Lecture 20: Solution to Solar \( \nu \) Problem

No class Oct 30
Friday: Rex Tayloe on LSND
Monday: Mark Messier on Atmospheric \( \nu \)

Cl experiment sees about \( \frac{1}{3} \) of Solar model flux.

We want some but not all of \( \nu \) Flux to oscillate

1. The resonance density is neutrino energy dependent.

\[
P_e^0 = \frac{\Delta m^2}{2 \pi^2 G_f E} \cos 2E
\]

Choose \( \Delta m^2 \) so large that \( P_e^0 \) is greater than central density of \( \alpha \) sun for low \( E \) but not for high \( E \). Thus low \( E \) \( \nu \) don’t oscillate away because they never pass through resonance.

\[
P_e^0 = 1.5 \times 10^3 \text{ particles}\text{ cm}^{-3}\text{ g}^{-1} \frac{6.02 \times 10^{23}}{g} \left[197.33 \text{ MeV} \times 10^{-13} \text{ cm} \right]^3 \text{ cm}^{-3}
\]

\[
P_e^0 = 6.9 \times 10^{-7} \text{ MeV}^3
\]
Assume \( \cos 2\theta_v = 1 \)

\[
E_{\nu} = \left( \frac{\Delta m^2}{\text{MeV}^2} \right)^{-1} \left( \frac{10^{-12} \text{ev}^2/\text{MeV}^2}{1.16 \times 10^{-11} \text{MeV}^2} \right) \frac{1}{6.9 \times 10^{-7} \text{MeV}^3} \]

\[
E_\nu = 4.4 \times 10^4 \text{ MeV} \frac{\Delta m^2}{\text{MeV}^2}
\]

If \( \Delta m^2 = 10^{-4} \text{ ev}^2 \) than a 4.4 MeV \( \nu_\mu \) just reaches resonace in center of sun. If \( E_\nu \ll 4.4 \text{ MeV} \) resonace density \( \gg \rho_0 \) and neutrino does not oscillate appreciably.

2. Alternatively, \( \Delta m^2 < 10^{-4} \text{ ev}^2 \) so all neutrinos reach resonace somewhere in sun. However, mixing angle is so small that transition is only partially adiabatic and \( \text{P}_{0 \nu} > 0 \)

3. Third alternative is that vacuum mixing angle is large but nonmaximal thus \( \cos 2\theta_v < 1 \) survival probability is

\[
\text{P}_{\nu_e \rightarrow \nu_e} = \frac{1}{2} + \frac{1}{2} \cos 2\theta_v \cos 2\theta_i
\]

\text{If } \cos 2\theta_i = -1 \text{ if } \cos 2\theta_v < 1 \text{ then } \text{P}_{\nu_e \rightarrow \nu_e} \neq 0.
CL experiment can be explained by triangular shaped region.

Add constraints from Ga low threshold and Kamiokande. Only two allowed regions: small mixing angle (SMA) and large mixing angle (LMA) MSW solutions.

Note 1) has large survival for low \( E \nu \) while 2) has large survival for high \( E \nu \) and 3) \( \theta \) has survival prob. about energy independent. \( P_{\nu_e \rightarrow \nu_e} = \frac{1}{2} - \frac{1}{2} \cos 2 \theta \)

Finally SNO greatly favors LMA over SMA.

All present solar \( \nu \) experiments are well described by LMA

\[ \Delta m^2 = 10^{-4} \text{ eV}^2 \]

\[ \theta_{12} \approx 30^\circ \]