NOAO Observing Proposal *Standard proposal* **Panel:** *For office use.*
Date: March 26, 2002 **Category:** Cosmology

Cosmology with High-Redshift Type Ia Supernovae

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

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	GEM-NQ	GMOSN	4	dark	Sep - Nov	Sep - Dec
2	GEM-NQ	NIRI6	4	bright	Sep - Nov	Sep - Dec
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 redshfits 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 possibiliby of a low-density open universe.

Further measurements of high-redshift supernova 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 may be done today. For example, if the dark energy has a true value of $w = -0.8$, within five years we could have sufficient supernova data to rule out vacuum energy.

Second, more and better measurements of supernovae will allow us to minimize the effects of systematic errors on the results. Supernova evolution may be addressed by observing supernova lightcurves and spectra at many different redshifts (and, hence, lookback times). 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: This proposal will measure supernovae at two redshift regimes. First, we will obtain spectra of supernovae at $0.5 < z < 0.8$ produced by the CTIO Rolling Search for High-Redshift Supernova (proposed as a NOAO survey project by Knop *et al.*, proposal ID# N0021), allowing that survey to maximize its potential. The possible improvements on the cosmology due to this five-year survey (implicitly including redshifts obtained by this proposal) are shown in Figure 1. This proposed Gemini spectroscopy will allow the CTIO rolling survey to reach its full potential, both in measuring w and setting limits on the effects of supernova evolution and host galaxy extinction.

In addition, with Gemini we propose to perform both spectroscopic and infrared photometric observations of supernovae at $z \gtrsim 1$, which will be discovered both by the CTIO rolling search and by Subaru during its (NAME OF SURVEY). Supernovae at these highest redshfits are the most challenging to follow; however, they have a large scientific impact. They provide the greatest leverage in decoupling measurements of Ω_M and Ω_Λ, thereby shortening the long axis of the confidence ellipse which results from measurements of supernovae at $z < 1$ (see Figure 1). Second, they are at a high enough redshift that observing them allows us to look back to the era of deceleration. Observations of supernovae at $z > 1$ together with intermediate redshifts of $z < 1$ provide a complete picture which can clearly distinguish an accelerating cosmological expansion from systematic effects. These most distant supernovae require measurements in the infrared, since rest-frame B- and V-band, where supernovae are best understood as standard candles, are redshifted out beyond wavelengths of $1\mu m$.

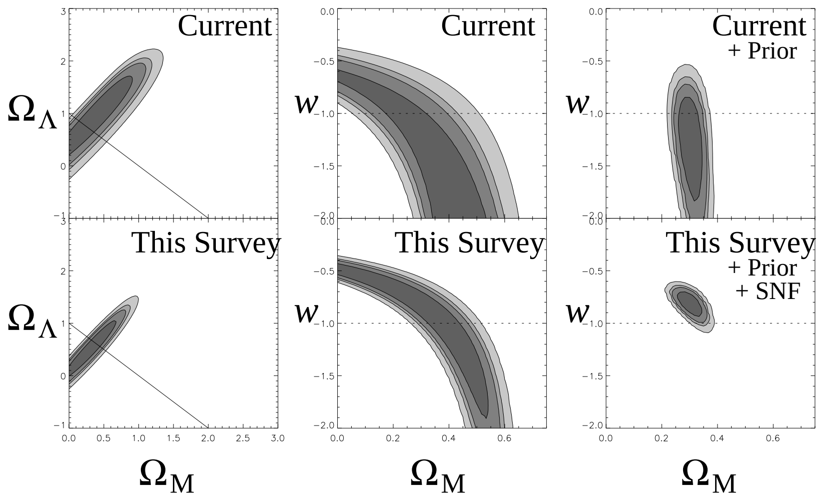

Figure 1: Simulated 68%, 90%, 95%, and 99% confidence limits on cosmological parameters from 330 high-redshift supernovae at $z < 0.8$ discovered by this survey. All plots explicitly include statistical errors due to host galaxy correction and measured uncertainties in E(B-V). Upper panels show the SCP's current best limits, including the results from 10 supernovae discovered at CTIO in 1997-1998 and followed with the HST (Knop *et al. 2001*). Lower panels show simulated results from this proposed survey. On the left is Ω_M, the mass density, and Ω_Λ, the cosmological constant. To the right are joint confidence limits on Ω_M and w, the equation of state of the dark energy. The middle panels show the limits just from the supernovae; the right panel includes a 0.3 ± 0.04 prior on Ω_M, which simulates what will likely be available from independent measurements in five years. The lower-right panel also includes a simulated dataset of 300 SNe Ia spanning $0.03 < z < 0.08$ from the Nearby Supernova Factory (Aldering & Pain 2001).

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 propose to use GMOS for spectroscopy, and NIRI for infrared imaging, to obtain spectra and lightcurves of supernovae in two redshift regimes: $0.4 < z < 0.7$ and $z > 1$.

GMOS OBSERVATIONS

The proposed CTIO rolling search would proceed over four months one semester each year for five years, using the Mosaic camera to simultaneously find and obtain high-quality lightcurves of > 300 supernovae at $z < 0.8$. We propose to use GMOS on Gemini to complete the identification and measurement of redshifs of supernovae out to $z \sim 0.7$ which are too dim for the KPNO 4m and MMT time proposed as a part of that survey. During the first semester of the survey, this will amount to 25–35 supernovae at $z < 0.7$. Supernovae at the targeted redshifts have I-band magnitudes between 22 and 23.5; a screening observation of < 1 hr is sufficient for a single object, and thus we request 3 nights (27 hours) of observing time for this set of supernovae.

These observations will provide us with the redshifts and identifications necessary to make maximum use of the full set of supernovae produced by the rolling survey. For example, that survey will address evolution by measuring the rise-time of high-redshift supernovae to ~ 0.7 days (AKN2001)– which will require a good redshift measurement to take into account the effects of time dilation. According to the models of Domínguez *et al* 2001 this will allow us to constrain evolution in the mean peak SN brightness between low- and high-redshift to within 0.07 mag. Likewise, the R-I colors produced by the survey will allow a measurement of a shift in the mean extinction between high- and low-redshift supernovae as low as 0.015 mag.

In addition, we propose to obtain spectra of two (HOW MANY?) candidates at $z > 1$, produced by the CTIO rolling survey and/or the (WHAT?) search we will be performing during 2002B with the SuprimeCam wide-field imager on the 8m Subaru telescope. This will require an additional night (9 hours) of time with GMOS. Building up observations of these higher-redshift supernovae will allow us to shorten the long axis of the confidence region on the Ω_M/Ω_Λ plane (shown in Figure 1 *without* any $z > 1$ supernovae). Additionally, these measurements will contribute to a statistically significant sample of supernovae during the era of deceleration, allowing us to distinguish a dark energy cosmology from "grey dust" which causes supernovae to become ever dimmer at higher redshifts.

GMOS IMAGING

Do we want to do z here for the z¿1's?

NIRI OBSERVATIONS

(To be written.)

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.*

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.*

Observing Run Details for Run 1: GEM-NQ/GMOSN

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).*

[NEED TO UPDATE. BELOW IS 2002A] GMOS Spectroscopy: We aim to obtain spectra of 5 SNe Ia candidates to confirm the SN type and obtain a redshift. Typical exposure times of 3600s each are sufficient for an initial screening of 5 candidates in the magnitude range 23–25. More exposure time would then be spent on two candidates that appear to be likely $z > 1$ type Ia supernovae —either from those screened by GMOS or from elsewhere. These will require additional exposure times of 3 hours each. Note that the final spectra can be smoothed heavily to reveal the supernova features (Fig. 3).

The total on-source time requested is 11 hours. Following the GMOS web page guidelines, we add 30 minutes per new target, plus 25% of elapsed time to take into account the overheads. Here, we assume that obtaining the I-band flats to reduce the effects of fringing is included in the 25% overhead. We therefore require 17.2 hours for the GMOS spectroscopy observations.

Division of time between TACS: This proposal is being submitted on behalf of the Supernova Cosmology Project, and we are also applying for Gemini time for this program via the U.K. TAC —see proposal by Hook *et al. Cosmology with High-Redshift Type Ia Supernovae.* We request that the time be divided between the U.S. and U.K. allocations in approximately the proportion of partner shares, i.e. 23.5 hours (US) and 11.7 hours (UK).

Summary: We will use Gemini/GMOS for the spectroscopic confirmation of 5 SNe, including 2 at a redshift $z > 1$

Instrument Resources

Filters:
Dispersers:
Focal Plane Units:

R.A. range of principal targets (hours): 1 to 3

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

Target Table for Run 1: GEM-NQ/GMOSN

Obj ID	Object	α	δ	Epoch	Mag.	Obs. time	WFS stars	IQ %	SB %	WV %	CC %	Comment
1001	SN1	2:00:00	0:00:00.	J2000	24.2	3200	PPO	50	80	any	50	Obs. over weeks

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 $z > 1$, we need to determine the rest-frame B-V color with S/N ratio of 10. (Cosmological models at these higher redshifts are easier to differentiate than at lower redshifts.) The noise will be dominated by the J-band (rest-frame V) measurement, and since this measurement will involve subtracting a final J-band reference frame (to be obtained in a future semester) from the at-peak J-band data requested here, the current J-band data must reach a S/N of 14. (Restframe B will be determined to S/N > 20 from HST 850LP and/or VLT Z-band, as mentioned above).

In the J-band, SNe Ia in the redshift range of interest are predicted to have peak magnitude of $J = 23.8$. To estimate the required exposure time we have used the NIRI ITC with the following assumptions: 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, in good agreement with the results from the observations taken in semester 2001a on the $z = 1.06$ SN "Satie" (Fig. 3). Observing one new supernova and the reference image for Satie will therefore require 87,600 seconds = 24.3 hours on target.

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 8.6 hours. We include an additional 2 hours to obtain photometric calibration for the two SN fields. Suitable standards will be chosen once the target positions are known. At this stage we include photometric calibration time as an overhead on top of the target exposure time. The total request is therefore 34.9 hours.

Division of time between TACs: This proposal is being submitted on behalf of the Supernova Cosmology Project, and we are also applying for Gemini time for this program via the U.K. TAC (see proposal by Hook *et al.* "Cosmology with High-Redshift Type Ia Supernovae"). We request that the time be divided between the U.S. and U.K. allocations in approximately the proportion of partner shares, i.e. 23.3 hours (US) and 11.6 hours (UK).

Instrument Resources

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

R.A. range of principal targets (hours): 1 to 3

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

Target Table for Run 2: GEM-NQ/NIRI6

Obj ID	Object	α	δ	Epoch	Mag.	Obs. time	WFS stars	IQ %	SB %	WV %	CC %	Comment
2001	SN1	2:00:00	0:00:00	J2000	23.8	43800	Pp	50	any	80	50	
2002	SN2	2:00:00	0:00:00	J2000	23.8	43800	Pp	50	any	80	50	

NOAO observing proposal LaTeX macros v2.6.