Calibrating Photometric Redshifts for LSST

J. A. Newman[1], A. J. Connolly[2], J. A. Tyson[3], M. Schneider[3], V. E. Margoniner[3], D. M. Wittman[3], H. Aihara[4], S. Miyazaki[5], and the LSST Collaboration
([1]U.C. Berkeley, [2]U. Pittsburgh, [3]U.C. Davis, [4]U. Tokyo, [5]NAOJ)

Many of the cosmological tests to be performed with LSST will require extremely well-characterized photometric redshift measurements. The true mean redshift of the objects in each photo-z bin must be known to better than ~0.002(1+z) if errors in cosmological measurements are not to be degraded. We are addressing this issue in many ways, both observational and theoretical, to ensure that the power of LSST is not limited by redshift calibration errors. We have applied recent photometric redshift algorithms to weak lensing measurements using Deep Lens Survey data, and are obtaining further wide-field photometry in LSST passbands using Subaru/Suprime-Cam to forecast LSST precision. We are also investigating new techniques: (A) One approach relies on extremely deep, multi-wavelength photometry over a small fraction of the LSST area. In these regions, photometric redshifts may be calibrated using relatively bright galaxies with spectroscopy, and then applied to fainter galaxies using the many-band photometry. The accurate multi-wavelength photometric redshifts obtained for these fainter galaxies can then be used to calibrate the LSST photometric redshift system. (B) A complementary approach is to exploit the clustering of galaxies to test or perform photometric redshift calibrations. The angular cross-correlation between separate photometric redshift bins provides a measure of the degree to which those bins overlap in redshift, allowing photometric redshift outlier fractions to be measured. High precision results may be obtained by measuring the angular cross-correlation between objects in some photometric redshift bin and objects with known spectroscopic redshift, as a function of the spectroscopic z. This allows the true redshift distribution of the photometric sample to be reconstructed in detail, even if it includes objects too faint for spectroscopy or if spectroscopic samples are highly incomplete (like existing samples at high z). With currently planned spectroscopic samples this method can reach LSST calibration goals.

1. An Urgent Need

Much of the science to come from LSST - e.g. using cosmic shear measured with weak lensing, (see Poster 086.10) or measurements of the angular scale of Baryonic Acoustic Oscillations to determine the cosmic equation of state (see Poster 086.09) - depends on having extremely well-calibrated photometric redshifts (photo-*z*'s). Improving these calibrations was one of the top priorities from the Dark Energy Task Force.

The LSST Collaboration has been working on both new observations and theoretical investigations to develop and test calibration methods which can reach the accuracy required for LSST cosmological constraints not to be degraded. **To reach this limit, any bias (after calibration) in the photo-*z*'s must be smaller than δz=0.002(1+z)** (Ma, Hu, & Huterer 2005)**.**

2. New Tests with Observations

We are now assembling a variety of datasets for testing calibration techniques. This involves both gathering larger spectroscopic samples in fields with LSST-like photometry, and obtaining LSST-like photometry in fields with spectroscopic samples. Spectroscopic redshifts can then be used to test and calibrate photo-*z*'s.

Most of these efforts are building on the recently-completed Deep Lens Survey (DLS) dataset (Wittman et al. 2002), which has obtained *BVRz*' imaging in seven 2x2 degree fields, providing one of the largest deep imaging datasets to date. Tests of both photometric redshift algorithms and methods for template and filter curve refinement using DLS data are now underway (**Margoniner et al. 2007**, in prep**.**).

LSST will utilize somewhat different passbands than DLS, however (*ugrizy* as opposed to *BVRz*'). We are now working to supplement the DLS imaging with Subaru/Suprime-cam *griz* to allow direct comparisons. Campaigns to obtain many more spectra in DLS fields will begin in 2007, using the Keck Telescopes (with the DEIMOS and LRIS-B instruments; PI: J. A. Tyson), Magellan (using IMACS; PI: D. Eisenstein) and the Anglo-Australian Telescope (with AAOmega; PI: B. Schmidt).

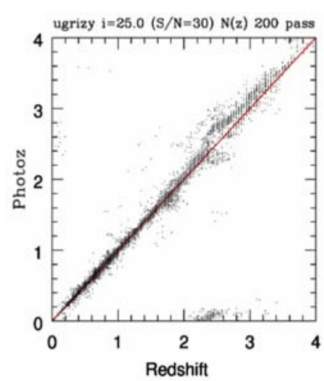


Fig. 1: Monte Carlo simulation of 6-band LSST photometric redshifts. No luminosity or surface brightness priors were used. Our critical task is to calibrate the bias and errors in photo-*z*'s to high precision for 0<*z*<3.

3. Multi-wavelength Calibration

LSST will reach magnitudes much too faint to assemble large spectroscopic samples. Therefore, photo-*z* calibrations will be able to rely on only spectroscopic redshifts for brighter objects. We are now exploring several techniques to deal with this.

One promising method is to obtain both deep spectroscopy and many-band, deep, multi-wavelength photometry (from UV to near-IR) in some set of fields. Multi-wavelength photometric redshifts ("super-photo-zs") are more robust than those based solely on optical photometry, due to the presence of features (e.g. the Lyman break and 1.6μm bump) which are strong in galaxies of almost all star-formation histories (see **Figs. 1 & 2**).

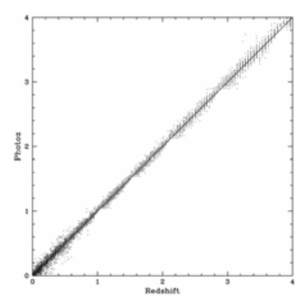


Fig. 2: Test of a simulated super-photo-*z* system; as Fig. 1, but using 12 logarithmically spaced bands from 0.15 to 2 microns in place of *ugrizy*. Photo-*z* errors are <0.03 at most z, and outliers are greatly reduced.

An example of this procedure would be (cf. **Tyson, Connolly, & Newman 2006**):

Step 1) A set of regions with deep spectroscopy, *HST*/ACS, and Spitzer/IRAC near-IR imaging are selected.

Step 2) These fields are imaged deeply in all bands feasible, ranging from UV to IR, from both ground and space.

Step 3) To fill any holes in our understanding of galaxy SEDs (e.g. regions of color space where redshift samples are incomplete), these data will be used to design a follow-up spectroscopic campaign requiring ~100 nights on large telescopes to calibrate the super-photo-z system.

Step 4) The ~10^6 galaxies with super-photo-*z*s in each training field are then used to calibrate 6-band photo-z's for LSST. Galaxies in regions of color space which are poorly constrained could be excluded from cosmological analyses with minimal impact (**Jain, Connolly, & Takada 2006**).

4. Large-Scale Structure-based Calibrations

Even at magnitudes much brighter than LSST will reach (*R*~24 vs. *r*~27), spectroscopic samples are far from 100% complete. This poses a significant problem for calibrating photo-*z*'s, especially if the SEDs of brighter galaxies do not span the range covered by fainter ones (as is true locally, and may be a worse issue at high *z*; see Jimenez & Haiman 2006).

Calibrations which rely on large-scale structure (LSS) information can avoid these problems. All populations of galaxies cluster with each other in three dimensions, and hence also cluster in projection. Since this clustering is local, the observed angular clustering between two sets of galaxies will depend on the degree to which they overlap in *z*, in addition to the strength of their clustering in 3D (i.e., their 'bias').

One application is to measure correlations on the sky between galaxies in separate photo-*z* bins (**Schneider et al. 2006**)**.** These correlations are proportional to the overlap between the bins' *z* distributions, yielding a strong test for outliers.

High-precision results can be obtained by measuring cross-correlation between a photometric sample (e.g. objects in a single photo-*z* bin) and members of a spectroscopic sample, as a function of the spectroscopic *z* (**Newman 2006; Fig. 3**). This provides sufficient information to reconstruct the *z* distribution of the photometric sample. This method can achieve LSST calibration requirements with spectroscopic samples currently underway. Tests with catalogs from N-body simulations are promising (**Wittman 2007**, in prep.; **Fig. 4**).

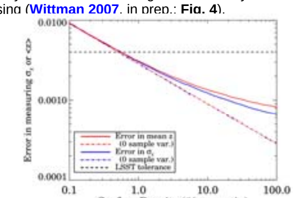
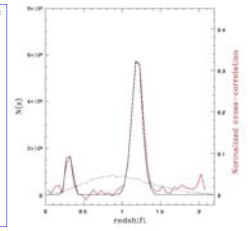


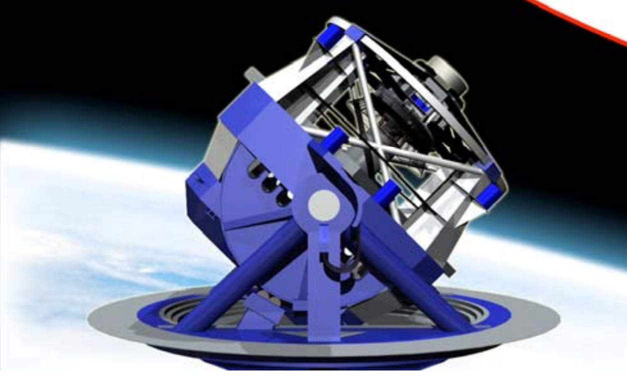
Fig. 3: Predicted errors in measuring the bias and uncertainty of photo-*z*'s as a function of the surface density of the photo-*z* bin, given a sample of 25,000 spectroscopic redshifts per unit *z* and that the true dispersion of the bin is σ_z=0.1. Errors are well within LSST tolerances for *z*=1 unless surface densities are very low (**Newman 2006**)**.**

Fig. 4: A preliminary test of cross-correlation reconstruction using a mock catalog from the N-body simulations of M. White (**Wittman 2007**)**.** In **black** is shown the true *z* distribution for a multimodal photo-z bin; in **red** is the distribution recovered using cross-correlations with a spectroscopic sample given by the black, dotted curve.



For more details, see:

Margoniner et al. 2007: in prep.
Tyson, Connolly, & Newman 2006:
http://www.lsst.org/Science/photoz.shtml
Jain, Connolly, & Takada 2006:
astro-ph/0609338
Schneider *et al.* 2006: *Ap. J.*, 651, 14
Newman 2006: *Ap. J.*, submitted
http://astro.berkeley.edu/~jnewman/xcorr/xcorr.pdf
Wittman et al. 2007: in prep.



The effort to build the Large Synoptic Survey Telescope is overseen by the LSST Corporation, a non-profit 501(c)3 corporation formed in 2003, with headquarters in Tucson, AZ. The LSST research and development effort is funded in part by the National Science Foundation under Scientific Program Order No. 9 (AST-0551161) through Cooperative Agreement AST-0132798. Additional funding comes from private donations, in-kind support at Department of Energy laboratories and other LSSTC Institutional Members.

Research Corporation • University of Arizona • NOAO • University of Washington • Brookhaven National Laboratory (BNL) • Harvard-Smithsonian Center for Astrophysics (CfA)
Johns Hopkins University • Las Cumbres Observatory, Inc. • Lawrence Livermore National Laboratory (LLNL) • Stanford Linear Accelerator Center (SLAC)
Stanford University Kavli Institute for Particle Astrophysics (KIPAC) • University of Pennsylvania • The Pennsylvania State University
University of California, Davis • University of California, Irvine • University of Illinois at Urbana-Champaign • Google Inc.