



Application Form for Telescope Time

1. Title of Proposal

Dark Energy Measurements using SNIa in Elliptical Galaxies

2. Principal Investigator

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3. Scientific Category

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|--|---|---|---|
| <input type="checkbox"/> Solar System | <input type="checkbox"/> Normal Stars | <input type="checkbox"/> Extrasolar Planets | <input type="checkbox"/> Star and Planet Formation |
| <input type="checkbox"/> Compact Objects and SNe | <input type="checkbox"/> Milky Way | <input type="checkbox"/> Local Group | <input type="checkbox"/> ISM |
| <input type="checkbox"/> Nearby Galaxies | <input type="checkbox"/> Starburst Galaxies | <input type="checkbox"/> AGN and QSO Activity | <input type="checkbox"/> QSO Absorption Lines and IGM |
| <input type="checkbox"/> Clusters of Galaxies | <input type="checkbox"/> Gravitational Lenses | <input type="checkbox"/> High- z Galaxies | <input type="checkbox"/> Deep Surveys |
| <input type="checkbox"/> Large-Scale Structure | <input checked="" type="checkbox"/> Cosmological Parameters | <input type="checkbox"/> Miscellaneous | |

4. Abstract (*approximately 200 words*)

We propose to perform the ground-based component of an approved major 219-orbit HST program which uses a new approach to measure cosmological expansions with “dust free” Type Ia supernovae (SNe Ia). By targeting massive galaxy clusters at $z \gtrsim 1$ we obtain a five-times higher efficiency in detection of SNe Ia in ellipticals, providing a well-understood host galaxy environment. HST/ACS repeated imaging will give ~ 30 SN light curves, among which we expect ~ 10 SNe Ia in elliptical hosts. Subaru/FOCAS superb image quality enables us to carry out deep spectroscopy of SN candidates and hosts to give their SN types and redshifts. The expected SN data set will make possible a factor of two improvement on supernova constraints on dark energy time variation, and much larger improvement in systematic uncertainty. We will also carry out follow-up spectroscopy of host galaxies of 10 SNe found with Suprime-Cam in order to put their light curves on SNIa Hubble diagram at redshifts $z \gtrsim 1$.

5. Co-Investigators

Name	Institute	Name	Institute
Naoki Yasuda	University of Tokyo	Takashi Ihara	University of Tokyo
Nobunari Kashikawa	NAOJ	Saul Perlmutter	LBL
Tomoki Morokuma	University of Tokyo	Chris Lidman	ESO
Naohiro Takanashi	University of Tokyo	Greg Aldering	LBL
Koichi Tokita	University of Tokyo	David Schlegel	LBL

6. List of Applicants' Related Publications (*last 5 years*)

Lidman, C. et al. 2005, *A&A*, 430, 843, “Spectroscopic confirmation of high-redshift supernovae with the ESO VLT”
 Tegmark, M. et al. 2004, *PhRvD*, 69, 10, 103501 “Cosmological parameters from SDSS and WMAP”
 Doi, et al., 2003, *IAUC*, 8120, “Supernovae 2002km-2002ky”
 Knop, R. A. et al., 2003, *ApJ*, 598, 102, “New Constraints on Ω_M , Ω_Λ , and w from an Independent Set of 11 High-Redshift Supernovae Observed with the Hubble Space Telescope”
 Sullivan, M. et al., 2003, *MNRAS*, 340, 1057, “The Hubble diagram of type Ia supernovae as a function of host galaxy morphology”
 Yasuda, N. et al. 2003, *Very High Redshift Supernova Discoveries with Subaru/Suprime-Cam*, *AAS*, 203.8211Y
 Yasuda, N. et al. 2002, *Supernovae 2002fc, 2002fd, 2002fe, 2002ff, 2002fg, 2002fh*, *IAUC* 7971
 Miyazaki, S. et al., 2002, *PASJ*, 54, 833 “Subaru Prime Focus Camera – Suprime-Cam”
 Doi, M. et al., 2001, *IAUC*, 7649, “Supernovae 2001cq, 2001cr, 2001cs, 2001ct, 2001cu, 2001cv, 2001cw”

information for these purposes. The entire proposal including scientific justification will be passed to support astronomers for preparation of observations upon acceptance.

7. Title of Proposal

Dark Energy Measurements using SNIa in Elliptical Galaxies

8. Observing Run **Too many nights requested!**

Instrument	# Nights	Moon	Preferred Dates	Acceptable Dates	Observing Modes
FOCAS	10	Gray	Sep-Jun	Sep-Jun	grism

Total Requested Number of Nights Minimum Acceptable Number of Nights

9. List of Targets (*Use an additional sheet if this space is not sufficient*)

I do **not** want observatory staff to see the target names for the technical review.

Target Name	RA	Dec	Equinox	Magnitude (Band)
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10. Scheduling Requirements Request Remote Observation

We request 1 night every month or two nights every other month, depending on the telescope schedule. HST/ACS search observations will be allocated from Sep.2005 to June 2006. Since we have to coordinate HST observations, it is very (extremely) important to contact us to coordinate with the HST schedule before fixing the Subaru schedule. "Dark" nights are favorable since our targets are very faint, although "Grey" nights are acceptable if necessary.

11. Instrument Requirements

12. Experience

We have enough experiences of using FOCAS, and successfully obtained faint SN spectra since 2001.

13. Backup Proposal in Poor Conditions (*specify object names*)

Under poor conditions we will do spectroscopy of bright SNe in the same field.

Please describe in detail about instrument configuration, exposure time, required sensitivity, and so on.

We use 300B grating with SY47 order-cut filter ($z \lesssim 1$) or 300R grating with SO58 ($z \gtrsim 1$). We use a long slit of the width of 0.8 arcsec as the default, although we will change the slit width depending on seeing. We will have default binning of 2 by 2, although we will change binning parameters depending on seeing and target magnitude.

Our previous experiences show that 2.5 – 3 hours (including overhead) can go deep enough to obtain the necessary S/N for SNe at $z \sim 1$, and we spend more if the target is really promising and fainter.

HST/ACS SN searches will give us ~ 3 SN candidates per month, and ~ 1 SN candidates in an elliptical host galaxy. We will typically observe 2 of these per month, requiring 6 hours. We also require spectra of 10 host galaxies of SNe Ia whose redshifts are unknown, for which we already have Subaru/Suprime-Cam lightcurves that indicate $z \gtrsim 1$. We will typically observe 1 of these per month on average, requiring an additional 3 hours. Thus, in total we propose to observe 3 candidates per month with Subaru/FOCAS spectroscopy. Therefore we request a total of 10 nights from Sep.2005 to June 2006.

15. Condition of Closely-Related Past Observations

Please fill in here, if this proposal is a continuation of (or inextricably related with) the previously accepted proposals. This is to describe what kind of relevant/similar proposals have existed in the past and how such previous observations were carried out.

Proposal ID	Title (may be abbreviated)	Observational condition	Achievement (%)
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16. Post-Observation Status and Publications

Please report the status or outcome of your main Subaru observations carried out in the past. All observations relevant to this proposal (e.g., those enumerated in the above entry 15) must be included here; otherwise, only those within last 3 years suffice.

Year/Month	Proposal ID	PI name	Status: data reduction/analysis	Status: publication
04/03	S03B-227	M.Do	completed	in preparation
02/11	S02B-IP-04	M.Do	completed	published in part
02/04	S02A-174	M.Do	completed	published in part
02/04	S02A-174	M.Do	completed	published in part

17. Thesis Work

This proposal is linked to the thesis preparation of _____

18. Subaru Open Use Intensive Programs

This is a proposal for Intensive Programs.

I do **not** want observatory staff to see the target names for the technical review.

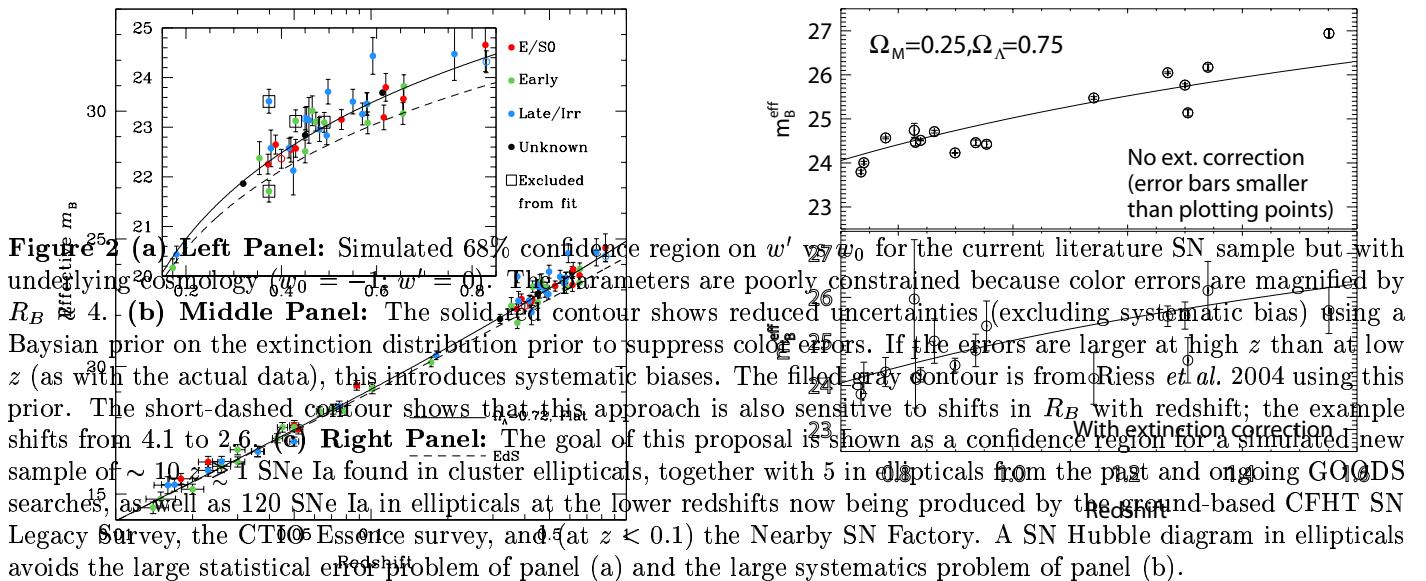
Target Name	RA	Dec	Equinox	Magnitude (Band)
SuF02-007	02 18 52.4	-05 01 14	J2000.0	$i = 25$
SuF02-012	02 18 51.6	-04 47 26	J2000.0	$i = 24.7$
SuF02-026	02 18 51.9	-04 46 57	J2000.0	$i = 23.2$
SuF02-034	02 18 31.2	-05 01 25	J2000.0	$i = 24.2$
SuF02-051	02 17 27.5	-04 40 45	J2000.0	$i = 25$
SuF02-056	02 20 00.0	-04 44 21	J2000.0	$i = 23.3$
SuF02-057	02 20 13.9	-05 07 36	J2000.0	$i = 25$
SuF02-058	02 17 59.7	-04 52 27	J2000.0	$i = 22.9$
SuF02-J02	02 18 42.9	-05 04 12	J2000.0	$i = 22.3$
SXDS-1-b	02 17 09.7	-04 57 48	J2000.0	$i = 24.4$
1012.28	14 34 16.0000	+34 26 0.00	J2000.0	$i = 24.5$
1012.52	14 32 43.0000	+33 32 0.00	J2000.0	$i = 24.5$
1214.18	14 28 37.0000	+34 29 0.00	J2000.0	$i = 24.5$
1214.19	14 34 52.0000	+34 25 0.00	J2000.0	$i = 24.5$
1214.30	14 35 26.0000	+33 06 0.00	J2000.0	$i = 24.5$
1315.12	14 34 58.0000	+35 19 0.00	J2000.0	$i = 24.5$
1416.21	14 32 8.0000	+32 37 0.00	J2000.0	$i = 24.5$
1517.1	14 30 48.0000	+32 32 0.00	J2000.0	$i = 24.5$
CL1604+43	16 04 0.0000	+43 04 0.00	J2000.0	$i = 24.5$
RCS0220-03	02 20 42.0000	-03 33 0.00	J2000.0	$i = 24.5$
RCS0221-03	02 21 54.0000	-03 22 0.00	J2000.0	$i = 24.5$
RCS0337-28	03 37 30.0000	-28 45 0.00	J2000.0	$i = 24.5$
RCS0439-29	04 39 48.0000	-29 00 0.00	J2000.0	$i = 24.5$
RCS1329+30	13 29 0.0000	+30 19 0.00	J2000.0	$i = 24.5$
RCS1416+53	14 16 40.0000	+53 05 0.00	J2000.0	$i = 24.5$
RCS2118-63	21 18 0.0000	-63 00 0.00	J2000.0	$i = 24.5$
RCS2156-04	21 56 0.0000	-04 00 0.00	J2000.0	$i = 24.5$
RCS2319+00	23 19 36.0000	+00 00 0.00	J2000.0	$i = 24.5$
RDSCS0848+44	08 48 48.0000	+44 53 0.00	J2000.0	$i = 24.5$
RDSCS0910+54	09 20 0.0000	+54 22 0.00	J2000.0	$i = 24.5$
RDSCS1252-29	12 52 42.0000	-29 27 0.00	J2000.0	$i = 24.5$
XMM33	22 35 0.0000	-25 57 0.00	J2000.0	$i = 24.5$

The key goal of the most ambitious cosmology projects being designed or built this decade is the detailed, accurate measurement of the universe’s expansion history, from deceleration through acceleration, to look for clues of the properties and identity of dark energy. Of the small handful of known measurement techniques, only Type Ia supernovae (SNe Ia) have actually been developed to the point of routine use. Initial studies of the decelerating universe using SNe at $z \gtrsim 1$ by both the Higher-Z Team (Riess *et al.* 2004) and the Supernova Cosmology Project (Faddeev *et al.* 2004) clearly point to the limiting factor for both statistical and systematic uncertainties: extinction correction of the host galaxy.

We have been awarded one of the largest–ever HST programs (219 orbits) to use a new approach to the measurements in this difficult decelerating redshift range. By studying “clean” SNe discovered specifically in galaxy-cluster ellipticals, we can remove this primary statistical and systematic uncertainty. This Subaru proposal is for the crucial ground-based component of this project: the spectroscopy.

How problematic is the extinction correction uncertainty at $z \gtrsim 1$?

The correction for the extinction of SNe from dust in the host galaxies is currently the single dominant source of both statistical and systematic error for SNe distances and the derived cosmological parameters – dramatically so at $z > 1$ (see Figure 1b).



How is it known that dust is not an issue in $z \gtrsim 1$ cluster ellipticals?

Although evidence for dust is found in about 50% of nearby elliptical galaxies, the quantity of dust is generally very small and confined to a central disk where its cross-section is very small. The clearest line of evidence that dust has little effect on stars in elliptical galaxies comes from the tightness of the color-magnitude relation. The dispersion in the colors of early-type galaxies has long been known to be very small in clusters ranging from Coma to intermediate redshifts (Bower *et al.* 1992; Ellis *et al.* 1997; Stanford, Eisenhardt & Dickinson 1998; van Dokkum *et al.* 2001; Blakeslee *et al.* 2003, Nakata *et al.* 2005). Recent results from HST imaging show the same strikingly small dispersion in color extends to redshifts $z \gtrsim 1$.

There are number of systematic surveys of SNIa for nearby and intermediate redshifts (e.g. SDSS-II, SN Factory, ESSENSE, SNLS) which will give such "clean" SNIa sample eventually. But in order to measure the cosmological expansion over last 10Gyears, we need deeper observations.

In order to find SNe Ia in elliptical hosts at $z \gtrsim 1$, we were awarded 219 orbits of HST/ACS telescope time in cycle 14 (July 2005 – June 2006). We proposed repeated photometry (F850LP) of 22 clusters of galaxies with HST/NICMOS2 followup photometry (F110W). HST/ACS is the best instrument since these observations will also give us resolved host morphology as well as deep SN light curves. The requested 219 orbits are fully awarded (note that this is one of the largest program in HST proposals). We will discover ~ 30 SNe among which ~ 10 SNe Ia in elliptical hosts are expected. Fig.3 shows how light curves will be continuously observed based on simulated data for the HST program, providing good targets for spectroscopy every month.

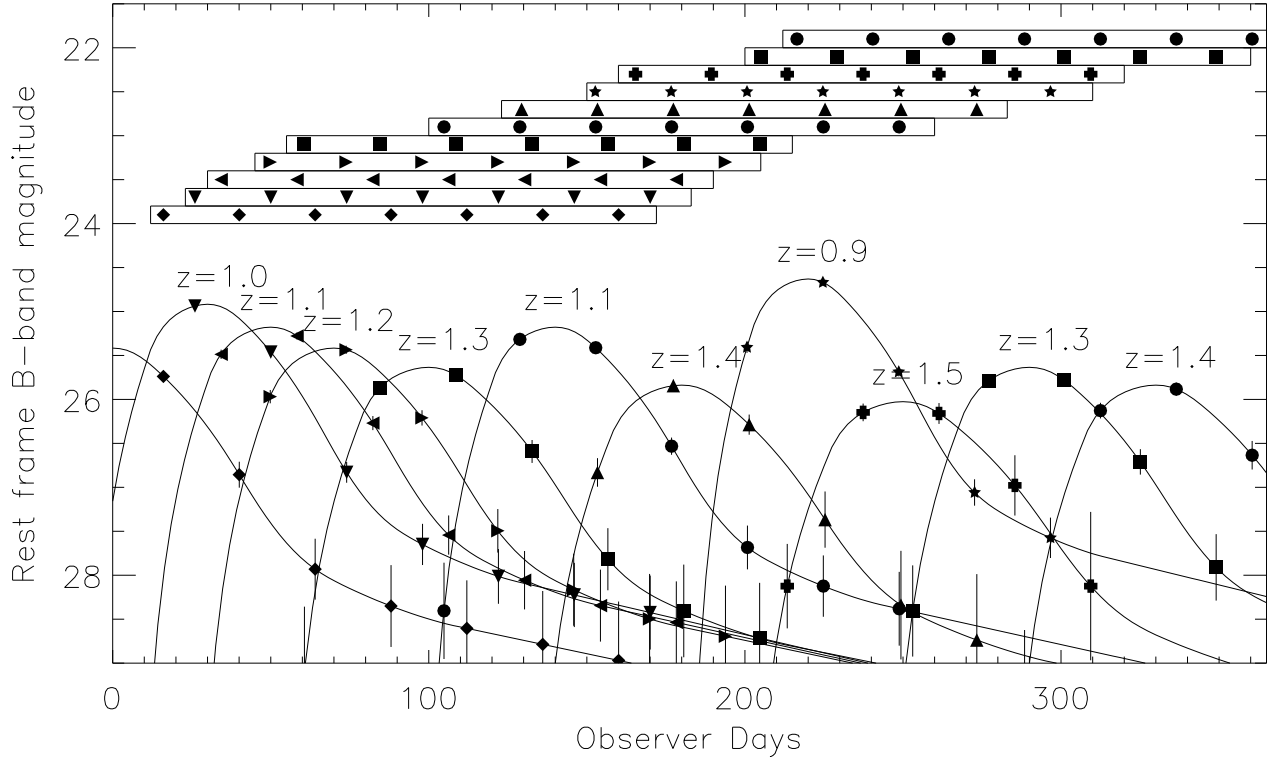


Figure 3 The simulated HST data set for this proposal, with signal-to-noise at a given redshift and SN epoch based on our previous SN from HST/ACS and HST/NICMOS. The simulated data was fit with our lightcurve analysis program to test the cadence feasibility. We obtain typical errors of 0.07 to 0.13 mag for $0.9 < z < 1.5$, including the in the lightcurve timescale stretch correction uncertainty. The bars and symbols at top show the observing time period and scheduled observations for each cluster (with different cadences depending on the cluster z). The same symbols are used for the observations on the lightcurves, to show where a SN might be discovered and followed in its cluster's time window. Note that the observations are well spread throughout the year (allowing easy HST scheduling, with flexibility since there are other clusters to study if one is difficult to schedule). There are therefore SNe to be observed in this proposed Subaru observing program at almost any time, in addition to the host galaxies that can be observed any time.

In order to get spectra of SN candidates to classify SN type, and in order to get the redshifts of the SNe and/or their host galaxy, we are requesting Subaru follow-up spectroscopy. HST/ACS grism observations give SNe Ia spectra at $z \gtrsim 1$ (Riess et al. 2004, Gibbons et al. 2005), but good ground-based telescopes can also give those (Lidman et al. 2004). Fig.4 shows an example that Subaru/FOCAS gave a similar spectrum as HST/grism did. Our previous experiences show that the success rate of FOCAS spectroscopy of high- z SNe is quite high even among other 8–10-m class telescopes possibly due to its superb image quality. Although we have 219 HST orbits, no grism observations are included. Hence we definitely need Subaru/FOCAS to follow precious “dust free” SNe Ia and obtain the redshift of host galaxies.

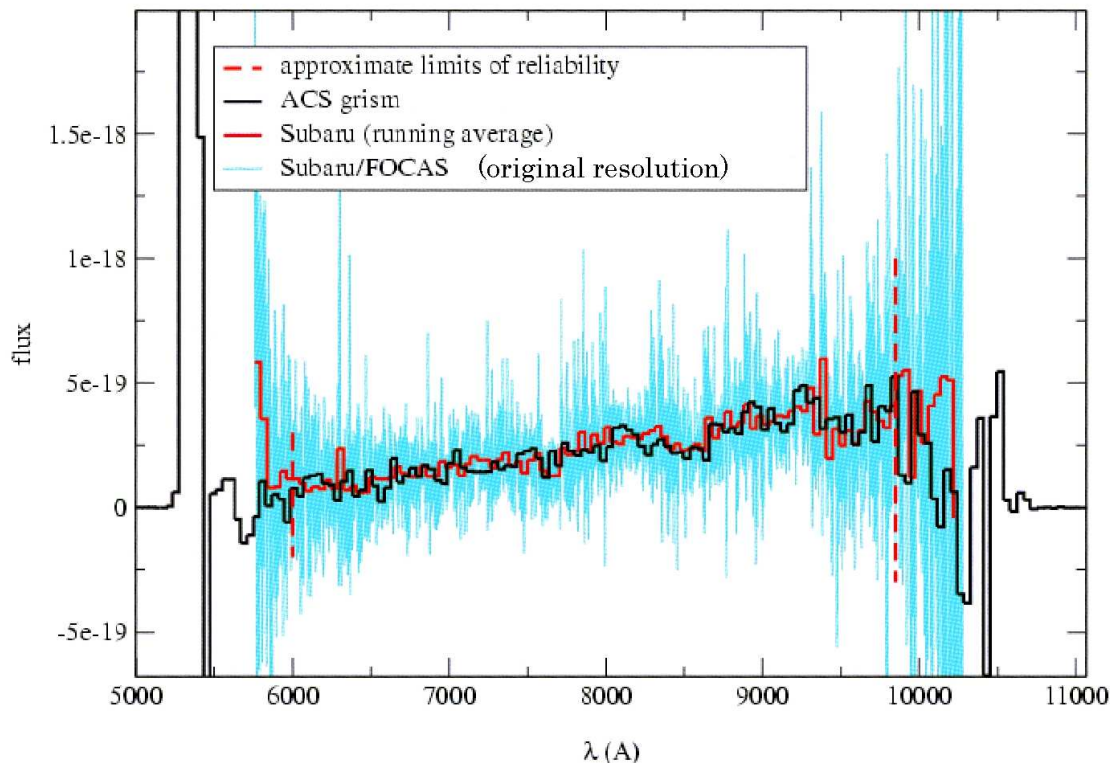


Figure 4 Comparisons of spectra of SN2002lc ($z \sim 1.3$) which was found with Suprime-Cam rolling searches (S02B-IP-04). The black line shows a spectrum of SN2002lc taken with HST/ACS G800L grism observations with ~ 12000 sec exposures. The blue line shows a spectrum of the same SN taken with Subaru/FOCAS spectroscopy with ~ 7200 sec exposures, and the red line is the same FOCAS data but binned to a similar spectral resolution to that of ACS grism spectrum. ACS and FOCAS spectra agree quite well within the reliable wavelength range shown in dashed red lines. FOCAS observation date was Nov.12, 2002 which was 5 days earlier than ACS observations. This comparison clearly shows that FOCAS is one of the best instrument in the world to take faint SN spectra.

Additional observations to follow SNe found with Suprime-Cam

In addition to follow-up spectroscopy of precious “dust free” SNe Ia, we also propose taking spectra of host galaxies of SNe which were found with Suprime-Cam. Fig.5 shows light curves and a preliminary Hubble diagram of 2002 Fall SXDS rolling searches (S02B-IP-04). Blue circles are SNe Ia with spectroscopic redshifts, while red circles are possible SNe Ia with unknown redshifts. As is compared in the figure, there are not many data points at high redshift yet. And we can almost double the number of data points at $z \gtrsim 0.9$ if we measure all redshifts of SNe in red circles.

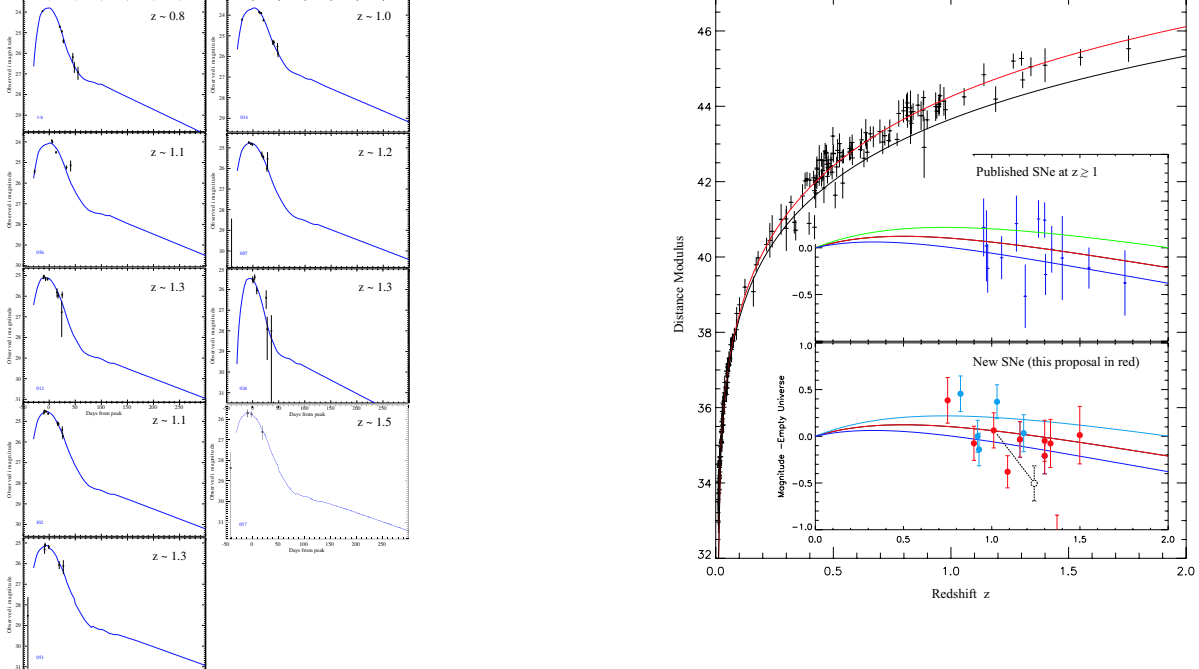


Figure 5 (a) Left Panel: The i' -band lightcurves for the nine supernovae targeted by this proposal. The light curves here were taken with Suprime-Cam (S02B-IP-04), and each of these SNe also has R- and z' -band photometry points near maximum light (not shown). Note that for these nine SNe the integrated host galaxy light in a $1''$ aperture is significantly brighter than the SN in almost every case. **(b) Right Panel:** The Hubble plot for SN Ia, based on a compilation of SNe in the literature discovered primarily by both the Supernova Cosmology Project and the High-Z SN Search (Riess et al. 2004). The solid curves show flat cosmologies with $\Omega_M = 0.3$ (top) and 1.0 (bottom). At the highest redshifts – in the epoch of deceleration – the plot is very sparsely populated. *Upper Inset:* The magnitude residual from an empty universe ($\Omega_M = \Omega_\Lambda = 0$) for the SNe from this compilation at the highest redshifts. The solid curves show flat cosmologies with $\Omega_M = 0.2, 0.3,$ and 0.4 (top to bottom). *Lower Inset:* The magnitude residual from an empty universe for the new SNe discovered in our Subaru-based search for SNe at these decelerating redshifts. The SN indicated by blue points have spectroscopically measured redshifts, while those indicated with red points are plotted using *approximate* redshifts estimated from the time-dilation of the lightcurve timescale. The dashed-line point shows the $\sim 1\sigma$ range of variation of this redshift estimate, *assuming* the known dispersion of lightcurve timescales (from Perlmutter et al. 1999 and Knop et al. 2003). (This dashed-line point is at the same magnitude as its corresponding solid-line point, but the different assumed redshift gives a very different residual from the empty universe.) We here propose to obtain the exact spectroscopic redshift for the host galaxies of each of these SNe.

Conclusions

The spectroscopy observations proposed here are the key ground-based component of a very large approved HST program using known approach to SN measurements which will provide a first significant, *and unbiased* measurement of w_0 vs. w' . The emphasis on high redshift and attention to systematics are the opening steps in bringing to maturity cosmological methods of the next generation, and this program will serve as a bedrock scientific legacy for dark energy studies.

References

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