DESI and DESI-II

Kyle Dawson, University of Utah
DESI co-Spokesperson

P5 Cosmic Frontier Town Hall
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Lawrence Berkeley National Laboratory

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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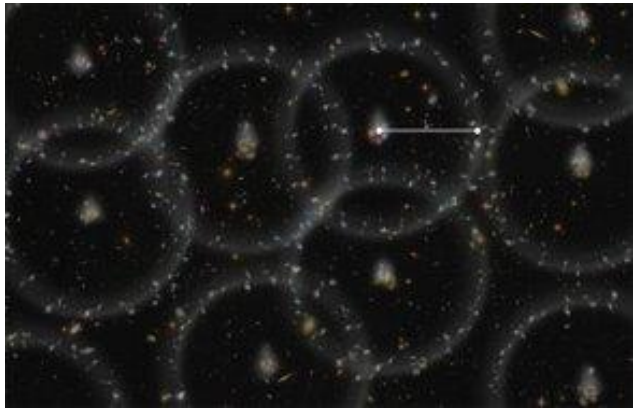
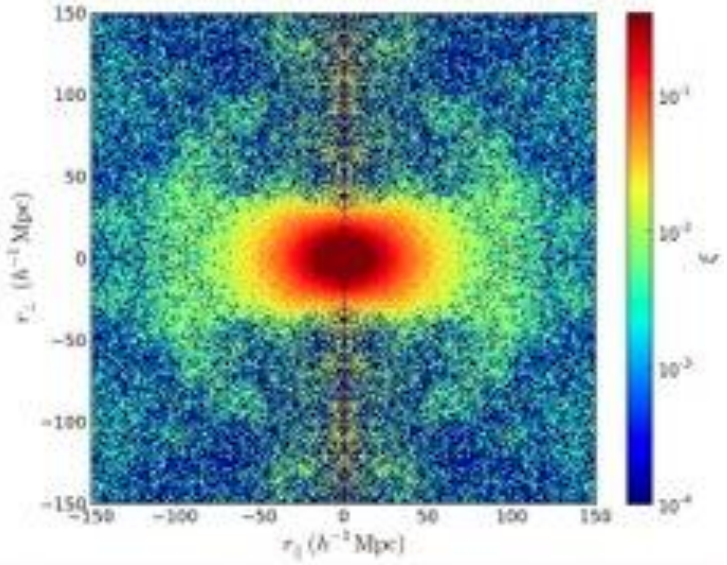
Cosmology with Spectroscopic Surveys

- **Baryon Acoustic Oscillations (BAO)**
  - Preferred scale in clustering of matter and galaxies
  - Direct expansion measurement
- **Redshift Space Distortions (RSD)**
  - Anisotropy in clustering due to peculiar velocities induced by gravitational collapse
  - Growth of structure
- **Stage-IV Dark Energy Experiment**
  - Expansion history and growth of structure to probe accelerating expansion
  - 10X improvement to $w_0 w_a$ posterior area compared to Stage-II measurements

Artist Rendition of BAO



RSD as measured in galaxy clustering



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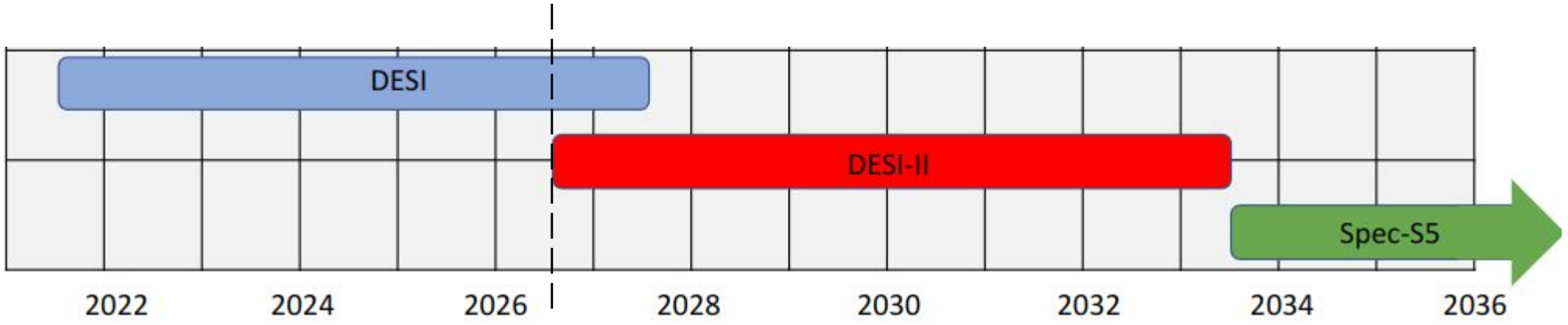
Staging Spectroscopic Surveys

- **Dark Energy Spectroscopic Instrument (DESI; primarily z<1.5)**
  - Dark Energy with Baryon Acoustic Oscillations (BAO) and Redshift Space Distortions (RSD)
- **DESI-II (primarily z>2)**
  - As powerful as DESI, but at z>2
  - Early dark energy and growth of structure in matter-dominated regime
  - Synergies with other Cosmic Frontier experiments
- **Spec-S5**
  - Primordial physics (more constraining than the CMB in important areas)



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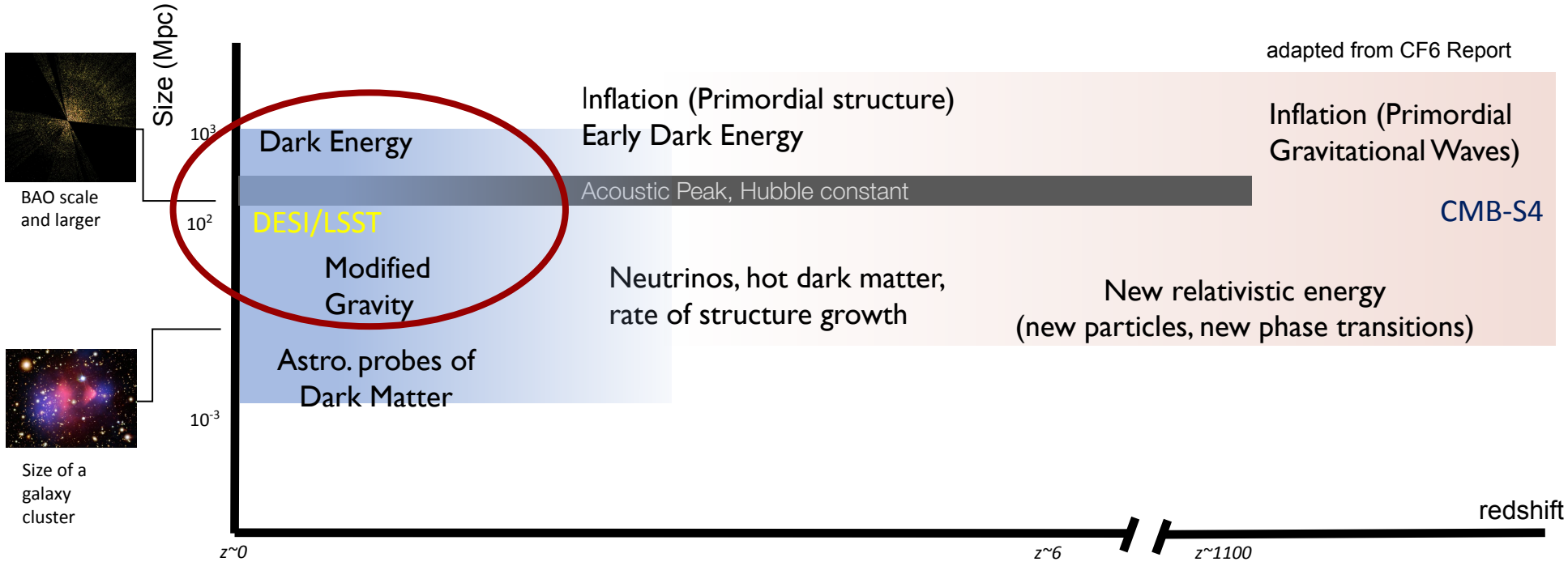
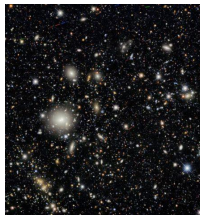
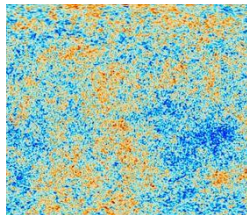




Galaxies emitting in optical wavelengths and spatially resolved.



Hot dense state. Detectable relics include CMB, gravitational waves and neutrinos.

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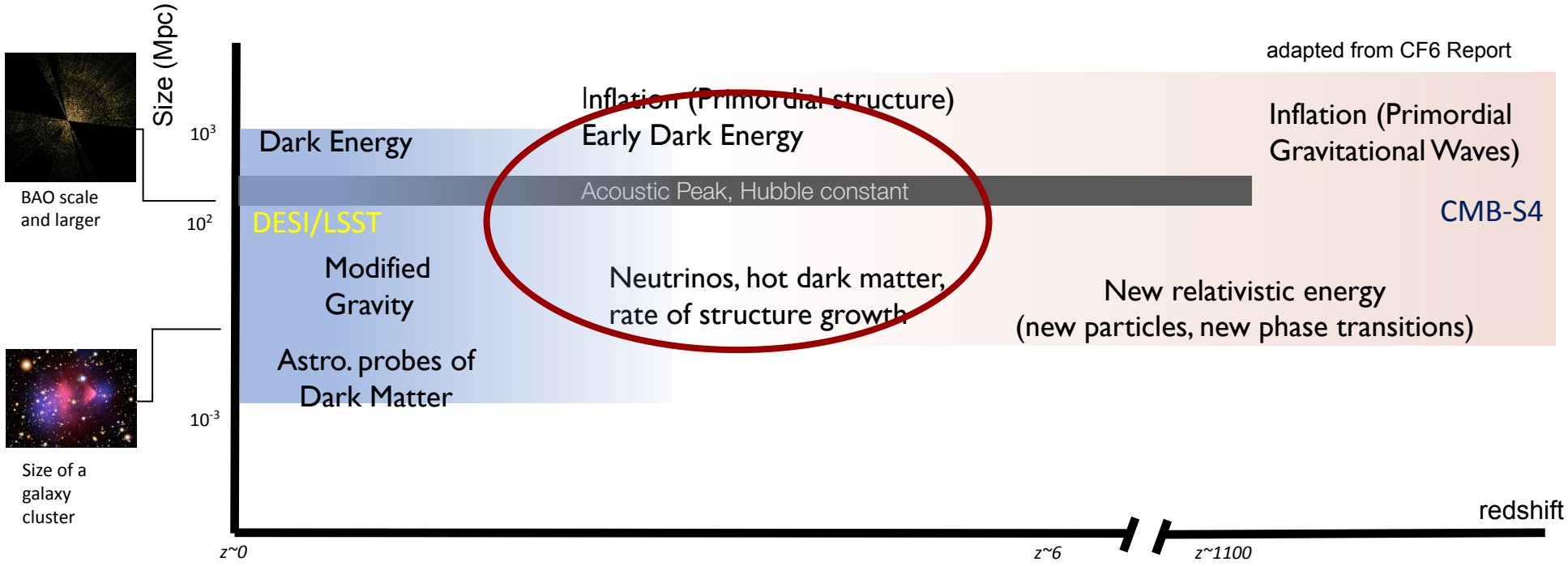
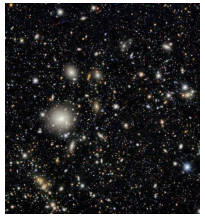
DESI-II and Spec-S5





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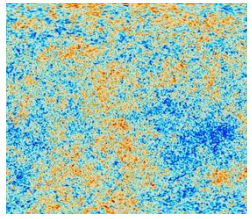

Hot dense state. Detectable relics include CMB, gravitational waves and neutrinos.

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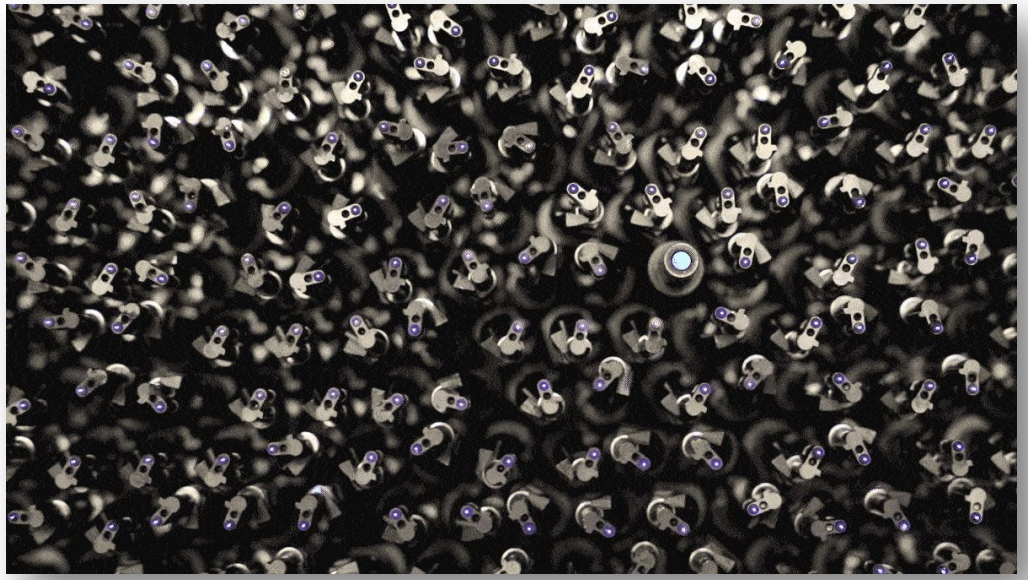
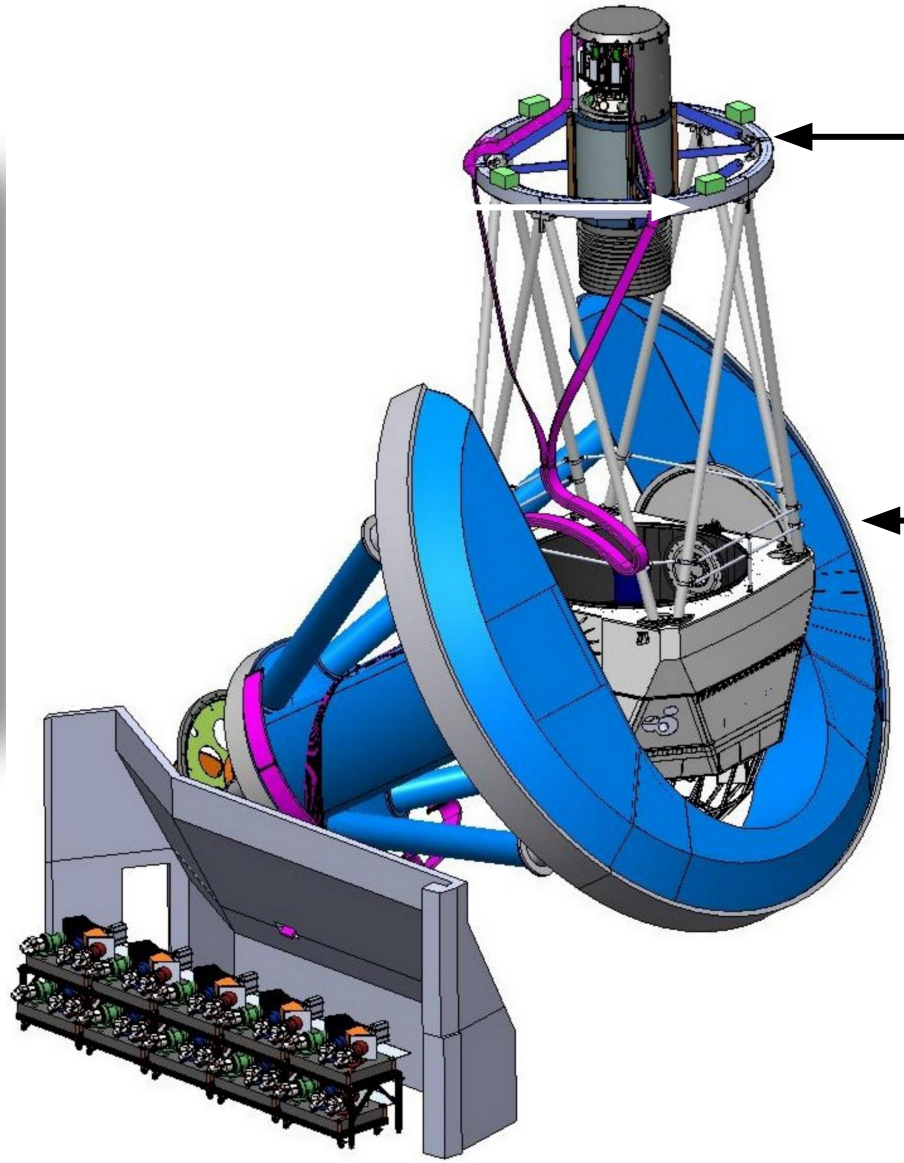
DESI: Massively-multiplexed Spectroscopy



Robotic fiber positioners!



Focal plane assembly with 5000 fiber positioners

Mayall 4m telescope

10 spectrographs (360-980nm)

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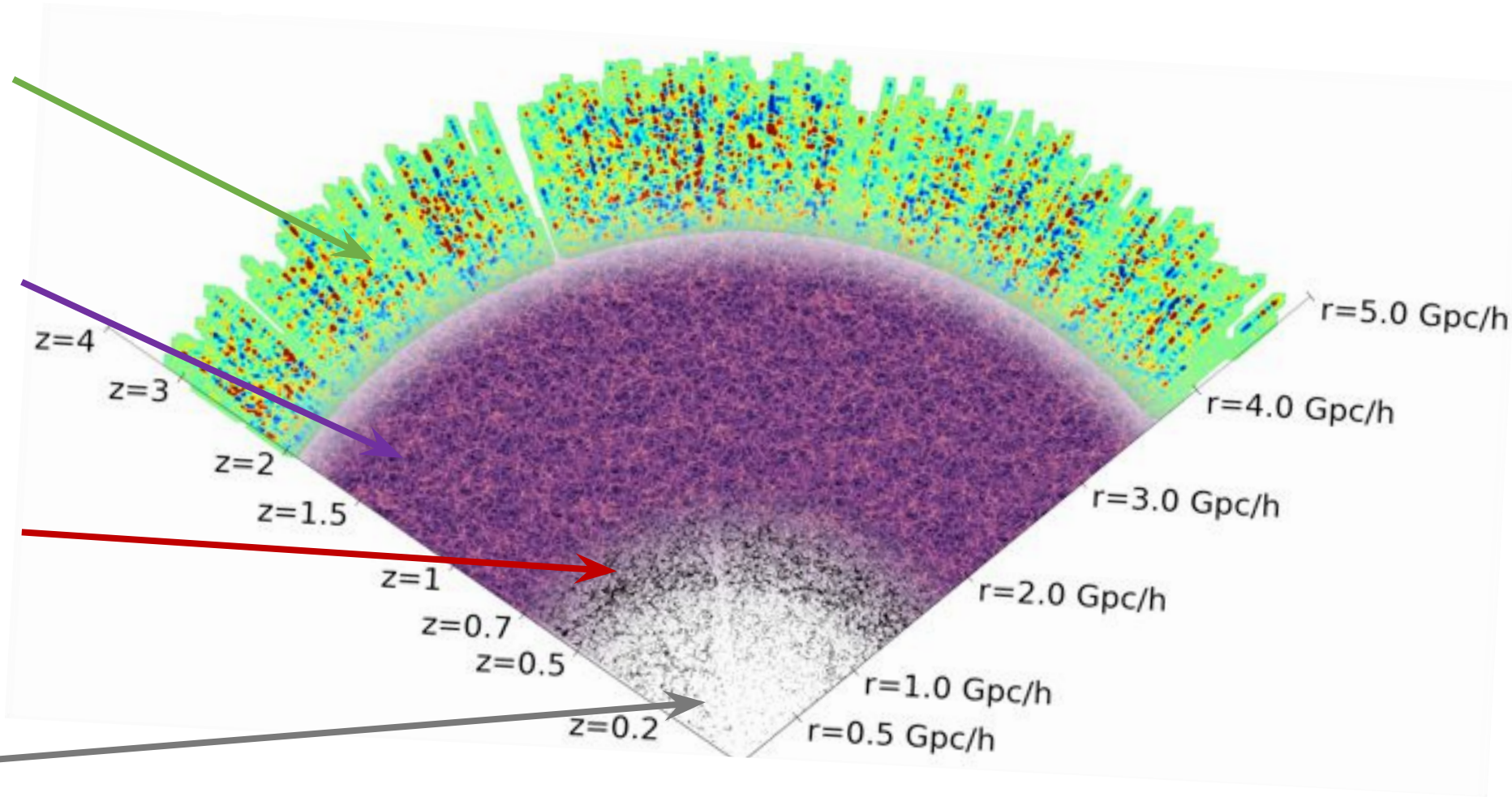
Uninterrupted Galaxy and Quasars from 0<z<3.5

3 million quasars + Ly-α forest (1 < z < 3.5)

16 million Emission Line Galaxies (0.6 < z < 1.6)

8 million Luminous Red Galaxies (0.4 < z < 1.1)

13 million Bright Galaxies (0.0 < z < 0.4)



40M extragalactic redshifts plus 10M Milky Way stars

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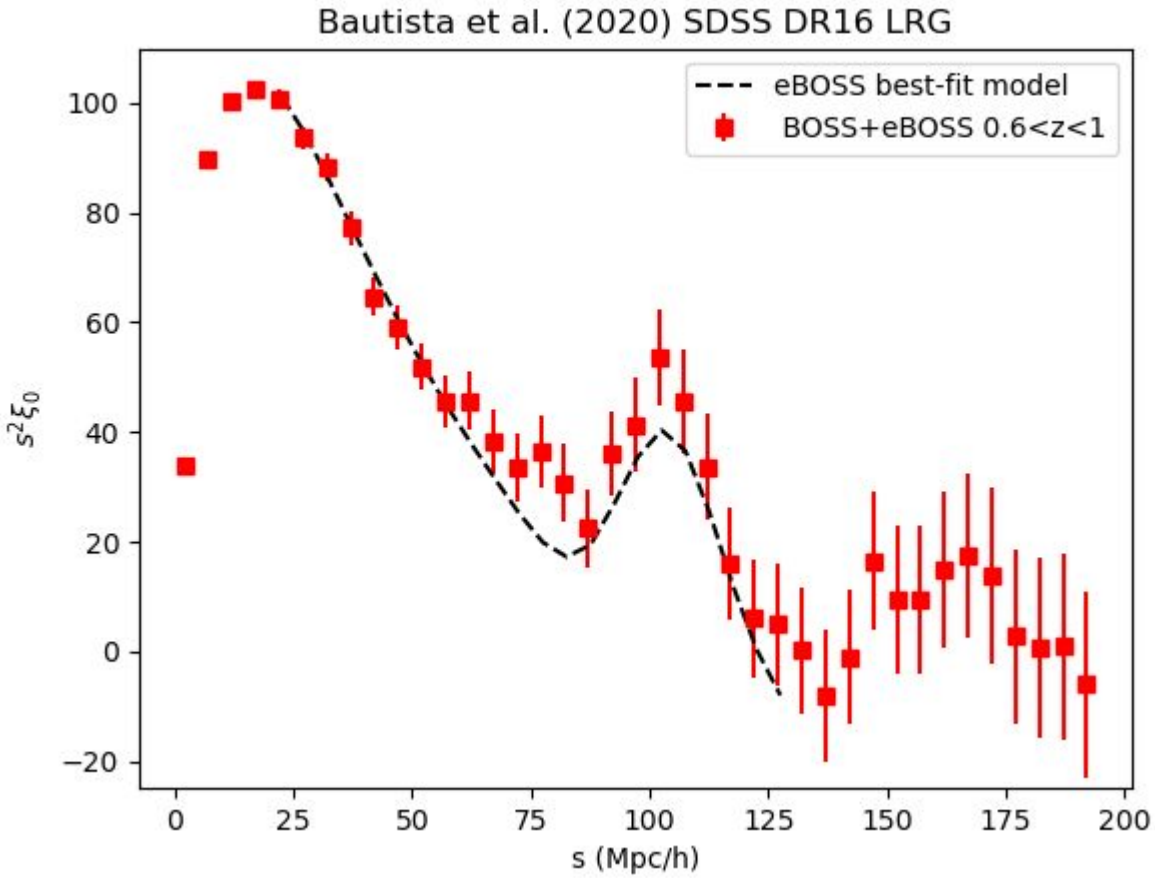
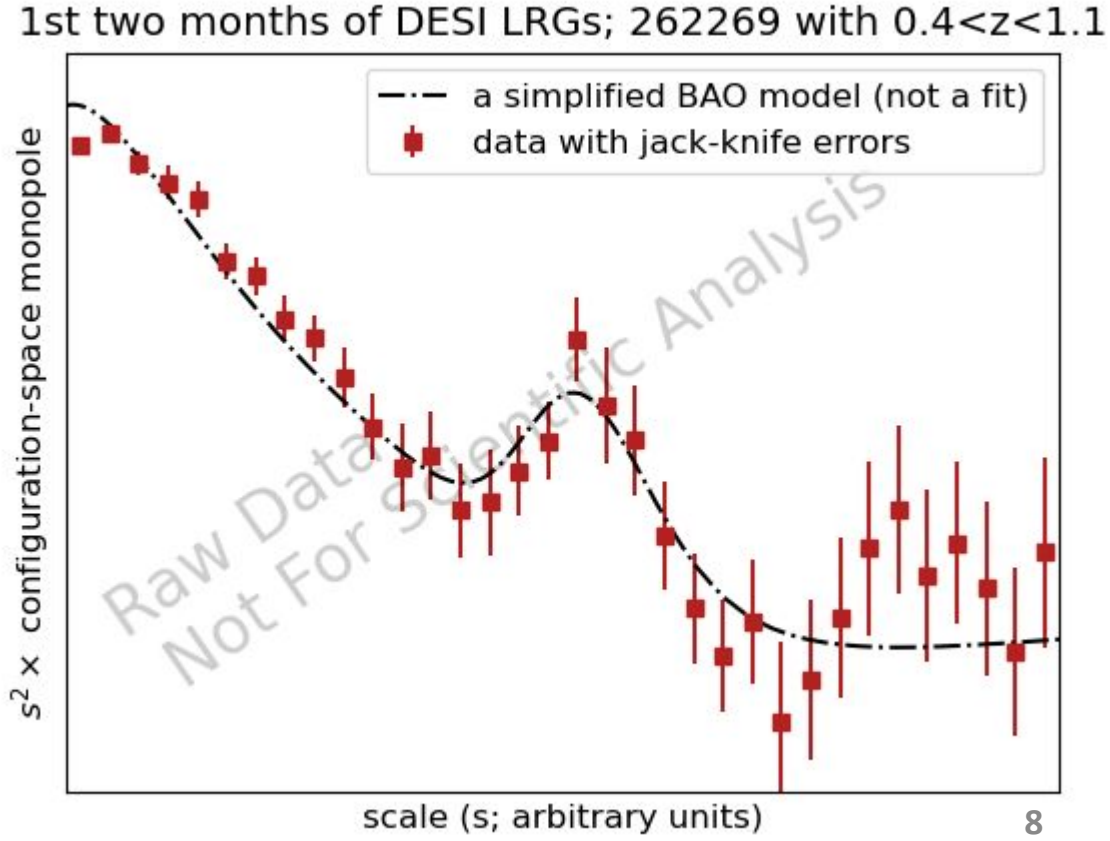
Two Months of DESI

(e)BOSS: 2-3M extragalactic redshifts
Two Months: Competitive with all of Stage-III
One year: More than 14M extragalactic redshifts





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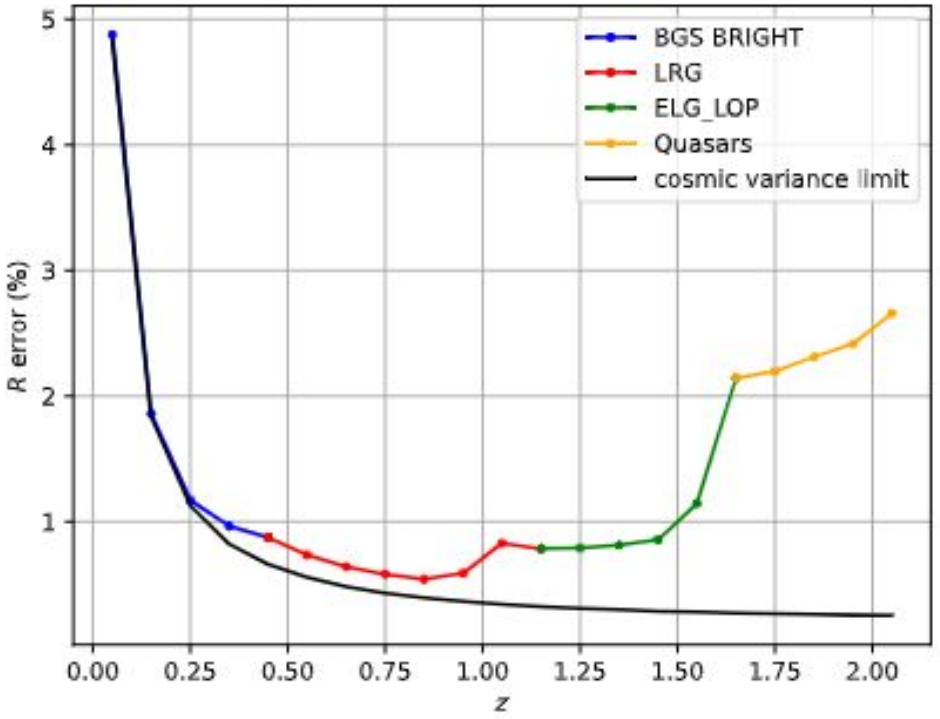
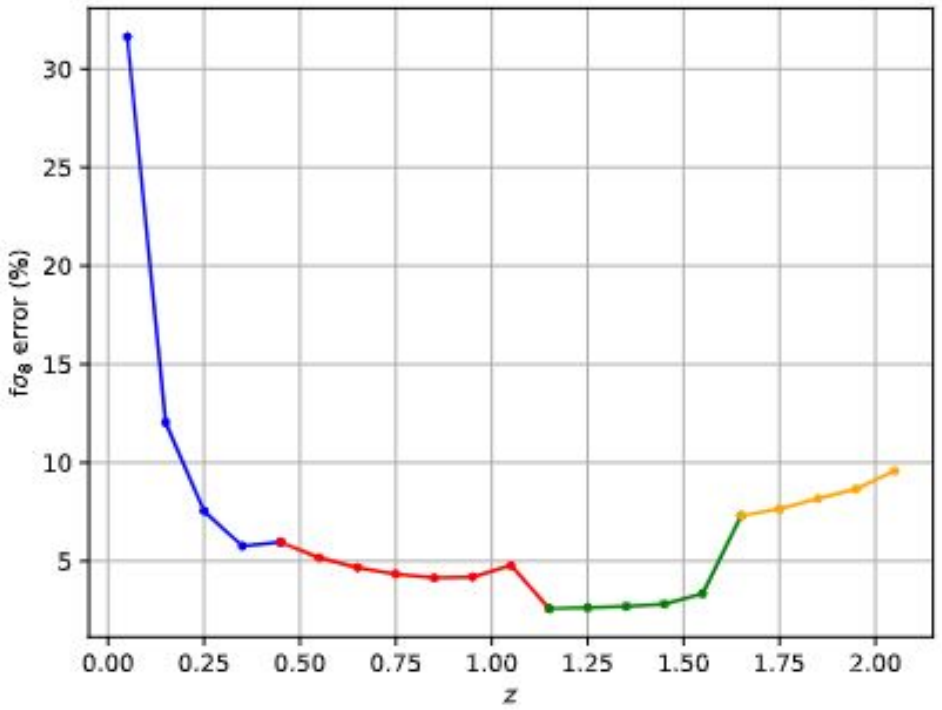
Forecasts from DESI Main Samples

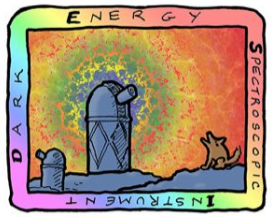
- Nearly all BAO information available in 14,000 sq deg survey (Cosmic Variance limit)
- **DESI is and will remain the most competitive instrument for wide-field spectroscopic surveys on the planet!**

Baryon Acoustic Oscillations



Redshift Space Distortions





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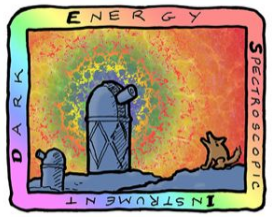
- Recommended project by P5 in 2014
  - First science observations in 2020
- ~1200 person collaboration
  - 280+ grad students
  - 69 Institutional members
  - 39 International partners
- Expects to meet mission goals (demonstrated by survey validation data):
  - Measure the isotropic cosmic distance scale R(z) from the BAO method to 0.28% precision aggregated over the redshift bin $0.0 < z < 1.1$
  - Measure the isotropic cosmic distance scale R(z) from the BAO method to 0.39% precision in the redshift bin $1.1 < z < 1.9$.
  - Measure the Hubble parameter at $1.9 < z < 3.7$ from the BAO method to 1.05%.

- Constructed on schedule and within budget



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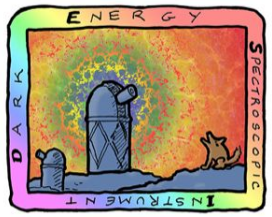
Beyond the Main DESI Samples

- **Snowmass:** "Continue operation of DESI (via a new DESI-II program) to constrain dark energy in new domains and as a step towards a Stage V spectroscopic facility (Spec-S5)."
  - Provide new insights into the high redshift Universe
  - Strengthen synergies with other Cosmic Frontier facilities
  - Provide a bridge to a Stage V experiment.
- Pilot Surveys
  - Explore capabilities of DESI spectrograph beyond core BAO/RSD program
- >100,000 spectra collected in Rubin Deep Drilling fields
  - z>2 galaxies for primordial physics
  - host galaxies for supernova cosmology
  - faint galaxies for photometric redshift calibration
  - z<1 galaxies for galaxy-galaxy lensing science
  - dwarf galaxies for dark matter



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Wide reaching DESI-II program

- Confirmed by pilot surveys
  - **Dark Time: dedicated LSS survey at z>2 for early dark energy**
  - Dark Time: spare fibers for faint Rubin source galaxies
  - Gray Time: time-series observations of Rubin deep drilling fields
  - Gray Time: z<1 galaxies to characterize Rubin lens population
  - Bright Time: stellar spectroscopy to probe Milky Way dark matter

Designed for broad BSM discovery potential while being sensitive to existing tensions.

Snowmass: "New data from other facilities will be needed as a complement to unlock the full constraining power of LSST, including follow-up observations of strong gravitational lenses, supernovae, and gravitational wave standard sirens, as well as measurements of spectroscopic redshifts for deep training samples of objects to enable precision photometric redshift measurements."

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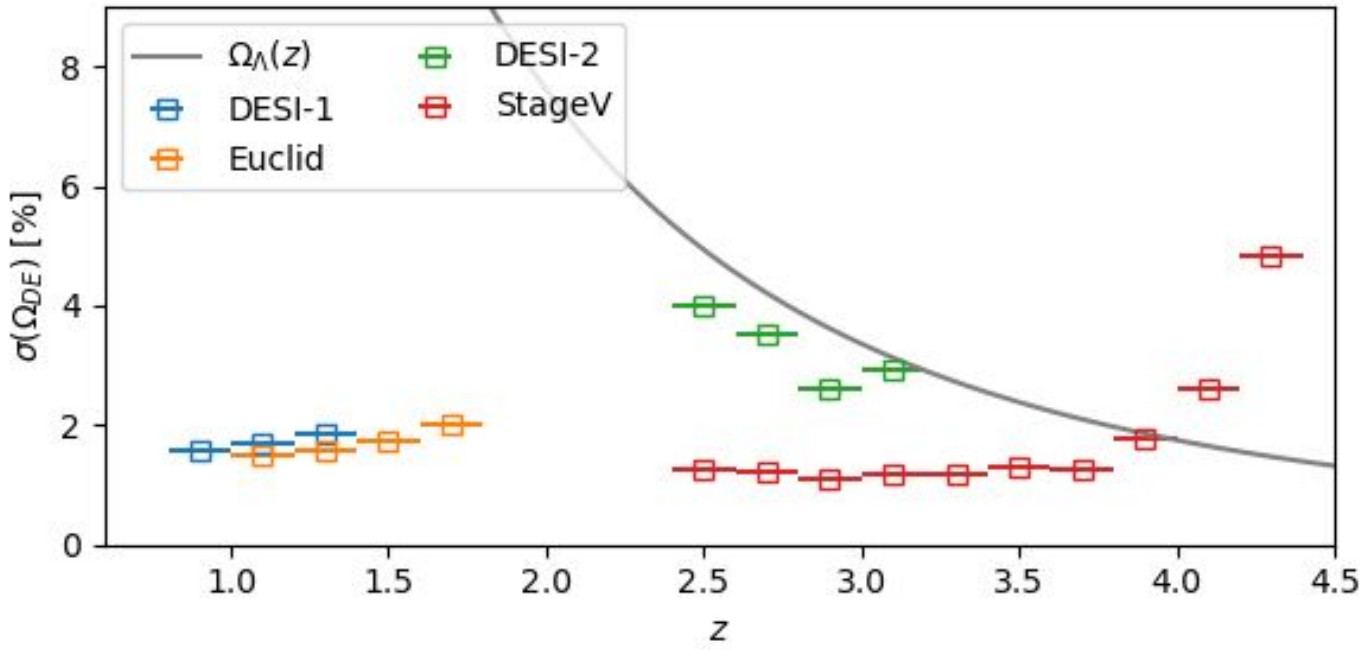
DESI-II Science: Early Dark Energy

- Baryon Acoustic Oscillations
  - 5000 square degrees
  - sub-percent precision distance measurements at z>2

Measurement of dark energy deep in matter-dominated regime



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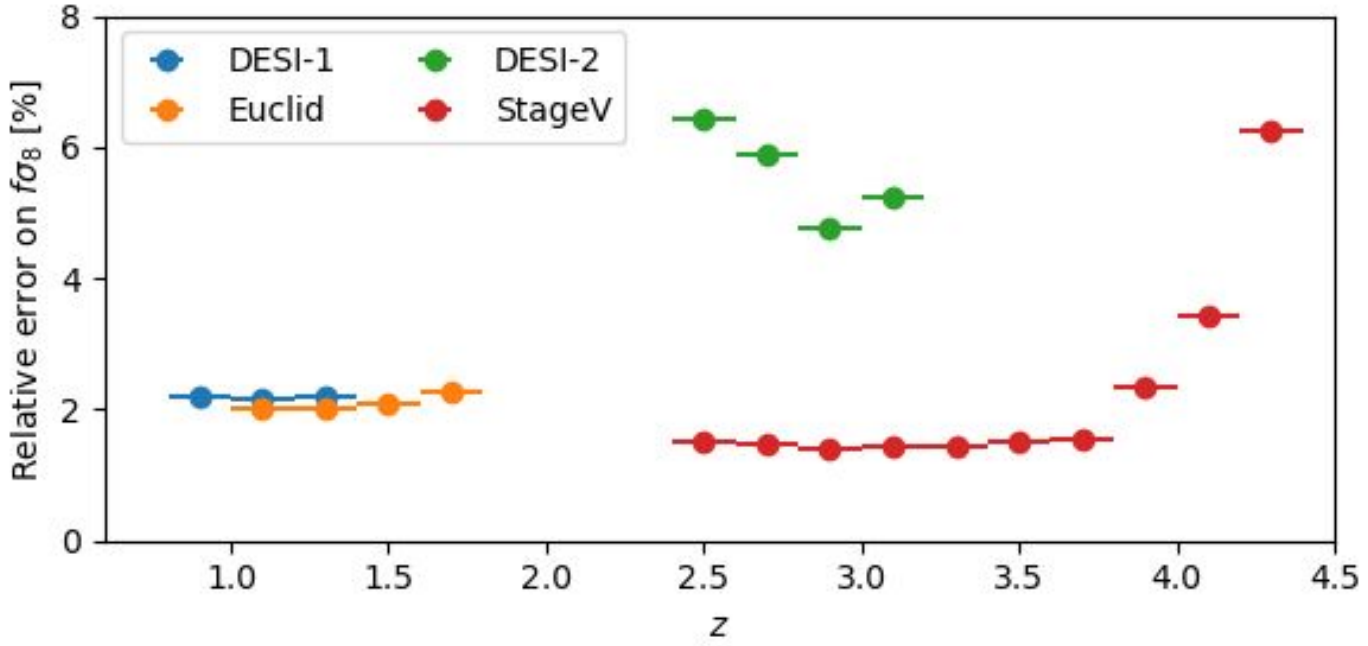
DESI-II Science: Growth of Structure

- Sigma8 tension: Redshift Space Distortions
  - Identical to BAO sample
  - Independent measurements in growth-dominated regime

Test “low redshift low sigma8” and “CMB lensing average sigma8” at z>2

Stepping stone to Spec-S5 for BAO and RSD measurements



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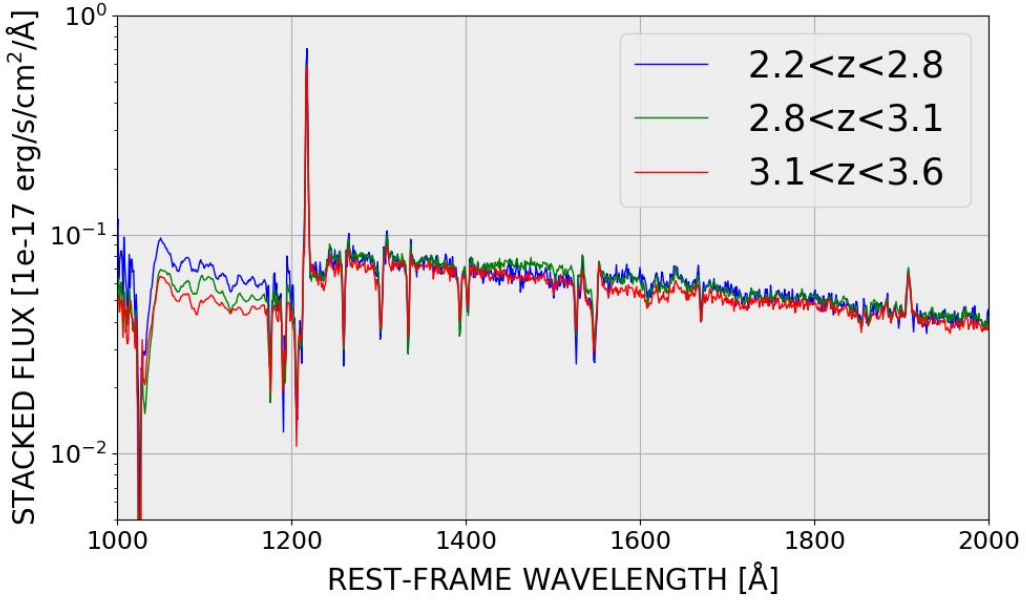
Capabilities: LSS at z>2

- DESI at z>2
  - *Snowmass2021 Cosmic Frontier White Paper: Cosmology and Fundamental Physics from the three-dimensional Large Scale Structure*
  - **Pilot studies prove we can measure redshifts of faint, distant galaxies**
  - Can match volume of current DESI program in entirely new redshift range

Composite DESI Spectra: based on preliminary target selection algorithm



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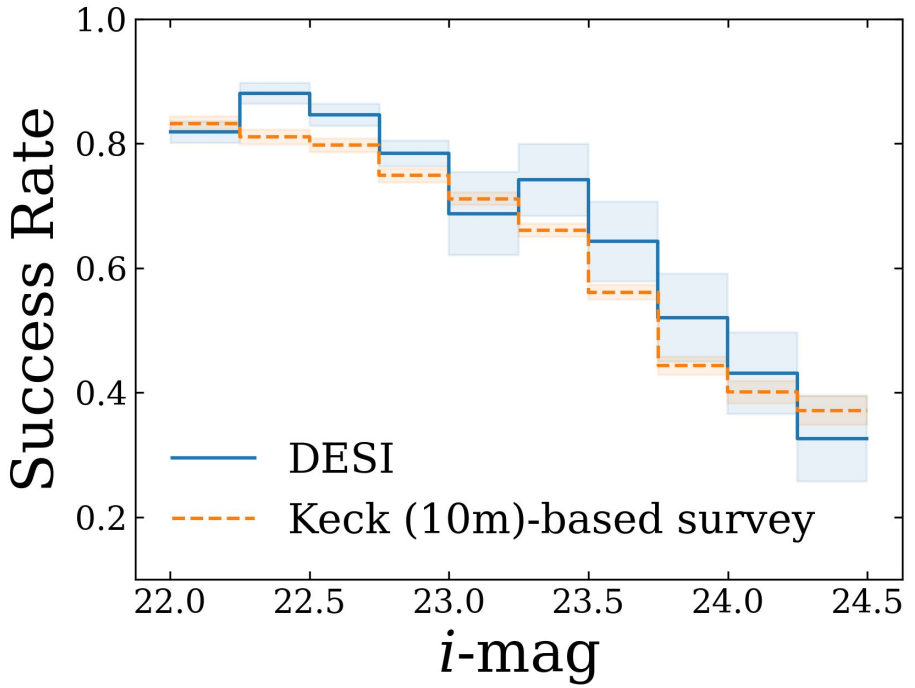
Capabilities: Supporting Rubin Cosmology

- 99% redshift completeness for z<1 galaxies
  - order of magnitude increase in surface density relative to DESI
- Galaxies at 22<i<24.5
  - Comparable to 10m class telescopes in only 50% more observing time
  - 40 times more galaxies per exposure
- Characterize lens and source populations for cosmic shear and lensing studies



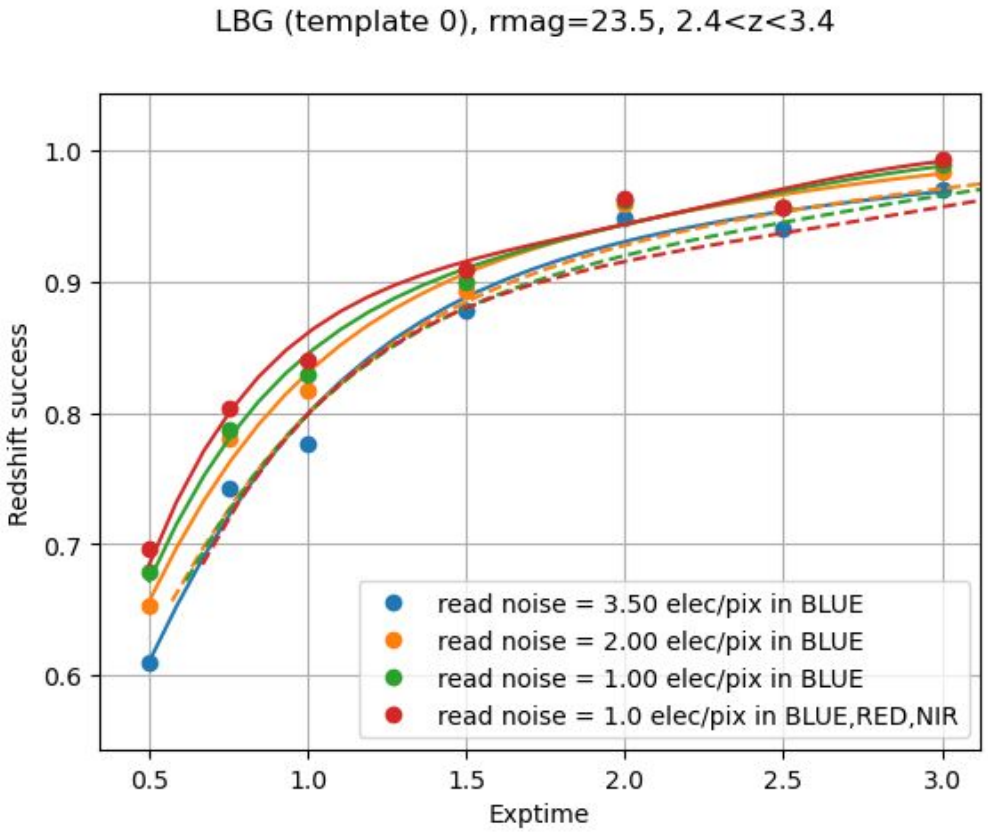
DESI-II: Pathway to Better Performance

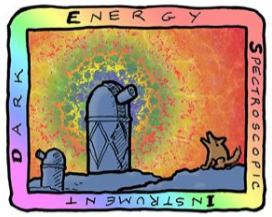
- R&D: up to 50% improvement in survey speed possible
  - Implement for DESI-II
  - **Early deployment of Spec-S5 technologies**

- Single electron counting CCDs (Skipper CCDs)
  - Developed by Berkeley Lab & Fermilab for dark matter detectors
  - read noise <1 electron

- Upgraded gratings

- Facility improvements
  - Improved mirror cooling





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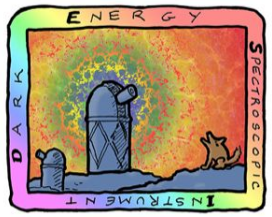
DESI-II Cost Estimates

- Operations and minor hardware upgrades
- $11M/yr are the current operating costs of DESI
  - includes cost of operating and maintaining the Mayall 4m telescope
  - includes cost of operating and maintaining the DESI instrument
  - includes cost of the lead observers (night-shift operators)
  - includes cost of the nightly data reductions/QA and nightly selection of targets
  - includes cost of the major data releases, calibrations, redshift catalogs
- Expect this level of operating costs to continue into DESI-II

- Cost of hardware upgrades: approximately $5M
  - new skipper-CCDs
  - new blue channel gratings
  - improved mirror cooling

While DESI-II does not require these upgrades, together they greatly improve the survey speed and are needed improvements for Spec-S5.



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Summary

- DESI
  - Order of magnitude increase over preceding spectroscopic samples
  - Sub-percent distance and growth measurements to $z<2$
  - Lyman-alpha forest distance measurements at $z>2$
- DESI capabilities
  - Tens of millions of galaxies accessible with current instrument
  - Even more powerful with modest upgrades
- Wide reaching DESI-II program
  - **Dark Time: dedicated LSS survey at $z>2$ for primordial physics**
  - Dark Time: spare fibers for faint Rubin source galaxies
  - Gray Time: time-series observations of Rubin deep drilling fields
  - Gray Time: $z<1$ galaxies to characterize Rubin lens population
  - Bright Time: stellar spectroscopy to probe Milky Way dark matter

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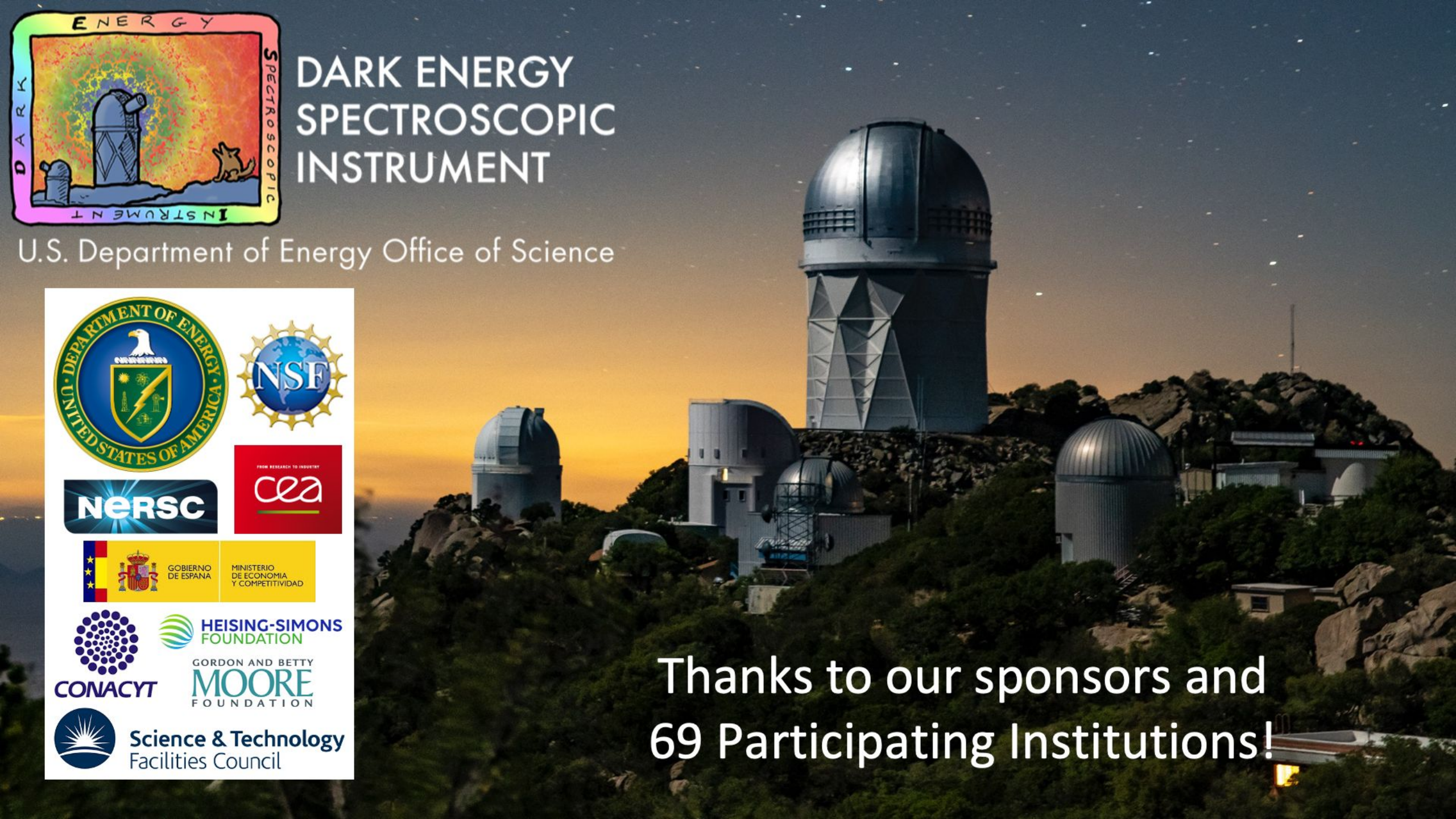
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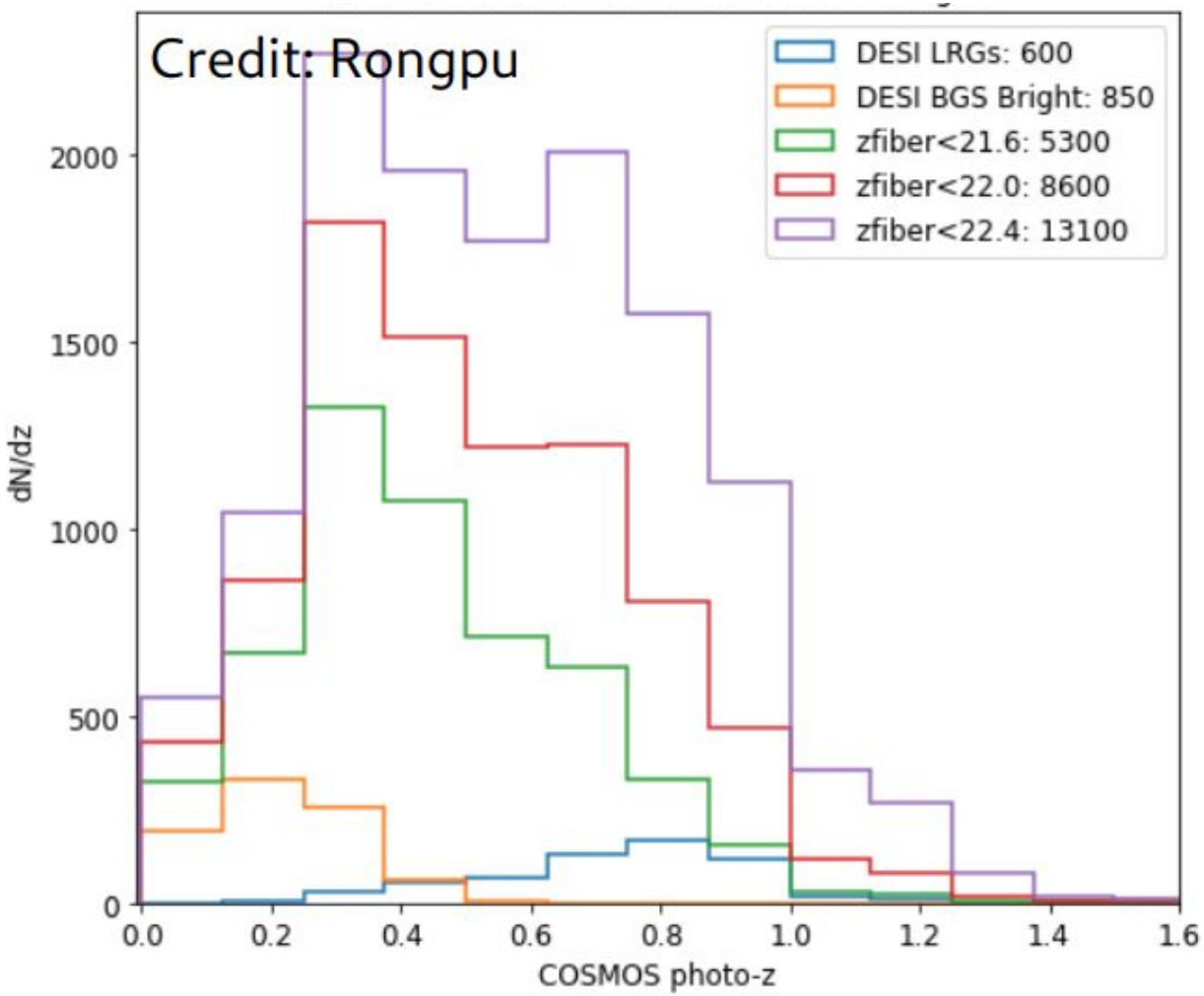
Capabilities: Supporting Rubin Cosmology

- 99% redshift completeness for z<1 galaxies
  - z_fib<21.6
  - 5300 per sqdeg

Characterize low-mass end of halo-mass function for galaxy-galaxy lensing studies



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Target Selection: LSS at z>2

- Select galaxy targets in the redshift range(s) that we want: 2.0<z<3.5.
  - UNIONS deep imaging: targets at high declination
  - Rubin ugriz: targets in LSST-DESC overlap
  - DECam medium band filters: emission line galaxies for efficient redshift classification
- Densities well matched to DESI focal plane for BAO and RSD