Search for Neutrino Bursts from Supernova Explosions at Super-Kamiokande

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Abstract

We present the results of a search for neutrino bursts from Type II supernova explosions using 1704 days of data from Super-Kamiokande. There is no evidence of such supernova explosions during the data-taking period, and the 90% C.L. upper limit on the rate of supernova explosions within 100 kpc is obtained to be 0.49 explosions per year.

1. Introduction

A type II (or Ib) supernova explosion, which is caused by the gravitational core collapse of a massive star, emits all types of neutrinos with a total energy output of $\sim 3 \times 10^{53}$ ergs. The temperature of each neutrino species obeys a Fermi distribution where their averaged energies are calculated to be, e.g. $\langle E_{\nu_e} \rangle \sim$ 11 MeV, $\langle E_{\bar{\nu}_e} \rangle \sim$ 16 MeV, and $\left\langle E_{\nu_\tau,\nu_\mu} \right\rangle \sim$ 25 MeV [4].

Super-Kamiokande (SK) [2], an imaging water Čherenkov detector, has 22.5 ktons of the fiducial mass for neutrino measurements and should detect such neutrino bursts. The total number of events is expected to be around 4000 $\sim$ 9000 in case of an explosion at 10 kpc distance. At SK, about 80% of the observable neutrino events from supernova explosions are expected to result from the absorption reaction $\bar{\nu}_e + p \rightarrow e^+ + n$. About 2% of events are expected from νe scatterings which have directional correlation with the direction of supernova.

In this paper, the result of a search for neutrino bursts using SK is reported. The observation started on the 31st of April, 1996, and terminated on the 15th of July, 2001. The total supernova live-time is 1703.9 days.

2. Supernova burst search

According to theoretical calculations of supernova explosions, the time profile of each type of neutrino has a unique shape. During the initial 10 milliseconds, ν_e's from the neutronization are released with a total energy of order 10^{51} ergs. After the neutronization, all flavors of neutrinos are produced and released with a

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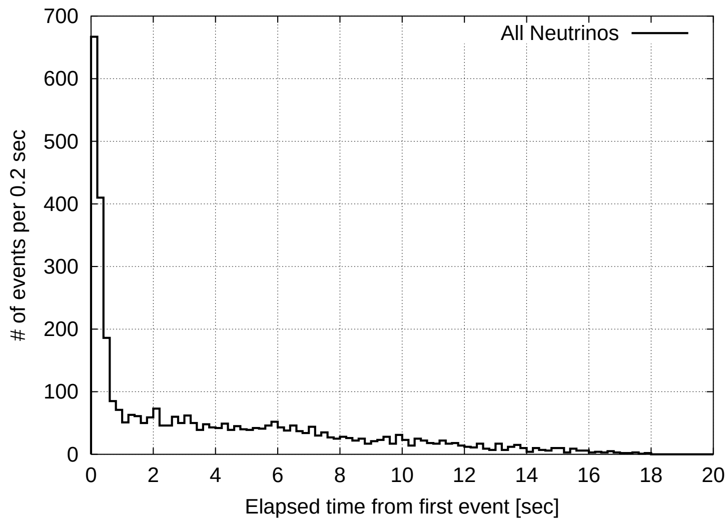

Fig. 1. Expected number of events in SK as a function of elapsed time assuming a 12 $M_\odot$ supernova explosion at 10 kpc distance.

total energy of order 10^{53} ergs with a time scale of several seconds. An expected time profile of events in SK is shown in Fig. 1. which is based on a Monte Carlo simulation in ref. [4].

We search for time-clustered events in the obtained data using three time windows. These time windows are 0.5, 2, and 10 seconds wide. The thresholds in the number of events of each time window to detect candidates are 3, 4, and 8 events, respectively. Once the number of events in one of the windows exceeds the threshold, we define the events within 20 seconds from the first event as candidates, and this number of events is defined as the multiplicity. This time cluster search was done after the data reduction and will be described later.

Fig. 2. shows the detection efficiency of supernova explosions as a function of the distance to the supernova in the case of a 12 solar mass progenitor. Most candidates are detected by the first condition (3 events in 0.5 sec). Full efficiency is maintained up to around 100 kpc.

Vertex and energy reconstruction techniques are the same as those used in our solar neutrino analysis [1, 3]. Fiducial volume for the supernova search is also 22.5 kton though the energy threshold is 6.5 MeV to avoid the high data rates associated with lower energy background. Data reduction steps are also similar. The first reduction includes removing events due to electronics noise and flashing PMT's and events with a vertex outside of the fiducial volume. A spallation cut removes events which are produced by energetic muons by using a likelihood method in which both the time difference and distance between the parent muon and subsequent events are considered. Mis-reconstructed events are also removed.

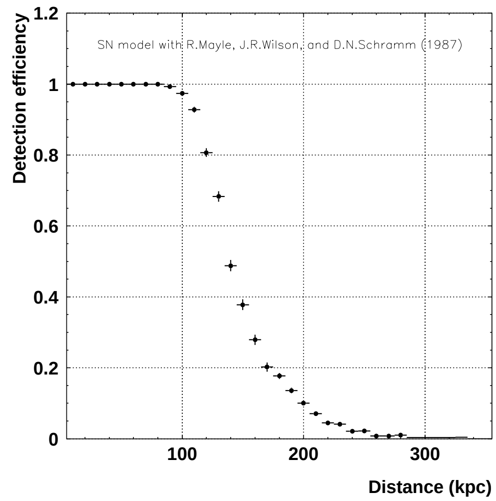

Fig. 2. Detection efficiency as a function of the distance to a supernova assuming a specific supernova model [4] with 12 $M_{\odot}$.

After the data reduction, there are a total of 149 supernova cluster candidates found in the search. Among them, 98, 43, and 8 clusters are detected by the 0.5, 2.0, and 10 sec time window respectively.

The clusters are checked by studying the correlation between the multiplicity and the spatial distribution of the vertex of events (R_{mean}). Here, the multiplicity is defined as the number of events in a 20 sec timing window, and R_{mean} is defined as the averaged spatial distance of all combinations of clustered events. Since actual neutrinos from a supernova explosion interact uniformly in the fiducial volume, R_{mean} should have a larger value than that resulting from spatially clustered events such as spallation products.

In Figure. 3., the correlations between multiplicity and R_{mean} for supernova simulation events (a) and for the observed clusters (b) are shown. As shown in (a), $R_{mean} \sim 1800$ cm is favored and almost no tail exists below $R_{mean} \leq 1000$ cm. Therefore, a cut, $R_{mean} \geq 1000$ cm, is applied to select supernova burst events. The efficiencies of this cut are estimated to be 96.7%, 98.9%, and 99.8% for multiplicities equal to 3, 4, and 5, respectively. On the other hand, almost all of the observed clusters distribute $R_{mean} \leq 1000$ cm and only 3 events survive after the cut. As for the cut clusters, the low multiplicity clusters are the remaining events of spallation products and higher multiplicity clusters are caused by LINAC calibration events.

The final three candidates are summarized in Table 1. At the same time of these clusters, strong blasting was conducted in the Kamioka mine. Due to the shaking of the PMT's, such powerful blasting tends to cause flashing of the PMT's. Therefore, we concluded that there is no evidence for supernova neutrino

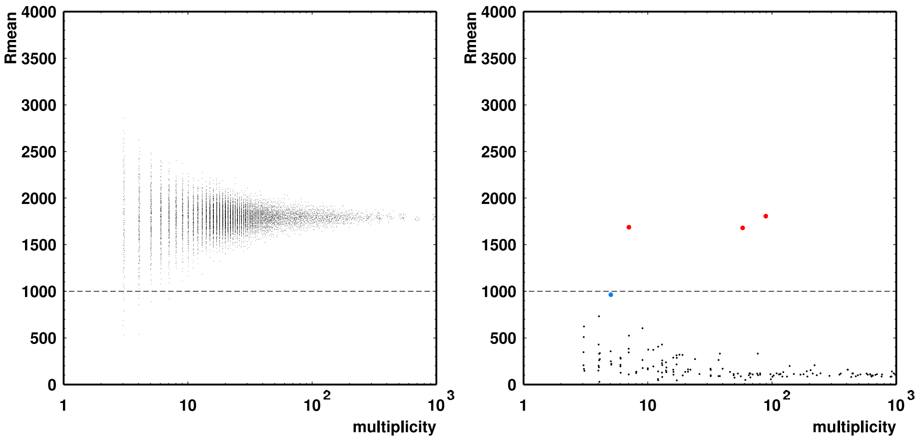

Fig. 3. Correlations between multiplicity and R_{mean}. The left figure (a) is obtained by supernova simulation events, and the right figure (b) is the same correlation for the obtained candidates.

Candidate	Date and Time (JST)	multiplicity	R_{mean}
No. 1	Jul. 13th, 1999 19:00	7	1705.9
No. 2	May 12th, 2000 11:06	58	1676.4
No. 3	Oct. 12th, 2000 19:03	89	1815.2

Table 1. Summary table of the final remaining candidates. These times correspond to the mine blasting in the Kamioka mine.

bursts in the 1703.9 days' data obtained by SK. From this conclusion, the 90% C.L. limit for the supernova explosion rate up to 100 kpc is obtained to be 0.49 per year.

3. Conclusions

A search for the supernova neutrino burst was conducted using 1703.9 days of SK data. From the absence of discernible bursts, the upper limit for the supernova explosion rate up to 100 kpc is obtained to be 0.49 per year at 90% C.L.

4. References

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4. Mayle R., Wilson J.R., Schramm D.N. 1987, ApJ 318, 288