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Astroparticle Physics 23 (2005) 543–556

Astroparticle Physics

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Evidence for solar neutrino flux variability and its implications

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Received 23 September 2004; received in revised form 28 April 2005; accepted 4 May 2005
Available online 15 June 2005

Abstract

Although KamLAND apparently rules out resonant-spin-flavor-precession (RSFP) as an explanation of the solar neutrino deficit, the solar neutrino fluxes in the Cl and Ga experiments appear to vary with solar rotation. Added to this evidence, summarized here, a power spectrum analysis of the Super-Kamiokande data reveals significant variation in the flux matching a dominant rotation rate observed in the solar magnetic field in the same time period. Three frequency peaks, all related to this rotation rate, can be explained quantitatively. A Super-Kamiokande paper reported no time variation of the flux, but showed the same peaks, there interpreted as statistically insignificant, due to an inappropriate analysis. This modulation is small (7%) in the Super-Kamiokande energy region (and below the sensitivity of the Super-Kamiokande analysis) and is consistent with RSFP as a subdominant neutrino process in the convection zone. The data display effects that correspond to solar-cycle changes in the magnetic field, typical of the convection zone. This subdominant process requires new physics: a large neutrino transition magnetic moment and a light sterile neutrino, since an effect of this amplitude occurring in the convection zone cannot be achieved with the three known neutrinos. It does, however, resolve current problems in providing fits to all experimental estimates of the mean neutrino flux, and is compatible with the extensive evidence for solar neutrino flux variability.

PACS: 26.65.+t; 14.60.Pq; 14.60.St

Keywords: Solar neutrinos; Sterile neutrinos; Resonant-spin-flavor-precession; Flux variability

1. Introduction

Results from the KamLAND experiment [1] seem to confirm the large-mixing angle (LMA) solution to the solar neutrino deficit and rule out the resonant-spin-flavor-precession (RSFP)

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doi:10.1016/j.astropartphys.2005.05.001

explanation [2]. On the other hand, there is increasing evidence [3–10] that the solar neutrino flux is not constant as assumed for the LMA solution, but varies with periods that can be attributed to well-known solar processes. This suggests that the solar neutrino situation may be more complex than is usually assumed, and that RSFP may be subdominant to LMA [11,12], requiring a large transition magnetic moment and hence new physics. Since, this recent information on solar neutrino variability is not widely known, a brief summary is presented here of analyses of radiochemical neutrino data, along with newer input from the Super-Kamiokande experiment [13]. Although the 10-day averages of Super-Kamiokande solar neutrino data [14] show no obvious time dependence, power-spectrum analyses [15–17] displayed a strong peak at the frequency $26.57 \pm 0.05\ \mathrm{yr}^{-1}$ (period 13.75 days), as well as one at $9.42\ \mathrm{yr}^{-1}$. These were clearly an alias pair, due to the extremely regular 10-day binning for which the timing had a strong periodicity with frequency $35.99\ \mathrm{yr}^{-1}$ (= 26.57 + 9.42). A subsequent Super-Kamiokande paper [18] provided 5-day averages of the data, and there was no longer evidence for the $26.57\ \mathrm{yr}^{-1}$ peak, showing it to be an alias of the $9.42\ \mathrm{yr}^{-1}$ peak (which will be explained later) due to the extremely regular 10-day binning. In the 5-day data the $9.42\ \mathrm{yr}^{-1}$ is enhanced. We also find a peak at $39.28\ \mathrm{yr}^{-1}$, which is the frequency of a dominant rotation-related oscillation in the photospheric magnetic field. Another notable peak at $43.72\ \mathrm{yr}^{-1}$ may be attributed to the same physical process as that responsible for the peak at $9.42\ \mathrm{yr}^{-1}$.

A suggested subdominant process that is compatible with these periodicities involves an RSFP transition in which the solar ν_e changes to a different flavor, and the spin is flipped. As in the MSW process [19], this can occur resonantly at an appropriate solar density. The two processes, LMA MSW and RSFP, would take place sequentially at different solar radii. If the RSFP process were to be achieved with the three known active neutrinos, their measured mass differences would require that RSFP occurs at a smaller solar radius than that at which the MSW effect takes place, placing it in the solar core. This case has been analyzed [12], with the result that the flux modulation produced by RSFP is very small, varying with neutrino energy from 0.8% at 2.5 MeV to 4% at 13 MeV for a product of field and magnetic moment of $10^{-6}\ \mathrm{G}\mu_\mathrm{B}$.

Another model was suggested in an earlier version of this paper, and predictions from it have been calculated [11]. This model utilizes a sterile neutrino that couples to the electron neutrino only through a transition magnetic moment. The lack of mixing with active neutrinos avoids all known limitations on sterile neutrinos, and the sterile final-state also makes irrelevant the usual constraints on RSFP from the null observations of solar antineutrinos. The solar data require a mass-squared difference between the electron and sterile neutrinos of $\Delta m^2 \sim 10^{-8}\ \mathrm{eV}^2$. This is different from the mechanism and the sterile state suggested by de Holanda and Smirnov [20] for a subdominant transition to improve agreement with the Homestake data [21] and the Super-Kamiokande energy dependence [13], but again a decided improvement in the fit to the solar neutrino data is obtained [11]. This improvement, and also the reason RSFP by itself actually provides a better fit to mean solar data than does LMA [22,23], results from the shape of the RSFP neutrino survival probability. It has a resonance pit at a density that suppresses the 0.86 MeV ^{7}Be line (as does the Small-Mixing Angle [SMA] solution), but tends toward 1/2 and hence fits the Super-Kamiokande spectrum, whereas the survival probability goes to unity in the SMA case. The high-energy rise includes the neutral current scattering of the products of the spin-flavor flips, which need to be active, and hence Majorana neutrinos are required in order to fit [23] the SNO data [24] for RSFP by itself. In the case of subdominant RSFP, the high-energy behavior is determined mainly by the MSW transition, since the observed flux modulation is found to be small (∼7%) in the ^{8}B neutrino region. Going down to intermediate energies, the dip toward the resonance pit reduces the predicted rate for the Homestake experiment [21], improving agreement with the data, and eliminates the rise below ∼8 MeV which is predicted by the LMA solution but not observed by Super-Kamiokande [13] or SNO [24]. The electron–neu-