Astro2020 Science White Paper

Type Ia Supernova Cosmology with *TSO*

Thematic Areas: ☐ Planetary Systems ☐ Star and Planet Formation
☑ Formation and Evolution of Compact Objects ☑ Cosmology and Fundamental Physics
☐ Stars and Stellar Evolution ☐ Resolved Stellar Populations and their Environments
☐ Galaxy Evolution ☐ Multi-Messenger Astronomy and Astrophysics

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Abstract: Comprehensive restframe optical through near-infrared measurements of Type Ia supernovae (SNe Ia) offer unique and compelling opportunities to advance our understanding of the relationship between dark energy and dark matter and of SNe Ia themselves. Space-based 1–2.5 m class observatories with imaging and spectroscopic instruments covering $0.3 < \lambda < 4.5$ μm offer significant opportunities not available from the ground, particularly in pursuit of high-quality, well-calibrated observations of Type Ia supernovae from $0.01 < z < 1.5$. SNe Ia in the restframe NIR are more standard than in the optical and less affected by dust. Observatories with low observation overheads are critical to observing the thousands of transients necessary to improve our cosmological measurements, and fast response times – on the order of minutes – may be our best hope of determine the progenitor systems for SNe Ia. Measuring progenitor clues consistently from $0.01 < z < 1.5$ will allow us to measure population drift in the progenitor population of SNe Ia. We here focus on the unique potential of the proposed Time-domain Spectroscopic Observatory (*TSO*) to observe from 0.3–4.5 μm with both imaging and spectroscopic capabilities.

1. Restframe UV-optical-NIR Observations from $0.01 < z < 1.5$

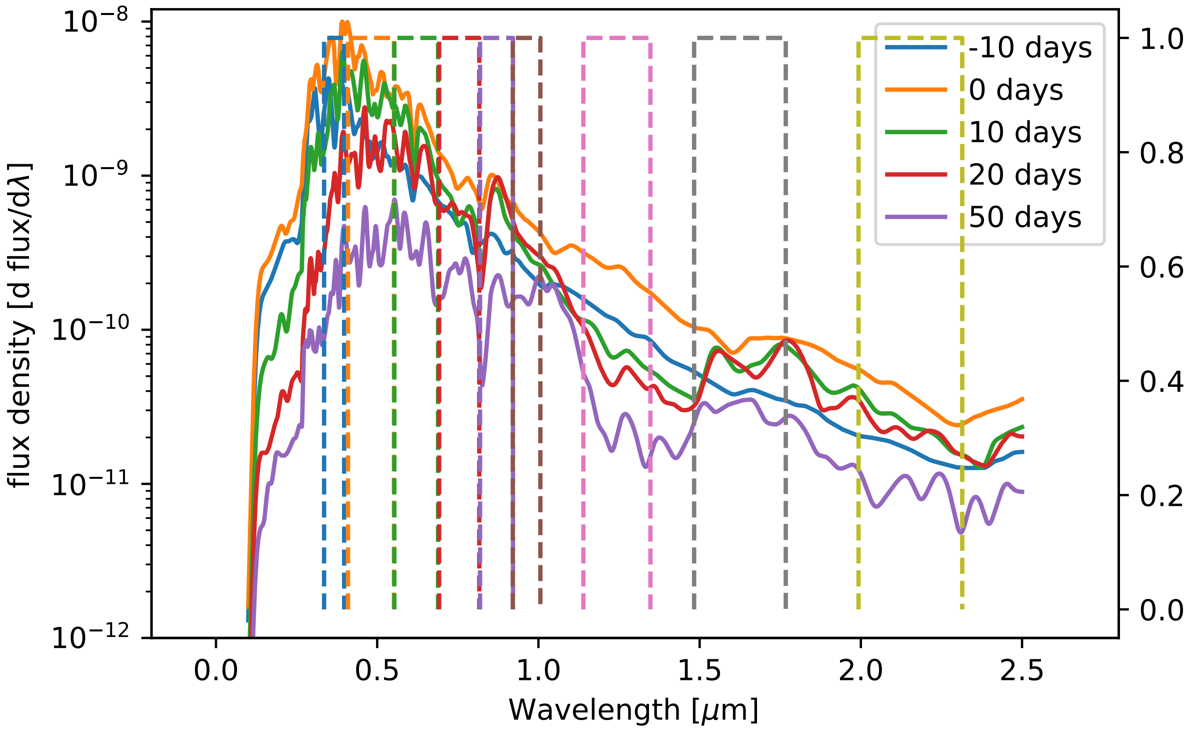
Type Ia supernovae continue to be a key part of our overall efforts to measure dark energy and dark matter through the cosmic evolution of the Universe. As we scale up from the 1,000 SNe Ia of current measurements to 10,000 from the Dark Energy Survey and Pan-STARRS, to 100,000 of the next decade from LSST, we hit new challenges in achieving the needed calibration, understanding the progenitor population, and making full use of the wealth of primarily photometric observations. There are planned missions to provide the capability to explore restframe optical lightcurves of SNe Ia at higher-redshifts, most notably *WFIRST* (Spergel et al. 2015; Hounsell et al. 2018) and *Euclid* (Astier et al. 2014). Together with LSST, these missions will substantially advance our understanding of dark energy through SN Ia luminosity distances and achieving new standards in photometric calibration. However, they (1) do not fully take advantage of the improve standard luminosity of SNe Ia in the near-infrared and (2) are unlikely to improve our understanding of the SN Ia themselves, leaving these efforts open to concern about astrophysical evolution in the population(s) of SNe Ia and dust in their host galaxies.

There is a related Astro2020 white paper on the future of supernova cosmology led by Saul Perlmutter and Dan Scolnic. This present paper is focused on the aspects uniquely enabled by complete restframe coverage from the optical through the NIR. We specifically argue here for a program to observe SNe Ia from restframe optical to NIR from $0.01 < z < 1.5$ to provide nearly bolometrically-complete observations over 10 Gyr of cosmic history from the first hints of dark energy, to our current epoch of accelerated expansion, and that we can studying the host environments of these important cosmic probes. Obtaining restframe observations from 0.3–1.8 μm will require observer-frame measurements from 0.3–4.5 μm. Such observations also have significant potential to improve our knowledge about the progenitor systems of these explosions.

While we argue for programs that pursue a rest-frame NIR focus at the $z < 0.5$ enabled by *WFIRST* and *Euclid*, that is not a sufficient redshift reach to understand any departures from dark energy being consistent with a cosmological constant. *TSO* can substantially increase the scientific return of the SN Ia cosmology programs of both *WFIRST* and *Euclid* by observing SNe Ia out to restframe H-band at $z \sim 1.5$.

2. Type Ia Supernova Progenitors and Cosmology with Rapid UV-Optical-NIR Followup

LSST will obtain good lightcurves for 100,000 SNe Ia over 10 years. These will allow for measurements of the expansion of the Universe out to $z \sim 0.8$ based on restframe optical observations. Achieving the most accurate and precise constraints on dark energy will require improved understanding of SN Ia behavior across cosmic time and robust, well-calibrated luminosity distances using both restframe optical+infrared.



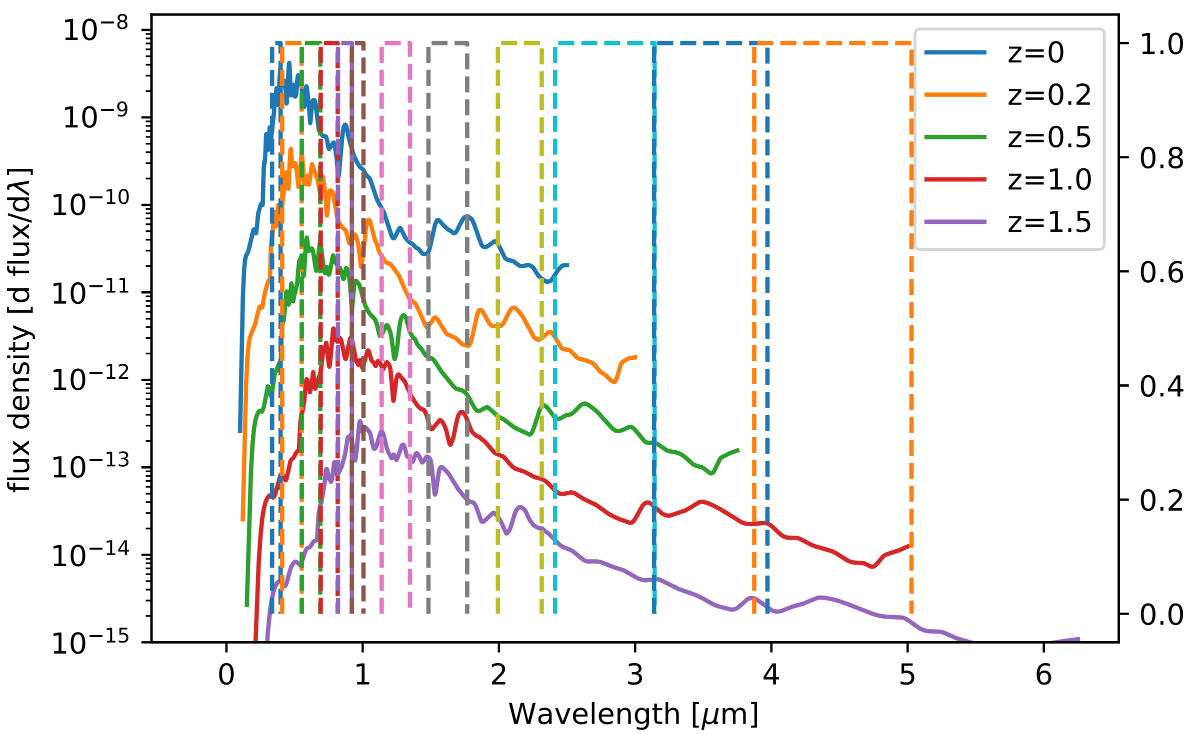


Fig. 1.— (top) SN Ia spectrum at [-10, 0, +10, +20, +50] days at $z = 0$. (bottom) SN Ia spectrum at phase=+15 days at z=0, 0.2, 0.5, 1.0, and 1.5 at observer-frame wavelength. Note that the H-band shifts beyond 2 μm even by $z\ 0.5$. Observing to $z \sim 1.5$ requires observing frame observations to 4.5 μm. Flux density scale and shift for each redshift sn arbitrary.

Type Ia supernovae are intrinsically less variable in the restframe NIR, in particular through H-band (1.5–1.8 μ) (Krisciunas et al. 2004a,b,c; Wood-Vasey et al. 2008; Contreras et al. 2010; Stritzinger et al. 2011; Kattner et al. 2012) and suffer less uncertainty due to the effects of dust in their host galaxy and our own Milky Way.

Photometric calibration remains a key limitation in supernova cosmology (Scolnic et al. 2018). Achieving consistent relative calibration from the optical through to the NIR to 2% will be key to making accurate and precise measurements of luminosity distance that will allow for the measurement of the equation of state parameter of dark energy, ω, and any potential variation with redshift. Close coordination between LSST and spaced-based observations both in observed samples of SNe Ia and calibration of their overall systems is vital toward maximizing the science potential of SN Ia cosmology in the decade to come.

Astier et al. (2014) presented a clear case for joint LSST+Euclid observations, and Spergel et al. (2015); Hounsell et al. (2018) describe SN Ia cosmology with *WFIRST*. We here argue for the addition of spectroscopic observations as (i) key indicators of SN Ia populations and potential variation, and (ii) an increase in wavelength coverage to $\lambda \sim 4.5\mu$m to allow for rest-frame H-band observations.

2.1. SN Ia Progenitors and Hosts

Obtaining UV-NIR observations of the host galaxies of SNeIa will provide comprehensive stellar age distributions and allow for targeted. Resolutions of $0.1''$as achievable from space will allow for spatially resolved photometric estimation of the stellar age distribution and mass of host galaxies. At $z \sim 1$, $\sim 0.15''$resolves 0.84 kpc, which is the current scale being probe by nearby host galaxy studies from MaNGA, AMUSING, CALIFA (add references).

The lack of knowledge about SN Ia progenitor systems casts a shadow over treating SNeIa as standardizable across 10 Gyr ($z \sim 1.5$) of cosmic history. Efforts to identify progenitor systems for detected SNeIa have so far come up with nothing, and the very constraining limits in the case of the two closest SNeIa of the past decade SN 2011fe (Li et al. 2011; Bloom et al. 2012) and SN 2014J (Nielsen et al. 2014; Pérez-Torres et al. 2014; Goobar et al. 2015; Sand et al. 2016; Graur & Woods 2019) strongly suggest we may never independently observe a SN Ia progenitor system.

Two key avenues for understanding progenitor systems are (i) obtaining specific data from the explosion from very early-time measurements (starting at ¡1 hour) that illuminates the system through unique absorption, reflection, and ionization signatures. (ii) obtaining a full set of observations in time and wavelength that capture the entirety of the energy from originally created Ni^{56}.

If observed within hours on a short time scale, the light from the explosion can illuminate key

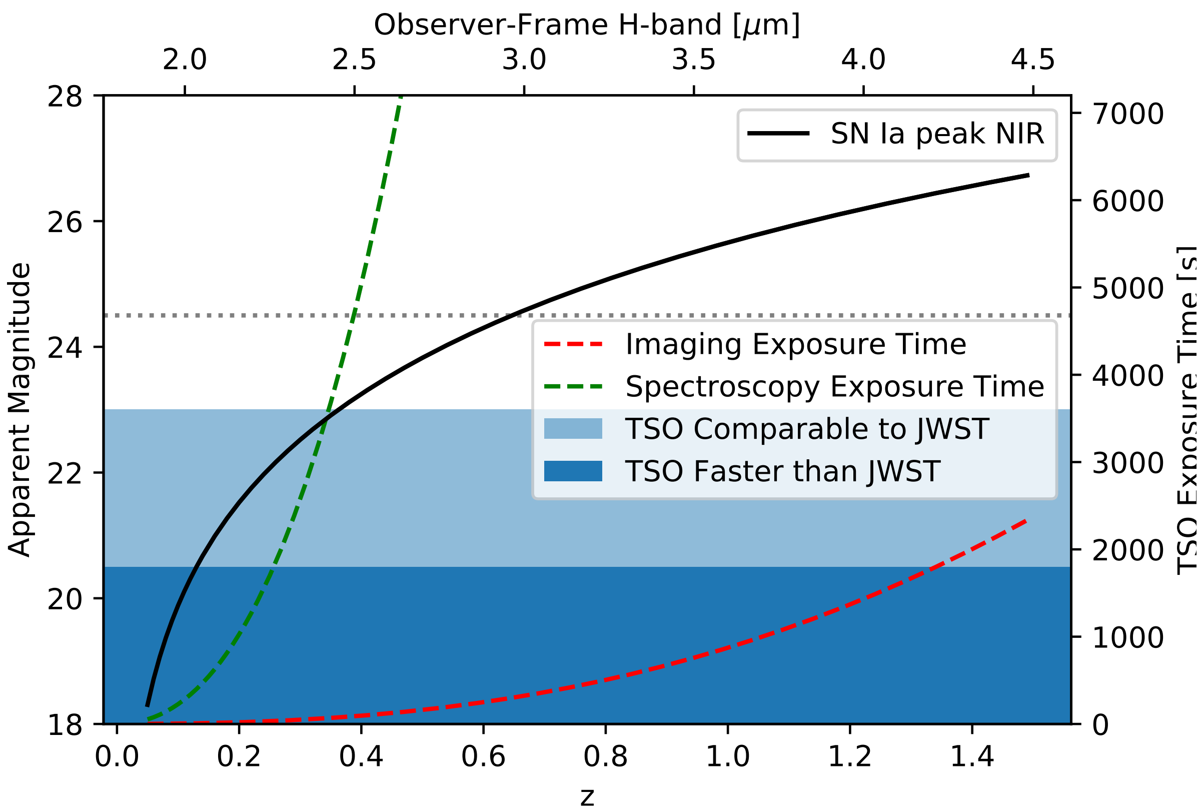


Fig. 2.— *TSO* is able to observe SNe Ia at $SNR \sim 10$ in the restframe H-band out to $z \sim 1.5$. Assuming a 1800-sec minimum visit time for JWST, *TSO* requires less total time to take images of SNe Ia than JWST out to $z \sim 1.4$. It can take

features of the progenitor system (Ganeshalingam et al. 2011; Foley et al. 2012; Noebauer et al. 2017; Dimitriadis et al. 2019). Rapid spectroscopic observations provide the most sensitive probes. The three key progenitor system features would be * Any accretion disk+stream from a non-degenerate companion onto a degenerate companion. * The shadow of the companion itself. * Ejected mass from the system. The most boring answer of "nothing" would indicate that the progenitor system was very compact, likely from two degenerate objects.

The amount of Ni^{56} produced in a SN Ia explosion is a fundamental prediction of the SN Ia explosion models, while the elements produced reveal the details of the explosion dynamics, in particular the transition from a deflagration to a detonation in the propagation of the nuclear burning front.

SN Ia emission is line-blanketed through the expanding photosphere so severely that there's no significant emission blueward of the UV. At least 99% of the flux comes out between the UV and 2.5 μm. A bolometric SED in observer frame 0.3μm–5.0 μm thus captures almost all of the EM emission out $z \sim 1$ giving a full accounting of both the energetic and elemental signatures.

3. Future Facilities

Euclid[1] is a 1.2-m telescope with a visible imager (a single band from $550 < \lambda < 900$ nm), and a NIR (Y, J, H) photometric imager. It will launch in 2022 and operate at L2 for a nominal 6-year mission. Its basic survey will observe 15,000 $\square^\circ$ plus three deep fields totalling 40 $\square^\circ$. It is well-suited to an supernova imaging complement to LSST (Astier et al. 2014), but has no spectroscopic capabilities. Astier et al. (2014) explore the potential for a 6-month SN Ia-focused *Euclid* survey to be carried out in coordination with LSST.

JWST[2] is a 6.5-m telescope with a rich instrumentation suite covering $0.7 < \lambda < 29$ μm in imaging, spectroscopy, coronograph, and IFU. With a target launch date of 2021 it will operate at L2 for a 5-year nominal mission. This is the only mission with the capabilities to go to 4.5 μm and can do so both in imaging and spectra. However, it is really designed to expose for hours after acquisition times of > 20 minutes; while JWST it will be useful for a limited number of SN Ia studies, it is particularly poorly suited to rapid-response observations and very inefficient at observations that require less than an hour.

WFIRST[3] is a 2.4-m telescope with a wide-field optical+NIR imager ($0.48 < \lambda < 2.0$ μm) with slitless spectroscopic capabilities from $0.8 < \lambda < 1.9$ μm at $70 < R < 850$. It also features a coronagraphic mode including a integral-field spectrograph covering $0.60 - -0.98$ μm at R 70. With a target launch data in the mid-2020s it will operate at L2 for a 6-year nominal mission. It will make significant contributions to SN Ia cosmology, but is limited to ~ 2 μm.

TSO The *Time-domain Spectroscopic Observatory* (*TSO*; PI J. Grindlay) is a proposed NASA Probe-class 1.3-m space telescope at L2, with imaging and spectroscopy ($R = 200, 1800$) in 4 bands ($0.3 - -5$ μm) and rapid slew ($\sim$minutes) capability to 90% of the sky. See Grindlay *et al.* TSO Mission Science White Paper for further details. The design goal is to achieve imaging SNR of 10-σ for a 24.5 mag (AB) object in 300 seconds, and SNR 10-σ per spectral resolution element in 4,000 seconds for a 23 mag AB object. For sources at these limits, *TSO* can obtain observations **in the same time as JWST**. For observations of sources brighter than 22 mag, *TSO* is **faster than JWST**.

[1]https://www.euclid-ec.org

[2]https://www.jwst.nasa.gov

[3]https://wfirst.gsfc.nasa.gov

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