OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jan–Jun **Proposal type:** short-term⋆

Studying Absorption Lines as a Probe of Supernova Extinction and CSM

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CoI(s): Nathan Smith (Steward)

Abstract of Scientific Justification

We propose to use the MAESTRO instrument on the MMT to observe supernovae that are being observed with the *Swift* satellite to detect and measure the strength and shape of the NaD, Ca H&K, Diffuse Interstellar Bands (DIB) and K absorption lines. Concentrating primarily on type Ia supernovae grouped as NUV-red/blue, we will attempt to better measure the amount of host galaxy dust along the line of sight to each supernova. This information is important for the determination of the UV/OPT absolute magnitudes of type Ia supernova, which is critical for the potential use of rest-frame U-band emission as cosmological distance indicators, but more importantly to test the finding of an accelerating universe. Detections of the NaD lines at multiple epochs will search for any evidence of time evolution of the absorption equivalent width, which has been interpreted as evidence of circumstellar material (CSM) around a few nearby SNe Ia. The entire sample will be checked for blueshift and redshift of the individual lines, statistically measuring the fraction of SNe Ia featuring CSM. Detection of CSM would be evidence of non-degenerate companion, affording insight into the nature of the progenitor system that leads to type Ia SNe.

Summary of observing runs requested for this project

Run	Telescope	Cage	Instrument	PI	AO	Nights	Moon	Scheduling Optimal	Scheduling Acceptable	Sharing Poss.	Sharing Adv.
1	MMT	f/9	MAESTRO			4	grey-bright	Jan–June	Jan–June	yes	yes

Scheduling constraints and unusable dates *(up to 4 lines)*: None

no text past this line

A ⋆ appended to the proposal type indicates a continuation proposal; a ⋆ appended to the name of a proposer indicates the proposer is a (graduate) student; a proposer whose name is underlined is certified on the proposed telescope/instrument combination; if a ∗ appears within the PI or AO box in the observations summary table, the instrument is a PI instrument and/or Adaptive Optics are requested – signatures are required on the next page.

Target list (attach list if longer than 26 objects)

#	Object	RA	Dec	mag / color / type / redshift / comment / etc.
1	SN2014dg	03:48:19	+70:07:54	dummy target

Approval for Instrument Use from PI: yes

Graduate students *(provide the following information for* ***each*** *student named as PI or CoI on the cover page. Have the advisor's signature(s) appear on* ***all*** *submitted copies)*

Student's Name	Advisor's Name	Advisor's Signature	2nd-yr	Thesis

Scientific Justification

Extinction Estimation for *Swift* UVOT Photometry

The *Swift* mission has been observing supernovae of all types since March 2005. More than half of the over 10,000 epochs of UV photometry are of type Ia supernovae (SNe Ia), making the UVOT instrument the most prolific UV observational tool for the study of SNe Ia. Milne et al. (2010), Brown et al. (2010) and Milne et al. (2013) (M13) have presented collective studies of the constantly increasing collection of SN Ia light curves, finding a number of interesting features in the UV light curves. The most notable finding for the normal SNe Ia regularly used in cosmology is that there are two sets of UV-optical color curves within that group, so called “NUV-red” and “NUV-blue” SNe Ia (Fig 1: left panel). Spectrophotometry of high-z SNe Ia show that while NUV-red SNe dominate at low-z, NUV-blue SNe dominate at high-z (Fig. 2: left panel from Milne, Foley, Brown & Narayan, ApJ submitted), meaning that the accelerating universe discovery was based upon a different variety of SNe Ia than those that dominate the SN templates.

The existence of two different groups of normal SNe Ia means that determination of the reddening and extinction is an issue. As the primary distinguishing characteristic between the NUV-red/blue groups is an offset in color, establishing that the offset is not caused by reddening is paramount. Reddening estimation to date uses the SN colors at peak (Phillips et al. 1999), at a late “tail” epoch (Lira 1995), or the entire peak light curve (MLCS2k2: Jha, Riess & Kirshner 2007), but does not differentiate between NUV-red/blue SNe Ia. As the NUV-blue group is roughly 1/3 of all low-z events, the techniques listed above are dominated by the NUV-red group. Indeed, as the NUV-blue events appear to be bluer in B-V by 0.15 mag (Fig 1: right panel), the reddening estimates for the 7 NUV-blue SNe Ia in Milne et al. 2013 are all negative. More work needs to be done to better understand SN Ia host galaxy extinction/reddening beyond existing methods.

M13 also report a strong correlation of NUV-blue events with the detection of unburned carbon in the early-epoch optical spectra, and comparisons of UV spectra reveal relatively less iron-peak absorption for NUV-blue events. This supports the existence of two groups, and leads to the question as to whether the NUV-optical color difference is due to optical faintness or UV excess. Since the determination of absolute magnitudes depends upon extinction estimation, knowing E(B-V) at the 0.1 mag level is our goal.

The method that we plan to explore is the estimation of dust extinction through correlation with the strength of each of the NaD and Ca H&K absorption lines. This correlation is based upon the hypothesis that sodium and calcium in gas traces dust (the extinction source). This correlation has been tested and quantified by observations of stars through Milky Way Galaxy (MWG) dust (Richmond et al. 1994 (R94); Munari & Zwitter 1997 (MZ97), Poznanski, Prochaska & Bloom 2012 (PPB12)). Most studies have presented a linear relation between EW(NaD) and E(B-V), such as the Barbon relation: E(B-V)=0.25 EW[/AA/]. MZ97 suggested that the relation is linear only for E(B-V) $\leq$ 0.4, deriving a curve-of-growth treatment for higher extinction, and estimating δE(B-V) to be in the range 0.05-0.15 mag. PPB12 present the most elaborate empirical relations for each line, finding: $\log_{10}$(E(B-V))=2.16 x EW(D_2) -1.91, $\log_{10}$(E(B-V))=2.47 x EW(D_1) -1.76 and $\log_{10}$(E(B-V))=1.17 x EW(D_1 +D_2) -1.85.

High-resolution spectra permit the separation of MWG NaD absorption from host galaxy absorption. MWG extinction is relatively well-determined from the dust maps of Schlafly & Finkbeiner 2011, and is the basis for the calibration of the NaD-E(B-V) relations. The real challenge is to estimate the host galaxy extinction from NaD. NaD-E(B-V) relations have also been explored through comparisons of NaD widths and SN color relations (Barbon et al. 1990, Turatto, Bennetti & Cappellaro 2003), but with a cautionary note to not attempt the correlation with low-resolution SN Ia spectra (Poznanski, Ganeshalingam, Silverman & Filippenko 2011). The situation is further complicated by the findings from many SN researchers that the dust that causes SN extinction in other galaxies differs from MWG dust (R_V=3.1). Lower values are reported both in multi-wavelength studies of single SNe Ia (Krisciunas et al. 2000, Altavilla et al. 2004, Elias-Rosa et al. 2006, Elias-Rosa et al. 2007) as well as providing the lowest Hubble residuals for extinction estimation from multi-light-curve shape fitting (MLCS2k2: Jha et al. 2006, Hicken et al. 2009). Wang et al. 2009 claims that SNe Ia with high-velocity SiIIλ6355 absorption features follow a different extinction law than lower-velocity SNe Ia, although Foley et al. 2012 argues that when highly-extincted SNe are eliminated and peak color differences are recognized for high/low-velocity, R_V=3.1 can explain both groups. Our study will combine NaD estimation from these spectra with UV-optical-NIR photometry from UVOT and ground-based data to simultaneously explore EW(NaD), EW(CaHK), E(B-V), and R_i for optical and NIR photometric bands for each SN. We will then look for differences between NUV-red/blue SNe Ia, high and low velocity SNe Ia and with/without unburned carbon in the early spectra SNe Ia. Through this multi-parameter investigation, we intend to improve the estimation of the extinction for the *Swift* UVOT sample.

Recently, two other tracers of extinction were investigated by Phillips et al. (2013), the Diffuse Insterstellar Bands (DIB: 5780Å) and K (7665, 7699Å) lines. Phillips et al. (2013) suggested that the DIB would trace host galaxy ISM extinction better than the NaD lines and the K lines are useful in situations where NaD lines saturate. That study was perfomed with the MIKE instrument on the Magellan-Clay telescope. With MAESTRO on the MMT, all these lines could be simulataneously obtained, providing an efficient, multi-line estimate of extinction. The wide wavelength range of the MAESTRO instrument make it ideal for the task of high-resolution, wide wavelength range optical spectroscopy.

Time Evolution of NaD Absorption as Evidence of CSM

For a handful of SNe Ia, multiple epochs of high-resolution spectra have been obtained for the NaD and Ca H&K aborption lines. For a few cases, the strength of the NaD line has changed (SN2006X: Patat et al. 2007; SN2007le: Simon et al. 2009; SN1999cl: Blondin et al. 2009). This has been interpreted as evidence of CSM surrounding the type Ia progenitor system, the variability due to the SN emission disrupting the CSM NaD lines, but not the bluer Ca H&K lines. Detecting CSM around a SN Ia, and estimating the location and amount of CSM is all valuble information towards determining the binary pair that led to the thermonuclear explosion. This is very important for SN Ia science, as one of the major avenues of current research is to attempt to determine which explosion scenario(s) accounts for the majority of SNe Ia. The NAVAR project has observed many SNe Ia and 1/6th of their candidates featured time-variable NaD absorption (Patat). We will attempt to obtain multiple-epochs of spectra for some targets, to search for evidence of CSM.

Line Profiles as Probes of SN Ia Explosions

High-resolution spectra of NaD absorption lines permit the investigation as to the line profiles. Sternberg et al. (2011) showed that half of all SNe Ia with detectable host-galaxy NaD absorption have line profiles with significant blueshifted wings. This was interpreted to be related to the SN explosion and evidence of strong winds. Foley et al. (2012) demonstrated that the blueshifted absorption feature was correlated with higher ejecta velocities, as measured from the dominant SiIIλ6355 absorption feature. Foley et al. (2012) further argued that the blueshifted, high-velocity events have redder colors at maximum light. Maguire et al. (2013) showed an excess of blueshifted NaD absorption lines, compared to redshifted absorption lines, statistically demonstrating that 20% of SNe Ia appear to feature detectable CSM. Interestingly, all 3 NUV-blue SNe in the Maguire et al. 2013 sample show no NaD, while all 3 NUV-red SNe Ia show blueshifted NaD. By concentrating on UVOT SNe Ia, we intend to dramatically improve the sampling. By simultaneously obtaining NaD, Ca H&K, and K line profiles, we will have multiple examples of each line profile for verifying any interesting features. MAESTRO spectra of 3-4 SNe Ia has already been obtained during MAESTRO commissioning and have demonstrated the promise of the pairing of MMT & MAESTRO.

References

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[2] Elias de la Rosa, N., Benetti, S., Cappellaro, E., et al., *MNRAS* **369**, 1880 (2006).
[3] Foley, R. et al., *ApJ*, **752**, 101 (2012).
[4] Maguire, K. et al., *MNRAS*, in press, astroph 1308.3899
[5] Brown, P. J., et al. 2010, ApJ, 721, 1608
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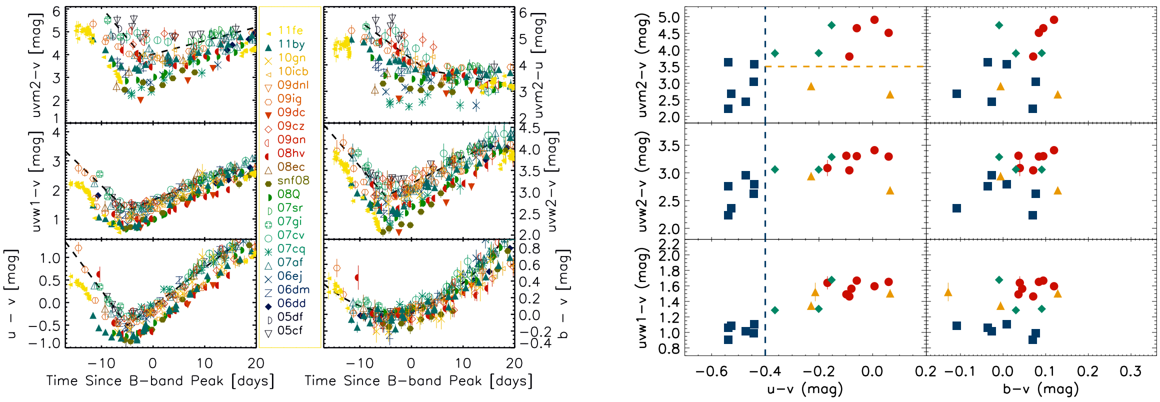

Figure 1: Left: UV-optical colors of 23 SNe Ia as observed with *Swift* UVOT. Roughly one-third of the SNe are offset and bluer than the larger group. These are the NUV-blue and NUV-red groups, respectively. Right: Color-color plots of SNe Ia obtained from *Swift* UVOT photometry. The NUV-blue group (blue filled symbols) are much bluer in $u - v$ and UV-v colors, but are also slightly bluer in $b - v$.

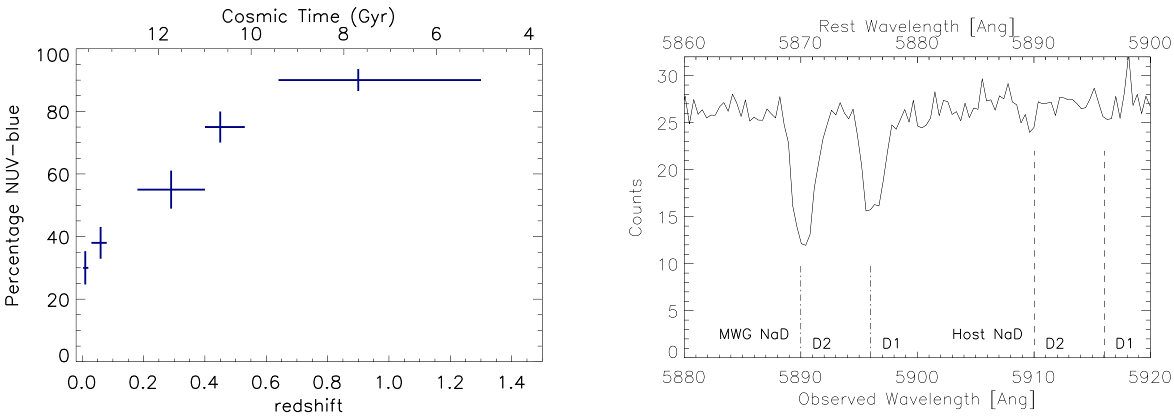

Figure 2: Left: Ratio of NUV-blue to NUV-red SNe Ia as a function of redshift. At low-z, there are more NUV-red events, but with increasing redshift, the NUV-blue events become the dominant group. Right: A spectrum obtained on the 1.8m VATTSPEC spectrometer showing MWG NaD absorption for SN 2013ak. The wavelength for any host galaxy absorption is indicated with dashed lines.

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Experimental Design & Technical Description *Describe your overall observational program. How will these observations contribute toward the accomplishment of the goals outlined in the science justification? If you've requested long-term status, justify why this is necessary for successful completion of the science. **(up to one page)***

The proposed observations will be a continuation of a series of NaD observations of UVOT SNe. We intend to obtain NaD EWs for UVOT SNe for the duration of the *Swift* mission. Once we have a collection of $\sim$10 SNe Ia, we should have enough information to develop a basic understanding of whether spectra of NaD absorption will be able to demonstrate a systematic failure of existing extinction-estimation formulae to accurately extimate E(B-V) for NUV-red/blue SNe Ia.

We request 2 hours of observing per night during two-2 night runs of the MAESTRO instrument on the MMT, totalling 8 hours over 4 nights, but spread out over UAO MAESTRO runs to increase the sample size. The requested nights can be grey or bright time, as the high dispersion makes the observations relatively less affected by moonlight.

Summary of Time Requested and Awarded *The TAC needs to understand the scope of this project — (1) tell us how many UAO nights you've already had for this project, how many you request this time, and (a good guess of) how many you need to complete the project; (2) if a substantial amount of observing for this project comes from non-UAO telescopes, tell us about that observing, and how the UAO part fits in; (3) if you are collaborating with people who have telescopes, especially if you are part of a large collaboration, tell us who is leading the project, and how UAO time and your participation fit in. (**up to one page**)*

We request a portion of 4 nights, split into two runs of two nights per run. Ideally, the runs would be separated in time by 2 months to permit the study of more UVOT SNe Ia and to search for time evolution of the absorption lines in previously observed SNe. Sharing would be ideal, as there are normally not enough targets to jusstify an entire night of SN observing. We intend this project to continue for the duration of the *Swift* mission, to provide support for the SN program. It is realistic to expect the mission to continue for 5 or so more years. We will collaborate with other observers to try to obtain the same information for southern telescopes.

Previous Use of Steward Facilities *List **all** allocations of telescope time for the present project and allocations for other projects on facilities available through UAO during the past 2 years, together with the current status of the data (cite publications where appropriate). Mark those allocations related to the present proposal (i.e, precede text with* `\related` *command). (**up to one page**)*

The Super-LOTIS, Kuiper and Bok telescopes have all been used to observe the SNe that are the proposed targets of this proposal. Observations of seven normally- and super-luminous SNe Ia comprised the data presented in Lair et al. 2007.

Lair, J.C., Leising, M.D., Milne, P.A., & Williams, G.G., *AJ* **132**, 2024 (2006).

Observations of SNe 2003gs, 2003hv, 2007ax, 2008D, 2006bp, GRB070115, GRB070419A have all been obtained as part of this program and published as a portion of a larger effort.

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