PROCEEDINGS OF SCIENCE

Sterile neutrino mixing now and in the next 10+ years

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Short-baseline neutrino oscillation anomalies indicate that there may be a sterile neutrino at the eV scale. We briefly review the theory of neutrino oscillations in the framework of 3+1 mixing with one sterile neutrino and the status of the global fit of short-baseline neutrino oscillation data. We also briefly discuss the sensitivities of future experiments.

Neutrino Oscillation Workshop
4 - 11 September, 2016
Otranto (Lecce, Italy)

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PoS(NOW2016)031

In this review we consider the LSND [1, 2], Gallium [3–7] and reactor [8–10] short-baseline neutrino oscillation anomalies and we discuss their explanation in the framework of an effective 3+1 mixing scheme with one sterile neutrino at the eV scale (see Ref. [11]). In this framework, the interacting left-handed flavor neutrino fields ν_{eL}, $\nu_{\mu L}$, $\nu_{\tau L}$, are unitary linear combinations of four left-handed massive neutrino fields ν_{1L}, ν_{2L}, ν_{3L}, ν_{4L} with respective masses m_1, m_2, m_3, m_4:

$$\nu_{\alpha L} = \sum_{k=1}^{4} U_{\alpha k} \nu_{kL} \qquad (\alpha = e, \mu, \tau), \tag{1}$$

where U is the 4×4 unitary mixing matrix. The oscillation probabilities of the flavor neutrinos in short-baseline experiments are given by [12]

$$P^{(\mathrm{SBL})}_{\overset{(-)}{\nu}_\alpha \to \overset{(-)}{\nu}_\beta} \simeq \left| \delta_{\alpha\beta} - \sin^2 2\vartheta_{\alpha\beta} \sin^2\left(\frac{\Delta m^2_{41} L}{4E}\right) \right|, \quad \text{with} \quad \sin^2 2\vartheta_{\alpha\beta} = 4|U_{\alpha 4}|^2 \left| \delta_{\alpha\beta} - |U_{\beta 4}|^2 \right|, \tag{2}$$

and $\Delta m^2_{41} = m^2_4 - m^2_1$.

Figures 1(a), 2(a), and 3(a) show the allowed regions in the $\sin^2 2\vartheta_{e\mu}$–Δm^2_{41}, $\sin^2 2\vartheta_{ee}$–Δm^2_{41} and $\sin^2 2\vartheta_{\mu\mu}$–$\Delta m^2_{41}$ planes obtained in the pragmatic 3+1 global (PrGLO) fit of short-baseline neutrino oscillation data [11, 13, 14]. These regions are relevant, respectively, for $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ appearance, $\overset{(-)}{\nu}_e$ disappearance and $\overset{(-)}{\nu}_\mu$ disappearance searches. Figure 1(a) shows also the region allowed by $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ appearance data and the constraints from $\overset{(-)}{\nu}_e$ disappearance and $\overset{(-)}{\nu}_\mu$ disappearance data. The best-fit values of the oscillation parameters are $(\Delta m^2_{41})_{\mathrm{bf}} = 1.6\,\mathrm{eV}^2$, $(|U_{e4}|^2)_{\mathrm{bf}} = 0.027$, $(|U_{\mu 4}|^2)_{\mathrm{bf}} = 0.012$, which imply $(\sin^2 2\vartheta_{e\mu})_{\mathrm{bf}} = 0.0013$, $(\sin^2 2\vartheta_{ee})_{\mathrm{bf}} = 0.10$ and $(\sin^2 2\vartheta_{\mu\mu})_{\mathrm{bf}} = 0.050$.

Figure 3(a) shows a comparison of the allowed regions in the $\sin^2 2\vartheta_{\mu\mu}$–$\Delta m^2_{41}$ plane with the exclusion curves obtained recently by the IceCube [15] and MINOS [16] experiments. One can see that they disfavor the low-Δm^2_{41} and high-$\sin^2 2\vartheta_{\mu\mu}$ part of the allowed region. This is confirmed by the results presented in Ref. [17], where the 3+1 global fit of Ref. [18] was updated with the addition of the IceCube data.

Because of the scarcity of sensitive data, of the possible existence of unknown systematic errors, and of the appearance-disappearance tension (see Ref. [19]), the possible existence of light sterile neutrinos at the eV scale is controversial and needs new reliable experimental checks. Fortunately, there is an impressive program of new experiments which are planned to check the existence of eV sterile neutrinos (see the reviews in Refs. [11, 20–22]). Figures 1(b), 2(b), and 3(b) show a comparison of the sensitivities of future experiments with the corresponding allowed regions for, respectively, $\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$ transitions (SBN [23], nuPRISM [24], JSNS^2 [25]), $\overset{(-)}{\nu}_e$ disappearance (CeSOX [26], BEST [27], IsoDAR@KamLAND [28], IsoDAR@C-ADS [29], DANSS [30], NEOS [31], Neutrino-4 [32], PROSPECT [33], SoLid [34], STEREO [35], KATRIN [36]), and $\overset{(-)}{\nu}_\mu$ disappearance (SBN [23], KPipe [37]).

Let us finally emphasize that the discovery of the existence of sterile neutrinos would be a major discovery which would have a profound impact not only on neutrino physics, but on our whole view of fundamental physics, because sterile neutrinos are elementary particles beyond the Standard Model. The existence of light sterile neutrinos would prove that there is new physics

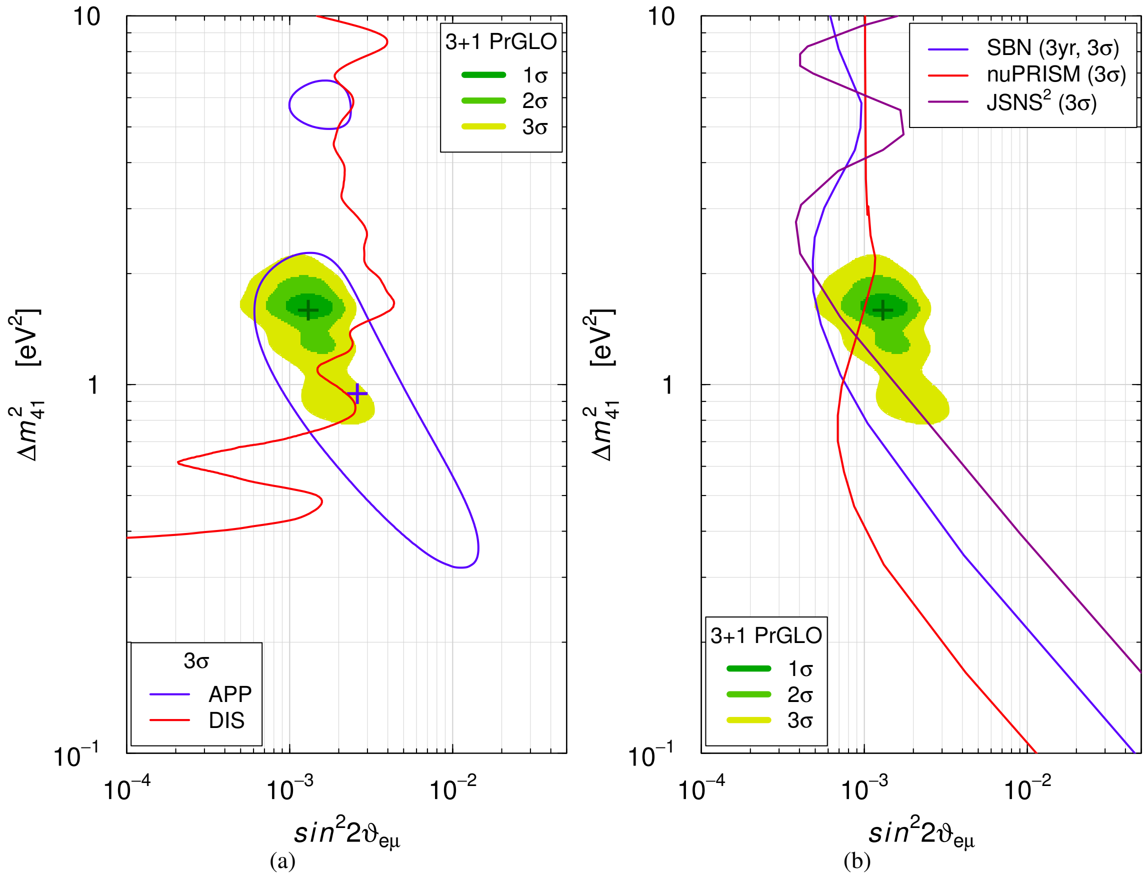

Figure 1: Allowed regions in the $\sin^2 2\vartheta_{e\mu}$–Δm^2_{41} plane obtained in the pragmatic 3+1 global (PrGLO) fit of short-baseline neutrino oscillation data [11, 13, 14]. (a): comparison with the 3σ allowed regions obtained from $\overset{(-)}{\nu}_{\mu} \to \overset{(-)}{\nu}_{e}$ short-baseline appearance data (APP) and the 3σ exclusion curve obtained from short-baseline disappearance data (DIS). (b): comparison with the sensitivities of future experiments. The best-fit points of the global (PrGLO) and APP fits are indicated by crosses.

beyond the Standard Model at low energies and their properties can give important information on this new physics.

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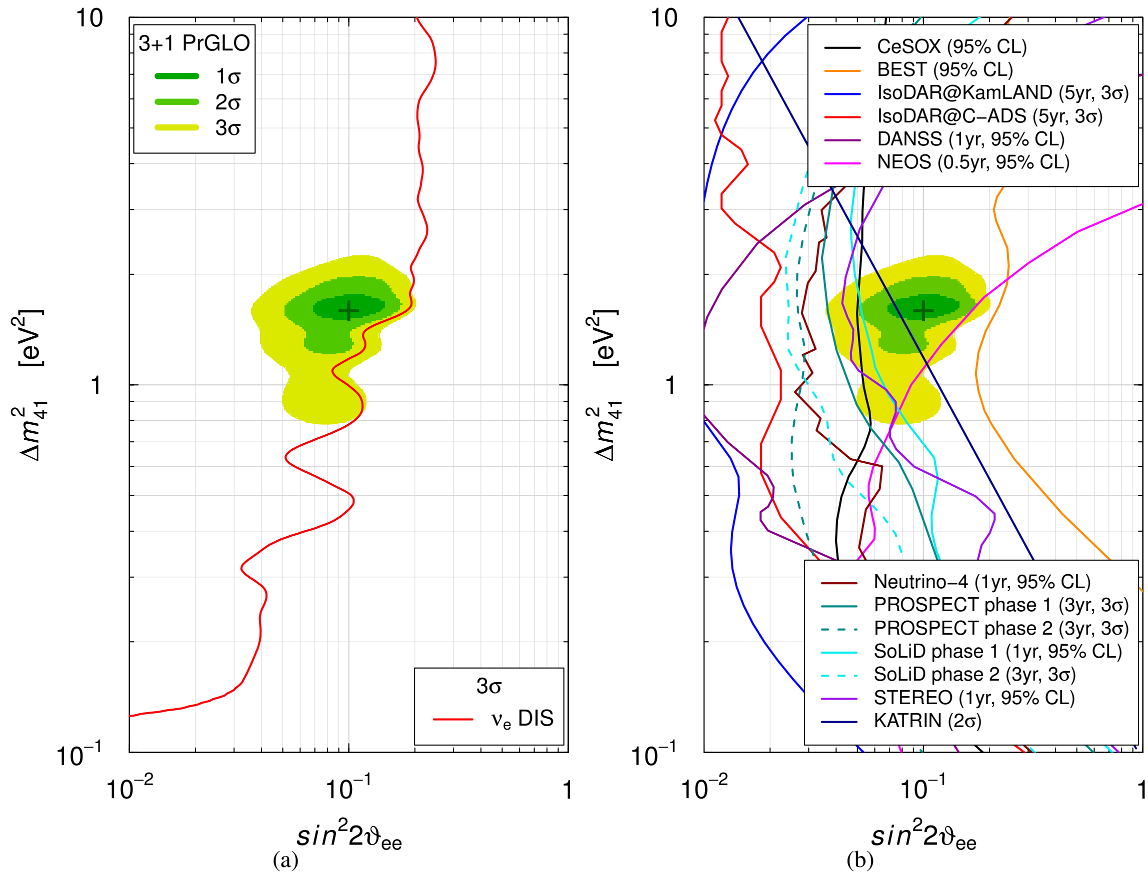

Figure 2: Allowed regions in the $\sin^2 2\vartheta_{ee}$–Δm^2_{41} plane obtained in the pragmatic 3+1 global (PrGLO) fit of short-baseline neutrino oscillation data [11, 13, 14]. (a): comparison with the 3σ exclusion curve obtained from $\overset{(-)}{\nu}_e$ short-baseline disappearance data (ν_e DIS), (b): comparison with the sensitivities of future experiments. The best-fit point of the global (PrGLO) fit is indicated by a cross.

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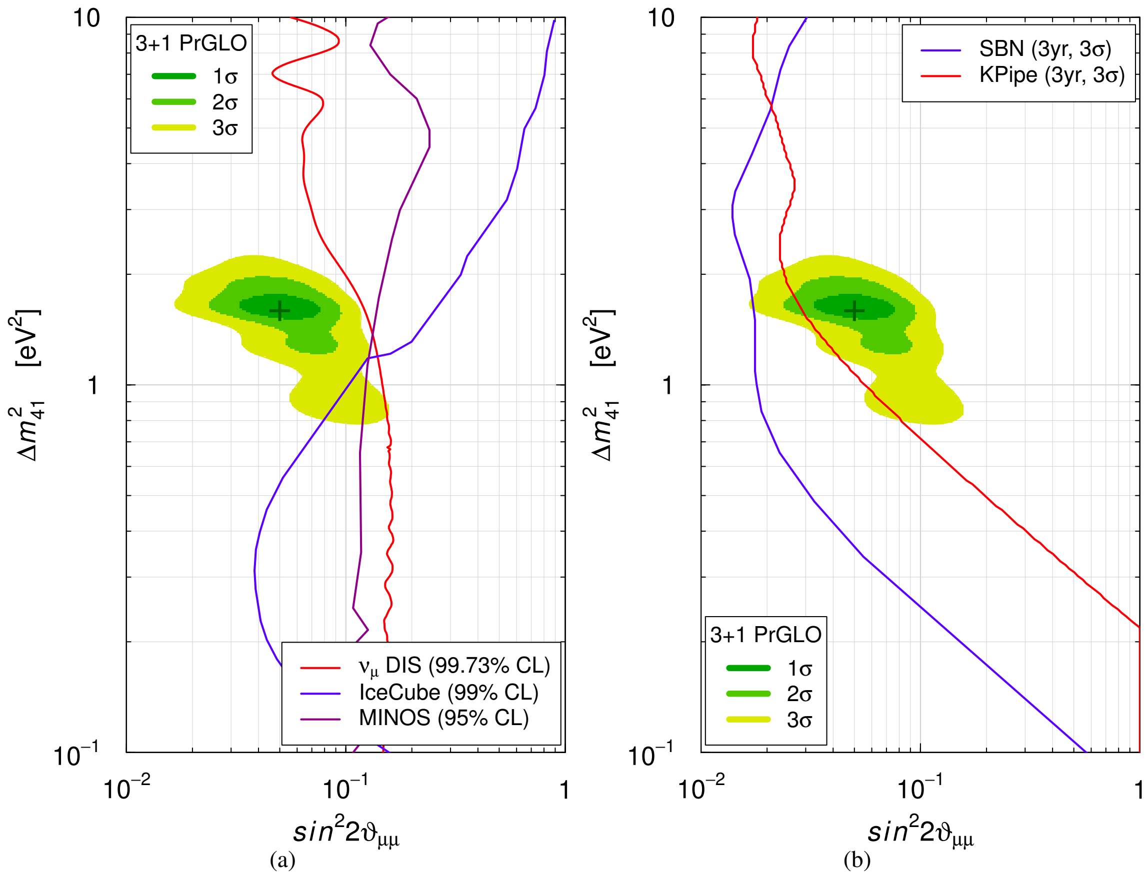

Figure 3: Allowed regions in the $\sin^2 2\vartheta_{\mu\mu}$–$\Delta m^2_{41}$ plane obtained in the pragmatic 3+1 global (PrGLO) fit of short-baseline neutrino oscillation data [11, 13, 14]. (a): comparison with the 3σ exclusion curve obtained from $\overset{(-)}{\nu}_\mu$ short-baseline disappearance data (ν_μ DIS), (b): comparison with the sensitivities of future experiments. The best-fit point of the global (PrGLO) fit is indicated by a cross.

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