Large extra dimensions and reactor antineutrino anomaly

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Abstract. We present an alternative explanation to the reactor antineutrino anomaly through neutrino oscillation induced by the presence of a large flat extra dimension with a size in the sub-micrometer range. We also show that the solution is consistent with the other existing oscillation data.

1. Introduction

Currently, almost all the neutrino data can be perfectly explained by the standard three flavors neutrino mixing scenario. However, there are some data which indicate the presence of extra neutrino species beyond the standard three flavors. First, results from the LSND [1] and the MiniBOONE [2] experiments favor the presence of at least one species of SU(2) singlet neutrino, the so called sterile neutrino, which must be separated, in terms of mass squared difference, by \(\sim (0.1 - 1)\) eV\(^2\) from the standard active ones. Second, although not so significant, the Ga solar neutrino calibration experiments performed by the GALLEX [3] and the SAGE [4] collaborations also hinted at \(\nu_e\) to sterile oscillation driven by a mass squared difference compatible with the LSND/MiniBOONE anomaly [5]. In addition to these indications, some cosmological data favor an extra relativistic degree of freedom, beyond the standard model expectation of 3.046, which could also be interpreted as due to the presence of a sterile neutrino [6].

More recently, a re-evaluation of the reactor \(\bar{\nu}_e\) flux [7, 8] resulted in an increase of the flux of 3.5\%, which induced an average deficit of 5.7\% in the observed event rates for short baseline (< 100 m) reactor neutrino experiments, leading to the 98.6\% CL deviation from unity, which has been referred to as the reactor antineutrino anomaly [9]. This could also be explained by oscillation between \(\bar{\nu}_e\) and one or more species of sterile neutrinos [9, 10].

In this short contribution, based on our works [11, 12], we show that two of these anomalies seen in the disappearance channels can be explained by neutrino oscillation induced by the presence of large extra dimensions (LED) [13].
2. LED and Ga and Reactor Antineutrino Anomalies

In Fig. 1 we show the $\nu_e$ and $\bar{\nu}_e$ survival probabilities in the presence of LED as a function of the baseline distance together with the data from the GALLEX and the SAGE experiments as well as 19 short baseline ($<\,100$ m) reactor experiments. The relevant parameters in our analysis are the size of the largest extra dimension $a$ (we assume that only the largest LED make contribution to modify the probability) and the lightest neutrino mass, $m_0$. Due to the lack of space, we ask the readers to look at [12, 13] to understand how the oscillation probability can be computed.

Using the probabilities calculated as shown in Fig. 1, we quantified how well LED can explain the anomalies through a $\chi^2$ analysis of the reactor data and a Bayesian analysis of the Ga anomalies. In Fig. 2 we show in the $m_0 - a$ plane, the regions of LED parameters favored by GALLEX and SAGE (left panels), by 19 reactor neutrino data (middle panels) and by the combination of these data set (right panels). We have performed our analysis for normal (inverted) mass hierarchy as shown in the upper (lower) panels of Fig. 2.

Let us comment on the compatibility of these results with other data. In the left panel of Fig. 3 we show the excluded parameter regions by the data coming from CHOOZ, KamLAND and MINOS obtained in [12]. We conclude that most of the allowed regions in Fig. 2 are not excluded by this. In the right panel of Fig. 3, for the case where $\delta = 2$ ($\delta$ being the number of LED which has the same largest size), we show the range of LED parameters which are excluded by other considerations/data [14, 15, 16]. We observe that constraints from neutron stars [15] exclude our solution (however, these bounds are model dependent). Recent bounds from a test of Newton’s Law [16] exclude some regions of the LED parameters.

Finally, let us comment about some future prospects. In Fig. 4 we show survival probabilities for the energy range relevant to the MINOS+ project [17] (left panel) and the regions which can be excluded by the future MINOS+ data (right panel), for different values of POT. We see that the most favored region could be probed by the MINOS+ experiment. Despite that, a large parameter region would still remain allowed.
GALLEX and SAGE Reactors with $L < 100$ m Combined

Normal hierarchy
$m_0 = 0$ eV

Inverted hierarchy
$m_0 = 0.2$ eV

Figure 2. Regions of $m_0$ and $a$ allowed at 1, 2 and 3 $\sigma$ CL (indicated by blue, green, and red shaded regions, respectively) by the Ga source calibration experiments (left panels), by short baseline reactor data (middle panels) and by the combined case of these two data sets (right panels). The upper (lower) panel correspond to the normal (inverted) hierarchy.

Figure 3. The left panel shows the excluded parameter regions by the current data from CHOOZ, KamLAND and MINOS. The right panel shows the parameter range of $a$ and $M_D$ (fundamental scale of gravity, see [14] for its definition) which are excluded by other data for the case where $\delta = 2$ [14, 15, 16].

3. Conclusions
We presented an alternative explanation to the Ga neutrino and reactor antineutrino anomaly by neutrino oscillation induced by the presence of a sub-micrometer size flat extra dimension. See [11, 12] for more details.

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Figure 4. The left panel shows the $\nu_\mu$ survival probability for $a = 0.5$ $\mu$m and $m_0 = 0$ as a function of the neutrino energy for the MINOS experiment baseline (735 km). The right panel shows the parameter regions which can be excluded (to the right of the colored curves) by the future MINOS+ project data [17].

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