PASCOS 2026, Sheffield, 23.06.2026

Cosmological tension on neutrino mass

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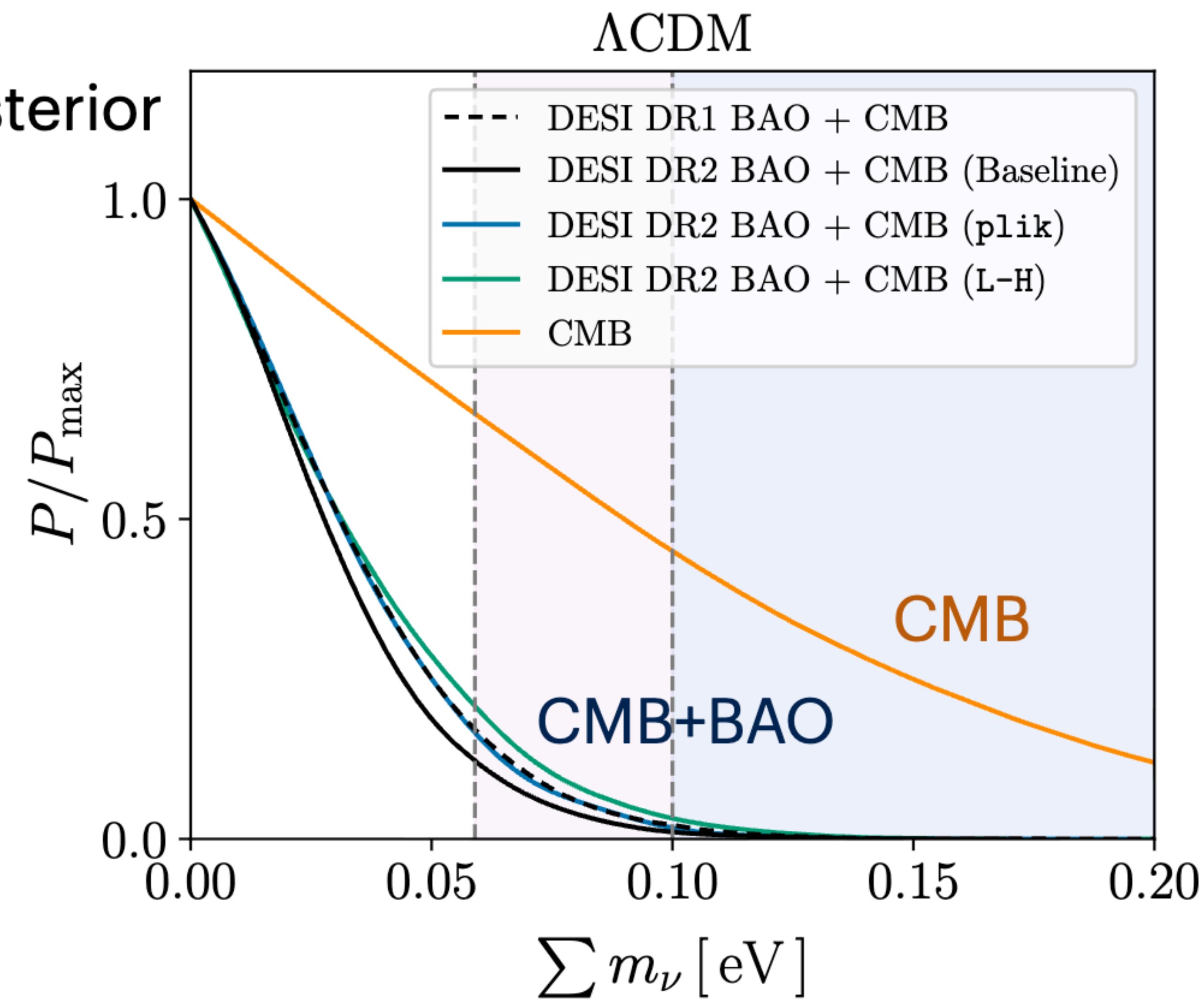
Tension on Σm_ν between cosmology and laboratory

Posterior



Calabrese et al. 2503.14454

- Cosmology with ΛCDM: $\Sigma m_\nu < 0.055$ eV(95%, Planck+ACT+SPT+DESI)

Camphuis et al. 2506.20707

- Laboratory (oscillations): - $\Sigma m_\nu > 0.058$ eV (95%, Normal Hierarchy),
  - $\Sigma m_\nu > 0.098$ eV (95%, Inverted hierarchy)

Explaining the Σm_ν tension

1. Statistical fluke, unaccounted systematics, future observations may still bring evidence for non-zero mass while assuming ΛCDM…

2. We live in a neutrinoless Universe

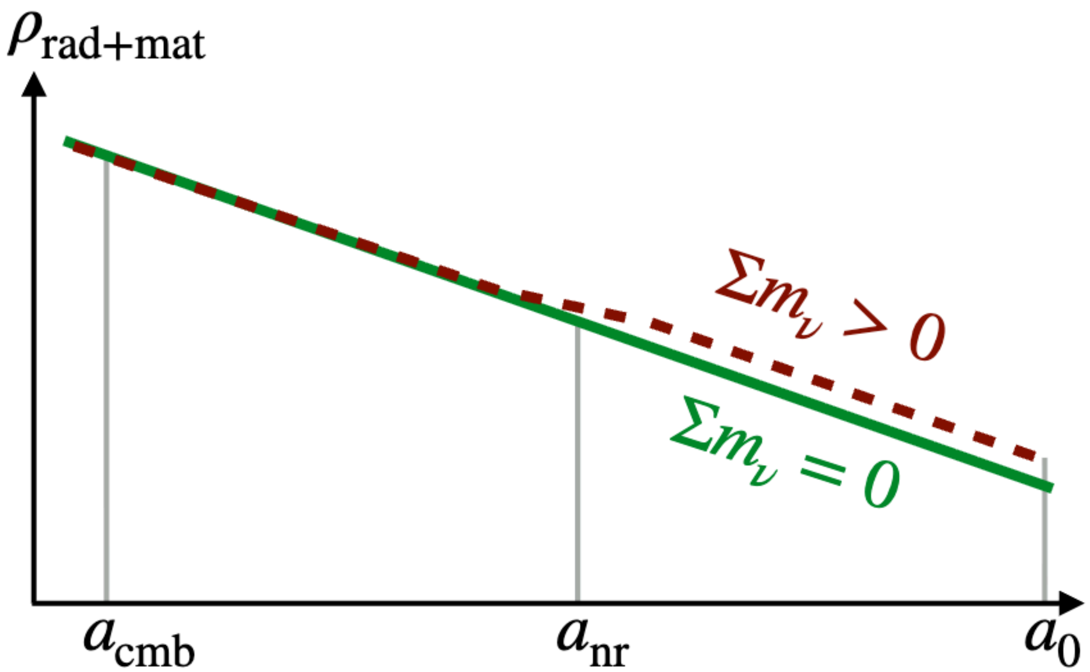
   e.g. decay into massless scalar $\nu_i \bar{\nu}_i \longrightarrow \phi$

   e.g. Beacom et al. astro-ph/0404585, Escudero et al. 2007.04994, Barenboim et al. 2011.01502, Franco Abellan et al. 2112.13862, Craig et al. 2405.00836

3. Neutrino mass bounds are (cosmological) model-dependent and ΛCDM is not the right framework (as suggested by other tensions; common origin and solution?)

Testable cosmological effects of Σm_ν

- Geometrical effect [$d_A(z)$, H(z)]



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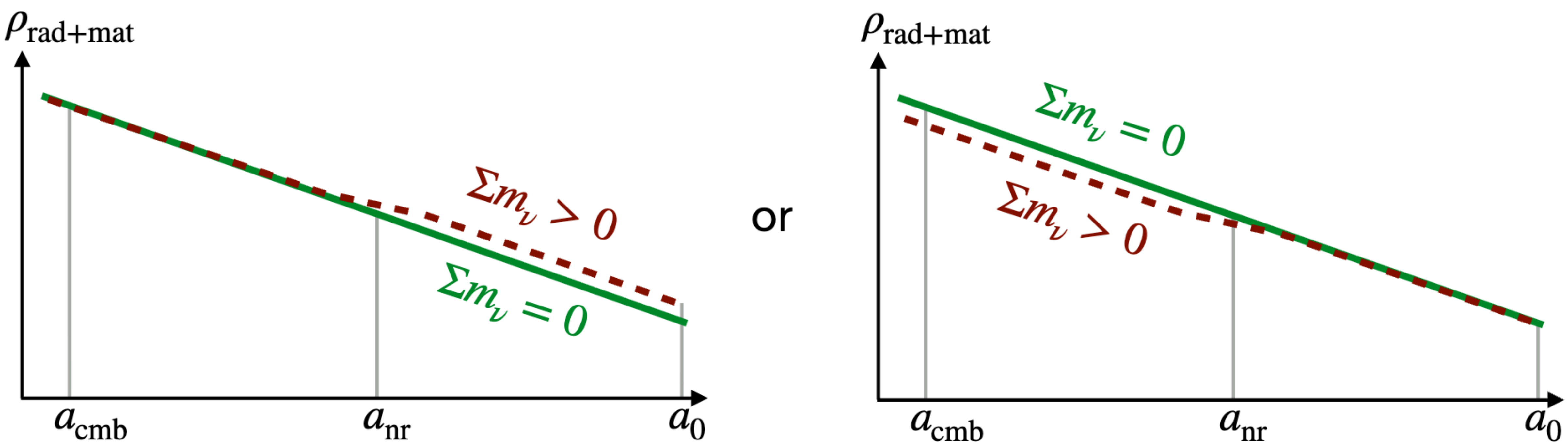

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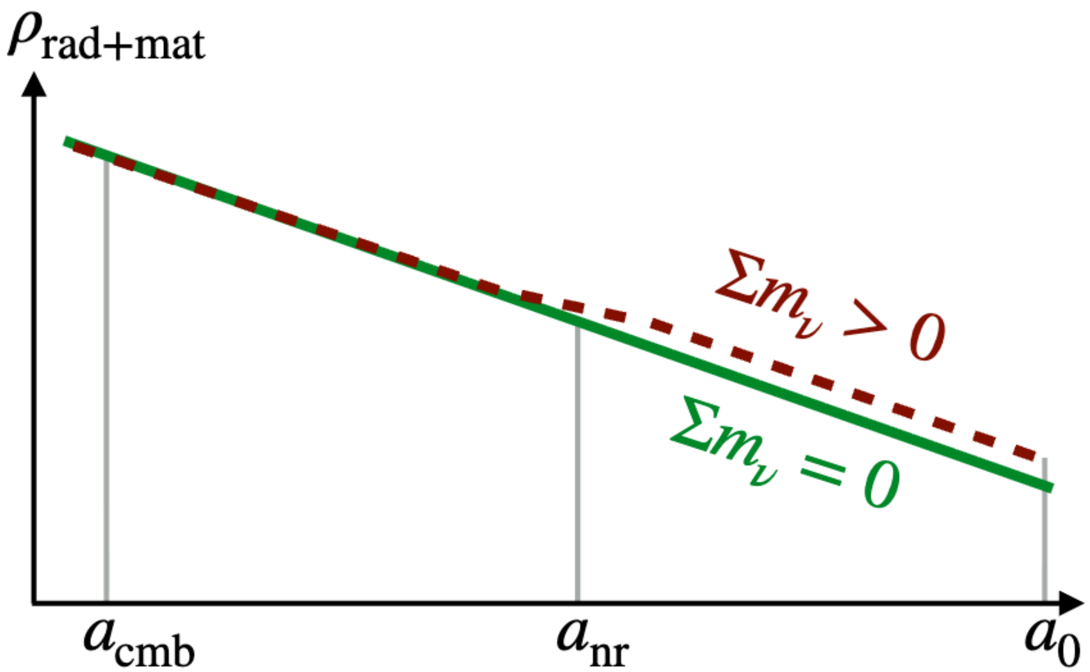
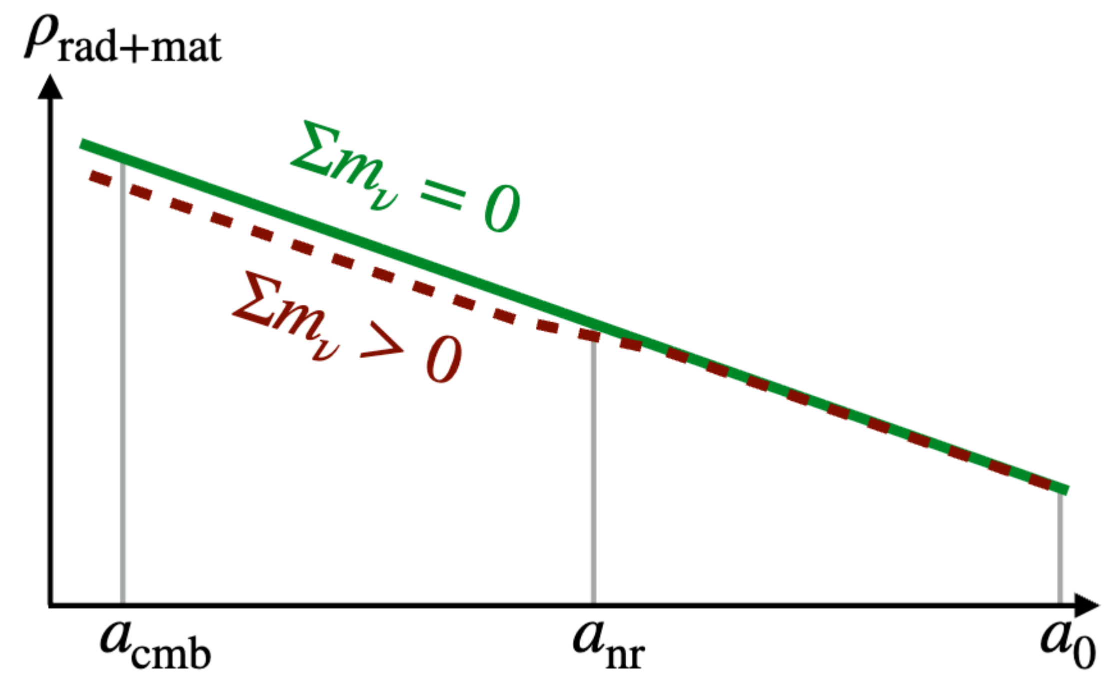


or



- Early ISW effect on CMB

Testable cosmological effects of Σm_ν

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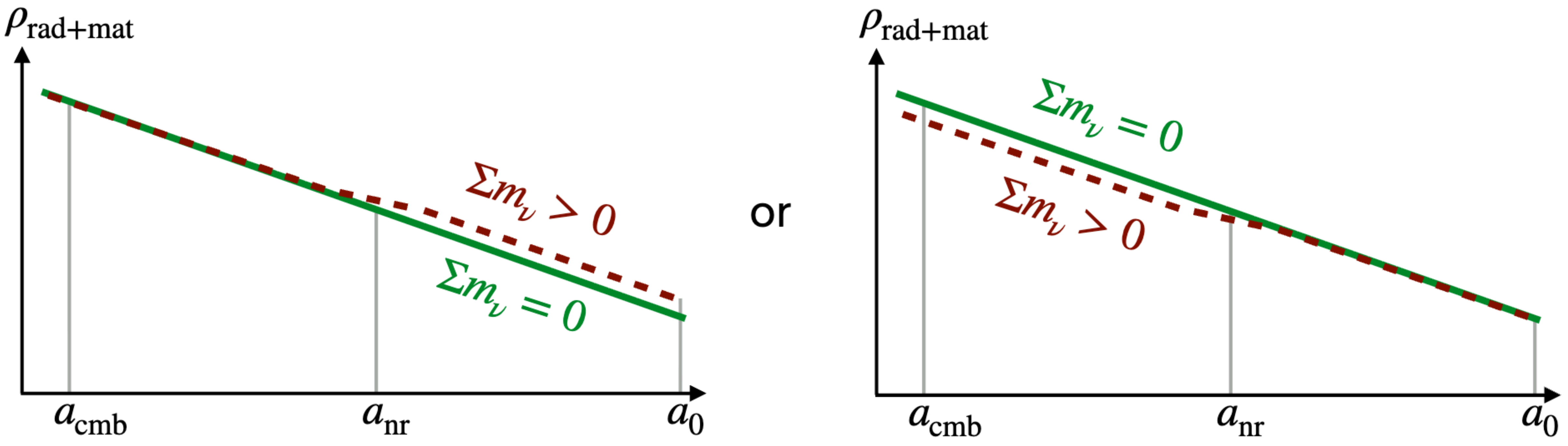

- Early ISW effect on CMB
- Free-streaming effect on structure growth [$P(k)$]

Testable cosmological effects of Σm_ν

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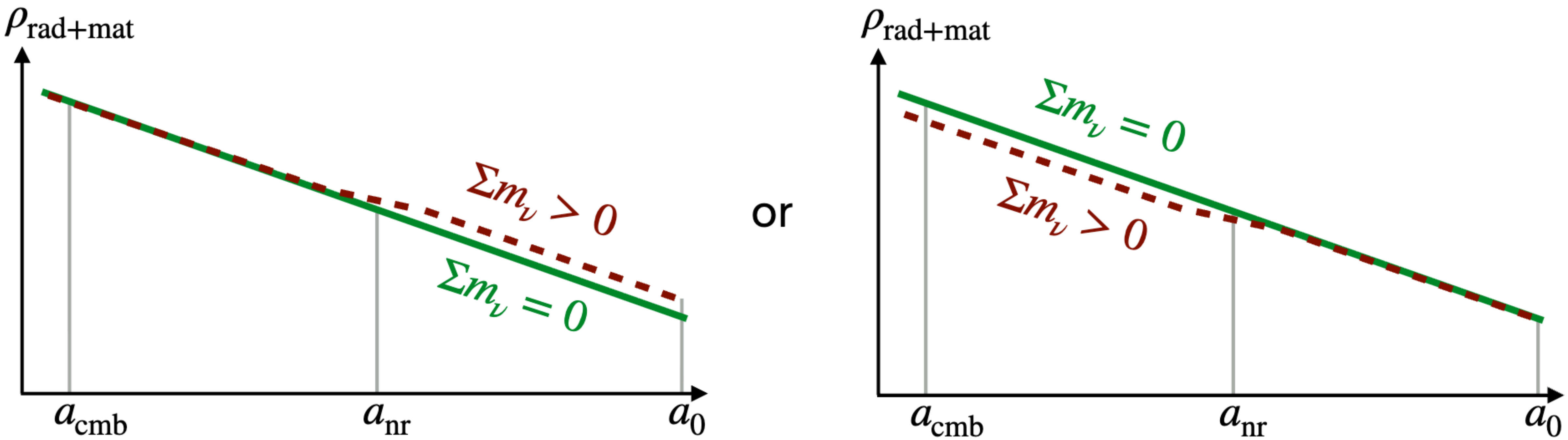

- Early ISW effect on CMB
- Free-streaming effect on structure growth [$P(k)$]

- Free-streaming effect on CMB 4-point [CMB lensing spectrum]
- Free-streaming effect on CMB 2-point TT,TE,EE [CMB lensing: smoothing, tail]

Testable cosmological effects of Σm_ν

- Geometrical effect [$d_A(z)$, H(z)]: strong (BAO+CMB peak scale: < 0.1 eV , 95%)

- Early ISW effect on CMB: subdominant (WMAP alone: < 1.2 eV, 95%)

- Free-streaming effect on $P(k)$: subdominant from galaxy full-shape

- Free-streaming effect on CMB 4-point: subdominant

- Free-streaming effect on CMB 2-point TT,TE,EE: strong

(CMB data indicates significant lensing effect)

Elbers et al. 2407.10965, LoVerde & Weiner 2410.00090, Sharma & JL 2510.15835, ...

Role of CMB/BAO tension

- CMB peak / BAO scale measure $[H_0 r_d] / \frac{H_0}{H(z)}$ and $[H_0 r_{d,s}] / \int_0^z \frac{H_0}{H(\tilde{z})} d\tilde{z}$ at $\neq z$
- $\frac{H(z)}{H_0}$ = expansion history normalised to 1, depends on:
  - DE parameters ($\Omega_\Lambda = 1 - \Omega_\mathrm{m}, w_0, w_a, \ldots$),
  - curvature (Ω_k),
  - neutrino mass (Σm_ν), …
- In ΛCDM: only $H_0 r_d$ and Ω_m $(= 1 - \Omega_\Lambda)$

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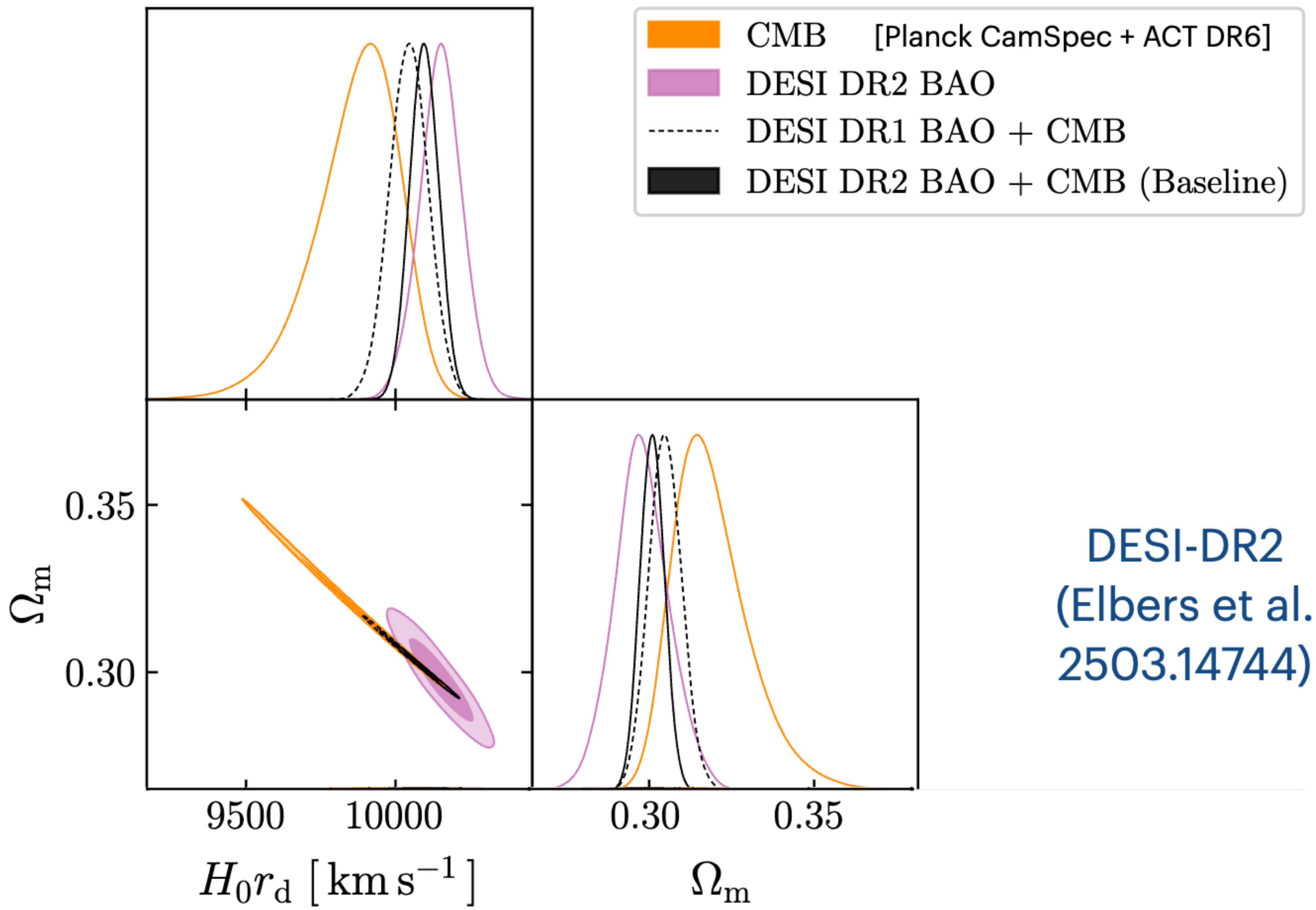
- Tension in ΛCDM:



DESI-DR2 (Elbers et al. 2503.14744)

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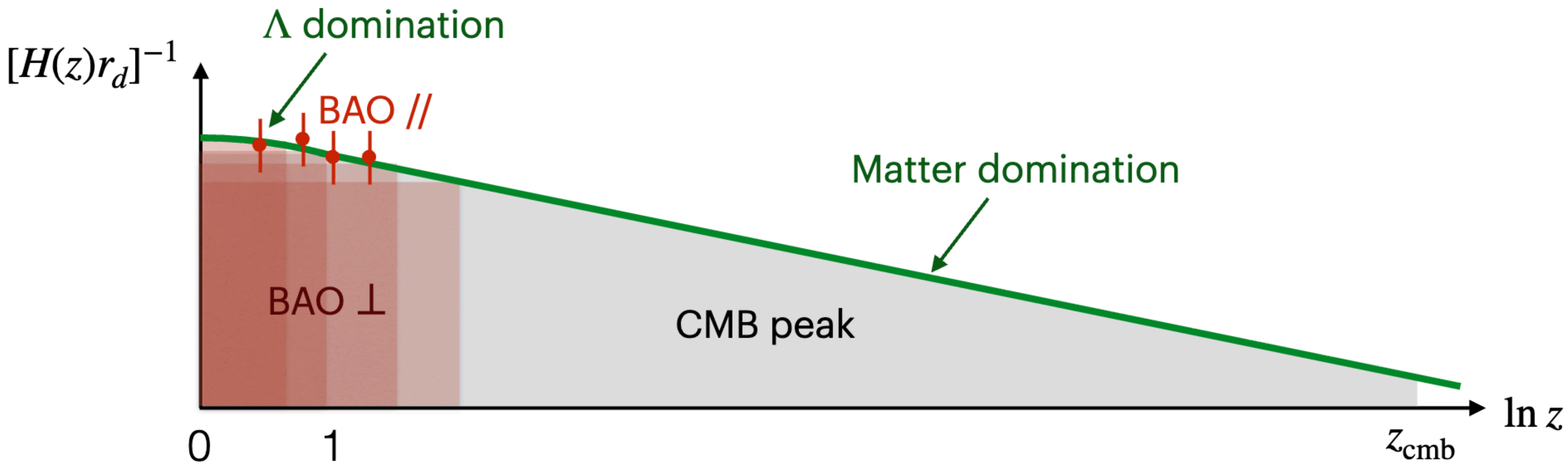

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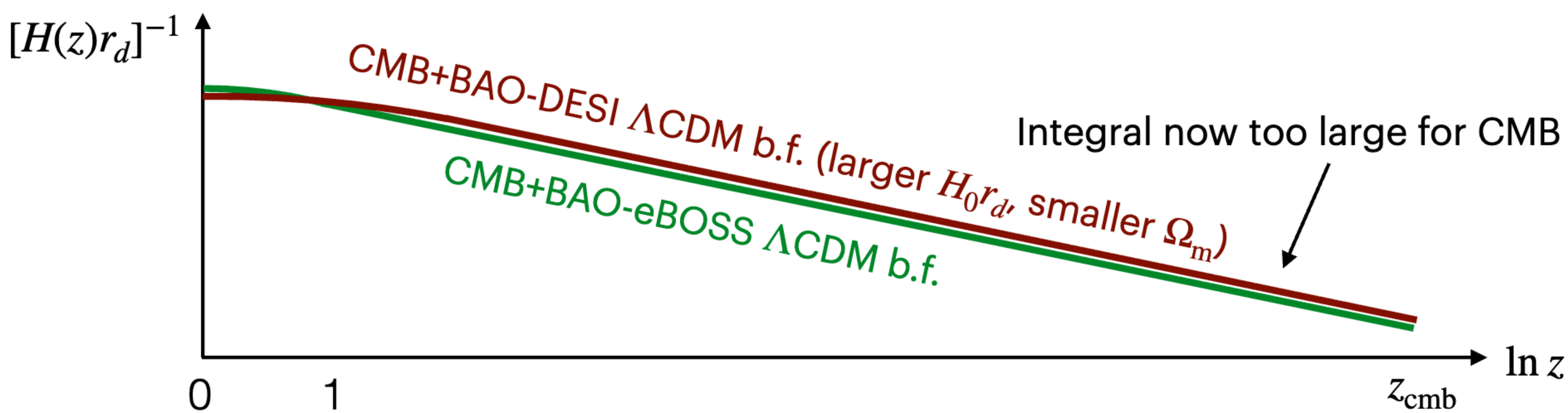

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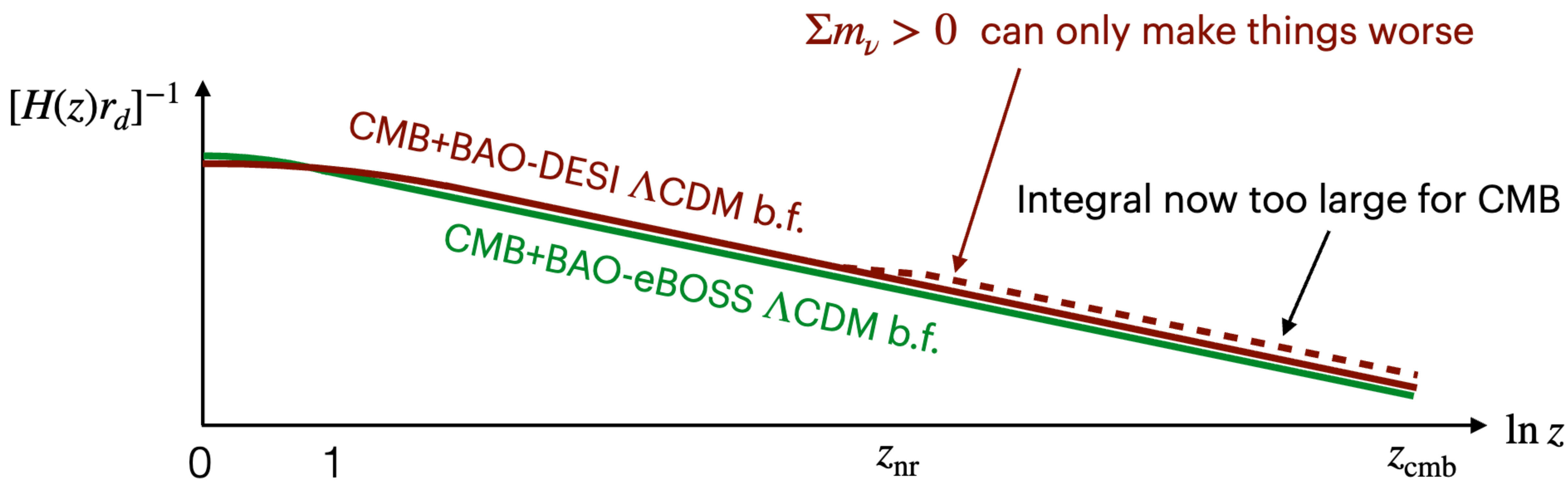
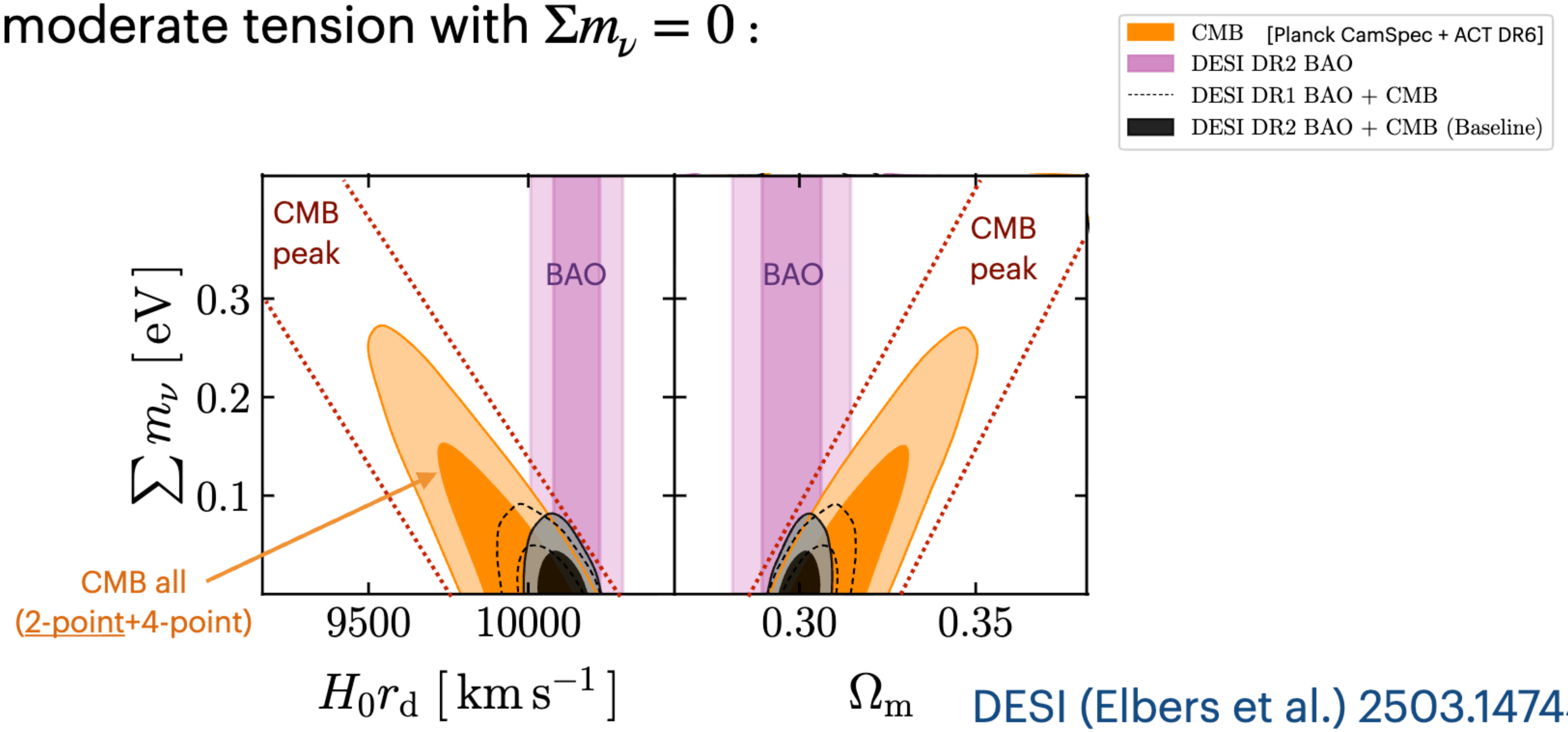


Role of CMB/BAO tension

- CMB/BAO tension in ΛCDM: $\Sigma m_\nu > 0$ can only make things worse
- already a moderate tension with $\Sigma m_\nu = 0$:

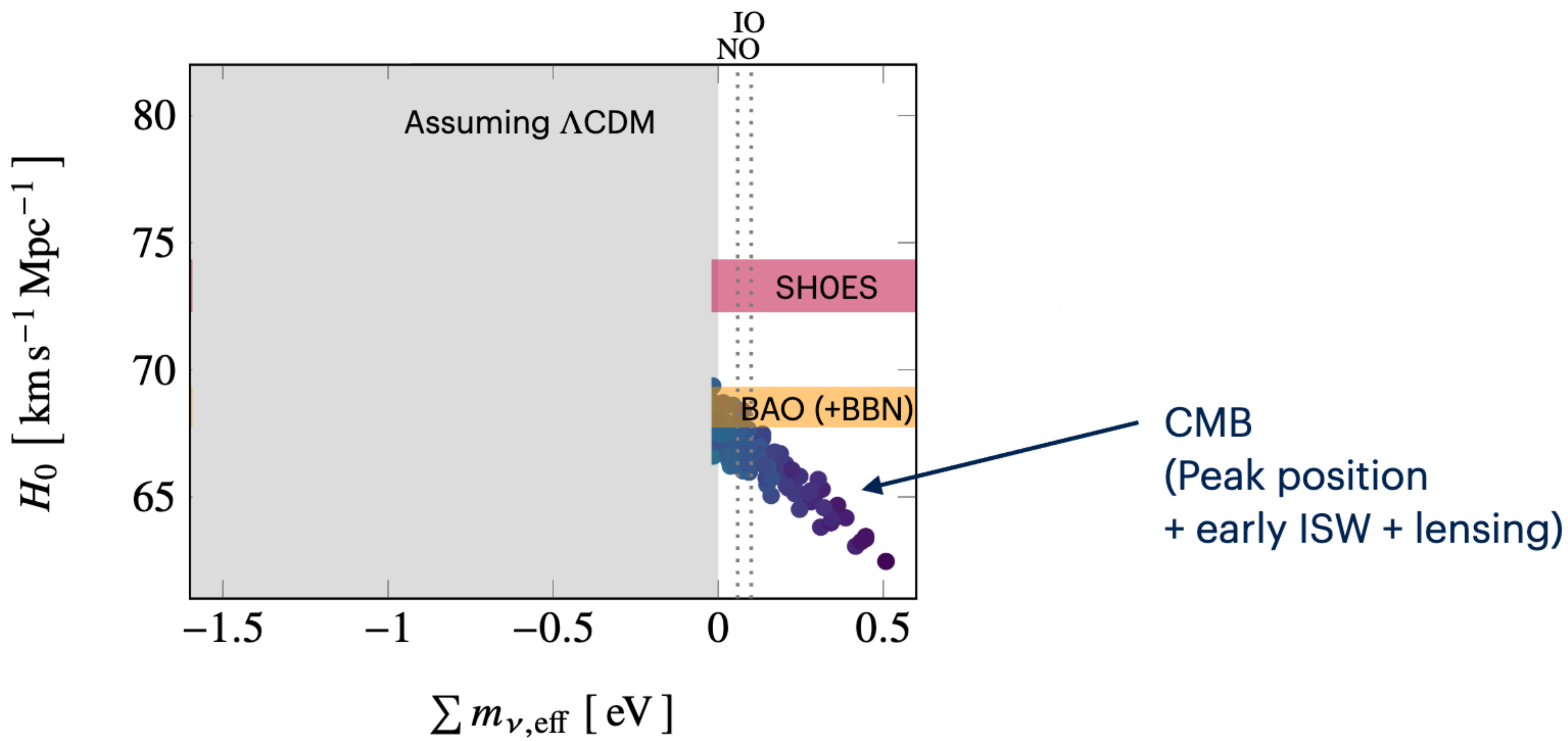


DESI (Elbers et al.) 2503.14744

- CMB 2-point worsens it, but tension fundamentally driven by geometrical effect

Role of CMB/BAO + Hubble tension

- Also for Hubble tension in ΛCDM: $\Sigma m_\nu > 0$ can only make things worse



Adapted from Elbers et al. 2407.10965

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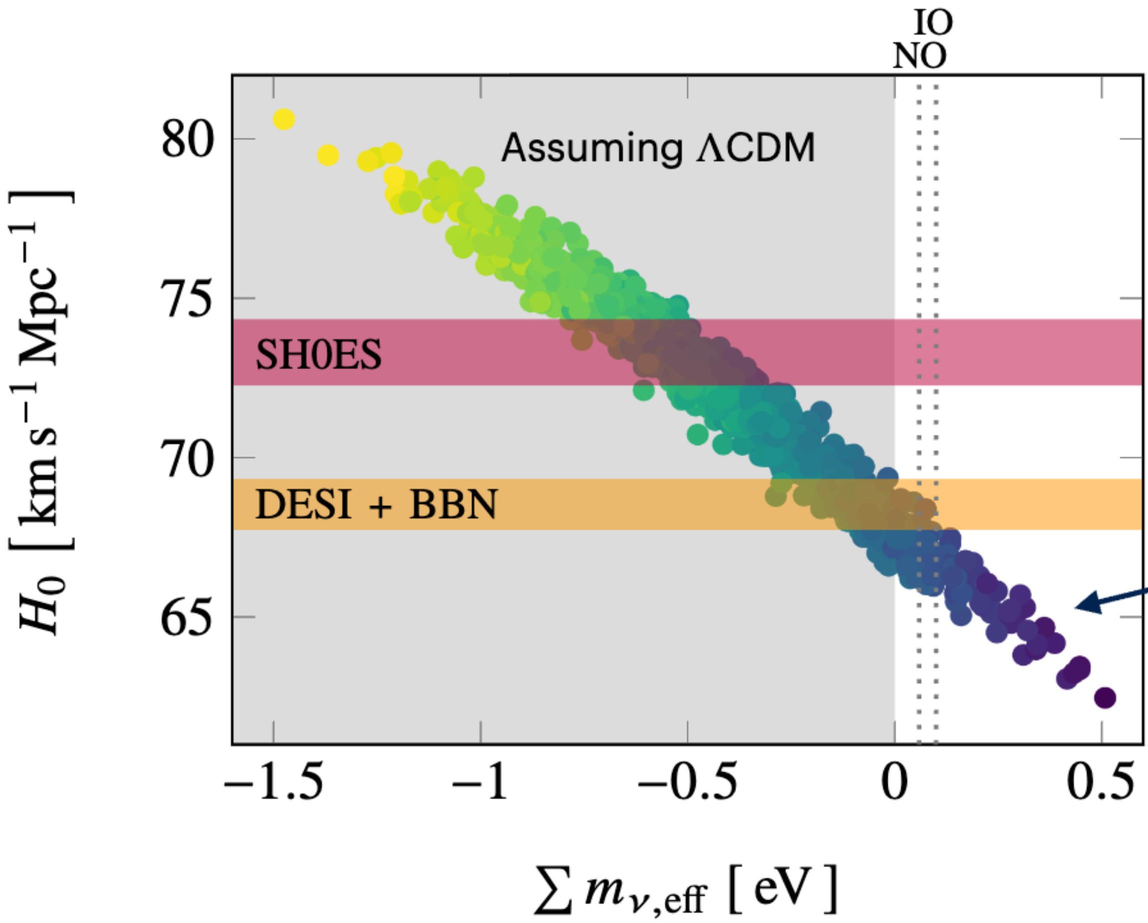


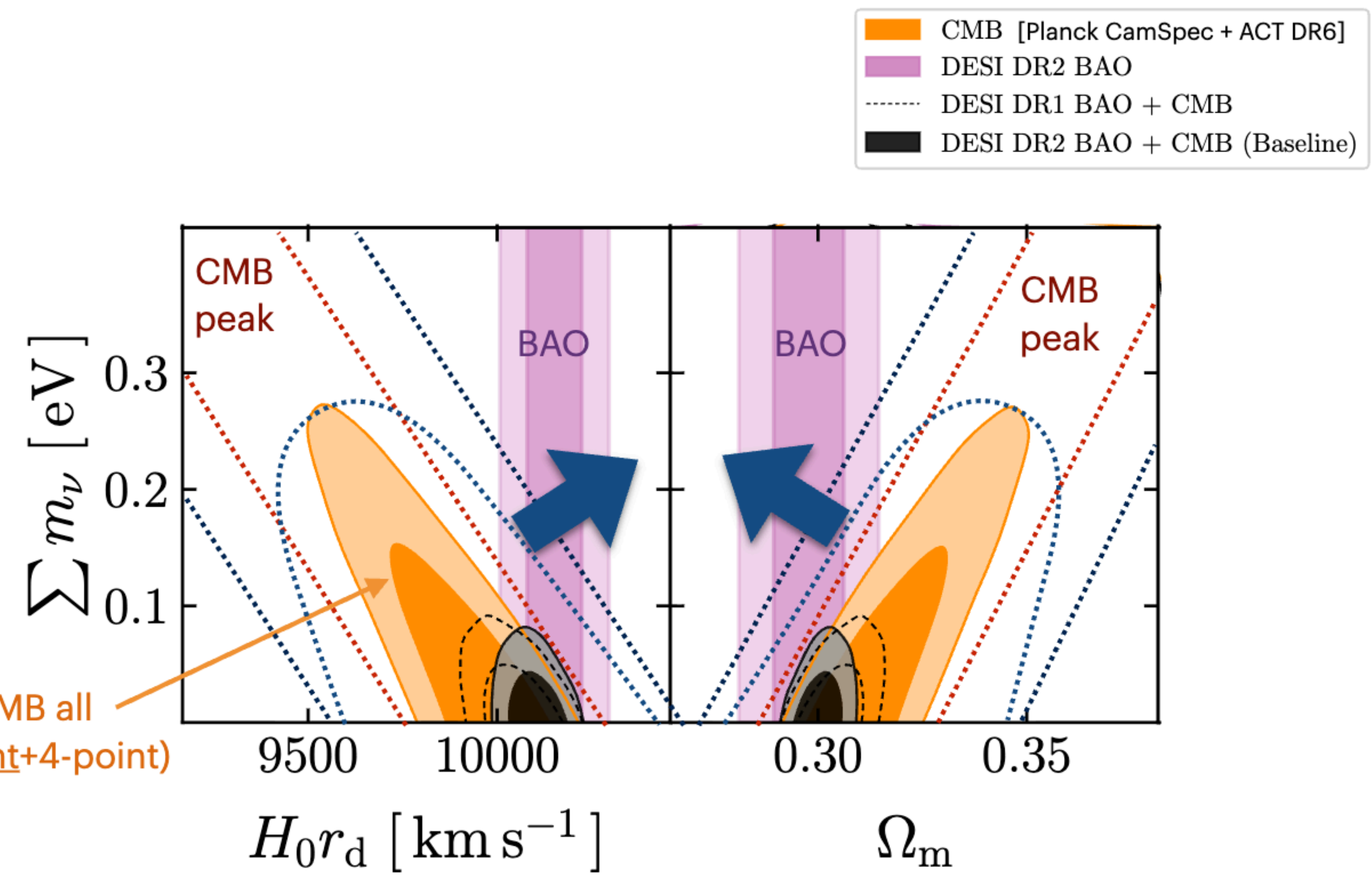
CMB
(Peak position
+ early ISW + lensing)

Elbers et al. 2407.10965

How to relax the neutrino mass bound?

Any model relaxing CMB/BAO tension also relaxes neutrino mass bound !

1. Add freedom in expansion history
2. Add freedom in lensing effects in 2-point CMB
3. Add freedom in $\theta_s \leftrightarrow$ CMB peak scale relation



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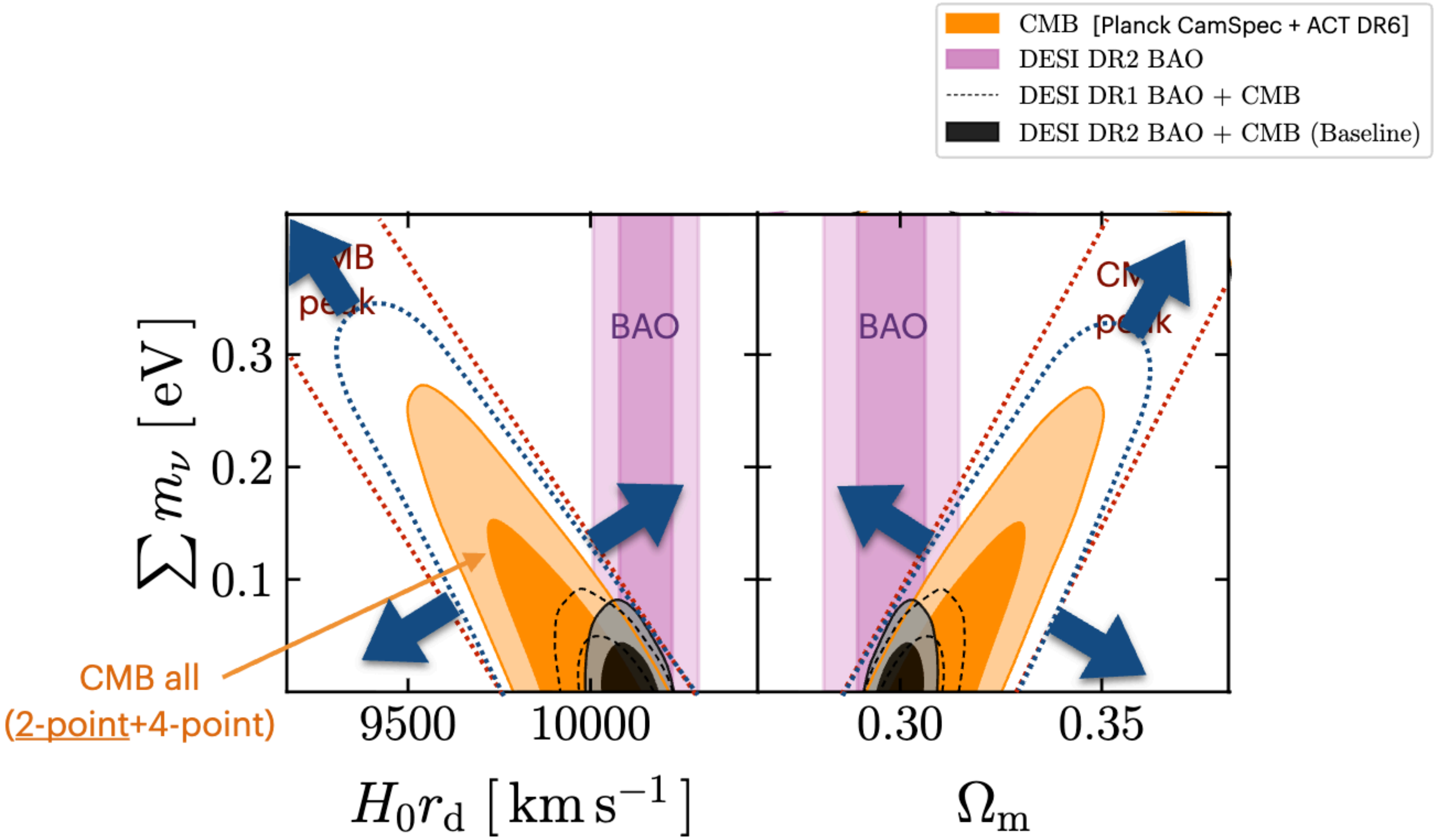

DESI (Elbers et al.) 2503.14744

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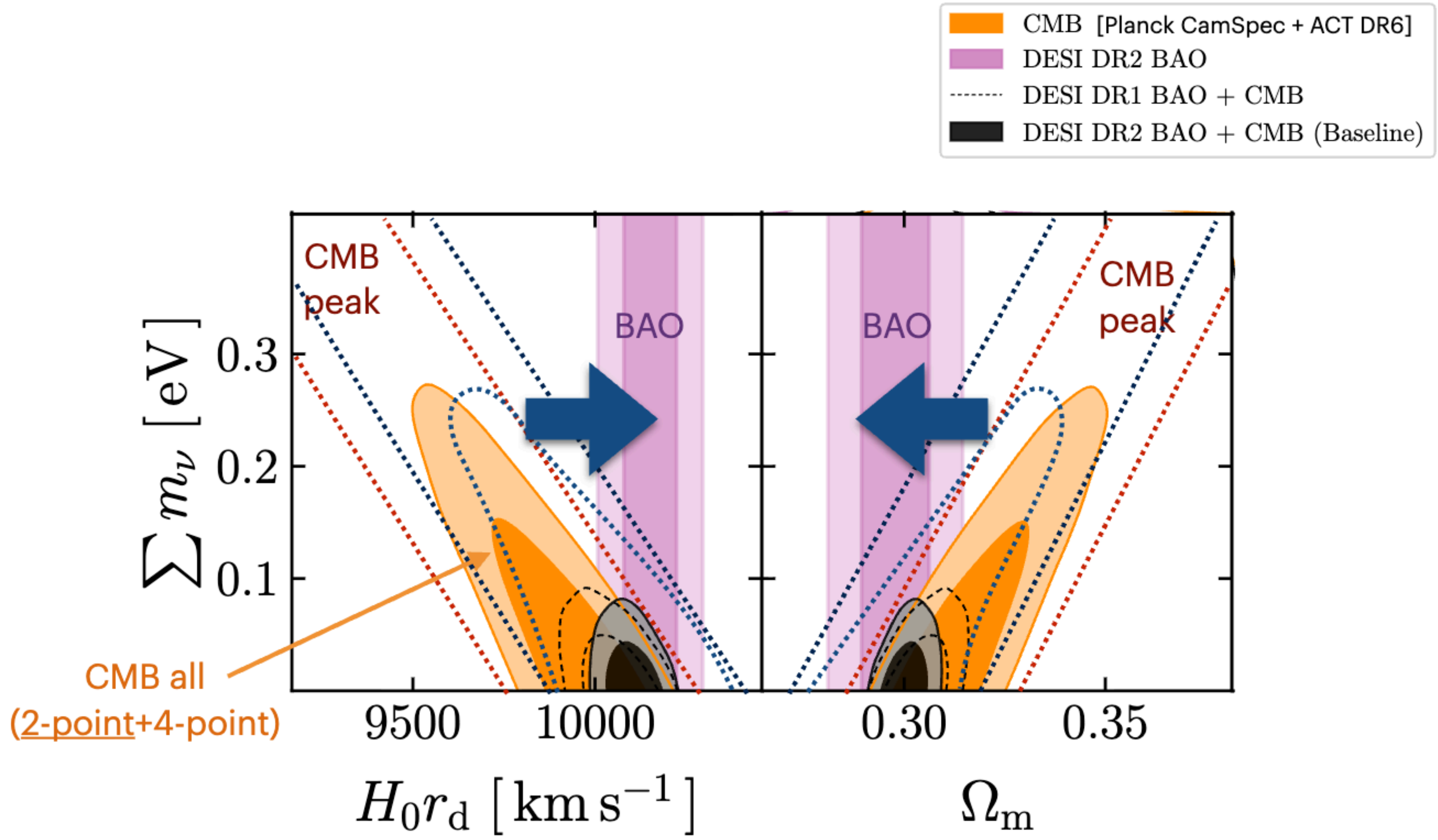
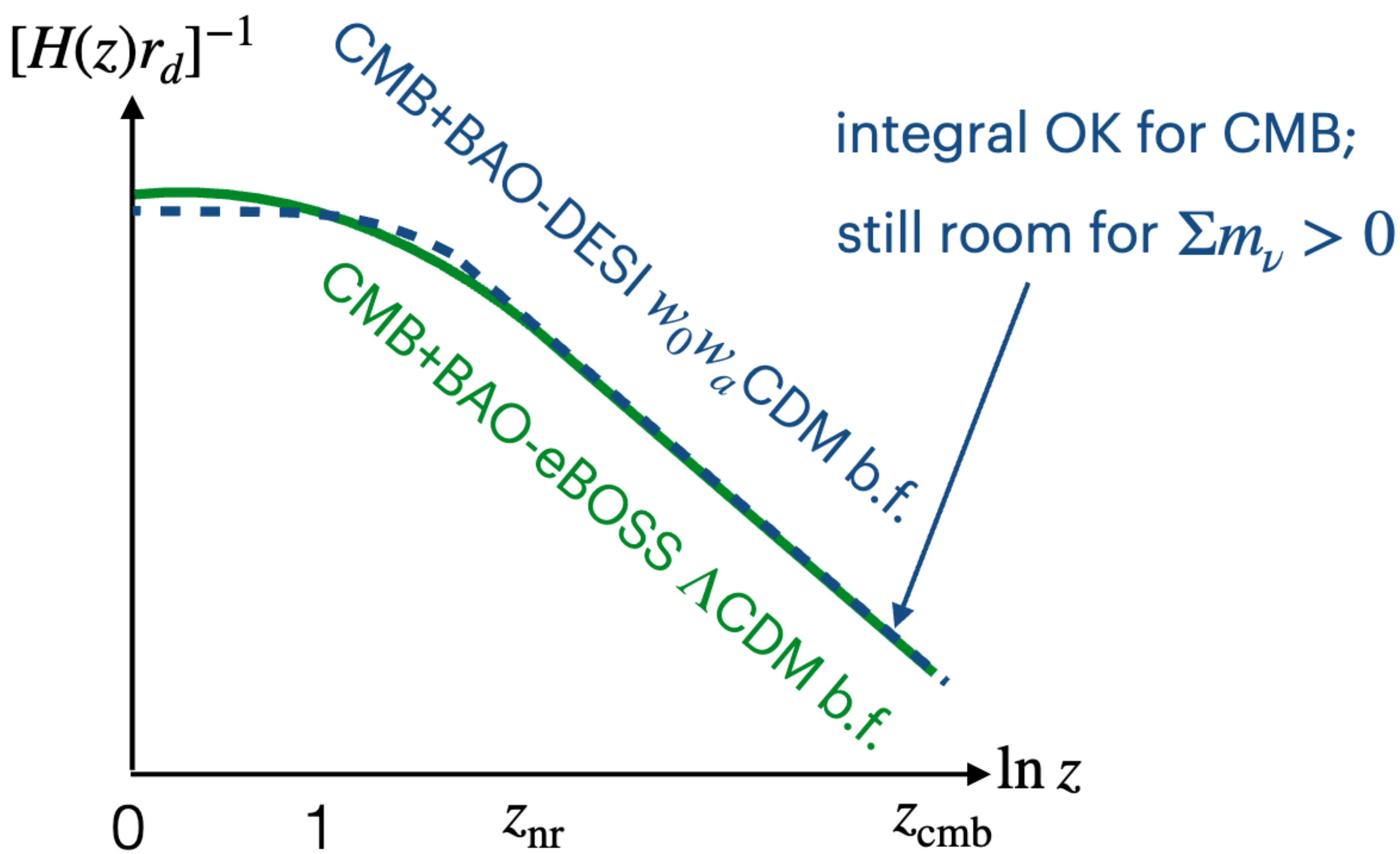


DESI (Elbers et al.) 2503.14744

1. Add freedom in late expansion history: dynamical dark energy

- dynamical DE with e.g. CPL parametrisation: $w(z) = w_0 + w_a z/(1+z)$



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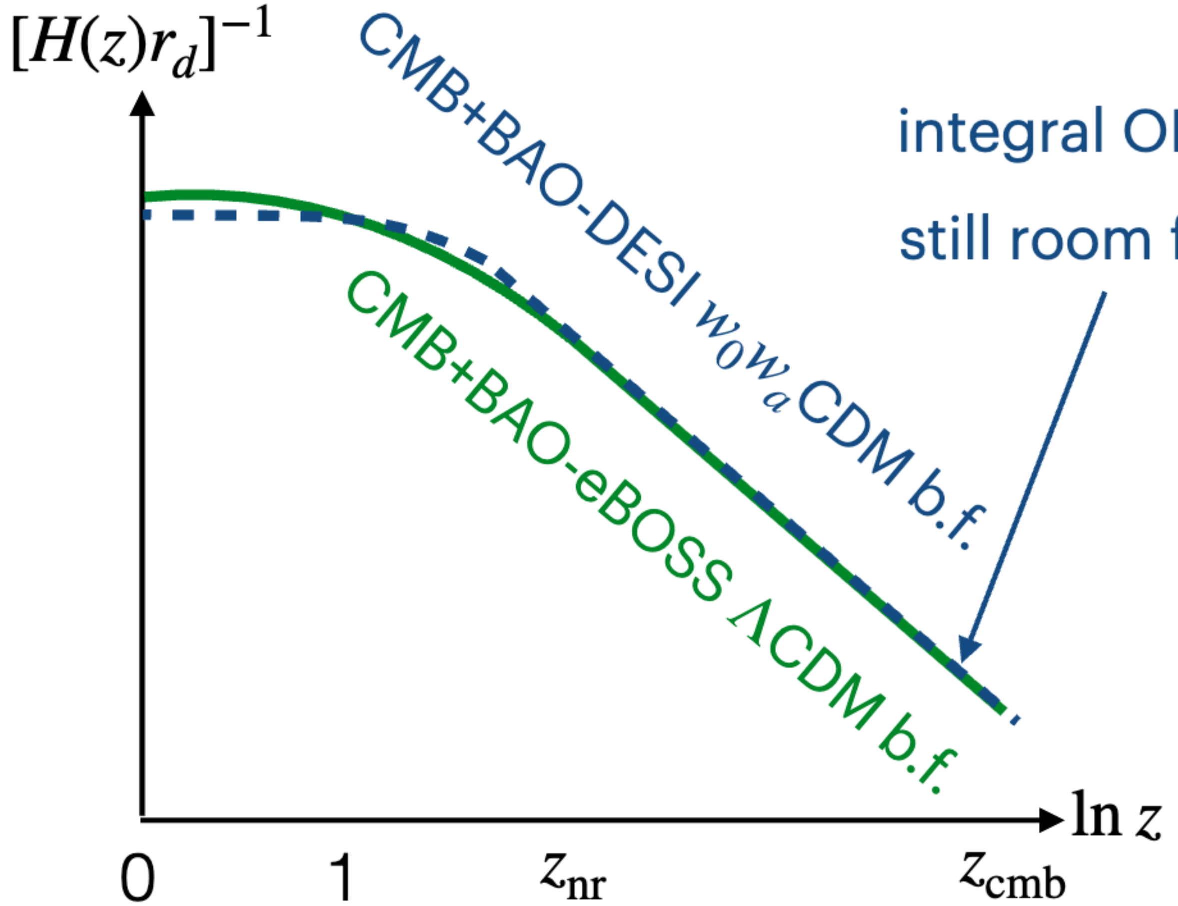

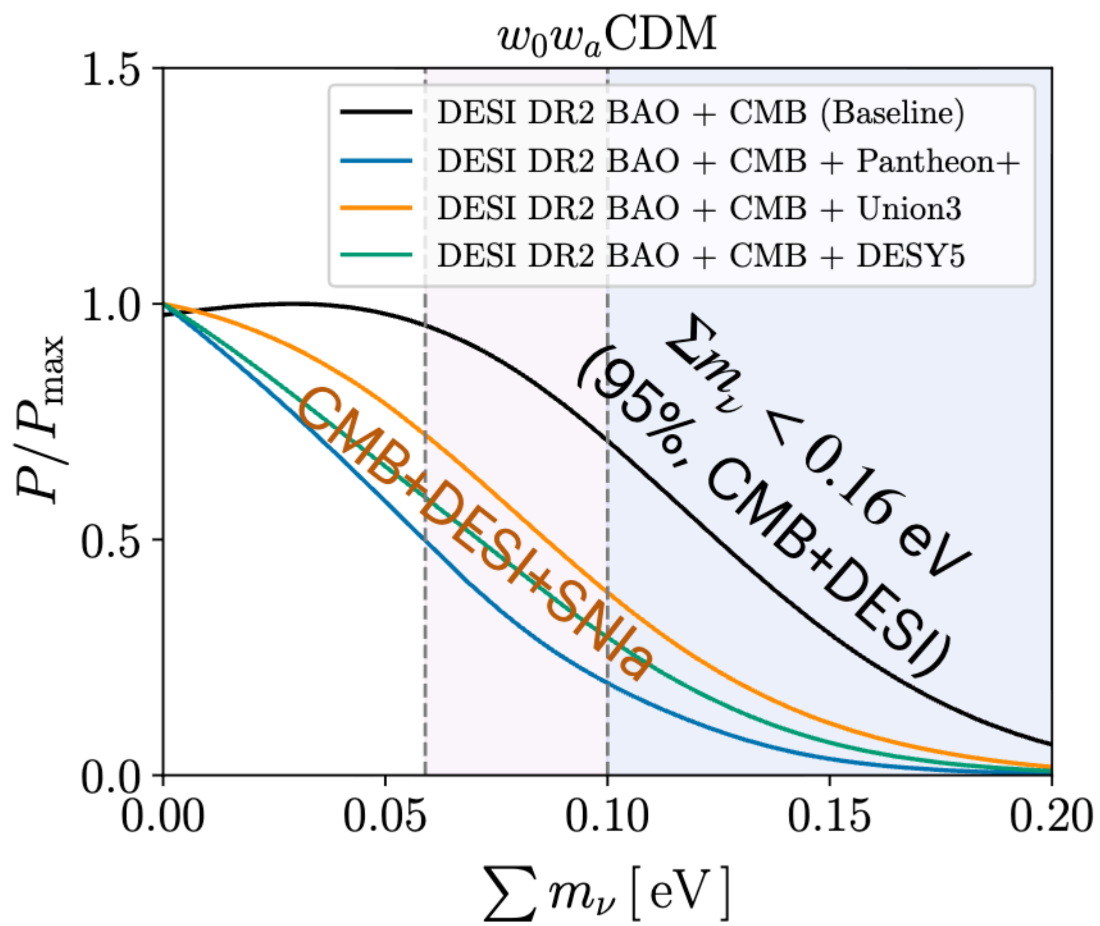

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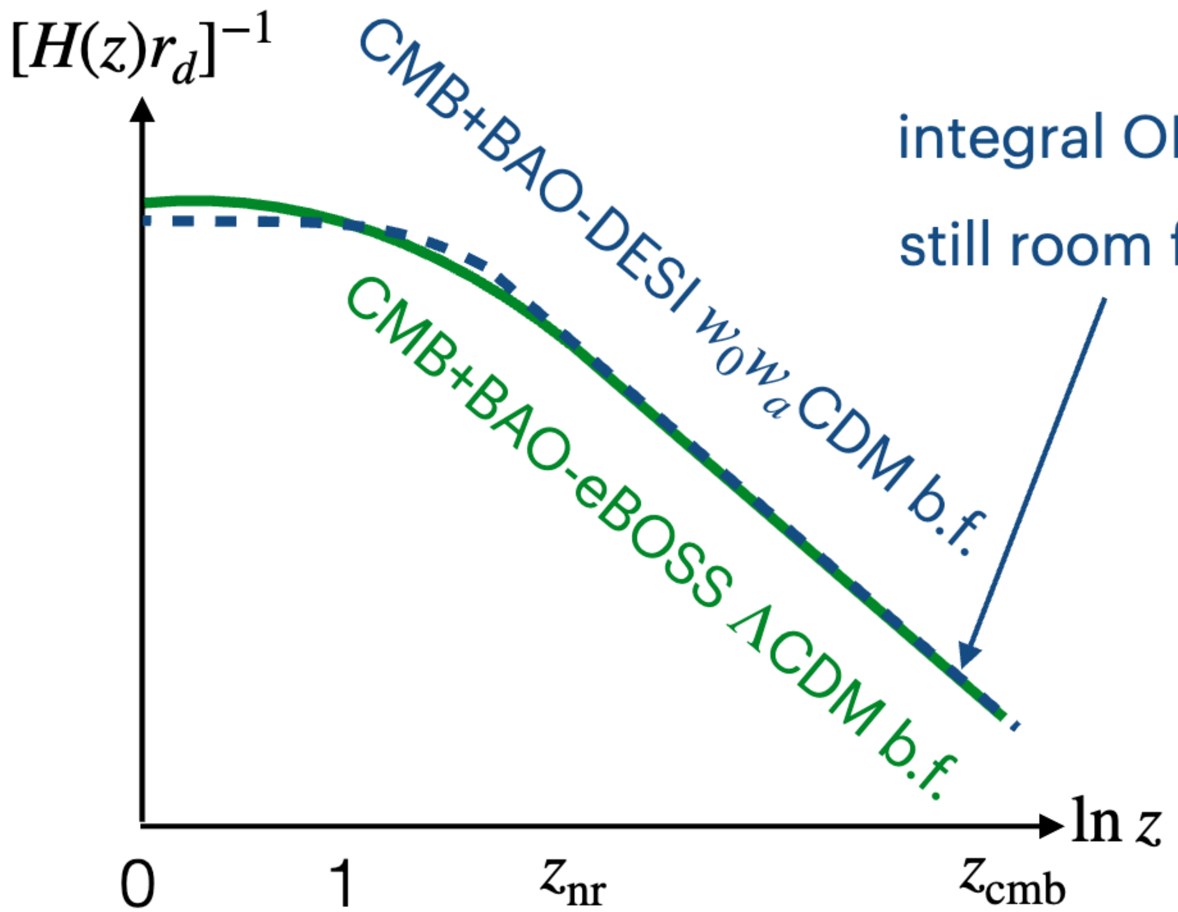
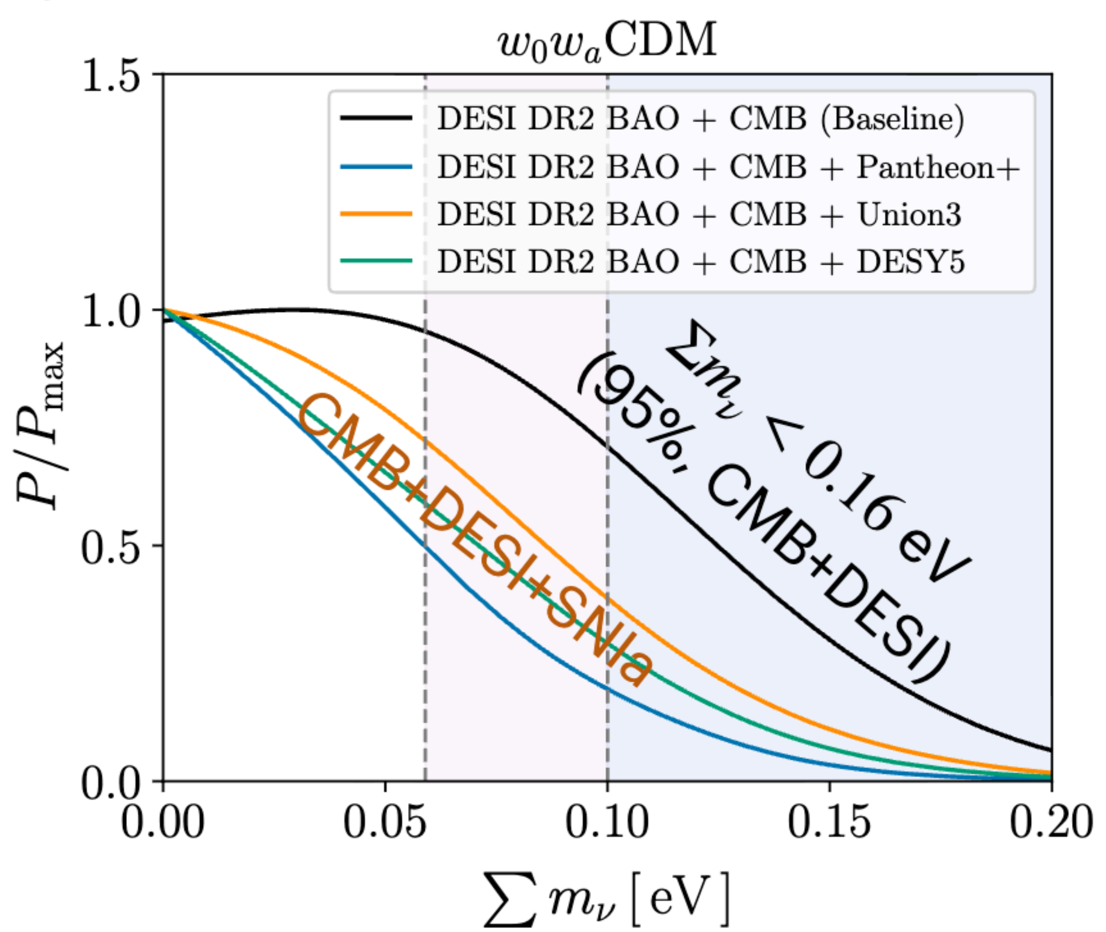


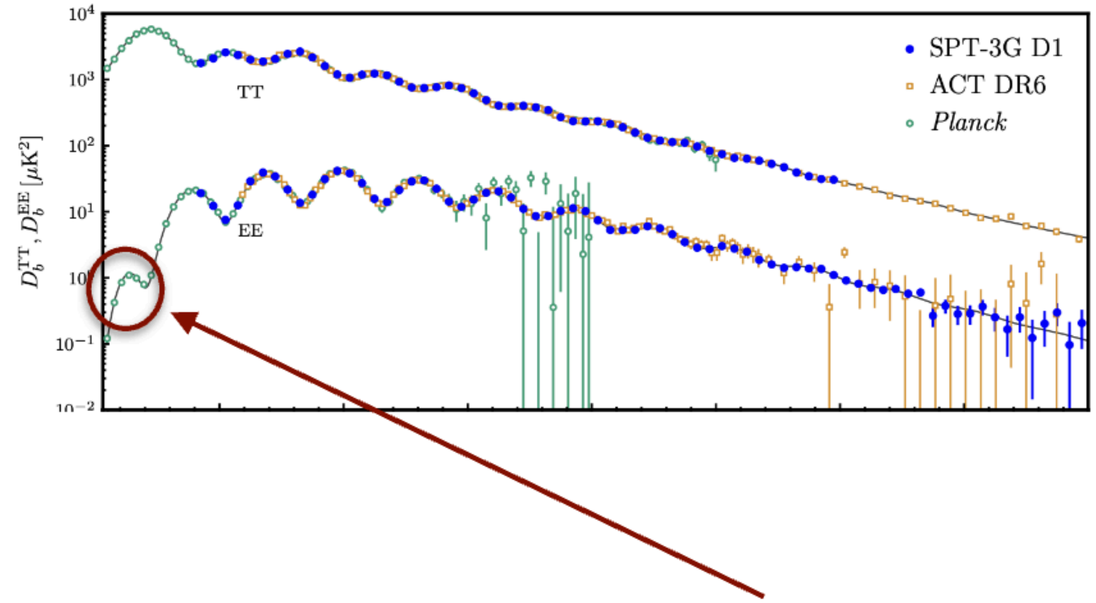


DESI (Elbers et al.) 2503.14744

- 2 tensions solved (not Hubble)
- theoretical issues (phantom DE, ...)

2. Add freedom in lensing effects in 2-point CMB

- Amplitude of primary CMB spectra given by $e^{-2\tau} A_s$



- Degeneracy $\tau \leftrightarrow A_s$ only lifted by small-scale CMB polarisation:

  Measurement of reio. optical depth $\tau = 0.054 \pm 0.007$ dominated by Planck

- Amplitude of CMB lensing effects given approx. by $(1 - 8 f_\nu) A_s$

2. Add freedom in lensing effects in 2-point CMB

Higher τ

↓

Higher A_s (from CMB), more CMB lensing

↓

Higher Σm_ν still compatible with observed CMB lensing (CMB 2-point)

↓

To preserve CMB peak scale, lower $\Omega_{\rm m}$ / higher $H_0 r_{\rm d}$

↓

Resolution of CMB/DESI and Σm_ν tensions without dynamical DE

↓

(H_0 also slightly larger: reduced tension)

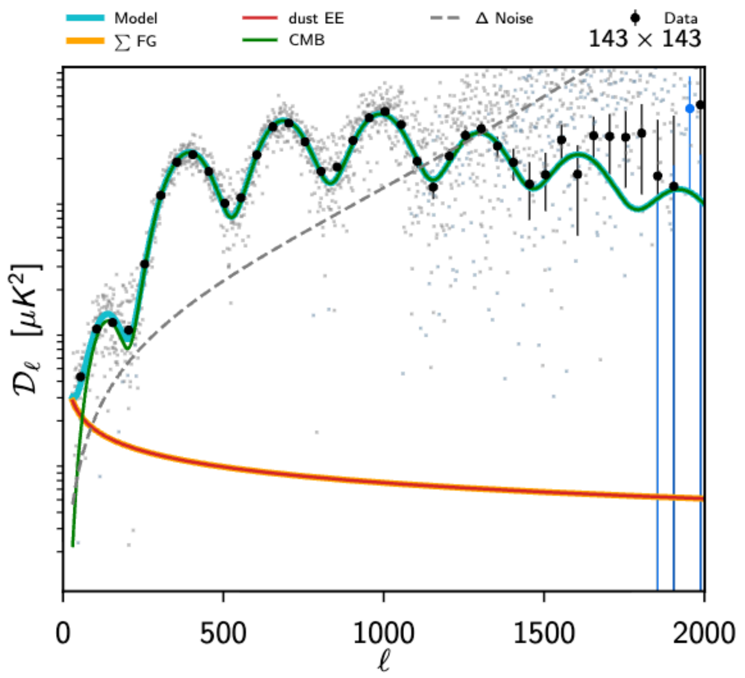
All 3 tensions removed/reduced with $\tau \simeq 0.055 \longrightarrow \sim 0.09$

Sailer et al. 2504.16932, Jhaveri et al. 2504.21813

2. Add freedom in lensing effects in 2-point CMB

- PROS:
  - Solve / reduce 3 tensions without new physics.
  - Low $\tau = 0.054 \pm 0.007$ (68%) only from Planck.
  - High τ compatible with WMAP: $\tau = 0.089 \pm 0.014$ (68%)
  - τ measurement by Planck difficult due to foregrounds.

- CONS:
  - Planck / WMAP posteriors compatible ($\sim 2\sigma$), much higher S/N in Planck.
  - Not so many polarised foregrounds on large angular scales (thermal dust).



  - Previous tensions reformulated as a new $\sim 5\sigma$ "tension on τ"

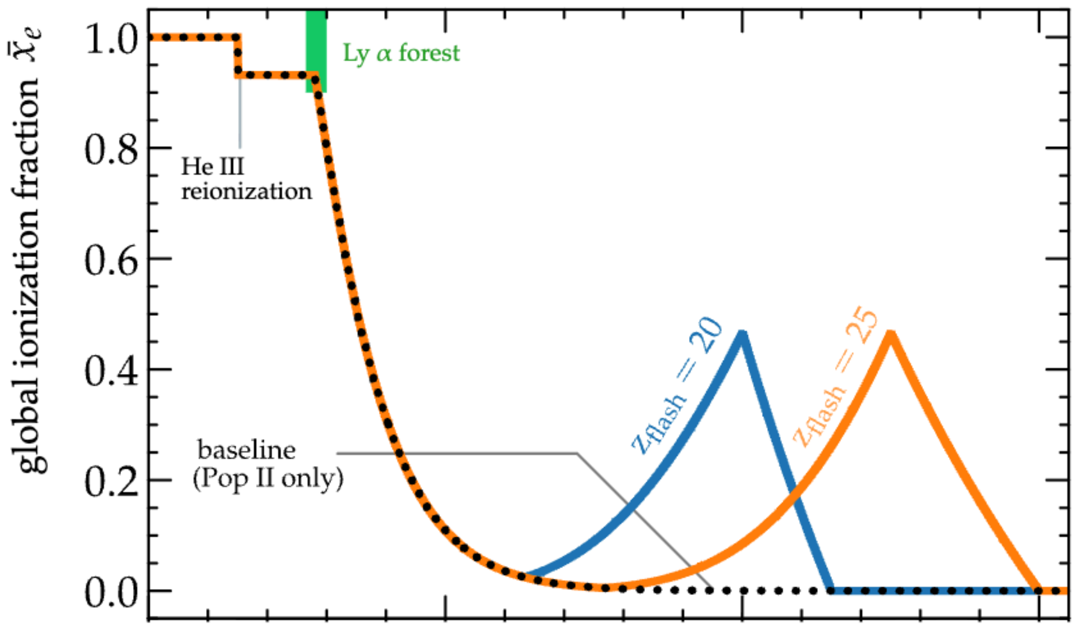
2. Add freedom in lensing effects in 2-point CMB

- At least, high-τ solutions would be compatible with astrophysics:
  - Lyman-α in quasar spectra: reionisation ends around $z \simeq 6.5$
  - patchy kinetic SZ effect: most Universe reionised very quickly

- Compatible with $\tau \sim 0.09$ assuming

  Pop III.1 star flash-ionisation

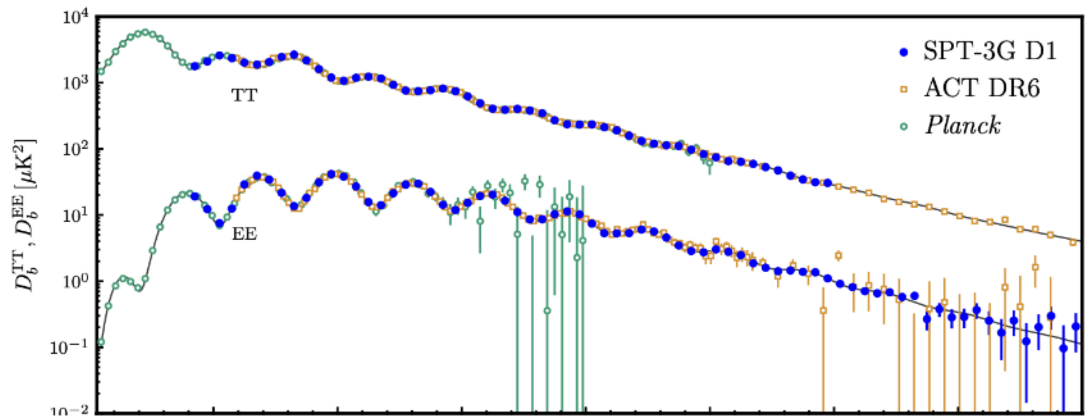
  followed by inhibition and cooling



Aggarwal et al. 2606.19459

3. Change $\theta_s \leftrightarrow$ CMB peak scale relation

- CMB observations constrain $l_n^{\rm peak}$



- Relation $l_n^{\rm peak} \leftrightarrow \theta_s$ inferred from fitting full spectra to data
- $\theta_s = r_s / r_a(z_{\rm dec})$ gives geometrical constraint complementary to BAO
- Relation $l_n^{\rm peak} \leftrightarrow \theta_s$ independent of ΛCDM parameters
- With additional dark radiation, neutrino drag effect: $l_n^{\rm peak} \leftrightarrow \theta_s + \delta\theta(\Delta N_{\rm eff})$

Bashinsky & Seljak astro-ph/0310198

JL et al, *Neutrino Cosmology*, CUP 2013

3. Change $\theta_s \leftrightarrow$ CMB peak scale relation

- $\Delta N_{\rm eff} > 0$ can solve CMB/BAO tension and reduce Hubble tension
- Strong upper bounds from BBN and CMB
- $\Delta N_{\rm eff}$ may increase after BBN (entropy release)
- Free-streaming DR disfavoured by CMB, self-interacting DR less constrained

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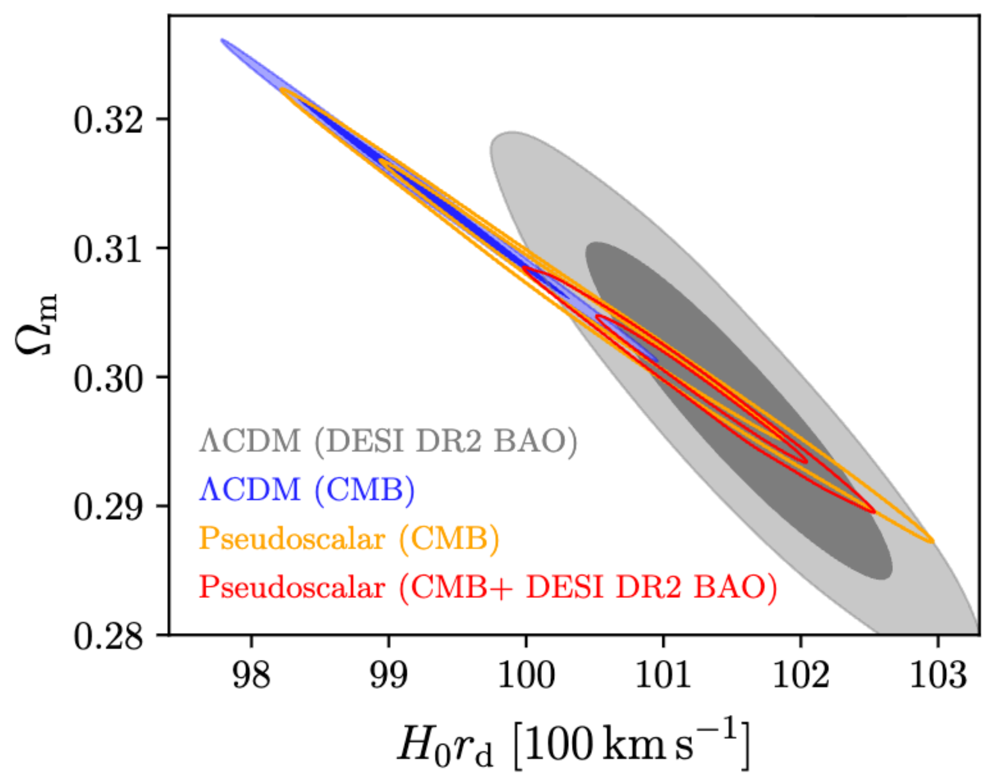
Example: sterile neutrino with secret interactions (mediated by pseudo-scalar)

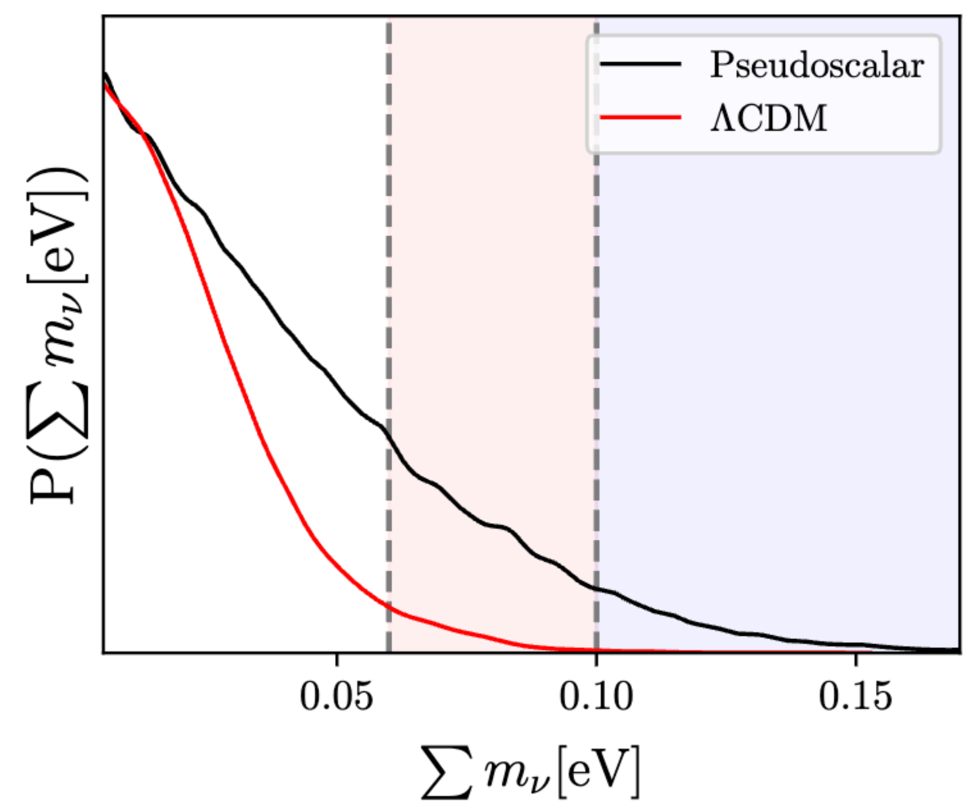
Archidiacono et al. astro-ph/1404.5915

- Interaction $\mathscr{L} \sim \phi\,\bar{\nu}_4 \gamma_5 \nu_4$ with $m_\phi \simeq 0, \quad m_{\nu_4} \sim \mathrm{eV}$
- Non-trivial evolution of sterile neutrino + scalar fluid
    - $\Delta N_{\rm eff}$ increasing after BBN,
    - self-interacting before decoupling,
    - annihilation into massless pseudo-scalar in recent universe.

3. Change $\theta_s \leftrightarrow$ CMB peak scale relation

Recoupled Dark Radiation Sharma, Archidiacono, JL 2605.18716





- CMB/BAO tension solved, no need for dynamical DE
- Neutrino tension solved: $\Sigma m_\nu < 0.10$ eV (95%, Planck+SPT+DESI-DR2)
- Hubble tension reduced: $6\sigma \longrightarrow 2.4\sigma$ (Planck+SPT+DESI-DR2)

3. Change $\theta_s \leftrightarrow$ CMB peak scale relation

- PROS:
  - Requires new physics to solve / reduce 3 tensions, but grounded on solid particle physics
  - Existence of light sterile neutrinos still debated after MiniBoone. New experiment under discussion. Diaz et al. 1906.00045

- CONS:
  - Works well with Planck+SPT, not Planck+SPT+ACT
  - ACT: stronger bound on $N_{\rm eff} = 2.73 \pm 0.14$ (68%, Planck+ACT)
  - We need $N_{\rm eff} \sim 3.1 - 3.2$

3. Change $\theta_s \leftrightarrow$ CMB peak scale relation

- However: suspicious contradictory $N_{\rm eff}$ results between Planck+ACT and Planck+SPT ($\sim 3\sigma$). Tension between measured high-l tails.

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- Issue with foreground modelling?
  - Not only: consistent and conservative foreground modelling in Tristram et al. 2511.04733, and:

$$N_{\rm eff} = 3.20^{+0.21}_{-0.23} \quad (Planck)$$
$$N_{\rm eff} = 2.45^{+0.17}_{-0.25} \quad (\mathrm{ACT})$$
$$N_{\rm eff} = 3.23^{+0.32}_{-0.38} \quad (\mathrm{SPT})$$

  - But combined bound compatible with our model at 2σ

$$N_{\rm eff} = 3.031 \pm 0.130\,(\mathrm{stat}) \pm 0.045\,(\mathrm{fg}) \quad (Planck\mathrm{+ACT+SPT}).$$

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- Issue with polarised beams modelling?
  - Not enough freedom in ACT?
  - Too much freedom in SPT?
  - Project to launch calibrated polarised source on a satellite for SO

Conclusion

- Just three examples, other models (e.g. DM $\longrightarrow$ DE)
- Encouraging: some models may resolve/reduce several tensions at the same time
- Independent tests of these models:
  - Dynamical DE: better SNIa, galaxy surveys;
  - High τ : LiteBird, SKA, Hera
  - Sterile neutrino: SO, future oscillation experiments

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  - High τ : LiteBird, SKA, Hera
  - Sterile neutrino: SO, future oscillation experiments
- Cosmological bounds on neutrino mass fragile because dominated by generic effects (geometry, CMB lensing) with lot of parameter degeneracy
- Need to probe a more direct effect: scale-dependent growth factor induced by free-streaming (DESI, Euclid, LSST full-shape)