A SUPERNOVA BURST OBSERVATORY TO STUDY μ AND τ NEUTRINOS[a]

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R. N. BOYD,[1] R. L. BRODZINSKY,[2] D. B. CLINE,[3] S. A. COLGATE,[4] E. J. FENYVES,[5] G. M. FULLER,[6] D. KNAPP,[7] D. LEWIN,[8] S. E. LABOV,[7] R. MARSHALL,[9] M. M. NIETO,[4] D. A. SANDERS,[3] P. F. SMITH[8] K. STEVENS,[9] E. R. SUGARBAKER,[1] W. VERNON,[6] J. R. WILSON[7]

The Supernova Neutrino Burst Observatory (SNBO) is a proposed dedicated detector for μ and τ neutrinos from a supernova in our Galaxy. Observation of the time profile for 1000 events would enable a non-zero μ or τ neutrino mass greater than 5 eV to be measured through the time-of-flight difference and, in conjunction with the electron antineutrino signal from Super-Kamiokande and other world detectors, would provide unique information on neutrino mixing effects over Galactic distances.

The SNBO is based on the use of natural rock as target, detecting the neutrinos by nuclear excitation, which releases neutrons detected by underground neutron counters. Using loaded scintillator, a new neutron-collection arrangement has been devised which improves the original scheme by a factor of 30. This new scheme is known as SNBO II, and enables 100 tons of target rock to be monitored with only 1 ton of scintillator; and 100 tons of scintillator would be sufficient to observe 1000 events from a supernova at 8 kpc. A suitable underground site would be the DOE-owned salt mine near Carlsbad, New Mexico. Neutron background measurements in this site are consistent with the levels expected from the low U and Th levels in the rock, demonstrating the suitability of this site for a supernova observatory. A coincident detector array could be accommodated in the Boulby Salt mine, UK.

1 The SNBO

The majority of supernovae in our Galaxy are obscured optically, but would be observable as a neutrino burst a few seconds in duration. During the past 1000 years, there have been six visible supernovae within about 5 kpc of the Sun, consistent with a total 30-100 in the Galaxy as a whole. Thus Galactic supernovae occur on average every 20 ± 10 years, the majority emitting most of their energy as a neutrino burst

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[1] Ohio State University; [2] Batelle, Pacific Northwest Laboratory; [3] University of California, Los Angeles; [4] Los Alamos National Laboratory; [5] University of Texas, Dallas; [6] University of California, San Diego; [7] Lawrence Livermore National Laboratory; [8] Rutherford Appleton laboratory, UK; [9] University of Manchester, UK.

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containing all three neutrino types in approximately equal proportions. For Galactic distances (5–25 kpc), a non-zero neutrino mass would produce time-of-flight differences in the range 0.1 – 1.0 s, allowing a cosmologically significant mass (> 5 eV) to be extracted from the time profile. Therefore, it would be of considerable interest to measure the relative arrival-time profile of the μ and τ neutrino components.

Existing large water-based detectors (Super-Kamiokande, SNO) and scintillator-based detectors (MACRO, LVD) detect mainly electron antineutrinos through charged-current events; they do not see a sufficient number of neutral-current events from μ and τ neutrinos. Several years ago, a method of observing the latter was devised by members of this collaboration, using any material, including natural rock, as target.[1] Neutral-current excitation of nuclei by the incoming neutrinos releases neutrons that can be detected within ~ 1 ms to give the time profile of the neutrino burst. Moreover, because this process has an (energy)^2 dependence, the signal arises principally from the μ and τ neutrinos, since these are released in the supernova at a higher temperature (~25–27 MeV) than the electron neutrinos (11–15 MeV). The simplicity of this concept suggested that it could be used as the basis of a permanent, dedicated underground observatory for supernova neutrinos.[2]

2 SNBO II

The original scheme (SNBO I) was based on boron trifluoride counters embedded in the rock for which simulations show a count of 0.4 events/m^3 for a supernova at 8 kpc.[1] Thus, despite the zero-cost target, 1000 events would have required the provision of a 2500 m^3 neutron detector. However, new Monte Carlo studies have shown three types of improvements in detection efficiency:[3]

1. Placing detectors in open space in underground caverns, to take advantage of multiple neutron scattering in the cavern (Fig 1);
2. Using a mixture of neutron absorber and thermalizer (*e.g.*, a Li- or B-loaded scintillator) to minimize absorption by the hydrogen thermalizer;
3. Reshaping the detectors for optimum area/thickness.

Each of these changes gains approximately a factor 3. Figure 2 shows the sequence of improvements: Fig. 2A shows an example of improvement No. 1; Fig. 2B shows the additional improvements (Nos. 2 and 3) to produce a typical form of SNBO II.

Further substantial improvements are possible, in principle, through the addition of materials with lower neutron absorption to the cavern (*e.g.*, lead, iron, or their natural mineral compounds). We refer to this extension as SNBO III, but it is not yet known

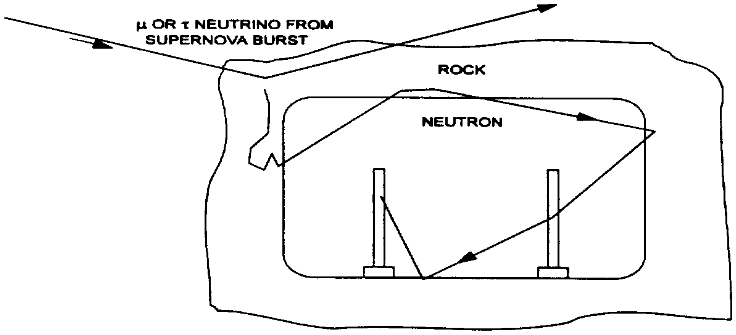

Figure 1: Multiple neutron scattering in the cavern in an open geometry.

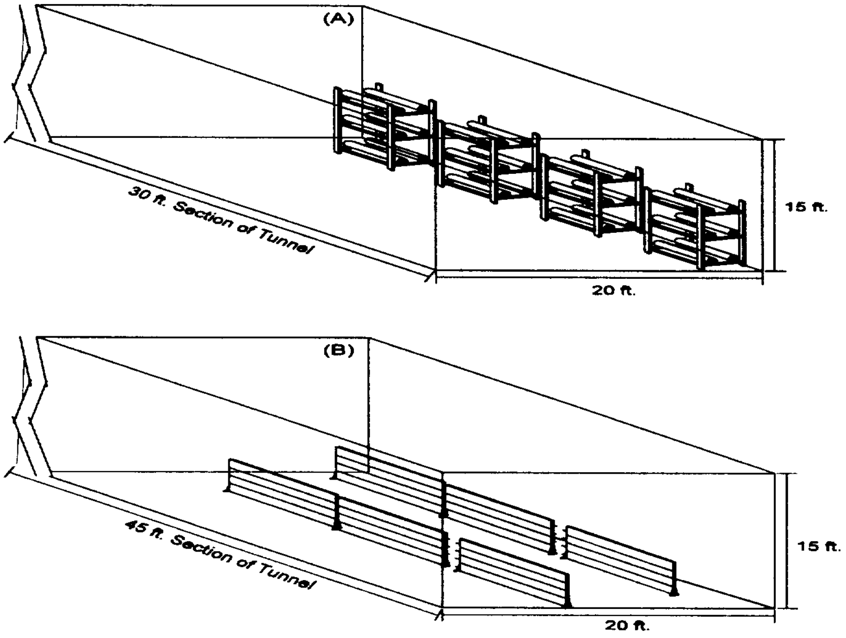

Figure 2: Examples of (A) BF_3 and (B) loaded scintillator (distributed along open tunnels in the rock[3]) detectors in a tunnel.

whether the gain in event collection outweighs the additional cost of adding these materials.

3 Event Numbers and Effective Target Mass

The neutron collection capability is increased, with SNBO II, to ~10–12 events/m ≡ 10–12 events/ton scintillator, compared with the ~0.3 events/ton scintillator obtained by direct detection in MACRO or LVD. Thus SNBO II, in addition to its unique capability of observing μ and τ neutrinos, also provides a very low cost method of supernova detection. Another way of illustrating this is through the effective target mass. The figure of > 10 events detected per ton of scintillator is for a production of 0.1 neutrinos/ton rock (estimated for an 8-kpc supernova). Combining these, it is seen that only 1 ton of scintillator is required to monitor 100 tons of the target rock. In addition, the required minimum of 1000 μ/τ neutrino events can be achieved with only 100 tons of liquid scintillator.

4 Comparison of Detectors

Table 1 compares event numbers in SNBO II with four other world detectors, showing the combined ability to observe all three neutrino types.[2,3]

5 Sites and Background

Neutron background arises from muon interactions and from spallation by alphas from U and Th in the rock. Production by muons is reduced to below the U and Th production at depths > 500 MWe. The major USA site under construction is the DOE-owned salt mine in New Mexico, planned as a Waste Isolation Pilot Plant (WIPP). This site has areas that are some distance from the proposed waste storage region and, thus, which could be used without any background problems. In addition, a supernova array could provide an automatic monitor of the integrity of the nuclear waste over periods of 100s of years – a possibility that exists and has been discussed. Recent measurements (by UCLA–Ohio) of the neutron background flux in the salt tunnels have given results consistent with the known U and Th levels in the rock (*i.e.*, with a continuous neutron production rate of 0.01/tons·s throughout the rock.

This continuous background can be subtracted, leaving only the Poisson fluctuations in the time-binned data. For the first few seconds of a supernova burst, these fluctuations are smaller than the Poisson fluctuations in the signal itself. Similar background levels are obtained at the Boulby salt mine, UK, where an area is currently set aside for dark matter experiments.

Table 1: Comparison of typical SNBO II and III performance with world detectors based on direct detection with water and scintillator targets, showing event numbers for each neutrino type.[2,3]

	Target Material	Fiducial Mass (ton)	Target Elements	ν_e	$\bar{\nu}_e$	$\nu_{\mu,\tau} + \bar{\nu}_{\mu,\tau}$
Combined target-detector						
Super-Kamiokande	H_2O	32000	p,e,O	180	8300	50
LVD	CH_2	1200	p,e,C	14	540	30
MACRO	CH_2	1000	p,e,C	8	350	25
SNO	H_2O	1600	p,e,O	16	520	6
SNO	D_2O	1000[a]	p,e,O	190	180	300[a]
Separated target & detector						
SNBO II:						
rock + neutron detector	Rock	>10 ton/ event effective[b]	All nuclei (nc)	< 50 (nc)	< 50	1000
Direct interaction with scintillator	CH_2	+ 100 tons CH_2	p,e,C	1	40	3
SNBO III:						
lined caverns + neutron detector	Rock + Fe/Pb	>10 ton/ event effective[c] + 10-20 tons CH_2	Fe/Pb	< 50 (nc)	< 50 (nc)	1000

[a] D_2O target not permanently available.

[b] No defined fiducial target mass. Effective mass = events/(production/g).

[c] Optimum rock-metal combination not yet studied.

6 Development Work

Development work is required to optimize the choice of neutron detector and readout, and studies have begun at Ohio, UCLA, and Manchester. Options include panels of loaded scintillator with wavelength-shifting fiber readout, or multi-wire versions of proportional gas detectors with improved thermalization.

7 Conclusion

There is a strong neutrino physics case for constructing SNBO II to observe the μ/τ neutrino profile from the next Galactic supernova, in order to provide a measurement of a cosmologically significant neutrino mass, together with mixing effects, over Galactic distance.

8 References

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