SNEWS: THE SUPERNOVA EARLY WARNING SYSTEM

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Abstract

The world's leading neutrino and gravitational wave detectors have come together in a collaboration with the aim of providing traditional optical astronomers an early warning of an impending Galactic supernova. It is expected that a robust alert can be issued within 15 minutes of the neutrino and gravitational wave detection, leading to an early warning of between 15 minutes and eight hours of the optical signal's arrival, depending on the progenitor. Additionally, the direction of the supernova can be determined to around 5°. Such an alert will provide invaluable warning, allowing the more precise location necessary for the world's premier telescopes to be determined more quickly, through both all-sky monitors and amateurs ready to start observing upon issuance of an alert. This talk describes the motivation and implementation of SNEWS, the current status, and the planned methods for distribution of an alert to astronomers.

1. Motivation

A star of mass greater than about eight solar masses evolves over a period of upwards of 10 million years, through successive stages of nuclear burning, until it is left with an iron/nickel core surrounded by layers of successively lighter elements (Burrows *et al.* 1990). At this stage, the core, being unable to generate the thermal pressure required to support the star's own weight, collapses on a timescale of tens of milliseconds. The process of core-collapse is complicated, but predictions agree that around 99% of the energy emitted will be in the form of neutrinos. Furthermore, these neutrinos are emitted over a timescale of seconds, which is the timescale for them to escape the dense stellar core, whereas light will have to propagate through the entire star before it escapes.

This delay in the emission of light from a supernova is clearly dependent on the progenitor type, and is expected to be of order 30 minutes for bare-core stars, and as much as 8 hours in the case of a red giant. These basic features were confirmed by the 20-or-so neutrinos detected in SN1987A (Bionta *et al.* 1987; Hirata *et al.* 1987), which preceded the first optical detection by about 2.5 hours. Gravitational waves, though as yet never detected, are also expected to be emitted promptly by a supernova (Abramovici 1992).

Hence, if the neutrinos from a core collapse could be detected, they would provide an early warning of an impending optical supernova. With the world's current generation of neutrino detectors it is expected that the limit of sensitivity of such a signal is to a distance of around 100 kpc of the Earth.

2. Benefits of an Early Warning system

An early warning of an impending supernova would facilitate several astrophysically valuable observations (Bahcall 1999). The very early light curve of a supernova is rarely observed for extragalactic supernovae, and has never been observed with the detail that might be possible. The environment close to the progenitor star will be probed by such observations, for example, revealing effects of a binary companion. It is also expected that there should be a UV and X-ray flash as the supernova shock bursts through the photosphere. Indeed, the International Ultraviolet Explorer satellite was able to collect the tail of such an effect in the case of SN1987A (Kirshner *et al.* 1987). It is also important to emphasize that there are likely to be new and unexpected phenomena associated with these, as yet unexplored, observation opportunities.

3. Participating detectors

The SNEWS collaboration currently consists of five existing neutrino detectors (Super-Kamiokande, MACRO, SNO, LVD, and AMANDA), one that is proposed (OMNIS), and a gravitational wave detector that is under construction (LIGO). Future neutrino and gravitational wave detectors are expected to join. A few relevant details of these detectors are given in Table 1, and many further details may be found via the SNEWS home page (http://hep.bu.edu/~snnet/).

Table 1. Some relevant properties for the detectors which form the SNEWS collaboration.

Detector	*Type*	*Mass (kTon)*	*Location*	*# events @ 8kpc*	*status*
Super-K	H_2O Cerenkov	32	Japan	8000	online
MACRO	Scintillator	0.6	Italy	150	online
LVD	Scintillator	0.7	Italy	170	online
SNO	H_2O Cerenkov	1.4	Canada	300	running
	D_2O Cerenkov	1.0		450	2001+
AMANDA	Long string	N/A	Antarctica	N/A	running
OMNIS	Neutral Current	14	USA	2000	2002+
LIGO	Gravity wave	N/A	USA	N/A	2002

While each of the detectors is individually able to see a statistically significant signal from a Galactic supernova, each is subject to experimental effects which might mimic such a signal. Hence, the imposition that two or more detectors see a signal in coincidence vastly improves the credibility of a fast alert. Further precautions, such as secure electronic communication methods, notification which can be verified, and a requirement that a valid coincidence must come from physically isolated sites (for example, not MACRO and LVD, which are both in the Gran Sasso cavern), further reduce the chances of incorrect alerts being issued. With these precautions we are aiming for a false alarm rate of less than one per century.

4. Directional information

Any information the SNEWS could provide concerning the expected direction of an impending supernova would greatly enhance the ability of astronomers to pinpoint an exact location, thus allowing more detailed measurements to be made earlier. Directional information may be gained by two methods (Beacom and Vogel 1999).

5. Asymmetric neutrino reactions

In water Cerenkov detectors, such as Super-Kamiokande, and the smaller SNO detector, a fraction of the events will be from neutrino-electron scattering, a process in which the electron which is detected may be related to the trajectory of the incoming neutrino with an accuracy of around 25°. Given that, for a supernova at the center of the Galaxy, Super-Kamiokande would be expected to see a few hundred such events (and SNO a few tens), analysis of these events alone can point back to the supernova with an accuracy of around 5°.

6. Triangulation of the neutrino signal

In principle, as the wavefront of the neutrino burst passes across the Earth, different observatories will register the onset of events at different times. It will take just over 40ms for the wavefront to pass over the entire Earth, and so, in order to gain useful directional information by triangulation of the different onset times, it will be necessary to make measurements to rather better than 1ms. Except in the case of an unusually close supernova, the rate of events in the various detectors is not expected to rise much above 1000Hz, making the achievable directional uncertainty from this method of order 15°. However, the collaboration is pursuing this possibility, as even such an error box would confirm any error box issued on the basis of asymmetric reactions alone.

7. Mechanics and Distribution of the alert

The data acquisition systems of each of the participating detectors run a "monitor" program which analyzes the on-line data for a signature consistent with the prediction of the signal from a supernova for that detector. If found, a UDP protocol client/server set-up makes a direct network connection to a central machine, sending an alarm datagram containing the Universal Time of the observation. The central machine runs a "server" program, arranging alarms in a queue sorted by UT time stamp, and searches for coincidences within a 10-second window. If there are two or more datagrams in coincidence, an alarm is issued. Currently, Super-Kamiokande, MACRO, and LVD are running client programs, with notifications being sent to a server machine located at the Super-Kamiokande site in Mozumi, Japan. Future planned additions include that the datagrams will also contain (i) the significance (strength) of the signal, (ii) that upon a valid coincidence, all clients will be requested to provide a statement of their status at the time of the observation, to ensure consistency, and (iii) there will be additional servers running simultaneously to provide redundancy and to enhance security.

The alert will be distributed initially via e-mail. The SNEWS collaboration is currently constructing a list of those who wish to be notified, and to sign up one needs either to visit the world-wide-web SNEWS homepage, or send an e-mail to snews-alert-request@budoe.bu.edu. The e-mail sent out in the event of an alert will use a PGP-key to ensure authenticity.

Alternatively, *Sky & Telescope* magazine has offered to coordinate the amateur astronomer community (Robinson 1999) via the AstroAlert news service. One needs to register either by visiting the AstroAlert world-wide-web homepage (http://www.skypub.com/news/astroalert/astroalert.html), or sending a request to nearby-supernova-alert@skypub.com. These services use the MAJORDOMO e-mail mechanism to ensure authenticity.

8. Current status and summary

Currently, the SNEWS is running in test mode with inputs being received from Super-Kamiokande, MACRO, and LVD. SNO has recently started taking data, and after a short period of calibration will also provide an input. Once that has been shown to be working, the test period will end, and a fully automated alert to the community at large will commence operation. This is anticipated to occur by January 1, 2001. AMANDA awaits upgrades in connectivity this Austral summer, before being able to provide an input, and LIGO is still under construction. OMNIS just received funding for research and development studies, with the start of construction hoped for in about two years.

Additionally, the SNEWS collaboration has been actively making preparations so that the issuance of an alert can be distributed as widely and efficiently as possible. To this end, presentations have been made at recent major astrophysics and astronomy conferences, of which this is one, and Target-of-Opportunity proposals have been submitted to several telescopes, including the Hubble Space Telescope (Bahcall 1999), so that a clear procedure is in place in the event of an alert being issued.

In conclusion, in the near future, a fully-automated early warning of an impending Galactic supernova will be available to the astronomical community. In order that the benefits such a warning can provide be optimally utilized, preparations for its use must be taken now.

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