Resubmission of 12B-0500

NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: March 29, 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 32 nights of WIYN+WHIRC time to obtain 59 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 the last semesters of SweetSpot. We previously only sought templates for supernovae that we deemed to have heavy contamination of host galaxy flux via individual image inspection. However, we are unable to make quantitative arguments for 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. This includes high redshift supernovae in galaxies with small angular size or low surface brightness. To be more precise in all of our measurements, we also request to observe all remaining supernovae without templates, which corresponds to 51% of the total SweetSpot data set.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	WIYN	WHIRC	11	bright	Sep-Jan	Sep-Jan
2	WIYN	WHIRC	17	bright	Sep-Jan	Sep-Jan
3	WIYN	WHIRC	4	bright	Jan	Jan
4						
5						
6						

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

Run 1 is a list of priority objects that we need to observe to make quantitative estimations on when a supernova needs a host galaxy template. Run 2 is a full list of unobserved host galaxies (Not including Run 1, Run 3, or previously observed hosts). Run 3 contains host galaxies whose supernovae were observed in a Spring semester and are only observable in January. We can make use of T&E nights throughout 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: 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 ~ 0.10–0.15 mag level (~ 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 have devoted time to obtain needed host galaxies templates for SNeIa from the previous year. We requested 6 additional nights in the 2015B–2016A semesters to finish host galaxy templates from the last original SweetSpot year of 2014B-2015A. We obtained 12 host galaxy templates during this awarded extension time, but unfortunately a bit of poor weather in 2016A prevented us from finishing the last 2 host galaxy observations. We were able to observe these 2 templates in 2017A after a second half night became available in March.

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 presenting 34 lightcurves out of the 74, because the other 40 supernova are heavily contaminated by their host galaxy. Our argument was that by visual inspection we did not find a significant amount of host galaxy flux at 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 wide range of host galaxy templates to quantify this especially for supernova at higher redshifts where we can barely see any flux from the host galaxy. These higher redshift supernovae are key to probing the smooth Hubble flow.

We would like to explore these different templates to justify when we need or do not need host galaxy templates (see sample in Observing Run 1). Moreover, to be able to remove any possible host galaxy flux and give proper errors on our measured fluxes, we would like to observe host galaxy templates for all of our SweetSpot supernovae. We currently need 59 templates which accounts for 51% of our total sample.

Additionally, 4 of these supernovae are heavily contaminated by their host but had not previously prioritized host galaxy template observations due to their sparsely sampled lightcurves. Without these host galaxy template references, we will not be able to produce lightcurves for these 4 supernovae.

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.

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 32 nights for WHIRC observations of host galaxies of SNeIa and standard stars.

We will observe the 4 host galaxies from SweetSpot that will require template observations due to significant inferred host galaxy light contributions at the location of the SNeIa. These were not previously taken because they only have one lightcurve point; however, they are still useful in our dataset once they have templates. We will observe 15 host galaxies that will aid in our understanding and calculations of when a host galaxy template is needed. The other 40 hosts consist of the full sample of SweetSpot that are not obviously heavily contaminated. However to get the most precise measurements of flux, we still need to observe their host galaxies.

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 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 fifth survey to observing supernova with NIR light curves including 13 SweetSpot supernova that still need host galaxy templates. The AMUSING survey is conducted using the MUSE IFU mounted on the VLT and already has several semesters of host galaxy observations of 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 so far to observe SweetSpot host galaxies in the northern sky.

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, and we are currently working through the first referee report [21]. 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 the WIYN to observe spatially resolved spectra of host galaxies. We successfully observed 32 host galaxies and the data reduction is nearly complete. 7 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).*

Run 1 consists of host galaxy templates that will help is to quantitatively estimate when a host galaxy needs a template and when it does not. It also includes host galaxies for supernovae that were heavily contaminated by their hosts, but did not make our previous quality cuts for getting a host galaxy template, as well as host galaxies that were observed with HexPak but did not previously get templates.

We need to obtain 18 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 80 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 10 nights on the telescope. We then add a 10% contingency for issues setting up or any unforeseeable problems to give the final number of 11 nights.

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 and which have high levels of contamination (HC).

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 +46

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

Target Table for Run 1 - Priority Targets

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
001	PTF13ddg	00:47:50.83	+31:49:17.5	2000		H	60	200	14	phot	1	
002	PTF13dad	01:48:08.39	+37:33:29.1	2000		J,H	60	150,150	14	phot	1	
003	iPTF13ebh	02:21:59.98	+33:16:13.7	2000		J,H,Ks	60	25,25,25	14	phot	1	HexPak
004	LSQ13cwp	04:03:50.662	-02:39:18.57	2000		J,H	60	125,125	14	phot	1	
005	PSNJ08351668	08:35:16.68	+48:19:01.1	2000		J,H,Ks	60	75,125,50	14	phot	1	
006	PS15mb	08:59:40.20	+15:11:12.5	2000		J,H	60	125,75	14	phot	1	HexPak
007	ASASSN-15hg	09:53:48.62	+09:11:37.8	2000		J,H,Ks	60	50,50,50	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	LSQ14aeg	10:19:36.79	+19:33:20.3	2000		J,H	60	125,75	14	phot	1	HexPak
010	PSNJ10292799	10:29:27.99	+22:00:46.8	2000		J,H	60	150,150	14	phot	1	HexPak
011	iPTF15xi	12:12:27.85	+32:09:54.5	2000		J,H	60	150,150	14	phot	1	
012	SN2012bm	13:05:45.621	+46:27:52.39	2000		J,H	60	25,25	14	phot	1	HC
013	SN2013bo	13:17:29.19	+42:44:29.6	2000		J,H	60	75,75	14	phot	1	
014	SN2013fn	21:00:23.673	-14:29:52.42	2000		J,H,Ks	60	50,50,50	14	phot	1	HexPak
015	LSQ14fmg	22:16:46.1	+15:21:14.1	2000		J,H	60	150,125	14	phot	1	
016	CSS121006	23:28:54.52	+08:54:51.4	2000		H	60	125	14	phot	1	
017	ASASSN-14iu	09:10:39.53	+50:22:48.26	2000		J,H,Ks	60	25,25,25	14	phot	1	HC
018	iPTF14gnl	00:23:48.33	-03:51:27.9	2000		J,H	60	150,150	14	phot	1	HC

Observing Run Details for Run 2: 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).*

Run 2 includes all other supernovae that do not have host galaxy templates. These are fields that we did not deem as a priority to determine how to quantitatively measure when a supernova needs a host galaxy template.

We need to obtain 31 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). Most of these targets will use the 5x5x15" dither script which take $\sim$ 33 minutes to run. Some may use 4x4x20" dither which takes roughly 20 minutes to run. This sample needs 122 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 15.5 nights on the telescope. We then add a 10% contingency for issues setting up or any unforeseeable problems to give 17 nights.

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.

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): -36 to +69

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

Target Table for Run 2 - All SweetSpot fields not yet observed

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment

Observing Run Details for Run 3: 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).*

Run 3 includes host galaxies that are only observable for the month of January. These fields were originally observed in Spring semesters. All other targets have at least 2 months of visibility.

We need to obtain 11 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 28.7 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 10.5 hours in a night, we need 3.5 nights on the telescope. We then add a 10% contingency for issues setting up or any unforeseeable problems to give 4 nights.

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 have high levels of contamination (HC).

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): 12 to 16

Dec. range of principal targets (degrees): -17 to +61

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

Target Table for Run 3 - Targets only available in January

Obj ID	Object	α	δ	Epoch	Mag.	Filter	Exp. time	# of exp.	Lunar days	Sky	Seeing	Comment
001	SN2011jh	12:47:14.42	-10:03:47.2	2000		J,H	60	50,50	14	phot	1	
002	SN2011iy	13:08:58.38	-15:31:04.0	2000		J,H	60	50,50	14	phot	1	
003	PTF11qri	12:47:06.276	-06:19:49.46	2000		J,H	60	75,75	14	phot	1	
004	PTF11qri	12:47:06.276	-06:19:49.46	2000		J,H	60	75,75	14	phot	1	
005	SN2012bo	12:50:45.215	-14:16:07.69	2000		J,H	60	25,25	14	phot	1	
006	SN2013cs	13:15:14.839	-17:57:55.24	2000		J,H,Ks	60	25,25,25	14	phot	1	
007	SN2013bt	14:21:15.185	+61:34:15.42	2000		J,H	60	75,100	14	phot	1	
008	PS1-14ra	14:41:28.44	+09:25:58.7	2000		J,H	60	75,50	14	phot	1	
009	PSNJ15024996	15:02:49.96	+48:47:06.2	2000		J,H,Ks	60	75,50,75	14	phot	1	
010	PS15sv	16:13:11.74	+01:35:31.1	2000		J,H,Ks	60	100,100,50	14	phot	1	HC
011	SN2012bp	16:18:12.451	+36:28:51.87	2000		J,H	60	25,50	14	phot	1	