# SNEWS: The SuperNova Early Warning System

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**Abstract.** World-wide, several detectors currently running or nearing completion are sensitive to a prompt core collapse supernova neutrino signal in the Galaxy. The SNEWS system will be able to provide a robust early warning of a supernova's occurrence to the astronomical community using a coincidence of neutrino signals around the world. This talk describes the nature of the neutrino signal, detection techniques and the motivation for a coincidence alert. It describes the implementation of SNEWS, its current status, and its future, which can include gravitational wave detectors.

## THE EXPECTED NEUTRINO SIGNAL

When the core of a massive star at the end of its life collapses, nearly all of the total gravitational binding energy of a neutron star is emitted in the form of neutrinos, some $E_b \sim 3\times10^{53}$ ergs. Less than 1% of this energy is expected to be released in the form of kinetic energy and optically visible radiation. The remainder is radiated in neutrinos, of which approximately 1% will be electron neutrinos from an initial "neutronization" burst and the remaining 99% will be neutrinos from the later cooling reactions, equally distributed among flavors. Average neutrino energies are expected to be about 12 MeV for electron neutrinos, 15 MeV for electron antineutrinos, and 18 MeV for all other flavors. The neutrinos are emitted over a total timescale of tens of seconds, with about half emitted during the first 1-2 seconds, and with the spectrum eventually softening as the proto-neutron star cools. Reference [1] summarizes the expected neutrino signal. The basic features of neutrino emission models were well confirmed in 1987A with the observation of neutrinos from SN1987A. We await the next Galactic supernova to learn more.

## NEUTRINO DETECTORS

There are several classes of detectors capable of detecting a burst of neutrinos from a gravitational collapse in our Galaxy. Table 1 gives a brief overview; more details can be found via reference [2]. Table 2 lists some specific supernova neutrino detectors and their capabilities.

**TABLE 1.** Supernova neutrino detector types.

| Detector type | Material | Energy | Time | Point | Flavor |
|---|---|---|---|---|---|
| scintillator | C,H | y | y | n | $\bar{\nu}_e$ |
| water Cherenkov | $H_20$ | y | y | y | $\bar{\nu}_e$ |
| heavy water | $D_20$ | NC: n | y | n | all |
| | | CC: y | y | y | $\nu_e$,$\bar{\nu}_e$ |
| long string water Cherenkov | $H_2O$ | n | y | n | $\bar{\nu}_e$ |
| liquid argon | Ar | y | y | y | $\nu_e$ |
| high Z/neutron | NaCl, Pb, Fe | n | y | n | all |
| radio-chemical | $^{37}$Cl, $^{127}$I, $^{71}$Ga | n | n | n | $\nu_e$ |

## EARLY SUPERNOVA OBSERVATION

The neutrino burst produced by the core collapse emerges promptly from the stellar envelope. However, the the shock wave produced by the collapse takes some time to travel outwards from the core to the photosphere of the star. The time of first shock breakout of a supernova is highly dependent on the nature of the stellar envelope, and can range from minutes for bare-core stars to hours for red giants. For SN1987A, first light was observed about 2.5 hours after the neutrino burst; the first observable photons probably occurred about one hour earlier than that.

The observation of very early light from a supernova just after shock breakout is astrophysically very interesting [4], and rare for extragalactic supernovae. The environment immediately around the progenitor star is probed by the initial stages of the supernova. For example, any effects of a close binary companion upon the blast would occur very soon. In addition, shock breakout may also be accompanied by a UV and soft x-ray flash. The tail of such a flash was observed by the EUVE satellite for SN1897A. And of course, an observation of very early supernova light

**TABLE 2.** Specific supernova neutrino detectors.

| Detector | Type | Mass (kton) | Location | # of events @8.5 kpc | Status |
|---|---|---|---|---|---|
| Super-K | $H_2O$ Ch. | 32 | Japan | 5000 | online |
| MACRO | scint. | 0.6 | Italy | 150 | online |
| SNO | $H_2O$, | 1.4 | Canada | 300 | running |
| | $D_2O$ | 1 | | 450 | |
| LVD | scint. | 0.7 | Italy | 170 | online |
| AMANDA | long string | Meff $\sim$0.1/pmt | Antarctica | | running |
| Baksan | scint. | 0.33 | Russia | 50 | running |
| Borexino | scint. | 0.3 | Italy | 100 | 2001 |
| KamLAND | scint. | 1 | Japan | 300 | 2001 |
| OMNIS (Pb/Fe) | high Z | 5 | USA | 2000 | 2000+ |
| LAND (Pb) | high Z | | Canada | | 2000+ |
| Icanoe | liquid argon | 9 | Italy | | 2000+ |

could also yield entirely unexpected effects.

It is possible that a core collapse event will not yield an optically bright supernova, either because the explosion “fizzles”, or because the supernova is in an optically obscured region of the sky. In the latter case there may still be an observable event in some wavelengths, or in gravitational radiation.

## COINCIDENCE OF NEUTRINO SIGNALS

There are several benefits from a system which coordinates neutrino signals from two or more different detectors. All detectors are subject to false alarms due to bursts of events due to detector pathologies or other non-Poissonian phenomena (for example, flashing phototubes or other sources of spurious light, electronic noise, correlated radioactivity events due to muon spallation of nuclei, etc.). Therefore, if an individual experiment is to issue an alarm, a human operator must first check the event burst to confirm its supernova-like nature, which can take significant time even when a fast-response human alert system is set up. Requiring a coincidence between independent detectors will add great confidence to the detection of a supernova neutrino burst, to the extent that a completely automated alert may be possible. The automation could save enough time that important early observations would not be lost.

## THE SNEWS SYSTEM: IMPLEMENTATION OF A COINCIDENCE MONITOR

Software for a prototype international supernova watch coincidence system has been designed by Alec Habig and Kate Scholberg. It is written in standard C and uses a standard UDP protocol client/server setup to make direct network connections using sockets. Dedicated phone lines could be used to increase reliability if it proves necessary. Figure 1 shows the setup.

A central machine runs a “server” program, which sits and waits for input from the outside. The individual experiments participating in the project run “client” programs. Whenever an experiment detects a candidate burst, the client program makes a connection to the server machine and sends it an alarm datagram via direct socket connection. The alarm message contains information about which experiment observed the burst, along with the time stamp information. The datagram will be expanded in the future to include information about the significance and size of the burst.

When the server receives an alarm message from any experiment, it places the alarm in a queue sorted by UT time, and searches through all alarm messages in the queue for a coincidence within a given time window (currently 10 seconds). If there are two or more different experiments in coincidence, it sends out an alarm. A test coincidence server has been set up at the Super-K site in Mozumi, Japan.

Currently, MACRO, Super-K and LVD are connected. Privacy is maintained, and security precautions are taken. Additional servers can be set up at other sites.

## WHAT DO ASTRONOMERS WANT?

What astronomers want from an early supernova alert can be summarized by the “three P’s”: “prompt”, “pointing” and “positive”. This section describes how SNEWS can address these “P’s”.

### A “Prompt”

The alert must be as prompt as possible to catch the early stages of shock break-out. All detectors currently in the coincidence can provide an alert datagram within 30 minutes (worst case, and to be improved) of the time of the first event in the detector, and in most cases within only a few minutes. Delays are usually due to buffering at the detectors. The coincidence itself and resultant alarm message take only the time needed for a network connection. It will be entirely feasible to have a coincident alarm message produced within about 15 minutes of the neutrino signal.

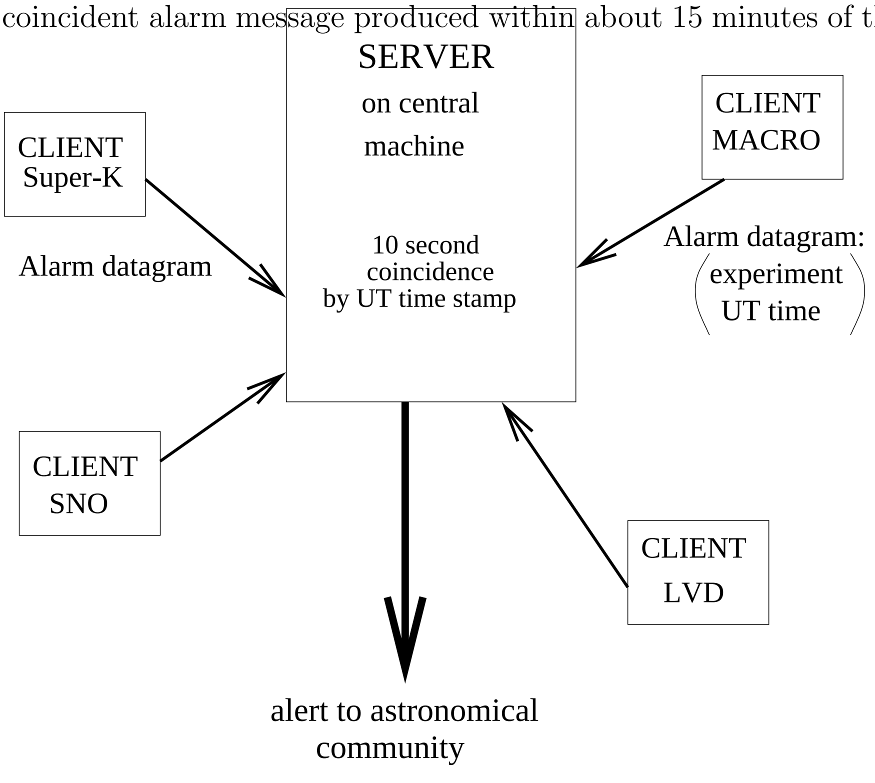


**FIGURE 1.** SNEWS setup.

## B "Pointing"

Clearly, the more accurately we can point to a core collapse event using neutrino information, the more likely it will be that early light turn on will be observed by astronomers. Even for the case when no directional information is available (e.g. for a single scintillator detector online) it is still useful for astronomers to know that a gravitational collapse event has occurred. However any pointing information at all is extremely valuable. The question of pointing to the supernova using the neutrino data has been examined in detail in reference [3].

- **Asymmetric reactions:** Water Cherenkov detectors can exploit the neutrino-electron elastic scattering reaction, to point back to the supernova source. For a collapse at the center of the Galaxy, a few hundreds of elastic scattering events are expected in Super-Kamiokande and tens are expected in SNO. The recoil electrons follow the neutrino direction with an opening angle of about 25°. One can make a rough, optimistic estimate of the pointing resolution from $\delta\theta \sim \frac{25^\circ}{\sqrt{n}}$, where $n$ is the number of observed events; for 200 elastic scattering events, $\delta\theta \sim 2^\circ$. However, the problem is really that of finding the center of a peak on top of background, and more realistic estimates of the resolution yield somewhat worse results. Reference [3] estimates a correction factor of 2-3, giving 5 degree pointing for Super-K and 20 degree pointing for SNO.

- **Triangulation:** In principle source direction information can be deduced from the timing of neutrino events at the different detectors. Since flight time across the Earth is of order tens of ms, for successful triangulation the time of the neutrino pulses at the individual detectors must be tagged to milliseconds or less. Since the neutrinos in the pulse are emitted over tens of seconds, the individual detectors must perform a pulse registration with limited sampling statistics. Reference [3] has studied the statistical problem in detail, concluding that with the current generation of detectors (Super-K and SNO), concluding that triangulation is not promising even in the best case. There are additional practical difficulties: a prompt triangulation requires immediate and complete exchange of event-by-event information, which is difficult in practice. However, for a very close supernova, or if the neutrino pulse comprises unexpectedly sharp features, triangulation may still be feasible. Any information is better than none and the triangulation may at least provide a cross-check of the elastic scattering pointing.

## C "Positive"

SNEWS must not disseminate any false supernova alarms to the astronomical community. One cannot realistically decrease the false alarm rate to zero, since individual experiments will usually have a residual rate of false alarms from Poissonian

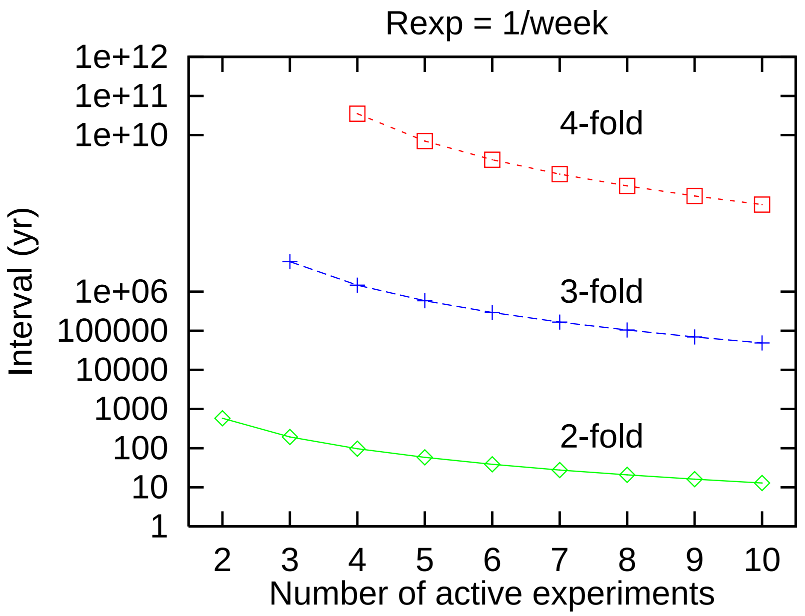


**FIGURE 2.** Average time between accidental coincidence alarms between experiments, as a function of number of experiments online, for a 10 second coincidence time window, for 2-fold, 3-fold and 4-fold coincidences. The assumed individual experiment alarm rate is $R$ =1/week.

and non-Poissonian sources; there will then be accidental coincidences between signals from the individual detectors. One must weigh the increased sensitivity from lowering of the alarm thresholds (both for the individual experiments and for the coincidence) against potential waste of resources (and loss of credibility) from issuance of false alerts.

We have chosen the nominal acceptable average false alarm rate to be one per century. Assuming equal, constant, uncorrelated alarm rates for each experiment, and a 10 second coincidence window, one can calculate the average interval between accidental alarms for an $n$-fold coincidence of $N$ experiments. Figure 2 shows the result for an individual experiment background alarm rate of 1 per week: this rate is acceptable only if fewer than 4 experiments are online, or if a 3-fold coincidence if required; otherwise a lower individual experiment rate is required. We are also investigating any possibility of non-Poissonian alarms correlated between experiments.

## THE ASTRONOMICAL ALERT

The astronomical alert from a SNEWS coincidence will be sent out to a mailing list of interested parties. In an ideal case, the coincidence network provides the astronomical community with an event time and an error box on the sky at which interested observers could point their instruments. In a realistic case, the error box, which is dependent on the location of the supernova and experiments which are online, may be very large. However, members of the mailing list with wide-angle viewing capability (satellites, small telescopes and amateurs) should be able to pinpoint an optical event quickly.

## AN ADDITIONAL ROLE FOR SNEWS?

So far, SNEWS has been intended to provide an early warning for astronomers. However, it has another potential role. If a core collapse supernova happens in the Galaxy, it will be an unprecedented opportunity for science, and all possible data – neutrinos, electromagnetic, gravitational waves, perhaps other kinds – would be extremely valuable. But many detectors which are capable of providing useful information are not necessarily capable of triggering themselves on a supernova burst and may not be continuously archiving information. They may be noisy and/or may not know what kind of signal to look for from a supernova. Some examples of detectors in this category would be: some of the long string detectors (ANTARES, Baikal), gravitational wave detectors (if not all data is archived), and surface neutrino-sensitive detectors with a high rate of cosmic ray background. The SNEWS neutrino coincidence will be a high confidence indication that a supernova has occurred. Noisy SN detectors could therefore arrange to use the SNEWS coincidence as an input – they could set up a buffering system to record data (for hours or days, depending on resources available) that would routinely be overwritten, but which could be saved to permanent storage in the case of a SNEWS coincidence. This approach would greatly enrich the world's supernova data sample.

## CURRENT STATUS AND FUTURE

Currently, a test coincidence server is running at the Super-K site in Mozumi. Three experiments are online (Super-K, MACRO and LVD), sending alarm datagrams in test mode. SNO and AMANDA are expected to join within about 6 months. There is no automated alert to astronomers yet; we expect the automated alert to be activated after a test period.


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