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Resolving CMB-BAO tension with a large cosmic birefringence angle during reionization

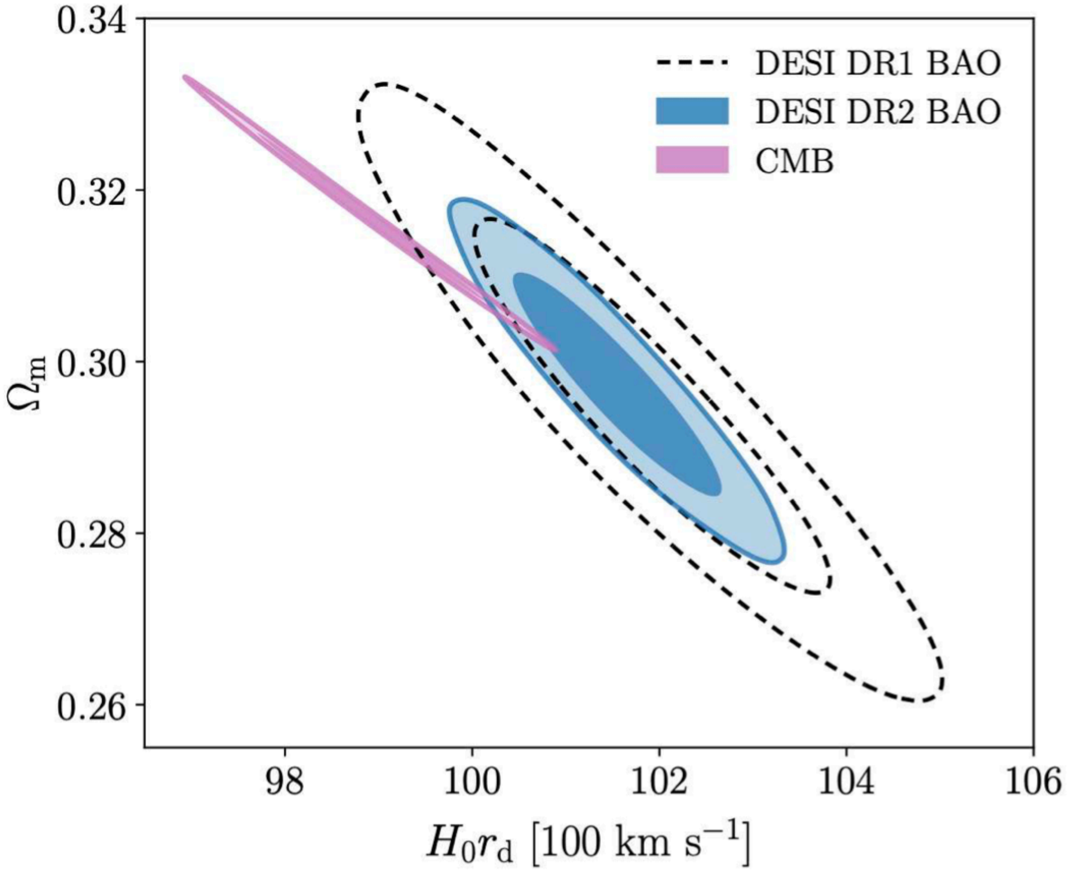
@ Challenges at the CMB Frontier, Suwa (Nagano), Japan

Salvatore Samuele Sirletti

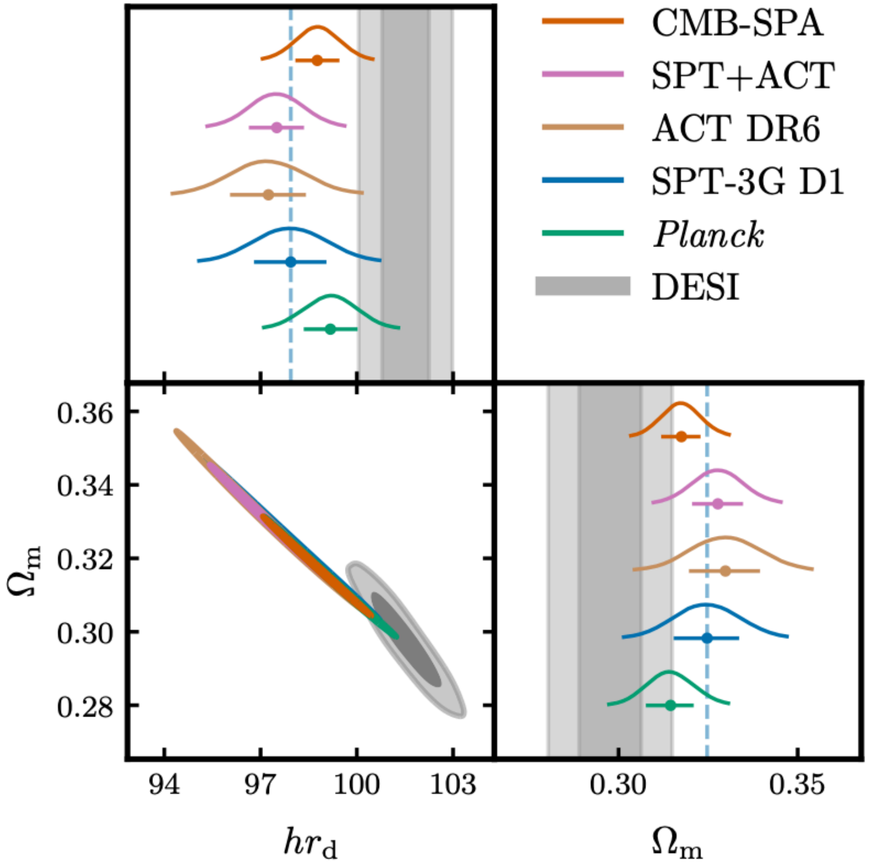
(in collaboration with Toshiya Namikawa and Blake D. Sherwin)

A mild CMB-BAO tension

Comparing CMB and DESI BAO data reveals a ***mild tension on the Ω_m*** value *[1]*.



[1]



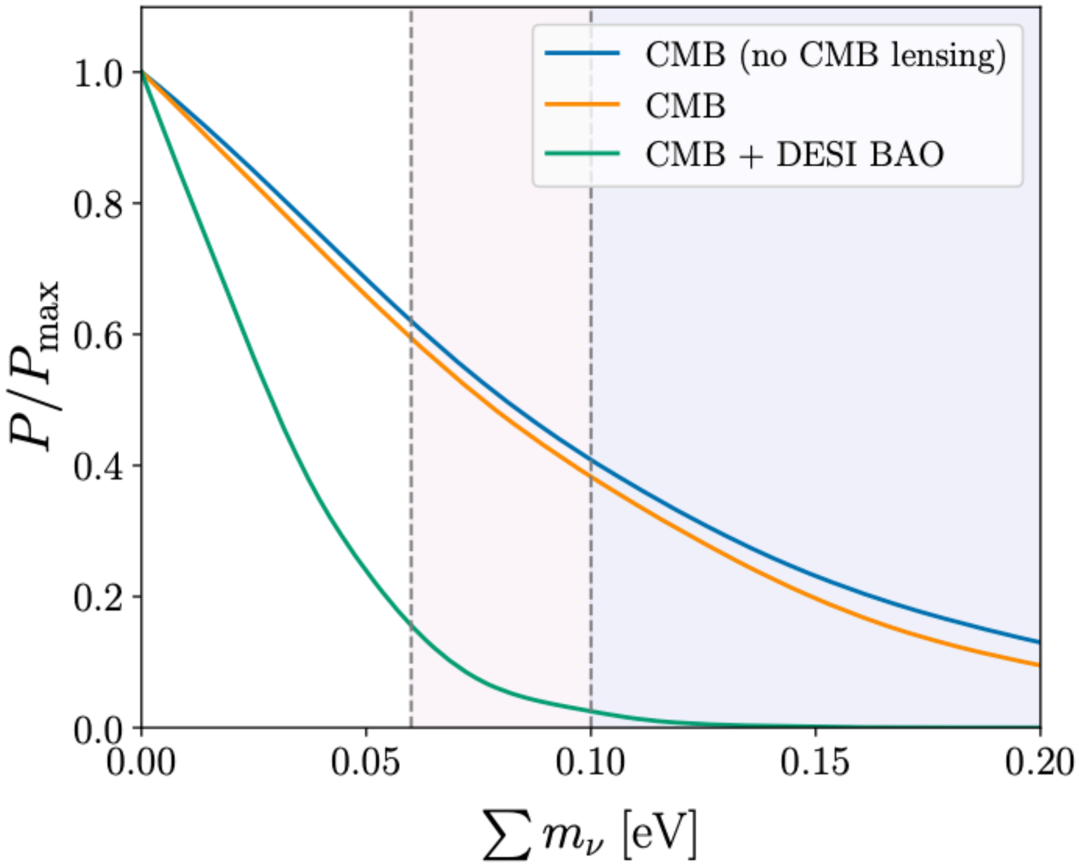
[2]

Distance to DESI
$2.8\,\sigma$
$3.7\,\sigma$
$3.1\,\sigma$
$2.5\,\sigma$
$2.0\,\sigma$

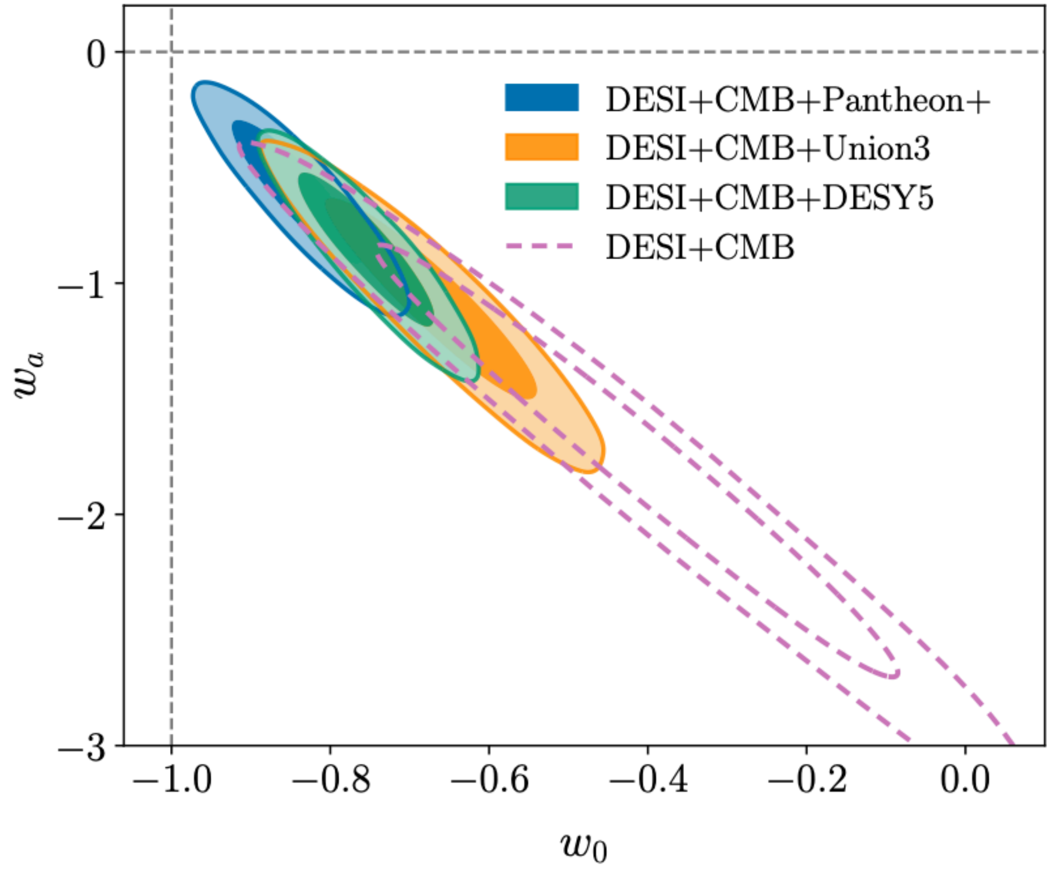
[1]: DESI Collaboration , W. Elbers et al.
[2]: SPT Collaboration , Camphuis et al.

A mild CMB-BAO tension

This mild tension can manifest as *negative neutrino mass*, or preference of *dynamical dark energy* when combining the datasets.



[1]



In the joint fits, parameter degeneracy can shift the *inferred τ to higher* values with respect to $\tau_{\mathrm{Planck}} = 0.05$ *[3]*.

[1]: DESI Collaboration , W. Elbers et al.
[3]: Sailer et al., Phys.Rev.Lett. 136 (2026)

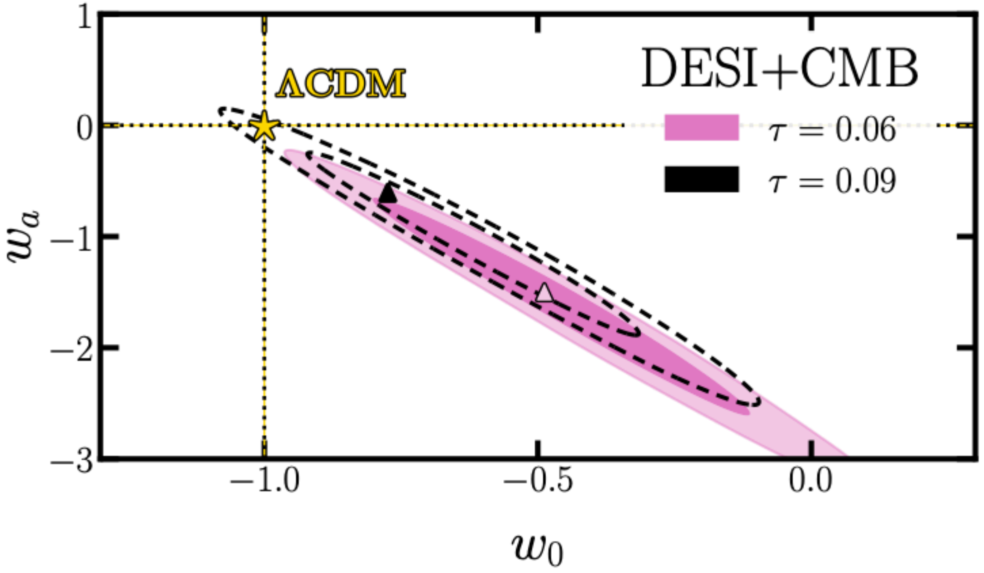
Tension in τ

By increasing τ it is possible to:

1) restore $\sum_\nu m_\nu$ back to 0.06 eV;

2) alleviate the $w_0 w_a$CDM - ΛCDM discrepancy as well.

But *$\tau \simeq 0.09$ is inconsistent with Planck low-ℓ EE reionization bump* at $> 3\sigma$ (RB $\sim \tau^2$).



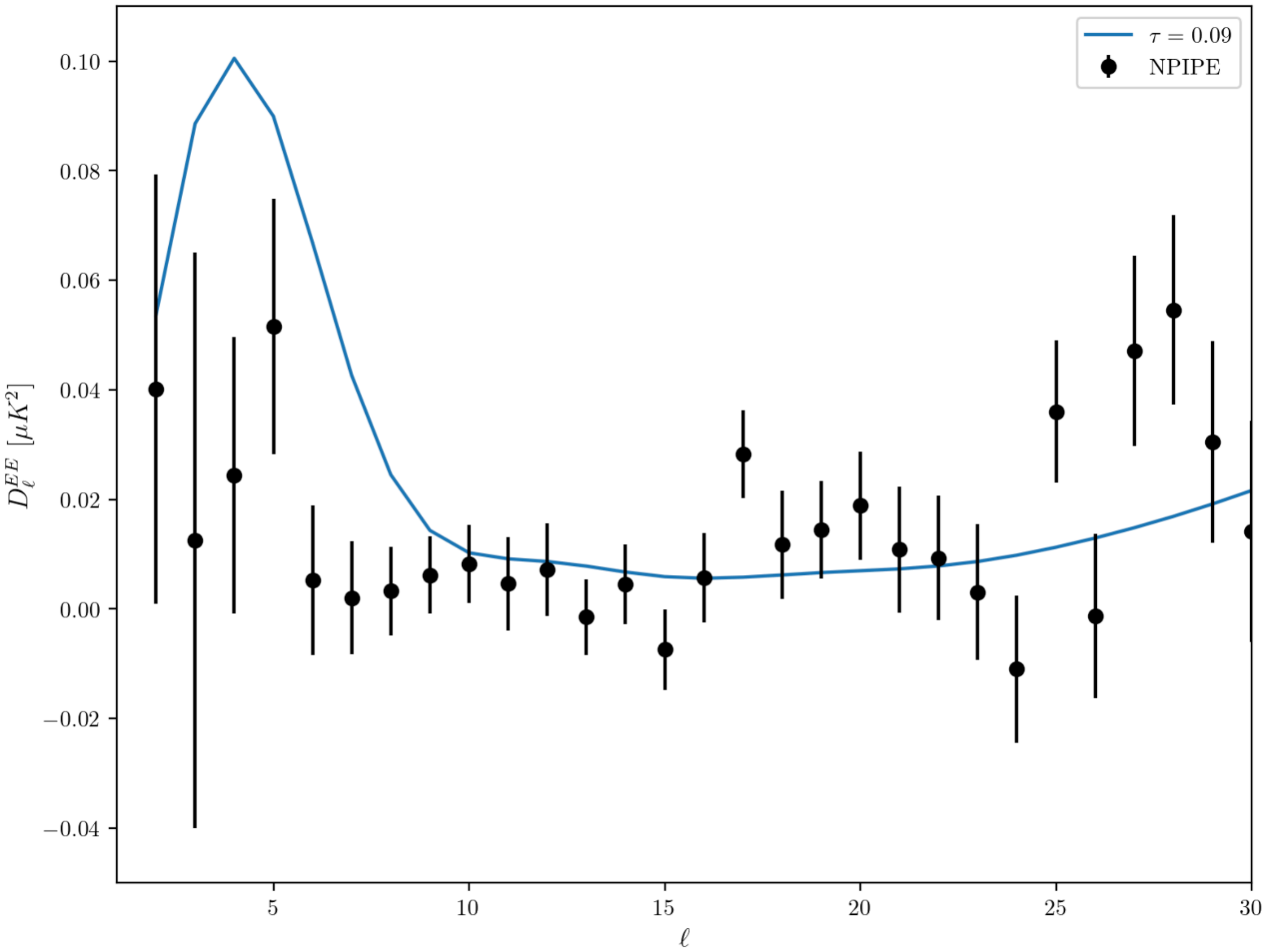
[3]

Consistent with?	$\tau = 0.06$	$\tau = 0.09$
Planck low-ℓ polarization	✔	✗
WMAP low-ℓ polarization	✔	✔
BAO within ΛCDM	✗	✔
$\sum m_\nu \geq 0.06$ eV	✗	✔
Cosmological constant Λ	✗	✔

To justify such results, we need to find a *mechanism able to suppress the reionization bump* even when the true τ is larger.

[3]: Sailer et al., Phys.Rev.Lett. 136 (2026)

The reionization bump problem if $\tau = 0.09$



Suppressing the reionization bump through cosmic birefringence

Namikawa proposed that a ***large cosmic birefringence angle*** during reionization can suppress the observed EE reionization bump even with $\tau \simeq 0.09$ *[4]*.

A scalar field ϕ (axion or ALP) interacts with the electromagnetic field through the Chern-Simons Lagrangian

$$\mathscr{L} = -\frac{1}{4} g_{a\gamma} \phi F_{\mu\nu} \tilde{F}^{\mu\nu},$$

This breaks the parity symmetry inducing crossing modes between E and B polarization: C_ℓ^{EB} arises

$$C_\ell^{EB,obs} = \frac{1}{2} \sin(4\beta) \left(C_\ell^{EE} - C_\ell^{BB} \right)$$

Phase degeneracy induced by the sine

$$\beta = \beta_0 \pm n\pi$$

$$\beta_0 = 0.34^\circ \pm 0.09^\circ$$

The cosmic birefringence angle β is given by the ϕ dynamics through

$$\beta(\eta) = \frac{g_{a\gamma}\phi_{ini}}{2} \frac{\phi(\eta_0) - \phi(\eta)}{\phi_{ini}}$$

[4]: Namikawa, Phys.Rev.Lett. 135 (2025) 16

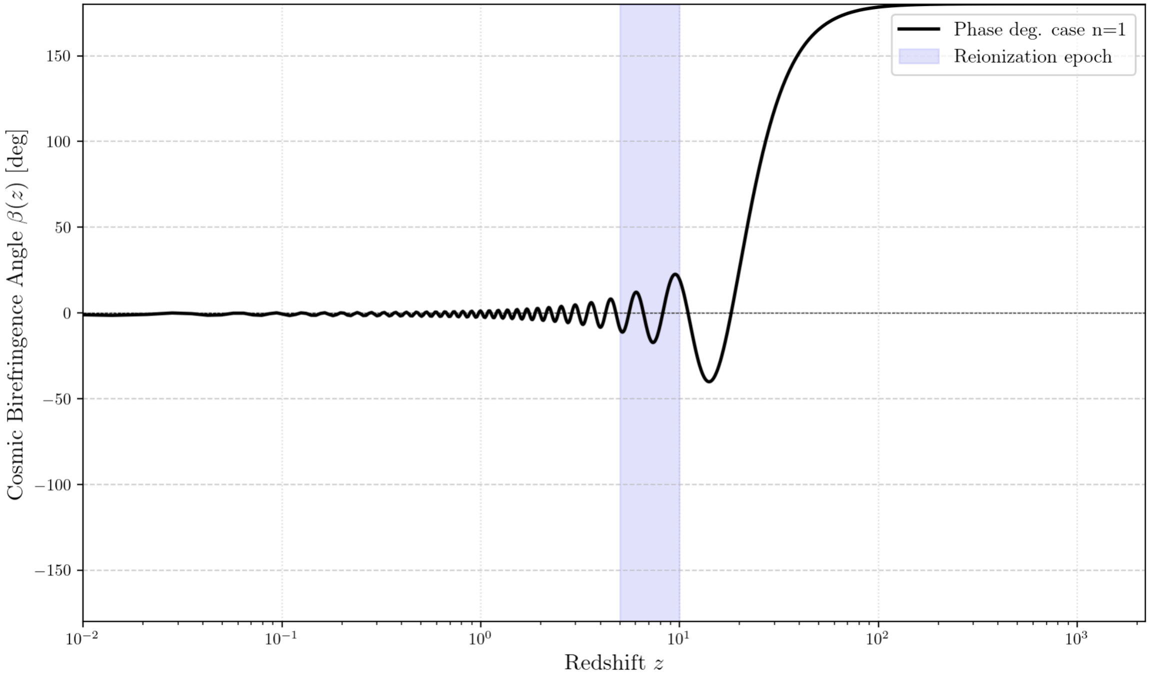
Suppressing the reionization bump through cosmic birefringence

With cosmic birefringence, the E-mode amplitude sourced during reionization is modified as:

$$\Delta_E^{\text{rei}} \propto \int_{\text{rei}} d\eta \; e^{-\tau(\eta)} \; \Pi(\eta) \;\; \cos[2\beta(\eta)]$$

- $n = 0$: here $\cos[2\beta(\eta)] \sim 1$ during the reionization. A large τ would enhance the reionization bump, being the latter $\sim \tau^2$.

- $n = 1$: during the reionization $\beta(\eta)$ oscillates, then $\cos[2\beta(\eta)]$ oscillates too—> opposite contributions cancel out each other and the reionization bump is suppressed even with a large τ.



We now ask weather a *concrete dynamical model* can generate a large birefringence angle during the reionization.

Energy exchange in the dark sector (DM $\rightleftarrows$ DE)

We explore this possibility in an interacting dark energy scenario with energy injection into the axion sector.

Interacting Dark Energy-Dark Matter models assume the energy is conserved in the dark sector and it is exchanged between dark energy and dark matter *[5]:*

$$\dot{\rho}_{\mathrm{DM}} + 3H\rho_{\mathrm{DM}} = Q$$

$$\dot{\rho}_{\mathrm{DE}} + 3H(1 + w_{\mathrm{DE}})\rho_{\mathrm{DE}} = -Q$$

These models are returning back to the spotlight thanks to $w_0 w_a$CDM.

The ***simplest model*** is a Q linear in density*:*

$$Q = 3\xi H\rho_{\mathrm{DM}}$$

Assuming the axion as a spectator field, $m_a \sim [10^{-31}, 10^{-30}]$ eV, and $\xi(z) \neq 0$ only in a narrow redshift bin, it is possible to study if this model can produce a large CB angle.

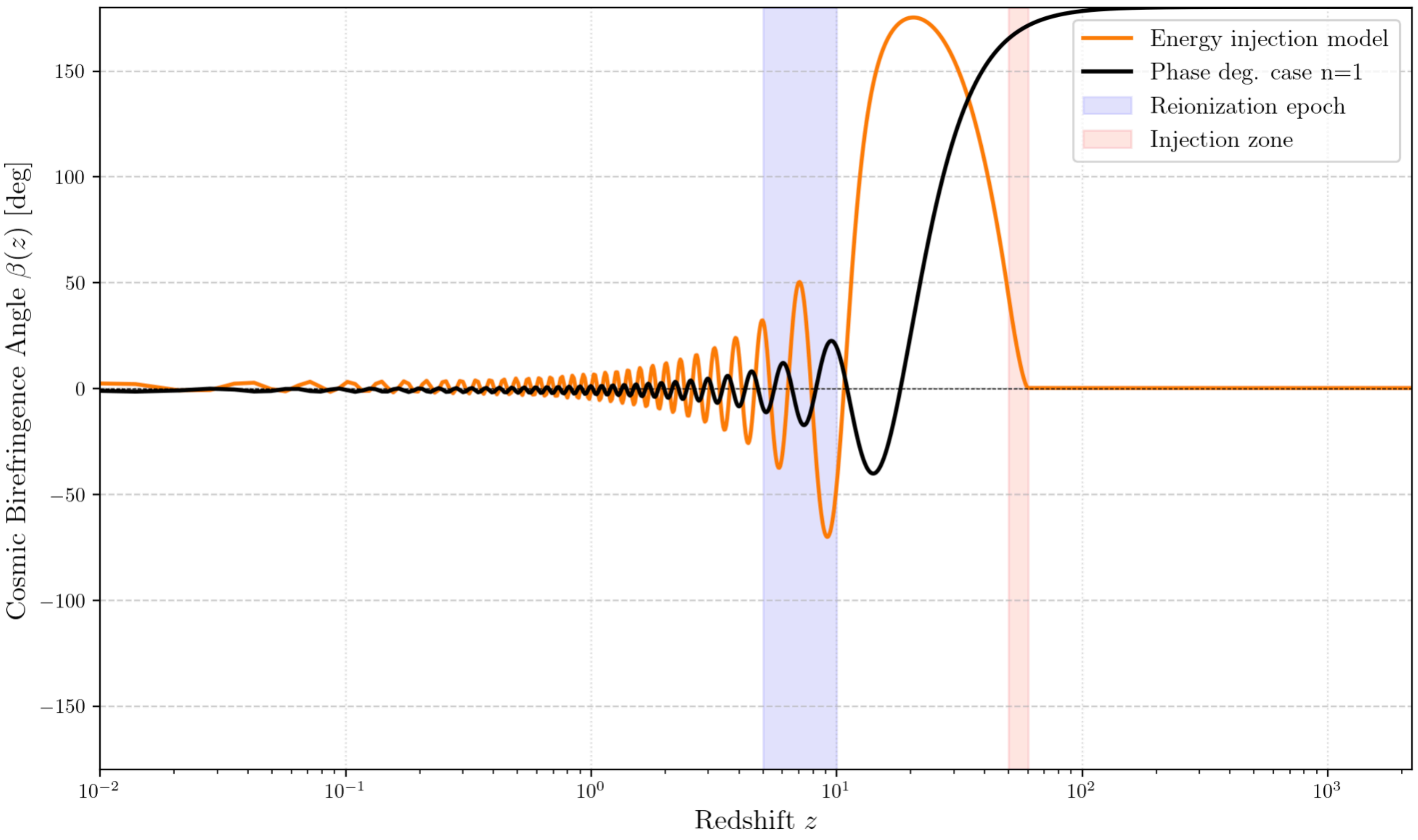
[5]: B. Wang et al, Rept.Prog.Phys. 79 (2016)

The injection model equations

$\Delta z \in [50,60]$ $\log(m_a/\mathrm{eV}) = -30.5$

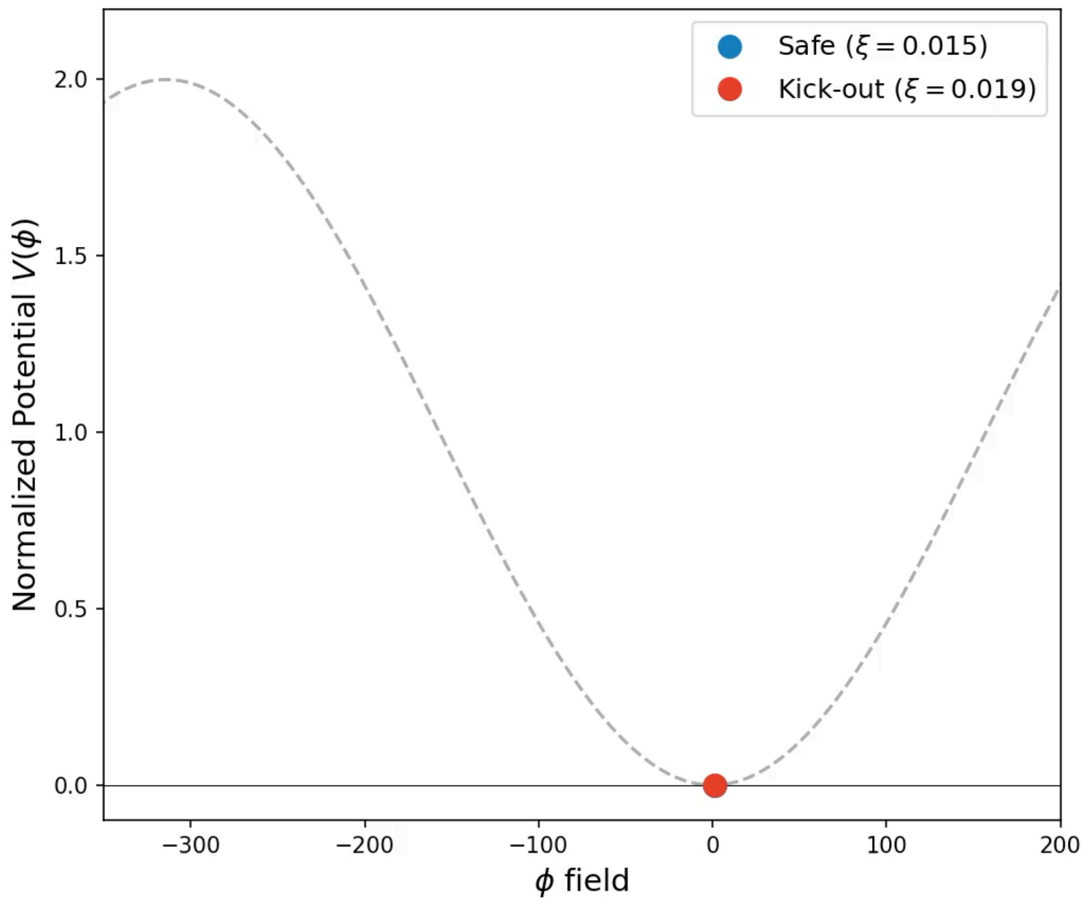
$$V(\phi) = m^2 f^2 \left(1 - \cos\frac{\phi}{f}\right)$$

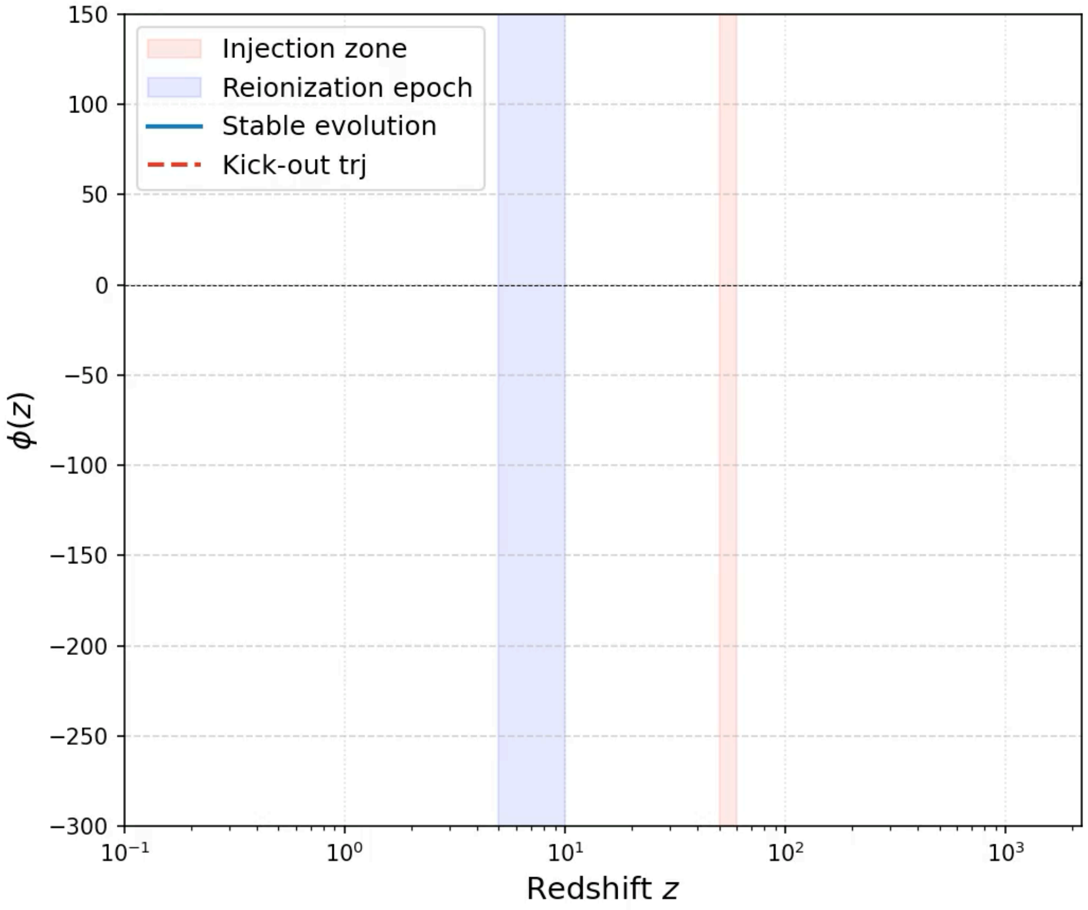
$$\xi(z) = \begin{cases} \xi & \text{in } \; z_{\text{end}} \le z \le z_{\text{sta}} \\ 0 & \text{otherwise} \end{cases}$$



The kick-out limit and the EE power spectrum

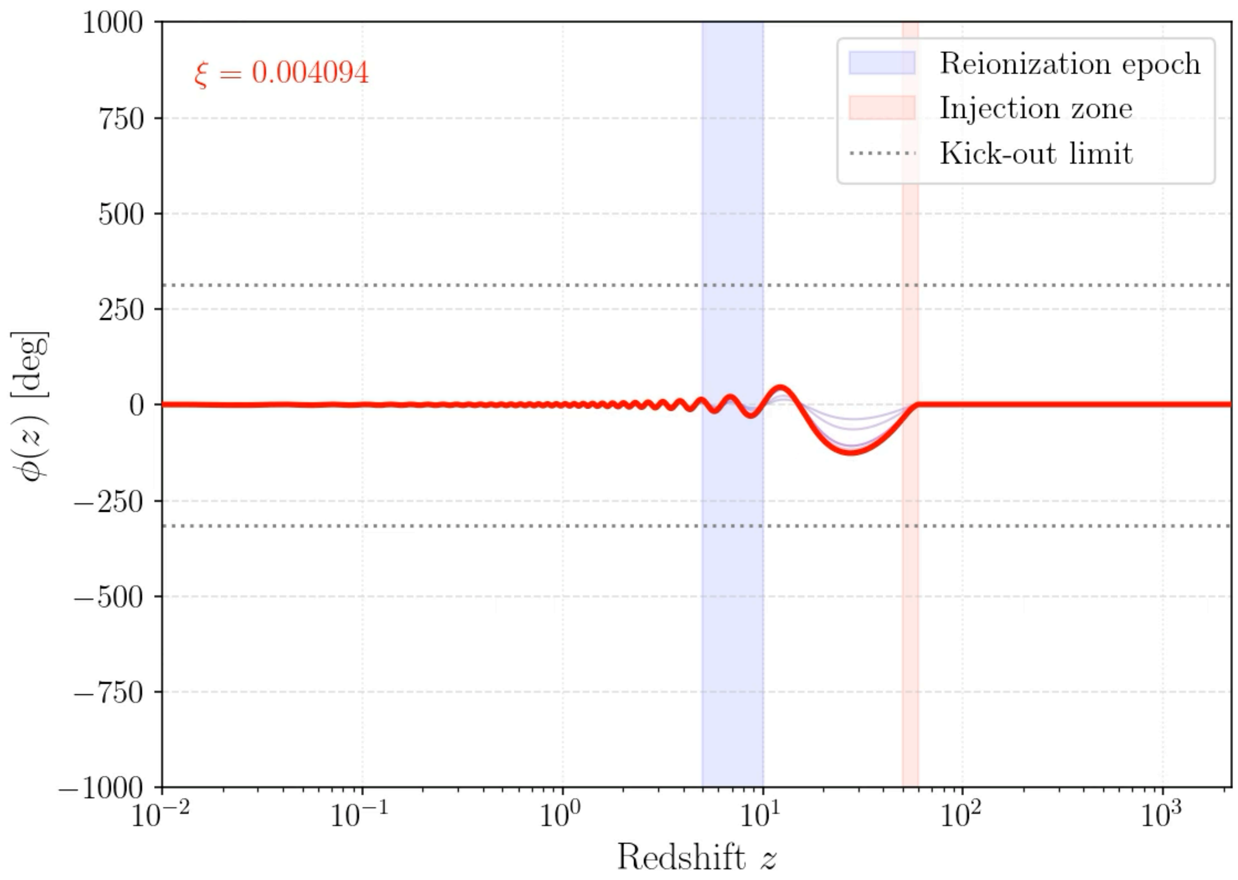
Being $V'(\varphi) \propto \sin\left(\frac{\phi}{f}\right)$, a ***kick-out limit*** is expected: if if the injection is too large, $\xi \geq \xi_{\rm crit}$, the axion receives enough energy to escape the potential well and oscillate around a different minimum. In that regime, the resulting CB angle is suppressed and the dynamics approaches the no-injection case.

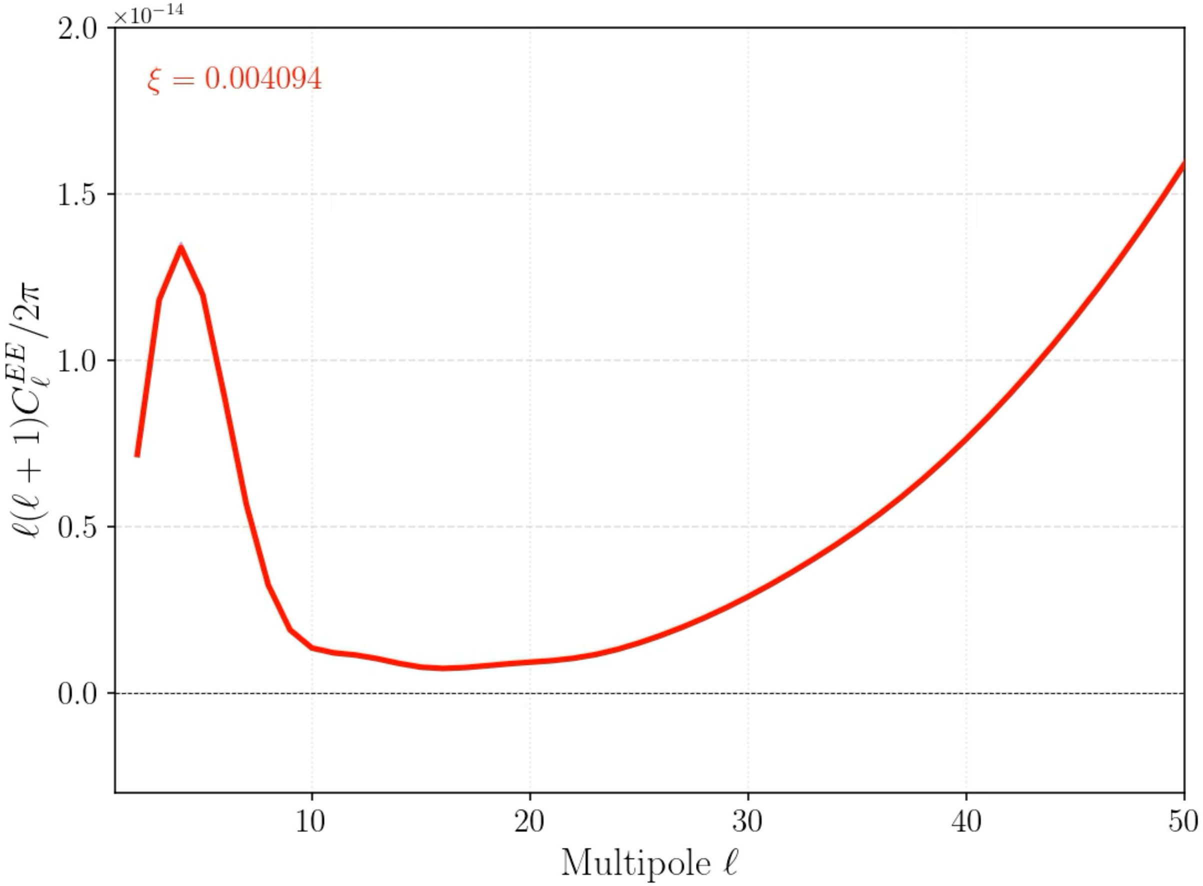




The kick-out limit and the EE power spectrum

$z_i \in [50{,}60]$ $\log(m) = -30.5,\ \tau = 0.09$ $\xi_{\rm crit}(z_i) \simeq$ 1.63e-02



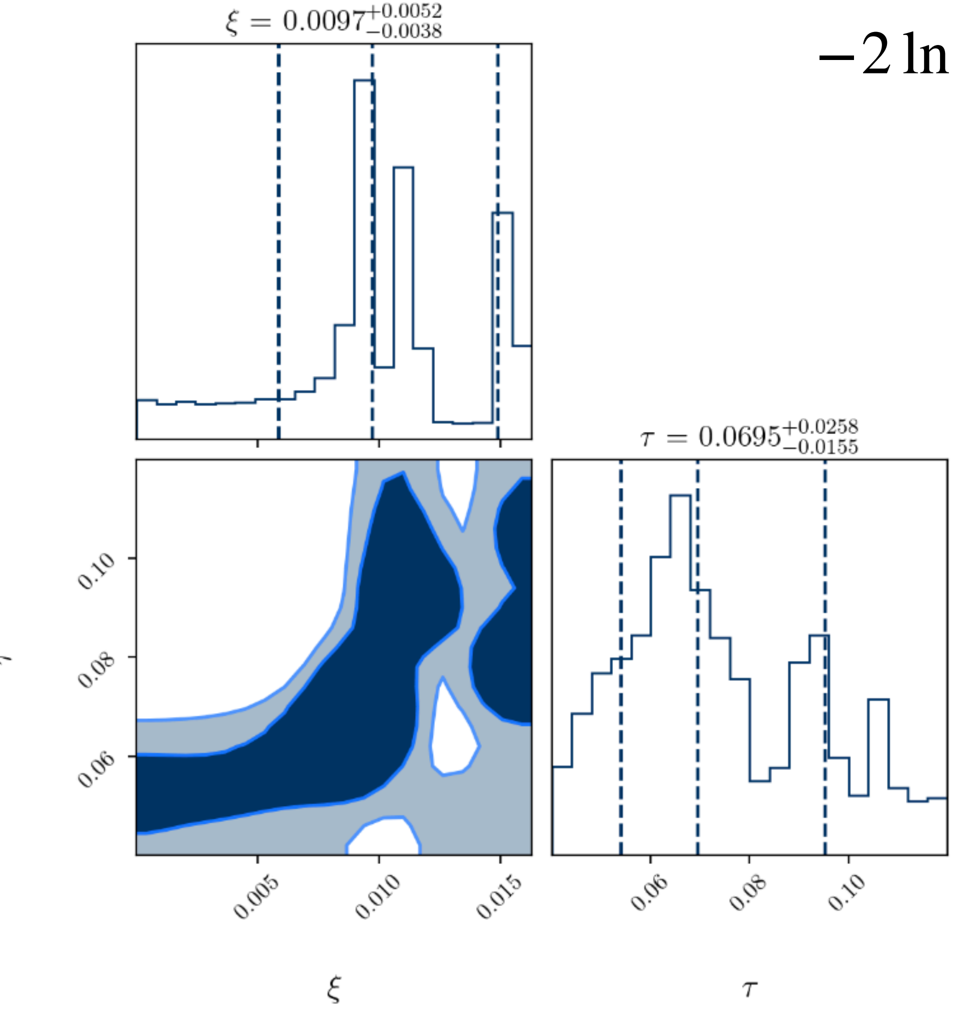


C_ℓ^{EE} computed including CB in CLASS (***birefCLASS*** code) ***[6]***.

[6]: H. Nagatsuka, T. Namikawa, E. Komatsu, *Phys.Rev.D* 105 (2022)

Running MCMC

By using low-ℓ EE+BB+EB Planck 2020 data, we performed an MCMC over (ξ, τ) parameter.

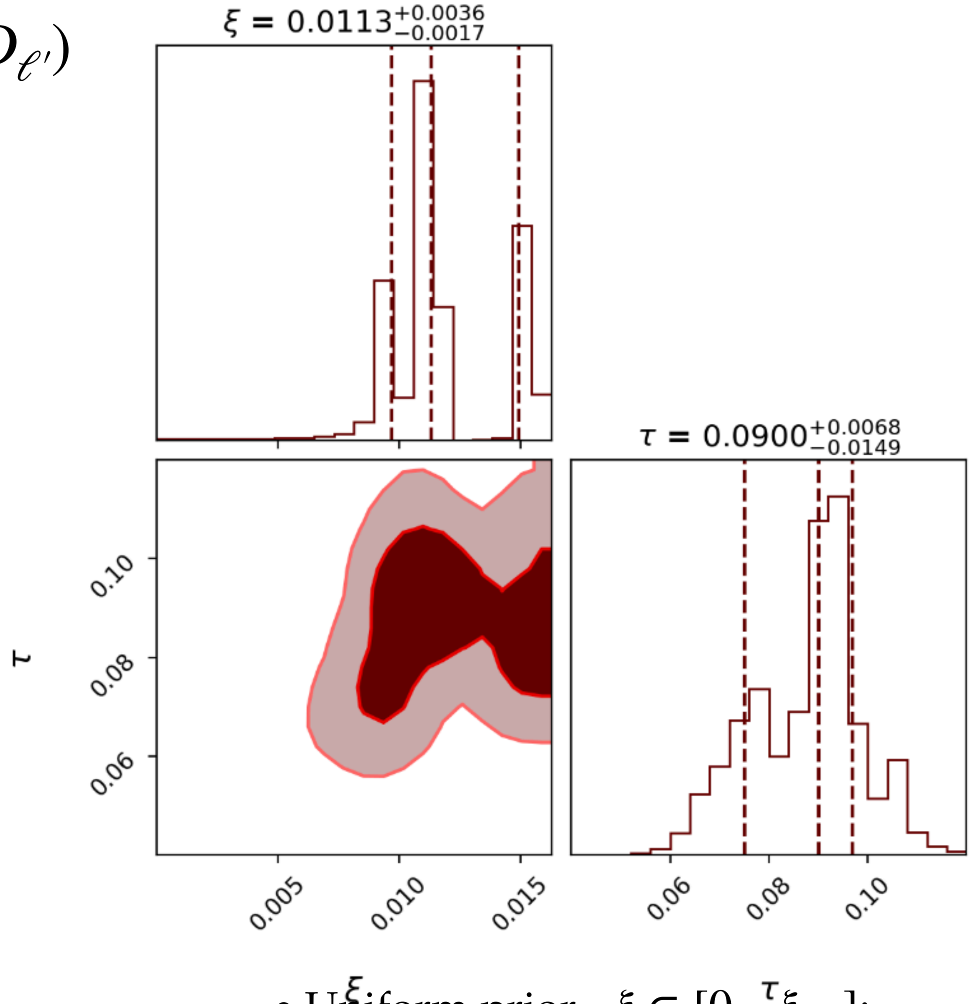


- Uniform prior - $\xi \in [0\ ,\ \xi_{\mathrm{crit}}]$;
- Uniform prior - $\tau \in [0.04\ ,\ 0.12]$

$$-2\ln\mathscr{L} = (\Delta D_\ell)^T \cdot C^{-1}_{\ell\ell'} \cdot (\Delta D_{\ell'})$$

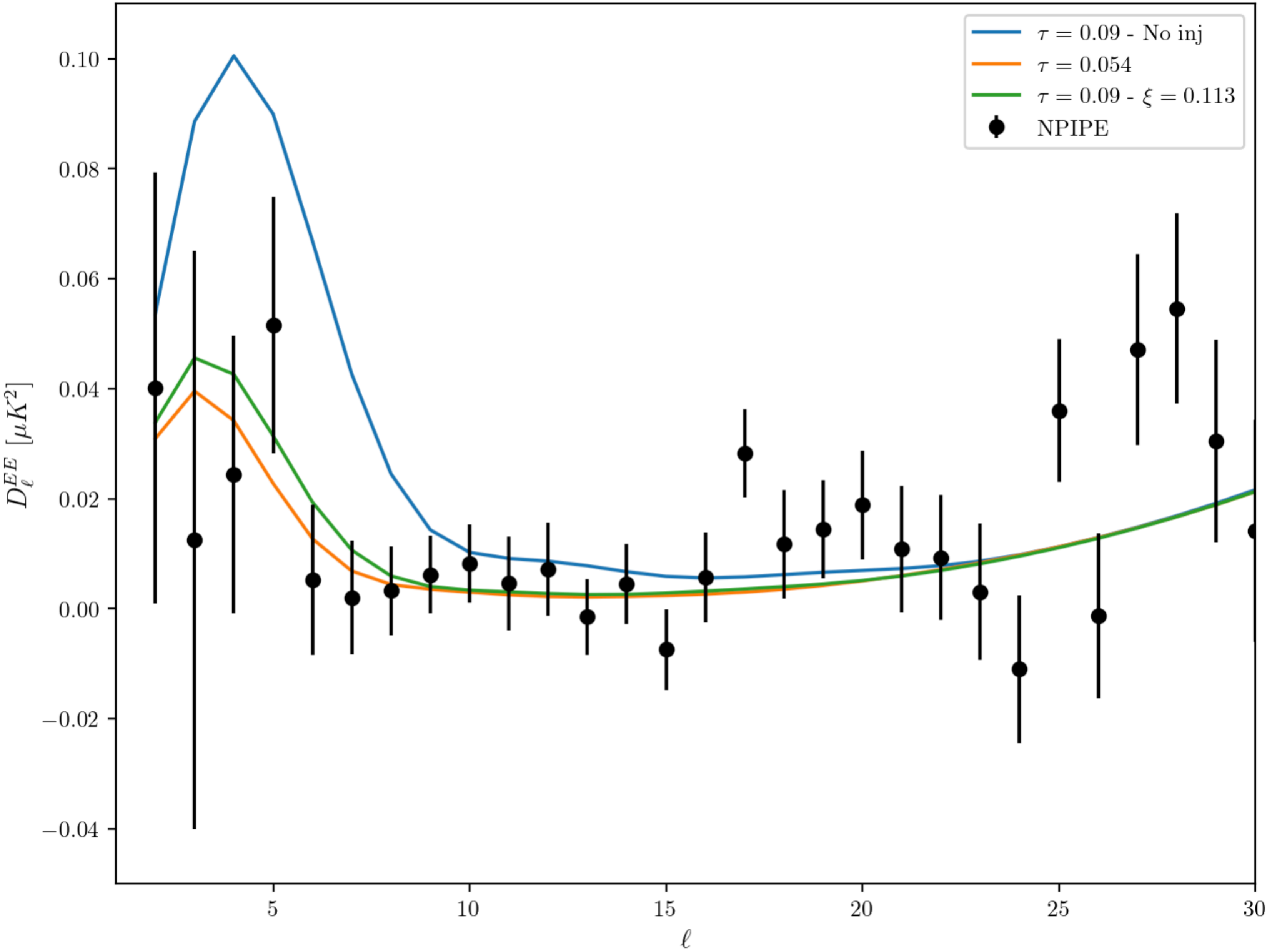
$$\Delta z \in [50,60]$$

$$\log(m_a/\mathrm{eV}) = -30.5$$



- Uniform prior - $\xi \in [0\ ,\ \xi_{\mathrm{crit}}]$;
- Gaussian prior on τ peaked at $\tau_{\mathrm{CMB+BAO}} = 0.09$

MCMC results vs Planck data



We recover the phenomenology found in *[4]*, but now with an explicit dynamical model.

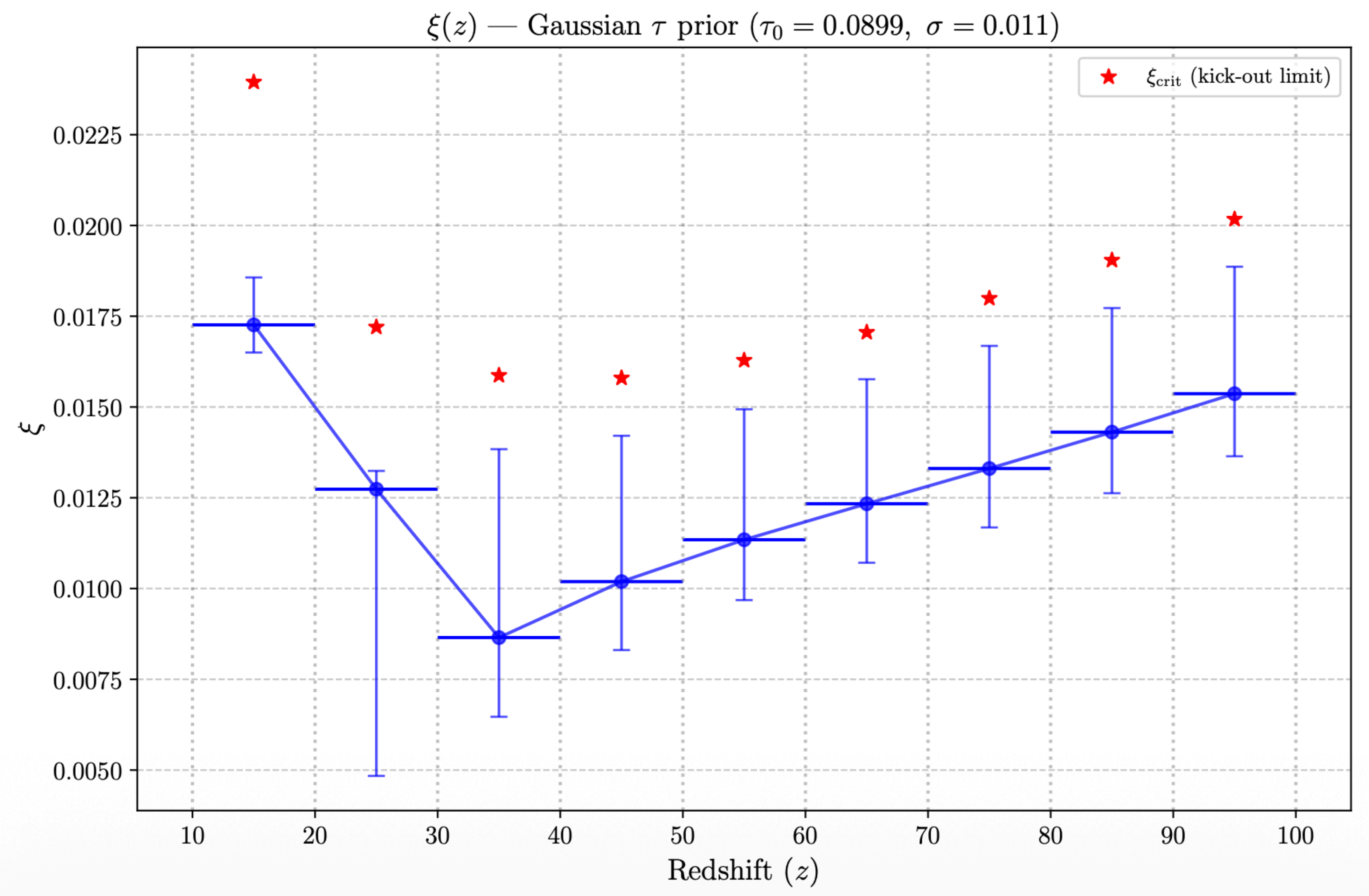
[4]: Namikawa, Phys.Rev.Lett. 135 (2025) 16

Investigating other redshift bins and other masses

$\xi_{\mathrm{crit}} = \xi_{\mathrm{crit}}(\Delta z)$

Injecting energy at different epochs changes the effect at the reionization epoch.

The results are stable across different redshift bins: the data, assuming a higher tau, prefer a non-zero injection amplitude.



Next steps and summary

- We are testing *other values of the mass* in the range $-31 \leq \log(m_a/\mathrm{eV}) \leq -30$ proposed in *[4]*. Across all cases the data consistently prefer $\xi > 0$ in the case $\tau = 0.09$.

- *Next steps:* 1) Test alternative injection models;
  2) Derive an analytical expression of $\xi_{\rm crit}(z)$;
  3) Full inference analysis.

Final remarks:

- We have shown that a cosmic birefringence angle sourced by axion energy injection during reionization *can suppress the reionization bump required by* $\tau_{\rm CMB+BAO}$, providing a physically motivated candidate mechanism in the case $\tau > \tau_{\rm Planck}$ will be confirmed from external analysis.

[4]: Namikawa, Phys.Rev.Lett. 135 (2025)

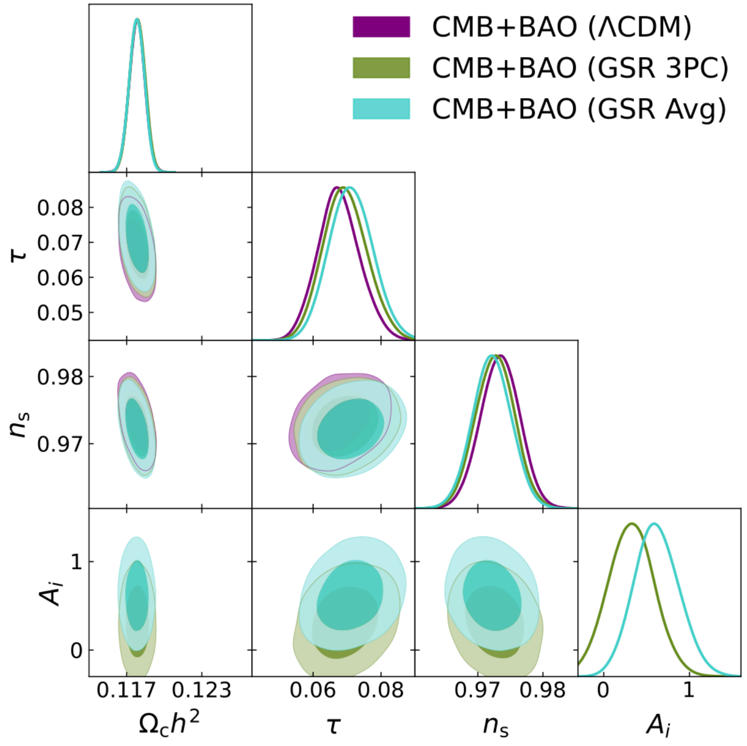
Thank you for your attention

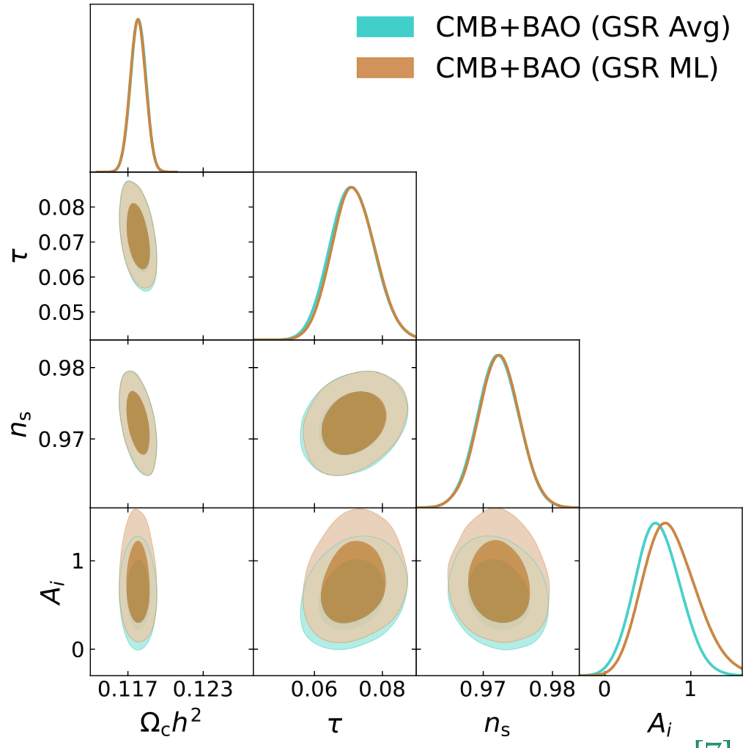
Suppressing the reionization bump through primordial features in the PPS

Some new theoretical models are being proposed.

[7] $$\ln \mathcal{P}(k) = \ln A_s + (n_s - 1) \ln \left(\frac{k}{k_0} \right) + A_i \mathcal{T}_i(k),$$

Some models of primordial features (3PC, avg, ML) suppress the PPS and the reionization bump. To be consistent with low-ℓ data, an increasing of τ is needed.





[7]: Jhaveri, Hu, Miranda (2606.20795v1)