Phenomenology of MaVaN's Models in Reactor and Solar Neutrino Data

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First of all...

Calm down, I work in a Fermilab experiment...

This is just my past showing up...

A naive look into

Phenomenology of MaVaN's Models in Reactor and Solar Neutrino Data

Mateus F. Carneiro

Outline

- Informal Motivation for MaVaN's Models
- Neutrino Oscillation
- Looking for Reactor Neutrinos
  - A Study of the Environment
- Extending for Solar Neutrinos
- Conclusions and New Perspectives (pun intended)

Mass Varying Neutrinos!

- Dark Energy and the Coincidence problem

  - Today $\rho_{CDM}/\rho_\Lambda \sim 1/3$, but this ratio evolves as a function of the scale factor with $1/a^3$

  - "*The cosmic coincidence problem asks why the cosmic acceleration began when it did. If cosmic acceleration began earlier in the universe, structures such as galaxies would never have had time to form and life, at least as we know it, would never have had a chance to exist.*"

Mass Varying Neutrinos!

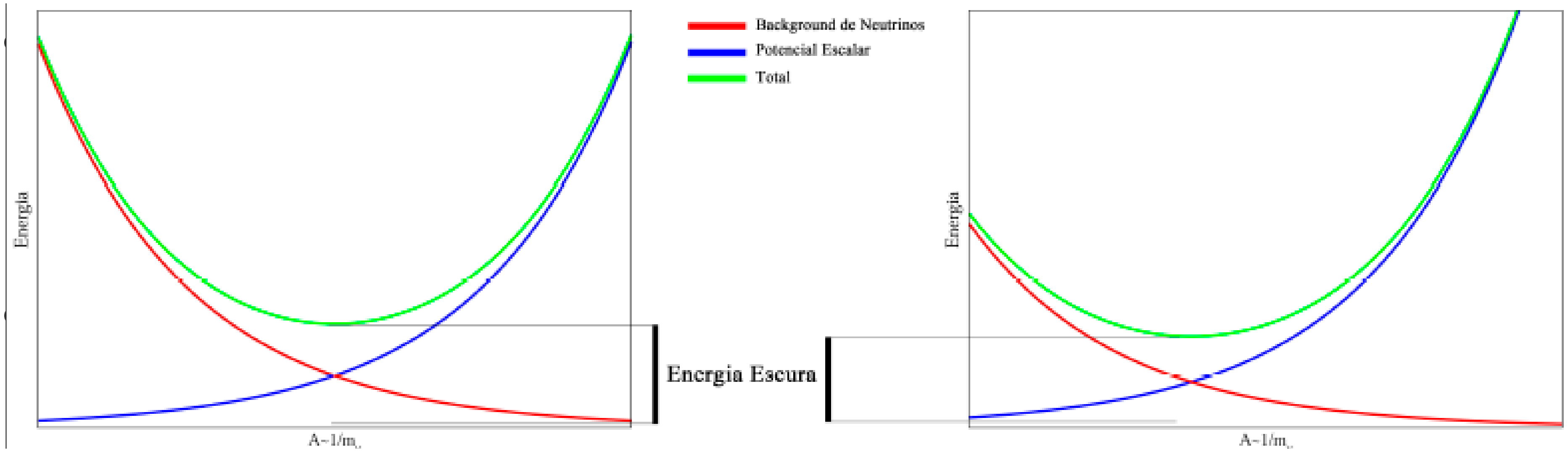
- R. Fardon, A. E. Nelson, and N. Weiner (2004) [1]
- P. Gu, X. Wang, and X. Zhang (2003) [2]

- Similarity of scales, (2E−3 eV)^4 for dark energy and (E−2eV)^2 for the neutrino mass split
-Neutrino mass as a dynamic quantity, depending on the value of a scalar field φ.

Mass Varying Neutrinos!

- The potential φ is then considered very flat and its magnitude dependent on the density of cosmological neutrinos.
- MaVaN's become heavier with the decrease of its density.
- The total energy of the fluid (contained in the neutrinos and in the field φ), identified as dark energy, may vary smoothly while the density of neutrinos decreases

Mass Varying Neutrinos!



- The total energy of the fluid (contained in the neutrinos and in the field φ), identified as dark energy, may vary smoothly while the density of neutrinos decreases

Mass Varying Neutrinos!

- This would explain not only the origin of dark energy, but can also:

  - modify the limits of cosmological neutrino mass [1],
  - modify the relationship between the mass of the neutrino and leptogenesis [2],
  - modify expected change in the split of flavors for neutrinos and cosmic background from distant astrophysical sources [3].

Mass Varying Neutrinos!

- N. Weiner and K. M. Zurek (2006) [4]

  - Interactions of sub-gravitational force can occur naturally between ordinary matter and the field φ
  - Neutrinos with masses dependent on the density of the medium and new effects in the flavor oscillation

Mass Varying Neutrinos!

- Phenomenological effects of this type of model

  - on the Sun [5,6,7]
  - in atmospheric neutrinos [8,9]
  - in supernovae [10,11]
  - reactor neutrinos [12,13]
  - neutrinos propagating on Earth [14].

Oscillation Effects

- M. Gonzalez-Garcia, P. de Holanda, and R. Zukanovich Funchal (2006) [5]
  - phenomenological approach
  - two families

$$i\frac{d}{dr}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix} = \frac{1}{2E_\nu}\, U_{\theta_{12}} \begin{pmatrix}(m_1^0 - M_1(r))^2 & M_3^2(r)\\ M_3^2(r) & (m_2^0 - M_2(r))^2\end{pmatrix} U_{\theta_{12}}^\dagger + \begin{pmatrix}V_{\mathrm{CC}}(r) & 0\\ 0 & 0\end{pmatrix} \begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix}\Bigg|_{r=0}$$

Oscillation Effects

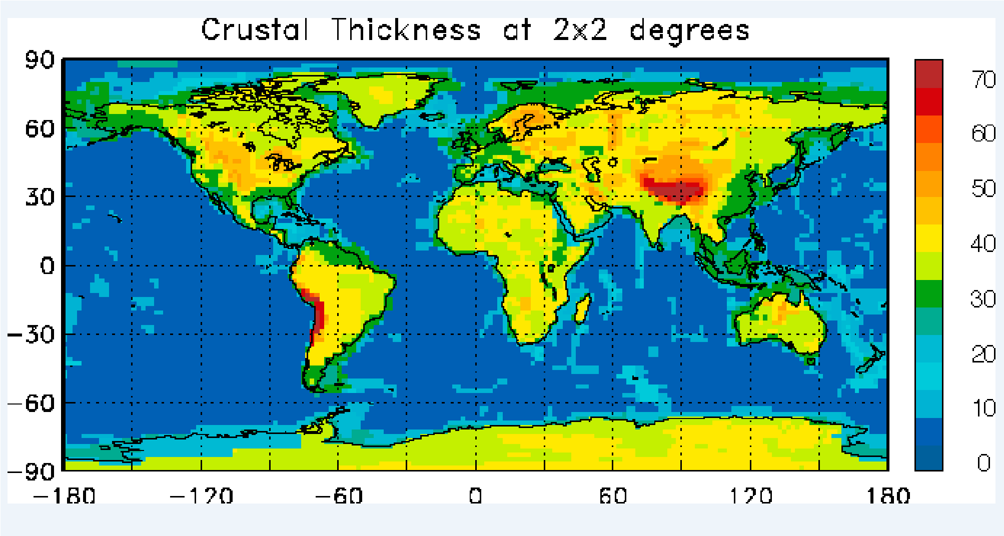
$$M_i(r) = M_{0i} \tanh\left[\lambda_i \frac{\rho(r)}{(\mathrm{g/cm^3})}\right]$$

- P. C. de Holanda (2009) [6] parametrization

  - linear growth with baryonic density for small values
  - saturation of the environmental dependence for large values

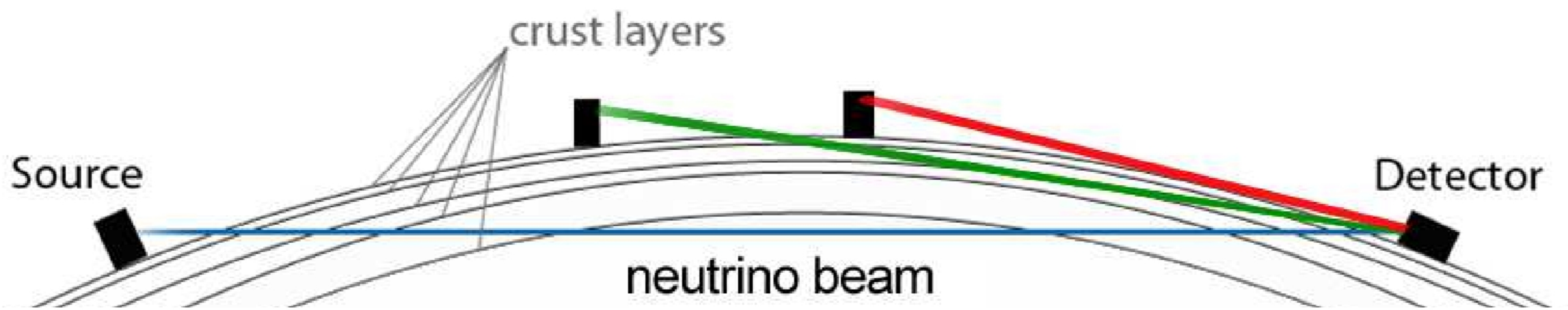
Earth's Crust Model

- CRUST 2.0 [15]
  - grid of 2x2 degrees on the terrestrial surface
- Each individual profile is a one-dimensional description of 7 layers
  - ice
  - water
  - soft sediments
  - hard sediments
  - upper crust
  - middle crust
  - lower crust



- Density and Thickness

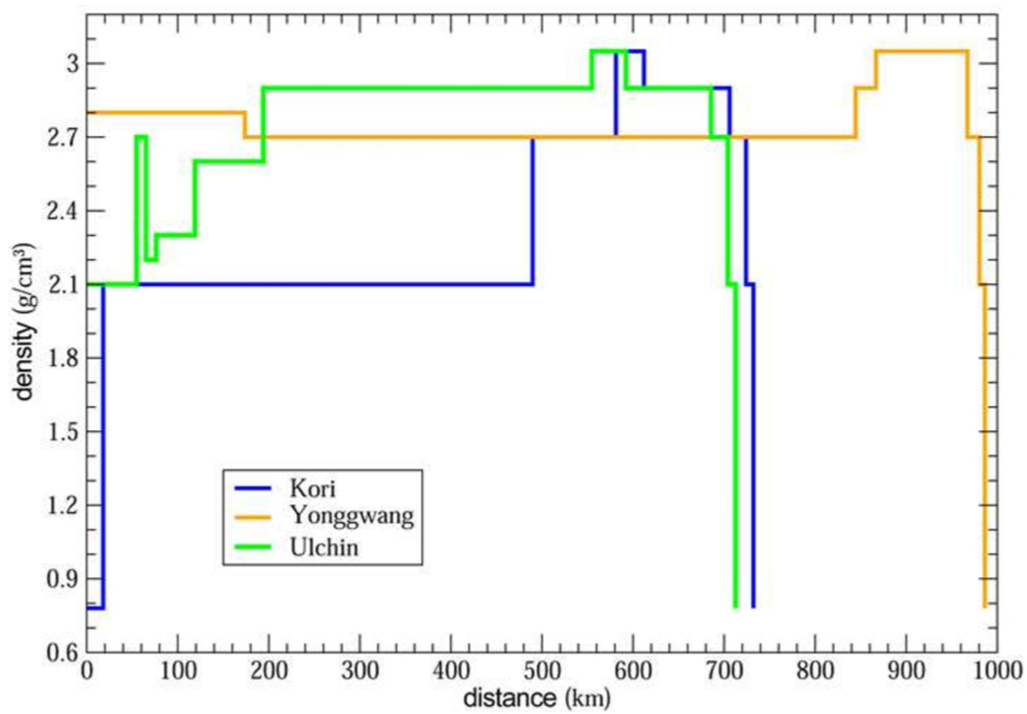
Density Maps



Different sources

↓

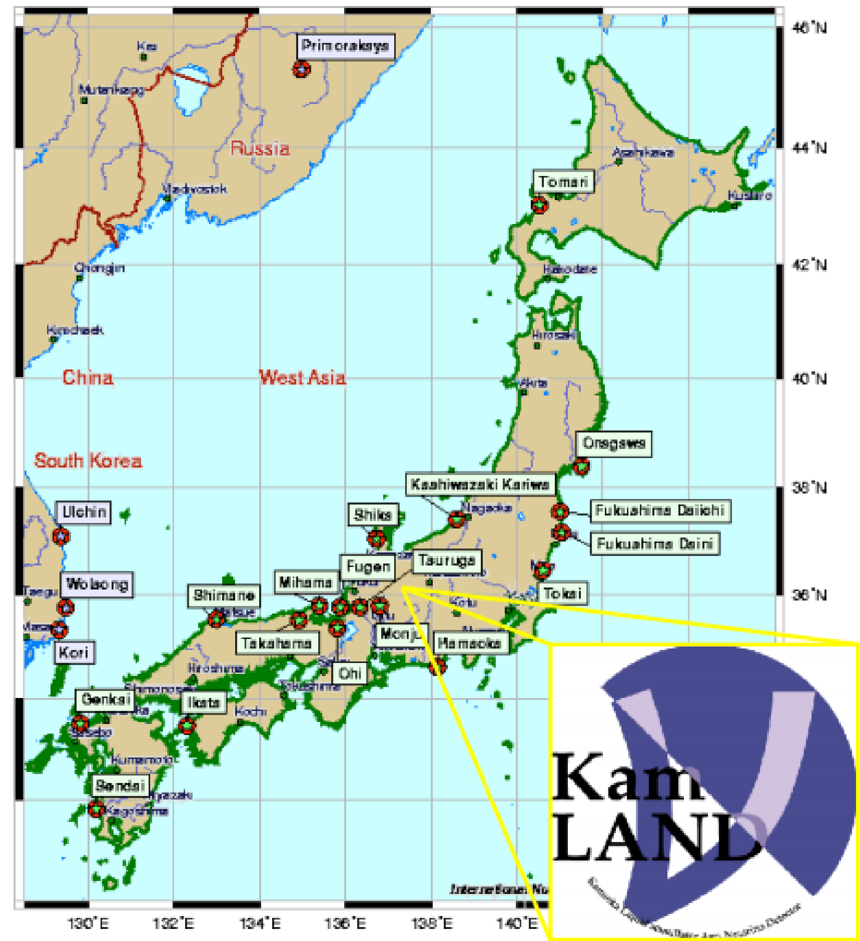
Different density maps



KamLAND Sources

- The KamLAND experiment uses several different reactors as source
- Geographic location of each reactor

  - 26 different maps of density

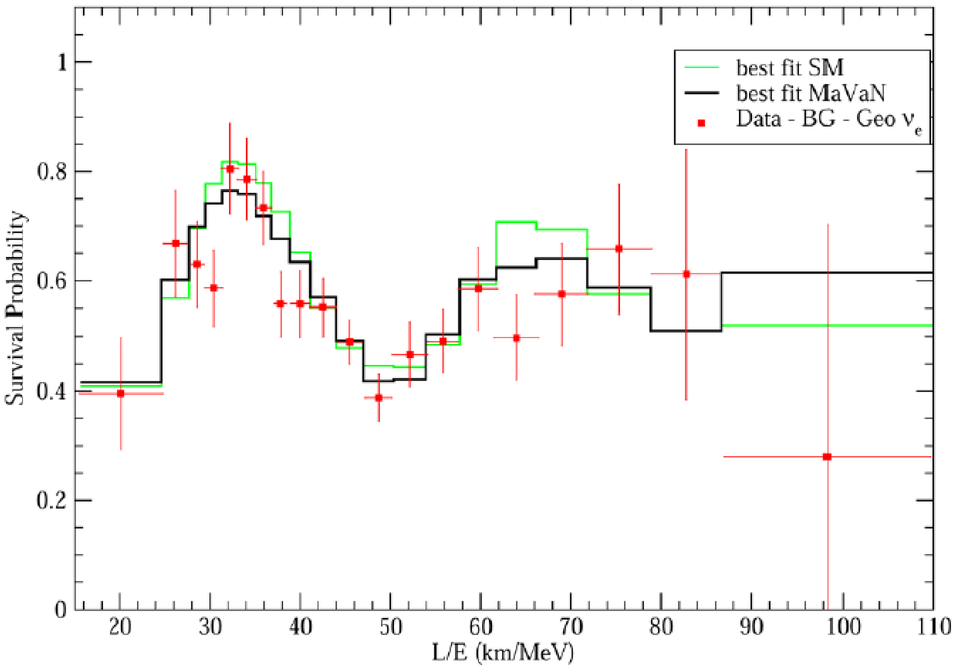


KamLAND Status

Survival Probability Results [16]

We find the best fit point

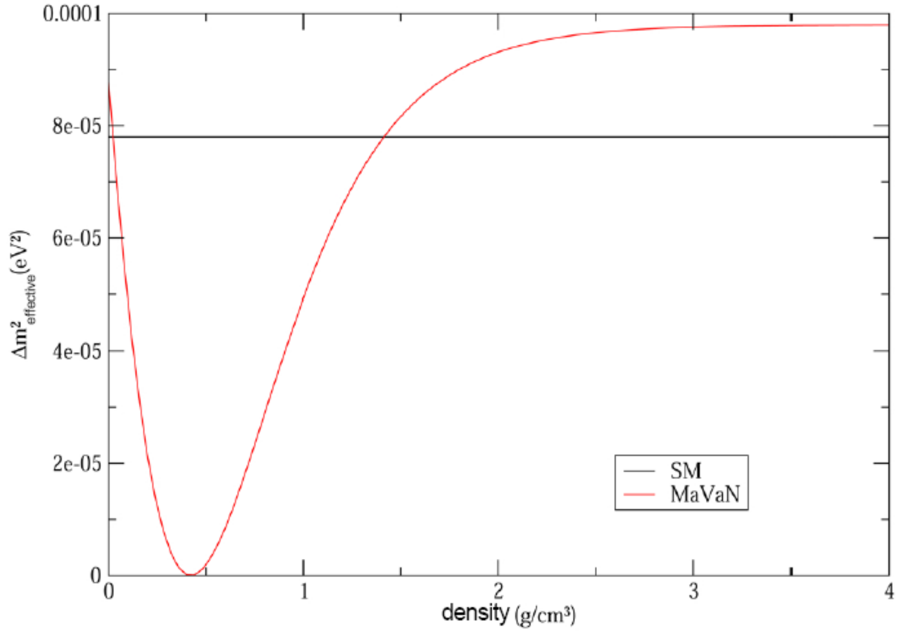
$$\tan^2\theta_{12} = 0.448^{+0.072}_{-0.058},$$
$$\Delta m^2_{21} = 8.8^{+0.1}_{-0.2} \times 10^{-5}\mathrm{eV}^2,$$
$$\lambda_2 = 1.258^{+0.051}_{-0.108},$$
$$M_{02} = 1.90^{+0.01}_{-0.01} \times 10^{-2}\mathrm{eV},$$

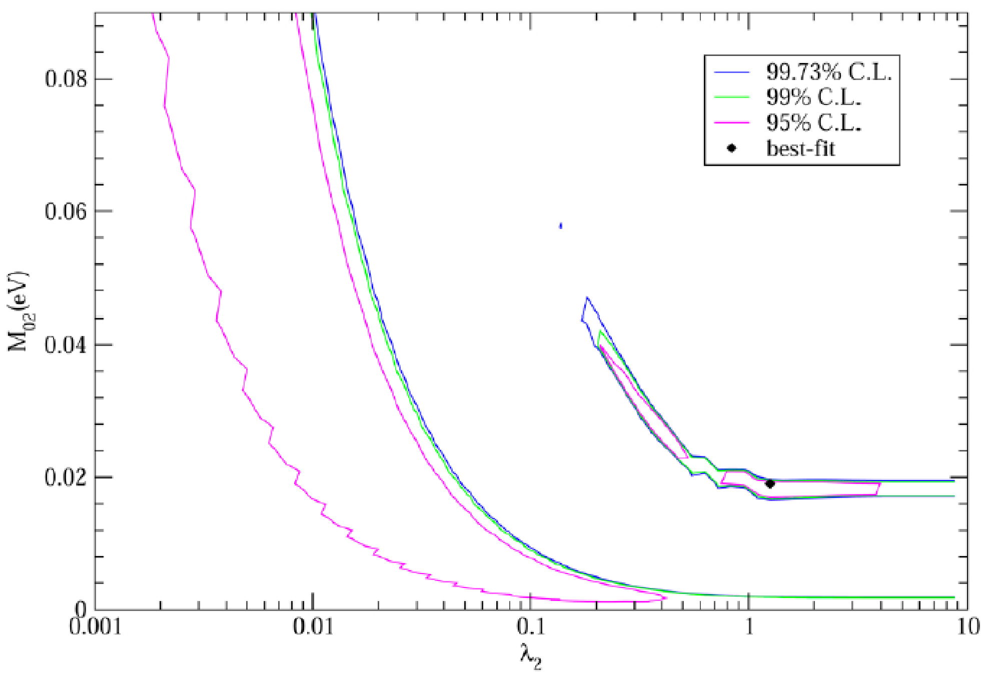


	Chi²/d.o.f.
Standard Oscillation	2.02
MaVaN	1.34

Survival Probability Results

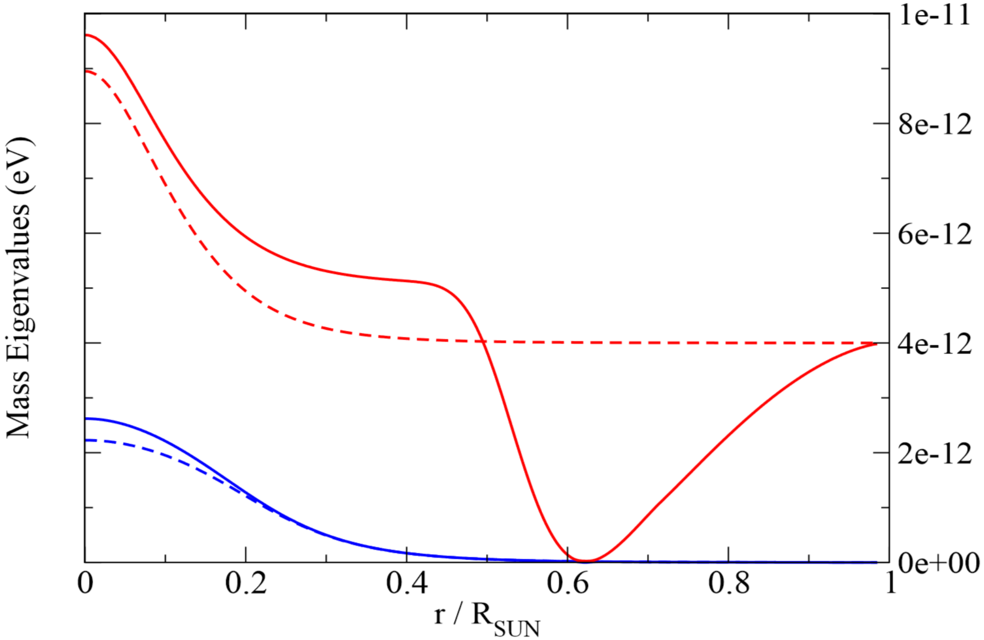
- Non-homogneity effect of the Earth's Crust
- Resonance creates a better description of the data

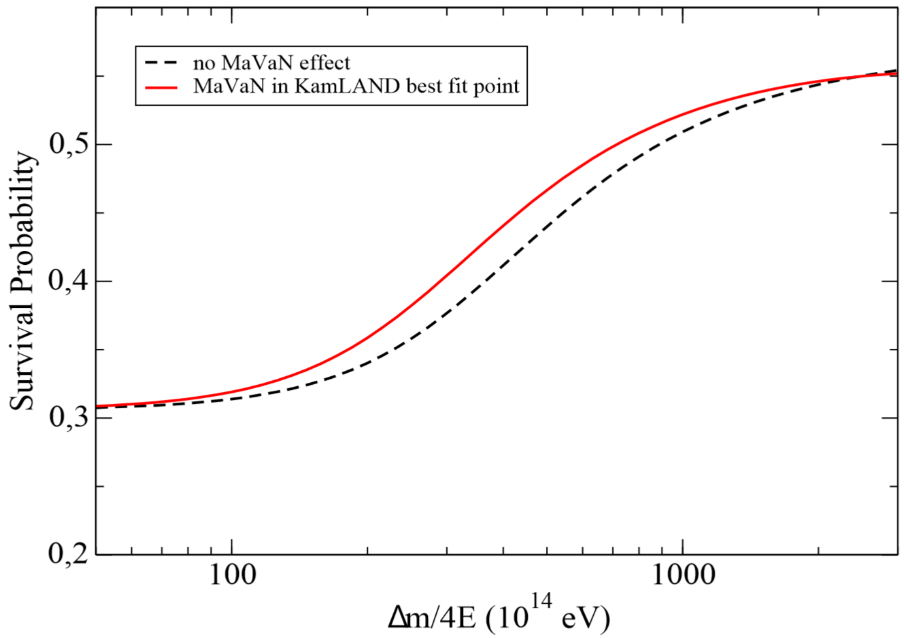




- Degeneracy of parameters
- We're not excluding tha SM

Extending to Solar Neutrinos





- We performed a fit to all available solar neutrino data, and compared our fit with the standard analysis. For the specific point we tested here we obtained an increase in the value of the chi² worsen the fit to data

Conclusion and Next Steps

- We managed to find a strong effect justified by an specific MaVaN model that had a better fit for KamLAND data
- This case has an parameters degeneracy
- For solar neutrinos the same parameter values had worst results
- Full Phase Space for Solar Neutrinos?
- Monte Carlo?
- NovA, MINOS, LBNE, Opera... ?

[1] R. Fardon, A. E. Nelson, and N. Weiner, JCAP 0410, 005 (2004)
[2] P. Gu, X. Wang, and X. Zhang, Phys.Rev. D68, 087301 (2003)
[3] P. Q. Hung and H. Pas, Mod.Phys.Lett. A20, 1209 (2005)
[4] N. Weiner and K. M. Zurek, Phys.Rev. D74, 023517 (2006)
[5] M. Cirelli, M. Gonzalez-Garcia, and C. Pena-Garay, Nucl.Phys. B719, 219 (2005)
[6] V. Barger, P. Huber, and D. Marfatia, Phys. Rev. Lett. 95, 211802 (2005)
[7] P. C. de Holanda, JCAP 0907, 024 (2009)
[8] D. R. Gratieri and O. L. B. Peres, arXiv:1405.7053.
[9] K. Abe et al. (Super-Kamiokande Collaboration), Phys.Rev. D77, 052001 (2008)
[10] F. Rossi-Torres, M. Guzzo, P. de Holanda, and O. Peres, Phys.Rev. D84, 053010 (2011)
[11] M. M. Guzzo and F. Rossi-Torres, Physicæ 9 (2010).
[12] M. Gonzalez-Garcia, P. de Holanda, and R. Zukanovich Funchal, Phys.Rev. D73, 033008 (2006)
[13] T. Schwetz and W. Winter, Phys.Lett. B633, 557 (2006)
[14] V. Barger, D. Marfatia, and K. Whisnant, Phys.Rev. D73, 013005 (2006)
[15] C. L. G. Bassin and G. Masters, EOS Trans AGU 81 (2000).
[16] M. F. Carneiro and P. C. de Holanda, Advances in High Energy Physics, Article ID 293425 , (2013)

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Probability Calculation

- The description for KamLAND leads to a completely non-adiabatic evolution for the neutrino
  - can't use analytic survival probability
- Probability amplitudes allows local calculation for each region of constant density
  - neutrino propagate as plane wave for this regions

$$A_{\text{total}} = A_n \ldots A_1 A_0 |\nu_0 >= A_n \ldots A_1 |\nu_1 >;$$

Probability calculation

$$0 = M_1 = M_3 = m_1 < m_2 < m_3,$$

$$A_{\rm f} = \begin{pmatrix} \cos\left(\frac{\Delta m^2_{\rm f,KL}}{4E_\nu}L_i\right) + i\cos 2\theta^m_{21}\sin\left(\frac{\Delta m^2_{\rm f,KL}}{4E_\nu}L_i\right) & -i\sin 2\theta^m_{21}\sin\left(\frac{\Delta m^2_{\rm f,KL}}{4E_\nu}L_i\right) \\ i\sin 2\theta^m_{21}\sin\left(\frac{\Delta m^2_{\rm f,KL}}{4E_\nu}L_i\right) & \cos\left(\frac{\Delta m^2_{\rm KL}}{4E_\nu}L_i\right) - i\cos 2\theta^m_{21}\sin\left(\frac{\Delta m^2_{\rm f,KL}}{4E_\nu}L_i\right) \end{pmatrix}$$

$$\cos 2\theta^m_{\rm f,12} = \frac{\Delta\tilde{M}^2_{21}(r_f)\cos 2\tilde{\theta}_{\rm f,12} - 2E_\nu V_{\rm CC}(r_f)}{\Delta m^2_{\rm f,KL}}.$$

$$\Delta\tilde{M}^2_{21}(r_{\rm f}) = (m_2 - M_2(r_{\rm f}))^2$$

$$(\Delta m^2_{\rm f,KL})^2 = (\Delta\tilde{M}^2_{21}(r_f)\cos 2\theta_{12} - A_{\rm CC}(r_{\rm f}))^2 + (\Delta\tilde{M}^2_{21}(r_{\rm f})\sin 2\theta_{12})^2,$$

$$M_2(r_{\rm f}) = M_{02}\tanh\left(\lambda_2\frac{\rho(r_{\rm f})}{g/cm^3}\right),$$

$$P_{\bar{\nu}_e\bar{\nu}_e} = 1 - |A_{21}|^2$$

chi²

- Poisson Distribution

$$\chi^2 \equiv \sum_j^n 2\left[KN_j^{\mathrm{teo}} - N_j^{\mathrm{obs}} + N_j^{\mathrm{obs}} ln\left(\frac{N_j^{\mathrm{obs}}}{KN_j^{\mathrm{teo}}}\right)\right]$$