Snowmass2021 - Letter of Interest

Next-generation Spectroscopic Surveys with DESI

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
■ (CF3) Dark Matter: Cosmic Probes
■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

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Abstract: After its initial five-year spectroscopic survey to use the clustering of matter as a probe of dark energy, the Dark Energy Spectroscopic Instrument (DESI) will remain one of the world's best facilities for wide-field spectroscopy. In this letter of interest, we present options for the continued use of DESI for further constraining the nature of dark energy, neutrinos, inflation, and physics beyond the standard model in the second half of the decade. More about the DESI instrument and survey can be found at https://www.desi.lbl.gov.

Optical spectroscopy will provide key science opportunities in observational cosmology over the next decade[2]. Spectroscopy reveals the large-scale structure of the Universe in three dimensions, samples the growth of structure through redshift-space distortions, records the redshifts of gravitational lens systems, and resolves the fine detail of galaxy groups and clusters. While optical and near-infrared imaging capability will soon leap forward with LSST, Euclid, and Roman, spectroscopic capacity to leverage these opportunities is more limited. The DOE-led Dark Energy Spectroscopic Instrument (DESI) will remain at the forefront of spectroscopic facilities in the second half of the decade. Here, we provide a brief summary of DESI and describe several key science cases that motivate continued operations until the end of the decade.

Mapping the Universe with DESI: DESI is an ambitious multi-fiber optical spectrograph on the Kitt Peak National Observatory Mayall 4-meter telescope. DESI will conduct the Stage IV spectroscopic dark energy experiment using 5000 robotically-positioned fibers in an 8 deg^2 focal plane. Fibers feed a bank of 10 triple-arm spectrographs that measure the full bandpass from 360 nm to 980 nm at a spectral resolution of 2000 in the UV and over 4000 in the red and IR[6]. DESI is designed for efficient operations and exceptionally high throughput.

Starting in 2021, DESI will be used to conduct a five-year survey[3] of galaxies and quasars over 14,000 deg^2, yielding 34 million redshifts to $z = 3.5$. These data will be used to constrain the nature of dark energy through cosmic distance scale measurements with the baryon acoustic oscillation (BAO) method and through the study of the growth of structure with redshift-space distortions (RSD). The survey will further allow measurement of other cosmological quantities, such as neutrino mass and primordial non-Gaussianity. Beyond these stand-alone, mission-need spectroscopic cosmological analyses, combination of DESI with LSST and CMB experiments will provide further tests of the cosmological model, such as with the kinetic Sunyaev-Zel'dovich effect and weak gravitational lensing.

DESI uses a number of target classes to probe dark energy and cosmic structure over a wide range of redshift. The emission-line galaxy (ELG) sample is the largest, consisting of roughly 20 million targets ($\sim$2200 deg^{-2}) covering $0.6 < z < 1.6$. ELG targets are selected near the imaging limits of the DECaLS grz photometry and observed in dark and gray-time exposures equivalent to 1000 seconds in good conditions. To extend the map to higher redshift, DESI will observe 2.5M quasars to $r = 22.7$ using grz and WISE photometry, providing direct tracers and Lyman-α forest measurements of large-scale structure. At a somewhat lower redshift than the ELG sample, DESI will produce a dense sample of luminous red galaxies (LRG) at a density of roughly 500 deg^{-2} over $0.3 < z < 1$ to a limiting $z-$magnitude around 20.8.

In bright time, DESI will conduct a flux-limited survey of 10M galaxies ($\sim$700 deg^{-2}) to $r \approx 19.5$, with a median redshift around $z = 0.2$. This will allow dense sampling of a volume over 10 times that of the SDSS MAIN and 2dF GRS surveys, spurring development of the non-linear regime of structure formation as a cosmological probe.

Key Science Goals for DESI Beyond 2025: A second phase of DESI will offer exciting survey opportunities for the 2025–2030 timeframe. Imaging surveys such as HSC, Vera Rubin Observatory/LSST, Euclid, SphereX, Roman Space Telescope, and eROSITA will yield new spectroscopic targets over areas of thousands to tens of thousands of deg^2. DESI's field of view, multiplex, throughput, and resolution make it an ideal complement to the coming generation of imaging surveys. DESI will remain a state-of-the-art facility for wide-field spectroscopic surveys in the second half of the decade, with the highest survey speed among dedicated survey platforms. Further, we note that while Euclid and Roman will offer space-based platforms for slitless IR spectroscopy, optical spectroscopy remains a highly efficient way to get redshifts both at $z < 1.6$ and $z > 2$. The combination of spectroscopy and imaging data can enhance studies of dark energy, modified gravity, and inflation beyond what is possible with any one survey alone. There are at least five fertile areas of potential targets for such a survey:

1) A high-density galaxy survey at $z < 1$: Using exposure times of 1000 seconds, DESI could conduct a clustering program exceeding 2000 targets per square degree to $z < 1$. Candidates can be readily identified either with extensions to the DESI LRG or ELG selections or through a magnitude-limited selection fainter than the DESI bright galaxy sample. A high-density sample with precise spectroscopic redshifts would allow identification of groups and redshift-space distortions in the non-linear regime within the cosmic acceleration epoch. As demonstrated in Krause & Eifler[5], scaling measurements of large-scale structure to smaller scales and exploiting information in the one-halo term can lead to significant improvements in precision on the dark energy equation of state parameters.

2) An ELG survey at $1 < z < 1.6$: Improved selection of $1 < z < 1.6$ emission-line galaxies will be possible using the deeper LSST imaging or follow-up of low-quality emission-line galaxy candidates from Euclid and SPHEREx. A dedicated survey with DESI would increase the sampling of the large volume available at higher redshift, leading to enhanced BAO and RSD studies beyond what will be possible with the five-year DESI sample.

3) A quasar and galaxy survey at $z > 2$: Quasars, Lyman-break galaxies (LBG), and Lyman-α emitting galaxies (LAE) can act as spectroscopic probes at the highest redshifts, where the sampling will remain shot-noise limited after DESI completes its five-year program. DESI could achieve increased depth and sampling in the Lyman-α forest by reobserving the known $z > 2$ quasars and by adding fainter quasar candidates from the newly available imaging data. Selection of LAE using narrow-band filters and LBG/LAE targets identified by UV dropouts can produce up to 1,000 high-redshift galaxies deg^{-2} in exposure times of roughly one hour[8]. Quasars, LBG, and LAE can be used as direct tracers to enhance BAO, RSD, and inflation measurements at $z > 2$, or to calibrate the redshift distributions for studies of primordial non-Gaussianity through cross-correlation of CMB lensing with galaxy clustering[7]. Such a program could span as large an area as possible at a density of roughly 500 deg^{-2} or could pursue deeper, higher-density observations over a smaller area to resolve the cosmic web through the Lyman-α forest.

4) Coordinated spectroscopy with the Vera Rubin Observatory: Follow-up observations of LSST sources will enhance dark energy science by calibrating photometric redshifts and providing redshifts of galaxy cluster members and other sources used as cosmological probes. DESI could perform faint-target spectroscopy of smaller, deeper samples in deep-drilling fields or could survey large areas to gather rarer targets and further average over large-scale structure. The fiber separations of roughly one arcminute allow for redshifts of tens to hundreds of members per cluster, depending on the number of visits to a field.

5) Time-domain and transient host spectroscopy: DESI can obtain redshifts for transients such as Type Ia supernovae (SNe Ia), strong lensing systems, and gravitational wave sources that have lightcurves from the Vera Rubin Observatory and other sources. A large number of low redshift SNe Ia lightcurves can be combined with RSD, for example, to measure the gravitational growth index predicted from General Relativity to a precision of roughly 4%[4]. Strong-lensing time delays[9] and gravitational wave source[1] can be used to derive more precise measurements of the Hubble constant and help resolve the tension with estimates derived from models invoking the sound horizon[10]. A time domain survey would likely have insufficiently sampling of targets to fill the DESI fibers and be conducted in parallel with another program.

Technical Drivers: While the DESI instrument could continue to be usefully operated in the same configuration as the pre-2025 phase, there may be opportunities for augmentations. Notably, the focal plane and spectrographs are modular and could be altered or replaced, subject to cost and space constraints, if the adopted science goals called for it. E.g., one could use Ge CCDs to extend [OII] coverage to $z = 2.1$.

Organization, Status, and Schedule: A science collaboration for post-2025 operations has not yet been formed, but many of the current participants would likely be interested in continuing. The Mayall telescope remains property of the National Science Foundation, while the DESI equipment is DOE property.

References

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