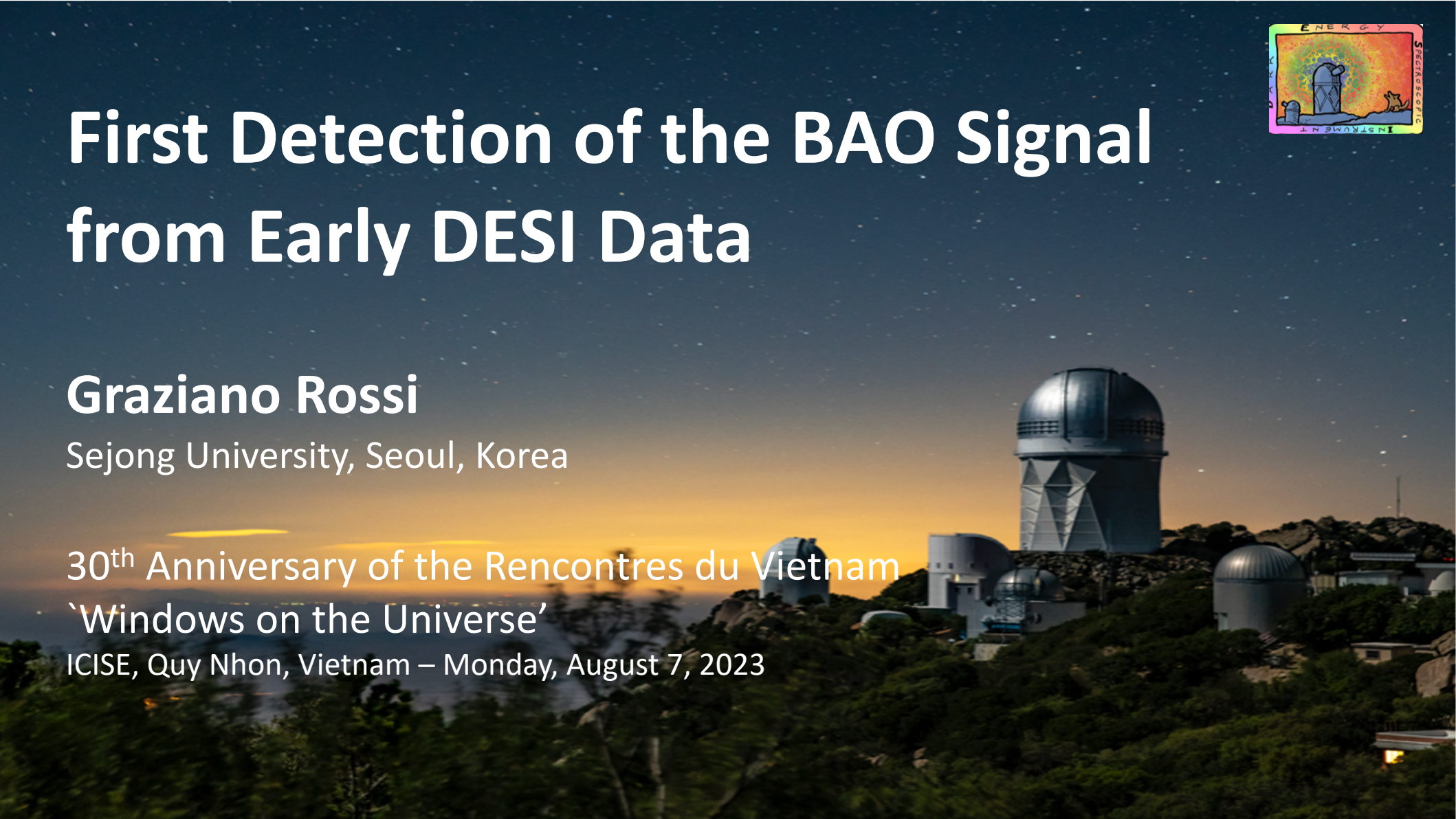


First Detection of the BAO Signal from Early DESI Data

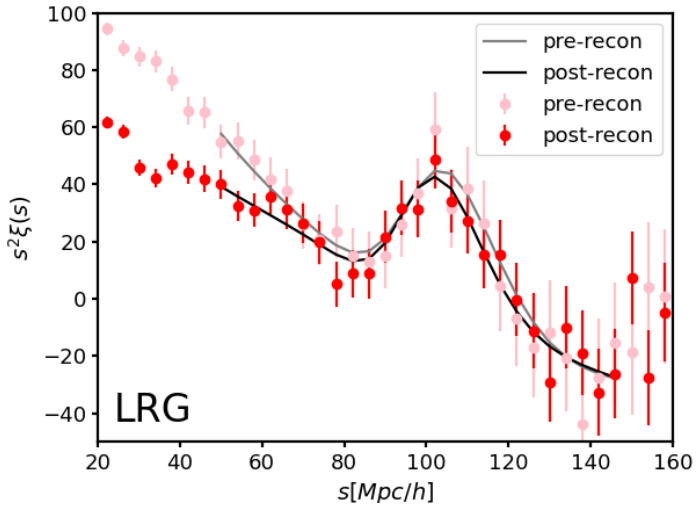
Graziano Rossi
Sejong University, Seoul, Korea

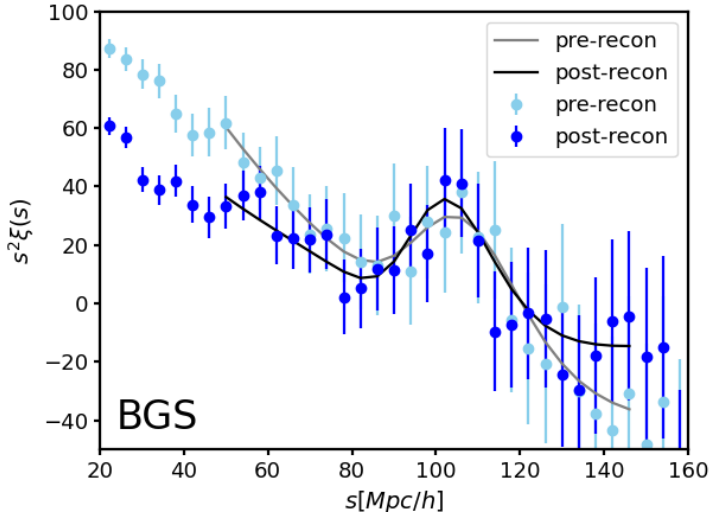
30th Anniversary of the Rencontres du Vietnam
`Windows on the Universe'
ICISE, Quy Nhon, Vietnam – Monday, August 7, 2023

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Key Results & Main Messages



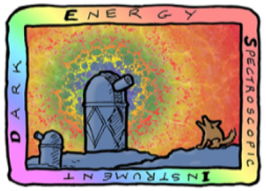


Key Results

- **DESI-M2 LRG** $\rightarrow 5\sigma$ BAO detection with 1.7% precision
- **DESI-M2 BGS** $\rightarrow 3\sigma$ BAO detection with 2.6% precision

Main Messages

1. **Key milestone** $\rightarrow$ 2 months of DESI data $\equiv$ BOSS DR12
2. Early validation of DESI spectroscopic pipeline and data management system + spectrograph quality control
3. DESI on target to achieve 0.29% precision BAO detection with Y5 LRG sample $\rightarrow$ set novel standards in cosmology



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Outline

1. Baryon Acoustic Oscillations: Overview
2. DESI: A Powerful Stage-IV Instrument
3. **Early DESI Data: First BAO Detection**

- Summary and Outlook

PRIMARY REFERENCE

First Detection of the BAO Signal from Early DESI Data
J. Moon et al. (2023) – arXiv: **2304.08427**

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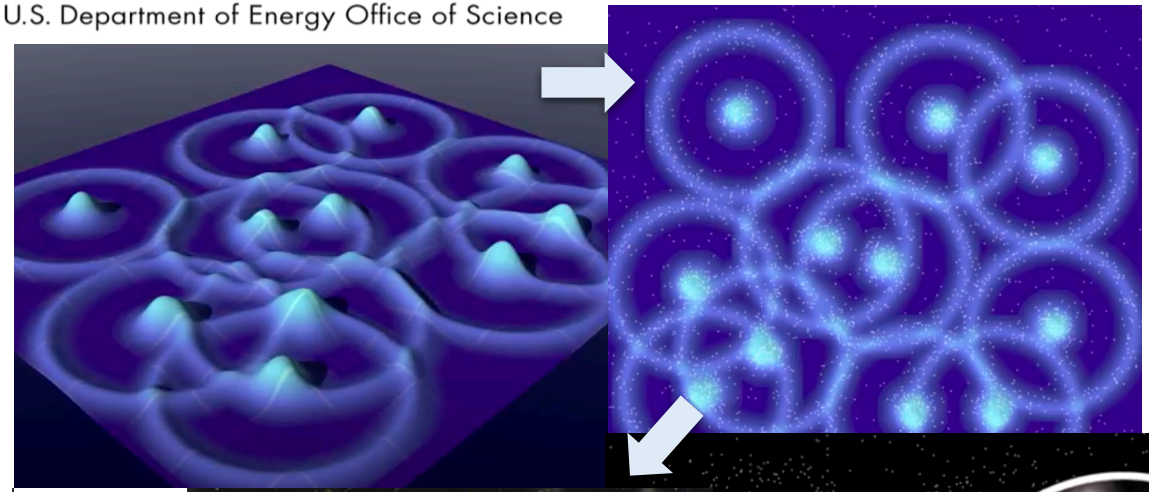
Baryon Acoustic Oscillations



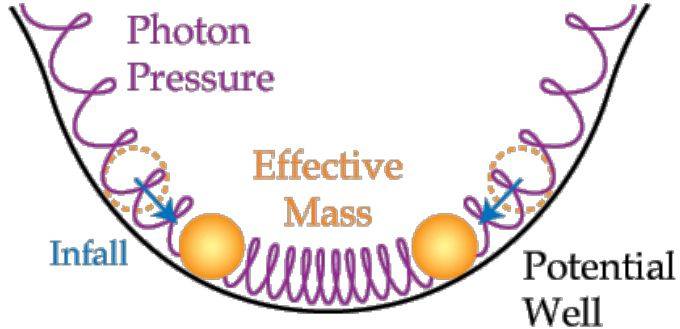
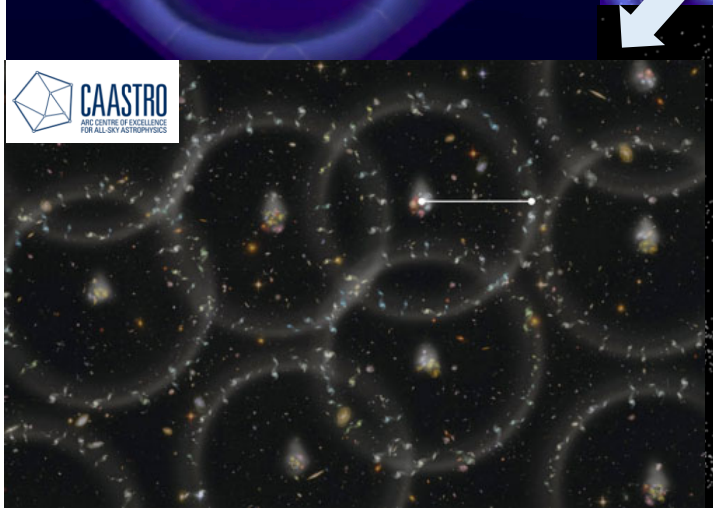
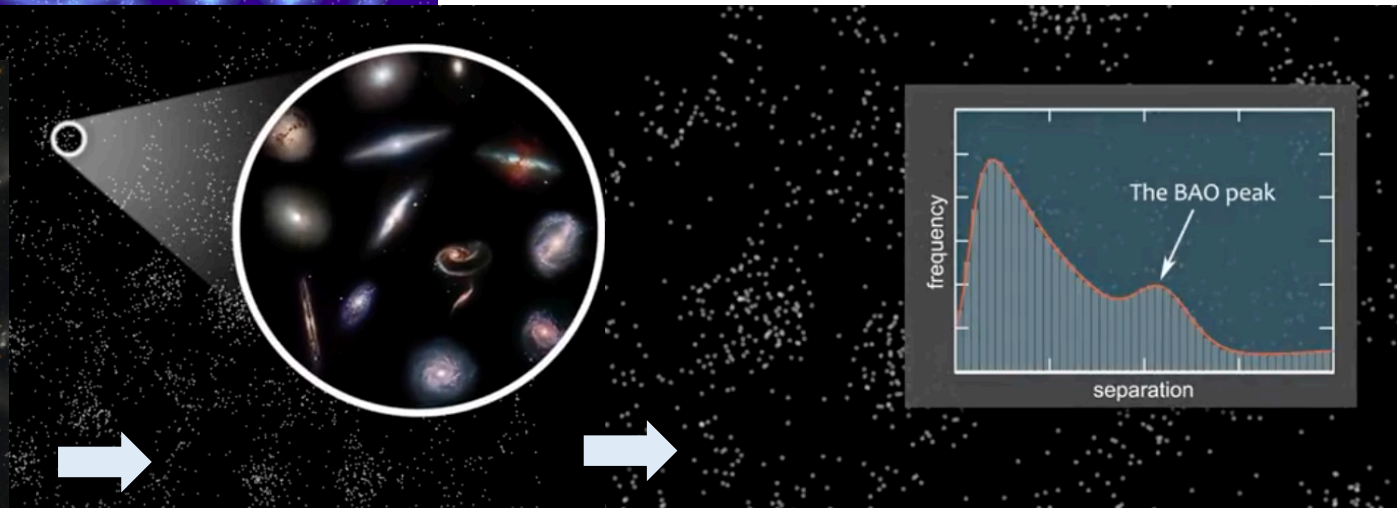


Image Credit: Wayne Hu





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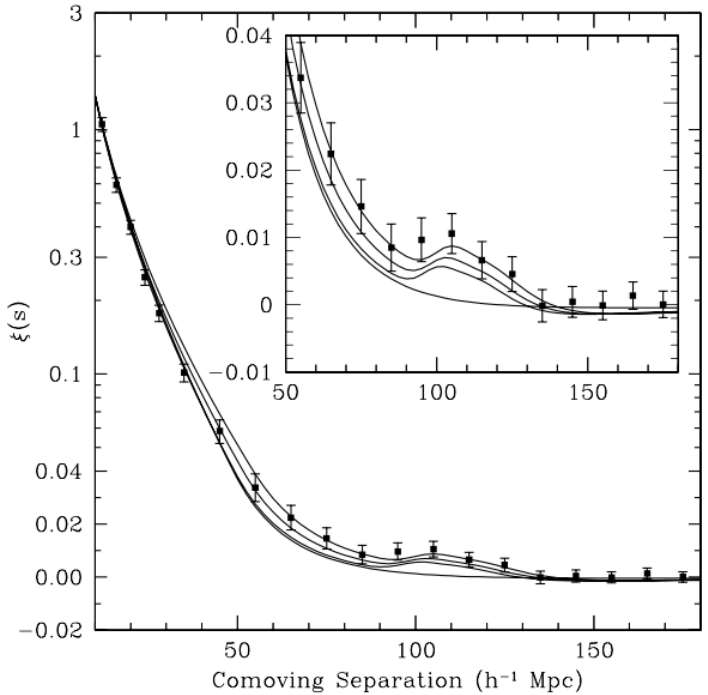
BAO Detection: Basics

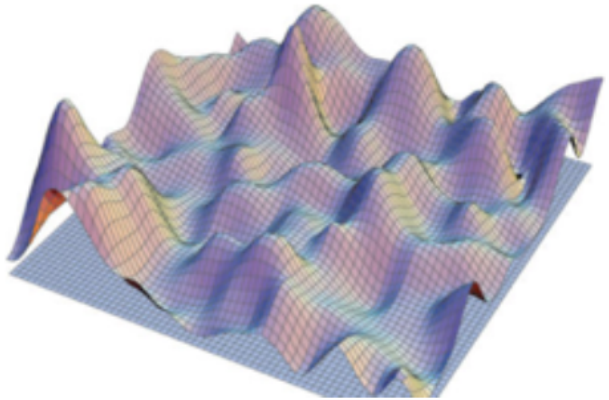
2PCF

$$dP = n[1 + \xi(r)]dV$$

$$dP = N[1 + \omega(\theta)]d\Omega$$



Eisenstein et al. (2005)

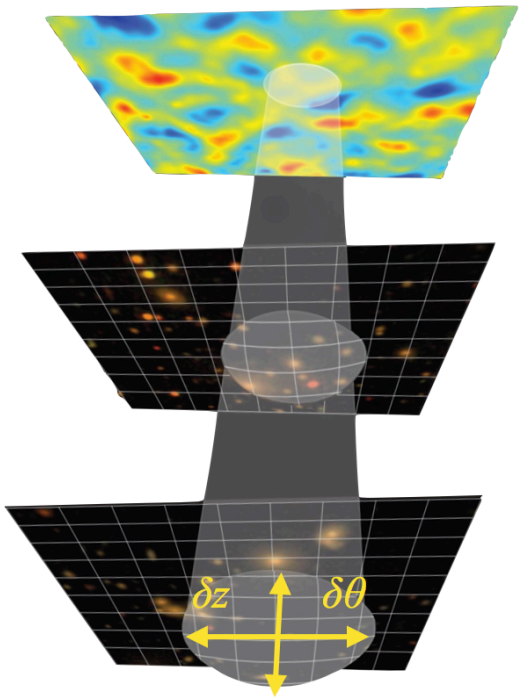


AP Parameters

$$\alpha_{\parallel} = \frac{H'(z_{\rm m})}{H(z_{\rm m})}\frac{r_{\rm d}'}{r_{\rm d}}$$

$$\alpha_{\perp} = \frac{D_{\rm M}(z_{\rm m})}{D_{\rm M}'(z_{\rm m})}\frac{r_{\rm d}'}{r_{\rm d}}$$

Image Credit: Wayne Hu



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`Traditional' LSS Tracers

LRGs

credit: http://news.mit.edu/2012/

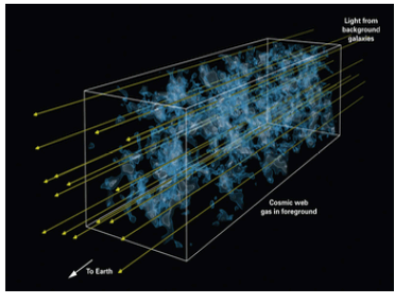
ELGs

credit: http://www.sci-news.com/astronomy/

QSOs

credit: http://www.eso.org/public/

Ly-α



Credit: Casey Stark (UC Berkeley) and Khee-Gan Lee (MPIA)

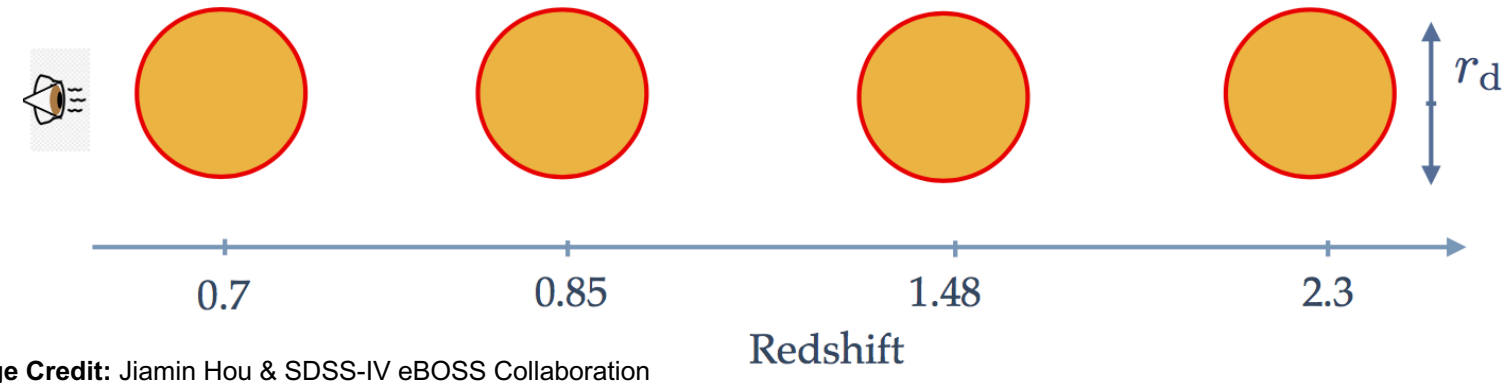


Image Credit: Jiamin Hou & SDSS-IV eBOSS Collaboration

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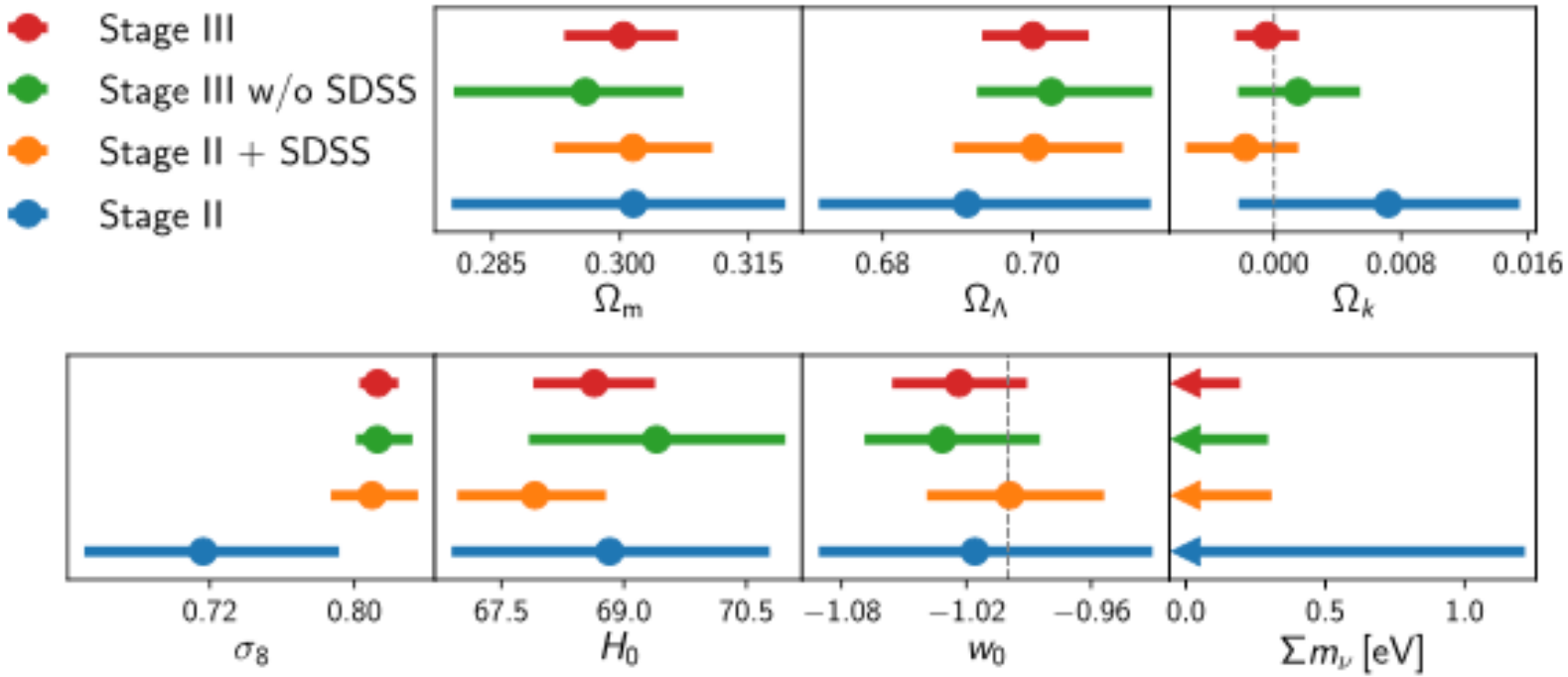
Cosmology from BAOs



eBOSS Consensus (2021) – PRD, Vol 103, Issue 8

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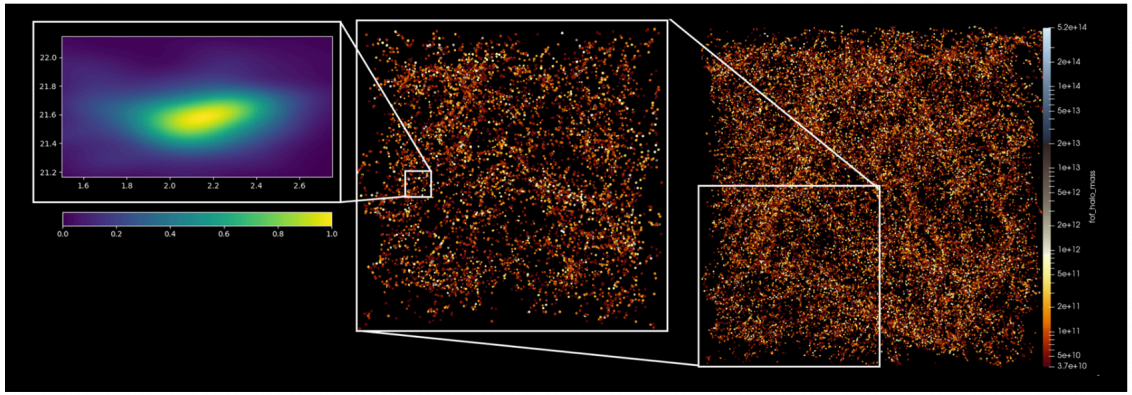
BAO Mock Challenges



Baseline Simulation

Outer Rim (Heitmann et al. 2019)

HOD Model Styles

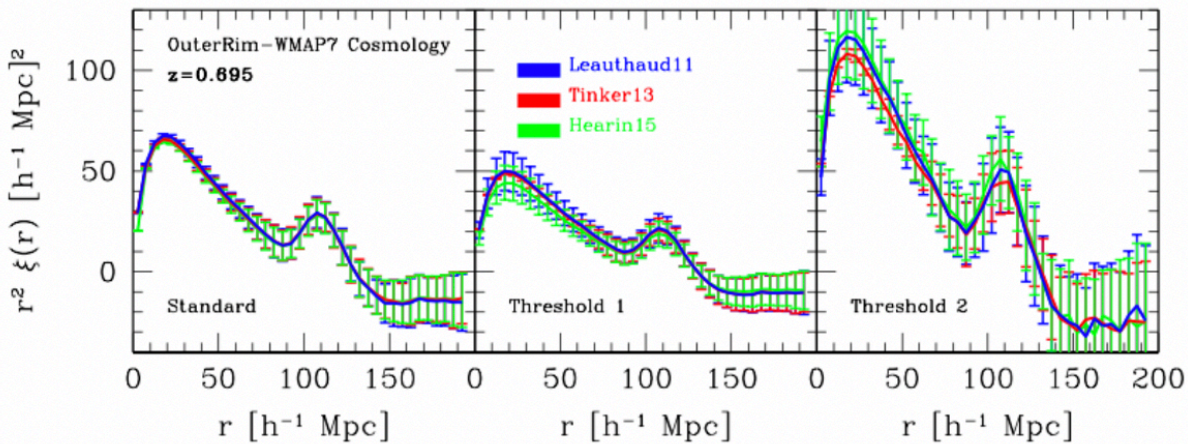
- Traditional HOD → **Zheng07, Leauthaud11**
- HOD with color/SFR → **Tinker13**
- Decorated HOD → **Hearin15**
- Customized HOD → **Zheng07** with additions

BAO Systematics

- Performance of BAO template
- Impact of Reference cosmology
- Effect on Non-Periodicity on BAO
- Impact of HODs on BAO

RSD Systematics

- Optimal Range of scales
- Performance of RSD Modeling
- Impact of Reference cosmology
- Effect on Non-Periodicity on RSD Modeling
- Impact of HODs on RSD Modeling

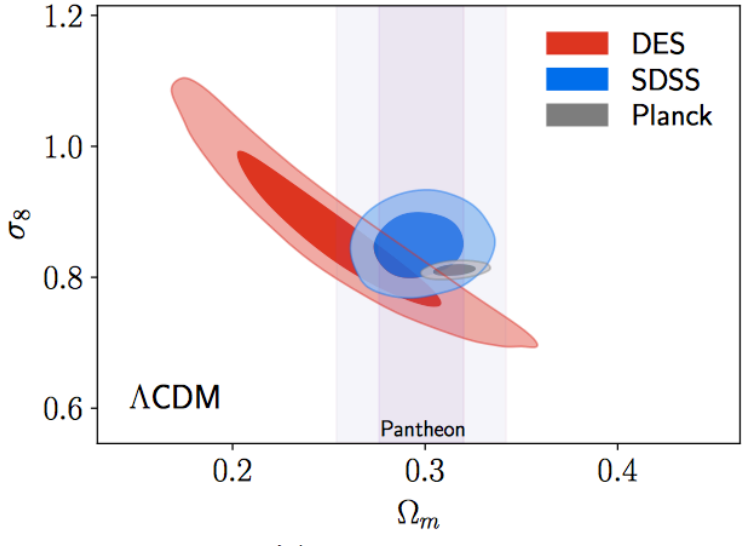


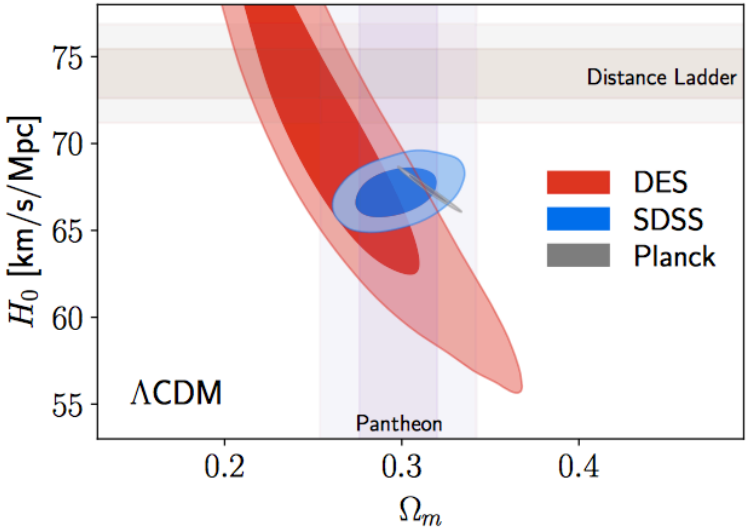
G. Rossi, P.D. Choi, J. Moon, et al. (2021), MNRAS, 505, 377

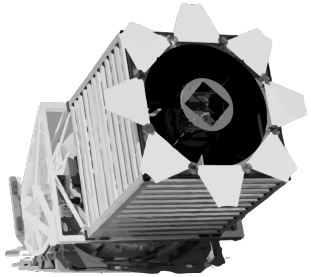
DARK ENERGY SPECTROSCOPIC INSTRUMENT

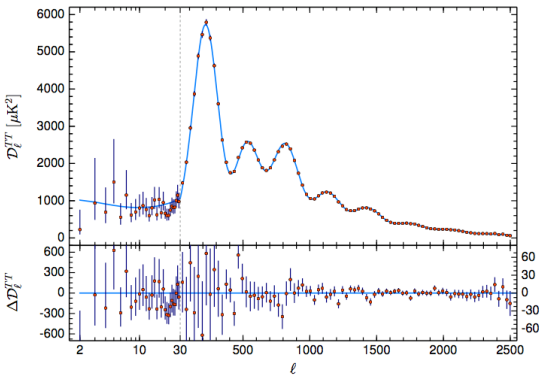
U.S. Depc

Consistency with BAO









SDSS DR16 (**eBOSS Collab. et al. 2021**)

PLANCK 2018 (**Planck Coll. 2020 - VI**)

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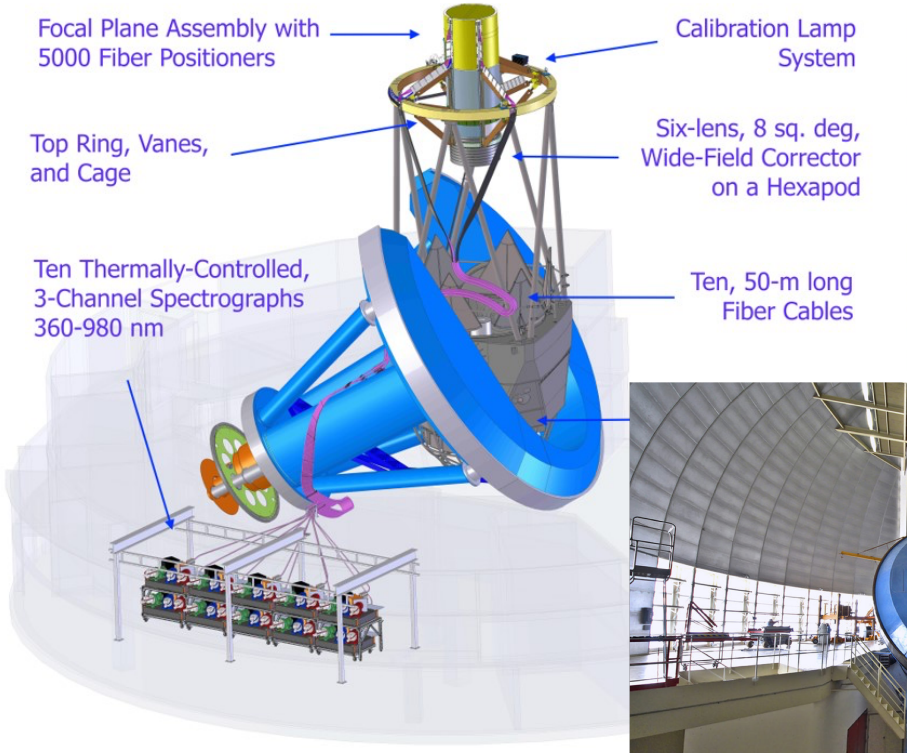
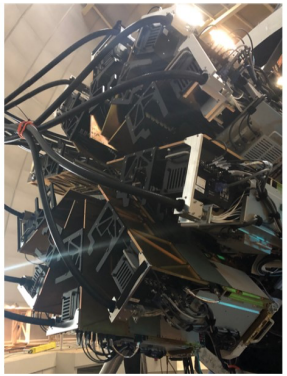
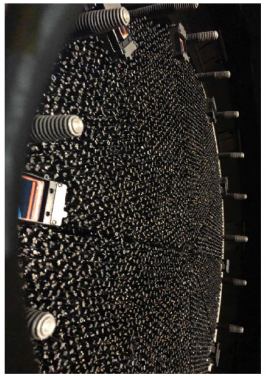
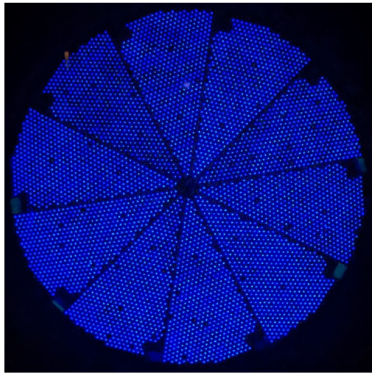
U.S. Department of Energy Office of Science

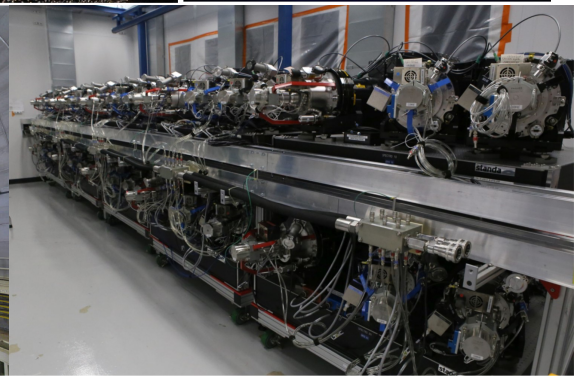
DESI: A Stage-IV Experiment











DESI → only Stage-IV experiment currently taking data

DARK ENERGY SPECTROSCOPIC INSTRUMENT

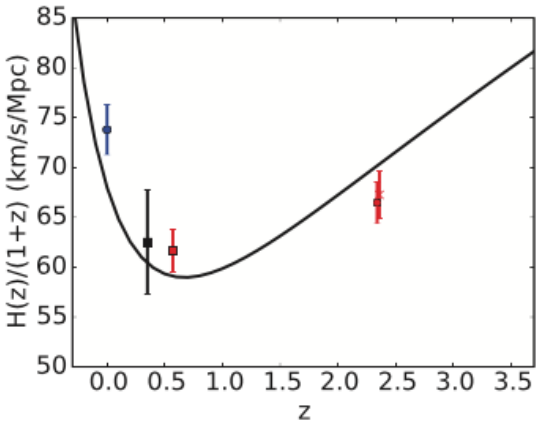
U.S. Department of Energy Office of Science

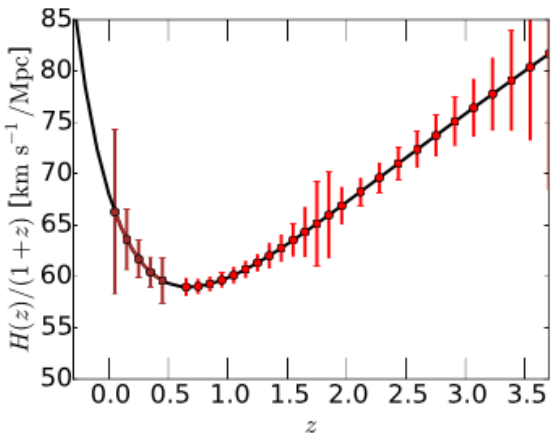
DESI Science

DESI Primary Science Targets

- **BAO, RSD, DE** → 1% level measurements of distance scale in 35 *z*-bins
- **Neutrino mass** → $\sigma_{M_\nu} = 0.020$ eV
- **Modified gravity** → stringent bounds
- **PNG & Inflation** → $\sigma(f_{\rm NL}) \sim 5$

26 Approved DESI Secondary Programs





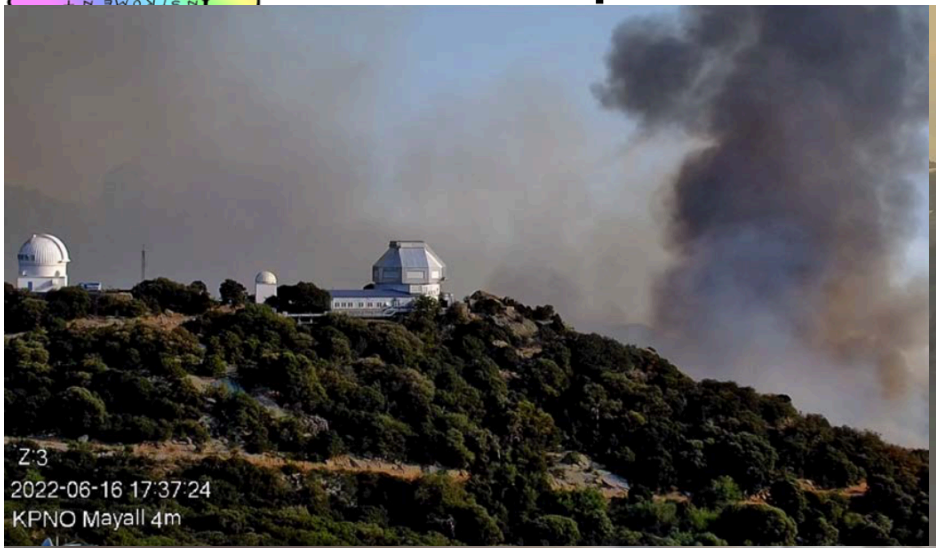
DESI Collaboration
@Durham, July 2023

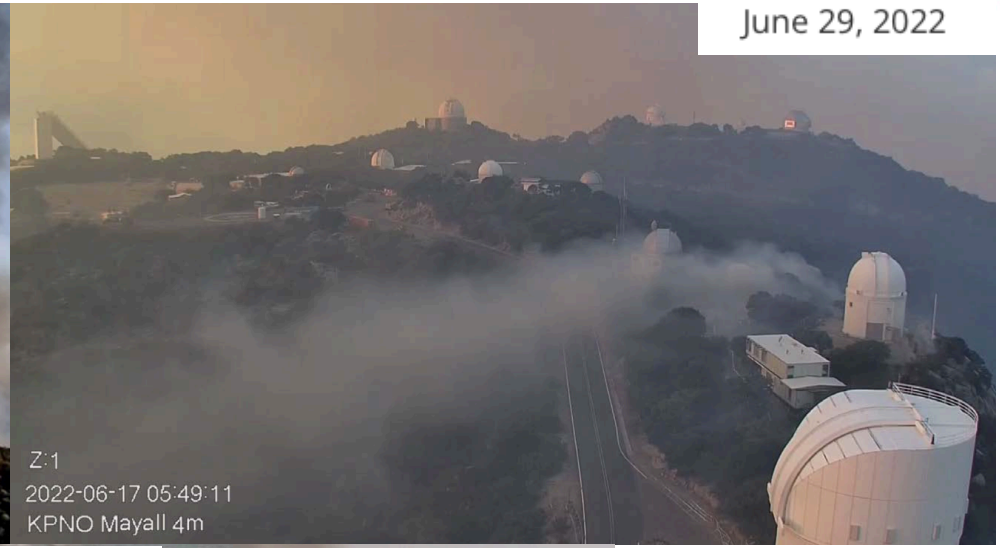
DESI → order-of-mag improvement in volume surveyed & in # of galaxies over SDSS-IV eBOSS

DARK ENERGY SPECTROSCOPIC INSTRUMENT

DESI on Fire …

June 29, 2022





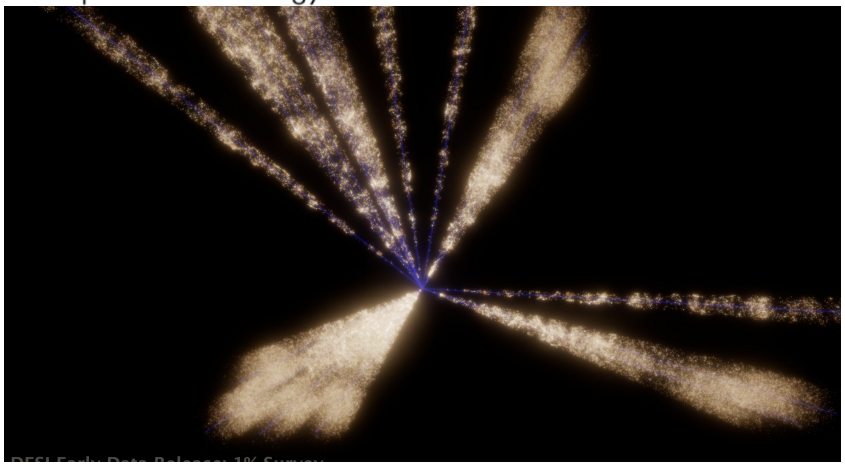
Contreras Fire Threatens DESI and Kitt Peak National Observatory

@Graziano Rossi 2023

DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

DESI EDR Public on June 13, 2023



ARTICLE · COSMIC FRONTIERS

DESI Early Data Release Holds Nearly Two Million Objects

June 13, 2023

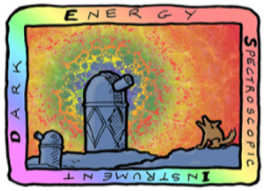
https://newscenter.lbl.gov/2023/06/13/desi-early-data-release-holds-nearly-two-million-objects/

The Early Data Release of the Dark Energy Spectroscopic Instrument

DESI Collaboration: A. G. Adame,[1] J. Aguilar,[2] S. Ahlen,[3] S. Alam,[4] G. Aldering,[2] D. M. Alexander,[5,6]

Validation of the Scientific Program for the Dark Energy Spectroscopic Instrument

DESI Collaboration: A. G. Adame,[1] J. Aguilar,[2] S. Ahlen,[3] S. Alam,[4] G. Aldering,[2] D. M. Alexander,[5,6] R. Alfarsy,[7] C. Allende Prieto,[8,9] M. Alvarez,[2] O. Alves,[10] A. Anand,[2]



DARK ENERGY SPECTROSCOPIC INSTRUMENT

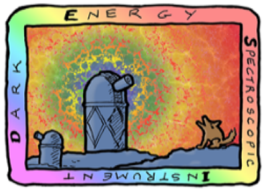
U.S. Department of Energy Office of Science

DESI Early BAO Paper

First Detection of the BAO Signal from Early DESI Data

Jeongin Moon,[1,2]★ David Valcin,[3] Michael Rashkovetskyi,[4] Christoph Saulder,[5] Jessica Nicole Aguilar,[6] Steven Ahlen,[7] Shadab Alam,[8] Stephen Bailey,[6] Charles Baltay,[9] Robert Blum,[10] David Brooks,[11] Etienne Burtin,[12] Edmond Chaussidon,[12] Kyle Dawson,[13] Axel de la Macorra,[14] Arnaud de Mattia,[12] Govinda Dhungana,[15] Daniel Eisenstein,[4] Brenna Flaugher,[16] Andreu Font-Ribera,[17] Cristhian Garcia-Quintero,[18] Julien Guy,[6] Malik Muhammad Sikandar Hanif,[19] Klaus Honscheid,[20,21] Mustapha Ishak,[18] Robert Kehoe,[22] Sumi Kim,[23] Theodore Kisner,[6] Anthony Kremin,[6] Martin Landriau,[6] Laurent Le Guillou,[24] Michael Levi,[6] Paul Martini,[25,21] Patrick McDonald,[6] Aaron Meisner,[10] Ramon Miquel,[17,26] John Moustakas,[27] Adam Myers,[28] Seshadri Nadathur,[29] Richard Neveux,[30] Jeffrey A. Newman,[31] Jundan Nie,[32] Nikhil Padmanabhan,[9] Nathalie Palanque-Delabrouille,[6,12] Will Percival,[33,34] Alejandro Pérez Fernández,[14] Claire Poppett,[35,6] Francisco Prada,[36] Ashley J. Ross,[25,21] Graziano Rossi,[1]† Hee-Jong Seo,[3] Gregory Tarlé,[19] Mariana Vargas Magana,[14] Andrei Variu,[37] Benjamin Alan Weaver,[10] Martin J. White,[38] Sihan Yuan,[39] Cheng Zhao,[37] Rongpu Zhou,[6] Zhimin Zhou,[32] and Hu Zou[32]

- https://arxiv.org/abs/2304.08427 (to appear in MNRAS, 2023)



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Rationale and Goals

- **First Early Data Quality Check**
  - DESI first 2 months (i.e., DESI-M2) unblinded for testing
  - Can we detect BAO with just 2 months of DESI observations?
  - Important milestone towards DESI Y1 & Y5 Key Science

- **Early DESI Pipeline Validation / Complex Instrument Tests**

- **Estimates for Expected Quality of Completed Survey**
  - DESI Y5 Fisher forecasts based on early DESI BAO results

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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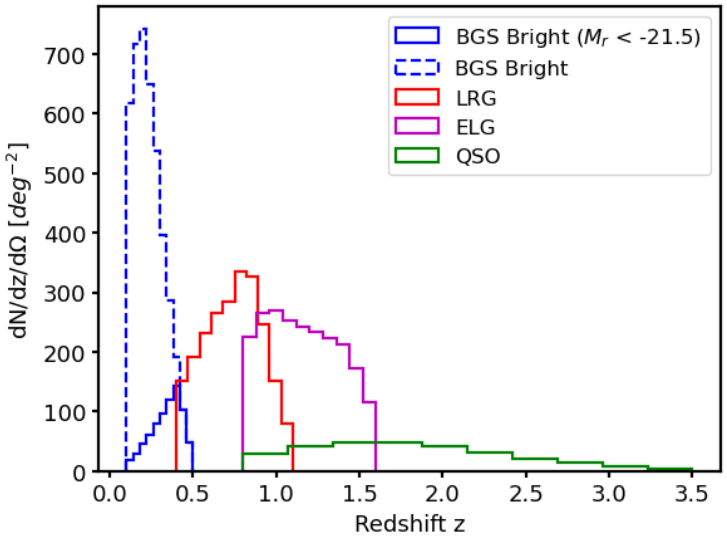
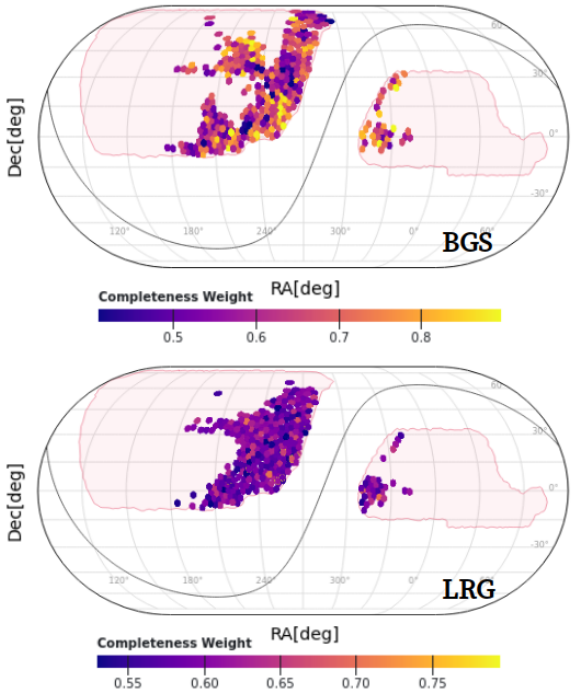
Main Tracers: LRGs & BGS





Target	$N_{\rm North}$	$N_{\rm South}$	$N_{\rm Total}$	z range	Area [deg^2]	Completeness
BGS Bright	239492	390988	630480	0.1 - 0.5	3677	0.500
BGS Bright, M_r < −21.5	38472	71051	109523	0.1 - 0.5	3677	0.500
LRG	80651	180640	261291	0.4 -1.1	1651	0.579
ELG	55383	117145	172528	0.8 - 1.6	976	0.297
QSO	70337	153453	223790	0.8 - 3.5	2906	0.778

- First 2 months of **main survey** observations => **DESI-M2** (*May 14 - July 9, 2021*)
- Mostly first pass tiles that do not overlap each other
- Quite incomplete, unblinded
- In *dark time* → QSO, LRG, ELG
- In *bright time* → BGS, MWS
- Focus on LRGs & BGS (most complete and enough # density)
- BGS flux-limited and sample variance limited to z <0.5
- BGS mag cut
- 4 types of weights → COMP, SYS, ZFAIL, FKP

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Mock Catalogs

Mocks used for →

- (1) Statistical tests of performance of BAO fits
- (2) Validation of covariances in terms of BAO fitting

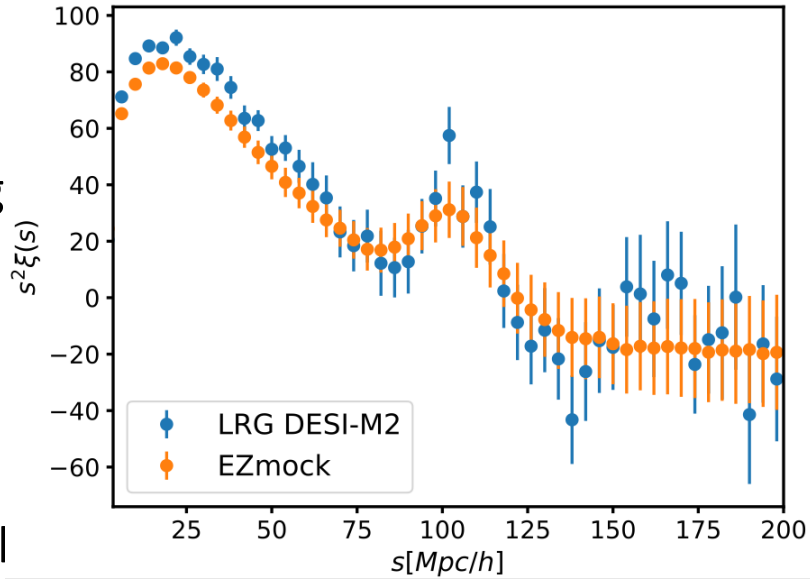
Mock Types →

(1) *AbacusSummit* Mocks

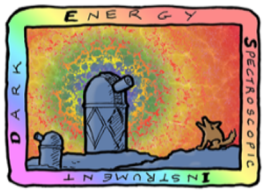
- *N*-body-based mocks (*Maksimova et al. 2021*)
- 25 cutsky realizations, 2Gpc/h + HOD + subsampl

(2) *EZmocks*

- Extended Zel'dovich approximation (*Zhao et al. 2021*)
- 1000 realizations + HOD + subsamp



- **Survey realism** → sets of masks
- **Calibration** → `One Percent Survey Data'



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Methodology

- **Template-based BAO fitting strategy**

- Anisotropic *z*-space CF with LS estimator (200 bins in angle)

- Only monopole (SN considerations) → Isotropic scale dilation parameter

- BOSS/eBOSS pipeline (*Xu et al. 2012; Ross et al. 2017*)
  for density field reconstruction and template fitting (4 fixed params)

- Advances necessary for exquisite precision for DESI Y1 & Y5

- Data fit → 5 parameters: α, B & 3 nuisance parameters

- Best-fit α by computing χ^2 goodness-of-fit indicator

  Fitting range : 50-150 Mpc/h & Bin size : 4 Mpc/h

  => Fits over 25 points using 5 param —> 20 dof

$$\alpha = \frac{D_{\rm V}(z) r_{\rm d}^{\rm fid}}{D_{\rm V}^{\rm fid}(z) r_{\rm d}}$$

$$D_{\rm V}(z) = \left[cz(1+z)^2 H(z)^{-1} D_{\rm A}^2(z) \right]^{1/3}$$

$$\xi_{\rm mod}(s) = B\xi_{0,\rm t}(s\alpha) + A_0 + A_1/s + A_2/s^2$$

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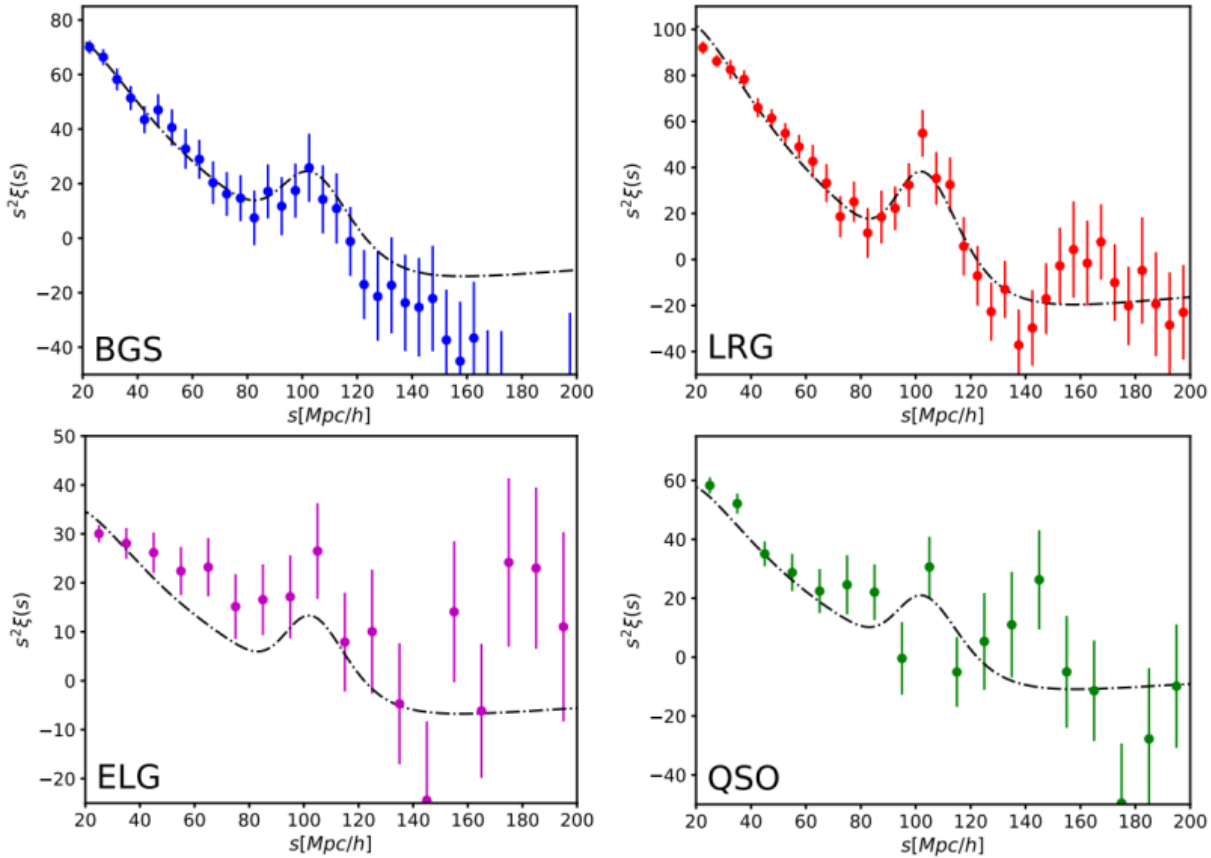
2PCF Measurements



- *Dashed lines* → Damped linear theory
- No clear BAO peak in ELGs & QSOs
- BGS lower $\xi(s)$ at large s → Bin-to-bin correlations, $\xi(s)$ fitted up to ~150 Mpc/h

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Covariances

Name	Tracer	Notes
DESI-M2-EZ	LRG	Constructed from EZmock clustering
RascalC-EZ	LRG	RascalC calibrated on EZmock clustering
RascalC-LRG	LRG	RascalC calibrated on DESI-M2 LRG clustering
RascalC-BGS	BGS	RascalC calibrated on DESI-M2 BGS clustering

- **RascalC Covariances**
  - Semi-analytical, semi-empirical covariance (*Philcox et al. 2020; Rashkovetskyi et al. 2023*)
  - Fast, flexible, precise → good agreement with mock-based cov
  - Just need input 2PCF → analytical + internal approach
  - Assume Gaussian & rescale shot-noise calibrated by data jackknife cov
  - Random catalog for survey geometry

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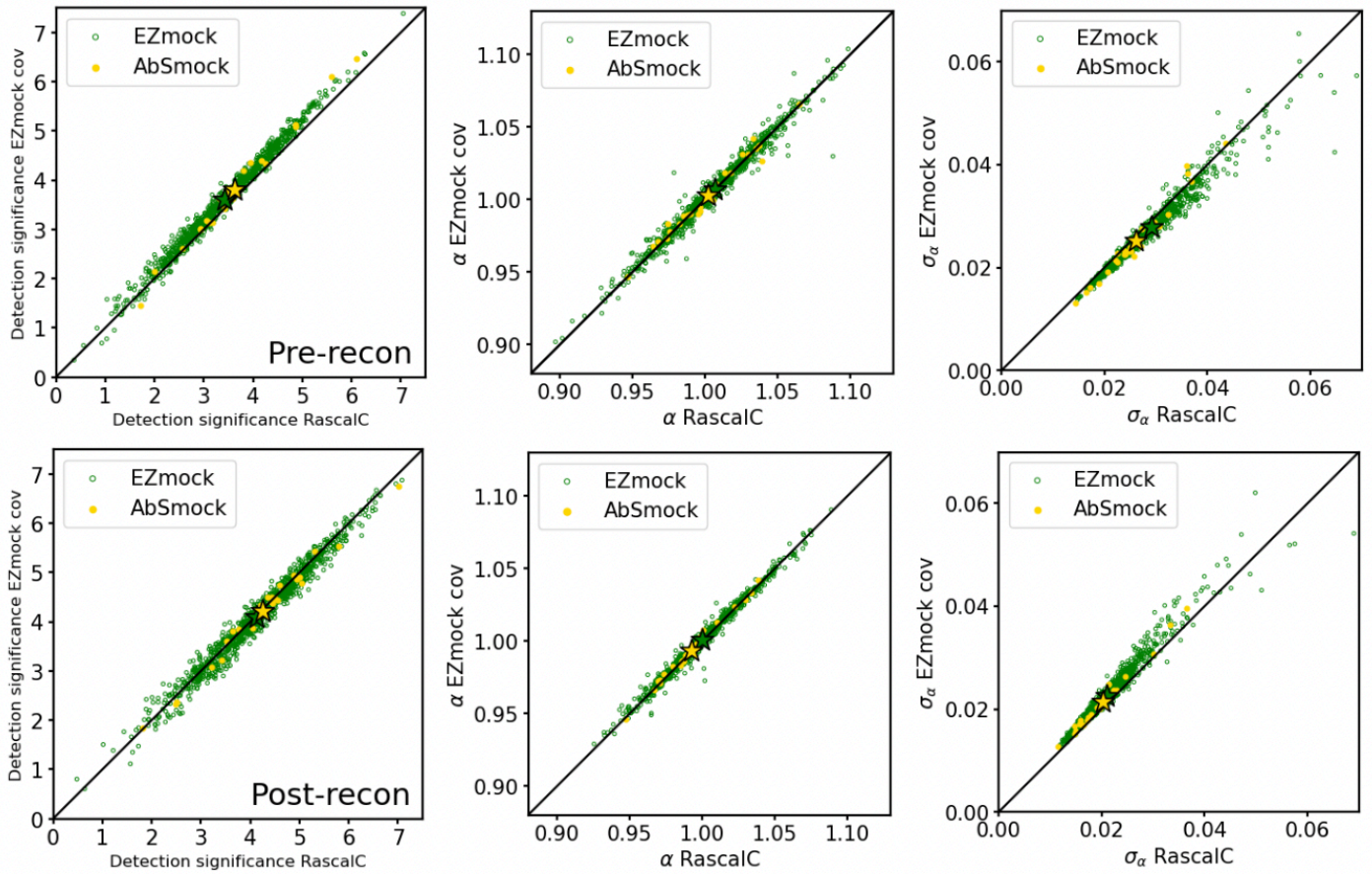
Validation of BAO Fitting Cov



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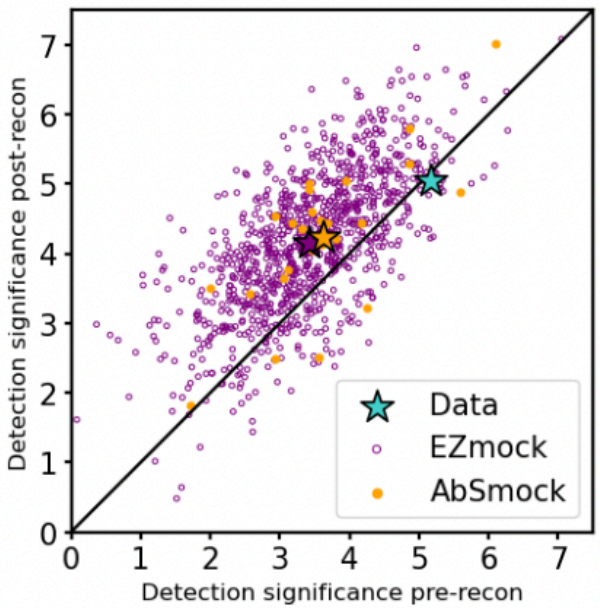
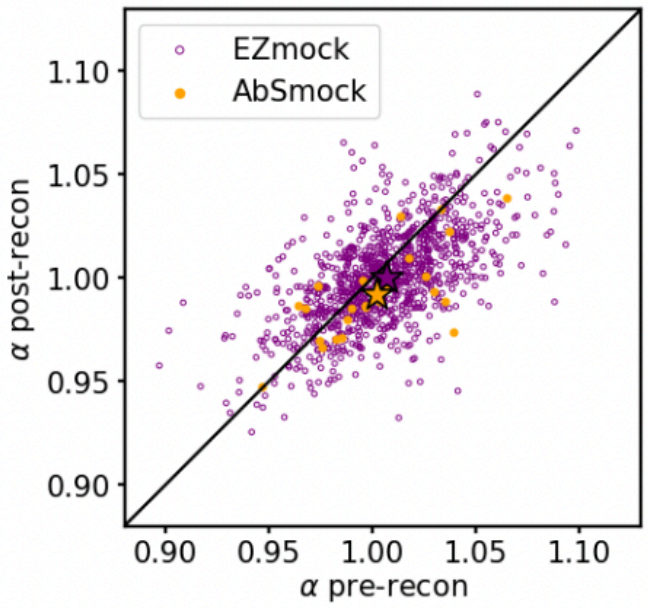
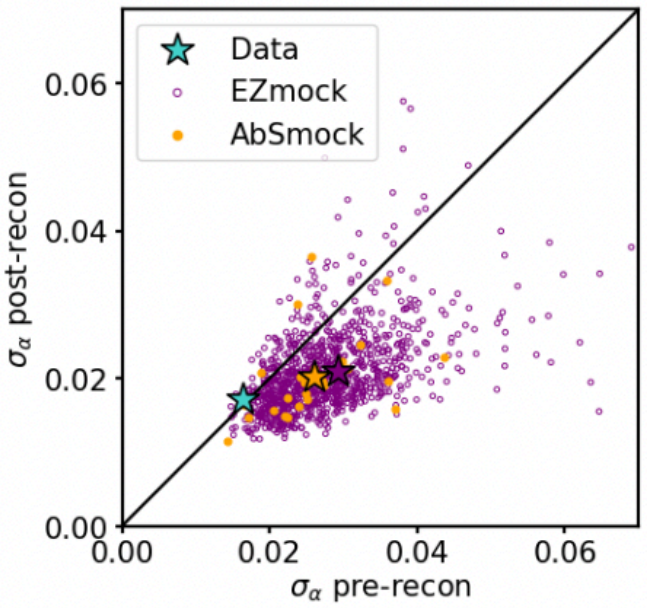
BAO Reconstruction Efficiency

IterativeFFTReconstruction algorithm (*Burden et al. 2015)*







Fits → *adopting RascalC-EZ covs*

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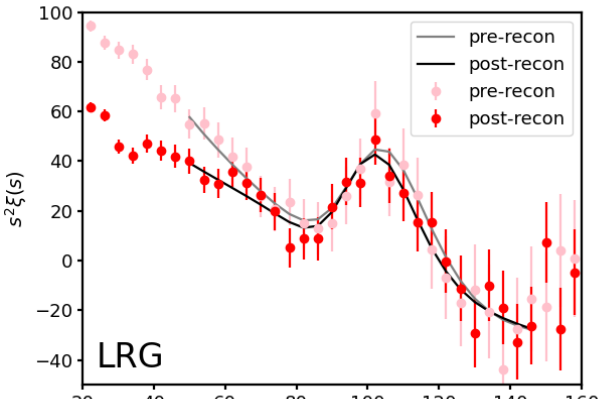
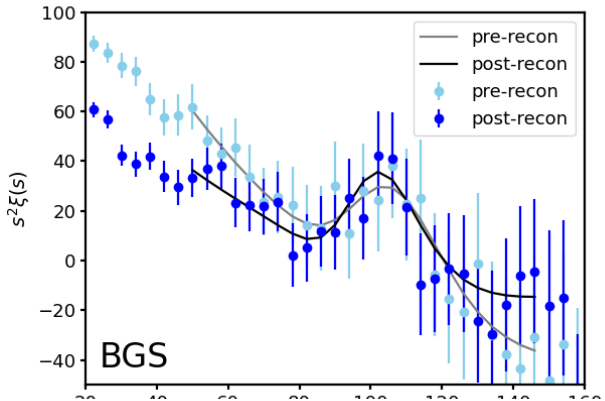
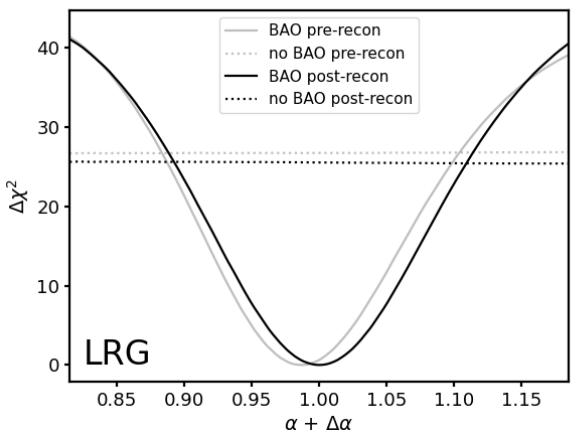
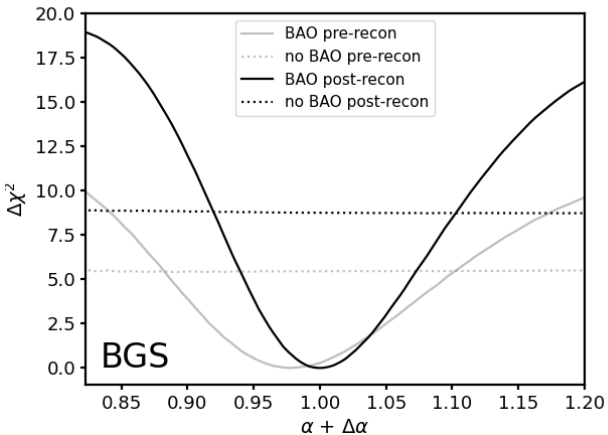
BAO Detection: Main Results









LRGs → ~5σ with 1.7% precision

(BOSS DR9 1.6%, DR12 1.0%, 0.43 < z < 0.7)

BGS → ~3σ with 2.6% precision

(BOSS DR12 1.7%, 0.15 < z < 0.43)

Shifted α values by $\Delta\alpha$

→ min$\Delta\chi^2$ of post-recon LRG is at unity

→ Mag of shift < 1σ → fid. cosmology consistency

Sample	Reconstruction	BAO Detection Significance	$\alpha + \Delta\alpha$	min(χ^2)/dof
DESI-M2 LRG	Pre-recon	5.170	0.987 ± 0.016	15.619 / 20
	Post-recon	5.050	1.000 ± 0.017	13.463 / 20
DESI-M2 BGS	Pre-recon	2.337	0.980 ± 0.040	13.172 / 20
	Post-recon	2.963	1.001 ± 0.026	16.724 / 20

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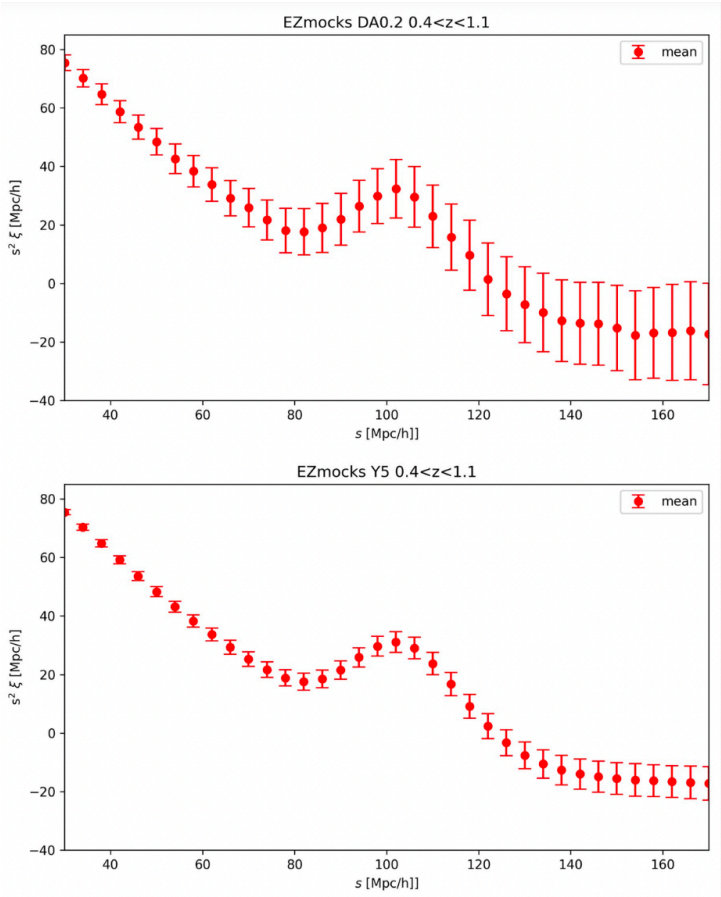
Fisher Forecasts: DESI-M2 LRG

- Fisher on LRG isotropic BAO scale
- Post-recon EZmock DESI-M2 LRG cov + Post-recon Ezmock cov Y5 + Best-fit monopole for DESI-M2
- Factor of ~**5.8** improvement for full survey →
  ~0.29% BAO precision expected for Y5 LRG sample over 0.4 < z <1.1



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Outreach & Promoting DESI

APS April 2023

First Detection of the BAO Signal from Early DESI Data

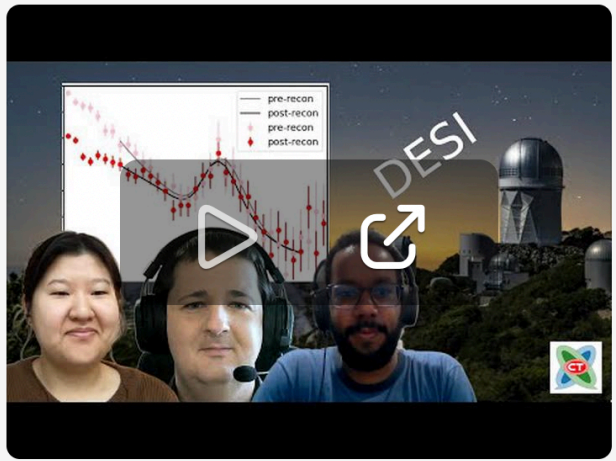
Tue. April 18, 1:42 p.m. – 1:54 p.m. GMT-5
Marquette V - 2nd Floor

We present the detection of the baryon acoustic oscillations (BAO) signal using unblinded data collected during the initial two months of operations of the Stage-IV ground-based Dark Energy Spectroscopic Instrument (DESI). From 261,291 Luminous Red Galaxies spanning redshifts $0.4 < z < 1.1$ and 1651 sq. deg. with a 57.9% completeness, we report a 5σ level BAO detection at a precision of 1.7%. Using 630,480 Bright Galaxy Sample over $0.1 < z < 0.5$, 3677 sq. deg. with a 50.0% completeness, we also detect the BAO feature at 3σ significance with a 2.6% precision. These are an important milestone which confirms the choice of the survey design, quality performance of the complex robotically-actuated, fiber-fed DESI spectrograph, validates the spectroscopic pipeline and data management system. Based on these first promising results, we forecast that DESI is on target to achieve a high-significance BAO detection at a sub-percent accuracy with the completed 5-year survey data, meeting the Level 1 science requirements on BAO measurement precision. This will set novel standards in cosmology, and confirm DESI as one of the most competitive Stage-IV BAO experiments for large-scale spectroscopic surveys for the remainder of this decade.

Presented By

- Michael Rashkovetskyi (Center for Astrophysics | Harvard & Smithsonian)

Cosmology Talks - Youtube



Actual DESI Results! - BAO with BOSS Precision after just two months (Moon, Valcin & Saulder)

Cosmology Talks 구독자 1.77천명 구독 22 공유 클립

조회수 492회 2023. 5. 13.
For notifications about Cosmology Talks miniworkshops and live discussions, sign up to mailing list here:
https://forms.gle/jT1KfGKf6qTUMtnE8

Jeongin Moon, David Valcin and Christoph Saulder tell us about the first cosmologically relevant results from DESI (The Dark Energy Spectroscopic Instrument). Specifically, they are presenting the first detection of the BAO (Baryon Acoustic Oscillations) from DESI.

With a "first detection" one would expect something mediocre, but even this result, using only two months of DESI data, has similar precision to the final BOSS data after years of operation. This is a very exciting time for cosmology as we wait for the full one year DESI results and cosmological constraints.

Jeongin, David and Christoph talk us through the galaxy subsets DESI will use (and which they have used in this analysis) as well as the statistical significance of the BAO detection and modelling required to quantify this.

With this detection they are able to also provide a forecast for the one year and five year results that is actually data driven, based on what they've actually seen so far (rather than just optimistic modelling). The forecast for the five year measurement looks exquisite.

Cosmology from Home - Online conference

C. Saulder J. Moon D. Valcin M. Rashkovetskyi | First Detection of BAO Signal from Early DESI Data

일부 공개

Cosmology from Home 구독자 974명 구독 좋아요 공유 클립

조회수 61회 2023. 6. 27.
Parallel Talk | Cosmology from Home 2023
https://www.cosmologyfromhome.com/

Talk title: First Detection of the BAO Signal from Early DESI Data
Speakers: Christoph Saulder, Jeongin Moon, David Valcin & Michael Rashkovetskyi

Talk abstract:
The Dark Energy Spectroscopy Instrument (DESI) is a highly efficient multiobject fibre spectrograph that has been designed to measure the expansion rate of the universe over a wide redshift range using the baryon acoustic oscillations (BAO). We present the first detection of the BAO signal using a selected sample of luminous red galaxies at already up to 5σ level obtained during the first two months of observation. Using this early data as well as simulations, we forecast DESI to achieve a high-significance BAO detection at sub-percent precision with the completed 5-year survey data. This exquisite level of precision will set new standards in cosmology and confirm DESI as the most competitive BAO experiment for the remainder of this decade.

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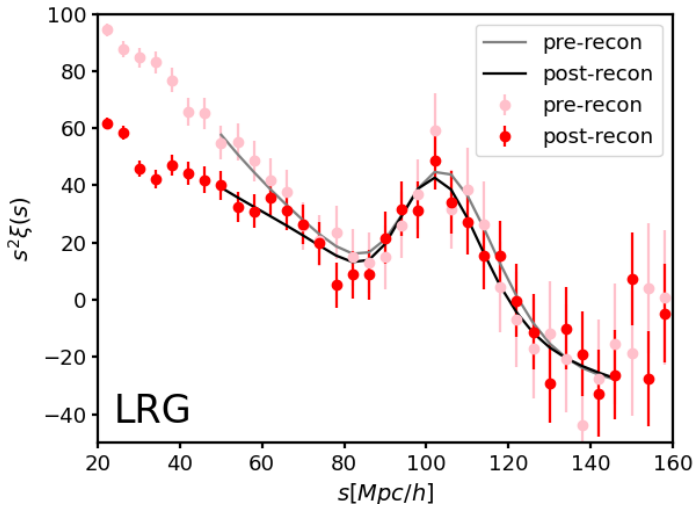
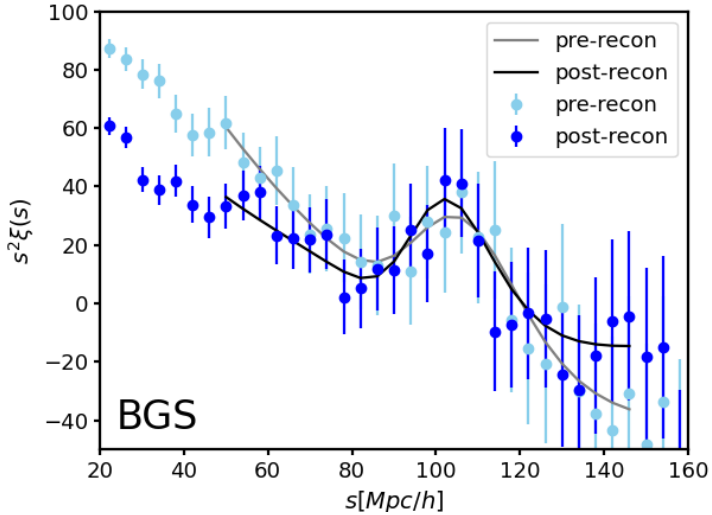
Summary, Contributions, Impact





Key Results

- **DESI-M2 LRG** $\rightarrow 5\sigma$ BAO detection with 1.7% precision
- **DESI-M2 BGS** $\rightarrow 3\sigma$ BAO detection with 2.6% precision

Main Messages

1. **Key milestone** $\rightarrow$ 2 months of DESI data $\equiv$ BOSS DR12
2. Early validation of DESI spectroscopic pipeline and data management system + spectrograph quality control
3. DESI on target to achieve 0.29% precision BAO detection with Y5 LRG sample $\rightarrow$ set novel standards in cosmology