Future Supernova Neutrino Detectors

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Abstract.
This joint neutrino-gravitational wave session talk will describe current, near future and farther future supernova neutrino detectors. I will comment on the potential of future supernova neutrino-gravitational wave correlation searches.

1. Current and Future Supernova Neutrino Detectors
A core collapse supernova will produce a burst of neutrinos of all flavors with a few tens of MeV energy, over a period of a few tens of seconds. Reference [1] and references therein give an overview of supernova neutrino detection; reference [2] is a recent summary what may be learned from the observation of a supernova neutrino burst. So far the only supernova neutrino observation is from SN1987A [3, 4, 5, 6], and we expect enormously enhanced information from the next nearby observation.

Table 1 summarizes existing and planned detectors. Currently running detectors have sensitivity primarily to the $\bar{\nu}_e$ component of the signal, via inverse beta decay $\bar{\nu}_e + p \rightarrow n + e^+$, which is the dominant component in for water Cherenkov and scintillator. For supernova burst detection, one wants not only statistics but also diversity of flavor sensitivity: neutral current sensitivity, which gives access to the $\nu_\mu$ and $\nu_\tau$ components of the flux, and $\nu_e$ sensitivity are particularly valuable. Near future (within next five years or so) detectors with supernova neutrino sensitivity should enrich the sample: these are highlighted below.

- The SNO+ experiment [7] in Sudbury comprises 0.77 ktons of liquid scintillator filling the SNO acrylic vessel. It should have supernova sensitivity comparable to that of KamLAND.
- Another future detector now under construction is the HALO experiment [8]: this makes use of 76 tons of lead instrumented with the unused SNO NCD counters to record neutrons and electromagnetic signals. Although this detector is small, it will have unique sensitivity.
- The ICARUS detector at Gran Sasso is a 600 ton liquid argon time projection chamber. It will have excellent electron neutrino sensitivity [9] via $\nu_e + ^{40}\text{Ar} \rightarrow e^- + ^{40}\text{K}^*$, for which de-excitation gammas will be visible. In principle one may tag modes using gamma spectrum information.
- In spite of large cosmic ray background, new surface detectors like NOνA may observe a statistically significant spike of supernova neutrino events above background [10].

Other future ideas include exploitation of neutral current coherent elastic neutrino-nucleus scattering [11, 12] in dark matter or novel detectors.
Table 1. Summary of neutrino detectors with supernova sensitivity. Neutrino event estimates are approximate and have a fairly large uncertainty. See reference [1] for individual detector references. Not included are are smaller detectors (e.g. reactor neutrino scintillator experiments) and detectors primarily sensitive to coherent elastic neutrino nucleus scattering.

| Detector | Type | Mass (kton) | Location | Events at 8.5 kpc | Live period |
|----------|------|-------------|----------|-------------------|-------------|
| Baksan   | C$_n$H$_{2n}$ | 0.33        | Caucasus | 50                | 1980-present |
| Super-K  | H$_2$O    | 32          | Japan    | 8000              | 1996-present |
| LVD      | C$_n$H$_{2n}$ | 1          | Italy    | 300               | 1992-present |
| KamLAND  | C$_n$H$_{2n}$ | 1          | Japan    | 300               | 2002-present |
| MiniBooNE| C$_n$H$_{2n}$ | 0.7        | USA      | 200               | 2002-present |
| Borexino | C$_n$H$_{2n}$ | 0.3        | Italy    | 100               | 2005-present |
| IceCube  | Long string | 0.4/PMT    | South Pole | N/A            | 2007-present |
| SNO+     | C$_n$H$_{2n}$ | 0.8        | Canada   | 300               | Near future |
| HALO     | Pb        | 0.07        | Canada   | 80                | Near future |
| Icarus   | Ar        | 0.6         | Italy    | 230               | Near future |
| NO$_\nu$A| C$_n$H$_{2n}$ | 15         | USA      | 3000              | Near future |
| LBNE LAr | Liquid argon | 5          | USA      | 1900              | Future      |
| LBNE WC  | H$_2$O    | 300         | USA      | 78,000            | Future      |
| MEMPHYS  | H$_2$O    | 440         | Europe   | 120,000           | Future      |
| Hyper-K  | H$_2$O    | 500         | Japan    | 130,000           | Future      |
| LENA     | C$_n$H$_{2n}$ | 50         | Europe   | 15,000            | Future      |
| GLACIER  | Ar        | 100         | Europe   | 38,000            | Future      |

Very promising for the future are a number of planned mega-detectors, which aim to deploy very large volumes of water, scintillator, or liquid argon: see the table and references [13, 14, 15, 16, 17]. Some such detectors can hope to collect individual neutrino events every few years from beyond the Local Group of galaxies (few Mpc) [18], assuming that background can be reduced sufficiently. In such a regime, some kind of external (non-neutrino) trigger will be essential to distinguish supernova neutrino-induced events from background.

2. What a Gravitational Wave Coincidence Could Add

Gravitational waves (GW) will be produced by core collapses [19], although there are currently significant uncertainties in the scale and nature of the signal. Requiring a coincidence between neutrino and GW signals has the potential to improve the sensitivity of both channels by allowing relaxation of the criteria for detection. For example, Super-K’s recent “distant” burst search [20] requires two neutrino events (with energy threshold 17 MeV) within 20 seconds, which corresponds to approximately 8% probability of detecting a supernova in Andromeda. The accidental fake rate for this coincidence criterion is less than one per year; the single event rate at this threshold is about 1 per day. If one could achieve an acceptable accidental coincidence rate by requiring coincidence of a single neutrino event with a GW signal, then the probability of core collapse in Andromeda satisfying the search criterion is about 35%. See Figure 1. Distant burst search parameters could be re-optimized with respect to current ones; the neutrino event energy threshold could potentially be reduced, further improving sensitivity. References [21, 22] explore the possibilities of a neutrino trigger for a GW search.

We note that coordination of gravitational-wave and neutrino experiments will become even more important in the future as the sensitivity of experiments improve. The Advanced LIGO and Virgo detectors [23, 24] are expected to come online starting in 2014, and are expected to be more sensitive than the current generation of detectors by a factor of ~10. Because gravitational
Figure 1. Estimated probability to satisfy Super-K burst search criterion as a function of distance. Red: standard search parameters [20]. Green: probability if only a single neutrino event is required, in coincidence with a GW signal.

Wave signals are prompt (in contrast with optical detection, which will have a time window of hours), coincident detection with gravitational waves is very promising. Note also that some supernovae may not produce substantial (or any) optical fireworks, and gravitational waves may be the only way to tag “optically silent” supernovae.

In summary, correlation analysis of gravitational wave and neutrino experiments in a search for core collapse events presents an interesting prospect for the future.

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