Title: Cosmology from the DESI Data Release 1

Speakers: Otávio Alves

Collection/Series: Cosmology and Gravitation

Subject: Cosmology

Date: October 22, 2024 - 11:00 AM

URL: https://pirsa.org/24100119

Abstract:

On April 4th, 2024, the Dark Energy Spectroscopic Instrument (DESI) released its first set of cosmological results based on measurements of the baryon acoustic oscillations (BAO) scale in the spatial distribution of galaxies and quasars, and in the Lyman-alpha forest. Those measurements constrain the expansion history of the Universe in the redshift range 0.1 < z < 4.16, with implications for studies of dark energy, neutrino cosmology and the Hubble constant. To make the most of the cosmological information content of the galaxy & quasar distributions, we now analyze the full shape of their power spectra, constraining the evolution of the large scale structure of the Universe over the range 0.1 < z < 2.1. In this talk, following a brief overview of the DESI instrument and observations, we will present the latest public results, discuss some of their main cosmological implications, highlight efforts towards the full shape results and expectations for the next data release.

DARK ENERGY SPECTROSCOPIC INSTRUMENT

cosmology results from the Data Release 1

Otávio Alves
University of Michigan

OUTLINE

1. DESI
2. The instrument
3. Baryon acoustic oscillations
4. Cosmology results
5. The future

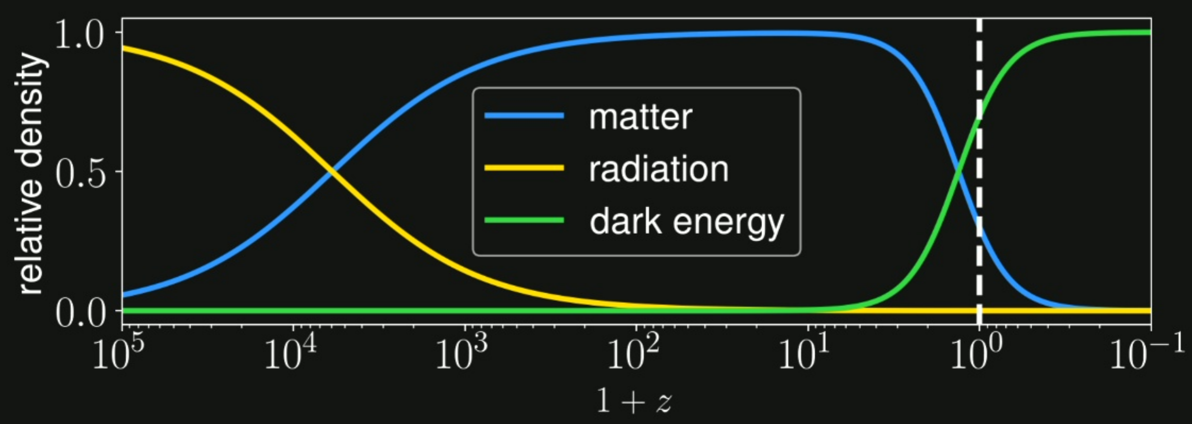
Art: Jonathan Reynolds


DARK ENERGY SPECTROSCOPIC INSTRUMENT
• Kitt Peak National Observatory
• Nicholas Mayall telescope
• Tohono O'odham Nation
• 40M spectra
Image: KPNO/NOIRLab/NSF/AURA/P. Marenfeld

DARK ENERGY IS OUR MAIN TARGET 🎯

Characterize the expansion history in the *Dark Energy* era

Baryon acoustic oscillations



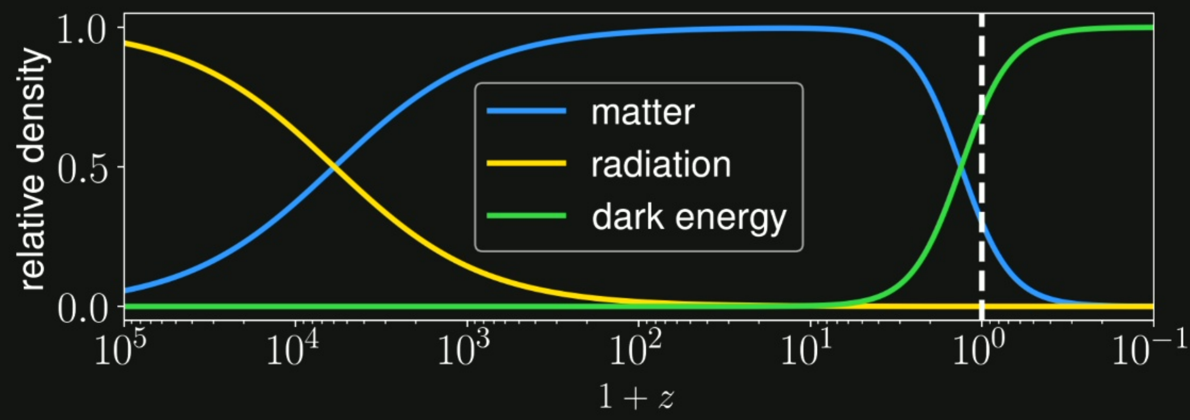
DARK ENERGY IS OUR MAIN TARGET 🎯

Characterize the expansion history in the *Dark Energy* era

Baryon acoustic oscillations

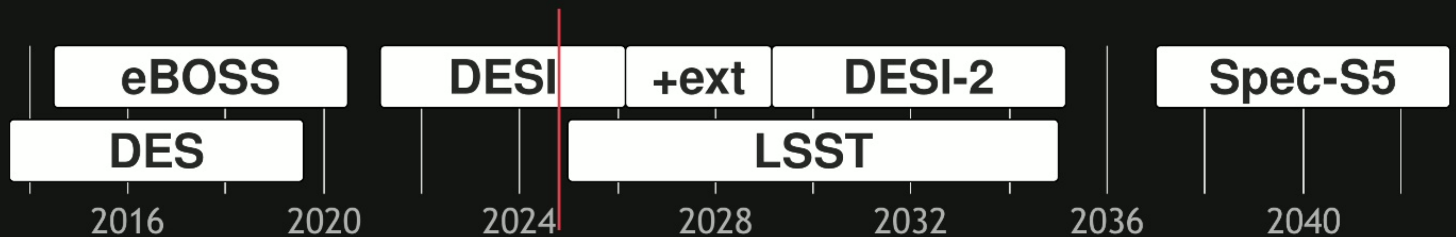
Characterize growth of large scale structure

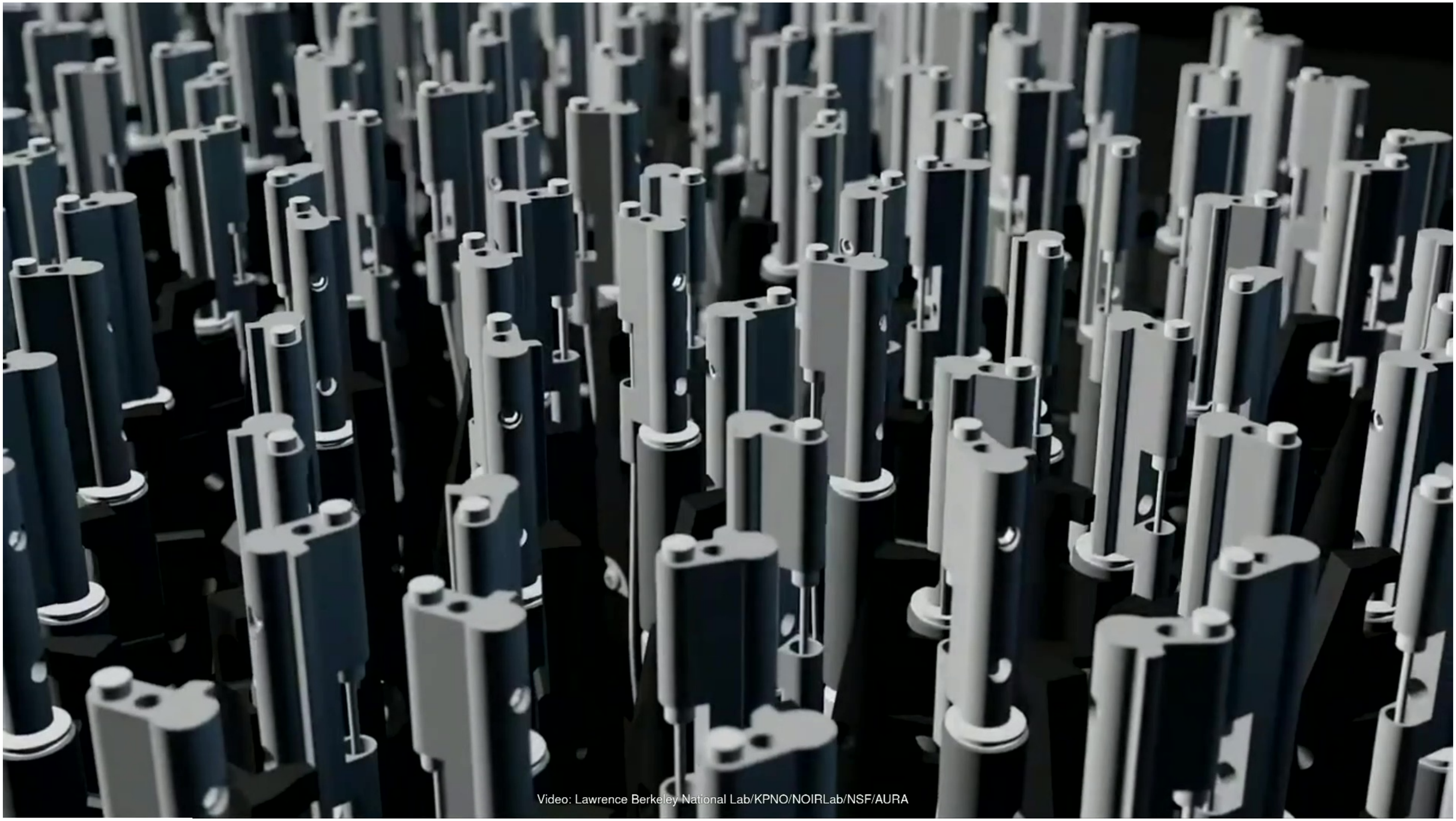
Redshift-space distortions

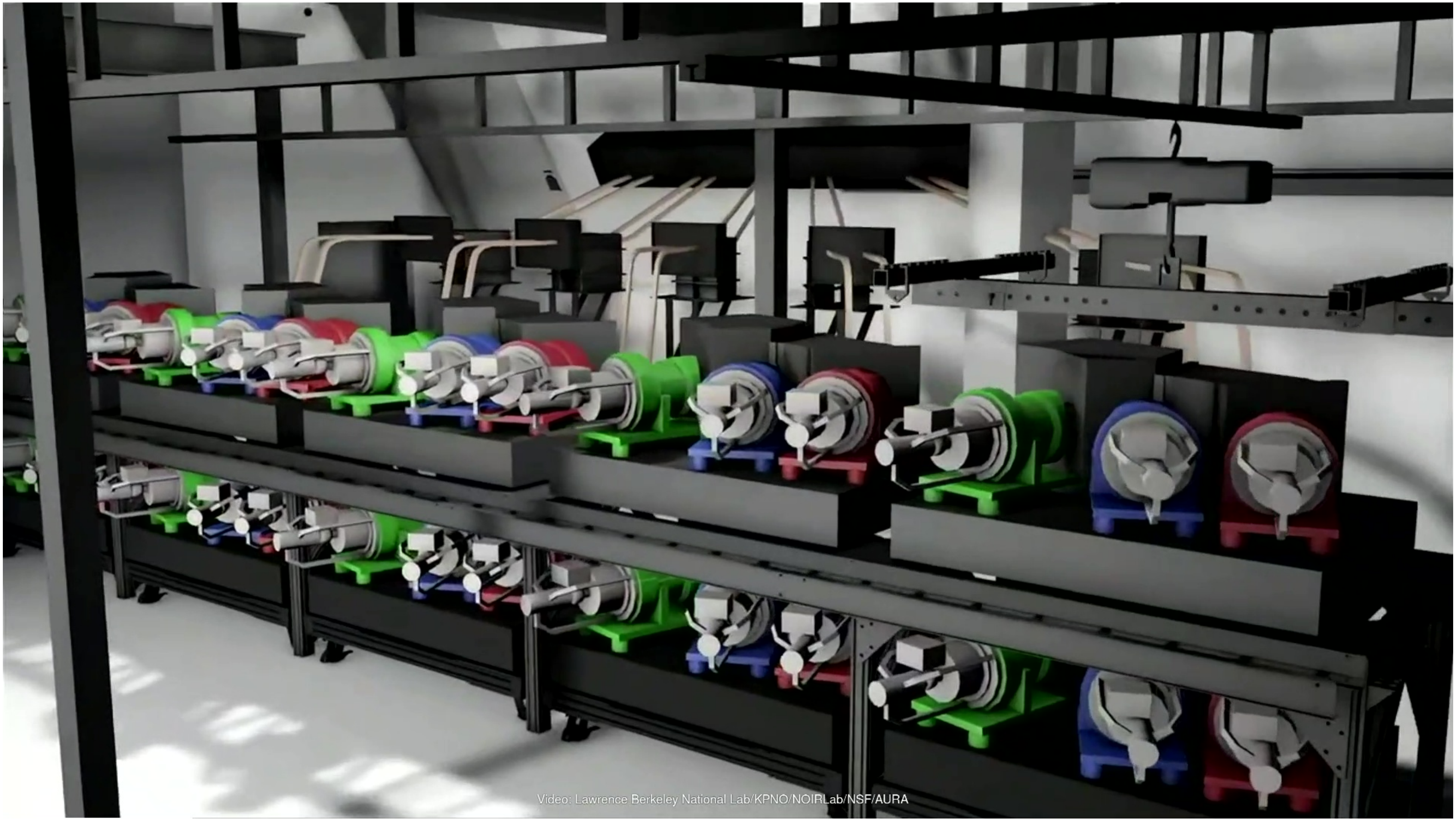


DARK ENERGY TASK FORCE (2006, 2012)

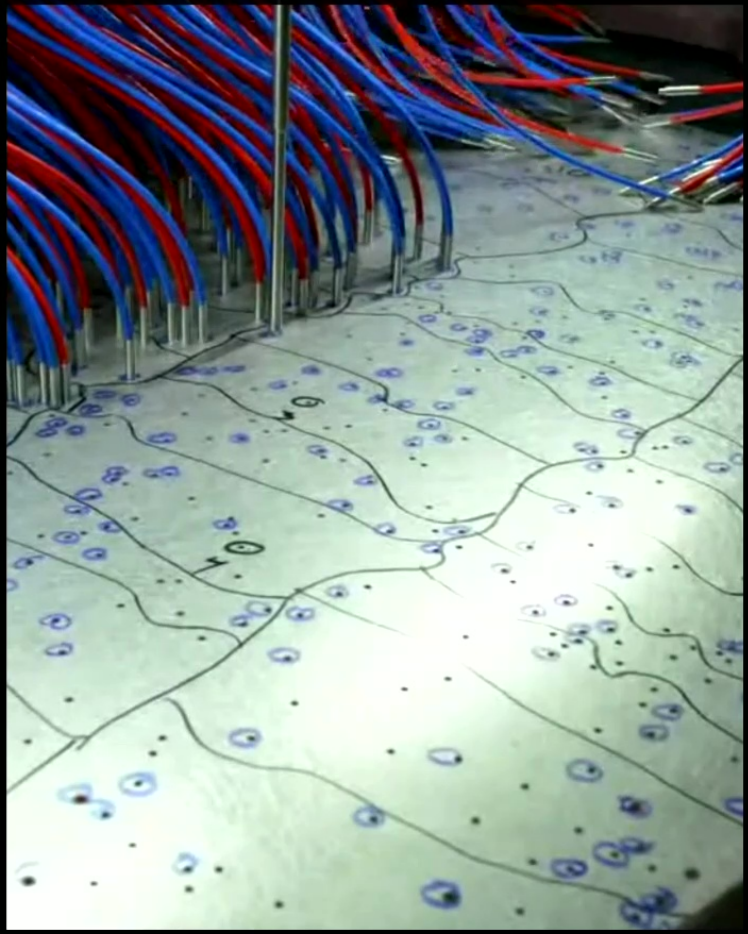
- Stages I & II: Discovery phase & 2000s
- Stage III: BOSS/eBOSS, DES, +
- **Stage IV: DESI, LSST, +**




Video: Lawrence Berkeley National Lab/KPNO/NOIRLab/NSF/AURA


Video: Lawrence Berkeley National Lab/KPNO/NOIRLab/NSF/AURA

SDSS

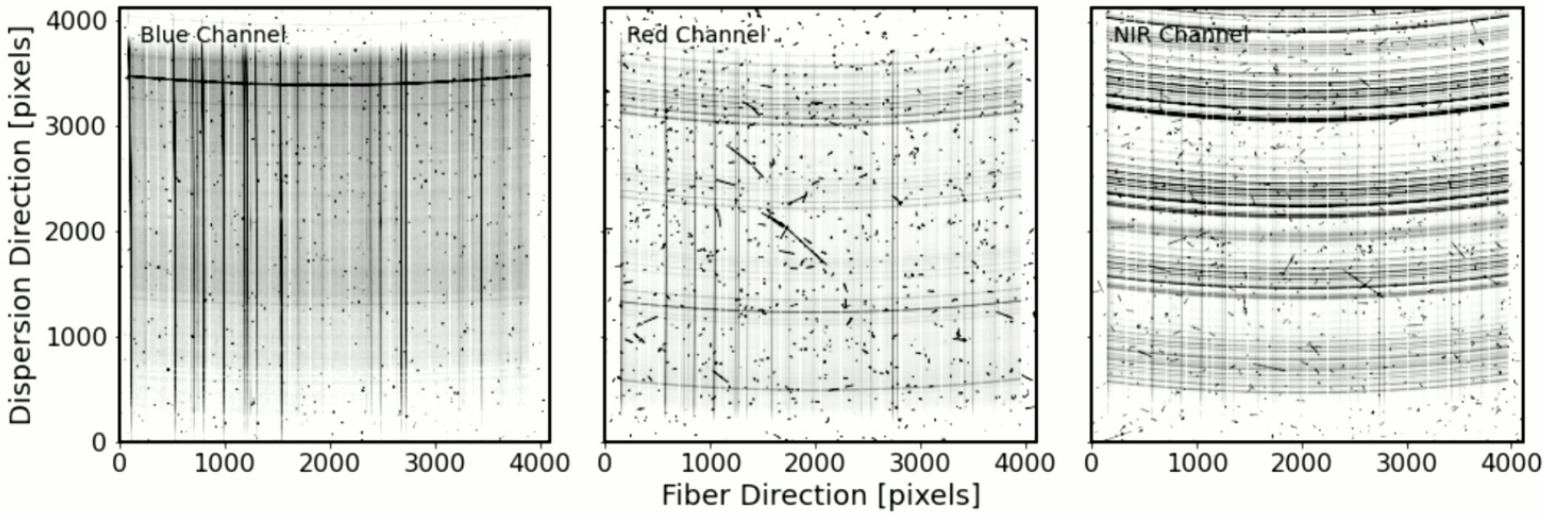


DESI

Videos: Apache Point Observatory (SDSS) & Claire Poppett (DESI)

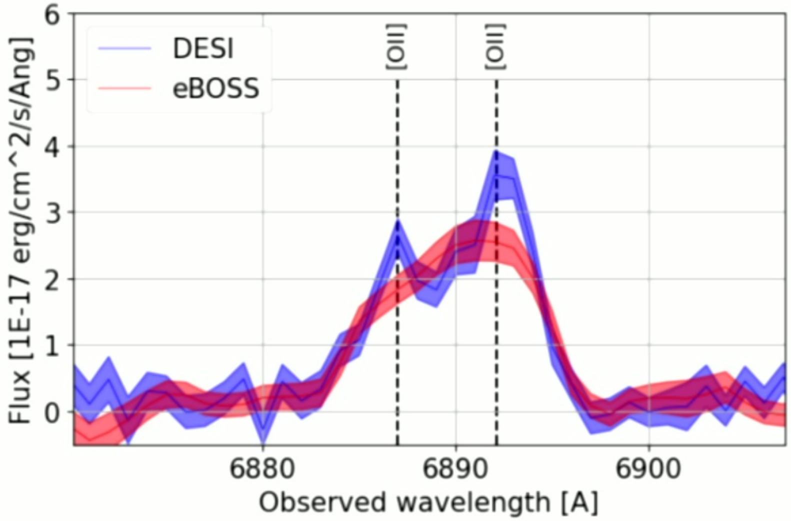

Video: Marilyn Chung/Berkeley Lab

5000 SPECTRA IN 30 MINUTES



Overview of the Instrumentation for DESI (2022)

AT HIGH RESOLUTION



Exposure times:

- **DESI:** 15 minutes
- **eBOSS:** 1 hour

Raichoor et al (2022)

Resulting in a 3D map of galaxies and quasars

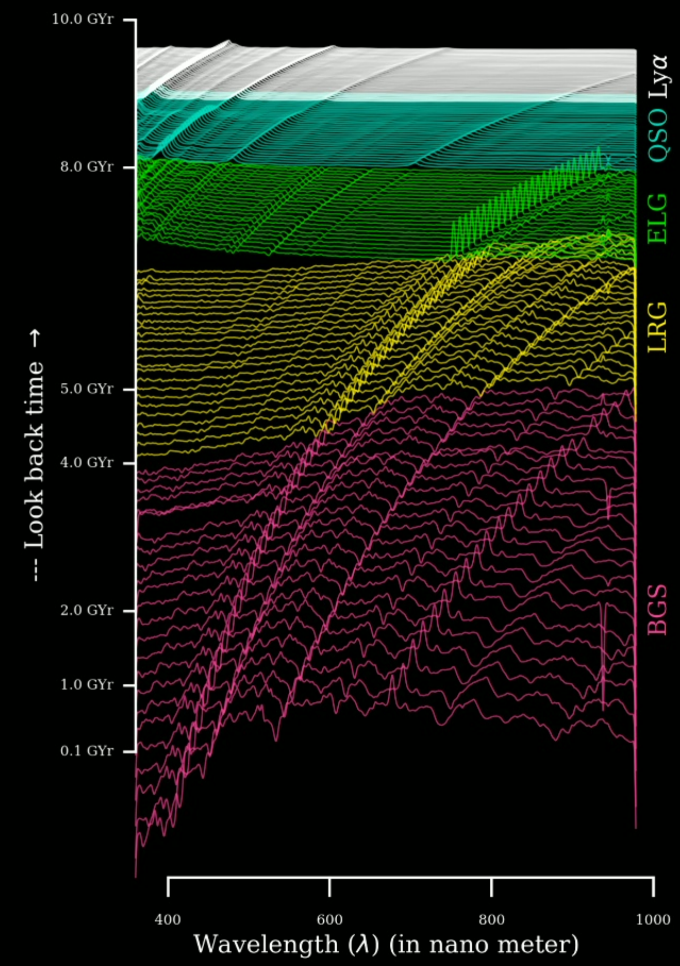


Figure: Shadab Alam

LEGACY SURVEYS

The Astronomical Journal, 157:168 (29pp), 2019 May Dey et al.

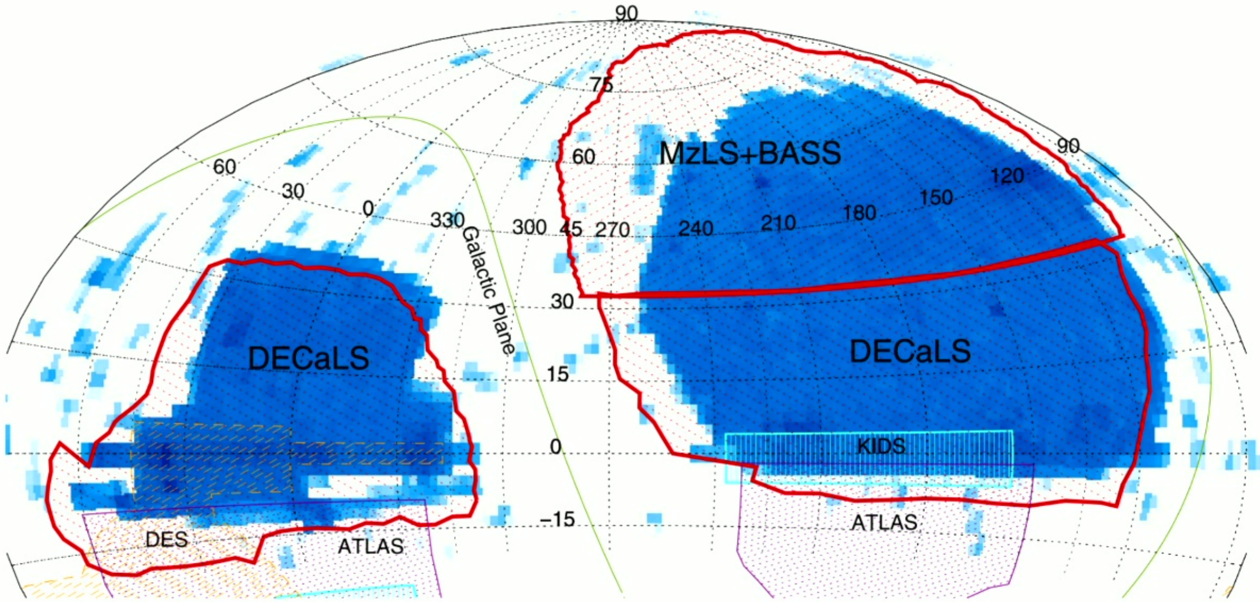


Figure 1. Footprints of the optical imaging surveys contributing to DESI imaging, demarcated by the thick red outlines, are shown here in an equal-area Aitoff projection in equatorial coordinates. The region covered by the BASS and MzLS surveys is almost entirely in the North Galactic Cap (NGC) at declinations $\delta \geqslant +32°$, and DECaLS covers the entire South Galactic Cap and the $\delta \leqslant +34$ regions in the NGC. The regions covered by existing wide-area spectroscopic redshift surveys (SDSS, 2dF, and BOSS; Colless et al. 2001; Abazajian et al. 2009; Abolfathi et al. 2018) are shown in the blue gray scale in the map provided, where the darker colors represent a higher density of spectroscopic redshifts. The Legacy Surveys provide deeper imaging and can leverage the existing spectroscopy in these regions, unlike most other existing or ongoing deep imaging surveys (e.g., DES, ATLAS, KIDS, etc.; The Dark Energy Survey Collaboration 2005; de Jong et al. 2015; Shanks et al. 2015).

Dey et al. (2019)

OBSERVATIONS >70% COMPLETED

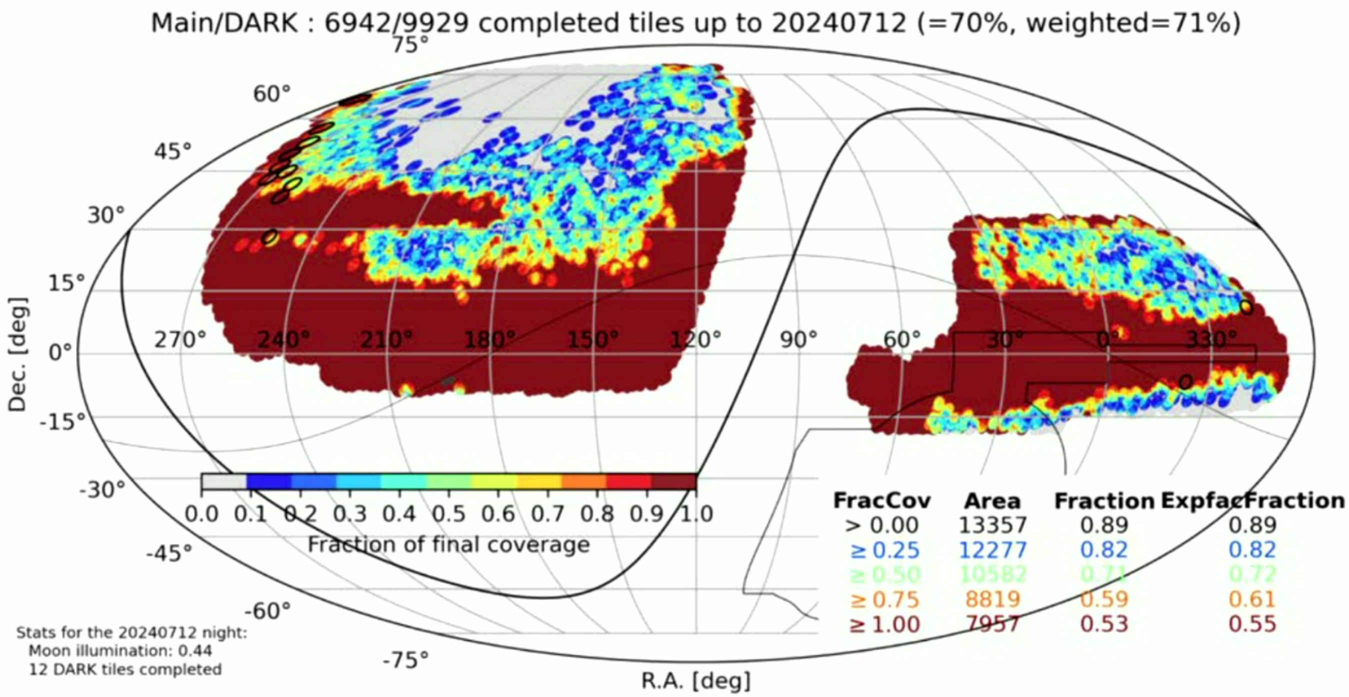


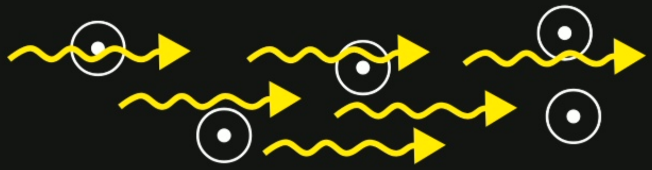
Figure 5. Fraction completed for the dark-time program, with red indicating areas that have achieved full coverage.

BARYON ACOUSTIC OSCILLATIONS

Art: yasai

PHYSICAL MECHANISM

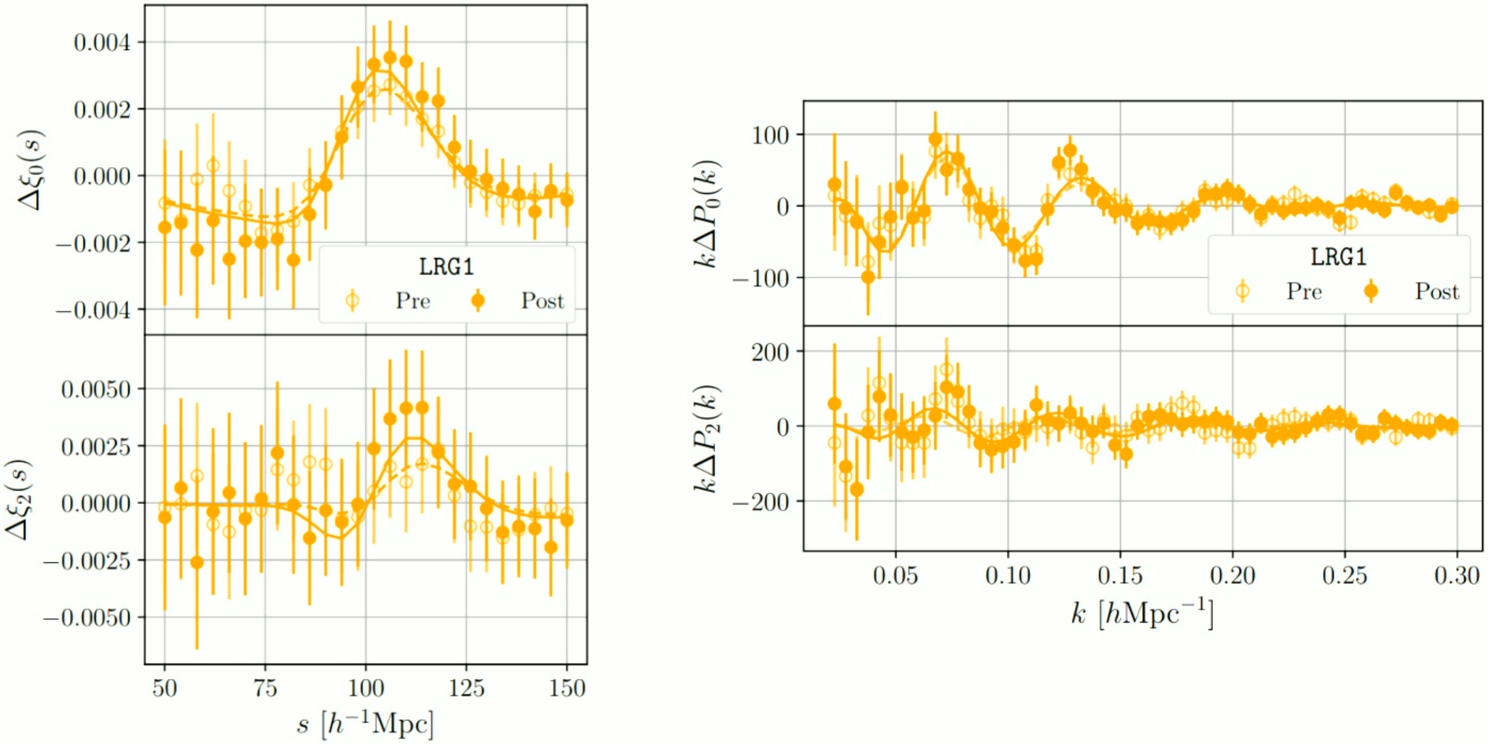
- At $z \approx 1100$, temperature is low enough to form HI. Acoustic oscillations stop.



- Acoustic modes can be observed in the distribution of matter (and photons). Fundamental mode is given by:

$$r_{\rm d} = \int_{z_{\rm d}}^{\infty} \frac{c_{\rm s}(z)}{H(z)} dz$$

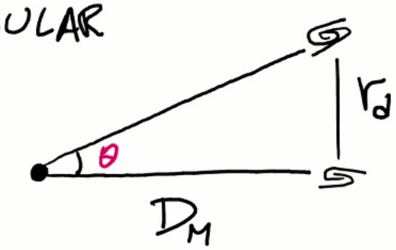
BAO IN THE GALAXY DISTRIBUTION



DESI 2024 III: BAO measurements

BAO AS A STANDARD RULER

ANGULAR



$$\frac{1}{\theta} = \frac{D_M(z)}{r_d} = \frac{c}{r_d}\int_0^z \frac{dz}{H(z)}, \quad H(z) = H_0\sqrt{\Omega_m(1+z)^3 + \dots}$$

RADIAL

$$\frac{\Delta z}{r_d} \sim \frac{c\Delta z}{H(z)} = r_d \implies \frac{1}{\Delta z} = \frac{c}{H(z)\, r_d} \equiv \frac{D_H(z)}{r_d}$$

ANOTHER BASIS:

- ISOTROPIC: $\frac{D_V}{r_d} = \left[z\left(\frac{D_M}{r_d}\right)^2\left(\frac{D_H}{r_d}\right)\right]^{1/3}$
- ANISOTROPIC: $\frac{D_M}{D_H}$

THE BAO MEASUREMENTS

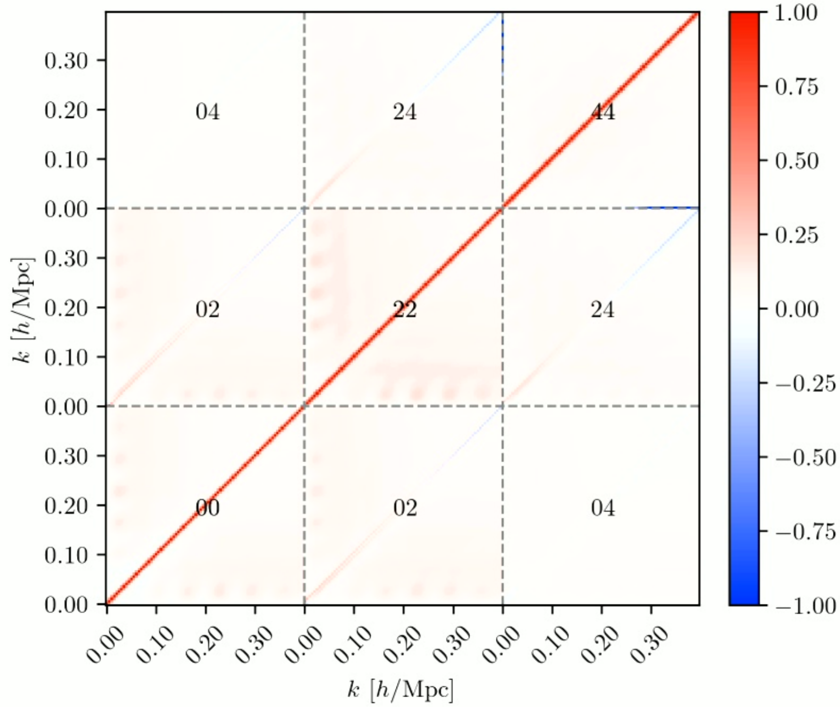
tracer	redshift	N_{tracer}	z_{eff}	D_M/r_d	D_H/r_d	r or D_V/r_d	V_{eff} (Gpc^3)
BGS	$0.1-0.4$	300,017	0.30	—	—	7.93 ± 0.15	1.7
LRG	$0.4-0.6$	506,905	0.51	13.62 ± 0.25	20.98 ± 0.61	-0.445	2.6
LRG	$0.6-0.8$	771,875	0.71	16.85 ± 0.32	20.08 ± 0.60	-0.420	4.0
LRG+ELG	$0.8-1.1$	1,876,164	0.93	21.71 ± 0.28	17.88 ± 0.35	-0.389	6.5
ELG	$1.1-1.6$	1,415,687	1.32	27.79 ± 0.69	13.82 ± 0.42	-0.444	2.7
QSO	$0.8-2.1$	856,652	1.49	—	—	26.07 ± 0.67	1.5
Lya QSO	$1.77-4.16$	709,565	2.33	39.71 ± 0.94	8.52 ± 0.17	-0.477	—

Table 1. Statistics for the DESI samples used for the DESI DR1 BAO measurements used in this paper. For each tracer and redshift range we quote the number of objects (N_{tracer}), the effective redshift (z_{eff}) and effective volume (V_{eff}). Note that for each sample we measure either both D_M/r_d and D_H/r_d, which are correlated with a coefficient r, or D_V/r_d. Redshift bins are non-overlapping, except for the shot-noise-dominated measurements that use QSO (both as tracers and for Lyα forest).

DESI 2024 VI: BAO cosmology


Johannes Lange
DESI x lensing
Sikandar Hanif
Fiber assignment
Minh Nguyen
Cosmology analysis
Uendert Andrade
Blinding validation
Tianke Zhuang
Cosmology analysis
Otávio Alves
Covariance matrix
Dragan Huterer
co-lead Cosmology analysis
Greg Tarlé
Positioners
Humna Awan
Ly-alpha
Michael Schubnell
Positioners
Monica Valluri
Milky-way science
Tim Fanning
Positioners
Sean MacBride
Focal plane, detectors
Rebekah Sebok
Focal plane
Jiaming Pan
Cosmology analysis

COVARIANCE MATRICES



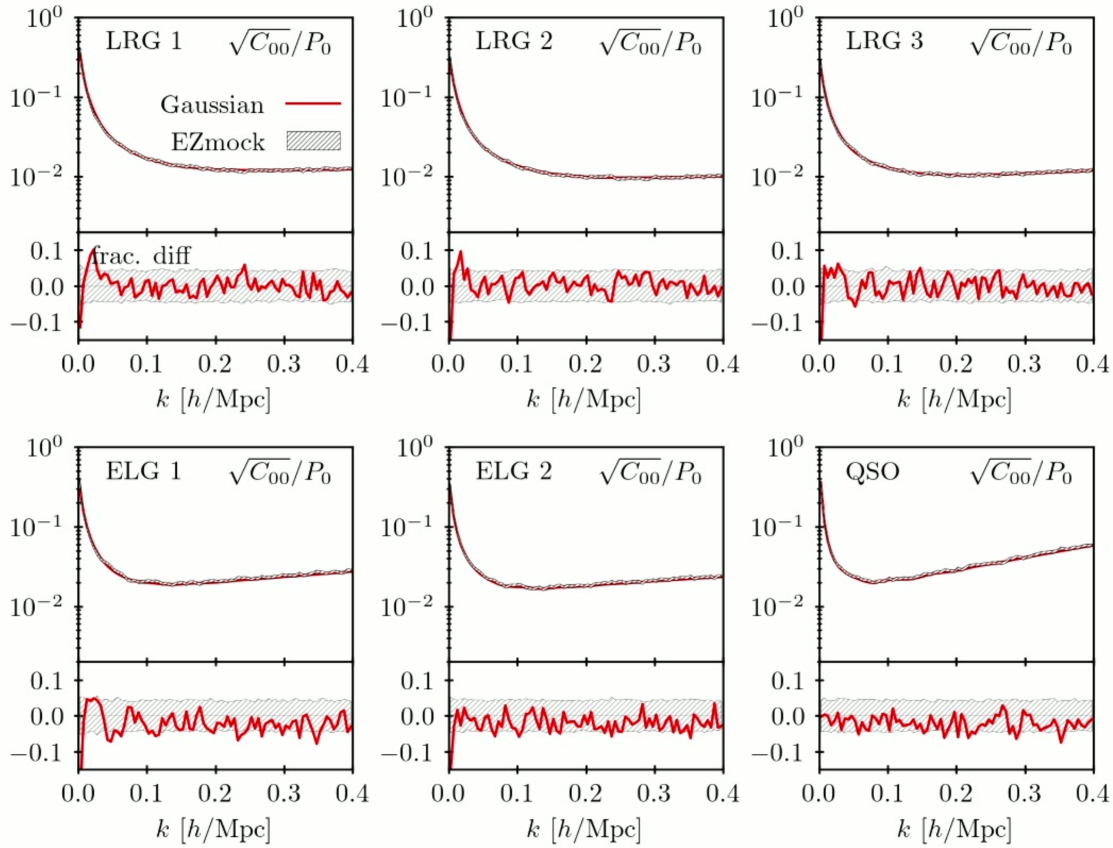
thecov

theoretical covariances of power spectrum multipoles

- Based on **Wadekar & Scoccimarro 2019**.
- Trispectrum at tree-level using **Kobayashi 2023**.

OA et al. (in prep.)

VALIDATED AGAINST MOCKS

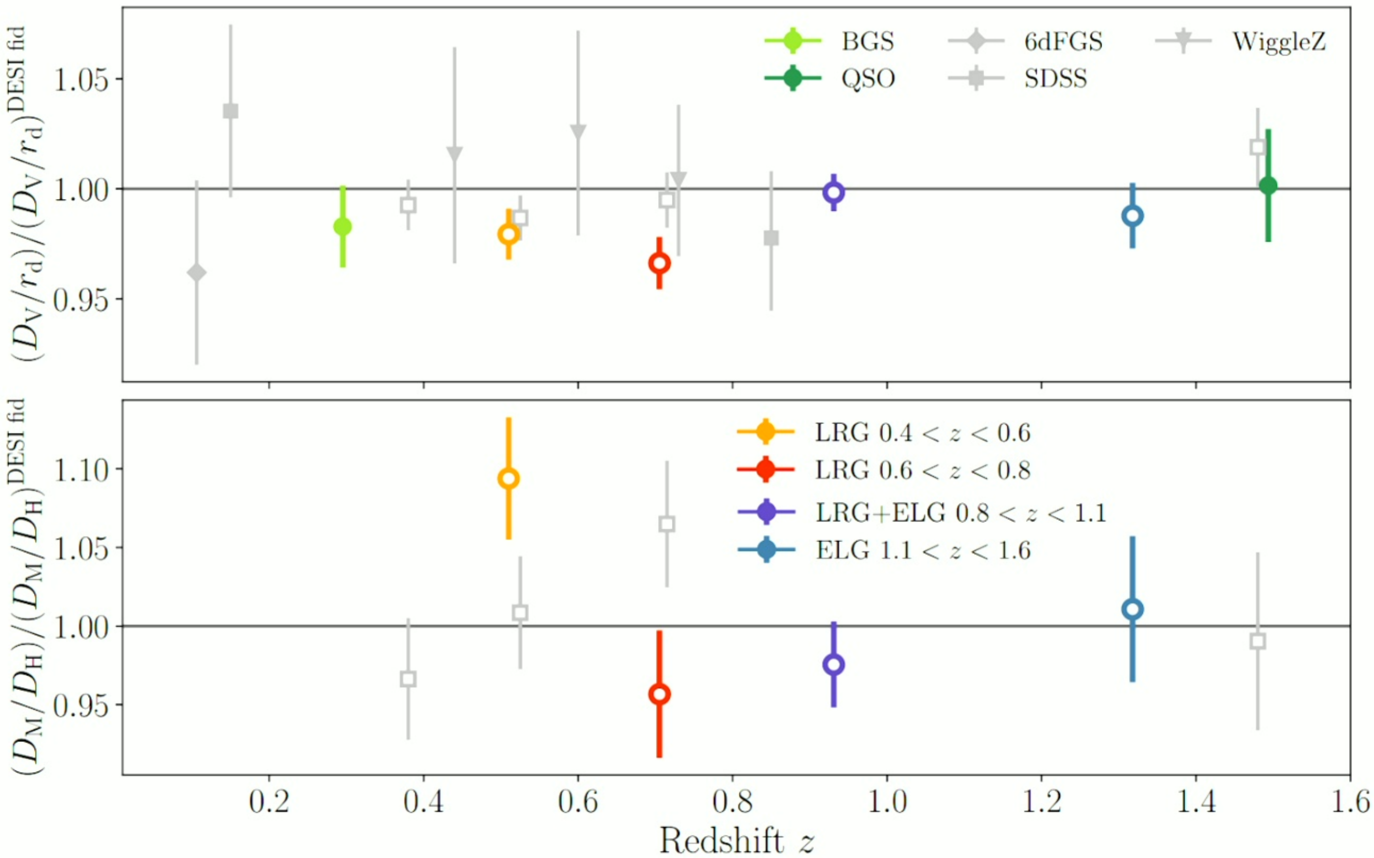


OA et al. (in prep.)

COSMOLOGY RESULTS

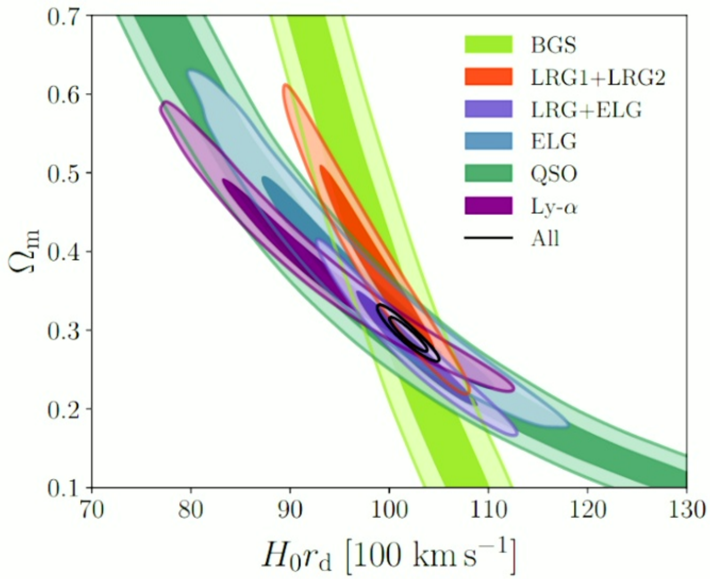
Art: yasai

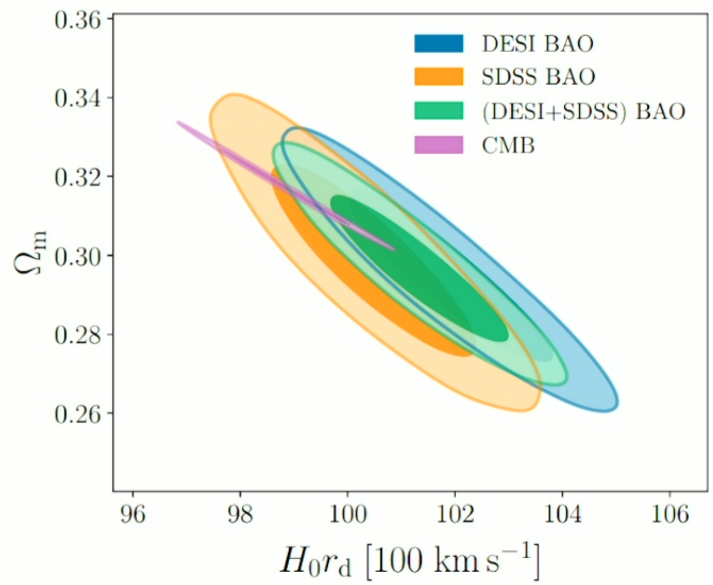
THE BAO MEASUREMENTS



DESI 2024 VI: BAO cosmology

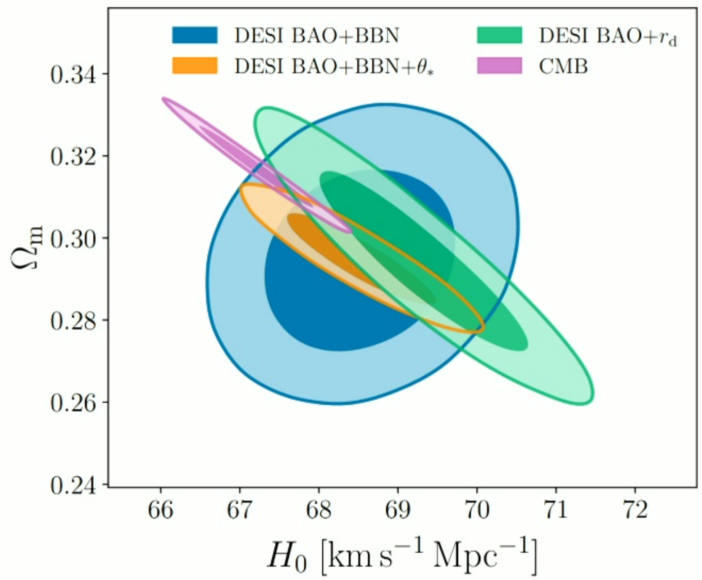
COMBINING BAO FROM MULTIPLE REDSHIFTS

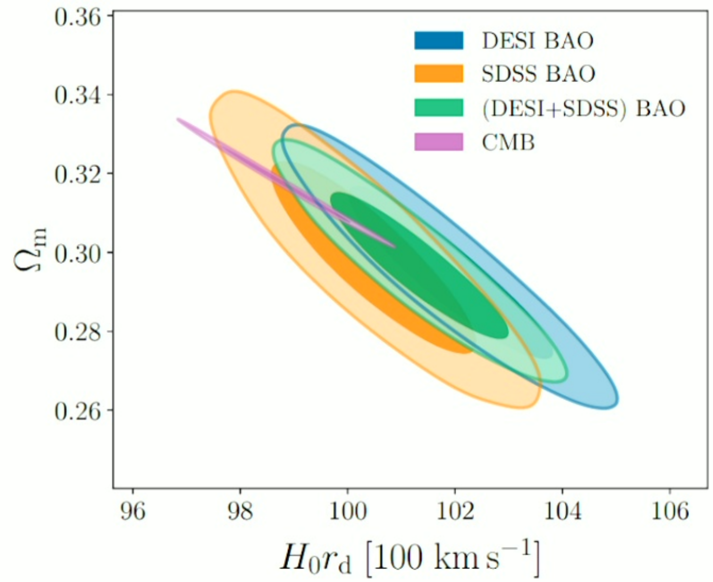




DESI 2024 VI: BAO cosmology

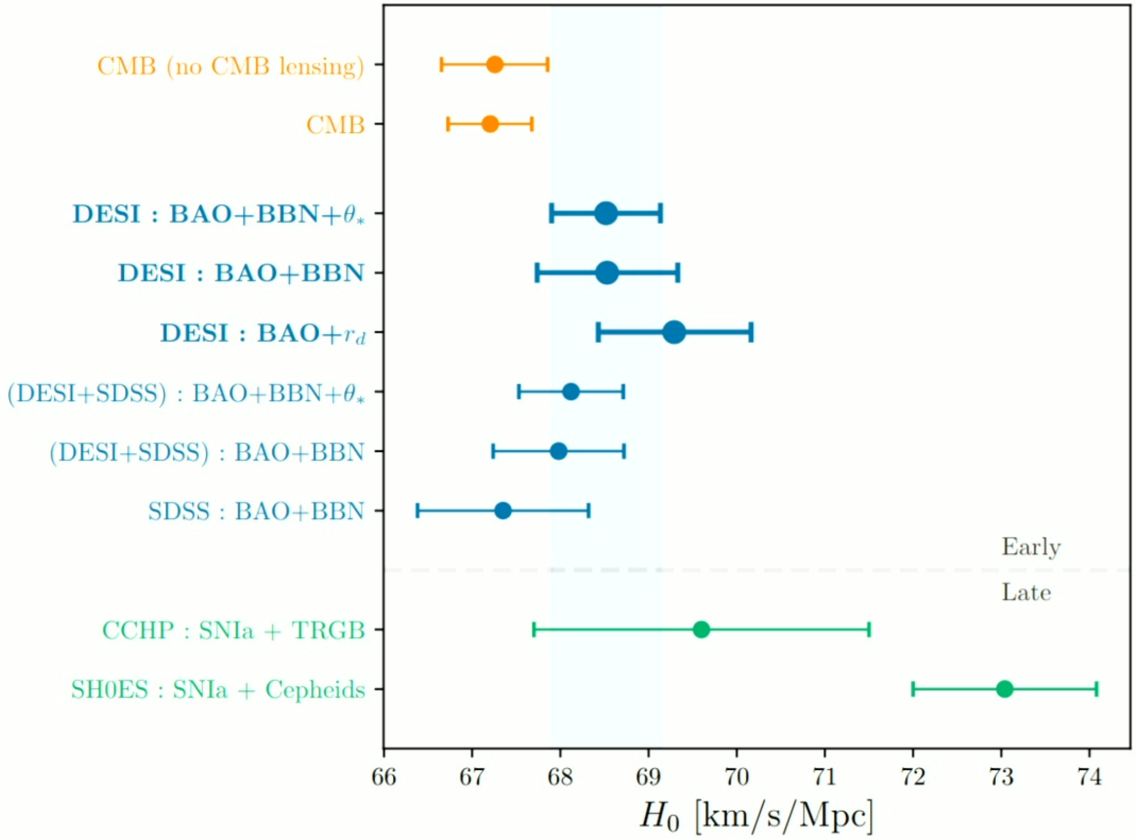
ADDING INFO ON THE SOUND HORIZON SCALE





DESI 2024 VI: BAO cosmology

YIELDS AN H_0 CONSTRAINT



DESI 2024 VI: BAO cosmology


NEUTRINOS
Art: yasai

NEUTRINO MASSES

Neutrino oscillations constrain squared mass **differences**.

Lowest total mass of the neutrino sector:

- Normal hierarchy: 0.059 eV
- Inverted hierarchy: 0.10 eV

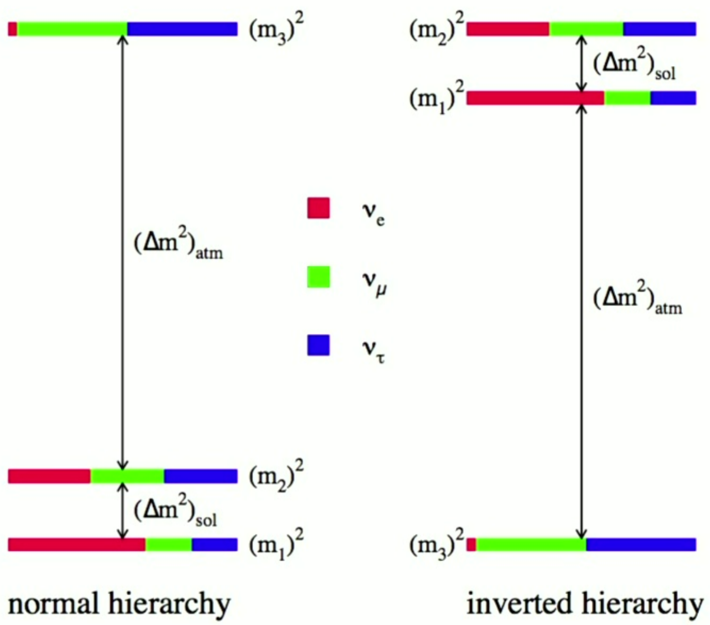


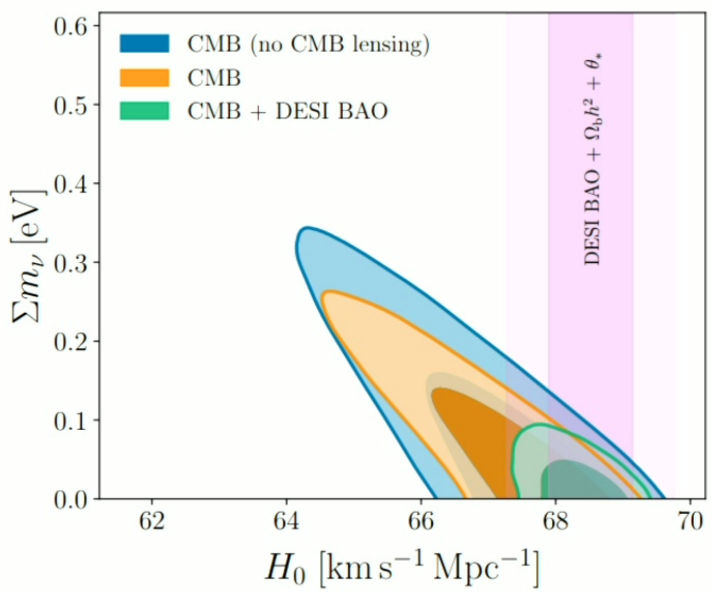
Figure: **Cahn et al. (2013)**

CMB IS SENSITIVE TO THE SUM OF MASSES

angular diameter distance to recombination

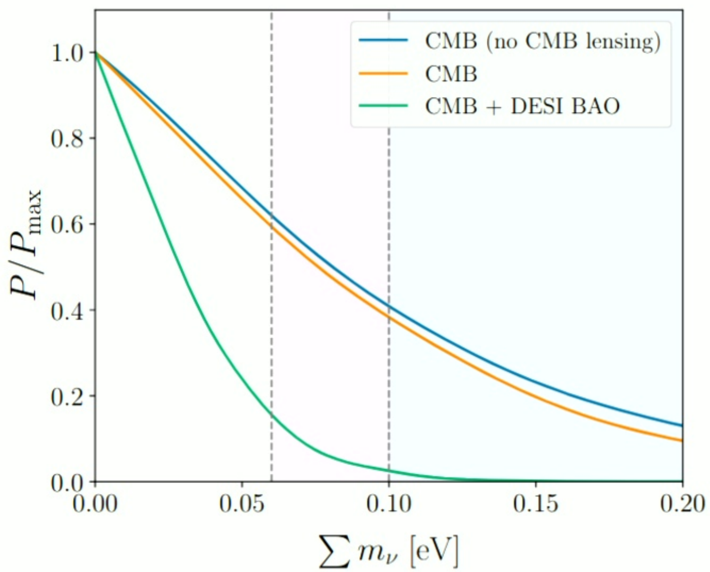
neutrino effects in CMB lensing

But thats's degenerate with the **Hubble constant** and **matter density**.



DESI 2024 VI: BAO cosmology

COMBINING WITH DESI BAO



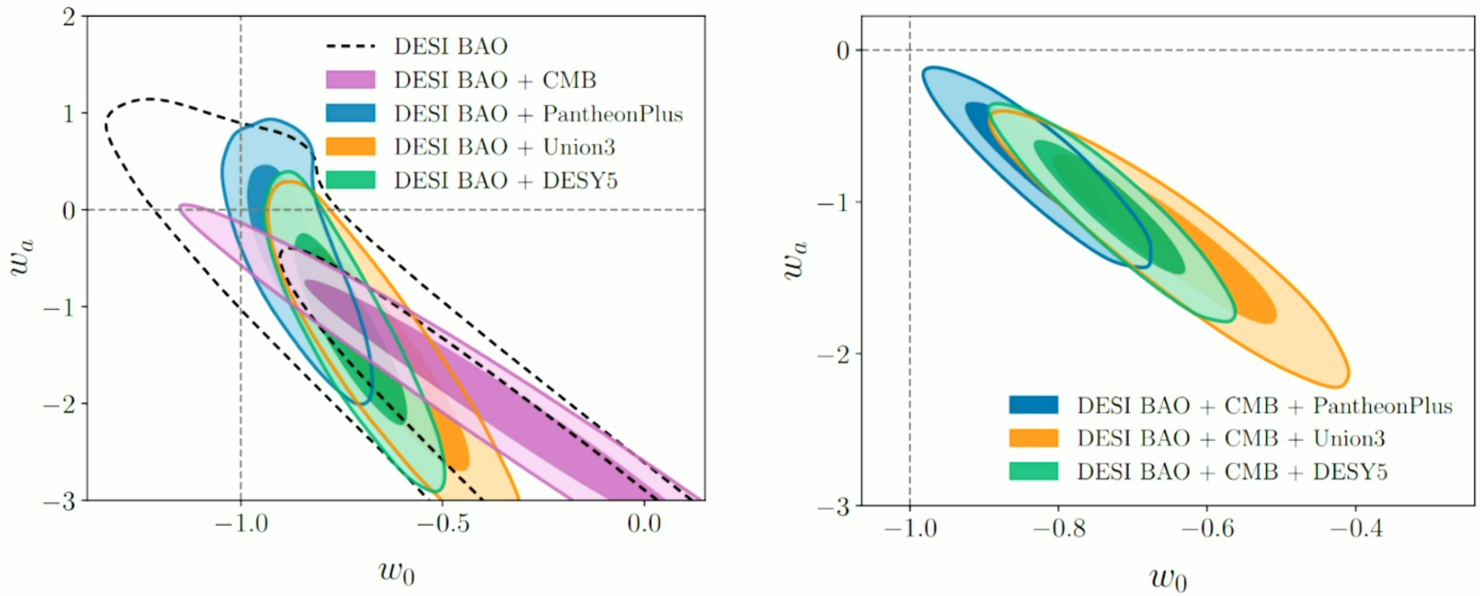
$$\sum m_\nu < 0.072\,\mathrm{eV} \quad (95\,\%,\ \mathrm{DESI\ BAO{+}CMB}),$$

$$\sum m_\nu < 0.113\,\mathrm{eV} \quad (95\,\%,\ \mathrm{DESI\ BAO{+}CMB};\ \sum m_\nu > 0.059\,\mathrm{eV}),$$

$$\sum m_\nu < 0.145\,\mathrm{eV} \quad (95\,\%,\ \mathrm{DESI\ BAO{+}CMB};\ \sum m_\nu > 0.10\ \mathrm{eV}).$$

DESI 2024 VI: BAO cosmology

DESI+SN+CMB → HINTS OF TIME-EVOLVING w



DESI 2024 VI: BAO cosmology

model / dataset	Ω_m	H_0 [km s^{-1} Mpc^{-1}]	Σm_ν [eV]	$N_{\rm eff}$
ΛCDM+$\sum m_\nu$				
DESI+CMB	0.3037 ± 0.0053	68.27 ± 0.42	< 0.072	—
ΛCDM+$N_{\rm eff}$				
DESI+CMB	0.3058 ± 0.0060	68.3 ± 1.1	—	3.10 ± 0.17
wCDM+$\sum m_\nu$				
DESI+CMB	0.282 ± 0.013	$71.1^{+1.5}_{-1.8}$	< 0.123	—
DESI+CMB+Panth.	0.3081 ± 0.0067	67.81 ± 0.69	< 0.079	—
DESI+CMB+Union3	0.3090 ± 0.0082	67.72 ± 0.88	< 0.078	—
DESI+CMB+DESY5	0.3152 ± 0.0065	67.01 ± 0.64	< 0.073	—
wCDM+$N_{\rm eff}$				
DESI+CMB	0.281 ± 0.013	$71.0^{+1.6}_{-1.8}$	—	2.97 ± 0.18
DESI+CMB+Panth.	0.3090 ± 0.0068	67.9 ± 1.1	—	3.07 ± 0.18
DESI+CMB+Union3	0.3097 ± 0.0084	67.8 ± 1.2	—	3.06 ± 0.18
DESI+CMB+DESY5	0.3163 ± 0.0067	67.2 ± 1.1	—	3.09 ± 0.18
w_0w_aCDM+$\sum m_\nu$				
DESI+CMB	$0.344^{+0.032}_{-0.026}$	$64.7^{+2.1}_{-3.2}$	< 0.195	
DESI+CMB+Panth.	0.3081 ± 0.0069	68.07 ± 0.72	< 0.155	—
DESI+CMB+Union3	0.3240 ± 0.0098	66.48 ± 0.94	< 0.185	—
DESI+CMB+DESY5	0.3165 ± 0.0069	67.22 ± 0.66	< 0.177	—
w_0w_aCDM+$N_{\rm eff}$				
DESI+CMB	$0.346^{+0.032}$	$63.9^{+2.2}$	—	2.89 ± 0.17

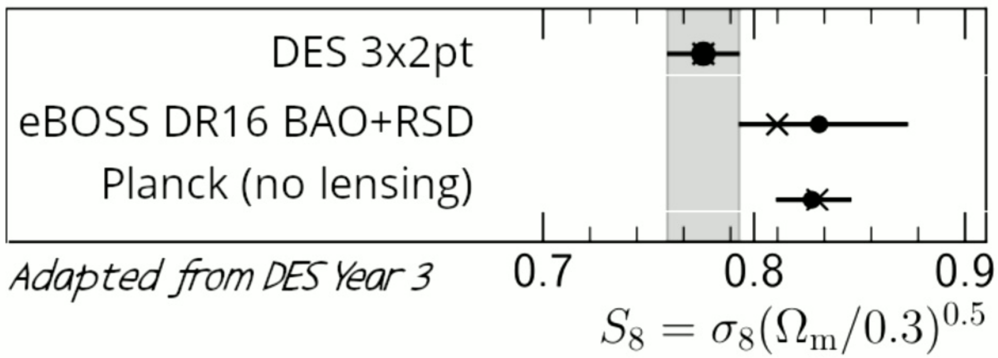
DESI 2024 PAPERS

- DESI 2024 I: First year data release
- DESI 2024 II: DR1 catalogs
- ✅ **DESI 2024 III: BAO from Galaxies and Quasars at $z < 2$**
- ✅ **DESI 2024 IV: BAO from the Lyman-α Forest at $z > 2$**
- DESI 2024 V: RSD from Galaxies and Quasars at $z < 2$
- ✅ **DESI 2024 VI: Cosmological constraints from BAO measurements**
- DESI 2024 VII: Cosmological constraints from RSD measurements
- + many supporting papers.

P.S.: Next BAO release is right around the corner.

EXPECTATIONS FOR FULL-SHAPE MEASUREMENTS

S_8 **"tension"**

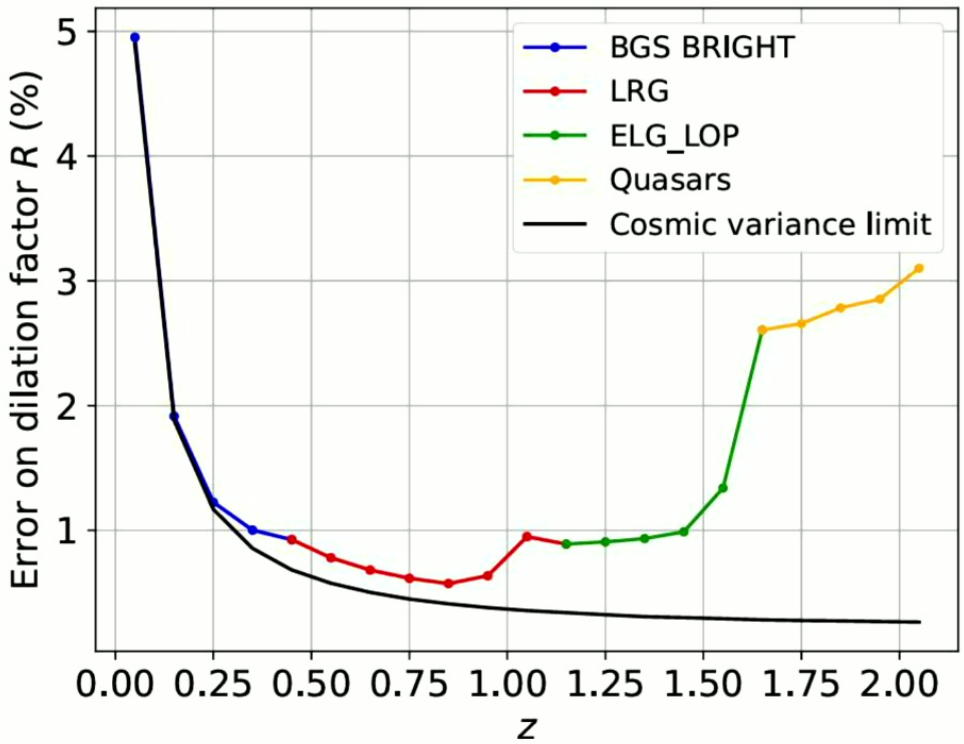


Neutrino masses: addition of broadband information,

Dark energy: impact on growth of structure,

+ other models **beyond ΛCDM**.

THERE'S MARGIN FOR FURTHER IMPROVEMENT



BGS
cosmic variance limited

LRG
new targets and easy redshifts

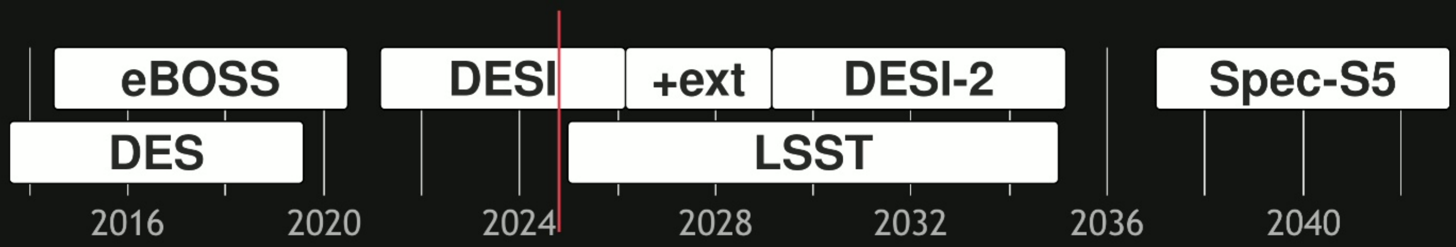
ELG
more targets than fibers

QSO
hard to identify new targets

Figure: Kyle Dawson

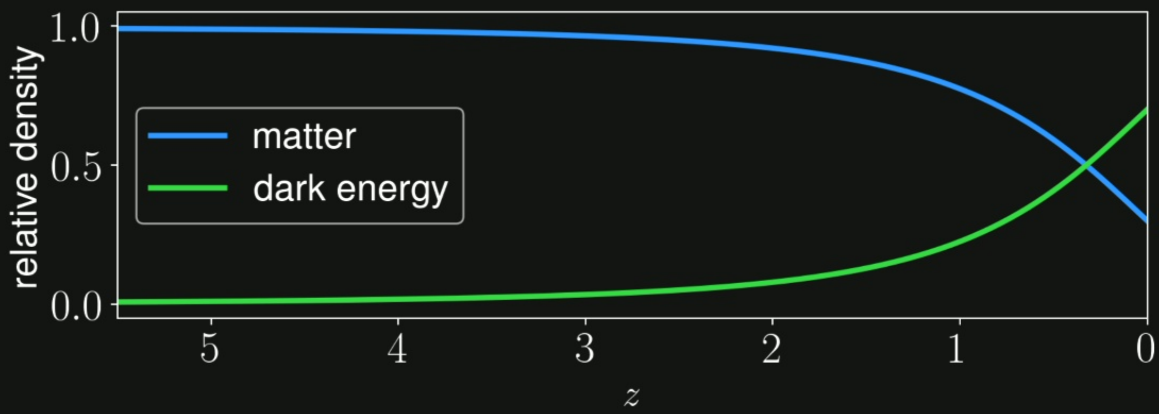
DESI EXTENSION

- Same instrument
- +20% area
- +50% overlap with LSST
- +50% LRG targets



DESI-2

- Focus at higher redshifts: $2.2 < z < 5$
  - More linear modes for primordial physics studies
  - Dark Energy in the matter-dominated era



- Instrument upgrades: Skipper CCDs for blue
- New tracers: Lyman-break galaxies (LBG) & Lyman-α emitters (LAE)

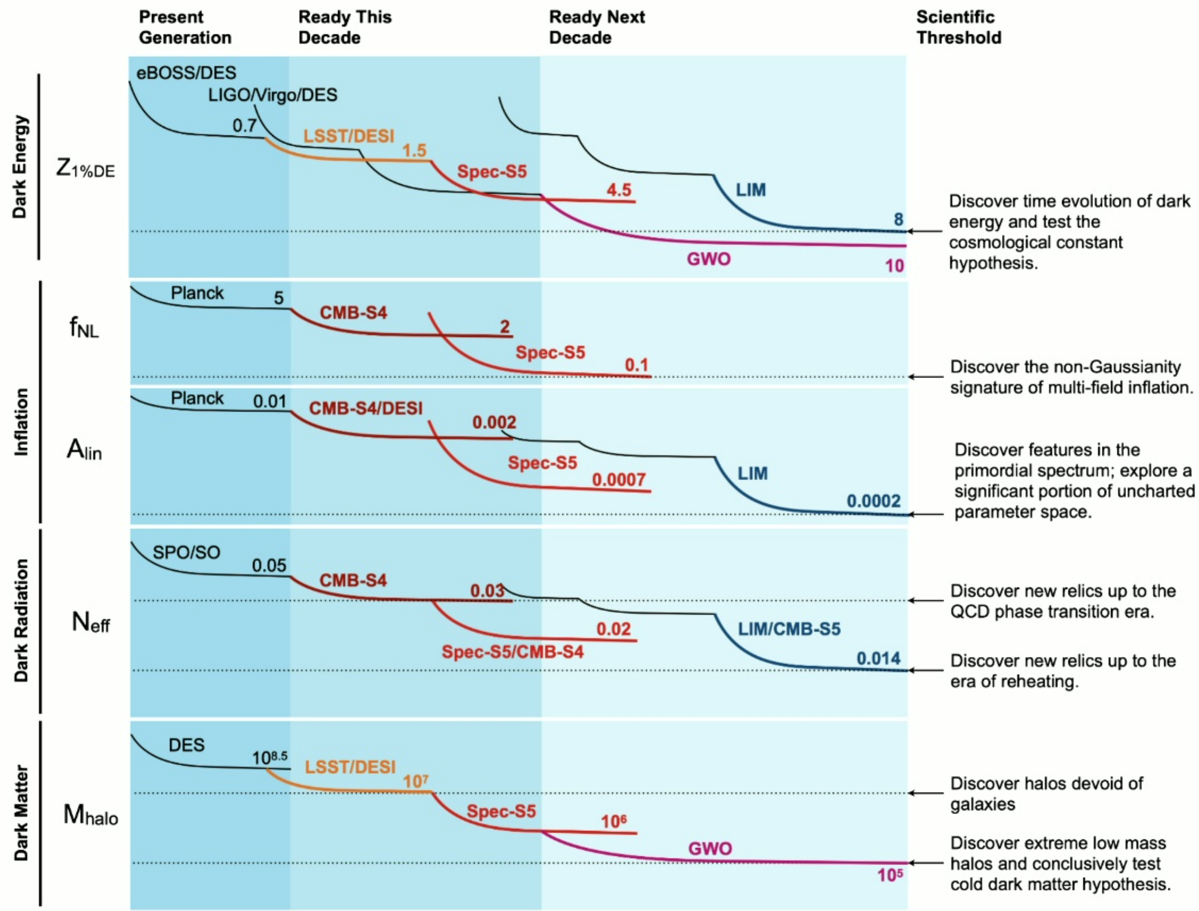
EARLY RESULTS FROM BOTH **DESI** AND LSST WILL **SHAPE** FUTURE PRIORITIES

Together with a potential **DESI upgrade**, they will inform the design of a **next-generation spectroscopic survey** by telling us **which** potential **science goals** should be emphasized.

P5 2023 report

SPEC-S5

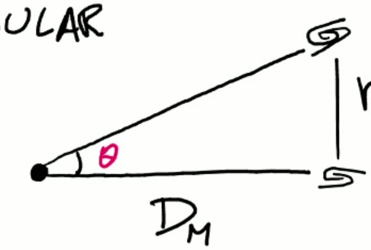
- 2 telescopes: Mayall + Blanco
- Mirror upgrade: from 4m to 6m
- Instrument upgrade: 3 fibers per positioner = 26k fibers per telescope
- Science cases:
  - High redshift program
  - High number density at $z < 2$
  - Milky Way science (50M stellar spectra), stellar streams, dark matter



Snowmass 2021

BAO AS A STANDARD RULER

ANGULAR



$$\frac{1}{\theta} = \frac{D_M(z)}{r_d} = \frac{c}{r_d}\int_0^z \frac{dz}{H(z)}\,, \quad H(z) = H_0\sqrt{\Omega_m(1+z)^3 + \dots}$$

RADIAL

$$\frac{\Delta z}{r_d} \;\mathfrak{S}\; \frac{c\Delta z}{H(z)} = r_d \implies \frac{1}{\Delta z} = \frac{c}{H(z)r_d} \equiv \frac{D_H(z)}{r_d}$$

ANOTHER BASIS:

- ISOTROPIC ◎ $\frac{D_V}{r_d} = \left[z\left(\frac{D_M}{r_d}\right)^2\left(\frac{D_H}{r_d}\right)\right]^{1/3}$
- ANISOTROPIC ⊕ $\frac{D_M}{D_H}$

SUMMARY

- Galaxy spectroscopic surveys entered a new era with DESI
- DR1 BAO measurements have interesting implications for:
  - Neutrinos, Dark Energy
- Full-shape measurements coming up soon
- Next BAO release not long after that
- Spectroscopic surveys = good data for a few decades
- DESI-2 will explore higher redshifts
- Spec-S5 will push constraints in primordial physics