Scientific Justification

Expansion Measurements using SNIa in elliptical galaxies. M. Doi *et al.*

The signature goal of the most ambitious cosmology projects being designed or built this decade (LSST/LST/Panstarrs, Dark Energy Camera, JDEM/SNAP/Destiny, and the South Pole Telescope and other SZ experiments) 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 (SN Ia, cluster counts, S-Z, weak lensing, and baryon oscillations), 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 (Fadeyev, Aldering *et al.* 2004) clearly point to the limiting factor for both statistical and systematic uncertainties: extinction correction of the host galaxy.

One of possible systematic errors come from host galaxy dust extinction, as was discussed in previous studies of nearby galaxies (e.g. Altavilla et al. 2004, Reindl et al. 2005). To be free from possible systematics due to dust extinction or due to luminosity dependence of SNe Ia on host galaxy properties, we propose to make a clean SNIa sample whose host galaxy is early type galaxies with small extinction.

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 $z > 1$ even with HST (see Figure 1b). [**restate this for Subaru?**] The typical color uncertainties for HST-studied $z > 1$ SNe is $0.08 - 0.1$ in $B - V$, leading to uncertainties in extinction correction (after accounting for intrinsic color uncertainty) of >0.4 mag! This dispersion grows worse, $\sigma \approx 0.5$, after accounting for the uncertainty in the dust reddening coefficient, $R_B \equiv A_B/E(B - V)$, which Draine (2003) notes can vary from the fiducial value 4.1 by ± 0.5. (Note that the actual dispersion about the Hubble-line fit for $z > 1$ SNe Ia corrected for extinction matches this 0.5 mag value.)

These large dispersions in extinction correction have been dealt with, e.g. in Riess *et al.* (2004), by applying a strong Bayesian prior to the distribution, assuming knowledge of the dust and SN distribution in the $z > 1$ host galaxies (shaded contour of Fig. 2b). However, such Bayesian priors are necessarily one-sided (no negative reddening) and hence are known to introduce systematic biases when the error bars are larger at high-redshift than low-redshift (Perlmutter *et al.* 1999). This bias can be seen in Fig. 2b as the difference between the long-dashed contour and the solid contour. This approach to the extinction analysis is also subject to other obvious sources of systematic biases, for example if the mean value of R_B drifts from low to high redshift, as shown by the short-dashed contour of Fig. 2b.

How is this problem solved using SNe Ia in ellipticals?

In Sullivan *et al.* (2003), we showed that the dispersion (including ground-based measurement error) about the Hubble diagram for elliptical-hosted SNe is 0.16 mag — three times smaller than just the measurement uncertainty for extinction-corrected SNe Ia at $z > 1$ — primarily due to the absence of dust. Thus, SNe Ia in ellipticals are statistically each worth *nine times* that of SNe in spirals when making cosmological measurements – and without the aforementioned systematics associated with extinction correction.

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). Recent results from HST imaging show the same strikingly small dispersion in color extends to redshifts $z \gtrsim 1$.

Why is Suprime-Cam the right instrument to use to generate a sample of SNe at $z \gtrsim 1$ in elliptical hosts?

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. Although there are several instruments of ground based telescopes which can go deep enough to find distant SNe, only Suprime-Cam can find enough number of SN candidates because of its large field of view. HSTACS can go deeper (Yasuda et al. 2003) but the field of view is about 1/100, and telescope time is very expensive to get a large enough statistical sample.

Our previous studies show that about 5-10 SNe per Suprime-Cam field (field value), and we can get light curves of these just as we did in 2002 as a part of the SXDS observatory project (Doi et al. 2002, Yasuda et al. 2003, Lidman et al. 2004). As we show in Fig.2 we successfully obtained light curves of more than 15 high-z SNe, and we got a preliminary Hubble diagram (fig.3) for 5 SNe Ia, and also about 10 SNe Ia whose host redshift will be soon observed with Keck and VLT.

(fig.2, 3 light curves and revised Hubble diagram of 2002fall SNe from Keck draft.) In this proposal we propose to carry out rolling SN Ia searches in the same SXDS fields plus several distant clusters of galaxies where we can find many early type galaxies. Our target clusters are all rich clusters at redshift of 0.8-1.2. Since the ratio of early type galaxies is significantly higher than the standard field value, we expect about 2-3 SNe Ia with early-type host per field, and about 10 SNIa in total. We will choose i-band (z-band) for clusters of $z\sim0.8$($z\sim1.2$) for light curve observations, and we will take z-band (i-band) images for a couple of epochs to obtain color information of SNe.

In order to identify the object and in order to get redshift, we are requesting follow-up telescope time of Keck, VLT, and HST. However, even without this supplementary time, we can use photometric redshifts obtained from Suprime-Cam multi-color images, many of which were already taken as a part of PISCES project (Kodama et al. 2005). We already have images in four bands (VRi'z') of RXJ0152.7-1357, five bands (BVRi'z') for RXJ0848.9+4452, and two bands (VR) for MS1054.4-0321. We also will carry out SN searches in SXDS where we have deep photometry in five bands (BVRi'z') as well as spectroscopic or X-ray data for many galaxies. The images taken here will be also used to study galaxies in clusters and in field environments.

References

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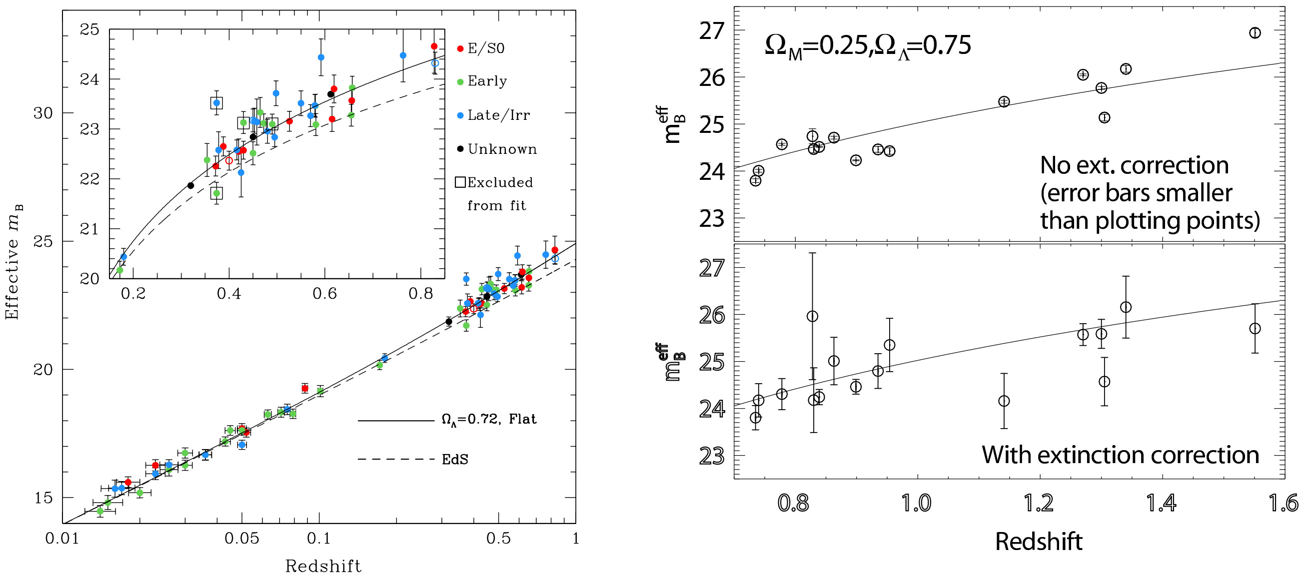

Figure 1: **(a) Left Panel:** The SCP SN Ia Hubble diagram broken into host galaxy types from Sullivan et al. (2003). The SNe in elliptical hosts (filled red circles) show significantly less dispersion, $\sigma = 0.16$ mag, including measurement error. (This ground-based measurement error for this $z \sim 0.5$ sample is quite close to the HST measurement error at $z > 1$ in this proposal.) **(b) Right Panel:** The comparison of the Hubble diagram, before and after extinction correction, for a mixture of SNe Ia in all host types shows the dramatic increase in error bars due to the uncertainty in $B - V$ color being multiplied by $R_B \approx 4$ and by the uncertainty in R_B. The data shown is from the SCP (Knop et al. 2003) and the Riess et al. 2004 GOODS search samples. For the SNe at redshifts $z > 1$ this yields an uncertainty of ~0.5 mag, which is consistent with the measured dispersion of 0.5 mag. The ratio of this dispersion to the elliptical-hosted dispersion of panel (a) makes the elliptical-hosted SNe each worth 9 of the extinction-corrected others.

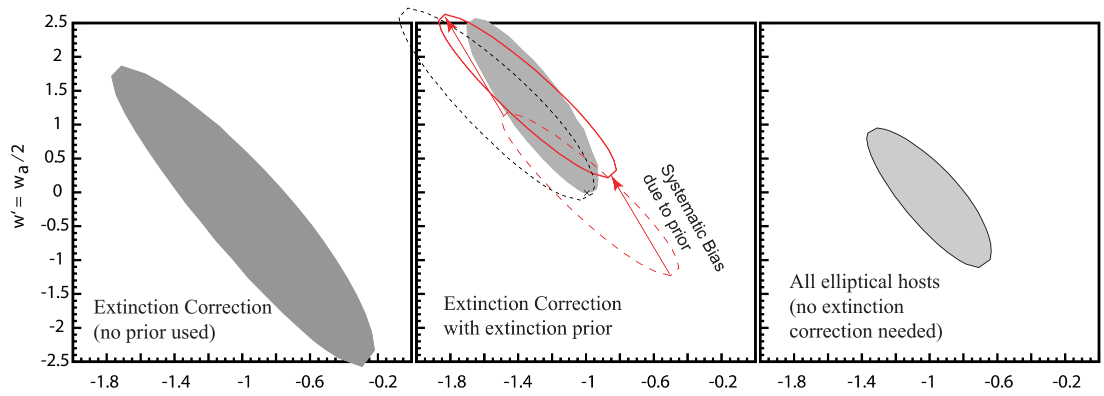

Figure 2: **(a) Left Panel:** Simulated 68% confidence region on w' vs w_0 for the current literature SN sample but with underlying cosmology ($w_0 = -1$; $w' = 0$). The parameters are poorly constrained because color errors are magnified by $R_B \approx 4$. **(b) Middle Panel:** The solid red contour shows reduced uncertainties (excluding systematic bias) using a Baysian prior on the extinction distribution prior to suppress color errors. If the errors are larger at high z than at low z (as with the actual data), this introduces systematic biases. The filled gray contour is from Riess *et al.* 2004 using this prior. The short-dashed contour shows that this approach is also sensitive to shifts in R_B with redshift; the example shifts from 4.1 to 2.6. **(c) Right Panel:** The goal of this proposal is shown as a confidence region for a simulated new sample of ~ 10 $z \gtrsim 1$ SNe Ia found in cluster ellipticals, together with 5 in ellipticals from the past and ongoing GOODS searches, as well as 120 SNe Ia in ellipticals at the lower redshifts now being produced by the ground-based CFHT SN Legacy Survey, the CTIO Essence survey, and (at $z < 0.1$) the Nearby SN Factory. A SN Hubble diagram in ellipticals avoids the large statistical error problem of panel (a) and the large systematics problem of panel (b).

Figure 3: FOCAS SPECTRUM HERE.

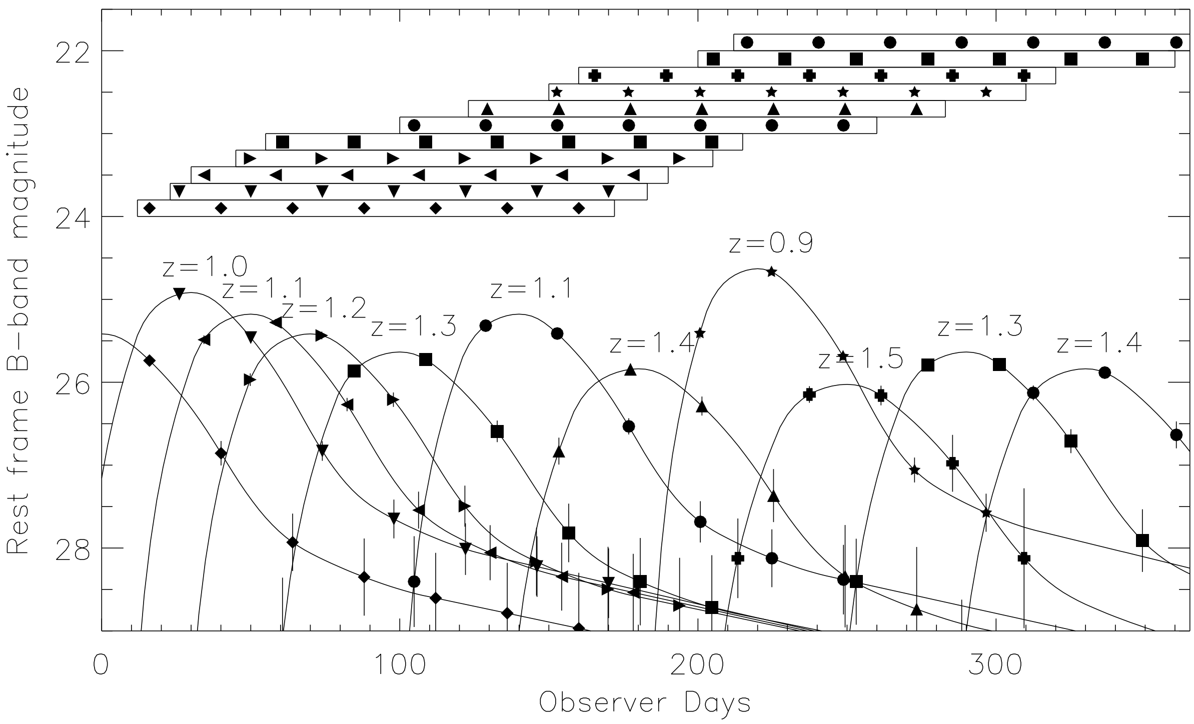

Figure 4: The simulated data set for this proposal, with signal-to-noise at a given redshift and SN epoch based on our previous SN from ACS and NICMOS. The simulated data was fit with our lightcurve analysis program to test the cadence feasibility. We obtain typical errors of 0.07 to 0.13 mag for $0.9 < z < 1.5$, 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 our ground-based observing program at almost any time, in addition to the host galaxies that can be observed any time.