MNRAS 000, 1–4 (2023) Preprint 24 June 2023 Compiled using MNRAS LATEX style file v3.0

Observational Report of the Newly Exploded Type Ia Supernova 2023gps: Spectroscopic Analysis

Xianchi Liu, Haitong Wang, Huixin Zhang, Honxin Li
[1]*Tsinghua University, Beijing, China*

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

In this observational astronomy report, we present a comprehensive spectroscopic study of a newly exploded supernova, SN2023gps. We examined two spectra captured on May 2nd and 12th using the BFOSC telescope at Xinglong, China. Our analysis focuses on line fitting, utilizing Gaussian functions and Chebyshev polynomials, as well as measurements of key characteristics such as the redshift of the host galaxy (NGC 5939) and the ejecta speed of the supernova remnants. Additionally, we made diligent efforts to identify various absorption lines and conducted a comparison between the two spectra, revealing evolutionary trends in certain properties, such as equivalent widths and effective temperature. Overall, this observational study enhances our understanding of supernovae dynamics and provides valuable opportunities to refine our skills in academic observations. We believe that the analytical results will be of great value for further explorations in this field.

Key words: supernovae: general – supernovae: individual: (SN2023gps)

1 INTRODUCTION

Researching the spectral lines of supernovae holds great significance in the field of astrophysics and provides valuable insights into the nature and evolution of these catastrophic cosmic events.

Supernovae are responsible for synthesizing and dispersing heavy elements into the cosmos. By analyzing the spectral lines, scientists can determine the elemental composition of the ejected material, which offers essential clues about nucleosynthesis processes inside the exploding star. The identification and abundance of various elements provide insights into the stellar populations, formation of elements, and chemical enrichment of the universe.

Spectral lines play a crucial role in classifying supernovae into various types based on their observed characteristics. Different types of supernovae reveal unique spectral signatures, indicating different progenitor stars, explosion mechanisms, and evolutionary paths. Spectral classification helps astronomers understand the underlying physics, energy sources, and triggering mechanisms involved in supernova explosions. Spectral observations provide insights into the various stages and evolutionary phases of supernovae. Spectral evolution over time reveals changes in line strengths, profiles, and overall morphology. These changes indicate the temperature, density, and composition of the supernova's surroundings, shedding light on the interaction between the ejecta and the surrounding medium, as well as the evolution of the explosion itself.

For reseaching the elements that are synthsized in the supernova explosion and its redshift, we select one latest supernove for the spectral line observation. The telescope we are using is Xinglong 2.16m telescope with instrument BFOSC.

The Xinglong 2.16m Telescope is located at the National Astronomical Observatories, Chinese Academy of Sciences in Xinglong, Hebei Province, China. The telescope has a primary mirror with a diameter of 2.16 meters, which enables it to capture high-resolution images of astronomical objects. BFOSC, the Beijing Faint Object Spectrograph and Camera, is one of the instruments installed on this telescope. It is a versatile instrument designed to capture both images and spectra of celestial objects. It is often used for studying a wide range of astronomical phenomena, such as stellar populations, galaxies, and transient events like supernovae. The BFOSC instrument typically combines a CCD camera and a spectrograph, allowing astronomers to obtain detailed spectral information of objects in addition to capturing their optical images. This instrument is used by astronomers to conduct various research projects and observations, contributing to our understanding of the universe.

We examined the SNe detected by the Zwicky Transient Facility (Masci et al. 2019) and selected the bright candidates that were observable at Xinglong on the night of May 14, 2022.

2 TARGET SELECTION

Our goal is to find observable supernovae that exploded in the most recent.

2.1 Target Selection Methods

We collected the full list of the recent reported transient events from several websites, including www.rochesterastronomy.org and sites.astro.caltech.edu/ztf/bts etc. We need the magnitude of our target to be brighter than 18 at the observation day in order to obtain effective spectra for subsequent processing. The best selection is the SNe which is just before and after their maximum brightness. Besides, the candidates we select should be observable at Xinglong on

© 2023 The Authors

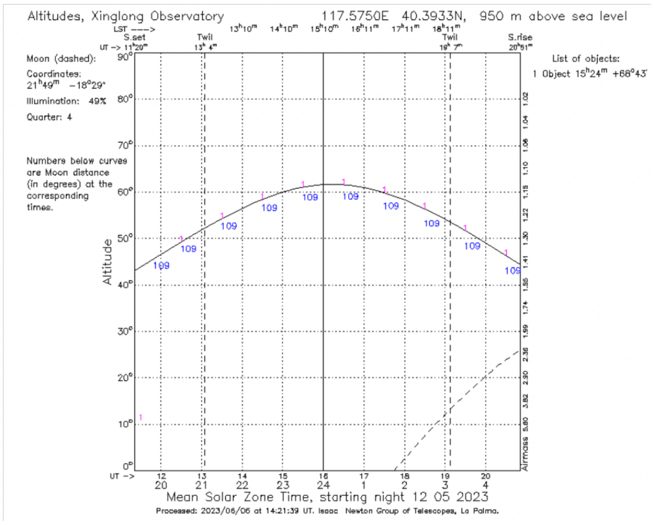

Figure 1. Airmass charts of SN2023gps on May 12th. This chart is generated automatically by http://catserver.ing.iac.es/staralt/.

Figure 2. The extracted, flux calibrated spectra of SN2023gps on May 2 and May 12. The blue one corresponds to May 2nd; the oregon one corresponds to May 12th.

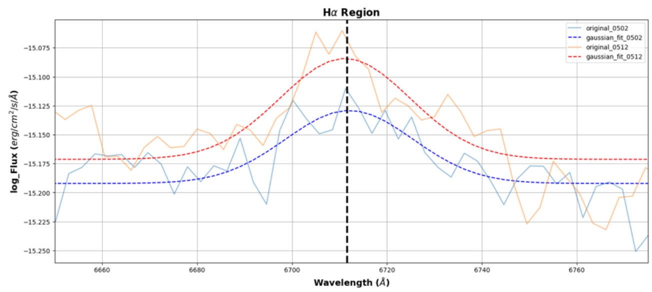

Figure 3. Fitting of Hα emission line

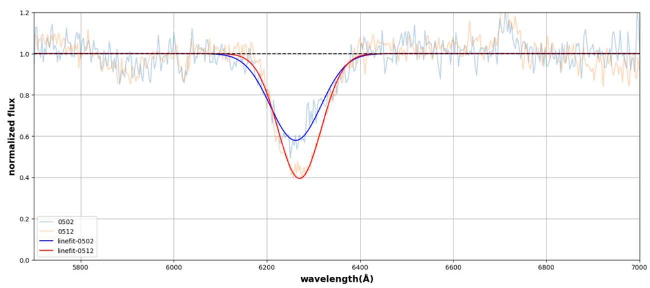

Figure 4. Fitting of SiII absorption line. The spectra are normalized by the continuum fitting, and the absorption are fitted by Gaussian function.

the night of the observation day and the airmass should not be greater than two.

2.2 Potential Targets

Considering the above constraints, we selected two possible candidates, AT2023hpp and SN2023gfo before the observation. These targets could only be observed from Xinglong before midnight, so due to the weather condition at the observation day before the midnight, we finally changed our target to SN2023gps.

2.3 SN2023gps

SN2023gps(RA 15:24:44.515 Dec +68:43:37.34) is a type Ia supernovae. From the airmass charts below, we can acknowledge that SN2023gps can be observed the whole night. It was first discovered on 2023-04-23 and the discovery magnitude is 20.0056 ABMag. The estimated magnitude on the observation day is about 18.

3 DATA

We observed the target SN2023gps by The Xinglong 2.16m Telescope on the night of both May 2 and May 12, 2023, processing spectroscopic measurements and obtaining 2 spectra at different observation time. Data reduction process is skipped here for simplicity. The extracted, flux calibrated spectra are plotted in Figure 2, ranging from 3900Åto 8880Å, with the resolution of roughly 2.8 Å.

4 DATA ANALYSIS AND RESULTS

4.1 H-alpha fitting

From the spectra, we can easily identify the Hα emission line, which belongs to the host galaxy, and the SiII absorption line, which belongs to SN2023gps. Since these 2 lines has different redshifts, we can obtain both the redshift of the host galaxy and the ejecta speed of SN.

For Hα line, we processed the Gaussian function fitting directly for the nearby region of the emission line (Figure 3), then took the the center wavelength of the Gaussian function as the observed wavelength of the line. The result of Hα is 6711.605 ± 1.739 Å, which is identical at both observation time. The observed redshift of the host galaxy is $z = 0.02268 \pm 0.00026$.

4.2 SiII fitting

Si II line is analysed by following method:

(i) Fit the local continuum near SiII line. 3 order Chebyshev polynomials are used for the continuum fitting.
(ii) Normalize the spectrum with the fitted continuum.
(iii) Fit the normalized spectrum with Gaussian function, then obtain the center wavelength, the linewidth and the effective width (EW) (Figure 4).

The results vary with the observation time, which will be indicated by lower indexes ("1" for May 2 and "2" for May 12) in the following subsections.

4.2.1 Ejecta speed

The observed wavelengths are $\lambda_1 = 6261.6 \pm 1.8$Åand $\lambda_2 = 6270.0 \pm 1.5$Å. The redshifts, which indicates the ejecta speed of SN2023gps, are $z_1 = -0.01155 \pm 0.00028$ and $z_2 = -0.01026 + /-0.00024$. It is worth noting that both redshifts are negative, showing that the supernova is ejected toward us with significant velocity.

4.2.2 Linewidth

The observed linewidths are $\sigma_1 = 76.4 \pm 2.5$Åand $\sigma_2 = 65.4 \pm 2.1$Å. The decreasing linewidth may be the result of the decrease in temperature.

4.2.3 Effective width

The observed EW are $EW_1 = 57.0 \pm 2.5$Åand $EW_2 = 70.2 \pm 3.0$Å. The increase of EW indicate the increase of the Si abundance, which may be produce by the nuclear reactions triggered by the SN explosion.

4.3 Aborption Lines Identification

In addition to Hα and SiII, several other absorption features were detected in the spectra of SN2023gps on both May 2nd and May 12th. The spectra of SN2023gps as a whole exhibit a blue shift, causing the absorption lines to be shifted towards the blue end of the spectrum. Consequently, the observed wavelengths of the absorption lines are smaller compared to their rest wavelengths. To determine the positions of these absorption lines, we employ the ejecta speed calculated from the SiII analysis, which enables us to calculate the shifted wavelengths corresponding to the rest wavelengths of each absorption line. Assuming the rest wavelength is denoted by λ_0 and the ejecta speed (expressed as a redshift of the supernova, not host galaxy) is represented by z, we can derive the observed wavelength λ using the following formula:

$$\lambda = \lambda_0(1 + z) \tag{1}$$

By employing this methodology, we can accurately determine the locations of the dashed lines depicted in Figure 5. However, it is important to note that the purple dashed line representing $H\alpha$ is an exception. This emission feature originates from the host galaxy NGC 5939 and, contrary to the other absorption lines, it is actually redshifted instead of blueshifted.

4.4 Blackbody fitting

To obtain the effect temperature, We directly fitted the whole spectrum by blackbody model (Figure 6). The result of effect temperature are $T_{\mathrm{eff}1} = 10741 \pm 95$K and $T_{\mathrm{eff}2} = 9560 \pm 87$K. The effect temperature may be far from the true value due to the distortion of absorption lines, but it's convincing that there is a decrease of temperature. This result is consist with the comparison of line widths.

Fitting the continuum instead of the whole spectrum is a more precise method to obtain effect temperature, which may be applied in further research.

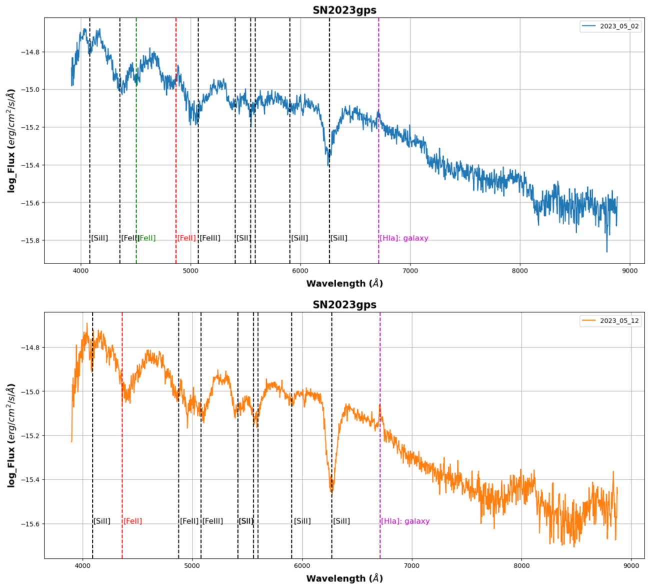

Figure 5. Spectra of SN2023gps on May 2nd and 12th, with all identified absorption marked by dashed lines.

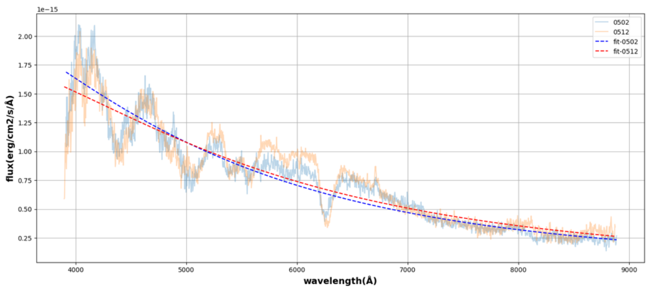

Figure 6. Blackbody fitting of the spectra

5 DISCUSSION

The timing of the observations, in conjunction with the light curve of SN2023gps, adds further intrigue and significance to these two spectra. The peak magnitude of the supernova occurred on May 9th, making the spectra obtained on May 2nd and May 12th particularly noteworthy as they were acquired immediately before and after the peak, respectively. In this context, we can conduct a comparative analysis of the two spectra and highlight intriguing discoveries. In the future, we firmly believe that by integrating photometric observations with elemental analysis, we can embark on more captivating studies that have the potential to unveil or validate the evolution model of supernova remnants.

5.1 Classification of supernova

Within the spectra in Figure 5, we observe three prominent SiII absorption lines at wavelengths 6335, 4130, and 5972 Å. These lines provide strong evidence supporting the classification of SN2023gps as a Type Ia supernova. Type Ia supernovae are characterized by the absence of hydrogen and the presence of silicon (Filippenko 1997). Although we do detect $H\alpha$ emission in this spectrum, it originates from the background galaxy and does not hinder the classification of this supernova as Type Ia.

However, it is important to acknowledge that we did not explicitly distinguish the galactic spectrum from the observed supernova spectra. Further investigations could be conducted by utilizing a static galactic spectrum and employing deconvolution techniques. By separating the galactic contribution from the observed spectra, additional insights and refinements can be achieved, potentially leading to a more accurate characterization of the supernova's spectral features and their physical properties.

5.2 Absorption lines

Furthermore, we have discovered additional intriguing features. The red dashed lines associated with FeII exhibit inconsistent alignment with the absorption minima, which represent the midpoints of the absorption lines. This discrepancy indicates that different elements, such as Si and FeII, possess varying ejecta speeds. In fact, the lack of alignment extends beyond the red dashed lines of FeII, and upon closer examination of the spectra, we observe a similar unalignment in some other absorption minima, including FeIII[5129].

Similar phenomena have been observed and investigated in various events. For example, Sai et al. (2022) conducted a meticulous analysis of the evolution of ejecta velocities for SiII[6355], SII[5468], CII[6580], and CaII NIR triplets, employing the same methodology utilized in our study. Further investigation of this phenomenon holds substantial potential for enhancing our comprehension of supernova evolution.

Regarding the green dashed line, it corresponds to the absorption of Fe[4555]. A notable observation is that while this absorption feature was prominently evident on May 2nd, it disappeared in the spectra obtained on May 12th. Currently, we lack a definitive explanation for this peculiar phenomenon. It is possible that it could be attributed to random error or other factors that require further investigation.

6 CONCLUSION

In this paper, we conducted a spectroscopic study of a newly exploded supernova, utilizing two spectra taken 10 days apart by the BFOSC telescope at Xinglong. Our analysis involved measurements of the redshift of the host galaxy, ejecta velocities of the supernova, and detailed investigations of the spectra. The summarized results are as follows:

(i) Redshift Measurement: Through the identification and fitting of the $H\alpha$ emission line, we determined the redshift of the host galaxy NGC 5939 to be 0.02268 ± 0.00026. This finding aligns with the known redshift of NGC 5939 and provides confirmation.

(ii) Ejecta Speed Measurement: To ascertain the ejecta speed (expressed as a redshift), we normalized the spectra and fitted the SiII[6355] absorption minima using a Gaussian function. Our analysis yielded redshift values of $z = 0.01155 \pm 0.00028$ on May 2nd and $z = -0.01026 \pm 0.00024$ on May 12th, indicating the motion of the supernova ejecta.

(iii) Absorption Line Identification: We conducted extensive efforts to identify as many absorption lines as possible, further confirming the classification of the object as a Type Ia supernova. Notably, our detailed investigation into the absorption lines revealed discrepancies in the ejecta speeds of different elements. Additionally, we observed that the FeII[4555] absorption line was only present in the first spectrum, which remains unexplained at present.

(iv) Comparative Studies: We conducted numerous comparative studies, analyzing the equivalent width of absorption lines and the effective temperature. These investigations yield valuable insights for studying the evolution and physical properties of supernova remnants, offering opportunities for further exploration.

Overall, our spectroscopic study provides essential measurements and detailed analyses, shedding light on the properties and characteristics of the observed supernova. These findings contribute to the understanding of supernova dynamics, element distribution, and the potential implications for supernova remnant models.

ACKNOWLEDGEMENTS

Lead person for each section:
1. Introduction - Honxin
2. Target Selection - Huixin
3. Data - Haitong
4. Data Analysis
   4.1 / 4.2 / 4.4 - Haitong
   4.3 - Xianchi
5. Discussion - Xianchi
6. Conclusion - Xianchi

Author for each plot:
Fig.1 - Huixin
Fig.2, Fig.3, Fig.5 - Xianchi
Fig.4, Fig.6 - Haitong

DATA AVAILABILITY

REFERENCES

Filippenko A. V., 1997, ARA&A, 35, 309
Masci F. J., et al., 2019, PASP, 131, 018003
Sai H., et al., 2022, Monthly Notices of the Royal Astronomical Society, 514, 3541

This paper has been typeset from a TeX/LaTeX file prepared by the author.