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Light sterile neutrinos and pseudoscalar interactions in Cosmology

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The Short BaseLine (SBL) neutrino oscillations anomalies hint at the presence of a sterile neutrino with a mass of around 1 eV. However, such neutrino is highly incompatible with the cosmological data, in particular from the Cosmic Microwave Background (CMB), if no new physics is assumed. An interesting possibility for reconciling the 1 eV sterile neutrino presence in cosmology is related to the existence of a new pseudoscalar interaction. If the sterile neutrinos experience such a pseudoscalar interaction, the cosmological analyses of the full CMB data prefer a sterile neutrino mass that is fully compatible with the SBL determinations. The additional interaction allows to obtain also an improved compatibility of the cosmological predictions with the local measurements of the Hubble parameter.

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1. Light Sterile Neutrinos

The so-called short-baseline (SBL) neutrino oscillation anomalies (see e.g. [1]) can be explained with the introduction of a third square mass difference Δm^2_{41}, that implies the existence of at least four neutrino mass eigenstates. Since the number of active flavor neutrinos that experience interactions with the standard model particles is three, the new eigenstate must correspond to a new sterile neutrino. Being Δm^2_{41} close to 1 eV^2, this new neutrino is called "light sterile neutrino" [1], and its properties can be studied using several cosmological observables, including the Cosmic Microwave Background (CMB) radiation [2].

CMB data are robust enough to obtain precise constraints on the energy density of relativistic particles in the early universe, parameterized through the effective number $N_{\rm eff}$. Recent calculations including the full analytic collisional terms confirmed that the contribution of the standard active neutrinos to $N_{\rm eff}$ is very close to 3, being it slightly larger because the decoupling of the neutrinos is not instantaneous: $N_{\rm eff} = 3.046$ [3, 4]. The light sterile neutrino also contributes to this number, and the calculations show that its contribution $\Delta N_{\rm eff} = N_{\rm eff} - 3.046$ should be very close to 1, if one considers $m_s \simeq 1$ eV and the best-fit mixing angles obtained from the SBL analyses [5, 6]. In the standard parameterization, hence, we would have $N_{\rm eff} \simeq 4$, if the light sterile neutrino exists.

The most recent constraints on $N_{\rm eff}$ show that there are no deviations from the standard value 3.046 [2, 7, 8], especially if one considers an additional neutrino with mass around 1 eV (see Fig. 1, where different cosmological data sets have been considered). If a light sterile neutrino exists, its presence in the early universe must be suppressed by some new mechanism.

2. Pseudoscalar interaction

One interesting possibility is to assume that a new interaction exists in the sterile sector. The role of the new interaction is to suppress the oscillations in the early universe and to prevent the thermalization of the light sterile neutrino. Here we consider a new interaction mediated by a new pseudoscalar boson [9, 7] that is nearly massless. If the coupling between the sterile neutrino and the pseudoscalar is strong enough, the oscillations in the early universe are blocked by the matter effect driven by the pseudoscalar fluid and $N_{\rm eff}$ can be smaller than 4.

At late times, the sterile neutrino decays and populates the pseudoscalar fluid. In this way, the cosmological bounds on the sterile neutrino mass do not apply. Indeed, in our analyses we find that a large value for $N_{\rm eff}$ is allowed also for a sterile neutrino with a mass larger than 1 eV. As we can see in Fig. 2, the preferred value for m_s is around 5 eV.

Comparing Fig. 1 and 2, we can also see how the presence of the sterile neutrino – pseudoscalar interaction allows to have larger values for the Hubble parameter H_0, reconciling the cosmological estimations with the local measurements [10].

3. Joint analyses

The Bayesian analysis mechanism allows to perform combined analyses of the cosmological and SBL data. In the past, usually the SBL constraints on m_s were considered as a prior in the cos-

[1] We use the approximation $m_s \simeq m_4 \simeq \sqrt{\Delta m^2_{41}}$, since the mixing angles ϑ_{i4} are small and $m_i \ll m_4$ (for $i = 1,2,3$).

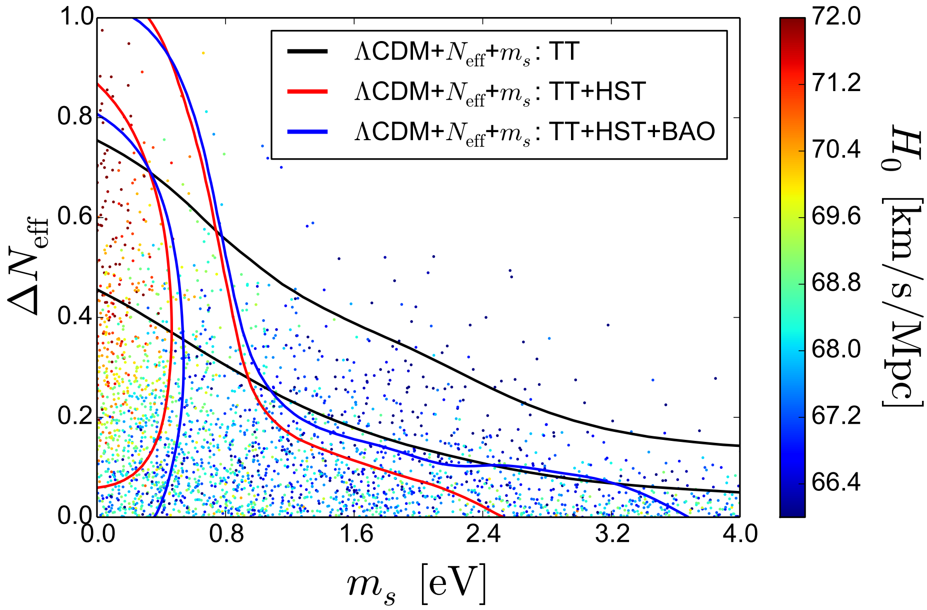

Figure 1: The cosmological constraints on the light sterile neutrino mass m_s and the contribution to the effective number $\Delta N_{\rm eff}$, obtained with different cosmological data combinations. The points are color coded by the corresponding value of the Hubble parameter H_0. From Ref. [7].

mological analysis. In Ref. [7], for the first time, the cosmological posterior probability distribution on m_s has been used as a prior in the SBL analysis.

The joint results in the $(\sin^2 2\vartheta_{e\mu},\, \Delta m^2_{41})$ plane are shown in Fig. 4. We can see that the SBL data are much stronger in constraining the sterile neutrino mass, and that the addition of the cosmological information only has an impact on the 3σ regions. When the cosmological data are included, indeed, these 3σ regions are modified by an enlargement of the $\Delta m^2_{41} \simeq 6\,\mathrm{eV}^2$ regions and by the appearance of new allowed regions at $\Delta m^2_{41} \simeq 8.5\,\mathrm{eV}^2$. These shifts agree with the recent results of IceCube and MINOS, which prefer a sterile neutrino heavier than 1 eV.

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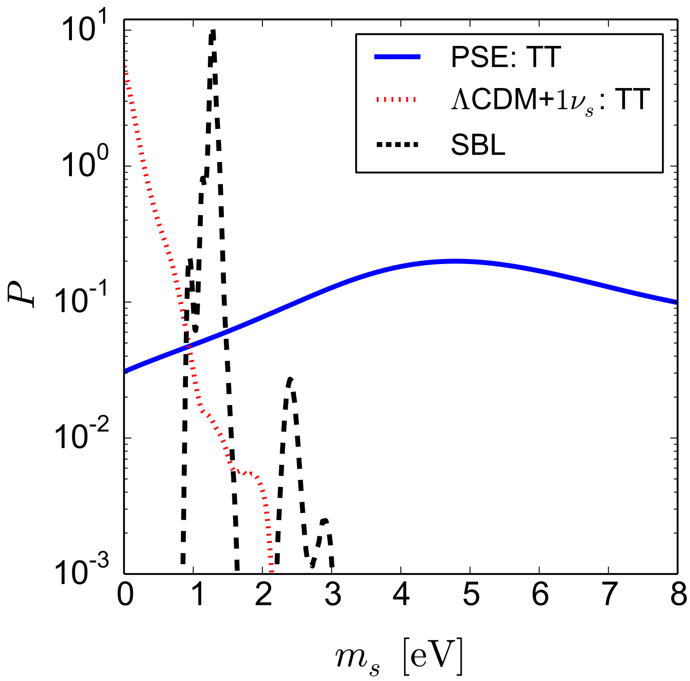

Figure 2: *Right panel*: the posterior distribution of the light sterile neutrino mass m_s as obtained from the SBL analyses (black dashed) is compared with the results obtained from cosmological analyses that use the standard light sterile neutrino parameterization with $\Delta N_{\rm eff} = 1$ (red dotted) or the pseudoscalar model (blue solid). From Ref. [7].

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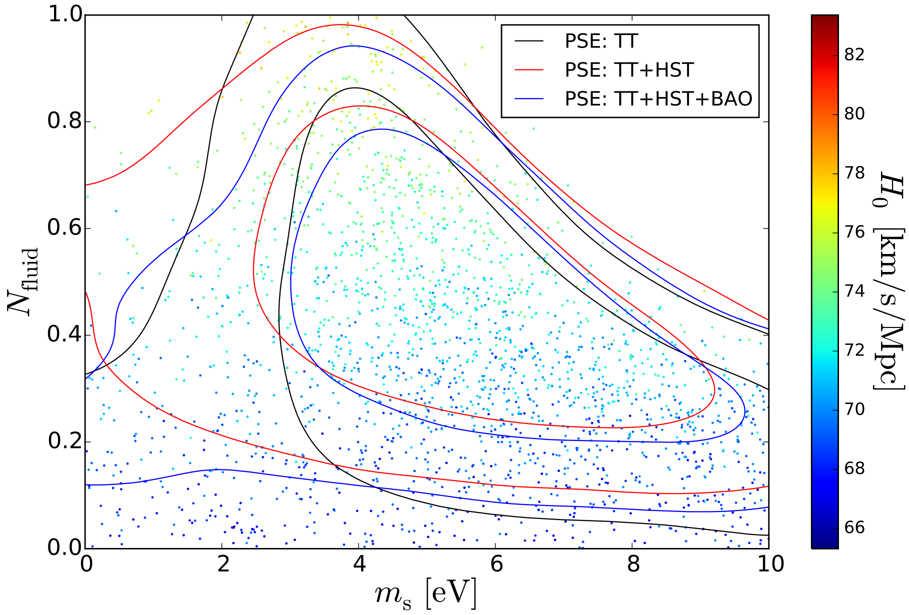

Figure 3: the same as in Fig. 1, but within the pseudoscalar model. From Ref. [7].

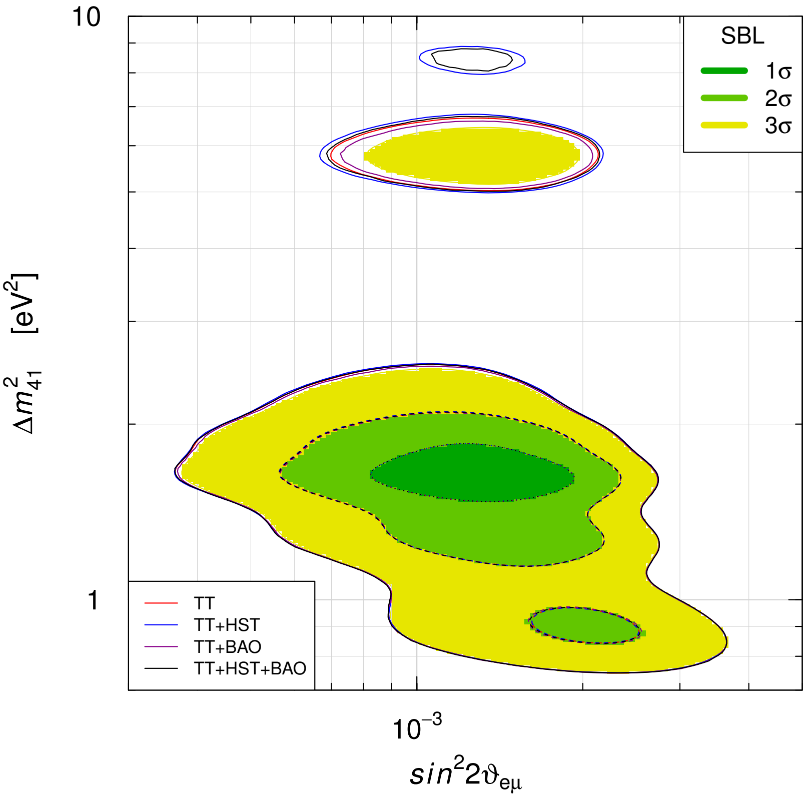

Figure 4: Results of the SBL analysis alone (filled regions) compared with the joint SBL + cosmological data analyses (colored contours), in the $(\sin^2 2\vartheta_{e\mu}, \Delta m^2_{41})$ plane. From Ref. [7].