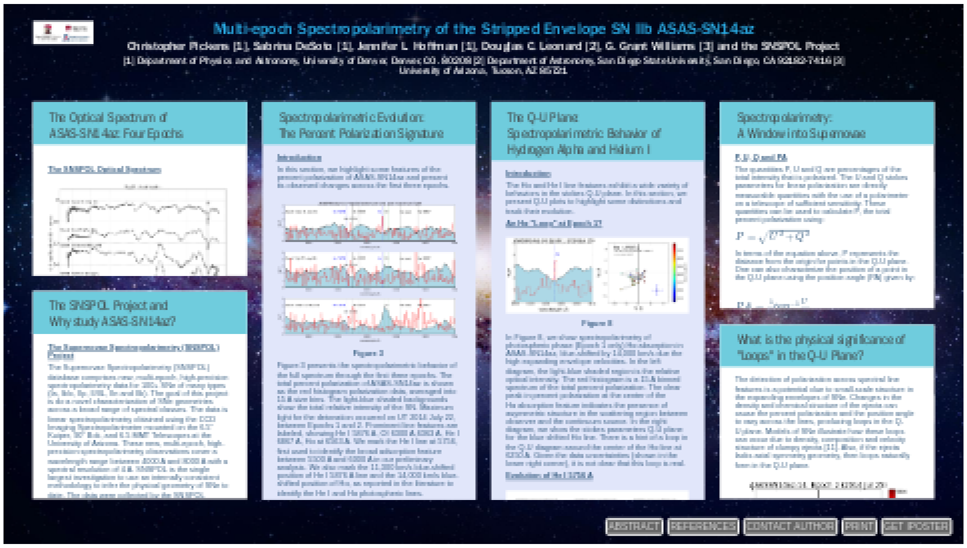
Multi-epoch Spectropolarimetry of the Stripped Envelope SN IIb ASAS-SN14az



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THE OPTICAL SPECTRUM OF ASAS-SN14AZ: FOUR EPOCHS

The SNSPOL Optical Spectrum

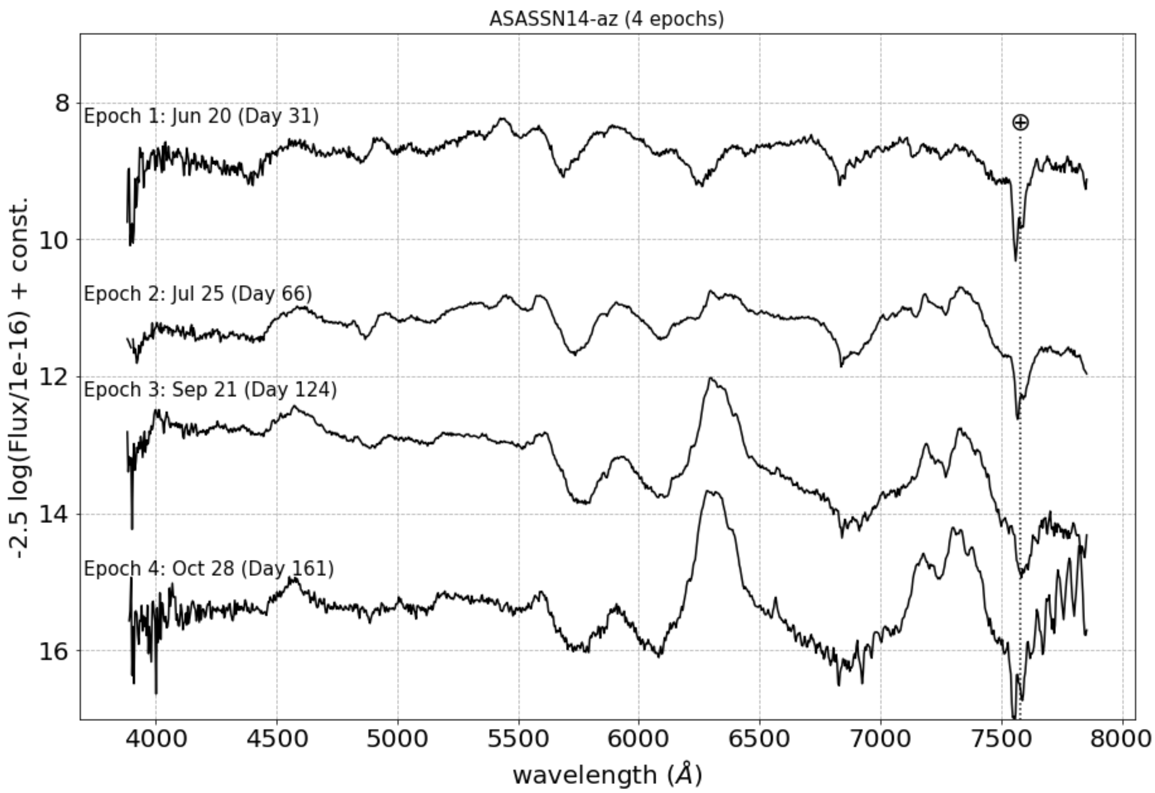

Figure 1

We present Supernovae Spectropolarimetry (SNSPOL) observations of the type IIb supernova (SN IIb) ASAS-SN14-az. Figure 1 presents optical spectra for four epochs (Days 31, 66, 124, 161, relative to the discovery date), showing relative intensity over a wavelength range from about 4000 A to 8000 A, with a spectral resolution of 4 A. Epochs 1 and 2 show the detonation through its photospheric phase, dominated by broad absorption lines. Epochs 3 and 4 show the SN through its later, nebular phase with promenient emission lines. In figure 2, we present a preliminary line identification report showing Hα, He I 5876 A, He I 5756 A, He I 6867 A and O I 6300,6363 A.

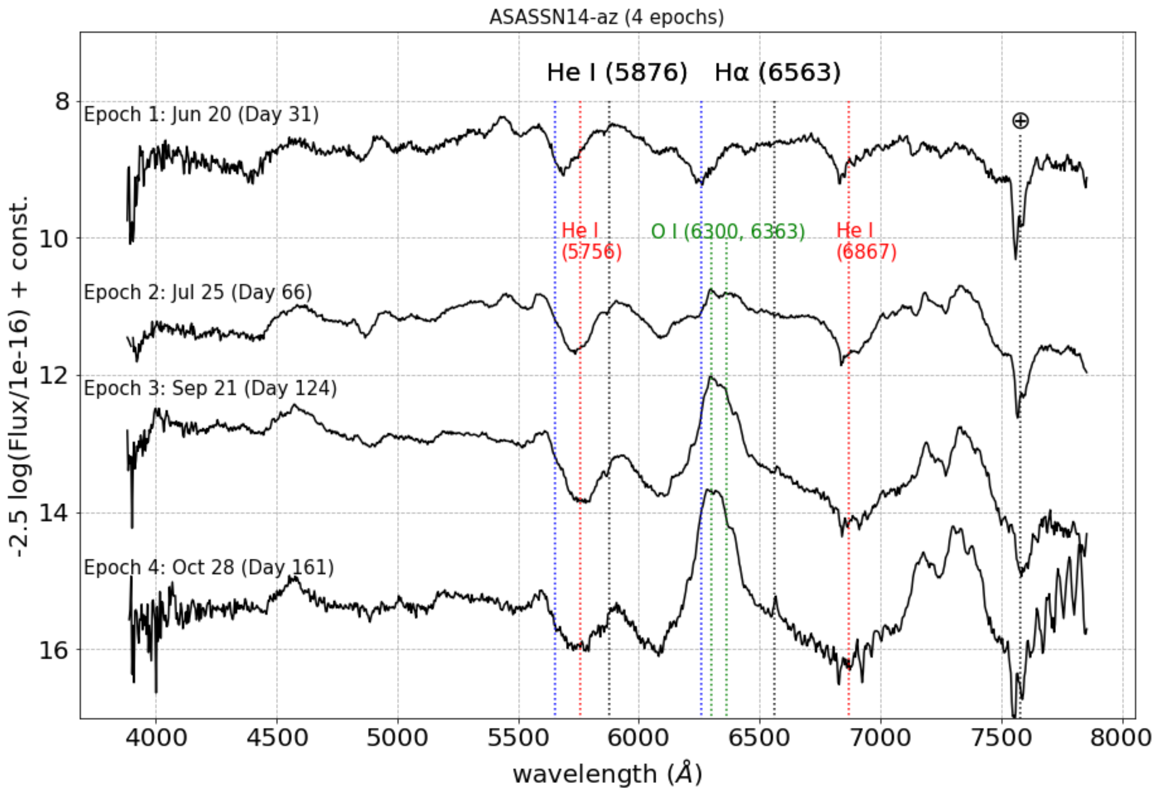

Figure 2

Hydrogen Alpha

The spectra of expanding envelopes of core-collapse supernovae (CCSNe) often exhibit absorption line features of hydrogen and helium that are shifted relative to their rest-wavelengths due to high ejecta velocities. Following Benetti et al 2014 [5], we overlay (Figure 2) the rest-frame positions of Hα at 6563 A, and mark with a vertical blue line the corresponding 14,000 km/s blue-shifted Hα feature. The rest-frame narrow Hα emission peak seen in Epoch 4 shows that ASASSN-14az as managed to maintain some hydrogen gas in its circumstellar environment well after the explosion. How the progenitors of SNe IIb can shed most of their layers at the time of explosion, while retaining enough mass to show hydrogen signatures in their spectra, is still under debate [2].

He I Lines

Benetti et al also reports a dominate He I line at 5876 A that has been blue shifted by 11,300 km/s. In this figure, we mark the rest-frame emission of He I at 5876 A and its corresponding 11,300 km/s blue-shifted position to mark the He I feature in ASASSN-14az spectra. The center of this He I line progressively moves to the right towards its rest-wavelength, indicating that the He I ejecta is slowing down.

General Background on ASASSN-14az

ASASSN-14az was discovered by the ongoing All Sky Automated Survey for SuperNovae (ASAS-SN or "Assassin"), on 2014 UT May 20.59. [3]. The SN event occurred in host galaxy PGC 1101367 (GALEXASC J234448.27-020653.4) at R.A. = 23 h 44 m 48 s and Declination -02° 07' 03".2, located 3".13 west and 7".78 south of the center of PGC 1101367. This discovery figure (http://www.astronomy.ohio-state.edu/~assassin/followup/ASASSN-14az.png) [4] shows the ASAS-SN reference image (top left), archival SDSS g-band image (top right), ASAS-SN May 18.61 subtraction image (bottom left), and the ASAS-SN discovery subtraction image (bottom right). The green circle has a radius of 5.0" at the position of the SN derived from the ASAS-SN image. Estimated distance to ASASSN-14az vary between 23 - 30 Mpc.

Spectral classification was performed by S. Benetti et al. 2014. [5] They report that an optical spectrogram (range 340-800 nm; resolution 1.1 nm), obtained on UT May 30.19 with the TNG (+ DOLORES spectrograph) under the Asiago Transient Classification Program [6], shows that ASASSN-14az is a type IIb supernova.

Assuming a recessional velocity of 2018 km/s for the host galaxy [7], Benetti et al. report that ASASSN-14az is a good match with SN IIb 2008ax [8] about 10 days after explosion [3]. The spectral comparison, shown here (https://sngroup.oapd.inaf.it/cgi-bin/output_class.cgi?post_one=ASASSN-14az), [9] illustrates that the spectra of both SNe are dominated by deep Hα and He I 587.6 nm absorptions from which Benetti et al. derived expansion velocities of about 14000 km/s and about 11300 km/s, respectively. This early, photospheric phase, optical spectrum (https://sne.space/sne/ASASSN-14az/) from the Open Supernova Catalog website shows the He-I line and Hα line blue-shifted by about 200 A and 300 A, respectively by the action of these high expansion velocities.

<u>The Stripped Envelope Transition</u>

Comparison of these spectra with the early Day 10 spectra (relative to the discovery date) demonstrates that ASASSN-14az exhibits the classic SN IIb spectral transition: SNe IIb exhibit spectroscopic features due to the presence of hydrogen in their early-epoch spectra. The hydrogen features quickly grower less prominent until they completely disappear, usually within a few weeks after detonation, at late times. As ASASSN14-az evolves, it makes a clear transition from hydrogen rich SNII-like spectra to a hydrogen-deficient SNe Type Ib/c. Between Epoch 1 and 2, ASASSN-14az developed through the date of its maximum light on its light curve (July 22 2017), showing Hα absorption typical of Type II SNe. Later, these Hydrogen features give way to ever strengthening He I absorption lines through Epoch 3 and 4, similar to those observed in SNe Ib.

THE SNSPOL PROJECT AND WHY STUDY ASAS-SN14AZ?

The Supernovae Spectropolarimetry (SNSPOL) Project

The Supernovae Spectropolarimetry (SNSPOL) database comprises new, multi-epoch, high-precision spectropolarimetry data for 100+ SNe of many types (Ia, Ib/c, IIp, II/IIL, IIn and IIb). The goal of this project is do a novel characterization of SNe geometries across a broad range of spectral classes. The data is linear spectropolarimetry obtained using the CCD Imaging Spectropolarimeter mounted on the 6.5" Kuiper, 90" Bok, and 6.5 MMT Telescopes at the University of Arizona. These new, multi-epoch, high-precision spectropolarimetry observations cover a wavelength range between 4000 A and 8000 A with a spectral resolution of 4 A. SNSPOL is the single largest investigation to use an internally consistent methodology to infer the physical geometry of SNe to date. The data were collected by the SNSPOL collaboration from 2010-2018.

Observing Log

Name	Type	Discovery Date	Date of Max	UT Date of Obs.	Telescope
ASASSN-14az	IIb	5/20/2014	7/22/2014		
Epoch 1				6/20/2014 (2) 6/21/2014 (2) 6/23/2014 (2) 6/24/2014 (2) 6/26/2014 (2)	61" Kuiper
Epoch 2				7/25/2014 (1)	90" Bok
Epoch 3				9/21/2014 (2) 9/22/2014 (2)	90" Bok
Epoch 4				10/28/2014 (2) 10/29/2014 (2)	61" Kuiper

Table 1

Table 1 is the SNSPOL Project (http://grb.mmto.arizona.edu/~ggwilli/snspol/) observing log of ASAS-SN14az. ASAS-SN14az was observed with SPOL at 4 different epochs, one of which (epoch1) is a pre-maximum light data set. See Background of ASAS-SN14az in "**The Optical Spectrum of ASAS-SN14az: Four Epochs**" panel of this poster for the discussion of the discovery date and spectral classification.

Why Study ASAS-SNAZ14?

ASAS-SN14az falls under the SN category of the "stripped envelope" Type IIb SNe. These events are relatively rare, constituting roughly 10% of all core-collapse supernovae (CCSNe) [1]. However, comparative optical spectroscopy of CCSNe suggests that SNe IIb represent an important transition from the SNe II to SNe Ib/c sub-type. SNe IIb progenitors are thought to have been stripped of most, but not all, of their hydrogen envelopes by stellar winds or mass transfer in binary systems. During detonation, SN IIb undergo a spectral metamorphosis during their evolution: their spectra present at early phases broad hydrogen features which later disappear after a few weeks, as signatures of helium become increasingly predominant, as is often seen in stripped envelope supernovae. Thus, they provide an opportunity to study the effects of mass-loss on stellar evolution. Of particular concern with this study, spectropolarimetric studies of CCSNe show evidence for significant departures from spherical symmetry in their ejecta and circumstellar environment. This raises fundamental questions regarding the explosion mechanism and the details of how mass loss affects their evolution. For the remainder of this poster, we present and discuss new spectropolarimetry of ASAS-SN-14az.

SPECTROPOLARIMETRIC EVOLUTION: THE PERCENT POLARIZATION SIGNATURE

Introduction

In this section, we highlight some features of the percent polarization of ASAS-SN14az and present its observed changes across the first three epochs.

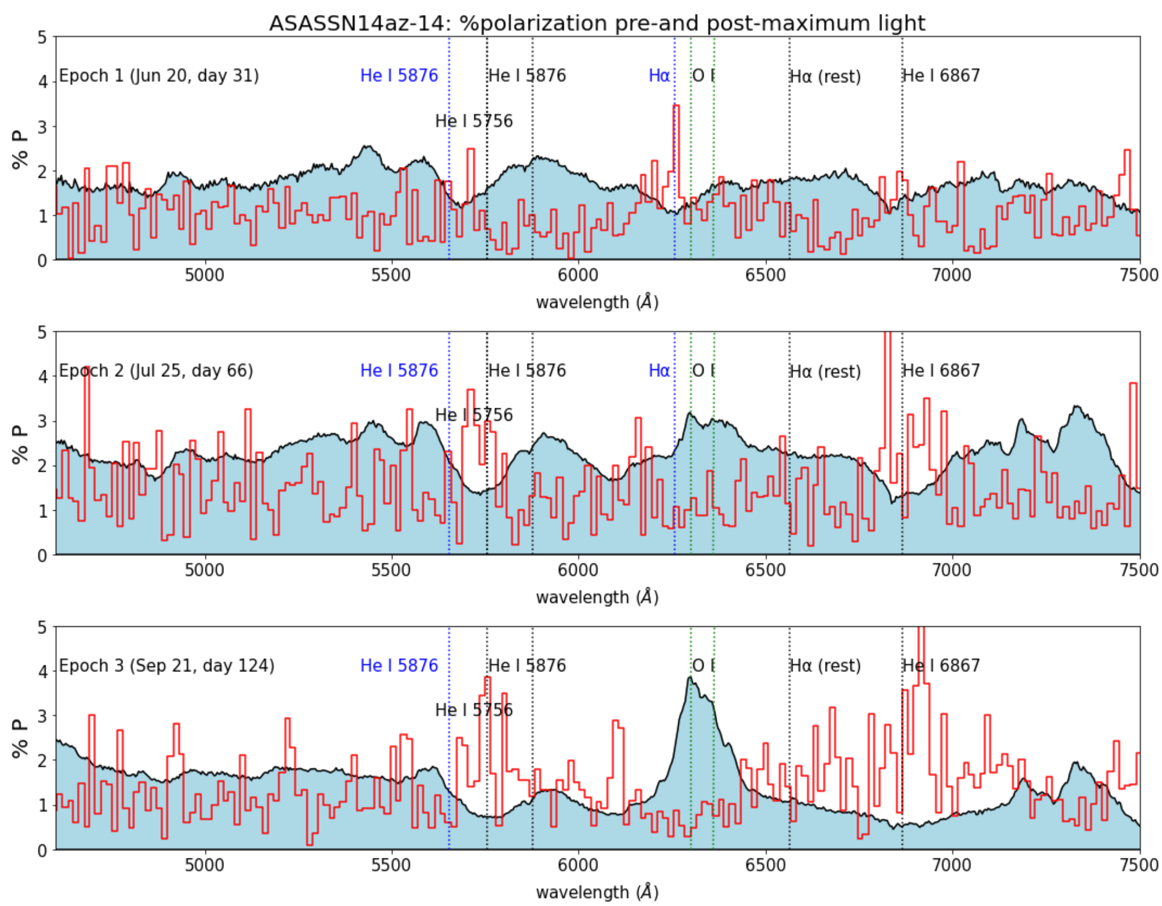

Figure 3

Figure 3 presents the spectropolarimetric behavior of the full spectrum through the first three epochs. The total percent polarization of ASAS-SN14az is shown as the red histogram polarization data, averaged into 15 A size bins. The light-blue shaded backgrounds show the total relative intensity of the SN. Maximum light for the detonation occurred on UT 2014 July 22, between Epochs 1 and 2. Prominent line features are labeled, showing He I 5876 A, OI 6300 A,6363 A, He I 6867 A, Hα at 6563 A. We mark the He I line at 5756, first used to identify the broad adsorption feature between 5500 A and 6000 A in our preliminary analysis. We also mark the 11,300 km/s blue-shifted position of He I 5876 A line and the 14,000 km/s blue-shifted position of Hα, as reported in the literature to identify the He I and Hα photospheric lines.

Hα

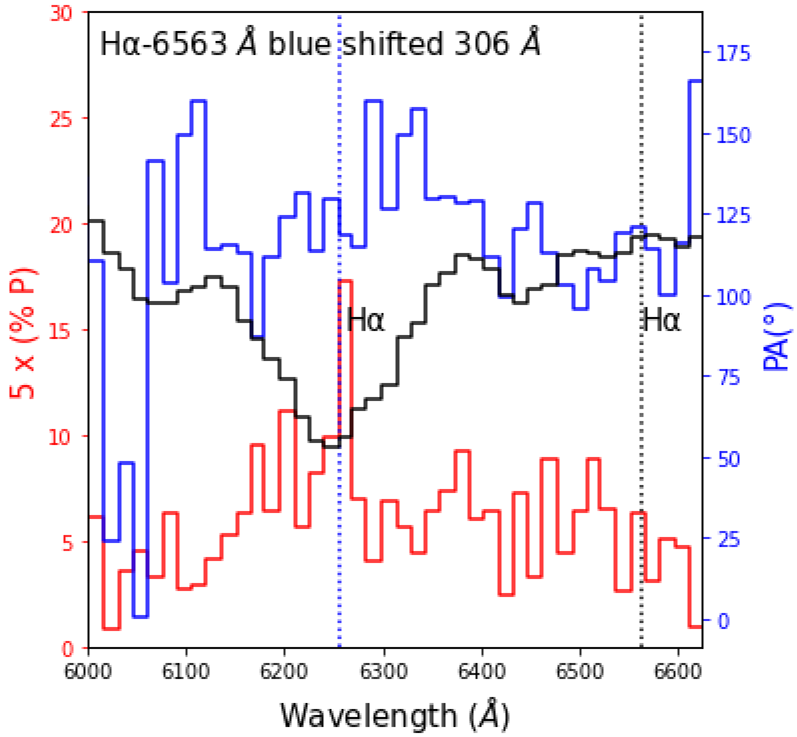

Figure 4

We report strong polarization at the location of the blue-shifted Hα line. Figure 4 shows the percent polarization (red), the position angle (blue) and the line feature (black) for epoch 1. The peak of the polarization signal is at about 3%, corresponding to the Hα absorption feature. We interpret these features as being due to the presence of an asymmetric structure in the SN ejecta passing between the observer and the SN continuum source. This signal decreases through Epoch 2 and Epoch 3 to approximately less than 1% polarization.

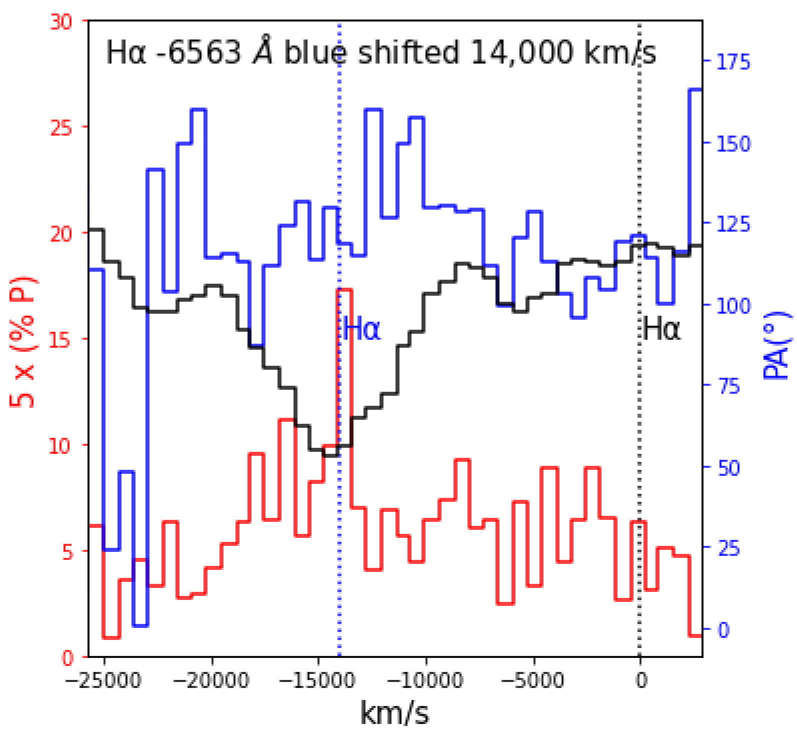

Figure 5

In Figure 5, we plot the same Hα profile from Figure 4 in velocity space. The center of the profile clearly shows a blue shift from rest-frame Hα. The Hα feature is a signature of the near side of the SN envelope expanding at high velocities. We estimate the hydrogen envelope velocity at roughly 14,000 km/s.

He I

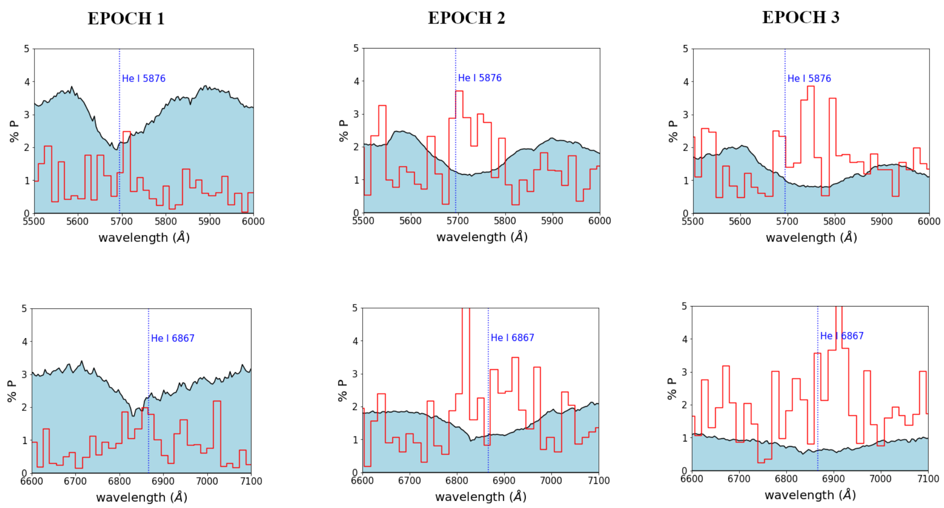

Figure 6

We find significant evolution in percent polarization associated with blue-shifted He I 5876 A and rest-frame He I 6867 A in the spectrum (Figure 6). We originally interpreted the feature at He I 5876 A as rest-frame He I 5756 A, but later identified it to be most likely He I 5876 A strongly blue-shifted by the SN winds, as reported by Benetti et al [5]. However, the detection of a strong polarization peak of about 4% corresponding to rest frame He I 5756 A requires further line identification analysis. Similar to the behavior of the total intensity and the total percent polarization at Hα, we suspect asymmetric substructure in the ejecta between the observer and the SN at these He I lines.

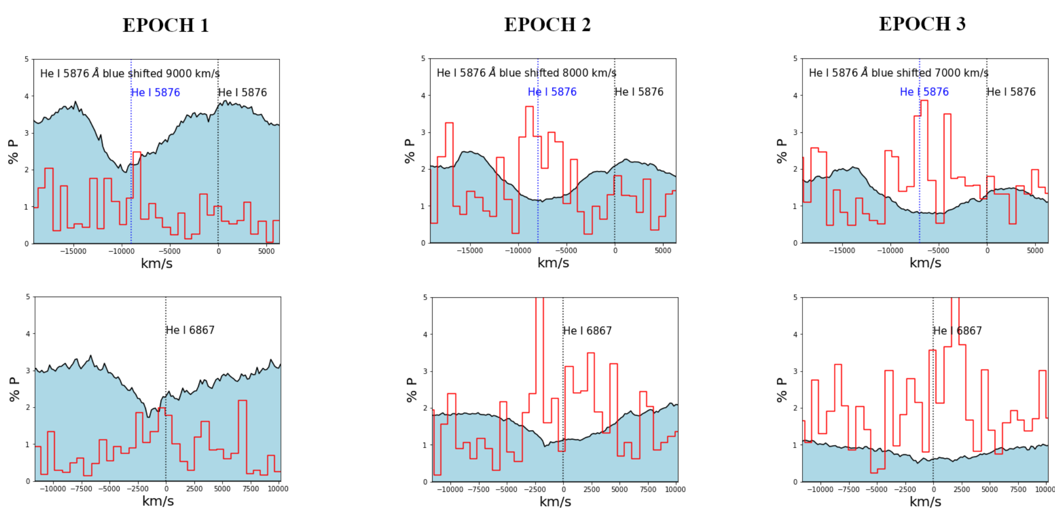

Figure 7

Figure 7 displays the same He I profiles from Figure 6 in velocity space. We report changes in the blue-shift of He I 5876 A line from epoch 1 to epoch 3, associated with 9000 km/s, 8000 km/s and 7000 km/s relative to rest He I 5876 A, respectively. This indicates that the SN envelope is slowly down with time.

THE Q-U PLANE: SPECTROPOLARIMETRIC BEHAVIOR OF HYDROGEN ALPHA AND HELIUM I

Introduction

The Hα and He I line features exhibit a wide variety of behaviors in the stokes Q-U plane. In this section, we present Q-U plots to highlight some distinctions and track their evolution.

An Hα "Loop" at Epoch 1?

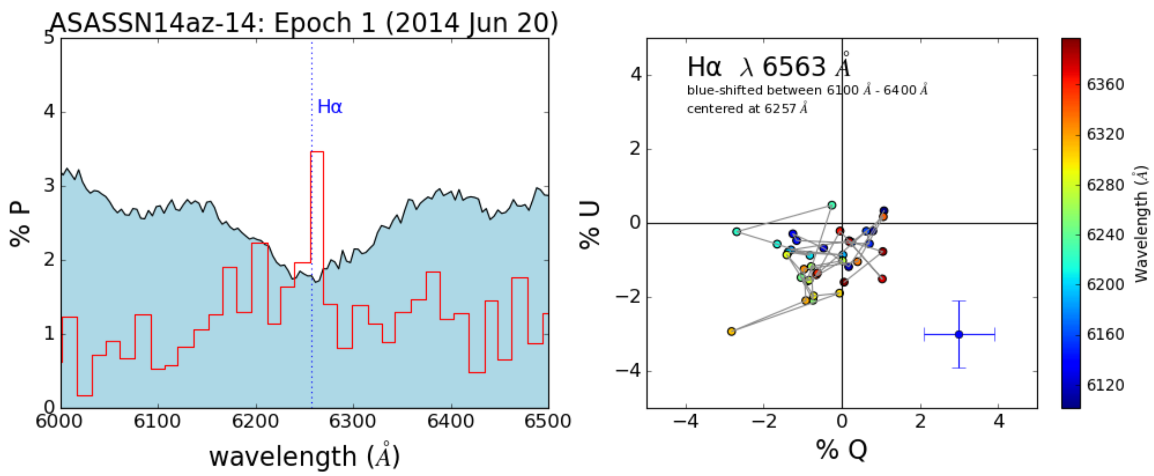

Figure 8

In Figure 8, we show spectropolarimetry of photospheric phase (Epoch 1 only) Hα absorption in ASAS-SN14az, blue-shifted by 14,000 km/s due the high expanding envelope velocities. In the left diagram, the light-blue shaded region is the relative optical intensity. The red histogram is a 15 A binned spectrum of the total percent polarization. The clear peak in percent polarization at the center of the Hα absorption feature indicates the presence of asymmetric structure in the scattering region between observer and the continuum source. In the right diagram, we show the stokes parameters Q-U plane for the blue shfited Hα line. There is a hint of a loop in the Q-U diagram around the center of the Hα line at 6250 A. Given the data uncertainties (shown in the lower right corner), it is not clear that this loop is real.

Evolution of He I 5756 A

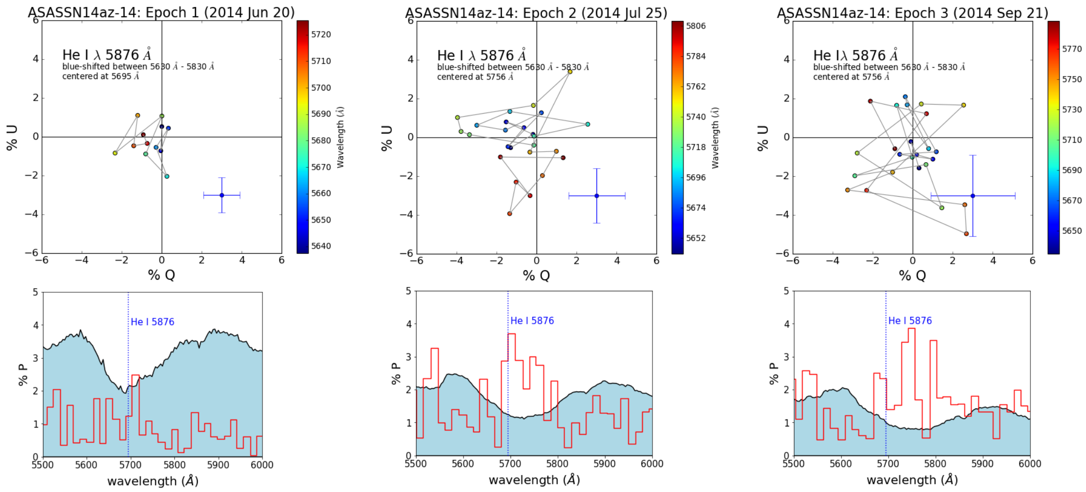

Figure 9

Figure 9 tracks the evolution of He I 5876 A through three epochs. There is a general trend of increasing percent polarization from epoch 1 to epoch 3. This trend can be seen either with the red-histogram data in the percent polarization spectra, or with the increasing distance between the points and the origin of the Q-U diagrams. Furthermore, in both epochs 1 and 2, there is clear spatial differentiation in Q-U space that trends with wavelength: the blue and red wings of the He I line features occupy different parts of the Q-U diagrams. Also, at epoch 2, there is the hint of two distinct loops. Finally, epoch 3 shows a hint of a large loop marked with “orange” wavelength points near the center of the He I 5876 line, blue-shifted to 5756 A.

<u>Evolution of He I 6867 A</u>

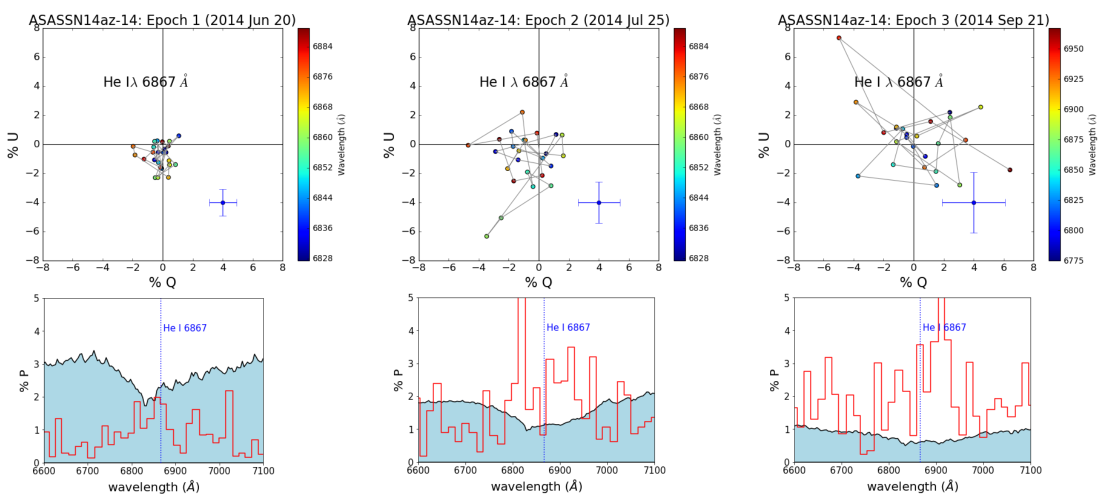

Figure 10

Figure 10 tracks the evolution of He I 6867 A through three epochs. There is a general trend of increasing percent polarization from epoch 1 to epoch 3. We note that measurement uncertainties are large for all epochs and for all line features.

SPECTROPOLARIMETRY:
A WINDOW INTO SUPERNOVAE

P, U, Q and PA

The quantities P, U and Q are percentages of the total intensity that is polarized. The U and Q stokes parameters for linear polarization are directly measurable quantities with the use of a polarimeter on a telescope of sufficient sensitivity. These quantities can be used to calculate P, the total percent polarization using:

$$P = \sqrt{U^2 + Q^2}$$

In terms of the equation above, P represents the distance from the origin for points in the Q-U plane. One can also characterize the position of a point in the Q-U plane using the position angle (PA) given by:

$$PA = \frac{1}{2} tan^{-1} \frac{U}{Q}$$

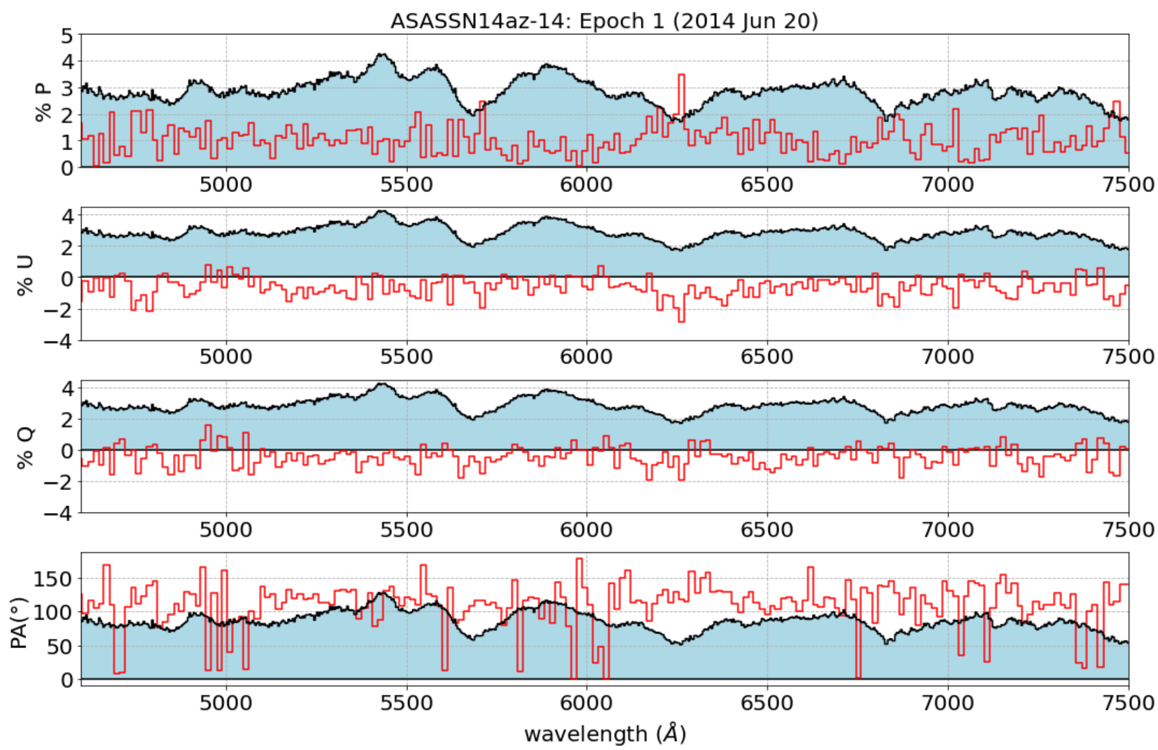

Figure 11

Figure 11 is an example of P, U, Q and PA spectra (15 A bins) for ASAS-SN14az at epoch 1. When searching for polarimetric signatures that indicate asphericity in the ejecta, an analysis is on the look out for non-zero values of P, large variations in PA, peaks in P at the location of absorption lines, and when either Q or U changes sign.

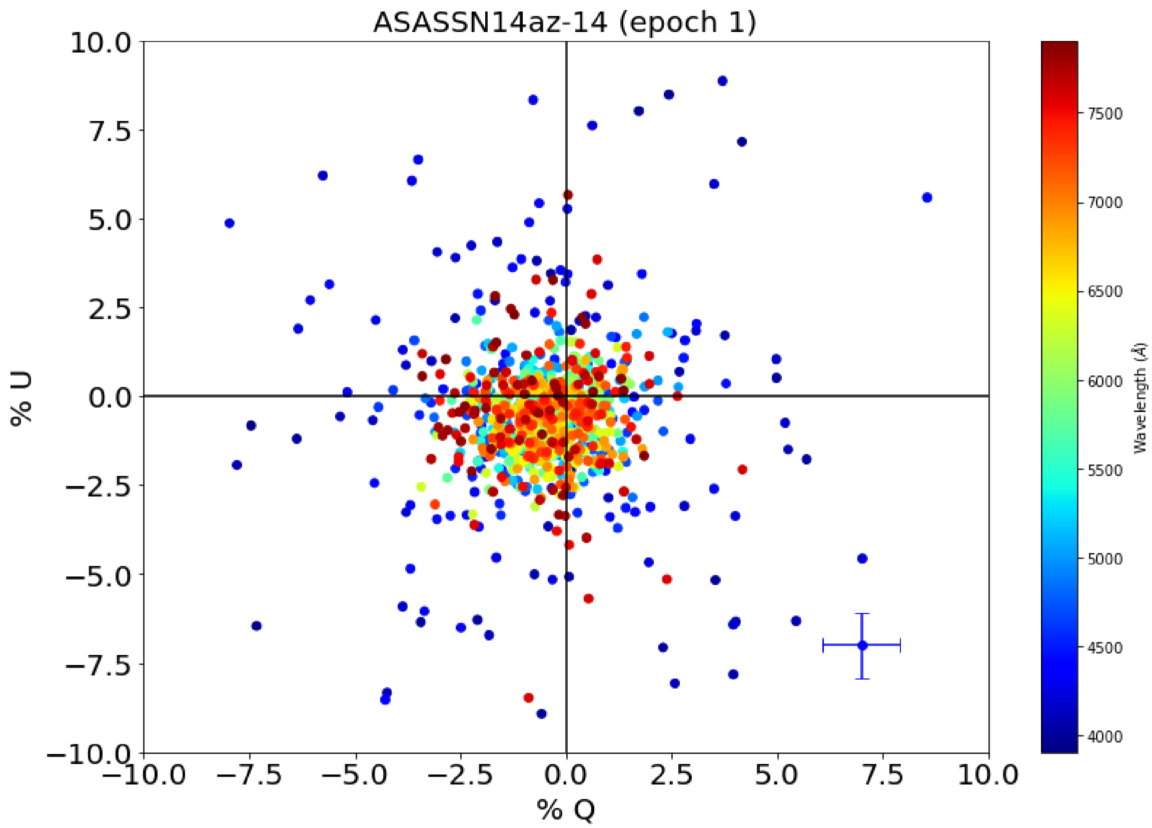

Figure 12

In the Q-U plane (Figure 12), one can look for a "dominant axis" (preferred direction) for the scattering region, where data points appear to form an approximate linear relationship. The scatter in Figure 10 is representative of all epochs for this data set of ASAS-SN14az: no preferred direction was found in this analysis.

Interstellar Polarization

Interstellar dust along the line of sight to SNe can also polarized light. This introduces the tricky complication to distinguish interstellar polarization (ISP) from a polarization signal that is intrinsic to SNe. Currently, there is no adequate method for deriving and subtracting the ISP from spectropolarimetry of SNe. However, generally speaking, polarization from SNe varies across line features and can change with time. On the other hand, the ISP's wavelength dependence has been well known from studies of stars in the Milky Way and does not change with time. Also, the ISP can cause a shift relative to the origin for the distribution of points in the Q-U plane. Figure 12 shows a distribution that is roughly centered at zero. While we have pause to make strong statements regarding the trends we see in the Q-U diagrams reported here, Figure 12 does suggest that the ISP toward ASASSN-az14 is low.

A Window into SNe Geometry

The spectropolarization signatures above can provide unique information on the three dimensional structure of SNe ejecta and their interaction with the circumstellar environment [9]. Since extragalactic SNe are spatially unresolved, only spectropolarimetry can reveal information regarding their explosion geometry by measuring the degree at which the light is linearly polarized [10].

The intense radiation field of a SN is capable of highly ionizing their expanding envelopes. Optical photons from the SNe are scattered by the free electrons in these expanding stellar atmospheres via Thompson scattering, which polarizes the radiation.

In a simple radiative transfer model, Shapiro and Sutherland [9] demonstrated that in highly ionized plasma that is spherically symmetry, the U and Q stokes vectors of the electric field of the radiation field are perfectly cancel out, leading to zero total polarization. However, if the plasma is asymmetric --- a prolate or oblate spheriod for example --- then perfect electric field cancellation does not occur in the scattering regions, producing a non-zero, net polarization. In the last 20+ years, SNe spectropolarimetric observations indicate that most SNe do in fact have some degree of anti-symmetry. There are still open questions regarding SNe and how they work; however, the current field has shifted toward more detailed physical modelling that explore explosion mechanisms that can account for this asymmetry. Thus, the SNSPOL project can provide crucial clues to the nature and evolution of SNe shapes and provide constraints and tests for the next generation of three-dimensional, dynamical models of SNe explosions [10].

WHAT IS THE PHYSICAL SIGNIFICANCE OF "LOOPS" IN THE Q-U PLANE?

The detection of polarization across spectral line features is a potential clue to small-scale structure in the expanding envelopes of SNe. Changes in the density and chemical structure of the ejecta can cause the percent polarization and the position angle to vary across the lines, producing loops in the Q-U plane. Models of SNe illustrate how these loops can occur due to density, composition and velocity structure of clumpy ejecta [11]. Also, if the ejecta lacks axial symmetry geometry, then loops naturally form in the Q-U plane.

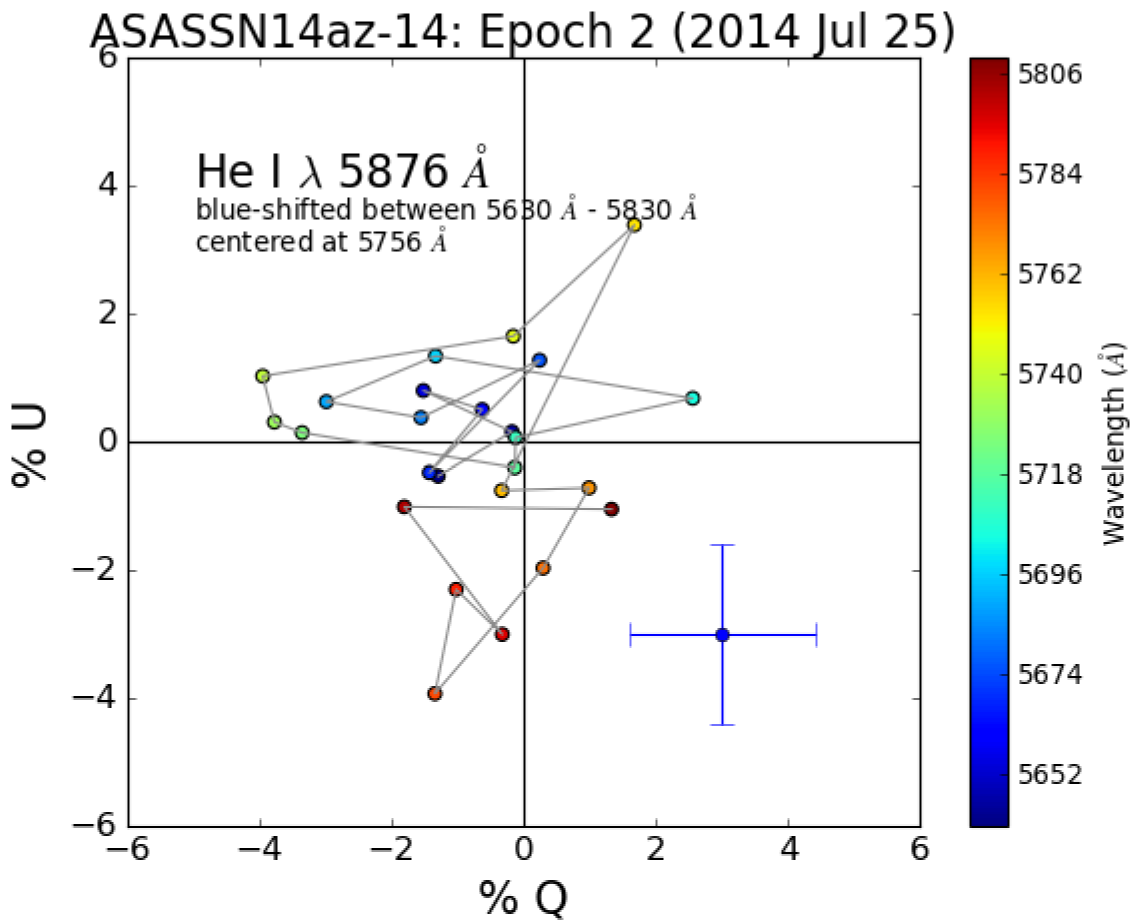

Figure 11

In figure 11, we reproduce the loops seen in Epoch 2 He I 5876 from figure 9 to illustrate the wavelength dependence of the loci of the loops in the Q-U plane. SNSPOL observations such as these require complex computational models of SNe to understand these loops in terms of an intrinsic geometry of the scattering ejecta [12].

ABSTRACT

Supernovae of Type IIb (SNe IIb) are relatively rare events, constituting roughly 10% of all core-collapse supernovae. However, comparative optical spectroscopy of core-collapse events suggest that SNe IIb represent an important transition from the SNe II to SNe Ib sub-type. SNe IIb progenitors are thought to have been stripped of most, but not all, of their hydrogen envelopes by stellar winds or mass transfer in binary systems. Thus, they provide an opportunity to study the effects of mass-loss on stellar evolution. Spectropolarization signatures of these SNe can provide unique information on the spatial distribution of their ejecta and circumstellar environment/interaction. We present multi-epoch spectropolarimetry of SNe IIb ASASSN-14za, selected from the database of SNSPOL. The observations were obtained using the SPOL instrument at the University of Arizona telescopes. We discuss the time-dependence of spectral features, the full polarization spectrum, stokes parameters spectra, and the spectropolarimetric signatures of H-alpha and He I. These time-dependent “snapshots” provide an important window into stripped-envelope SNe and provide further clues regarding the relationship between SNe IIb and other SNe sub-types.

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