DESI DR2: Cosmological Constraints and Challenges to the ΛCDM Model

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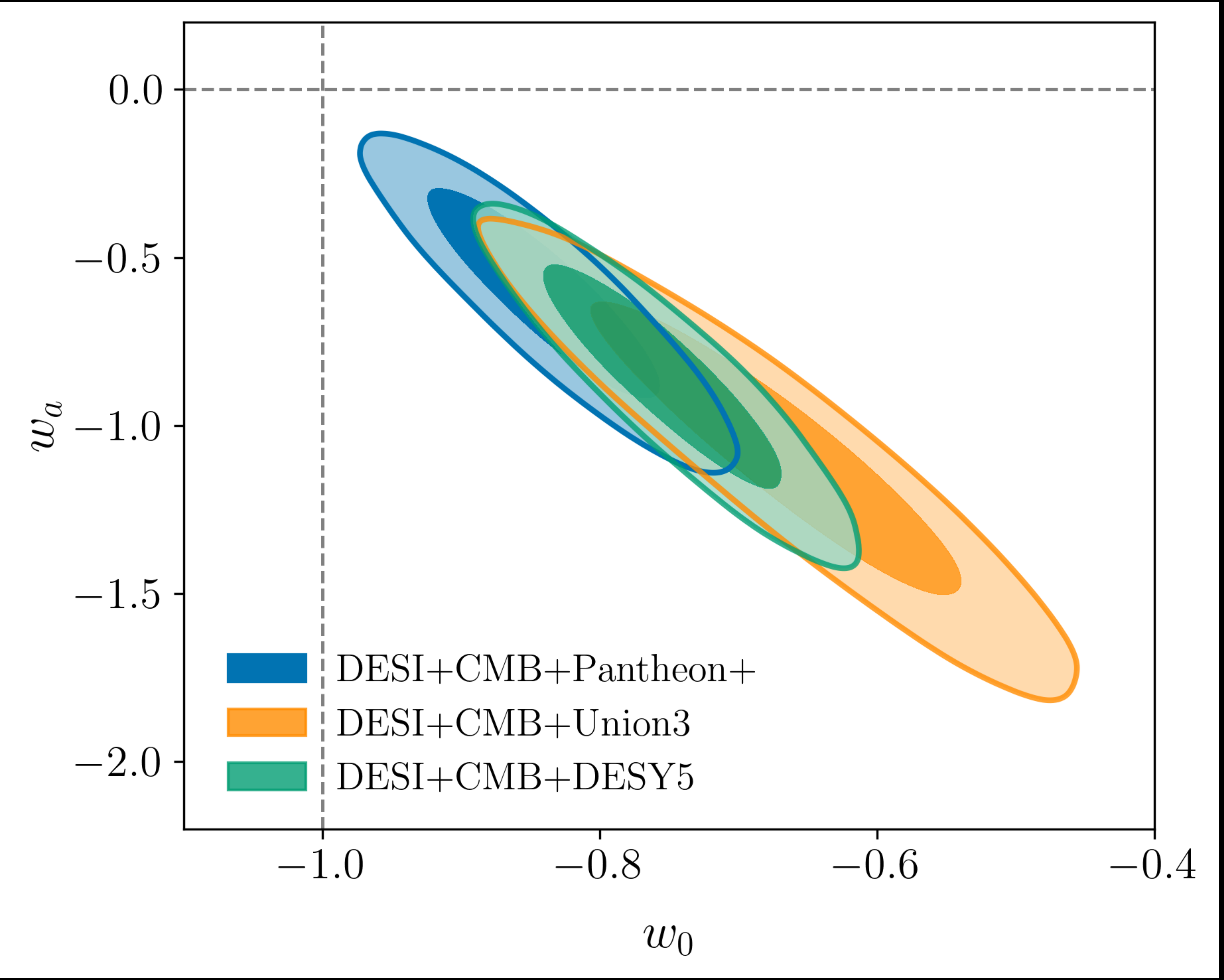
Madison, Wisconsin June 9-13 , 2025

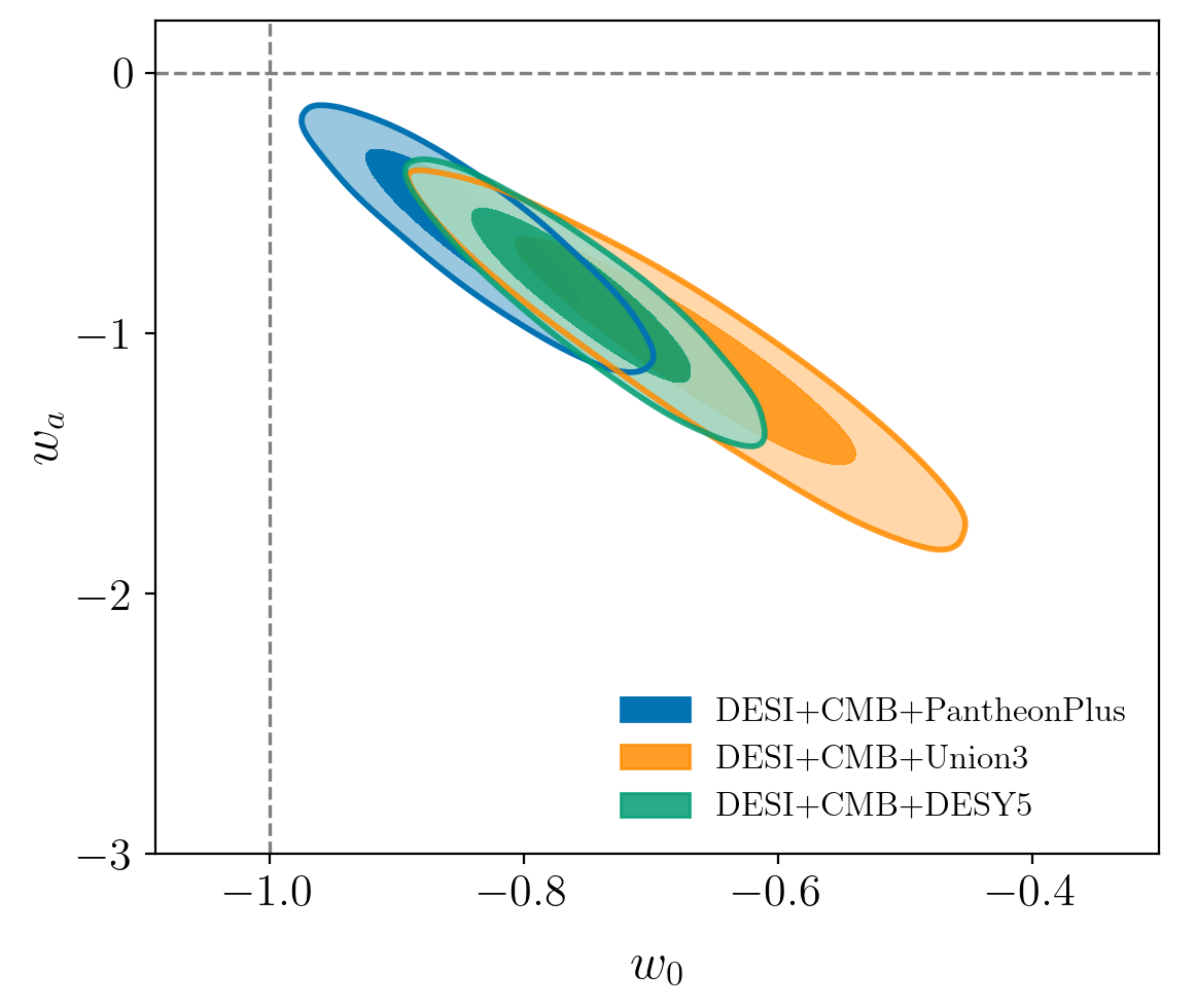
DR1: Dynamical Dark Energy - (w_0, w_a)

- 3.9σ tantalizing suggestion of deviations from the standard cosmological model



DR2: Dynamical Dark Energy - (w_0, w_a)

- 4.2σ
- Unless there is an **unknown systematic** error associated with one or more datasets, it is clear that ΛCDM is being challenged by the combination of DESI BAO with other measurements and that dynamical dark energy offers a possible solution



Transitioning from Stage-III to Stage-IV surveys

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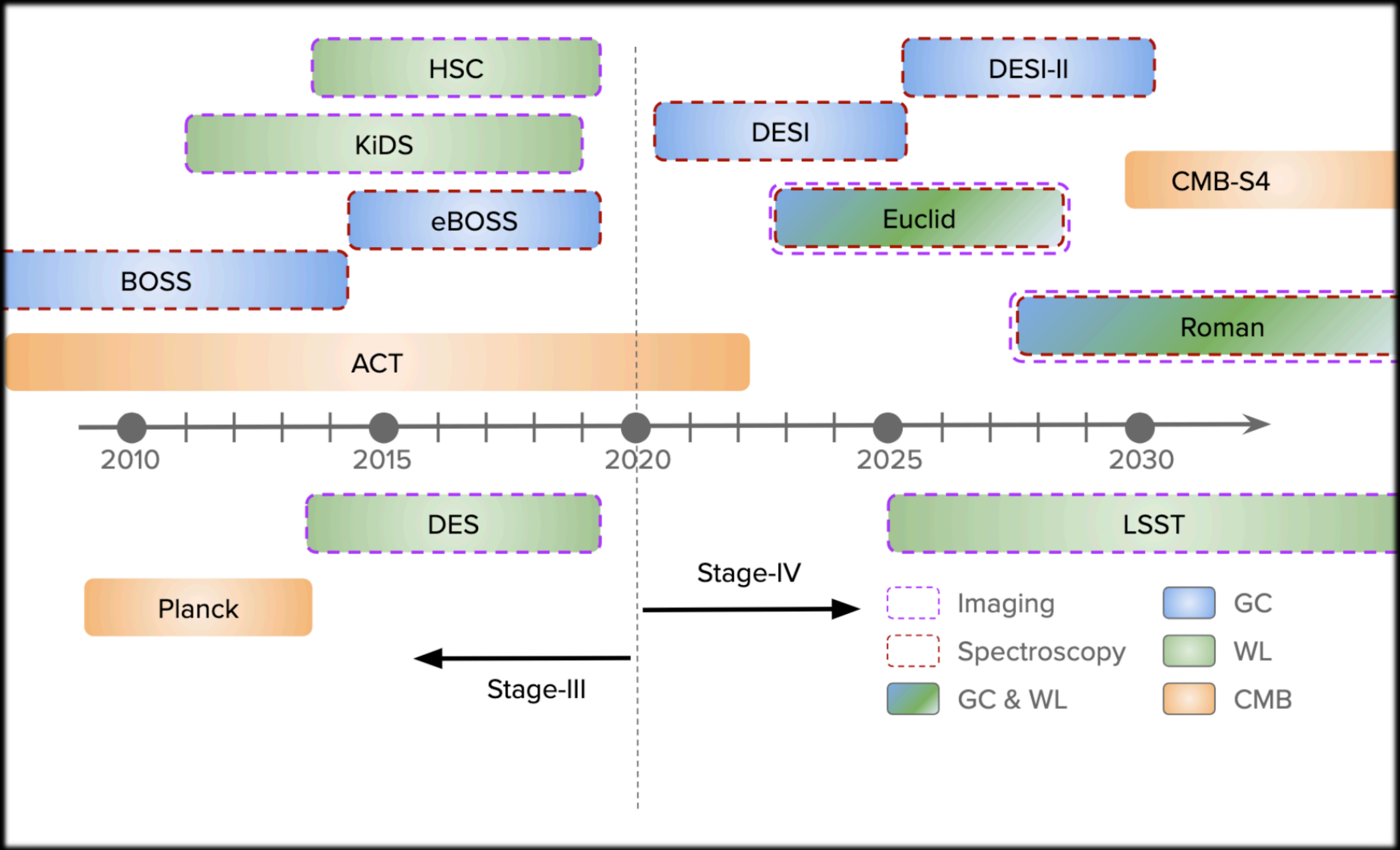

REPORT OF THE DARK ENERGY TASK FORCE 2006

III. We recommend that the dark energy program include a combination of techniques from one or more Stage III projects designed to achieve, in combination, at least a factor of three gain over Stage II in the DETF figure of merit, based on critical appraisals of likely statistical and systematic uncertainties.

IV. We recommend that the dark energy program include a combination of techniques from one or more Stage IV projects designed to achieve, in combination, at least a factor of ten gain over Stage II in the DETF figure of merit, based on critical appraisals of likely statistical and systematic uncertainties. Because JDEM, LST, and SKA all offer promising avenues to greatly improved understanding of dark energy, we recommend continued research and development investments to optimize the programs and to address remaining technical questions and systematic-error risks.


DARK ENERGY
SPECTROSCOPIC
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NERSC
cea
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DESI Survey: Making the Largest 3D Map of the Universe

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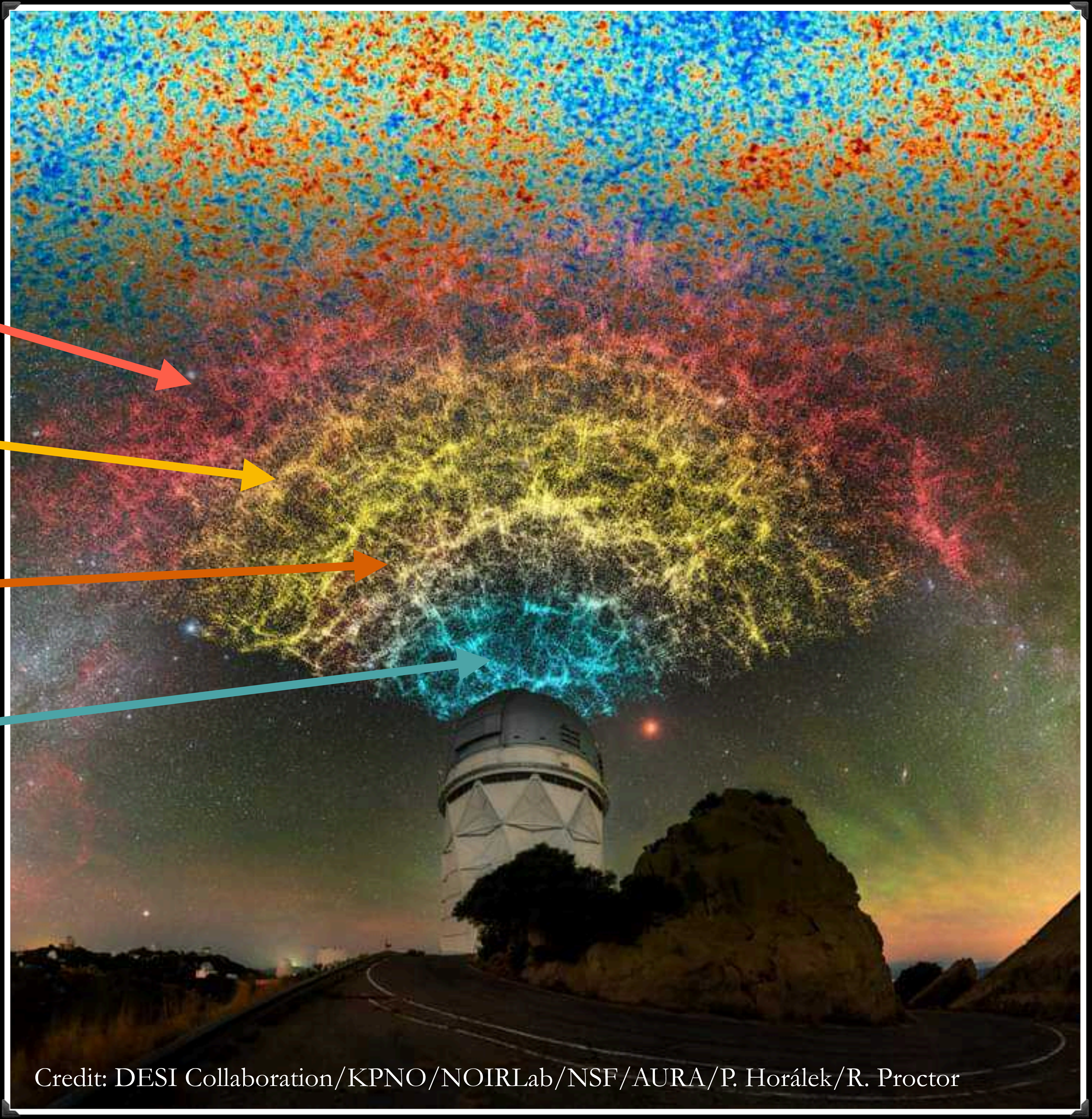
3 million
Quasars ($0.9 < z < 2.1$)
+ Ly-a forest ($2.1 < z$)

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

8 million Luminous Red Galaxies
($0.4 < z < 1$)

13.5 million Bright Galaxies
($0.0 < z < 0.4$)



Credit: DESI Collaboration/KPNO/NOIRLab/NSF/AURA/P. Horálek/R. Proctor

From 2021-2026 DESI will measure precise redshifts to ~40 million galaxies over 14,000 deg2

DESI Survey: Making the Largest 3D Map of the Universe

Science drivers:

- Baryon Acoustic Oscillations (BAO)
- Redshift Space Distortions (RSD)

DESI Survey: Making the Largest 3D Map of the Universe

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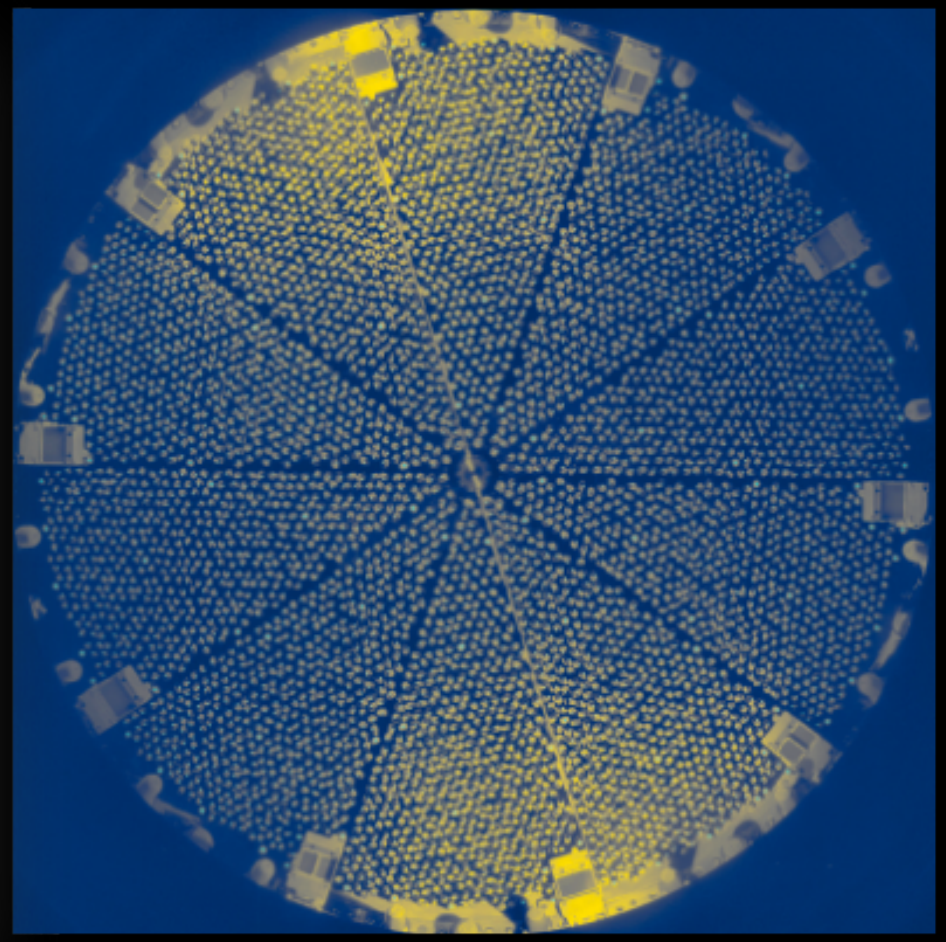
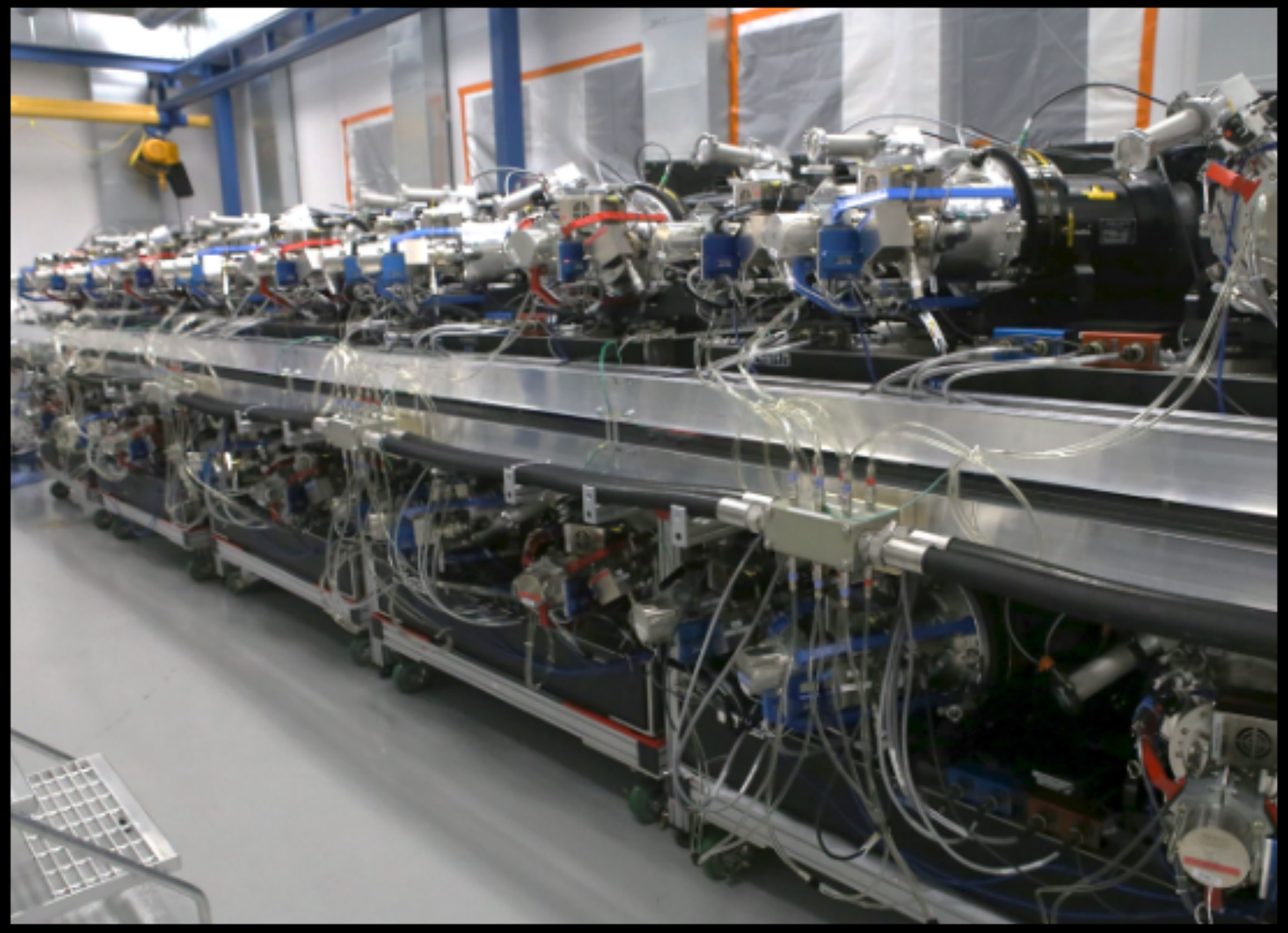
4m Mayall Telescope, KPNO, Arizona, USA

Wide Field Corrector 8 sq. deg. Field of View



Focal Plane with 5,000 Fiber Positioners

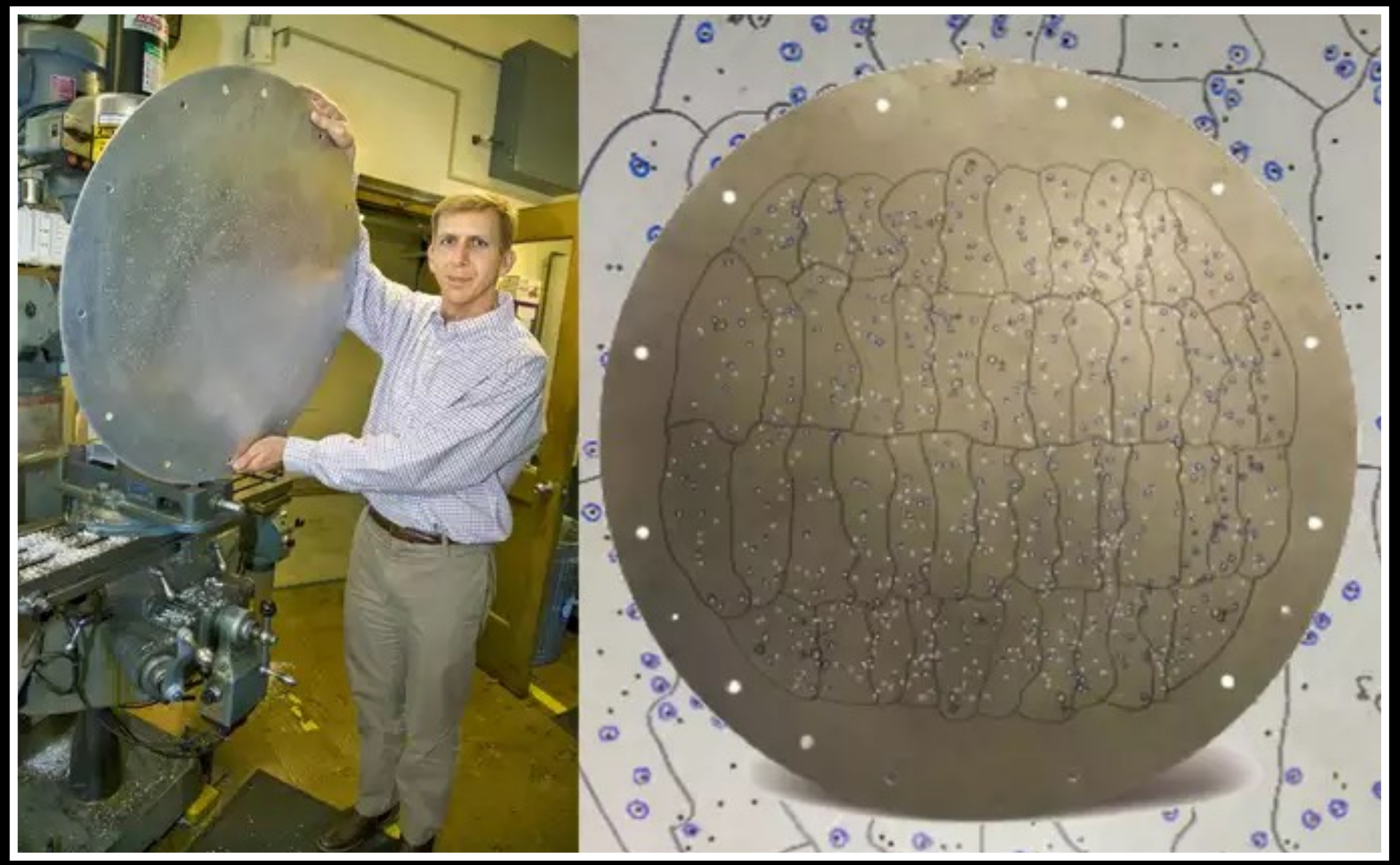


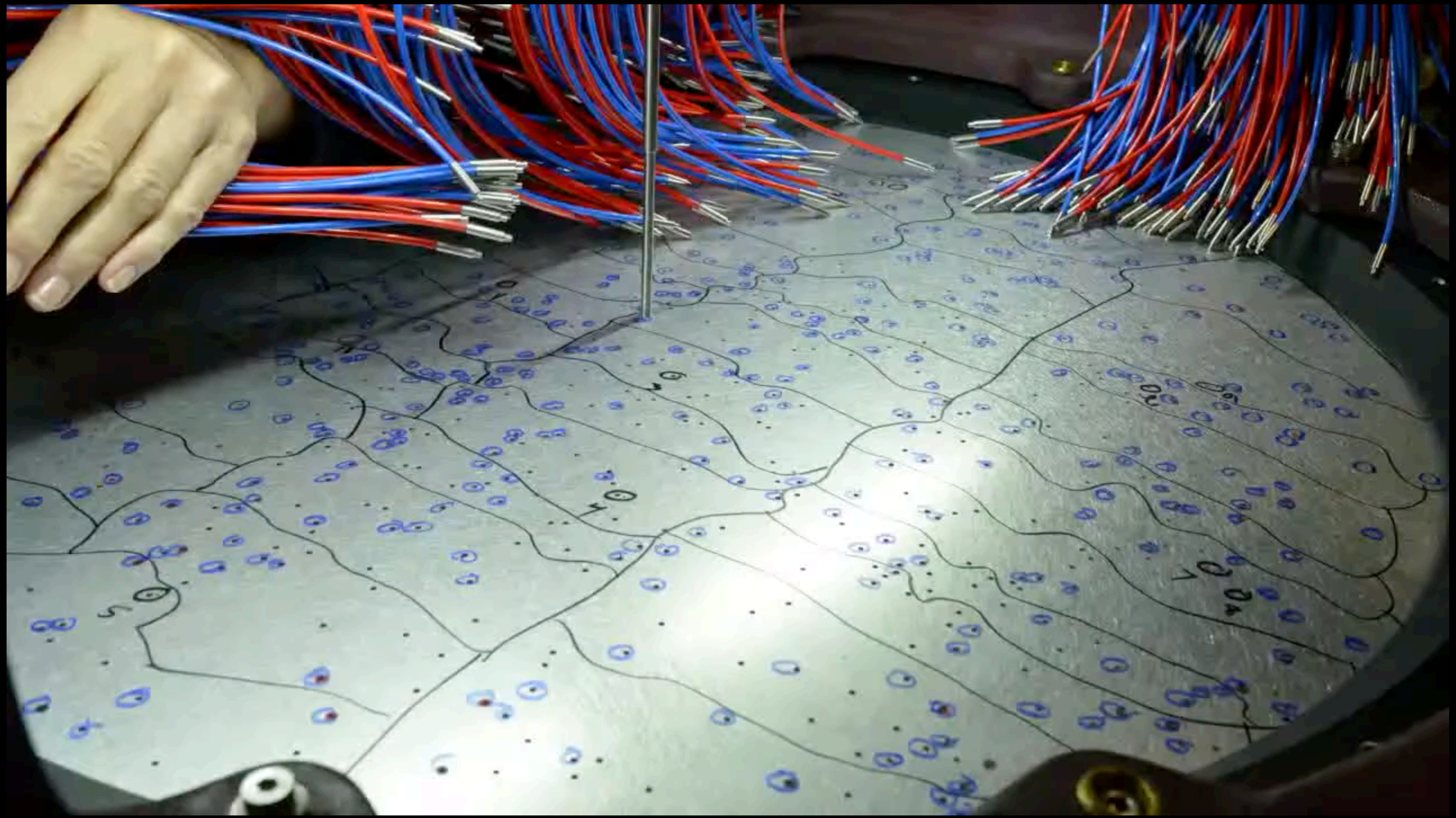
10 Multi-Object Spectrographs

Designed to optimize survey throughput:

- 5,000 fibers, wide field corrector, 10 spectrographs → maximum number of simultaneous targets
- remotely controlled fiber positioners; align, position, and readout in parallel → minimum reconfiguration time
- dynamic field selection, exposure time calculator, autofocus → maximum operational efficiency

Fiber assignment before DESI





- Process of plugging optical fibers into plates for observations for the Sloan Digital Sky Survey (SDSS)
- Each plate can take anything from 30 mins to several hours to be plugged by the expert SDSS Plate Pluggers

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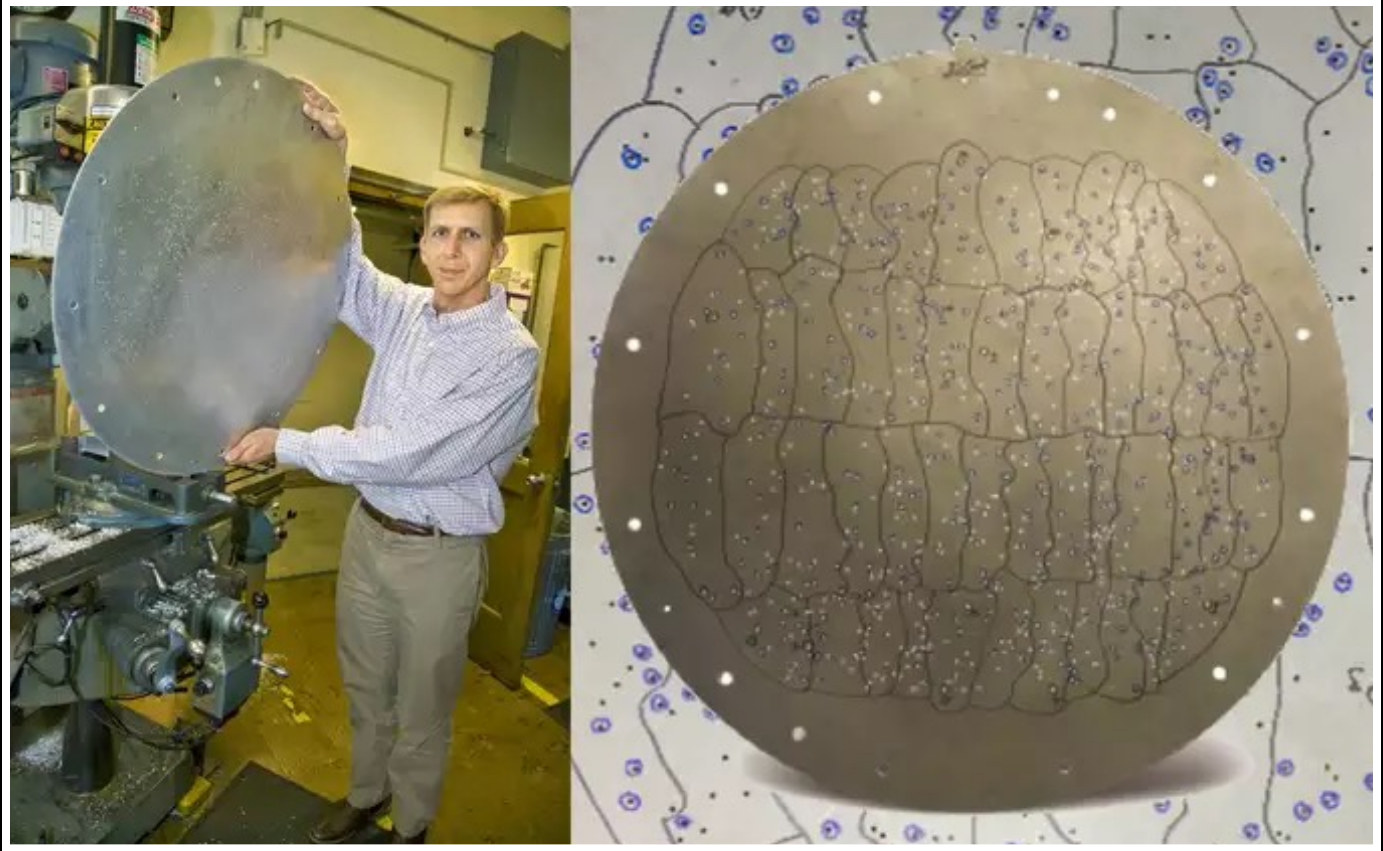

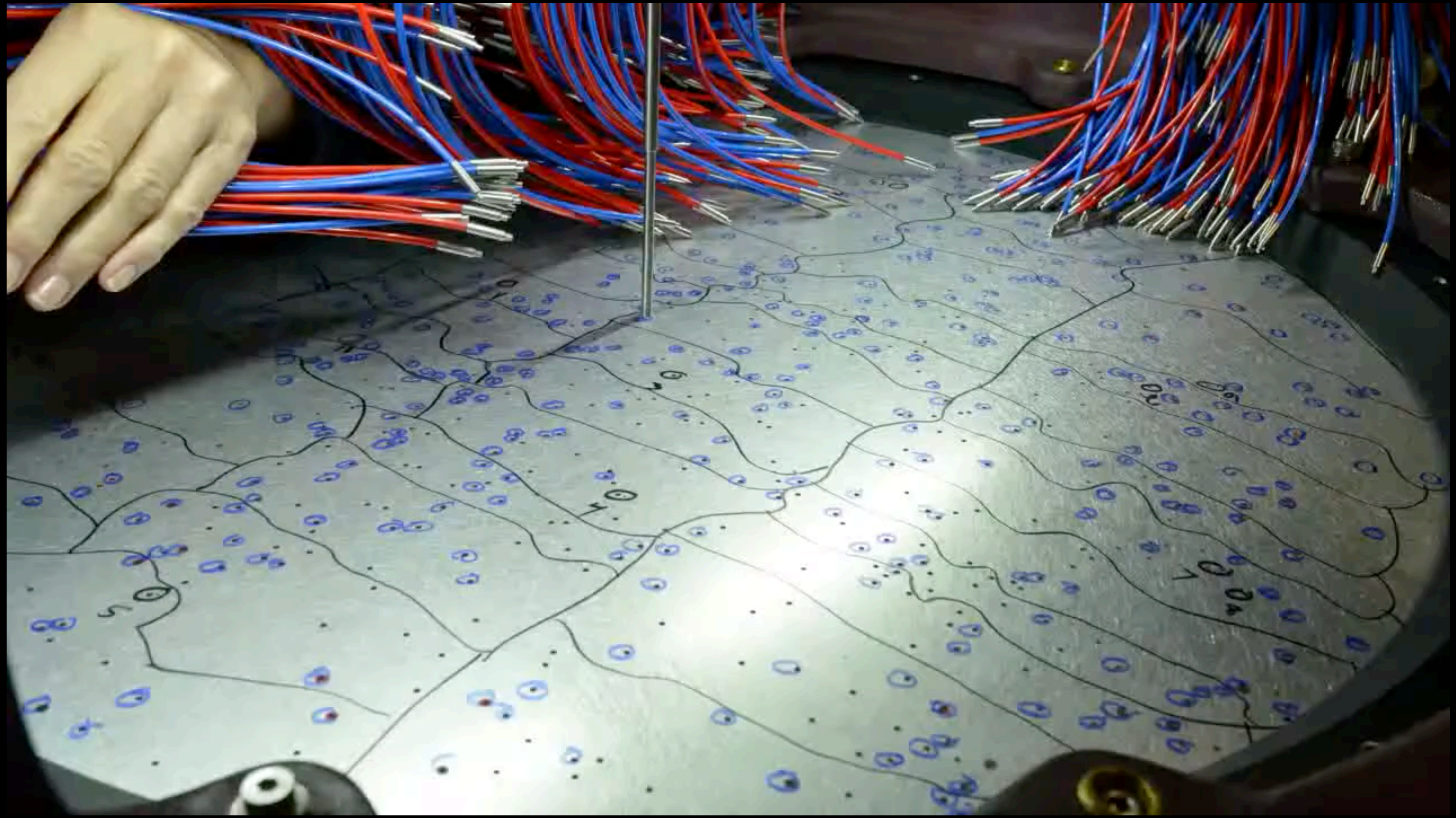

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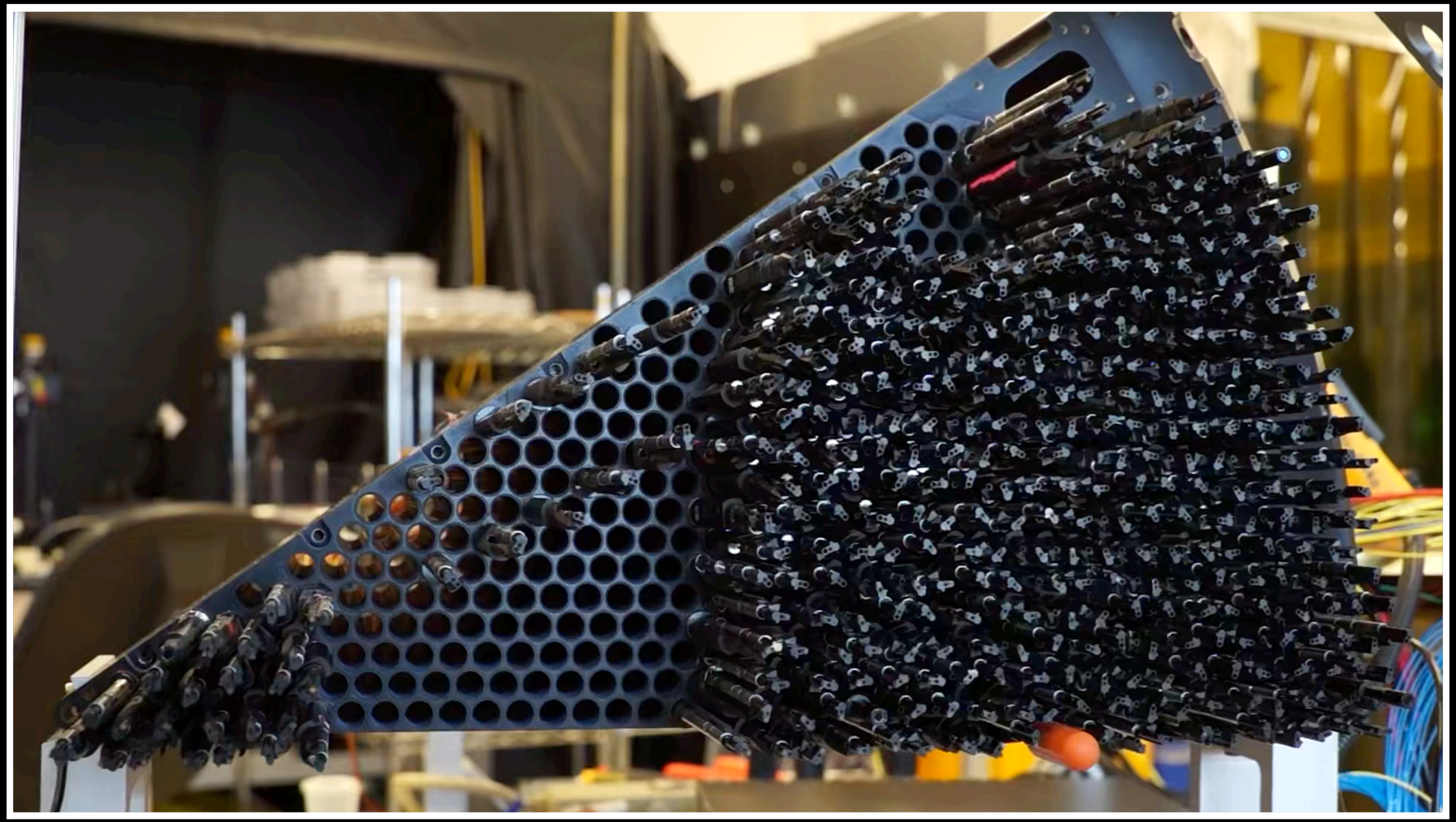
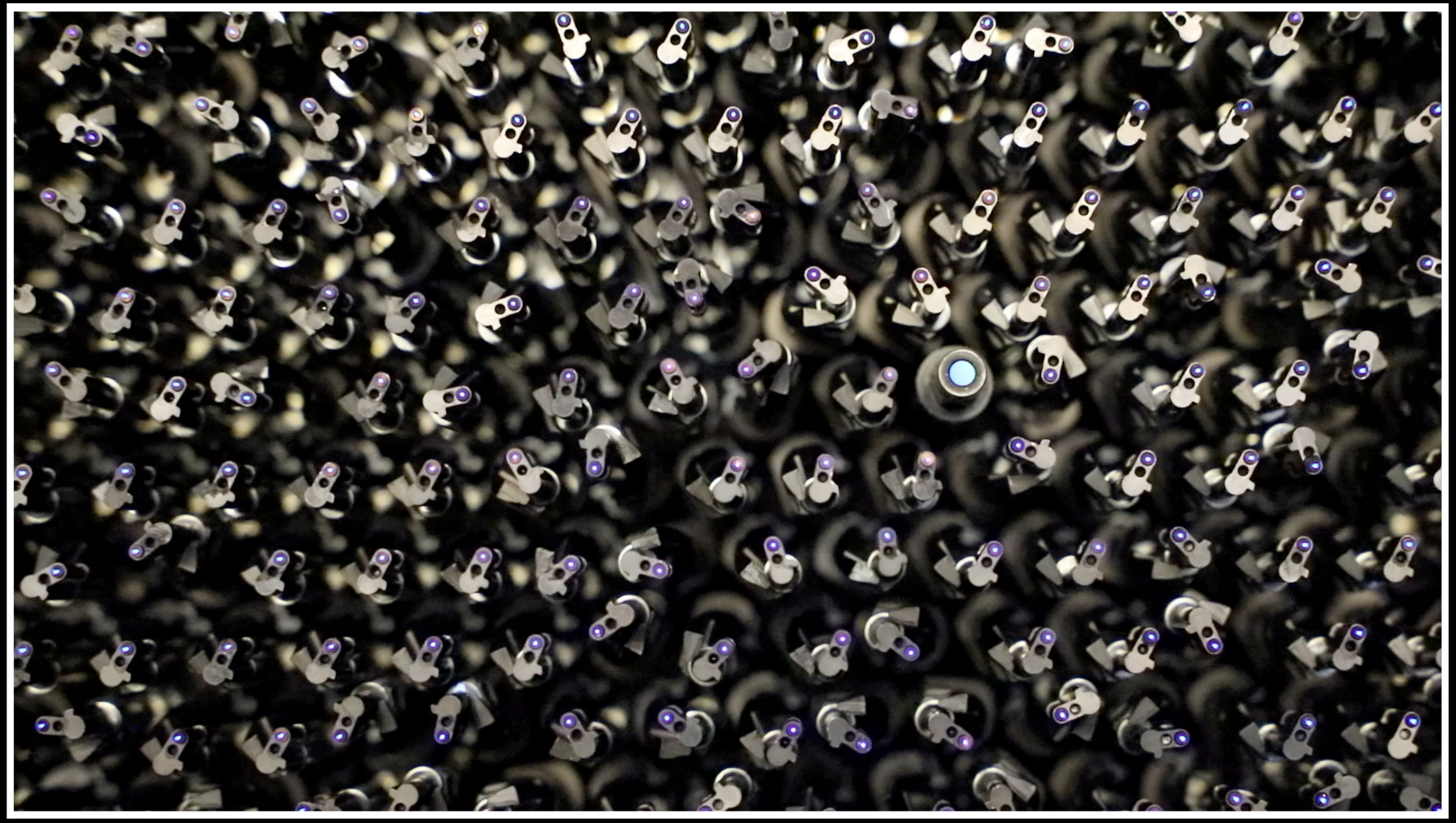
Automated dance of 5000 robotic positioners





University of Michigan undergraduate Clara Mateju doing a stage 1 assembly

Image credit: Curtis Weaverdyck

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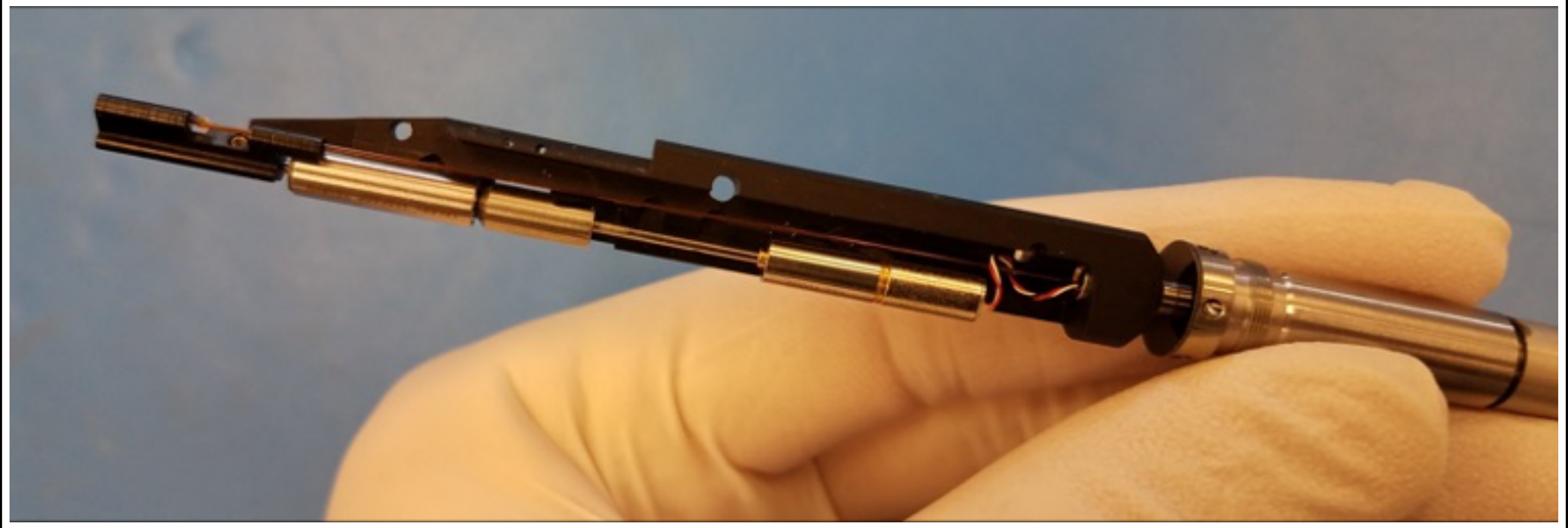

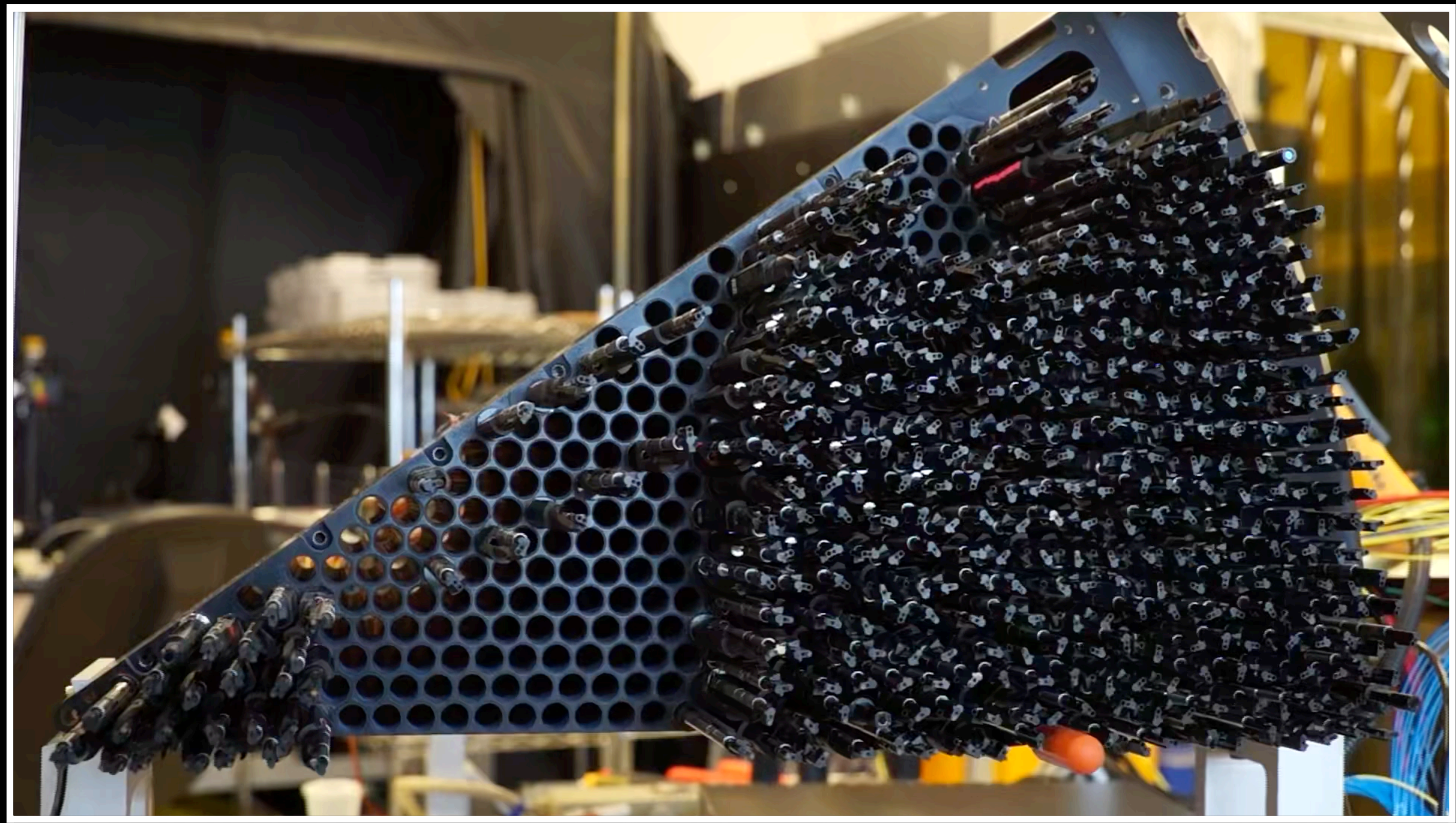

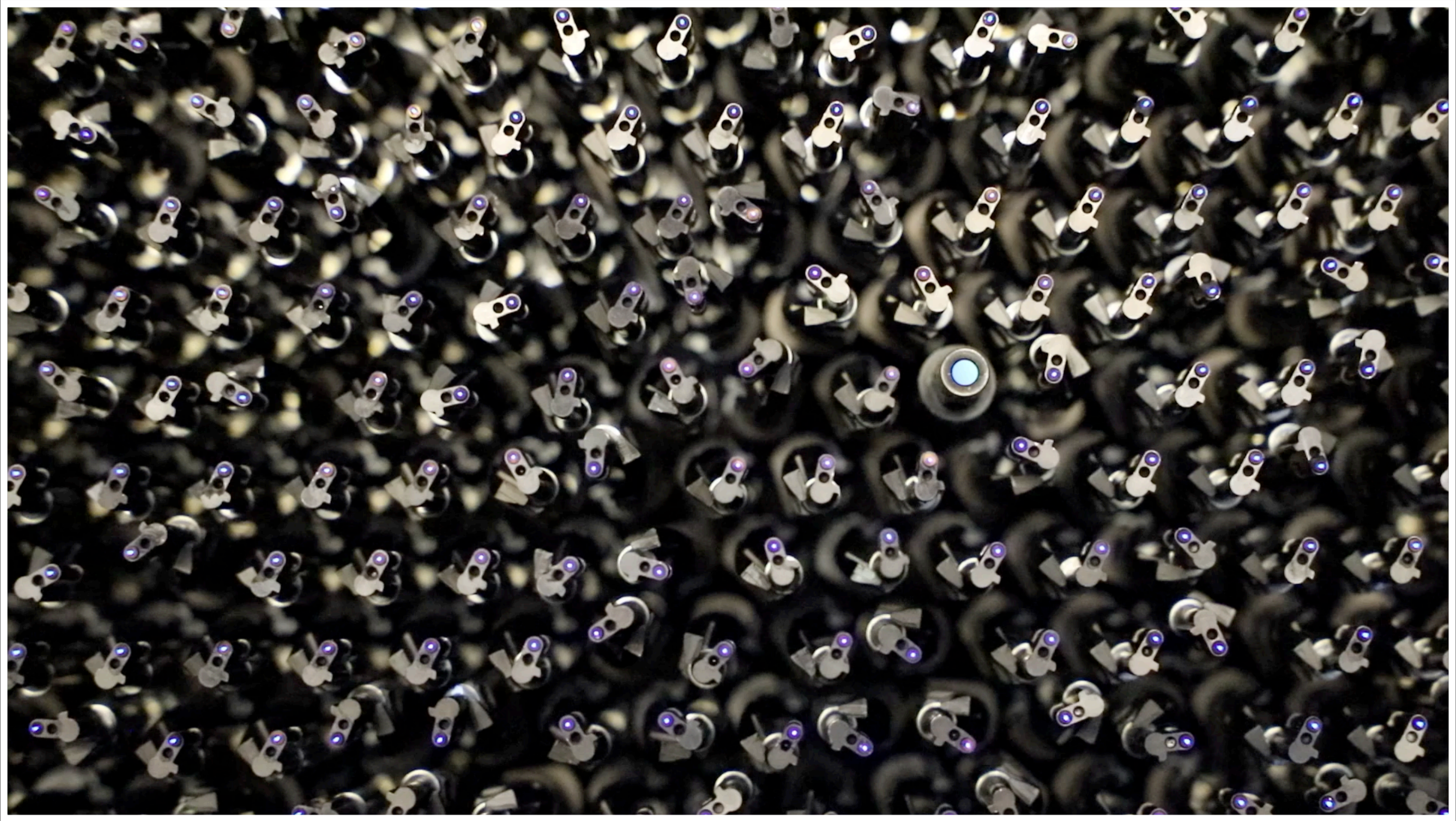

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From DESI DR1 to DR2 sample

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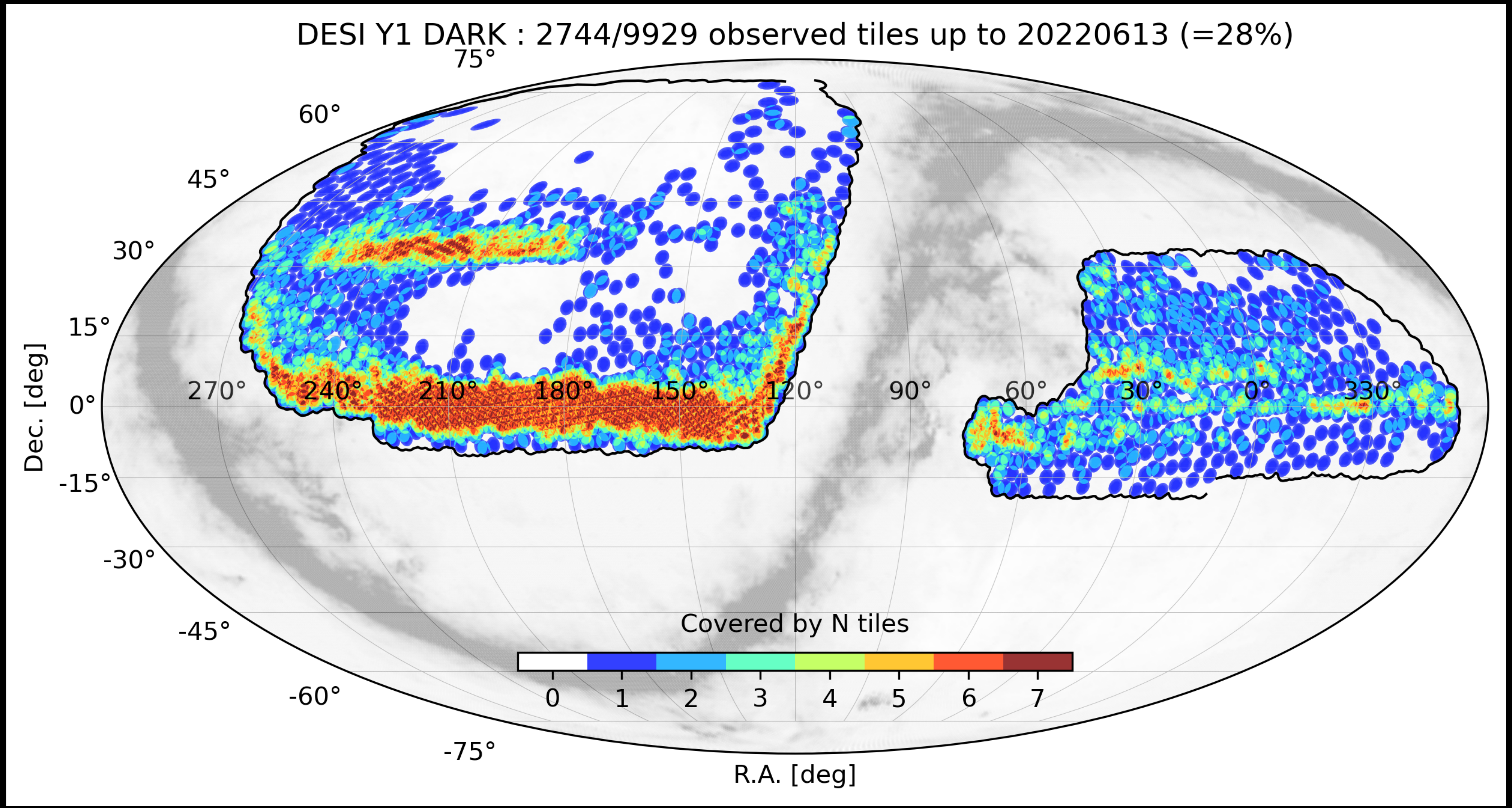
Observations from May 14th 2021 to April 12th 2022



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

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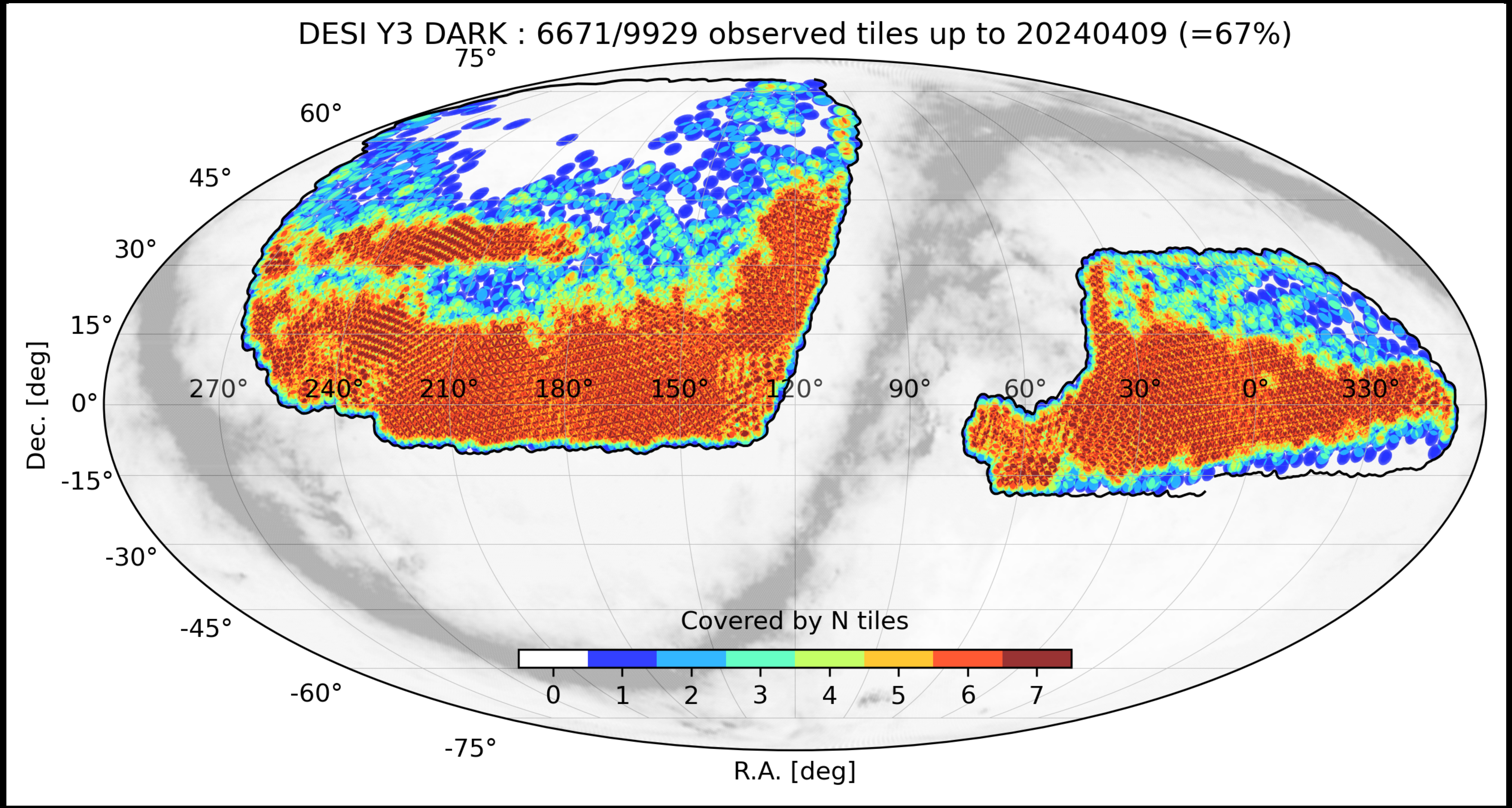

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The DESI DR2 sample

- Over 30M galaxy and quasar redshifts in 3 years of operation, ~14M of which are used in this analysis.
- Compared to DR1 (~6M redshifts), DR2 represents a factor of ~2.4 improvement in data volume.
- Including 820,000 Lyα QSO at $z > 2.09$ (420,000 in DR1)

Tracer	DR1	**DR2**
BGS	300,043	**1,188,526**
LRG	2,138,627	**4,468,483**
ELG	2,432,072	**6,534,844**
QSO	1,223,391	**2,062,839**
Total	6,094,133	**14,254,692**

Release of DESI DR2 (BAO) results

- March 19th 2025

- DESI 2024 I: First-year data release

First batch of DESI DR2 cosmological analyses: https://data.desi.lbl.gov/doc/papers/dr2

- DESI Collaboration *et al.* (2025) DESI DR2 Results I: Baryon Acoustic Oscillations from the Lyman Alpha Forest
- DESI Collaboration *et al.* (2025) DESI DR2 Results II: Measurements of Baryon Acoustic Oscillations and Cosmological Constraints

Companion supporting papers:

- Andrade et al. (2025), Validation of the DESI DR2 BAO measurements
- Lodha et al. (2025), Extended Dark Energy analysis
- Elbers et al. (2025), Constraints on Neutrino Physics
- Casas et al. (2025), Validation of the DESI DR2 Lyα BAO analysis using synthetic datasets
- Brodzeller et al. (2025), Construction of the Damped Lyα Absorber Catalog for DESI DR2 Lyα BAO

Clustering analysis in a nutshell

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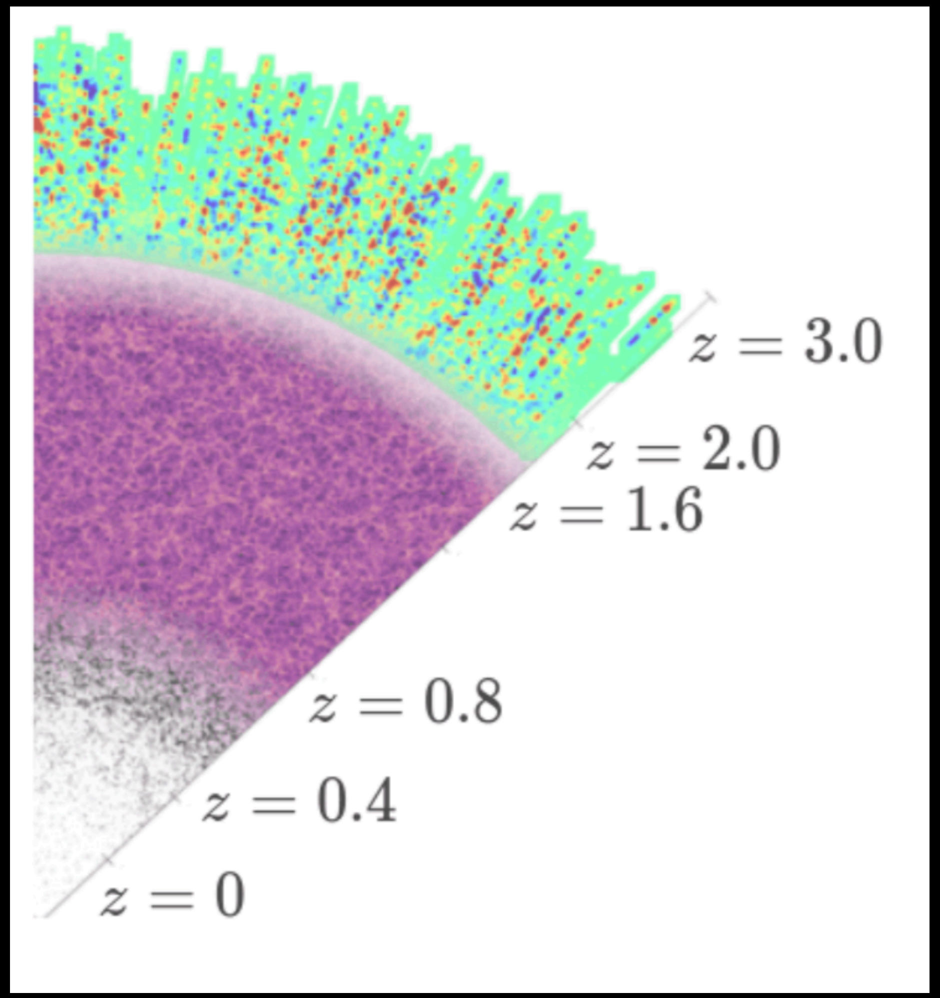

galaxy catalog

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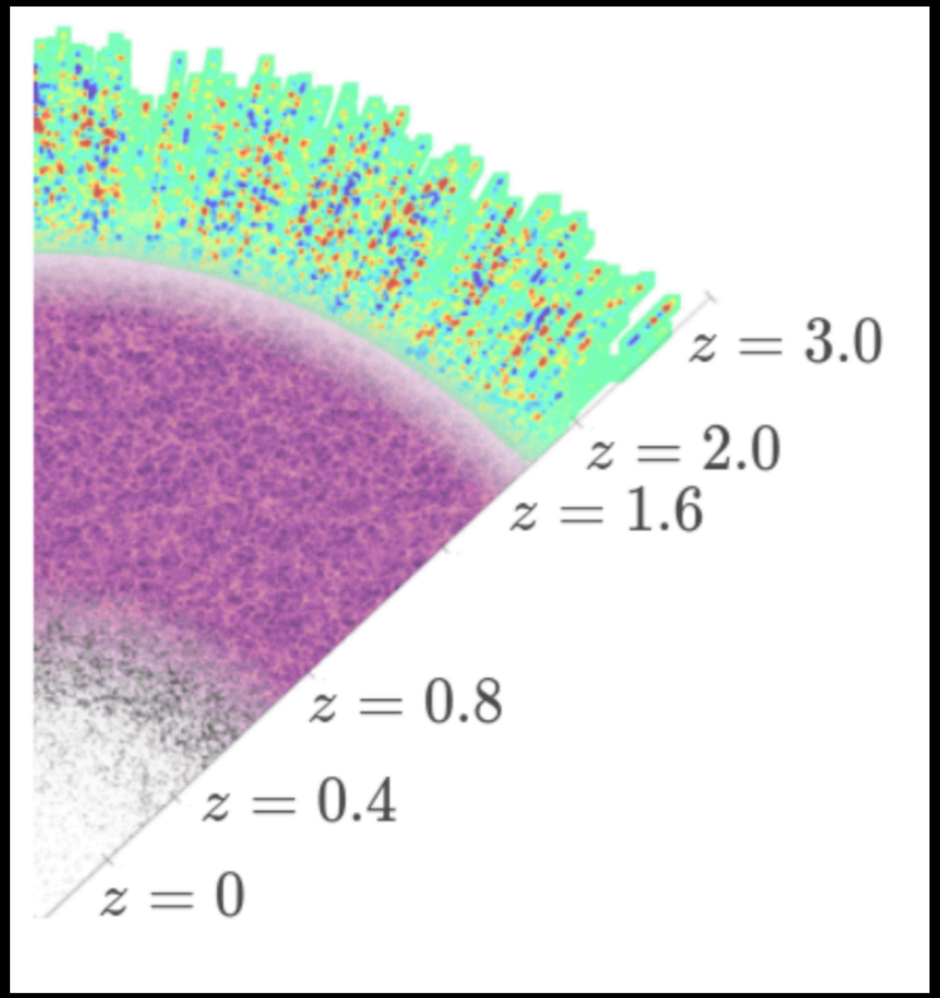

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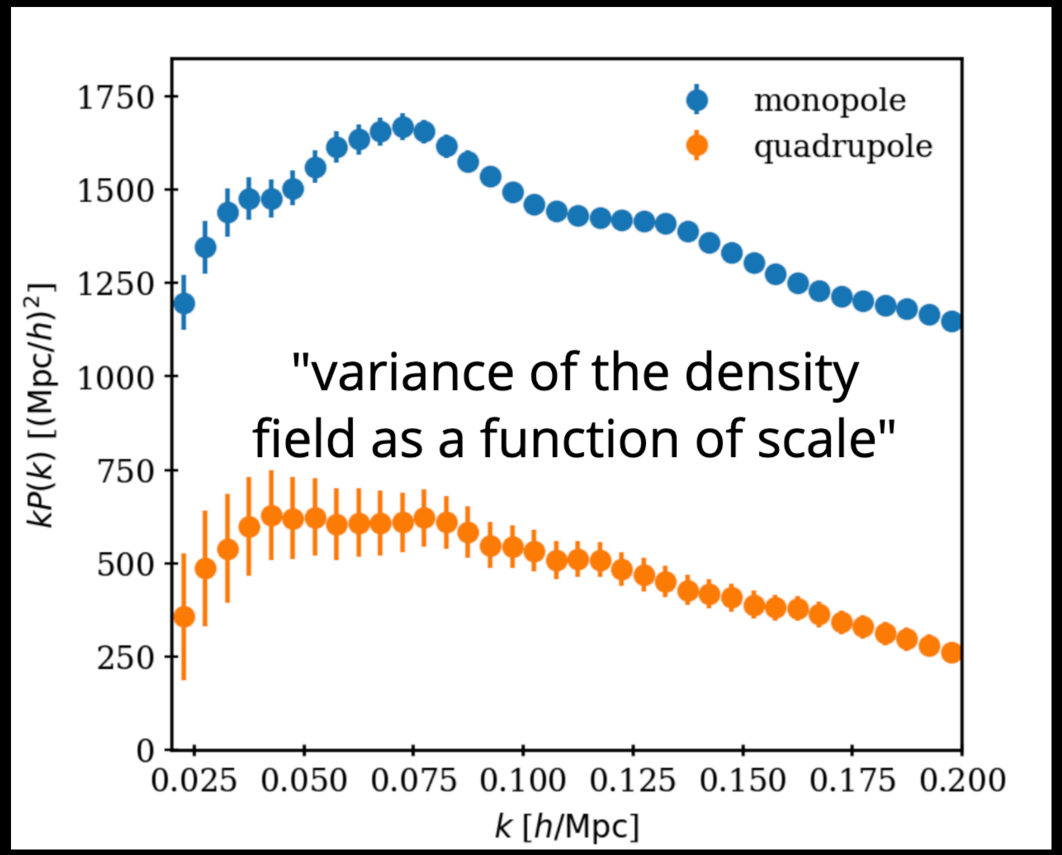

galaxy power spectrum
(or correlation function)

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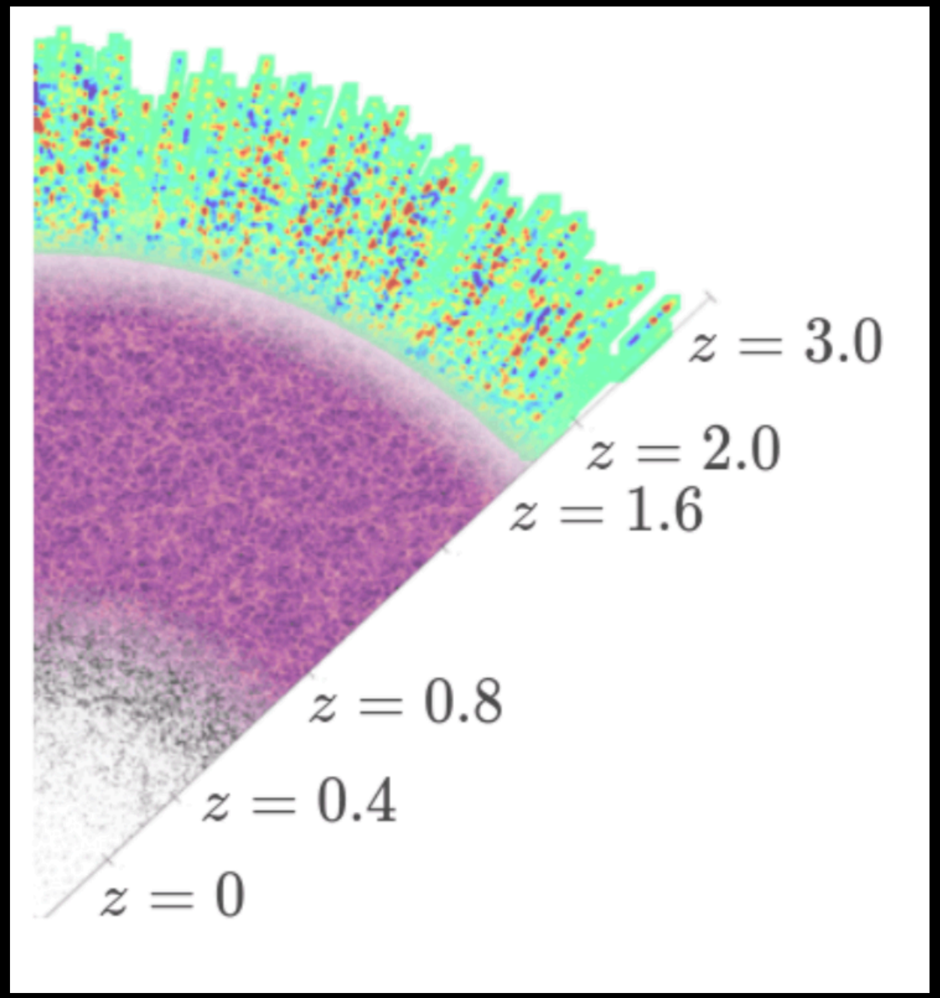

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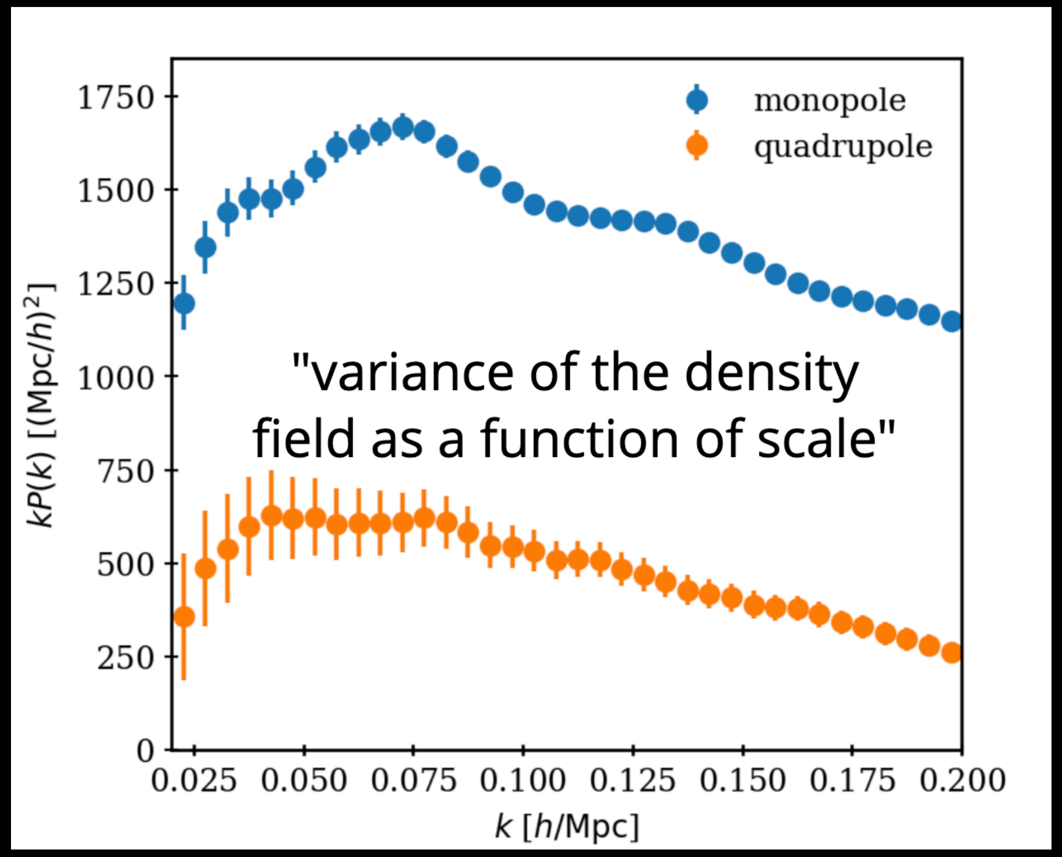
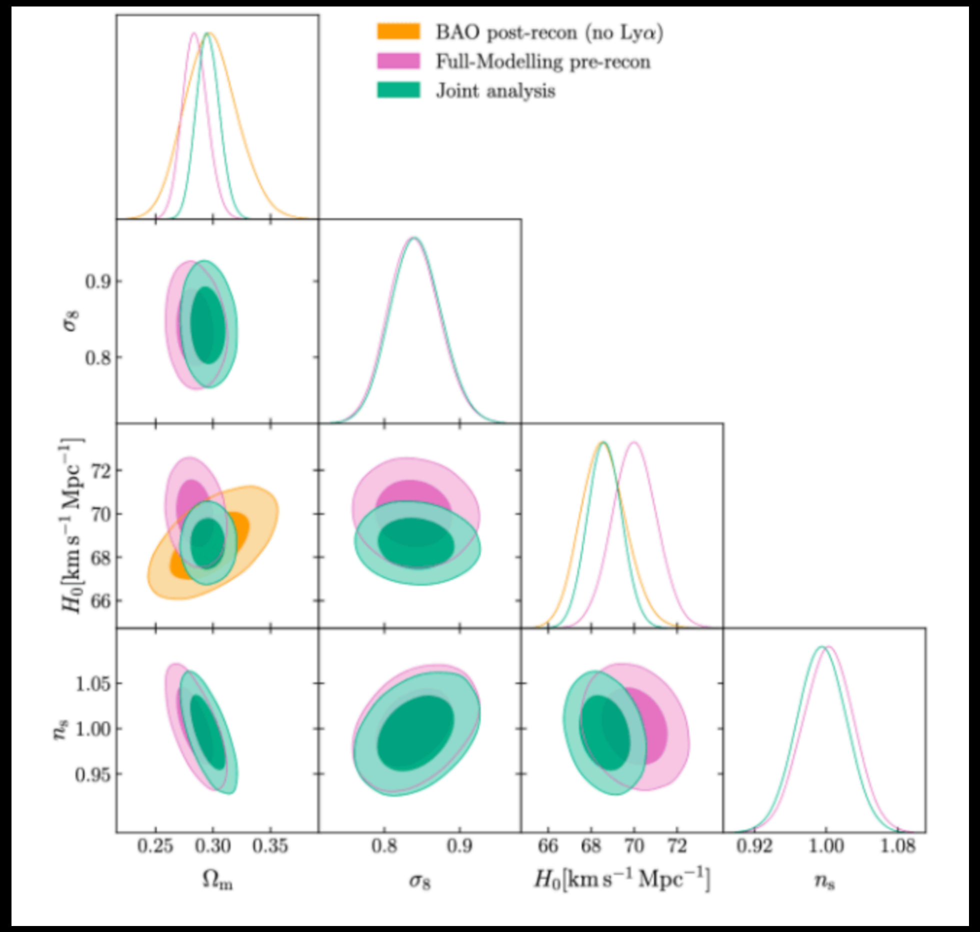


galaxy power spectrum
(or correlation function)

Full Shape
(baseline)



cosmological constraints

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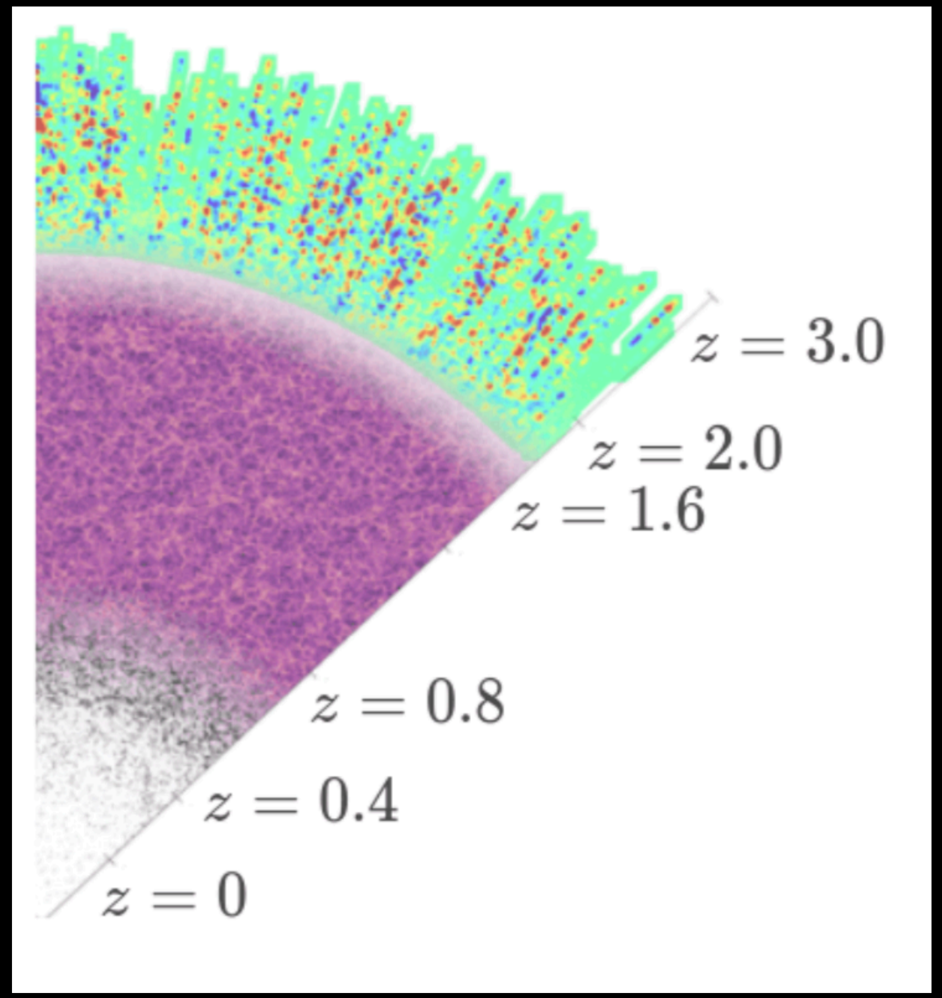

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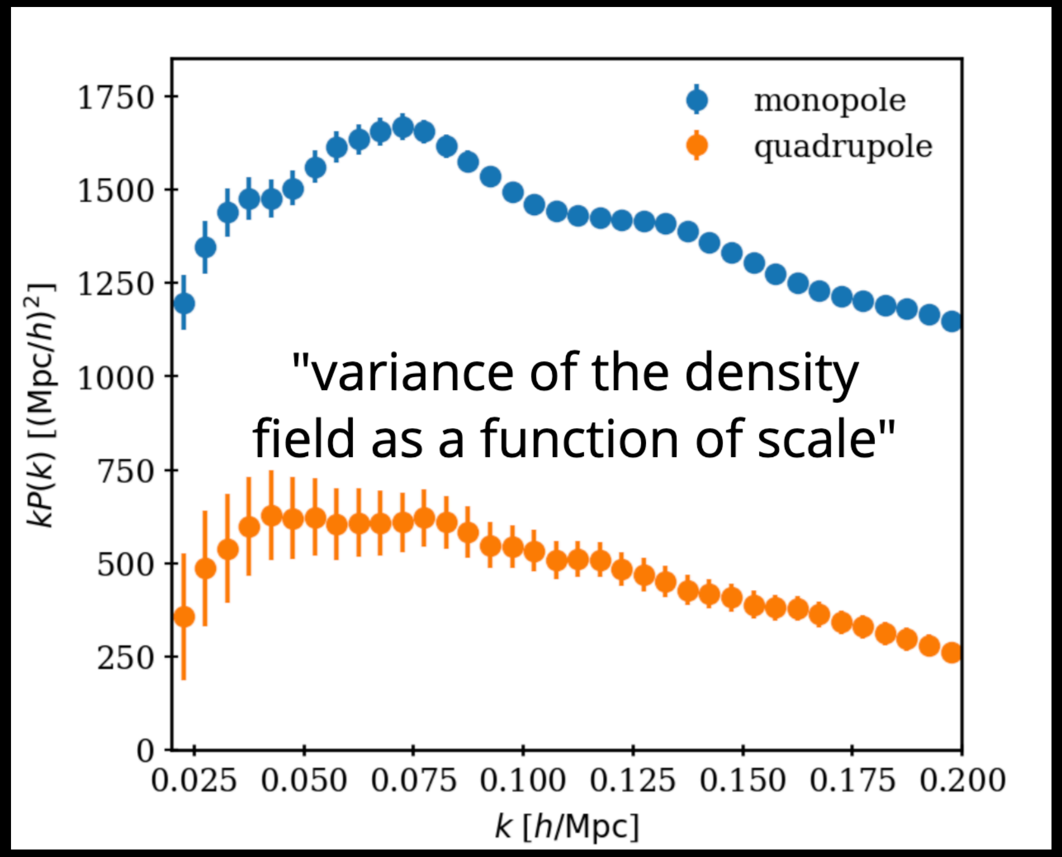

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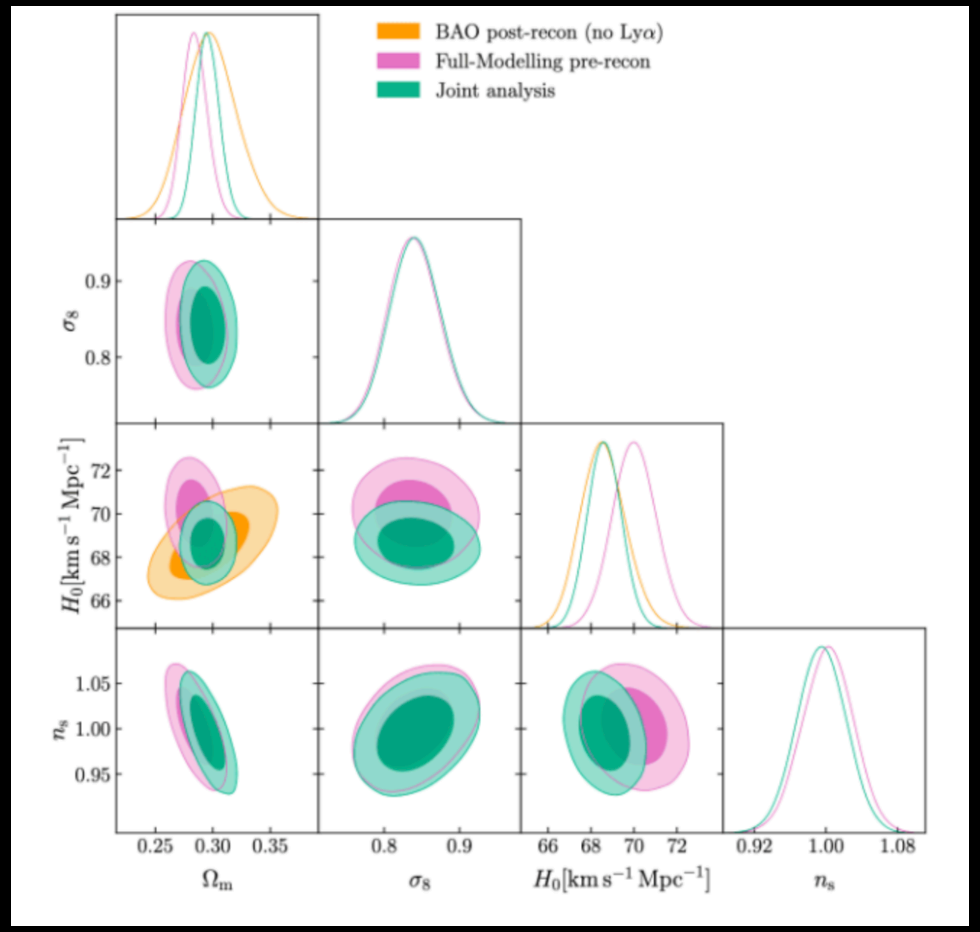

cosmological constraints

compression = "we measure specific features"

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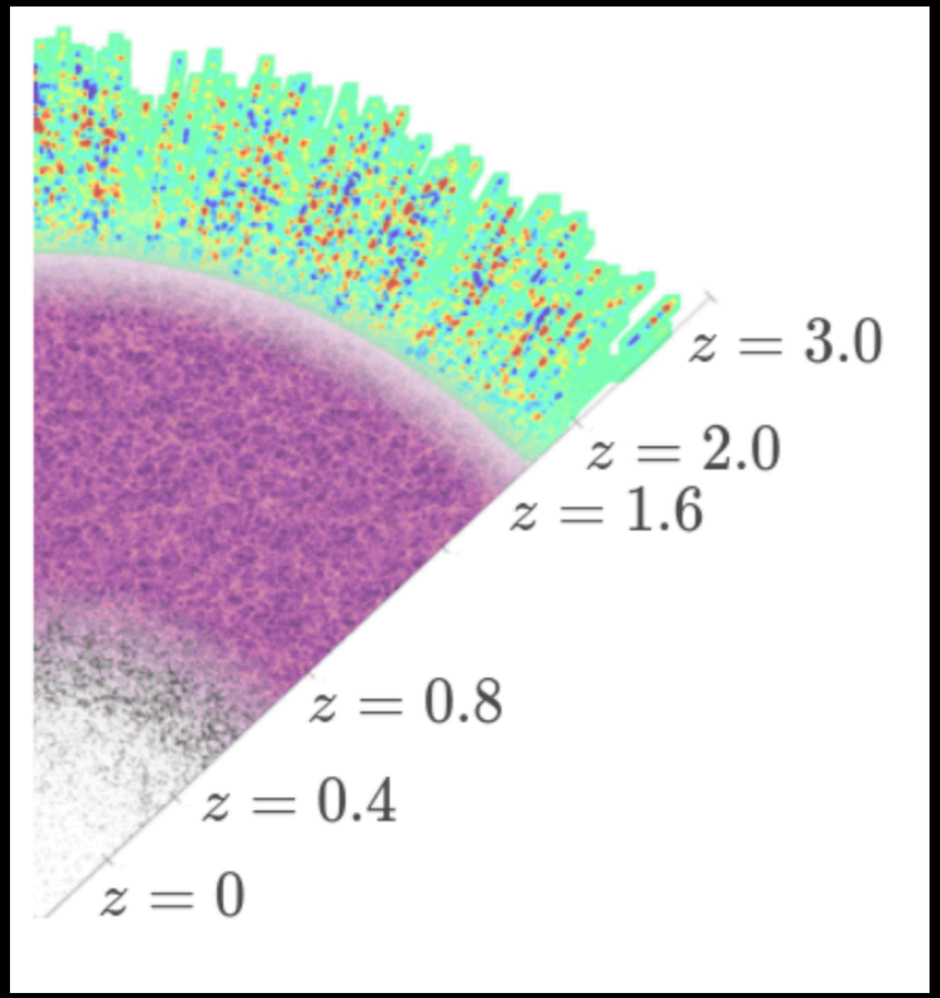

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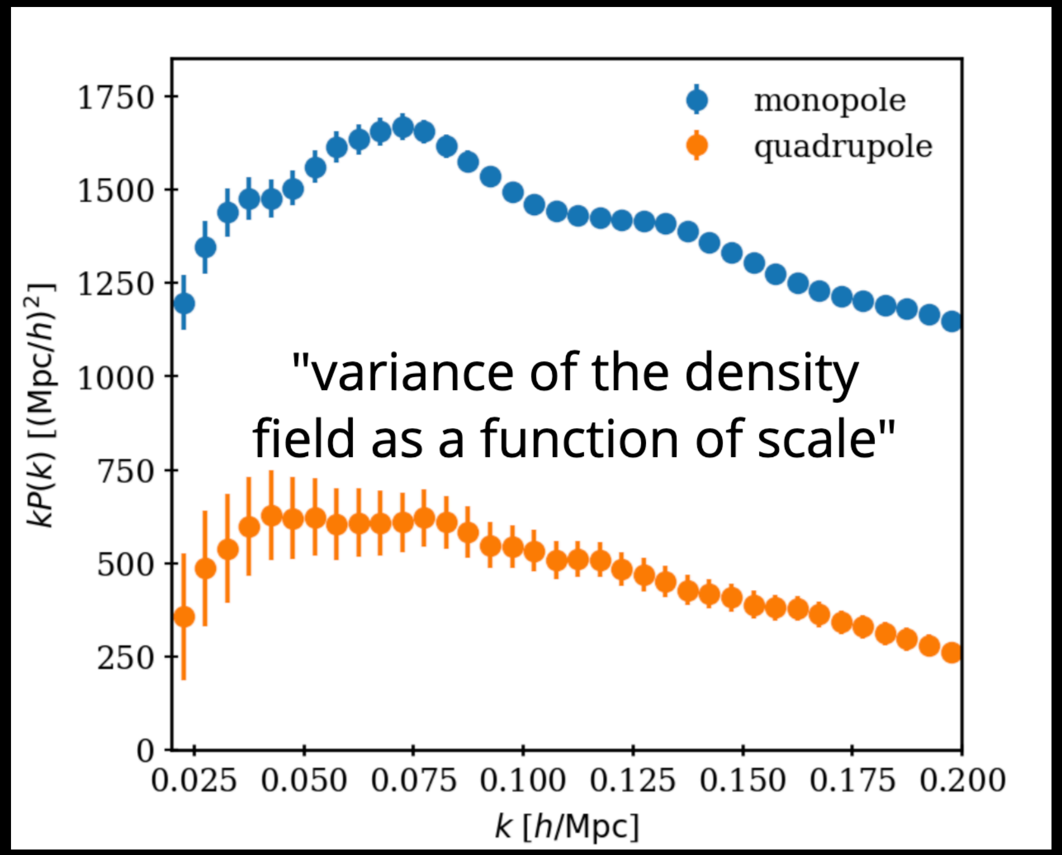

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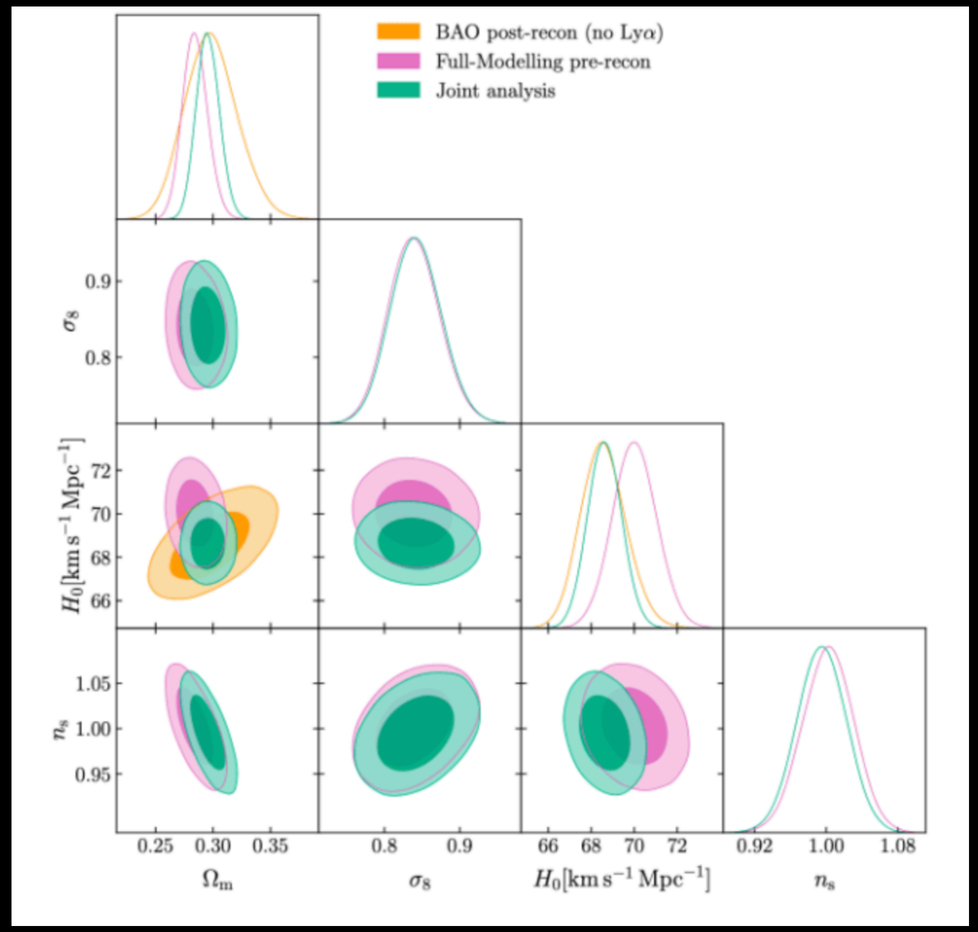


cosmological constraints

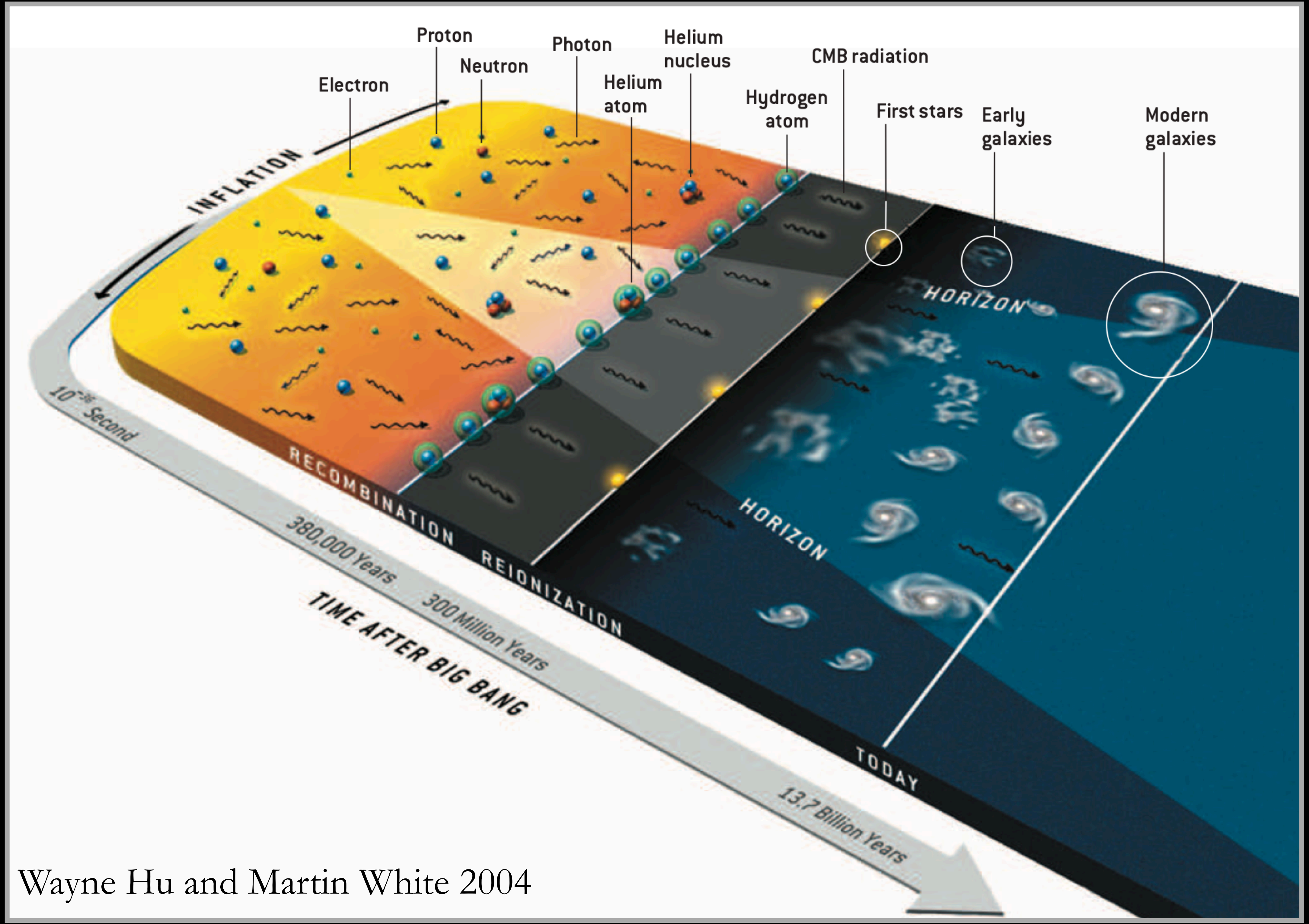
BAO

ShapeFit (alternative Full Shape)

compression = "we measure specific features"

Baryon Acoustic Oscillations (BAO)

- Gravity and pressure generated sound waves in the primordial plasma
- When baryons and photons decoupled, the sound waves stopped



Wayne Hu and Martin White 2004

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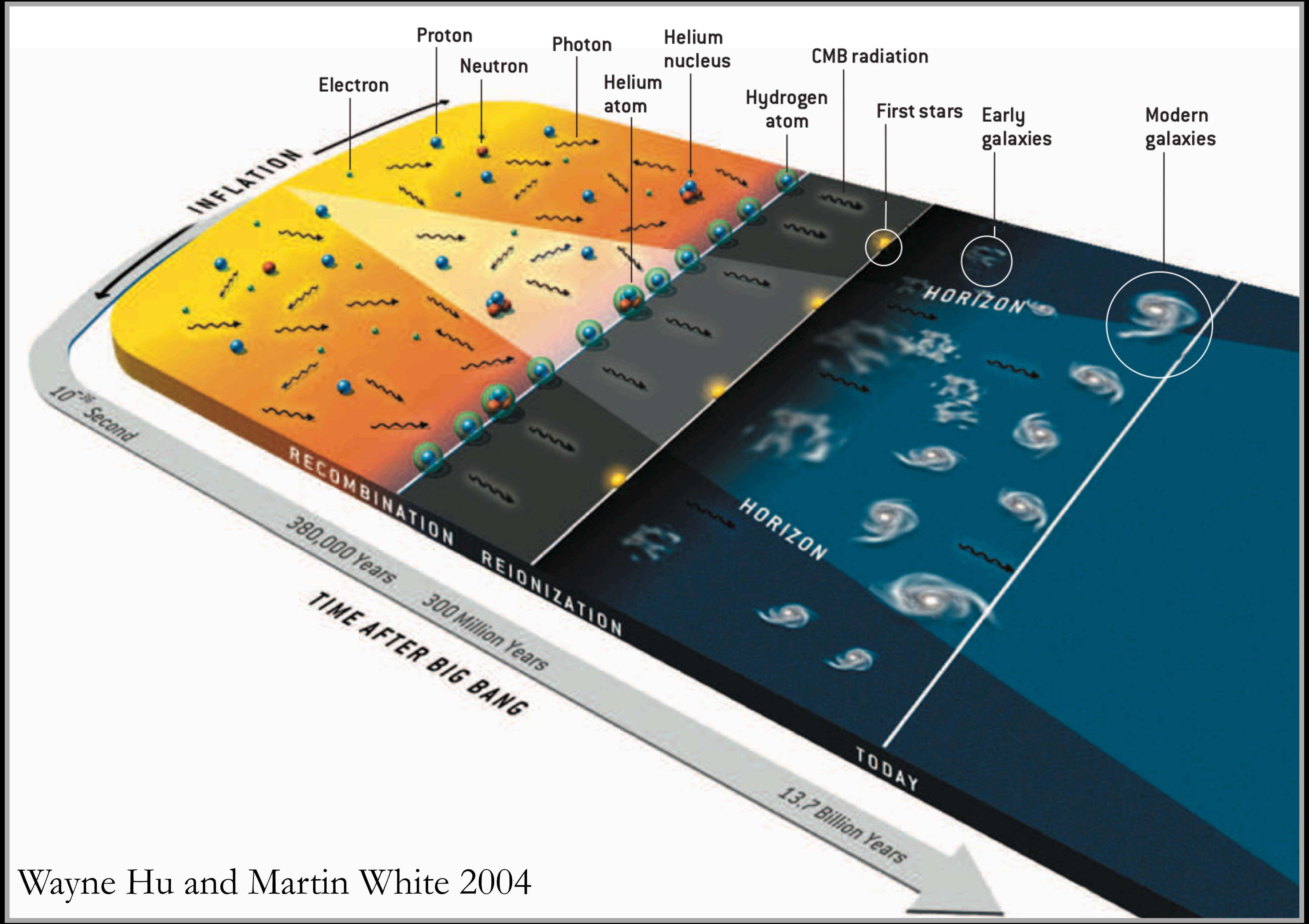

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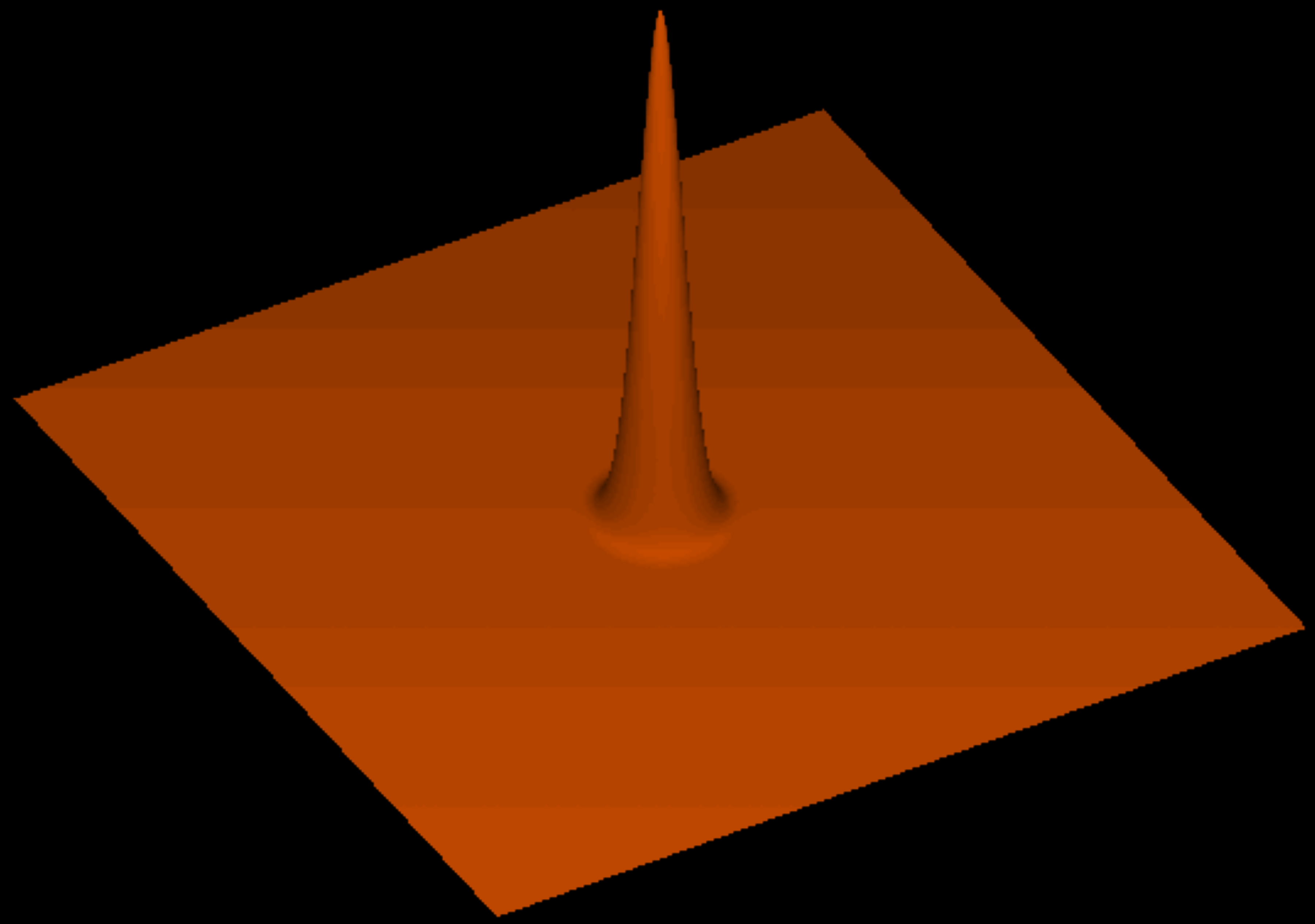

Credit: Daniel Eisentein


CAASTRO
ALL-SKY ASTROPHYSICS


CAASTRO
ALL-SKY ASTROPHYSICS

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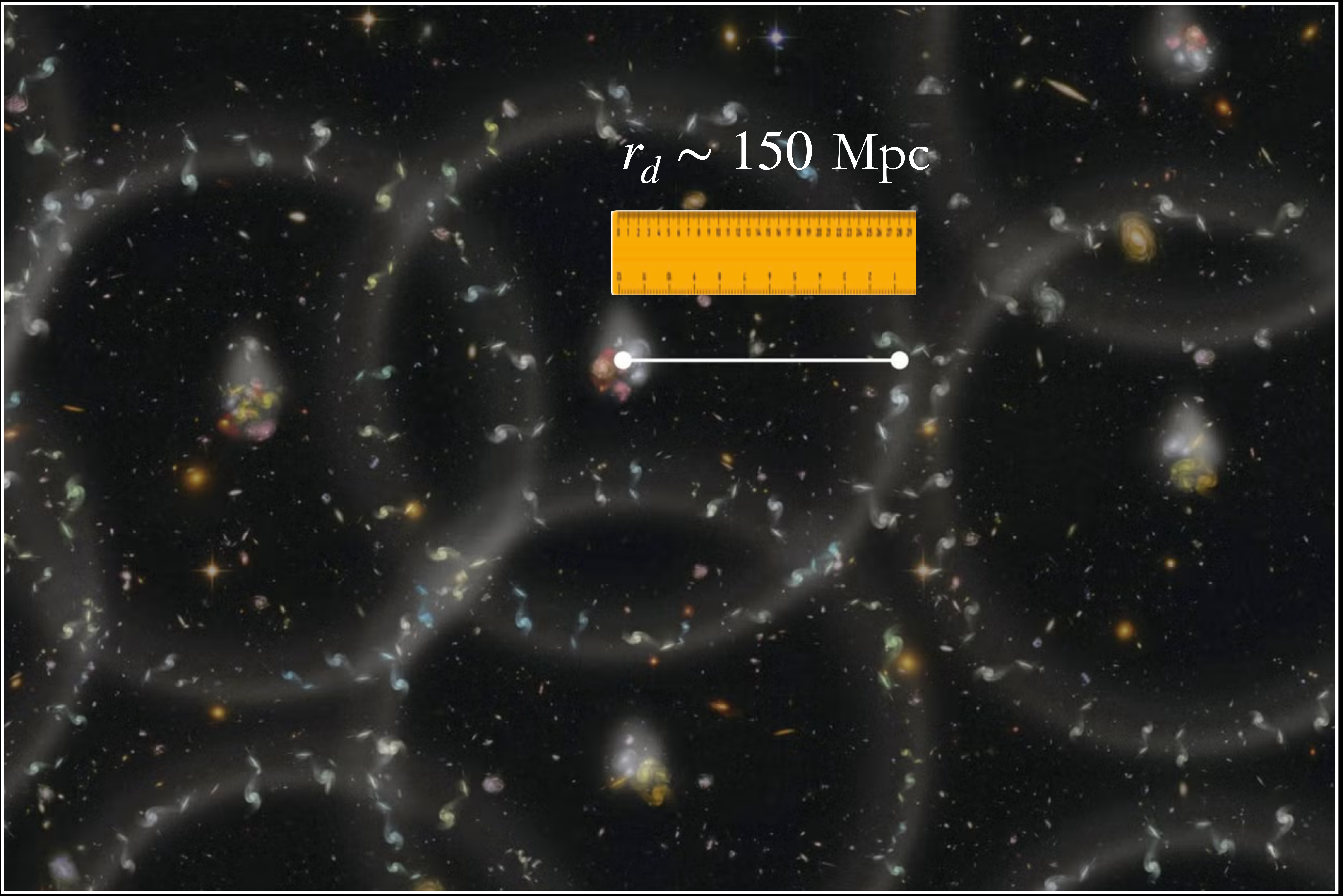

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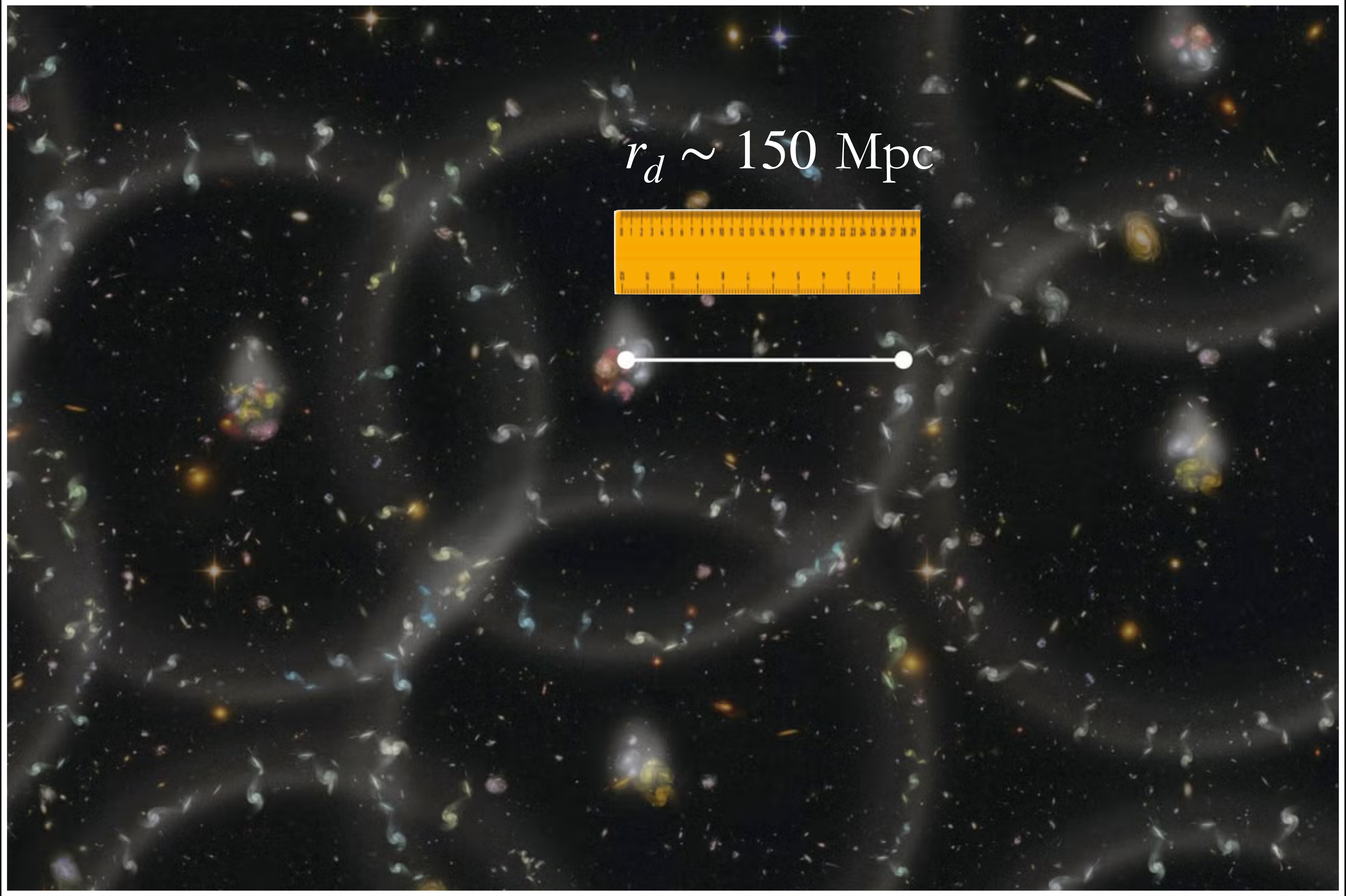

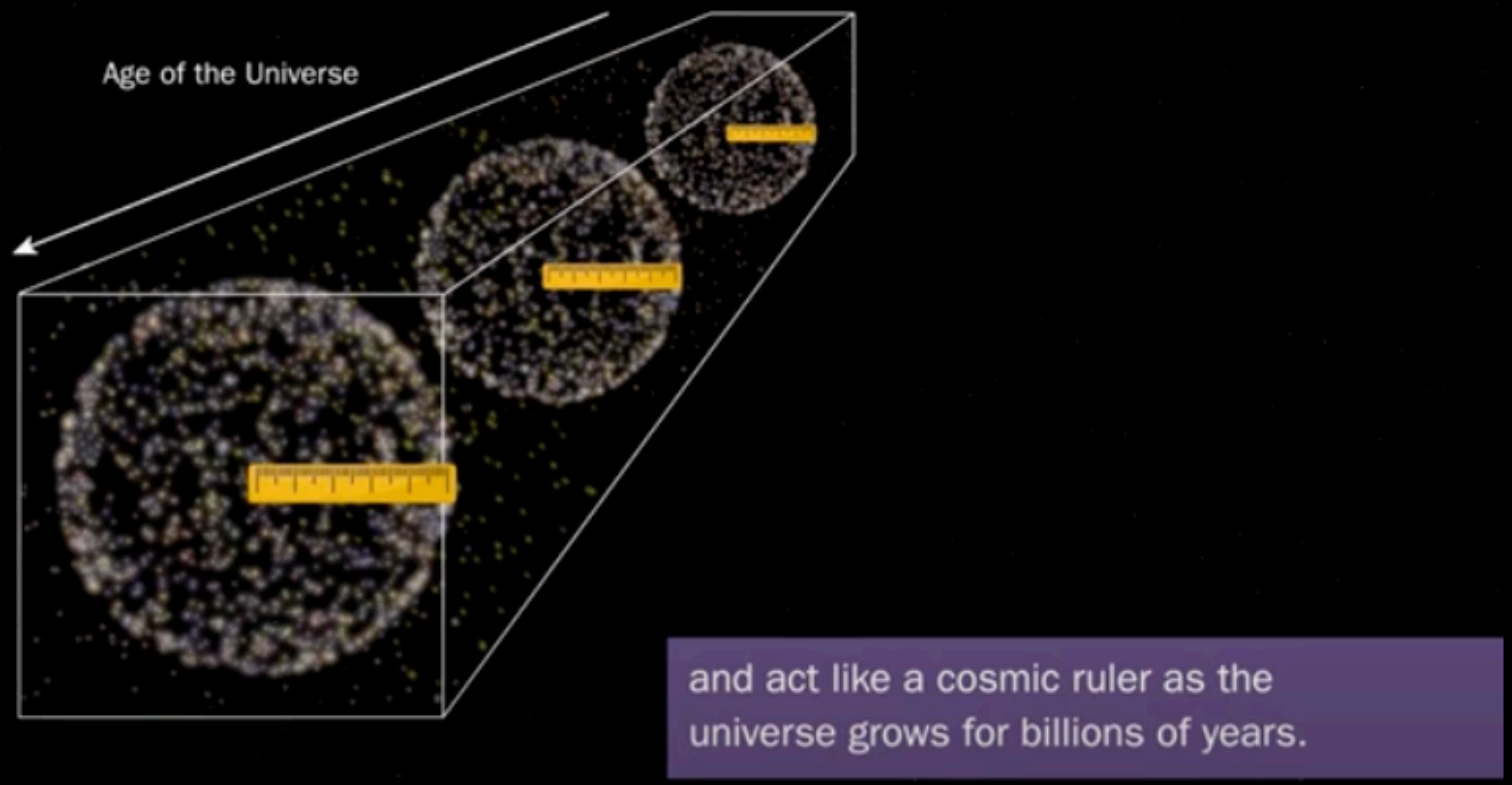

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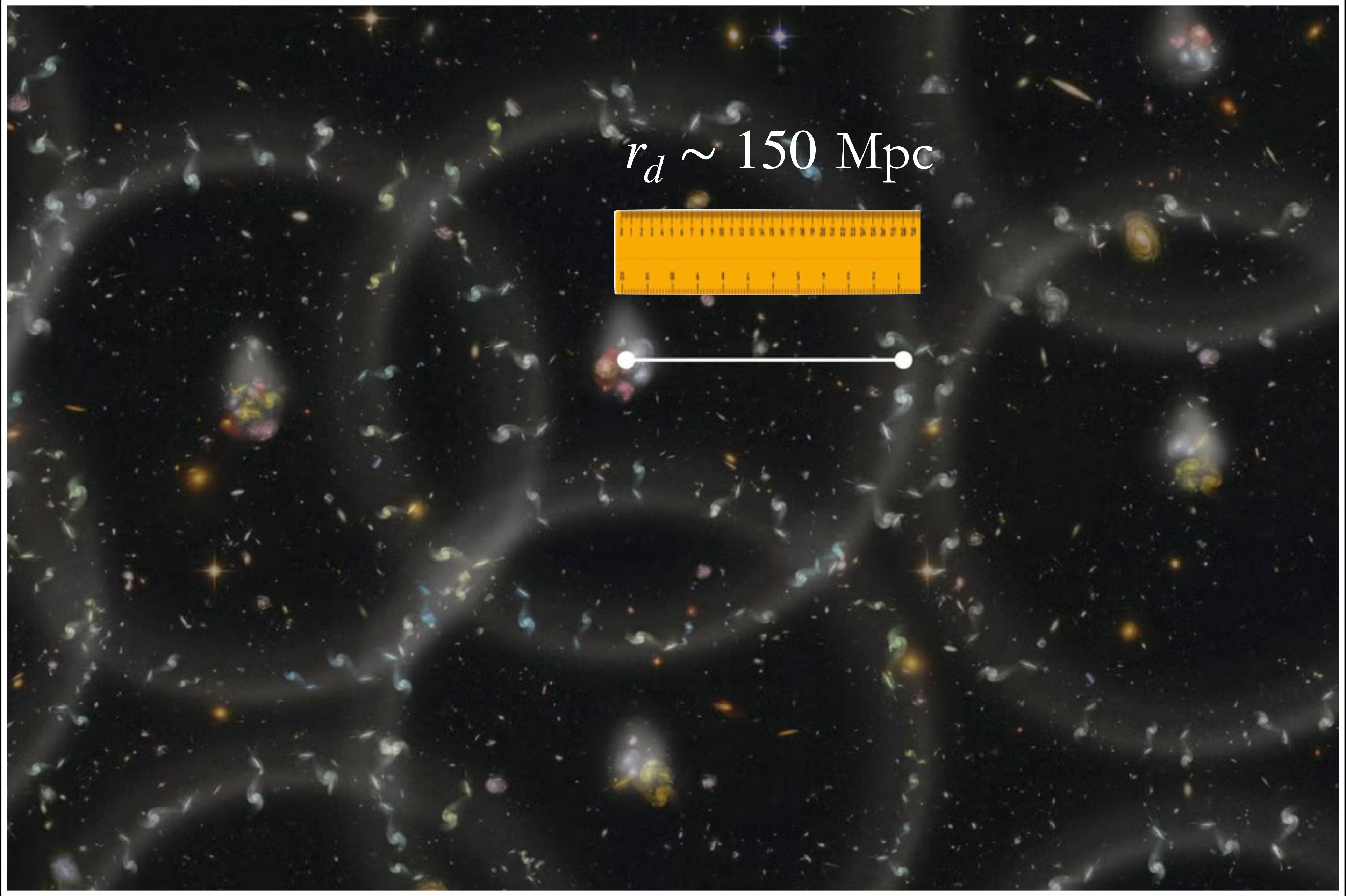

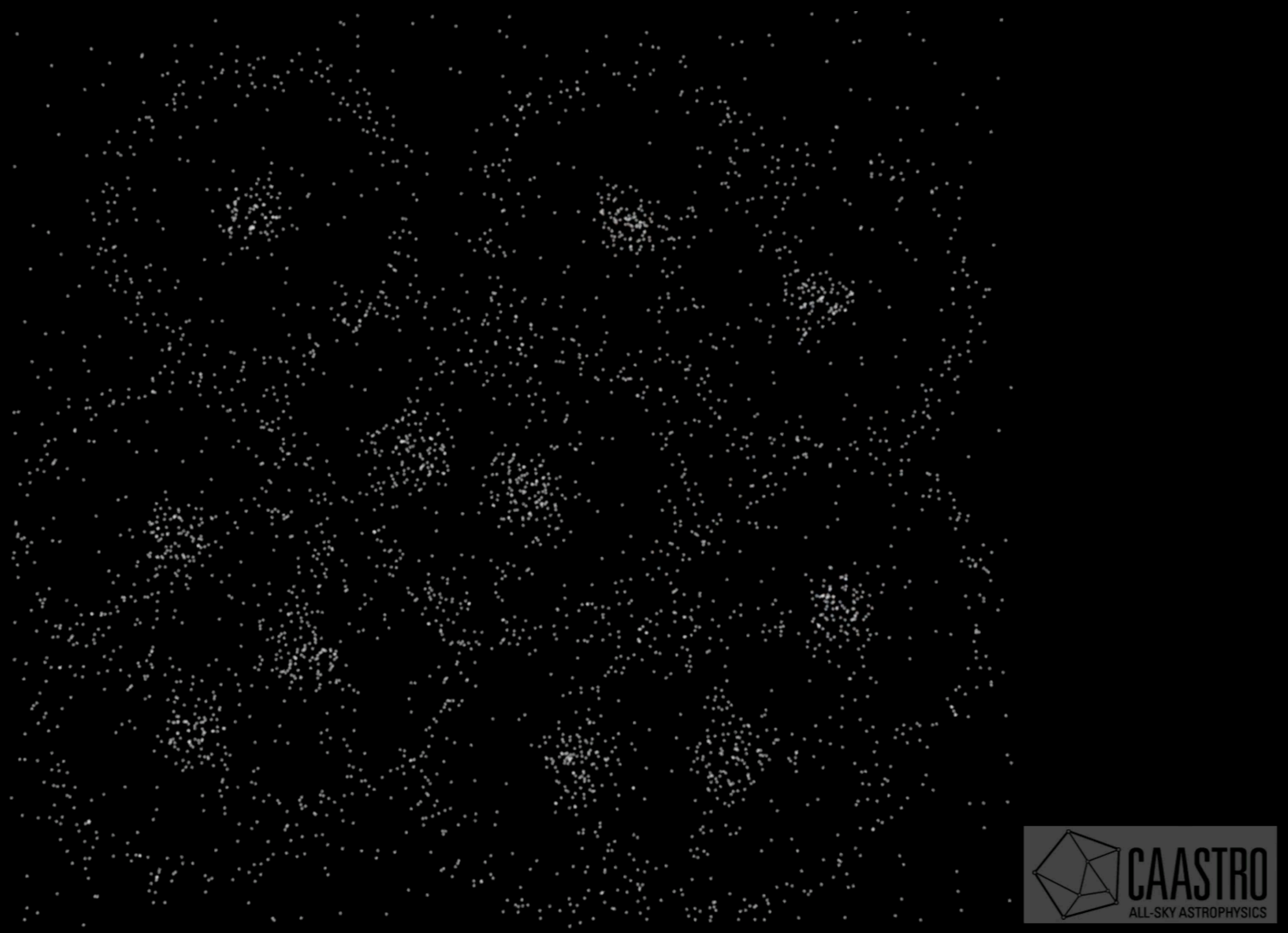

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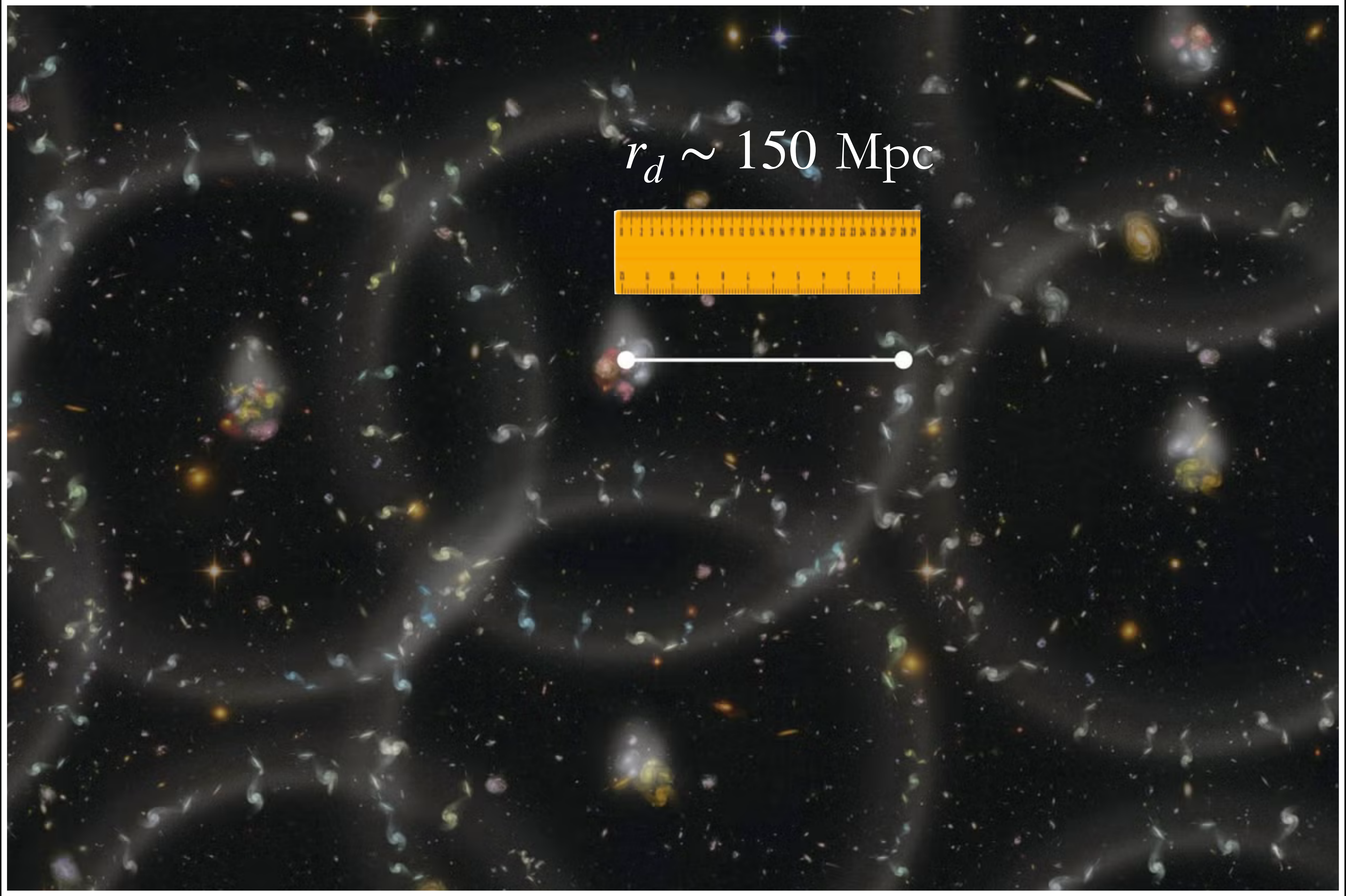

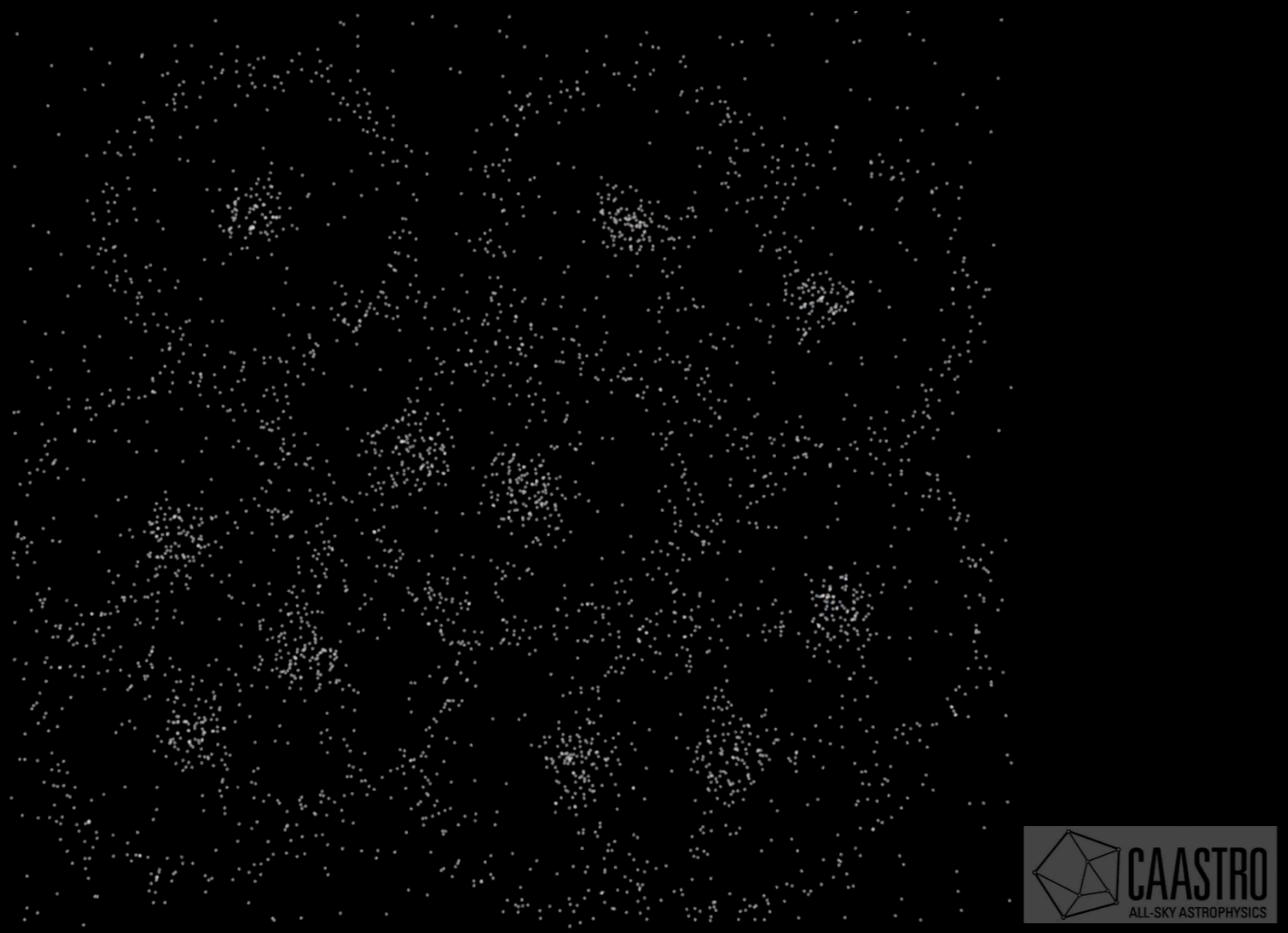

BAO in the matter power spectrum

- BAO is left as an imprint both in the distribution of photons (CMB), but also in the matter distribution

- What ***complicates*** extracting this signal from the matter power spectrum?

    1. Galaxies are biased tracers

    2. Peculiar velocities

    3. Have to assume a fiducial cosmology

    4. Nonlinear gravitational growth

BAO in the matter power spectrum

Putting all together

$$P_\ell(k) = \frac{2\ell+1}{2}\int_{-1}^{1} \underbrace{\left[b + f\mu^2\right]^2}_{\text{Bias \& Kaiser RSD}} \times \Bigg[\underbrace{F_{\rm FoG}(k,\mu) \times P_{\rm nw}(k)}_{\substack{\text{Small-scale damping on}\\ \text{broadband (FoG)}}} + \underbrace{e^{-k^2\Sigma^2_{\rm nl}(\mu)} \times P_{\rm w}(k)}_{\substack{\text{Nonlinear BAO damping}\\ \text{(bulk flows, nonlinear growth)}}} \Bigg] \times \mathcal{L}_\ell(\mu)\, d\mu$$

Where:

- b : Linear bias — how galaxies trace the underlying matter.
- $f\mu^2$: Redshift-space distortions (Kaiser effect), anisotropic squashing along LOS.
- $P_{\rm nw}(k)$: Smooth broadband (no-wiggle) power spectrum.
- $P_{\rm w}(k)$: Oscillatory BAO wiggles.
- $F_{\rm FoG}(k,\mu) = \dfrac{1}{1+\frac{1}{2}k^2\mu^2\Sigma_s^2}$: Small-scale damping from random motions (virial velocities).
- $e^{-k^2\Sigma^2_{\rm nl}(\mu)}$: Nonlinear BAO damping from bulk flows + nonlinear growth.
- $\Sigma^2_{\rm nl}(\mu) = \Sigma^2_\perp + \mu^2\left(\Sigma^2_\parallel - \Sigma^2_\perp\right)$: Anisotropic damping.
- $\mathcal{L}_\ell(\mu)$: Legendre polynomial for multipole ℓ.

Other effects applied before multipoles:

- **AP distortion:** $k_\parallel^{\rm obs} = \alpha_\parallel k_\parallel$ and $k_\perp^{\rm obs} = \alpha_\perp k_\perp$.
- **BAO template cosmology:** Peak position shifts if assumed r_d differs from true r_d.
- **Broadband marginalization:** Polynomial terms or nonlinear models (e.g., Halofit) may absorb broadband mismatches.

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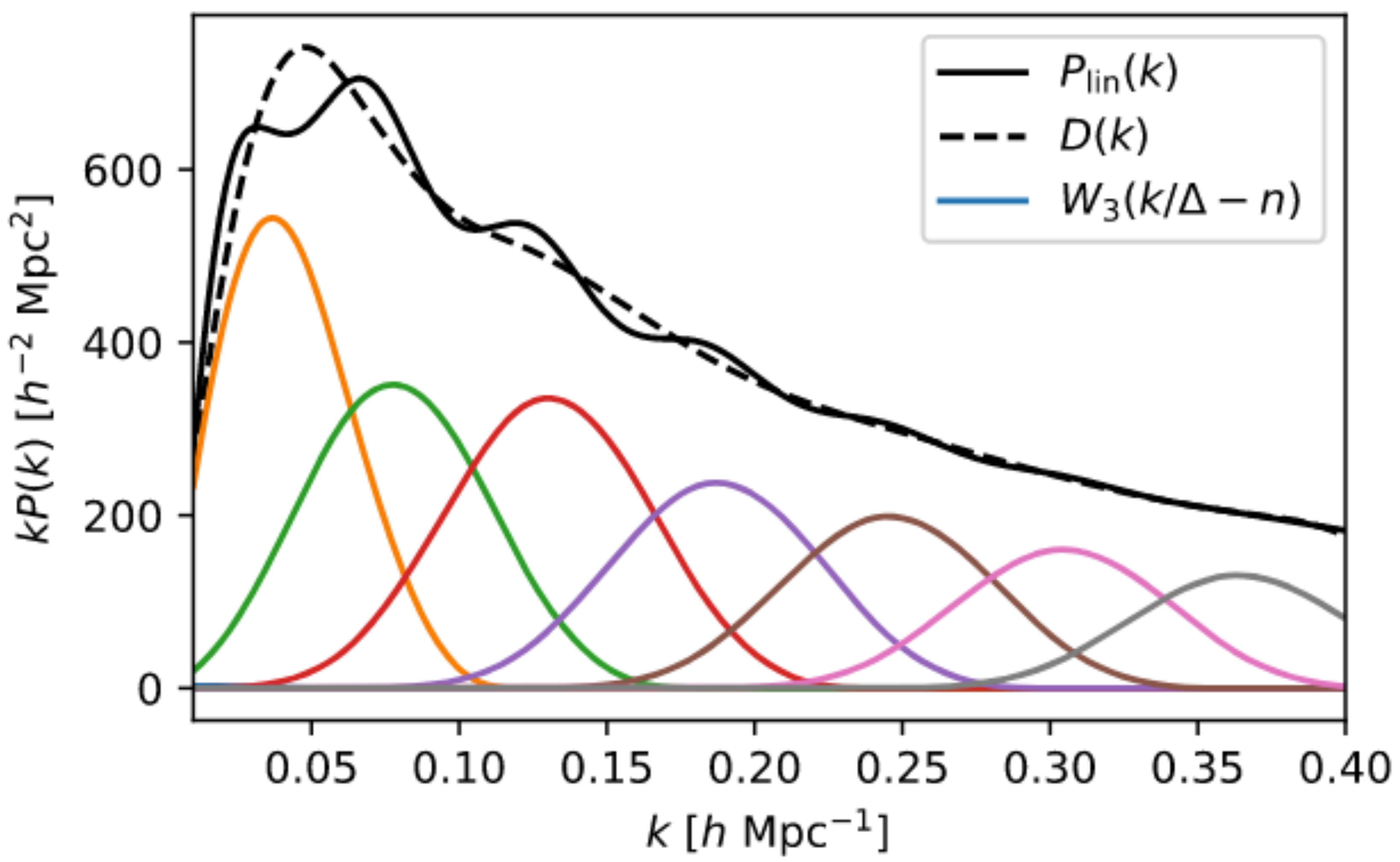
$$P_{\mathrm{g}}(k,\mu) = \mathscr{B}(k,\mu)P_{\mathrm{nw}}(k) + \mathscr{C}(k,\mu)P_{\mathrm{w}}(k) + \mathscr{D}(k)$$



Chen, Howlett et al. 2024

Broadband modeling:

- D(k) splines: local flexibility, robust to systematics, preserves BAO.

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Takeaway:
- BAO is robust and theoretically well understood
- regarded as a low-systematics method for constraining cosmology

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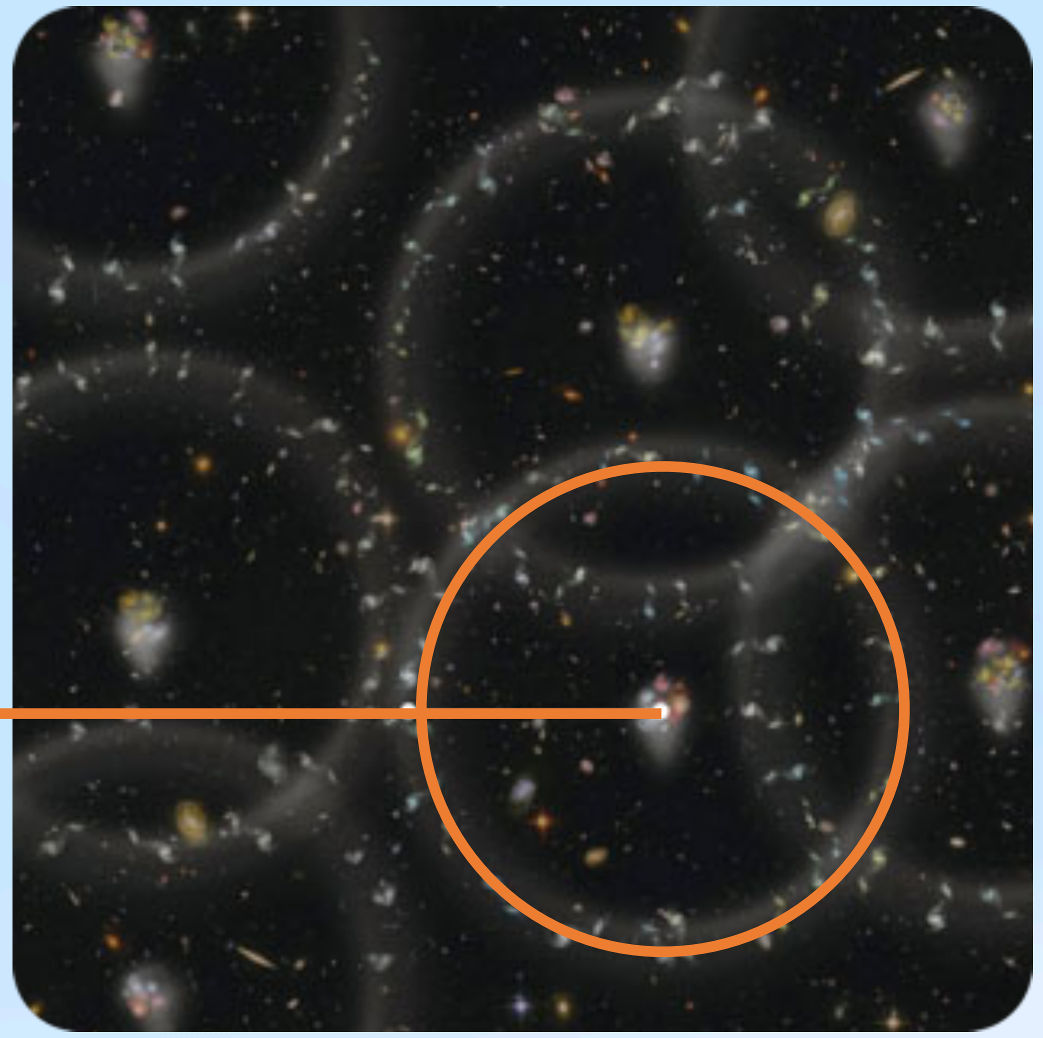
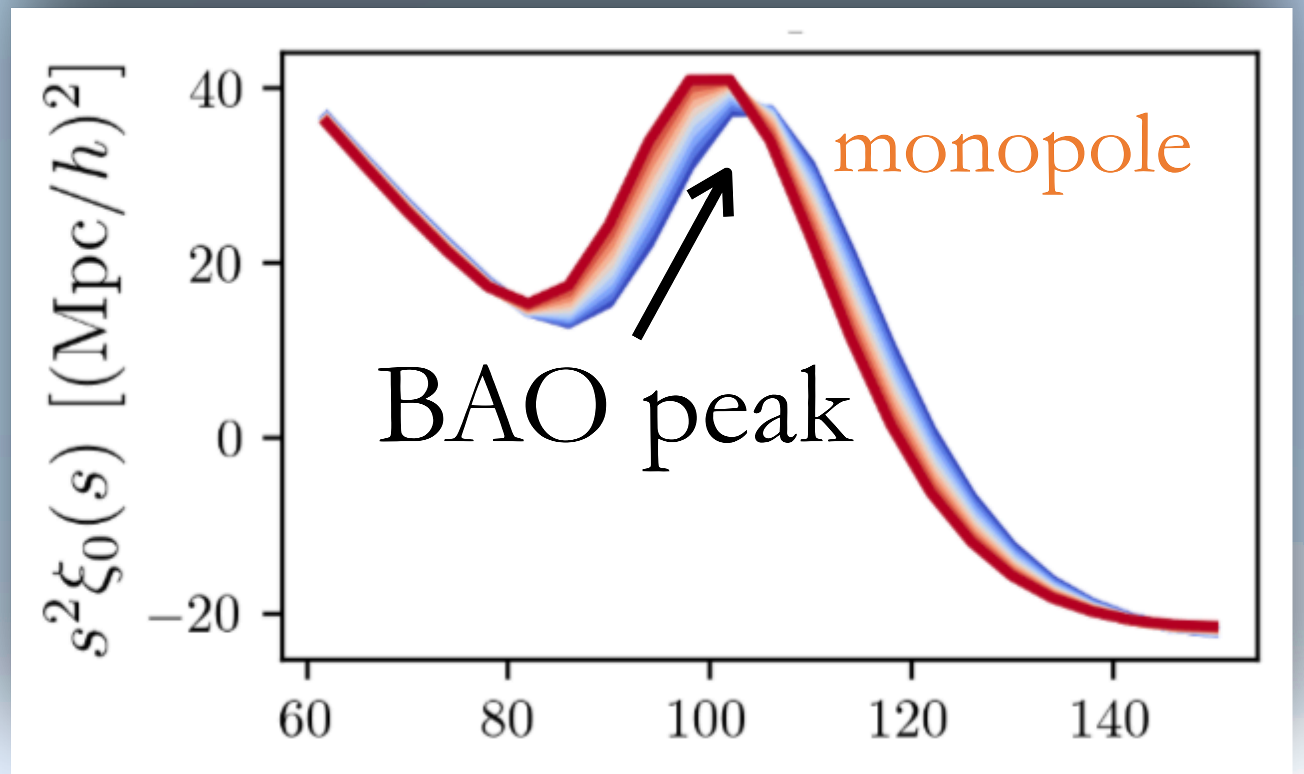
- **Broadband marginalization:** Polynomial terms or nonlinear models (e.g., Halofit) may absorb broadband mismatches.

What DESI BAO measures



correlation function



What DESI BAO measures

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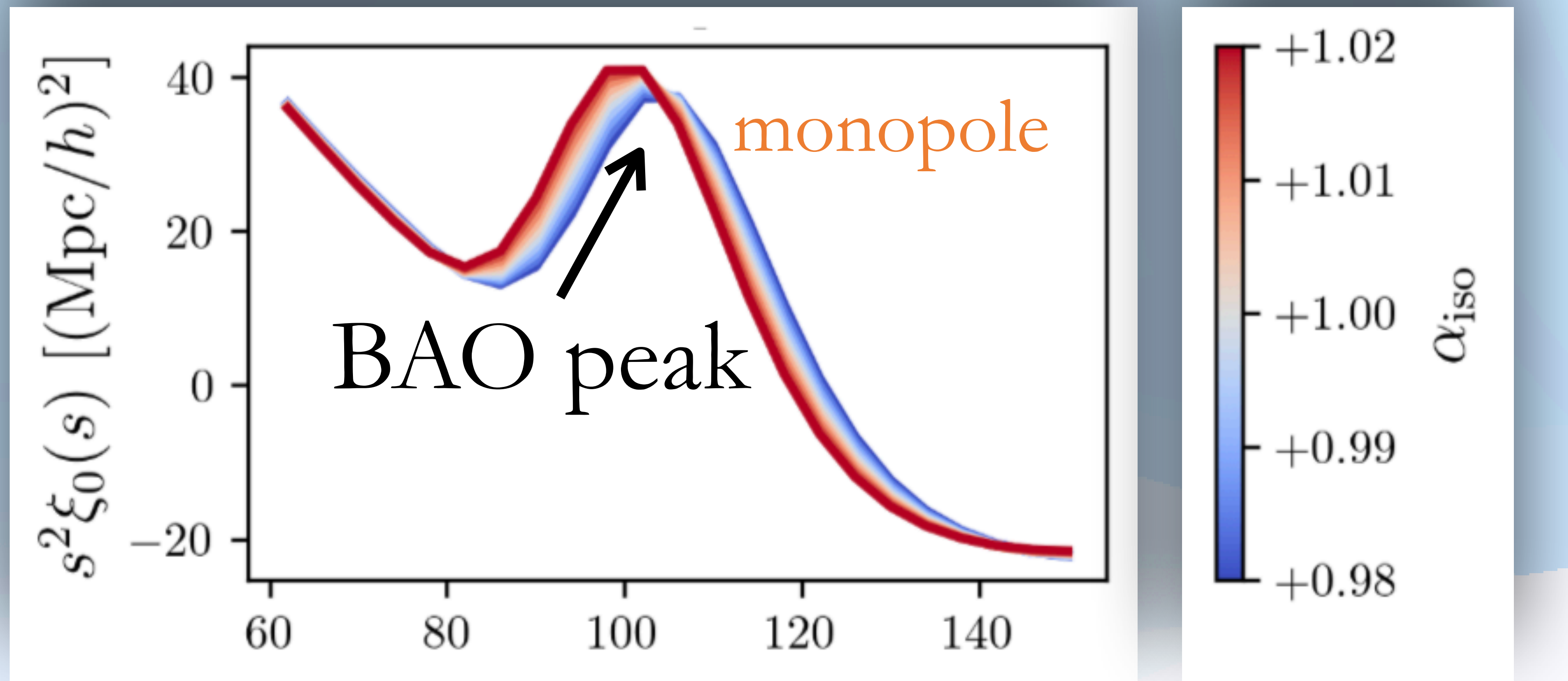
isotropic

correlation function



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

comoving transverse distance

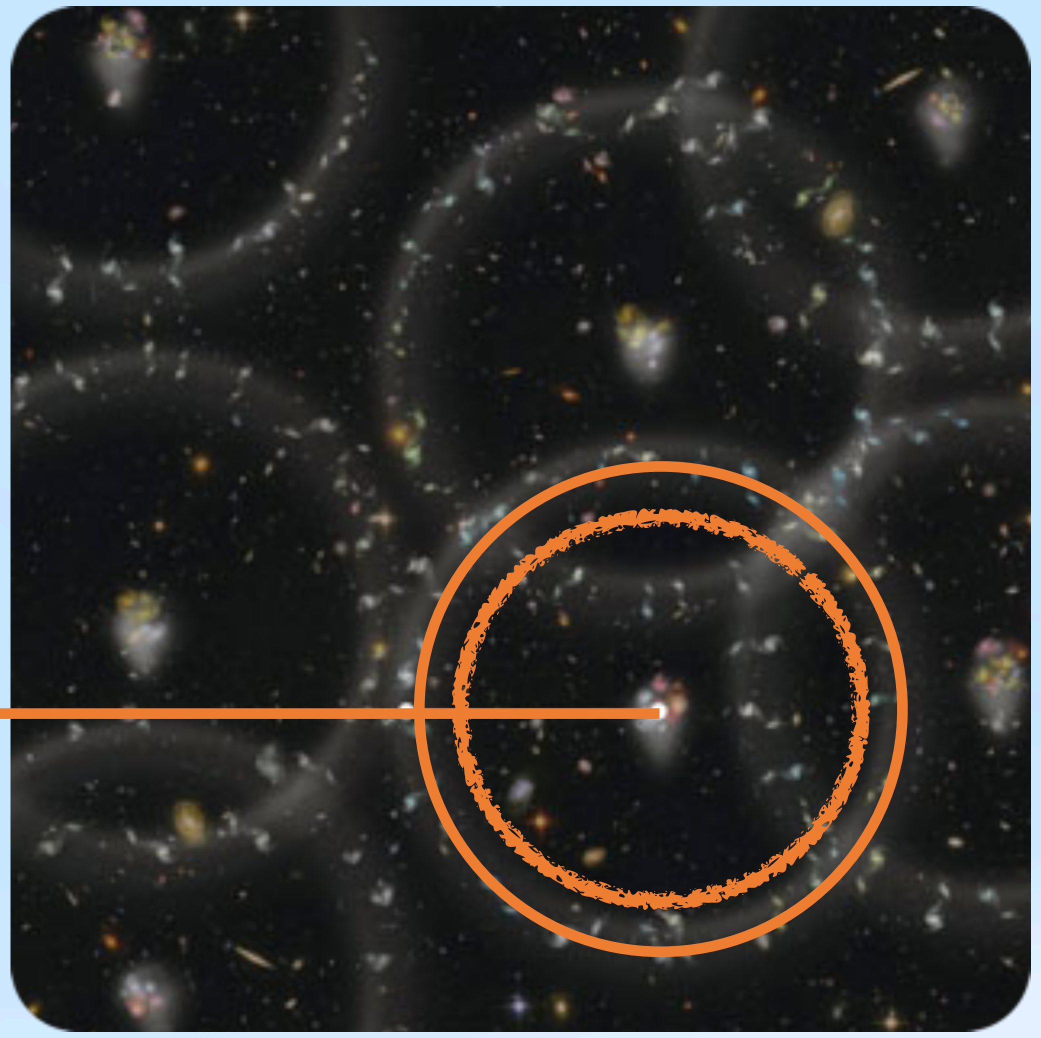
Hubble distance $c/H(z)$

sound horizon (standard ruler)

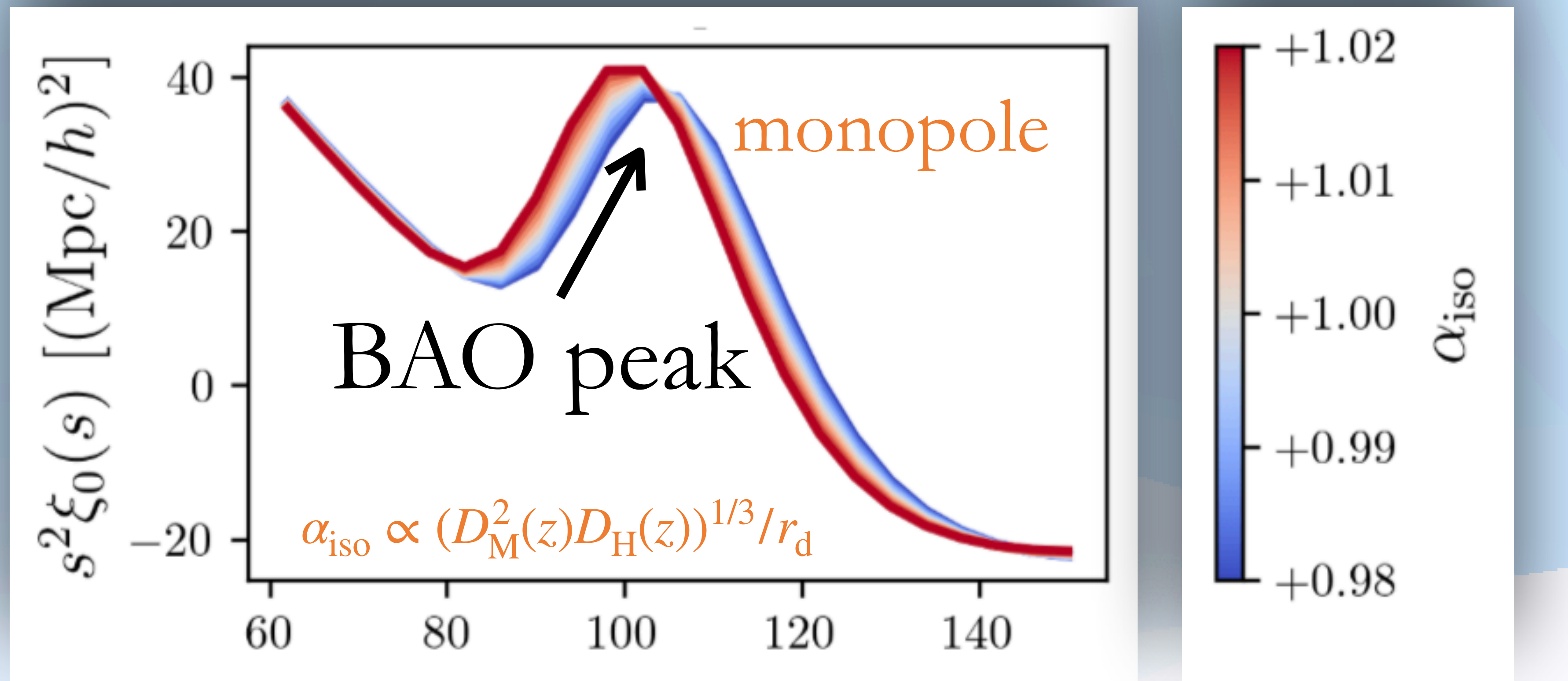
What DESI BAO measures

isotropic

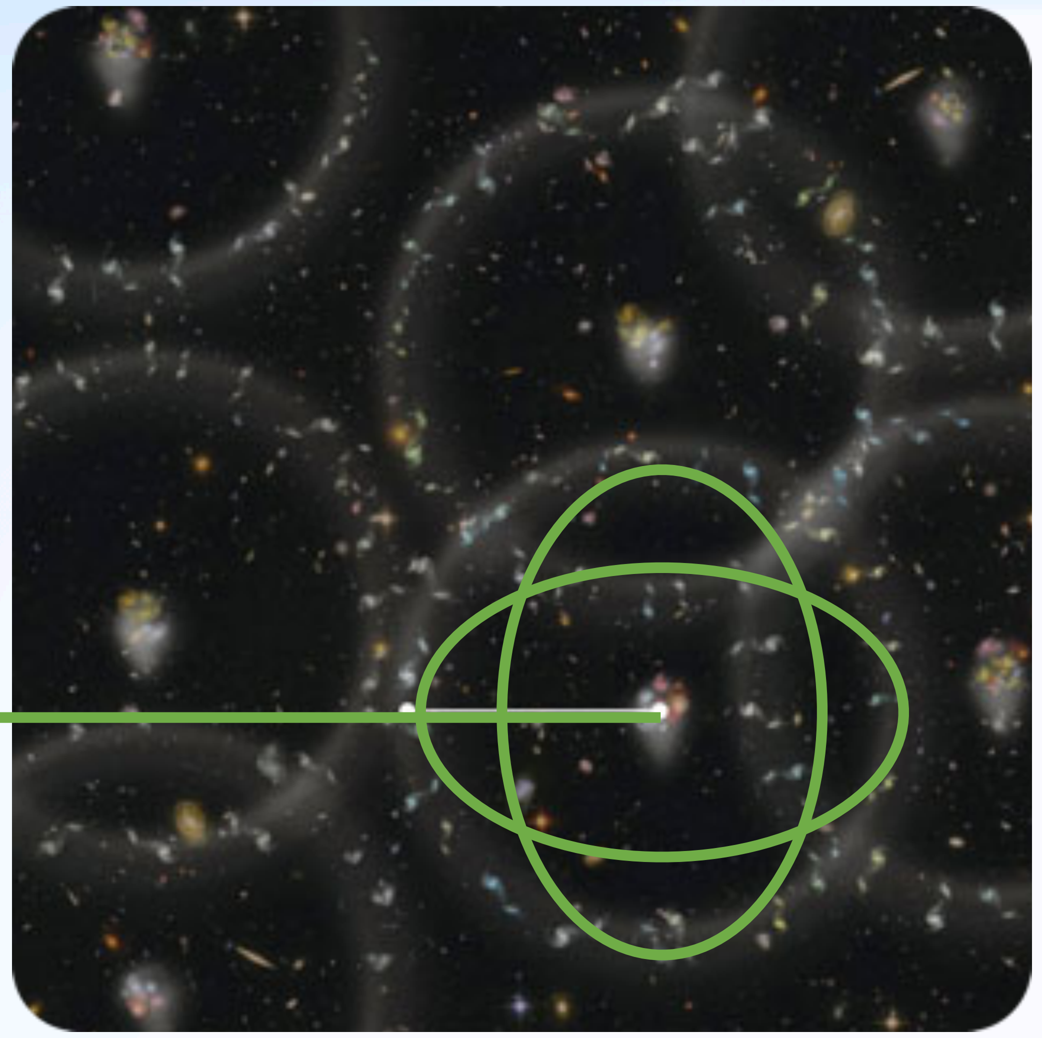
line of sight

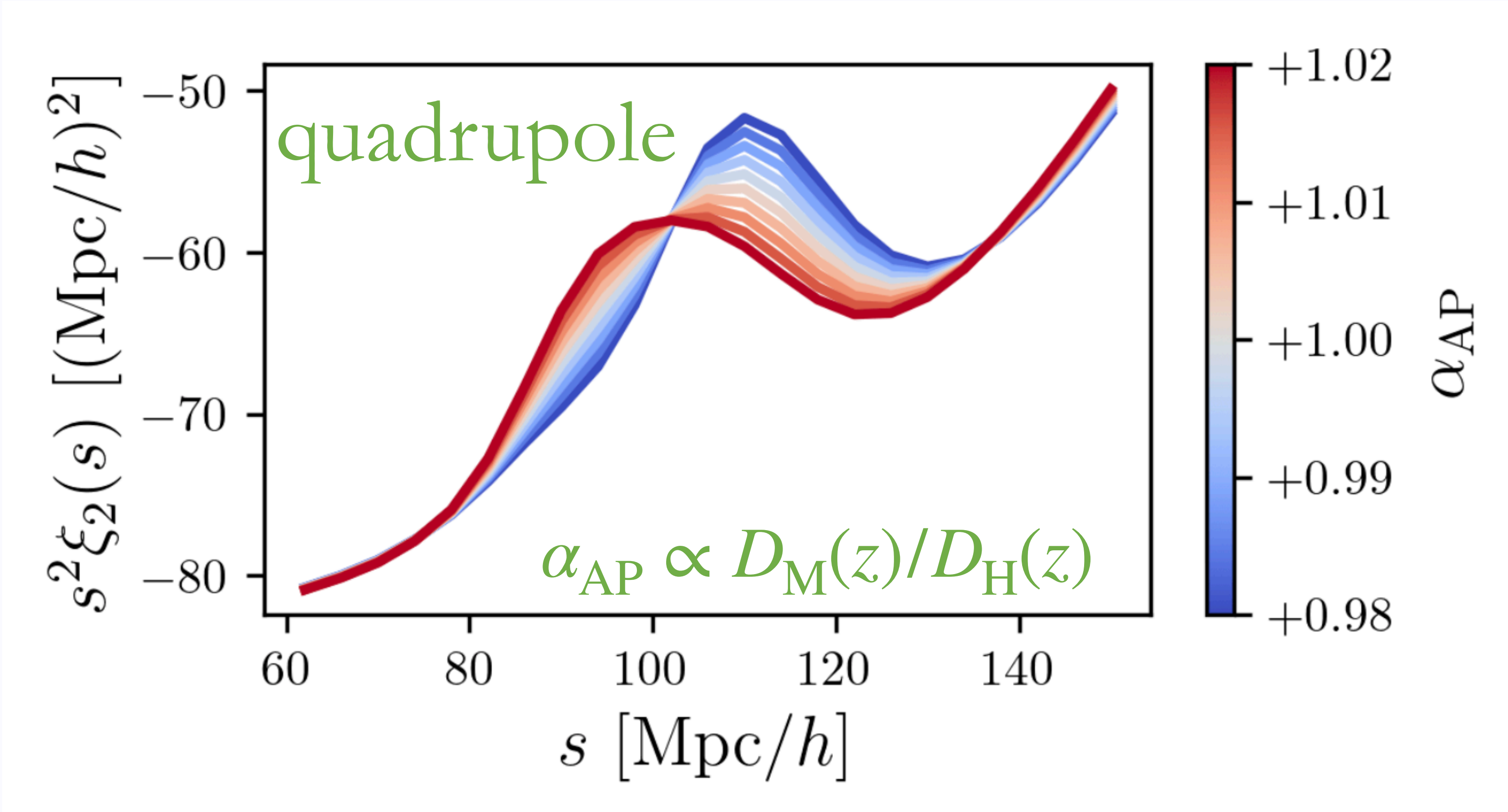


correlation function



line of sight





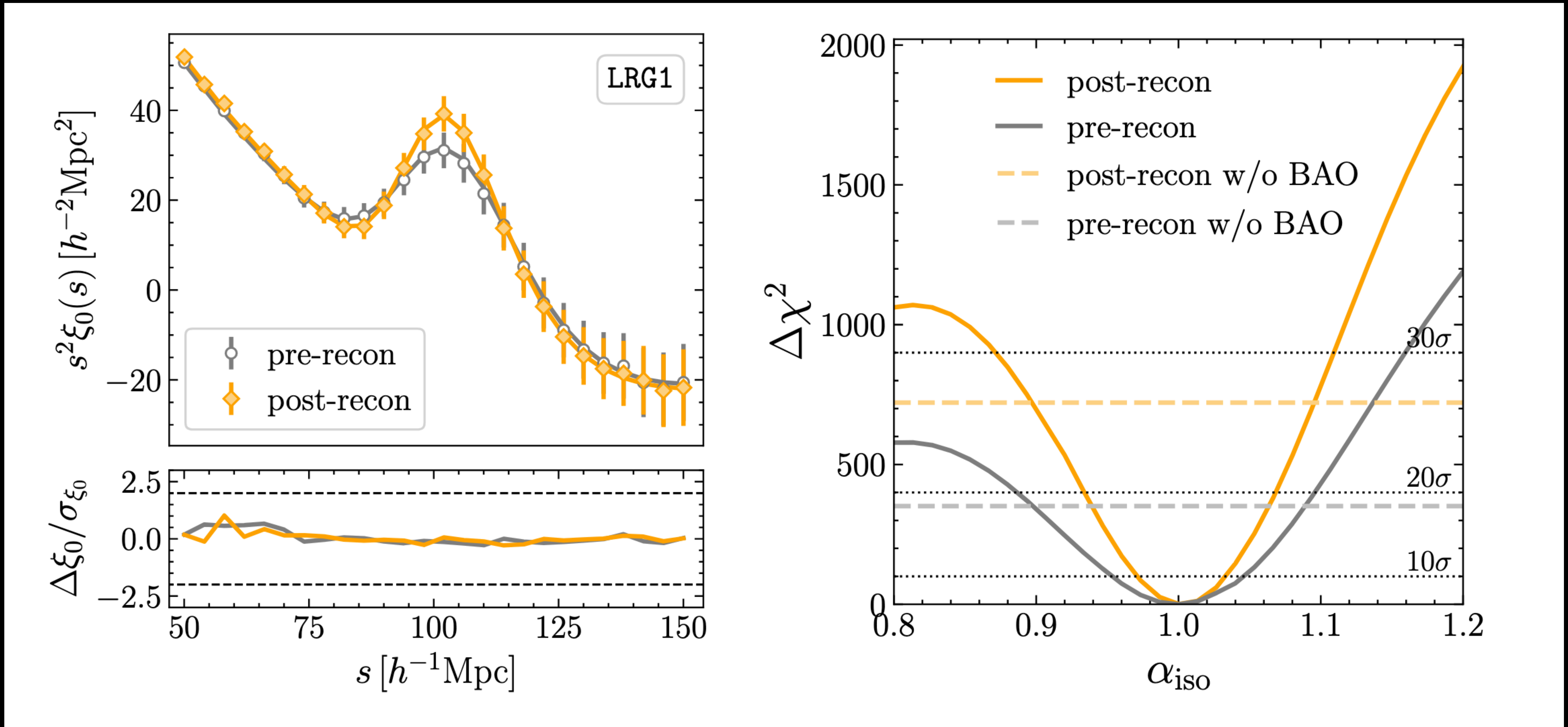
I. BAO Measurements

Blinding of the galaxy catalogs

- DESI DR2 BAO measurements were kept blinded during the validation process.
- For galaxies and quasars at $z < 2$: Catalog-level blinding that modifies galaxy redshifts and weights (Andrade++ 2024).
- For the Lyα forest, blinding of the data vector that shifts the BAO peak location (DESI Collaboration 2024).

Density field reconstruction

1. Reconstruction dramatically increases the BAO detection significance: from ~18σ to ~27σ

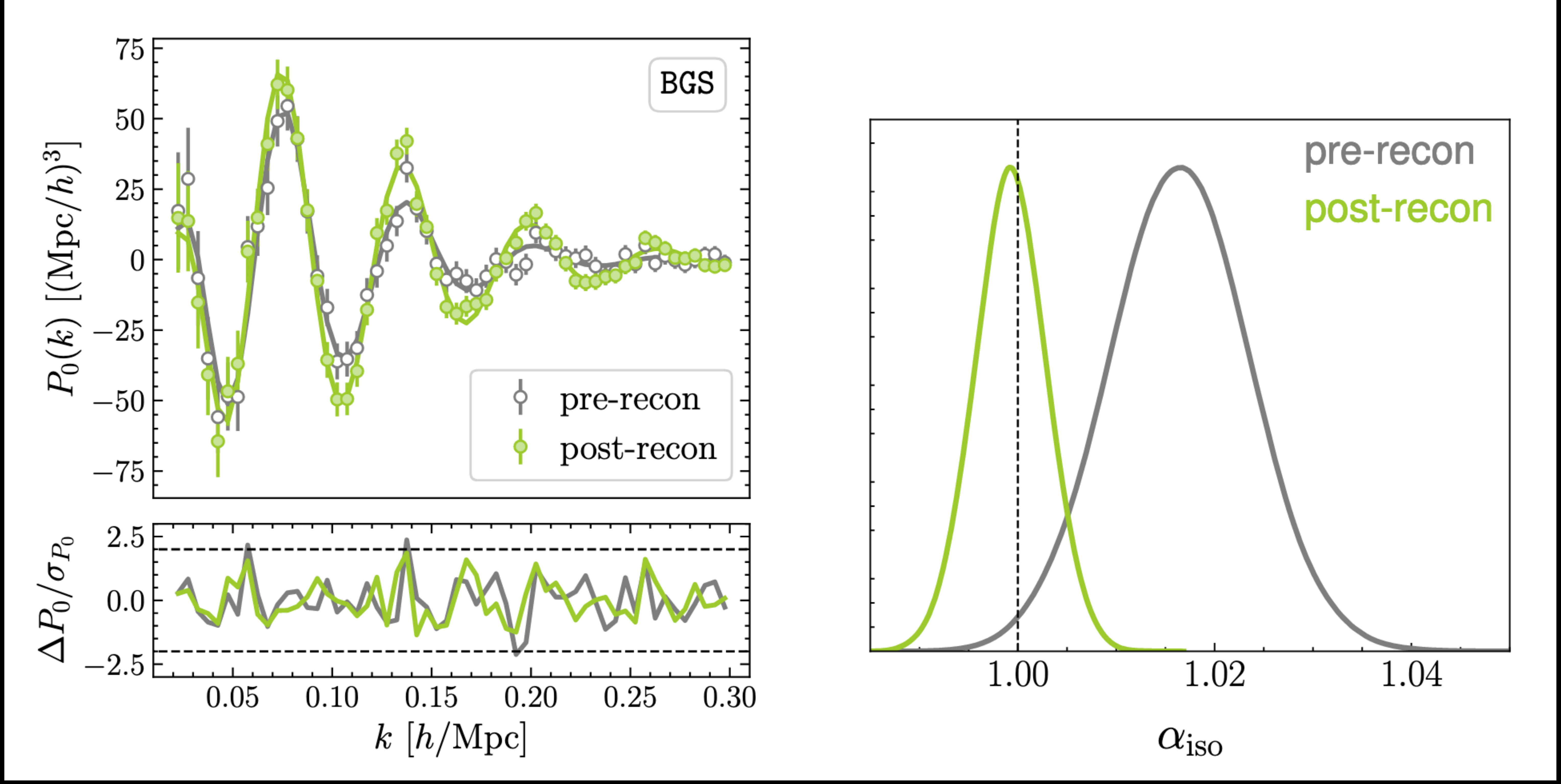


anlayis on AbacusSummit mocks

Reconstruction helps to sharpen the BAO peak by partially restoring the linearity of the density field

Density field reconstruction

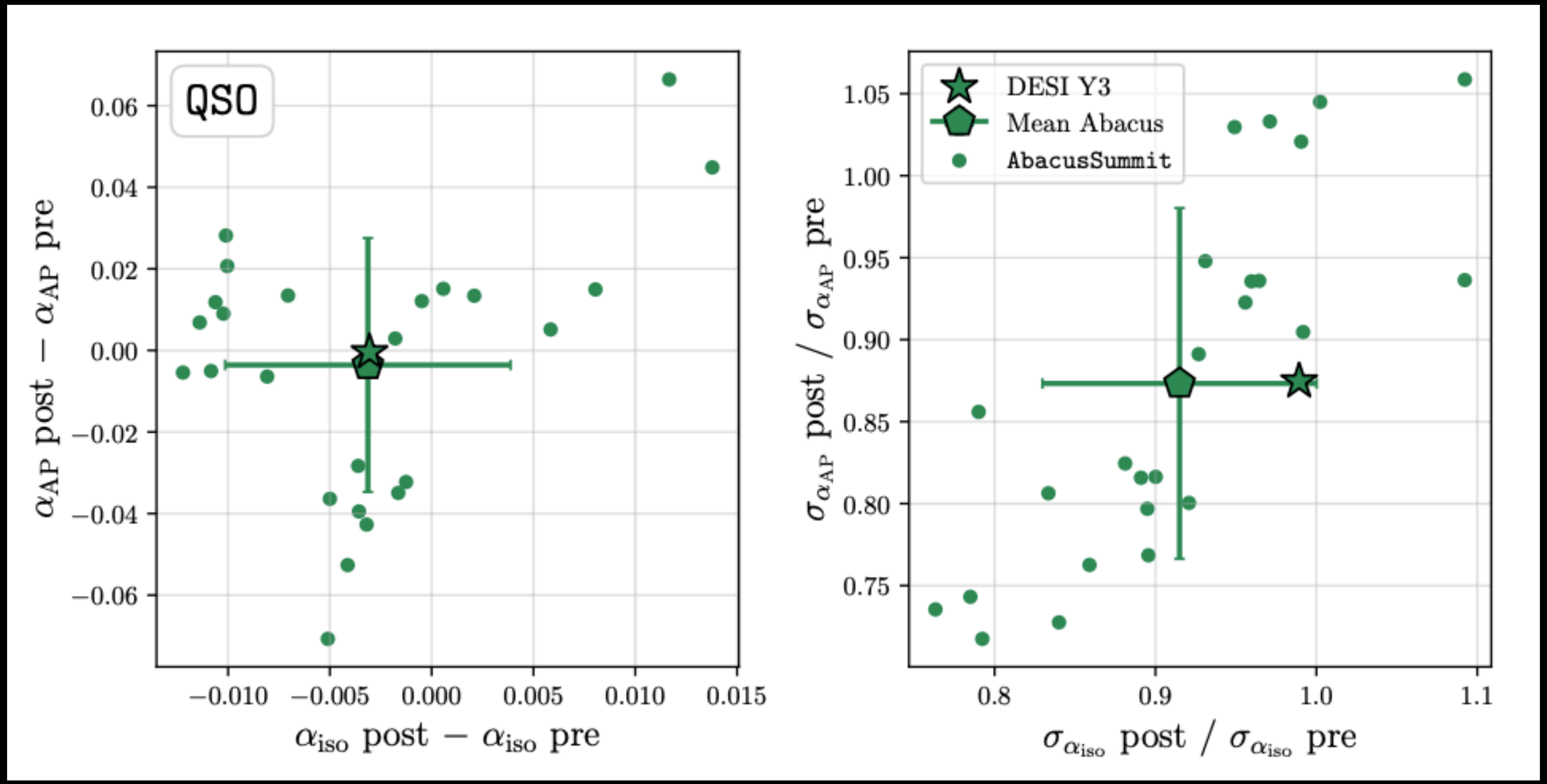
2. Reconstruction reduces bias in the BAO scale and improves precision

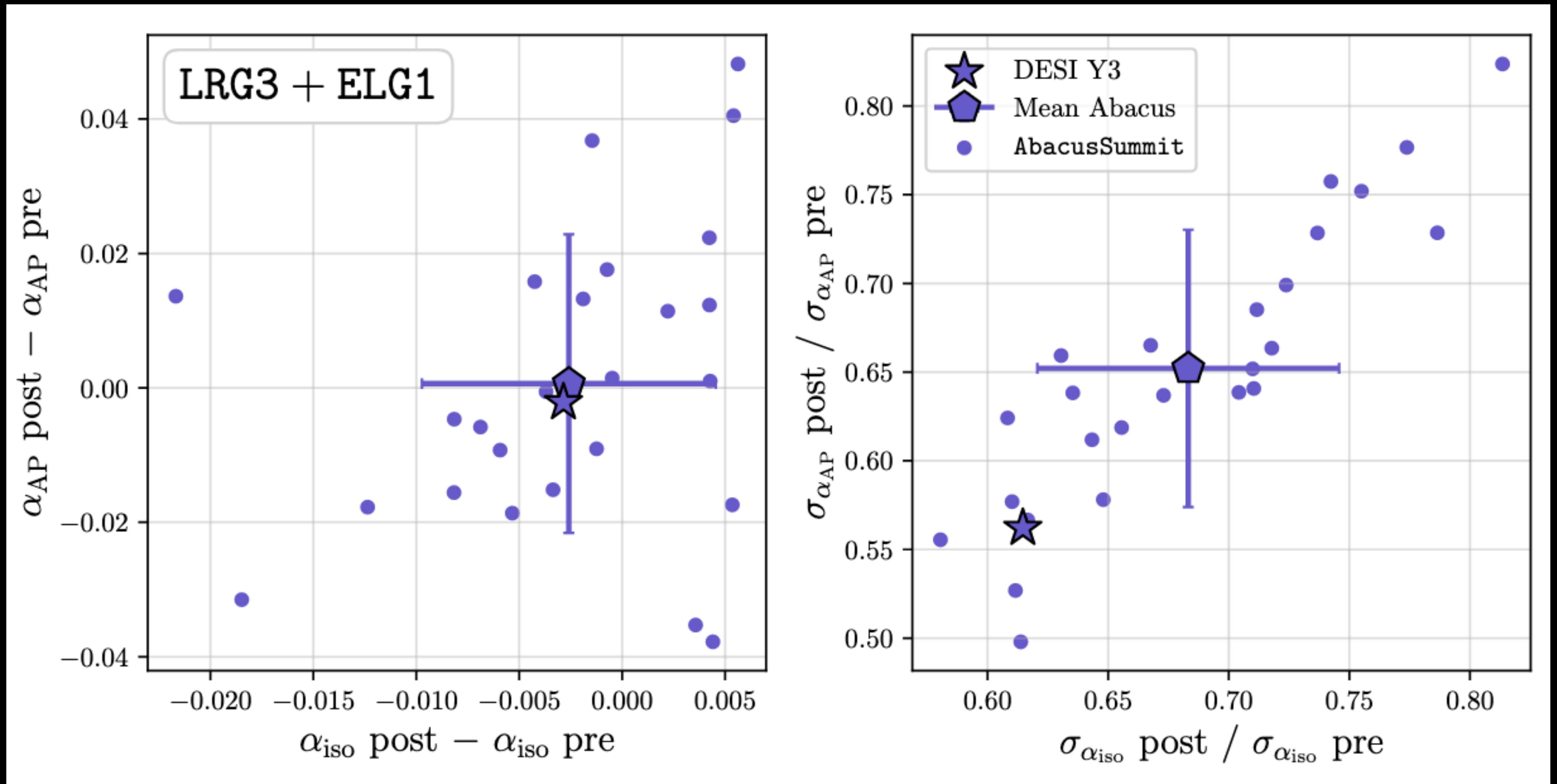


anlayis on AbacusSummit mocks

Reconstruction not only sharpens the BAO feature, but can also help removing systematic shifts in the location of the peak due to non-linear evolution and galaxy biasing.

Density field reconstruction





3.7% for QSO

42% for LRG3+ELG1

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

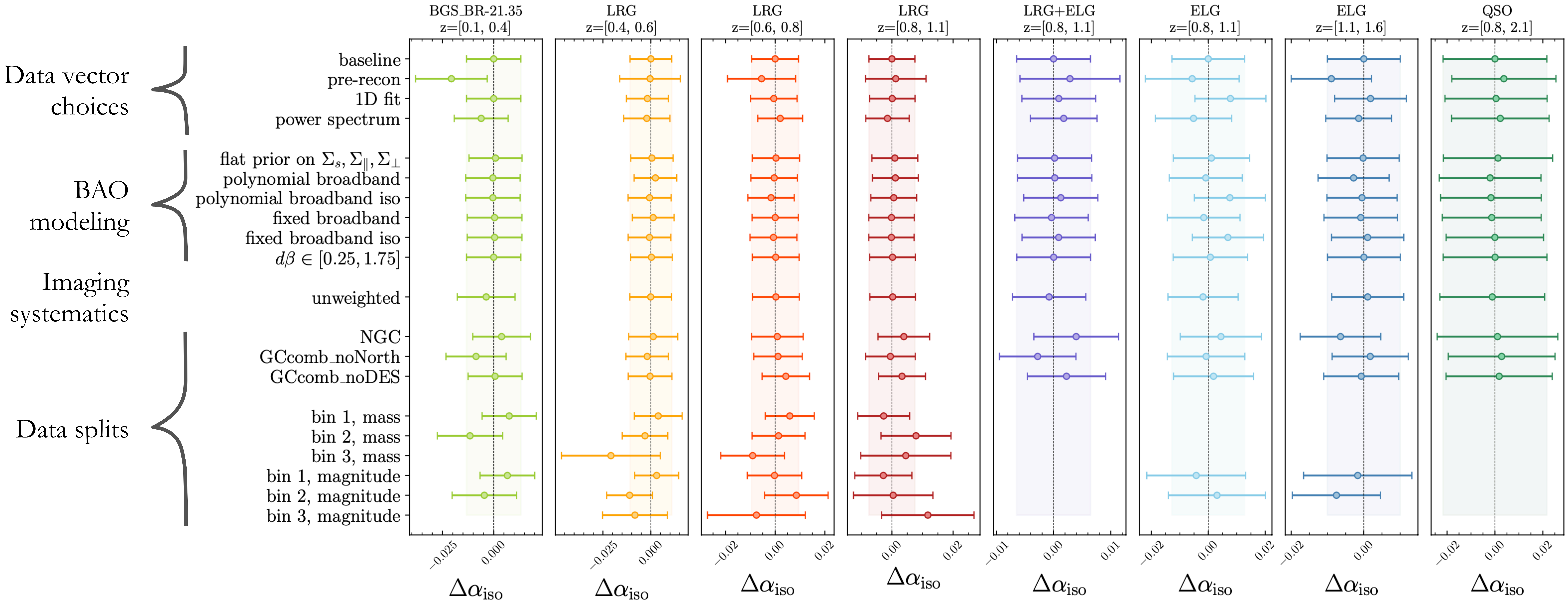
No systematics decected

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

systematics << statistics

Maximum effect: $\sigma_{\text{stat.+syst.}} < 1.06\ \sigma_{\text{stat.}}$

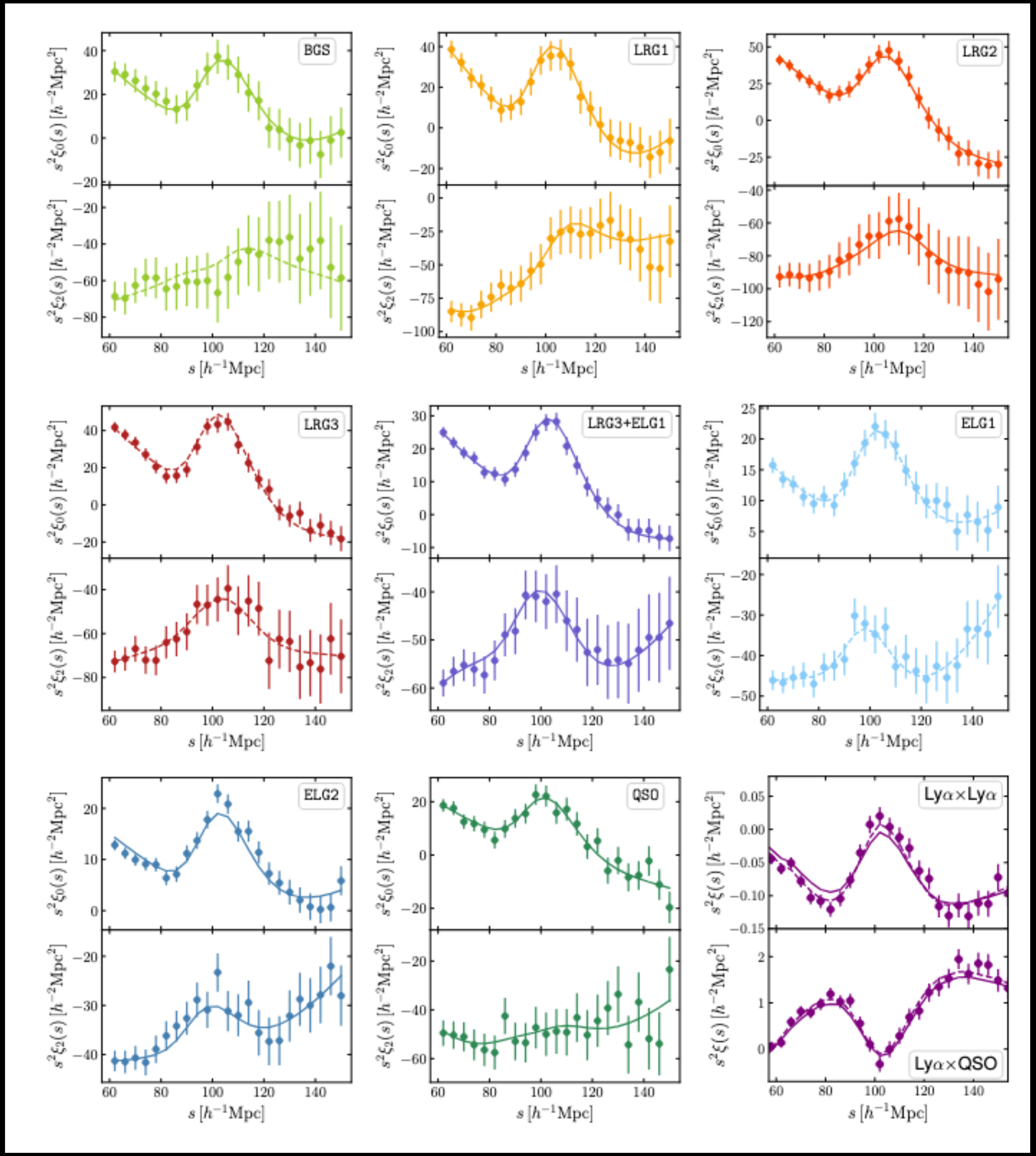
DR2 BAO is robust against different pipeline choices



Differences in the isotropic BAO dilation

Supporting paper: Validation of the DESI DR2 Measurements of Baryon Acoustic Oscillations from Galaxies and Quasars (Andrade++2025).

Final BAO Measurements in DESI DR2: The Most Precise to Date



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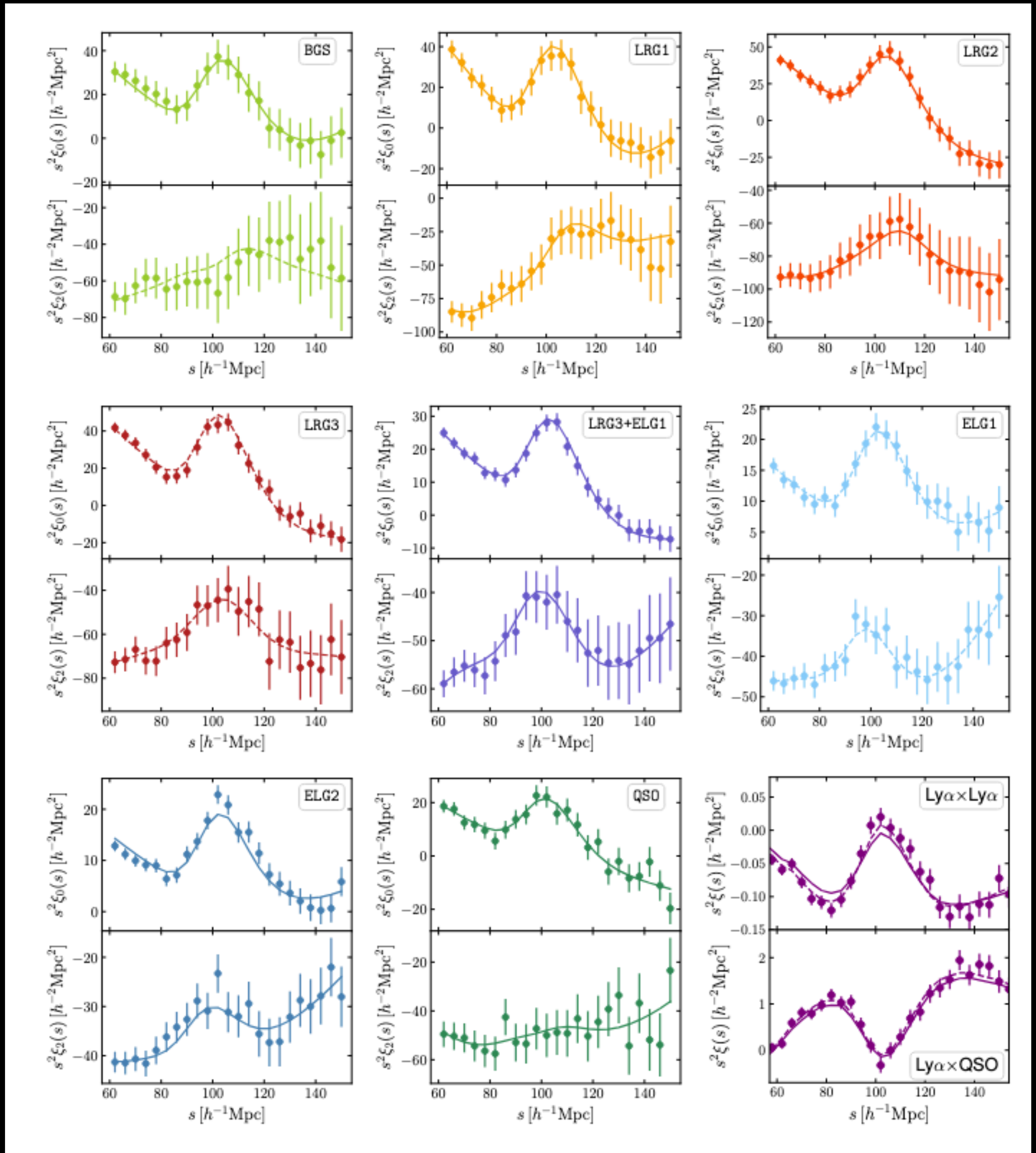
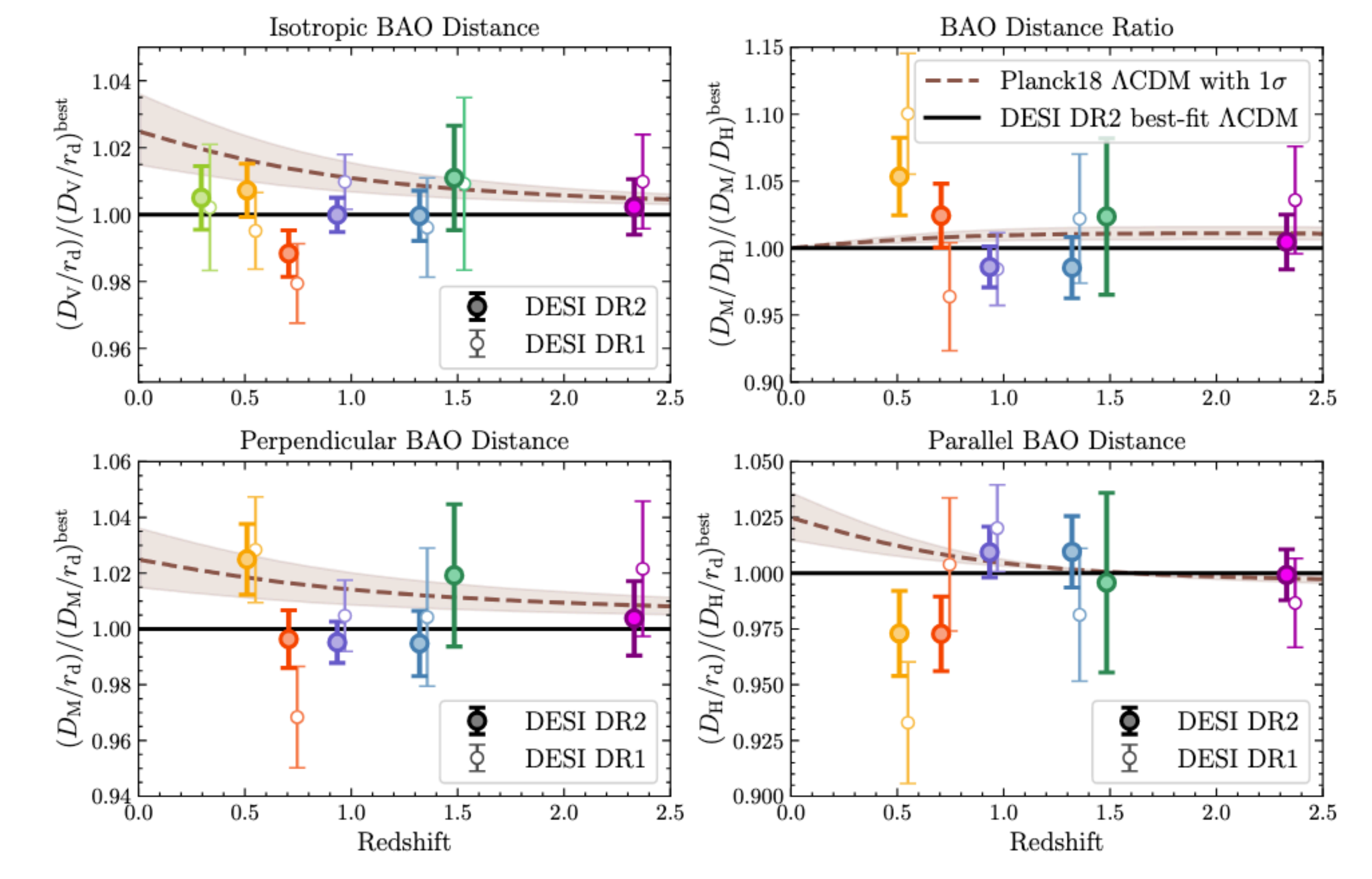


- ✅ Clear BAO peak detected in all tracers around ~100 Mpc/h.
- ✅ Detection significance ranges from 5.6σ (QSO) to 14.7σ (LRG+ELG)
- ✅ The most precise BAO measurements ever (40% more precise than DR1)
- ✅ DESI Collaboration *et al.* (2025), DESI DR2 Results I: Baryon Acoustic Oscillations from the Lyman Alpha Forest
- ✅ DESI Collaboration *et al.* (2025), DESI DR2 Results II: Measurements of Baryon Acoustic Oscillations and Cosmological Constraints

The final distance measurements and the Hubble Diagram



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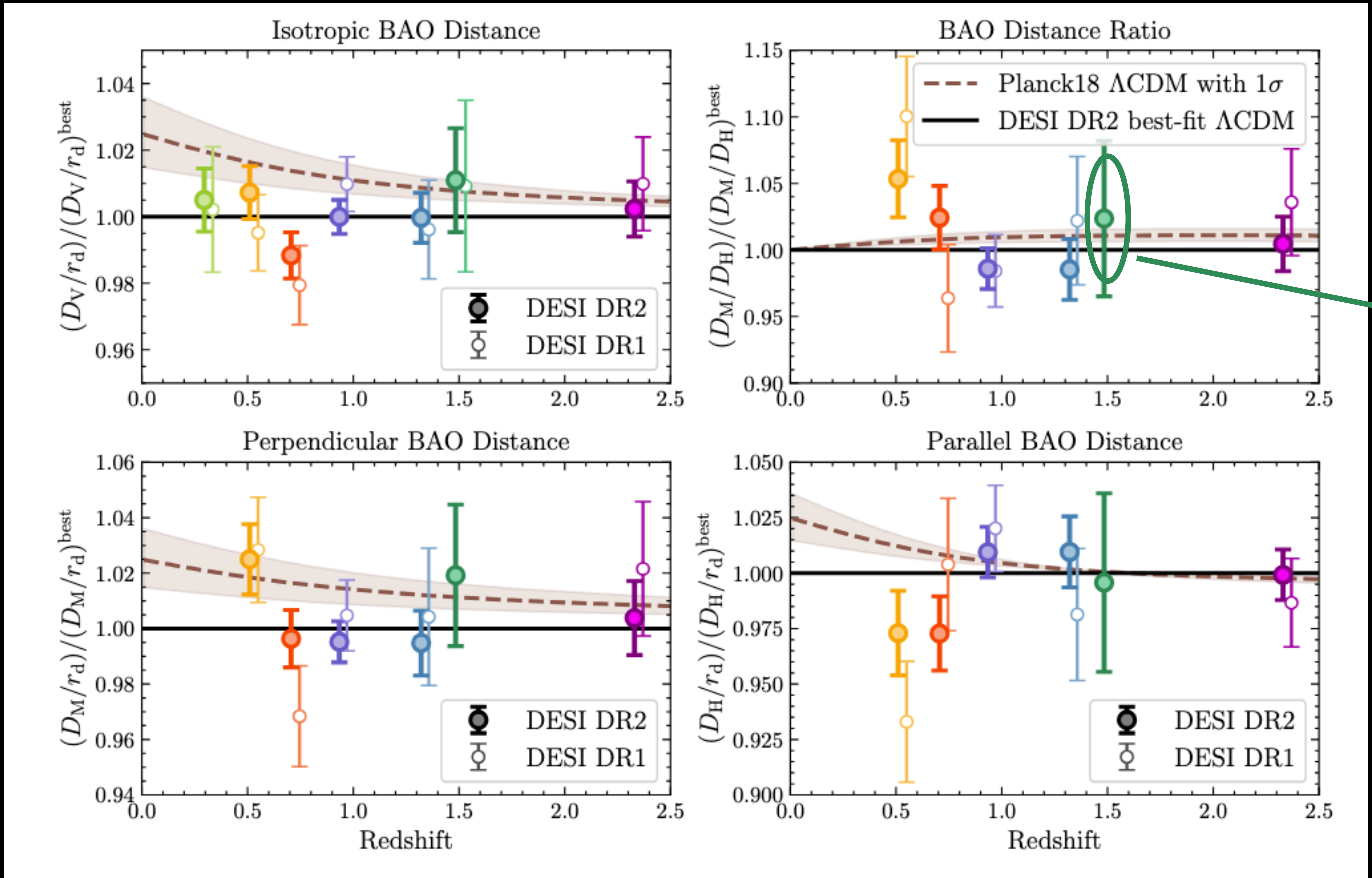
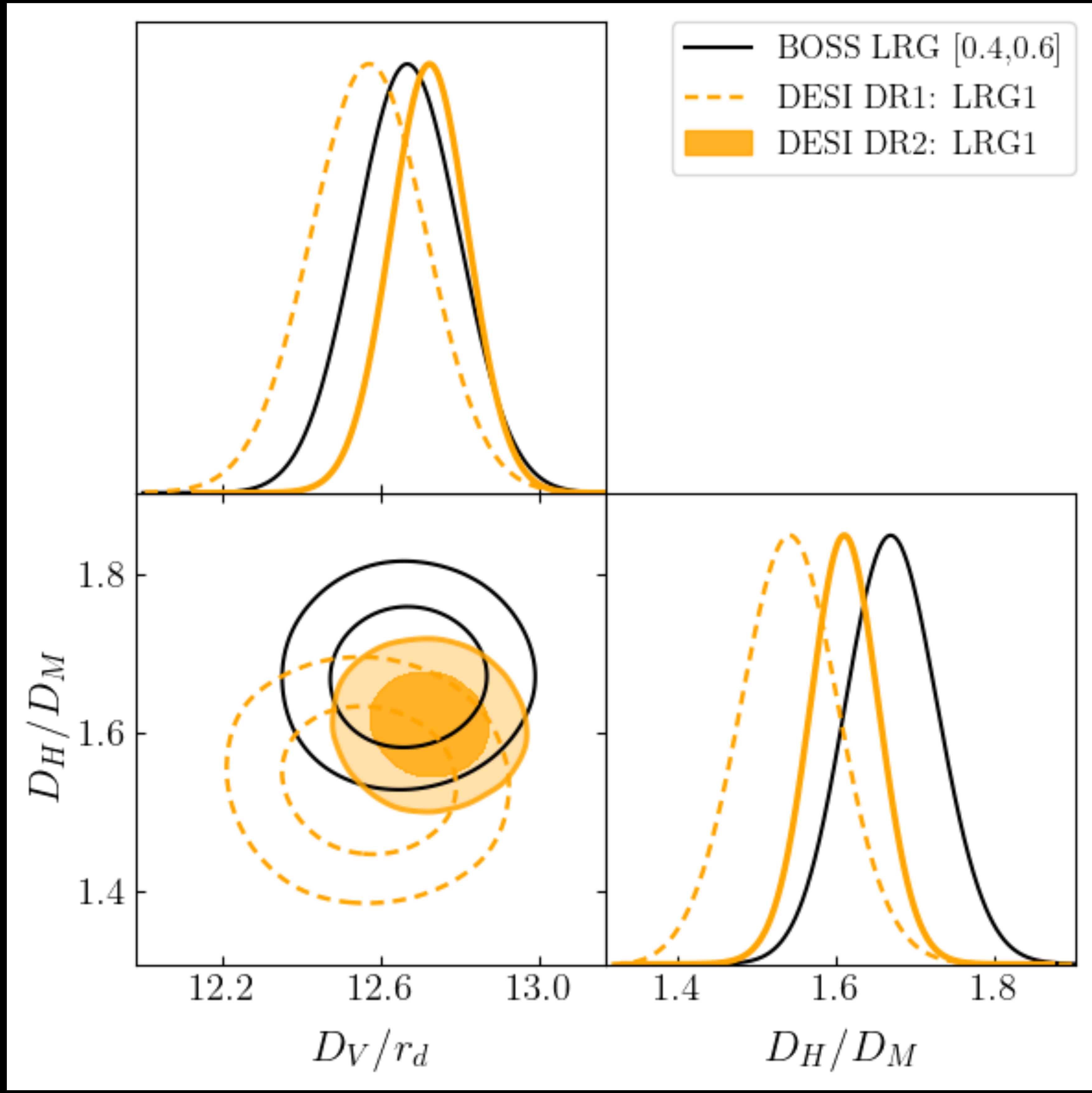


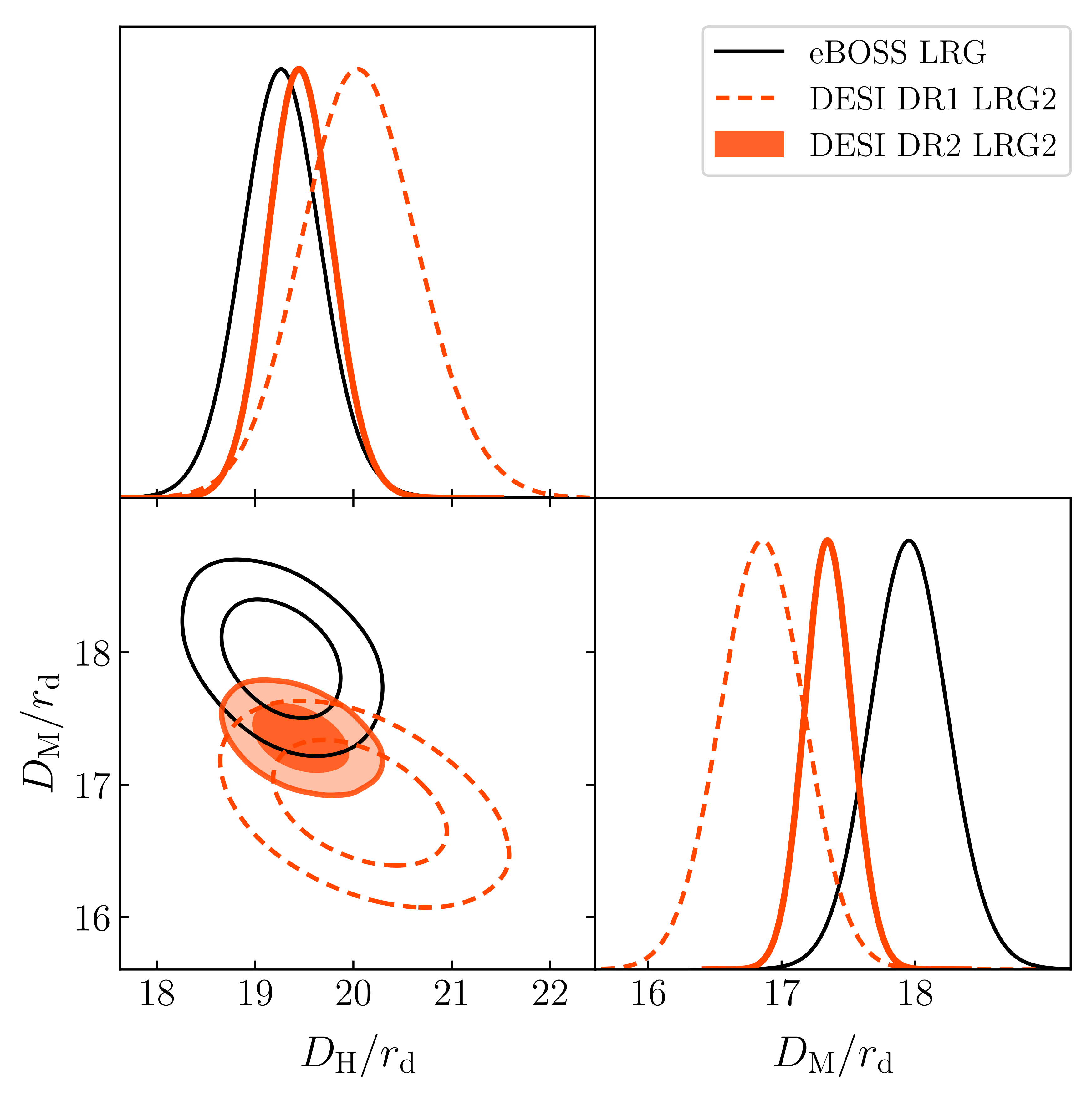
New QSO distance ratio measurement

DESI vs BOSS/eBOSS

LRG2 (worst case)

$\sim 3\sigma\,(\mathrm{DR1}) \Rightarrow 2.3\sigma\,(\mathrm{DR2})$

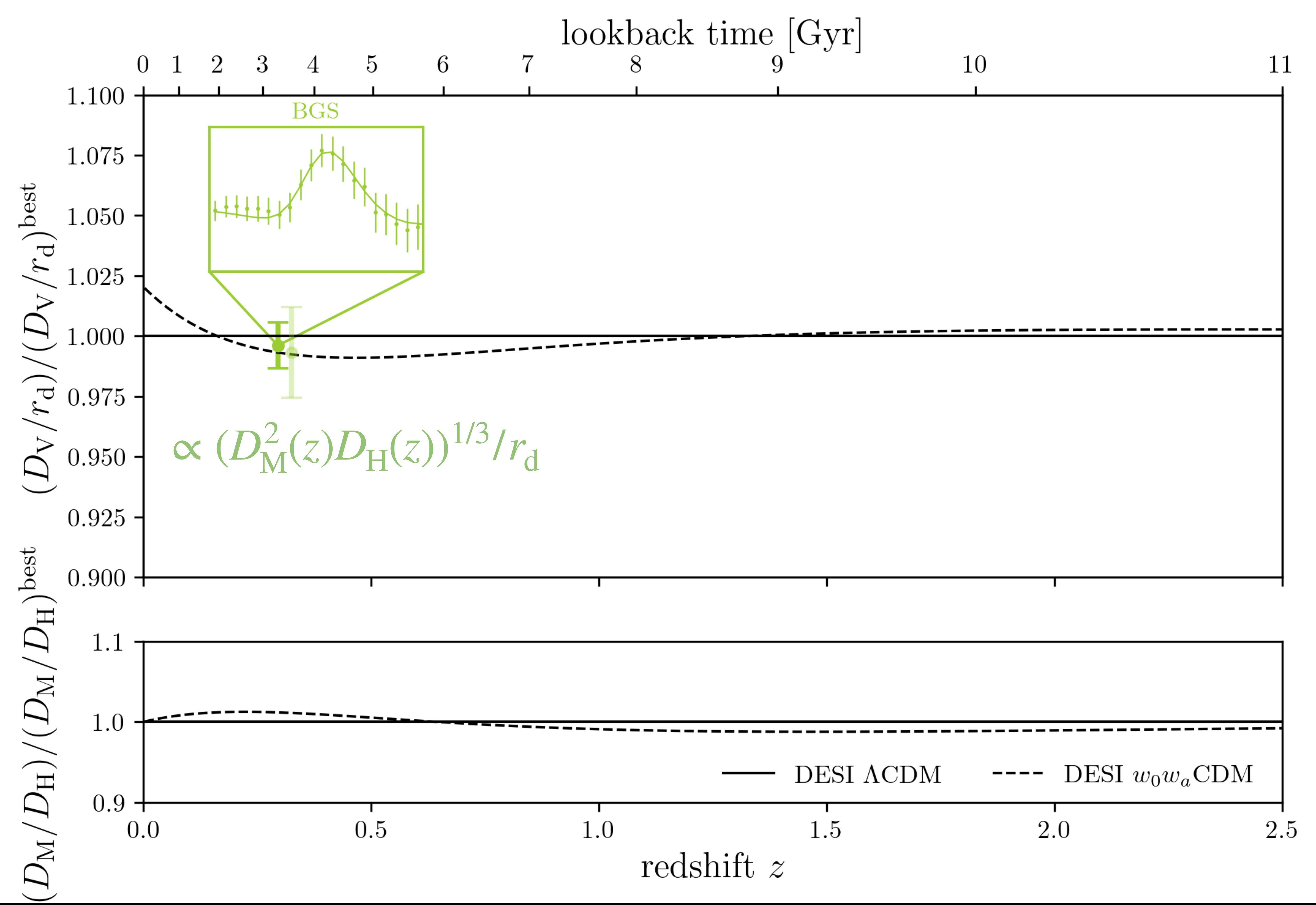


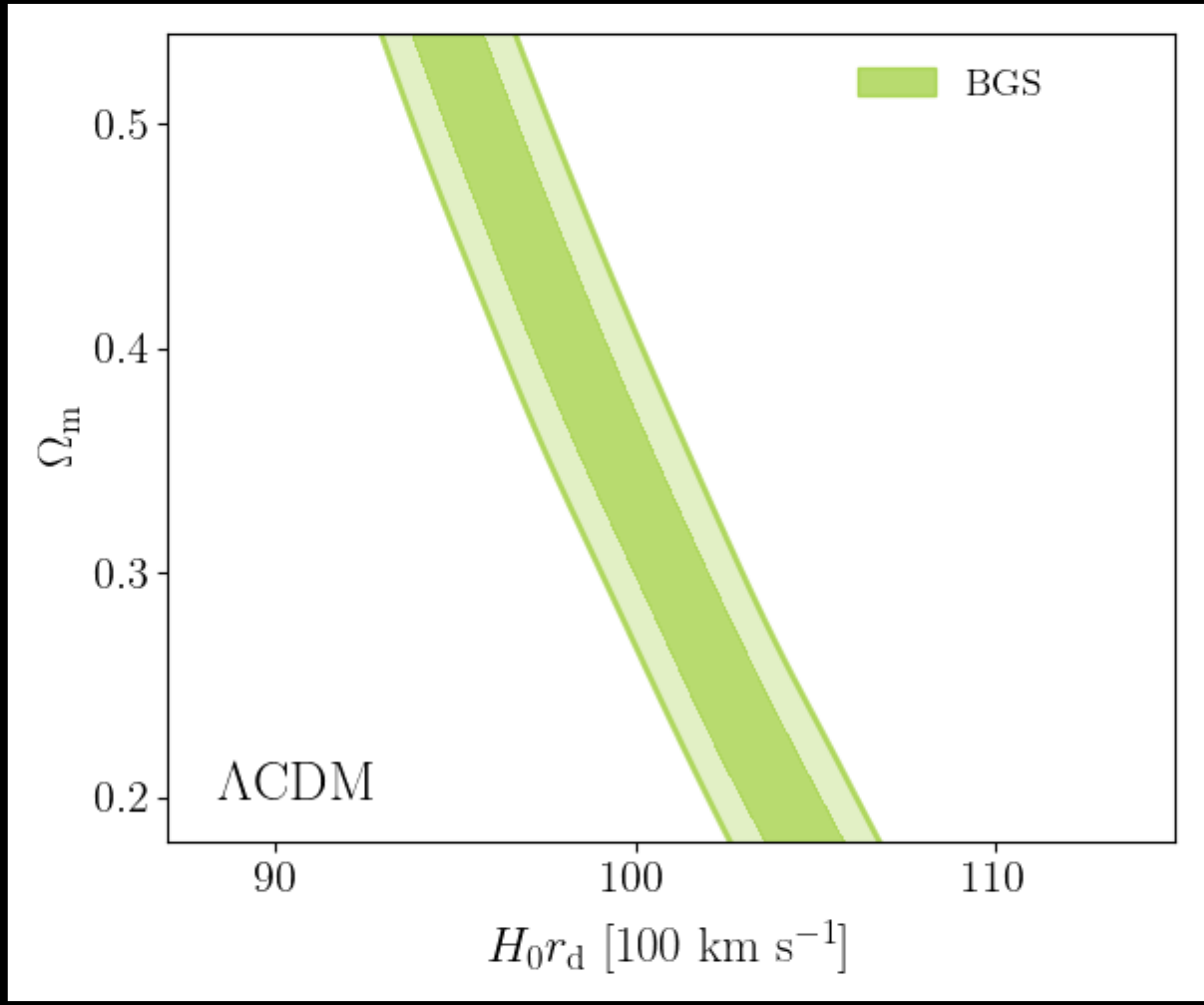


2.3σ when using C = 0.57 and only 1.5σ when assuming no correlation (it sets a lower limit)

DESI DR2 BAO

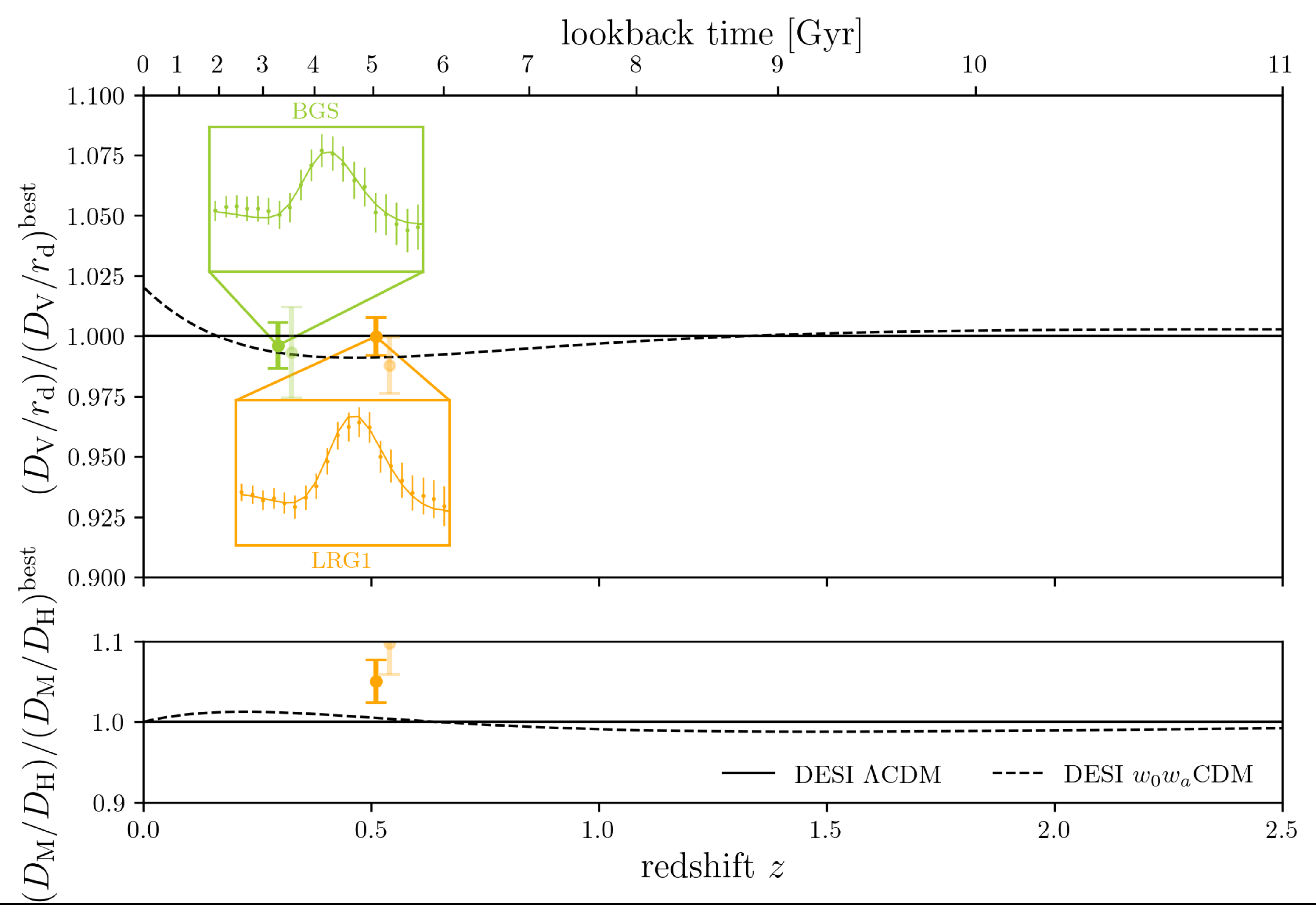
DESI DR2 BAO measurements

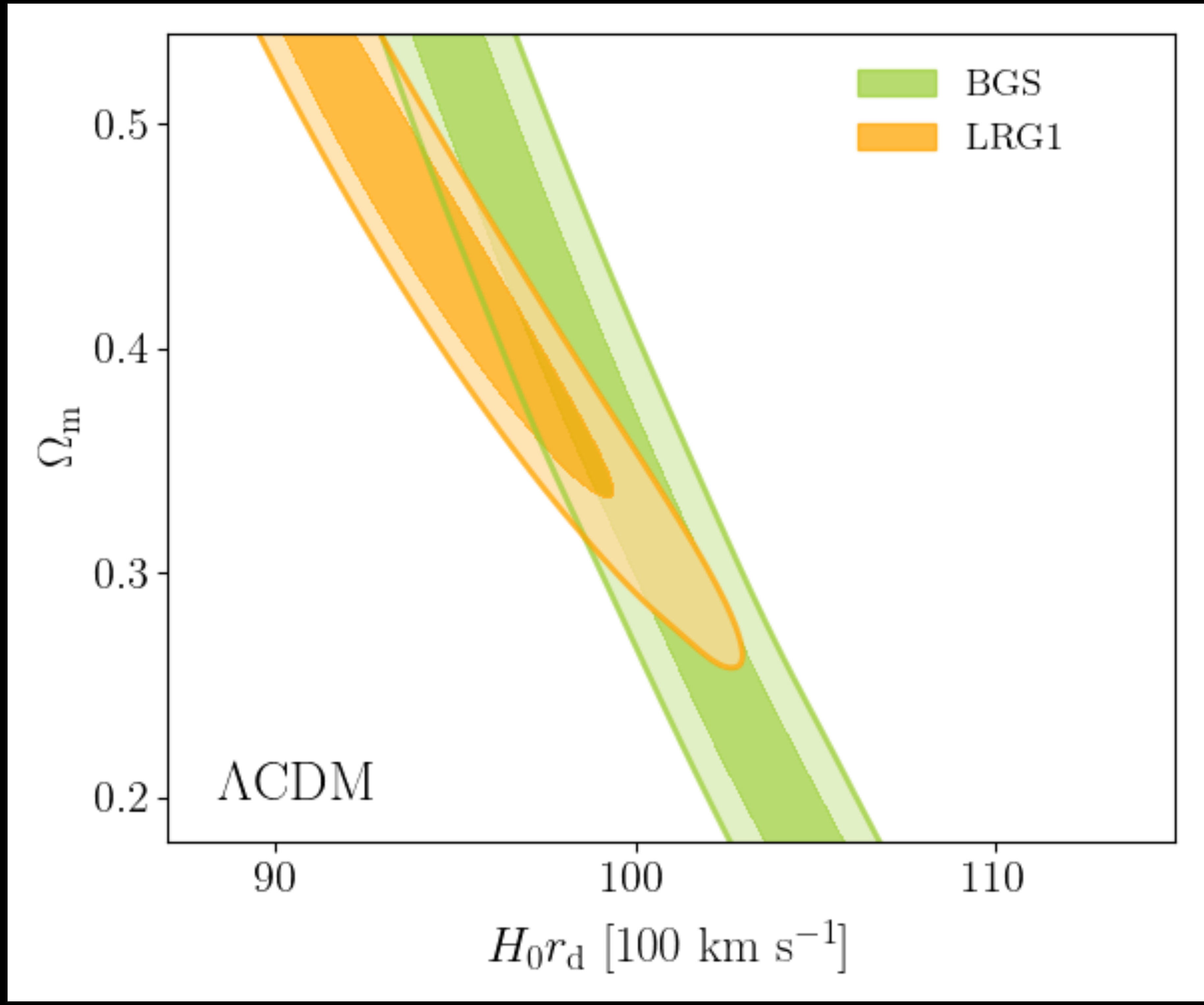




DESI DR2 BAO

DESI DR2 BAO measurements





DESI DR2 BAO

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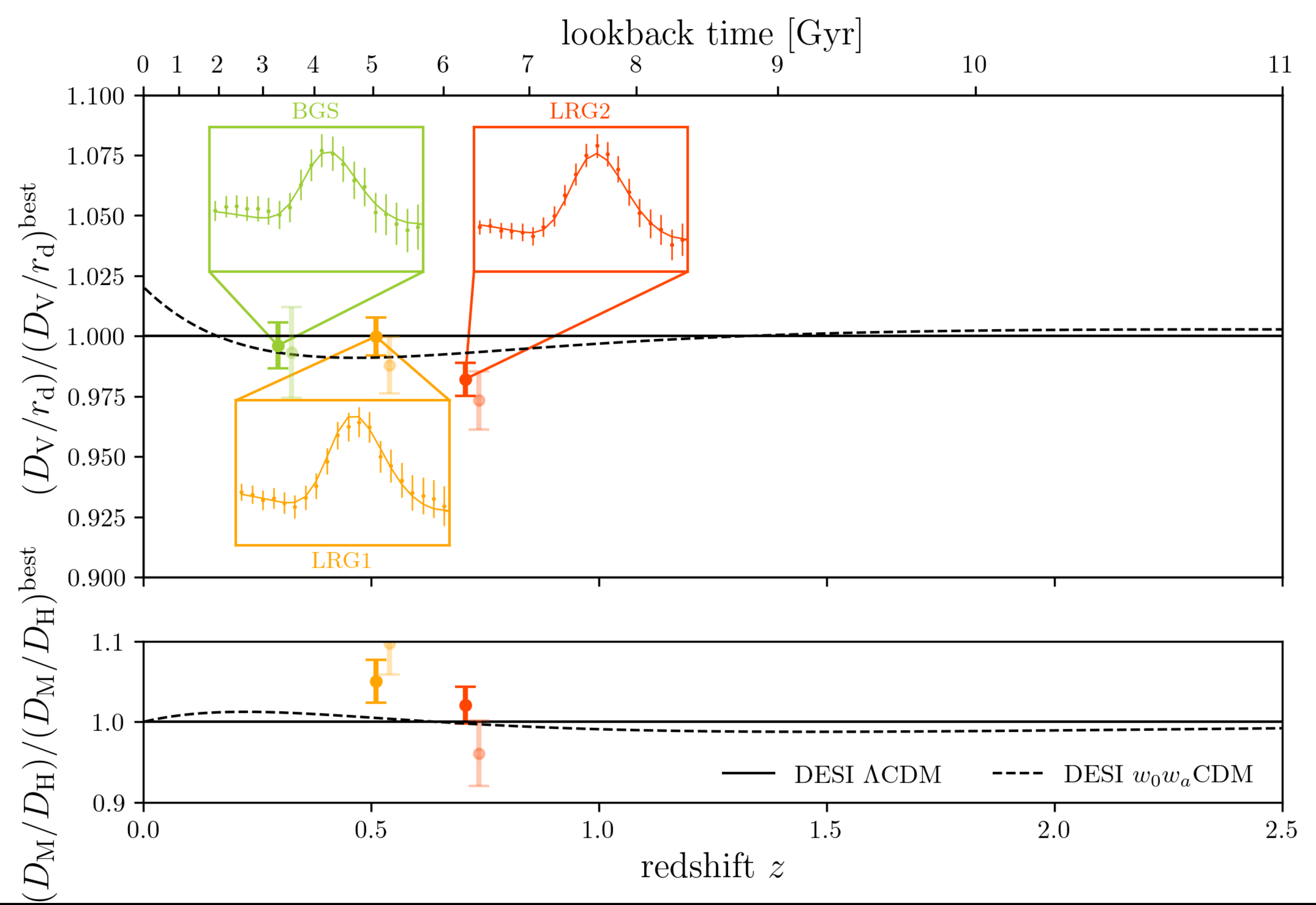
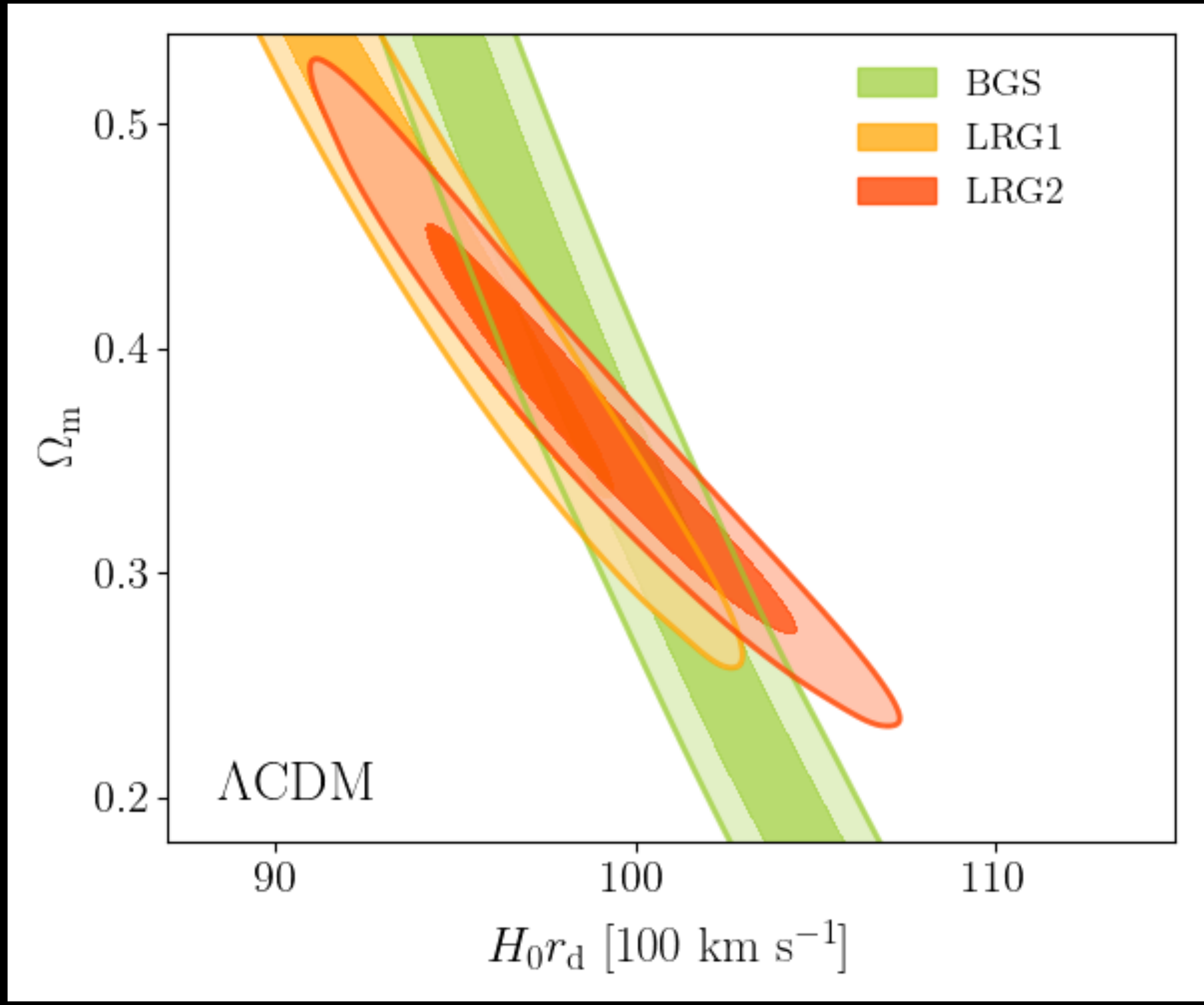
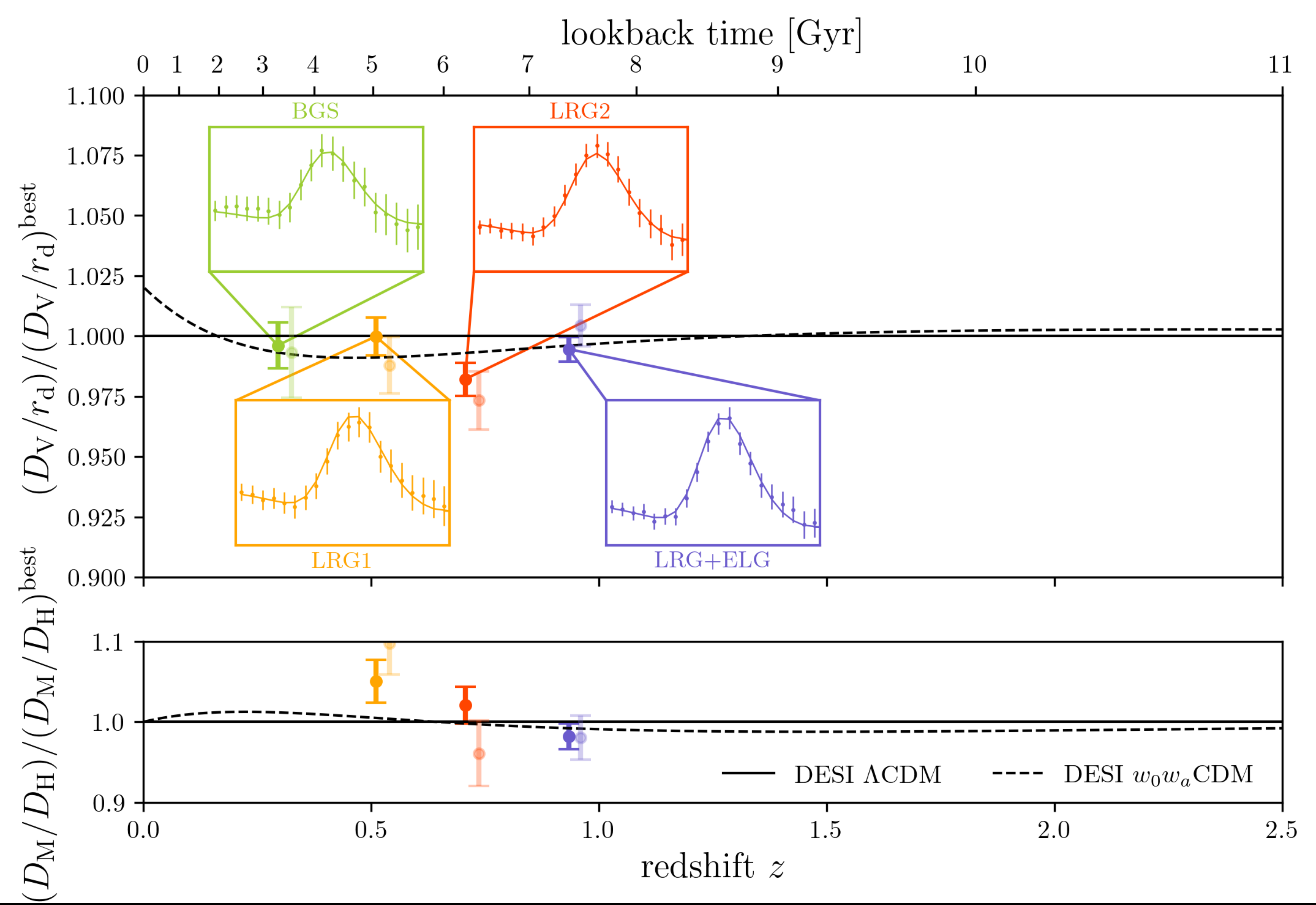
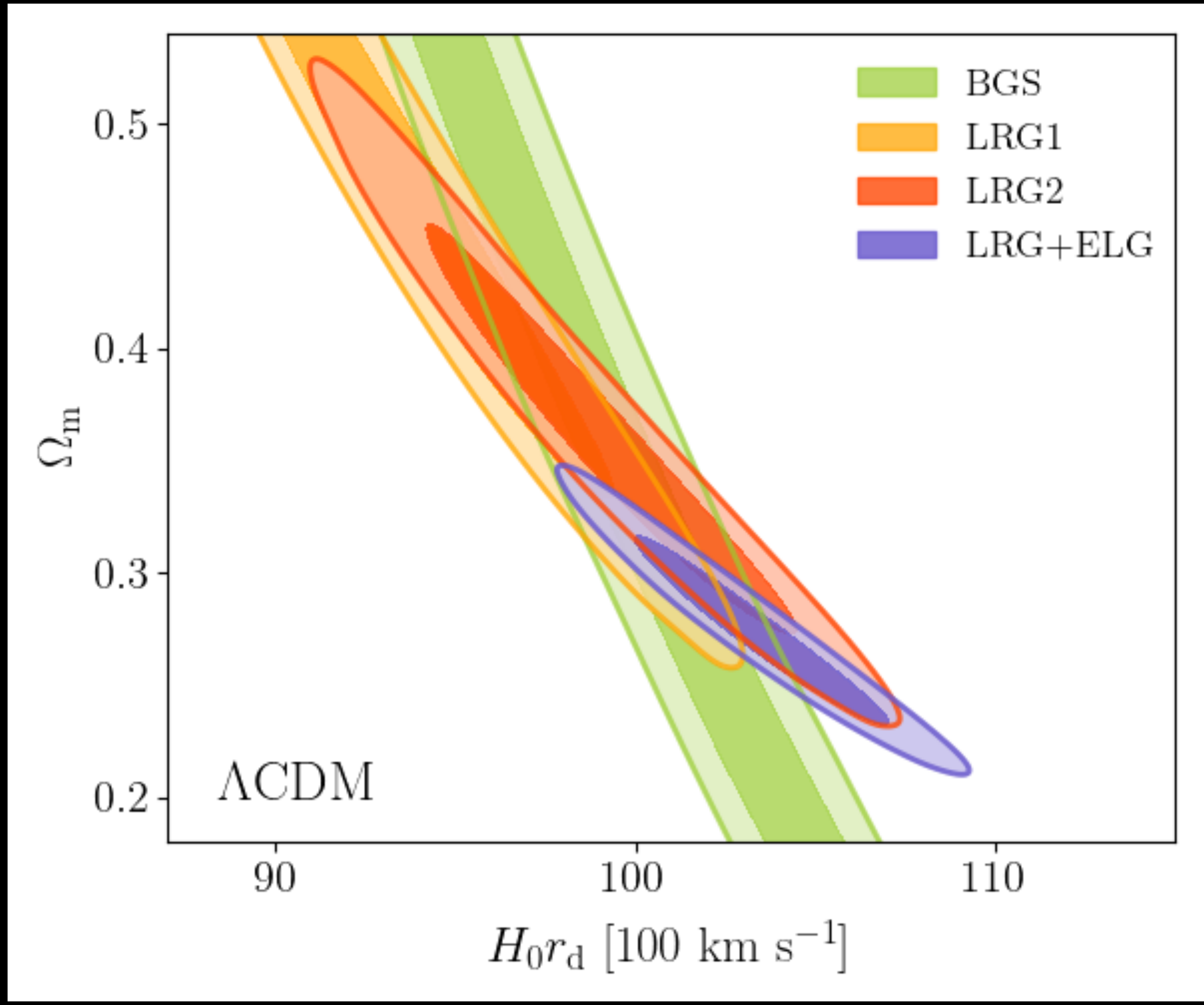




DESI DR2 BAO

DESI DR2 BAO measurements





DESI DR2 BAO

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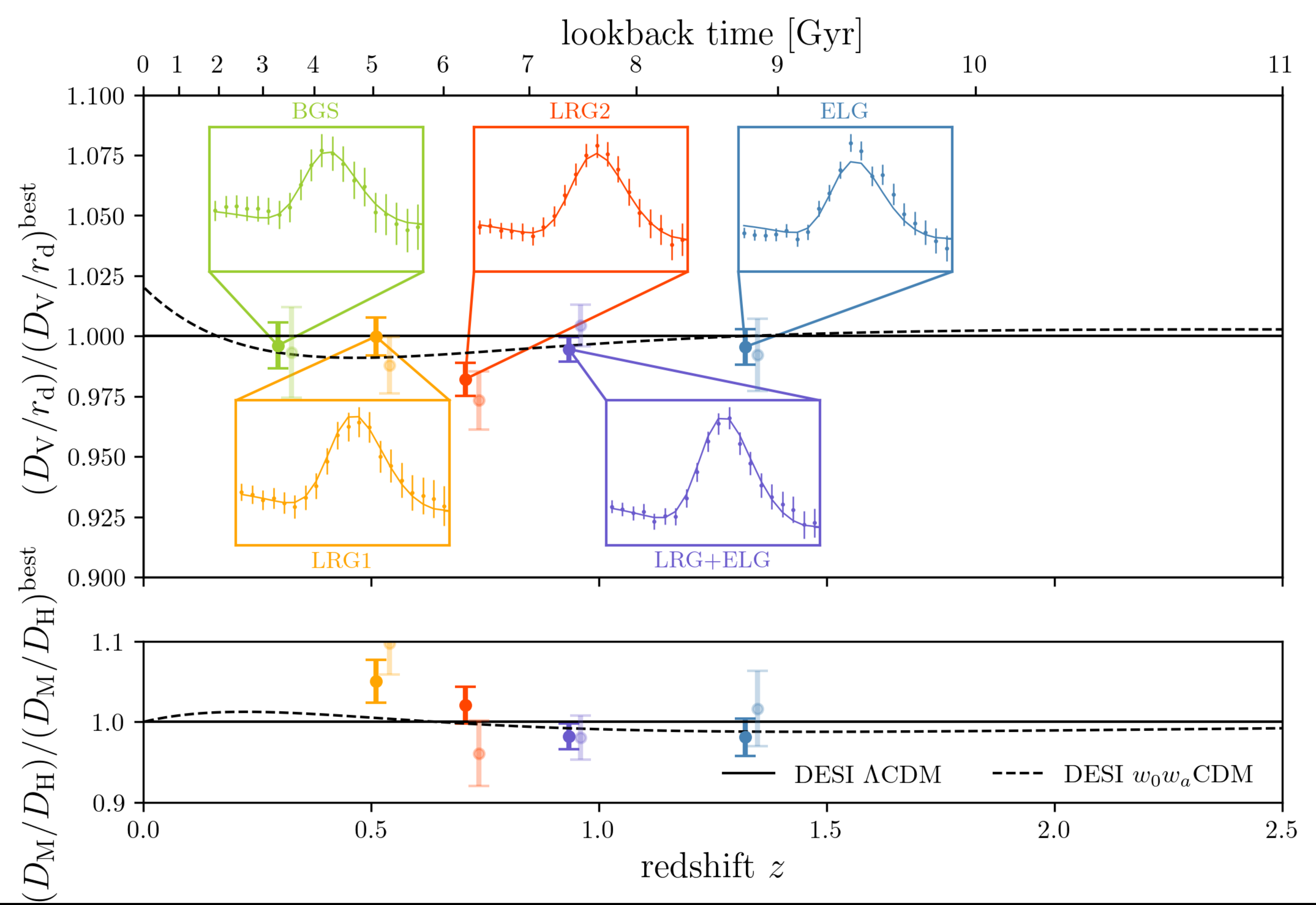

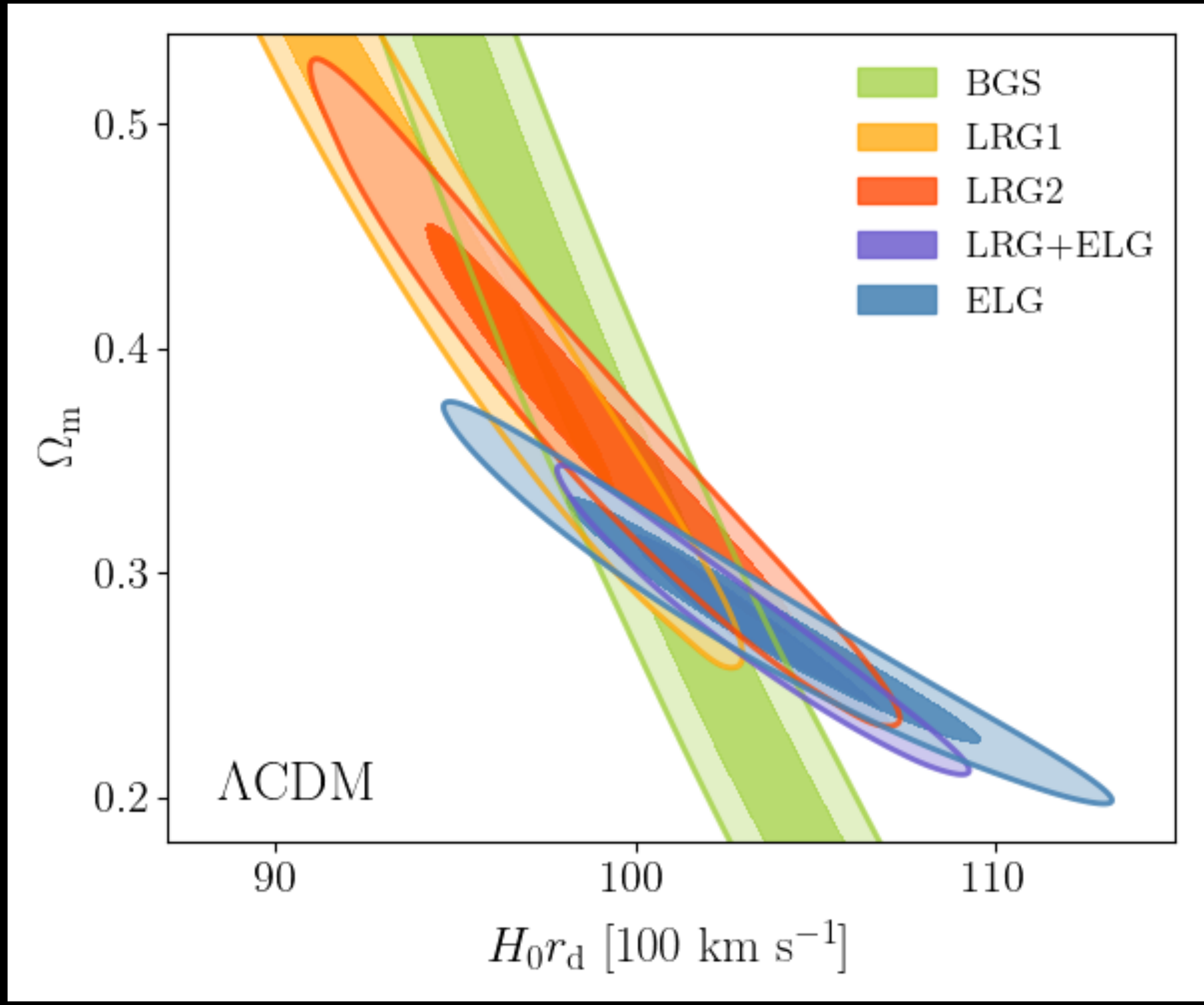

DESI DR2 BAO

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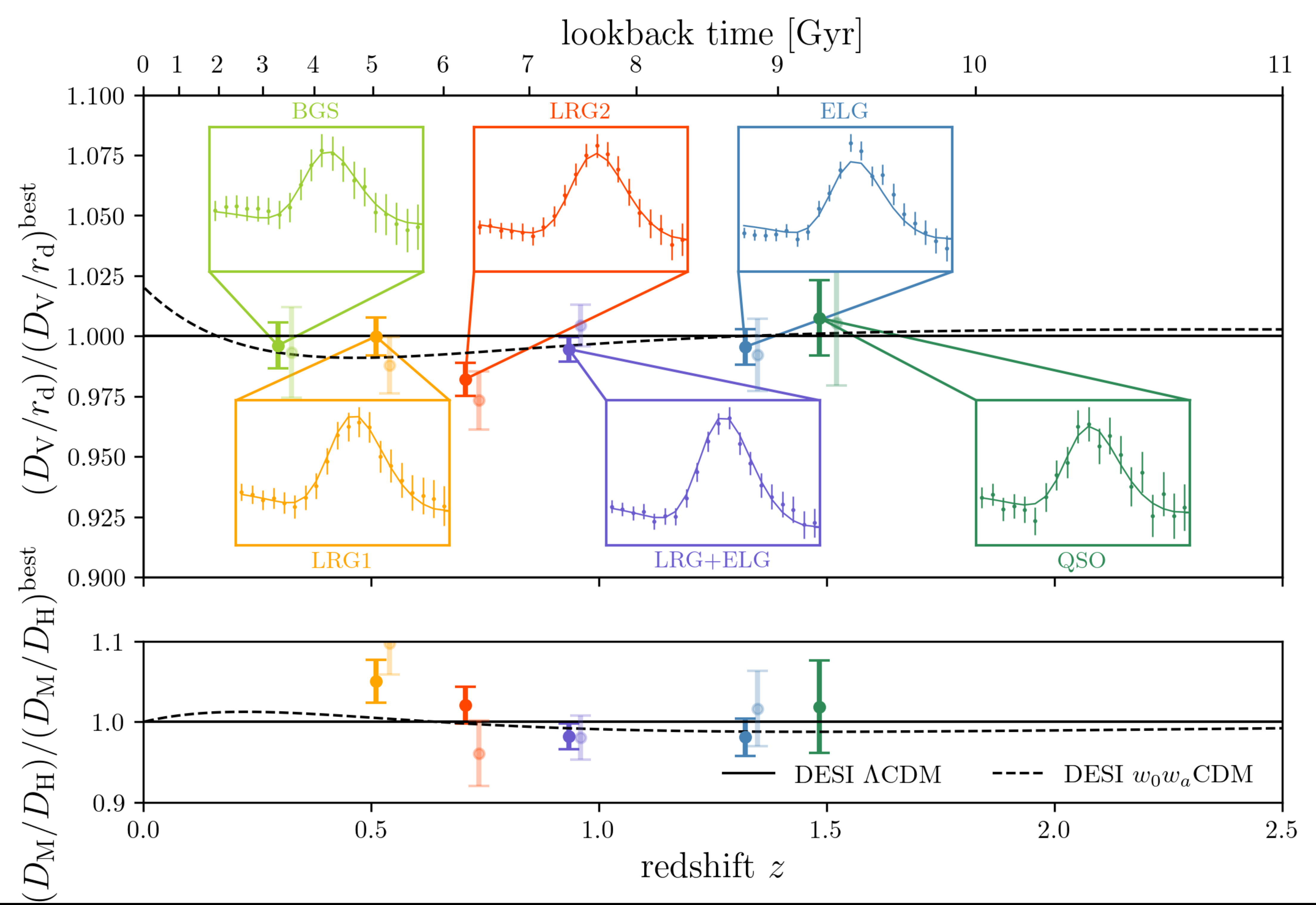

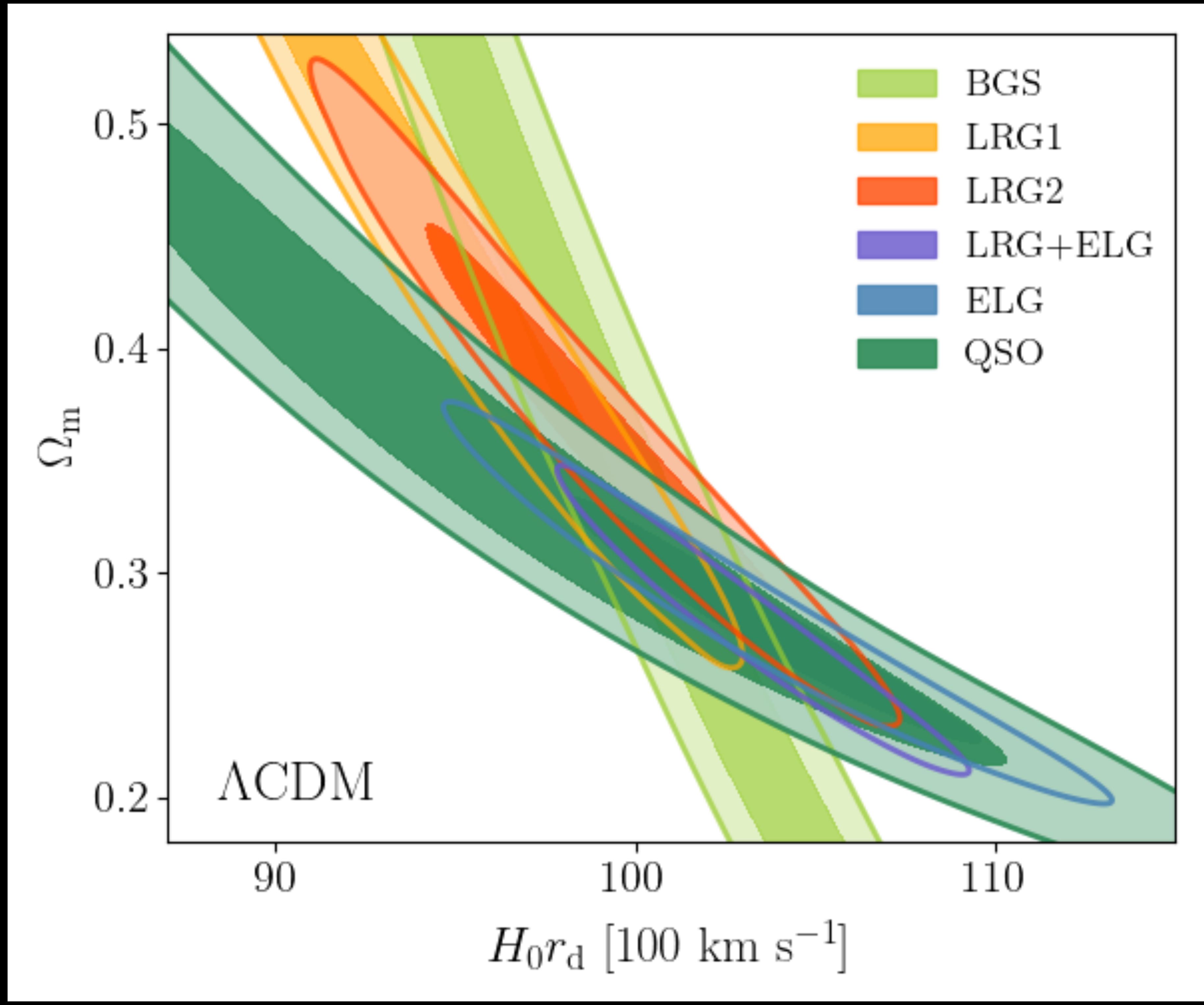

DESI DR2 BAO

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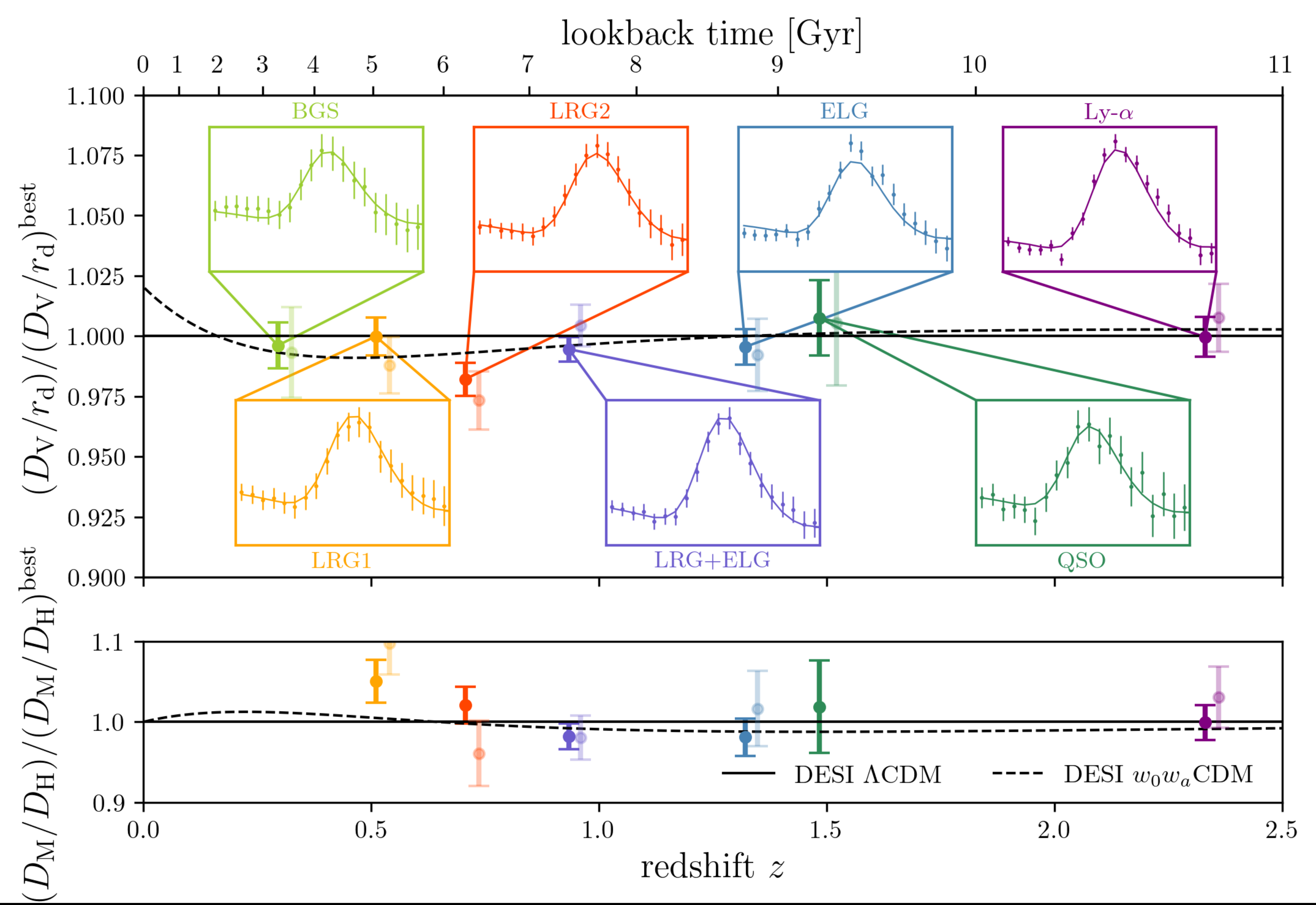
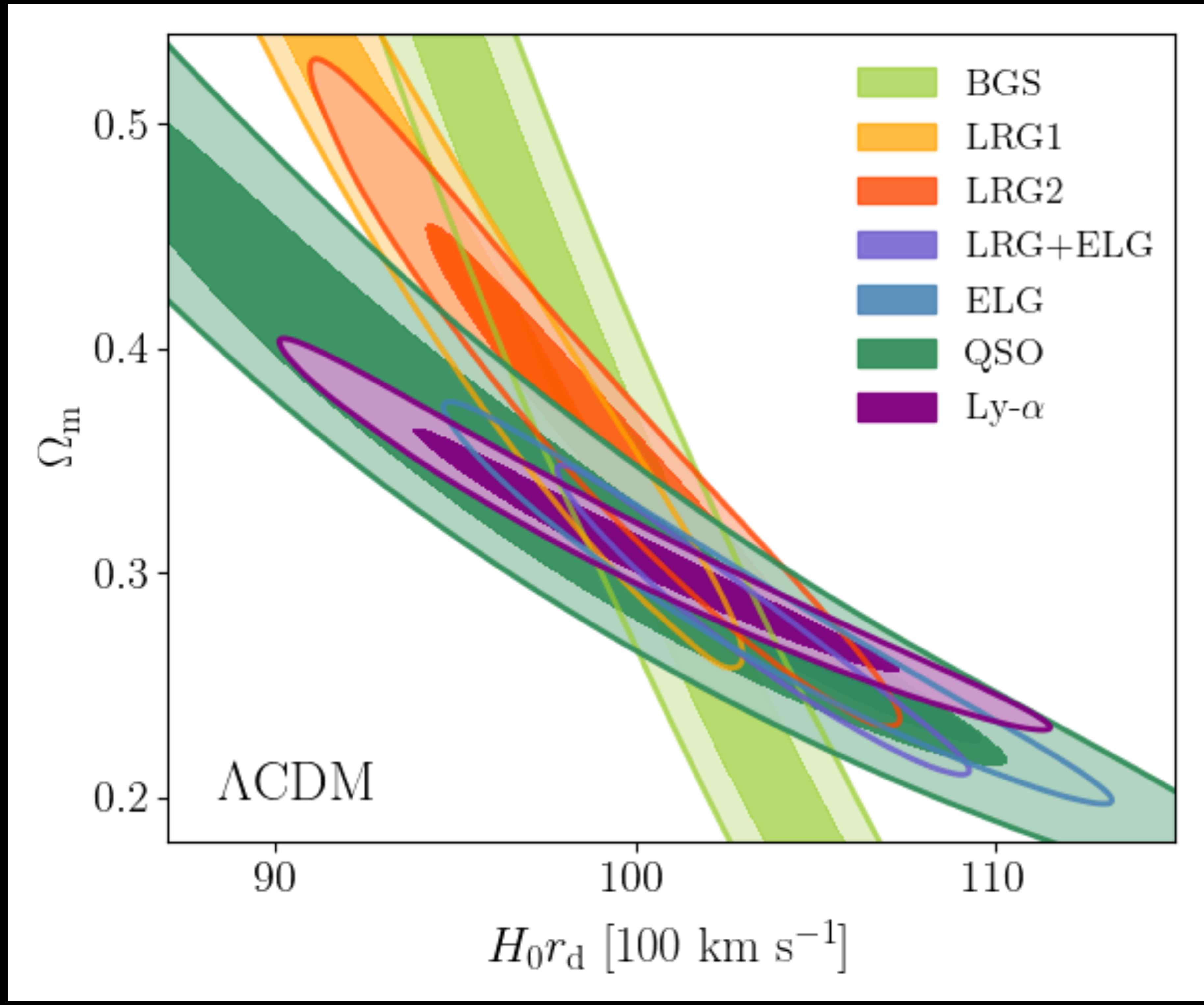




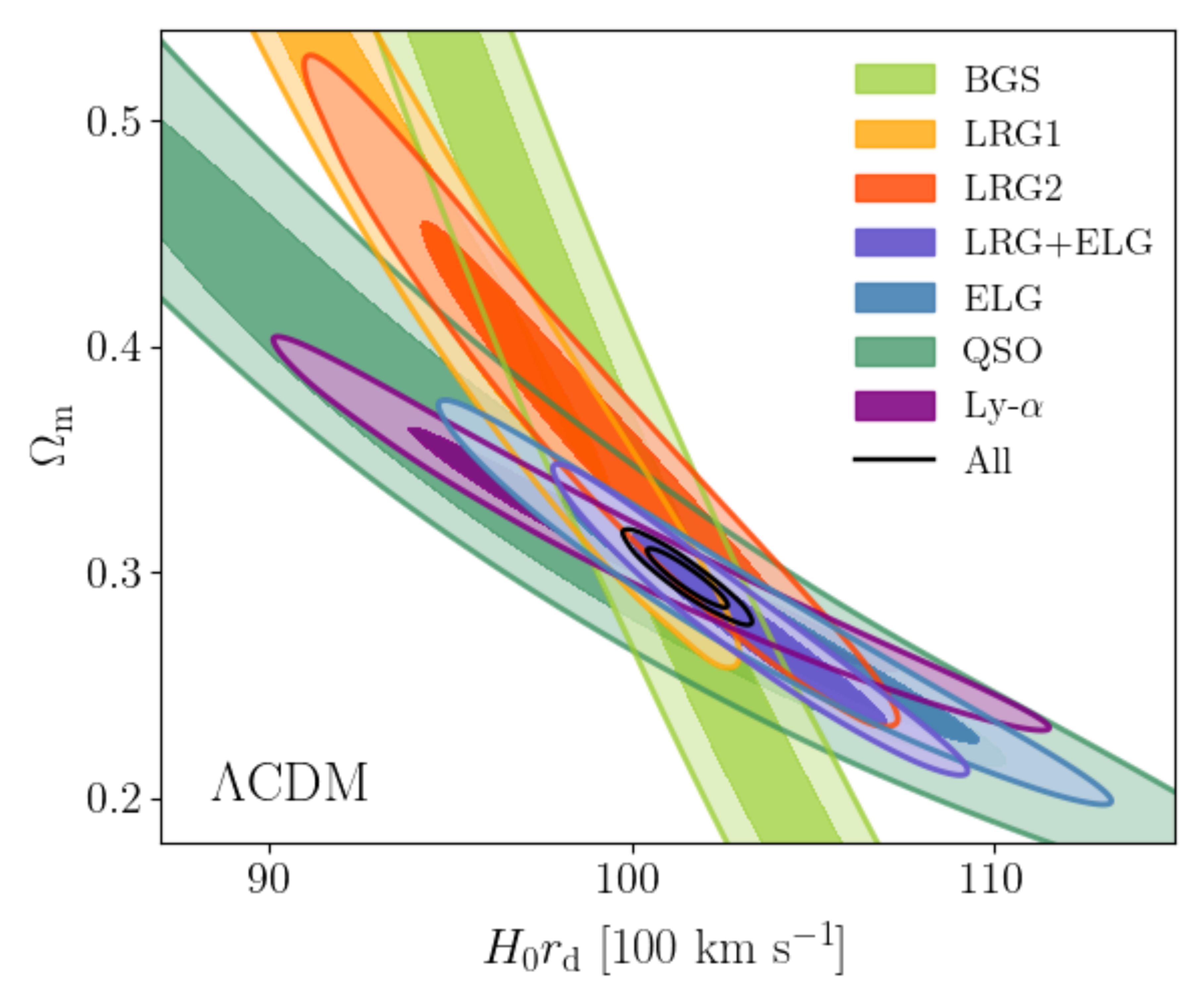
DESI DR2 BAO

DESI DR2 BAO measurements

Consistent with each other —

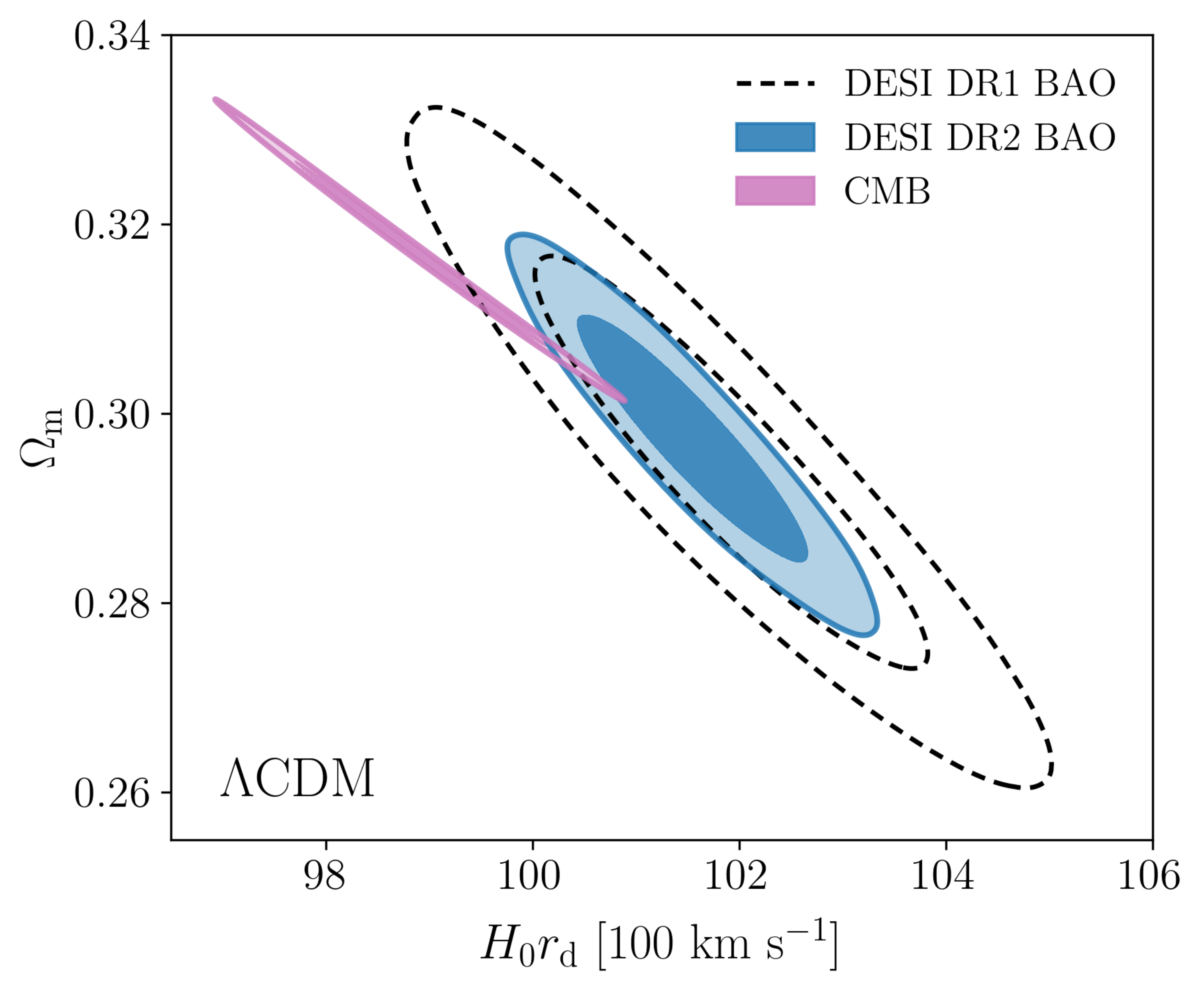
and complementary

$$\underbrace{\begin{aligned} \Omega_m &= 0.2975 \pm 0.0086 & (\mathbf{3.0\%}) \\ H_0 r_d &= (101.54 \pm 0.73)\,[100\,\mathrm{km\,s^{-1}}] & (\mathbf{0.7\%}) \end{aligned}}_{\text{DESI}}$$




Main Results
II. Constraints under ΛCDM

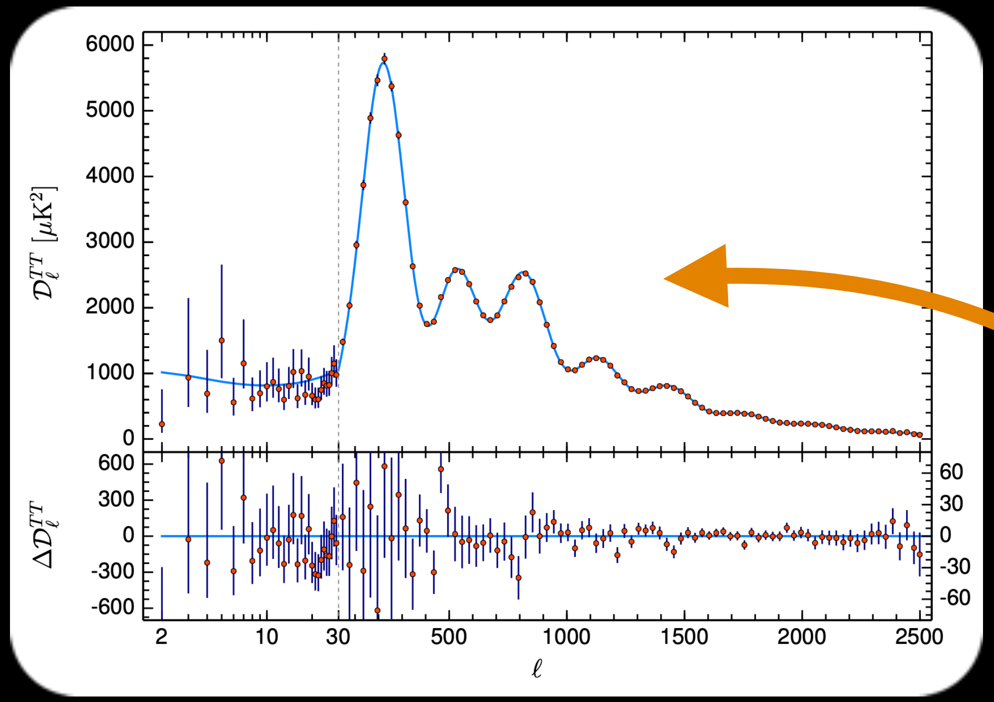
Constraints under ΛCDM

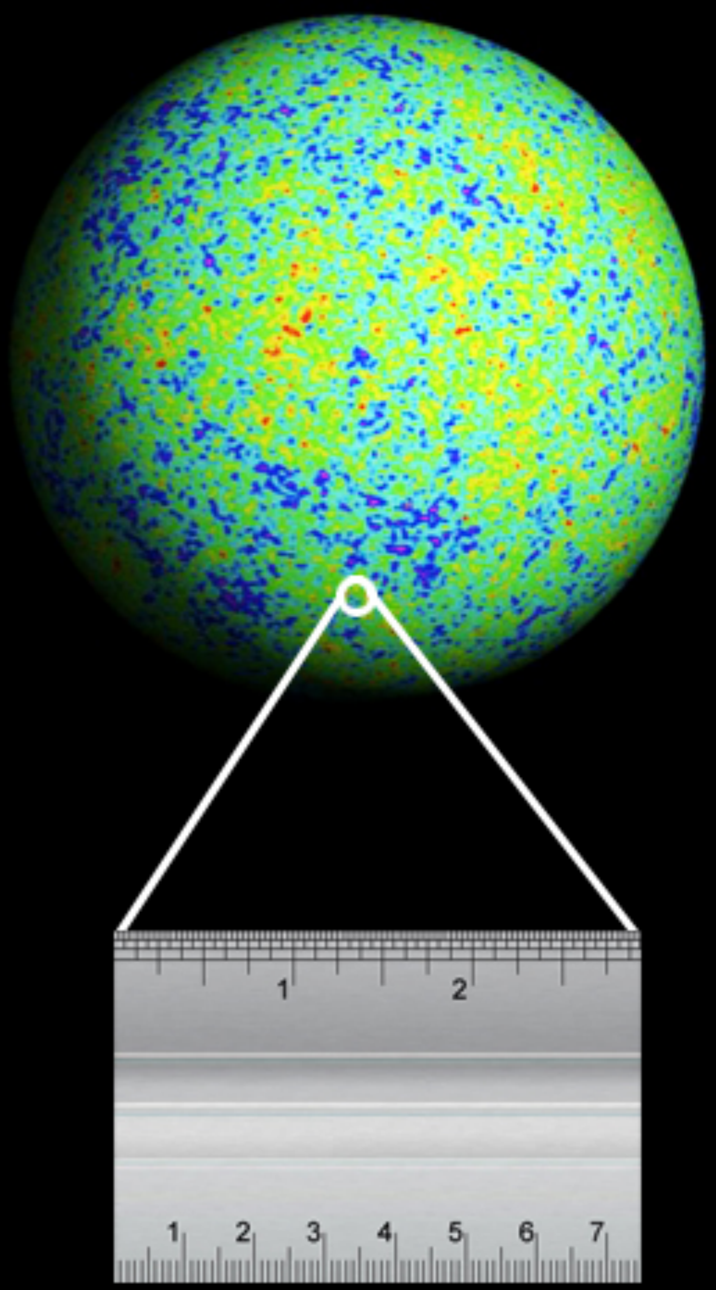


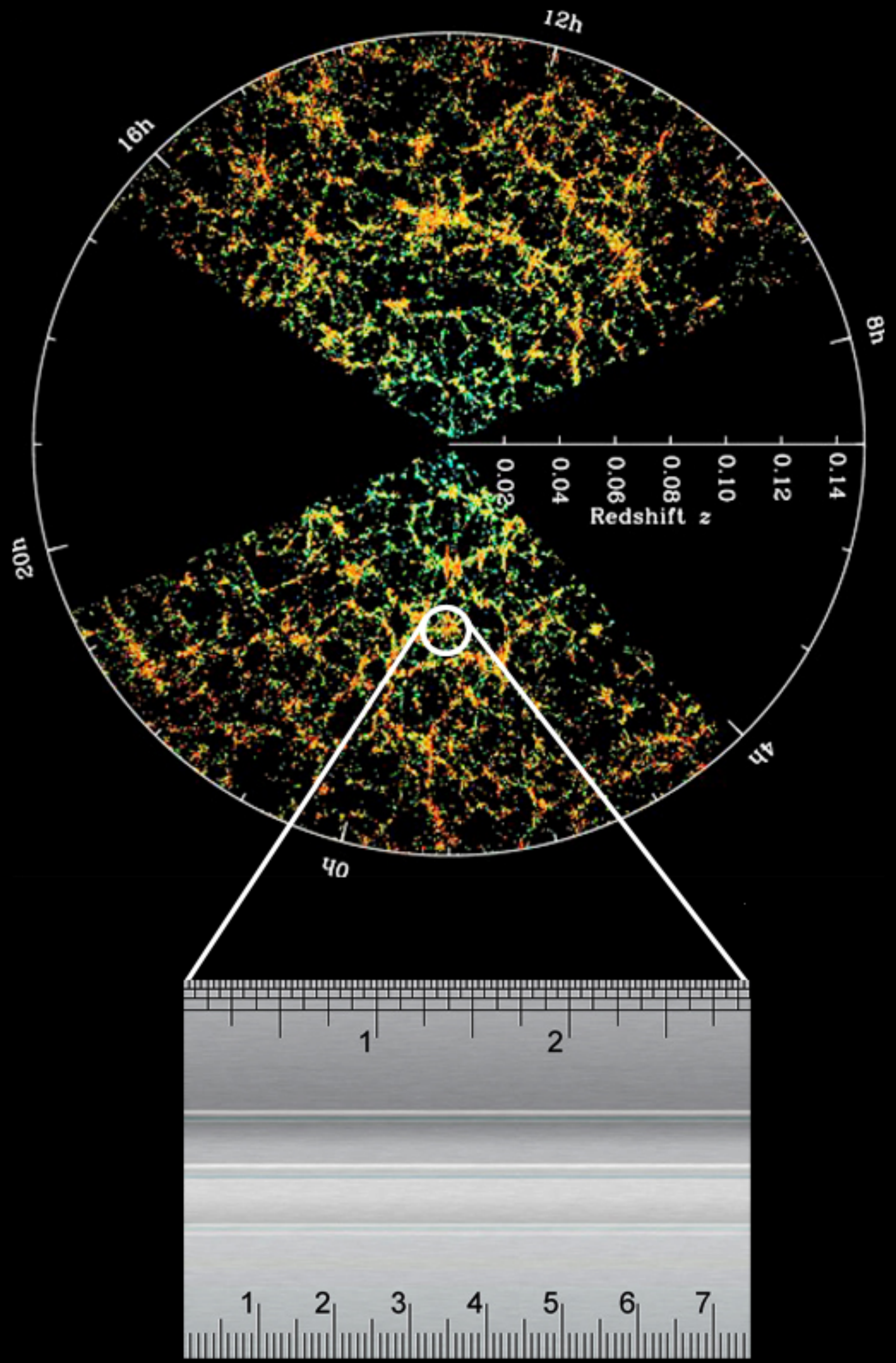
- 40% Improvement in the precision on Ω_m and hr_d compared to DR1.
- Discrepancy between BAO and primary primary CMB[1] + CMB lensing[2] has increased: 1.9σ (DR1) $\Rightarrow$ 2.3σ (DR2).

$$\underbrace{\begin{array}{ll} \Omega_m = 0.2975 \pm 0.0086 & (\mathbf{5.1}\%) \\ hr_d = (101.54 \pm 0.73)\ \mathrm{Mpc} & (\mathbf{0.3}\%) \end{array}}_{\text{DESI DR2}}$$

1. Planck PR4 CamSpec
2. Planck PR4 + ACT DR6 lensing







An external calibration on r_d allows us to constrain H_0 with BAO data.

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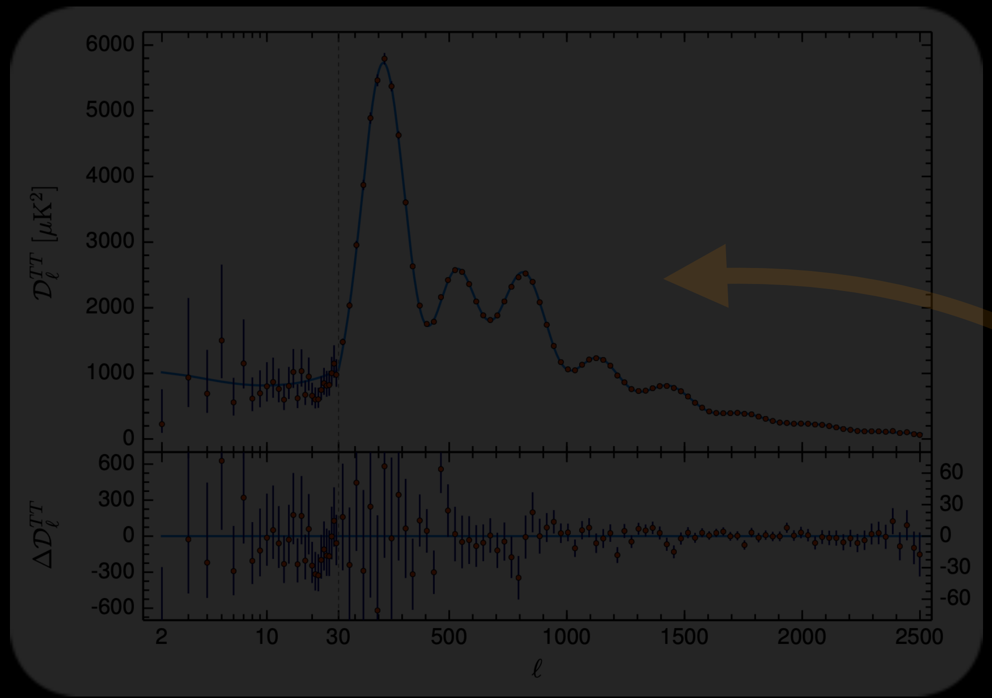

Big Bang Nucleosynthesis (**BBN**) prior (Schöneberg 2024):

$$\Omega_b h^2 = 0.02196 \pm 0.00063$$

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Constraints under ΛCDM

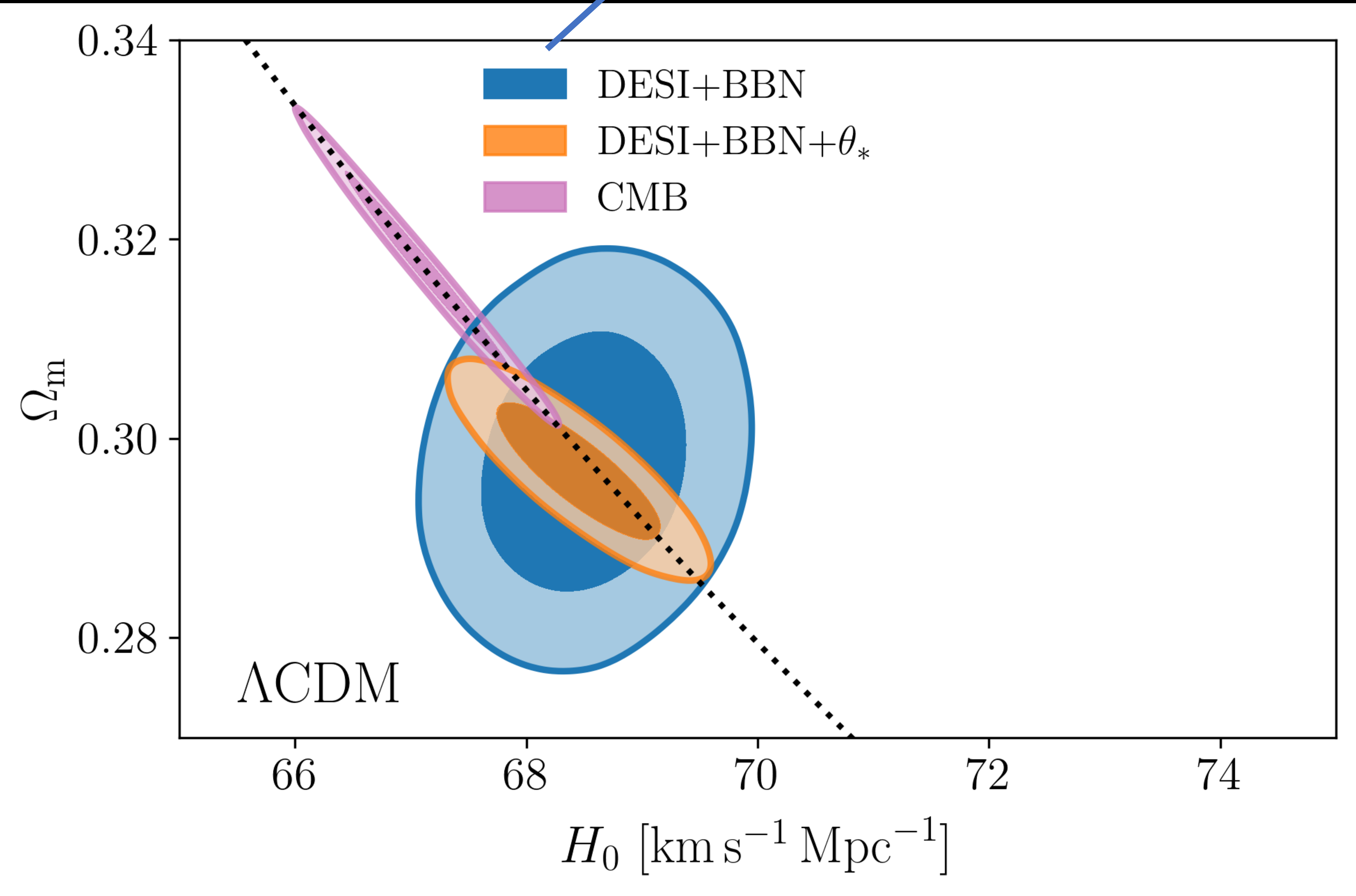
- By calibrating the BAO relative distance measurements using a BBN prior on ω_b, we obtain

$$\underbrace{H_0 = (68.51 \pm 0.58)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}}_{\text{DESI + BBN}}$$

- Adding a prior on the angular acoustic scale θ_* :

$$\underbrace{H_0 = (68.45 \pm 0.47)\,\mathrm{km\,s^{-1}\,Mpc^{-1}}}_{\text{DESI} + \theta_\star + \text{BBN}}$$

28% more precise than DR1



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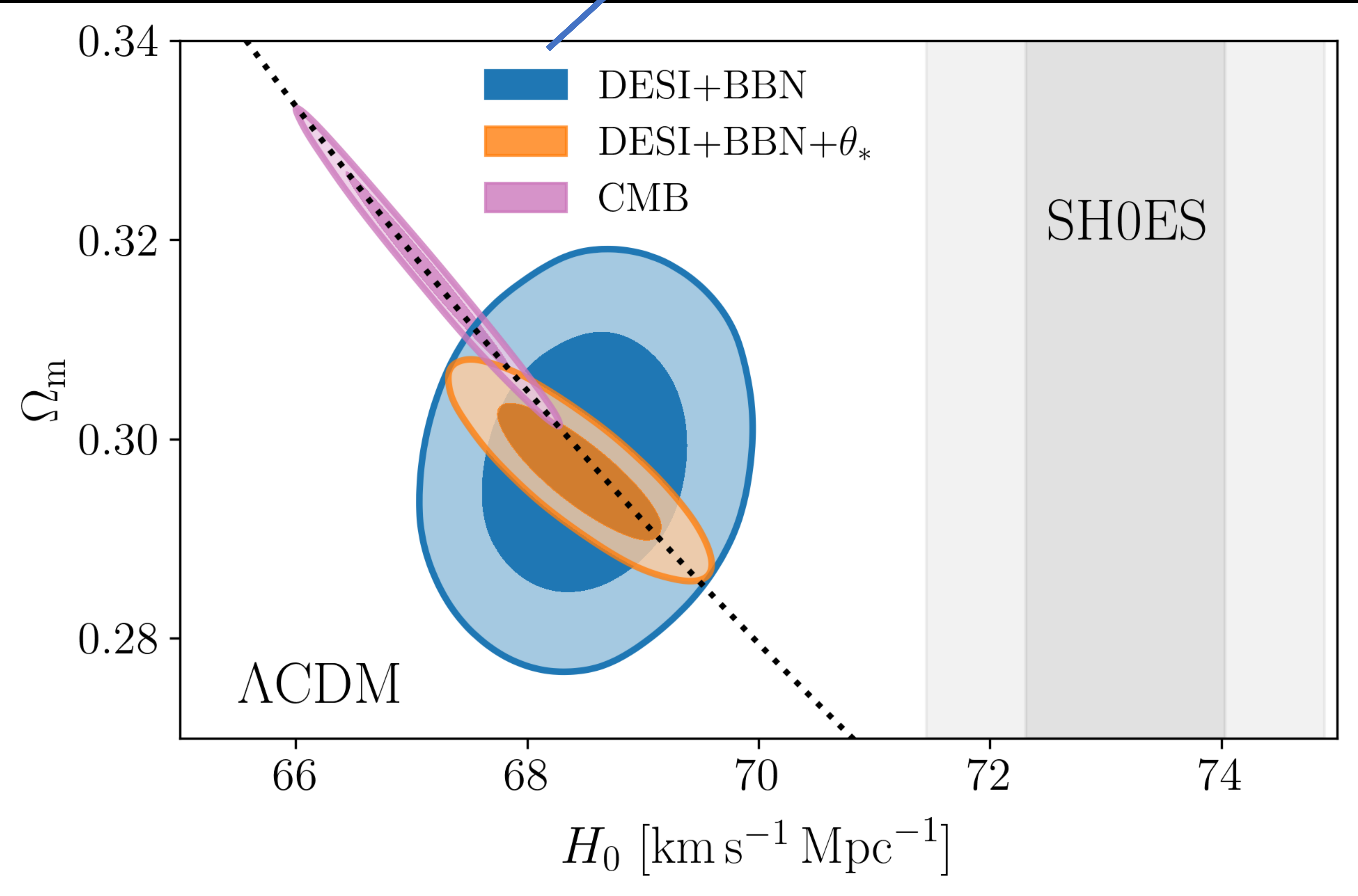
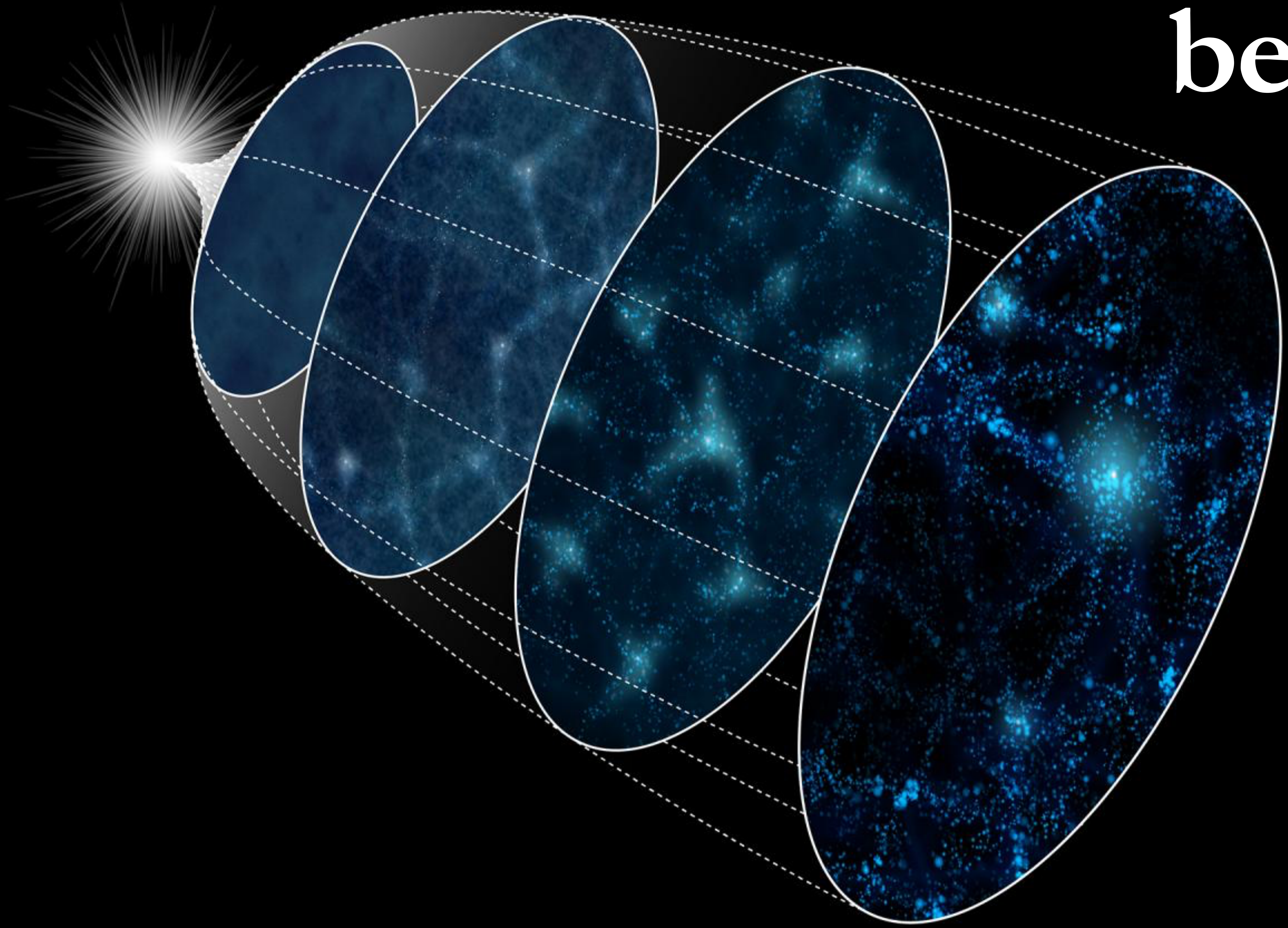
- In 4.5σ tension with SH0ES (Breuval et al. 2024) (independently of the CMB)

28% more precise than DR1



II. Dark Energy beyond ΛCDM



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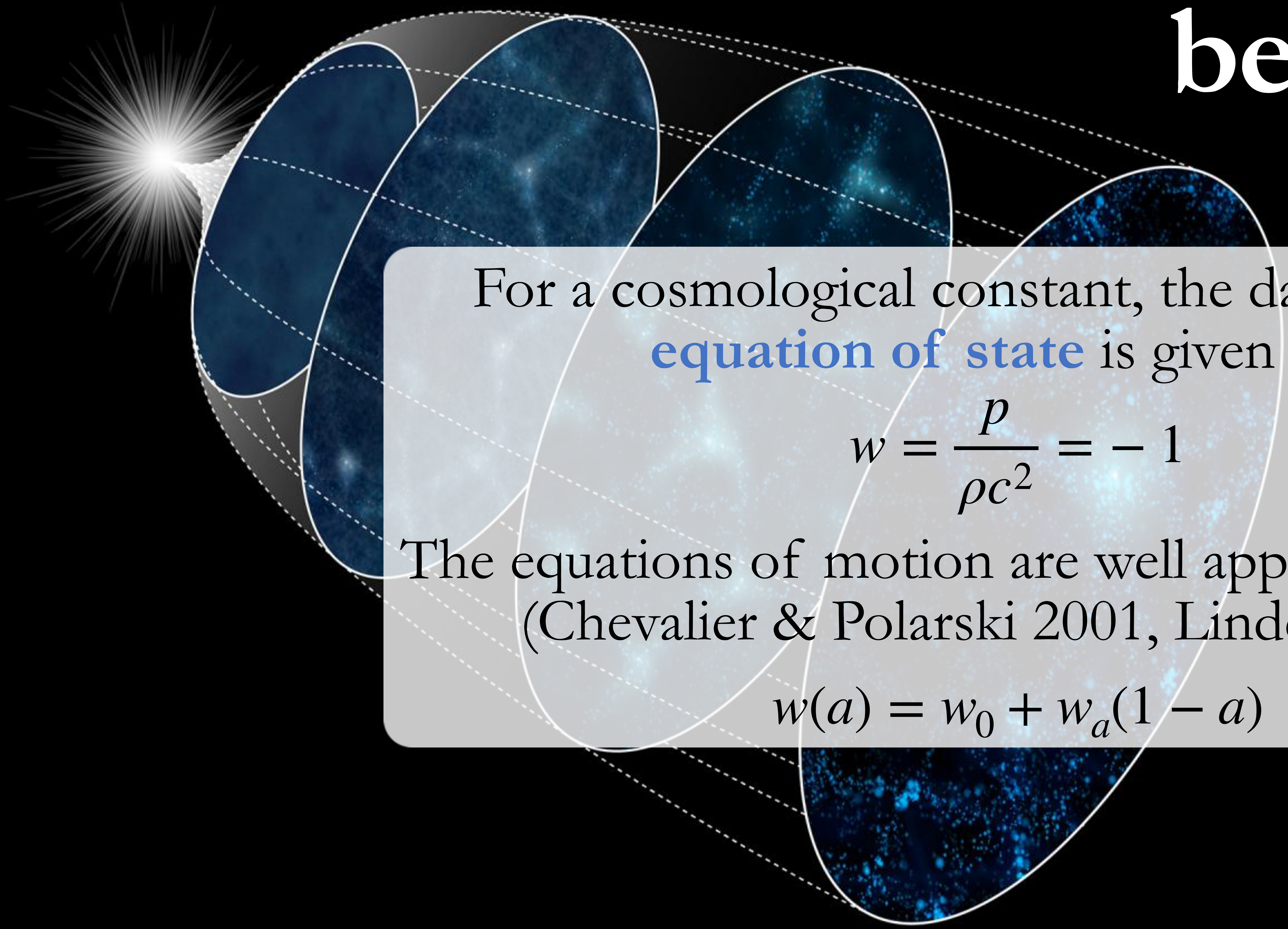


For a cosmological constant, the dark energy **equation of state** is given by

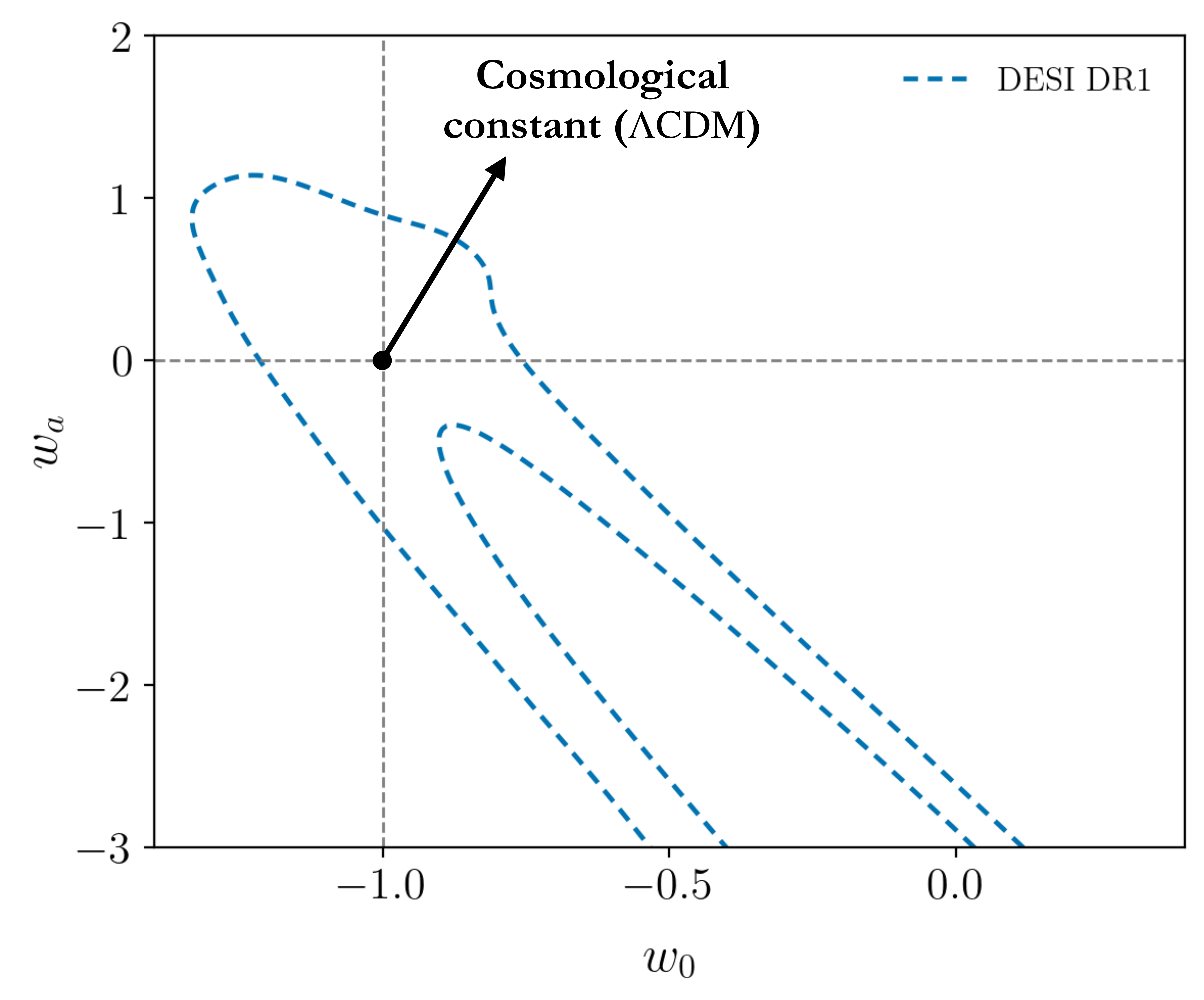
$$w = \frac{p}{\rho c^2} = -1$$

The equations of motion are well approximated by (Chevalier & Polarski 2001, Linder 2003)

$$w(a) = w_0 + w_a(1 - a)$$

Dynamical Dark Energy

- BAO data define a degeneracy direction in the w_0-w_a plane.
- No strong preference for dark energy evolution: 1.7σ from DESI data alone
- BAO data by itself does not rule out the cosmological constant, but its combination with more data sets leads to tight constraints.



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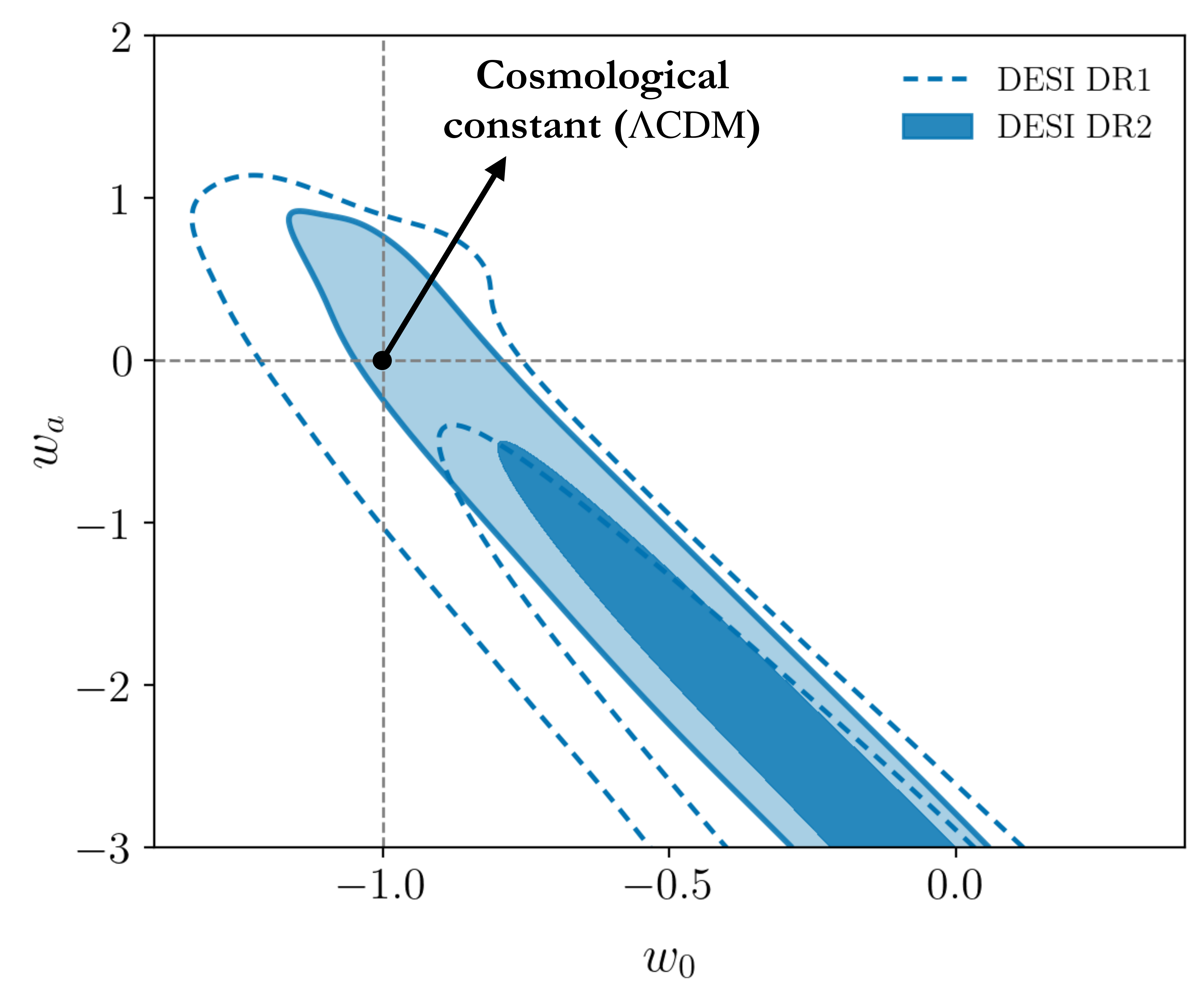
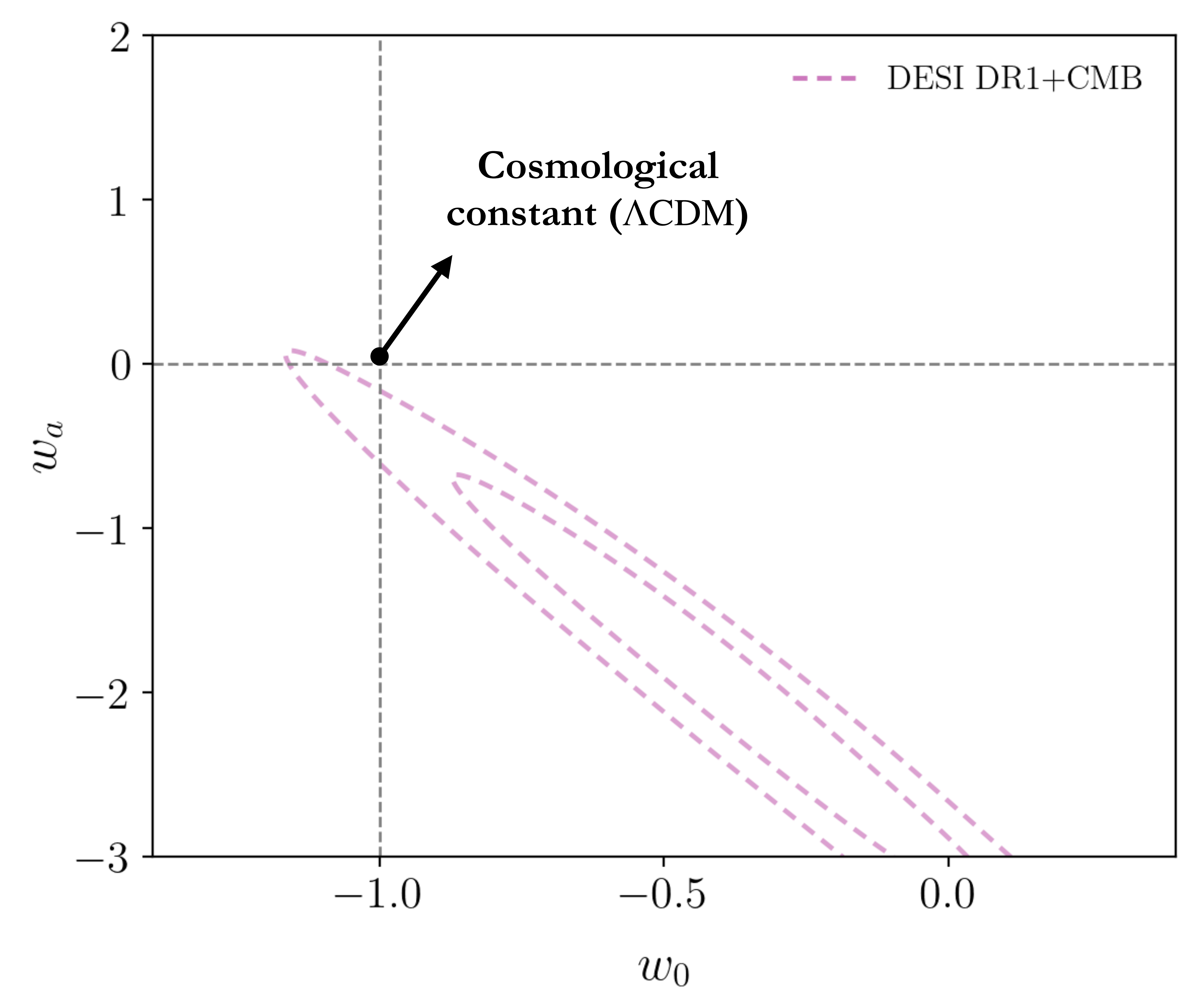


Dynamical Dark Energy

- Last year: 2.6σ preference for evolving dark energy from DESI BAO+CMB

$\longrightarrow$ 3.1σ in DR2

$$\underbrace{w_0 = -0.42 \pm 0.21 \qquad w_a = -1.75 \pm 0.58}_{\text{DESI + CMB} \implies 3.1\sigma}$$



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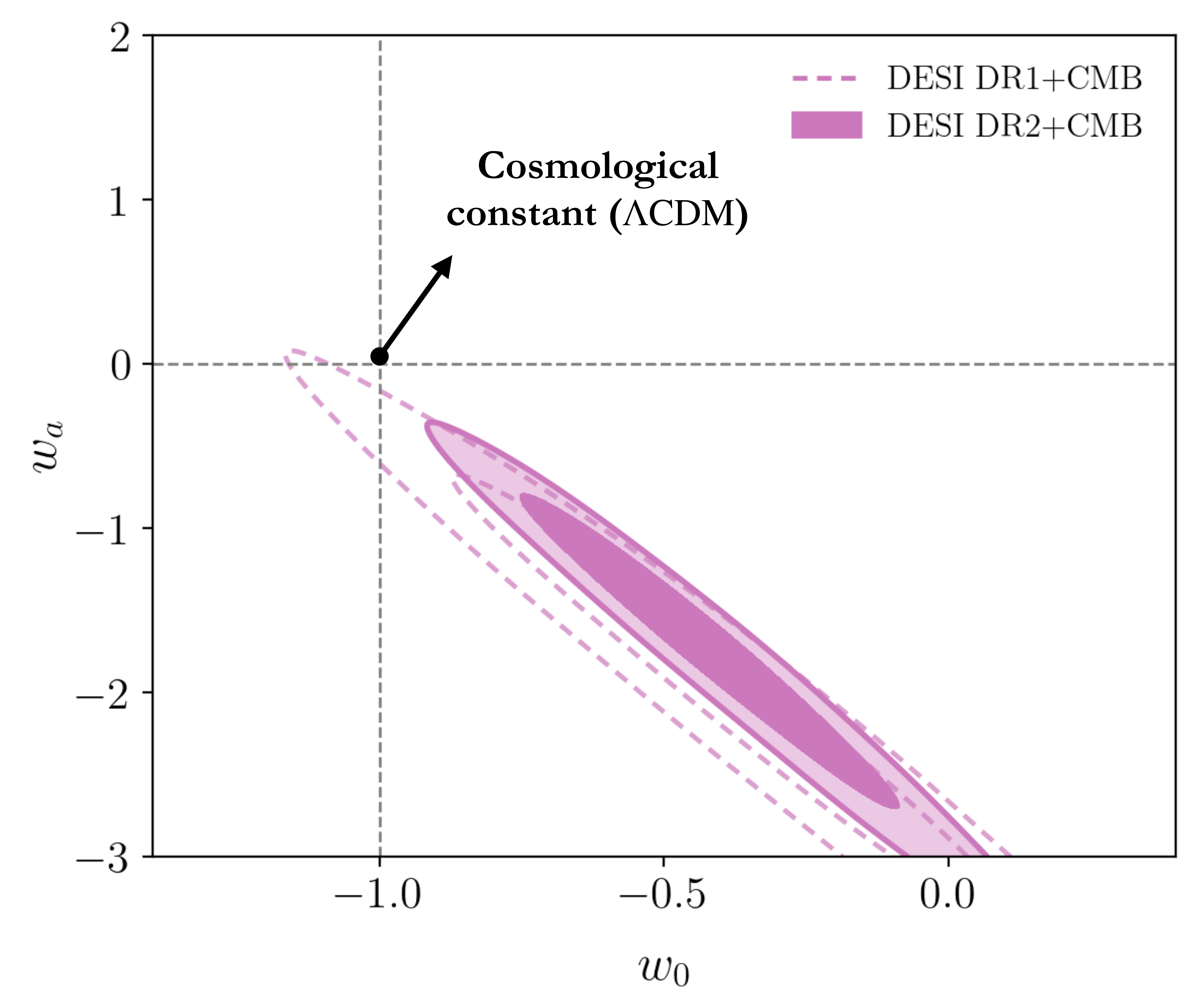
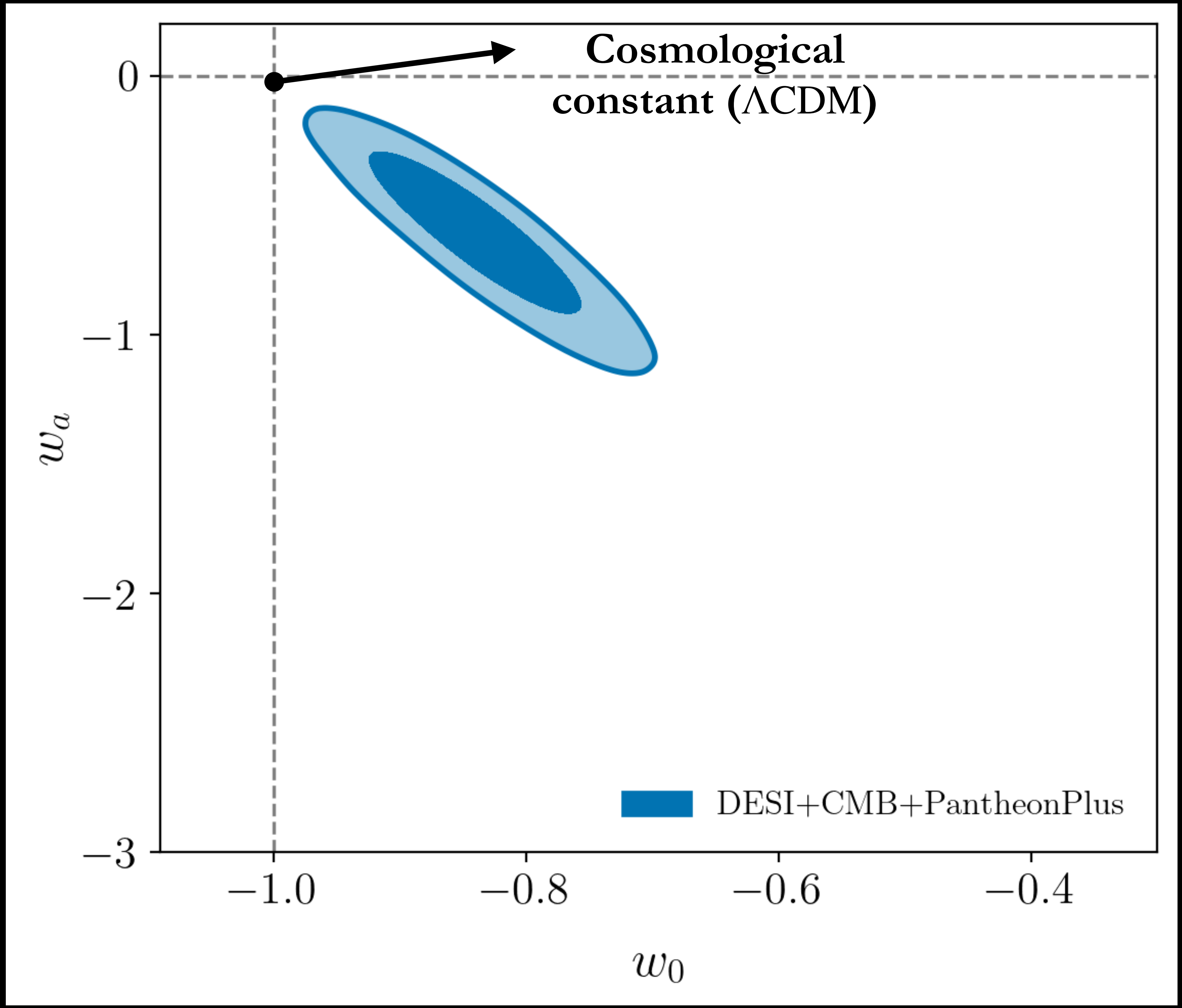


Dynamical Dark Energy

$$\underbrace{w_0 = -0.838 \pm 0.055 \qquad w_a = -0.62^{+0.22}_{-0.19}}_{\text{DESI + CMB + Pantheon+} \quad \Longrightarrow \quad 2.8\sigma}$$



Dynamical Dark Energy

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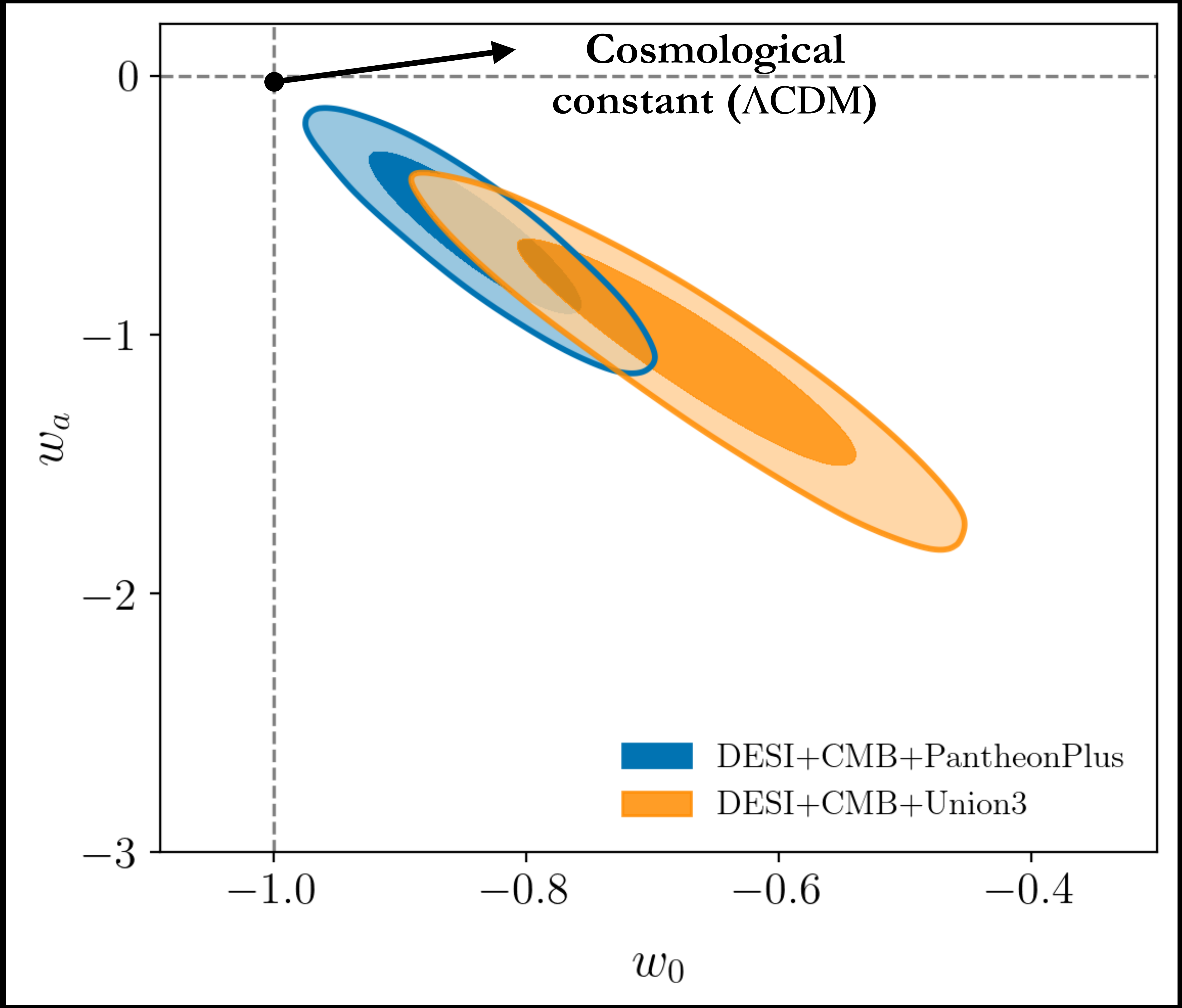
DESI + CMB + Pantheon+ $\implies$ 2.8σ

$$\underbrace{w_0 = -\,0.667 \pm 0.088 \qquad w_a = -\,1.09^{+0.31}_{-0.27}}$$

DESI + CMB + Union3 $\implies$ 3.8σ



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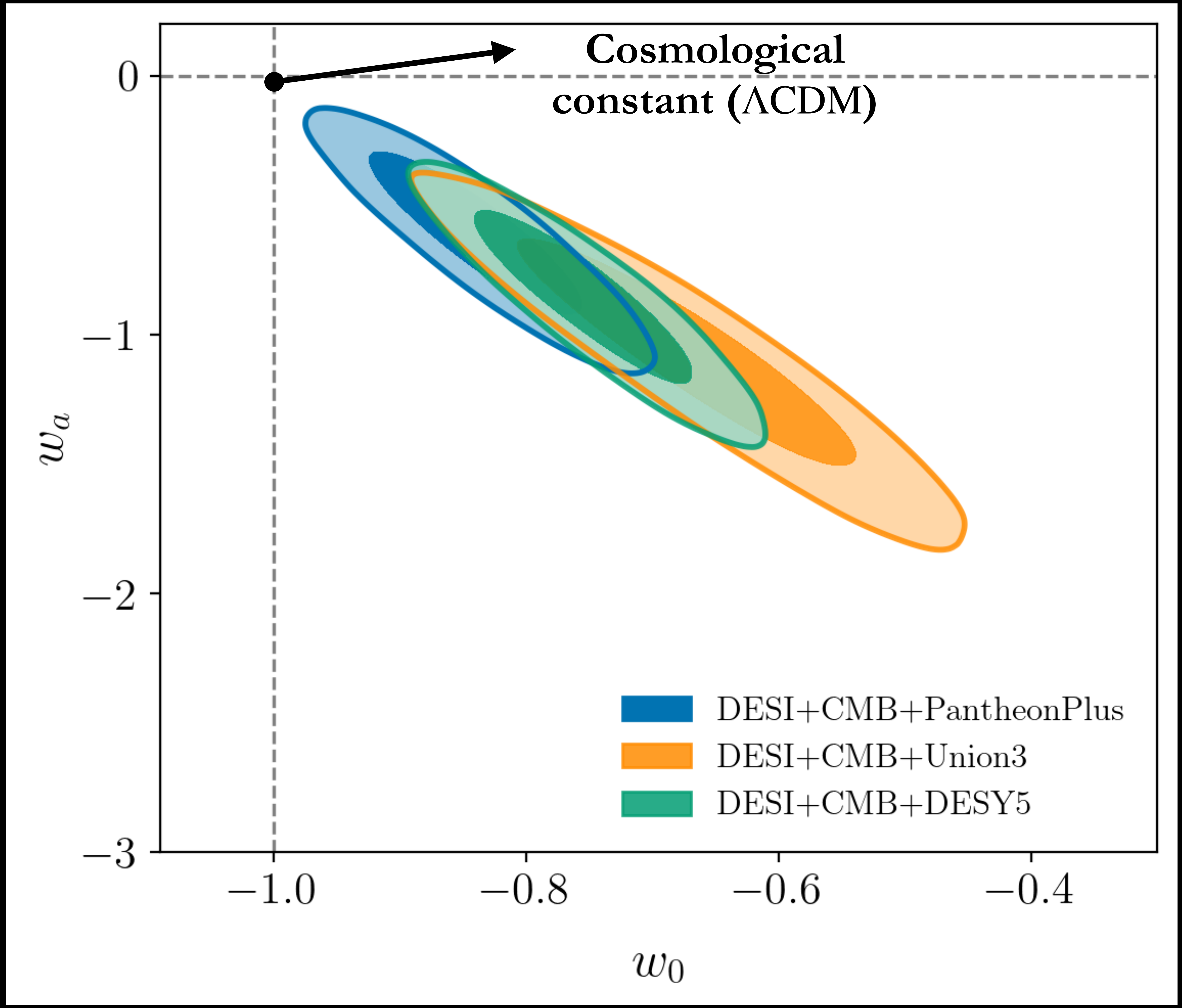
DESI + CMB + Union3 $\implies$ 3.8σ

$$\underbrace{w_0 = -0.752 \pm 0.057 \qquad w_a = -0.86^{+0.23}_{-0.20}}$$

DESI + CMB + DES-SN5YR $\implies$ 4.2σ



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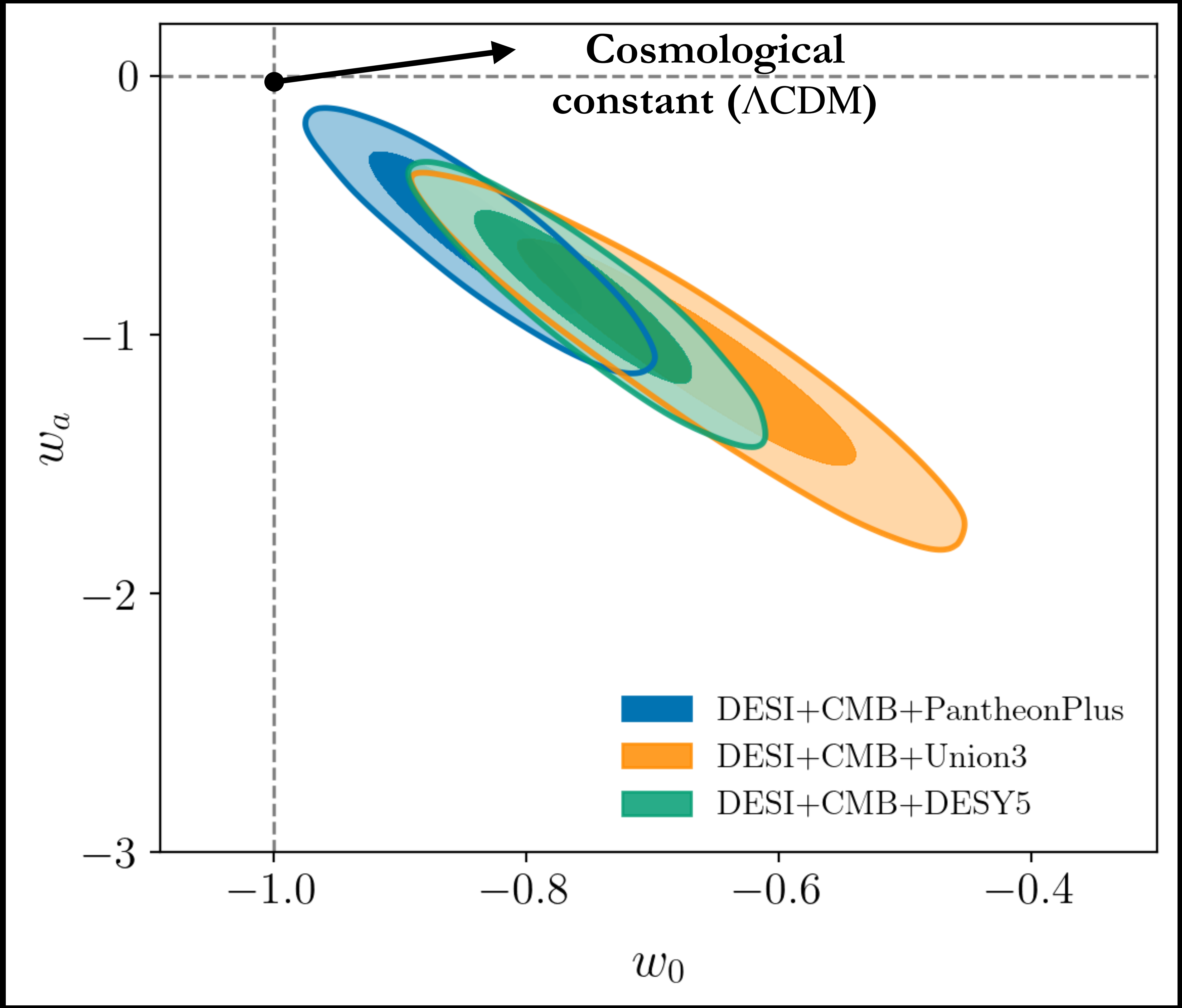
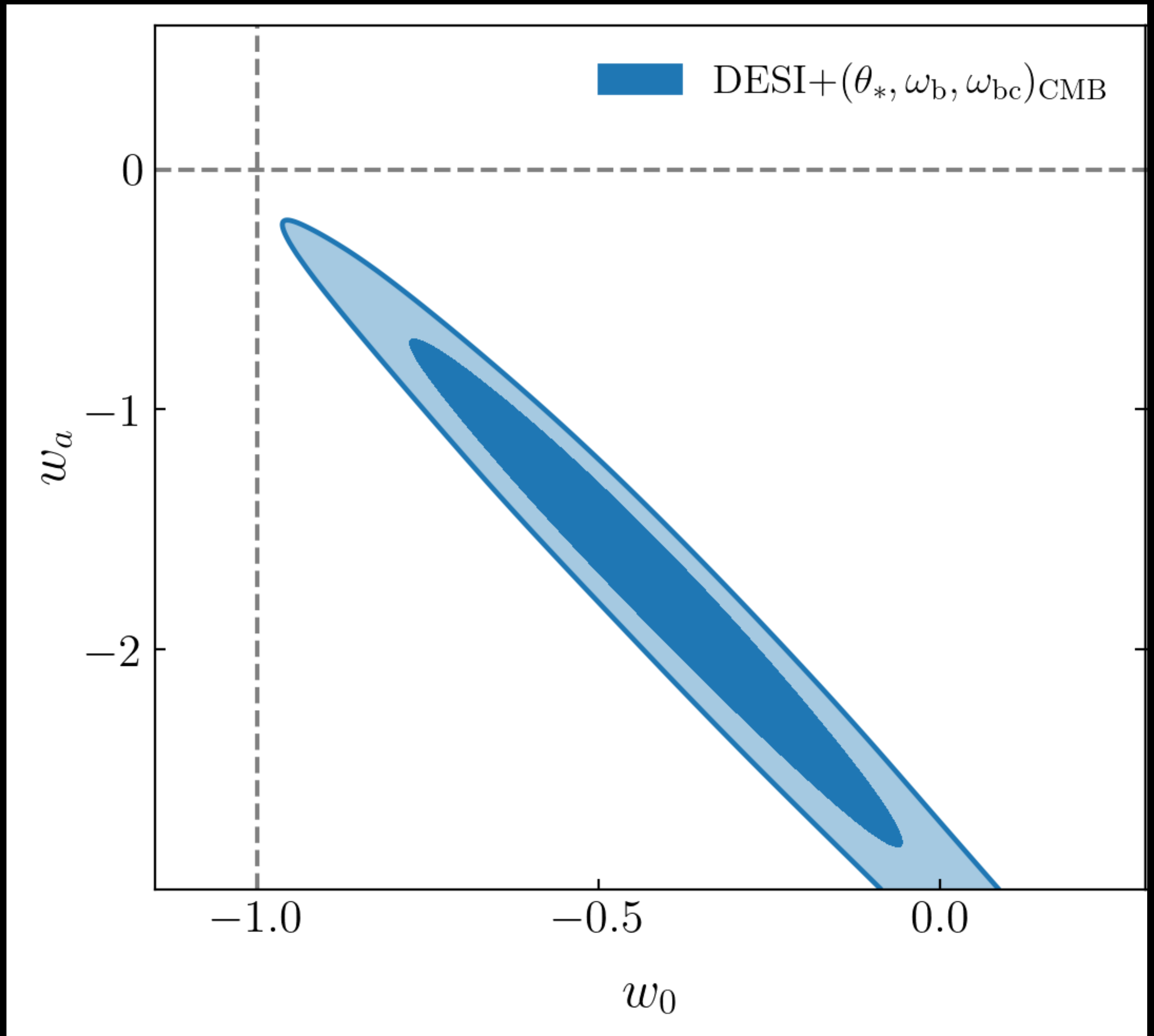
$+0.3\sigma$ compared to DR1



Robustness tests



- Combining DESI with **early-Universe priors** on $(\theta_*, \omega_b, \omega_{bc})$ derived from the CMB shows preference for evolving dark energy at the 2.4σ level.

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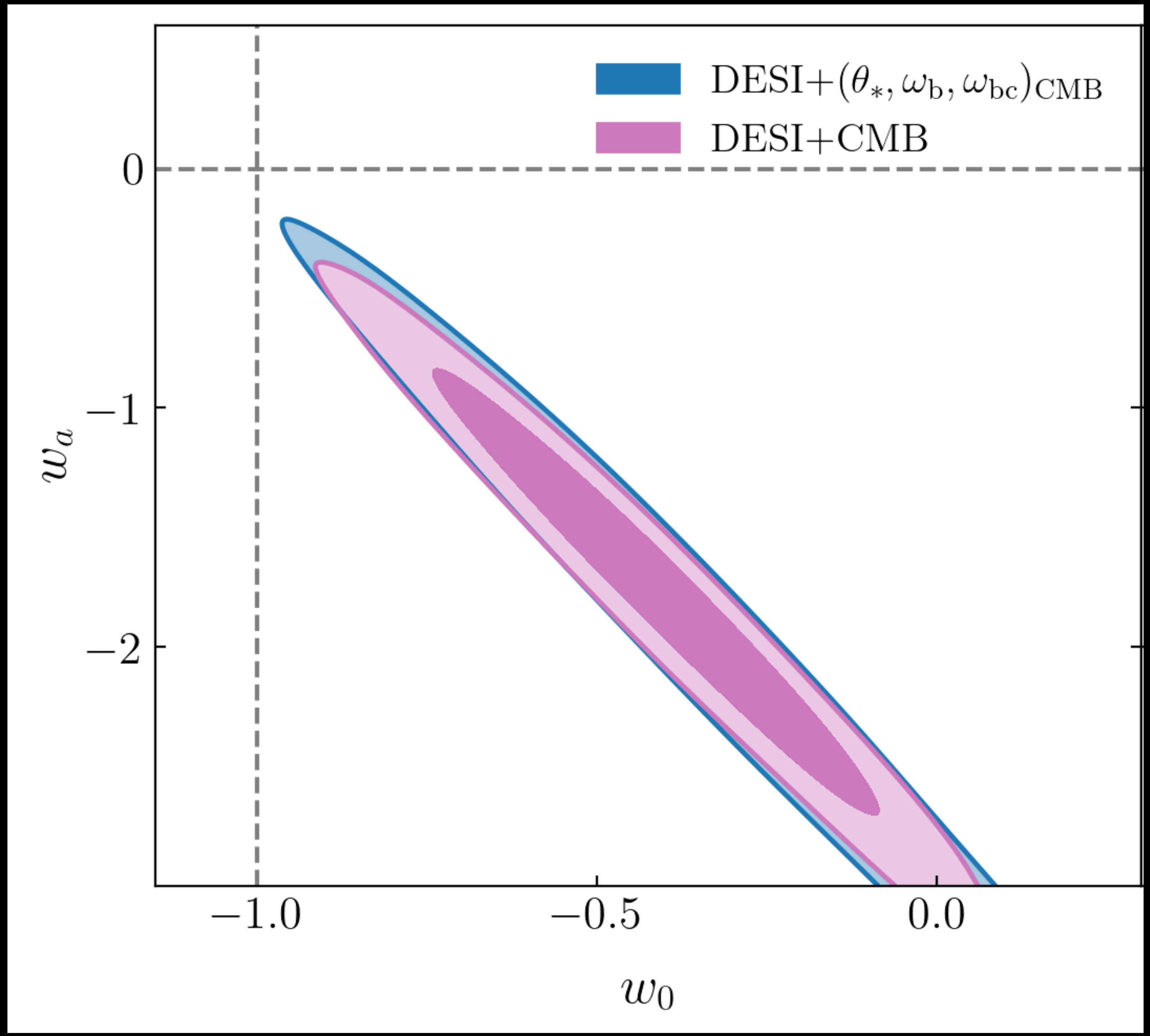
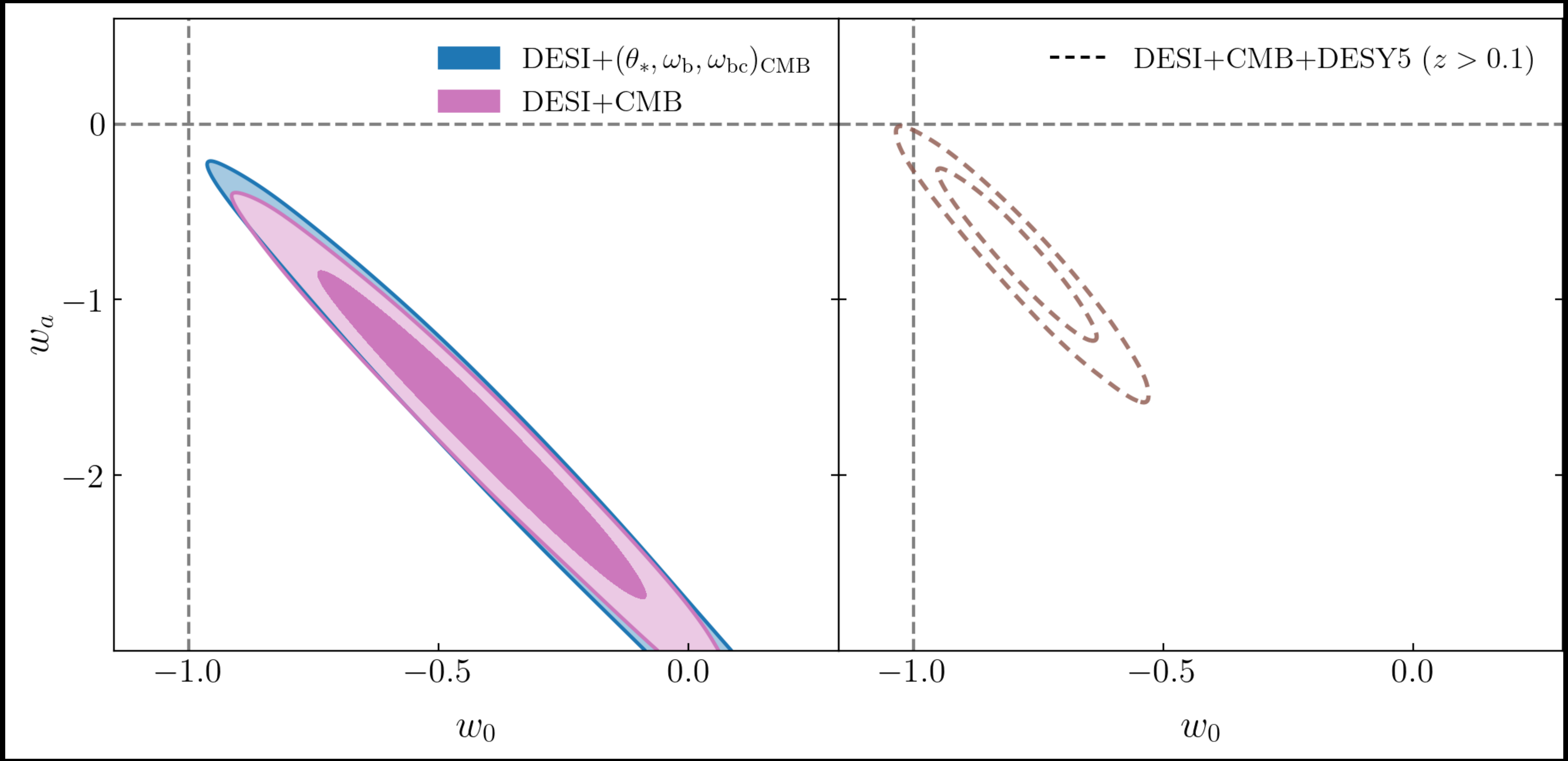
Robustness tests



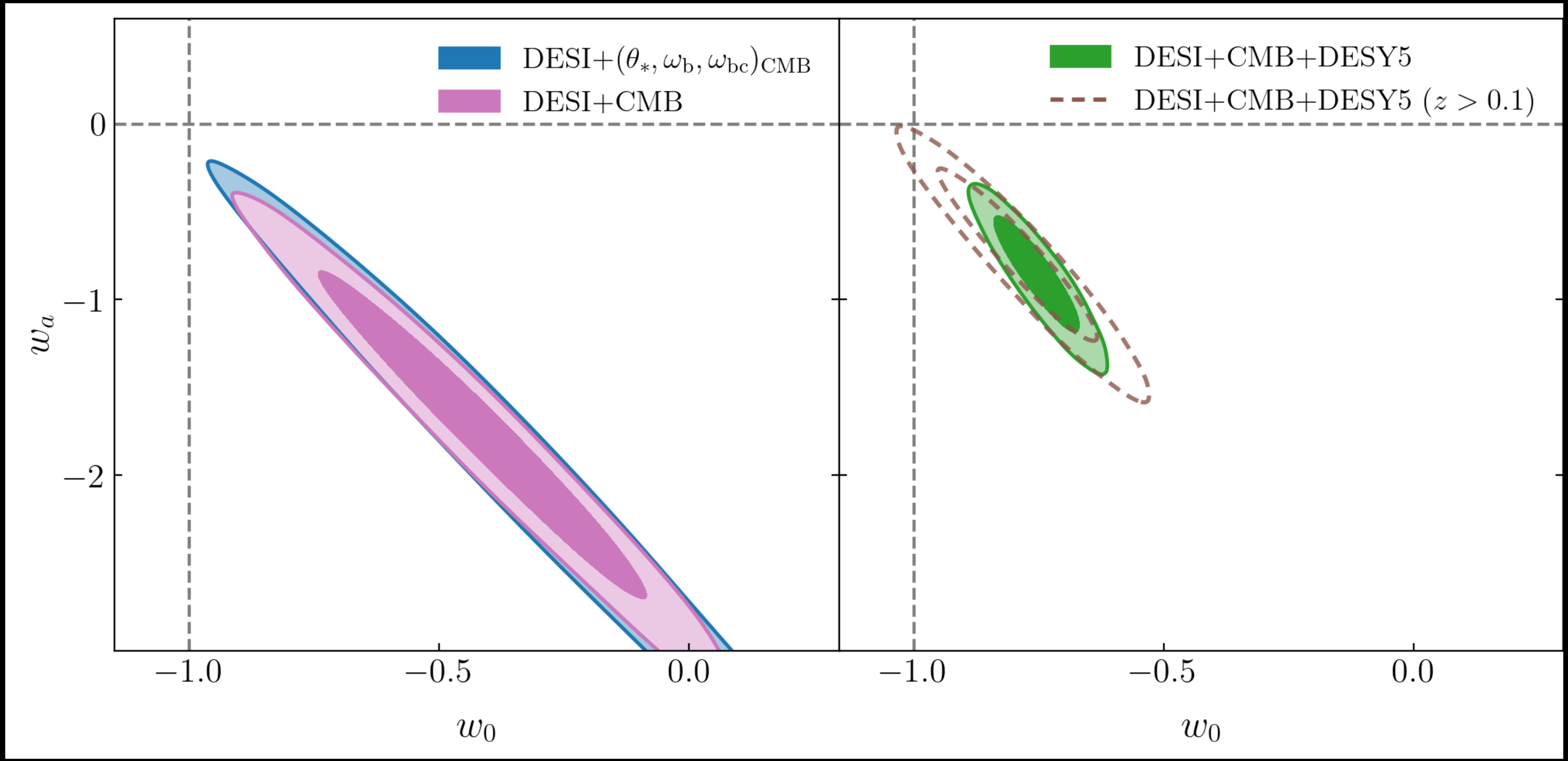
- Combining DESI with **early-Universe priors** on $(\theta_*, \omega_b, \omega_{bc})$ derived from the CMB shows preference for evolving dark energy at the 2.4σ level.

Robustness tests



- **Excluding z < 0.1 SNe** reduces the statistical significance of the dynamical DE detection, but the best-fit values for w_0, w_a remain far from ΛCDM.

Robustness tests



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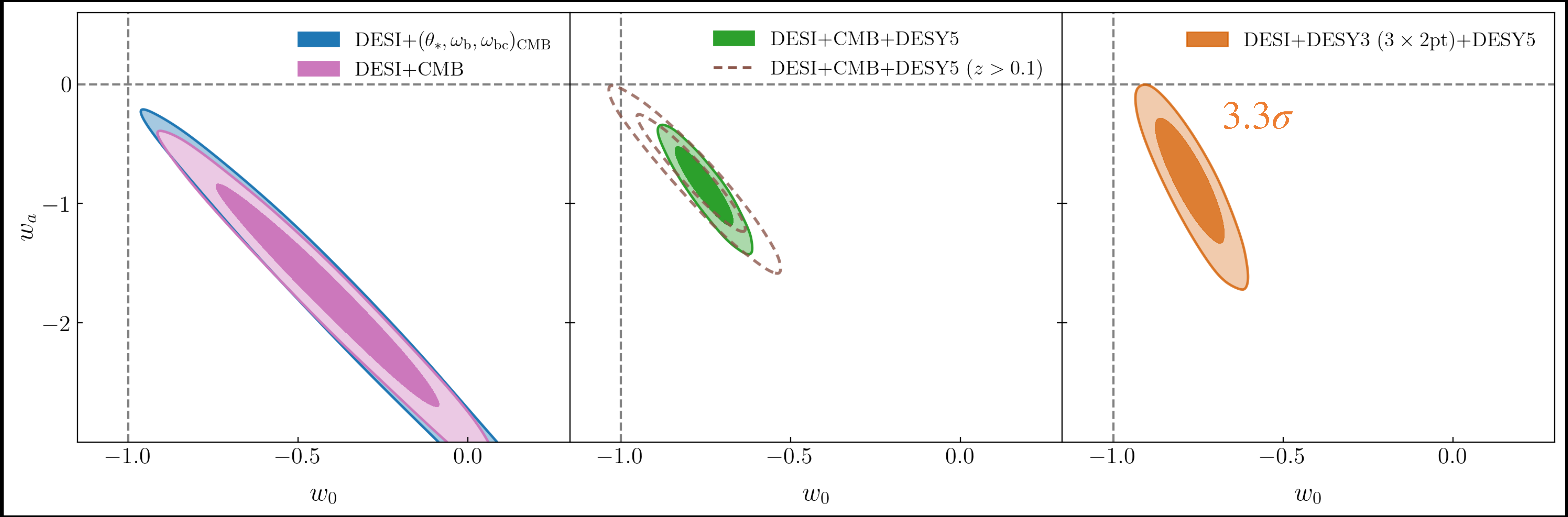
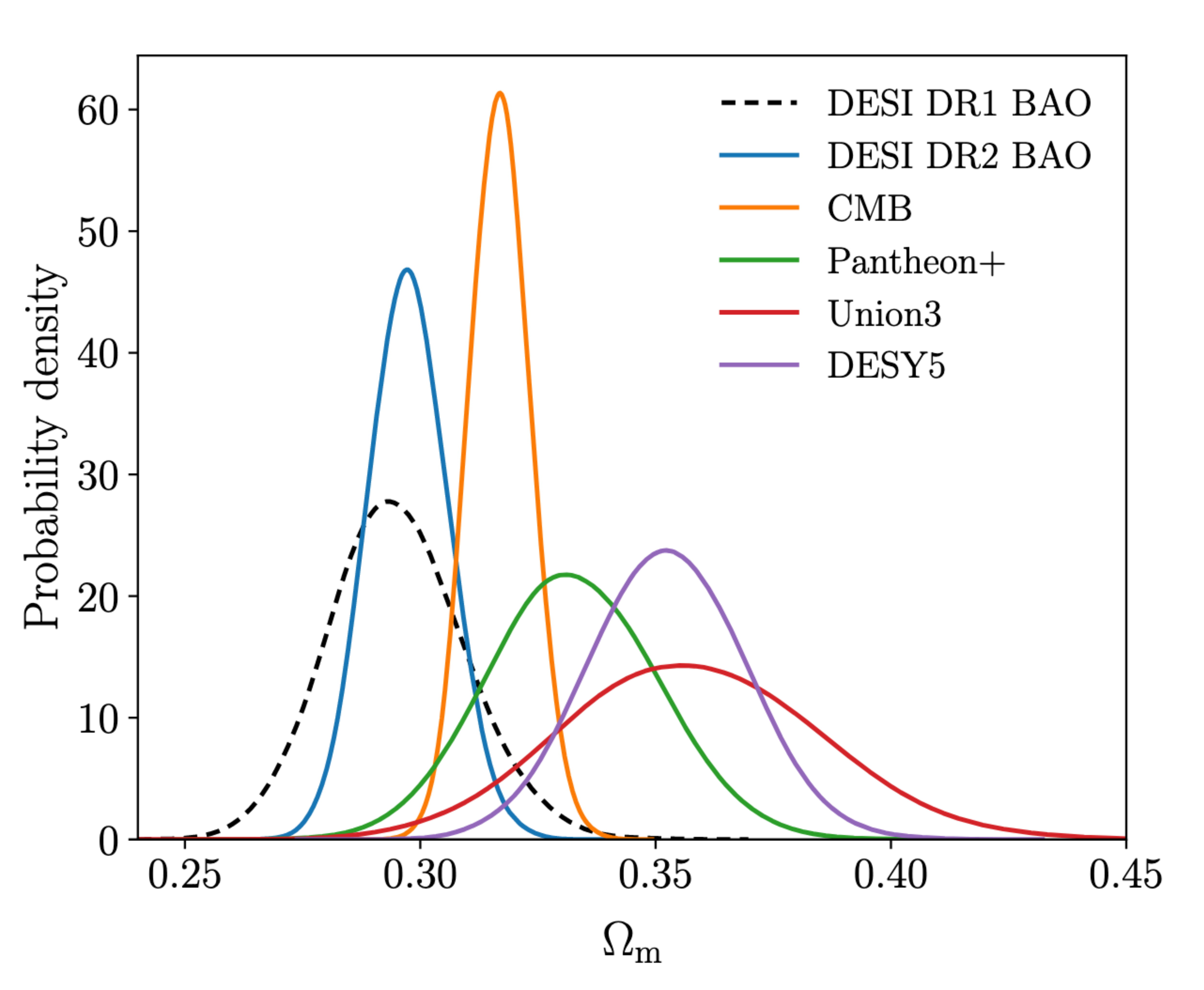


- **Replacing the CMB with DESY3 3x2pt** (weak lensing), we obtain a constraint coming entirely from low-redshift cosmological probes (BAO, weak lensing, SNe).

LCDM: the concordance model?



Understanding tensions

Understanding tensions

doesn't fit the SN!

Understanding tensions

doesn't fit the BAO!

Understanding tensions

***w*CDM not flexible enough to fit all 3 datasets!**

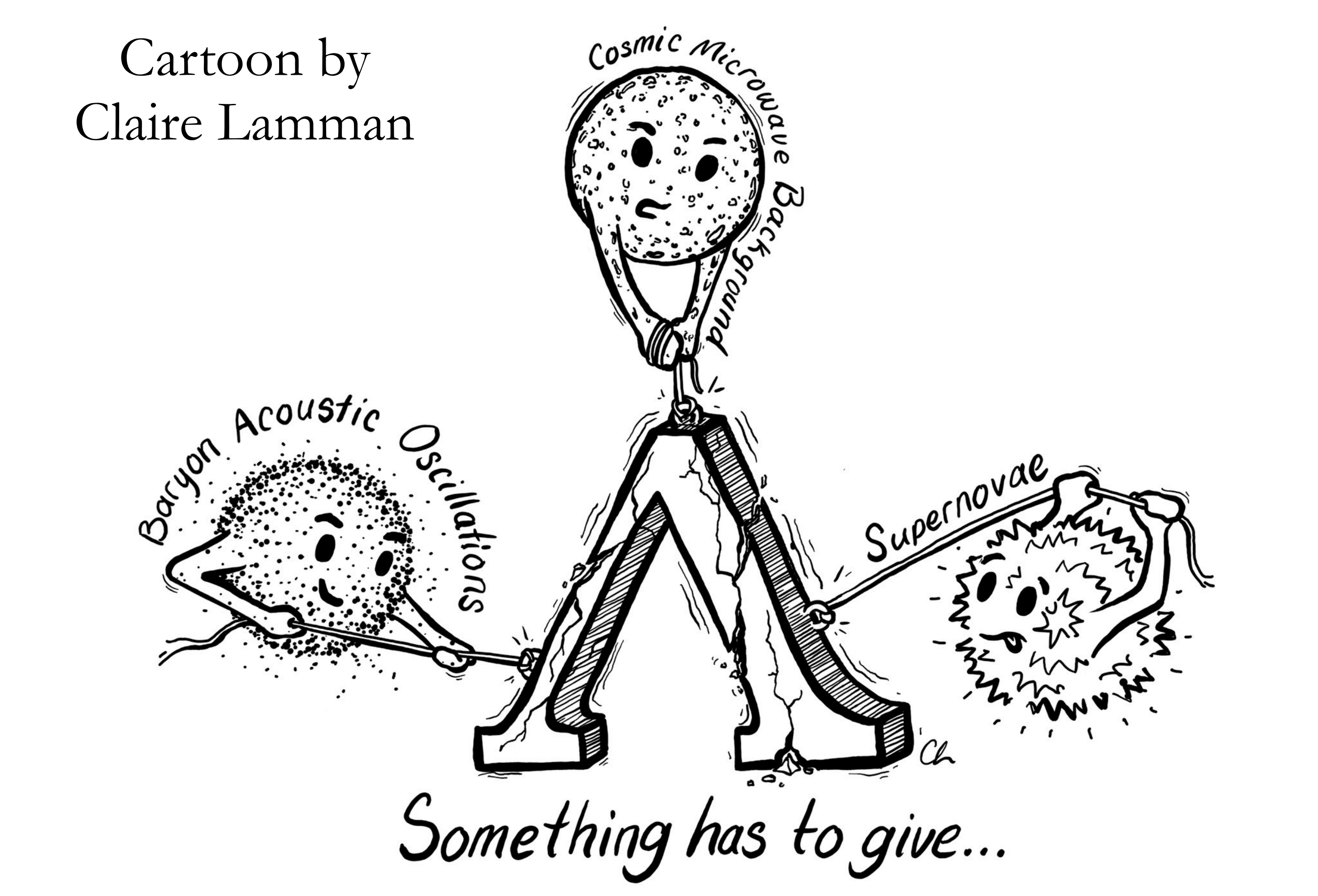
Understanding tensions

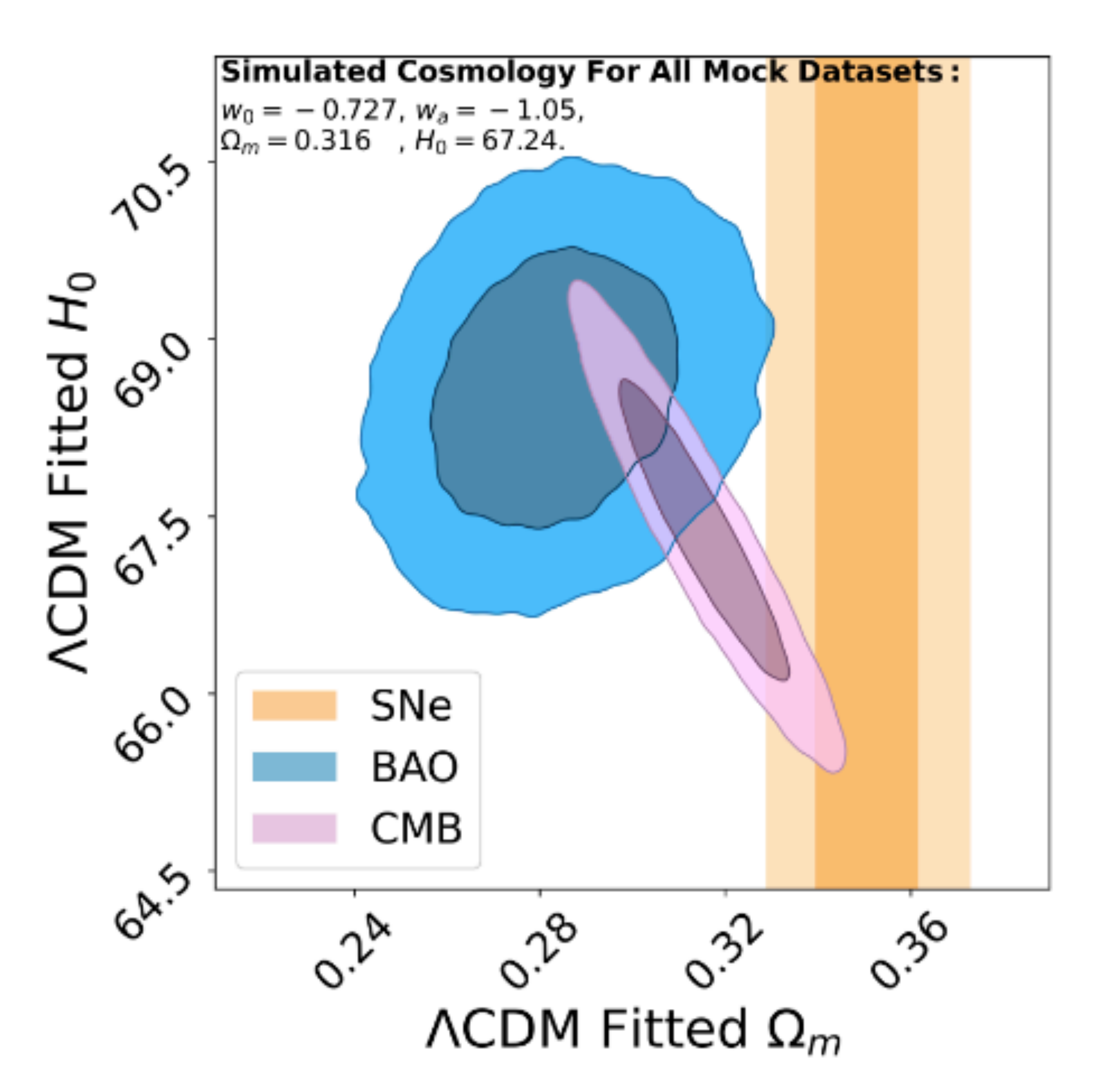
w_0w_aCDMfits all 3 datasets!

Cosmological tensions as source of dynamical dark energy?

- arXiv: 2412.04430
  X. TZ Tang, D. Brout, T. Karwal, C. Chang, V. Miranda, M. Vincenzi

- Using simulations, they found that the discrepancies between datasets in the $H_0 - \Omega_m$ plane mirror those seen in real observations





However, tensions have gone away before in cosmology… TBD

However, tensions have gone away before in cosmology… TBD

However, tensions have gone away before in cosmology… TBD

- Systematics in the BAO data?
  My own biased answer: I personally do not expect so.
  - Replacing some DESI BAO data points with the SDSS ones does not solve the tension (ArXiv: 2404.03002)
  - Using alternative BAO measurements, e.g. DES, still shows some departures when combined with SNe (see ArXiv: 2503.06712)
  - A coherent error in our BAO estimates would need a shift 10X more than allowed given our systematic error budget (see ArXiv: 2503.14738)

However, tensions have gone away before in cosmology… TBD

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- Systematics in the BAO data?
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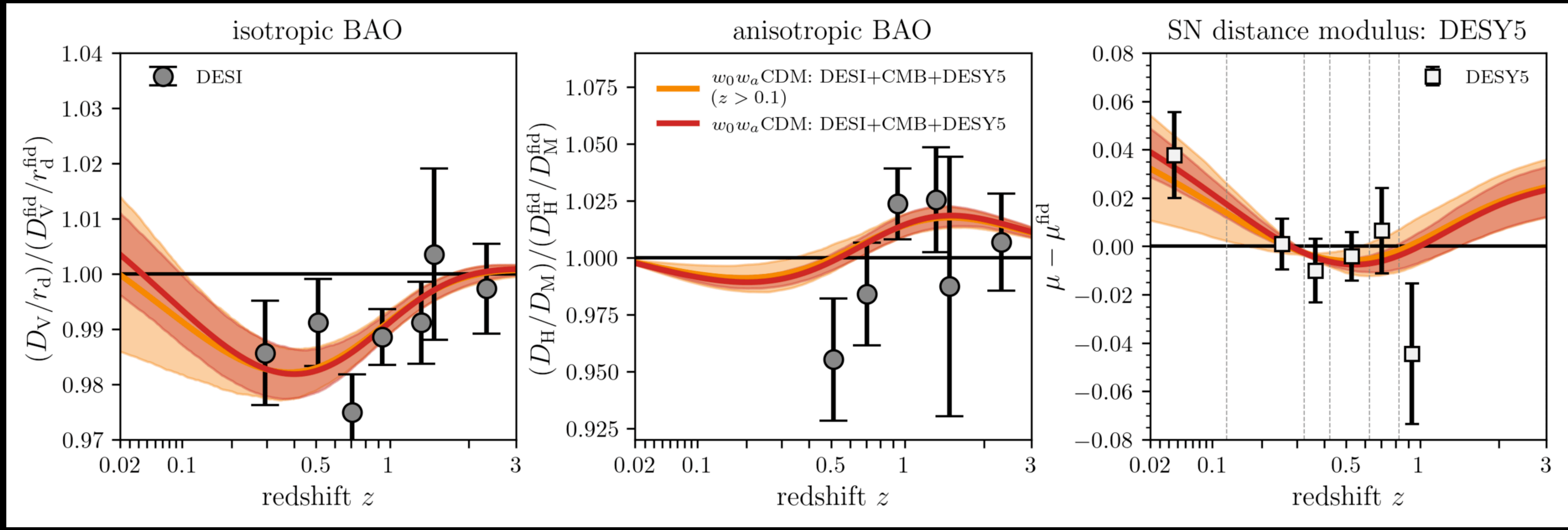
- Systematics in the SNe data?
  We may need to wait for ZTF, Rubin, or other reanalyses

Assuming $z > 0.1$ fit, including the $z < 0.1$ SN data $\Rightarrow \Delta\chi^2 = 186$, ndof $= 197$



DESY5 best χ^2 barely changes between $z > 0.1$ and full fit

However, tensions have gone away before in cosmology… TBD

- Systematics in the BAO data?
  My own biased answer: I personally do not expect so.

- Systematics in the SNe data?
  We may need to wait for ZTF, Rubin, or other reanalyses

- Systematics in the CMB data?
  Potential issues with τ-reionization?

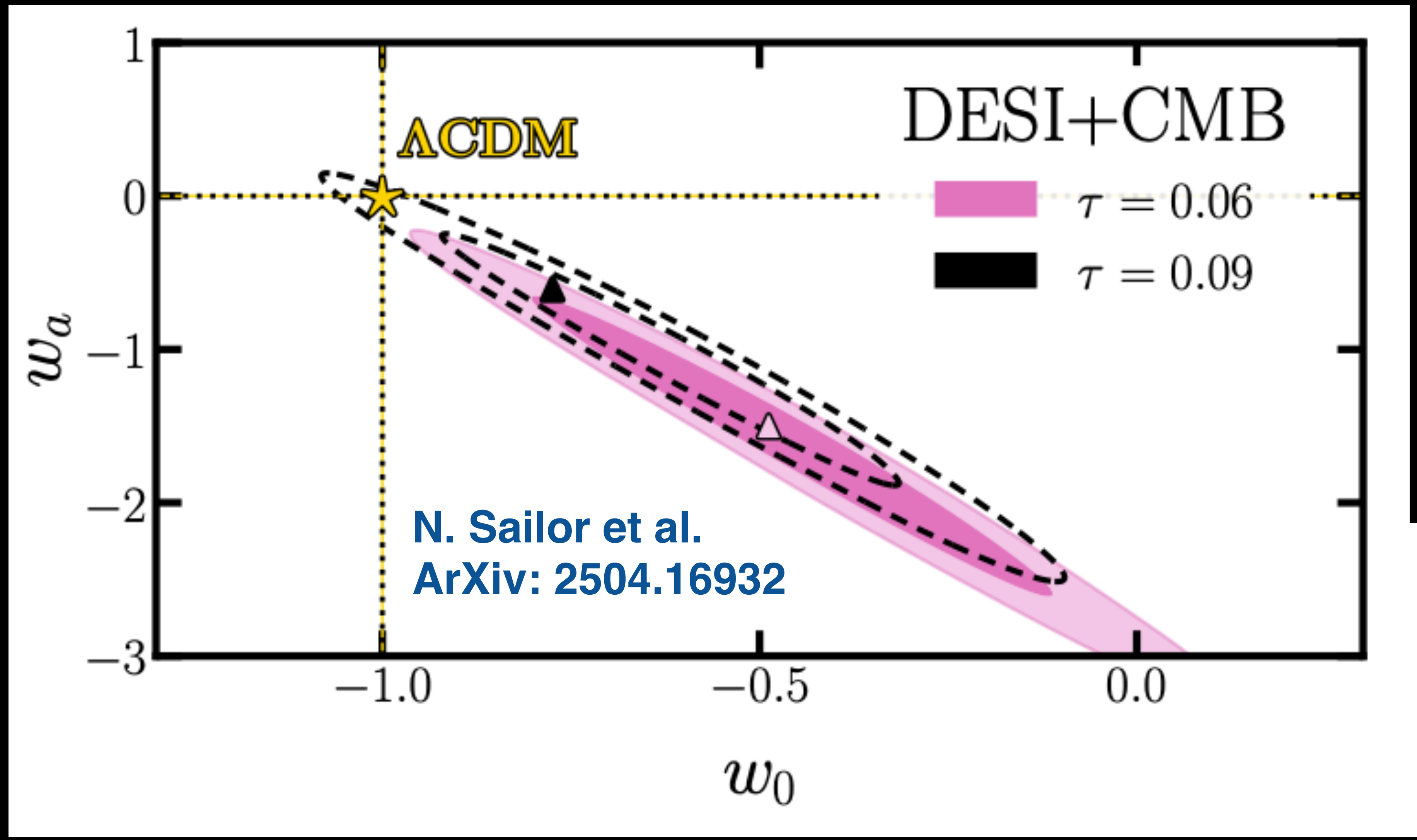


FIG. 3. Constraints on the w_0w_a model from the combination of high-ℓ primary CMB data, CMB lensing, DESI BAO and a prior on the optical depth. Locations of posterior maxima are indicated by triangles.

Summary

- DESI already has the most precise BAO measurements ever (40% more precise than DR1)

- DESI in mild, growing, tension with Planck (2.3σ) and SN ($\sim 2\sigma$) when interpreted in the ΛCDM model

- Tightest upper bound on $\sum m_\nu$, increasing tension with neutrino oscillations

- Evidence for time-varying Dark Energy equation of state has increased with the DR2 BAO data by 0.3σ: CMB: 3.1σ, SN: $2.8 - 4.2\sigma$. $w_0 w_a$CDM fixes above tensions (not H_0!).

Summary

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A LOT of work from a LOT of people!!!

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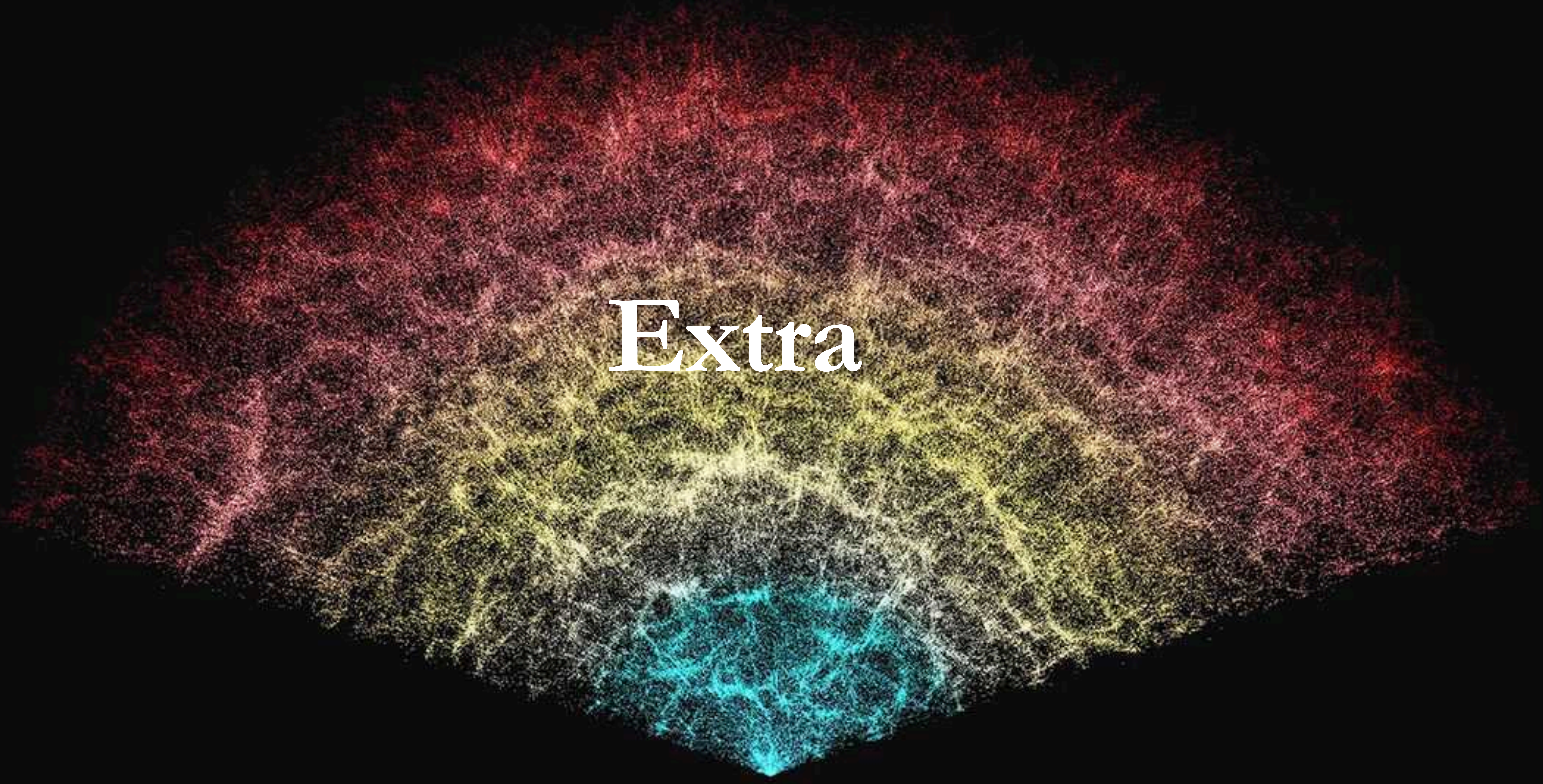
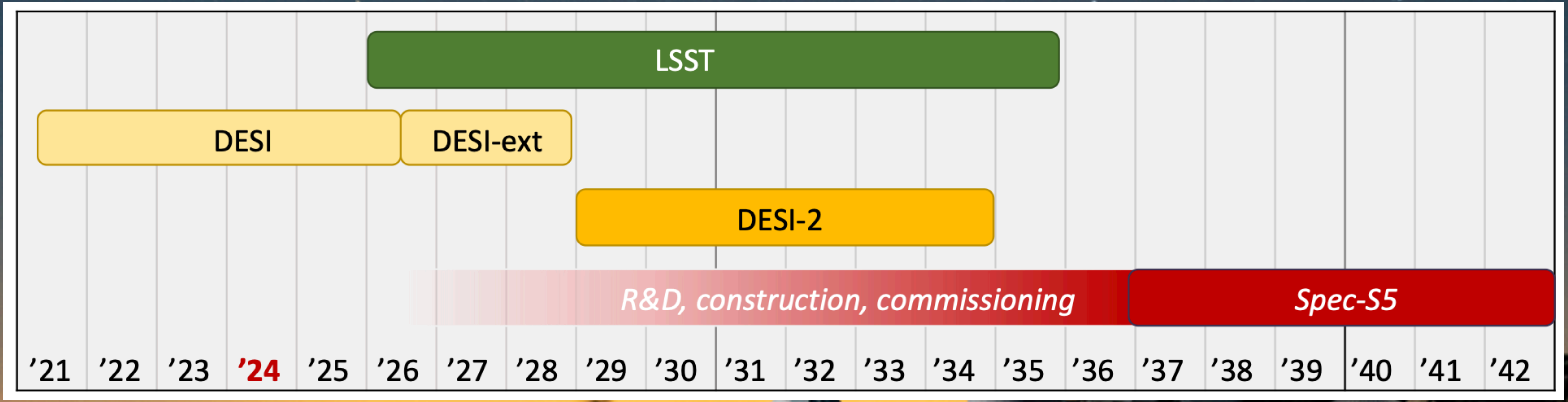
Extra



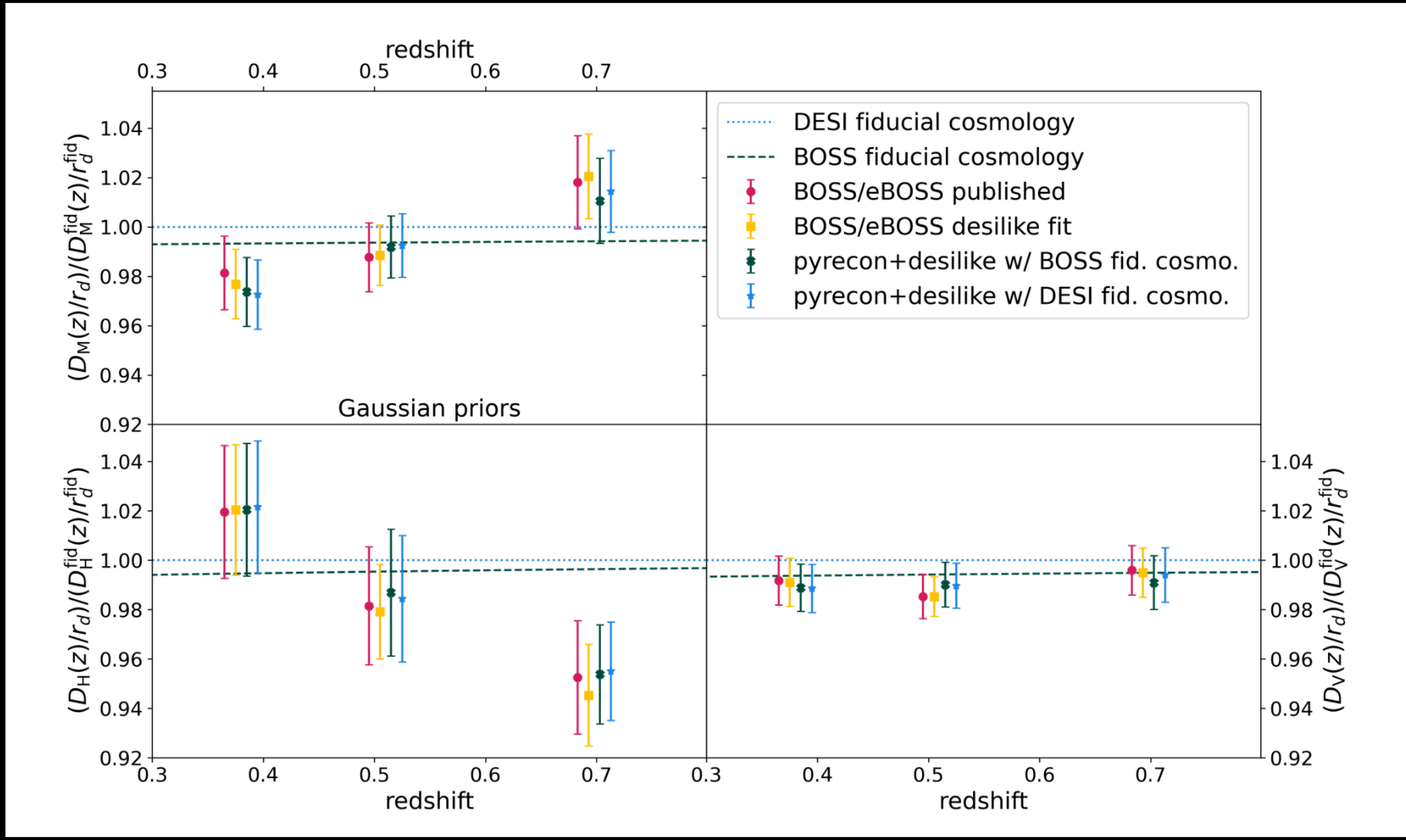
Beyond *nominal* DESI



Spec-S5 is a proposed all-sky spectroscopic instrument designed for carrying out large-scale, high-precision cosmological surveys. Which is a next-generation instrument that will build upon the DESI

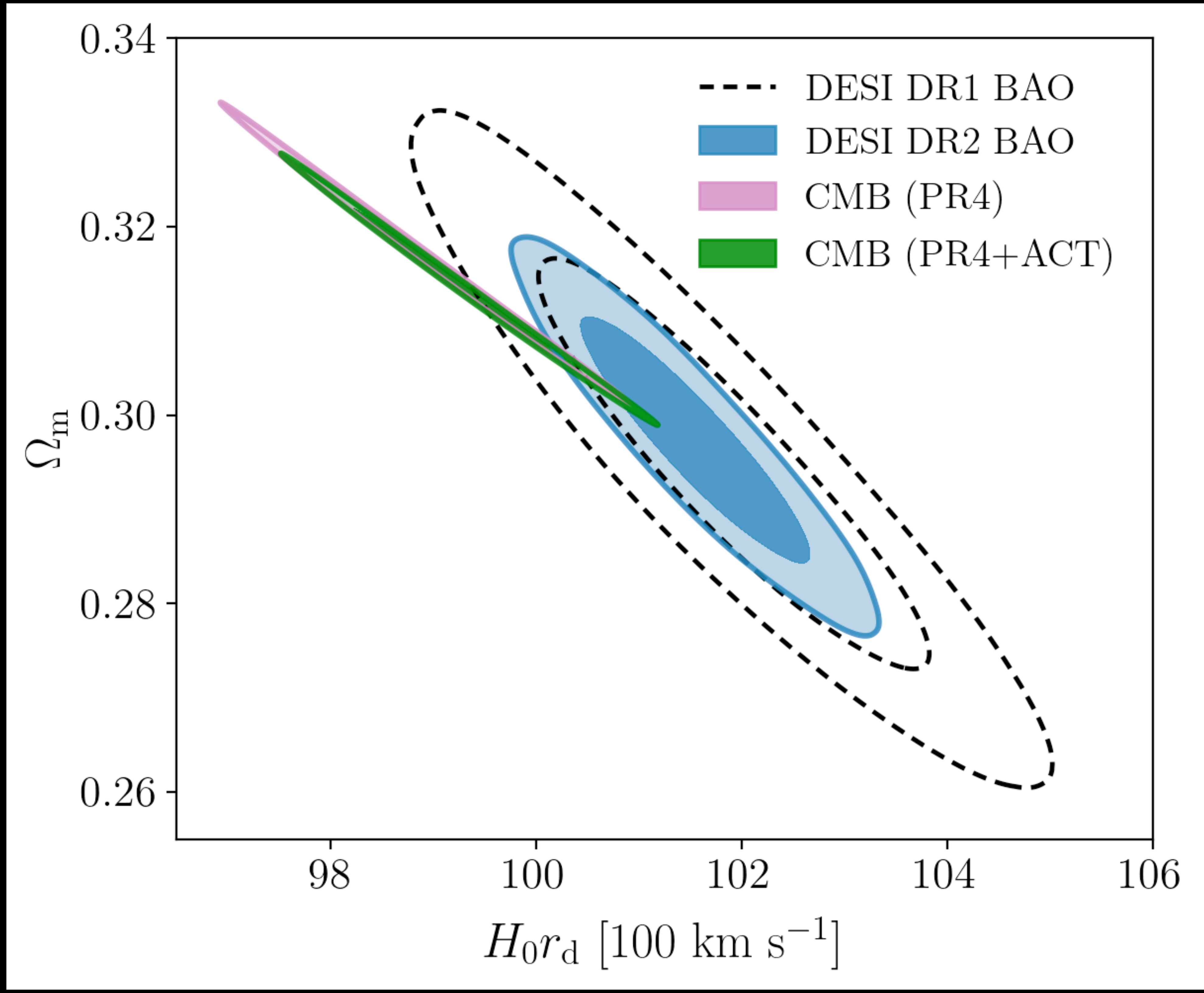
Impact of different pipelines

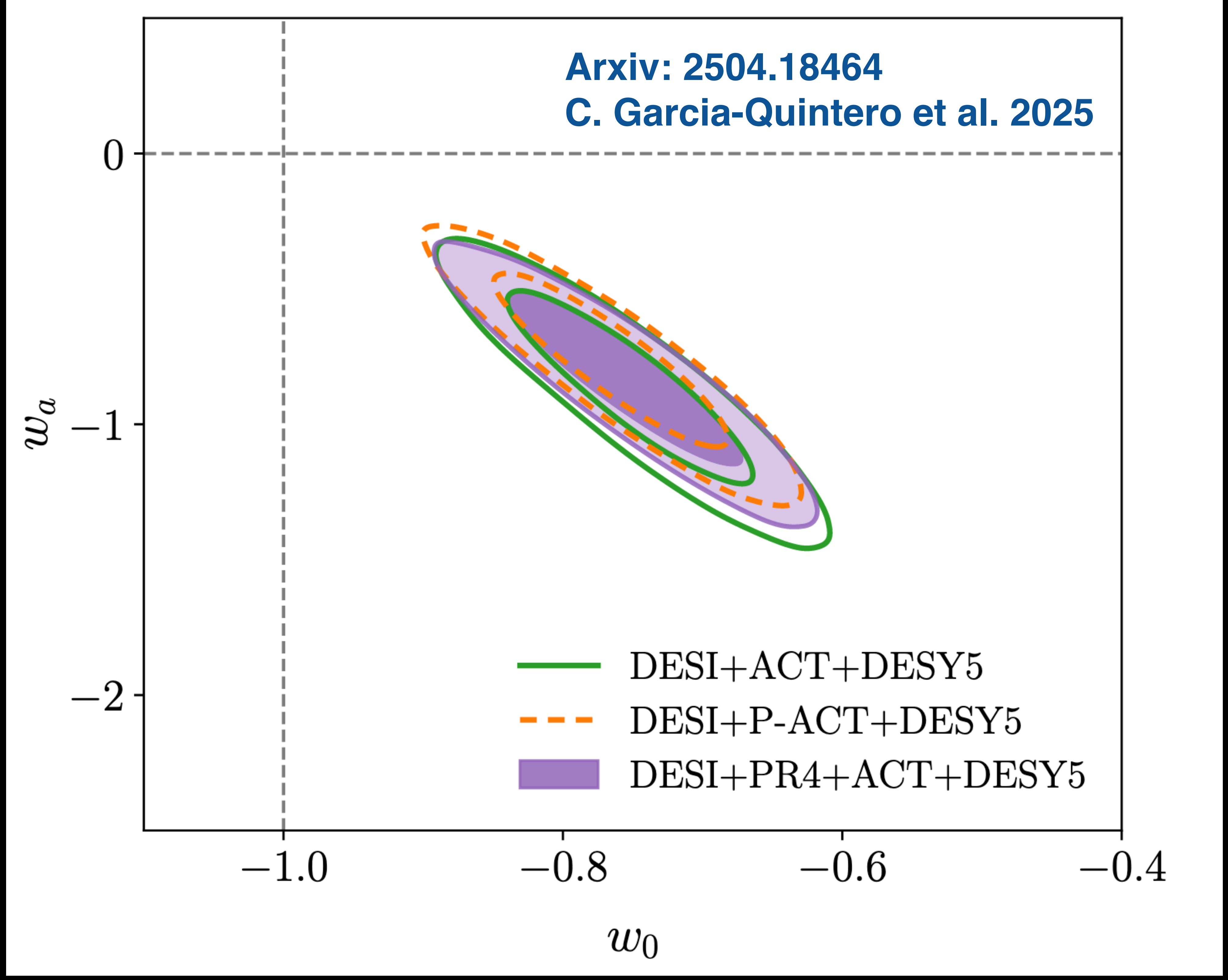
- Analyzing the published BOSS and eBOSS LRG data with the DESI pipeline yields consistent results with the published results.



Adding the latest ACT DR6 CMB data…

… dark energy results remain quite consistent across various combinations of Planck and ACT likelihoods with those obtained by our original results [DESI Collaboration *et al.* (2025), DESI DR2 Results II]





Neutrino masse is more sensitive, ranging from $\sum m_\nu < 0.061$ eV in our baseline analysis, to $\sum m_\nu < 0.077$ in the CMB likelihood combination chosen by ACT when imposing the physical prior $\sum m_\nu > 0$ eV.

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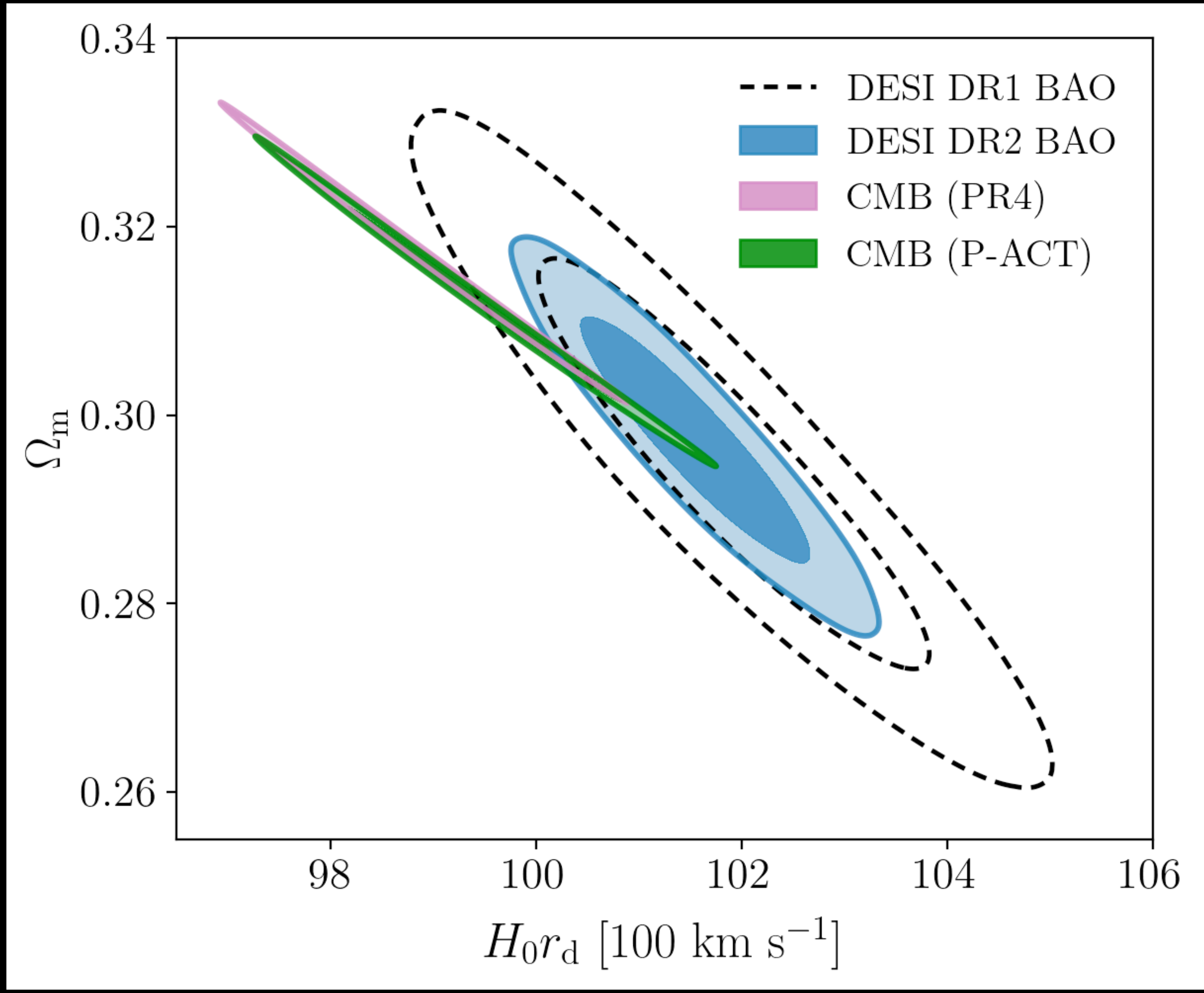

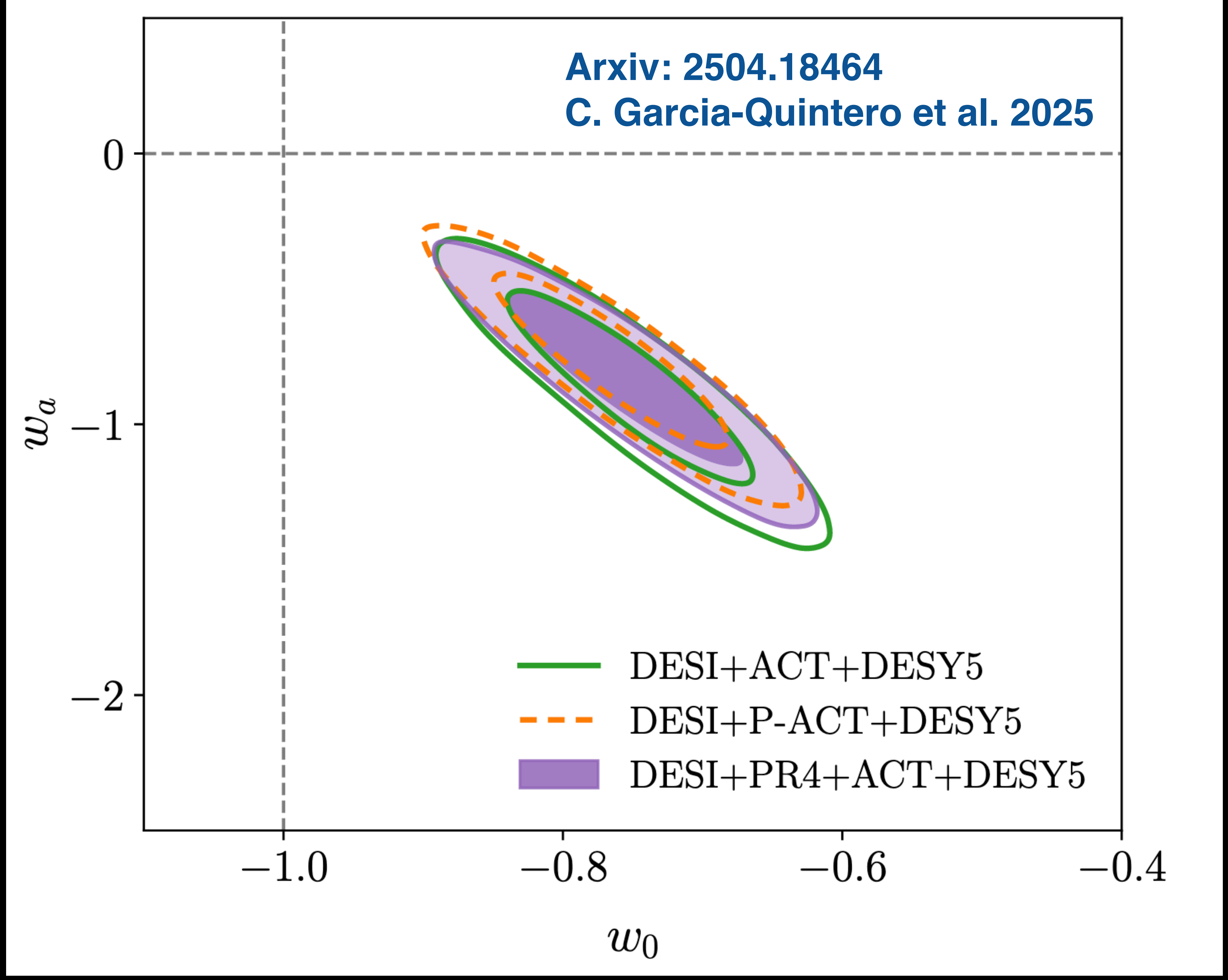

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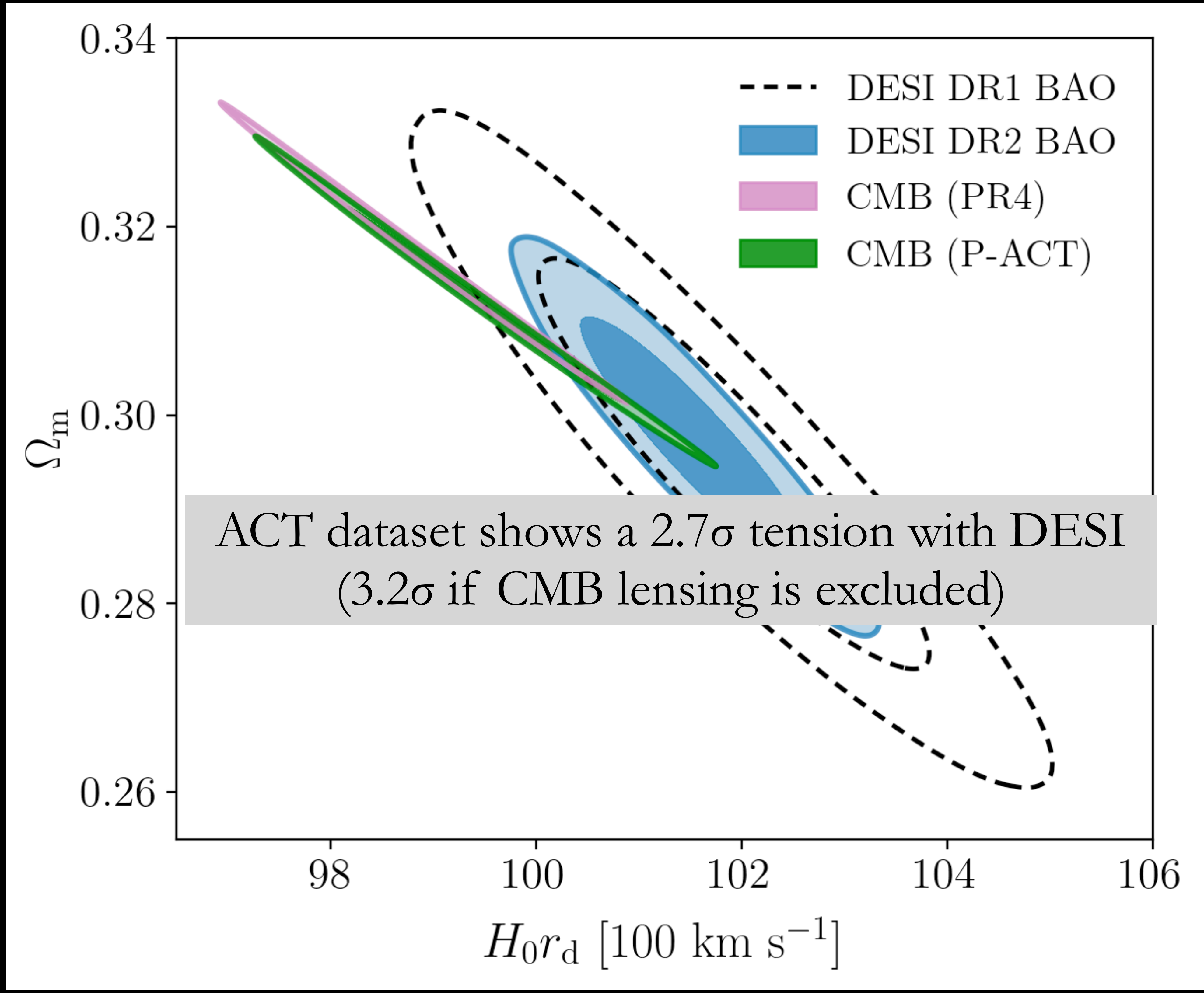

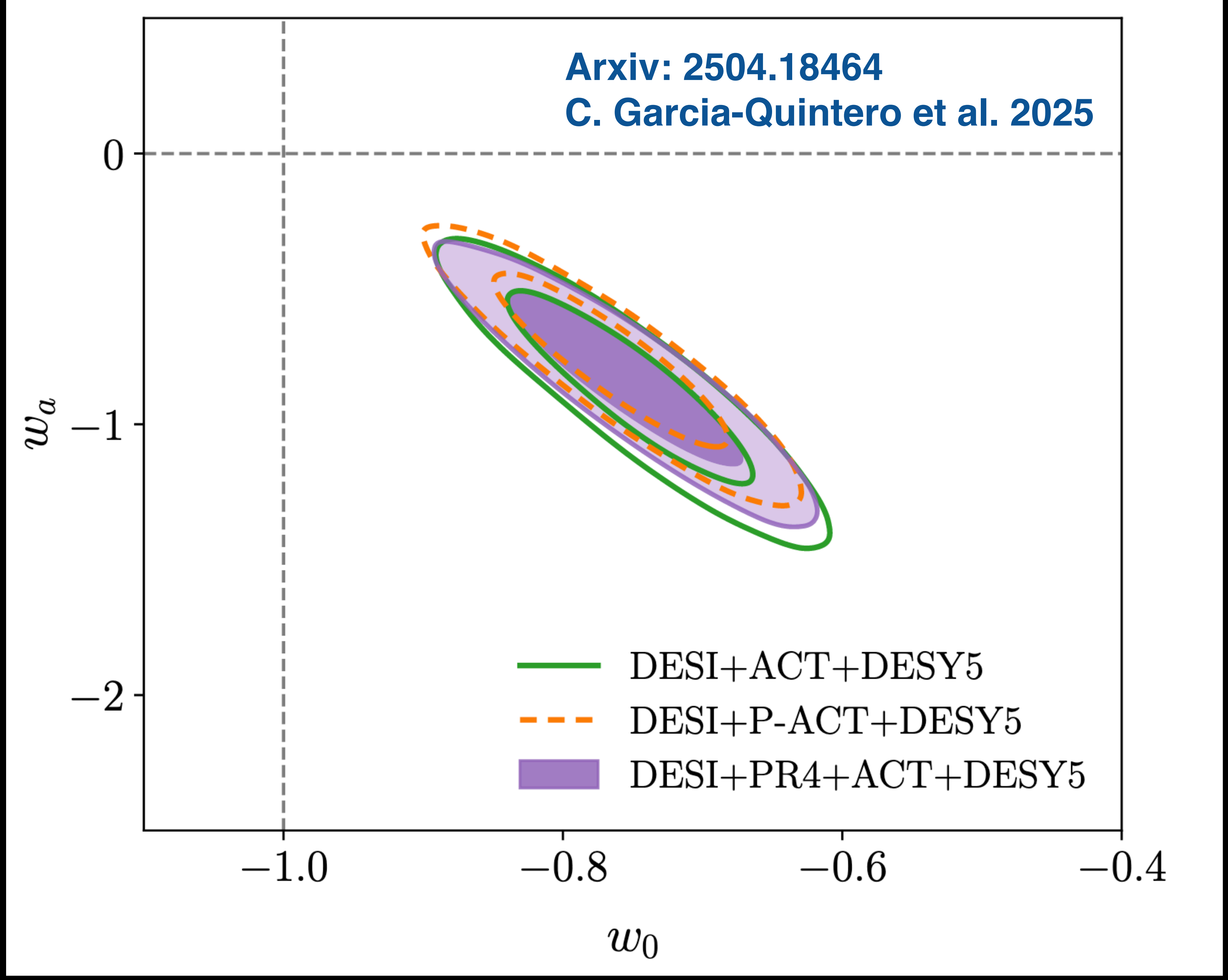

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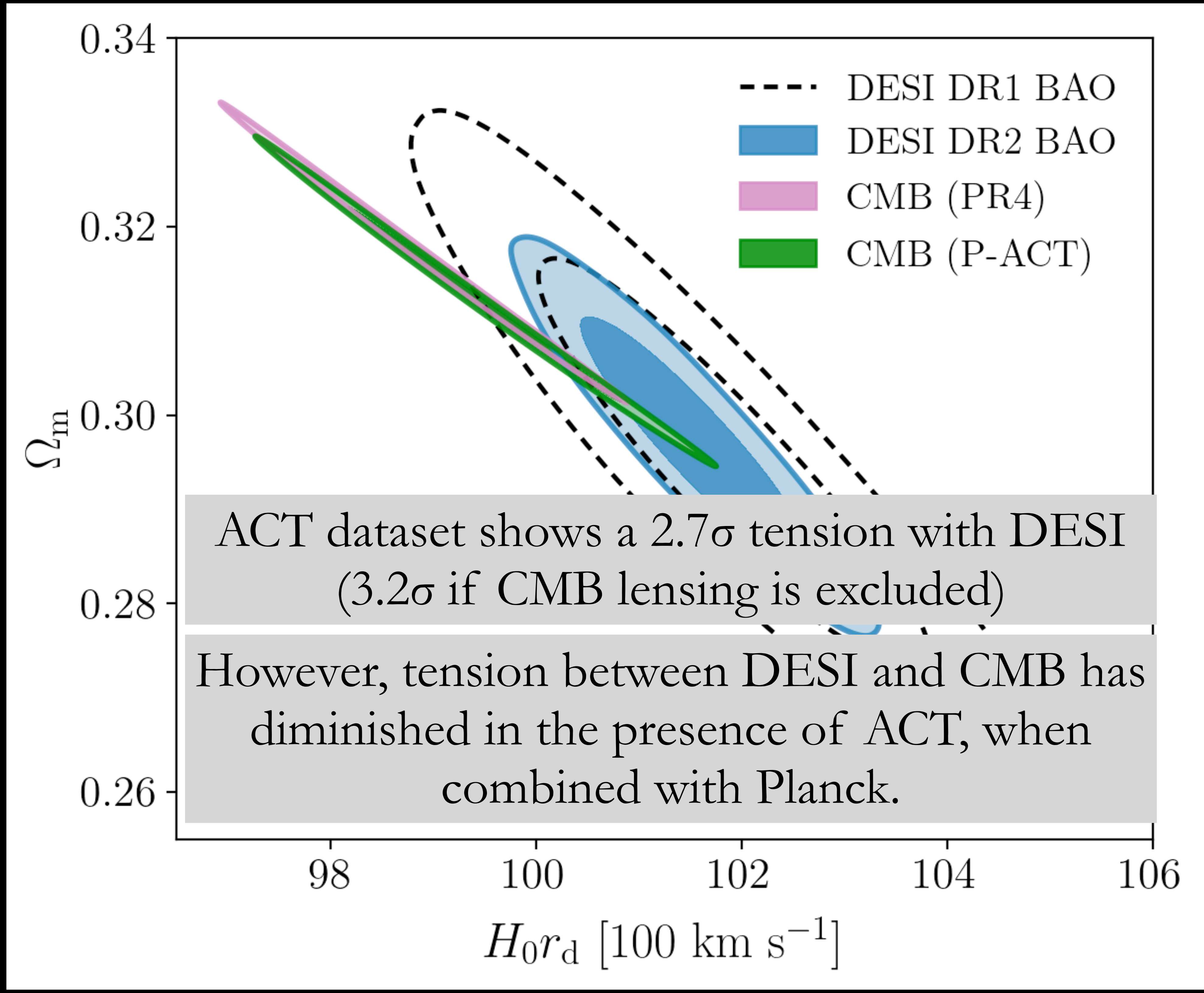

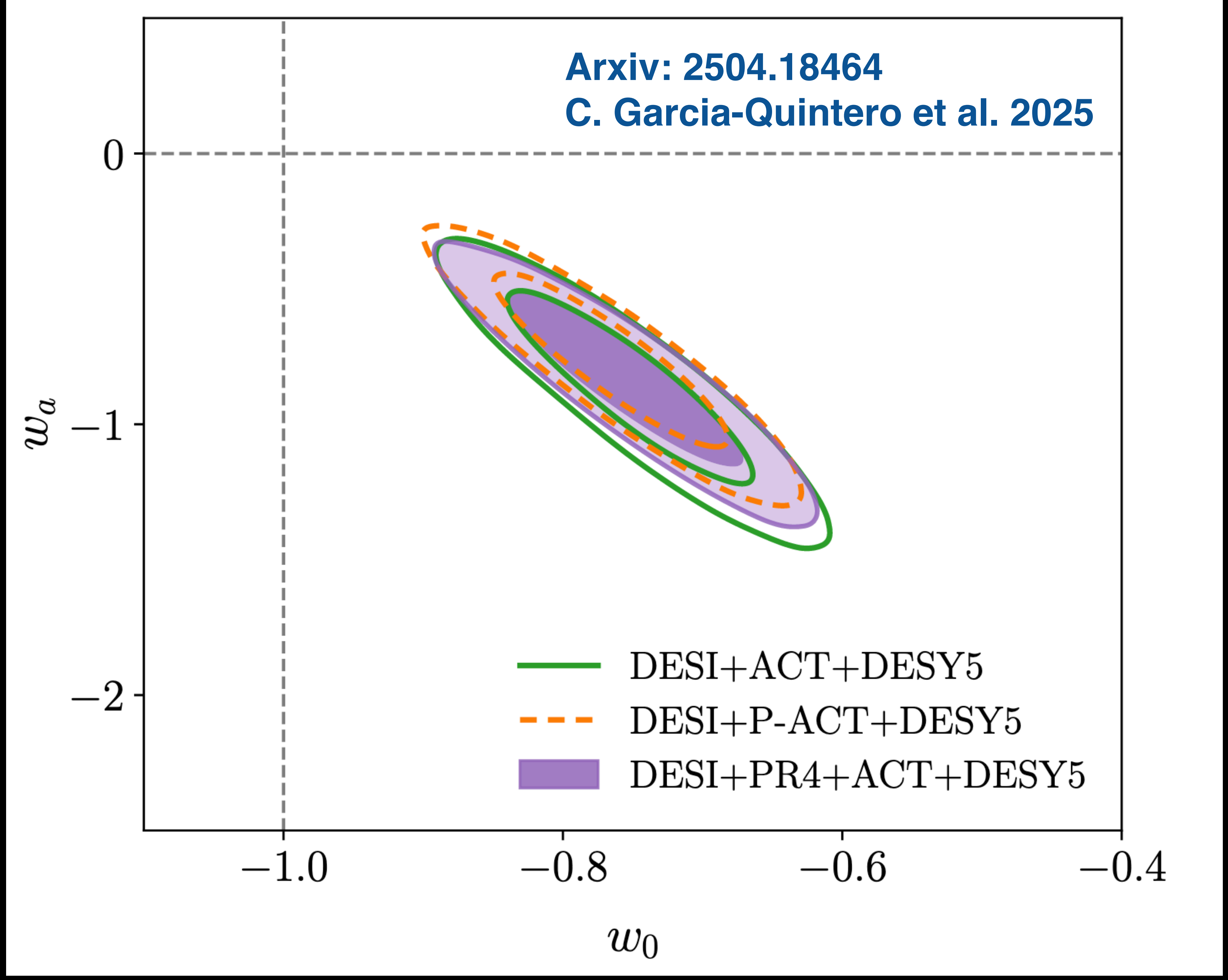

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Frequently Asked Questions for DR2 - by Sesh Nadathur

Frequently asked questions for DR

1. Are BAO and SN distance measurements in conflict?
2. Are DESI and DES parameter values inconsistent (in $w_0 w_a$CDM)?
3. Are there any BAO outliers?
4. What happened to tension between DESI and SDSS BAO?
5. I heard DESI DR2 is actually *more* consistent with Planck than DR1??
6. Why does the data give $w \simeq -1$ in fixed wCDM?
7. Does it matter which CMB likelihood you use?
8. Why do you use only a 1D BAO fit to BGS at $z = 0.3$?

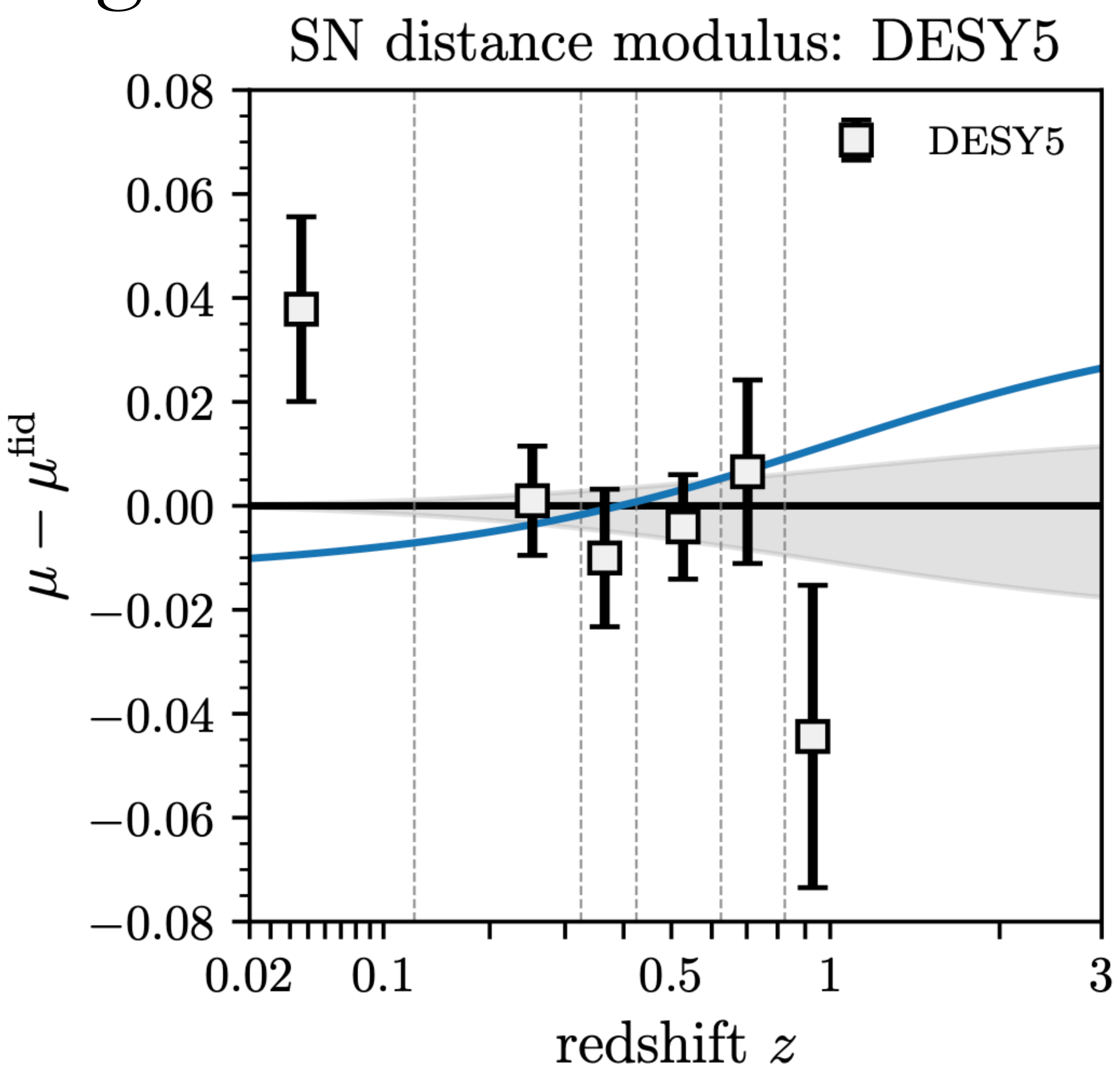
Q: Do BAO and SN give different distances?

A: **No**, in the overlapping redshift range they are very consistent!

From the paper:

pernovae. For supernovae at $z > 0.1$, which partially overlap the redshift range of DESI, the ΛCDM model that best fits the DESI data is also a good fit to the SNe data. Relative to models that best fit each of the DESY5, Union3 and Pantheon+ SNe samples alone, over the full redshift range, the DESI best-fit model gives only small shifts in the quality of the fit to the SNe data, with $\Delta\chi^2 = -1.2$, 1.5 and 2.3 respectively. Unfortunately, no

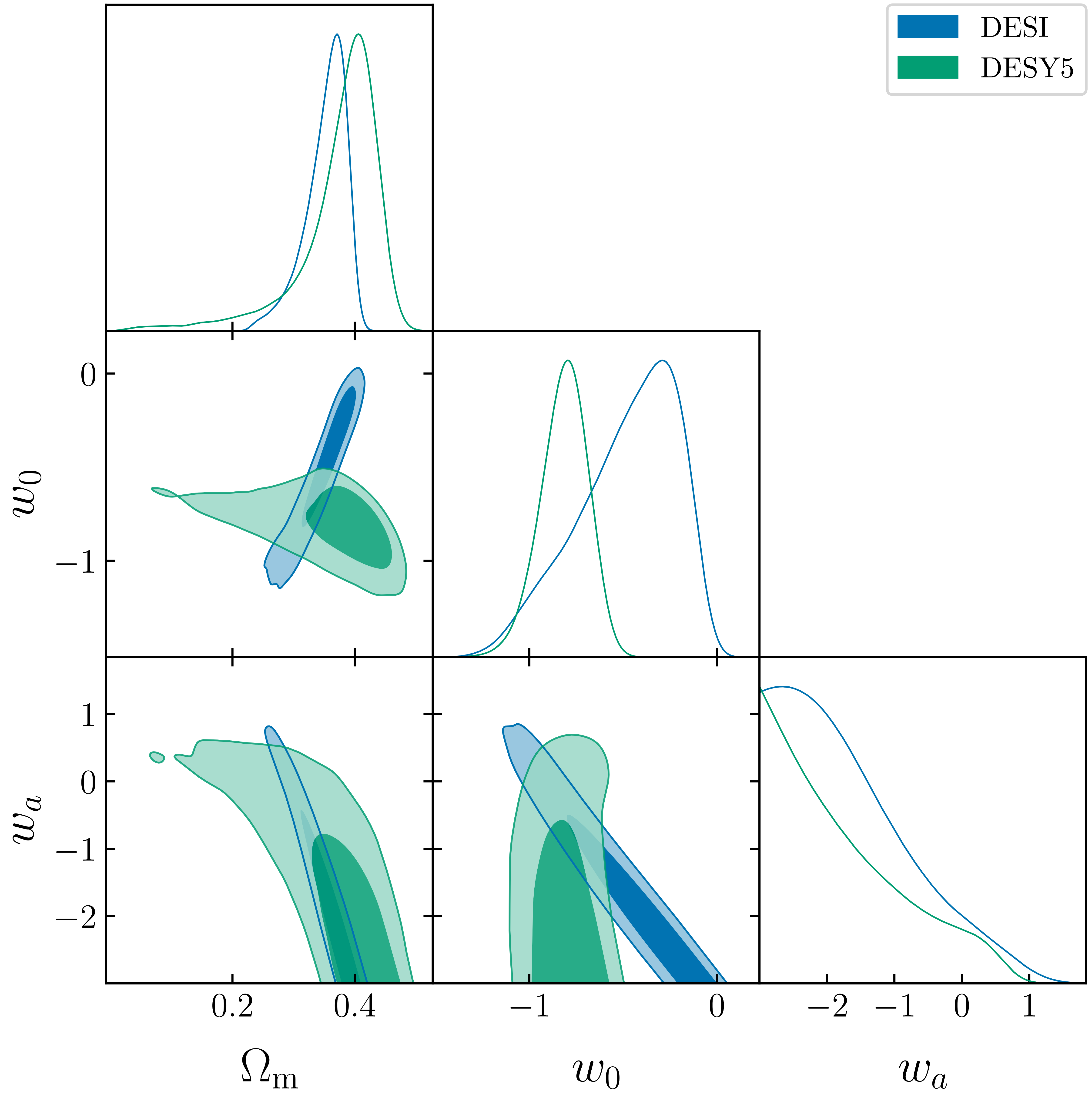
E.g.



Note: Some mistaken claims in the literature come because they compare *calibrated* SN (using SH0ES H_0) to *calibrated* BAO (using Planck H_0) – this is just the Hubble tension again.

Q: Are BAO and DES SN in conflict in $w_0 w_a$?

A: **No**, we don't think so!



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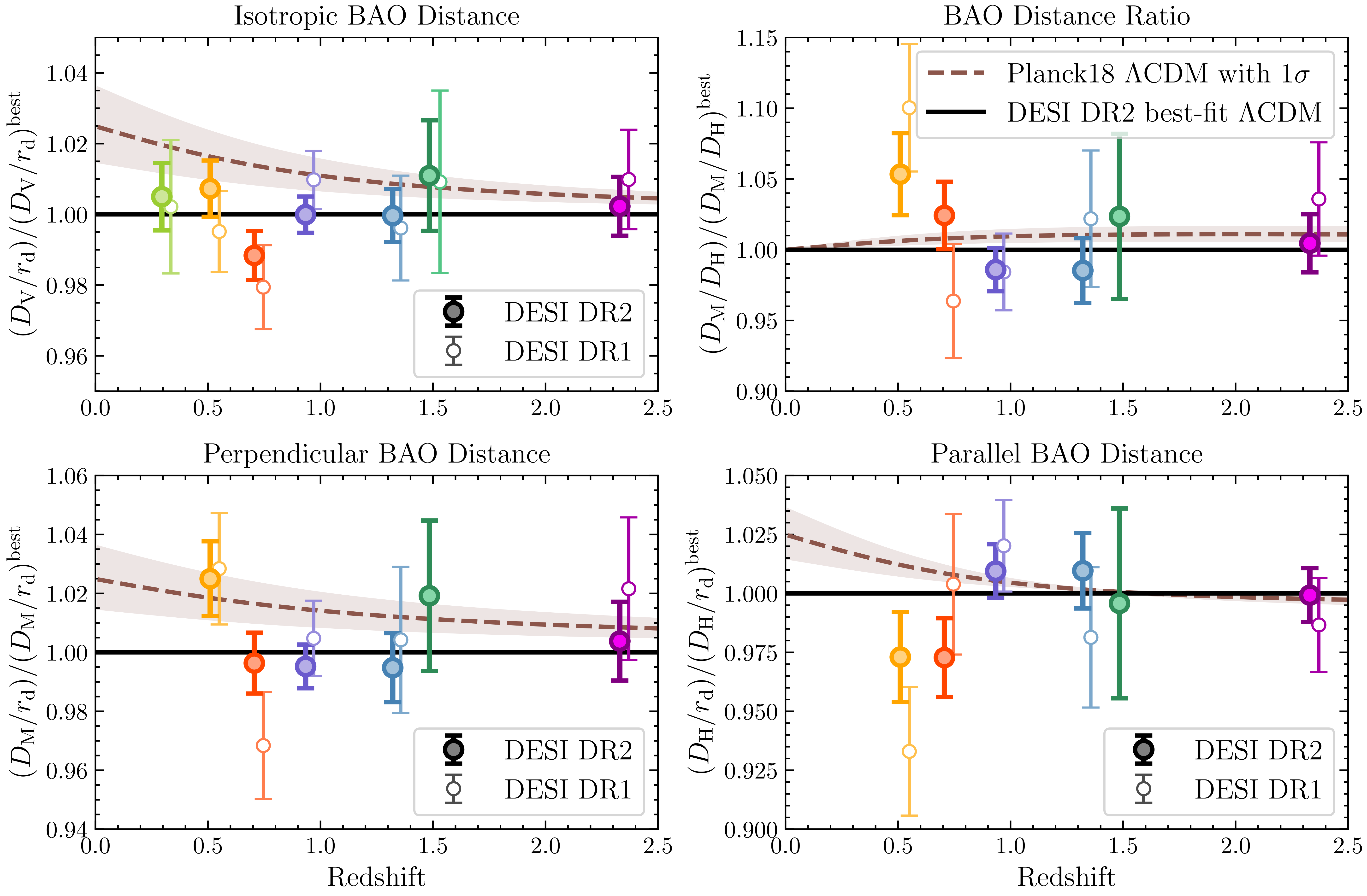
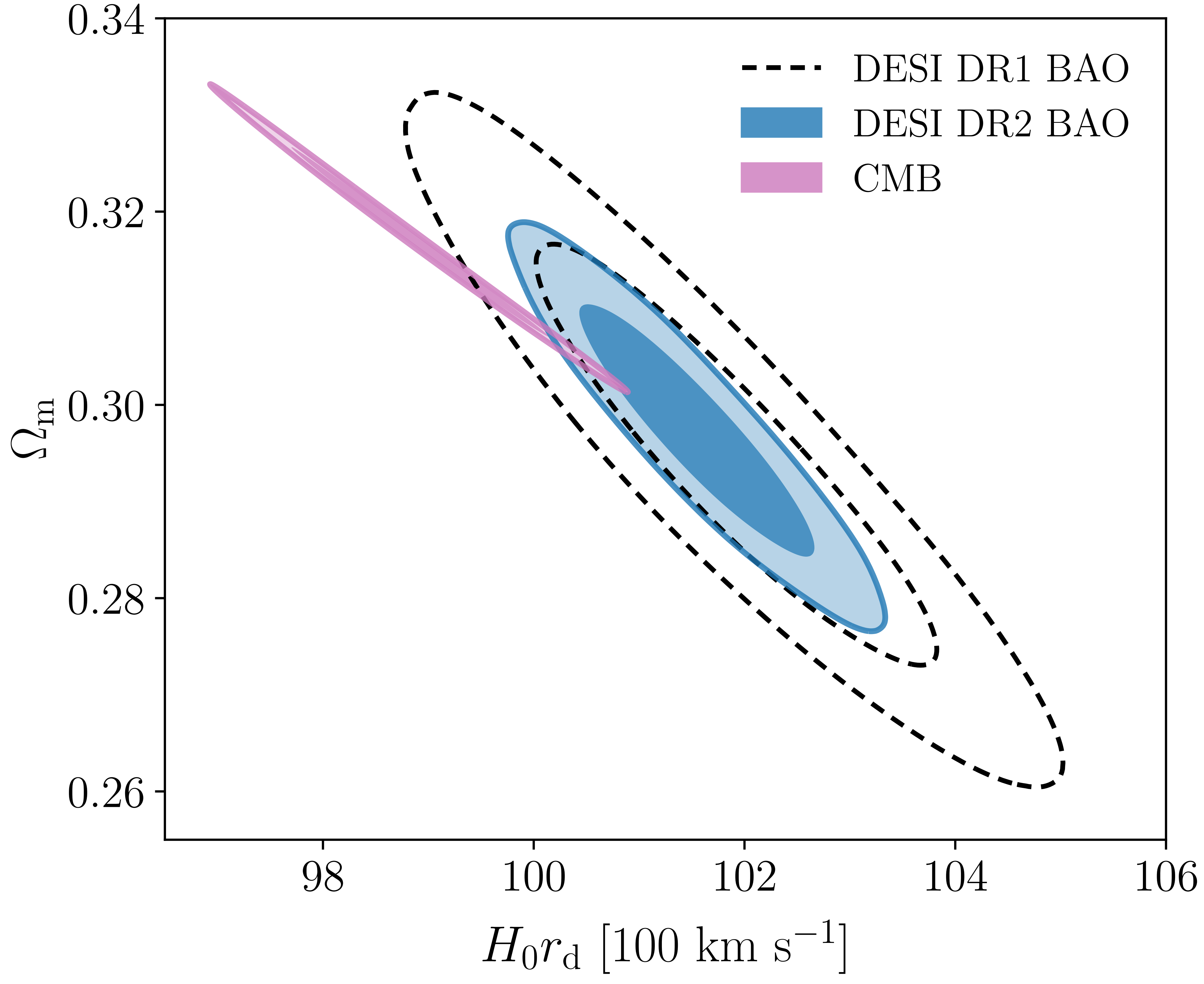
Q: BAO outliers/tensions with SDSS?

A: **No evidence** of unusual outliers; discrepancy between DESI and SDSS at $z = 0.71$ has **decreased** ($\sim$1.5 to 2.5σ) in DR2



Q: Is DR2 closer to Planck than DR1??

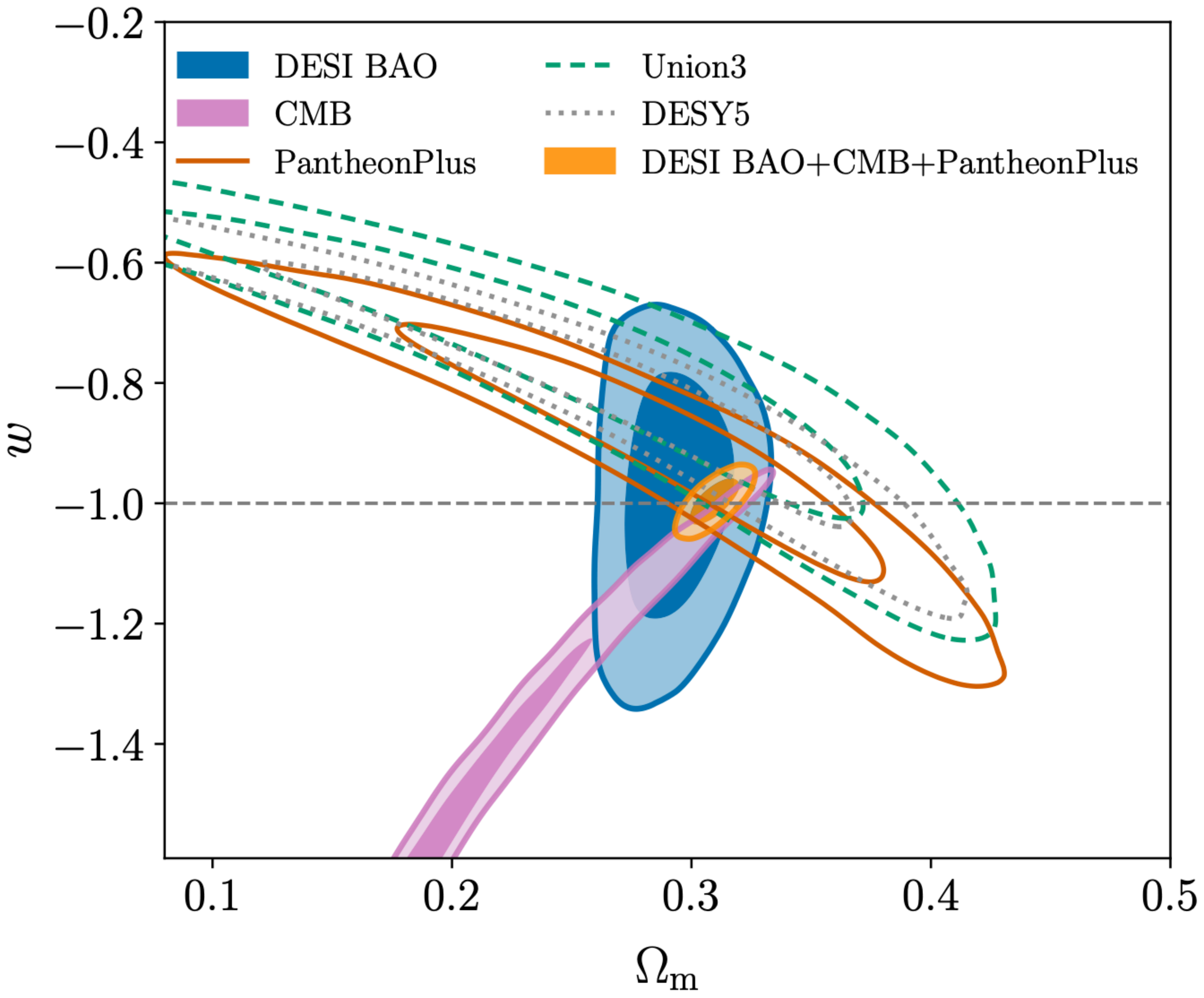
A: Judge for yourself!



Q: Why $w = -1$ in fixed wCDM?

Related Q: Why do you find $w(z) \simeq -1$ at the pivot redshift?

A #1: wCDM gives a (poor) compromise b/w high-z CMB and low-z SNe



Q: Why $w = -1$ in fixed wCDM?

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Related Q: Why do you find $w(z) \simeq -1$ at the pivot redshift?

A #2: This was answered in 2007!

https://arxiv.org/pdf/0708.0024.pdf

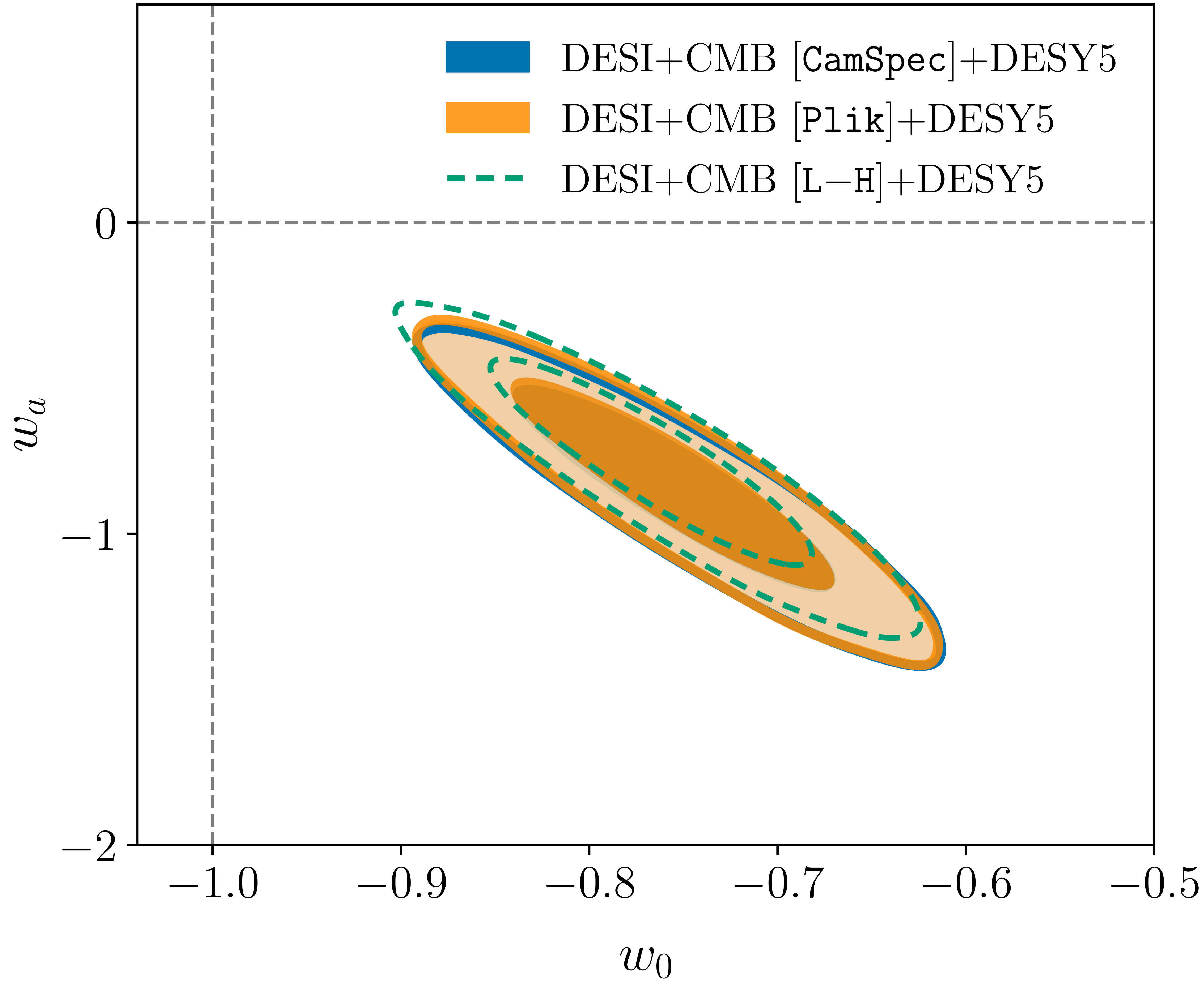
The Mirage of $w = -1$

Eric V. Linder
Berkeley Lab, University of California, Berkeley, CA 94720, USA

Thus a high redshift distance measurement consistent with LCDM virtually forces (within the picture so far) the value $w(z \approx 0.4) = -1$, irrespective of true time variation. However, low redshift measurements insufficiently sensitive to time variation measure only an averaged EOS that corresponds strongly to the value at a sweet spot or "pivot" redshift with the pivot near $z \approx 0.4$. That is,

Q: Does it matter which CMB likelihood?

A: **Not important for DE:**

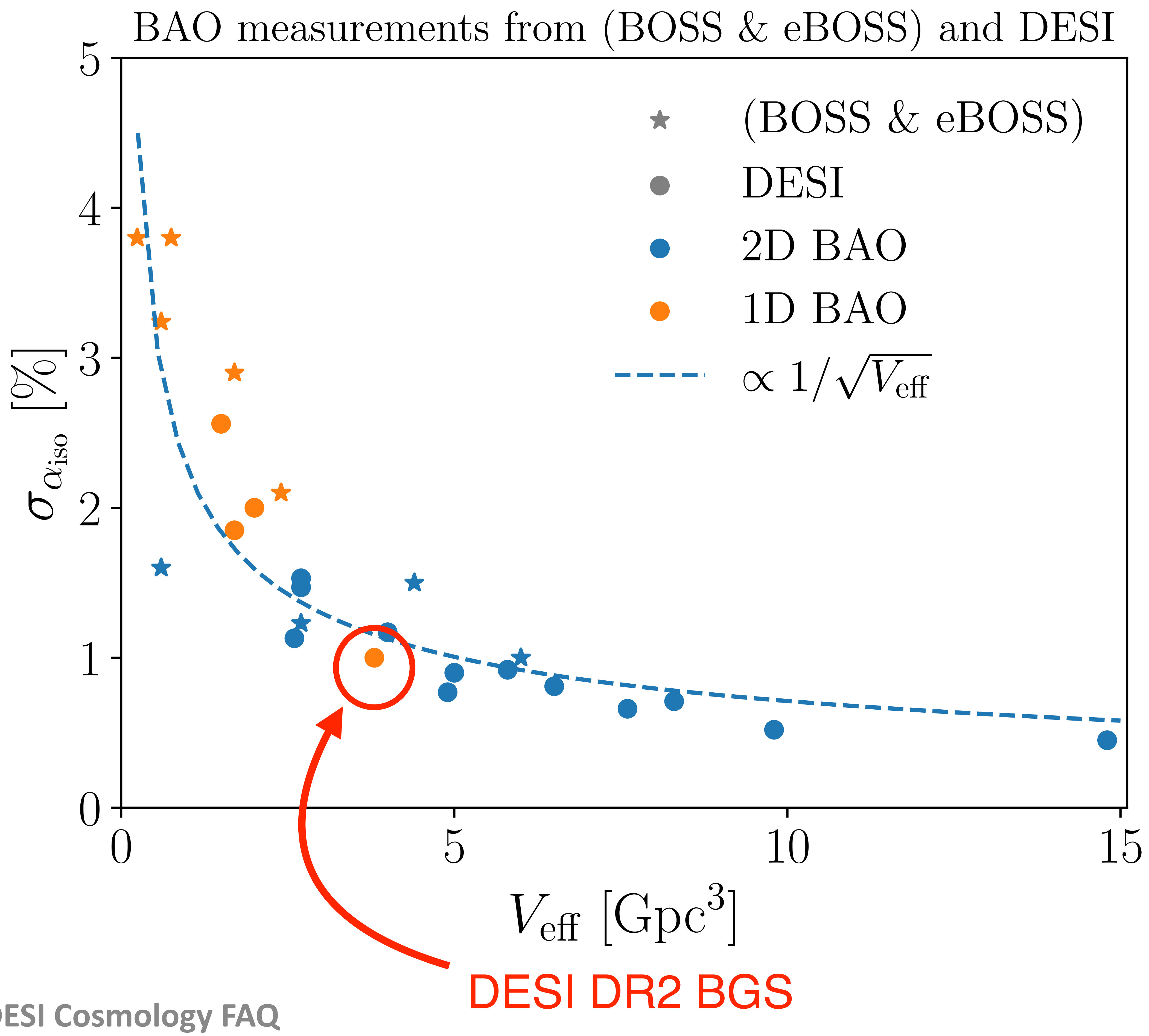


Q: Why only 1D BAO for BGS?

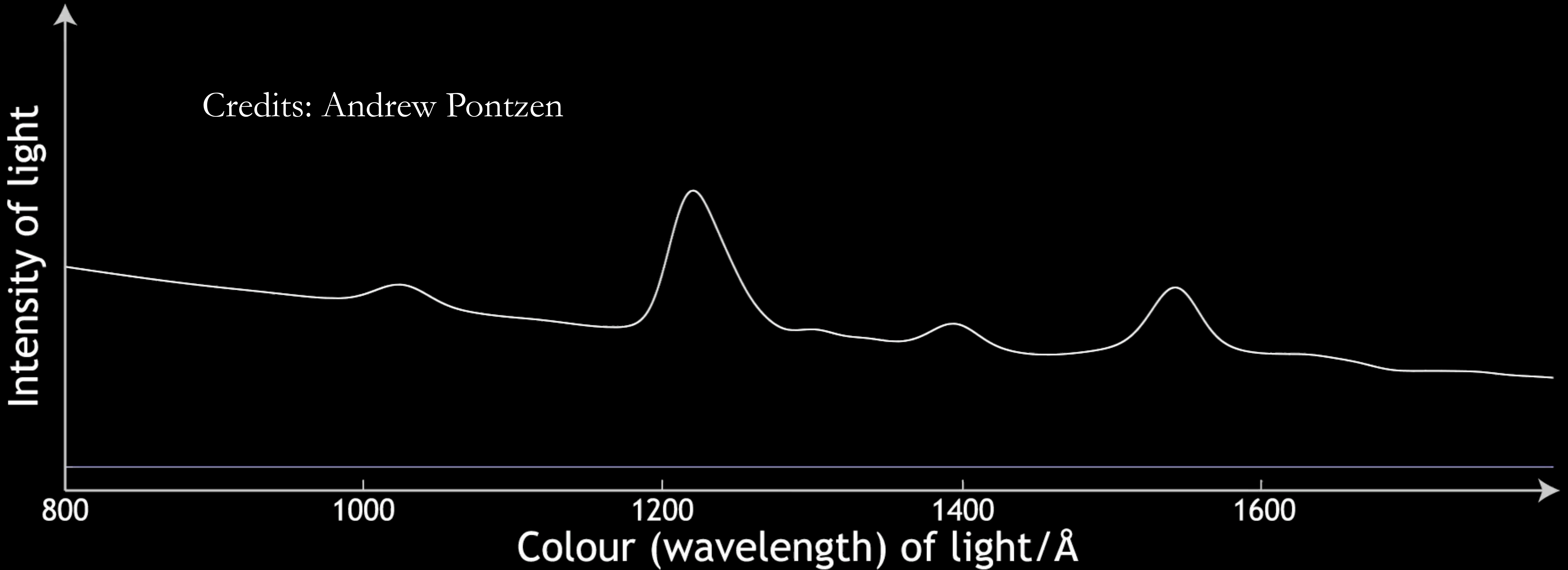
A: We made a **conservative** decision before unblinding

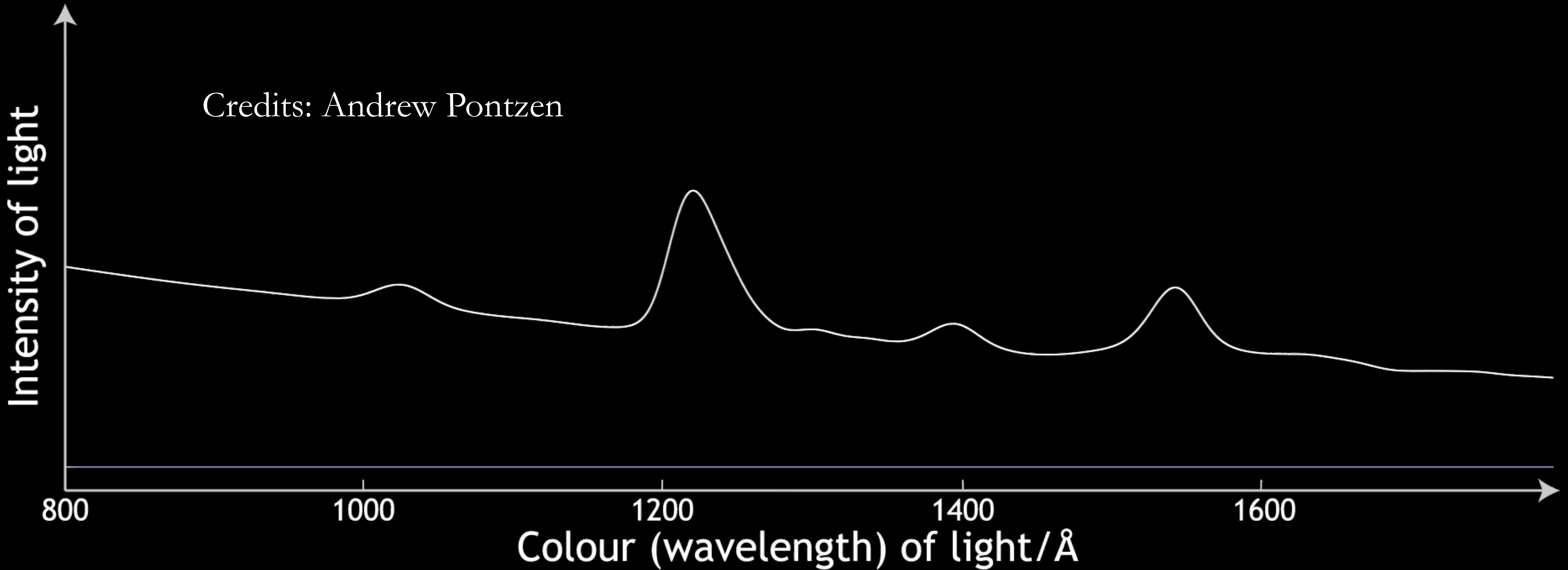
Factors considered:

- Blinded posterior for α_{AP} suggested possible non-Gaussianity
- $\sim 5\,\%$ precision on α_{AP} at BGS redshift adds very little cosmological information anyway
- Wanted to avoid any changes after unblinding

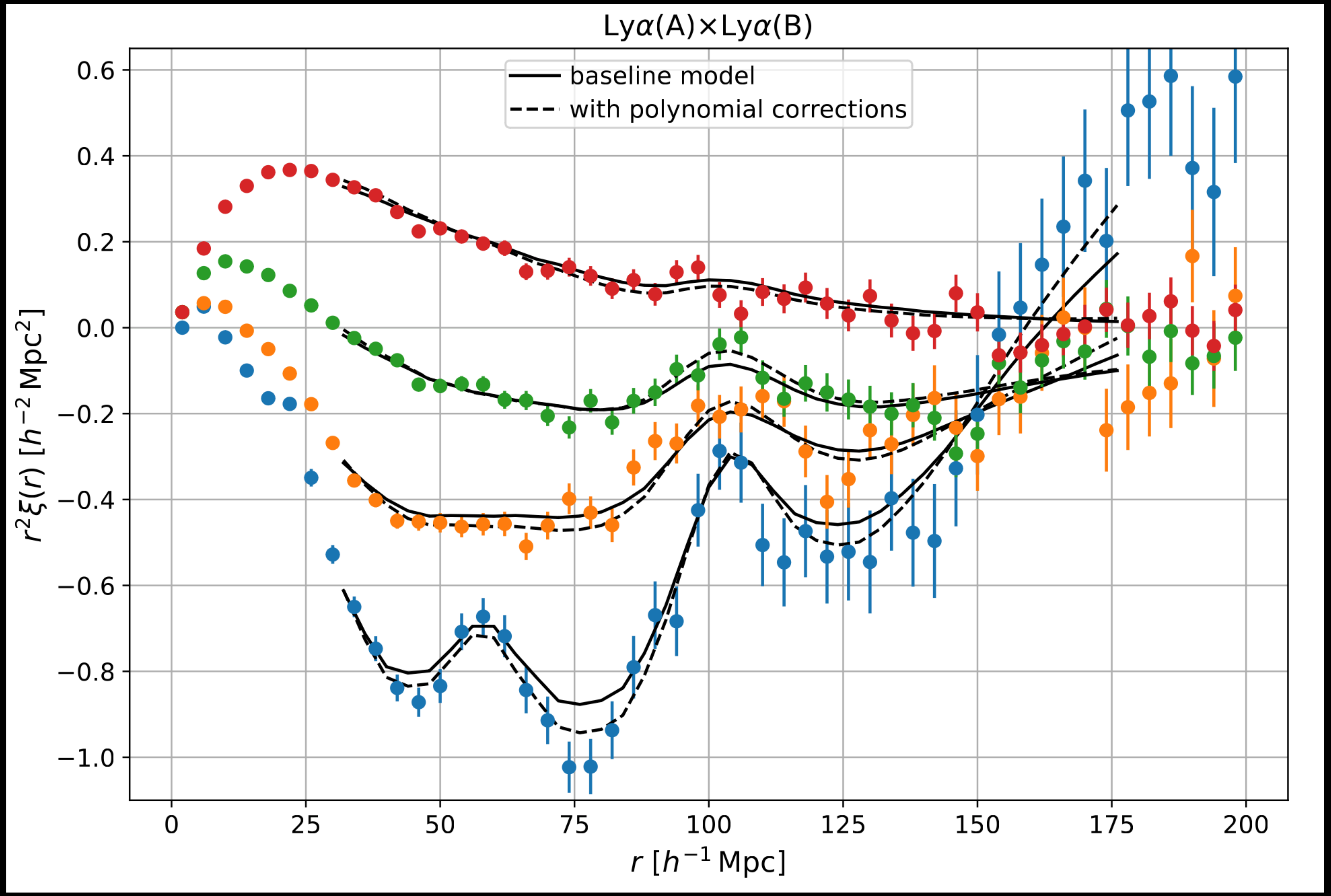


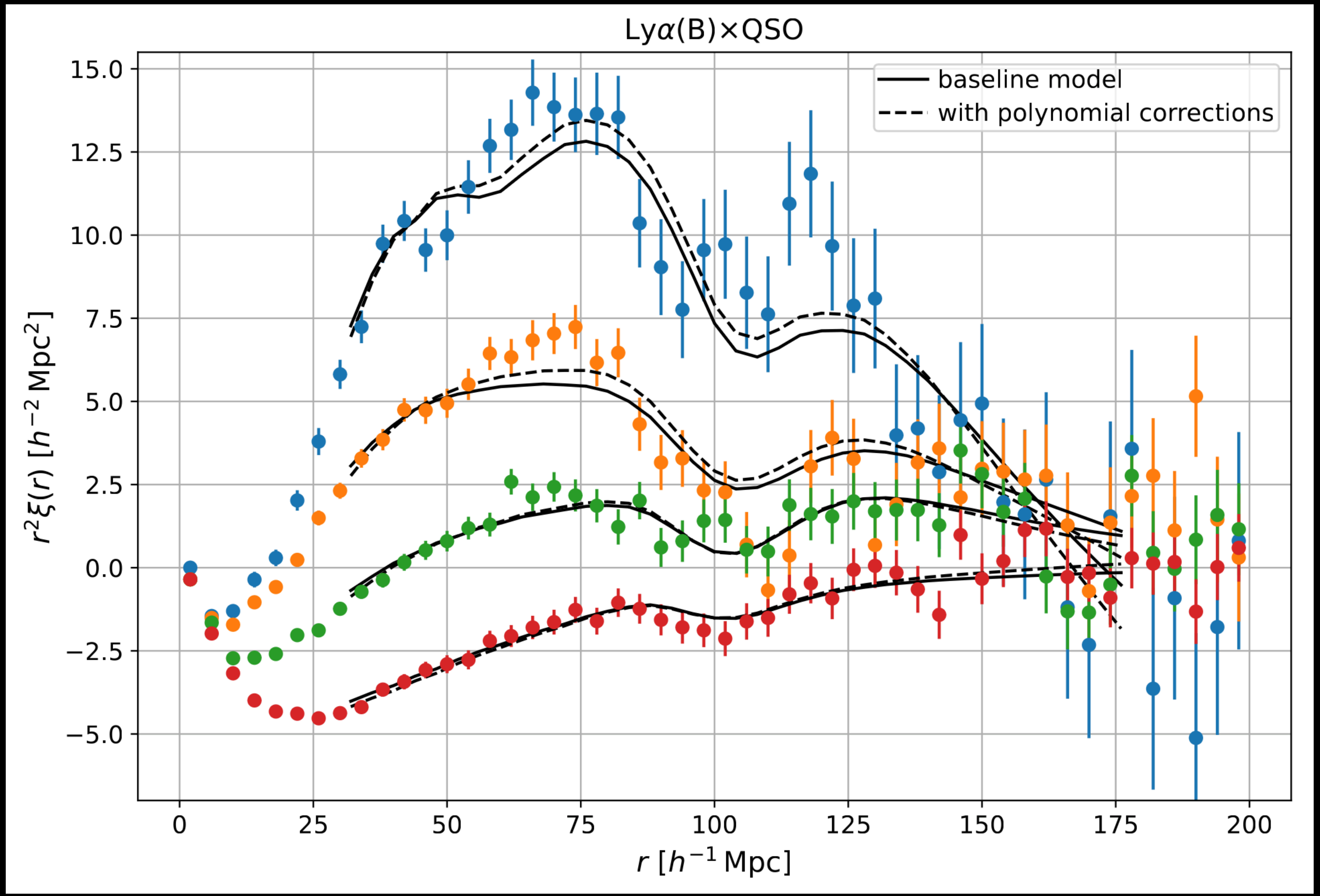
Credits: Andrew Pontzen




Credits: Andrew Pontzen
Intensity of light
800
1000
1200
1400
1600
Colour (wavelength) of light/Å

Lyman α Forest Correlations





Lyα forest autocorrelation

$$\xi(r) = \left\langle \delta_F(x)\ \delta_F(x+r) \right\rangle$$

Lyα-QSO cross-correlation

$$\xi(r) = \left\langle \delta_F(x)\ \mathrm{Q}(x+r) \right\rangle$$

DR1 Lyα BAO analysis: what's new?

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

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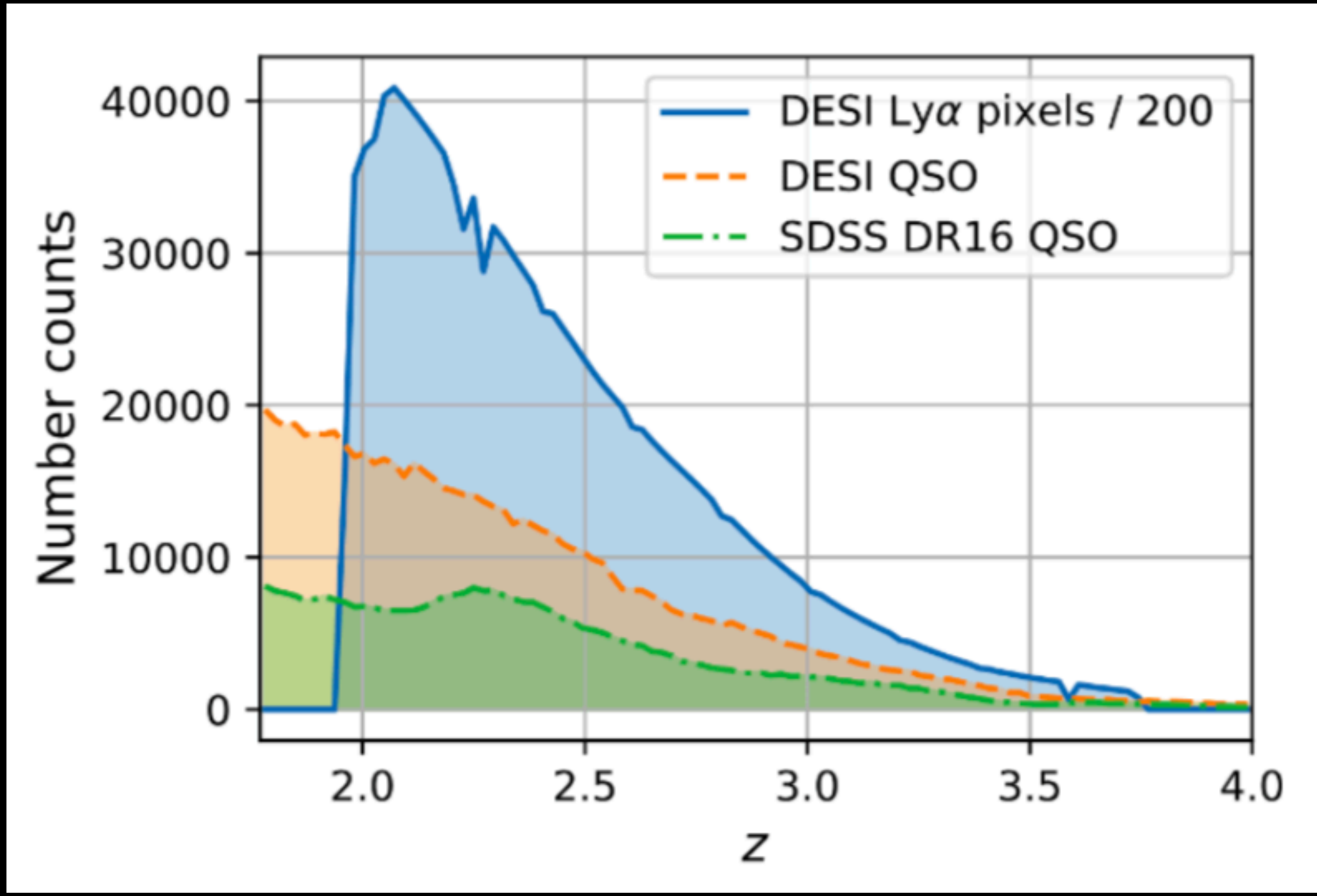


- **>420,000 Lyα QSO at** $z > 2.1$

$2\times$ **bigger** than SDSS!

DR1 Lyα BAO analysis: what's new?

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

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

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

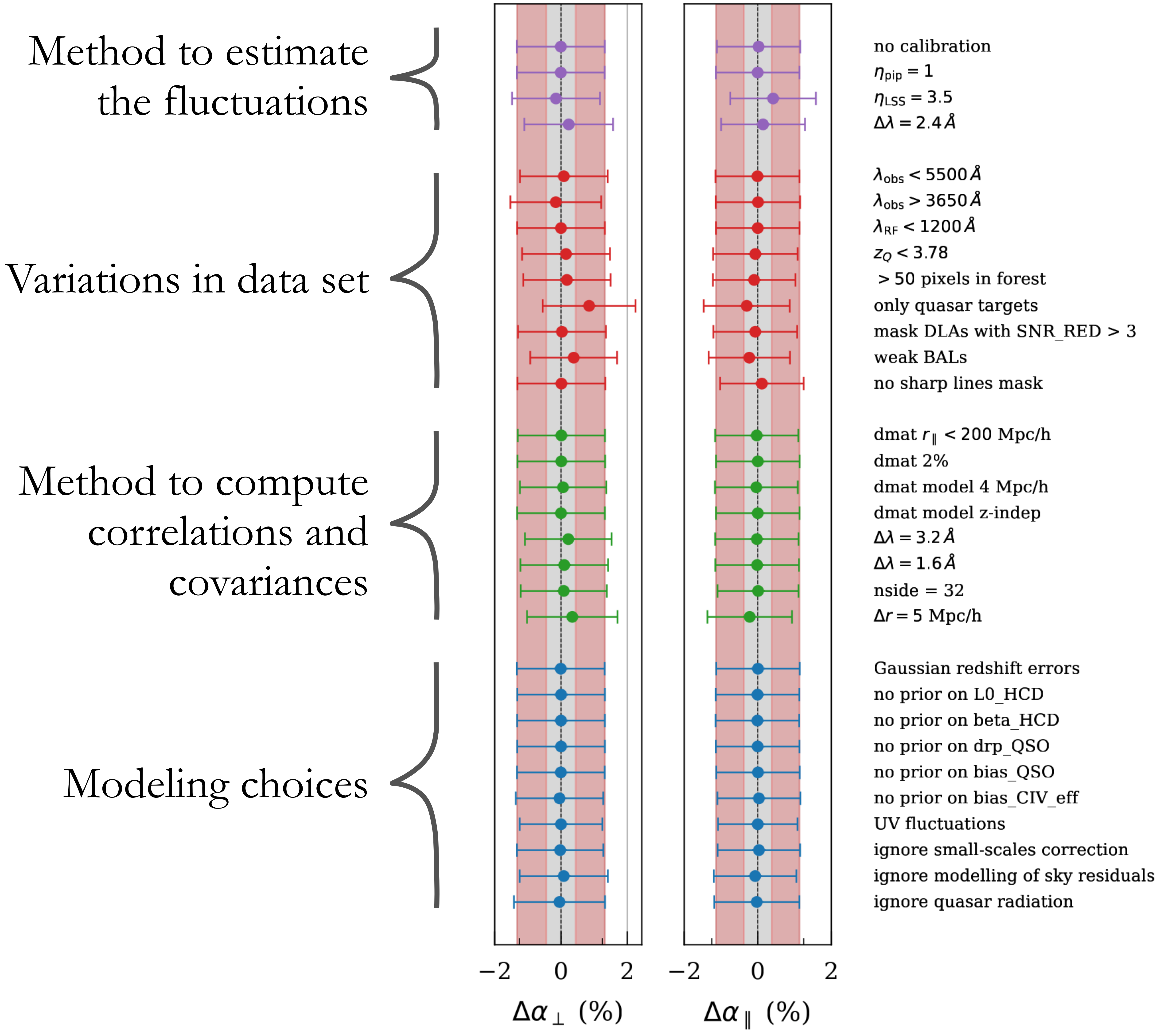
- Very stable results, systematic uncertainty neglected

DR2 BAO is robust against different pipeline choices

Key Paper I: Baryon Acoustic Oscillations from the Lyman Alpha Forest (DESI Collaboration).

Supporting paper: Validation of the DESI-Y3 Lyα forest BAO analysis (Casas++2025).

Supporting paper: Construction of the Damped Lyα Absorber Catalog for DESI DR2 Lyα BAO (Brodzeller++2025).



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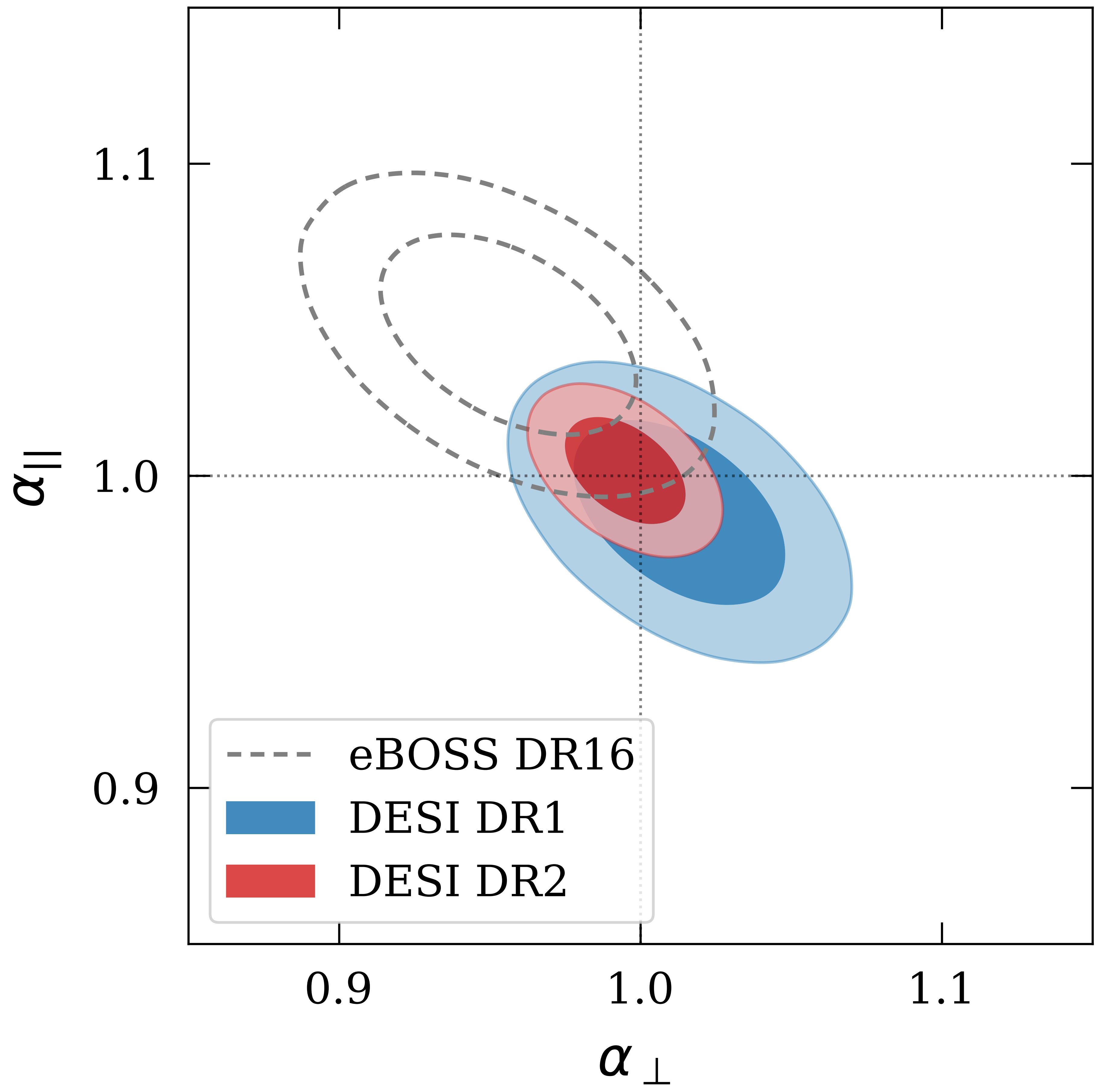
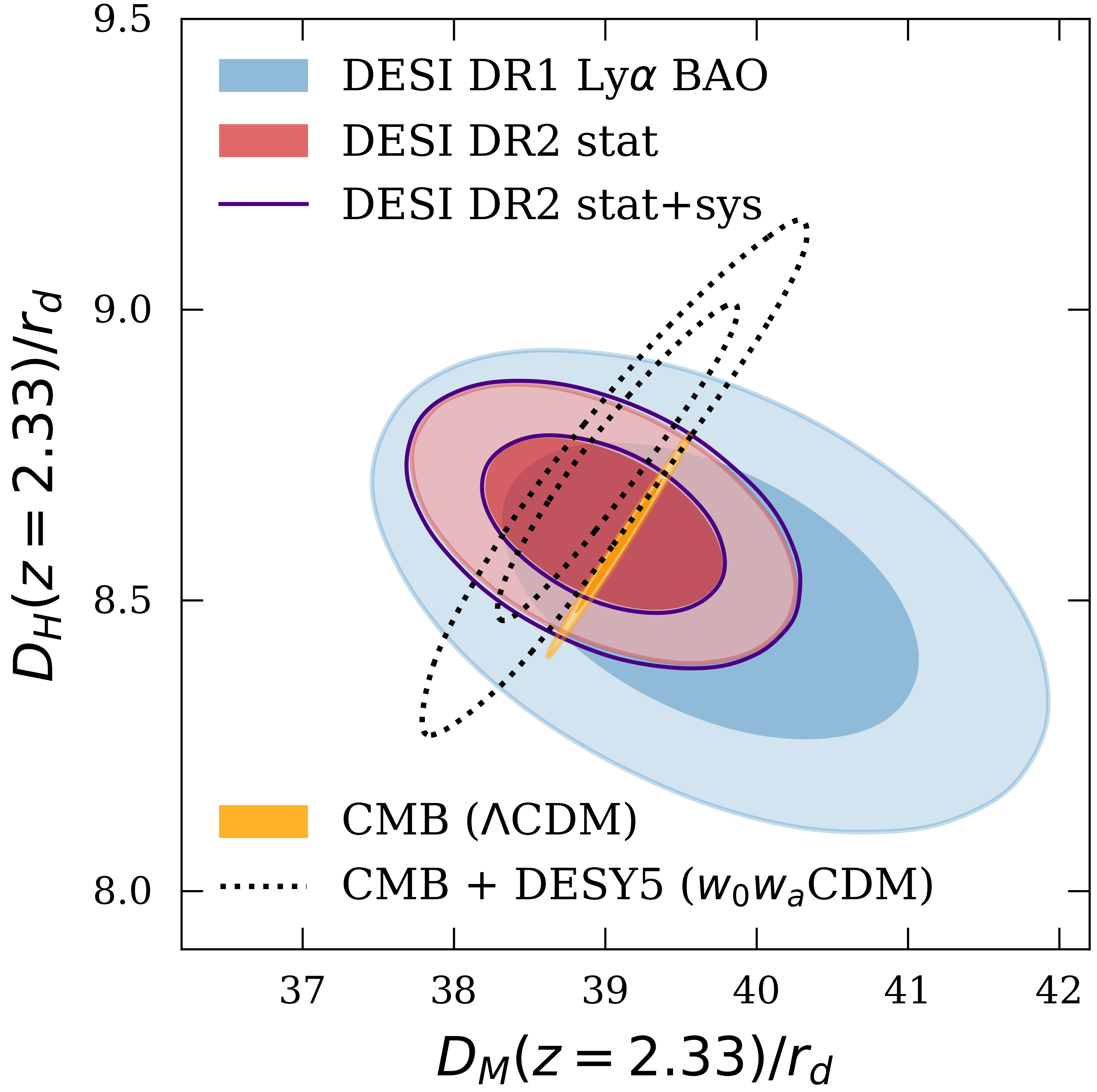
What's new in the analyses?

What's new in the analyses?

- Analysis pipelines are mostly the same as DR1
- Again, blind analyses:
  - discrete tracers: catalog-level blinding
  - Lyα: data vector-level blinding
- Specifics:
  - discrete tracers: more robustness tests, increased BGS density
  - Lyα: improved mocks/modeling (DLA, metals, continuum fitting)
- Some updates in BAO fitting
- Subdominant systematics: $\sigma_{\mathrm{stat+syst}} < 1.09\sigma_{\mathrm{stat}}$ for discrete tracers, $< 1.06\sigma_{\mathrm{stat}}$ for Lyα


1.1
1.0
0.9
$\alpha_{||}$
0.9
1.0
1.1
$\alpha_\perp$
eBOSS DR16
DESI DR1
DESI DR2


9.5
9.0
8.5
8.0
$D_H(z = 2.33)/r_d$
37
38
39
40
41
42
$D_M(z = 2.33)/r_d$
DESI DR1 Lyα BAO
DESI DR2 stat
DESI DR2 stat+sys
CMB (ΛCDM)
CMB + DESY5 (w_0w_aCDM)

Prior choice: $w_0 - w_a$

- DESI priors: $w_0 \sim \mathcal{U} = [-3, 1]$ $w_a \sim \mathcal{U} = [-3, 2]$.
- Does it lead to a violation of the null energy condition (NEC)?

Assessing observational constraints on dark energy

David Shlivko[a], Paul J. Steinhardt[a,b,*]

[a] *Department of Physics, Princeton University, Princeton, NJ 08544, USA*
[b] *Jefferson Physical Laboratory, Harvard University, Cambridge MA 02138, USA*

Abstract

Observational constraints on time-varying dark energy (*e.g.*, quintessence) are commonly presented on a w_0-w_a plot that assumes the equation of state of dark energy strictly satisfies $w(z) = w_0 + w_a z/(1+z)$ as a function of the redshift z. Recent observations favor a sector of the w_0-w_a plane in which $w_0 > -1$ and $w_0 + w_a < -1$, suggesting that the equation of state underwent a transition from violating the null energy condition (NEC) at large z to obeying it at small z. In this paper, we demonstrate that this impression is misleading by showing that simple quintessence models satisfying the NEC for all z predict an observational preference for the same sector. We also find that quintessence models that best fit observational data can predict a value for the dark energy equation of state at present that is significantly different from the best-fit value of w_0 obtained assuming the parameterization above. In addition, the analysis reveals an approximate degeneracy of the w_0-w_a parameterization that explains the eccentricity and orientation of the likelihood contours presented in recent observational studies.

Conclusion:

of $w_Q(0)$ predicted by the model. Finally, we have pointed out that the thawing quintessence models analyzed in this work, all of which obey the NEC (*i.e.*, have $w_Q(z) \geq -1$), are mapped onto (w_0, w_a) combinations that satisfy $w_0 > -1$ and $w_0 + w_a < -1$. An observational preference for this sector, therefore, does not require the kinds of exotic field theories needed to enable a transition from NEC violation at large z to NEC compliance at small z (see, *e.g.*, Ref. [25]).

This last finding has an important corollary: contrary to the suggestion in Ref. [26], we have shown that it is not just reasonable but crucially important for observational analyses to include combinations of (w_0, w_a) satisfying $w_0 + w_a < -1$ in their priors with high credence. Otherwise, these analyses would be inadvertently excluding families of simple, well-motivated models of thawing quintessence from consideration.

Slides borrowed from E. di Valentino

We should stop fitting the data to our beliefs.

We shouldn't interpret observations through personal, theoretical, or historical priors.
If data agree with our beliefs, we call them "robust."
If they don't, we dismiss them or question their reliability.

I'm not saying we need new physics:
but we've become too precise and not accurate enough.

We're cherry-picking datasets based on convenience:
Plik PR3 or CamSpec PR4? Pantheon+ or DESY5? DESI or SDSS?
Depends on which agrees better with "our" preferred results.

The same is happening with BAO: once considered a gold standard, is now questioned.
And we cannot just go back to using older data like SDSS only when it supports our narrative.

That's arbitrary and it's undermining scientific objectivity.

We should let the data breathe.

24

Concluding

If all data must agree with Planck LCDM to be trusted,
then we're no longer testing models, we're protecting them.

ΛCDM is a remarkably successful fitting model,
but it was never meant to be untouchable.
It's built on ingredients (dark matter, a cosmological constant, and inflation)
none of which have a fundamental theoretical explanation or direct detection.
We use them because they work phenomenologically,
not because we understand what they are.

Clinging to ΛCDM as the final word in cosmology
risks mistaking convenience for truth,
and turning precision cosmology into confirmation bias dressed as science.

We must stay open to what the data are really telling us,
let's not always dismiss deviations and anomalies as systematics and statistical flukes,
and be ready for a reassessment of both our methods and assumptions.