FERMILAB
MAY 9 1995
LIBRARY

Real Time Supernova Neutrino Observations

D. B. Cline

University of California, Los Angeles, Department of Physics and Astronomy, 405 Hilgard Ave., Los Angeles, CA., USA

We describe one aspect of the Neutrino Astrophysics working group at the 1994 Snowmass Workshop. The real-time detection of neutrinos from supernova will be of great importance to understanding the supernova process and the neutrino mass.

Fermilab Library
0 1160 0041880 0

1 Superova Observation: Now and Future

At this meeting there was a lively discussion of future supernova detection. There were presentations on ICARUS, SNO, AMANDA, and SNBO detectors and discussions of real time coinncidences between detection and with other detectors such as gravity wave detectors.

The major physics issues that were discussed was the determination of neutrino mass and the supernova dynamics. The major problem in this field is the unknown SNII rate on this galaxy and the difficulty of constructing a supernova detector large enough to be sensitive to extragalactic sources, we now turn to some of the specific issues in this field. Some of this part of the report is adapted from Reference (1) (2).

2 Cosmological Neutrinos

The issue of whether or not neutrinos have masses is important for astrophysics and cosmology. Unfortunately, terrestrial experimental probes of neutrino mass, especially the ν_μ and ν_τ masses, remain problematic. Astrophysical considerations may represent the best hope for inferring neutrino masses and mixings. In this paper we examine how proposed neutral-current-based supernova neutrino burst detectors, in conjunction with the next genneration water Cerenkov detectors, could use a galactic superova event to either measure or place costraints on the ν_μ and/or ν_τ masses in excess of 5 eV. 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 ad 100 eV would be highly significant for cosmology [2]. 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^{-1} sec^{-1} Mp^{-1}. Reasonable ranges for Ω_ν and h then give 1 eV to 92 eV as a cosmologically significant range. A neutrino with a mass is the higher end of this range, i.e., $10 \lesssim m_\nu \lesssim 92$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: i.e., hot and cold dark matter components $\Omega_{CDM} \sim 0.6$ and $\Omega_{HDM} \sim 0.3$. The hot dark matter (HDM) component could be provided by a neutrino with a mass of about 7 eV [3] [4] [5].

Despite the cosmological and particle physics interest in massive neutrinos there are very few terrestrial experimental means for measuring the neutrino masses. The electron neutirno mass is constrained by the tritium end point experiments to be less than about 7.2 eV. It is conceivable that $\nu_\mu \nu_\tau$ accelerator neutrino oscillation experiments, such as the NOMAD and CHORUS experiments at CERN, and the E803 experiment at Fermilab could be used to infer a mass in the cosmologically interesting range for ν_μ or ν_τ. This would depend on there being a fairly large vacuum mixing between these neutrino flavors. Nucleosynthesis from supernovas could possibley provide a signature for neutrinos with these masses.

3 Impact of Low Energy Neutrino Experiments

Recennt measurements of the neutral current processes on nuclei at (20 - 50 MeV) low energy by the KARMAN [2] group give additional confidennce for the rate estimates for supernova observatories. This group has measured $\nu +^{12} C \rightarrow \nu +^{12} C^*$ and found very good agreement with theoretical predictions. They have also measured the charged current processes $\nu_e +^{12} C \rightarrow e^- +^{12} N_{groundstate}$. Reactions like $\nu_e +^{12} C \rightarrow e^- +^{12} N^*$ most likely have been observed as well. The cross section for this reaction is expected to be $\sim 6.X10^{-42} cm^{-2}$ as estimated by the SNBO group for ann excited nuclear process in the same energy range.

TABLE I. Supernova neutrino detection methods in the 1990s.

Reactions	$\bar{\nu}_e p \rightarrow e^+ n$	$\nu_x e \rightarrow \nu_x e$	$\nu_x N \rightarrow \nu_x N$	$\nu_x N \rightarrow \nu_x N^* \rightarrow n$
Parameters				
Cross section	Large (KII,SK,IMB,LVD)	Small $\sim E_\nu^2$ (ICARUS)	Large for coherent process	Large at high E_{ν_x} SNO/SNBO
Neutrino energy estimate	Yes $\sim E_e$	Partial $E_{\nu_e} \sim f(E_e)$	No	No Threshold may set E_{ν_x}
ν direction	No	Yes	No	No
Time information	Yes	Yes	Yes	Yes
Down time speculation	$\gtrsim 10\%$	$\sim 30\%$	?	Could be small
Maximum detector size	2×10^5 ton (H_2O) LENA $\gtrsim 10^4$ ton liq. scint. (LVD)	$\sim 2\times10^5$ ton (H_2O) or $\sim 10^3$ ton Cryogenic (ICARUS)	? Kilograms No detector proposed	$\sim 10^5$-10^7 ton of NaCl (SNBO) or $\sim 10^3$ ton D_2O (SNO)
Backgrounds	Small if e^+ and n capture detected; OK for H_2O galactic signal	Small if directionally used to reject background	?	Depends on radioactivity of material

Perhaps the most straight forward and obvious signature of a massive neutrino would come from the lenghtening in flight time from a distant supernova. For example, the flight time difference between ν_τ and $\nu_e(\bar{\nu}_e)$ in seconds is

$$\Delta t = 5.14\times10^{-2} R_{kpc}\left[\left[\frac{m_{\nu_\tau}}{E_{\nu_\tau}}\right]^{-2} - \left[\frac{m_{\nu_e}}{E_{\nu_e}}\right]^{-2}\right] \text{sec.}$$

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

Thus neutrino masses might be obtained by comparing the observed neturino signal with the signal expected form supernova models. Since detectors such as Super-Kamiokande (SK) and IMB are relatively insensitive to ν_μ and ν_τ, they are unlikely to measure cosmologically sigificant neutrino masses for these flavors. One of the neutral-current-based detectors being build at present, the Sudbury Neutrino Observatory (SNO), (see Tables II, III, and IV). [1].

5 Recent Simulation Results on Supernova Explosions

Recently there has been real progress in supernova simulations giving an explosion [6]. These calculations give interesting predictions for the neutrino spectra as shown in Fig. 1 annd Fig. 2. Detectors like Super K and SNBO may be able to detect such effects, however, the SNBO detector may be of crucial importance for this study. Using these various detectors it should be possible to detect a finite neutrino mass as shown in Fig. 3 [1].

6 Various Detectors Being Constructed or Designed

The Kam and IMB groups observed the first real time neutrino detection of SN 1987A. [7]

We show that a schemetic of the Water Super Kamiokonde detector in Fig. 4. We note that this detector will be very sensitive to the $\bar{\nu}_e + p \rightarrow e^+ + n$ reaction and therefore for the $\bar{\nu}_e$ flux. The detector is in a state of construction.

6.2 *The ICARUS Detector at the Gran Sasso [2]*

The longest baseline neutrino beam will be from a supernova. In order to exploit this source we will need a complement of detectors on Earth to cover the possible time of flight difference for a massive neutrino (ie., 10eV) or to study the neutrino oscillations from either the MSW effect in the matter of the SN or the long baseline for vacuum oscillations in Table II we list some preliminary concepts concerning the separation of the different types of neutrino oscillations. We will return to SNBO later.

6.3 *SNO [2]*

The expected reaction rates for the Sudbury Neutrino Observatory for a Galactic Supernova II are given in Table III: The detector will consist of 1 Kilo ton of D_20.

7 Ideal Supernova Observatories

The major problem of supernova detection is the uncertain period of time between such processes in this galaxy. In addition complimentary detectors should be active when the supernova goes off to learn the maximum information about the explosion porcess and neutrino properties. In Table IV we list some of the requirments of such an ideal supernova observatory.

Lacking an ideal observatory a group of us have been

TABLE II. Events expected from a galactic supernova in further supernova ν detectors at 10 kpc.

Comparison of future supernova ν detectors						
Process	$\bar{\nu}_e p \to e^+ n$ $\bar{\nu}_e d \to pp e^-$	$\bar{\nu}_e e \to \bar{\nu}_e e$	$\bar{\nu}_x e \to \bar{\nu}_x e$ $x = \mu, \tau$	$\nu_e N \to N^* \nu_e$ $\to n$	$\nu_x N N \to N^* n_x$ $\to n$	ν_e prompt
Detectors						
ICARUS		~140	25			4[a]
SNO (1.6 kT):	~435	3	21	~117	~200	5[a]
($D_2O + H_2O$)	(H_2O shield $+ D_2O$)					5-20
LVD (1.8 kT): scint	~342					
MACRO (1 kT): scint	~220					
Kamiokande II (3 kT)	~355	~1				
Super Kam (40 kT) H_2O	~5310	~17				~5[a]
SNBO (100 kT)	100s			~100s	10000	
Comments	Measure t_ν, $E_\nu \sim E_e$ No direction	t_ν E_ν estimated from E_e Θ_ν measured		t_ν only No E_ν! No Θ_ν		$\Delta r \simeq 10$ ms

[a]Depends on energy spectrum of prompt ν_e and detector threshold.

TABLE III. SNO Supernova Event Rates (10 kpc)

Reaction	Target medium	Events in ν_e burst per kton	Events in cooling phase per kton
I. $\nu_e + d \to p + pe^-$	D_2O	10	33
II. $\nu_x + e^- \to \nu_x + e^-$	D_2O/H_2O	1	16
III. $\nu_x + d \to \nu_x + p + n$ $(n\,^{35}Cl \to {}^{36}Cl + \gamma)$	D_2O	6	760
IV. $\bar{\nu}_e + d \to n + ne^+$	D_2O	0	20
V. $\bar{\nu}_e + p \to n + e^-$	H_2O	0	120

TABLE IV. Ideal Supernova Observation

1) Operation Time > τ_{SN}

$\geq$ 60 Years Galactic
$\geq$ 20 Years Extra Galactic

Mass KT → Megaton
↑ ↑
Galactic SN Extragalactic SN

3) In "Coincidence" with Gravity Wave Detectors

4) Constructed of Simple System Requiring Very Little Maintenance or Operating Costs

5) Capable of Separating $\bar{\nu}_e$, ν_e, $\nu_\mu + \nu_e$ Interactions

6) Some Directions ($\nu_e + e \to \nu_e + e$) To Point Back to SN

studying a very large detector we call SNBO. Table V gives some of the guidelines for this detector [9] Fig. 6 gives some of the more detailed steps in the development of SNBO. We have located a possible site for the observatory near Carlsbad N.M., the WIPP site as shown in Fig. 7. We have studied the radioactive background at this site (measured by the OSU group) and find it acceptable for a galactic SN detector.

8 Real Time SN Detector

With a detector like SNBO, where 104 counts would be recorded, it will be possible to detect the SN within 100 ms of its start, and to alert the WWW to "Supernova in Progress". Table VI lays out some more information in this regard.

9 Long Term Operation in Extragalactic SN Detection

The real issue in SN ν detection is the long time needed to operate the detector between SN explosions in the galaxy, longer than most underground detectors have operated as illustrated in Table VII. One possibility is to build a large enough detector to "see" Extragalactic SN, Fig. 8 shows the possible rate with distance from our galaxy as given by E. Becklin. [8]. A 10^7 ton detector may observe a SN each year, this must be the long term goals of the SNBO prototype study!

TABLE V. SNBO

However in Order to Detect M_{ν_x} From a SNII

a) A NEUTRAL CURRENT DETECTOR
(i.e. $\nu_x + T \rightarrow \nu_x + T'$)
THAT <u>TAGS NEUTRINO FLAVOR</u>

b) ADEQUATE EVENT RATE TO MEASURE M_{ν_x}

THE SNBO GROUP HAS STUDIED THESE REQUIREMENTS AND CONCLUDED

A) TO DETECT $M_{\nu_x} > (5 - 10)$eV CAN BE CARRIED OUT USING GALACTIC SUPERNOVA AND A MASSIVE NEUTRAL CURRENT DETECTOR ($M_{SNBO} > 10^4$ TONS)

B) TO DETECT $1 < M_{\nu_x} < (5 - 10)$eV WILL REQUIRE EXTRAGALACTIC SNII DETECTION AND $M_{SNBO} > 10^7$ TONS

TABLE VI. Real Time Detection of SNII ν "Burst"

- IF RATE IN DETECTOR IS LARGE ENOUGHT
  (i.e. SNBO, SUPER K)
  IT SHOULD BE POSSIBLE TO DETECT THE SN IN $\leq$ 100 MS

- IF A DETICATED TRIGGER IS INSTALLED
  SNBO COULD SUPPLY A REALTIME SN SIGNAL

- IN CURRENT DETECTORS
  (KMAIII, MACRO, LUD0)
  THE PROCEDURE IS TO FLAG THE POSSIBLE EVENT AND
  MAKE A DECISION WITHIN $\sim$ 1 HOUR

TABLE VII. The Major Problems in Building and Operating a SNNO

The average time between SNII in this Galaxy 10 - 50 years?

τ_{SN}

The average "lifetime"" of underground detectors
NUSEX, FREJUS, HPW, IMB HOMESTAKE? KAM I, II
KOLARGOLD FIELDS, GALLEX... My Estimate
$\tau_{Exp} \lesssim$ 12 years - Experiments Finish!

NEED - $\tau_{SNNO} >< \tau_{SN} >\sim$ 30 years
Longer than DOE has been a agency
Large detectors required
$\geq$ few KT for Galactic SII
$\leq 10^6$ Ton for Extragalactic
Different tvpes of detectors needed to observe
-$\bar{\nu}_e$ (H_2O is good $\bar{\nu}_e + p \rightarrow e^+ + n$)
-ν_e eg (ν_e + AR $\rightarrow e^+$) ICARUS
ν_μ, ν_τ - Neutral Current Detectors
Put into coincidence with Gravity Wave Detectors

FIGURE 1. Neutrino luminosity and mean energy as a function of time for the 25 M⊙ progenitor. Time 0 corresponds to the bounce of the core.

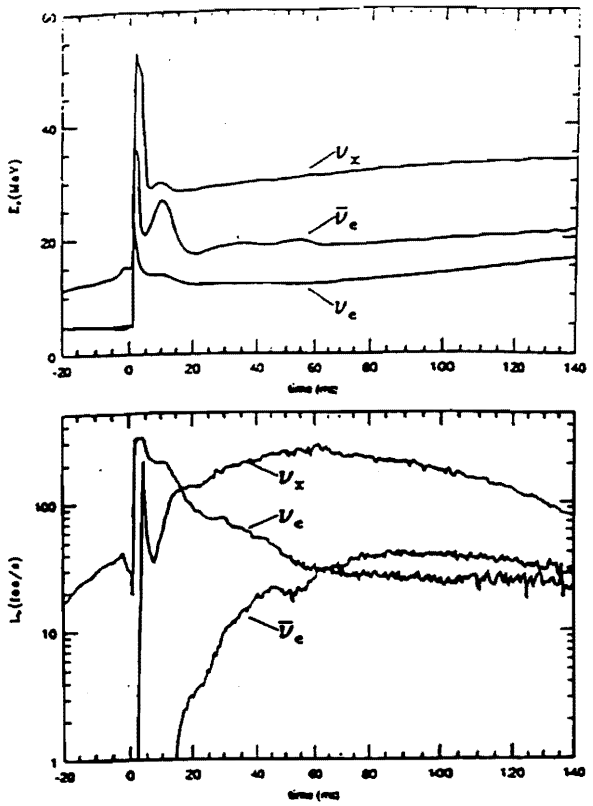


FIGURE 2. Time profile of Supernova Neutrinos near the Explosion
(A. Burrows, private conversation

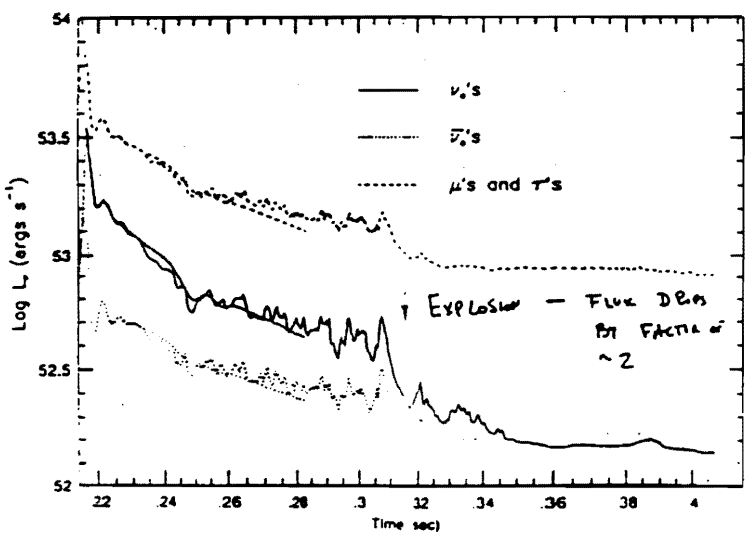


FIGURE 3. Time response of the SNBO detector to a Supernova II at 10 kpc for massive ν_τ. [1]

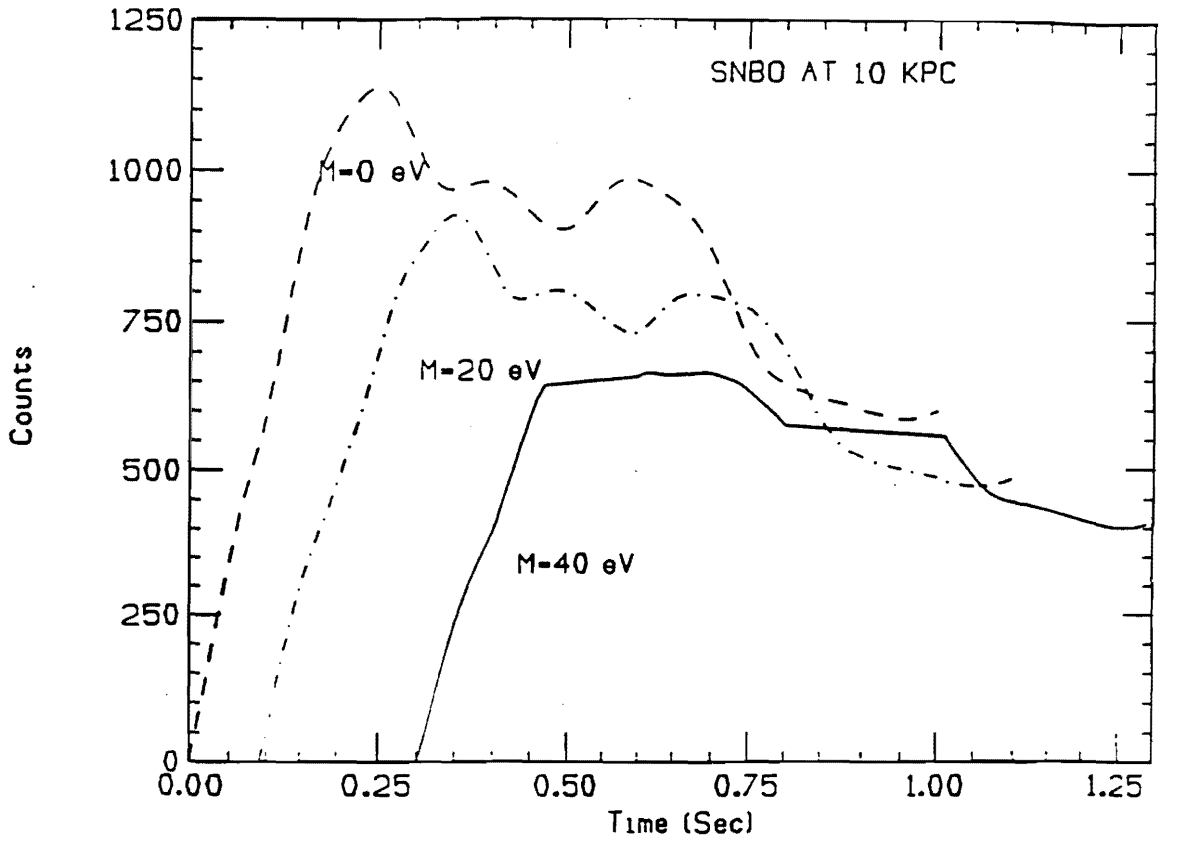


FIGURE 4. The Superkamiokande Detector

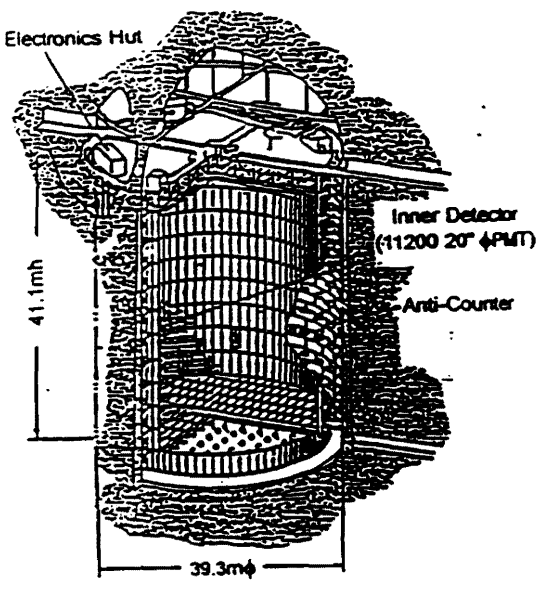


FIGURE 5. View of ICARUS Detector

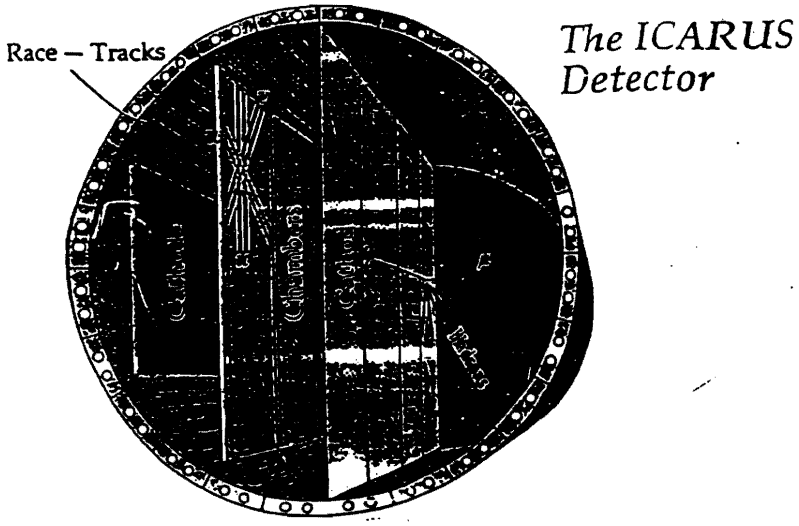


FIGURE 6.

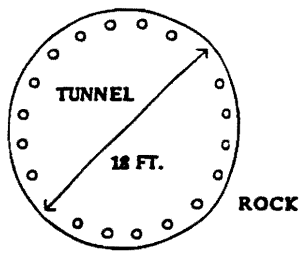
The Super Neutrino Burst Observatory Concept

1) GOAL: To measure τ neutrino mass
- direct unambiguous measurement -

2) METHOD: Use time of flight from Galactic SN

3) DETECTOR: Rock ($\nu + A \rightarrow \nu' + A' + n$)
(threshold exists since n is initially bound)

4) ENERGY: Average ν_τ energy is about 3/2 average ($\nu_e, \bar{\nu}_e$) energy



5) COUNTS: More than 10^4 counts expected from Galactic SN
Use "inexpensive" neutron detectors - and
detectors requiring little direct maintenance

6) FROM CALCULATIONS:
$\langle E_{\nu_e} \rangle = 12\text{MeV} \quad \langle E_{\bar{\nu}_e} \rangle = 15\text{MeV} \quad \langle E_{\nu_{\mu,\tau}} \rangle = 25\text{MeV}$

7) RISE TIME: $L_{\bar{\nu}_e}$ and $L_{\nu_{\mu,\tau}}$ rise rapidly at
almost the same time (about 0.1sec)

8) FIRST PREDICTION: Take model output for spectra and $L_{\bar{\nu}_e}$
and $L_{\nu_{\mu,\tau}}$ and feed into detector response
to predict first 0.35 seconds of detection

9) MEASUREMENT DATA: Use Kamiokande II data for supernova
in Milky Way to measure $L_{\bar{\nu}_e}$ rise time

10) LIMITS: Compare ν_μ and/or ν_τ signal to find limits on m_{ν_μ} and/or m_{ν_τ}

LLNL Cal. for SNBO Detector:

No. of Counts = $2 \times 10^4 \frac{V}{R^2}$ with V in meters^3, R in Mpc;

For Milky Way R = 0.01 Mpc; Let V = 10^4 meters^3

Then No. of Counts = 2×10^4

FIGURE 7. The WIPP Site at Carlsbad, New Mexico

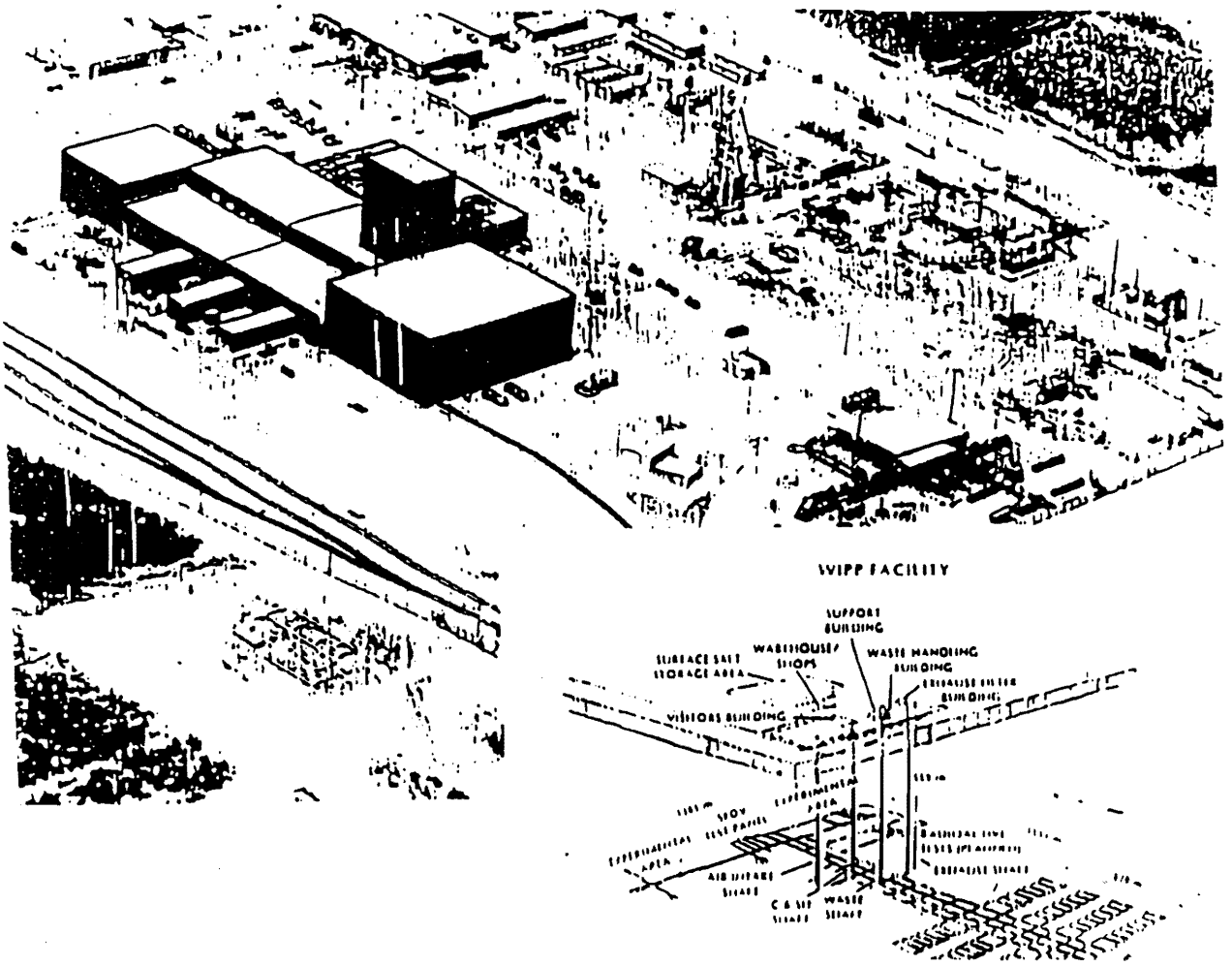
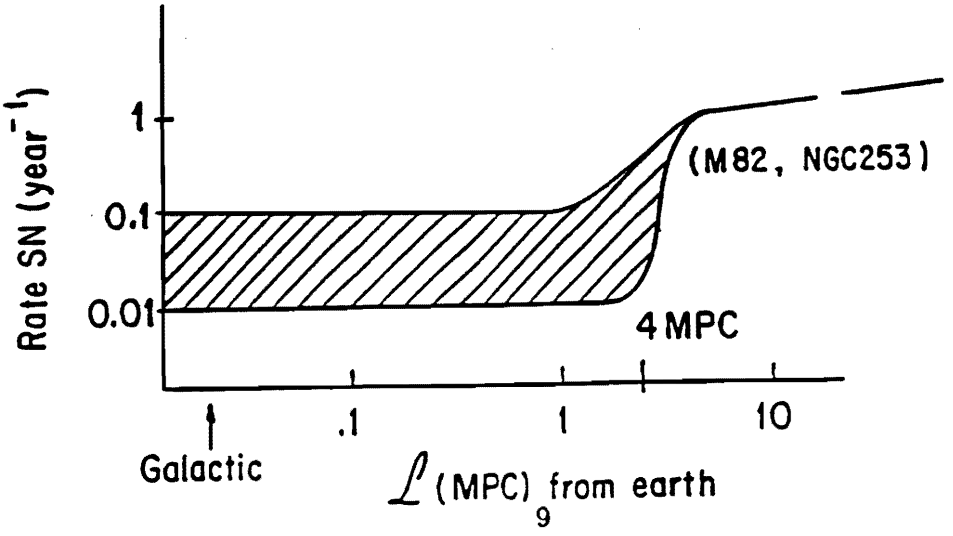


FIGURE 8. Estimated rate for Supernova explosions as a function of the distance from Earth



10 Acknowledgements

I wish to thank F. Halzen and G. Fuller for helping with the organization of the Neutrino Astrophysics Section: Also members of ICARUS, SNBO, and SNO for many discussions.

11 References

1. D.B. Cline, G.M. Fuller, W.P. Hong B. Meyer, and J. Wilson *Phys. Rev.*, **D50** 720 (1994).
2. Presentations to the Snowmass Workshop were made by members of the SNO, Super Kamonkande, AMANDA, SNBO and KARMAN groups that we report here.
3. G.F. Smooth, et al., *Astrophys. J.*, **396** L1 (1992).
4. R.K. Schaefer and Q. Shafi, *Nature* **311**, 517 (1984). (1992) 4088.
5. J.R. Bond, G.E. Efstathiou, and J. Silk, *Phys. Rev. Lett* **45**, (1980).
6. M. Herant, et al., *APJ* **58**, 1490 (1994), A. Burrows, private communication.
7. K. Hirata, el al., *Phys Rev. Lett* **58**, 1490 (1987); R.M. Bionta, et al., *Phys. Rev. Lett* **58**, 1490 (1987).
8. E. Becklin, private communication
9. The SNBO Group - Internal Reports (UCLA)

NAME	ID NO	MS

RETURN TO FERMILAB LIBRARY