Spring 2015

Determining the shape of a supernova explosion

Amber L. Porter
Clemson University

Mark D. Leising
Clemson University

Grant Williams
Clemson University

Peter Milne
Clemson University

Paul Smith
Clemson University

See next page for additional authors

Authors
Amber L. Porter, Mark D. Leising, Grant Williams, Peter Milne, Paul Smith, and Nathan Smith

Determining the shape of SN 2014J

Amber L. Porter (alporte@g.clemson.edu)[1], Mark D. Leising[1], G. Grant Williams[2], Peter Milne[3], Paul Smith[3], Nathan Smith[3], Doug Leonard[4], Jennifer Hoffman[5], Chris Bilinski[2], Luc Dessart[6], Leak Huk[5]
[1]Clemson University, [2]MMT Observatory, [3]University of Arizona, [4]San Diego State University, [5]University of Denver, [6]CNRS

Type Ia supernovae are used as standard candles to measure distances to galaxies across the universe and helped confirm the accelerating expansion of the cosmos. Understanding the intrinsic nature of these objects, including the geometry of the explosion, is necessary to improve extragalactic distance measurements.

Introduction

SN 2014J was a Type Ia supernova (SN) that exploded in the nearby galaxy M82 located at a distance of ~12 million light years.

The Supernova Spectropolarimetry (SNSPOL) Project obtained multi-epoch observations of this SN's polarized light to capture its aspherical nature using the 90" Bok and 6.5-m MMT telescopes. Spectropolarimetric observations can reveal two characteristics:

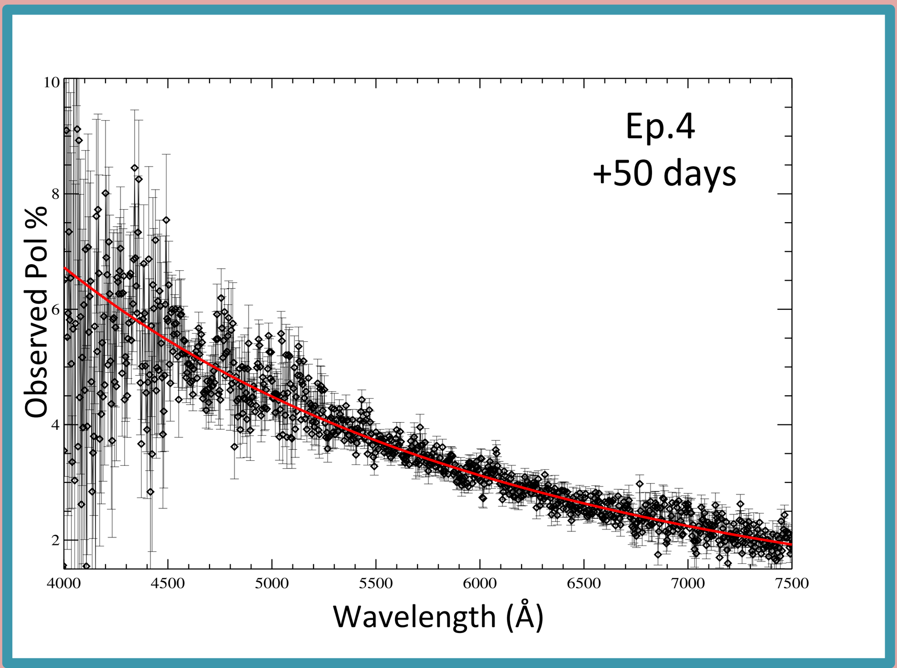
+ Continuum emission describes the overall asymmetry of the explosion

+ Polarization detected at the same wavelengths as certain absorption features (known as line polarization) illustrates the geometry of those ions within the ejecta

Light becomes polarized when it scatters off electrons in the ejecta of the supernova. The polarized light emerging from the surface of an explosion (the photosphere) is represented as vectors on the right. The vectors of a spherical photosphere cancel completely leading to a null polarization detection. Meanwhile, incomplete cancellation of an ellipsoidal photosphere's vectors will produce a non-zero polarization in the continuum emission.

Ions ejected in a clumpy manner unevenly block the underlying photospheric light resulting in line polarization.

Interstellar Polarization (ISP)



ISP must be estimated correctly to determine the level of polarization intrinsic to the SN, but it may also hold clues about the dust of the host environment.

+ Elongated dust grains aligned in the magnetic field of a galaxy preferentially absorb more light along one axis, a process that polarizes light as it traverses the galaxy.

+ Observed degree of polarization at the position of SN 2014J in the sky decreases steadily from ~6.5% at 4000Å to below 2% at 7000Å. We choose to fit this data with a Serkowski curve which has been shown to be a good fit to the polarization of dust grains within the Milky Way galaxy over optical wavelengths. However, we find quite unusual parameters for SN2014J.

$$P_{ISP} = P_{max} \times \exp[-K \times \ln^2(\lambda_{max}/\lambda)]$$

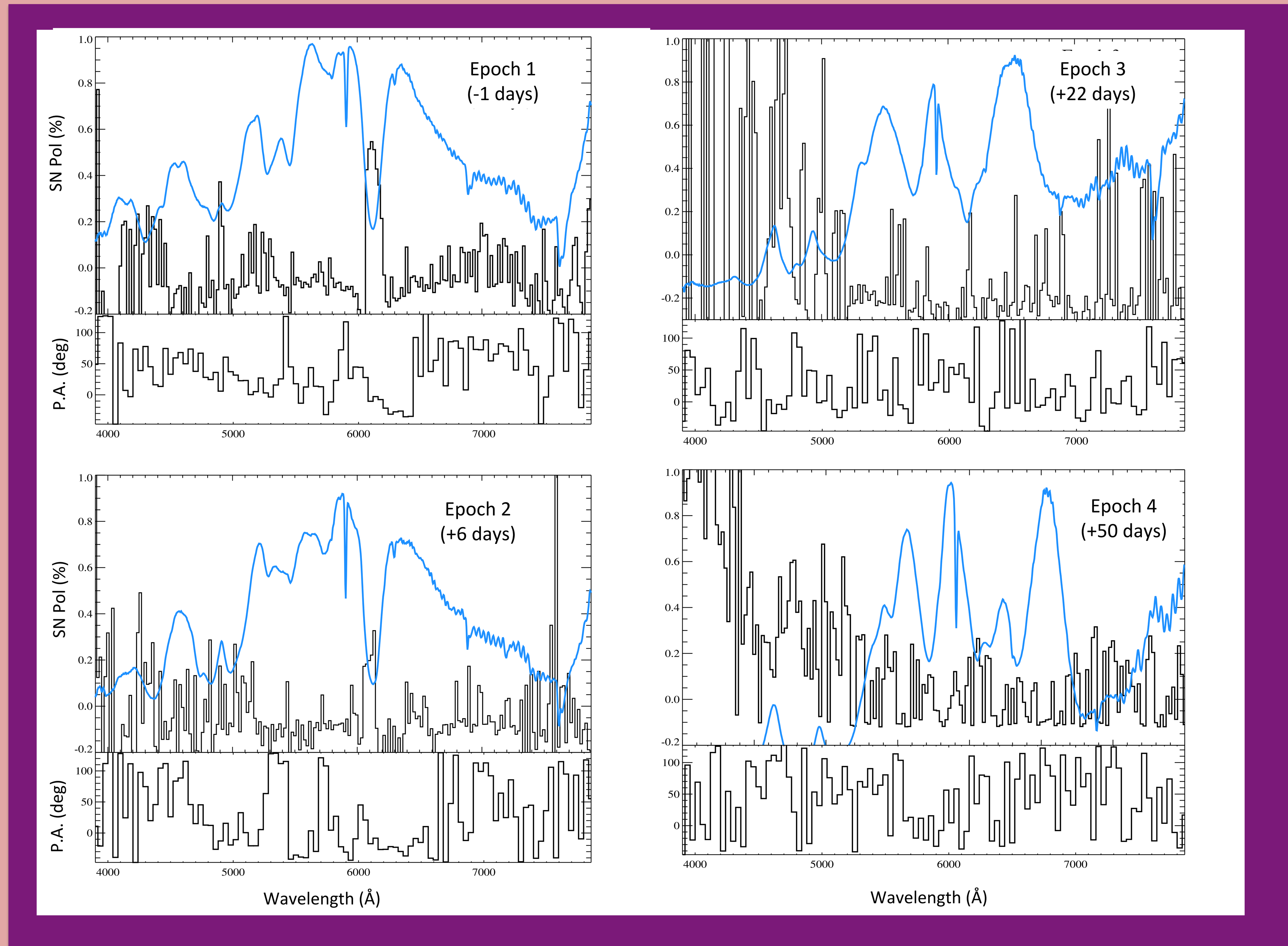
+ The wavelength at which the polarization peaks, λ_{max} = 570Å, is much shorter than the 5500Å typical of Galactic dust. If the Serkowski fit is valid, this could imply that the average radius of dust grains in M82 is smaller than in the Milky Way: a_{eff} = 0.015μm as compared to the Galactic a_{eff} = 0.15μm. Scattering (rather than absorption) by dust close to the SN explosion, which has not been taken into account here, may be able to explain the peculiar Serkowski parameters.

Summary

+ A Serkowski fit to the ISP shows interstellar dust in M82 is quite different from our galaxy, however the possibility of circumstellar scattering component needs to be investigated further.
+ Continuum polarization of SN 2014J is low indicating a low level of global asymmetry
+ Si II shows significant line polarization and change in polarization angle near maximum light indicating that it has most likely been ejected in a clumpy manner

Spectropolarimetry Results

Four epochs of SN 2014J's ISP-corrected degree of polarization and polarization angle (P.A.) are displayed below.



+ Polarization spectra are binned to 20Å and P.A. to 40Å. The smooth blue curves trace the unbinned flux spectra which has been arbitrarily scaled.

+ Continuum emission measured between 6600 and 7400Å where there are no strong features in the flux spectra is 0 ± 0.1% polarized at each epoch. This is consistent with a spherical explosion, but other supernovae have shown polarization levels indicative of an overall asymmetry that deviates from a perfect sphere by 20%.

+ Si II 6355Å line polarization decreases from 0.5 ± 0.1% in Epoch 1 to 0.2 ± 0.1% in Epoch 2. The feature is no longer detected by Epoch 3 and 4. This suggests clumps of Si II are present in the outer layers of ejecta after the star explodes, but the ejecta becomes smoother with time.

References

Foley et al., 2014, MNRAS, 443, 2887F
Goobar et al., 2014, ApJ, 784L, 12G
Kasen et al., 2003, ApJ, 593, 788K
Kawabata et al., 2014, ApJ, 795L, 4K
Patat et al., 2010, A&A, 510, A108
Serkowski et al., 1975, ApJ, 196, 261

We gratefully acknowledge support from the National Science Foundation under Collaborative Research award #AST-1210599