Search for extra-galactic supernova neutrinos in Super-kamiokande

スーパーカミオカンデにおける天の川銀河系外超新星由来のニュートリノイベント探索

第10回超新星ニュートリノ研究会

2024年2月29日@岡山大学

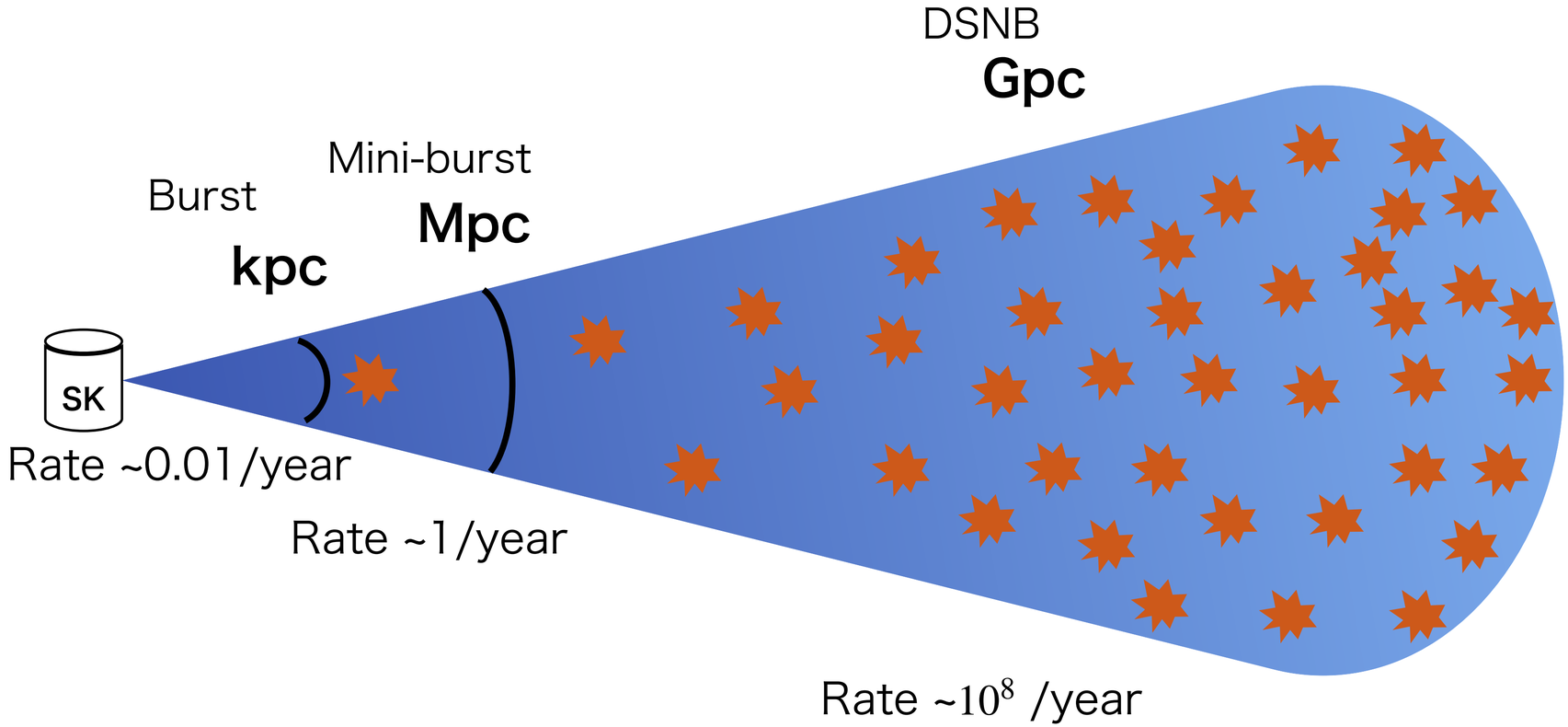
岡山大学 中西史美

Content

- Supernova rate nearby galaxy
- SN2023ixf
- Analysis method
- Cluster search
- Result
- Detection probability in SK
- Summary

Supernova rate nearby Galaxy

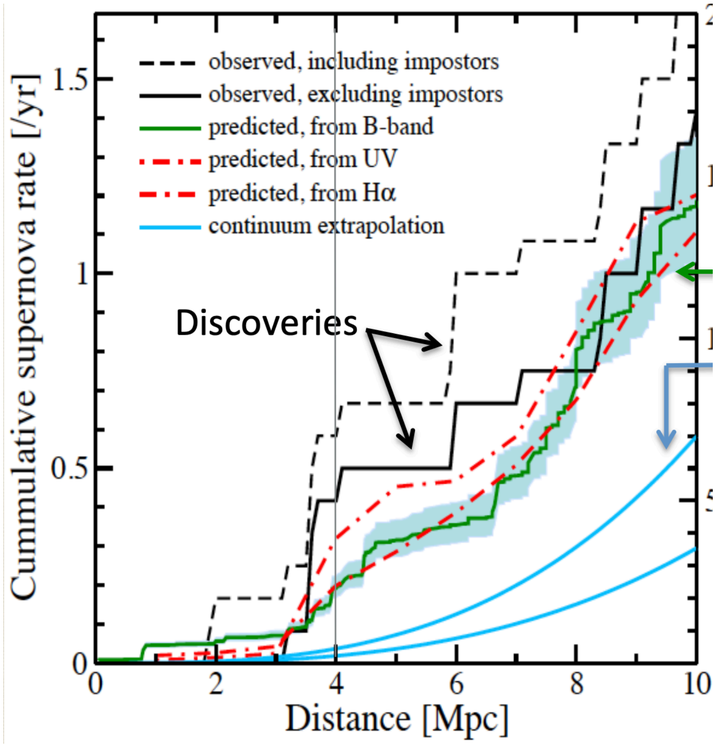
- Frequent phenomena in the universe

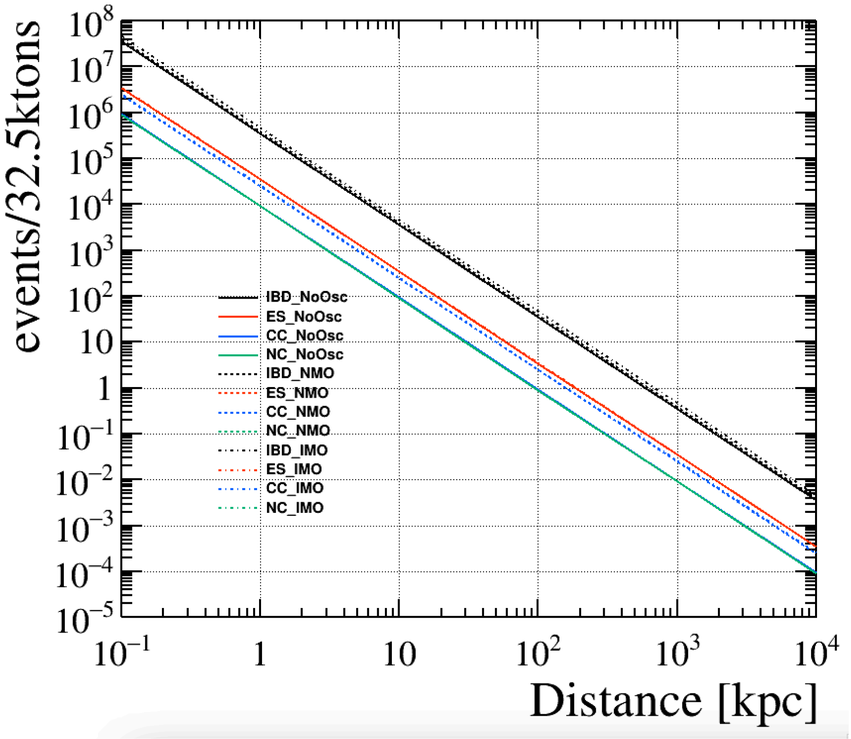


- Focus on “mini-burst”

Observable SN neutrinos in SK

- The CCSN rate is estimated in the Mpc region
  0.4 - 1.0/year at 6 Mpc
- Expected supernova neutrino in Full volume (32.5 kton)
  $\mathcal{O}(10^{-2})$ events at 6 Mpc

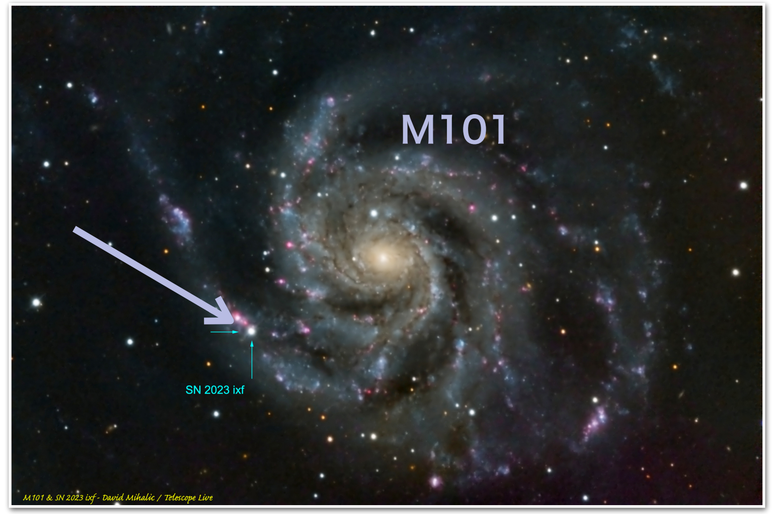




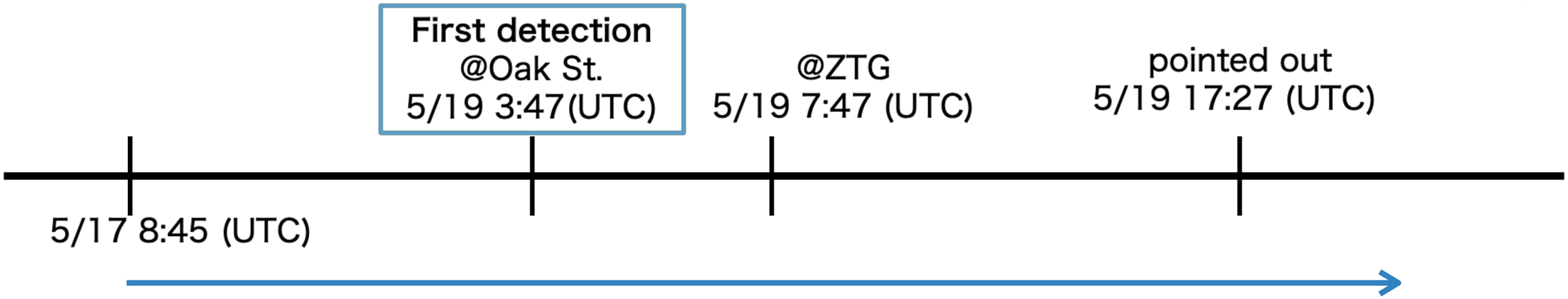
SN2023ixf

- Observed many optical scopes on May 19, 2023 https://www.wis-tns.org/object/2023ixf
- Typical Type II SN
- Distance: ~6.4 Mpc

- We guess the time of the burst started on May 19.



https://telescope.live/gallery/supernova-sn-2023-ixf-m101

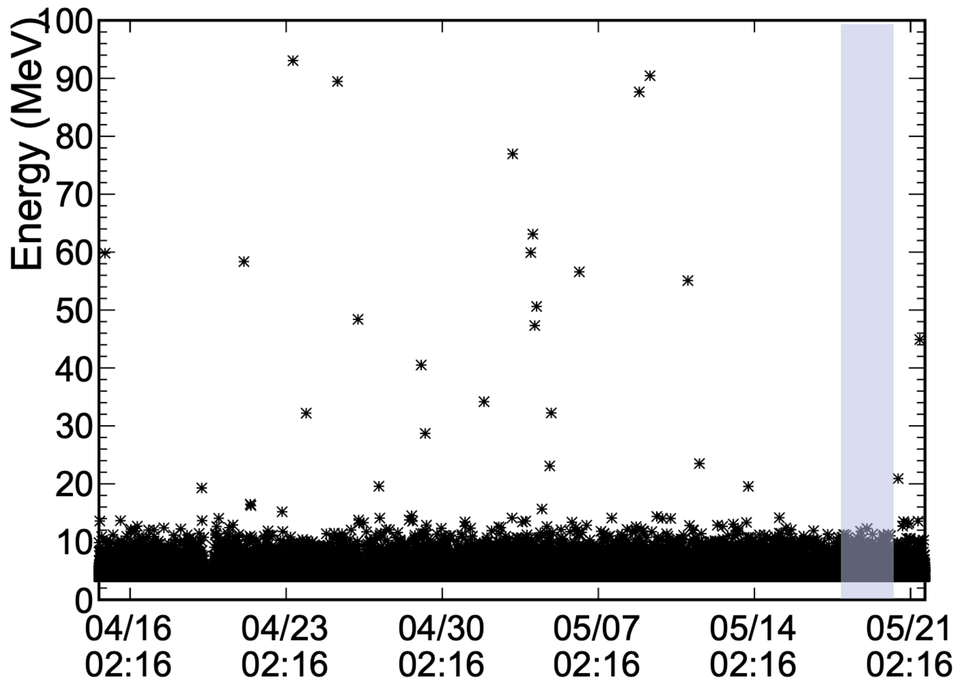


SK was running normally from 17 May

Analysis method

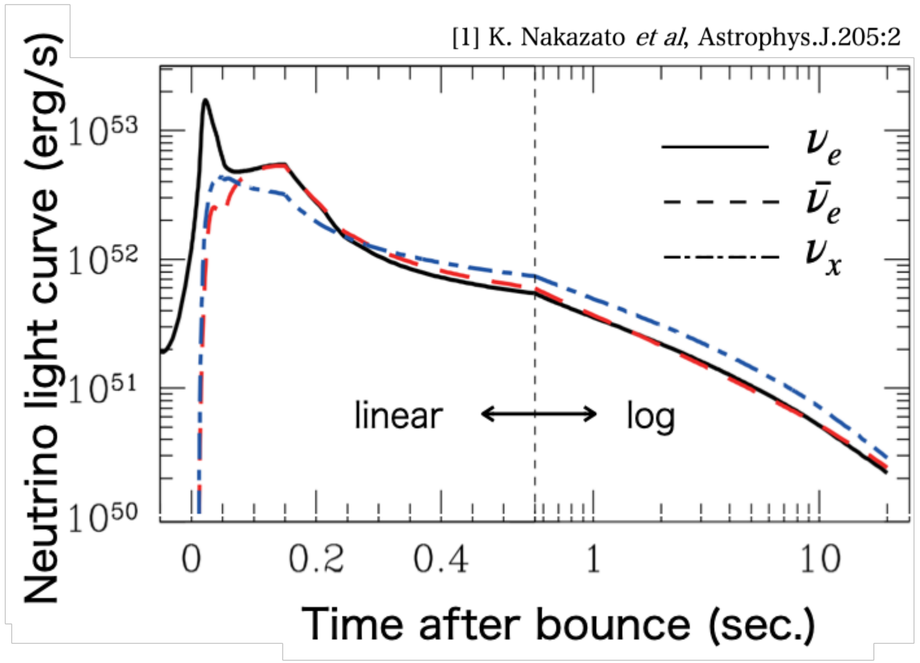
Energy vs time plot in SK
→Search event excess around this period

- Signal period:
  May 17, 2023 - May 20, 2023 (~2 days, JST)
- Background period:
  Apr. 14, 2023 - May 10, 2023 (~25 days, JST)
- No significant event in the signal region..
  117 events observed / 117.7 bkg expected



Cluster search

- The spectrum peak appears around 10 sec. from core collapse.
  →Condition: two events within 10 seconds with 7 MeV threshold



- The event rate of the 7 MeV threshold is 6.9×10^{-3} /10 sec
  →No significant cluster was observed

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

- Since there were no candidate neutrino events within 10 sec, we set $N_{90} = 2.3$.
- We assume the Nakazato model:
  $(13M_\odot$, shock revival time $= 200$ ms)
  $(20M_\odot$, shock revival time $= 200$ ms)

[2]Nakazato et al 2013 ApJS **205** 2

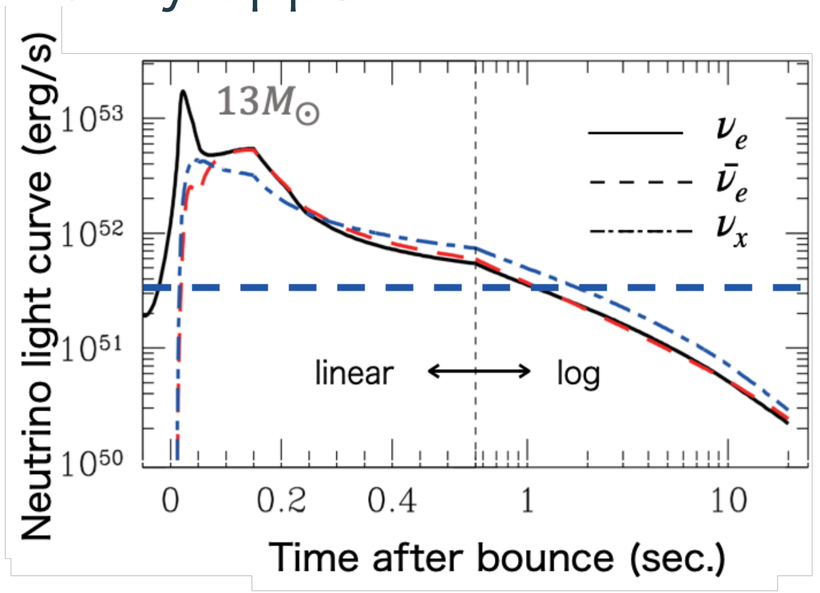
Supernova model		Fluence upper limit [/cm^2]
$13M_\odot$	Normal mass ordering	1.07×10^8
	Inverted mass ordering	8.96×10^7
$20M_\odot$	Normal mass ordering	1.11×10^8
	Inverted mass ordering	7.81×10^7

Luminosity upper limit

- From The fluence upper limit, we estimate the luminosity upper limit

$$E_{iso}[\mathrm{erg/s}] = 4\pi d^2 \times \Phi_{lowe} \int_{E_{min}}^{E_{max}} \lambda(E) E dE$$

- Luminosity upper limit $\mathcal{O}(10^{54})$
  →It was not an upper limit that the model could limit.



	Supernova model	Luminosity upper limit [erg/s]	Average luminosity [erg/s]
$13M_\odot$	Normal mass ordering	1.51×10^{54}	2.47×10^{51}
	Inverted mass ordering	1.34×10^{54}	2.47×10^{51}
$20M_\odot$	Normal mass ordering	1.54×10^{54}	2.28×10^{51}
	Inverted mass ordering	1.28×10^{54}	2.05×10^{51}

Notification of this report

- We reported to GCN circular and ATEL

https://gcn.nasa.gov/circulars/33916

https://www.astronomerstelegram.org/?read=16070

GCN Circular 33916

Subject Super-Kamiokande: Neutrino search for SN2023ixf
Date 2023-06-05T12:30:44Z (9 months ago)
From Yusuke Koshio at Super-Kamiokande <koshio@okayama-u.ac.jp>

M. Nakahata, Kamioka Observatory, Institute for Cosmic Ray Research,
University of Tokyo, reports on behalf of the Super-Kamiokande collaboration:

Super-Kamiokande, a 50 ktons water Cherenkov imaging detector situated 1000 meters underground in the Kamioka mine, Gifu, Japan, has searched for neutrino signal correlated with SN2023ixf in a time window 2 days before the detection by Oak St. Observatory (2023-05-17 08:45:13 to 2023-05-19 08:45:13), during which Super-Kamiokande took data stably without dead time. In the electron total energy region between 7.0 MeV and 100 MeV within a fiducial volume of 22.5 ktons, no significant signal was observed.

[Previous | Next | ADS]

Neutrino search for SN2023ixf in Super-Kamiokande

ATel #16070; *M. Nakahata (University of Tokyo) on behalf of the Super-Kamiokande collaboration*
*on **2 Jun 2023; 08:44 UT***
Distributed as an Instant Email Notice Supernovae
Credential Certification: H. Ishino (snconveners@km.icrr.u-tokyo.ac.jp)

Subjects: Neutrinos, Supernovae

Referred to by ATel #: 16075

𝕏 Post

Super-Kamiokande, a 50 ktons water Cherenkov imaging detector situated 1000 meters underground in the Kamioka mine, Gifu, Japan, has searched for neutrino signal correlated with SN2023ixf in a time window 2 days before the detection by Oak St. Observatory (2023-05-17 08:45:13 to 2023-05-19 08:45:13), during which Super-Kamiokande took data stably without dead time. In the electron total energy region between 7.0 MeV and 100 MeV within a fiducial volume of 22.5 ktons, no significant signal was observed.

Related

16075 Fermi-LAT gamma-ray observations of SN 2023ixf
16073 Chandra X-ray detection of supernova SN 2023ixf in M101
16070 Neutrino search for SN2023ixf in Super-Kamiokande
16065 SN 2023ixf continues to rise in hard X-rays
16060 Search the XMM-Newton archival data for the progenitor of SN 2023ixf
16052 uGMRT radio upper limit on Supernova SN 2023ixf in M101
16051 X-ray emission of SN 2023ixf and its progenitor
16049 NuSTAR detection of SN 2023ixf in M101
16047 Multi-Band Photometric Follow-up of SN 2023ixf
16045 Optical observations of SN 2023ixf at Teide Observatory
16043 SN 2023ixf: Upper limits from a neutrino search with IceCube

- We could notify for the first time on SK!

Detection probability

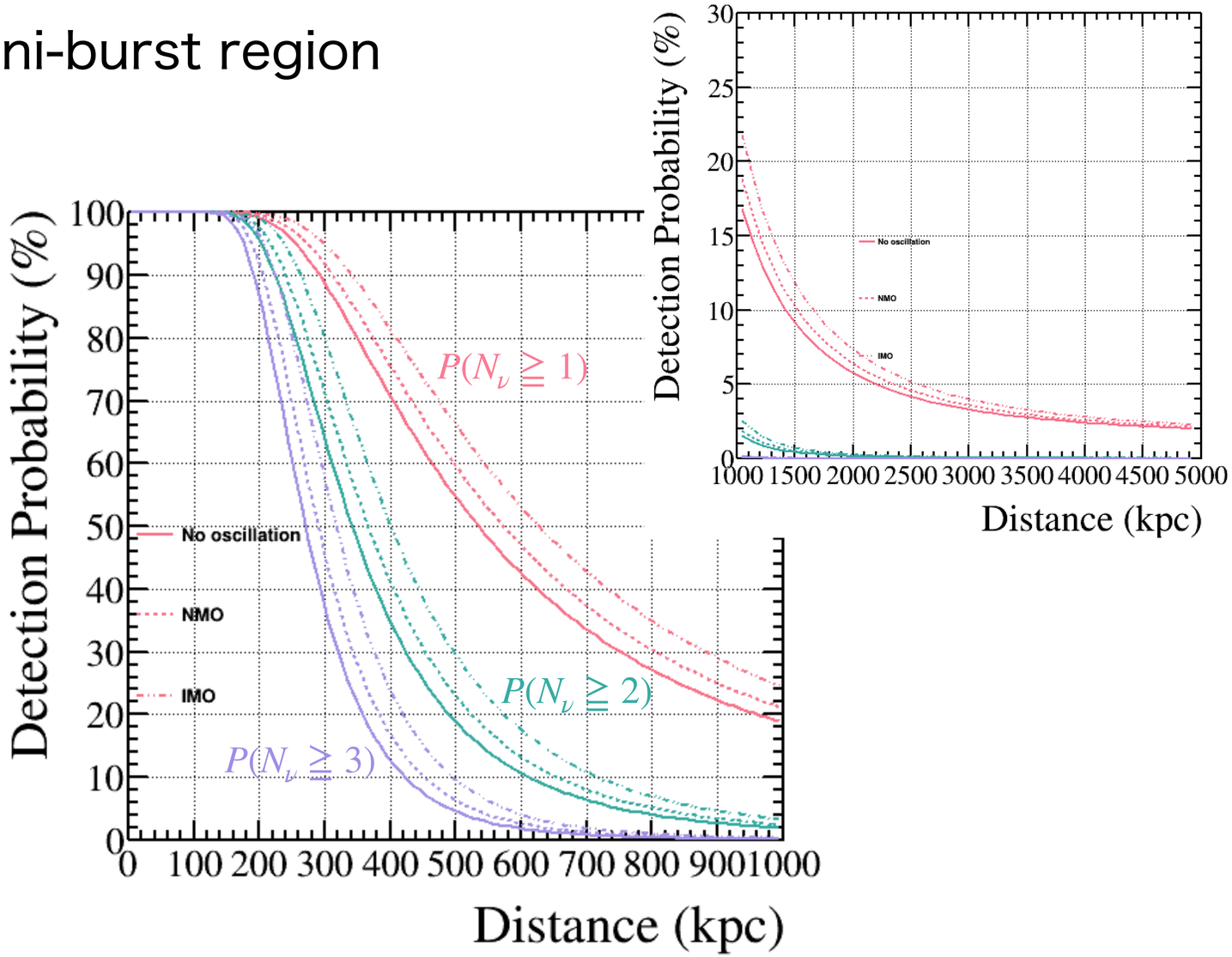
- SN neutrino event estimation
  - SN model: Nakazato model ($20M_{\odot}$, shock revival time = 200 ms)
  - Time window: 10 sec
  - Energy threshold: 7 MeV
  - SK tank volume: 22.5 kton (effective volume)
  - Applying spallation cut: reducing 20% for supernova event

- Background expected
  6.9×10^{-3} /10 sec (7MeV threshold)

Detection probability

- Detection probability (P) in mini-burst region
- $P \geq 5$ % in 2 Mpc

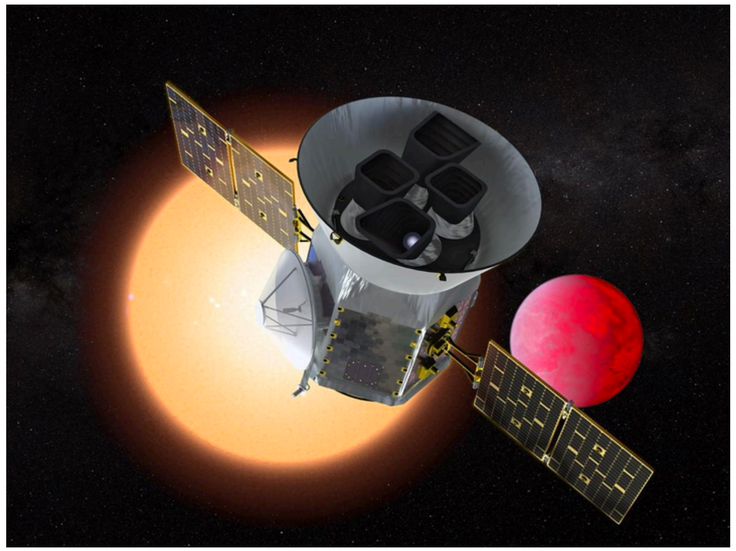
the time of the explosion needs to be determined within several ten sec.



Optical telescopes

- Several telescopes monitor objects in the “mini-burst” region
  →Many supernovae are observed, and it is opened in their catalog

TESS https://tess.mit.edu/



ASAS-SN https://www.astronomy.ohio-state.edu/asassn/

- I will search the supernova neutrinos with information of the catalog

Summary

- Extra-galactic supernovae within 10 Mpc are called “mini-burst”
- SN2023ixf was detected on May 19
  - We searched the cluster in 10 sec window
  - SK data showed no excess after reduction cuts and were consistent with the background expectation.
    →This is reported to ATEL and GCN
- We calculated the fluence upper limit within 10 sec window
  - The upper limit of luminosity: $\mathcal{O}(10^{54})$ [erg/s]
- The detection probability in the mini-burst region
  - 5 - 20 % chance of $P(N_\nu \geqq 1)$

Backup

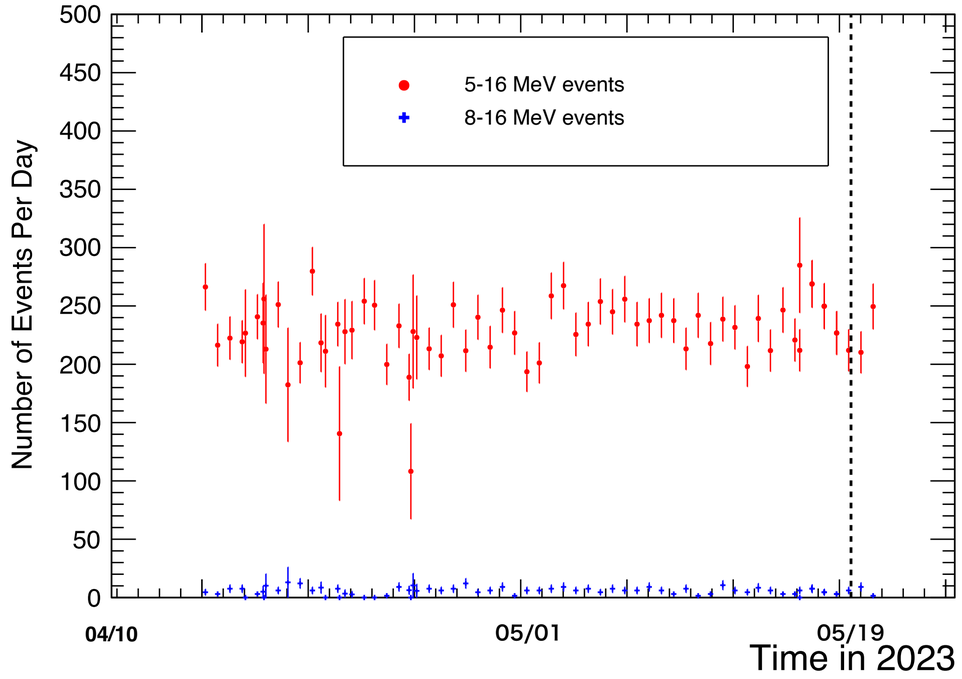
Analysis strategy

We use the data sample.

- Background period: Apr. 14, 2023 - May 10, 2023 (~25 days, JST)
- Signal period: May 17, 2023 - May 20, 2023 (~2 days, JST)

- Total energy criteria: 5 - 16 MeV
  - Spallation cut
  - 16N cut

- Total energy criteria: 16 - 100 MeV
  - Muon reduction
  - Spallation cut



Probability estimation

- Used poisson distribution $P(k) = \frac{e^{-\lambda}\lambda^{k}}{k!}$
- Calculated three probability

The probability which observe 0 event

$$P(N_\nu \geqq 1) = 1 - \exp(-(S+B))$$

The probability which observe 1 event

$$P(N_\nu \geqq 2) = P(N_\nu \geqq 1) - (S+B) \times \exp(-(S+B))$$

$$P(N_\nu \geqq 3) = P(N_\nu \geqq 2) - (S+B)^2 \exp(-(S+B)/2)$$

The probability which observe 2 event