Resubmission of 12B-0500

NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: March 31, 2017 **Category:** Cosmology

Understanding Host Galaxy Contamination of Supernovae observed in the "SweetSpot" Survey

Abstract of Scientific Justification *(will be made publicly available for accepted proposals)*:

We ask for 11 nights of WIYN+WHIRC time to obtain 20 host galaxy template images to complete the SweetSpot program to observe Type Ia supernovae in the NIR (2012B-0500). The originally approved SweetSpot observed 114 Type Ia supernovae during its six semester run. Host galaxy template images were gathered during the main survey and in additional time allotted in 2015B, 2016A, and 2017A semesters (2012B-0500, 2015B-0347). We require host galaxy template observations to assemble all necessary reference images to allow accurate measurement of the supernova flux, and thus distance, for the supernovae observed in SweetSpot. We previously only sought templates for supernovae that we deemed to have heavy contamination of host galaxy flux via individual image inspection. However, with the current sample of host galaxies, we are unable to make quantitative arguments of the level of host galaxy contamination for our full supernova sample. In order to answer this question, we request to observe a suite of fields that contained supernovae with various levels of contamination.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	WIYN	WHIRC	11	bright	Aug-Jan	Aug-Jan
2						
3						
4						
5						
6						

Scheduling constraints and non-usable dates *(up to six lines)*.

We request at least one half night in January since that is the only time one of our targets is observable. We can make use of T&E nights during the semester.

Investigators *List the name, status, and current affiliation for all investigators. The status code of "P" should be used for all investigators with a Ph.D. or equivalent degree. For graduate students, use "T" if this proposal is a significant part of their thesis project, otherwise use "G".*

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CoI: Peter Garnavich **Status:** P **Affil.:** University of Notre Dame
CoI: Lori Allen **Status:** P **Affil.:** NOAO

Scientific Justification *Be sure to include overall significance to astronomy. For standard proposals limit text to one page with figures, captions and references on no more than two additional pages.*

How Standard are Type Ia Supernovae Standard Candles in the Near-Infrared? In our quest toward precision measurements of dark energy with Type Ia supernovae (SNeIa) [1, 22, 14, 7, 13, 4, 3] we have became limited by systematic errors due to our incomplete understanding of SNIa colors, dust, and their host environments. SNeIa are superior distance indicators in the NIR, with more standard peak H magnitudes and relative insensitivity to reddening [18, 16, 15]. As a result, unlike optical Type Ia SNe, which are *standardizable* candles, NIR SNe Ia appear to be truly *standard* candles at the $\sim$ 0.10–0.15 mag level ($\sim$ 5–7% in distance) [16, 17, 23, 6, 20, 2, 8].

Motivated by this opportunity, the "SweetSpot" (PI Wood-Vasey; [20]) and the "CSP-II" (PI M. Phillips; [5, 19]) programs were undertaken to build a comprehensive sample of SNeIa observed in the NIR in the nearby Hubble flow. The scientific goals of SweetSpot are: **(1)** Testing if SNeIa are better standard candles in the NIR. **(2)** Breaking the color-dust degeneracy with NIR observations. **(3)** Investigating the nature of SNIa host galaxies using NIR and optical observations **(4)** Connecting local flows and motions with SNIa NIR to galaxies and convergence.

Obtaining final host galaxy images free from the contamination of the SN light will be critical in obtaining accurate apparent brightness measurements for the SN light curve. These observations will also help provide measurements of the host galaxy stellar mass along with detailed morphology.

Throughout the SweetSpot program, we devoted time to obtain needed host galaxies templates for SNeIa from the previous year. We gathered 36 host galaxy templates during the originally allotted SweetSpot survey time. After the program ended, we requested time in 2015B, 2016A, and 2017A to collect templates from supernovae observed in the last year of our program and any host galaxy templates that we had not previously been able to observe. We were able to gather 16 more host galaxy templates from the extra nights awarded

In February 2017, we submitted the first data release of SweetSpot: "The First Data Release from SweetSpot: 74 Supernovae in 36 Nights on WIYN+WHIRC"[21] for publication in the Astrophysical Journal. We are only presenting 34 lightcurves out of the 74, because the other 40 supernova are heavily contaminated by their host galaxy. For the lightcurves presented, our argument was that by visual inspection we did not find a significant amount of host galaxy flux surrounding the site of the supernova. However, our referee report notes that we should be able to quantitatively justify when we do and do not need a host galaxy template. We do not currently have enough data to answer this question. We need a wider variation in host galaxy templates to quantify this especially for supernova at higher redshifts where we can barely measure any flux from the host galaxy. These higher redshift supernovae are key to probing the smooth Hubble flow. We believe these 20 additional templates will provide the necessary information to quantitatively analyze when a host galaxy template is required. Figure 1 shows cutouts of 3 fields from our sample to illustrate different levels of contamination.

References

[1] Astier, P., et al. (2006) *A&A*, 447, 31.

[2] Barone-Nugent, R. L. et al. (2012) *MNRAS*, 425, 1007.

[3] Betoule, M. et al. (2014) *A&A*, 568, 22.

[4] Conley, A., et al. (2011), ApJS, 192, 1

[5] Contreras, C., et al. (2010) *AJ*, 139, 519.

[6] Folatelli, G., et al. (2010) *AJ*, 139, 120.

[7] Hicken, M., et al. (2009) *ApJ*, 700, 1097.

[8] Kattner, S. et al. (2012) *PASP*, 124, 114.

[9] Kauffmann, G., Heckman, T. M., and White, S. D. M. (2003) *MNRAS*, 341, 33.

[10] Kelly, P. L., et al. (2010) *ApJ*, 715, 743.

[11] Kelly, P. L., et al. (2015) *Science*, 2015 Mar 27. arXiv:1410.0961.

[12] Kennicutt, R. C. (1998) *ARA&AA*, 36, 189.

[13] Kessler, R., et al. (2009) *ApJS*, 185, 32.

[14] Kowalski, M., et al. (2008) *ApJ*, 686, 749.

[15] Krisciunas, K., et al. (2007) *ApJ*, 133, 58.

[16] Krisciunas, K., Phillips, M. M., and Suntzeff, N. B. (2004) *ApJL*, 602, L81.

[17] Krisciunas, K., et al. (2005) *AJ*, 130, 350.

[18] Meikle, W. P. S. (2000), *MNRAS*, 314, 782.

[19] Stritzinger, M., et al. (2011), *AJ*, 142, 156.

[20] Weyant, A. et al. (2014) *ApJ*, 784, 105.

[21] Weyant, A. et al. (2017) *ApJ submitted*, arXiv:1703.02402.

[22] Wood-Vasey, W. M., et al. (2007) *ApJ*, 666, 694

[23] Wood-Vasey, W. M., et al. (2008) *ApJ*, 689, 377.

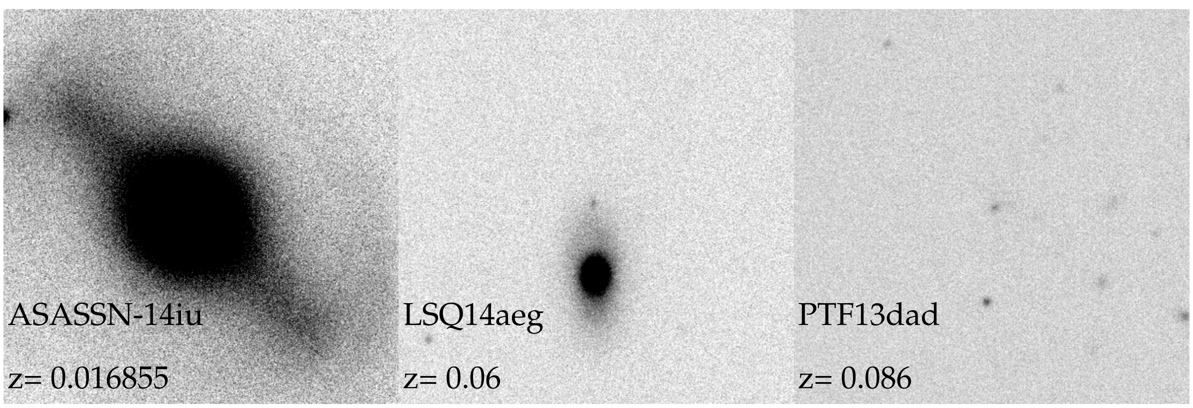

Figure 1: Postage stamps from 3 fields showing a heavily contaminated field (left), supernova on the edge of a galaxy (middle), and a high redshift supernova with faint host (right).

Experimental Design *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. (limit text to one page)*

We request a total of 11 nights for WHIRC observations of host galaxies of SNeIa and standard stars. We will observe 20 host galaxies that will aid in our understanding and calculations of when a host galaxy template is needed. Since these fields had supernovae in a wider variety of locations in the galaxy, we will be able to extrapolate if any of our other supernovae need a template or argue why they do not need templates. 8 of the host galaxies were also observed by us using HexPak (2015B-0347). Having these two data sets (photometry plus spatial spectroscopy) will provide added information to determining the level of host galaxy flux at the location of the supernova.

We will also observe several Persson standard stars in all 3 filters throughout the night.

These observations will be undertaken with WHIRC in J, H, and K_s depending on which filters were used for supernova observations and will provide reference flux values critical to obtaining SN lightcurves and improved PWV calibration. We will also use WTTM if available to improve the FWHM.

The host galaxy observations will also generate maps of the host galaxy at the high resolutions offered by the WIYN+WHIRC system for general study of detailed NIR morphology and host galaxy mass. For host galaxies also observed with an integral field unit, it will also help us model the old population in these galaxies and put constraints on R_V.

Proprietary Period: 18 months

Use of Other Facilities or Resources *(1) Describe how the proposed observations complement data from non-NOAO facilities. For each of these other facilities, indicate the nature of the observations (yours or those of others), and describe the importance of the observations proposed here in the context of the entire program. (2) Do you currently have a grant that would provide resources to support the data processing, analysis, and publication of the observations proposed here?"*

1. These observations will complement the data from other nearby supernova groups such as KAIT, the CfA Supernova group, and the Carnegie Supernova Project to produce the most complementary data sets to enable explorations of optical vs. NIR distance estimation, color, and host galaxy properties. The first steps toward higher redshift are currently being undertaken on *HST* through the RAISIN project (PI R. Kirshner). Farther in the future and going farther in the past, the nearby NIR SNIa set will provide a reference anchor for future higher-redshift restframe NIR work with *JWST* and *WFIRST*.

In order to examine global and local host galaxy properties to search for correlations with how bright the supernova was at time of maximum, we have observed many SweetSpot host galaxies with integral field units (IFUs). The All-weather MUse Supernova Integral field Nearby Galaxies (AMUSING) survey (PI: L. Galbany) has dedicated their fourth and fifth surveys (conducted during Oct 2016-Mar 2017 and Apr-Sep 2017, respectively) to observing supernova with NIR light curves, including 28 SweetSpot hosts in the 4th survey and 17 SweetSpot hosts planned for the 5th survey. The AMUSING survey is conducted using the MUSE IFU mounted on the VLT and already has several semesters of host galaxy observations for many different kinds of supernova. With Centro Astronomico Hispano Aleman (CAHA) PMAS+PPAK IFU (PI L. Galbany), the PI of SweetSpot and two Co-Is (L. Galbany and K. Ponder) have been awarded roughly 5 nights to date to observe SweetSpot host galaxies in the northern sky. To account for the other supernovae: 28 fields observable from the south already have data from previous surveys (AMUSING surveys, HexPak, PMAS, or MaNGA). In the north, 41 are observable with 14 proposed for PMAS 2017B, 5 planned for PMAS 2017A, 15 previously observed on PMAS or elsewhere, and 7 with no discernible host galaxy.

2. The PI is currently funded by NSF AST-1028162 to carry out the SweetSpot program and related nearby SNIa work. This grant will continue to support graduate students to do the observations, analysis and publications for these proposed observations.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the last 2 years for regular proposals, and at any time in the past for survey proposals (including participation of the PI as a Co-I on previous NOAO surveys), together with the current status of the data (cite publications where appropriate). Mark with an asterisk those allocations of time related to the current proposal. Please include original proposal semesters and ID numbers when available.*

This proposal will provide the final data necessary to complete our NOAO Survey program "Type Ia Supernovae in the Near-Infrared: A Three-Year Survey toward a One Percent Distance Measurement with WIYN+WHIRC" $\boxed{\star}$ 2012B-0500. We observed 114 SNeIa and 1 SN Ibn (SN 2015G) during the main program. The first results from this Survey were published in [20]. A first data release paper with 74 SNeIa and 34 light curves was submitted to the Astrophysical Journal and posted to the arXiv in February 2017[21], and we are currently working through the first referee report. Final data reductions of all targets have already begun in preparation for the second and full data release. Under the proposal ID of the original survey $\boxed{\star}$ 2012B-0500, we have collected host galaxy templates in 2015B, 2016A, and 2017A.

In 2015B, we had another proposal called "Final Host Galaxy Observations for 'SweetSpot': Calibrating the Supernova Host Galaxy Light and Environment" $\boxed{\star}$ 2015B-0347. The goal in this proposal was not only to observe more host galaxy templates, but also to use the IFU HexPak mounted on WIYN to observe spatially resolved spectra of host galaxies. We successfully observed 32 host galaxies and the data reduction is nearly complete. 8 of these galaxies do not have host galaxy templates. These templates will help us constrain the older populations in the host galaxy and also help us measure the amount of flux from the host galaxy for more precise errors.

PI Wood-Vasey was involved in the 6-year ESSENCE Supernova Survey (PI Suntzeff) that used the CTIO 4.0-m Blanco telescope to discover and study 213 Type Ia Supernovae to measure the dark energy equation-of-state during the past 8 billion years. This survey has so far led to 10 refereed publications that have been cited a combined 1,657 times.

G. Narayan et al. (2016), ApJS, 224, 36.
R. J. Foley et al. (2009), AJ, 137, pp. 3731-3742.
R. J. Foley et al. (2008), ApJ, 684, pp. 68-87.
S. Blondin et al. (2008), ApJ, 682, pp. 724-736.
A. C. Becker et al. (2008), ApJL, 682, pp. 53-56.
T. Davis et al. (2007), ApJ, 666, pp. 716-725.
W. M. Wood-Vasey et al. (2007), ApJ, 666, pp. 694-715.
G. Miknaitis et al. (2007), ApJ, 666, pp. 674-693.
S. Blondin et al. (2006), AJ, 131, pp. 1648-1666.
K. Krisciunas et al. (2005), AJ, 130, pp. 2453-2472.

Observing Run Details for Run 1: WIYN/WHIRC

Technical Description *Describe the observations to be made during this observing run. Justify the specific telescope, the number of nights, the instrument, and the lunar phase. List objects, coordinates, and magnitudes (or surface brightness, if appropriate) in the Target Tables section below (required for queue and Gemini runs).*

These host galaxy templates will help us to quantitatively estimate when a host galaxy needs a template and when it does not.

We need to obtain 20 host galaxy references. Observations need to be at least 3 times as long as the longest exposure of the field when the supernova was live (assuming 1″ seeing). Our template observations need have better signal to noise than our supernova observations for accurate template subtractions. See table below for total exposure times (# of exp. = total exposure time since each image is 60 seconds). All of these targets will use the 5x5x15" dither script which take $\sim$ 33 minutes to run. This sample needs 88 hours on sky to run the scripts. We then add in 90 minutes per night to observe standard stars and to set up on different targets. Assuming on average we have 9.5 hours in a night, we need 11 nights on the telescope.

Nights do not need to be photometric. The night sky is bright in the NIR regardless of the phase of the Moon; therefore, observations during bright time are acceptable.

In the comments section of the target table below, we identify which supernova fields have been observed with HexPak. The supernova that is starred is only observable in January.

Instrument Configuration

Filters: J, H, Ks	Slit:	Fiber cable:
Grating/grism:	Multislit:	Corrector:
Order:	λ_{start}:	Collimator:
Cross disperser:	λ_{end}:	Atmos. disp. corr.:

R.A. range of principal targets (hours): 00 to 23

Dec. range of principal targets (degrees): -14 to +50

Special Instrument Requirements *Describe briefly any special or non-standard usage of instrumentation.*

Target Table for

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
001	iPTF14gnl	00:23:48.33	-03:51:27.9	2000		J,H	60	150,150	14	phot	1	
002	PTF13ddg	00:47:50.83	+31:49:17.5	2000		H	60	200	14	phot	1	
003	PTF13dad	01:48:08.39	+37:33:29.1	2000		J,H	60	150,150	14	phot	1	
004	iPTF13ebh	02:21:59.98	+33:16:13.7	2000		J,H,Ks	60	25,25,25	14	phot	1	HexPak
005	LSQ13cwp	04:03:50.662	-02:39:18.57	2000		J,H	60	125,125	14	phot	1	
006	PSNJ0835166	08:35:16.68	+48:19:01.1	2000		J,H,Ks	60	75,125,50	14	phot	1	
007	PS15mb	08:59:40.20	+15:11:12.5	2000		J,H	60	125,75	14	phot	1	HexPak
008	SNhunt263	09:08:42.48	+44:48:13.2	2000		J,H,Ks	60	150,75,125	14	phot	1	HexPak
009	ASASSN-15ho	09:09:23.89	-04:43:30.10	2000		J,H	60	75,75	14	phot	1	HexPak
010	ASASSN-14iu	09:10:39.53	+50:22:48.26	2000		J,H,Ks	60	25,25,25	14	phot	1	
011	ASASSN-15hg	09:53:48.62	+09:11:37.8	2000		J,H,Ks	60	50,50,50	14	phot	1	HexPak
012	LSQ14aeg	10:19:36.79	+19:33:20.3	2000		J,H	60	125,75	14	phot	1	HexPak
013	PSNJ1029279	10:29:27.99	+22:00:46.8	2000		J,H	60	150,150	14	phot	1	HexPak
014	iPTF15xi	12:12:27.85	+32:09:54.5	2000		J,H	60	150,150	14	phot	1	
015	SN2012bm	13:05:45.621	+46:27:52.39	2000		J,H	60	25,25	14	phot	1	
016	SN2013bo	13:17:29.19	+42:44:29.6	2000		J,H	60	75,75	14	phot	1	
017	PS15sv	16:13:11.74	+01:35:31.1	2000		J,H,Ks	60	100,100,50	14	phot	1	*
018	SN2013fn	21:00:23.673	-14:29:52.42	2000		J,H,Ks	60	50,50,50	14	phot	1	HexPak
019	LSQ14fmg	22:16:46.1	+15:21:14.1	2000		J,H	60	150,125	14	phot	1	
020	CSS121006	23:28:54.52	+08:54:51.4	2000		H	60	125	14	phot	1	