SUPERNOVA DYNAMICS
AND
NEUTRINO DETECTORS

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Astronomy and Physics

Topics

1. **Introduction**
2. **Supernova Type II Dynamics and Explosion**
3. **Effects of Neutrino Mass on Spectra**
4. **New Analysis of 1987A Data**
5. **Detectors (New and Old)**
6. **Supernova Watch**

Physics – Uspekhi **43** (5) 509 513 (2000)

PHYSICS OF OUR DAYS

PACS numbers: **01.75. + m, 01.90. + g,** 97.60.Bw, 98.58.Mj

Supernova explosions and historical chronology

V S Imshennik

DOI: 10.1070/PU2000v043n05ABEH000753

Table. Parameters of recorded supernovae.

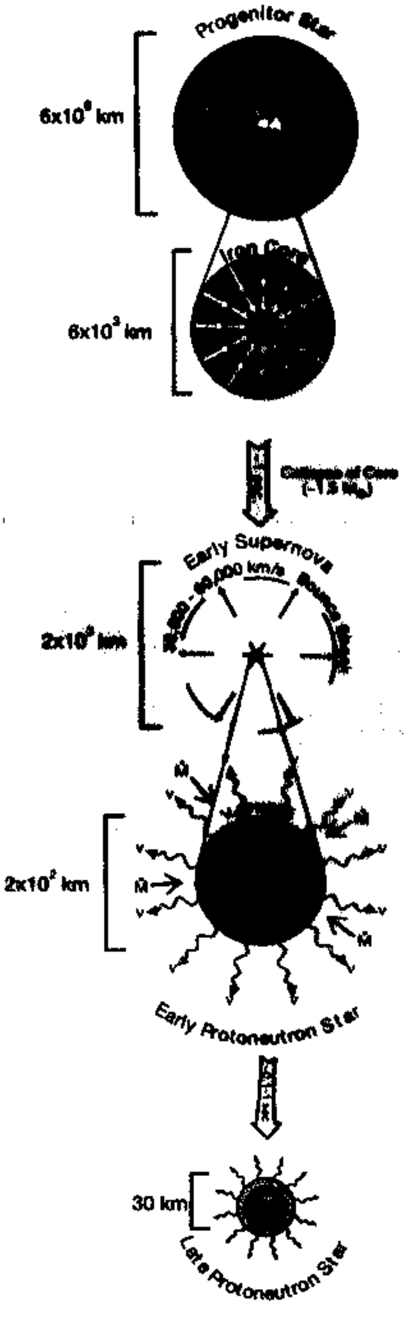
Notation of the recorded supernova	Notation of the SN remnant from **Catalog** of galactic supernovae	D, kpc	φ, arcmin	R, pc	V_{exp}, km/s	t_a, years (t_{SN}, years)	Reference
SH 837	G189.1 + 3.0; 3C157; IC443	1.5	40	9	3000	1170 (1156)	[6]
SH 1006	G327.6 + 14.6; PKS1459-41	1.2	30	5	2300	850 (980)	[5], table 5
SH 1054	G184.6 – 5.8; 3C144; Crab	2.0	6	1.75	1500	456 (932)	[5], table 6
SH 1181	G130.7 + 3.1; 3C58	2.6	8	3	1000	1170 (805)	[5], table 6
SH 1408	G69.0 + 2.7; CTB80	3.0	8	3.5	2000	684 (585)	[5], table 15; [6]
SH 1572	G120.1 + 1.4; 3C10; Tycho	3.0	3.6	3.3	3600	359 (414)	[5], table 5
SH 1604	G4.5 + 6.8; 3C358; Kepler	3.2	1.3	1.3	⩽ 300	1695 (382)	[5], table 5
SH 1604*	–"–	–"	–"–	–"–	3040	418 (395)	[5], table 5; [9]

Most seem to be Type II

— Non fault —

Super Nova Type II, (Ib, Ic) (Not Ia) Explosion

$10^6 - 10^8$ y



~10^{-2} sec

"A Neutrino Factory"

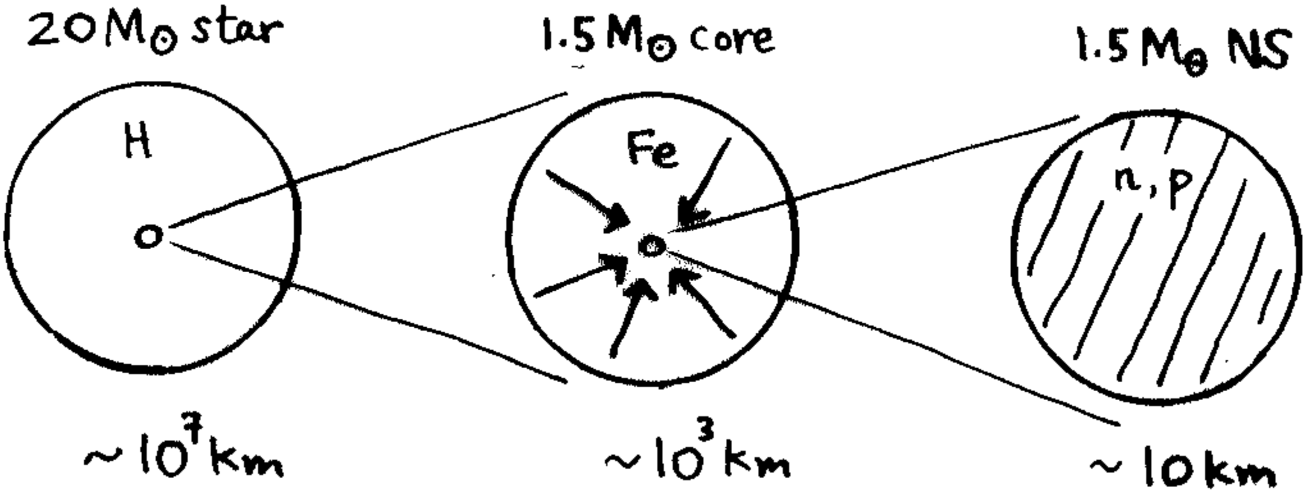
~ 10^{57} Neutrinos

All Flavors

(If we can detect all Flavors)

—Neutrinos Play a key Role in the Explosion Process—

Supernova: Core-Collapse



type-II SN : core collapse of an $M > 8 M_\odot$ star

$$\Delta E_B \simeq \frac{G M_\odot^2}{R_{NS}} - \frac{G M_\odot^2}{R_{core}} \simeq \boxed{3 \times 10^{53} \text{ ergs}}$$

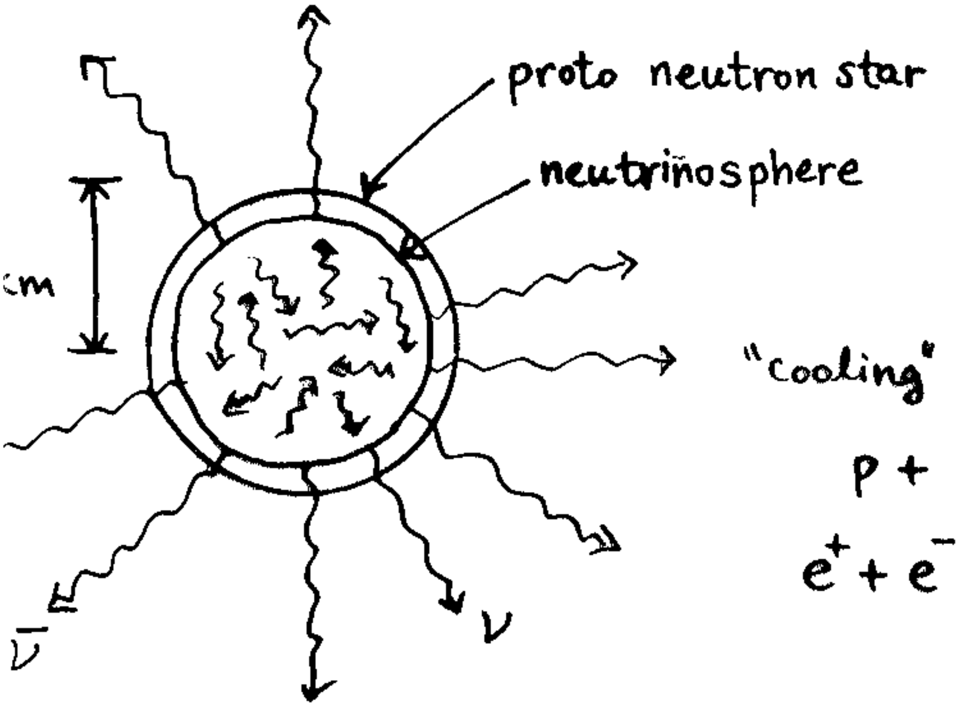
$$\simeq 2 \times 10^{59} \text{ MeV}$$

observations :

kinetic energy of explosion $\simeq 10^{-2} \cdot \Delta E_B$

electromagnetic radiation $\simeq 10^{-4} \cdot \Delta E_B$

Supernova: Energy Release



"cooling" by neutrino emission :

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

$$e^+ + e^- \longrightarrow \nu_e + \bar{\nu}_e,\ \nu_\mu + \bar{\nu}_\mu,\ \nu_\tau + \bar{\nu}_\tau$$

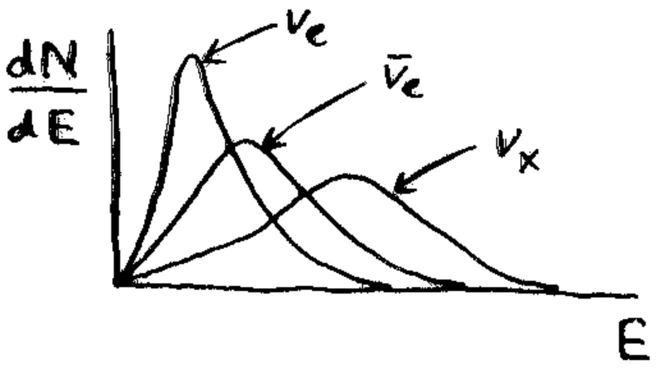
etc.

diffusion until $\lambda = 1/\rho\sigma$ from surface, then escape

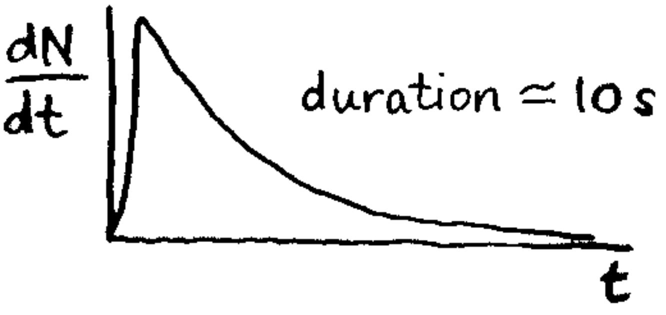
$\langle E_{\nu_e} \rangle \simeq 11$ MeV

$\langle E_{\bar{\nu}_e} \rangle \simeq 16$ MeV

$\langle E_{\nu_x} \rangle \simeq 25$ MeV

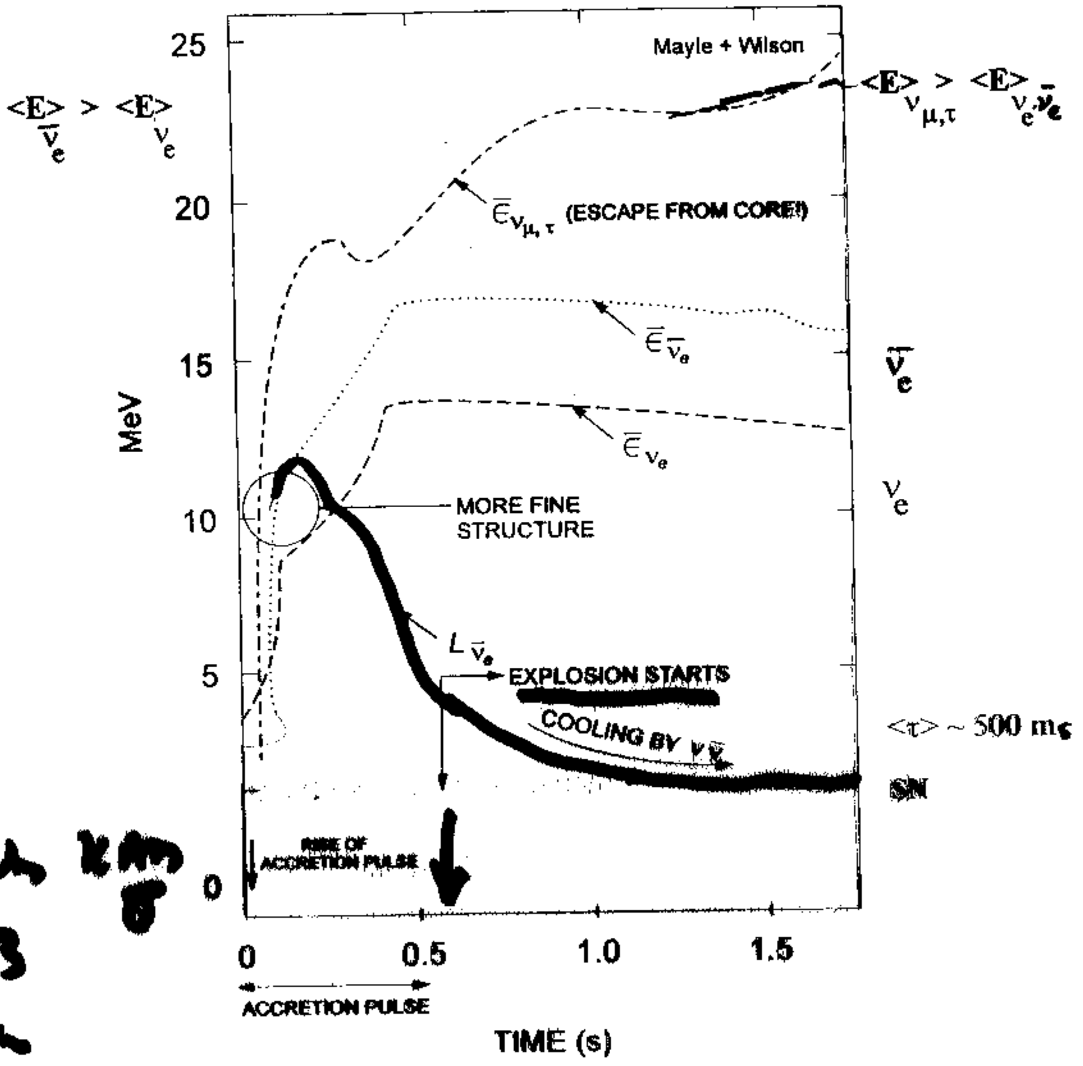


$_{\nu_e}(t) \simeq L_{\bar{\nu}_e}(t) \simeq L_{\nu_x}(t)$



duration $\simeq 10$ s

Mayle + Wilson



SN 1987 A
DATA

11 (12) Events Kam 8
8 IMB
5 Baksan

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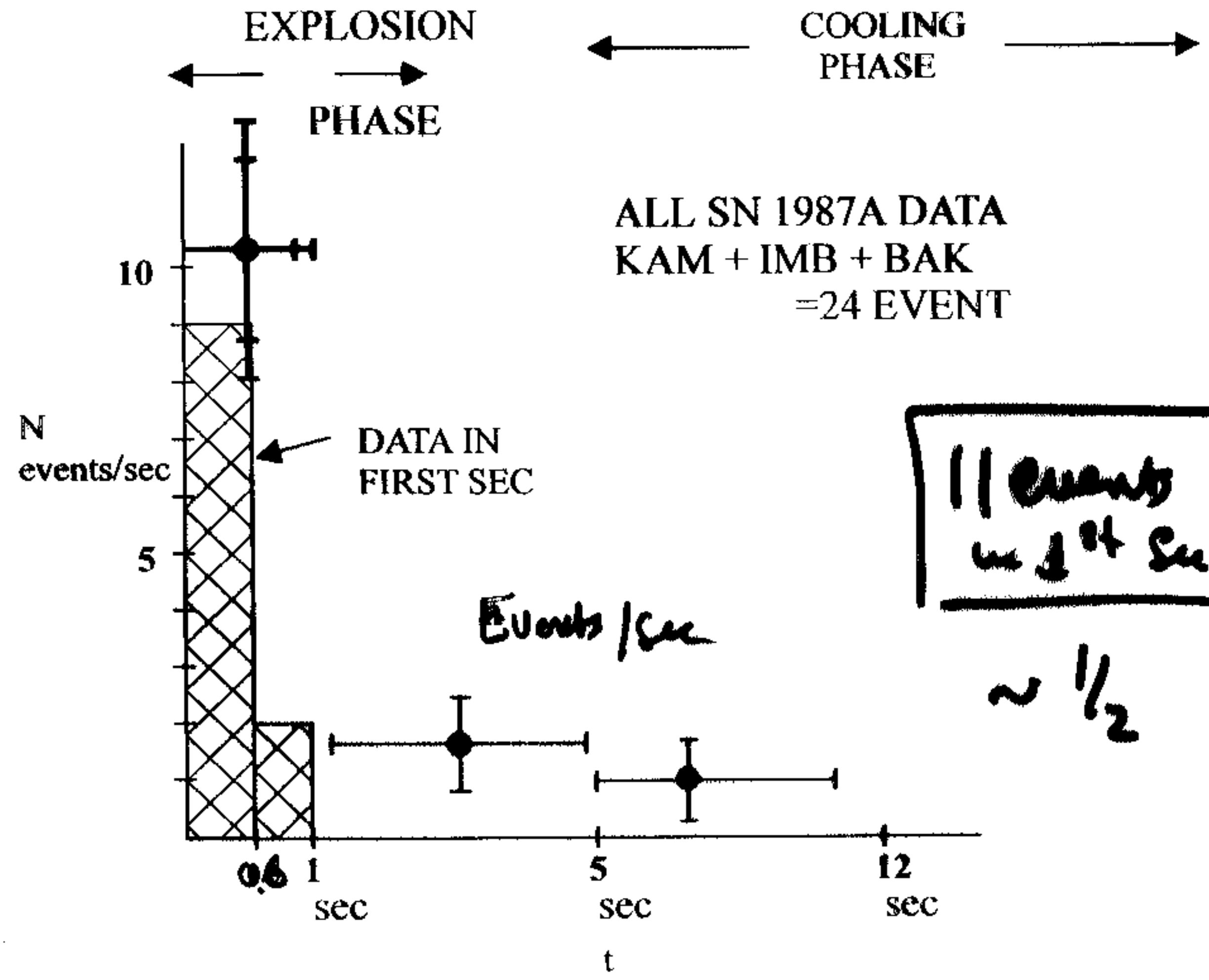
24 - 25
Events → ~ 1/2 of Events in First Sec

sharp rise in ν luminosity function $\lesssim 50$ ms

$\bar{E}_{\nu_\mu,\nu_\tau} > \bar{E}_{\nu_e}; \bar{E}_{\bar\nu_e}$

DATA KAM II 11 (+1) 12
IMB 8
BAKSAN 5
Events



ALL SN 1987A DATA
KAM + IMB + BAK
=24 EVENT

11 events in 1st Sec

~ 1/2

1987A Data Time Distribution consistent with Mayle/Wilson

General Questions about

Super Nova

(Why)
1) How do Super Nova Type II (Ib, Ic) EXPLODE

↓ Hydrogen Rich

Type Ia
H poor ✓

2) Can we learn more about the EXPLOSION [redacted] Mechanism By DETECTING ALL PRODUCTS ✓

ν, GRAVITY WAVES, LIGHT etc

↑ (99% of Energy Release)

3) How DO JETS FORM IN SUCH SYSTEMS ?

4) WHAT IS THE CONNECTION BETWEEN SN & GRB SOURCES ?

Wooley
"Every GRB a SN"

60 people

Physics Potential of Supernova II Neutrino Detection

Marina Beach Marriott
Marina del Rey, California
February 15 and 16, 2001

Thursday February 15: Registration (Sierra Ballroom) **8:00 – 9:00am**

Session I: **Supernova Dynamics; Chair: David Cline (Sierra Room)** **9:00am – 12:10pm**
R-Process Nucleosynthesis in Protoneutron Star Winds – **Adam Burrows** (Univ. of Arizona) 9:00
Structure of the SN1987A Ejecta – Lifan **Wang (LBL)** 9:25
LLNL SN explosion calculations – Comments from the Floor 9:50

Break 10:15-10:30

Chair: George Fuller
Mass Ejection by Supernovae II: The Expected Role of 2-D and 3-D Simulations of Convection – **Stirling Colgate** (LANL) 10:30
Newton Plus: **Approximate Relativity** for Supernova Simulations – **Christian Cardall (ORNL)** 10:55
Neutrino Transport in Supernovae: Determining the Important Ingredients – Bronson Messer (Univ. of Tennessee) 11:20
Extracting Neutrino Properties and Explosion Mechanism Diagnostics from Realistic SN Neutrino Signals – Stephen W. Bruenn (Florida Atlantic Univ.) 11:45
Collective Neutrino Interactions with the Plasma Sphere in Type II Supernovae – Hans-Thomas Elze (Instituto de Fisica, Univ. Federal do Rio de Janeiro) 12:10

SN Explosion

Lunch (Palisades Room) 12:35-1:35

Session II: Neutrino, Supernova and [illegible] Synthesis; Chair: Petr Vogel (Sierra Room) **1:35 – 6:25pm**
Neutrino Masses and Mixings, Nucleosynthesis, and Dark Matter – **G. Fuller** (UC San Diego) 1:35
Spectra Formation – G. Raffelt (Munich MPI) 2:00
Rocks, Stars, and Neutrinos– Yong-Zhong Qian (Univ. of Minnesota) 2:25
Effects of Neutrino Oscillation on the Supernova Neutrino Spectrum – K. Sato (Univ. of Tokyo) 2:50 x
Supernova Neutrino Oscillations: Nucleosynthesis and Detection – Gail McLaughlin (Stony Brook) 3:15

Break 3:40-3:55

Chair: A. Burrows
Supernova Neutrinos – A Probe of Matter at Extreme Density – Sanjay Reddy (Univ. of Washington) 3:55
Sterile Neutrinos and Core-collapse Supernovae – A. Balantekin (Univ. of Wisconsin) 4:20
Doublet-Singlet Neutrino Transformation in Core-Collapse Supernovae – Mitesh Patel (UC San Diego) 4:45
Neutrinos and Heavy Element Synthesis – Bradley S. Meyer (Clemson Univ.) 5:10 x
Value of the Cosmological Constant: Theory Versus Experiment – Moshe Carmeli and Tanya Kuzmenko (Ben Gurion Univ.) 5:35
Nonlinear and Collective Effects in Neutrino Transport in Supernovae II plasmas – Luis O. Silva (IST/UCLA) 6:00

Heavy Element Synthesis

Reception and Conference Dinner (Promenade Room) **6:30pm**
Special Discussion of a possible So. Cal. Underground Laboratory – H. Sobel (UCI) 8:00-9:00pm

Friday February 16: Coffee (Venice Room)	**7:00 – 8:00am**
Session III: Neutrino Signal ; Chair: Georg Raffelt (Venice Room)	**8:00-10:00**
Earth Matter Effects on Supernova Neutrinos – Cecilia Lunardini (Trieste)	8:00
Is the 1987A Kam. Data Consistent with the LMA Solar Neutrino Solution? – **David B. Cline** (UCLA)	**8:20**
Supernova **Neutrino Physics** – J. Beacom (FNAL)	**8:40**
Neutrino Oscillation and Supernova Signal – R. Schirato (UC San Diego/LANL)	9:00
Sterile **Neutrino Dark Matter** – **Kev** Abazajian (UC San Diego)	9:20
Using **Extra Dimensions to Fit Solar** Data and Implications for **Supernovae** – **David Caldwell** (SLAC)	9:40
Break	**10:00-10:20**
Session IVa: Experiments, Detectors, Underground Facilities; Chair: N. Smith (Venice)	**10:20-12:00**
Physics Opportunities at ORLaND Relevant to Supernova Detectors – **F. Avignone (Univ. of South Carolina/ORNL)**	10:20
MiniBooNE - A Definitive Test of the LSND Oscillation Results – W. Louis (LANL)	10:40
Work on OMNIS in the UK – Peter Smith (RAL)	**11:00**
OMNIS U.S. Program – R. Boyd (OSU)	**11:20**
OMNIS R & D – Kevin Lee (UCLA)	**11:40**
Lunch (Peninsula Room)	**12:00 – 1:00**
Session IVb: Experiments, Detectors, Underground Facilities; Chair: Tim Sumner (Venice)	**1:00-4:35**
Solar Neutrinos with ICARUS Detector – Ines Gil Botella (ETH/CERN)	**1:00**
Super K – M. Vagins (UC Irvine)	**1:20**
Supernova Detection with KamLAND – Petr Vogel (Caltech)	**1:40**
Supernova Trigger and Analysis with SNO – Reda Tafirout (Laurentian Univ.)	**2:00**
The LVD Experiment in Italy – F. Fulgione (INFN)	**2:20**
MOON (Molybdenum Observatory of Neutrinos) for Supernova Neutrino Detection – Hiroyasu Ejiri (RCNP, Osaka Univ.)	2:40
Break	3:00-3:20
Chair: K. Arisaka	
Neutrino Detection Using Lead Perchlorate – S. R. Elliott et al (Univ. of Washington)	3:20
Design of **a Modular Multipurpose** Neutrino Detector for the Homestake **Laboratory – Alfred** Mann (Univ. of Pennsylvania)	3:40
Facilities and **Experiments** at the UK Boulby Mine – N. Smith (RAL)	4:00
Comments on the Carlsbad Underground Site – David B. Cline (UCLA)	4:20
Session V: Worldwide SN Watch; Chair: A.K. Mann (Venice)	4:35-5:35
SN Watch – M. Vagins (UC Irvine)	4:35
SNEWS Status – Kate Scholberg (MIT)	4:55
LIGO – B. Barish (Caltech)	5:15

Neutrino Mass effects

Super NVs Type II & Detectors

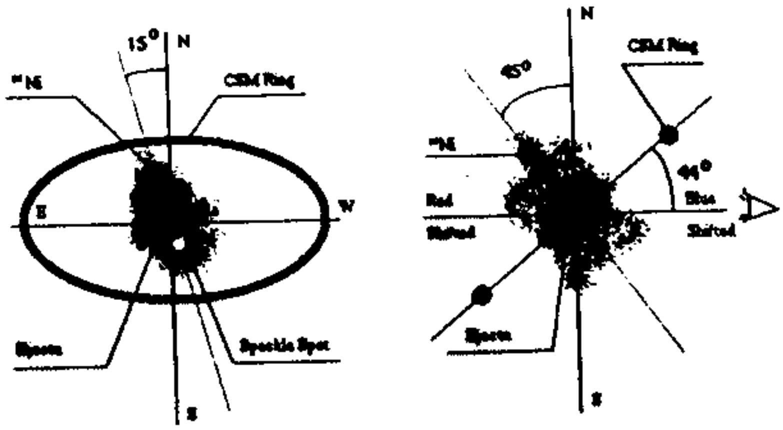
World Wide SN Watch

Lifan Wang

L Wang
LBL

Polarimetry of Supernovae

- The Stokes Q and U parameters and the Q-U plane
- Why do we expect linear polarizations from supernovae ?
- What are the possible mechanisms for linearly polarized supernova light ?
  - Aspherical density structure (Höflich 1991)
  - ^{56}Ni clumps (Lucy 1988, Chugai 1992, Höflich 1995)
  - Aspehrical distributions of chemical elements (Wang, Wheeler, & Höflich 1997)
  - Scattering by circumstellar dust particles (Wang & Wheeler 1996)
  - Scattering by materials in the ejecta-CSM shocks
- Broad Band Polarimetry
- Spectropolarimtery



Clear Evidence ?
on Asymmetry –
1987A
Jets ??

SITUATION IN THE SNII SIMULATION PROGRAM

1. **Some 1D Calculations give explosions regularly. (LLNL - J. Wilson, et. al.) Some do not (ORNL...) The difference is not understood but could be due to the equation of State used. However, all agree that the most complete physics can be put into 1D calculation.**

2. **Some 2D Calculations give explosion (A. Burrows, etc.), but the 1D Modeler claims the physics in the codes is marginal!**

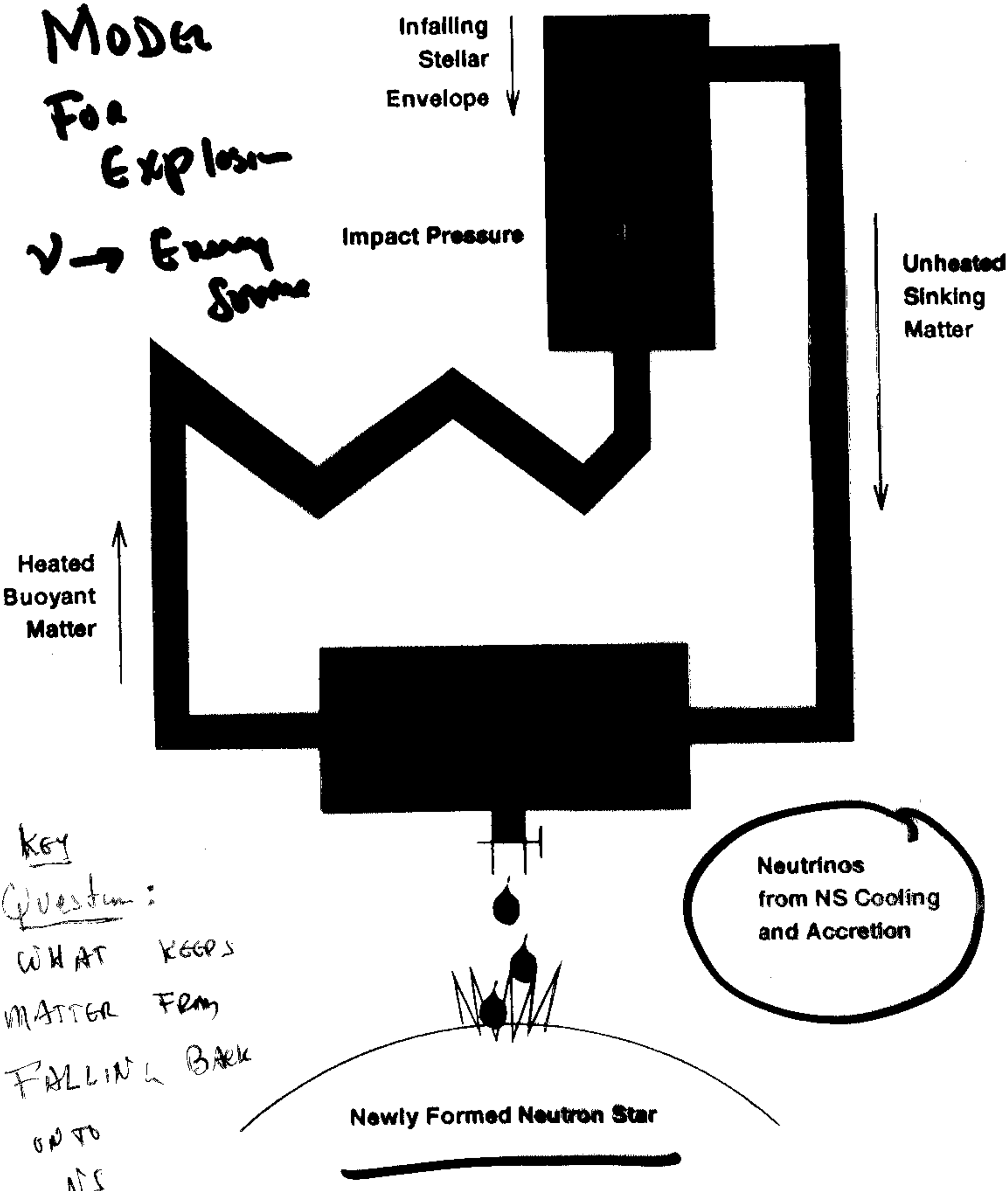
Still A State Of Confusion As To What Causes The Explosion

Perhaps detection of all Neutrino Flavor for a SNII will give the key information.

S. Colgate et al

MODEL FOR Explosion

$\nu \rightarrow$ Energy Source



KEY Question:
WHAT KEEPS MATTER FROM FALLING BACK ONTO NS

Neutrino Transport In Supernovae: Determining The Important Ingredients

Bronson Messer
Joint Institute for Heavy Ion Research
University of Tennessee / Oak Ridge National Laboratory

The delayed explosion mechanism of Wilson(1985; Bethe & Wilson 1985) remains as the centerpiece of modern supernova theory. *

Why?

Core collapse supernovae are neutrino events

Essentially ALL of the 10^{53} erg of gravitational binding energy is carried away in the form of neutrinos

Supernova neutrinos have been observed in broad agreement with the theory

SN1987a

Several groups pursuing spherically symmetric simulations incorporating sophisticated neutrino transport:

Burrows et al. (2000)
Rampp & Janka (2000)
Mezzacappa et al. (2001)

Improved Microphysics

Mezzacappa et al. (2001) and Rampp & Janka (2000) employ substantially identical microphysics to Bruenn (1985)

Recent work suggests several upgrades are in order:

improved electron capture rates on nuclei
    Heger et al. (2000), Langanke et al. (2001)

high density opacities incorporating medium effects
(e.g. strong interaction and Fermi effects)
    Reddy et al. (1998, 1999), Burrows & Sawyer (1998,1999)

nucleon-nucleon bremsstrahlung (especially for $\nu_{\mu,\tau}$)
    Hannestad & Raffelt (1998), Burrows et al. (2000)

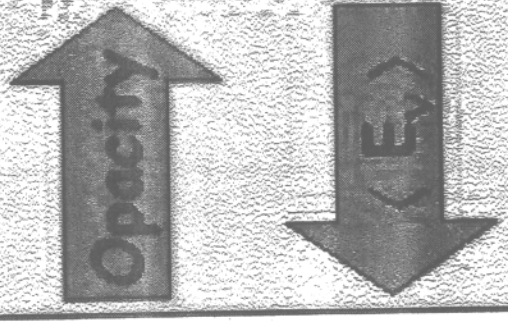
Neutrino Spectra from a Supernova Core

Different flavors are trapped by different reactions

$\nu_e + n \rightarrow p + e^-$

$\overline{\nu}_e + p \rightarrow n + e^+$

$\nu_{\mu,\tau}\ (\overline{\nu}_{\mu,\tau}) + N \rightarrow N + \nu_{\mu,\tau}\ (\overline{\nu}_{\mu,\tau})$



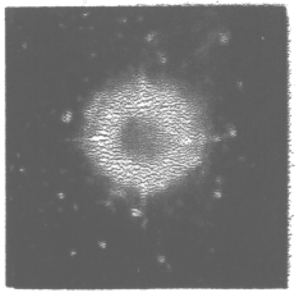
Beta reactions are more efficient than neutral-current scattering, and there are more n than p. Typical SN simulations yield a hierarchy of spectral temperatures

$$\langle E_\nu \rangle = \begin{cases} 10-12\ \text{MeV} & \text{for } \nu_e \\ 14-17\ \text{MeV} & \text{for } \overline{\nu}_e \\ 24-27\ \text{MeV} & \text{for } \nu_\mu, \nu_\tau, \overline{\nu}_\mu, \overline{\nu}_\tau \end{cases}$$

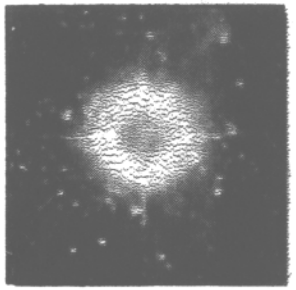
Approximate equipartition of energy among flavors

Neutrino oscillations can partially swap spectra

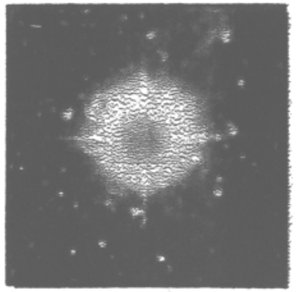
Conclusions



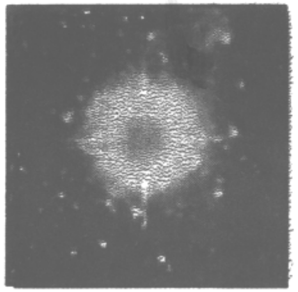
Spectra formation of mu- and tau-neutrinos can be well understood with a toy model consisting of
the **energy sphere** as a blackbody surface and
the **scattering atmosphere** as a "low-pass filter".



For average scattering depth τ_{ES} = 15 - 50 of E-sphere,
$T_{flux} \approx (0.5 - 0.6)\ T_{ES}$,
surprisingly insensitive to exact value of τ_{ES}.

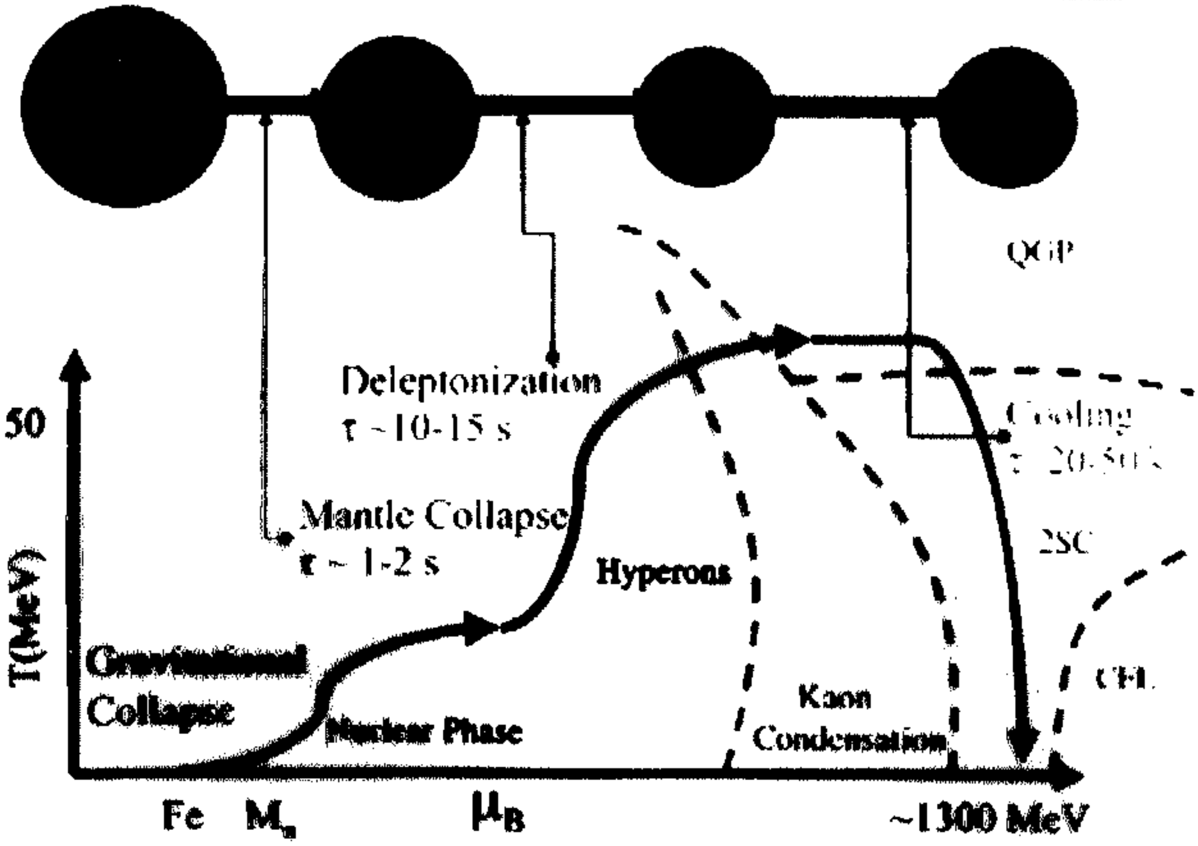


Neutrino energy exchange in scattering atmosphere
(e.g. by nucleon recoils)
reduces T_{flux} **by up to 20-30 %**,
depending sensitively on temperature profile

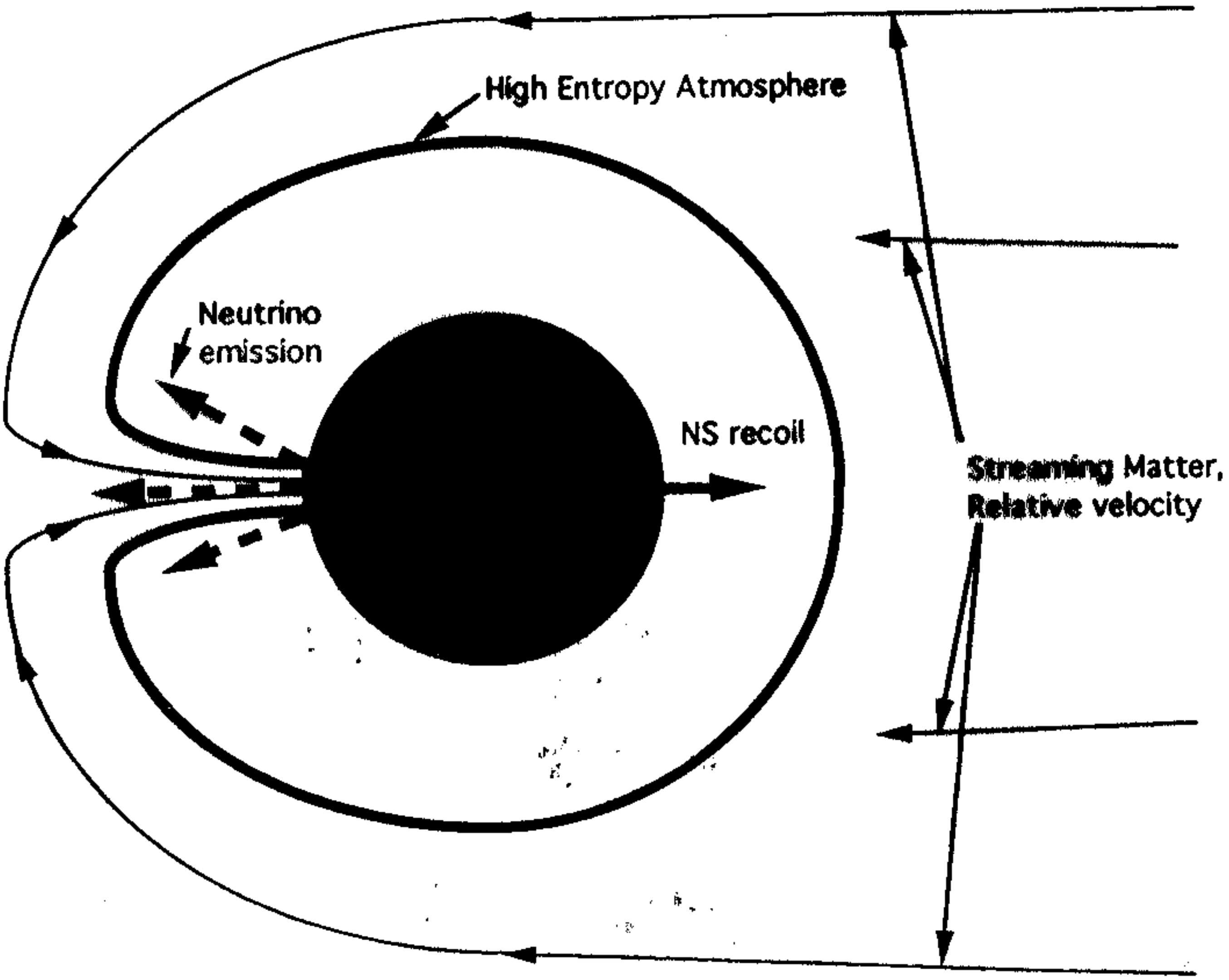


Spectral shift surprisingly
insensitive to exact efficiency of energy transfer,
detailed dynamical structure functions probably not crucial.

Exploring the QCD Phase Diagram- *using Gravity and Neutrinos*



Cause?


High Entropy Atmosphere
Neutrino emission
NS recoil
Streaming Matter,
Relative velocity

A Burrows

Features in Supernova Neutrino Signal

- "ν_μ" emission dominates (oscillation?) OMNIS !
- break-out flash of ν_e's
  (and sudden spectral change)
- slow (~20 ms) rise of $\bar{\nu}_e$'s (and ν_μ's)
- pulsations in L_ν
- **Drop in L's after "long-tem" explosion due to reversal of accretion:** Mechanism!
- **Post break-out** rise in average neutrino energy
- Long-term decay of L_ν and ε_ν
  (in 10's of seconds)
- **Black hole** formation (abrupt turn-off)
- Signatures of hydrodynamic instabilities ("convection") + ROTATION !!
- CAN DISCRIMINATE DELAYED EXPLOSION FROM PROMPT

Super Nova I Neutrinos Have
A Great Deal of Information

PHYSICAL REVIEW D, VOLUME 62, 033007

Identifying the neutrino mass spectrum from a supernova neutrino burst

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Alexei Yu. Smirnov[†]
The Abdus Salam International Center for Theoretical Physics, 34100 Trieste, Italy
and Institute of Nuclear Research, RAS, Moscow, Russia

(Received 31 January 2000; published 12 July 2000)

We study the role that the future detection of the neutrino burst from a galactic supernova can play in the reconstruction of the neutrino mass spectrum. We consider all possible 3ν mass and flavor spectra which describe the solar and atmospheric neutrino data. For each of these spectra we find the observable effects of the supernova neutrino conversions both in the matter of the star and the Earth. We show that studies of the electron neutrino and antineutrino spectra as well as observations of the neutral current effects from supernova will allow us (i) to identify the solar neutrino solution, (ii) to determine the type of mass hierarchy (normal or inverted) and (iii) to probe the mixing $|U_{e3}|^2$ to values as low as $10^{-4}-10^{-3}$.

PACS number(s): 14.60.Pq, 97.60.Bw

$\uparrow$ Θ_{13} — There is No other way (Including a Terrestial ν Factory) to
[illegible]

Also G. Fuller ..

Mass has Important Effect
Spectrum
INSIDE
SN

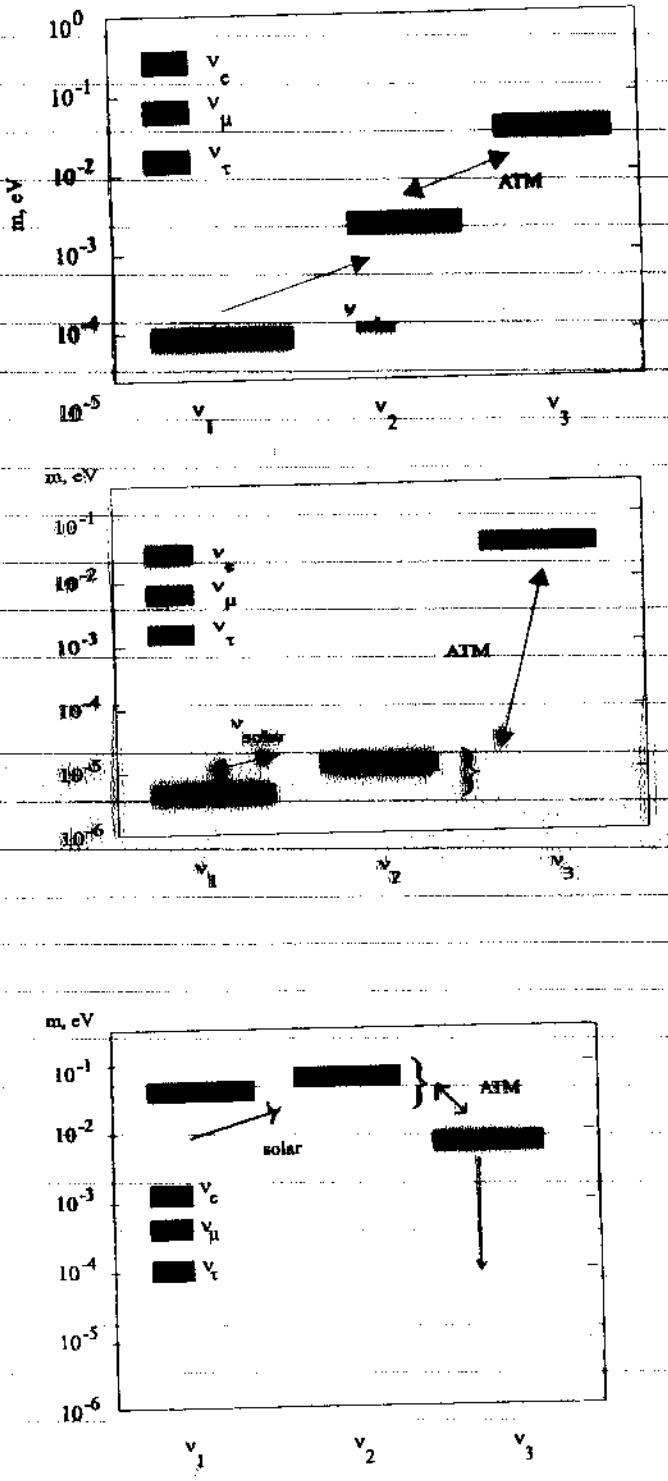


Fig. 2a, 2b, 2c. Different schemes for the Neutrino Mass spectrum adopted from Ref. 3

SN II ν Detection

Can Select the mass spectrum

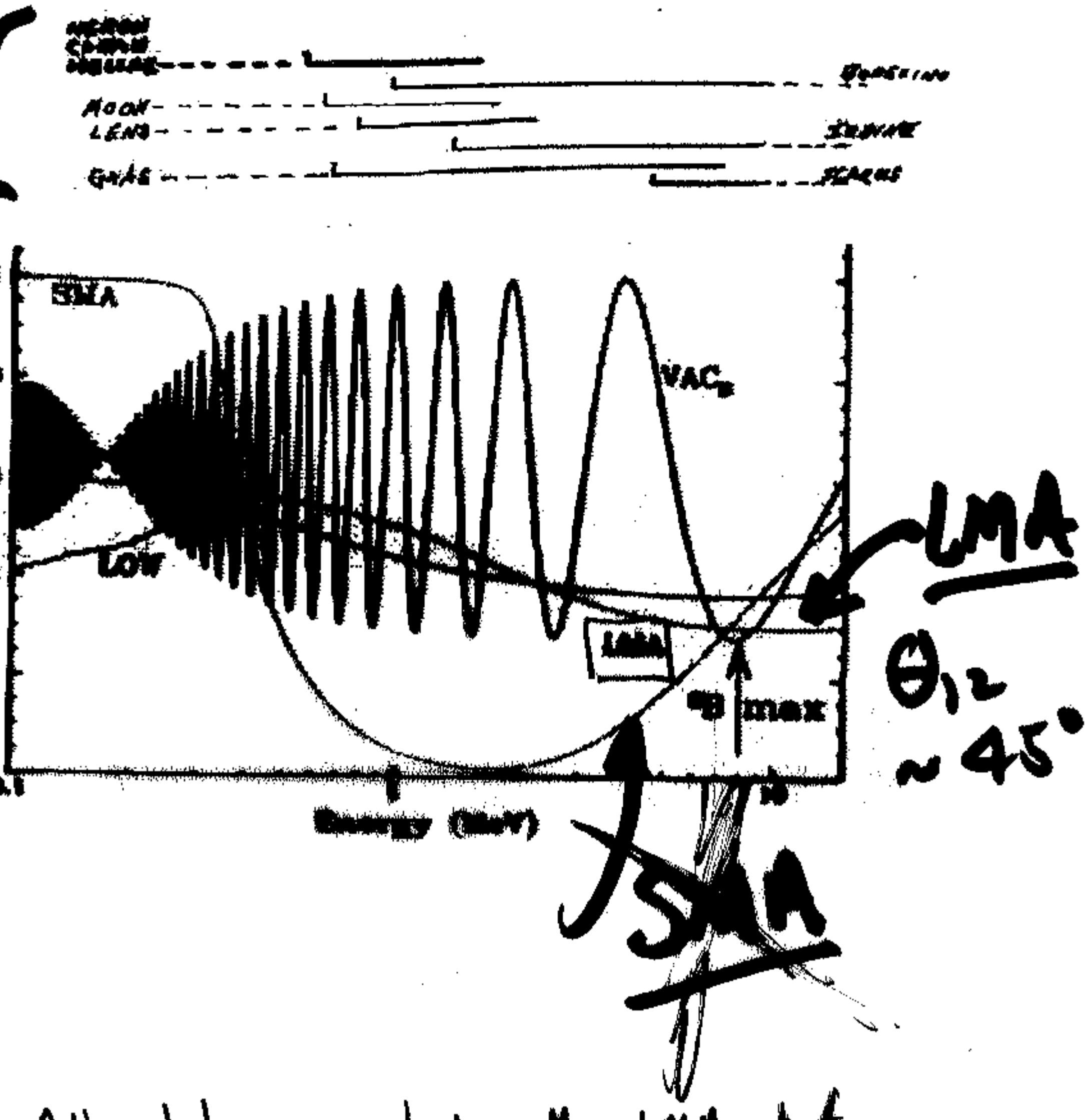
TABLE II. The observable effects of various scenarios for (i) the neutronization peak, (ii) the nature of final ν_e and $\bar{\nu}_e$ spectra, and (iii) the Earth matter effects. The interpretation of the entries in the table is given in the beginning of Sec. IV.

			Neutronization	Spectrum		Earth effects	
			peak	ν_e	$\bar{\nu}_e$	ν_e	$\bar{\nu}_e$
I	SMA	Normal	$\approx \nu_x$	Hard	Soft	≈ 0	≈ 0
		Inverted ●	ν_e, ν_x	Composite	Hard ●	√	≈ 0
	LMA	Normal	$\approx \nu_x$	Hard	Composite	≈ 0	√
		Inverted	ν_e, ν_x	Composite	Hard	√	≈ 0
	VO	Normal	$\approx \nu_x$	Hard	Composite	≈ 0	≈ 0
		Inverted	ν_e, ν_x	Composite	Hard	≈ 0	≈ 0
II	SMA	Normal	ν_e, ν_x	Composite	Soft	√	≈ 0
		Inverted	ν_e, ν_x	Composite	Composite	√	≈ 0
	LMA	Normal	ν_e, ν_x	Composite	Composite	√	√
		Inverted	ν_e, ν_x	Composite	Composite	√	√
	VO	Normal	ν_e, ν_x	Composite	Composite	≈ 0	≈ 0
		Inverted	ν_e, ν_x	Composite	Composite	≈ 0	≈ 0
III	SMA	Normal	ν_e, ν_x	Composite	Soft	√	≈ 0
		Inverted	ν_e, ν_x	Composite	Soft	√	≈ 0
	LMA	Normal	ν_e, ν_x	Composite	Composite	√	√
		Inverted	ν_e, ν_x	Composite	Composite	√	√
	VO	Normal	ν_e, ν_x	Composite	Composite	≈ 0	≈ 0
		Inverted	ν_e, ν_x	Composite	Composite	≈ 0	≈ 0

Need to measure ν_e, $\bar{\nu}_e$, ν_x **Spectra**

B lann
Seattle mtg

New
Solar ν
Experiments



LMA

$\theta_{12} \sim 45°$

SMA

All data consistent with LMA but

New analysis of 1987A data suggest

~~LMA~~ ??

⇒ ICARUS could still help with question — are $\nu_e \to \nu_x$ in Sun

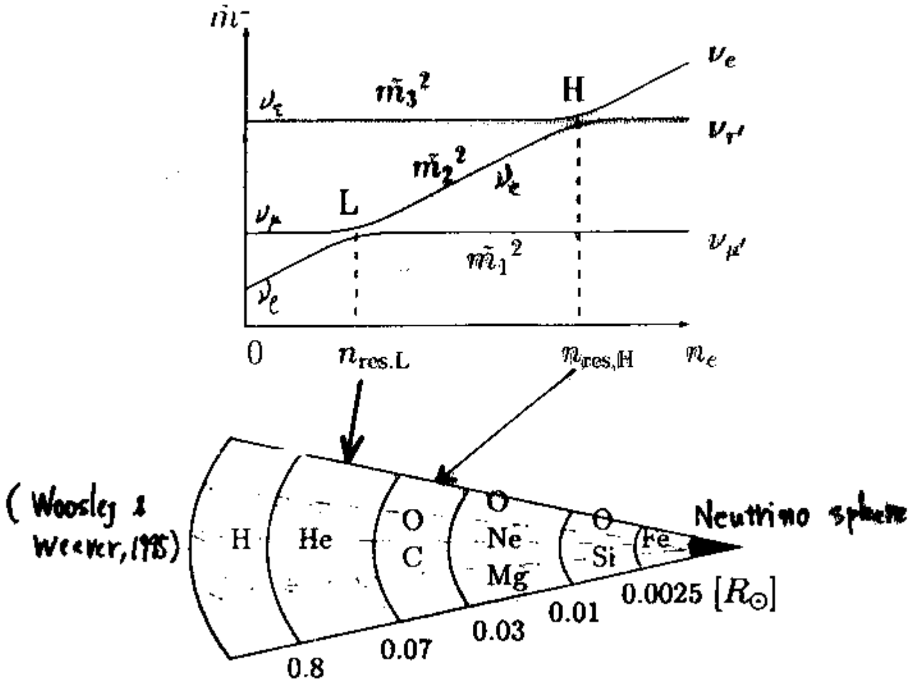
[redacted]

Effects of neutrino oscillation on the detection of supernova neutrino burst

M.Watanabe,T.Totani and K. Sato
U. Tokyo

Might even
measure
θ_{13} with
Next
Super Nova

SATO



Resonance Condition: $n_e = n_{\mathrm{res}} = \frac{1}{2\sqrt{2}G_F}\frac{\Delta m^2}{E}\cos 2\theta$

Two resonances (H at C+O、 L at He)
shell shell

Then ↓

How are ν_e, ν_μ, ν_τ coverted each other ?
How are the energy spectra deformed ?

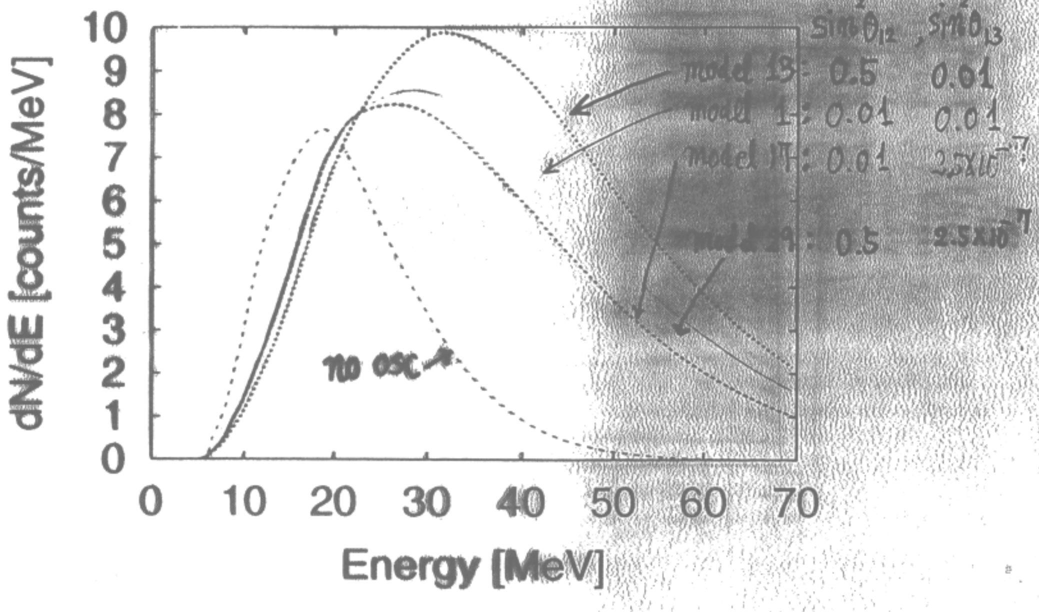
Preceding works :

- Dighe, Smirnov hep-ph/9907423

$$\frac{dN}{dE_e}(E_e) = \sum_{\text{reactions}} \int dt \frac{d^2F}{dtdE_\nu}(E_\nu, t)\sigma(E_\nu)N_{\text{target}}$$

$\frac{d^2F}{dtdE_\nu}(E_\nu, t)$: differential number luminosity [counts/sec MeV cm^2]

$\sigma(E_\nu)$: cross section [cm^2]



- Events come from the both $\nu_e, \bar{\nu}_e$.
  → Both effects MSW and vacuum oscillation are important.
- Models can be distinguished by the ratio of events

Go Back
to
1987 A
Data
24(25)
Events

Further Analysis
of Kam II/IMB
Data

ELSEVIER

Nuclear Physics B 437 (1995) 243–256

NUCLEAR
PHYSICS B

Updated limits on the electron neutrino mass and large angle oscillations from SN1987A

Peter J. Kernan, Lawrence M. Krauss [1]

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Received 24 October 1994; revised manuscript received 19 December 1994; accepted 22 December 1994

Joint
Analysis
of
Kam II
IMB
Data

Abstract

We supplement Maximum Likelihood methods with a Monte-Carlo simulation to re-investigate the SN1987A neutrino burst detection by the IMB and Kamiokande experiments. The detector simulations include background in the the latter and "dead-time" in the former. We consider simple neutrinosphere cooling models, explored previously in the literature, to explore the case for or against neutrino vacuum mixing and massive neutrinos. In the former case, involving kinematically irrelevant masses, we find that the full range of vacuum mixing angles, $0 \leq \sin^2 2\theta_V \leq 1$, is permitted, and the Maximum Likelihood mixing angle is $\sin^2 2\theta_V = 0.45$. In the latter case we find that the inclusion of "dead-time" reduces previous m_{ν_e} upper bounds by 10%, and supplementing the Maximum Likelihood analysis with a Monte-Carlo goodness-of-fit test results in a further 15% reduction in the m_{ν_e} upper limit. Our 95% C.L. upper limit for m_{ν_e} is 19.6 eV, while the best fit value is ~ 0 eV.

1. Introduction

Galactic neutrino astronomy began in 1987 with the observation of 20 neutrinos from the supernovae burst SN1987A in the Large Magellanic Cloud (LMC). Two terrestial detectors, IMB [1] and Kamiokande [2], found unequivocal evidence for supernovae neutrino events with the former collaboration claiming detection of 8 SN1987A events, and the latter 12. This momentous observation generated enormous excitement in the scientific community, and of course a plethora of papers soon followed. We have returned

---

[1] Also Department of Astronomy.

Elsevier Science B.V.
SSDI 0550-3213(94)00595-8

Replotted

Though about

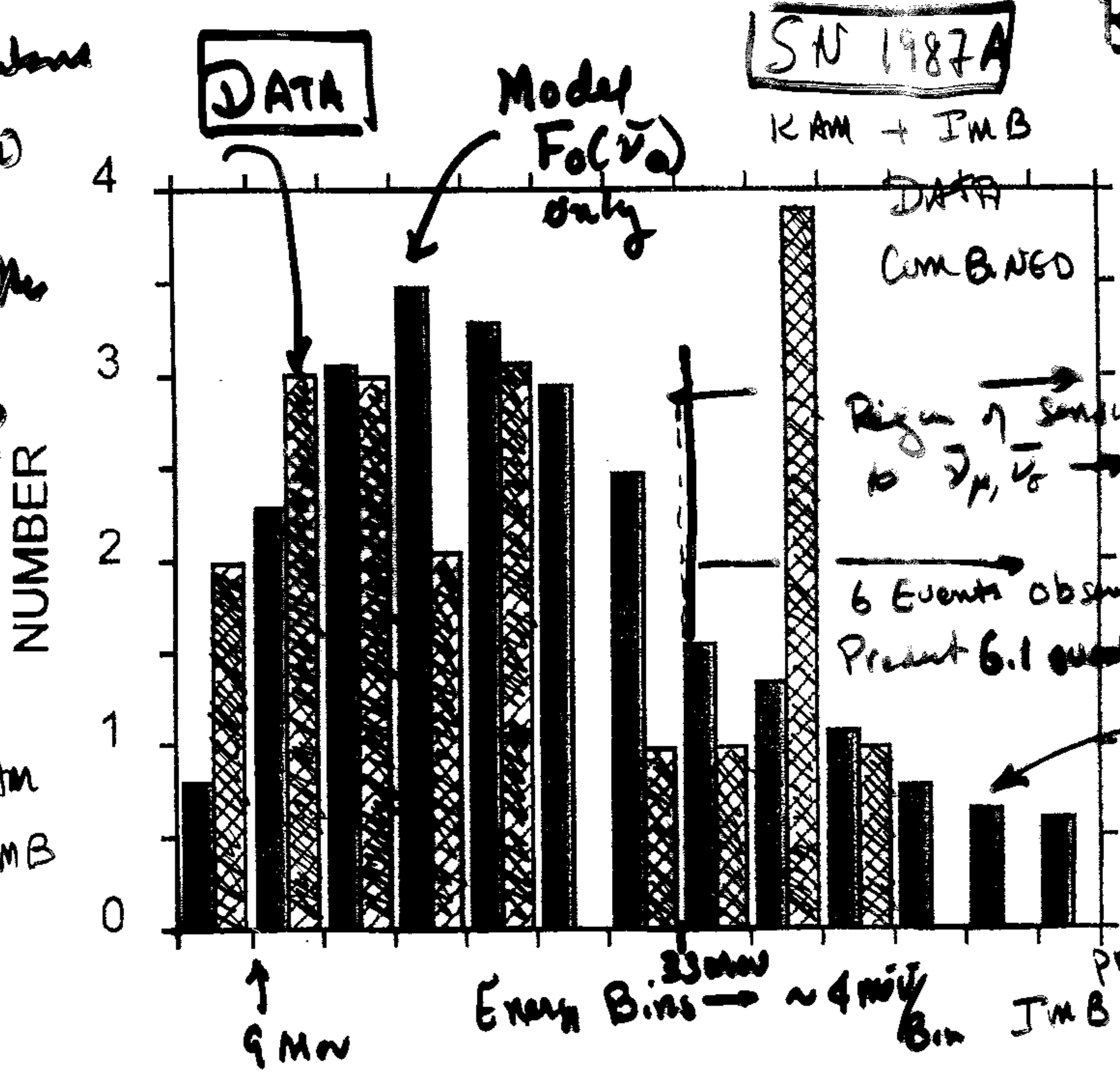
10,000

events

from the

Next

SN II



▨ KAM

▧ IMB

20 events

LKrauss Nature 1987

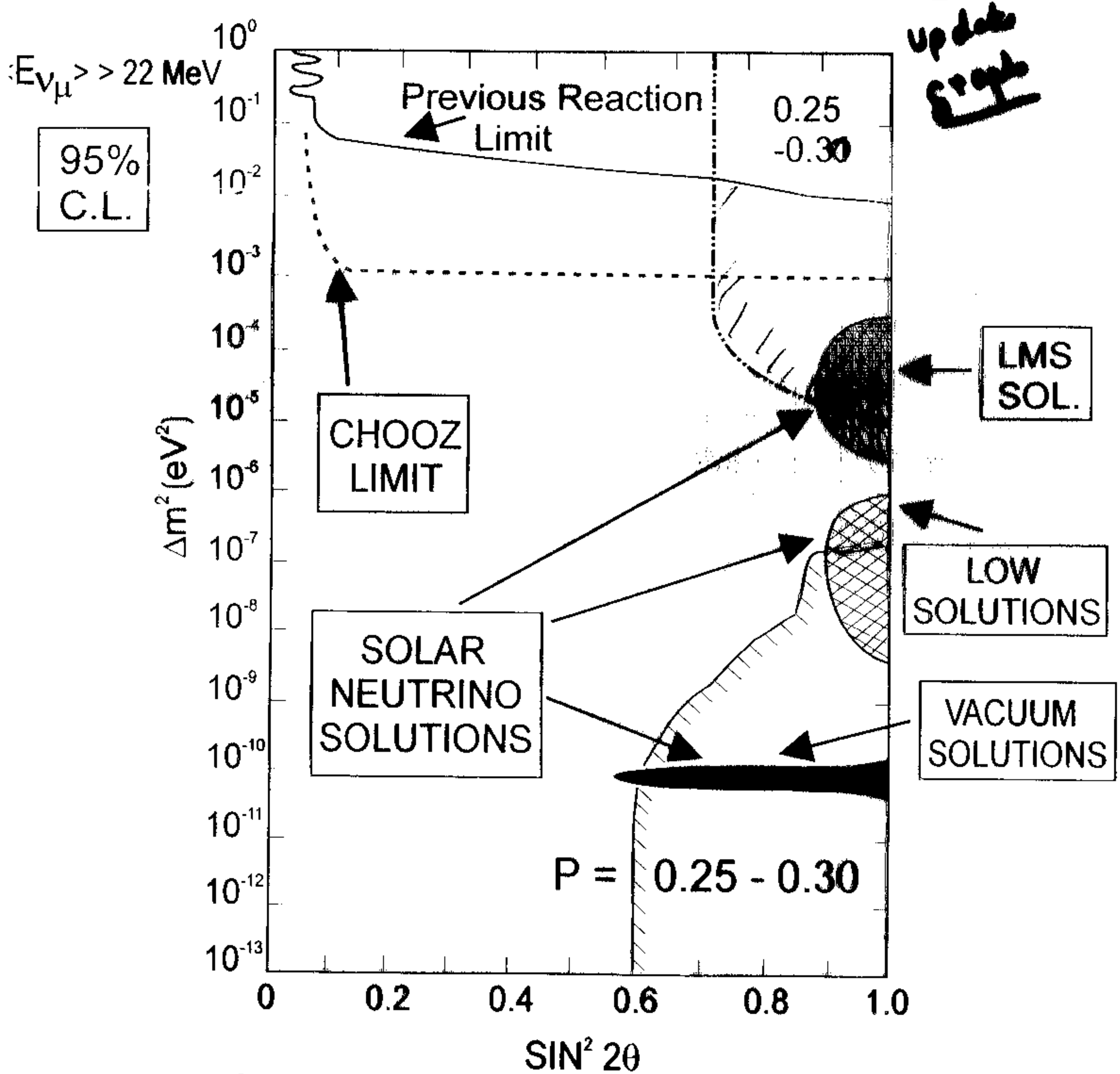
Model by LKrauss with T = 4.5 MeV

+ proper IMB threshold effect

Limits on $\bar{\nu}_e \rightleftharpoons \bar{\nu}_\mu$ FROM SN(1987A)
SMIRNOV, SPERGEL, BAHCALL
PHYS. REV 49, 1389 (1994)

Replots

update graph



Paper claims much of Parameter Space excluded –

$\bar\nu_x \to \bar\nu_e$

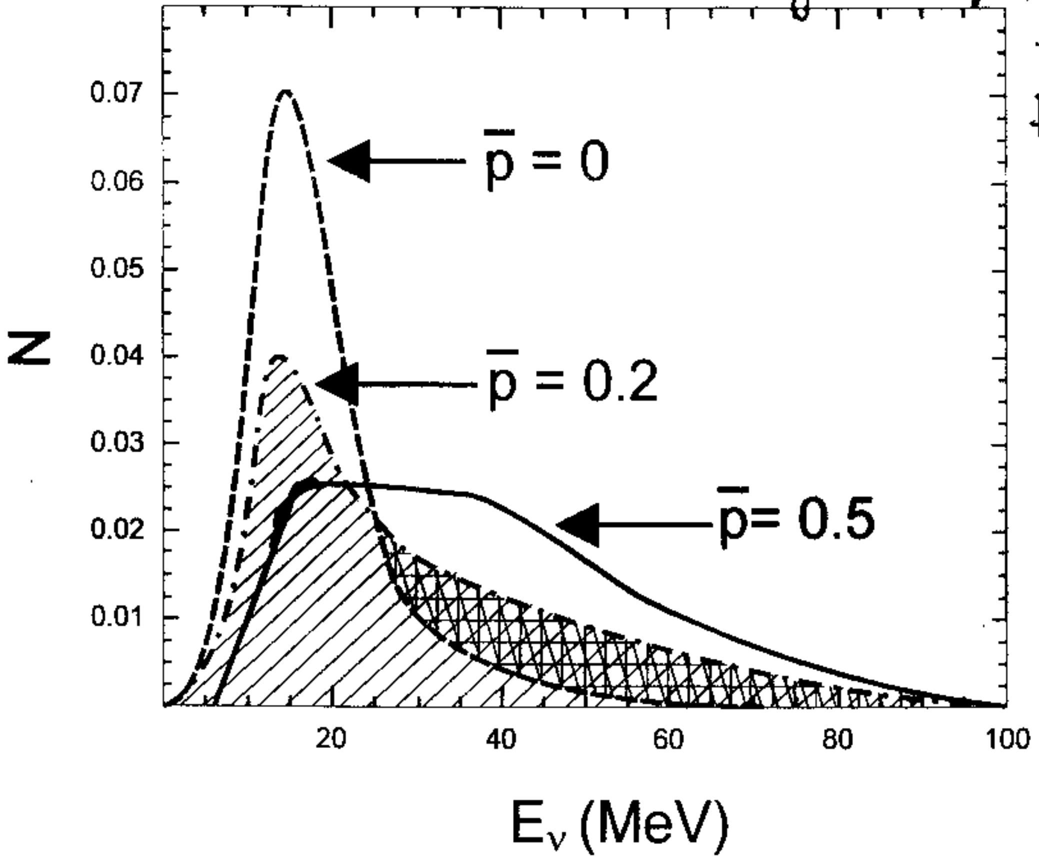
{ Dighe, Smirnov PR.D 033002
G Fuller et al PRD
DBC et al PRD }

$$\langle \bar\nu_e \rangle = [1-\bar p]\langle \bar\nu_e \rangle_0 + \bar p \langle \bar\nu_x \rangle_0$$

Dighe, Smirnov

Modified Mayle/Wilson Spectrum

Fuller
Haxton } et al



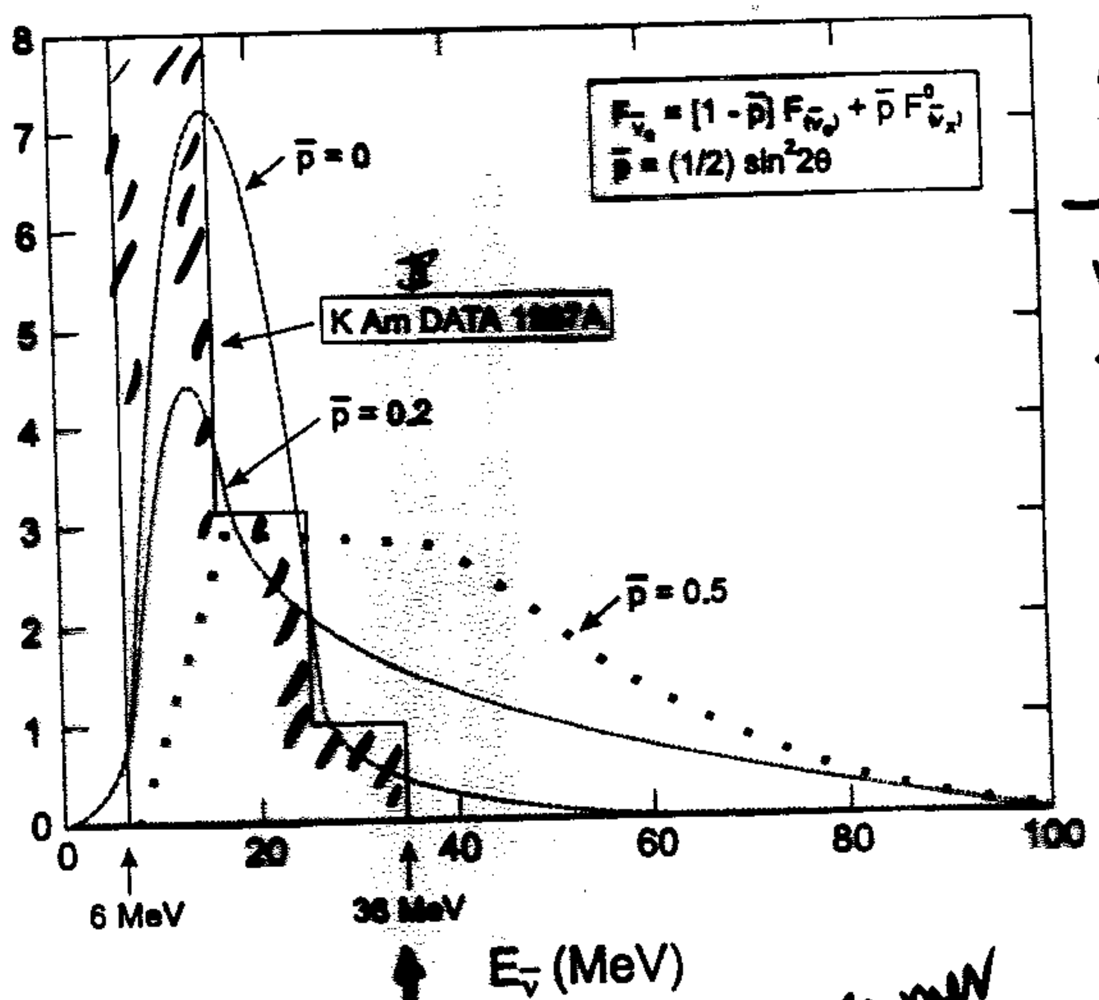
$$\boxed{\bar p = \frac{1}{2}\sin^2 2\theta}$$

For LMA Solution

$$\bar p \sim \frac{1}{2}$$

Our Viewpoint
the KAM II data
is the only set
of data with low
energy data so
a SHAPE ANALYSIS
CAN BE
CARRIED OUT

THE IMB &
BAKSAN DATA
BOTH HAVE
HIGHER ENERGY
THRESHOLDS



A New
Analysis

- Use
KAM II
DATA
ONLY

No Events above 40 MeV

Figure 7. Comparison of the Kamiokande data with the neutrino oscillation models.

Table 2. Kolmogurov Test for the Model and data in Fig. 8.

Parameter, $\bar{p}$	Probability of Hypothesis (%) Confidence Level (%)
0	58 42
0.2	3.6 96.4 excluded ←
0.5	0.02 > 99 excluded ←

The small [illegible] η km.?
Events still produce
a strong constraint on the
$\bar{p}$ parameter

Include MSW

Neutrinos from SN1987A, Earth matter effects and the LMA solution of the solar neutrino problem

C.Lunardini[a)], A.Yu.Smirnov[b)]

a) SISSA-ISAS, via Beirut 2-4, 34100 Trieste, Italy

and INFN, sezione di Trieste, via Valerio 2, 34127 Trieste, Italy

b) The Abdus Salam ICTP, Strada Costiera 11, 34100 Trieste, Italy

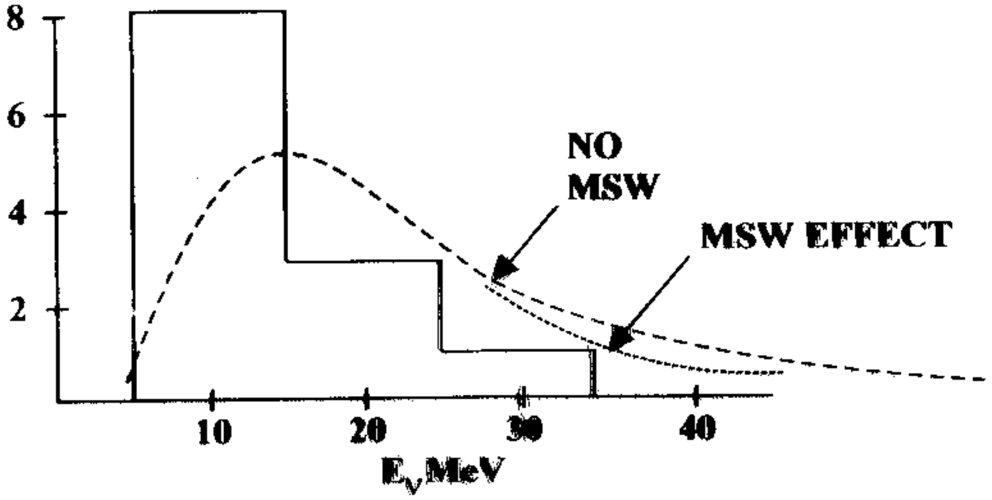
and Institute for Nuclear Research, RAS, Moscow, Russia

(Received:)

Abstract

We study properties of the oscillation effects in the matter of the Earth on antineutrino fluxes from supernovae. We show that these effects can provide explanation of the difference in the energy spectra of the events detected by Kamiokande-2 and IMB detectors from SN1987A as well as the absence of high-energy events with $E \gtrsim 40$ MeV. This explanation requires the neutrino oscillation parameters Δm^2 and $\sin^2 2\theta$ to be in the region of the LMA solution of the solar neutrino problem and the normal mass hierarchy if $|U_{e3}|^2 \gtrsim 10^{-3}$. The hierarchy can be inverted if $|U_{e3}|^2 \ll 10^{-3}$. The solution of the solar neutrino problem based on ν_e-conversion to a pure sterile state is disfavoured by SN1987A data.

PACS: 14.60.Pq, 97.60.Bw



Probability Fit

No MSW : 0.018

MSW Included : 0.029

— If all KAM II DATA USED THE MSW EFFECT DOES NOT HELP THE FIT —

WHAT CAN BE LEARNT?

EARTH EFFECTS CAN:

- **SELECT THE SOLUTION OF $\nu_\odot$ PROBLEM:**

  OSCILLATIONS $\Longrightarrow$ LMA

  LOCALIZED DISTORTION $\rightsquigarrow$ SMA (ν_e ONLY)

- "STAR-INDEPENDENT" INFO ON MASS HIERARCHY

  BOUNDS ON $|U_{e3}|^2$ ($\leftarrow P_H$)

P_H	$\lvert U_{e3}\rvert^2$	HIERARCHY	EARTH EFFECT (LMA) ν_e	$\bar{\nu}_e$
~ 0	$> 10^{-3}$	NORMAL	NO	YES
		INVERTED	YES	NO
~ 1	$\ll 10^{-3}$	NORMAL	YES	YES
		INVERTED	YES	YES

- RESTRICTION OF THE $\Delta m^2 - \sin^2 2\theta$ REGION (BY OBSERVING DIFFERENCES)

EXPECTED SPECTRA :

$\alpha_* = -28.9°$
(GALACTIC CENTER)

$D_* = 10$ kpc , $t = 1$ h

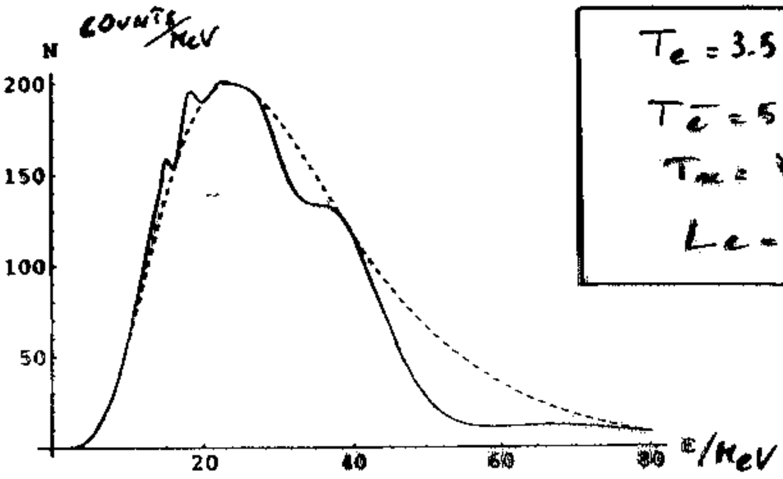
$T_e = 3.5$ MeV,
$T_{\bar e} = 5$ MeV,
$T_\mu = 8$ MeV
$L_e = L_{\bar e} = L_\mu = 3\cdot 10^{52}$ eg

$\Delta m^2 = 2\cdot 10^{-5}$ eV
$\sin^2 2\theta = 0.9$

SK

CORE CROSSING

$\bar\nu_e - p$ EVENTS

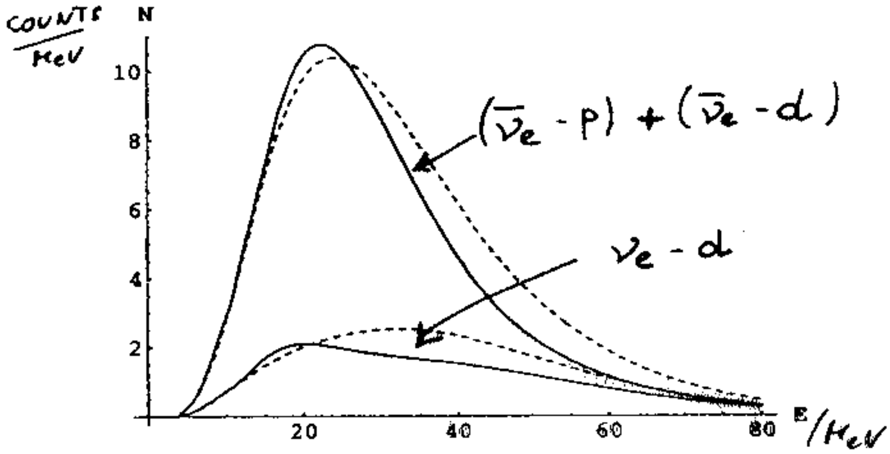


SNO

MANTLE ONLY

$\bar\nu_e - p$, $\bar\nu_e - d$,

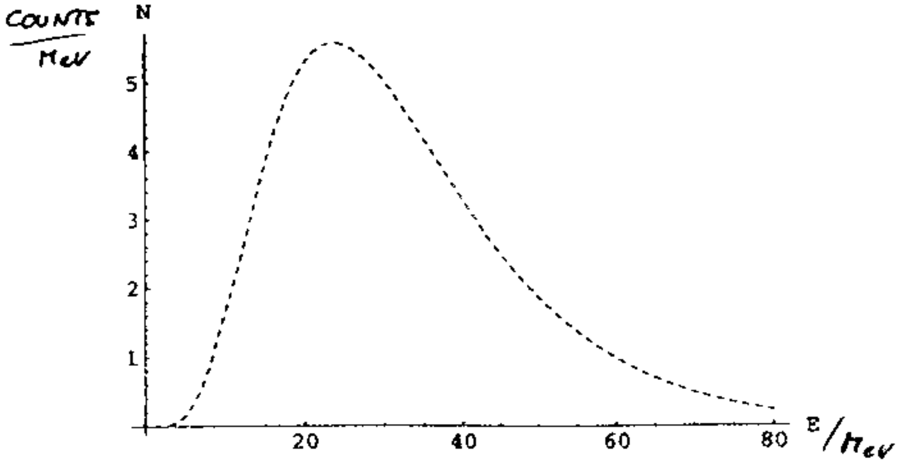
$\nu_e - d$



LVD

STAR ONLY

$\bar\nu_e - p$



A KEY PAPER!!

Prospects for Detecting Supernova Neutrino Flavor Oscillations

George M. Fuller,[1] and Wick C. Haxton,[2] and Gail C. McLaughlin[2*]
[1] *Department of Physics, University of California, San Diego, La Jolla, CA, 92093-0319*
[2] *Institute for Nuclear Theory, Box 351550, and Department of Physics, Box 351560,*
University of Washington, Seattle, WA 98195, USA
(September 13, 1998)

$\nu_{\mu\tau} \to$ [illegible]
[illegible] $\to 2n$

Abstract

The neutrinos from a Type II supernova provide perhaps our best opportunity to probe cosmologically interesting muon and/or tauon neutrino masses. This is because matter enhanced neutrino oscillations can lead to an anomalously hot ν_e spectrum, and thus to enhanced charged current cross sections in terrestrial detectors. Two recently proposed supernova neutrino observatories, OMNIS and LAND, will detect neutrons spalled from target nuclei by neutral and charged current neutrino interactions. As this signal is not flavor specific, it is not immediately clear whether a convincing neutrino oscillation signal can be extracted from such experiments. To address this issue we examine the responses of a series of possible light and heavy mass targets, ^{9}Be, ^{23}Na, ^{35}Cl, and ^{208}Pb. We find that strategies for detecting oscillations which use only neutron count rates are problematic at best, even if cross sections are determined by ancillary experiments. Plausible uncertainties in supernova neutrino spectra tend to obscure rate enhancements due to oscillations. However, in the case of ^{208}Pb, a signal emerges that is largely flavor specific and extraordinarily sensitive to the ν_e temperature, the emission of two neutrons. This signal and its flavor specificity are associated with the strength and location of the first-forbidden responses for neutral and charge current reactions, aspects of the ^{208}Pb neutrino cross section that have not been discussed previously. Hadronic spin transfer experiments might be helpful in confirming some of the nuclear structure physics underlying our conclusions.

> 2n signal from $\nu_x \to \nu_e$

14.60.Pq, 26.50.+x, 25.30.Pt

Sensitive to small values of θ_{13}

For OMNIS Detector

Typeset using REVTEX

---

[*] Current Address: TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. Canada V6T2A3. Electronic address: `gail@alph01.triumf.ca`

Neutrino Oscillation $\langle E_{\nu_e} \rangle > \langle E_{\bar{\nu}_e} \rangle$

Since $\nu_x \to \nu_e$

Detection of ν_μ and ν_τ From SuperNova Neutrinos In **REAL TIME**

Two Possibilities:

a) $\nu_x + e^- \rightarrow \nu_x + e^-$

- Rate Low because $\sigma_{\nu_x e}$ Small
- Background from $\nu_e e \rightarrow \nu_e e$

b) $\nu_x + N \rightarrow \nu_x + N'$

$N = D, C, O, NaCl, Pb, Fe...$

$N' \rightarrow n + X$
- SNO
- SNBO/OMNIS

$N' \rightarrow \gamma + X$
- Super K
- LVD / ICARUS

☐ **SIGNAL DEPENDS ON ν_μ, ν_τ ENERGY SPECTRUM**

Supernova Neutrino Observatories

Beacon, J

Seattle mtg
Sept 2000

Time of
Flight
From SN

Direct Mass Tests

Assume $m_{\nu_2} \simeq m_{\nu_3}$ $(\delta m^2_{ATM} \simeq 10^{-3} eV^2)$

- Model-independent, based on $<t>$

SNO :	$m_{\nu_\mu}, m_{\nu_\tau} \lesssim 20$ eV
SK :	$m_{\nu_\mu}, m_{\nu_\tau} \lesssim 30$ eV

Beacom & Vogel, 1998

- Model-dependent, based on risetime features

$\simeq 3$ times smaller
equivalent to a factor $\simeq 100$ in volume

Beacom, 2000, in preparation

- Model-independent, based on BH formation

OMNIS : $m_{\nu_\mu}, m_{\nu_\tau} \lesssim 6$ eV

Beacom, Boyd, Mezzacappa, PRL (2000

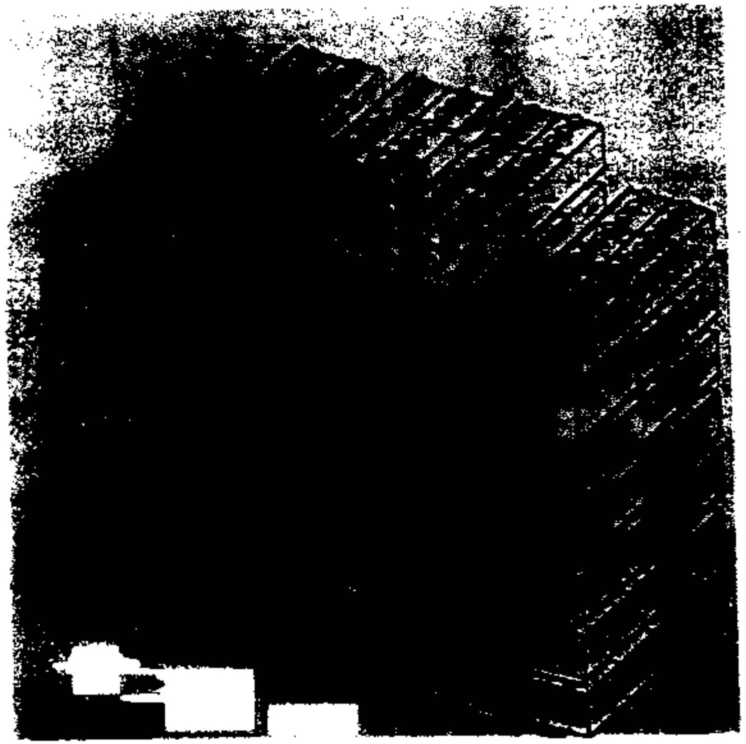
• EARTH

$\Delta t \sim$ few Hundred ms

May Re
few eV
in ν_μ, ν_τ
mass from
Next SN?? in

The LVD neutrino observatory

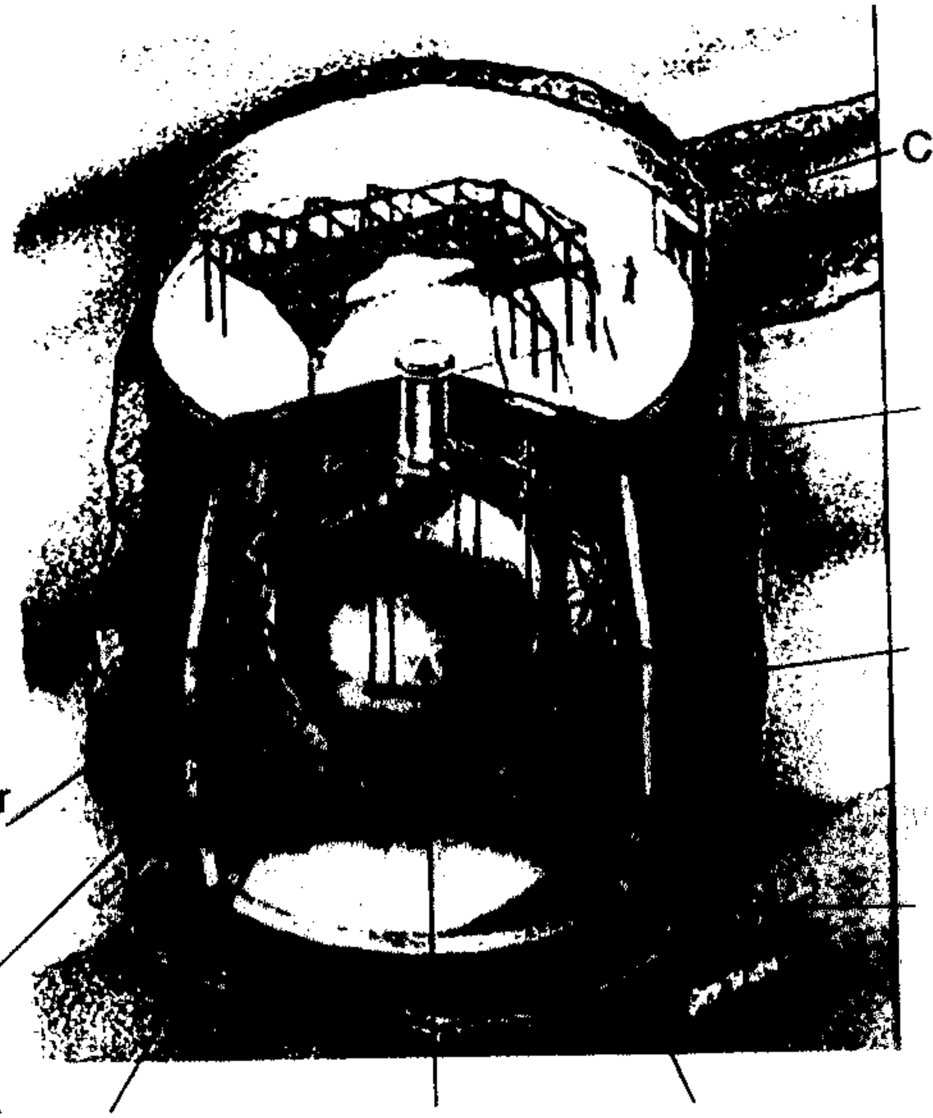
W.Fulgione



A massive (1 kton)
scintillator detector
for neutrino
astronomy in the **Gran**
Sasso underground
Laboratory

The SNO Detector

2039 m to surface
10^{11} m to Sun



Control room

Vectran support ropes

Urylon liner

Norite rock

12 m diameter acrylic vessel

Support structure for 9500 PMTs, concentrators

5300 tonnes light water

1000 tonnes heavy water

1700 tonnes light water

- **Location:** 6800 ft. level of INCO's Creighton mine near Sudbury, ON, Canada (~70 muons / day)

- **SNO Detector:** $9438_{\text{inward}} + 91_{\text{outward}}$ Hamamatsu 8" PMTs + concentrators = **64% coverage**

Supernova Detection Simulation

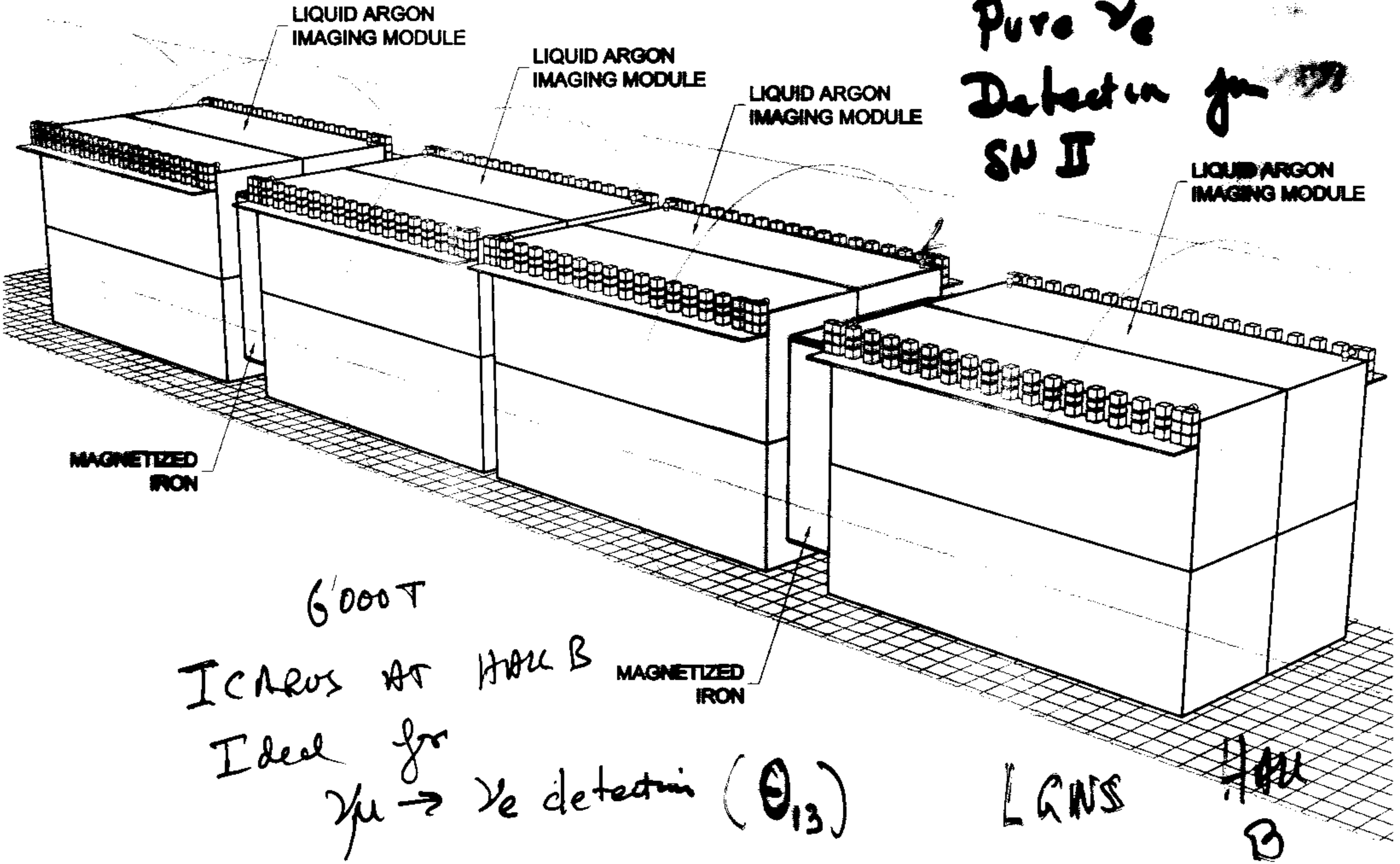
Simulation Ingredients:

1. SNO **energy** threshold set to ~2 **MeV**
2. Use **detected** particle counts from **100** supernova **bursts** (in the case of the NCDs, **expect ϵ = 45%** $_{[NCD]}$ + **12%** $_{[D_2O]}$)

Number of Particles From **10 kpc** Supernova:

Neutrino Reaction	**Type**	**SNO Counts [ϵ = 100%]**	**SNO Counts [monte carlo]**
$\overline{\nu}_e + p_{H_2O} \rightarrow n + e^+$	CC	356	331
$\overline{\nu}_e + p_{D_2O} \rightarrow n + e^+$	CC	0.2	
$\overline{\nu}_e + p_{AV} \rightarrow n + e^+$	CC	5	
$\nu_e + d \rightarrow p + p + e^-$	CC	83	72
$\overline{\nu}_e + d \rightarrow n + n + e^+$	CC	53 (× 3)	82 $_{[D_2O]}$ 138 $_{[salt]}$ 90 $_{[NCD]^*}$
$\nu_e + {}^{16}O \rightarrow {}^{16}F + e^-$	CC	1	
$\overline{\nu}_e + {}^{16}O \rightarrow {}^{16}N + e^+$	CC	3	
$\nu_e + d \rightarrow \nu_e + p + n$	NC	36	12 $_{[D_2O]}$ 30 $_{[salt]}$ 20 $_{[NCD]^*}$
$\overline{\nu}_e + d \rightarrow \overline{\nu}_e + p + n$	NC	36	12 $_{[D_2O]}$ 32 $_{[salt]}$ 21 $_{[NCD]^*}$
"ν_μ" $+ d \rightarrow$ "ν_μ" $+ p + n$	NC	192	60 $_{[D_2O]}$ 164 $_{[salt]}$ 110 $_{[NCD]^*}$
"ν_μ" $+ {}^{16}O \rightarrow (n, \gamma, n + \gamma)$	NC	7	
$\nu_e + e^- \rightarrow \nu_e + e^-$	ES	26	20
$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_e + e^-$	ES	9	8
"ν_μ" $+ e^- \rightarrow$ "ν_μ" $+ e^-$	ES	12	9
TOTAL SNO SN COUNTS:		**917**	**606** $_{(D_2O)}$ **804** $_{[salt]}$ **681** $_{(NCD)}$

> 2005 ICARUS
Pure ν_e
Detection for
SN II



6'000 T

ICARUS AT Hall B

Ideal for
$\nu_\mu \to \nu_e$ detection (θ_{13})

LGNS Hall B

A Novel Supernova Detector

David B. Cline

University of California Los Angeles, Dept. of Physics & Astronomy, Box 951547, Los Angeles, CA 90095-1547 USA

Abstract. We discuss the prospects for detecting $\nu_{\mu,\tau}$ and ν_τ neutrinos from Type II supernovas using the novel detector at the Supernova Burst Observatory (SNBO) or OMNIS that is being designed for an underground laboratory in the USA. This detector would collect ~2000 flavor selected events from a Galactic supernova and could probe neutrino mass down to a few eV, as well as the dynamics of the supernova process. We believe this is essential to further our understanding of the neutrino section of elementary particle physics.

INTRODUCTION

The issue of whether or not neutrinos have masses is important for astrophysics and cosmology. Astrophysical considerations may represent the best hope for determining neutrino masses and mixings. In this paper, we examine how proposed neutral-current-based, supernova neutrino-burst detectors, in conjunction with the next generation water-Čerenkov detectors, could use a galactic supernova event to either measure or place constraints on the $\nu_{\mu,\tau}$ masses in excess of 5 eV[1,2]. Such measurements would have important implications for our understanding of particle physics, cosmology, and the solar neutrino problem and would be complementary to proposed laboratory vacuum-oscillation experiments.

A light neutrino mass between 1 eV and 100 eV would be highly significant for cosmology. In fact, if a neutrino contributes a fraction Ω_ν of the closure density of the Universe, it must have a mass $m_\nu \approx 92\,\Omega_\nu h^2$ eV, where h is the Hubble parameter in units of 100 km s^{-1} Mpc^{-1}. Reasonable ranges for Ω_ν and h then give 1 eV to 30 eV as a cosmologically significant range. A neutrino with a mass in the higher end of this range (*i.e.*, $10 \le m_\nu \le 30$ eV) could contribute significantly to the closure density of the Universe. The cosmic background explorer (COBE) observation of anistropy in the microwave background, combined with observations at smaller scales, and the distribution of galaxy streaming velocities, have been interpreted as implying that there are two components of dark matter: hot ($\Omega_{HDM} \sim 0.3$) and cold ($\Omega_{CDM} \sim 0.6$). The hot dark matter (HDM) component could be provided by a neutrino with a mass of about 7 eV.[3-5]

MEASURING THE NEUTRINO MASS BY TIME OF FLIGHT

Perhaps the most straightforward and obvious nature of a massive neutrino would come from the lengthening in flight time from a distant supernova. For example, the flight time difference between ν_τ and ν_e ($\bar{\nu}_e$) in seconds is

$$\Delta t = 5.14 \times 10^{-2} R_{kpc} \left[\left(\frac{m_{\nu_\tau}}{E_{\nu_\tau}} \right)^{2} - \left(\frac{m_{\nu_e}}{E_{\nu_e}} \right)^{2} \right] s \ .$$

where E_{ν_τ} is the neutrino energy in MeV, m_{ν_τ} is in eV, and R_{kpc} is the distance to the supernova in units of 10 kpc. A finite neutrino mass would alter the neutrino spectra in characteristic ways that could result in broadening and flattening of the observed signal.

Some arguments, which arose during this meeting, for detecting the neutrinos are given in Table 1. Event rates for various detectors for a galactic supernova are given in Table 2.[7] We believe the detection of these supernova neutrino signals will be essential to our understanding of the neutrino sector.

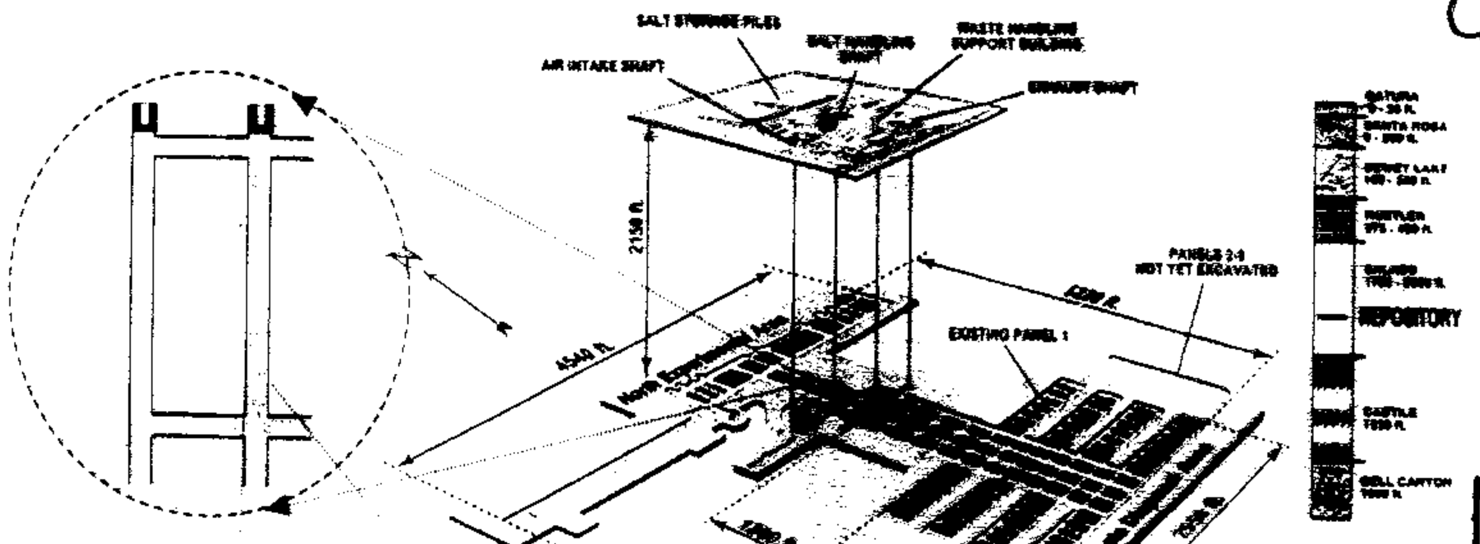
Thus, neutrino masses might be obtained by comparing the observed neutrino signal with the signal expected from supernova models. Since detectors such as Superkamiokande (SK) are relatively insensitive to ν_μ and ν_τ, they are unlikely to measure cosmologically significant neutrino masses for these flavors. One of the neutral-current-based detectors being built at present is the Sudbury Neutrino Observatory (SNO). A general comparison of the methods of measuring neutrino mass is given in Table 3.[1,7] The rate of interaction for the world's detectors is shown in Fig. 1.

CP533, *Next Generation Nucleon Decay and Neutrino Detector*, edited by M. V. Diwan and C. K. Jung

OMNIS – REAL TIME SNE ν_μ, ν_τ DETECTION

DBC
K Lee
UCLA

WIPP Facility and Stratigraphic Sequence

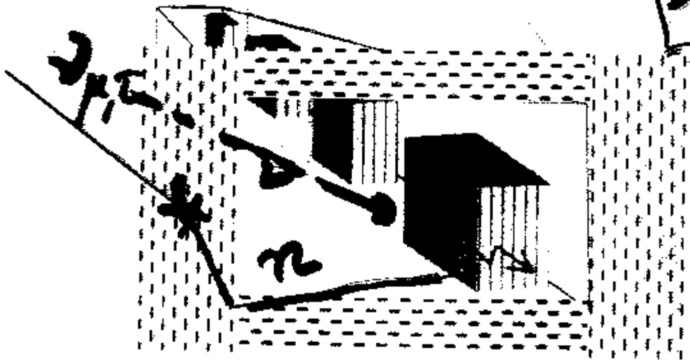


CARLSBAD
NEW MEXICO

NEW UNDERGROUND LAB IN USA

Expanded view of CARUS footprint in WIPP

ν_x Detector ⇒ 2000 Events



A schematic layout for OMNIS in a CARUS tunnel with a neutron detected

Fig. 1a

Fig. 1

+ BOULBY MINE

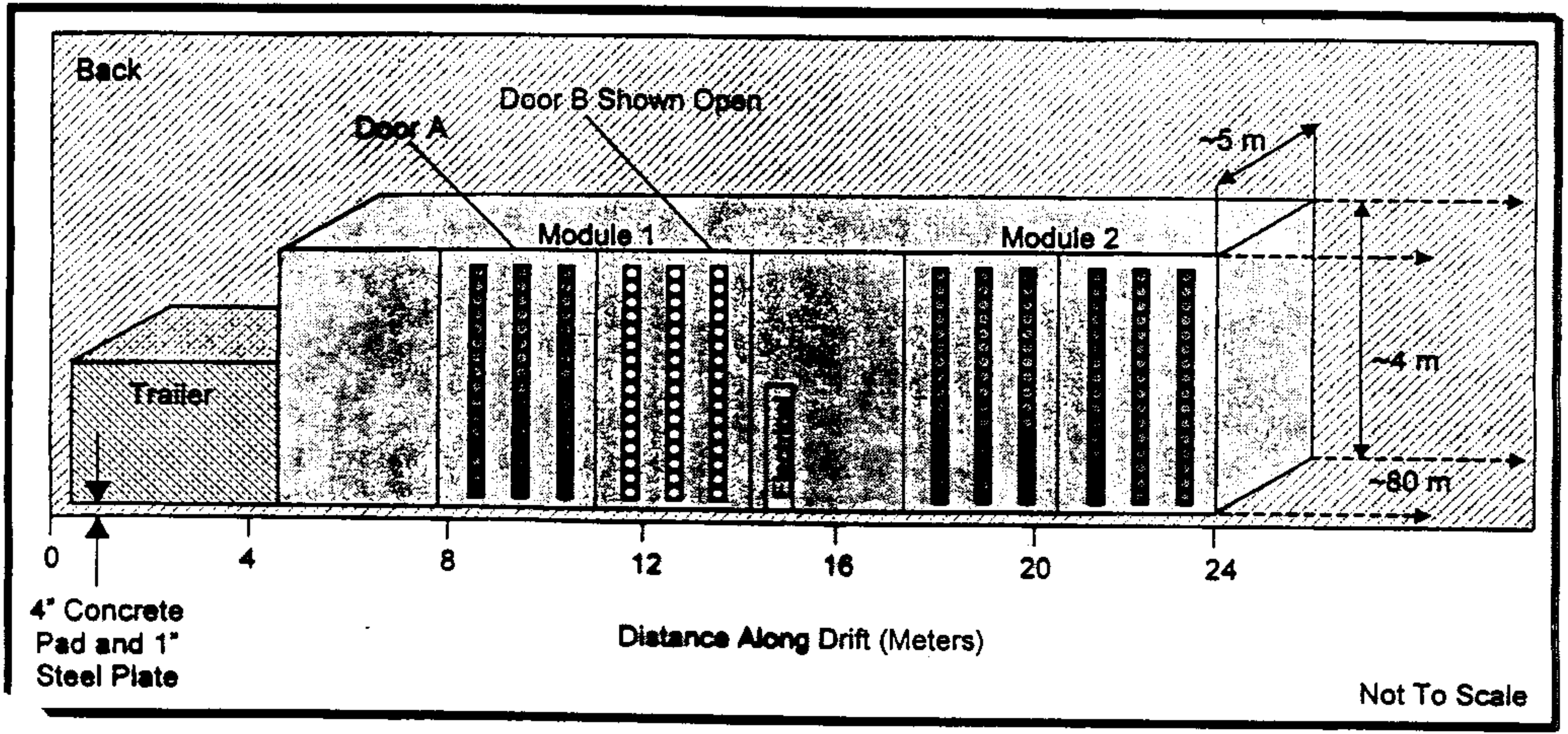


Figure 2-1. OMNIS Lead Detector

TABLE 5: YIELDS OF SUPERNOVA NEUTRINO DETECTORS

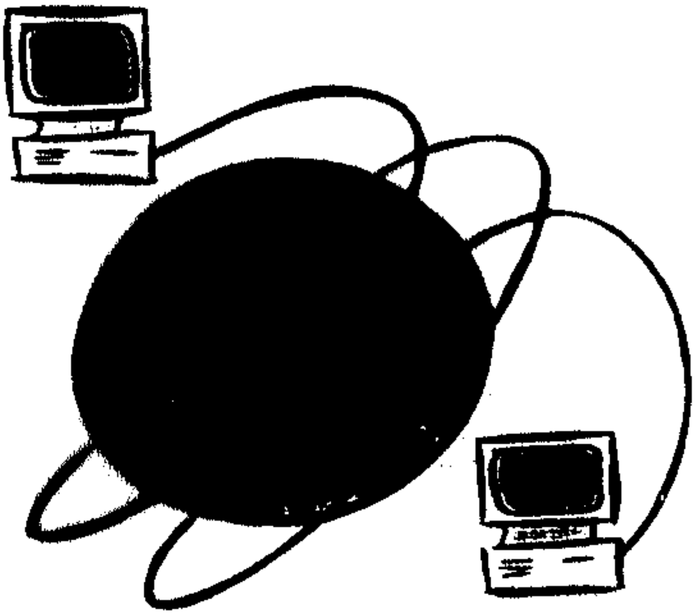
Detect\or	Target Material	Fiducial Mass (Ton)	Target Element	Yield (υ_e)	Yield $(\overline{\upsilon_e})$	Yield $(\upsilon_\mu + \upsilon_\tau + \overline{\upsilon_\mu} + \overline{\upsilon_\tau})$
Super K	H_2O	32000	p, e, O	180	8300	50
LVD	CH_2	1200	p, e, C	14	540	30
SNO	H_2O	1600	p, e, O	16	520	6
SNO	D_2O	1000	d, e, O	190	180	300
OMNIS	*Fe*	8000	*Fe*	20*	20*	1200*
OMNIS	*Pb*	2000	*Pb*			
no osc.				110**	40**	860**
$\upsilon_\mu \rightarrow \upsilon_e$ osc.				** 44 20†	40**	640**

* Assumes same efficiency as in Smith 1997

** Assumes a single neutron detection efficiency of 0.6

† Include
2n Event

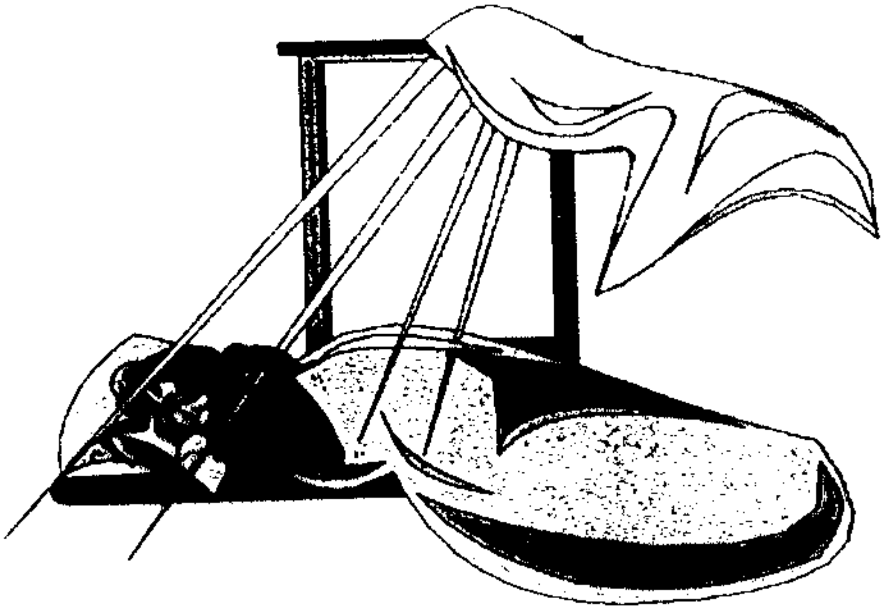
Worldwide Supernova Watch



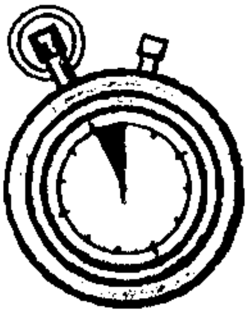
Mark Vagins
University of California, Irvine

Marina del Rey, CA
February 16, 2001

So, if a SN neutrino burst is detected, we would like to be able to **warn** the astronomical community that something important is **about** to happen, the beginning of which they would quite likely otherwise miss:

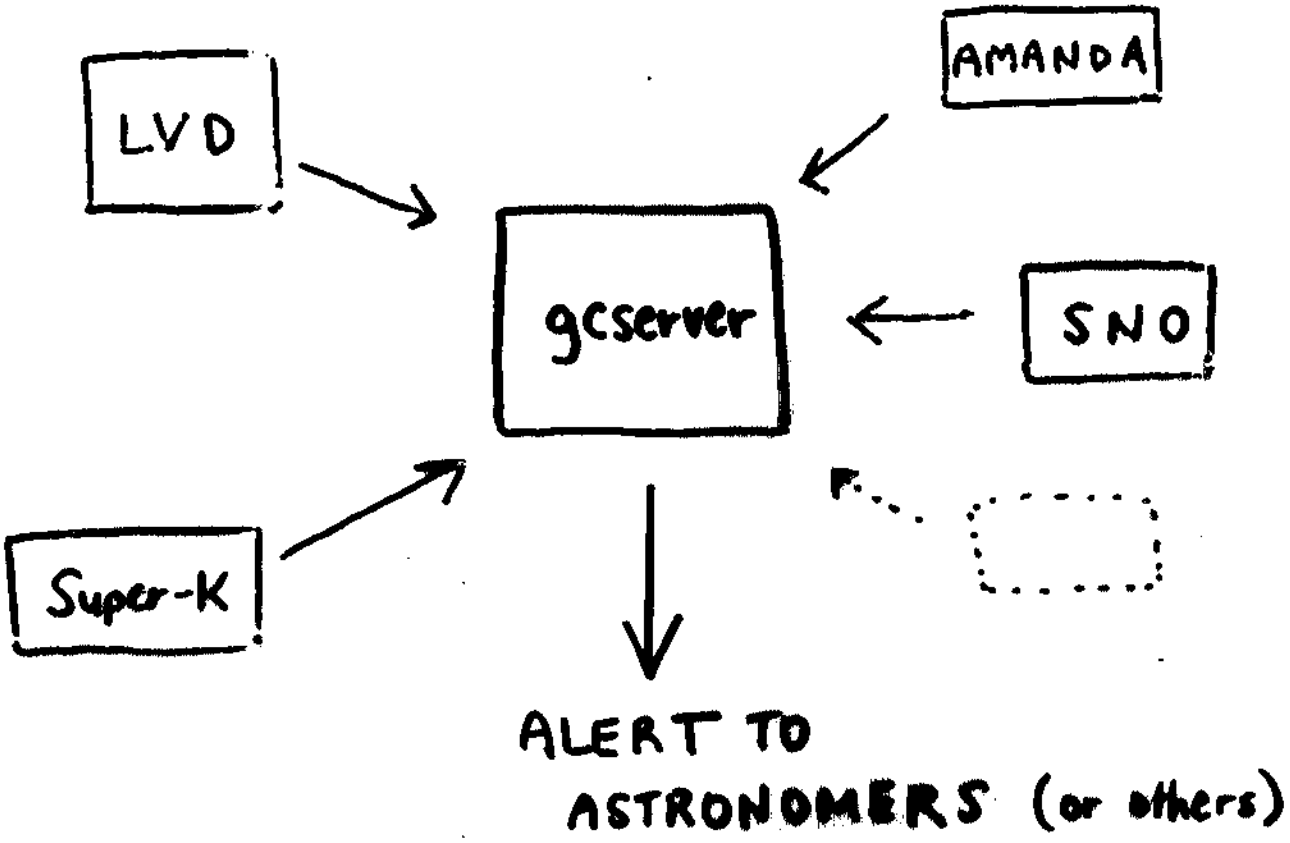


Obviously, time is of the essence...



K. Scholberg

SNEWS IMPLEMENTATION



Each experiment sends a datagram if it finds a burst with:

- experiment no.
- time of 1st event

Current configuration: kaboom server @ Kamioka

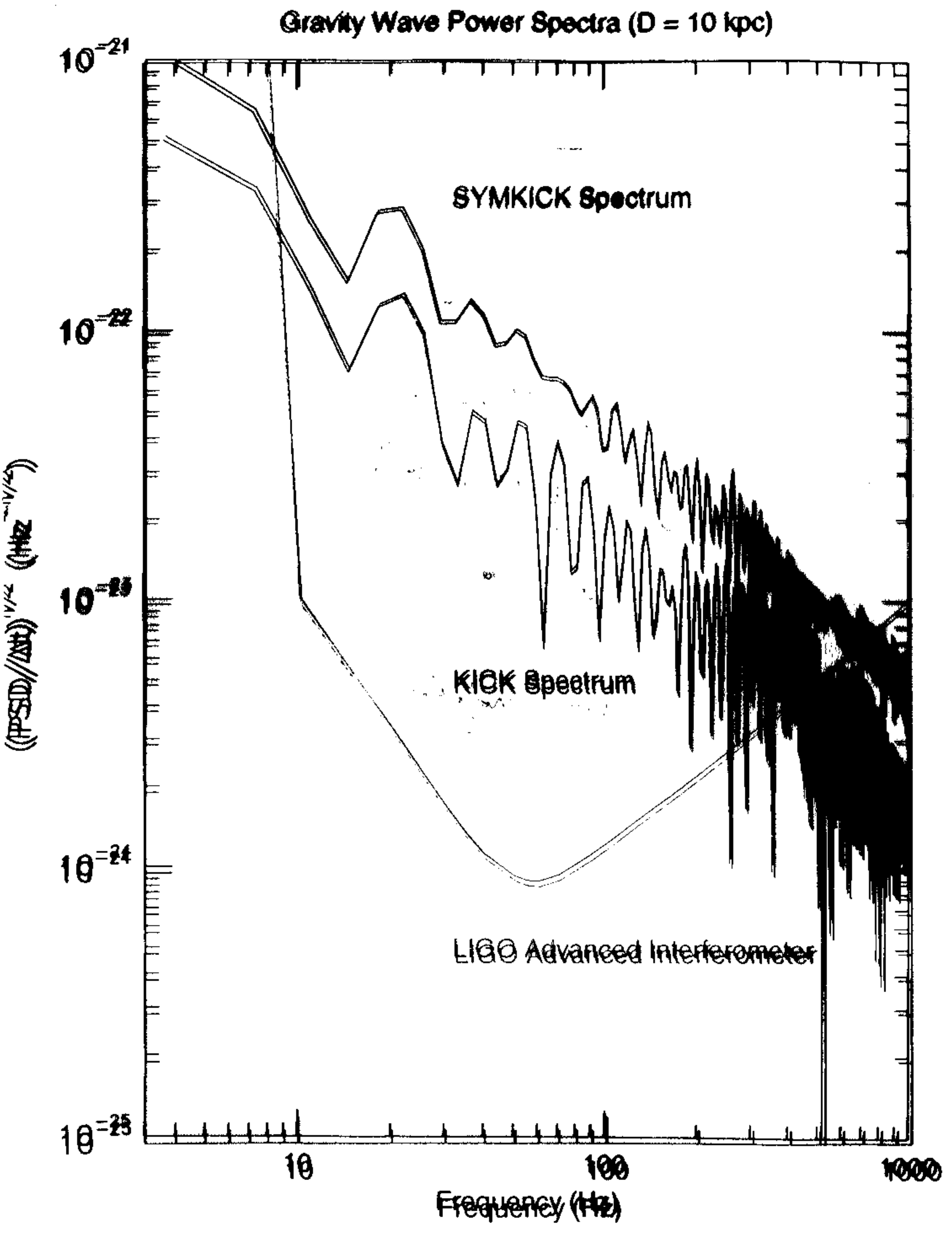
Alert if ≥ 2 different exp'ts within 10 seconds

Alert message does not yet go automatically

ALERTING ASTRONOMERS

- HST 'Target of Opportunity' proposal
  'Observing the Next Nearby Supernova'
  J. Bahcall

- Sky & Telescope Astro-Alert
  L. Robinson
  R. Sinnott
  mailing list, ~4000 members
  - working on test with known variable object



BURROWS + HAYES 1996

Conclusion

1) SN Dynamic Simulation still
confuse 1D → good
physics
sometimes
explosion

2D → Poor Physics
some time

ν heating and
Convection
is
Key

2) SN 1987A Fits time profile but
does not seem to like LMA Solar ν
Solution

3) A New generation of detectors
and the SN Watch (with Ligo/Virgo…)
could yield a great new
"LABORATORY IN THE SKY"