SUPERNOVAE, THE SOLAR NEUTRINO PROBLEM, AND THE ULTIMATE FATE OF THE UNIVERSE: NEUTRINO OSCILLATION AND CROSS SECTION MEASUREMENTS AT THE PROPOSED ORLaND NEUTRINO DETECTOR

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Neutrino oscillation experiments and neutrino–nucleus cross section measurements that are central to the proposed experimental program at ORLaND will not only help advance the frontiers in fundamental particle and nuclear physics but will also help advance the frontiers in astrophysics. The copious production of neutrinos by the Spallation Neutron Source and, consequently, the opportunity to investigate neutrino oscillations and neutrino–nucleus interactions present a unique opportunity to make significant advances toward solving *three* among the long-standing, most difficult and most important problems in contemporary astrophysics and cosmology: the solar neutrino problem, the core collapse supernova problem, and the dark matter problem.

Among the solutions to the solar neutrino problem, the proposition that neutrino oscillations are responsible for the discrepancy between the predicted neutrino flux from the standard solar model and the detected fluxes in the Homestake, GALLEX/SAGE, and Kamiokande experiments is favored. Measurements of the mixing angle and neutrino mass differences for electron-neutrino–muon-neutrino oscillations, both for vacuum and matter-enhanced scenarios, are critical to finally laying this problem to rest, if in fact oscillations are responsible for the discrepancy. Moreover, given evidence for neutrino mass and given the prevalence of neutrinos in the universe owing to its early evolution, neutrinos may be a significant source of (hot) dark matter and contribute nonnegligibly to the closure density of the universe.

The overlap in the ORLaND neutrino spectra and the spectra of neutrinos produced during core collapse supernovae is nothing short of serendipitous, and it is this overlap that opens up the exciting possibility of connecting ground-based nuclear experiments with the ultimate fate of massive stars. Of particular importance are the proposed neutrino oscillation experiments and their relevance for supernova neutrino signature predictions and our ability to use neutrino detections to improve current supernova models. Moreover, measurements of neutrino–nucleus inelastic scattering cross sections, particularly in the energy range relevant for supernovae, will allow us to supplant theoretical predictions of cross sections for a wide range of reactions central to r-process and neutrino nucleosynthesis in supernovae. The former is responsible for producing half of the solar system's abundance of heavy elements, and there is a list of elements that owe their existence entirely to the latter.

As an illustrative example, plotted in Figs. 1 and 2, which are taken from supernova simulations by Bruenn and Mezzacappa [1], are the predicted neutrino signatures for Super-K and SNO for a 15 solar mass model and both the zero neutrino mass and the nonzero neutrino mass (with oscillations) cases. In these simulations, the neutrino mass hierarchy was chosen to follow the lepton mass hierarchy, i.e., $m_{\nu_\tau} >> m_{\nu_\mu} > m_{\nu_{\rm e}}$, and the tau neutrino mass was given a cosmologically significant mass of 25 eV. The vacuum mixing angles were chosen to be $\theta_{\rm V} = 10^{-3}$ for ν_τ–$\nu_{\rm e}$ oscillations (within the range considered by

Fuller et al. [2]) and $\sin^2 2\theta_{\rm V} = 6 \times 10^{-3}$ for ν_μ–$\nu_{\rm e}$ oscillations. The latter was motivated by the small-mixing-angle solution to the solar neutrino problem.

Looking at the figures, it is evident that there are qualitative differences between the neutrino signatures in the zero mass and nonzero mass cases. For example, when neutrino oscillations are included, the electron neutrino burst (which occurs when the shock passes the electron neutrino sphere on its way out of the iron core, i.e., when the electron neutrinos behind the shock escape) is converted to tau neutrinos and, because of their nonzero mass, the "burst" is delayed and significantly broadened in time.

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[1] S. W. Bruenn and A. Mezzacappa, to be submitted to *Astrophys. J.* (1998).

[2] G. Fuller, R. Mayle, B. S. Meyer, and J. R. Wilson, *Astrophys. J.* **389**, 517 (1992).

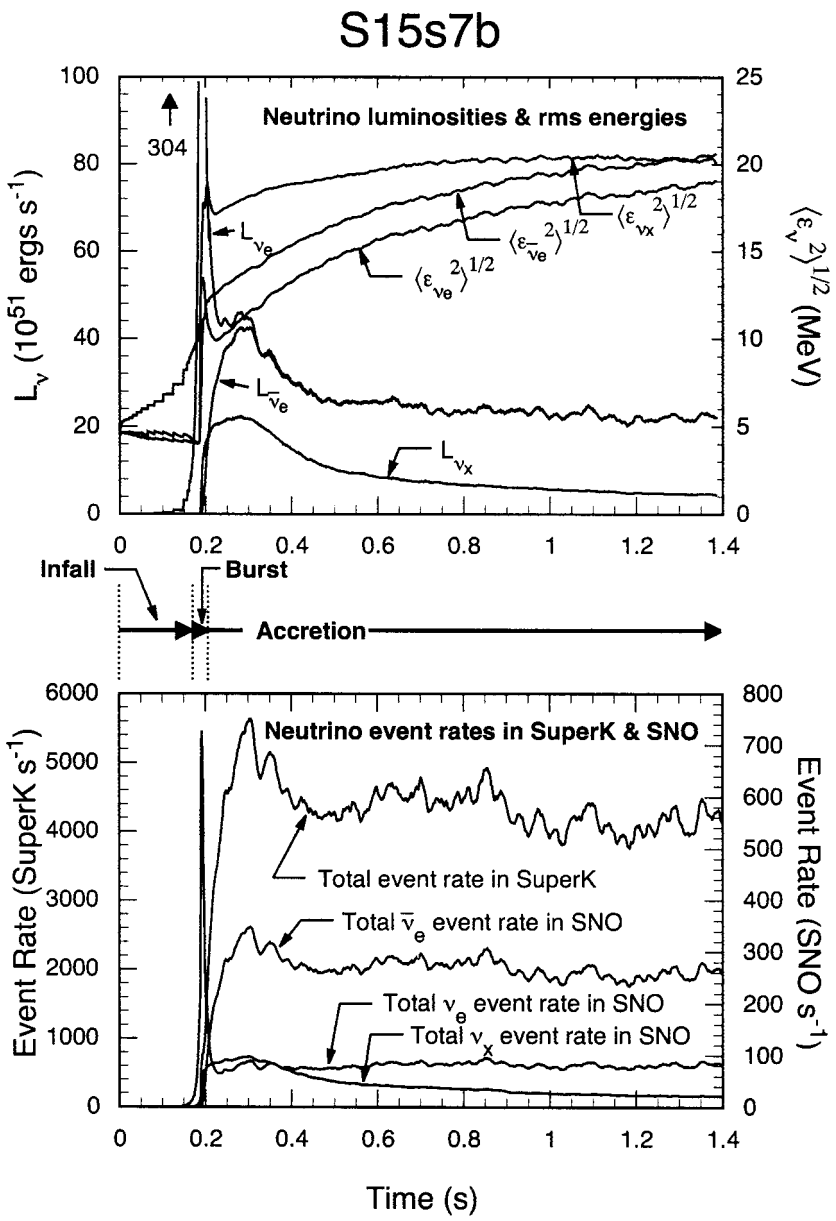

Figure 1: Neutrino luminosities, rms energies, and predicted event rates in Super-K and SNO for a 15 solar mass model with no mixing.

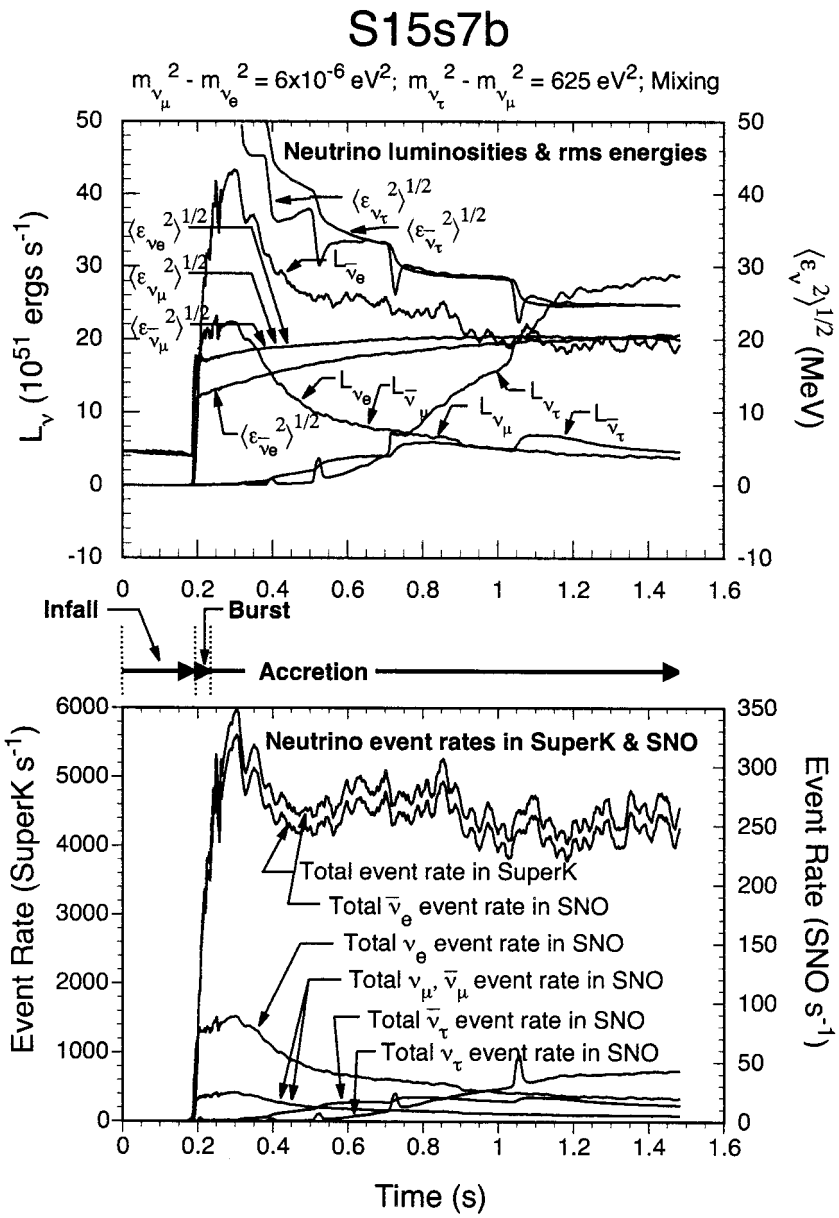

Figure 2: Neutrino luminosities, rms energies, and the predicted event rates in Super-K and SNO for a 15 solar mass model with mixing.