6000$ Å was observed, due to the high extinction (see Section 4.1) and the low signal-to-noise ratio (S/N) of later spectra.

Figure 9 (left panel) shows the results of the blackbody fit to the spectra up to $\approx +5$ days. As discussed by Rabinak & Waxman (2011), the timescale of the cooling phase subsequent to the SN shock breakout heating of the progenitor envelope strongly depends on the initial progenitor properties, such as its radius, density profile, opacity, and composition. Using their formalism (i.e., their Equation (12)), we infer a rough estimate of the progenitor radius fitting the temperature evolution of DLT16am during the first $\approx 5$ days of its spectroscopic evolution (see Rabinak & Waxman 2011 and Rubin & Gal-Yam 2017, for an analysis on the limitations of analytic models). Figure 9 (right panel) shows the resulting fit (obtained assuming an explosion energy of $10^{51}$ erg and a typical optical opacity for a H-rich gas, $\kappa = 0.34$ cm$^2$ g$^{-1}$; Rabinak & Waxman 2011), along with the temperature evolution obtained for other SNe II.

Direct imaging in deep pre-SN archival images confirmed the claim that the majority of SNe II have red super-giant (RSG) progenitors (see, e.g., Maund et al. 2005; Smartt 2009; Fraser et al. 2011; Van Dyk et al. 2012a, 2012b). We therefore adopt the typical mass range for RSG progenitors (8–17 $M_{\odot}$, Smartt 2009), and using the Rabinak & Waxman (2011) formalism we obtain a radius of 30–660 $R_{\odot}$ for the progenitor of DLT16am, where the uncertainty is largely due to the error on the estimated reddening. Although the model is weakly dependent on the mass of the progenitor (see Rabinak & Waxman 2011), the large uncertainty on the derived temperatures does not allow us to rule out a blue super-giant (BSG) star as a viable progenitor for DLT16am (see Figure 9, right panel).

From $+24$ days a broad FWHM (FWHM $\approx 9000$ km s$^{-1}$) Hα feature in emission starts to dominate the flux, masking the presence of the host [S II] lines, with blueshifted peaks typical of SNe II (see Anderson et al. 2014a, for a discussion). Following Anderson et al. (2014a) and Gutierrez et al. (2014), we measure the Hα blueshifted emission offset and the ratio between the EWs of its absorption and emission P-Cygni components ($a/e$). We find a significant blueshifted Hα peak ($V \approx 3300$ km s$^{-1}$) at $+30$ days and a small contribution of the absorption component to the Hα P-Cygni profile ($a/e \approx 0.06$), both indicative of fast-declining light curves during the plateau phase and in agreement with the results of our photometric analysis (see Section 7). From the same phase we also detect the NIR (8498, 8542, 8662 Å) Ca II and O I (7772, 7774, 7775 Å) triplets, both becoming more evident at later phases. Ca I $\lambda 4959$ and Mg II $\lambda 29218$ lines appear between $+58$ and $+59$ days, while forbidden [Ca II] lines are visible from $+91$ days, marking the onset of the nebular phase, possibly blended with the [O II] 7319, 7330 Å doublet. From the same phase we note a significant change in the relative strengths of the Ca II NIR triplet, which is likely caused by the appearance of the nebular [O I] 8446 Å line.

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41 https://www.scipy.org/
From the positions of the minima of the P-Cygni absorption profiles, we derived an estimate of the expansion velocities for different ions. Hα P-Cygni profiles are clearly visible only from +30 days, when we derive an expansion velocity of \( \approx 8700 \text{ km s}^{-1} \), slowly declining to \( \approx 7100 \text{ km s}^{-1} \) at +97 days (see also Figure 10, panel a). While the Fe II λ5169 line is generally assumed as a good tracer of the photospheric velocity, we could not detect this line in any of our spectra of DLT16am due to the high extinction (see Section 4.1). We therefore obtained a rough estimate of the photospheric velocity from the minima of the prominent O I triplet, getting a relatively fast evolution from \( \approx 6300 \text{ km s}^{-1} \) (at +30 days) to \( \approx 3000 \text{ km s}^{-1} \) (at +97 days; see Section 7 and Figure 10 for a detailed discussion). The Ca II NIR triplet was partially resolved, and we inferred an expansion velocity declining from \( \approx 6400 \text{ km s}^{-1} \) to \( 5000 \text{ km s}^{-1} \) for the blend of the 8498, 8542 Å lines, and from 7500 to 3900 km s\(^{-1}\) for the 8662 Å line.

### 6.2. Near Infrared Spectra

At +7 days, our SOFI spectrum shows an almost featureless continuum, while at later phases spectra show a significant metamorphosis, as broad H lines with prominent P-Cygni profiles start to dominate the flux. Following the NIR line identifications proposed for SNe 2004et (Maguire et al. 2010) and 1998BS (Pozzo et al. 2004), we identify most of the main H Paschen (from Paα up to Paζ) and Brackett (from Brγ up to Brγ) lines, although the Paγ line is most likely a blend with He I (10830 Å). Beginning on +34 days, we also detect the Ca II NIR triplet. We also identify Sr II λ10327 in the blue part of the spectra beginning on +43 days, when the feature is still partially blended with the Paα line, becoming more evident at later phases.

C I and Mg II lines appear from +54 days, in agreement with the analysis performed on the optical spectra (although we cannot rule out the presence of these lines also at +43 days). From the Paβ absorption minima, we infer an expansion velocity decreasing from \( \approx 8340 \text{ km s}^{-1} \) at +34 days to \( \approx 3460 \text{ km s}^{-1} \) at +107 days, which is consistent with the evolution derived from Hα (see above); while measuring the prominent blue minimum in the blue part of the Paγ+HeI 10830 Å profile, we infer higher expansion velocities, declining from \( \approx 9000 \text{ km s}^{-1} \) to \( \approx 5660 \text{ km s}^{-1} \) from +34 days to +107 days, respectively.

From +43 days we notice a second absorption feature in the blue part of the P-Cygni absorption component of Paβ, becoming more evident at later phases, which might be attributed to a rapidly expanding outer H shell moving at a roughly constant velocity (9400−9500 km s\(^{-1}\)). High-velocity (HV) components not evolving in time were observed also in the Hα profile and He I 10830 Å of other SNe II (see, e.g., the case of SNe 2009bw; Inserra et al. 2012, 1999em and 2004dj; Chakraborti et al. 2012 and the discussion in Chugai et al. 2007) and attributed to weak interaction between the SN ejecta and a pre-existing CSM surrounding the progenitor star. Analyzing HV components in the Hα and He I 10830 Å profiles during the photospheric phase, Chugai et al. (2007) computed a model for ejecta–circumstellar interaction in SNe II-P. Although the expansion velocities inferred from the Paγ/P-Cygni minimum suggest that the entire absorption component might be mainly attributed to the He I 10830 Å line, Figure 11 shows that a similar feature was never observed in the Hα profile at any phase, with the possible exception of the +58 days spectrum. On the other hand, the S/N of our spectra is not sufficient to safely rule out the presence of this feature at optical wavelengths.

### 7. Comparison with Other SNe II

In Figure 6 we compared the main photometric properties of a sample of luminous and more canonical SNe II. The left panels show that DLT16am is brighter than the normal Type II SNe 2014cx (Huang et al. 2016) and 2013ej (Valenti...
et al. 2014, although the large uncertainties on the extinction suggest comparable plateau magnitudes), while high luminosities are not unusual among SNe II (see, e.g., the case of SN 2013by; Valenti et al. 2015).

Following the prescriptions of Valenti et al. (2016), we estimate photometric parameters using the V-band photometric evolution. As the V-band maximum we consider the point at which the variation in magnitude is less than 0.1 mag day$^{-1}$, while $S_{50V}$, the decline rate in mag/50 days, was computed soon after the maximum (10 days after the explosion) to +50 days after the explosion. Figure 12 summarizes the results of this analysis, compared to those obtained for other SNe II (Valenti et al. 2016). The V-band maximum for DLT16am occurs on JD = 2457719.95, corresponding to an absolute magnitude $M_V = -18.48 \pm 0.77$ mag (where the error is almost entirely due to the uncertainty on the reddening and the distance modulus) and to a relatively fast rise time of 7.4 \pm 1.0 days. At redder wavelengths we find longer rises (10.9, 11.4, and 11.9 days in the r-, i-, and z-bands, respectively), in agreement with the results obtained by González-Gaitán et al. (2015) on a large sample of SNe II. In the r-band, on the other hand, we find that DLT16am has a relatively slow rise if compared to the sample of Rubin et al. (2016).

Comparing the early-time absolute r-band light curve of SN 2010id with those of SNe 2005cs (Pastorello et al. 2009) and SN 2006bp (Quimby et al. 2007), Gal-Yam et al. (2011) suggested a possible trend for subluminous and “normal” events, with faster rises with a sharp onset of the flat plateau for fainter objects, with SN 2006bp showing a more gradual transition over a longer period. Including the slow-rising SNe 2009bw (Inserra et al. 2012) and 2013ej R-band light curves in the comparison, Valenti et al. (2014) also argued that slow-rising SNe II might be brighter than fast-rising transients. The fast rise and the bright absolute magnitude shown by DLT16am seem to contradict these predictions, confirming the results obtained by Rubin et al. (2016) on a sample of R-band light curves of SNe II. Figure 12, left panel, we compare the early V-band absolute light curve of DLT16am with those of a sample of subluminous (SNe 2005cs; Pastorello et al. 2009 and 2010id; Gal-Yam et al. 2011), normal (SNe 2006bp; Quimby et al. 2007 and 2013ej Valenti et al. 2014), and luminous (SN 2013by; Valenti et al. 2015 and DLT16am) SNe II, all scaled to the luminosity of the plateau of SN 2010id, in order to gain better insight into their different rise times. We find a particularly good match with the subluminous SN 2005cs,
while more luminous transients, like SNe 2006bp and 2013ej, seem to have significantly longer rises to maximum light. This trend is confirmed by the comparison with a larger sample of SNe II shown in Figure 12 (right panel). DLT16am lies close to the brighter end of the absolute peak magnitude range, with a rise time comparable to those displayed by the faintest objects. Comparing the r-band absolute peak magnitude and rise time to the sample of Rubin et al. (2016; see their Figure 10), on the other hand, we find a longer rise time, while DLT16am falls in a scarcely populated region of their luminosity-rise time diagram. On the other hand, we have to remark that this might be due to the lack of transients with well constrained explosion epochs (see, e.g., the case of SN 2008fq and the large uncertainties in the rise times of the brightest objects).

The historical classification of Type II in II-P and II-L SNe has recently been debated (see, e.g., Arcavi et al. 2012; Anderson et al. 2014b; Faran et al. 2014a, 2014b; Sanders et al. 2015; Valenti et al. 2016). In order to give an accurate classification of DLT16am, in Figure 13 we compare the V-band light curve of DLT16am to the Type II-P and II-L SNe templates computed by Faran et al. (2014b, 2014a). Although DLT16am shows photometric features typically observed in SNe II-P (namely an extended plateau after maximum, with a subsequent steep drop in magnitude around +80 days), like SN 2013by (Valenti et al. 2014) its V-band light curve lies close to the bright end of the II-L templates, in an intermediate region between II-L and II-P templates. This is in agreement with the decline rate derived from the V-band light curve ($S_{\text{SOY}} = 0.84 \pm 0.04$ mag/50 days), which, according to Faran et al. (2014a), is greater than the limit for SNe II-P (0.5 mag/50 days; see Figure 13). Following Rubin & Gal-Yam (2016) and their proposed classification based on the early light curves morphology, we compare the r-band light curve of DLT16am to the results of their analysis on the sample of Rubin et al. (2016), obtaining a good match with their fast rise–fast decline (II-FF) cluster of SNe II.

Figure 14 shows a comparison of our +59 days spectrum with those of other SNe II, based on the best fits of the spectral features to archival spectra obtained using the “Supernova Identification” (SNID\textsuperscript{42}; Blondin & Tonry 2007) tool. While the best match was obtained with the Type II-P SN 2006bp (Quimby et al. 2007; Dessart et al. 2008), good fits of the spectral features were also obtained with the Type II-P SNe 2004et (Sahu et al. 2006; Misra et al. 2007; Maguire et al. 2010) and 1999en (Hamuy et al. 2001; Leonard et al. 2002; Elhmamdi et al. 2003; Dessart & Hillier 2006). Based on this similarity, we compared the expansion velocities of DLT16am with those obtained for SN 2006bp, obtaining similar values for all the ions visible in both sets of spectra (see Figure 10). Due to the high extinction, we could not compare the expansion velocities inferred from Fe ii (5169 Å) or Sc ii (6246 Å), which are typically considered good indicators of the photospheric velocity. On the other hand, SN 2006bp shows similar Fe ii (5169 Å) and O i (7773 Å) expansion velocities (see Figure 10, panel b) and based on the strong spectroscopic similarities between the two transients, we can therefore use the velocity evolution inferred from the O i minima as a rough estimate of the photospheric expansion velocity for DLT16am. Using the existing luminosity–velocity relation for SNe II (Hamuy & Pinto 2002; Hamuy 2003b), we can therefore perform an independent consistency check on the derived host galaxy reddening in the direction of DLT16am (see Section 4.1). Hamuy & Pinto (2002) used +50 days as an indicative epoch (roughly the midpoint of the plateau phase), and although DLT16am shows a relatively short plateau lasting $\sim$80 days, we will adopt the same approach, comparing the expansion velocity and absolute V-magnitude with those obtained from the sample of Hamuy (2003b) at similar phases. A similar approach was also adopted for the absolute V-band luminosity, where we took the uncertainty on the distance modulus and the total extinction as an estimate of the error on the derived magnitude. In Figure 15 we compare the results for DLT16am with those obtained for the sample of Hamuy (2003b). With a photospheric velocity of $\sim$4585 km s$^{-1}$.

\textsuperscript{42} https://people.lam.fr/blondin.stephane/software/snid/
and an absolute V-band magnitude at +50 days of \( M_V = -17.73 \pm 0.77 \) mag, DLT16am falls in the region of other luminous SNe II, in agreement with the expectation that luminous transients have higher expansion velocities (see also Rubin et al. 2016). The correlation between absolute peak magnitudes and expansion velocity was recently confirmed by Gutiérrez et al. (2017), who also confirmed the previous claim of Anderson et al. (2014a) and Valenti et al. (2016) that brighter SNe II show shorter plateau phases and steeper decline rates. Similar results were also reported by Galbany et al. (2016) by analyzing the light curves of a large sample of SNe II.

8. Summary and Conclusions

We have discussed the results of our analysis of the photometric and spectroscopic data obtained during our follow-up campaign of the Type II SN DLT16am (also known as SN 2016ija). The transient was discovered during the ongoing DLT40 survey, which is monitoring a sample of galaxies in the nearby universe in search of young SNe within the first days after explosion.

Early spectra showed a highly reddened, nearly featureless continuum, while H, Ca II, and O I lines with prominent P-Cygni profiles gradually appear at later phases. A comparison of the colors of DLT16am with those of other similar transients during the plateau phase suggests a contribution of \( E(B-V) = 1.95 \pm 0.15 \) mag from the host galaxy (NGC 1532) to the total extinction (see Section 4.1 and Figure 6). Although DLT16am was clearly detected by our survey at redder optical wavelengths, its substantial extinction of \( A_V \approx 6 \) mag supports the claim that optical surveys might be missing a significant fraction of nearby, highly reddened SNe (e.g., Mattila et al. 2012; Jencson et al. 2017). Other examples of recent heavily obscured CCSNe observed in nearby galaxies include SN 2009hd (Elias-Rosa et al. 2011), SN 2005at (Kankare et al. 2014a), and SN 2013cf (Kangas et al. 2016), SPIRITS15c and SPIRITS14buu; Jencson et al. 2017, or SNe 2008cs, 2011hi, and 2010P Kankare et al. 2008, 2012, 2014b). Such events can have important implications for a comparison between CCSN rates and cosmic star formation history.

Assuming a standard \( (R_V=3.1) \) extinction law (Cardelli et al. 1989) and a distance modulus \( \mu = 31.51 \pm 0.43 \) mag (Tully et al. 2013), we obtain a relatively bright absolute peak magnitude \( (M_V = -18.48 \pm 0.77 \) mag) compared to those displayed by other Type II-P-like SNe.

The absolute magnitude at +50 days is consistent with the photospheric velocity inferred at the same phase, according to the existing luminosity–velocity relation for SNe II (see Hamuy & Pinto 2002; Hamuy 2003b, and Figure 15). The derived slope within 50 days from the explosion \( (S_{50V}; \text{see Section 7}) \) suggests a relatively steep decline during the plateau phase \( (S_{50V} = 0.84 \pm 0.04 \) mag/50 days), which, according to Faran et al. (2014a; who gave a limit of 0.5 mag/50 days to the maximum slope for SNe II-P), means that DLT16am should be considered an SN II-L. A similar conclusion was reached by Valenti et al. (2014) in their analysis of SN 2013by, which, like DLT16am, showed an extended plateau, with a drop in magnitude around 80 days after the explosion (see also Figure 6).

In Figure 12 we have shown a comparison of the fundamental photometric parameters inferred for DLT16am with those obtained for a sample of SNe II. The fast rise time \( (7.4 \pm 1.0 \) days) and the bright V-band absolute magnitude at maximum \( (M_V = -18.48 \pm 0.77 \) mag) seem to contradict the prediction that luminous SNe II have long rise times compared to those of subluminous events. The lack of other SNe II in the region where DLT16am falls highlights its peculiarity, but might also be due to the lack of transients with well constrained explosion epochs.

It is therefore crucial to increase our sample of SNe II with well constrained explosion epochs and rise times, providing early discoveries and subsequent multi-wavelength data. With its estimated rate of \( \approx 4-5 \) SNe II per year discovered within 1 day from the explosion, confirmed by the number of discoveries during the first year of operations, the DLT40 survey will significantly increase the number of early discoveries, helping to further explore correlations between fundamental parameters of SNe II.

This work is based on observations collected at: the Very Large Telescope operated by the European Organisation for Astronomical Research in the Southern hemisphere, Chile as part of the ESO large programme 198.A-0915; ESOO La Silla Observatory as part of PESSTO (197.D-1075.191.D-0935); the Gemini Observatory, under program GN-2016B-Q-57, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the National Research Council (Canada), CONICYT (Chile), Ministerio de Ciencia, Tecnología e Innovación Productiva (Argentina), and Ministério da Ciência, Tecnologia e Inovação (Brazil).

This work is based on observations made with the Nordic Optical Telescope, operated by the Nordic Optical Telescope Scientific Association at the Observatorio del Roque de los Muchachos, La Palma, Spain, of the Instituto de Astrofísica de Canarias.

This paper includes data gathered with the 6.5 m Magellan Telescopes located at Las Campanas Observatory, Chile.

This work makes use of observations from the Las Cumbres Observatory network of telescopes.

This work includes data obtained with the Swope Telescope at Las Campanas Observatory, Chile, as part of the Swope Time Domain Key Project (PI Piro, Co-PIs Shappee, Drout, Madore, Phillips, Foley, and Hsiao).

SNooPy is a package for SN photometry using PSF-fitting and/or template subtraction developed by E. Cappellaro. A package description can be found at http://sngroup.oapd.inaf.it/snoopy.html.

FOSCGUI is a graphic user interface aimed at extracting SN spectroscopy and photometry obtained with FOSC-like instruments. It was developed by E. Cappellaro. A package description can be found at http://sngroup.oapd.inaf.it/fosogui.html.

Research by D.J.S. and L.T.L. is supported by NSF grants AST-1412504 and AST-1517649.

C.G. acknowledges support from the Carlsberg Foundation. R.C. and M.S. acknowledge support from STFC grant ST/L000679/1 and EU/FP7-ERC grant No. 615929. T.W.C. acknowledges the support through the Sofia Kovalevskaja Award to P. Schady from the Alexander von Humboldt Foundation of Germany.
Part of the funding for GROND (both hardware as well as personnel) was generously granted from the Leibniz-Prize to Prof. G. Hasinger (DFG grant HA 1850/28-1).

Support for G.P. is provided by the Ministry of Economy, Development, and Tourism’s Millennium Science Initiative through grant IC120009, awarded to The Millennium Institute of Astrophysics, MAS.

J.H. acknowledges financial support from the Finnish Cultural Foundation and the Vilho, Yrjö, and Kalle Väisälä Foundation of the Finnish Academy of Science and Letters. D.A.H., C.M., and G.H. are supported by NSF grant 1313484.

M.D.S. acknowledges support by a research grant (13261) from the VILLUM FONDEN and for financial support of NUTS by the Instrument Center for Danish Astrophysics (IDA).

L.G. was supported in part by the US National Science Foundation under grant 13-11862.

M.P., N.M., and E.Y.H. acknowledge the support provided by the National Science Foundation under grant No. AST-1008343, AST-1613472, and AST-1613426.

A.G.-Y. is supported by the EU via ERC grant No. 725161, the Quantum Universe I-Core program, the ISF, the BSF Ernest Rutherford Fellowship. K.M. acknowledges support from the STFC through an Ernest Rutherford Fellowship.

The UCSC group is supported in part by NSF grant AST-1518052, the Gordon & Betty Moore Foundation, and from fellowships from the Alfred P. Sloan Foundation and the David and Lucile Packard Foundation to R.J.F.

Facilities: VLT:Kueyen (X-shooter spectrograph Vernet et al. 2011), NTT (EFOSC2 Buzzoni et al. 1984 and OFOS Moorwood et al. 1998 spectrographs), Gemini:Gillett (GNIRS spectrograph; Elias et al. 2006), NOT (ALFOSC and NOTCam cameras), Magellan:Baade (FIRE spectrograph), FTN, FTS (FLOYDS spectrographs), LCOGT, Swope, Liverpool2m (IO:O camera), Max Planck:2.2m (GROND camera), CTIO:PROMPT (PROPT5 telescope; Reichart et al. 2005).


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