Scientific Justification (all)

Type Ia supernovae (SNe Ia) have been reliable luminosity distance measures, and important cosmological probes for decades. The discovery of dark energy can be attributed to SNe Ia luminosity distance measurements and many next generation dark energy experiments such as the *Nancy Grace Roman Space Telescope* focus on high-z SNe Ia to further our understanding of this new frontier. These experiments hinge on the assumption that SNe Ia luminosities remain constant with redshift, which is an open question. The goal of this program is to find out whether this assumption holds true for the highest redshift SN Ia discovered till date: SN 2023adsy.

SN 2023adsy was discovered in *James Webb Space Telescope* NIRCam imaging from the *JWST* Advanced Deep Extragalactic Survey (JADES) program (3; 2, hereafter, P24). This SN, found at $z = 2.9$, was highly reddened compared to the general SNe Ia population. It is yet unclear if the high reddening of this object is due to a redshift evolving property of SN Ia or whether this is an anomaly. Obtaining a host spectra of SN 2023adsy provides context about the environment of the SN allowing us to begin understanding the dust vs. intrinsic color relation for high-z Ias. Additionally, host spectra can also shed light on SN-host relations at high redshift. This is the first step towards high-precision cosmological distance measurements that can unearth the mysteries of dark energy.

SN 2023adsy: Understanding High-z SNe Ia

THIS PROGRAM obtains NIRSpec host spectra for SN 2023adsy, the highest redshift SN Ia ever discovered. For less than 115000s, this program will extend the host galaxy relation for SNe Ia to beyond $z \sim 2.9$. This program will also probe the dust vs intrinsic color relation for this highly-reddened SN, providing insight into whether Type Ia luminosities evolve with redshift.

Dust vs Intrinsic Color: Evolution with redshift?

Cosmological distance measurements with SNe Ia requires proper line-of-sight dust correction as well as untangling the flux of the host from the SN flux. These corrections rely on a reddening law to calculate the extinction. A recent work (1) showed that increasing the host reddening has a significant effect on the measured distance modulus of SN 2023adsyas seen in Figure 1. If the extinction ratio (R_V) evolves from $0 < z < 2$ then it may significantly bias dark energy constraints (4). For $z < 1.5$, evolving luminosity distances could be due to dark energy or evolving SN Ia intrinsic luminosity. However, in the dark matter dominated universe ($z \gtrsim 1.5$) this behavior strongly indicates intrinsic SN Ia luminosity evolution. Thus, SN 2023adsy, located at $z = 2.9$, has unique leverage on systematics in an unexplored regime. Obtaining a spectra for the host galaxy of SN 2023adsy can resolve this ambiguity which is important in understanding the Hubble residuals seen in the bottom panel of Figure 1 and has long-term consequences for our understanding of high-z SNe Ia.

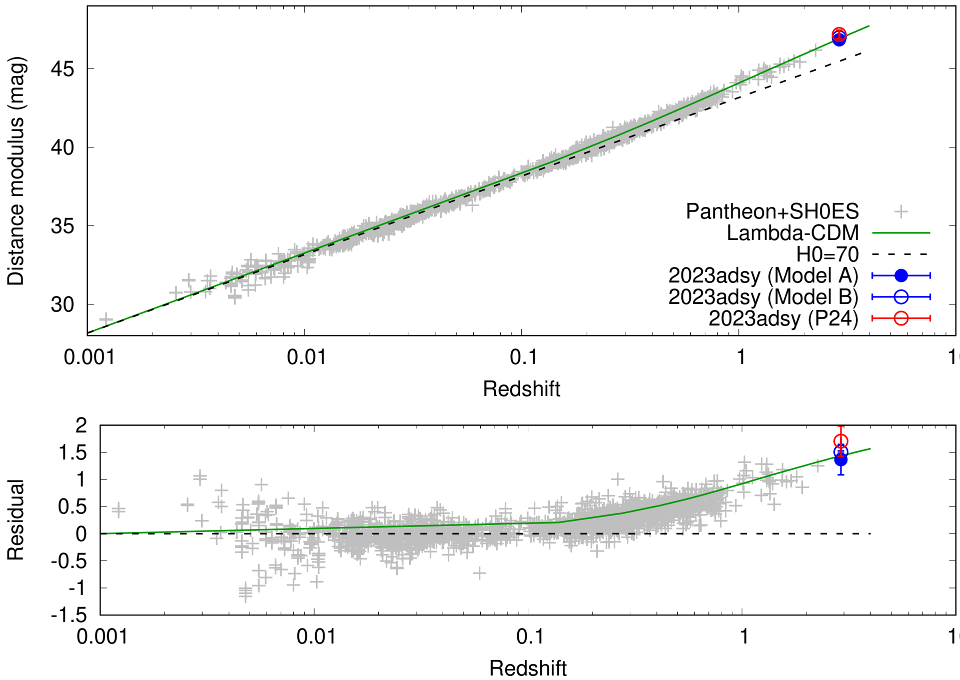

Figure 1: Figure 4 from (1). (Top) The distance modulus-redshift relation for the Flat ΛCDM model with $\Omega_M = 0.3$. The Pantheon+ SN and SH0ES datasets are shown in grey markers. Distance moduli values of SN 2023adsy from (2) (red marker) and both models assumed in (1) (blue markers) are plotted as well. (Bottom) Hubble Residuals are shown in units of mag, highlighting the level of scatter in the SNe Ia population.

SN in Context: Host properties

Precisely measuring the flux of SNe Ia without host contamination is key to accurate distance measurements. Figure 2 shows the photometric measurements of SN 2023adsy as modeled by PROSPECTOR in P24 which shows that the fit may be biased due to host flux.

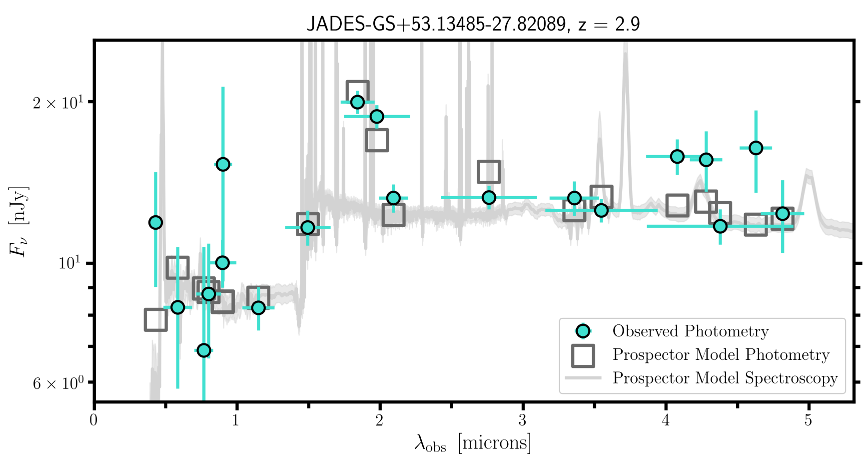

Figure 2: Photometry for SN 2023adsy (blue circles) fitted with prospector model photometry (grey squares) and prospector model spectroscopy (grey line).

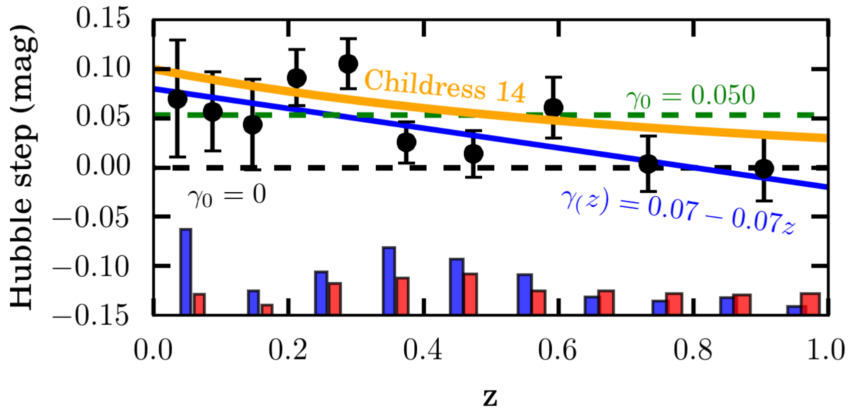

Figure 3: The Hubble step as a function of redshifts from $0 < z < 1$ from (5). The bar graph shows the relative numbers of high and low mass hosts. The dashed and solid line show different predictions for this relation.

Getting the host spectra of SN 2023adsy is vital in not only ensuring that host contamination is removed but also in understanding high-z SN-host relations. Figure 3 shows the Hubble step for $0 < z < 1$ with various models of this relationship (5). Current data is insufficient in determining if this relation evolves with redshift. Host spectra of SN 2023adsy can provide a useful anchor for the models shown in Figure 3. This plays an important role for SNe Ia distance measurements as context is crucial for proper corrections. Moreover, understanding the host environment of SNe Ia gives insight into intrinsic color and spectral variations that can help explain the scatter in Hubble residuals. Reducing this scatter through corrections for these relations goes a long way in reducing the uncertainty in measurements of the Hubble constant leading the way to the first studies of precision cosmology at high redshift.

Program Objectives

THE OBJECTIVE of this proposal is to obtain template spectra for SN 2023adsy.

Based on our current photometric and spectroscopic measurements, this program will:

- Clear up any ambiguity regarding the classification of SN 2023adsy.
- Provide a vital anchor point to understand extinction ratio (R_V) evolution with redshift.
- Give crucial context to understand SN-host relations at high-z

Technical Justification (GO/DD only)

NIRSpec Observation : The goal of this program is to obtain spectra of the Host galaxy of SN 2023adsy. For this, we will collect NIRSpec Fixed Slit Observations. As this is a faint source, we opt for the PRISM/CLEAR grating to optimize exposure time as well as achieve the necessary S/N to perform our analysis. The spectral lines used to classify this SN used the $H\alpha$ and O [III] lines which fall at rest-frame wavelengths $6565\mathring{A}$ and $5008\mathring{A}$ respectively. These correspond to observer-frame wavelengths of $2.56\mu m$ and $1.95\mu m$. Table 1 gives the required exposure times found using the Exposure Time Calculator for the wavelengths of concern. The calculations were normalized for a source flux of $\sim$ 10.9 nJy in F200W NIRCam imaging obtained from JADES data (3). We use the S200 A1 slit due to it's optimal wavelength range, with the FULL subarray and NRSIRS2 readout pattern for best S/N. We have not use any offsets as the whole host galaxy can fit within the array, provided the array is centered on the source. This strategy is ideal for our observations as:

1. It gives the largest S/N while optimizing the time needed.
2. It achieves a S/N $\gtrsim 5$ for the wavelengths required to get a more accurate classification of SN 2023adsy.
3. The wavelength range chosen is vital for exploring the host environment of SN 2023adsy.

Position Angle: We make no restrictions on PA to increase schedulability. We will be able to cleanly extract the spectra of the host from the SN irrespective of PA. Due to the high redshift and morphology of the object, no particular PA value is favored over others when obtaining spectra. Moreover, since no offsets are used, the chosen PA makes even less of a difference when the array is properly centered on the galaxy.

Timing: We make no restrictions on the visibility window in order to increase schedulability. The second visibility window is longer and occurs after a longer time since the SN that SN flux is no longer contaminating the host and is therefore preferred, but the first visibility window increases schedulability and is also valuable.

Wavelength (λ) (μm)	Spectral Line	Rest Wavelength (μm)	Expected S/N	Exposure (s)
2.56	$H\alpha$	0.6565	$\sim$ 7.98	$\sim 112918s$
1.95	O[III]	0.5008	$\sim$ 5.08	$\sim 112918s$

Table 1: The S/N for the two spectral lines used in (2) to classify SN 2023adsy using the observing strategy proposed above. The observed wavelength, detected wavelength and exposure times are given for each spectral line. These S/N values are at par or higher than the spectra taken of the SN and will allow us to separate the host flux from the SN flux.

References

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[4] S. Dhawan, B. Popovic, A. Goobar, *arXiv e-prints* p. arXiv:2409.18668 (2024)

[5] D. M. Scolnic, D. O. Jones, A. Rest 859, 101. doi:10.3847/1538-4357/aab9bb (2018)