1 Scientific Justification

The Hubble diagram for Type Ia supernovae (SNe Ia) at high-redshift (Fig. 1), provides the most direct current measurement of the expansion history of the universe—and hence the most direct evidence for an accelerating expansion. The "first generation" of supernova cosmology work developed a systematic approach to this measurement (Perlmutter *et al.* 1997, 1998, 1999) that resulted in a determination, based on 42 SNe at $0.18 < z < 0.83$, of $\Omega_M = 0.28^{+0.09}_{-0.08}$ for a flat universe (Perlmutter *et al.* 1999; see also Riess *et al.* 1998). These measurements indicate the presence of a new, exotic "dark energy" that can cause acceleration, and which current theories of fundamental particle physics are unable to explain. This conclusion is strongly supported by current CMB measurements of Ω_k.

There is a fundamental difference between a Cosmological Constant and other potential forms of dark energy. This distinction can be addressed by constraining the dark energy's average equation-of-state, $\langle w \rangle \equiv \langle p/\rho \rangle$. The importance and possibility of determining $\langle w \rangle$ well enough to rule out the $w = -1$ of a cosmological constant has led to a new second generation of supernova cosmology studies: large multi-year multi-observatory programs with major commitments of dedicated time for "rolling searches," which can find and follow SNe over many months of repeated wide-field imaging, and identify them with coordinated spectroscopy. The challenging second-generation goals are: (1) to constrain $\langle w \rangle$ well enough to potentially rule out $w = -1$, by building an order-of-magnitude larger statistical sample (i.e. $\sim$500) of SNe in the redshift range $z = 0.3 - 0.8$ where $\langle w \rangle$ is best measured; (2) to study the transition to deceleration by building a first significant sample ($\sim$15) of SNe Ia in the redshift range $z = 1 - 1.4$; and (3) to improve the systematic uncertainties by studying low-redshift supernovae in detail and comparing specific SN properties between low- and high-redshift. Fully exploiting samples from (1) and (2) to improve the *statistical* uncertainties will depend on (3) reducing the *systematic* uncertainties correspondingly.

These goals clearly require an ambitious effort on the part of the SN Ia community to build up the necessary SN dataset, and we have developed a coherent program to carry this out. We have developed the Nearby Supernova Factory to carry out (3), and are continuing our Subaru/HST SDF and SXDF programs to generate the $z > 1$ sample (2). To address (1) we are now beginning work with the new SN search portion of the Megacam CFHT Legacy Survey (SNLS) to begin to generate the large $z = 0.3$–0.8 sample, and it is the SNLS SNe which are the target of this 2003A proposal. By strategic Keck studies of these samples to determine the value of $\langle w \rangle$, we aim to answer the key question: Is the dark energy something other than Einstein's Cosmological Constant?

An Unprecidented SN Ia Dataset to Measure Dark Energy

The SN Ia redshift-magnitude diagram in the redshift range $z = 0.3$– 0.8, (where dark energy dominates over dark matter) is one of the only known ways to constrain the physics of the dark energy. The simplest measurement to characterize this dark energy is to measure $\langle w \rangle$ averaged over the expansion history from the observer to the source. As shown in Figure 2, the current constraints on $\langle w \rangle$ are consistent with a very wide range of dark energy theories, including Einstein's Cosmological Constant (Perlmutter *et al.* 1999, Garnavich *et al.* 1998).

The CFHT Legacy Survey is the most ambitious of the planned wide-field surveys, with an imager field 4 times larger than the next largest survey camera (at CTIO), and twice as much time devoted to the survey. The full five-year CFHTLS dataset, when combined with a large sample of well-measured nearby SNe from the Nearby Supernova Factory, will provide a major improvement in the determination of the dark energy parameters. First, assuming $w = -1$, we can provide even stronger confirmation of the existence of dark energy by measuring $\{\Omega_M,\, \Omega_\Lambda\}$ to $\{\pm 0.06,\, \pm 0.10\}$. Alternately, assuming a flat universe errors on $\{\Omega_M,\, \langle w \rangle\}$ of $\{\pm 0.07,\, \pm 0.18\}$ can be achieved. Even with the first few years' statistics from this survey, we will be able to see evidence for a non-Cosmological Constant dark energy if $\langle w \rangle$ is more than 0.1 away from -1. It is important to note that these results assume a precision on z of better than 1% and so a spectroscopic redshifts are needed for all SNe.

The Keck Observatory will take the lead for the northern hemisphere spectroscopy of this landmark project. It is essential that each supernova be identified, classified (within a few weeks of its maximum brightness), and its precise redshift determined for this heavy investment in multi-color lightcurves to pay off in a Hubble diagram. The SNLS fields include the Groth Strip for which a northern telescope is required; this is a DEEP field and simultaneous synergy with the DEEP project may be possible; see Technical Details.

Addressing Systematic Uncertainties with this Proposed Dataset

Perlmutter *et al.* (1997, 1999) discuss systematics in the measurement of Ω_M, Ω_Λ; we found that uncertainties due to K-corrections, gravitational lensing, and Malmquist bias are quite small compared to the statistical error of the current SN samples. We showed that SN Ia evolution and abnormal dust within, or even between, galaxies were possible, but unlikely. The large SNLS sample will reduce the statistical errors to the point that some systematics such as Malmquist bias will again be important. The SNLS data set itself will allow more powerful tests and constraints on several of these key systematics.

Multi-color Lightcurves. The rolling search with multiple filters will generate the first SN Ia dataset with complete color coverage throughout the lightcurves. This will enable more comprehensive extinction studies than previously possible. This is key because SNe Ia show a color-luminosity relation — currently taken from low-redshift SNe, which can be checked in the SNLS sample independent of extinction. It may also be possible to examine the consistency of the stretch-corrected peak magnitudes in restframe B with those in redder bands, where the stretch-luminosity relation is not at strong. SNLS lightcurves will also allow better K-corrections since extrapolation of the SN SED will not be necessary.

High-statistics Subsamples. Figure ? shows our recent study (Sullivan et al. 2002) in which our 42 SNe were divided into subsamples based on host galaxy morphology. This is an important first test of evolutionary and dust effects that will differ in different host galaxy environments. The large SNLS sample will allow us to perform such tests with better statistics and in more detail. As in Sullivan et al., the narrow galaxy emission and absorption lines detectable with Keck spectroscopy of SN+host provide valuable constraints on host galaxy stellar populations.

Conclusion. This proposal focuses on the unusual science opportunities presented beginning with the Semester 2003A by the CFHT Legacy Survey. With a large increase in statistics for the mid-redshift range, we will make major strides in our ongoing multi-semester campaign to build a well-measured SN Ia Hubble diagram. These data are crucial for studying the cosmological parameters and the nature of dark energy. They also serve to refine our evolution/dust checks on systematics. This second-generation of SN studies provides our first chance to test whether the dark energy is consistant with a Cosmological Constant. Its conclusions and refinements in the use of large, well-studied SN Ia samples will shape future third-generation projects, such as *SNAP*, designed to probe the variation of w with time. Keck can and should continue to play a leading role in this fundamental science.

References

Aldering, G., *et al.*, 1998, IAUC 7046.
Aldering, G., Knop, R., Nugent, P., 2000, AJ 119, 2110
Garnavich, P., *et al.*, 1998, ApJ, 509, 74.
Goldhaber, G., *et al.*, 2001, Ap. J., 558, 359
Jaffe, A. H., *et al.*, 2001, Phys. Rev. Lett., 86,3475
Kim, A., *et al.*, 1997, Ap. J., 476, L63
Knop, R., *et al.*, 2001, AAS, 199, 1607
Nobili, S. *et al.*, 2001, AAS, 199, 1611
Pain, R., *et al.*, 1996, Ap. J., 473, 356
Pain, R., *et al.*, (2002), Accepted for pub. ApJ.
Perlmutter, S., *et al.*, 1997, Ap. J., 483, 565.
Perlmutter, S., *et al.*, 1998, Nature, 391, 51.
Perlmutter, S., *et al.*, 1999, ApJ, 517, 565.
Riess, A., Nugent, P., Filippenko, A.V., Kirshner, R.P., & Perlmutter, S., 1998, ApJ, 504, 935.
Riess, A., *et al.*, 1998, AJ, 116, 1009.
Sullivan, M., *et al.*, 2002, submitted to MNRAS.

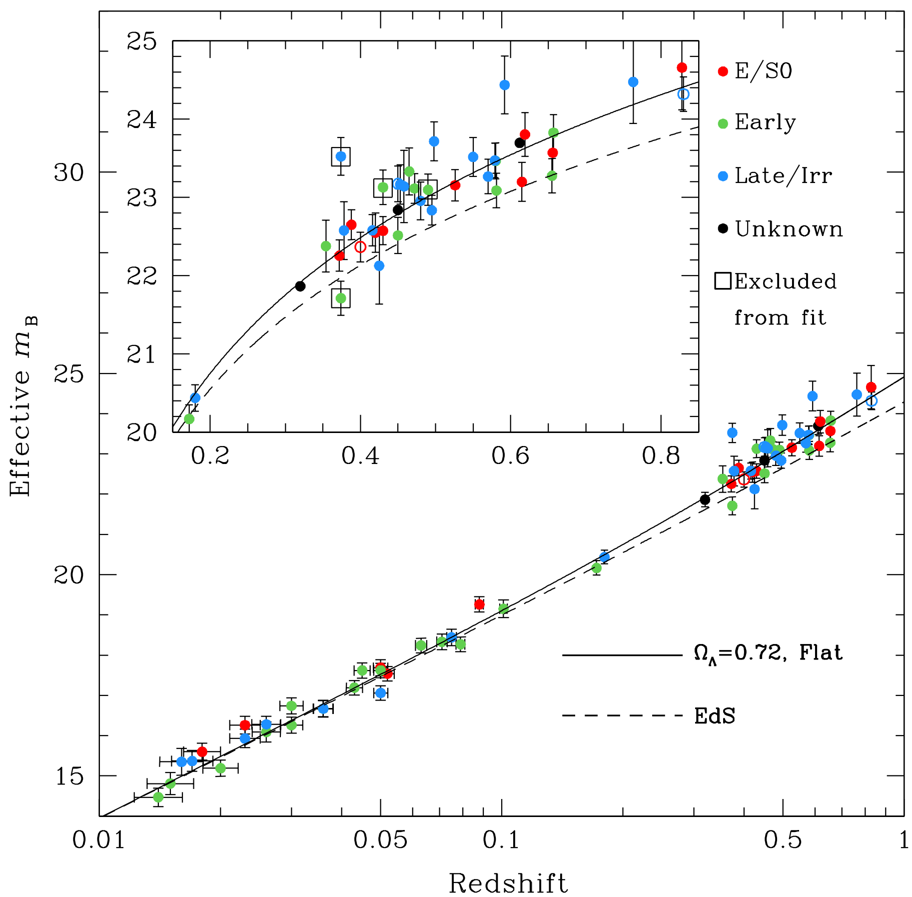

Figure 1: The stretch-corrected SNe Ia Hubble diagram for the SCP (Perlmutter *et al.* 1999) dataset plotted according to the class of the host galaxy. The inset shows the high-redshift SNe, the main panel the Hubble diagram for the entire sample. Boxed points show SNe excluded from the P99 solution. (See Sullivan *et al.* (2002)

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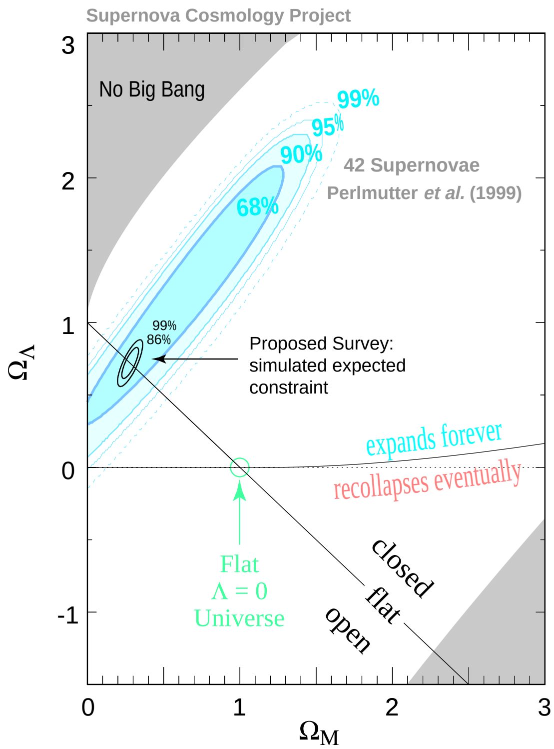

Figure 2: [caption here]

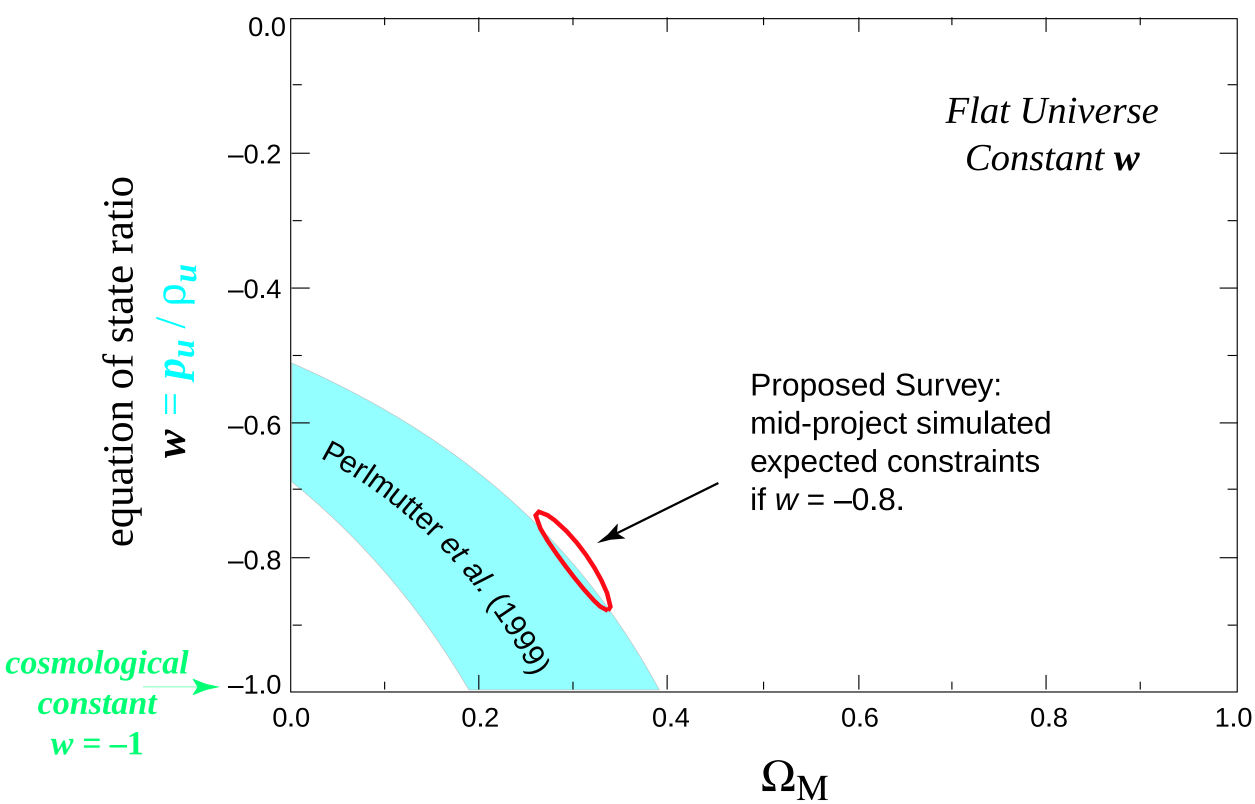

Figure 3: [caption here]

2 Progress to Date

Prior to fall 1998 we concentrated on mid-redshift SNe Ia. — and we will be returning to that work with this proposal. The 1995-1997 portion of the mid-redshift cosmological program was published in Perlmutter et al. 1999 and the 1997-1998 portion — including 11 SNe Ia observed with Keck and HST — will appear in Knop et al. 2002. The cosmological results from the eleven SNe Knop *et al.* are in close agreement with results from the first supernova results (Perlmutter *et al.* 1999) that gave direct evidence for a cosmological constant.

Beyond these Hubble-diagram-cosmology presentations and publications, this year we have also publishd results based on this project's Keck measurements on the study of SN Ia variations over time/redshift. In Sullivan *et al.* (2002, submitted) we present new results on the Hubble diagram of SNe Ia as a function of host galaxy morphology that demonstrates that host galaxy extinction is unlikely to systematically dim distant SN Ia in a manner that would produce a spurious cosmological constant. The internal extinction implied is small, even for late-type systems ($A_B < 0.3$), and the cosmological parameters derived from those SNe Ia hosted by (presumed) dust-free early-type galaxies are consistent with our previous determination of a non-zero Λ. This result was based on Keck spectroscopy and HST STIS "snapshot" images of SNe spanning the range $0.3 < z < 0.8$. In Pain *et al.* (2002) we present the changing SN Ia rates in the redshift range $z \sim 0.65$, which constrain the models for SN Ia progenitors. Additional papers now in progress include a determination of the rates of SNe Ia at even higher redshifts, $z > 1$, an analysis constraining metallicity variations and evolution from our SNe Ia spectra, and an analysis of the relation between SNe and the luminosities of their host galaxies.

Between fall 1998 and fall 2002 we have concentrated on the highest redshift SNe Ia. Significant samples of well-studied SNe Ia at the higher redshifts are essential for shortening the major-axis of the error ellipse in the Ω_M,$\Omega_\Lambda$plane and for checking the consistency of the SNe Ia results. We built up the foundations for this work beginning in October 1998 with our very successful pilot study using Keck imaging and spectroscopy in order to demonstrate that SNe Ia up to $z = 1.2$ could be found and studied using existing facilities. SN 1998eq at $z = 1.200$ was the key discovery from this run, and we obtained its complete I-band and J-band light curves using HST (Aldering *et al.* 1998, 2002). ($z = 1.2$ is still the highest-redshift for which there is spectroscopic confirmation of a Type Ia. See Fig. 3b.) Since then we have successfully transferred the *searches* to telescopes, such as Subaru, CFHT and CTIO (Doi *et al.* 2001) — with wide-field imagers which give a larger $A \cdot \Omega$ product than LRIS. The Keck spectroscopy runs of 1999B, 2000A, 2001A, and 2002A, demonstrated that the resulting high-z SNe can be efficiently targeted and studied. In particular, the most recent run, 2002A, identified 21 SNe, while the previous run, 2001A, had identified 17 SNe. The 2002A run yielded two SNe with $z > 1$ which were observed with ACS on HST, while the previous year yielded three which were observed with WFPC2. The results of these highest-redshift searches are now being analyzed. Their data points will fill in the sparse/empty regions of the Hubble diagram beyond $z \sim 0.7$ (See Fig. 1).

A detailed discussion of the results from all previous Keck runs is presented later: we have now discovered ~ 120 SNe using these techniques, with a redshift distribution between 0.2 and 1.2, peaking at $z \sim 0.6$.

3 Technical Justification

Feasibility: We have repeatedly demonstrated our ability to *a)* discover large numbers of high–z SNe Ia, *b)* obtain spectroscopic follow-up to confirm the SN type and redshift, *c)* acquire light curve photometry, and *d)* analyze the data to obtain peak magnitudes and measure Ω_M and Ω_Λ. We have demonstrated this capability out to $z = 1.20$. The SN program of CFHTLS (SNLS) is a much larger program than our previous searches with the CFHT, and offers us the opportunity to continue SNe Ia cosmological studies with greatly increased statistics and even greater reliability.

The SNLS is a rolling SN search which will observe four 1×1 deg^2 fields in Sloan g, r, i, z every 2-3 nights during dark/gray time for 5 months per semester using MegaCam on CFHT, beginning in February 2003. The exposures of 15m, 30m, 60m and 30m per band will provide the discovery and well-sampled multicolor lightcurves for SNe Ia in the redshift range 0.3 to 0.9 (with discoveries up to $z \sim 1.2$). Photometric redshifts for host galaxies and color screening of the SNe candidates will allow SNLS to eliminate AGN and $z > 0.9$ SNe from the spectroscopic target list. Keck's role will be to measure the redshifts and tell-tale SN Ia features, especially for the highest redshift SNe Ia in the CFHTLS northern field — a role only it can perform with the quickness and reliability to keep up with the SNLS discovery rate.

Targets: All of the supernovae to be observed in this proposal will be discovered in the four SNLS survey fields, two of which are visible this spring. In particular, with Keck we will focus on the SNe discovered in the Groth Strip field at 14h18m+52d. We expect to have a target list of roughly 15 objects per lunation, most of which will be SNe Ia at $z > 0.5$. This selection purity is another important advantage of the rolling SN search approach compared to a classic 2-epoch SN search.

Exposures: *All our exposure times are based on experience with real Keck data for high-z SNe.* Although our observing technique and candidate weighting scheme select against SNe II and AGN's, some of these pass through to our list of candidates, and so when estimating the number of SNe Ia we will confirm, we include a $\sim 10\%$ allowance for these interlopers. Under average conditions at Keck a SN Ia at $z \sim 0.5$ requires an exposure of about 30 min to produce a classification-quality spectrum. A SN Ia at $z \sim 0.9$ requires 4-5 30 min exposures to produce a reliable redshift and a classification somewhere between probable and certain. The $z \sim 0.9$ SNe Ia are made difficult not only by the faintness of the SN, but by the increasing sky brightness and the loss of key SNe Ia spectral features in going to higher redshift.

Telescope Time Requested. There are two key requirements for the spectroscopic program to succesfully exploit the SNLS — temporal coverage and speed. With Keck's aperture and sensitive spectrographs, and our specialized acquisition and reduction methods developed for SN spectroscopy at Keck, we can obtain redshifts and spectral classifications for up to 15 SNe candidates per night out to $z \sim 0.9$. Thus, in one Keck night we can cover the majority of the higher-redshift SNe Ia the SNLS will produce in one lunation. SNLS will operate for 5 months this semester, meaning that there a 4 lunations which need to be covered after accounting for edge effects (i.e. elimnation of SNe with only partial lightcurves which occur at the beginning and end of the 5 month period.)

Although many of the SNe will have spectra peaking at red wavelengths, important spectral features (e.g. metallicity indicators) extend down to observer-frame V-band. Therefore, these observations can not tolerate too much contamination from moonlight. In general we have found that we can observe at most 5 days from new moon before our program suffers significantly.

In total, obtaining the spectroscopy of this spring's SNLS SNe Ia's requires 4 one-night runs on Keck during dark time in early March, early April, late April, and late May.

We note that this SNLS spectroscopic follow-up campaign does not require the precise timing that was needed for our past $z \sim 0.5$ searches (and still required for our $z > 1$ searches) since the photometry of all the SN is obtained automatically. However, since this is the first semester of SNLS and MegaCam is still untested it is **important that the Keck scheduler consult with us prior to scheduling specific dates.**

Instrumentation. In the past we have used both LRIS and ESI for our SN spectroscopy program. At the highest redshifts we have found that ESI is superior for our purposes, primarily because the high resolution of ESI separates out the night sky lines, allowing them to be excised from the data before smoothing to identify SNe and galaxy features. However, we have also seen that DEIMOS is producing excellent sky subtraction, and might be competitive with ESI (with poorer OH suppression but better throughput). Moreover, since SNLS observations are planned for the Groth Strip — one of the DEEP program's target fields — we are discussing with the DEEP team the possibility of obtaining Groth Strip galaxy spectra in parallel with the SN observations requested here.

At this time, for 2003A we will request the ESI spectrograph for all 4 nights. Subject to the outcome of our discussions with the DEEP team, we may request a switch to DEIMOS for some or all of our nights. It is most efficient for us to stick with a limited number of instruments during the semester given that we will have isolated one-night runs (and already have real-time observing and analysis software that we are now using with ESI). However, if scheduling pressure on Keck II is severe we would consider LRIS as a backup choice.

Backup Programs

Given the large commitment of queue-scheduled time for the SNLS we consider it next to certain that we will have a full schedule of SNe to observe on each of our nights. If transparency or seeing precludes spectroscopy at $z > 0.5$ we will observe the lower redshift SNLS SNe otherwise reserved for smaller telescopes. In addition, we are pursuing studies of the host galaxies of SNe we have discovered in the past in order to understand the relationship between SN Ia properties and global properties (metallicity, morphology, etc.) of the hosts. Several of these programs, such as measuring the gas-phase metallicity of the host of the hypernova SN 1999as using the [NII]/Hα ratio, determining the colors of the $M_B \sim -11$ host galaxy of SN 1999aw, or measuring the age and metallicity of the nearby ($z = 0.054$) Hubble-flow elliptical host galaxy of SN 1999av with high-resolution high S/N spectroscopy, can be carried out as back-up programs.

Status of Previously Approved Keck Programs

Semester 2002B: Four Keck II/ESI nights have been scheduled for November 2002.
Semester 2002A: We were awarded six nights for ESI spectroscopy of SNe from our spring 2002 search campaign which consisted of a "rolling" search at CFHT (a pilot-study for the SNLS) as well as "classical" searches at Subaru and CTIO. Essentially all the Keck time was lost due to bad weather, with the dome closed for most of the nights. Of our three

nights in April, we were able to use about one half night. We observed two CFHT SNe (at $z \sim 0.3$) and two Subaru candidates (at $z = 0.56$ and $z = 0.88$). The three nights in May were completely lost due to weather.

Semester 2001A: In this highly successful six-night run we used one night of LRIS + Keck I and five nights of ESI + Keck II to obtain specta of 17 SNe, including three SNe Ia at $z > 1$. Our strategy of observing for six nights in one semester paid off, as we were able to use the three poorer seeing (~ 1 arcsec) nights and one cirrusy night to confirm brighter targets, and use the two better seeing nights to study SNe at $z > 1$. The Keck spectra allowed us to classify the SNe, obtain redshifts, and select the highest redshift targets for HST. In addition, the spectra are being compared to low redshift SNe Ia to test for the effects of evolution in the high-z sample. This run also gave us extensive experience with ESI, enabling us to refine our reduction techniques to best exploit ESI's advantages (and compensate for small remaining problems).

Semester 2000A: The highlight of this two-night run at Keck was spectroscopy of 2000fr, supernova candidate (from our CFHT search) that turned out to be a Type Ia SN at $z = 0.54$ at a very early phase in its light curve (only ~ 6 days after explosion). This early discovery allowed us to begin an intensive monitoring campaign to study the supernova in great detail, including near-IR imaging with ISAAC on the VLT. This data set allows us to make a detailed comparison with nearby Type Ia supernovae to check for signs of evolution or extinction by dust (Nobili *et al.* (2001)). These results have encouraged us to pursue detailed spectroscopy of another $z \sim 0.5$ SN Ia.

Semester 1999B: Three nights were awarded for the second week of October, 1999. The time was used for spectroscopy of candidate SNe that were discovered in a search at CFHT earlier that month. Out of the 10 candidates discovered, we were able to observe 6 of them, and two of those were found to have $z \sim 0.9$.

Semester 1999A: One night was awarded, and was not usable.

Semester 1998B: Three nights were awarded for a pilot study to find very high-z SNe. Two nights were used for imaging and one for spectroscopy, resulting in three Type Ia SNe with $z = 1.2$, 0.84 and 0.11. The SN with $z = 1.200$ (1998eq) is (still) at the highest redshift that Type Ia SNe have yet been confirmed (IAUC 7046). The discovery of this supernova demonstrates that it is feasible to find and obtain spectra for Type Ia events even for redshifts $z > 1$. The two highest redshift SNe from this run, both of which were discovered close to maximum light, were observed in I-band and J-band with HST WFPC2 and NICMOS.

Semesters 1997B and 1998A: In December 1997 and March 1998 we carried out searches using the BTC on the CTIO 4-m. The resulting SN candidates were observed spectroscopically with Keck on approximately 4 usable nights (over the two semesters). A total of 36 candidates were observed and 26 were confirmed as Type Ia, with mean redshifts of approximately 0.6–0.7. These were followed-up from the ground with CTIO-4m, WIYN, ESO 3.6m, WHT and INT telescopes, and 11 of these were also followed photometrically with HST using WFPC2 and NICMOS. The corresponding final reference images have been obtained for these SNe and the results presented in Knop *et al.* (2001).

Earlier Semesters: Final host galaxy images have been obtained for nearly all the SNe discovered prior to the above semesters. These SNe have been analyzed and formed the basis of the analysis presented in Perlmutter *et al.* (1999), which highlights the evidence for a cosmological constant. Nine additional papers based on our Keck work describe (i) the first measurements of cosmological parameters based on the first seven SN discoveries (Perlmutter *et al.*, 1997); (ii) a measurement of the rate of Type Ia SNe at $z \sim 0.4$ (Pain *et al.*, 1996), (iii) the rate of Type Ia SNe at $0.35 < z < 0.85$ (Pain *et al.*, 2002), (iv) constraints on the spatial variation of the Hubble constant from our data (Kim *et al.*, 1997), (v) a study of the timescale stretch parameterization of type Ia supernova B-band light curves (Goldhaber *et al.*, 2001), (vi) the use of SN spectra for the determination of subtype and age of SNe Ia (Riess *et al.*, 1998), (vii) results on the $z = 0.83$ supernova 1997ap, and implications for cosmological measurements (Perlmutter *et al.*, 1998), (viii) the consistency of rise times measured for low and high-z supernovae (Aldering *et al.*, 2000), (ix) that our evidence for a non-zero cosmological constant is independent of host galaxy morphology. (Sullivan, *et al.*, 2002).

Research is in progress which will result in additional papers. These include (i) a determination of the rates of SNe Ia at $z > 1$, (ii) an analysis constraining metallicity variations and evolution from our SN spectra, and (iii) new limits on the cosmological parameters and possible systematics (grey dust or evolution) from SN 1998eq at $z = 1.20$. All these papers use the results from Keck spectroscopy obtained as part of our supernova cosmology program. A number of papers on these topics have also appeared in conference proceedings.

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 3727Å) or absorption (e.g. Ca II 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. (In cases where there is no significant light from the host, redshifts will come from the supernova spectrum itself.) The SN spectra are smoothed on a scale of $\sim$ 20Å (after removing any lines due to the host galaxy – and in the case of ESI – deweighting the spectral regions covered by OH lines) and compared with those of nearby SNe to ascertain the SN type.

The Keck redshifts will be used along with rolling photometry from the SNLS to plot the Keck SNe Ia on the Hubble diagram. This requires that the light-curve time of maximum, peak flux, and width, be measured. The light-curve width is strongly correlated with the intrinsic supernova brightness, and is used to standardize SNe Ia. K-corrections — which we have developed using the spectra of low-z SNe Ia (Nugent, Kim, & Perlmutter 2002) — must also be applied, followed by correction for dust extinction from the host galaxy and the Galaxy. The extinction correction requires a knowledge of the unreddened intrinsic SN colors, which we have determined from low-z SNe Ia in elliptical galaxies (and will improve with future low-redshift data) and do not result in overcorrection for extinction (as is the case for some other treatments in the literature). Once the SNe Ia have been standardized, we can solve for the confidence intervals for the cosmological parameters. We have extensive software to undertake such light-curve fitting, corrections, and parameter fitting.

The Keck spectroscopy will allow us to test for the effect on our cosmological fits due to any spectroscopically peculiar SNe Ia, and to set better limits on systematic uncertainties which could be caused by unrecognized spectroscopically peculiar SNe Ia. For our $z \sim 0.5$ (brighter) SN Ia where the host galaxy light does not significantly contaminate the SN spectrum, stronger tests, including comparison of the metallicity-dependent UV spectral features with our Cycle 9 and Cycle 11 HST UV spectra of nearby SNe Ia (from a separate program) will be possible.

Technical Concerns

Since our targets are faint, accurate offseting is critical to take advantage of the narrow slit widths possible under the best seeing conditions. On our last ESI run we developed a direct acquisition capability for the faintest targets, which involved taking direct images with ESI, automatically performing the astrometric alignment of the ESI image with our SN discovery image, and offseting the telescope. (Note that we can't just use the ESI image directly because host-galaxy light is blended with — and spatially offset from — the SN.) For brighter targets, where the direct acquistion set-up time is not warrantted, we found that comparing guider image captures with our deep search images allowed for better offsets than standard offseting from a single bright star, since the slit position relative to numerous field objects could be determined with high accuracy. Monitoring of the frames also allowed us to compensate for changes in atmospheric refraction, (small) flexure of the guider camera, and monitor the seeing. Therefore, we will request that the night assistant be prepared to continuously run the save-to-disk option for the guider. This can impact disk-space on the summit.

There are no technical concerns with the searches, as a dedicated team with extensive experience in finding SNe for Keck with be running the SNLS.

The Keck SN candidate spectroscopy runs must be coordinated with the SNLS search, scheduled to start in February 2003, so *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 successful runs using LRIS and/or ESI on Keck each semester for the last seven years. To reduce and analyze the spectra, our group has developed techniques that are specific to high-z supernova work. Our group has also developed extensive techniques for the photometry of high-z 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 supernova group consists of three permanent staff scientists, two UC professors, a scientist/project coordinator, five postdocs and three graduate students. The group uses the extensive computing facilities available at LBNL.

We note that one of the many advantages of the SNLS is that deep images will be available which are uncontaminated by SN light *before* the SN explodes. Therefore, unlike in the past, we will not have to wait a year to obtain final reference images. This makes it possible to start final the reductions and analysis shortly after the end of each semester. For mid-redshift SNe Ia we have been able to get the results into press within roughly a year. As examples, SN1997ap was discovered in March 1997, and a paper describing the data and results from that supernova was published by *Nature* in January, 1998. The results from the first 42 SNe (data obtained from Spring 1995 to Spring 1998, including final follow-up photometry on the Spring 1997 SNe) was published in *ApJ* in Fall 1999.

Publications

(* = Keck data contributed to this publication.)

* Hubble Diagram of Type Ia Supernovae as a Function of Host Galaxy Morphology, M. Sullivan *et al.*, submitted for publication in MNRAS.

* The distant Type Ia supernova rate, R. Pain, *et al.*, 2001, astro-ph/0205476, accepted for publication in the Astrophysical Journal.

K-corrections and Extinction Corrections for Type Ia Supernovae, Peter Nugent, Alex Kim, Saul Perlmutter, 2002, PASP 114, 803.

*The Distant Type Ia Supernovae Rate, R.Pain, *et al.*, presented at the January 2002 AAS meeting.

*Verifying the Use of Type Ia Supernovae as Probes of the Cosmic Expansion, R.Ellis, *et al.*, presented at the January 2002 AAS meeting.

*Ω_M and Ω_Λ from 11 HST-Observed Supernovae at z=0.36-0.86, R.Knop, *et al.*, presented at the January 2002 AAS meeting.

*NICMOS Photometry of High Redshift Supernovae, S.Burns, *et al.*, presented at the January 2002 AAS meeting.

*Type Ia Supernovae: Tests for Evolution and Grey Dust.Ground and Spaced Based Follow up of a Type Ia Supernova at z=0.54, S.Nobili, *et al.*, presented at the January 2002 AAS meeting.

*Results from Recent high-redshift Type Ia Supernovae Searches, K.Schahmaneche, *et al.*, presented at the January 2002 AAS meeting.

*Interpretation of high-z SN spectra, P.Nugent, *et al.*, presented at the January 2002 AAS meeting.

A New Set of Nearby SN Ia Lightcurves, N.Regnault, *et al.*, presented at the January 2002 AAS meeting.

Accurate Multi-epoch Optical Spectroscopy of 18 Low-z Type Ia Supernovae, G.Garavini, *et al.*, presented at the January 2002 AAS meeting.

Nearby Supernova Searches: Results and Future Plans, G.Aldering, presented at the January 2002 AAS meeting.

* Timescale Stretch Parameterization of Type Ia Supernova B-Band Light Curves, G. Goldhaber, D. E. Groom, A. Kim, G. Aldering, P. Astier, A. Conley, S. E. Deustua, R. Ellis, S. Fabbro, A. S. Fruchter, A. Goobar, I. Hook, M. Irwin, M. Kim, R. A. Knop, C. Lidman, R. McMahon, P. E. Nugent, R. Pain, N. Panagia, C. R. Pennypacker, S. Perlmutter, P. Ruiz-Lapuente, B. Schaefer, N. A. Walton, T. York, 2001, Astrophysical Journal, 558, 359

* Latest Cosmological Results from Type Ia Supernovae, R. Knop, *et al.*, 2000, Bulletin of the American Astronomical Society, 197, 950

* The Rise Times of High- and Low-Redshift Type Ia Supernovae Are Consistent, G. Aldering, R. Knop, P. Nugent 2000, Astronomical Journal, 119, 2110.

* The acceleration of the Universe: measurement of cosmological parameters from type Ia supernovae, A. Goobar, S. Perlmutter, G. Aldering, G. Goldhaber, R.A. Knop, P. Nugent, P. G. Castro, S. Deustua, S. Fabbro, D. E. Groom, I. M. Hook, A. G. Kim, M. Y. Kim, J. C. Lee, N. J. Nunes, R. Pain, C. R. Pennypacker, R. Quimby, C. Lidman, R. S. Ellis, M. Irwin, R. G. McMahon, P. Ruiz-Lapuente, N. Walton, B. Schaefer, B. J. Boyle, A. V. Filippenko, T. Matheson, A. S. Fruchter, N. Panagia, H. J. M. Newberg, W. J. Couch, 2000, Physica Scripta, T85, 47.

Metallicity Effects in NLTE Model Atmospheres of Type Ia Supernovae, E. J. Lentz, E. Baron, D. Branch, P. H. Hauschildt, & P. E. Nugent, 2000, Astrophysical Journal, 530, 966L.

* Constraining Dark Energy with SNe Ia and Large-scale Structure, S. Perlmutter, M. S. Turner, & M. White 1999, Phys. Rev. Lett., 83, 670.

* The Cosmic Triangle: Revealing the State of the Universe, N. Bahcall, J. P. Ostriker, S. Perlmutter, P. J. Steinhardt 1999, Science, 284, 1481.

High Redshift SNe in the Hubble Deep Field, R. L. Gilliland, P. E. Nugent & M.M. Phillips, ApJ, vol. 521, p.30-49, 1999

* Measurements of Ω and Λ from 42 High-Z Supernovae, S. Perlmutter, G. Aldering, G. Goldhaber, R.A. Knop, P. Nugent, P. G. Castro, S. Deustua, S. Fabbro, A. Goobar, D. E. Groom, I. M. Hook, A. G. Kim, M. Y. Kim, J. C. Lee, N. J. Nunes, R. Pain, C. R. Pennypacker, R. Quimby, C. Lidman, R. S. Ellis, M. Irwin, R. G. McMahon, P. Ruiz-Lapuente, N. Walton, B. Schaefer, B. J. Boyle, A. V. Filippenko, T. Matheson, A. S. Fruchter, N. Panagia, H. J. M. Newberg, W. J. Couch, Astrophysical Journal, 517, 565 (1999).

* Snapshot Distances to SNe Ia – All in 'One' Night's Work", A. Riess, P. Nugent, A. Filippenko, R. Kirshner and S. Perlmutter, Astrophysical Journal, September, 1998.

Gravity: From the Hubble Length to the Planck Length, G. Goldhaber, XXVI SLAC Summer Institute, August, 1998

* Discovery of a Supernova Explosion at Half the Age of the Universe and its Cosmological Implications, S. Perlmutter, G. Aldering, M. Della Valle, S. Deustua, R. S. Ellis, S. Fabbro, A. Fruchter, G. Goldhaber, A. Goobar, D. E. Groom, I. M. Hook, A. G. Kim, M. Y. Kim, R.A. Knop, C. Lidman, R. G. McMahon, P. Nugent, R. Pain, N. Panagia, C. R. Pennypacker, P. Ruiz-Lapuente, B. Schaefer and N. Walton, Nature, 391, 51 (1998).

* Measurements of the Cosmological Parameters Ω and Λ from the First 7 Supernovae at $z \geq 0.35$. S. Perlmutter, S. Gabi, G. Goldhaber, D. E. Groom, I. M. Hook, A. G. Kim, M. Y. Kim, J. Lee, C. R. Pennypacker, I. A. Small, A. Goobar, R. Pain, R. S. Ellis,

R. G. McMahon, B. J. Boyle, P. S. Bunclark, D. Carter, M. J. Irwin, K. Glazebrook, H. J. M. Newberg, A. V. Filippenko, T. Matheson, M. Dopita, and W. J. Couch, Astrophysical Journal, 483, 565 (1997).

*Implications for the Hubble Constant from the First Seven Supernovae of $z > 0.35$, A. Kim *et al.*, Astrophysical Journal, 476, L63 (1997).

*The Type Ia supernova rate at $z \sim 0.4$, R. Pain, I. Hook, S. Perlmutter, *et al.*, Astrophysical Journal, 473, 356 (1996).

*Observation of cosmological time dilation using type Ia supernovae as clocks. (The Supernova Cosmology Project: III.) G. Goldhaber, *et al.*, in Thermonuclear Supernovae, NATO ASI, eds. R. Canal, P. Ruiz-LaPuente, and J. Isern (1996).

*K corrections for type Ia supernovae and a test for spatial variation of the Hubble constant. (The Supernova Cosmology Project: II.) A. Kim, *et al.*, in Thermonuclear Supernovae, NATO ASI, eds. R. Canal, P. Ruiz- LaPuente, and J. Isern (1996).

A generalized K correction for type Ia supernovae: Comparing R-band photometry beyond $z = 0.2$ with B, V, and R-band nearby photometry. A. Kim, A. Goobar, and S. Perlmutter, Publications of the Astronomical Society of the Pacific, 108, 190 (1996).

Feasibility of measuring the cosmological constant Λ and mass density Ω using supernova standard candles. A. Goobar and S. Perlmutter, Astrophysical Journal, 450, 14 (1995).

The distant supernova search and implications for the cosmological deceleration. A. Goobar, B. Boyle, P. Bunclark, D. Carter, R. Ellis, S. Gabi, G. Goldhaber, M. Irwin, A. Kim, M. Kim, R. McMahon, R. Muller, R. Pain, C. Pennypacker, S. Perlmutter, and I. Small, Nuclear Physics B (Proc. Suppl.) 43, 78 (1995).

The blue and visual absolute magnitude distributions of type Ia supernovae. T. Vaughan, D. Branch, D. L. Miller, and S. Perlmutter, Astrophysical Journal, 439, 558 (1995).

A Type Ia supernova at $z = 0.457$. S. Perlmutter, C. Pennypacker, G. Goldhaber, A. Goobar, J. Desai, A. Kim, M. Kim, R. Muller, H. Newberg, I. Small, R. McMahon, B. Boyle, D. Carter, M. Irwin, P. Bunclark, K. Glazebrook, and R. Ellis, Astrophysical Journal Letters, 440, L41 (1995).

Discovery of the most distant supernovae and the quest for Ω. G. Goldhaber, B. Boyle, P. Bunclark, D. Carter, R. Ellis, S. Gabi, A. Goobar, A. Kim, M. Kim, R. McMahon, R. Pain, C. Pennypacker, S. Perlmutter, I. Small, and R. Terlevich, Nuclear Physics B (Proc. Suppl.) 38, 435 (1995).

Publications In Preparation

New Limits on Cosmological Parameters Ω_M and Ω_Λ from HST Observations of Eleven Supernovae at Redshifts z=0.36-0.86, R. Knop, *et al.*, 2002, in preparation

Results from a Deep Supernova Search at Keck, G. Aldering, *et al.*, 2002, in preparation

Type Ia Supernovae and Host Galaxy Extinction, E. Commins, *et al.*, 2002, in preparation

The Host Galaxies of Type Ia Supernovae at High Redshift, G. Aldering, *et al.*, 2002, in preparation

Supernova Discoveries In IAU Circulars

More than 120 discoveries of supernovae, reported in International Astronomical Union Telegrams and Circulars, including:

Supernovae 1994F, 1994G, 1994H, Circular 5956, 24 March 1994, S. Perlmutter, *et al.*

Supernovae 1993al, 1994al, 1994am, 1994an, Circular 6263, 18 November 1995, S. Perlmutter, *et al.* (The Supernova Cosmology Project).

*Eleven High-Redshift Supernovae: 1995aq through 1995az, and 1995ba, Circular 6270, 6 December 1995, S. Perlmutter, *et al.* (The Supernova Cosmology Project).

*Fourteen High-Redshift Supernovae: Circular 6540, 17 January 1997, Supernova Cosmology Project.

*Sixteen High-Redshift Supernovae: Circular 6596, 20 March 1997, Supernova Cosmology Project.

*Nine High-Redshift Supernovae: Circular 6621, 9 April 1997, Supernova Cosmology Project.

*Seventeen High-Redshift Supernovae: Circular 6804, 6 January 1997, Supernova Cosmology Project.

*Twenty High-Redshift Supernovae: Circular 6881, 22 April 1998, Supernova Cosmology Project.

*Three High-Redshift Supernovae: Circular 7046, 5 November 1998, Supernova Cosmology Project.

*Supernova 1999ab, Circular 7109, Supernova Cosmology Project.

*Supernovae 1999ae, 1999af, 1999ag, 1999ah, 1999ak, 1999al, Circular 7177, Supernova Cosmology Project.

*Supernova 1999am, Circular 7122, Supernova Cosmology Project.

*Supernovae 1999ap, 1999aq, 1999ar, Circular 7125, Supernova Cosmology Project.

*Supernovae 1999as, 1999at, Circular 7128, Supernova Cosmology Project.

*Supernovae 1999au, 1999av, 1999aw, 1999ax, 1999ay, Circular 7130, Supernova Cosmology Project.

Supernovae 1999ax and 1999ay, Circular 7357 A. Gal-Yam, D. Moaz, R. A. Stathakis, & G. Aldering.

*Supernovae 1999az, 1999ba, 1999bb, Circular 7131, Supernova Cosmology Project.

*Supernovae 1999bc, 1999bd, Circular 7133, Supernova Cosmology Project.

*Supernovae 1999be, 1999bf, Circular 7134, Supernova Cosmology Project.

Supernovae 1999bi, 1999bj, 1999bk, 1999bl, 1999bm, 1999bn, 1999bo, 1999bp, 1999bq, Circular 7136, Supernova Cosmology Project.

*Supernova 1999bh, Circular 7138, Supernova Cosmology Project.

Supernova 2000ca, Circular 7413, G. Aldering & A. Conley

Supernova 2000cc, Circular 7414, G. Aldering & A. Conley

Supernova 2000cb, Circular 7410, G. Aldering & A. Conley

Supernova 2001ay in IC 4423, Circular 7612, P. Nugent, G. Aldering, I. Hook, S. Perlmutter, L. Wang

Supernovae 2001cq, 2001cr, 2001cs, 2001ct, 2001cu, 2001cv, 2001cw, Circular 7649, M. Doi, H. Furusawa, F. Nakata, M. Ouchi, N. Yasuda, S. Miyazaki, N. Kashikawa, Y. Komiyama, Y. Ohyama, M. Yagi, K. Aoki, I. Hook, S. Perlmutter, G. Aldering

*Supernovae 2001gk, 2001gl,2001gm,2001go, 2001gp,2001gq,2001gr, 2001gs, 2001gt, 2001gu, 2001gv, 2001gw, 2001gx, 2001gy, 2001gz, 2001ha, 2001hb, 2001hc, 2001hd, 2001he, Circulars 7763 & 7764, Supernova Cosmology Project.