A Low-Redshift Preference for an Interacting Dark Energy Model

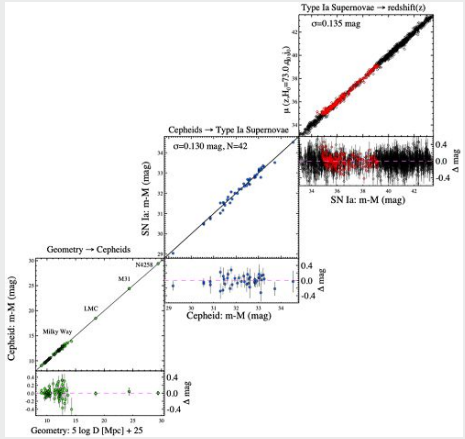
Yuejia Zhai

Based on work with Marco de Cesare, Carsten van de Bruck, Eleonora Di Valentino, and Edward Wilson-Ewing.
arXiv: 2503.15659

CosmoVerse@Istanbul
25 June 2025

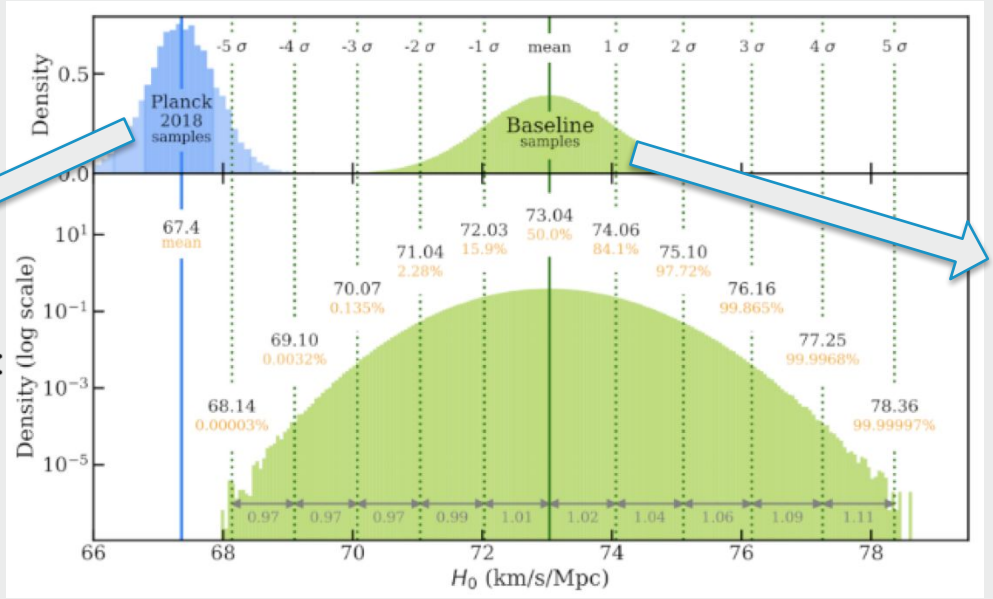
Hubble Tension

- Probability distribution from MCMC sampling



Riess et al. (2022)

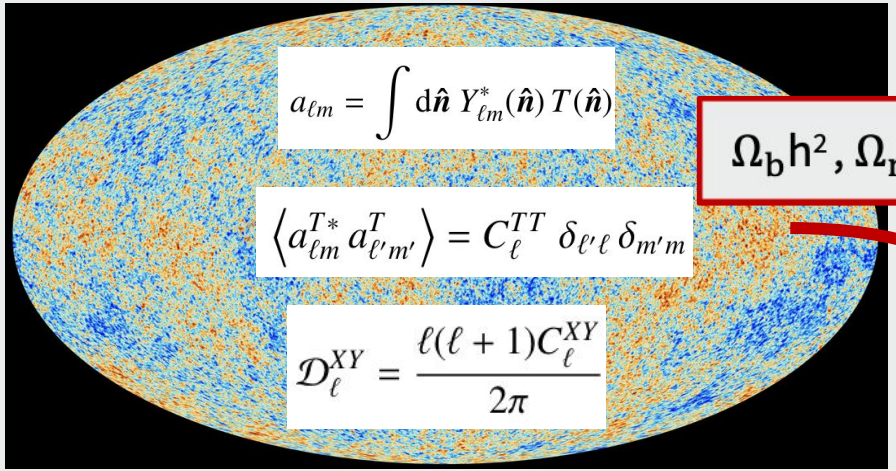
Assuming a ΛCDM cosmological model:
H_0 = 67.27 ± 0.60 km/s/Mpc



Riess et al. (2022)

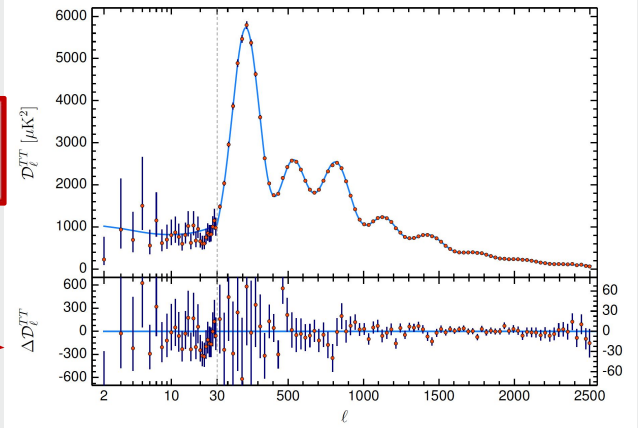
SH0ES collaboration, directly measuring the distance ladder:
H_0 = 73.04 ± 1.04 km/s/Mpc

ΛCDM - 6 parameter cosmology



Credit: ESA/Planck Collaboration

$\Omega_b h^2, \Omega_m h^2, \theta_s, n_s, \tau, A_s$



Planck Collaboration et al. (2021)

Interactions between dark matter and dark energy

- Potential solution to tensions via DM-DE energy transfer

Interacting Dark Energy model can offer a solution

- Energy conservation equations:

$$\nabla_\mu T^\mu_{DM\nu} = +\frac{Q(v_{DM})_\nu}{a}$$

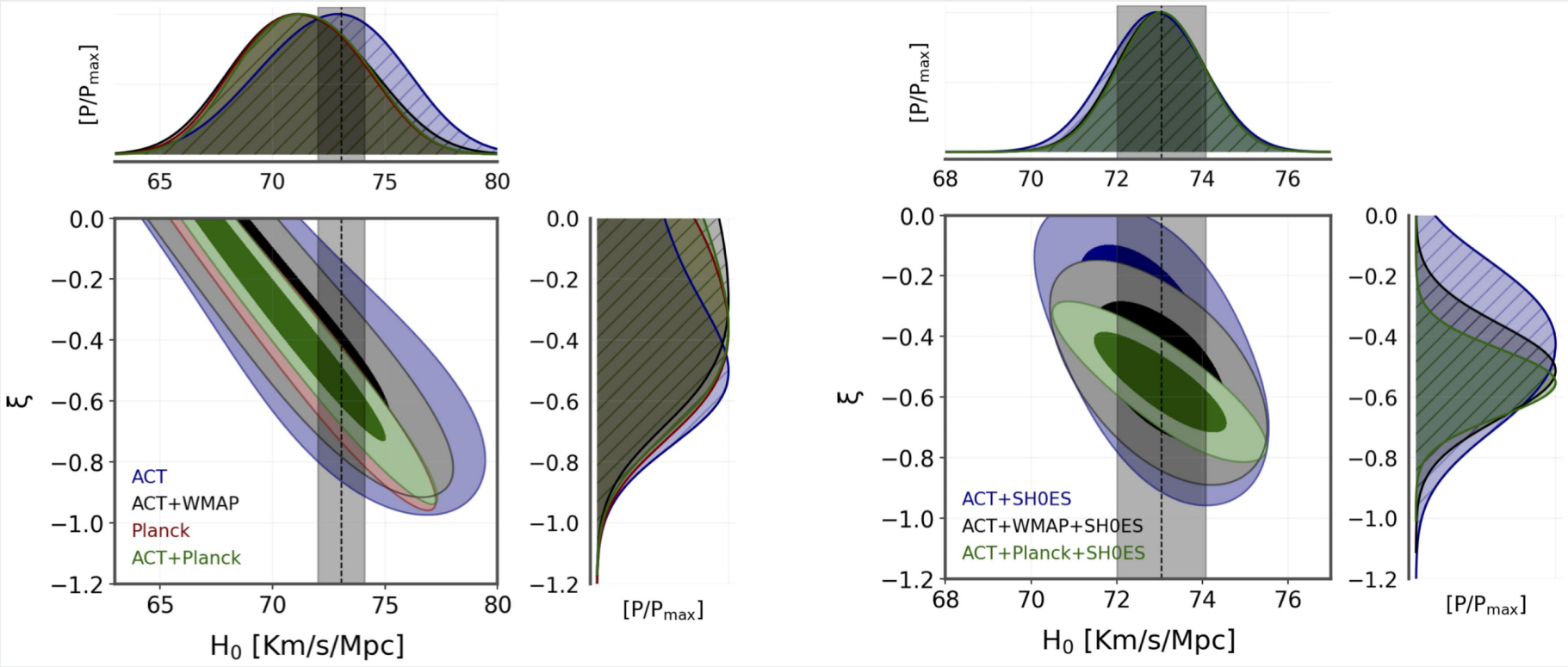
$$\nabla_\mu T^\mu_{DE\nu} = -\frac{Q(v_{DM})_\nu}{a}$$

with energy density transfer rate: ($\xi < 0$)

$$Q = \xi \mathcal{H} \rho_{DE}$$

Valiviita et al. (2008) arXiv: 0804.0232

Interacting Dark Energy model can offer a solution



Zhai et al. (2023) arXiv: 2303.08201

Can we achieve similar observational performance with more minimal phenomenological modification to the theory?

Interacting Dark Energy model (IDE)

The Einstein Equations are:

$$G_{\mu\nu} = 8\pi G T_{\mu\nu} + Q g_{\mu\nu}$$

- We have an **effective cosmological constant** Q.

$$Q = 8\pi G \epsilon \rho_{DM} + const.$$

Key parameter: ϵ is a dimensionless constant, denoting the strength of the interaction between DM and DE.

- Energy flows from **DM** $\rightarrow$ **DE** when $\epsilon > 0$

de Cesare and Wilson-Ewing (2022) arXiv: 2112.12701

Stability & Theoretical Insights

- $\epsilon > 0$ avoids gradient instability
- Minimal modifications to Einstein equations that retains **gauge invariance**
- Dark energy EOS $w_{DE} = -1$

- Energy conservation can be rewritten as:

$$\nabla_\mu T^\mu_{DM\,\nu} = -\frac{1}{8\pi G}\nabla_\nu Q$$

de Cesare and Wilson-Ewing (2022) arXiv: 2112.12701

Methodology

- Datasets:
  - Planck 2018 CMB temperature and polarization power spectrum with CMB lensing
  - DESI 2024 BAO
  - Pantheon+ (1550 SNIa)
- Tools:
  - Modified CLASS for IDE dynamics
  - Bayesian analysis with COBAYA

- Flat priors:

Parameter	Prior
$\Omega_{\rm b}h^2$	$[0.005, 0.1]$
$\Omega_{\rm c}h^2$	$[0.001, 0.990]$
$\tau_{\rm reio}$	$[0.01, 0.80]$
$n_{\rm s}$	$[0.8, 1.2]$
$\log(10^{10}A_{\rm s})$	$[1.61, 3.91]$
$100\theta_{\rm s}$	$[0.5, 10]$
ϵ	$[0, 0.1]$

arXiv: 2503.15659

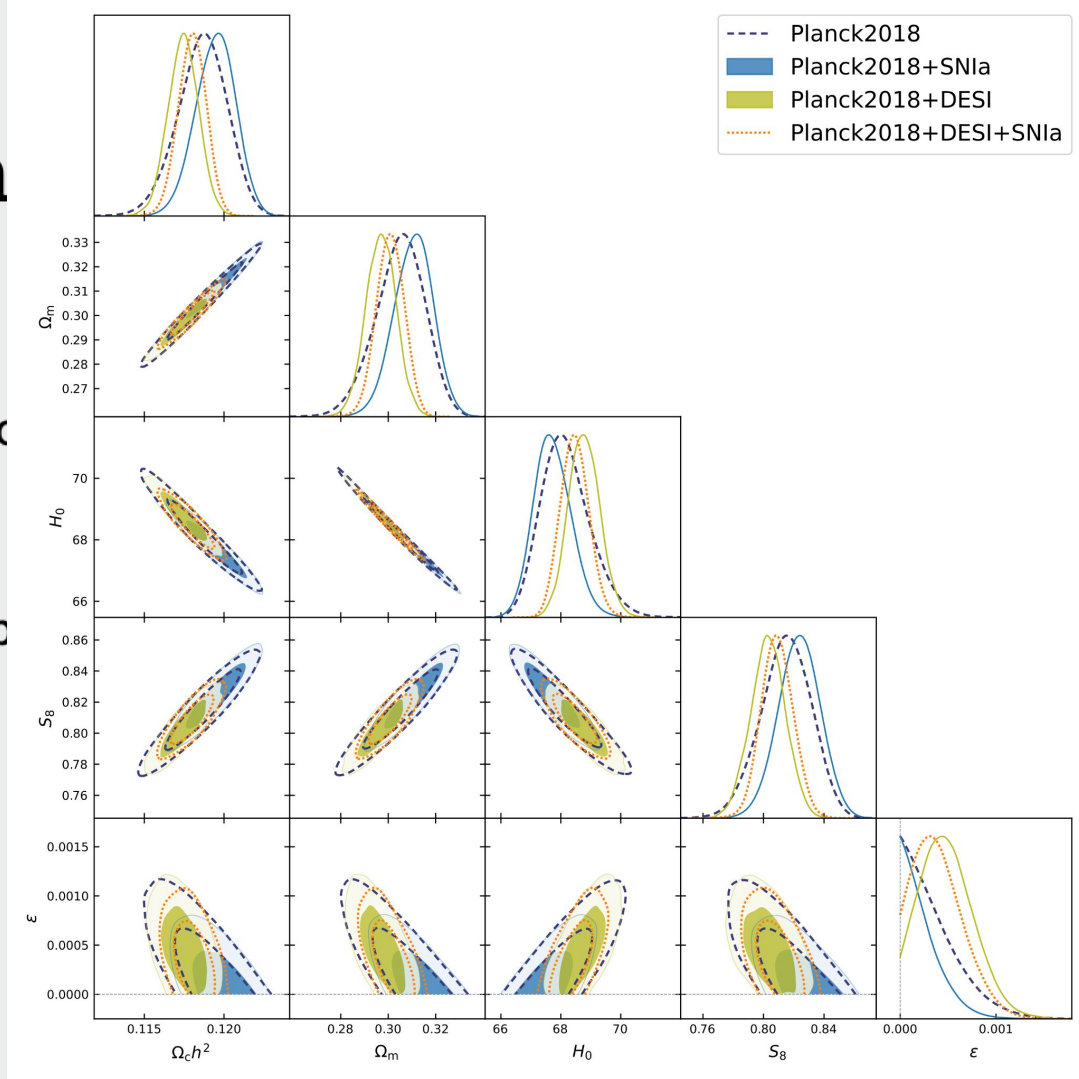
Results – Constraints on ϵ

- Planck Alone:
  - $\epsilon < 0.0009$ (95% CL) – no interaction preferred
- Planck + DESI:
  - $\epsilon = 0.00049^{+0.00022}_{-0.00033}$ – mild **1σ** preference
- Planck + SNIa:
  - Tighter upper limit ($\epsilon < 0.0006$)

arXiv: 2503.15659

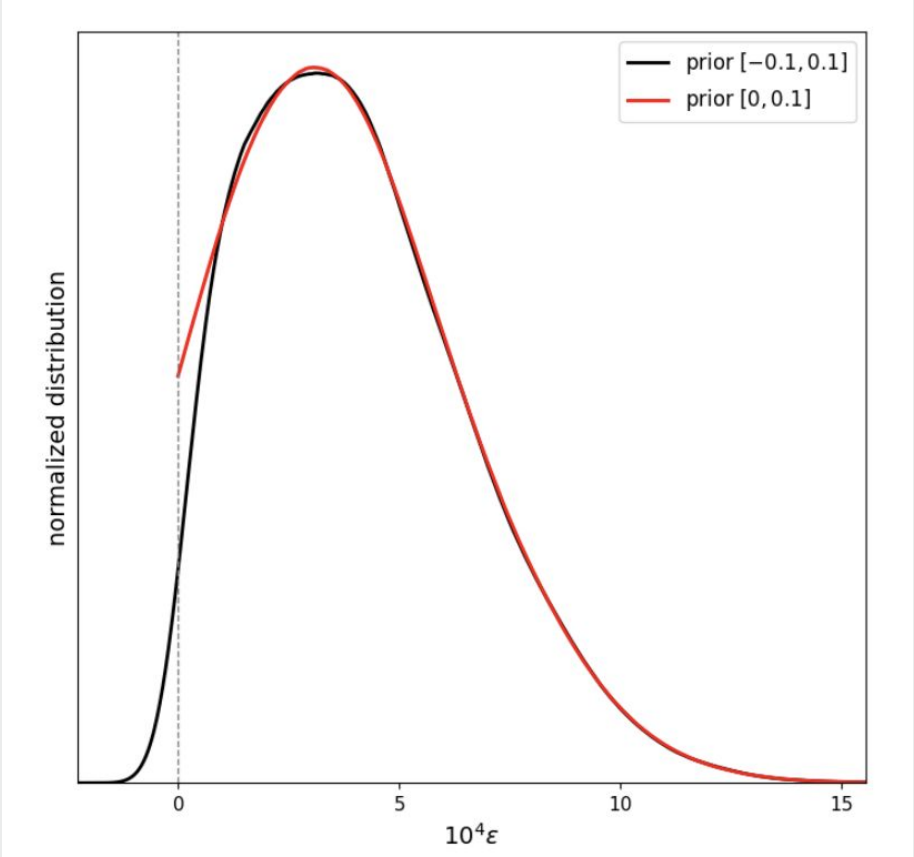
Results – Constrain

- Planck Alone:
  - $\epsilon < 0.0009$ (95% CL) – no interactio
- Planck + DESI:
  - $\epsilon = 0.00049^{+0.00022}_{-0.00033}$ – mild **1σ** p
- Planck + SNIa:
  - Tighter upper limit ($\epsilon < 0.0006$)

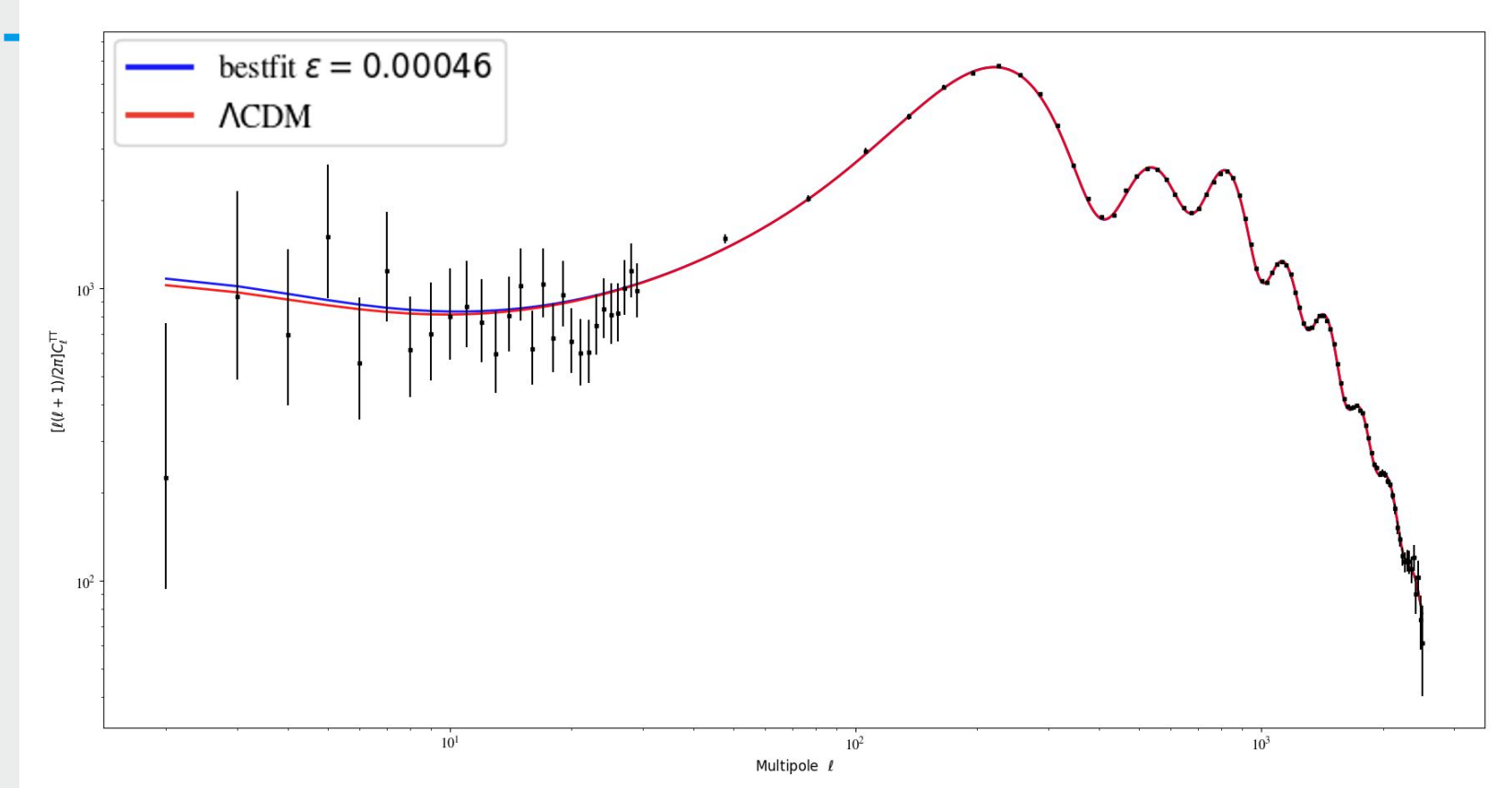


arXiv: 2503.15659

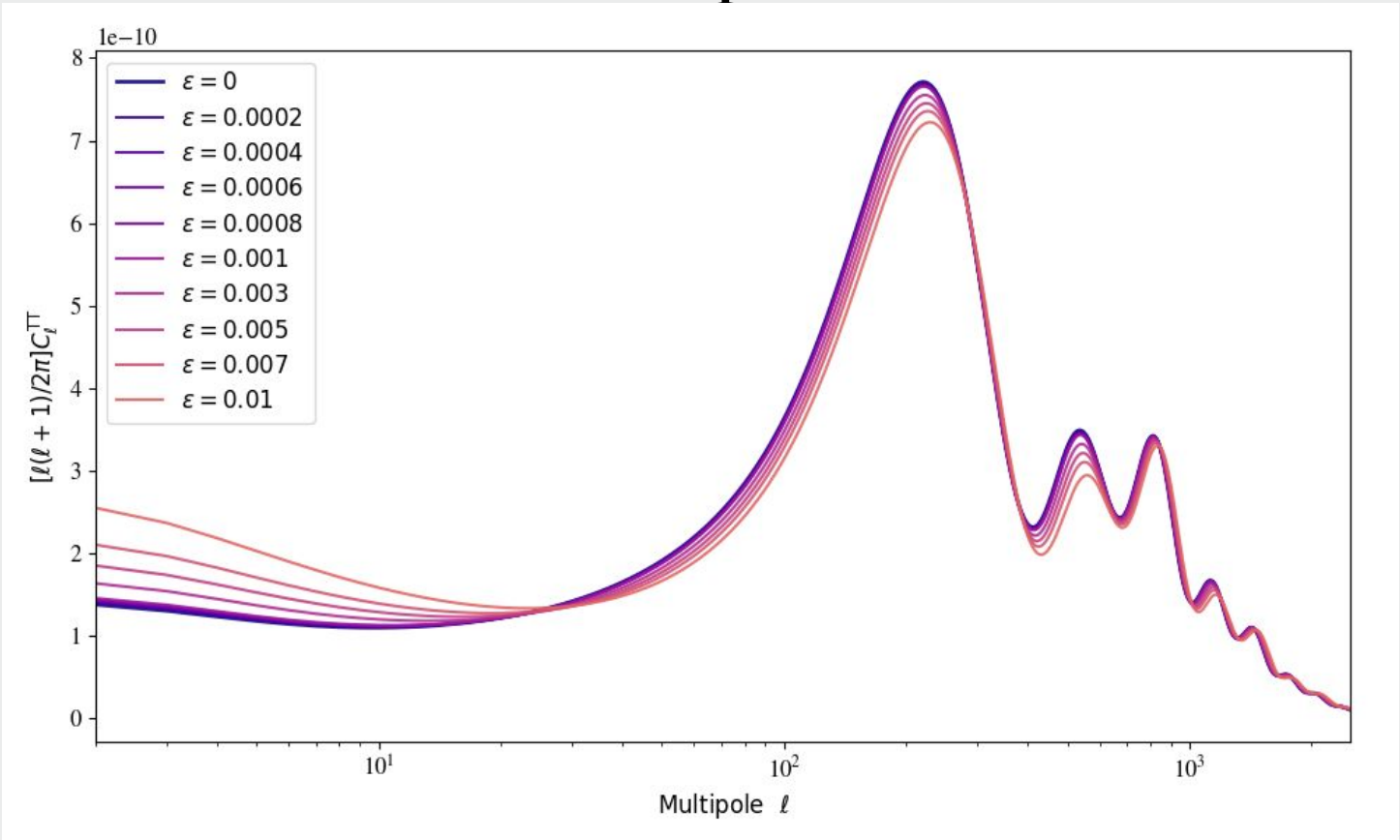
Allowing negative ϵ shows no significant difference



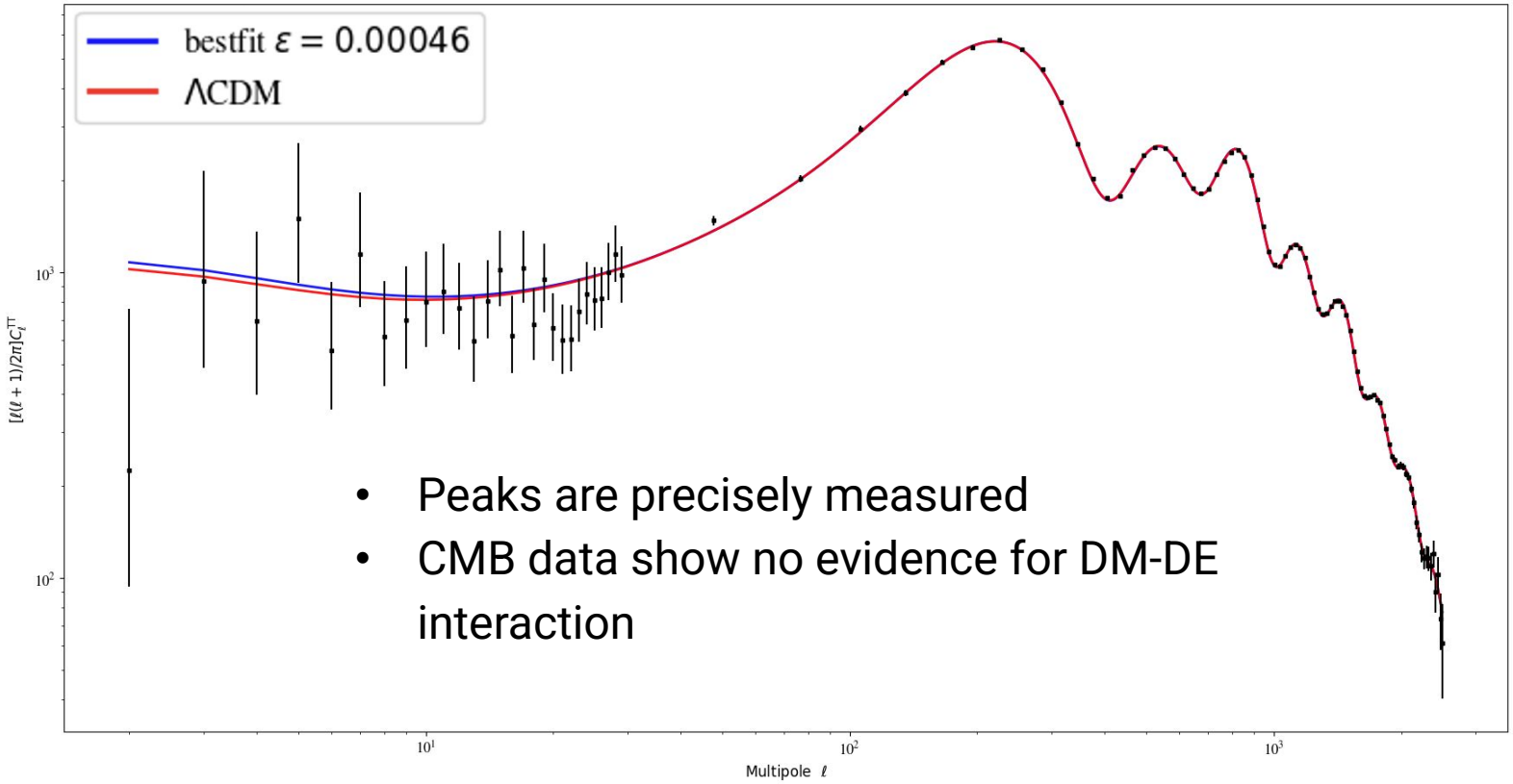
CMB constraints



Theoretical CMB TT prediction

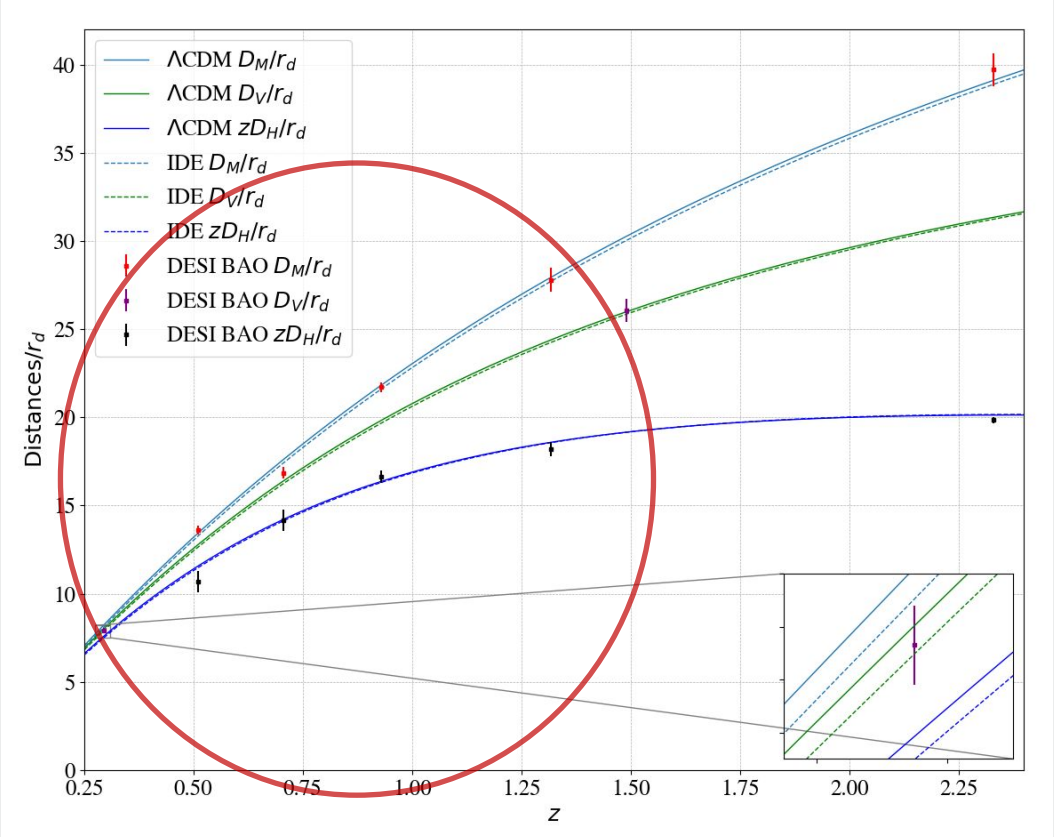


CMB constraints



- Peaks are precisely measured
- CMB data show no evidence for DM-DE interaction

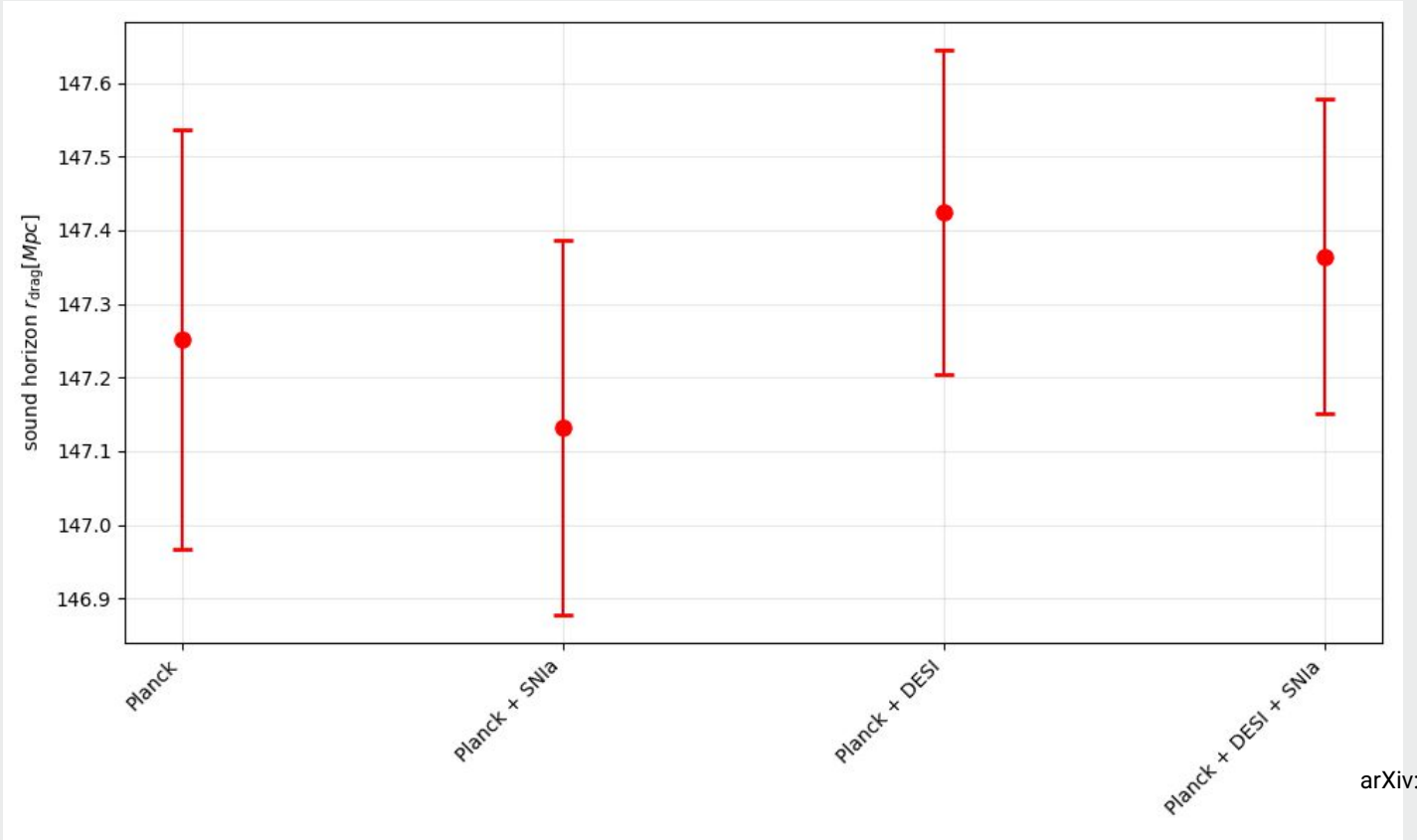
DESI 2024 BAO constraints



- CMB data show no evidence for DM-DE interaction
- The preference for such interaction comes from DESI BAO measurements

arXiv: 2503.15659

Sound horizon at drag epoch



arXiv: 2503.15659

Conclusions

- Weak Interaction:
  - DESI 2024 BAO data introduces a mild 1σ signal ($\epsilon \sim 10^{-4}$), driven by DESI's low-z distance measurements;
  - CMB and SNIa data remain consistent with ΛCDM , with tight constraints on ϵ.
- Mild shift towards higher H_0 and S_8, but tensions are not alleviated;
- IDE can accommodate $w_{DE} = -1$ without introducing instabilities.

Conclusions

- Weak Interaction:
  - DESI 2024 BAO data introduces a mild 1σ signal ($\epsilon \sim 10^{-4}$), driven by DESI's low-z distance measurements;
  - CMB and SNIa data remain consistent with ΛCDM , with tight constraints on ϵ.
- Mild shift towards higher H_0 and S_8, but tensions are not alleviated;
- IDE can accommodate $w_{DE} = -1$ without introducing instabilities.

Thank you!

Perturbations

$$\delta_c' = -\frac{1}{1-\epsilon}\left(\theta_c + \frac{h'}{2}\right) \ ,$$

$$\theta_c' = -\frac{1-4\epsilon}{1-\epsilon}\mathcal{H}\theta_c + \epsilon k^2 \delta_c \ .$$

Results – Constraints on ϵ

Parameter	Planck2018	Planck2018+DESI	Planck2018+SNIa	Planck2018+DESI+SNIa
$\Omega_{\rm b}h^2$	0.02232 ± 0.00015	0.02237 ± 0.00015	0.02230 ± 0.00015	0.02234 ± 0.00015
$\Omega_{\rm c}h^2$	$0.1186^{+0.0017}_{-0.0014}$	0.11744 ± 0.00095	$0.1195^{+0.0013}_{-0.0012}$	0.11800 ± 0.00088
$\tau_{\rm reio}$	0.0542 ± 0.0076	$0.0567^{+0.0069}_{-0.0077}$	0.0529 ± 0.0071	0.0560 ± 0.0071
$n_{\rm s}$	0.9660 ± 0.0044	0.9684 ± 0.0036	0.9646 ± 0.0040	0.9674 ± 0.0036
$\log(10^{10}A_{\rm s})$	3.043 ± 0.015	$3.047^{+0.014}_{-0.016}$	3.042 ± 0.014	3.046 ± 0.014
H_0	$68.16^{+0.67}_{-0.93}$	68.78 ± 0.52	$67.72^{+0.56}_{-0.69}$	68.47 ± 0.47
$\Omega_{\rm m}$	$0.305^{+0.012}_{-0.009}$	0.2970 ± 0.0063	$0.3107^{+0.0088}_{-0.0076}$	0.3008 ± 0.0058
σ_8	0.8082 ± 0.0060	$0.8071^{+0.0058}_{-0.0064}$	0.8095 ± 0.0058	0.8079 ± 0.0058
S_8	$0.815^{+0.018}_{-0.016}$	0.803 ± 0.011	0.824 ± 0.014	0.809 ± 0.011
ϵ	$< 0.000432 (< 0.000907)$	$0.00049^{+0.00022}_{-0.00033} (< 0.000970)$	$< 0.000293 (< 0.000635)$	$0.00041^{+0.00015}_{-0.00035} (< 0.000880)$

TABLE II. Constraints at 68% (95%) CL on parameters from various combinations of datasets.