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OMNIS—A Galactic Supernova Observatory

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A type II (or Ib) supernova explosion releases most of its energy as neutrinos and antineutrinos with a time constant of a few seconds, with all three neutrino types and their antiparticles produced in comparable numbers. The emission time profile from a typical model is shown in Fig. 1 [1]. This provides a unique opportunity to discover neutrino properties which are difficult or impossible to determine using terrestrial neutrino sources. In particular a non-zero neutrino mass will alter the time profile arriving at the earth (Fig. 2), allowing direct time-of-flight measurement of the mass of at least one neutrino type. In particular the most likely distance range for Galactic supernovae ($\sim$ 2–20 kpc) is ideal for time-of-flight measurement of a "cosmologically significant" neutrino mass—i.e. a mass in the range 10–100 eV, for which it would form a major component of the mass of the universe and could be a candidate for the Galactic dark matter.

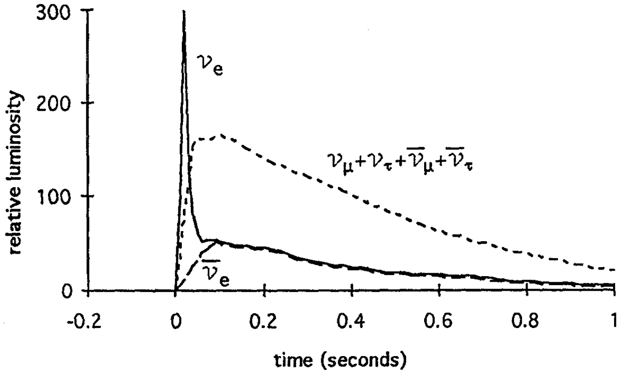

Figure 1: Time profiles of neutrinos emitted by supernova explosion. The mu and tau neutrinos have identical profiles when emitted.

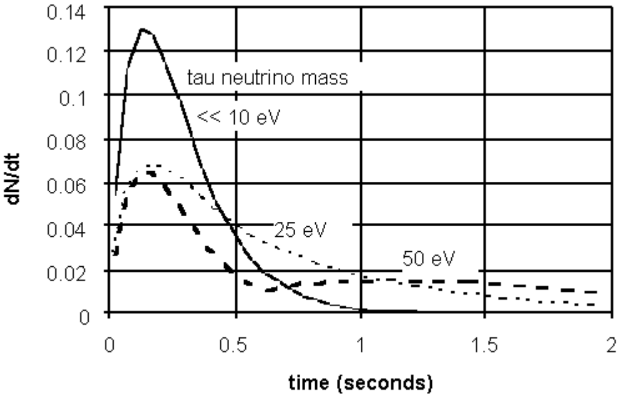

Figure 2: Effect of non-zero mass on mu/tau neutrino arrival time profile from distance 8 kpc.

The frequency of Galactic supernovae is uncertain. There is a substantial discrepancy between the expectation of 1 per 30–100 years, from various astrophysical estimates, and the historical record which indicates a higher frequency [2, 3]. Figure 3 shows the locations of known supernovae in our Galaxy during the past 1000 years. Only those within 4 kpc of the sun are visible optically with high efficiency. A prediction of 1 in 50 years for the whole Galaxy would imply an expectation of only 1 within 4 kpc of the sun, whereas in fact 4 or 5 type II+Ib have been observed within this radius in the past millennium. This observation appears to exclude, with 90% confidence, an interval as large as 30 years or more, and is consistent with a total Galactic rate of 1 in 15 ± 5 years.

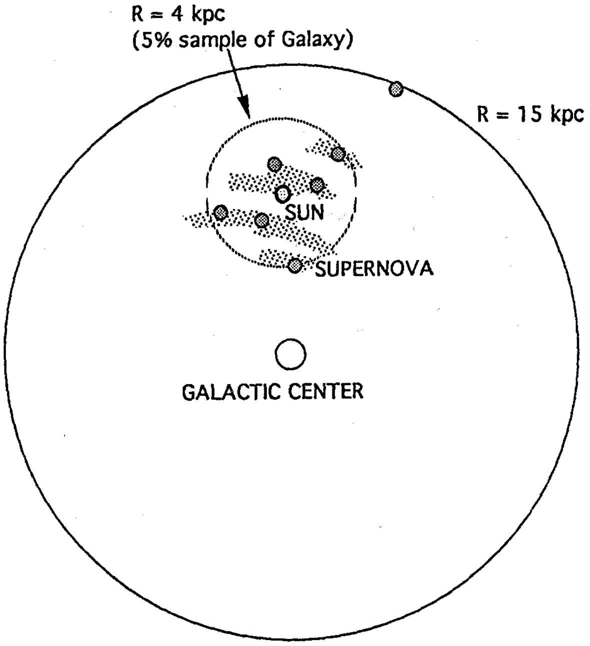

Figure 3: Galactic map of recorded supernova for past 1000 years, showing that only the closest 5% are visible optically. The much larger number from the whole Galaxy would be observable as neutrino bursts.

With a time interval of this order, it becomes reasonable to set up an underground detector array for such an event, run on a part-time basis in parallel with other astrophysics and particle physics projects. For a statistical precision sufficient to determine a neutrino mass in the 10–100 eV range, we require about 2000 events (1000 each of mu and tau neutrinos). A number of existing world detectors are sensitive to supernova neutrinos, in particular Super-Kamiokande, LVD, MACRO, and SNO. However, these detect principally the electron antineutrino component through charged current interactions, and have relatively low sensitivity to neutral current events [4]. Numerical estimates in Table 1 show that from an 8 kpc supernova Super-Kamiokande would register $\sim$ 8000 charged current events, but only 1% of that number from neutral currents. We describe here a low cost detection scheme which would be sensitive principally to the mu/tau neutrino component. This would provide the first direct observation of a cosmologically significant neutrino mass, and would complement the electron antineutrino signal from other world detectors to provide data on mixing between all three neutrino generations. Information on the profile shape for all three neutrino types would be also of considerable astrophysical interest.

The proposed detector array is referred to as OMNIS—an observatory for multiflavour interactions from Galactic supernovae. It has evolved from the Supernova Neutrino Burst Observatory (SNBO) proposed by D.B. Cline et al., based on neutrino detection by neutral current nuclear excitation in natural underground rock [5]. The excited nucleus would emit neutrons, which could be captured by counters embedded in the rock. The E2 dependence of the excitation cross section makes the detector sensitive principally to the higher temperature mu/tau neutrinos, producing a dominant neutral current signal. The evolution of OMNIS from SNBO is described in a more detailed paper [6]. There are two major improvements: (a) neutron collection efficiencies higher by an order of magnitude are obtained by siting optimised detectors in open caverns, and (b) additional target materials are used, in particular Fe and Pb, which give higher neutron production rates and with Pb also having a charged current excitation route [7, 8, 9]. Thus differences between lead, iron and rock signals can be used to infer mixing between mu/tau and electron neutrinos.

A possible arrangement of detector/target modules for OMNIS is shown in Fig. 4. Standard Gd or Li-loaded scintillator could be used for the neutron detection, in modules of about 0.5–1 ton. About 200–300 modules would be needed to observe 2000 events from an 8 kpc supernova. This demonstrates the uniquely high efficiency of the detector array, giving it a unit cost much lower than other world neutrino detectors. An average of over 10 events per ton scintillator could be achieved using indirect neutron detection compared with the 0.3 events per ton scintillator achieved with direct charged current detection in MACRO. The estimated neutron production rates in salt rock, iron, and lead are 0.06, 0.15, 1 per ton for a

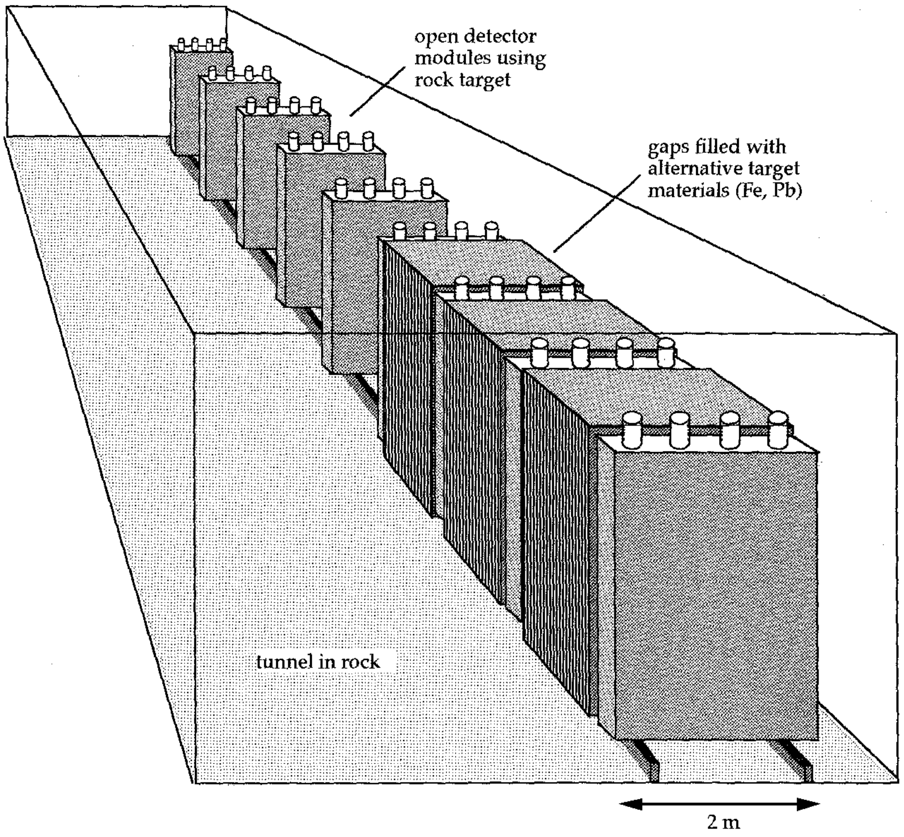

Figure 4: Possible arrangement of target materials and neutron detectors for OMNIS.

Table 1: Comparison of proposed OMNIS multi-target observatory with world detectors based on direct detection with water and scintillator targets. Approximate event numbers for each neutrino type shown for a supernova at 8 kpc.

	Target Material	Fiducial Mass (tons)	Target Elements	Event Number 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[a]	D_2O	1000	d, e, O	190	180	300
Separated Target & Detector:						
OMNIS						
200 t Scintillator	NaCl (rock)	"8000"	Na, Cl	10	10	400
+ Natural Rock	Fe	4000	Fe	10	10	600
+ Installed Targets	Pb	4000	Pb	280	30	1000
Direct Interaction			**Total:**	**300**	**50**	**2000**
With Scintillator	"CH_2"	200	p, e, C	2	70	5

[a] Heavy water target not available indefinitely

supernova at 8 kpc. In addition, higher collection efficiency is possible from Fe and Pb due to lower absorption [6], giving them an effectiveness in the ratio 1 : 4 : 30. Thus lead is by far the most effective target to maximise event numbers, but the design must include a sufficient quantity of the other targets to provide information on mixing between mu/tau and electron neutrinos, based on the fact that this would enhance the charged current excitation in Pb but not in Fe or rock.

Table 1 shows the event numbers of different neutrino types from principal world detectors, compared with those from the proposed OMNIS detector. Note that the neutron background from U/Th in the rock would not be significant compared with the signal burst, and for sites with depths > 600 m, the neutron background from muons would also be an order of magnitude below the signal. Thus the project is technically straightforward and based on conventional low-cost neutron detection technology. Neutron background is discussed in more detail in [6] where some discussion is also included on the enormously greater background problem for extra-Galactic supernova detection. For discrimination of supernova events from local neutron showers from cosmic ray muons, it is desirable to split the array between several underground caverns, and also between several world sites, also permitting estimates of supernova direction by arrival time differences.

In conclusion the relatively low unit cost of the OMNIS scheme makes it possible to propose a dedicated Galactic supernova neutrino observatory, capable of observing the time profile of the mu and tau neutrino component. This would provide the first direct measurement of a cosmologically-significant neutrino mass, and the use of several different target elements, in conjunction with the large electron antineutrino signal from SuperKamiokande would also provide data on the presence or absence of neutrino mixing on the Galactic distance scale. It could be designed to run largely unattended, with minimal maintenance, so would be a part-time activity for the participating groups, alongside other underground experiments. The current collaboration on this project involves groups from RAL, Manchester, Sheffield, Imperial College (for the UK Boulby Mine site) and UCLA, UCSD, Ohio, LLNL, LANL, UT-Dallas, PNL, for the US Carlsbad site, both sites in low activity salt rock and already containing suitable infra-structure installed for other purposes. First prototype modules could now be set up in these sites and funding is being sought for this. New collaborators would be welcome to strengthen the case for construction of the full array.

Acknowledgments

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