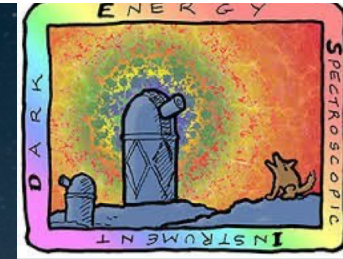


Mapping the Cosmic Expansion History with DESI

Andrei Cuceu

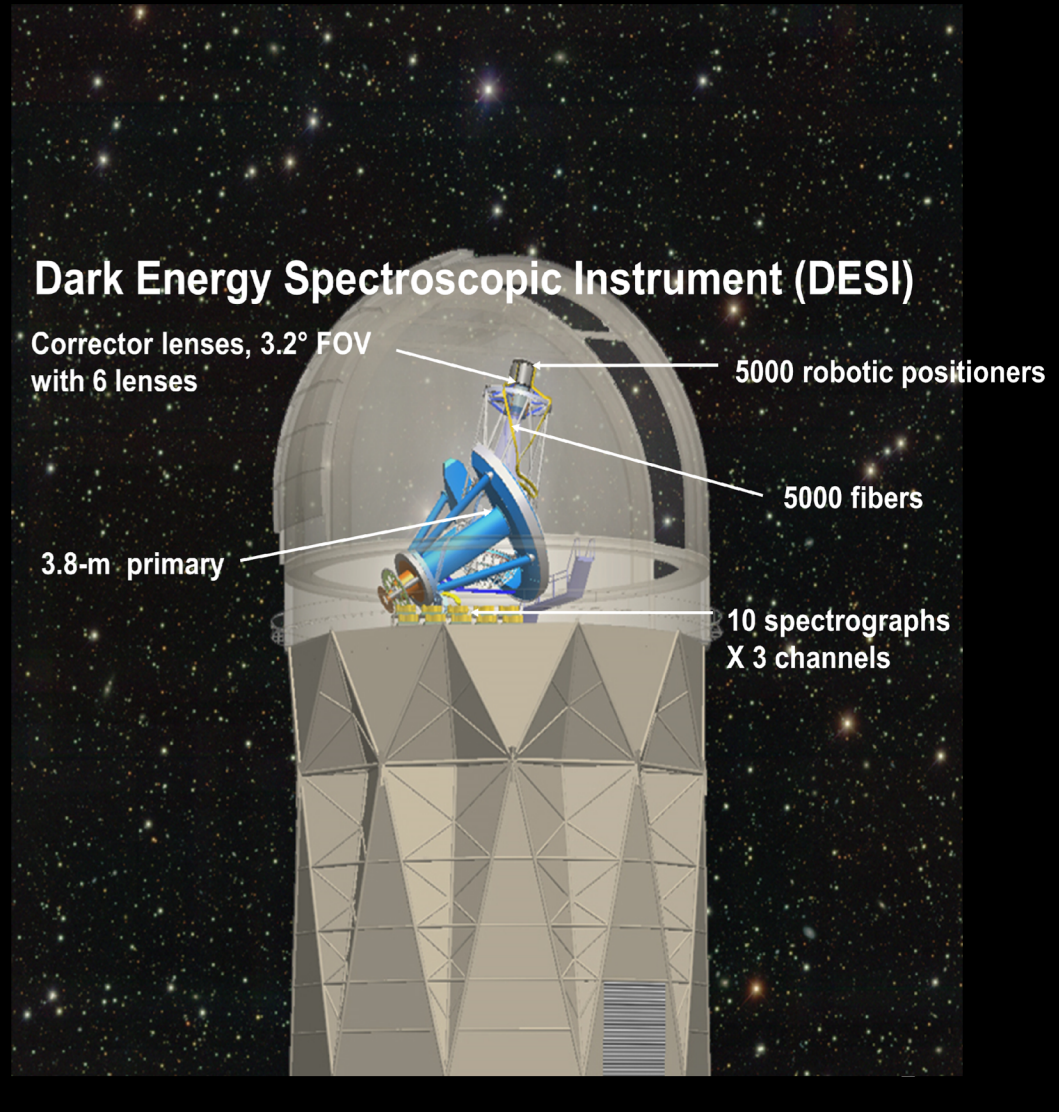
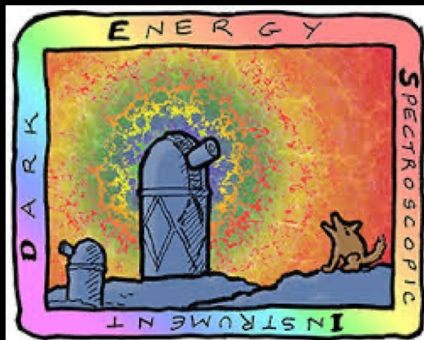
Lawrence Berkeley National Laboratory



NASA Hubble
Fellowship Program

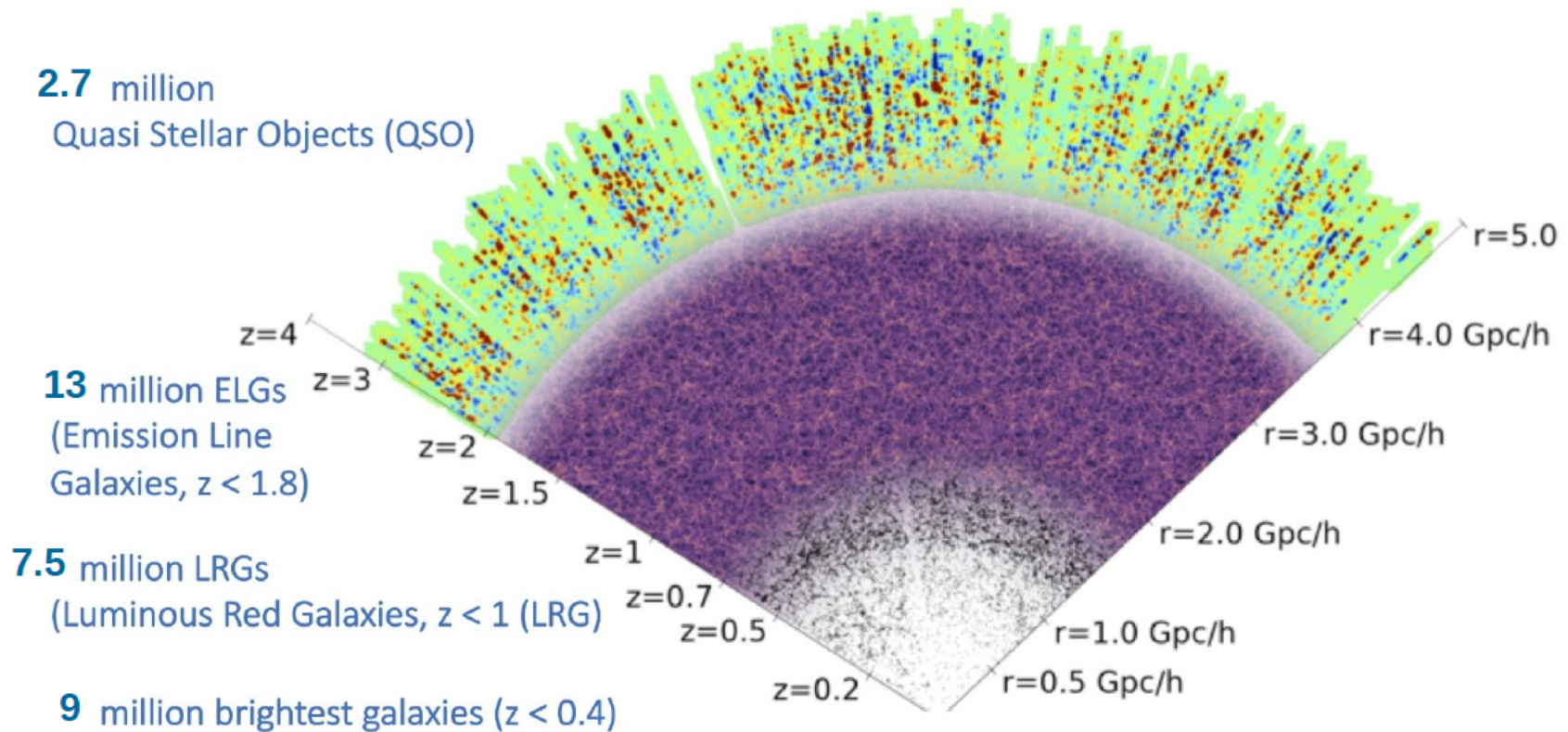
Dark Energy Spectroscopic Instrument (DESI)

- Designed for precision dark energy from $z = 0 \rightarrow 3$
- First Stage 4 experiment
- Nominal Survey: 2021 \rightarrow 2026
- 5000-robot army \rightarrow 5000 fibers \rightarrow 10 spectrographs
- 5000 spectra every ~ 15 min



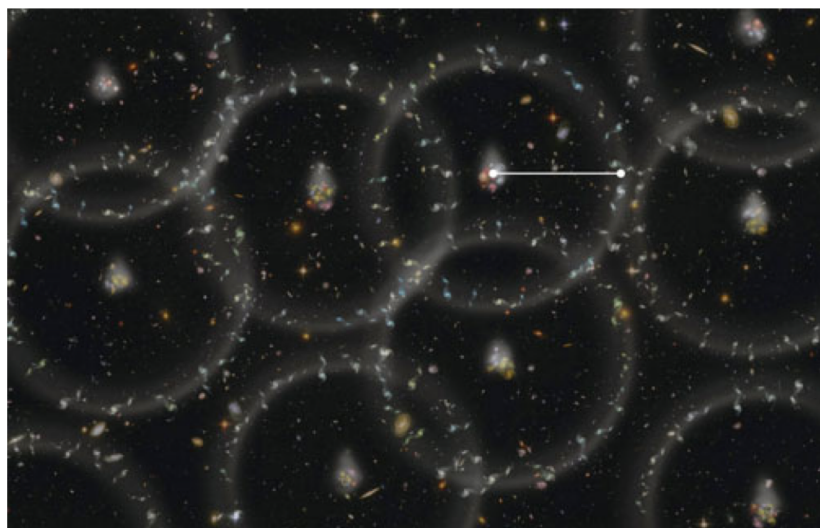


DESI is creating a 3D Map of the Universe

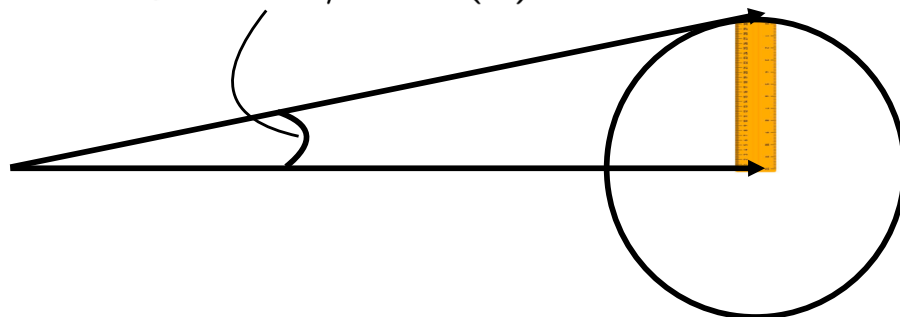


DESI 5000-robot army → 5000 fibers → 5000 spectra every ~15 min

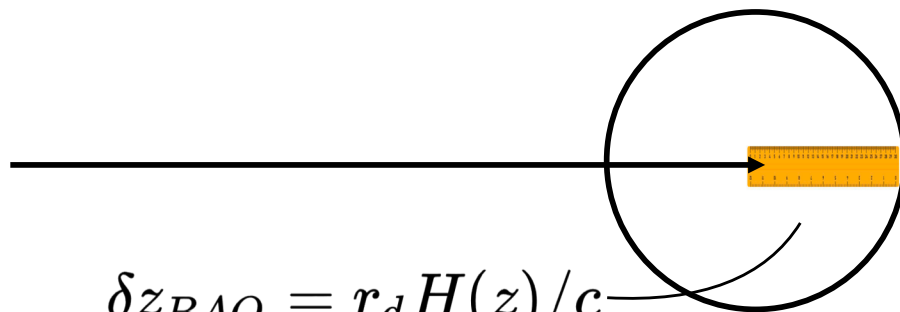
Baryon Acoustic Oscillations (BAO) → standard ruler



$$\theta_{BAO} = r_d / D_M(z)$$

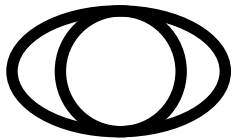


$$\delta z_{BAO} = r_d H(z) / c$$



$D_M(z)$ and $H(z)$ encode **expansion history** of the Universe

BAO scaling parameters



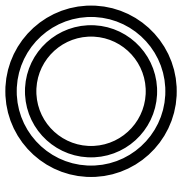
perpendicular ruler size

$$\alpha_{\perp} = \frac{D_M/r_d}{[D_M/r_d]_{fid}} \quad \text{and} \quad \alpha_{\parallel} = \frac{D_H/r_d}{[D_H/r_d]_{fid}}$$



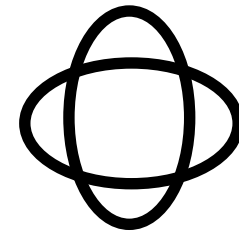
line-of-sight ruler size

OR

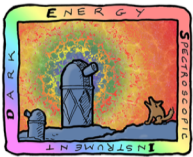


Isotropic BAO scale

$$\alpha_{iso} = (\alpha_{\perp}^2 \alpha_{\parallel})^{1/3} \quad \text{and} \quad \alpha_{AP} = \frac{D_H/D_M}{[D_H/D_M]_{fid}}$$



anisotropy of BAO
(Alcock-Paczynski effect)

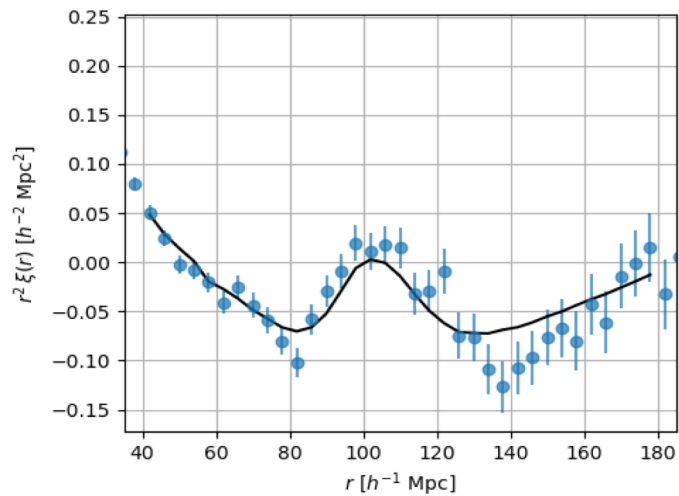
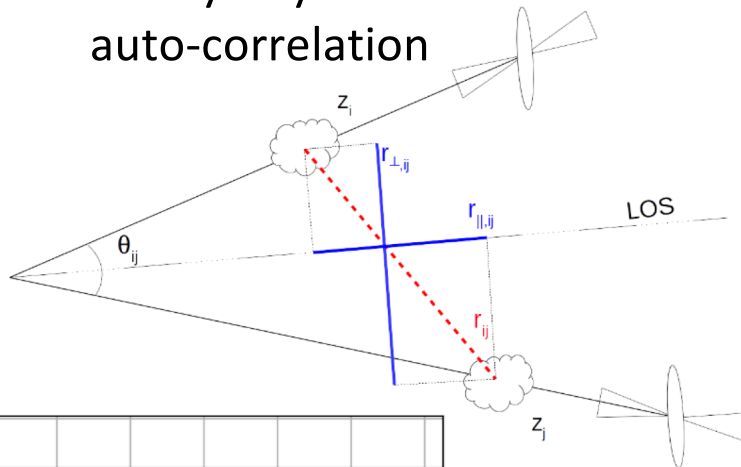


DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

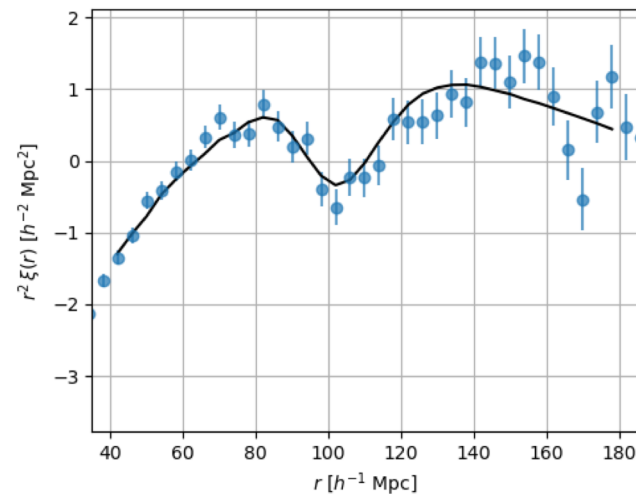
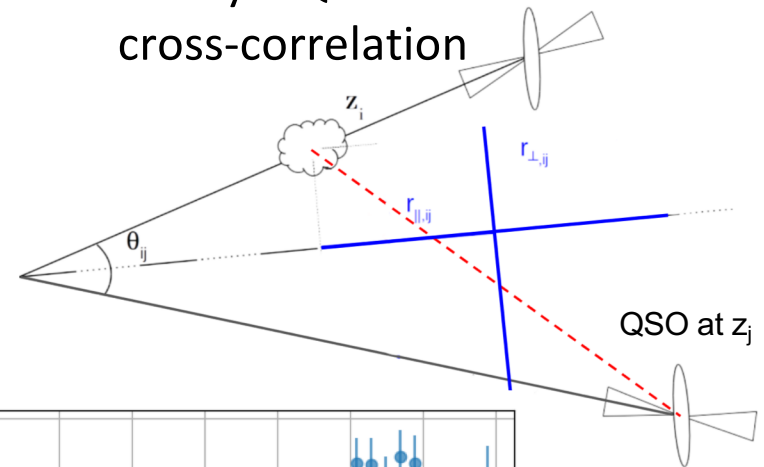
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Ly α forest analysis

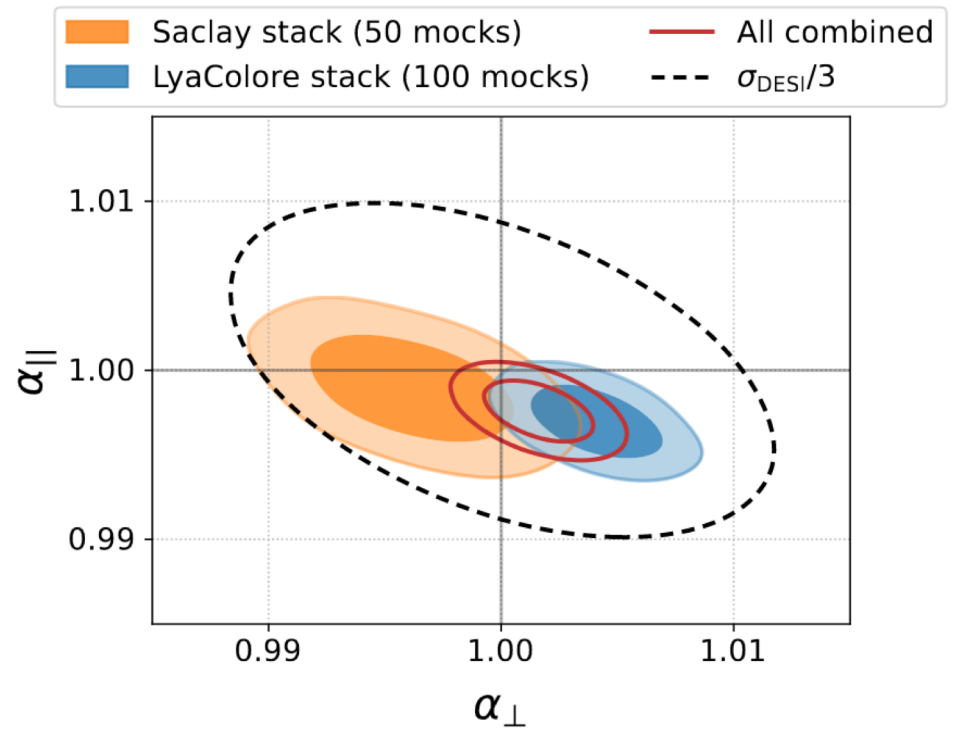
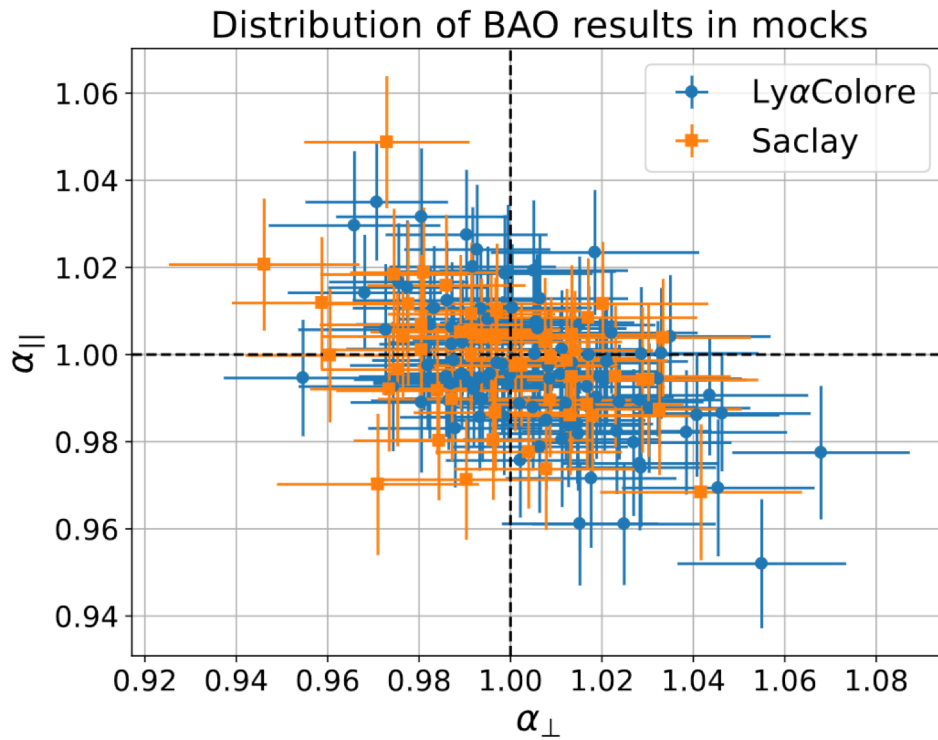
Ly α -Ly α
auto-correlation



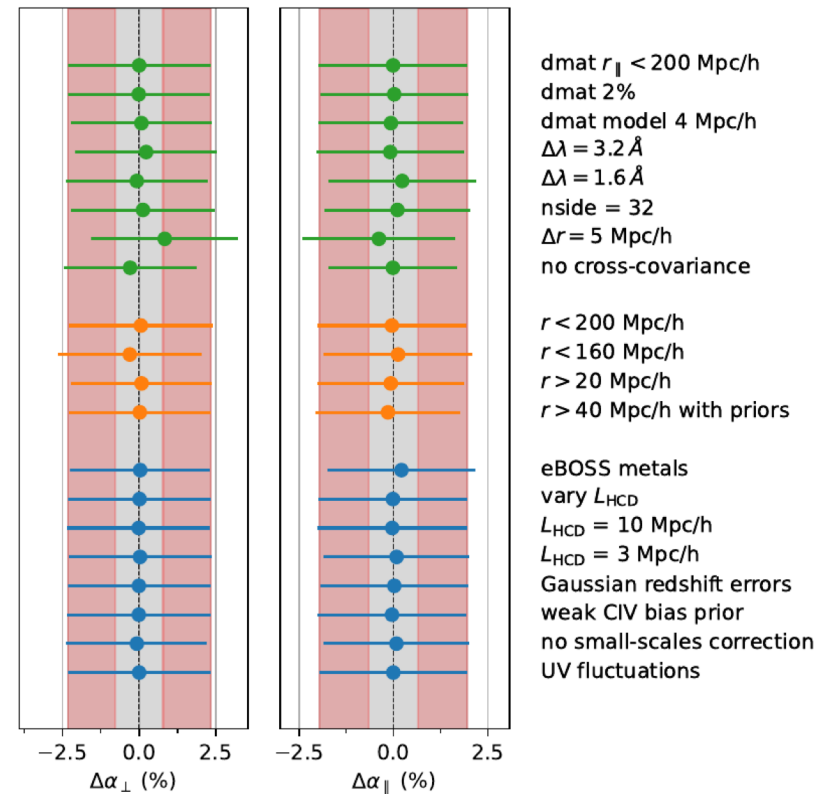
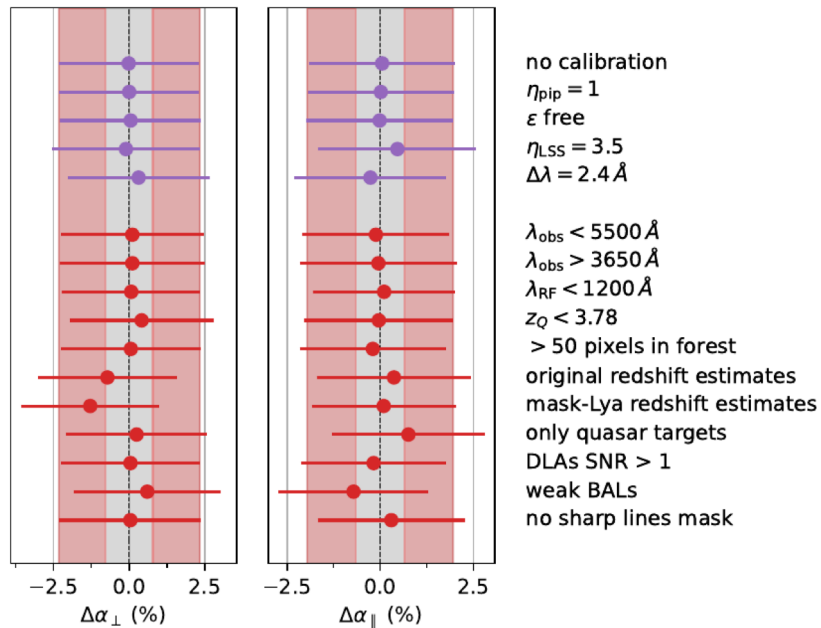
Ly α -QSO
cross-correlation



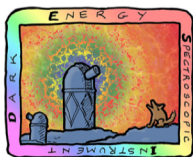
Validation with mocks



Variations in the analysis



- Tests with same data set (purple, green, orange, blue):
BAO shifts < 1/3 stat (gray band)
- Tests with varying data sets (red):
BAO shifts consistent with statistical fluctuations



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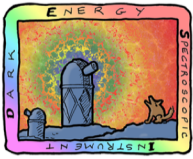
A blinded analysis from end-to-end



Analysis fully developed with
mocks and blinded data

Validation tests defined in advance

Unblinded in December 2023



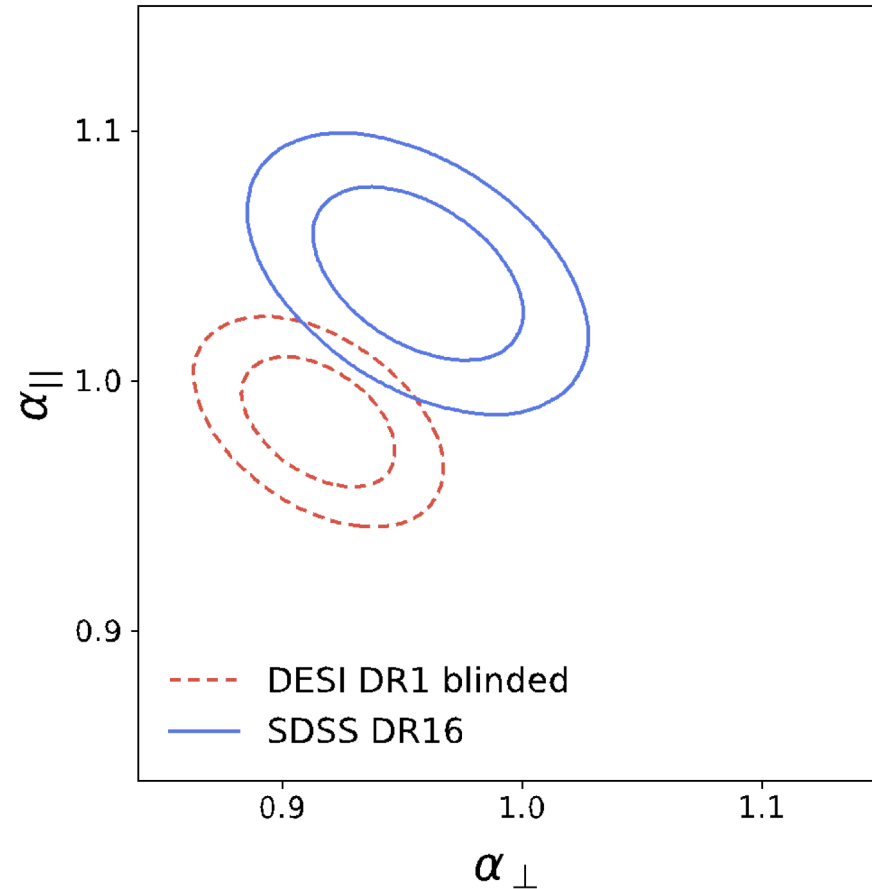
DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

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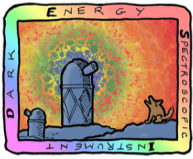
Unblinding the DESI DR1 Ly α BAO

December 8th 2023 was quite an exciting day!

$$\alpha_{\parallel} = \frac{D_H(z_{\text{eff}})/r_d}{[D_H(z_{\text{eff}})/r_d]_{\text{fid}}}$$
$$\alpha_{\perp} = \frac{D_M(z_{\text{eff}})/r_d}{[(D_M(z_{\text{eff}})/r_d)_{\text{fid}}]}$$



DESI Collaboration et al. 2024a



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Unblinding the DESI DR1 Ly α BAO

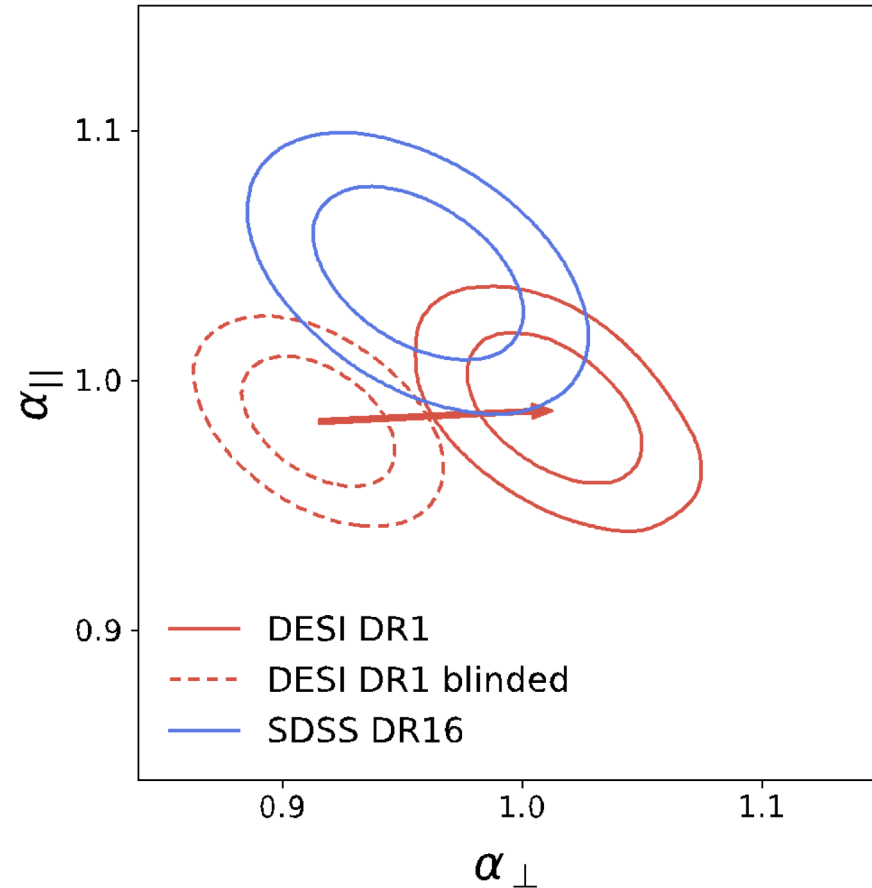
December 8th 2023 was quite an exciting day!

$$\alpha_{\parallel} = \frac{D_H(z_{\text{eff}})/r_d}{[D_H(z_{\text{eff}})/r_d]_{\text{fid}}}$$
$$\alpha_{\perp} = \frac{D_M(z_{\text{eff}})/r_d}{[(D_M(z_{\text{eff}})/r_d)_{\text{fid}}]}$$

$$\alpha_{\parallel} = 0.989 \pm 0.020$$

$$\alpha_{\perp} = 1.013 \pm 0.024$$

Blinding of transverse BAO was quite extreme!



DESI Collaboration et al. 2024a

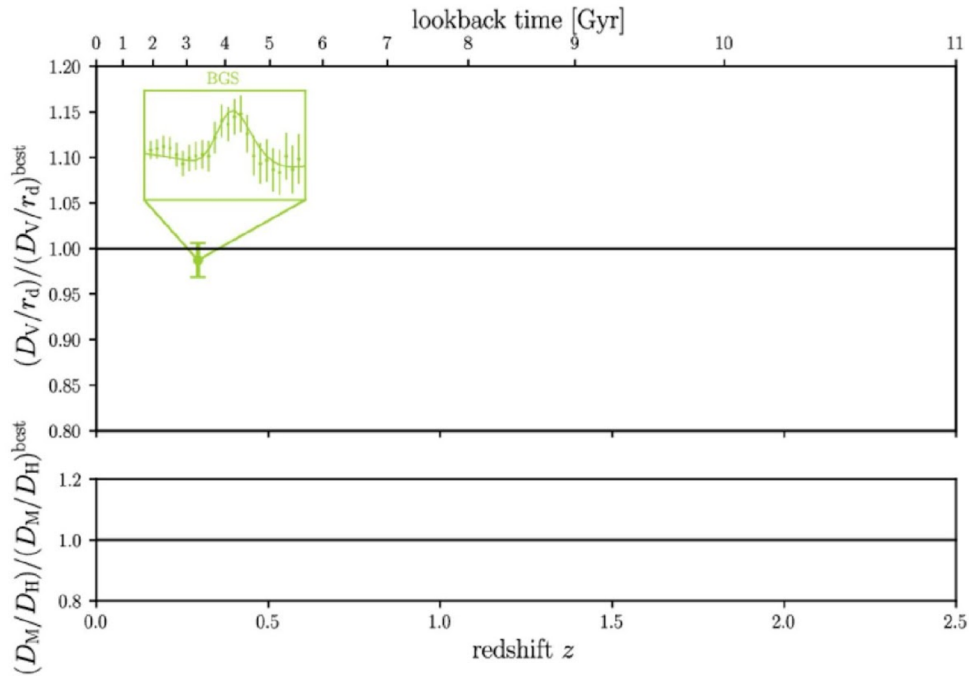


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INSTRUMENT

DESI Y1 BAO

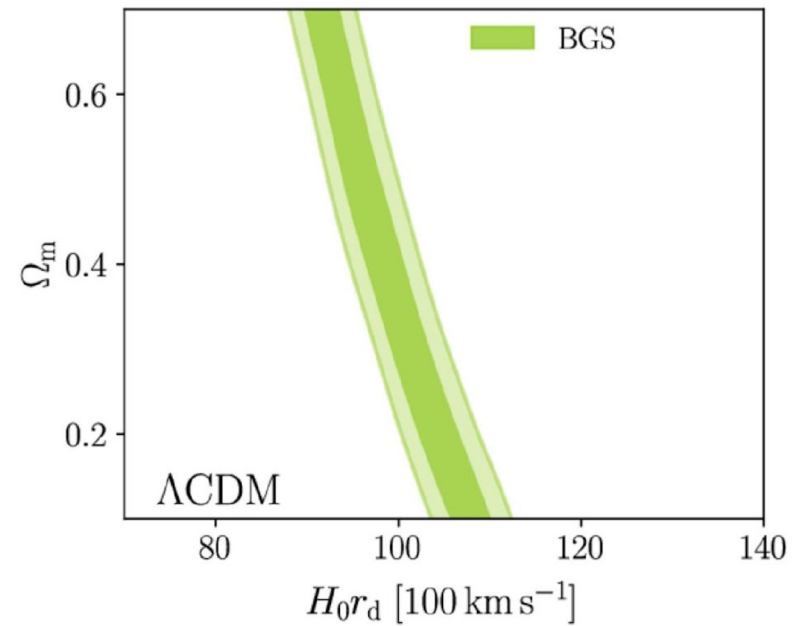
U.S. Department of Energy Office of Science

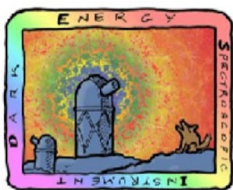
DESI BAO measurements



DESI Collaboration et al. 2024b,c

Flat Λ CDM



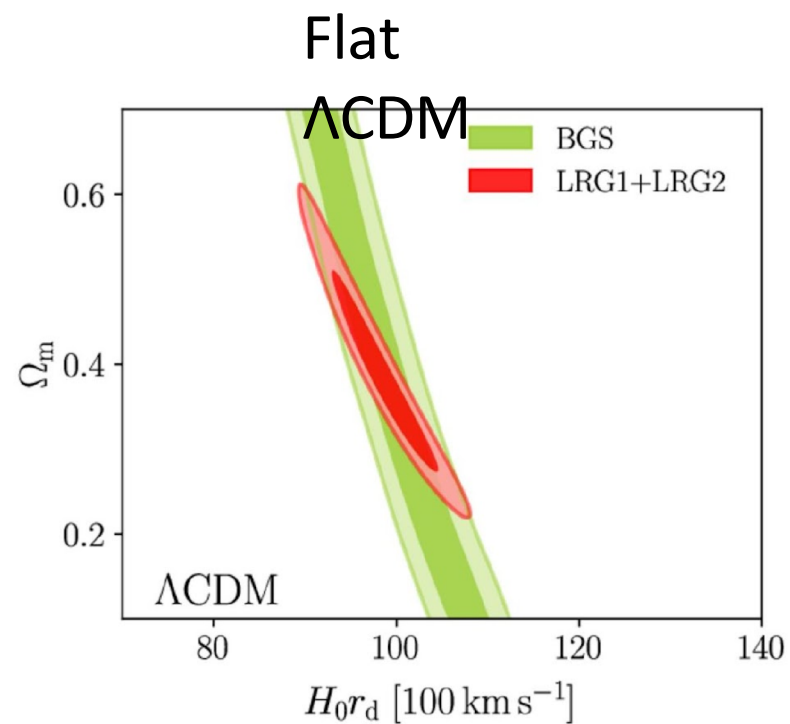
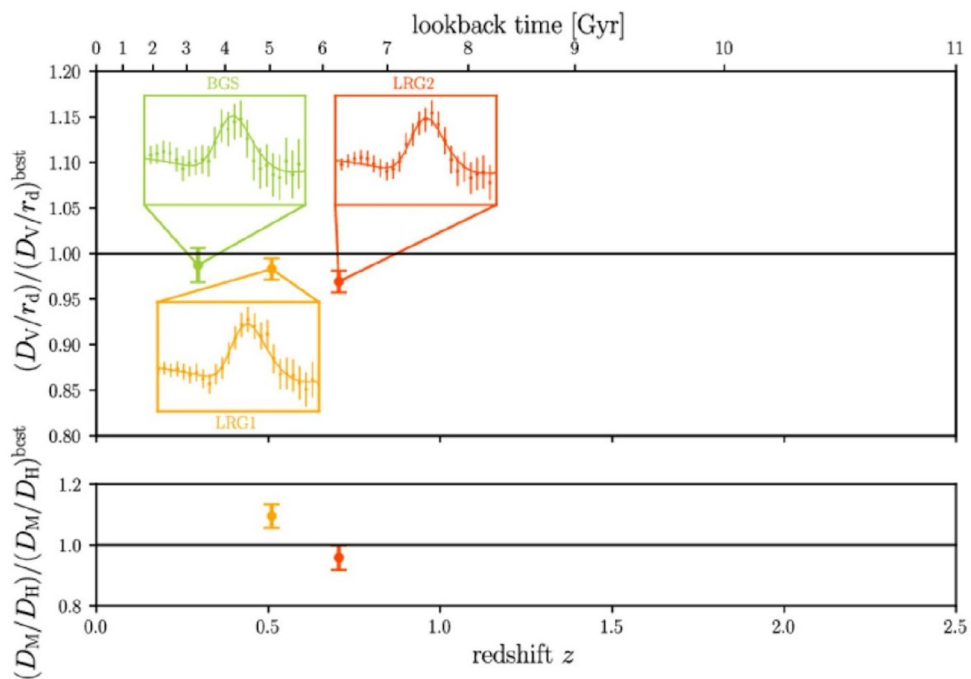


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DESI Y1 BAO

U.S. Department of Energy Office of Science

DESI BAO measurements



DESI Collaboration et al. 2024b,c

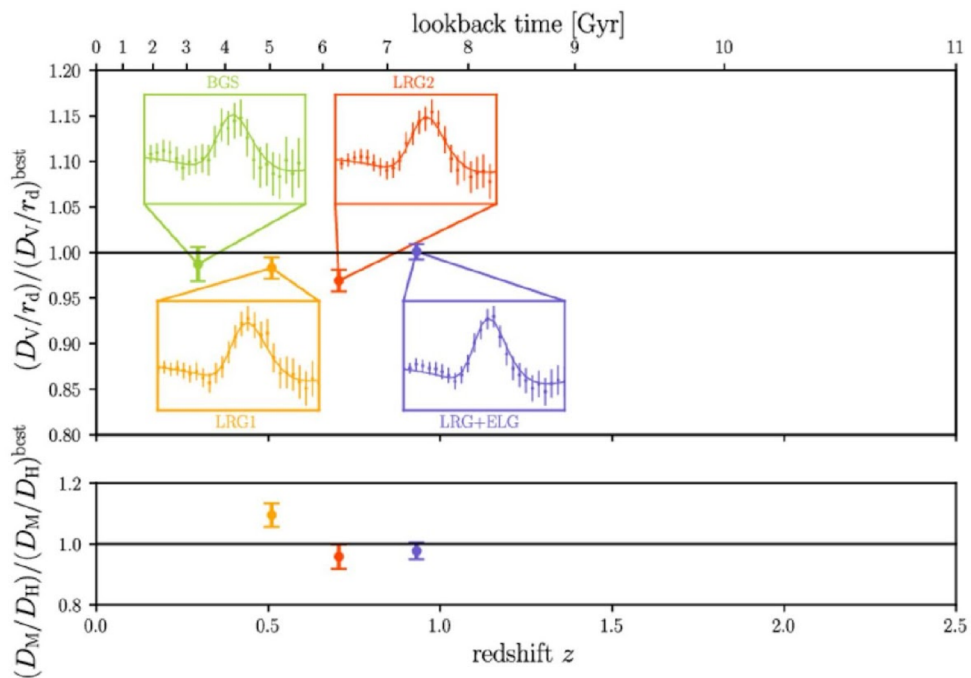


DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

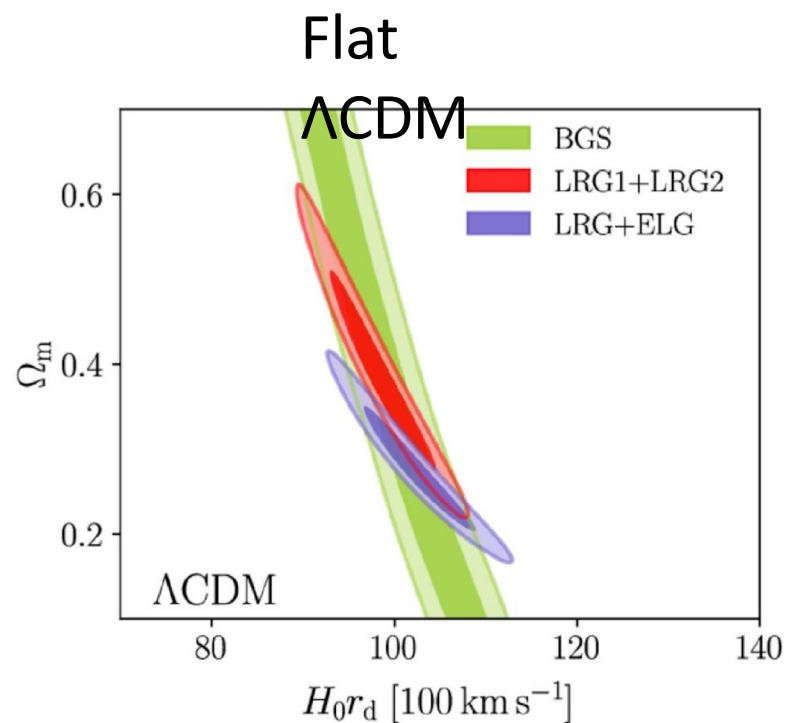
DESI Y1 BAO

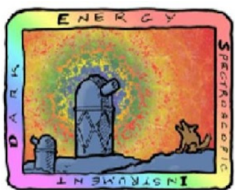
U.S. Department of Energy Office of Science

DESI BAO measurements



DESI Collaboration et al. 2024b,c



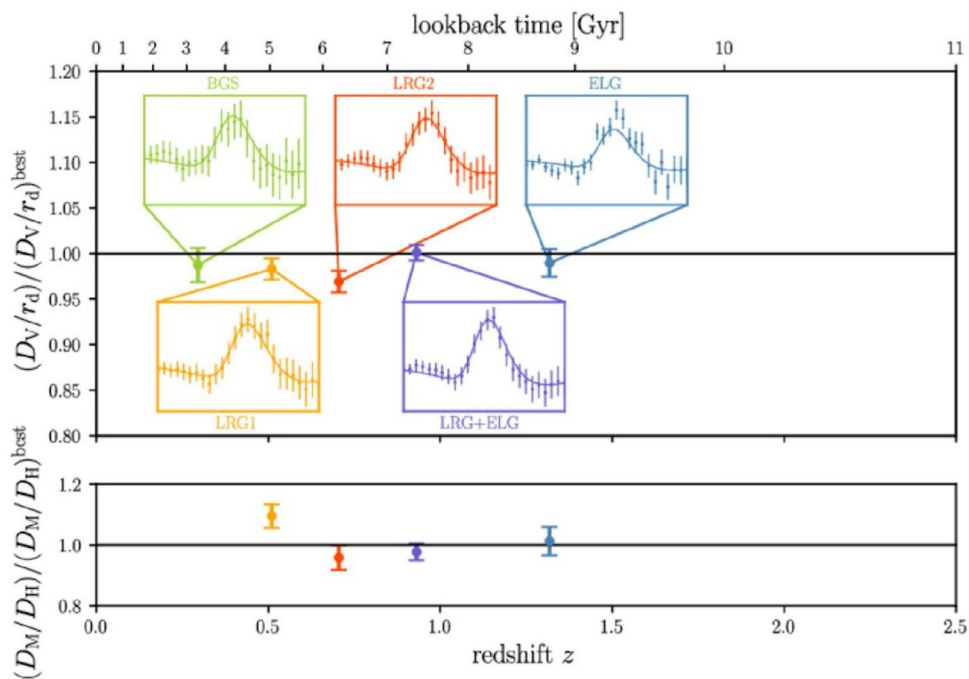


DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

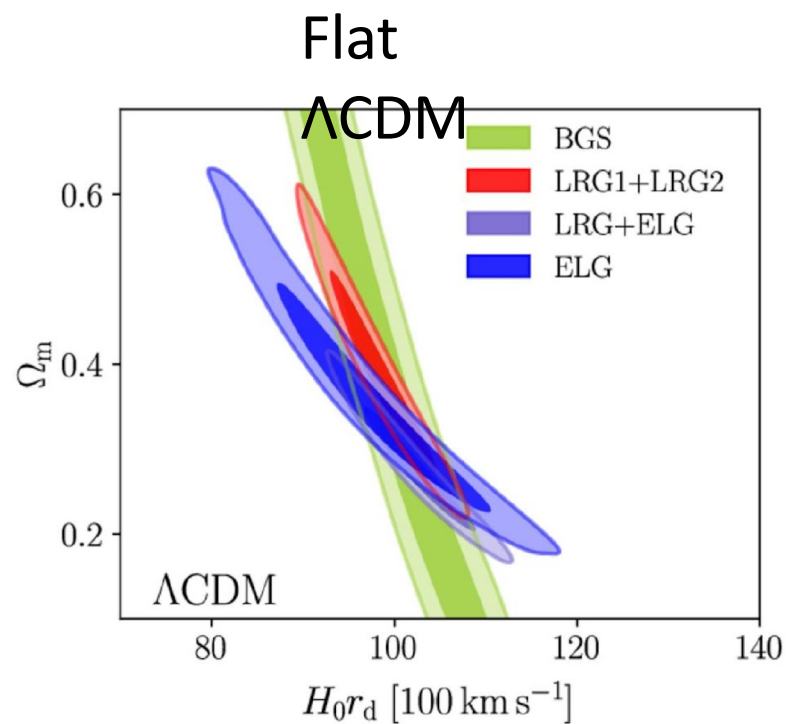
DESI Y1 BAO

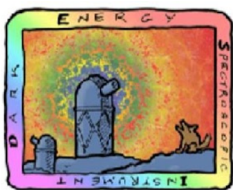
U.S. Department of Energy Office of Science

DESI BAO measurements



DESI Collaboration et al. 2024b,c



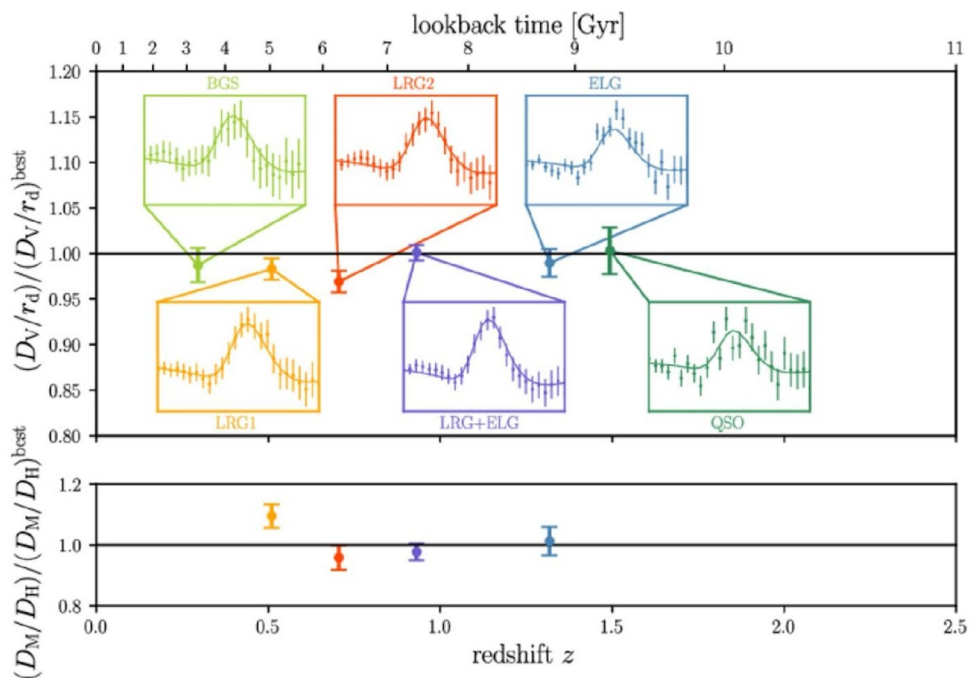


DARK ENERGY
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INSTRUMENT

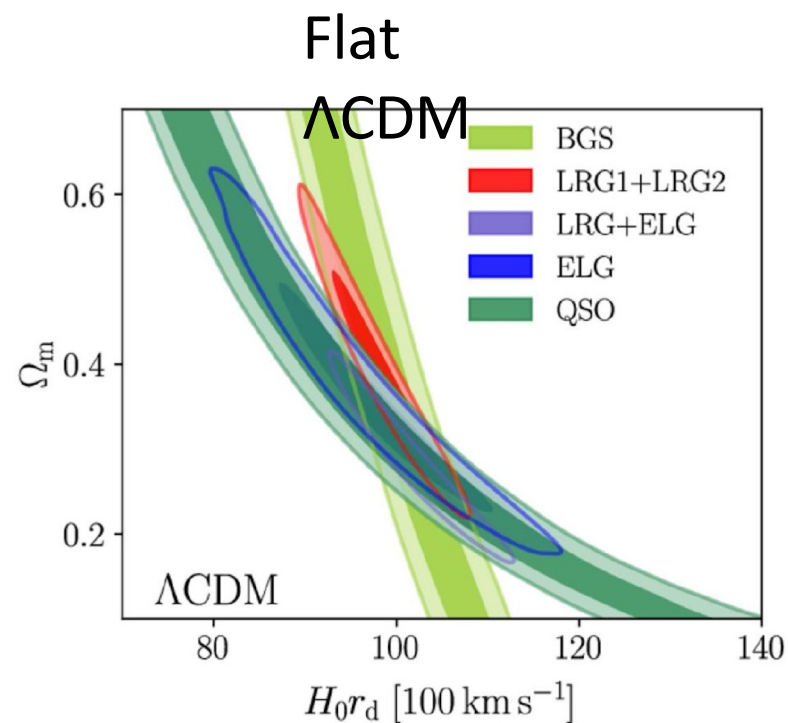
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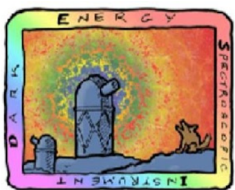
U.S. Department of Energy Office of Science

DESI BAO measurements



DESI Collaboration et al. 2024b,c



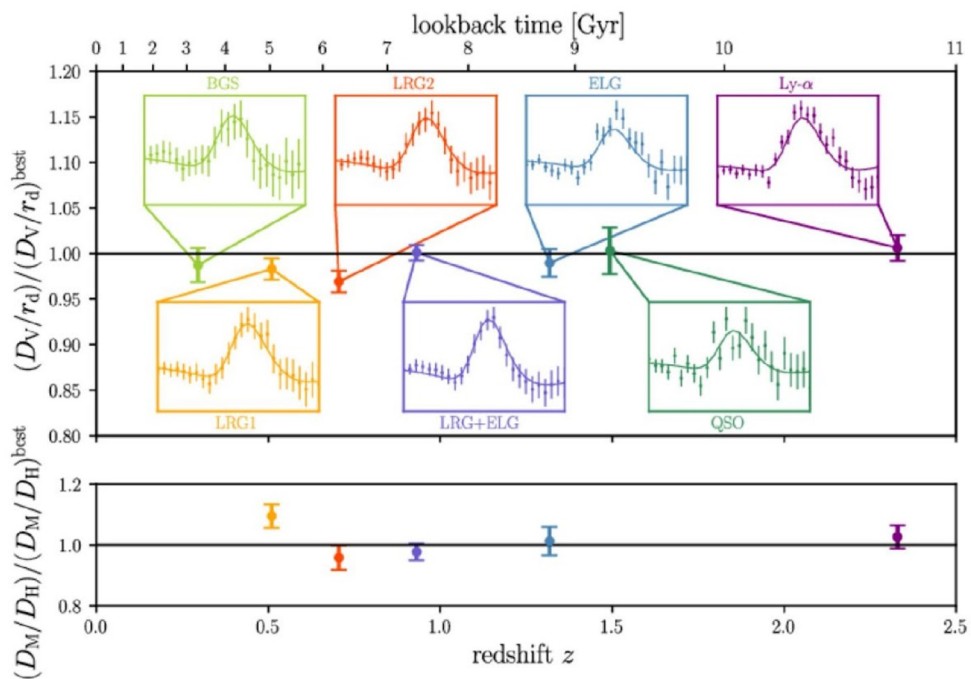


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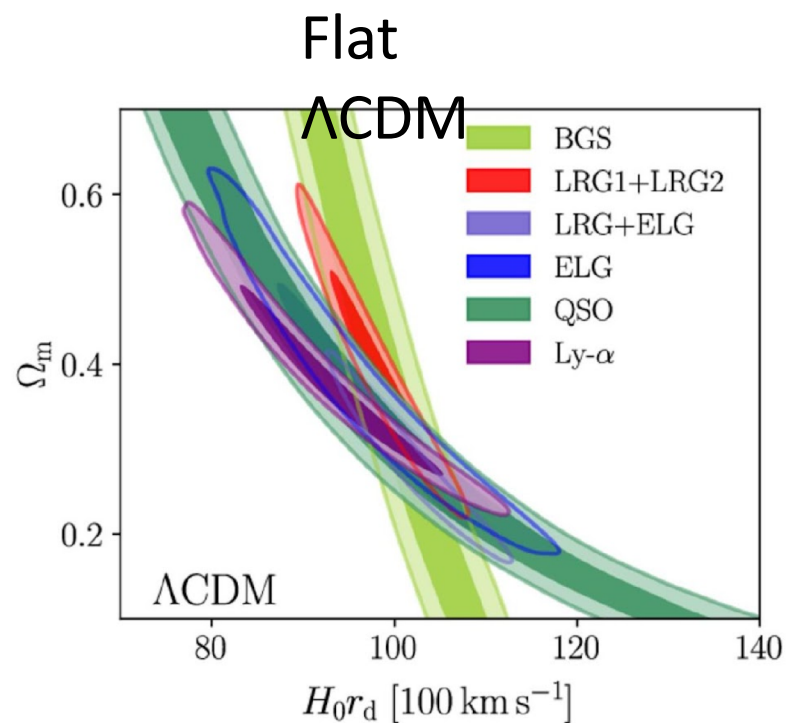
DESI Y1 BAO

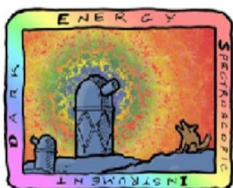
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DESI BAO measurements



DESI Collaboration et al. 2024b,c





DARK ENERGY
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DESI Y1 BAO

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DESI BAO measurements

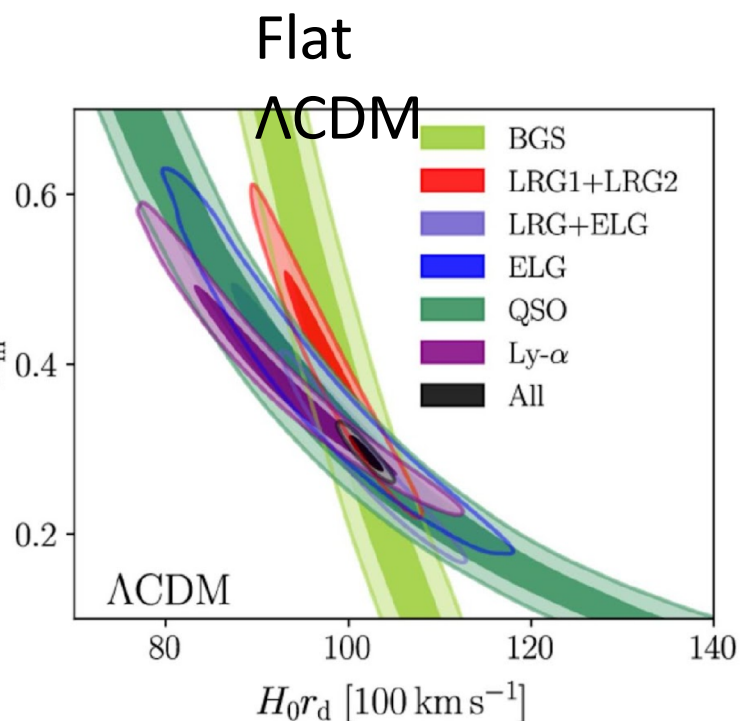
Consistent with each other,
and complementary

$$\Omega_m = 0.295 \pm 0.015 \quad (5.1\%)$$

$$H_0 r_d = (101.8 \pm 1.3) [100 \text{ km s}^{-1}] \quad (1.3\%)$$

DESI

DESI Collaboration et al. 2024b,c



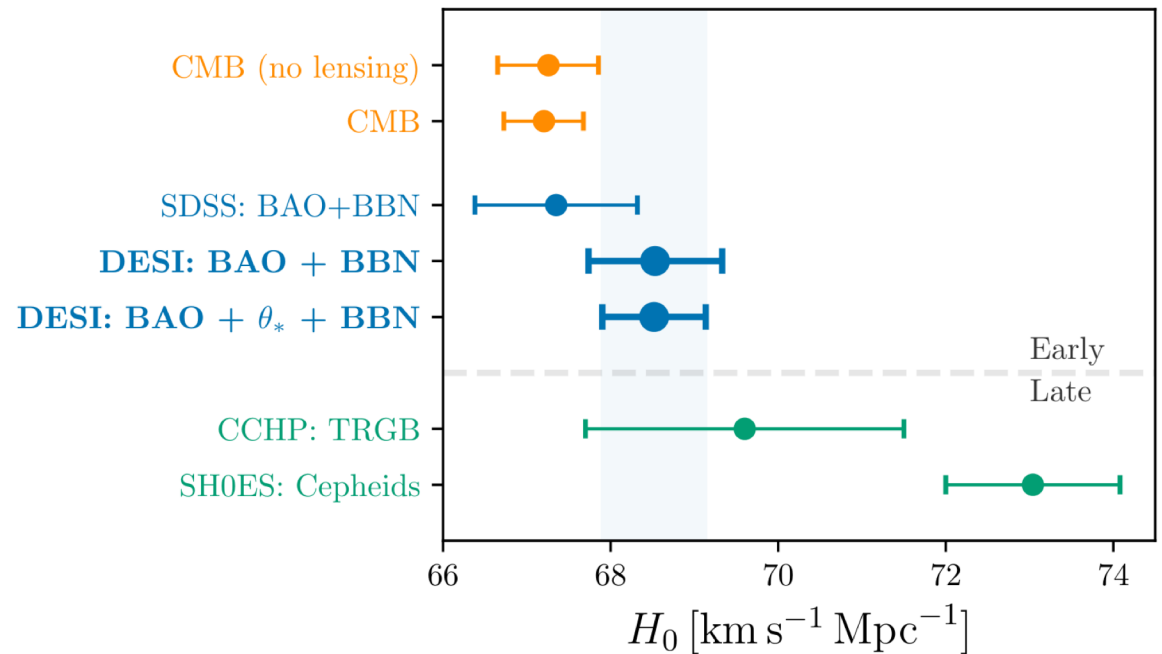
Hubble Constant

- In flat Λ CDM: BAO $\rightarrow \Omega_m, H_0 r_d$

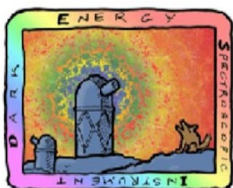
$$r_d \rightarrow (\Omega_m h^2, \Omega_b h^2)$$

- Big Bang Nucleosynthesis (BBN) $\rightarrow \Omega_b h^2$

- DESI + BBN:
 $H_0 = 68.53 \pm 0.8 \text{ km/s/Mpc}$



DESI Collaboration et al. 2024c



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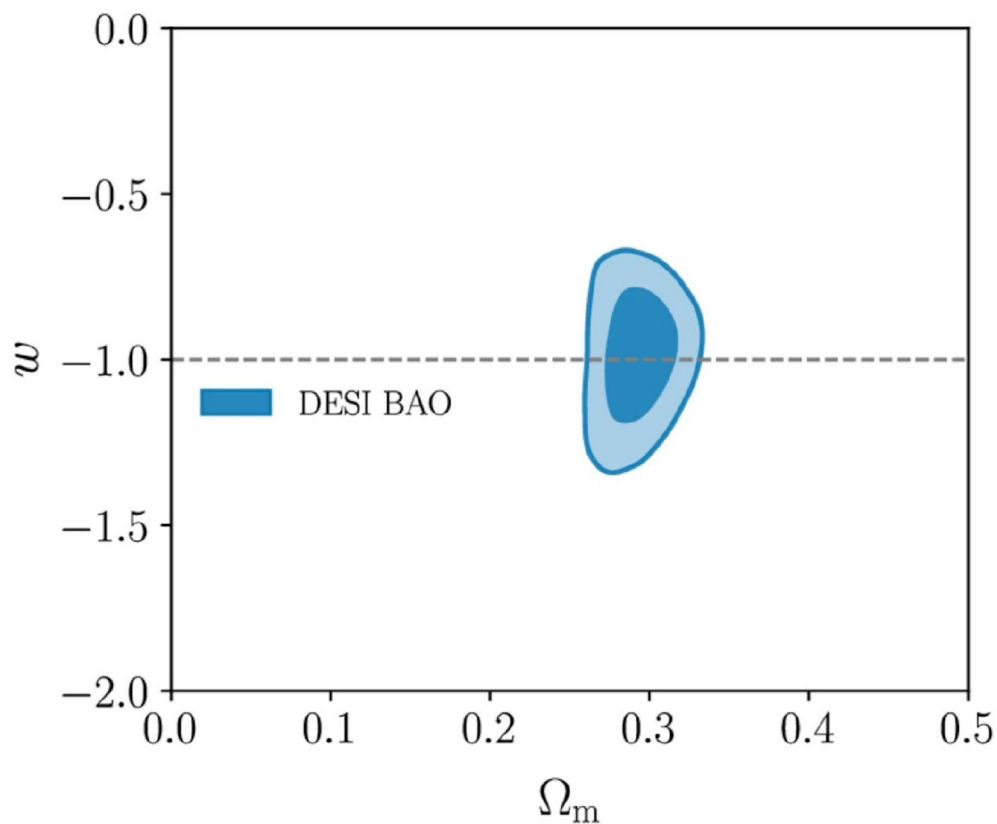
Dark Energy Equation of State

Constant EoS parameter w

$$\Omega_m = 0.293 \pm 0.015 \quad (5.1\%)$$

$$w = -0.99^{+0.15}_{-0.13} \quad (15\%)$$

DESI



DESI Collaboration et al. 2024c



DARK ENERGY
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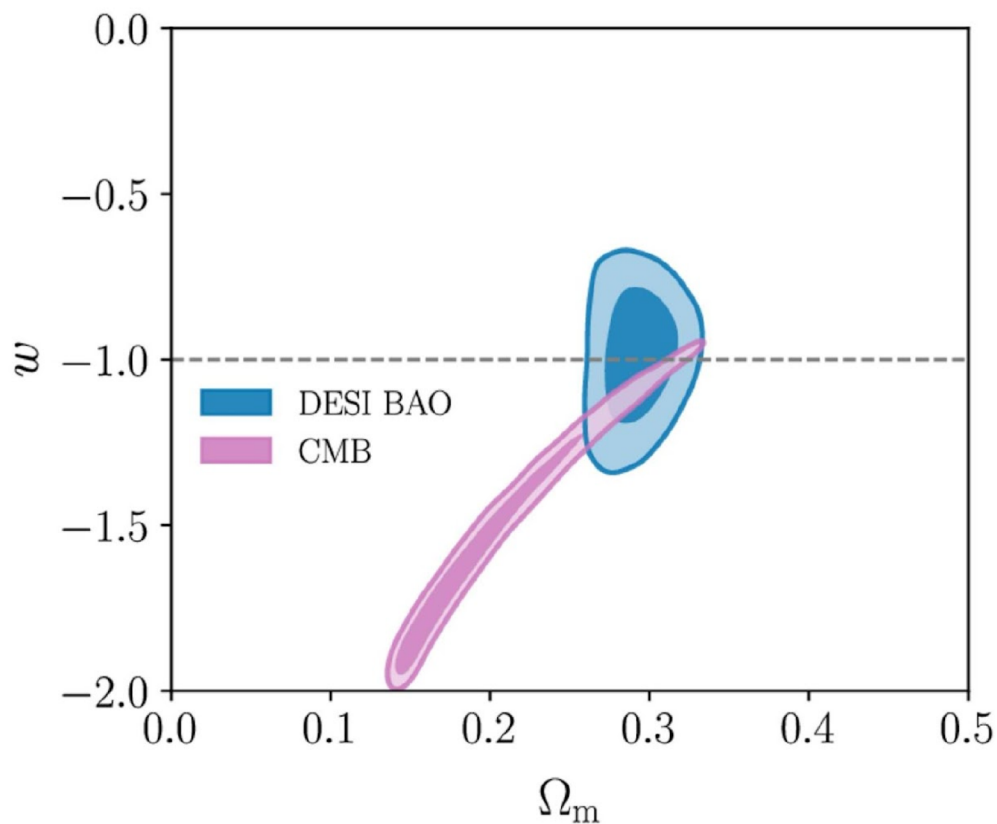
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DESI



DESI Collaboration et al. 2024c



DARK ENERGY
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INSTRUMENT

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Dark Energy Equation of State

Constant EoS parameter w

$$\Omega_m = 0.293 \pm 0.015 \quad (5.1\%)$$

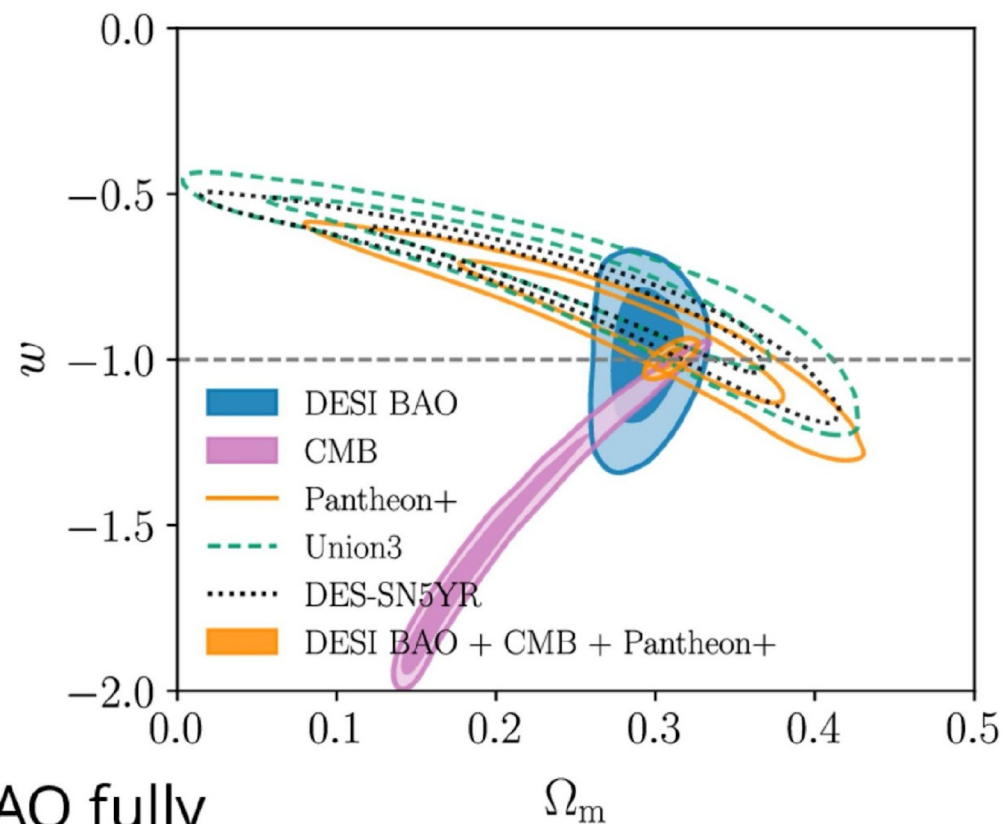
$$w = -0.99^{+0.15}_{-0.13} \quad (15\%)$$

DESI

$$\Omega_m = 0.3095 \pm 0.0065 \quad (2.1\%)$$

$$w = -0.997 \pm 0.025 \quad (2.5\%)$$

DESI + CMB + Pantheon+

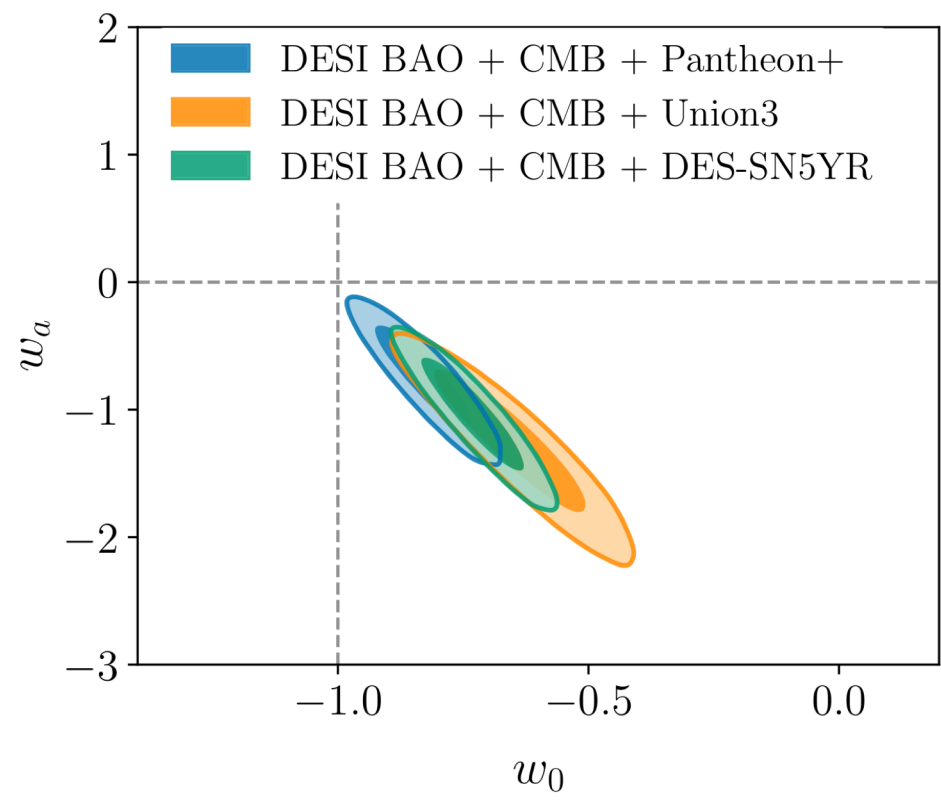


Assuming a **constant** EoS, DESI BAO fully compatible with a cosmological constant...

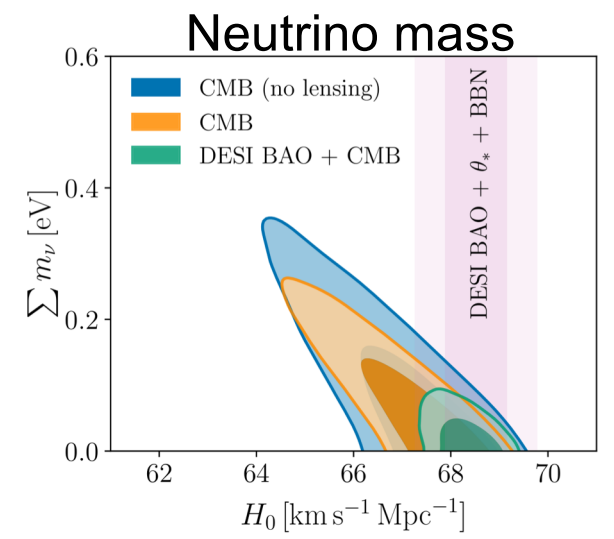
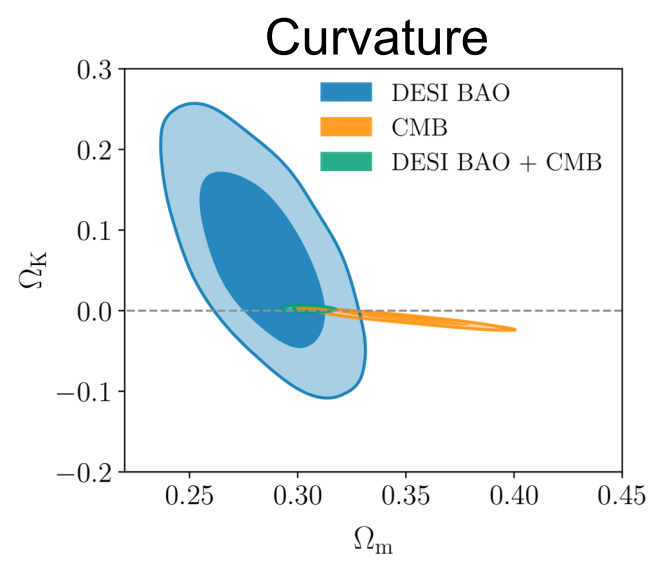
DESI Collaboration et al. 2024c

Cosmology from DESI BAO

Hints of evolving dark energy!

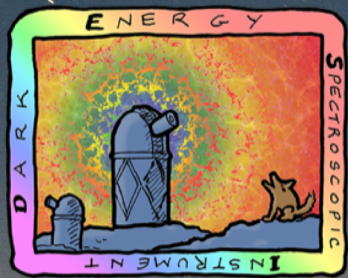


2.5 σ , 3.5 σ , 3.9 σ deviations from Λ



Conclusions

- DESI Year 1 BAO constrains expansion history from $z = 0 \rightarrow 3$
- Analysis fully developed on blinded data and included thorough validation process.
- Mostly consistent with CMB, previous BAO data, and flat Λ CDM.
- Except, we find hints of evolving dark energy!
- Full-shape results from Year 1 coming this fall.
- This is just the beginning! We finished collecting Year 3 data in March 2024.



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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NASA Hubble Fellowship Program



Thanks to our sponsors and
72 Participating Institutions!





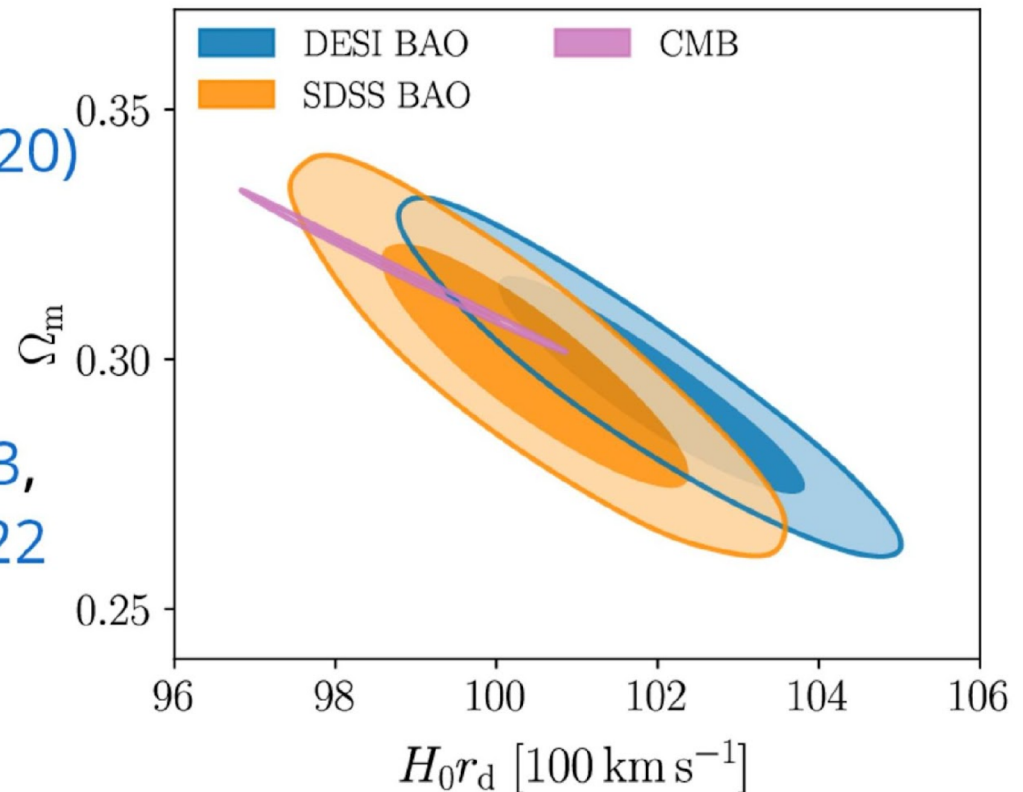
DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

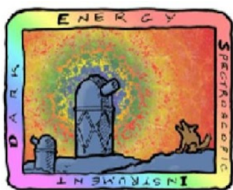
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Consistency with other probes

DESI Y1 BAO consistent with:

- SDSS (eBOSS Collaboration, 2020)
- primary CMB: Planck Collaboration, 2018 and CMB lensing: Planck PR4 + ACT DR6 lensing ACT Collaboration, 2023, Carron, Mirmelstein, Lewis, 2022





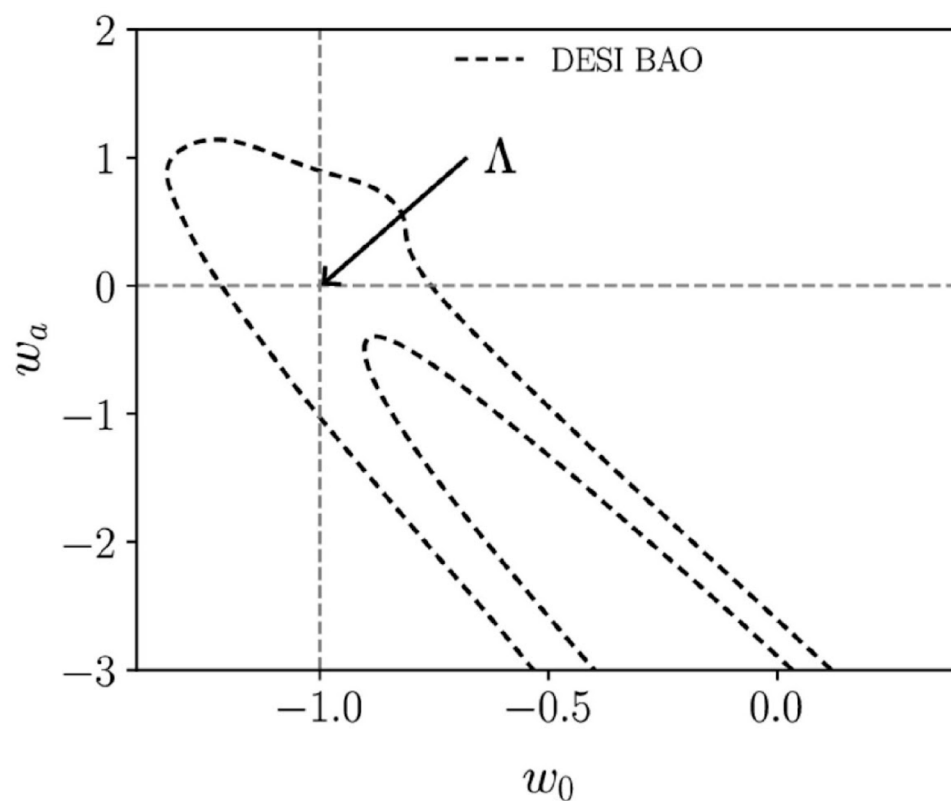
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Dark Energy Equation of State

Varying EoS

$$w(a) = w_0 + (1 - a)w_a \quad (\text{CPL})$$





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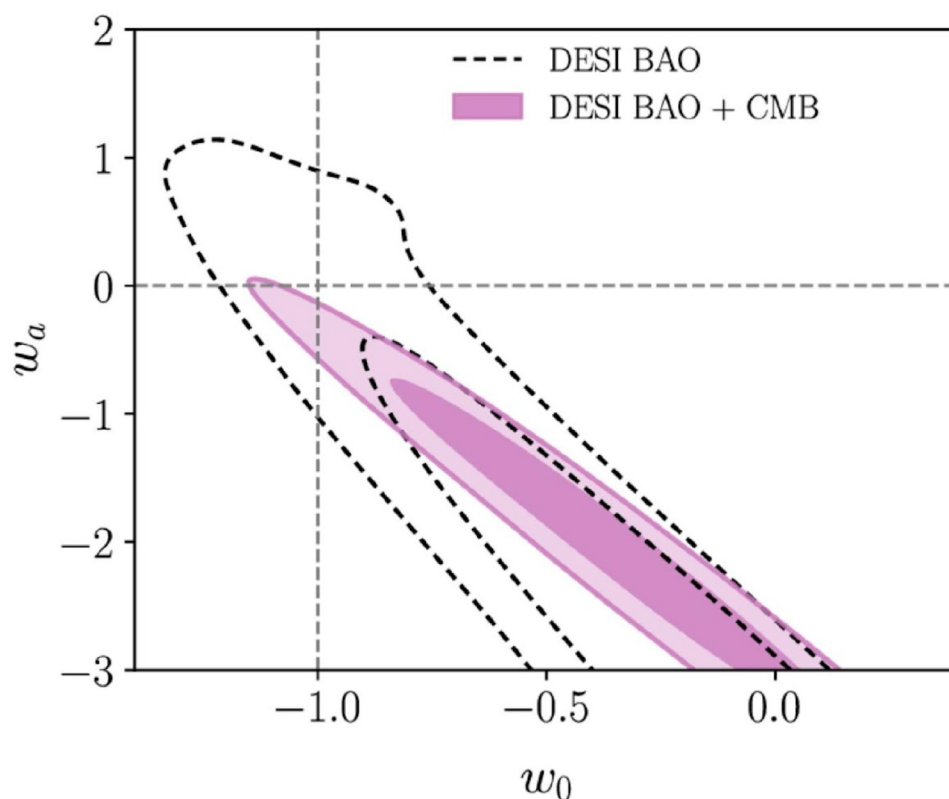
U.S. Department of Energy Office of Science

Dark Energy Equation of State

Varying EoS

$$w(a) = w_0 + (1 - a)w_a \quad (\text{CPL})$$

$$\underbrace{w_0 = -0.45^{+0.34}_{-0.21} \quad w_a = -1.79^{+0.48}_{-1.00}}_{\text{DESI + CMB} \Rightarrow 2.6\sigma}$$





DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

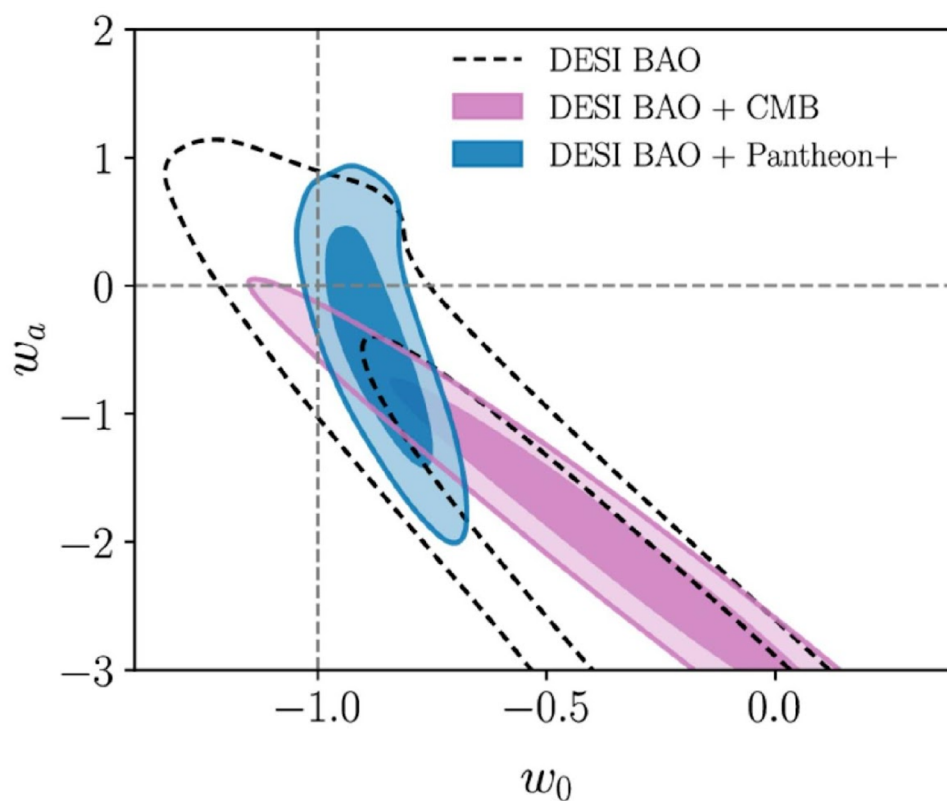
U.S. Department of Energy Office of Science

Dark Energy Equation of State

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DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

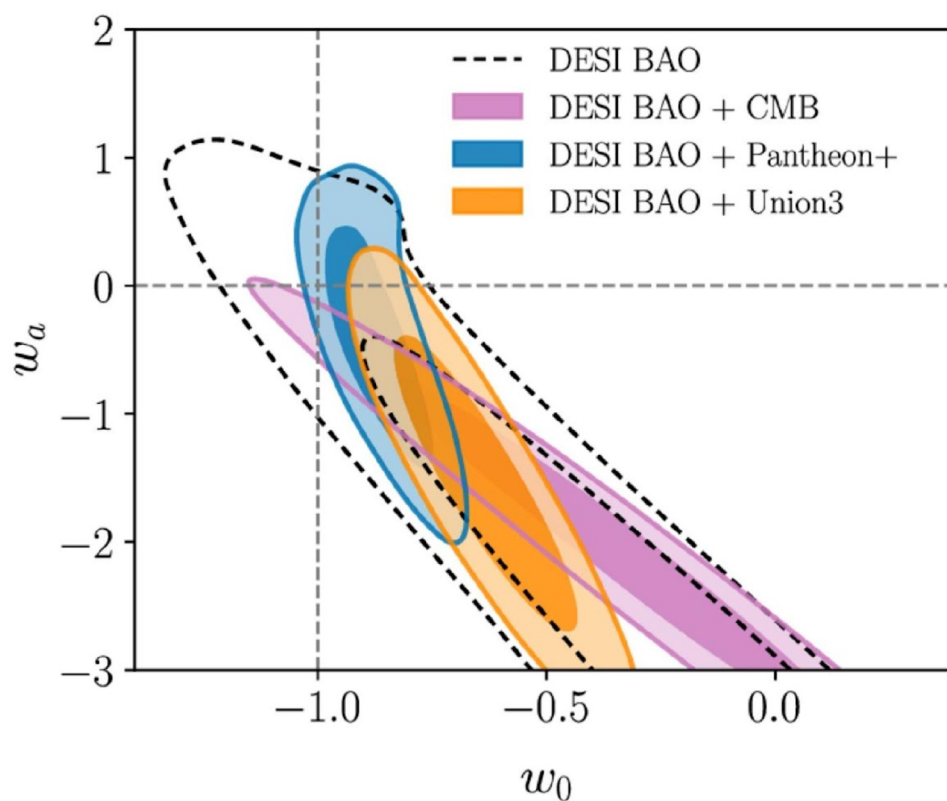
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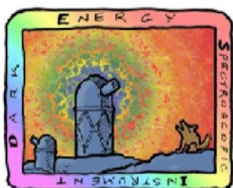
Dark Energy Equation of State

Varying EoS

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$$\underbrace{w_0 = -0.45^{+0.34}_{-0.21} \quad w_a = -1.79^{+0.48}_{-1.00}}_{\text{DESI + CMB} \Rightarrow 2.6\sigma}$$





DARK ENERGY
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Dark Energy Equation of State

Varying EoS

$$w(a) = w_0 + (1 - a)w_a \quad (\text{CPL})$$

$$w_0 = -0.45^{+0.34}_{-0.21} \quad w_a = -1.79^{+0.48}_{-1.00}$$

DESI + CMB $\Rightarrow 2.6\sigma$

