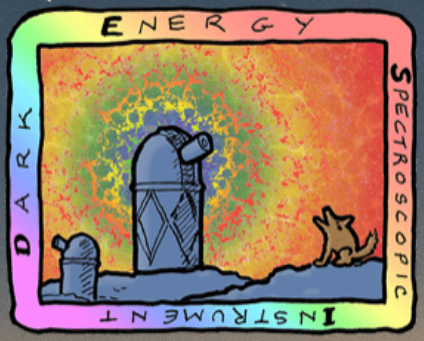
DESI 2024: Survey Overview and Cosmological constraints from Baryon Acoustic Oscillations

Arnaud de Mattia
CEA Saclay

EDSU Tools, June 4th



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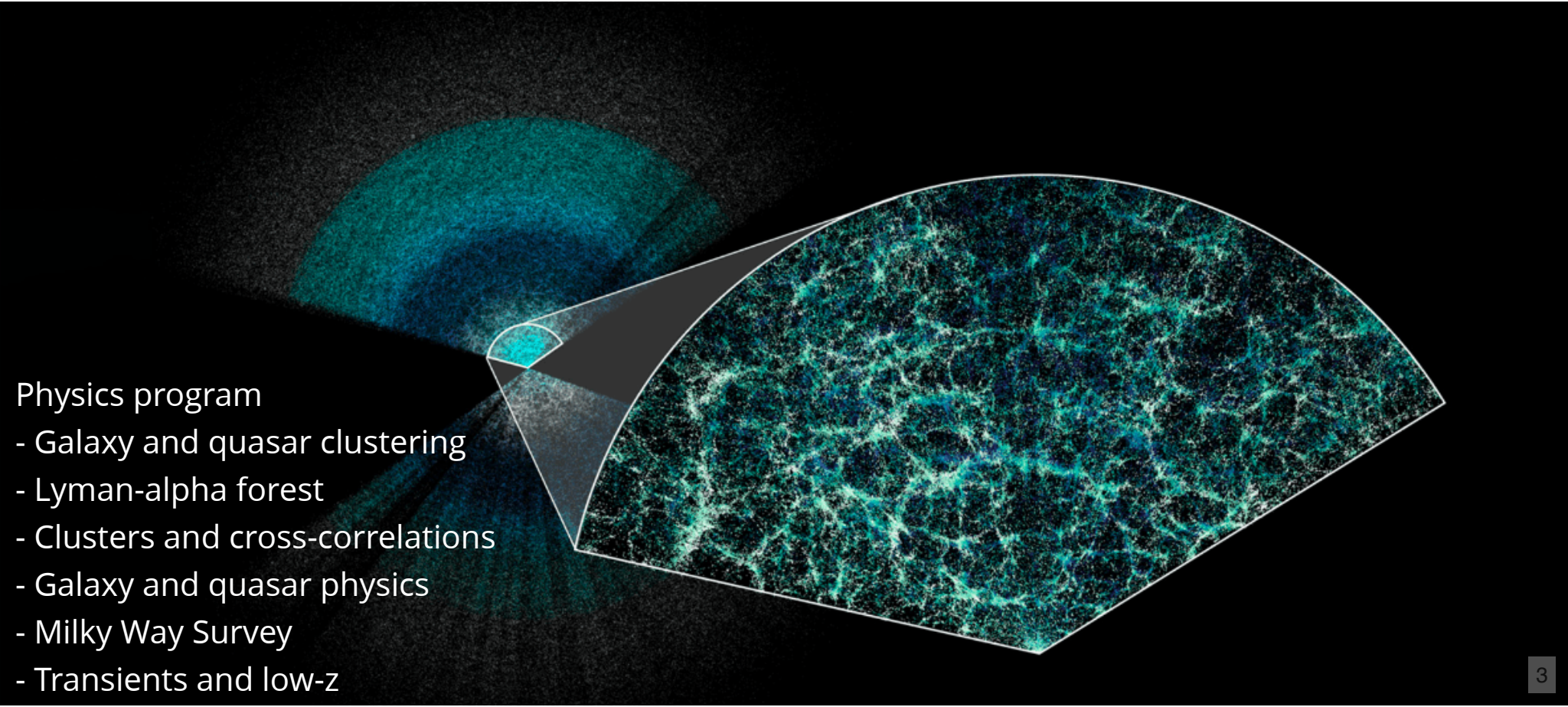
DESI 3D Map



Physics program
- Galaxy and quasar clustering
- Lyman-alpha forest
- Clusters and cross-correlations
- Galaxy and quasar physics
- Milky Way Survey
- Transients and low-z

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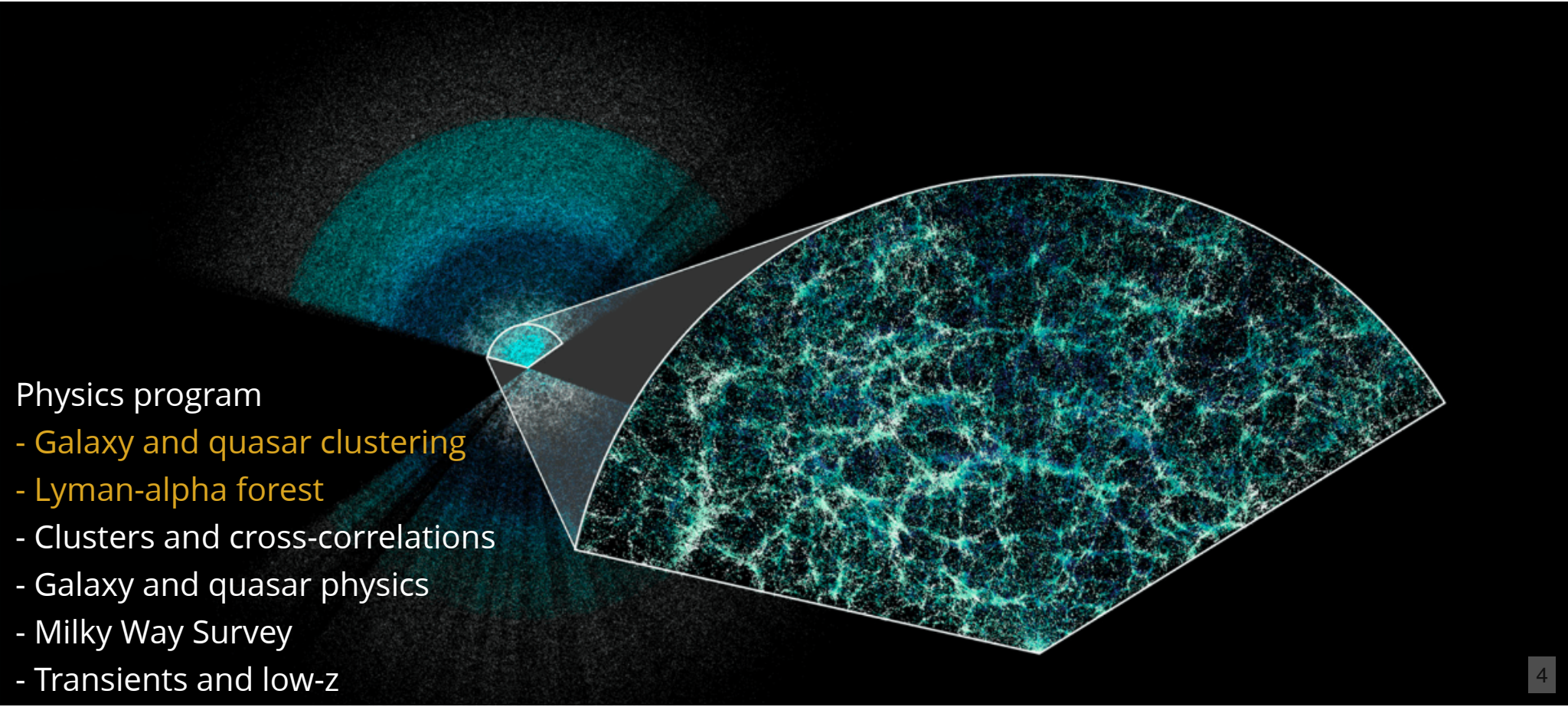

Physics program

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DESI Y5 galaxy samples

Y5 ~ 40 M galaxy redshifts!

3 million QSOs

Lya $1.8 < z$

Tracers $0.8 < z < 2.1$

16 million ELGs

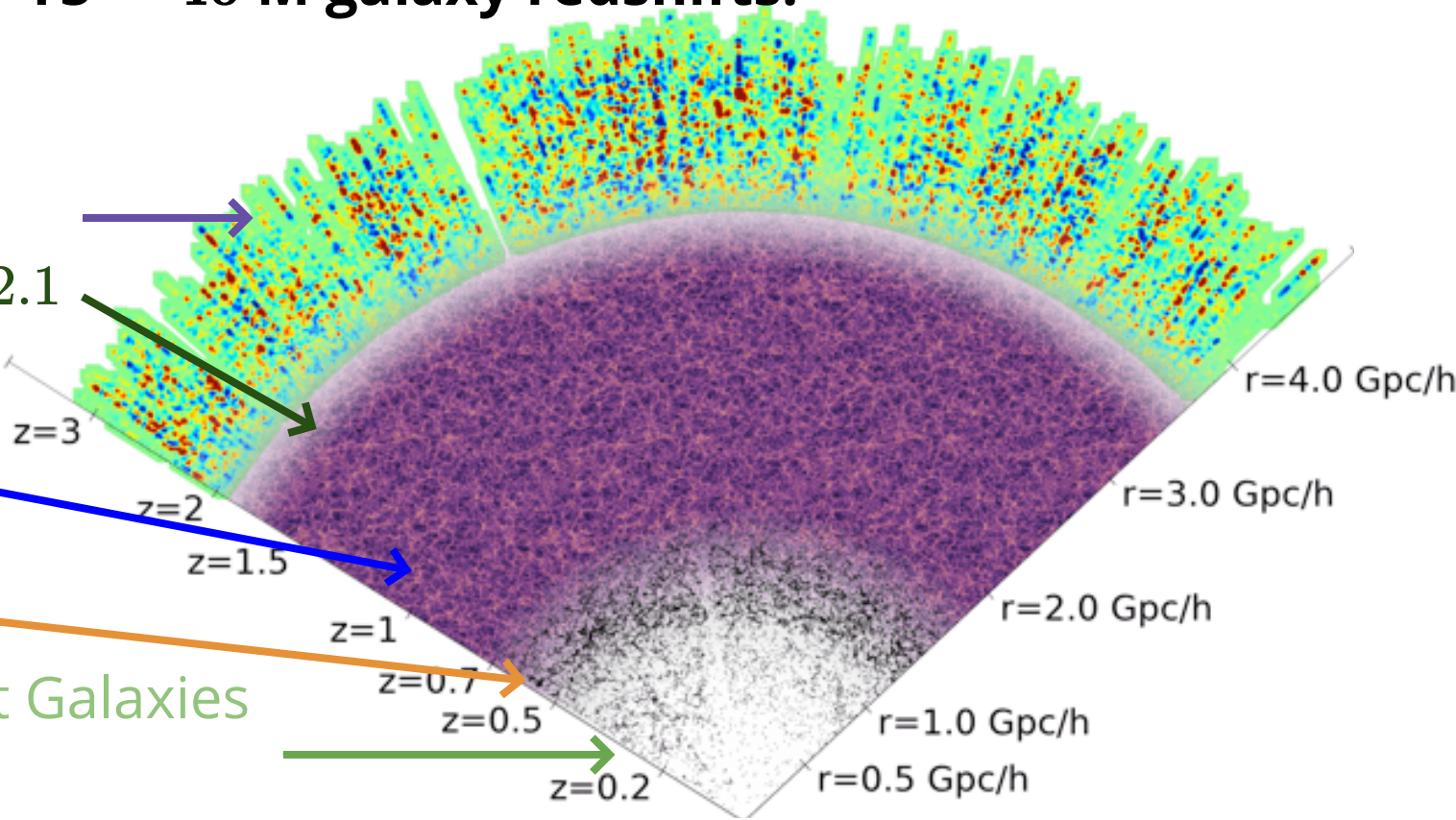
$0.6 < z < 1.6$

8 million LRGs

$0.4 < z < 0.8$

13.5 million Bright Galaxies

$0 < z < 0.4$



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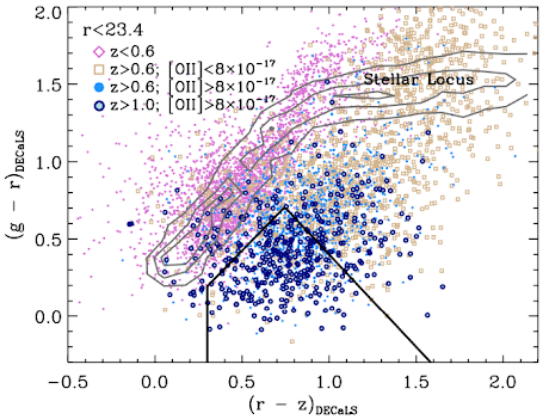
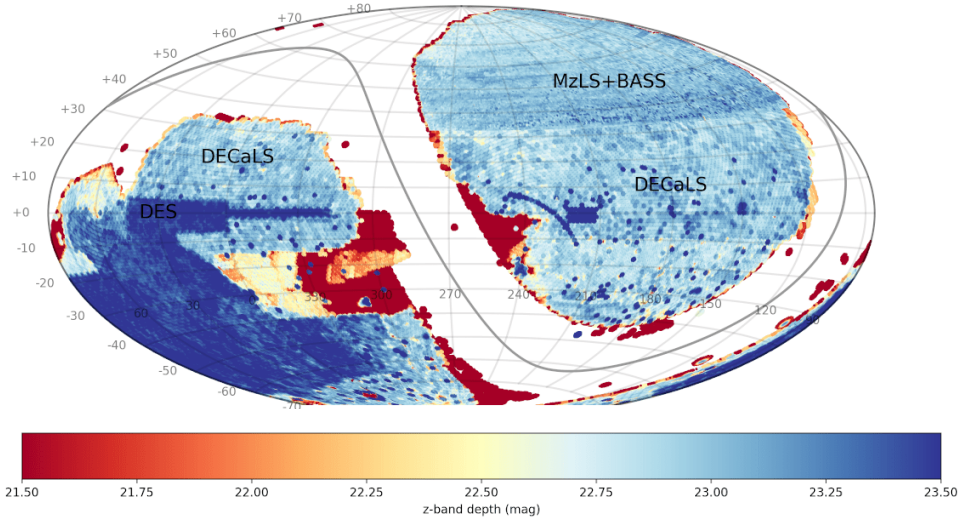
From images to redshifts

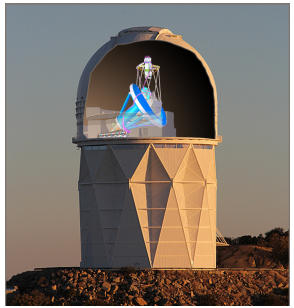
target selection

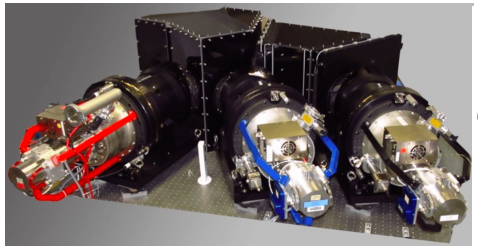


imaging surveys (2014 - 2019) + WISE (IR)

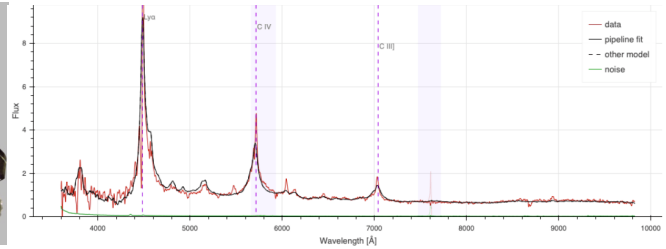


spectroscopic observations





spectra and redshift measurements



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Mayall Telescope

Kitt Peak, AZ

focal plane 5000 fibers

wide-field corrector

FoV $\sim 8\ \mathrm{deg}^2$

49 m, 10-cable fiber run

ten 3-channel spectrographs

fiber view camera

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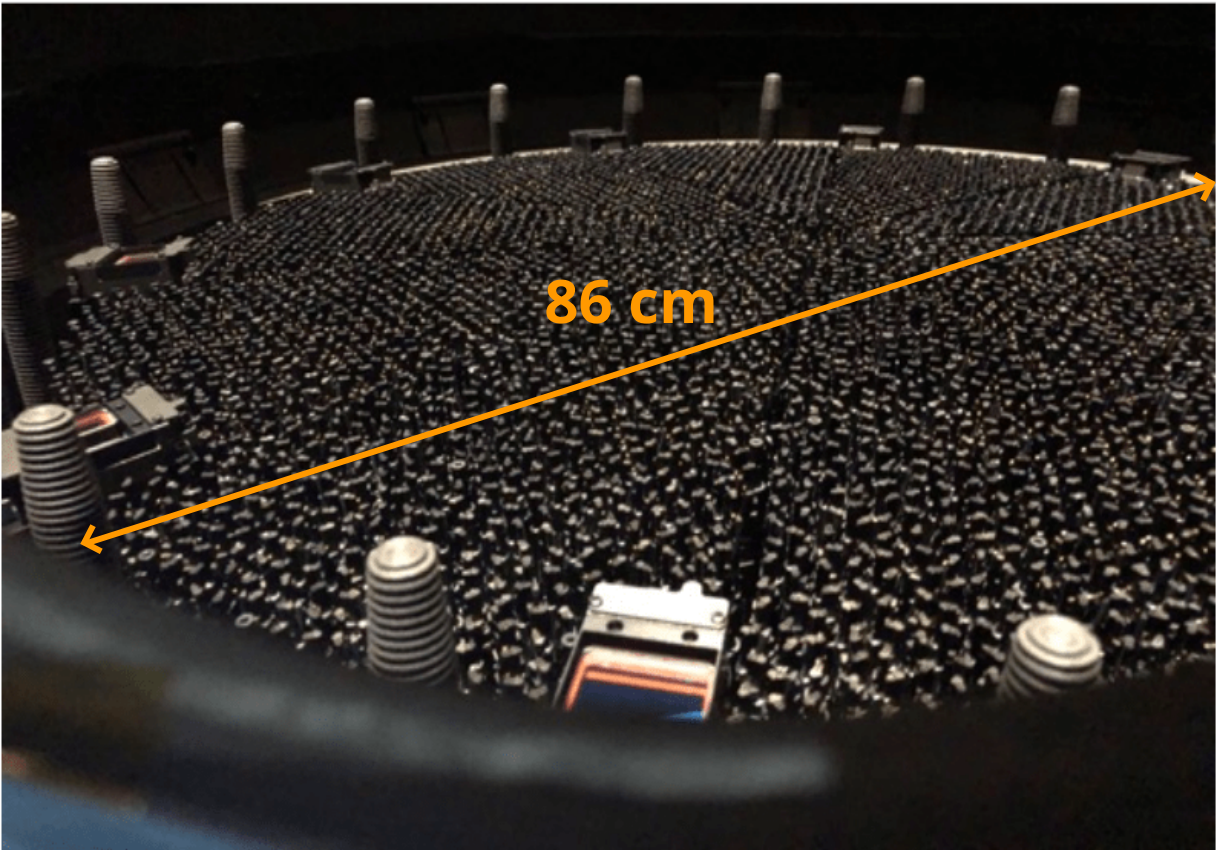
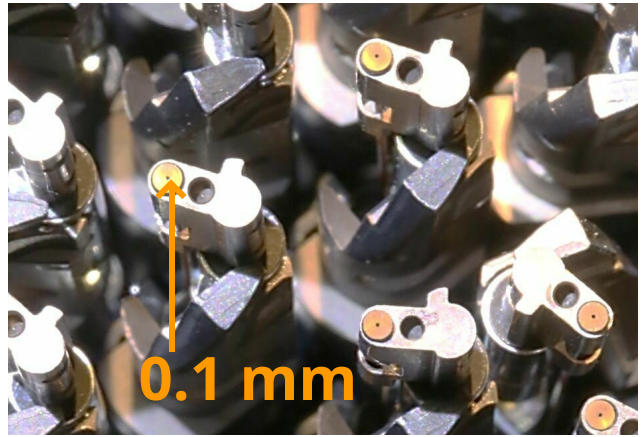
Focal plane: 5000 robotic positioners



Exposure time (dark): **1000 s**

Configuration of the focal plane	**140 s**
CCD readout	
Go to next pointing	



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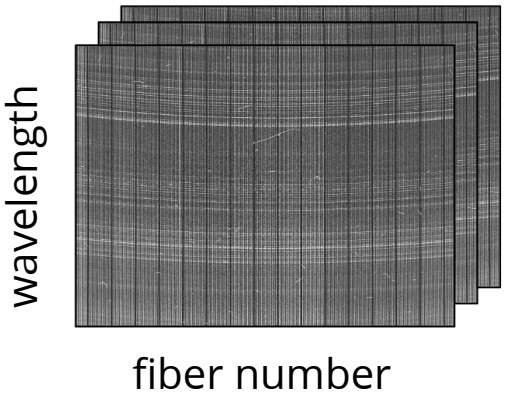
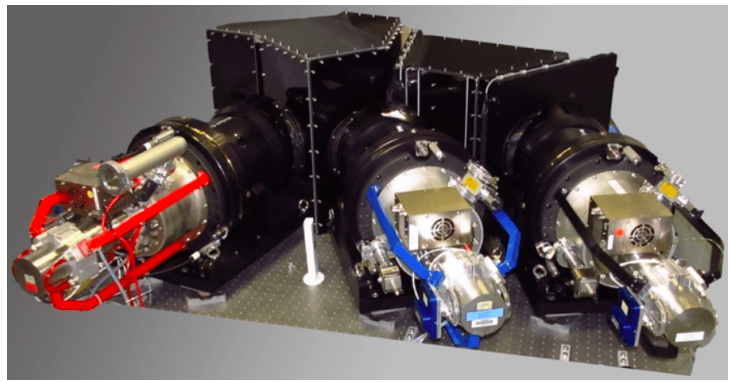
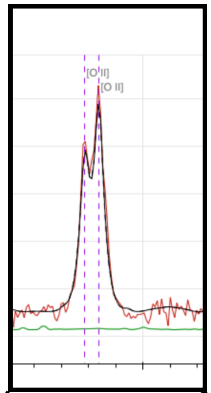
Spectroscopic pipeline

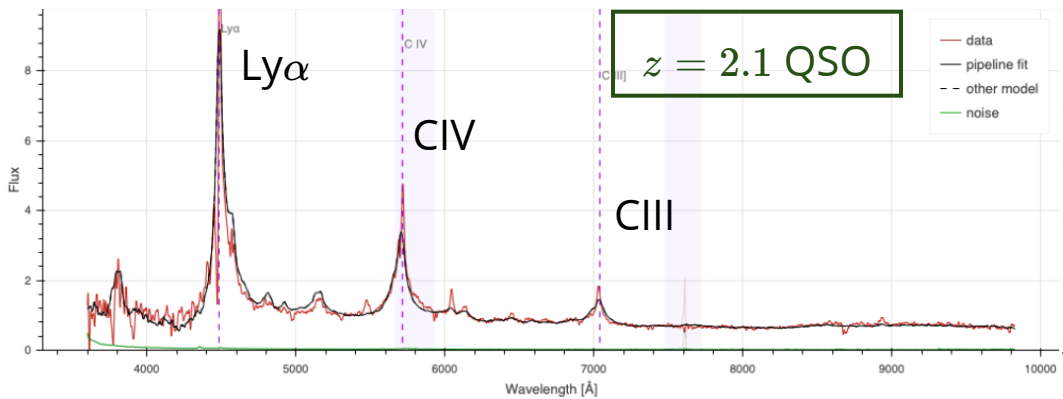


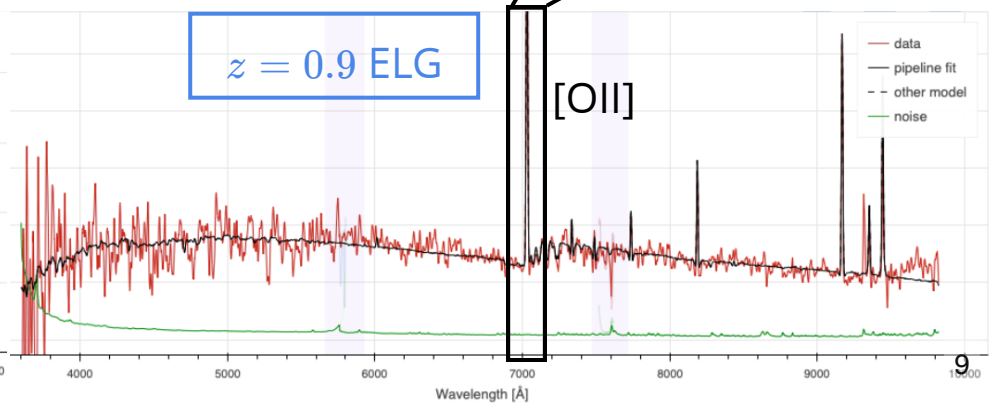




Lyα at $1216\mathring{A}$ down to $z = 2.0$

[OII] doublet at $2727\mathring{A}$ up to $z = 1.6$





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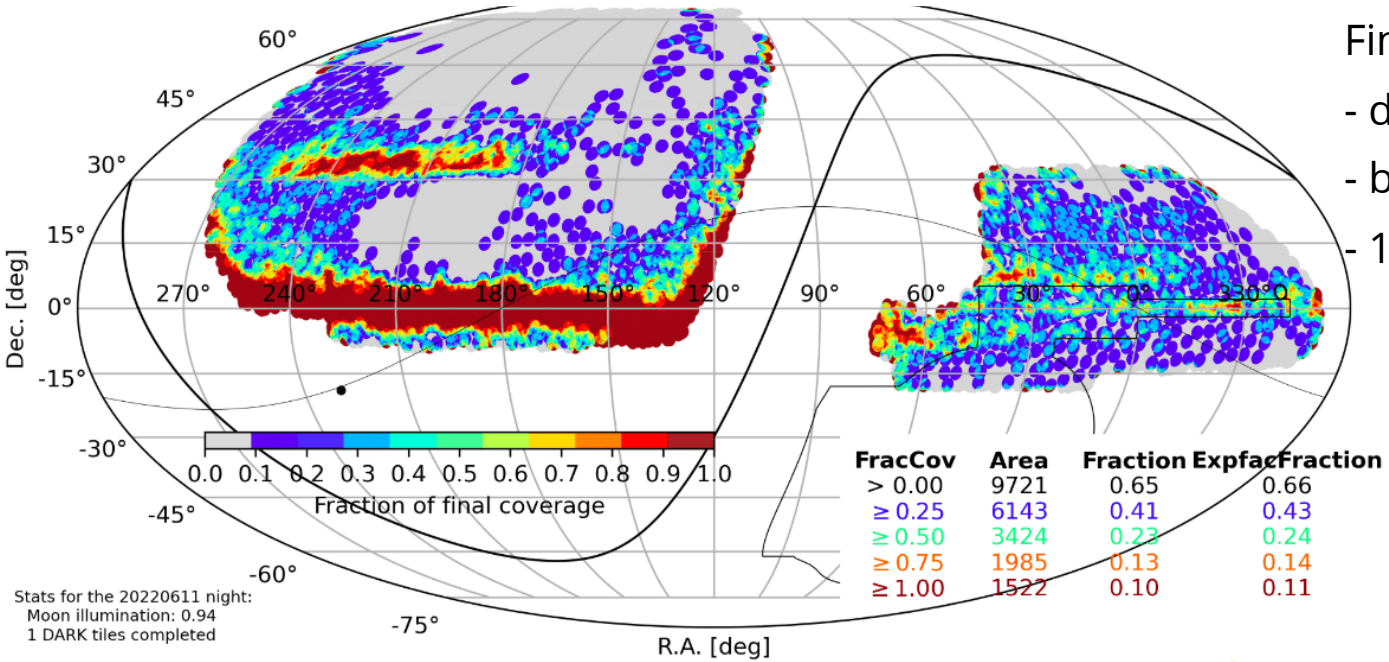
DESI data release 1 (DR1)

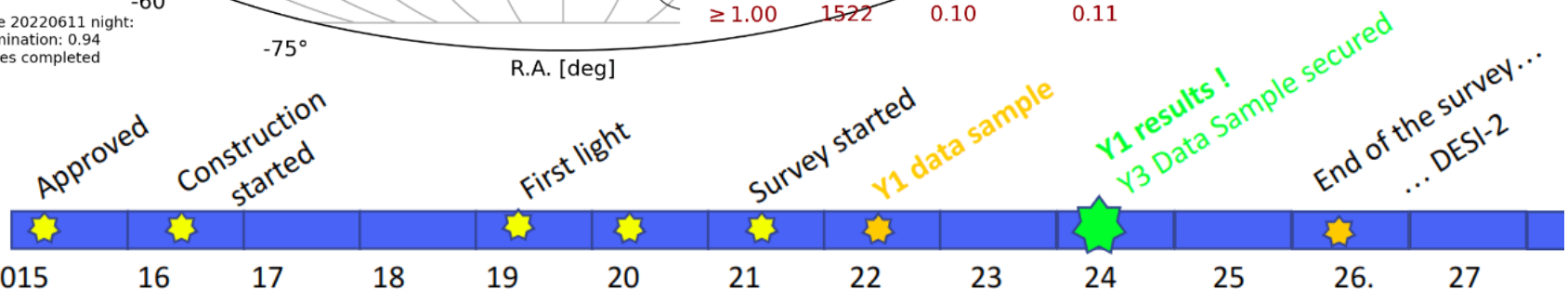
Observations from May 14th 2021 to June 12th 2022

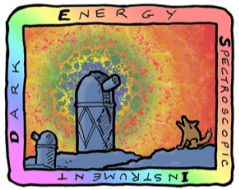


FracCov	Area	Fraction	ExpfacFraction
> 0.00	9721	0.65	0.66
≥ 0.25	6143	0.41	0.43
≥ 0.50	3424	0.23	0.24
≥ 0.75	1985	0.13	0.14
≥ 1.00	1522	0.10	0.11

Final survey

- dark time (LRG, ELG, QSO): 7 visits
- bright time (BGS): 5 visits
- 14,000 deg^2





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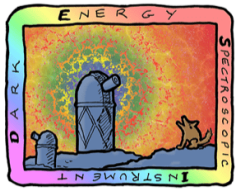
Release of DESI DR1 (BAO) results

April 4th 2024

First batch of DESI DR1 cosmological analyses
https://data.desi.lbl.gov/doc/papers/

- DESI 2024 I: First year data release
- DESI 2024 II: DR1 catalogs
- DESI 2024 III: BAO from Galaxies and Quasars
- DESI 2024 IV: BAO from the Lyman- Forest
- DESI 2024 V: RSD from Galaxies and Quasars
- DESI 2024 VI: Cosmological constraints from BAO measurements
- DESI 2024 VII: Cosmological constraints from RSD measurements



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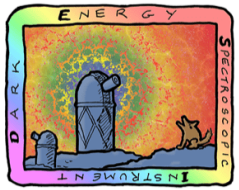

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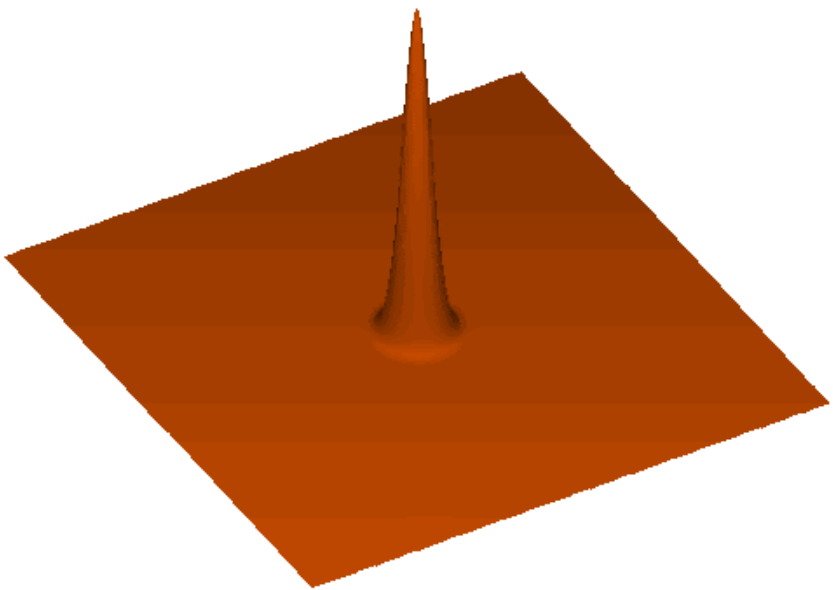
Baryon acoustic oscillations

Sound waves in primordial plasma



At recombination ($z \sim 1100$)

- plasma changes to optically thin
- baryons decouple from photons
- sound wave stalls

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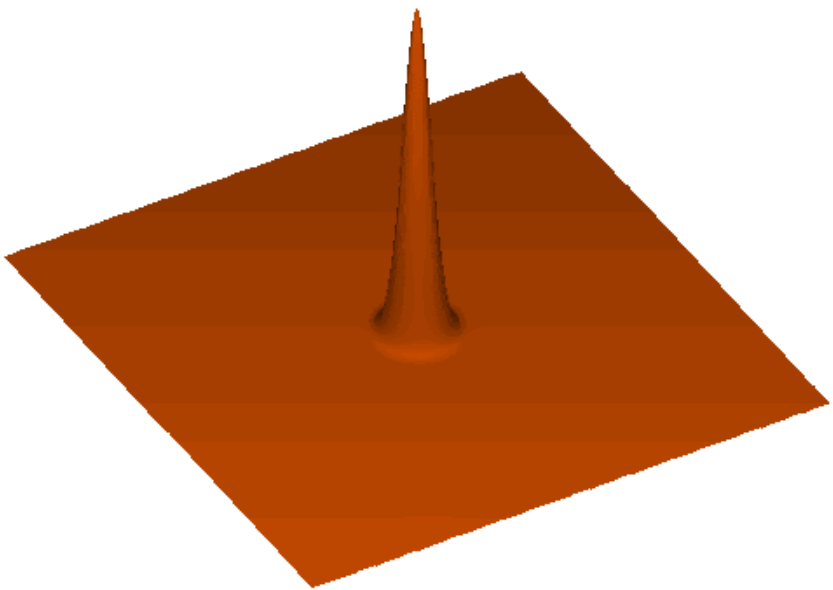
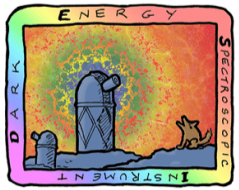


At recombination ($z \sim 1100$)

- plasma changes to optically thin
- baryons decouple from photons
- sound wave stalls

spherical shell in the distribution of galaxies, of radius the distance that sound waves travelled

= **sound horizon scale at the drag epoch** $r_{\rm d} \sim 150\ {\rm Mpc} \sim 100\ {\rm Mpc}/h$



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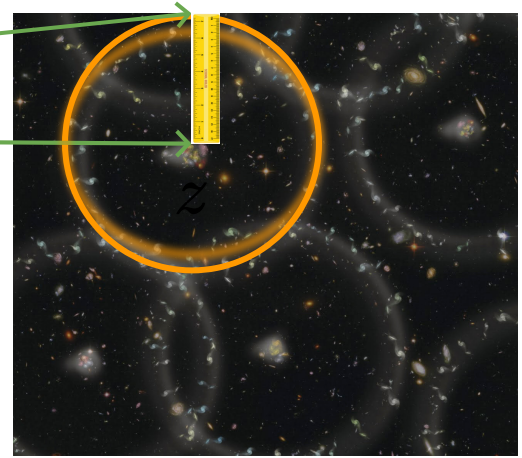
BAO measurements

- transverse to the line-of-sight: $D_{\mathrm{M}}(z)/r_{\mathrm{d}}$

$$\theta_{\mathrm{BAO}} = r_{\mathrm{d}}/D_{\mathrm{M}}(z)$$



sound horizon r_d transverse comoving distance

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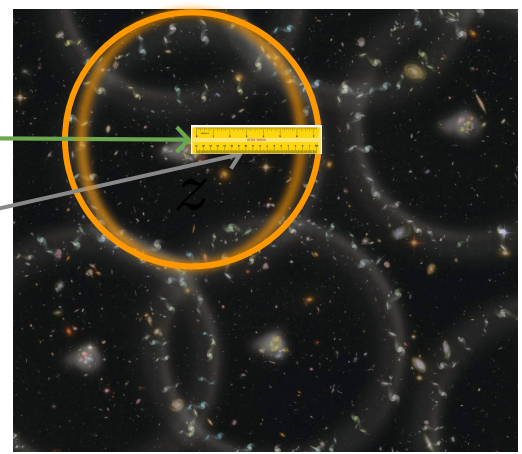
BAO measurements

- transverse to the line-of-sight: $D_{\rm M}(z)/r_{\rm d}$
- along the line-of-sight: $D_{\rm H}(z)/r_{\rm d} = c/(H(z)r_{\rm d})$

$$\Delta z_{\rm BAO} = r_{\rm d}/D_{\rm H}(z)$$



sound horizon r_d Hubble distance

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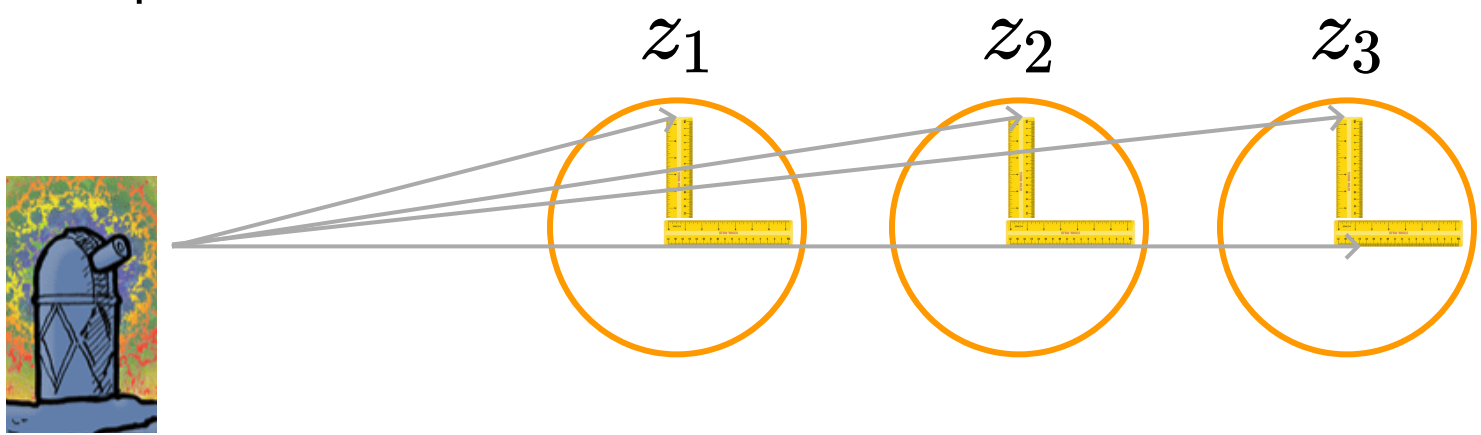
BAO measurements

- transverse to the line-of-sight: $D_{\rm M}(z)/r_{\rm d}$
- along the line-of-sight: $D_{\rm H}(z)/r_{\rm d} = c/(H(z)r_{\rm d})$

At multiple redshifts z



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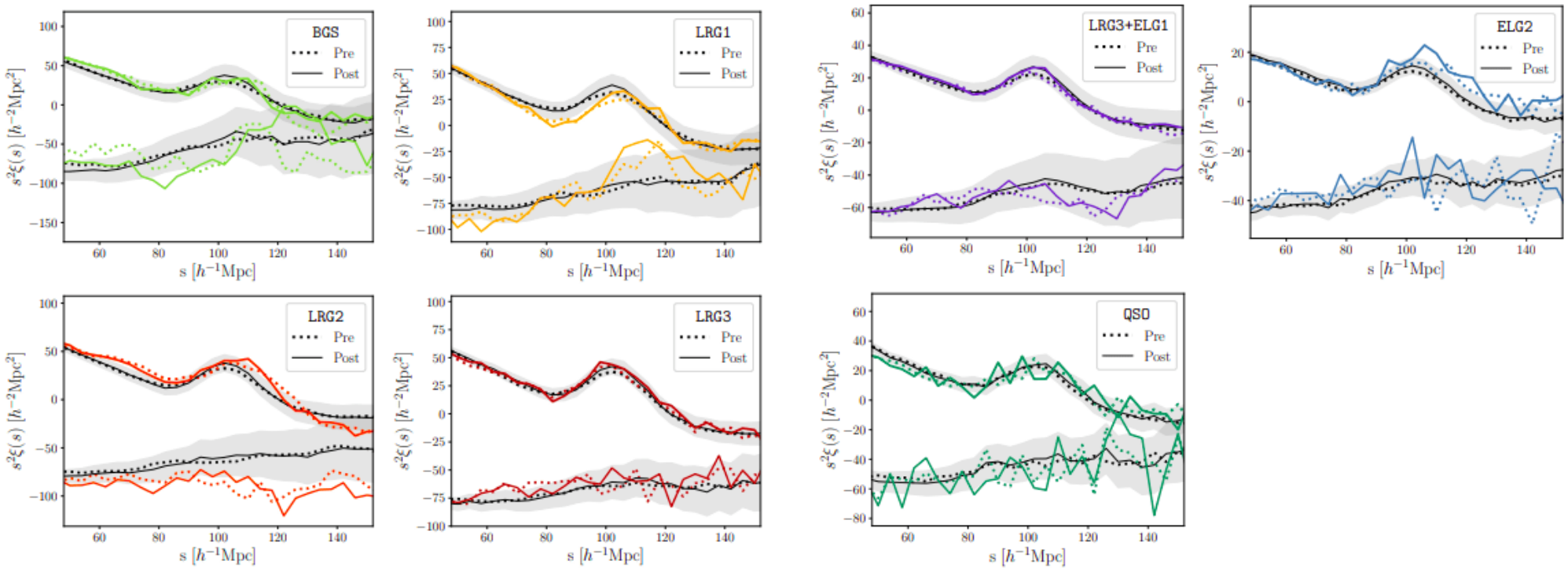
Correlation functions

Excess probability to find 2 galaxies separated by a separation s



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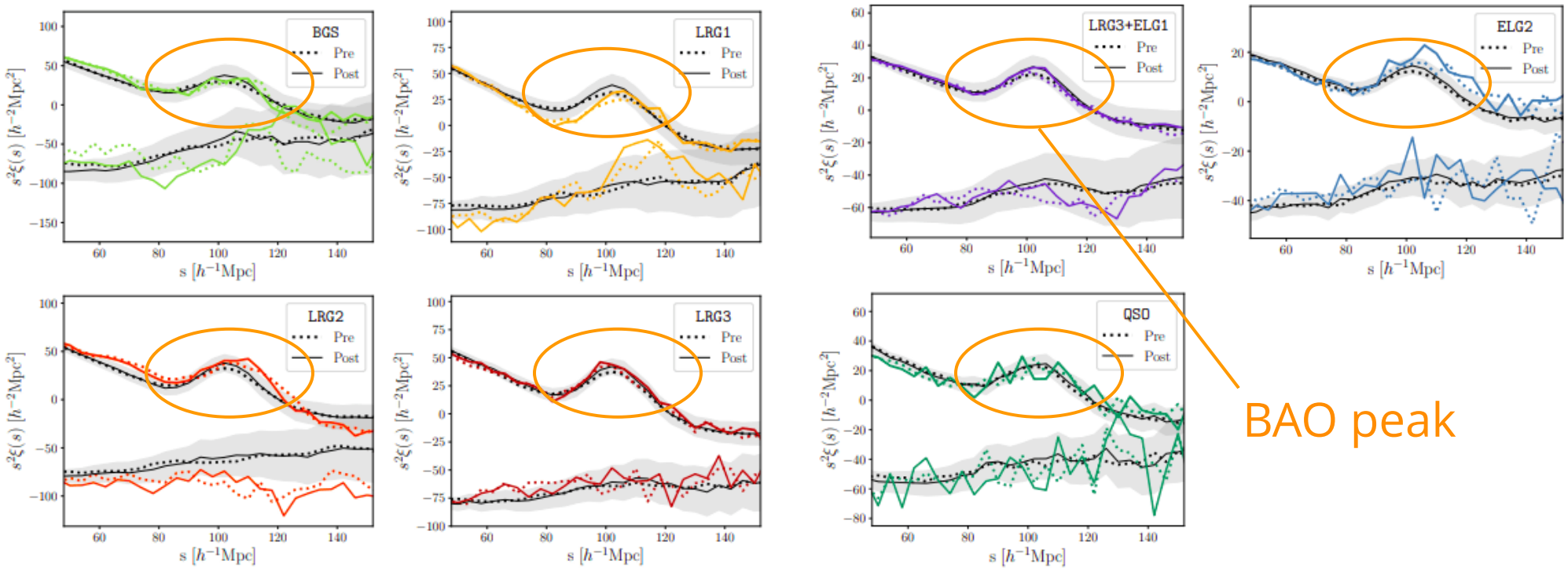

BAO peak

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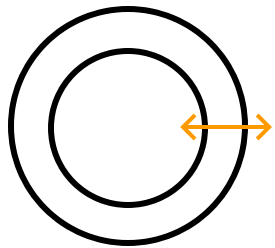
Some fits: configuration space

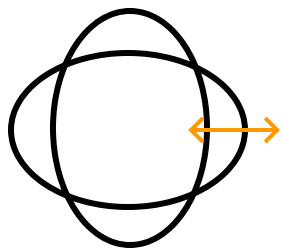
isotropic measurement

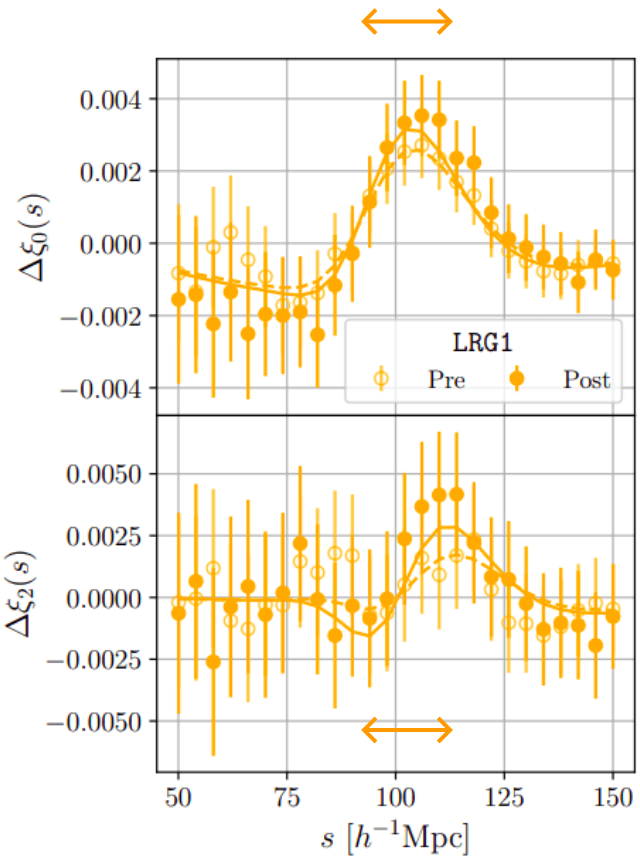
$$\propto (D_{\rm M}^2(z) D_{\rm H}(z))^{1/3}/r_{\rm d}$$



anisotropic measurement

$$\propto D_{\rm M}(z)/D_{\rm H}(z)$$





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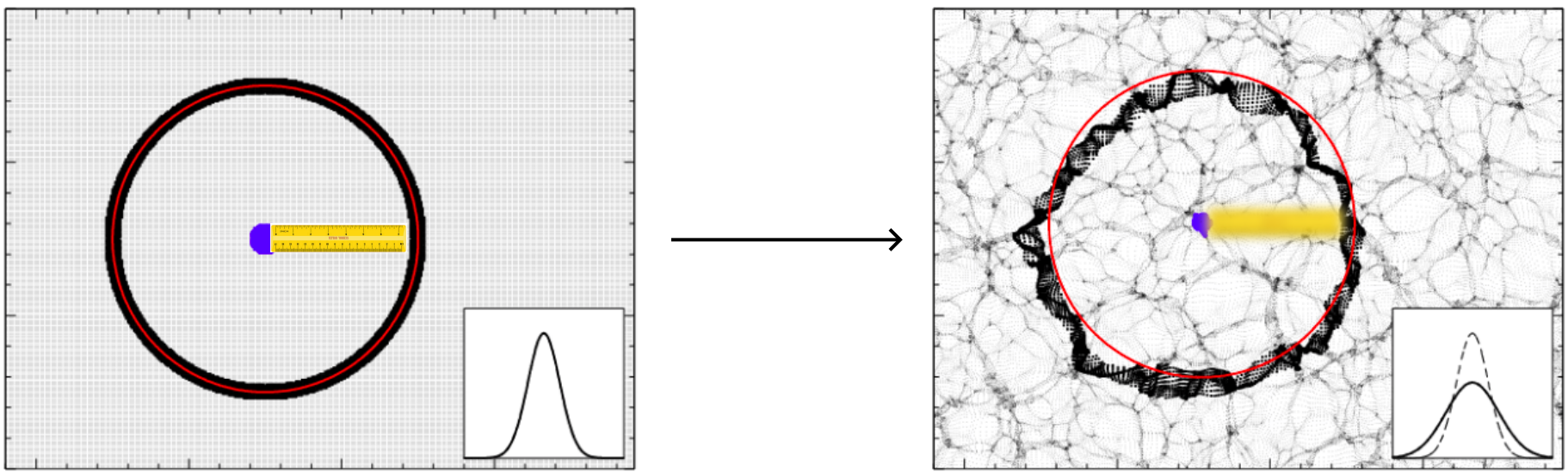
Non-linear evolution

Non-linear structure growth and peculiar velocities **blur** and **shrink** (slightly) the ruler

Eisenstein et al. 2008, Padmanabhan et al. 2012



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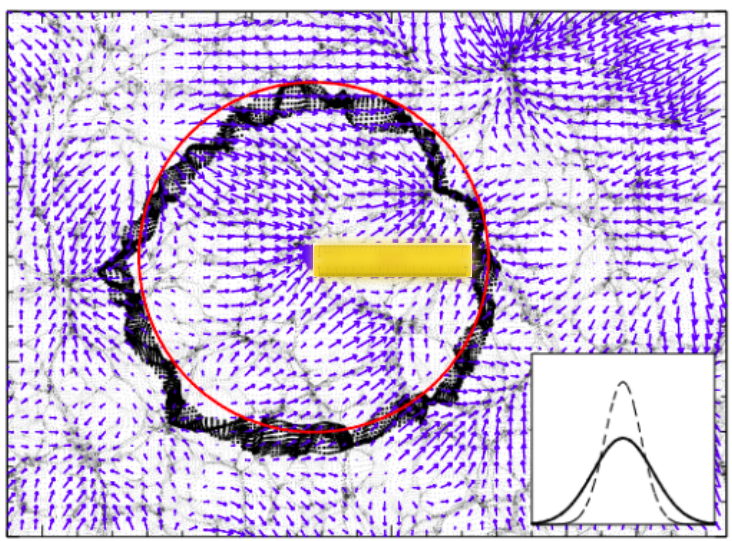
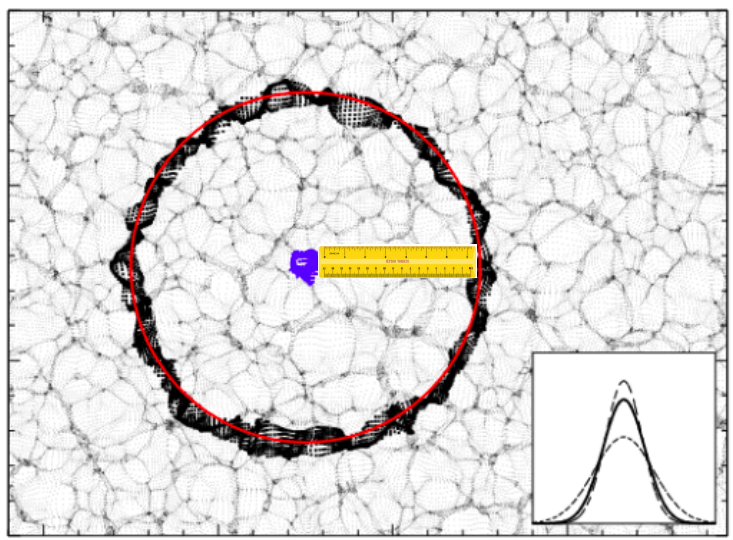
Density field reconstruction

Estimates Zeldovich displacements from observed field and moves galaxies back: **refurbishes the ruler** (improves precision and accuracy)



reconstruction



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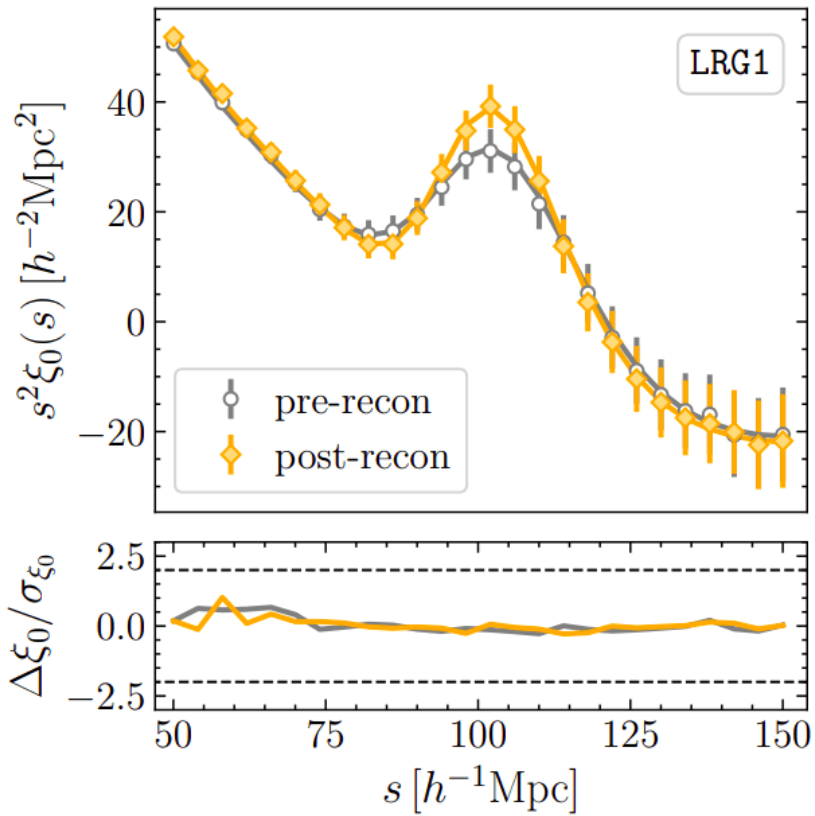

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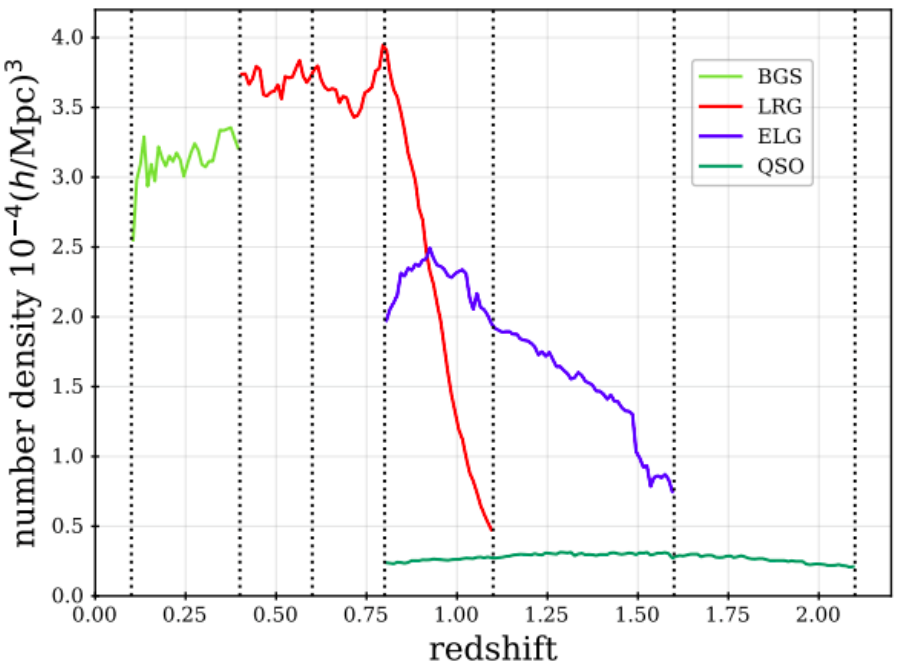
DESI DR1 BAO analysis

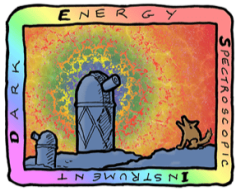
- **Biggest ever spectroscopic BAO dataset** ($N_{\rm tracer}$ and V)



5.7 million unique redshifts

Effective cosmic volume $V_{\rm eff} = 18\ \mathrm{Gpc}$

3× bigger than SDSS!



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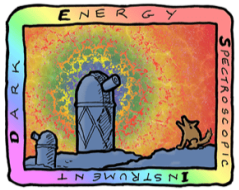
- **Biggest ever spectroscopic BAO dataset** (N_{tracer} and V)
- **Blind analysis** to mitigate observer / confirmation biases (catalog-level blinding)

$$(\mathrm{R.A.}, \mathrm{Dec.}, z) \Longrightarrow (x, y, z) \Longrightarrow (\mathrm{R.A.}', \mathrm{Dec.}', z')$$

fiducial cosmology

blinded cosmology ($\Omega_{\mathrm{m}}, w_0, w_a$)

(random & unknown)



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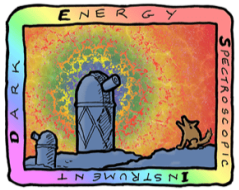
DESI DR1 BAO analysis

- **Biggest ever spectroscopic BAO dataset** (N_{tracer} and V)
- **Blind analysis** to mitigate observer / confirmation biases (catalog-level blinding)
- Improvements in the theory and methodology, **unified BAO pipeline**



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Tests of systematic errors

Considered many possible sources of systematic errors using simulations and data:

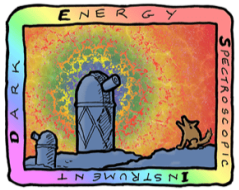
- observational effects (imaging systematics, fiber collisions)
- BAO reconstruction (2 algorithms compared)
- covariance matrix construction

no systematics detected

- incomplete theory modelling
- choice of fiducial cosmology
- galaxy-halo (HOD) model uncertainties

systematics << statistics

Max effect: $\sigma_{\text{stat.+syst.}} < 1.05\sigma_{\text{stat.}}$



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- **DESI 2024 IV: BAO from the Lyman- Forest**
- DESI 2024 V: RSD from Galaxies and Quasars
- DESI 2024 VI: Cosmological constraints from BAO measurements
- DESI 2024 VII: Cosmological constraints from RSD measurements

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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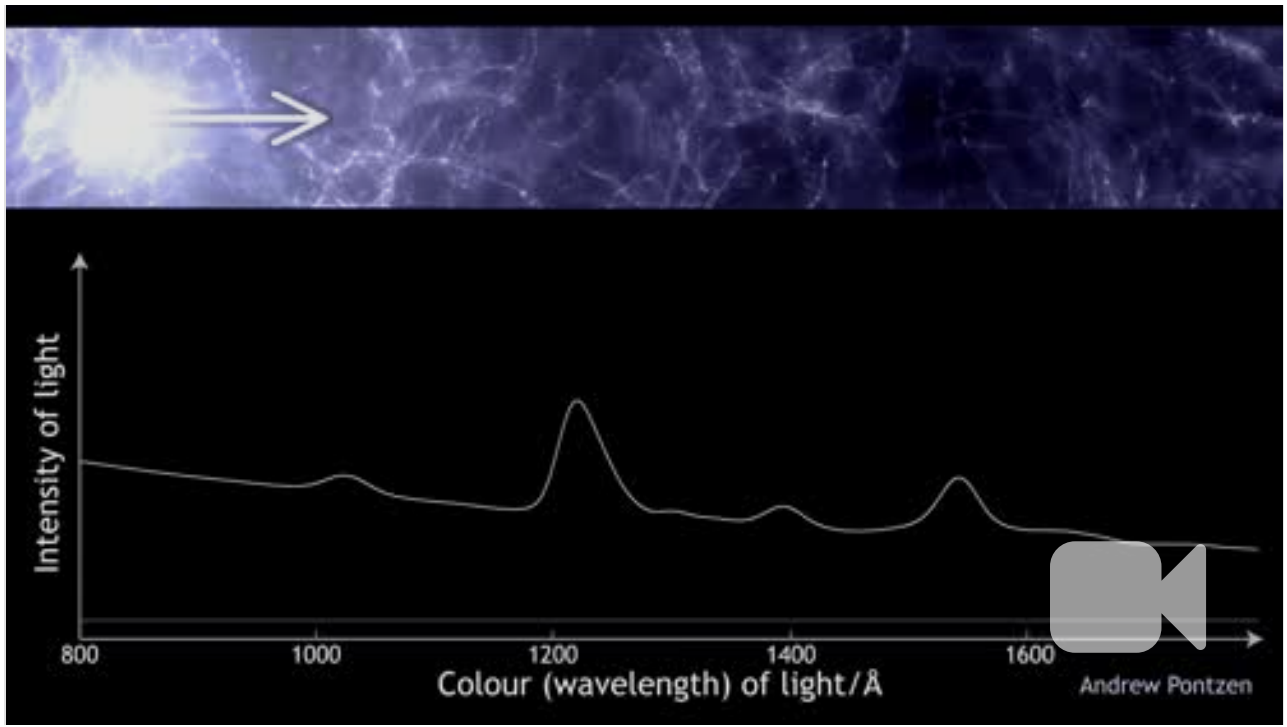
Lyα forest

credit: Andrew Pontzen



Absorption in QSO spectra by neutral hydrogen in the intergalactic medium: $\lambda_{\rm abs} = (1 + z_{\rm HI}) \times 1215.17\ \mathring{A}$

Transmitted flux fraction $F = e^{-\tau}$ probes the fluctuation in neutral hydrogen density, $\tau \propto n_{\rm HI}$

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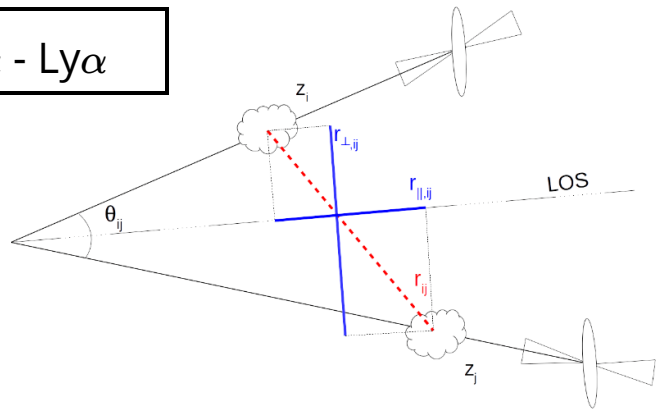
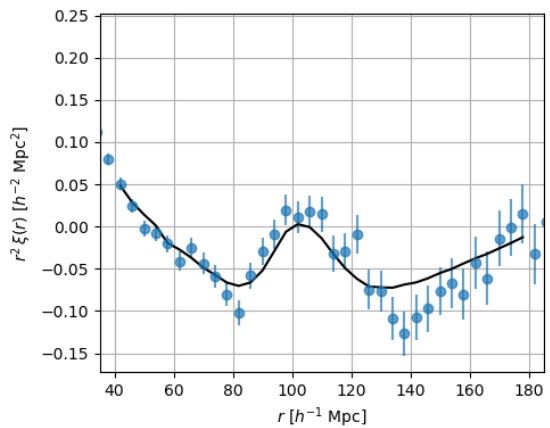
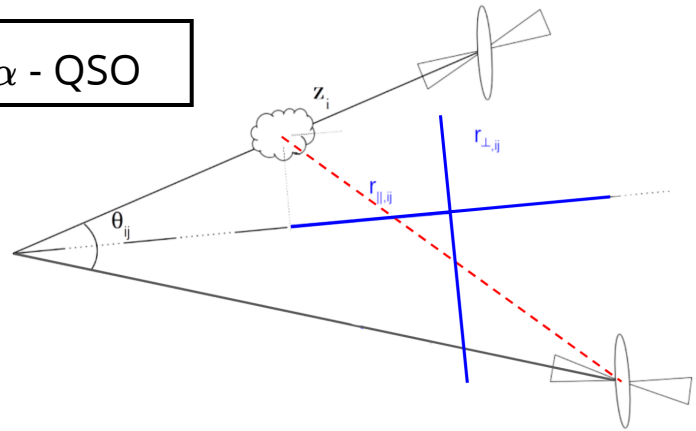
Lyα correlation functions in DESI DR1

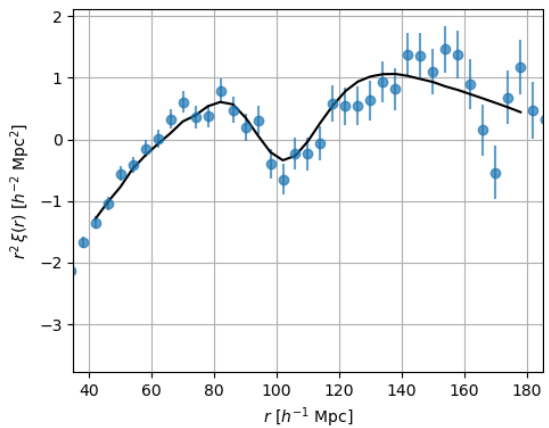
Lyα - Lyα





Lyα - QSO





DARK ENERGY SPECTROSCOPIC INSTRUMENT

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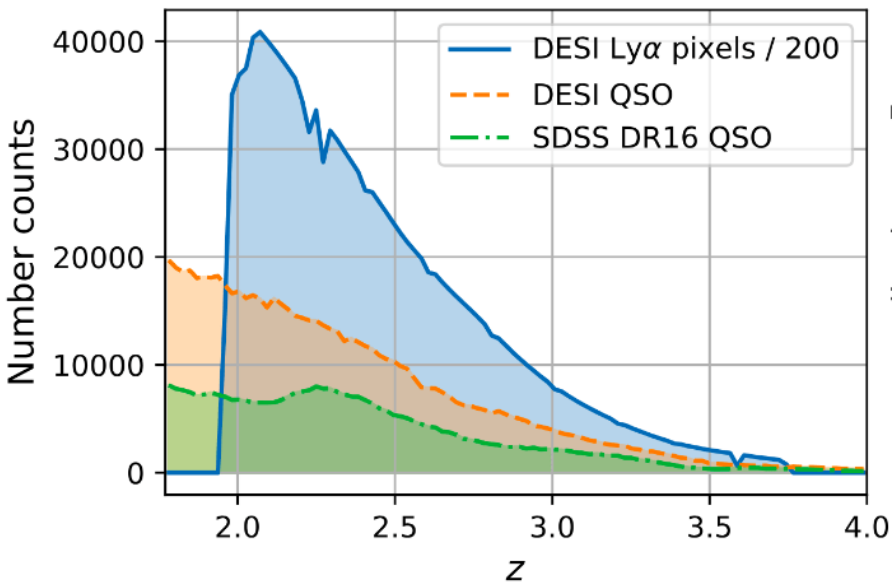
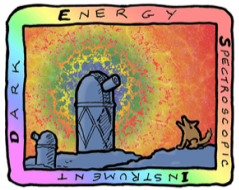
DESI DR1 Lyα BAO analysis

- **Biggest ever Lyα dataset** (N_{tracer})



>420,000 Lyα QSO at z > 2.1

2$\times$ more than SDSS!



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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DESI DR1 Lyα BAO analysis

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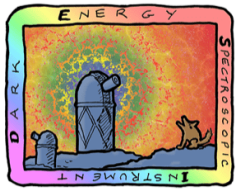
- **First blind analysis** to mitigate observer / confirmation biases (correlation function-level blinding)



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DESI DR1 Lyα BAO analysis

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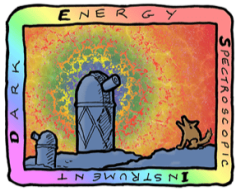
- Modelling of the correlation function: cosmological signal, and many contaminants!



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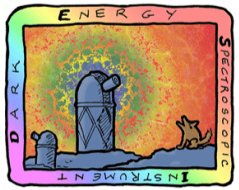
DESI DR1 Lyα BAO analysis

- **Biggest ever Lyα dataset** (N_{tracer})
- **First blind analysis** to mitigate observer / confirmation biases (correlation function-level blinding)
- Modelling of the correlation function: cosmological signal, and many contaminants!
- Very stable results, systematic uncertainty neglected



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Release of DESI DR1 (BAO) results

April 4th 2024

First batch of DESI DR1 cosmological analyses
https://data.desi.lbl.gov/doc/papers/

- DESI 2024 I: First year data release
- DESI 2024 II: DR1 catalogs
- DESI 2024 III: BAO from Galaxies and Quasars
- DESI 2024 IV: BAO from the Lyman- Forest
- DESI 2024 V: RSD from Galaxies and Quasars
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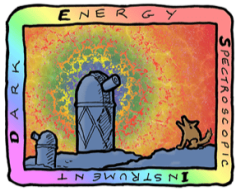

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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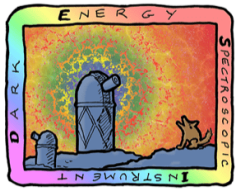
BAO measurements

BAO measures ratios of distances over the sound horizon scale at the drag epoch ["standard ruler"] r_d

- transverse to the line-of-sight: $D_\mathrm{M}(z)/r_\mathrm{d}$
- along the line-of-sight: $D_\mathrm{H}(z)/r_\mathrm{d} = c/(H(z)r_\mathrm{d})$
- low S/N, isotropic average: $D_\mathrm{V}(z)/r_\mathrm{d} = (zD_\mathrm{M}^2(z)D_\mathrm{H}(z))^{1/3}/r_\mathrm{d}$



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BAO measurements

These quantities directly relate to base cosmological parameters

Let's factor out the h terms:

- $[D_{\rm M}(z)h](\Omega_{\rm m}, f_{\rm DE}, \Omega_{\rm K}, ...)/[r_{\rm d}(\Omega_{\rm m}h^2, \Omega_{\rm b}h^2)h]$
- $[D_{\rm H}(z)h](\Omega_{\rm m}, f_{\rm DE}, \Omega_{\rm K}, ...)/[r_{\rm d}(\Omega_{\rm m}h^2, \Omega_{\rm b}h^2)h]$

BAO measurements **at different z** constrain:

- energy content $(\Omega_{\rm m}, f_{\rm DE}, ...)$
- constant-over-z product $r_{\rm d}h$ i.e. $H_0 r_{\rm d}$

$h = H_0/[100\ {\rm km/s/Mpc}]$

$\Omega_{\rm m}$ fractional energy density of matter

$f_{\rm DE}$ dark energy

$\Omega_{\rm K}$ curvature

Ω_b baryons

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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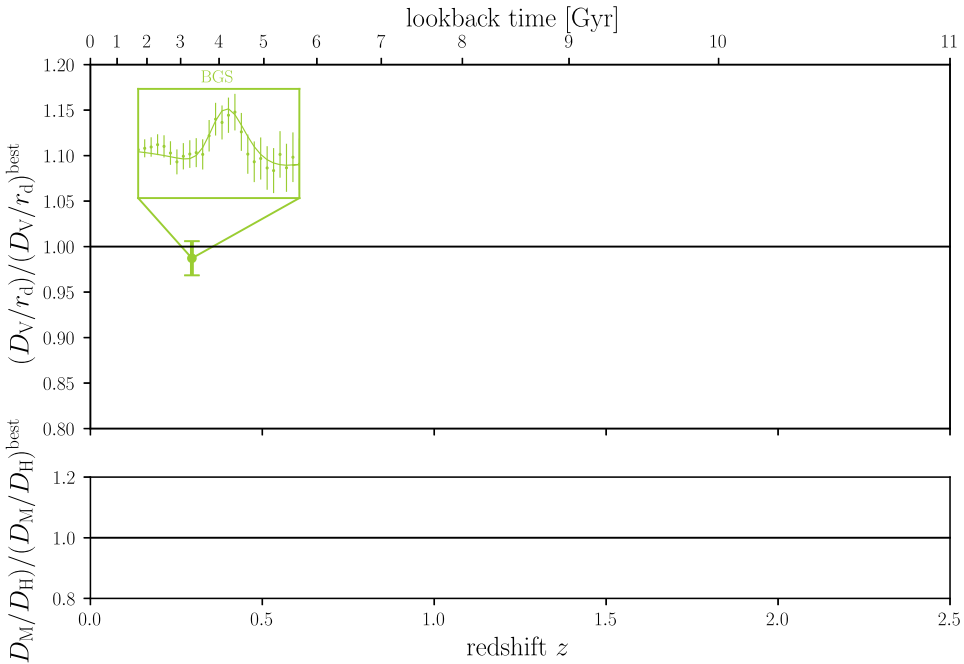
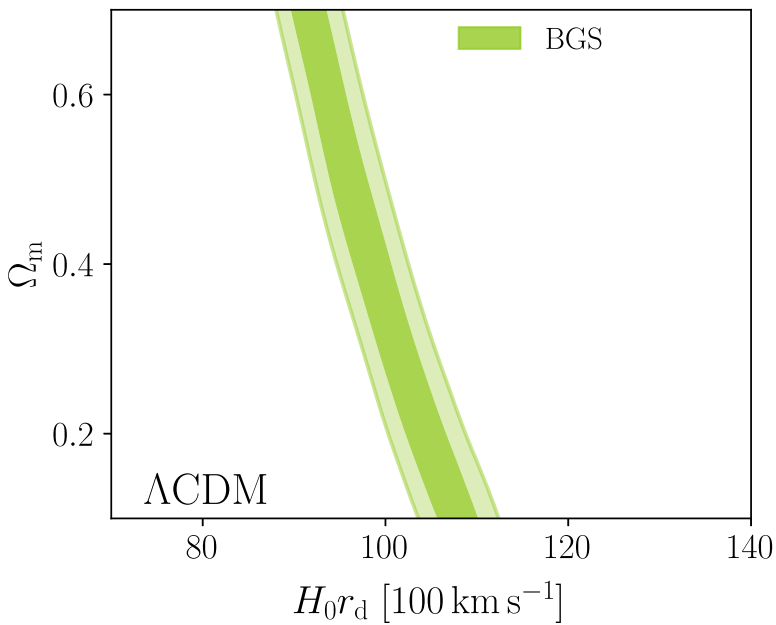
DESI Y1 BAO

DESI BAO measurements





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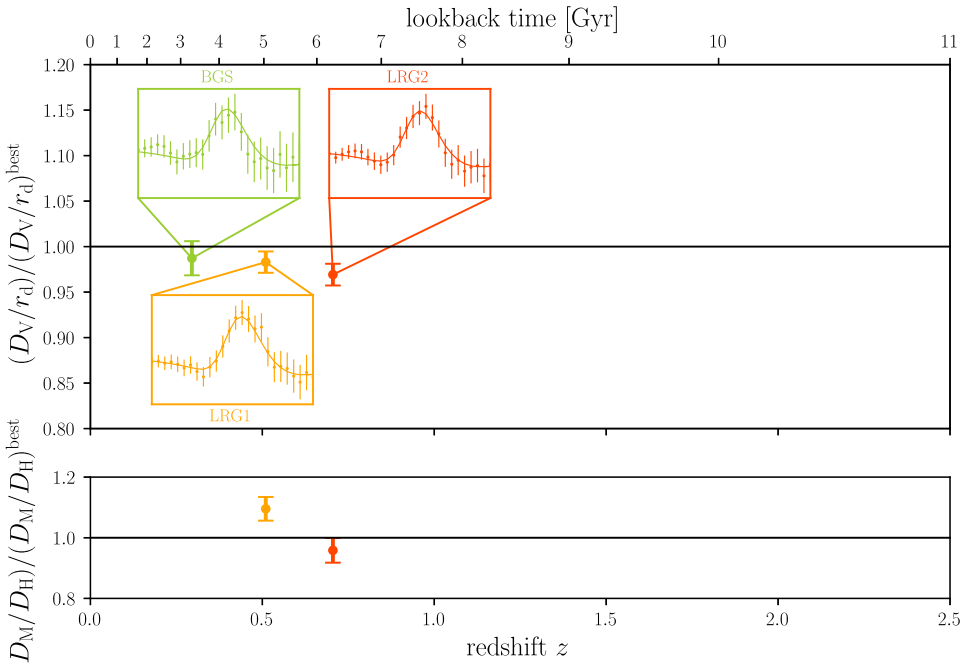
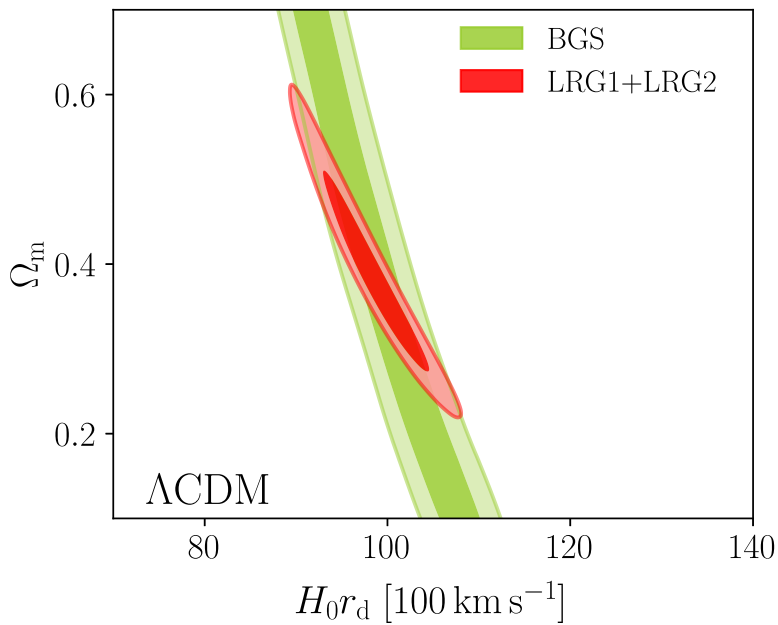
DESI BAO measurements





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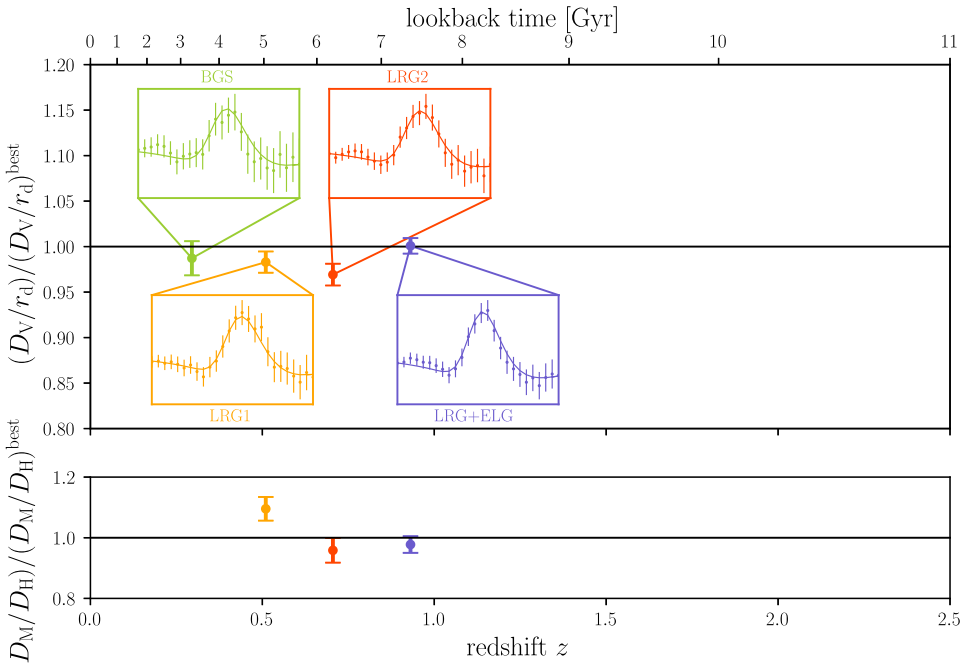
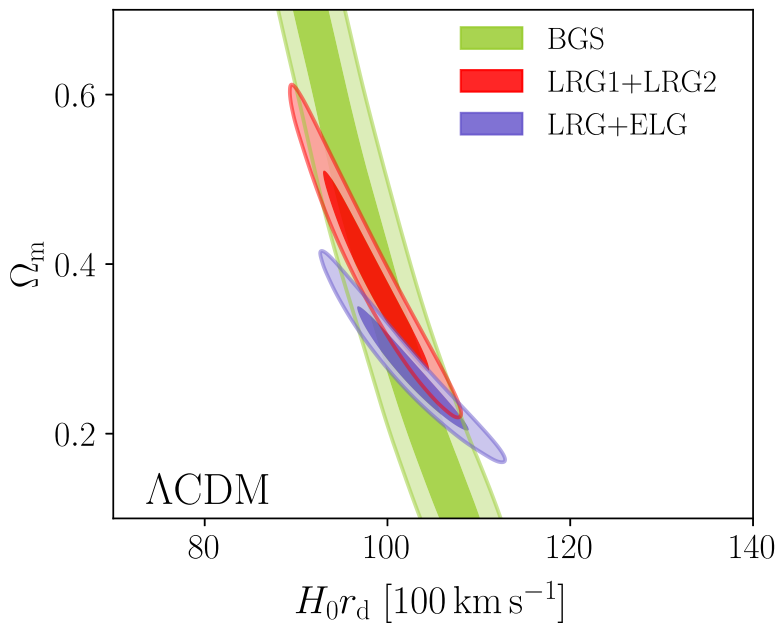
DESI BAO measurements





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DESI Y1 BAO

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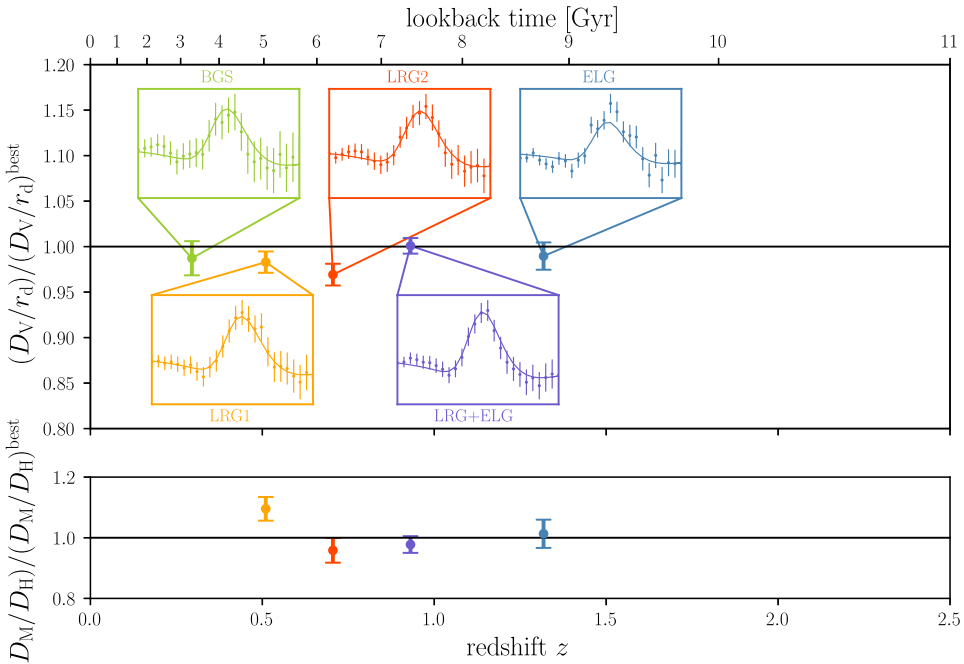

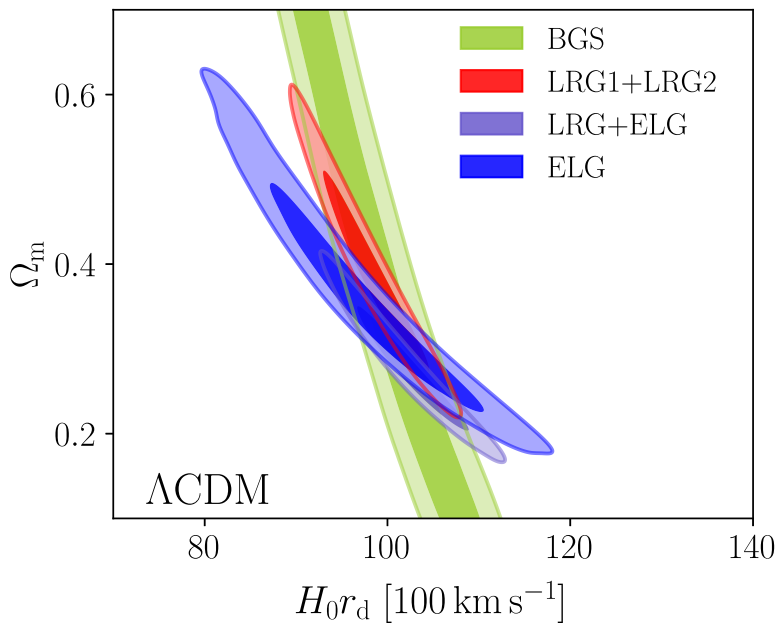

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DESI Y1 BAO

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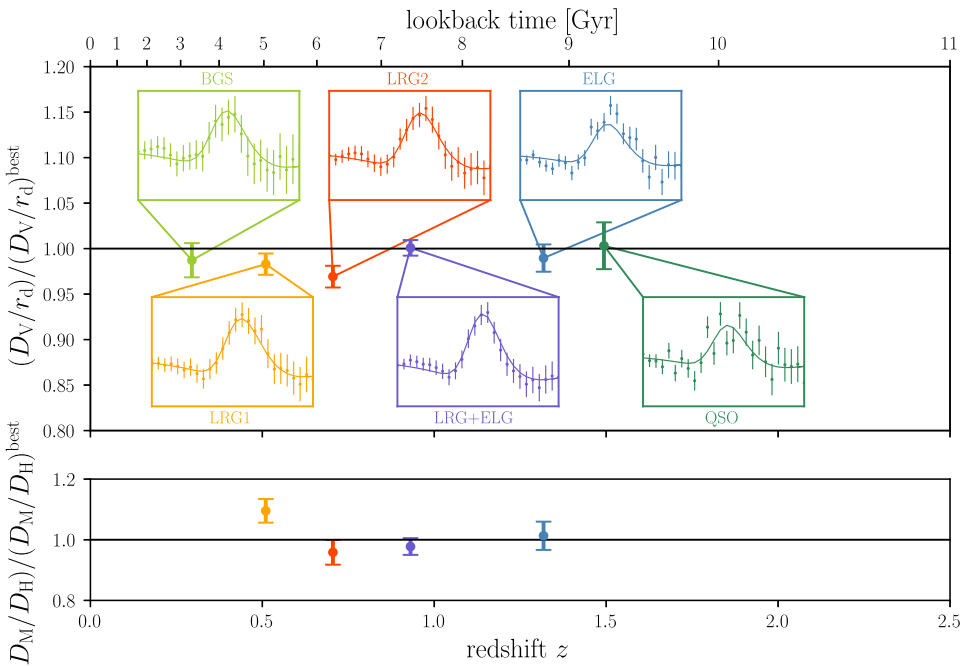

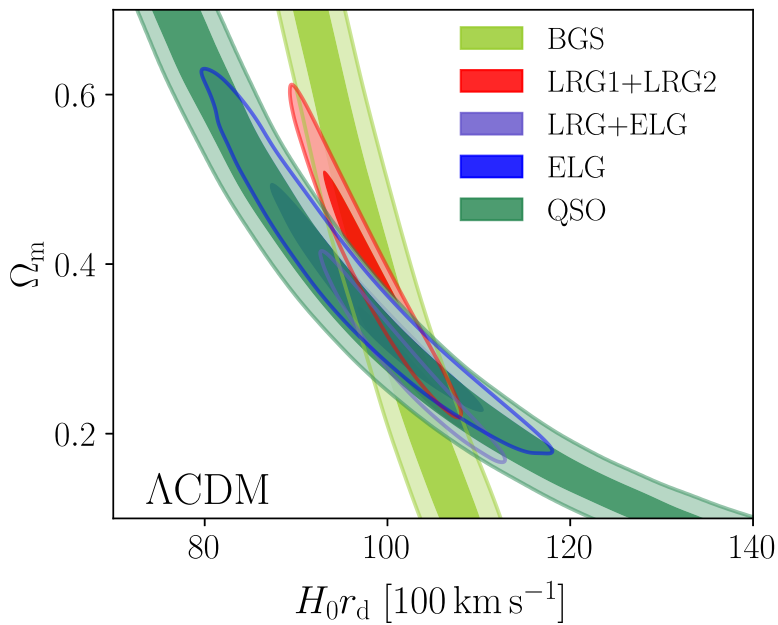

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DESI Y1 BAO

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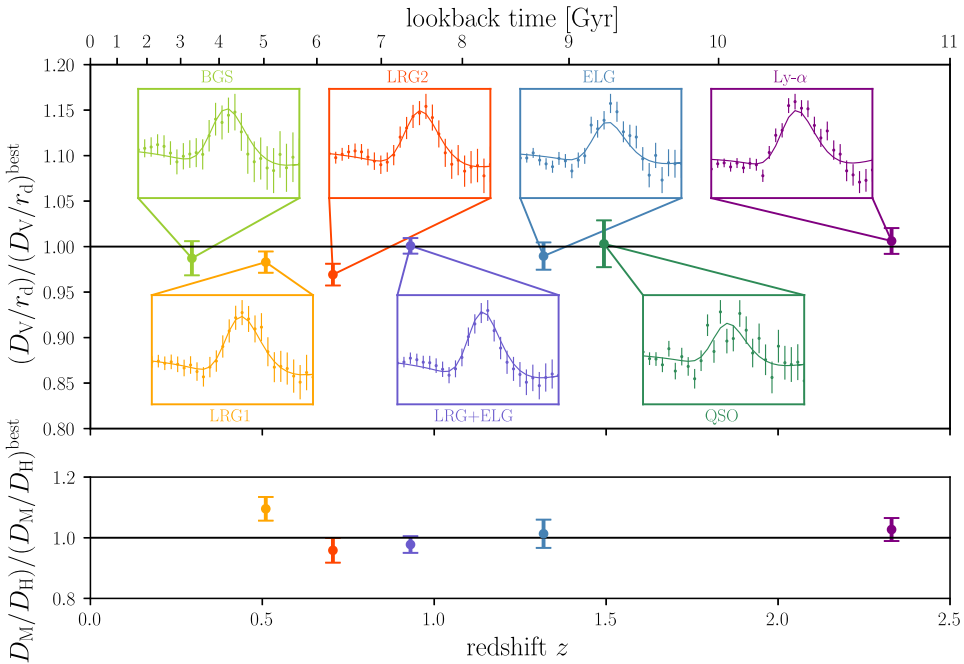

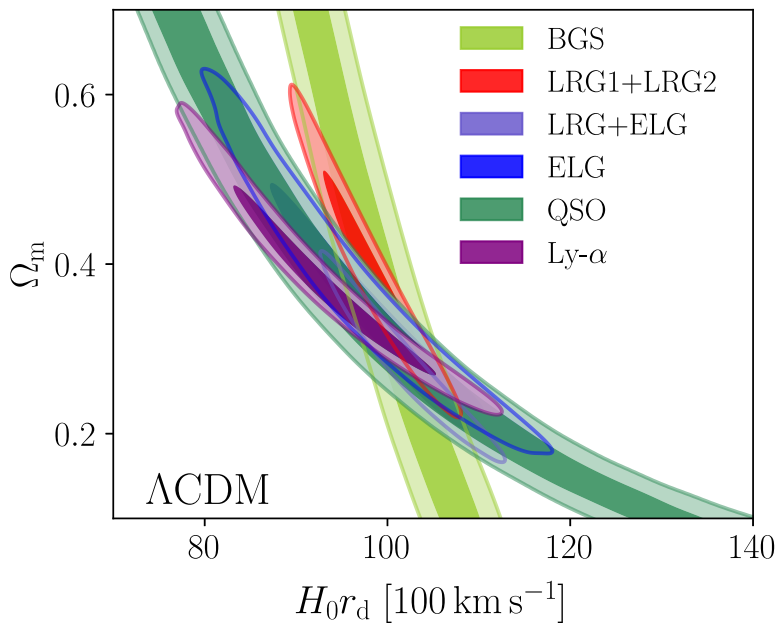

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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DESI Y1 BAO

DESI BAO measurements

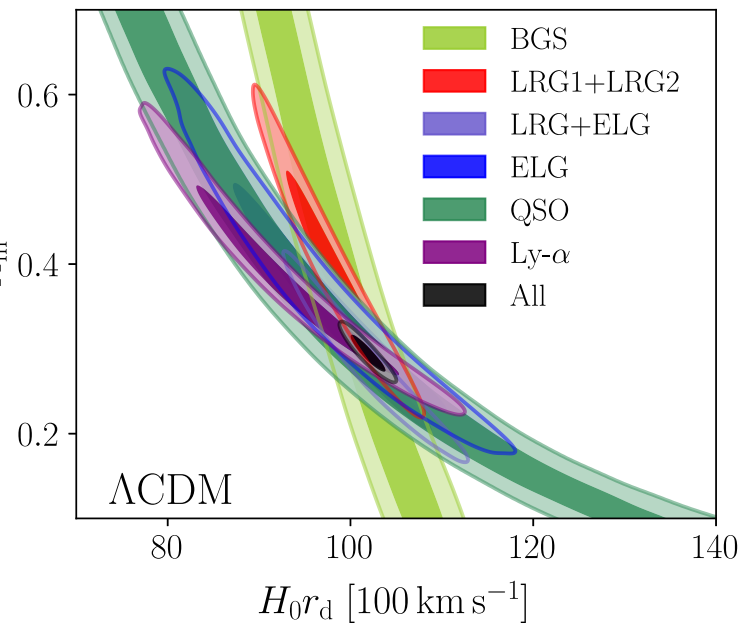
Consistent with each other,

and complementary

$$\Omega_{\rm m} = 0.295 \pm 0.015 \quad (\mathbf{5.1\%})$$

$$H_0 r_{\rm d} = (101.8 \pm 1.3)\,[100\,{\rm km\,s^{-1}}] \quad (\mathbf{1.3\%})$$

$$\underbrace{\qquad\qquad\qquad\qquad}_{\rm DESI}$$



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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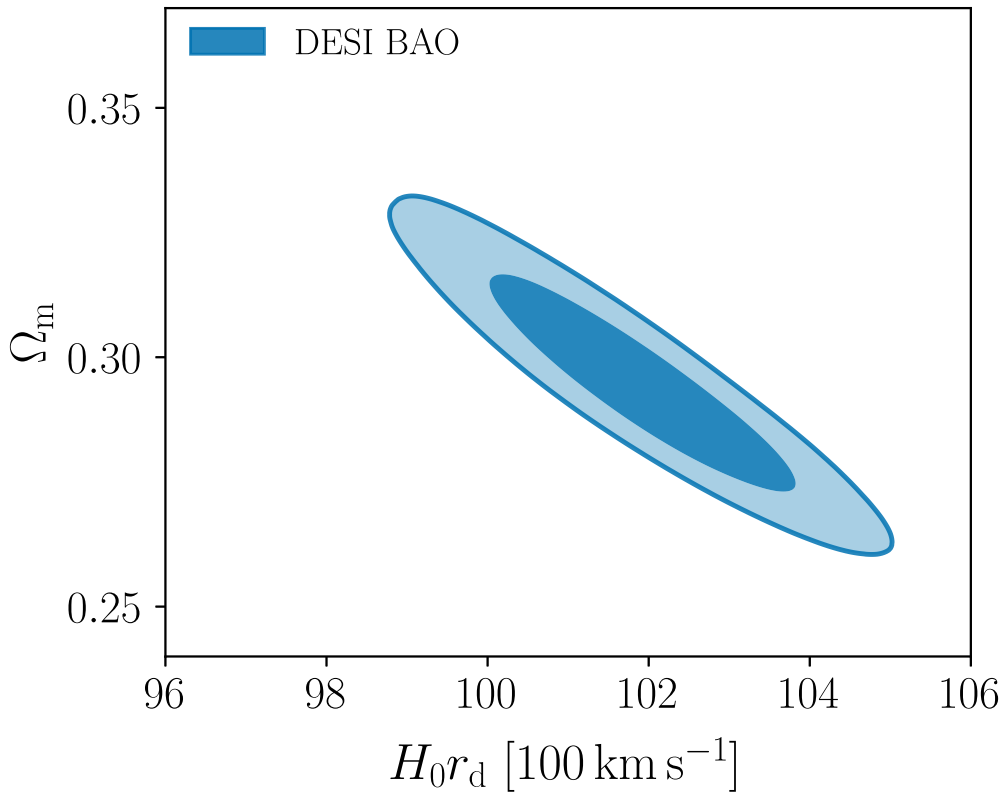
Consistency with other probes

DESI Y1 BAO consistent with:



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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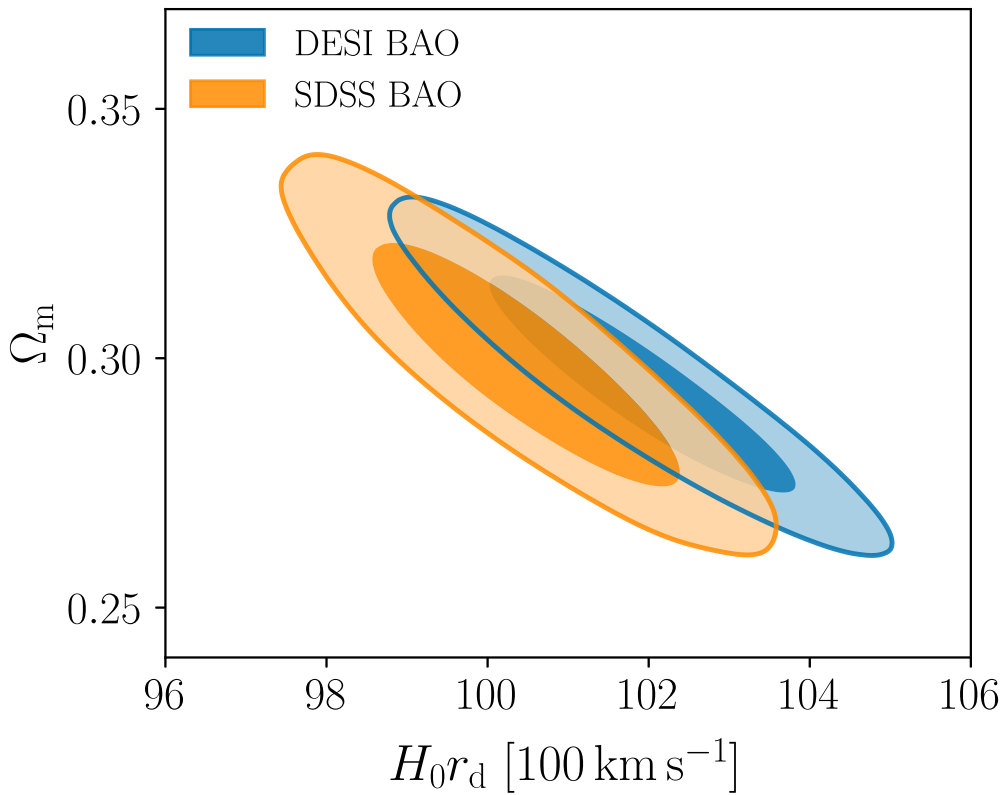
Consistency with other probes

DESI Y1 BAO consistent with:

- SDSS eBOSS Collaboration, 2020



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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Consistency with other probes

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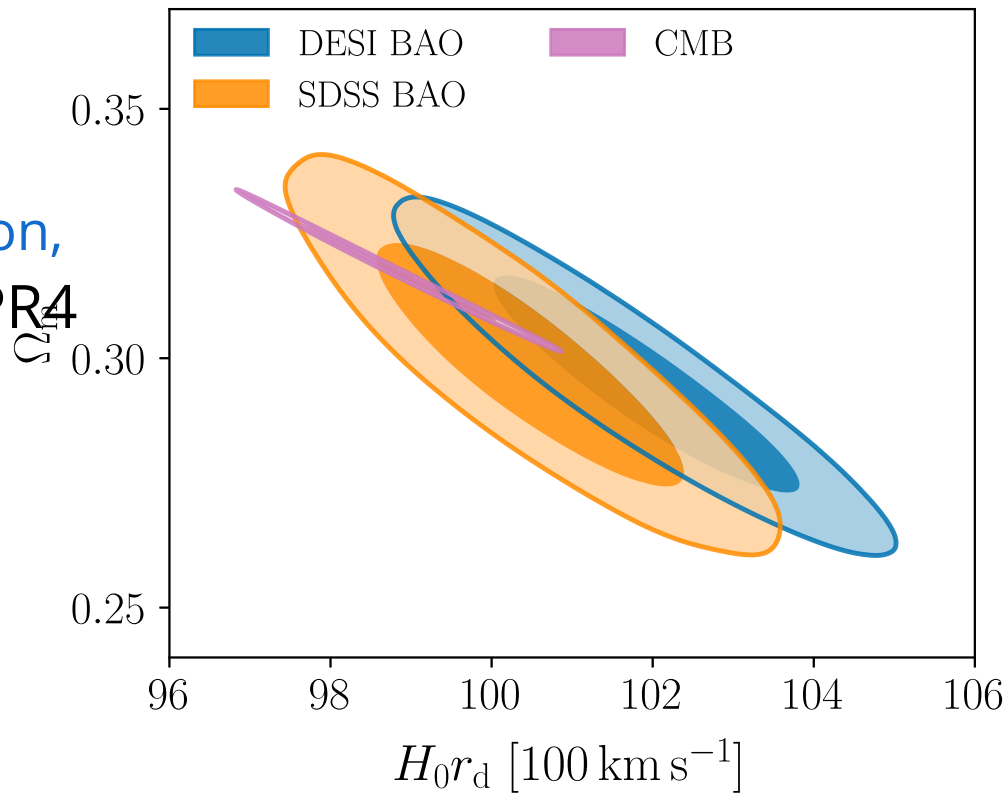
- primary CMB: Planck Collaboration, 2018 and CMB lensing: Planck PR4 + ACT DR6 lensing ACT Collaboration, 2023, Carron, Mirmelstein, Lewis, 2022



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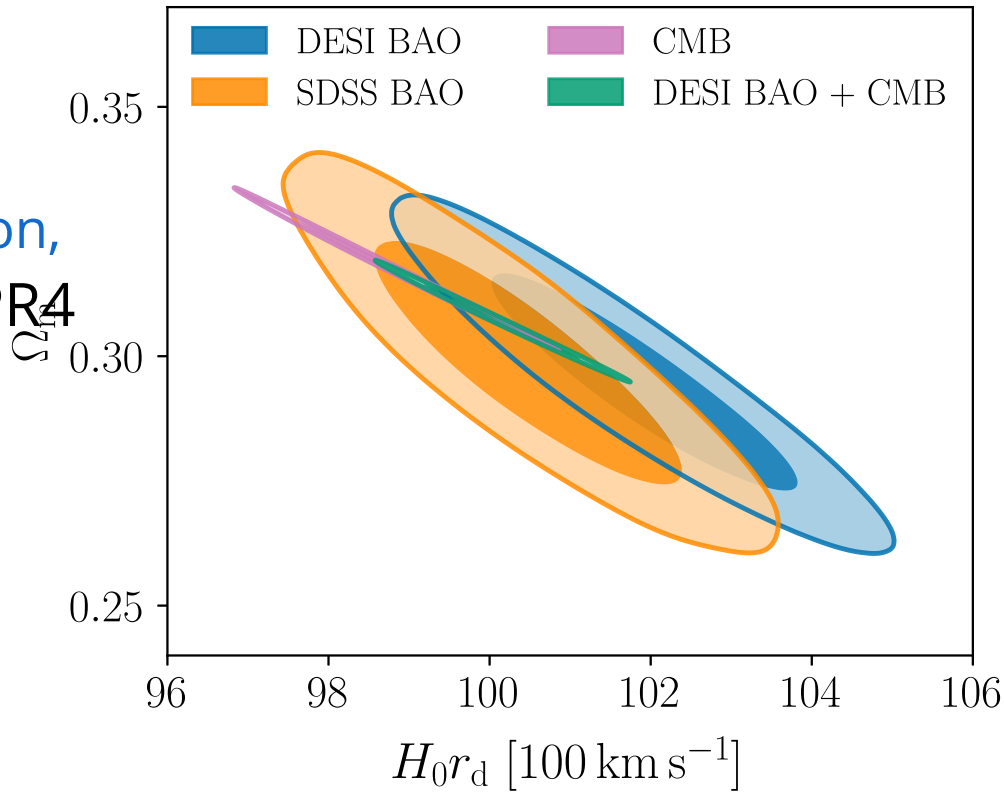
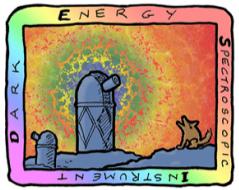
$$\underbrace{\Omega_{\rm m} = 0.3069 \pm 0.0050\ (\mathbf{1.6\%})}_{\text{DESI + CMB}}$$



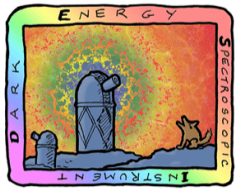


DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Hubble constant

- BAO constrains $r_{\mathrm{d}}(\Omega_{\mathrm{m}}h^2, \Omega_{\mathrm{b}}h^2)h$

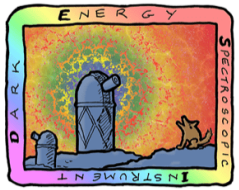


DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Hubble constant

- BAO constrains $r_{\rm d}(\Omega_{\rm m}h^2, \Omega_{\rm b}h^2)h$
- $\Omega_{\rm m}$ constrained by BAO at different z



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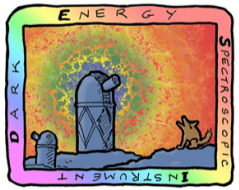

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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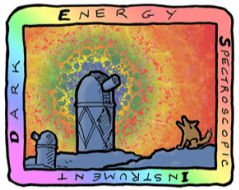
- Ω_{m} constrained by BAO at different z
- $\Omega_{\mathrm{b}}h^2$ can be constrained by light element abundance from Big Bang Nucleosynthesis (BBN): Schöneberg et al., 2024

$\Longrightarrow$ constraints on h i.e. $H_0 = 100h\ \mathrm{km/s/Mpc}$



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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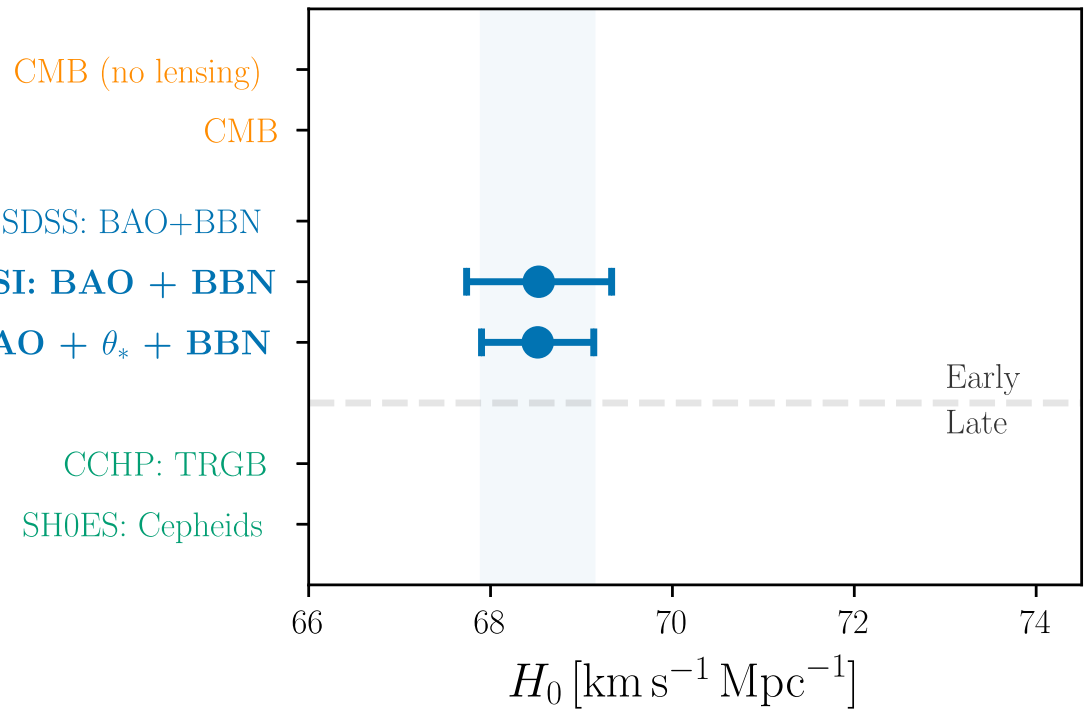
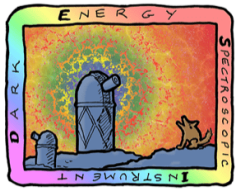
Hubble constant

$$\underbrace{H_0 = (68.53 \pm 0.80)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}}_{\mathrm{DESI + BBN}}$$

$$\underbrace{H_0 = (68.52 \pm 0.62)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}}_{\mathrm{DESI + \theta_* + BBN}}$$

θ_* CMB angular acoustic scale





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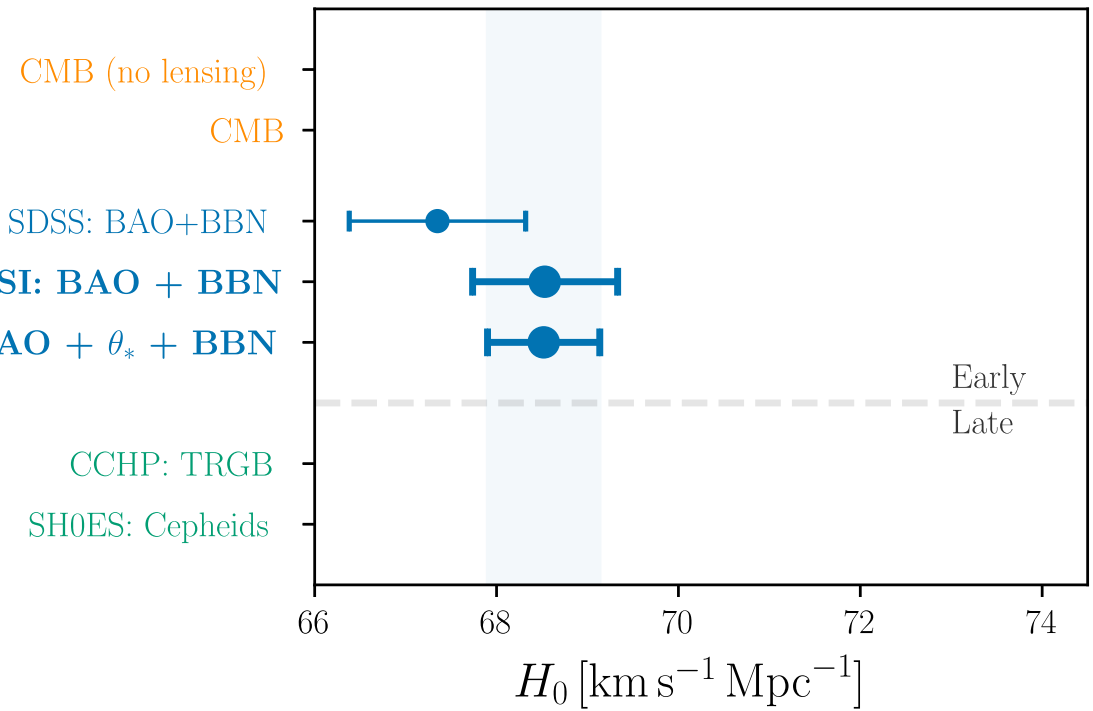
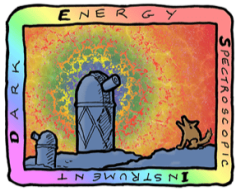
- Consistency with SDSS





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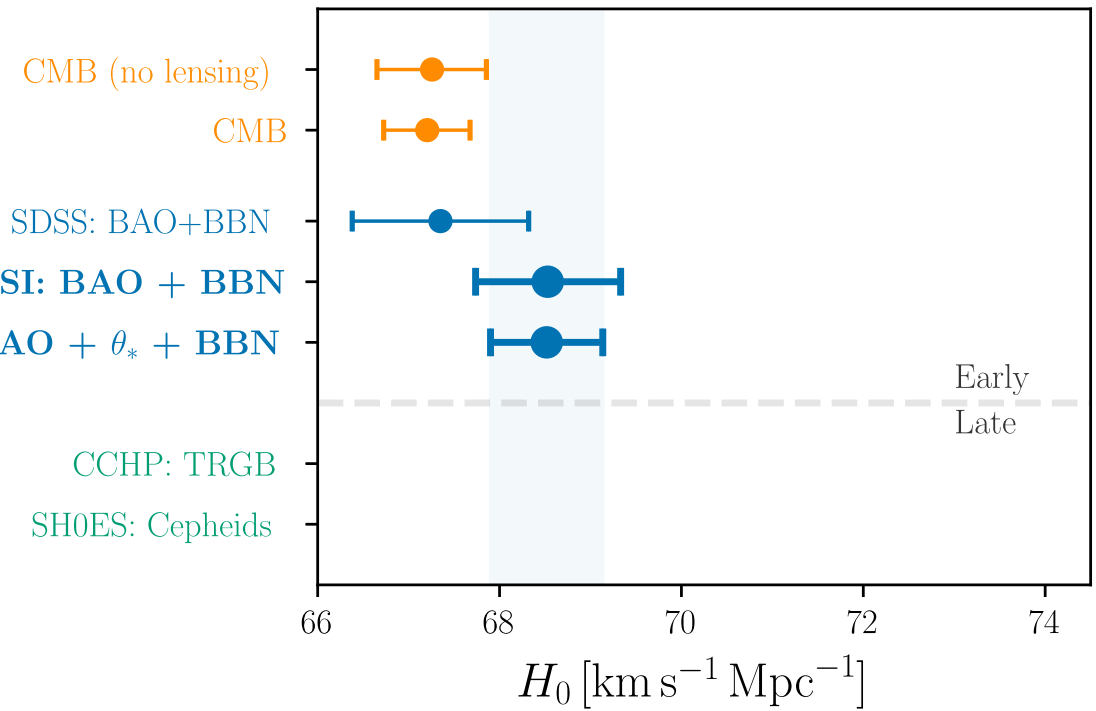
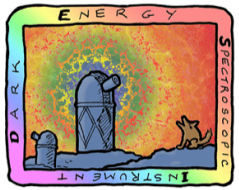
- Consistency with SDSS
- In agreement with CMB





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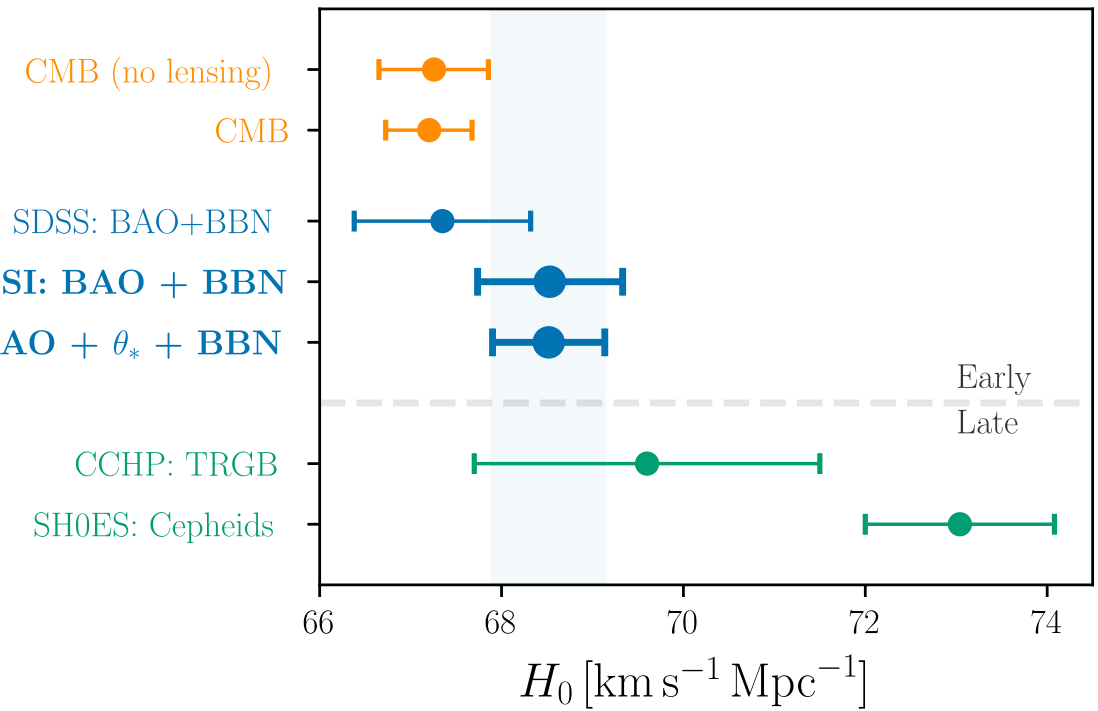
Hubble constant

$$\underbrace{H_0 = (68.53 \pm 0.80)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}}_{\mathrm{DESI + BBN}}$$

$$\underbrace{H_0 = (68.52 \pm 0.62)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}}_{\mathrm{DESI + \theta_* + BBN}}$$

- Consistency with SDSS
- In agreement with CMB
- In 3.7σ tension with SH0ES



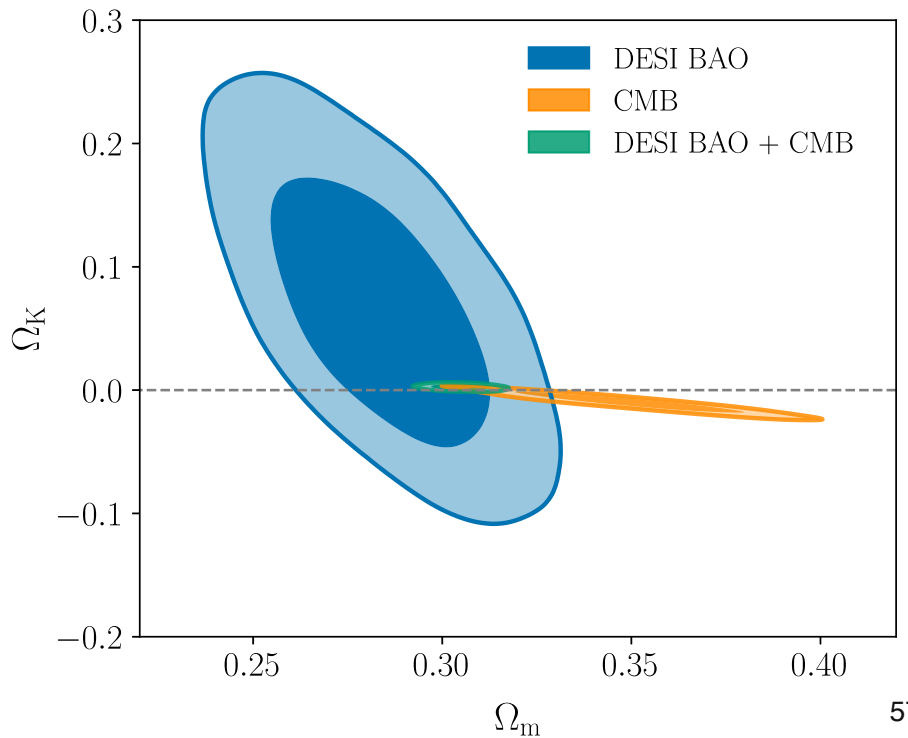
DARK ENERGY SPECTROSCOPIC INSTRUMENT

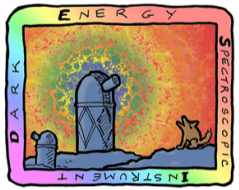
U.S. Department of Energy Office of Science

Spatial curvature

DESI + CMB measurements favor a flat Universe

$$\Omega_K = 0.0024 \pm 0.0016 \text{ (DESI + CMB)}$$





DARK ENERGY SPECTROSCOPIC INSTRUMENT

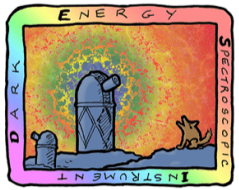
U.S. Department of Energy Office of Science

Dark Energy Equation of State

Dark Energy fluid, pressure p, density ρ

Equation of State parameter $w = p/\rho$

Linked to the evolution of Dark Energy $w(z) = -1 + \frac{1}{3}\frac{d\ln f_{\rm DE}(z)}{d\ln(1+z)}$



DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

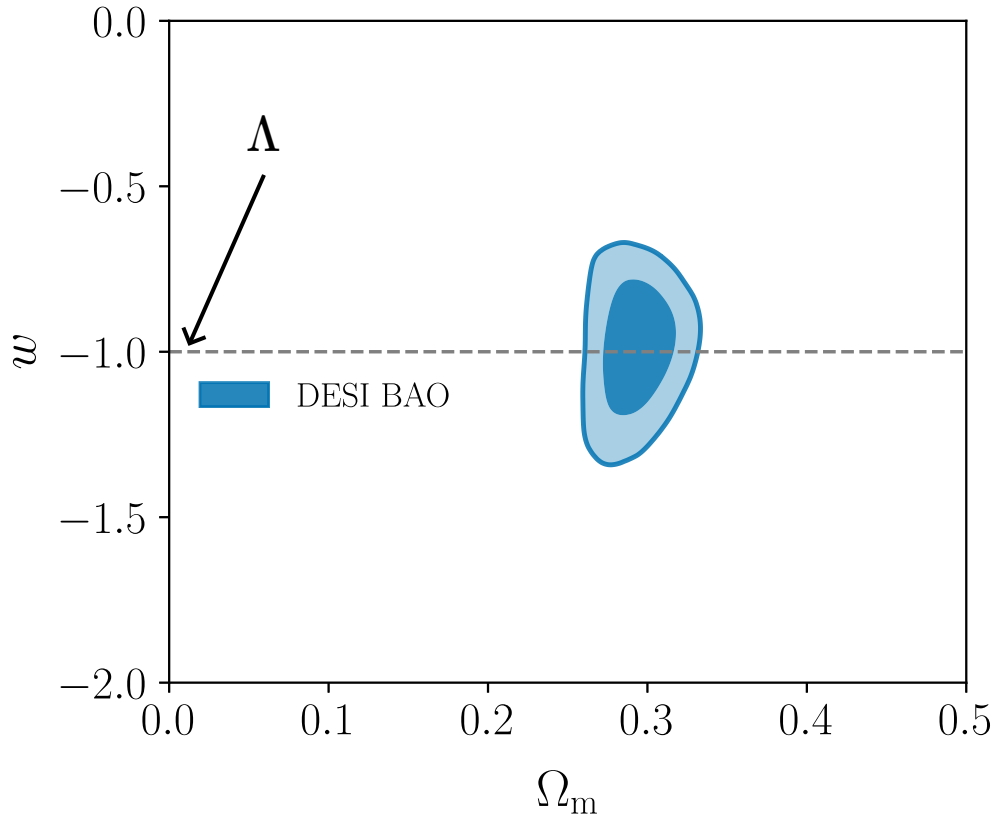
Dark Energy Equation of State

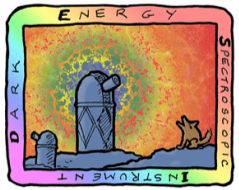
Constant EoS parameter $w = p/\rho$

$$\Omega_{\rm m} = 0.293 \pm 0.015 \quad (\mathbf{5.1\%})$$

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

DESI





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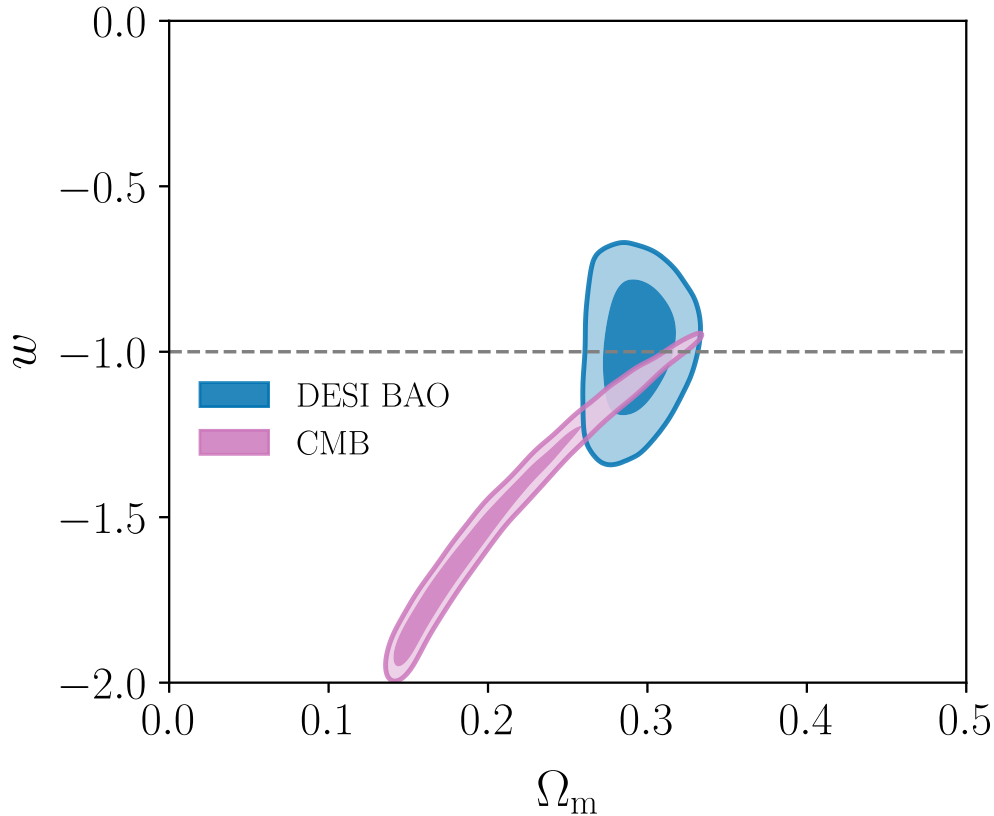

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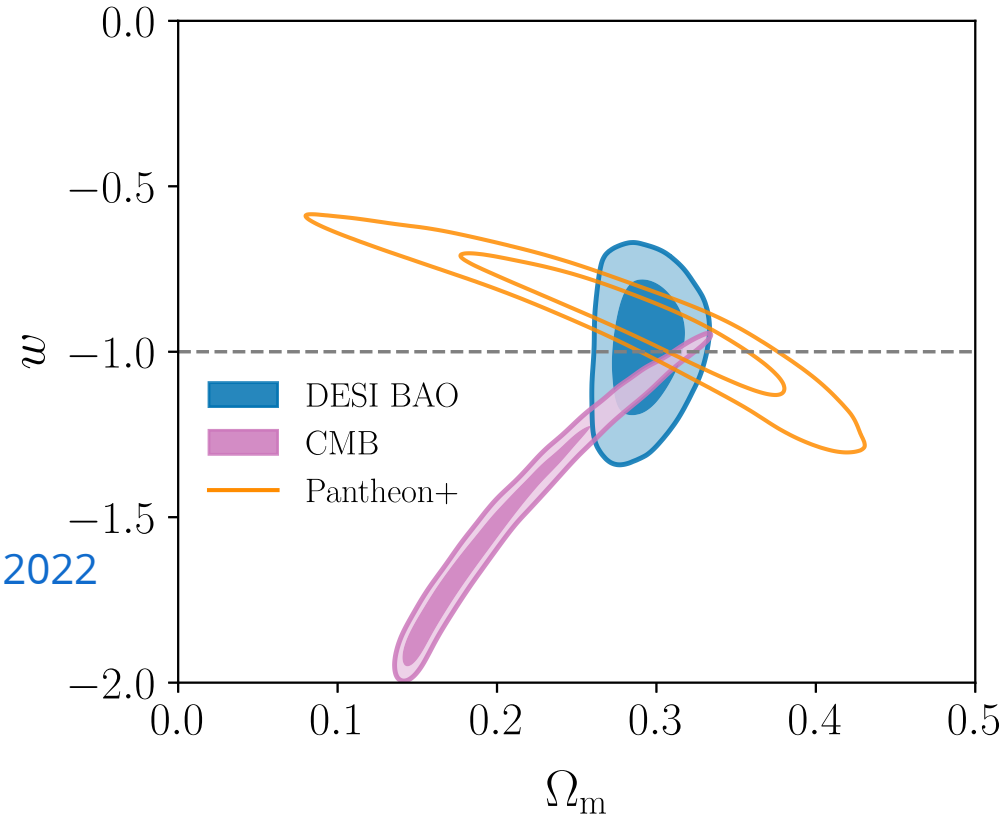
DESI

SNe:

- Pantheon+ Brout, Scolnic, Popovic et al., 2022



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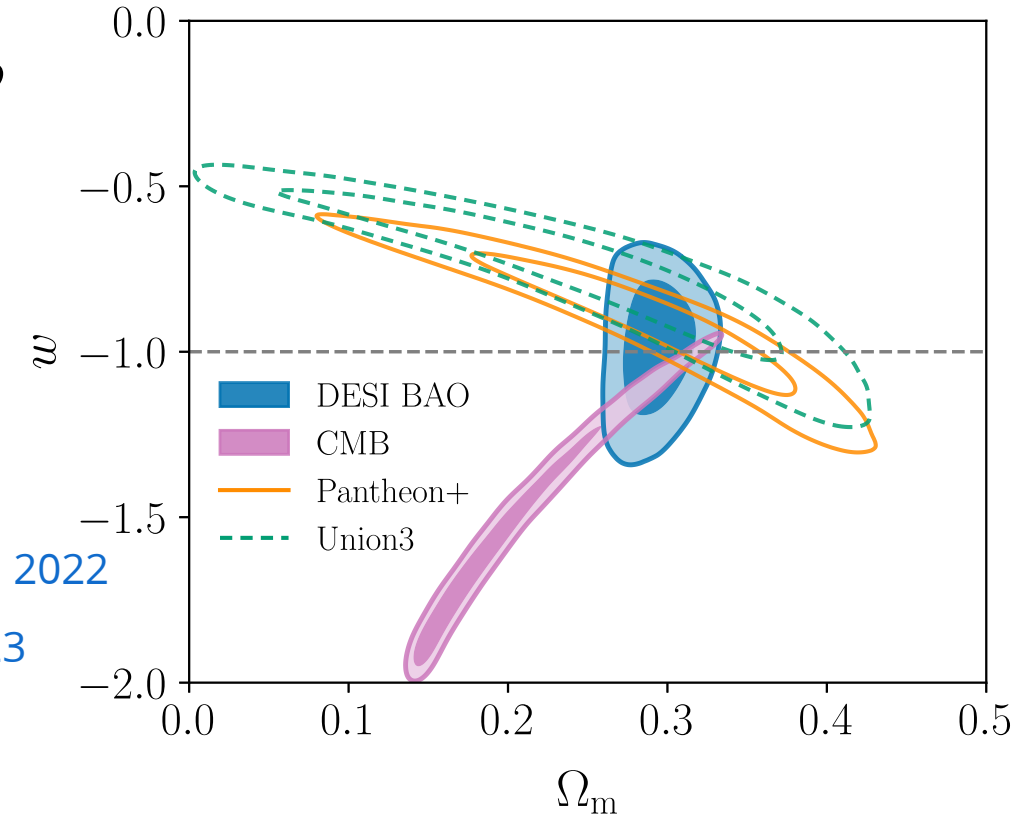

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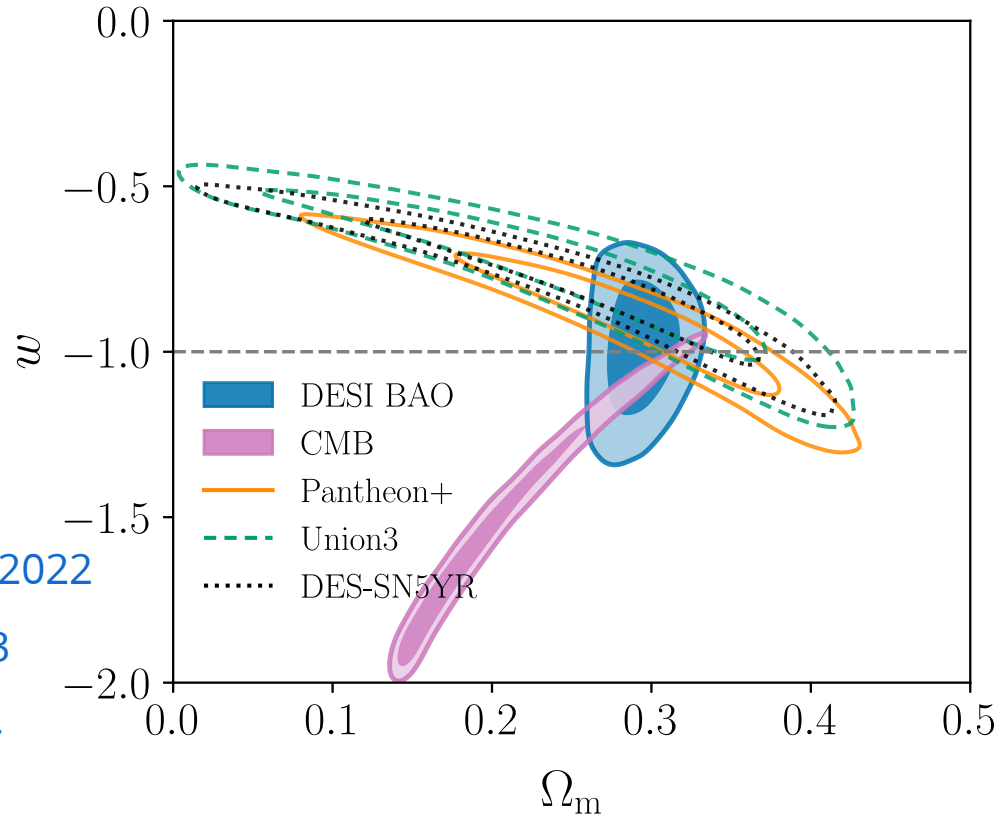
- Union3 Rubin, Aldering, Betoule et al. 2023
- DES-SN5YR DES Collaboration et al. 2024



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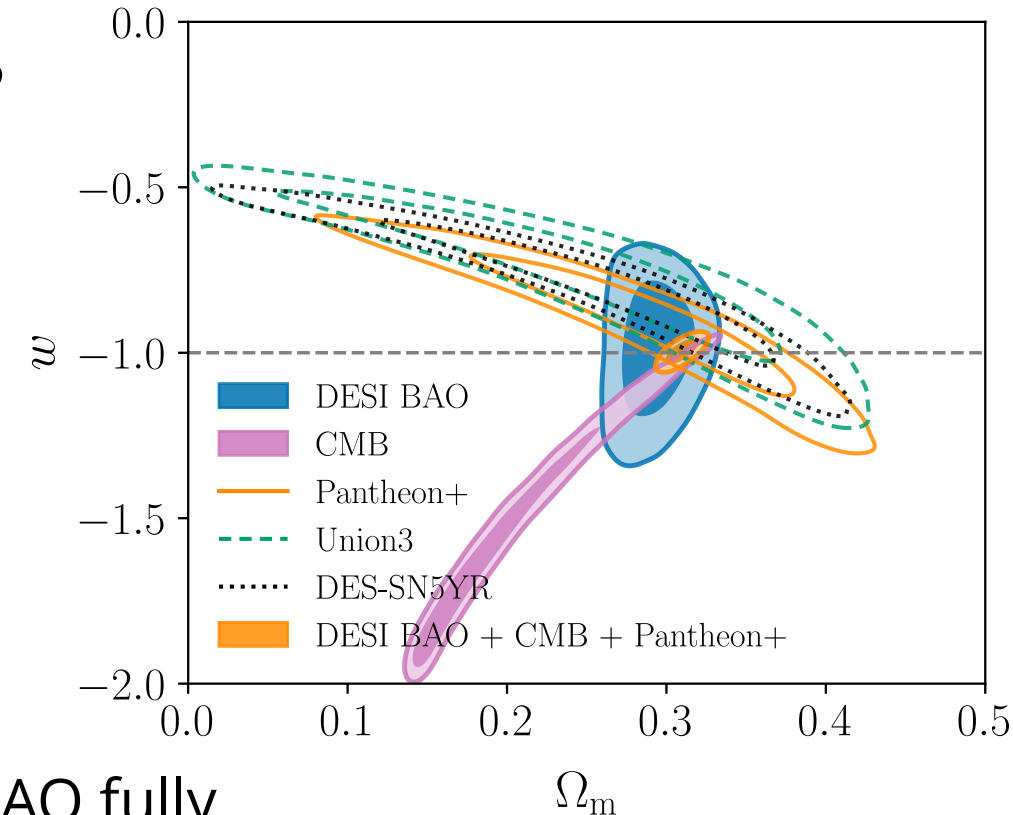
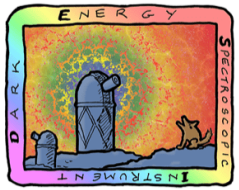
DESI

$$\Omega_{\rm m} = 0.3095 \pm 0.0065 \quad (\mathbf{2.1\%})$$
$$w = -0.997 \pm 0.025 \quad (\mathbf{2.5\%})$$

DESI + CMB + Pantheon+



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



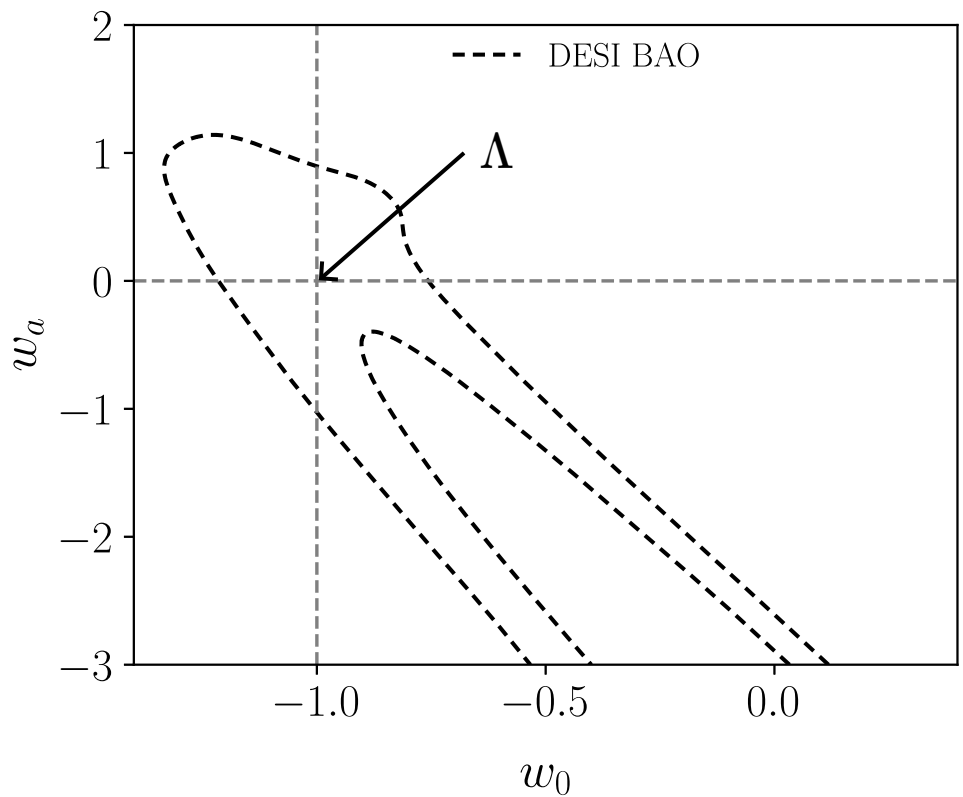
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Dark Energy Equation of State

Varying EoS

$$w(z) = w_0 + \frac{z}{1+z} w_a \qquad \text{(CPL)}$$



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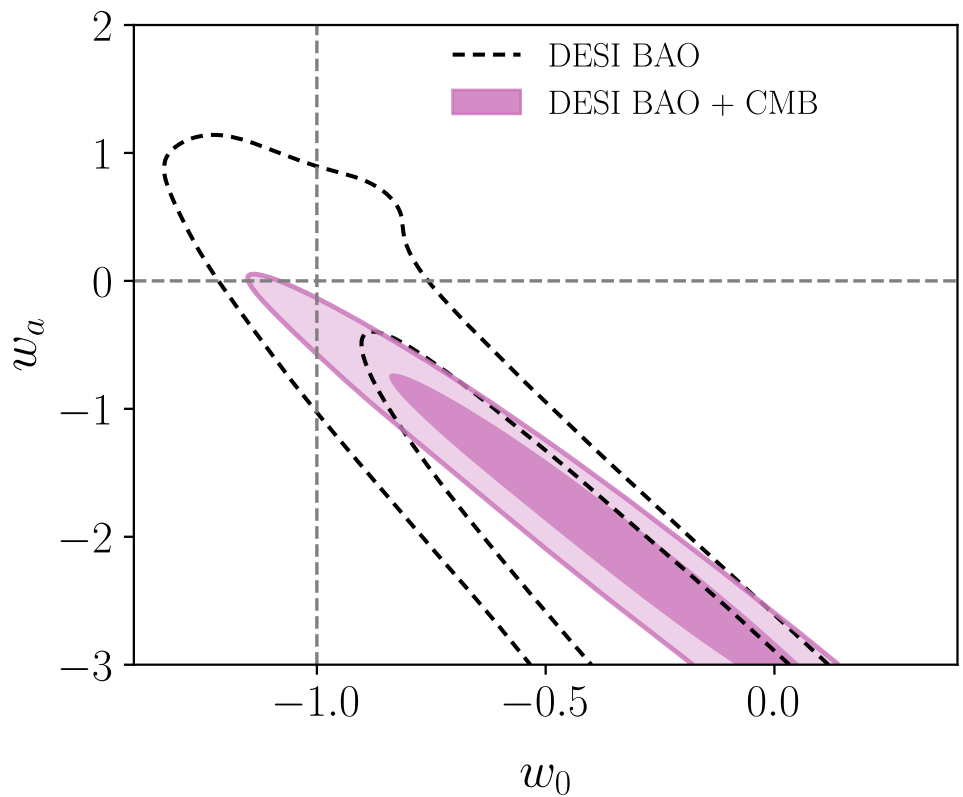
$$w(z) = w_0 + \frac{z}{1+z} w_a \qquad \text{(CPL)}$$

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



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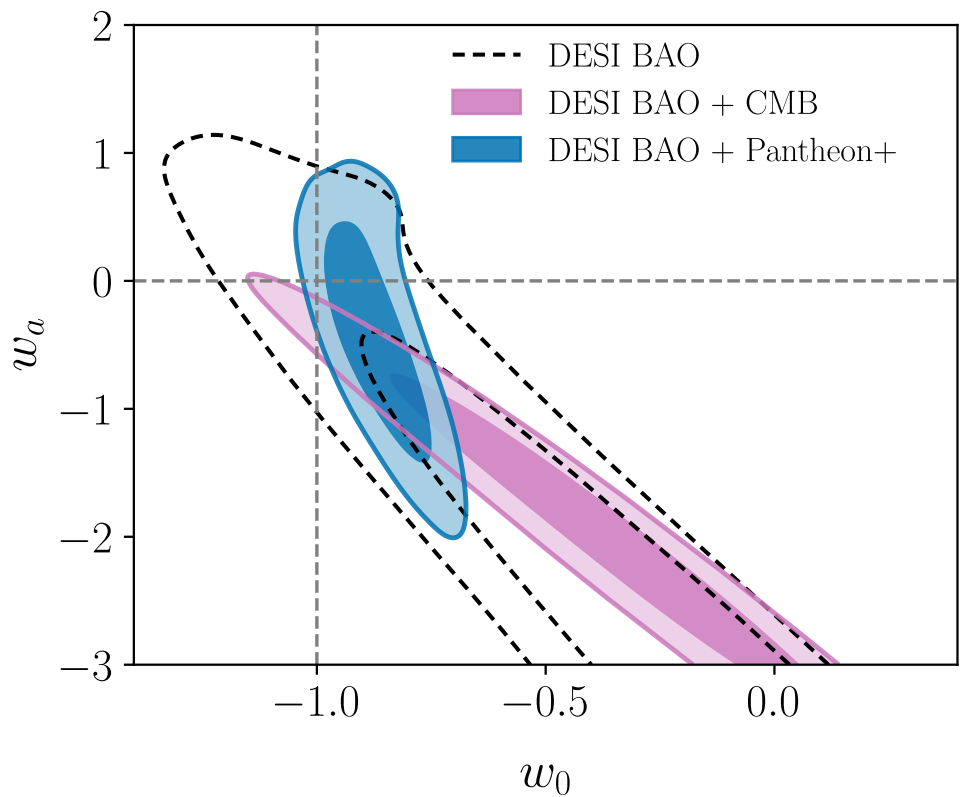

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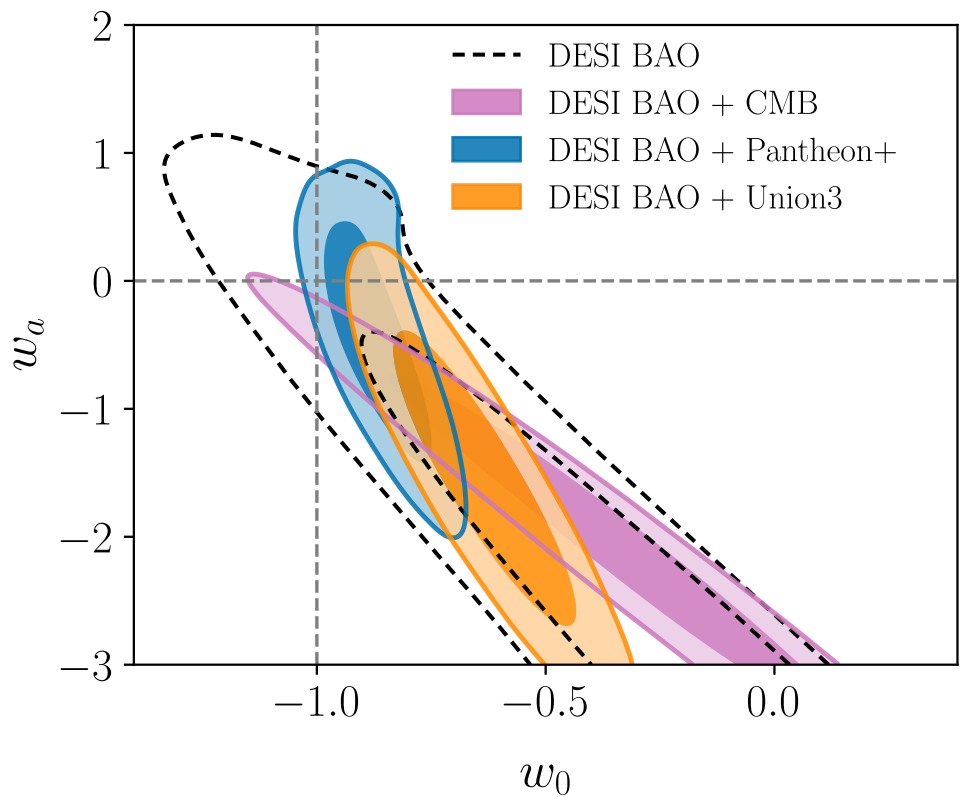

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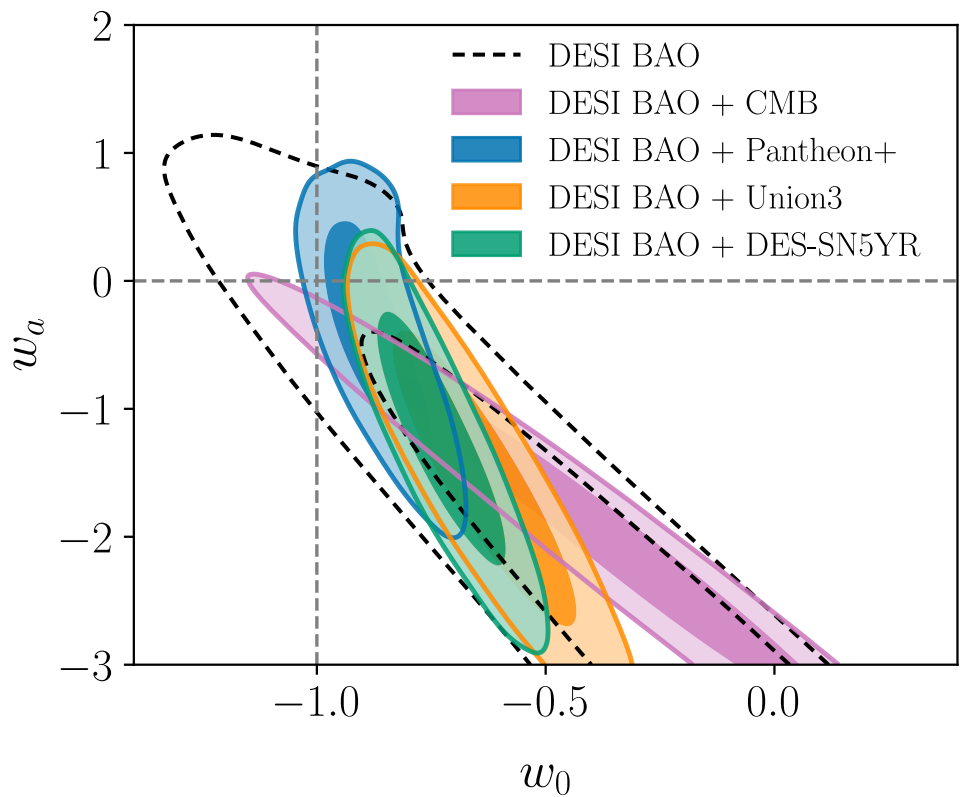


DARK ENERGY SPECTROSCOPIC INSTRUMENT

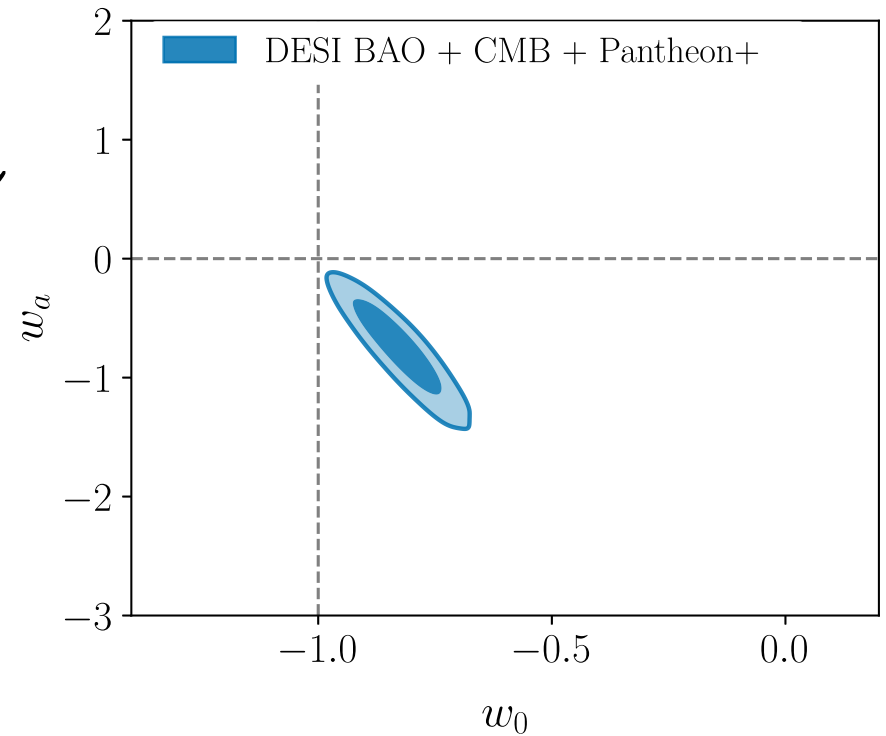
U.S. Department of Energy Office of Science

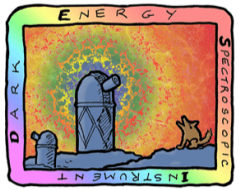
Dark Energy Equation of State

Combining all DESI + CMB + SN

$$w_0 = -0.827 \pm 0.063 \qquad w_a = -0.75^{+0.29}_{-0.25}$$

$$\text{DESI} + \text{CMB} + \text{Pantheon+} \implies 2.5\sigma$$





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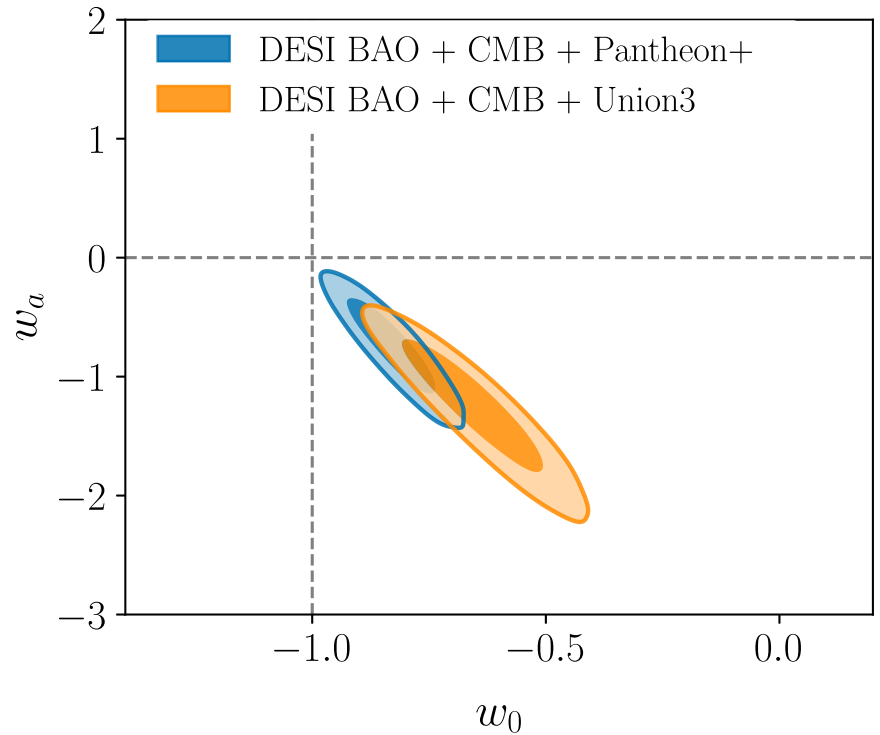
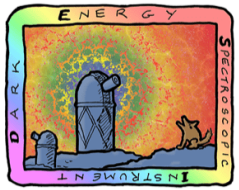
$$\text{DESI} + \text{CMB} + \text{Union3} \implies 3.5\sigma$$





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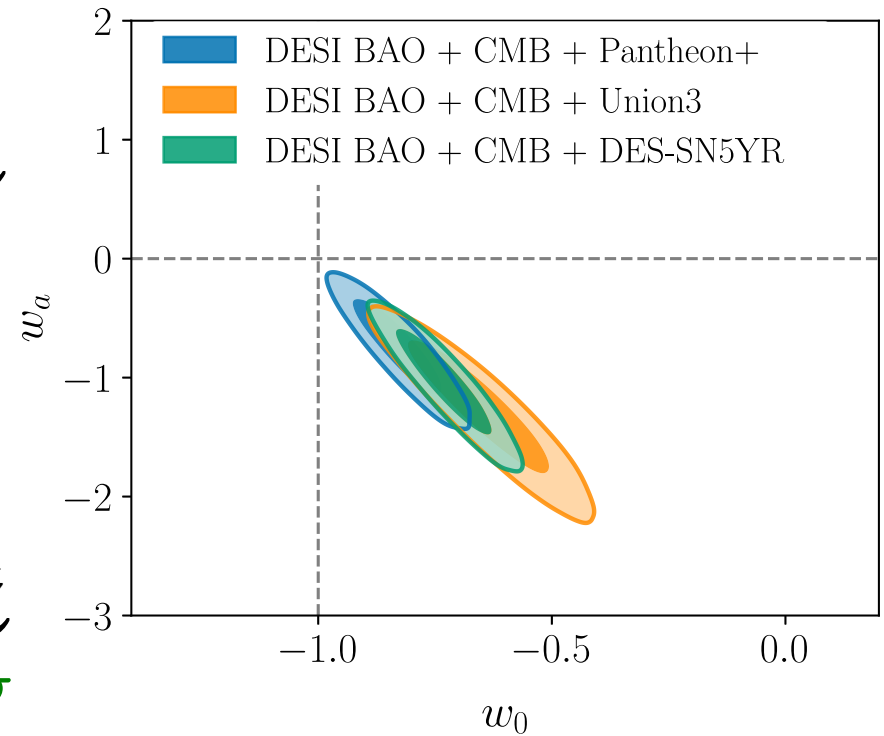
$$w_0 = -0.727 \pm 0.067 \qquad w_a = -1.05^{+0.31}_{-0.27}$$

$\text{DESI} + \text{CMB} + \text{DES-SN5YR} \implies 3.9\sigma$



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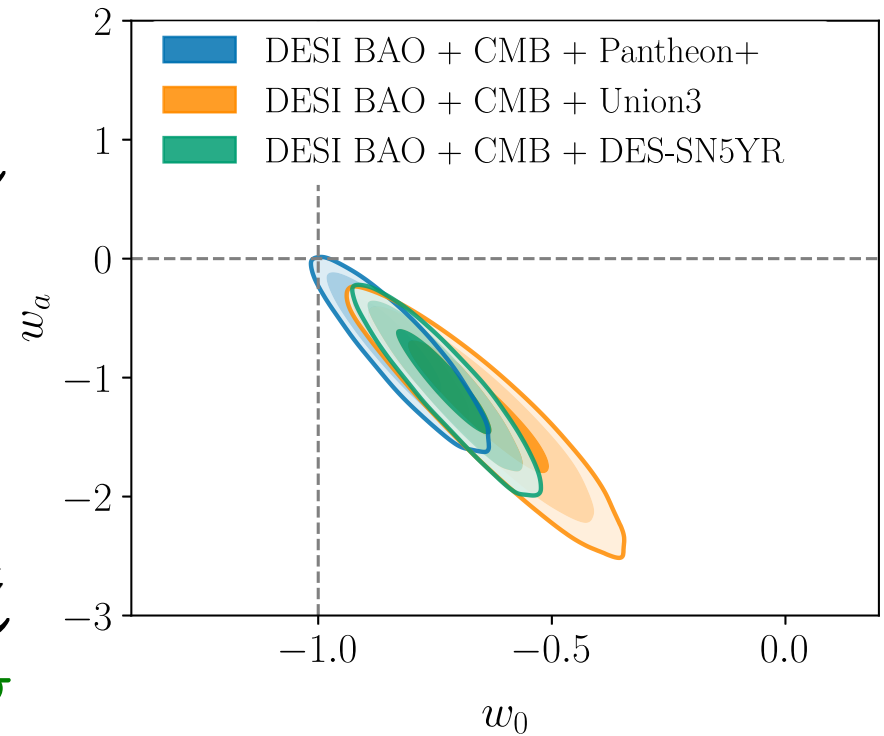


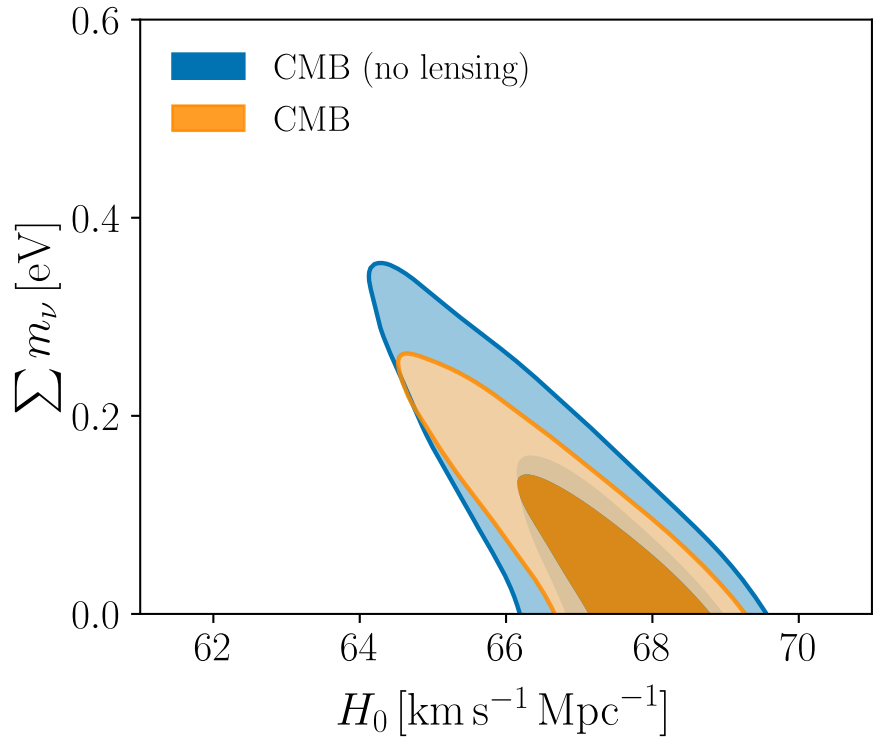
$w_0 > -1, w_a < 0$ favored, level varying on the SN dataset

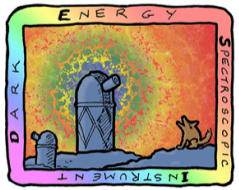
DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Sum of neutrino masses

Internal CMB degeneracies limiting precision on the sum of neutrino masses





DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Sum of neutrino masses

Internal CMB degeneracies limiting precision on the sum of neutrino masses

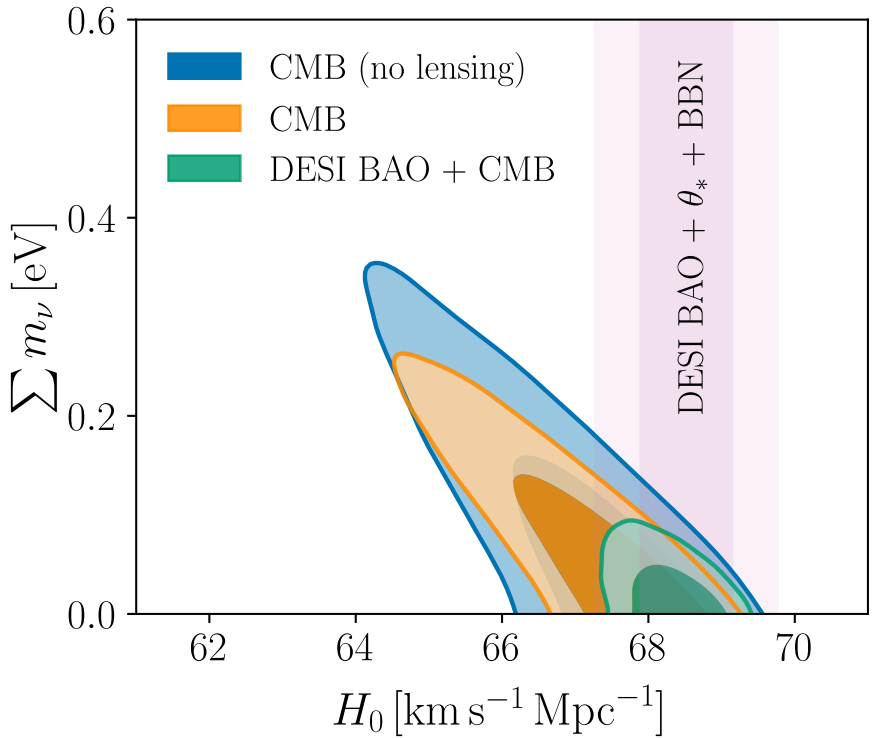
Broken by BAO, especially through H_0

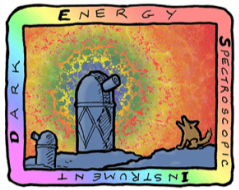
Low preferred value of H_0 yields

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

Limit relaxed for extensions to $\Lambda\mathrm{CDM}$

$\sum m_\nu < 0.195\,\mathrm{eV}$ for $w_0 w_a\mathrm{CDM}$





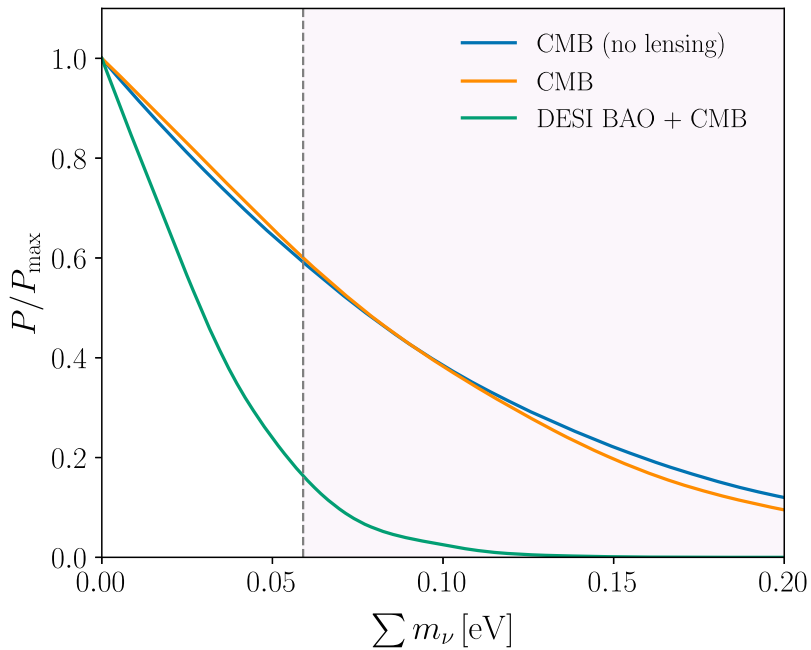
DARK ENERGY SPECTROSCOPIC INSTRUMENT

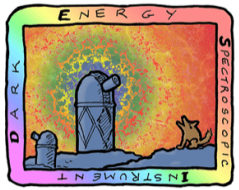
U.S. Department of Energy Office of Science

Neutrino mass hierarchies

With $> 0.059\,\mathrm{eV}$ prior (NH)

$$\sum m_\nu < 0.113\,\mathrm{eV}\ (95\%, \mathrm{DESI} + \mathrm{CMB})$$





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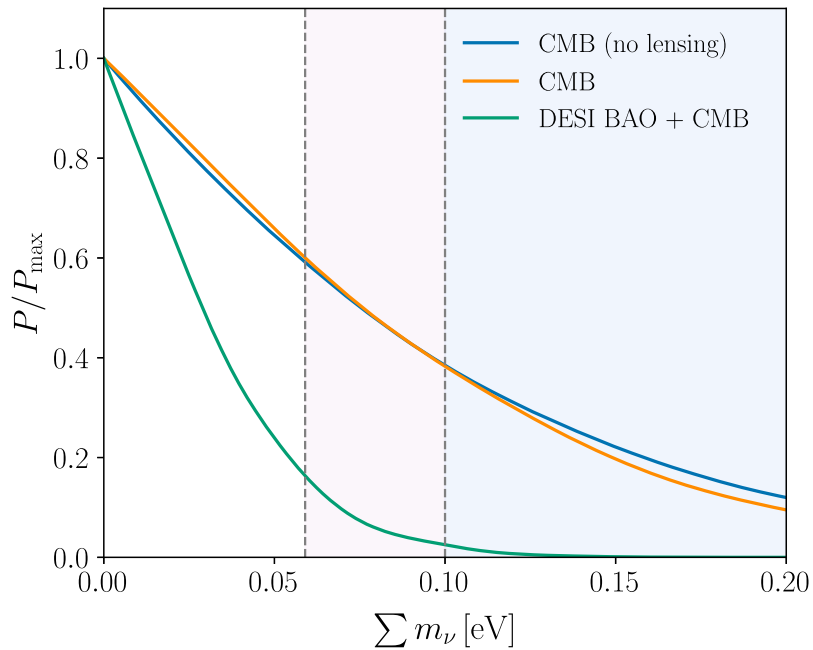
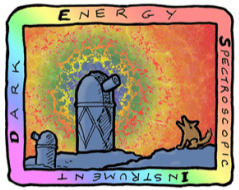
With $> 0.1\,\mathrm{eV}$ prior (IH)

$$\sum m_\nu < 0.145\,\mathrm{eV}\ (95\%, \mathrm{DESI} + \mathrm{CMB})$$





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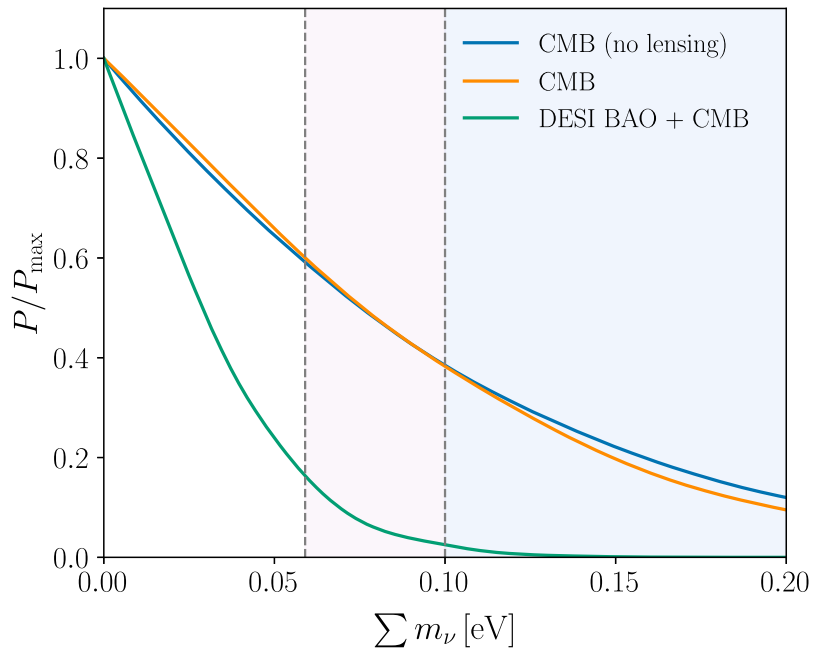
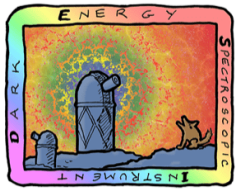


Current constraints do not strongly favor normal over inverted hierarchy ($\simeq 2\sigma$)

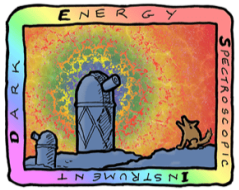


DARK ENERGY
SPECTROSCOPIC
INSTRUMENT

U.S. Department of Energy Office of Science

Summary

DESI already has the most precise BAO measurements ever



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SPECTROSCOPIC
INSTRUMENT

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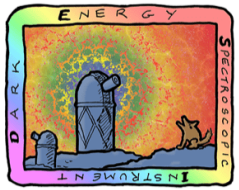
Summary

DESI already has the most precise BAO measurements ever

DESI BAO is consistent (at the $\sim 1.9\sigma$ level) with CMB in flat ΛCDM



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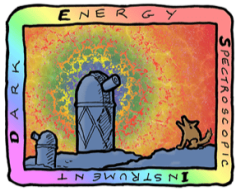
In flat ΛCDM, DESI prefers "small $\Omega_{\rm m}$, large H_0 (though 3.7σ away from SH0ES), small $\sum m_\nu$"



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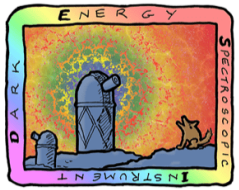
DESI already has the most precise BAO measurements ever

DESI BAO is consistent (at the $\sim 1.9\sigma$ level) with CMB in flat ΛCDM

In flat ΛCDM, DESI prefers "small $\Omega_{\rm m}$, large H_0 (though 3.7σ away from SH0ES), small $\sum m_\nu$"

Some hint of time-varying Dark Energy equation of state especially when combined with supernovae measurements



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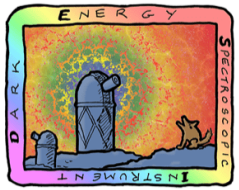
What's next?

"Full shape" (not only BAO peak measurement) analysis

Y3 data on disk!



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Other datasets

- SDSS BAO (for comparisons only): eBOSS Collaboration, 2020
- Primary CMB: Planck Collaboration, 2018
- CMB lensing: Planck PR4 + ACT DR6 lensing ACT Collaboration, 2023, Carron, Mirmelstein, Lewis, 2022
- BBN: Schöneberg et al., 2024
- SN: Pantheon+ Brout, Scolnic, Popovic et al., 2022, Union3 Rubin, Aldering, Betoule et al. 2023, DES-SN5YR DES Collaboration

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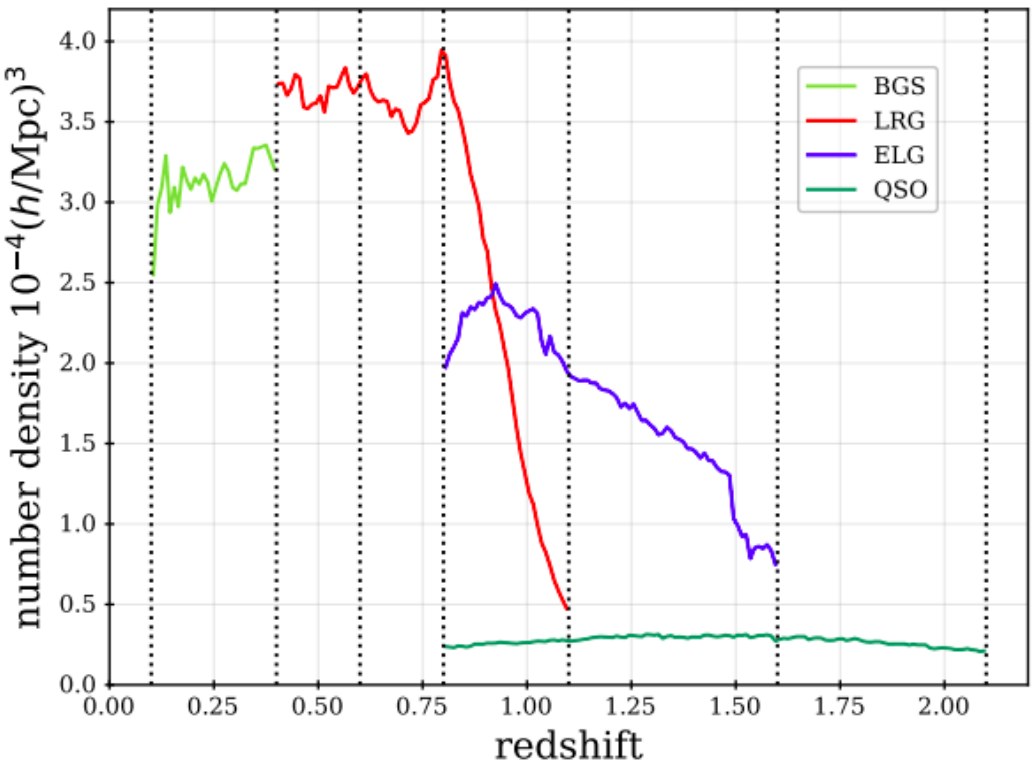
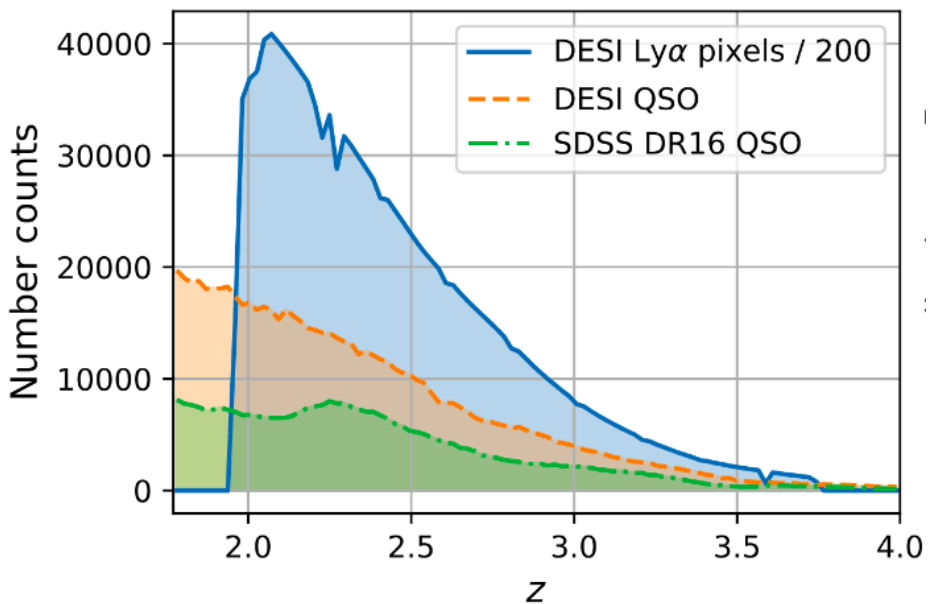
DESI data release 1 (DR1)

5.7 million unique redshifts at z < 2.1 and **> 420,000 Lyα QSO** at z > 2.1





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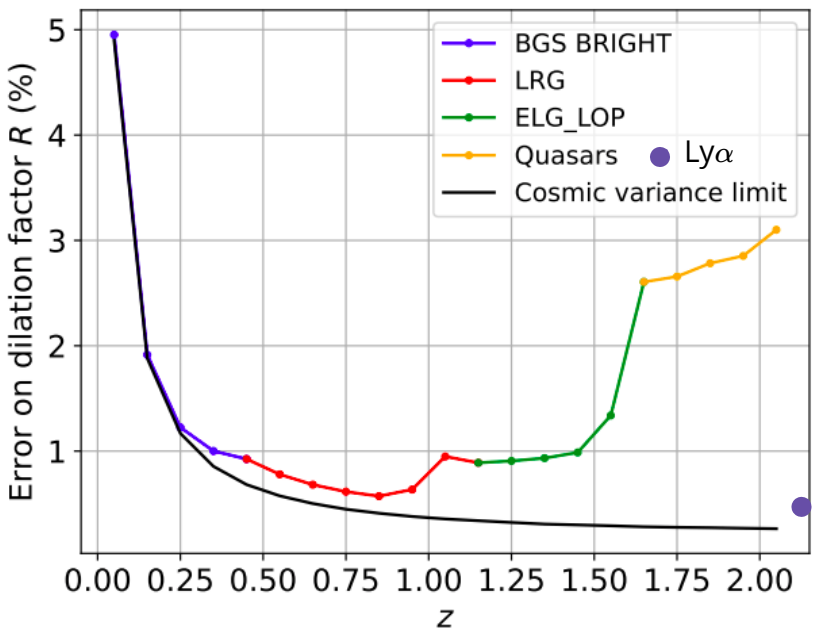
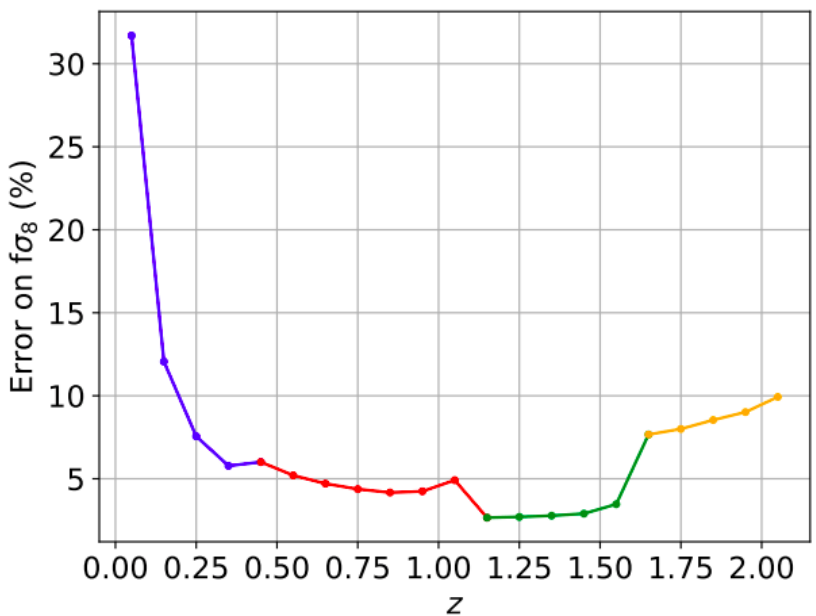
DESI Y5 forecasts

Survey Validation (arXiv:2306.06307)

BAO and RSD constraints at the end of the survey ($\Delta z = 0.1$)





DARK ENERGY SPECTROSCOPIC INSTRUMENT

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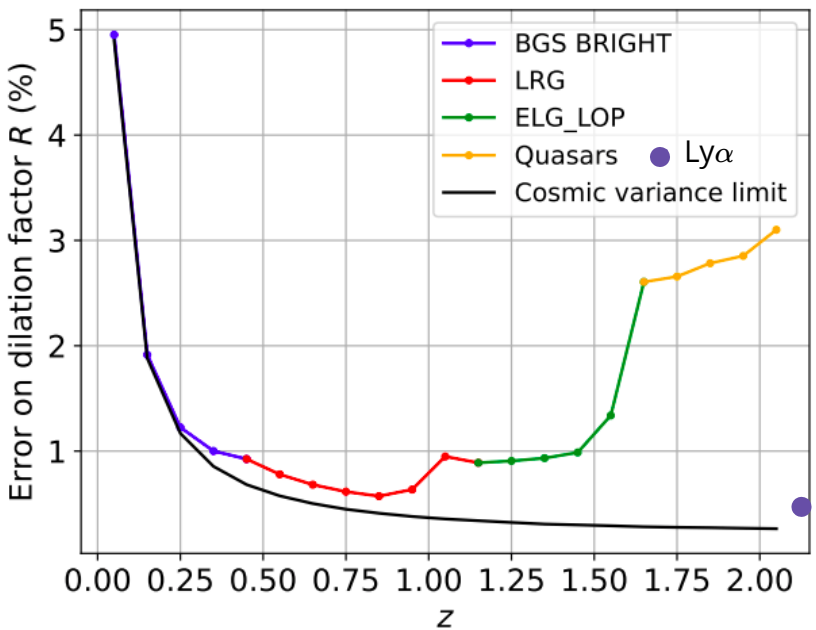

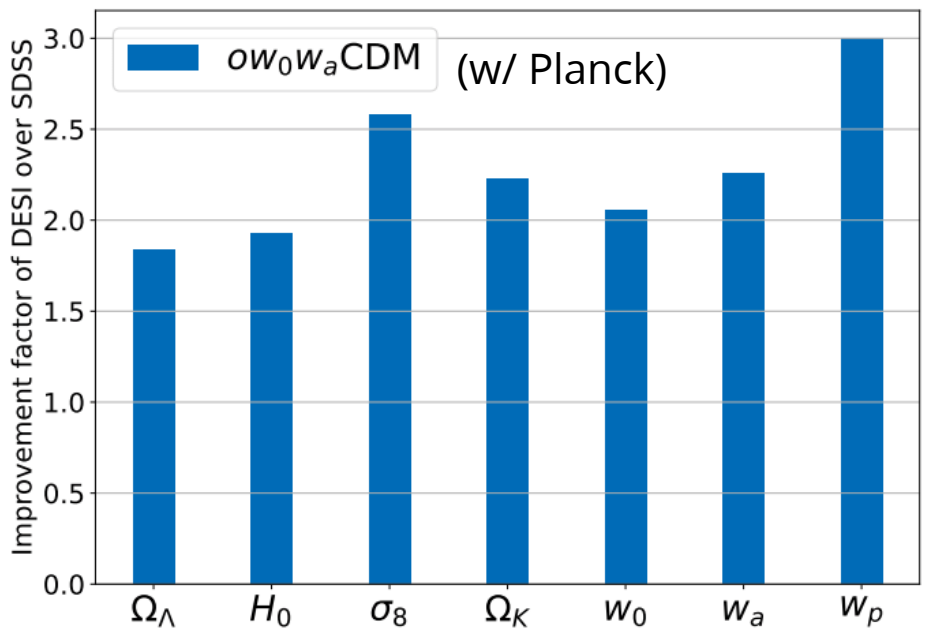

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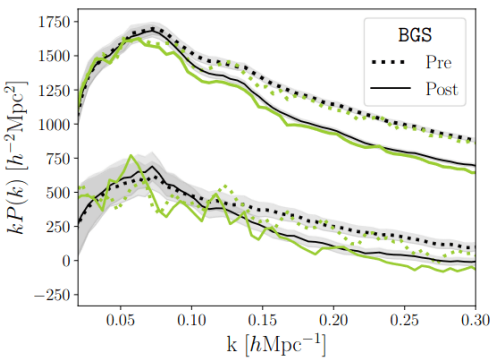
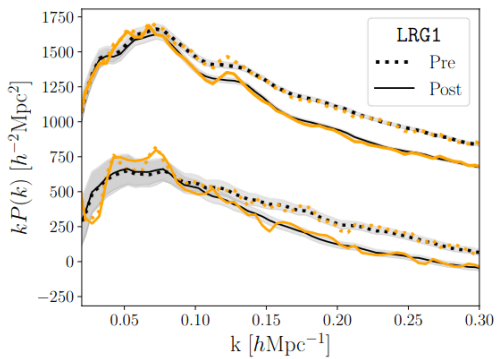
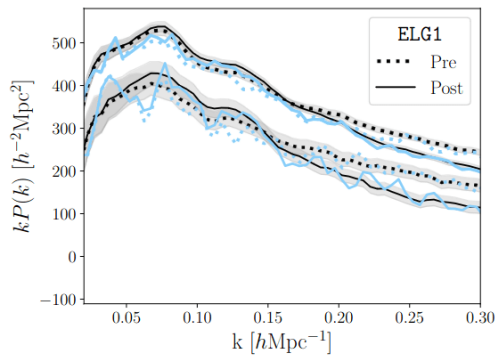
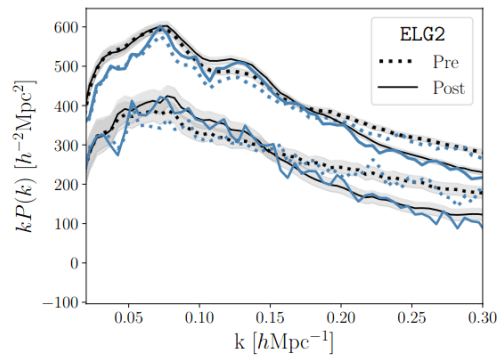
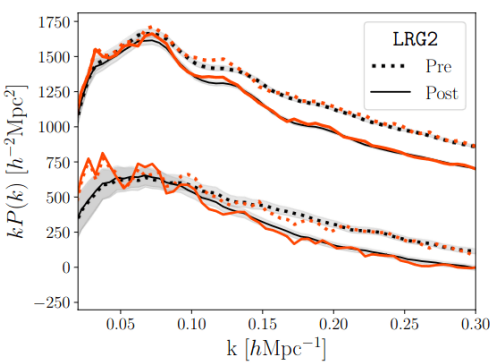
Power spectra

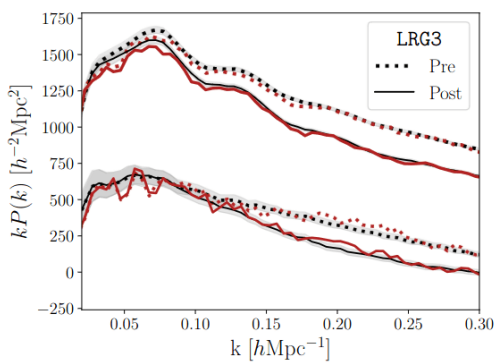


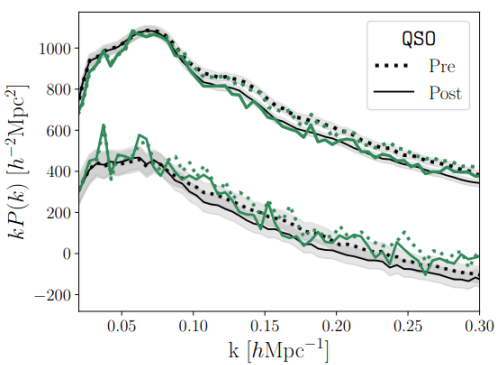












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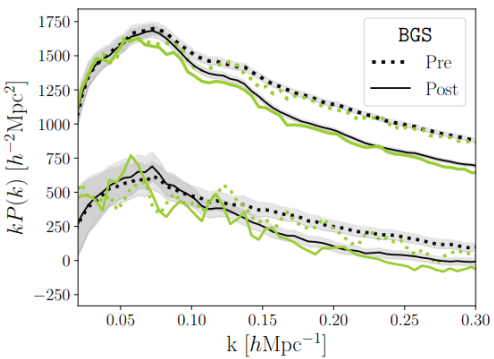
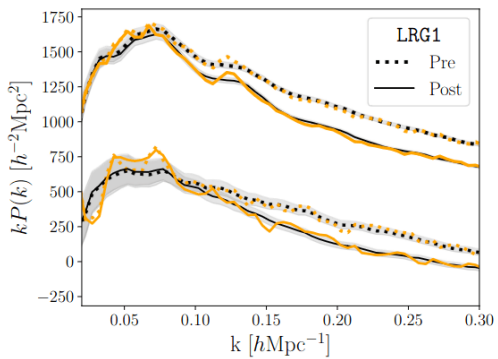
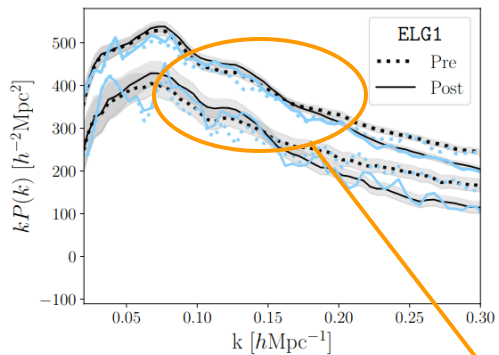
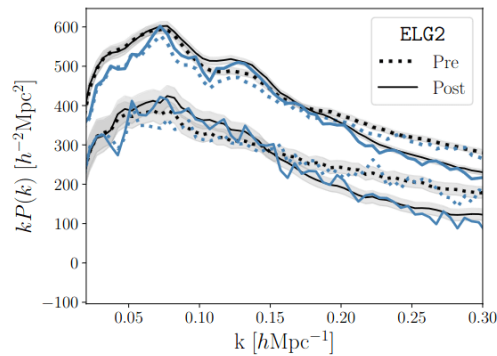
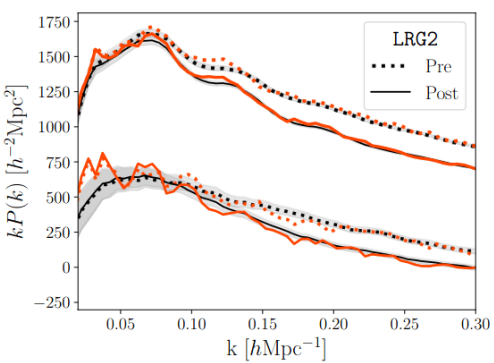
Power spectra

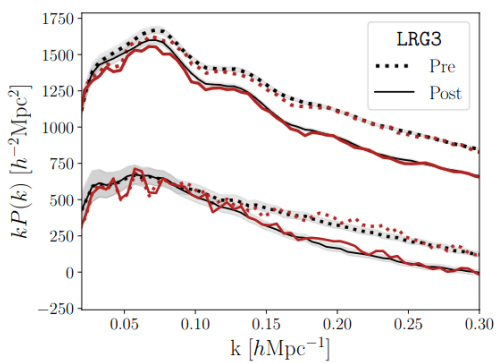


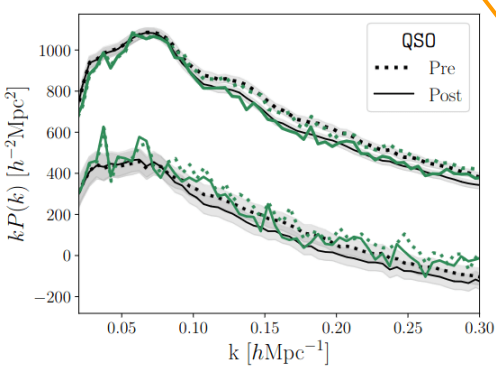












BAO wiggles

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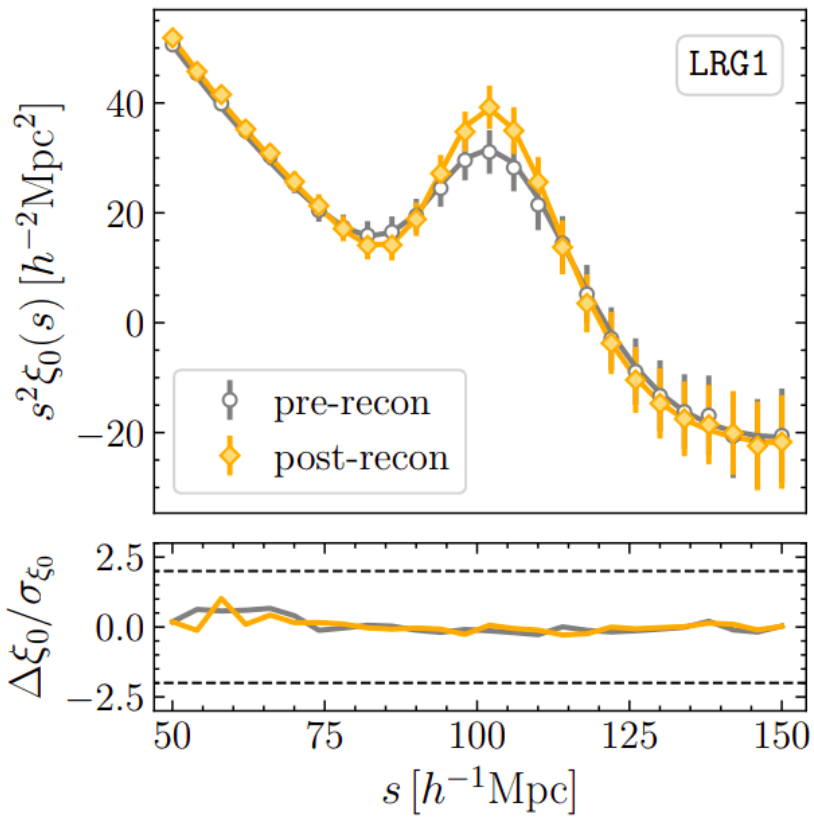
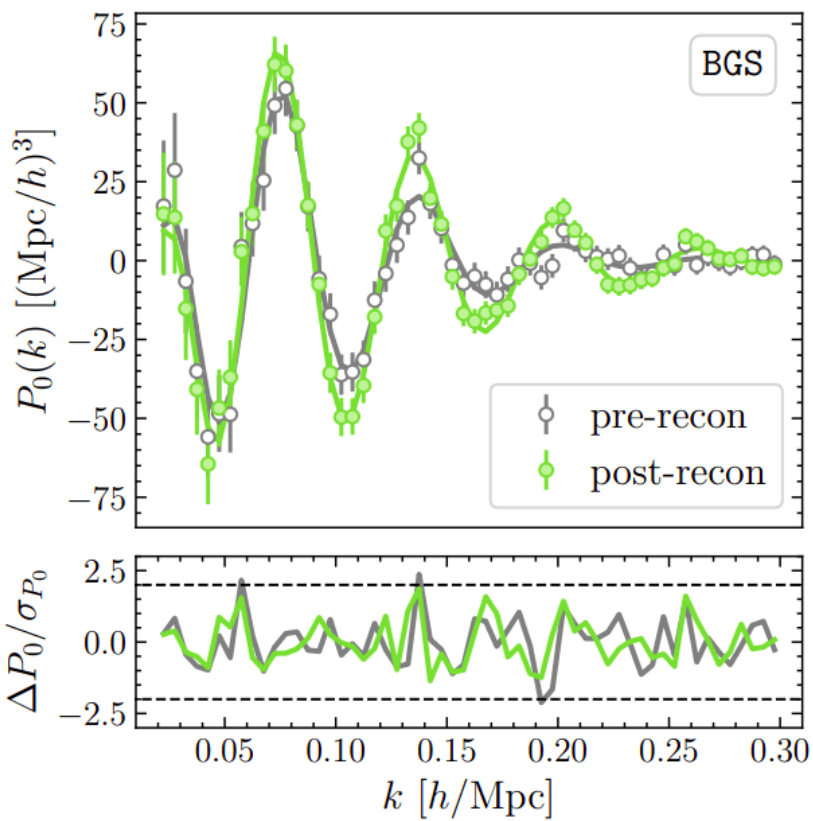
Density field reconstruction





DARK ENERGY SPECTROSCOPIC INSTRUMENT

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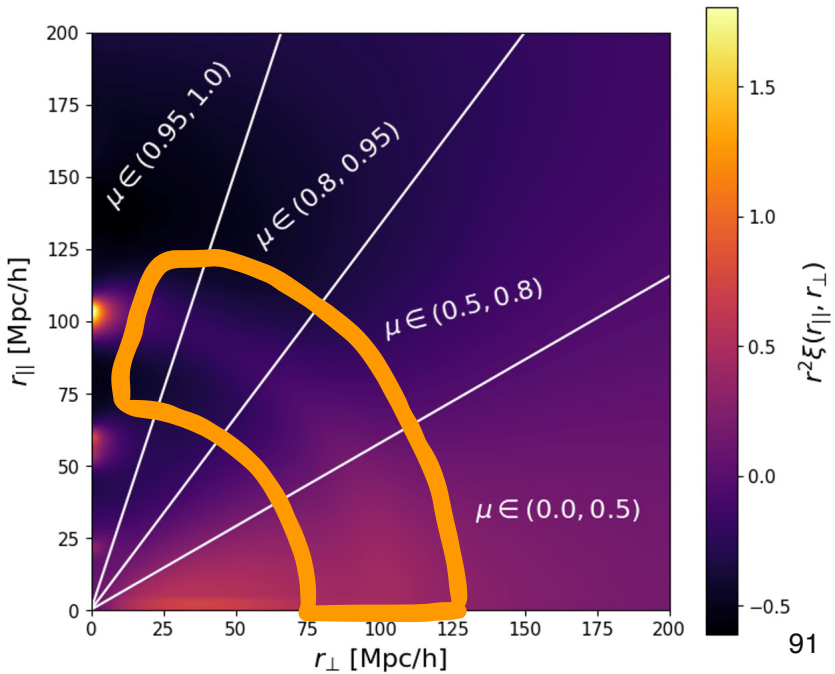
DESI DR1 Lyα BAO analysis

- **Biggest ever Lyα dataset** ($N_{\rm tracer}$)
- **First blind analysis** to mitigate observer / confirmation biases (correlation function-level blinding)
- Modelling of the correlation function:
  - cosmo signal

$$\mu = r_\parallel / \sqrt{r_\parallel^2 + r_\perp^2}$$

$$P_{\rm Ly\alpha}(k,\mu) = b^2(1+\beta\mu^2)^2 P_{\rm lin}(k,\mu) F_{\rm NL}(k,\mu)$$

linear bias + RSD BAO hydro-sim



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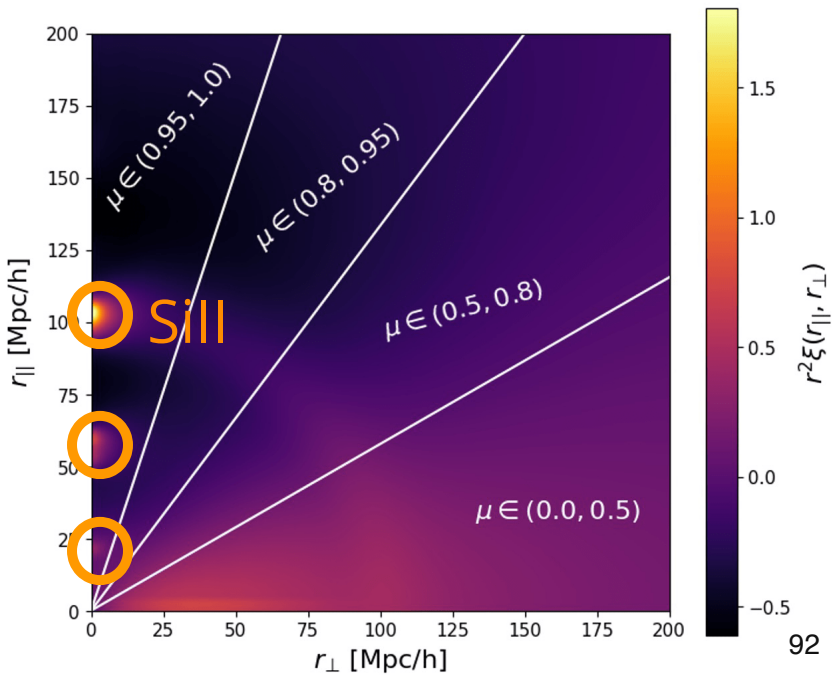
- Modelling of the correlation function:
  - cosmo signal
  - high-column density
  - metal absorbers $r_{\parallel} \propto \left| \frac{1}{\lambda_{\mathrm{Ly}\alpha}} - \frac{1}{\lambda_{\mathrm{metal}}} \right|$



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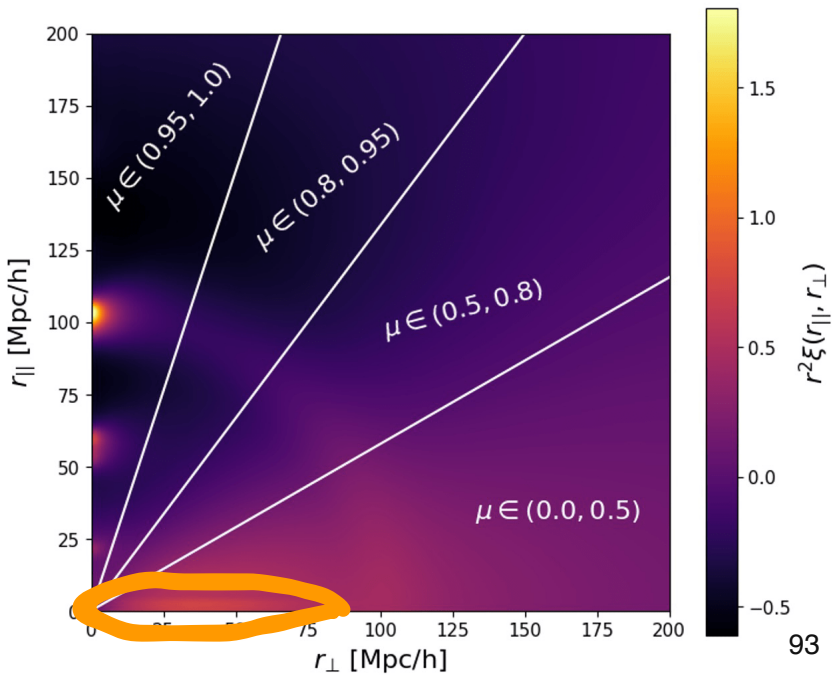
  - correlated noise (sky subtraction)



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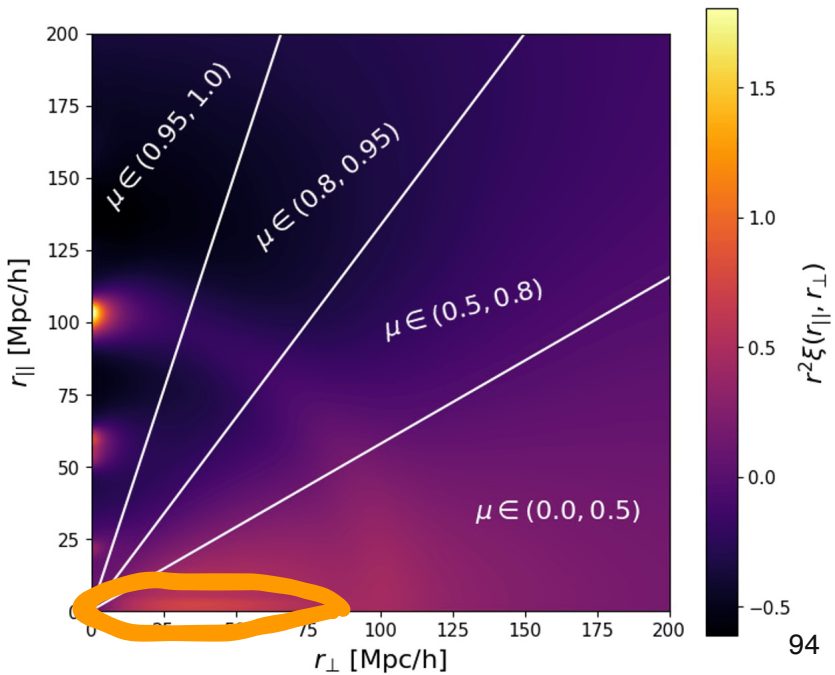

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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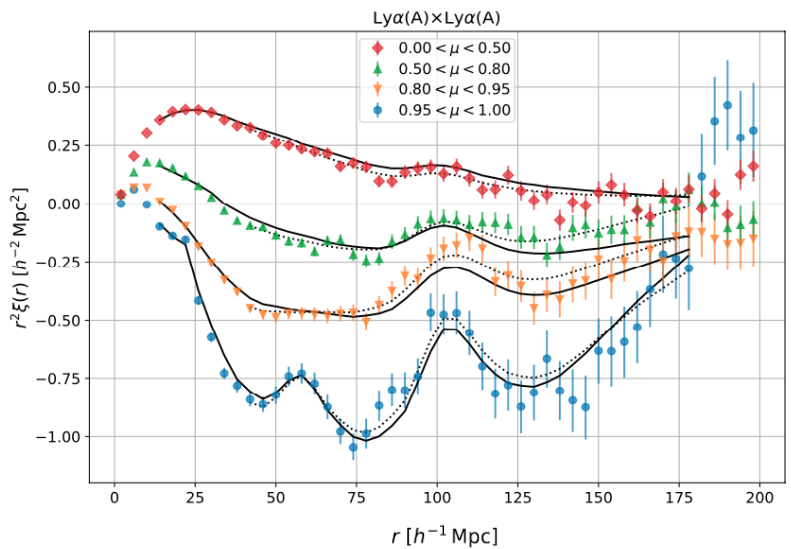
- Modelling of the correlation function

broadband: $< 0.1\sigma$



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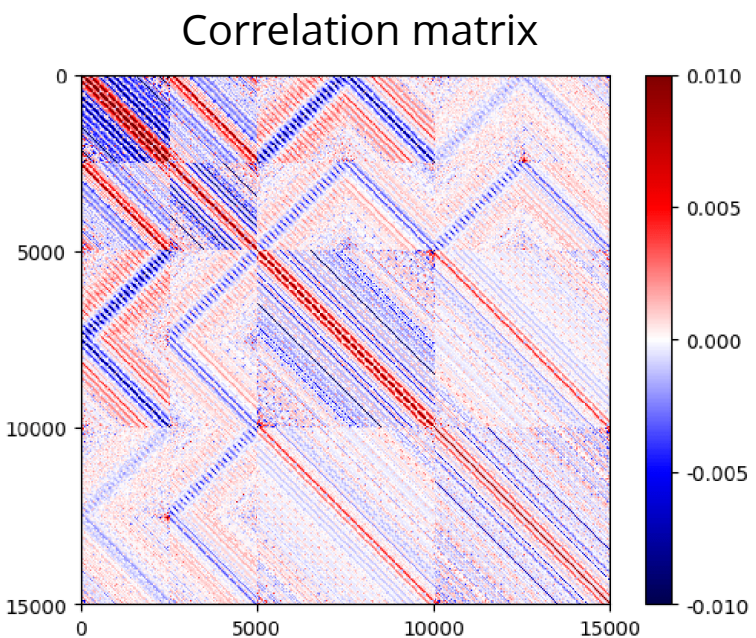
DESI DR1 Lyα BAO analysis

- **Biggest ever Lyα dataset** (N_{tracer})
- **First blind analysis** to mitigate observer / confirmation biases (correlation function-level blinding)
- Modelling of the correlation function
- Covariance matrix

  smoothed jackknife, validated with mocks



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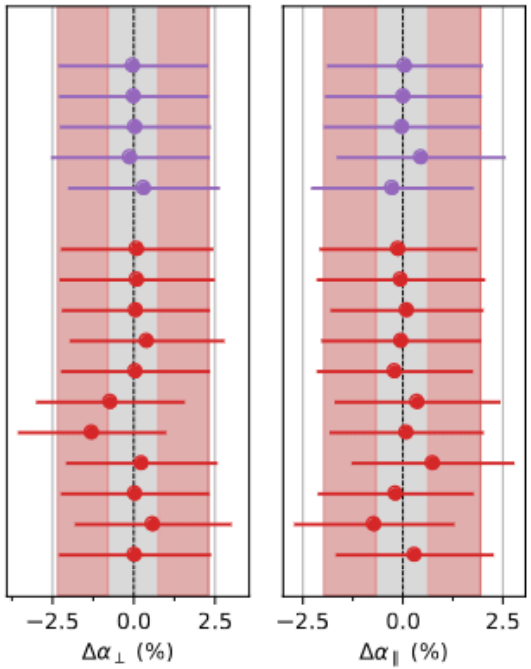
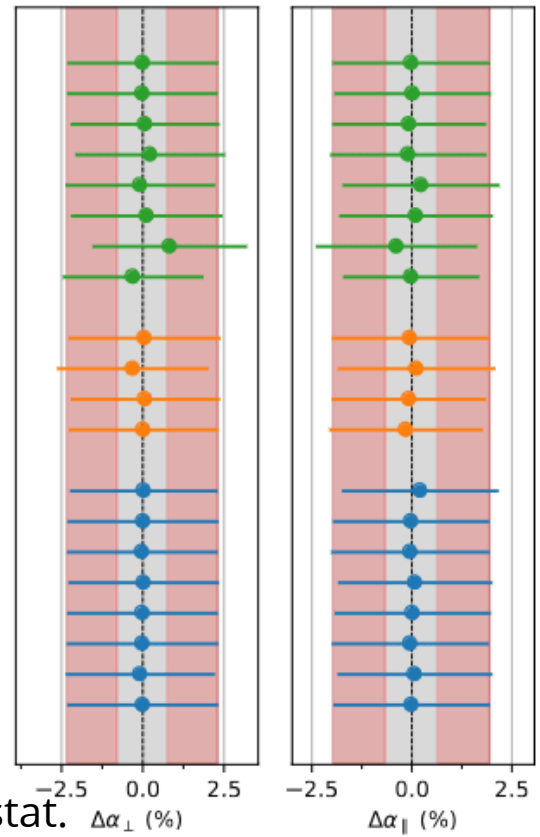
Tests of systematic errors



no calibration
$\eta_{pip} = 1$
ϵ free
$\eta_{LSS} = 3.5$
$\Delta\lambda = 2.4\,Å$

$\lambda_{obs} < 5500\,Å$
$\lambda_{obs} > 3650\,Å$
$\lambda_{RF} < 1200\,Å$
$z_Q < 3.78$
> 50 pixels in forest
original redshift estimates
mask-Lya redshift estimate
only quasar targets
DLAs SNR > 1
weak BALs
no sharp lines mask



dmat $r_\parallel < 200$ Mpc/h
dmat 2%
dmat model 4 Mpc/h
$\Delta\lambda = 3.2\,Å$
$\Delta\lambda = 1.6\,Å$
nside = 32
$\Delta r = 5$ Mpc/h
no cross-covariance

$r < 200$ Mpc/h
$r < 160$ Mpc/h
$r > 20$ Mpc/h
$r > 40$ Mpc/h with priors

eBOSS metals
vary L_{HCD}
$L_{HCD} = 10$ Mpc/h
$L_{HCD} = 3$ Mpc/h
Gaussian redshift errors
weak CIV bias prior
no small-scales correction
UV fluctuations

tests with same dataset (not red): shifts $< \sigma_{stat}/3$

tests with varying datasets (red): shifts consistent with stat.

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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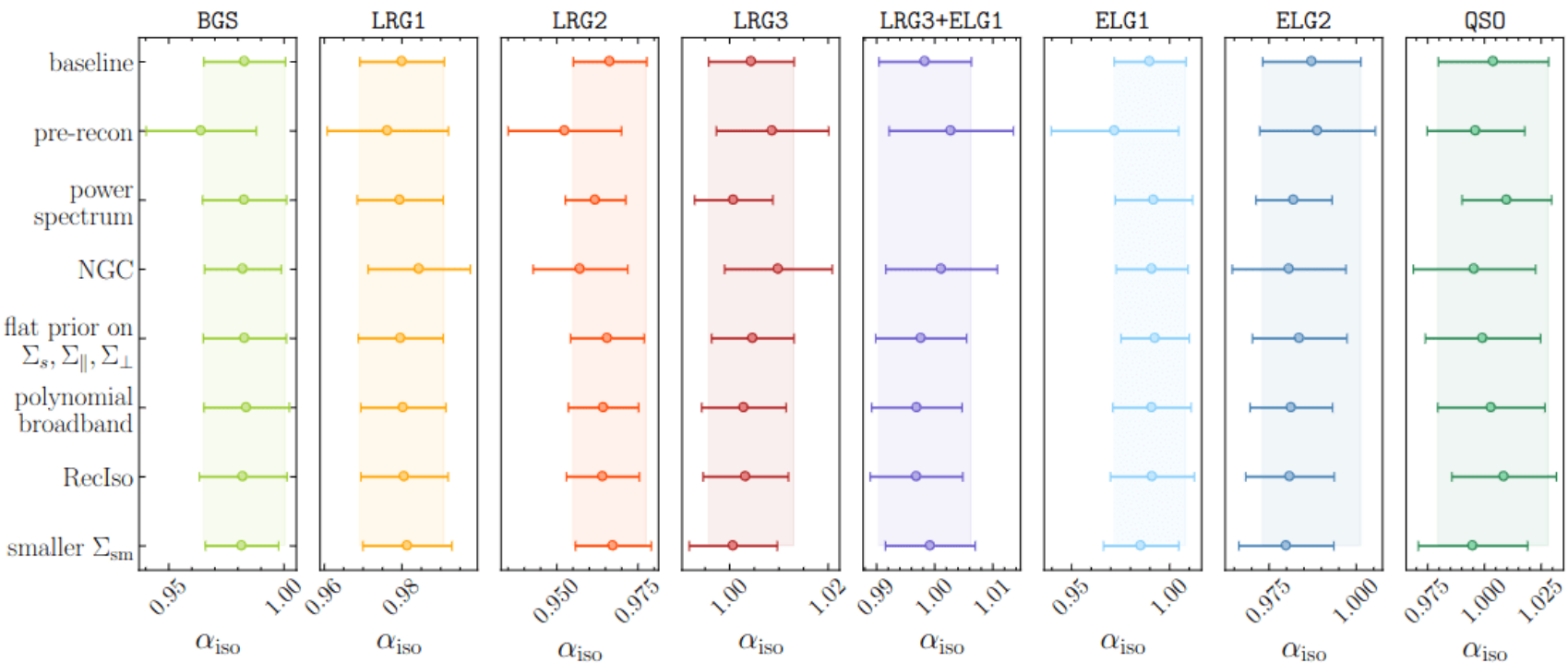
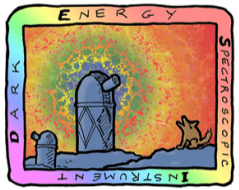
Tests of systematic errors





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DESI DR1 BAO analysis

- **Biggest ever spectroscopic BAO dataset** ($N_{\rm tracer}$ and V)
- **Blind analysis** to mitigate observer / confirmation biases (catalog-level blinding)

$$(\mathrm{R.A.}, \mathrm{Dec.}, z) \Longrightarrow (x, y, z) \Longrightarrow (\mathrm{R.A.}', \mathrm{Dec.}', z')$$

fiducial cosmology

blinded cosmology ($\Omega_{\rm m}, w_0, w_a$)

(random & unknown)

+ **RSD blinding**: change reconstructed peculiar velocities

+ $f_{\rm NL}$ **blinding**: add clustering-dependent signal on large scales with weights

DARK ENERGY SPECTROSCOPIC INSTRUMENT

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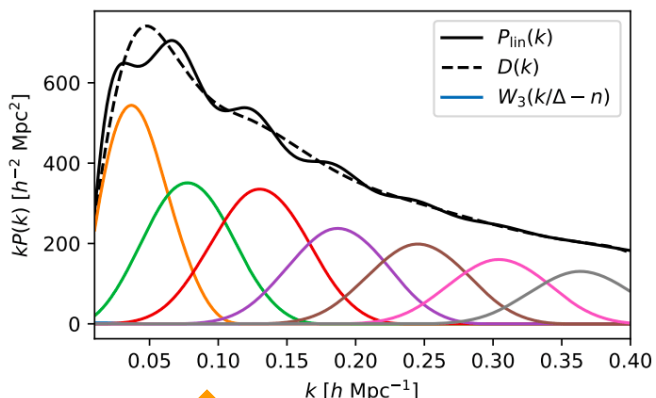
DESI DR1 BAO analysis

- **Biggest ever spectroscopic BAO dataset** ($N_{\rm tracer}$ and V)
- **Blind analysis** to mitigate observer / confirmation biases (catalog-level blinding)
- Theory developments in BAO fitting code



Chen, Howlett et al. 2024

$$P_{\rm gg}(k,\mu) = \mathcal{B}(k,\mu)P_{\rm nw}(k) + \mathcal{C}(k,\mu)P_{\rm w}(k) + \mathcal{D}(k,\mu)$$

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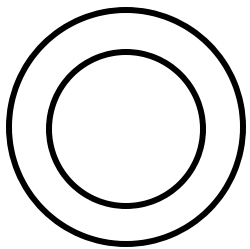
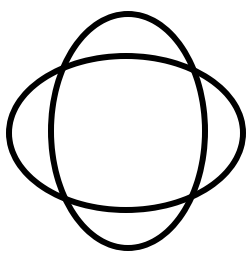
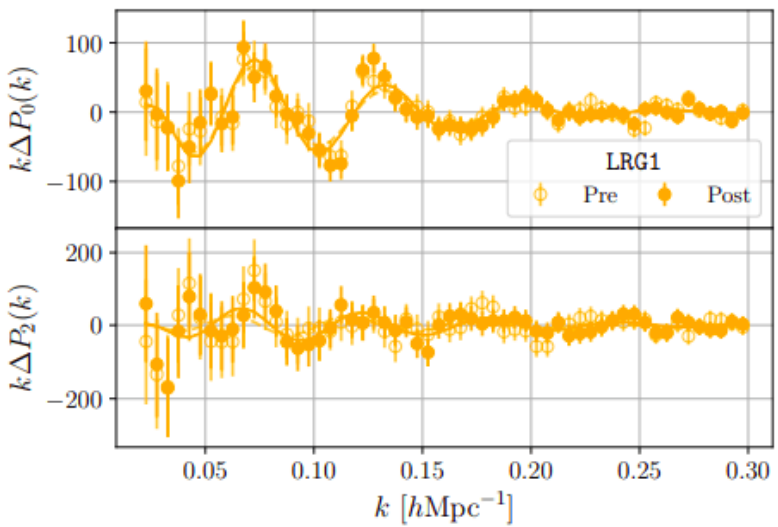
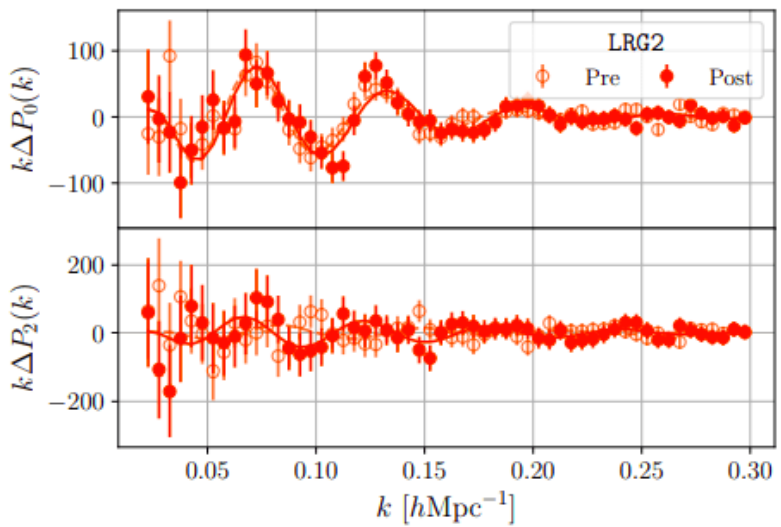
Some fits: Fourier space









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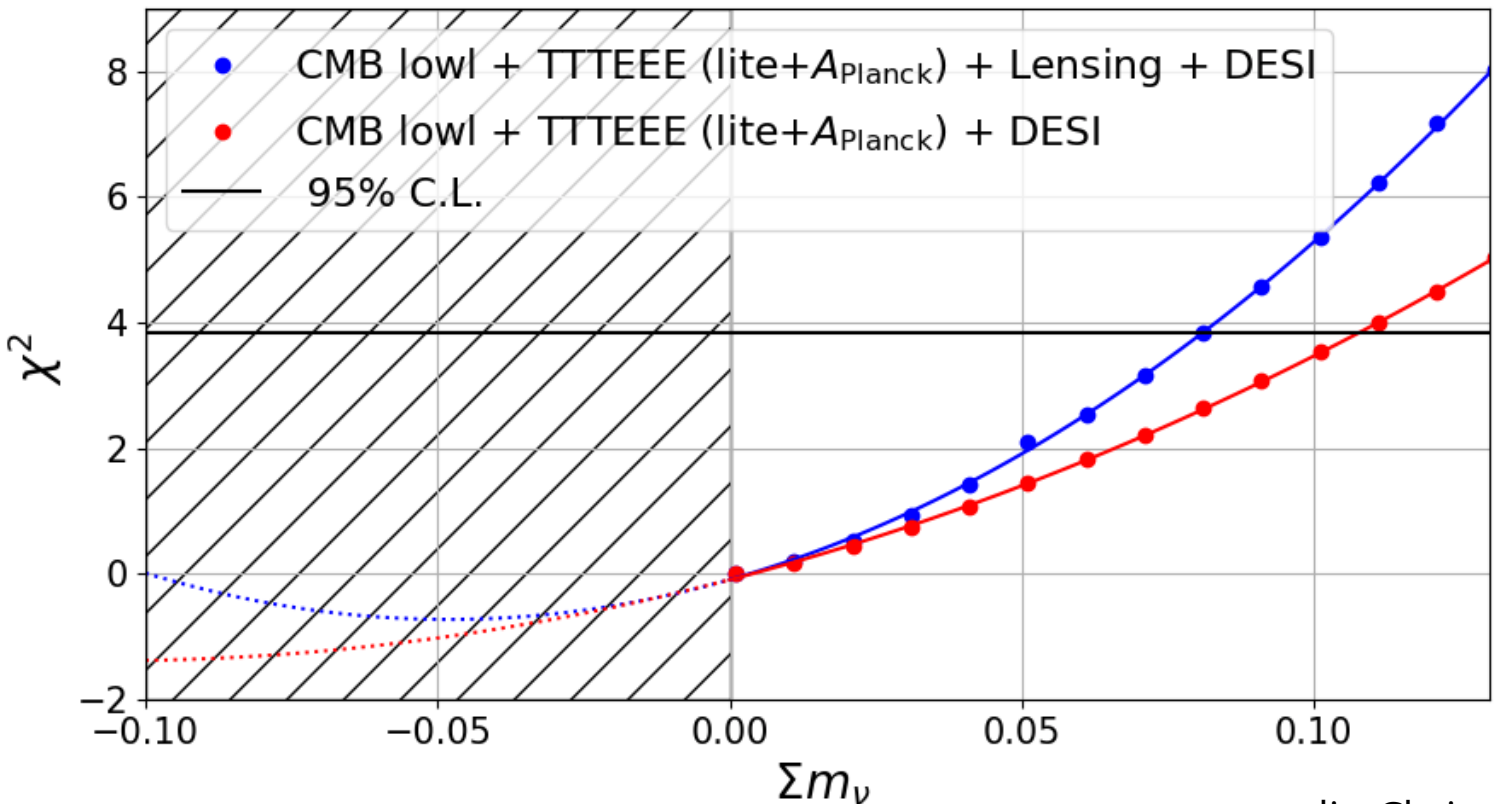
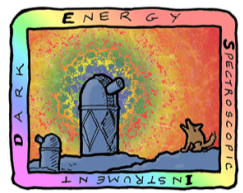
$\sum m_\nu$



credit: Christophe Yèche



DARK ENERGY SPECTROSCOPIC INSTRUMENT

$w(z)$

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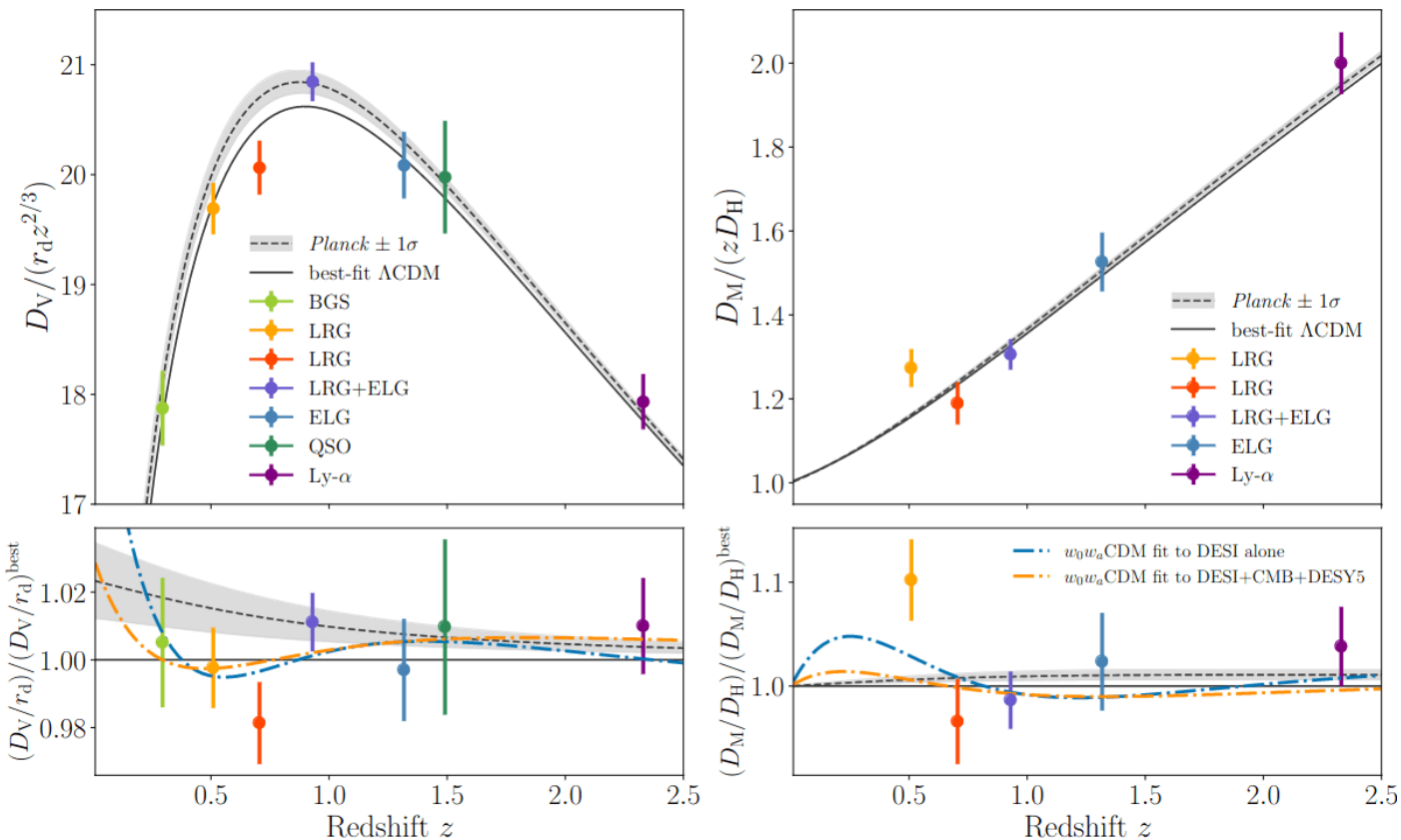

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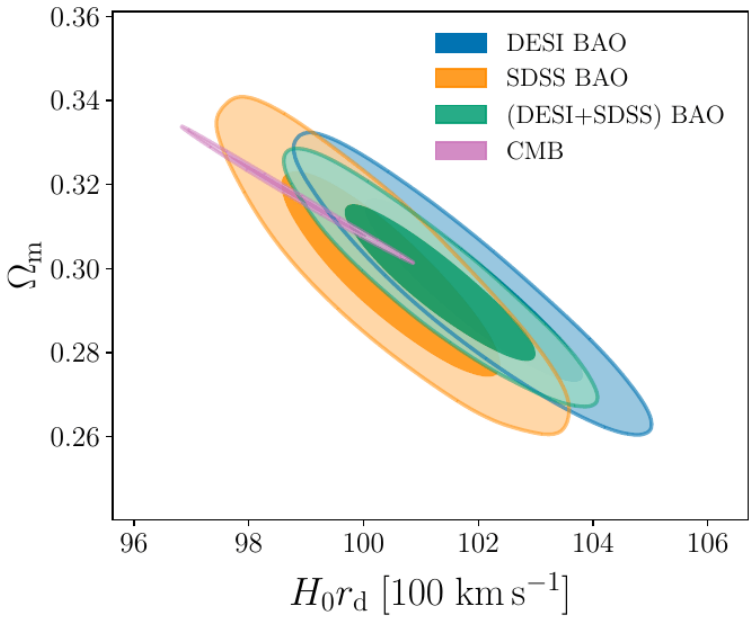
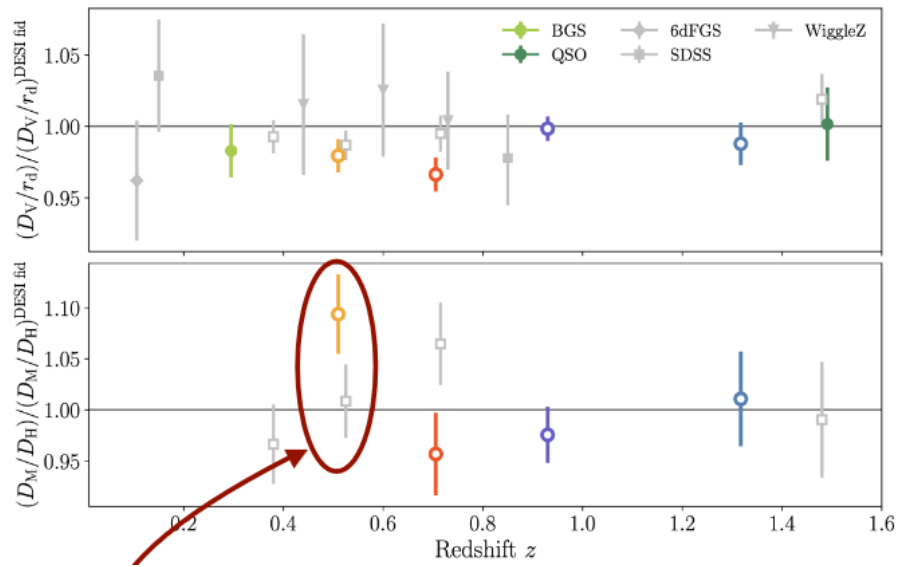
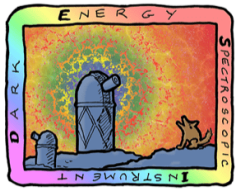
DESI - SDSS consistency (Ω_m)



Perfectly consistent!



Using these 2 points alone moves Ω_m by $< 2\sigma$



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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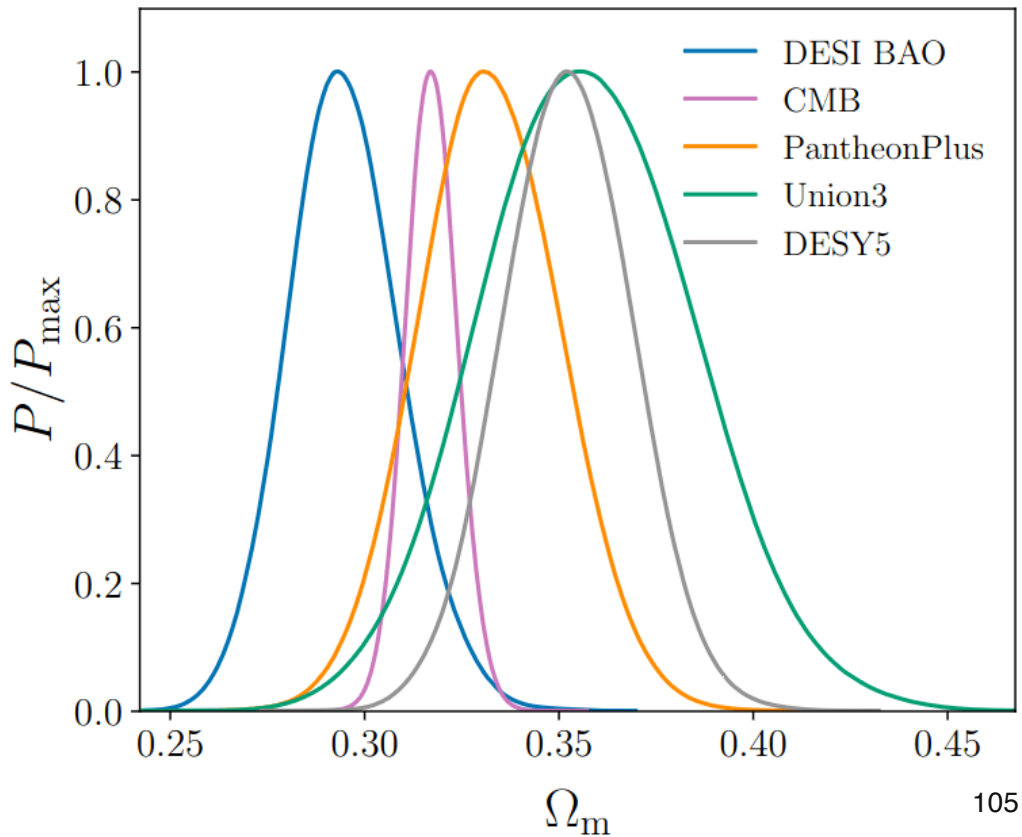
Are SN Ω_m consistent?

Not so much in flat ΛCDM...

(so we do not combine them in this model!)



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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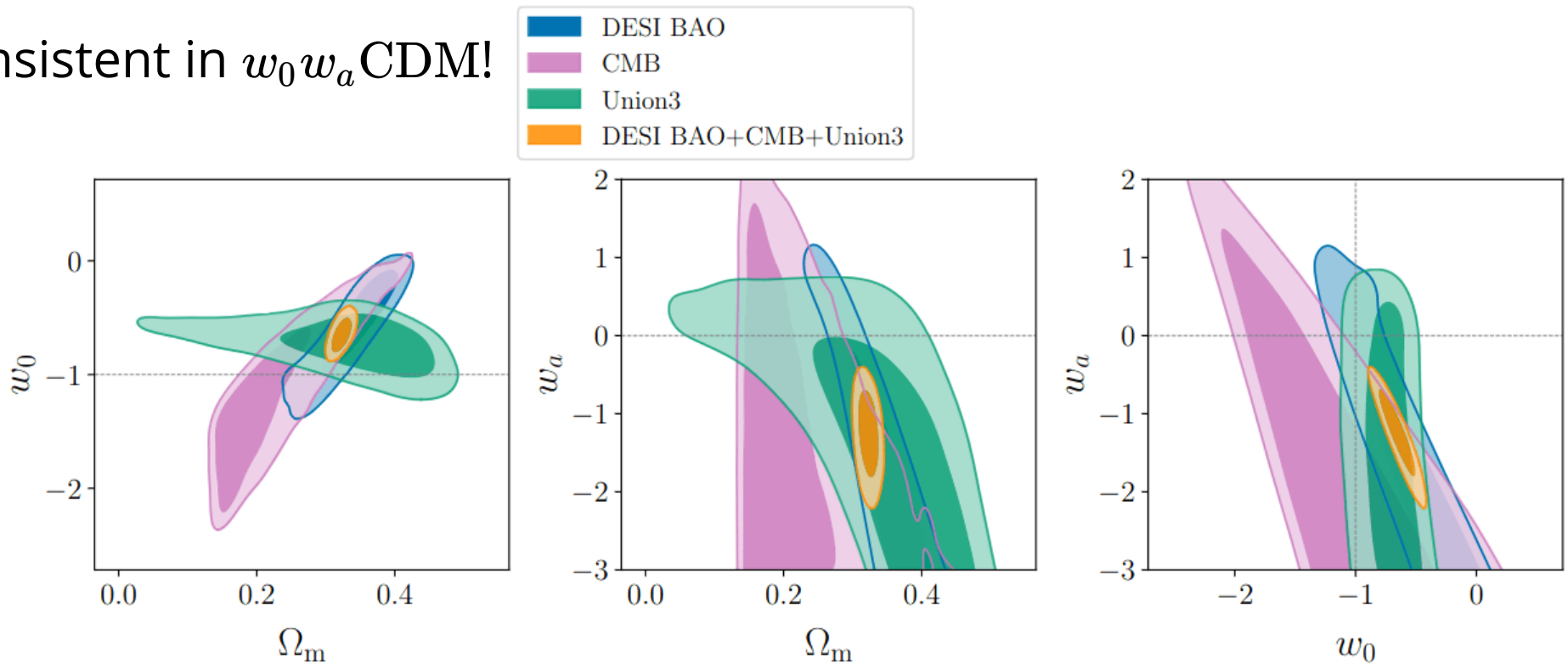
Are SN Ω_m consistent?

Consistent in $w_0 w_a$CDM!



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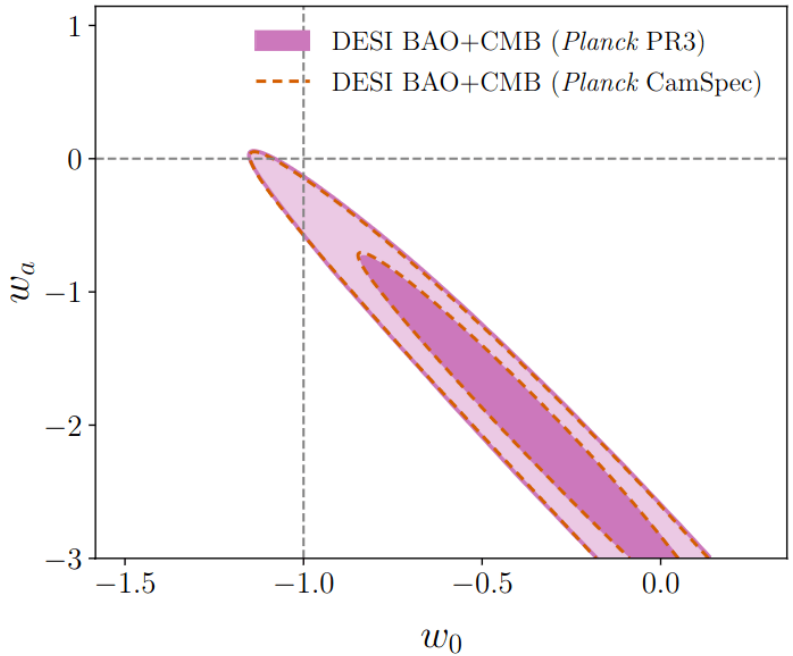
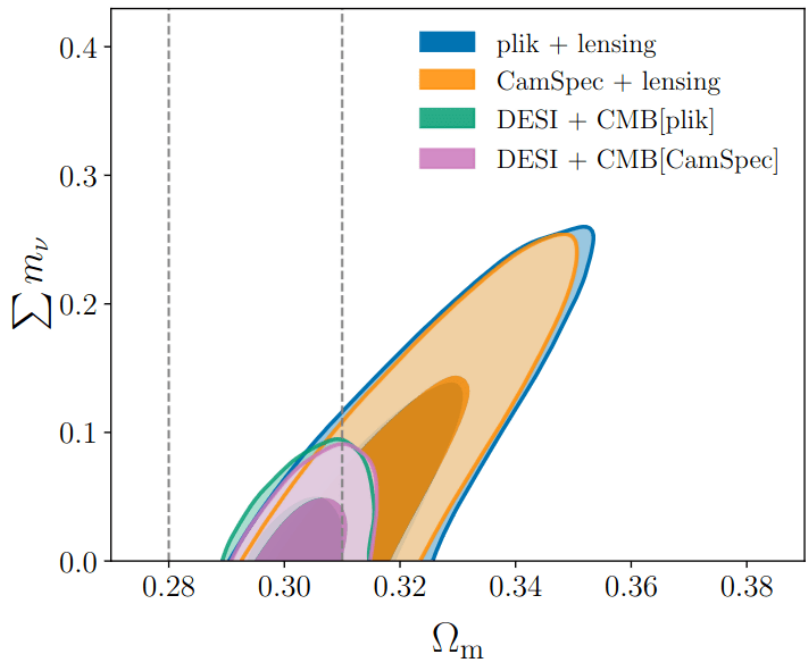
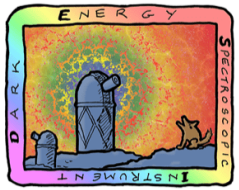
plik vs PR4 Planck likelihoods

Appendix B







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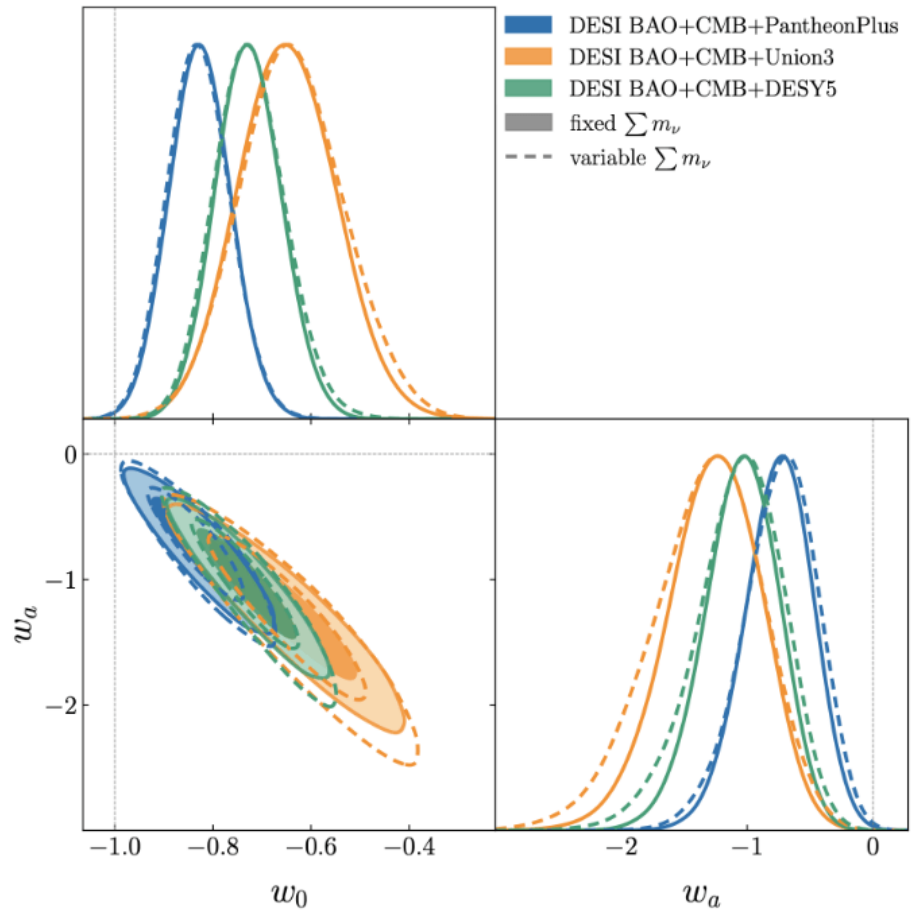
$w_0 - w_a$ with $\sum m_\nu$ free



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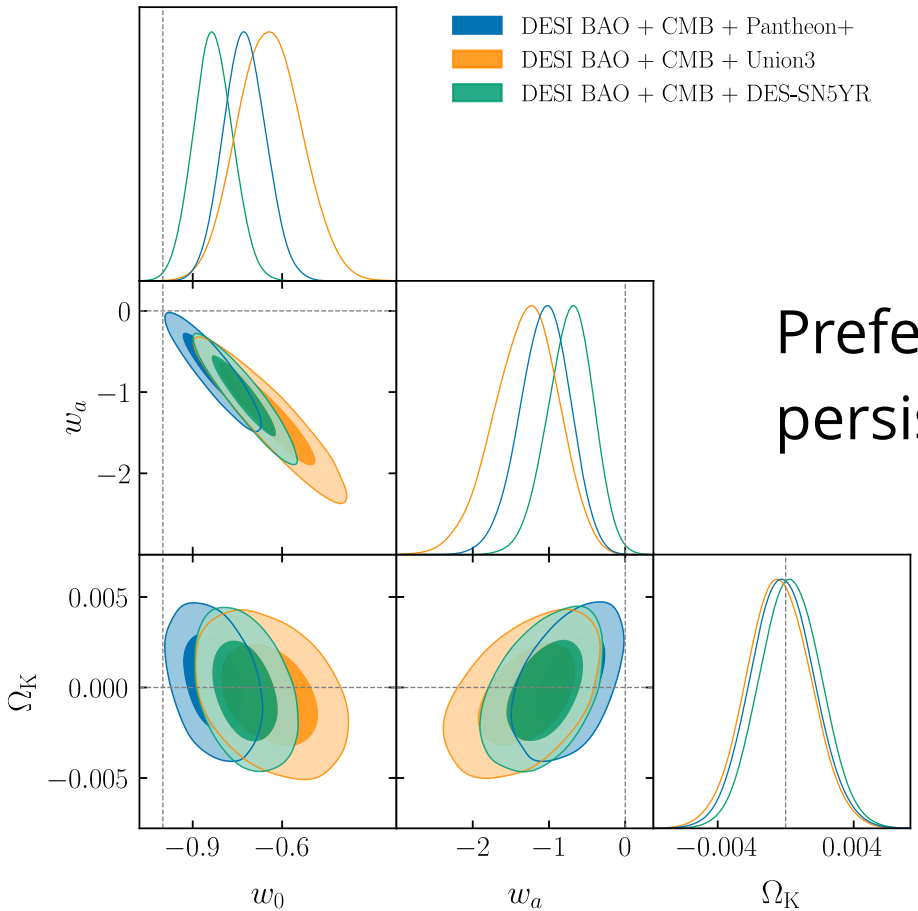
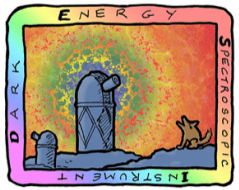
$w_0 - w_a$ with Ω_K



Preference for $w_0 > -1, w_a < 0$ persists when curvature is left free



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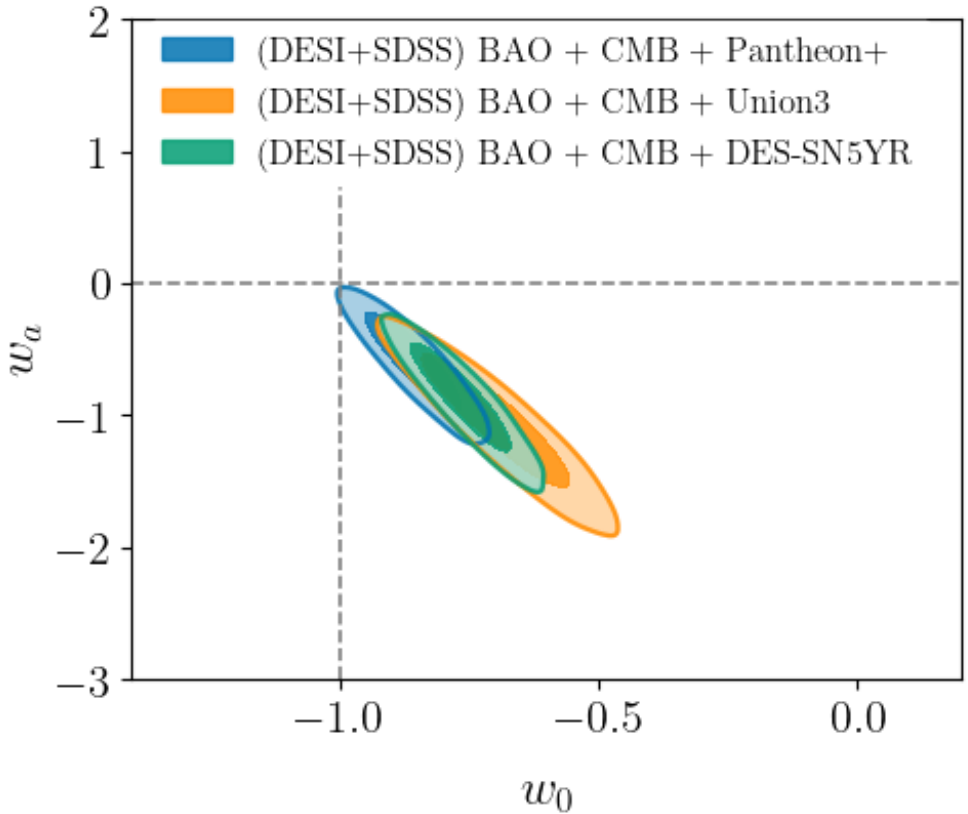
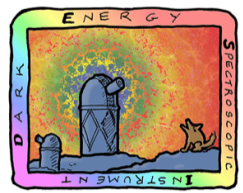
DE constraints driven by low-z ?

Not that much!

DESI + SDSS swaps DESI measurements with SDSS for $z < 0.6$

-0.4σ compared to DESI only





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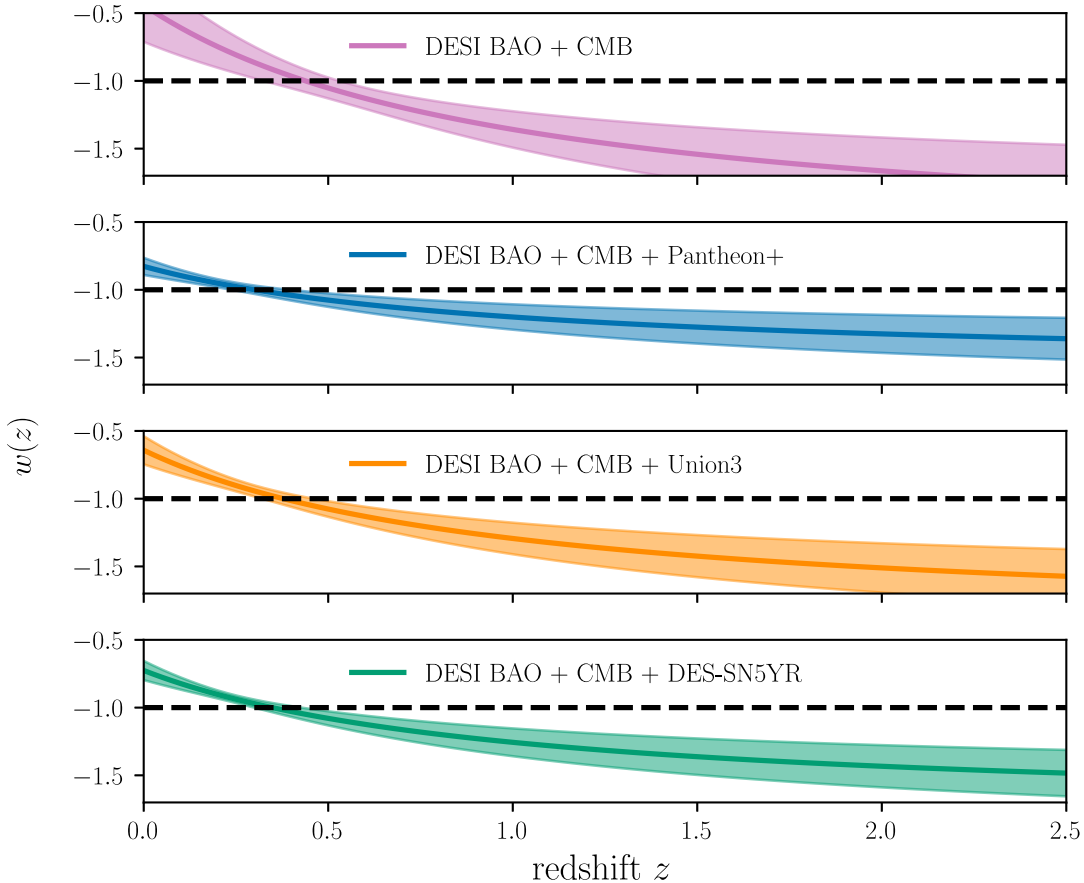
$w(z)$



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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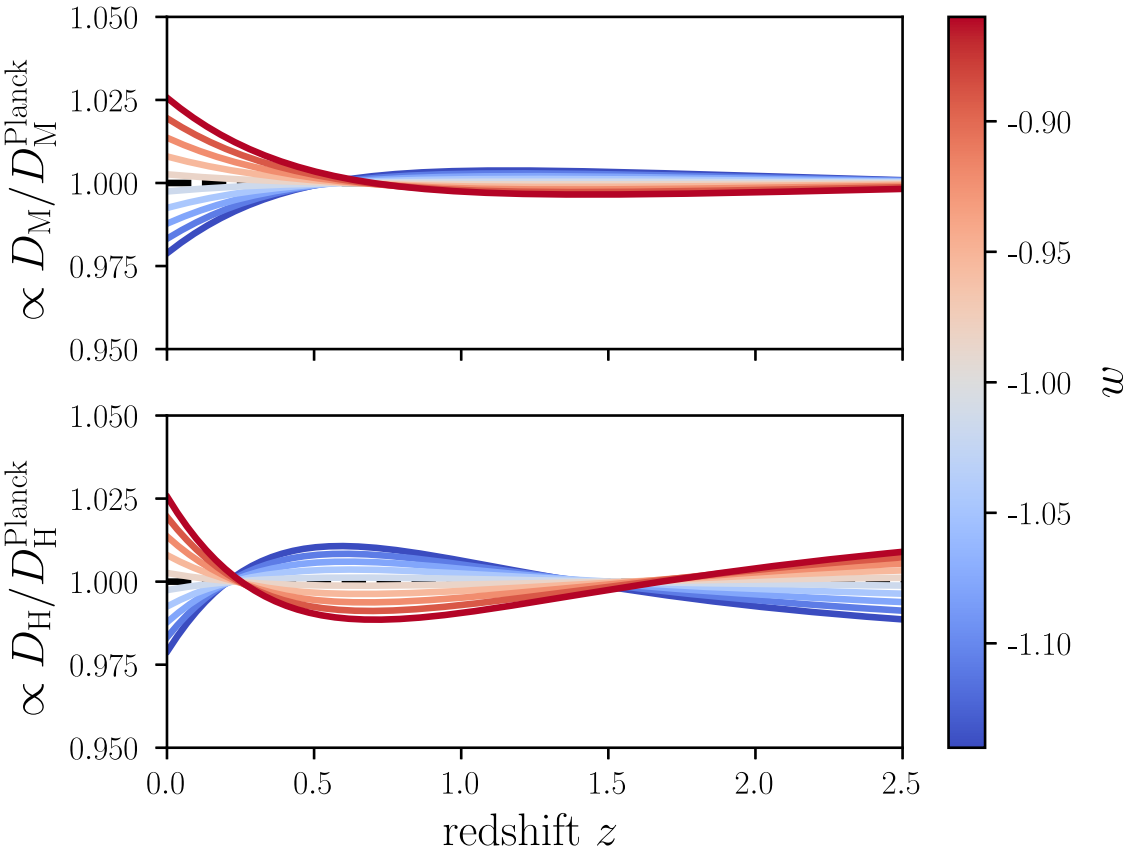
BAO measurements: dark energy

Dark energy equation of state:

$$P = w\rho$$

- w = constant



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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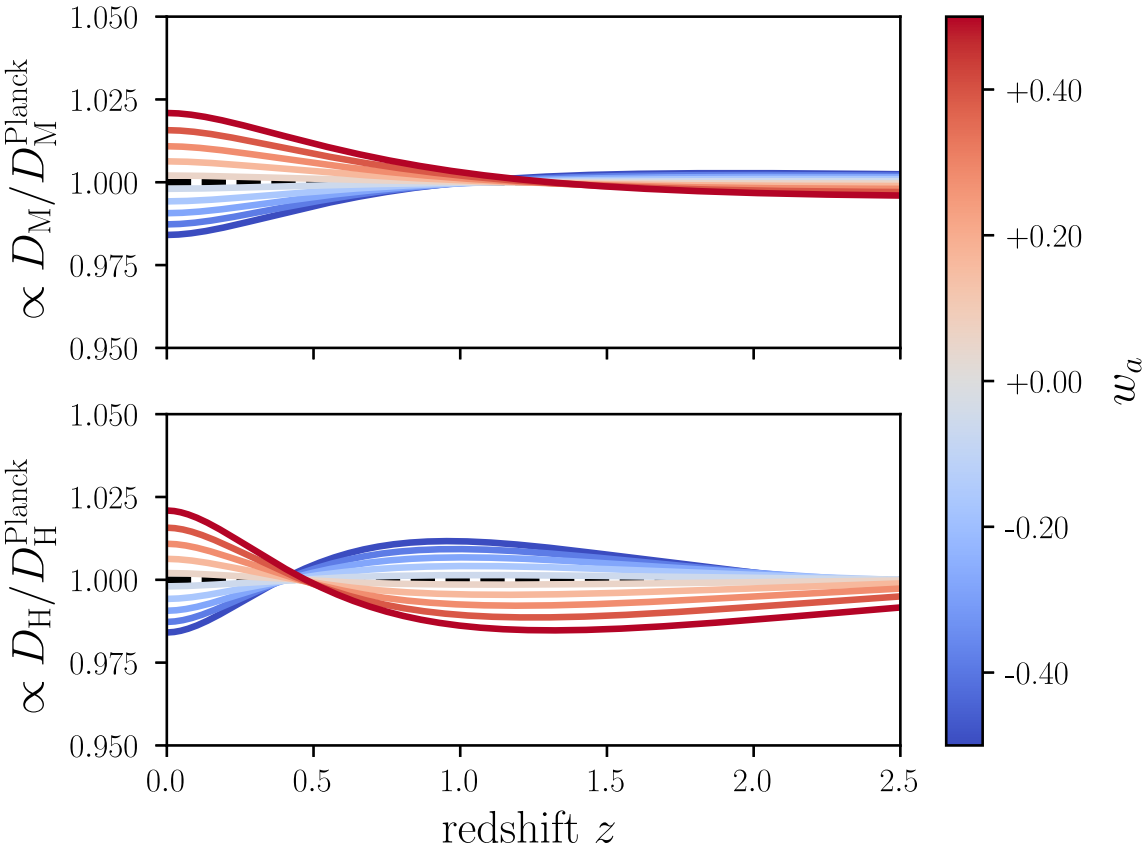
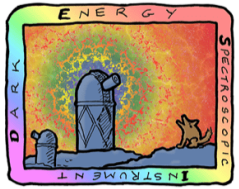
BAO measurements: dark energy

Dark energy equation of state:

$$P = w\rho$$

- CPL parameterization:
  $w(a) = w_0 + (1-a)w_a$





DARK ENERGY SPECTROSCOPIC INSTRUMENT

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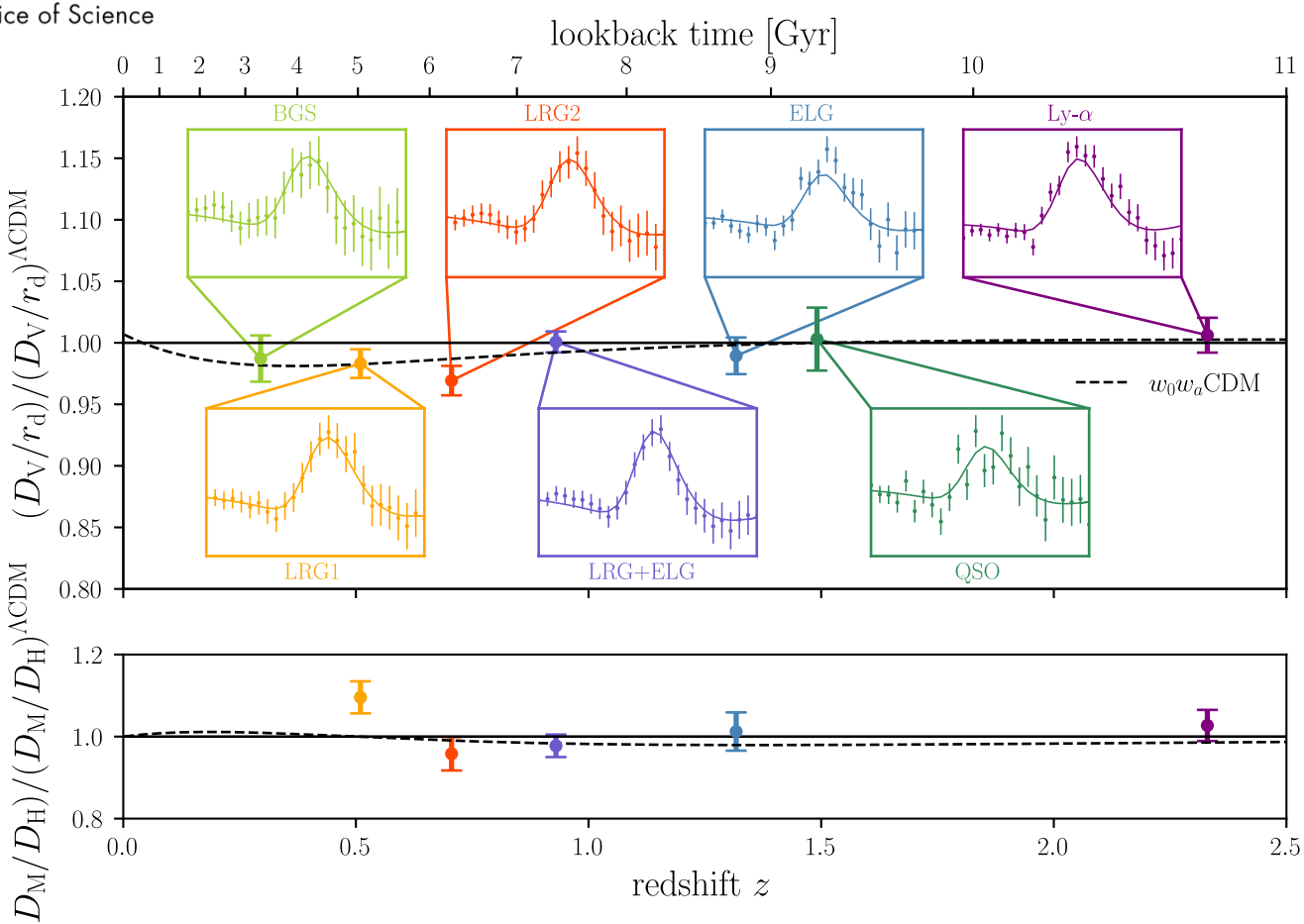
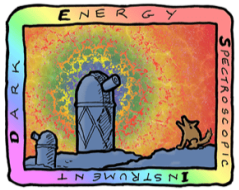
$w(z)$



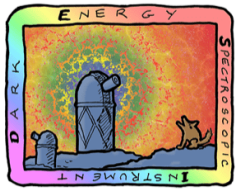


DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Full tables

model/dataset	$\Omega_{\rm m}$	H_0 $[{\rm km\,s^{-1}\,Mpc^{-1}}]$	$10^3\Omega_{\rm K}$	w or w_0	w_a
Flat ΛCDM					
DESI	0.295 ± 0.015	—	—	—	—
DESI+BBN	0.295 ± 0.015	68.53 ± 0.80	—	—	—
DESI+BBN+θ_*	0.2948 ± 0.0074	68.52 ± 0.62	—	—	—
DESI+CMB	0.3069 ± 0.0050	67.97 ± 0.38	—	—	–
ΛCDM+$\Omega_{\rm K}$					
DESI	0.284 ± 0.020	—	65^{+68}_{-78}	—	—
DESI+BBN+θ_*	0.296 ± 0.014	68.52 ± 0.69	$0.3^{+4.8}_{-5.4}$	—	—
DESI+CMB	0.3049 ± 0.0051	68.51 ± 0.52	2.4 ± 1.6	—	—

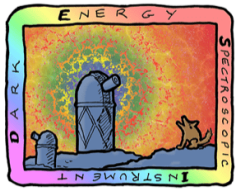


DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Full tables

model/dataset	$\Omega_{\rm m}$	H_0 $[\,{\rm km\,s^{-1}\,Mpc^{-1}}]$	$10^3\Omega_{\rm K}$	w or w_0	w_a
wCDM					
DESI	0.293 ± 0.015	—	—	$-0.99^{+0.15}_{-0.13}$	—
DESI+BBN+θ_*	0.295 ± 0.014	$68.6^{+1.8}_{-2.1}$	—	$-1.002^{+0.091}_{-0.080}$	—
DESI+CMB	0.281 ± 0.013	$71.3^{+1.5}_{-1.8}$	—	$-1.122^{+0.062}_{-0.054}$	—
DESI+CMB+Panth.	0.3095 ± 0.0069	67.74 ± 0.71	—	-0.997 ± 0.025	—
DESI+CMB+Union3	0.3095 ± 0.0083	67.76 ± 0.90	—	-0.997 ± 0.032	—
DESI+CMB+DESY5	0.3169 ± 0.0065	66.92 ± 0.64	—	-0.967 ± 0.024	—
w_0w_aCDM					
DESI	$0.344^{+0.047}_{-0.026}$	—	—	$-0.55^{+0.39}_{-0.21}$	< -1.32
DESI+BBN+θ_*	$0.338^{+0.039}_{-0.029}$	$65.0^{+2.3}_{-3.6}$	—	$-0.53^{+0.42}_{-0.22}$	< -1.08
DESI+CMB	$0.344^{+0.032}_{-0.027}$	$64.7^{+2.2}_{-3.3}$	—	$-0.45^{+0.34}_{-0.21}$	$-1.79^{+0.48}_{-1.0}$
DESI+CMB+Panth.	0.3085 ± 0.0068	68.03 ± 0.72	—	-0.827 ± 0.063	$-0.75^{+0.29}_{-0.25}$
DESI+CMB+Union3	0.3230 ± 0.0095	66.53 ± 0.94	—	-0.65 ± 0.10	$-1.27^{+0.40}_{-0.34}$
DESI+CMB+DESY5	0.3160 ± 0.0065	67.24 ± 0.66	—	-0.727 ± 0.067	$-1.05^{+0.31}_{-0.27}$
w_0w_aCDM+$\Omega_{\rm K}$					
DESI	0.313 ± 0.049	—	87^{+100}_{-85}	$-0.70^{+0.49}_{-0.25}$	< -1.21
DESI+BBN+θ_*	$0.346^{+0.042}_{-0.024}$	$65.8^{+2.6}_{-3.5}$	$5.9^{+9.1}_{-6.9}$	$-0.52^{+0.38}_{-0.19}$	< -1.44
DESI+CMB	$0.347^{+0.031}_{-0.025}$	$64.3^{+2.0}_{-3.2}$	-0.9 ± 2	$-0.41^{+0.33}_{-0.18}$	< -1.61
DESI+CMB+Panth.	0.3084 ± 0.0067	68.06 ± 0.74	0.3 ± 1.8	-0.831 ± 0.066	$-0.73^{+0.32}_{-0.28}$
DESI+CMB+Union3	$0.3233^{+0.0089}_{-0.010}$	66.45 ± 0.98	-0.4 ± 1.9	-0.64 ± 0.11	$-1.30^{+0.45}_{-0.39}$
DESI+CMB+DESY5	0.3163 ± 0.0065	67.19 ± 0.69	-0.2 ± 1.9	-0.725 ± 0.071	$-1.06^{+0.35}_{-0.31}$



DARK ENERGY SPECTROSCOPIC INSTRUMENT

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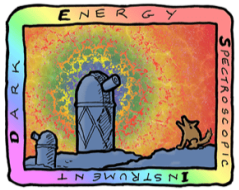
Full tables

model / dataset	$\Omega_{\rm m}$	H_0 [$\rm km\,s^{-1}\,Mpc^{-1}$]	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

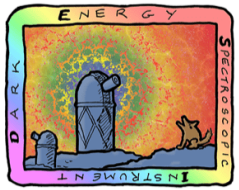


DARK ENERGY SPECTROSCOPIC INSTRUMENT

U.S. Department of Energy Office of Science

Full tables

model / dataset	$\Omega_{\rm m}$	H_0 [km s^{-1} Mpc^{-1}]	Σm_ν [eV]	$N_{\rm eff}$
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	$0.346^{+0.032}_{-0.026}$	$63.9^{+2.2}_{-3.3}$	—	2.89 ± 0.17
DESI+CMB+Panth.	0.3093 ± 0.0069	67.5 ± 1.1	—	2.93 ± 0.18
DESI+CMB+Union3	0.3245 ± 0.0098	65.9 ± 1.3	—	2.91 ± 0.18
DESI+CMB+DESY5	0.3172 ± 0.0067	66.6 ± 1.1	—	2.92 ± 0.18



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Hubble tension