A Deep Supernova Survey with Photometric Redshifts using LSST

Large Synoptic Survey Telescope

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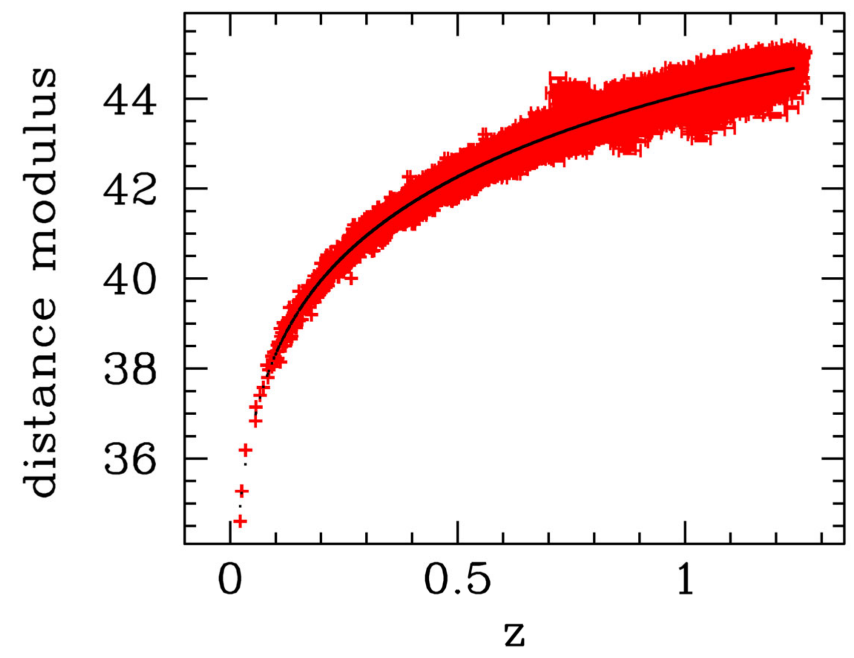
ABSTRACT: LSST's standard operating procedure will be to take two back-to-back, 10-second exposures, and then move on to its next field. It will revisit most fields every few days. In this mode, it will discover more than 250,000 type Ia supernovae per year to a redshift z~0.8. (See the poster in the session by Garnavich et al. for more information on "standard" cadence supernova science.)

Because supernova lightcurves evolve on a timescale (days) comparable to the "standard" cadence revisit time, stacking images of the same field taken on subsequent visits will not allow measuring lightcurves for fainter supernovae. We have investigated a deeper supernova search, made possible by LSST's flexible, automatic scheduling and the robotic nature of the system.

By dwelling for ten minutes per night on a single ten-square-degree field, LSST will be able to obtain lightcurves for over 6000 supernovae per year to redshifts well beyond z~1.2. This will enhance LSST's potential for supernova science beyond that of the much larger but shallower all-sky sample.



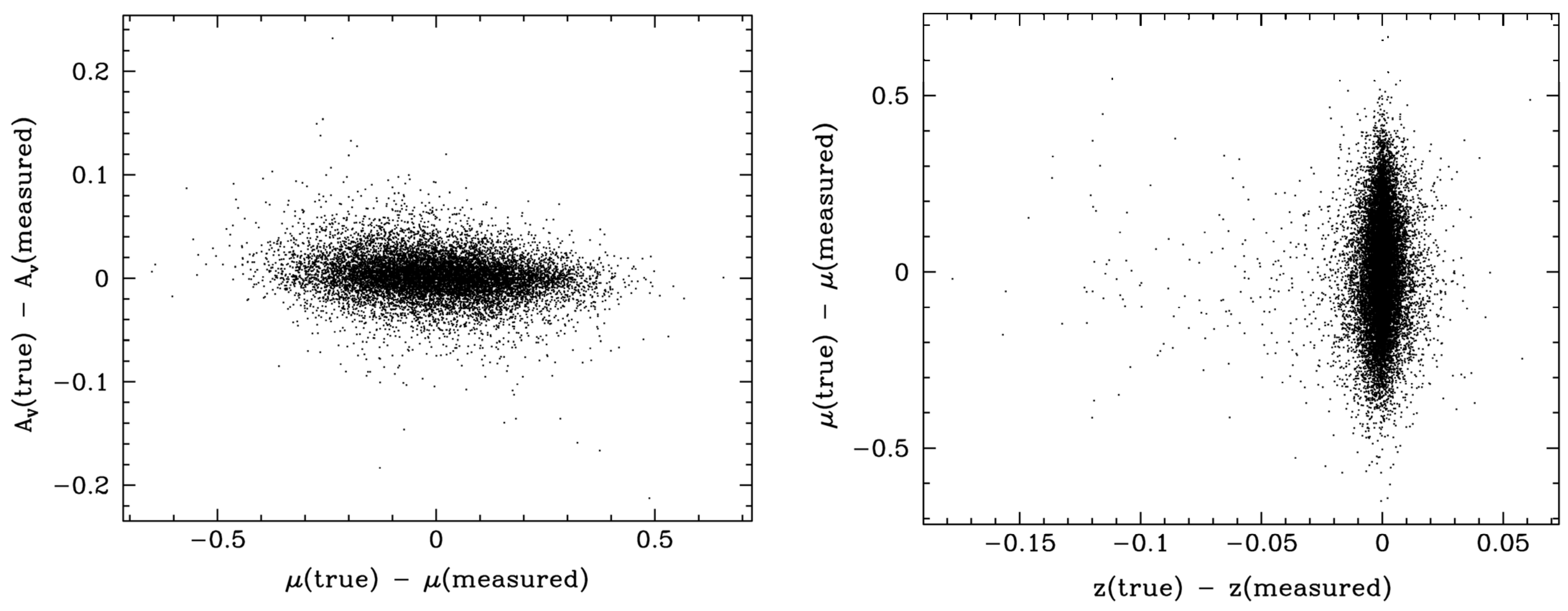
The Hubble diagram for 30,000 supernovae for which good lightcurves were obtained over five years. Regions of apparently-increased scatter are actually quite a small number (of order a hundred) of cases where the fitting procedure did not perform as well as usual. The cut-off near z~1.3 occurs as the supernovae redshift out of the spectral range of the grizY filter set.

Self Follow-up through Photometric Redshifts from Supernova Lightcurves

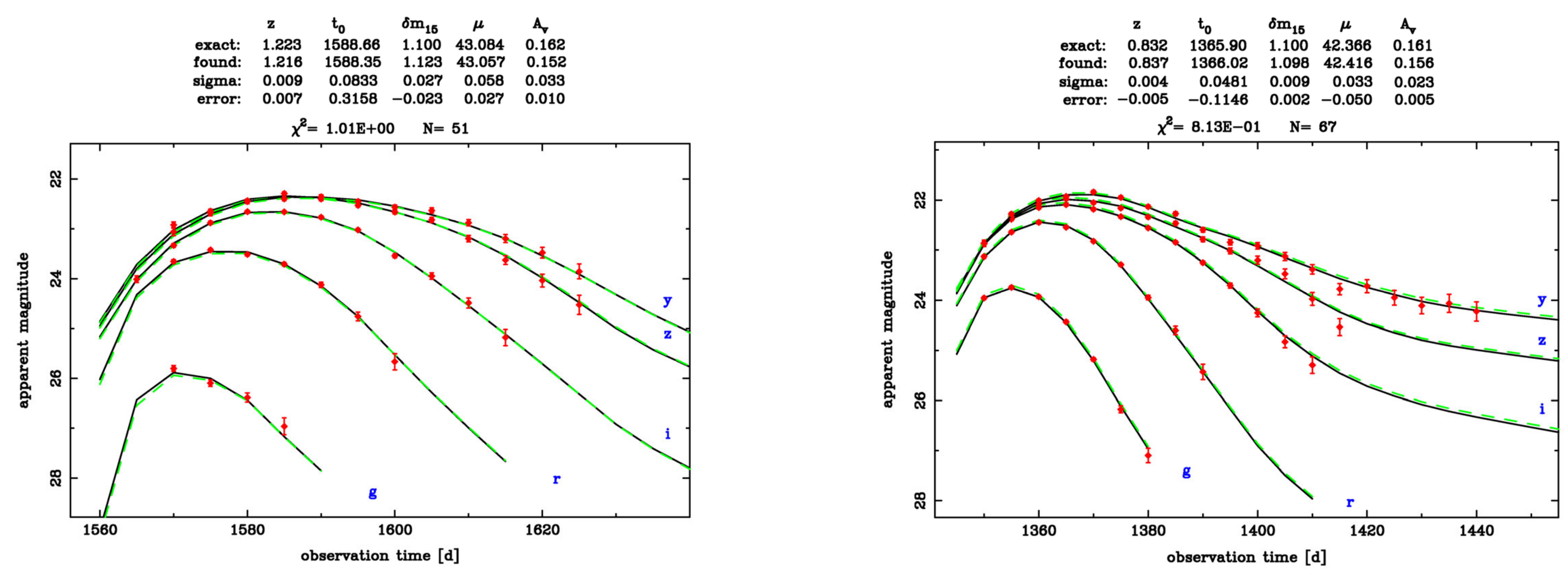
LSST will detect roughly 700 supernovae per day between its shallow and deep searches. Following these up spectroscopically to determine their redshifts is likely to remain impossible for the foreseeable future. LSST's lightcurves will be far more detailed than those obtained from present-day searches, however; this makes it possible to obtain photometric redshifts from the supernovae themselves, in addition to those obtained from their host galaxies.

A Type Ia supernova spectrum has a number of strong spectral features which provide the same opportunity for photometric redshift determination as do galaxies. Unlike a galaxy spectrum, however, the supernova spectrum evolves with time in a very specific way, one highly correlated with the width parameter as measured from the lightcurve. Thus, supernovae should be better-suited than galaxies for photometric redshift determination.

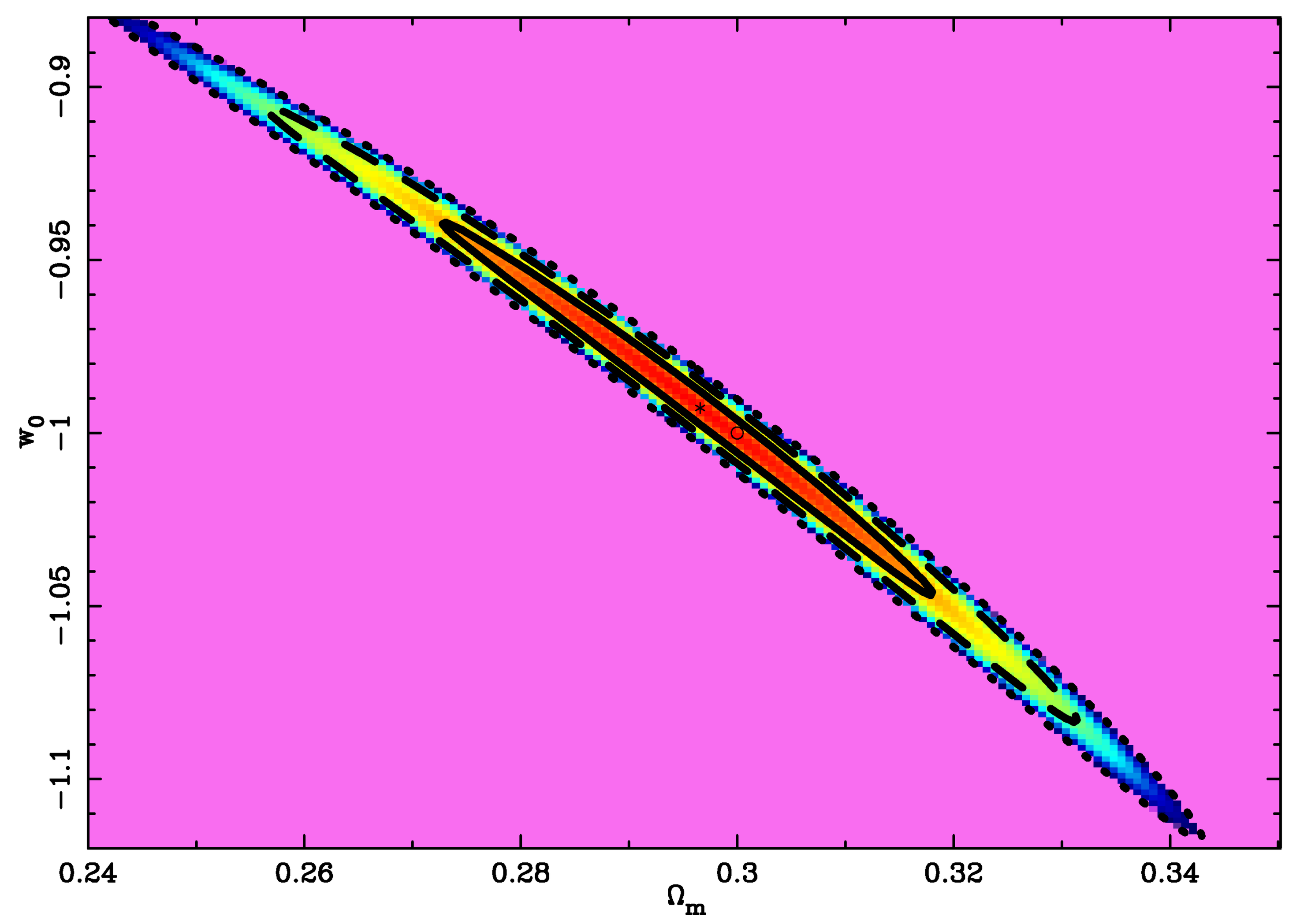
To test this hypothesis, we have performed a simulation of a deep supernova search. Observations are made for ten minutes per night, dividing this time in a five-day cadence among the grizY filter set. Supernovae are sampled from the width-luminosity relation, given a random host-galaxy reddening, and are created uniformly within a standard (0.3,0.7) cosmology with a constant dark energy equation of state (w_0=-1). K-corrections were obtained from a set of synthetic spectra (Pinto & Eastman, 2000). Synthetic lightcurves are obtained from a fairly complete simulation of the observing and data reduction process, including the effects of weather, variable seeing, photon statistics, and other sources of photometric errors. Each lightcurve is then subjected to a five-parameter fit, for time of explosion, width parameter, redshift, host-galaxy reddening, and distance modulus.



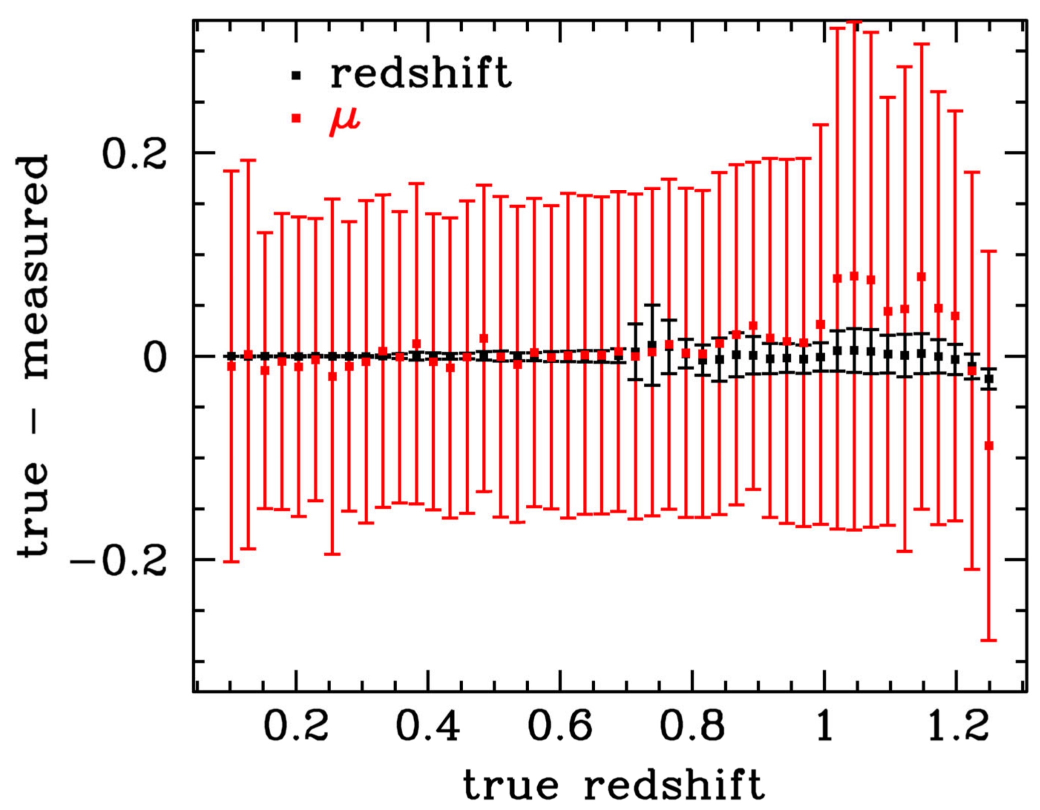
There is very little correlation between the errors in photometric redshift and those in reddening and distance modulus. A more sophisticated fitting procedure, one which includes a luminosity prior, would likely reduce the number of outliers in the redshift diagram.



Typical lightcurves and the fits obtained for the five parameters: explosion time, width, redshift, reddening and distance modulus. The solid lines are fits; the green curves are the real lightcurves.



A fit for cosmological parameters w_0 and Ω_m using 15,000 supernovae to a redshift z~0.85. The color map corresponds to the χ^2 of the best fit for H_0 and Ω_Λ for each value in the w_0 - Ω_m plane; the black lines are 1, 2 and 3-σ contours. When combined with weak lensing or *PLANCK* data, such a sample is easily capable of determining cosmological parameters at the 1% level. Monte Carlo simulations such as these will be essential, however, to understanding and controlling systematic errors.



Errors in photometric redshift and distance modulus as functions of redshift. The largest mean redshift error is 0.01, near z~0.7; typical errors are 5-10 times smaller. Closer than z=1, the largest mean error in distance modulus is 0.03. The error bars of the distance modulus determinations are dominated by the σ = 0.15 mag Gaussian distribution of supernova luminosities at a given lightcurve width. Further optimization of observing cadence and perhaps filters is necessary to reduce errors at greater distances, which are typically slightly larger than the Malmquist bias.