Maximizing the Joint Science Return of LSST and DESI

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Abstract

LSST will deliver the forefront optical astronomy imaging survey of the next decade, providing new insights into our Solar System, the Milky Way Galaxy, the dark Universe, and the transient and variable sky. Many additional astrophysical applications of LSST will rely on the availability of comparably ambitious survey spectroscopy of the LSST fields. In this white paper, we highlight the near-term opportunity for imaging+spectroscopic synergy between LSST and the Dark Energy Spectroscopic Instrument (DESI), and advocate in favor of a proposed LSST footprint that would maximize the science return from this combination of facilities.

1 White Paper Information

1. **Contact information:** Adam Bolton, bolton@noao.edu;
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4. **Observing Strategy Category:** an integrated program with science that hinges on the combination of pointing and detailed observing strategy

2 Scientific Motivation

The LSST+DESI Opportunity — As shown by the Sloan Digital Sky Survey (SDSS: York et al. 2000), the combination of large, high-quality imaging and spectroscopic data sets enables extremely diverse research. Accordingly, survey-scale spectroscopic follow-up of LSST has been identified consistently as one of the highest scientific priorities for the next decade (e.g. Elmegreen et al., 2015; Najita et al., 2016).

The DESI project (DESI Collaboration et al., 2016) is a Stage IV experiment to constrain the nature of dark energy through the signature of baryon acoustic oscillations (BAO) and redshift-space distortions (RSD). DESI is a high-throughput 5,000-fiber spectrograph with an 8 $\deg^2$ field of view sited at the 4m Mayall Telescope at Kitt Peak National Observatory (KPNO). With a five-year survey starting early in 2020, DESI will collect over 30 million spectroscopic galaxy and quasar redshifts over a footprint of $14{,}000\,\deg^2$, along with spectra of $\sim$10 million stars in the Milky Way.

We advocate increasing the area of overlap of the LSST "Wide-Fast-Deep" (WFD) survey with DESI, as well as carrying out an extended LSST Mini Survey up to declination $\delta = +32$. This strategy will maximize the total science return from both LSST and DESI, and will increase the scientific potential for *future* (post-2025) spectroscopic surveys with the DESI facility targeted from LSST data.[1]

Despite being located in the northern hemisphere, DESI offers many advantages for combination with LSST: • The DESI project is fully funded, the instrument is nearing completion of its construction, and survey commissioning will begin within the next year. • The footprint overlap of LSST with the planned DESI survey could be increased to almost 10,000 $\deg^2$ (see below). • Although DESI was originally designed to enable cosmology with $z > 0.8$ emission-line galaxies and Lyman-α forest absorbers, it is superb for lower-redshift galaxies as well, and the survey will include over 10 million galaxies at $z < 0.5$. • DESI spectra and catalogs are planned to be released publicly on an annual basis, ensuring timely availability to the entire LSST user community. • The initial DESI survey will be the world's leading wide-field galaxy redshift survey in the first half of the next decade, and the DESI facility will likely remain the world's best resource for wide-area spectroscopy for the bulk of the LSST 10-year mission. • DESI is the only one of the next-generation wide-field faint-sky spectrographs being built on a U.S. telescope and by a U.S.-led consortium.

Scientific Highlights — Several applications of the combination of LSST and DESI are worth particular note. First, the combination of LSST weak-lensing data with DESI spectroscopic redshifts can enable an important cosmological test by the use of galaxy-galaxy lensing around lenses of known spectroscopic redshift (e.g., Yoo et al., 2006; van den Bosch et al., 2013). Combining lensing masses with the very precise 3-dimensional auto-correlation of the galaxy clustering allows measurement of the amplitude of matter clustering. This is

[1] We note that the imaging needed for spectroscopic targeting of the entire 2020-2025 DESI survey is already in hand, and DESI is forecast to meet its key-project science requirements without any imaging contributions from LSST.

an area of tension in current cosmological data sets, with CMB inferences running high and some cluster and lensing data sets running low (e.g., Mandelbaum et al., 2013; Hildebrandt et al., 2017; Leauthaud et al., 2017; Troxel et al., 2018; Hikage et al., 2018). The combination of LSST galaxy-galaxy lensing and DESI clustering will represent a key systematic cross-check on the cosmic shear results from LSST. The comparison of the lensing signals to galaxy clustering and galaxy pair-wise dynamics can also be used to test modified gravity theories (e.g., Amon et al., 2018; Singh et al., 2019).

Second, galaxy-galaxy weak lensing of DESI galaxies will help to constrain uncertainties in intrinsic alignment (IA), baryonic feedback and cooling processes, and galaxy bias in LSST cosmological analyses (see e.g., Krause & Eifler, 2017, for a simulated joint analysis of galaxy clustering, weak lensing, and galaxy cluster counts). Even though the DESI lens sample will have substantially lower number density compared to the LSST photometric lens samples, the precise redshift information of DESI will remove degeneracies between photo-z uncertainties and the aforementioned astrophysical systematics. Such an analysis will allow for a cleaner characterization of these effects compared to LSST only. The DESI $z < 1$ galaxy sample will probe the halo mass range where the impact of baryonic effects on cosmic shear signals is expected to be the largest ($M_{\rm halo} \sim 10^{14}$ $M_\odot$). DESI will provide accurate spectroscopic redshifts for groups and clusters in this range, thus minimizing the impact of projection effects that impact photometric cluster selections. Lensing for groups and clusters in the overlap region will help to constrain the halo mass dependence of baryonic effects.

Third, the cross-correlation between DESI spectroscopic redshifts and LSST photometric samples will permit a precision calibration of LSST photo-z's in regions where the full-depth LSST WFD survey overlaps with the DESI footprint (Newman, 2008; Ménard et al., 2013; McQuinn & White, 2013). DESI is excellent for this, as it provides redshift tracers over an unmatched volume at low redshift (where sample/cosmic variance is an issue), while also extending out to $z = 3.5$ and beyond. This method is complementary to direct calibration of photo-z templates and training samples, and it is particularly effective for measuring the redshift distributions of sources too faint for high-multiplex spectroscopic observations.

Fourth, DESI redshifts will be available for a significant number of LSST transients or their hosts, scaling approximately with the total number of LSST visits within the DESI footprint, and allowing for improved prompt classification of transients and better astrophysical prioritization of follow-up observations. This is particularly valuable at low redshift where photometric redshift errors will leave a substantial uncertainty in the luminosity distance. At $z < 0.3$, DESI will perform a flux-limited survey, ensuring that a wide variety of host galaxy types are included. An increase in SN Ia host statistics and a larger solid angle of the combined LSST+DESI survey will also improve tests of gravity and ΛCDM using peculiar-velocity measurements of SNe Ia (e.g. Huterer et al., 2017).

Fifth, the availability of LSST imaging over a more northern footprint would enhance the targeting possibilities for a "DESI-2" survey at KPNO after 2025. The science focus and targeting strategy of such a survey has not yet been defined, but it is clear that deep and well-characterized LSST data would open new opportunities. We note that any applicable LSST data would need to be taken before 2025 to be available in time for a DESI-2 survey.

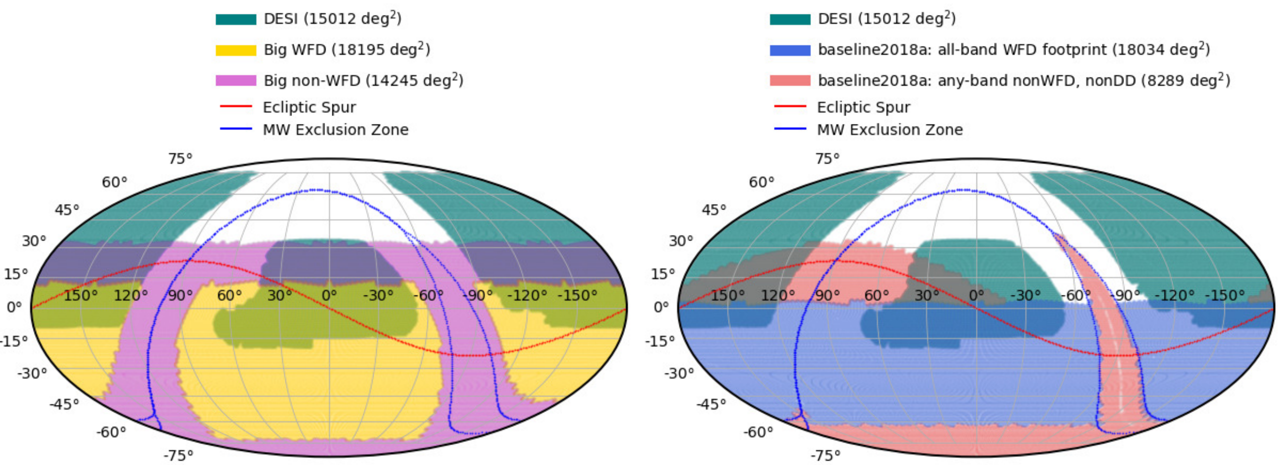

Figure 1: A comparison of the overlap between LSST and DESI under the proposal of Olsen et al. that we endorse in the current white paper (left), compared to the overlap corresponding to the current baseline LSST strategy (right). *(Figure reproduced with permission from Olsen et al., credit: H. Awan.)*

3 Technical Description

3.1 High-level description

Since the LSST survey must address the aspirations of a diverse scientific stakeholder community, we elect not to design and advocate for a DESI-specific approach to the optimization of LSST's survey strategy, but rather to endorse the "Big Sky" consensus-oriented strategy proposed by Olsen et al. in a separate white paper being submitted to the present call ("A Big Sky Approach to Cadence Diplomacy"), with some additional DESI-specific considerations addressed below. Briefly, this proposal would extend LSST's WFD component further north from its baseline limit of $\delta = +2$ to a new limit of $\delta = +12$, and would furthermore image all of the sky accessible from Cerro Pachón (up to $\delta = +32$) to somewhat shallower depth. This increased area coverage would be achieved relative to the baseline LSST plan by restricting the WFD footprint to Galactic latitudes $|b| > 15$ at all Galactic longitudes.

The 14,000 deg^2 DESI survey footprint includes the low-extinction northern sky down to $\delta = -10°$ in the NGC and $-20°$ in the SGC. Relative to the baseline LSST WFD footprint, the proposed change would increase the overlap of WFD with DESI from about 3,200 deg^2 to about 5,600 deg^2. Including the shallower "Big Sky" region, the total overlap between LSST and DESI would be about 9,800 deg^2. The experimental variance of most DESI+LSST scientific applications would be directly reduced by the same factor by which the proposed area of overlap increases (about 1.7 and 3.0 respectively for WFD and total).

See Figure 1 for an illustration of this proposed LSST footprint strategy relative to the DESI survey footprint.

3.2 Footprint – pointings, regions and/or constraints

We endorse the footprint recommendation of Olsen et al., the details of which can be found in that white paper. This footprint consists of a WFD component at $-72.25 < \delta < +12.4$ and $|b| > 15$, plus an "extended" component covering all non-WFD areas south of $\delta = +32$.

Below, we will refer to the subset of the "extended" component at $\delta > +12.4$ and $|b| > 15$—i.e., the part of the extended component that is relevant for LSST+DESI science—as the "EXThigh" region (for "high galactic latitude").

3.3 Image quality

The high airmass of the EXThigh region will degrade the image quality in a region where we want to measure lensing shapes. We recommend that the EXThigh region be treated equivalently to WFD for seeing conditions, prioritizing better seeing to the deeper shape-measurement bands.

3.4 Individual image depth and/or sky brightness

(Also see Olsen et al.)

We recommend that visits for EXThigh be the same as for WFD, so that the survey is simpler and more consistent as regards the single-visit properties.

3.5 Co-added image depth and/or total number of visits

For EXThigh, we propose to keep the survey similar to the relative depths of WFD. While EXThigh will be about a factor of 2 shallower (less exposure time and worse imaging conditions), it is still useful for the full range of co-added WFD science applications. In particular, it is important that all 6 filters be available to support photometric redshifts in a manner similar to WFD.

3.6 Number of visits within a night

This white paper does not take a detailed position on cadence.

3.7 Distribution of visits over time

If this LSST imaging is to be used for DESI-2 targeting in 2025, then it is important that some substantial imaging of the EXThigh region be taken before 2025. Further, we expect that many science applications would benefit from medium-depth static sky imaging early in the survey.

As a strawman for an EXThigh cadence, LSST could observe 4 visits in all 6 filters in each of the first two years, thereby building an 8-visit depth template image suitable for many static-sky applications even in this early data set. In the remaining 8 years, LSST could continue with 2 visits in all 6 filters to continue annual monitoring, while allocating the remaining 106 visits to the intensive period(s) of a rolling cadence.

3.8 Filter choice

As mentioned above, all 6 filters should be used in the EXThigh region to support WFD-like photometric redshifts.

3.9 Exposure constraints

(See Olsen et al.)

3.10 Other constraints

As stated above, supporting future DESI targeting requires that some imaging of EXThigh happen before 2025. A survey plan that delayed all of EXThigh to happen after WFD would not satisfy that. Such early coverage benefits many other applications, not just the combination of LSST with DESI.

3.11 Estimated time requirement

(See Olsen et al.)

3.12 Technical trades

(Also see Olsen et al.)

We expect science gain to scale linearly with EXThigh survey area but sub-linearly with increasing EXThigh exposure time. Therefore we argue that full coverage of the EXThigh footprint is more important than the exact depth: i.e., we would propose that LSST reduce depth before reducing area for the EXThigh region. A framework for assessing this trade is described in the next section.

As there are many "Big Sky" science applications that depend on the static depth, we argue that there is value in ensuring a uniform minimum depth early in the survey. A rolling cadence later in the survey is acceptable.

4 Performance Evaluation

(Also see Olsen et al.)

We suggest that a useful quantitative metric of LSST+DESI science opportunity could be formulated as the integrated product of (1) the overlap area of LSST with the DESI footprint and (2) the number density of "well-measured" galaxies from LSST in the overlap regions. We suggest that "well-measured" means suitable for lensing and photo-z applications, as such quality would be good for many applications. For example, one could use the effective number density of a lensing sample; we expect that the LSST DESC will have the tools to compute this for different depths. Alternatively, one might simplify this to 20σ detection in the i band, assuming a WFD-based split of exposure time across the filters. Our expectation is that the EXThigh footprint offers a substantial gain in the total number of well-measured high-latitude galaxies, while the static-sky science gain per area will be sub-linear with exposure time.

5 Special Data Processing

(See Olsen et al.)

6 Acknowledgements

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