A strong ultraviolet pulse from a newborn type Ia supernova

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Type Ia supernovae are destructive explosions of carbon-oxygen white dwarfs. Although they are used empirically to measure cosmological distances, the nature of their progenitors remains mysterious. One of the leading progenitor models, called the single degenerate channel, hypothesizes that a white dwarf accretes matter from a companion star and the resulting increase in its central temperature and pressure ignites thermonuclear explosion. Here we report observations with the Swift Space Telescope of strong but declining ultraviolet emission from a type Ia supernova within four days of its explosion. This emission is consistent with theoretical expectations of collision between material ejected by the supernova and a companion star, and therefore provides evidence that some type Ia supernovae arise from the single degenerate channel.

On UTC (Coordinated Universal Time) 2014 May 3.29 the intermediate Palomar Transient Factory (iPTF, a wide-field survey designed to search for optical transient and variable sources) discovered an optical transient, internally designated as iPTF14atg, in the apparent vicinity of the galaxy IC 831 at a distance of 93.7 Mpc (see Methods subsection 'Discovery'). No activity had been detected at the same location in the images taken on the previous night and earlier, indicating that the supernova probably exploded between May 2.29 and 3.29. Our follow-up spectroscopic campaign (see Extended Data Table 1) established that iPTF14atg was a type Ia supernova.

Upon discovery we triggered observations with the Ultraviolet/Optical Telescope (UVOT) and the X-ray Telescope (XRT) onboard the Swift space observatory (observation and data reduction is detailed in Methods subsection 'Data acquisition'; raw measurements are shown in Extended Data Table 2). As can be seen in Fig. 1, the ultraviolet brightness of iPTF14atg declined substantially in the first two observations. A rough energy flux measure in the ultraviolet band is provided by $f_{UV} \approx 3 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$ in the ‘uvm2’ band. Starting from the third epoch, the ultraviolet and optical emission began to rise again in a manner similar to that seen in other type Ia supernovae. The XRT did not detect any X-ray signal at any epoch (Methods subsection ‘Data acquisition’). We thus conclude that iPTF14atg emitted a pulse of radiation primarily in the ultraviolet band. This pulse with an observed luminosity of $L_{UV} \approx 3 \times 10^{41}$ erg s$^{-1}$ was probably already declining by the first epoch of the Swift observations (within four days of its explosion).

Figure 1 also illustrates that such an early ultraviolet pulse from a type Ia supernova within four days of its explosion is unprecedented. We now seek an explanation for this early ultraviolet emission. As detailed in Methods subsection ‘Spherical models for the early ultraviolet pulse’, we explored models in which the ultraviolet emission is spherically symmetric with the supernova explosion (such as shock cooling and circumstellar interaction). These models are unable to explain the observed ultraviolet pulse. Therefore we turn to asymmetric models in which the ultraviolet emission comes from particular directions.

A reasonable physical model is ultraviolet emission arising in the ejecta as the ejecta encounters a companion. When the rapidly moving ejecta slams into the companion, a strong reverse shock is generated in the ejecta that heats up the surrounding material. Thermal radiation from the hot material, which peaks in the ultraviolet part of the spectrum, can then be seen for a few days until the fast-moving ejecta engulfs the companion and hides the reverse shock region. We compare a semi-analytical model to the Swift/UVOT lightcurves. For simplicity, we fix the explosion date at 2014 May 3. We assume that the exploding white dwarf is close to the Chandrasekhar mass limit (1.4 solar masses) and that the supernova explosion energy is $10^{51}$ erg. These values lead to a mean expansion velocity of $10^3$ km s$^{-1}$ for the ejecta. Since the temperature at the collision location is so high that most atoms are ionized, the opacity is probably dominated by electron scattering. To further simplify the case, we assume that the emission from the reverse shock region is blackbody and isotropic. In order to explain the ultraviolet lightcurves, the companion star should be located 60 solar radii away from the white dwarf (model A; black dashed curves in Fig. 1).

There are several caveats in this simple semi-analytical model. First, the model parameters are degenerate. For example, if we reduce the supernova energy by a factor of two and increase the binary separation to 90 solar radii, the model lightcurve can still account for the observed ultraviolet luminosities (model B; blue dashed curves in Fig. 1). Second, the emission from the reverse shock region is not isotropic. The ultraviolet photons can only easily escape through the conical hole carved out by the companion star and therefore the emission is more concentrated in this direction. Third, the actual explosion date is not well constrained, so that when exactly the companion collision happened is not clear. Our multi-wavelength observations soon after discovery of the supernova provide a good data set for detailed modelling.

We also construct the spectral energy distribution from the photometry and spectrum of iPTF14atg obtained on the same day of the first UVOT epoch and compare it with the blackbody spectra derived from models A and B. As can be seen in Fig. 2, the model blackbody spectra are consistent with the overall shape of the spectral energy distribution, indicating that the emitting regions can be approximated...
by a blackbody with a temperature of 11,000 K and a radius of 6,000 solar radii.

Next, given the diversity of type Ia supernovae, we investigate the specifics of iPTF14atg using its multi-band lightcurves (Fig. 3) and spectra (Fig. 4). First, the existence of SiII and S II absorption features in the pre-maximum spectra indicates that iPTF14atg is spectroscopically a type Ia supernova. Second, iPTF14atg, with a peak absolute magnitude of $M_B = 17.9$ mag in the $B$ band, is 1.4 magnitudes fainter than normal type Ia supernovae, which are used as cosmological distance indicators. Subluminous type Ia supernovae belong to three major families, with prototypical events being SN 1991bg, SN 2002cx, and SN 2002es. A comparative analysis of lightcurves and spectra between iPTF14atg and the three families (detailed in Methods subsection ‘Supernova specification’) shows that iPTF14atg is more luminous than SN 1991bg and evolves more slowly than SN 1991bg in both the rise and decline phases. The expansion velocity of iPTF14atg estimated from absorption lines is systematically lower than that of SN 1991bg. SN 2002cx and iPTF14atg have similar lightcurves, but iPTF14atg shows deep silicon absorption features in the pre-maximum spectra that are not seen in SN 2002cx and the post-maximum absorption features of iPTF14atg are generally weaker than those seen in SN 2002cx. We have only limited knowledge about the evolution of SN 2002es. Despite the fact that SN 2002es is one magnitude brighter at peak than iPTF14atg and that the lightcurve of SN 2002es shows an accelerating decline about 30 days after its peak, which is not seen in iPTF14atg, iPTF14atg shows a reasonable match to SN 2002es in both lightcurve shape and spectra with higher line velocities. In addition, the host galaxy IC 831 of iPTF14atg is an early-type galaxy. This is consistent with the host galaxies of known events similar to SN 2002es, while the majority of events like SN 2002cx occur in late-type galaxies.

Figure 1 | Swift/UVOT lightcurves of iPTF14atg. iPTF14atg lightcurves are shown with red circles and lines and are compared with those of other type Ia supernovae (grey circles). The magnitudes are in the AB system. The 1σ error bars include both statistical and systematic uncertainties in measurements. Lightcurves of other supernovae and their explosion dates are taken from previous studies. In each of the three ultraviolet bands (uvw2, uvm2 and uvw1), iPTF14atg stands out as exhibiting a decaying flux at early times. The blue and black dashed curves show two theoretical lightcurves derived from companion interaction models.

Figure 2 | The spectral energy distribution of iPTF14atg. The spectral energy distribution of iPTF14atg on 2014 May 6 (three days after the explosion) is constructed by using the iPTF r-band magnitude (red), an optical spectrum (grey), and Swift/UVOT measurements (green circles) and upper limit (green triangle). The error bars denote 1σ uncertainties. The blue and black blackbody spectra correspond to the model lightcurves as in Fig. 1.

Figure 3 | The multi-colour lightcurve of iPTF14atg. Following the convention, the magnitudes in the B and V bands are in the Vega system while those in the $g$, $r$ and $i$ bands are in the AB system. Error bars represent 1σ uncertainties. For clearer illustration, the lightcurves in different filters are offset (plus or minus) as indicated by the numbers following the filter labels.
fraction of events with companion interaction and thus the rate of events from the single degenerate channel.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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METHODS

Discovery. The intermediate Palomar Transient Factory (iPTF) uses the 48-inch Samuel Oschin telescope (P48) at Palomar Observatory, California, USA to characterize optical transients and variable stars.11 A single P48 frame has a field of view of 7.2 square degrees and achieves a detection threshold of r(AB) = 21 mag (5σ, that is, 99.9999% confidence level, CL). From February to June in 2014, iPTF conducted a fast-cadence experiment to search for young transients. Every field was monitored twice, separated by about an hour every night (weather permitting). Transients were identified in real time by a monitoring group aided by machine-learning classifiers.22,30 Panchromatic follow-up of young transients was carried out within hours after discovery.28

The supernova iPTF14atg was discovered on UTC 2014 May 22.03 and classified as a SNr-band magnitude of 20.3 upon discovery. No source was detected at the same location on images taken on UT 2014 May 22.05 and 22.29 down to a limiting magnitude of r = 21.4 (99.9999% CL). No activity had been found at this location in the iPTF archival data in 2013 (3 epochs) and 2014 (101 epochs) down to similar limiting magnitudes. This supernova was also independently discovered by the All-Sky Automated Survey for Supernovae on May 22 34 and classified as a SN 1991bg-like 1a supernova on June 3.28

SDSS (Data Release 12) measured the redshift of IC 831 to be 0.02129. With the cosmological parameters measured by Planck (Ω0 = 0.678 ± 0.014, Ωm = 0.298 ± 0.014, Ωb = 0.049 and ΩΛ = 0.001),18 we calculate a co-moving distance of 93.7 Mpc and a distance modulus of 34.9 mag for IC 831.

The photometric source data for Fig. 3 is available in the online version of the paper. Both photometric and spectroscopic data will also be made publicly available on WISEREP.9 (http://wiserep.weizmann.ac.il).

Data acquisition. Swift observations and data reduction. Starting on May 6, the Ultraviolet and Optical Telescope (UVOT)10 and the X-ray Telescope (XRT)10 onboard the Swift Space Observatory11 observed iPTF14atg for fourteen epochs in May and June (summarized in Extended Data Table 2). To subtract the host galaxy contamination, reference images were taken six months after the supernova explosion. Visual inspection to the reference images ensures that the supernova has faded away.

Photometric measurements of the UVOT images were undertaken with the uvotSOURCE routine in the HEASoft package (http://heasarc.nasa.gov/heasoft/). Instrumental fluxes of iPTF14atg were extracted with an aperture of radius 3′ centred at the location determined by the iPTF optical images and the sky background is calculated with an aperture of radius 20′ in the vicinity of iPTF14atg. The fluxes were then corrected by the growth curves of UVOT point spread functions and for coincidence loss. Then the instrumental fluxes were converted to physical fluxes using the most recent calibration11. The host galaxy flux is measured with the same aperture in the reference images. The XRT data were analysed with the XRT Science Analysis Software (XSAW) package. We estimated count rate upper limits at a 99.7% CL at the location of iPTF14atg for non-detections.

We use WebPIMMS (http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/w3pimms/w3pimms.pl) to convert the XRT upper limit on May 6 to physical quantities. As shown in Fig. 2, the optical and ultraviolet data taken on the same day can be characterized by a single P48 frame has a field of view of 7.2 square degrees and achieves a detection threshold of r(AB) = 21 mag (5σ, that is, 99.9999% confidence level, CL). From February to June in 2014, iPTF conducted a fast-cadence experiment to search for young transients. Every field was monitored twice, separated by about an hour every night (weather permitting). Transients were identified in real time by a monitoring group aided by machine-learning classifiers.22,30 Panchromatic follow-up of young transients was carried out within hours after discovery.

We also triggered LCOGT to follow up iPTF14atg in the griBV filters. Because no hydrogen is seen in the iPTF14atg spectra, we assume that the sphere is dominated by helium, so that A = 4 and Z = 2.

In case 1, the circumstellar gas is heated up by high-energy photons from the supernova shock breakout. The temperature of the gas is roughly 11,000 K, as determined by the optical–ultraviolet spectral energy distribution. To account for a ultraviolet luminosity of 3 × 10^43 erg s^-1, the radius R_e should be as large as 3 × 10^2 cm. The total mass of the sphere would be 10 solar masses and the total thermal energy would be 10^{52} erg. If the optical depth of the sphere is larger than unity, then we will end up with an even more massive sphere. So we are forced to invoke a sphere containing a mass much larger than a typical type Ia supernova. The absence of strong Na i D lines also argue against such massive circumstellar...
material. In addition, the elliptical host galaxy with no star-forming activity also excludes the existence of massive stars.

In case 2, the circumstellar gas is ionized by the supernova shock. The supernova shock has a typical velocity between 20,000 km s$^{-1}$ and 5,000 km s$^{-1}$. Hence, within four days of the supernova explosion, the supernova shock travelled to $R_s = 10^{15}$ cm. To account for the ultraviolet pulse, this small radius then requires an extremely high temperature of 10$^7$ K, which is inconsistent with the observed spectral energy distribution. Therefore we discard this model.

** Supernova specification.** We performed comparative analysis among iPTF14atg, SN 1991bg, SN 2002cx and SN 2002es on the photometric and spectroscopic evolution and host galaxy and demonstrate that iPTF14atg is likely to belong to the SN 2002es family.

**Photometry.** The multiband lightcurve of iPTF14atg is shown in Fig. 3. Note that there is an approximately 0.2 mag difference between the PTF r-band and LCOGT r-band magnitudes. We calculated synthetic photometry using the iPTF14atg spectra and the filter transmission curves and found that this difference was mainly due to the filter difference.

Because iPTF14atg is not a normal type Ia supernova, the usual lightcurve fitting tools for normal type Ia supernovae (for example, SALT2,54,55, SNoPy52) are not suitable to determine the lightcurve features. Thus we fit a 5th-order polynomial to the B-band lightcurve and derived a B-band peak magnitude of 17.1 mag on May 22.15 and Δm15 = 1.2 mag (Δm15 is the magnitude change of a type Ia supernova in 15 days from its peak, which astronomers use to measure the shape of its light curve). We also infer that the line-of-sight extinction is low because the Galactic extinction in this direction is A_B = 0.032 and because we do not see any sign of strong Na D absorption in all of our low-resolution and medium-resolution spectra of iPTF14atg. Hence, given the host galaxy distance modulus of 34.9 mag, we conclude that iPTF14atg has an absolute peak magnitude of −17.8 mag and that iPTF14atg is a subluminous outlier of the well-established relation between the peak magnitude and Δm15 (ref. 48).

We compare iPTF14atg with the three major families of subluminous type Ia supernovae with the prototypical events SN 1991bg, SN 2002cx and SN 2002es. From Extended Data Fig. 1, we can see that: (1) the peak magnitude of iPTF14atg is brighter than that of SN 1991bg, similar to SN 2005hk (a typical SN 2002cx-family event), and fainter than SN 2002es. However, both SN 2002cx and SN 2002es families have ranges of peak magnitudes54,55, (2) iPTF14atg evolves more slowly than SN 1991bg in both rise and decline phases. (3) iPTF14atg has a slower rise than SN 2005hk. (4) Unlike SN 2002es, iPTF14atg does not have a break in the lightcurve about 30 days after the peak. A caveat about this comparison is that the lightcurve of iPTF14atg, especially the very early part, might be distorted by the supernova–companion collision.

We present the near-ultraviolet and optical colour evolution of iPTF14atg in Extended Data Fig. 2 and compare it with SN 2011fe (also known as PTF11klk1, a normal type Ia supernova in the Pinwheel Galaxy 6 Mpc away from Earth1,49), SN 2002es, SN 2005hk and SN 1991bg. The figure shows that iPTF14atg was initially bluer in $u'w'2 - w'1$ by more than two magnitudes than was SN 2011fe, which is classified as a near-ultraviolet blue event2. Though SN 2011fe gradually becomes bluer while approaching its peak, iPTF14atg remains the same colour and still bluer at $u' - w'1$ than SN 2011fe by one magnitude. The optical colour, indicated by $B - V$, of iPTF14atg was initially red; it quickly became blue within a few days and then followed the evolution of SN 2002es. Though SN 2011fe was also red initially, it gradually became blue during the supernova rise, reached its bluest colour near the supernova peak and turned red later on.

**Spectroscopy.** The spectral evolution of iPTF14atg is presented in Extended Data Fig. 3 and is compared with those of SN 1991bg, SN 2005hk and SN 2002es in Extended Data Fig. 4. On May 6 (within four days after the explosion) when the ultraviolet excess was detected, the spectrum of iPTF14atg consisted of a blue continuum superposed by some weak and broad absorption features. In Fig. 2 and Extended Data Fig. 4, we tentatively identified Si ii, S ii and Ca ii lines. Combining the photometry from Swift/UVOT, the spectral energy distribution can be approximated by a blackbody spectrum of temperature 11,000 K and radius 6,000 solar radii (Fig. 2). None of the known subluminous type Ia supernovae have been observed at such an early time and are therefore unavailable for comparison, so we turned to SN 2011fe2. Unlike iPTF14atg, the spectra of SN 2011fe taken within two days after explosion show clear absorption features commonly seen in a pre-maximum type Ia supernova, such as Si ii, S ii, Mg ii, O i and Ca ii. We therefore suggest that this spectrum of iPTF14atg has a dominant thermal component from the supernova–companion interaction and a weak supernova component from the ejecta regions of the supernova photosphere. In the next spectrum taken three days later, spectral features such as Si ii and Ca ii have emerged. In the spectrum taken on May 11, we clearly identified Si ii around 6,100 Å, with its minimum at a velocity of 10,000 km s$^{-1}$. This velocity is lower than that of a normal type Ia supernova at a similar phase28.
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Extended Data Figure 1 | Comparative analysis of iPTF14atg lightcurve.

The lightcurves of iPTF14atg are compared to the Nugent template light curves of SN 1991bg-like events, (the Nugent supernova template is available at https://c3.lbl.gov/nugent/nugent_templates.html), and observed lightcurves of a typical SN 2002cx-like event SN 2005hk and SN 2002es. The error bars denote 1σ uncertainties of magnitudes. The red triangles are upper limits at a 99.9999% CL for non-detections of iPTF14atg.
Extended Data Figure 2 | Comparative analysis of iPTF14atg colour evolution. The colour curves of iPTF14atg are compared to SN 1991bg, SN 2005hk, SN 2002es and a normal event SN 2011fe. The error bars denote 1σ uncertainties.
Extended Data Figure 3 | The spectral evolution of iPTF14atg. Ticks at the top of the figure label major absorption features.
Extended Data Figure 4 | Comparative analysis of iPTF14atg spectra. The spectra of iPTF14atg at different phases are compared with those of SN 1991bg, SN 2005bl (SN 1991bg-like), SN 2005hk, SN 2002es and PTF10ujn (SN 2002es-like) at similar phases.
## Extended Data Table 1 | Spectroscopic observation log

| Date (UT) | Telescope/Instrument | $\Delta \lambda$ (Å) | Wavelength (Å) | Observer        | Data Reducer |
|-----------|----------------------|-----------------------|----------------|-----------------|--------------|
| May 6.32  | ARC-3.5m/DIS<sup>a</sup> | 10                    | 3500 - 9500   | Cao             | Cao          |
| May 6.96  | NOT/ALFOSC<sup>b</sup> | 16.2                  | 3500 - 9000   | O. Smirnova     | Taddia       |
| May 9.25  | ARC-3.5m/DIS<sup>a</sup> | 10                    | 3500 - 9500   | Kasliwal        | Cao          |
| May 11.04 | NOT/ALFOSC<sup>b</sup> | 16.2                  | 3500 - 9000   | Y. F. Martinez  | Taddia       |
| May 15.96 | NOT/ALFOSC<sup>b</sup> | 16.2                  | 3500 - 9000   | A. Nyholm       | S. Papadogiannakis |
| May 21.31 | ARC-3.5m/DIS<sup>a</sup> | 10                    | 3500 - 9500   | Cao             | Cao          |
| May 24.21 | Hale/DBSP<sup>c</sup> | 10                    | 3300 - 10000  | A. Waszczak     | A. Rubin & O. Yaron |
| May 26.35 | Keck-II/DEIMOS<sup>d</sup> | 1.5                  | 5700 - 8200   | Cao             | A. De Cia    |
| May 28.33 | Keck-I/LRIS<sup>e</sup> | 7                     | 3300 - 10000  | D. A. Perley    | D. A. Perley |
| June 3.15 | ARC-3.5m/DIS<sup>a</sup> | 10                    | 3500 - 9500   | Cao             | Cao          |
| June 6.23 | Hale/DBSP<sup>c</sup> | 10                    | 3300 - 10000  | A. Waszczak     | O. Yaron     |
| June 29.30| Keck-I/LRIS<sup>e</sup> | 7                     | 3300 - 5500   | Cao & G. E. Duggan | D. A. Perley |
|           |                      | 4.7                   | 5800 - 7400   |                 |              |
| July 30.24| Keck-I/LRIS<sup>e</sup> | 4                     | 3300 - 5500   | Cao             | D. A. Perley |
|           |                      | 2.5                   | 5400 - 7000   |                 |              |
| August 20.24| Gemini-N/GMOS<sup>f</sup> | 3                     | 4000 - 9000   | Kasliwal        |              |

<sup>a</sup>The Dual Image Spectrograph (DIS) on the ARC 3.5 m telescope at the Apache Observatory, New Mexico, USA.
<sup>b</sup>The Andalucia Faint Object Spectrograph and Camera (ALFOSC) on the Nordic Optical Telescope (NOT) at La Palma, Spain.
<sup>c</sup>The Double Spectrograph (DBSP)<sup>7</sup> on the Palomar 200-inch Hale telescope at Palomar Observatory, California, USA.
<sup>d</sup>The DEep Imaging Multi-Object Spectrograph (DEIMOS)<sup>8</sup> on the Keck-II telescope at Mauna Kea, Hawaii, USA.
<sup>e</sup>The Low Resolution Imaging Spectrometer (LRIS)<sup>9</sup> on the Keck-I telescope at Mauna Kea, Hawaii, USA.
<sup>f</sup>The Gemini Multi-Object Spectrograph (GMOS)<sup>10</sup> on the Gemini-N telescope at Mauna Kea, Hawaii, USA.
Extended Data Table 2 | Swift Observation of iPTF14atg

| UT Time          | uvw2 ± uncertainty | uvm2 ± uncertainty | uvw1 ± uncertainty | u ± uncertainty  | b ± uncertainty  | v ± uncertainty  | XRT counts/sec ± uncertainty |
|------------------|--------------------|--------------------|--------------------|------------------|------------------|------------------|---------------------|
| May 06.67 - 06.74| 0.297 ± 0.028      | 0.176 ± 0.014      | 0.399 ± 0.044      | 1.251 ± 0.116    | 2.354 ± 0.168    | 1.491 ± 0.131     | < 3.7 x 10^{-3}       |
| May 08.53 - 08.61| 0.112 ± 0.010      | 0.096 ± 0.014      | 0.324 ± 0.041      | 1.374 ± 0.151    | 2.444 ± 0.212    | 1.472 ± 0.163     | < 4.9 x 10^{-3}       |
| May 12.98 - 13.12| 0.208 ± 0.010      | 0.182 ± 0.019      | 0.578 ± 0.044      | 2.974 ± 0.152    | 4.515 ± 0.194    | 2.288 ± 0.136     | < 5.2 x 10^{-3}       |
| May 15.25 - 15.38| 0.351 ± 0.057      | 0.296 ± 0.041      | 0.681 ± 0.100      | 3.606 ± 0.414    | 5.557 ± 0.531    | 2.945 ± 0.371     | < 2.2 x 10^{-3}       |
| May 18.99 - 19.05| 0.452 ± 0.051      | 0.297 ± 0.024      | 1.081 ± 0.094      | 5.381 ± 0.372    | 6.600 ± 0.417    | 3.580 ± 0.285     | < 8.8 x 10^{-3}       |
| May 20.31 - 20.46| 0.404 ± 0.034      | 0.325 ± 0.024      | 0.956 ± 0.067      | 5.758 ± 0.307    | 7.084 ± 0.347    | 3.178 ± 0.214     | < 6.5 x 10^{-3}       |
| May 21.45 - 21.46| 0.437 ± 0.067      | 0.262 ± 0.042      | 0.809 ± 0.115      | 6.015 ± 0.578    | 7.454 ± 0.669    | 3.178 ± 0.407     | < 2.4 x 10^{-2}       |
| May 25.45 - 25.65| 0.166 ± 0.019      | 0.156 ± 0.014      | 0.483 ± 0.041      | 4.228 ± 0.219    | 6.808 ± 0.291    | 3.590 ± 0.195     | < 3.6 x 10^{-3}       |
| May 27.65 - 27.85| 0.124 ± 0.023      | 0.084 ± 0.014      | 0.440 ± 0.053      | 3.595 ± 0.274    | 6.804 ± 0.400    | 3.494 ± 0.266     | < 6.8 x 10^{-3}       |
| May 30.24 - 30.52| 0.078 ± 0.018      | 0.029 ± 0.009      | 0.352 ± 0.045      | 2.551 ± 0.227    | 4.883 ± 0.330    | 3.490 ± 0.257     | < 7.0 x 10^{-3}       |
| Jun 07.38 - 07.65| 0.041 ± 0.011      | 0.019 ± 0.006      | 0.187 ± 0.028      | 1.101 ± 0.119    | 2.936 ± 0.195    | 2.279 ± 0.162     | < 3.8 x 10^{-3}       |
| Jun 17.39 - 17.60| 0.052 ± 0.014      | 0.027 ± 0.009      | 0.143 ± 0.023      | 0.859 ± 0.102    | 2.235 ± 0.168    | 1.782 ± 0.196     | < 5.4 x 10^{-3}       |
| Jun 21.37 - 21.45| 0.039 ± 0.011      | 0.023 ± 0.006      | 0.127 ± 0.024      | 0.833 ± 0.107    | 2.377 ± 0.176    | 1.851 ± 0.143     | < 4.9 x 10^{-3}       |
| Jun 25.24 - 25.53| 0.045 ± 0.012      | 0.018 ± 0.007      | 0.120 ± 0.026      | 0.801 ± 0.113    | 1.624 ± 0.153    | 0.413 ± 0.039     | < 4.6 x 10^{-3}       |
| Nov 12.04 - 12.11c| 0.004 ± 0.010      | 0.017 ± 0.008      | 0.080 ± 0.025      | 0.559 ± 0.115    | 1.576 ± 0.189    | 0.953 ± 0.156     |                     |

a The uncertainties are at a 68.3% CL.
b The upper limits are at a 99.7% CL.
c This is a reference epoch to remove host galaxy contamination.
Erratum: A strong ultraviolet pulse from a newborn type Ia supernova

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In this Letter, the superscript in the ultraviolet luminosity was listed incorrectly as ‘$2^{41}$’ rather than ‘$41$’ in the last sentence of the second paragraph from the bottom in the left column of page 1. It should have read $L_{\text{UV}} \approx 3 \times 10^{41}$ erg s$^{-1}$. This has been corrected online.