NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
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Host Galaxy Reference Images of Type Ia Supernovae

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
WIYN/MIMO, supernovae, final references, 3 nights.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	WIYN	MIMO	3	dark	May - May	May - Jun
2						
3						
4						
5						
6						

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

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.*

The Hubble diagram for Type Ia Supernovae (SNe Ia) provides the most direct current measurement of the expansion history of the universe— and hence the most direct evidence for an accelerating expansion. The Supernova Cosmology Project (SCP) developed an approach to this measurement (Perlmutter *et al.* 1997, 1998, 1999) that resulted in a determination, based on 42 SNe with redshifts between 0.18 and 0.83, of $\Omega_M \sim 0.3$ for a flat universe (Perlmutter *et al.* 1999; see also Riess *et al.* 1998); balloon-based CMB measurements have strengthened the evidence for an accelerating universe by indicating that the geometry of the universe is flat, ruling out the possibility of a low-density open universe.

In the Spring of 2002, the SCP carried out a search for high-redshift SNe with the CTIO 4m telescope, taking reference images in April and search images in May. Despite marginal weather conditions during the April run, the search was relatively successful (see "previous uses" section). Although the poor seeing during the reference run prevented discoveries of SNe at $z > 1$, one SN at $z = 0.912$ (a region of the Hubble diagram which remains poorly populated) was discovered, and followed with the Hubble Space Telescope. In addition, the search found five other supernovae at cosmologically interesting redshifts: four at z =0.4–0.5, plus one at $z = 0.2$. These intermediate redshift SNe, plus an additional SN at $z = 0.35$ discovered with Subaru, were followed using the TNG and WHT telescopes, as well as with the WIYN telescope using NOAO time granted to the SCP on May 17, May 31, and June 6–8.

Use of these supernovae for cosmology requires measuring the peak magnitude and the decay rate of the lightcurve. The aforementioned time series of observations obtained for these SNe will serve this purpose. However, to properly use them, each lightcurve requires a host galaxy reference image taken once the supernovae has faded from view. For the one SN at $z = 0.912$, search fields taken the previous year serve. This proposal requests time on the WIYN 3.6m telescope at KPNO to obtain these "final reference" images for the remaining SNe. Although a template lightcurve may be fit to the data in the absence of a final reference, this increases both systematic and statistical errors. Because the seeing varies between different images of the same supernovae, a different amount of host galaxy contaminates the aperture on each image, and hence a single "zero" level in the template fit will not truly be correct for each image. In addition, any peculiarities or deviations from a SN Ia lightcurve may be hidden by the addition of another parameter to the fit. A final reference fixes the zero level of the lightcurve; it may be convolved to the image quality of each image on the supernova lightcurve, allowing an accurate host galaxy subtraction.

Because the final reference image is subtracted from each supernovae lightcurve point, it must be deeper than the best lightcurve point so that the subtraction does not overmuch degrade the quality of the original data. In addition, the image quality of the data should be no worse than the best seeing from all of the lightcurve images. (The final reference images are still necessarily, if not optimal, if the seeing is worse.) The best image quality on the lightcurves in question come from the WIYN data obtained in May and June of 2002, with seeings of $\sim 0.8''$. Hence, we request time on the WIYN telescope during the Spring of 2003 to obtain the necessary final reference images for these six supernovae at $0.2 < z < 0.5$ so that they might be used for cosmology.

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)*

Supernovae were discovered at the CTIO 4m telescope in May 2002 by using a search of two depths. Two adjacent MOSAIC fields (the "deep" fields), plus a third to an intermediate depth, were imaged in the I-band, with the goal of finding supernovae at $z > 1$. These fields were observed as long as they were at a favorable airmass. In addition, at the end of the night (after the deep field was too low in the sky), additional "intermediate" fields were imaged in the R-band, with the goal of finding another ~ 6 supernovae at redshifts $z < 0.6$. The search technique employed the classical method which the SCP has used successfully over the last several years. The fields were imaged in April, and again ~ 3 weeks later in May. Images from the search run in May were convolved to match the point spread function of the images from the reference run in April, and subtracted. Residual signals were measured spectroscopically at Keck, Gemini, and VLT to determine supernovae identification and to obtain a redshift.

Adverse weather conditions during the reference run in April 2002 limited the depth of the search. Some time was lost to clouds, and when the sky was clear the seeing was worse ($\sim 1.2'' - 1.6''$) than what was required to find supernovae at the highest redshifts. Nonetheless, the run was successful. One candidate was discovered at $z = 0.912$, and followed with the HST. In addition, five more SNe at $0.2 < z < 0.5$ were discovered (see the table in the Technical Description section). These latter supernovae were followed with ground based telescopes through May and June, including with the WIYN telescope during five nights in three different runs. In addition, a SN at $z = 0.35$ discovered simultaneously at Subaru was followed during these ground-based runs.

The only necessary data still required to use these supernovae for cosmology is a final reference image, as described in the Scientific Justification section. This "final" reference image may be obtained either before the supernova explodes, or after the supernovae light has sufficiently decayed. The reference image used for the search is insufficient, because frequently the supernova are already on the beginning of the rising part of their lightcurve during that run. In addition, some of the follow-up images were deeper than the search images, and as such deeper host galaxy reference images are required. The best advantage will be obtained from the lightcurve reference points if the noise added from the host galaxy subtraction is subtantially smaller than the noise in that lightcurve image. For the highest-redshift SN discovered at CTIO 4m, we have images of the field from a year earlier. For the remaining supernovae, we will obtain images with the MIMO imager on the WIYN telescope in the Spring of 2003 as final reference images.

Use of Other Facilities *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.*

The observations proposed here will naturaly complement all of the observations of these supernovae taken during the Spring 2002 sememster. In addition to the search at CTIO and the imaging run from WIYN, this includes imaging runs at the WHT and TNG telescopes at the La Palma observatory which obtained additional lightcurve points in May and June. Spectroscopy of these supernovae were obtained with the Gemini North and VLT 8m telescopes. The acquisition of final reference images will allow an accurate determination of the supernova lightcurve parameters, and as such will enable the cosmological application of all of these existing obsevations.

In addition to the specific application to the lightcurves of the supernovae on the target list, the observations will contribute to a larger project of placing SN Ia on the Hubble diagram to improve measurements of Ω_M and Ω_Λ, as well as the goal of increasing the statistics available for performing systematic studies. The SCP has made obsevations at a large number of observatories, including those already mentioned, the Keck 10m telescope, and the Hubble Space Telescope, and others in pursuing this survey.

Previous Use of NOAO Facilities *List allocations of telescope time on facilities available through NOAO to the PI during the past 2 years, 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.*

In the Spring of 2001, the Supernova Cosmology Project (SCP) discovered 17 supernovae (SNe) including two at $z \sim 1.1$ during a search at CTIO (see IAUC 7763 and 7764). These SNe were followed with a variety of ground based telescopes including with MIMO on WIYN, with NIRI on Gemini; the supernovae at the highest redshifts were also observed with HST. Final ground-based reference images were obtained during Spring 2002, and the data analysis is in progress.

In Spring 2002 (NOAO proposal $\boxed{\star}$ 2002A-0330 with Perlmutter as PI), the SCP discovered six SNe with the CTIO 4m telescope, as described in previous sections of this proposal. These supernovae were followed photometrically with WIYN/MIMO, HST, and other telescopes, and spectroscopically with GMOS on Gemini North. The observations proposed here will complete the lightcurves and allow photometric and cosmological analysis of these SNe to proceed.

During the Fall semester of 2002, a joint US/UK proposal (PIs Knop and Hook, program GN-2002B-Q-30) was granted 33.6 hours on the Gemini North telescope, using both GMOS and NIRI. This time will be used to obtain spectroscopic confirmation of supernovae discovered as part of the Subaru Big Project (with discoveries scheduled for the end of October, 2002), as well as for infrared photometry of 1–2 supernovae at redshifts $z > 1$.

Observing Run Details for Run 1: WIYN/MIMO

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 WIYN-2hr, WIYN-SYN, YALO, and Gemini runs).*

This run will use the MIMO Camera on the WIYN telescope to obtain final reference images for supernovae lightcurves. Each of these candidates have photometry with host galaxy plus supernova light taken during April, May, and June of 2002, with the CTIO 4m, the TNG, the WHT, and the WIYN telescopes. The final reference images must be deeper than any individual previous observation. In addition, it is advantageous if they have an image quality (seeing) that is no worse than the seeing of the lightcurve images, as described in previous sections. The best seeing images obtained of these supernovae were with MIMO on WIYN, with seeing of $0.7''$–$1''$.

The targets, their coordinates, their redshifts, and exposure time necessary to complete the lightcurve of each SN are listed in the table below. Exposure times are based on existing observations of these targets; previous observations were made during the dark half of the lunar phase, and we are requesting the same phase for the final reference images. Magnitudes listed in the table are *discovery magnitudes* for the supernovae candidates. They are estimates, as the absence of a final reference currently prevents an accurate discovery magnitude estimate. Additionally, many of the previous observation of the SNe were 1–2 magnitudes dimmer, as the lightcurve had faded. They will have faded completely from view by the time of the run. The final reference images obtained will be psf-matched and subtracted from the lightcurve images, following the procedure used extensively in the past by the Supernova Cosmology Project.

Table: Targets

SN	RA (2000)	Dec (2000)	z	Discovery Magnitude	Exp. R (min)	Exp. I (min)
S02-064	13:25:46.6	+27:34:20.9	0.35	22.8	90min	120min
T02-028	15:36:25.5	+09:28:18.2	0.44	22.9	90min	120min
T02-047	15:36:29.9	+09:38:42.9	0.49	22.9	90min	120min
T02-029	15:37:07.5	+09:36:18.7	0.21	21.3	60min	90min
T02-030	15:43:24.4	+07:53:57.8	0.51	23.3	90min	120min
T02-037	15:46:57.0	+08:12:36.6	0.49	22.3	90min	120min

Although good image quality helps, there is no benefit to obtaining images with *better* image quality than what was obtained for the supernovae lightcurve points, since the final reference images of the host galaxy will be convolved out to the seeings of those images. As such, MIMO alone on WIYN will be able to obtain images which are ideal for their intended purposes. The relatively large field of view of MIMO is also useful, as it provides a substantial number of field objects which may be used as secondary standard stars for relative photometry (making the data useful even if conditions are not strictly photometric).

If, during the observing run, the seeing is marginal ($> 1''$), we will consider the option of using the WIYN Tip-Tilt Module (WTTM) to obtain images of improved seeing. The NOAO newsletter of September, 2002 suggests that switching between MIMO and the tip-tilt camera is a relatively fast operation, and may be performed repeatedly during an observing run. As such, we will allow the conditions during the run to determine which is the camera that will best serve the goals of the project. Exposure times we quote in the target table are given using the baseline assumption that MIMO images will be the best choice. In the event that we use WTTM for the images, the slightly lower efficiency (if such still exists during the run) will affect the depth of the final reference images. Although they will then not be as good, they will still be useful for completing the supernovae lightcurves with slightly higher statistical errors.

All told, the observations requested will require three nights on the WIYN telescope. Since most of the targets are at similar Right Ascensions, we will make best use of the telescope with an observing run in May when the targets are at a favorable airmass throughout the night. An observing run during the dark half of the moon's phase in June will also be usable, though not as efficient.

Instrument Configuration

Filters: R, I	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): 13 to 16

Dec. range of principal targets (degrees): 7 to 27

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

NOAO observing proposal LaTeX macros v2.7.