Scientific Justification

Introduction

The mysterious cause of the accelerating expansion of the universe is a "key scientific question of our day" identified by the NRC Committee on the Physics of the Universe (Tur02). In the years following the first detection of the acceleration using Type Ia supernovae (SN Ia; Per99,Rie98), the SN evidence has grown ever stronger. Complementary CMB measurements have indicated that the Universe has zero curvature, making the SN Ia result more determinative, and – in combination with the SNe — pointing to a [$\Omega_M \approx 0.3, \Omega_\Lambda \approx 0.7$] cosmology. This is consistent also with other astronomical mass density measurements (Sper03, Eis05).

The SN Hubble diagram remains the primary approach to study acceleration. Studies of all known relevant sources of systematic uncertainty continue, but none show biases sufficient to challenge the basic acceleration results. These include: changes with z in host-galaxy extinction by ordinary dust (Per99,Rie98,Sul03 – in particular see our comprehensive HST-based study in Kno03); extinction by intergalactic gray dust (Mor03); gravitational-lensing (de)amplification (Per99); discovery selection effects (Per99,Rie98); K-correction systematics (Nug02); and population drifts in SN environment (Sul03). Moreover, the extensive HST programs focused on $z > 1$ have shown the transition to deceleration (Rie04) which would be hard for dust or evolution to mimic.

With these advances in hand, the focus has now shifted to the *cause* of the acceleration — be it Einstein's cosmological constant Λ, a general dynamical scalar field (like that invoked for inflation), or something more exotic. Rarely in science do we have the opportunity to measure a parameter whose value can so deeply shake and shape our fundamental physical understanding.

The Supernova Legacy Survey

It is within the grasp of current large ground-based projects – in particular, the CFHT SuperNova Legacy Survey (SNLS) – to test the hypothesis that the accelerating expansion is not driven by Λ. This is done by measuring the time-averaged equation-of-state ratio $w \equiv p/\rho$ of the "dark energy", which is equal to -1 for a cosmological constant. If $w = -1$ is ruled out by the observations, then something other than a cosmological constant must be responsible for the observed acceleration.

SNLS will measure lightcurves for >700 high-redshift SNe Ia. An unprecedented investment of telescope time on CFHT (202 nights over 5 years for the CFHTLS-DEEP survey) is providing high-quality multicolor $griz$ data. The SNe are found before maximum light, and spectroscopic follow up (for determination of the SN types and redshifts) is being obtained using a correspondingly large investment of time on VLT, Keck, and Gemini. The 700 well-measured SNe Ia, together with an independent measurement of Ω_M to $\pm$0.03 (i.e. 10%, from LSS & CMB), will allow us to determine w to a statistical precision of ± 0.07, distinguishing between $w > -0.8$ and $w = -1$ at 3σ. As the name "Legacy" implies, the SN dataset will be the best available for many years to come, being a large sample with broad wavelength coverage, comprehensive lightcurve sampling and spectroscopic data. Figure 2 shows a preliminary SNLS B-band Hubble diagram.

LSS and CMB data act as complements to this SN measurement, but they themselves currently offer only modest sensitivity to w. Likewise, $z > 1$ SN Ia programs have placed only modest constraints on w due to the very small sample sizes (Rie04). Therefore SNLS is expected to become, and should remain, the leading window on the dark energy equation of state this decade.

The statistical breakthrough from SNLS can be realized only if it is matched by a corresponding improvement in systematic uncertainty. In some areas, increased statistics can facilitate reduced systematics; for example, population drifts in SN environment can be controlled by measuring w within subsamples grouped by galaxy age spanning the range from low to high z. However constraining other systematics, in particular possible extinction by dust or evolution in SN colors, requires multi-color data. From low to high z, not only may the intrinsic properties of dust vary systematically, but also may the intrinsic color of SNe, biasing estimates of the amount of intervening dust. For instance, SNLS dataset could examine the inferred intrinsic color — at a given lightcurve width — across SNe arising from stellar populations with a range of star formation histories. Multi-color data will also decrease the systematic uncertainties due to K-corrections by allowing interpolation between bandpasses, rather than requiring extrapolation outside the observed bandpasses. Such studies require a large sample with excellent multi-color data.

SNLS is designed to provide as broad a wavelength coverage as possible from the ground. The $griz$ CFHT data provides useful *rest-frame* B measurements for SNe to $z \sim 0.9$, V to $z \sim 0.6$, R to $z \sim 0.5$ and I to $z \sim 0.2$. Providing multi-color data for the higher redshift SNe involves observations in the near-IR. Out to $z \sim 0.5$ these NIR measurements are being made from the ground – albeit with great effort on the best nights — as an extension to the SNLS using the PANIC imager on Magellan. However the higher redshift SNe are fainter and require observations at longer wavelengths where the ground-based sky background is bright. Hence for SNe at $z > 0.5$ multi-color observations are only feasible from space.

Extending the Reach of SNLS

Here we propose to significantly enhance the reach of SNLS by extending the range of SNe Ia with accurate color measurements out to $z \sim 0.9$ and by constructing a rest-frame I-band Hubble diagram which will measure w with less sensitivity to extinction by dust. We propose to accomplish this with NICMOS F110M and F145M photometry of many of the *same* SNe that will be continuously discovered by SNLS, in the redshift range 0.4–0.9. These filter/redshift combinations approximately correspond to restframe I where dust extinction is $2\times$ smaller than in B. These observations will ensure that all SNLS SNe Ia have the multi-color observations required to correct for extinction, determine accurate K-corrections and test for systematics. Separately and in combination with the Magellan program, these data will allow construction of the first high-z I-band Hubble diagrams. Such I-band Hubble diagrams will provide complimentary cosmological constraints, with statistical power comparable to the SNLS B-band Hubble diagram. Further systematic gains will be achieved by extending not only the number of usable SNe but also the usable redshift range of the SNLS. In particular LH03 show that extending SNLS from $z_{max} = 0.6$ to $z_{max} = 0.9$ results in a 25–40% improvement in the combined statistical and systematic measurement of w. (The improvement for a time-varying w is even more dramatic – a factor of 2.)

Fighting systematics with a larger redshift baseline: SNLS will produce roughly 100 SNe Ia in each $\Delta z = 0.1$ redshift bin for $0.3 < z < 0.9$. The combined uncertainty from measurement error and intrinsic dispersion will be better than 0.20 mag for each bin out to redshift 0.6. Therefore, the average uncertainty in each redshift bin will be < 0.02 mag. While SNLS uses discovery and follow-up strategies, and target redshifts, such that there will be negligible systematics from Malmquist bias, gravitational lensing, or K-corrections, the 0.02 mag statistical uncertainty will be below likely systematic uncertainties (Per99, PeSc03, Kno03). LH03 have shown that when luminosity-distance measurements are dominated by systematic errors, the measurement of w and be improved by going to higher redshift. Our program will primarily focus on obtaining the accurate color for $0.6 < z < 0.9$ SNLS SNe Ia which will allow them to be corrected by dust extinction and put on the Hubble diagram. LH03 show that such an extension in the redshift range for SNLS will improve the systematics-dominated measurement of w by 25–40%. This is an extremely cost-effective means of improving the measurement of w.

Fighting systematics by suppressing extinction: The standard SNLS dataset will be corrected for extinction using $A_B = R_B$E(B-V) out to $z = 0.6$. Our proposed subsample observed in restframe I-band will be corrected for dust extinction using $A_I = R_I$E(B-I) out to $z = 0.9$. Here E(B-V) and E(B-I) are differences between the observed colors and the nominal intrinsic SNe Ia colors $(B\text{-}V)_0$ and $(B\text{-}I)_0$. For a standard CCM89 extinction law the extinction in I-band is 2× smaller than in B-band. Therefore, if there are shifts in the intrinsic SN colors or in the values of $R_{B,I}$ between low- and high-z, our measurements will be significantly less sensitive to such shifts.

As a quantitative example, let us take the current uncertainty in intrinsic SN Ia color of $\sigma(B\text{-}V)_0 \approx 0.03$ mag (Phi99). If there were a systematic change with z in this color of only half this dispersion it would produce an error in the extinction correction of $\Delta A_B \approx 0.06$ mag for a B-band Hubble diagram. For an I_{max} Hubble diagram using E(B-V) this error would be reduced to $\Delta A_I \approx 0.03$ mag. In Fig. 1c we show an example where such a systematic error of $\Delta m \sim 0.03$ would lead these experiments to incorrectly conclude that dark energy is not Λ. Fortunately with rest-frame I data we would be able to use E(B-I) rather than E(B-V), dropping the systematic uncertainty in I_{max} by another 2×, even accounting for the less certain intrinsic B-I color ($\sigma(B\text{-}I)_0 \approx 0.045$ mag (Phi99)). Systematic errors due to changes in R_I would be reduced in an analogous way. This drop in systematic uncertainty gained with the NICMOS data would bring extinction systematic errors down to the level of the SNLS statistical uncertainties.

Complementarity with other HST SN Ia programs: This approach complements our companion Cycle 14 proposals. The 1st of these proposes to observe SNe Ia is elliptical host galaxies inhabiting rich $z \gtrsim 1$ clusters, as a different way of avoiding the large statistical and systematic uncertainties associated extinction correction at $z > 1$. That dataset will perform a crucial test for extinction systematics and evolution within simple stellar populations in the epoch of deceleration. The 2nd proposes to use HST archival and snapshot imaging and SNLS colors to study the Hubble diagram of SN Ia subsets segregated by host galaxy type. Together these proposals provide essential cross-checks on the SN Ia technique, while improving the measurement on w so long as this technique continues to pass these increasingly stringent tests. By contrast, the current proposal will enable the reliable use of SNLS SNe Ia in all galaxy types thereby bringing to bear the full statistical power of the large SNLS sample.

Conclusion

The HST has a key opportunity to test the possibility that dark energy is not Λ, by taking advantage of the ground-based SNLS project that is committing very large amounts of dedicated telescope time with wide-field instruments. We here propose a highly efficient use of NICMOS to achieve this goal, and thereby provide the crucial improvement in control of systematic uncertainties necessary to measure w at the best currently possible level of precision.

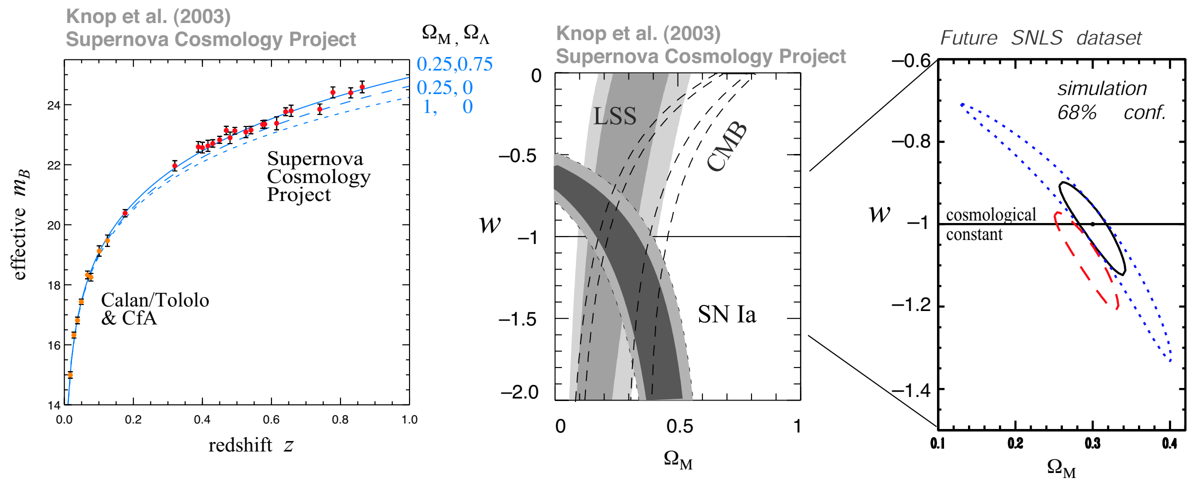

Figure 1: (Left): Our major new result based on several cycles of HST data showing the averaged Hubble diagram (SNe within $z < 0.01$ of each other have been combined) for all SNe from our low-extinction subsample. The solid curve overlaid on the data represents our best-fit flat-universe model, $(\Omega_M, \Omega_\Lambda = (0.25, 0.75)$. Two other cosmological models are shown for comparison. (Center): Our latest joint measurements of Ω_M and w assuming $\Omega_M + \Omega_\Lambda = 1$ and that w is not time-varying. Confidence regions (68% and 90%) are shown for the SCP SN Ia data overlaid with LSS measurements and combined CMB measurements. (Right): 68% statistical confidence intervals on the dark energy equation of state possible from SNLS when it is completed 5 years from now, assuming a flat universe (from CMB measurements), and with (solid) and without (dotted) a prior on Ω_M from LSS. If a small systematic error is introduced, the statistical confidence interval will miss the correct simulated Λ $(w = -1)$ solution by 2σ (long-dash).

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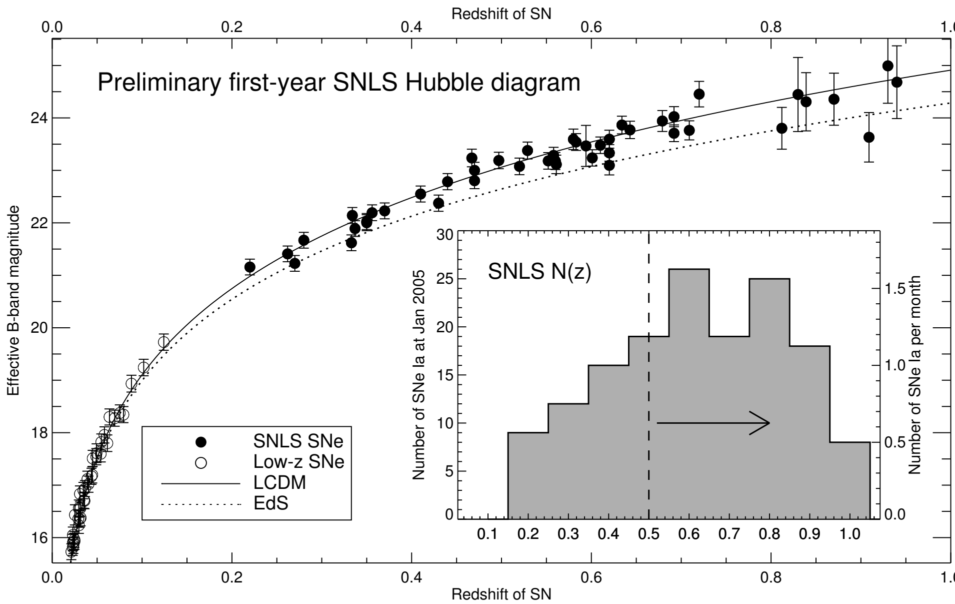

Figure 2: Preliminary SNLS B-band Hubble diagram. The restframe I observations we propose would allow uniformly small uncertainties out to $z \sim 0.9$, whereas currently poor color measurements limit high-quality measurements to $z \gtrsim 0.6$. In addition, we will generate I-band Hubble diagram which will be largely independent of the B-band Hubble diagram.

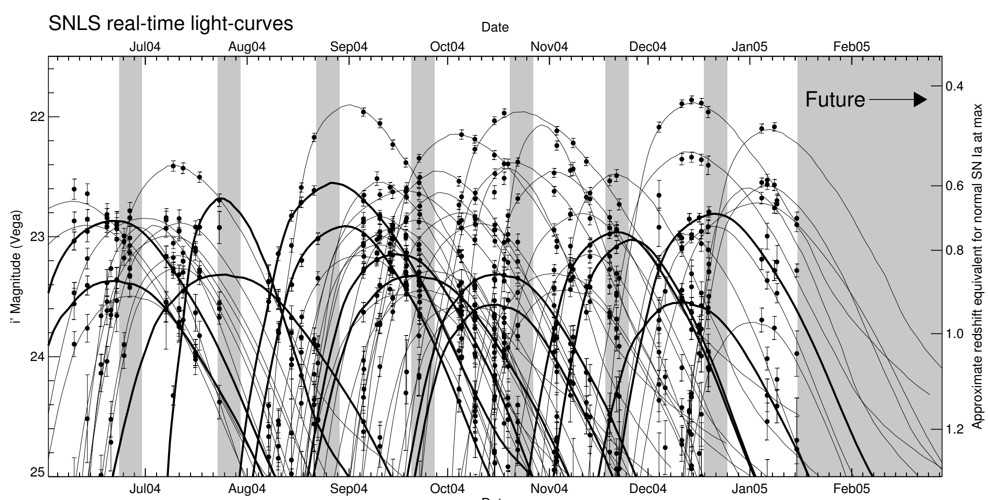

Figure 3: Actual SNLS lightcurves, showing the "rolling" nature of the search. Shaded vertical regions indicate example times when HST could be pre-scheduled. The bold lightcurves then indicate the example SNe Ia that we could follow using the observing strategy we propose here. Note that suitable SNe are always available in this pre-scheduled mode, so no disruptive ToO is required.

Description of the Observations

This proposal requests NIC1 F110M or F145M observations of 30 SNe Ia in the redshift range $0.4 < z < 0.9$ at maximum light. 18 of these SNe Ia will require two orbits in F145M, while 12 will require one orbit in F110M, to measure the restframe I-band peak magnitude. From previous HST work in this redshift range, we have found that for half of the SNe (in this case 15 out of 30) it is necessary to observe final images of the host galaxy after the SN has faded to ensure the proper subtraction of the host-galaxy light, as required by our goal to limit systematics at the few-percent level. This will require one additional orbit per SN for these 15 SNe. Our total request this cycle is therefore $1 \times 12 + 2 \times 18 + 15 = 63$ orbits. Note that our plan would be to continue this HST program in each future cycle during which the the SNLS experiment is active.

Redshift Range: Ground-based NIR observations can obtain restframe I-band lightcurve measurements at maximum light for SNe Ia out to $z \sim 0.5$. SNLS-only color measurements become poor beyond $z \sim 0.6$. Therefore, our program will focus on SNe Ia at $z > 0.6$, where fully half of the SNLS SNe Ia are found. However, in order to have a continuous I-band Hubble diagram we will regularly include SNe Ia down to $z \sim 0.5$. Moreover, ground-based programs will sometimes be unable to cover lower-redshift SNe Ia and we can profitably include SNe Ia down to $z \sim 0.4$. Therefore, our overall redshift range will be $0.4 < z < 0.9$.

Filter Choice: We will observe using the F110M or F145M filter. The F110M filter provides a good match to restframe I for $0.4 < z < 0.6$ while F145M matches restframe I-band for $0.6 < z < 0.9$ The F110W filter is more sensitive, but it is so broad that on the red side it will contain SN light for which there is no reference data, while its blue side extends into the restframe V and B thereby negating the decreased sensitivity to extinction which is central to our program. F110M and F145M are available only on NIC1 — the superior resolution of NIC1 will help in separating host light from SN light.

Exposure Times: Our data quality goal is to match the SNLS fitted restframe B-band peak brightness uncertainty, which is typically 0.02–0.06 mag for $0.4 < z < 0.9$. Better measurements would not lead to significantly better cosmological constraints or systematics controls since the known intrinsic brightness and color dispersion amongst SNe Ia would then dominate the error budget. Lower quality HST measurements would significantly limit the additional cosmological constraints or systematics controls achievable with this unique SN sample. SNe Ia with $0.4 < z < 0.6$ observed at maximum light in F110M will require one orbit to achieve $\sigma_I \sim$ 0.02–0.03 mag. To achieve the requisite $\sigma_I \sim$ 0.04–0.06 mag at $0.6 < z < 0.9$ in F145M will require two orbits per SN. These S/N estimates have been determined using the NICMOS ETC, as well as scaling from our Cycle 13 NIC2 photometry of high-redshift SNe.

Sample Size: Our program goal is intended to achieve a I-band Hubble diagram having statistical power comparable to, and systematics control exceeding, the SNLS B-band Hubble diagram. This is possible because correction for dust dominates the statistical (and possibly the systematic) uncertainties in the B-band Hubble diagram, while our I-band Hubble diagram will have $2.4\times$ smaller sensitivity to dust as well as a significantly larger redshift baseline. (We are presently short of this goal, since SNLS SNe Ia at high redshift were not observed with HST in Cycle 13.)

SNLS is now producing roughly 60 well-measured SNe Ia per year in the $0.4 < z < 0.9$ redshift range. Of these, our observing strategy (see below) will allow us to observe 30 per year in restframe I-band. As the statistical weight of each of our SNe will be roughly twice that of each point on the SNLS B-band Hubble diagram due to the decreased dust sensitivity (this gain is limited by the intrinsic dispersion of 0.10 mag for extinction-corrected SNe Ia in the I-band), the overall statistical weight of our sample will rival that of the main SNLS measurement. Observing fewer than 30 SNe Ia simply weakens our constraints and underutilizes the tremendous existing investment in ground-based imaging and spectroscopy of the SNLS SNe Ia.

Strategy: The SNLS program monitors four fields, known as D1, D2, D3 and D4. D2 covers the COSMOS field, while D3 overlaps the Extended Groth Strip. Each field subtends a solid angle of one square degree, so the angular separation between the field center and any SN in a given field is within the HST 2-degree telescope offset limit. Each field is visible for more than 40 minutes per orbit for windows of at least 5 days for periods ranging from 5 to 6 months. Each month roughly 3 SNe Ia are discovered in our target redshift range in each field. We would preschedule two one-orbit visits near the end of dark time (i.e. after the SNe have been spectroscopically confirmed) in each field during its prime visibility period. A week prior to the pre-scheduled observation we will provide the exact coordinates of one higher-redshift or two lower-redshift SNe to be observed. Figure 3 shows actual SNLS lightcurves of SNe from the past year, with the gray bands indicating example periods when we would have scheduled HST observations and thick lightcurves indicating SNe that could have been chosen had this program been operative in Cycle 13. This demonstrates that such a passive scheme allows efficient and effective observations of suitable SNe Ia during each scheduled period.

The Need for HST: Our targets have $22.0 < J < 23.2$ and $22.6 < H < 23.5$ at maximum light. As stated earlier, ground-based telescopes can reach the brighter end of this range at the requisite S/N with exposures of several hours under excellent conditions. However, beyond z ~0.5 such observations become heroic, whereas our program requires that good measurements be obtained for many SNe Ia on a regular basis. Even on queue-scheduled 8-m's we have found that NIR instrumentation is often relegated to bright time. The SNe which would come to maximum light at that time will have poor ground-based optical data, which is a necessary complement to the restframe I-band data and needed to obtain the lightcurve width and the peak B-band magnitude. The proposed space-based follow-up will not suffer from this problem and will be homogeneous and robust. In contrast, our experience with ground-based follow-up programs carried out over the last several years with comparable NIR requirements has been that problems of instrument availability, schedulability at the correct epochs, cross-telescope calibration, etc., result in a significant reduction of the sample that is ultimately usefully observed. In these cases the full potential of a substantial number of SNe Ia is lost after an already significant investment to find them and obtain their spectra. (Note that adaptive optics techniques have not been developed for precision photometry – this is expected to be a difficult future challenge – and that the observing conditions needed for adaptive optics observations are even more restrictive.)

Strategy for Two-Gyro Observations

The science proposed here can be done in two gyro mode through minor adjustments to the overall program. The primary impact is that the viewing window for some fields is shortened due to HST two-gyro pointing constraints. Taking as our criteria that a field be visible with HST for 40 minutes per orbit for at least 5 days in a month, we find the following: The D2 field is the hardest hit – it can only be targeted for 4 months out of 6 months it will be observed by SNLS. D1 is observable for 5 out of 6 months, while D4 is observable for 4 out of 5 months. D3 is the least affected – it can be observed all 6 months. Thus in two gyro mode we can observe our targets for 19 of the possible 23 field-months, or 83% of the time that would be available in three-gyro mode. As we expect roughly 50% more SNe Ia per field than we have proposed to observe with HST, this reduction in viewing time should have a negligible affect.

An additional constraint imposed by two-gyro mode is that it restricts the number of days a field can be observed in certain months, possibly complicating the scheduling of observations. To alleviate these possible scheduling pressures we will only request to schedule an observation in a given month if the field can be observed for at least 5 days in that month during a period near or somewhat after new moon.

Our program has no ORIENT constraints. We will check for suitable guide stars at the time we have a candidate for HST follow-up. Therefore, we do not anticipate any unusual acquisition difficulties. Unlike other HST SN follow-up programs, we have no requirement for return visits, other than to obtain a final reference image the following year for some of the SNe Ia.

If two-gryo guiding is poor, this would reduce our S/N. It could also make PSF-fitting slightly more difficult due to the probable lack of other stellar sources in the small NIC1 field. Fortunately, the high fidelity simulator indicates that image quality degradation should be small ($< 10\%$) relative to the telescope diffraction limit in the NIR.

Special Requirements

As described below, we will arrange with the HST schedulers to put on the HST calendar two orbits for each field every lunation (right around 1st quarter moon) throughout this observing Cycle. Depending on the time of year, we will be monitoring 1 or 2 fields, so this is a very minor load on the schedule. Prior to the building of the flight calendar we will provide HST with the precise coordinates of each target. This will be similar to, but even simpler than, arrangements we have made with HST over the last several Cycles for the observation of high-z SNe Ia.

Coordinated Observations

SNLS is discovering SNe in a "rolling search" mode, in which the same fields are revisited every few nights (with observations in multiple filters) over several months (Fig. 2e,2f). This means that any SN in the field can be discovered within a few days of explosion, and all the SNe in the field are followed with photometry every few nights over the following few months. The SNe that will be used for this current proposal will come from the SNLS since most of the proposers are either affiliate or members of the SNLS team (in particular, Reynald Pain is a leader of that project).

There are several advantages for this proposal from this mode of discovery and follow-up. First, there will be a continuous rate of SN discoveries in the redshift range of interest — approximately 60 per year from the SNLS search. This allows just a few orbits to be scheduled per month for this HST program (to follow two to four SNe at maximum), providing more HST scheduling flexibility. These discoveries will all be in one of the few predetermined SNLS survey fields, which are small enough that the HST can be scheduled many weeks in advance to observe a target in the field and then the final exact coordinates given one week in advance of the observation. This observing mode (which we have used extensively for HST follow up of high-redshift SNe) avoids the inefficiency of ToO observations.

The discoveries are triggered about two observer-weeks before the SN reaches maximum light in restframe I-band (which is just a couple of days before the B-band maximum). We are obtaining Keck, VLT and Gemini spectroscopy to determine the redshift, type (Ia, II, etc.), and lightcurve phase for each SN. SNLS photometry provides photometric redshifts to help with the selection of spectroscopic targets, and can provide photometric redshifts as back-up. The SN spectroscopy and photometry will provide predictions of the date of maximum, allowing the selection of just the right SNe Ia and a ± 3 day prediction of the date of I-band maximum. The "rolling search" and follow-up yields sufficiently high S/N observations in restframe B-band that all HST I-band SNe Ia will have good supporting observations.

As each SN Ia is identified, it will be ranked against the other new SNe Ia, and the best choice will be placed into the next available observing slot closest to its date of maximum light. This program is powerful, yet robust to weather and as simple an HST SN program as is possible.

In addition, we have two independent supporting programs. The Nearby Supernova Factory is obtaining extensive $0.34 < \lambda < 1.0$ μm spectrophotometry of nearby Hubble-flow SNe Ia, which will greatly improve the calibration in the restframe I-band and provide the reference for obtaining relative distances to the high-z SNe Ia from this HST program. The Carnegie Supernova Program is obtaining restframe I-band photometry for $z < 0.5$ SNLS SNe Ia, which will connect the low-redshift and higher-redshift I-band Hubble diagrams. A few $0.4 < z < 0.5$ SNe Ia will be observed to provide a cross-comparison with the CSP measurements.

Justify Duplications

None - these are all unique observations of transient events.

Previous Related HST Programs

By combining observations from a series of GO programs over a number of HST cycles we have obtained a cumulative sample of high redshift SNe which has yielded new determinations of cosmological parameters $(\Omega_M, \Omega_\Lambda, w)$. Equally important, these HST observations have been the basis for studies of possible systematics of the SN technique, such as host-galaxy extinction or evolution. Two such multi-cycle HST studies were published recently and both provided confirmation and improved precision on the earlier ground-based accelerating universe results. Knop *et al.*, 2003 (based on G0-7336, GO-7590, GO-8346) presented an analysis of an independent set of 11 high redshift SNe. The high-quality lightcurves available from photometry on WFPC2 make it possible for this sample alone to provide measurements of the cosmological parameters comparable in statistical weight to the previous results. In addition to high-precision lightcurve measurements, this data offered greatly improved color measurements of the high-redshift supernovae, and hence improved host-galaxy extinction estimates. These extinction measurements show no anomalous negative $E(B-V)$ at high redshift. The precision of the measurements is such that it was possible to perform (for the first) time a host-galaxy extinction correction directly for individual supernovae without any assumptions or priors on the parent $E(B-V)$ distribution.

Sullivan *et al.* 2003 (based on GO-8313, GO-9131) presented the Hubble diagram of distant type Ia supernovae (SNe Ia) segregated according to the type of host galaxy. This allowed us to confirm our previous evidence for a cosmological constant by explicitly comparing SNe residing in galaxies likely to contain negligible dust with the larger sample. These data provide a key test of evolutionary systematics, and a follow-on program is being proposed for application to SNLS SNe.

Other such multi-cycle analyses, described below, are in progress. In particular, this year we are completing final observations of host galaxies after the SNe faded for SNe discovered in GO-9075 and GO-8585. These observations are discussed in Lidman *et al.* (in press) and Nobili *et al.* (submitted).

GO-9727: This cycle 12 program obtained observations spring 2004 using ACS to do a new search for very high redshift $(1.2 > z > 1.6)$ SNe Ia in the GOODS-N field. In coordination with Riess (GO-9728), images from 15 ACS pointings were taken approximately every 45 days at four epochs and searched for candidates. In this seach we discovered Type Ia SNe at $z \sim 1.0$ and $z \sim 1.6$, for which follow-up ACS grism spectroscopy was obtained. For the $z \sim 1.6$ SN Ia we also obtained a full NICOMS lightcurve. A comparable number of discoveries were followed by Riess. We are proceding with the analysis on the $z \sim 1.6$ SN as it does not require final reference observations, and preliminary results were shown in Gibbons *et al.* 2005, BAAS.

GO-9075: In this program, we pushed our SNe Ia studies to the highest redshifts that are feasible for a ground-based discovery and spectroscopic identification campaign. HST follow-up observations for this program started after servicing mission 3B in March 2002 and have been completed for the most part. Unfortunately, we are still awaiting final reference images for several of these SNe. Coordinated with three large search campaigns using the Subaru 8.2 m and also with simultaneous smaller searches using the CTIO 4 m and CFHT 3.6 m, we obtained ACS/WFC and NICMOS/NIC2 photometry for multi-epoch lightcurves of eight Type Ia SNe at high redshift $(0.9 < z < 1.3)$. For two of the highest redshift SNe, ACS grism spectra were taken. Analysis of this ACS data is in progress. With the refurbished NICMOS, we obtained final reference images of the host of SN1998eq, which we had previously studied in G0-8088, and these images have allowed us to at last complete the analysis of this important SN.

GO-8585: In GO 8585 we observed six Type Ia supernovae with HST using WFPC. The supernovae were discovered in ground based searches at the CTIO 4-m, CFHT and Subaru telescopes. We obtained both U- and B-band restframe photometry (using either F814W or F850LP depending on the redshift) for each supernova for a period of 2 months. Analysis of this data is presented in the PhD thesis of J. Raux (Univ. of Paris, 2003), presented at the January 2004 AAS meeting. A publication is in progress.

GO-8313: The objective of this project, which has now been completed with the publication (Sul03) mentioned above, was to obtain snapshot unfiltered STIS images of distant galaxies of known redshift which have hosted supernovae (SNe) of Type Ia found by the SCP, 20 of which are used in the Hubble diagram of 42 type Ia SNe (Perlmutter *et al.* 1999). 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. The brightness scatter about the Hubble line for SNe Ia in these early-type hosts is also significantly smaller than for the SNe Ia in late-type galaxies. This result was based on HST STIS "snapshot" images and Keck spectroscopy of SNe spanning the range $0.3 < z < 0.8$.

GO-8346: We had the unique opportunity of following up SN2000fr, which had been discovered *14 days prior* to maximum light in its restframe. Because this supernova at z=0.54 was discovered so early we were able to obtain excellent light curves from HST in F555W, F675W and F814W spanning the period from one week prior to maximum light to 6 weeks after Several spectra of the supernova were taken at VLT and Keck along with NIR photometry at VLT. These HST observations were published in Knop, R. *et al.* 2003, and are utilized for the NIR analysis of several high-redshift SNe Ia by Nobili, S. *et al.* (submitted). This SN was also highlighted in an ESO Messanger article by C. Lidman (Lidman, C. 2004, ESO Messanger, 118, 24).

DD-8088: WFPC2 and NICMOS (cycle 7) observations were obtained for SN1998eq at $z = 1.20$ (Aldering, *et al.*, 1998,IAUC,7046). The preliminary photometry is consistent with the previous results for Ω_M, Ω_Λ. With the final NICMOS image of the galaxy without the supernova obtained, this analysis is completed and a paper is being prepared.

GO-7850 and balance of **GO-7336** and **DD-7590**: WFPC2 and NICMOS observations were obtained for 11 Type Ia supernovae in the redshift range 0.36—0.86. These observations, including final references where necessary, are now complete, and the results were published in Knop, R., *et al.* 2003 as mentioned above. The color information provided by NICMOS (Burns, S., *et al.*, 2001,AAS,199.1610B), was only possible with HST.

GO-7336 and **DD-7590**: Perlmutter *et al.*, 1998, Nature, 391, 51 reported the results of our HST and ground-based imaging and Keck spectroscopic observations of SN1997ap. The HST portion is based on a total of 4 orbits. Also from this program, HST observations of two $z = 0.83$ SNe Ia are included in the analysis in Per99 which reports on the results from our HST and ground-based imaging and Keck spectroscopic observations of 42 type Ia supernovae with $0.18 < z < 0.86$. The paper rules out a flat $\Omega_M = 1$ universe and presents very strong evidence for a positive cosmological constant.