NOAO Observing Proposal *Survey proposal* **Panel:** *For office use.*
Date: March 15, 2002 **Category:** Cosmology

A Rolling Search for High-Redshift Supernovae

PI: Robert A. Knop **Status:** P **Affil.:** Vanderbilt University
Department of Physics and Astronomy, VU Station B 351807, Nashville, TN 37235-1807 USA
Email: r.knop@vanderbilt.edu Phone: (615)322-6165 FAX: ________

CoI: Saul Perlmutter **Status:** P **Affil.:** Lawrence Berkeley National Laboratory
CoI: Greg Aldering **Status:** P **Affil.:** Lawrence Berkeley National Laboratory
CoI: Peter Nugent **Status:** P **Affil.:** Lawrence Berkeley National Laboratory
CoI: Eric Smith **Status:** T **Affil.:** Vanderbilt University
CoI: Isobel Hook **Status:** P **Affil.:** University of Oxford/Gemini Observatory
CoI: Gerson Goldhaber **Status:** P **Affil.:** University of California at Berkeley

Nicolas Regnault
Shane Burns
Rene Ortman
Eugene Commins
D. Andy Howell
Lifan Wang
Rachel Gibbons
Anthony Spadafora
Alex Conley
Michael Wood-Vase
Dan Kasen
Robert Vogel
Ariel Goobar
Reynald Pain
Donald Groom
Susana Deustua

Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
We propose a five-year survey using the Mosaic camera on the CTIO 4m to conduct a highly efficient search that will simultaneously discover and follow up over 330 Type Ia supernovae (SNE Ia) at redshifts $0.3 < z < 0.7$ with multi-band lightcurves. The search will image 6.9 square degrees of the sky with Mosaic for several days each month for four months each year. The resulting significant step forward in quantity and quality of the high-redshift SN Ia data will yield dramatic improvements in our measurement of the cosmological parameters Ω_M and Ω_Λ. It will specifically address one of the key questions of our day: Is the accelerating "dark energy" Einstein's cosmological constant or a new physics entity? By collecting an extremely consistent high-signal-to-noise multi-band dataset for an entire SN Ia sample, the survey enables systematic studies of observable properties of the SN explosion (e.g., rise time to maximum) across a range of redshifts, allowing the study of evolutionary differences and dust effects. As part of this work, we will coordinate a multi-telescope spectroscopic follow-up campaign — including use of the KPNO 4m and MMT telescopes (also proposed here) to obtain spectra of supernovae discovered at $z < 0.5$ — providing SN identification and measurement of the redshifts.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-4m	MOSAIC	75	dark	Sep - Dec	Sep - May
2	KP-4m	MARS	45	dark	Sep - Dec	Sep - May
3	MMT	RCHAN	15	grey	Sep - Nov	Sep - May
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.*

Type Ia Supernovae as Cosmological Tools. In the last five years, measurements of SNe Ia discovered at redshifts $0.3 < z < 0.9$ have provided substantial evidence that the expansion of the universe is currently accelerating, and that the cosmological constant Ω_Λ has a positive value. SNe Ia are uniquely powerful cosmological tools because they are both very bright — thus visible at great distances — and consistent enough to be used as calibrated standard candles. The Supernova Cosmology Project (SCP) led by Saul Perlmutter developed the technique to find large numbers of these SNe in batches. The SCP and the High-Z team led by Brian Schmidt (now led by Chris Stubbs) have each independently produced consistent measurements of Ω_M and Ω_Λ (Perlmutter *et al,*, 1999; Riess *et al.* 1998). Together with measurements of the Cosmic Microwave Background which indicate the Universe is flat (Balbi, 2000; Melchiorri, 2000), SNe provide estimates of the cosmological parameters $\Omega_M \simeq 0.3$ and $\Omega_\Lambda \simeq 0.7$.

The evidence for the presence of some kind of "dark energy" with an equation of state $w \equiv p/\rho < -0.6$ (where $w = -1$ would represent a cosmological constant or vacuum energy) is one of the most important astronomical discoveries in the last decade. We propose to take the measurements of high-redshift SNe Ia an order of magnitude further in statistical weight. This will begin to address the identity of the dark energy by determining w with an accuracy sufficient to potentially rule-out a cosmological-constant explanation. Figure 2, discussed below, shows the striking improvement thus possible in the statistical limits on the cosmological parameters and, in particular, on the equation of state of dark energy. By including the future complementary constraints on curvature from CMB, and on Ω_M from, e.g. large scale structure, we should be able to measure w almost five times more accurately than today's data with these same complementary constraints (right panels). In fact, the example shown would rule out $w = -1$. This level of statistical improvement must be backed up by a corresponding improvement in systematics; the data from this survey is well suited to addressing this requirement, as described below.

This Survey: a Rolling Search for Supernovae. This proposed survey will use the Mosaic wide-field imager on the CTIO 4m Blanco telescope in a "rolling search" to discover and produce high-quality lightcurves of ~ 330 SNe Ia at $z < 0.8$ over the five-year duration of the survey. The survey will be conducted by the SCP, whose members have extensive experience coordinating major multi-month and multi-telescope SN search-and-follow-up surveys, including comparable scale projects at the CTIO 4m telescope. In addition, this survey requests time to obtain spectroscopy to confirm the type and redshift of the brightest 75% of the SN candidates (those with $z < 0.5$) using the KPNO 4m and the MMT. Follow-up time to obtain spectra for the remaining 25% of high-quality SNe and spectroscopy and lightcurve photometry for much higher-redshift (up to $z \sim 1$), will be requested elsewhere (e.g. Gemini and Keck).

In contrast to traditional "two epoch" high-redshift SN searches (where images from a reference and a search run are subtracted from each other; Perlmutter et al 1995), this survey will image the same target fields repeatedly to two depths (termed "deep" and "shallow" fields) in R and I for four months; the nature of the search runs are described in detail in the technical description section. In addition, deep B and V images will be obtained once for each field for purposes of obtaining photometric redshifts of the SNe Ia host galaxies.

The great advantage of this mode of search is that the same telescope time is used for discovery and for high-quality lightcurve measurements; for SNe at the primary target redshifts, no additional photometric followup is necessary (as it is for a two-epoch search). Moreover, since the same fields are observed at every epoch, there will be observations of the rise of the SN lightcurve which are taken *before discovery.* The survey will produce an unprecedented number SNe with photometric observations starting at the epoch of the explosion in addition to excellent post-maximum lightcurve measurements. Multiple points on the lightcurve before discovery, together with BVRI photometric redshifts of host galaxies, will allow better discrimination of candidates for further spectroscopic followup, thereby increasing the success rate and efficient of use of time.

Figure 1(a) shows the expected SN discoveries over the course of this survey, in redshift bins of $\Delta z = 0.1$. The SN rates are based on our previous deep SNe Ia searches at the CTIO 4m (Pain *et al* 1996, 2002). A primary set of ~ 240 SNe out to z =0.6—0.7 will have R-I color uncertainties less than 0.05 magnitudes; 90 additional SNe out to $z = 0.8$ will have R-I color uncertainties in the range 0.05–0.1. Another $\sim 80+$ SNe will be discovered at redshifts another 0.1–0.3 beyond $z = 0.8$; those SNe will require additional photometric followup from larger or space-based telescopes, which will be applied for separately from this proposal.

Figure 1b shows a simulated lightcurve for a SN Ia at $z = 0.45$ in one of the "shallow" fields of this survey, together with data for a SN at a similar redshift observed with the Hubble Space Telescope (HST). The quality of the lightcurve is such that this survey by itself will provide estimates of a SN's peak magnitude, light curve width, and R-I color which are *equivalent in quality* to those of a SN discovered using a traditional search and followed with the HST. This survey will produce lightcurves of this quality for every SN out to a redshift of $z \sim 0.6$ in the "shallow" fields, and out to $z \sim 0.7$ in the "deep" fields. This will greatly improve the confidence limits on Ω_M and Ω_Λ, and on the equation of state parameter w; Figure 2 shows the improvement in the statistical errors on the cosmological parameters.

Moreover, because the coverage of the lightcurves will be more complete (especially before maximum light) than is possible with SNe discovered in a traditional survey and followed with HST, these data will be better for calibrations, corrections, and evolutionary tests which rely on the shape of the lightcurve. For instance, the early lightcurve coverage will allow the risetime to be measured to an accuracy of ~ 0.7 days (AKN2001), with little correlations between the lightcurve fit parameters. 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, our sample of ~ 240 SNe with excellent measurements of R-I (good to < 0.05 magnitudes) will allow us to directly address changes in the extinction distribution of low- versus high-redshift SNe Ia. For instance, we will be able to measure a shift in the mean of the extinction distribution as small as 0.015 mag. Furthermore, at least 30 of our SNe Ia should be in nominally dust-free galaxies (elliptical's and the outer parts of S0's), allowing a powerful check on the extinction corrections being applied to SNe Ia in spiral galaxies (see Ellis *et al* 2001).

The essential redshift and spectral confirmation determinations will be obtained through a combination of the KPNO 4m and MMT time being requested for this survey and time at additional telescopes to which the SCP has had regular access. Experience indicates that 3–4 SNe at $z < 0.4$ may be spectroscopically confirmed by a 4m telescope during the course of one night. Nine nights on the KPNO 4m, divided into 2–4 night runs during the each of the first three months of the survey, would be sufficient to confirm most of the SNe discovered at z <0.4 each year. An additional three nights on the MMT (one per month) will allow us to confirm most of the additional SNe out to $z < 0.5$. The SCP will apply to other telescopes to confirm all of the remaining SNe up to $z \sim 0.65$, as well as some at higher redshifts.

Relation to Other Supernova Surveys. The SCP and other teams are currently engaged with other SN surveys; this survey would be complementary with the others. The Nearby Supernova Factory (Aldering & Pain 2001) is aimed at discovering ~ 300 SNe Ia in the low-redshift Hubble flow, $0.03 < z < 0.08$, which will be used as calibrator objects for SNe at higher redshifts. The CFHT Legacy Survey (CFHT-LS) plans a SN search which goes deep in g, r, i, z over 4 square degrees for 5 yrs. Our survey is competitive despite the 2× larger $A \cdot \Omega$ product of CFHT+MEGACAM, because we concentrate on $z < 0.65$. Beyond this redshift, expensive Z-band observations would otherwise be required to cover V-band in the SN restframe. (One can try to work with restframe U-B, but models show that U has a strong metallicity dependence.)

Looking further ahead, this survey coupled with the others mentioned will help build the necessary understanding of systematic and statistical properties of SNe Ia so as to make the best use of even larger future projects, such as LSST and SNAP.

Other Astronomical Uses. Although the timing of the observations are optimized for the measurement of SN Ia lightcurves, at the end of each year the survey will have very deep BVRI measurements of 6.9 square degrees. The total summed time in R and I will provide a S/N=10 limiting magnitude of 25.7 in R and 25.2 in I in the 1.4 square degrees of "deep" fields; it will be 0.5 magnitudes less deep in the 5.4 square degrees of "shallow" fields. The B and V observations obtained for photometric redshifts will round out the data set for deep BVRI fields. Contiguous fields will be repeated for two years (thereby providing deep final references for SNe discovered at the beginning of the previous year), and then shifted, thus doubling the total area of sky observed by the end of the survey.

The SCP has collaborated in the past with other groups who used our search data for cluster searches and weak lensing measurements. The much greater depth, areal coverage, and consistency of these proposed data will make them far more useful for these purposes. An important example will be the planned SZ cluster surveys (such as APEX and the NSF South Pole Telescope) that will require approximate redshifts for the thousands of clusters they will find. By the end of the 5-year period, our proposed survey will produce deep BVRI images of as much as 13.8 square degrees of the sky observable from the south, ideal for providing such photometric cluster redshifts. This will make it possible for these SZ projects to provide key cosmology measurements, which will be complementary to our measurements of Ω_M, Ω_Λ, and w.

This survey will also produce a treasure trove of lightcurves for core collapse SNe (types II, IIn, Ib, Ic) as well as other transients, such as orphaned GRB afterglows. It may even be possible to detect the ultra-hot shock break-out phase of SNe at very high redshifts where the FUV is redshifted into the optical.

Educational uses of this survey would include a proposed astronomical lab course at Vanderbilt University, proposed by the PI, R. Knop, which will be based around high-redshift SN searches. This will allow students to become involved in the search and participate in one of the most exciting current groundbreaking astronomical research projects.

References

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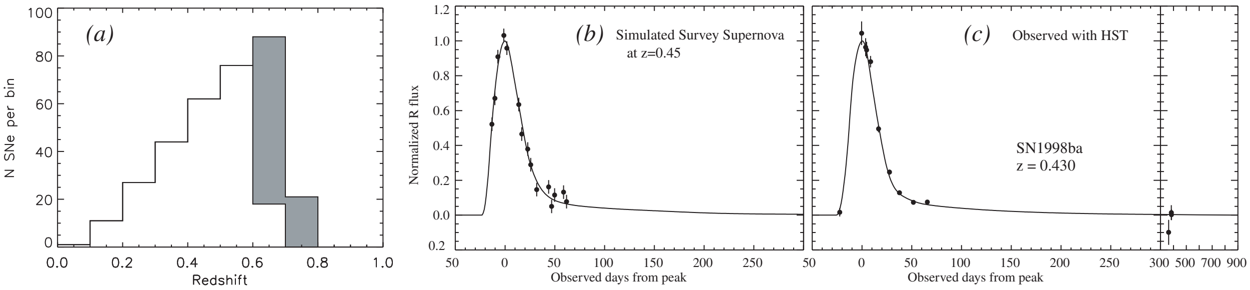

Figure 1: Left (a): Predicted number of supernovae discovered by five years of the survey in fields to two depths. Open bars represent supernovae with observed R-I color uncertainties better than 0.05 magnitudes; solid bars have R-I color uncertainties in the range 0.05–0.10 magnitudes. Middle (b) and right (c): a simulated lightcurve of a SN Ia at z=0.45 (middle) produced by the observations in the "shallow" field of this survey, compared with a measured lightcurve from a supernova discovered at $z = 0.43$ (right), observed with the CTIO 4m (reference and discovery points before and at max) and WFPC2 on HST (points after maximum light with very small error bars).

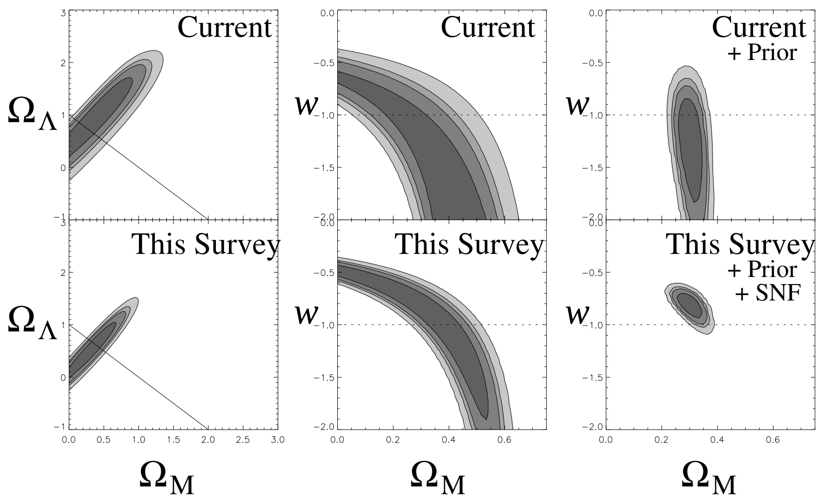

Figure 2: Simulated 68%, 90%, 95%, and 99% confidence limits on cosmological parameters from 330 high-redshift supernovae at $z < 0.8$ discovered by this survey. All plots explicitly include statistical errors due to host galaxy correction and measured uncertainties in E(B-V). Upper panels show the SCP's 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).

Management Plan *Describe the overall plan for conducting the proposed survey, including the experimental design, survey deliverables, staffing requirements, and a list of all observing runs requested for this survey. See the Survey Program instructions for details.*

The PI of this project, R. Knop, together with his research team at Vanderbilt University, will lead the performance and management of this search and related observations. They will be supported by the rest of the international SCP collaboration, including the supernova team at Lawrence Berkeley National Laboratory (LBNL), which includes five research scientists, four post-docs, three graduate students, and other support personnel. The SCP has access to substantial computing resources both at Vanderbilt and at LBNL's National Energy Research Scientific Computing (NERSC) supercomputing center; these resources will be more than ample to perform the search and ensure efficient use of on-sky telescope time. Details are discussed in the Technical Description for the CTIO Mosaic runs.

R. Knop is in the process of applying for external funding to support travel as well as a post-doc and/or 2–3 graduate students to work on this survey. Even in the absence of direct support for the members of the SCP at Vanderbilt University, the supernova team at LBNL (funded by the DOE) as well as the rest of the SCP is committed to the success of this survey, and will help provide travel money, manpower, and equipment to ensure that it succeeds. R. Knop has been the primary researcher responsible for coordinating the actual search during SCP campaigns of recent years, and has been the primary maintainer of the search software. As such, he is uniquely qualified to manage this rolling supernova search.

This project will take advantage of the survey data pipeline being developed by the NOAO Data Products Group. This pipeline will produce overscan, bias, and flatfield corrected images from Mosaic at CTIO. (If the Data Products Group pipeline is not available at the beginning of this survey, we will use the SCP pipeline which has been successfully used during numerous previous CTIO 4m searches; in the past, the preliminary reduction pipeline ran on a small number of laptop computers brought to the observatory by the observers.) These flatfielded images will then be transferred to computers at LBNL and Vanderbilt, where they will be combined and subtracted using the proven SCP search software which has been used to discover SNe at CTIO and other telescopes. This survey will be an excellent test of both the pipeline of the Data Products group, as well as in the efficient use of data produced by that group. It will rely on the Data Products Group to provide flatfielded images in a timely manner, and will then quickly turn these flatfielded images into SN discoveries which will be reported in IAU circulars, as well as observed spectroscopically by other telescopes and published in the astronomical literature. Furthermore, this survey will serve as a testbed for involvement of LBNL's NERSC supercomputing center in the National Virtual Observatory (NVO), as it provides facilities to distribute this dataset.

The impact of the survey on NOAO resources will be modest. The SCP will send 1–2 observers to CTIO during each month's run to perform the observations during each half-night of the survey. Past experience indicates that there will be more than sufficient network bandwidth to send one half-night's worth of flatfielded data over the course of one night. While the use of the network connection will be intermittently high, the survey will not need significant bandwidth to the USA for more than (conservatively) ~ 10 hours every three to four nights. An additional observer will be sent to KPNO and then MMT to perform spectroscopic observations during the nights of those runs.

The runs requested are listed at the end of this section. Please note that the exact timing of the runs is flexible, as discussed in detail in the Technical Description for the CTIO 4m Mosaic runs. It is possible, for example, that subsequent years of the survey may use fields at different declinations. For example, the first two years of the survey could search equatorial fields as described in the default plan here; the last three years could move to a large negative declination (in which case the survey could proceed without the KPNO 4m and MMT time requested, and would be replaced time we would propose to use on SOAR and Gemini South).

We understand that Chris Stubbs' High-z team is also proposing a large supernova survey. If both proposals are given time, the SCP will coordinate with the other team to ensure that the two surveys are run so as to maximize the scientific benefit of both.

Observing Runs Requested for Each of the Five Years of this Project

Semester	Telescope	Instrument	# of Nights	Moon	Acceptable Months
2002B	CTIO-4m	Mosaic	3.5	dark	Sep or Jan
2002B	KPNO-4m	MARS	2	dark	Sep or Jan
2002B	MMT	RCHAN	1	grey	Sep or Jan
2002B or 2003A	CTIO-4m	Mosaic	4.5	dark	Oct or Feb
2002B or 2003A	KPNO-4m	MARS	3	dark	Oct or Feb
2002B or 2003A	MMT	RCHAN	1	grey	Oct or Feb
2002B or 2003A	CTIO-4m	Mosaic	3.5	dark	Nov or Mar
2002B or 2003A	KPNO-4m	MARS	4	dark	Nov or Mar
2002B or 2003A	MMT	RCHAN	1	grey	Nov or Mar
2002B or 2003A	CTIO-4m	Mosaic	3.5	dark	Dec or Apr

This same sequence of runs is repeated for each of the subsequent four years of the survey.

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 SCP is an international collaboration involved in a number of projects related to supernova cosmology. It has a successful track record in applying for observing time at a number of national observatories, as well as the observatories of the University of California (including the 10m Keck telescopes). During the course of this survey, it would apply for time at these observatories and the NOAO Gemini telescopes to perform follow-up of SNe at higher redshifts, including those discovered beyond the primary redshift range on which this survey will focus. The SCP has demonstrated over the last decade that it is capable of quickly turning around supernova discoveries into fruitful followup observations, and that it has the manpower, computing, and telescope resources to make the best use of these discoveries.

Release of Data *Describe the timeline and mechanism for the release of data subsets, the complete dataset, and catalogs to the astronomical community.*

The individual images will be archived and made available to the public as a part of the work of the Data Products Group at CTIO. The timeline for release of these images will be set by the Data Products Group's standard policies. In addition, at the end of each year's observations the SCP will, within 12 months, release deep, co-added, cosmic-ray rejected, and calibrated images which combine data throughout all of the nights of the survey. These additional deep images will be made available over the Internet from LBNL (and NOAO, if they wish to mirror these images). LBNL's connectivity to the Internet is sufficient to provide access to these deep co-added images to any astronomer in North America.

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.*

Demonstrated Successes: Over the past few years we have discovered and studied >100 SNe ($\sim$ 80 at CTIO) at redshifts $z = 0.03$–1.20. We have followed each of these SNe with photometry over the light curve (beginning before or at maximum light in almost every case) and spectroscopy near peak for most. Almost all of our SNe are Type Ia since SNe Ia are typically 2 magnitudes brighter than the other types. Eighteen SNe Ia have been observed by the HST. Nineteen others formed the core of the Spring 1999 Nearby Campaign (a campaign to study low-redshift, $z < 0.1$, SNe Ia). The results have been published in Perlmutter *et al.*, 1997, Perlmutter *et al.*, 1998, and Perlmutter *et al.*, 1999, Knop *et al.*, 2000, Goldhaber *et al.*, 2001, Pain *et al.* (submitted). Additional papers are in preparation (including topics such as new limits on cosmological parameters, properties of host galaxies, high redshift SN spectra, etc.) and 10 presentations were made at the January 2002 Meeting of the AAS with preliminary results for these papers.

Spring 2002a SNe Ia Search: Six nights have been scheduled for the CTIO-4m/Mosaic for a "two-epoch" search. In addition, confirmation and follow-up time has been scheduled for Gemini-N/GMOS (35 hours), Gemini-N/NIRI (35 hours), and WIYN (5 nights).

Spring 2001a SNe Ia Search: We were awarded 3 nights in March 2001 and 3 nights in April 2001 at CTIO-4.0m/Mosaic for the Spring 2001 SNe Ia search, as well as 2 nights at WIYN/MIMO and 35 hours at Gemini/NIRI for the follow-up. The search campaign was a striking success, as more than 17 SNe Ia have been discovered in the redshift range $z = 0.35$–1.1 (reported in IAUC 7763 and 7764), and HST follow-up photometry was triggered for five of the highest redshift SNe. Although half of the WIYN time was lost due to bad weather conditions, this telescope allowed us to gather good 3rd epoch points for the SNe Ia detected in the redshift range $z = 0.35$–0.55. Observations of the most distant SNe Ia —$z \sim 1.055$ detected with CTIO/MOSAIC and $z \sim 1.12$ detected at CFHT/12x8k— have been carried out at Gemini/NIRI. Because of cancellation of the queue this program was not carried out in queue mode. However it was used as a test program for NIRI SV (broadband imaging mode with the f/6 camera). About 12 hours of useful data were obtained in this way, approximately half of our original request (when overheads are taken into account). The data quality is good, and the images are currently being reduced. Final analysis awaits acquisition of final reference images of the SN's underlying host galaxy.

UV Observations of Nearby Type Ia Supernovae: The program "UV Observations of Nearby Type Ia Supernovae" was successfully carried out last spring at several ground-based facilities and HST. The spectra of Hubble-flow SNe Ia observed from HST and from the ground were taken at weekly intervals over a range in time starting slightly before maximum light and extending to +30 days. These observations were aimed at accomplishing the following three goals: (1) Calibration of the rest frame UV light curves of SNe Ia and an assessment of their potential use as distance indicators through UV light curve shape analyses. (2) Improvement in our understanding of the physics of SNe Ia, metallicity/evolutionary effects and correlations between peak brightness and UV spectral features. (3) Calibration of the SNe Ia previously observed by HST at high-redshift.

$\boxed{\star}$ CTIO 0.9-m Apr/May 01 We were awarded 2 nights on the CTIO 0.9-m for the photometric screening of the nearby supernova candidates and initial UBVRI photometry. Both nights were good and the data is currently being analyzed.

$\boxed{\star}$ CTIO 1.5m Apr/May 01 We were awarded 3 nights on the CTIO 1.5-m for follow-up photometric observations of the supernovae, particularly concentrating on U-band photometry. All of the nights were good and the data is currently being reduced.

$\boxed{\star}$ YALO Apr/May 01 We were awarded $\sim$ 20 hrs on the YALO 1.0-m for the BVI photometric follow-up of the 2 HST observed supernova candidates. The light curves from these observations are almost completely reduced.

$\boxed{\star}$ KPNO 2.1-m Apr/May 01 We were awarded 6 nights on the KPNO 2.1-m for both spectroscopic screening of supernova candidates and spectroscopic follow-up of our HST supernova. All nights were good and we issued reports of supernova discovered/classified in IAUC's: 7612, 7614, 7618, 7640.

$\boxed{\star}$ KPNO 4.0-m Apr/May 01 We were awarded 1 night on the KPNO 4.0-m which was used for late-time spectroscopic follow-up of the HST observed supernovae. The red observations have been reduced.

Detection and Observation of Nearby Type Ia Supernovae: To control the systematic errors affecting the $(\Omega_m, \Omega_\Lambda)$ measurements it is necessary to gather as much information as possible on the intrinsic properties of SNe Ia. In particular, measuring the intrinsic colors of SNe Ia with good precision allows for the correction for absorption by dust. Also studying the spectral evolution of SNe Ia helps to constrain theoretical models of these objects. Such studies are only possible on nearby SNe Ia, $z < 0.15$. In Spring 1999, we undertook a large nearby supernova search in collaboration with other groups. More than 50 SNe were discovered, among which 19 were SNe Ia in the nearby Hubble flow discovered near maximum (Aldering 2000). Papers are near submission on the overluminous SN Ia SN1999aw and on the hypernova SN1999as; analysis of the balance of the dataset is underway. CTIO and KPNO instruments played a key role in the photometric and spectroscopic follow-up of these events, as follows:

$\boxed{\star}$ CTIO 4-m Mar/Apr 00 We were awarded four nights for final reference spectra of SNe from the very successful Spring 1999 Nearby Campaign. Substantial time was lost over the four nights due to technical problems at the telescope. Final reference spectra (i.e. after the SN has faded) and improved host-galaxy redshifts were obtained for 10 SNe. Additionally, three SNe were confirmed in IAUCs.

$\boxed{\star}$ CTIO 1.5-m Feb/Apr 00 We were awarded six nights for final $UBVRI$ photometry reference points for SNe from the Spring 1999 Nearby Campaign. We obtained final references (i.e. after the SN has faded) for 15 SNe.

$\boxed{\star}$ KPNO 4-m Apr 99 We were awarded two nights at the KPNO 4-m to obtain spectral time series for SNe Ia discovered as part of the Nearby Campaign. On the first of these nights we successfully obtained spectra for 14 SNe Ia from the total sample of 19 SNe Ia which had intensive follow-up. The second of these nights was unusable due to strong winds.

$\boxed{\star}$ KPNO 2.1-m Apr 99 We were awarded four nights to obtain $UBVRI$ photometry of Nearby Campaign SNe Ia. Half of this time was lost due to clouds or strong winds.

$\boxed{\star}$ CTIO 1.5-m Mar/Apr 99 We were awarded seven nights to obtain $UBVRI$ photometry of Nearby Campaign SNe Ia. Most of this time was usable, and the resulting photometry was reduced after the final references were taken in Spring 2000.

$\boxed{\star}$ CTIO 0.9-m Mar/Apr 99 We were awarded four Director's Discretionary nights during bright time to obtain $UBVRI$ photometry of the brighter Nearby Campaign SNe Ia. Most of this time was usable, and the photometry is now reduced.

$\boxed{\star}$ CTIO 4-m Mar 99 We were awarded four nights to screen and obtain spectral time series for nearby supernova discovered as part of the Spring 1999 Nearby Campaign. With the CTIO 4-m we screened the bulk of the 40 SNe discovered in this Campaign, and obtained over half of the spectral time-series data for the Campaign. The discoveries from CTIO were reported in

IAUC's 7128 (SN1999as), 7130 (SN1999aw, SN1999ax, SN1999ay), 7131 (SN1999az, SN1999ba, SN1999bb), 7134 (SN1999be, SN1999bf), and 7136 (SN1999bi, SN1999bj, SN1999bk, SN1999bl, SN1999bm, SN1999bo, SN1999bp). Along with the other SNe discovered in the Campaign, this is the largest number of spectroscopically confirmed SNe ever discovered in such a short period of time.

Previous Detection and Observation of High-z type Ia Supernovae:

$\boxed{\star}$ CTIO 4-m Apr 99: We were awarded two nights for final photometric followup at the CTIO 4-m to provide high quality reference images in both R and $I-$ for most of the high-z SNe discovered in the previous two semesters. Both nights were clear, but half of the first night was lost to computer problems. Analysis of the SNe lightcurves for which final reference images were obtained has been presented in Knop *et al.* (2000). The photometry has been combined with HST photometry to obtain new constraints (shown in Figure 2) on the cosmological parameters, which agree well with the previous results.

$\boxed{\star}$ CTIO 4-m Dec 98/Jan 99: We were awarded five nights of final photometric followup at the CTIO 4-m to provide high quality reference images in both R and $I-$ for most of the high-z SNe discovered in the previous two semesters. All but one of these nights was clear, and the resulting data went into the Knop *et al.*, (2000, 2002) analysis.

$\boxed{\star}$ CTIO 4-m Mar 98/Apr 98, Keck Apr 98: On this our third run with the BTC we were able to discover > 20 high-z SN candidates at CTIO, 13 of which were spectroscopically confirmed including 8 SNe Ia observed with multi-color photometry with HST. Using the final reference images from the following year's observing runs (above two items), the photometry analysis of these SNe was completed, combining both ground-based and HST data (Knop *et al.* 2000, 2002).

Observing Run Details for Run 1: CT-4m/MOSAIC

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).*

The exact timing and nature of the Mosaic survey runs is very flexible. The SCP is aware that a large survey project such as this, especially one which is requesting half nights, will have an impact on the scheduling of CTIO. The SCP will work closely with the CTIO staff on when the survey would best fit their schedule, for example to share the nights of Chris Stubbs' existing SuperMacho survey. Below, we present the ideal timing for this survey's nights, optimizing the use of telescope time for this project. However, this survey can succeed with other timings; the primary requirement is that enough target fields far from the plane of the galaxy (i.e. with Galactic extinction E(B-V)$<\sim$ 0.03) be observable over the four months of the survey. If necessary, for some years the survey could work during any time of the night during the fall, observing one of the fields we have already identified as suitable at very negative declination.

Because the search runs at Mosaic each year are identical, this section describes all of those runs. We are proposing each year to perform four runs of seven half-nights centered around the new moon of four successive months. Our optimization study indicates that the ideal spacing would be every other night furthest from new moon, and every four nights right around new moon. It is important to obtain data throughout 14—18 nights each month; in this scheme, even SNe which come to maximum during the gap at full moon will have observations within five rest-frame days both before and after maximum light. A larger gap, which would result from more closely spaced half-nights during new moon, would lead to much poorer quality lightcurve fits for those SNe Ia which come to maximum during the middle of the gap.

The table below shows a *sample* spacing of nights for this survey. For reference, the half and full nights used by the Stubbs SuperMacho project are shown, along with the nights of that survey where this project might use the other half of that survey's night. This table also shows a sample timing for the KPNO and MMT spectroscopic runs (and possible Gemini queue time).

```
              Lunation 1 (September)      Lunation 2 (October)
Day #              11111111112222222222333333333344444444445555555555
         012345678901234567890123456789012345678901234567890123456789
Moon                   N              F             N              F
Stubbs
Mosaic          > > >   >   > > >            > > >  B>   > > >
4m Spectroscopy             KK M                       KKK M
Proposed Gemini           [4-7 hrs]                    [6-9 hrs]

             Lunation 3 (November)        Lunation 4 (December)
Day      666666666677777777778888888888999999999900000000001111111111
         012345678901234567890123456789012345678901234567890123456789
Moon                  N              F             N               F
Stubbs          > > > > > >> >                 > > > S S S
Mosaic      < < <   <   < <  <             < < <   <  < < <
Spectroscopy           KKKK M
Proposed Gemini        [8-11 hrs]
```

```
KEY :
  N = New moon
  F = Full moon
  Stubbs = SuperMacho survey nights (using the 2001-2002 schedule)
  Mosaic = Nights on the CTIO 4m for this survey
  Spectroscopy = K: MARS on KPNO 4m , M: MMT
  Proposed Gemini = Hours of Gemini time, proposed for separately
  < = use of first half of night
  B = full night used for B&V imaging (photometric redshifts)
  > = use of second half of night
  S = Full nights used by the Stubbs SuperMacho Survey
```

Two ideal periods of time for this survey would be September–December, and January–April. This survey might also make use of the "off half" of some of the nights of the existing SuperMacho survey, by overlapping the beginning of their period with the end of our period (or vice versa); this would require no sacrifice in data quality for either program, since one would naturally want the end of the night while the other would naturally want the beginning of the night. In this sample scheme, fields are assumed to be placed equatorially so that follow-up from telescopes in both hemispheres (including the time requested on the KPNO 4m and MMT for this survey) will be possible. However, if necessary, the survey could work at a very negative declination any time of the night. In years where this is deemed advantageous, SOAR/Gemini-South time would be requested to replace the currently requested KPNO/MMT time.

Given the constraints of telescope time, natural sky brightness, moonlight, SN brightness with redshift, etc. we have optimized the scientific results obtainable as a function of field depth and numbers. During each half-night of the survey, fields will be observed with Mosaic in the R and I bands at each epoch, which are the wavelengths most useful for SNe Ia at $0.3 < z < 0.7$. Fields will be observed to two depths with exposure times and SN yields as listed below:

Num.	# SNe @ z							S/N=10 @		Exp. (s)		Net
fields	.15	.25	.35	.45	.55	.65	.75	R	I	R	I	Time(h)
4	2	6	9	13	16	18	(21)	24.0	23.5	420	700	1.5
15	9	21	35	48	60	(70)		23.5	23.0	180	300	2.8

Numbers of SNe in parentheses indicate those whose R-I color measurement uncertainties are greater than 0.04–0.05, but less than 0.1. These chosen depths maximize the number of cosmologically useful SNe discovered without sacrificing too much time to overhead reading out the CCDs as a result of very short exposure times.

In addition, at the beginning of the survey each year the target fields would be observed to a S/N=5 depth of 26.0 in B and 25.5 in V (for "shallow" and "deep" fields respectively), with split exposures for rejecting cosmic rays, requiring an additional night of observations during dark time. These will allow BVRI photometric redshifts, as well as classification from the color information, of host galaxies of discovered SNe. This will also enhance the value of the data set for other scientific uses.

Image reductions will be performed by the data pipeline of the Data Products Group at CTIO, and will be transferred to LBNL and Vanderbilt where the extremely successful SCP search software will process it and detect and measure SNe. The turn-around time for these discoveries will be less than one day after the observations in which a SN passes the detection threshold; the SCP has extensive experience in making and following supernovae on this schedule.

The co-adding, psf matching, and image subtraction will be run on computers at LBNL's NERSC supercomputing center and on the VAMPIRE Beowulf cluster at Vanderbilt University. These supercomputers and large farms of PC's provide more than sufficient computing resources, together with support manpower, for the analysis of the data as well as subsequent storage and dissemination. The resources of NERSC (the largest unclassified computer center in the United States), for example, will allow us to apply the computationally expensive "LAcosmic" cosmic-ray rejection routine (van Dokkum, 2001) to the images prior to the image subtraction during a search. That, and combining images from subsequent nights, will allow the search to succeed even without performing cosmic-ray splits during one night of observing (which is expensive in telescope time, as it reduces the R-band exposure time in the "shallow" fields to less than the 100s readout time of the Mosaic camera). This consideration has been factored in to the times necessary to observe the target fields to the depths listed in the table above.

Instrument Configuration

Filters: B, V, 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): 1 to 3

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

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

Please contact the PI of this survey before scheduling any nights. Because it is a large project combining data from multiple telescopes, it is necessary that the nights of the different telescopes be properly coordinated.

Observing Run Details for Run 2: KP-4m/MARS

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).*

MARS Spectroscopy: The search will generate approximately 3, 5 and 7 SN candidates at each of the first three lunations which are bright enough (with $z < 0.40$ for a SN Ia within 10 days of maximum light) to confirm the SN type and obtain a redshift with MARS spectroscopy. We estimate that exposure times of 1 hr for $z = 0.3$ and 4 hr for $z = 0.4$ are required in order to confidently detect (SNR$\sim$15 per 30Å) redshifted SN Ia features (Si 6150Å, CaII 3900Å). (These calculations assume optimal point-source extraction with a 1.5 arcsec slit, 1.0 arcsec seeing, airmass=1.3 and dark time.) Assuming 70% weather & seeing efficiency, 2, 3 and 4 dark night are needed during the first three lunations each year of the search. This totals 9 nights per year. The high throughput of MARS — made possible in part by one of our LBNL red-sensitive fringeless CCD's — is crucial to obtaining such spectra on a 4-m class telescope.

Note that our BVRI imaging of the host galaxies prior to the SNe explosions will allow us to crudely estimate the redshift of many of the candidates prior to spectroscopic observations. Lightcurve shapes and colors will also help to eliminate non-Ia SNe and allow us to estimate in advance the time when each SN will reach peak brightness. In this way, we can optimize the selection of candidates and their assignment for follow-up at the KPNO 4m, the MMT, or other facilities such as Gemini. Such additional information is not generally available for classicial SN searches, so the rolling search method is more efficient in its use of telescope time for spectroscopy too.

Instrument Configuration

Filters:	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): 1 to 3

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

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

Please contact the PI of this survey before scheduling any nights. Because it is a large project combining data from multiple telescopes, it is necessary that the nights of the different telescopes be properly coordinated.

During any years of this survey when the target fields are at a very negative declination, this time on the KP-4m telescope will be replaced by time requested on the SOAR telescope.

Observing Run Details for Run 3: MMT/RCHAN

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).*

MMT Spectroscopy: The search will generate roughly 2, 5 and 5 SN candidates at each of the first three lunations which are too faint for the KPNO 4-m but too bright to efficiently utilize 8-m class telescopes. The MMT fills a key niche by concentrating on these $0.4 < z < 0.5$ SNe Ia. The MMT runs should be scheduled after the KPNO 4-m runs so that they can also serve as a source of back-up observations of lower-z SNe missed at KPNO.

We estimate that exposure times with the MMT Red Channel spectrograph of roughly 1.5-2 hrs for $z = 0.5$ are required in order to confidently detect (SNR$\sim$15 per 30Å) redshifted SN Ia features (Si 6150Å, CaII 3900Å). (These calculations assume optimal point-source extraction with a 1.0 arcsec slit, 0.8 arcsec seeing, airmass=1.3, and grey time.) Assuming 70% weather & seeing efficiency, 1 dark night is needed for each of the first three lunations each year of the search. This totals 3 nights per year.

The $\sim$ 15 higher redshift SNe found each year that still have high-quality lightcurves will be spectroscopically-observed elsewhere (Gemini, VLT, Keck).

Instrument Configuration

Filters:	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): 1 to 3

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

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

Please contact the PI of this survey before scheduling any nights. Because it is a large project combining data from multiple telescopes, it is necessary that the nights of the different telescopes be properly coordinated.

During any years of this survey when the target fields are at a very negative declination, this time on the MMT telescope will be replaced with proposals for time on Gemini South.

NOAO observing proposal LaTeX macros v2.6.