

**Title:** Enabling Dark Energy Measurements from DESI and LSST

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**Period covered:** 6/1/2019-4/30/2021

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**Award:** DE-SC0020256

**Unexpended funds:** \$2,559.75

## **1. Results of work to date:**

**Summary of the project:** Considerable resources are being invested in experiments to study the Dark Energy which are now reaching fruition. This research grant was focused on activities which will enable the flagship dark energy experiments of the next decade, DESI and the Vera Rubin Observatory Legacy Survey of Space and Time, to succeed.

The principal objectives of the proposed research were:

(1) To lead the Survey Validation of the Luminous Red Galaxy (LRG) sample for DESI, entailing intensive to prepare target samples, test their performance with post-commissioning DESI spectroscopy, and validate that the requirements of the survey for this key sample are met. Luminous Red Galaxies represent the gold standard target class for Baryon Acoustic Observation experiments

(2) Co-leading the Follow-up Task Force within the LSST Dark Energy Science Collaboration (LSST DESC), which is intended to help develop collaborations with external groups and to produce cross-working group proposals for telescope time, policy proposals and white papers as needed in order to help the collaboration obtain and make use of complementary data which will strengthen LSST Dark Energy constraints. The PI has been particularly engaged in efforts to obtain access to spectroscopic training sets for LSST photometric redshifts in the first years of the survey, which requires developing relationships with groups that are obtaining such data for other purposes.

(3) Additional effort to improve LSST DESC pipeline infrastructure for photometric redshifts.

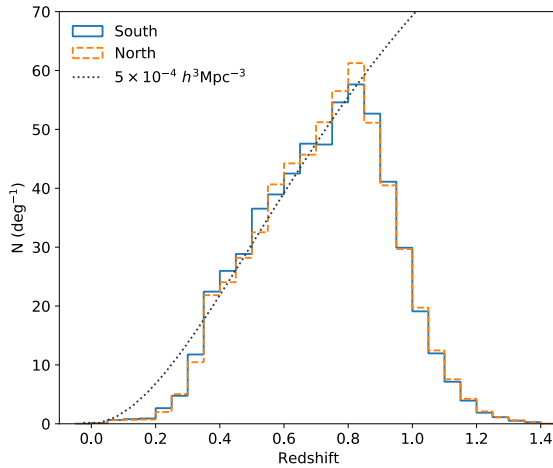
The labelling of this work changed slightly when the DESC Follow-up Task Force was formalized as the DESC External Synergies Working Group in 2019, giving it an ongoing status. The PI has continued as co-convener since that transition, however, and efforts did not change in nature significantly (this change was reported to DOE in 2020).

### ***Accomplishments:***

#### ***DESI:***

- Over the duration of this grant we developed, refined and finalized the survey validation target samples for Luminous Red Galaxies (LRGs) in DESI, analyzed the survey validation samples, and produced the final selection for DESI now being used in the survey.

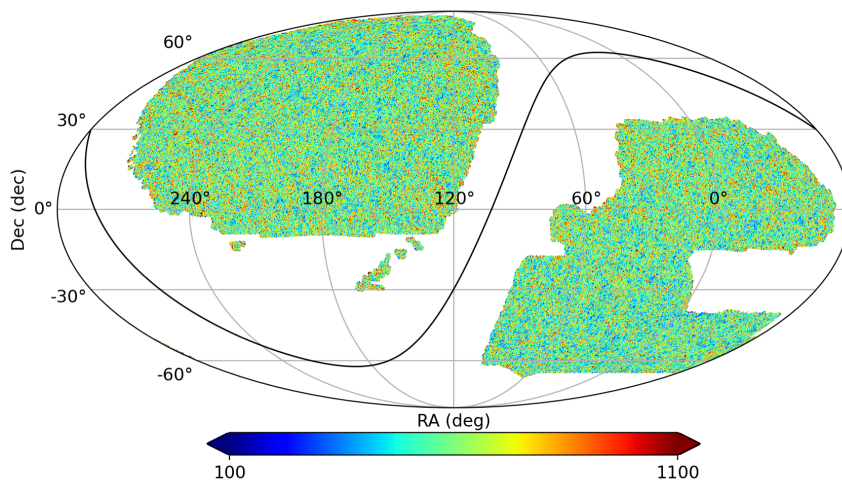
This selection has been extremely successful; as illustrated in the below plot, it provides a nearly-constant number density of LRGs over the redshift range  $0.4 < z < 0.8$ , with a significant tail of objects useful for BAO clustering measurements extending to  $z > 1$ .



This selection has been sufficiently effective that the LRG sample was expanded both in redshift range and density compared to the initial plans for the survey presented in the DESI Final Design Report; we are able to still maintain a high redshift success rate and purity for fainter objects than we originally anticipated would be possible with DESI.

One key aspect of our work was testing that the LRG sample would meet all relevant DESI Science Requirements.

- We have performed a number of tests of the uniformity of the LRG sample across regions of the sky that have different imaging data or as imaging and astrophysical foreground systematics vary. The LRG selection has been highly uniform in the presence of all of these. For instance, unlike the case for other DESI target classes, the density of the LRG targets across the sky shows no clear signatures of stellar contamination or of the borders between where DES-depth or shallower imaging data is used for selection, as seen in the below figure.



The cleanness of the DESI LRG sample will make it very easy to analyze; indeed, even in a few months' worth of DESI data the baryon acoustic oscillation signature can be seen easily in the LRG clustering.

- We also developed target selection algorithms for a new target class, a high-density, intermediate-redshift filler sample that would boost cosmology at the transition from the DESI Bright Galaxy Survey to the LRGs. Such a sample was proposed to be used as 'filler' objects, targeted on fibers where no other DESI target class is available. We demonstrated that selections for such a class can be developed and optimized using already-planned SV observations for objects fainter than the standard BGS selection. Ultimately, such a filler sample was not incorporated into DESI targeting; however, similar samples are now being evaluated as part of the targets for a DESI-2 survey.

#### *LSST:*

- The DESC Follow-up Task Force has evolved into the DESC External Synergies Working Group, with a broader mandate than before (including, e.g., complementarities with CMB datasets such as CMB-S4). A major activity we undertook was assessing the needs for external data across the collaboration, as well as potential telescope resources to meet those needs, in advance of the process for evaluation of potential LSST in-kind contributions, so that DESC could make informed decisions on what activities to support. The Working Group has had extremely active sessions in the DESC Collaboration meetings.

- One major activity of the External Synergies Working Group was the development and submission of three Letters of Interest to the Snowmass 2021 process, on *Wide-field Multi-object Spectroscopy to Enhance Dark Energy Science from LSST*, *Deep Multi-object Spectroscopy to Enhance Dark Energy Science from LSST*, and *Single-object Imaging and Spectroscopy to Enhance Dark Energy Science from Rubin Observatory's LSST*. PI Newman contributed to the authoring and editing of all three white papers and produced updated calculations of photometric redshift training survey times for them.

- The ES Working Group also developed the DESC response to the DOE-NASA RFI in 2020; PI Newman again contributed substantially to both authoring and editing this document.

- PI Newman discussed potential in-kind contributions from Japan with the Subaru/PFS team and gave a talk on LSST-DESC synergies at the Subaru Telescope 20th Anniversary - Optical & Infrared Astronomy for the Next Decade conference; PFS would be the most efficient option for obtaining photo-z training spectroscopy for LSST before the late 2020s. He gave a follow-up talk to a PFS meeting in February of 2021. He has also actively been engaged with the Maunakea Spectroscopic Explorer team, another potential source of spectroscopy.

- PI Newman made substantial progress on an Annual Reviews of Astronomy and Astrophysics article on *Photometric Redshifts for Next-Generation Surveys* during the period of this grant (with Daniel Gruen as co-author). This article focuses on identifying the chief challenges that Stage IV imaging experiments will face in obtaining optical cosmology constraints due to photometric redshift systematics, as well as on identifying possible solutions. This paper is intended to help structure community efforts to improve photo-z methods for LSST going forward.

- We also devoted some effort to developing improved photo-z methods for low redshifts, which can benefit LSST dark energy and dark matter science.

## **2. Papers exclusively acknowledging HEP:**

Zhou, R., et al. 2021, "The clustering of DESI-like luminous red galaxies using photometric redshifts," *Monthly Notices of the Royal Astronomical Society*, 501, 3309

Zhou, R., et al. 2020, "Preliminary Target Selection for the DESI Luminous Red Galaxy (LRG) Sample," *Research Notes of the American Astronomical Society*, 4, 181

Newman, J., & DESI Collaboration 2021, "Status of DESI Target Selection," *APS April Meeting Abstracts*, 2021, Z08.003

## **3. Papers acknowledging HEP and other support:**

Zhao, G.-B., et al. 2021, "The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: a multitracer analysis in Fourier space for measuring the cosmic structure growth and expansion rate," *Monthly Notices of the Royal Astronomical Society*, 504, 33

Alam, S., et al. 2021, "Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Cosmological implications from two decades of spectroscopic surveys at the Apache Point Observatory," *Physical Review D*, 103, 083533

de Mattia, A., et al. 2021, "The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: measurement of the BAO and growth rate of structure of the emission line galaxy sample from the anisotropic power spectrum between redshift 0.6 and 1.1," *Monthly Notices of the Royal Astronomical Society*, 501, 5616

Raichoor, A., et al. 2021, "The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: large-scale structure catalogues and measurement of the isotropic BAO between redshift 0.6 and 1.1 for the Emission Line Galaxy Sample," *Monthly Notices of the Royal Astronomical Society*, 500, 3254

Hou, J., et al. 2021, "The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: BAO and RSD measurements from anisotropic clustering analysis of the quasar sample in configuration space between redshift 0.8 and 2.2," *Monthly Notices of the Royal Astronomical Society*, 500, 1201

Bautista, J. E., et al. 2021, "The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: measurement of the BAO and growth rate of structure of the luminous red galaxy sample from the anisotropic correlation function between redshifts

0.6 and 1," Monthly Notices of the Royal Astronomical Society, 500, 736

Schmidt, S. J., et al. 2020, "Evaluation of probabilistic photometric redshift estimation approaches for The Rubin Observatory Legacy Survey of Space and Time (LSST)," Monthly Notices of the Royal Astronomical Society, 499, 1587

Neveux, R., et al. 2020, "The completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: BAO and RSD measurements from the anisotropic power spectrum of the quasar sample between redshift 0.8 and 2.2," Monthly Notices of the Royal Astronomical Society, 499, 210

Wang, Y., et al. 2020, "The clustering of the SDSS-IV extended baryon oscillation spectroscopic survey DR16 luminous red galaxy and emission-line galaxy samples: cosmic distance and structure growth measurements using multiple tracers in configuration space," Monthly Notices of the Royal Astronomical Society, 498, 3470

Sridhar, S., Song, Y.-S., Ross, A. J., Zhou, R., Newman, J. A., Chuang, C.-H., Blum, R., Gaztañaga, E., Landriau, M., & Prada, F. 2020, "Clustering of LRGs in the DECaLS DR8 Footprint: Distance Constraints from Baryon Acoustic Oscillations Using Photometric Redshifts," The Astrophysical Journal, 904, 69

Raichoor, A., et al. 2020, "Preliminary Target Selection for the DESI Emission Line Galaxy (ELG) Sample," Research Notes of the American Astronomical Society, 4, 180

Yèche, C., et al. 2020, "Preliminary Target Selection for the DESI Quasar (QSO) Sample," Research Notes of the American Astronomical Society, 4, 179

Gil-Marín, H., et al. 2020, "The Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: measurement of the BAO and growth rate of structure of the luminous red galaxy sample from the anisotropic power spectrum between redshifts 0.6 and 1.0," Monthly Notices of the Royal Astronomical Society, 498, 2492

Ross, A. J., et al. 2020, "The Completed SDSS-IV extended Baryon Oscillation Spectroscopic Survey: Large-scale structure catalogues for cosmological analysis," Monthly Notices of the Royal Astronomical Society, 498, 2354

Nicola, A., et al. 2020, "Tomographic galaxy clustering with the Subaru Hyper Suprime-Cam first year public data release," Journal of Cosmology and Astroparticle Physics, 2020, 044

Korytov, D., et al. 2019, "CosmoDC2: A Synthetic Sky Catalog for Dark Energy Science with LSST," The Astrophysical Journal Supplement Series, 245, 26

Bolton, A., et al. 2019, "Towards a Spectroscopic Survey Roadmap for the 2020s and Beyond," Bulletin of the American Astronomical Society, 51, 240

Marshall, J., et al. 2019, "The Maunakea Spectroscopic Explorer," Bulletin of the American Astronomical Society, 51, 126

**4. People working on this research activity:**

Rongpu Zhou: Rongpu completed his Ph.D. in 2019 and is now a postdoctoral researcher at LBNL working on DESI.

Biprateep Dey: Biprateep began his Ph.D. studies in 2018 and is making excellent progress towards his dissertation.

Jeffrey Newman: PI of the grant.

**5. Unexpended funds:** \$2,559.75