NEUTRINO SIGNATURES FROM CORE COLLAPSE SUPERNOVAE

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The uncertainties associated with the development of convection in the proto-neutron star[5,6] and the improvements in the high-density neutrino opacities,[7,4] among other uncertainties associated with other phenomena, such as rotation, that have not beeen fully explored, have an impact on the ability of current models to make neutrino signature predictions.

The neutrino signatures can be compartmentalized into four phases: the infall, burst, accretion, and cooling phases. During the infall phase, electron neutrinos are produced during core collapse by electron capture and escape. This phase is not expected to yield a significant number of events in the detectors and will not be discussed here. The burst phase occurs as the shock wave passes the electron neutrinosphere, above which electron neutrinos freely escape from the core. These neutrinos are also produced by electron capture, but now, on the dissociation-liberated protons behind the shock. During the accretion phase, the neutrino luminosities are dominated by the luminosity of matter accreted onto the surface of the proto-neutron star below the stalled shock, and it is during this phase that the explosion is initiated. The cooling phase follows the accretion phase and is characterized by the neutrino luminosities from a cooling, contracting proto-neutron star at the center of the explosion. Improvements in neutrino transport modeling might lead to significant changes in the signature predictions for the burst phase and the rise time and luminosity maxima for the three-flavor luminosities. Proto-neutron star convection, if vigorous, might lead to an enhancement in the neutrino luminosities and, consequently, neutrino signature predictions during the accretion phase, and neutrino opacity corrections might result in different signature predictions at the end of the accretion phase/beginning of the proto-neutron star cooling phase after the explosion has been initiated.

In light of the above discussion, it is clear that supernova models have not yet advanced to the stage where they can make exact quantitative predictions of neutrino signatures from core collapse supernovae. The question naturally arises: What can they predict? In Figs. 1 and 2 we plot the neutrino luminosities and rms energies and the total event rates for Super-Kamiokande (Super-K) and SNO for our 11 and 25 $M_\odot$ models. These models were computed with fully general relativistic hydrodynamics and multigroup flux-limited diffusion neutrino transport, in one dimension (spherical symmetry), and assume that the neutrinos are massless.[2,3] The 11 $M_\odot$ model is an exploding model, whereas the 25 $M_\odot$ model is not. What are the generic neutrino signature features we can identify? First, there is an electron neutrino burst in both models, which is followed by a sharp rise in the three-flavor neutrino luminosities. In the exploding model this sharp rise is followed by a sharp drop as (a) the explosion develops, (b) the accretion luminosities drop off, and (c) the luminosities come to be dominated by the core luminosities. The proto-neutron star then exhibits its characteristic exponential cooling behavior. In the nonexploding 25 $M_\odot$ model, accretion is maintained, the three-flavor accretion luminosities remain high, and finally, within one second, a black hole forms, followed by a sudden

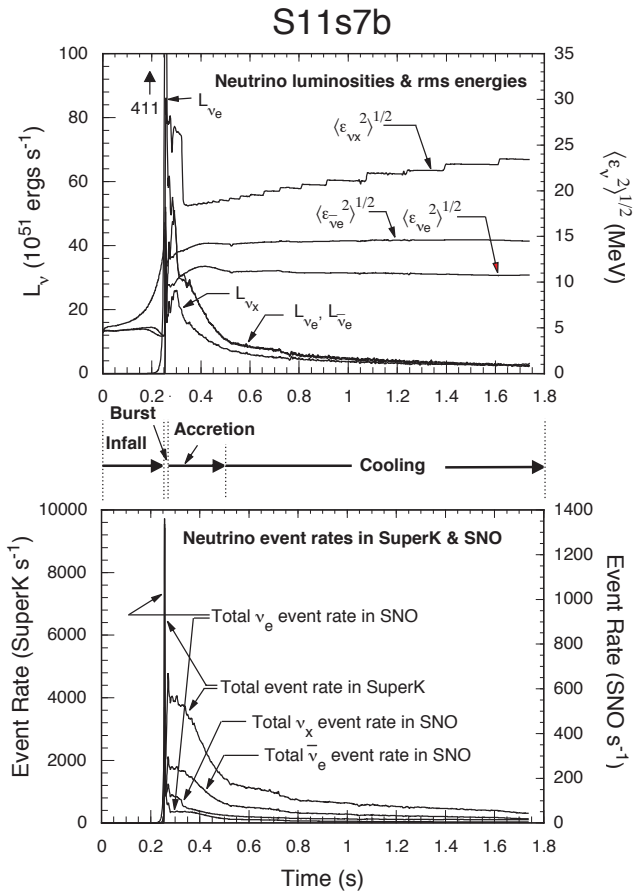

Figure 1: Three-flavor luminosities, rms energies, and event rates in Super-K and SNO as a function of time for our exploding 11 solar mass model.

drop in luminosity. Of course, these "generic" features may be altered by neutrino oscillations. For example, the electron neutrino burst may not be present in either model, although the other features would remain.

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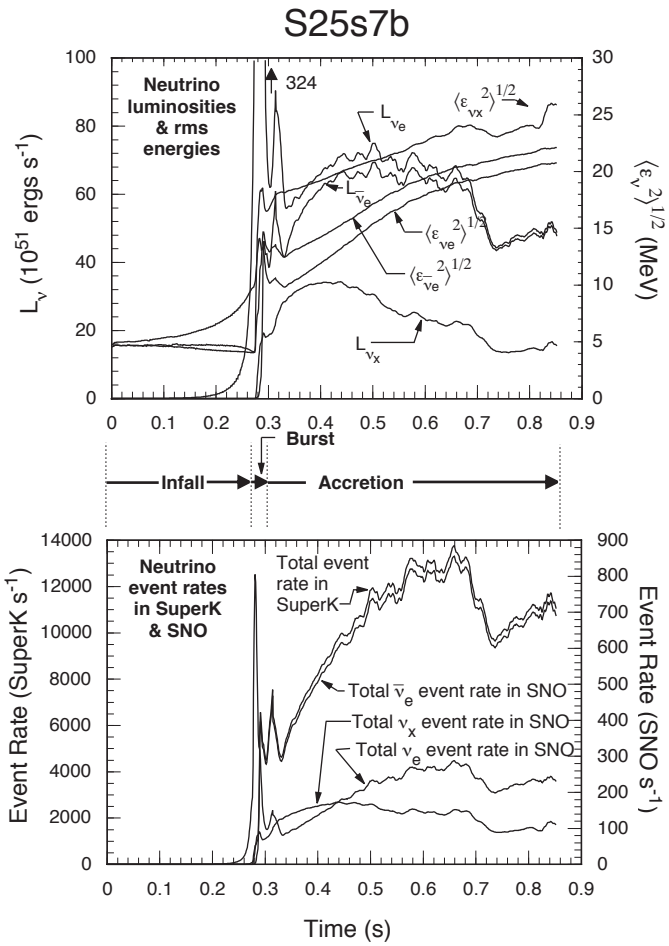

Figure 2: Three-flavor luminosities, rms energies, and event rates in Super-K and SNO as a function of time for our nonexploding 25 solar mass model.