Probing the physics of bright SNe with high-cadence photometry

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Motivation

- Explore short-timescale and low-amplitude variability properties of SN light curves
- Probe supernova physics (e.g. explosion, ejecta)
- Learn about SN progenitor system

X-ray: (NASA/CXC/Penn State/S.Park et al.)
SN 2014J in M82 (3.3 Mpc) reached $V_{\text{max}}=10.6$ mag (Foley et al. 2014)

High-cadence photometry obtained with the 2.3m Aristarchos telescope, Helmos Observatory, Greece

“Fast variability is not expected from supernovae (because the shell is too large to change fast), but then no one has ever looked. Similarly, no one expected fast variations from novae during their optically-thick shell phase, but the first time anyone looked, for U Sco in 2010, the nova was seen to have many hour-long flares, with these still being completely unexplained.”

B. Schaefer 2014, AAVSO Alert Notice 495

http://helmos.astro.noa.gr/
SN 2014J

SN 2014J in M82 (3.3 Mpc) reached $V_{\text{max}}=10.6$ mag (Foley et al. 2014)

High-cadence photometry obtained with the 2.3m Aristarchos telescope Helmos Observatory, Greece

February 16-19, 2014
5 sec (V) & 20 sec (B) exposures
2 min cadence

http://helmos.astro.noa.gr/
Results

evidence for rapid variability
amplitude: 0.02–0.05 mag
(2–5% in flux)
timescale: 15–60 min
precision: 3–6 mmag

Siverd et al. (2015)

Results

Measured decline rate per night of a Type Ia SN for the first time

1σ error from aperture photometry is 1.4 mmag

3–6 mmag precision (based on red noise estimation, Pont et al. 2006)

2–5% variability corresponds to a 1–2.5% fractional change in radius (104 AU on day 17) and is consistent with 4.5% (3σ) upper limit from Siverd et al. (2015)

Table 1. Decline rates \( \alpha \) (mag day\(^{-1}\)) and values of \( \sigma_w \), \( \sigma_r \), \( \sigma_N \) (mag) based on SN–S1 of the V- and B-band light curves of SN 2014J.

<table>
<thead>
<tr>
<th>Night</th>
<th>Filter</th>
<th>( \alpha_{SN-S1} )</th>
<th>( \alpha_{SN-S2} )</th>
<th>( \alpha_{SN-S3} )</th>
<th>( \alpha_{SN-S4} )</th>
<th>( \alpha_{SN-S5} )</th>
<th>( \alpha_{SN_{TFA}} )</th>
<th>( \sigma_w )</th>
<th>( \sigma_r )</th>
<th>( \sigma_N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>V</td>
<td>0.06 ± 0.01</td>
<td>0.15 ± 0.01</td>
<td>0.17 ± 0.02</td>
<td>0.15 ± 0.03</td>
<td>0.16 ± 0.02</td>
<td>0.14 ± 0.02</td>
<td>0.0086</td>
<td>0.0045</td>
<td>0.0048</td>
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<tr>
<td>2</td>
<td>V</td>
<td>0.09 ± 0.01</td>
<td>0.09 ± 0.01</td>
<td>0.10 ± 0.02</td>
<td>0.08 ± 0.03</td>
<td>0.07 ± 0.03</td>
<td>0.07 ± 0.01</td>
<td>0.0107</td>
<td>0.0050</td>
<td>0.0053</td>
</tr>
<tr>
<td>3</td>
<td>V</td>
<td>0.10 ± 0.01</td>
<td>0.07 ± 0.02</td>
<td>0.04 ± 0.03</td>
<td>...</td>
<td>0.08 ± 0.03</td>
<td>0.09 ± 0.04</td>
<td>0.0177</td>
<td>0.0052</td>
<td>0.0061</td>
</tr>
<tr>
<td>4</td>
<td>V</td>
<td>0.03 ± 0.01</td>
<td>0.04 ± 0.01</td>
<td>0.05 ± 0.02</td>
<td>0.02 ± 0.03</td>
<td>0.03 ± 0.02</td>
<td>0.04 ± 0.01</td>
<td>0.0131</td>
<td>0.0046</td>
<td>0.0052</td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>0.09 ± 0.01</td>
<td>0.19 ± 0.01</td>
<td>0.24 ± 0.03</td>
<td>0.21 ± 0.03</td>
<td>0.17 ± 0.05</td>
<td>0.22 ± 0.05</td>
<td>0.0104</td>
<td>0.0025</td>
<td>0.0031</td>
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<tr>
<td>2</td>
<td>B</td>
<td>0.14 ± 0.01</td>
<td>0.12 ± 0.01</td>
<td>0.12 ± 0.03</td>
<td>0.10 ± 0.03</td>
<td>0.07 ± 0.04</td>
<td>0.09 ± 0.01</td>
<td>0.0074</td>
<td>0.0033</td>
<td>0.0036</td>
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<tr>
<td>3</td>
<td>B</td>
<td>0.16 ± 0.01</td>
<td>0.13 ± 0.02</td>
<td>0.11 ± 0.03</td>
<td>...</td>
<td>0.20 ± 0.04</td>
<td>0.15 ± 0.03</td>
<td>0.0186</td>
<td>0.0036</td>
<td>0.0050</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>0.07 ± 0.01</td>
<td>0.06 ± 0.02</td>
<td>0.11 ± 0.03</td>
<td>0.09 ± 0.04</td>
<td>0.12 ± 0.04</td>
<td>0.06 ± 0.01</td>
<td>0.0128</td>
<td>0.0059</td>
<td>0.0063</td>
</tr>
</tbody>
</table>

\[
\sigma_N^2 = \frac{\sigma_w^2}{N} + \sigma_r^2
\]
Results

Night 3:
0.05 mag (8.2σ in V, 10σ in B)

Night 4:
0.04 mag (7.7σ in V, 6.3σ in B)
Origin of variability in SN 2014J

- clumping of ejecta, possibly caused by structures of intermediate mass elements in the outer layers (Hole et al. 2010)
- interaction of the ejecta with circumstellar material (Foley et al. 2014)
- asymmetry of the ejecta (non-spherically symmetric explosion, Wang & Wheeler 2008)
- onset of secondary maximum (Pinto & Eastman 2000)
SNe from the Kepler K2 mission

Olling et al. (2015, 3 Type Ia SNe)
no signature of ejecta interaction with companion

Garnavich et al. (2016, 2 Type IIp SNe)
detection of shock breakout in KSN 2011d
Bright supernovae

SNe with $V_{\text{max}} < 15$ mag

2014:
21 SNe (14 north)

2015: 28 SNe (18 north)

2016 (Jan-May):
8 SNe (5 north)

http://www.rochesterastronomy.org/snimages/snmag.html
Future

Follow-up future bright supernovae with 2.3m Aristarchos telescope (9 nights in Fall 2016)

Use NELIOTA lunar imager on 1.2m Kryoneri telescope to monitor future bright supernovae (starting in Fall 2016)
NELIOTA lunar monitoring

NELIOTA is an ESA project aiming to establish an operational system at Kryoneri Observatory, Greece to conduct lunar monitoring. The goal is to determine the distribution and frequency of Near Earth Objects (NEOs) by detecting lunar flashes.

The Lunar Imager has a dichroic and 2 sCMOS Andor cameras and will observe in the R and I-bands at 30 fps.

http://neliota.astro.noa.gr/
Conclusions

- High-cadence photometry is a powerful tool for probing supernova physics (e.g. clumping, asphericity, shock breakout)
- Evidence for rapid variability at the 2-5% level on 15-60 min timescale detected in SN 2014J on 4 consecutive nights
- First measurement of intraday decline rate for a SN Type Ia
- Future monitoring of bright supernovae planned with 1.2m Kryoneri (NELIOTA Lunar Imager) and 2.3m Aristarchos telescopes

Stay tuned!