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The Deep Lens Survey

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Abstract

The Deep Lens Survey (DLS) is a deep $BVRz'$ imaging survey of seven $2° \times 2°$ fields, with all data to be made public. The primary scientific driver is weak gravitational lensing, but the survey is also designed to enable a wide array of other astrophysical investigations. About 100 nights on the CTIO and KPNO 4-m telescopes have been allocated, with roughly 75% of the observing already completed. We review the scientific goals of the DLS, basic parameters (area, filter set, exposure times), field selection, and data products. Finally, we mention some preliminary results on clusters of galaxies which can be found in more detail in other papers in these proceedings. More information is available on our website `http://dls.bell-labs.com`.

1.1 Science Drivers and Basic Parameters

The primary purpose of the DLS is to study the evolution of mass clustering over cosmic time using weak gravitational lensing. Secondary goals include studying the relationship between mass and light through galaxy-galaxy lensing, galaxy and galaxy-quasar correlation functions, and optical searches for galaxy clusters; time-domain astrophysics stemming from the transient search and followup; and enabling a broad array of astrophysics by publicly releasing a large, uniform dataset of images and catalogs.

The DLS weak lensing program is multifaceted, including cosmic shear, cluster counts, and studies of individual clusters. For cluster studies, the key difference between lensing and other techniques is that it is sensitive to all types of matter (luminous or dark, baryonic or not), in any dynamical state. No assumptions of hydrostatic equilibrium or virialization need be made. A major goal of the DLS is to compile a shear-selected cluster catalog and compare it with more traditional cluster-finding techniques based on emission from baryons and on assumptions of equilibrium.

These weak lensing projects imposed the following qualitative requirements on the data:

- imaging in 4-5 different filters with a wavelength baseline sufficient to derive photometric redshifts accurate to 20% in $(1+z)$ out to at least $z \sim 1.5$. The accuracy requirement is rather lenient because the random orientation of each galaxy contributes more noise than does its redshift uncertainty.
- deep enough to derive photometric redshifts for $\sim$ 50–100 galaxies arcmin^{-2}
- subarcsecond resolution, so that shape information about distant galaxies is retained even after dilution by seeing

- at least 5 independent, well-separated fields, selected without regard to already-known structures, to get a handle on cosmic variance
- in each field, coverage of an area of sky sufficient to include the largest structures expected

We chose the Kitt Peak National Observatory (KPNO) and Cerro Tololo Inter-American Observatory (CTIO) 4-m telescopes for their good combination of aperture and field of view. Each telescope is equipped with an 8k × 8k Mosaic imager (Muller et al. 1998), providing a $35'$ field of view with $0.25''$ pxels and very small gaps between three-edge-buttable devices.

To keep the total amount of telescope time reasonable, we wanted to use the absolute minimum number of filters necessary for estimating photometric redshifts to 20% in $(1+z)$. Simulations showed that four was the minimum. We chose a wavelength baseline from Harris B to Sloan z', which is the maximum possible without taking a large efficiency efficiency hit from the prime focus correctors in U or from a switch to infrared detectors on the other end. Between these extremes, we chose Harris V and R, where throughput is maximized; simulations showed that photometric redshift performance did not depend critically on these choices.

Our depth goal is a 1-σ sky noise of 29 mag arcsec^{-2} in BVR and 28 in z', which required total exposure times of 12 ksec in BVz' and 18 ksec in R according to exposure time calculators, for a total of 54 ksec exposure on each patch of sky (see below for discussion). We divided this total time into 20 exposures of 600 (900) seconds each in BVz' (R). Twenty exposures was a compromise between efficiency (given a read time of $\sim$ 140 seconds) and the need to take many dithered exposures to obtain good dark-sky flats.

The metric size of expected mass structures, and the redshift at which they most effectively lens faint background galaxies, sets the angular scale for a field. In order to study the mass clustering on linear scales (out to $15h^{-1}$ Mpc at z=0.3), we must image $2° \times 2°$ regions of the sky. With Mosaic providing a $40'$ field of view after dithering, we assemble each $2°$ field from a 3×3 array of Mosaic-size subfields. Thus each field requires a total exposure time of 9×54 ksec, or 486 ksec.

Although subarcsecond resolution is common for individual exposures on these telescopes, achieving this resolution in the final product of a large survey is another matter, as a large range of seeing conditions is to be expected. We address this problem by observing in R when the seeing conditions are $0.9''$ or better, and switching to B, V, or z' when the seeing becomes worse than $0.9''$. Thus the final R images are guaranteed to be $0.9''$ or better. We will then make the weak lensing shape measurements in R and use the other filters only for color information.

1.2 Field Selection and Observing Strategy

The first consideration in field selection was availability of deep spectroscopy for verifying photometric redshifts in at least one field. After choosing that one field, the gross location of the other fields fell into place through traditional considerations such as avoiding the plane of the Galaxy and spacing the fields to share nights smoothly. The precise location was then chosen to avoid bright stars as much as possible. Fields were not chosen with regard to known structures such as clusters.

We chose the Caltech Faint Galaxy Redshift Survey (CFGRS,Cohen et al. 1999) for our deep spectroscopy, so we centered our first field (F1) in the north at 00:53:25.3 +12:33:55 (all coordinates are J2000). The second field (F2) must then be $\sim$5 hours earlier or later to

Field	RA	DEC	l,b	E(B-V)
F1	00:53:25.3	+12:33:55	125,-50	0.06
F2	09:18:00	+30:00:00	197, 44	0.02
F3	05:20:00	-49:00:00	255,-35	0.02
F4	10:52:00	-05:00:00	257,47	0.025
F5	13:55:00	-10:00:00	328,49	0.05
F6	02:10:00	-04:30:00	166,-61	0.04
F7	14:32:06	+34:16:48	57,63	0.015

Fig. 1.1. Field information. Coordinates are J2000, at the field center. F6 and F7 are subsections of the NOAO Deep Wide-Field Survey, and their exact positions within the larger NDWFS fields will not be set until the image quality and wavelength coverage variations of the NDWFS are known. Extinctions are from the maps of Schlegel et al and represent rough averages over large areas which vary somewhat.

be able to share nights with this field. Earlier is impractical because it would require summer observing during the monsoon season at Kitt Peak. A later field would have to be further north to avoid the plane of the Galaxy. We chose 09:18:00 +30:00:00 because it had few bright stars and low extinction.

In the south, we wanted our fields complementary in RA to those in the north, so that we would not have simultaneous observing runs in the same month. It was difficult to find three southern fields for the 5–15 h range evenly spaced in RA, while avoiding the galaxy. The middle of the three (F4) was fixed at 10:52 -05:00 because redshifts would be available from the 2dF Galaxy Redshift Survey (2dFGRS, Colless et al. 2001). (This is a low-extinction region within the vastly larger 2dFGRS. Note that the 2dFGRS is of much less importance than the CFGRS in verifying our photometric redshifts because the 2dFGRS goes to only $z \sim 0.3$.) The late field (F5) was chosen to be very near the ecliptic to help the hunt for Kuiper belt objects (KBOs); 13:55 -10:00 was chosen for low extinction, and partial overlap with the Las Campanas Distant Cluster Survey (LCDCS; Gonzalez et al. 2001). The early field (F3) was the most difficult to place because it was up against the Galaxy. We chose 05:20 -49:00, which at a Galactic latitude of -35 is the closest field to the plane.

1.3 Data Products

Each year in August, we release data for completed subfields. Currently seven have been released, and the number of completed subfields will increase rapidly. Major data products are:

- Each subfield has 4 FITS images, for each of the 4 filters $BVRz'$. Each image is 8192×8192 pixels, or 35.1' on a side (0.257 arcsec per pixel). This is the full-depth area after dithering; at the completion of the survey, dithers in adjacent subfields will be folded in to reach a larger full-depth area with no gaps between subfields. The four FITS files are registered, and have a World Coordinate System (for converting x,y to RA,DEC) built in. To save space and bandwidth, the images have been integerized and then gzipped (little is lost by integerizing, as the sky noise is 5-10 counts). The resulting files are 50-60 MB each.

- Catalogs produced by SExtractor (Bertin & Arnouts 1996). For the first data release (August 2001) we made double-image mode catalogs: detection is on the R image (the deepest and sharpest image), and evaluation is on each of the four filters $BVRz'$. For the second data release (September 2002), objects are detected individually in each band and then matched. As a result not every object has information in all four bands. Upon completion of the survey, all data will be cataloged uniformly using the procedure which is determined to be better. Catalogs are roughly 30 MB gzipped.
- Color JPEGs, which are great for visualizing the data. On our website, the JPEGs are clickable, with the RA, DEC coordinates of the clicked point returned and readied for a database search.
- Transient detections, which are covered in more detail in Wittman et al. (2002).

We regret that we do not have space to discuss data reduction here; details may be found in Wittman et al. (2002) and on our website `http://dls.bell-labs.com`.

1.4 Current Status and Preliminary Results

Observing started in the fall of 1999. After three observing seasons, we have completed 7 of the 63 subfields. Outside of these, the coverage is variable due to the twin constraints of switching to R in good seeing and maximizing the transient productivity. The full status of each subfield and filter is best visualized at `http://dls.bell-labs.com/progress.html`, which is updated after each run. We released deep images and catalogs of the first two completed subfields in August 2001, and will release five more in August/September 2002. Refer to the DLS website `http://dls.bell-labs.com` for the latest details.

We found that the night sky was significantly brighter in R and z' than assumed by the exposure time calculators, because we started observing near solar maximum while the calculators had been calibrated closer to solar minimum. We are maintaining the planned exposure times while assessing the impact on depth. It appears that we will still reach our goal of 50–100 galaxies arcmin^{-2} with photometric redshifts and shape measurements; we are getting around 60 in the few subfields which are up to full depth. Of course, there is a tradeoff between density of sources and accuracy of redshifts, and that is the subject of continuing refinement. But such details should not obscure the overall good performance of the photometric redshifts. Figure **??** shows that the rms error is less than 20% in $1+z$, with very little bias ($<1\%$), using the template-fitting method (specifically, the HyperZ software, Bolzonella et al. 2000) plus a luminosity function prior.

The first lensing result is on the discovery and tomography of a cluster at $z = 0.68$ (Wittman et al. 2003). This is only the second cluster discovered via weak lensing, and its redshift is more than twice that of the first (Wittman et al. 2001). Preliminary results on lensing cluster detection over a much larger area of 12 deg^2 appear in these proceedings (Margoniner et al.). In brief, we are finding several clusters per square degree; eight of these are scheduled for Chandra X-ray observations, and four more with XMM. We are also comparing with optical cluster selection techniques on the same data (Cohen et al., these proceedings). Work is also in progress on many different ways of proving the data, including cosmic shear, angular correlation functions, searches for cool stars, quasar-mass correlations, and using the photometric redshifts to assess intrinsic ellipticity correlations.

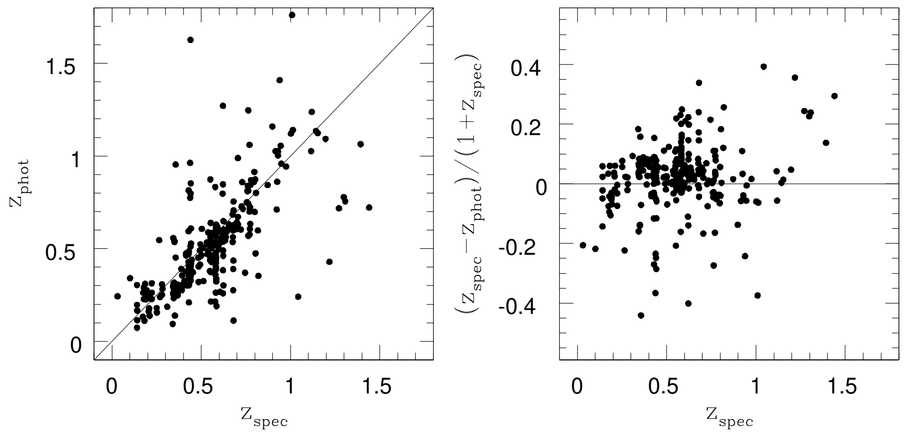

Fig. 1.2. Upper panel: photometric versus spectroscopic redshift in a subfield of F1 including hundreds of galaxies from the CFGRS. Lower panel: residuals versus spectroscopic redshift.

1.5 Acknowledgements

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