OBSERVING REQUEST
University of Arizona Observatories

Year: 2015 **Term:** Jul–Dec **Proposal type:** long-term⋆ **Proposal ID:** L275

The Supernova Spectropolarimetry (SNSPOL) Project; Using SPOL to Probe the 3-D Nature of Supernova Explosions

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CoI(s): Paul Smith (SO), Nathan Smith (SO), Peter Milne (SO), Chris Bilinski⋆ (SO)

Abstract of Scientific Justification

This is a progress report on a previously awarded long-term proposal, L275. The following is the abstract from the original proposal. With the resources available at Steward Observatory we are uniquely poised to make a significant contribution to the understanding of the three dimensional nature of supernova explosions. To do so requires regular access to telescopes of various aperture, from modest to large, and a sensitive polarimeter. Here we are proposing to use the 61" Kuiper, the 90" Bok, and the 6.5-m MMT (using director's time) telescopes together with the SPOL instrument to identify spherical asymmetries in supernovae and monitor their evolution. Polarimetry allows us to probe scales in a supernova that cannot be imaged from earth or space. Spectropolarimetry enhances the power of this technique by allowing us to probe the geometry of specific ionic species, a very powerful tool in the study of supernovae. In recent years, evidence has grown that nearly *all* supernovae have departures from spherical symmetry. These findings, together with advances in computing power that enable full 3-D modeling, have lead to suggestions that asymmetries are not just observable consequences of supernovae but may in fact be a *necessity* of the explosion mechanism. We propose to use SPOL to observe the brightest core collapse and thermonuclear explosions during multiple epochs. Our goal is to complete a long-term *comprehensive* survey of all types of supernovae. The principal objective of this effort is to improve our understanding of the predominance and characteristics of asymmetries in the different types of supernovae. Sep. 1, 2014 marked the start of the third year of a three year NSF/AAG grant that was awarded to carry out this survey. At the end of 2014 we'd observed 53 supernovae, 43 of which have multi-epoch observations.

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	90"	f/9	SPOL	*		1	grey	Sep	Aug–Oct	yes	no
2	90"	f/9	SPOL	*		1	grey	Oct	Sep–Nov	yes	no
3	90"	f/9	SPOL	*		1	grey	Nov	Oct–Dec	yes	no
4	90"	f/9	SPOL	*		1	grey	Dec	Nov–Dec	yes	no
or:											
1a	61"	f/13	SPOL	*		1	grey	Sep	Aug–Oct	yes	no
2a	61"	f/13	SPOL	*		1	grey	Oct	Sep–Nov	yes	no
3a	61"	f/13	SPOL	*		1	grey	Nov	Oct–Dec	yes	no
4a	61"	f/13	SPOL	*		1	grey	Dec	Nov–Dec	yes	no

Scheduling constraints and unusable dates *(up to 4 lines)*: Nights should be scheduled adjacent to (either before or after) or during the time awarded to Paul Smith's Fermi blazar proposal. We are requesting one night every month at either the 90" or 61".

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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	SN 2015??			$V \leq 16.0$
2	SN 2015??			$V \leq 16.0$
3	SN 2015??			$V \leq 16.0$
4	SN 2015??			$V \leq 16.0$
5	SN 2015??			$V \leq 16.0$
6	SN 2015??			$V \leq 16.0$
7	SN 2015??			$V \leq 16.0$

Approval for Instrument Use from PI: Paul Smith, the PI of SPOL, is a CoI on this proposal. He has approved the use of the instrument.

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
Chris Bilinski	Nathan Smith		no	yes

Scientific Justification

This proposal has already been granted long-term status (L275) in 2015A and therefore no additional scientific justification is required.

References

Li, W., Leaman, J., Chornock, R., Filippenko, A. V., Poznanski, D., Ganeshalingam, M., Wang, X., Modjaz, M., Jha, S., Foley, R. J., & Smith, N. 2011, Monthly Notices of the Royal Astronomical Society, 412, 1441

Mauerhan, J., Williams, G. G., Smith, N., Smith, P. S., Filippenko, A. V., Hoffman, J. L., Milne, P., Leonard, D. C., Clubb, K. I., Fox, O. D., & Kelly, P. L. 2014, Monthly Notices of the Royal Astronomical Society, 442, 1166

Smith, N., Mauerhan, J. C., Cenko, S. B., Kasliwal, M. M., Silverman, J. M., Filippenko, A. V., Gal-Yam, A., Clubb, K. I., Graham, M. L., Leonard, D. C., Horst, J. C., Williams, G. G., Andrews, J. E., Kulkarni, S. R., Nugent, P., Sullivan, M., Maguire, K., Xu, D., & Ben-Ami, S. 2015, ArXiv e-prints

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)***

Because a supernova photosphere recedes through the ejecta with time, multi-epoch observations will probe different depths in the ejecta. The typical result is that specific absorption or emission lines will dramatically change in either degree of polarization, position angle or both.

Our goal is to obtain at least three well sampled epochs of spectropolarimetric data for each target supernova. Ideally, these epochs would span the evolutionary periods of the SN: well before peak (~ -14 days), near peak (~ 0 days) and at least one measurement after peak ($\sim +14$ days). However, from a sky brightness/background polarization perspective this fourteen day cadence is far from ideal since it is one half a lunation. Furthermore, the epoch of a given observation is at the mercy of the explosion and discovery dates for each SN. Therefore, the instrument and telescope availability is the principal driver in our request for time.

Since P. Smith's long-term Fermi blazar monitoring proposal (L198) uses SPOL, the instrument is likely to be scheduled on either the 61" or 90" approximately one week every month. We would like to piggy-back on that program and therefore request that one night be added to each of those runs for this program. The observing time for the entire SPOL run will utilize a queue mode thereby optimizing the efficiency for both the blazar monitoring program and the SN program.

The use of SPOL in queue mode is extremely valuable to the success of this program. It essentially *guarantees* that our high priority SN targets will be observed once per month. Losing time because of weather for even a single month could have a negative impact on the results for multiple targets. However, the queue arrangement virtually eliminates that risk. The impact of any time lost to weather will be minimized because it will be spread over the entire run rather than a single night.

Because of the evolution of SNe and the resultant change in apparent magnitude, having access to telescopes with multiple apertures with the same instrument is a powerful capability. Again, in an ideal case, we'd choose the telescope for each run based on the brightness of our highest priority targets but, since we do not know a priori how bright a given target will be during our run, we have no preference for a specific aperture for a given run. We realize that the over subscription rate for the 90" in dark and gray time is expected to be significantly larger than usual because of commitments to large programs. However, the use of the 90" has been critical to this program because of the larger collecting area (allowing good signal-to-noise on our fading targets) and access the circum-polar region. Therefore we maintain our request for some 90" time with the 61" as back-up.

Finally, the observations proposed here will be augmented with observations at the MMT. Twice per semester we will schedule two to three director's discretionary nights on the MMT with SPOL to enable observations of targets that have either faded or are intrinsically faint. This is also critical to the program since measuring polarization at a level of $\sim 0.1\%$ is extremely difficult and becomes even more difficult as a given SN ages.

We initially used the SN rates published in Li et al. (2011) to estimate the number of potential new SPOL targets per semester. We estimated that roughly one *new* SN will be observable every month. In practice we've been able to observe a slightly higher number of approximately 1.25 new SNe per month. The number that are observable during any one epoch will depend on discovery date relative to peak and the decay rate, which is largely a function of type. However, we plan to observe each target during at least three epochs and therefore will observe from three to five targets per observing run.

By its nature, this survey requires a long-term commitment to achieve observations of many supernovae of all types during multiple epochs. Therefore, we request long-term status with observations over both semesters for a total of ~ 11 nights (one per month excluding August). At the end of the year we will have completed multi-epoch observations of approximately fourteen targets.

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**)*

This is our fourth long-term proposal for this project. We were granted long-term status in 2012, proposals L51 & L57, in 2013, proposals L60 & L54, in 2014, proposals L56 & L56, and in 2015A, proposal L275. During the 2015B semester we are requesting a single night every month, i.e. a total of four nights. These nights should be added to, either before or after, the nights awarded to P. Smith's Fermi blazar proposal.

Since there will be new potential SN targets every month, this project could continue indefinitely. Our NSF proposal has been funded through August 2015 but we plan to request a one year no-cost extension and therefore hope to continue observing through at least the 2015B semester. Although we can obtain useful data during just a single semester, the best and most comprehensive results will be obtained over a longer timescale. This will enable multi-epoch observations for several supernovae of different types. Therefore, we submitted a long-term proposal to continue the project for another year. We are requesting a total of 11 nights, one per month (excluding summer shutdown) over the course of the year.

This project was awarded four nights in 2012a, three nights in 2012b, four nights in 2012c, seven nights in 2013A, four nights in 2013B, seven nights in 2014A, four nights in 2014B and seven nights in 2015A. Twenty three of the 40 nights were scheduled on the 90" (1/28/12, 2/12/12, 3/26/12, 7/23/12, 9/7/12, 12/4/12, 1/18/13, 2/1/13, 3/4/13, 5/14/13, 7/2/13, 11/25/13, 12/25/13, 2/7/14, 3/1/14, 3/25/14, 5/21/14, 7/19/14, 9/19/14, 12/26/14, 1/26/15, 5/22/15 & 7/20/15) and seventeen nights were scheduled on the 61" (4/28/12, 5/16/12, 6/19/12, 10/11/12, 11/8/12, 4/15/13, 6/1/13, 9/11/13, 10/12/13, 4/25/14, 6/19/14, 10/27/14, 11/27/14, 2/12/15, 3/24/15, 4/19/15 & 6/20/15). Although scheduled classically, the observations for this program are being obtained in a queue mode along with proposals from P. Smith (L198) and D. Tutar-Özdarcan (S221). This significantly increases the probability that all of our SN targets will be observed each month. In addition to the time awarded through the TAC, 24.5 nights of director's discretionary time have been scheduled on the MMT with SPOL (4/13-15/12, 7/11-13/12, 9/20/12, 9/23/12, 1/7-9/13, 6/13-14/13, 10/27-29/13, 4/18-20/14, 7/2/14, 12/13-14/14 & 4/26-28/15).

Observations to date have been extremely successful in terms of observing coverage. Table 1 provides a log of observations for this project. Since we combine multiple nights into a single epoch, the table provides both number of nights and number of epochs. This already represents one of the best spectropolarimetric surveys of SNe, particularly since most types of supernovae have been observed.

We are spearheading this project and are collaborating with D. Leonard at San Diego State University, J. Hoffman at University of Denver and L. Dessart at Observatoire de la Côte d'Azur, France. Almost all of the observations for this program will be obtained on UAO telescopes. We are not requesting MMT time in this proposal since we plan to use director's discretionary time at the MMT. D. Leonard may have limited access to spectropolarimetry data obtained at the Shane 3-m Telescope at Lick Observatory and has a different project to study type IIP SNe at VLT. Although the Steward data alone would provide a very good data set, occasionally augmenting this with the Shane and/or VLT data will help fill in the time coverage and help confirm SPOL results.

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**)*

⋆ To date, we've been awarded 40 nights for this project spanning the last three years. Those nights were distributed between semester and telescope as follows:

2012a @ 90": 1/28, 2/12, 3/26, **2012a @ 61":** 4/28, **2012b @ 90":** 7/23, **2012b @ 61":** 5/16, 6/19, **2012c @ 90":** 9/7, 12/4, **2012c @ 61":** 10/11, 11/8, **2013A @ 90":** 1/18, 2/1, 3/4, 5/14, 7/2, **2013A @ 61":** 4/15, 6/1, **2013B @ 90":** 11/25, 12/25, **2013B @ 61":** 9/11, 10/12, **2014A @ 90":** 2/7, 3/1, 3/25, 5/21, 7/19, **2014A @ 61":** 4/25, 6/19, **2014B @ 90":** 9/19, 12/26, **2014B @ 61":** 10/27, 11/27, **2015A @ 90":** 1/26, 5/22, 7/20, **2015A @ 61":** 2/12, 3/24, 4/19, 6/20.

Observations obtained during these observing runs are shown in Table 1. All the data for all of the runs prior February 2015 have been reduced. Results from four supernovae, SN 2010jl, SN 2011fe, SN 2011dh & SN 2012au, were presented in a block of four posters highlighting results from the SNSPOL project at the 223rd AAS Meeting in Washington, DC in January 2014. Also, graduate student C. Bilinski presented a poster providing an overview of the project and results at the conference "F. O. E. Fifty One Erg" in Raleigh, NC May 13–17, 2013. In addition to Mauerhan et al. (2014) and Smith et al. (2015), there are currently six publications in preparation that focus on six individual events: SN 2010jl (Williams et al.), SN 2011dh (Mauerhan et al.), SN 2011fe (Milne et al.), SN 2012au (Hoffman et al.), SN 2013ej (Leonard et al.). & SN 2014ab (Bilinski et al.). We hope to submit most of these papers prior the 2016A proposal deadline.

The SNSPOL website (`http://grb.mmto.arizona.edu/~ggwilli/snspol/`) provides a complete list of refereed and non-refereed publications as well as public presentations that contribute to the broader impacts of the project.

Table 1: SPOL observations of supernovae through December 2014.

Target	SN Type	Telescope	# of Nights	# of Epochs
SN 2010jl	IIn	61”	11	4
		90”	18	6
		MMT	1	1
SN 2011cc	IIn	90”	1	1
SN 2011dh	IIb	61”	2	1
		90”	2	1
SN 2011fe	Ia	61”	1	1
		90”	13	6
		MMT	1	1
SN 2011ht	IIn	90”	7	2
PTF11iqb	IIn	90”	1	1
SN 2012A	IIP	61”	3	1
		90”	17	3
		MMT	1	1
SN 2012ab	IIn	90”	1	1
		MMT	1	1
SN 2012aw	IIP	61”	11	3
		90”	11	2
		MMT	3	2
SN 2012au	Ib	61”	11	3
		90”	6	1
		MMT	2	2
SN 2012bv	II	MMT	2	1
SN 2012cg	Ia	61”	11	2
SN 2012ch	IIP	MMT	2	1
SN 2012ec	IIP	61”	6	2
		90”	11	4
		MMT	3	2
SN 2012ej	Ic	61”	2	1
		90”	2	1
		MMT	4	2
PTF12gzk	Ic-Pec	61”	1	1
		MMT	4	1
SN 2009ip	IIn	61”	6	2
		90”	3	1
		MMT	3	1
SN 2012fg	IIb	90”	10	2
		MMT	2	1
SN 2012fh	Ic	61”	1	1
		90”	13	4
		MMT	2	1
SN 2012ho	IIP	MMT	1	1
SN 2012ht	Ia	90”	2	1
		MMT	1	1
SN 2013ab	IIP	61”	5	2
		90”	5	2
		MMT	2	1
SN 2013ak	IIb	61”	4	1
		90”	1	1
SN 2013am	II	61”	8	2
		90”	3	1
		MMT	1	1
SN 2013bi	IIP	61”	4	1
		90”	5	2
		MMT	2	1
iPTF13bvn	Ib	90”	3	1
SN 2013bu	II	61”	4	1
		90”	3	1
		MMT	2	1
SN 2013df	IIb	90”	2	1
		MMT	2	1
SN 2013ee	II	90”	4	1
		MMT	1	1
SN 2013ej	IIP	61”	4	2
		90”	5	2
		MMT	2	1
SN 2013ff	Ic	90”	4	1
		MMT	3	2
SN 2013fs	IIP	61”	3	1
		90”	4	2
		MMT	2	1
SN 2013fw	Ia-HV	MMT	1	1
SN 2013ge	Ic	90”	6	2
SN 2013hj	II	90”	2	1
		MMT	1	1
SN 2014A	IIP	90”	1	1
		MMT	2	1
SN 2014G	IIL	90”	7	3
		MMT	1	1
SN 2014J	Ia-HV	90”	6	4
		MMT	1	1
SN 2014L	Ic	90”	8	3
		MMT	2	1
SN 2014ab	IIn	61”	8	2
		90”	7	2
		MMT	2	1
SN 2014ad	Ic	61”	2	1
		90”	4	2
		MMT	1	1
SN 2014ao	Ia	61”	3	1
		MMT	1	1
SN 2014as	BL-Ic	MMT	2	1
SN 2014bc	IIP	90”	1	1
ASASSN-14az	IIb	61”	7	2
		90”	3	2
SN 2014ce	II	90”	3	1
SN 2014cx	II	61”	4	2
		90”	4	2
		MMT	1	1
SN 2014cy	IIP	61”	2	1
		90”	2	1
ASASSN-14lp	Ia	90”	3	1
		MMT	1	1
M12045	Ib	61”	4	1
		90”	4	1
		MMT	1	1
J07285	IIn	61”	4	1
		MMT	1	1
ASASSN-14kg	II	61”	2	1
		MMT	1	1
ASASSN-14il	IIn	61”	4	2