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A Program of Correlated Observations Using the EGRET Instrument on GRO and the IMB Neutrino Detector

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Final Technical Report

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Abstract

A reliable, real-time supernova monitoring system was devised using the IMB neutrino detector to serve as an "early-warning" system for EGRET and other instruments on GRO. New methods and software were developed to allow the IMB monitoring computer in Cleveland to: 1) recognize that a trigger burst had occurred, 2) make a judgement on whether the burst was spurrious or an actual supernova, 3) prepare brief summary files and "quick-look" data so that a final disposition could be made by a trained scientist, and 4) contact the "watch" scientist via personal beeper in Baton Rouge. This system ran from December 1990 to April 1991, when the neutrino detector failed for unrelated reasons. In addition to the supernova system, high-energy neutrino data was prepared and formatted for comparison with EGRET gamma-ray data.

I. Supernova Watch

The Problems

Neutrinos can provide an "early-warning" system for light telescopes because the explosion takes several hours to move through the mantle of the exploding star, while the neutrinos exit the core and pass through the star with only a few seconds delay due to trapping. Thus in December 1990, work began under the auspices of this proposal to make the IMB detector in Cleveland capable of responding to a detected neutrino burst on a time scale of less than one hour. This required solving several problems:

1. the detector normally operates unattended. Thus there is normally no operator to respond to a detected neutrino burst. All procedures for handling a burst would have to be pre-programmed into a computer.

2. data reduction to find the neutrino bust from SN1987a took about two weeks (for both IMB and Kamiokande). The success of this project required reducing this analysis cycle to less than 1 hour.
3. There must be virtually *no* "false alarms", which could lead to uneccessary spacecraft manuevers and/or wasted personnel effort.
4. A detected neutrino burst must be validated at a central site with access to IAU telegrams, network connections, and people experienced in the detector operation.

The Solutions - Cleveland

At the IMB mine site, major sections of the real-time software for the VAX3200 monitoring computer was re-written to monitor the incoming data stream (20 Kbytes/sec) for coincidences in the arrival times of low-energy events. Virtually all of this data is due to the cosmic-ray muon flux which manages to penetrate the 600m of rock overburden to reach the detector (2.7 per second). Background neutrinos from cosmic ray air showers occur about twice a day, and in the energy range of supernova (SN) neutrinos, only once every three days. It is finding these neutrino "needles" in the cosmic ray muon "haystack" that consumes many days of computer processing and manual scanning.

In order to reduce the analysis time, it was decided early on to not try and separate the neutrinos from the muons in the monitoring process, but rather to make use of the time structure and energy range information gained from SN1987a. SN neutrinos should arrive in bursts lasting on the order of ten seconds and fire less

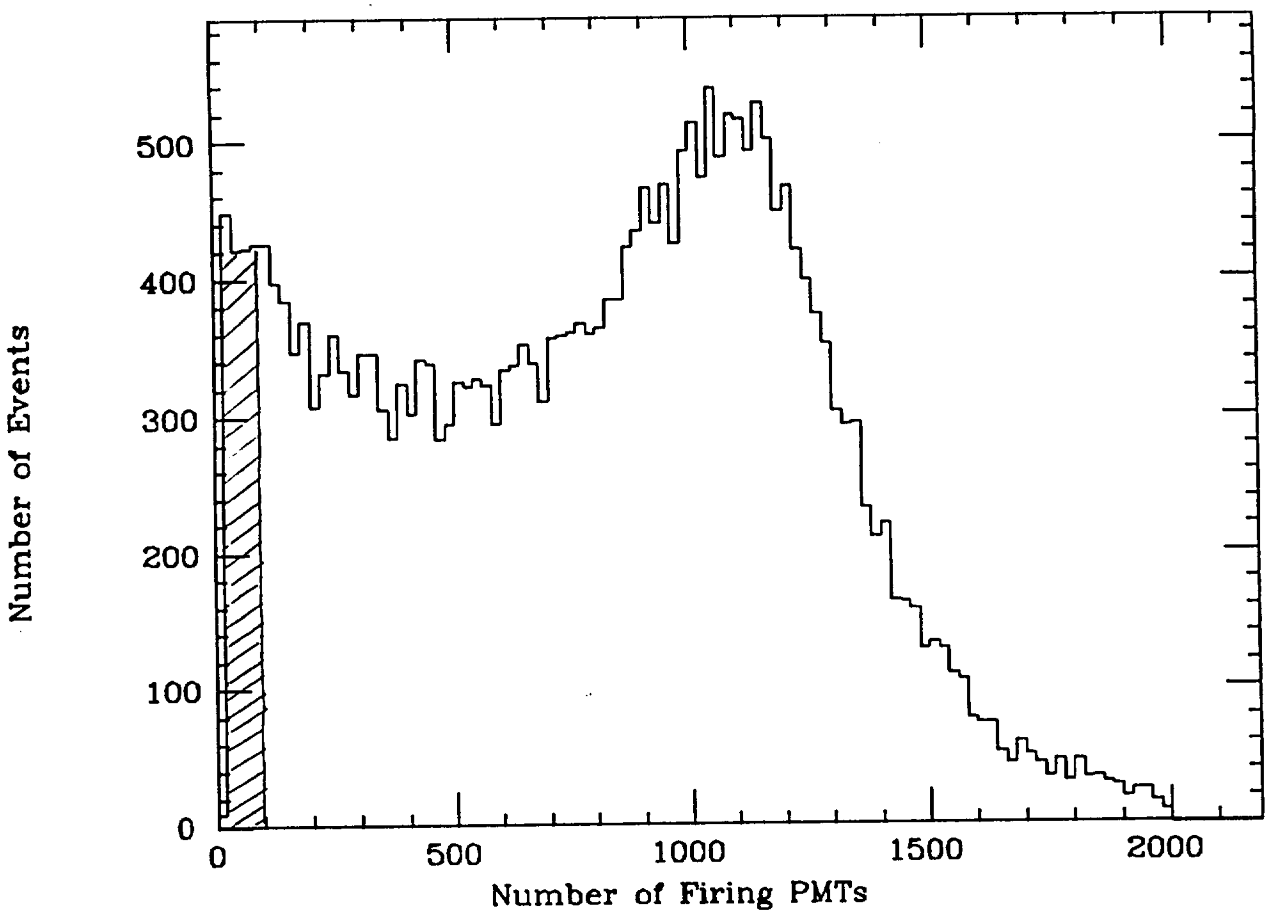

Figure 1: Distribution of the number of firing PMT's in the events in the raw IMB data stream. The hatched region indicates the region containing all the SN1987a neutrino events.

than 70 photomultiplier tubes (PMT's) of the 2048 available in the IMB detector. On the other hand, figure 1 shows the distribution of the number of firing PMT's in an event for a typical data tape. The hatched region indicates the region of SN neutrino energy. It can be seen that much of the muon data can be excluded by only looking at low PMT events.

The rate of such low energy events is about 0.2 events/second. Thus the probability (P) of getting n such events in a ten-second window is easily calculated using Poisson statistics. Unfortunately, after much late-night trials and tribulations, it was discovered that the data stream of events with less than 30 PMT's was *non-random* and so Poisson statistics did not work. The non-random correlations between events was determined to be due to two sources: 1) cross-talk between some PMT channels through their common high-voltage sources, and 2) low-level arcing in the PMT dynode for some tubes. Figure 2 shows the distribution of low-energy events in the raw data. A lower cut made at 30 PMT's eliminates the non-Poisson "bump" and

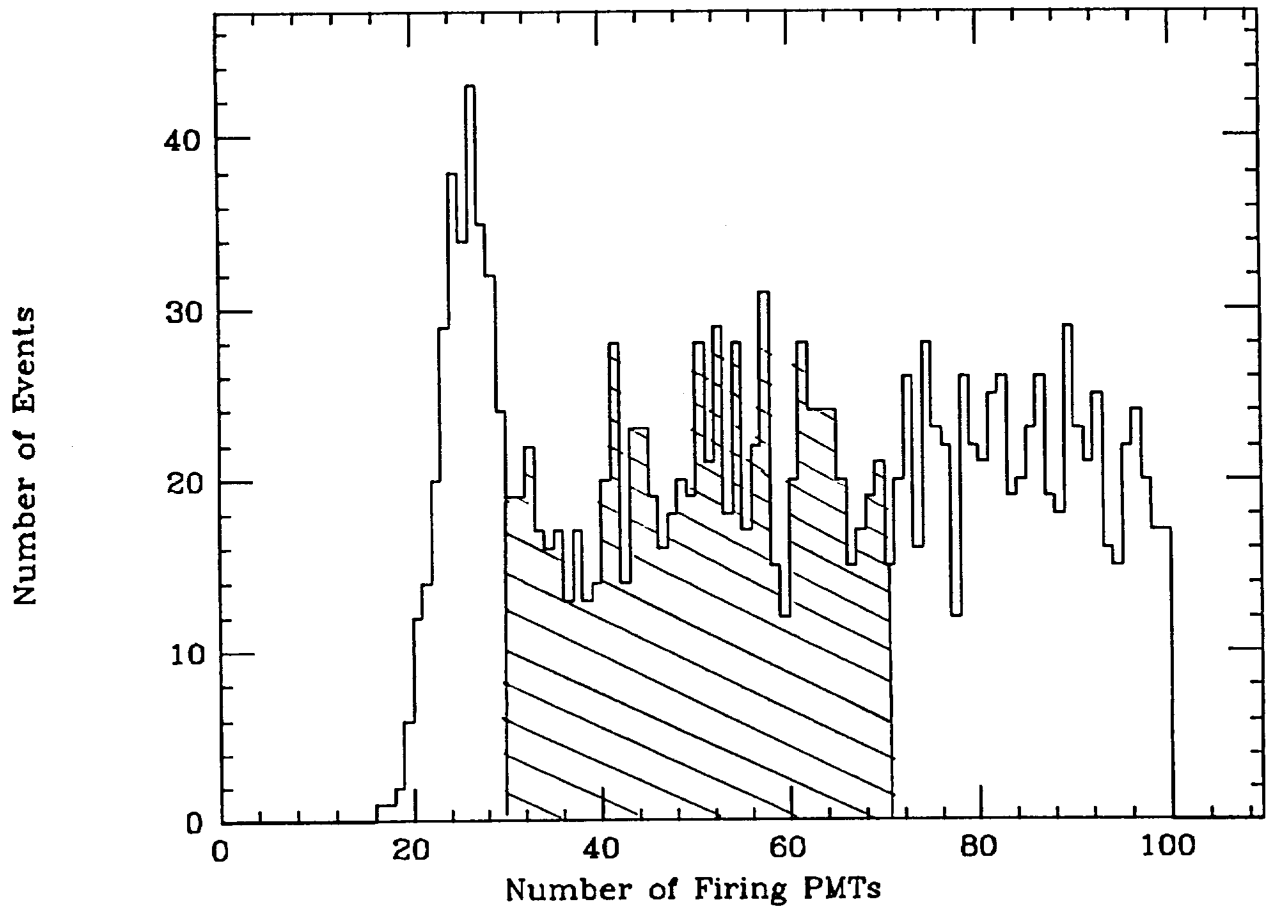

Figure 2: Distribution of the number of firing PMT's in the events in the raw IMB data stream. The bumb is due to non-random correlations. The hatched region was selected as the target region.

still keeps almost all neutrino events expected from a galactic SN. Figure 3 shows the number of events into equal time bins. The histogram is data and the X's are the expected values based on the Poisson formula. The agreement was now quite satisfactory to allow the calculation of the operator alarm rate (from random alignments in time) versus the threshold number of events in a time bin required to generate an alarm. The results of these calculations are shown in Table 1.

Thus a threshold of 9 was selected in order to give the lowest possible threshold without an undue number of operator alarms. Figure 4 shows the results of calculations done by R.Miller (the graduate student supported by this proposal) for the SN distance versus the number of actual neutrino interactions expected. As can be seen, the monitor setpoint allows sensitivity out to 50 kpc, effectively encompassing the whole galaxy.

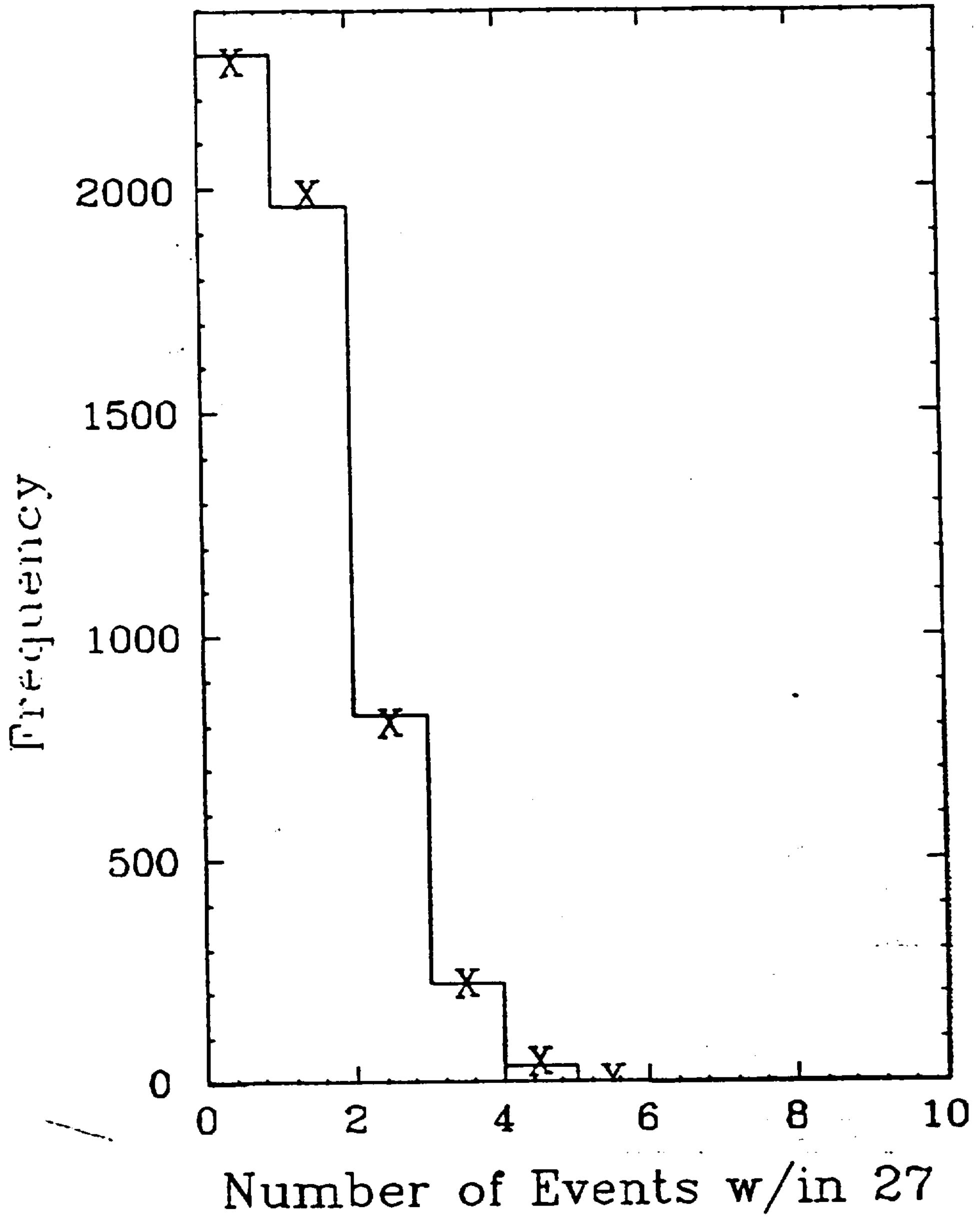

Figure 3: Distribution of the number of in a time bin for the target region events in the raw IMB data stream. The solid lines are the data and the X's are the predictions from Poisson statistics.

Table 1: Operator Alarm Rate versus Threshold Number of PMT's

number of PMT's	probability per 10 sec. bin	alarms/year)
6	5.9×10^{-4}	1862
7	8.3×10^{-5}	262
8	1.0×10^{-5}	32
9	1.1×10^{-6}	3.4
10	1.1×10^{-7}	0.35

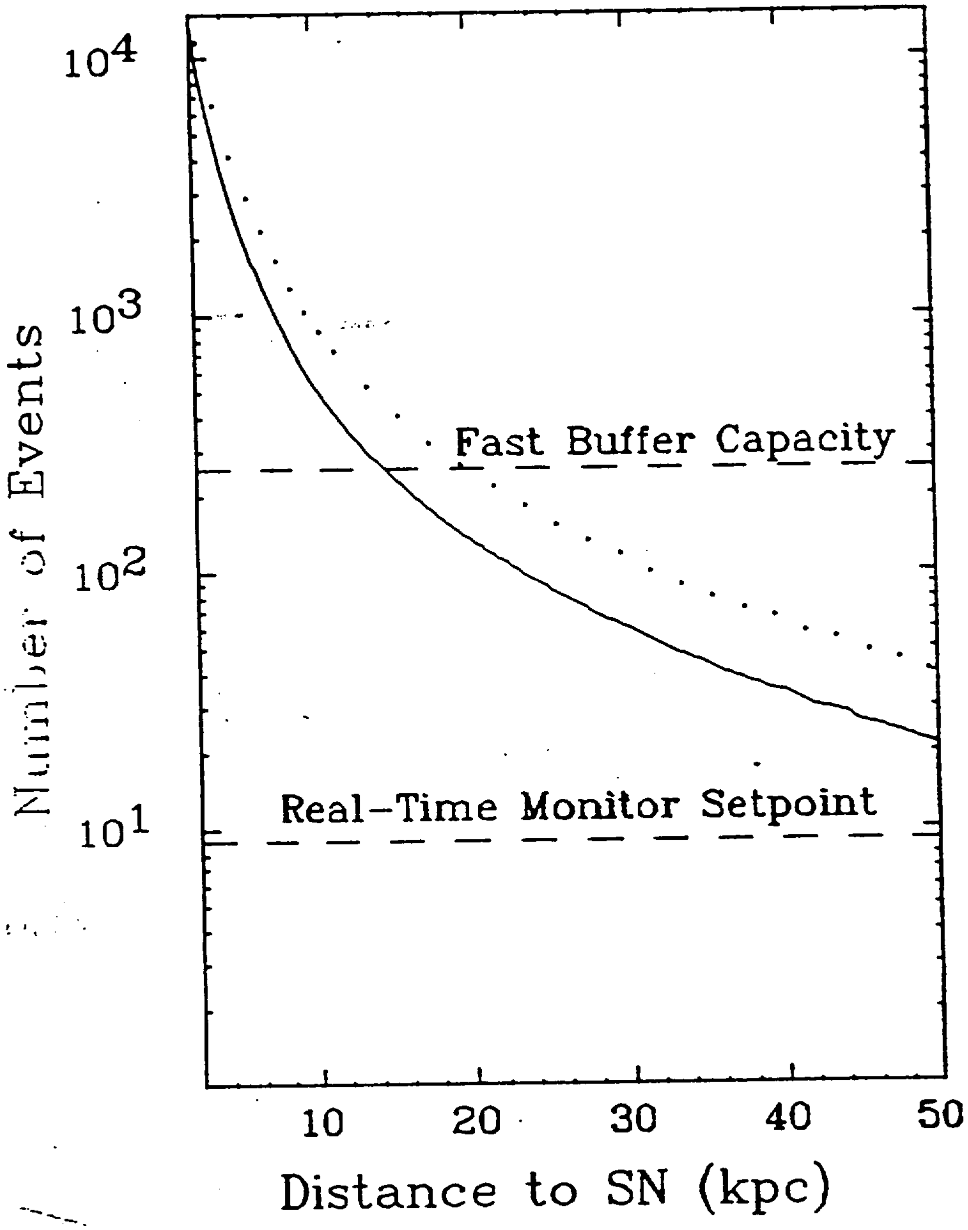

Figure 4: Distance of a supernova versus number of detected neutrino interactions in the IMB detector. The monitor setpoint is low enough to extend the range out to 50 kpc.

In determining the time standard to use, it was found that neither the internal clock of the computer or the WWVB system achieved the reliability required to keep the number of Operator Alarms to a minimum. The most reliable "clock" was found to be the high-energy cosmic ray muon flux itself. Using this method 27 total events corresponded to 10 ± 2 seconds in real time. Thus at the mine, the computer would monitor the data stream in the targeted region to look for 9-fold or higher coincidences of low energy events out of 27 total events.

When a coincidence was detected, the computer would take steps to alert a local operator (if present) or a remote site (LSU). The detected "burst" would then be subjected to the standard event validation algorithms to determine whether a true neutrino burst had occured, or just a random alignment of cosmic-ray muon events or other problems (such as an arcing PMT).

The Solutions - Baton Rouge

Most of the operators in Cleveland were not scientists and were not trained in performing neutrino event validation. It was decided early on that a Operator Alarms would be validated independently by two member scientists of the IMB team before an actual Neutrino Burst was declared. Since this all has to take place in less than an hour, it was necessary to have the real-time monitor in Cleveland prepare "quick-look" data files and to contact the lead project cience team at LSU in Baton Rouge, Louisiana. This was done by running the raw data stream through a software FIFO buffer such that the events that caused the alarm would still be in memory when the alarm was generated. In practice, the buffer was made several minutes long so that not only the alarm-generating events could be written to a special file, but also a sample of data before and after the alarm. This proved very useful in catching electronics anomalies and other "glitches".

Software was written for the real-time computer to call out on a modem to a commercial nationwide "beeper" company. Physicists in Baton Rouge manned the "SN Alert Beeper" 24 hours a day, each taking a one-week shift. Modems and computer terminals were installed at the residence of the Watch Scientists so that they would be able to respond to alarms while not in the vicinity of the university. If the beeper went of, the scientist would call out and connect up with the mine modem. Upon connection, custom software would given a quick summary of what caused the alarm, what time it occured, how many events were involved, etc. The custom software would also send the raw event data over the modem line to Baton Rouge where event validation could be done.

In order to test the system, custom software was written to allow the on-site operators to enter false Operator Alarms once a week on a random basis. This not only ensured that the hardware and software was working, but allowed for realistic measurements of the response time (since Watch Scientists would not know the time of the weekly test).

This system was run successfully for several months, and in practice worked quite well. Response times were typically 15-45 minutes (depending on where the Watch Scientist was when the beeper went off!). *No* "false alarms" were generated to the GRO team (though there were several Operator Alarms due to electronics problems). A request was then made for connection of the IMB detector directly into SPAN to cut out the 5-10 minute transfer time associated with moving the data through telephone lines. This request was approved, but installtion was not carried through due to a catastrophic water leak which permanently damaged the neutrino detector in April, 1991. Nevertheless, it was shown that a reliable, fast neutrino watch system could be achieved at a rather low cost. These results were presented to other neutrino groups at several conferences (listed below).

II. High Energy Neutrino/Gamma-Ray Correlations

In addition to establishing a real-time supernova watch, the proposal called for the correlation the IMB high-energy neutrino data (1 GeV and above) with the EGRET gamma-ray data. The goal was to investigate "bumps" in the relatively smooth distribution of "albedo" neutrinos detected by IMB during its ten years of operation (presented at the International Conf. on High Energy Physics, Singapore in 1990). This work is still in progess and will be published upon its completion.

III. Talks Given

Talks on the supernova watch and high-energy neutrinos were given at:

1. The 22nd International Cosmic Ray Conference, HE 5.4, 11-23 August, 1991, Dublin, Ireland (by R.Svoboda).
2. First EGRET/OSSE Workshop, 5-6 February, 1991, Greenbelt, Maryland (by R.Svoboda).
3. Weekly Astrophysics Colloquium, Goddard Space Flight Center, 6 August, 1991, (by R.Svoboda).
4. IMB Collaboration Meeting, 9 March, 1991, Univ. of Hawaii (by R.Miller).