LSST Supernova Cosmology

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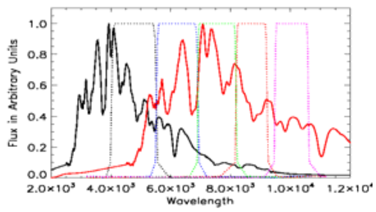
Large Synoptic Survey Telescope

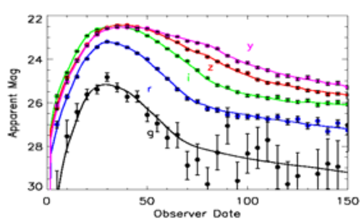
In its normal survey mode, LSST will discover more than 1,000,000 Type Ia supernovae (SNe Ia) per year across the visible sky to a redshift of ~0.8. With a deep, pointed search in several 10-deg² fields, it will discover and closely monitor 10,000 SNe annually to a redshift of z ~1.2. Using these SNe for cosmology will rely upon spectroscopic follow-up capabilities and upon novel methods of deducing photometric redshifts from multi-band supernova light curves. This poster provides a sample of how LSST SNe Ia will be used as cosmological probes. A primary goal will be to detect systematics affecting the supernova cosmology program and, at the same time, to constrain cosmological parameters. This will be feasible because LSST's extremely large sample size allows for multiple parameter fits which can self-calibrate systematics in ways not accessible to current surveys. The systematic relations deduced from these SNe will be helpful for current and future space-based projects targeting SNe at even higher redshifts. Such large samples will also enable discoveries of SNe Ia affected by foreground gravitational lensing. We explore the use of LSST's SNe in constraining the behavior of dark energy and show how their combination with baryonic oscillation investigations will make LSST a particularly powerful experiment to this end. Finally, we show how the distribution of so many well-observed SNe across the sky will constrain the angular variation of cosmological parameters.

Photometry

LSST will detect roughly 2,700 SNe every night between its **shallow and deep searches**, with far more detailed lightcurves than those obtained by present-day searches. For the deep search, observations are made for ten minutes per night, dividing this time in a five-day cadence among the grizY filter set. The resulting lightcurves will have unprecedented time and color sampling, following tens of thousands of SNe throughout their evolution with over 100 photometric points per lightcurve.



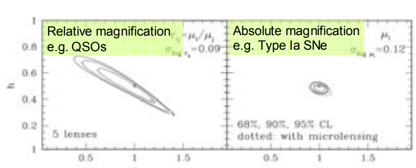
Above: The filter set of LSST plotted together with SNe Ia spectra at optical maximum, at redshift zero (black solid line) and at redshift of 0.8 (red solid line). The band passes are sketched in dotted lines for g (black), r (blue), i (green), z (red), and Y (purple).



Above: Simulated lightcurves from the LSST deep survey for a SN at z=0.832. The solid lines are the input light curves. Such detailed light curves, combined with knowledge derived from the exceedingly large number of nearby supernova observed, will likely allow determining redshifts to better than 1% based on photometric data alone. Such detailed data are also important for extinction corrections and for the control of systematics arising from variations intrinsic to the supernovae themselves.

Gravitationally lensed SNe

A fraction (0.1 ~ 1%) of z ~ 1 SNe will be gravitationally lensed by foreground galaxies. Observations of lensed SNe will provide precise determinations of the **Hubble constant** H_0 (see poster 26.03), crucial for achieving tight constraints on dark energy from SNe when Ω_K is a free parameter (Linder 2005).



Above (Taken from Oguri & Kawano 2003, MNRAS, 338, L25): Constraints on the radial mass profile β and the Hubble constant h from 5 quadruple lens events of QSOs (left panel) and Type Ia SNe (right panel). SNe have well-calibrated luminosities that allow for an absolute measure of the magnification and thus break the mass-sheet degeneracy suffered by other lensing measurements.

Photo-z/Spectroscopy

Spectroscopy could be obtained for a large number of **low-redshift Type Ia** SNe without breaking the 30 sec cadence if a fiber spectrograph is attached to LSST. In any LSST field, there will be typically about 1 type Ia SN below redshift 0.17 at any time of observation. These SNe (~10,000/year) are bright enough so that short exposures will yield sufficient S/N ratio for spectral identifications.

Alternatively, a large sample of nearby SNe can also be followed up spectroscopically by wide field spectroscopic survey facilities such as the Large sky Area Multi-Object Spectroscopic Telescope (LAMOST) being constructed in China. With a field of view of 20 square degrees and an aperture of 4 meters, there are about 11 Type Ia SNe at any time in the LAMOST field that are at redshift below 0.3. bright enough for spectroscopic observations. With typical exposure time of 1.5 hours, LAMOST can observe about 10,000 Type Ia SNe during its survey mode every year.

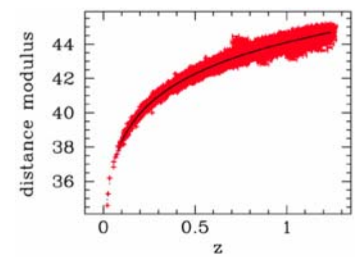
Spectroscopy of **SNe at redshifts higher than 0.3** is likely to remain difficult for the foreseeable future. A sub-sample of these SNe may be selected for spectroscopic studies but the total number of such observations is likely to be small. LSST's lightcurves will be far more detailed than those obtained from present-day searches, however; this makes it possible to obtain photometric redshifts from the SNe themselves, in addition to those obtained from their host galaxies. A Type Ia SN spectrum has many strong spectral features which provide the same opportunity for photometric redshift determination as in galaxies. Unlike a galaxy spectrum, however, the SN spectrum evolves with time in a very specific way, one highly correlated with the width parameter as measured from the lightcurve. Thus, SNe should be better-suited than galaxies for photometric redshift determination. The large number of SNe at redshifts below 0.3 can be used to calibrate photometric redshifts of SNe.

To test the hypothesis of deducing **photometric redshifts** from multi-epoch SN lightcurves, we have performed a simulation of a deep SN search. 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. The preliminary results show that it is possible to derive SN redshifts to better than 1%.

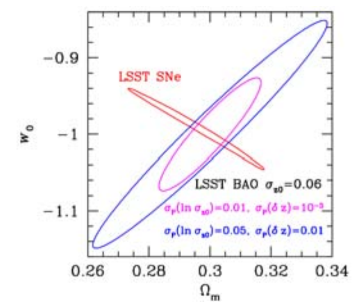
Each year, LSST will be able to observe 30,000 Type Ia SNe at redshift below 0.3, with high-quality multi-band photometry and spectroscopy from follow up observations. Such a large number of SNe will enable us to sub-classify Type Ia SNe into much finer grids. This may eventually make it possible to significantly reduce the dispersion of distance estimates caused by variations in the intrinsic properties of SNe. The knowledge deduced from the low redshift SNe will also be used to constrain systematic errors of photometric redshift estimates necessary for SNe at much higher redshifts.

Summary: Current cosmological applications of Type Ia SNe are based on very simple models in which the intrinsic properties of SNe Ia are characterized by only one or two parameters. Nonetheless, these models, based upon data from fewer than 100 nearby Type Ia SNe, have provided distance estimates as accurate as 7%. The LSST will observe more than 200 times as many nearby Type Ia SNe each year. An LSST selected area survey will have unprecedented time and color sampling and follow more than 100,000 SNe per field up to z ~ 1.2 throughout their lightcurves. Such large numbers of SNe will significantly improve our understanding of these explosions and allow determining additional lightcurve parameters. This will substantially reduce systematic errors in distance estimates and will achieve constraints on the nature of dark energy and other cosmological parameters of unprecedented precision.

Cosmology



Above: Hubble diagram for 30,000 SNe obtained over three years in a single field, with redshifts determined photometrically. Regions of apparently increased scatter actually contain quite a small number (~100) of cases where the fitting procedure did not perform as well as usual. The cut-off near z~1.3 occurs as the SN redshift out of the spectral range covered by LSST's grizY filter set.



Above: One-σ error contours in the w_0—Ω_m plane for LSST **SNe** (red line) and LSST **baryon acoustic oscillations** (BAO, blue and magenta lines). We assume a flat universe with constant dark energy equation of state w_0. These LSST SN constraints are obtained with 15,000 SNe to a redshift z ~ 0.85. For BAO, we assume a surface density of 48 galaxies per square arcmin. The survey is divided into 7 roughly equal-width redshift bins from z = 0.2 to 3. Photometric redshift errors of galaxies are modeled with a Gaussian distribution of rms $\sigma_z = \sigma_{z0}$ (1 + z) and bias δz. The magenta line corresponds to optimistic priors on σ_{z0} and δz, while the blue line to pessimistic priors. LSST SN and BAO constraints are nearly orthogonal to each other, such that the combination will be less prone to uncertainties of the galaxy photo-z error distribution. In addition, LSST **weak lensing** shear co-spectra will place independent (w.r.t. SNe) constraints that make a large angle with the error contour from SNe. **With all three precision probes – Type Ia SNe, BAO, and weak lensing – LSST will be a powerful tool for studying the properties of dark energy and its evolution.**

LSST SNe will also constrain angular variations of cosmological parameters across the sky. Such measurements serve two purposes. They help control systematics due to incomplete understanding of the local universe, such as those from the Milky Way dust correction; they provide observational constraints on large-scale velocity fields in the local universe; and they constitute a direct test for homogeneity of cosmological parameters.

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