Cosmology in an extended parameter space: new constraints on dark energy and neutrino masses with DESI BAO

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Talk at ASROC, NFU, Taiwan

This Talk is based on ...

- **Shouvik Roy Choudhury**, Teppei Okumura,
  "*Updated cosmological constraints in extended parameter space with Planck PR4, DESI BAO, and SN: dynamical dark energy, neutrino masses, lensing anomaly, and the Hubble tension*,"
  arXiv: 2409.13022, Astrophys.J.Lett. 976 (2024) 1, L11
- **Shouvik Roy Choudhury**,
  "*Cosmology in Extended Parameter Space with DESI DR2 BAO: A $2\sigma+$ Detection of Non-zero Neutrino Masses with an Update on Dynamical Dark Energy and Lensing Anomaly*,"
  arXiv: 2504.15340

Cosmological Evolution

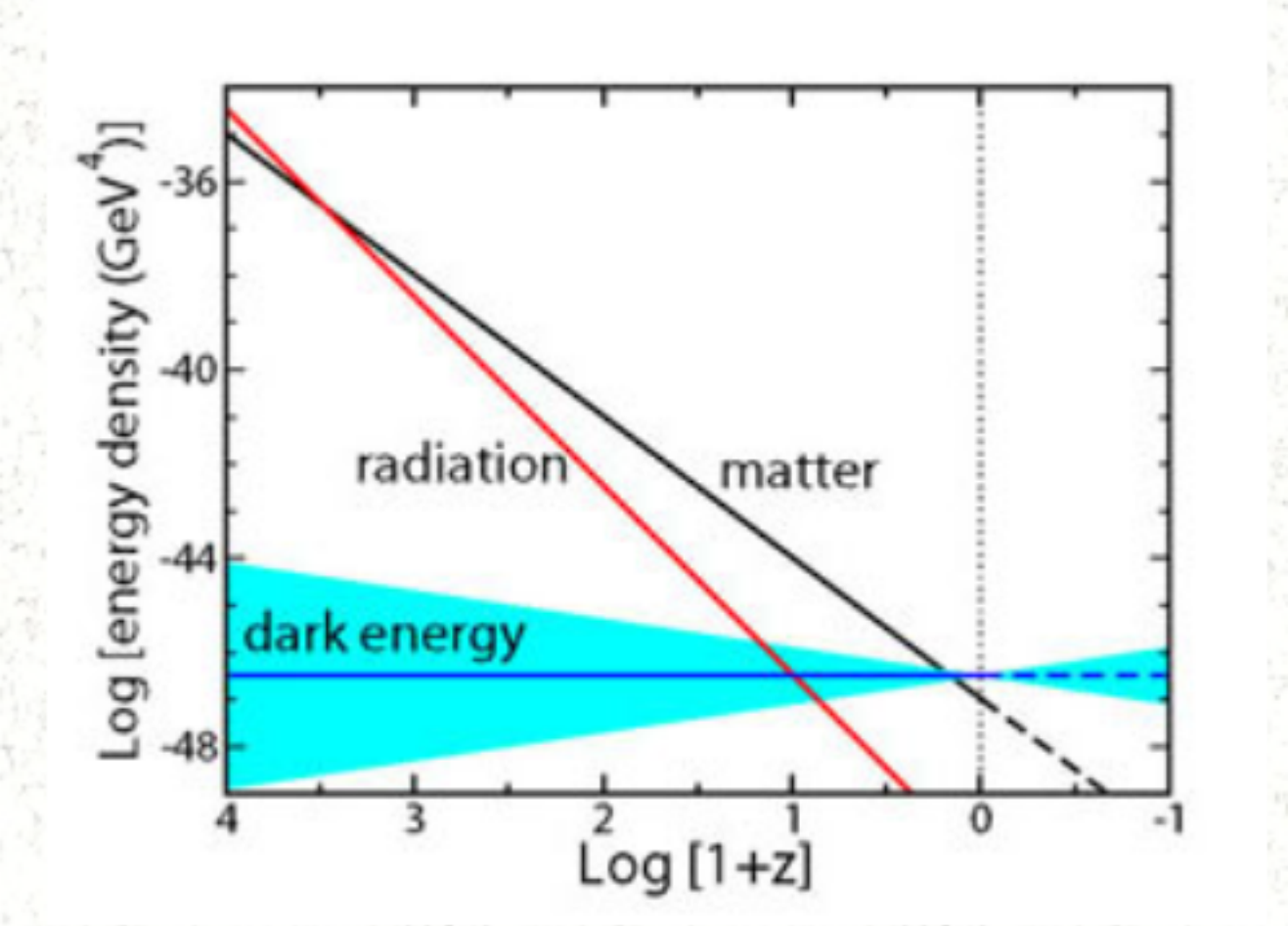


Figure: Image credit: NED, CalTech

DESI BAO DR1 results on dynamical dark energy

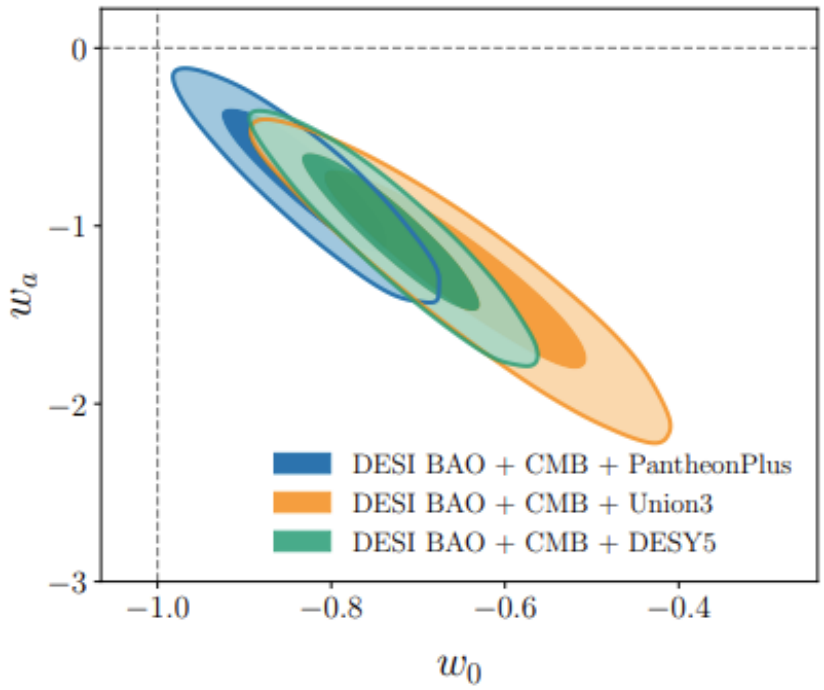


Figure: Image credit: DESI BAO Collab., arXiv: 2404.03002

- Dark energy equation of state: $w(z) = w_0 + w_a\ z/(1+z)$
- Cosmological constant is rejected at 2.5-3.9σ varying on the Supernovae dataset.

DESI BAO DR2 results on dynamical dark energy

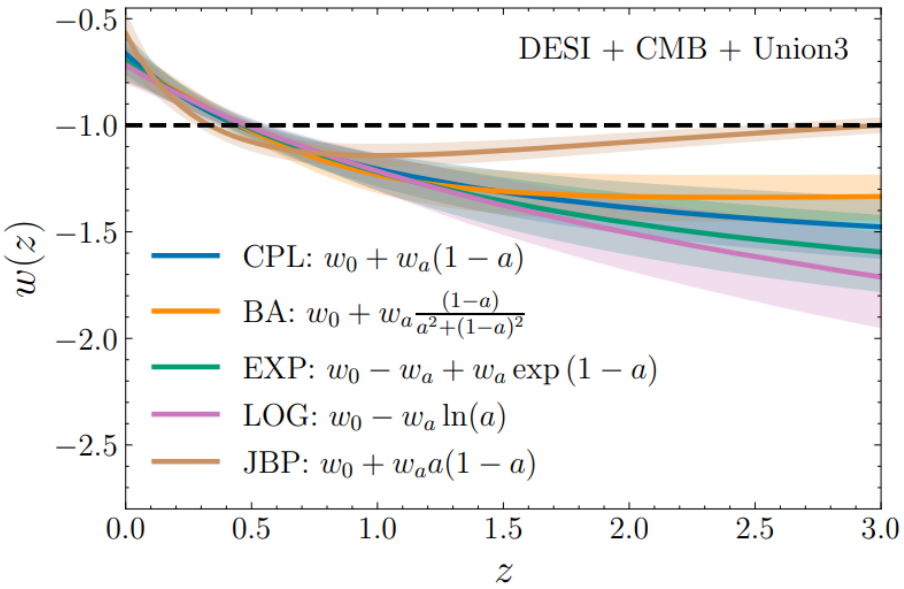


Figure: Image credit: DESI BAO Collab., arXiv: 2503.14743

- Phantom crossing seen at $z \sim 0.5$.

DESI BAO DR1 results on neutrino masses

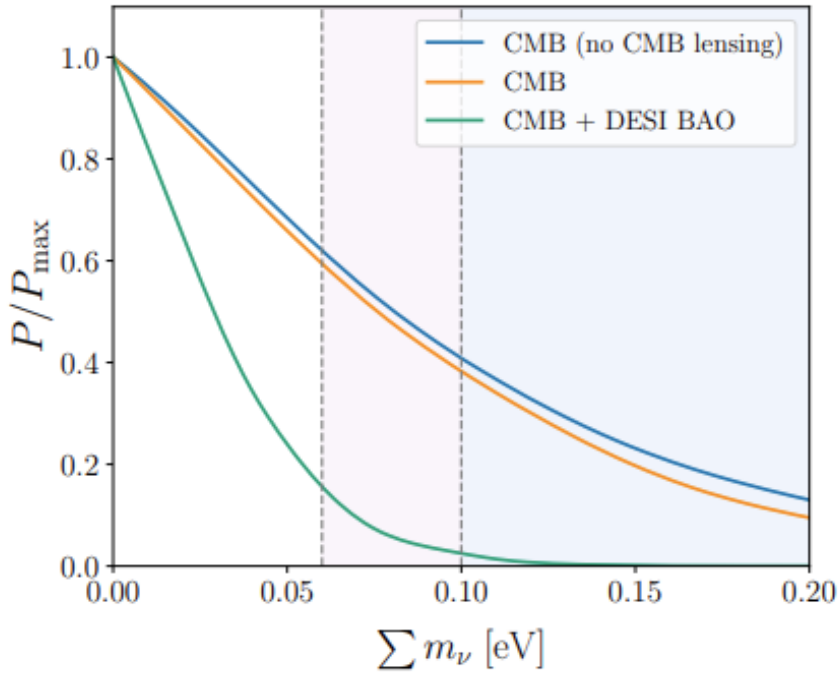


Figure: Image credit: DESI BAO Collab., arXiv: 2404.03002

- In ΛCDM+$\sum m_\nu$, the bound is $\sum m_\nu < 0.072$ eV (95%) with CMB+DESI.
- Bounds relax with dynamical dark energy to $\sum m_\nu \lesssim 0.2$ eV.

Our 12 parameter extended cosmological model

$$\theta \equiv \left[\omega_c,\ \omega_b,\ \Theta_s^*,\ \tau,\ n_s,\ \ln(10^{10}A_s), w_{0,\rm DE}, w_{a,\rm DE}, N_{\rm eff}, \sum m_\nu, \alpha_s, A_{\rm lens}\right].$$

- $w(z) \equiv w_{0,\rm DE} + w_{a,\rm DE}\ z/(1+z)$ (CPL parametrization)
- $N_{\rm eff}^{\rm SM} = 3.044$
- $\alpha_s \equiv dn_s/d\ln k$

$$\ln\ \mathcal{P}_s(k) = \ln\ A_s + (n_s - 1)\ \ln\left(\frac{k}{k_*}\right) + \frac{\alpha_s}{2}\left[\ln\left(\frac{k}{k_*}\right)\right]^2. \qquad (1)$$

Our main goals

- To check whether the preference for **dynamical dark energy** survives in a largely extended parameter space.
- To provide a reasonable bound on the $\sum \boldsymbol{m_\nu}$ parameter which can be used by the cosmology and particle physics community.
- To give a definitive answer regarding the **lensing anomaly** in a dynamical dark energy scenario with Planck PR4 likelihoods.
- To assess the level of this **Hubble discrepancy** in our 12 parameter extended cosmological model with the new datasets.

Datasets

- **CMB: Planck Public Release (PR) 4**: HiLLiPoP (high-l TT, TE, EE), LoLLiPoP (low-l EE), and Commander (Planck 2018 low-l TT)
- **CMB lensing**: Planck PR4 lensing +ACT DR6 lensing (Notation: **lensing**)
- **BAO**: DESI Data Release (DR) 1 & 2 (Notation: **DESI** & **DESI2**)
- **SNeIa**: Pantheon+ (Notation: **PAN+**)
- **SNeIa**: DES Year 5 (Notation: **DESY5**)
- **Weak Lensing**: DES Year 1 (Notation: **WL**)

We note here that PAN+ and DESY5 have supernovae that are common to both samples. Thus the two datasets are never used together, to avoid any double counting.

Results: Dynamical Dark Energy parameters with DESI 1

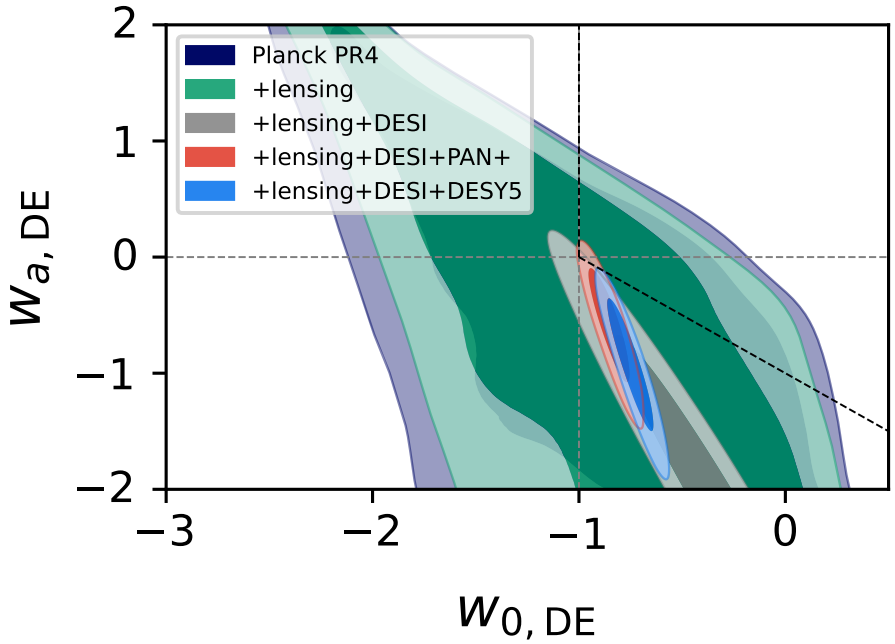


Figure: **SRC** and Okumura, arXiv: 2409.13022 (ApJL)

- With Pantheon+, the cosmological constant is included in 2σ, but not with DES Y5.
- Some quintessence/non-phantom ($w(z) \geq -1$) parameter space is also allowed at 2σ with Pantheon+.
- DES Y5 SN might have systematics (arXiv: 2408.07175)

Results: Dynamical Dark Energy parameters with DESI 2

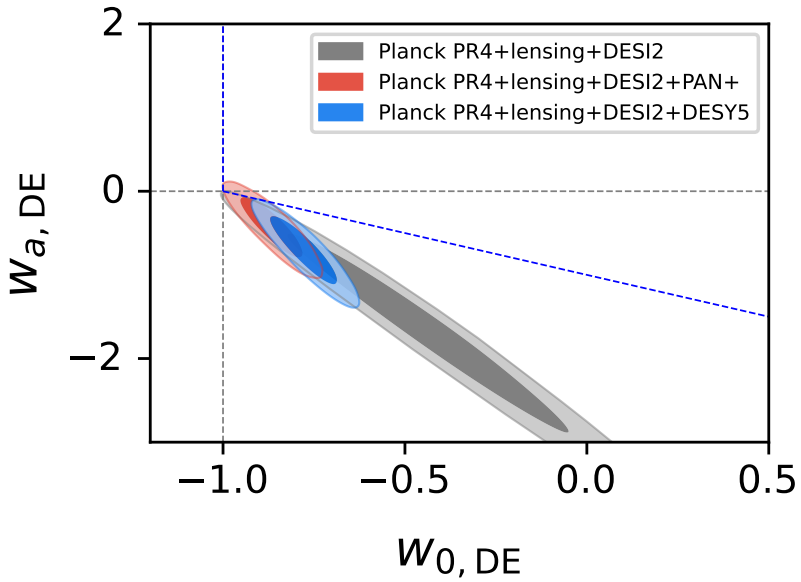


Figure: **SRC**, arXiv: 2504.15340

- With Pantheon+, the cosmological constant is at the margin of the 2σ contour, but rejected at greater than 2σ with DES Y5.
- Some quintessence/non-phantom ($w(z) \geq -1$) parameter space is also allowed at 2σ with Pantheon+.

Results: Neutrino masses with DESI 1

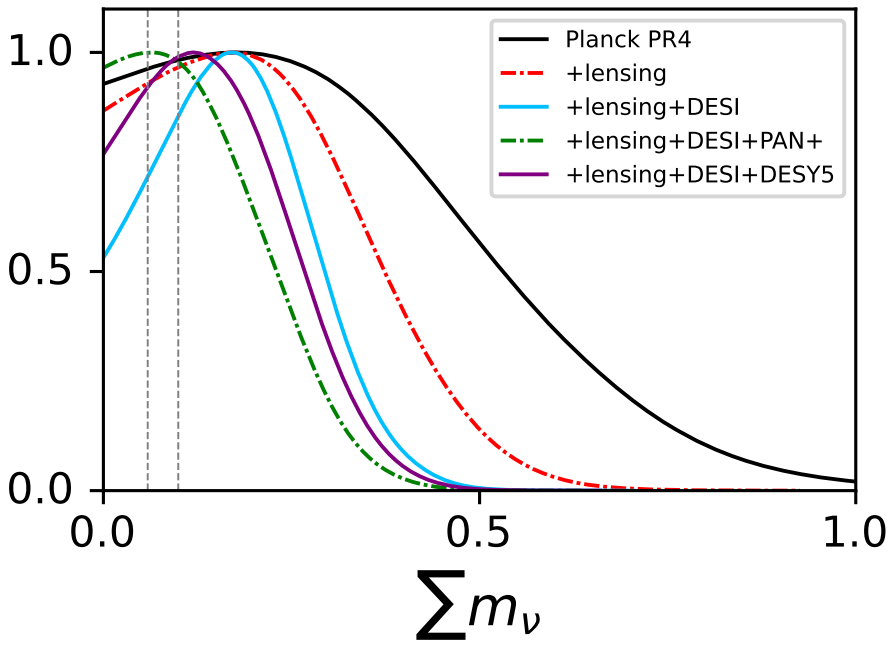
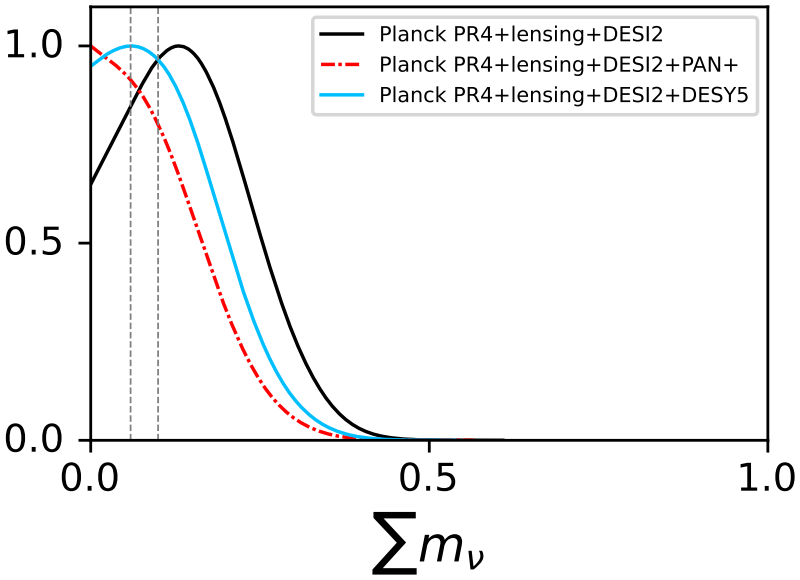


Figure: **SRC** and Okumura, arXiv: 2409.13022 (ApJL)

- With Pantheon+, $\sum m_\nu < 0.292$ eV (95%). With DESY5, it is $\sum m_\nu < 0.318$ eV (95%)
- We see peaks in the posterior for all data combinations, with 1σ detection in three cases.

Results: Neutrino masses with DESI 2



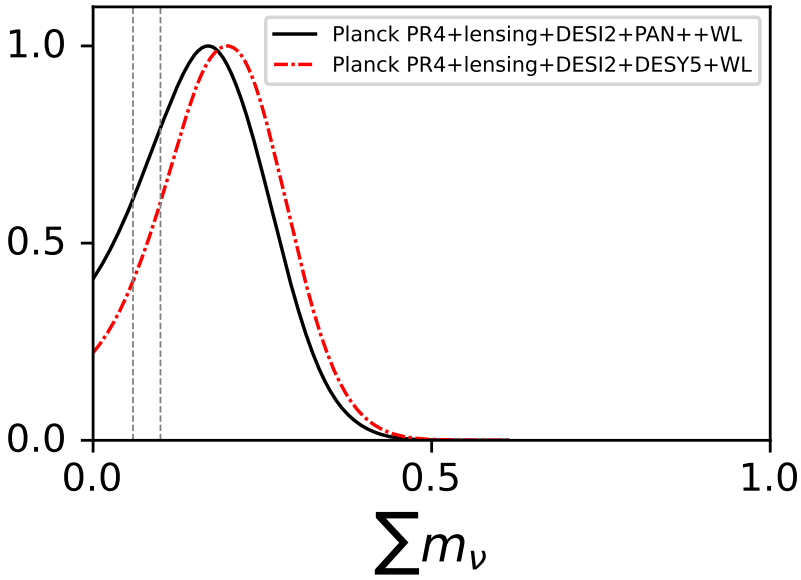


Figure: **SRC**, arXiv: 2504.15340

- With CMB+BAO+DESY5+WL, we get a 2.1σ detection $\sum m_\nu = 0.19^{+0.15}_{-0.18}$ (95%). With Pantheon+ instead of DESY5, we still get a $\sim 1.9\sigma$ detection

Results: Lensing Anomaly with DESI 2

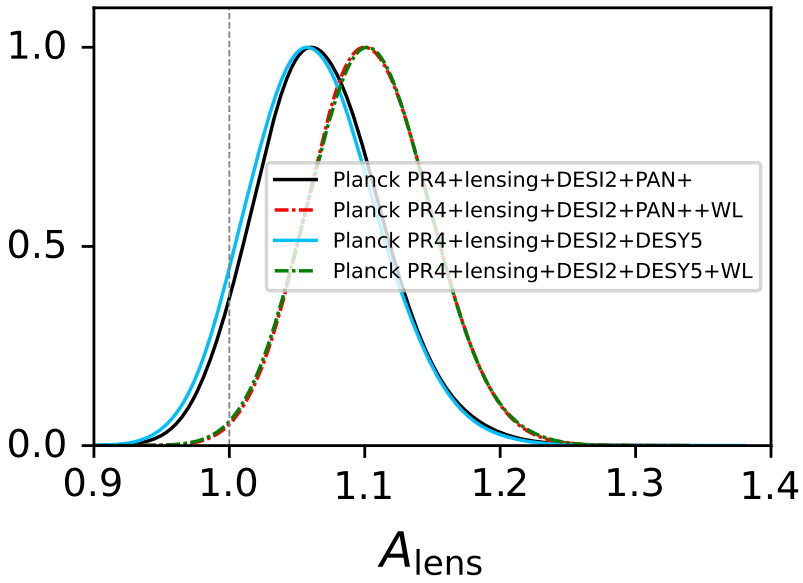


Figure: **SRC**, arXiv: 2504.15340

- With the addition of WL data, we see $A_{\rm lens} = 1$ is rejected at more than 2σ.
- For the first time, we show that existence of lensing anomaly can depend on non-CMB datasets.

Results: Hubble tension

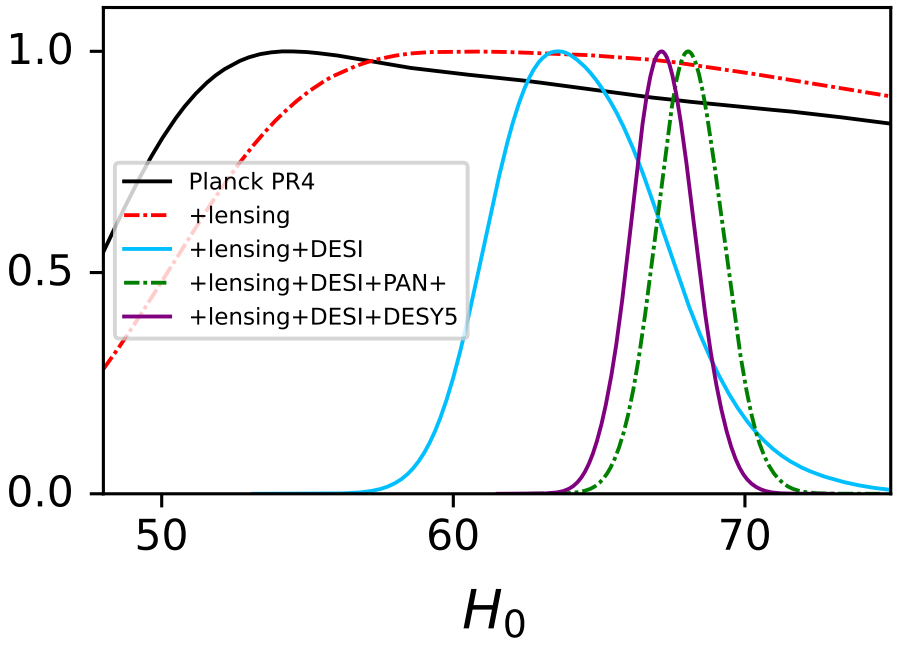


Figure: **SRC** and Okumura, arXiv: 2409.13022 (ApJL)

- Hubble tension persists at 3.2-3.9σ after considering CMB+BAO+SNe.
- This changes to 3.6-4.2σ with DESI DR2 BAO instead of DESI DR1.

Results: S8 tension

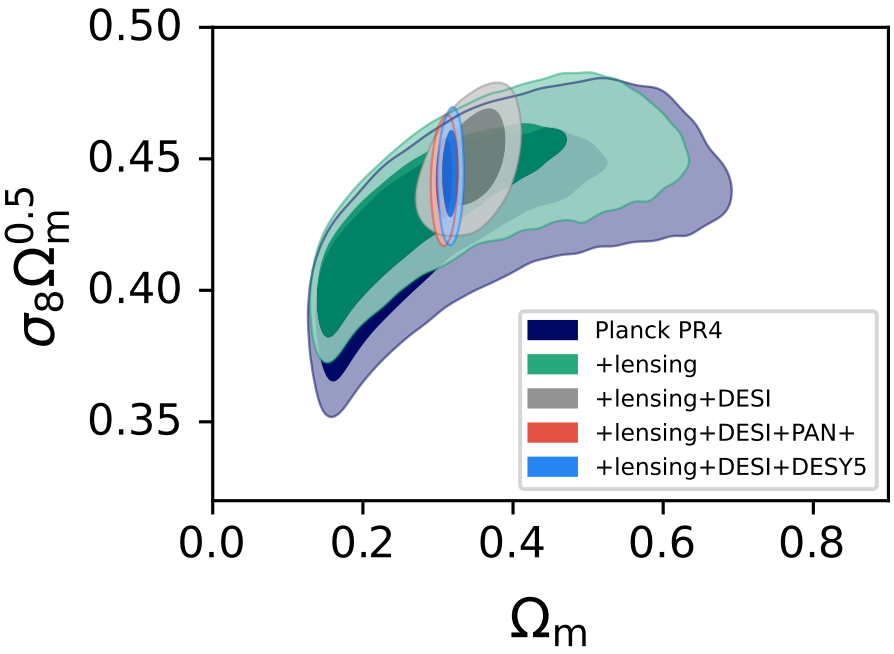


Figure: **SRC** and Okumura, arXiv: 2409.13022 (ApJL). $S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$

- S8 tension with DES Y3 weak lensing data is reduced to only $\sim 1.4\sigma$ after considering CMB+BAO+SNe. Main effect might be due to Planck PR4. With Planck PR3 the tension was $\sim 2.4\sigma$.

A few degeneracies

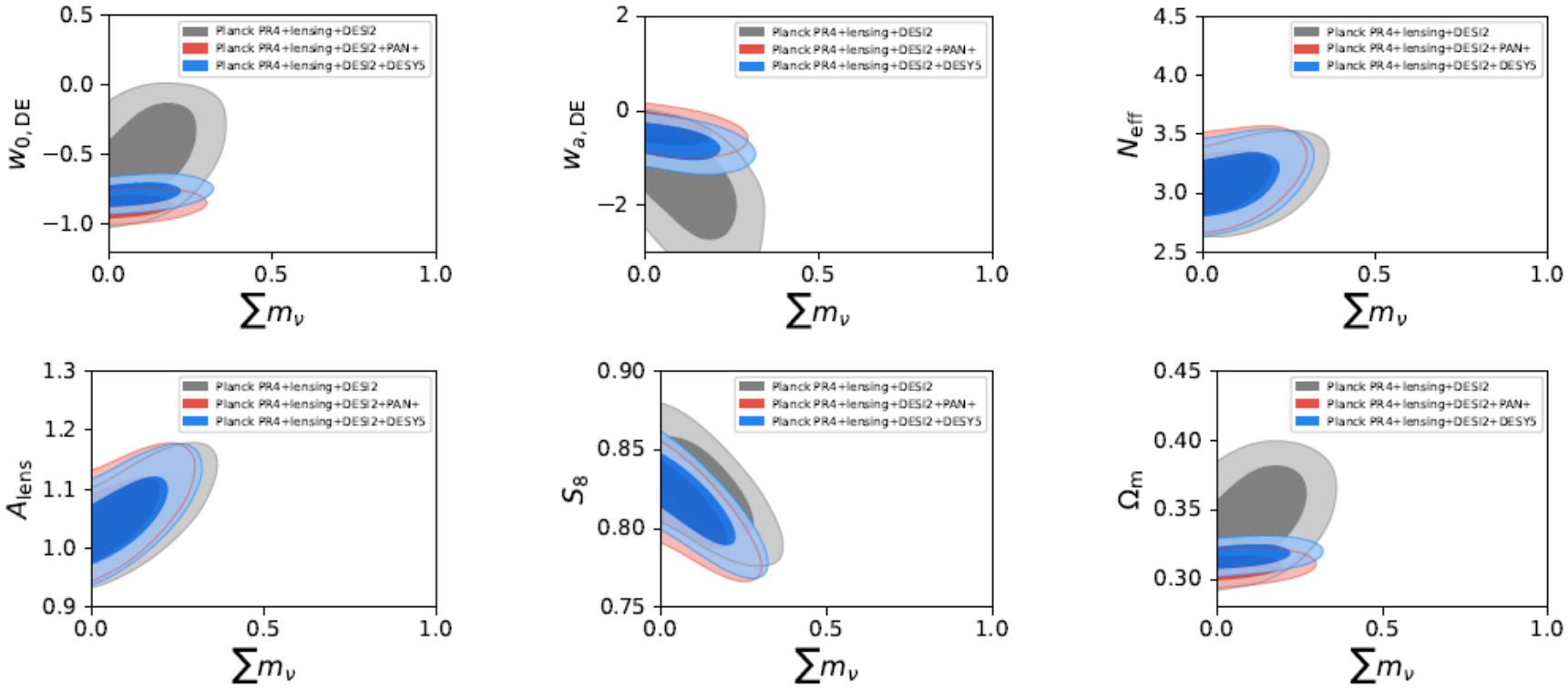


Figure: **SRC**, arXiv: 2504.15340

Summary

- Given that CMB+BAO+Pantheon+ allows the cosmological constant at the edge of the 95% contour, **the evidence for a dynamical dark energy component is not yet compelling or robust.**
- We got the first $2\sigma+$ detection of non-zero positive neutrino mass sum. The peaks in the $\sum m_\nu$ posteriors indicate a **promising trend towards a possible 5σ future detection of non-zero neutrino masses.**
- We recommend that the bound of $\sum \boldsymbol{m_\nu} = \mathbf{0.19^{+0.15}_{-0.18}}$ eV (95%) is used by the cosmology and particle physics communities as a reference.
- **The lensing anomaly with the Weak Lensing data** suggests for the first time that the existence of lensing anomaly could depend on non-CMB datasets.
- The simple extensions to $\boldsymbol{\Lambda}$CDM explored in this study are insufficient to resolve the Hubble tension to below the $\boldsymbol{2\sigma}$ level.
- The $\boldsymbol{S_8}$ tension with DES Year 3 analysis is reduced to $\boldsymbol{\simeq 1.4\sigma}$ with CMB+BAO+SNe data.