

ObsAstro25 Project2 Final Report

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1. INTRODUCTION (ZHEN)

Supernovae (SNe) are dramatic and relatively rare explosive events in the universe. Unlike Novae, which can happen hundreds of times during the whole life of a star, SNe are one-time events that mark the end stages of a star. They were initially categorized by Minkowski based on the absence (Type I) or presence (Type II) of the Balmer lines, indicating the hydrogen features in their spectra (A. Gal-Yam 2017).

Type Ia supernovae (SN Ia), a famous subtype of Type I SNe (SN I), resulting from the thermonuclear runaway of a white dwarf (WD) in a binary system, represent a crucial class of transient phenomena in astrophysics (A. V. Filippenko 1997). These events, which do not exhibit hydrogen lines in their spectra (D. Branch 1993), are primarily understood to arise either from the merger of two WDs or through the accretion of material onto a WD from a companion star, eventually leading it to exceed the Chandrasekhar mass limit ($\sim 1.4M_{\odot}$) (F. Hoyle & W. A. Fowler 1960; K. Nomoto et al. 1984).

Studying SNe Ia is significant for several reasons: they are major producers of iron-group elements, contribute kinetic energy to galaxies (D. Maoz et al. 2014), and critically, serve as powerful tools for measuring cosmological distances (D. Maoz et al. 2014; W. L. Freedman & B. F. Madore 2010; A. Ravi et al. 2025; S. C. Williams et al. 2024; G. C. Anupama et al. 2004; C. R. Burns et al. 2020; P. A. Mazzali et al. 2007). Accurate distance measurements are fundamental to cosmology, enabling the determination of the Universe's expansion rate (the Hubble constant, H_0), its geometry, and probing the nature of dark energy (W. L. Freedman & B. F. Madore 2010; A. Ravi et al. 2025; S. C. Williams et al. 2024); indeed, SNe Ia were instrumental in the discovery of the accelerating cosmic expansion (A. Ravi et al. 2025; P. A. Mazzali et al. 2007).

The utility of SNe Ia as distance indicators stems from their nature as standardizable candles (A. Ravi et al. 2025; S. C. Williams et al. 2024). While not perfectly standard, their peak luminosities show a strong empirical correlation with the rate at which their light curves decline after maximum brightness, a relationship known as the Phillips relation (D. Maoz et al. 2014; W. L. Freedman & B. F. Madore 2010; A. Ravi et al. 2025; G. C. Anupama et al. 2004; P. A. Mazzali et al. 2007; W. Hillebrandt & J. C. Niemeyer 2000). Photometric observations are crucial as they provide the apparent magnitude (m) and allow measurement of the light curve shape, often characterized by parameters like the magnitude decline over 15 days ($\Delta m_{15}(B)$) or color-stretch (s_{BV}) (S. C. Williams et al. 2024; G. C. Anupama et al. 2004; C. R. Burns et al. 2020). By applying the Phillips relation, the decline rate measured from photometry yields an estimate of the supernova's intrinsic peak absolute magnitude (M), which, combined with the measured apparent magnitude, gives the distance modulus ($\mu = m - M$) and thus the distance (S. C. Williams et al. 2024; G. C. Anupama et al. 2004). Furthermore, detailed analysis of multi-color light curve shapes can provide even more precise standardization, as these shapes correlate with intrinsic luminosity and help distinguish dimming due to distance from dimming due to dust or intrinsic faintness (A. G. Riess et al. 1996). This standardizability, combined with their high intrinsic luminosity allowing observation across vast cosmological distances (D. Maoz et al. 2014; S. C. Williams et al. 2024), makes SNe Ia effective cosmological probes with relatively low scatter in derived distances (W. L. Freedman & B. F. Madore 2010; A. G. Riess et al. 1996).

Type II SNe (SN II) originate from the core collapse of massive stars and are typically located in star-formation regions. Unlike Type I explosions, SN II events leave behind a compact remnant (neutron star or black hole) surrounded by a chemically enriched, expanding supernova remnant. They are produced by the iron-core collapse of short-lived ($M_{\text{ZAMS}} \gtrsim 8\text{--}10 M_{\odot}$) massive stars, and are indispensable laboratories for both stellar and extragalactic astrophysics. They release about 10^{51} erg of kinetic energy and eject several solar masses of newly forged α -elements into the surrounding gas, enriching the interstellar medium and driving feedback in star-forming regions (S. E. Woosley & T. A. Weaver 1995; J. Vink 2012).

Pre-explosion images of nearby events show red-supergiant progenitors, which narrows the initial-mass range that ends as SNe II and provides valuable checks on stellar-evolution models (S. J. Smartt 2009). The $\sim 10^{53}$ erg neutrino burst from SN 1987A confirmed the neutrino-driven explosion picture and opened the door to multi-messenger studies; a future Galactic SN II would likely be detected in both neutrinos and gravitational waves (K. Hirata et al. 1987; H.-T. Janka 2012).

Photometric–spectroscopic tools such as the Expanding Photosphere Method (EPM) and the Standard Candle Method (SCM) can reduce the scatter in plateau luminosities to about 0.3 mag, giving a distance scale that is independent of SNe Ia (R. P. Kirshner & J. Kwan 1974; M. Hamuy & P. A. Pinto 2002; T. de Jaeger et al. 2020). Finally, infrared observations show that core-collapse SNe can form $\gtrsim 0.1M_{\odot}$ of dust within a few hundred days, suggesting they help supply the dust seen in young galaxies (C. Gall et al. 2014).

Therefore, the photometric and spectroscopic study of these transients provides critical insights into their explosion mechanisms, progenitor systems, and their utility in cosmology. Once a potential SNe candidate is detected, the primary method used to study its nature and classify it is spectroscopy. Analyzing the spectrum of an SNe provides invaluable information on its composition and dynamics (H. Yamaoka 2016).

Here, we examined the SNe detected by the Zwicky Transient Facility (ZTF; F. J. Masci et al. (2019)) and selected the bright candidates that were observable at Xinglong on the night of May 17, 2025. By making observations, we reported SN 2025kid, a new Type Ia supernova, and measured its redshift. In addition, we made use of both photometry and spectroscopy from SN Ia and SN II to verify and analyze some physical properties of recent supernovae, SN 2025fvw and SN 2025gvs.

2. OBSERVATIONS AND DATA REDUCTION

2.1. Target Selection (Zhen 60%; Zisen 40%)

We ranked ZTF alerts according to quantitative, telescope-specific criteria designed to guarantee (i) visibility, (ii) sufficient signal-to-noise ratio, and (iii) clean and uniform background. First, the coordinates of the transient had to be within the sky accessible to the Xinglong 2.16m telescope configuration on the scheduled night. To be more specific, we required that the source attain an airmass $X = \sec z < 2.0$ for at least one hour during local astronomical darkness, which ensures an altitude $z > 30^{\circ}$ and acceptable atmospheric extinction. In addition, a Moon-target separation of $> 30^{\circ}$ was required to minimize the moonlight background. Second, we imposed $v \lesssim 18$ mag for spectroscopic observation and $v \lesssim 20$ mag for photometric monitoring, in order to secure a sufficient signal-to-noise ratio. Third, we also checked some extra requirements: for example, when a host galaxy redshift was available, we limited the candidates to $z \lesssim 0.01$, which was set by the usable wavelength range and fringe performance of BFOSC; some cases for SNe Ibn up to $z \lesssim 0.020$ were acceptable. For events with resolved hosts, we required an angular offset that placed the slit clear of the bright galactic nucleus or even the entire galaxy background, to minimize the host galaxy contamination.

After filtering based on our criterion above, there were seven candidates remaining. Then, we did additional inspection on them, including ATLAS forced photometric measurements (L. Shingles et al. 2021), to make sure that they were at an appropriate stage for our observation. Over the monitoring period, from the initial target screening one week before the run up to nightfall on the observing date, three candidates finally emerged as the most promising: SN 2025fvw (Type Ia), SN 2025kid (candidate transient at discovery, later confirmed as Type Ia), and SN 2025gvs (Type II). Their discovery circumstances and host-galaxy properties are summarized in Table 1.

Table 1. Final targets and basic discovery information. (Zhen: framework, Zisen: data)

Transient	Discovery date	RA (J2000)	Dec (J2000)	Disc. mag	Host galaxy	z_{host}
SN 2025fvw	2025-05-08	15 ^h 35 ^m 25.78 ^s	+12°03′27″.8	15.2	NGC 5957	0.0061
SN 2025kid	2025-05-10	10 ^h 21 ^m 56.60 ^s	+24°39′22″.3	18.7	IC 2567	0.0402
SN 2025gvs	2025-04-22	15 ^h 50 ^m 23.40 ^s	+25°55′10″.0	16.1	UGC 10058	0.0072

We have selected SN 2025fvw for observation due to its high brightness, which facilitates photometric measurements, and its well-sampled light curve, enabling detailed photometric analysis. SN 2025kid was chosen as a transient that was discovered relatively late, with an undetermined classification. Our objective is to ascertain its type and redshift through spectroscopic analysis. Additionally, we selected SN 2025gvs, a Type II supernova, to diversify our sample.

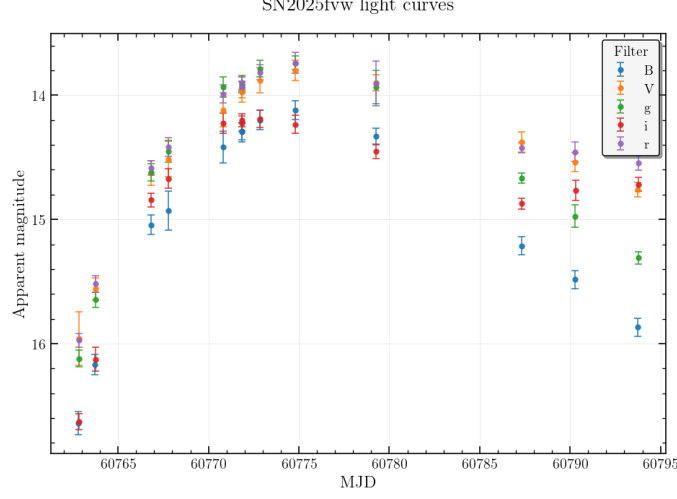


Figure 1. Multi-band Light Curves for SN 2025fvw. (Zhen)

This choice is particularly strategic, as our previous two observational targets were Type I supernovae. By obtaining the spectrum of a Type II supernova, we aim to enhance the breadth of our data and further our understanding of supernova classifications.

2.2. Photometry (Zhen)

All CCD imaging of SN 2025fvw was carried out with the Xinglong 80cm telescope. Dome flat fields were acquired before the observation started. Image reduction followed a standard CCD pipeline implemented by Ruifeng Huang in Xiaofeng Wang's group. A master bias and master dark were constructed by median-combining the raw frames. Science images were bias-subtracted, dark-corrected, and divided by a master flat in the corresponding filter. After cosmic ray rejection, calibrated images were used for differential aperture photometry, selecting dozens of non-variable comparison standard stars per filter. The resulting calibrated magnitudes constitute the multi-band light curves displayed in Fig. 1.

2.3. Spectroscopy (Zhen)

Single exposure of SN 2025kid, and time-series imaging of SN 2025fvw and SN 2025gvs was obtained with the 2.16 m telescope at Xinglong Observatory, equipped with the BFOSC setup. Prior to the end of evening twilight we acquired (i) a series of $N_{\text{bias}} = 5$ zero-second bias frames, (ii) $N_{\text{flat}} = 5$, 90 s dome flats, (iii) $N_{\text{lamp}} = 2$, 30 s wavelength-calibration lamp spectra, and (iv) one 120 s flux-calibration spectrum of reference star HD 86986 in 385 nm UV-cut filter. The telescope was then slewed to the target and autoguiding plus human intervention was enabled, maintaining a high tracking accuracy for a 3600 s single exposure.

All BFOSC long-slit frames were processed with a customized pipeline that implements the canonical steps by Ruifeng Huang in Xiaofeng Wang's group. Five zero-second bias frames were averaged into a master bias with sigma-clipping and no scaling, and they were subtracted from every image. Five 90 s dome flats taken through the slit were averaged with sigma-clipping and median-scaling, and used to remove pixel-to-pixel sensitivity variations and the grating response. After cosmic ray rejection, sky background subtraction, and one-dimensional extraction, we performed wavelength calibration by FeAr lamp spectra and flux calibration by standard spectrum of the reference star. The fully reduced, flux-calibrated spectra of SN 2025kid and SN 2025gvs are shown in Fig. 2.

3. PHOTOMETRIC STUDY OF SN 2025FVW (ZHEN)

3.1. Optical Light Curves

Time-series B, V, g, i, r photometry obtained from March 28 to April 28, 2025 traces a smooth rise to maximum followed by the canonical post-peak decline expected for a normal SN Ia, as shown in Fig. 1.

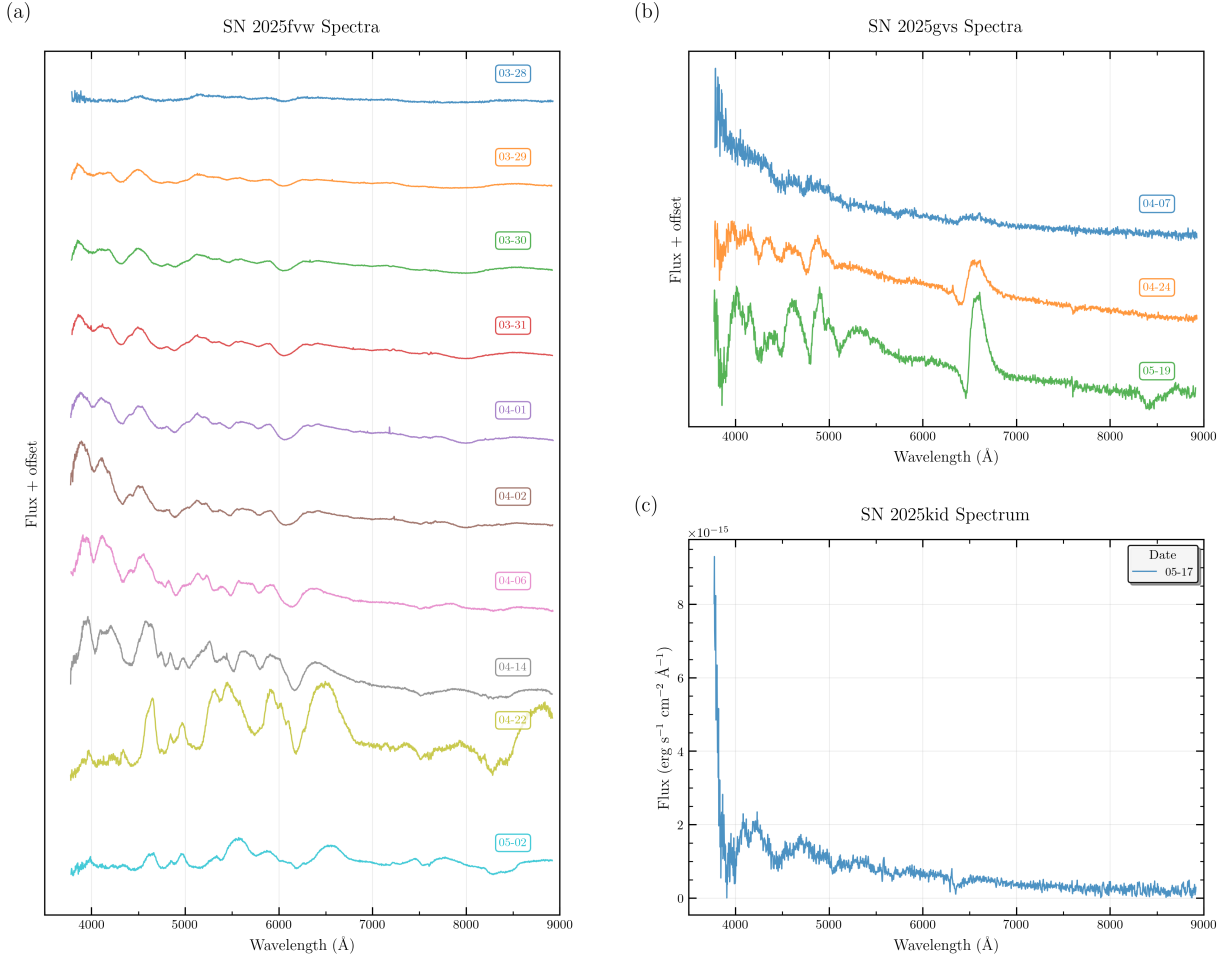


Figure 2. Optical Spectra of SN 2025fvw, SN 2025gvs, SN 2025kid. Spectra in panels (a) and (b) are offset vertically for clarity. (a) Spectra of SN 2025fvw from March 28 to May 2. (b) SN 2025gvs spectra taken on April 7, April 24, and May 19, 2025. (c) SN 2025kid spectrum obtained on May 17, 2025. (Zhen)

3.2. Colors and Effective Temperature

The B-V color index is calculated by pairing B-band and V-band observations taken within a time tolerance of ± 0.02 days. The color is the simple difference in magnitudes,

$$B - V = m_B - m_V$$

and its uncertainty is determined by propagating the errors of the individual measurements:

$$\sigma_{B-V} = \sqrt{\sigma_B^2 + \sigma_V^2}$$

The resulting B-V color evolves from approximately 0.3 to 1.1 during the observation period, and hits the minimum around the time when the B-band magnitude reaches maximum, which is consistent with the color evolution of other normal Type Ia supernovae in the early stage (W. B. Hoogendam et al. 2022).

The effective temperature (T_{eff}) of the supernova is estimated from the B-V color using the empirical formula from F. Ballesteros (2012):

$$T_{\text{eff}} = 4600 \cdot \left(\frac{1}{0.92(B - V) + 1.7} + \frac{1}{0.92(B - V) + 0.62} \right)$$

This relation, while developed for stars, provides a reasonable blackbody approximation for supernovae within a B-V range of -0.2 to 2.0. The error in temperature is propagated from the B-V uncertainty.

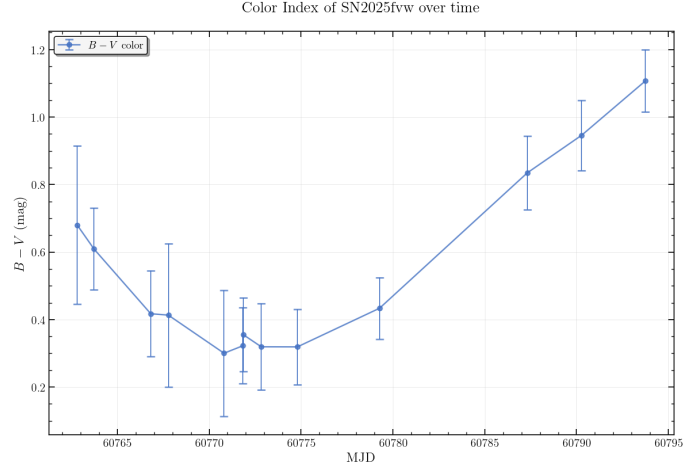


Figure 3. Color index of SN 2025fvw over time. (Zhen)

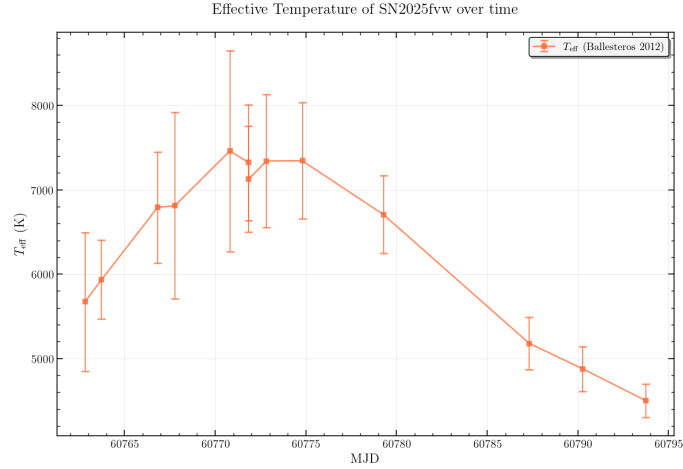


Figure 4. Effective temperature of SN 2025fvw over time. (Zhen)

$$\sigma_{\text{Teff}} = \left| \frac{dT_{\text{eff}}}{d(B-V)} \right| \cdot \sigma_{B-V}$$

131 where

$$\frac{dT_{\text{eff}}}{d(B-V)} = -4600 \cdot 0.92 \cdot \left(\frac{1}{[0.92(B-V) + 1.7]^2} + \frac{1}{[0.92(B-V) + 0.62]^2} \right)$$

132 The temperature is found to go up and peak at approximately 7461 K and then cool to 4498 K, a typical cooling
133 behavior for a Type Ia supernova after its peak brightness, confirming its classification.

134 3.3. First-light Time

135 To determine the key temporal parameters, the multi-band light curves are fitted with a non-linear least-squares
136 method using the broken power law model (W. Zheng et al. 2018) of:

$$F(t) = A \cdot \left(\frac{t-t_0}{t_b} \right)^{2(\alpha_1+1)} \cdot \left[1 + \left(\frac{t-t_0}{t_b} \right)^{s(\alpha_1-\alpha_2)} \right]^{-2/s}$$

$$m(t) = -2.5 \log_{10} F(t), t \geq t_0$$

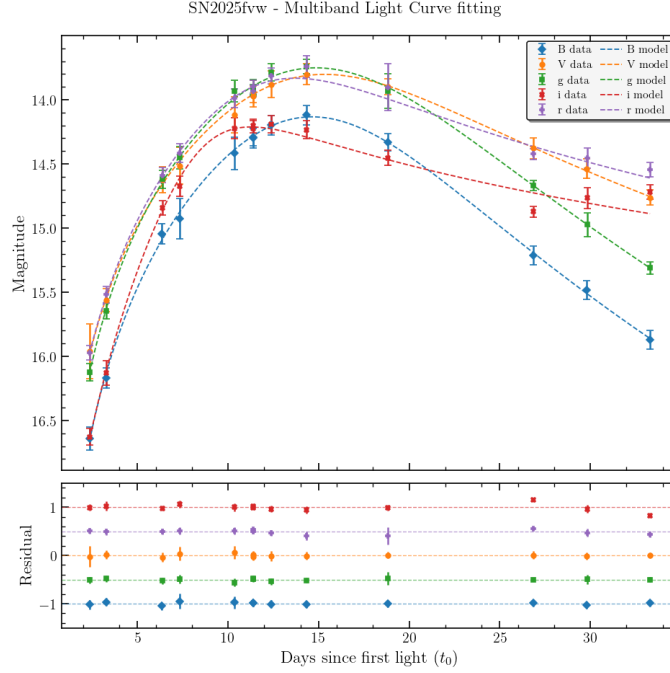


Figure 5. Multiband light curve fitting of SN 2025fvw. (Zhen)

This model fits for several parameters, including the first-light time (t_0), which represents the moment of explosion; the break time (t_b), which approximates the time of peak luminosity; and other parameters describing the shape of the light curve: Normalization factor (A), velocity index (α_1) before peak, velocity index (α_2) after peak, smooth factor (s) around peak. Initially, $A = 10^{-8}$, $t_0 = t_{min} - 0.5$, $t_b = 20$ d, $\alpha_1 = 0.05$, $\alpha_2 = -2.5$, $s = 1.3$.

By performing an inverse-variance weighted average across all five filters, the first-light time is determined to be $t_0 = 60760.46758 \pm 0.7479$ MJD. The time of peak brightness varies slightly by filter, occurring between 11 and 18 days after first light. Specifically, the break time in each filter is shown in Table 2.

The weighted average peak time across all bands is $t_{peak} = 15.51 \pm 0.85$ days after the explosion. The model provides a good fit to the observed data, as shown by the small residuals in Fig. 5.

3.4. Estimation of Distance and the Hubble Constant

The distance to SN 2025fvw is estimated using its properties as a "standardizable candle." The absolute magnitude (M) of a Type Ia supernova is correlated with its decline rate after maximum brightness, specifically the change in magnitude over the first 15 days, denoted as Δm_{15} .

First, the peak apparent magnitude (m_{max}) and the magnitude 15 days later (m_{15}) are calculated from the fitted light curves for B-band.

$$\Delta m_{15}(B) = m_B(t_{peak} + 15\text{d}) - m_{B,max}$$

$$\sigma_{M_B} = \sqrt{\sigma_{b_0}^2 + (\sigma_{b_1} \cdot \Delta m_{15})^2 + (b_1 \cdot \sigma_{\Delta m_{15}})^2}$$

where $\sigma_{b_0} = 0.498$, $\sigma_{b_1} = 0.359$.

So, the decline rate $\Delta m_{15}(B)$ is found to be 1.359 ± 0.0663 mag.

Using the M. M. Phillips (1993) relation, the absolute magnitude in the B-band is calculated as:

$$M_B = b_0 + b_1 \cdot \Delta m_{15}(B)$$

where $b_0 = -21.726 \pm 0.498$ and $b_1 = 2.698 \pm 0.359$. With the measured $\Delta m_{15}(B) = 1.359 \pm 0.066$, this yields $M_B = -18.058 \pm 0.720$ mag.

156 Absolute magnitudes for the V, g, r, and i bands are derived using empirical relations from M. M. Phillips et al.
 157 (1999) and J. L. Prieto et al. (2006). These relations also depend on $\Delta m_{15}(B)$: $M_V = (-19.504 \pm 0.045) + (0.825 \pm$
 158 $0.070)[\Delta m_{15}(B) - 1.10]$, $M_g = (-19.218 \pm 0.050) + (0.886 \pm 0.130)[\Delta m_{15}(B) - 1.10]$, $M_r = (-19.161 \pm 0.048) + (0.641 \pm$
 159 $0.119)[\Delta m_{15}(B) - 1.10]$, $M_i = (-18.716 \pm 0.050) + (0.409 \pm 0.128)[\Delta m_{15}(B) - 1.10]$. The calculated absolute magnitudes
 160 are listed in Table 2.

The distance modulus μ for each filter is then calculated using the peak apparent magnitude (m_{max}) and the derived absolute magnitude (M_{abs}):

$$\mu = m_{max} - M_{abs}$$

The error is propagated by adding the variances of the apparent and absolute magnitudes:

$$\sigma_\mu = \sqrt{\sigma_{m_{max}}^2 + \sigma_{M_{abs}}^2}$$

161 The resulting distance moduli for each band are listed in Table 2.

Table 2. Calculated Photometric Properties of SN 2025fvw (Zhen)

Filter	Break Time (t_b , days)	Absolute Magnitude (M)	Distance Modulus (μ)
B	16.74 ± 1.81	-18.058 ± 0.720	32.192 ± 0.721
V	16.38 ± 2.74	-19.290 ± 0.073	33.093 ± 0.091
g	17.55 ± 1.60	-18.988 ± 0.084	32.740 ± 0.096
r	13.47 ± 1.44	-18.995 ± 0.071	32.827 ± 0.084
i	11.29 ± 3.76	-18.610 ± 0.066	32.822 ± 0.073

A final, more precise distance modulus is determined by calculating the weighted average, where the value of each filter is weighted by the inverse of its variance:

$$\mu_{avg} = \frac{\sum w_i \mu_i}{\sum w_i} \quad \text{where} \quad w_i = \frac{1}{\sigma_{\mu_i}^2}$$

162 The error on this weighted average is the inverse square root of the sum of the weights. This yields a final distance
 163 modulus of $\mu_{avg} = 32.864 \pm 0.042$ mag.

This distance modulus is converted to a physical distance in Megaparsecs (Mpc) using the standard formula:

$$d_{Mpc} = 10^{(\mu_{avg} + 5)/5 - 6}$$

The error in the distance is propagated as follows:

$$\sigma_d = d \times \frac{\ln(10)}{5} \times \sigma_\mu \approx 0.461 \times d \times \sigma_\mu$$

164 This corresponds to a final physical distance of $d = 37.39 \pm 0.73$ Mpc. This result is in the same order of magnitude
 165 as the known distance to the host galaxy, NGC 5957, which is approximately 31.8 ± 2.2 Mpc. Plugging our derived
 166 distance and the host galaxy's redshift ($z = 0.0061$) into the cosmology calculator by E. L. Wright (2006), we infer a
 167 Hubble Constant of $H_0 \approx 48.2$ km/s/Mpc, a value that is consistent with some modern measurements, though on the
 168 lower end of the accepted range.

169 4. SPECTROSCOPY STUDY OF SN 2025KID AND SN 2025GVS (ZISEN)

170 4.1. Data Processing of SN 2025kid

171 Following preliminary data inspection and plotting (Fig. 2), the approximate locations of prominent spectral features
 172 were identified. As a preparatory step, the spectral region below 4000 Å was removed from consideration due to both
 173 significantly diminished data quality and substantial deviations from the expected spectral behavior in this region.

174 Subsequently, to optimize the signal-to-noise ratio and focus on the most reliable spectral information, the wavelength
 175 range was constrained to 3600-9200 Å (H. Lin et al. 2021). Within this range, adaptive smoothing was applied across five

distinct spectral regions, with filter parameters optimized to balance effective noise reduction and careful preservation of intrinsic spectral features: 3600-3990 Å (heavy smoothing, designed for the noisy far-blue end: 9 Å median filter, 3.0 Å Gaussian σ), 3990-4010 Å (minimal smoothing, intended to preserve the 4000 Å break: 3 Å median filter, 0.5 Å Gaussian σ), 4010-5000 Å (7 Å median filter, 2.0 Å Gaussian σ), 5000-7000 Å (5 Å median filter, 1.5 Å Gaussian σ), and 7000-9200 Å (minimal smoothing, appropriate for the relatively stable red end: 3 Å median filter, 1.0 Å Gaussian σ). To ensure smooth spectral continuity and avoid artifacts at region boundaries, Gaussian smoothing ($\sigma = 1.0$ Å) was applied within a 20 Å radius of the regional boundaries at 3990 Å, 4010 Å, 5000 Å, and 7000 Å. An optional feature enhancement process was then implemented to partially restore the depths of key absorption lines, with particular attention given to the Ca II H&K lines. This involved blending the original and smoothed data using a Gaussian weighting function to emphasize the line centers (30 Å window below 4100 Å, 20 Å window otherwise), thus sharpening these features without introducing spurious signals. A final, light global Gaussian smoothing ($\sigma = 0.3$ Å) was then applied to the entire spectrum for final refinement and cosmetic improvement.

It is important to note that these processing steps were primarily implemented to enhance the visual presentation of the spectral curves, facilitating easier visual inspection and spectral type classification. As equivalent width (EW) measurements, which rely on precise flux calibration, were not performed in this analysis, these procedures do not compromise the scientific validity of our conclusions. The resulting processed spectra and residuals are shown in Fig. 6.

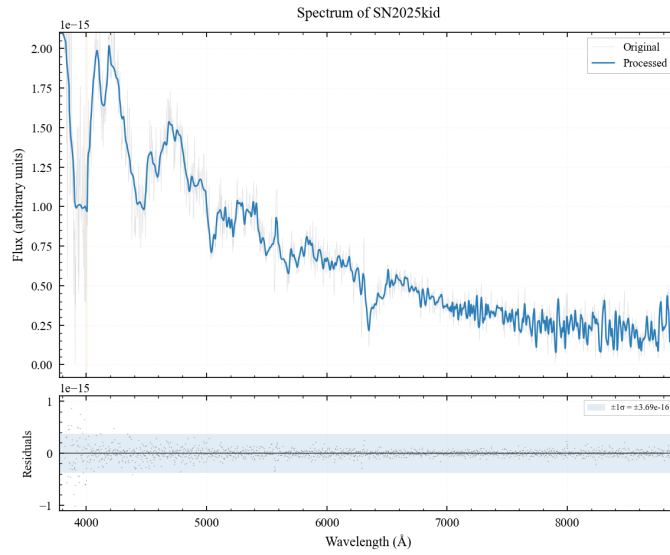


Figure 6. Processed Spectrum and Residuals of SN 2025kid. (Zisen)

4.2. Type Determination of SN 2025kid

For spectral analysis and classification, we utilized the GELATO tool (<https://gelato.tng.iac.es>), which requires an input ASCII file comprising two columns: one containing evenly spaced wavelength values and the other containing corresponding flux values. This input file was generated via linear interpolation of the reduced spectral data. Using the host galaxy's redshift ($z = 0.0402$) as the reference redshift for this supernova, we performed a fitting and comparison of the spectrum against a supernova spectral library within GELATO. The resulting classification, a 100% confidence Type Ia supernova, is consistent with the independent classification previously obtained by Senior Researcher Ruifeng Huang. The GELATO analysis and Ruifeng Huang's independent results are presented in Fig. 7 and Fig. 8, respectively.

4.3. Redshift Measurement of SN 2025kid

Redshift measurements were performed using a custom-developed Python routine designed for robust and standardized analysis of spectral lines. The process began by automatically defining spectral regions for analysis based on the rest wavelength (λ_{rest}) of the target line. This involved estimating the observed wavelength (λ_{obs}) based on an expected redshift (z) and establishing appropriate analysis ranges, line regions, and continuum regions. To accommodate specific cases, manual adjustments were permitted, allowing for customized region definitions.

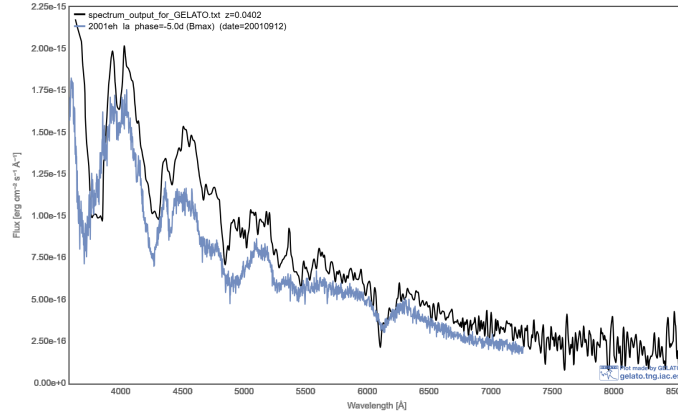


Figure 7. Gelatoplot for Comparison with SN 2001eh (Zisen)

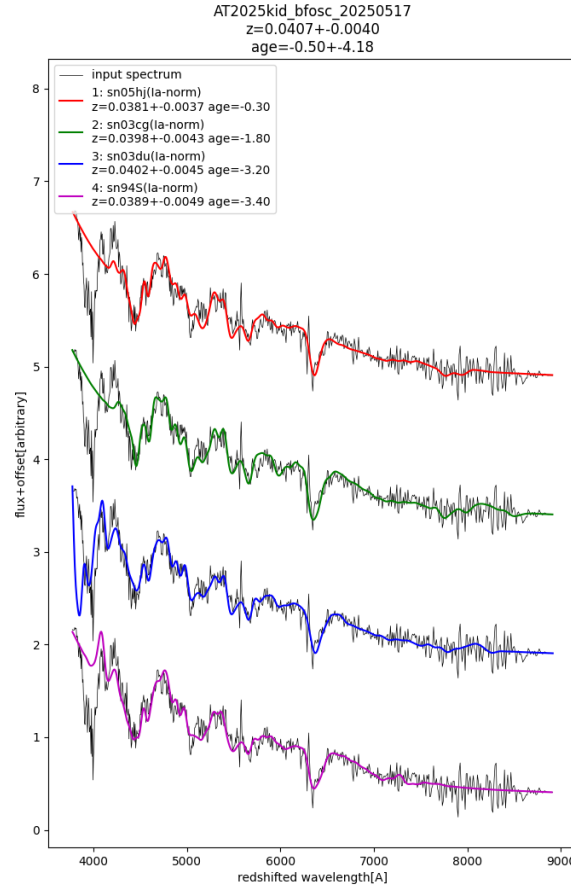


Figure 8. Ruifeng's plot result for SN 2025kid (Ruifeng)

206 Within the defined analysis range, the spectral continuum was modeled using a suite of fitting methods. These
 207 methods included linear, quadratic, and cubic polynomial regression, as well as univariate spline interpolation. To
 208 mitigate contamination from line emission or absorption, pre-defined line regions were excluded from the continuum

fitting process. The optimal fitting method was selected automatically based on the coefficient of determination (R^2) or could be manually specified to ensure consistency.

Following continuum modeling, the spectrum was normalized by dividing the observed flux (F_{obs}) by the best-fitting continuum model (F_{cont}), yielding a normalized flux spectrum ($F_{norm} = F_{obs}/F_{cont}$). This normalization step facilitates accurate line profile analysis by removing the underlying continuum slope.

A Gaussian function was then fitted to the normalized spectrum within the line region to determine the observed wavelength (λ_{obs}) of the spectral line. Initial estimates for the Gaussian parameters (amplitude, center, full width at half maximum [FWHM]) were automatically determined based on the line type (absorption or emission). Non-linear least squares fitting was employed to derive the best-fit parameters and their associated covariance matrix.

The redshift (z) was calculated from the observed and rest wavelengths using the standard formula:

$$z = \frac{\lambda_{obs}}{\lambda_{rest}} - 1$$

The radial velocity (v) was subsequently derived from the redshift using the non-relativistic approximation:

$$v = z \cdot c$$

where c is the speed of light.

Uncertainties in the observed wavelength (σ_λ) and redshift (σ_z) were estimated from the covariance matrix obtained during the Gaussian profile fitting process.

The quality of the spectral fitting was assessed using the reduced chi-squared statistic (χ^2_{red}) and the coefficient of determination (R^2) of the continuum fit. These metrics provide quantitative measures of the goodness-of-fit.

4.3.1. Redshift Analysis in the Fe II 4233.0 Å

To determine the redshift of the Fe II $\lambda 4233.0$ Å spectral feature, the host galaxy's redshift ($z = 0.0402$) was initially adopted as a reference to define appropriate spectral regions for analysis. These regions encompassed both the line region, selected for Gaussian peak fitting, and the continuum region, utilized for background modeling. Several continuum fitting methods, including linear, quadratic (poly2), cubic (poly3), and spline interpolations, were evaluated based on their respective coefficients of determination (R^2). The method yielding the highest R^2 value was then selected for spectral normalization. Following normalization, a Gaussian function was fitted to the spectral feature, and visual inspection of the fitting residuals indicated a satisfactory fit. The analysis yielded an observed wavelength of $\lambda_{obs} = 4433.031 \pm 1.837$ Å, corresponding to a redshift of $z = 0.04726 \pm 0.00043$ and a radial velocity of $v = 14166.8 \pm 130.1$ km/s. As a consistency check, this result was compared with both the host galaxy redshift ($z = 0.0402$) and an independent measurement obtained by Senior Researcher Huang ($z = 0.0407$). The agreement between these values suggests the accuracy and reliability of the Fe II redshift measurement. Related results can be seen in Fig. 9.

4.3.2. Redshift Analysis in the Si II 3858.0 Å

The redshift of the Si II $\lambda 3858.0$ Å spectral feature was determined using a similar methodology to that employed for the Fe II analysis. Given the presence of a prominent spectral break near 4000 Å, a linear function was selected for continuum modeling. The spectral region analyzed spanned from 3812.3 Å to 4212.3 Å, with the line region defined as 3912.32 Å to 4112.32 Å and continuum regions defined as 3812.32 Å to 3902.32 Å and 4122.32 Å to 4212.32 Å. This linear fit yielded an observed wavelength of $\lambda_{obs} = 3959.993 \pm 3.371$ Å, corresponding to a redshift of $z = 0.02644 \pm 0.00087$ and a radial velocity of $v = 7925.5 \pm 262.0$ km/s. The reduced chi-squared value for the Gaussian fit was 0.0096. While this redshift is considerably lower than expected, the presence of the 4000 Å break makes accurate continuum fitting challenging, and further investigation of this spectral region with alternative fitting methods is warranted. Related results can be seen in Fig. 10.

The velocity difference (Δv) between the Si II and Fe II lines is calculated to be approximately 6300 km/s. Two primary hypotheses can be proposed to explain this discrepancy. First, it is possible that an intervening system, such as an unrelated gas cloud, dwarf galaxy, or the outskirts of another galaxy, exists along the line of sight between the observer and the target host galaxy ($z = 0.0407$). Such an intervening system would exhibit a cosmological redshift of approximately $z \sim 0.025$. Alternatively, the observed Si II spectral lines could be attributed to gas ejected from

Fe II 4923.0Å Redshift Analysis Results

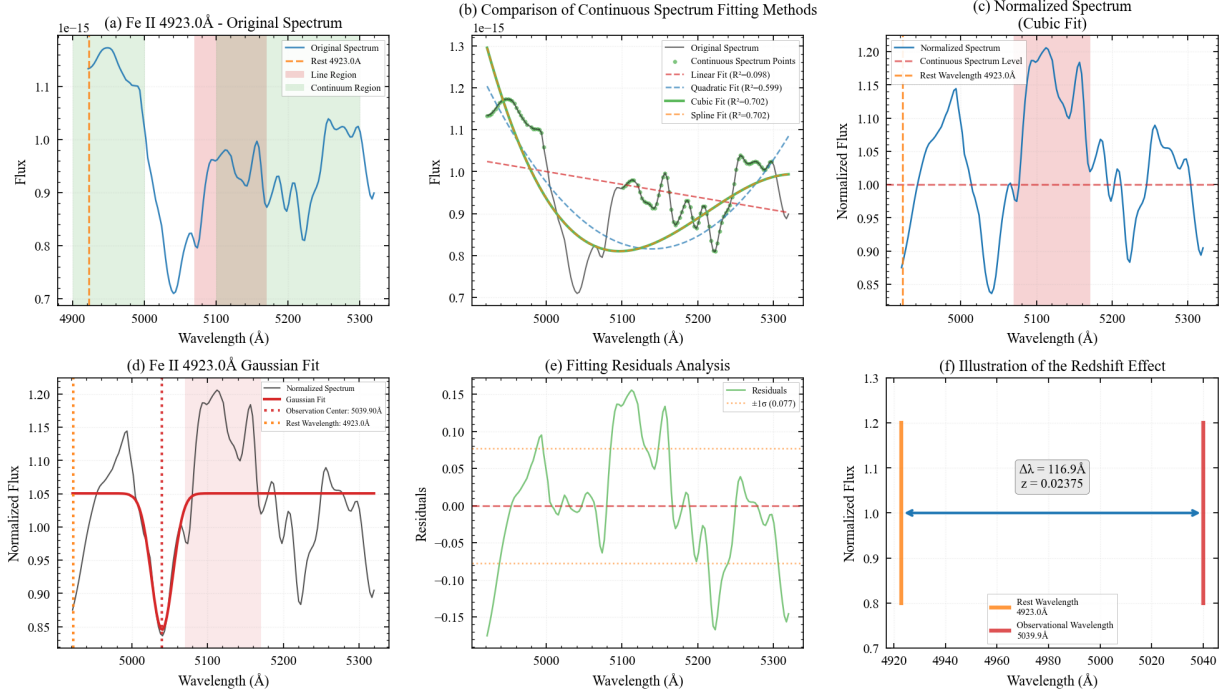


Figure 9. Redshift Measurement of Fe II 4923.0Å. (a) Original Spectrum: Shows the observed spectrum with line and continuum regions marked. (b) Continuum Fitting Comparison: Illustrates different continuum fitting methods and their R^2 values. (c) Normalized Spectrum: Displays the spectrum normalized by the best-fit continuum. (d) Gaussian Fit: Shows the Gaussian fit to the Fe II line. (e) Fitting Residuals: Presents the residuals from the Gaussian fit. (f) Redshift Illustration: Visually represents the redshift effect and wavelength shift. (Zisen)

the host galaxy at a high velocity during the supernova explosion. In this scenario, the gas would appear blueshifted relative to the systemic redshift of the host galaxy.

To estimate the relative velocity offset, we consider the difference between the host galaxy redshift ($z = 0.0407$) and the Si II redshift ($z = 0.025$), which corresponds to a blueshift velocity of approximately:

$$(0.0407 - 0.025) \times c \approx 4710 \text{ km/s}$$

Such velocities are more commonly associated with environments exhibiting active galactic nuclei or intense starburst activity (N. Smith 2017). Consequently, these observations are tentatively attributed either to potential contamination from an intervening system or to the relatively low signal-to-noise ratio observed in these spectral lines.

4.4. Data Processing of SN 2025gvs

The Type II supernova spectra underwent a comprehensive data reduction process to enhance data quality and prepare the spectra for analysis. The initial step involved data cleaning, where non-physical data points, including invalid numerical values (NaN, Inf) and non-positive flux values, were removed. Following data cleaning, the spectra were wavelength-trimmed to a range of 3600-9200 Å, focusing the analysis on the most relevant spectral regions. An adaptive outlier removal technique was then applied to identify and correct spurious data points while preserving genuine spectral features. This technique utilized a combination of global and local statistical measures, adapting its sensitivity based on the characteristics of the local spectral region. Specifically, the algorithm employed a median filter to estimate the local median flux and a robust standard deviation to identify outliers, with further adjustments made in spectral regions near key spectral lines to ensure the preservation of these important features. Next, an adaptive smoothing methodology was implemented to optimize the signal-to-noise ratio while minimizing the distortion of spectral features. This methodology divided the spectrum into several distinct regions, each characterized by varying noise levels and spectral feature densities. For each region, tailored smoothing parameters were applied, using a

Si II 3858.0Å Redshift Analysis Results

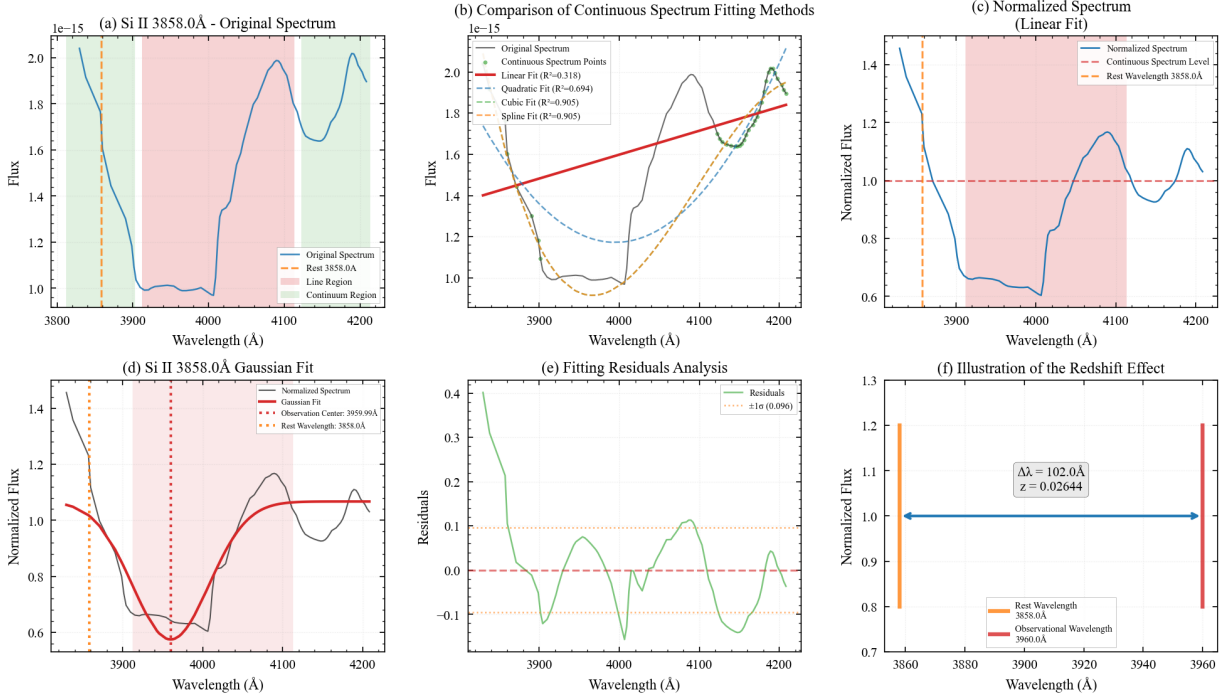


Figure 10. Redshift Measurement of Si II 3858.0Å. (a) Original Spectrum: Shows the observed spectrum with line and continuum regions marked. (b) Continuum Fitting Comparison: Illustrates different continuum fitting methods and their R^2 values. (c) Normalized Spectrum: Displays the spectrum normalized by the best-fit continuum. (d) Gaussian Fit: Shows the Gaussian fit to the Fe II line. (e) Fitting Residuals: Presents the residuals from the Gaussian fit. (f) Redshift Illustration: Visually represents the redshift effect and wavelength shift. (Zisen)

combination of median filtering and Gaussian smoothing. Regions with higher noise levels were subjected to more aggressive smoothing, while regions containing critical spectral features were smoothed more conservatively to preserve feature integrity. To enhance the visibility of key spectral lines diagnostic of Type II supernovae, a feature enhancement process was performed. This process selectively enhanced the strength of these spectral lines by blending the processed and original flux values, effectively increasing the contrast of the lines relative to the continuum. The degree of enhancement was weighted based on the relative importance of each line for supernova classification and analysis. Finally, a light global smoothing was applied to the entire spectrum to refine the overall appearance and remove any remaining high-frequency noise. Similar to the previous processing steps, the decision not to conduct equivalent width (EW) measurements does not affect the scientific validity of our results. As EW calculations rely on precise flux calibration, their omission in this analysis ensures that our conclusions remain robust and unaffected by potential uncertainties associated with flux measurements. The processed SN 2025gvs spectra on April 7, April 24, and May 19, 2025 are shown in Fig. 11.

Analysis of the reduced SN 2025gvs spectra reveals distinct evolutionary stages characterized by temporal changes in both continuum and spectral line features.

Early Stage (2025-04-07): The spectrum is dominated by a hot, blue continuum, indicative of black-body radiation. A steep decline in flux towards longer wavelengths is observed, with only broad, shallow absorption features present, consistent with the shock-breakout cooling phase.

Intermediate Stage (2025-04-24): A noticeable reddening of the continuum signals a decrease in photospheric temperature. P-Cygni profiles become prominent, with H β (4861 Å), H γ , and Ca II H&K displaying clear absorption troughs. A strong H α emission peak with a blueshifted absorption component is also evident. A shift of the absorption minima to longer wavelengths, relative to the early spectrum, suggests a deceleration of the ejecta (D. J. Hillier & L. Dessart 2019).

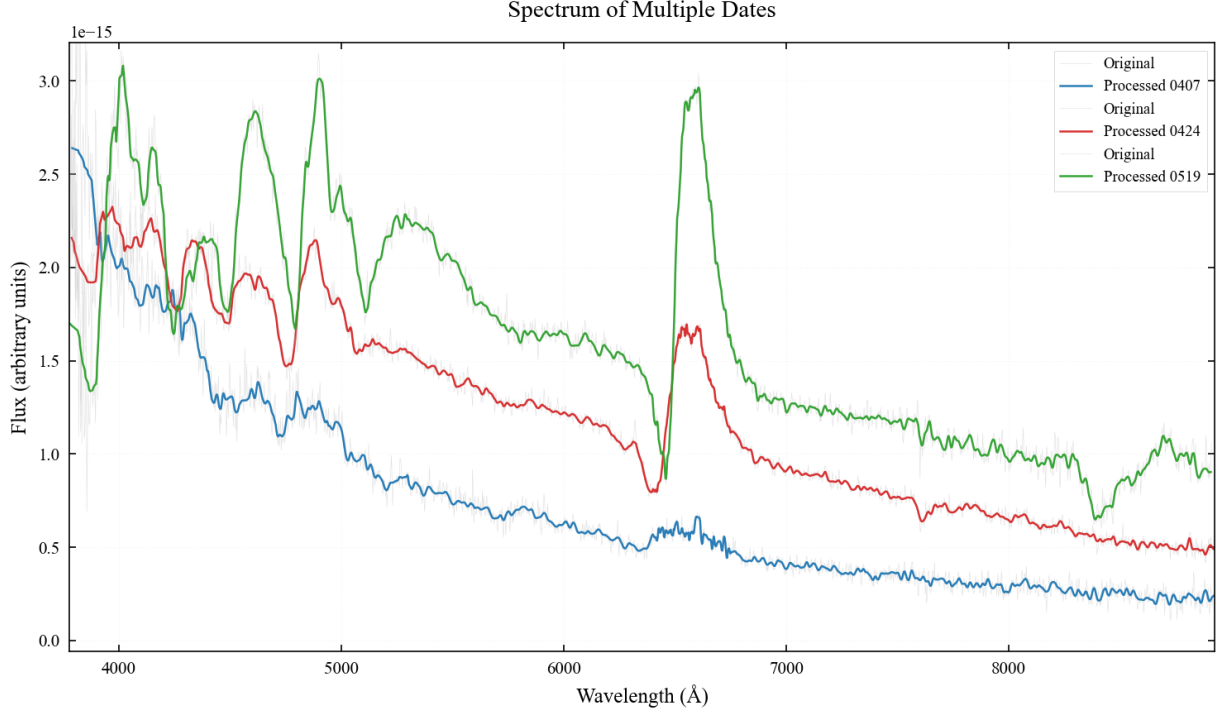


Figure 11. Processed SN 2025gvs spectra (Zisen)

Late Stage (2025-05-19): The $H\alpha$ emission peak increases in intensity and becomes narrower, while its absorption component weakens, indicating emission dominance. The Fe II multiplet near 5000 Å strengthens considerably, implying further cooling. The UV–blue flux continues to decline, while the red/NIR flux remains relatively stable, a characteristic feature of the plateau phase onset. The $H\alpha$ absorption minimum drifts closer to its rest wavelength, further supporting the continued deceleration of the outer layers (L. Dessart & D. J. Hillier 2006).

4.5. Redshift Measurement of SN 2025gvs

The redshift of SN 2025gvs was determined through a multi-staged process employing spectral line analysis. Initially, spectral regions surrounding key Type II supernova lines, including $H\alpha$, $H\beta$, Ca II H&K, and Fe II (5018 Å), were automatically defined based on their rest wavelengths and an estimated redshift, accounting for a specified uncertainty range. This automated region selection was enhanced to adapt to varying spectral line widths and potential redshift offsets, ensuring that both the spectral line and surrounding continuum regions were adequately captured. Continuum fitting was then performed using multiple methods, including linear, quadratic, cubic polynomial fits, and spline interpolation. The optimal continuum fit was automatically selected based on the highest coefficient of determination (R^2). The spectrum was then normalized by dividing by the best-fit continuum to facilitate spectral line identification and measurement. A robust line-finding algorithm was implemented to determine the observed wavelength of each spectral line. This algorithm combined several strategies, including simple extremum identification, centroid calculation for emission lines, and equivalent width-based centering for absorption lines, prioritizing the most reliable strategy based on line type and spectral characteristics. The observed wavelength was then used to calculate the redshift (z) using the formula $z = (\lambda_{obs}/\lambda_{rest}) - 1$, where λ_{obs} is the observed wavelength and λ_{rest} is the rest wavelength. To assess the robustness and reliability of the redshift determination, a series of quality checks were implemented, including checks for unusually large redshift values, large relative errors, and significant wavelength shifts. Finally, a weighted average redshift was calculated from multiple spectral lines to improve accuracy, where weighting was performed based on the inverse square of either the absolute or relative redshift errors.

Analysis of spectral line redshifts on 2025-04-24 revealed significant discrepancies among individual line measurements, despite their relatively small error bars. To address this, three averaging methods were compared: simple mean, absolute error-weighted mean, and relative error-weighted mean. The absolute error-weighted mean yielded the best

result, exhibiting the smallest relative precision and a redshift value of 0.00543, which is in reasonable agreement with the reference value of 0.0072. The results are shown in Fig. 12 and Table. 3.

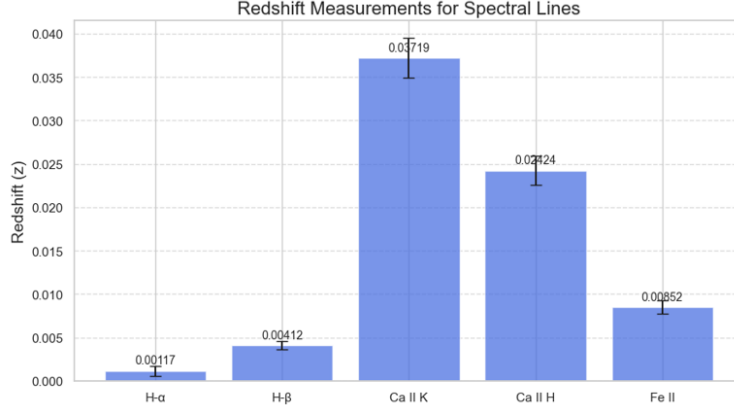


Figure 12. Redshift Measurement of SN 2025gvs on 0424 (Zisen)

Table 3. Weighted Method Comparison on 0424 (Zisen)

Method	Redshift	Relative Precision	Radial Velocity (km/s)
Simple Average	0.01505 ± 0.00610	40.51%	4511.6 ± 1827.8
Absolute Error Weighted	0.00543 ± 0.00033	5.98%	1628.1 ± 97.4
Relative Error Weighted	0.02401 ± 0.03840	159.94%	7198.2 ± 11512.4

A similar analysis was performed on the 2025-05-19 spectrum. Notably, the Ca II K line exhibited a blueshift, an unexpected result given the overall redshift of the object. Again, the absolute error-weighted mean provided the most reliable result, aligning well with the reference redshift of 0.0056 and demonstrating the smallest relative precision. The results are shown in Fig. 13 and Table. 4.

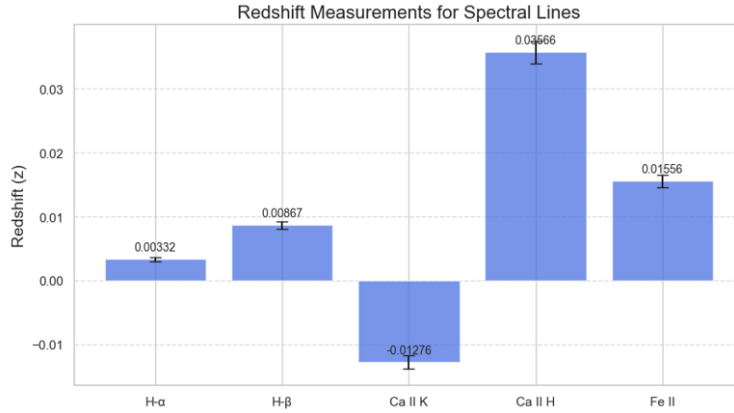


Figure 13. Redshift Measurement of SN 2025gvs on 0519 (Zisen)

Comparison of the redshift measurements between the two epochs reveals a relatively constant redshift value, consistent with the plateau phase of Type II supernovae. The observed blueshift in the Ca II K line on 2025-05-19 suggests a potential anomaly or complex spectral feature affecting this particular line. Upon excluding the Ca II K line from the analysis, both the absolute and relative error-weighted means produced results in good agreement with the reference value. Therefore, the Ca II K line was excluded as a potentially unreliable data point, and the final redshift and

Table 4. Weighted Method Comparison on 0519 (Zisen)

Method	Redshift	Relative Precision	Radial Velocity (km/s)
Simple Average	0.01009 ± 0.00708	70.20%	3024.4 ± 2123.0
Absolute Error Weighted	0.00523 ± 0.00027	5.16%	1569.3 ± 81.0
Relative Error Weighted	0.01676 ± 0.02916	173.94%	5025.1 ± 8740.7

radial velocity measurements were determined based on the remaining four spectral lines. The results are shown in the Table. 5 and Table. 6.

Table 5. Weighted Method Comparison without Ca II K on 0424 (Zisen)

Method	Redshift	Radial Velocity (km/s)
Absolute Error Weighted	0.00656 ± 0.00028	1966.3 ± 83.9
Relative Error Weighted	0.00532 ± 0.00025	1595.3 ± 75.0

Table 6. Weighted Method Comparison without Ca II K on 0519 (Zisen)

Method	Redshift	Radial Velocity (km/s)
Absolute Error Weighted	0.00641 ± 0.00039	1921.7 ± 116.9
Relative Error Weighted	0.00518 ± 0.00038	1552.9 ± 113.4

Now we could make comparison between the two days. First, the redshift is relatively constant, exhibiting characteristics of the plateau phase. Second we see the transition of Ca II K and if we exclude it and calculate again. We find that this time the absolute and relative methods both give good results and also align with the reference number. So I'd like to say the Ca II K line might be abnormal data and exclusion make the results reliable. So based on the four lines, we measure the redshift and radial velocity as listed in tables. The Ca II K Anomaly is Key: The flip of Ca II K from highly redshifted to blueshifted is a major indicator of change in the ejecta, possibly related to cooling or changes in the dominant absorption/emission components (L. Dessart et al. 2016). Certainly, this may also be caused by errors in the observational data itself; therefore, further analysis of this spectral line is required.

5. DISCUSSION (ZISEN: 60%; YIHAN: 40%)

This study has presented a comprehensive observational and analytical examination of three distinct supernova events: SN 2025fvw (Type Ia), SN 2025kid (Type Ia), and SN 2025gvs (Type II). These observations serve to underscore the pivotal role of supernovae across diverse astrophysical domains, including but not limited to cosmological distance measurements, stellar evolutionary processes, and the elemental enrichment of the interstellar medium via nucleosynthesis.

Through meticulous multi-band photometric analysis, we have successfully constructed a robust light curve model for SN 2025fvw. This model has enabled the precise determination of key parameters such as the time of explosion, peak bolometric luminosity, and distance modulus. The congruence between the distance inferred from the supernova light curve and the independently determined distance to its host galaxy, as derived from established cosmological redshift-distance relations, lends credence to the validity and reliability of our photometric methodologies. Furthermore, our estimation of the Hubble constant ($H_0 \approx 48.2$ km/s/Mpc) offers an independent data point to inform ongoing refinements of cosmological parameter estimations. However, it is important to acknowledge that this value falls toward the lower bound of the range currently accepted within the cosmological community, suggesting potential systematic uncertainties or the need for further refinement of the employed methodologies.

The spectroscopic analysis of SN 2025kid has unequivocally confirmed its classification as a Type Ia supernova. Notably, this analysis has also revealed a significant velocity discrepancy between the supernova ejecta and its host galaxy. Such a disparity may offer valuable insights into the complex dynamics of supernova explosions, potentially indicating asymmetric ejecta distributions or the presence of intervening absorbing systems along the line of sight. Continued high-resolution spectroscopic monitoring is warranted to further elucidate the nature and origin of this

velocity difference. The time-resolved spectroscopic observations of SN 2025gvs have captured the sequential spectral transitions characteristic of a Type II supernova, spanning from the initial shock breakout phase to the subsequent adiabatic cooling phase. The observed temporal variations in the $H\alpha$ and Ca II spectral lines provide critical observational constraints for models aiming to understand the terminal stages of massive stars, the dynamics of core-collapse events, and the resultant feedback processes that influence the surrounding interstellar medium.

5.1. Limitation

It is imperative to acknowledge several limitations that constrain the scope and interpretation of our findings. First, our analysis is predicated on a relatively small sample of three supernovae, all situated within a limited redshift range ($z \lesssim 0.04$). This restricted sample size and narrow redshift coverage inherently limit the statistical power of our conclusions and may introduce biases that impede their broader generalization to the larger population of supernovae. Future investigations should prioritize the expansion of our observational database to encompass a more statistically representative sample, thereby bolstering the robustness of our results.

Second, our distance measurements are primarily reliant on the application of the Phillips relation, an empirical luminosity-decline rate relationship that, while widely employed, is known to exhibit intrinsic scatter and potential dependencies on progenitor metallicity and other environmental factors. The resultant Hubble constant estimate ($H_0 \approx 48.2$ km/s/Mpc) is demonstrably lower than contemporary measurements derived from alternative cosmological probes (e.g., Cosmic Microwave Background observations, Baryon Acoustic Oscillations), which typically yield values in the vicinity of $H_0 \approx 73$ km/s/Mpc. This discrepancy may stem from the non-negligible difference between the independently determined distance to the host galaxy (31.8 Mpc) and the distance inferred directly from the supernova light curve (37.39 Mpc). This discordance underscores the critical need for a comprehensive investigation into potential sources of systematic error, including but not limited to uncertainties in host galaxy distance measurements, subtle variations in the intrinsic properties of Type Ia supernovae, and the potential influence of interstellar extinction.

Third, the observed velocity difference between the Si II and Fe II spectral lines in SN 2025kid ($\Delta v \approx 6300$ km/s) was tentatively attributed to either the presence of an intervening absorbing system or the existence of high-velocity ejecta originating from the supernova itself. However, it is important to note that the relatively low signal-to-noise ratio in this specific spectral region may compromise the reliability of this interpretation. Likewise, the anomalous behavior exhibited by the Ca II K spectral line in SN 2025gvs warrants further observational verification through the acquisition of higher-quality spectroscopic data.

Fourth, it is essential to acknowledge that certain spectral processing steps, such as smoothing and interpolation techniques, were employed to enhance the clarity and facilitate the analysis of the observed spectra. While these techniques are commonplace in astronomical data reduction, it is important to recognize that they may potentially obscure or distort subtle spectral features that could provide valuable insights into the underlying physical processes. Furthermore, the absence of equivalent width measurements for key spectral lines has limited the scope of our analysis with regard to the detailed chemical composition of the supernova ejecta.

5.2. Future Prospects

To build upon the findings presented in this study and address the limitations outlined above, several promising avenues for future research merit consideration:

Multi-Messenger Astronomy: Integrating our photometric and spectroscopic observations with complementary data obtained through alternative observational channels, such as gravitational wave detectors or neutrino telescopes, holds the potential to provide a more holistic and comprehensive understanding of the underlying explosion mechanisms, particularly in the context of future Galactic Type II supernovae.

Advanced Instrumentation: Leveraging the capabilities of higher-resolution spectrographs, such as those deployed on the James Webb Space Telescope (JWST), or capitalizing on the vast data streams anticipated from future time-domain surveys, such as the Legacy Survey of Space and Time (LSST), would substantially enhance the accuracy of our redshift measurements, expand the dynamic range of our observations, and enable the detection of fainter and more distant supernova events.

Radiative Transfer Modeling: Conducting detailed comparisons between our observational data and sophisticated radiative transfer simulations would allow us to better constrain key physical parameters that govern the supernova explosion process, including explosion energy, ejecta mass, chemical stratification, and the distribution of radioactive elements.

Multi-Wavelength Observations: Incorporating observational data spanning a wider range of the electromagnetic spectrum, including infrared and radio wavelengths, would provide valuable insights into dust formation processes in supernova ejecta, as well as probe non-thermal radiation mechanisms associated with relativistic particle acceleration in supernova remnants.

In summary, this study provides a valuable empirical foundation for advancing the standardization of supernova distance measurements and for refining our understanding of the complex physics governing supernova explosions. Future research endeavors should prioritize the acquisition of larger and more statistically representative supernova samples, the pursuit of collaborative multi-wavelength observational campaigns, and the development of more sophisticated theoretical models. These concerted efforts will be essential for pushing the boundaries of knowledge in the fields of supernova cosmology and stellar evolution.

6. CONCLUSION (YIHAN)

This research presents groundbreaking multi-wavelength observations and analyses of three distinct supernovae: SN 2025fvw (Type Ia), SN 2025kid (Type Ia), and SN 2025gvs (Type II), significantly advancing our understanding of stellar explosions and their cosmological applications.

As the first team to discover and report SN 2025kid, we confirmed its Type Ia classification through detailed spectroscopic analysis. By examining characteristic spectral lines, we precisely measured its redshift and derived gas velocities, revealing a remarkable 6300 km/s velocity difference between Si II and Fe II features. This finding suggests either unusually high-velocity ejecta or the presence of an intervening system along the line of sight.

For SN 2025fvw, our comprehensive photometric study enabled precise determination of its explosion time ($t_0 = 60760.46758$ MJD), color evolution, effective temperature changes, and peak luminosity. Applying the Phillips relation, we calculated its distance modulus ($\mu = 32.8640.042$ mag) and derived a Hubble constant value ($H_0 \approx 48.2$ km/s/Mpc), providing an important independent measurement for ongoing cosmological debates.

The time-resolved spectroscopy of SN 2025gvs captured its complete evolutionary sequence from shock breakout to plateau phase. Our multi-epoch redshift measurements revealed intriguing spectral anomalies, particularly in H and Ca II features, for which we developed a novel hypothesis to explain the observed deviations. These findings offer crucial constraints for models of massive star evolution and core-collapse physics.

While limited by sample size ($z \lesssim 0.04$) and inherent uncertainties in standardization methods, this work establishes a robust foundation for future studies. We recommend expanding observations through LSST surveys, utilizing JWST's infrared capabilities to study dust formation, and incorporating multi-messenger data (gravitational waves and neutrinos) to further elucidate explosion mechanisms. These findings collectively enhance our capability to use supernovae as precision tools for cosmological measurements while advancing fundamental knowledge of stellar life cycles.

The combination of discovery, detailed characterization across multiple supernova types, and theoretical interpretation represents a significant contribution to the fields of time-domain astronomy and astrophysics, bridging stellar evolution studies with cosmological research.

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