NOAO Observing Proposal *Survey proposal* **Panel:** *For office use.*
Date: March 14, 2002 **Category:** Cosmology

A Rolling Search for High-Redshift Supernovae

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Abstract of Scientific Justification *(will be made publicly available for accepted proposals)***:**
We propose a survey which will use the Mosaic camera on the CTIO 4m telescope "rolling search" for supernovae at redshifts $z < 0.8$. In addition, the survey will use the KPNO 4m telescope to obtain spectra of many of the supernovae discovered at $z < 0.45$, for purposes of identification and measurement of the redshifts. The search will image 7.2 square degrees of the sky with Mosaic for several days each month for four months each year. By the end of the five-year survey, we will have ~ 360 supernovae with high-quality lightcurves, all with multiple measurements while the lightcurve is still rising. This will dramatically improve our measurement of the cosmological paramters Ω_M and Ω_Λ, and will begin to address the nature of the dark energy. This survey will also provide the ideal data set for addressing and limiting potential systematic errors in supernovae at $0.3 < z0.8$, which is of great importance since it is supernovae at that redshift range on which the evidence for dark energy current rests. The supernoave observed by this survey will have lightcurves equivalent in quality to those discovered with a traditional two-epoch high-redshift supernova search and followed with HST.

Summary of observing runs requested for this project

Run	Telescope	Instrument	No. Nights	Moon	Optimal months	Accept. months
1	CT-4m	MOSAIC	140	dark	Sep - Dec	Sep - May
2	KP-4m	MARS	45	grey	Sep - Dec	Sep - May
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.*

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, and 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 supernovae in batches. The SCP and the High-Z team led by (Chris Stubbs?) have each independently produced consistent measurements of Ω_M and Ω_Λ (Perlmutter, 1999; Riess 1998). Together with measurements of the Cosmic Microwave Background which indicate the Universe is flat (Balbi, 2000; Melchiorri, 2000), supernovae 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 $p/\rho = w < -0.6$ (where $w = -1$ would represent a cosmological constant or vacuum energy) is one of the most important astronomical discoveries in the last decade. Measurements of high-redshift SNe Ia may be taken further to begin to address the properties of the dark energy by refining the measurement of w by both increasing the statistics at the current redshift range and pushing the observations out to higher redshift. Figure 3, discussed below, shows the potential improvement in the statistical limits on the cosmological parameters from this survey.

Because the current evidence for dark energy rests on SNe Ia at redshifts z=0.3–0.9, it is crucial that we better understand these objects. An NOAO survey using the Mosaic camera on the 4m CTIO telescope is perfectly suited to address the two primary plausible sources of potential systematic error in SNe Ia: evolution, and the effects of dust extinction. Evolution of the supernova population is best addressed by high-quality measurements of SNe at low ($z < 0.1$) and high redshifts, including a good measurement of the rise of the lightcurve for supernovae in both samples (Aldering 2000). The possible effects of dust extinction on supernovae include the effects of "gray dust" (ref) and concerns about the estimations of the effects of standard host-galaxy reddening on the current set of supernovae (ref). Grey dust may best be addressed by observing supernovae in the optical and infrared wavelengths at a range of redshifts (including $z < 1$ and $z > 1$), so as to have strong measurements of supernovae across the epochs of both acceleration and deceleration. Host galaxy extinction is best addressed by obtaining a large sample of well-observed supernovae at the redshifts on which the current cosmological results rest. Good color measurements of this large sample will allow high-quality direct estimates of E(B-V) from dust extinction. Moreover, with a sufficiently large sample, enough ($\sim 1/8$) will be in elliptical galaxies, allowing an estimation of the cosmological parameters from a statistically significant set of supernovae unlikely to be affected by host galaxy dust extinction; discovery of $\gtrsim 300$ SNe Ia in all hosts would therefore provide a sample *entirely hosted in elliptical galaxies* which is equivalent in size to the set of supernovae which provide today's measurement of dark energy. This survey will address these issues by providing high-quality color and lightcurve measurements of supernovae at the redshift range that provides our best evidence today for dark energy.

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 $\sim$ 360 SNe Ia at $z < 0.8$ over the five-year duration of the survey. The survey will be run by the SCP, a leading team in supernova cosmology, and the first team to successfully discover high-redshift SNe Ia in batches at the CTIO 4m telescope. In addition, this survey requests 9 nights of time each year on the KPNO 4m Mayall telescope (WHICH INSTRUMENT?) to perform spectroscopic confirmation and redshift measurements of SNe at redshifts $z < 0.5$. Equipped with LBNL red-sensitive CCDs (ref), this instrument is ideal for this work.

In contrast to traditional "two epoch" high-redshift supernova searches (where images from a reference and a search run are subtracted from each other), this survey will image a number of target fields every 2–4 nights within 8–9 days of new moon for four months. Observing for a period of 17–19 days each month ensures that *every* supernova which explodes in the surveyed area during the survey gets a measurement of the lightcurve with a point no more than $\sim$ 5 rest-frame days from maximum light both before and after the time of maximum; a greater gap around full moon would lead to supernovae "lost" due to not having a measurement close to maximum light. The survey proposes to use half-nights: the second half of the night for the first two months, and the first half of the night for the second two months, so as to minimize the airmass to the chosen target fields. Fields will be observed in the R and I bands at each epoch, which are the wavelengths most useful for SNe Ia at $0.3 < z < 0.8$. Six "deep" fields (2.4 square degrees) would be observed to a limiting magnitude of 24.0 (with S/N=10) in R and 23.5 in I. Twelve "shallow" fields (4.8 square degrees) would be observed to a limiting magnitude of 23.5 in R and 23.0 in I. These observations require 4.5 hours of time, including a 100s readout time for each exposure.

In addition, at the beginning of the survey each year the target fields would be observed to a depth of 24.0 or 24.5 (for "shallow" and "deep" fields respectively) in B and V, requiring an additional night of observations. These will allow BVRI photometric redshifts, as well as classification from the color information, of host galaxies of discovered supernovae. This will also enhance the value of the data set for other scientific uses.

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 supernovae 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 supernova lightcurve which are taken *before discovery*. The survey will produce an unprecedented number supernovae 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 "hit rate" and efficiency of use of that time.

Figure 1 shows the expected supernova discoveries over the course of this survey, in redshift bins of width 0.1. A primary set of $\sim$ 270 supernovae out to $z = 0.6$ will have R-I color uncertainties less than 0.05 magnitudes; 90 additional supernovae out to $z = 0.8$ will have R-I color uncertainties in the range 0.05–0.1. Another $\sim$ 100+ supernovae will be discovered at redshifts another 0.1–0.3 beyond $z = 0.8$; those supernovae will require additional photometric followup from larger or space-based telescopes.

Figure 2 shows a simulated lightcurve from this survey for a SN Ia at $z = 0.45$ in one of the "shallow" fields of this survey, together with data for a supernova 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 supernova's peak magnitude, light curve width, and R-I color which are *equivalent in quality* to those of a supernova discovered using a traditional search and followed with the HST. This survey will produce lightcurves of this quality for every supernova 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 3 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 supernovae 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. The sample of ~ 270 supernovae with excellent measurements of R-I (good to $\lesssim 0.05$ magnitudes) will allow us to directly address the issues of dust extinction discussed above.

Redshifts and spectral confirmation will be obtained through a combination of the KPNO 4m time being requested for this survey, and by additional telescope time for which the SCP applies each year. Experience indicates that 3–4 supernovae at $z < 0.5$ may be spectrally confirmed by a 4m telescope during the course of one night. Nine nights on the KPNO 4m, divided into three nights during the each of the last three months of the survey, would be sufficient to confirm most of the supernovae discovered at $z <$0.4–0.5 each year. The SCP will use its other observing resources to confirm many of the remaining supernovae, both at these redshifts and at higher redshifts.

Relation to Other Supernova Surveys

The SCP and other teams are currently engaged with other supernova surveys; this survey would be complementary with the others. The Supernova Factory (ref) is aimed at discovering a large number of supernovae at redshifts $z < 1$, which will be used as calibrator objects for supernovae at higher redshifts. The CFLS survey at CFHT (*how should we state the SCP's relationship??*), as well as ongoing searches at Subaru in collaboration with Momoru Doi, are designed primarily to find supernovae at higher redshifts of $z > 1$. This survey will discover supernovae at the intermediate redshift range. The CTIO 4m telescope is the ideal instrument for discovering supernovae at this range, and as stated above this is the range in which it is currently most important to understand and limit systematic errors on high-redshift supernovae.

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 the SNAP satellite mission, which if approved will be launched in $\sim$ 2010and will discover and follow thousands of supernovae

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 in 7.2 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 2.4 square degrees of "deep" fields; it will be 0.5 magnitudes less deep in the 4.8 square degrees of "shallow" fields. The B and V observations obtained for photometric redshifts will round out the data set for deep BVRI fields. These fields will be chosen to be contiguous; although this is not necessary for the supernova work, it will maximize their value for other uses. Fields will be repeated for two years (thereby providing deep final references for supernovae 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. By the end of the 5-year survey, there will be deep BVRI images of a contiguous 14.4 square degree region of the sky, ideal for cluster searches and SZ measurements.The SCP has collaborated in the past with other groups who used their search data for cluster searches and weak lensing measurements. The much greater depth, areal coverage, and consistency of these data will make them fare more useful. (Help: other uses I should mention?) √

The survey will also have direct educational uses. The PI, R. Knop, is proposing an astronomical lab course at Vanderbilt University which will be based around high-redshift supernova searches. Although the course will primarily rely on pre-existing data, the timing of the course and the survey may allow the students to become involved in the search and participate in one of the most exciting current groundbreaking astronomical research projects.

References

Aldering, G., Knop, R., and Nugent, P., 2000, AJ, 119, 2110.
Balbi, A., *et. al.*, 2000, ApJ, 545, 1.
Melchiorri, A., *et. al.*, 2000, ApJ, 536, 63.
Perlmutter, S., *et. al.*, 1999, ApJ, 517, 565.
Riess, A., *et. al.*, 1998, AJ, 116, 1009.
van Dokkum, P., 2001, PASP, 113, 1420.

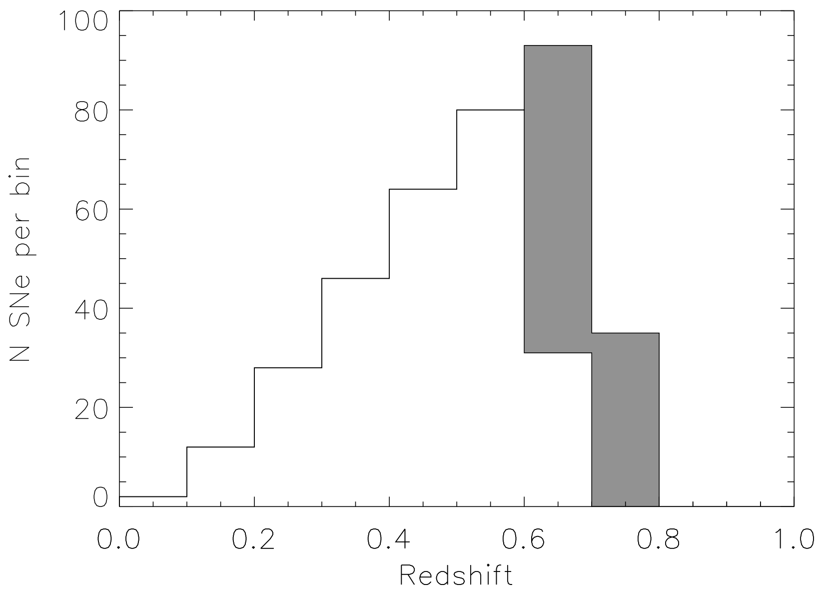

Figure 1: Predicted number of supernovae discovered by five years of the survey in fields to two depths. Open bars represent supernovae with observed R-I color uncertainties better than 0.05 magnitudes; solid bars have R-I color uncertainties in the range 0.05–0.10 magnitudes.

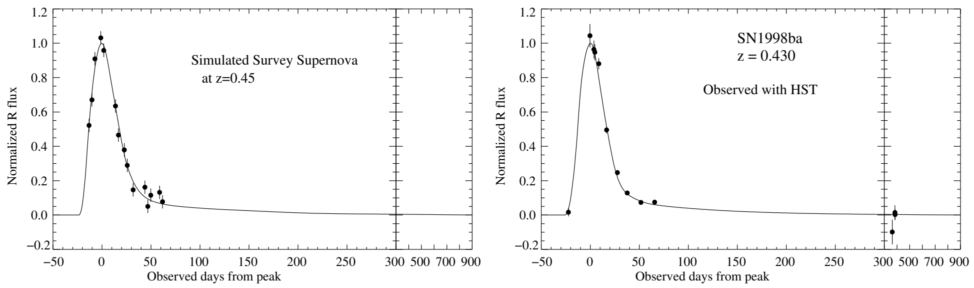

Figure 2: Left, a simulated lightcurve of a SN Ia at z=0.45 produced by the observations in the "shallow" field of this survey, discovered in the second month of the survey, assuming observations every three days and that each day has a 25% chance of being lost to weather. Right, the measured lightcurve from a supernova discovered at $z = 0.43$, observed with WFPC2 on HST.

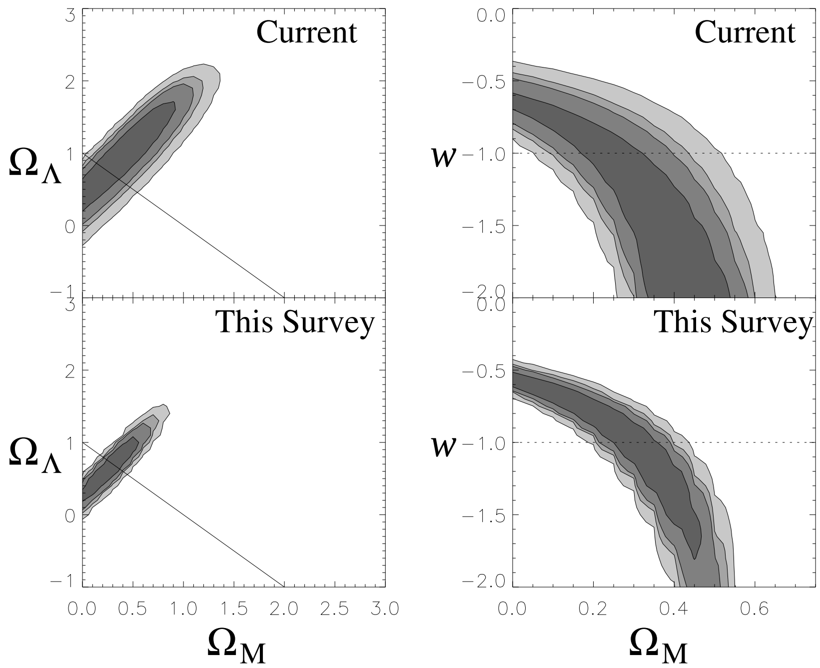

Figure 3: Simulated 68%, 90%, 95%, and 99% confidence limits on cosmological parameters from 360 high-redshift supernovae at $z < 0.8$ discovered by this survey. All plots explicitly include statistical errors due to host galaxy correction and measured uncertainties in E(B-V). On the left are the limits on the mass density Ω_M and the cosmological constant Ω_Λ. On the right are the joint limits on Ω_M and the equation of state parameter w for dark energy, under the assumption that the universe is flat. The upper plots show the SCP's current limits, including the results from 10 supernovae discovered at CTIO in 1997-1998 and followed with the HST, are shown in outline on each plot. The lower plots include only the high-redshift supernovae of this survey, plus an assumed 40 supernovae at $z < 1$. (In practice, many more supernovae at $z < 0.1$ will be available from the Supernova Factory (ref ??).)

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 have as their primary research activity the performance and management of this search and related observations. They will be supported by the rest of the international SCP collaboration, including particularly the supernova team at Lawrence Berkeley National Laboratory (LBNL), which includes five research scientists, four post-docs, three graduate students, and other support personnel. At Vanderbilt University, the SCP has accesses to substantial computing resources including the VAMPIRE Beowulf cluster. At LBNL, access to the NERSC supercomputing center provides 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 the NERSC supercomputer center will allow us to apply the computationally expensive LAcosmic 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 twice the 100s readout time of the Mosaic camera). √

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 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 Data Products Group led by Chris Smith at CTIO. This pipeline will produce overscan, bias, and flatfield corrected images from Mosaic at CTIO. These flatfielded images will then be transferred to computers at LBNL and Vanderbilt, where they will be combined and subtracted using the extremely successful SCP search software which has been used to discovered supernovae at CTIO and other telescopes over the last several years. 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 supernova discoveries which will be reported in IAU circulars, as well as observed spectrally by other telescopes and eventually published in the astronomical literature. Furthermore, this survey will serve as a testbed for involvement of NERSC (the largest unclassified supercomputing center in the world) in NWO (GREG– what is this? New World Order?). √

The impact of the survey on NOAO resources will be modest. The SCP will send one or two observers to CTIO around new moon each month 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) $\sim$ 10 hours every three to four nights. An additional observer will be sent to KPNO to perform spectroscopic observations during the nights of those runs.

The runs requested are listed at the end of this section. Please note, however, that the exact timing of the runs flexible, and the SCP is open to negotiation with the CTIO staff on when the survey would best fit their schedule. While the simulations have assumed an optimum schedule with seven nights around each new moon spaced three days apart, the survey will still succeed with some modification to this schedule. The only real requirement is that a large enough equatorial target field 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; KPNO spectroscopy time should be situated toward the end of a single month's run with Mosaic at CTIO. Two ideal periods of time for this survey would be September–December, and January–April. This survey may also make use of the "off half" of some of the nights of the existing SuperMacho survey, by overlapping the end of their period with the beginning 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. Note, however, that as mentioned above this survey benefits greatly from data as many as 8 or 9 days after new moon, whereas the SuperMacho survey only takes data within 3–4 days of full moon; thus, although a large degree of overlap with SuperMacho nights would be possible in the first or last month of the survey, there are some differences in timing which should be taken into consideration.

The SCP is aware that the High-z team is also proposing a large supernova survey. If both proposals are given time, the SCP expects and hopes to coordinate with the other team to ensure that the two surveys are run in the most efficient manner so as to maximize the scientific benefit of both. For instance, if one team has additional observing time at other telescopes during the time of the other team's survey, the second team might give higher-redshift candidates requiring additional observations to the first time, thereby benefiting both teams as well as the scientific knowledge of the community.

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

Semester    Telescope   Instrument  # of Nights  Moon  Acceptable Months
-----------------------------------------------------------------------
200xB or A  CTIO-4m     Mosaic      3.5          dark  Sep or Jan
200xB or A  KPNO-4m     ???         3            grey  Sep or Jan (late)
200xA or B  CTIO-4m     Mosaic      3.5          dark  Oct or Feb
200xA or B  KPNO-4m     ???         3            grey  Oct or Feb (late)
200xA or B  CTIO-4m     Mosaic      3.5          dark  Nov or Mar
200xA or B  KPNO-4m     ???         3            grey  Nov or Mar (late)
200xA or B  CTIO-4m     Mosaic      3.5          dark  Dec or Apr
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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. Each year it applies for observing time at a number of national observatories, as well as the observatories of the University of California (including the 10m Keck telescopes). These resources will be used to spectrally confirm and measure the redshifts of those additional supernovae not observed spectrally at the KPNO 4m, and at higher redshifts. 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 SCP will release all of the images to the public at the end of the four-month period of the survey each year. In addition, deep co-added, cosmic-ray rejected, and calibrated images which combine data throughout all of the nights of the survey 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 any subset of the data to any astronomer in North America. The SCP will develop a web interface and search engine providing easy access to the specific data, which will include information about depth, image quality, and exposure time for each frame available.

(NOTE: How soon should we make this data available? We could have it out within days or weeks, but we might want to sit on it until the end of each four-month period.) $\boxed{\surd}$

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.*

The SCP has been the leading team using the NOAO facilities for the discovery and follow-up of supernovae at a wide range of redshifts. It has been performing successful searches for high-redshift supernovae at the CTIO 4m telescope from 1995 through the present. Many of these supernovae have been followed up on the Gemini and WIYN telescopes. In 1999, the team collaborated with Lou Strolger and Chris Smith to find low-redshift supernovae on the 0.9m Curtis Schmidt telescope; spectra of these objects were obtained at, among other facilities, the KPNO and CTIO 4m telescopes. $\boxed{\surd}$

(Yeah, yeah, I need to put in details of the last couple of years of runs.) $\boxed{\surd}$

Why CTIO? *(For CTIO proposals only.) Explain why access to the southern hemisphere is needed to achieve your scientific goals.*

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).*

DUMMY TEXT - FROM 2002A

Search Technique: The search technique we have developed and used so successfully works as follows: We obtain reference images just after new moon using the MOSAIC camera on the CTIO 4-m telescope, and with SuprimeCam on the Subaru telescope. Just before the next new moon, we observe the same fields again, and examine the tens of thousands of high redshift galaxies ($z \sim 0.3$–1.5) to find those showing the new light of a SN that was not there on the previous observation.

We have regularly demonstrated our ability to find and follow distant supernovae in this way over the last several years (See International Astronomical Union Telegrams and Circulars by the Supernova Cosmology Project in which we have reported more than 100 discoveries of supernovae), including spectroscopically confirmed SNe Ia at the highest redshifts (e.g. SN1998eq at $z = 1.2$, as well as the $z = 1.055$ and $z = 1.12$ SNe Ia detected in Spring 2001 on the CTIO-4.0 m and CFHT).

We have developed extensive software to find and accurately identify these supernova candidates within days of the observations. As in our 2001A run where we discovered 17 SNe, we will determine redshifts for around 15 of the faint (likely high-redshift) candidates and from this will select 2 $z > 1$ SNe Ia for detailed follow up.

The targets will be found in search fields with declination near 0° so that they can be observed by telescopes in both hemispheres. We will also take care to select regions of low Galactic extinction. The final selection of fields depends on the dates scheduled for searching.

Note that we will guarantee the discoveries for all the follow-up by providing complementary searches at other telescopes with different weather (see above.)

Imaging depth: Our deepest imaging must reach SNe Ia at $z = 1.2$, having $I = 24.5$ at maximum. To allow for discovery 0.4 mag below maximum (pre-max) and a dispersion of 0.3 mag, we aim at detecting $I = 25.2$ on the subtraction. Based on our previous successful search experience to this depth and guidance from the NOAO exposure time calculator, we estimate that MOSAIC under good conditions (i.e lunar phase 0–7 days, airmass 1.0–1.5, seeing 1.1″) can detect $I = 25.2$ point sources at $> 7\ \sigma$ *after subtraction* with 5.4 hours of integration. Note that a 7 σ threshold is necessary to suppress spurious candidates given the 10^7 independent samples present in such large images, and the great expense of spurious candidates targeted for spectroscopic follow-up at the faintest targeted magnitudes.

For the shallow search ($0.35 < z < 0.8$), we aim to detect ~ 10 SNe Ia, including at least one ~ 10 rest-frame days before maximum at 7 σ. This requires images reaching $R = 24.2$. This depth can be achieved in less than 10 minutes. Split exposures are needed to veto cosmic rays and asteroids.

Areal coverage: Using our rate determinations [Pai96, Pai01], we have conducted Monte-Carlo simulations to estimate the number of pre-max SNe detectable with a search to $I = 25.2$ with an optimal 3-week spacing between epochs. The rate is based on actual observations (conducted the same way as proposed here), so it already includes any detection inefficiencies. These simulations showed that we should detect ~ 8 SNe Ia/$\square^\circ$ before maximum with $0.8 < z < 1.2$ (median z=1). In order to guarantee discovery of 5 SNe Ia with $0.8 < z < 1.2$ to be followed with HST, three MOSAIC pointings (1.14 $\square^\circ$) are required.

Note that HST requires target coordinates to within 1° three weeks *prior to discovery* of our SNe Ia. Since the SN Ia locations are not known yet, all of our deep search fields must be located within a single 1° radius on the sky. The result is that the deep field can be observed for at most 6 hrs per night. These crucial deep observations comprise the bulk of our observing time request.

For the shallow search, 10 pre-max SNe Ia to be followed with WIYN, NTT, Gemini and VLT are desired. Our simulations indicate that 20 pointings reaching $R = 24.2$ are required to meet this target. For many of these objects, the S/N will be good enough for the photometry on the detection image to contribute significantly to the light curve, especially because early discovery helps constrain measurement of the lightcurve width. As in previous searches in this redshift range, we will search in R- and I-bands, making it possible to have early photometry points in both these bands.

The need for closely timed epochs: Only SNe Ia discovered at or before maximum produce useful light curves. Therefore two successive imaging epochs must be separated by 3–4 weeks since the time from explosion to 7 rest-frame days before peak is 3 weeks at $z = 0.5$ and 4 weeks at $z = 1.0$. Since each faint SN-candidate requires $\sim$ 4 hrs on Keck, Gemini or VLT, spectroscopy of post-max SNe Ia is an expensive waste of large-aperture telescope time. Larger epoch spacings can result in up to 60% of candidates being post-max. For this reason the basic proposed timing of the observations is crucial, and we cannot simply use pre-existing deep imaging as references (e.g. from DeepLens) for this search. The discovery images must be completed several days prior to new moon so that confirming spectroscopy at Keck, Gemini and VLT and follow-up photometry from HST, Gemini, WIYN, NTT and VLT can commence by new moon.

Search scheduling: At this time, our preference is for a reference run near new moon in April (April 13-15) and a search run near 3rd quarter in May (May 6-8). Alternatively a similar timing for a March reference (March 14-16) and an April search (6-8) could be preferable —depending on timing of the HST servicing mission. Depending on the HST and Keck availability, it is also possible to split the discovery observations over two epochs. The timing of the search dictates the scheduling at all follow-up telescopes (including HST). Therefore, *it is essential that we be contacted prior to scheduling as coordination amongst the participating telescopes is vital.* The exact target fields are to be determined based on the time of year the CTIO observations are scheduled.

Image analysis resources: In our past searches, the data rate–bandwidth ratio has allowed us to ship our search data to LBNL over the Internet for reduction and analysis within hours of data taking. The larger search data set which MOSAIC will produce, combined with the remoteness of CTIO, may require that image co-addition take place at CTIO and that co-added images then be sent via the Internet to LBNL for searching. We will take the necessary UNIX-compatible laptops to the search run for this purpose. Note that we have a proven success at reducing data at the telescope in this way, and sending it up to LBNL for further processing.

Rationale for a concentrated annual search: The science is now requiring us to study SNe Ia at higher redshifts, in turn requiring more imaging time to find and follow the supernovae, and more spectroscopy time to confirm their types and redshifts. This is clearly science that will not work with too little telescope time scheduled once a semester. Based on just Poisson statistics alone, for such a small sample at the higher redshifts, the expectation value of wasted HST orbits would be twice as large if this program were divided into two semesters; the comparison is even worse if typical observing conditions are factored in. Therefore, for the 2000B through 2002A observing semesters we have been requesting sufficient telescope time scheduled once a year; In accordance with this plan, we did not request time for semester 2001B.

Reference Images for the SNe Ia Discovered During the 2001 Run: Note that the deep images taken during the next run will serve a double purpose, as they will also be used as final I-band reference images needed for the photometric follow-up of last Spring's 2001A run. This will allow us to save a large amount of observation time on other telescopes like WIYN. Note also that for the search run, we will build deeper images by combining the first period reference images with observations of the same fields taken at CTIO-4.0m during the previous runs.

Summary of the observing time request: The deep search requires three pointings of 5.4 hrs exposure (plus 0.4 hrs of overhead) in I-band at two epochs. The deep search region is visible for only 6 hrs per night (see above), so 3 nights (3×5.8 hrs/6 hrs visibility per night = 3 nights) at each epoch. The balance of each night will be necessary to conduct the shallow search, which requires twenty pointings of 10 minutes in R-band and 10 minutes in I-band at two epochs. *3 nights per epoch for two epochs brings our total request to 6 nights.* The MOSAIC time requested here is absolutely essential to the success of this international, multi-telescope campaign.

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): 8 to 9

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

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

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).*

DUMMY FILE - FROM 2002A GMOS (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.

(b) GMOS Imaging: GMOS will also be used to obtain lightcurves for two SNe Ia discovered in the redshift range $z \sim 0.7$–0.85 —higher redshift SNe Ia require HST for optical observations.

Exposure Times and Overheads: We intend to obtain 5 i' points —rest frame B— and 1 z point —rest frame V— around maximum, with a S/N ratio of 20. The table below presents representative exposure times for a $z \sim 0.8$ SNIa observed at GMOS. It shows that obtaining a lightcurve takes about 6.75 hours per supernova. The corresponding time for a $z = 0.75$ SN Ia is 5.3 hours. Therefore, the total on-source time requested is 12 hours. Adding 25% of elapsed time, plus 15 minutes per visit to take into account the overheads, we therefore request 18 hours on GMOS. We also assume that the z and i images at peak can be obtained with the spectroscopy, removing the acquisition overhead for these. The target table summarizes the photometric observations we plan to carry out at GMOS.

Day Observer Frame	I-Mag	Z-Mag	S/N [I]	S/N [Z]	Exp. I[s]	Exp. Z[s]	Total
0	23.1	23.1	20	20	480	2820	3300
10	23.3	—	20	—	660	—	660
20	23.7	—	20	—	1380	—	1380
30	24.3	—	20	—	4140	—	4140
40	25.0	—	20	—	14880	—	14880

Summary: We will use Gemini/GMOS for the spectroscopic confirmation of 5 SNe, including 2 at a redshift $z > 1$, and the follow-up of two SNe Ia discovered in the redshift range $z = 0.7$–0.8. We request 35.2 hours (US+UK) in May and June for this purpose.

Instrument Configuration

Filters:
Grating/grism:
Order:
Cross disperser:

Slit:
Multislit:
λ_{start}:
λ_{end}:

Fiber cable:
Corrector:
Collimator:
Atmos. disp. corr.:

R.A. range of principal targets (hours): 3 to 4

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

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