

SN 2024afav: A Superluminous Supernova with Multiple Light Curve Bumps and Spectroscopic Signatures of Circumstellar Interaction

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ABSTRACT

We present a comprehensive optical and near-infrared spectroscopic study of SN 2024afav – a hydrogen-poor superluminous supernova (SLSN-I) that peaks at ≈ -20.7 mag and exhibits an unusual multi-bumped light curve. Our spectroscopic observations, spanning phases of -14 to $+160$ d, reveal several unusual features: (i) a narrow ($1,800 \text{ km s}^{-1}$) and blueshifted ($11,000 \text{ km s}^{-1}$) absorption from H α starting at $+20$ d; (ii) persistent optical and NIR He I lines at all available phases, showing double absorption structure in NIR spectra at $+23$ d, with a high velocity component at a similar velocity to H α ; (iii) early appearance of nebular [O III] emission starting at $\approx +50$ d; and (iv) strong [O II] + [Ca II] 7300 Å emission complex starting at $\approx +110$ d. These unusual features, and their onset at the time of the light curve bumps, provide compelling evidence of circumstellar interaction between the SN ejecta and a nearby hydrogen-rich shell, as well as the presence of helium in both the outer layers of the progenitor star and in the circumstellar medium. A comparison of SN 2024afav to other SLSNe-I showing bumpy light curves and similar spectral properties (PTF10hgi, SN 2017egm, SN 2019hge), points to a rare sub-group of SLSNe-I in which CSM interaction provides an important modulation to the energy input.

Keywords: Supernovae() — Optical astronomy() — Transient() — near-IR Spectroscopy() — Astronomical spectroscopy()

1. INTRODUCTION

Hydrogen-poor superluminous events are one of the brightest stellar explosion events in the Universe, with an absolute magnitude $M \lesssim -21$ and total radiated energy exceeding 10^{50} - 10^{51} ergs (R. M. Quimby et al. 2011; L. Chomiuk et al. 2011; A. Gal-Yam 2012; M. Nicholl et al. 2015; C. Inserra et al. 2017; D. A. Howell 2017; R. Lunnan et al. 2018a; M. Nicholl 2021; T. J. Moriya 2024). Typically discovered in low-metallicity dwarf galaxies (R. Lunnan et al. 2014; D. A. Perley et al. 2016; T.-W. Chen et al. 2017; B. Hsu et al. 2024), these events exhibit characteristic O II and C II absorption features in their early-time spectra, indicating high temperatures, and show no signs of hydrogen (H) lines (P. A. Mazzali et al. 2016; M. Nicholl et al. 2016; R. M. Quimby et al. 2018; C. R. Angus et al. 2019; A. Gal-Yam 2019a,b; A. Aamer et al. 2025a). Recent large-scale sample studies of these events by S. Gomez et al. (2024), Z. H. Chen et al. (2023), and A. Aamer et al. (2025a) have revealed a significant diversity in their light curve behavior and spectral properties, challenging the existing progenitor models.

The powering mechanism of SLSNe-I has been debated over the last few years. Several models of SLSNe-I powering mechanism have been proposed such as a highly spinning, magnetized neutron star (magnetar) spin-down model (D. Kasen & L. Bildsten 2010; S. E. Woosley 2010; R. Lunnan et al. 2014; B. D. Metzger et al. 2015; D. A. Perley et al. 2016; T.-W. Chen et al. 2017; M. Nicholl et al. 2017; G. Hosseinzadeh et al. 2022; S. Gomez et al. 2024), interaction between dense ejecta and circumstellar medium (CSM) (E. Sorokina et al. 2016; J. C. Wheeler et al. 2017; R. Lunnan et al. 2018b; L. Yan et al. 2020; A. Fiore et al. 2021), pulsational/pair-instability supernova (A. Gal-Yam et al. 2009; A. Kozyreva & S. Blinnikov 2015; M. Pursiainen et al. 2022; W. Lin et al. 2023) or fallback accretion (J. Dexter & D. Kasen 2013; T. J. Moriya et al. 2018). Among these, magnetar models are potentially the only ones that can consistently explain the peak luminosities of SLSNe based on large-scale light curve fits, as shown in several recent studies (B. Hsu et al. 2021; M. Nicholl et al. 2017; S. Gomez et al. 2024).

While the magnetar spin-down model provides a good fit for the majority of the events, some SLSNe-I exhibit bumpy light curves that deviate significantly from the smooth spin-down curve of the magnetar model. For example, a well-studied SN 2017egm shows a chaotic light curve which has been explained via a complex CSM interaction model (J. Zhu et al. 2023; W. Lin et al. 2023). Similar to SN 2017egm, some other SLSNe-I favour CSM interaction models over magnetar (E. Sorokina et al. 2016; J. C. Wheeler et al. 2017; R. Lunnan et al. 2018b; L. Yan et al. 2020; A. Fiore et al. 2021).

At least 30%, if not more, SLSNe-I exhibit multiple bumps in their post-peak light curves, unexplained by the favorite magnetar model (G. Hosseinzadeh et al. 2022). A few such examples are well-studied events, such as PTF12dam (A. Tolstov et al. 2017), iPTF13ehe (L. Yan et al. 2015), SN 2015bn (M. Nicholl et al. 2018), 2017egm (J. Zhu et al. 2023), PTF10hgi (L. Yan et al. 2020), SN 2019hge (L. Yan et al. 2020), and SN 2019umb (S. J. Prentice et al. 2021), among others. The origin of these bumps has been a long-standing mystery. For some of the events where bumps appear to be somewhat periodic, J.-P. Zhu et al. (2024); B. Zhang et al. (2025); J. R. Farah et al. (2025) used a magnetar precession-based model to explain their origin. Bumps in SN 2017egm, SN 2017gci and other similar events were explained through CSM interaction models (S. Bose et al. 2018; A. Fiore et al. 2021; J. Zhu et al. 2023). While these models attempt to explain the early-time light curve bumpy behavior, the majority of these events lack sufficient light curve coverage to test these models over a longer period, where well-followed events like SN 2015bn clearly show non-periodic behavior (M. Nicholl et al. 2018), suggesting a need for detailed follow-up of such events and spectroscopic study to unveil the mystery of the origin of bumps in SLSNe-I.

A handful of these bumpy events have shown very unusual spectroscopic signatures that deviate from the SLSNe-I spectra template. PTF10hgi and other SLSNe-I present in L. Yan et al. (2020) are illustrative examples of such a sample. These objects show signs of helium and, in some cases, hydrogen as well, in their spectra. L. Yan et al. (2020) study associates the presence of He I with bumps, suggesting that CSM interaction can provide a natural mechanism to excite helium and produce bumps in the light curves of these events. Similarly, in SN 2017egm the presence of helium and [O III] is associated with a helium-rich CSM interaction with ejecta that is mainly dominated by oxygen, producing both features (S. Bose et al. 2018; J. Zhu et al. 2023). These events suggest that there exists a subclass of events where CSM interaction plays a crucial role in shaping the light curve and spectral features. These events may have a different progenitor channel or chaotic mass-loss history than those of typical SLSNe-I. A deeper understanding of the correlation between light curve bumps, the presence of helium, and other unusual spectral features in the spectra is crucial for understanding the progenitor and explosion physics of these events.

We present SN 2024afav—a $M \approx -20.7$ luminosity SLSN-I with multiple bumps in the light curve. In the first paper of a two-part paper series, we present a precessing magnetar model that can explain the first few bumps J. R. Farah et al. (2025). The study suggested that the presence of late-time bumps could be explained by possible interaction with the CSM. Here, we present a detailed spectroscopic study of SN 2024afav to investigate the presence of CSM interaction and its implications on the light curve. Our extensive spectroscopic campaign reveals that SN 2024afav exhibits rare features, including the presence of early [O III] lines, the detection of helium, the emergence of a narrow hydrogen absorption line, and the appearance of late-time [O II] lines. We provide a detailed discussion on light curve morphology, temperature evolution, spectral evolution, and a possible breakthrough in the detection of CSM interaction in SLSNe-I. This study represents a significant step towards a more detailed and systematic analysis of a large-scale sample of SLSNe-I spectra with bumpy light curves. The paper is outlined as follows: In §2 we describe the photometric & bolometric light curve, spectroscopic observations of SN 2024afav. We provide the light curve morphology and photometric evolution in §3, followed by spectroscopic evolution in a §4. In §5, we discuss the unusual features in 2024afav and compare it to objects with similar light curves and spectral properties, and discuss the

implications of these features. Finally, we summarize the key results and outline the future direction of this study in §6.

2. OBSERVATIONS AND DATA

2.1. Discovery

SN 2024afav was discovered by the Asteroid Terrestrial-impact Last Alert System (ATLAS; J. L. Tonry et al. 2018) survey on 2024 December 12.71 UT, with an ATLAS-orange magnitude of 18.3, at R.A.=12^h49^m12^s.5, Decl.=−18° 06′ 12″.61 (A. Kumar et al. 2024). S. de Wet et al. (2025) classified SN 2024afav as a hydrogen-poor superluminous supernova at a tentative redshift of $z \approx 0.09$, using spectra obtained on 2025 January 24. We used our high-quality spectra to refine the redshift to $z = 0.0724 \pm 0.0001$ ($d_L \approx 340$ Mpc), which we employ throughout this paper. The SN is located $\approx 0.5''$ from the center of a faint galaxy detected in Legacy survey images, with magnitudes of $m_g \approx 22.2$, $m_r \approx 21.7$, $m_i \approx 21.6$, and $m_z \approx 21.6$. At the redshift of the galaxy, the corresponding absolute magnitudes are $M_g \approx -15.3$, $M_r \approx -15.8$, $M_i \approx -16.0$, and $M_z \approx -16.0$. Using the SDSS luminosity function from A. D. Montero-Dorta & F. Prada (2009), we infer a host luminosity of $L_g \approx 1.47 \times 10^8 L_{g,\odot} \approx 0.011 L_g^*$, $L_r \approx 1.50 \times 10^8 L_{r,\odot} \approx 0.006 L_r^*$.

2.2. Optical/UV Photometric Observations

We obtained multi-band photometric observations using the Las Cumbres Observatory network (LCO; T. M. Brown et al. 2013), and the Fred Lawrence Whipple Observatory (FLWO⁹) 1.2-m telescope equipped with Keplercam¹⁰. The observations were performed in g, r, i, z filters. The LCO data were reduced using the `lcogtsnpipe` pipeline (S. Valenti et al. 2016), while Keplercam data were reduced using a python-based photometric pipeline following standard reduction procedures. In addition to our follow-up observations, we obtained publicly available photometry from the ATLAS.

We additionally obtained observations with the *Neil Gehrels Swift* UV/optical telescope in six filters: UVW2, UVM2, UVW1, U , B , V (PI: Kumar), and utilized other publicly available UVOT data (PIs: Farah, Schulze). We performed photometry using UVOTSOURCE¹¹ of HEASoft, a part of the Swift software suite, with an aperture of 5'' radius and standard aperture corrections.

The entire photometric campaign spans 255 days from the date of discovery (see Table 2). A subset of the optical photometry has been previously presented in J. R. Farah et al. (2025). The photometric dataset presented here is in the AB magnitude system for all filters, and has been corrected for Galactic extinction, with $E(B - V) = 0.062$ mag (E. F. Schlafly & D. P. Finkbeiner 2011), assuming the E. L. Fitzpatrick (1999) reddening law with $R_V = 3.1$. No host extinction correction has been applied. The multi-band light curves are shown in Figure 1. The c, o band and pseudo-bolometric light curves peak at MJD = 60703.3 which we use as Phase = 0 throughout the paper (see Figure 2 and §3 for details)

2.3. Optical Spectroscopic Observations

Following the initial classification of SN 2024afav as a SLSN-I, we obtained an extensive spectroscopic sequence spanning phases of +20 d to +160 d using LCO, the 6.5-m Multi-mirror Telescope (MMT), the 6.5-m Magellan telescopes, and the 8.2-m Gemini-South telescope. Additionally, we included publicly available spectra on WISerEP¹² (O. Yaron & A. Gal-Yam 2012) obtained at −14 d and −4 d phases.

Low-resolution ($R \approx 400$) spectra were obtained with the FLOYDS spectrographs mounted on the 2-m LCO Faulkes telescopes North (FTN) at Haleakalā, and South (FTS) at Siding Spring, Australia. The observations were undertaken as part of the Global Supernova Project from phase +20 d to +91 d. We used a 2'' slit along the parallactic angle (A. V. Filippenko 1982), covering a wavelength range of 3400 – 10000 Å. One-dimensional spectra were extracted, reduced, and calibrated following standard procedures using `floyds_pipeline`¹³ (S. Valenti et al. 2014).

On MMT, we used the Binospec spectrograph (D. Fabricant et al. 2019) with the LP3800 filter in combination with the 270 lines/mm grating and a 1''-wide slit covering a wavelength range of 3825 – 9200 Å with $R \approx 1500$. Two spectra were obtained at phases of +54 d and +139 d.

We used the Low Dispersion Survey Spectrograph 3 (LDSS3; K. B. Stevenson et al. 2016) on the Magellan/Clay 6.5-m telescope with the VPH-All grism and a 1''-wide slit, covering a wavelength range of 4265 – 9650 Å with $R \approx 700$.

⁹ <https://www.cfa.harvard.edu/facilities-technology/cfa-facilities/fred-lawrence-whipple-observatory-mt-hopkins-az>

¹⁰ <https://pweb.cfa.harvard.edu/facilities-technology/telescopes-instruments/12-meter-48-inch-telescope>

¹¹ <https://www.swift.ac.uk/analysis/uvot/mag.php>

¹² URL <https://wiserep.org>

¹³ https://github.com/LCOGT/floyds_pipeline

Four spectra were obtained at phases spanning +30 d to +160 d. Furthermore, we obtained a high-resolution spectrum using the Magellan Inamori Kyocera Echelle (MIKE), with three exposures of 1800 sec each at 2×2 binning and $1''$ -wide slit resulting in a resolution of $R \approx 19,000$ and $R \approx 25,000$ on the red and blue sides, respectively, covering a wavelength range of $3350 - 9500 \text{ \AA}$ at a phase of +53 days.

We used the GMOS spectrograph on the Gemini-South telescope to obtain a spectrum at +24 d phase, with the R150 grating, GG455 filter, and a $1''$ -wide slit, covering a wavelength range of $4744 - 9999 \text{ \AA}$ with $R \approx 300$.

The spectra from MMT, Magellan, and Gemini were reduced using the `PyPeIt` package (J. X. Prochaska et al. 2020) in a standard manner. The one-dimensional spectra were extracted and flux-calibrated using a standard star observation obtained with the same configuration. Data from the high-resolution MIKE spectrograph was reduced using a python-based `CarPy` pipeline (D. D. Kelson et al. 2000; D. D. Kelson 2003)

2.4. NIR Spectroscopic Observations

We obtained NIR spectra with FLAMINGOS2 (S. Eikenberry et al. 2006) on Gemini-North and GNIRS (J. H. Elias et al. 2006) on Gemini-South. The FLAMINGOS2 spectra were obtained at phases of -2 d and $+3$ d using the medium-resolution configuration with a 2-pixel wide slit and an HK filter, covering $1.26 - 2.50 \mu\text{m}$ with $R \approx 900$. The GNIRS spectrum was obtained at a phase of +23 d with the short camera, 32 l/mm grating, a 3-pixel-wide slit, and cross-dispersed, covering a wavelength range of $0.82 - 2.52 \mu\text{m}$ with $R \approx 1200$. The NIR spectra were reduced using the `PyPeIt` package, including flat-fielding using `GCALflats` and sky subtraction obtained on the same night as the spectra. Flux calibration was performed on the extracted spectra using standard star observations obtained on the same night. Finally, a telluric correction was applied to account for atmospheric absorption features.

3. LIGHT CURVE EVOLUTION

3.1. Light curve Morphology

The multi-band light curves of SN 2024afav, shown in Figure 1, exhibit an unusual evolution. The light curve rises for ≈ 46 days after discovery and peaks at $\text{MJD} \approx 60703.3$ with $M_c \approx -20.70$ and $M_o \approx -20.51$ (K-corrected; D. W. Hogg et al. 2002). The light curve shows a slight dip in brightness following the initial peak, and then brightens again to a second, equally bright peak at +40 d, with $M_c \approx -20.60$, $M_o \approx -20.57$, and $M_g \approx M_r \approx -20.50$. Following the second peak, the light curve shows a sharp decline, followed by a third peak at +72 d with $M_g \approx -19.3$ and $M_r \approx -19.9$. After the first three peaks, the light curve shows four more low-scale undulations at +94 with $M_r \approx -19.1$, at +109 with $M_r \approx -18.8$, at +142 with $M_r \approx -18.0$, and at +175 with $M_r \approx -17.0$. The light curve starts to show the start of another peak; however, no photometric coverage is available due to visibility constraints. The peak absolute magnitude is at the 78th percentile of the SLSNe-I population (S. Gomez et al. 2024).

The $g - r$ and $c - o$ colors are initially ≈ -0.2 to 0 mag during the first two peaks, and then redden rapidly after the second peak to a mean value of $\approx +0.6$ mag. However, the densely-sampled $g - r$ color curve exhibits changes to a bluer color at the time of subsequent light curve peaks.

Peak Number	MJD	Phase (days)	L_{bol} (erg s^{-1})	FWHM (days)
1	60703.3	0	7.48×10^{43}	23.0
2	60745.7	+40	5.41×10^{43}	29.6
3	60781.1	+72	2.24×10^{43}	8.8
4	60803.7	+94	1.25×10^{43}	12.1
5	60819.8	+109	0.96×10^{43}	11.6
6	60851.9	+142	0.48×10^{43}	12.5
7	60890.5	+175	0.18×10^{43}	14.1

Table 1. The properties of significant peaks in the pseudo-bolometric light curve.

3.2. Temperature and Radius Evolution

We used the `extrabol` python package (I. Thornton et al. 2024) to determine the bolometric light curve, photospheric temperature, and radius evolution of SN 2024afav, assuming a blackbody spectrum. The results are shown in Figure 2.

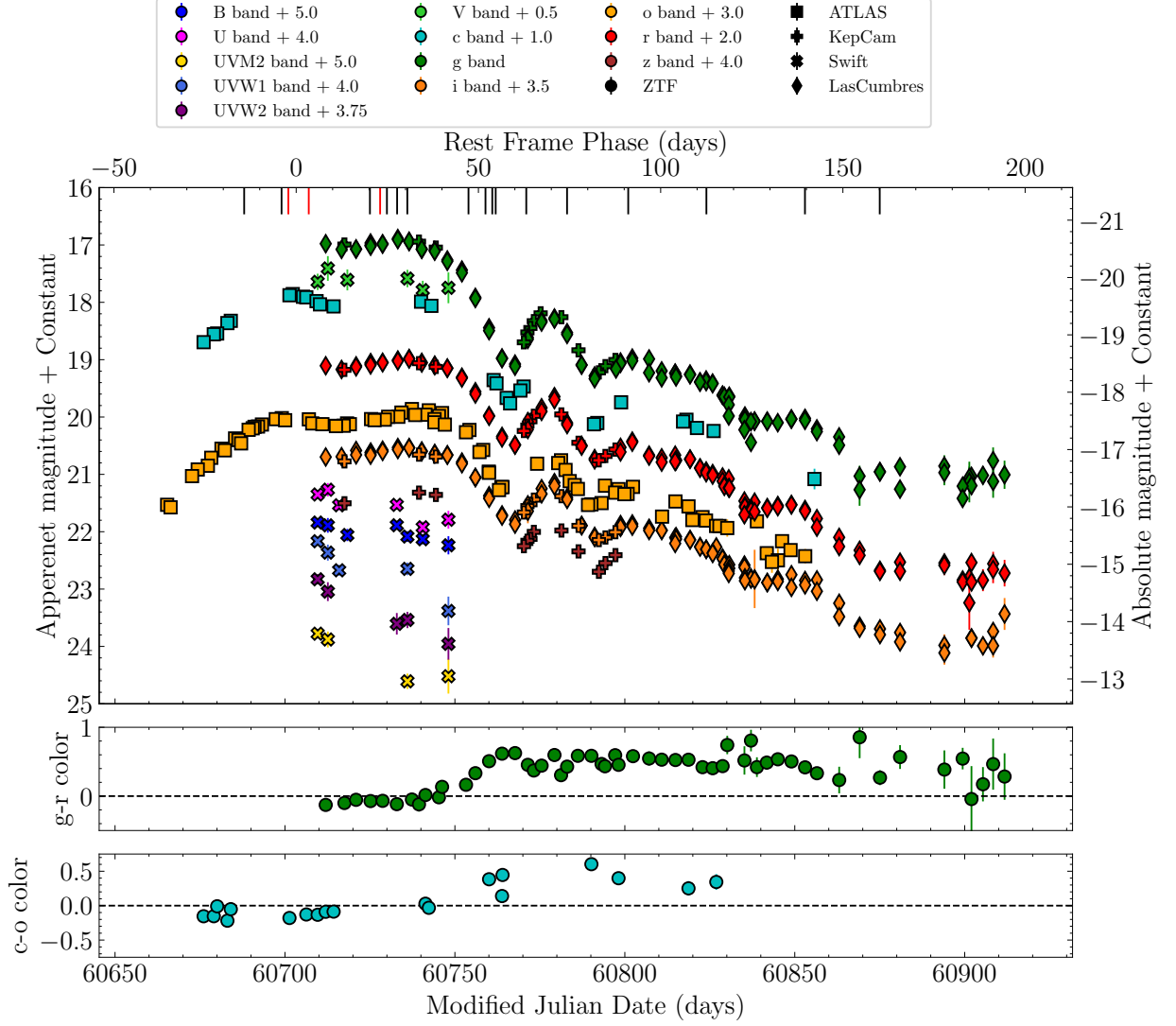


Figure 1. Optical/UV light curves of SN 2024afav with magnitudes in the AB system and corrected for Galactic Extinction. The solid vertical ticks on the top axis mark the epochs of optical (black lines) and near-IR (red lines) spectroscopic observations. The black lines represent optical and the red lines represent epochs of Near-IR spectroscopic observations. The light curve rises from discovery to the first peak in ≈ 46 d and peaks at an absolute magnitude of $M_c \approx -20.7$. Subsequently, it exhibits a second peak of comparable brightness ≈ 38 d later, before decaying sharply and displaying multiple subsequent undulations over the remainder of its evolution in all bands. The $g - r$ (green) and $c - o$ (blue) colors show an overall evolution from blue to red, but with changes to bluer colors around the light curve peaks.

We fit a smooth curve to the overall light curve using a large bin size of 30 to minimize the effects of undulation on the fitted curve. This trend was then subtracted from the bolometric light curve and `scipy.signal.find_peaks` python package was used to get the peaks in the light curve. Including the primary peak, the light curve shows a total of seven peaks in the bolometric light curve (see Table 1). We estimate a peak luminosities of $\approx 7.5 \times 10^{43}$ erg s^{-1} for primary peak. The positions, $L_{p, \text{bol}}$ and half widths, for all peaks have been listed in Table 1. Integrating the light curve, we find a total radiated energy of $\approx 5.1 \times 10^{50}$ erg, on the lower end of the SLSNe-I population (S. Gomez et al. 2024).

The temperature declines from $\approx 12,700$ K at the first epoch to $\approx 10,340$ K until the primary peak. Thereafter, the temperature decreases further to $\approx 8,500$ K around the secondary peak, before showing a sudden decline to $\approx 5,900$ K at +60 d phase. After this epoch, the temperature shows a rise to $\approx 6,870$ K, following the third peak in the light

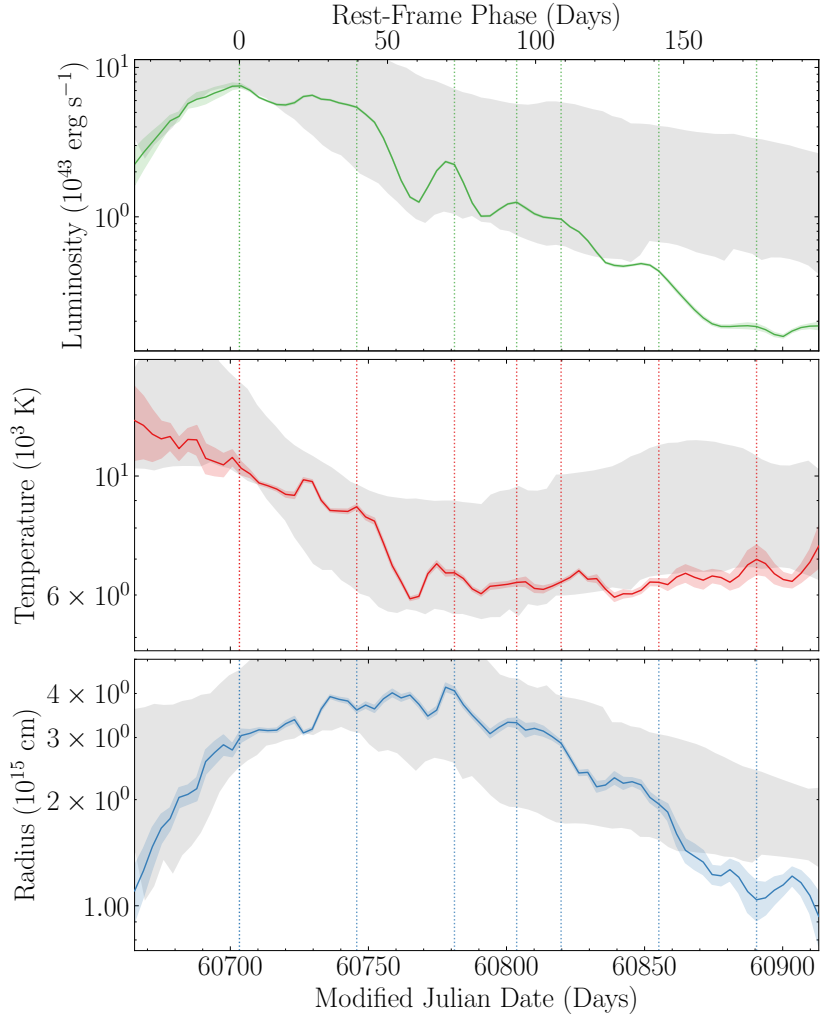


Figure 2. The pseudo-bolometric light curve (top), photospheric temperature (middle), and photospheric radius (bottom) of SN 2024afav. The grey-shaded regions represent the range of parameters for quantities in the SLSN-I population, as reported by S. Gomez et al. (2024). The pseudo-bolometric light curve exhibits multiple bumps (marked by vertical lines). The peak luminosity and width of each peak are provided in Table 1. The temperature and radius fluctuations closely follow the peaks.

curve at $\approx +70$ d phase. After the third peak, the temperature evolution shows small fluctuations and closely follows the light curve undulations and remains close to $\approx 6,000$ K.

The photospheric radius shows an increase from $\approx 10^{15}$ cm at first detection to $\approx 3 \times 10^{15}$ cm at the primary peak. Subsequently, the radius continues to rise more gradually past the secondary peak to a maximum value of $\approx 3.9 \times 10^{15}$ cm at +40 d. The radius then declines back to $\approx 10^{15}$ cm at +180 d. Throughout this overall evolution, the photospheric radius exhibits smaller fluctuations during the multiple light curve peaks.

4. SPECTROSCOPIC ANALYSIS

4.1. Optical Spectral Evolution Overview

The complete optical spectral sequence from phase -14 to $+160$ d is shown in Figure 3, and a detailed identification of features using SN 2017egm, PTF10hgi and median spectra from A. Aamer et al. (2025b), is marked in Figure 4 at the $+51$ d and $+112$ d phases. The spectral evolution follows a typical trend observed in SLSNe-I, from a hot, blue continuum with absorption lines at early times to a cooler, emission-line-dominated spectrum in the near-nebular phase. The early pre-peak spectra exhibit the typical “w”-shape broad features of O II in the $3500 - 5000 \text{ \AA}$ region with a velocity $\approx 11,600 \text{ km s}^{-1}$. The early spectra also show features in the $5000 - 6000 \text{ \AA}$ region commonly associated with Na ID and Si II and sometimes He I (Z. H. Chen et al. 2023; S. Gomez et al. 2024; A. Aamer et al. 2025a).

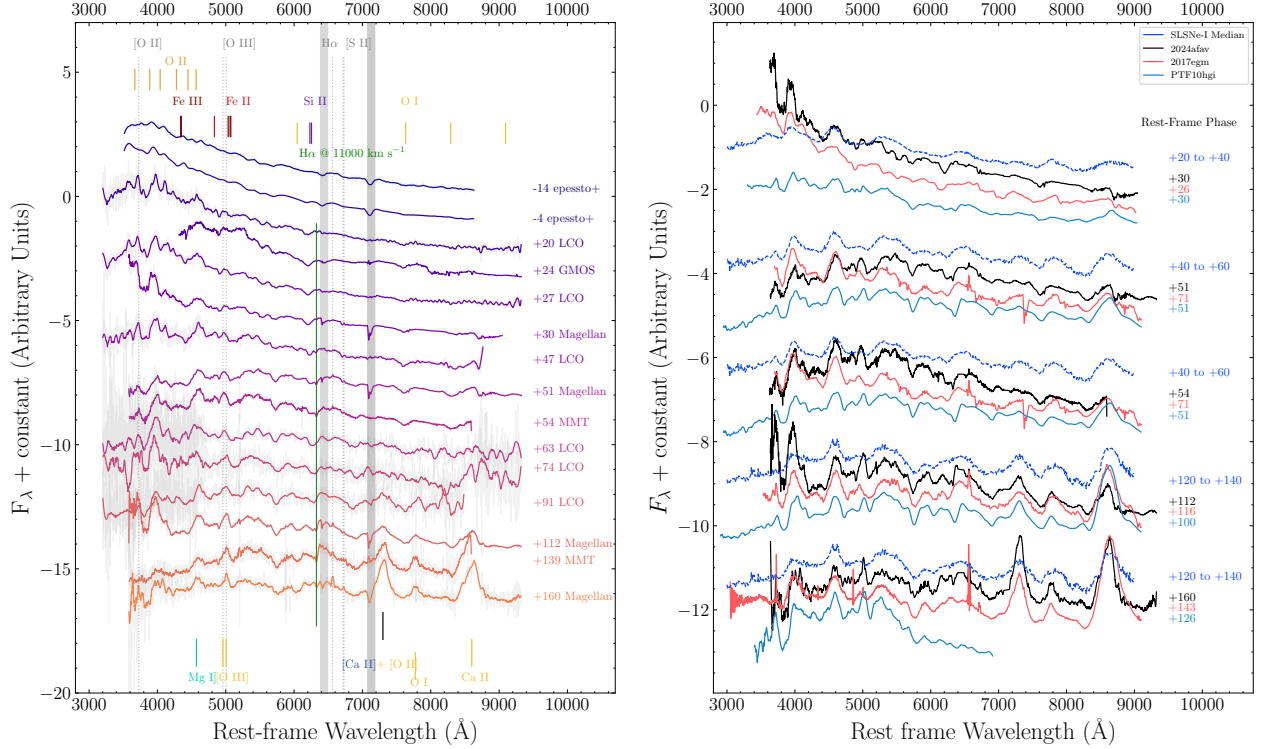


Figure 3. *Left:* Optical spectra of SN 2024afav covering phases of -14 d to $+160$ d. The early-time spectra are blue, with characteristic O II features. In the post-peak phases we observe other common SLSNe-I features of Fe II, Fe III, Na ID, Si II and O I, along with unusual narrow features such as [O III] emission and H α absorption. The $\gtrsim +112$ d spectra show nebular NIR Ca II triplet and [Ca II] + [O II] complex. The colored spectra are smoothed using the Savitzky–Golay filter (M. A. Selver et al. 2018). *Right:* Comparison of SN 2024afav spectra to SN 2017egm, PTF10hgi, and median SLSNe-I spectra (A. Aamer et al. 2025b) at several phases. SN 2024afav shows remarkable similarity to SN 2017egm, PTF10hgi and SN 2019hge including the unusual [O III] and [Ca II] + [O II] complex emission features. The narrow H α feature in the SN 2024afav spectra is at a similar velocity and width to H α in PTF10hgi (L. Yan et al. 2020). A detailed identification of all features in the post-peak phase is provided in Figure 4.

Post-peak, as the temperature declines to $\lesssim 10^4$ K, the O II lines weaken and the $3500 - 5000$ Å region is dominated by Fe II and Fe III lines with noticeable presence of $\lambda 5169$ Å feature. The $5000 - 6500$ Å region shows three absorption features that increase in strength over time, which we identify as He I $\lambda 5876$ Å and Na ID $\lambda\lambda 5890, 5896$ Å complex, O I $\lambda\lambda 6150$ Å and Si II $\lambda 6355$ Å. Meanwhile, O I $\lambda 7774$ Å appears in the $+20$ d spectrum and becomes stronger over time until $+63$ d, where it starts to show an associated emission component. From $+20$ d to $+74$ d, the velocity decreases from $\approx 7,500$ km s⁻¹ to $\approx 6,300$ km s⁻¹, estimated using isolated Si II and O I features.

Starting at a phase of $+91$ d, the spectra begin to exhibit near-nebular emission lines of Mg I $\lambda 4571$ Å and the Ca II $\lambda\lambda 8498, 8542, 8662$ Å NIR triplet. Furthermore, the O I $\lambda 7774$ Å feature changes from absorption to emission and becomes stronger over time until our last spectrum at $+160$ days. We estimate a velocity of $\approx 6,000$ km s⁻¹ at a phase of ≈ 100 d using O I $\lambda 6158$ Å and $\lambda 7774$ Å. Moreover, we find an emission feature of [Ca II] and [O II] centered at ≈ 7300 Å starting at $+112$ d, which becomes stronger thereafter. This feature is discussed in detail in §4.2.

SN 2024afav spectral features exhibit lower velocities than the median spectra of SLSNe-I (A. Aamer et al. 2025b); as shown in Figure 3. The spectral evolution, features, and velocity progression most closely resemble those of the unusual events SN 2017egm and PTF10hgi (J. Zhu et al. 2023; L. Yan et al. 2020), which share a few distinctive features in their optical spectra. We discuss the distinctive feature in detail in § 4.2 and § 5. The spectral similarities from peak to post-peak phases make SN 2024afav a spectral analog of PTF10hgi and SN 2017egm events.

4.2. Unusual Spectral Features

While most of the spectral features in SN 2024afav are typical of SLSNe-I, some are unusual; we show the evolution of these features in Figure 5 and discuss them in detail below.

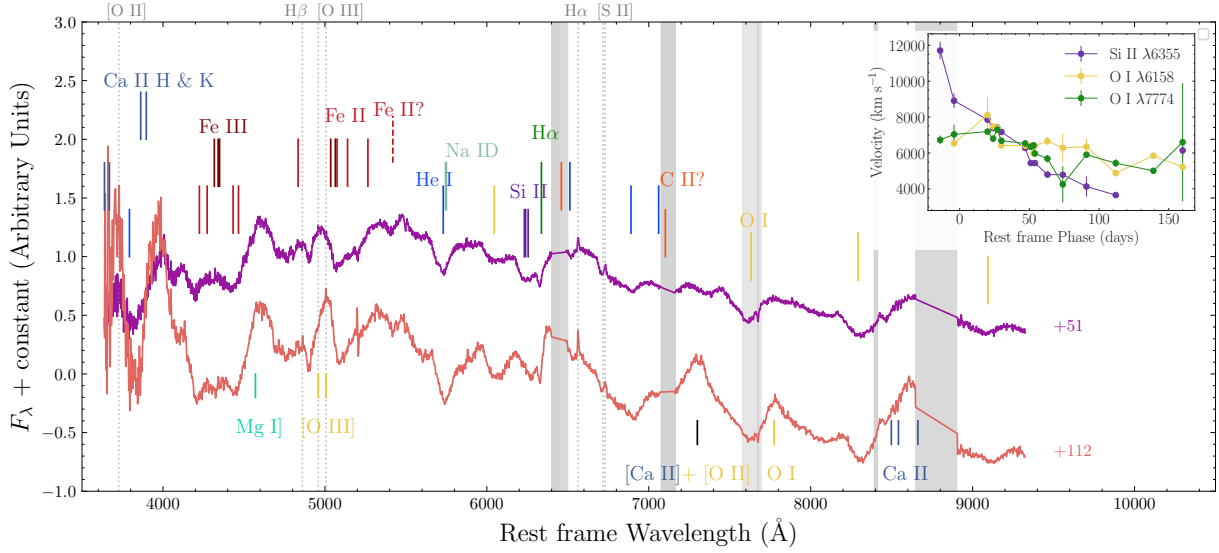


Figure 4. Detailed identification of spectral features in the optical spectra at +51 and +112 d. The majority of the absorption features are marked above the spectra using a blueshifted velocity of $7,500 \text{ km s}^{-1}$, while the Fe II, Fe III and Si II are at $5,500 \text{ km s}^{-1}$. The SN emission features are marked below the spectra at their rest frame wavelengths. The host galaxy emission lines are marked with vertical gray dotted lines. The inset shows the photospheric velocity evolution estimated using relatively isolated features of Si II $\lambda 6355 \text{ \AA}$, O I $\lambda 6158 \text{ \AA}$, and O I $\lambda 7774 \text{ \AA}$.

4.2.1. $[O \text{ III}] \lambda\lambda 4969, 5007 \text{ \AA}$

From +20 d onwards, we observe an unusual emission feature at $\approx 4940 \text{ \AA}$ with a possible absorption component centered at $\approx 4880 \text{ \AA}$. The overall profile of the emission feature changes with time, with the peak shifting to a wavelength of $\approx 5000 \text{ \AA}$ at later epochs (left panel of Figure 5). While it is plausible to associate this unusual absorption and emission feature with Fe II $\lambda 4924 \text{ \AA}$, a detailed study of the SLSN-I sample shows that Fe II $\lambda 5169 \text{ \AA}$ is stronger than Fe II $\lambda 4924 \text{ \AA}$ at all phases (A. Aamer et al. 2025b), but we do not find a strong Fe II $\lambda 5169 \text{ \AA}$ feature in SN 2024afav. This, and the shift in line centroid, indicate that this feature is not predominantly due to Fe II $\lambda 4924 \text{ \AA}$, and instead has a significant contribution from the $[O \text{ III}] \lambda\lambda 4969, 5007 \text{ \AA}$ doublet. Using our high-resolution MIKE spectrum at +53 d we fit the emission profile and find the definitive presence of $[O \text{ III}] \lambda\lambda 4969, 5007 \text{ \AA}$, as well as a contribution from Fe II $\lambda 4924 \text{ \AA}$ (Figure 5). Based on the overall evolution from early to later phase, we conclude that at $\lesssim +50 \text{ d}$ this feature is a complex of Fe II $\lambda 4929 \text{ \AA}$ and $[O \text{ III}] \lambda\lambda 4959, 5007 \text{ \AA}$. At $\gtrsim +50 \text{ d}$, the $[O \text{ III}]$ feature becomes stronger, explaining the wavelength shift and enhanced strength of this emission feature compared to typical SLSN-I.

4.2.2. $H\alpha$

We observe a narrow absorption feature centered at $\approx 6330 \text{ \AA}$ starting at +30 d (and potentially even at +20 d; center panel of Figure 5). We identify this feature as a potential high velocity $H\alpha$ absorption using a spectral match to PTF10hgi (L. Yan et al. 2020). This feature retains a nearly constant velocity of $\approx -11,000 \text{ km s}^{-1}$ and narrow FWHM width of $\approx 1,800 \text{ km s}^{-1}$. Using our high-resolution MIKE spectrum at +53 d, we fit the profile of this feature and find that it requires an additional weak emission component on the bluer side (bottom-right panel of Figure 5), which we identify as a potential O I $\lambda 6300 \text{ \AA}$ feature. We conclude that the absorption feature is a narrow, blueshifted $H\alpha$, retaining constant velocity and width throughout the spectral sequence.

4.2.3. $[O \text{ II}] \lambda\lambda 7319, 7330 \text{ \AA}$ and $[Ca \text{ II}] \lambda\lambda 7292, 7324 \text{ \AA}$

A distinctive emission profile emerges at $\approx 7300 \text{ \AA}$ at +112 d (right panel of Figure 5). This feature shows some asymmetry on the bluer end due to the presence of He I $\lambda 7281 \text{ \AA}$. We fit a multi-Gaussian profile and find three components in the line profile: a narrow component centered at $7330 \text{ \AA}$, a wider component at $7300 \text{ \AA}$, and a broad, lower-intensity component fitting the continuum. We identify these features as the $[O \text{ II}] \lambda\lambda 7319, 7330 \text{ \AA}$ and $[Ca \text{ II}] \lambda\lambda 7292, 7324 \text{ \AA}$ doublets. The center of the overall profile is closer to the $[O \text{ II}]$ doublet, implying that the feature is dominated by $[O \text{ II}]$. Additionally, this feature becomes stronger at the same time when the $[O \text{ III}] \lambda 5007 \text{ \AA}$ feature

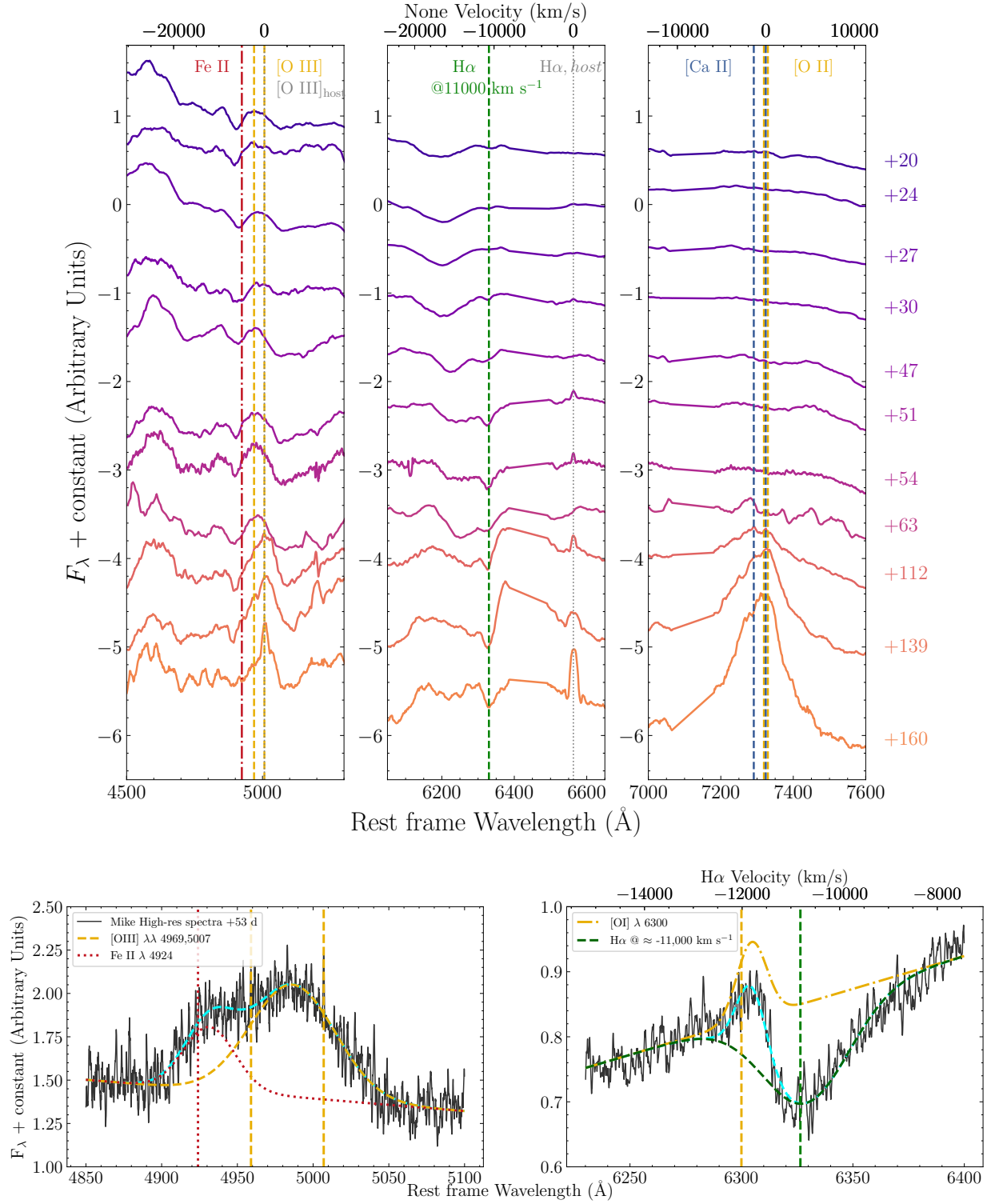


Figure 5. Top: Evolution of the unusual spectral features [O III] (*left*), H α (*middle*) and the [O II] + [Ca II] complex (*right*). The [O III] feature exhibits contamination from Fe II in early spectra and displays a shift towards [O III] over time. The H α feature (green dashed line) is narrow (1,800 km s $^{-1}$) and remains at a constant blueshift velocity of $\approx 11,000$ km s $^{-1}$. The [O II] + [Ca II] complex appears at $\approx +112$ d and becomes stronger over time. This feature is centered on [O II] implying the stronger presence of [O II] compared to [Ca II]. Telluric absorption is masked in the middle and right panels. *Bottom:* Line fits to the [O III] $\lambda\lambda 4969, 5007$ $\text{\AA}$ (*left*) and H α (*right*) profiles in the MIKE echelle spectrum at +53 d. The fitted profile shows a clear presence of [O III] and a contribution from Fe II $\lambda 4924$ $\text{\AA}$. The H α profile exhibits asymmetric absorption, which is due to emission from [O I] $\lambda 6300$ $\text{\AA}$.

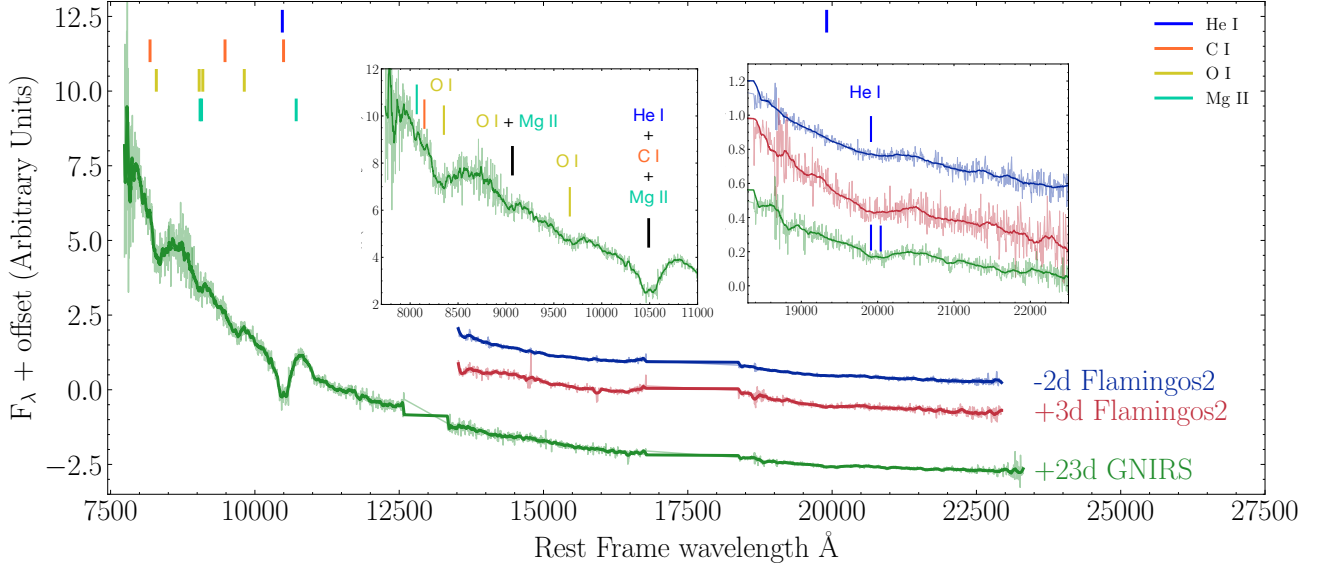


Figure 6. Near-IR spectra at -2 , $+3$, and $+23$ d. The insets show zoomed-in versions of the spectra in the 1 and $2\ \mu\text{m}$ regions. All three spectra show He I $\lambda 2.058\ \mu\text{m}$, implying the presence of helium in the ejecta. The $1\ \mu\text{m}$ region exhibits broad features of O I, C I, and Mg II in addition to He I $\lambda 1.083\ \mu\text{m}$. We find that both He I $\lambda 1.083\ \mu\text{m}$ and $\lambda 2.058\ \mu\text{m}$ at $+23$ d exhibit a “w”-shaped profile, potentially indicative of CSM interaction. The blueshift velocity of He I $\lambda 2.058\ \mu\text{m}$ feature is $10,500\ \text{km s}^{-1}$ at -2 d, $10,000\ \text{km s}^{-1}$ at $+3$ d, and $10,500\ \text{km s}^{-1}$ and $7,500\ \text{km s}^{-1}$ for the two minima at $+23$ d for faster and slower components respectively. In $+23$ d spectra He I $\lambda 1.083\ \mu\text{m}$ feature has same velocity as $\lambda 2.058\ \mu\text{m}$ features for both components.

becomes weaker at $\gtrsim +100$ d, implying a transition from [O III] to [O II]. For our spectra at $\gtrsim +112$ d, we estimate the L_{7300}/L_{6300} ratio $\approx 4.82 \pm 1.14$ using the $7300\ \text{\AA}$ and $6300\ \text{\AA}$ features. The L_{7300}/L_{6300} ratio for SN 2024afav is greater than the typical values estimated from other SLSNe-I (M. Nicholl et al. 2019; P. K. Blanchard et al. 2025). Furthermore, the ratio estimated from the $\gtrsim +100$ d phase spectra of SN 2024afav exhibits an increasing trend (see Table 4), similar to some SLSNe-I such as SN 2017egm, PTF10hgi, and LSQ14an that show possible CSM interaction (M. Nicholl et al. 2019; P. K. Blanchard et al. 2025).

4.3. NIR spectroscopic analysis

We show the NIR spectra of SN 2024afav in Figure 6. The near-peak NIR spectra obtained at -2 d and $+3$ d cover $\approx 1.35 - 2.3\ \mu\text{m}$ and exhibit a single broad absorption feature, corresponding to He I $\lambda 2.058\ \mu\text{m}$ (He I $2\text{-}\mu\text{m}$ line hereafter) with a blueshifted velocity of $-10,500\ \text{km s}^{-1}$. No other features are detected, for example, Si I, Mg I, and Si I which are commonly observed in Type Ib/c (M. Shahbandeh et al. 2022).

The next NIR spectrum at $+23$ d, covering $0.78 - 2.3\ \mu\text{m}$ exhibits the same He I $2\text{-}\mu\text{m}$ absorption, but with an apparently bimodal velocity structure, with velocities of $7,500$ and $10,500\ \text{km s}^{-1}$ (inset of Figure 6). The strongest feature in the spectrum, at $\approx 1.05\ \mu\text{m}$ is a blend of Mg II $\lambda 1.095\ \mu\text{m}$, He I $\lambda 1.083\ \mu\text{m}$, and possibly C I $\lambda 1.069\ \mu\text{m}$ (see Figure 6). This absorption feature also shows two distinctive absorption troughs at $\approx 1.045\ \mu\text{m}$ and $\approx 1.055\ \mu\text{m}$, mirroring the profile of the He I $2\text{-}\mu\text{m}$ line. The possible blend of several features in this wavelength range makes the interpretation of the line profile complicated, but the similarity to the unblended He I $2\text{-}\mu\text{m}$ line suggests that it is dominated by He I $\lambda 1.083\ \mu\text{m}$ at two different velocities.

Additionally, it shows a series of absorption features centered at $\approx 8250, 9000, 9700\ \text{\AA}$. These features correspond to O I $\lambda 8446\ \text{\AA}$, $\lambda 9263\ \text{\AA}$ with some possible contribution from C I $\lambda 8335\ \text{\AA}$, $\lambda 9405\ \text{\AA}$ and Mg II $\lambda \lambda 9218, 9244\ \text{\AA}$ features; however, since we do not see conclusive evidences of carbon lines in the optical spectra and no signs of Mg II $\lambda 21062\ \text{\AA}$ features, suggesting the NIR features are likely dominated by oxygen. Regardless of the interpretation, we conclusively detect He I, providing strong evidence of its presence in ejecta of SN 2024afav.

5. DISCUSSION

5.1. Spectroscopic Evidence for Post-Peak CSM Interaction

The presence of narrow and blueshifted $H\alpha$ absorption, persistent He I optical and NIR lines, and early appearance of forbidden high-ionization oxygen line emission ([O II] and [O III]) are highly unusual for SLSNe-I. By definition, these events do not show signatures of hydrogen, with the exception of a few events that, unlike SN 2024afav, showed hydrogen only at very late time (L. Yan et al. 2017). The He I features have similarly only been detected in a few SLSNe-I to date, generally near peak when a small amount of helium retained by the progenitor is non-thermally excited by the central magnetar (P. A. Mazzali et al. 2016; M. Nicholl et al. 2019; S. Gomez et al. 2024). These features weaken in the post-peak phase when the ejecta expand and the engine energy input declines, as seen recently in SN 2024rmj (H. Kumar et al. 2025). The late-time presence of He I in SN 2024afav requires a different excitation mechanism, likely CSM interaction (e.g., L. Yan et al. 2020; L. Dessart 2024a). Similarly, when detected, the [O II] and [O III] lines are generally observed only in the late nebular phase, indicative of ionization of the inner ejecta by the central engine (M. Nicholl et al. 2019; P. K. Blanchard et al. 2025). In a few cases, the early appearance of [O III] has been interpreted as a signature of CSM interaction (A. Aamer et al. 2024; S. Schulze et al. 2024). We thus conclude that the appearance and properties of these features are indicative of CSM interaction in the post-peak phase.

The narrow width, large blueshift, and appearance starting only at +20 d of $H\alpha$ absorption are distinct from other spectral features in SN 2024afav (Figure 4), suggesting that hydrogen is not part of the initial SN ejecta and was instead swept up by the fast ejecta from the surrounding CSM. The lack of an $H\alpha$ emission component further indicates that the hydrogen was most likely present in a narrow shell rather than in a diffuse CSM, commonly seen in interacting SNe such as SN IIn (L. Dessart et al. 2016; R. A. Chevalier & C. Fransson 2017; L. Dessart & D. J. Hillier 2022; L. Dessart 2024b).

The broad optical and NIR helium in the pre- and near-peak spectra (before the appearance of narrow $H\alpha$ absorption) indicate that the bulk of the helium is present in the ejecta, and therefore that the progenitor star retained a helium layer prior to explosion. On the other hand, the clear post-peak bimodal velocity structure of He I $\lambda 2.058 \mu\text{m}$, with an emerging component at the same velocity as $H\alpha$ and at the same phase, indicates that helium is also present in the CSM. The optical helium features persist until our last spectrum at +160 d, indicating that the CSM interaction-based excitation continues to this late phase.

The [O II] $\lambda\lambda 7320, 7330 \text{ \AA}$ feature is rare and observed in some of SLSNe-I only in the nebular phase when the ejecta is nearly transparent, revealing the inner regions (M. Nicholl et al. 2019). Moreover, the [O III] $\lambda\lambda 4959, 5007 \text{ \AA}$ feature is seldom seen and requires an excitation mechanism to produce a higher ionization state and a low-density region in ejecta. In SN 2024afav, the early appearance of [O III] starting at about +50 d and [O II] at +110 d, requires such a region in the outer part of ejecta, as the rest of the spectrum suggests that the ejecta has not reached a nebular state. Such a low-density and high-ionization region in the outer ejecta can be produced by the interaction of ejecta with the CSM, explaining these features at such early epochs (A. Aamer et al. 2024).

Finally, we note that in addition to the emergence of the various interaction-dominated spectral features at about +20 d, the light curve begins to exhibit its first bump, and the photospheric temperature exhibits an increase, at the same phase – indicators of the same CSM interaction.

Combining the available spectroscopic and photometric information, we can provide a rough picture of the CSM. The multiple bumps (and lack of $H\alpha$ emission) point to a patchy or shell-like CSM rather than a smooth wind-like CSM. The CSM is hydrogen- and helium-rich. Using the fastest velocity of $\approx 12,000 \text{ km s}^{-1}$ for $H\alpha$ at +20 d, and an explosion date at $\approx -49 \text{ d}$ (J. R. Farah et al. 2025), we estimate that the nearest CSM shell is located at $\approx 7 \times 10^{15} \text{ cm}$; for a CSM velocity of $\sim 1,000 \text{ km s}^{-1}$, this shell would have been ejected $\approx 2.2 \text{ yr}$ before explosion. The CSM shell is swept by the ejecta, producing a forward shock (N. Smith 2017) that accelerates the CSM to the ejecta velocity, thereby creating the blueshifted narrow $H\alpha$ absorption (and high-velocity component of He I) as the shocked region is viewed above the photosphere. This layer encounters no obstacles in the absence of a diffuse CSM until another shell is encountered, at which point it maintains the same velocity (and produces additional bumps in the light curve). The reverse shock produced during the CSM interaction ionizes the outer layers of the ejecta, which are primarily composed of oxygen and helium. This helps to sustain the excitation of helium, and moreover, low-density regions in these layers produce the [O III] emission. Subsequently, as the ejecta expand, the low-density regions transition to a lower ionization state, explaining the emergence of [O II] at a later phase than [O III].

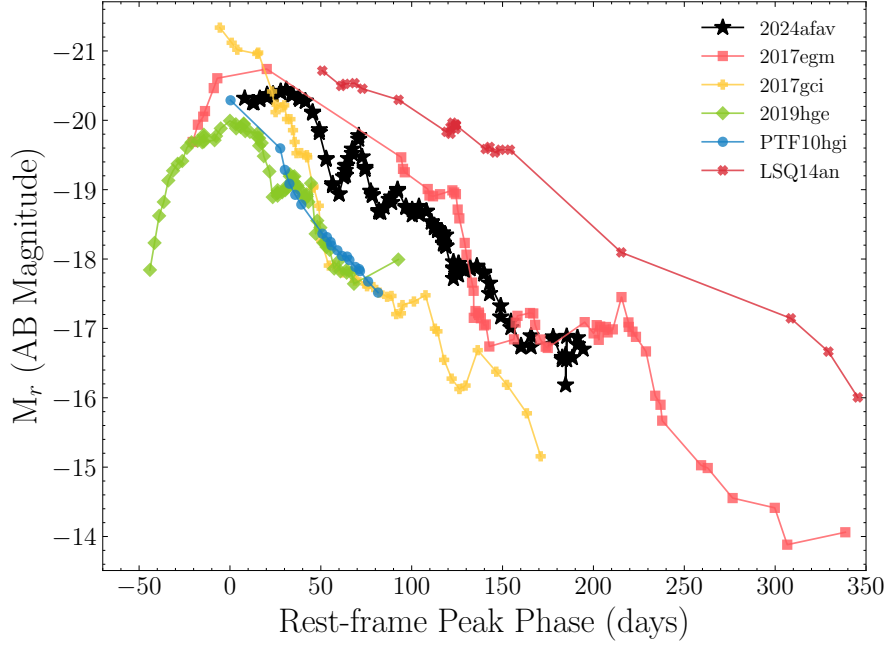


Figure 7. The r -band light curves of a few SLSNe-I with multiple light curve bumps. All events except PTF10hgi have both photometric and spectral coverage well past +100 d, enabling a meaningful comparison. We find that these objects exhibit similar spectral features (see Figure 8), yet they have dissimilar bump shapes.

To summarize, post-peak CSM interaction provides a consistent explanation for the unusual spectral features, light curve bumps, and their temporal correlation. The interaction-induced forward shock explains the presence of a narrow H α (and He I), while the reverse shock provides a source of helium excitation and oxygen ionization in the outer ejecta.

5.2. Comparison to Previous Multi-Peaked SLSNe-I

Inspired by the spectral similarity of SN 2024afav to PTF10hgi and SN 2017egm, we searched for similar events in the SLSN-I sample (S. Gomez et al. 2024; A. Aamer et al. 2025b), which satisfy the following criteria: (i) the optical light curve exhibits more than two bumps; and (ii) the spectral coverage extends to $\gtrsim +100$ d. We find 4 SLSNe SN 2017egm, SN 2017gci, SN 2019hge and LSQ14an, that satisfy these criteria. We also include PTF10hgi in the comparison sample, despite its limited photometric coverage (until phases of $< +100$ days) and the absence of significant bumps in its light curve, as it exhibits close spectral similarity to SN 2024afav. We caution that this sample is by no means comprehensive, as the identification is limited to visual inspection with the goal of finding similar events, rather than creating a complete sample. The r -band light curves SN 2024afav and the 5 comparison events are shown in Figure 7.

We compare the spectra of SN 2024afav with the 5 comparison events at $\approx +50$ and $+110$ d in Figure 8. The median SLSN-I spectrum at these phases from A. Aamer et al. (2025a) is shown for reference. The comparison reveals that 3 of 5 events (SN 2017egm, SN 2019hge, and PTF10hgi) exhibit similar spectral features and evolutionary patterns to SN 2024afav. These events show a remarkably different 5000 Å region compared to median SLSNe-I spectra due to the presence of [O III] features. In the $\approx +110$ -d spectra, these 4 events exhibit a very weak [O I] line and a stronger 7300 Å feature centered at [O II]. Another noticeable aspect is the presence of strong absorption at the locations of the He I lines. In SN 2024afav (and possibly SN 2019hge; L. Yan et al. 2020), the presence of helium is demonstrated with NIR spectra. In SN 2017egm and PTF10hgi, previous claims of helium have relied on the optical spectra (L. Yan et al. 2020; J. Zhu et al. 2023); the similarity to SN 2024afav confirms these claims. We conclude that the spectral and light curve similarities of these 4 events suggest that they share a similar progenitor configuration.

The other two events in the comparison sample, LSQ14an and SN 2017gci, exhibit different spectral properties. LSQ14an exhibits an early presence of the 7300 Å feature (+48 d), which appears asymmetric and centered on the [Ca II] lines, and shows no signs of helium features. However, LSQ14an shows a P-Cygni feature at $\approx 6300 - 6400$ Å, similar to SN 2024afav, SN 2019hge and PTF10hgi, and exhibits strong [O III]. The presence of strong [O III] and 7300 Å features, but lack of helium in LSQ14an indicates that its progenitor may have been stripped of its helium

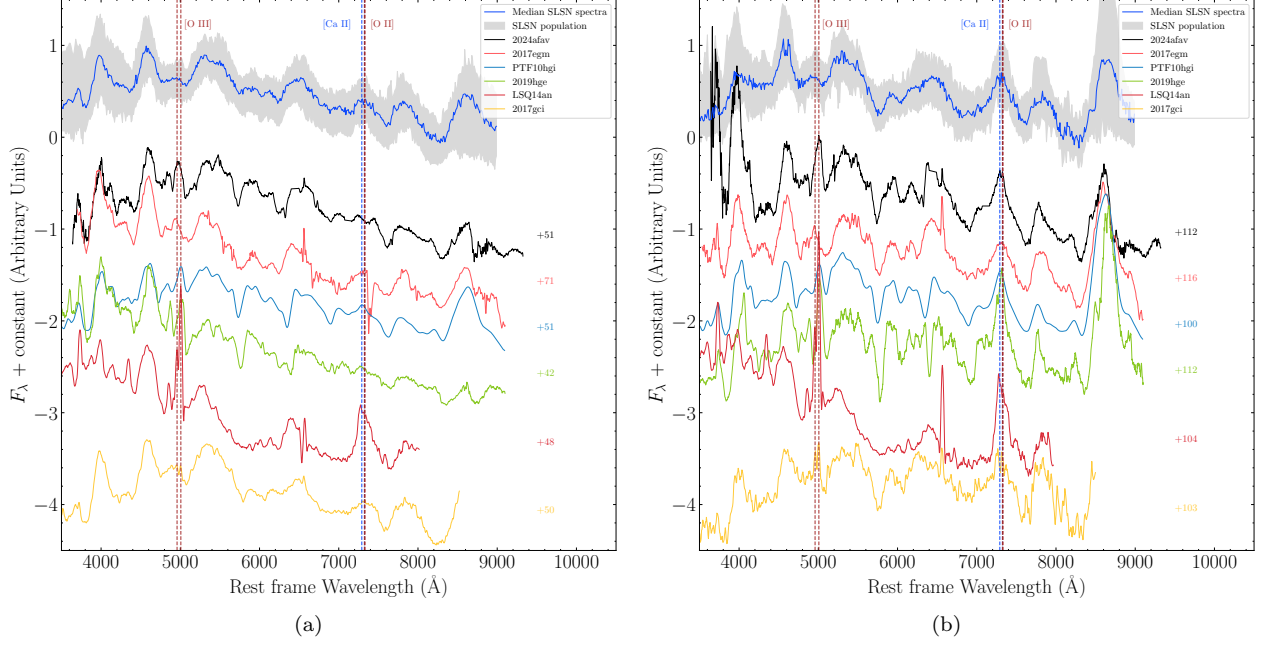


Figure 8. Comparison of SN 2024afav spectra at $\approx +50$ d (Left) and $\approx +112$ d with SLSNe-I population from A. Aamer et al. (2025a), and SLSNe-I with multiple bumps & spectral coverage at similar epochs. These objects represent a small sample of SLSNe-I with multiple bumps in their light curves and a strong presence of the 7300 Å feature. We observe that PTF10hgi, SN 2019hge, and SN 2024afav show the presence of [O III], He I features at all epochs, and 7300 Å emission features at $\approx +112$ d phase. The spectral similarity and bumpy light curves of these objects imply a common progenitor. The other two objects in the spectra exhibit bumpy light curves and 7300 Å emission features, indicating CSM interaction and a potential connection between bumps and CSM interaction in SLSNe-I. Both SN 2017egm, and SN 2017gci do not show a strong presence of [O III] features; however, they show [O II] features at late times, implying weaker ionization in ejecta compared to other objects in the sample.

layer completely and potentially some of its oxygen layer, contributing to the CSM. SN 2017gci has a much weaker 7300 Å feature, centered on the [Ca II] lines, He I features, and no unusual feature in the $\approx 6300 - 6400$ Å region. The differences in spectral features between SN 2024afav and LSQ14an and SN 2017gci suggests that the light curve bumps do not necessarily require hydrogen or helium in the CSM.

6. CONCLUSIONS

We presented detailed optical/NIR spectroscopic observations of SN 2024afav, spanning -14 to $+160$ d, covering the main peak and multiple post-peak light curve bumps. The key findings are as follows:

- SN 2024afav has an unusual light curve compared to the majority of SLSNe-I, exhibiting seven significant bumps in the post-peak phase.
- The pre-peak spectra exhibit typical SLSNe-I features and closely match the early spectra of SN 2017egm and PTF10hgi.
- Post-peak, the spectra show several unusual features indicating CSM interaction with narrow hydrogen and helium shells:
 - A narrow, high velocity H α absorption feature, starting at $+20$ d.
 - Persistent optical and NIR He I lines at all available phases. At $+23$ d, the NIR spectrum showed a high-velocity component of helium at a similar velocity to that of hydrogen, suggesting the presence of helium in both the ejecta and the CSM.
 - Early appearance of [O III] emission starting at $\approx +50$ d. Additionally, a strong [O II] + [Ca II] 7300 Å complex starting at $\approx +110$ d.

These spectroscopic features indicate that SN 2024afav underwent CSM interaction with narrow shells that primarily consist of hydrogen, with a possibly small amount of helium.

- We compare SN 2024afav with a subset of SLSNe-I that exhibit bumpy light curves with late time spectral coverage. These objects exhibit some combination of early presence of [O III], an excess of the [O II] + [Ca II] complex, and persistent helium features until late phases, suggestive of CSM interaction. Our comparison sample suggests that the bumps in lightcurves and these unusual features are potentially correlated.

In the upcoming era of Rubin Observatory / LSST, detailed late-time light curves of SLSNe-I will be available in abundance. Systematic follow-up of events with multiple bumps will elucidate the fraction of events in which CSM interaction can significantly modify the post-peak light curves and spectra.

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This work makes use of observations from the Las Cumbres Observatory global telescope network. The authors wish to recognize and acknowledge the very significant cultural role and reverence that the summit of Haleakalā has always had within the indigenous Hawaiian community. We are most fortunate to have the opportunity to conduct observations from the mountain.

We acknowledge the use of public data from the Swift data archive.

This research made use of `PypeIt`,¹⁴ a `python` package for semi-automated reduction of astronomical slit-based spectroscopy (J. X. Prochaska et al. 2020; J. X. Prochaska et al. 2020). This research made use of WISEREP¹⁵ (O. Yaron & A. Gal-Yam 2012).

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¹⁴ <https://pypeit.readthedocs.io/en/latest/>

¹⁵ URL <https://wiserep.org>

This research has made use of the NASA Astrophysics Data System (ADS), the NASA/IPAC Extragalactic Database (NED), and NASA/IPAC Infrared Science Archive (IRSA, which is funded by NASA and operated by the California Institute of Technology) and IRAF (which is distributed by the National Optical Astronomy Observatory, NOAO, operated by the Association of Universities for Research in Astronomy, AURA, Inc., under cooperative agreement with the NSF).

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AUTHOR CONTRIBUTIONS

Facilities: ATLAS, FLWO 1.2m, LCO, Magellan, MMT, Swift(UVOT), and ZTF

Software: `astropy` ([Astropy Collaboration et al. 2013, 2018, 2022](#)), `SExtractor` (E. Bertin & S. Arnouts 1996) `NumPy` (C. R. Harris et al. 2020), `photutils` (L. Bradley et al. 2022), `PyRAF` ([Science Software Branch at STScI 2012](#)), `SciPy` (P. Virtanen et al. 2020), `UVOTSOURCE`, `extrabol` (I. Thornton et al. 2024), `PypeIt` (J. X. Prochaska et al. 2020), `lcogtsnpipe` (S. Valenti et al. 2016), and `MOSFiT` (J. Guillochon et al. 2017),

APPENDIX

A. PHOTOMETRY

MJD	Filter	Magnitude $\pm$ e_magnitude	Telescope
60665.33	<i>o</i>	18.53 ± 0.09	ATLAS
60666.34	<i>o</i>	18.57 ± 0.09	ATLAS
60672.65	<i>o</i>	18.03 ± 0.05	ATLAS
60674.33	<i>o</i>	17.92 ± 0.04	ATLAS
60676.06	<i>c</i>	17.70 ± 0.03	ATLAS
60677.31	<i>o</i>	17.85 ± 0.04	ATLAS
60678.31	<i>o</i>	17.71 ± 0.03	ATLAS
60679.05	<i>c</i>	17.56 ± 0.02	ATLAS
60680.04	<i>c</i>	17.54 ± 0.03	ATLAS
60681.32	<i>o</i>	17.55 ± 0.03	ATLAS
60682.31	<i>o</i>	17.58 ± 0.02	ATLAS
60683.06	<i>c</i>	17.36 ± 0.02	ATLAS
60684.06	<i>c</i>	17.32 ± 0.02	ATLAS
60685.32	<i>o</i>	17.37 ± 0.02	ATLAS
60686.30	<i>o</i>	17.40 ± 0.02	ATLAS
60687.09	<i>o</i>	17.46 ± 0.03	ATLAS
60689.31	<i>o</i>	17.22 ± 0.03	ATLAS
60690.49	<i>o</i>	17.20 ± 0.02	ATLAS
60691.04	<i>o</i>	17.17 ± 0.03	ATLAS
60692.07	<i>o</i>	17.17 ± 0.03	ATLAS
60693.22	<i>o</i>	17.13 ± 0.03	ATLAS
60697.29	<i>o</i>	17.04 ± 0.03	ATLAS
60699.06	<i>o</i>	17.02 ± 0.02	ATLAS
60700.05	<i>o</i>	17.06 ± 0.02	ATLAS
60701.32	<i>c</i>	16.88 ± 0.01	ATLAS
60702.30	<i>c</i>	16.86 ± 0.01	ATLAS
60705.30	<i>c</i>	16.9 ± 0.01	ATLAS
60706.28	<i>c</i>	16.91 ± 0.01	ATLAS
60707.03	<i>o</i>	17.04 ± 0.02	ATLAS
60708.02	<i>o</i>	17.11 ± 0.02	ATLAS
60709.29	<i>c</i>	16.98 ± 0.02	ATLAS
60709.61	<i>UVW1</i>	18.17 ± 0.08	Swift
60709.62	<i>U</i>	17.35 ± 0.07	Swift
60709.62	<i>B</i>	16.84 ± 0.07	Swift
60709.62	<i>UVW2</i>	19.08 ± 0.09	Swift
60709.62	<i>V</i>	17.14 ± 0.14	Swift
60709.63	<i>UVM2</i>	18.78 ± 0.09	Swift
60710.30	<i>c</i>	17.04 ± 0.02	ATLAS
60711.01	<i>o</i>	17.12 ± 0.02	ATLAS
60711.99	<i>g</i>	16.98 ± 0.01	LCO
60711.99	<i>r</i>	17.11 ± 0.01	LCO
60711.99	<i>i</i>	17.2 ± 0.02	LCO
60712.61	<i>UVW1</i>	18.36 ± 0.14	Swift
60712.61	<i>U</i>	17.27 ± 0.12	Swift

60712.61	<i>B</i>	16.89 ± 0.13	Swift
60712.61	<i>UVW2</i>	19.29 ± 0.16	Swift
60712.62	<i>V</i>	16.91 ± 0.22	Swift
60712.62	<i>UVM2</i>	18.88 ± 0.14	Swift
60714.31	<i>c</i>	17.07 ± 0.01	ATLAS
60714.99	<i>o</i>	17.16 ± 0.02	ATLAS
60715.03	<i>o</i>	17.15 ± 0.02	ATLAS
60715.94	<i>UVW1</i>	18.67 ± 0.1	Swift
60715.94	<i>U</i>	17.54 ± 0.09	Swift
60716.65	<i>g</i>	17.08 ± 0.01	LCO
60716.65	<i>r</i>	17.17 ± 0.02	LCO
60716.65	<i>i</i>	17.19 ± 0.02	LCO
60717.29	<i>o</i>	17.15 ± 0.03	ATLAS
60717.48	<i>r</i>	17.18 ± 0.05	FLWO
60717.49	<i>g</i>	16.99 ± 0.05	FLWO
60717.50	<i>i</i>	17.27 ± 0.06	FLWO
60717.51	<i>z</i>	17.50 ± 0.07	FLWO
60718.28	<i>o</i>	17.11 ± 0.04	ATLAS
60718.35	<i>B</i>	17.06 ± 0.11	Swift
60718.35	<i>V</i>	17.11 ± 0.18	Swift
60719.09	<i>o</i>	17.13 ± 0.03	ATLAS
60720.92	<i>g</i>	17.07 ± 0.02	LCO
60720.92	<i>g</i>	17.07 ± 0.02	LCO
60720.93	<i>i</i>	17.08 ± 0.03	LCO
60720.93	<i>r</i>	17.11 ± 0.02	LCO
60720.93	<i>r</i>	17.13 ± 0.02	LCO
60720.93	<i>i</i>	17.16 ± 0.03	LCO
60725.18	<i>g</i>	16.97 ± 0.02	LCO
60725.18	<i>g</i>	17.00 ± 0.02	LCO
60725.19	<i>r</i>	17.08 ± 0.02	LCO
60725.19	<i>r</i>	17.09 ± 0.02	LCO
60725.19	<i>i</i>	17.14 ± 0.03	LCO
60725.19	<i>i</i>	17.17 ± 0.02	LCO
60725.21	<i>g</i>	17.01 ± 0.01	LCO
60725.21	<i>g</i>	17.02 ± 0.02	LCO
60725.21	<i>r</i>	17.05 ± 0.02	LCO
60725.21	<i>r</i>	17.06 ± 0.02	LCO
60725.22	<i>i</i>	17.12 ± 0.02	LCO
60725.22	<i>i</i>	17.12 ± 0.02	LCO
60725.34	<i>o</i>	17.04 ± 0.03	ATLAS
60726.36	<i>o</i>	17.05 ± 0.02	ATLAS
60728.72	<i>g</i>	16.98 ± 0.01	LCO
60728.73	<i>g</i>	16.98 ± 0.01	LCO
60728.73	<i>r</i>	17.05 ± 0.02	LCO
60728.73	<i>r</i>	17.05 ± 0.02	LCO
60728.73	<i>i</i>	17.08 ± 0.02	LCO
60728.73	<i>i</i>	17.10 ± 0.02	LCO
60729.36	<i>o</i>	17.05 ± 0.02	ATLAS
60730.36	<i>o</i>	17 ± 0.02	ATLAS
60732.90	<i>U</i>	17.53 ± 0.08	Swift

60732.90	<i>B</i>	16.89 ± 0.08	Swift
60732.90	<i>UVW2</i>	19.86 ± 0.19	Swift
60733.20	<i>g</i>	16.89 ± 0.01	LCO
60733.20	<i>g</i>	16.91 ± 0.01	LCO
60733.21	<i>r</i>	17.01 ± 0.02	LCO
60733.21	<i>r</i>	17.02 ± 0.02	LCO
60733.21	<i>i</i>	17.03 ± 0.02	LCO
60733.21	<i>i</i>	17.07 ± 0.02	LCO
60733.35	<i>o</i>	17 ± 0.02	ATLAS
60734.26	<i>o</i>	16.92 ± 0.02	ATLAS
60736.02	<i>UVW1</i>	18.65 ± 0.11	Swift
60736.03	<i>B</i>	17.08 ± 0.09	Swift
60736.03	<i>UVW2</i>	19.79 ± 0.14	Swift
60736.03	<i>V</i>	17.09 ± 0.15	Swift
60736.04	<i>UVM2</i>	19.61 ± 0.13	Swift
60736.53	<i>g</i>	16.94 ± 0.01	LCO
60736.53	<i>g</i>	16.94 ± 0.01	LCO
60736.53	<i>r</i>	16.99 ± 0.01	LCO
60736.54	<i>r</i>	16.98 ± 0.01	LCO
60736.54	<i>i</i>	17.03 ± 0.02	LCO
60736.54	<i>i</i>	17.04 ± 0.02	LCO
60737.35	<i>o</i>	16.86 ± 0.02	ATLAS
60738.30	<i>o</i>	16.96 ± 0.01	ATLAS
60739.42	<i>r</i>	17.06 ± 0.07	FLWO
60739.43	<i>g</i>	16.94 ± 0.07	FLWO
60739.43	<i>i</i>	17.16 ± 0.07	FLWO
60739.44	<i>z</i>	17.32 ± 0.08	FLWO
60740.04	<i>c</i>	16.99 ± 0.01	ATLAS
60740.24	<i>g</i>	17.07 ± 0.02	LCO
60740.25	<i>r</i>	17.05 ± 0.03	LCO
60740.25	<i>r</i>	17.06 ± 0.02	LCO
60740.25	<i>g</i>	17.07 ± 0.02	LCO
60740.25	<i>i</i>	17.09 ± 0.02	LCO
60740.26	<i>i</i>	17.10 ± 0.02	LCO
60740.53	<i>U</i>	17.92 ± 0.1	Swift
60740.53	<i>B</i>	17.13 ± 0.09	Swift
60740.54	<i>V</i>	17.29 ± 0.16	Swift
60741.34	<i>o</i>	16.96 ± 0.02	ATLAS
60742.33	<i>o</i>	16.88 ± 0.02	ATLAS
60743.07	<i>c</i>	17.06 ± 0.02	ATLAS
60743.98	<i>o</i>	17.09 ± 0.02	ATLAS
60744.00	<i>o</i>	17.04 ± 0.04	ATLAS
60744.06	<i>g</i>	17.10 ± 0.01	LCO
60744.06	<i>g</i>	17.11 ± 0.01	LCO
60744.07	<i>r</i>	17.10 ± 0.02	LCO
60744.07	<i>r</i>	17.10 ± 0.01	LCO
60744.07	<i>i</i>	17.14 ± 0.02	LCO
60744.07	<i>i</i>	17.14 ± 0.02	LCO
60744.38	<i>r</i>	17.13 ± 0.06	FLWO
60744.39	<i>g</i>	17.05 ± 0.07	FLWO

60744.39	<i>i</i>	17.19 ± 0.06	FLWO
60744.40	<i>z</i>	17.36 ± 0.07	FLWO
60745.30	<i>o</i>	16.98 ± 0.02	ATLAS
60746.22	<i>o</i>	16.93 ± 0.03	ATLAS
60747.04	<i>o</i>	17.13 ± 0.04	ATLAS
60747.77	<i>r</i>	17.15 ± 0.03	LCO
60747.77	<i>r</i>	17.15 ± 0.02	LCO
60747.77	<i>g</i>	17.26 ± 0.03	LCO
60747.77	<i>g</i>	17.29 ± 0.02	LCO
60747.78	<i>i</i>	17.16 ± 0.04	LCO
60747.78	<i>i</i>	17.17 ± 0.04	LCO
60748.09	UVW1	19.38 ± 0.25	Swift
60748.09	<i>U</i>	17.79 ± 0.16	Swift
60748.09	<i>B</i>	17.24 ± 0.16	Swift
60748.09	UVW2	20.21 ± 0.28	Swift
60748.09	<i>V</i>	17.25 ± 0.27	Swift
60748.09	UVM2	19.52 ± 0.3	Swift
60752.06	<i>r</i>	17.31 ± 0.03	LCO
60752.06	<i>r</i>	17.32 ± 0.03	LCO
60752.06	<i>g</i>	17.44 ± 0.03	LCO
60752.06	<i>g</i>	17.49 ± 0.02	LCO
60752.07	<i>i</i>	17.28 ± 0.04	LCO
60752.07	<i>i</i>	17.31 ± 0.04	LCO
60753.27	<i>o</i>	17.27 ± 0.03	ATLAS
60754.27	<i>o</i>	17.23 ± 0.03	ATLAS
60756.02	<i>g</i>	17.91 ± 0.02	LCO
60756.02	<i>g</i>	17.93 ± 0.02	LCO
60756.03	<i>i</i>	17.55 ± 0.02	LCO
60756.03	<i>i</i>	17.55 ± 0.02	LCO
60756.03	<i>r</i>	17.56 ± 0.02	LCO
60756.03	<i>r</i>	17.60 ± 0.02	LCO
60757.23	<i>o</i>	17.61 ± 0.03	ATLAS
60758.32	<i>o</i>	17.57 ± 0.03	ATLAS
60759.97	<i>o</i>	17.95 ± 0.05	ATLAS
60760.02	<i>o</i>	17.97 ± 0.05	ATLAS
60760.05	<i>r</i>	17.98 ± 0.02	LCO
60760.05	<i>g</i>	18.44 ± 0.02	LCO
60760.05	<i>g</i>	18.49 ± 0.02	LCO
60760.06	<i>i</i>	17.87 ± 0.02	LCO
60760.06	<i>i</i>	17.92 ± 0.03	LCO
60760.06	<i>r</i>	17.99 ± 0.02	LCO
60761.39	<i>c</i>	18.36 ± 0.07	ATLAS
60762.23	<i>c</i>	18.41 ± 0.06	ATLAS
60762.98	<i>o</i>	18.27 ± 0.06	ATLAS
60763.68	<i>o</i>	18.22 ± 0.03	ATLAS
60763.86	<i>g</i>	18.97 ± 0.02	LCO
60763.86	<i>g</i>	18.98 ± 0.02	LCO
60763.87	<i>i</i>	18.21 ± 0.03	LCO
60763.87	<i>i</i>	18.23 ± 0.03	LCO
60763.87	<i>r</i>	18.34 ± 0.02	LCO

60763.87	<i>r</i>	18.37 ± 0.02	LCO
60764.02	<i>o</i>	18.22 ± 0.05	ATLAS
60765.24	<i>c</i>	18.67 ± 0.05	ATLAS
60766.25	<i>c</i>	18.76 ± 0.07	ATLAS
60767.69	<i>r</i>	18.49 ± 0.02	LCO
60767.69	<i>g</i>	19.08 ± 0.03	LCO
60767.69	<i>g</i>	19.11 ± 0.03	LCO
60767.70	<i>i</i>	18.30 ± 0.03	LCO
60767.70	<i>i</i>	18.37 ± 0.04	LCO
60767.70	<i>r</i>	18.48 ± 0.03	LCO
60769.27	<i>c</i>	18.54 ± 0.06	ATLAS
60770.23	<i>c</i>	18.47 ± 0.06	ATLAS
60770.28	<i>r</i>	18.24 ± 0.04	FLWO
60770.29	<i>g</i>	18.70 ± 0.05	FLWO
60770.30	<i>i</i>	18.16 ± 0.04	FLWO
60770.30	<i>z</i>	18.25 ± 0.07	FLWO
60771.32	<i>r</i>	18.15 ± 0.05	FLWO
60771.33	<i>g</i>	18.52 ± 0.07	FLWO
60771.34	<i>i</i>	18.05 ± 0.05	FLWO
60771.34	<i>z</i>	18.16 ± 0.08	FLWO
60771.46	<i>i</i>	18.03 ± 0.07	LCO
60771.46	<i>r</i>	18.08 ± 0.03	LCO
60771.46	<i>r</i>	18.22 ± 0.09	LCO
60771.46	<i>g</i>	18.61 ± 0.04	LCO
60771.46	<i>g</i>	18.65 ± 0.05	LCO
60771.47	<i>i</i>	18.14 ± 0.21	LCO
60772.20	<i>r</i>	18.08 ± 0.05	FLWO
60772.21	<i>g</i>	18.45 ± 0.05	FLWO
60772.22	<i>i</i>	18.02 ± 0.04	FLWO
60772.23	<i>z</i>	18.13 ± 0.10	FLWO
60773.20	<i>r</i>	17.98 ± 0.06	FLWO
60773.21	<i>g</i>	18.33 ± 0.08	FLWO
60773.22	<i>i</i>	17.94 ± 0.07	FLWO
60773.22	<i>z</i>	18.00 ± 0.09	FLWO
60774.19	<i>o</i>	17.81 ± 0.05	ATLAS
60775.22	<i>g</i>	18.19 ± 0.05	FLWO
60775.50	<i>r</i>	17.84 ± 0.03	LCO
60775.50	<i>r</i>	17.90 ± 0.03	LCO
60775.50	<i>g</i>	18.32 ± 0.03	LCO
60775.50	<i>g</i>	18.34 ± 0.03	LCO
60775.51	<i>i</i>	17.75 ± 0.03	LCO
60775.51	<i>i</i>	17.84 ± 0.03	LCO
60779.29	<i>i</i>	17.64 ± 0.05	LCO
60779.29	<i>r</i>	17.64 ± 0.04	LCO
60779.29	<i>r</i>	17.70 ± 0.04	LCO
60779.29	<i>g</i>	18.27 ± 0.03	LCO
60779.29	<i>g</i>	18.29 ± 0.04	LCO
60779.30	<i>i</i>	17.70 ± 0.05	LCO
60780.40	<i>o</i>	17.8 ± 0.05	ATLAS
60781.23	<i>o</i>	17.75 ± 0.05	ATLAS

60781.32	<i>r</i>	17.95 ± 0.04	FLWO
60781.33	<i>g</i>	18.26 ± 0.07	FLWO
60781.33	<i>i</i>	17.88 ± 0.04	FLWO
60781.34	<i>z</i>	17.98 ± 0.07	FLWO
60782.55	<i>o</i>	17.92 ± 0.03	ATLAS
60783.01	<i>g</i>	18.53 ± 0.03	LCO
60783.01	<i>g</i>	18.56 ± 0.02	LCO
60783.02	<i>i</i>	17.90 ± 0.03	LCO
60783.02	<i>i</i>	17.94 ± 0.03	LCO
60783.02	<i>r</i>	18.10 ± 0.02	LCO
60783.02	<i>r</i>	18.13 ± 0.03	LCO
60783.77	<i>o</i>	18.12 ± 0.04	ATLAS
60785.25	<i>o</i>	18.19 ± 0.08	ATLAS
60786.18	<i>o</i>	18.25 ± 0.05	ATLAS
60786.35	<i>r</i>	18.45 ± 0.08	FLWO
60786.36	<i>g</i>	18.84 ± 0.09	FLWO
60786.36	<i>i</i>	18.40 ± 0.08	FLWO
60786.37	<i>z</i>	18.34 ± 0.09	FLWO
60787.28	<i>r</i>	18.49 ± 0.03	LCO
60787.28	<i>g</i>	19.09 ± 0.02	LCO
60787.28	<i>g</i>	19.09 ± 0.02	LCO
60787.29	<i>i</i>	18.39 ± 0.03	LCO
60787.29	<i>i</i>	18.40 ± 0.03	LCO
60787.29	<i>r</i>	18.51 ± 0.03	LCO
60789.17	<i>o</i>	18.53 ± 0.04	ATLAS
60790.16	<i>o</i>	18.52 ± 0.06	ATLAS
60790.90	<i>c</i>	19.13 ± 0.06	ATLAS
60791.11	<i>g</i>	19.33 ± 0.02	LCO
60791.12	<i>i</i>	18.58 ± 0.03	LCO
60791.12	<i>i</i>	18.60 ± 0.03	LCO
60791.12	<i>r</i>	18.72 ± 0.02	LCO
60791.12	<i>r</i>	18.75 ± 0.02	LCO
60791.12	<i>g</i>	19.28 ± 0.02	LCO
60791.89	<i>c</i>	19.10 ± 0.08	ATLAS
60792.34	<i>r</i>	18.76 ± 0.04	FLWO
60792.35	<i>g</i>	19.22 ± 0.05	FLWO
60792.35	<i>i</i>	18.65 ± 0.04	FLWO
60792.36	<i>z</i>	18.70 ± 0.11	FLWO
60793.15	<i>o</i>	18.50 ± 0.06	ATLAS
60794.15	<i>o</i>	18.20 ± 0.04	ATLAS
60794.27	<i>r</i>	18.68 ± 0.03	FLWO
60794.29	<i>g</i>	19.11 ± 0.07	FLWO
60794.29	<i>i</i>	18.60 ± 0.05	FLWO
60794.30	<i>z</i>	18.55 ± 0.08	FLWO
60797.15	<i>o</i>	18.32 ± 0.09	ATLAS
60797.22	<i>r</i>	18.57 ± 0.04	FLWO
60797.23	<i>g</i>	19.01 ± 0.06	FLWO
60797.23	<i>i</i>	18.51 ± 0.05	FLWO
60797.24	<i>z</i>	18.41 ± 0.08	FLWO
60797.40	<i>g</i>	19.16 ± 0.03	LCO

60798.15	<i>o</i>	18.26 ± 0.05	ATLAS
60798.73	<i>r</i>	18.53 ± 0.03	LCO
60798.73	<i>r</i>	18.61 ± 0.03	LCO
60798.73	<i>g</i>	19.04 ± 0.03	LCO
60798.73	<i>g</i>	19.06 ± 0.03	LCO
60798.74	<i>i</i>	18.38 ± 0.03	LCO
60798.74	<i>i</i>	18.42 ± 0.03	LCO
60798.91	<i>c</i>	18.74 ± 0.06	ATLAS
60799.88	<i>o</i>	18.34 ± 0.05	ATLAS
60800.81	<i>o</i>	18.34 ± 0.05	ATLAS
60802.19	<i>r</i>	18.42 ± 0.04	LCO
60802.19	<i>r</i>	18.44 ± 0.04	LCO
60802.19	<i>g</i>	18.97 ± 0.05	LCO
60802.19	<i>g</i>	19.02 ± 0.05	LCO
60802.20	<i>i</i>	18.36 ± 0.04	LCO
60802.20	<i>i</i>	18.40 ± 0.04	LCO
60802.39	<i>o</i>	18.22 ± 0.05	ATLAS
60807.13	<i>r</i>	18.68 ± 0.07	LCO
60807.13	<i>g</i>	18.99 ± 0.07	LCO
60807.13	<i>g</i>	19.23 ± 0.08	LCO
60807.14	<i>i</i>	18.44 ± 0.09	LCO
60807.14	<i>i</i>	18.48 ± 0.08	LCO
60807.14	<i>r</i>	18.66 ± 0.08	LCO
60810.84	<i>r</i>	18.71 ± 0.04	LCO
60810.84	<i>r</i>	18.79 ± 0.04	LCO
60810.84	<i>g</i>	19.20 ± 0.05	LCO
60810.84	<i>g</i>	19.32 ± 0.05	LCO
60810.85	<i>i</i>	18.47 ± 0.04	LCO
60810.85	<i>i</i>	18.48 ± 0.04	LCO
60810.95	<i>o</i>	18.74 ± 0.10	ATLAS
60814.81	<i>r</i>	18.78 ± 0.08	LCO
60814.81	<i>g</i>	19.24 ± 0.03	LCO
60814.81	<i>g</i>	19.24 ± 0.03	LCO
60814.82	<i>i</i>	18.60 ± 0.06	LCO
60814.82	<i>r</i>	18.67 ± 0.05	LCO
60814.82	<i>i</i>	18.70 ± 0.10	LCO
60814.89	<i>o</i>	18.47 ± 0.11	ATLAS
60815.06	<i>g</i>	19.28 ± 0.02	LCO
60815.06	<i>g</i>	19.30 ± 0.02	LCO
60815.07	<i>i</i>	18.59 ± 0.03	LCO
60815.07	<i>r</i>	18.75 ± 0.02	LCO
60815.07	<i>r</i>	18.76 ± 0.02	LCO
60815.08	<i>i</i>	18.63 ± 0.03	LCO
60817.14	<i>c</i>	19.08 ± 0.08	ATLAS
60818.12	<i>c</i>	19.05 ± 0.08	ATLAS
60818.73	<i>o</i>	18.56 ± 0.05	ATLAS
60819.18	<i>g</i>	19.25 ± 0.02	LCO
60819.19	<i>r</i>	18.73 ± 0.02	LCO
60819.19	<i>r</i>	18.74 ± 0.02	LCO
60819.19	<i>g</i>	19.26 ± 0.02	LCO

60819.20	<i>i</i>	18.64 ± 0.03	LCO
60819.20	<i>i</i>	18.65 ± 0.02	LCO
60819.87	<i>o</i>	18.80 ± 0.07	ATLAS
60821.22	<i>c</i>	19.19 ± 0.12	ATLAS
60822.12	<i>g</i>	19.39 ± 0.03	LCO
60822.12	<i>g</i>	19.39 ± 0.05	LCO
60822.13	<i>r</i>	18.89 ± 0.02	LCO
60822.13	<i>r</i>	18.89 ± 0.02	LCO
60822.14	<i>i</i>	18.76 ± 0.03	LCO
60822.14	<i>i</i>	18.77 ± 0.03	LCO
60822.86	<i>o</i>	18.75 ± 0.07	ATLAS
60823.88	<i>o</i>	18.80 ± 0.10	ATLAS
60823.92	<i>g</i>	19.35 ± 0.02	LCO
60823.93	<i>r</i>	18.94 ± 0.02	LCO
60823.93	<i>r</i>	18.97 ± 0.02	LCO
60823.93	<i>g</i>	19.38 ± 0.02	LCO
60823.94	<i>i</i>	18.81 ± 0.04	LCO
60823.94	<i>i</i>	18.81 ± 0.04	LCO
60825.82	<i>g</i>	19.41 ± 0.02	LCO
60825.83	<i>r</i>	19.01 ± 0.02	LCO
60825.83	<i>g</i>	19.42 ± 0.02	LCO
60825.84	<i>i</i>	18.88 ± 0.03	LCO
60825.84	<i>r</i>	18.99 ± 0.02	LCO
60825.85	<i>i</i>	18.87 ± 0.03	LCO
60826.13	<i>c</i>	19.24 ± 0.09	ATLAS
60826.84	<i>o</i>	18.90 ± 0.07	ATLAS
60826.91	<i>i</i>	18.77 ± 0.09	LCO
60827.84	<i>o</i>	18.90 ± 0.07	ATLAS
60828.75	<i>g</i>	19.62 ± 0.03	LCO
60828.75	<i>g</i>	19.62 ± 0.03	LCO
60828.76	<i>i</i>	18.97 ± 0.04	LCO
60828.76	<i>r</i>	19.05 ± 0.03	LCO
60828.76	<i>r</i>	19.12 ± 0.03	LCO
60828.77	<i>i</i>	18.96 ± 0.04	LCO
60829.28	<i>i</i>	19.07 ± 0.05	LCO
60829.28	<i>i</i>	19.07 ± 0.05	LCO
60829.28	<i>r</i>	19.19 ± 0.03	LCO
60829.28	<i>r</i>	19.21 ± 0.03	LCO
60829.28	<i>g</i>	19.64 ± 0.03	LCO
60829.28	<i>g</i>	19.64 ± 0.03	LCO
60830.13	<i>o</i>	18.94 ± 0.15	ATLAS
60830.58	<i>r</i>	19.08 ± 0.06	LCO
60830.58	<i>i</i>	19.19 ± 0.09	LCO
60830.58	<i>i</i>	19.23 ± 0.09	LCO
60830.58	<i>r</i>	19.24 ± 0.07	LCO
60830.58	<i>g</i>	19.79 ± 0.10	LCO
60830.58	<i>g</i>	19.98 ± 0.13	LCO
60830.72	<i>g</i>	19.64 ± 0.05	LCO
60830.72	<i>g</i>	19.65 ± 0.05	LCO
60830.73	<i>i</i>	19.07 ± 0.05	LCO

60830.73	<i>r</i>	19.24 ± 0.04	LCO
60830.73	<i>r</i>	19.24 ± 0.04	LCO
60830.74	<i>i</i>	19.14 ± 0.05	LCO
60835.17	<i>g</i>	20.22 ± 0.15	LCO
60835.18	<i>r</i>	19.46 ± 0.11	LCO
60835.18	<i>r</i>	19.70 ± 0.14	LCO
60835.18	<i>g</i>	20.03 ± 0.15	LCO
60835.19	<i>i</i>	19.08 ± 0.11	LCO
60835.19	<i>i</i>	19.12 ± 0.13	LCO
60835.33	<i>i</i>	19.30 ± 0.05	LCO
60835.33	<i>i</i>	19.35 ± 0.05	LCO
60835.33	<i>r</i>	19.55 ± 0.04	LCO
60835.33	<i>r</i>	19.57 ± 0.04	LCO
60835.33	<i>g</i>	19.98 ± 0.04	LCO
60835.33	<i>g</i>	20.05 ± 0.04	LCO
60837.10	<i>g</i>	20.08 ± 0.08	LCO
60837.11	<i>r</i>	19.59 ± 0.08	LCO
60837.11	<i>g</i>	20.44 ± 0.13	LCO
60837.12	<i>i</i>	19.30 ± 0.08	LCO
60837.12	<i>i</i>	19.33 ± 0.08	LCO
60837.12	<i>r</i>	19.64 ± 0.08	LCO
60838.17	<i>g</i>	20.07 ± 0.11	LCO
60838.17	<i>g</i>	20.07 ± 0.12	LCO
60838.18	<i>r</i>	19.48 ± 0.07	LCO
60838.18	<i>r</i>	19.65 ± 0.08	LCO
60838.19	<i>i</i>	19.32 ± 0.51	LCO
60838.19	<i>i</i>	19.34 ± 0.08	LCO
60838.86	<i>o</i>	18.82 ± 0.12	ATLAS
60841.76	<i>o</i>	19.37 ± 0.11	ATLAS
60841.90	<i>g</i>	20.07 ± 0.08	LCO
60841.90	<i>g</i>	20.08 ± 0.09	LCO
60841.91	<i>i</i>	19.39 ± 0.06	LCO
60841.91	<i>r</i>	19.58 ± 0.06	LCO
60841.91	<i>r</i>	19.59 ± 0.06	LCO
60841.92	<i>i</i>	19.39 ± 0.06	LCO
60843.28	<i>o</i>	19.53 ± 0.19	ATLAS
60845.00	<i>g</i>	20.10 ± 0.03	LCO
60845.01	<i>r</i>	19.54 ± 0.03	LCO
60845.01	<i>r</i>	19.56 ± 0.03	LCO
60845.02	<i>i</i>	19.33 ± 0.03	LCO
60845.02	<i>i</i>	19.37 ± 0.04	LCO
60845.03	<i>o</i>	19.50 ± 0.20	ATLAS
60846.26	<i>o</i>	19.16 ± 0.10	ATLAS
60848.76	<i>o</i>	19.32 ± 0.11	ATLAS
60849.00	<i>g</i>	20.03 ± 0.03	LCO
60849.00	<i>g</i>	20.04 ± 0.03	LCO
60849.01	<i>r</i>	19.53 ± 0.04	LCO
60849.01	<i>r</i>	19.53 ± 0.04	LCO
60849.02	<i>i</i>	19.25 ± 0.05	LCO
60849.02	<i>i</i>	19.47 ± 0.07	LCO

60853.01	<i>g</i>	20.06 ± 0.02	LCO
60853.02	<i>r</i>	19.61 ± 0.03	LCO
60853.02	<i>r</i>	19.64 ± 0.03	LCO
60853.02	<i>g</i>	20.02 ± 0.02	LCO
60853.03	<i>i</i>	19.35 ± 0.04	LCO
60853.03	<i>i</i>	19.43 ± 0.05	LCO
60853.06	<i>o</i>	19.43 ± 0.13	ATLAS
60855.80	<i>c</i>	20.08 ± 0.18	ATLAS
60856.50	<i>g</i>	20.21 ± 0.06	LCO
60856.50	<i>g</i>	20.25 ± 0.06	LCO
60856.51	<i>i</i>	19.54 ± 0.09	LCO
60856.51	<i>r</i>	19.77 ± 0.06	LCO
60856.51	<i>r</i>	19.92 ± 0.07	LCO
60856.52	<i>i</i>	19.34 ± 0.07	LCO
60863.05	<i>g</i>	20.35 ± 0.13	LCO
60863.05	<i>g</i>	20.49 ± 0.13	LCO
60863.06	<i>r</i>	20.10 ± 0.12	LCO
60863.06	<i>r</i>	20.26 ± 0.14	LCO
60863.07	<i>i</i>	19.75 ± 0.12	LCO
60863.07	<i>i</i>	19.98 ± 0.15	LCO
60869.07	<i>g</i>	21.03 ± 0.18	LCO
60869.07	<i>g</i>	21.27 ± 0.28	LCO
60869.08	<i>r</i>	20.32 ± 0.12	LCO
60869.08	<i>r</i>	20.41 ± 0.12	LCO
60869.09	<i>i</i>	20.15 ± 0.13	LCO
60869.09	<i>i</i>	20.18 ± 0.13	LCO
60875.05	<i>g</i>	20.95 ± 0.06	LCO
60875.05	<i>g</i>	20.96 ± 0.07	LCO
60875.06	<i>r</i>	20.67 ± 0.08	LCO
60875.06	<i>r</i>	20.69 ± 0.08	LCO
60875.07	<i>i</i>	20.19 ± 0.09	LCO
60875.07	<i>i</i>	20.29 ± 0.10	LCO
60880.96	<i>g</i>	20.87 ± 0.14	LCO
60880.96	<i>g</i>	21.26 ± 0.14	LCO
60880.97	<i>r</i>	20.53 ± 0.09	LCO
60880.97	<i>r</i>	20.69 ± 0.11	LCO
60880.98	<i>i</i>	20.26 ± 0.11	LCO
60880.98	<i>i</i>	20.42 ± 0.11	LCO
60894.00	<i>g</i>	20.85 ± 0.19	LCO
60894.01	<i>r</i>	20.58 ± 0.17	LCO
60894.01	<i>g</i>	20.97 ± 0.22	LCO
60894.02	<i>i</i>	20.48 ± 0.19	LCO
60894.02	<i>r</i>	20.55 ± 0.16	LCO
60894.03	<i>i</i>	20.61 ± 0.20	LCO
60899.39	<i>r</i>	20.87 ± 0.11	LCO
60899.39	<i>g</i>	21.42 ± 0.11	LCO
60899.40	<i>r</i>	20.84 ± 0.08	LCO
60899.40	<i>g</i>	21.21 ± 0.10	LCO
60901.36	<i>r</i>	20.81 ± 0.20	LCO
60901.36	<i>g</i>	21.06 ± 0.19	LCO

60901.36	<i>g</i>	21.13 ± 0.35	LCO
60901.36	<i>r</i>	21.24 ± 0.47	LCO
60901.98	<i>g</i>	21.03 ± 0.08	LCO
60901.99	<i>r</i>	20.54 ± 0.08	LCO
60901.99	<i>g</i>	21.20 ± 0.09	LCO
60902.00	<i>i</i>	20.35 ± 0.13	LCO
60902.00	<i>i</i>	20.36 ± 0.10	LCO
60902.00	<i>r</i>	20.88 ± 0.11	LCO
60905.37	<i>i</i>	20.49 ± 0.16	LCO
60905.37	<i>r</i>	20.84 ± 0.19	LCO
60905.37	<i>g</i>	21.02 ± 0.16	LCO
60908.36	<i>i</i>	20.49 ± 0.21	LCO
60908.36	<i>r</i>	20.66 ± 0.24	LCO
60908.36	<i>g</i>	20.76 ± 0.23	LCO
60908.37	<i>i</i>	20.24 ± 0.14	LCO
60908.37	<i>r</i>	20.56 ± 0.21	LCO
60908.37	<i>g</i>	21.12 ± 0.28	LCO
60911.72	<i>g</i>	21.01 ± 0.25	LCO
60911.73	<i>i</i>	19.93 ± 0.28	LCO
60911.73	<i>r</i>	20.72 ± 0.23	LCO

Table 2. Photometry of SN 2024afav. All magnitudes have are in AB system and corrected for Galactic extinction.

Phase (days)	Velocity (km s ⁻¹)		
	Si II $\lambda 6355$ Å	O I $\lambda 6158$ Å	O I $\lambda 7774$ Å
-14	11707 $\pm$ 483	-	O 6729 $\pm$ 242*
-4	8911 $\pm$ 395	6540 $\pm$ 54*	7037 $\pm$ 543
+20	7858 $\pm$ 41	8116 $\pm$ 972	7190 $\pm$ 141
+24	7388 $\pm$ 39	7473 $\pm$ 49	6800 $\pm$ 43
+27	7417 $\pm$ 33	7387 $\pm$ 46	7304 $\pm$ 133
+30	7171 $\pm$ 25	6418 $\pm$ 95	6683 $\pm$ 74
+47	6282 $\pm$ 64	6411 $\pm$ 126	6535 $\pm$ 68
+51	5443 $\pm$ 43	6415 $\pm$ 66	6341 $\pm$ 108
+53	-	5976 $\pm$ 76*	6426 $\pm$ 37
+54	5439 $\pm$ 83	6392 $\pm$ 105	5971 $\pm$ 71
+63	4799 $\pm$ 75	6663 $\pm$ 231	5685 $\pm$ 211
+74	4786 $\pm$ 84	6284 $\pm$ 778*	4254 $\pm$ 1010*
+91	4131 $\pm$ 566	6355 $\pm$ 444	5906 $\pm$ 127
+112	3657 $\pm$ 57	4879 $\pm$ 162	5434 $\pm$ 222
+139	-	5851 $\pm$ 140*	5008 $\pm$ 51
+160	6140 $\pm$ 432*	5224 $\pm$ 104	6603 $\pm$ 3289*

Table 3. Velocity evolution measurement using spectral sequence of SN 2024afav

Phase (days)	Area					L_{7300}/L_{6300}
	[O III] $\lambda 4959$ Å	[O III] $\lambda 5007$ Å	[O I] $\lambda 6300$ Å	[O II] $\lambda 7319, 7330$ Å	[Ca II] $\lambda 7291, 7324$ Å	
+112	9.29 ± 2.25	48.51 ± 3.86	5.32 ± 0.57	14.26 ± 3.94	11.40 ± 4.21	4.82 ± 1.14

+139	10.81 ± 1.95	44.31 ± 3.16	3.12 ± 0.15	65.66 ± 5.92	43.50 ± 4.87	34.99 ± 2.50
+160	4.70 ± 0.92	34.72 ± 1.53	6.07 ± 5.18	120.49 ± 5.40	206.05 ± 15.49	53.80 ± 46.24

Table 4. Area in unit of flux density for the the [O III], [O II] and [O I] features, estimated using line profile fitting. We estimated the L_{7300}/L_{6300} ratio for each epoch and found an increasing ratio trend.

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