Large Synoptic Survey Telescope

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The LSST Deep Drilling Program

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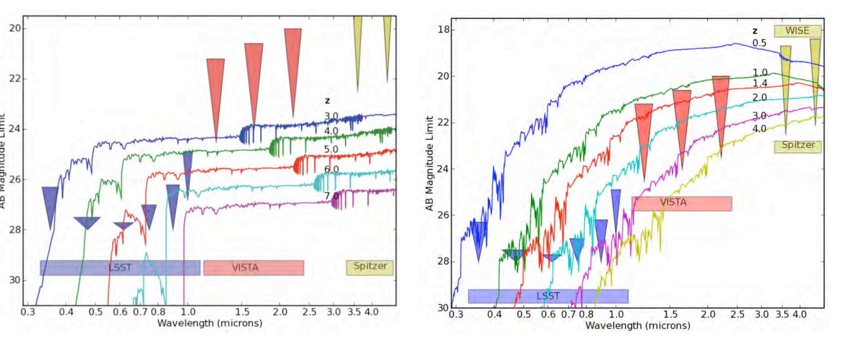
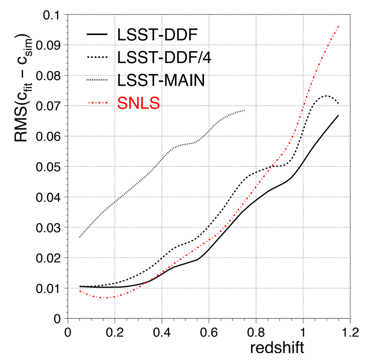
Approximately 10% of LSST's survey time will be dedicated to mini-surveys designed to enhance science beyond the Wide, Fast Deep (WFD) mode of typical LSST operations. One planned type of mini-survey is the Deep Drilling (DD) program, which proposes to survey a limited number of fields to deeper limiting magnitudes and with higher cadence than the WFD baseline. By observing more frequently and using many filters during each sequence, the DD program will provide rich data sets for discovering and characterizing supernovae and other transient objects. By observing to much deeper limiting magnitudes, the DD program delivers higher SNR for galaxy shape and photometric redshift measurements, providing a clean calibration sample to correct for biases within the WFD, and will also detect objects to much higher redshifts. Deep drilling fields will be targeted towards a wide range of science goals, including discovering faint (r=27) solar system objects to explore planetesimal size distributions, characterizing L and T dwarfs by adding deeper i band exposures, and obtaining dense light curves for variable stars and transients within our Local Group, as well as measuring faint high redshift galaxies and SN. A DD Interest Group, drawn from the LSST Science Collaborations, has been tasked with exploring deep drilling program implementations. Members of this group have written a series of white papers, available on the web, detailing their various science goals and observational requirements. The LSST Operations Simulation group has completed a first set of runs to investigate how these requirements mesh with the overall survey; preliminary analysis of these runs is presented here. The first four DD pointings have been announced by the LSST Science Council to provide opportunities for precovery or multiwavelength surveys, and are discussed here. Further refinement of the DD program to optimize science return of both DD and WFD fields will continue until shortly before the start of LSST operations.

Deep Drilling Science Goals

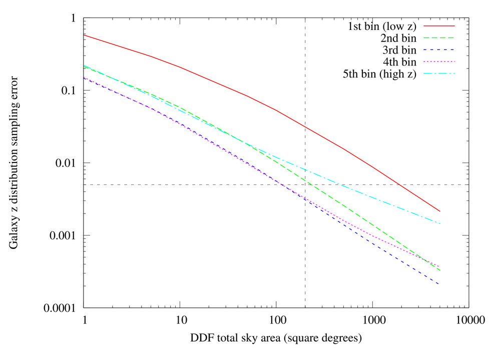
The deep drilling field observations are motivated by a diverse set of science goals, described in a series of white papers (see list of Deep Drilling White Papers, below). Some of those goals include:



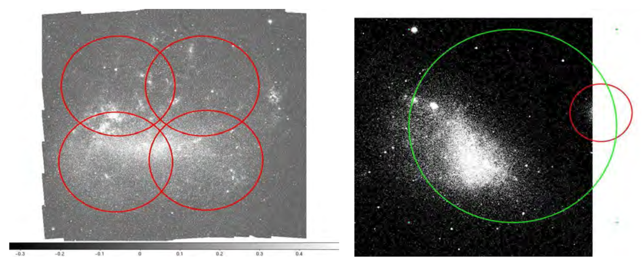
Detecting faint galaxies: The DD fields will detect galaxies at redshifts between 2<z<6 at flux limits far below the WFD survey limits, providing both a higher redshift galaxy sample and a higher SNR comparison sample for the WFD. The figure above shows LSST DD limiting magnitudes compared to the SED of high-redshift star-forming galaxies (above left) and passively evolving red-sequence galaxies (above right) [Ferguson et al.].



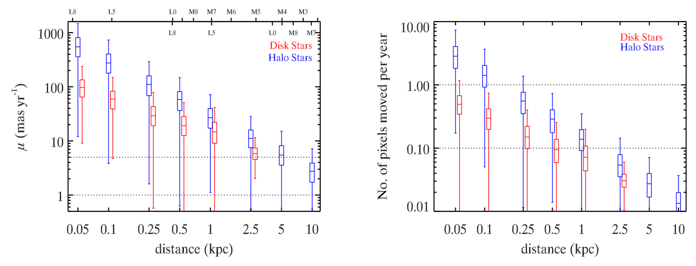
Improving SN light curve templates: With higher photometric precision and faster sampling cadence, the DD fields provide significantly improved SN light curves than the WFD fields, as shown above [Kessler et al.].



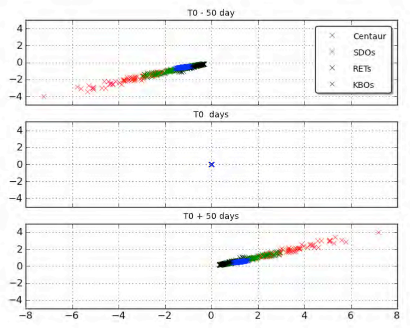
Improving weak lensing: Weak lensing studies require accurate and unbiased photo-z measurements; DD fields can provide more accurate photo-z's due to higher SNR photometry. The DD photo-z's can also be used to calibrate the estimated redshift distribution of galaxies observed in WFD fields; the error in this calibration depends on the area observed in the DD, as shown in the figure to left [Ma et al.].



Discovering unknown transients and variables: Adding intensive time coverage of a small number of well-chosen fields (such as the LMC (left above) and SMC + 47Tuc (right above), shown with the LSST field of view) will improve identification of these same kinds of variables and transients in WFD fields [Szkody et al.]



Mapping ultracool dwarfs and subdwarfs: Increasing coverage in gri bands allows identification of these extremely red stars (otherwise visible in only z and y). Compressing these observations to span only 2 years allows coadded images of these relatively high proper motion stars (as in figure above) to reach fainter limiting magnitudes [Dhital et al.].



Discovering faint Solar System objects: By observing fields in a manner suitable for Shift-and-Stack to recover TNOs and MBAs as faint as r=27 over ~86 sq deg, DD fields can detect changes in the size distribution of these planetesimals, constraining planet formation theories. A large fraction of these TNOs can also be followed for ~1 year (their shear is illustrated in figure to left), thus determining their orbits in addition to their sizes, distances, and light curves [Becker et al.].

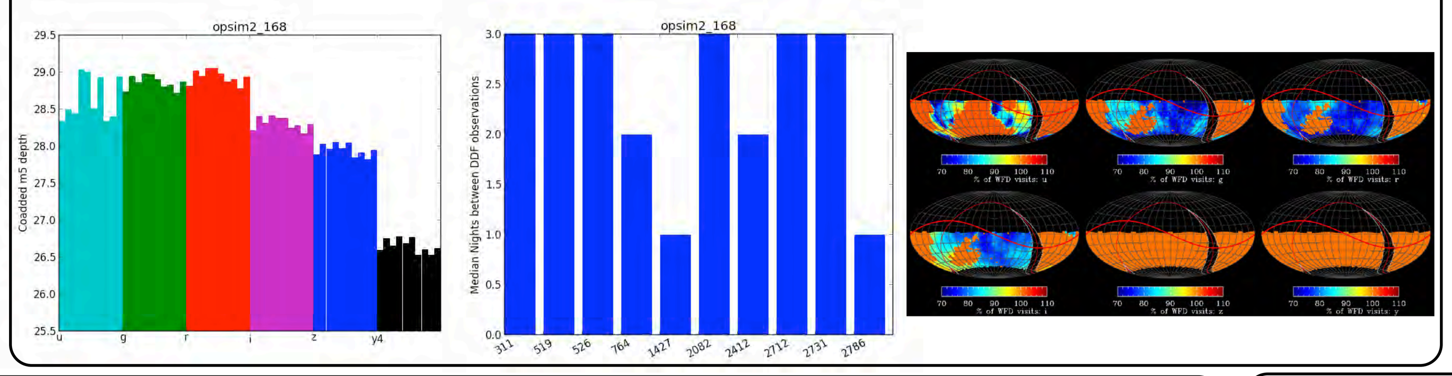
Simulating Deep Drilling Observations

These diverse science goals can be grouped based on their observational requirements. For example, science programs with goals related to measuring high redshift objects (galaxies, AGN, SN) all need observations in fields with low Galactic extinction and can use a similar cadence of observations. On the other hand, the solar system program has tight restrictions on observational cadence and requires pointings fairly close to the ecliptic plane. The table below presents a preliminary summary of the observational requirements for the DD fields.

Extragalactic fields	grizy sequences every few nights (weighted toward z) Add u band exposures during dark time (u=28.5)	5 fields with 265 nights of grizy, and additional u band - 1675 hrs total ugrizy limits (coadded) = 28.5/28.7/28.9/28.4/28.0/27.0
	grizy sequences every few nights (weighted toward z) Add u band exposures during dark time (u=28.0)	5 fields with 265 nights of grizy, and additional u band - 1547 hrs total ugrizy limits (coadded) = 28.0/28.7/28.9/28.4/28.0/27.0
Milky Way fields	30 nights of izy/izy/izy sequences, every night gri sequences spread over 2 years	3 fields - 407 hrs total grizy limits (coadded) = 29.0/28.9/27.0/25.6/24.9
Transients and Variable Stars fields	1 hour of g band observations followed by observations spaced over 3 nights; repeat in r; later repeat in g and r	6 fields - 192 hrs total gr limits (coadded) = 28.3/28.1
Solar System fields	8 nights of 85 minutes of continuous r band observations, spaced at particular intervals over one year	9 fields - 102 hrs total r limits (coadded) = 28.1 (r=27 on individual nights)

Test runs: The LSST OpSim group has created a series of opsim runs incorporating the requested extragalactic fields (adding other DD fields is underway). The results of these runs are under analysis by the DD Interest Group. Early results indicate that the DD fields are generally meeting the desired depths (left), with the desired cadence (middle), but the program needs some additional tweaks to minimize impact on the WFD fields.

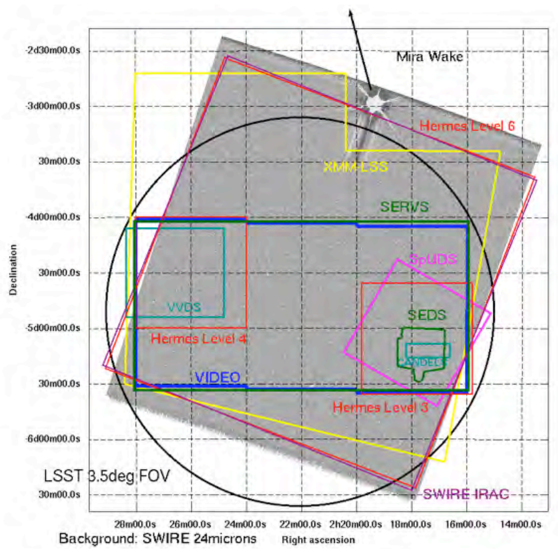
Run Name	Short Description
opsim6.24	No DD observations
opsim4.262	6 opsim3.61-style DD fields
opsim8.27	4 SC-approved DD fields
opsim8.26	4 SC DD fields, 2x visits
opsim2.168	4 SC + 6 DDWG DD fields
opsim4.267	4 + 6 DD fields, 2x visits



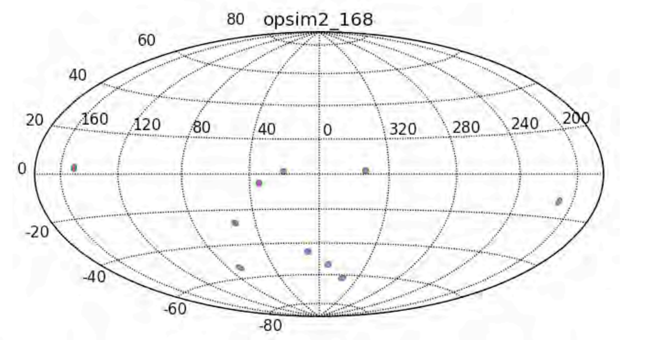
Deep Drilling Field Placement

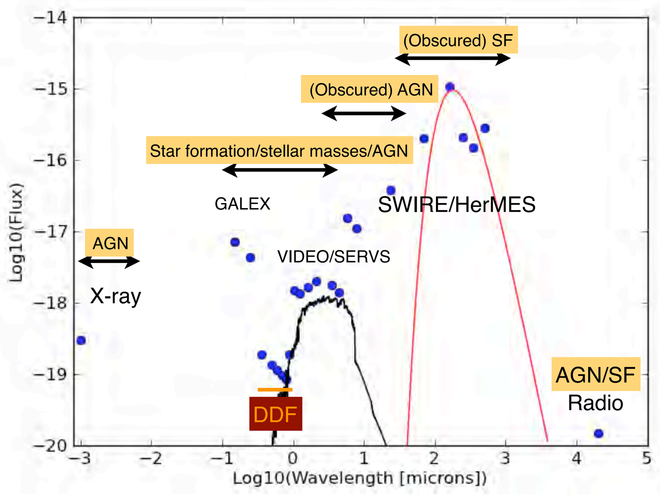
Many of the science goals for the deep drilling fields, particularly the extragalactic fields, are enhanced by multi-wavelength observations that may have to be obtained before LSST is on-sky. To aid in securing this multi-wavelength coverage, four of the extragalactic DD fields have already been chosen and announced - these four fields are listed in the table below. Each field is approximately 3.5 x 3.5 degrees, covering 9.6 square degrees. These first fields were chosen due to existing multi-wavelength coverage and other desirable attributes, such as low Galactic extinction.

ELAIS S1	RA 2000 = 00 37 48 DEC 2000 = -44 00 00	Galactic l = 311.30 Galactic b = -72.90 Ecliptic lat = -43.18
XMM-LSS	RA 2000 = 02 22 50 DEC 2000 = -04 45 00	Galactic l = 171.20 Galactic b = -58.77 Ecliptic lat = -17.90
Extended Chandra Deep Field-South	RA 2000 = 03 32 30 DEC 2000 = -28 06 00	Galactic l = 224.07 Galactic b = -54.47 Ecliptic lat = -45.47
COSMOS	RA 2000 = 10 00 24 DEC 2000 = +02 10 55	Galactic l = 236.83 Galactic b = 42.09 Ecliptic lat = -9.39



Field Details: Additional details are still to be determined. These include the exact centers of these fields (slight adjustments may be necessary to avoid bright stars, see example to the left), the exact cadence of observations, filter balances, and details of the dithering patterns (to fill CCD gaps and aid in artifact removal and calibration).





Other DDFs: The location and exact number of the remaining DD fields - which could range from 20 to 40 fields (not all focused on extragalactic science) is also undecided. Our preliminary opsim runs have included extragalactic DDFs at the locations shown in the figure above.

Multi-wavelength science: The figure to the left illustrates the range of science that multi-wavelength coverage enables; LSST wavelengths are indicated by the region marked 'DDF'.

Deep Drilling White Papers (References)

More information on specific deep drilling science goals available within the white papers posted online at https://www.lsstcorp.org/content/whitepapers32012.

Becker, A. C., et al, 2011, "Opportunities for Solar System Science"

Crotts, A., 2011, "Standard Candle Relations and Photo-Diversity of Type Ia Supernovae"

Dhital, S., et al, 2011, "Mapping the Milky Way's Ultracool Dwarfs, Subdwarfs, and White Dwarfs"

Ferguson, H. C., 2011, "LSST Deep Drilling for Galaxies"

Gawiser, E., et al, 2011, "Ultra-deep ugrizy Imaging to Reduce Main Survey Photo-z Systematics and to Probe Faint Galaxy Clustering, AGN, and Strong Lenses"

Kessler, R., et al, 2011, "Supernova Light Curves"

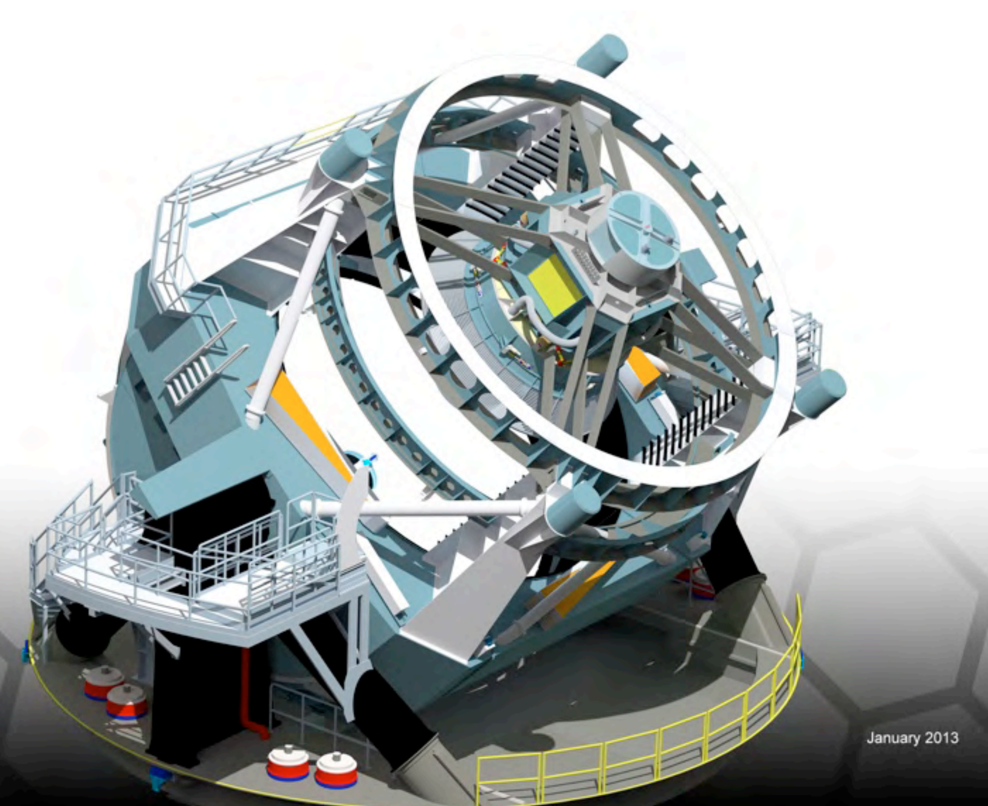
Ma, Z., et al, 2011, "Using LSST Deep Drilling Observations to Improve Weak Lensing Measurements"

Szkody, P., et al, 2011, "High Cadence Observations of the Magellanic Clouds and Select Galactic Cluster Fields"

Future Development

Further work is required to evaluate the optimal deep drilling strategy and its place within the structure of the main (WFD) survey operations. Pointings for the remaining DD fields will be chosen, and methods will be improved for interleaving DD and WFD observations. Additional analysis methods will be developed, to ensure that the DD observations meet the science goal requirements. The DD interest group is open to additional input - please email lsst-deepdrill@lsstcorp.org.

We expect to continue refining the Deep Drilling observational strategy until close to first light, with the Deep Drilling Interest Group working closely with the Operations Simulation team and the LSST Science Council, culminating in a formal review.



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