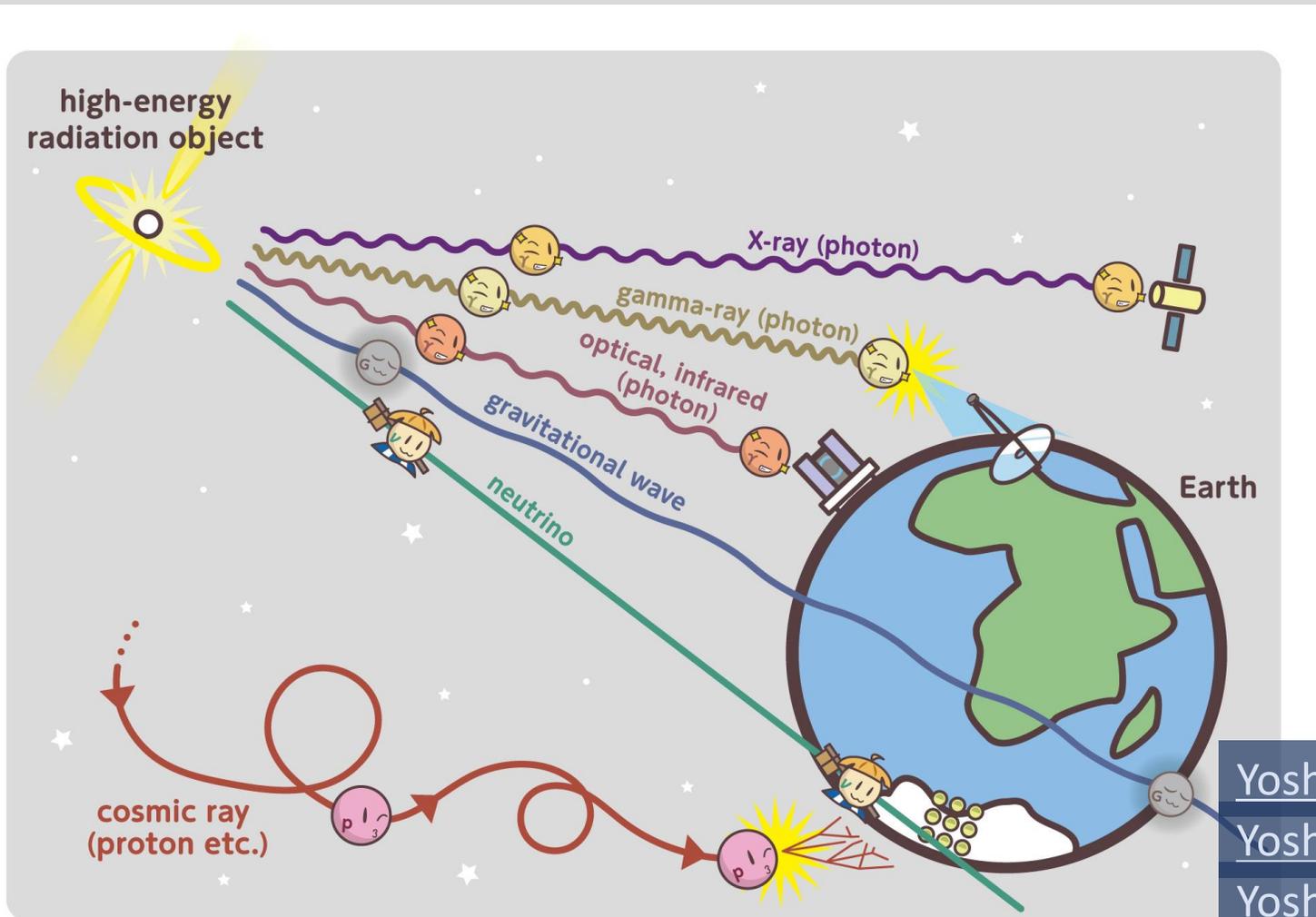


# Identifying cosmic ray transient sources with multimessenger observations



Shigeru Yoshida

International Center for Hadron  
Astrophysics

Chiba University

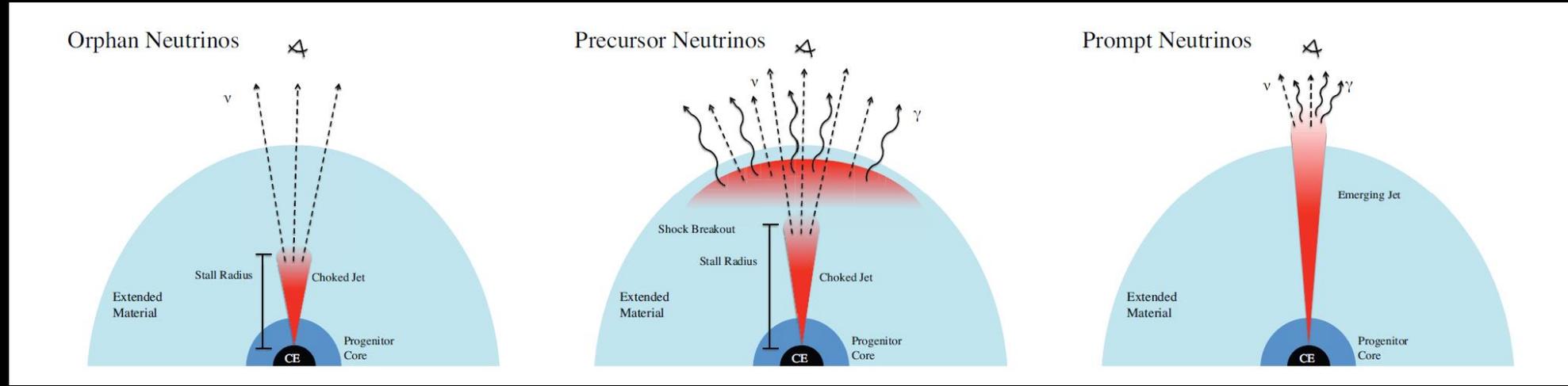
Yoshida, Murase, Tanaka, Shimizu, Ishihara, ApJ(2022)

Yoshida & Murase PRD (2020)

Yoshida & Murase PRD (2024)

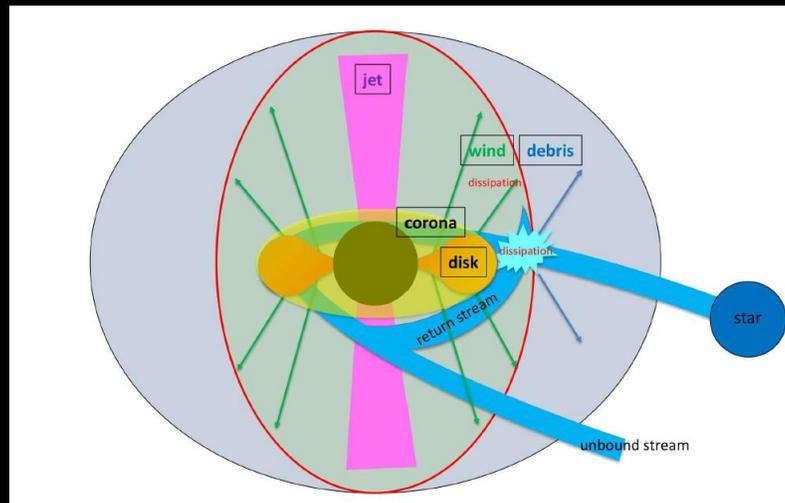
# High-Energy Neutrino Transients

GRB (SN) -like  
(mildly) relativistic jet



Seno, Murase, Meszaros PRD (2016)

TDE-like  
corona, wind..



Murase+ ApJ (2020)

# They are (either) optical-NIR and/or Xray transients

## Optical-NIR

Circumstellar Matter (CSM) Supernova      Observed as Type II, sometimes Type Ibc

optical emission powered by the CSM interactions  
collisions between SN ejecta and CSM provide CR acceleration

Wind-driven TDE

## X-ray

Low-luminosity GRB, jetted TDE

CR acceleration in mildly relativistic jet

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# The optical transient sky is too busy



~ **100** SNe are found in  $z < 2$  within  $1 \times 1 \text{ deg}^2$  sky patch!

We can't tell which one out of ~100 SNe is the neutrino source!

These SNe are **background**, but a few of them could be **signals**

Type 1A – definitely **BACKGROUND**

core-collapse SNe, wind-driven SNe, low-luminosity GRBs

→ They can be  $\nu$  **SOURCES**, but may appear as **Type Ibc or II**

**A difficult business**

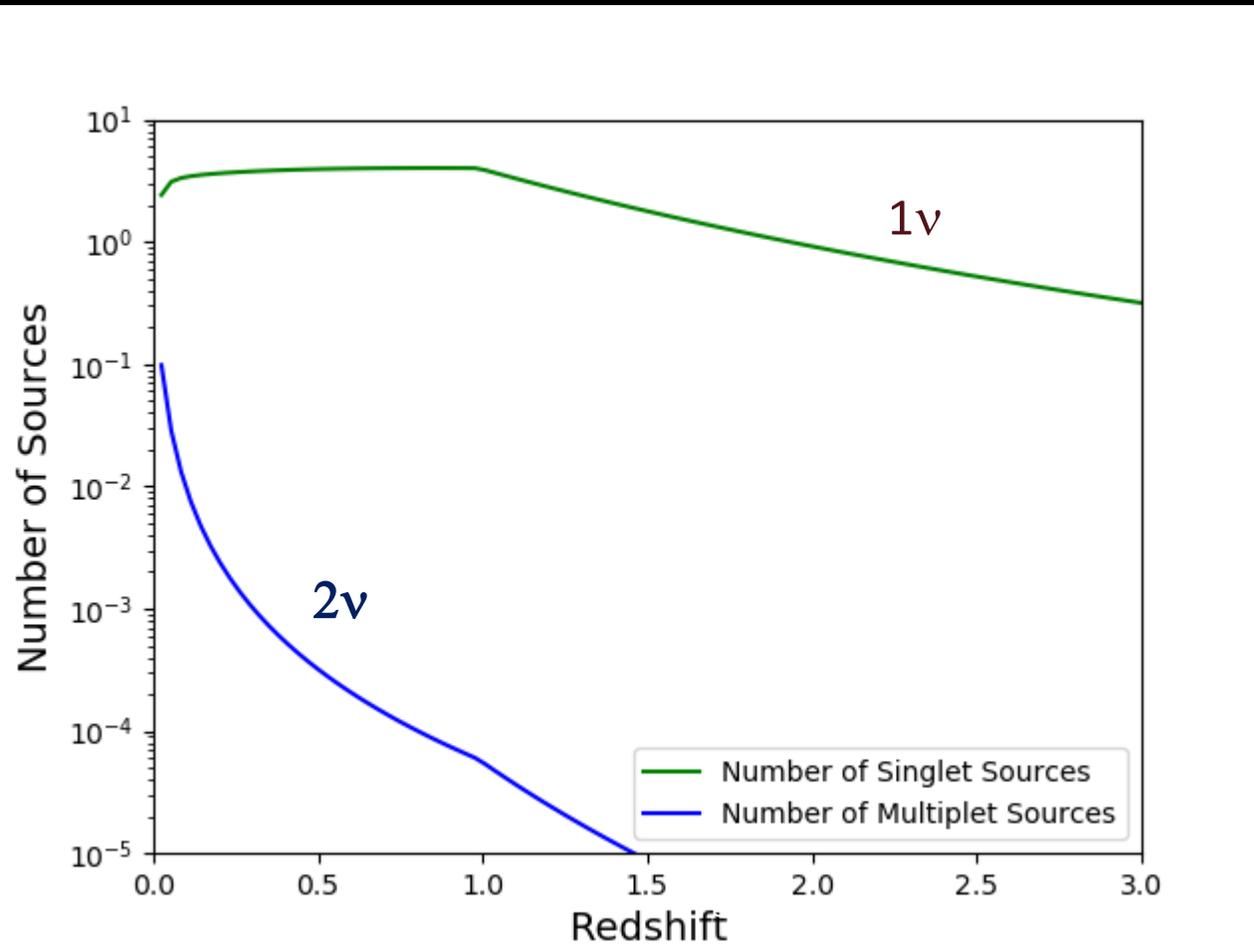
We need to filter out SNe but a few of them may be our sources

# Demanding $\nu$ doublet detection

**2  $\nu$**  from the same direction within a time of  $\Delta T$  (**30 days**)

Example

$$E_\nu = 3 \times 10^{49} \text{ erg} \quad \rho_\nu = 3 \times 10^{-6} \text{ Mpc}^{-1} \text{ yr}^{-1}$$



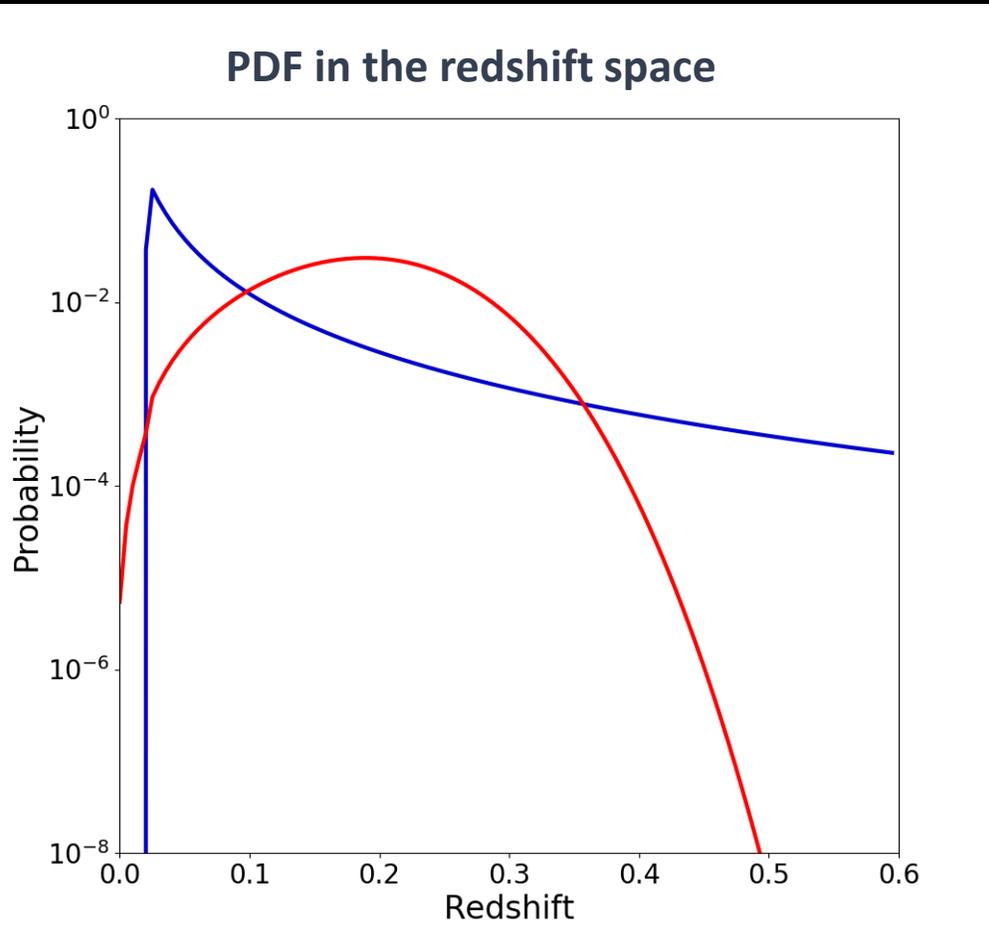
88% of sources to yield  $\nu$  doublet detection are  $z < 0.15$

→ Limits the transient counterparts!

Yoshida, Murase, Tanaka, Shimizu, Ishihara, ApJ(2022)

# Identify the $\nu$ source

Test the hypothesis that the closest transient object is the  $\nu$  doublet source



Select the **closest** (the smallest  $z$ ) object found in the  $\Delta\Omega = 1 \text{ deg}^2$

- Yes! It is the source to yield  $\nu$  doublet detection
- Nope. Unassociated SN tracing SFR-like evolution

Example:

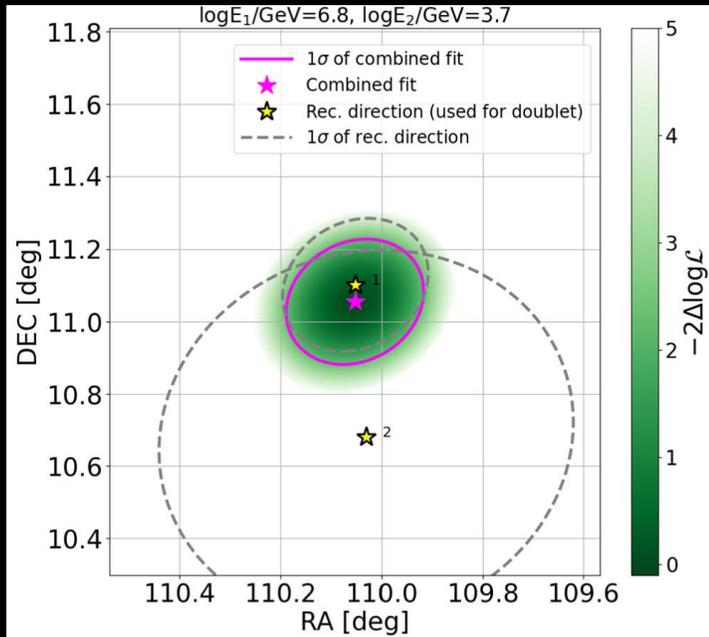
Found a transient at  $z = 0.05$

p-value to support **—** is  $9 \times 10^{-3}$   
( $\sim 2.4 \sigma$  rejection)

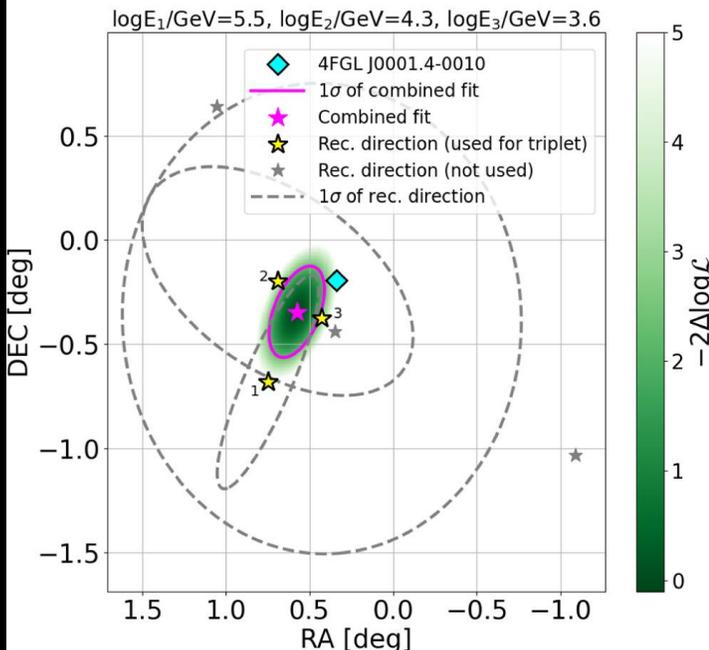
Yoshida, Murase, Tanaka, Shimizu, Ishihara, ApJ(2022)

# Two potentially interesting multiplets detected by IceCube

(but post-trial p-values are  $\sim 1\sigma$  only)



doublet



triplet

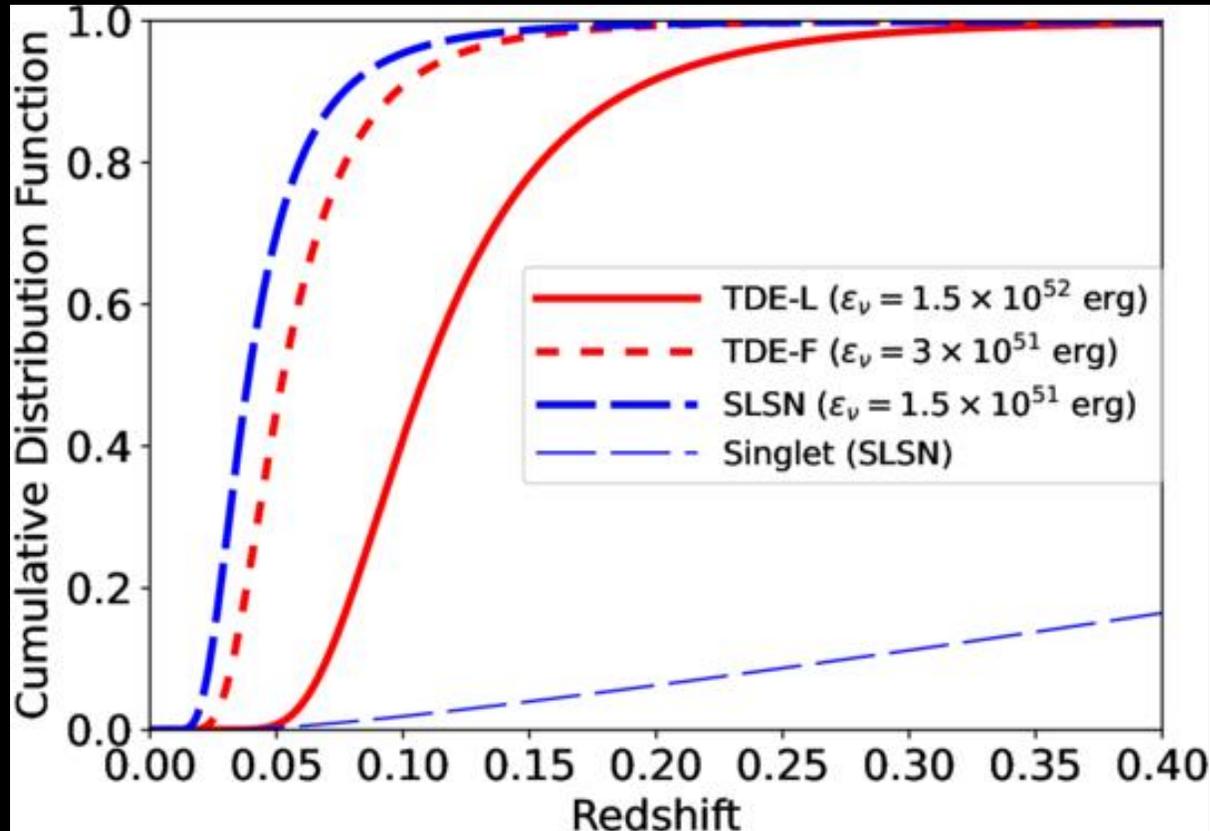
Signalness  $\sim 60\%$

Optical followup searches by ZTF

Toshikage+ ApJ (2025)

IceCube Collaboration ApJ (2025)

# Limiting redshift by demanding multiplet indeed benefits the counterpart searches

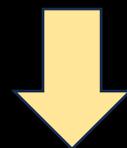


With the ZTF sensitivity

Toshikage+ ApJ (2025)

# Constraints on the parameters of the neutrino-optical transients

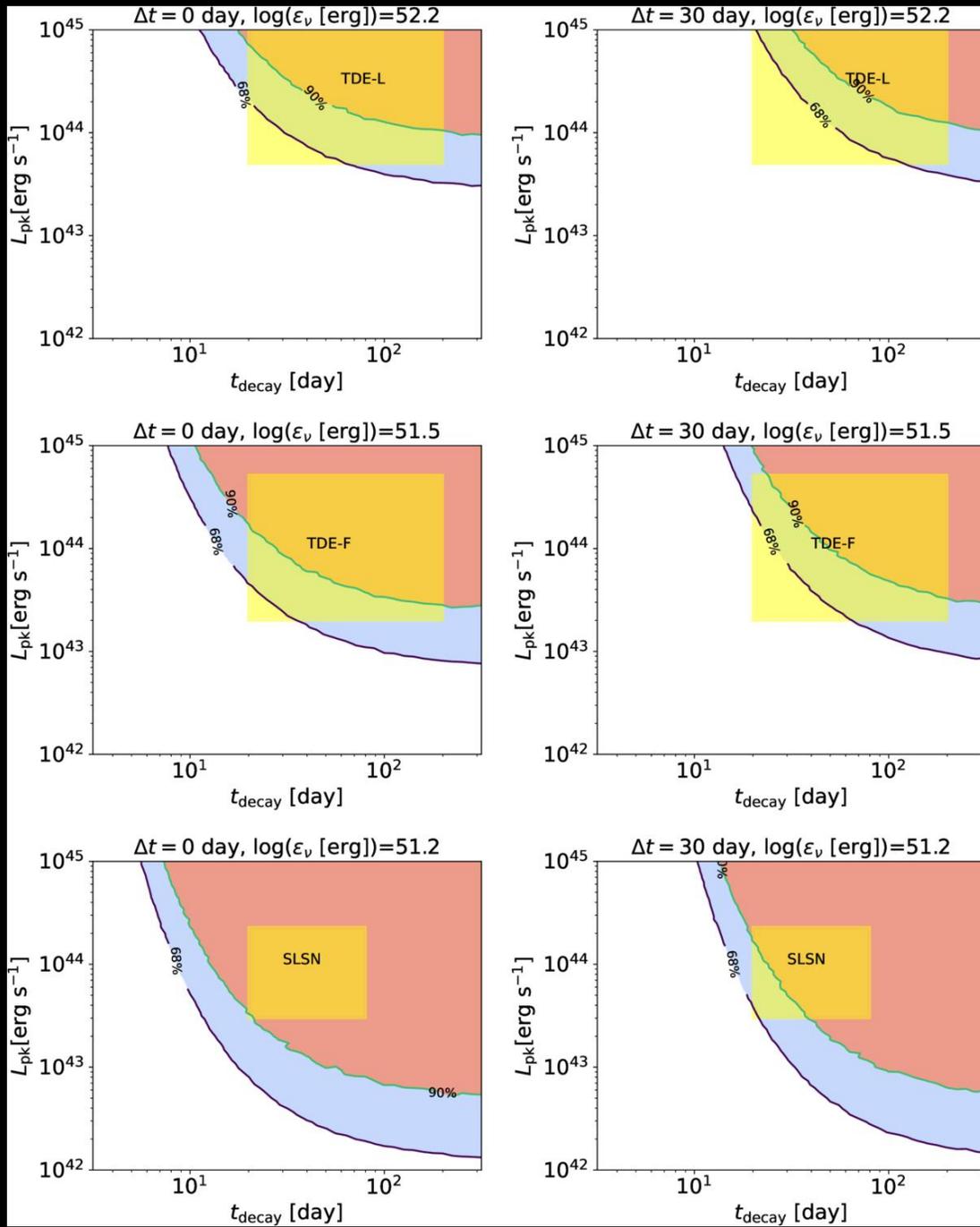
We know the redshift distributions of transients to yield the IceCube triplet for a given neutrino energy fluence



The IceCube all-sky cosmic  $\nu$  background intensity can tell this (will explain next)

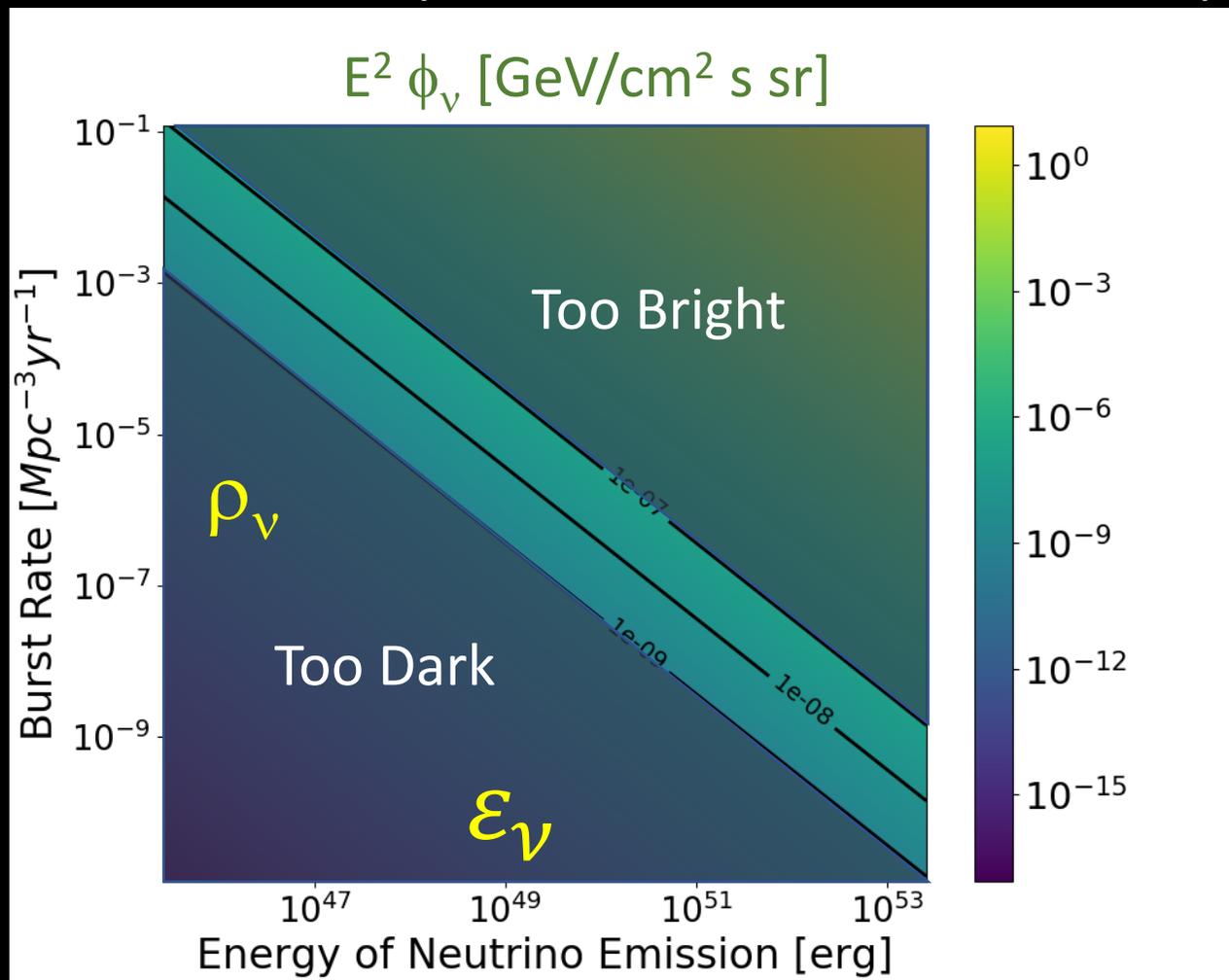
It enables us to directly constrain **source luminosities** (not just fluxes)!

Toshikage+ ApJ (2025)



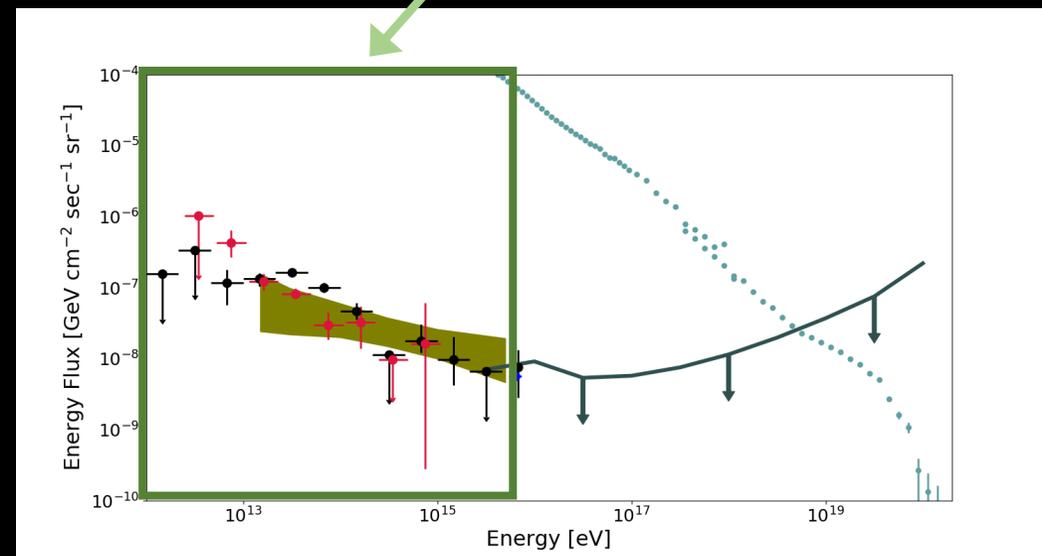
# The parameter space estimated by the all-sky cosmic neutrino background flux

Self consistency – the sources should not overproduce the cosmic background flux



the cosmic background flux measured by IceCube

$$E^2 \phi_\nu = 10^{-8} \sim 10^{-7} \text{ GeV/cm}^2 \text{ s sr}$$



We know  $\epsilon_\nu$  [erg] for a given  $\rho_\nu$

Yoshida, Murase, Tanaka, Shimizu, Ishihara, ApJ(2022)

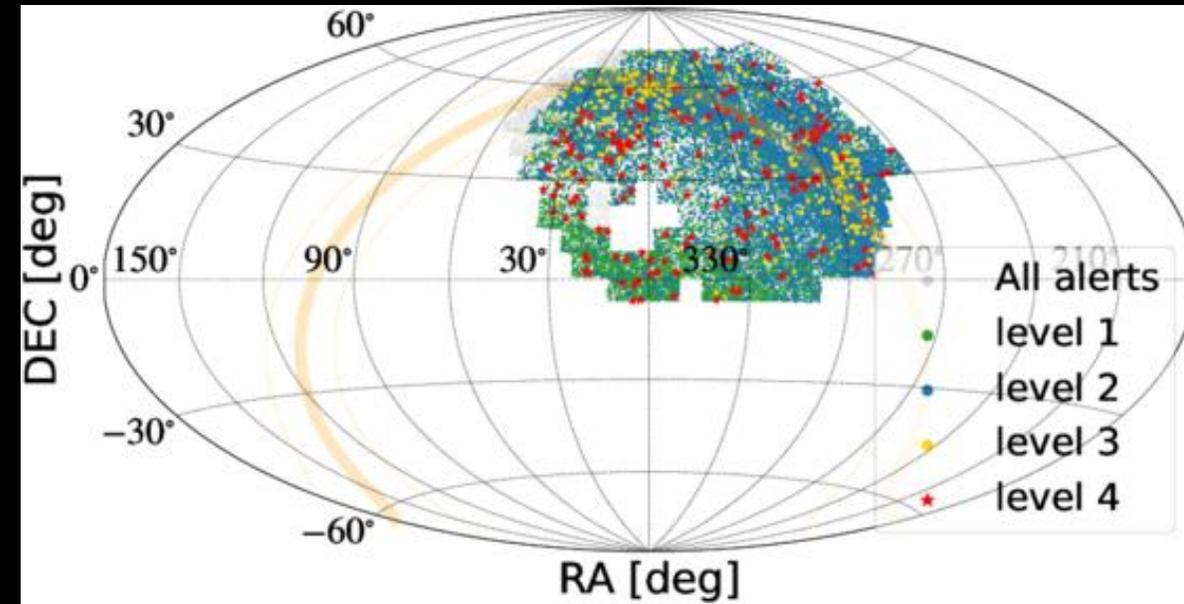
# The limited distance range of the $\nu$ triplet source brings benefits to an optical counterpart search.

We get a nearly background-free environment

**Table 2**  
Summary of the Performance of Our Filtering System

Selection		TPR	WF	Number of background WF (deg <sup>-2</sup> )	ME2 (deg <sup>-2</sup> )
All 5 $\sigma$ detections		...	126,645	19.5 $\pm$ 0.1	...
level 1 selection (removing bogus detections)	g-band	0.628 $\pm$ 0.010	33,339	5.13 $\pm$ 0.03	...
	r-band	0.578 $\pm$ 0.009			...
level 2 selection (removing moving objects)	g-band	0.948 $\pm$ 0.007	11,622	1.79 $\pm$ 0.02	...
	r-band	0.995 $\pm$ 0.003			...
level 3 selection (removing known variable sources)	sgscore	0.9950 $\pm$ 0.0004	1,809	0.279 $\pm$ 0.007	0.241 $\pm$ 0.017
	Gaia variable	0.9987 $\pm$ 0.0004	449	0.069 $\pm$ 0.003	0.111 $\pm$ 0.012
	Gaia proper motion	0.9985 $\pm$ 0.0004	416	0.064 $\pm$ 0.003	0.102 $\pm$ 0.011
	AGN	0.9973 $\pm$ 0.0005	397	0.061 $\pm$ 0.003	0.094 $\pm$ 0.011
level 4 selection (removing variable sources using light curves)	Duration ( $\Delta t_{\text{neg}}$ )	0.9977 $\pm$ 0.0016	138	0.021 $\pm$ 0.002	0.084 $\pm$ 0.010

**Note.** For the level 1 and level 2 selections, we show the TPR for detections in the typical magnitude range (18.5–19.0 mag). The 1 $\sigma$  uncertainties reported for TPRs are calculated based on binomial distribution. For the number of background objects, we show the cumulative number of alerts for the detection-wise criteria (level 1 and level 2) and the cumulative number of objects for the object-wise criteria (level 3 and level 4) with the 1 $\sigma$  statistical uncertainties ( $\pm \sqrt{N}$  of the original numbers of background objects).



The rate of the backgrounds (mostly unassociated SN-like objects and AGNs) was estimated by the control data sample in a blind analysis scheme

Toshikage+ ApJ (2025)

# They are (either) optical-NIR and/or Xray transients

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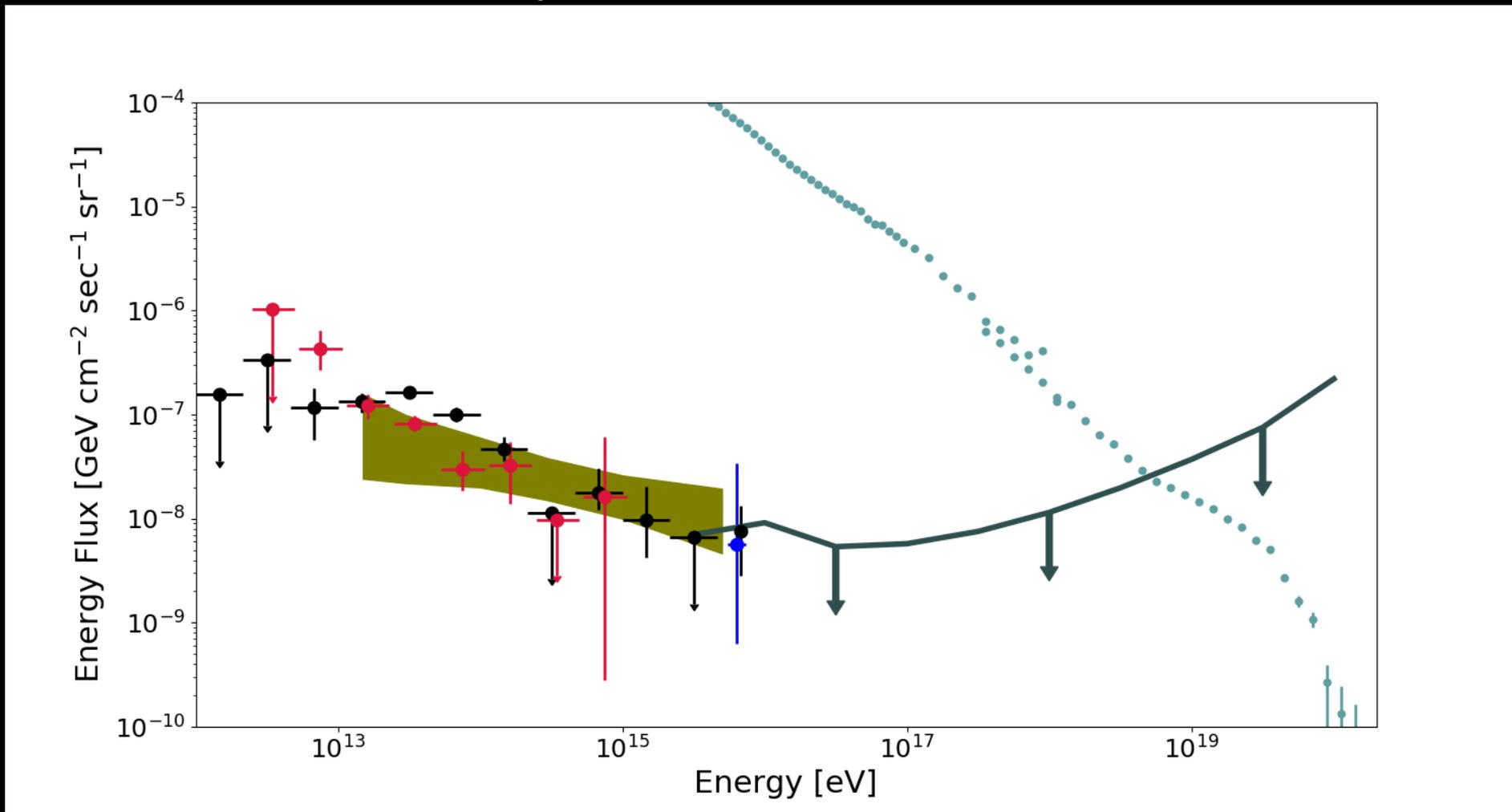
EeV

PeV

EeV

# The UHE Cosmic Background Radiations

Updated : as of 2025



TeV

PeV

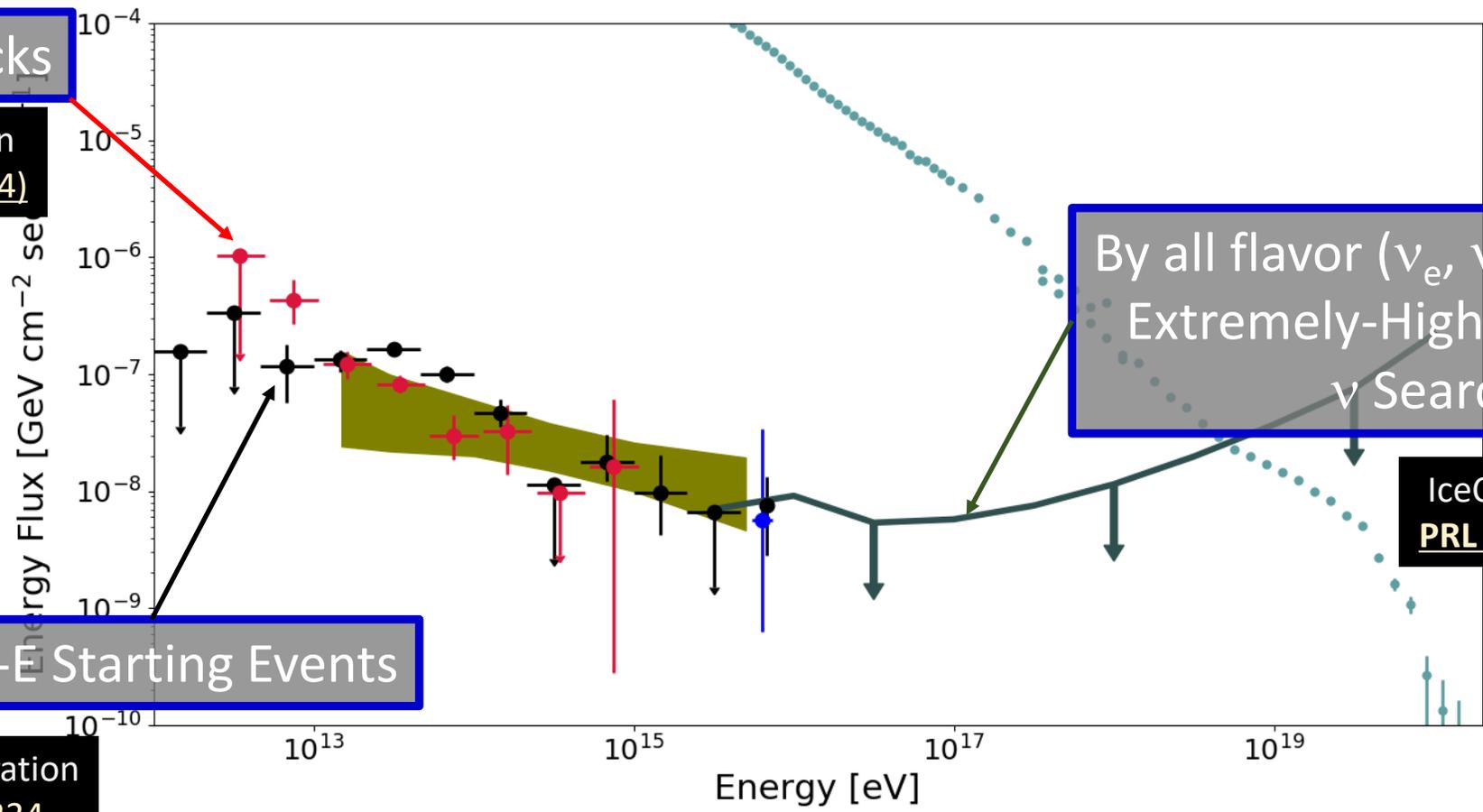
EeV

# The UHE Cosmic Background Radiations

Updated : as of 2025

By Starting Tracks

IceCube Collaboration  
PRD 110 022001 (2024)



By all flavor ( $\nu_e, \nu_\mu, \nu_\tau$ ) sensitive  
Extremely-High Energy (EHE)  
 $\nu$  Searches

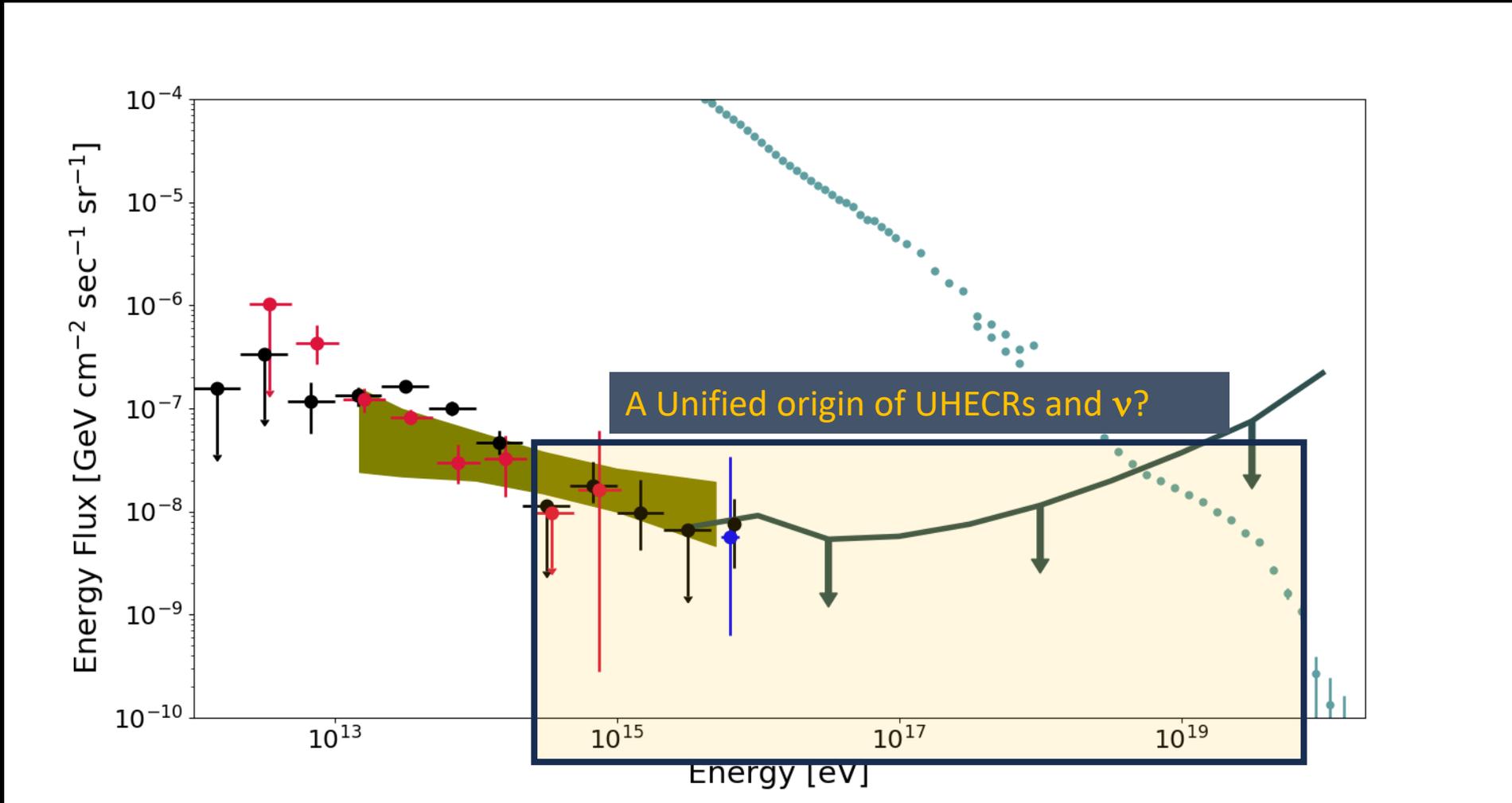
IceCube Collaboration  
PRL 135 031001 (2025)

By Medium-E Starting Events

IceCube Collaboration  
arXiv:2507.22234  
arXiv:2507.22234

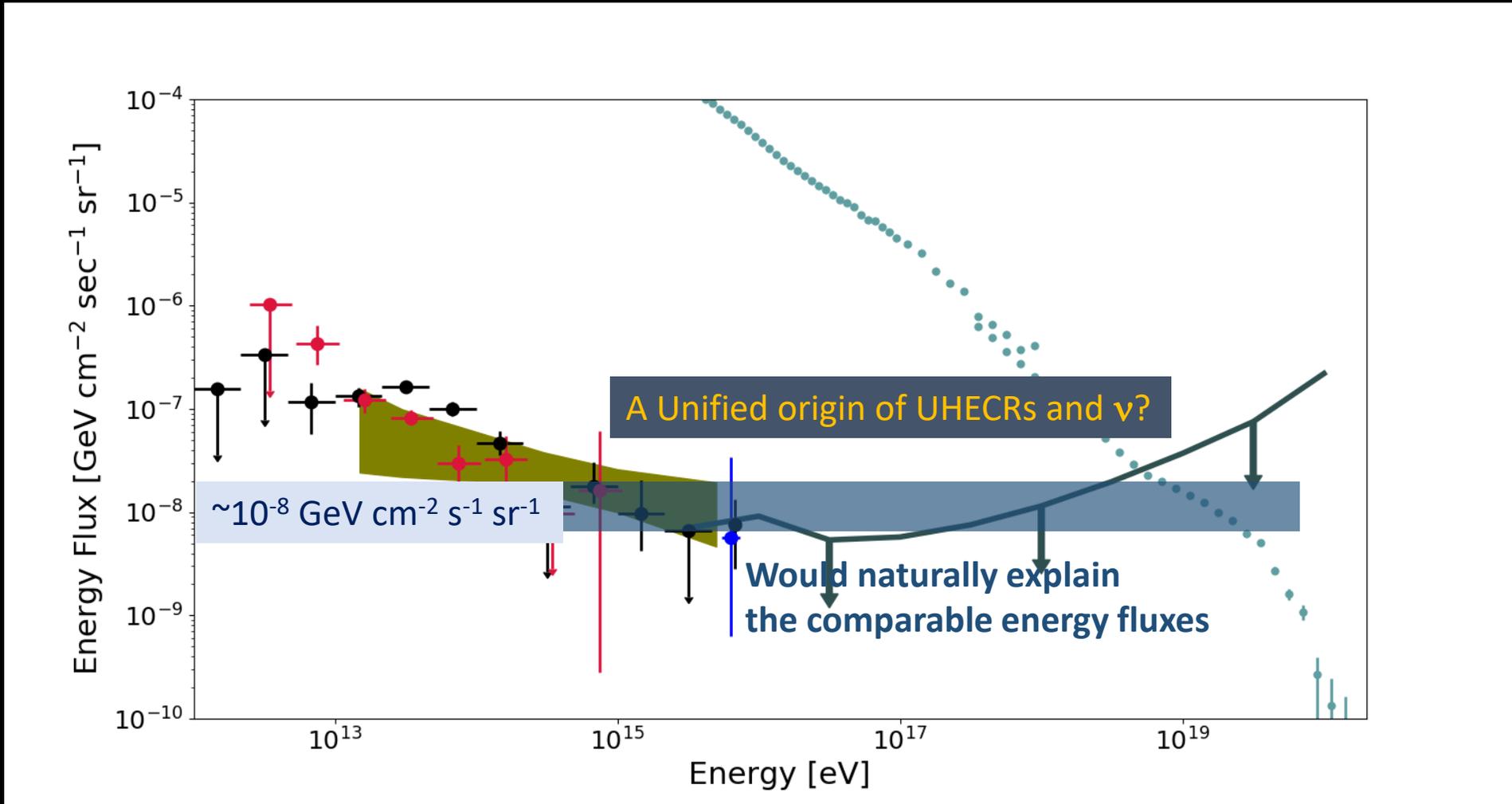
# The UHE Cosmic Background Radiations

## The UHE Cosmic Ray + Neutrino Energy Fluxes

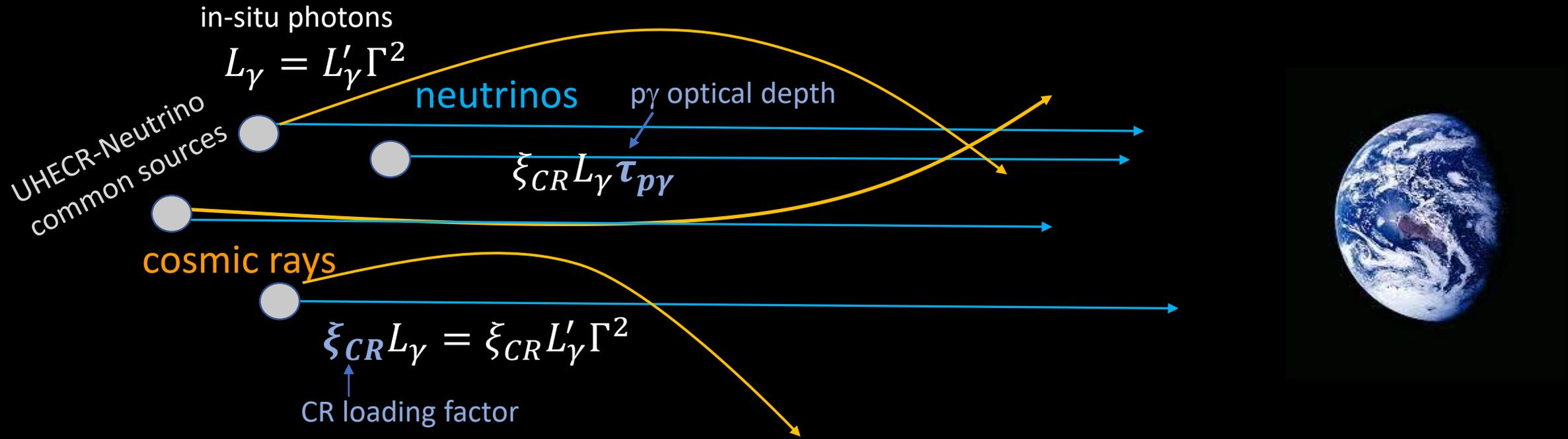


# The UHE Cosmic Background Radiations

## The UHE Cosmic Ray + Neutrino Energy Fluxes



# The generic **unification scheme** via photo-hadronic framework

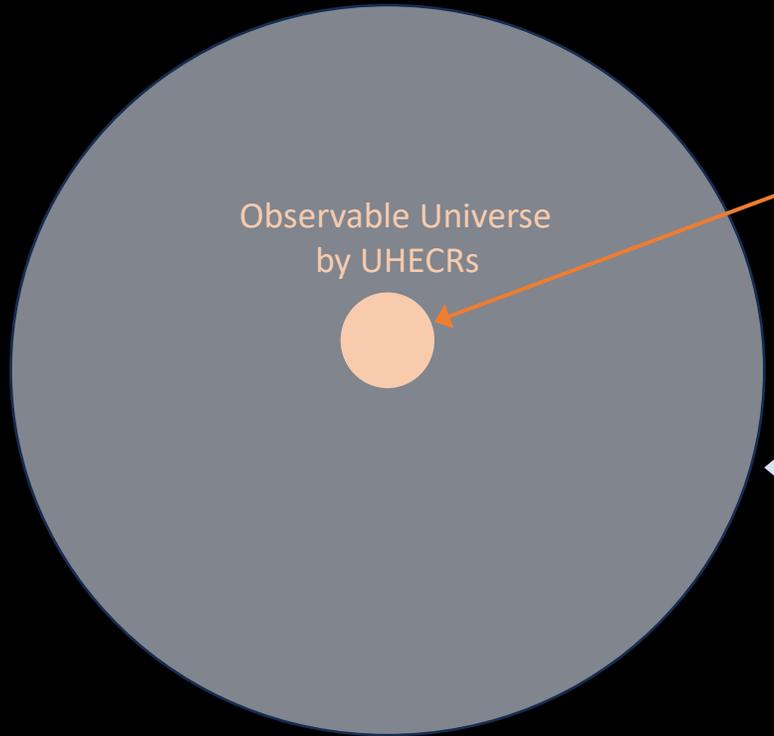


The in-situ photon luminosity {

- A gauge of the source power
- The gauge of the neutrino emission power via the optical depth
- The gauge of the UHECR emission power via the CR loading factor

# Conditions for UHECR sources I

## Energetics



We know UHECR energy density  
in this local universe by the observations



assuming uniformity of high energy universe

The UHECR luminosity density in the observable universe

Murase & Fukugita PRD (2019)

$$Q_{\text{UHECR}} \Big|_{E \geq 10 \text{ PeV}} \simeq (1 \sim 2) \times 10^{45} \text{ erg Mpc}^{-3} \text{ yr}^{-1}$$

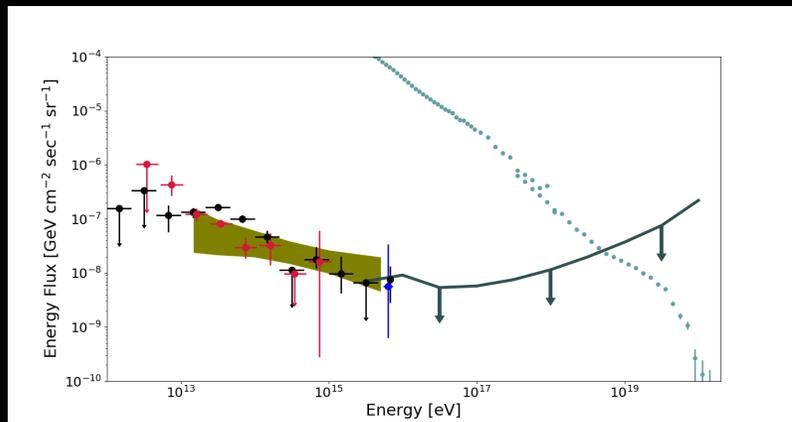
$$\approx n_0 \xi_{CR} L_\gamma$$

Observable Universe

$$\therefore \xi_{CR} \sim 7 \left( \frac{L_\gamma}{10^{47} \text{ erg/s}} \right)^{-1} \left( \frac{n_0}{10^{-10} \text{ Mpc}^{-3}} \right)^{-1}$$

# Conditions for UHECR sources II

## Neutrino Flux



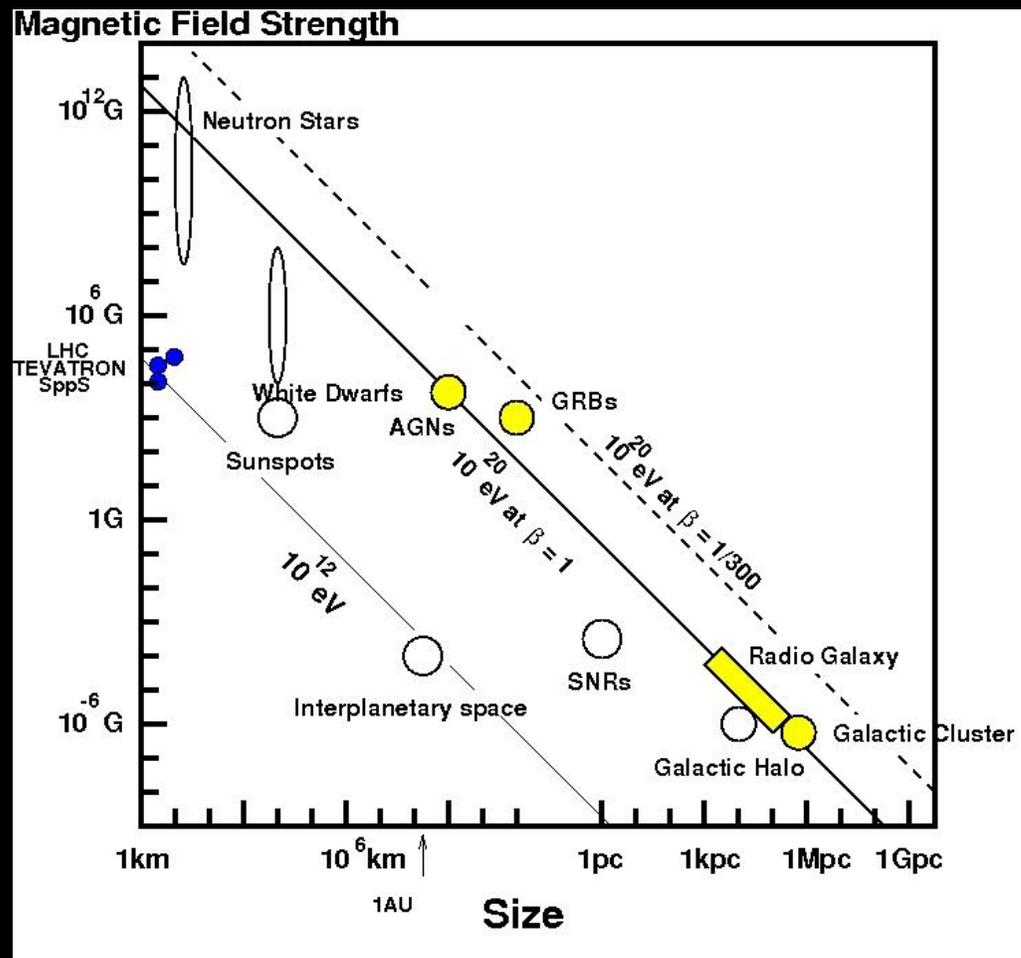
$$\tau_{p\gamma} Q_{UHECR} \approx 10^{44} \left( \frac{E_\nu^2 \Phi_\nu}{2 \times 10^{-8} \text{GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}} \right) \left( \frac{\xi_z}{2.8} \right)^{-1} \text{erg Mpc}^{-3} \text{yr}^{-1}$$

↑  
We know this (see the previous slide)

$$\therefore \tau_{p\gamma} \gtrsim 0.04 \left( \frac{\xi_z}{2.8} \right)^{-1}$$

# Conditions for UHECR sources III

## Cosmic-ray Acceleration



$$\xi_B \gtrsim \frac{1}{2} c \eta^2 \beta^2 \Gamma^2 L_\gamma^{-1} \left( \frac{\epsilon_{\text{UHECR}}^{\text{max}}}{Ze} \right)^2$$

$$\gtrsim 0.2 \eta^2 \beta^2 \left( \frac{L_\gamma}{10^{47} \text{ erg/s}} \right)^{-1} \left( \frac{\Gamma}{10^{0.5}} \right)^2 \left( \frac{\epsilon^{\text{max}}}{Z 10^{11} \text{ GeV}} \right)^2$$

$\xi_B$  Equipartition parameter of B-Field

$$\xi_B \equiv U'_B \left( \frac{L_\gamma}{4\pi\Gamma^2 R^2 c} \right)^{-1}$$

# Conditions for UHECR sources IV

## Cosmic-ray **Escape**

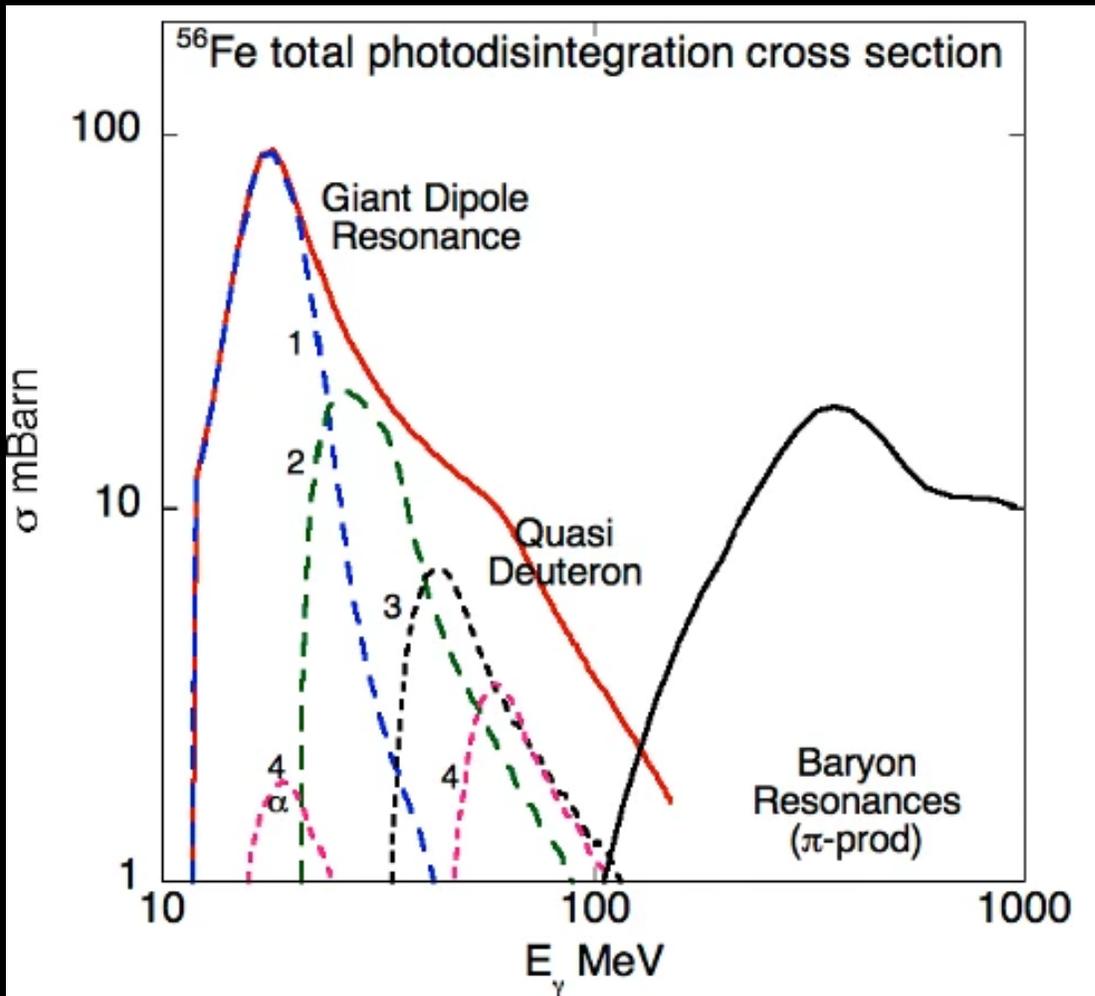
cosmic rays must run away from their emission region before being cooled down by the energy loss process

⇒ (At least) the dynamical time scale must be faster than the synchrotron cooling time

$$\tau_{p\gamma} \lesssim 0.06 \xi_B^{-1} \beta^{-1} \left( \frac{A}{Z} \right)^4 \left( \frac{\epsilon^{\max}}{10^{11} \text{GeV}} \right)^{-1}$$

# Conditions for UHECR sources V

## Cosmic-ray Nuclear **Survival**



Photodisintegration process



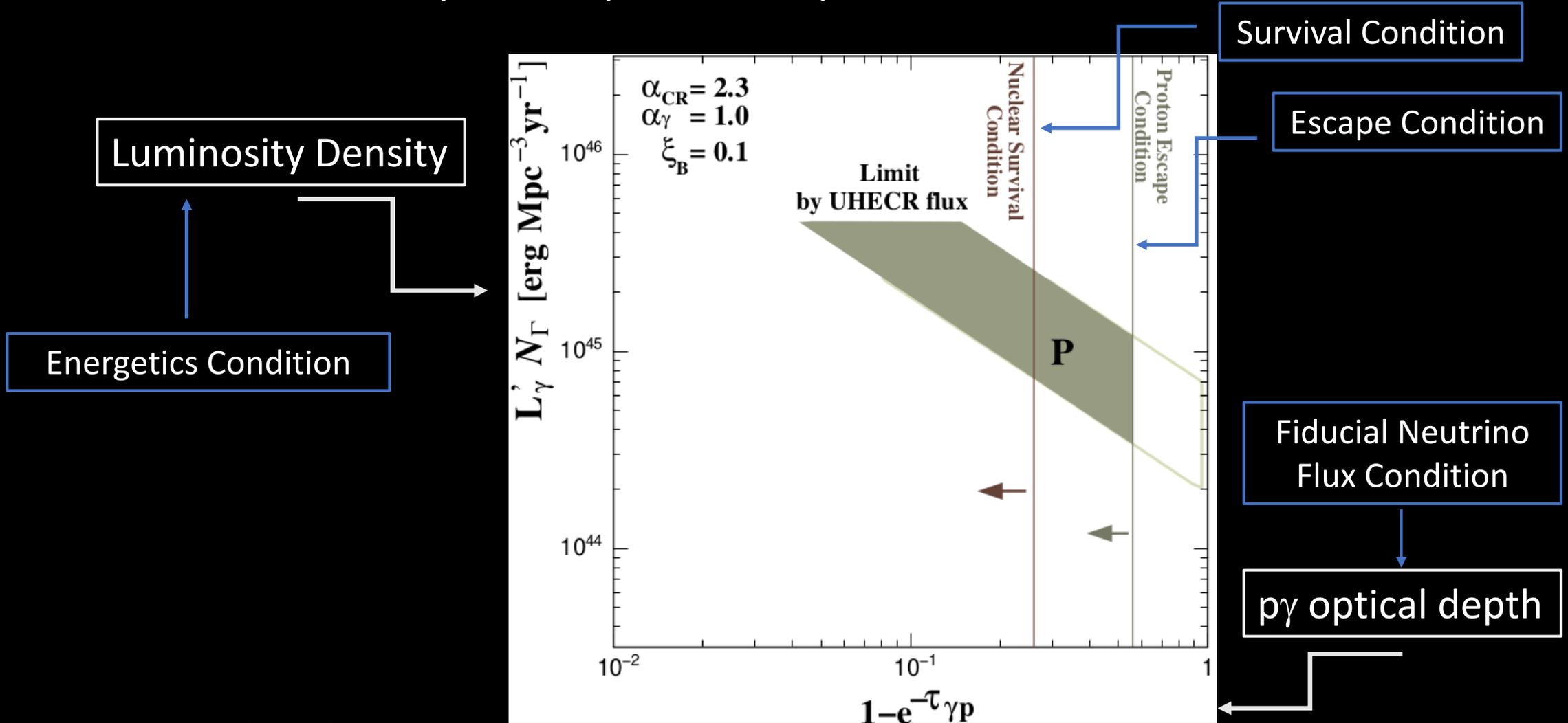
$$\Rightarrow \tau_{A\gamma} \lesssim A$$

Nuclei would break down into protons/neutrons before escaping the sources, otherwise

$$\therefore \tau_{p\gamma} \lesssim 0.4 \left( \frac{A}{56} \right)^{-0.21}$$

# The conditions the Common Sources must meet

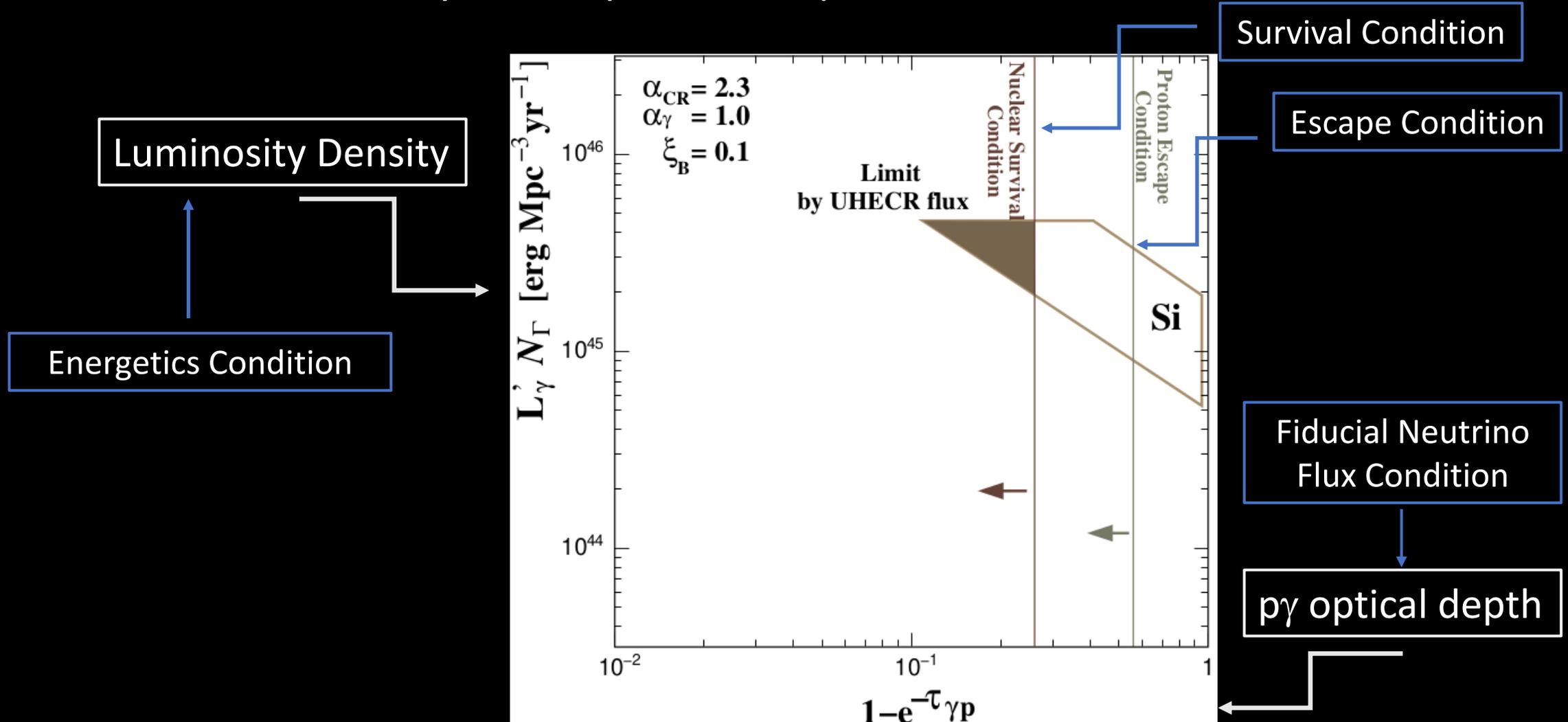
The only narrow parameter space is allowed!



Yoshida & Murase PRD (2020)

# The conditions the Common Sources must meet

The only narrow parameter space is allowed!



Yoshida & Murase PRD (2020)

Are they UHECR and PeV  $\nu$  sources?

# The scorebook of individual **transient** astronomical object classes

	Energetics	Fiducial $\nu$ flux	Acceleration	Escape	Survival $\tau_{p\gamma} \lesssim 0.4(A/56)^{-0.21}$
<b>jetted TDE</b> Biehl+ 2018	<b>Challenging</b> $\xi_{CR} = 100 - 1000$	<b>OK</b> $\tau_{p\gamma} \gtrsim 0.1$	<b>OK with nuclei</b> $\xi_B \gtrsim 10^{-2}(z/10)^{-2}$	<b>OK</b> $\tau_{p\gamma} \lesssim 1 (A/2Z)^4$	<b>Maybe</b>
<b>TDE wind</b> Murase+ 2020	<b>OK</b> $\xi_{CR} = 1 - 10$	<b>Challenging</b> $\tau_{p\gamma} \gtrsim 0.1$	<b>Maybe</b> $\xi_B \gtrsim 1(z/10)^{-2}$	<b>OK</b> $\tau_{p\gamma} \lesssim 3 (A/2Z)^4$	<b>OK</b>
<b>Low L GRB</b> Murase+ 2006	<b>Maybe</b> $\xi_{CR} = 10 - 100$	<b>OK</b> $\tau_{p\gamma} \gtrsim 0.03$	<b>OK with nuclei</b> $\xi_B \gtrsim 10^{-2}(z/10)^{-2}$	<b>OK</b> $\tau_{p\gamma} \lesssim 1 (A/2Z)^4$	<b>OK</b>
<b>Engine-driven SN</b> Zang+ 2019	<b>OK</b> $\xi_{CR} = 0.1 - 1$	<b>Challenging</b> $\tau_{p\gamma} \gtrsim 0.03$	<b>Maybe</b> $\xi_B \gtrsim 1(z/10)^{-2}$	<b>OK</b> $\tau_{p\gamma} \lesssim 3 (A/2Z)^4$	<b>OK</b>

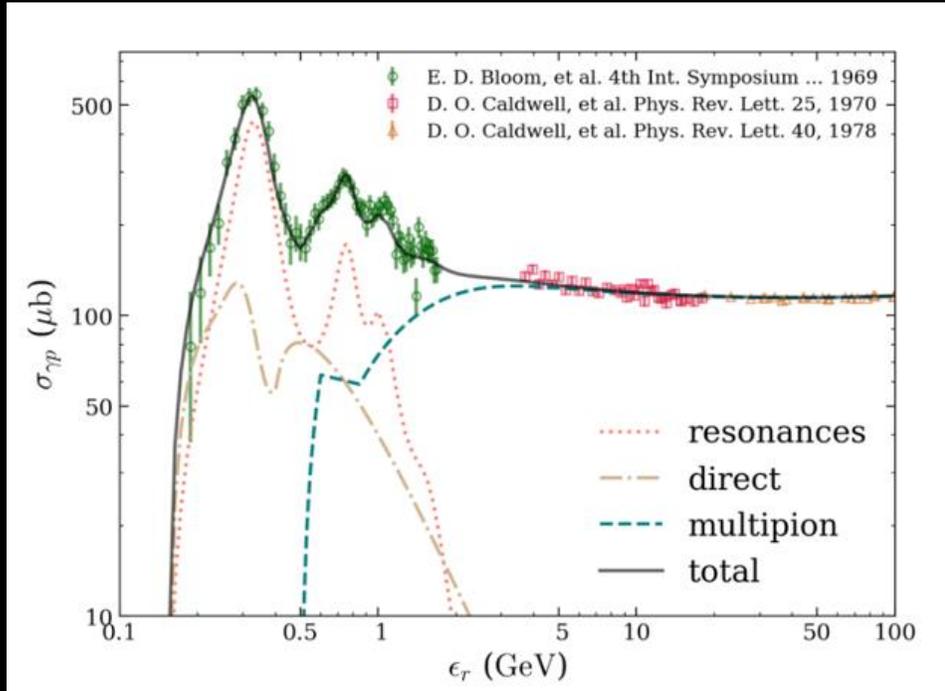
Yoshida & Murase PRD (2024)

Side Note: This is a one-zone model

# The most likely target photons are in X-ray range in the **relativistic** plasma flows

Photohadronic interactions

e.g.  $p\gamma \rightarrow \Delta^+ \rightarrow n\pi^+$



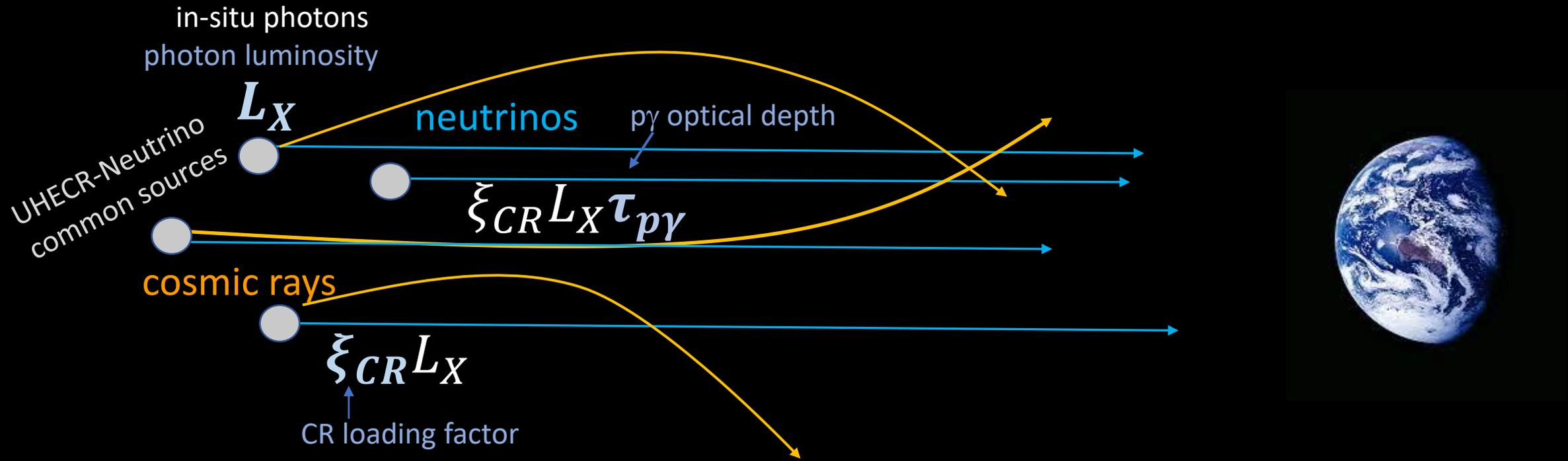
$$\varepsilon'_{\gamma 0} \approx \frac{(s_{\Delta} - m_p^2)}{4} \frac{\Gamma}{\varepsilon_{p0}}$$

$$\longrightarrow \varepsilon_X = 15 \left( \frac{\Gamma}{10} \right)^2 \left( \frac{\varepsilon_p}{1 \text{ PeV}} \right)^{-1} \text{ keV}$$

$\Gamma$  Lorentz factor of  
(jet) plasma



# The generic **neutrino source scheme** via photo-hadronic framework



- The in-situ photon luminosity
- A gauge of the source power
  - The gauge of the neutrino emission power via the optical depth
  - The gauge of the UHECR emission power via the CR loading factor

# Here is the issue – the *degeneracy*

Neutrino flux

based upon [Yoshida & Murase PRD \(2020\)](#)  
[Yoshida & Murase PRD \(2024\)](#)

$$\propto \boxed{\xi_{CR}} \times B \times L_X \times (\sqrt{L_X}, 1) \times f(\Gamma)$$

We want to know  
this

MW observation/  
theory could tell

This could be any value!  
We need to determine/constrain this

Bulk Lorentz factor  
of the plasma (jet)

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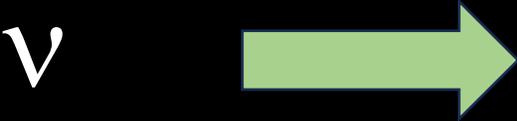
We want to know this

MW observation/  
theory could tell

This could be any value!  
We need to determine/constrain this

Bulk Lorentz factor  
of the plasma (jet)

Search for X-ray signals associated with neutrino events!

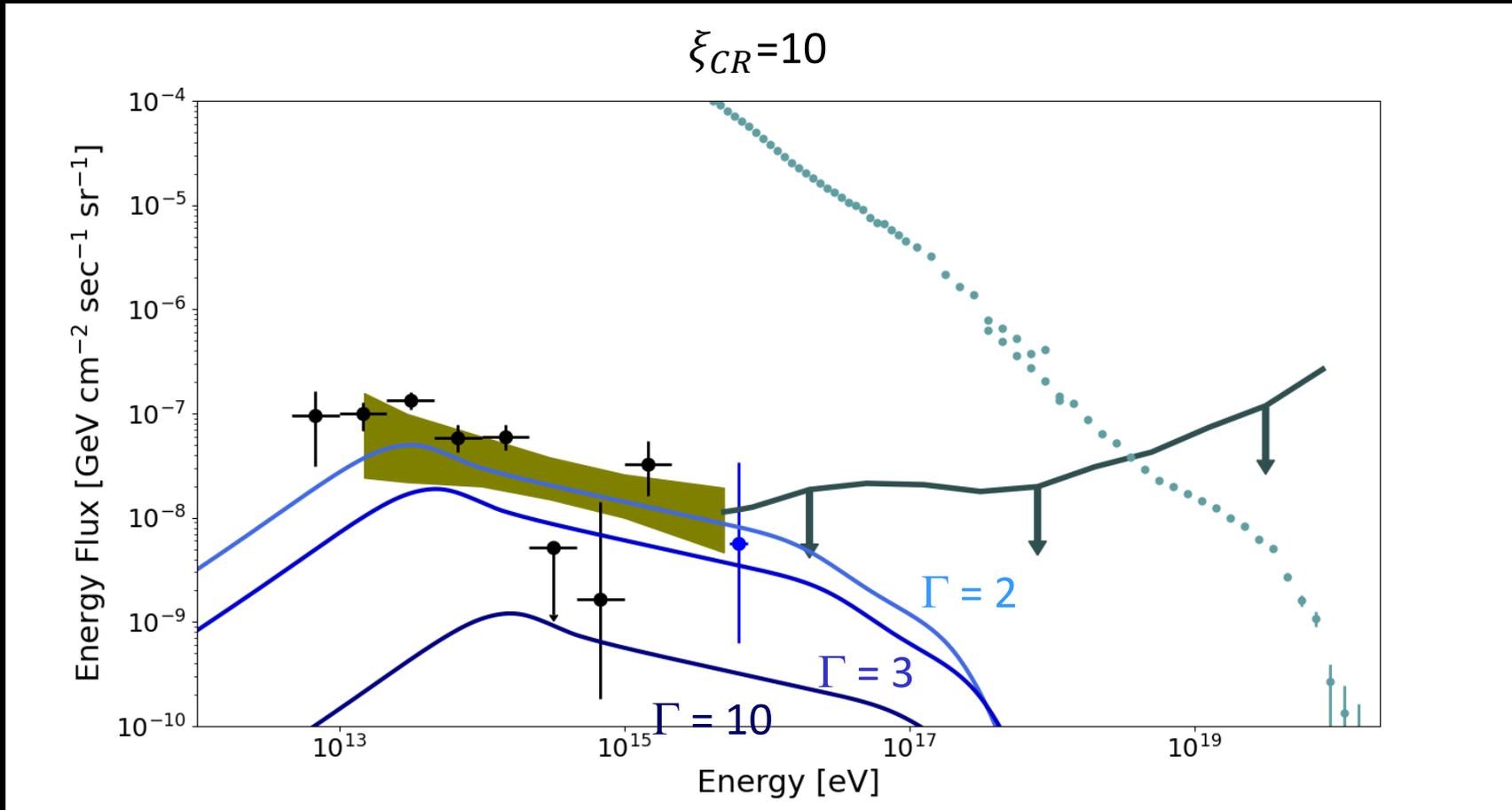


A typical burst/flare time scale  
 $\Delta T$   $10^{3-4}$  sec (LL GRBs)  $10^{6-7}$  sec (TDEs)

# The UHE Cosmic Background Radiations

$L_x$  (2-10 keV)  $5 \times 10^{46}$  erg/s (low luminosity GRB-like)

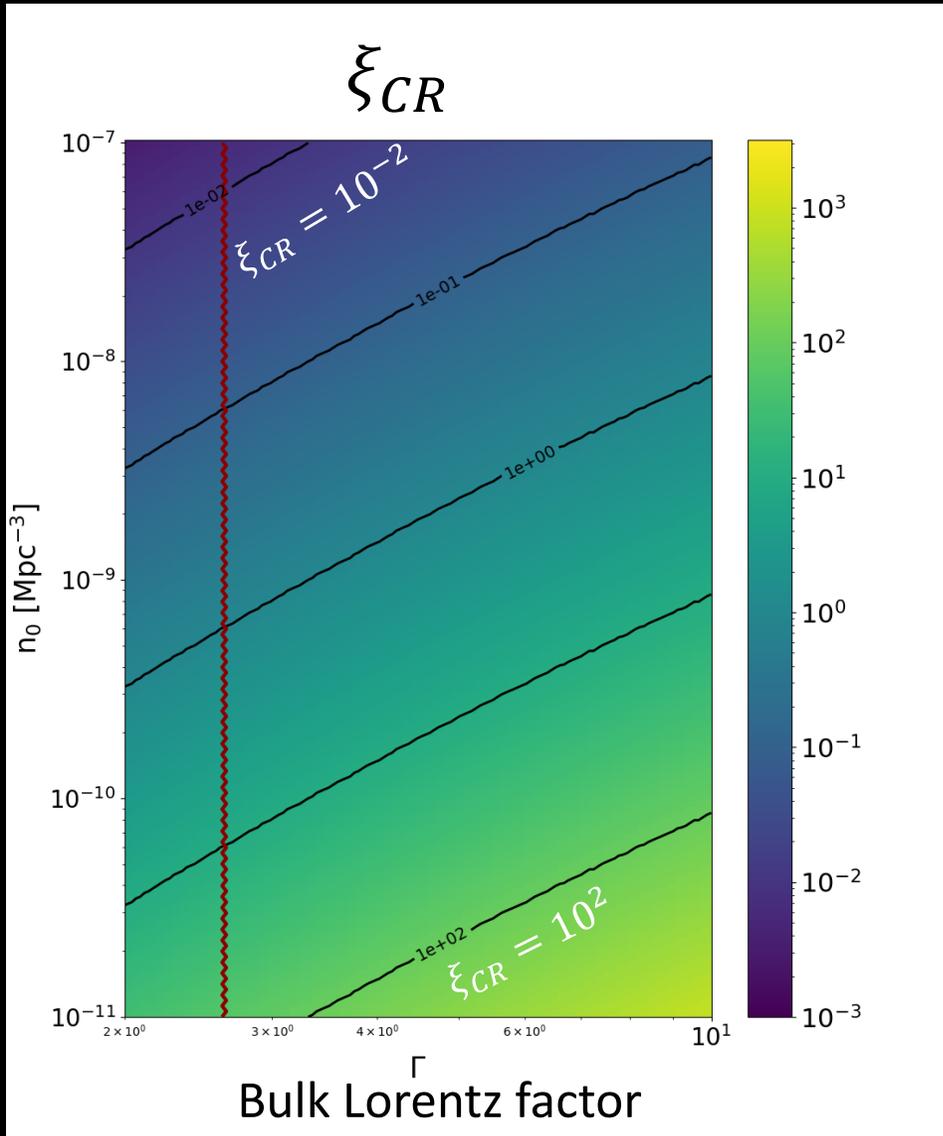
The expected cosmic neutrino background flux predicted by a generic model



# The most likely CR loading factor

$L_X = 5 \times 10^{46}$  erg/s favored by the diffuse flux data

local source number density



For a given  $n_0$  [Mpc<sup>-3</sup>] and  $\Gamma$

$$\Phi_\nu \propto \xi_{CR} \times L_X \times (\sqrt{L_X}, 1)$$

diffuse

You can determine this!

Now we know this by the stacking analysis

We know this by the I<sup>3</sup> diffuse data

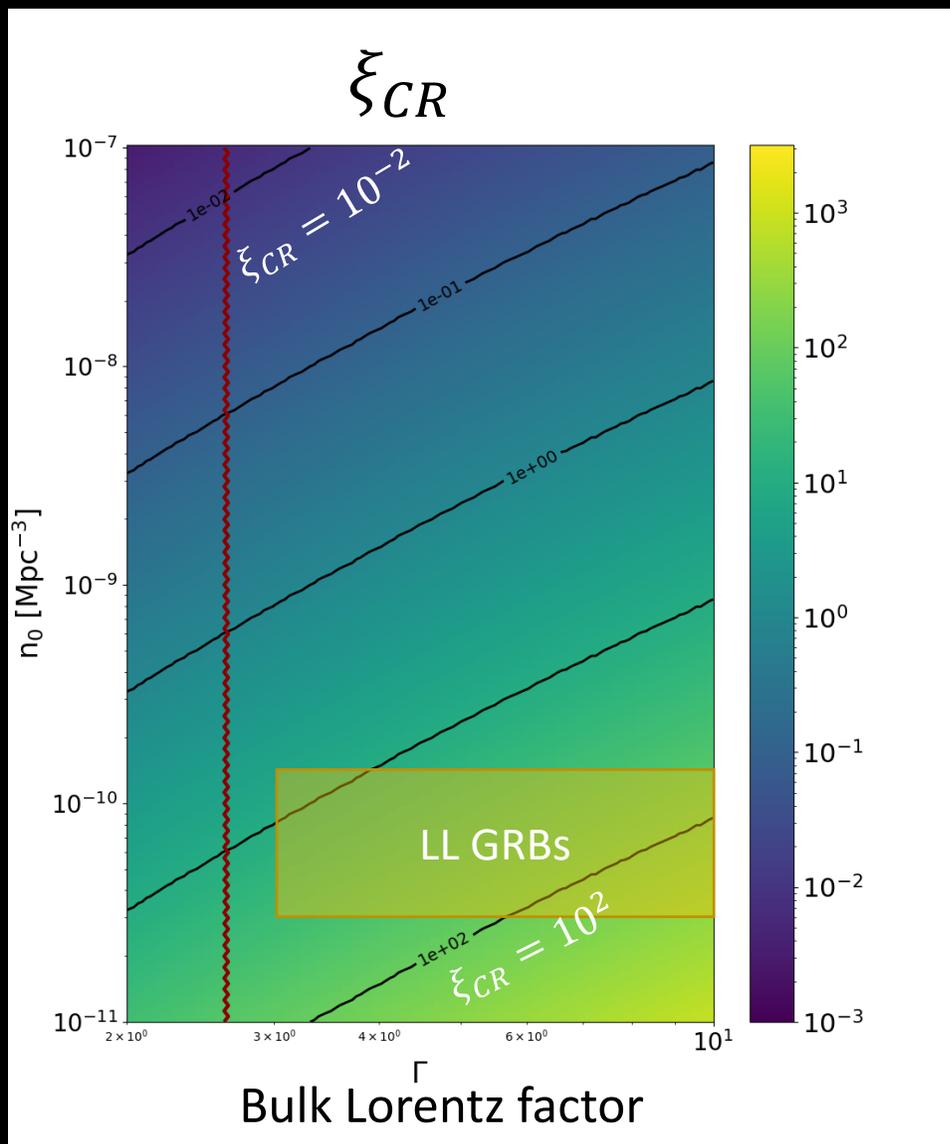
We have determined  $\xi_{CR}(n_0, \Gamma)$

# The most likely CR loading factor

$$L_X = 5 \times 10^{46} \text{ erg/s}$$

avored by the diffuse flux data

local source number density



For a given  $n_0$  [ $\text{Mpc}^{-3}$ ] and  $\Gamma$

$$\Phi_\nu \propto \xi_{CR} \times L_X \times (\sqrt{L_X}, 1)$$

diffuse

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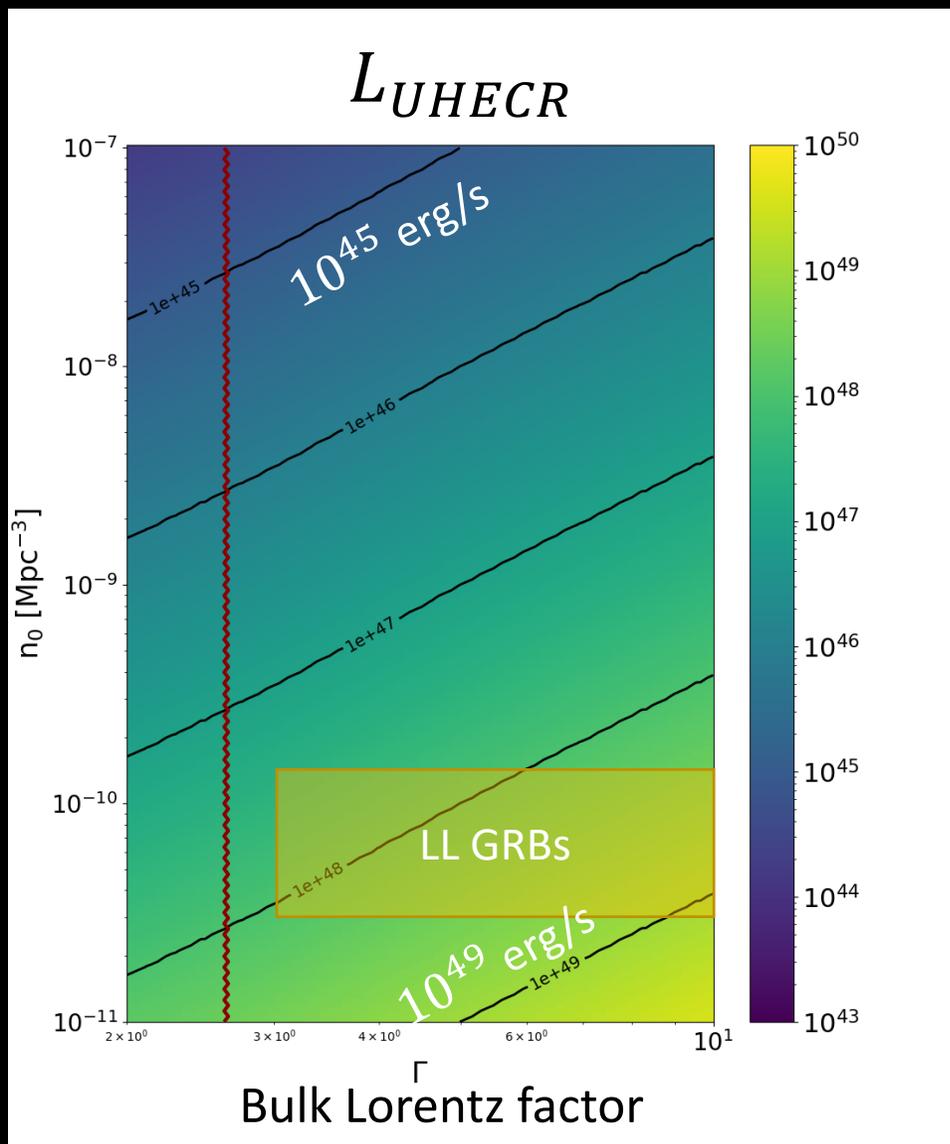
We know this  
by the  $I^3$  diffuse data

We have determined  $\xi_{CR}(n_0, \Gamma)$

# The most likely UHECR Luminosity

$L_X = 5 \times 10^{46}$  erg/s favored by the diffuse flux data

local source number density



For a given  $n_0$  [ $\text{Mpc}^{-3}$ ] and  $\Gamma$

$$\Phi_{\nu} \propto \xi_{CR} \times L_X \times (\sqrt{L_X}, 1)$$

You can determine this!

Now we know this by the stacking analysis

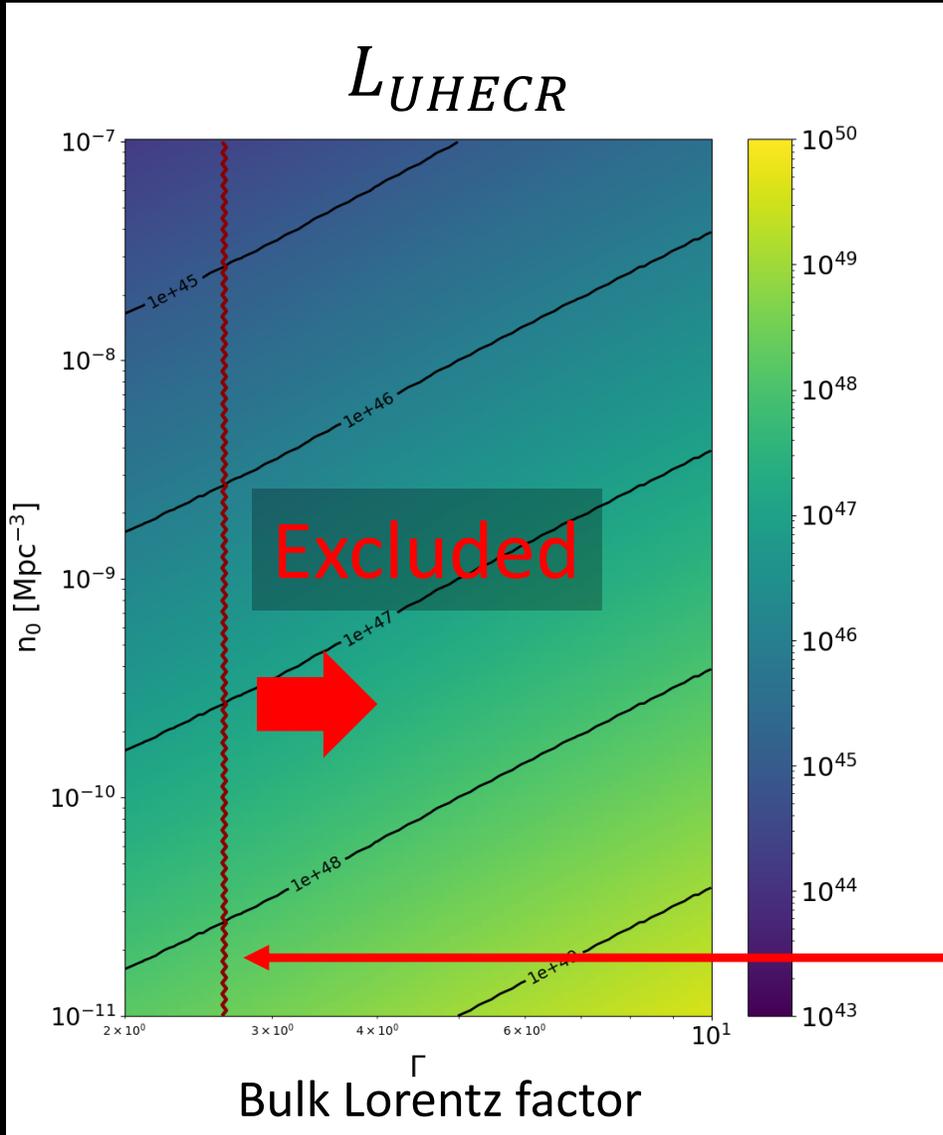
We know this by the  $I^3$  diffuse data

We have determined

$$L_{UHECR}(n_0, \Gamma) = \xi_{CR} \times L_X$$

# The Excluded parameter space for UHECR sources determined by **UHECR energetics**

local source number density



$$n_0 \xi_{CR} L_X \lesssim Q_{UHECR}$$

$$\lesssim 9 \times 10^{44} \text{ erg Mpc}^{-3} \text{ yr}^{-1}$$

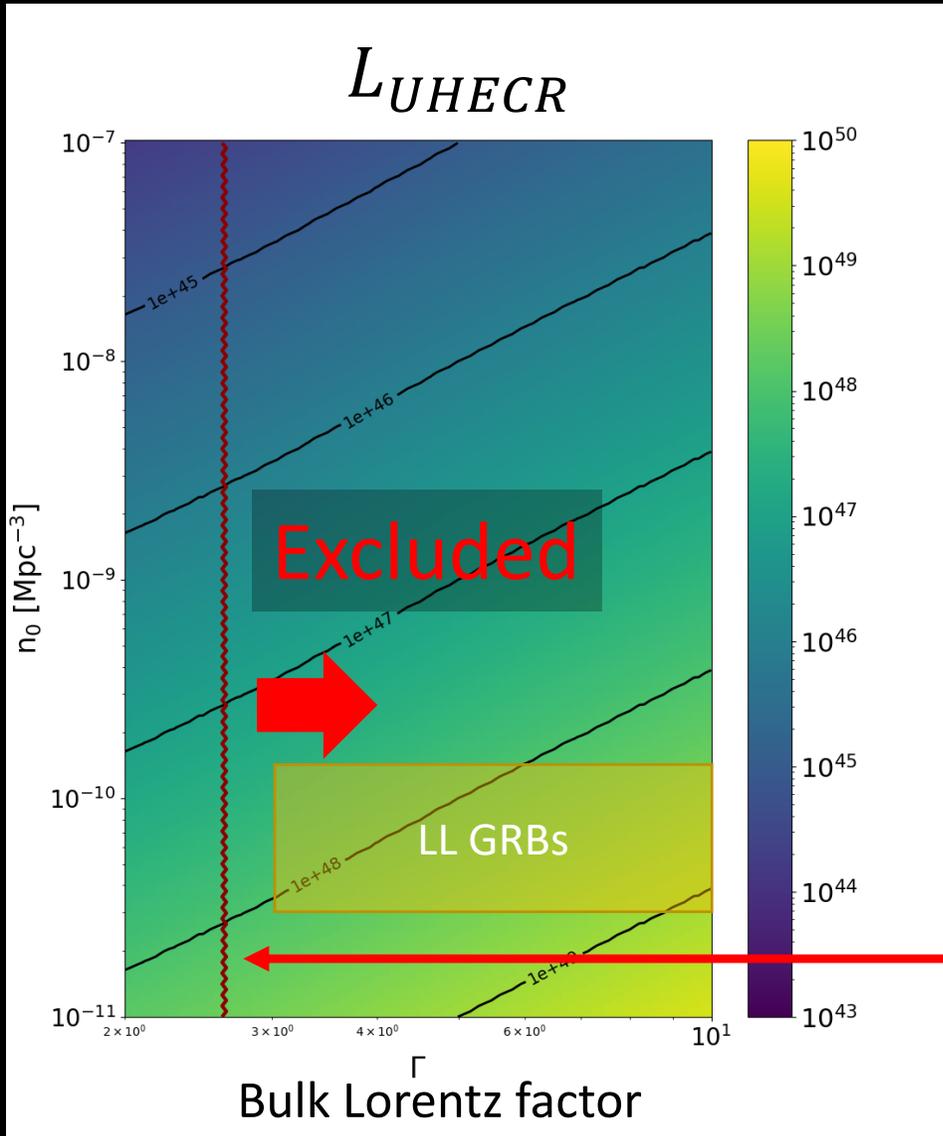
$\epsilon_{CR} \geq 10 \text{ PeV}$

Otherwise these sources would overproduce UHECRs!

The line of  $Q_{UHECR}$

# The Excluded parameter space for UHECR sources determined by **UHECR energetics**

local source number density



$$n_0 \xi_{CR} L_X \lesssim Q_{UHECR}$$

$$\lesssim 9 \times 10^{44} \text{ erg Mpc}^{-3} \text{ yr}^{-1}$$

$\epsilon_{CR} \geq 10 \text{ PeV}$

Otherwise these sources would overproduce UHECRs!

The line of  $Q_{UHECR}$

What can we do if we see nothing in X-rays?

# Neutrino and X-ray stacking search

X

A conservative scenario

Suppose

The sub-threshold detection sensitivity

$$2 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$$



For a given  $n_0$  [ $\text{Mpc}^{-3}$ ]

$$L_X \lesssim 3 \times 10^{45} \left( \frac{n_0}{5.2 \times 10^{-9} \text{ Mpc}^{-3}} \right)^{-\frac{2}{3}} \text{ erg/s}$$

density of GRB190829A-like sources

$\nu$

$$\Phi_{\nu}^{\text{diffuse}} \propto \xi_{CR} \times L_X \times (\sqrt{L_X}, 1)$$

We know this

Yes, now we get  
**Lower Bound!**

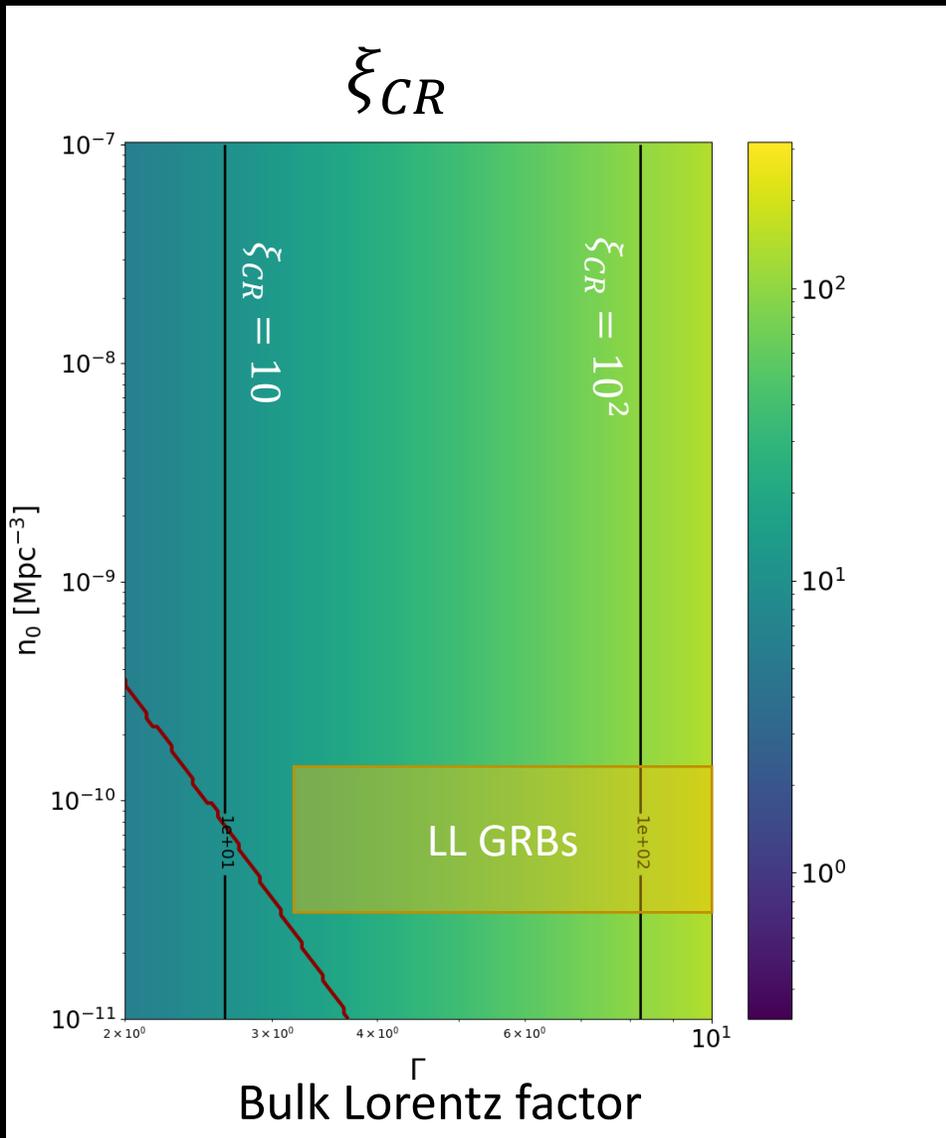
Now This is  
the **Upper Limit**

# The **lower bound** of CR loading factor to explain the cosmic background flux data

$$F_X \lesssim 2 \times 10^{-10} \text{ erg/cm}^2 \text{ s}$$

or  $L_X \lesssim 3 \times 10^{45} \left( \frac{n_0}{5.2 \times 10^{-9} \text{ Mpc}^{-3}} \right)^{-\frac{2}{3}} \text{ erg/s}$

local source number density



For a given  $n_0$  [ $\text{Mpc}^{-3}$ ] and  $\Gamma$

$$\Phi_\nu \propto \overset{\text{diffuse}}{\xi_{CR}} \times L_X \times (\sqrt{L_X}, 1)$$

Yes, now we get  
**Lower Bound!**

The upper limit is placed by the stacking analysis

We know this by the  $I^3$  diffuse data

We have determined  $\xi_{CR}^{LL}(n_0, \Gamma)$

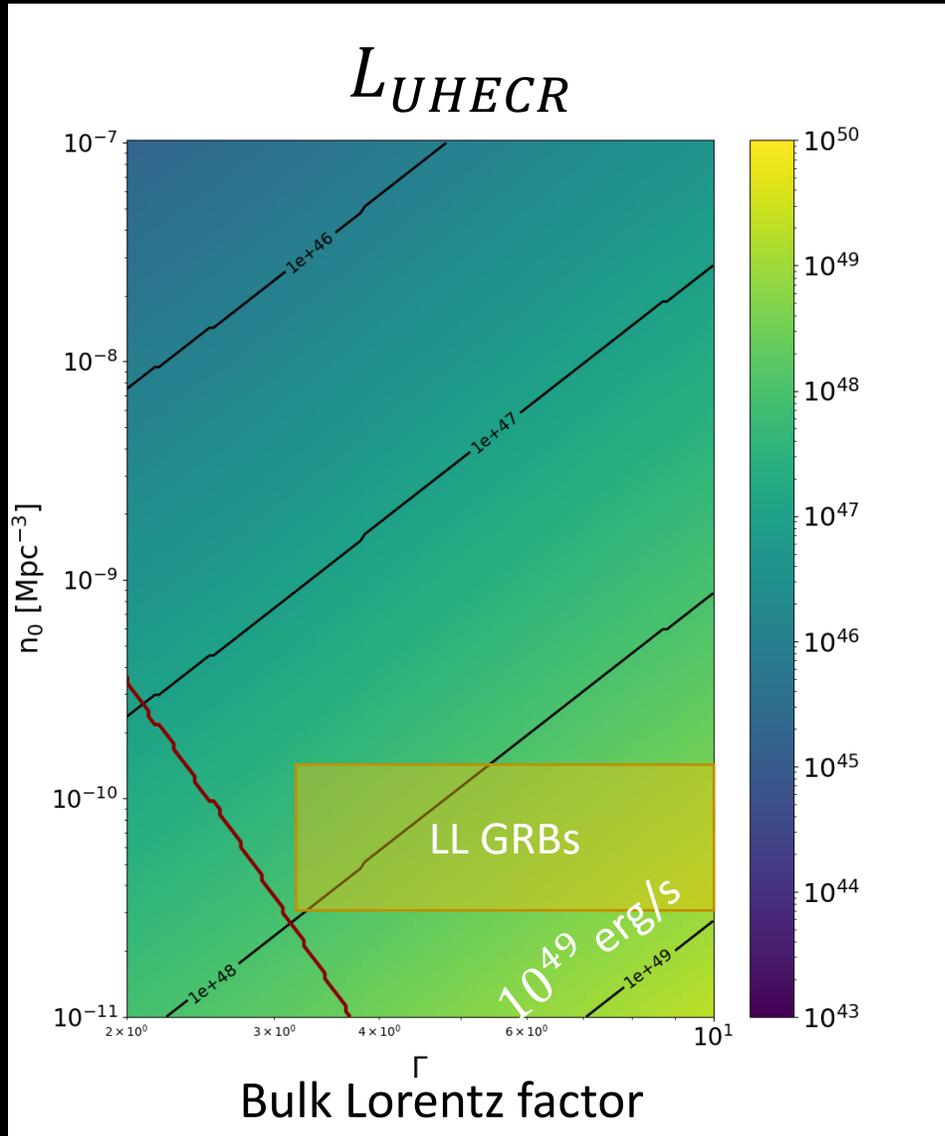
# The lower bound of UHECR luminosity

to explain the cosmic background flux data

$$F_X \lesssim 2 \times 10^{-10} \text{ erg/cm}^2 \text{ s}$$

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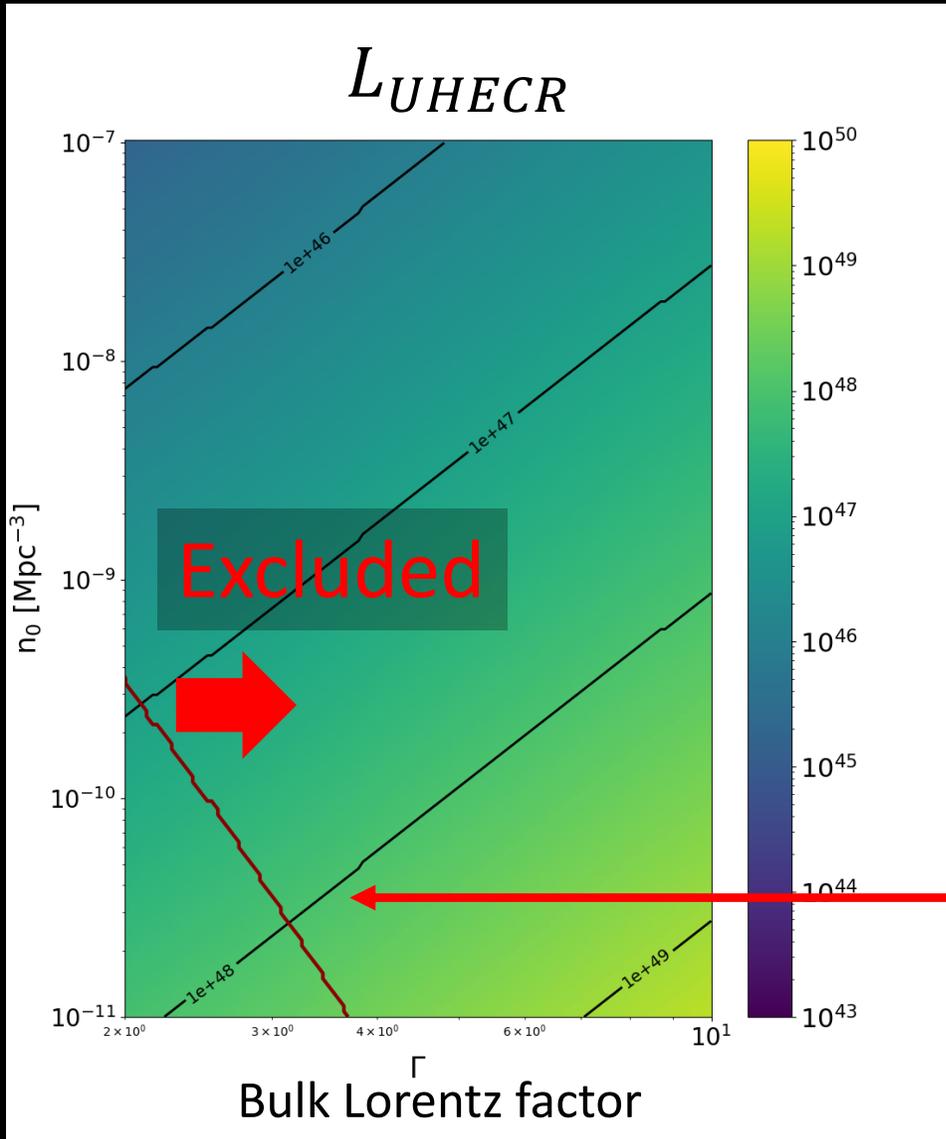
We have determined

$$L_{UHECR}(n_0, \Gamma) = \xi_{CR} \times L_X$$

# The Excluded parameter space for UHECR sources

$F_X \lesssim 2 \times 10^{-10} \text{ erg/cm}^2 \text{ s}$   
 or  $L_X \lesssim 3 \times 10^{45} \left( \frac{n_0}{5.2 \times 10^{-9} \text{ Mpc}^{-3}} \right)^{-\frac{2}{3}} \text{ erg/s}$  determined by **UHECR energetics**

local source number density



$$L_{UHECR} = \xi_{CR} L_X$$

$$n_0 L_{UHECR} \approx Q_{UHECR} \approx 9 \times 10^{44} \text{ erg Mpc}^{-3} \text{ yr}^{-1}$$

$\epsilon_{CR} \geq 10 \text{ PeV}$

Otherwise these sources would overproduce UHECRs!

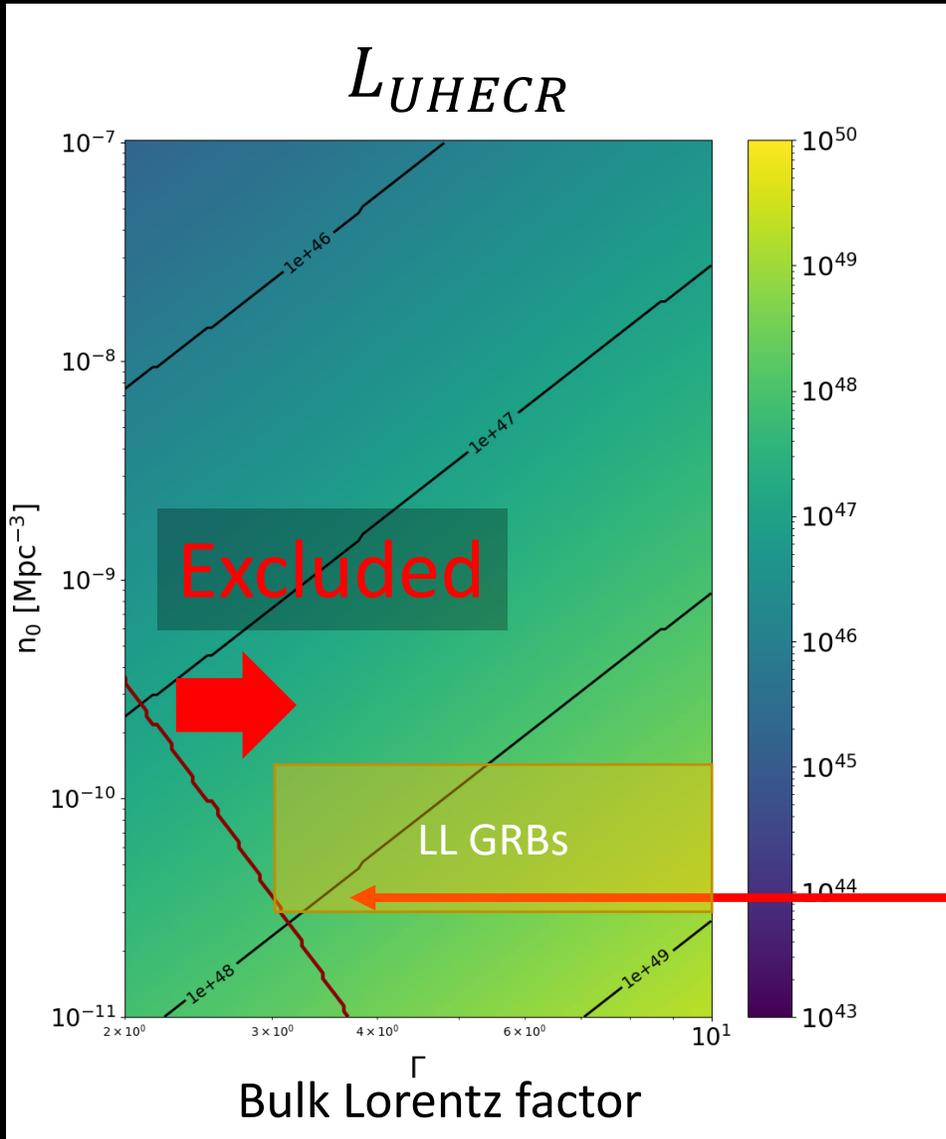
The line of  $Q_{UHECR}$

Yoshida & Murase PRD (2024)

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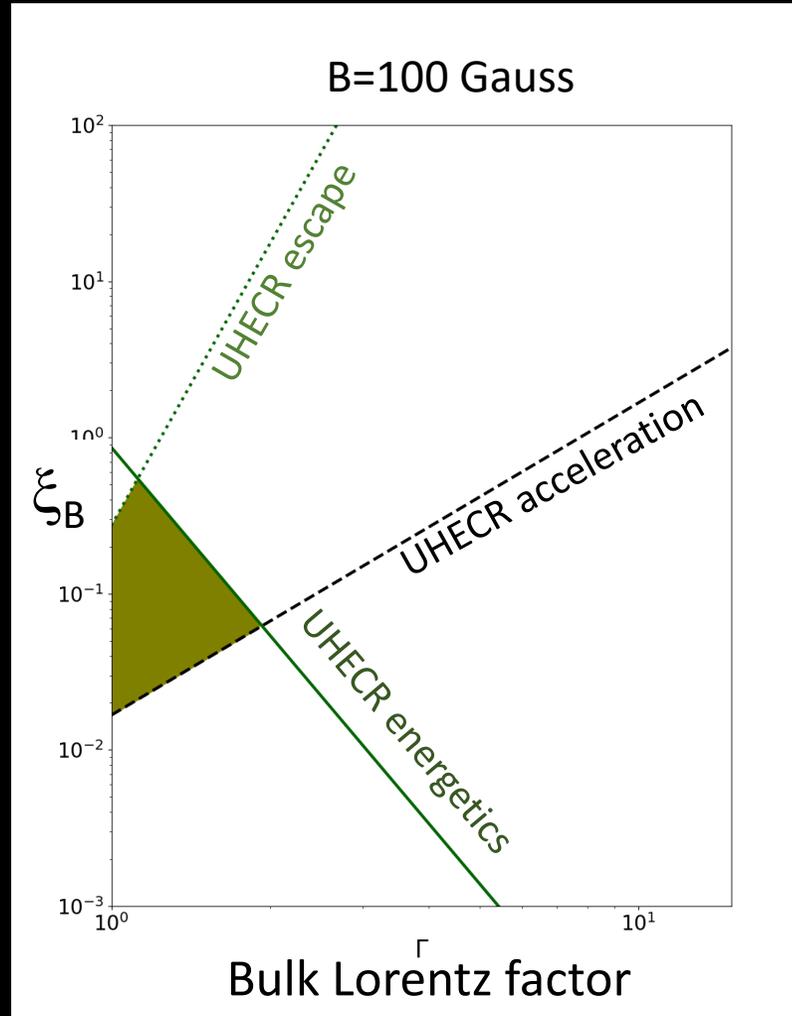
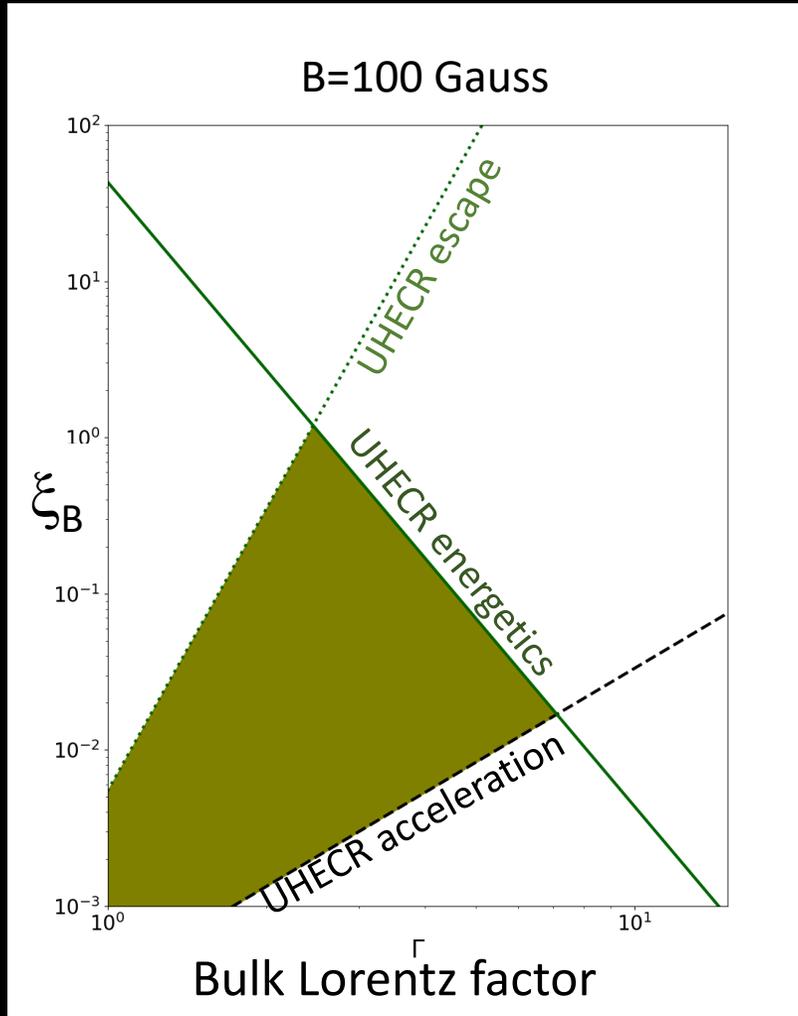
The line of  $Q_{UHECR}$

Yoshida & Murase PRD (2024)

# Constraints on $B$ , $\xi_B$ , and $\Gamma$

$$L_x = 5 \times 10^{46} \text{ erg/s}$$

$$L_x < 1 \times 10^{45} \text{ erg/s}$$



$$\Gamma \lesssim 7 \left( \frac{L_x}{5 \times 10^{46} \text{ erg/s}} \right)^{\frac{1}{3}} \left( \frac{B}{100 \text{ G}} \right)^{\frac{1}{3}}$$

Exclude sources with  $\Gamma \gg 1$

Yoshida & Murase PRD (2024)

# Neutrino and X-ray stacking search



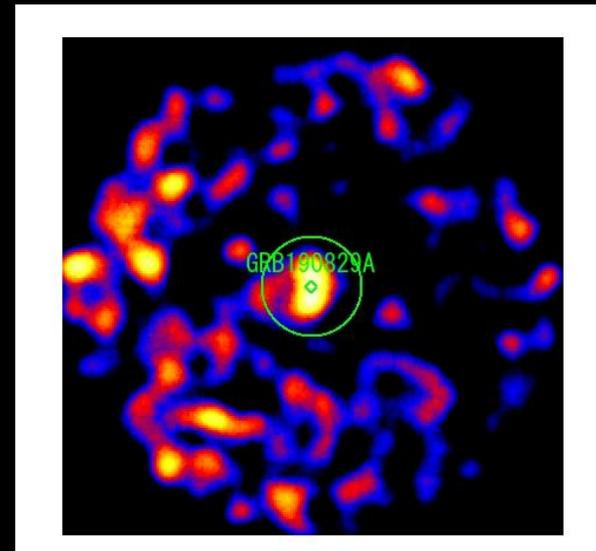
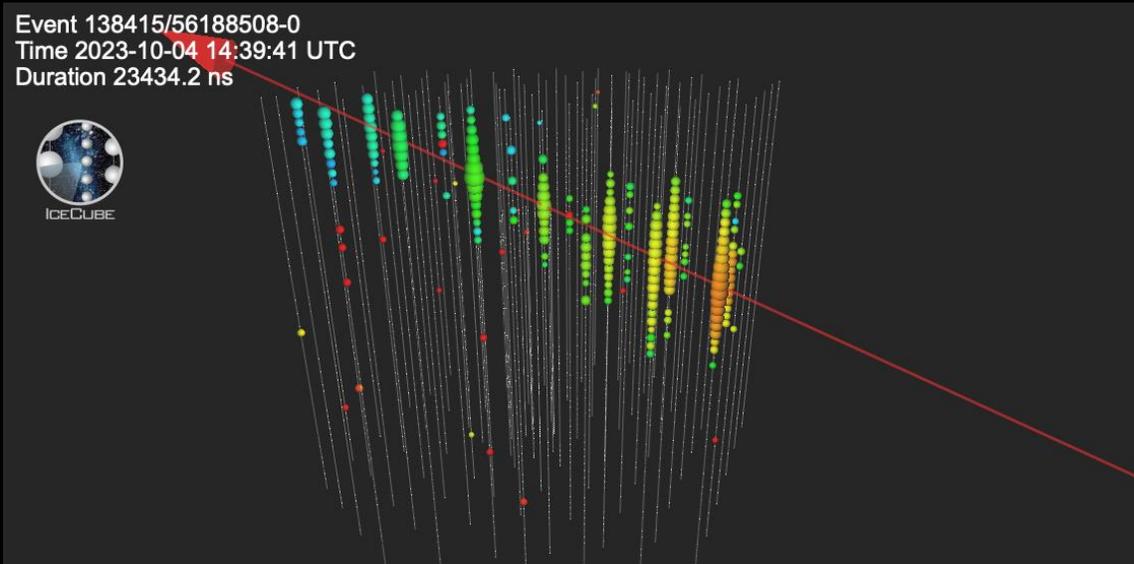
the both facilities monitor all-sky and  
the data has been archived



$\Delta T$   $10^{3-4}$  sec



A neutrino event



2keV-10keV

# Neutrino and X-ray stacking search



the both facilities monitor all-sky and  
the data has been archived

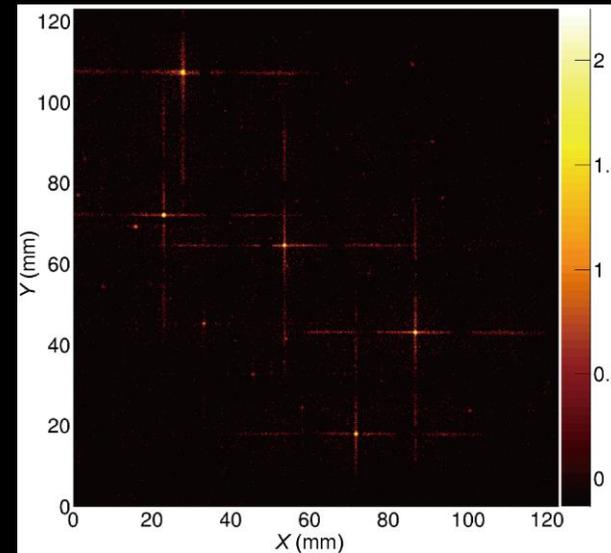
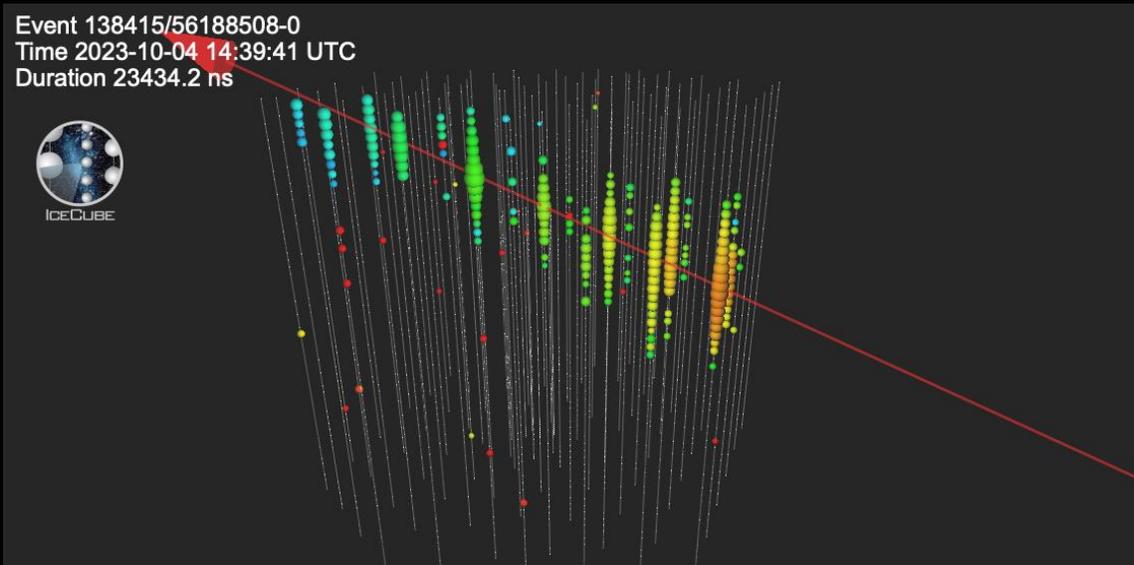


$\Delta T$   $10^{3-4}$  sec



爱因斯坦探针  
einstein probe

A neutrino event



0.5keV-4keV

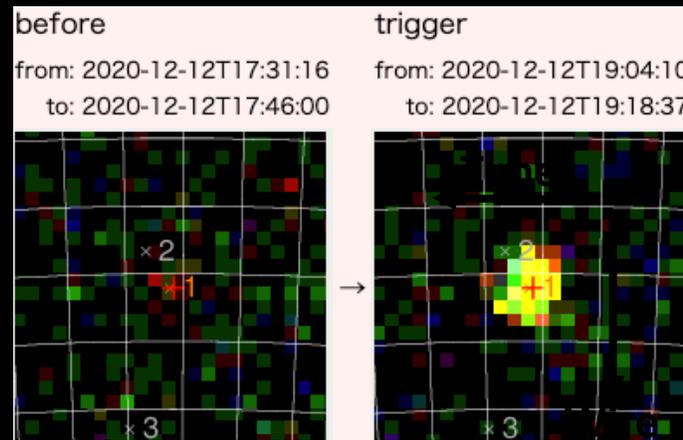
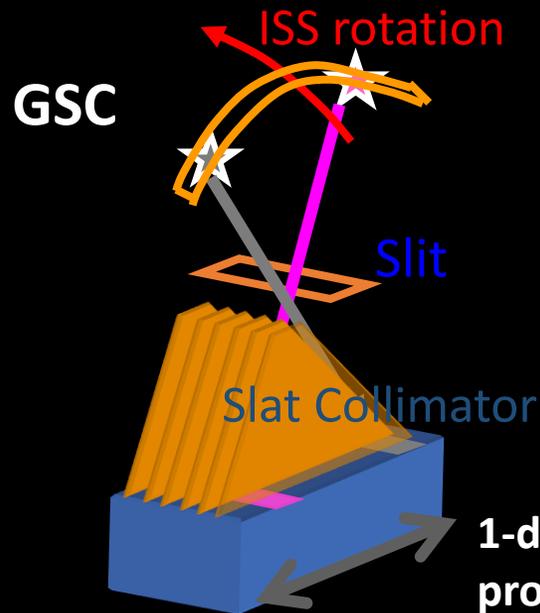
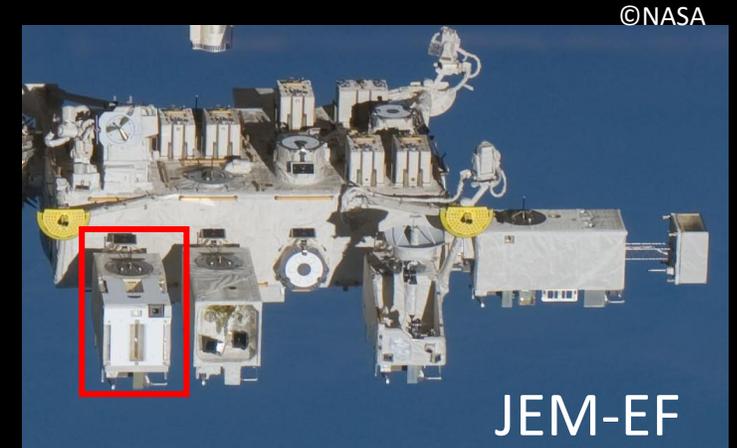
# X-rays! All-sky monitor MAXI is joining the $\nu$ campaign

- On board the International Space Station (ISS)
- Scans all-sky every 92 minutes with ISS rotation

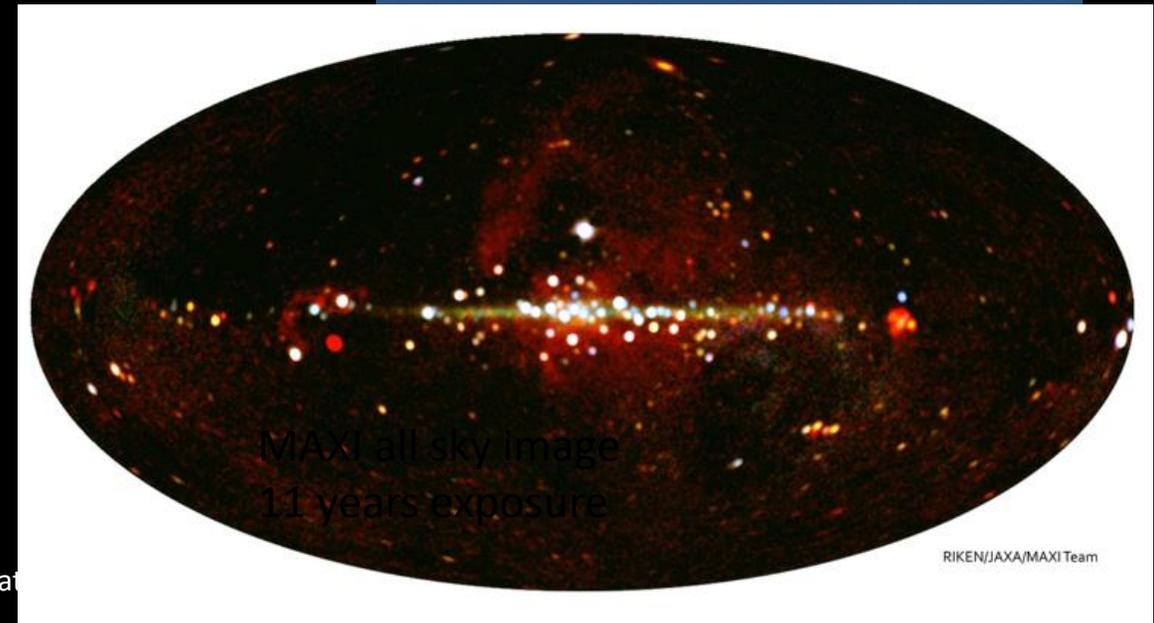
searching for X-ray transients, monitoring hundreds of X-ray sources, with Gas Slit Camera (GSC) in 2-20 keV

- Operated since 2009 August 15 (over **15 years**)
- The only all-sky X-ray monitor currently in operation
- Data downlinked in real time  $\rightarrow$  Real time alert

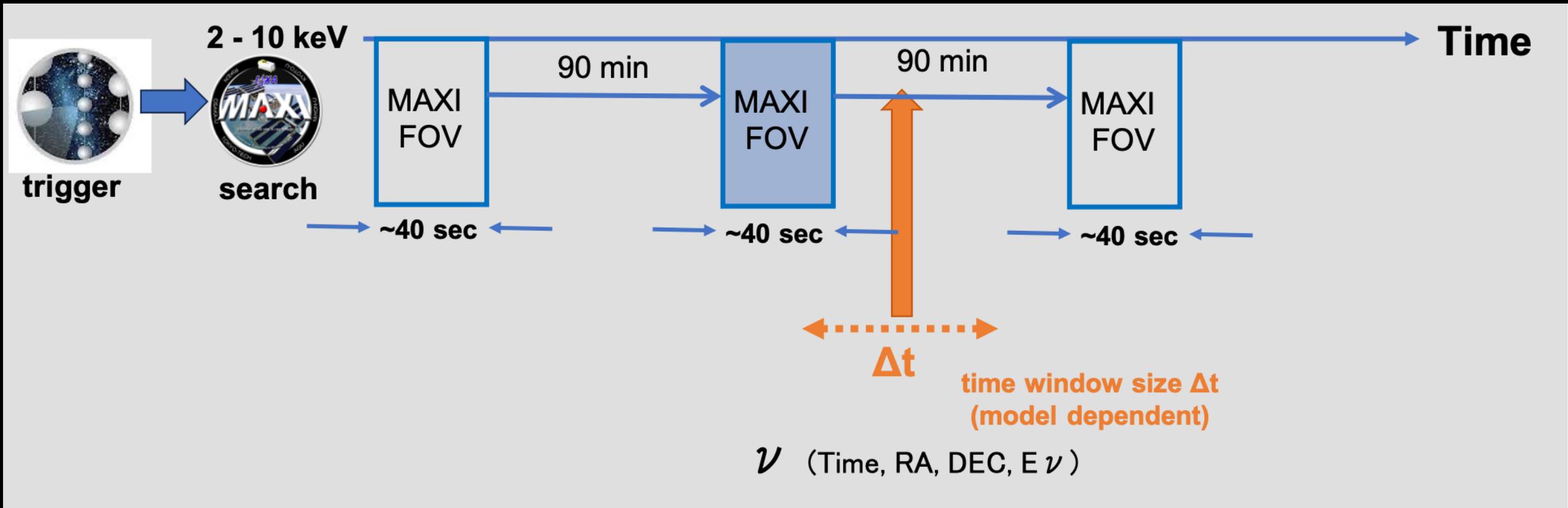
**Add great synergy to MM astronomy**



**1-dimensional position sensitive proportional counter**  
Shigeru Yoshida - Yukawa Internat



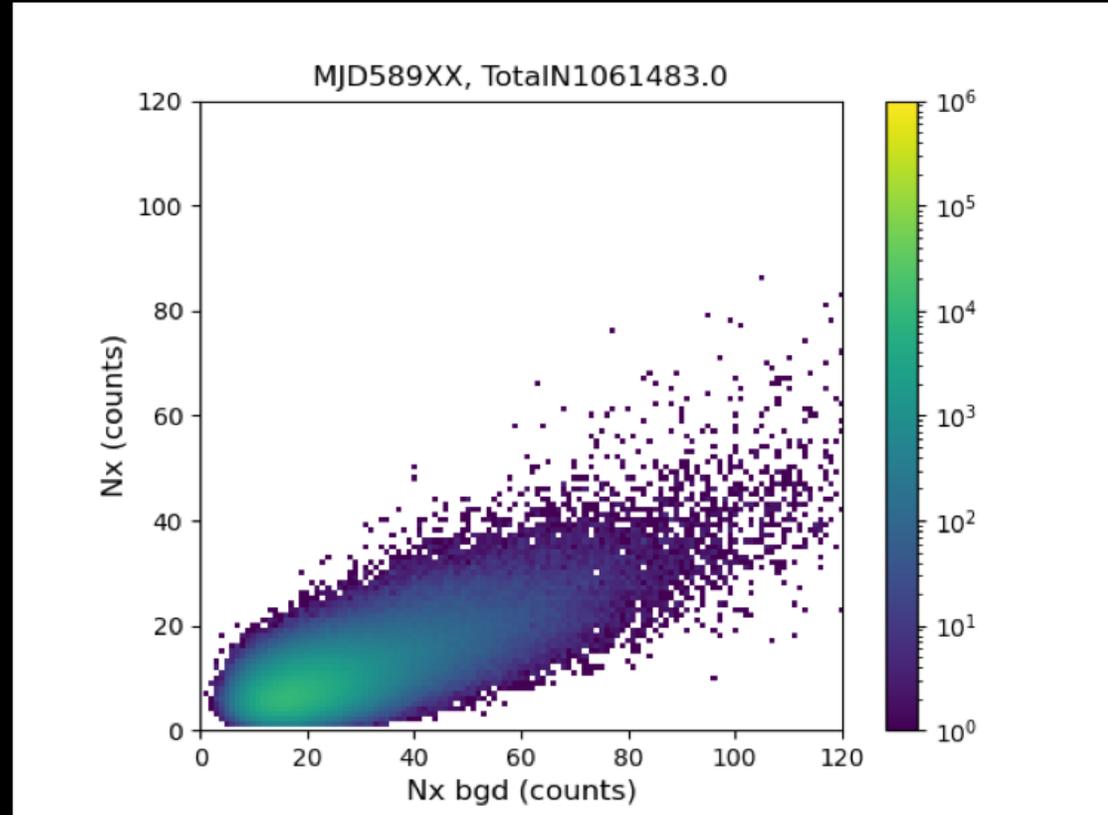
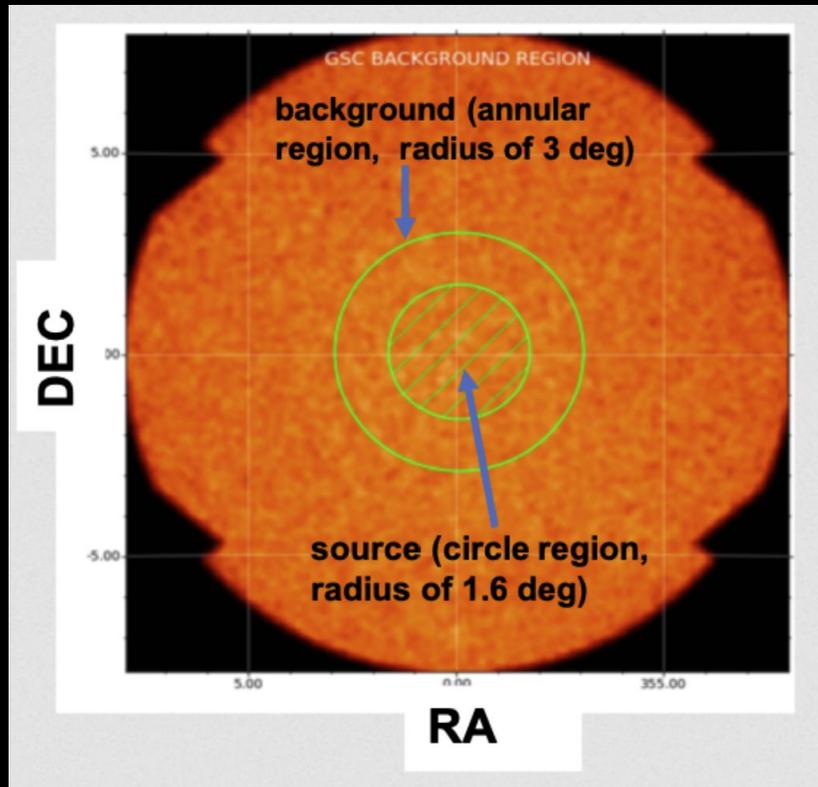
# The search scheme



We employed  $\Delta T = 10^3$  sec

# Looking at excess of X-ray photons

PDF of the photon counts by the data driven approach



# Likelihood Construction

running over all the IceCube – MAXI data pairs

$$\mathcal{L}_{\text{sig+bgd}} = \frac{n_{\text{sig}}}{n_{\text{atm}} + n_{\text{dif}}} P_{\nu}^{\text{sig}}(E_{\nu}, \delta) \times P_X^{\text{sig}}(N_X, \mu_{X\text{sig}}(L_{X\text{ref}}, z)) + \frac{1}{n_{\text{atm}} + n_{\text{dif}}} \left\{ n_{\text{dif}} P_{\nu}^{\text{dif}}(E_{\nu}, \delta) - n_{\text{sig}} P_{\nu}^{\text{sig}}(E_{\nu}, \delta) \right\} P_{X\text{DB}}^{\text{bgd}}(N_X) + \frac{n_{\text{atm}}}{n_{\text{atm}} + n_{\text{dif}}} P_{\nu}^{\text{atm}}(E_{\nu}, \delta) P_{X\text{DB}}^{\text{bgd}}(N_X)$$

$n$  : expected numbers of each component

$P$  : Probability Density Function

$\delta$  : direction of the events

$E_{\nu}$  : energy of the events

$N_X$  : Number of X-ray events

$\mu_{X\text{sig}}$  : Expected number of X-ray signals from the model

$L_{X\text{ref}}$  : Assumed X-ray luminosity of the SXT model

$z$  : Assumed distance distribution of the SXT model

# Running Pseudo-experiments

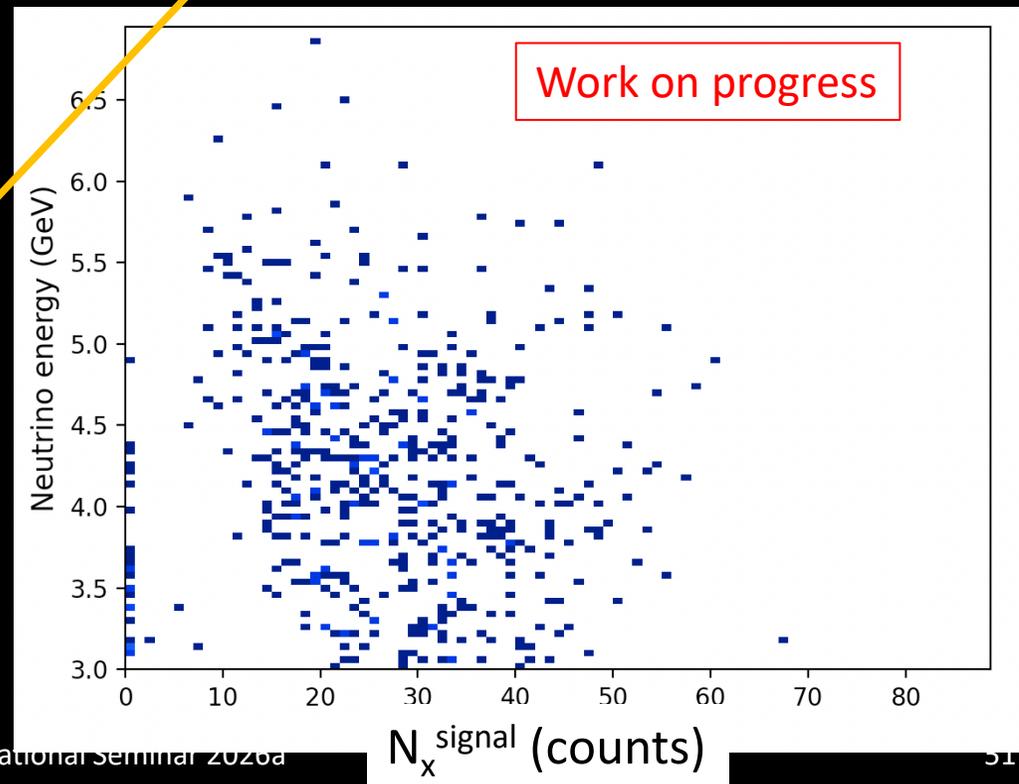
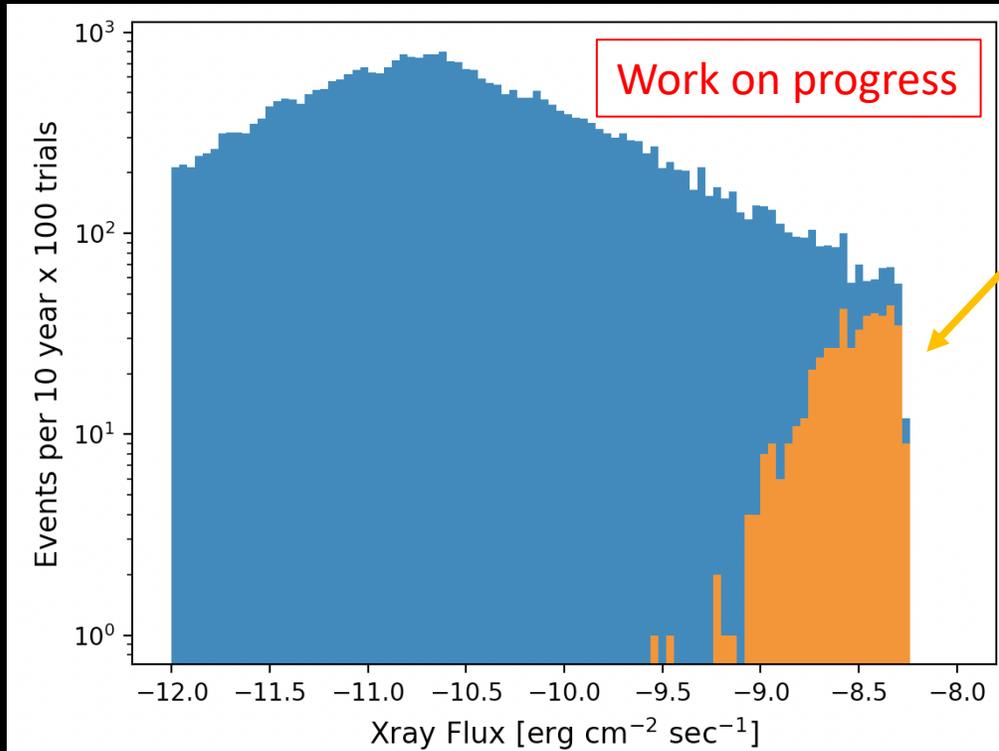
When follow up neutrino direction **200k times**

taken from 12yr long IceCube archival data, dominated by atmospheric neutrinos.  
Purity of astrophysical neutrinos is  $\lesssim 0.1\%$

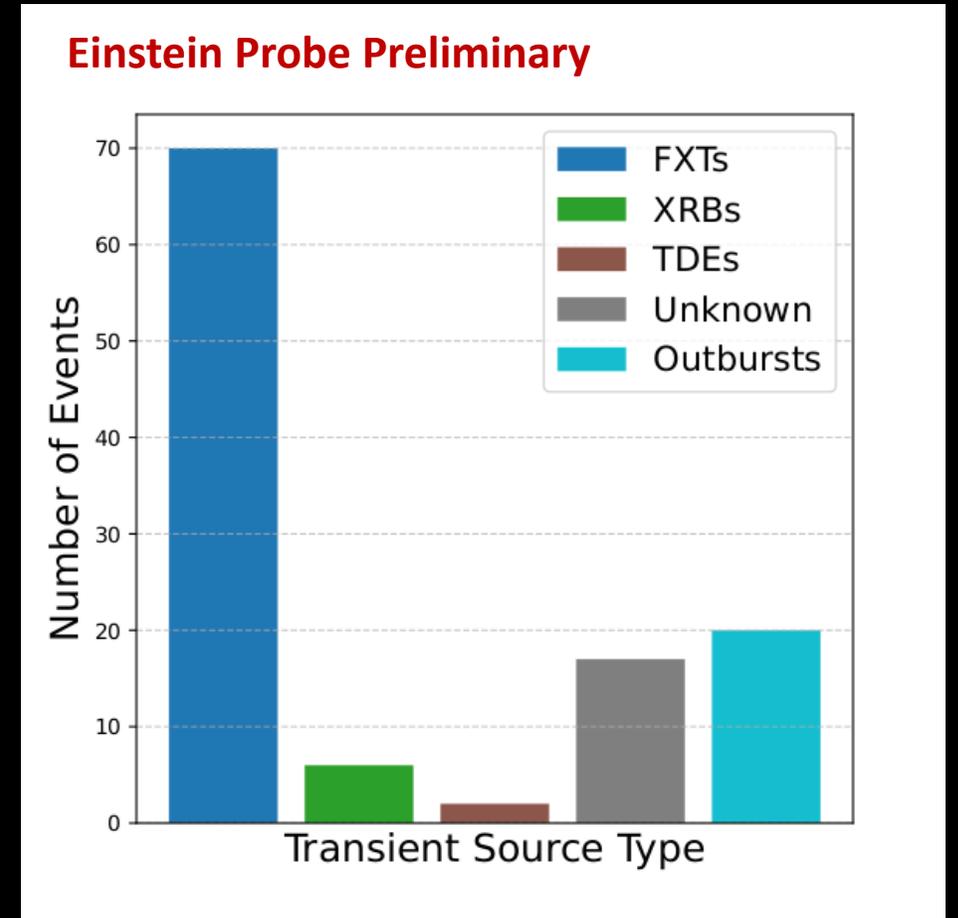
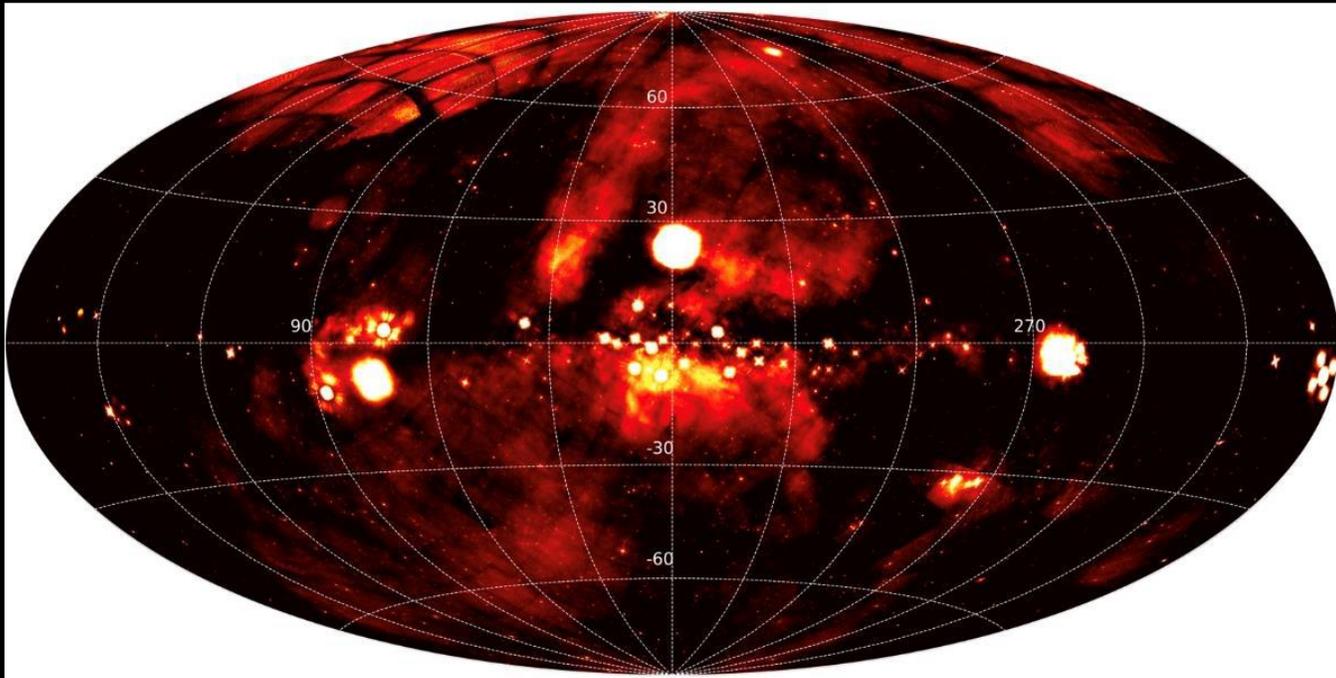
IceCub – MAXI  
work on progress

$$L_X = 10^{46} \text{ erg/s} \quad n_0 = 5 \times 10^{-9} \text{ Mpc}^{-3}$$

$$\frac{\mathcal{L}_{sig}(L_X)}{\mathcal{L}_{bgd}} > 0.5$$



# New soft X-ray sky monitored by Einstein Probe - WXT



# Take-Away messages

- The all-sky cosmic neutrino background flux has been measured

$$E_\nu \lesssim 10\text{TeV}$$

A fraction of them comes from (X-ray bright) Seyfert Galaxies

$$10\text{PeV} \lesssim E_\nu$$

yet to be discovered, but the present limit tells  
UHE cosmic-ray origins must be weakly evolved  
and/or emit nuclei, not protons

$$10\text{TeV} \lesssim E_\nu \lesssim 10\text{PeV}$$

Low Luminosity AGNs? ← wait for IceCube-Gen2

Transients (LL GRBs, LL TDEs)? ← multimessenger (X-ray, Opt/IR)

Connections to UHE cosmic ray origins are interesting possibility

# Summary

- Multiple neutrino detection (“**multiplet**”) is key for identifying **optical transients**
- **Xray transients** (e.g. LL GRBs) are the most promising candidate of **the UHECR – neutrino unified origin**
- Neutrino – Xray **multimessenger** search will measure/constrain the cosmic ray target Xray luminosity  $L_x$  [erg/s]
- The requirements of UHECR energetics, accelerations, and escape conditions in addition to  $L_{\text{UHECR}}$  demanded by  $L_x$  will provide the solid diagnosis of the UHECR-neutrino unified models.

# Backup