Solar Neutrino Day-Night Effect

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We summarize the results of Ref. [1] in which we determine the effects of three flavor mixing on the day-night asymmetry in the flux of solar neutrinos. Analytic methods are used to determine the difference in the day and night solar electron neutrino survival probabilities and numerical methods are used to determine the effect of three flavor mixing at detectors.

Due to matter effects in neutrino oscillations, the passage of solar neutrinos through the Earth can affect the electron neutrino survival probability P_{ee} . The resulting asymmetry

$$A_{n-d} = 2 \frac{N - D}{N + D}, \quad (1)$$

of the flux of solar electron neutrinos at some detector, where N and D are the night and day rates, respectively, is known as the day-night asymmetry.

In a scenario with two neutrino flavors, the difference P_{n-d} between the night and day-time survival probabilities is given by

$$P_{n-d} = -D_{2\nu} \frac{KV_E}{4a^2} \sin^2(2\theta) \sin^2(aL), \quad (2)$$

where

$$D_{2\nu} = \int_0^{R_\odot} dr f(r) \cos(2\hat{\theta}(r)), \quad (3)$$

$$a = \frac{1}{2} \sqrt{V_E^2 - 2KV_E \cos(2\theta) + K^2}, \quad (4)$$

$K = \Delta m^2/(2E)$, $\hat{\theta}$ is the mixing angle in matter, $f(r)$ the normalized spatial distribution function of neutrino production in the Sun, L the length the neutrinos travel in the Earth, and V_E the effective Earth potential.

The matter effects of the Sun are included in the parameter $D_{2\nu}$ and the matter effects of the Earth in the effective Earth potential V_E . The expression for P_{n-d} has many nice limits, in particular, $P_{n-d} = 0$ when $D_{2\nu}$, L , or V_E vanish.

In the LMA region, P_{n-d} is well approximated by

$$P_{n-d} \simeq -D_{2\nu} \frac{V_E}{K} \sin^2(2\theta) \sin^2\left(\frac{K}{2}L\right). \quad (5)$$

In the three flavor case, we can make the well-motivated approximation that the third mass eigenstate is not affected by the propagation in matter because of the small effective matter potential. As a result of this approximations, we obtain for the three flavor case

$$P_{n-d} = -c_{13}^6 D_{3\nu} \frac{KV_E}{4a^2} \sin^2(2\theta_{12}) \sin^2(aL), \quad (6)$$

where

$$D_{3\nu} = \int_0^{R_\odot} dr f(r) \cos(2\hat{\theta}_{12}(r)), \quad (7)$$

$$a = \frac{1}{2} \sqrt{c_{13}^4 V_E^2 - 2K c_{13}^2 V_E \cos(2\theta) + K^2}, \quad (8)$$

and $\hat{\theta}_{12}$ is calculated as $\hat{\theta}$ in the two flavor case using the effective potential $V_{\text{eff}} = c_{13}^2 \sqrt{2} G_F N_e$.

In the LMA region, the three flavor expression for P_{n-d} is well approximated by

$$P_{n-d} \simeq -c_{13}^6 D_{3\nu} \frac{V_E}{K} \sin^2(2\theta_{23}) \sin^2\left(\frac{K}{2}L\right). \quad (9)$$

REFERENCES

1. M. Blennow, T. Ohlsson and H. Snellman, Phys. Rev. D **69** (2004) 073006, hep-ph/0311098.