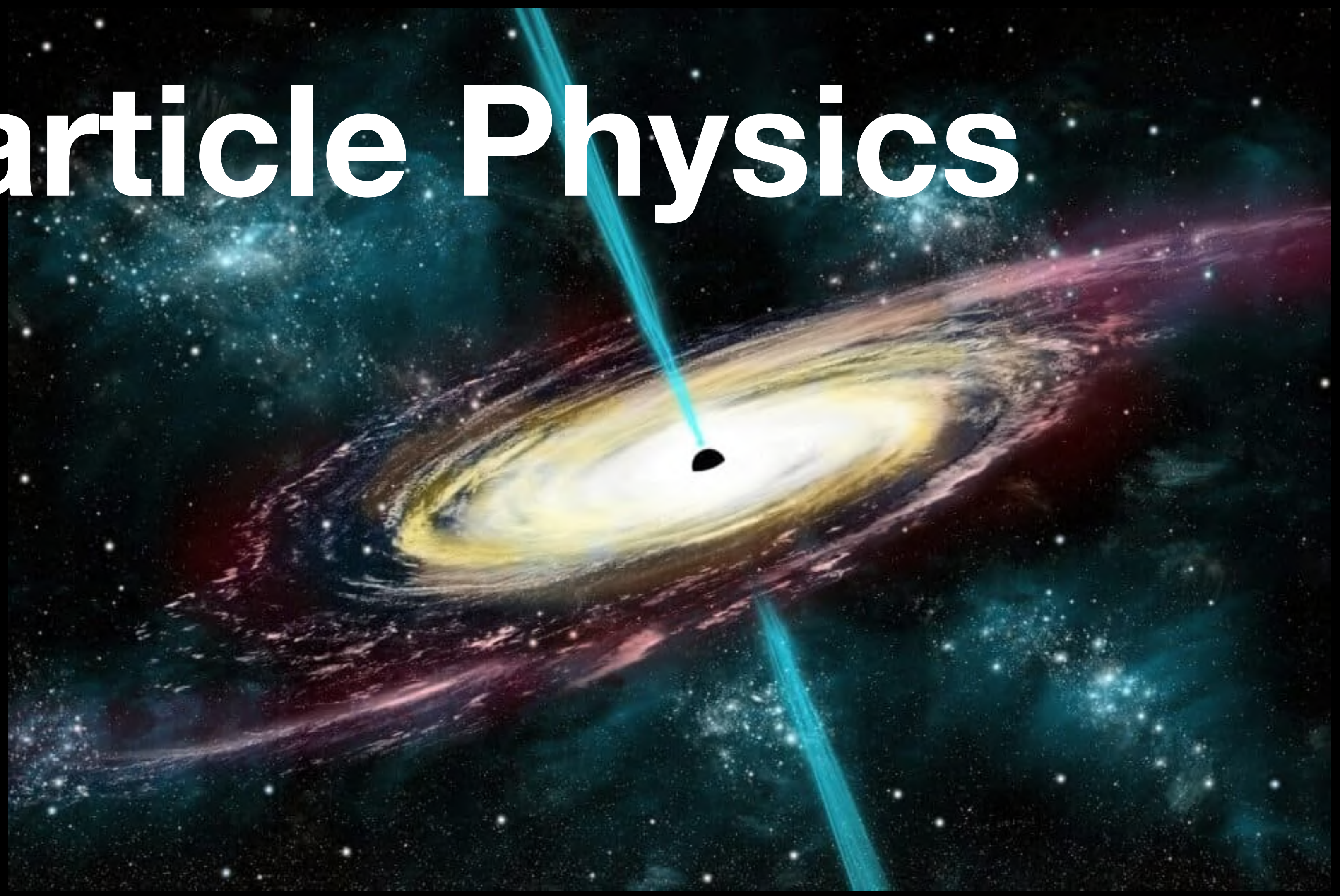
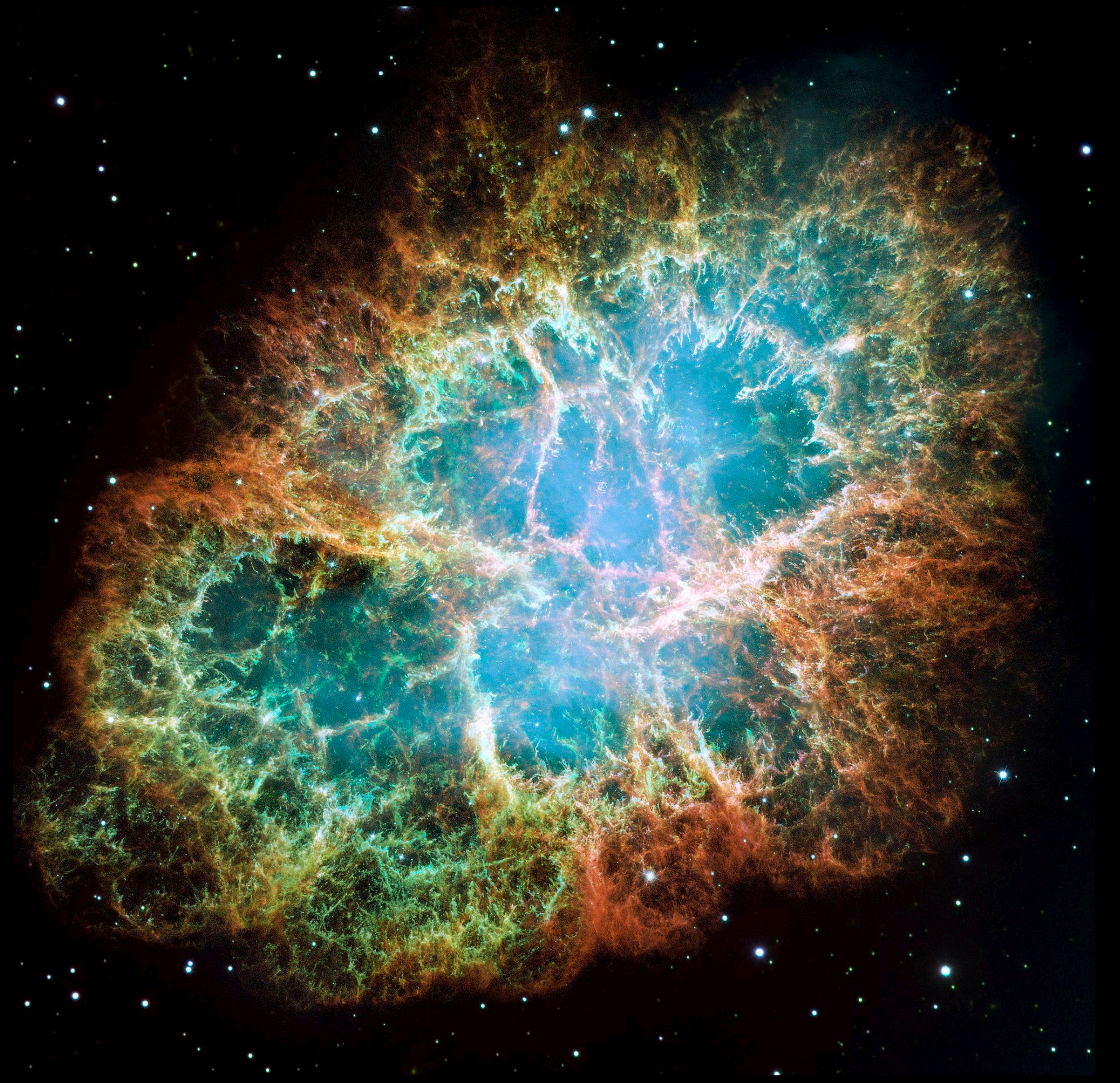
International Workshop on New Opportunities for Particle Physics (NOPP2026)
Institute of High Energy Physics, August 16th, 2026

Overview of astro-neutrinos

ASHIDA, Yosuke (Tohoku University)
芦田 洋輔 (東北大学)
yosuke.ashida.a1@tohoku.ac.jp

Astrophysics
~ Astronomy + Particle Physics



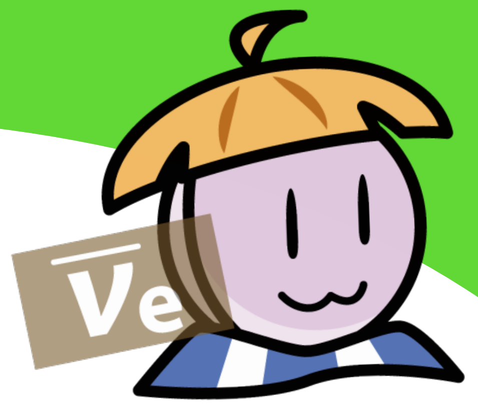


CRAB NEBULA

Photons

γ

Neutrinos



ν

TODAY

MULTI-MESSENGER ASTRONOMY

p

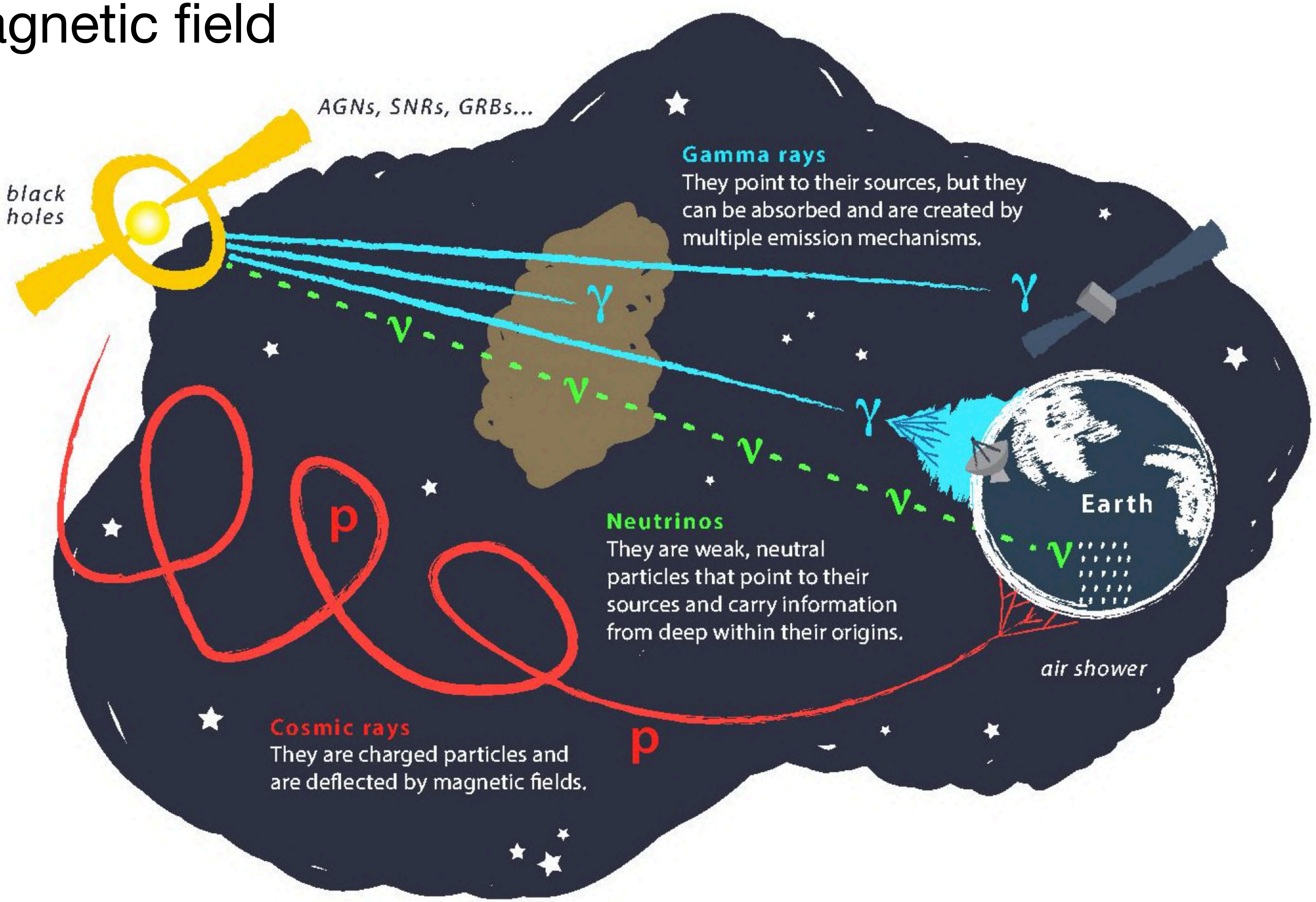
Cosmic rays

GW

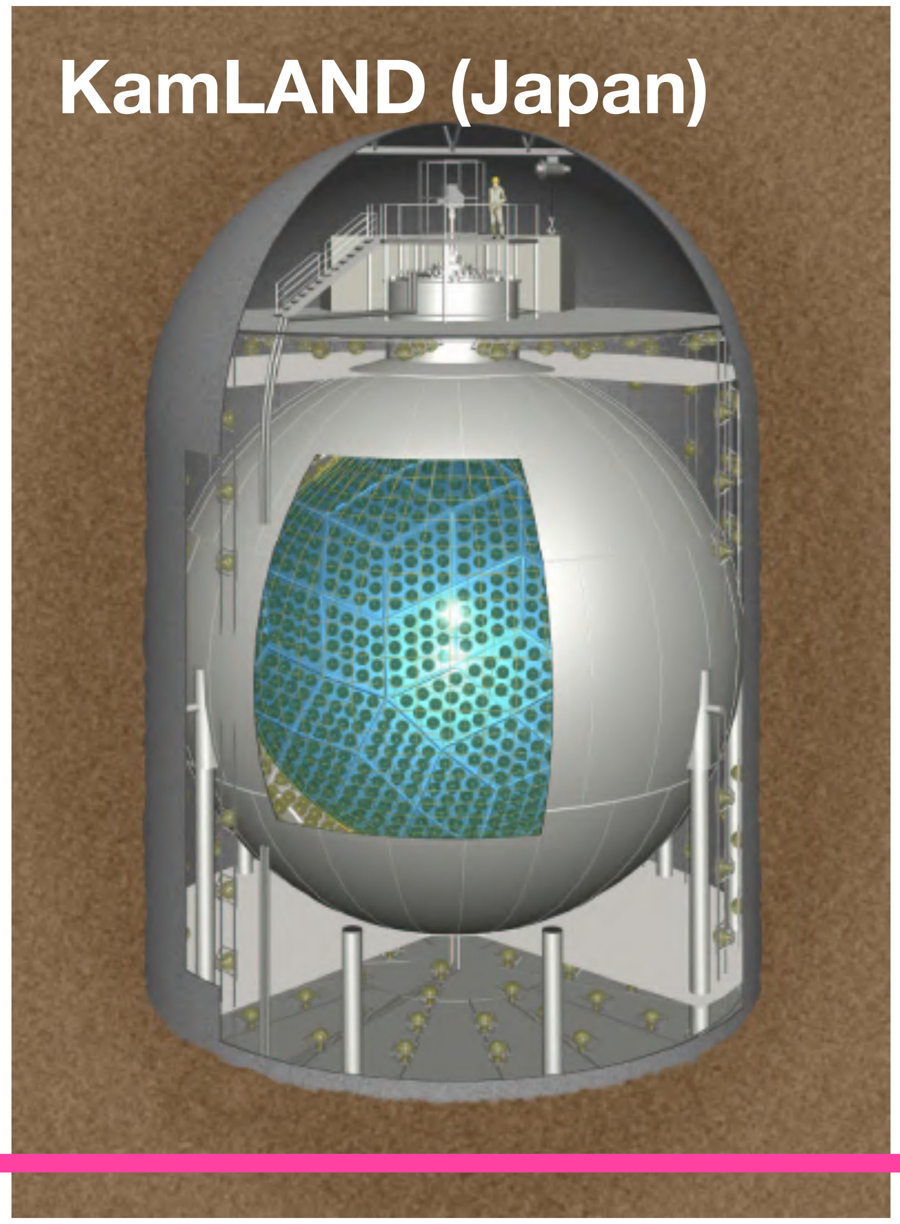
Gravitational Wave

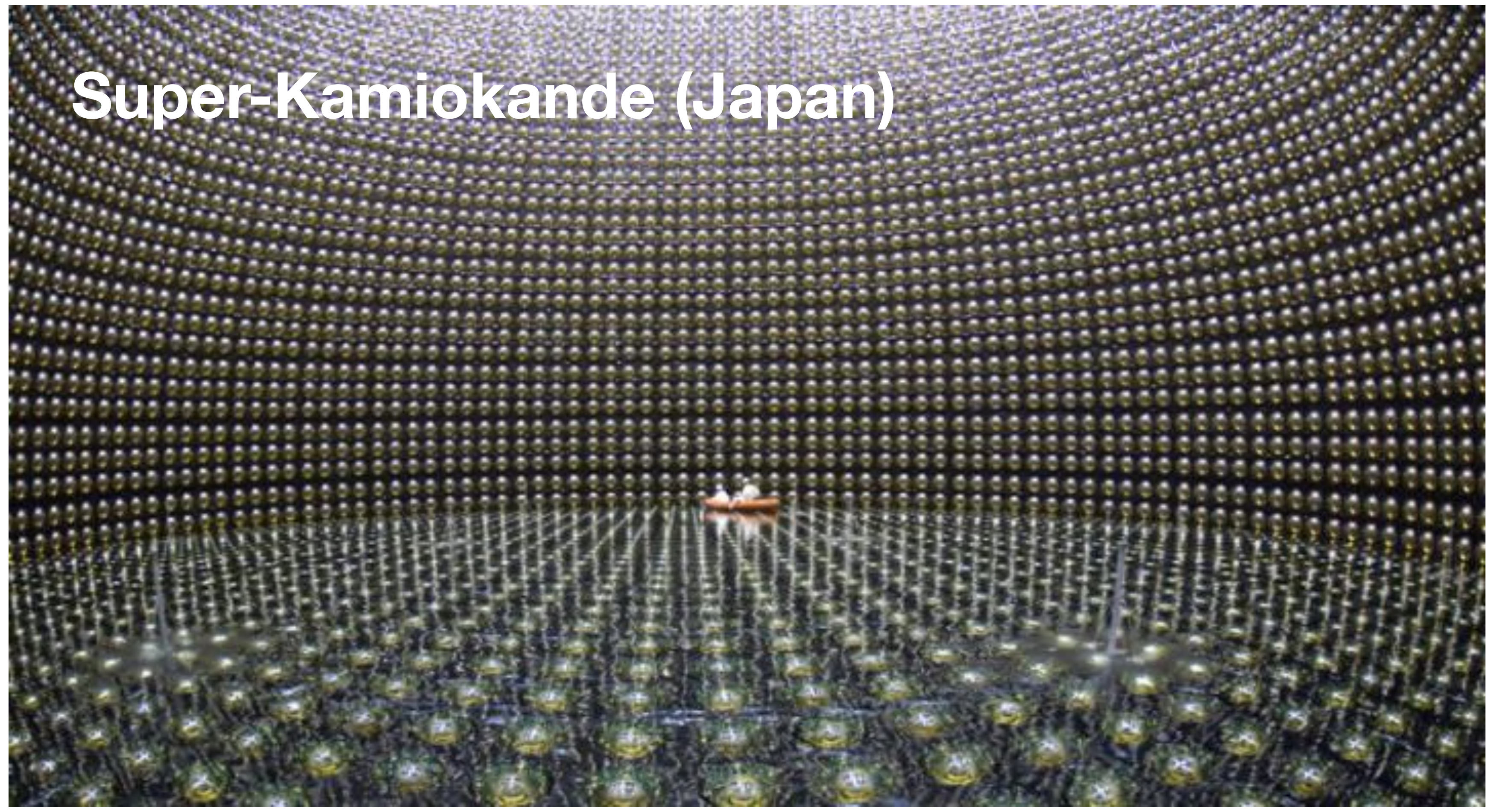
Neutrinos interact only *weak*ly

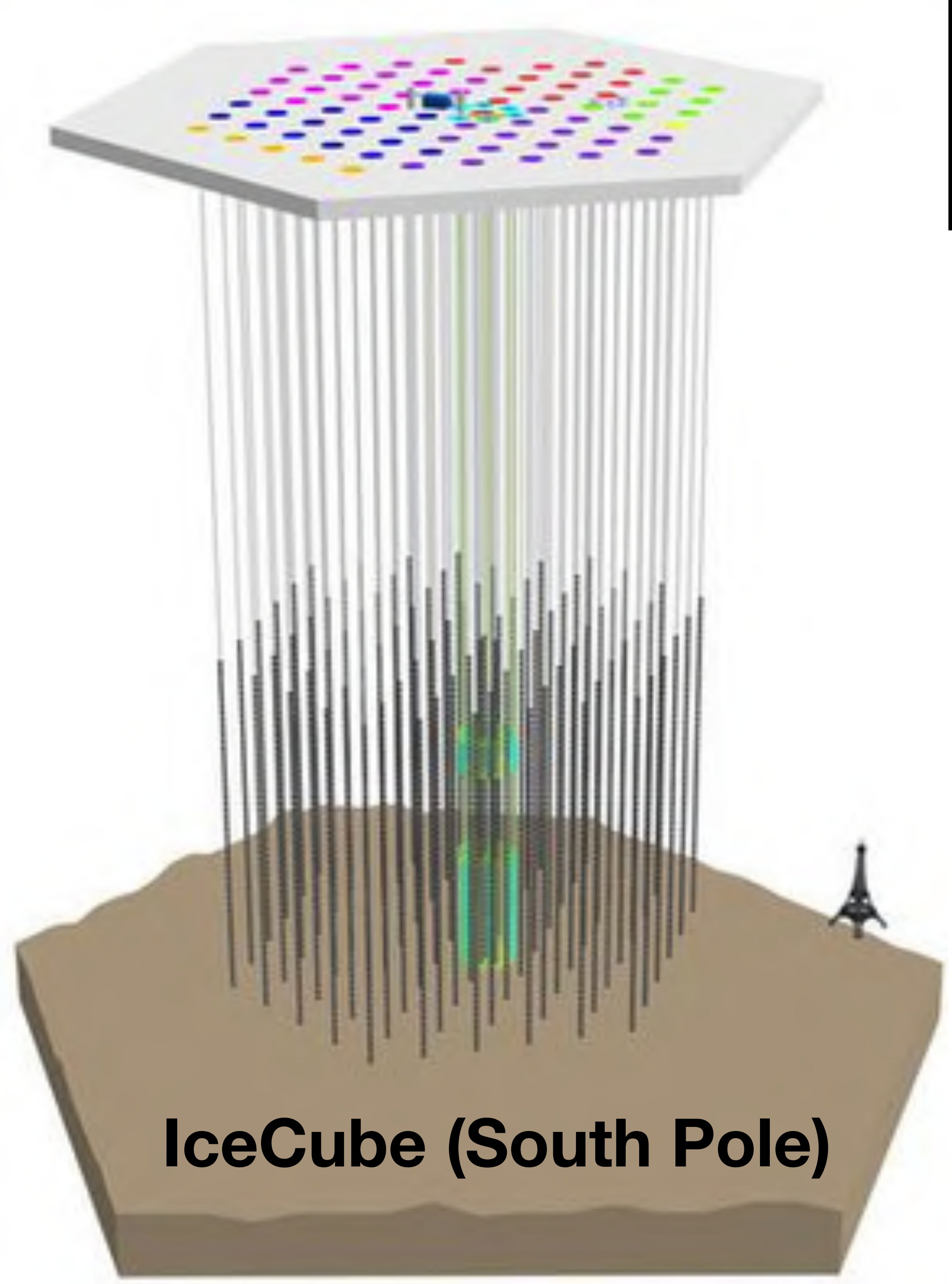
- Escape from extremely dense area
- Travel over the long distance
- Not deflected by cosmic magnetic field



Neutrino Telescopes (So Far)







MeV

MeV ~ TeV

TeV ~ PeV

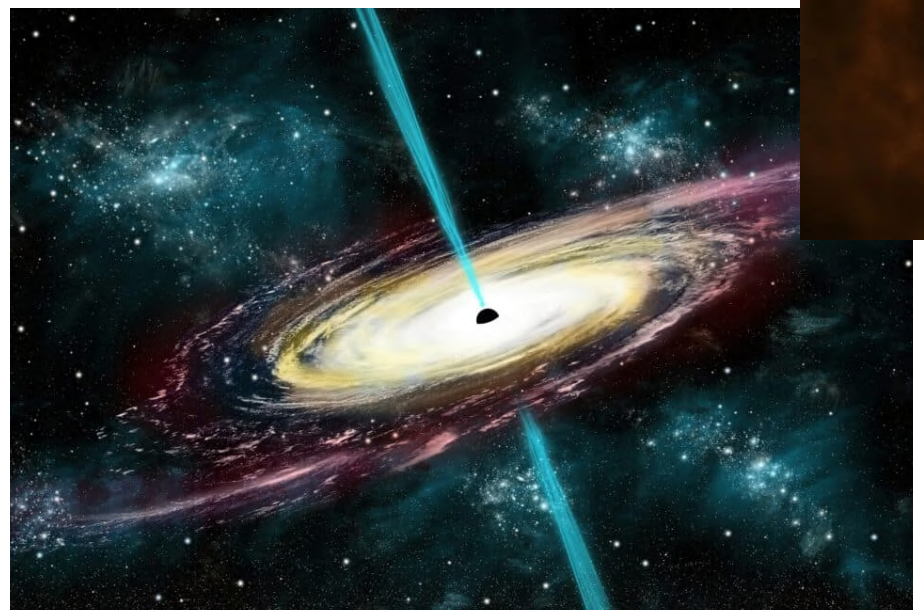
Different expertise in target energy and flavor

Neutrino Telescopes (Soon)

Astrophysical Neutrino Sources

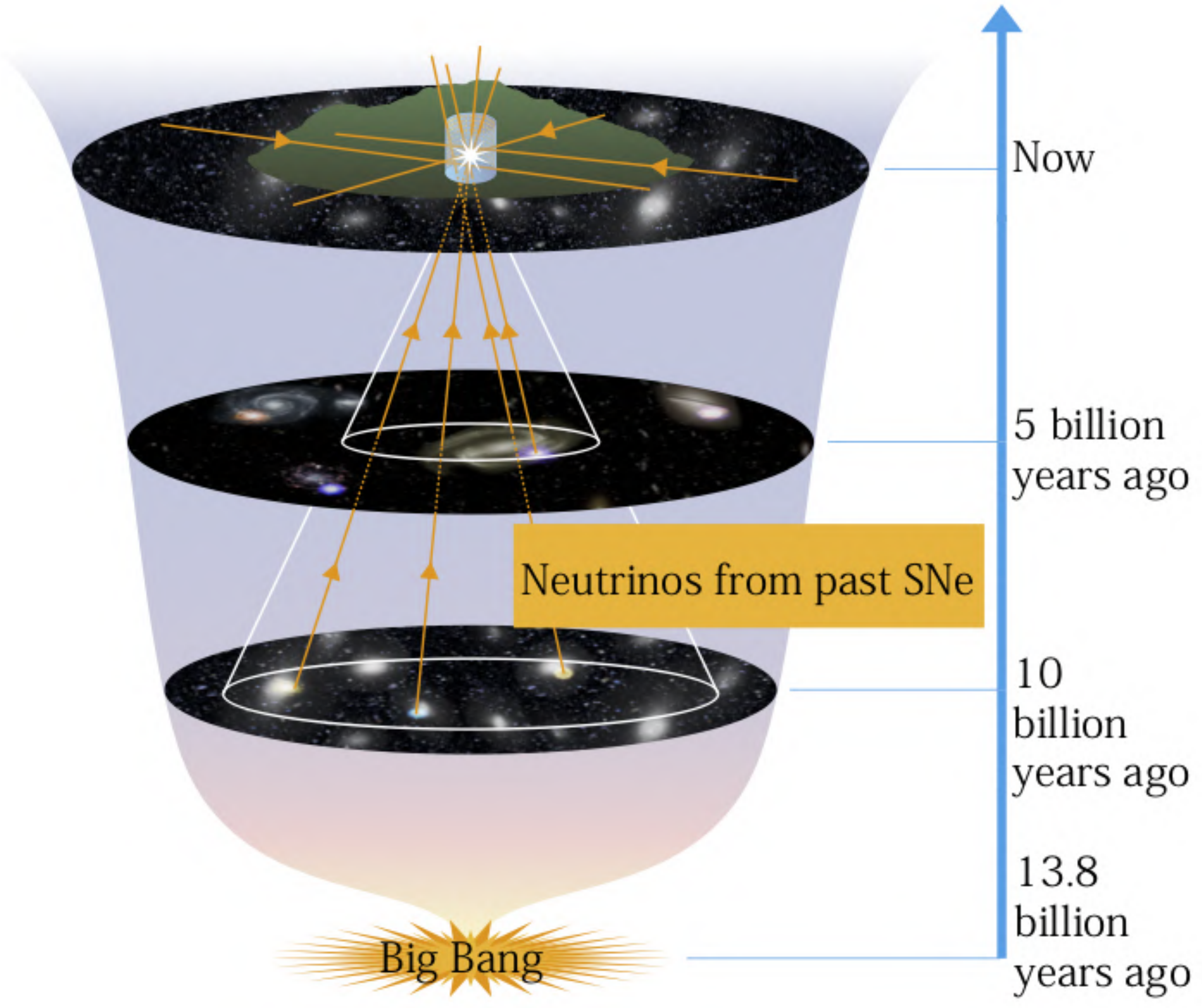
Transient ~ *temporal* emission

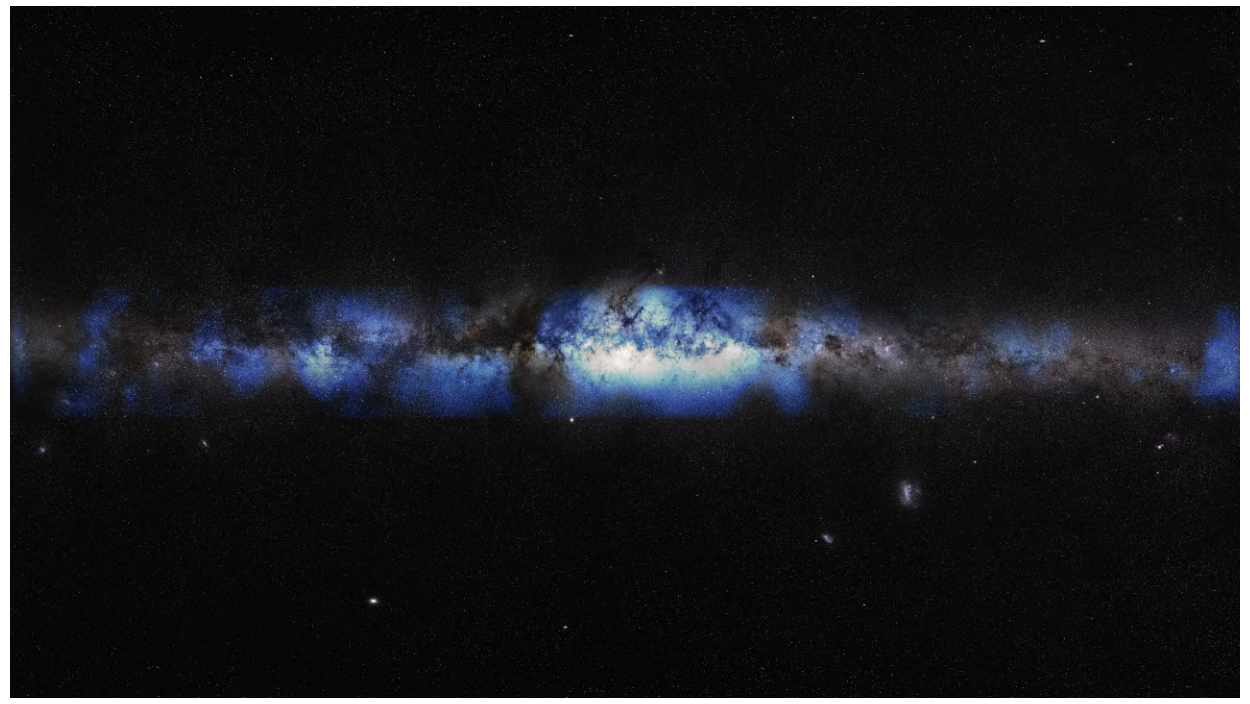
- Supernova (CCSN)
- Blazar
- Gamma-ray burst (GRB)
- … etc

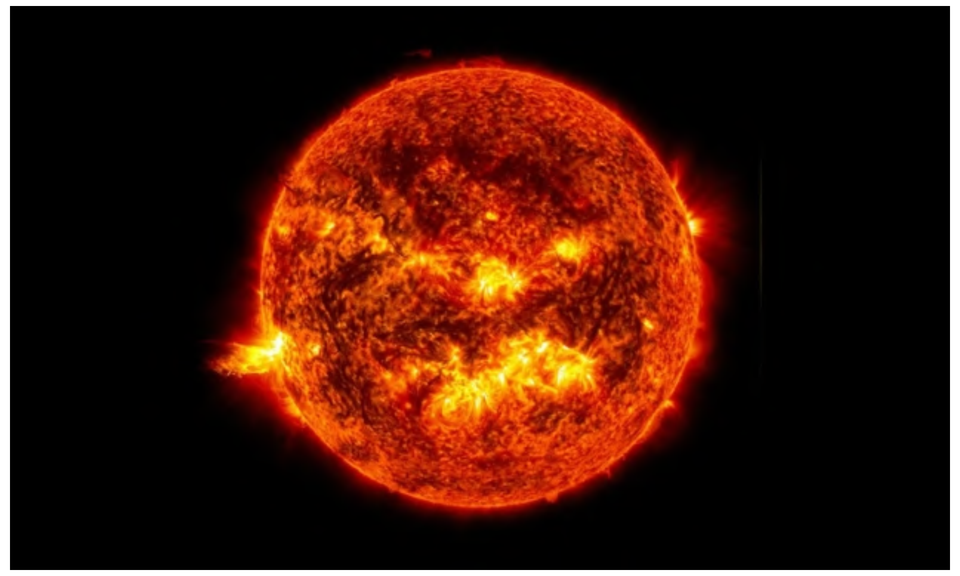


Diffuse ~ *continuous* emission

- Diffuse supernova neutrino background (DSNB)
- Most familiar stars (Sun, Earth)
- Active galactic nuclei (AGN)
- Galactic Plane
- … etc

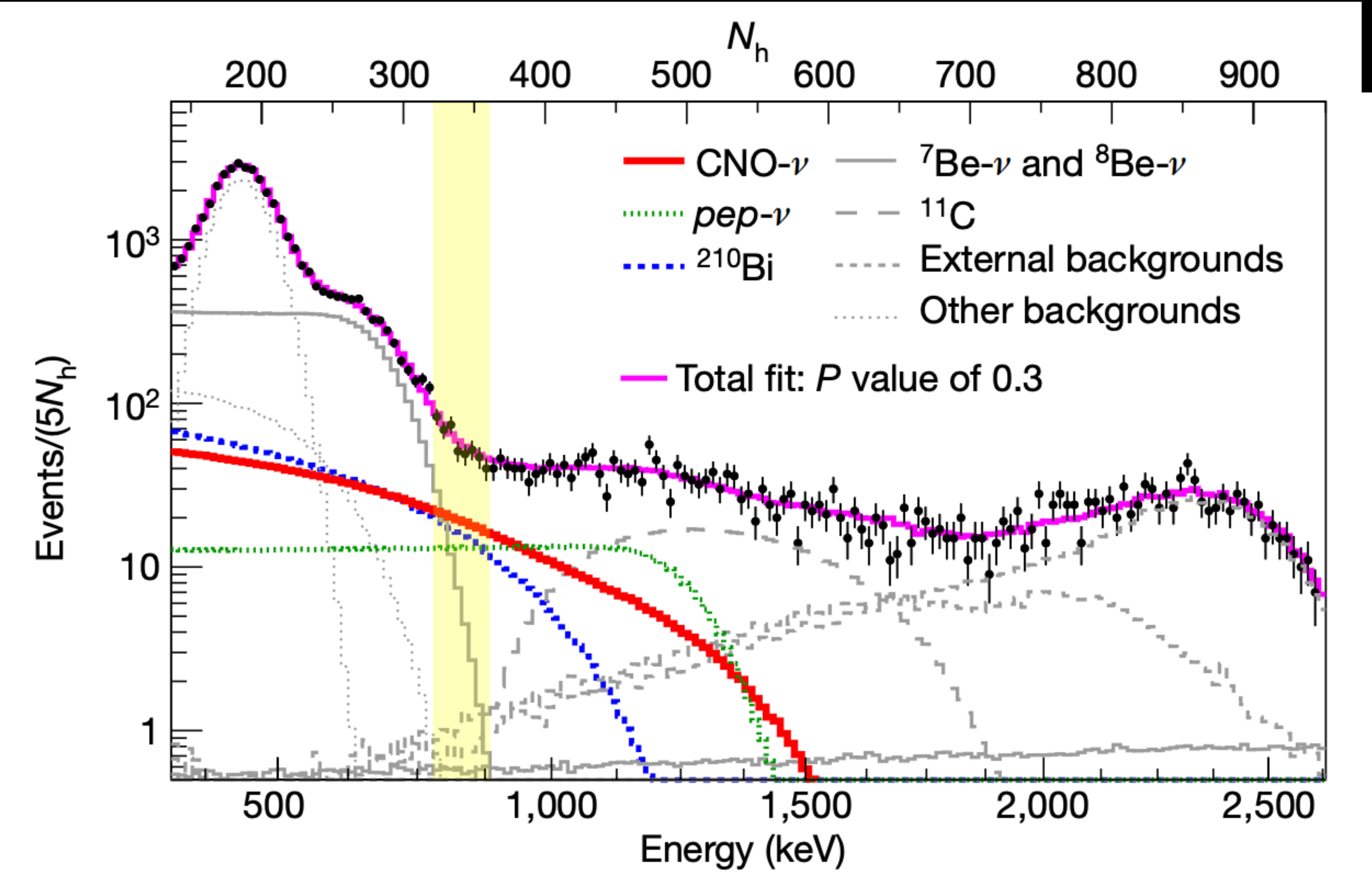


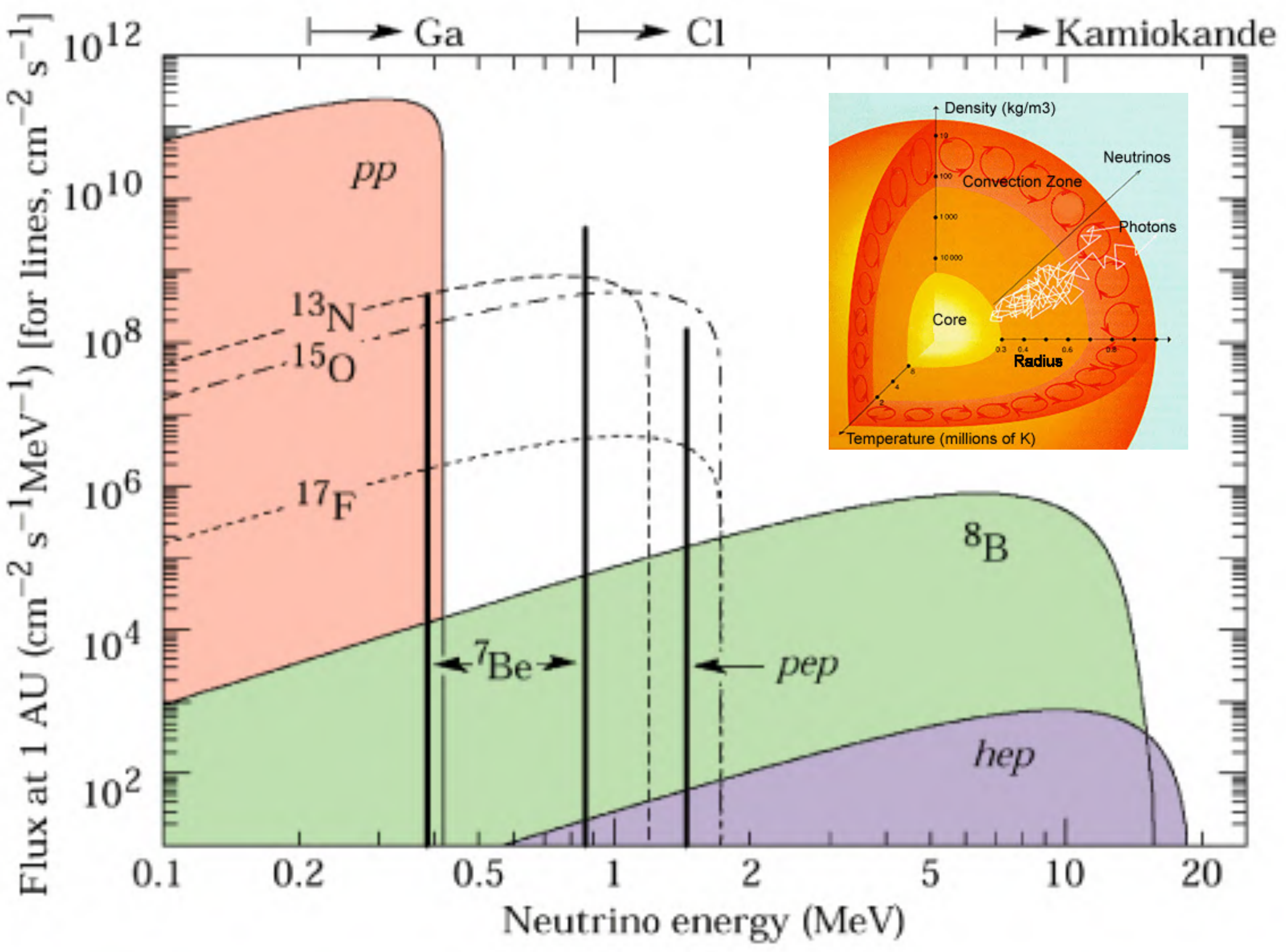


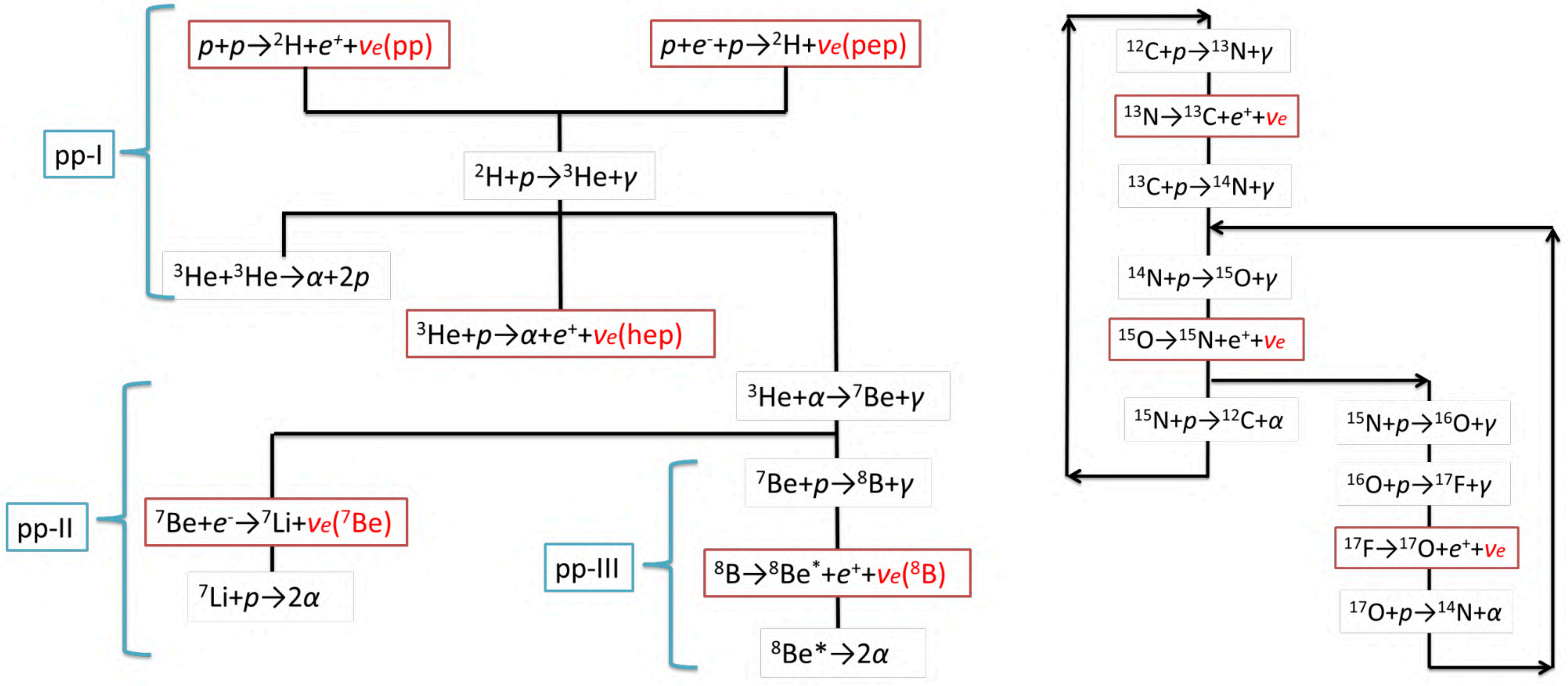


Neutrinos from the Sun

- Electron neutrinos are produced inside the Sun, which initiated **neutrino oscillation** studies (resolved by SNO and Super-K).
- Neutrinos from different processes have been measured by many experiments (especially Borexino played greatly).



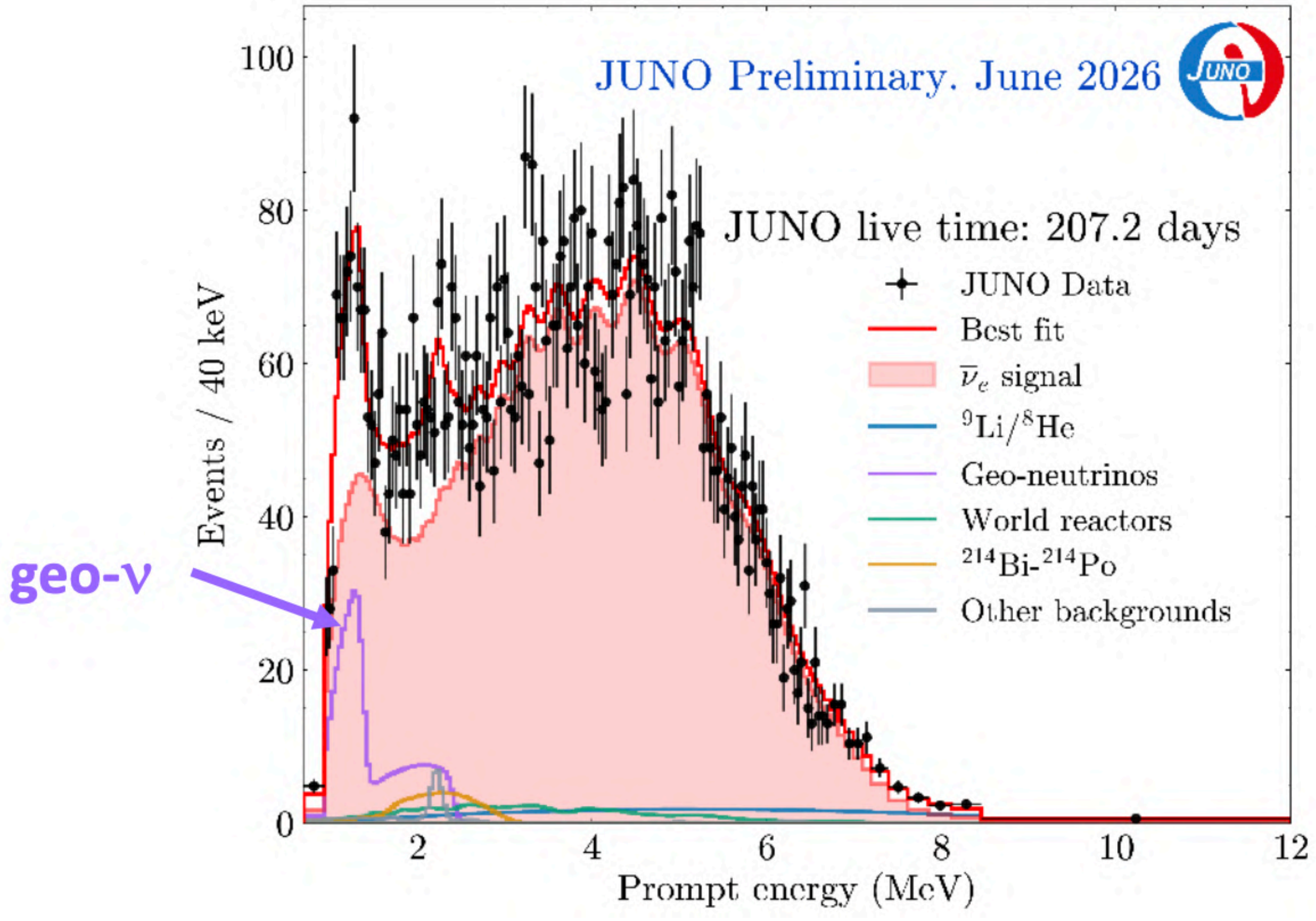


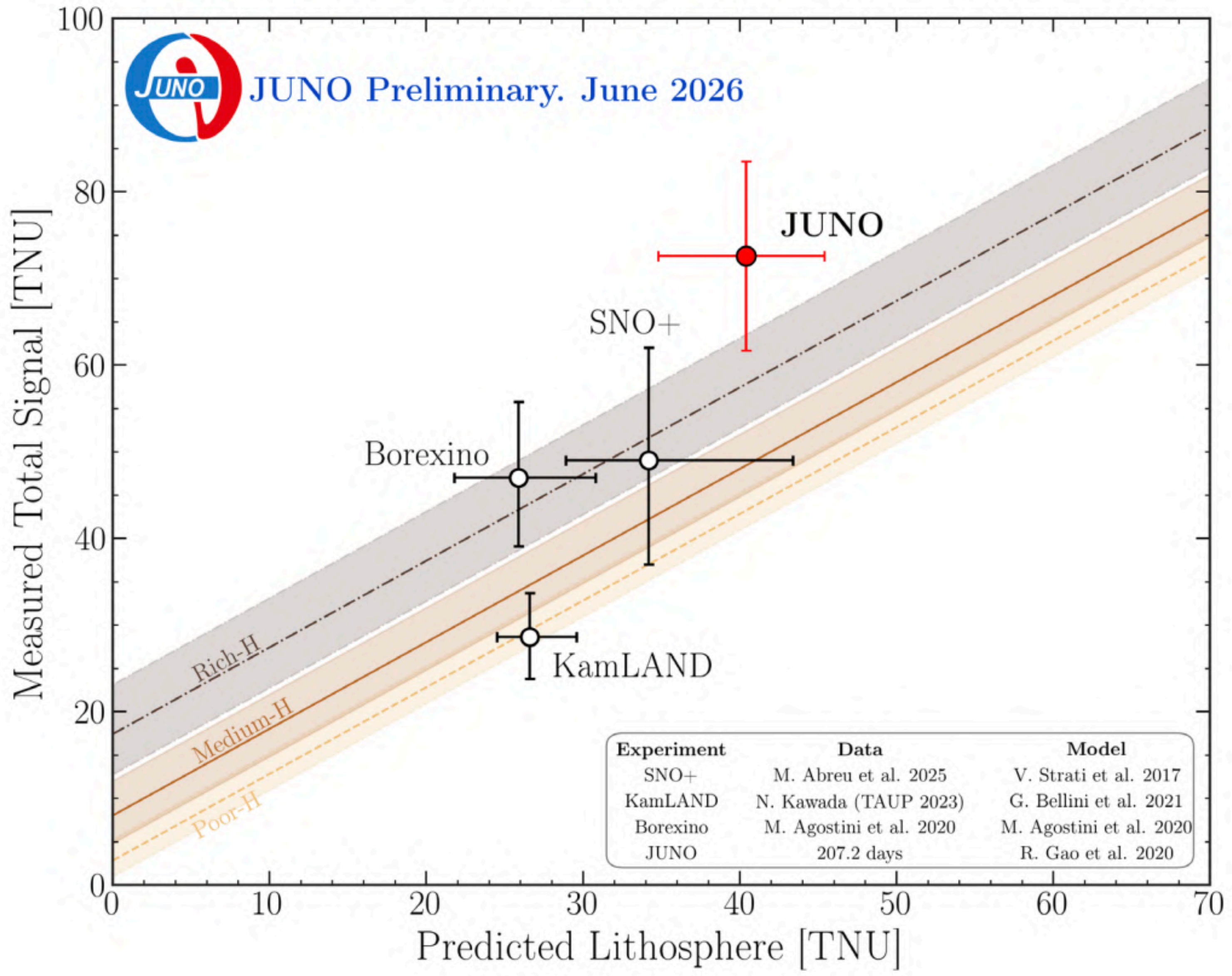


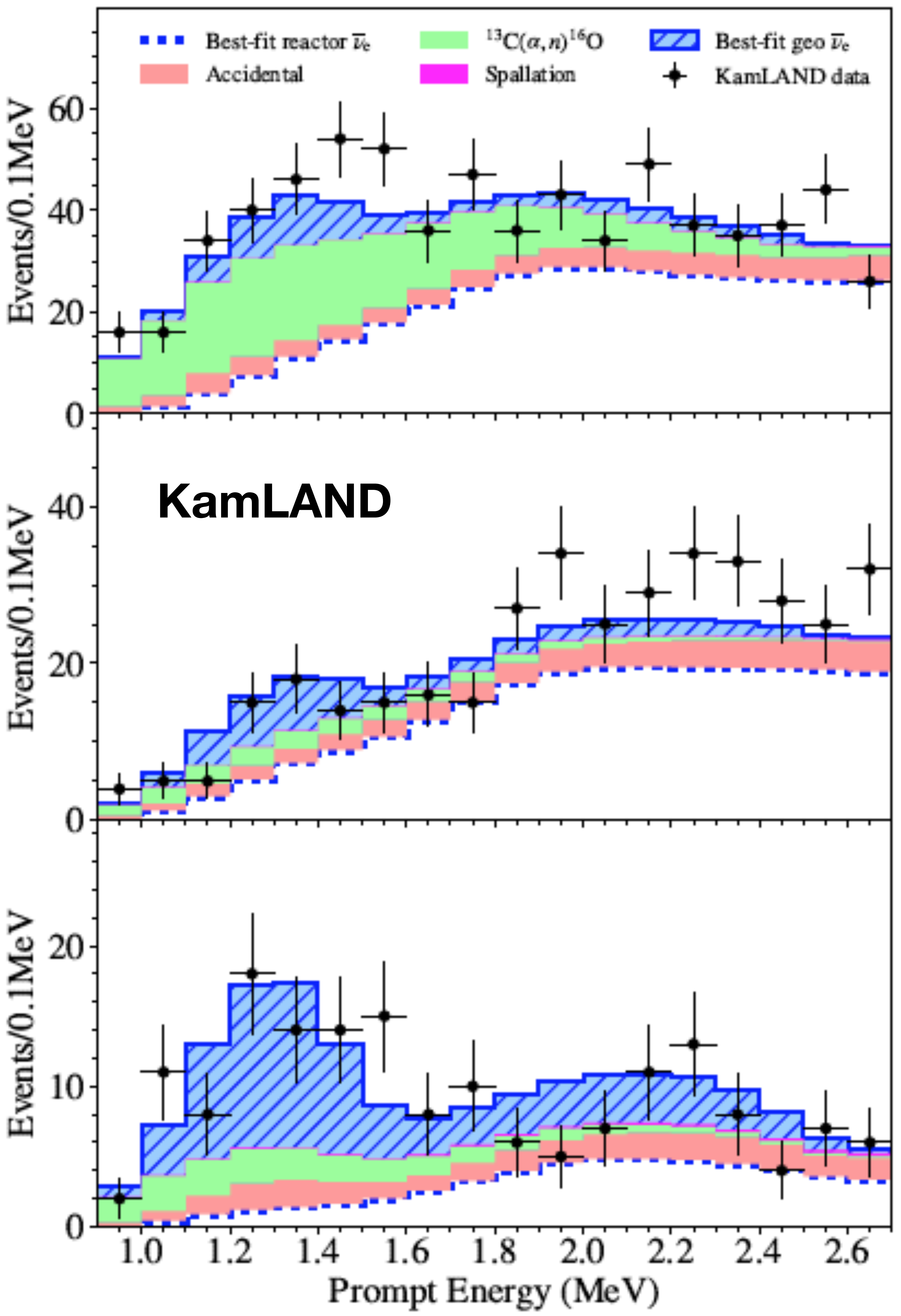
Neutrinos from the Earth

https://www.awa.tohoku.ac.jp/KamLAND/geonu2022/data-release.html

- Neutrinos are emitted from inside of the Earth through the decay of naturally occurring radionuclides, such as Uranium and Thorium.
- First observed by KamLAND, and followed by other experiments.
    - JUNO with 207 days already showed a very clear signal.



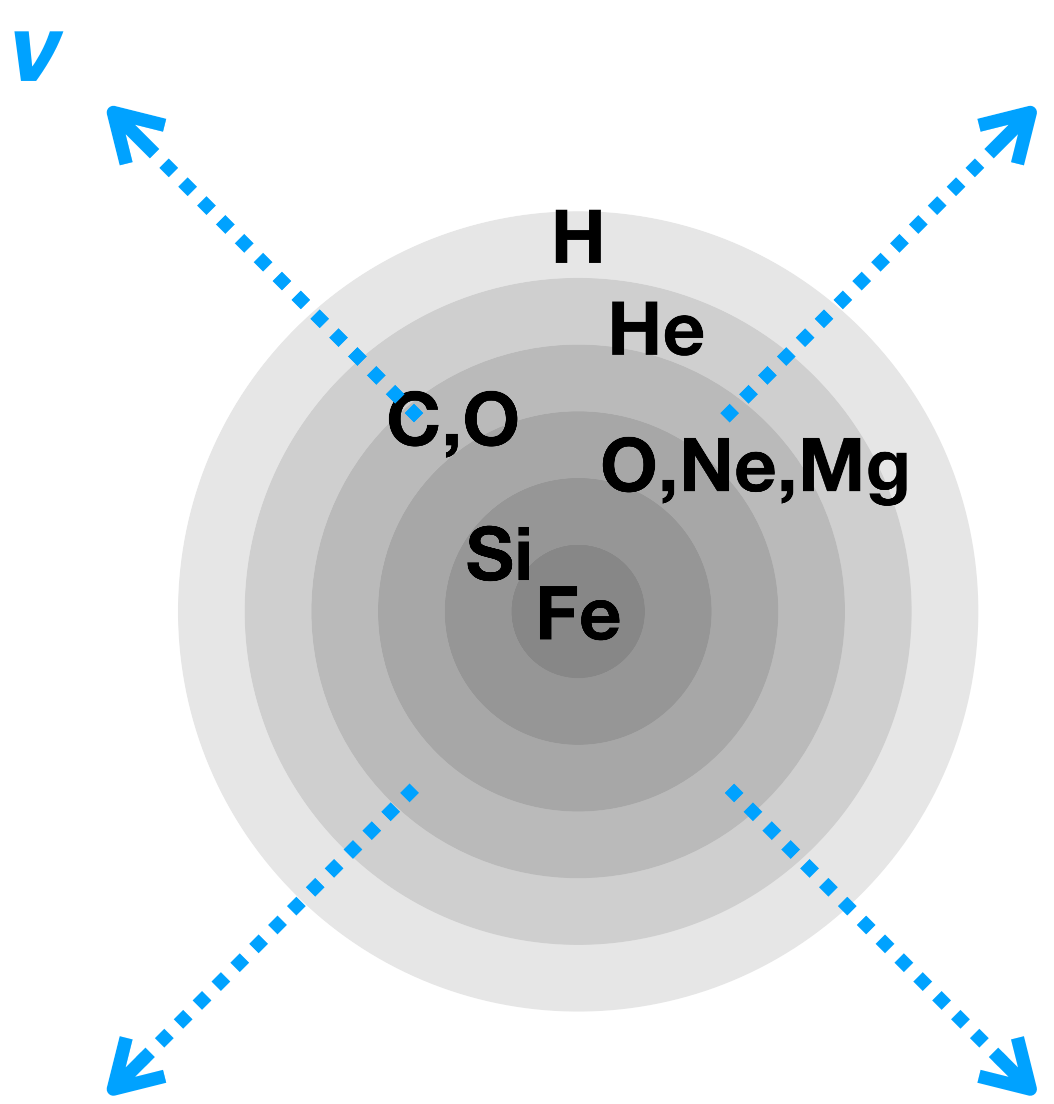




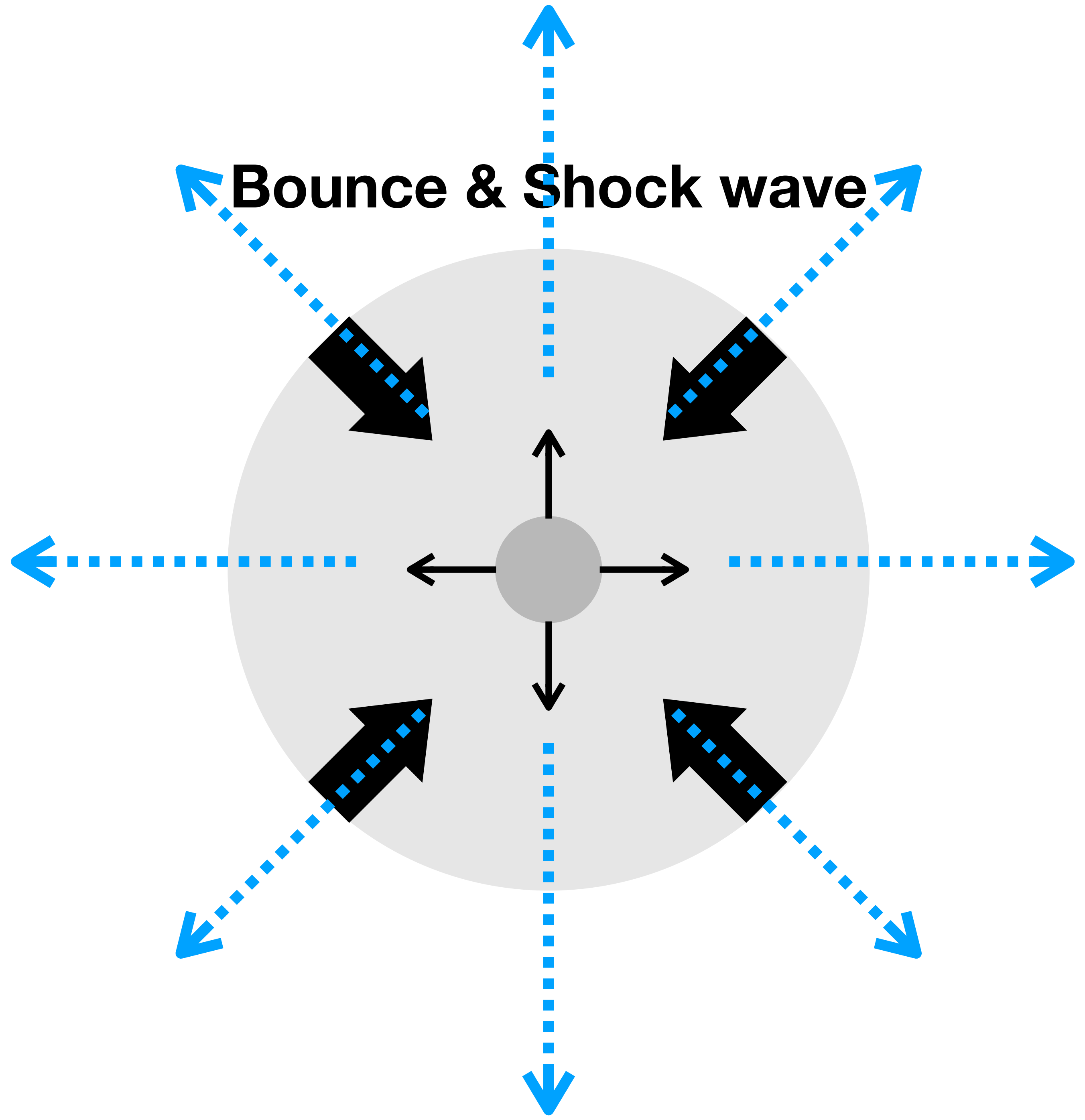
https://indico.global/event/15740/contributions/155563/attachments/72452/141000/JUNO-Neutrino2026-Vfinal.pdf

Neutrinos from Collapsing Stars

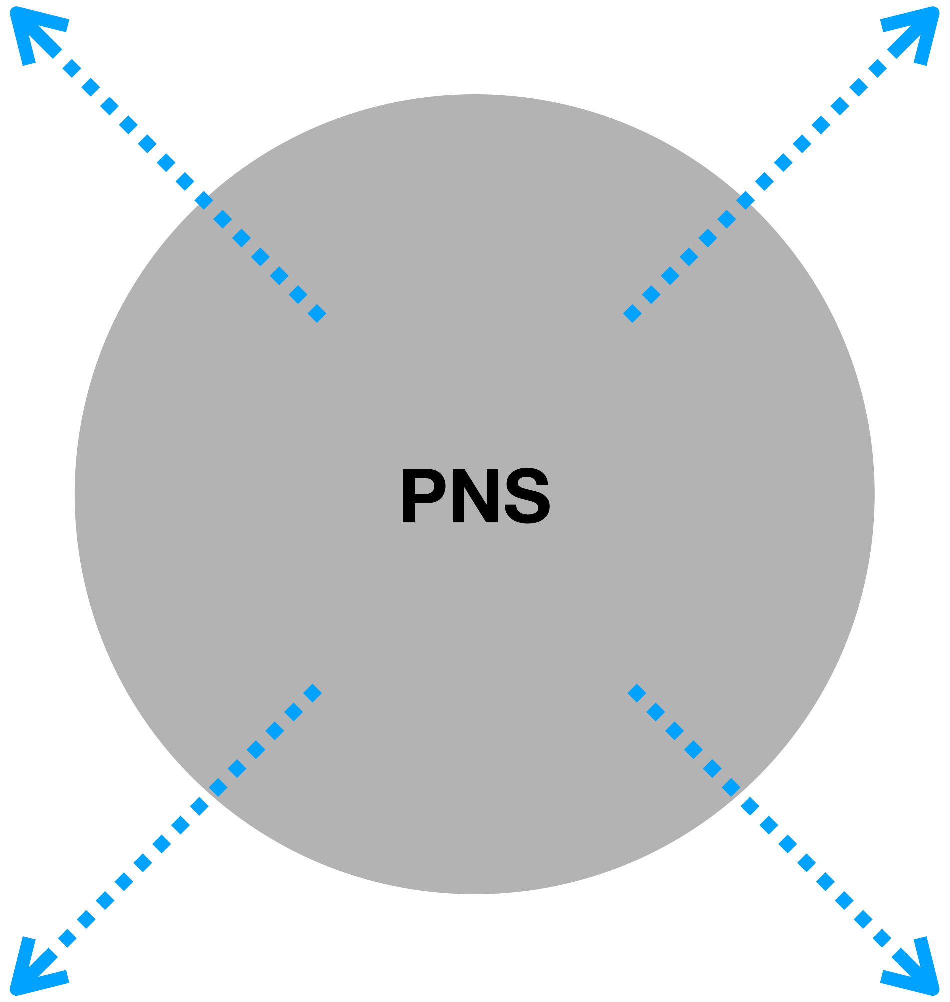
Neutrino emission from proto-neutron star cooling

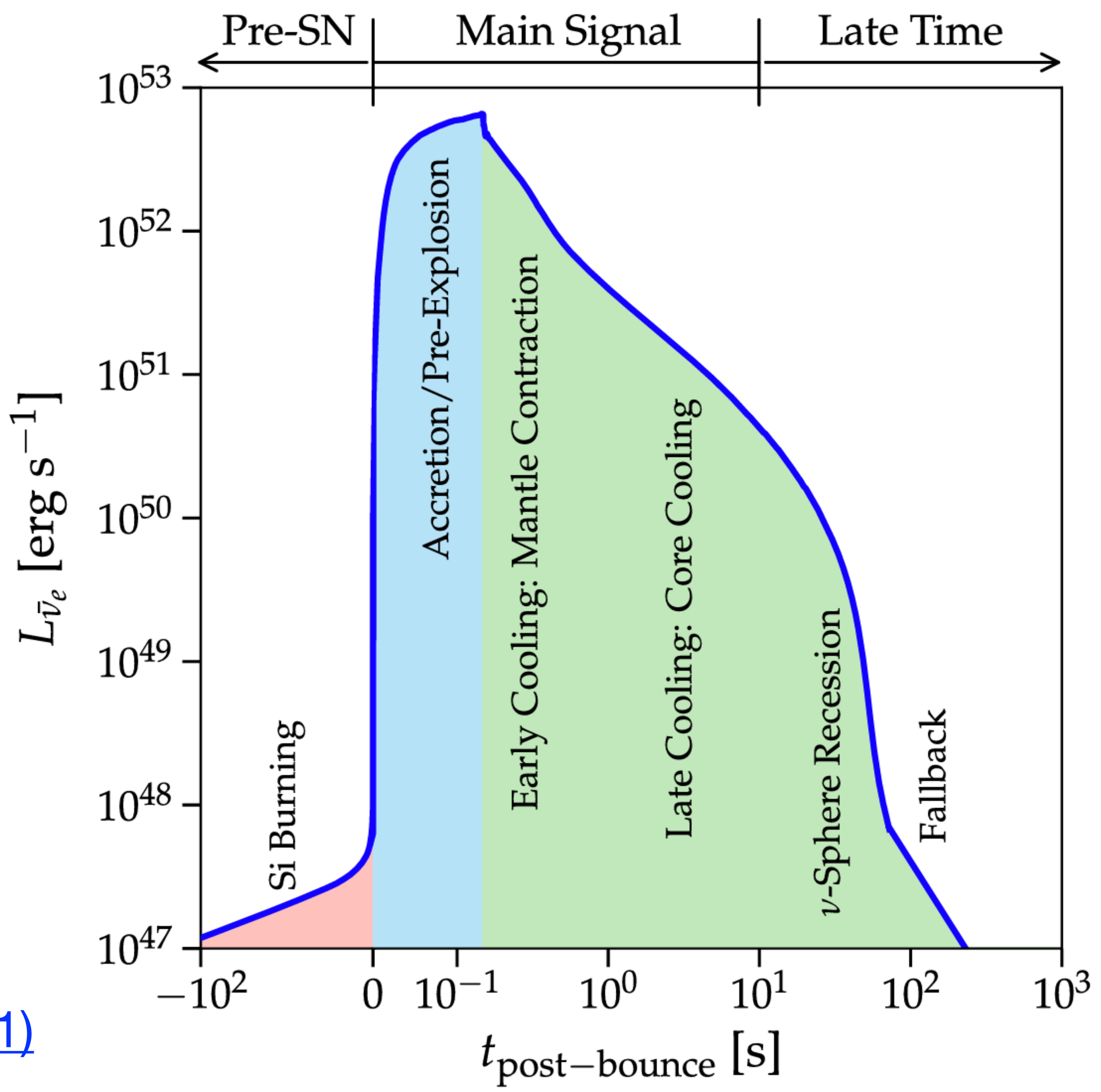


Efficient neutrino emission after carbon core (= pre-supernova neutrinos)



Neutrino emission along shock transition

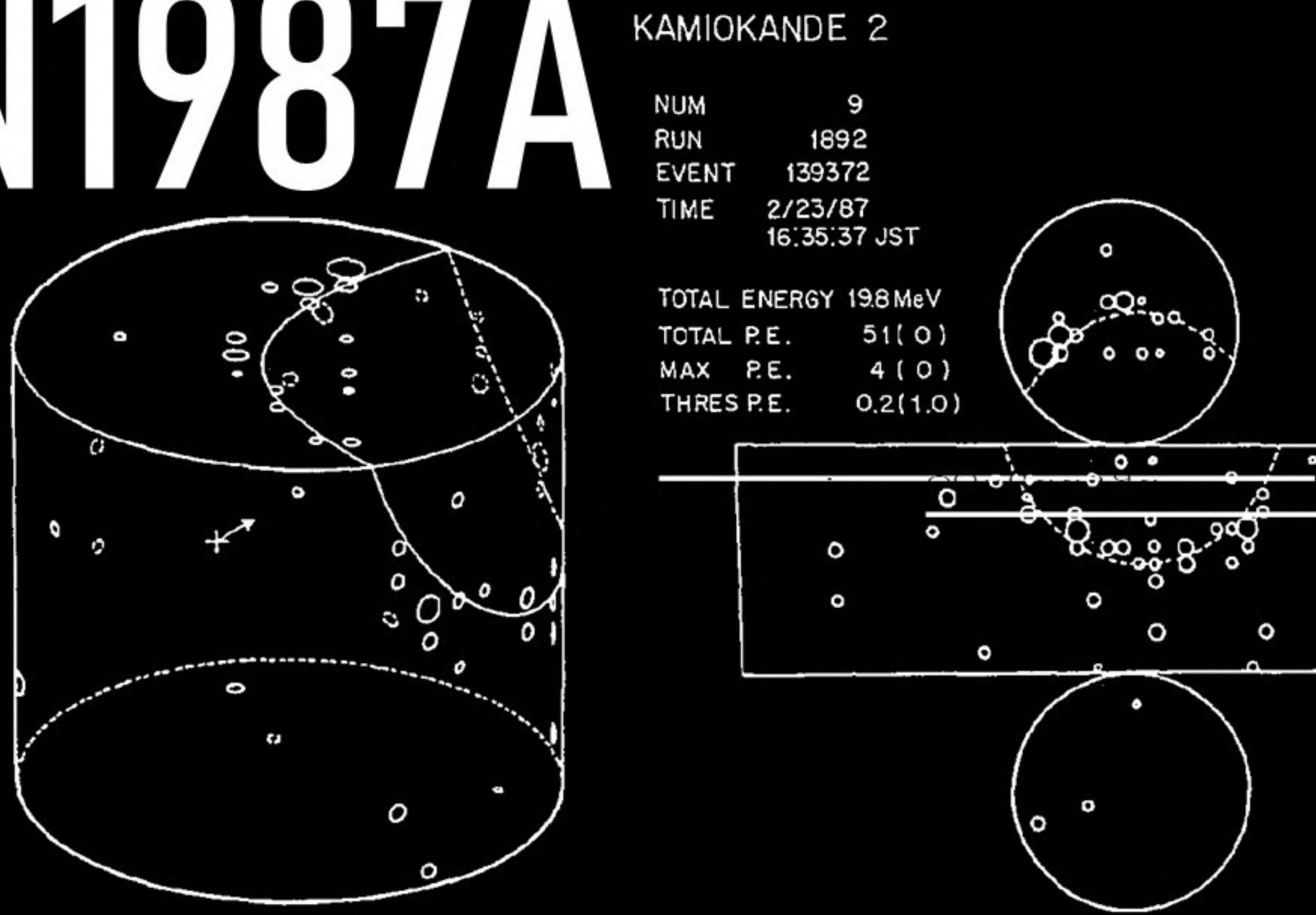


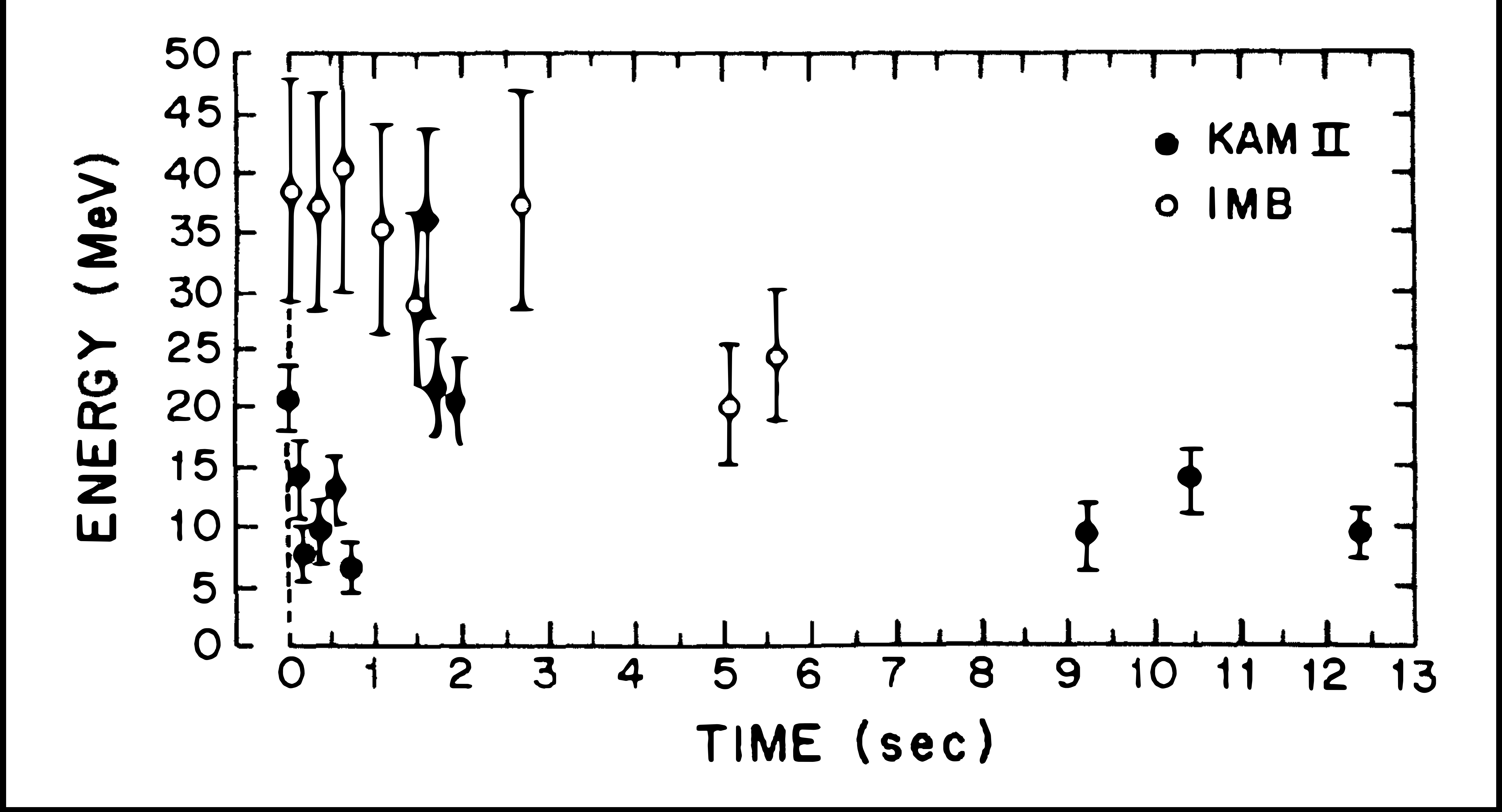


~99% of energy released as "neutrinos"

S. W. Li, L. F. Roberts, and J. F. Beacom, PRD 103, 023016 (2021)

SN1987A

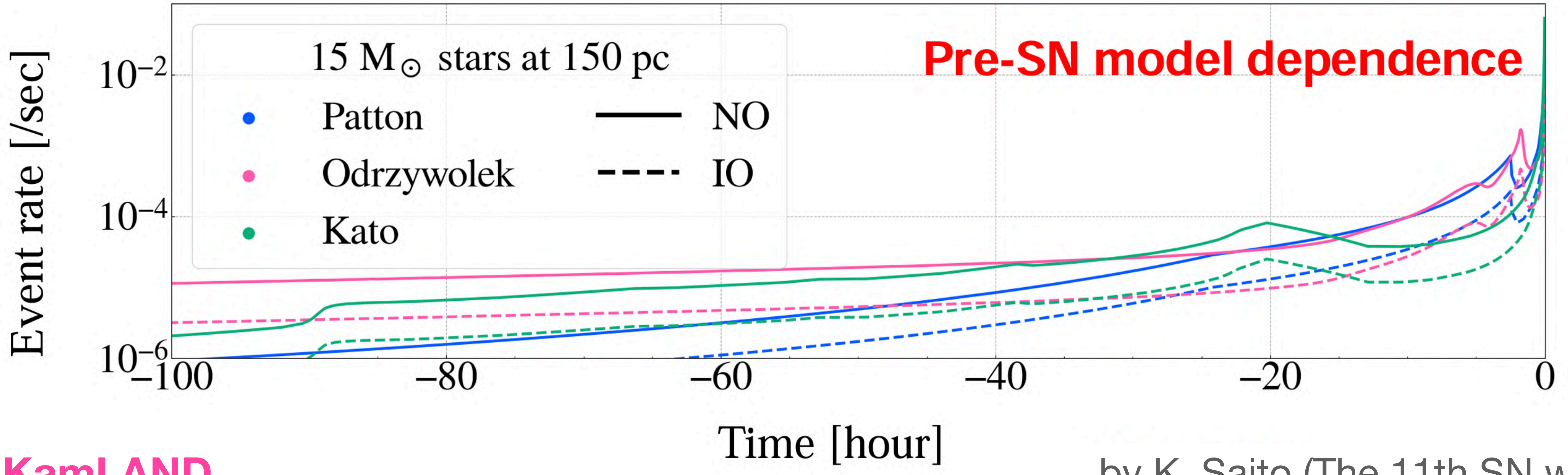


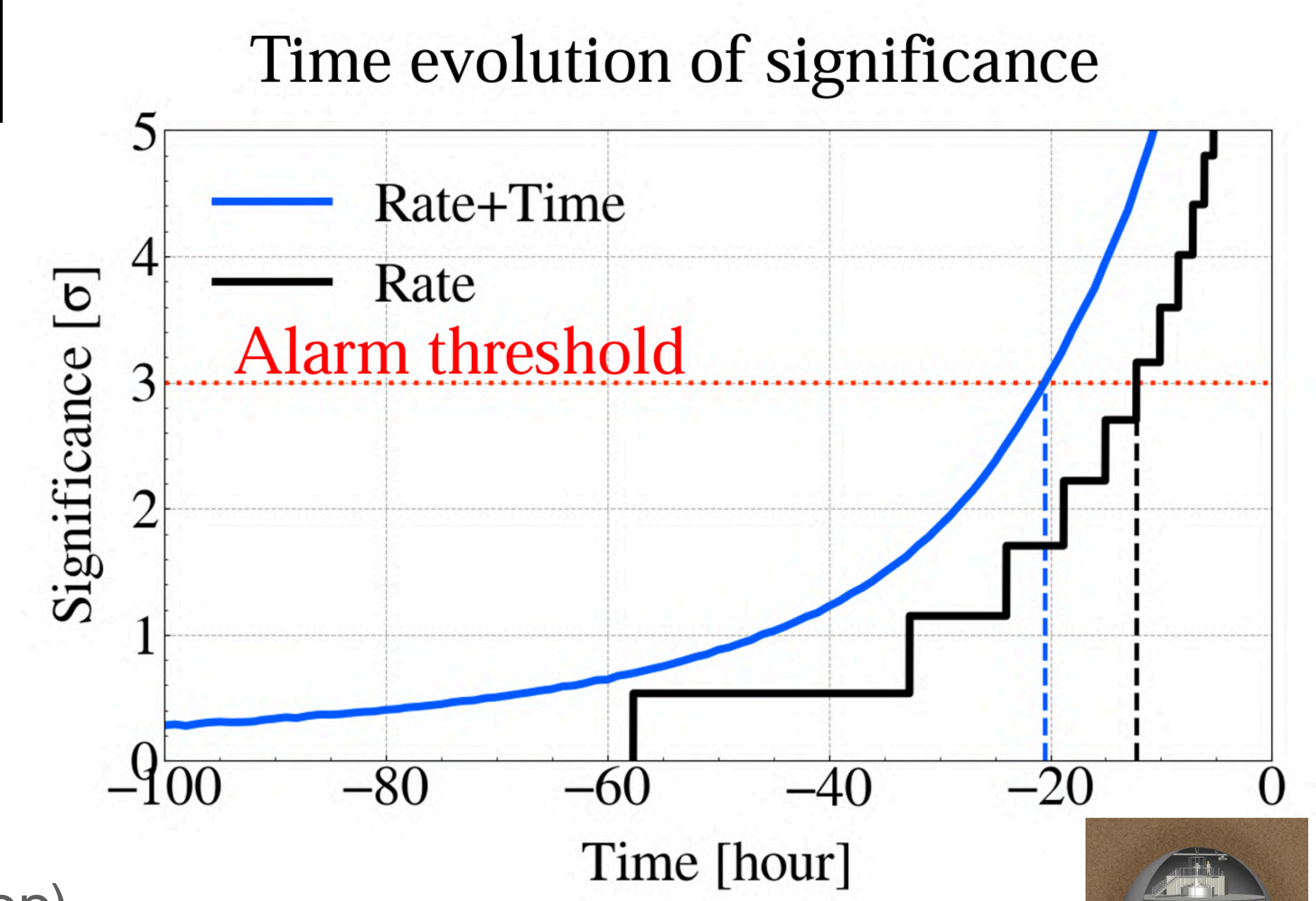


Only one case so far, the *historic* SN 1987A

We are waiting for the next one!

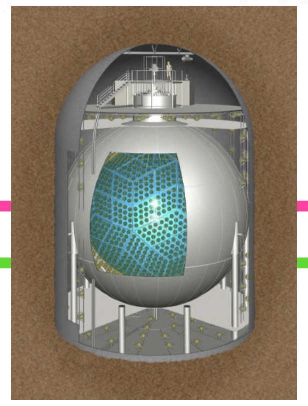
Alerting Pre and Burst SN Neutrinos

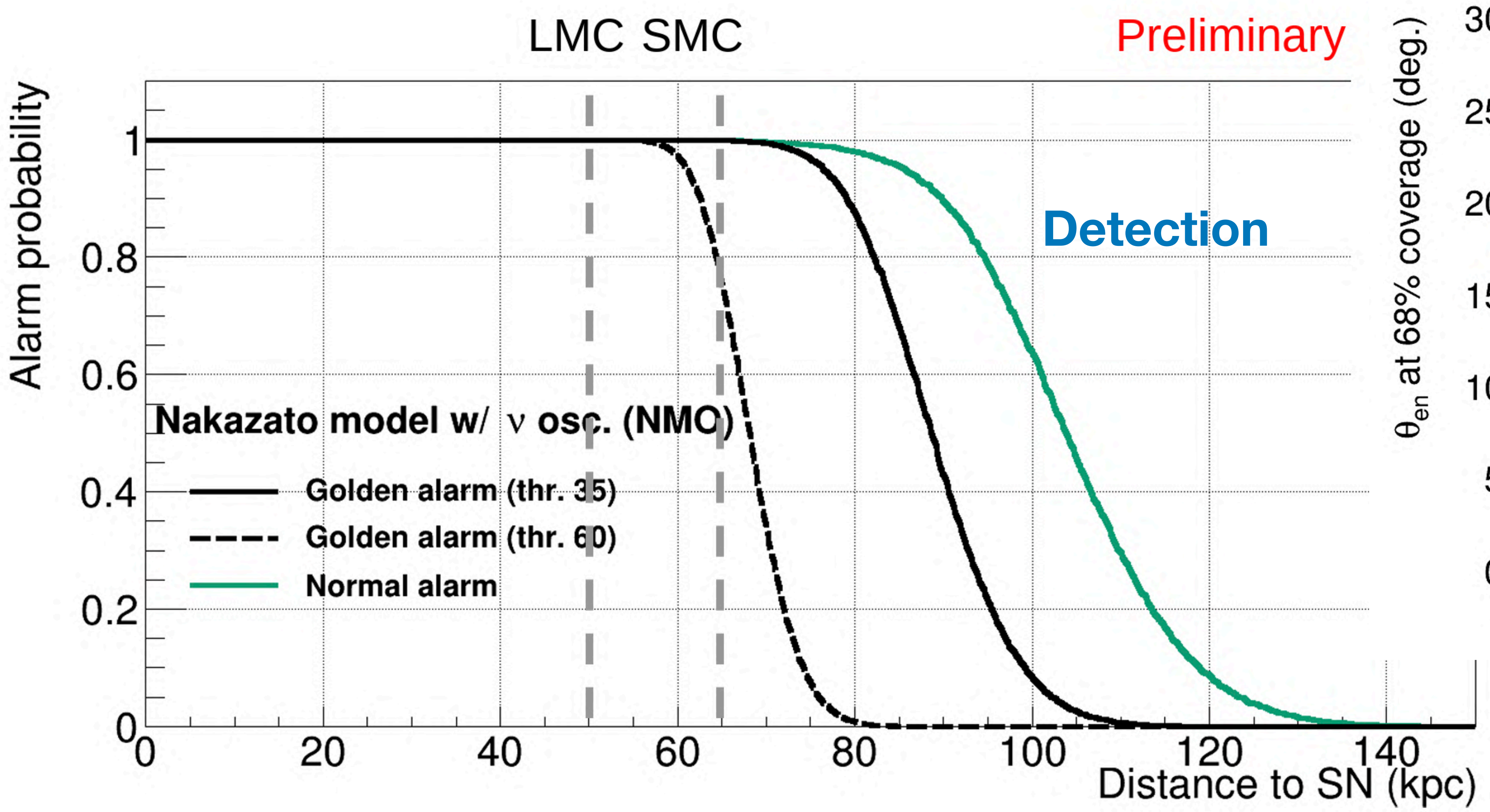


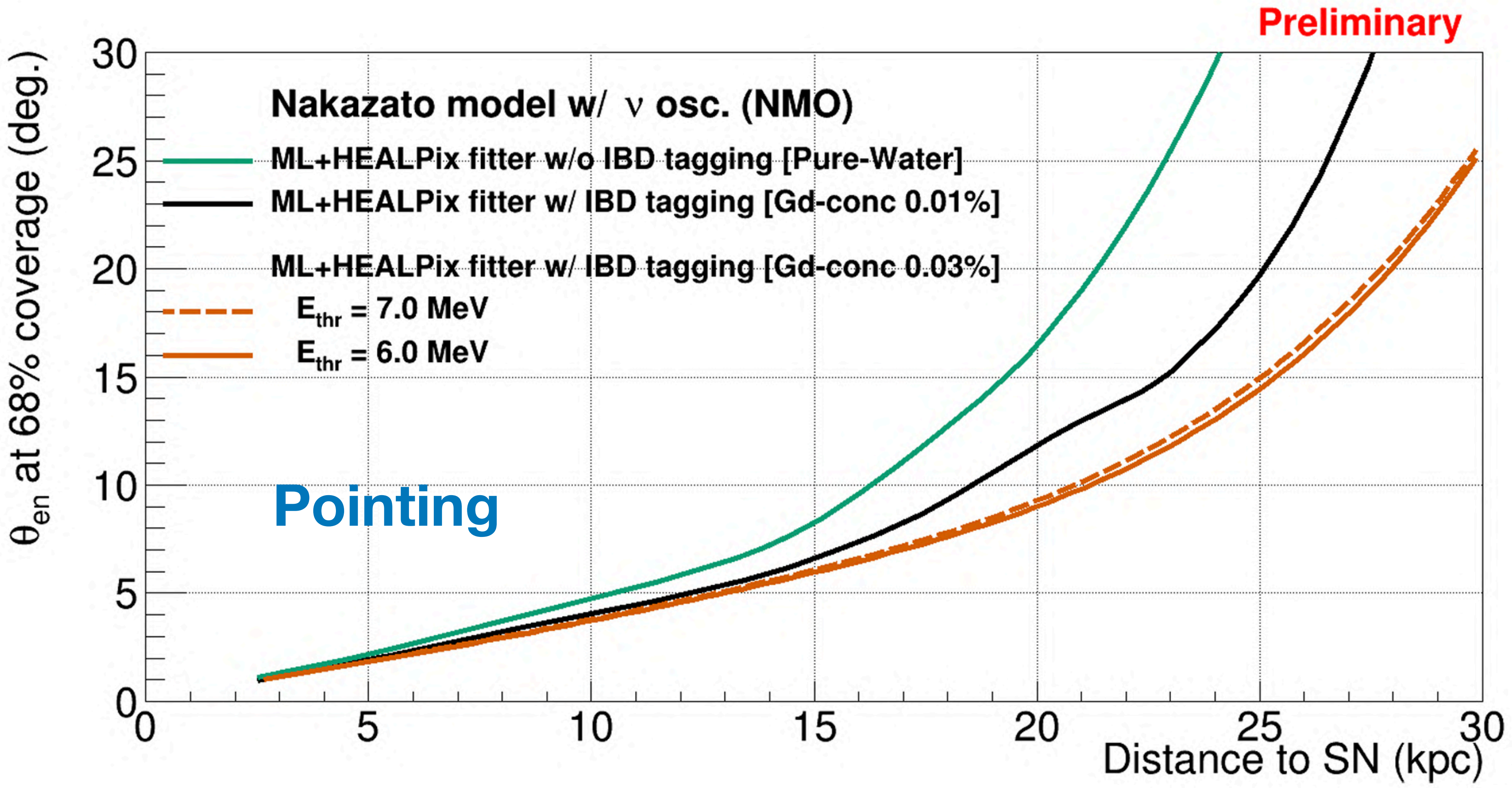


KamLAND

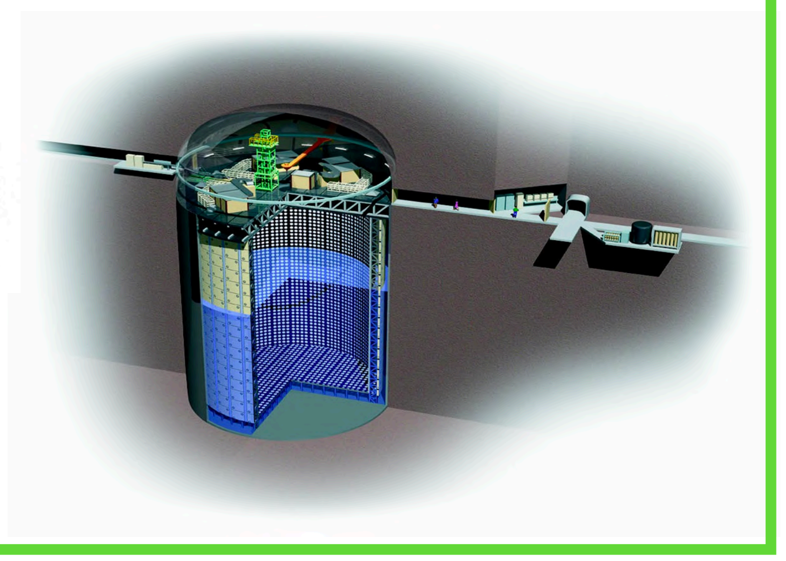
by K. Saito (The 11th SN workshop)







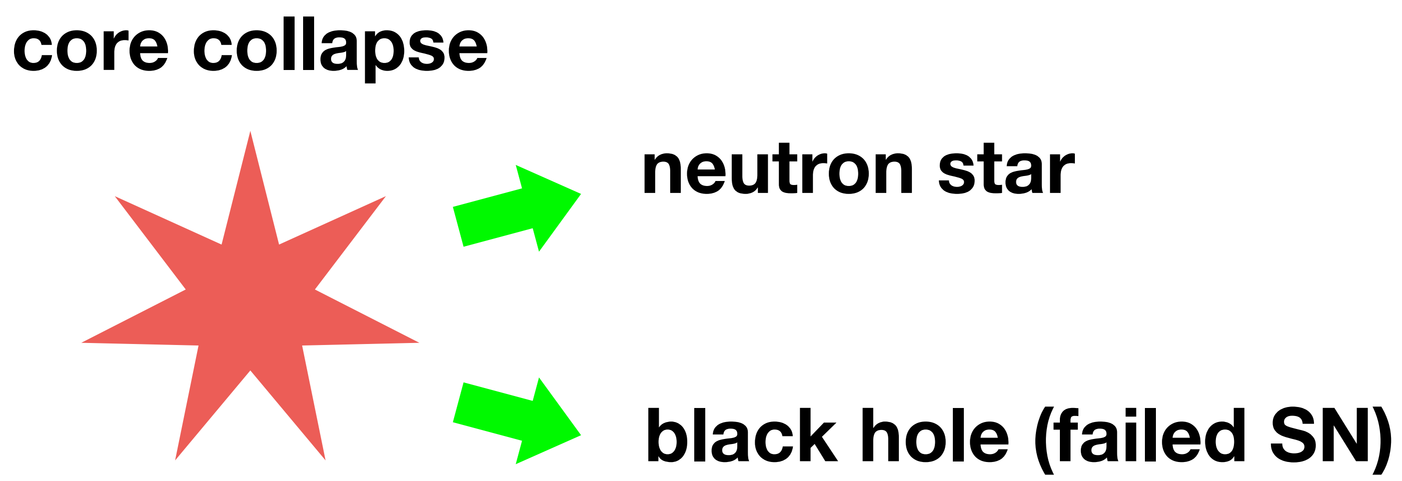
Super-K

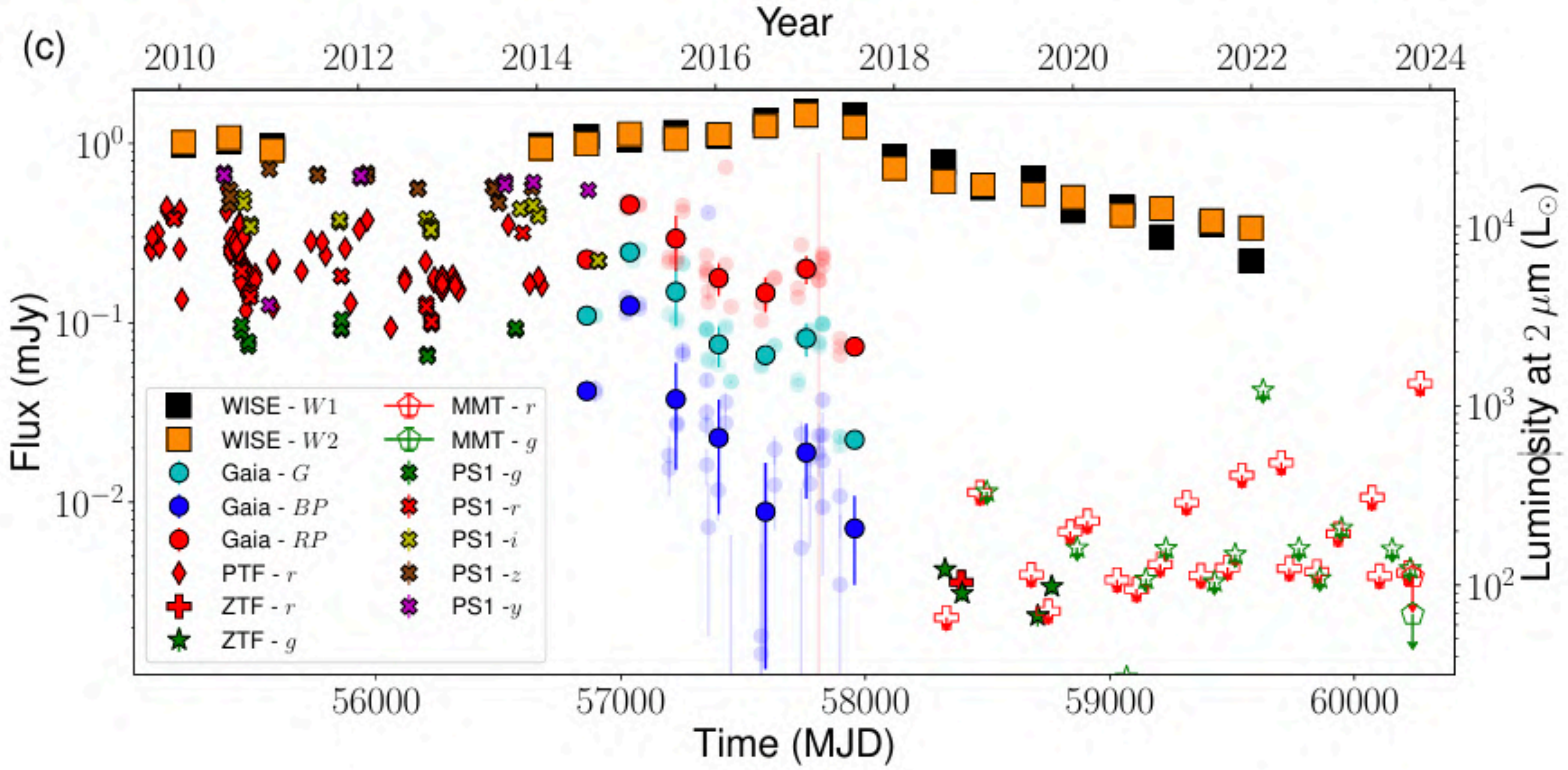


by G. Pronost (The 11th SN workshop)

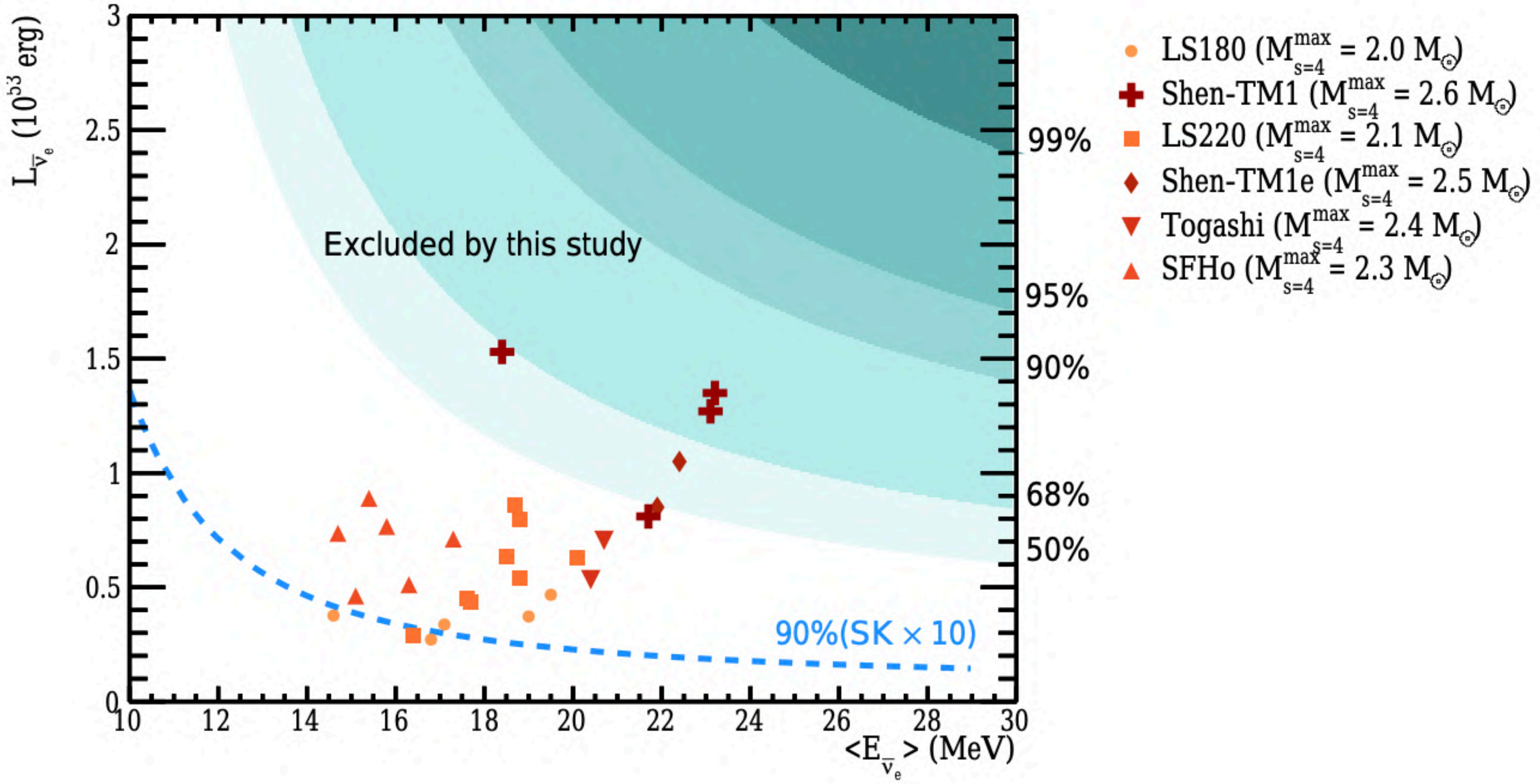
Knowledge from Non-detection of “Failed” Explosion

- Observation of **a failed SN in Andromeda, M31 (~780 kpc)** was reported.
- Super-K data in the corresponding period didn’t find any cluster events.
- Numerical models on failed SNe are constrained from this *non*-detection.





K. De et al., Science Vol 391, Issue 6786 (2026)



Y. Suwa et al., The Open Journal of Astrophysics, Volume 8 (2025)

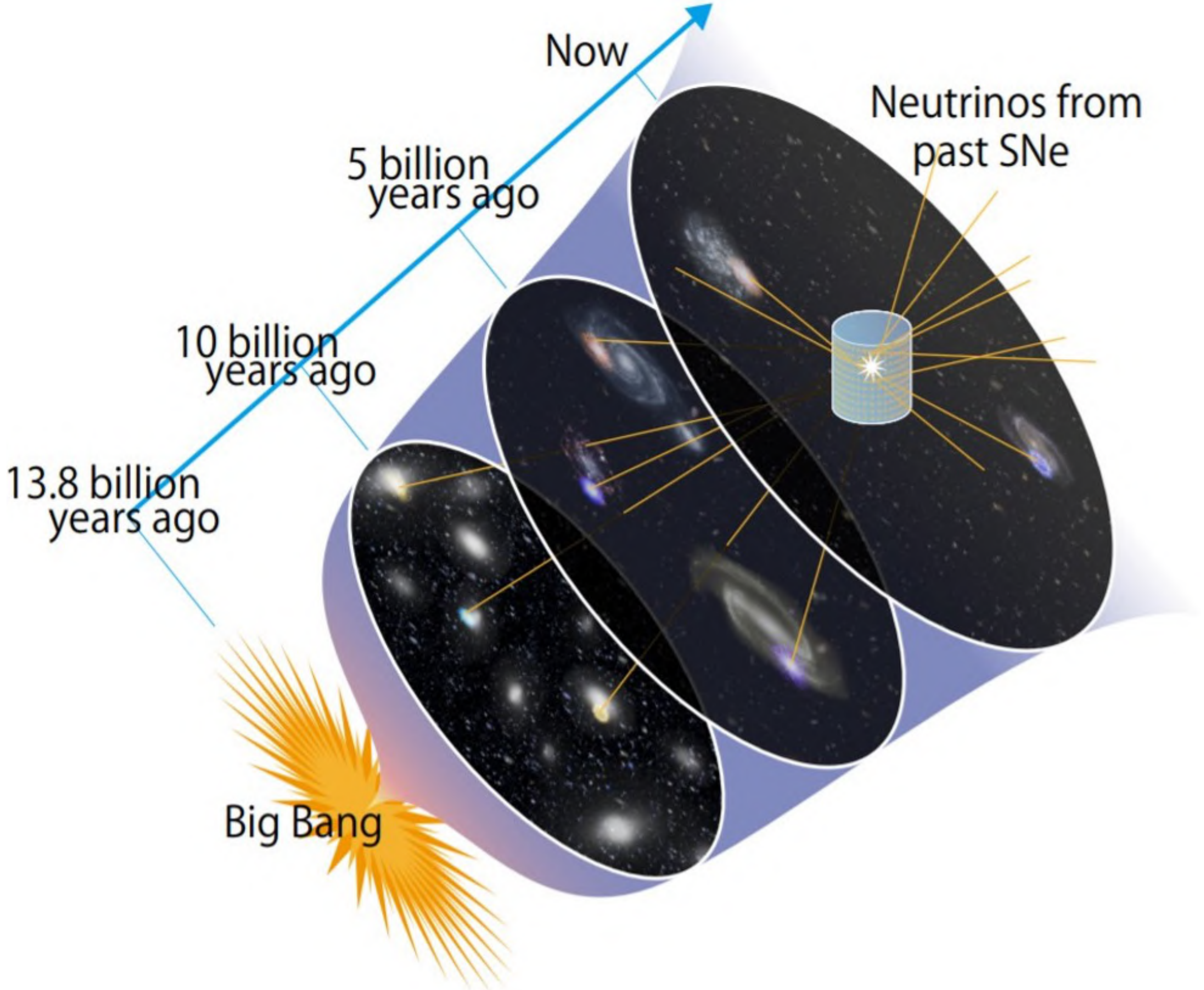
F. Nakanishi et al. (Super-Kamiokande Collaboration), ApJL 997, L9 (2026)

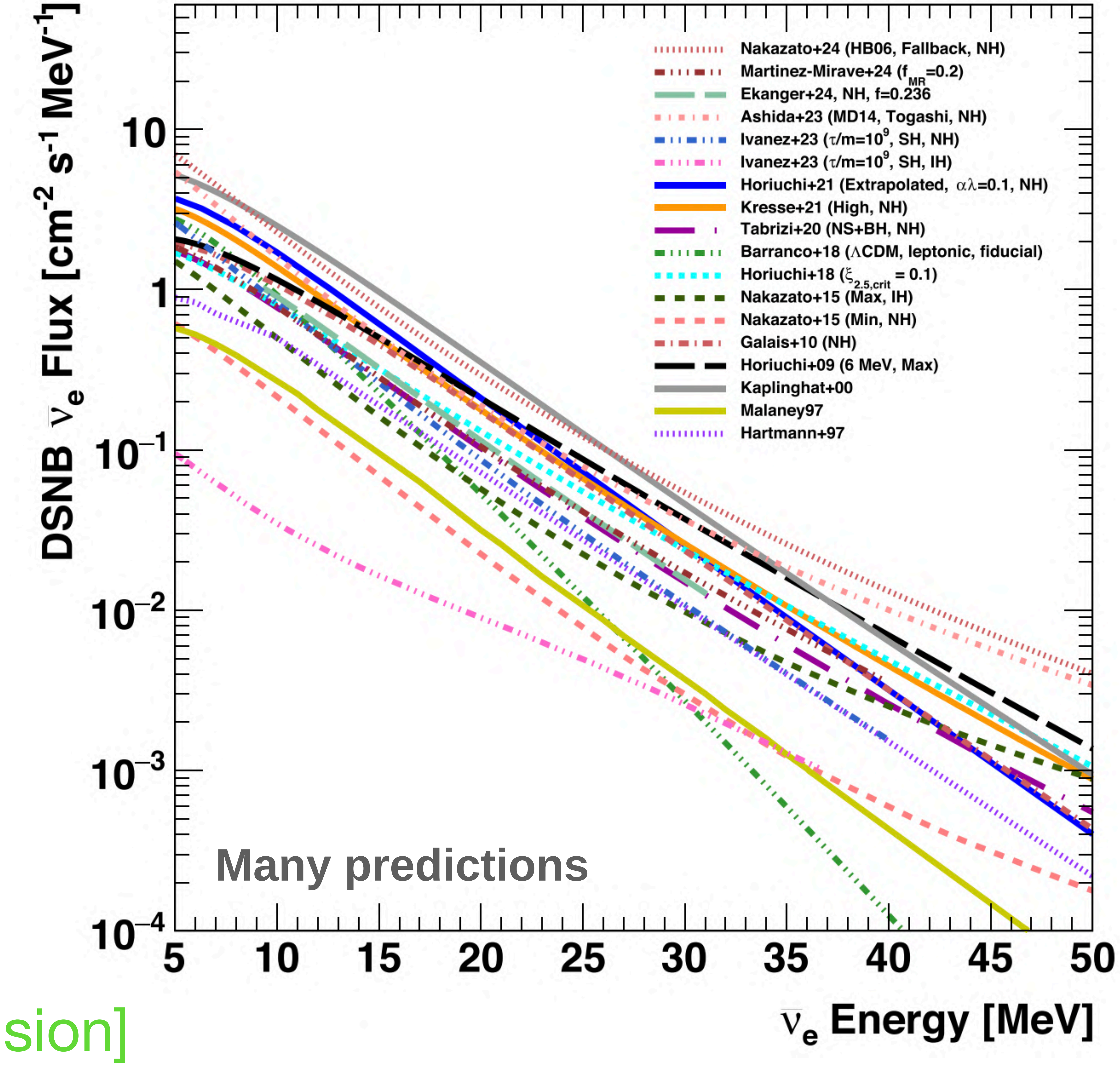
Diffuse Flux of SN Neutrinos

Y. Ashida, K. Nakazato, ApJ 937, 1 (2022)
Y. Ashida, K. Nakazato, T. Tsujimoto, ApJ 953, 2 (2023)
K. Nakazato, R. Akaho, Y. Ashida, T. Tsujimoto, ApJ 975, 1 (2024)

The accumulated flux of neutrinos released from stellar core collapse over the cosmic history

= **Diffuse Supernova Neutrino Background; DSNB**

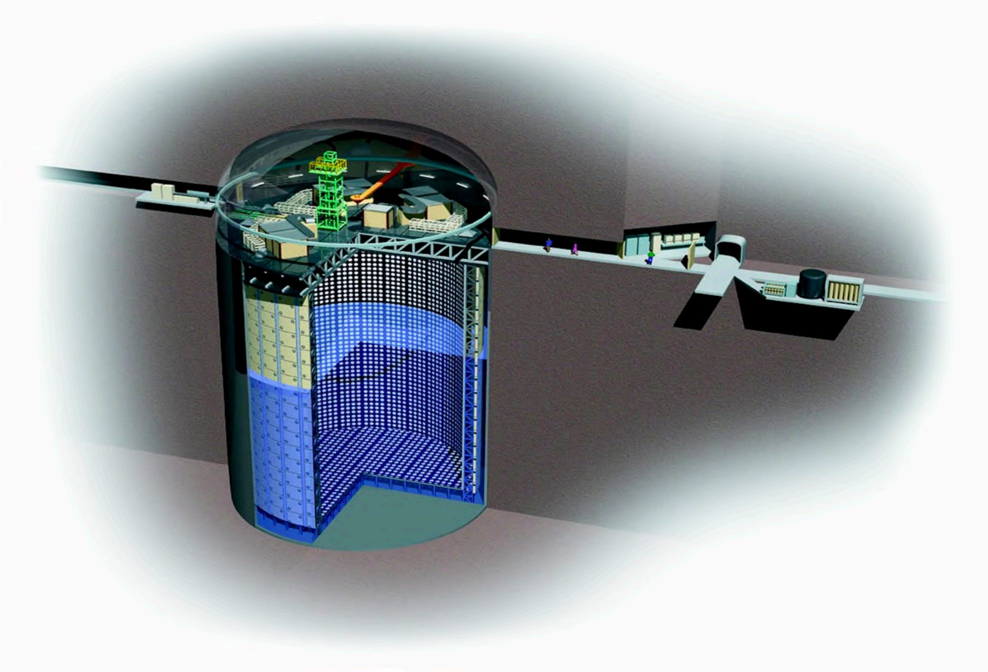


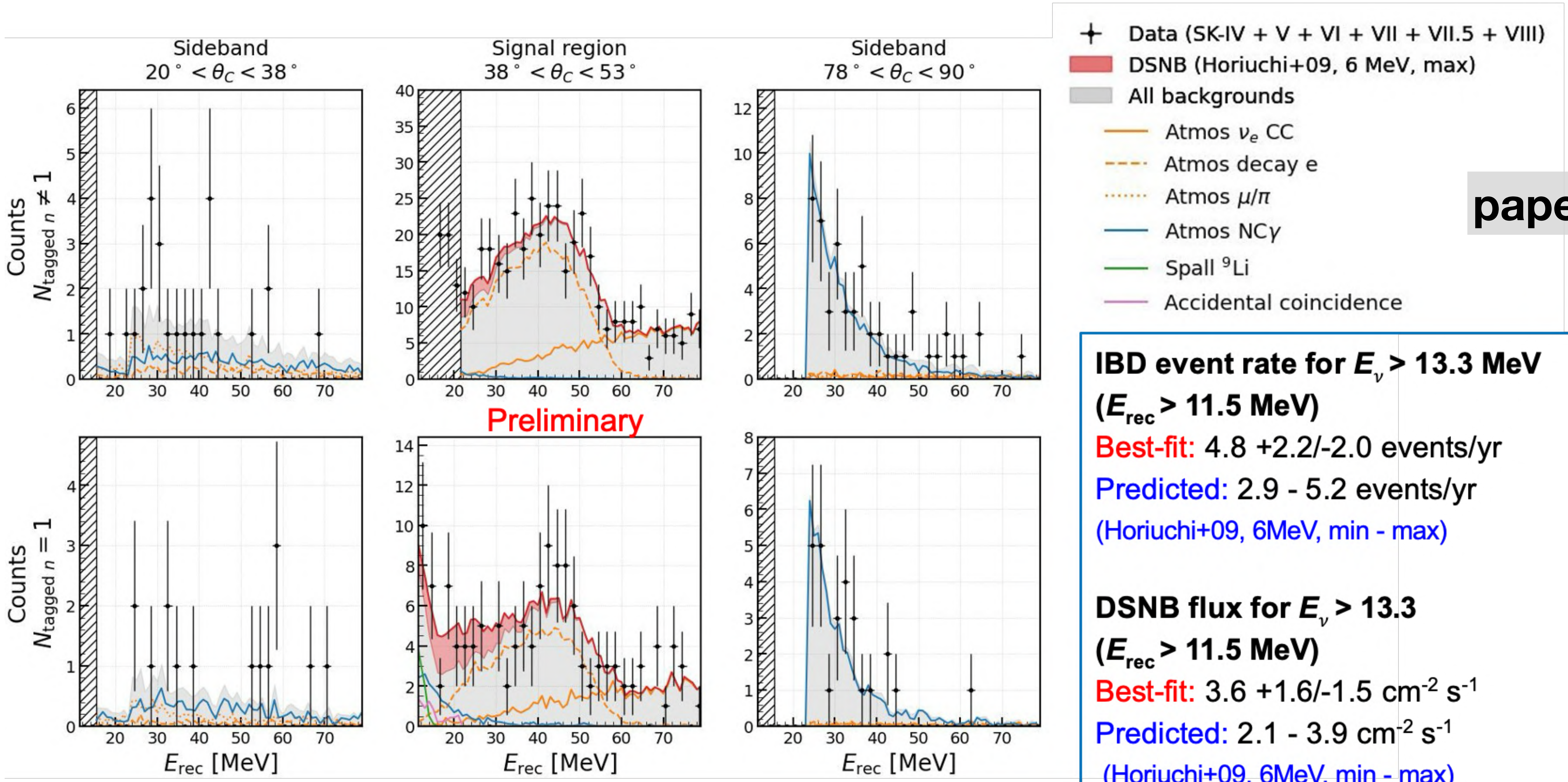


$\Phi = \int$ [ν emission] $\otimes$ [Star formation] $\otimes$ [Universe expansion]

Recent DSNB Search Result from Super-K

- A search based on 5003 days of Super-K data shows a **2.6σ** significance (**99.5% C.L.**).
  - **1.4σ** (pure water phase only)
  - **2.2σ** (Gd water phase only)
- **This is the first *indication* of the DSNB electron antineutrino signature!**



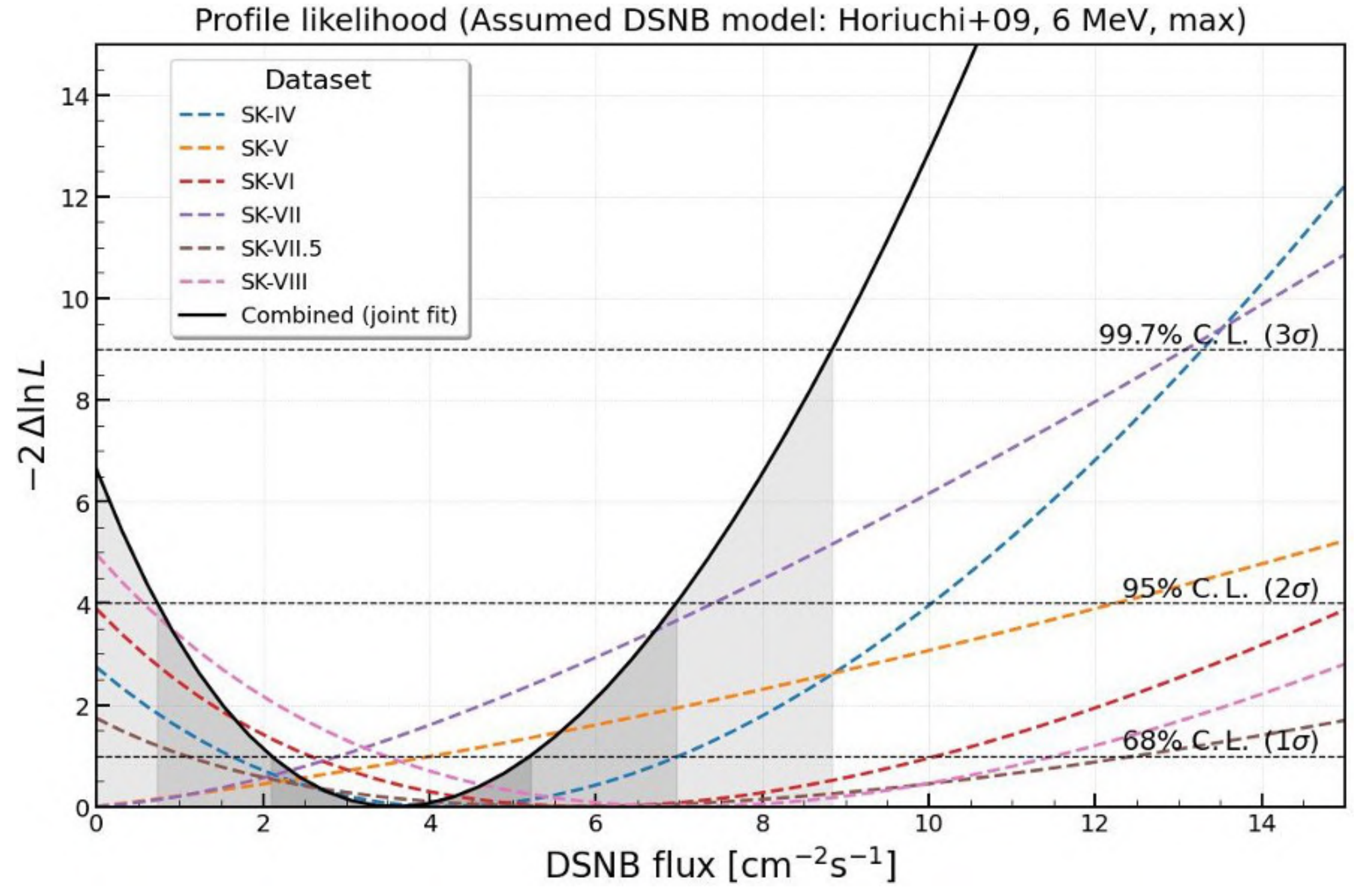


paper in prep

2.6σ

IBD event rate for E_ν > 13.3 MeV
(E_{rec} > 11.5 MeV)
Best-fit: 4.8 +2.2/-2.0 events/yr
Predicted: 2.9 - 5.2 events/yr
(Horiuchi+09, 6MeV, min - max)

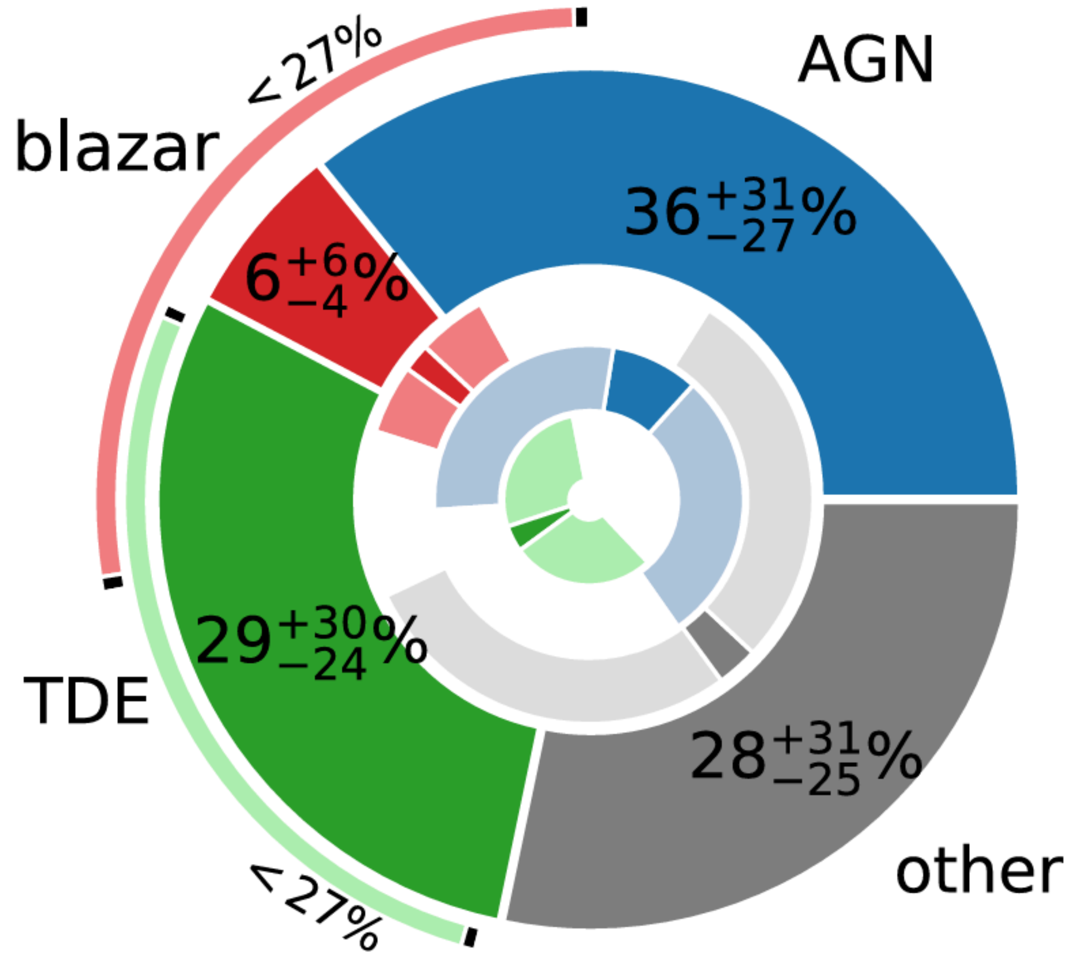
DSNB flux for E_ν > 13.3
(E_{rec} > 11.5 MeV)
Best-fit: 3.6 +1.6/-1.5 cm^{-2} s^{-1}
Predicted: 2.1 - 3.9 cm^{-2} s^{-1}
(Horiuchi+09, 6MeV, min - max)



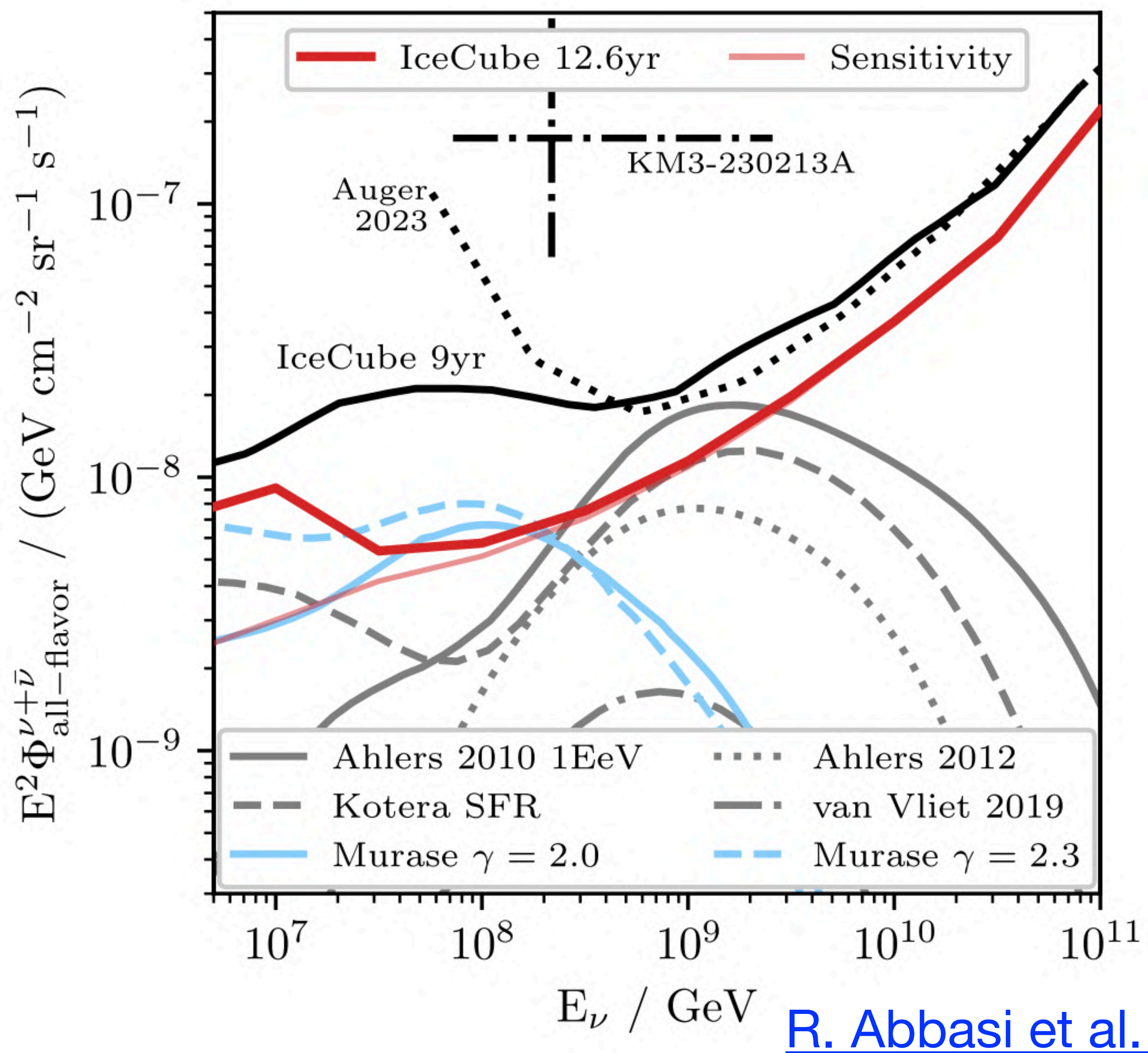
High-Energy Astrophysical Neutrinos

- IceCube had confirmed and is now precisely measuring the extragalactic astrophysical neutrino flux; also confirmed significant high-energy neutrino emissions from the galactic plane.
  - Followed by Baikal; KM3NeT started its operation (reported a **~220 PeV** neutrino).
- Remaining mysteries (but we may gradually approach the answer?)
  - Major contributor to the observed astrophysical flux
  - Reason for the observed broken power spectrum
  - Flux of cosmogenic (GZK) neutrinos

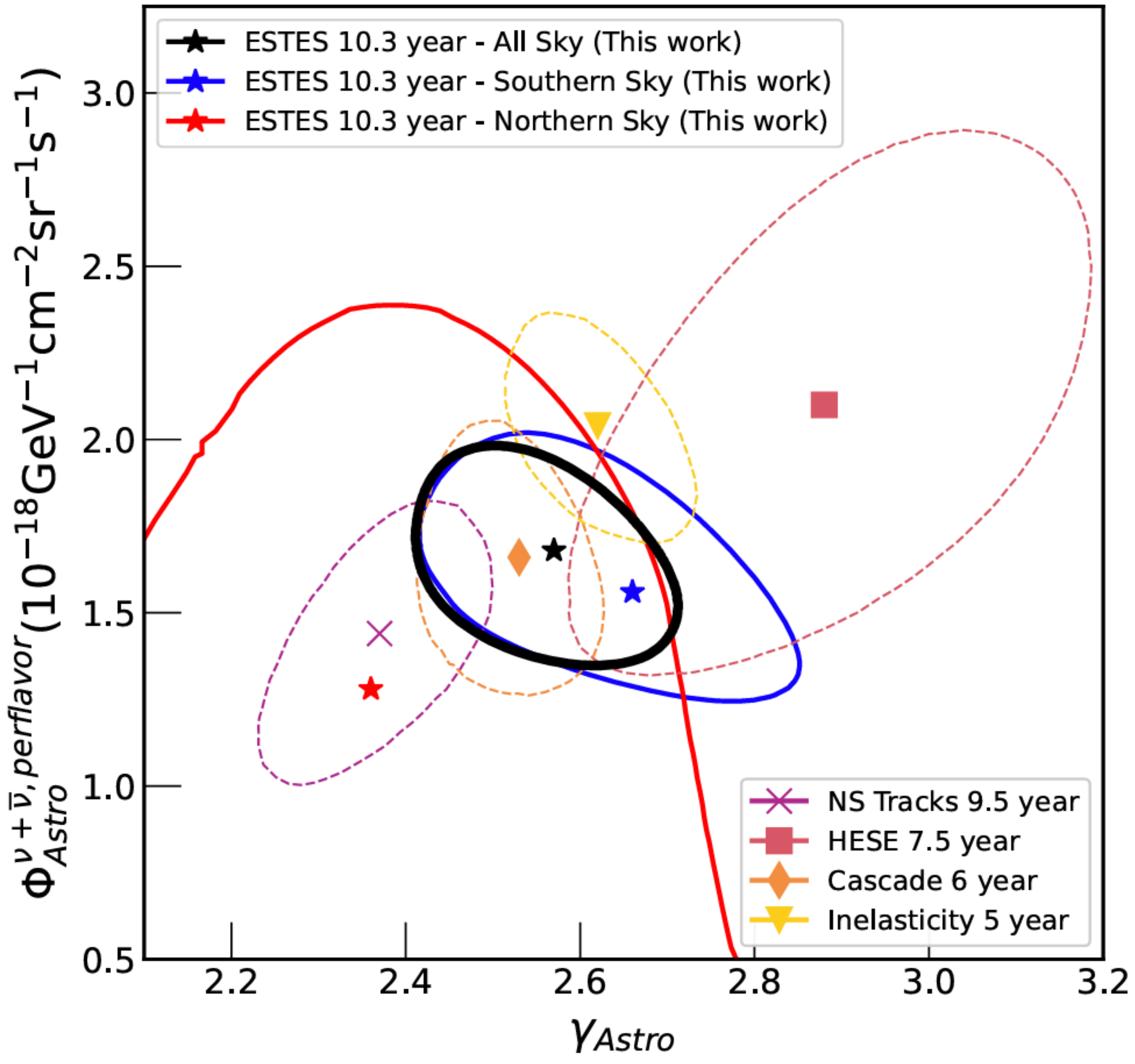
R. Abbasi et al. (IceCube Collaboration), PRD 110, 022001 (2024)



I. Bartos et al., ApJ 921, 45 (2021)



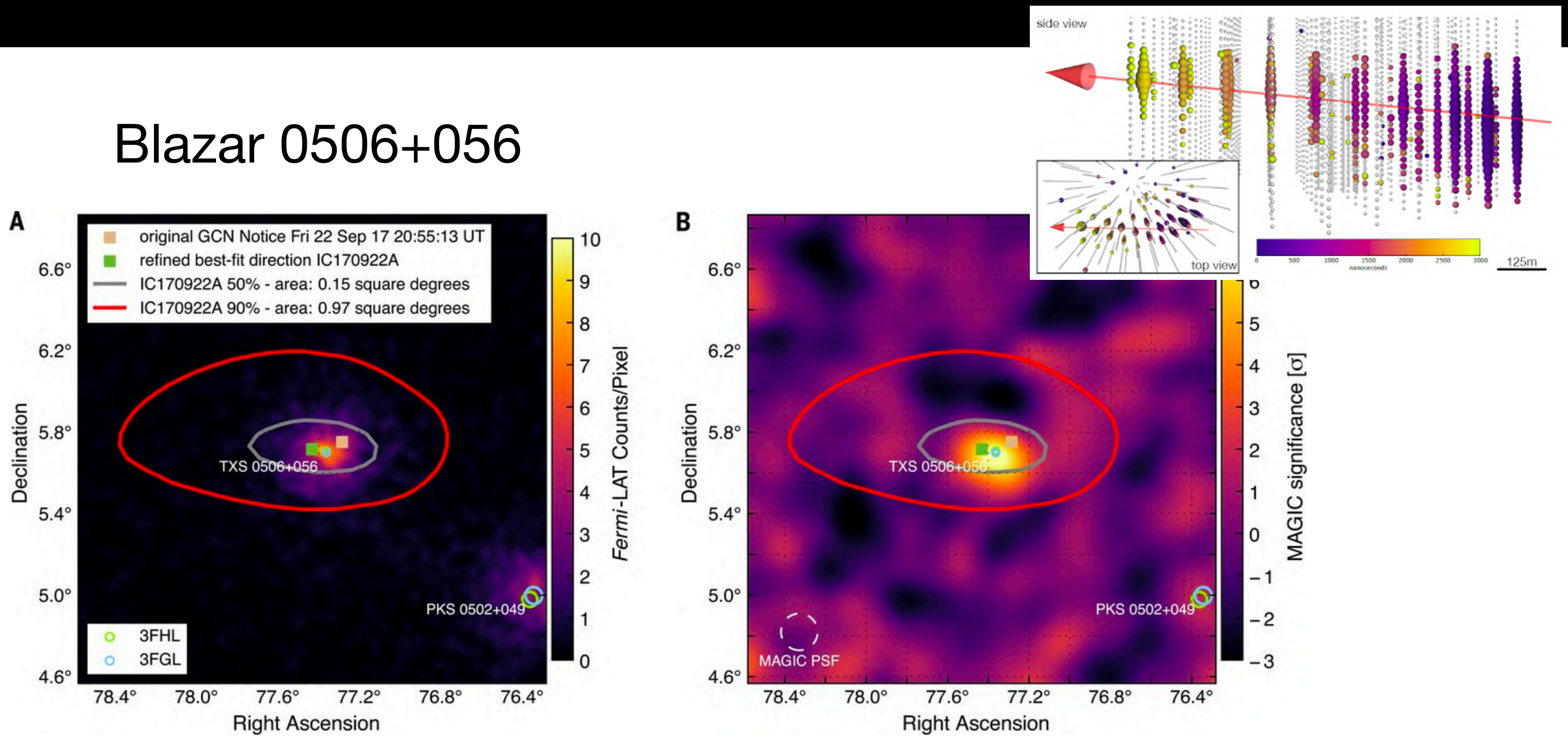
R. Abbasi et al. (IceCube Collaboration), PRL 135, 031001 (2025)

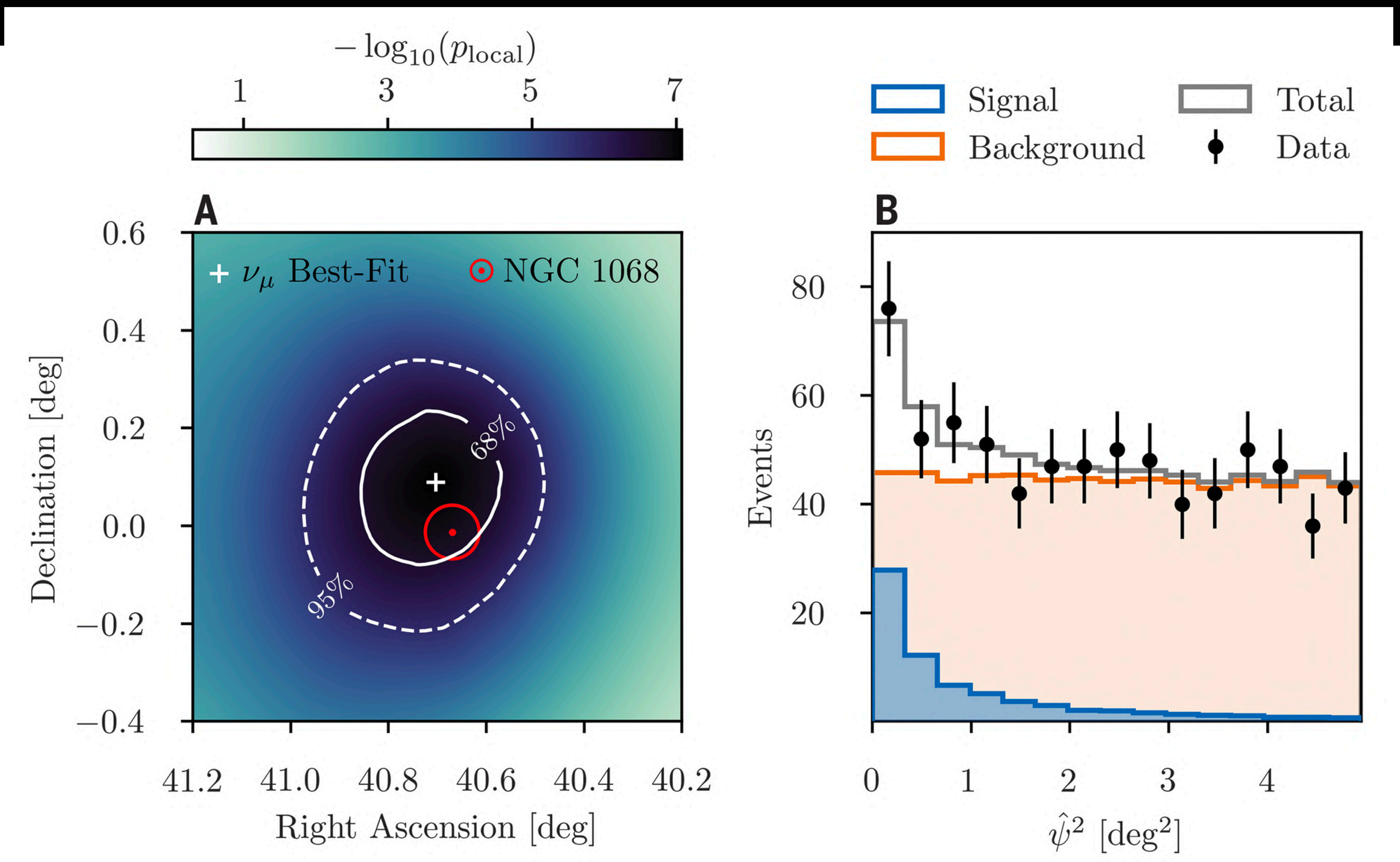


Identified Sources

Seyfert galaxy NGC 1068

Blazar 0506+056





The Astrophysical Journal Letters, 1000:L26 (20pp), 2026 March 20 https://doi.org/10.3847/2041-8213/ae4aad

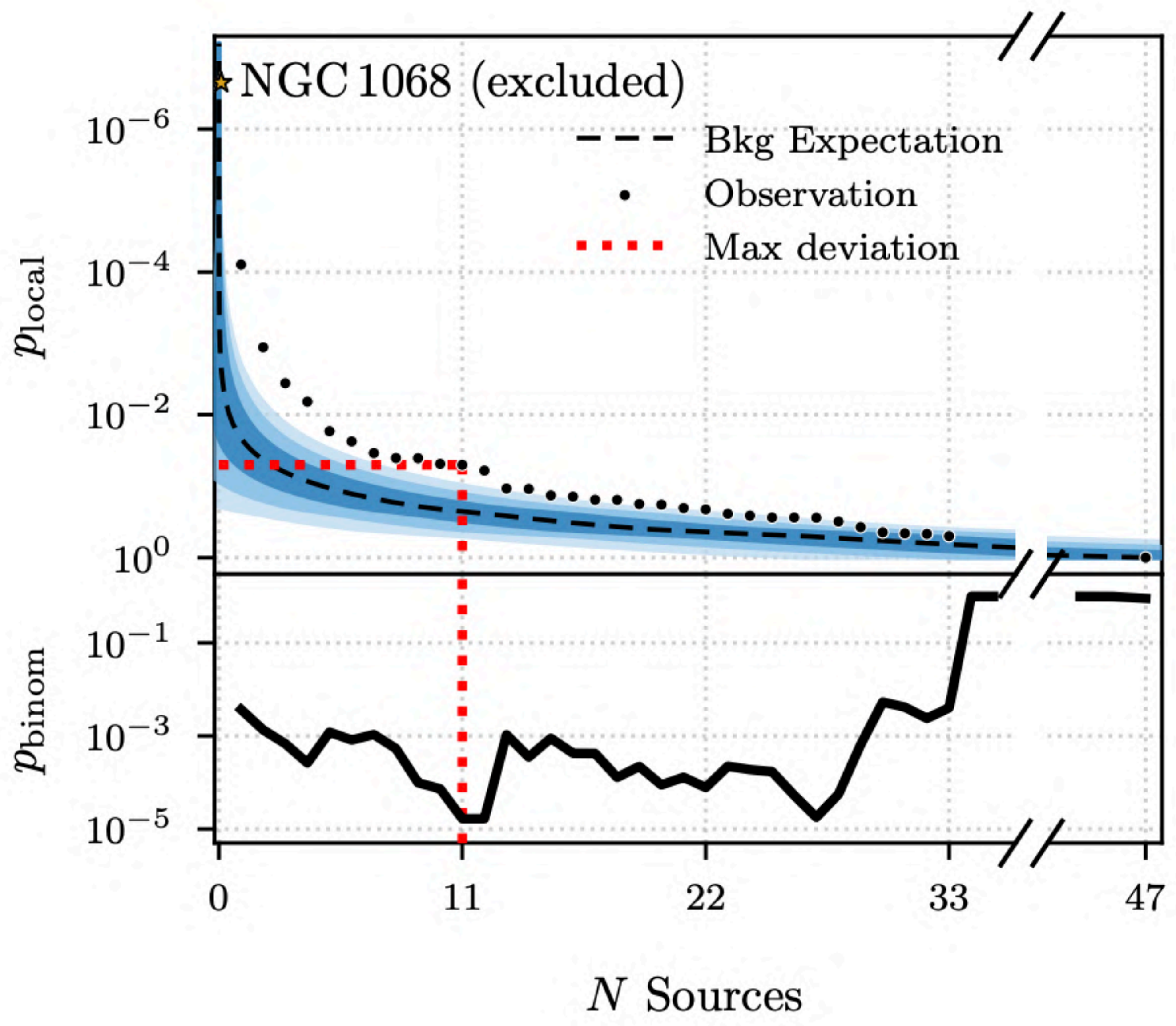
Evidence for Neutrino Emission from X-Ray-bright Active Galactic Nuclei with IceCube

R. Abbasi[1], M. Ackermann[2], J. Adams[3], S. K. Agarwalla[4,64], J. A. Aguilar[5], M. Ahlers[6], J. M. Alameddine[7], S. Ali[8], N. M. Amin[9], K. Andeen[10], C. Argüelles[11], Y. Ashida[12], S. Athanasiadou[2], S. N. Axani[9], R. Babu[13], X. Bai[14],

The Astrophysical Journal Letters, 1000:L37 (11pp), 2026 April 1 https://doi.org/10.3847/2041-8213/ae4aac

Evidence for Neutrino Emission from X-Ray Bright Seyfert Galaxies in the Southern Hemisphere Using Enhanced Starting Track Events with IceCube

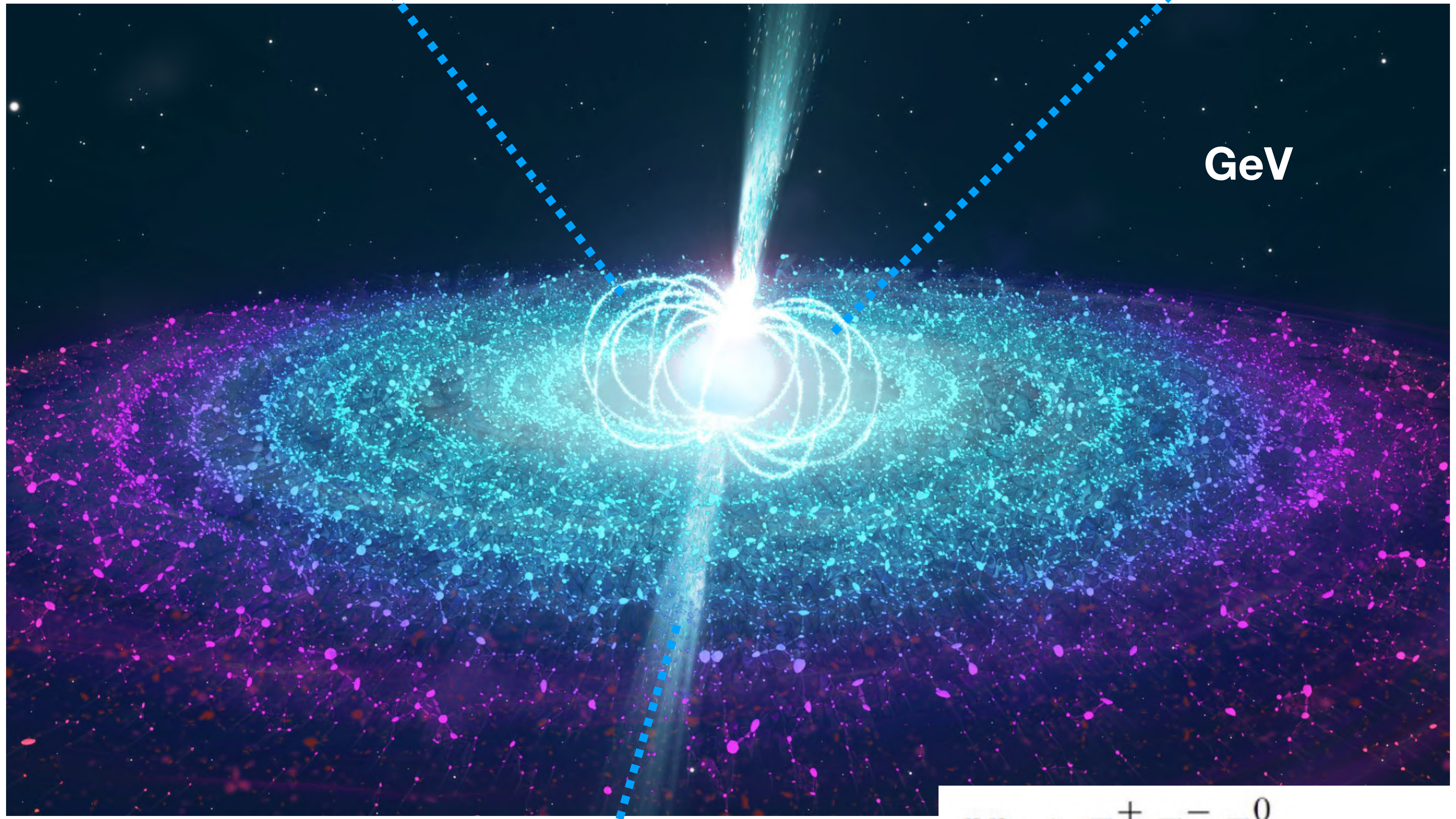
R. Abbasi[1], M. Ackermann[2], J. Adams[3], S. K. Agarwalla[4,64], J. A. Aguilar[5], M. Ahlers[6], J.M. Alameddine[7], S. Ali[8], N. M. Amin[9], K. Andeen[10], C. Argüelles[11], Y. Ashida[12], S. Athanasiadou[2], S. N. Axani[9], R. Babu[13], X. Bai[14], J. Baines-Holmes[4], A. Balagopal V.[4,9], S. W. Barwick[15], S. Bash[16], V. Basu[12], R. Bay[17], J. J. Beatty[18,19],



Seyfert galaxies

Quasi- or Non-thermal SN Neutrinos

Rapidly rotating and strongly magnetized PNS



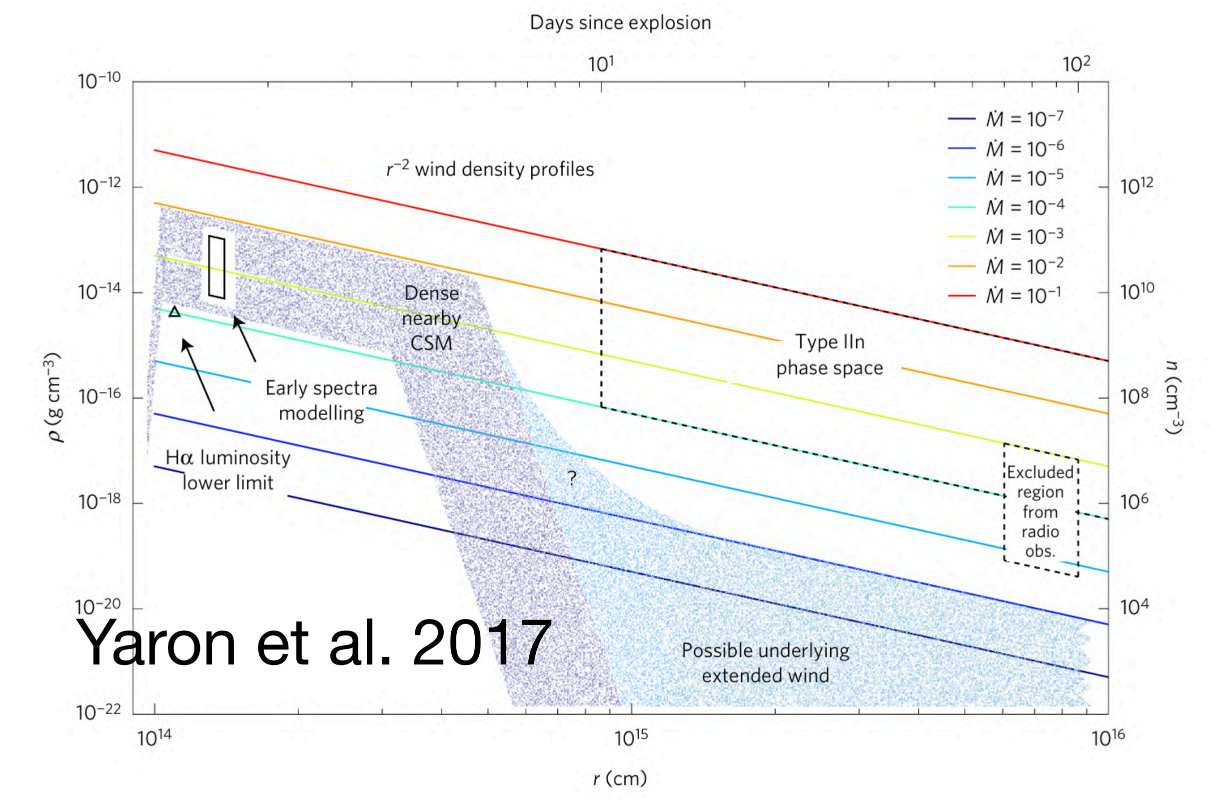
$$pp \to \pi^+ \pi^- \pi^0.$$

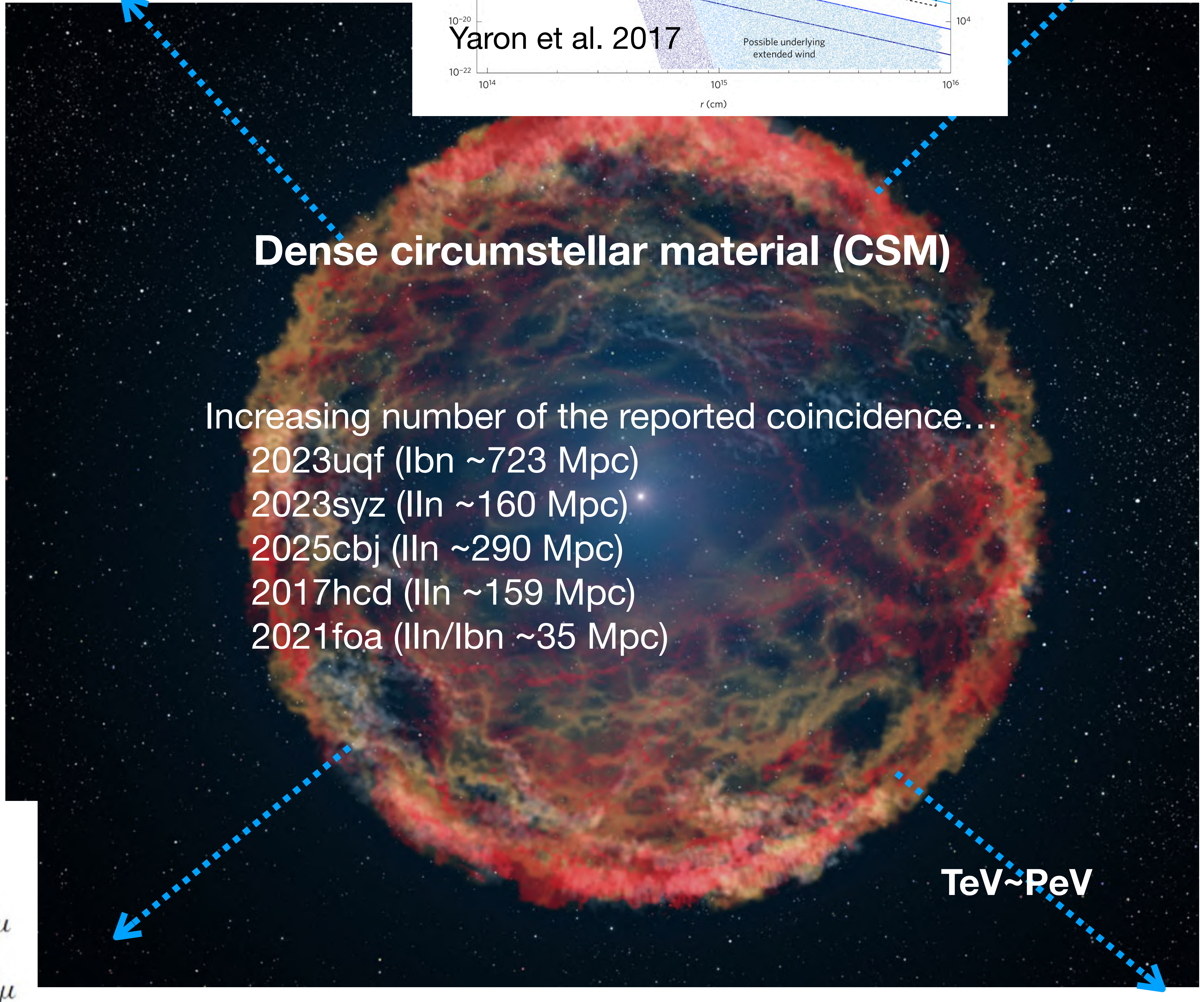
e.g.

$$\pi^+ \to \mu^+ \nu_\mu \to e^+ \nu_e \overline{\nu}_\mu \nu_\mu$$

$$\pi^- \to \mu^- \overline{\nu}_\mu \to e^- \overline{\nu}_e \nu_\mu \overline{\nu}_\mu$$

J. A. Carpio et al., PRD 110, 083012 (2024)





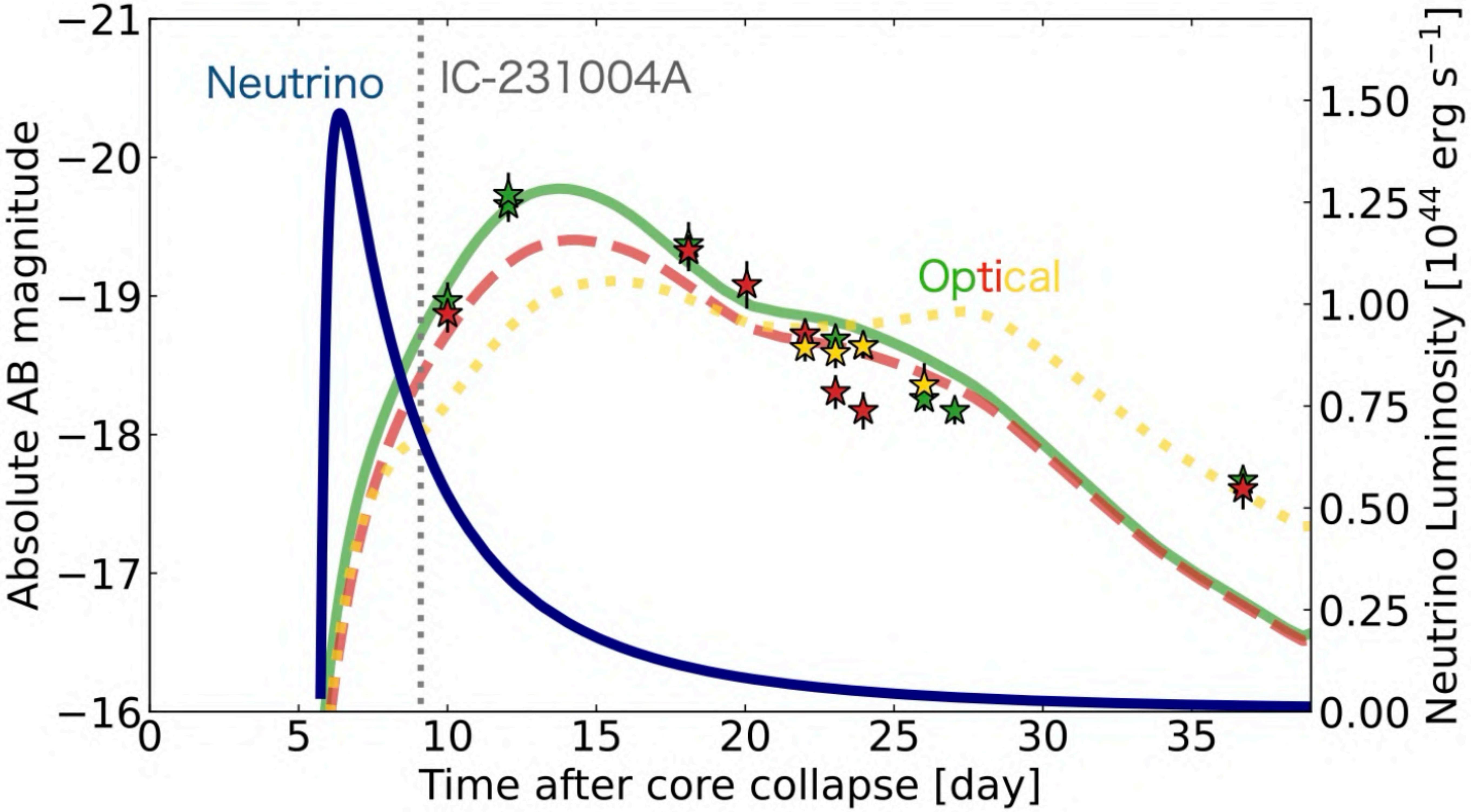
K. Murase, PRD 97, 081301(R) (2018)

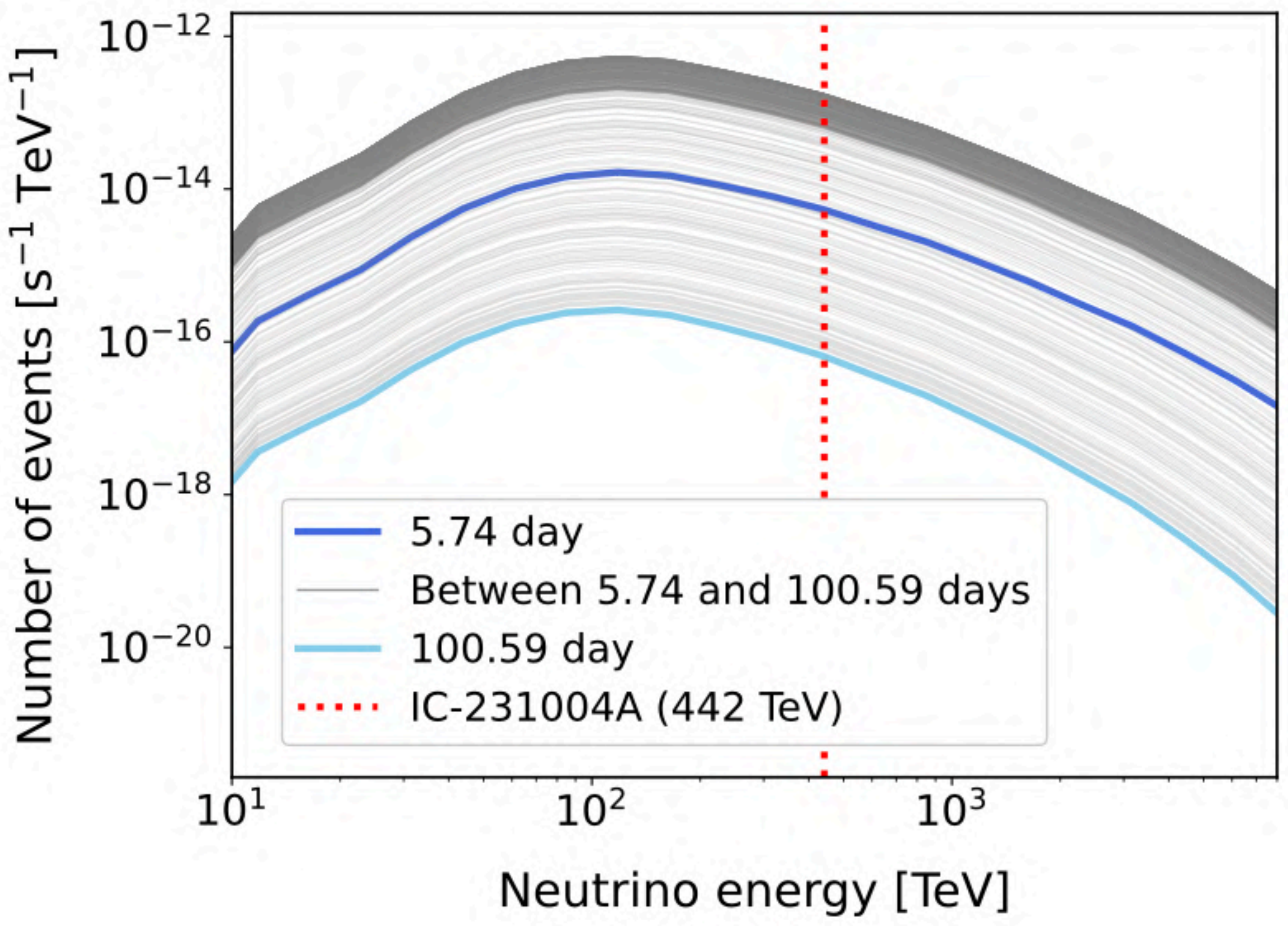
K. Murase, PRD 109, 103020 (2024)

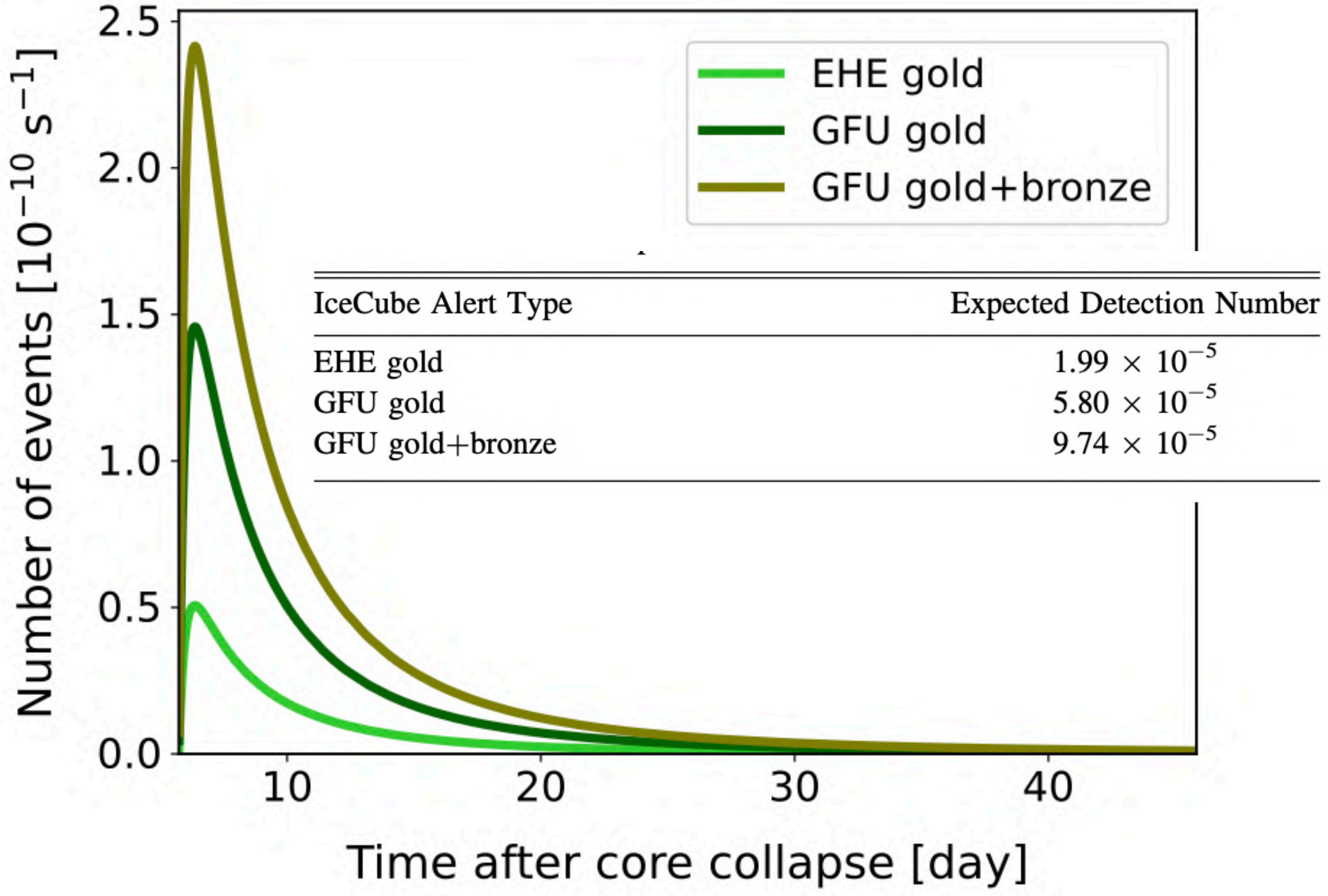
SN 2023uqf: Modeling of Optical-Neutrino Emissions

- **CSM structure** is modeled by RHD calculations with STELLA to reproduce optical light curve of SN 2023uqf.
- Neutrino emission is calculated for the optimized CSM structure.
- Event rate of ~10^{-4} can explain ~O(1) for ~O(10^3) Ibn SNe × ~10 years.

R. Sawada, Y. Inoue, Y. Ashida, ApJL 1005, 2 (2026)







IceCube Alert Type	Expected Detection Number
EHE gold	1.99×10^{-5}
GFU gold	5.80×10^{-5}
GFU gold+bronze	9.74×10^{-5}

Possibility of Multi-Energy Detection?

R. Sawada, Y. Ashida, ApJ 982, 2 (2025)

SN burst neutrinos ~O(10) MeV

pre-SN neutrinos ~MeV

$\dot{M}_{\rm csm} \propto L_{\text{pre-}\nu}$

bounce

shock breakout

origin?

CSM density structure [g cm^{-3}]

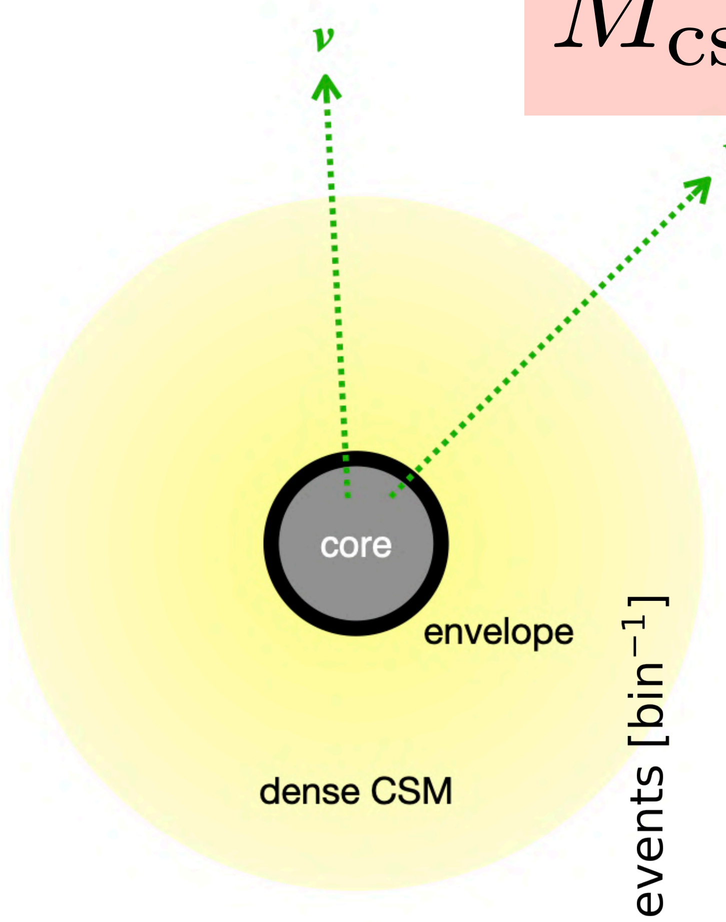
surface

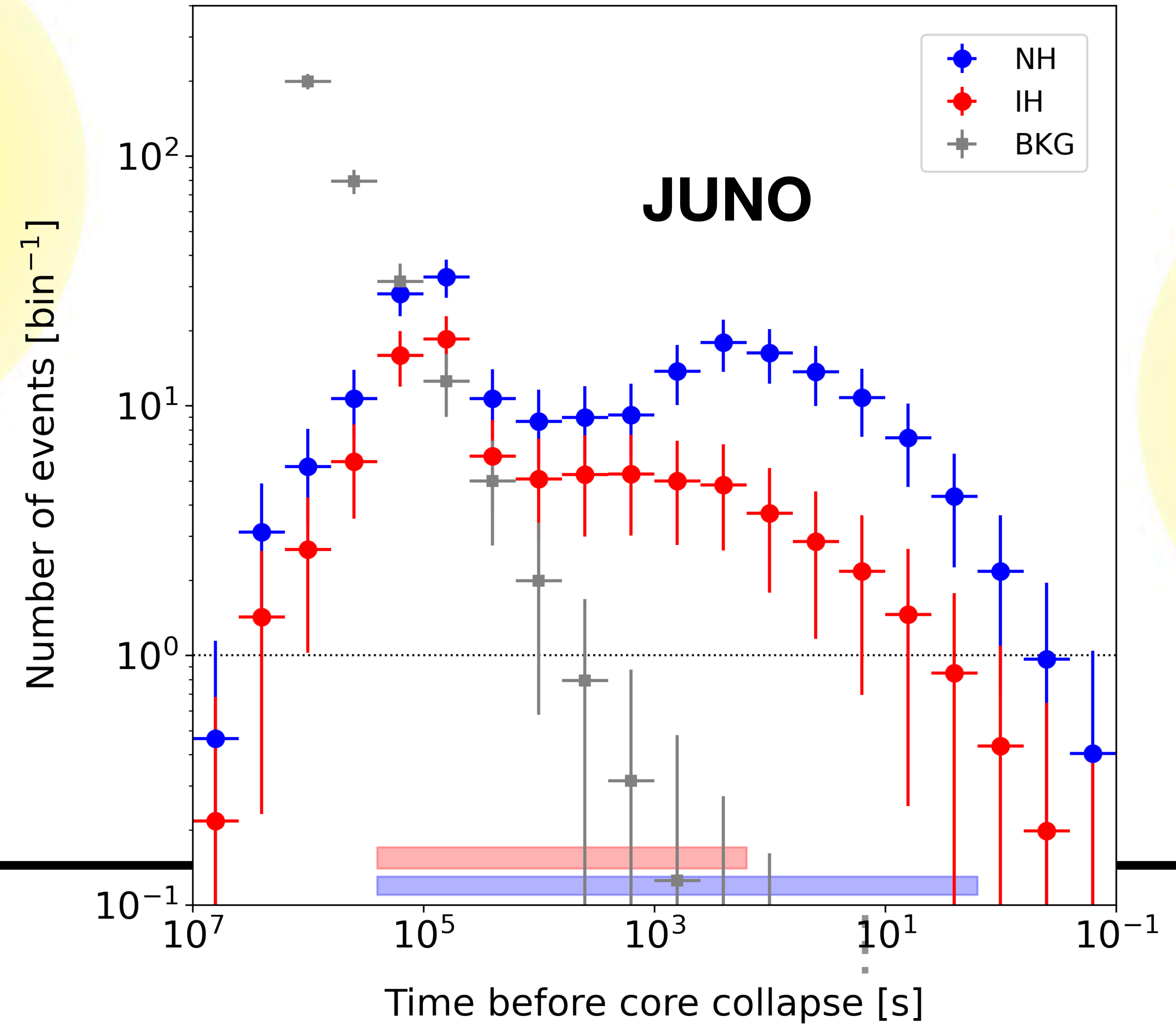
radius

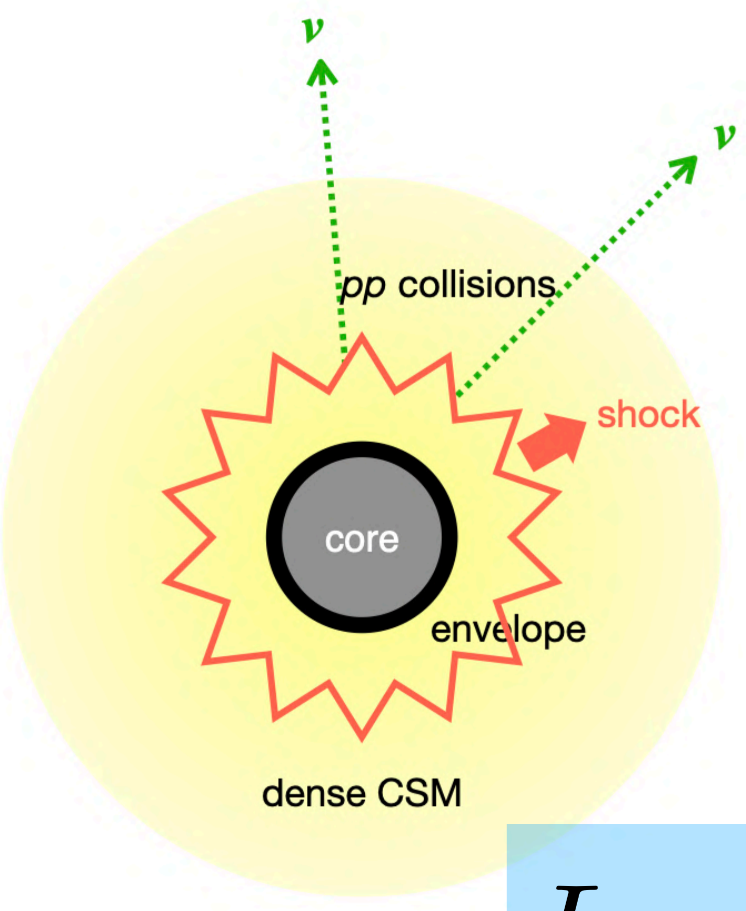
$L_{\text{csm-}\nu} \propto \dot{M}_{\rm csm}$

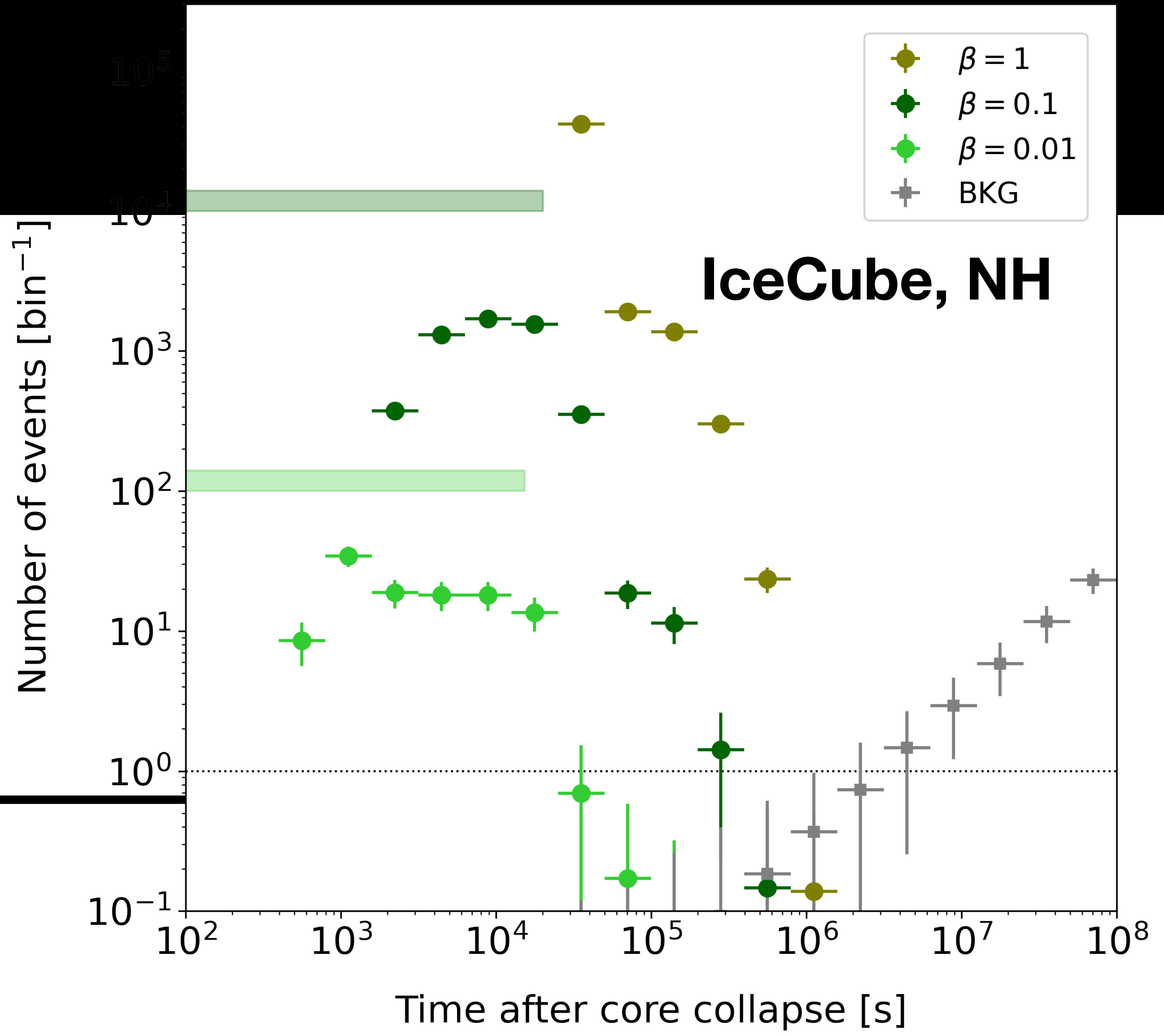
SN non-thermal neutrinos ~TeV

time









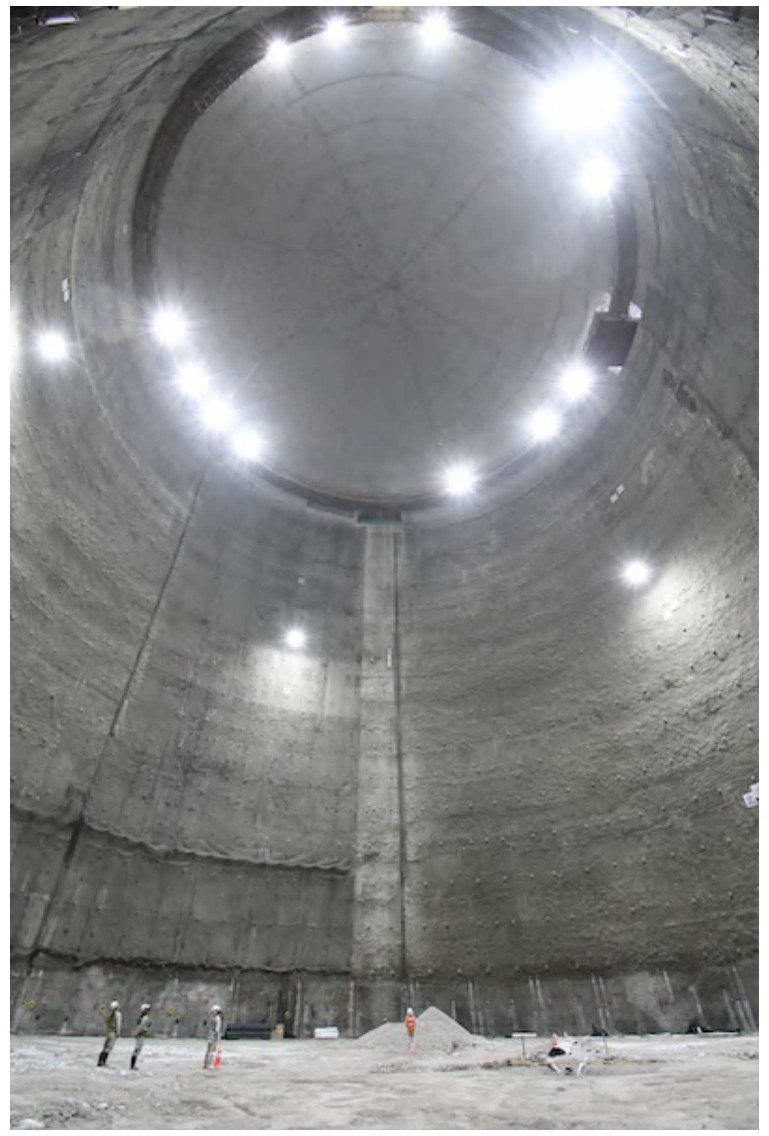
Correlation in temporal structure between pre-SN neutrinos and CSM-origin neutrinos?

Summary

- **Neutrino astronomy has been progressing over the last decade.**
  - A unique probe, compensating other messengers (= *multi*-messenger astronomy).
  - Potential study with neutrinos from different mechanisms (= *multi*-energy neutrino astronomy).
  - Many telescopes in the world to make a dream work! (= *multi*-detector neutrino astronomy)

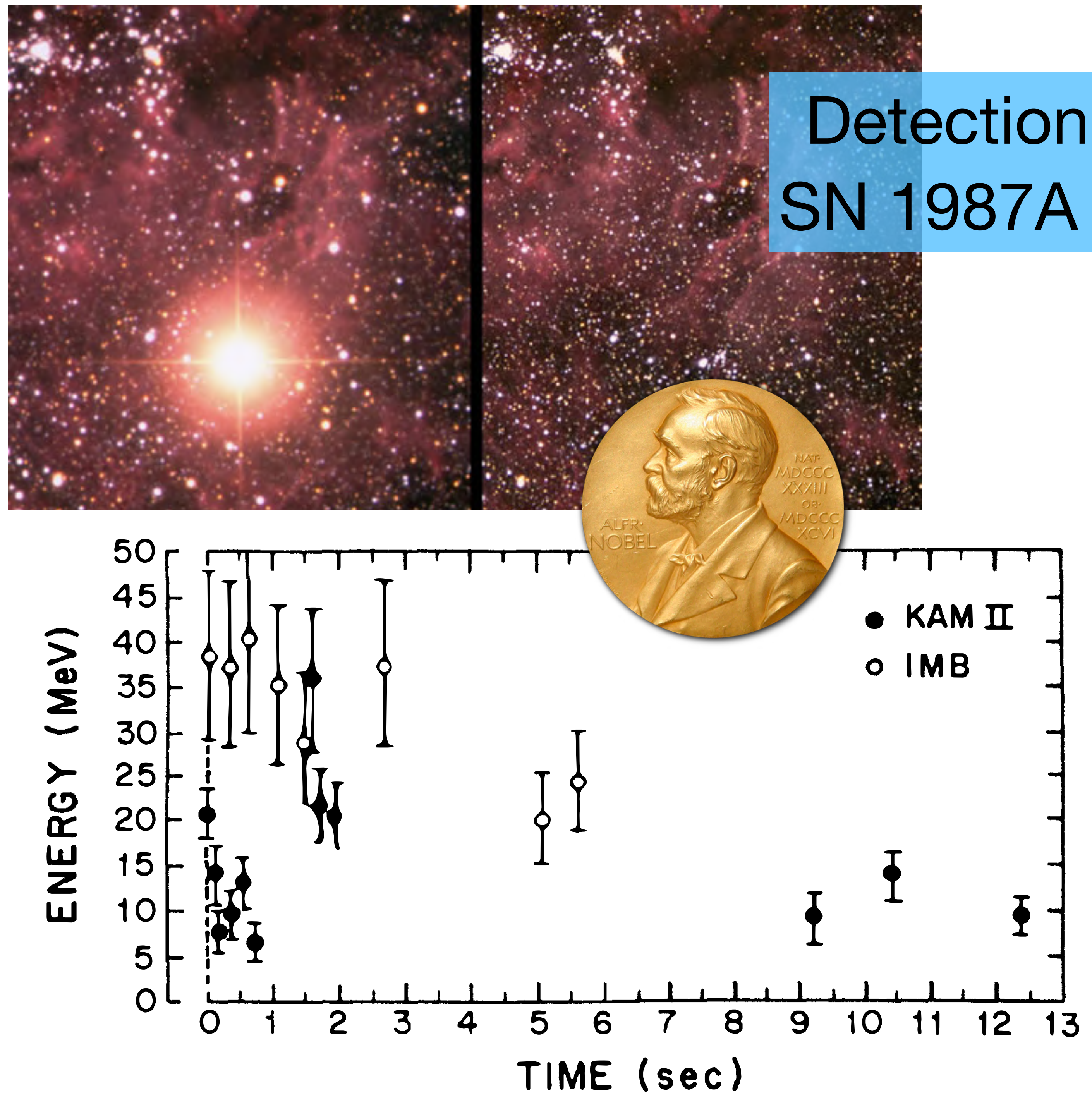
- **Both diffuse and transient studies are important.**
  - First indication of the DSNB signal at Super-K; HE diffuse is now being precisely measured.
  - HE diffuse sources are being resolved; AGN looks promising!
  - CCSNe stays among the most interesting sources in both LE and HE regimes.

- **Many neutrino telescopes will start operating soon.**
  - Hyper-K, JUNO, IceCube-Gen2, KM3NeT, TRIDENT/HUNT/NEON, DUNE, …
  - Next decade should be the most ever exciting era for neutrino astronomy!



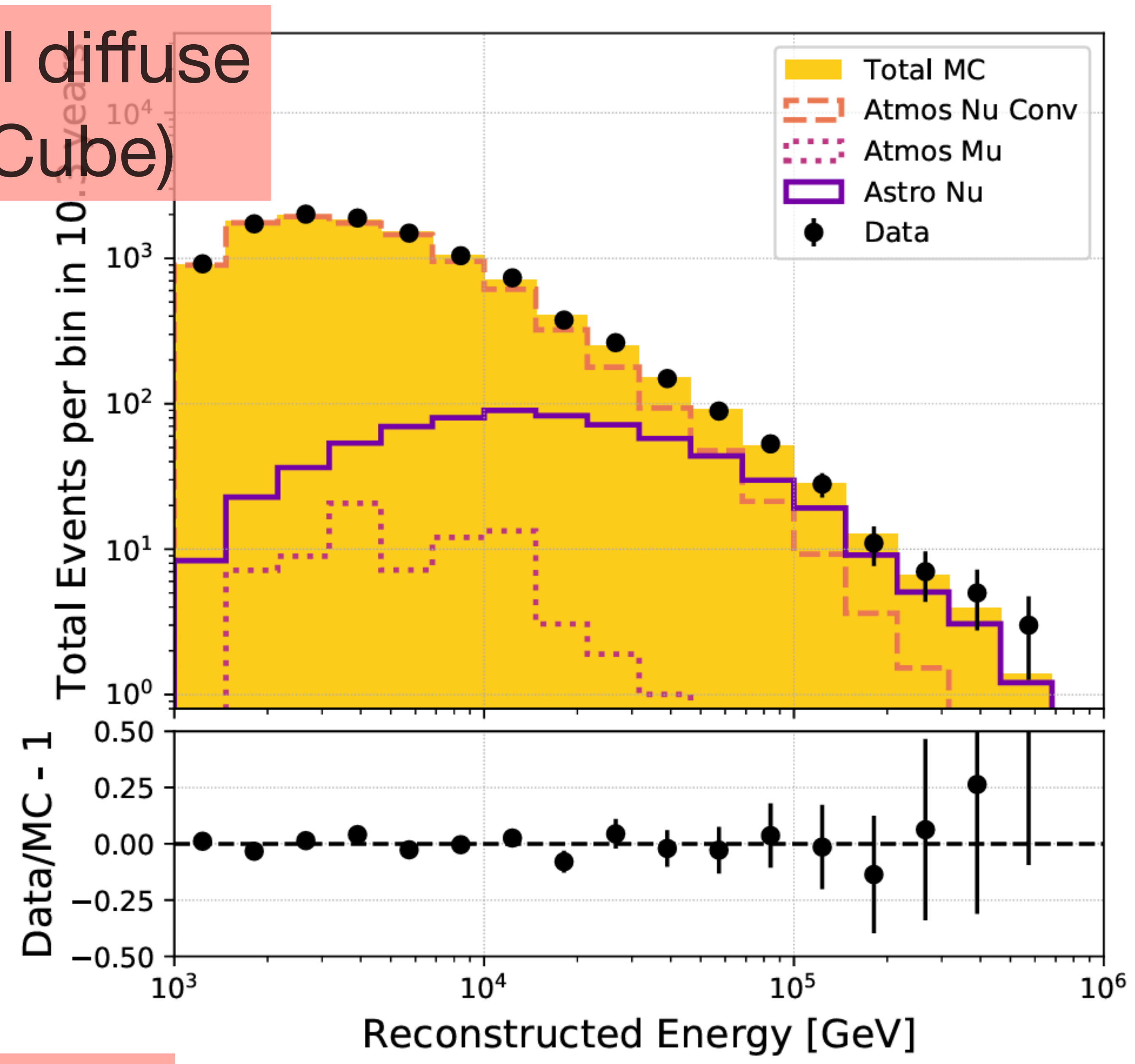
Thanks for your attention!

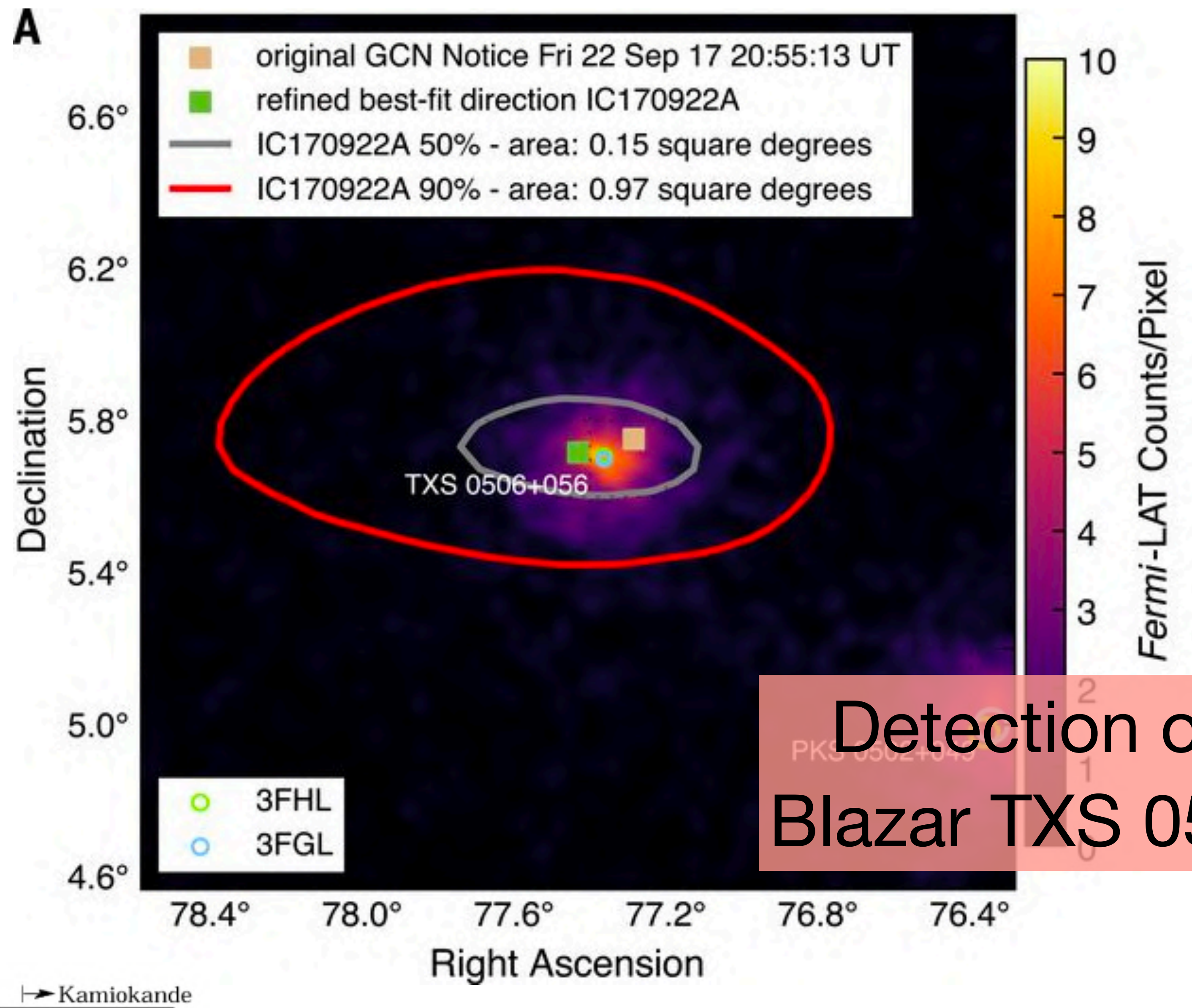
Supplements



Detection of neutrinos from SN 1987A (Kamiokande else)

Confirmation of astrophysical diffuse high-energy neutrinos (IceCube)

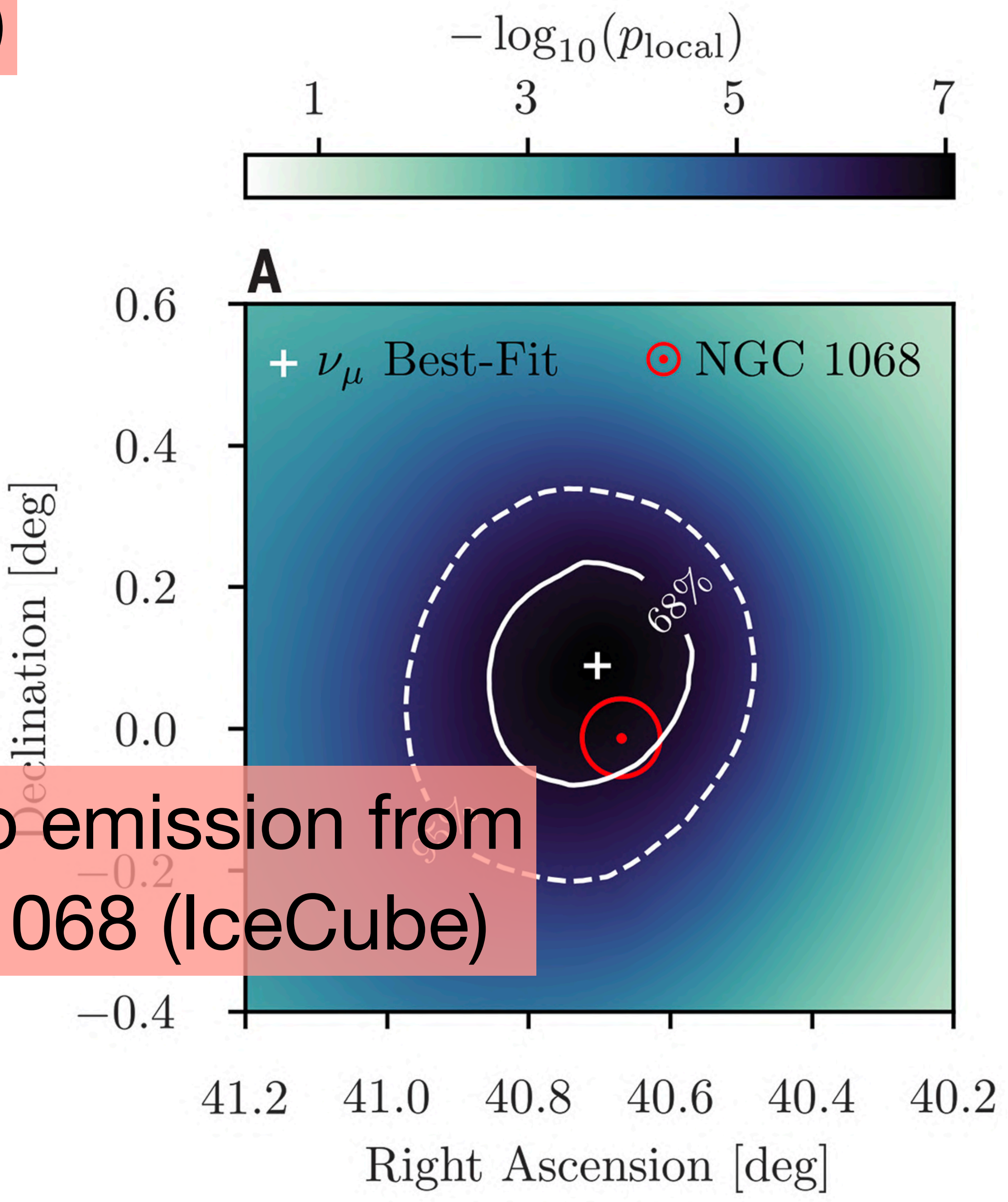




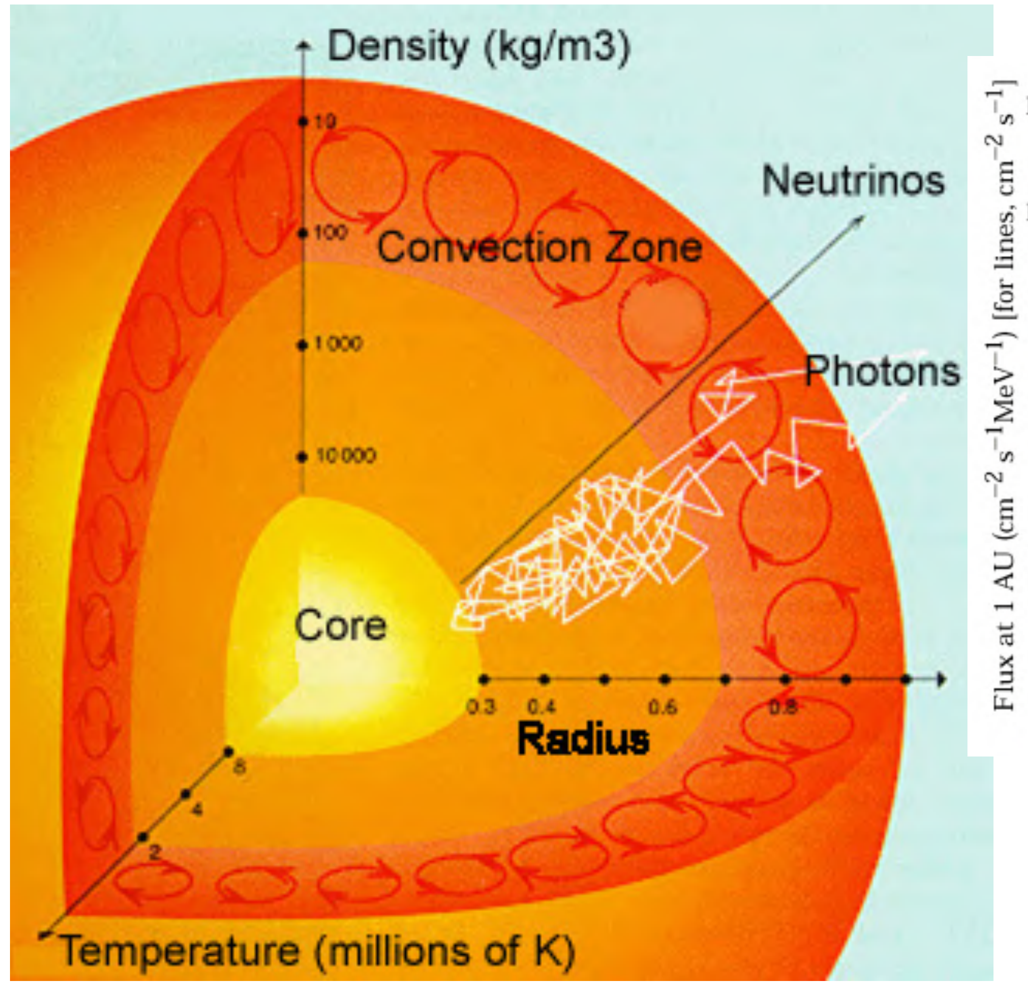
Detection of a neutrino from Blazar TXS 0506+056 (IceCube)

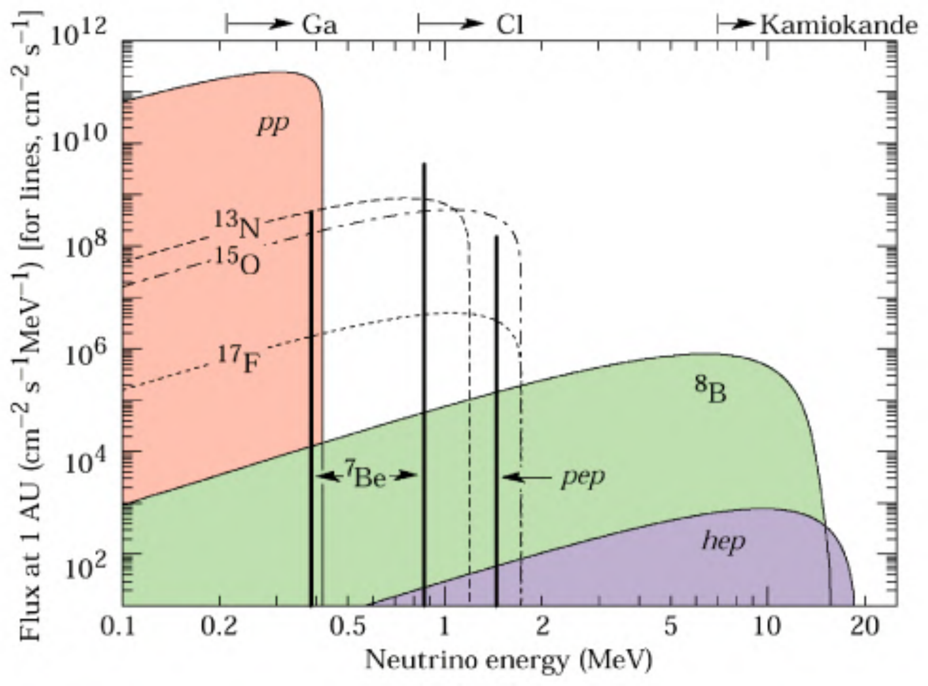
thermal

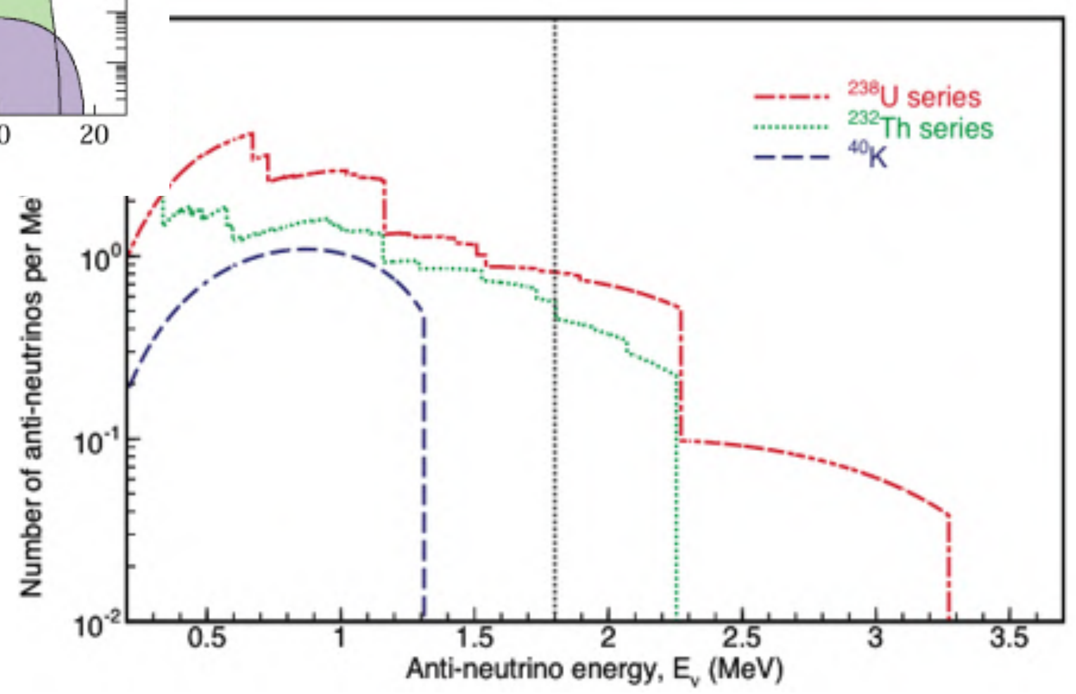
non-thermal



Observation of neutrino emission from Seyfert galaxy NGC 1068 (IceCube)

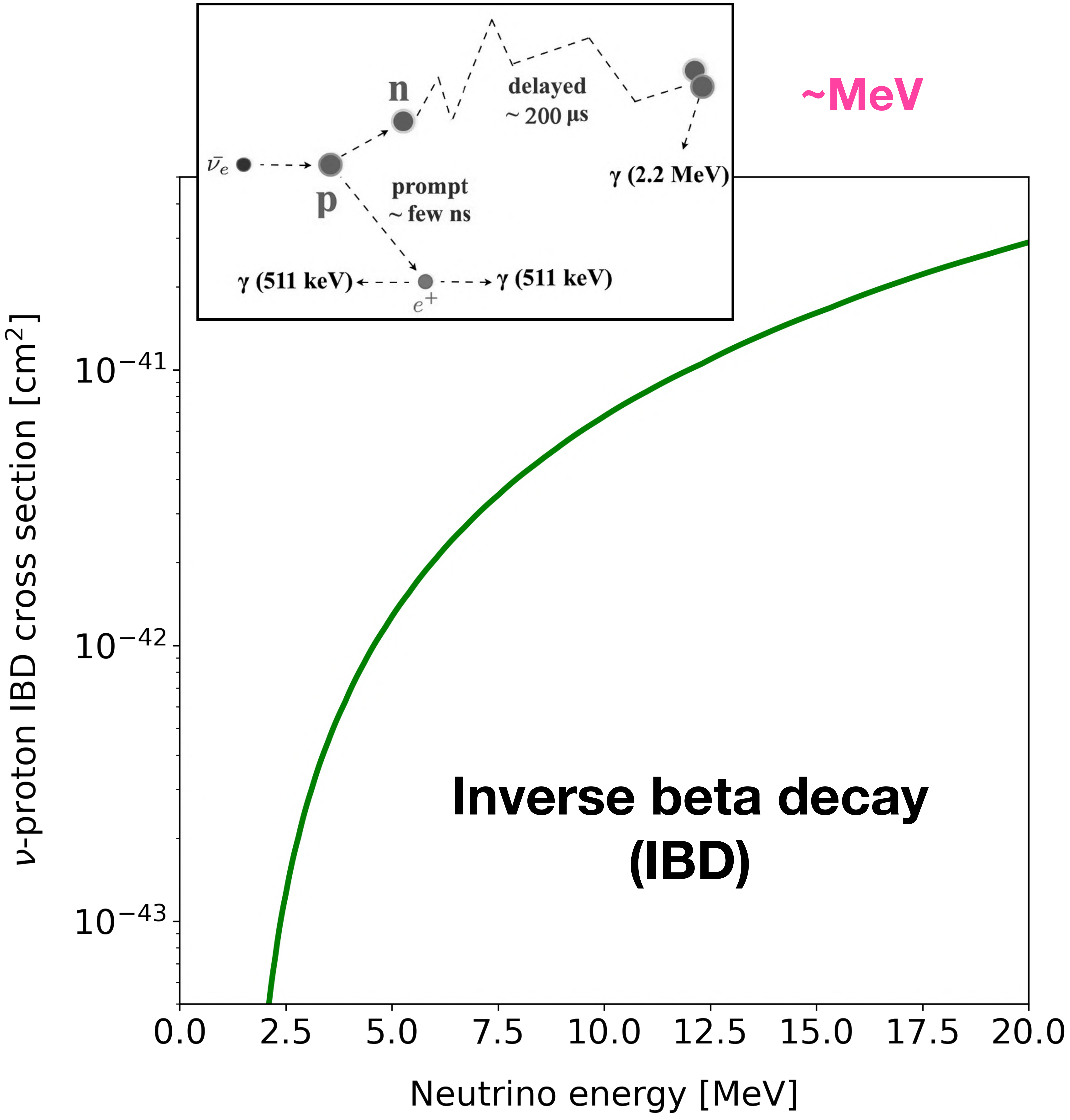


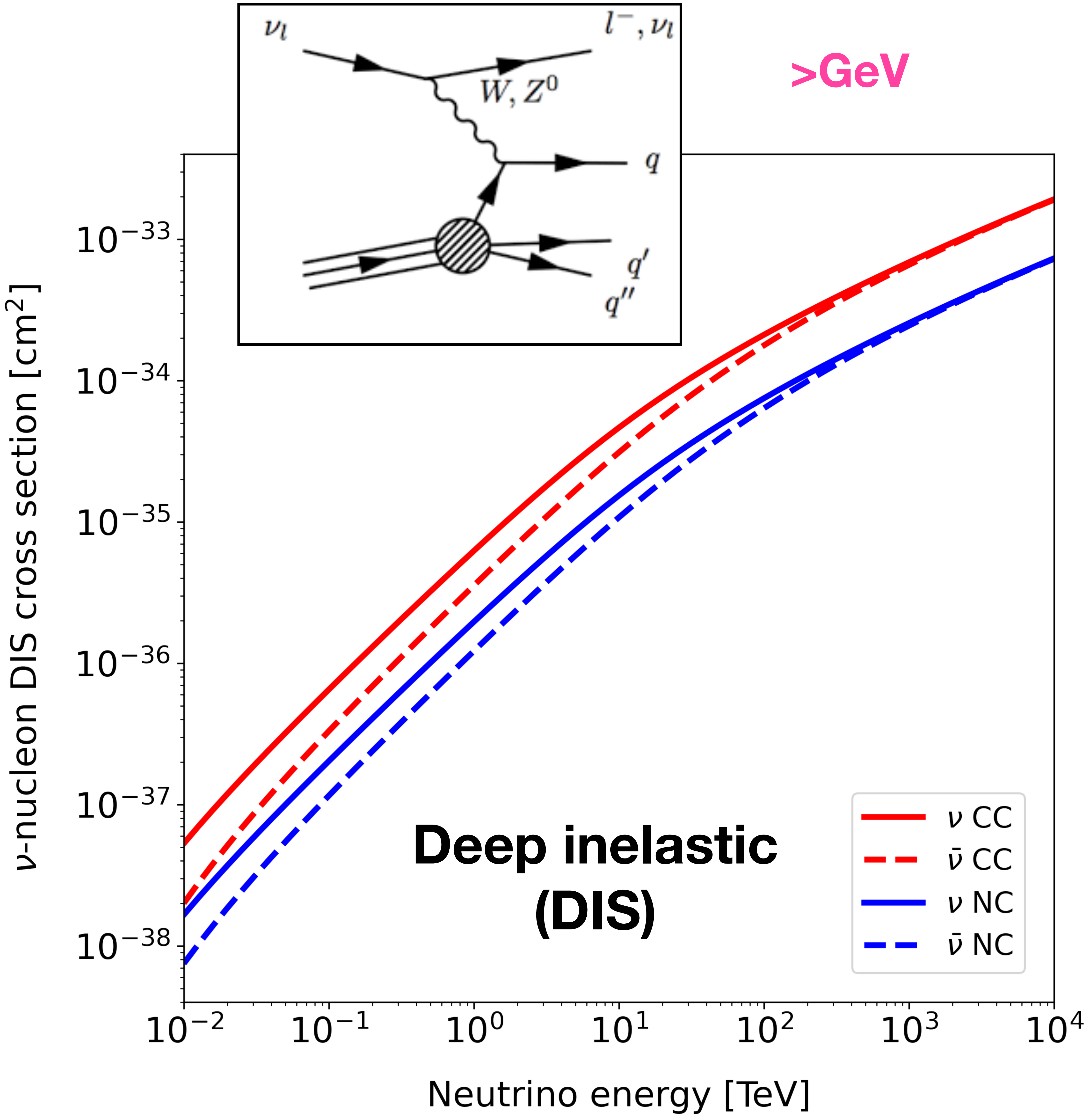




Detection of neutrinos from the Sun and Earth (Kamiokande, KamLAND else)

Detection Channel

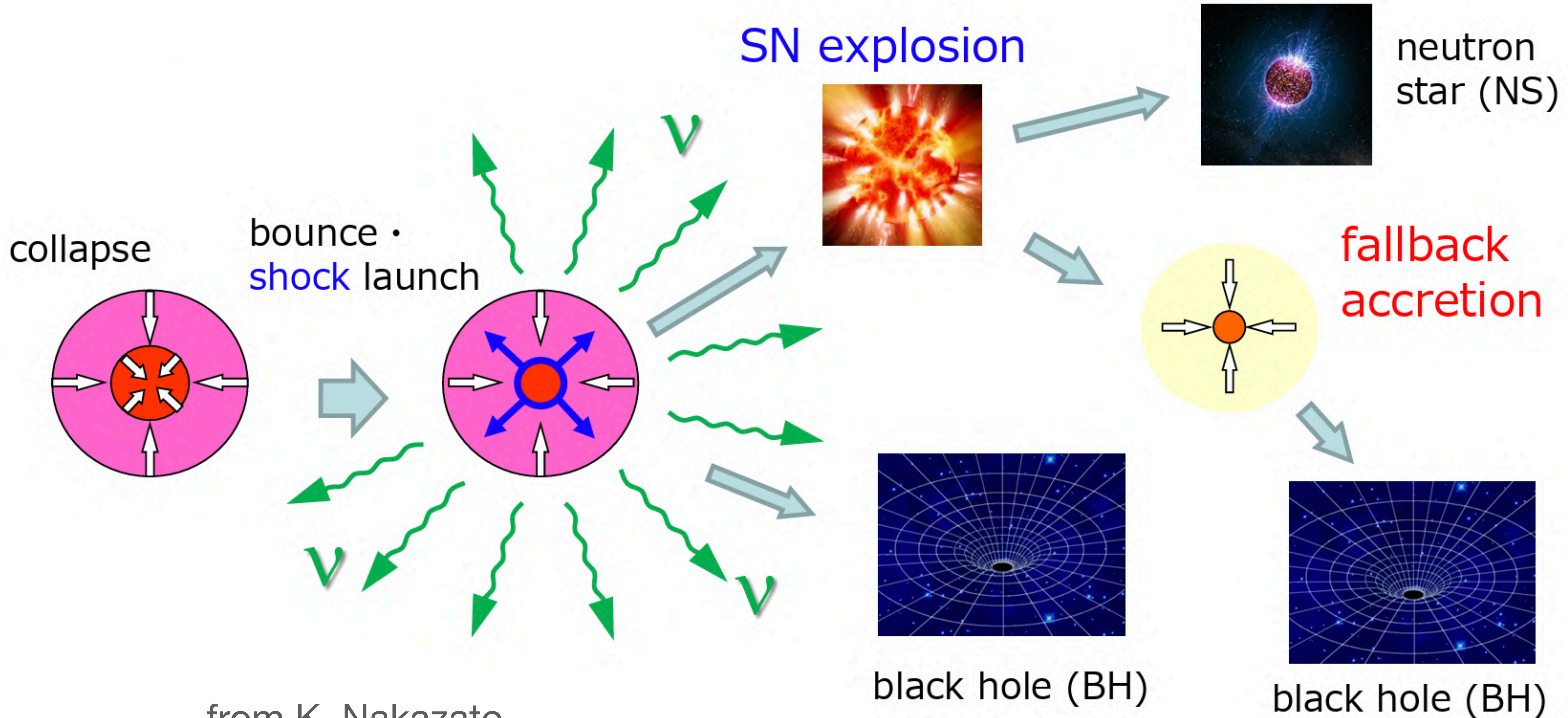




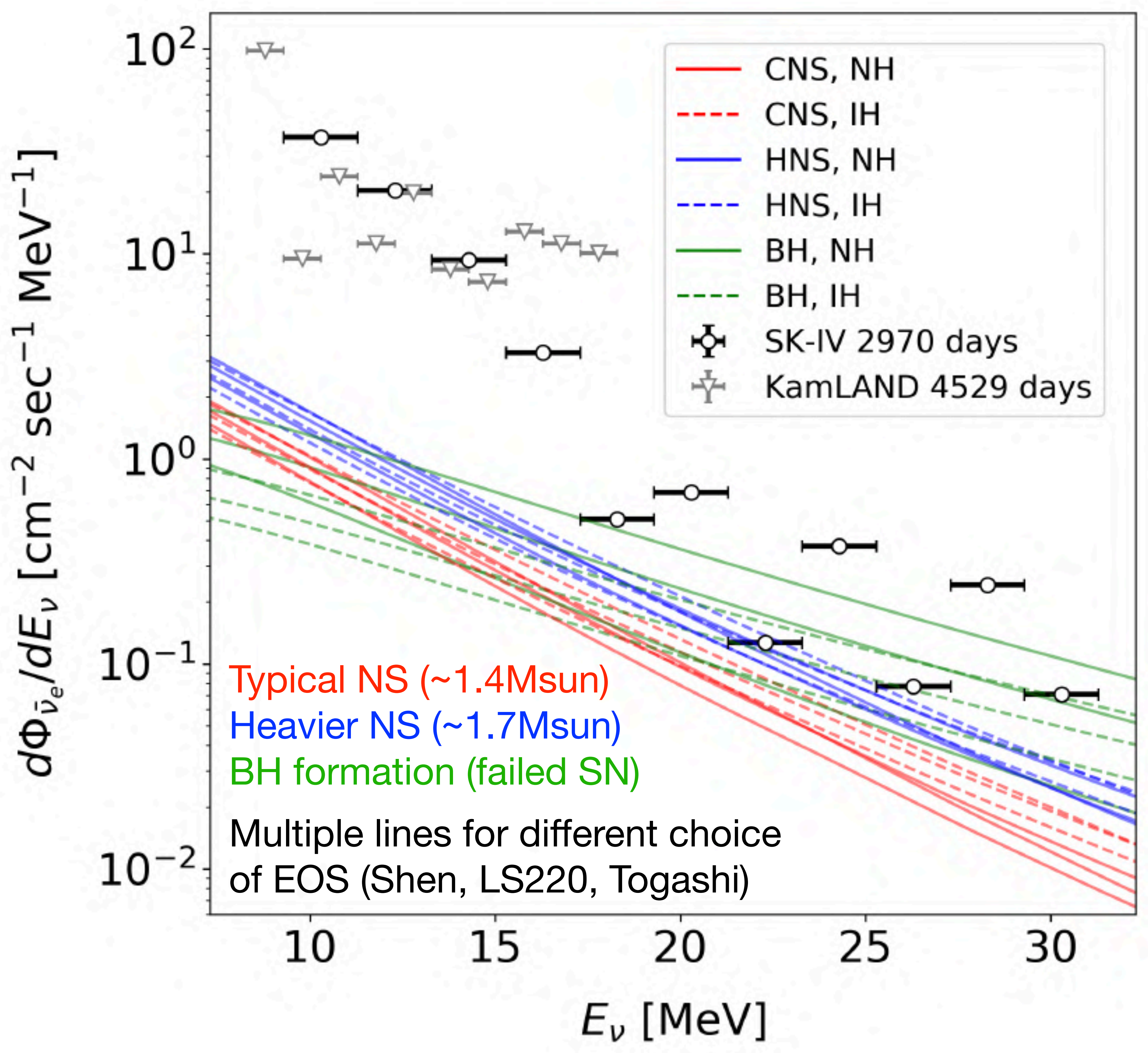
Core Collapse Fate and DSNB

- Emitted ν spectrum is expected to depend on the remnant after core collapse ("*fate*").
  - Information about the fate are accessible by other observations (pulsar, failed SN monitoring, GW etc).

- Consider three major cases as a fate and calculate DSNB flux for each.
  - Canonical mass neutron stars (~1.4M_{sun})
  - High mass neutron stars (~1.7M_{sun})
  - Black holes (failed SNe)

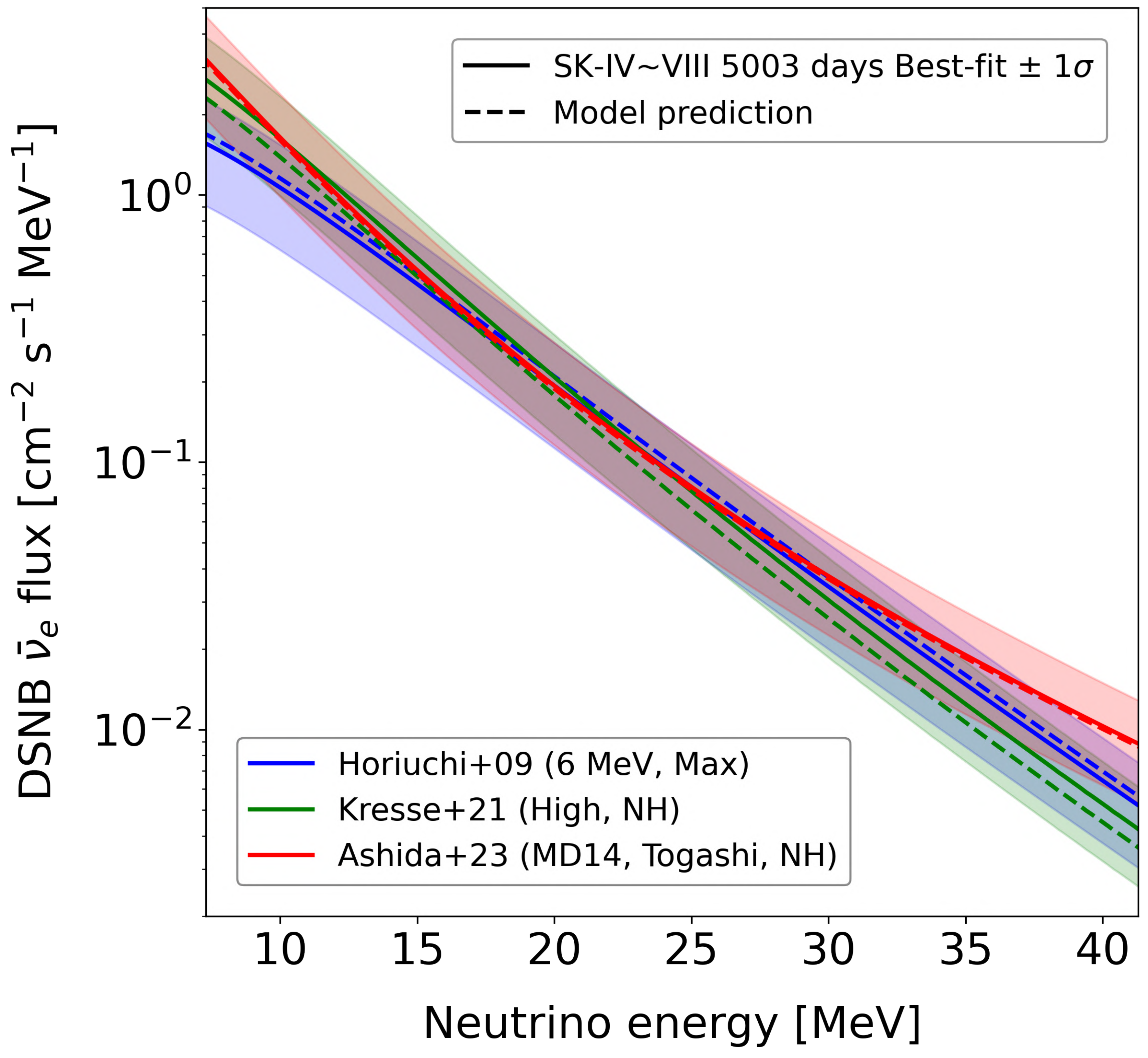


from K. Nakazato



Fitting with Other DSNB Models

- Three models (which have different shapes) were tested.
- The fitting consistently shows a significance of ~2.6σ against the null DSNB hypothesis.
- Our analysis is not capable of model discrimination.

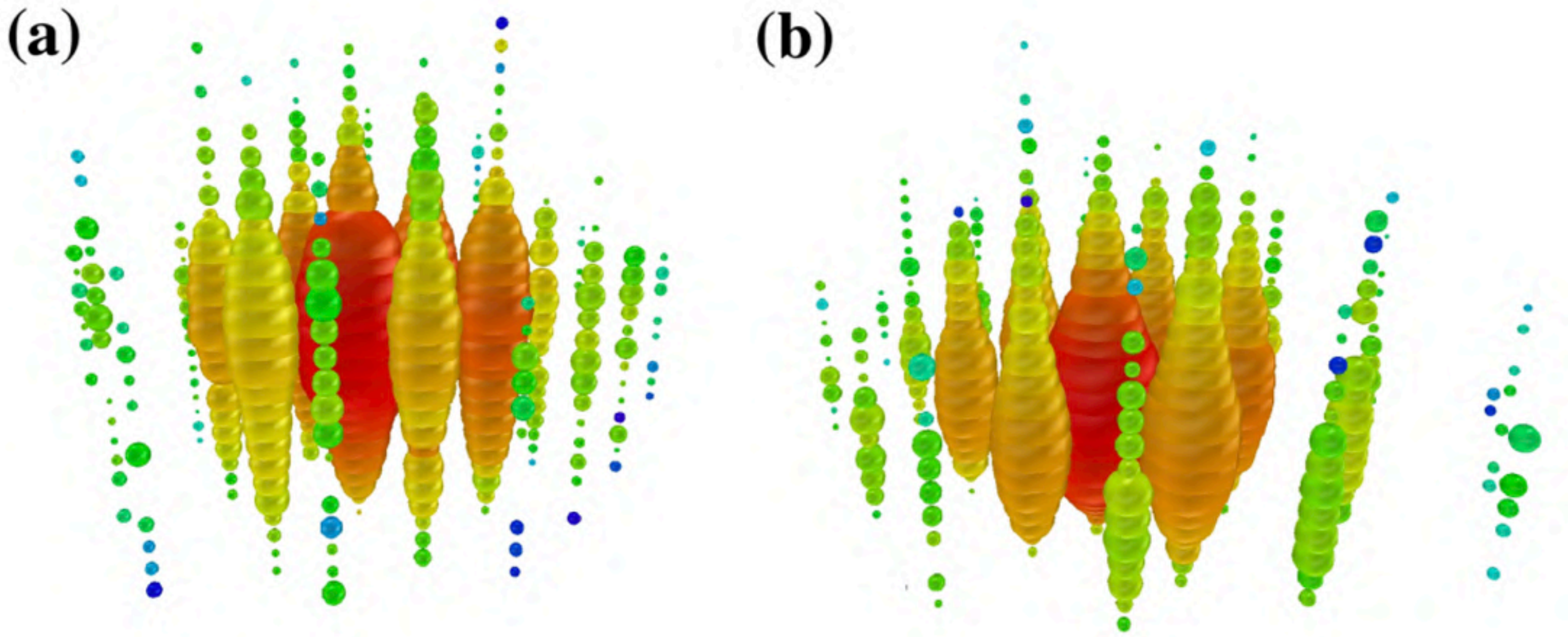


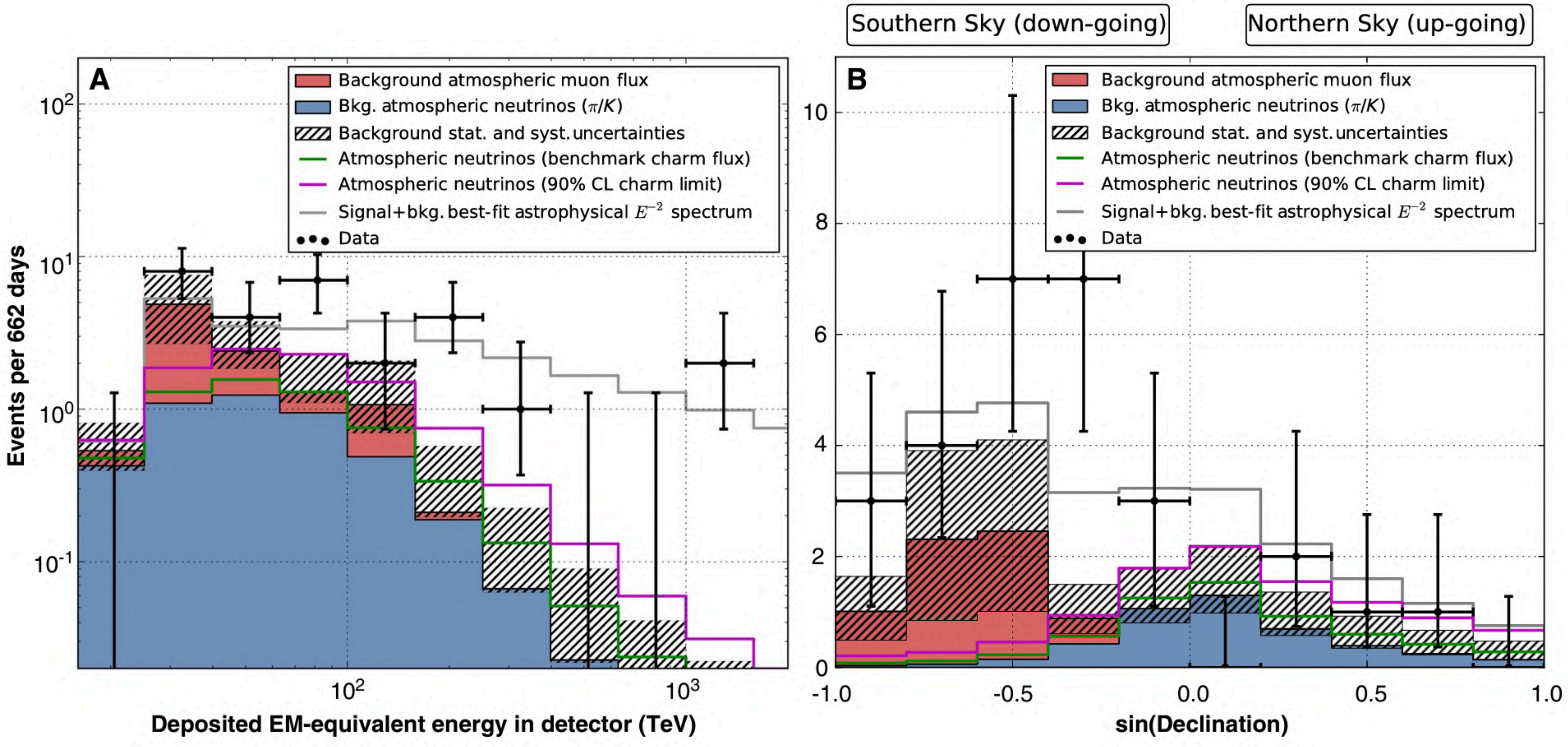
Preliminary

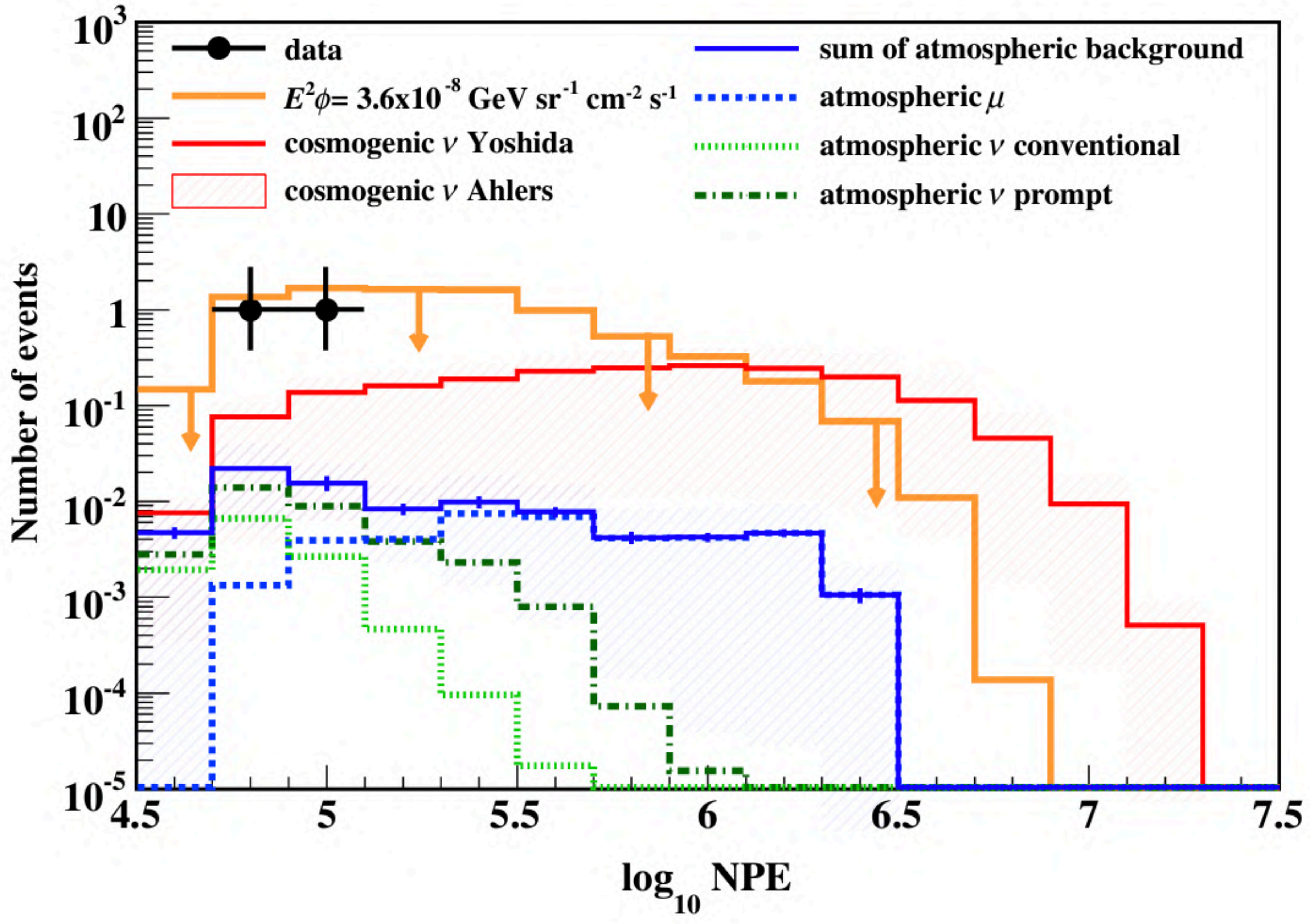
	IBD event rate [events/year]		DSNB flux [cm^{-2} s^{-1}]		Significance (SK-IV ~ VIII joint fit)	Maximum Likelihood Value
	Best-fit	Pred	Best-fit	Pred		
Horiuchi+09 6 MeV, max	4.8 +2.2/-2.0	5.2	3.6 +1.6/-1.5	3.9	2.6σ	1226.1
Kresse+21	5.1 +2.2/2.0	4.3	4.1 +1.8/-1.6	3.5	2.7σ	1225.3
Ashida+23	5.7 +2.5/-2.3	5.5	4.0 +1.8/-1.6	3.9	2.6σ	1225.9

First Observation of HE Astrophysical Neutrinos

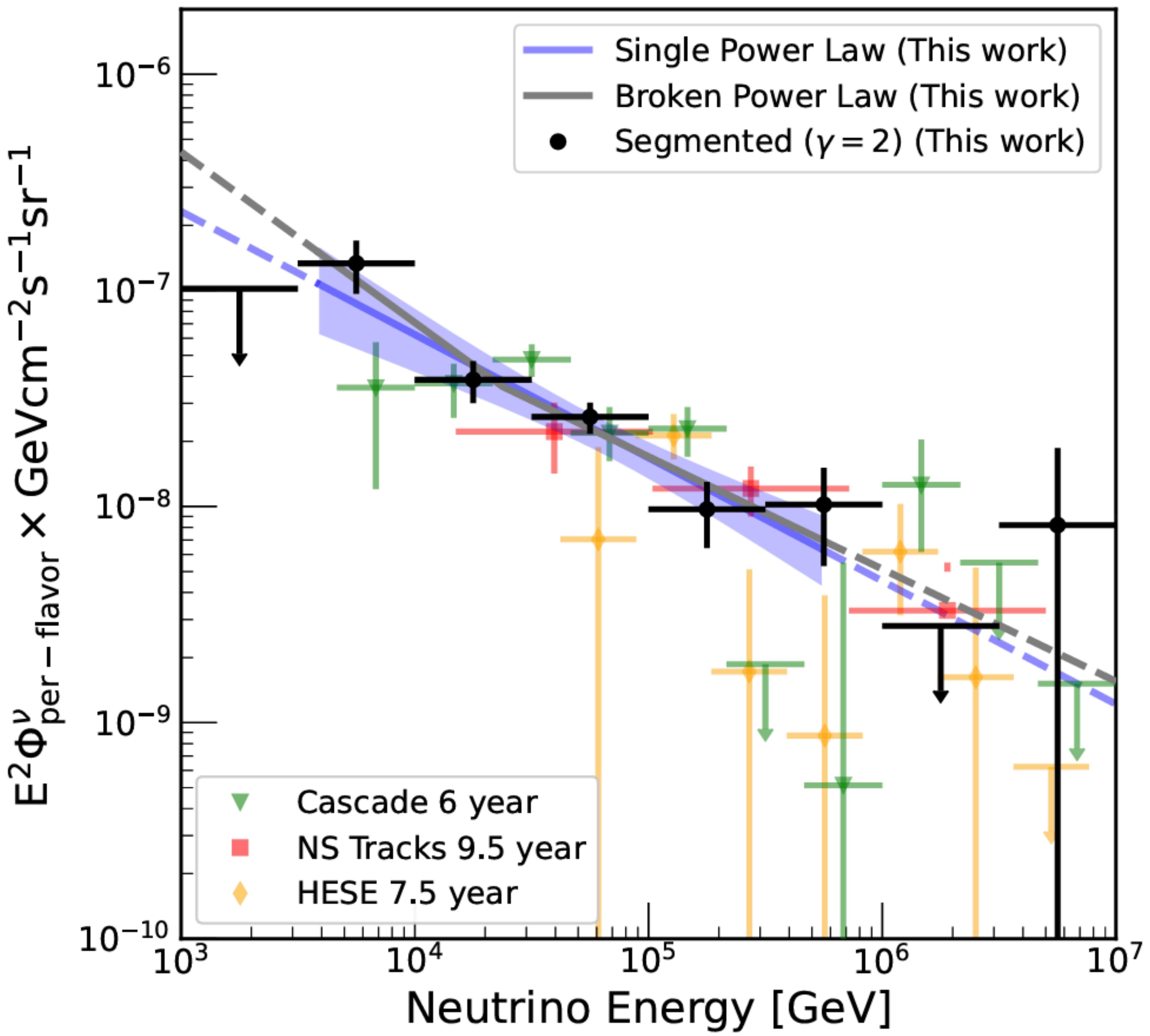
- Two highest energy neutrinos: **1.04±0.16 PeV**, **1.14±0.17 PeV**
- High Energy Starting Event (HESE) sample confirmed the flux.
- More improvements came up afterwards.
  - Better reconstruction tools (ML-based)
  - Lower energy threshold

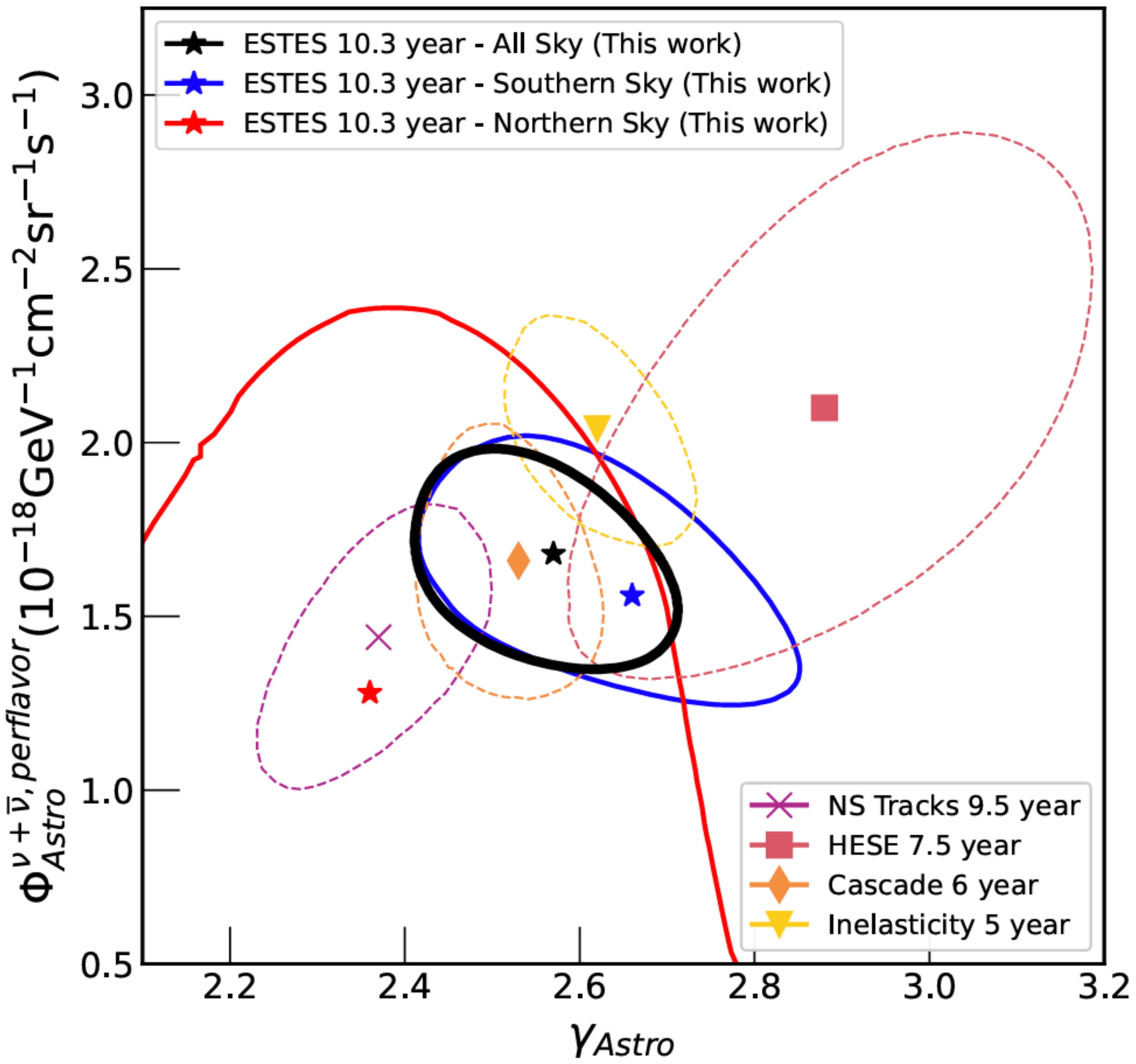






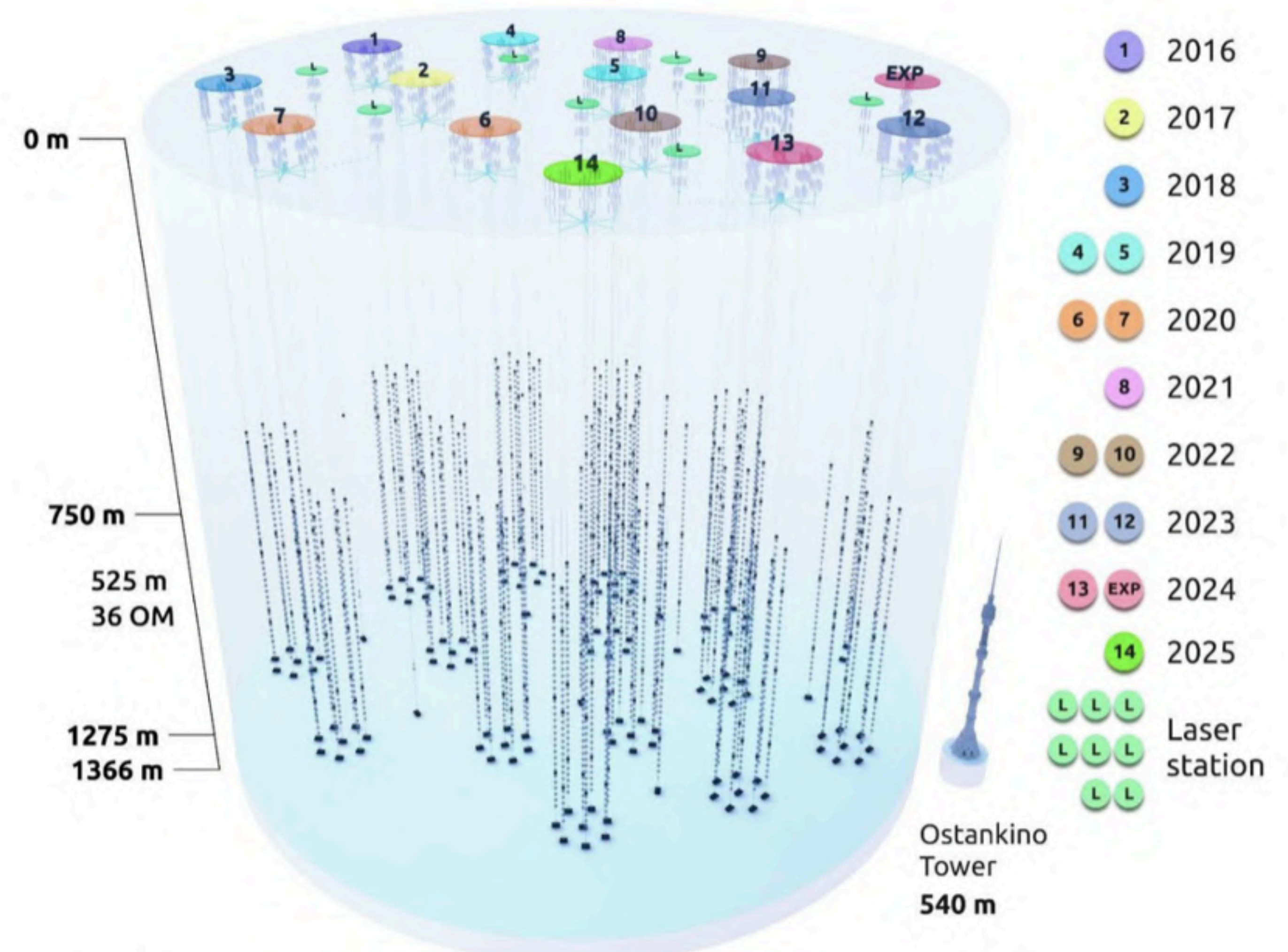
Diffuse HE Neutrino Flux





First independent observation from IceCube

Baikal-GVD



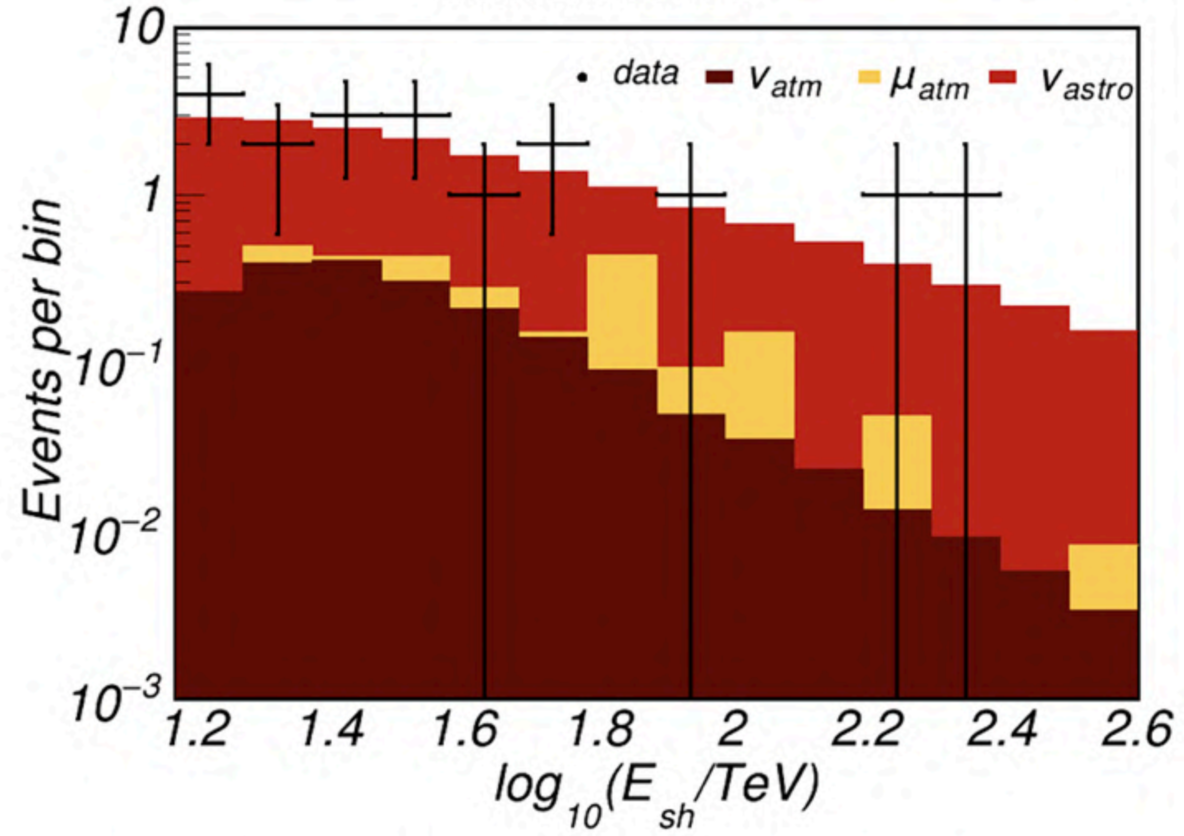
Size 1 km³, in construction at Lake Baikal at 1400 m depth

14 clusters already deployed, actual size 0.7 km³

see Dmitry Zaborov talk on 28 August parallel session

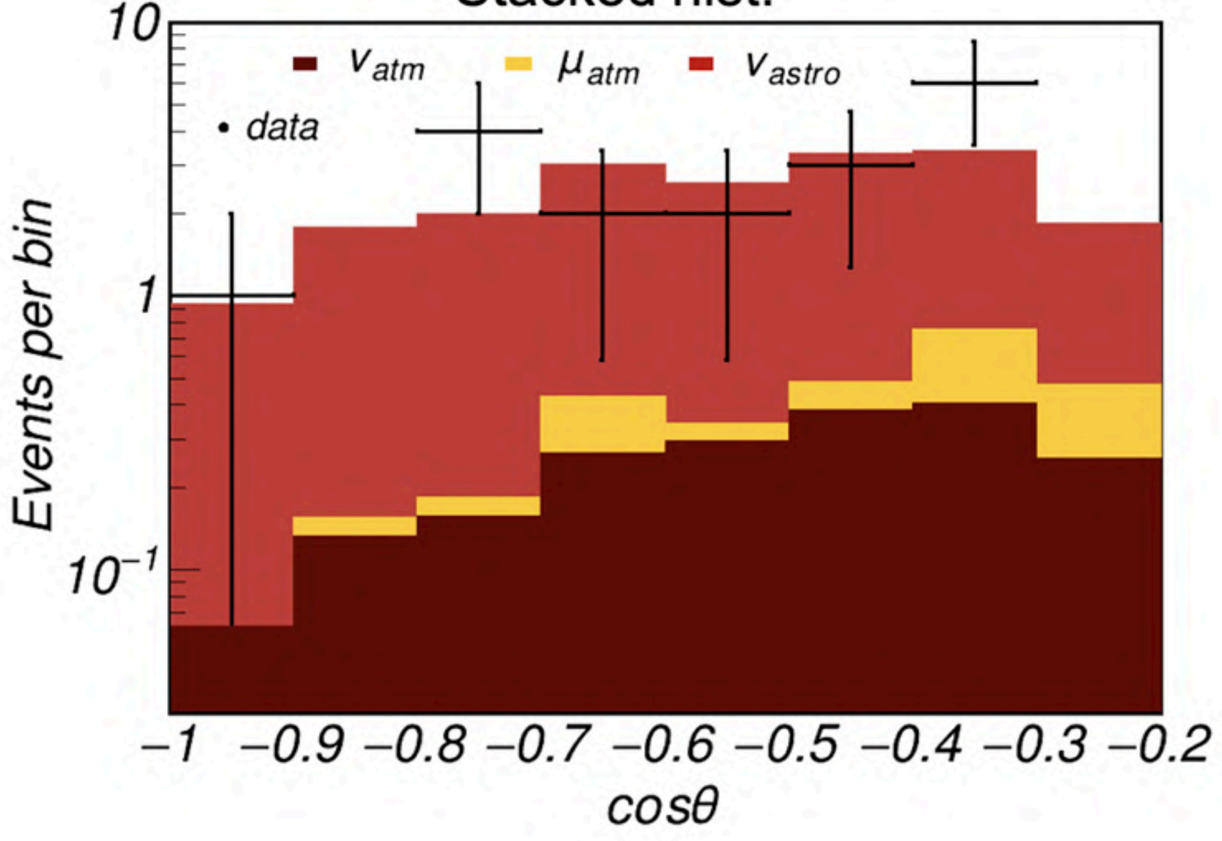
Energy distribution (18-23)

Stacked hist.



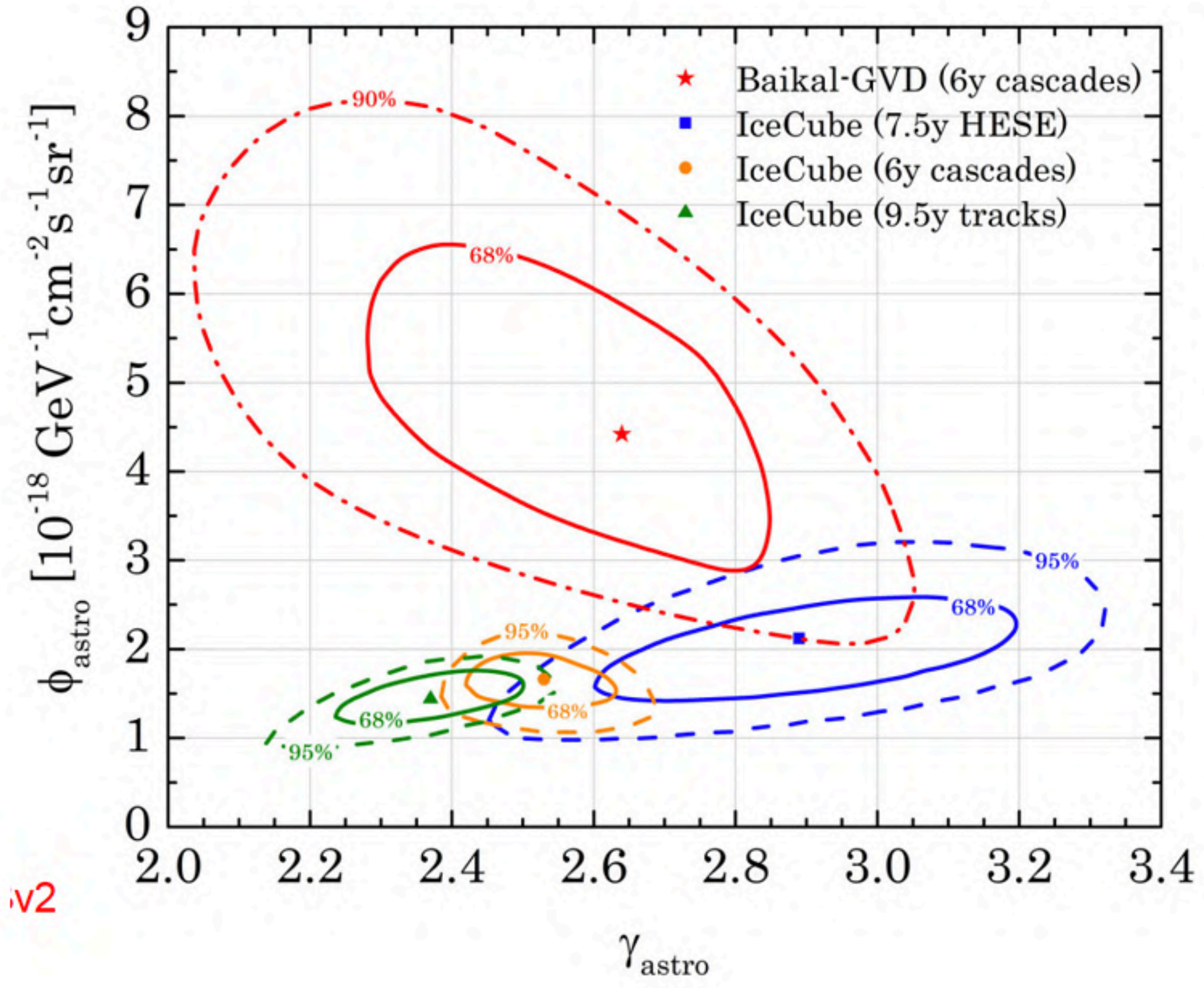
Zenith distribution (18-23)

Stacked hist.



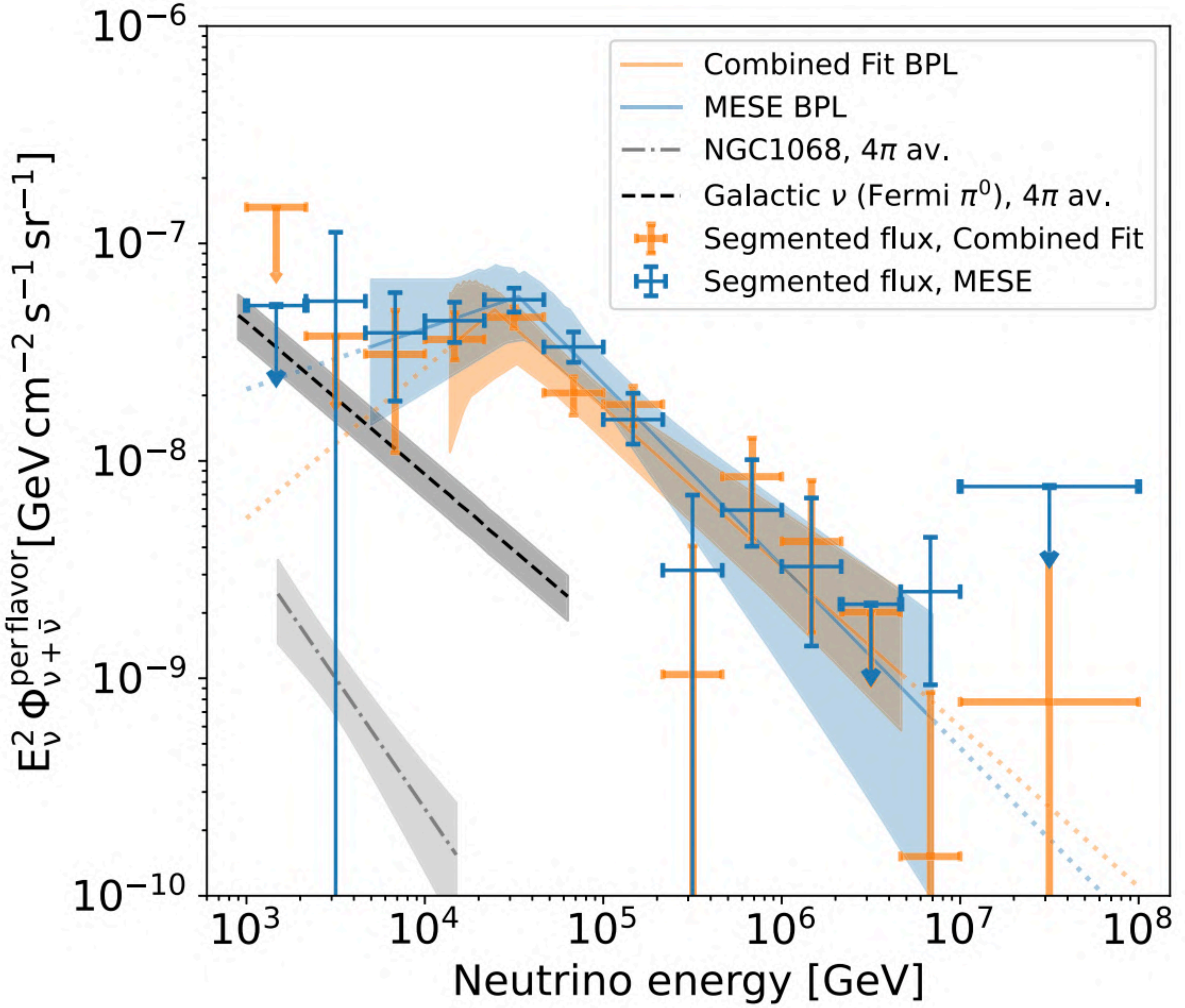
First independent observation of diffuse cosmic neutrino flux at 5.1 sigma!!!

- upgoing cascade on 2018-2023 data sample
- flux larger than IceCube flux



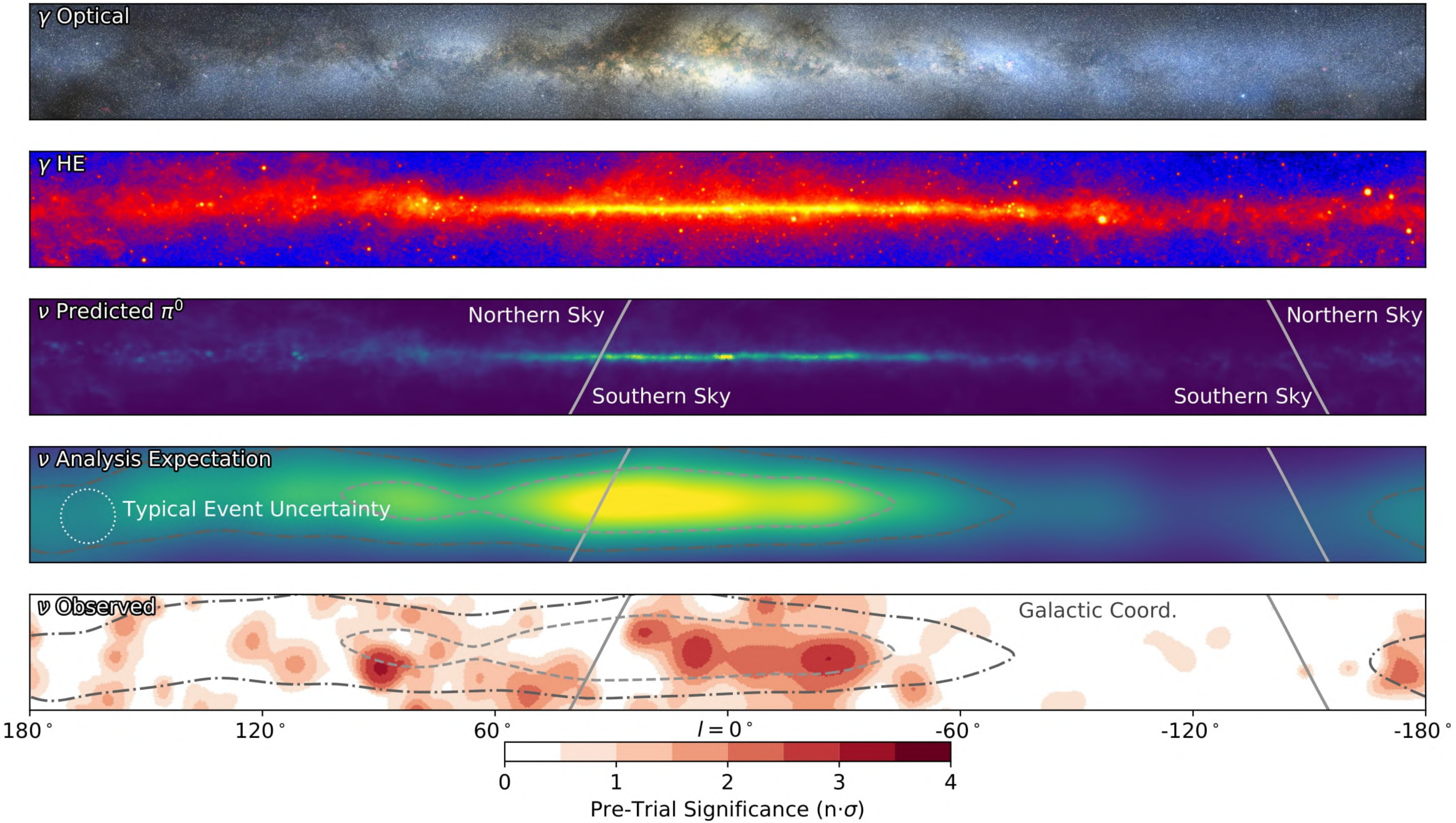
Baikal is located in North hemisphere!!

Evidence for Spectral Break



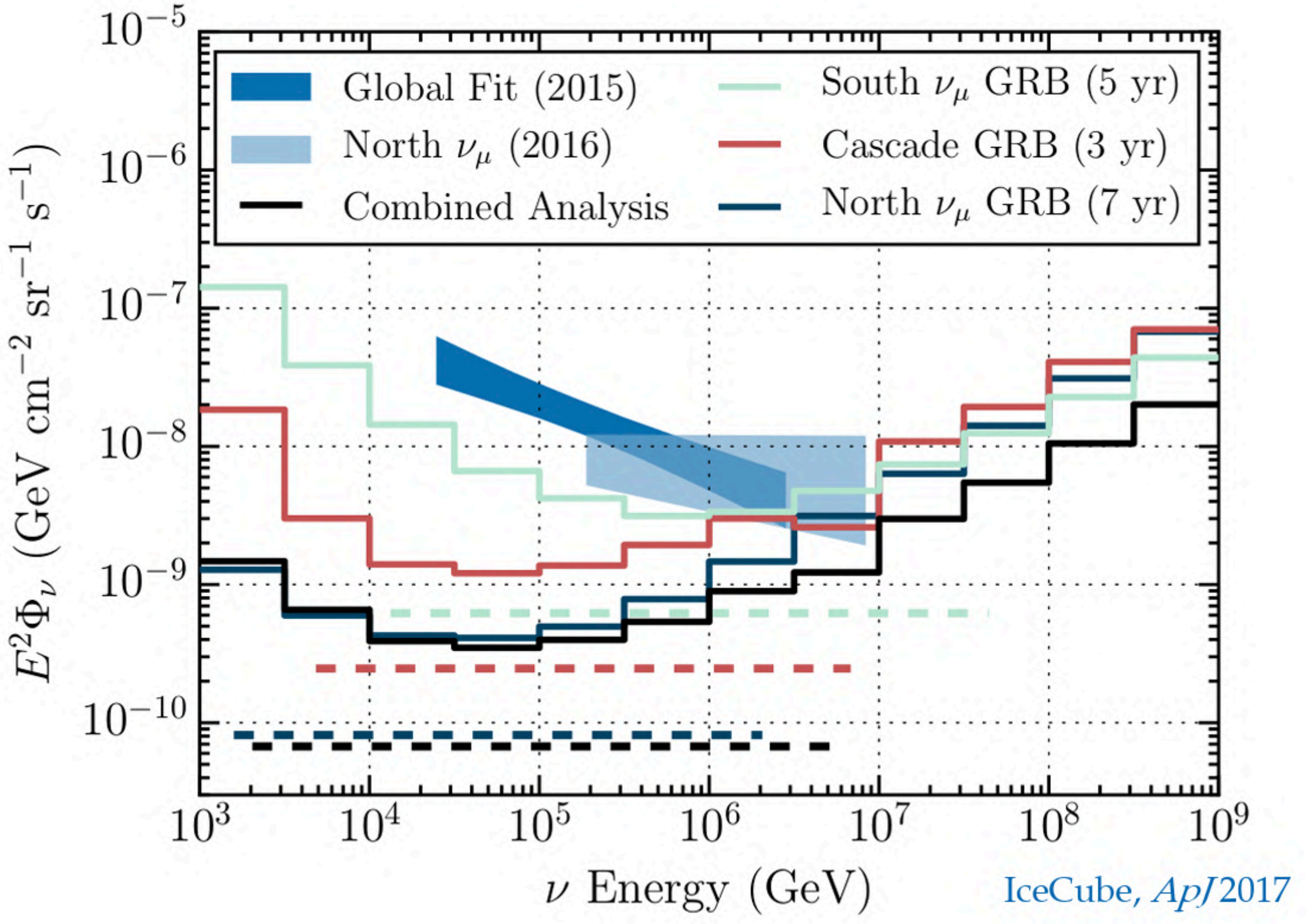
R. Abbasi et al. (IceCube Collaboration), PRL 136, 121002 (2026)

Galactic Plane in Neutrinos



Gamma-ray bursts and blazars – *not* dominant

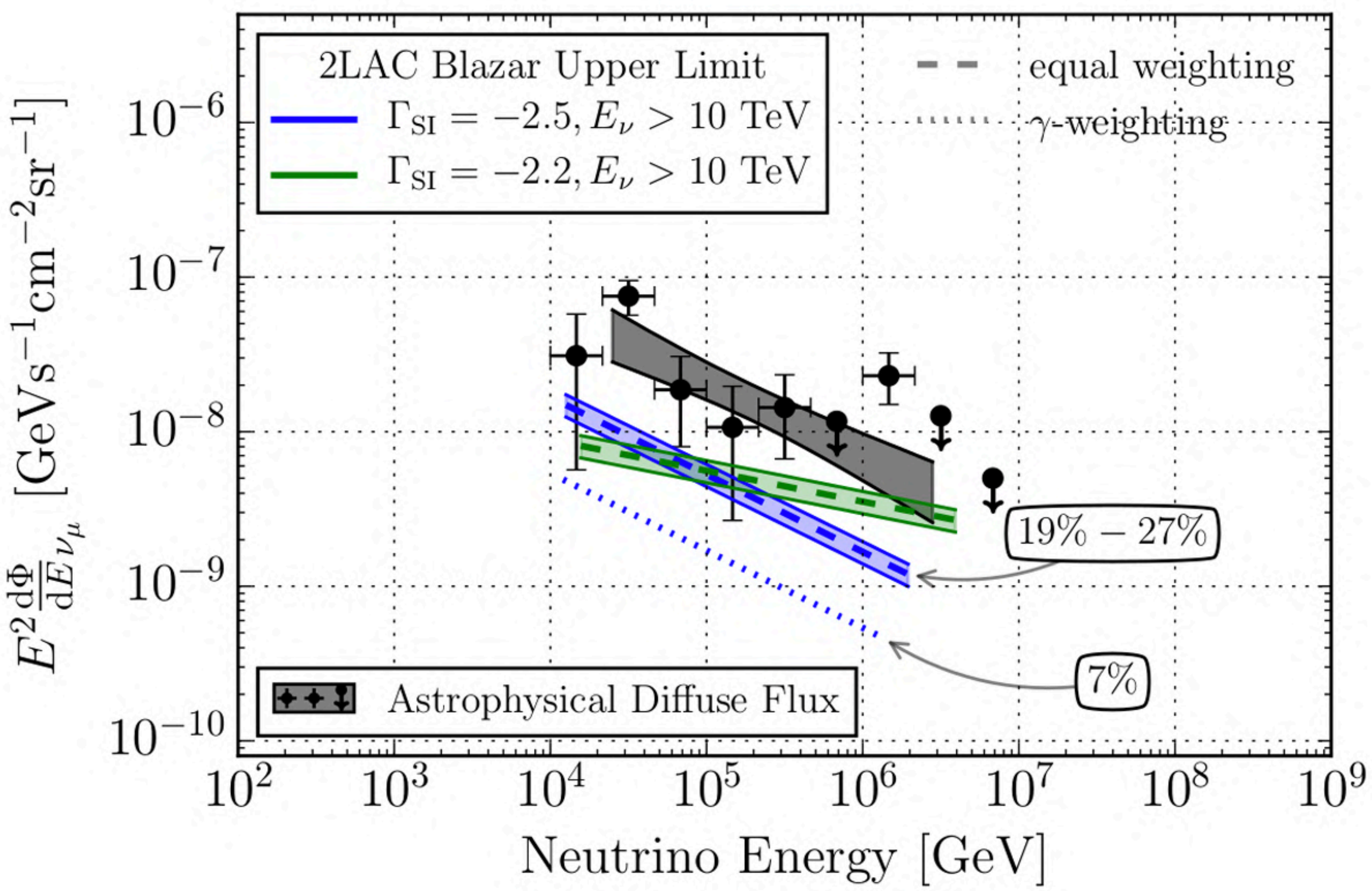
Gamma-ray bursts



1172 GRBs inspected, no correlation found

$< 1\%$ contribution to diffuse flux

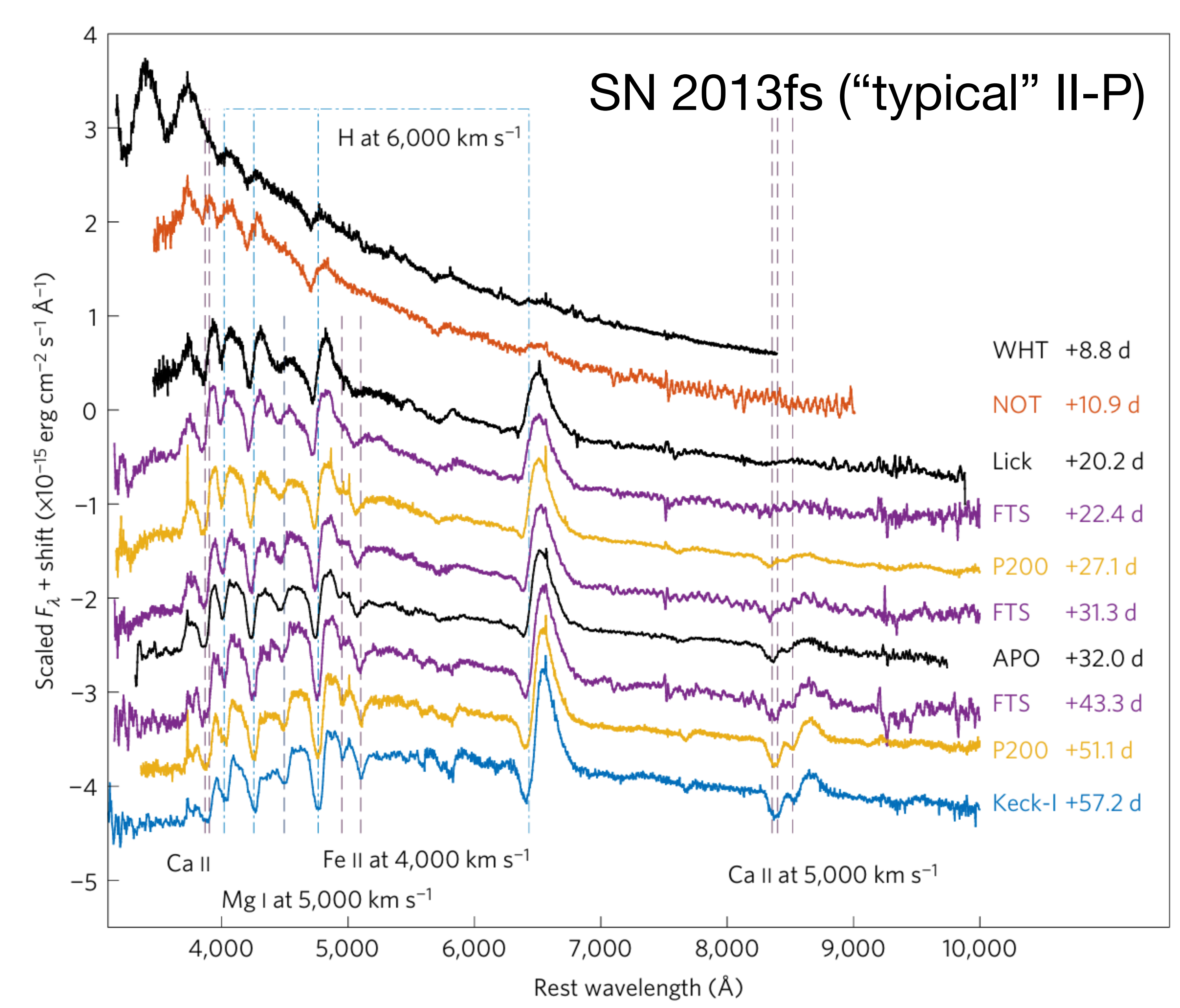
Blazars



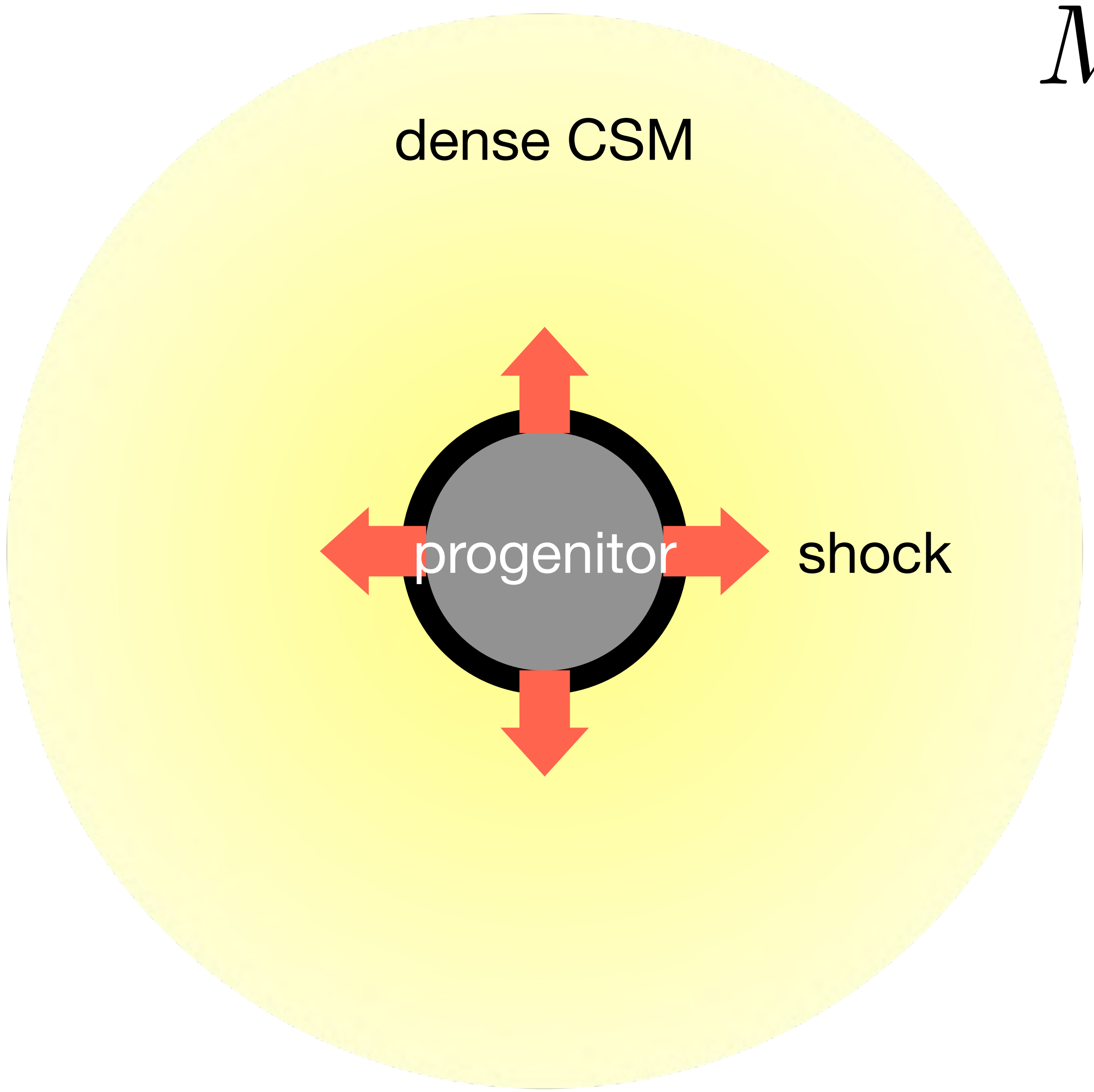
862 blazars inspected, no correlation found

$< 27\%$ contribution to diffuse flux

Dense Circumstellar Material

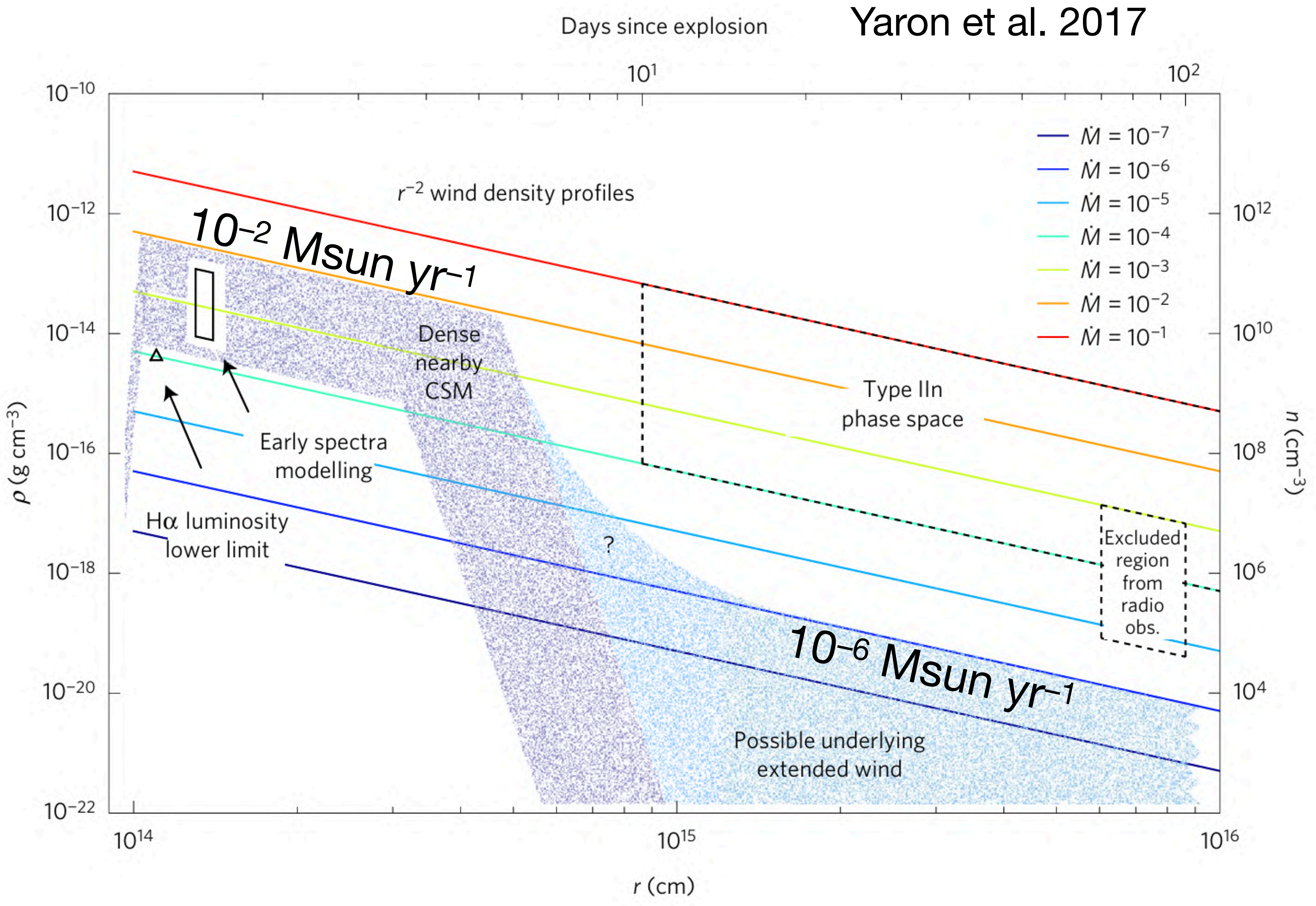


- Existence of **dense CSM** is proposed from optical surveys.
- Its cause is still unknown; mass-loss rate increases at the very end?
  - Core convection
  - Mass exchange in a binary system
  - … etc



$$\dot{M}_{\rm loss} = 4\pi\rho v_{\rm esc} r^2 = {\rm const.}$$

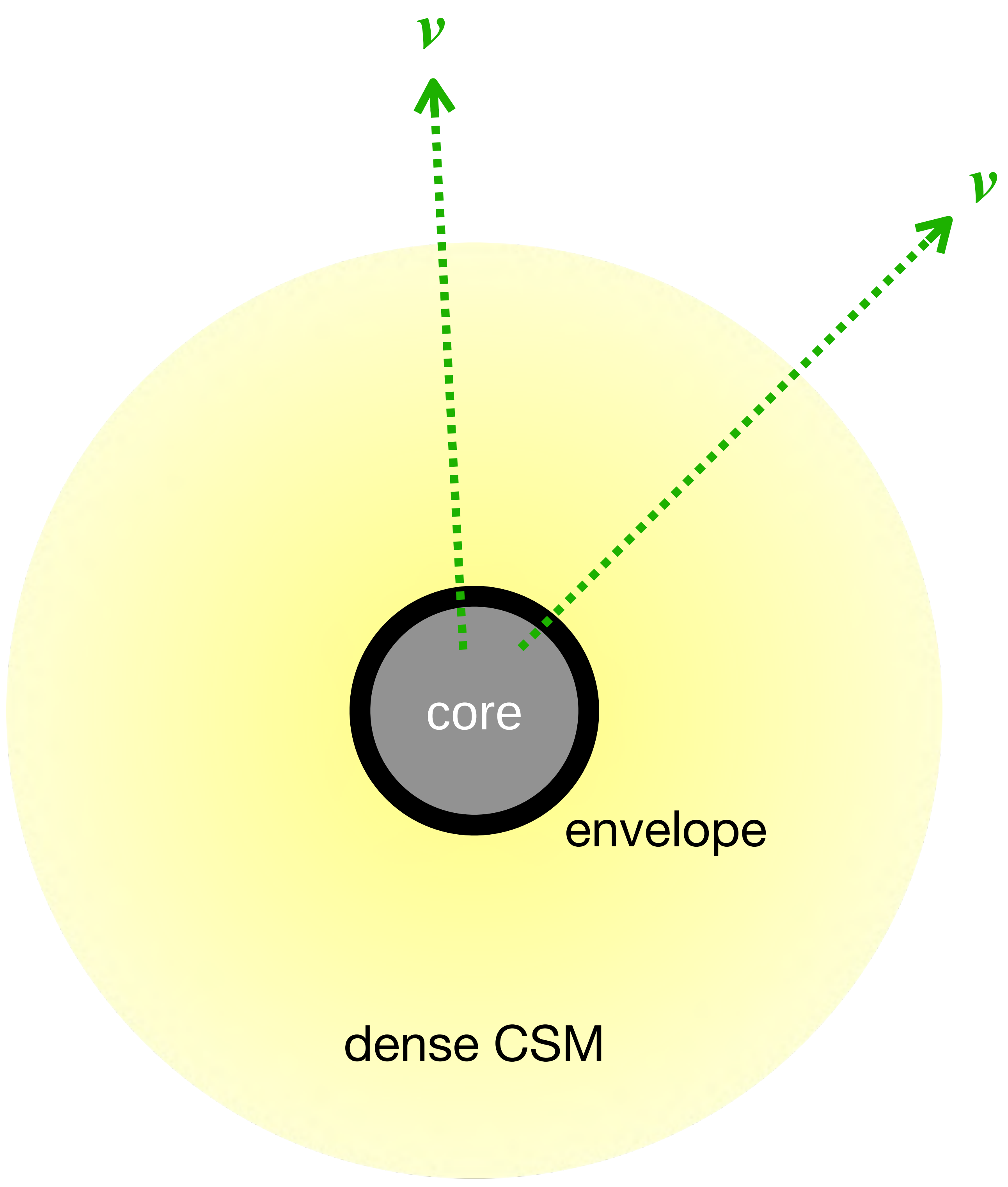
$$\Rightarrow \rho \propto r^{-2}$$



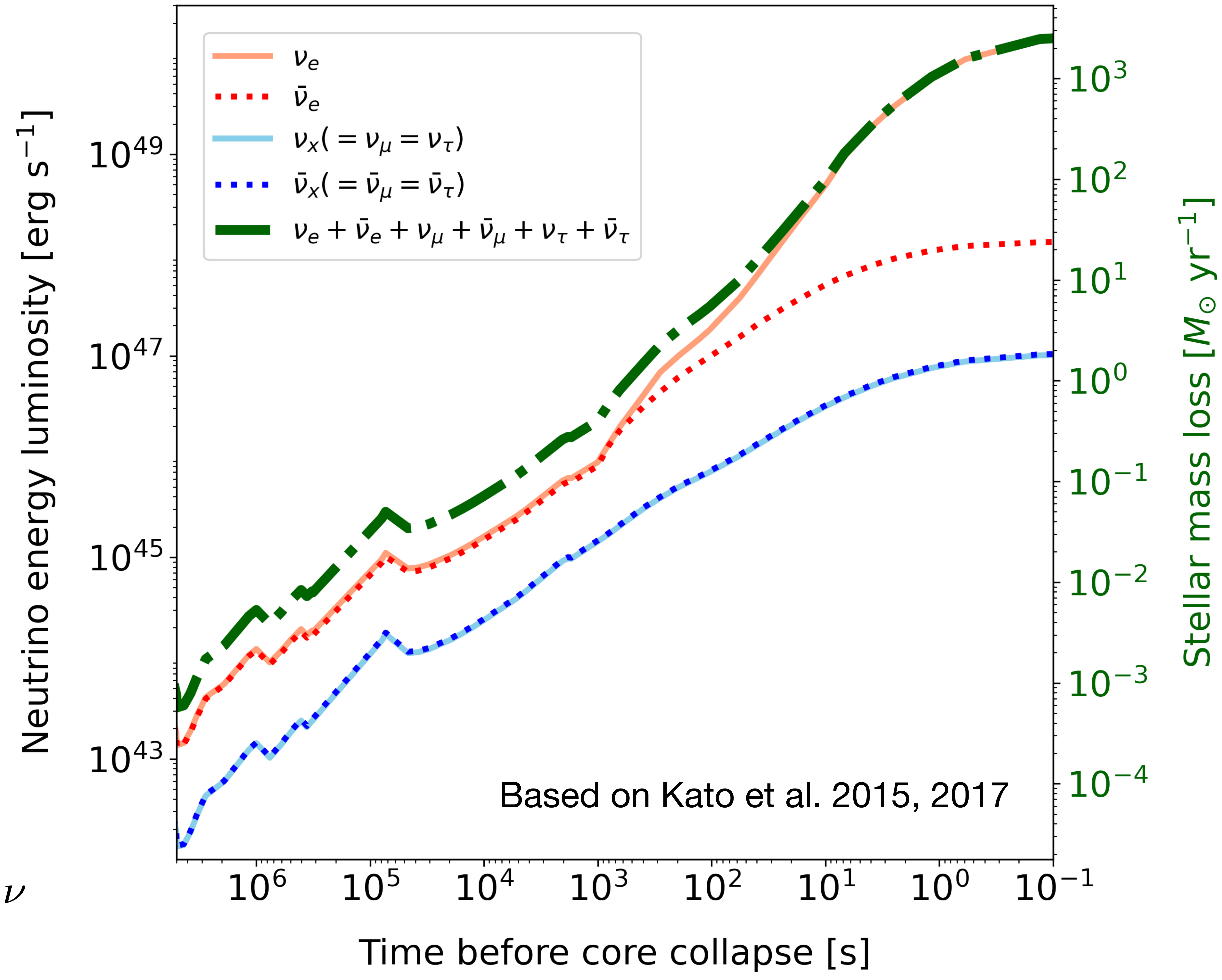
Pre-SN Neutrino Release for CSM Formation

Gravitational bind gets weaker due to pre-SN neutrino release, leading to stellar mass loss?

$$\dot{M}_{\rm loss} = \frac{L_\nu}{c^2} = 6.8 \times 10^{-3} \left(\frac{L_\nu}{10^{11} L_\odot} \right) M_\odot \ {\rm yr}^{-1}$$



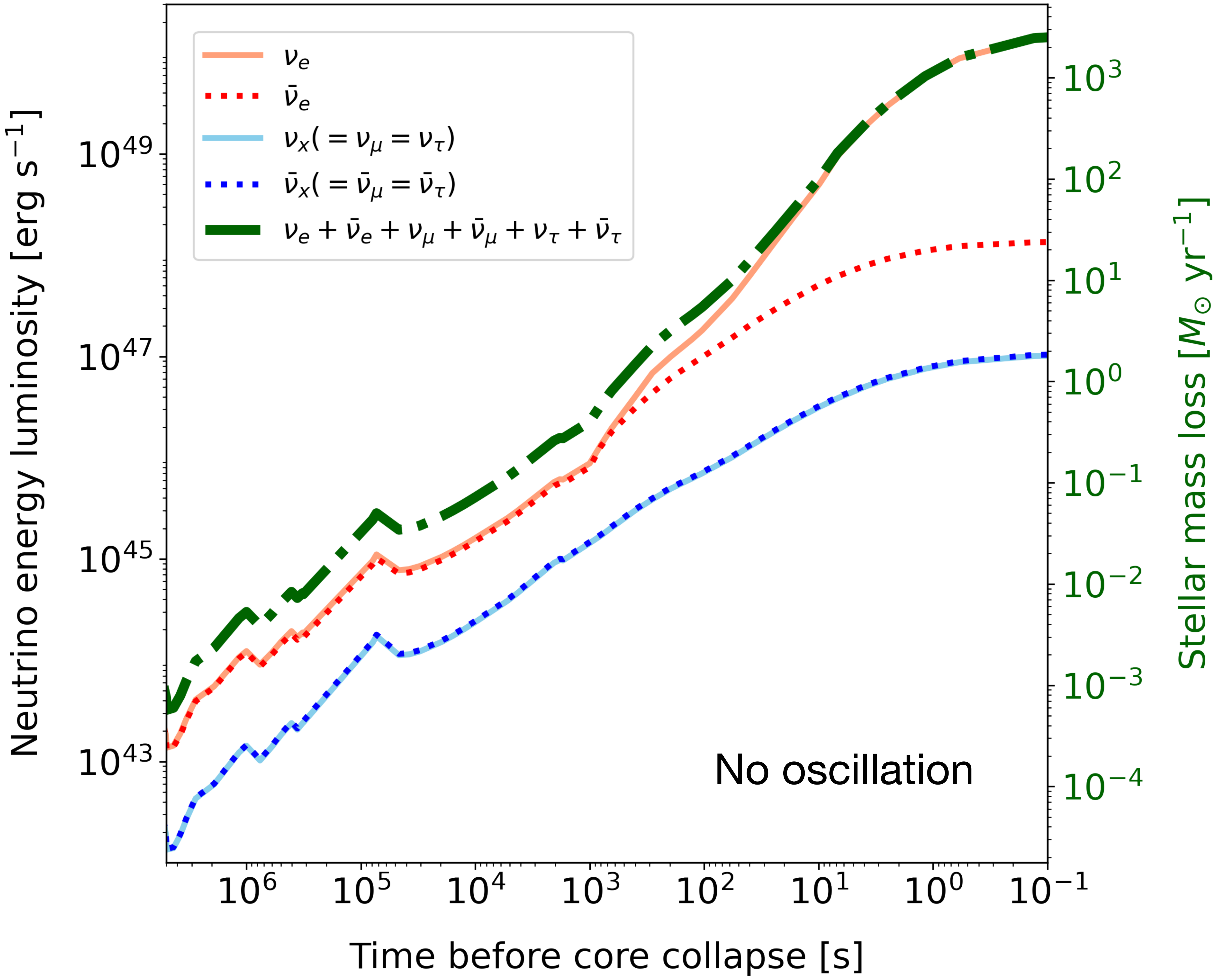
$$\dot{M}_{\rm csm} \propto L_{\text{pre-}\nu}$$



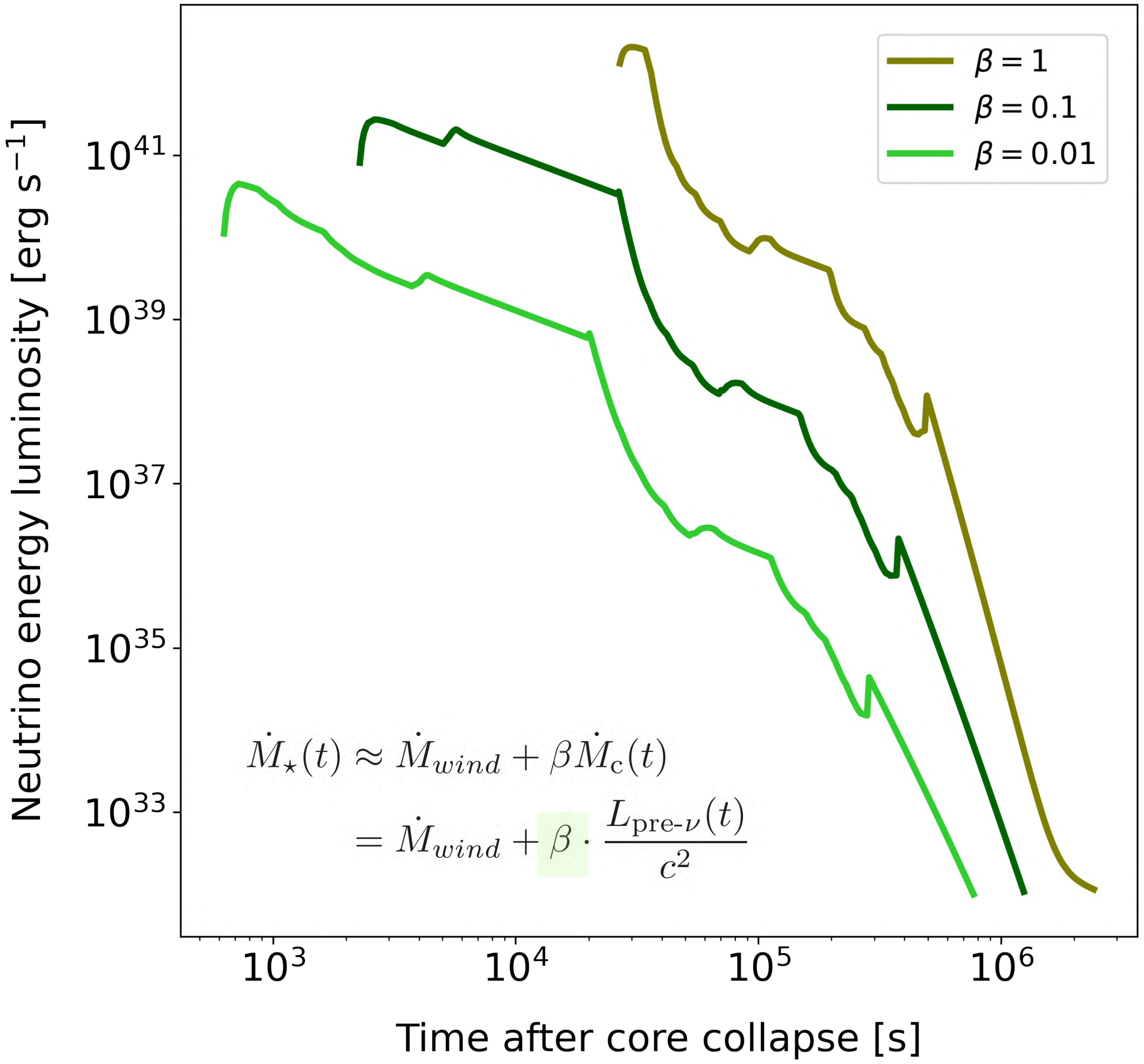
Neutrino Light Curve

R. Sawada, Y. Ashida, ApJ 982, 2 (2025)

pre-SN ν



CSM ν

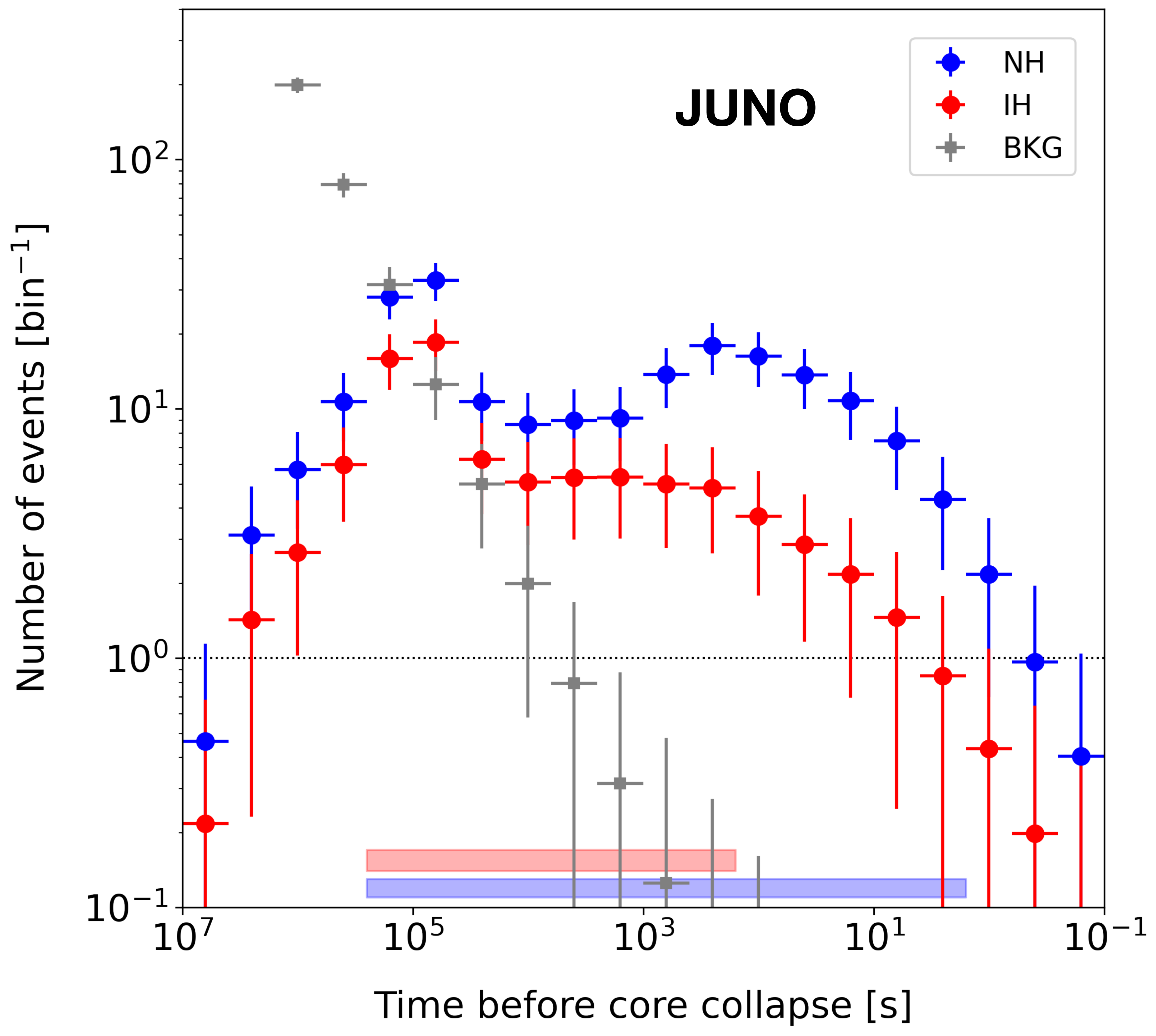


Expected Event Rate (300 pc)

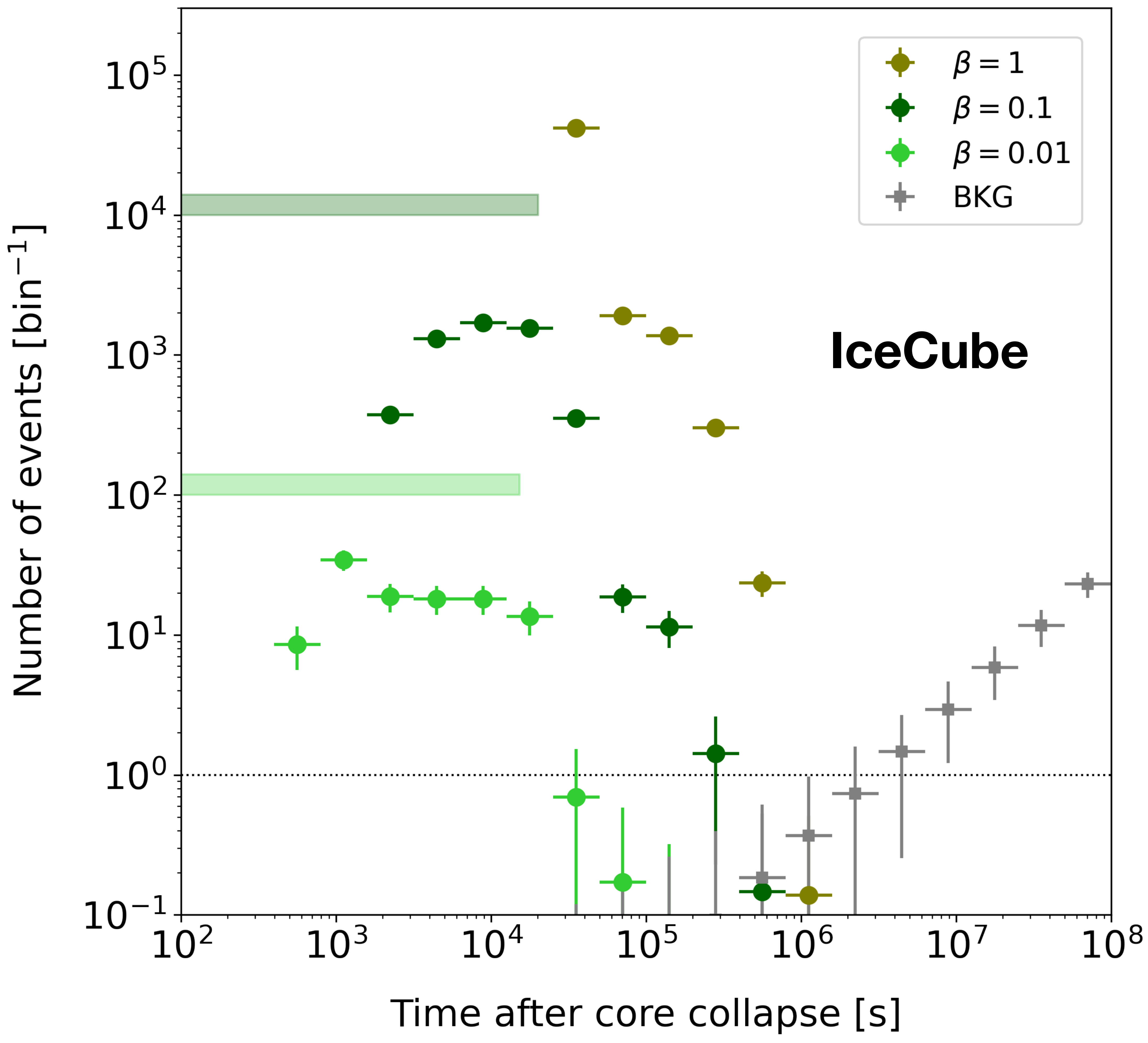
R. Sawada, Y. Ashida, ApJ 982, 2 (2025)

Detectable range: $\frac{N_{\rm sig}}{\sqrt{N_{\rm sig}+N_{\rm bkg}}} > 2$ and $N_{\rm sig} > 1$

pre-SN ν



CSM ν



Applicable Parameter Space

R. Sawada, Y. Ashida, ApJ 982, 2 (2025)

- Estimation performed along distance and mass-loss efficiency.

- Applicable up to **~500 pc**, which could be extended to **O(1) kpc**.
  - Wider analysis window at JUNO
  - Background reduction at JUNO (e.g., reactor)
  - Combined data from multiple experiments

- A few candidate Walf-Rayet stars in ~1 kpc (closest is WR 11 at ~340 pc).

- Hyper-K is probably able to detect both pre-SN and CSM neutrinos alone.