# Pseudoscalar sterile neutrino self-interactions in light of Planck, SPT and ACT data

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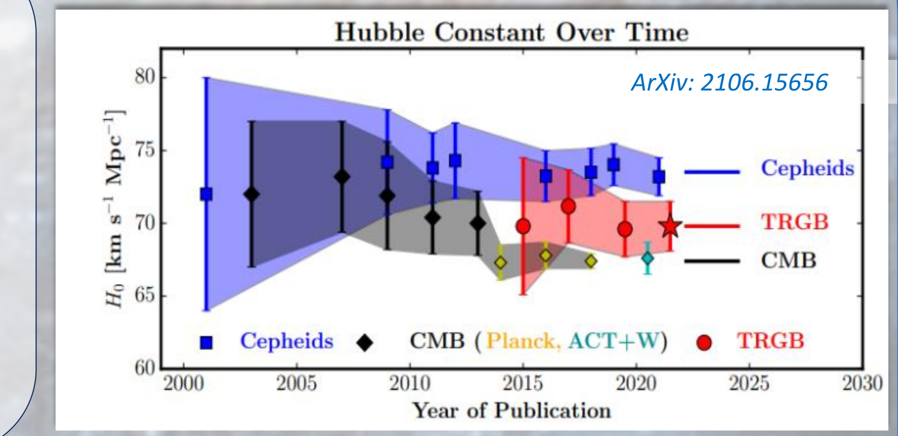
## Cosmological Tensions

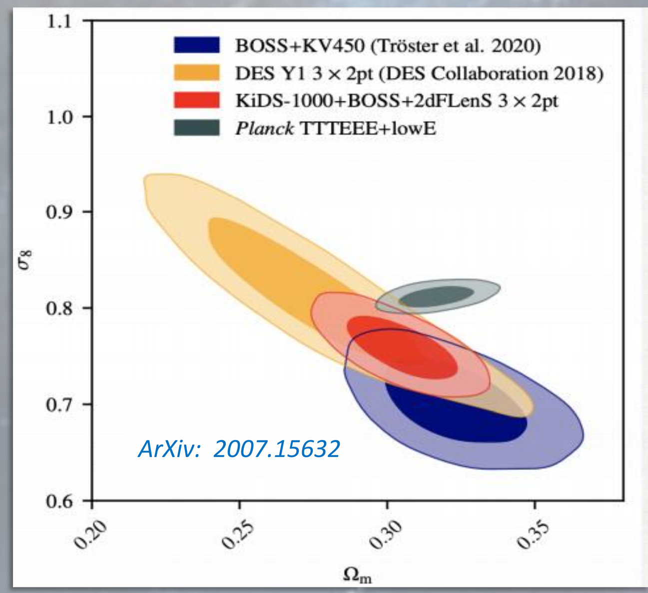
### The Hubble Tension

- *Hubble tension:* $4-6\,\sigma$ discrepancy between the low-redshift value of the Hubble parameter $H_0$ measured with local observations compared with that estimated from early-Universe data, assuming the ΛCDM model [2, 3].



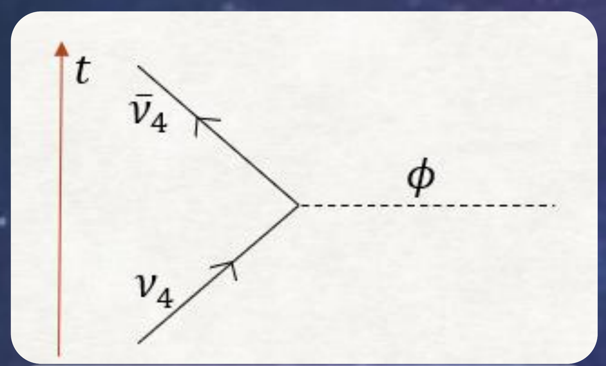

### The $S_8$ tension

- $S_8$ *tension:* $2-4\,\sigma$ discrepancy related to Large Scale Structure (LSS) observables, which systematically find a lower amplitude of the late-time gravitational clustering of matter, compared to that inferred from *Planck* Cosmic Microwave Background (CMB) within ΛCDM.




? A **sterile neutrino** with a mass in the **eV range** might provide an explanation to long-standing anomalies in short-baseline (**SBL**) neutrino oscillation experiments!

✗ CMB and LSS data **strongly constrain** the simplest scenario where the new sterile neutrino component is a **non-interacting** and **free-streaming** species. In such a minimal scenario, it is very unlikely to find a common resolution to SBL anomalies and cosmological tensions.



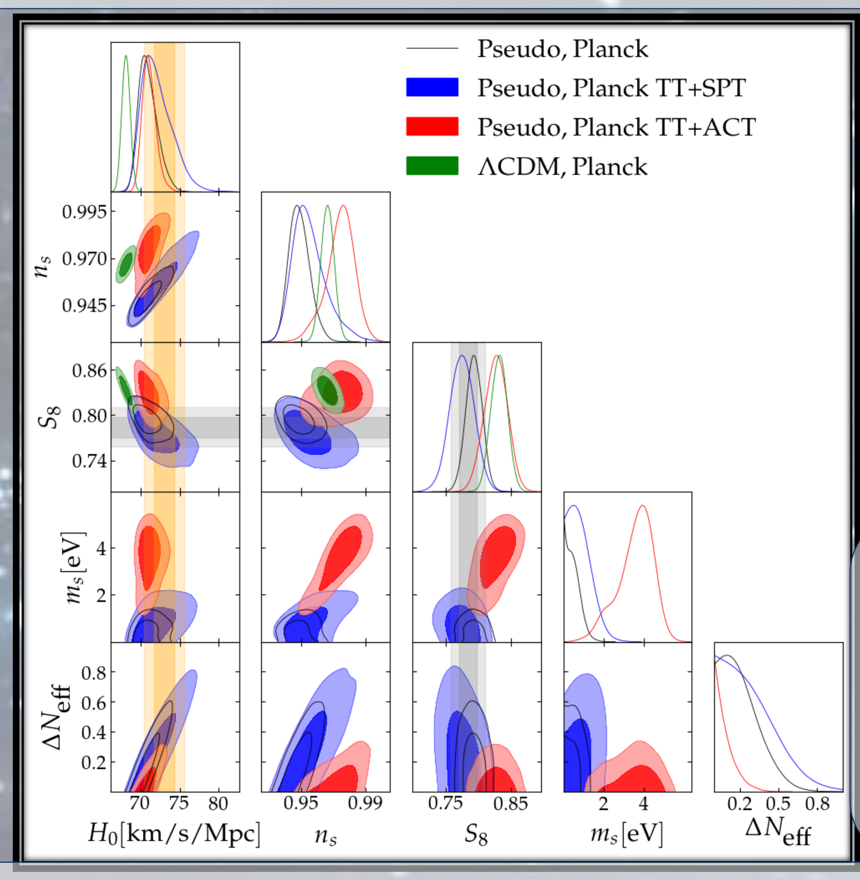

✓ The **pseudoscalar model** introduced in Ref. [4] can evade such limits by introducing a new interaction between the sterile neutrino and a **pseudoscalar field** $\phi$ described by the Lagrangian

$$\mathcal{L} = g_s \phi \bar{\nu}_4 \gamma^5 \nu_4,$$

where $g_s$ is the coupling characterizing the interaction.

## Main Results and Discussion

- ➢ Our baseline ΛCDM is described by $\{\omega_b, \omega_{\rm cdm}, \theta_s, n_s, A_s, \tau_{\rm reio}\}$.
- ➢ The pseudoscalar scenario is fully characterized by two additional parameters, namely the **sterile neutrino mass**, $m_s$, and its **contribution to the effective number of relativistic degrees of freedom**, $\Delta N_{\rm eff}$.




- Orange band: Direct measurement of $H_0$ from SnIa (*Riess, 2021* [5])
- Gray band: Direct measurement of $S_8$ from Weak lensing surveys (*DES-Y3* [6])

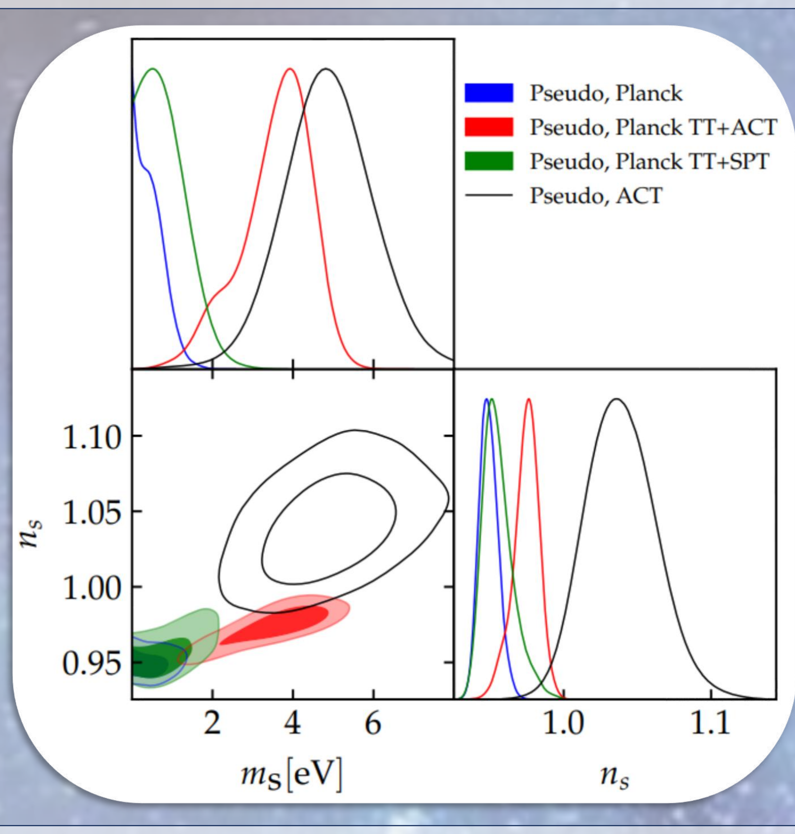
✓ The model is able to simultaneously alleviate the $H_0$ and $S_8$ tension.

✗ High-$\ell$ *Planck* and SPT polarization data strongly constrain $m_s$ due to its correlation with $n_s$.

✗ The pseudoscalar model does not provide a good fit compared ΛCDM in the *Planck* and in the joint *Planck* TT+SPT analysis ($\Delta\chi^2 \sim 13$ and $\Delta\chi^2 \sim 8$ respectively).

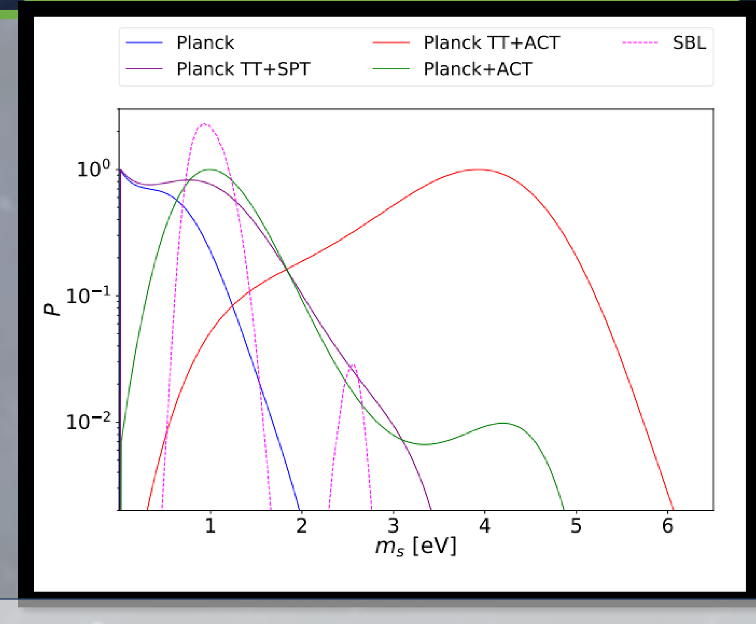
? When trading *Planck* TE-EE data for those from ACT, we find a $> 3\sigma$ **preference** for a non-zero sterile neutrino mass of $m_s = 3.6^{+1.1}_{-0.6}$ eV (68% C.L.)!!

✓ In the joint ***Planck* TT+ACT** analysis the global fit is only mildly degraded compared to ΛCDM ($\Delta\chi^2 \simeq +3$), due to the fact that **the pseudoscalar model provides a better fit of ACT** data than the ΛCDM model ($\Delta\chi^2 \simeq -6$ ), balancing the worse fit to high-$\ell$ *Planck* TT data ($\Delta\chi^2 \simeq +9$ ).




! The preference for a non-zero value of $m_s$ is mostly driven by ACT **favouring a higher value for the primordial spectral index $n_s$** with respect to *Planck* and SPT!

## Comparison with SBL




- ➢ In the figure above we compare the posterior distributions of $m_s$ in the pseudoscalar model obtained from the cosmological analyses performed, and the posterior obtained with SBL data.
- ➢ The SBL posterior shows a main peak around $m_s \simeq 1$ eV and a secondary peak around $m_s \simeq 2.5$ eV.
- ➢ There is a **clear compatibility** between the cosmological indications and SBL within the pseudoscalar framework.

## Conclusions and Perspectives

✓ We confirm the capability of the model under study to provide **higher values for $H_0$** with respect to ΛCDM.

✓ We show that the pseudoscalar model **does not worsen the $S_8$ tension**, being indeed able to solve it for some data combinations.

! The pseudoscalar model provides a **better fit to ACT data** compared to ΛCDM ($\Delta\chi^2 \simeq -6$ ).

? ACT data predicts larger value of $n_s$ with respect to *Planck* and SPT both in the ΛCDM and in the pseudoscalar model.

! Due to the positive $n_s - m_s$ correlation, **ACT predicts non-zero values of $m_s$** even in a combined analysis with *Planck*.

✓ We show that discrepancy between *Planck* and ACT prediction comes from intermediate multipoles ($350 < \ell < 1000$) and that it can lead to highly non-trivial results in the pseudoscalar framework! See also similar analyses performed in Refs. [7,8] in models featuring early dark energy at early times.

References:
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[6] DES collaboration, e-print 2110.10141 (2021)
[7] ACT collaboration, e-Print: 2109.04451 (2021)
[8] Poulin et al., *Phys. Rev. D* 104 12, 123550 (2021)

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