Solar mass-varying neutrino oscillations

hep-ph/0502196

Danny Marfatia
University of Kansas

with V. Barger and P. Huber

Why mass-varying neutrinos?

- coupling neutrinos to a light scalar may explain

$\Omega_\Lambda \sim \Omega_{matter}$ R. Fardon, A. Nelson, N. Weiner

- quintessence without extremely light scalars (10^{-33} eV)

Consequences

- neutrino masses vary with their number density

- neutrino masses vary with matter density if the scalar induces couplings to matter

- new matter effects in neutrino oscillations...

Framework

2-flavor case

$$H_{MaVaN} = \frac{1}{2E} U \begin{pmatrix} (m_1 - M_1(r))^2 & M_3(r)^2 \\ M_3(r)^2 & (m_2 - M_2(r))^2 \end{pmatrix} U^\dagger$$

Ordinary matter potential

$$H_m = \frac{1}{2E} \begin{pmatrix} 2\sqrt{2} G_F E_\nu n_e(r) & 0 \\ 0 & 0 \end{pmatrix}$$

General form of M_i

$$M_i = \frac{\lambda_{\nu_i}}{m_\phi^2\left(n_e, n_{\nu_i}\right)}\left[\lambda_e n_e + \sum_i \lambda_{\nu_i}\left(n_{\nu_i}^{C\nu B} + \frac{m_{\nu_i}}{E_{\nu_i}} n_{\nu_i}^{rel}\right)\right]$$

$$\lambda_e < 0.01\, m_N / M_{Pl} \sim 10^{-21}$$

Adelberger, *et al.*

$n_{\nu_i}^{C\nu B} \sim 10^{-12}\,\mathrm{eV}^3$ and $n_e = 10^6 - 10^{11}\,\mathrm{eV}^3$

Max. solar neutrino contribution is for pp neutrinos in the prod. region

$$\frac{m_{\nu_i}}{E_{\nu_i}} n_{\nu_i}^{rel} = \frac{1\text{eV}}{0.3\text{MeV}} 7 \cdot 10^{-8}\,\text{eV}^3 \sim 10^{-13}\,\text{eV}^3 \ll n_{\nu_i}^{C\nu B}$$

$\lambda_{\nu_i} \sim 10^{-4} - 10^{-3}$ and $m_\phi^2 \sim 10^{-11}\,\text{eV}^2$ gives $M_i \sim 10^{-3} - 10^{-2}\,\text{eV}$ at neutrino production

$$M_i = \frac{\lambda_{\nu_i}}{m_\phi^2}\left(O\left(10^{-15} - 10^{-10}\right) + O\left(10^{-16} - 10^{-15}\right)\right)\,\text{eV}$$

We set $m_1 = 0$, $M_1 = 0$

and assume as density dependence for the M_i

$$M_i(r) = \mu_i \cdot \left(\frac{n_e(r)}{n_e^0} \right)^k$$

where $n_e(r) \propto \exp(-r/r_c)$

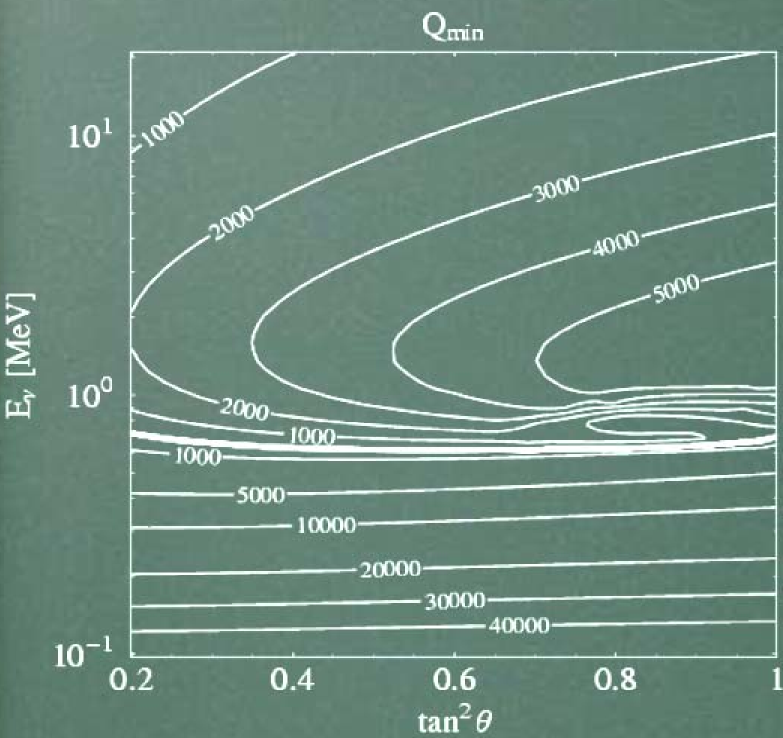
μ_i and k are free parameters

Is the propagation inside the sun still adiabatic?

$$Q(r) = \frac{\Delta(r)}{4E\left|\dot{\theta}(r)\right|}$$

Adiabatic propagation $\Leftrightarrow Q \gg 1 \;\forall r$

$\Rightarrow$ Determine Q_{min} for each energy



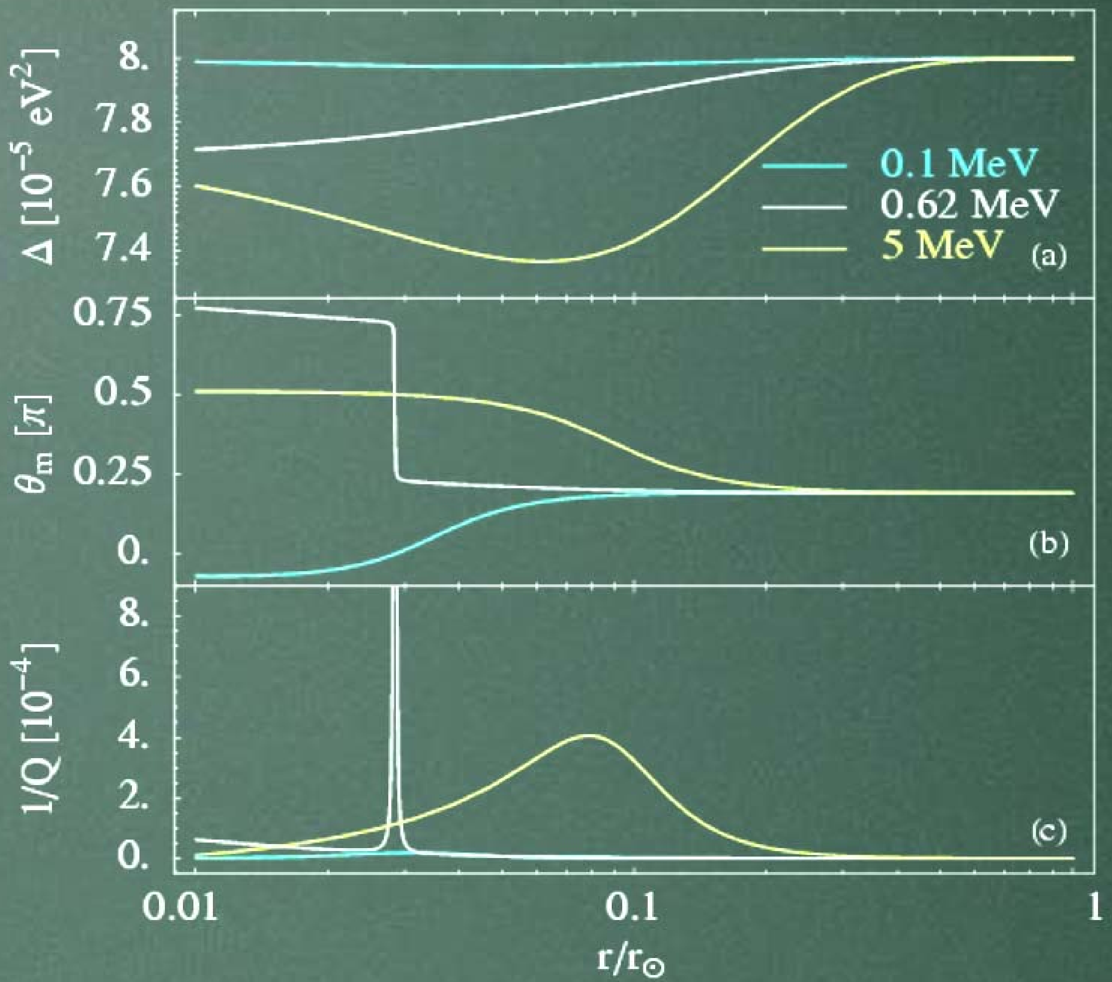
$Q \ll 10$ in a narrow energy range

Everywhere else $Q \gg 1 \Rightarrow$ adiabatic approximation

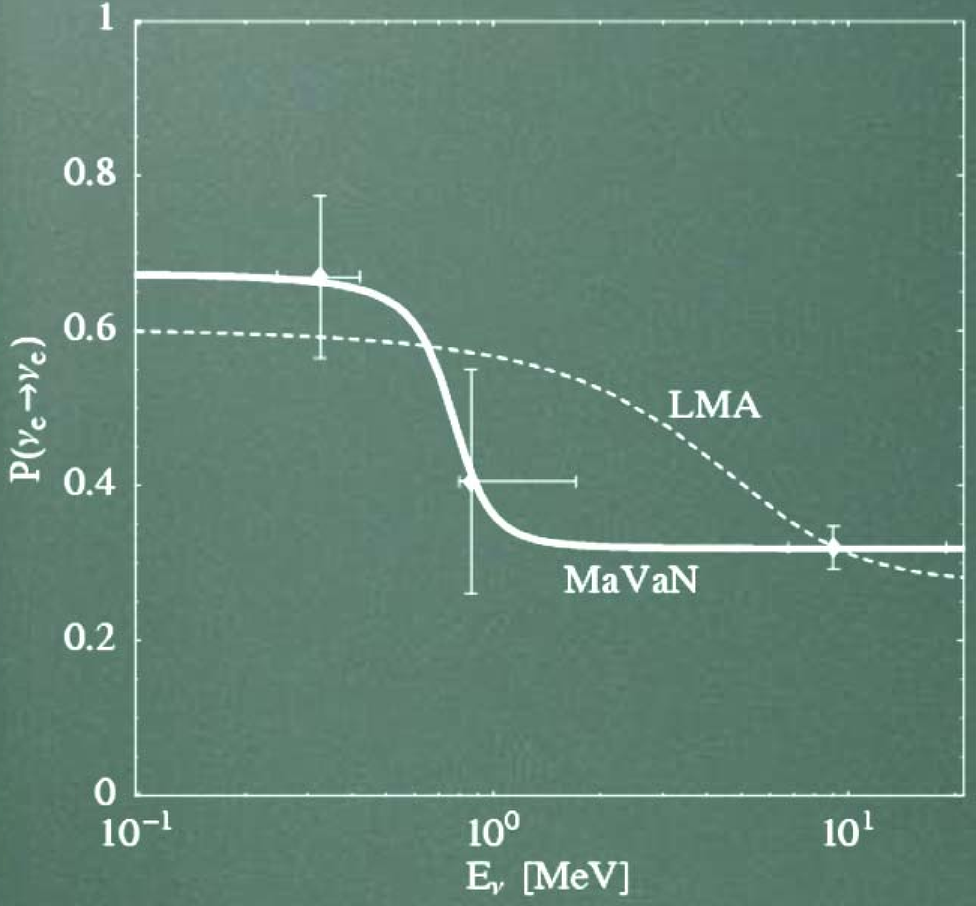
$$P = \frac{1}{2} + \frac{1}{2} \cos 2\theta_m^0 \cos 2\theta$$

$$\tan 2\theta_m^0 = \frac{(m_2 - \mu_2)^2 \sin 2\theta + 2\mu_3^2 \cos 2\theta}{(m_2 - \mu_2)^2 \cos 2\theta - 2\mu_3^2 \sin 2\theta - A^0}$$

which is independent of K!

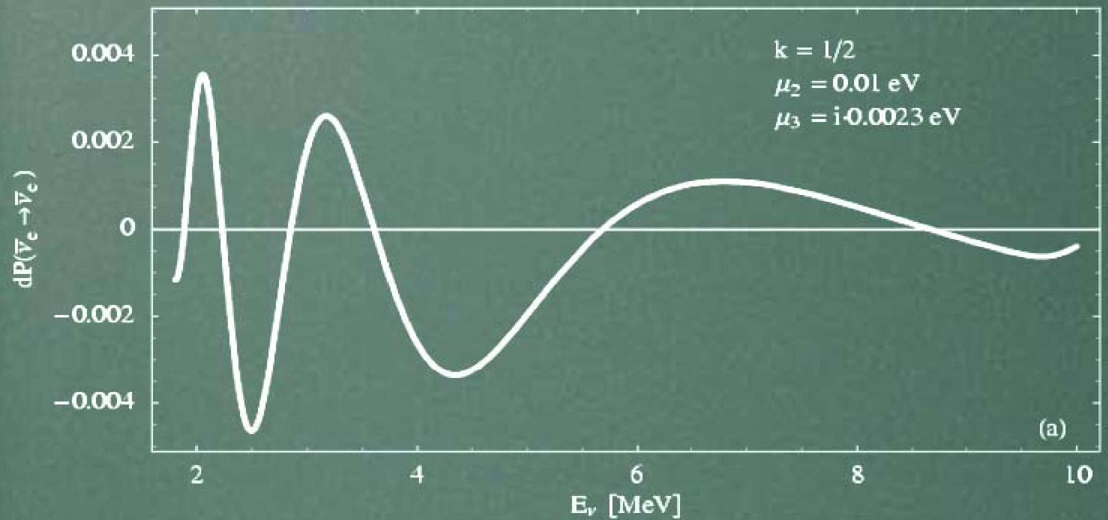


$$\dot{\theta}(r) \rightarrow \infty \Leftrightarrow Q \rightarrow 0$$



- K-independent
- excellent fit
- flat SK spectrum

Is this in accordance with KamLAND data?



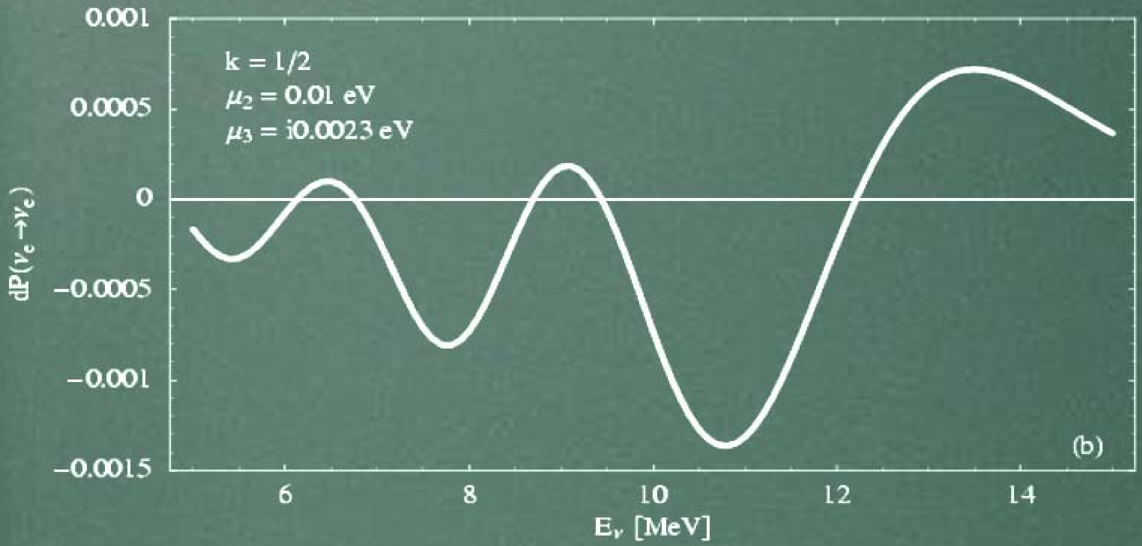
$L = 180$ km

$$dP = P^{SM}_{\bar{e}\bar{e}} - P^{MaVaN}_{\bar{e}\bar{e}}$$

K-dependence

$$\text{MaVaN effects} \propto \left(\frac{\rho_{KamLAND}}{\rho^{0}_{sun}} \right)^{k} \approx 0.015^{k}$$

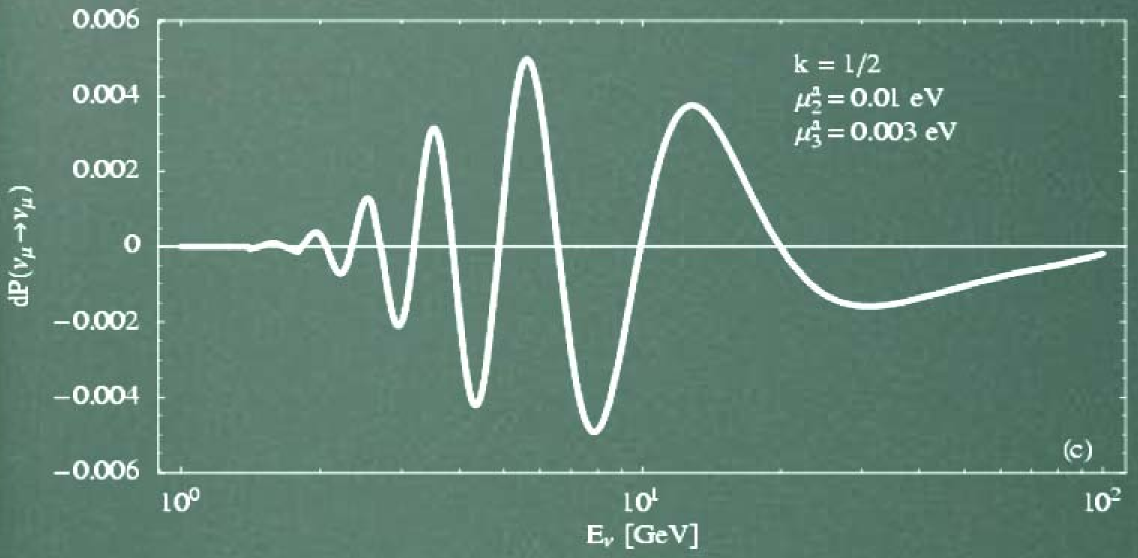
Are Day-Night effects small?



$\cos\theta_z = -1$

$dP = P_{ee}^{SM} - P_{ee}^{MaVaN}$

Is a MaVaN contribution of the same size consistent with atmospheric neutrino data?



$\cos\theta_z = -1$

$dP = P_{\mu\mu}^{SM} - P_{\mu\mu}^{MaVaN}$

Conclusions

MaVaN oscillations that result in exotic matter effects of the same size as standard matter effects

- are allowed by neutrino data
- improve the fit to solar data
- give solar survival probabilities that are independent of how the suppression of neutrino masses varies with density
- can be tested by MeV and lower energy solar neutrino experiments