Pablo Martínez-Miravé
(IFIC, CISC - UV)
with Abhish Dev (Maryland U.) and
Pedro Machado (Fermilab)

Signatures of ULTRALIGHT SCALARS in neutrino oscillation experiments

An **ultralight scalar field**, due to its large occupational number, can be approximated as

$$\phi(x,t) \simeq \frac{\sqrt{2\rho_{DM}}}{m_\phi}\sin(m_\phi(t-\vec{v}\cdot\vec{x}))$$

If it coupled to SM fields, it would induce a **time dependence of the masses and couplings**.

The existance of such a ligh scalar, with a mass of order 10^{-22} eV, could provide a solution to some small scale cosmological puzzles (acting as fuzzy dark matter).

In particular, if it was effectively coupled to **neutrinos**,

$$\mathcal{L}_{eff} = -m_\phi\left(1+y\frac{\phi}{\Lambda}\right)\overline{\nu}\nu + h.c.$$

then the **mass splittings** (and depending on the flavour structure of the coupling) the **mixing angles**, would acquire a time dependence [1,2,3]:

$$\Delta m^2_{ij}(t) = m^2_i(t) - m^2_j(t) \simeq \Delta m^2_{ij}(1+2\eta\sin(m_\phi t))$$

$$\theta_{ij}(t) \simeq \theta_{ij} + \eta\sin(m_\phi t)$$

The **mass of the ultralight dark matter** candidate is related to the **period of the modulation induced.**

$$\tau_\phi \equiv \frac{2\pi\hbar}{m_\phi} = 0.41\left(\frac{10^{-14}eV}{m_\phi}\right)$$

$$m_\phi \sim 10^{-13}\ \text{eV} \quad \longrightarrow \quad \tau_\phi \sim 10\ \text{ms}$$

$$m_\phi \sim 10^{-23}\ \text{eV} \quad \longrightarrow \quad \tau_\phi \sim 10\ \text{years}$$

If the **modulation period** is
- smaller than the running time of the experiment
- larger than the inverse of the event rate

one could observe a **MODULATION OF THE SIGNAL WITH TIME.** Searches can be performed using the **Lomb-Scargle Periodogram**.

If the modulation is faster, it gets averaged in a non trivial way, leading to a **DISTORTED NEUTRINO OSCILLATIONS [2]**.

The distortion is similar (but not equal) to the smearing expected from the **finite energy resolution** of the detector.

See FIG. 1 for an example in DUNE from [4]

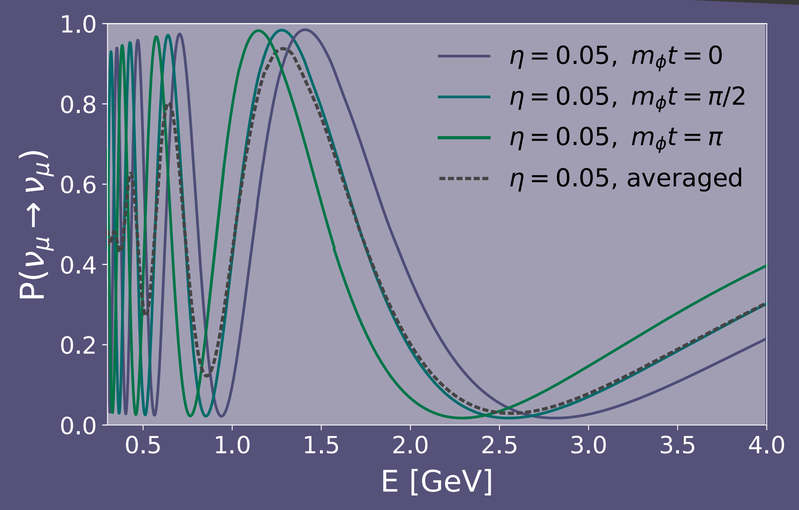

FIG 1. Disappearance probability in DUNE for a modulating mass splitting Δm_{31}^2. It shows how a fast modulation would distort the probability.

As the modulation period approaches the neutrino time of flight, the modulation manifests as if neutrinos were travelling through a very fast varying matter potential. Eventually, this scenario can not be distinguish from standard oscillations .

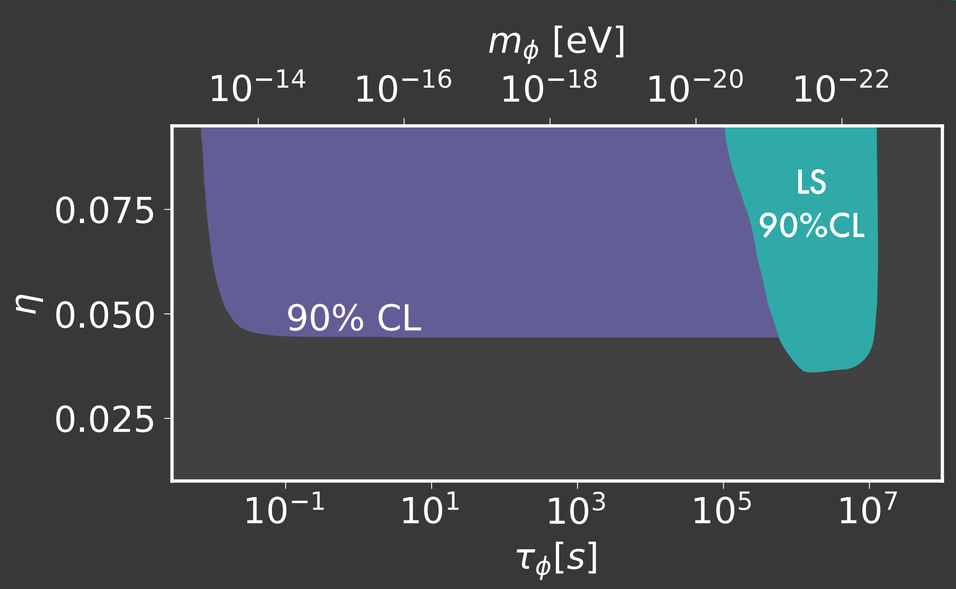

FIG 2. Sensitivity of DUNE to ultralight scalars via the modulation of the mass splitting Δm_{31}^2.

CONCLUSIONS

Combining the Lomb Scargle approach with searches for Distorted Neutrino Oscillations experiments like DUNE could probe almost 10 orders of magnitude in the mass of the scalar and a wide range of amplitudes.

REFERENCES:
[1]A. Berlin; Phys. Rev. Lett. 117, 231801 (2016).
[2] G. Krnjaic, P.A. N. Machado, L. Necib; Phys. Rev. D 97, 075017 (2018).
[3] V. Brdar, J. Kopp, J. Liu, P. Prass, X.-P. Wang ;(Phys. Rev. D 97, 043001 (2018).
[4]A. Dev, P.A. N. Machado, P. Martínez-Miravé : JHEP 01 (2021) 094.