Solar Neutrino Day-Night Effect

Mattias Blennow\textsuperscript{a}, Tommy Ohlsson\textsuperscript{a}, Håkan Snellman\textsuperscript{a}

\textsuperscript{a}Division of Mathematical Physics, Department of physics, Royal Institute of Technology (KTH), AlbaNova University Center, SE-106 91 Stockholm, Sweden

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

$$A_{n-d} = \frac{N - D}{N + D},$$

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

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

where

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

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

$K = \Delta m^2/(2E)$, $\theta$ 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

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

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

$$P_{n-d} = -c^{6}_{13} D_{3\nu} \frac{K V_E}{4a^2} \sin^2(2\theta_{12}) \sin^2(aL),$$

where

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

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

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

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

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

REFERENCES