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Gallium data variability
and
KamLAND

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Gallium data, SFP and KamLAND

Time modulation of the solar neutrino flux is probably the most important issue after LMA has been asserted as the dominant solution for the $\odot\nu$ problem.

Many efforts have been recently undertaken to look into modulation (SK, SNO collabs., Stanford Group, Calcutta Group, ...)

If confirmed it will probably imply the existence of a sizable neutrino magnetic moment μ_ν and hence a wealth of new physics.

VVO (1986) explained the claimed periodicity of the Chlorine event rate but the effect remained inconclusive. In summary it works as follows:

Active neutrinos can be converted to sterile ones owing to the interaction of μ_ν with the solar field $B_\odot$.

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At times of intense solar activity

$$Strong\ B_{\odot} \rightarrow large\ \mu_{\nu} B_{\odot} \rightarrow large\ conversion$$

with little or no conversion otherwise. Hence a neutrino flux anticorrelated to solar activity.

OUR CLAIM

Striking fact: Gallium data have been consistently decreasing. This may be the effect of a long term periodicity. In fact

Period	1991-97	1998-03
SAGE+Ga/GNO	77.8 ± 5.0	63.3 ± 3.6
Ga/GNO only	77.5 ± 7.7	62.9 ± 6.0
av. no. of suspots	52	100

(Table 1)

Notice a 2.4σ discrepancy in the combined results over the two periods: possible anticorrelation of Ga event rate with the 11-year solar cycle.

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Ga are the only experiments with a significant contribution of pp, ${}^{7}Be$ neutrinos (together they account for $\simeq 80\%$ of event rate and $> 99\%$ of total $\odot\nu$ flux). No other experiments show such a variational effect, so the time dependence of these fluxes becomes an open possibility.

We propose an alternative to the conventional solar+KamLAND fit:

DO NOT completely average over time: it may erase important information. Instead attempt at two separate fits to the two Ga data sets consistent with all other solar and KamLAND data.

THE MODEL

Introduce sterile neutrinos. In the vacuum they do not mix with the active ones

$$\begin{pmatrix} \nu_s \\ \nu_e \\ \nu_x \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_\theta & s_\theta \\ 0 & -s_\theta & c_\theta \end{pmatrix} \begin{pmatrix} \nu_0 \\ \nu_1 \\ \nu_2 \end{pmatrix} \tag{1}$$

while in matter active neutrinos communicate to sterile ones through the magnetic moment

$$\mathcal{H}_{\rm M} = \begin{pmatrix} \frac{-\Delta m^2_{10}}{2E} & \mu_\nu B & 0 \\ \mu_\nu B & \frac{\Delta m^2_{21}}{2E} s^2_\theta + V_e & \frac{\Delta m^2_{21}}{4E} s_{2\theta} \\ 0 & \frac{\Delta m^2_{21}}{4E} s_{2\theta} & \frac{\Delta m^2_{21}}{2E} c^2_\theta + V_x \end{pmatrix} . \tag{2}$$

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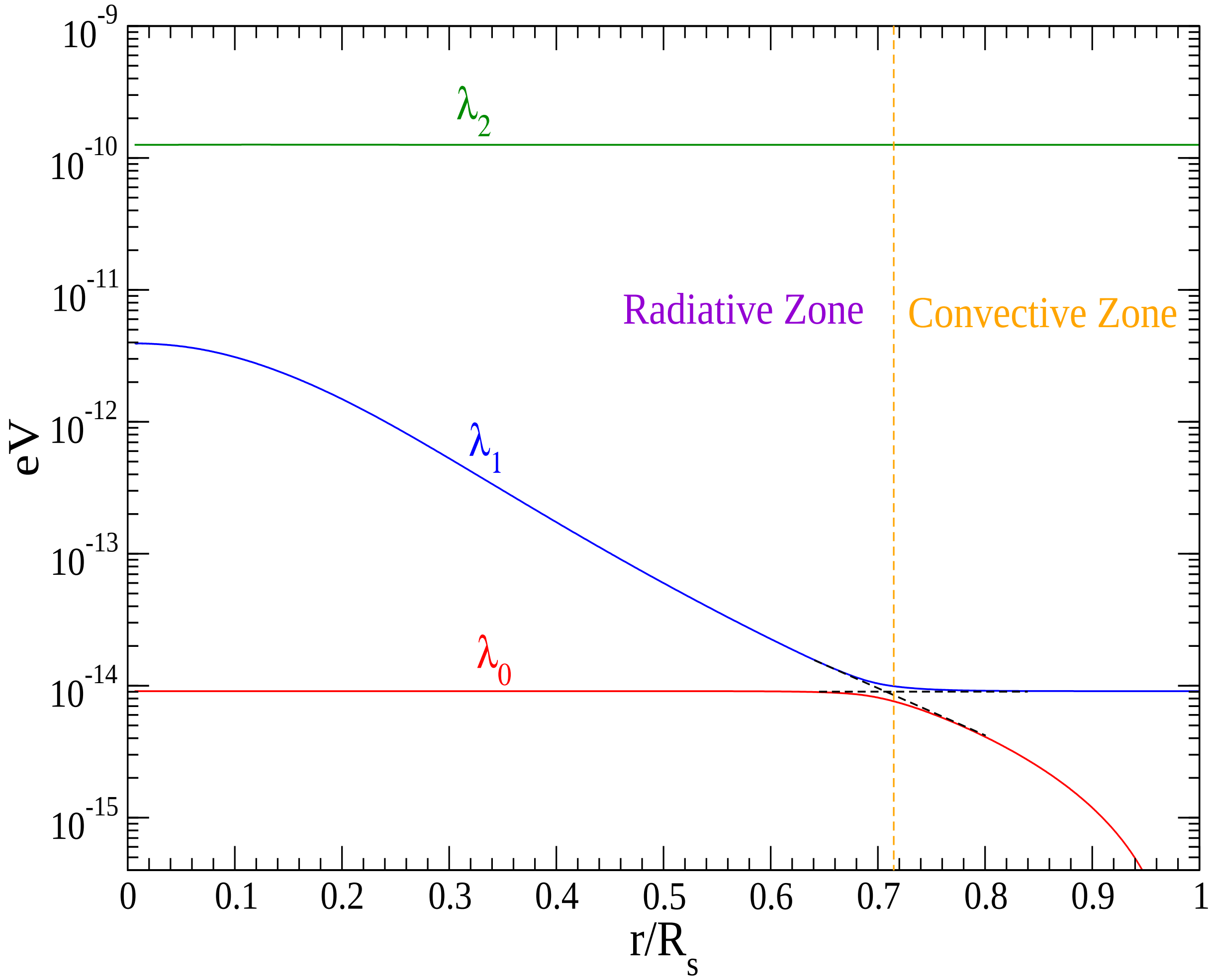
The parameter $\Delta m^2_{10} = m_1^2 - m_0^2$ dictates the location of the active → sterile transition. ($\Delta m^2_{21} = m_2^2 - m_1^2$ defines the location of the conventional LMA transition).

$B_{peak} = 220kG,\ \Delta m^2_{10} = -6.0 \times 10^{-9} eV^2$

$E =< E_{pp} >= 0.33 MeV$



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Why sterile neutrinos? Because we need

$$\Delta m^2_{10} = O(10^{-8} eV^2)$$

which excludes conversion to active neutrinos for which both known values of the mass square differences are larger.

The large order of magnitude discrepancy between the two mass square differences

$$\Delta m^2_{21} = O(10^{-4}) eV^2 \quad \Delta m^2_{10} = O(10^{-8}) eV^2$$

(Table 2)

implies the two resonances to be located far apart (LMA in the core and SFP at the bottom of the convective zone) so that they do not interfere.

In all our calculations $\mu_\nu = 10^{-12} \mu_B$.

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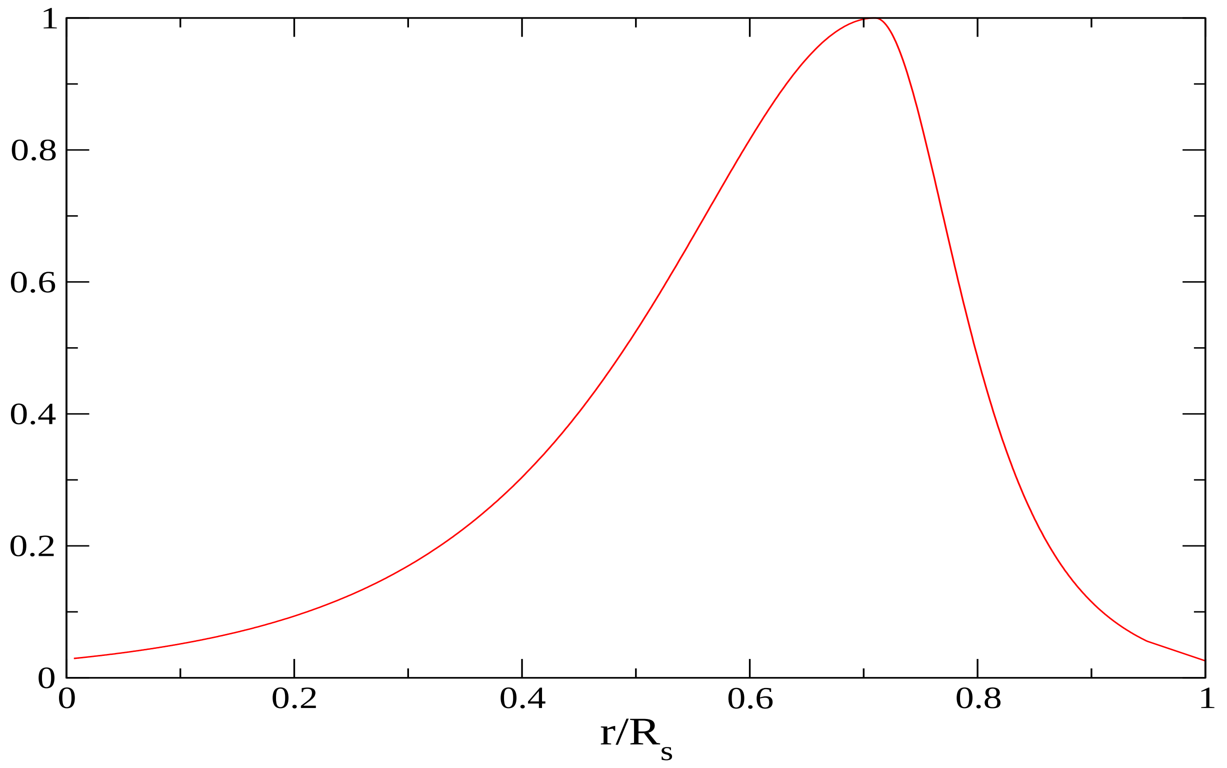
FIELD PROFILE (normalized) - peaks near the bottom of the convective zone $[B_{peak} = (200 - 300) kG]$



$\Delta m^2_{10} = O(10^{-8} eV^2) \rightarrow pp, {}^7Be$ resonances located near B_{peak}.

Field time dependence (possibly in connection to solar activity) leads to a modulation of the low energy neutrino flux

$\rightarrow$ *mainly* pp *and* ${}^7Be$

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RESULTS

For the global best fit we obtain

	Ga	Cl	K (SK)	SNO_{NC}	SNO_{CC}	SNO_{ES}
Set (I)	71.7	2.66	2.29			
Set (II)	69.6		2.18	5.53	1.54	2.16
LMA	64.8	2.74	2.30	5.10	1.75	2.28

(Table 3)

Set (I): period 1991-97. Only 3 experiments were available: Ga, Cl, Kamiokande

Set (II): period 1998-03. Cl not available and Kamiokande → SuperK

Parameters ($\chi^2/d.o.f. = 18.4/13,\ 107.9/94,\ 104.3/95$)

$$\Delta m^2_{21} = 8.2 \times 10^{-5} eV^2\ (7.9),\ tan^2\theta = 0.31\ (0.46)$$

$$\Delta m^2_{10} = -6.5 \times 10^{-8} eV^2$$

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However:

Global b.f. is not a good measure for the investigation of the time variability of low energy neutrinos, as its information is dissimulated within the wealth of solar and KamLAND data.

A slight change in the parameters:

$$\Delta m^2_{21} = 8.4 \times 10^{-5} eV^2, \; tan^2\theta = 0.27$$

$$\Delta m^2_{10} = -1.7 \times 10^{-8} eV^2$$

yields $(\chi^2/d.o.f. = 18.7/13, \; 121.1/94)$

	Ga	Cl	K (SK)	$\mathrm{SNO_{NC}}$	$\mathrm{SNO_{CC}}$	$\mathrm{SNO_{ES}}$
Set (I)	74.7	2.63	2.28			
Set (II)	60.5		2.28	5.82	1.53	2.24

(Table 4)

Recall: for LMA (KamLAND only),

$$\Delta m^2_{21} = 7.9 \pm^{0.6}_{0.5} \times 10^{-5} eV^2, \; tan^2\theta = 0.46 \pm^{4.5}_{0.25} \, (2\sigma)$$

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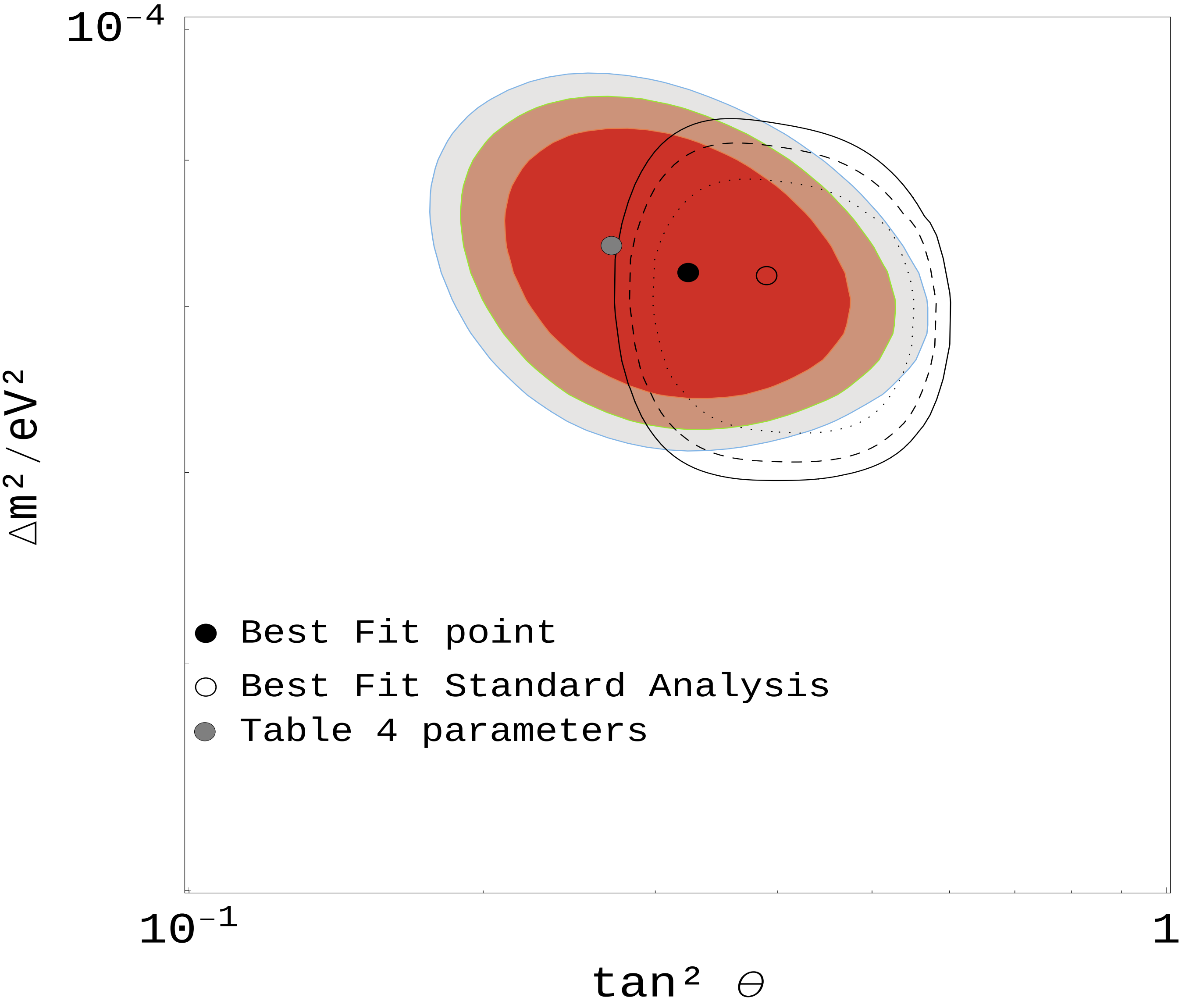
Solar+KamLAND analyses (Standard and ours)



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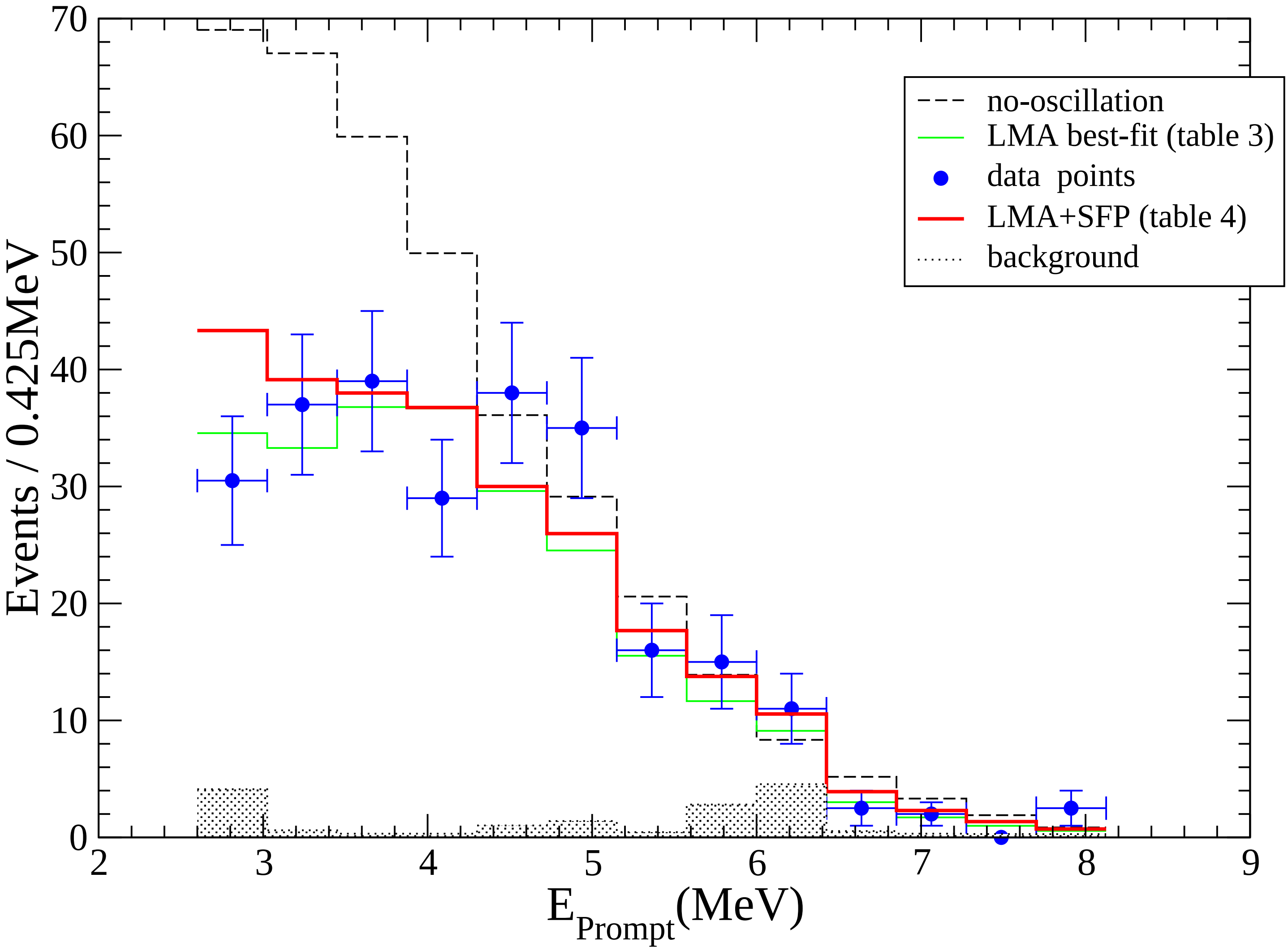
Consistency of solution with KamLAND data

(I) KamLAND e^+ spectrum



The two fits are equally comparable in quality

LMA best fit $\chi^2 = 15.0/11 d.o.f.$

Table 4 fit $\chi^2 = 16.5/11 d.o.f.$

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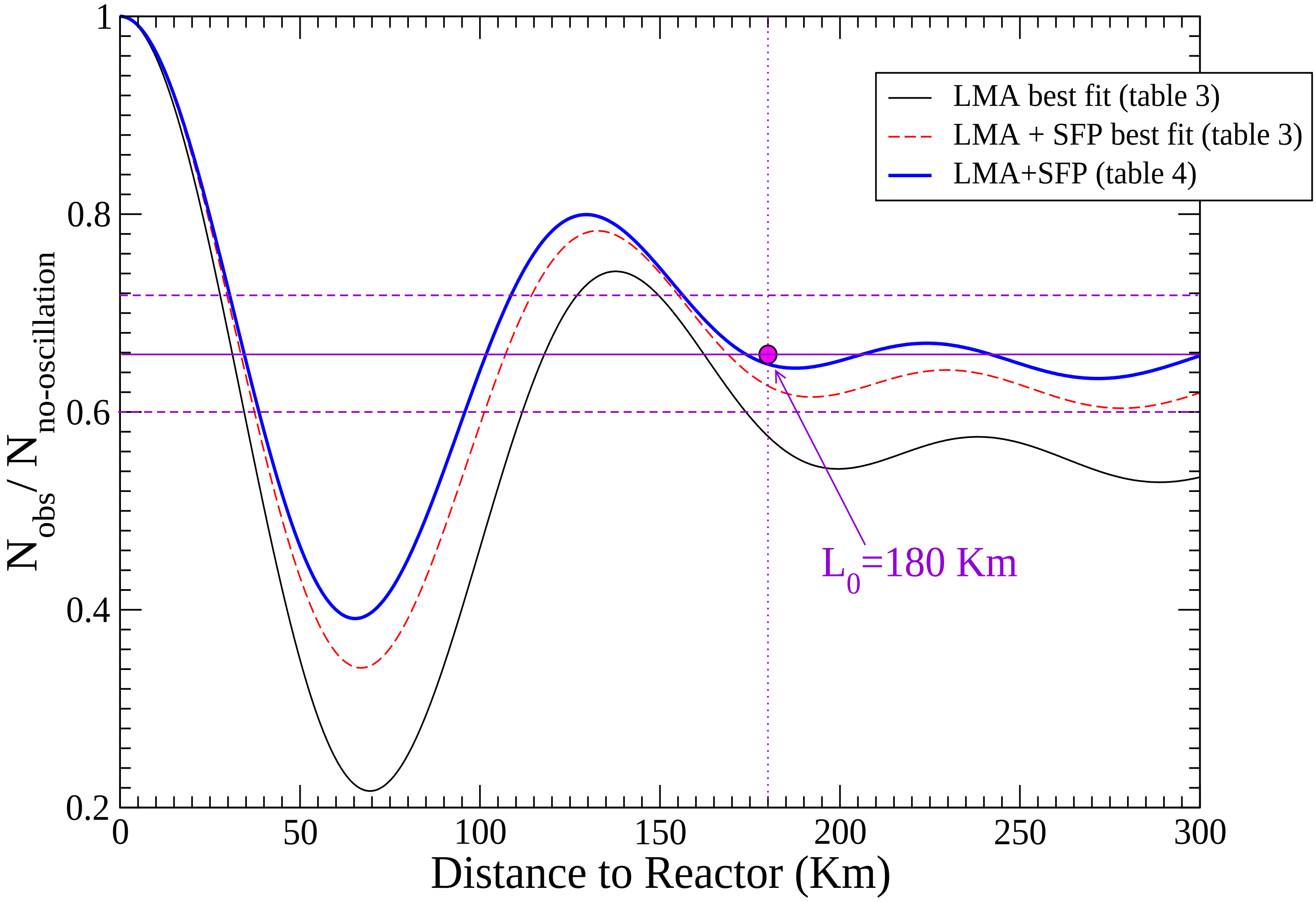
Consistency ... (continued)

(II) Antineutrino survival probability

$$P_{osc}(E_{\bar{\nu}}, L) = 1 - sin^2 2\theta sin^2 \left(\frac{\Delta m^2_{21} L}{4 E_{\bar{\nu}}} \right)$$



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$P_{LMA} = 0.576, \; P_{BF} = 0.623, \; P_{Table\ 4} = 0.651$

Compare with data: $P = 0.658 \pm 0.064$

Best of 3 fits is for the parameter choice of table 4

$$\Delta m^2_{21} = 8.4 \times 10^{-5} eV^2, \; tan^2\theta = 0.27$$

Recall that this parameter choice is the one leading to the Ga data sets which lie the furthest apart: 74.7 and 60.5 SNU.

A clear distinction between Table 4 scenario and LMA one will only be possible either with data improvement or average distances below 110-120km or both.

New reactors may come into operation while others cease and fluxes almost constantly change.

CONCLUSIONS

Investigating variability of $\odot$ ν flux is the most important challenge facing us in $\odot$ ν physics, now that LMA is known to play a major role for the solution to the SNP.

Variability of LE $\odot$ ν flux is hinted by Ga data, possibly in connection to $\odot$ activity, hence the importance of forthcoming LE experiments: KamLAND ($\odot$ mode), LENS, Borexino, ...

KamLAND (reactor $\bar{\nu}$ mode) will no doubt help telling ’pure LMA type’ solution from ’LMA+SFP type’ both through improvement of data accuracy and shift of effective reactor-detector distance.