Last time we talked about commercial fusion and why we can't use the same cycle as the sun to produce energy here.

Previously, we talked about the proton-proton cycle which gives about 26MeV of energy. Other cycles are possible too.

proton - proton

$^1H + ^1H \rightarrow ^2H + e^+ + \nu$ (1.18MeV) $E_{\nu_{max}} = 0.42MeV$

$^2H + ^1H \rightarrow ^3He + \gamma$ (5.49 MeV)

$^3He + ^3He \rightarrow ^4He + 2\,^1H$ + (12.86 MeV)

$^3He + ^4He \rightarrow ^7_4Be + \gamma$

$^7Be + e^- \rightarrow ^7_3Li + \nu_e$ $E_\nu = 0.86MeV$

$^1H + ^7Li \rightarrow ^4He + ^4He$

$^3He + ^4He \rightarrow ^7_4Be + \gamma$

$^1_1H + ^7Be \rightarrow ^8_5B + \gamma$

$^8_5B \rightarrow ^8_4B + e^+ + \nu_e$ $E_{\nu_{max}} = 14MeV$

$^8_4Be \rightarrow ^4He + ^4He$

assume suns energy is all from Proton - Proton 4×10^{38} protons/s consumed

or about 2×10^{38} neutrinos/s created

flux at earth is $\dfrac{2\times10^{38}/s}{4\pi(1.5\times10^{13}cm)^2} = 7\times10^{10}/cm^2s$

Thats alot!

To try and look at these decays, you can try to find a stable material that will undergo inverse electron capture

$$\nu_e \longrightarrow n \Rightarrow p + e^-$$

$\Rightarrow$ Rare $\Leftarrow$

1st technique, use a cleaning solution, deep underground (C_2Cl_4) $(B + Be\ \nu)$

$$\nu_e + {}^{37}_{17}Cl \Rightarrow {}^{37}_{18}Ar + e^-$$ $\left\{ \nu_e \text{ has to be a little above Q for this to work} \right\}$

in 100,000 gallons of this stuff, 1 Argon/day is produced (35 days later ($t_{1/2}$) Argon goes back via the electron capture)

problem - expect to see 3/day !

Other experiments

Kamiokande (Japan) - look @ B reaction neutrinos with cerenkov light ($\nu_e + e^- \Rightarrow \nu_e + e^-$) scattering
$\Rightarrow$ see $\frac{1}{2}$ of what they expect

Sage & Gallex $\Rightarrow$ Gallium $\nu_e + {}^{71}Ga \Rightarrow {}^{71}Ge + e^-$
See's all ν_e's

Here is the latest low down on the Solar Neutrino problem in detail.

Thats not the only trouble. If you've done the muon lifetime experiment, you know there are muons coming from the upper atomosphere. Muons are created when particles can beta decay with a Q > 105 MeV (won't happen for p → n !)

$$\pi^+ \to \mu^+ + \nu_\mu$$
$$\pi^- \to \mu^- + \bar{\nu}_\mu$$

&

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$
$$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$$

This means, for every μ created, should have a ν_μ, a $\bar{\nu}_\mu$ and a ν_e or $\bar{\nu}_e$

cerenkov detectors sensitive to these too

$$\text{expect } \# \quad \frac{\nu_\mu + \bar{\nu}_\mu}{\nu_e \text{ or } \bar{\nu}_e} = 2$$

see 1.4 !

Why is this so incredible?

Since the 1960's, the experimental evidence suggested that lepton number (why we have e^- & $\bar{\nu}_e$) must not only be conserved in a reaction, it must also be a lepton of the same kind! e.g. e, μ, τ

particle	e^-	e^+	ν_e	$\bar{\nu}_e$	μ^-	μ^+	ν_μ	$\bar{\nu}_\mu$	τ^-	τ^+	ν_τ	$\bar{\nu}_\tau$
L_e	+1	-1	+1	-1	0	0	0	0	0	0	0	0
L_μ	0	0	0	0	+1	-1	+1	-1	0	0	0	0
L_τ	0	0	0	0	0	0	0	0	+1	-1	+1	-1

so what?

So, if a ν_e can change into a ν_μ, there's not enough Q to make a muon in a nucleus. (looks like the ν_e's disappeared)

Can do similar tests with neutrino's from nuclear reactors (where they were first discovered) ⇒ looks at the rate of oscillation from one kind of neutrino into another

Have reactors at different distances from the detector. Look @ inverse β decay

$$\underset{\text{from } \beta \text{ decays in the reactor}}{\bar{\nu}_e} + p \Rightarrow e^+ + n$$

Table 1: Neutrino-producing reactions in the Sun (the first column) and their abbreviations (second column). The neutrino fluxes and event rates in chlorine and gallium solar-neutrino experiments predicted by Bahcall, Pinsonneault, and Basu [1] are listed in the third, fourth, and fifth columns respectively.

Reaction	Abbr.	BP2000 [1]		
		Flux ($\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$)	Cl (SNU*)	Ga (SNU*)
$pp \rightarrow d\, e^{+}\, \nu$	pp	$5.95(1.00^{+0.01}_{-0.01}) \times 10^{10}$	—	69.7
$pe^{-}p \rightarrow d\, \nu$	pep	$1.40(1.00^{+0.015}_{-0.015}) \times 10^{8}$	0.22	2.8
$^{3}\mathrm{He}\, p \rightarrow {}^{4}\mathrm{He}\, e^{+}\nu$	hep	9.3×10^{3}	0.04	0.1
$^{7}\mathrm{Be}\, e^{-} \rightarrow {}^{7}\mathrm{Li}\, \nu + (\gamma)$	$^{7}\mathrm{Be}$	$4.77(1.00^{+0.10}_{-0.10}) \times 10^{9}$	1.15	34.2
$^{8}\mathrm{B} \rightarrow {}^{8}\mathrm{Be}^{*}\, e^{+}\nu$	$^{8}\mathrm{B}$	$5.05(1.00^{+0.20}_{-0.16}) \times 10^{6}$	5.76	12.1
$^{13}\mathrm{N} \rightarrow {}^{13}\mathrm{C}\, e^{+}\nu$	$^{13}\mathrm{N}$	$5.48(1.00^{+0.21}_{-0.17}) \times 10^{8}$	0.09	3.4
$^{15}\mathrm{O} \rightarrow {}^{15}\mathrm{N}\, e^{+}\nu$	$^{15}\mathrm{O}$	$4.80(1.00^{+0.25}_{-0.19}) \times 10^{8}$	0.33	5.5
$^{17}\mathrm{F} \rightarrow {}^{17}\mathrm{O}\, e^{+}\nu$	$^{17}\mathrm{F}$	$5.63(1.00^{+0.25}_{-0.25}) \times 10^{6}$	0.0	0.1
Total			$7.6^{+1.3}_{-1.1}$	128^{+9}_{-7}

* 1 SNU (Solar Neutrino Unit) = 10^{-36} captures per atom per second.

3. *Solar Neutrino Experiments*

So far, seven solar-neutrino experiments have published

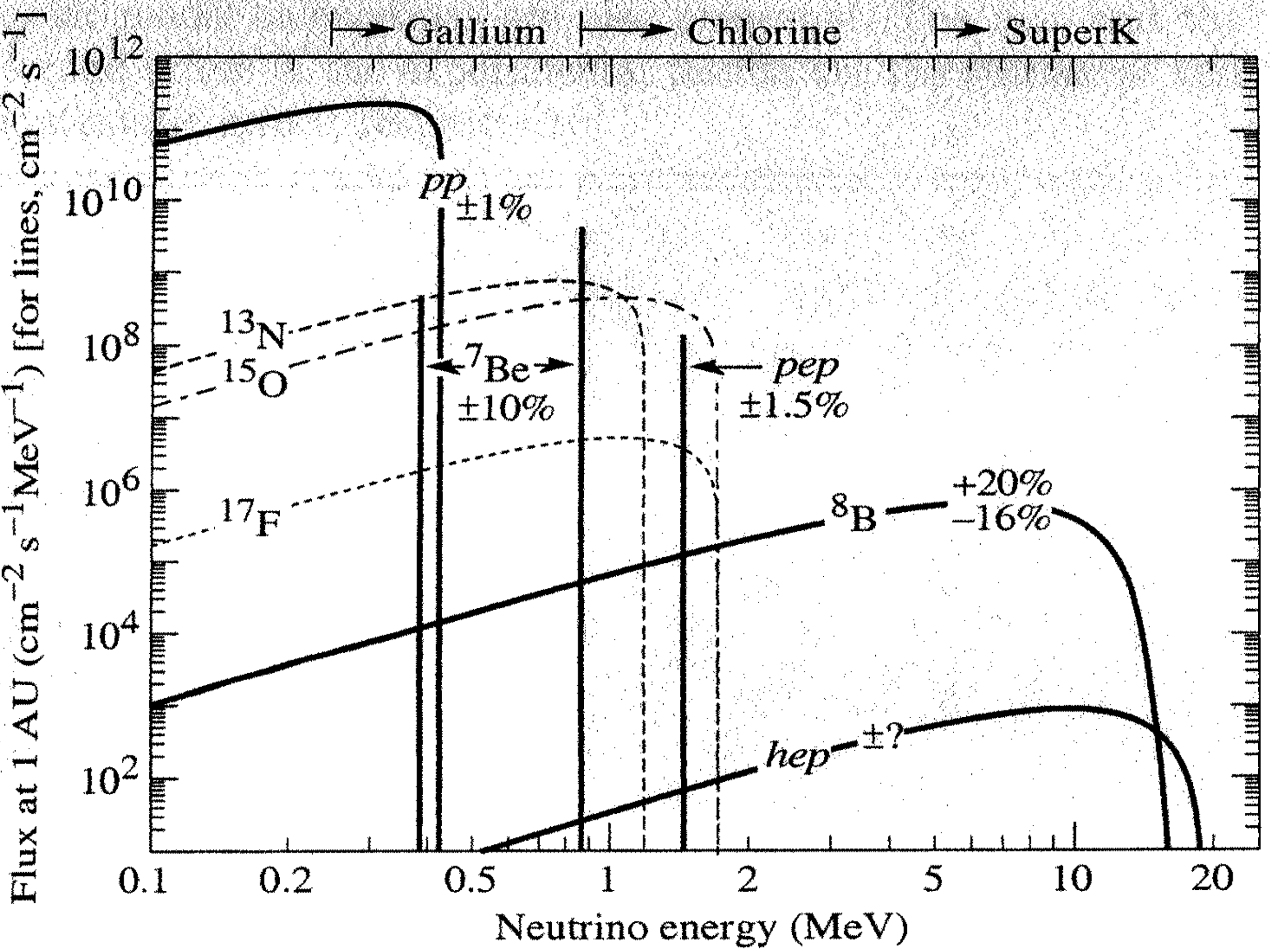

Figure 1: The solar neutrino spectrum predicted by the standard solar model. The neutrino fluxes from continuum sources are given in units of number $\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{MeV}^{-1}$ at one astronomical unit, and the line fluxes are given in number $\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Spectra for the *pp* chain, shown by the solid curves, are courtesy of J.N. Bahcall (2001). Spectra for the CNO chain are shown by the dotted curves, and are also courtesy of J.N. Bahcall (1995).

The Homestake chlorine experiment in USA uses the reaction

Table 2: Recent results from the seven solar-neutrino experiments and a comparison with standard solar-model predictions. Solar model calculations are also presented. The first and the second errors in the experimental results are the statistical and systematic errors, respectively.

	^{37}Cl$\rightarrow^{37}$Ar (SNU)	^{71}Ga$\rightarrow^{71}$Ge (SNU)	^{8}B ν flux (10^6cm^{-2}s^{-1})
Homestake			
(CLEVELAND 98)[5]	$2.56 \pm 0.16 \pm 0.16$	—	—
GALLEX			
(HAMPEL 99)[6]	—	$77.5 \pm 6.2^{+4.3}_{-4.7}$	—
GNO			
(ALTMANN 00)[7]	—	$65.8^{+10.2+3.4}_{-\ 9.6-3.6}$	—
SAGE			
(ABDURASHI...99B)[8]	—	$67.2^{+7.2+3.5}_{-7.0-3.0}$	—
Kamiokande			
(FUKUDA 96)[9]	—	—	$2.80 \pm 0.19 \pm 0.33^{\dagger}$
Super-Kamiokande			
(FUKUDA 01)[10]	—	—	$2.32 \pm 0.03^{+0.08}_{-0.07}{}^{\dagger}$
SNO			
(AHMAD 02)[11]	—	—	$1.76^{+0.06}_{-0.05} \pm 0.09^{\ddagger}$
	—	—	$2.39^{+0.24}_{-0.23} \pm 0.12^{\dagger}$
	—	—	$5.09^{+0.44+0.46}_{-0.43-0.43}{}^{*}$
(BAHCALL 01)[1]	$7.6^{+1.3}_{-1.1}$	128^{+9}_{-7}	$5.05(1.00^{+0.20}_{-0.16})$
(TURCK-CHIEZE 01)[2]	7.44 ± 0.96	127.8 ± 8.6	4.95 ± 0.72

[*] Flux measured via the neutral-current reaction.

[†] Flux measured via νe elastic scattering.

[‡] Flux measured via the charged-current reaction.

reaction products are chemically extracted and introduced into a low-background proportional counter, and are counted for a sufficiently long period to determine the exponentially decaying

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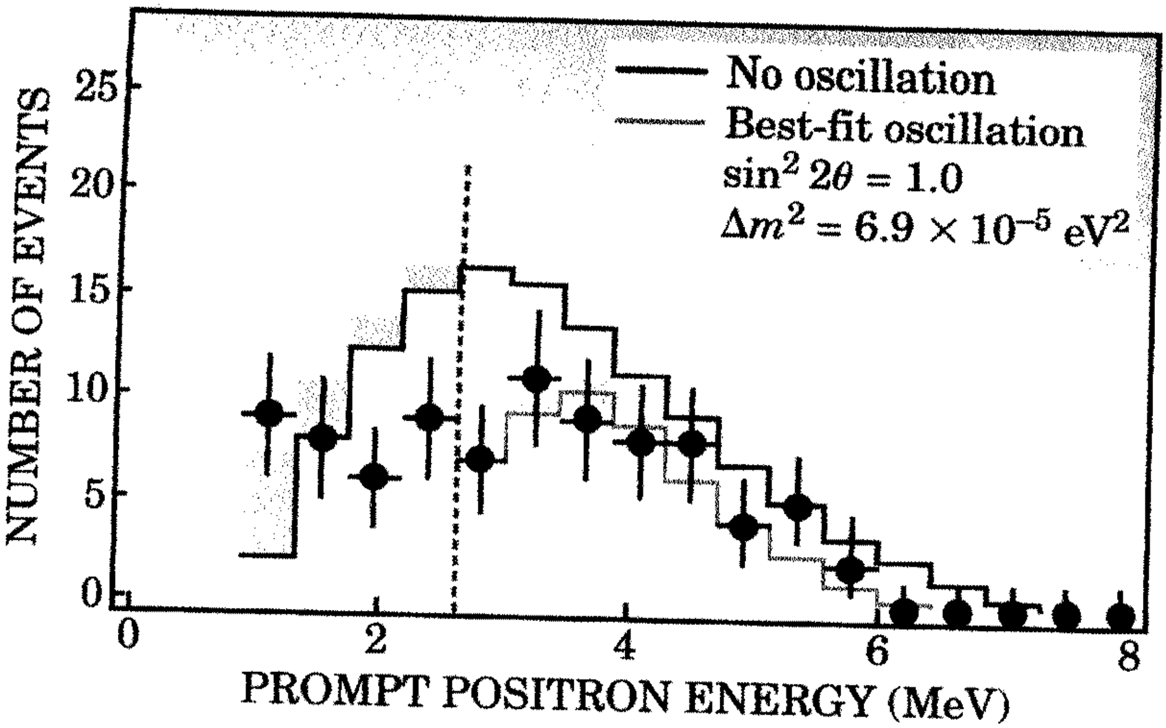

Energy distribution of neutrinos recorded by Kamland. The prompt positron scintillation energy approximates the incident neutrino energy minus 0.8 MeV. The black histogram shows what's expected in the absence of flavor oscillation. The shaded blue histogram is the prediction for the best oscillation-parameter fit to the Kamland data alone. The events with energies below the cut at 2.6 MeV are excluded because of the high probability of simulation (green shading) by radioactive backgrounds. (Adapted from ref. 1.)

posed," recalls Stuart Freedman (University of Calfornia, Berkeley), a spokesman for the collaboration's US contingent, "we had a hard time selling it to the community, because most of them were betting on the small-mixing-angle solution, to which Kamland wouldn't be sensitive."

In the first five months of data taking, the Kamland group found a total of 53 $\bar{\nu}_e$ events above an estimated

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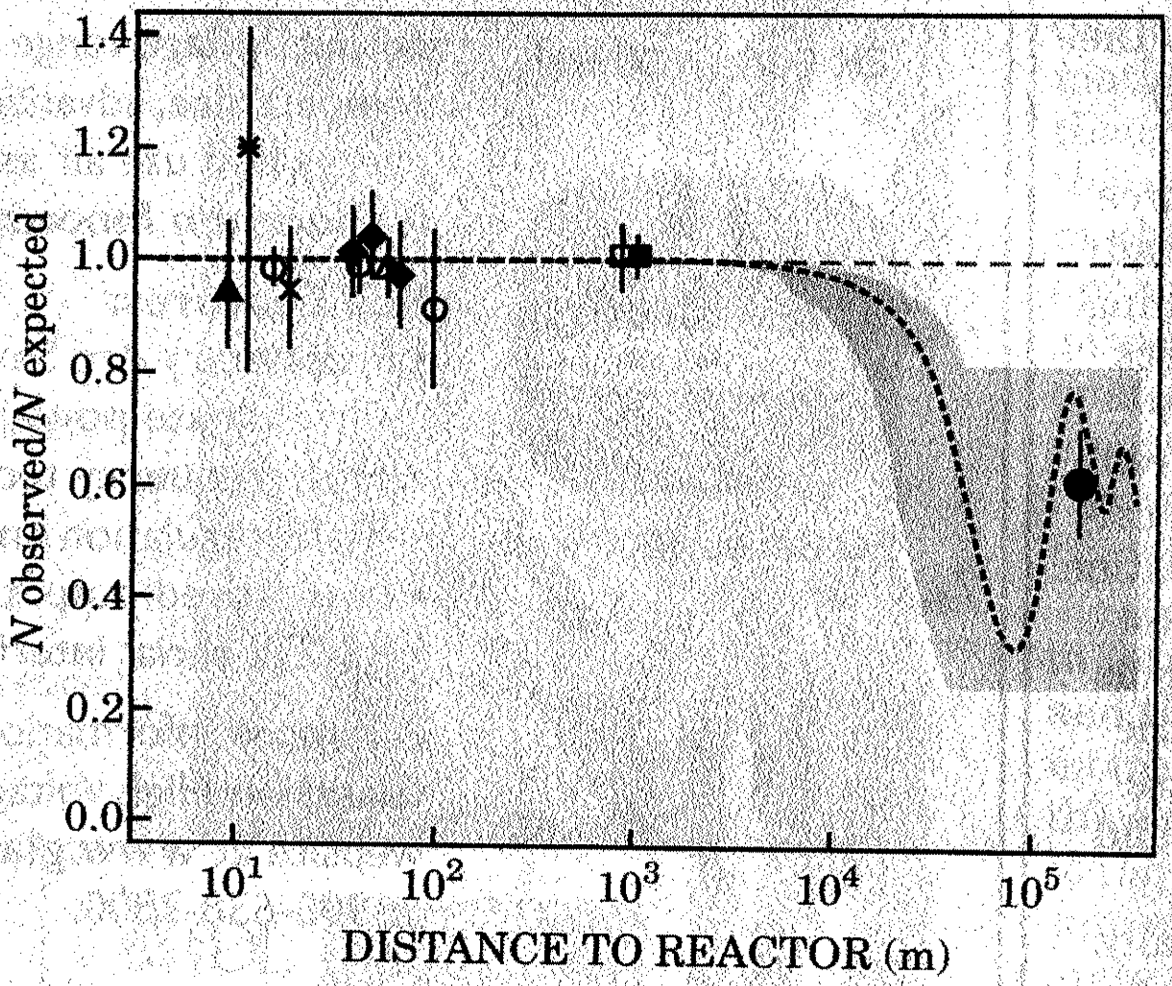

Shortfall of reactor neutrinos measured by various experiments. The ratio of observed number of neutrinos to the number expected in the absence of oscillation is plotted against the reactor's distance from the detector. For Kamland (the red point), the plotted distance is a flux-weighted average for 22 reactor sites. The dotted line is the prediction for oscillation parameters from a representative large-mixing-angle fit to the solar-neutrino data, and the shaded area indicates the range of such LMA fits. (Adapted from ref. 1.)

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