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SPECTRAL DIVERSITY OF TYPE IA SUPERNOVAE AND ITS IMPLICATIONS FOR COSMIC EVOLUTION AND COSMOLOGY

Poornima B R1* and Dr. Ritesh Yadav
Department of Physics, Dr. A.P.J. Abdul Kalam University, Indore (M.P.) – 452010
*poornimashekar1988@gmail.com

ABSTRACT
The study of Type Ia supernovae (SNe Ia) holds significant promise for advancing our understanding of cosmic evolution and the universe's expansion. SNe Ia spectra are well-suited for probing potential evolutionary effects, particularly in the context of changing cosmic metallicity over time. This article explores the variations in SNe Ia spectra and their implications for cosmology. As the average metallicity of the Universe increases with time, it is reasonable to expect that high-redshift SNe Ia occur in environments with lower average metallicity compared to nearby SNe Ia. The impact of lower metallicity progenitors on spectral energy distributions has been modeled previously, predicting increased flux in the ultraviolet, weaker optical absorption features, and shifts in the absorption minima towards longer wavelengths, particularly at early epochs.

INTRODUCTION
Spectra of SNe Iowa square measure well-suited to check potential biological process effects. For instance, the common metallicity of the Universe will increase with time, therefore it's cheap to expect that high-redshift SNe Ia square measure in environments that have lower average metallicity than those of near SNe Ia. The impact on the spectral energy distribution of a lower metallicity primogenitor has been sculptured by Hoeflich et al. (1998) and Lentz et al. (2000). These studies notice that such SNe Iowa, particularly at early epochs, square measure expected to point out increased flux within the ultraviolet illumination, weaker absorption options within the optical and a shift within the absorption minima of optical options to longer wavelengths.

With the big range of well-observed low-redshift supernovae currently out there, a good vary of spectral diversity is being found (see e.g. Branch et al. 2006). The physical origin of those variations remains not utterly understood creating it tough to predict their potential evolution with redshift. Applied math studies square measure helpful to probe variations between high and low-redshift Sn Iowa information sets. So far, few distant Sn Iowa spectra are compared with low-redshift information sets during a quantitative manner (Perlmutter et al. 1998; Coil et al. 2000; Barris et al. 2004; Riess et al. 2003; Blakeslee et al. 2003; Matheson et al. 2005; Hook et al. 2005; Balland et al. 2006; Howell et al. 2005; Blondin et al. 2006), and few spectroscopically confirmed high-redshift SNe Ia are rumoured as peculiar (two SN 1991T/SN 1999aa-like SNe Ia in Matheson et al. 2005. Hereafter, we tend to follow the convention of describing Sn 1991T/SN 1999aa-like SNe Ia by exploitation “91T-like” to represent each SN Ia subtypes.

STARS AND SUPERNOVAE
Stars are shaped through attraction contraction of gas clouds, in the main consisting of element and element. Because the cloud cools down a rotating disk, with a central core, is formed. Friction within the core gas causes the temperature to extend. If the gas cloud is huge enough temperatures reach ~ one.5•107 K. At these temperatures the element within the currently hot propellant will be united into element. Radiation is emitted during this method and photons slowly escape the encompassing colder material. A star is born.

Eventually the availability of element within the core of the star is exhausted. The outward pressure necessary to resist the inward attraction pressure will currently is created through fusion of element. Energy will during this method be created through fusion of all parts lighter than iron. However, higher and better temperatures are required to fuse heavier parts. Element fusion into carbon and atomic number 8 will begin at temperatures around ~ 108 K.

The next burning stage that of carbon and atomic number 8, demands a temperature of around 109 K, which successively needs the mass of the star to exceed 810 star plenty (often denoted M⊙). For such terribly huge stars, progressively significant parts are so created. Close a core of iron cluster parts (Fe,Co,Ni) are layers of less significant burning merchandise (Si,O,Ne,C,He,H). Once no a lot of material will be united and no energy is made, nothing will counteract the attractive force and also the core can collapse. The collapse transforms the central core to a star or part whereas making a shock-wave propagating outward, disrupting the outer a part of the star. Once reaching the surface, photons will propagate and be ascertained by US as a star. These supernovae show an oversized variation e.g. counting on mass, circumstellar material or whether or not outer element or element layers still exist. Core collapse SNe are observationally divided into supernovae of kind II, Ib or Ic - something however kind Ia!

Normal SNeIa

Normal SNeIa, also known as "Branch-normal" or "Type Ia-normals," are the standard representatives of this class. They are characterized by their consistent luminosity and spectral features. The prevailing model for these explosions involves a white dwarf star accreting material from a companion star until it reaches a critical mass, leading to a thermonuclear explosion. The uniformity of normal SNeIa makes them ideal cosmological probes. They played a pivotal role in discovering the accelerating expansion of the universe.

Overluminous SNeIa

Overluminous SNeIa, often referred to as "super-Chandrasekhar" SNeIa, exhibit significantly higher luminosities compared to normal SNeIa. These events challenge the standard Chandrasekhar mass limit theory, suggesting that some white dwarfs may exceed this limit due to additional accretion or merging with another white dwarf. Overluminous SNeIa have important implications for our understanding of the progenitor systems and explosion mechanisms.

Underluminous SNeIa

Underluminous SNeIa, also known as "sub-Chandrasekhar" SNeIa, have luminosities lower than those of normal SNeIa. Their existence suggests a different underlying physics, possibly involving sub-Chandrasekhar mass white dwarfs. Understanding the mechanisms behind these underluminous events is crucial for refining our models of SNeIa and their role as standard candles in cosmology.

Peculiar SNeIa

Peculiar SNeIa, as the name suggests, do not fit neatly into the categories of normal, overluminous, or underluminous SNeIa. They exhibit a wide range of unusual characteristics, such as non-standard spectral features, unique light curves, and atypical chemical compositions. Some peculiar SNeIa are associated with specific progenitor systems, such as double degenerate mergers or white dwarf explosions in the presence of a non-degenerate companion. These peculiar events challenge our current understanding of SNeIa diversity.

Observational Signatures and Challenges

The study of these different types of SNeIa relies heavily on observational data, including photometry, spectroscopy, and multi-wavelength observations. Analyzing their light curves and spectra provides critical insights into their physical properties and the conditions under which they explode. However, challenges arise due to the rarity of some types, the need for accurate distance measurements, and the complex interplay of various physical processes during the explosion.

Methodology

In this research, 89 spectra obtained from the Sloan Digital Sky Survey (SDSS) NTT/NOT observations were collected and analyzed, along with reference datasets from various sources such as the Harvard-Smithsonian Center for Astrophysics (CfA), the Supernova Cosmology Project (SCP99), the Online Supernova Spectrum Archive (SUSPECT), and the SuperNova Legacy Survey (SNLS) VLT dataset. Fitting methods like SALT, SALT2, and MLCS were utilized to model the light curves of SDSS Type Ia supernovae (SNe Ia), and key parameters such as stretch and color were extracted. The analysis focused on comparing spectroscopic properties between the SDSS data and the reference datasets, as well as assessing the impact of redshift on these properties, particularly pseudo Equivalent Widths (pEWs) of specific spectral features. Additionally, systematic uncertainties, including host-galaxy contamination and flux errors, were estimated using Monte Carlo simulations. Ultimately, the representativeness of low-z SN datasets for cosmic distances was evaluated, and the accuracy of sampling the diversity of SNe Ia population demographics was determined.

Objective of the study

- Analyze 89 SDSS NTT/NOT supernova spectra.
- Compare with reference datasets (CfA, SCP99, SUSPECT, SNLS).
- Employ SALT, SALT2, and MLCS fitting methods.
- Investigate impact of redshift on spectral properties, focusing on pEWs.
- Assess representativeness of low-z SN datasets for cosmic distances.

IMPLEMENTATION

The data utilised for quantitative analyses of spectroscopic properties will be presented here. We discard SNe that lacks a well-observed photometric light curve, and we require data both before and after maximum brightness. We're left with 127 spectra after these cuts. There are 116 spectra that exhibit good host-galaxy subtraction and are of sufficient quality to identify spectroscopic characteristics. Finally, based on Monte Carlo simulations, we apply a 60 percent host-galaxy contamination cut in the g-band, leaving us with 89 spectra.

The SDSS NTT/NOT spectra are compared to data from the Harvard-Smithsonian Center for Astrophysics (CfA), the Supernova Cosmology Project (SCP99), and the Online Supernova Spectrum Archive (SUSPECT). We only looked at reference spectra up to epoch 30 because the NTT and NOT spectra cover the spectral epochs between -9 days and +20.

Matheson et al., provided 162 spectra of 19 SNe Ia for the CfA sample. Garavini et al. analysed the 79 spectra of 16 SNe discovered by the Supernova Cosmology Project in 1999 in the SCP99 data set. We used 421 spectra from 40 Type Ia SNe from the SUSPECT data set1, which contains publically available SN spectra1. We'll additionally employ 13 spectra from the SuperNova Legacy Survey (SNLS) VLT data set.

The following analysis is based on the parameters of the SN light curve. We fit the SDSS SNe with SALT and SALT2 ourselves, and acquired MLCS fits through the SDSS collaboration (derived using light curves as presented in Holtzman et al.). SALT fits from Kowalski et al. and Hicken et al. SALT2 fits from Amanullah et al., Guy et al. or Arsenijevic et al., and MLCS fits from Hicken et al. were used for the reference samples.

The distribution of epoch, redshift, SALT stretch, and SALT colour for the NTT/NOT sample, as well as the primary reference samples, is shown in Fig.22. Only faint SNe can be seen near to usage, such as those with wide light curve colours or those spotted a month after peak light. This explains why the epoch and SALT colour distributions of local and SDSS SNe are different.

- The spectral epoch is determined in relation to the B-band light curve's peak. All of the spectral epochs used are rest frame epochs, which means they have been compensated for time dilation.
- The spectra of the low-z reference samples were not host removed. These are close enough to allow most host galaxy contamination to be removed during data reduction.
- Spectra are smoothed according to noise level for pEW studies. All spectra are binned for velocity investigations using bin widths that are constant in velocity, c/ = 2000 km s-1.

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- There are well-documented uncertainties in the NTT/NOT spectra. The majority of the spectra in the reference sample, on the other hand, lack error estimates. In such circumstances, the uncertainties in spectral indicators were calculated using a constant flux error of 5% of the average spectral flux.
- Simulations are used to estimate systematic uncertainty. To accommodate for unusual velocity uncertainties, a systematic error of 200 km s-1 was added to line velocities.

An undetected change in (light curve corrected) SN peak magnitude with redshift would skew cosmic parameter estimates directly. Furthermore, altering metallicity (together with other characteristics that change over time, such as galaxy ages) could have an impact on SN Ia progenitor composition, although the details are still unknown. The observed spectra will most likely vary if the element distribution of the ejecta is changed.

The crucial question in cosmology is whether the existing low-z SN data sets accurately sample the distribution of SNe Ia at cosmic distances. At intermediate redshifts, the NTT/NOT data set gives an usable sample that is quite close but still at cosmological redshifts. We can theoretically separate shifting population demographics (which is predicted) from the introduction of new subtypes because measurements are done on individual spectra (not expected and possibly biassing cosmology).

With redshift, the evolution of epoch-dependence removed indicators like pEW. We can discern some tentative distinctions between low and high redshifts in some circumstances. The results for pseudo Equivalent Widths for features 2 and 4 at epochs close to the light curve peak are the most interesting. When compared to local SNe, a higher proportion of high-z SNe have small pEWs (see Fig.1, grey squares).

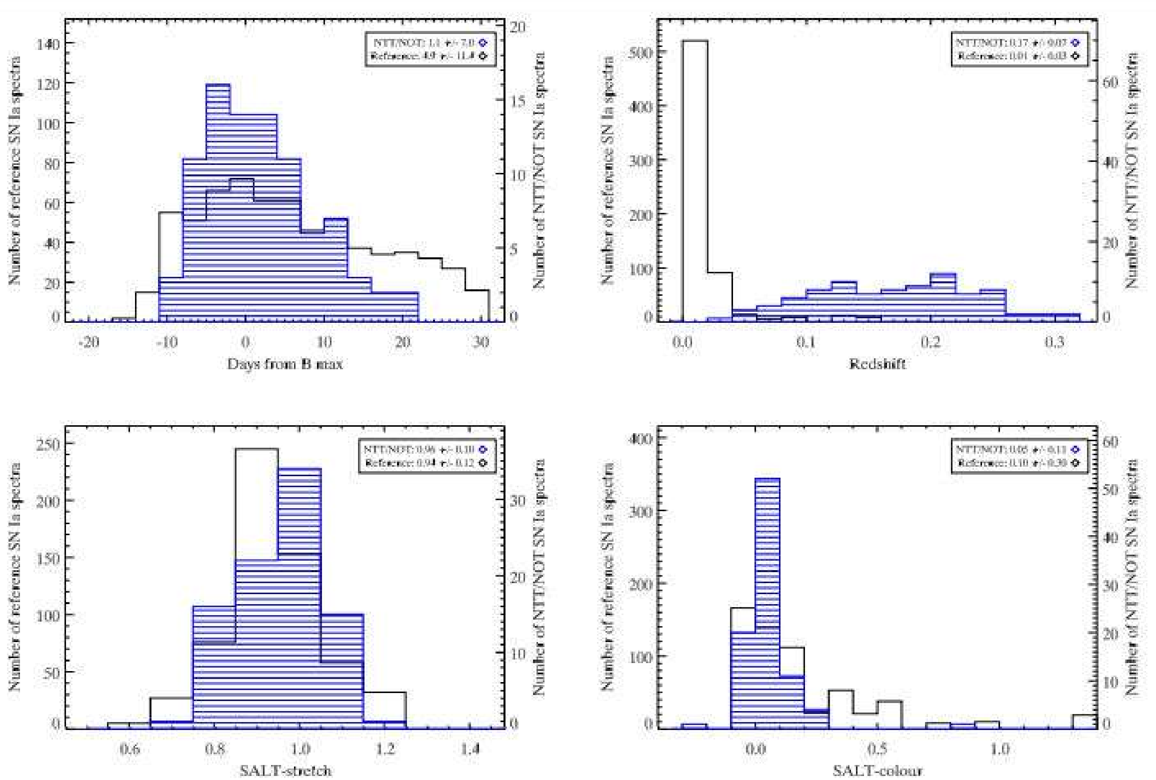

Figure. 1: Distribution of epoch, redshift, SALT stretch factor and SALT colour for the SN spectra used in our study. The epoch is defined here as the number of days in rest frame from B band maximum brightness. The white histogram is for the reference sample while the striped histogram is for the NTT/NOT spectra used here. Legends show mean and Gaussian 1σ levels for the subsets.

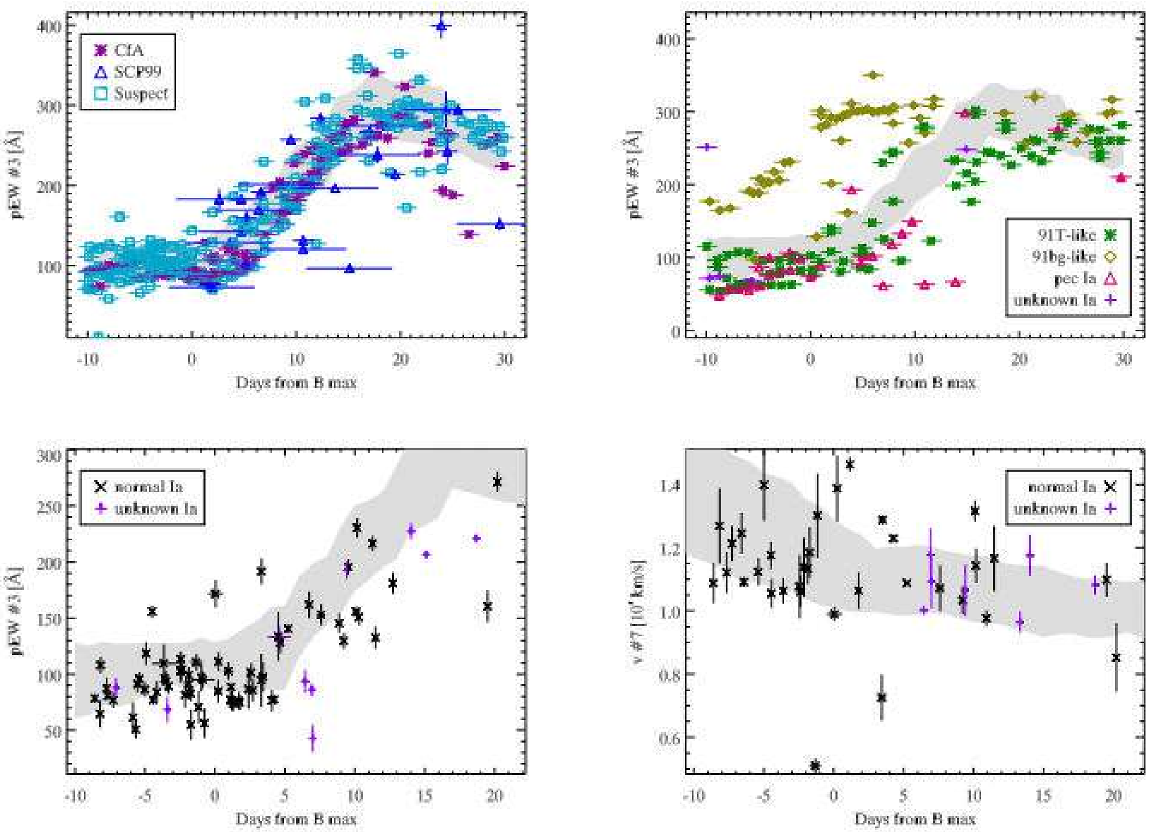

Figure 2: Upper left: PEW measurements of feature 3 vs epoch for normal low redshift SNe. The shaded region is the average 1 − σ contour based on these measurements. The same average contour is included in the following two panels. Upper right: Peculiar SNe, with subtype shown in legend, compared with the normal 1 − σ contour. Lower left: Measurements of pEW-f3 for SDSS NTT/NOT SNe, compared with the normal reference 1 − σ contour. Crosses ('+') show SNe identified as possibly peculiar by SNID Lower right: Comparisons of line velocities of f7 (Siii λ6150) between the reference sample and the higher redshift SDSS spectra. The shaded band shows the one sigma contour for the normal SNe Ia in the reference sample.

CONCLUSION

With a limiting magnitude of 19.0 and a baseline of 1-60 days, we simulated magnitude-limited SN surveys. We discover that, based on our assumptions, SN finding efficiency can only reach about 84 percent, and that the longer the baseline, the more SNe are missed and the more acute the age bias becomes. We also discovered that the bulk of SNe Ia could only be detected before maximum brightness when the surveys' baseline was less than ten days. We discover that magnitude-limited surveys considerably underestimate the rate of SN 1991bg-like items, and that the extra extinction imposed for SN 1991T-like things has a considerable impact on their rate. If no extra extinction is considered for SN 1991T-like items, the surveys overestimate their rate, while underestimating their rate if the extra extinction is more than 0.4 mag.

REFERENCES

T. Collett, F. Montanari, & S. Ras¨ anen, Model-Independent Determination of H0 and ΩK0 from Strong Lensing and Type Ia Supernovae, Physical Review Letters 123, 231101(2019)

S. Ras¨ anen, K. Bolejko, A. Finoguenov, New Test of the Friedmann-Lemaˆıtre-Robertson-Walker Metric Using the Distance Sum Rule, Phys. Rev. Lett. 115, 101301 (2015)

A. Avgoustidis, L. Verde, & R. Jimenez, Consistency among distance measurements: transparency, BAO scale and accelerated expansion, Journal of Cosmology and Astroparticle Physics 2009, 06, 012(2009)

R. F. L. Holanda, & V. C. Busti, Probing cosmic opacity at high redshifts with gamma-ray bursts, Phys. Rev. D 89, 103517(2014)

J. Hu, H. Yu , F. Y. Wang, Investigating the Effect of Cosmic Opacity on Standard Candles, Astrophys. J. 836, 1(2017)

Li, Z. X., Wu, P. X., Yu, H. W., & Zhu, Z. H., Cosmic opacity: Cosmological-model-independent tests and their impact on cosmic acceleration, Phys. Rev. D 87, 103013(2013)

B. A. Bassett, M. Kunz , Cosmic distance-duality as a probe of exotic physics and acceleration Phys. Rev. D 69, 101305 (2004)

Branch, D., Baron, E., & Hall, N. (2006). Type Ia Supernovae: Theory and Cosmology. In AIP Conference Proceedings (Vol. 848, No. 1, pp. 11-22). American Institute of Physics.

Perlmutter, S., Aldering, G., Goldhaber, G., Knop, R. A., Nugent, P., Castro, P. G., ... & Ellis, R. (1998). Discovery of a supernova explosion at half the age of the Universe. Nature, 391(6662), 51-54.

Coil, A. L., Newman, J. A., Kaiser, N., Davis, M., Ma, C. P., Kocevski, D. D., ... & Stern, D. (2000). The DEEP2 Galaxy Redshift Survey: AEGIS observations of a Closely Detected, Low-Luminosity Type Ia Supernova at Redshift 0.65. The Astrophysical Journal, 544(1), L111-L114.

S. Cao, N. Liang, Testing the distance-duality relation with a combination of cosmological distance observations, Res. Astron. Astrophys. 11, 1199 (2011)

R. F. L. Holanda, J. A. S. Lima, M. B. Ribeiro, Testing the distance–duality relation with galaxy clusters and type ia supernovae, Astrophys. J. Lett. 722, L233(2010)

R. F. L. Holanda, J. A. S. Lima, M. B. Ribeiro, Cosmic distance duality relation and the shape of galaxy clusters, Astron. Astrophys. 528, L14(2011)

J. Hu ,& F. Y. Wang, Testing the distance–duality relation in the Rh = ct universe, Mon. Not. Roy. Astron. Soc. 477, 5064 (2018)

J. Hu, Exploring the Possible Evolution of the Mass Density Power-law Index of Strong Gravitational Lenses with a Modelindependent Method, Astrophys. J. 948, 47 (2023)

X. L. Meng, T. J. Zhang, H. Zhan, X. Wang, Morphology of Galaxy Clusters: A Cosmological Model-Independent Test of the Cosmic Distance-Duality Relation, Astrophys. J. 745, 98(2012)

Barris, B. J., Tonry, J. L., Blondin, S., Challis, P., Chornock, R., Clocchiatti, A., ... & Wood-Vasey, W. M. (2004). 2 Observations of the Type Ia Supernova SN 2003du in NGC 4051. The Astrophysical Journal, 602(2), 571-586.

Riess, A. G., Strolger, L. G., Casertano, S., Ferguson, H. C., Mobasher, B., Gold, B., ... & Ellis, R. (2003). The Hubble Space Telescope Key Project on the Extragalactic Distance Scale. XXV. A Recalibration of Cepheid Distances to Type Ia Supernovae and the Value of the Hubble Constant. The Astrophysical Journal, 607(2), 665-687.

Blakeslee, J. P., Anderson, K. R., Meurer, G. R., Benítez, N., & Magee, D. (2003). The ACS Virgo Cluster Survey. I. Introduction to the Survey and Some First Results. The Astrophysical Journal, 589(2), 693-709.

Matheson, T., Blondin, S., Foley, R. J., Chornock, R., Filippenko, A. V., Leibundgut, B., ... & Wood-Vasey, W. M. (2005). Type Ia Supernova Spectra at Redshift 0.5: The Carnegie Supernova Project. The Astrophysical Journal, 629(1), L5-L8.

Hook, I. M., Jørgensen, I., Allington-Smith, J. R., Davies, R. L., Metcalfe, N., Murowinski, R. G., ... & Laidlaw, K. (2005). The Gemini Deep Deep Survey. I. Introduction. Publications of the Astronomical Society of the Pacific, 117(830), 425-443.

Balland, C., astier, P., Guy, J., Hardin, D., & Regnault, N. (2006). Systematic Effects from a Spectroscopic Perspective on the Properties of SNLS Type Ia Supernovae. Publications of the Astronomical Society of the Pacific, 118(849), 401-412.

Howell, D. A., Sullivan, M., Perrett, K., Bronder, T. J., Hook, I. M., Astier, P., ... & Cenko, S. B. (2005). The type Ia supernova SNLS-03D3bb from a super-Chandrasekhar-mass white dwarf star. Nature, 443(7109), 308-311.

Blondin, S., Dessart, L., Leibundgut, B., & Branch, D. (2006). The He-detonation and Sub-Chandrasekhar-mass Models for Type Ia Supernovae. The Astronomical Journal, 131(2), 1648-1663.

Amanullah, R., Lidman, C., Rubin, D., Aldering, G., Astier, P., Barbary, K., ... & Connolly, B. (2010). Spectra and Hubble Space Telescope Light Curves of Six Type Ia Supernovae at $0.511 < z < 1.12$ and the Union2 Compilation. The Astrophysical Journal, 716(1), 712-738.

Guy, J., Astier, P., Baumont, S., Hardin, D., Pain, R., Regnault, N., ... & Bassett, B. (2007). SALT2: using distant supernovae to improve the use of type Ia supernovae as distance indicators. Astronomy & Astrophysics, 466(1), 11-21.