1 Scientific Justification

Introduction

We have developed and demonstrated a method of scheduling the discovery of high redshift ($z \geq 0.35$) Type Ia Supernovae (SNe Ia), for the purpose of making cosmological measurements. The method can measure Ω and Λ by treating SNe Ia as "calibrated candles" rather than "standard candles." By taking into account SN Ia luminosity corrections calibrated by the width (rate of decline) of the light curve, the dispersion of the intrinsic peak magnitude can be as low as $\sigma_{\rm calib} \lesssim 0.2$mag, or $\sigma_{\rm calib} \lesssim 0.15$mag when reddening corrections are used (Hamuy *et al.* 1995, 1996; Riess, Press, & Kirshner 1995).

Using this method on the first 7 SNe at $z \sim 0.4$ discovered by the project, we derived a first measurement of Ω_M and Λ in combination, yielding an extended confidence region strip on the $\Omega_M - \Omega_\Lambda$ plane (Perlmutter *et al.* 1997). Under the *assumption* of a flat universe, we translated this confidence region into a measurement of $\Omega_M = 0.94^{+0.34}_{-0.28}$; under the assumption that $\Lambda = 0$, the confidence region corresponded to a result of $\Omega_M = 0.88^{+0.69}_{-0.60}$. Data from an additional ~ 40 SNe in the last 4 semesters, currently under analysis and awaiting final baseline and calibration data, will increase the sample size by a factor of ~ 6 and decrease the statistical uncertainty on these measurements by a factor of ~ 2.5.

For the next stage of the project, we will focus on two areas: breaking the degeneracy between Ω_M and Ω_Λ, and obtaining large enough subsets of SN events to check corrections for systematic effects. During 1998, we have been allocated 80 HST orbits to observe high-redshift SNe with WFPC-2 and NICMOS, and we have applied for additional NICMOS time during its shortened expected lifetime. The HST orbits allow very good measurements of the lightcurves of dim, very high redshift SNe. Additionally, infrared observations with NICMOS give greater leverage for measurement of host galaxy extinction. It is important to find and confirm SNe for this next stage of the project now, while NICMOS is still available.

Breaking the Ω_M-Ω_Λ degeneracy

In Goobar & Perlmutter (1995) we showed that by adding a sample of SNe at $z \gtrsim 0.8$ to our first seven SNe at $z = 0.3 - 0.5$, it is possible to measure Ω_M and Λ simultaneously. In March of 1997, a spectrum obtained at the Keck II telescope demonstrated that SN 1997ap was a $z = 0.83$ SN Ia (Figure 1). Photometric measurements of this SN including I-band data from WFPC-2 on HST allowed better measurements of the peak and date of max of the lightcurve than would be possible with just ground-based data on such a high-redshift object (Figure 2). A contour plot showing the expected constraints on Ω_M and Ω_Λ given by this SN in combination with our first seven is shown in Figure 3. Note that the extended confidence strip given by the $z = 0.3 - 0.5$ SNe becomes a truncated ellipse with the addition of one SN at $z = 0.83$. A further advantage of higher redshift SNe is that the difference in distance modulus of different cosmologies is greater by a factor of two at $z \sim 0.8$ than $z \sim 0.4$. As such, a statistical sample of SNe at $z \gtrsim 0.8$ observed with both Keck and the HST will allow us to decrease the uncertainty in the measurement of Ω_M and Λ.

Checking Techniques to Eliminate Systematics

Once the data on our current set of SNe is complete, the uncertainty in the cosmological parameters will be limited by our confidence in the techniques used to eliminate systematic effects, such as Malmquist bias, host-galaxy extinction, and evolution effects. In Perlmutter *et al.* (1997), we introduced several "subset comparison" tests to check for systematic errors potentially introduced in corrections for extinction and Malmquist bias. For example, Ω_M and Ω_Λ measurements from SNe Ia found in late spiral galaxies (*with* some extinction correction) are checked against measurements from SNe Ia found in ellipticals (with little or no extinction). Similarly, measurements from the subset of SNe that are at redshifts close to the detection limit for the search can be compared to measurements from the subset of SNe that are at redshifts where the entire distribution of SN Ia absolute magnitudes would have been discovered in the search. This checks for any residual Malmquist bias after all SN Ia "calibration" techniques and Malmquist correction techniques have been applied. These crucial checks for systematic errors require 2 to 3 times more SNe in each subset for statistical validity.

While we believe we understand and have under control the effects of Malmquist bias on our sample, host galaxy extinction is currently the largest single source of uncertainty in our calculation of the cosmological parameters. Figure 4 shows a histogram of preliminary Ω_M values (in the flat universe case) given by the SNe we have published and under analysis. Although we are still analyzing the colors and magnitudes of the SNe for final results, in this preliminary plot there appears to be a peak towards higher values of Ω_M (corresponding to brighter observed SNe magnitudes at a given z), with a broad shoulder extending to lower values of Ω_M. Those events furthest from the core of their host galaxies and thus least likely to be affected by extinction tend toward higher values of Ω_M. Preliminary extinction analysis is only complete for a small number of SNe; of these, the few which have been measured to be reddened are in the shoulder. Together, these observations suggest that the SNe towards the left side of the distribution may be those affected most by extinction. Good measurements of the magnitudes and colors of more SNe which are believed *not* to be strongly affected by extinction are necessary to test this hypothesis. To obtain such a set of SNe, in 1998A, among candidates believed to be at $z \sim 0.5$, we will observe on those which are farthest from their host galaxy, or in galaxies identified to be ellipticals by their colors (as measured during the previous year's search).

This Proposal

The high-redshift spectra provided by the Keck are crucial for this work. We request 4 dark/grey nights to obtain spectroscopy of ~ 10 $z \gtrsim 0.8$ SN candidates, and an additional 15–20 $z \sim$0.4–0.6 SN candidates. Our search strategy guarantees that all candidates will be observed near maximum light. Because the availability of NICMOS is limited, it is important that we have enough Keck time now to confirm and measure the spectra of a sample of ~ 6 high redshift SNe. The spectra will be used to (a) confirm a set of of $\sim$20 identified Type Ia SNe among the $\sim$30 candidates, (b) determine the redshift of the SN event, usually from narrow lines in the spectrum of the host galaxy, (c) check each SN individually for spectroscopic peculiarities that would indicate a "non-normal" SN (Nugent *et al.* 1995), (d) both calibrate the peak absolute magnitude and determine the age of the SN event at the time of the spectrum using correlations with spectral features (Riess *et al.* 1997b), and (e) study evolutionary spectral changes that might suggest departures from the calibration rule based on nearer SNe Ia. At these redshifts, the supernovae and many of the host galaxies are faint enough (R$\sim$23–24.5) that only the Keck telescopes can obtain this information for such a large set of faint targets.

2 Progress to Date

Semesters 1996B and 1997A

During the last two semesters we have carried out two successful "back-to-back" searches, one at the end of semester 1996B, and another at the start of semester 1997A. This strategy allowed us to obtain follow-up photometry of the 1996B discoveries "for free" while carrying out the 1997A

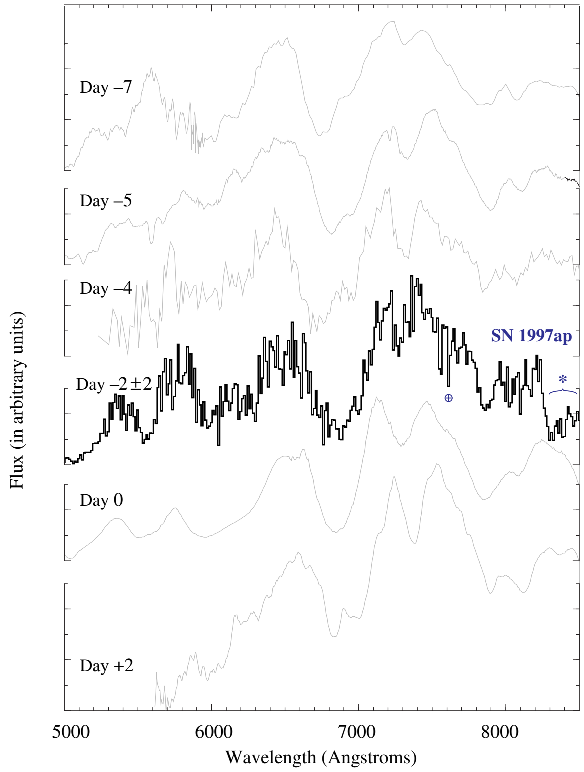

Figure 1: Spectrum of SN1997ap (solid line) at $z = 0.83$. Also shown are the spectra of nearby SNe at different epochs. The wavelengths of nearby SN spectra have been redshifted to match that of SN1997ap. The comparison between the spectrum of SN1997ap indicates unambiguously that SN1997ap is a SN Ia. Additionally, the epoch of the SN relative to maximum light is constrained to within ± 2 days from the comparison of features in the SN1997ap spectrum with features in the other spectra.

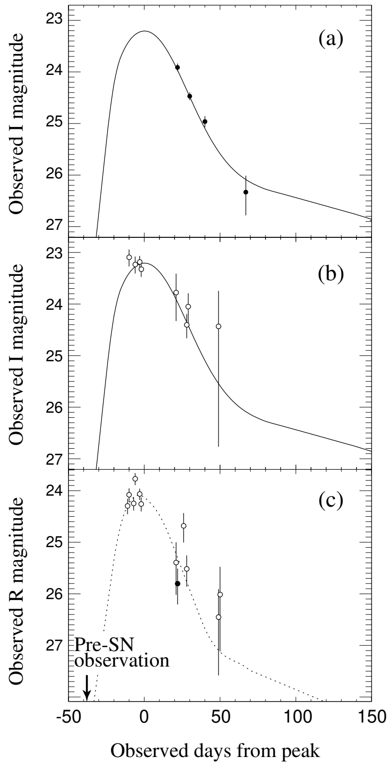

Figure 2: Lightcurve of SN1997ap, a SN Ia at $z = 0.83$. (a) The I-band lightcurve measured with WFPC-2 on HST. The signal to noise from the HST lightcurve provides an excellent measurement of the epoch and apparent peak magnitude of the lightcurve. (b) The ground-based I-band lightcurve. (c) The R-band lightcurve, including both ground-based points (open circles) and the single HST point (solid circle).

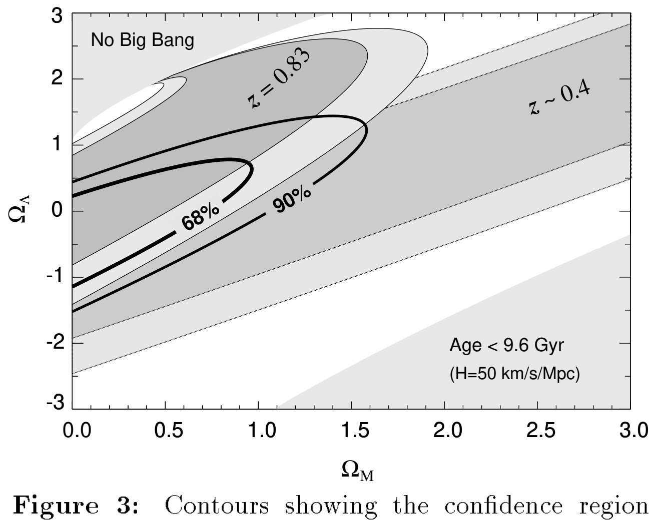

Figure 3: Contours showing the confidence region for Ω_M and Ω_Λ. The straight diagonal greyscale strip is the confidence region given from our first 7 SNe at $z \sim 0.4$ (Perlmutter *et al.* 1997). Overlayed on that is the greyscale region given by just SN1997ap at $z = 0.83$. The solid lines indicate the confidence region given by SN1997ap together with the first seven.

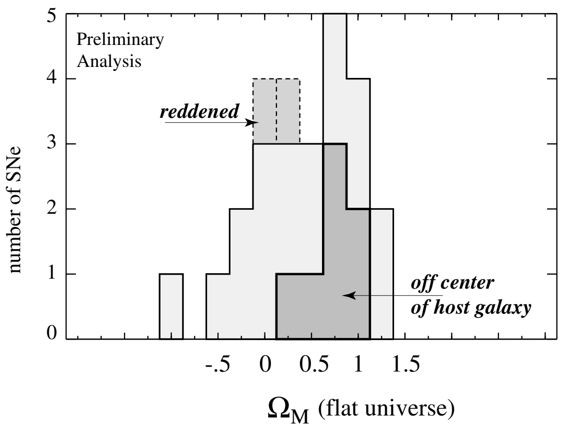

Figure 4: Preliminary histogram of Ω_M values from each of the SNe currently published and under analysis. The shaded subset represents those SNe furthest from the center of the host galaxy, and thus are the ones least likely affected by host galaxy extinction. Two SNe known to be reddened (and thus likely affected by extinction) are also indicated.

search. Keck spectra were obtained for both sets of discoveries while the SNe were near maximum light. These search runs produce ample SNe that we can select an appropriate subset of the best candidates for observation at Keck. We have now discovered ~ 50 SNe using this technique.

In January of 1997, we identified > 20 high-redshift SN candidates at the CTIO 4m using the 2048×2048 prime focus in 2 nights searching of ~ 4 square degrees. All save one of these SNe were discovered before or at maximum light, as planned. Two nights at Keck were scheduled two days after discovery. Both nights were clear and with reasonable seeing (typically $1.0''$). 14 SN candidates were observed at Keck, plus 5 brighter ones during scheduled time at the ESO 3.6m. Of the total of 19 candidates observed, 14 had spectra consistent with Type Ia SNe at $0.18 < z < 0.75$, median $z = 0.54$. The other non-Type Ia objects were either QSOs, Type II SNe, or BL Lacs. The rapid confirmation made possible an IAU telegram announcing the discoveries while they were still near maximum light (Perlmutter *et al.*1997, IAUC 6540).

A second search was carried out at CTIO in February-March 1997 using the new four-chip BTC camera. The greater area of this chip allowed us to both obtain deeper images of our search fields and find ~ 30 SN candidates for follow up. During only 1.3 clear nights on Keck-II (out of 3 scheduled), seeing conditions were unusually good when the sky was clear, we were able to use reduced exposure times for many candidates and make the most of the clear time available. We were able to observe and obtained redshifts for 14 SN candidates. Since f the 14 candidates observed, in the time available we were able to obtain spectra of nine which clearly showed Type Ia SN features. One of the others was a QSO, and another was possibly a Type II SN. The SNe Ia have redshifts in the range $0.32 < z < 0.83$, and a median $z = 0.58$ (see Perlmutter *et al.*1997, IAUC 6596).

During the March, 1997 run at Keck II, we obtained a high quality spectrum of SN 1997ap (Perlmutter *et al.* 1997b). At $z = 0.83$, this the highest known spectroscopically confirmed SN. Because the seeing was good during the observation of this candidate ($\lesssim 0.7''$), and because this SN has very little host background, we were able to measure a good quality spectrum in 1.5 hours of exposure time (Figure 1). Using the techniques of (Riess *et al.* 1997b), we were able to determine that this was a "normal" Type-Ia supernova, and to calculate that the spectrum was obtained 2 ± 2 days before maximum light in the rest frame. This time of maximum is consistent with the date measured from ground based and HST measurements of the photometric lightcurve (Figure 2).

1995-1996 analysis

Final host galaxy images have been obtained for the ~ 18 SNe discovered prior to the last two semesters. The last of these final reference images were obtained within the last few months. Analysis of these SNe is nearly complete. We are currently studying systematic effects such as host galaxy extinction. In Figure 3 we show preliminary results from these SNe appear, together with the final results from our first seven SNe and even more preliminary results from SNe discovered in the last two semesters. The spectra from these SNe have been reduced, and are being prepared for separate publication.

Progress on Publications

Currently, six papers based on our results are either recently published, submitted, or in preparation. These papers describe (i) the first measurements of cosmological parameters based on the first seven SN discoveries (Perlmutter *et al.* 1997); (ii) a second paper which is in preparation describing the results from subsequent discoveries; (iii) a measurement of the rate of Type Ia SNe at $z \sim 0.4$ (Pain *et al.* 1996; Pain *et al.* 1997), (iv) constraints on spatial variation of the Hubble constant from our data (Kim *et al.* 1997), (v) a study of cosmological time dilation of SN light curves (in final stages of preparation), (vi) the use of SN spectra for the determination of subtype and age of SNe Ia (Riess *et al.* 1997b), and (vi) results on the $z = 0.83$ supernova 1997ap, and implications for cosmological measurements (Perlmutter *et al.* 1997b). All six of these papers use Keck spectroscopy obtained in this program (as well as earlier Keck spectra obtained during LRIS commissioning by J.B. Oke, J. Cohen, and T. Bida). Conference proceedings papers on the first four topics are published in *Thermonuclear Supernovae* (1997, Ruiz-LaPuente *et al.*). We are preparing two data papers containing Keck spectra: one, in collaboration with Alex Filippenko, will describe the earlier spectra obtained through 1996A. The second, authored by Isobel Hook *et al.*, will discuss the results of the spectra obtained during 1996B and 1997A.

3 Technical Justification

Feasibility

Based on past experience, the Keck (and only the Keck) is capable of obtaining the necessary signal-to-noise spectra for > 20 candidates within the time window necessary to observe SNe near peak. For SNe at $z > 0.6$, only the Keck is able to obtain reasonable spectra at all. We have demonstrated that the rate of SN discoveries is sufficient to give the necessary SN targets for observation at Keck.

Targets and Exposures

Our search technique guarantees that SN explosions will be discovered a few days before maximum light and on a given date, allowing photometric and spectroscopic follow up to be scheduled in advance. In this technique, we obtain reference images just after new moon on a 4m class telescope (specifically, the BTC camera on the CTIO 4m telescope). Each field observed (out of 15–20 fields) contains thousands of galaxies at redshifts between 0.5 and 1. Just before the next new moon, we observe the same fields again, and examine the tens of thousands of high redshift galaxies to find the 30 or so showing the new light of a SN that was not there on the previous observation. The SNe generally do not have time to reach maximum light with only 3 weeks (approximately 11 to 14 days in the SN rest frame) between our reference and search images. We have developed extensive software to find and identify these supernova within hours of the observations, so that the photometric and spectroscopic follow-up may begin immediately.

We have been awarded 80 orbits of WFPC-2 and NICMOS time, and applied for additional NICMOS time during 1998. A discovery run at the end of 1997B on the CTIO 4m telescope is already scheduled, and we have applied for a second search at the start of 1998A (February-March). Because we can use some of the same fields in the two back-to-back searches, the reference and search images for the second search also serve as follow-up images for the first search. Searches at the CTIO 4m telescope are now performed with the 4-chip BTC camera, which allows us six times longer exposures than was previously possible, while maintaining a coverage of 4–5 square degrees. In our March 1997 run, we successfully used this camera, discovering $\gtrsim 30$ SN candidates out to at least $z = 0.83$. We obtained spectra of 14 candidates at Keck, out of 20 high priority candidates, as discussed in the Progress to Date section. The median redshift observed in March of 1997 is lower than we expect for 1998A, because (a) we will observe deeper images, and search in the I-band as well as the R-band, in order to generate a greater number of faint but well detected high redshift candidates, and (b) we favored brighter candidates in March 1997 at Keck due to time lost to weather.

The targets will be found in search fields with declination $\sim 0°$, so that they can be observed by telescopes in both hemispheres, and avoiding regions of high galactic extinction. The final selection of fields depends on the dates scheduled for searching.

Exposures. In the past, we have found that 2×1800s exposures with LRIS on Keck are typically sufficient to reach a signal-to-noise of $\sim$10–20 per pixel for a SN near maximum light at $z \sim 0.5$

(R$\sim$23 mag). This length of exposure is sufficient to identify absorption features in faint host galaxies (often without emission lines) and to obtain a reliable redshift. Longer exposures, of up to 2.5 hours, are required to achieve the same signal-to-noise for the faintest SNe; additional higher resolution spectra with a grating blazed to a higher wavelengths are necessary for the long wavelength end of SN spectra at higher redshifts. (Under especially good conditions, such as $\sim 0.5''$ seeing or candidates with very little host light, somewhat shorter exposures can suffice.) A 4m class telescope on an unusually good night, with several hours of integration, can barely show the broad features in the smoothed spectra of the brightest of our high-redshift SNe. No details such as spectral feature ratios can be measured reliably in this low signal-to-noise data, and only extremely large evolutionary differences would be seen. Moreover, identification of the redshift via narrow host galaxy lines is rarely possible in these 4m spectra. Thus, the reliable redshift information needed for this project and the detailed SN spectra needed for calibration of peak magnitude can only be obtained at Keck.

Observing Strategy. On the first night, we will obtain short exposures (10-30 mins depending on the magnitude of SN and host galaxy) of a large number ($\sim$20–30) of candidates in "survey mode." The analysis of the "survey" spectra will be carried out during this first night and the following day. Redshift estimates from this preliminary analysis may be made from either host galaxy features, or by comparing SN features to the spectra of nearby SN, with these exposure times. On subsequent nights, we will obtain longer spectra of the objects which are most useful scientifically. We will emphasize the most promising candidates at high redshifts of $z \gtrsim 0.8$, as these are the objects which most require followup observations with our scheduled HST orbits during the limited NICMOS lifetime. In addition, we will observe a set of SNe at intermediate redshifts of $z \sim 0.5$ which are distant from the center of their host galaxies, to construct a sample of SNe minimally affected by host galaxy extinction.

This screening improves the overall efficiency while increasing the quality and scientific value of the spectral data. The extra overhead of setting up for a second time on the selected objects is more than compensated by not making second and further exposures of additional objects. Because the Keck finder camera is deep enough to find objects close to the candidates suitable for offsets, and because in our experience these offsets have been reliable, the overhead for setting up on an object is only $\sim$5 minutes, in comparison to exposure times of four to six times longer.

Because we will be targeting SNe which are at a higher redshift than we have concentrated on previously, not only do we require longer exposure times, but also the spectrum towards the red end of the wavelength range becomes more important as features are redshifted into that wavelength range. The wavelength range $\lambda > 7000$Å is important for SNe at $z > 0.8$, because it is where the rest-frame B-band spectrum is redshifted. Of particular interest are the FeII-III features at $4000-5000$Å, which are redshifted to > 7200 at $z > 0.8$. These Fe features are useful for constraining the epoch of the spectrum (Riess *et al.* 1997). This wavelength range is where the lower resolution grating is least efficient, and where fringing in the detector is most serious. Additionally, the greater density of narrow skylines increases the background noise. Higher resolution spectra, each with an integration time of $\sim$ 1.5 hours, will allow easier handling of systematic effects such as sky and fringe subtraction. There will also be a greater number of resolution elements relatively unpolluted by unresolved skylines, allowing better measurement of the underlying SN spectrum. Finally, the higher resolution grating is more efficient at these wavelengths.

Telescope Time Requested. As expected, the two good nights we had at Keck in January, 1997 were just enough to obtain good spectra at $\sim$ 2.5Å/pixel with high signal-to-noise of 14 candidates, including 9 SNe Ia at $0.37 < z < 0.74$ with median $z = 0.59$. Since in this run we hope to measure $\sim$ 10 candidates at redshifts of $z > 0.8$, some SNe will be as faint as R$\sim$ 24.5. If $\sim \frac{2}{3}$ of these candidates turn out to be scientifically useful (the others most likely being distant AGN and more nearby SNe Type II), each will require exposure times of 1.5-2.5 hours, in addition to the $\sim \frac{1}{2}$ hour necessary to reject poor candidates (such as high redshift QSOs). An additional 10–30 min will be necessary to confirm the quality the 15–20 $z \sim 0.5$ candidates, with another $\sim$ 30min for each of the 10–15 we expect to be good candidates. It will require three nights to perform these observations. On the fourth night, we will return to the highest redshift SNe at higher resolution to obtain better spectra in the wavelengths > 7000Å.

All told, we are asking for 4 dark nights to obtain spectra of 20–30 candidates, including 16–25 SNe Ia. The best of these candidates will be given to HST to follow up with the time we already have assigned on WFPC-2 and NICMOS. The work on high-redshift $z \gtrsim 0.8$ SNe must be completed this year during the lifetime of NICMOS.

Instrumentation We use LRIS with the 300 line nm^{-1} grating blazed to 5000Å to observe both the supernova and its host galaxy simultaneously at 4700–9700Å. On the final night, we will use the 831/8200 grating to observe the highest redshift SNe at $\lambda > 7000$Å. We find that we can observe within 7 days of new moon, and we will schedule discovery of the SNe just before new moon.

Backup Programs

The CTIO search should discover > 30 good candidates. In the unlikely event that the search fails to find enough candidates, the primary backup program is the observation of host galaxies for previously discovered SNe after the SNe have faded, to make it possible to distinguish the features of the SN alone. As discussed above, this is important for measuring spectral line ratios to cross-check the calibration of the SN intrinsic luminosity, and for evolution studies. The SN host galaxies are faint (R$\sim$ 23 mag and fainter), and often have no emission lines, and thus are difficult observations for 4m class telescopes. It would be very important to observe them with a comparable setup to the original supernova spectrum on the Keck to make feature subtraction as clean as possible. While it may be possible to do this by subtracting a template galaxy spectrum, we believe it is important to check the results of this procedure in a number of cases by comparing with the results obtained using spectra of the actual host galaxies. We will apply in the future specifically for these Keck observations of the host galaxies, if they are not complete in the course of this program.

Even if the weather is poor we have found it possible to obtain useful spectra of distant SNe. These lower signal-to-noise spectra can be used for redshift and SN Type determination, although they cannot be used for detailed evolutionary studies. During gaps between clouds we have been able to obtain such spectra in 15 minutes for the lower redshift SNe.

Supplementary Observations

A comprehensive observing program is necessary to obtain a sufficient data set to characterize the SN types and luminosities, and to provided the color, spectra, and light curve shapes necessary to cross-check the luminosity calibration. No single telescope is able to provide guaranteed coverage of the light curves given the vagaries of weather and instrument scheduling, and no single telescope can provide the wide field necessary for efficient discovery and the 10-meter aperture needed for spectroscopy. The spectroscopic program is therefore tightly coordinated with photometry at several observatories. In each of the past semesters, we have been receiving time for photometry follow up at the CTIO-4m, WIYN, INT, ESO 3.6m, and WHT telescopes. With our collaborators, we are also applying for followup at the NOT, NTT and CFHT. The goal is to schedule these telescopes to trace out the $\sim$ 60 days over the peak of the light curves (in R and I bands) for all the SNe discovered. We organized this extensive ground and space-based collaboration for the semester 1997B to meet this need, and are now organizing the next semester's campaign. We have been awarded 80 orbits of HST for this project during the period, and we emphasize that the *Keck spectra are essential to screen for suitable high-z SNe to be observed with HST.* This must be done this year during the operational lifetime of NICMOS.

Spectra near maximum brightness, preferably at more than one epoch, are best for these goals. Spectra having good signal-to-noise ratios are necessary, but they are only achievable (over reasonable observing times) with the Keck telescope. We will notify all Keck observers who are scheduled at appropriate times of the upcoming supernova discovery/follow-up program, and will make coordinates and finding charts available. We recognize, of course, that most observers cannot afford to lose time from their programs.

Status of Previously Approved Keck Programs

See section 2, "Progress to Date." (This group does not have other programs ongoing at Keck.) A list of publications including those which used data from Keck is included at the end of this document.

Path to Science from Observations

As in the past, we will use spectral lines of the host galaxy to determine the redshift. These lines, whether seen in emission (e.g. OII 3272Å) or absorption (e.g. Ca H & K), can be identified even when the SN and galaxy light are blended, because the galaxy lines are much narrower than the SN lines. The SN spectra are smoothed or rebinned on a scale of $\sim$ 20Å (after removing any lines due to the host galaxy) and compared with those of nearby SNe to ascertain the SN type. In most cases, the host galaxy light significantly contaminates the SN spectrum, and therefore a template spectrum of the host galaxy at the supernova site will eventually be obtained for at least a few of these cases. This will be subtracted from the original (SN + galaxy) spectrum. We are also examining with A. Filippenko the use of catalogued galaxy spectra for this purpose.

With these final reduced SN spectra, we will directly test the hypothesis that distant SNe are spectroscopically similar to nearby SNe. With a sufficient number of distant SNe that pass this test, the $\Omega - \Lambda$ plane will be constrained from the magnitude-redshift relation. We will also study the possibility of using spectral features to calibrate the SN luminosity as a cross check of the light curve width calibration.

Technical Concerns

Since the targets are faint, we calculate for each candidate accurate offsets from nearby stars. A major advantage of the Keck telescope is the depth reached by the finder monitor. We are often able to see the SN candidate directly (after increasing the camera's integration time), which ensures accurate positioning of the slit on the target. This is not possible on 4m class telescopes.

We have developed, tested, and used extensively image analysis software (and the expertise to run it) that makes it possible to compare the images of all $100,000$ galaxies in the fields searched to their images on the earlier nights within 24 hours, to find the SNe before maximum light, and to identify the precise coordinates for follow-up spectroscopy and additional photometry.

Because the Keck run in which we obtain spectra of the SN candidates must be coordinated with the search run scheduled at CTIO, *please contact us before scheduling any nights allocated to us at Keck!*

Experience and Publications

Our group has extensive experience with faint object spectroscopy on telescopes around the world and has had four successful runs using LRIS on Keck in the last two years. To reduce and analyze the spectra, our group has developed a few techniques that are specific to very high-redshift supernova work. The planned observers have observed at Keck with LRIS for this project.

All of the current and previous members of the group will continue to be active participants in observing and data analysis.

Our group has also developed extensive techniques for the photometry of high-redshift SNe against the bright background of their host galaxies. A list of relevant publications appears at the end of this document.

Resources and Publication Timescale

The LBNL group consists of of four staff scientists/professors, three postdocs, two graduate students, and 2 undergraduate students. The group uses the extensive computing facilities available at LBNL. In addition, collaborators in Sweden, France, Germany, Chile, and the U.K. are actively participating in the project. Publication of the results will occur about a year after discovery of the SNe; it is necessary to wait for the SNe to fade before template images of the host galaxies (for the derivation of accurate light curves) can be obtained. If there is insignificant host light, we can occasionally publish sooner: SN1997ap was discovered in March 1997, and a paper describing the data and results from that supernova is now submitted.

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