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Spectral predictions for KamLAND solar mode

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Abstract
KamLAND plans to detect and analyse solar active neutrinos in the low-energy sector. We have performed spectral predictions for the ^{7}Be neutrino signal in KamLAND assuming pure large mixing angle (LMA) oscillations and a subdominant resonant spin flavor precision (RSFP) effect. Our results can be tested in the near future in the light of a wealth of data expected from the experiment.

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(Some figures in this article are in colour only in the electronic version.)

KamLAND is now preparing for the direct measurement of solar neutrinos. In this direction, it is aiming at the physics of low-energy solar neutrinos, in particular the ^{7}Be line, by lowering its threshold and eliminating the troubling background in the relevant energy range.

In this work, we perform predictions for the visible electron spectrum to be seen in KamLAND due to the ^{7}Be neutrino line. The present statistics of solar neutrino experiments are not enough to strictly rule out any sub-leading mechanism. Taking into account the claims of time modulation by the Stanford group [1] and an apparent hint of time variation noted in Ga rates [2], we assume that such effects are due to varying solar fields.

We perform the spectral predictions by using our model [3] in which a subdominant conversion, $\nu_e \rightarrow \nu_s$ is mediated by the interaction of neutrino magnetic moment with the solar magnetic field. Solar field varying with 11 year suspot cycle will affect the ^{7}Be neutrino flux and the spectrum, if neutrinos are endowed with large magnetic moments.

The biggest problem for the detection of solar neutrinos via elastic scattering (ES) in KamLAND is the colossal background. It has been shown that the specifications on the intrinsic concentrations of ^{238}U, ^{232}Th in the liquid scintillator can be met [4]. So, after statistical subtraction of ^{238}U, ^{232}Th backgrounds and purification after removing substantially ^{40}K, ^{85}Kr and ^{39}Ar and ^{210}Pb radio impurities there is a visible region for the ^{7}Be electron kinetic energy spectrum (280–750 keV) boundary-walled by ^{11}C and the huge amount of ^{14}C backgrounds.

The monochromatic ^{7}Be ν energy line (862 keV) can be observed as a Compton-like edge for ES around 665 keV. Due to the detector's finite resolution, the ^{7}Be ν energy line will be seen as a continuous spectrum: smeared around 665 keV. We expect to see a few hundred events per day.

The visible electron kinetic spectrum is calculated as

$$\int_0^{T_M'} \mathrm{d}T'\; f(T',T)\phi(E)\left[P_1(E)\frac{\mathrm{d}\sigma_W}{\mathrm{d}T'} + P_2(E)\frac{\mathrm{d}\sigma_{W'}}{\mathrm{d}T'}\right].$$

We simulated the background assuming a targeted purification of KamLAND, and the error estimates pertaining to 3 years of data acquisition. Preventing the external γ backgrounds from outside the liquid scintillator balloon, we take fiducial volume ($R < 4$ m) leading to 7.2×10^{31} target electrons. In order to avoid the troubling ^{210}Pb background below 400 keV, we study the ^{7}Be ν spectrum above 400 keV. We neglect the effect of time variations on the background due to (smaller flux weighted) *pep*, ^{15}O and ^{13}N neutrinos coming from the sun.

We chose a solar field profile peaked near the bottom of the convective zone, as preferred by the solar data fits [5] and suggested by the observations [6]. The new mass squared difference ($\Delta m^2_{10} = -1.3 \times 10^{-8}\,\mathrm{eV}^2$) is taken such that ^{7}Be neutrinos resonate at the peak of the solar field [7]. We fix the neutrino magnetic moment $\mu_\nu = 10^{-12}\mu B$ and vary the solar peak field ($\bar{B}_o$) in the range 10–300 kG.

Since ^{7}Be neutrinos consist of a single energy line, once the unknown mass squared difference Δm^2_{10} is fixed, all the

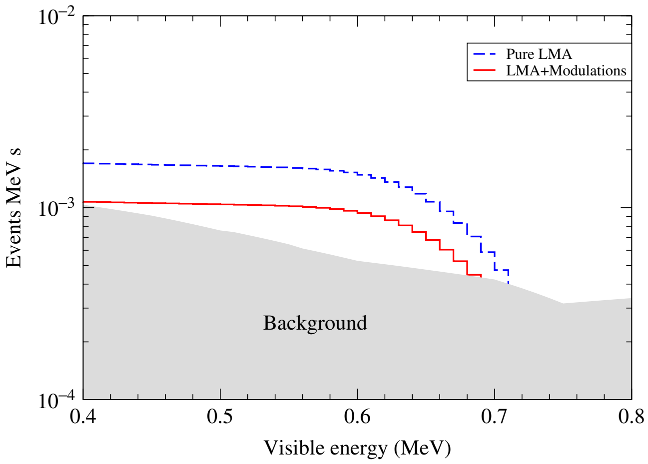

Figure 1. KamLAND visible electron spectra and background.

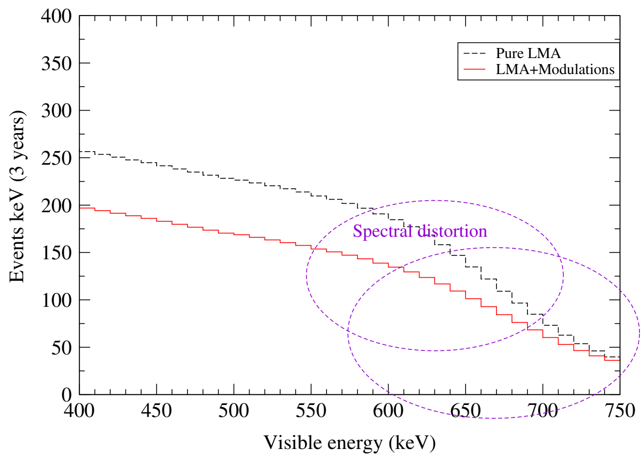

Figure 2. ^{7}Be ν spectral distortion in KamLAND.

neutrinos resonate exactly at the same position and experience the same field value. As a result, these neutrinos are blind to the shape of the solar field profile, and in this way the analysis is free from the uncertainties arising due to the infinite possibilities of field profile shape [7].

In figure 1, it is seen that at the sunspot maximum (LMA + modulations, lower curve), the KamLAND visible electron spectral shape is dominated by that of background, and it is hard to make out the background-independent ^{7}Be ν spectrum. However, at sunspot minimum (pure LMA, upper curve), the visible spectrum shape will be close to that of the ^{7}Be ν spectrum. Once the background is significantly reduced, the dominance of the ^{7}Be ν spectrum shape in the peak modulation period could be retrieved.

In figure 2, we see that a spectral distortion, as compared to pure LMA, is clearly visible in the energy range >600 keV.

A final comment: the predictions for spectral shape and distortion (figures 1 and 2) are general and can be applied for any other type of modulation effect. This is so because the ^{7}Be neutrinos come in a single energy line (862 KeV) such that all of them experience exactly the same suppression effect, so the effect is independent of the suppression source. In other words, all such effects which can cause suppression in the ^{7}Be neutrino line will show up in KamLAND in a similar way, but with different periodicities. To summarize, the conclusions drawn in this work are the same for any other type of time-dependent suppression due to neutrino production rate, earth matter effects, or axial asymmetry of the solar field, etc.

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