NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: September 30, 2002 **Category:** Cosmology

Host Galaxy Images for High Redshift Supernovae

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
Type Ia supernovae provide the most direct evidence for an accelerating universe. Continuing studies of supernovae will allow us to improve these measurements, reduce systematic errors, and begin to address the physical nature of the "dark energy" driving the acceleration. To be placed on the Hubble diagram, supernovae require measurements of the peak flux and decay rate of their lightcurves. These measurements in turn require supernova-free host galaxy images. This proposal requests time to obtain host galaxy images in R and I with WIYN/MIMO for six SNe at $z < 0.6$, and with NIRI on Gemini North for two supernovae at $z = 1.1$. In addition to furthering studies of the dependence of supernova properties and extinctions on host galaxy morphologies and luminosities, these host galaxy images are necessary to make use of existing observations taken during 2002 with the CTIO 4m, WIYN, VLT, Gemini North, and other telescopes, and will complement observations taken during the same period with ACS on HST.

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	GEM-NQ	NIRI6	3.4	bright	Mar - Jun	Mar - Jun
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 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. Figure 1 shows current preliminary results, including the SNe of Perlmutter *et al.* 1999, and an additional 11 observed with WFPC-2 on HST between 1998 and 2001 (Knop, 2002).

Further measurements of high-redshift supernovae hold promise for two things. First, over the next few years it will be possible to begin to address the properties of the "dark energy" which is driving the expansion of the universe, by measuring w, the equation of state (p/ρ); a value of $w = -1$ would indicate vacuum energy, or a cosmological constant. In a few years, sufficient supernova data at a range of redshifts together with independent constraints on Ω_M from, e.g. large scale structure, it will be possible to measure w to approximately five times better accuracy than can be done today.

Second, more and better measurements of supernovae will allow us to minimize the effects of systematic errors on the results. For example, the effects of host galaxy dust extinction may be addressed with high-quality color measurements of a large quantity of supernovae. The effects of "grey dust" are addressed by obtaining measurements of supernovae at intermediate ($z < 1$) and high ($z > 1$) redshifts, thereby looking into the epochs of both acceleration and deceleration.

This Proposal: The cosmological measurements described above will build on existing data, and will require the building up of statistics over time. In this proposal, we request the time necessary to complete the observations for eight SNe discovered during Spring, 2002, including five discovered with the CTIO 4m telescope and three with the Subaru 8m telescope. The resulting images of the host galaxy, uncontaminated by supernova light, will enable an accurate determination of the supernova lightcurve parameters (peak magnitude, decay rate, and rest frame B-V color), as described in the "Experimental Design" section. The SNe may then be placed in the Hubble Diagram and used to contribute to measurements of cosmological parameters and of systematic errors.

In addition to their use in obtaining accurate lightcurves for high-redshift supernovae, supernova-free images allow the properties (luminosity, size, color) of the host galaxies to be studied. Such measurements are crucial for understanding how the properties of high-redshift supernovae might be affected by the ages and metallicities of their stellar progenitors. These host galaxy measurements are also essential compliments to further host galaxy follow-up observations, as in the HST Snapshot study of Sullivan *et. al.* in which we demonstrated that fits to only the supernovae in elliptical galaxies by themselves strongly support the existence of dark energy. As with the supernovae themselves, red and NIR photometry allows study of the hosts in the rest-frame B- and V-bands at all redshifts.

References

Knop *et al.*, 2002, BAAS, 199, 1607 (to be submitted to ApJ)
Perlmutter, S., *et al.*, 1997, ApJ, 483, 565
Perlmutter, S., *et al.*, 1998, Nature, 391, 51
Perlmutter, S., *et al.*, 1999, ApJ, 517, 565
Riess, A., *et al.*, 1998, AJ, 116, 1009
Sullivan, M., *et al.*, 2002, MNRAS, submitted

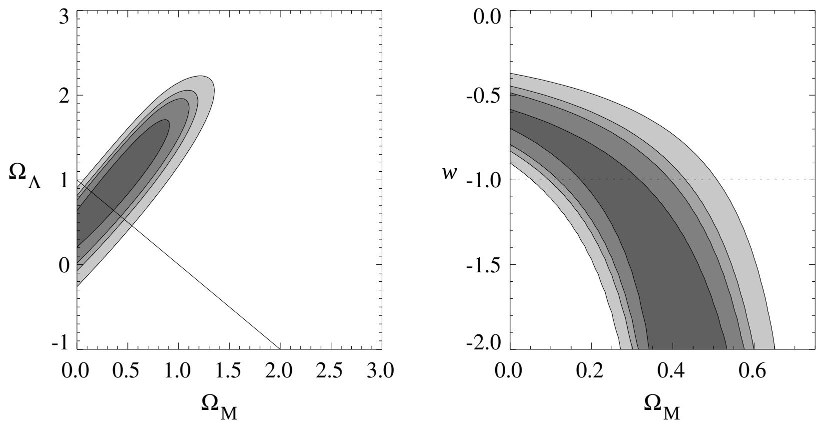

Figure 1: Preliminary limits on cosmological parameters, including data from Perlmutter (1999) plus 11 supernovae observed between 1998 and 2001 with WFPC-2 on HST. On the left are joint limits on Ω_M and Ω_Λ. On the right are joint limits on Ω_M and the equation of state w of the dark energy, under the assumption of a flat universe (motivated by CMB results). In both plots, confidence intervals plotted are 68%, 90%, 95%, and 99%.

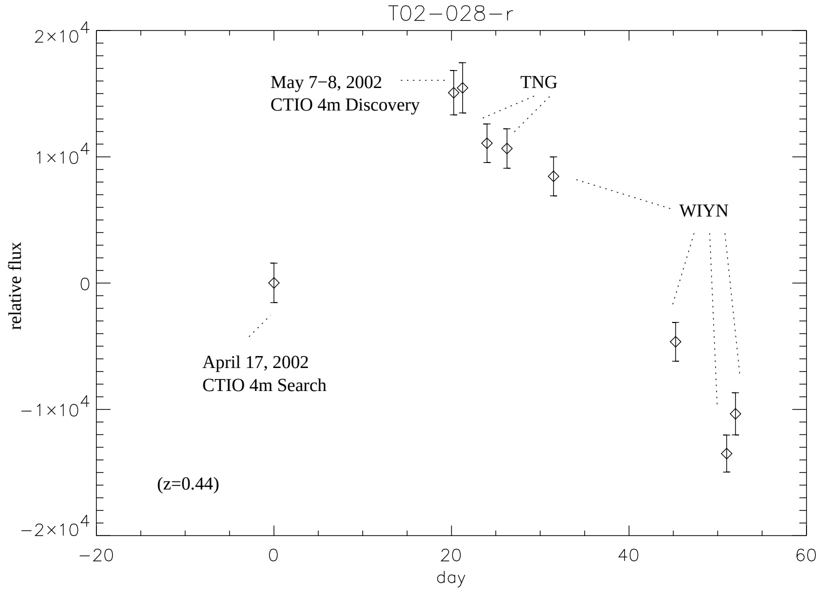

Figure 2: Preliminary R-band lightcurve of supernova T02-028 at z=0.44. Clearly, this supernova had already exploded by the time of the April, 2002 reference run; although the zero level of the flux has been set to the supernova flux on that date, a host galaxy image will allow a true determination of the zero level, plus a better subtraction from the other points (some of whose uncertainties are currently dominated by the uncertainty in the poor reference used).

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, and additionally in very deep searches in April and May 2002 with SuPrimeCam on the Subaru 8m telescope. Both searches employed the classical method which the SCP has used successfully over the last several years. The CTIO 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 a "reference run" in April, and subtracted. Six total supernovae were discovered and followed, including one at $z = 0.912$ and the five at $z < 0.6$ discussed in this proposal. Subaru employed a three epoch search, with fields imaged in March, April, and May, and searched in April and May. Supernova candidates from each subtraction were measured spectroscopically at Keck, Gemini, and VLT to determine supernova identification and to obtain a redshift.

This proposal focuses on eight of the SNe discovered during the Spring of 2002. Two SNe at $z > 1$ discovered with Subaru were followed in the i and z bands with ACS on HST. In addition, we obtained infrared observations of these supernovae with NIRI on Gemini North and ISAAC on VLT. The observations proposed here are essential to allow use of these existing observations from the previous year, so that the completed measurements may be used to estimate B-V colors of the supernovae. Additionally, five SNe discovered in the intermediate depth fields at CTIO at $0.2 < 0.5$, plus one SN at $z = 0.35$ discovered with Subaru, were followed in R and I with ground based telescopes through May and June, including with the WIYN telescope during five nights in three different runs. This proposal requests final reference images necessary to complete the lightcurves, and to measure peak magnitudes and colors for the SNe.

For the infrared data, where we only have a supernova image at one epoch, a host galaxy image is absolutely essential in order to measure the supernova magnitude. For the optical data, host galaxy images allow the best possible use of the existing time series of supernova images. As the seeing varies between different images of the same SNe, 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. (At the redshifts in question, sizes of host galaxies and separations between host galaxy cores and SNe are comparable in size to photometric apertures of $\sim 1''$.) A host galaxy image fixes the zero level of the lightcurve; it may be convolved to the image quality of each image on the SN lightcurve, allowing an accurate subtraction of the background galaxy light. The "reference images" from April, 2002 are not sufficient, because they may actually have been taken after the supernova exploded, and have some light from the early rising part of the lightcurve. Figure 2 shows a preliminary lightcurve for one of the supernovae discovered with the CTIO 4m telescope in May, 2002.

Because the final reference image is subtracted from each supernova image, it must be deeper than the best lightcurve point so that the subtraction does not significantly 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 infrared images were acquired with both Gemini and VLT, telescopes of comparable aperture; we are requesting time on NIRI with Gemini North to obtain host galaxy images for these two supernovae at $z = 1.1$. For the optical data, 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 SNe at $0.2 < z < 0.5$.

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 naturally complement all of the observations of these supernovae taken during the Spring 2002 semester. The two $z = 1.1$ supernovae discovered with the Subaru 8m telescope have also been observed with ACS on the Hubble Space Telescope, as well as at Gemini North and VLT. The SNe at $z = 0.2$–0.5 were discovered with Subaru and with the CTIO 4m telescope, were observed spectroscopically with Gemini North and VLT, and were followed photometrically with the WHT and TNG telescopes at the La Palma, and over three runs in May and June 2002 with WIYN/MIMO. 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 observations.

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.

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. One, at redshift $z = 0.912$, was followed with HST. The other five are described in previous sections of this proposal. and were were followed photometrically with WIYN/MIMO and other telescopes. All of these supernovae were observed 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 measurement. Additionally, many of the previous observation of the SNe were 1–2 magnitudes dimmer, as the lightcurve had faded; it was at these later epochs that the longest exposure times were acquired during Spring 2002. The SNe 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

For use with supernova lightcurves, images of the same quality as the best supernova images are sufficient; images of even better seeing will need to be convolved to match the psf of the supernova images. As such, MIMO alone will be able to obtain host galaxy images useful for the supernova lightcurve. The larger field of view of MIMO provides a greater number field stars useful as secondary standards for relative photometry. Although studies of host galaxy properties would benefit from the higher resolution of the WIYN Tip-Tilt Module (WTTM), if conditions are good MIMO will be the instrument of choice for this project.

During the observing run, if the seeing is marginal ($> 1''$), we will consider the option of using the WTTM to obtain images with 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 supernova lightcurves with slightly higher statistical errors.

If an LBNL-developed red-sensitive CCD camera becomes available at WIYN (as we have been told is possible), its use will greatly improve the I-band observations.

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.*

If available, we may switch between MIMO and WTTM during the run.

Observing Run Details for Run 2: GEM-NQ/NIRI6

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).*

Exposure times: For the two SNe Ia at $z = 1.1$, we need to determine the rest-frame B-V color with a S/N ratio of 10. (Cosmological models at these higher redshifts are easier to differentiate than at lower redshifts.) Rest-frame B-band measurements were made with the 850LP filter with ACS on HST. Rest-frame V-band measurements were made with J-band images on NIRI and with ISAAC on VLT, but require host galaxy images so that a supernova flux uncontaminated by galaxy light may be determined. The noise in the B-V color will be determined by the J-band (rest-frame) V measurement. Since the host galaxy image will be subtracted from the supernovae images taken during 2002, the host galaxy image alone must have a S/N of 14 *for an object of the supernova's magnitude.*

In the J-band, SNe Ia at $z = 1.1$ are predicted to have a peak magnitude of $J = 23.8$. Exposure time estimates are chosen to match those used during Spring 2002, because the same considerations apply. They assumed median image quality (using the PWFS but not the OIWFS since we are using the f/6 camera), median sky transparency, 80%-ile water vapor and sky background, and airmass$<$ 1.2. This gives an exposure time of 43800 seconds for one supernova. As there are two objects requiring final references, the total on-target time is 87,600 seconds, or 24.3 hours. These two supernovae are listed in the Target Tables.

In addition, we have listed three standard stars. These will be used to measure the magnitudes of other field objects, and as such will be useful for bootstrap calibrations of last year's images in addition to this year's images.

Overheads: Following the guidelines on the NIRI web page of 15 minutes per new target plus 25% of elapsed time used for off-setting, etc., the total overheads would be 9.8 hours, including the overheads necessary to obtain the standard star images. The total time request is therefore 34.1 hours.

Instrument Resources

Filters: BB: J (1.25 um)
Dispersers:
Focal Plane Units:

R.A. range of principal targets (hours): 14 to 14

Dec. range of principal targets (degrees): 5 to 6

Target Table for Run 2: GEM-NQ/NIRI6

Obj ID	Object	α	δ	Epoch	Mag.	Obs. time	WFS stars	IQ %	SB %	WV %	CC %	Comment
1001	SN2002fe	14:04:18.2	+05:19:25.0	J2000	23.8	730	PP	70	any	80	50	
1002	SN2002ff	14:03:39.9	+05:46:50.0	J2000	23.8	730	-	70	any	80	50	
1003	GD153	12:57:02.3	+22:01:52.8	J2000	14.0	1	p	70	any	80	50	standard
1004	lhs2924	14:28:43.4	+33:10:41.5	J2000	11.9	1	PP	70	any	80	50	standard
1005	s867-v	14:40:58.0	-00:27:46.6	J2000	12.0	1	PP	70	any	80	50	standard

NOAO observing proposal LaTeX macros v2.7.