A study of short-time periodic variation of the ^{8}B solar neutrino flux at Super-Kamiokande

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Abstract

Super-Kamiokande(SK) is a real-time detector capable of measuring the exact time of solar neutrino events. This, combined with a relatively high yield of these events of roughly 15 per day, allows a search for short-time variations in the observed flux. Using all 1496 days of SK-I's solar data, we looked for periodic variations of the observed solar neutrino flux, and found no significant periodicity. The Lomb test was used to find possible periodicities in the measured fluxes of 10 day long samples.

1. Introduction

It is widely accepted that neutrinos have masses based on observation of their oscillation [1] which suggests the presence of physics beyond the Standard Model. Neutrino magnetic spin-flavor precession would result in a reduction of the observed solar neutrino fluxes under the toroidal magnetic field in a convective zone of the Sun [2]. The time variation of the solar magnetic fields could introduce periodic modulations in the observed solar neutrino fluxes.

Super-Kamiokande (SK) is a water Cherenkov detector in Kamioka, Japan. Solar neutrino data were collected at SK from May 31st, 1996 to July 15th, 2001 yielding a total detector live time of 1,496 days. This data taking period is known as SK-I. The solar neutrino signal is extracted from the data using the $\cos\theta_{sun}$ distribution, the angular deviation between the Sun and the reconstructed direction of events with total energies ranging between 5 and 20 MeV [6]. From the strong forward peak due to elastic scattering of ^{8}B solar neutrinos with electrons, $22,400 \pm 200$(stat.) solar neutrino interactions were observed in 22.5 ktons of fiducial volume. The relatively high yield of real-time events in SK, 15 events per day, allows a search for short-time periodic modulations in the observed neutrino fluxes.

pp. 1243–1246

2. SK 10-day long sampled solar neutrino data

The solar neutrino data, selected over 1,871 elapsed days from the beginning of data-taking, are divided into roughly 10-day long samples. The time period of each 10-day sample is chosen from consecutive 10-day periods from May 31st. There are on and off periods of data-taking in the 10-day interval and thus the timing of each sample is calculated as a mean of the start and end times and corrected by SK livetime. Fig. 1. shows the measured solar neutrino fluxes of the 10-day samples. All given uncertainties are statistical and estimated by asymmetric Gaussian approximation of the unbinned maximum likelihood fit to the $\cos\theta_{sun}$ distributions. The $1/R^2$ (squared average distance in unit of A.U.) variation caused by the eccentricity of the Earth's orbit around the Sun is corrected for the measured solar neutrino fluxes.

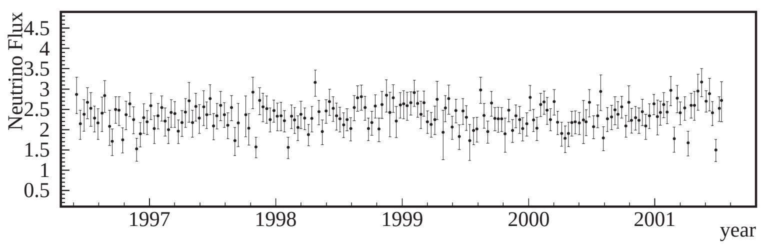

Fig. 1. Measured solar neutrino fluxes of 10-day long samples. The horizontal axis is time (year) from the beginning of the data-taking and the vertical axis is the measured neutrino flux in unit of 10^6 cm^{-2} s^{-1}. The 1/R^2 correction is included in the shown neutrino fluxes.

3. Search for Periodicity

The Lomb periodogram method, a spectral analysis for unevenly sampled data, is applied to search for possible periodicities in the measured 10-day long fluxes. The method finds periodicities based on maximum deviation of data relative to a constant in time. A detailed description of the method can be found in ref.[7]. The normalized Lomb power is given by

$$P_N(w) \equiv \frac{1}{2\sigma^2}\left\{\frac{[\sum_j(\phi_j-\bar{\phi})\cos\omega(t_j-\tau)]^2}{\sum_j\cos^2\omega(t_j-\tau)}+\frac{[\sum_j(\phi_j-\bar{\phi})\sin\omega(t_j-\tau)]^2}{\sum_j\sin^2\omega(t_j-\tau)}\right\} \quad (1)$$

where ϕ_j is the measured flux in j-th bin, t_j is the mean time with livetime correction in j-th bin, ω is the frequency in test, $\bar{\phi} \equiv \sum_{i=1}^{N}\phi_i/N$, $\sigma^2 \equiv \sum_{i=1}^{N}(\phi_i-\bar{\phi})^2/(N-1)$, and offset time τ is defined by $\tan(2\omega\tau) = \sum_j \sin 2\omega t_j/\sum_j \cos 2\omega t_j$. The resulting periodogram is shown in Fig. 2. (left figure) together with its

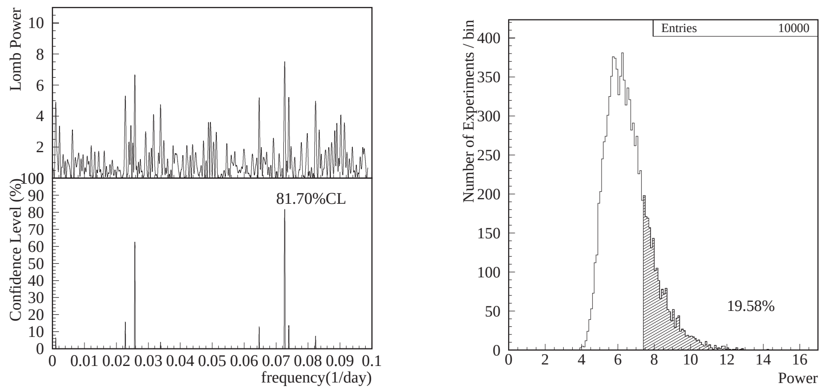

Fig. 2. The left figure shows a Lomb periodogram of the SK 10-day long solar neutrino data samples. The Lomb power and its corresponding confidence level are given as a function of frequency. The right figure shows distribution of maximum powers for 10,000 MC experiment sets. The horizontal axis is Lomb power, and the vertical axis is the number of MC experiment sets.

confidence level diagram. The maximum power appears at frequency f=0.0726 day^{-1} (or time period T=13.76 days) with Lomb power 7.51 corresponding to 81.70% C.L.

As a consistency check for the confidence level, 10,000 MC experiments are generated based on the observed timing information and the measured solar neutrino fluxes of the 10-day long data samples. The measured solar neutrino flux values are simulated according to a random Gaussian fluctuation. For making these null modulation samples the average of the measured fluxes (2.33×10^6 cm^{-2} s^{-1}) is taken as a Gaussian mean, and the standard deviation of the the measured flux (0.32×10^6 cm^{-2} s^{-1}) is taken as a Gaussian error [8]. The Lomb method is applied to each MC experiment to obtain a periodogram and the maximum power is selected. Fig. 2. also shows a distribution of maximum powers for the MC experiment sets. Out of 10,000 simulated experiments, 19.58% have maximum powers larger than 7.51. This demonstrates that the confidence level for the T=13.76 day period of SK data is consistent with that of no modulation.

4. Sensitivity of Finding a Periodicity vs. Modulation Amplitude

We have studied the sensitivity of the SK-I solar neutrino data to find if a true periodicity indeed exists. The sensitivity may depend on the magnitude of modulation because of experimental uncertainties in the SK-I data. We consider 13.76 days as a single modulation period for a MC study. One thousand MC experiment sets are generated to simulate the SK 10-day long solar neutrino fluxes for a given modulation amplitude. While varying the magnitude of modulation from 1% to 50% of the averaged total flux (2.33×10^6 cm^{-2} s^{-1}), we repeatedly generate 1,000 MC experiments at each amplitude. An individual MC experiment set is generated in the following way. Each 10-day timing is given by the observed mean-time, and its neutrino flux is generated by a random Gaussian fluctuation from the average of the single-modulation flux values over the SK livetime in the 10-day period. The Gaussian error is taken by the error in the measured neutrino flux of a 10-day sample. The Lomb periodogram method is applied to every set of MC experiment. We calculate the probability of finding a 13.76 day periodicity as a primary modulation at each amplitude. The primary modulation is selected to have the maximum Lomb power larger than 10.51 (99% C.L.). Based on the MC study, the Lomb method is expected to find the true periodicity of the SK-I data, if any, with an efficiency of 98% at modulation amplitude 35% of the averaged flux in case of 10-day long sample.

5. Summary

We have presented the measured solar neutrino fluxes of 10-day long samples using all 1,496 days of SK-I data. No significant periodicity is found from the SK-I solar neutrino data when a search was made to look for periodic modulations of the observed fluxes using the Lomb method. Based on a MC study, we have obtained the probability of finding a true periodicity in the SK-I data as a function of the modulation magnitude. The Lomb method should have found a periodic modulation in the SK-I solar neutrino data of 10-day long samples if the modulation magnitude were larger than 35% of the average of measured neutrino fluxes.

6. References

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