

CAN THE FUTURE OF NEUTRINO PHYSICS COMPARE WITH ITS PAST?

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... SUMMARIZING THE MARVELLOUS ACCOMPLISHMENTS
OF THE PAST DECADE & SKETCHING OUR CURRENT
UNDERSTANDING OF NEUTRINOS & CONCLUDING WITH A
PERSONAL LIST OF THE CHALLENGES REMAINING, PUT IN
ORDER OF URGENCY BY THE SPEAKER, WHOSE
MATERIAL BEING MORE PROVOCATIVE THAN NOVEL,
OFFERS AN APOLOGY FOR HIS INEVITABLE OMISSIONS,
DISTORTIONS, INEQUITIES AND INIQUITIES
RESULTING FROM HIS IGNORANCE OR INFIRMITUDE,
INATTENTION OR INEPTITUDE, AND HIS
INEXCUSABLE ARROGANCE.

THE WONDERFUL DECADE PAST

- 1994 LSND EXP'T, which for 2 REASONS shd. be OMITTED
- 1998 SUPER-K SOLVES the ATMOSPHERIC ν ANOMALY (FIRST NOTED BY IMB & KAMIOKA)
- 1999 CHOOZ SETS CURRENT LIMIT ON θ_{13} .
- 2000 DONUT SEES $\bar{\nu}$ NEUTRINOS AT FNAL.
- 2003 SNO DECISIVELY SOLVES SOLAR ν ANOMALY (AIDED & ABETTED BY SUPER-K, K, G₂, C1)
- 2003 KAMLAND SEES REACTOR ν DISAPPEARANCE
- 2005 " REPORTS detection of GEO (ANTI) ν 's.

PLEASE FORGIVE MY OMISSIONS AND DISTORTIONS

ALSO:

- 1995 NOBEL: F. REINES for the detection of the ν ⁴⁰ YEARS AFTERWARD
- 2002 NOBEL: R. DAVIS + M. KOSHBAR for their CONTR. to Astroph. IN PARTICULAR, the detection of COSMIC ν 's
- 2003 FERMI: J. BARHOALL & R. DAVIS for their INNOVATIVE RESEARCH in Astroph. LEADING to a REVOLUTION in UNDERSTANDING the PROPERTIES [of NEUTRINOS.]

WHAT HAVE WE LEARNED?

1. THERE SEEM TO BE 3 ACTIVE (WEAK DOUBLET) NEUTRINO STATES, AT LEAST TWO WITH SMALL MASSES.
2. MASSES + MIXINGS SEEM DESCRIBED BY A 3×3 MATRIX INVOLVING PRECISELY 6 OBSERVABLE PARAMETERS:
 θ_{12} (SOLAR), θ_{23} (ATM), θ_{13} (SUBDOM)
 $\Delta_{\text{SOLAR}} = m_1^2 - m_2^2$, $\Delta_{\text{ATM}} = m_2^2 - m_3^2$, δ (CP VIOL.)
3. NOTHING (EXCEPT LSND) SUGGESTS OR REQUIRES MIXING OF ν 'S W/ STERILE LIGHT SINGLET STATES.
4. NEUTRINO MASSES MAY JUST AS WELL BE MAJORITY (L-VIOLATING) AS DIRAC (L-CONSERVING). INTERMEDIATE POSSIBILITIES ARE DISFAVORED.
5. ALTHOUGH HUNDREDS OF PAPERS ARE WRITTEN, WE KNOW LITTLE ABOUT THE ORIGIN OF ν MASSES AND NOTHING ABOUT WHY THE PARAMETERS ARE WHAT THEY ARE.
6. NEUTRINO PROPAGATION ENABLES THE MOST SENSITIVE SEARCH FOR FLAVOR-DEPENDENT LORENTZ-SYMMETRY VIOLATION. NO EFFECT HAS BEEN SEEN.

A LIST OF TASKS REMAINING,
IN ORDER OF URGENCY
AS I BELIEVE

#1 (pour rendre UNE POLITESSE)

is THE STUDY OF GEONEUTRINOS

ANTI ν 's prod. by β decays WITHIN OUR PLANET.
WHY OUR EARTH SHD THIS BE INTERESTING? :-)

- BECAUSE THEIR PRECISE MEASUREMENT IS A DAUNTING AND DIFFICULT CHALLENGE FOR EXPERIMENTERS WHO THRIVE ON DOING THE NEAR IMPOSSIBLE.
- BECAUSE THEORISTS WRITE LOTS OF PAPERS ABOUT GEO- ν 's. EDER & MARX IN THE '60s; 13 MORE (INCLUDING ME) IN THE '80s.
- TO DETERMINE HOW U AND Th ARE DISTRIBUTED WITHIN EARTH.
- TO SEE WHETHER THERE'S A NUCLEAR REACTOR IN EARTH'S CORE.
- FOR MORE REASONS, KINDLY LISTEN TO THE LECTURES IN THIS CONFERENCE DEVOTED TO THE STUDY OF GEONEUTRINOS.

#2

NO ν $\beta\beta$ DECAY

- IF SEEN, WE WOULD KNOW THAT LEPTON NUMBER IS NOT CONSERVED: A MAJOR DISCOVERY
- IF SEEN, NEUTRINOS ARE LIKELY TO HAVE MAJORANA MASSES
- IF SEEN AND MEASURED, WE WILL HAVE A QUANT. TEST OF THE SIMPLIST PICT. OF ν MASSES & MIXING.
- ABSENCE AT A SUFFICIENT LEVEL WOULD SUGGEST OR REQUIRE DIRAC NEUTRINO MASSES.

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- IN 2001, KLAPDOR et al CLAIMED "EVIDENCE FOR NNPS" [Mod Phys Lett A16, 2109]. BUT, IN 2002, ARBETH et al. RESP. THAT "THERE IS NO BASIS TO [THIS CLAIM]." [Mod. Phys. Lett. A17, 1475]. AND SO?

- SEVERAL HIGH-PRECISION EXPTS ON DIFF'T ISOTOPES ARE URGENTLY NEEDED.
 - EXTRAORDINARY DISCOVERIES REQUIRE DECISIVE AND MULTIPLE PROOFS
 - NUCLEAR MS, ARE POORLY KNOWN. STUDIES WITH SEVERAL NOCLIDES NEEDED TO PIN DOWN OR CONSTRAIN MS

#3

SETTING THE PARAMETERS

of the 'MINIMAL MODEL'

a. θ_{13} , the subdom. angle, must be known to pursue CP violation in the D sector.
The current (Chooz) bound is:

$$\sin^2(2\theta_{13}) \leq 0.17$$

WE MUST DO (MUCH) BETTER:

MINOS/NUMI	MAY ACHIEVE	≤ 0.6	by ?
DOUBLE CHOOZ	" "	≤ 0.5	" '08
" "	" "	≤ 0.5	" '11
DAYA BAY*	" "	≤ 0.1	" '08

*Not yet approved in China. They are enthusiastic for US (etc) collaboration.

b. THE OTHER ANGLES.

How close is θ_{12} to 30° ?

How close is θ_{23} to 45° ?

[As well as How close is θ_{13} to 0° ?

a. THE SQUARED MASS DIFFERENCES

$$|\Delta_{23}| = 2-4 \times 10^{-3} \text{ eV}^2$$

$$|\Delta_{12}| = 8 \pm 0.5 \times 10^{-5} \text{ eV}^2 \text{ (KAMLAND)}$$

MINOS should measure $|\Delta_{23}|$ to 10%

#3 cont'd

(NORMAL VS INVERTED)

d. THE MASS HIERARCHY (or the sign of Δ_{23})
IS AN IMPORTANT ISSUE, which sh. be
ADDRESSED by NUMI-OFF AXIS, if...

e. CP VIOLATION - THE δ PARAMETER.

THERE CAN BE CP VIOLATION iff $\theta_{13} \neq 0$.

SEEING it will be difficult. PERHAPS
THE FIRST OPPORTUNITY WILL BE

J-PARC, which CAN ESTABLISH A 3 σ
EFFECT if $S^2(2\theta_{13}) > .02$ & δ IS MAXIMAL.

MORE & BETTER STUDIES NEEDED.

f. FINALLY, THE BIG QUESTION:
ARE ALL ASPECTS OF NEUTRINO
PROPAGATION DETERMINED BY THE
SIX PARAMETERS θ , Δ and δ ?

And if SO, WHAT MORE IS
TO BE DONE (BY EXPERIMENTERS)?
WILL THEY HAVE ACCOMPLISHED THEIR
APPOINTED TASK???

#4

WHAT ABOUT LSND?

They Allge to SEE $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ with a small mixing angle AND

$$\Delta = 0.1 - 10 \text{ eV}^2$$

This (third) Δ CANNOT BE EXPLAINED BY THE MINIMAL MODEL. HUNDREDS OF THEORISTS ARE IN HOT PURSUIT, BUT I AM NOT YET PERSUADED TO JOIN THE CHASE.

IT IS THE INTENT OF MINIBOONE TO CONFIRM OR REFUTE THE LSND RESULT, AND TO ANNOUNCE THEIR RESULT IN 2005. THERE ARE SEVERAL POSS¹ :

1. NO ANNOUNCEMENT
2. CONFIRMATION
3. REFUTATION
4. RESULT INDECISIVE

A FIRMLY NEGATIVE RESULT WOULD PUT THIS IMPORTANT ISSUE TO REST, BUT I FEAR THAT THEORISTS WILL BE PERMITTED TO CONTINUE THEIR GAMES.

#5

To Catch A SUPERNOVA

WE SAW A TOTAL OF 18 EVENTS FROM SN 1987A. HOW WONDERFUL IT WOULD BE TO SEE THOUSANDS OF NEUTRINOS FROM THE NEXT NEARBY SUPERNOVA
— IN A YEAR OR A CENTURY —

SO MUCH THE BETTER IF OUR EVER-READY STANDBY DETECTOR COULD (LIKE SNO) SEE AND DISTINGUISH CHARGED CURRENT AND NEUTRAL CURRENT EVENTS.

THIS DEVICE (WITH SOME COOPERATION FROM NATURE) COULD TELL US A LOT ABOUT BOTH NEUTRINOS AND SUPERNOVAE.

#6

NEUTRINO MASSES

OSCILLATION EXPERIMENTS ARE SENSITIVE TO SQUARED MASS DIFFERENCES, NOT ABSOLUTE MASSES. AT PRESENT, WE HAVE ONLY A WEAK LOWER BOUND

$$\sum |m_i| > 0.05 \text{ eV}$$

MEANWHILE, OUR ASTRO-COSMO COLLAQUES ASSURE US THAT

$$\sum |m_i| < 1 \text{ eV,}$$

AND PROMISE STRONGER FUTURE RESULTS. HOW STRONG AND HOW RELIABLE?

... AND IT'S JUST POSSIBLE THAT THE MASS SCALE WILL BE SET BY SEEING & MEASURING NO. V. $\beta\beta$.

ALSO IN THIS CHALLENGE IS THE ATTEMPT TO SET DIRECT LIMITS ON ν_e MASSES) FROM THE β -DECAY ENDPOINT, WHETHER TRITIUM OR RHENIUM-187.

THE CURRENT LIMIT: $m(\nu_e) < 2.2 \text{ eV}$

CAN WE EXPECT IMPROVEMENT?

[OF COURSE, DIRECT LIMITS ON $m(\nu_\mu)$ AND $m(\nu_\tau)$ CAN ALSO BE SET, BUT THESE ARE LIKELY TO BE IRRELEVANT.]

#7

COSMIC RAY NEUTRINOS

WE'VE SEEN EXTRATERRESTRIAL NEUTRINOS:

FROM SOLAR FUSION

" SUPERNOVA 1987A (18 events)

" SECONDARY or TERTIARY COSMIC RAYS

BUT WHAT ABOUT NEUTRINOS AS
PRIMARY COSMIC RAYS?

FROM GRBs (TRANSIENT)?

FROM POINT SOURCES?

U.H.E. NEUTRINOS?

"W-BURSTS" VIA THE G. RESONANCE?

NEUTRINOS FROM WIMP ANNIHILATION?

in \oplus or \odot

Will there be a true SCIENCE of
Neutrino Astronomy?

#8

SURPRISES?

STERILE NEUTRINOS?

MASS VARYING NEUTRINOS?

LORENTZ SYMMETRY VIOLATION?

EXTRA-DIMENSIONAL EFFECTS?

NEUTRINO MAGNETIC MOMENTS?

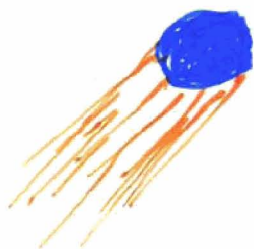
NEUTRINO DECAY?

DEPARTURES FROM FLAVOR UNIVERSALITY,

OR FROM ν -COUNTING VIA Z^0 DECAY? *

SOMETHING EVEN MORE INTERESTING?

AS ALWAYS, WE MUST ALLOW
NATURE TO CALL THE SHOTS



* $N_\nu = 2.984 \pm 0.008$
TWO-SIGMA DISCR'y
WHAT IF THIS DEPARTURE
FROM THE STD MODEL IS
CONFIRMED?