LSND and Other Sterile Neutrino Physics

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Conventional wisdom vs. sterile neutrinos

Solar neutrino connection (not conventional wisdom)

Conventional Wisdom Today

3 light active neutrinos only—no sterile neutrinos

Large-mixing-angle (LMA) solar neutrino solution

Total neutrino mass < 0.69 eV or largest $m_{\nu_i} < 0.23$ eV

From WMAP, 2df Galaxy Redshift Survey, Lyman α, etc.

All inputs have some problems (Abazajian, Dodelson)

Experimental Situation

LSND

New analysis removed problems; excess $\bar{\nu}_\mu \to \bar{\nu}_e$ 87.9±22.4±6.0

Unfortunately $\nu_\mu \to \nu_e$ data added to $\bar{\nu}_\mu \to \bar{\nu}_e$

$\nu_\mu \to \nu_e$ very difficult (1 signal instead of 2; no calibration)

Analysis optimized for $\bar{\nu}_\mu \to \bar{\nu}_e$

Do not use their Δm^2 vs. $\sin^2 2\theta$; use LSND-KARMEN plot

MiniBooNE

Have 40K ν events (7% of their goal)

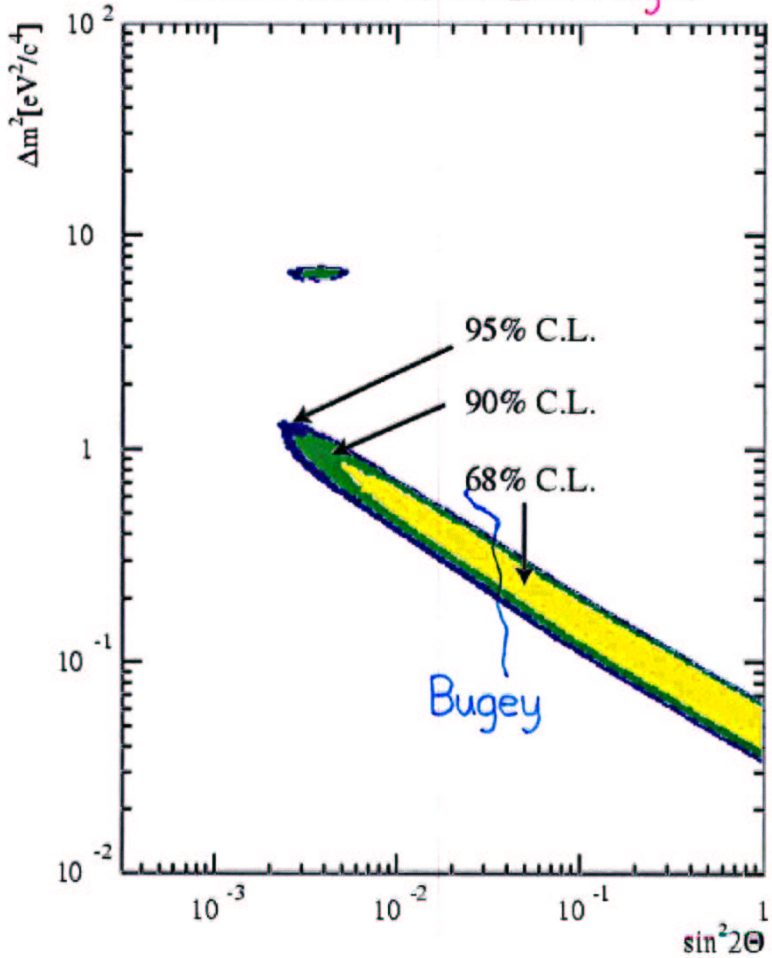
Beam was 1/10 of expected, now up, will be 1/2 in Spring

Guess: results in ~2 years

Need for sterile neutrino for supernova r-process

D.O.C., Fuller, Qian and McLaughlin, Fetter, Balantekin, Fuller

Joint LSND-KARMEN Analysis



Church, Eitel, Mills, Steidl

Case Against 2+2?

Negative view of LSND, ν_s, and especially 2+2

Peres, Smirnov sum rule: $\eta^s_\odot + \eta^s_{atm} = 1$ (η^s=fraction of ν_s)

Gonzalez-Garcia, Maltoni, Peña-Garay

Maltoni, Schwetz, Tórtola, Valle

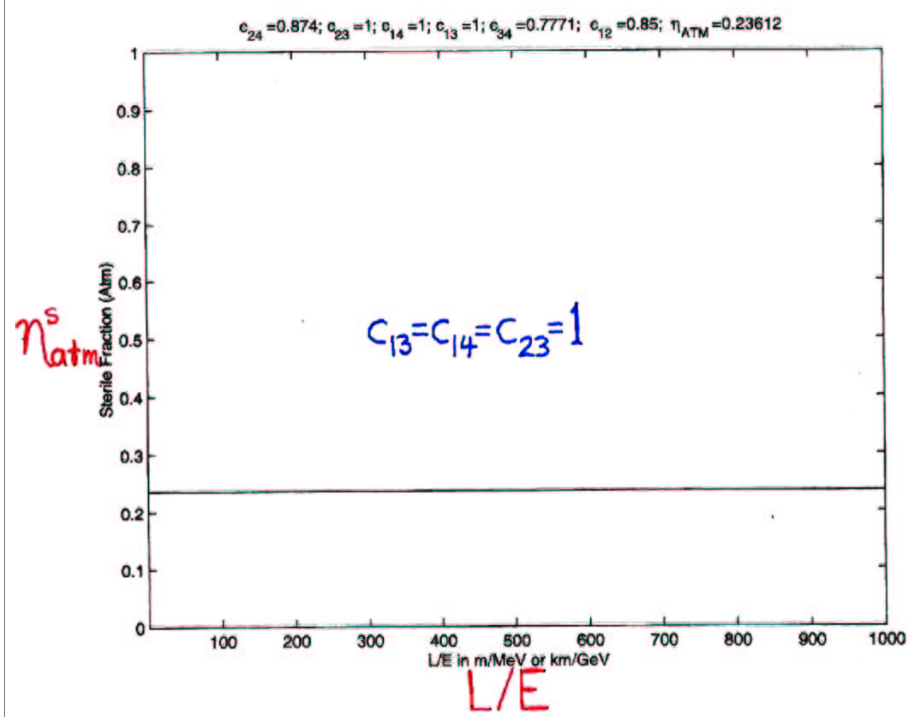
P-S put 4 zeros in mixing matrix; i.e., 3 angles are zero

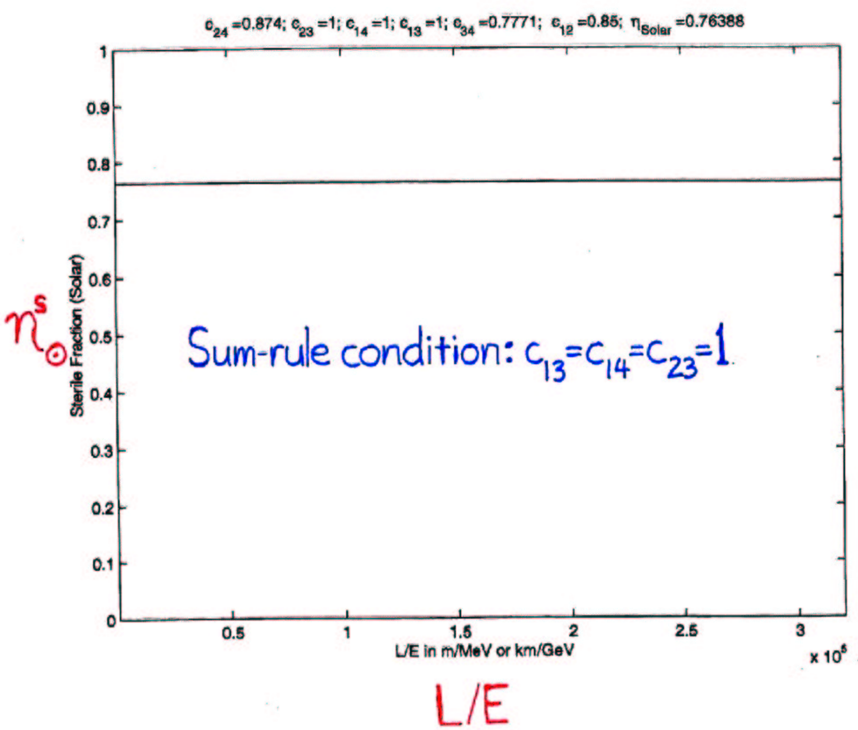
Consequence: ν_μ only in atmospheric pair; ν_e only in $\odot$ pair

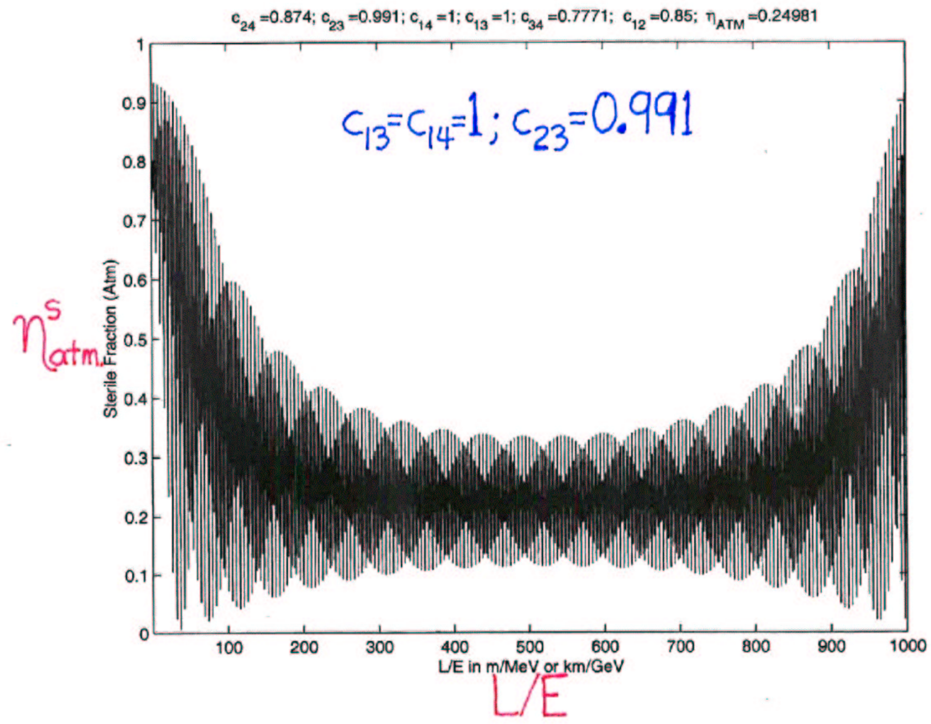
Limits show 4 terms small, but LSND needs ≥1 non-zero

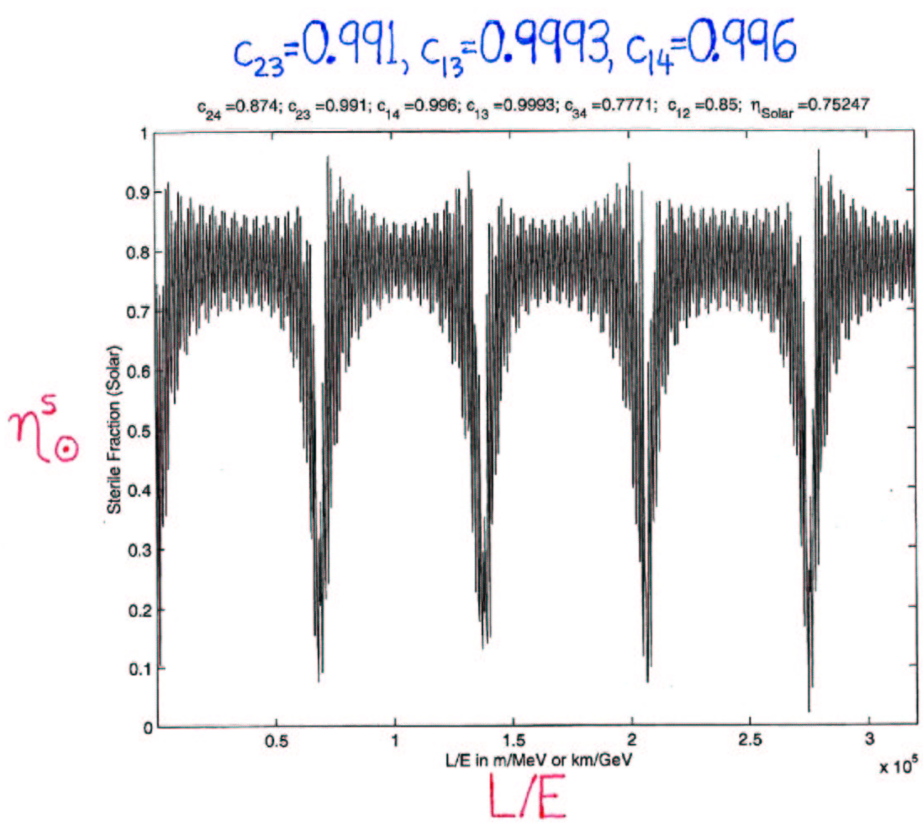
Tiny terms destroy sum rule D.O.C., Mohapatra, Yellin

Done much more completely by Päs, Song and Weiler

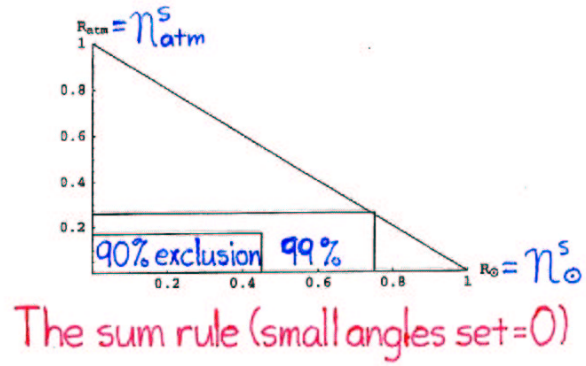



c24 =0.874; c23 =1; c14 =1; c13 =1; c34 =0.7771; c12 =0.85; ηSolar =0.76388
Sterile Fraction (Solar)
ηs⊙
Sum-rule condition: c13=c14=c23=1
L/E in m/MeV or km/GeV
x 10^5
L/E

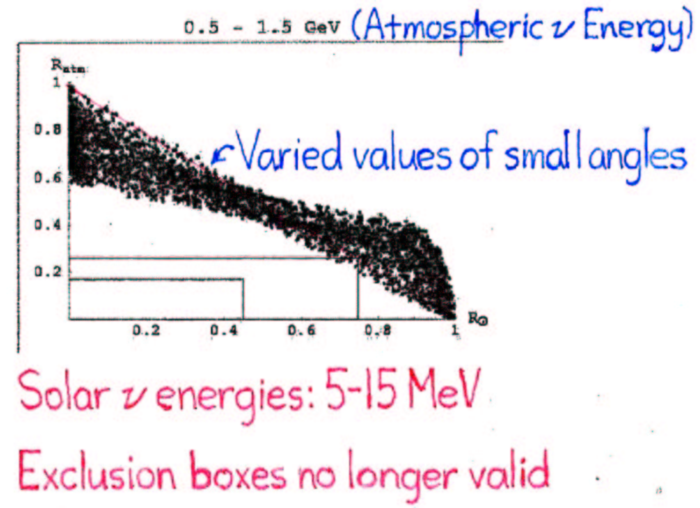

c24 =0.874; c23 =0.991; c14 =1; c13 =1; c34 =0.7771; c12 =0.85; ηATM =0.24981
c13=c14=1; c23=0.991
Sterile Fraction (Atm)
ηs atm.
L/E in m/MeV or km/GeV
L/E



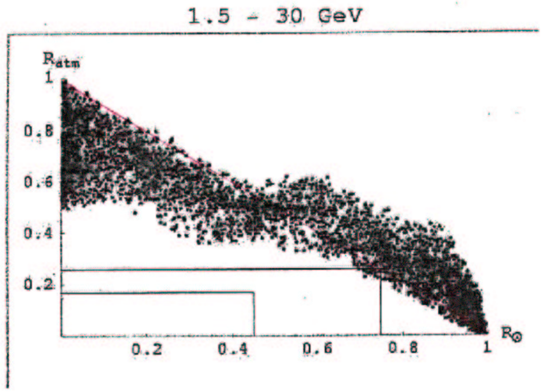
c23=0.991, c13=0.9993, c14=0.996
c24 =0.874; c23 =0.991; c14 =0.996; c13 =0.9993; c34 =0.7771; c12 =0.85; ηSolar =0.75247
Sterile Fraction (Solar)
L/E in m/MeV or km/GeV
x 10^5
L/E

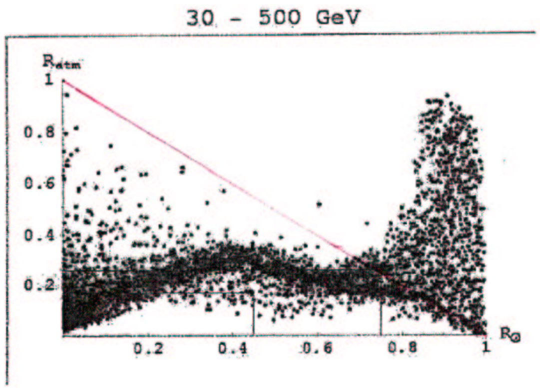


Ratm
0.2
0.4
0.6
0.8
1
R⊙
90% exclusion
99%
The sum rule (small angles set=0)



0.5 - 1.5 GeV (Atmospheric ν Energy)
Ratm
R⊙
Varied values of small angles
Solar ν energies: 5-15 MeV
Exclusion boxes no longer valid





The Puzzle

LMA solar neutrino solution

Important for preceding anti-(2+2) arguments

SNO/Super-Kamiokande→LMA→3 ν only

Widely believed, but is it right?

Solar neutrino flux variability

P. Sturrock, M. Weber, G. Walther, J. Scargle, M. Wheatland

Flux variation implies Resonant-Spin-Flavor Precession

KamLAND requires oscillation with $\Delta m^2 \sim 10^{-5} eV^2$

RSFP requires $\Delta m^2 \sim 10^{-8}$ eV^2 and small mixing

Please view the data with an open mind!

The Resonant–Spin-Flavor–Precession Solution

Invented ('88) for now-discredited solar-cycle dependence

RSFP needs neutrino magnetic moment for $\nu_e^L \to \nu_i^R$ ($i=\mu,\tau,s$)

Transition moment (likely for Majorana, possible for Dirac)

Models can give $\mu \sim 10^{-11}$–$10^{-12}\mu_B$ (Standard Model $\mu \sim \frac{m}{eV}10^{-19}$)

Like MSW, resonance is a density effect: $\Delta m^2/E = 2\sqrt{2}G_F N_{eff}$

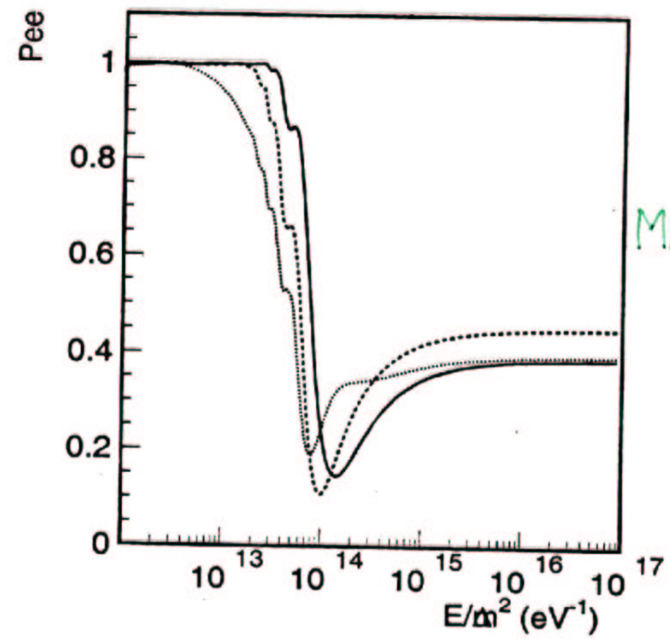
$N_{eff} = N_e - N_n$ (Majorana) or $N_e - N_n/2$ (Dirac); here $N_e \approx 6N_n$

Resonance adiabaticity: $\frac{2E}{\Delta m^2}(2\mu B_\perp)^2 [N_{eff}(\frac{dN_{eff}}{dr})^{-1}] > 1$

Cf. MSW: $N_{eff} = N_e/\cos 2\theta_0$ (∴ it is close but at larger r)

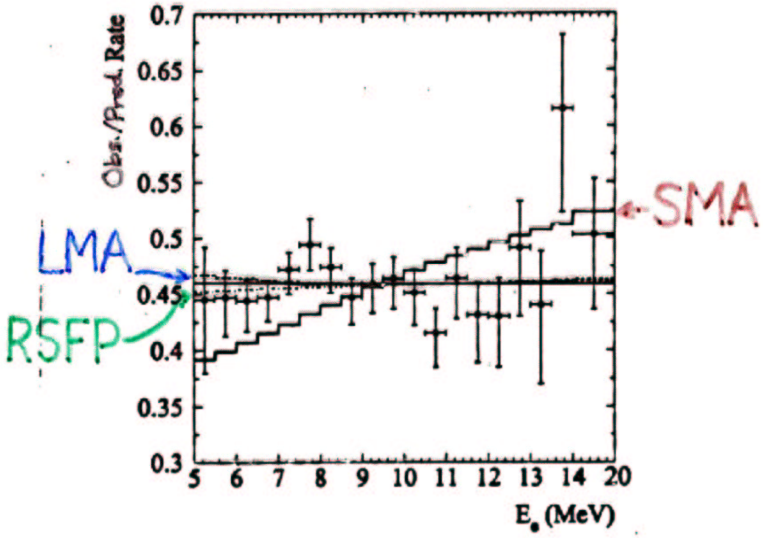
RSFP fits to data require Majorana neutrinos

ν_e^L Survival Probabilities for 3 $B_\perp$ Fields vs. $E_\nu/\Delta m^2$



Choosing the dip at 0.86 MeV (^{7}Be) makes $\Delta m^2 \sim 10^{-8} eV^2$

Super-Kamiokande Spectrum



Work of Sturrock and Collaborators

Homestake

Are Cl data compatible with a constant ν_e flux?

- Compared 10^3 108-run simulated data sequences
- Constant flux rejected at ≳99.9% confidence

Time-power spectrum analysis—what frequencies?

- 12.88 y^{-1} (28.4 d) frequency dominant at 97% CL
- 10.88, 11.88, 13.88, 14.88 sidebands due to Sun's tilt adds conf.
- ∴ modulating field localized in latitude; seen directly at 98% CL

SAGE and GALLEX-GNO

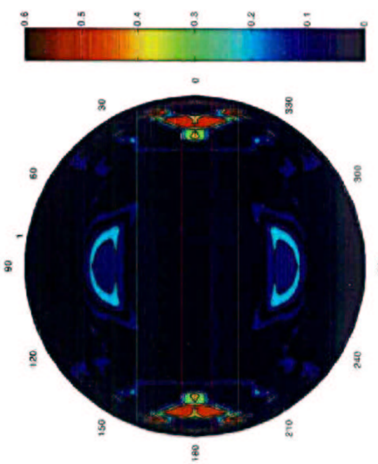
Also 12.88, but 13.59 y^{-1} (26.9 d) dominant and equatorial

Joint analysis with Homestake: stronger 13.59 evidence

Same frequencies seen in X-rays (SXT on Yohkoh spacecraft)

- 12.86 ± 0.02 y^{-1} at high latitudes
- 13.55 ± 0.02 y^{-1} at the equator

GALLEX-GNO



- Rotational Modulation Statistic formed from GALLEX-GNO spectrum and SOHO-MDI rotation profiles
- Probable location of modulating region shown in red

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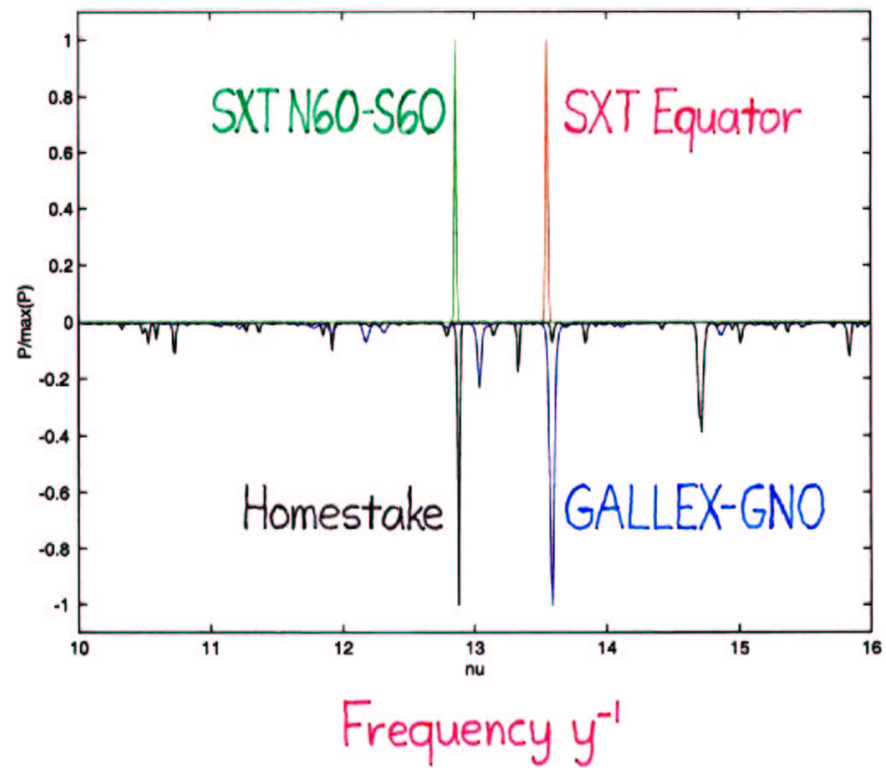
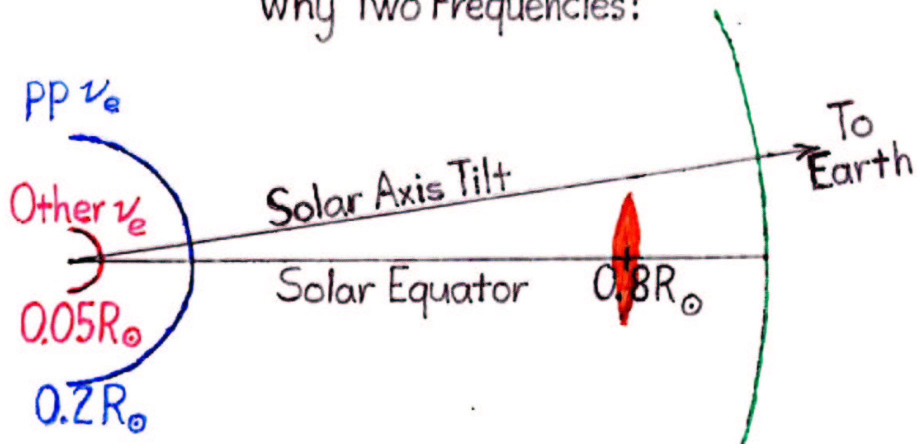
Time Spectra Normalized Probability Distribution Functions



Why Two Frequencies?



SAGE/GALLEX-GNO

Mainly pp ν_e (^{7}Be suppressed) produced at $\sim 0.2R_\odot$

Most ν_e modulated by equatorial field rotation ($13.6y^{-1}$)

Homestake

ν_e made near Sun's center at $\sim 0.05\ R_\odot$

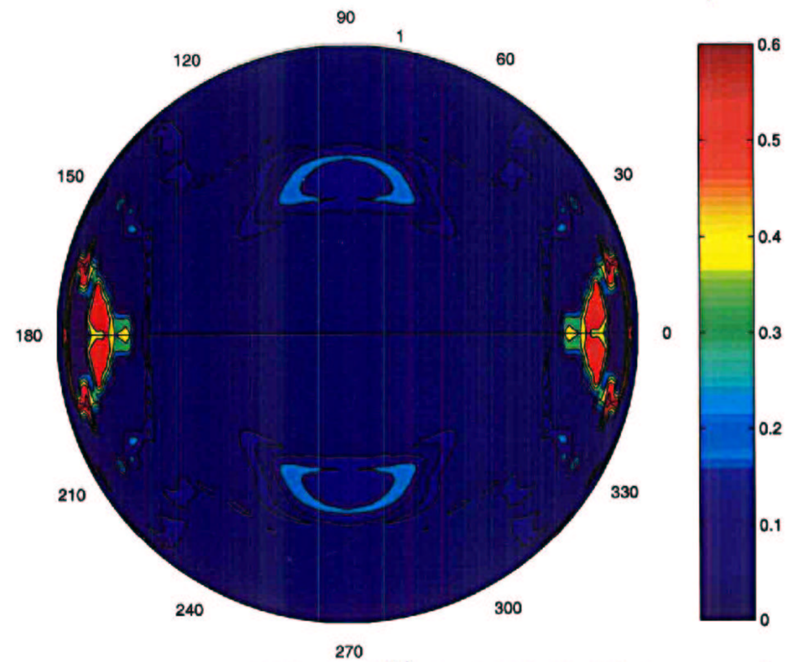
$7°$ axis tilt makes most ν_e miss equatorial field

Higher latitude field modulates most ν_e as it rotates

Get mainly $12.9\ y^{-1}$ rate

Locating the $13.6\ y^{-1}$ Modulation in the Sun

Use GALLEX data with SOHO-MDI rotation profiles

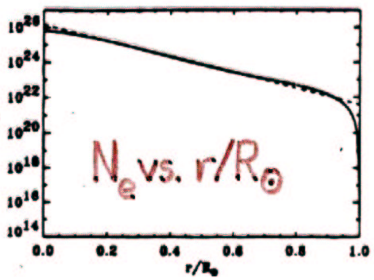


Resonance (red) in $\Xi(r,\lambda)=\int_{\nu_a}^{\nu_b} S(\nu)P(\nu|r,\lambda)d\nu$ gives location

Location of the Resonance

SOHO/MDI helioseismology convoluted with GALLEX-GNO data

- SOHO/MDI(ν,λ) matching Ga(ν)
- Near equator at $r=0.8R_\odot$
- Locating $\nu=13.6\,y^{-1}$ determines $\frac{\Delta m^2}{E}$
- $\frac{\Delta m^2}{E}=2\sqrt{2}G_F(N_e-N_n)=1\times10^{-14}eV$



- Recall ν_e survival probability for RSFP fit
- Exactly the $\Delta m^2/E$ needed
- Exponential (N_e-N_n) vs. r could give very different $\Delta m^2/E$

RSFP resonance for $12.9\,y^{-1}$ must be at $r>0.8R_\odot$

- Higher latitudes
- Either radiative-zone field or latitudinal wave
- Recall 12.9, 13.6 y^{-1} frequencies seen out to corona

Some Evidence for Rieger Frequencies

Known for 20 years in solar flares, sunspots, etc.

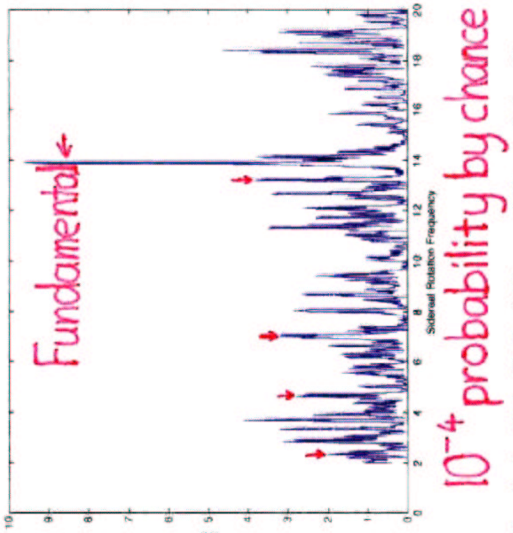
- 156-day period long known
- 78- and 52-day periods also seen

Identify with r modes (latitudinal motion) seen on earth

- $\nu(l,m)=\frac{2m\nu_R}{l(l+1)}$, for ν_R=sidereal frequency=synodic+1
- Rotating fluid sphere has $l\geq2$
- For $l=3$, expect to see ν_R-1, $\nu_R/6$, $\nu_R/3$, $\nu_R/2$ (periods above)

For $\nu_R=12.88\,y^{-1}+1$, get Rieger periods

Homestake and GALLEX-GNO



- Joint Spectrum Statistic (4th Order) Formed from Joint Spectrum Statistic (2nd Order) of Homestake and GALLEX-GNO
- Combining S(nu - 1), S(nu/2), S(nu/3), and S(nu/6)
- These represent the synodic rotation frequency and the l = 3, m = 1,2,3 R-mode frequencies

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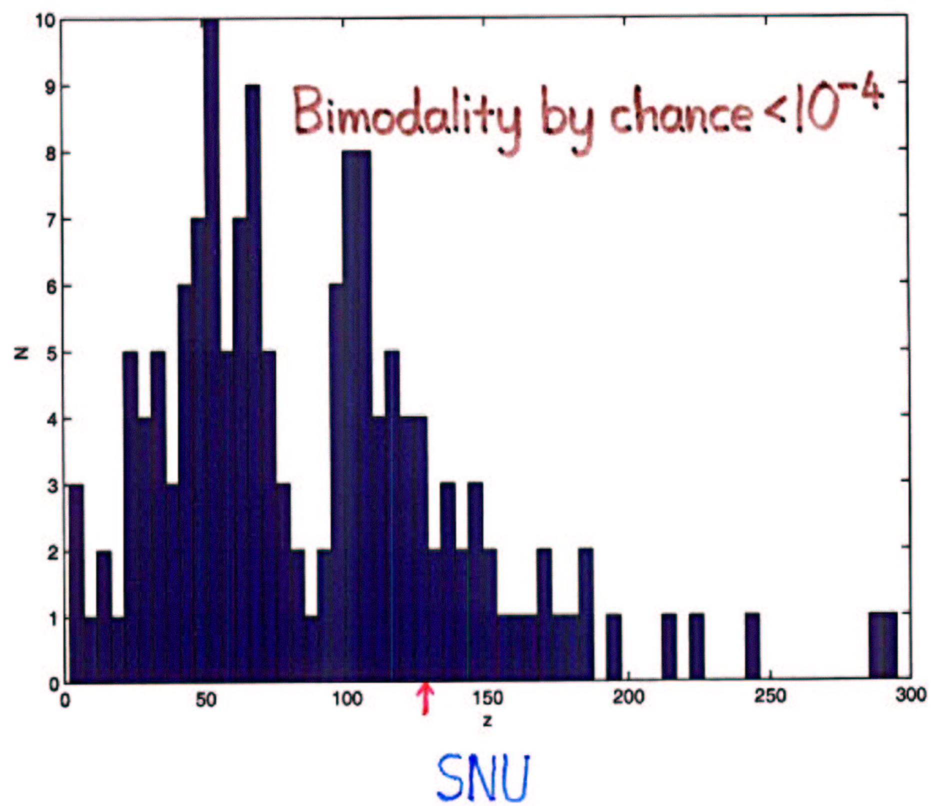
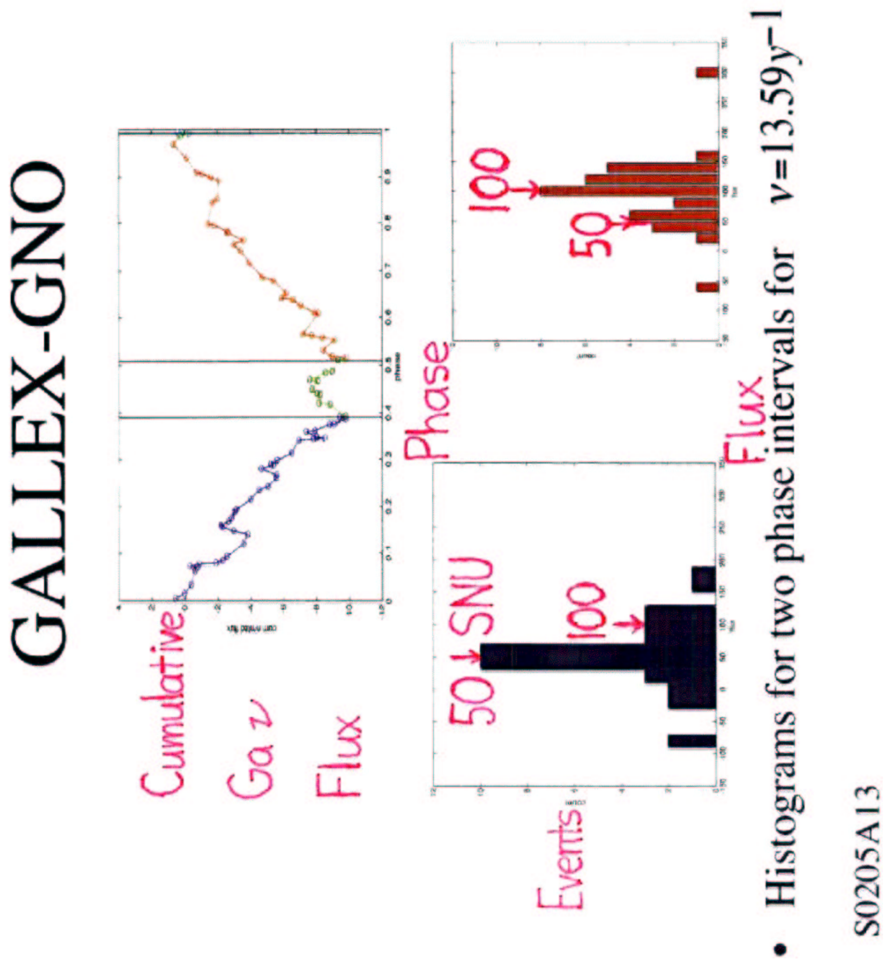
GALLEX-GNO+SAGE Event Distribution

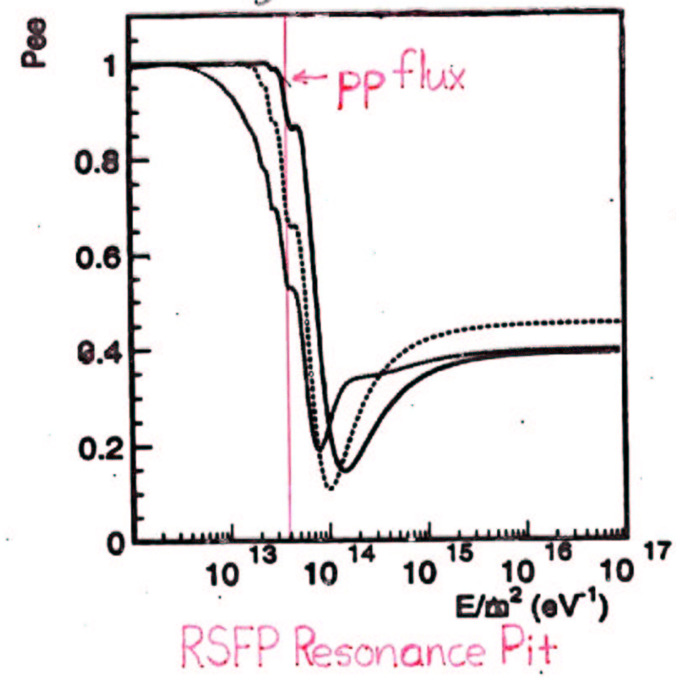


For no ν oscillations, expect 128^{+9}_{-7} SNU

Lower peak is half that; upper peak is 0.8-0.9



Understanding a Bimodal ν Flux Distribution



GALLEX flux dominated by pp ν_e (^{7}Be suppressed)

Rate determined by spectrum-pit overlap

$B_\perp$ change can give factor of 2 drop in rate (lower peak~50)

Always reduction of ^{8}B, ^{15}O, etc. (∴ upper peak~100)

Expected Convection-Zone Field Variation

Radiative-zone field can have spatial but not time variation

hep-ph/0202095

Convection-zone field should change at solar max. and min.

How would neutrinos show this field change with time?

If transitions stay adiabatic, field magnitude change unseen

Shape of field can affect pp neutrino rate (Ga)

Most sensitive: resonance-pit edge (rate; $13.6y^{-1}$ amount)

Change of azimuthal symmetry of $B_\perp$ changes modulation

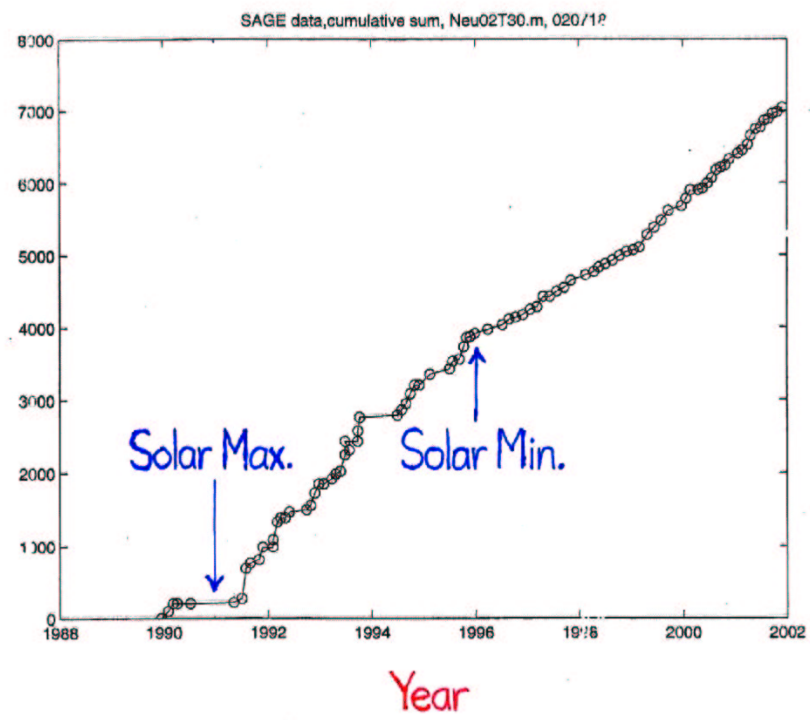
1989.6 solar maximum to the 1996.8 solar minimum

When $13.6\,y^{-1}$ is observed in GALLEX

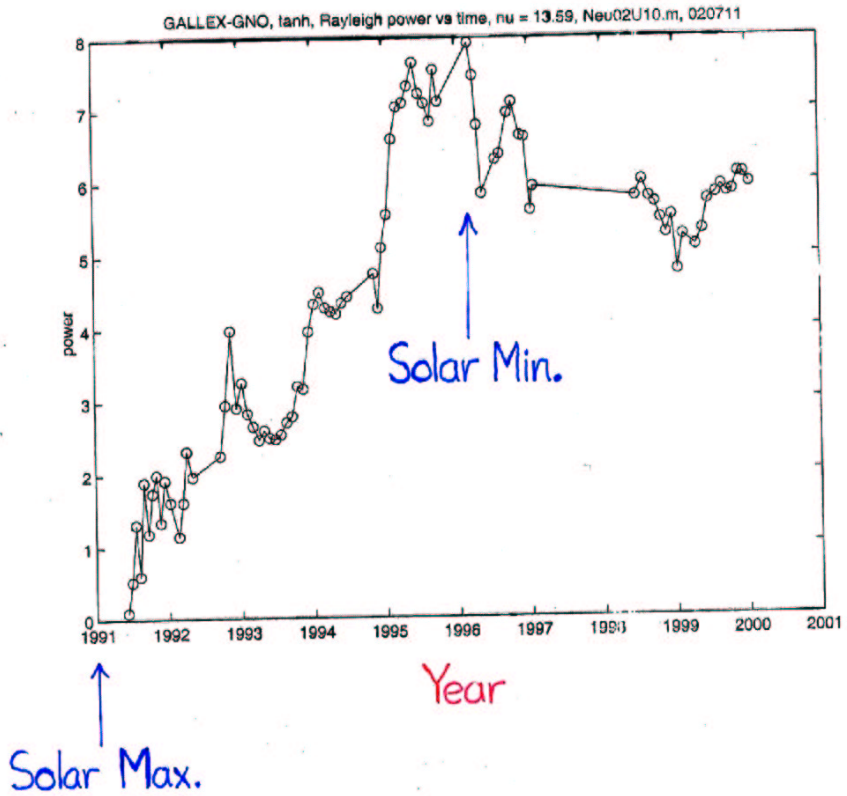
Also when main buildup of $12.9\,y^{-1}$ in Homestake

And when those frequencies were seen in SXT X-rays

SAGE: Cumulative Neutrino Flux



GALLEX-GNO: Cumulative Power of $\nu=13.59\ y^{-1}$



Super-Kamiokande Time Data

Predicting the result

SK started at about the 1996.8 solar minimum

Homestake (like SK, saw mainly $^8B\ \nu$) stopped then

SK ran from 5/96 to 7/01, just beyond solar maximum

No way from other data to predict SK time result

SK data

184 bins of 10 days each

Regular binning gives timing peak at $35.98\ y^{-1}$ (10.15 d)

Power spectrum big peak at $26.57\ y^{-1}$, next at $9.41\ y^{-1}$

$26.57+9.41=35.98$, so 9.41 is an alias Also, Milsztajn

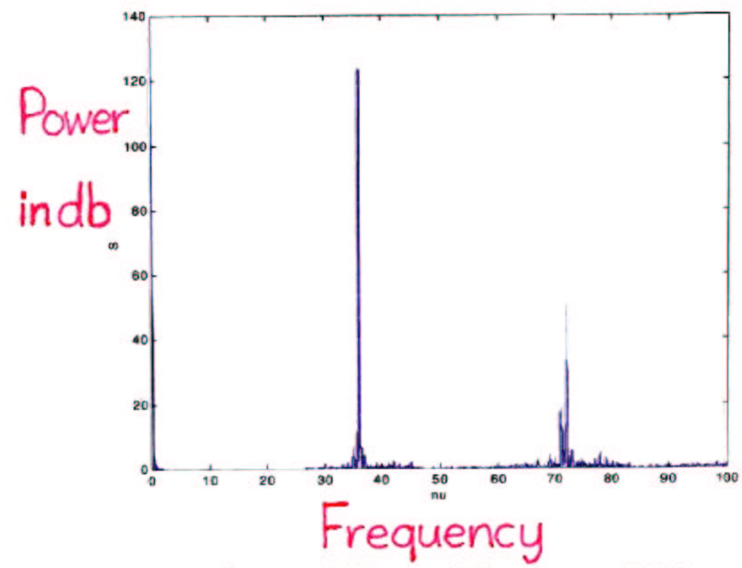
Tested by spectrum subtraction

$26.57\ y^{-1}$ frequency

Some seen in Ga, Cl data

2 circumferentially weak B-field regions

SUPER-KAMIOKANDE



Power Spectrum formed from Timing of Data Bins
Strong Periodicity at 35.98 cpy

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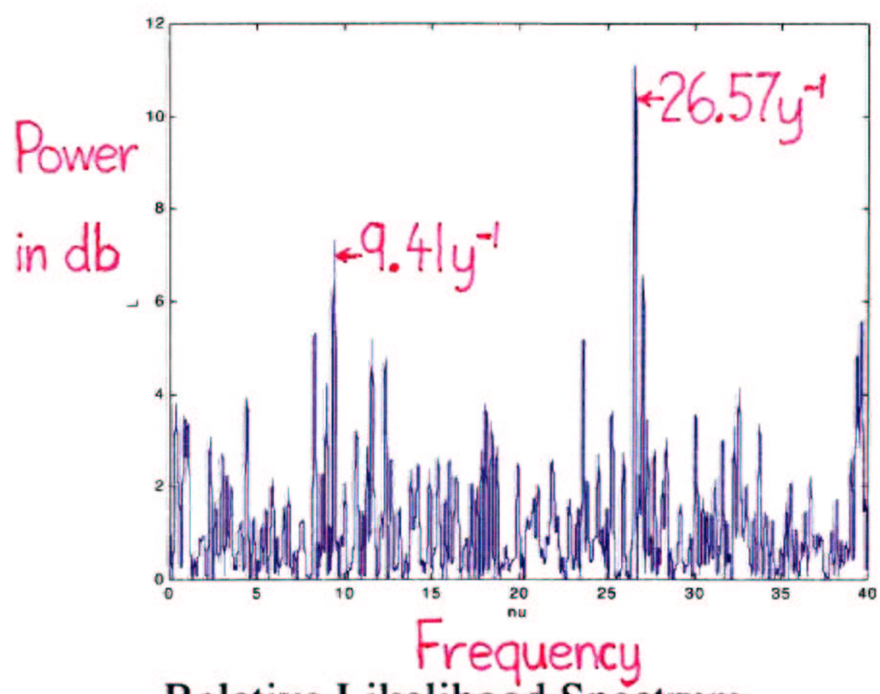
SUPER-KAMIOKANDE



Relative Likelihood Spectrum

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Conclusions

Sterile neutrinos can exist in 3+1 and even 2+2

Evidence for solar neutrino flux variability very strong

Observations can be understood in RSFP model

How to reconcile flux variability with KamLAND

- SFP subdominant to LMA (Akhmedov, Pulido)
- Possibilities for RSFP

12A WWW.MERCURYNEWS.COM

Tokyo residents face threat of summer power shortage

SAFETY COVERUP CLOSES 13 OF 17 NUCLEAR PLANTS

By Michael Zielenziger
Mercury News Tokyo Bureau

TOKYO — Tokyo's leading utility is pleading for customers to conserve electricity after the discovery of a safety coverup last year forced it to shut 13 of the company's 17 nuclear power plants for mandatory inspections.

Officials of Tokyo Electric Power Co. worry that a severe cold snap in March, when snowstorms frequently buffet metropolitan Tokyo, could leave the utility with no surplus generating capacity. The utility serves 17 million customers in the Tokyo metropolitan region, with 40 percent of its generating capacity relying on nuclear energy.

The utility's last four operating nuclear power reactors will be shut down in April for similar inspections. If none of the 17 nuclear plants can be reopened before the start of summer, city residents might be forced to suffer brownouts and go without air conditioning for long stretches, because of the shortage of electricity.

"It could be a very severe situation," said Kazuyoshi Takahara, a representative for Tokyo Electric Power.

Tokyo's major utility has been forced to close its reactors, one by one, after it was discovered that the operator had manipulated data and faked safety inspections to conceal cracks in core equipment at its nuclear reactors.

In one case, TEPCO officials fabricated the readings for the airtight seals of one of its containment buildings, designed as a last-resort to prevent dangerous radiation from leaking from a nuclear power plant into the surrounding environment. In another, officials failed to disclose cracks in pipes that carry coolant to prevent the nuclear core from overheating.

The utility was also accused of keeping two sets of inspection reports — an internal version, containing accurate data, and a doctored version for government regulators.

In a series of newspaper and TV advertisements, TEPCO has repeatedly apologized for endangering its own credibility, while also pleading for understanding from Japanese consumers as it requests conservation.

"We cannot make any excuse," one of the ads said. "We sincerely apologize. Because we thought we should never stop generating power, we couldn't foresee the most important thing. We did not realize the real responsibility to which you have entrusted us."

Utility executives say that during the summer peak season, consumers demand about 64,300 megawatts of power, but that if none of the nuclear facilities come back online they'll be about 10,000 megawatts short.

Officials say it is impossible to know when, or if, the reactors will restart, since they must win approval of local officials who are now angry about the safety coverups. Uniformed utility executives have visited more than 30,000 households in Niigata prefecture, where some of the plants are located, to apologize for the coverups and beg forgiveness.

Contact Michael Zielenziger at mzielenziger@krwashington.com.