SNe Ia: Polarimetry and Progenitors

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The Progenitors of Type Ia Supernovae
August 4-9, 2019
Lijiang, China
Observational signatures of SN Ia progenitors

1. The ejecta geometry
2. Ejecta/companion interaction
3. Ejecta/CSM interaction
4. The ISM

Why is polarimetry important?
How polarimetry works

1. Electron scattering and modulations by atomic line absorption

Conservation of symmetry axis

Breaking the spherical symmetry

Conservation of symmetry axis
How polarimetry works

1. Electron scattering and modulations by atomic line absorption

Increasing velocity cut above the photosphere
How polarimetry works

1. Electron scattering and modulations by atomic line absorption

Breaking axial symmetry
Mattia Bulla et al. (2015, 2016a, 2016b): Predicted polarization signatures for double-detonation, delayed-detonation and violent mergers models

Cikota et al. (2020, submitted)
In contrast, SN 1999by shows a well defined symmetry axis.

Axially symmetric ejecta fits well.
How polarimetry works

1. Dust absorptions and scattering

Figure 3. The echo image of 2002 December 17 (contours and greyscale image) with polarization electric vectors superimposed. The directions of the electric vectors are indicated by the red lines, whose lengths are proportional to the degree of polarization. The largest values are about 50%. Vectors are shown for every 30 pixels, and the polarization and position angles are the means and medians, respectively, averaged over 30 × 30-pixel boxes. This image has not been rotated to place north at the top, but instead remains in detector coordinates. Small tickmarks on the axes are separated by 1".5. Note that the electric vectors are generally perpendicular to the direction to the central star, as expected for light scattered off dust particles.

Sparks et al. 2008
How polarimetry works

1. Dust absorptions and scattering

Fig. 2.—(a) V-band polarimetry of SN 1987A; (b) Polarization spectrum at day 100.

Fig. 3.—Early infrared observations. Bolometric luminosity was scaled down by a factor of 10 for clarity.

Wang & Wheeler 2006
How polarimetry works

1. Dust absorptions and scattering

![Graphs showing polarization vs. wavelength and days since explosion.](image)

The polarization when the polarization degree in the $U$ band is maximized (For example, the timing shown in Figure 3 with dashed lines). In the case of $\tau_0(U) = 1.0$, where the optical depth for all the bands is less than unity, the polarization degree in a shorter wavelength is larger. While, the polarization degree is maximized around the $R$ or $I$ band in the case of $\tau_0(U) = 10.0$. These behaviors are interpreted mostly as effects of multiple scattering, which lead to depolarization of light (see Paper I). In the case with $\tau_0$ higher than ~2, the polarization does not become higher due to multiple scattering, even though the flux of the scattered echo is higher.

To distinguish the effects of the albedo ($\omega(\nu)$) and the scattering angle distribution ($g(\nu)$) from those of the optical depth of CS dust($\tau_0(\nu)$), we multiply the polarization degree in Figure 4(a) by $(\eta(\nu)/\eta(U))^{-1}(=\kappa_{\text{ext}}(U)/\kappa_{\text{ext}}(\nu))$. We can now see the wavelength dependence only from the albedo ($\omega(\nu)$) and the scattering angle distribution ($g(\nu)$), which is shown

Nagao, Maeda, & Tanaka, 2018

CSM scattering around SNIIP
How polarimetry works

1. Dust absorptions and scattering

Xiaofeng Wang et al. 2019
Hu et al. 2020, in prep
How polarimetry works

1. Dust absorptions and scattering

Nagao et al. 2018
Recent Observations

35 SNe Ia, observed at 127 epochs in total with VLT/FORS, between 2001 and 2015

Aim: systematically reduce the whole sample and perform a statistical study of the correlation among geometric structures and observable parameters

Cikota et al. (submitted)
Recent Observations

Si II polarization evolution

![Graph showing Si II polarization evolution over time from B-max (days)]
Recent Observations

Si II polarization evolution
Recent Observations

Si II polarization evolution

Note: In mass coordinate, the photosphere has been shrinking from ~12,000 km/sec to below ~8000 km/sec.
Putting it all together
Putting it all together
Putting it all together
The degree of polarization has a probability density distribution with a peak of about 0.5 per cent for 20 clumps covering the surface of the photosphere. Reducing the numbers of clumps introduces higher degrees of polarization and a larger dispersion of the degree of polarization.

**Typical size of clumps is around 1,000 km/sec!**

Wang et al. 2007: this trend provides strong support for delayed-detonation models, as the dimmer SNe, which burn less material to thermonuclear equilibrium, are expected to have larger chemical irregularities.

More M.C. simulation is needed
The degree of polarization has a probability density distribution with a peak of about 0.5 per cent for 20 clumps covering the surface of the photosphere.

Reducing the numbers of clumps introduces higher degrees of polarization and a larger dispersion of the degree of polarization.

**Typical size of clumps is ~ 3,000 km/sec!**
Where is the CSM?

Xiaofeng Wang et al. 2019
Dust at $\sim 10^{17}$ cm

Bulla, Goobar, & Dhawan 2018
Dust at $\sim 10^{18}$ cm
A definitive proof of CSM dust needs polarimetry

1. Detection of more than $5 \times 10^{-4}$ solar mass of CSM at a distance of $\sim 5.1 \times 10^{17}$ cm.
2. Non-detection at a distance of $\sim 6.1 \times 10^{16}$ cm and beyond the distance of $\sim 7.7 \times 10^{17}$ cm.

Yang et al. 2018
Figure 8. Schematic diagram explaining the non-local coherence of the polarization PA in the case that the grains in circumstellar dust clumps are aligned with the local interstellar magnetic field. Red bars illustrate dust grains aligned by an ad hoc coherent magnetic field, green dashed lines represent light from the SN, and blue arrows demonstrate the direction of E-vectors of the net polarized light. The observer is located outside the right edge of the figure. In the right panel, the net effect is a rotation in the QU plane through 180°; therefore, the scattered light does not impose a rotation on the PA of integrated light measured from the SN point source.
Finding the first SNeIa in the Universe

Use JWST to find and follow-up SNeIa, out to a redshift of 6

Using NIRCAM, NIRSpec, and NRISS

Four colors: F150W2, F200W, F322W2, and F444W, down to $27.5^{th}$ mag AB
A total of 178 hours of observing time per year
Multi-cadence survey, from 45 days to about 182 days
One sq. deg. Field
The First Light At REionization (FLARE)

Use JWST to find and follow-up SNeIa, out to a redshift of 6

Total number is 5 times of this table

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Regős & Vinkó, 2019
The First Light At REionization (FLARE)

Use JWST to find and follow-up SNeIa, out to a redshift of 6

Total number is 5 times of these curves

Regős & Vinkó, 2019
Finding the first SNeIa in the Universe

Follow up observations mostly done during the surveys.
Summary and Conclusions

1. An unambiguous detection of CSM dust can be achieved through early and late time polarimetry.
2. We are at the critical point of making significant progress of constraining the progenitor system by modeling the statistical properties of polarizations of SNeIa.
3. The age and metallicity effect can be broken by finding SNe beyond $z$ of 2.