Summary of discussion session I: the neutrino signal and triangulation

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The neutrino detection/triangulation discussion group was tasked with reviewing the current status of our theoretical understanding of the neutrino emissions that attend core-collapse supernova explosions and the birth of either neutron stars or black holes. Further, and importantly, we explored the feasibility of employing the Supernova Alert Network now being organized to triangulate on the burst and to derive a quick angular position that could be communicated to the astronomical community within hours of the detection. Eschewing the issues of the logisitics, politics, and practicality of such early warning, we investigated merely whether triangulation was theoretically possible.

There is a broad consensus on the basic features of the neutrino light curve from a supernova, but it should be recalled that the luminosities and timescales for different massive star progenitors will be different. Generically, infall may last from 200 to 600 milliseconds during which time electron neutrinos will predominate. They will have roughly a capture spectrum that gradually hardens until shock breakout. The rise time of the associated luminosity depends upon the nuclear symmetry energy, but is approximately 5 milliseconds. The total energy radiated during this phase is roughly 10^{51} ergs. Bounce is almost immediately followed by the formation of the shock in the neutrino-opaque regions (at near 20 kilometers). The shock starts with a velocity near 50,000 km/s and so very quickly achieves the neutrinosphere (50-100 kilometers) and breaks out. Shock breakout is announced by a prodigious burst of electron neutrinos produced by electron capture on free protons newly liberated by shock dissociation of the infalling nuclei. The electron neutrino luminosity may achieve 10^{54} ergs/second. The characteristic time of the breakout burst is $\sim$3-10 milliseconds and the total energy radiated in electron-type neutrinos during breakout is $\sim 3\times 10^{51}$ ergs. The magnitude of the latter will depend on the density structure of the collapsing Chandrasekhar core, and will be higher for the more massive progenitors. During this phase, perhaps 10 events in both SuperK and in ICARUS can be expected from a collapse at 10 kpc.

During breakout, the matter is heated to such a degree that anti-electron neutrinos and mu and tau neutrinos and anti-neutrinos (hereafter "ν_μ"'s) are thermally produced and radiated. The turnon timescale of this component is less than one millisecond, but the initial luminosity of the $\bar{\nu}_e$'s and the ν_μ's depends upon the degree of degeneracy of the electrons near the neutrinospheres and the magnitude of the production sources, still poorly known. It is thought that the initial anti-electron neutrino luminosity is within about one order of magnitude of its peak value ($\sim$20-50 milliseconds after breakout). Even at such a level, at 10 kpc both SuperK and SNO will register 100's of $\bar{\nu}_e$ events per second, in SuperK perhaps a kilohertz. After the abrupt rise, the anti-electron neutrino luminosity rises further to approximately meet the falling electron-type luminosity. After 20-50 milliseconds, the two decay together as the light curve transitions to the longer-term protoneutron star cooling and neutronization phase. Similarly, the "ν_μ" luminosity per species achieves a value not more than 30% away from the electron neutrino luminosity.

The decay is gradual and there may be some quasi-periodic pulsation of the luminosities during this phase. However, the shock wave launched with such fanfare stalls into an accretion shock at 100-200 kilometers within 10-20 milliseconds of breakout. There is a delay to explosion, that may last between a few hundred milliseconds and a second, during which time perhaps $\geq 10^{53}$ ergs of neutrinos may be radiated. Explosion, when it comes, and there is some debate about the details of explosion, should be accompanied by a decrease by about a factor of two over about 20 milliseconds in all the neutrino luminosities. This may be detectable. After explosion, the luminosities decay on timescales of seconds to a minute. Indeed, after as long as a minute, the event rate at 10 kpc in SuperK may still be as high as one per second. After breakout, the spectra of all the neutrino species first harden on timescales of hundreds of milliseconds, then soften, particularly after explosion, as the luminosity inexorably decays. The rise and fall timescales, as well as the explosion time, are not known theoretically with sufficient precision.

Hence, the features detectors should key in on are: the infall rise, the breakout, the early anti-electron neutrino rise, the production of mus, the signature of explosion, the rise and fall of the average neutrino energies, and the late-time persistence. In addition, if a black hole forms during the high-luminosity phase, the prediction is that the signal will stop within less than a millisecond. Such a phenomenon will be detectable.

Given this generic neutrino light curve, can we use accurate timing of the features in the burst to triangulate on the supernova? This will depend upon the signal strength (and, hence, the distance). At the canonical distance of 10 kpc, with the forward-peaked SuperK electron neutrino events ($\sim$100-150), one should be able to achieve $\sim$4 $^\circ$ pointing without the aide of the network. If the initial anti-electron-type signal is indeed as abrupt as we believe and if it starts at a high luminosity, then initial count rates near one kilohertz in SuperK, SNO, and LVD/MACRO/ICARUS might enable the network to locate a supernova to within $\sim$10° at 10 kpc. The fact that the current detectors are all in the northern hemisphere is a problem, as is the possible fuzziness of the initial luminosity rise. Those who have recently explored the viability of triangulation still disagree with each other [1, 2, 3], but the discussion group was optimistic that at least the statistical issues will soon be resolved. Furthermore, there was general excitement that the Network might indeed be able to announce, with whatever angular precision, the advent of a galactic supernova and allow the astronomical community the early warning it has never before enjoyed. Supernova 1987A was and is a spectacular event from which we detected not only a neutrino burst, but photons across the entire electromagnetic spectrum. The Boston University workshop was a testament to the hope and faith of the emerging supernova neutrino community that SN1987A was but a foretaste of what is to come.

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