Search for Neutrinos from Supernovae out to 10 Mpc in Super-Kamiokande

Poster: #169

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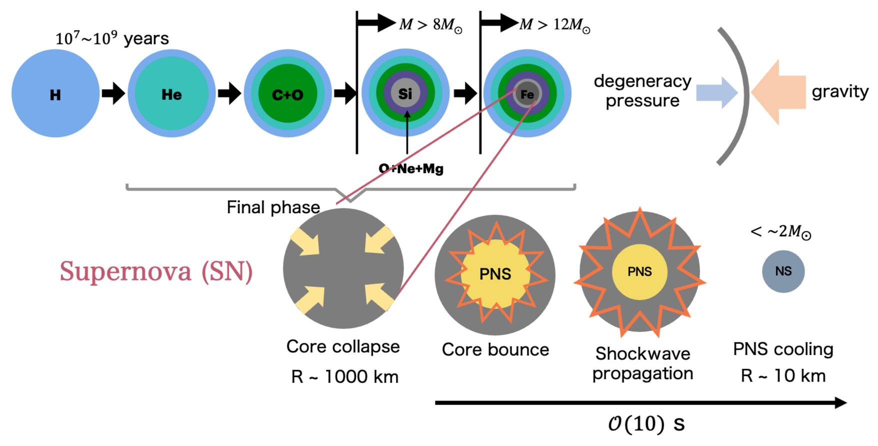
Chasing supernova neutrinos!

Abstract
Super-Kamiokande (SK) is renowned as the most sensitive detector for neutrinos from galactic supernovae. SK can also detect neutrinos from extragalactic supernovae within 10 Mpc from Earth, which are expected to occur ~1 supernova every few years. This poster presents the search results for supernova neutrinos from these extragalactic regions in SK.

1. Introduction: What we looked for?

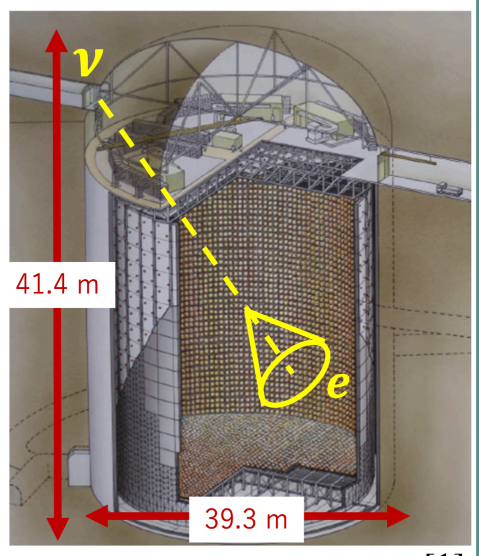
Supernova (SN) explosion

- >99% of gravitational energy in SN explosion is released as neutrino
- SN neutrino provides information about the explosion mechanism



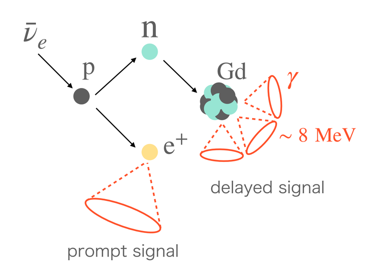
Super-Kamiokande (SK)

- Observe Cherenkov light from charged particles
- Determine the energy (E) and time (T) for each neutrino event accurately
- Started from 2020 as SK-Gd to improve neutron detection efficiency by thermal n-capture on Gd[2, 3]
- Background can be removed to $\mathcal{O}(10^{-1})$ - $\mathcal{O}(10^{-3})$



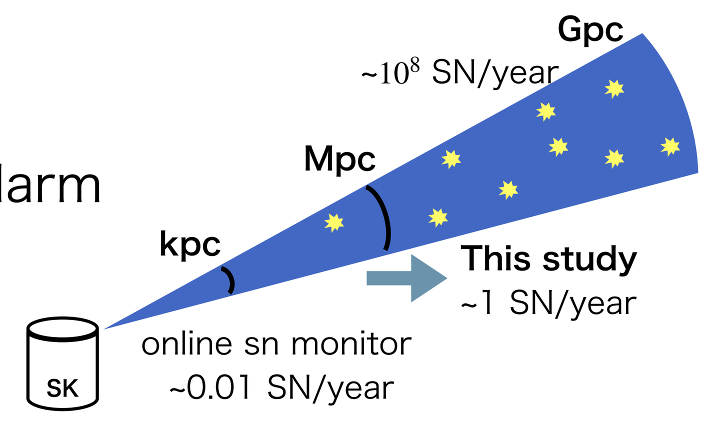
[1]

	Neutron identification performance
Pure water (from 2008)	~20%
SK-Gd (from 2022)	>60%



SN neutrino search in SK

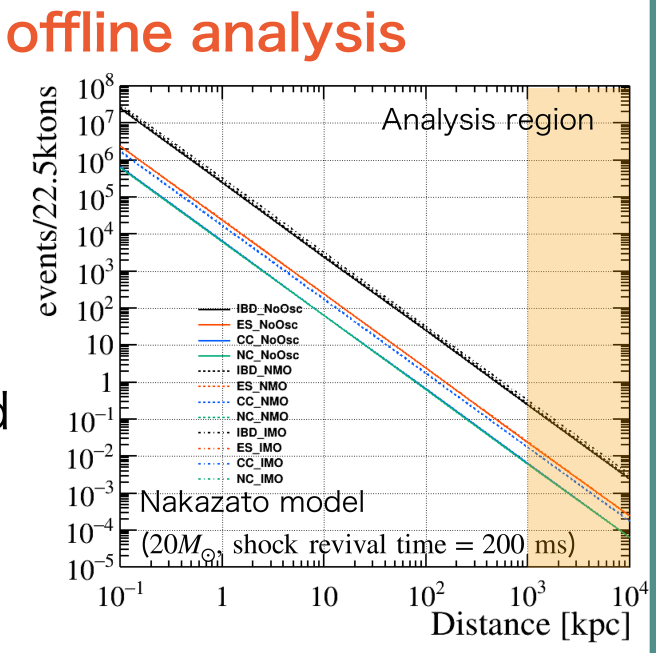
- Main channel: $\bar{\nu}_e + \mathrm{p} \rightarrow \mathrm{e}^+ + \mathrm{n}$
- SN burst within ~80 kpc makes enough neutrino events to trigger an automatic alarm with 100% probability.[4]
- In contrast, O(1) events in ~1 Mpc is expected in SK

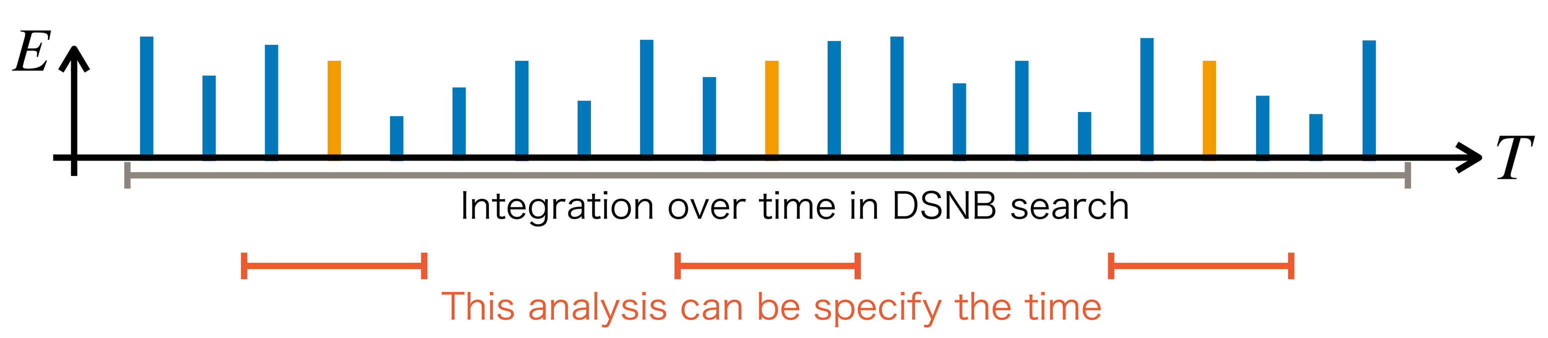


→SN neutrinos might be identified using offline analysis

SN out to 10 Mpc

- Time information on targeted SN is available
  - Accuracy of core collapse time determination is important for this search
  - Many background events can be removed by time information
  →It can be improve S/N



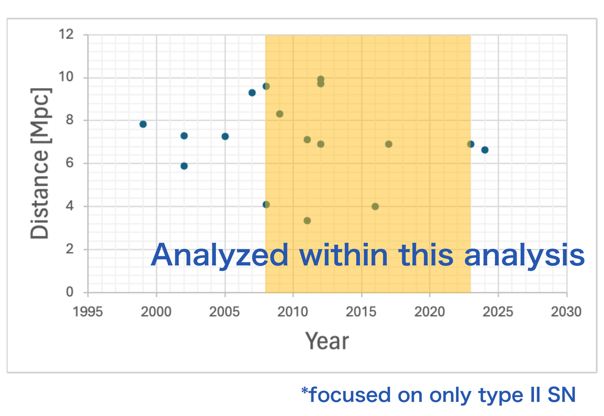


2. SN candidates: SN out to 10 Mpc from 2009

List of the SN explosion out to 10 Mpc

- Search for neutrinos from SNe since 2009

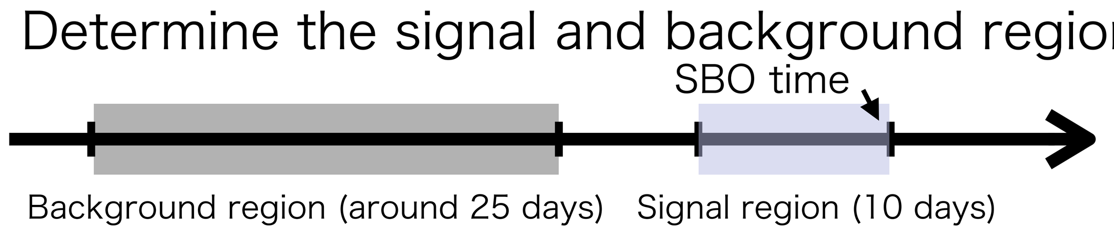
	Distance [Mpc]	Detection date	Estimated SBO date	Signal region	Search time [day]
SN2023ixf	~ 7	May 19, 2023	May 18, 2023	May 9 - 19, 2023	9.8
SN2017eaw	~ 7	May 14, 2017	May 06, 2017	Apr. 26 - May 07, 2017	11.1
SN2012aw	~ 10	Mar. 16, 2012	Mar. 15, 2012	May 03 - 16, 2012	9.8
SN2012A	~ 10	Jan. 07, 2012	Jan. 04 or 8, 2012	Dec. 26 - Jan. 08, 2012	9.7
SN2011dh	~ 7	May 31, 2011	May 31, 2011	May 20 - Jun. 1, 2011	11.8
SN2011ja	~ 3	Dec. 18, 2011	Dec. 12, 2012	Dec. 02- 13, 2011	9.6
SN2009hd	~ 8	Jul. 02, 2009	Jun. 19, 2009	Jun. 07 - 20, 2009	8.8

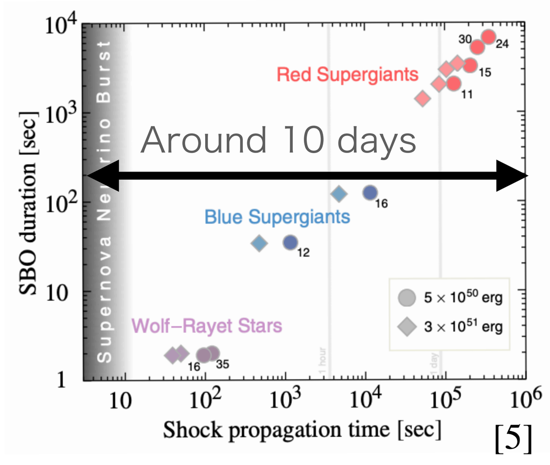


*focused on only type II SN

3. Analysis strategy: SN neutrino search method

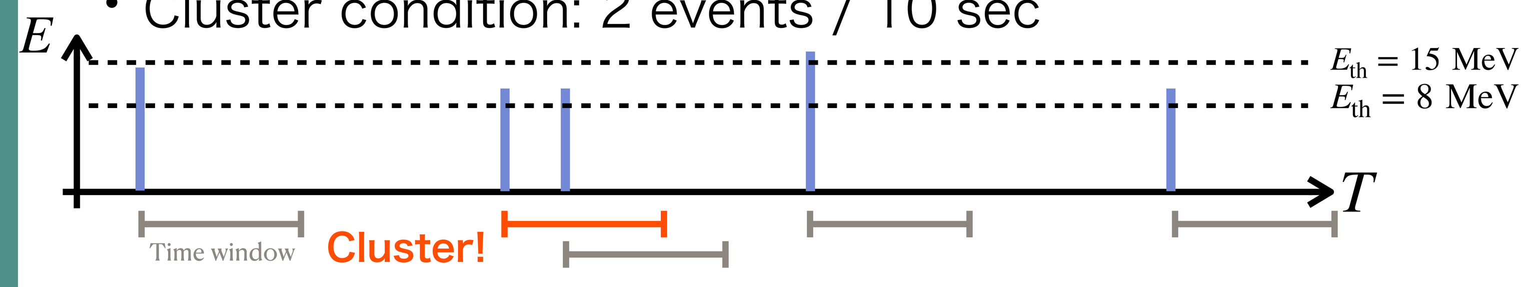
- Determine the signal and background region





[5]

1. Cluster search in the signal region
   - Sliding window search
   - Cluster condition: 2 events / 10 sec



2. Search for excess from background events

Analysis condition

1. Eth = 8 MeV, 15 MeV
2. Applying neutron tagging (Eth = 8 MeV)

4. Results: SN neutrinos were not found

1. Cluster search

→There was no cluster in the signal region

2. Search for excess from background events

Minimum p-value: 0.13

→There was no excess from the background

	BG exp	#of event	P-value	BG exp	# of event	P-value	BG exp (with ntag)	# of event (with ntag)
Energy thr.	8 MeV			15 MeV			8 MeV	
SN2023ixf	99.4±6.2	108	0.82	0.8±0.3	0	0.51	0.1±0.07	0
SN2017eaw	104.6±6.3	97	0.77	1.5±0.8	1	0.61	0.3±0.04	0
SN2012aw	108.6±6.5	105	0.63	1.9±0.9	1	0.71	0.2±0.04	0
SN2012A	105.2±6.3	102	0.62	1.9±0.8	1	0.72	0.2±0.04	0
SN2011dh	—	—	—*	1.6±0.8	3	0.13	0.3±0.04	0
SN2011ja	102.7±6.8	94	0.80	1.7±0.9	2	0.39	0.2±0.0.04	0
SN2009hd	—	—	—*	1.2±0.7	2	0.22	0.2±0.0.03	0

*There are no data less than 10 MeV

Fluence upper limit

$$\Phi_{lowe} = \frac{N_{90}}{N_T \int dE_\nu \lambda(E_\nu) \sigma(E_\nu) R(E_e, E_{vis}) \varepsilon(E_{vis})}$$

N_{90}: 90% C.L. limit on neutrino events; N_T: #of targets; $\lambda(E_\nu)$: number density; $\sigma(E_\nu)$: cross section; $\varepsilon(E_{vis})$: efficiency

We assume the Nakazato model[6] for number density:
($20M_{\odot}$, shock revival time = 200 ms, NMO)

Fluence upper limit [/cm^2]

	SN2023ixf	SN2017eaw	SN2012aw	SN2012A	SN2011dh	SN2011ja	SN2009hd
Eth = 8 MeV	5.36×10^8	3.01×10^8	3.48×10^8	3.46×10^8	–	2.89×10^8	–
Eth = 15 MeV	5.04×10^7	6.58×10^7	6.39×10^7	6.39×10^7	1.11×10^8	8.45×10^7	9.12×10^7
Eth = 8 MeV (with ntag)	7.42×10^7	1.72×10^8	1.72×10^8	1.72×10^8	–	1.72×10^8	–

5. Summary and prospects

- Search for neutrinos from supernovae within 10 Mpc
- Compared background events and the number of events in the signal region
  →could not find excess from background
- Searched cluster in the signal region
  →There was no cluster
- Next, we will search for neutrinos from all SN that occurred while SK was in operation since 1996
- The calculated fluence upper limit is $\mathcal{O}(10^7)$ [cm^2], which corresponds to a luminosity limit of $\mathcal{O}(10^{55})$ [erg]. It is considerably higher than the usual SN explosion expectation because it was calculated with individual SNs from a few Mpc. If multiple SN events are stacked, the sensitivity would be much higher.

[reference]
[1]Y. Suzuki, Eur. Phys. J. C, Vol. 79, No. 4,(2019) [2]K. Abe et al., Phys. Rev. D 104, 122002 (2021) [3] J. F. Beacom and M. R.Vagins, Phys. Rev. Lett. 93, 171101 (2004)
[4] Guillaume et al, NEUTRINO2024 poster 105 [5]M. Kistler et al., Astrophys.J.778:81,2013 [6]K. Nakazato et al., Astrophys.J.205:2