

Multimessenger Astrophysics and the Emerging Picture of High-Energy Neutrino Sources

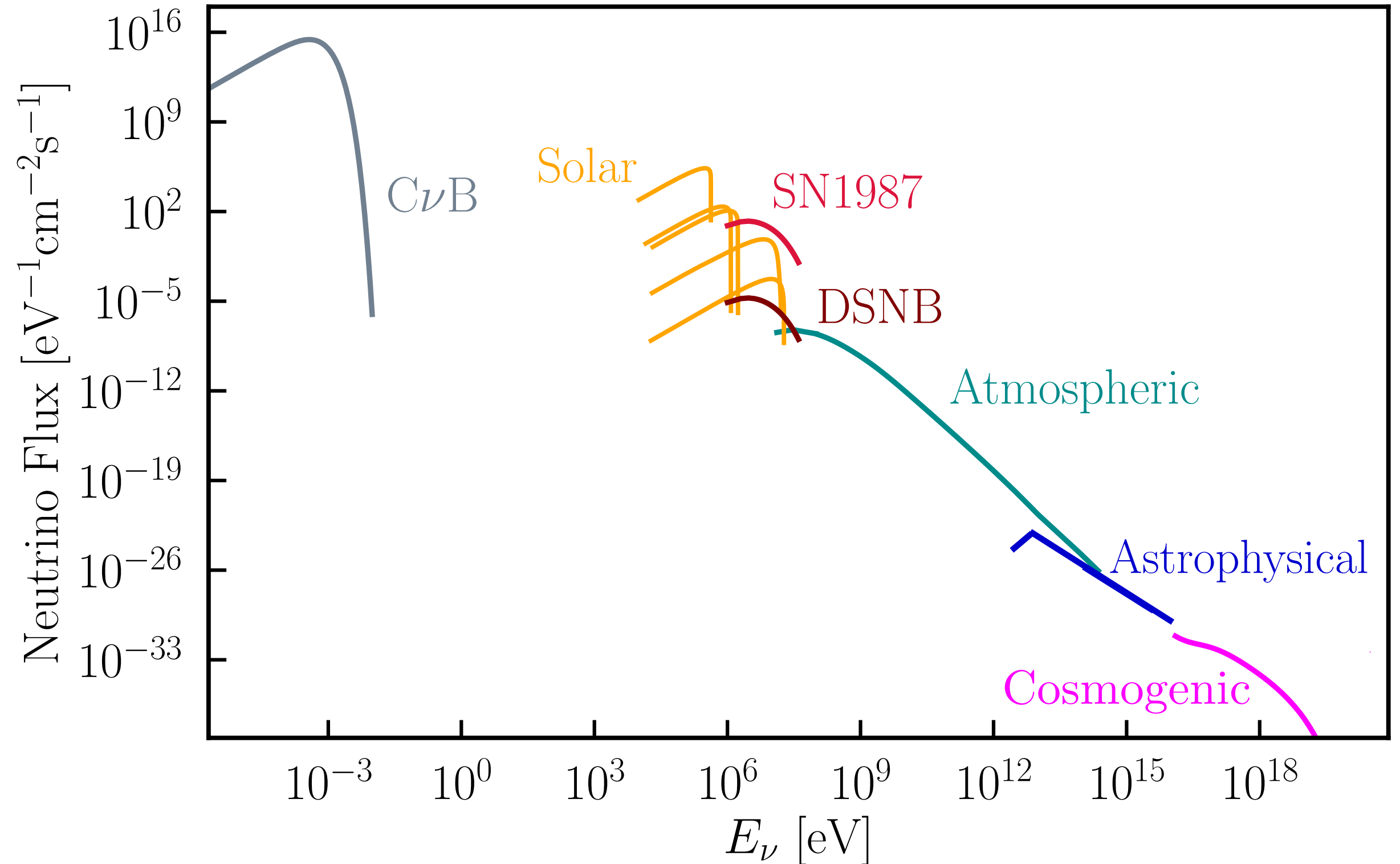
Ali Kheirandish
University of Nevada, Las Vegas

High-Energy Theory Seminar
Brookhaven National Lab

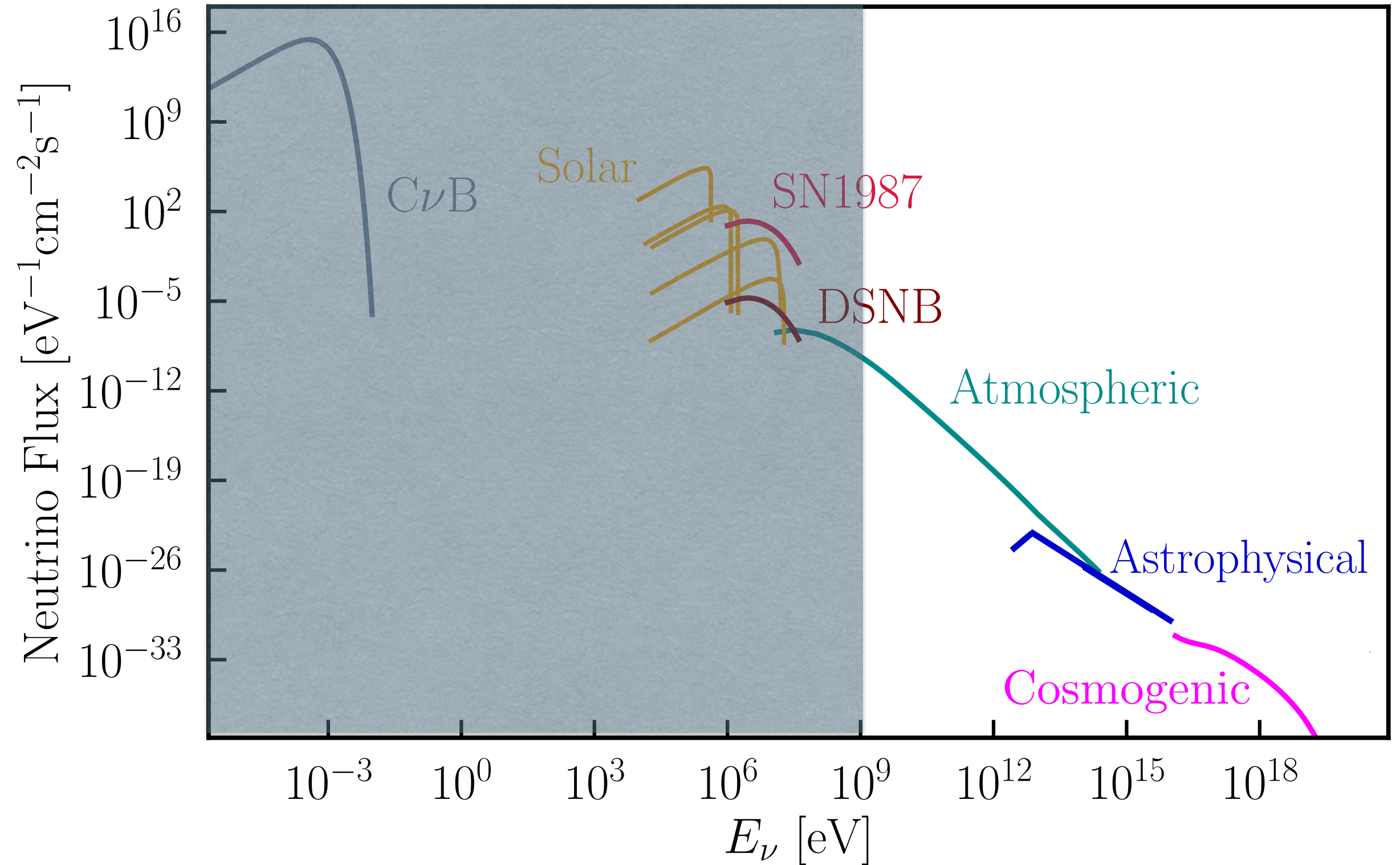
Oct 2026



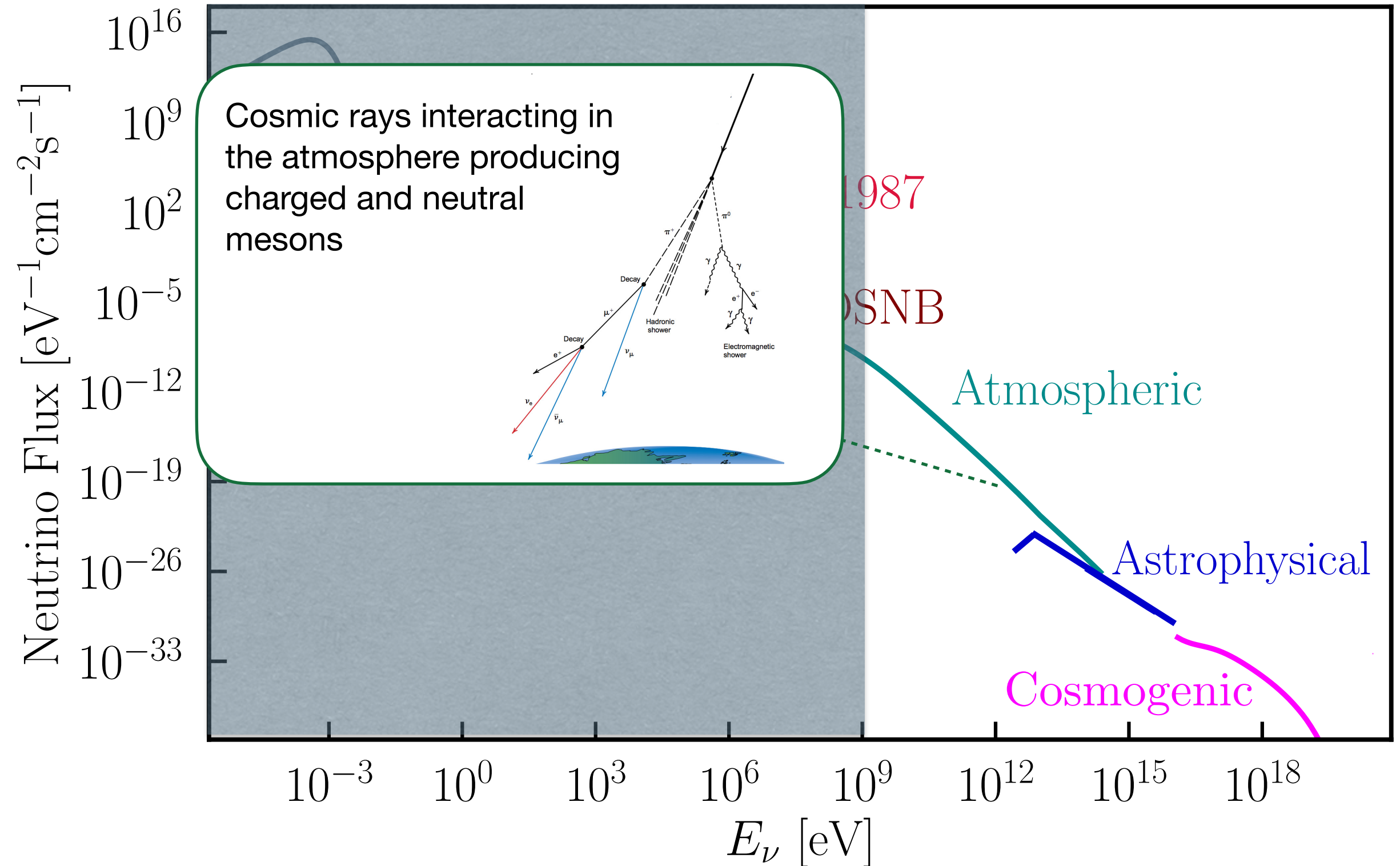
The Universe in Neutrinos



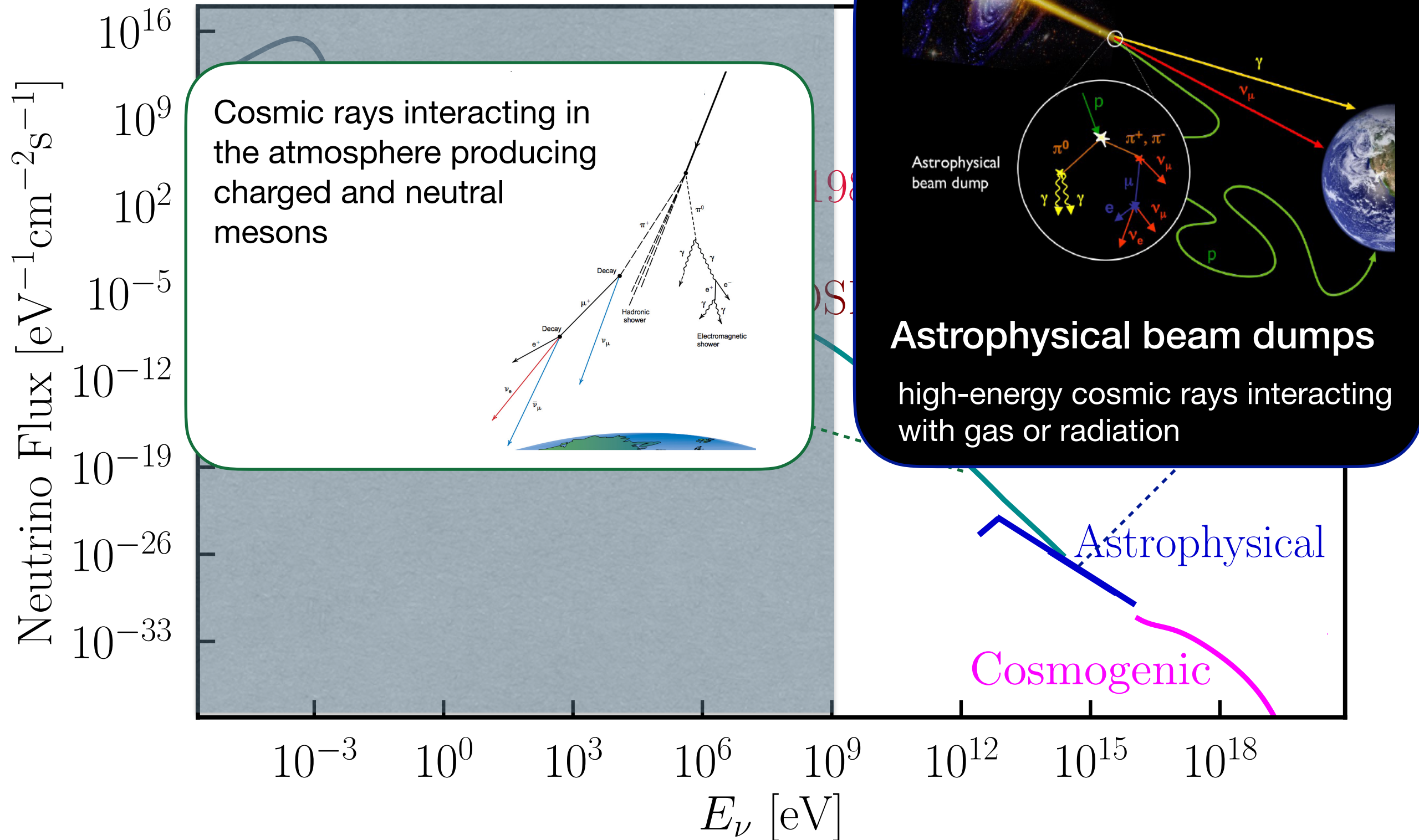
The Universe in Neutrinos



The Universe in Neutrinos



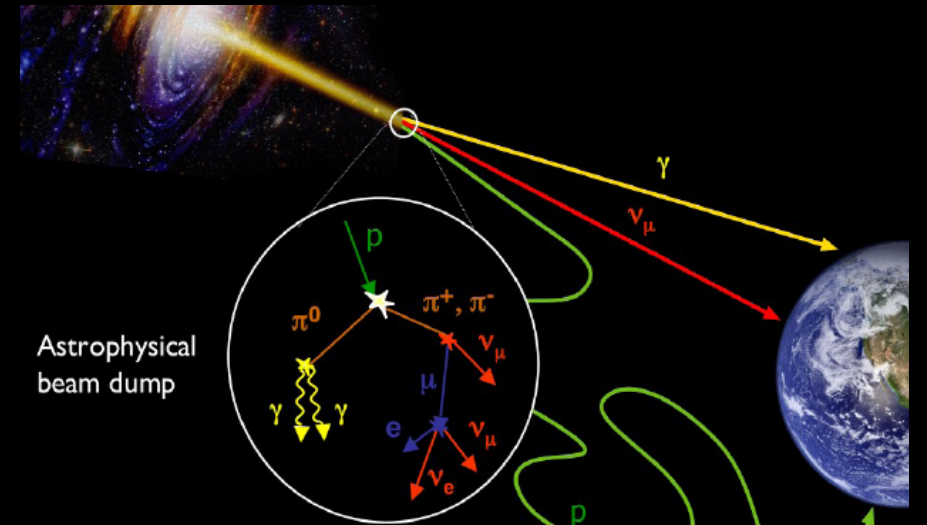
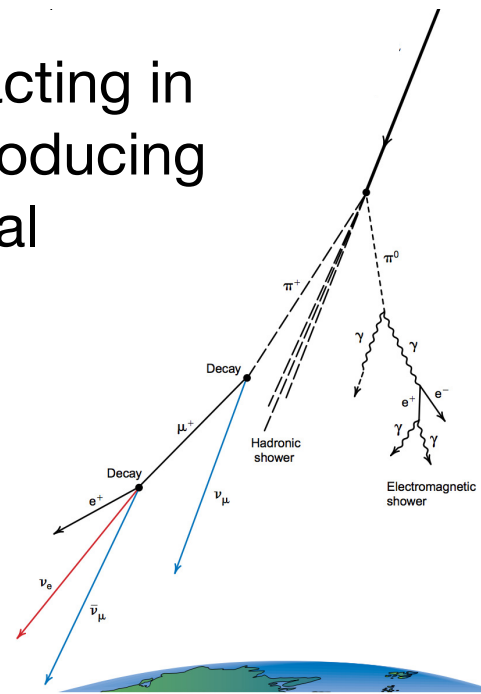
The Universe in Neutrinos



The Universe in Neutrinos

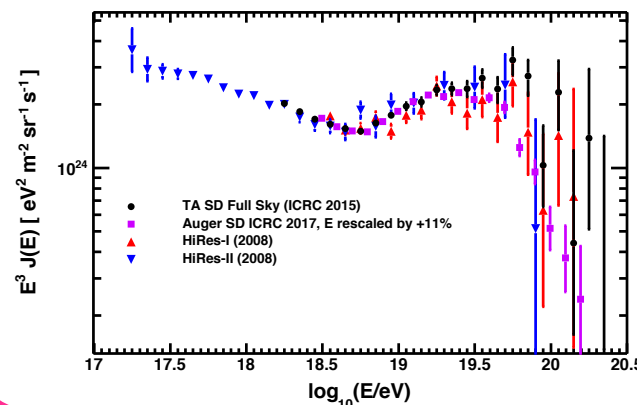
Neutrino Flux [$\text{eV}^{-1}\text{cm}^{-2}\text{s}^{-1}$]

Cosmic rays interacting in the atmosphere producing charged and neutral mesons

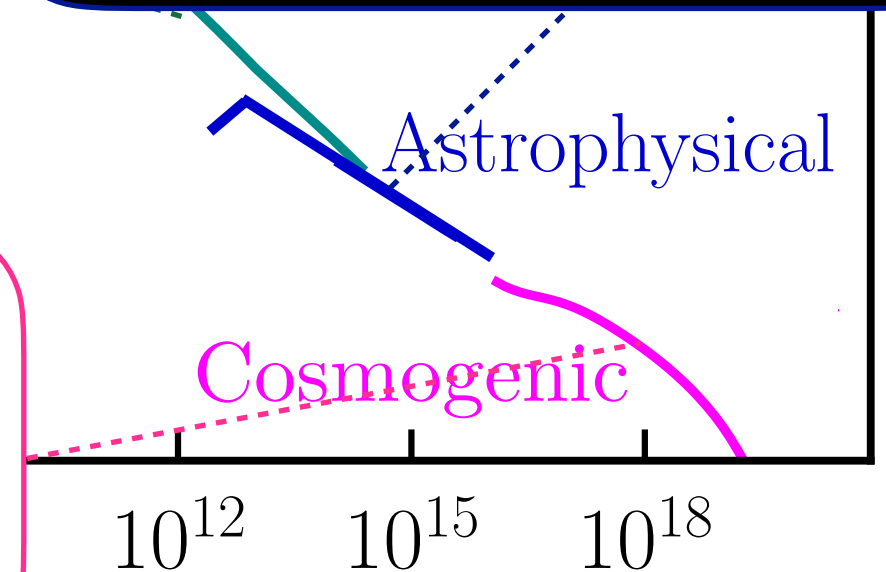


Astrophysical beam dumps

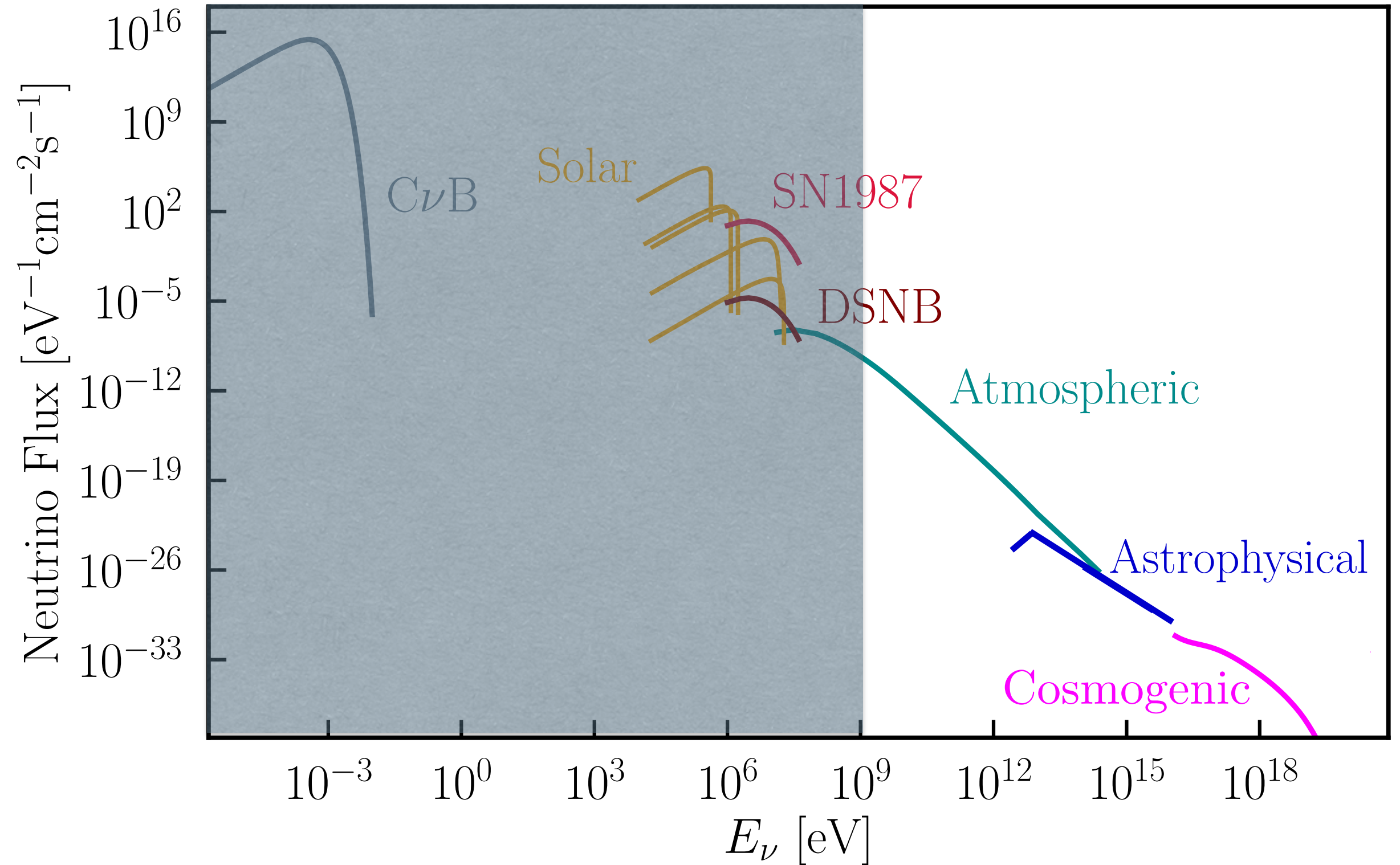
high-energy cosmic rays interacting with gas or radiation



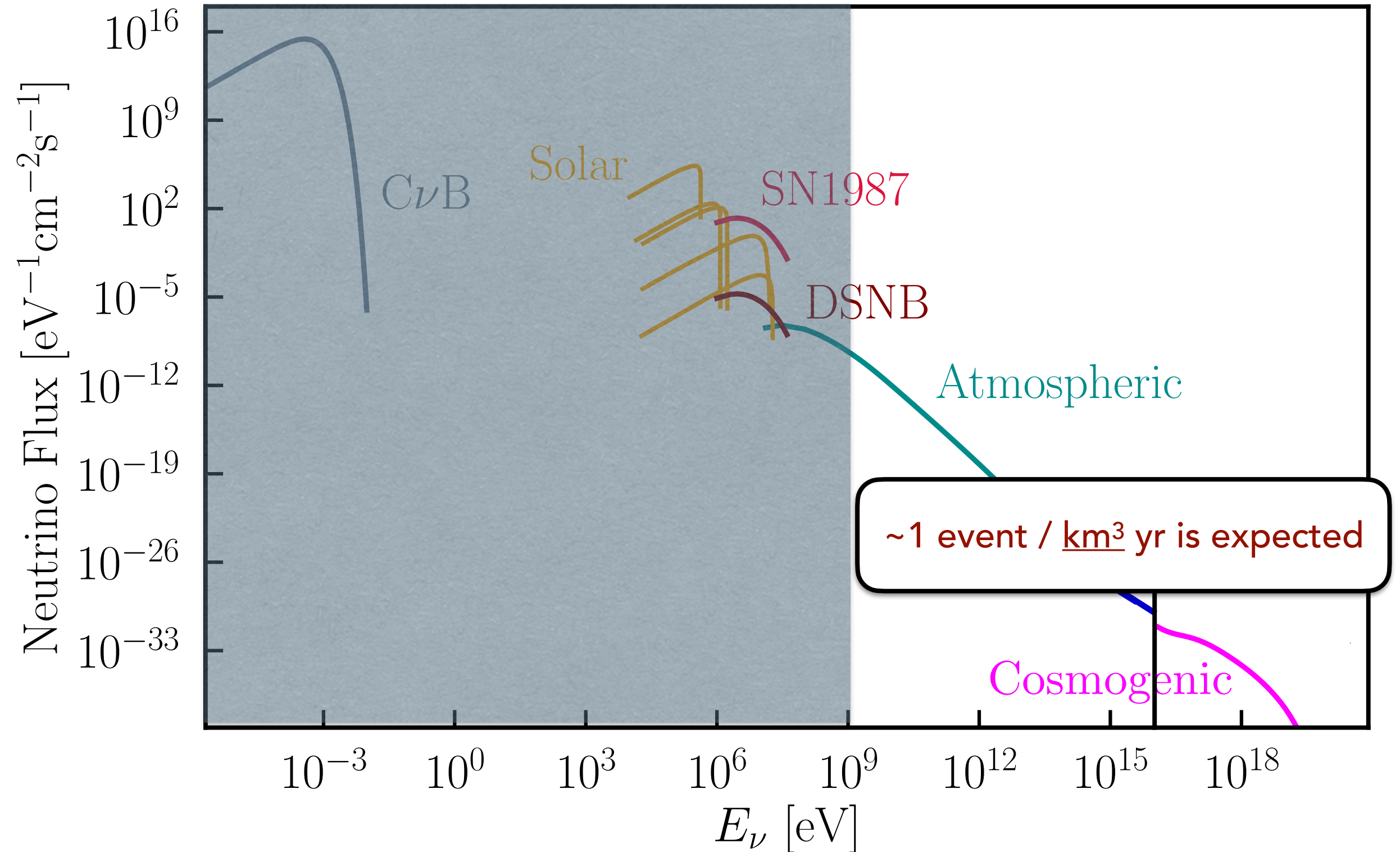
Ultra-high-energy cosmic rays interacting with the Cosmic Microwave Background



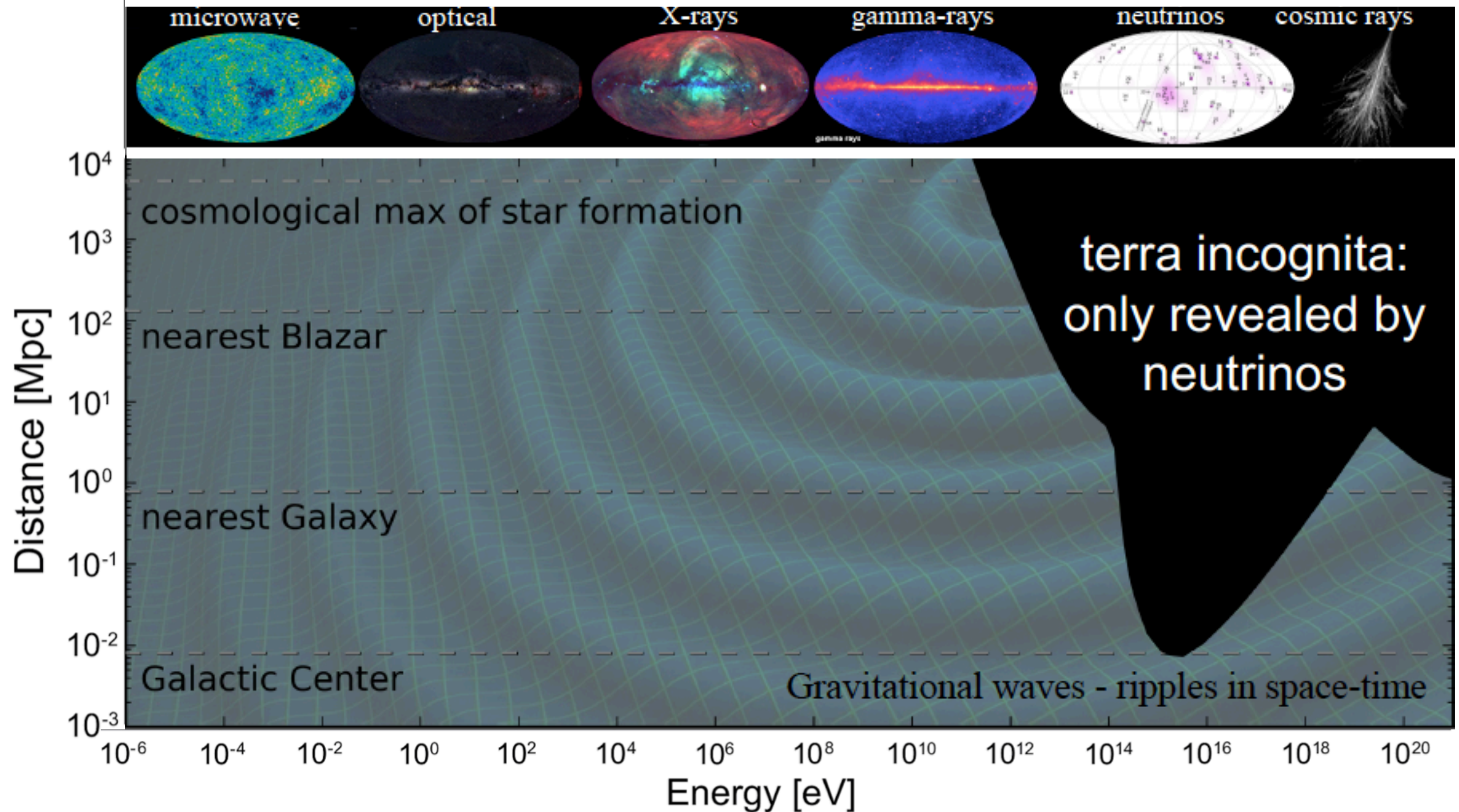
The Universe in Neutrinos



The Universe in Neutrinos



Observable Universe

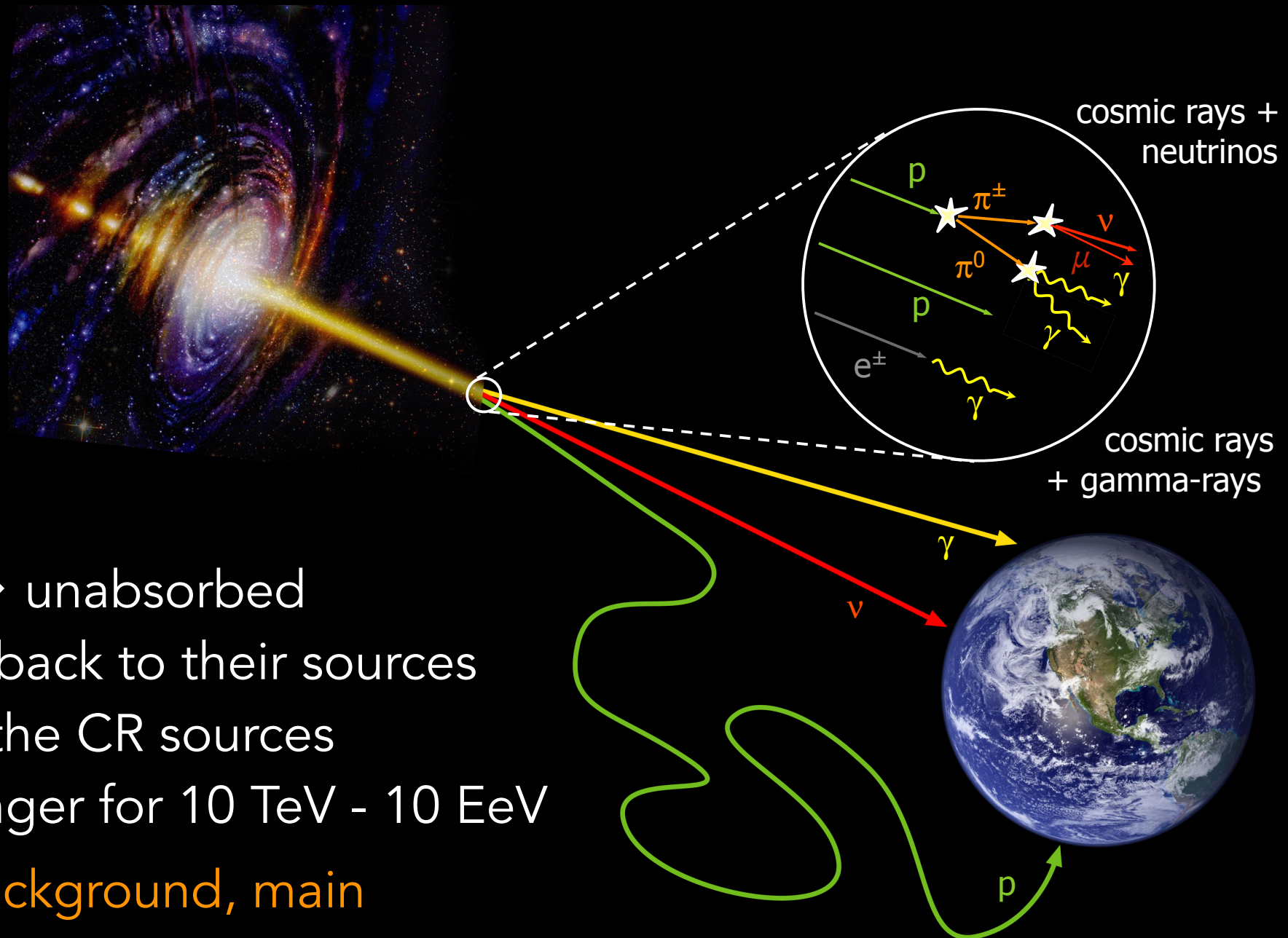


- 20% of the Universe is opaque to the EM spectrum
- non-thermal Universe powered by cosmic accelerators
- probed by gravity waves, neutrinos and cosmic rays

Neutrino Astronomy

- Soon after discovery it was realized neutrinos are ideal cosmic messengers.

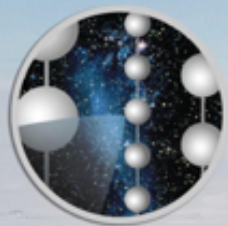
Accelerated CRs
interact with gas or
radiation in the beam
dump and produce
charged and neutral
pions.



► Neutrinos:

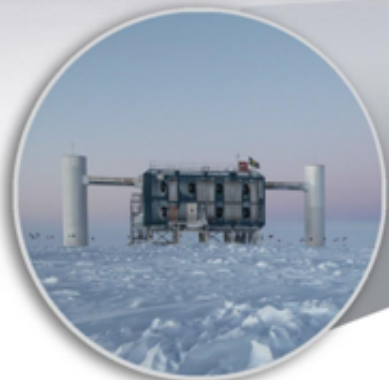
- ✓ Hardly interact → unabsorbed
- ✓ Neutral → point back to their sources
- ✓ Smoking gun of the CR sources
- ✓ Exclusive messenger for 10 TeV - 10 EeV

Low statistics and large background, main
challenges for neutrino astronomy.



ICECUBE

SOUTH POLE NEUTRINO OBSERVATORY



IceCube Laboratory

Data is collected here and sent by satellite to the data warehouse at UW-Madison



Digital Optical Module (DOM)

5,160 DOMs deployed in the ice

50 m

IceTop

1450 m

2450 m

IceCube detector

86 strings of DOMs, set 125 meters apart

DeepCore

Antarctic bedrock

DOMs are 17 meters apart

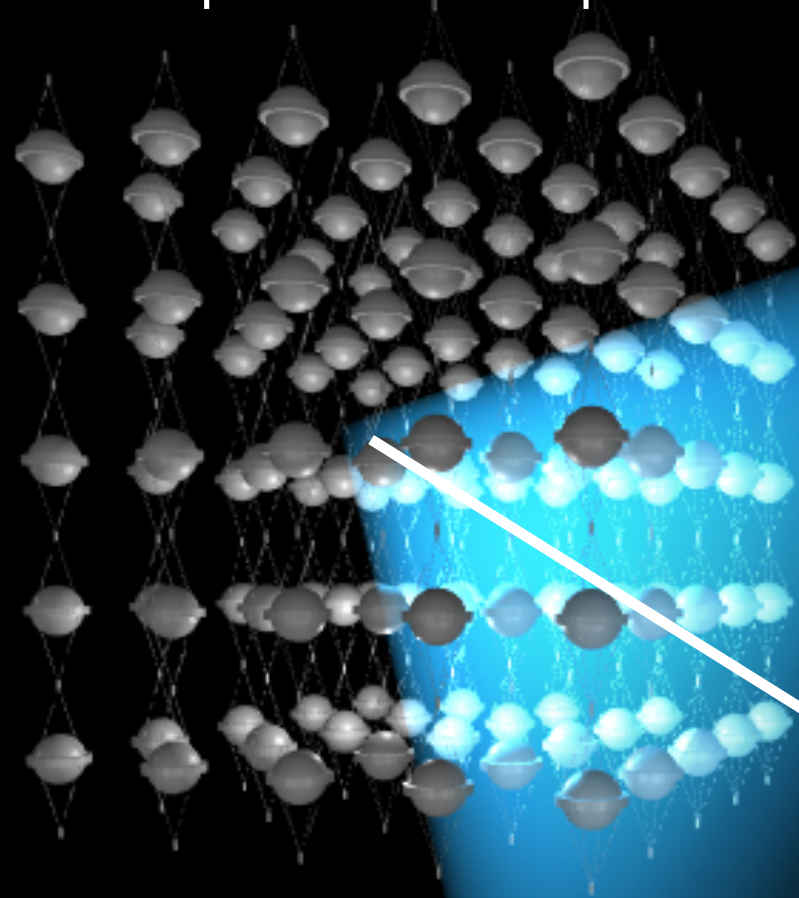
60 DOMs on each string



Amundsen-Scott South Pole Station, Antarctica

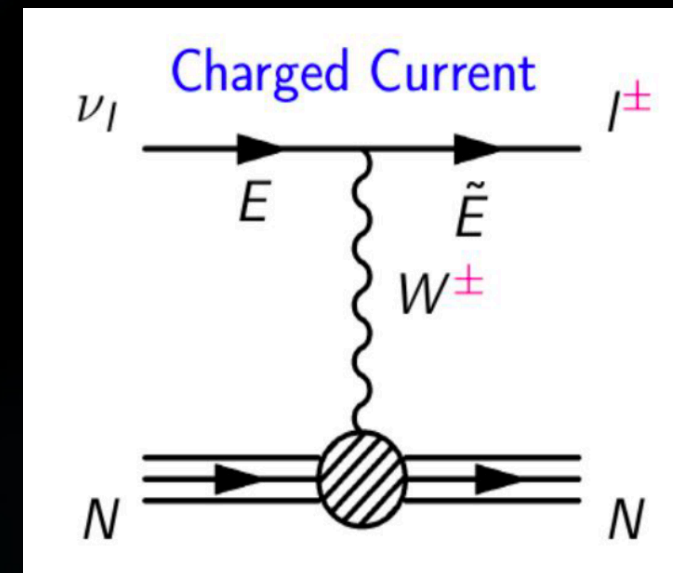
A National Science Foundation-managed research facility

- lattice of photomultipliers



High-energy charged particles, traveling faster than light in ice or water, produce *Cherenkov* light in the ice.

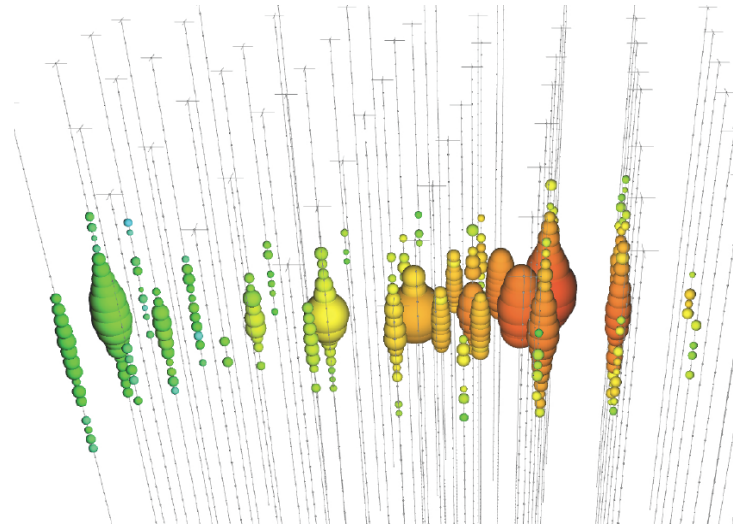
charged secondary particles produced as the neutrino interacts with a nucleus



neutrino

Event Morphologies

Charged-current ν_μ

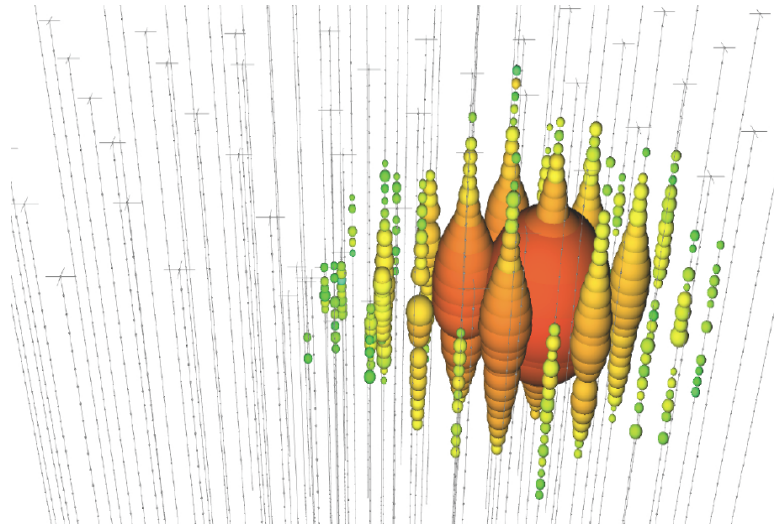


Tracks

Good (0.2–1 degree)
angular resolution

Factor of two muon
energy resolution

Neutral-current / ν_e

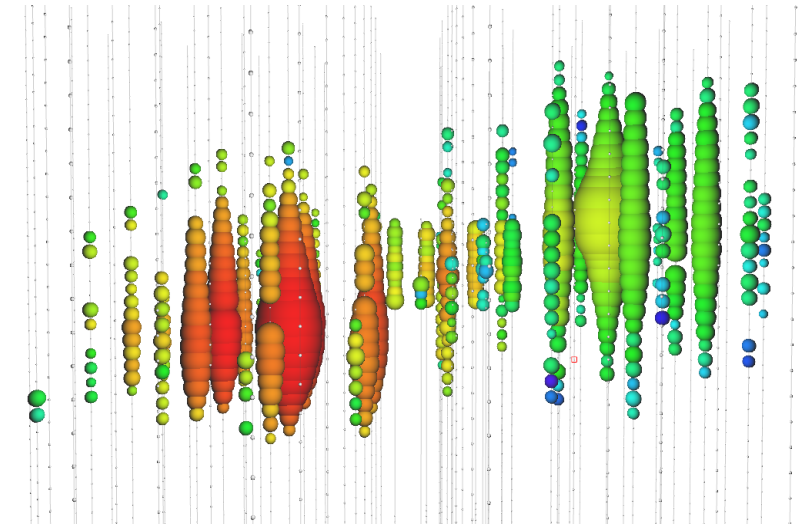


Cascades

Good (15%) energy
resolution

> 4 degrees
angular resolution

Charged-current ν_τ

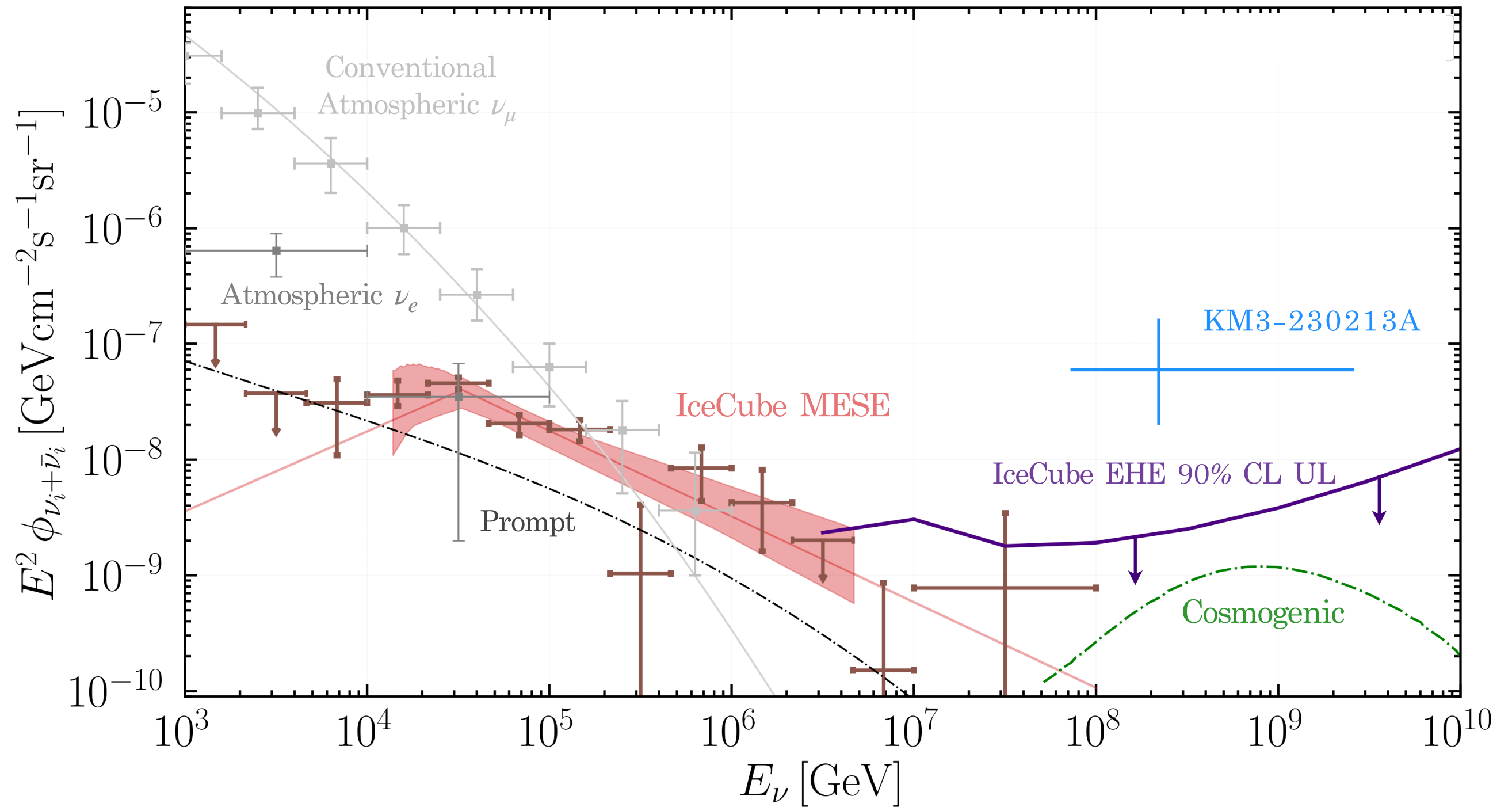


Double Cascades

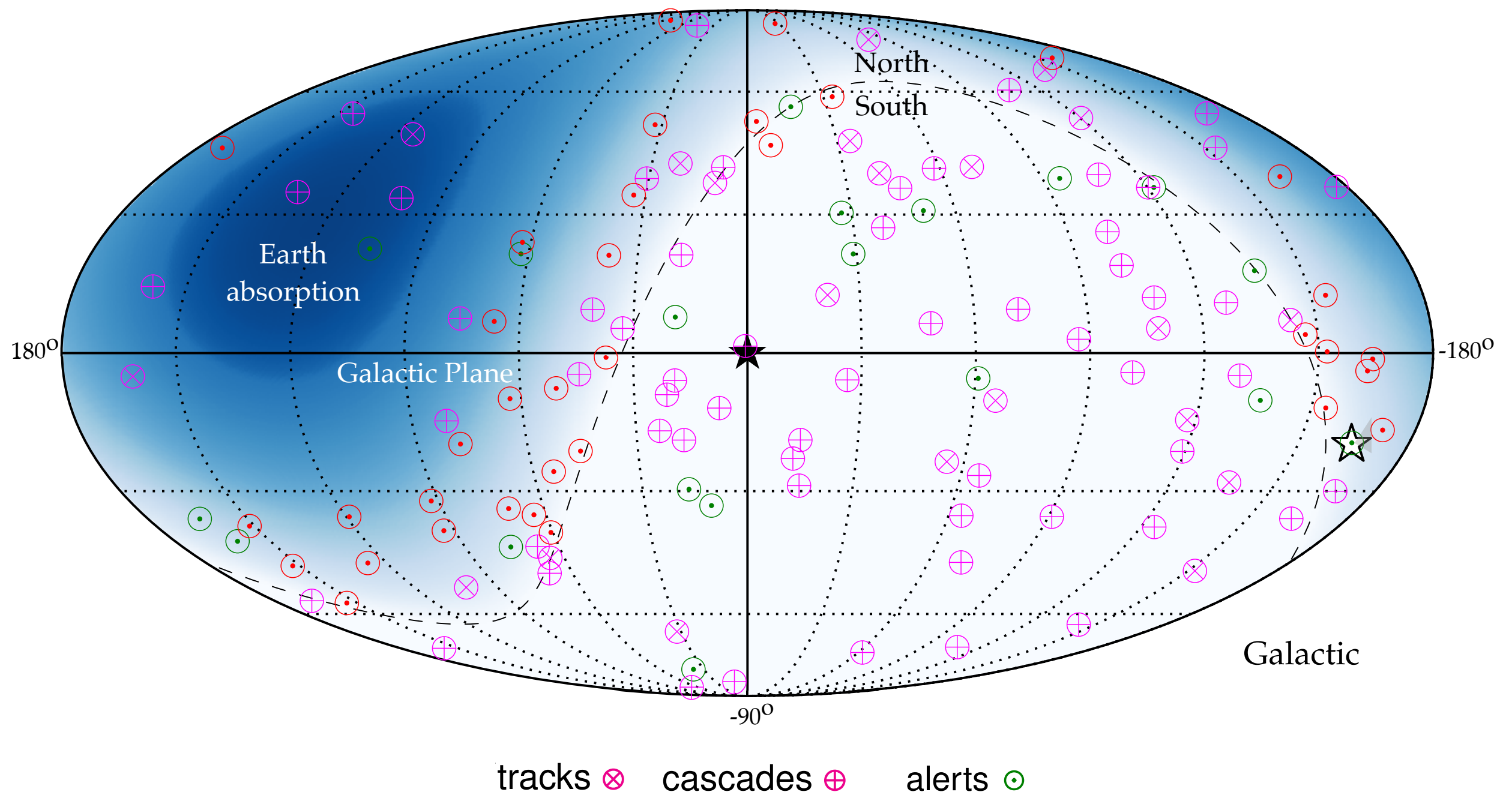
Resolvable at high
energies

High purity (i.e.,
astrophysicalness)

High-Energy Neutrino Flux

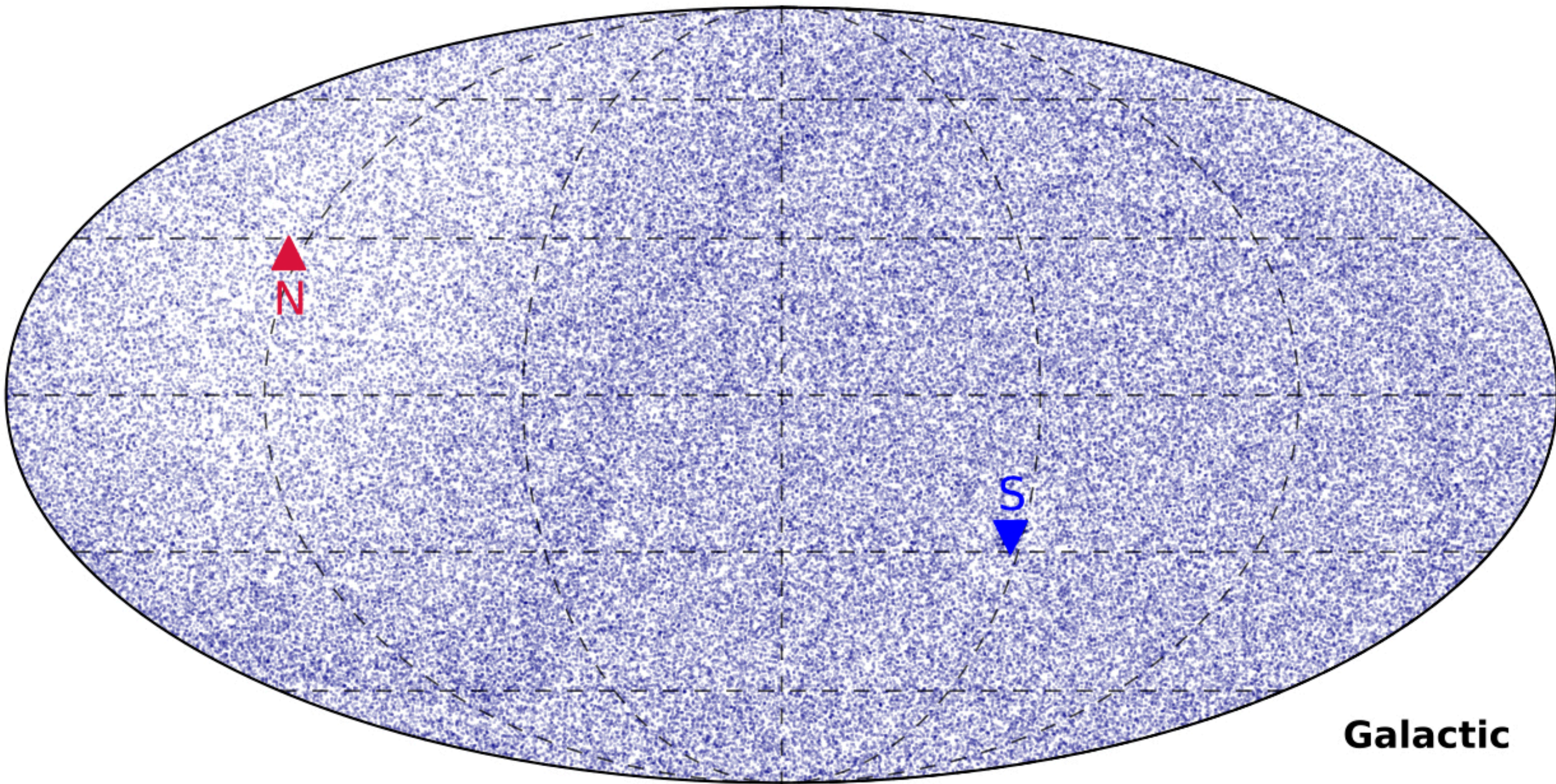


Arrival Direction of the Most Energetic Neutrinos



predominantly extragalactic origin

Spatial Distribution

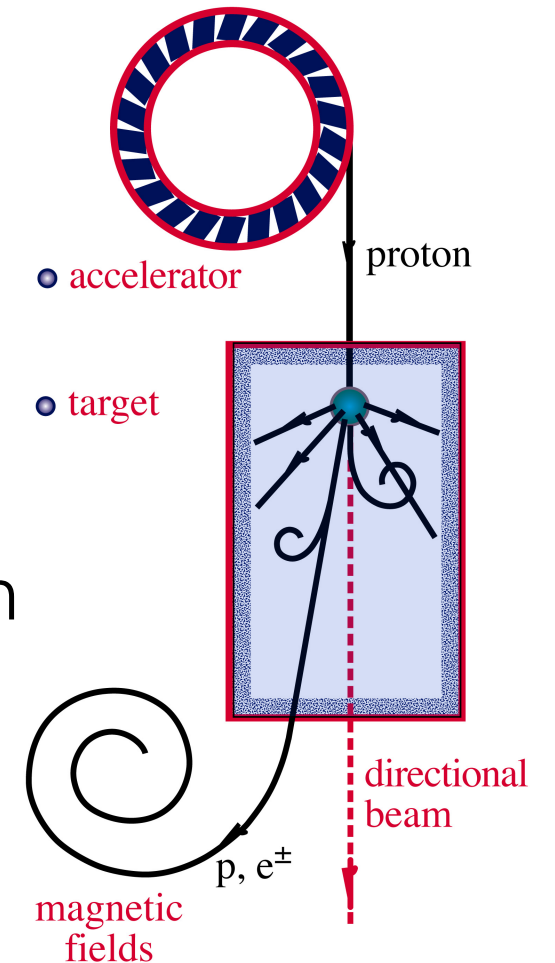


138322 neutrino candidates in one year

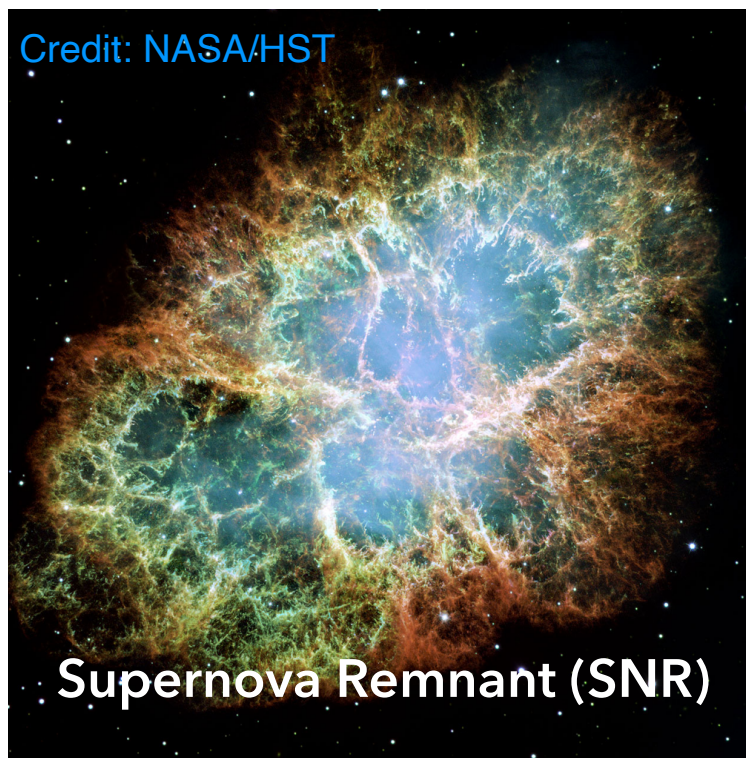
Possible Sources

Sources of TeV - PeV cosmic neutrinos should

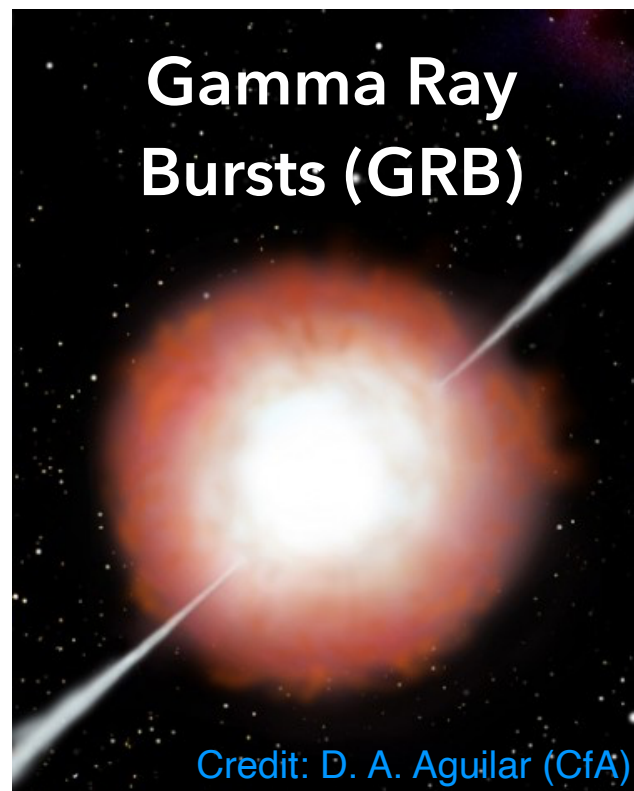
- ▶ Accelerate Cosmic Rays to $> \text{PeV}$ energies
 - ▶▶ sources of VHE & UHE CRs
- ▶ Poses beam dumps that facilitate CR interaction
 - ▶▶ environment that can provide gas and radiation with enough density



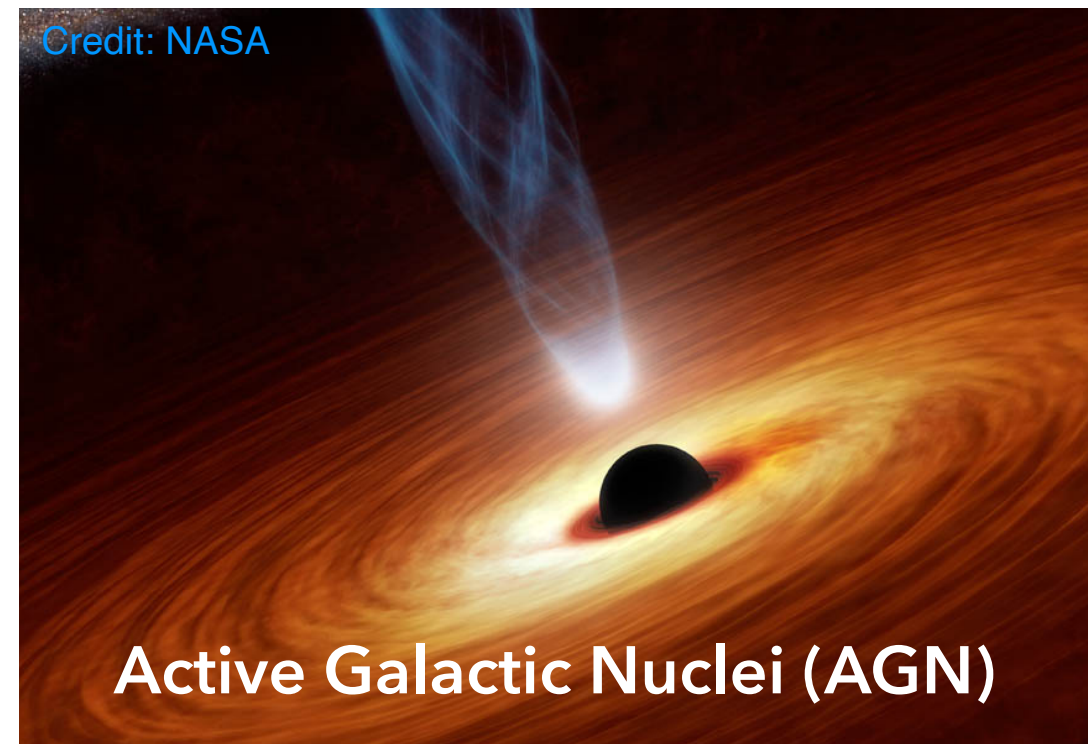
Credit: NASA/HST



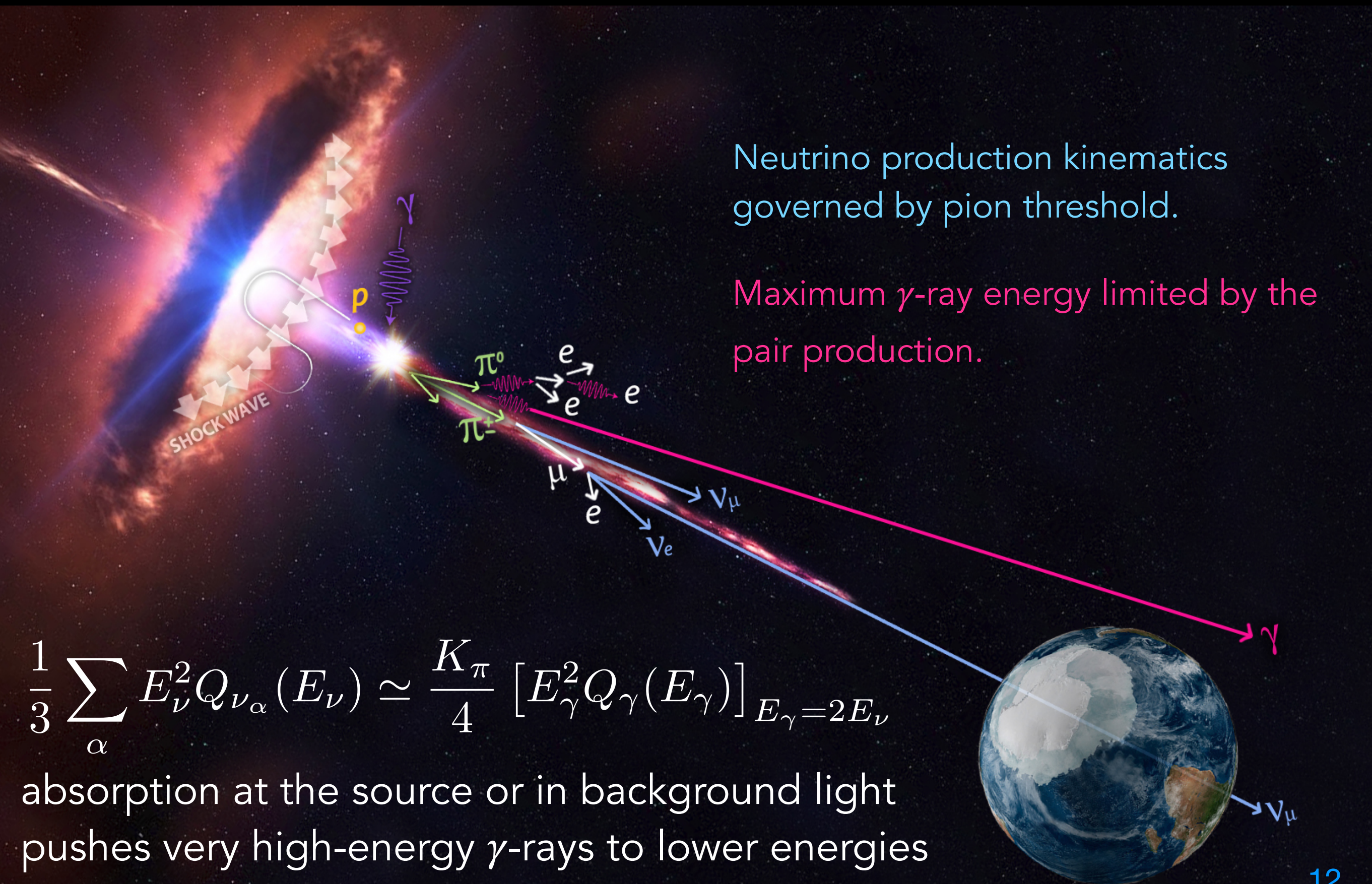
**Gamma Ray
Bursts (GRB)**



Credit: NASA

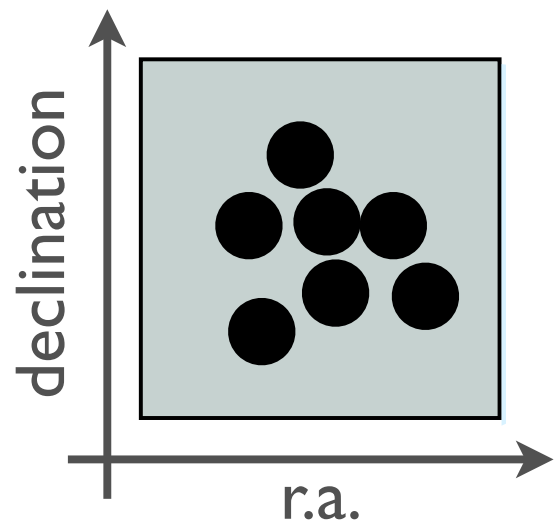


The Neutrino γ -ray Connection



Point Source Searches

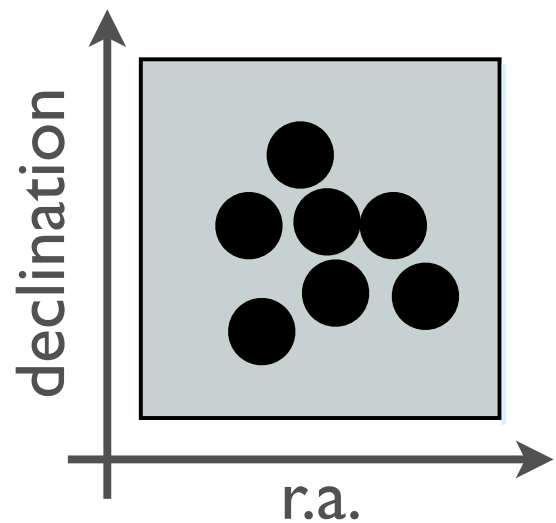
Point Source Searches



clustering

- Untriggered search in space & time

Point Source Searches

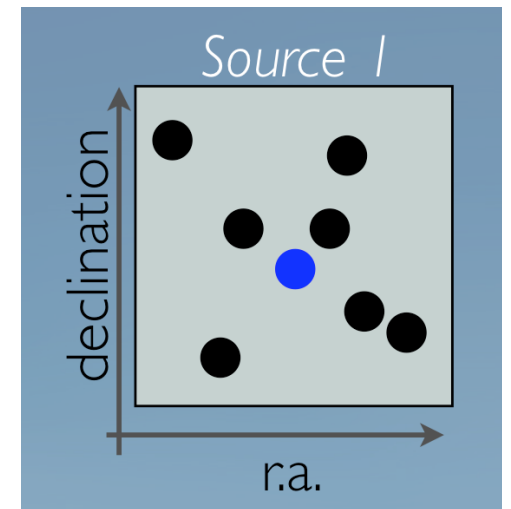


clustering

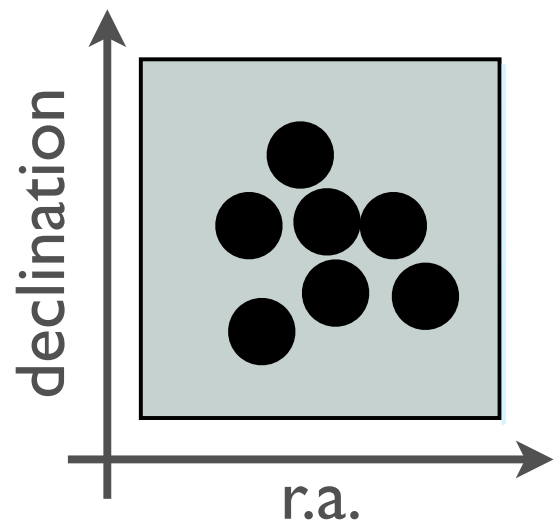
- Untriggered search in space & time

source search

- Triggered search for pre-identified locations



Point Source Searches

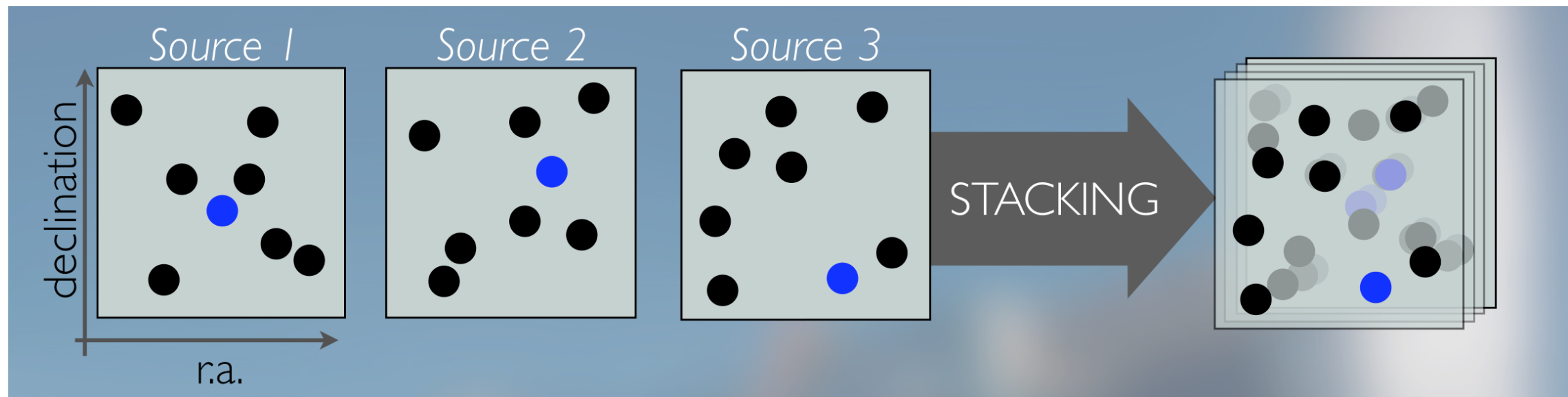
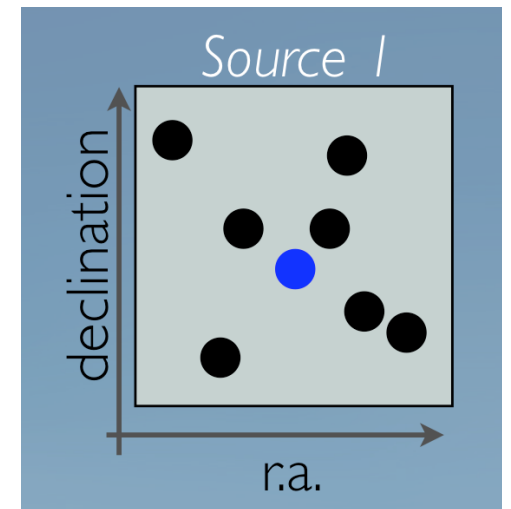


clustering

- Untriggered search in space & time

source search

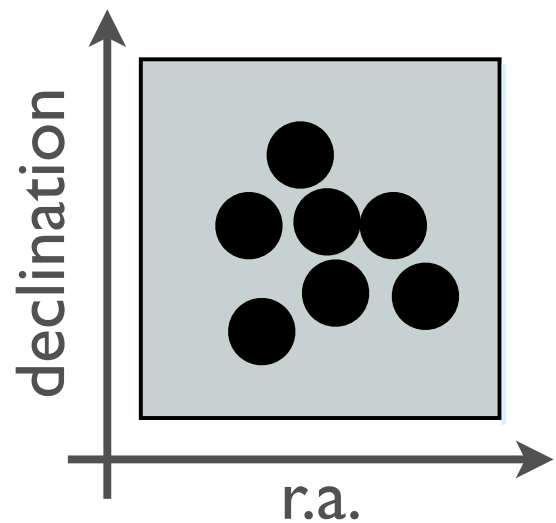
- Triggered search for pre-identified locations



Stacking Search

- Search for collective neutrino emission from a catalog/class of sources

Point Source Searches

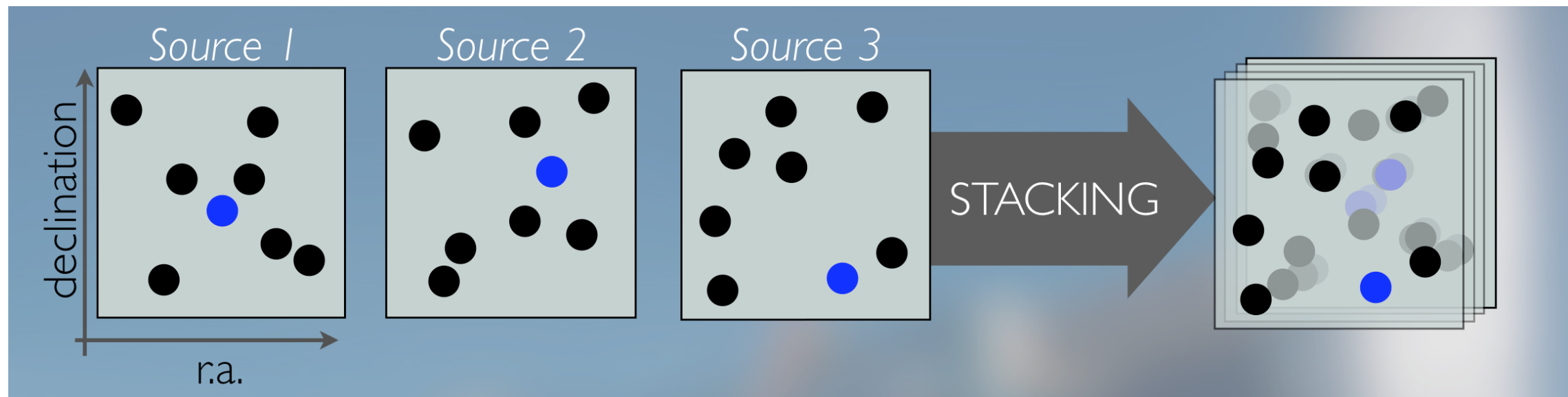
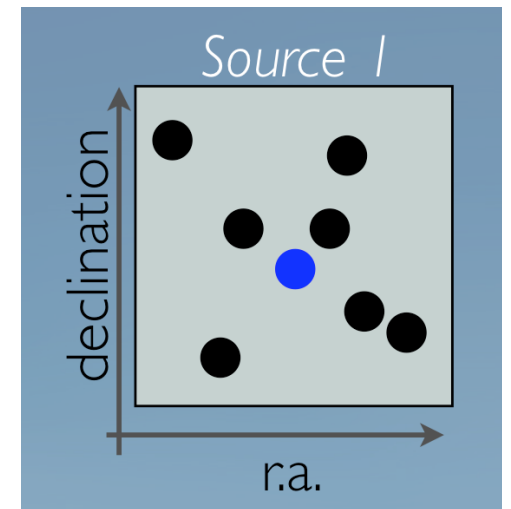


clustering

- Untriggered search in space & time

source search

- Triggered search for pre-identified locations

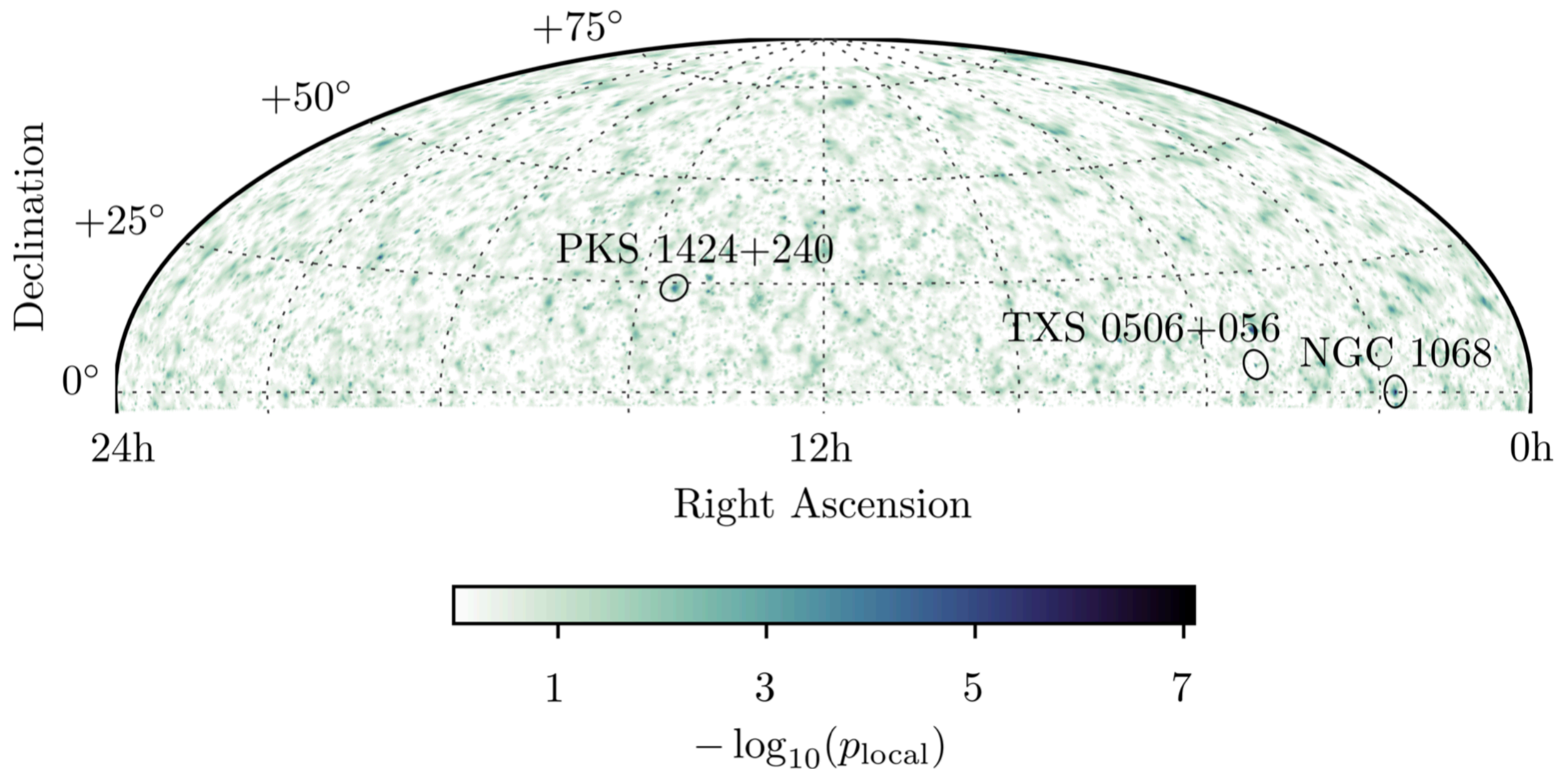


Stacking Search

- Search for collective neutrino emission from a catalog/class of sources

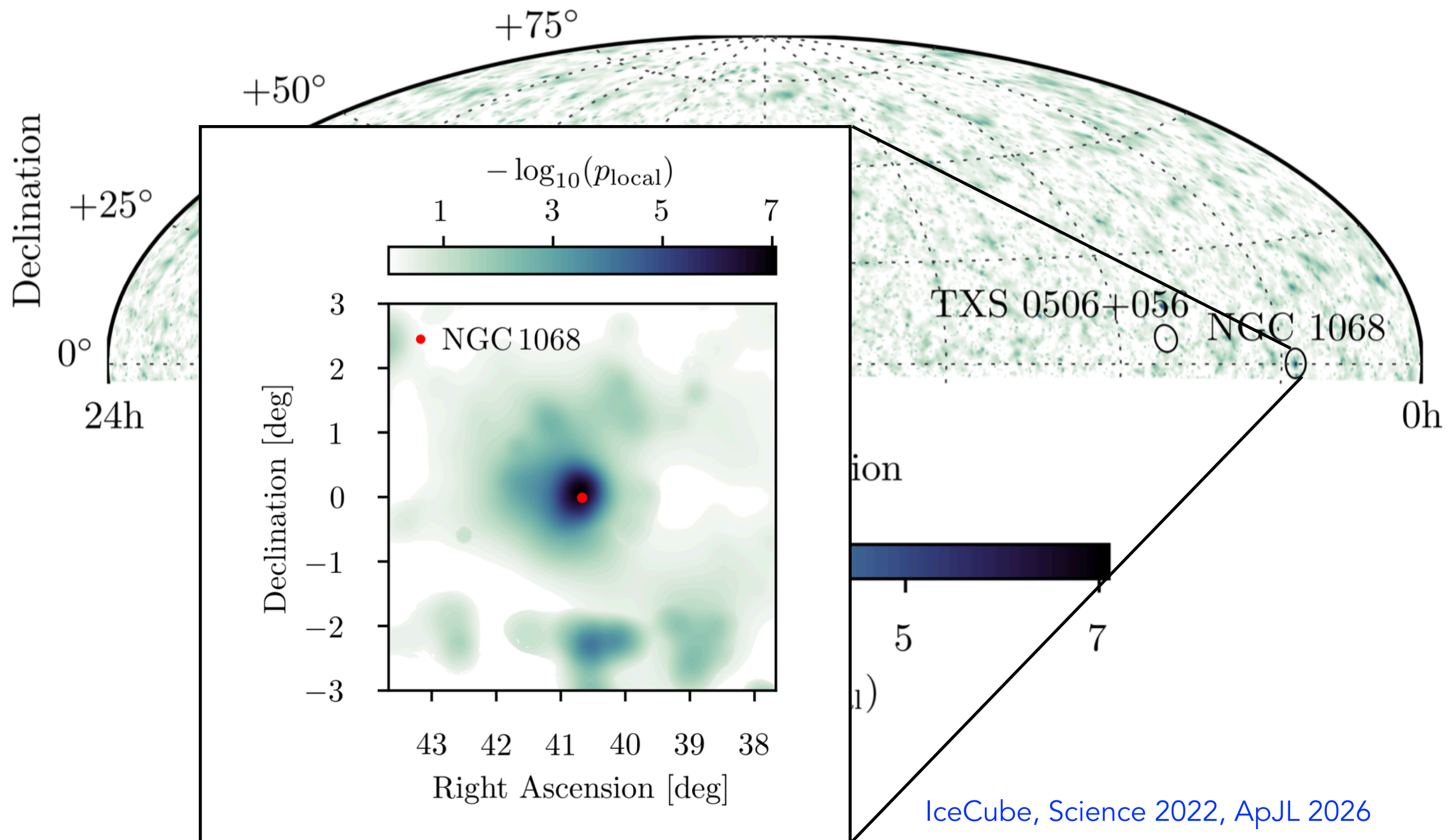
+ 🕒 *Realtime analysis and Neutrino alerts!*

NGC 1068; Brightest Source in Nu Sky

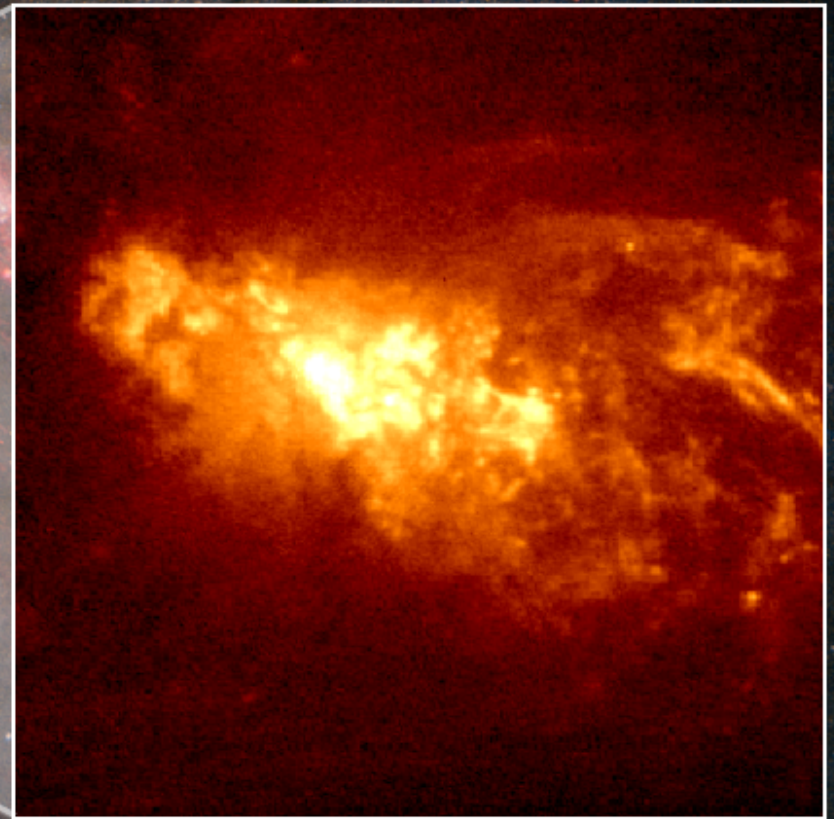
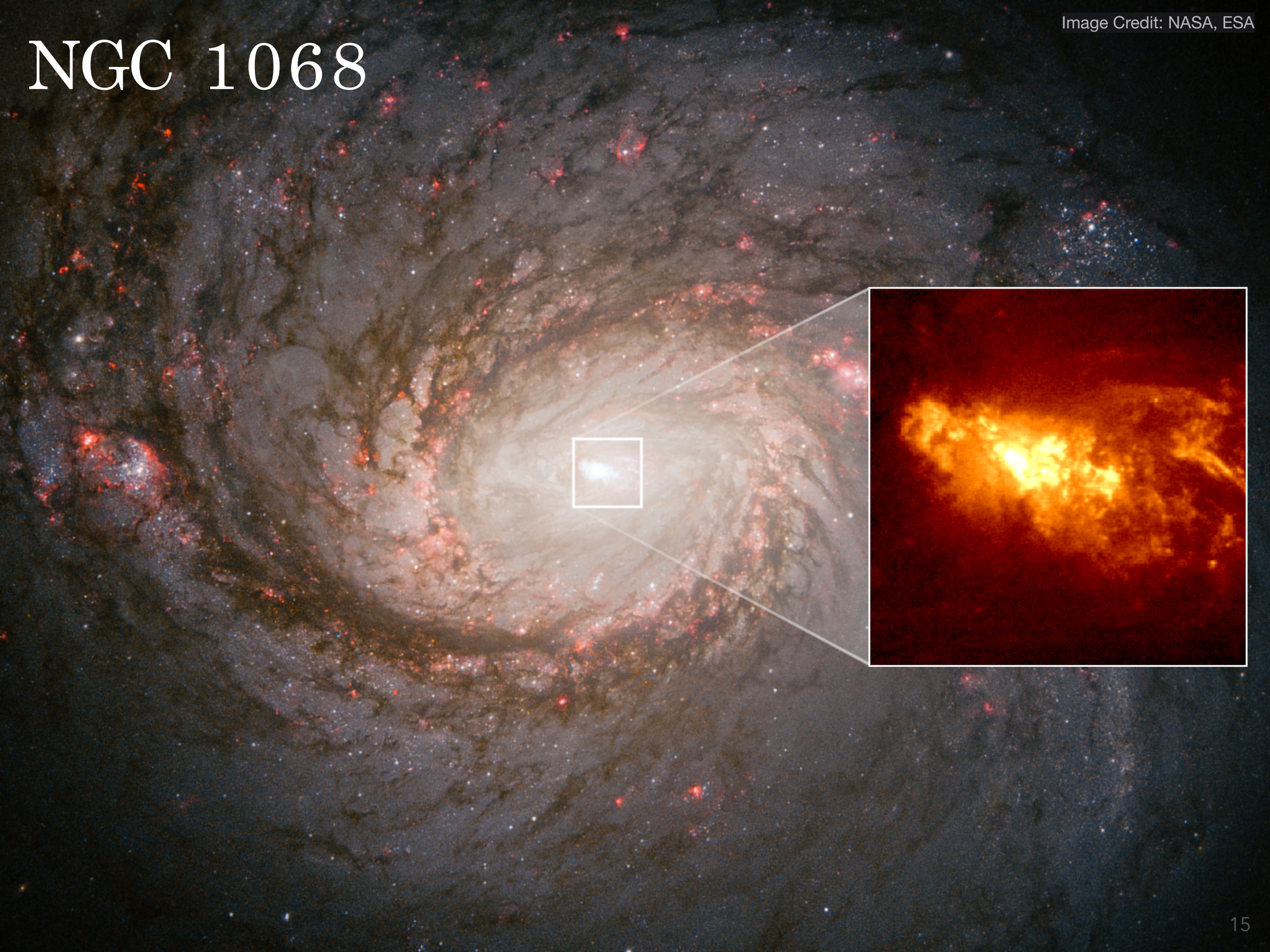


IceCube, Science 2022, ApJL 2026

NGC 1068; Brightest Source in Nu Sky

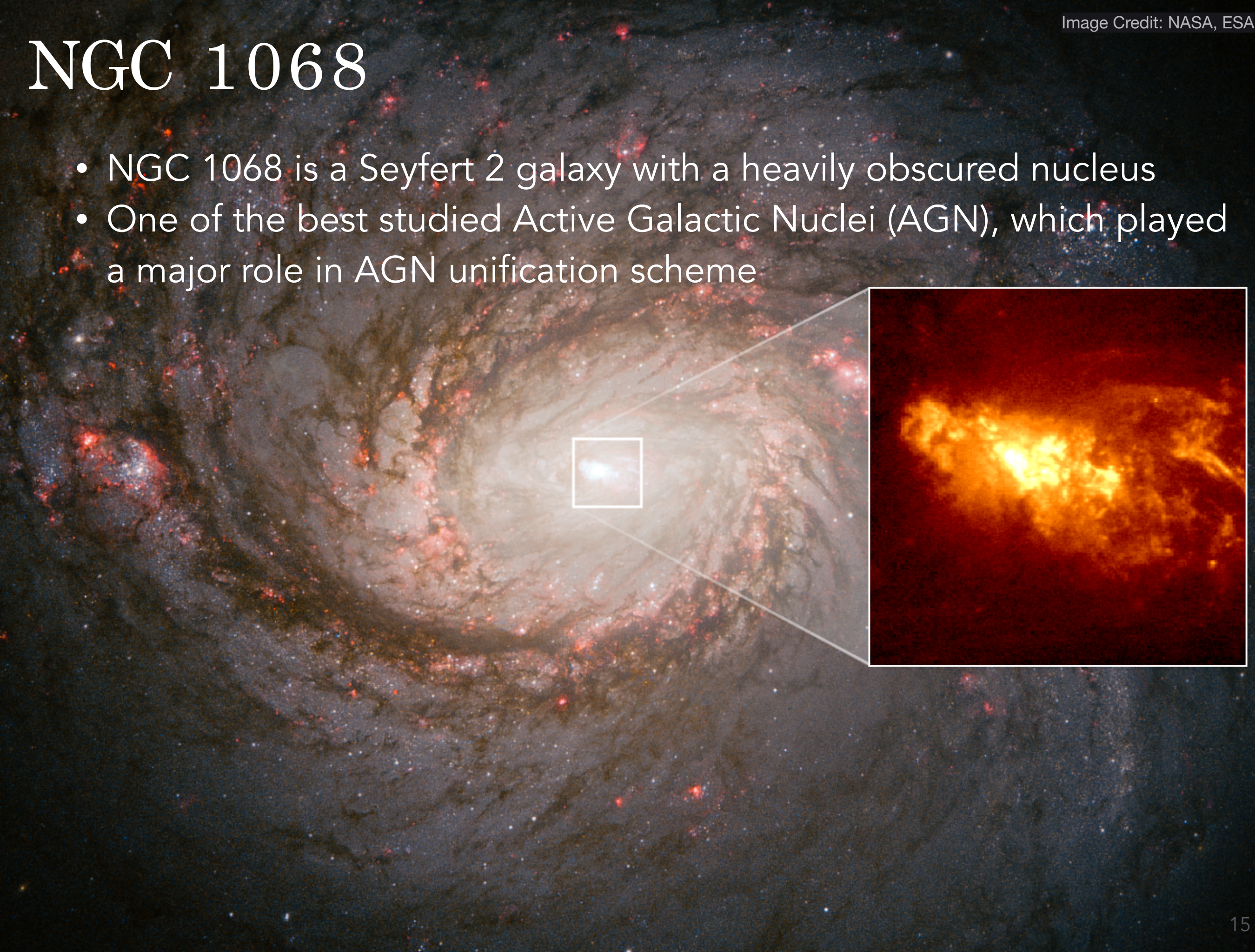


NGC 1068



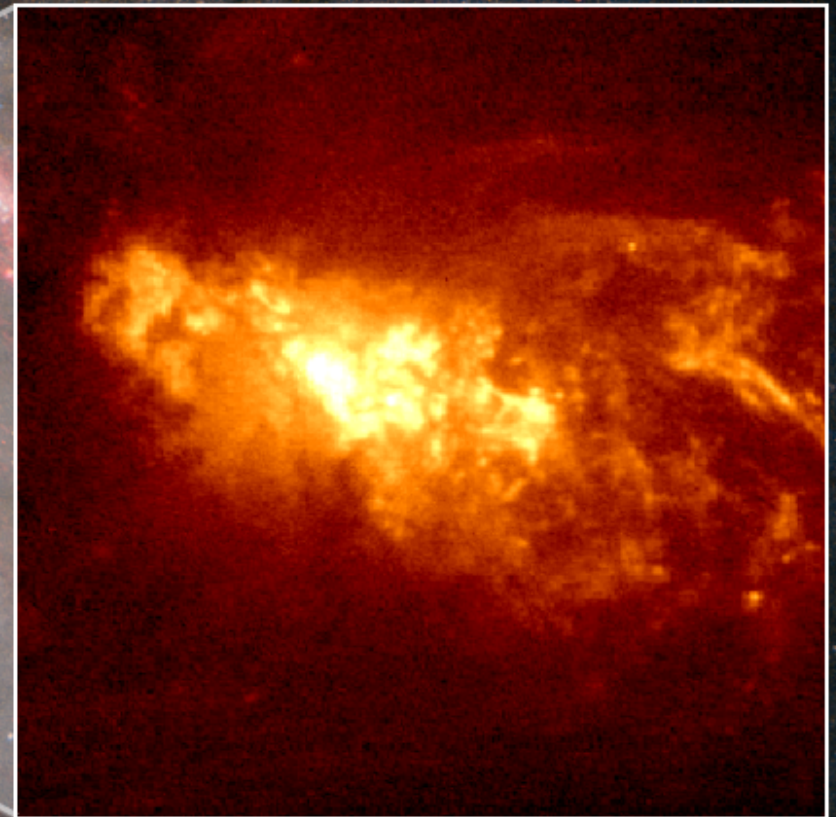
NGC 1068

- NGC 1068 is a Seyfert 2 galaxy with a heavily obscured nucleus
- One of the best studied Active Galactic Nuclei (AGN), which played a major role in AGN unification scheme



NGC 1068

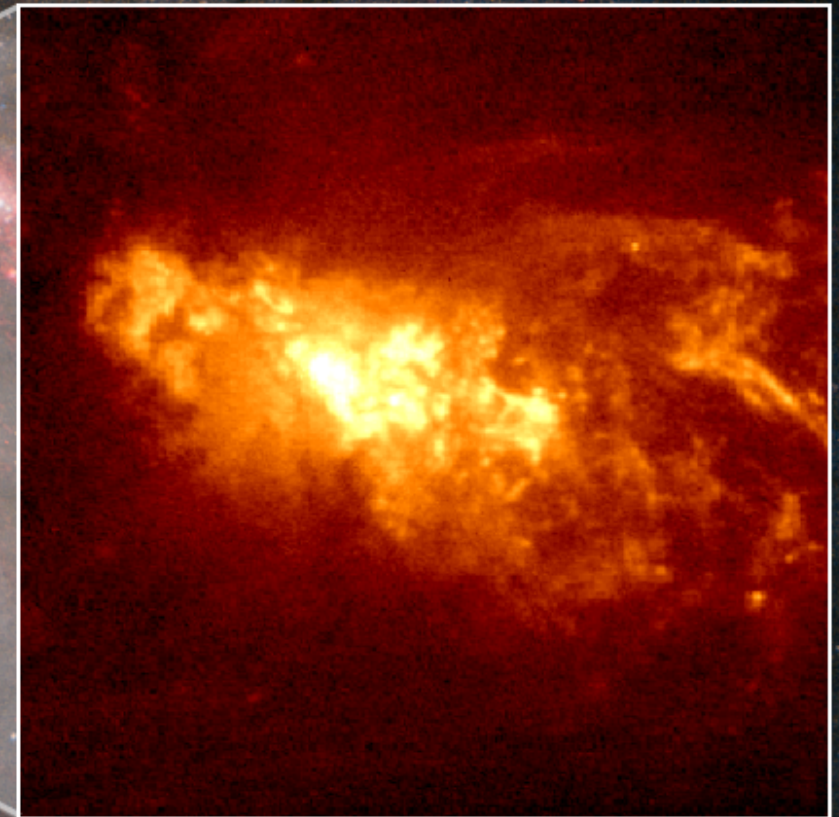
- NGC 1068 is a Seyfert 2 galaxy with a heavily obscured nucleus
- One of the best studied Active Galactic Nuclei (AGN), which played a major role in AGN unification scheme



- Compton thick environment with Column density $\sim 10^{25} \text{ cm}^{-2}$
- Bright in X-ray, and high infrared luminosity indicating high level of star formation

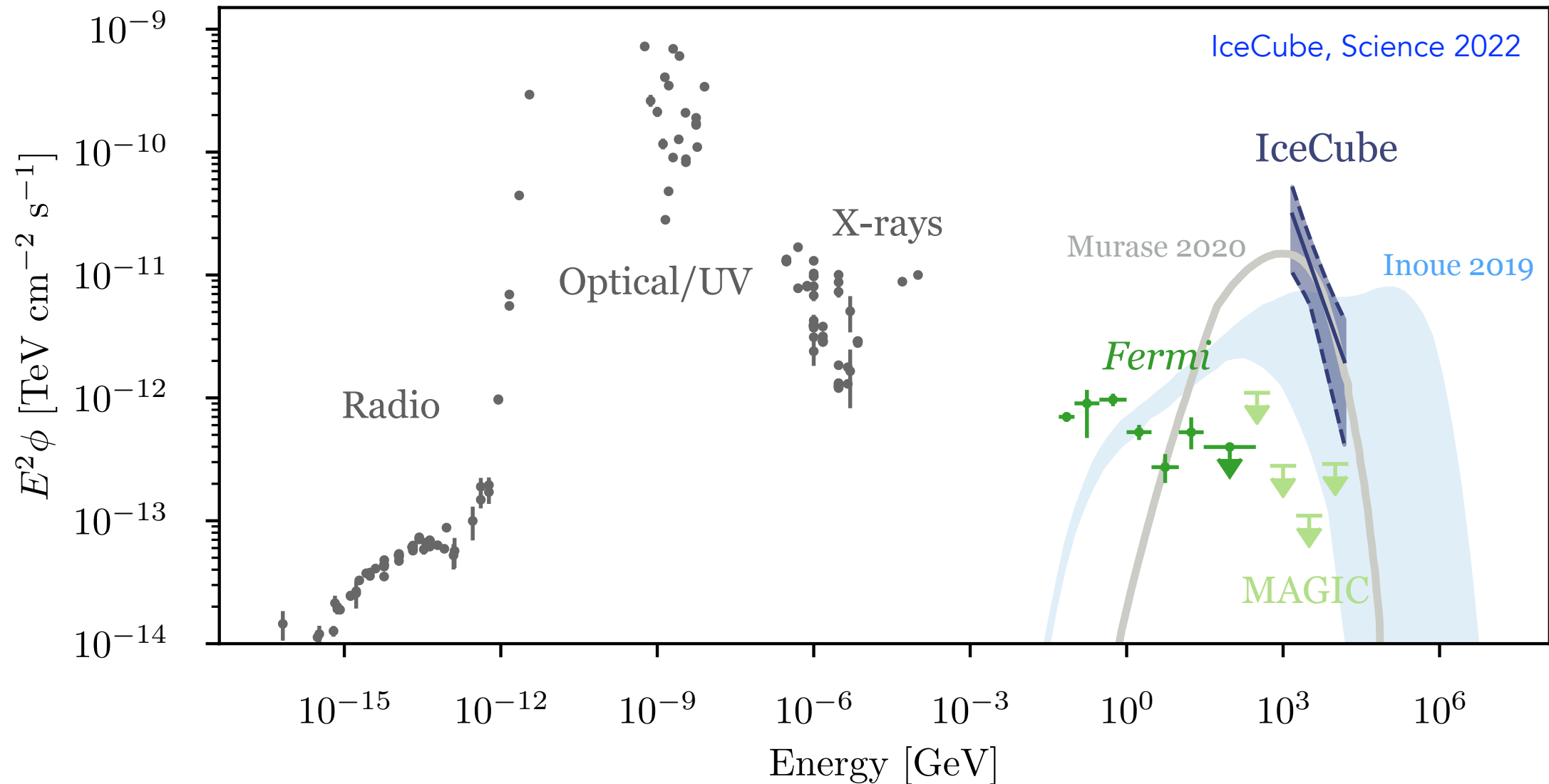
NGC 1068

- NGC 1068 is a Seyfert 2 galaxy with a heavily obscured nucleus
- One of the best studied Active Galactic Nuclei (AGN), which played a major role in AGN unification scheme



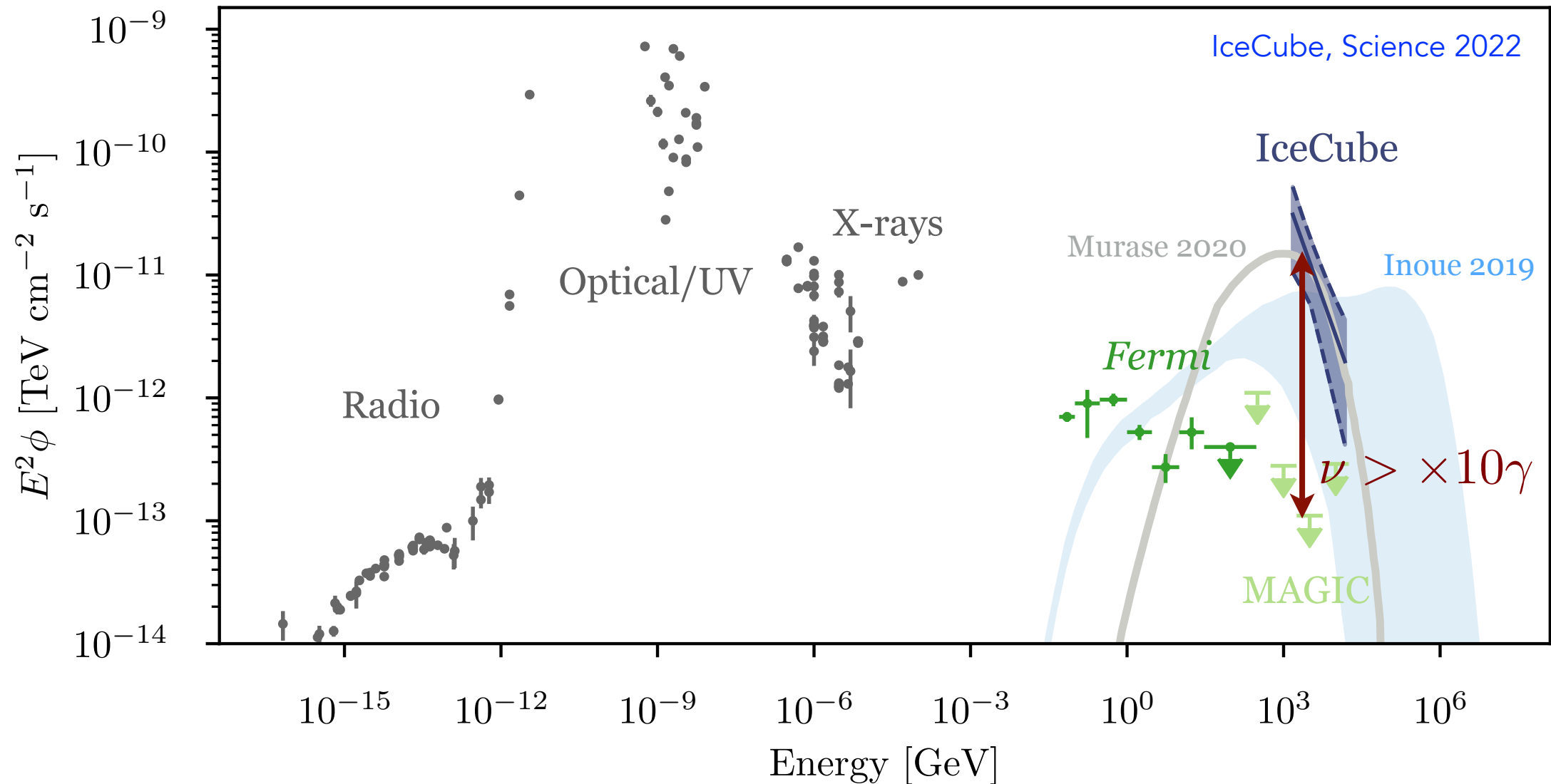
- Compton thick environment with Column density $\sim 10^{25} \text{ cm}^{-2}$
- Bright in X-ray, and high infrared luminosity indicating high level of star formation
 - ▶ *Historically considered as a promising cosmic-ray accelerator.*

NGC 1068 Spectrum



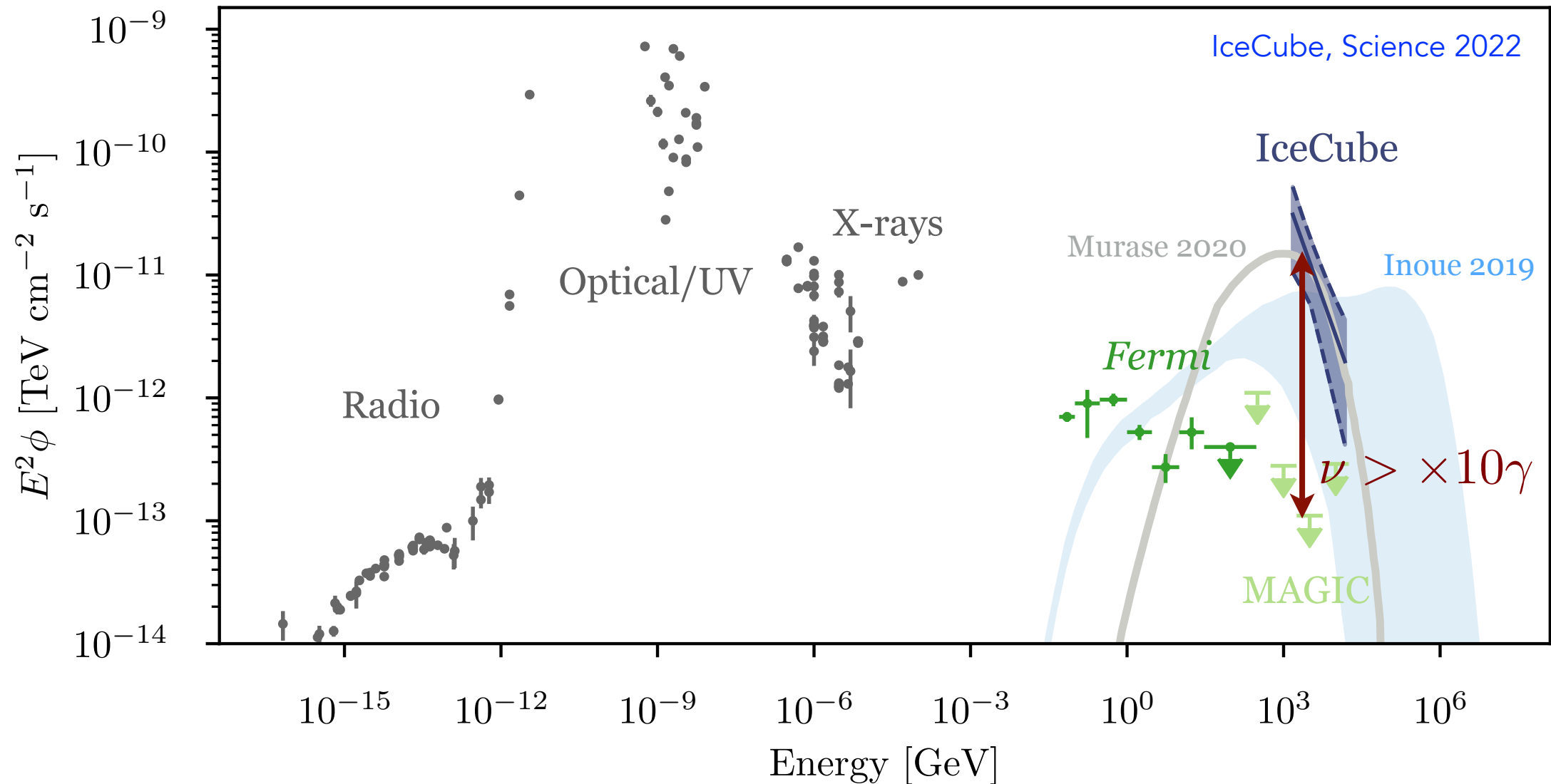
- ▶ The neutrino flux much higher than the measured γ -ray flux.
- ▶ Models built on Fermi γ -ray flux by cannot accommodate the neutrino flux.
- ▶ **Obscuring** necessary to absorb the pionic γ -ray accompanying neutrinos.
- ▶ The high opacity indicates that the neutrinos are produced in dense environment in the vicinity of AGN core ($< 100 R_s$)

NGC 1068 Spectrum



- ▶ The neutrino flux much higher than the measured γ -ray flux.
- ▶ Models built on Fermi γ -ray flux by cannot accommodate the neutrino flux.
- ▶ **Obscuring** necessary to absorb the pionic γ -ray accompanying neutrinos.
- ▶ The high opacity indicates that the neutrinos are produced in dense environment in the vicinity of AGN core ($< 100 R_s$)

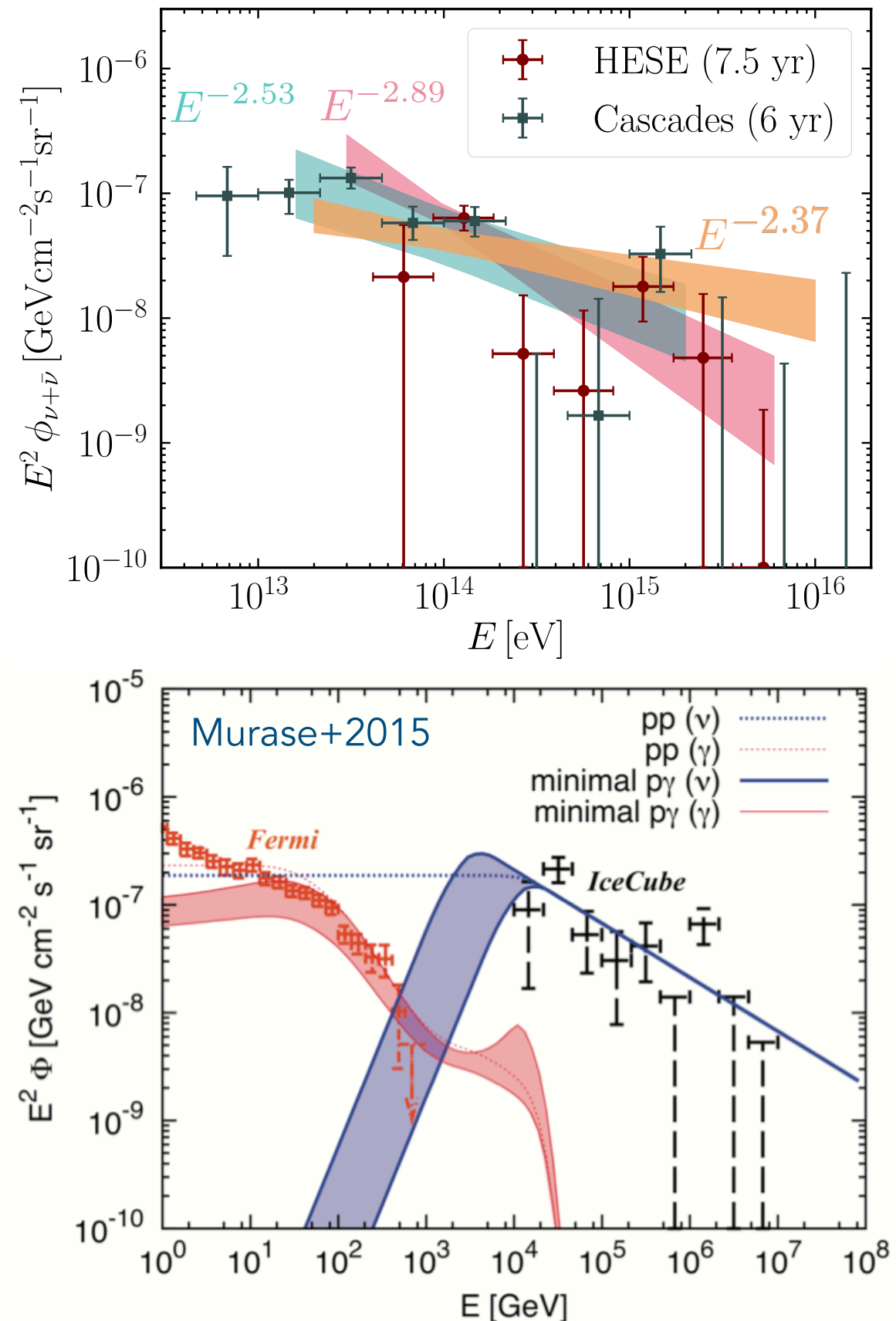
NGC 1068 Spectrum



- ▶ The neutrino flux much higher than the measured γ -ray flux.
- ▶ Models built on Fermi γ -ray flux by cannot accommodate the neutrino flux.
- ▶ **Obscuring** necessary to absorb the pionic γ -ray accompanying neutrinos.
- ▶ The high opacity indicates that the neutrinos are produced in dense environment in the vicinity of AGN core ($< 100 R_s$) ➔ Consistent with the multimessenger picture for the HE cosmic neutrino flux

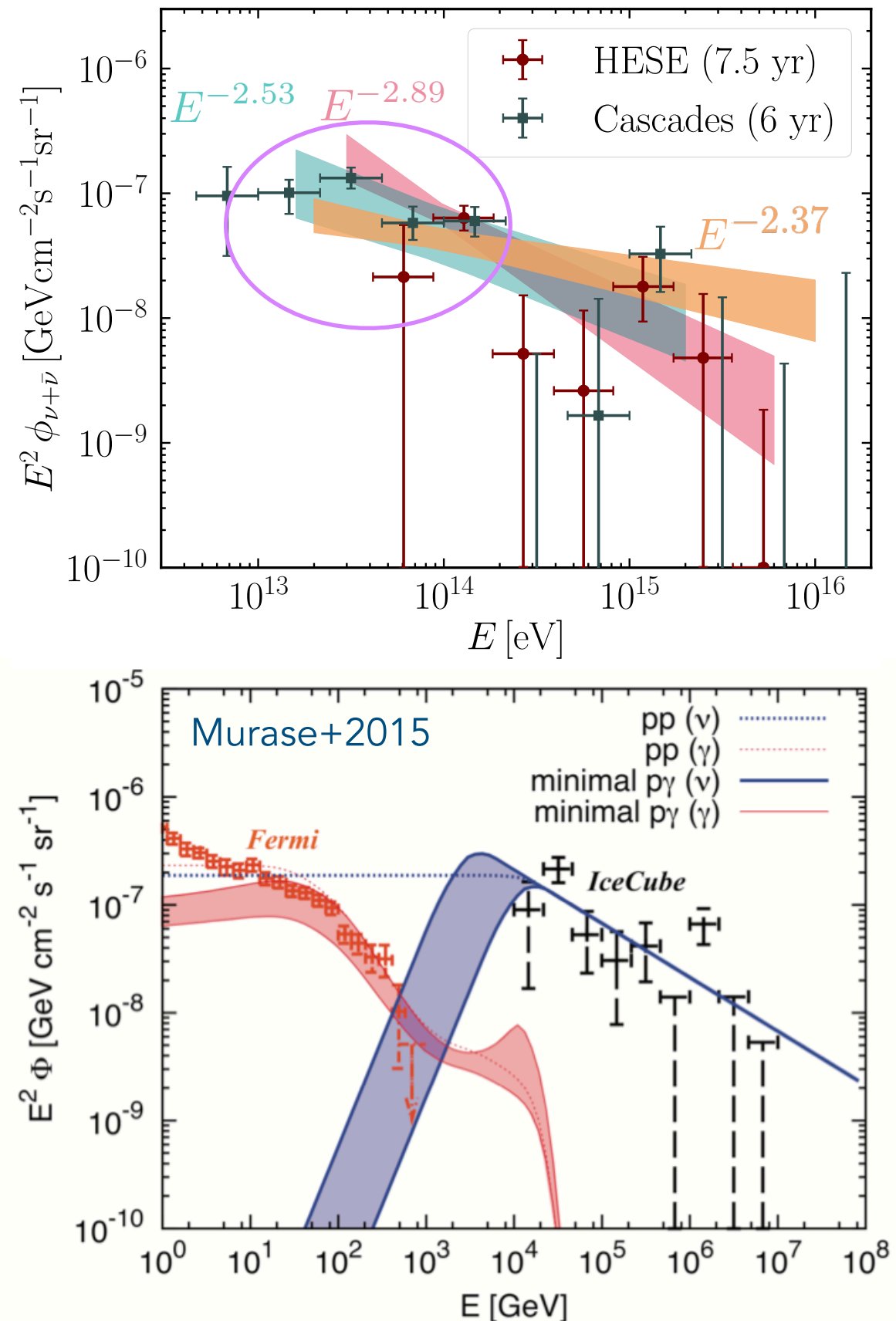
Medium-Energy Excess in Neutrino Flux

- ▶ Different slopes hint at structure in the flux of high-energy cosmic neutrinos.
- ▶ The magnitude of the flux at ~ 10 TeV energies is found to be higher than the flux at >100 TeV energies.
- ▶ Multimessenger connection dictates extragalactic sources of the high-energy neutrino flux at medium-energies to be **obscured** to GeV γ -rays. [Murase+ 2015, Fang+ 2022]
 - ▶ Core of AGN can meet these conditions.



Medium-Energy Excess in Neutrino Flux

- ▶ Different slopes hint at structure in the flux of high-energy cosmic neutrinos.
- ▶ The magnitude of the flux at ~ 10 TeV energies is found to be higher than the flux at >100 TeV energies.
- ▶ Multimessenger connection dictates extragalactic sources of the high-energy neutrino flux at medium-energies to be **obscured** to GeV γ -rays. [Murase+ 2015, Fang+ 2022]
 - ▶ Core of AGN can meet these conditions.



Neutrino Production in AGN Coronae

- **Cores** of the active galactic nuclei (AGN), which are optically thick for GeV-TeV γ -rays are one of the best candidates as the source of the high-energy neutrinos.
- In **Seyfert galaxies**, accretion dynamics and magnetic dissipation will form a magnetized **corona** above the disk.
- The **disk-corona** model for high-energy neutrino emission from the core of AGNs can successfully accommodate the flux of cosmic neutrinos at medium energies in the 10-100 TeV range. [\[Murase+2020\]](#)

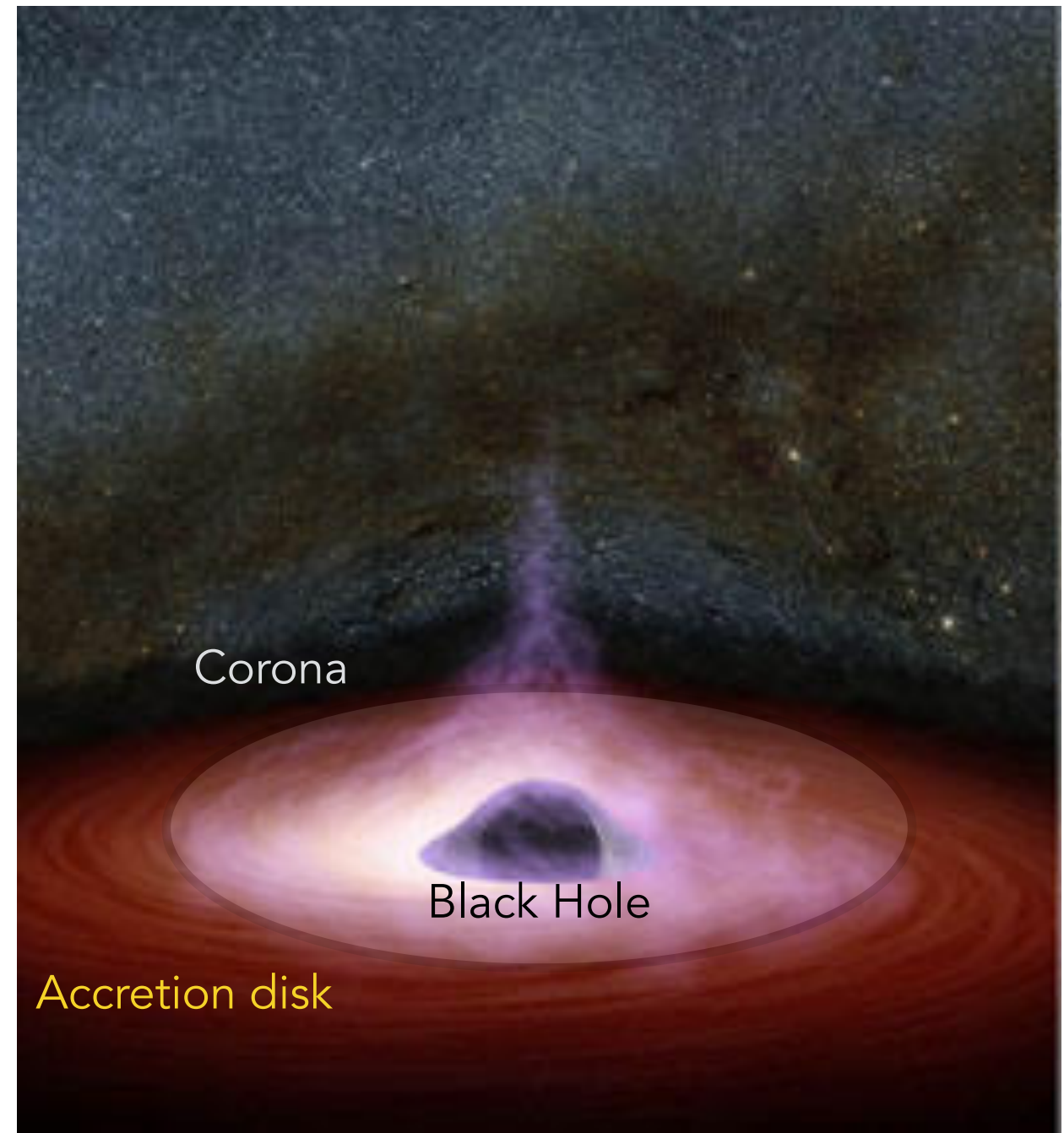


Image Credit: KITP/SLAC

Neutrino Production in AGN Coronae

- **Cores** of the active galactic nuclei (AGN), which are optically thick for GeV-TeV γ -rays are one of the best candidates as the source of the high-energy neutrinos.
- In **Seyfert galaxies**, accretion dynamics and magnetic dissipation will form a magnetized **corona** above the disk.
- The **disk-corona** model for high-energy neutrino emission from the core of AGNs can successfully accommodate the flux of cosmic neutrinos at medium energies in the 10-100 TeV range. [\[Murase+2020\]](#)

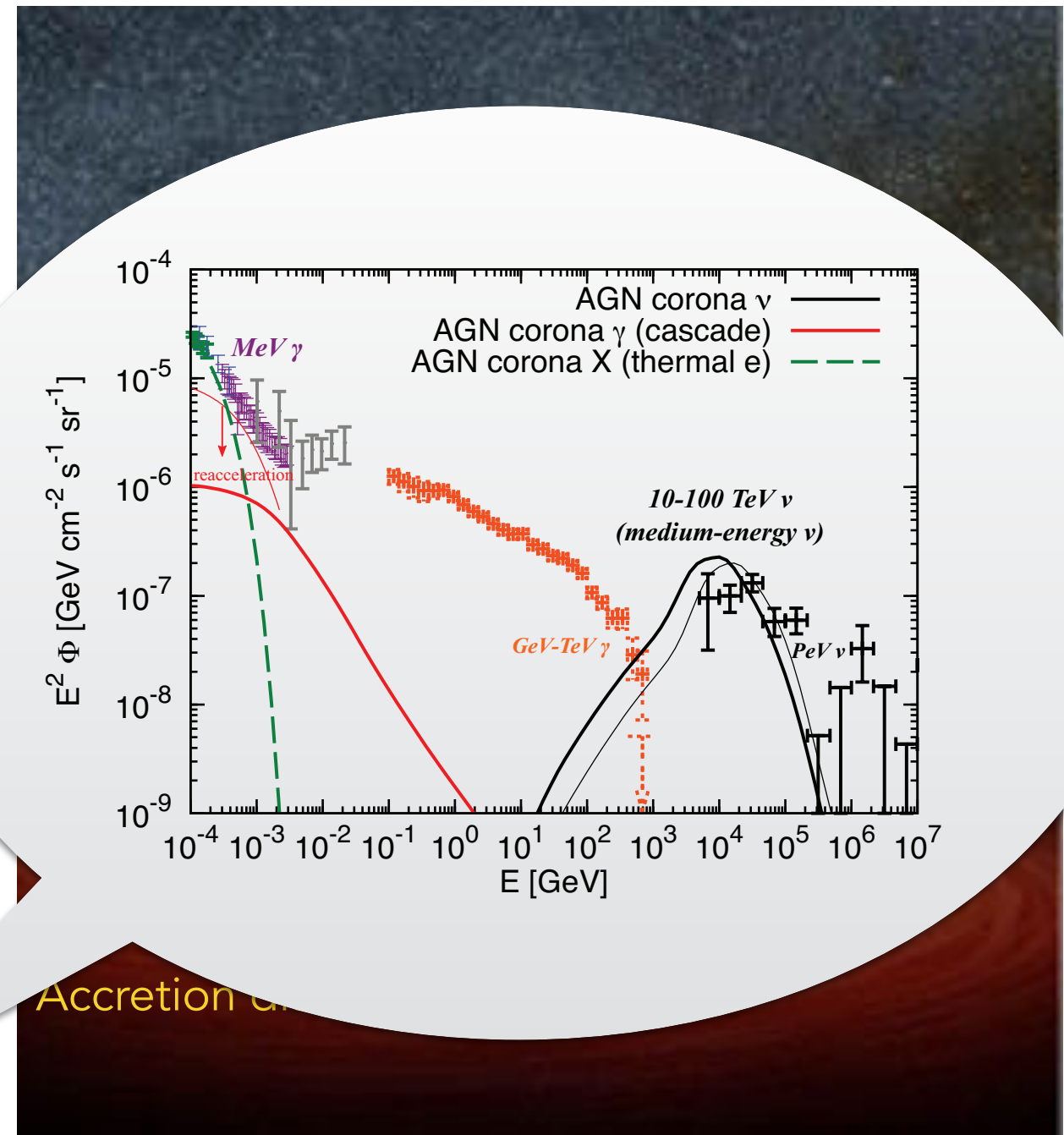
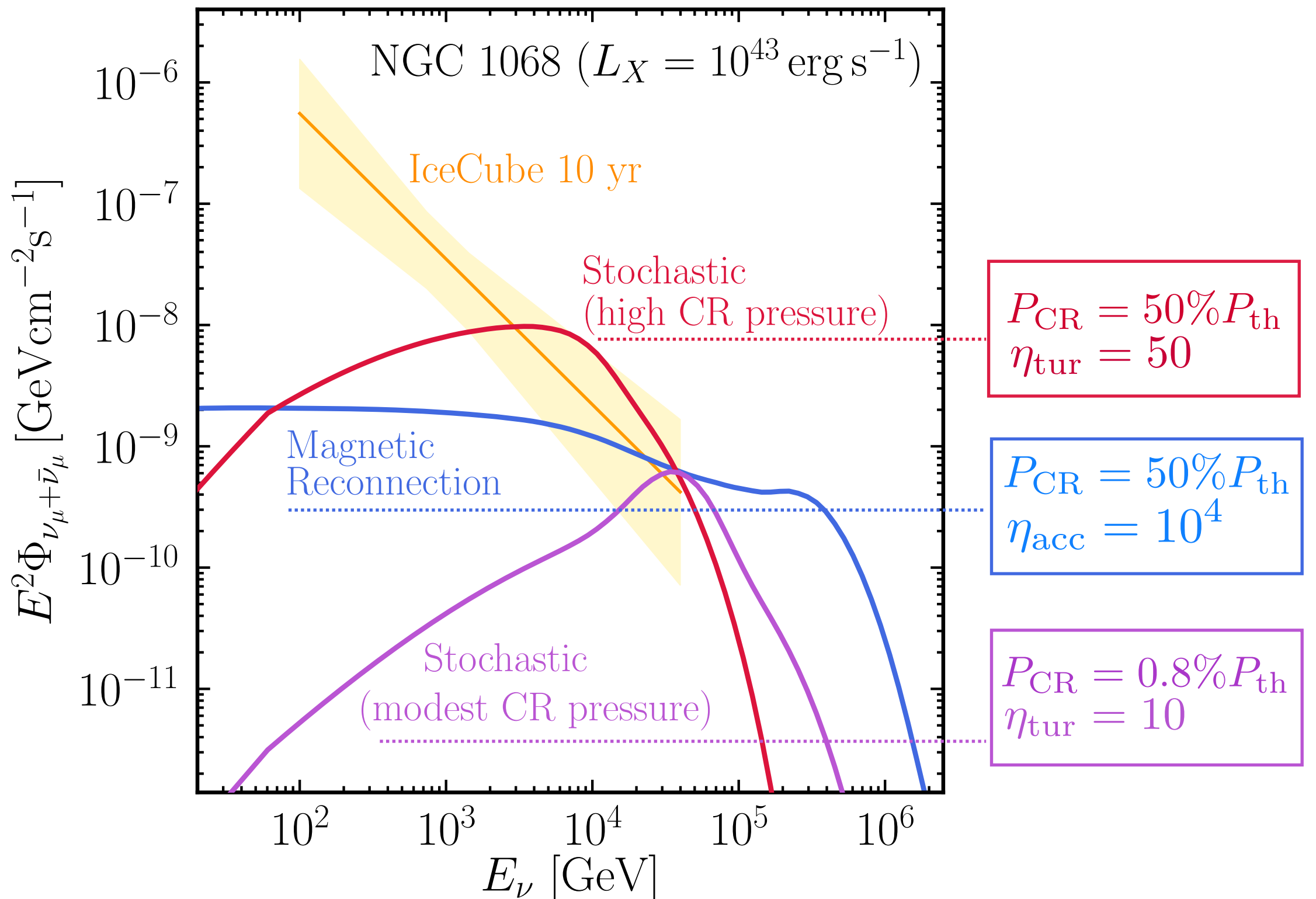


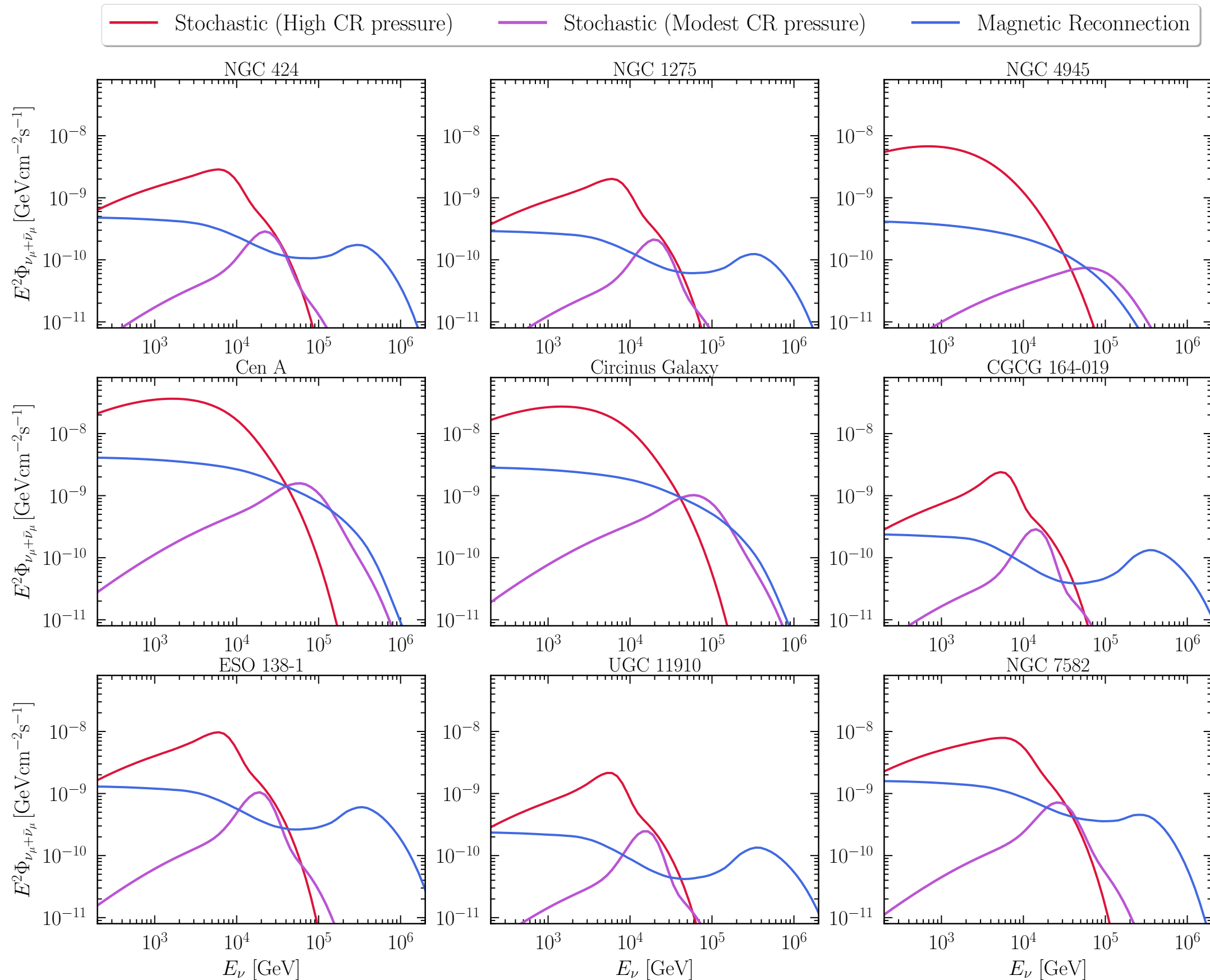
Image Credit: KITP/SLAC

NGC 1068 in AGN-Corona Model

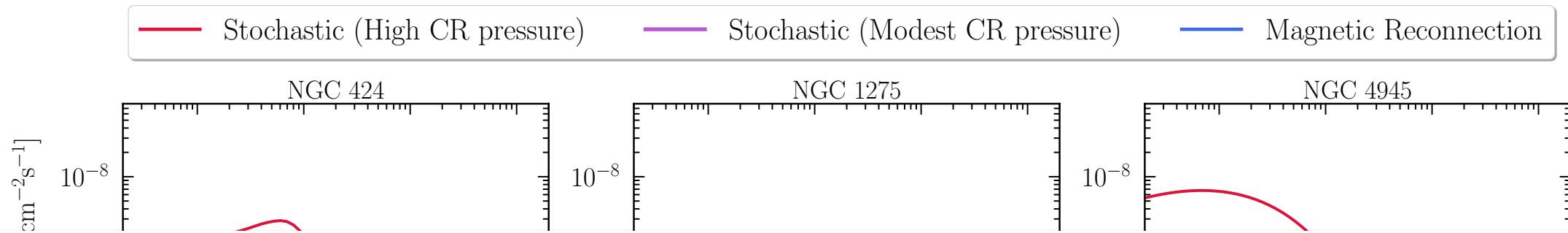
Adopting parameters compatible with IceCube 10 year source search



Neutrino flux from Bright Nearby Sources

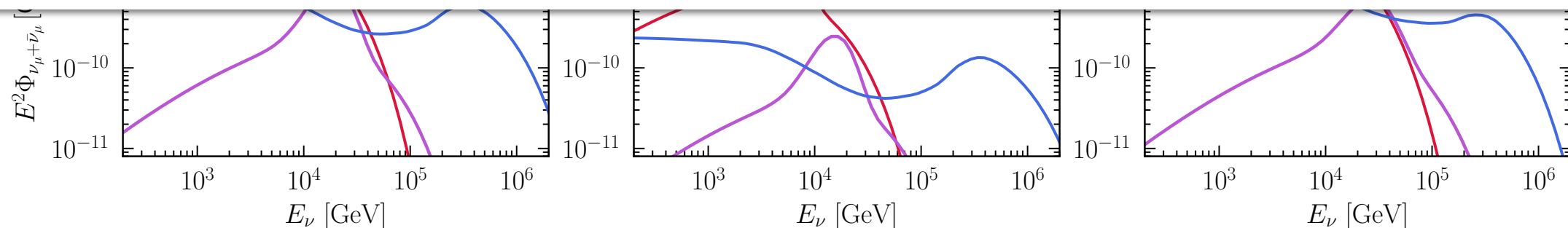


Neutrino flux from Bright Nearby Sources

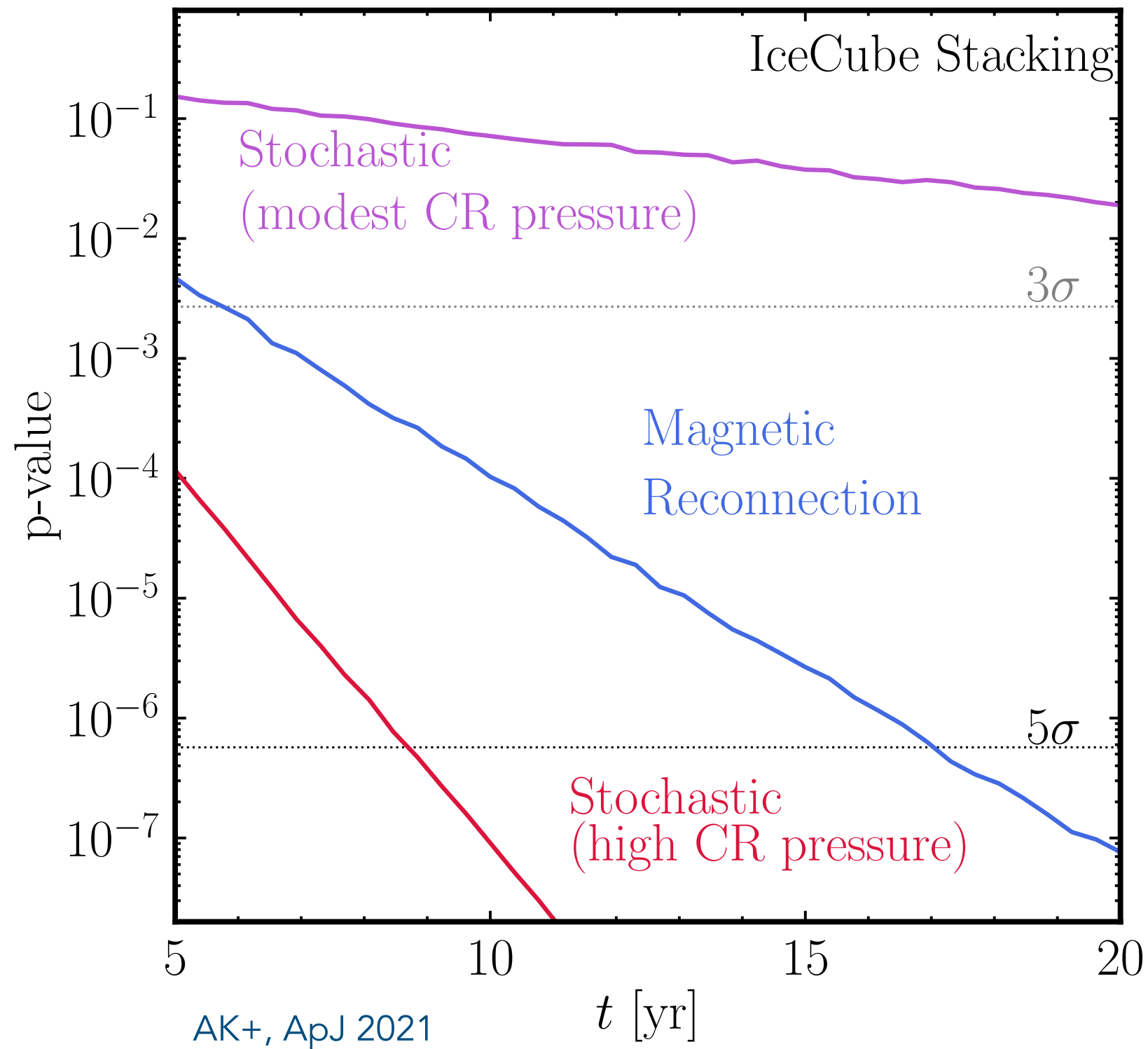


- ▶ **NGC 1068 is the brightest source in IceCube.**

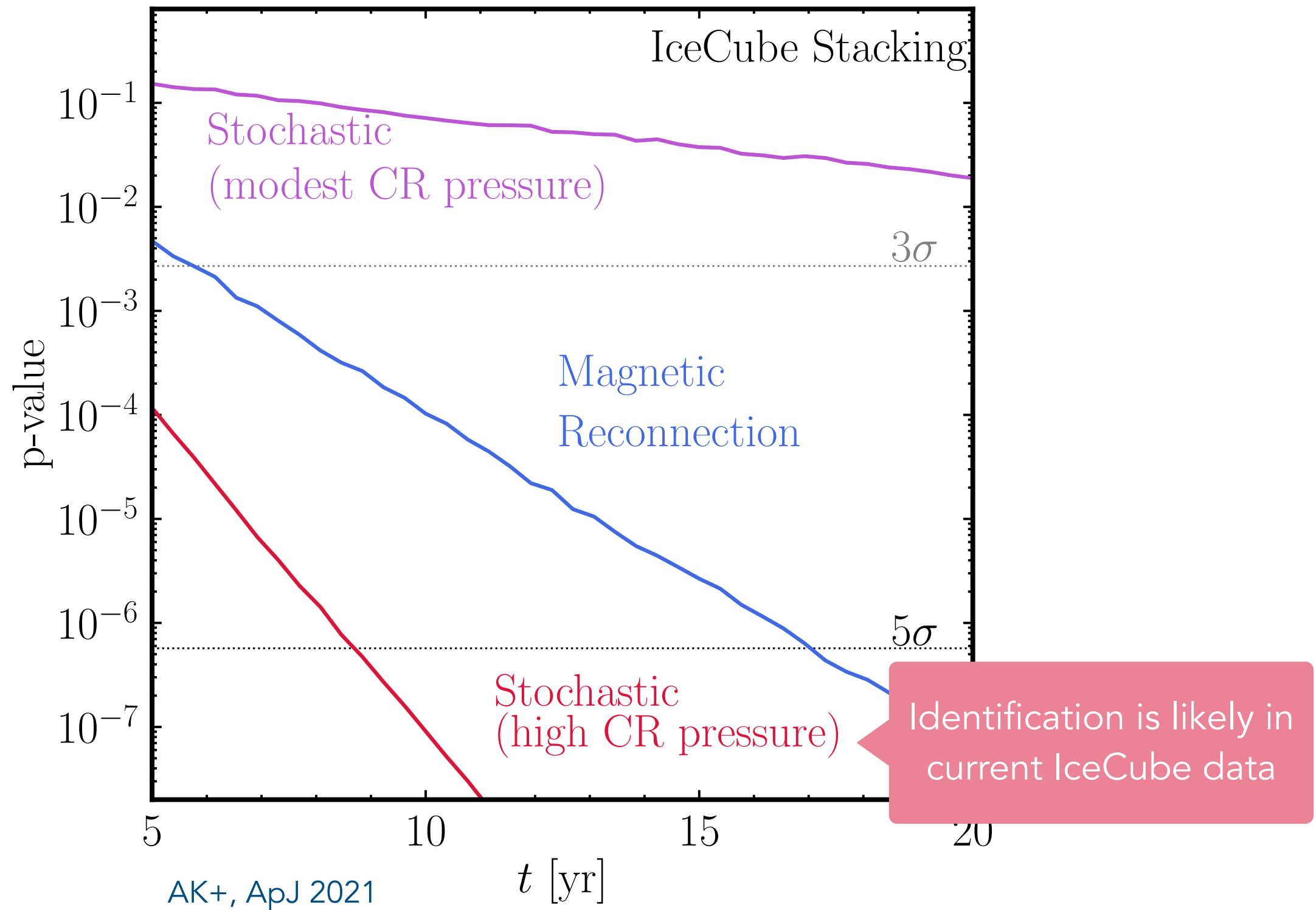
Source	p-value		
	Stochastic (High CR pressure)	Stochastic (Modest CR pressure)	Magnetic reconnection
NGC 1068	10^{-6}	0.09	1.8×10^{-4}
NGC 1275	0.03	0.3	0.1
CGCG 164-019	0.04	0.3	0.1
UGC 11910	0.1	0.4	0.09
Cen A	0.5	0.2	0.2
Circinus Galaxy	0.5	0.3	0.3
NGC 7582	0.5	0.5	0.1
ESO 138-1	0.5	0.5	0.09
NGC 424	0.5	0.5	0.5
NGC 4945	0.5	0.5	0.5



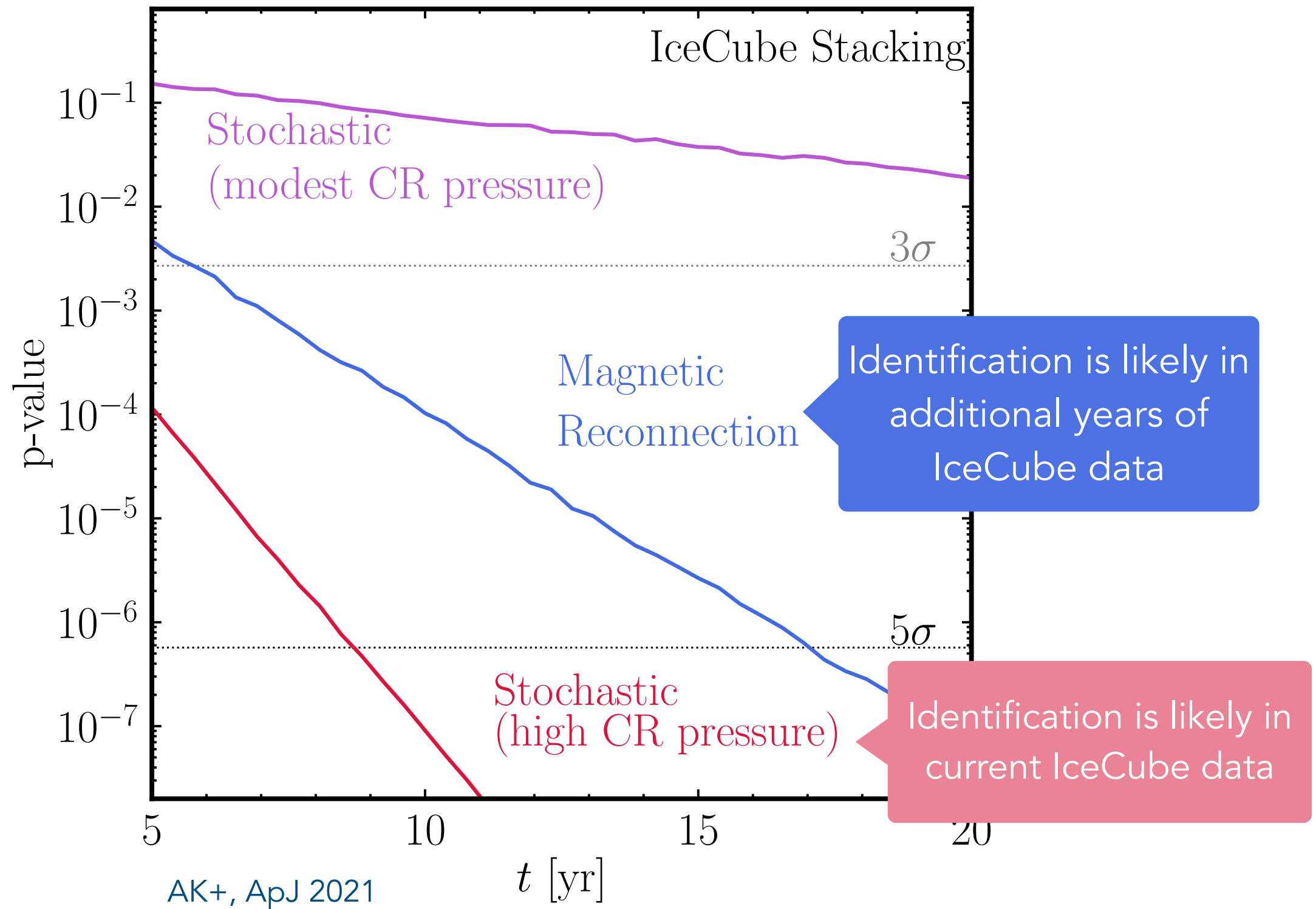
Bright Seyfert Galaxies: IceCube Prospects



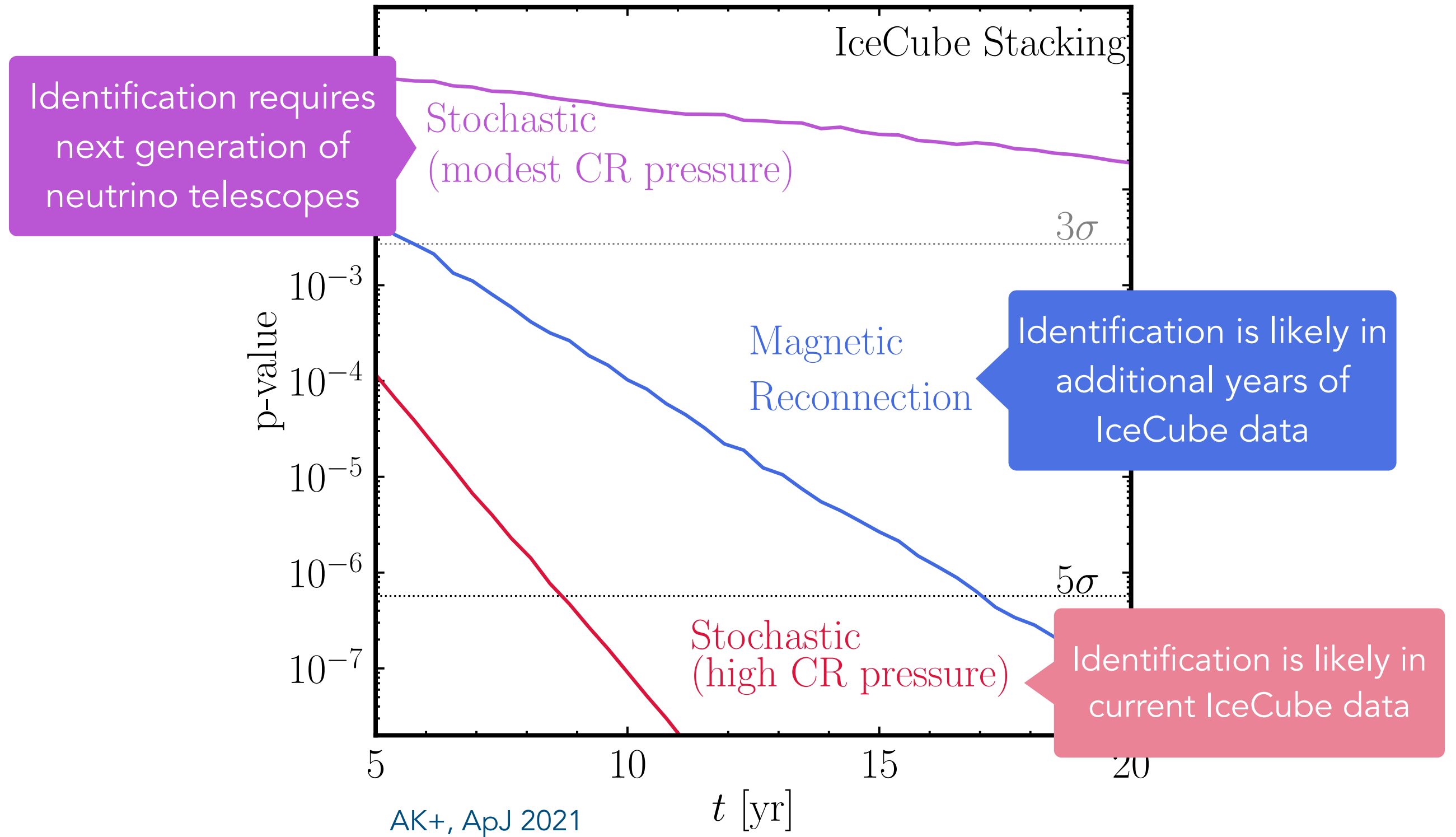
Bright Seyfert Galaxies: IceCube Prospects



Bright Seyfert Galaxies: IceCube Prospects



Bright Seyfert Galaxies: IceCube Prospects

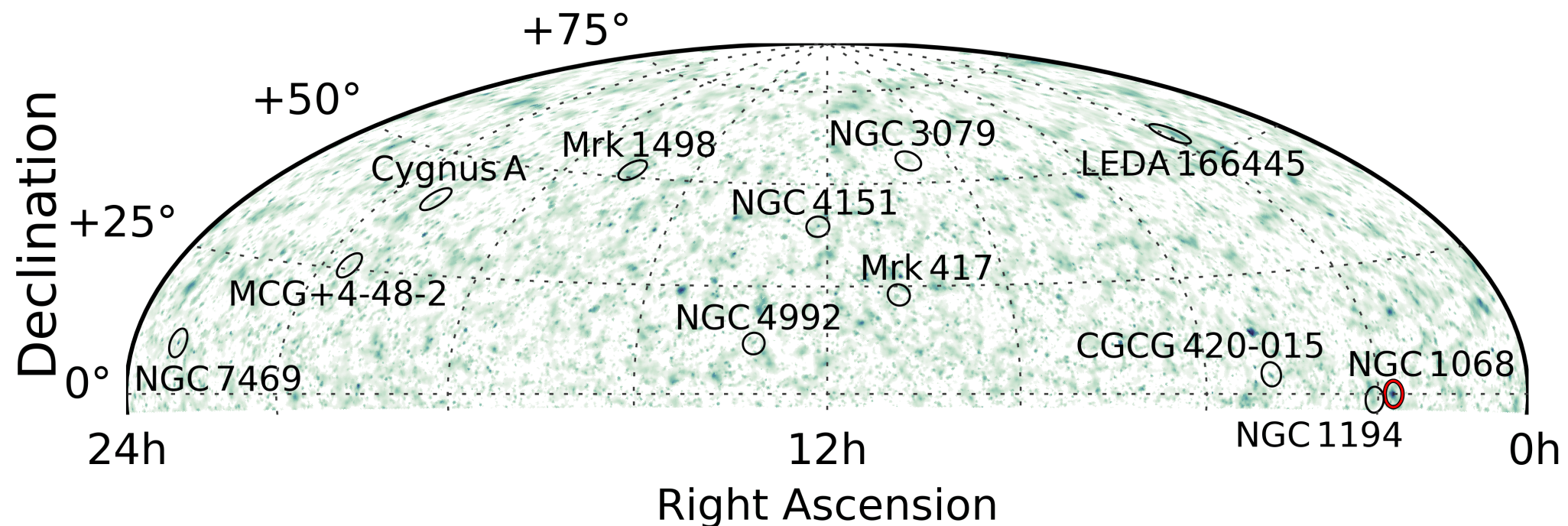


Neutrino-Bright AGN

- ▶ Accumulating evidence for correlation of IceCube neutrinos in the direction of γ -ray obscured AGN.
 - ▶ 3.3σ excess from ensemble of 11 sources in the Northern Sky (excluding NGC 1068)
 - ▶ 2.9σ excess from the direction of NGC 4151
 - ▶ 3.0σ excess in the stacking search in the Southern sky

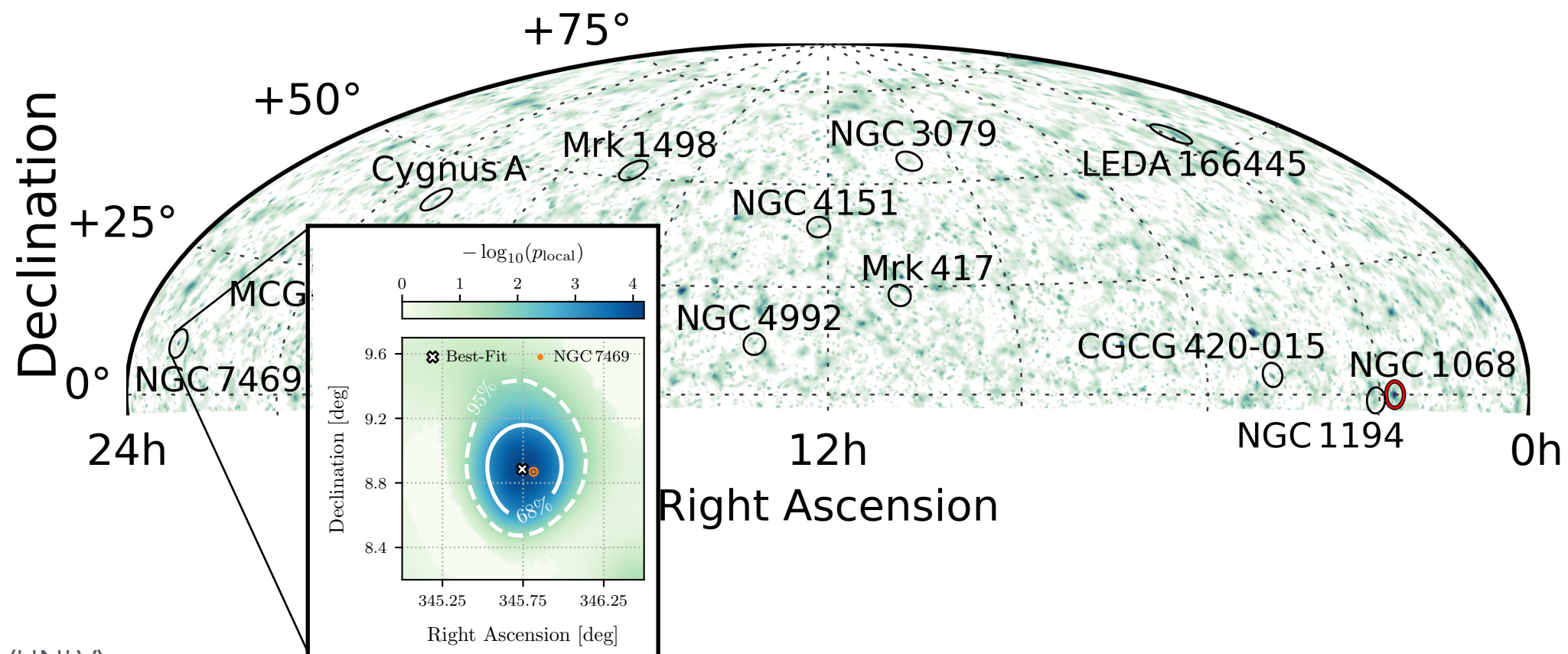
Neutrino-Bright AGN

- ▶ Accumulating evidence for correlation of IceCube neutrinos in the direction of γ -ray obscured AGN.
 - ▶ 3.3σ excess from ensemble of 11 sources in the Northern Sky (excluding NGC 1068)
 - ▶ 2.9σ excess from the direction of NGC 4151
 - ▶ 3.0σ excess in the stacking search in the Southern sky



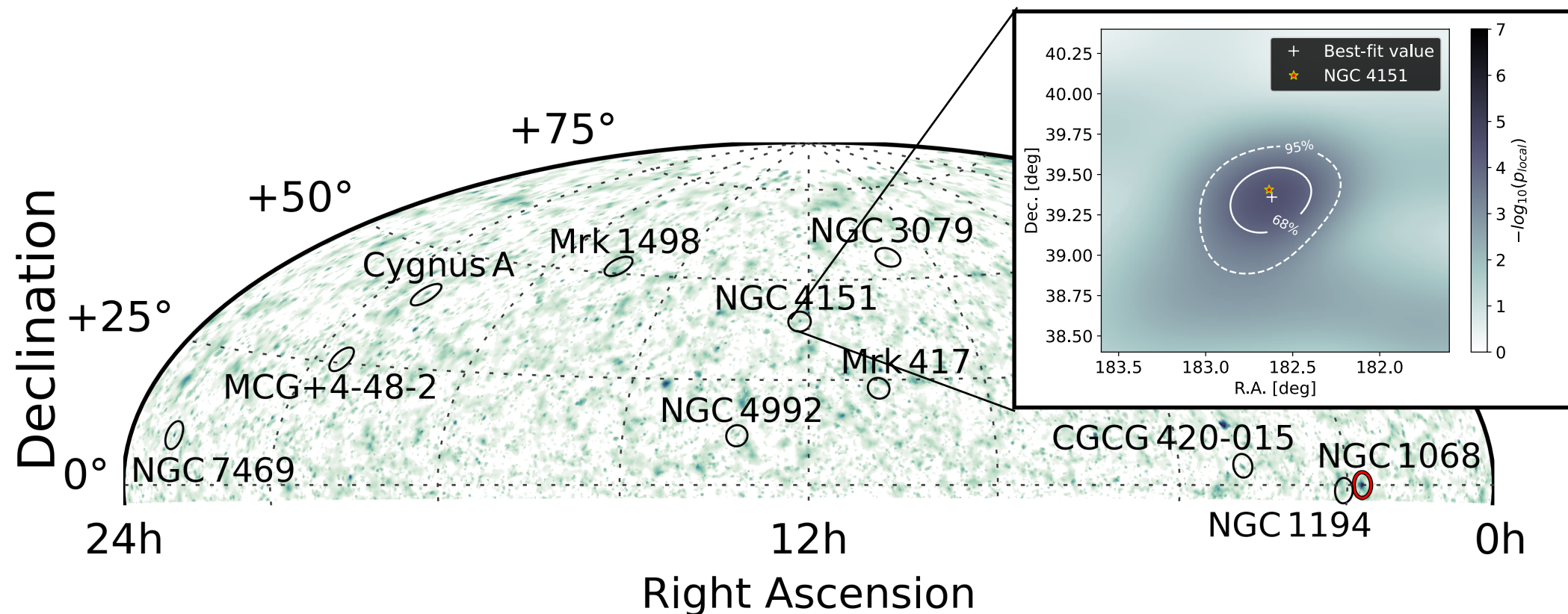
Neutrino-Bright AGN

- ▶ Accumulating evidence for correlation of IceCube neutrinos in the direction of γ -ray obscured AGN.
 - ▶ 3.3σ excess from ensemble of 11 sources in the Northern Sky (excluding NGC 1068)
 - ▶ 2.9σ excess from the direction of NGC 4151
 - ▶ 3.0σ excess in the stacking search in the Southern sky



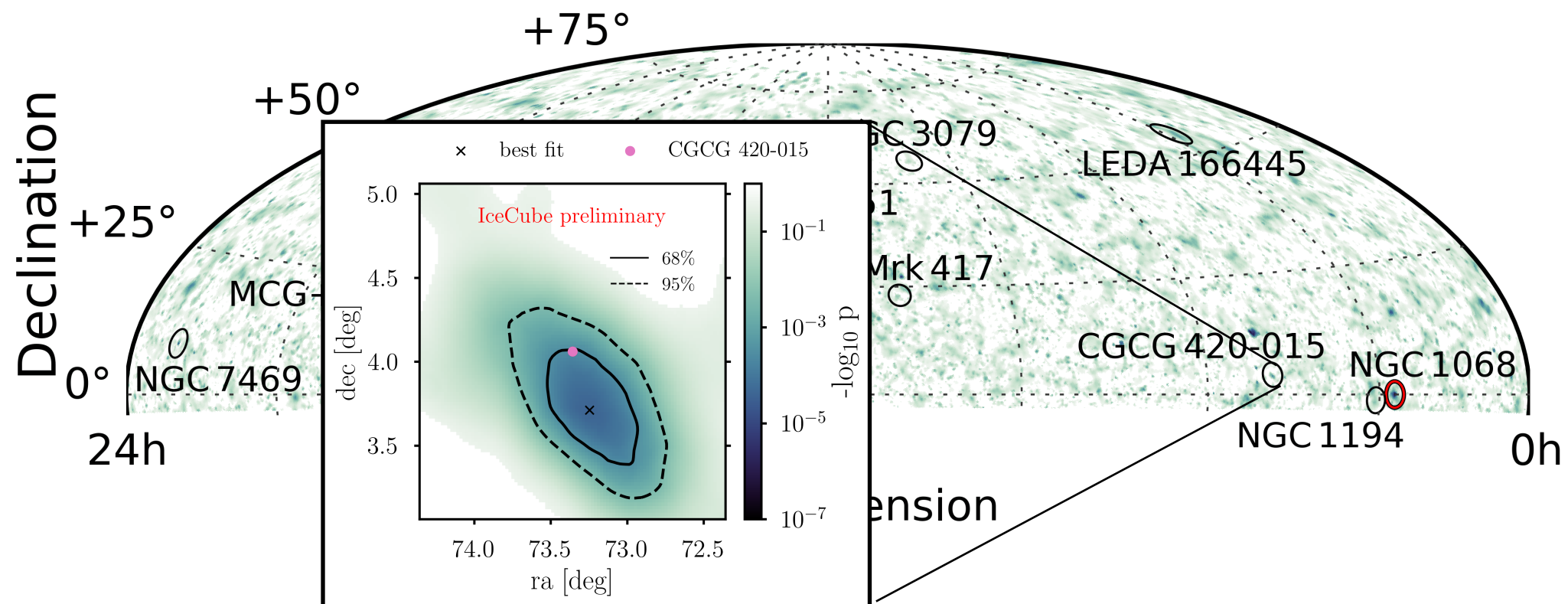
Neutrino-Bright AGN

- ▶ Accumulating evidence for correlation of IceCube neutrinos in the direction of γ -ray obscured AGN.
 - ▶ 3.3σ excess from ensemble of 11 sources in the Northern Sky (excluding NGC 1068)
 - ▶ 2.9σ excess from the direction of NGC 4151
 - ▶ 3.0σ excess in the stacking search in the Southern sky



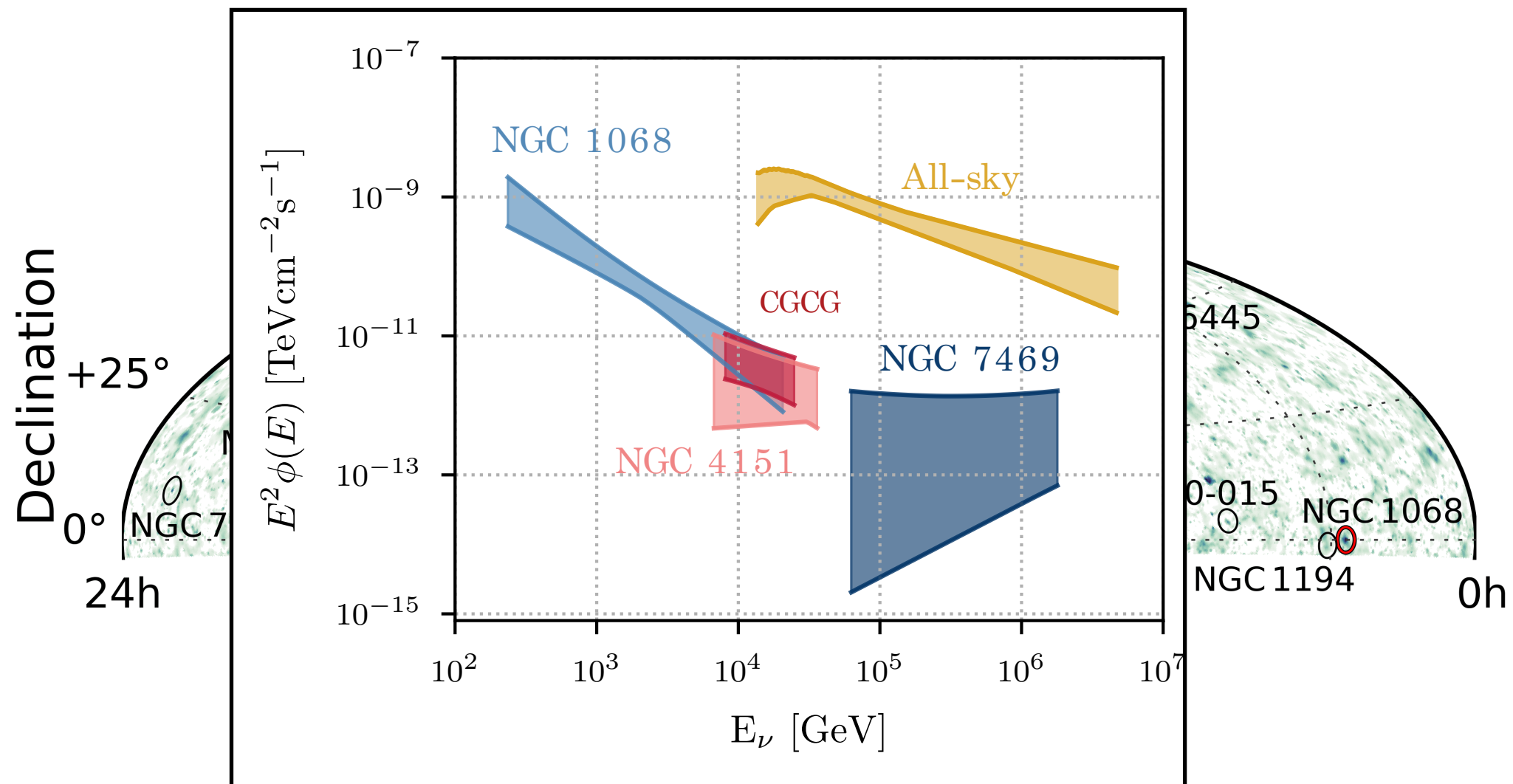
Neutrino-Bright AGN

- ▶ Accumulating evidence for correlation of IceCube neutrinos in the direction of γ -ray obscured AGN.
 - ▶ 3.3σ excess from ensemble of 11 sources in the Northern Sky (excluding NGC 1068)
 - ▶ 2.9σ excess from the direction of NGC 4151
 - ▶ 3.0σ excess in the stacking search in the Southern sky



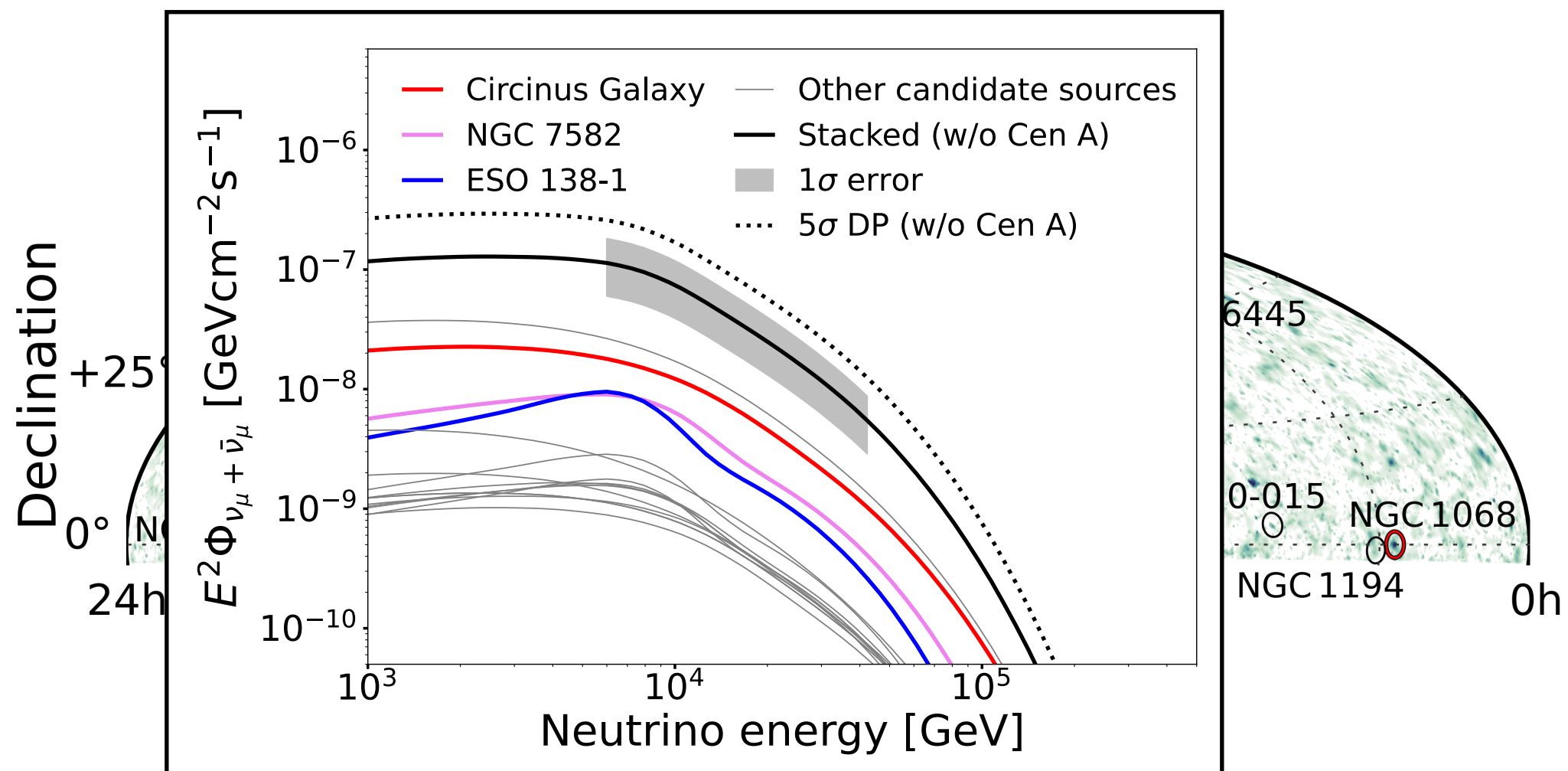
Neutrino-Bright AGN

- ▶ Accumulating evidence for correlation of IceCube neutrinos in the direction of γ -ray obscured AGN.
- ▶ 3.3σ excess from ensemble of 11 sources in the Northern Sky (excluding NGC 1068)
- ▶ 2.9σ excess from the direction of NGC 4151
- ▶ 3.0σ excess in the stacking search in the Southern sky



Neutrino-Bright AGN

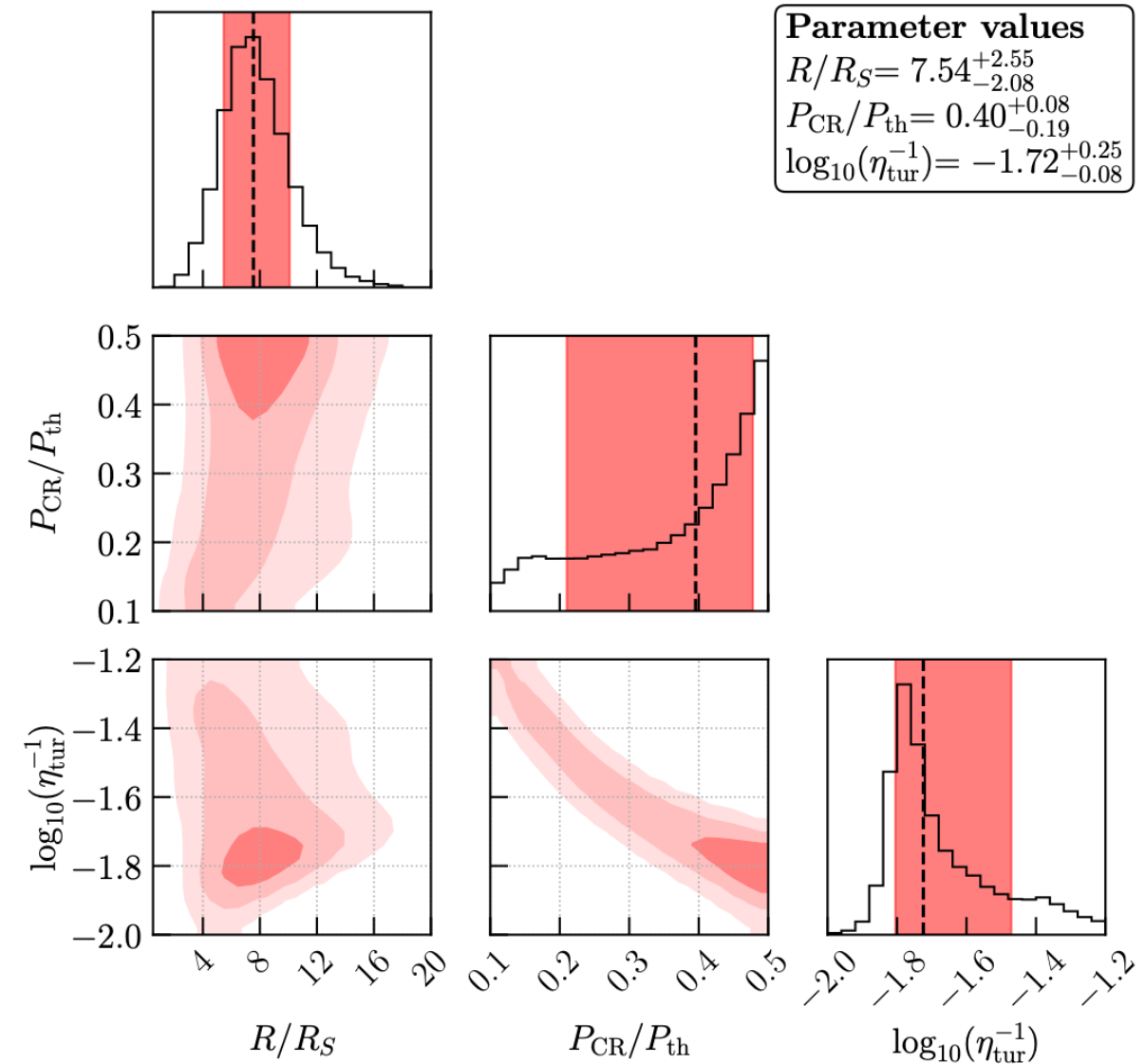
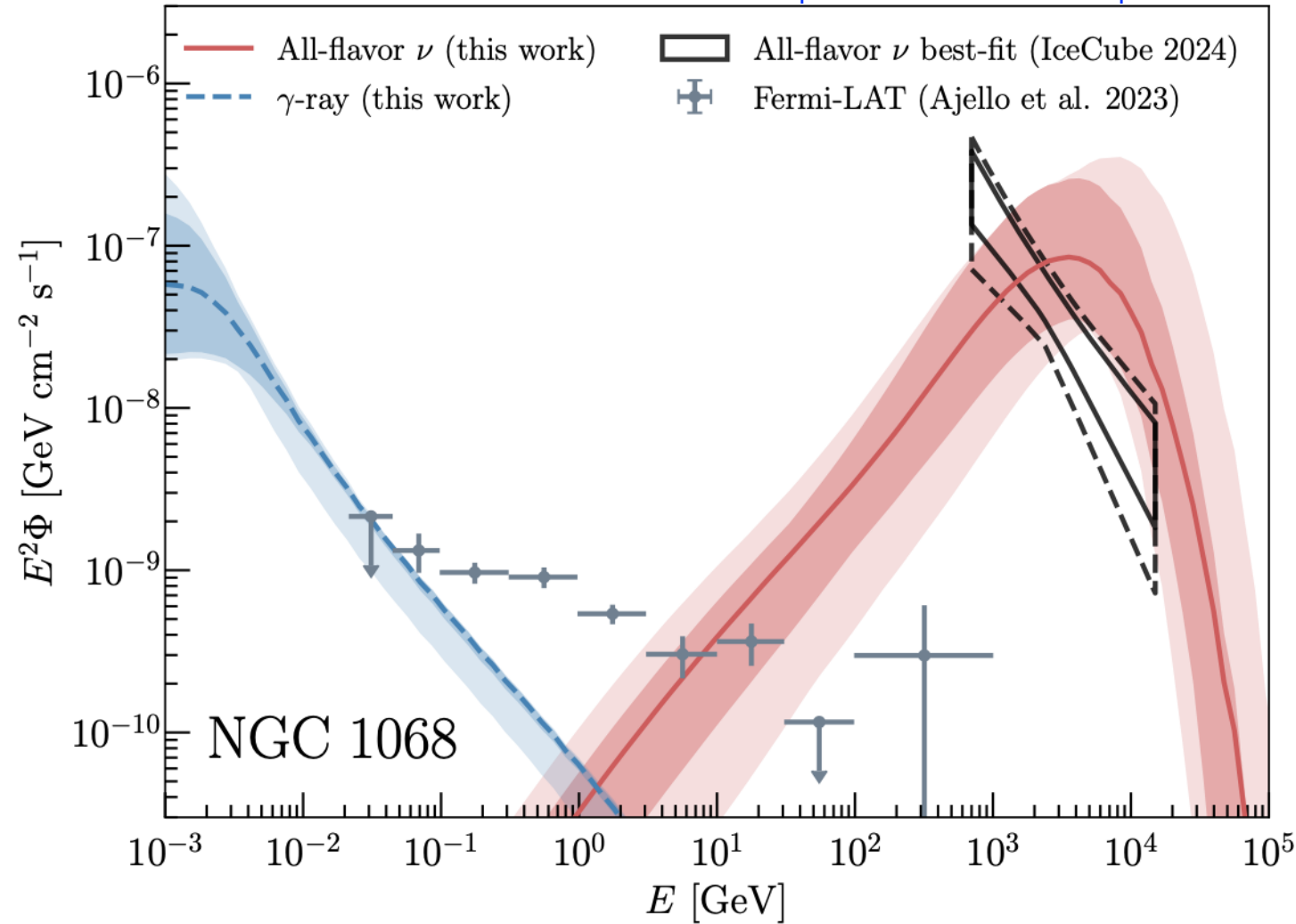
- ▶ Accumulating evidence for correlation of IceCube neutrinos in the direction of γ -ray obscured AGN.
 - ▶ 3.3σ excess from ensemble of 11 sources in the Northern Sky (excluding NGC 1068)
 - ▶ 2.9σ excess from the direction of NGC 4151
 - ▶ 3.0σ excess in the stacking search in the Southern sky



Multimessenger Input

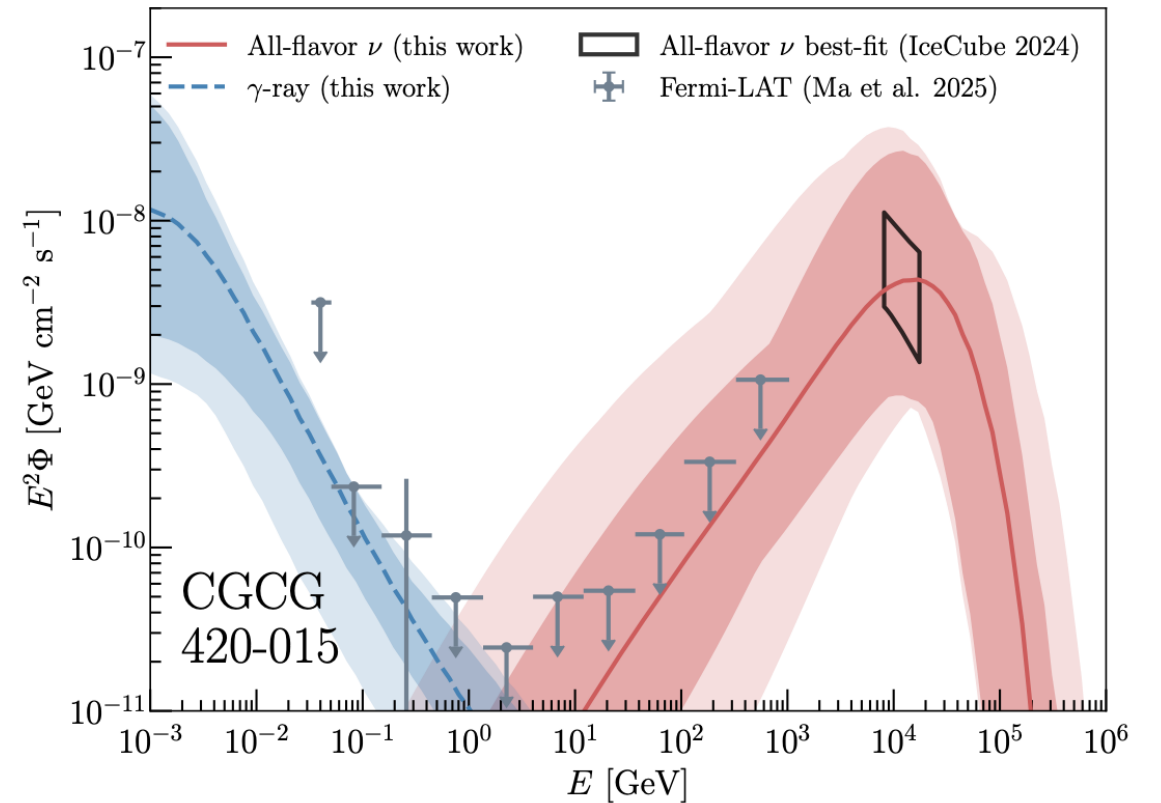
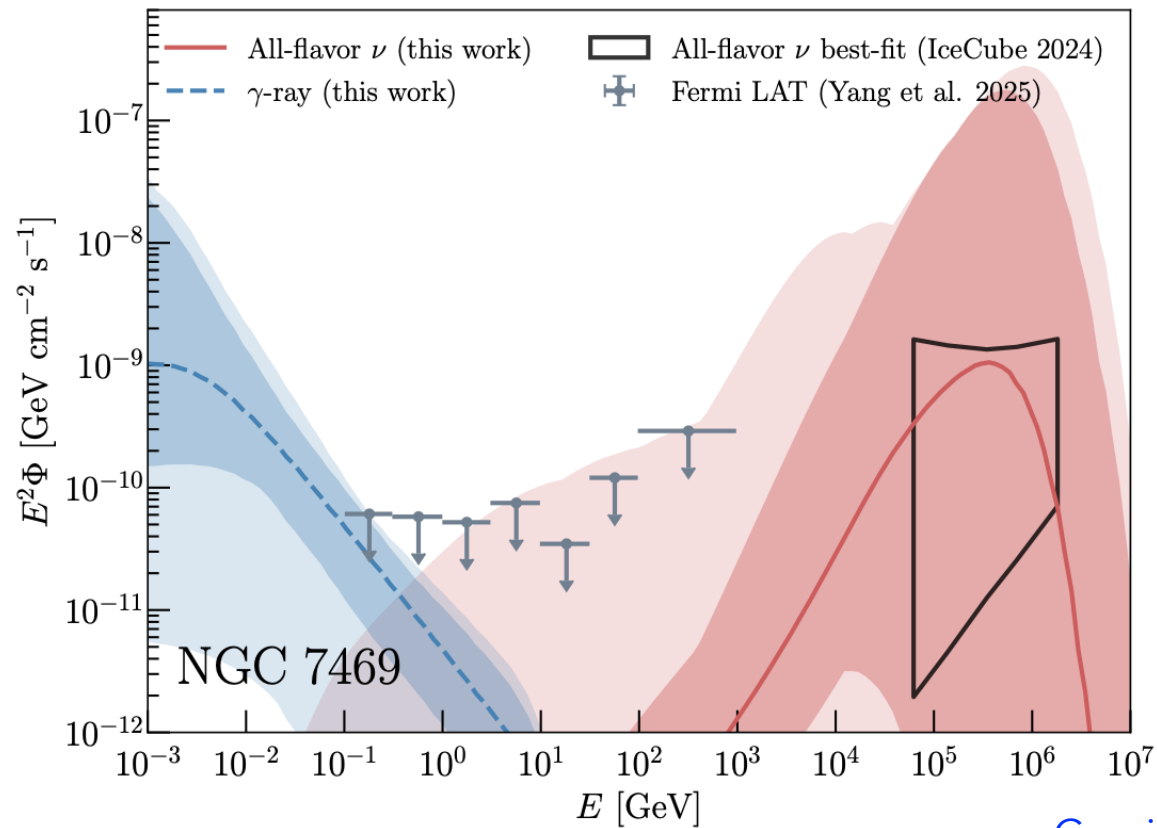
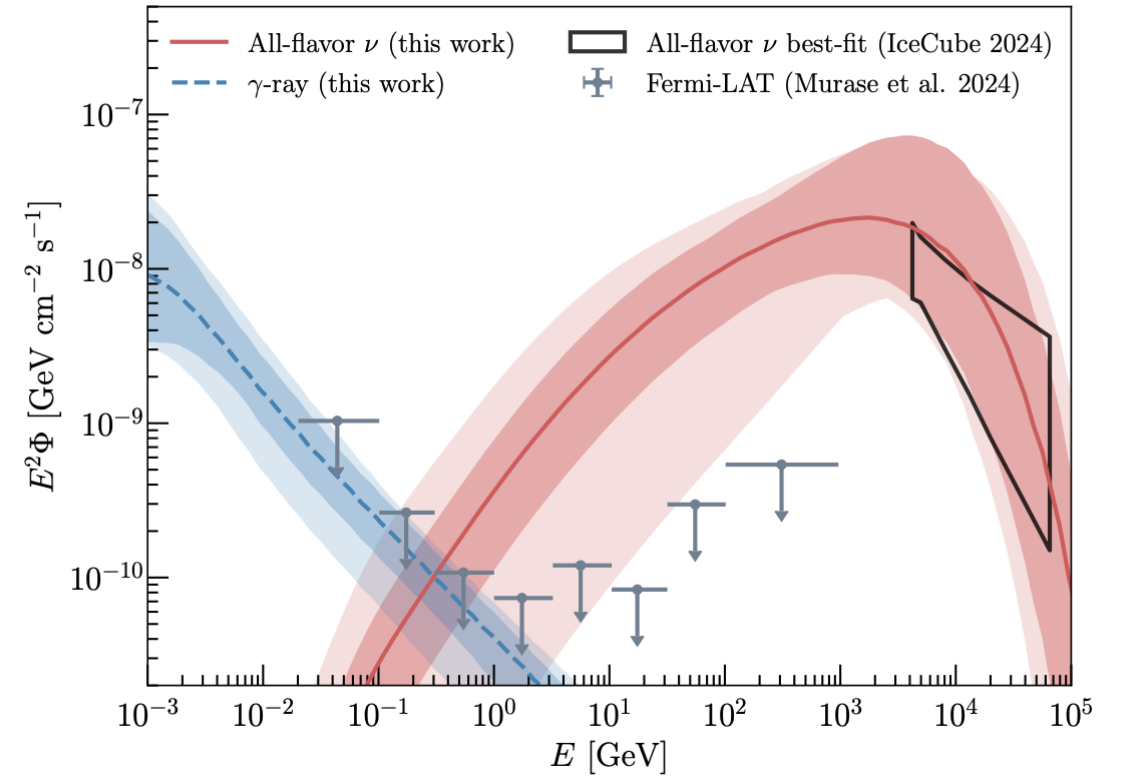
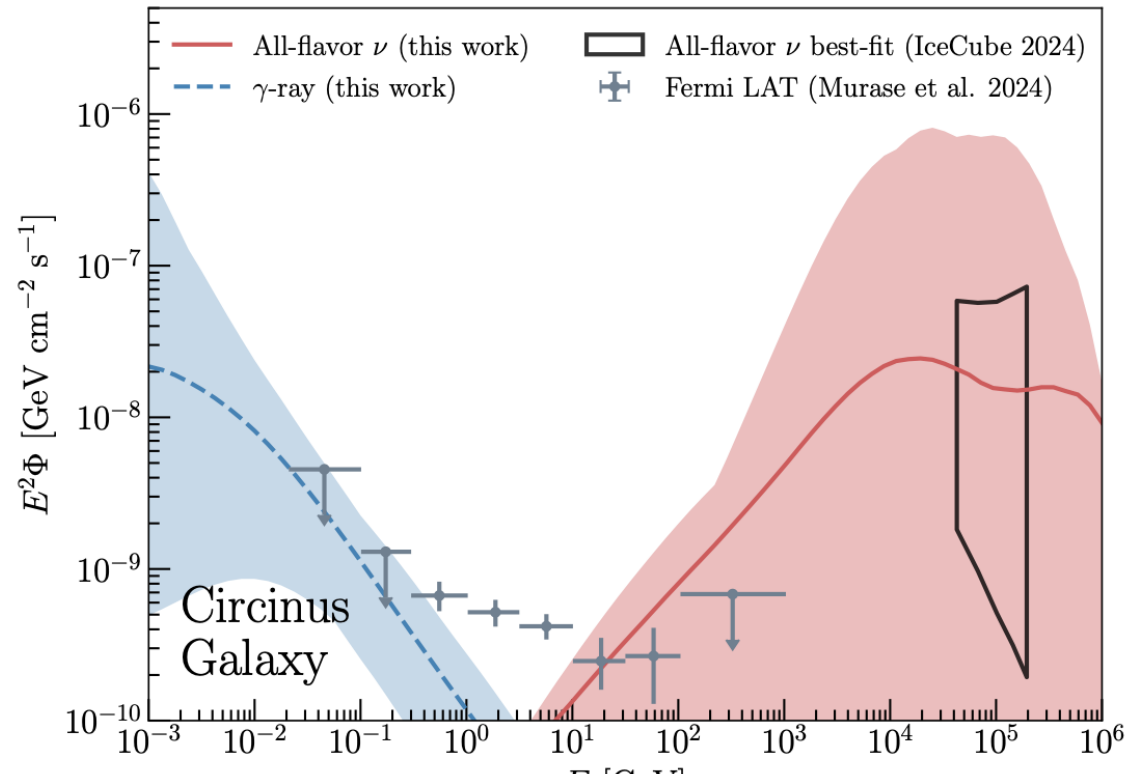
NGC 1068

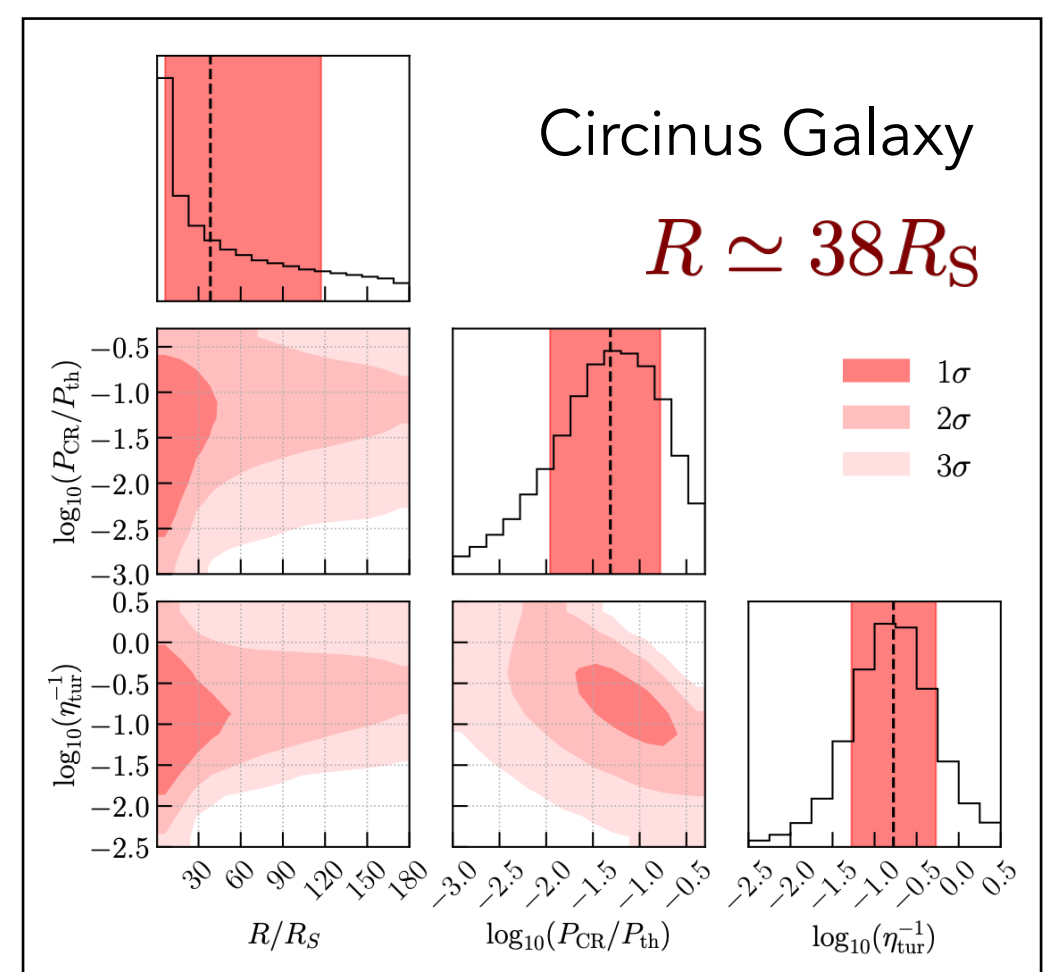
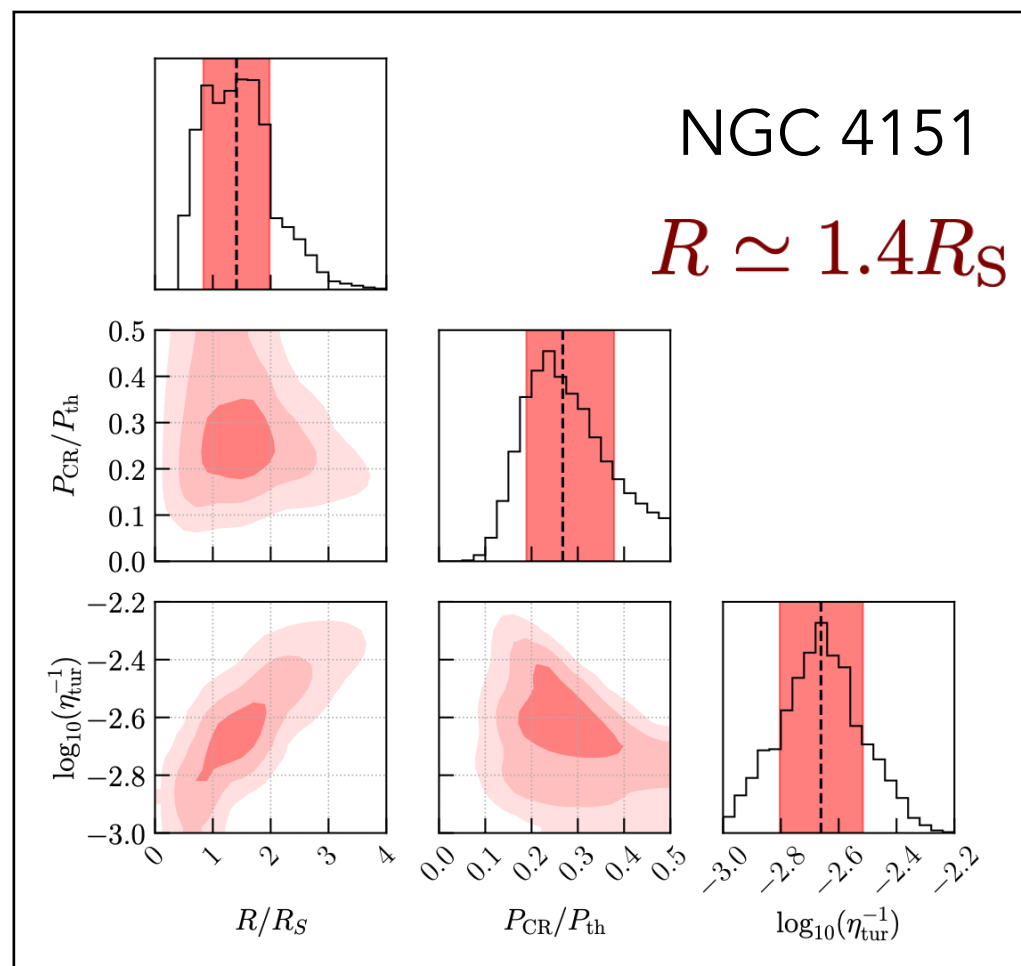
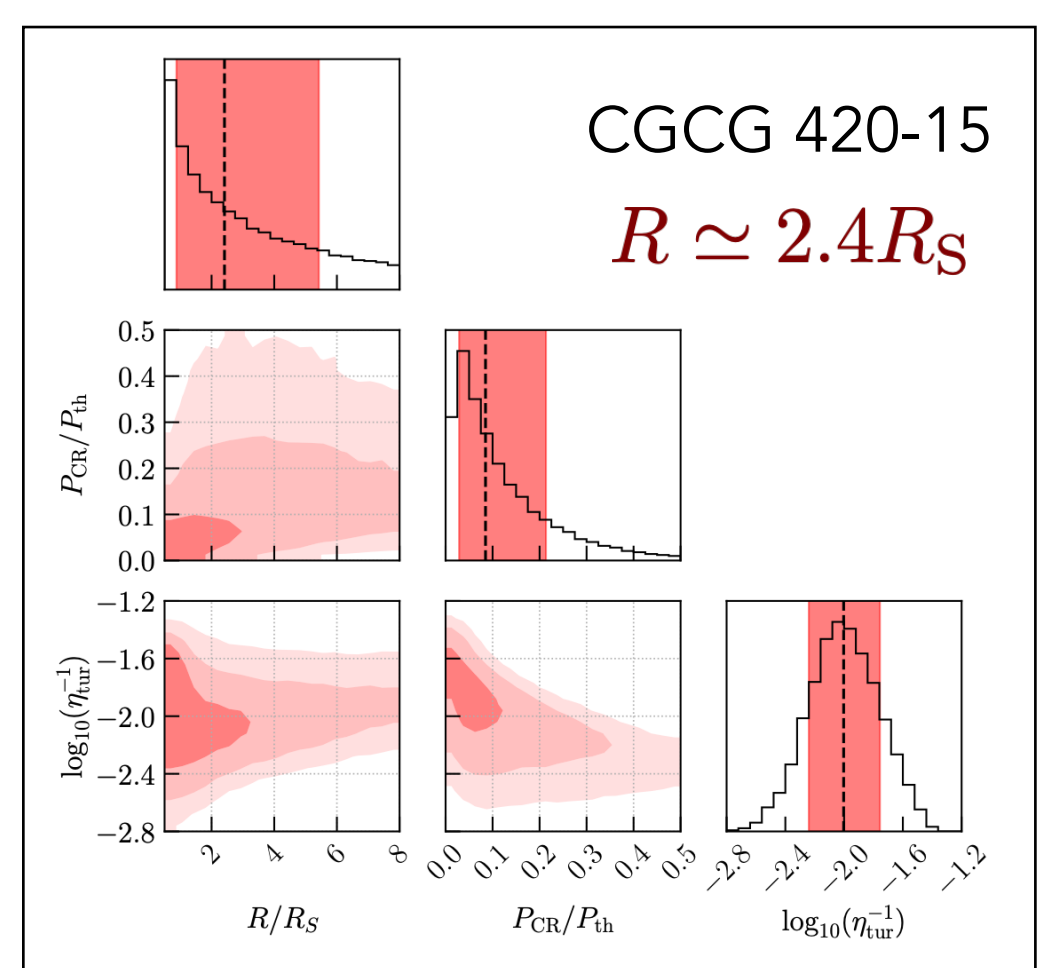
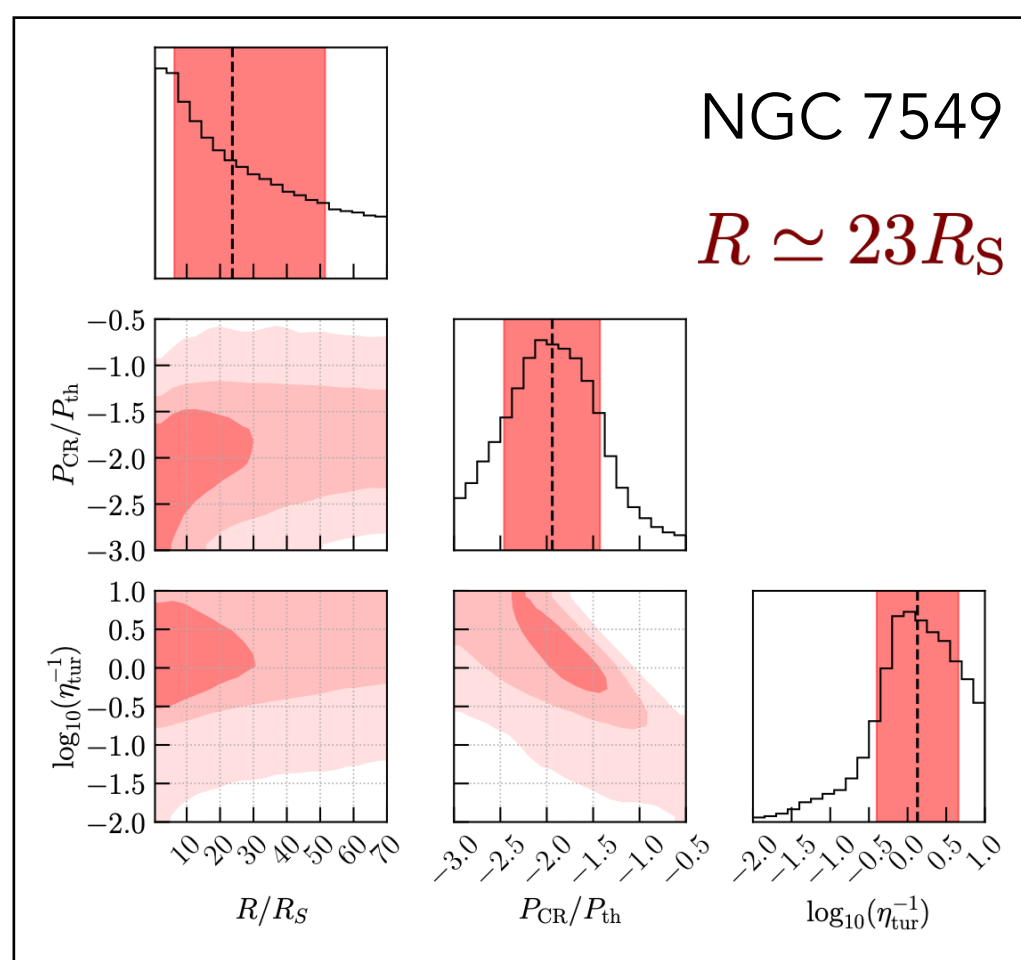
Carpio, AK, Murase, ApJ 2026



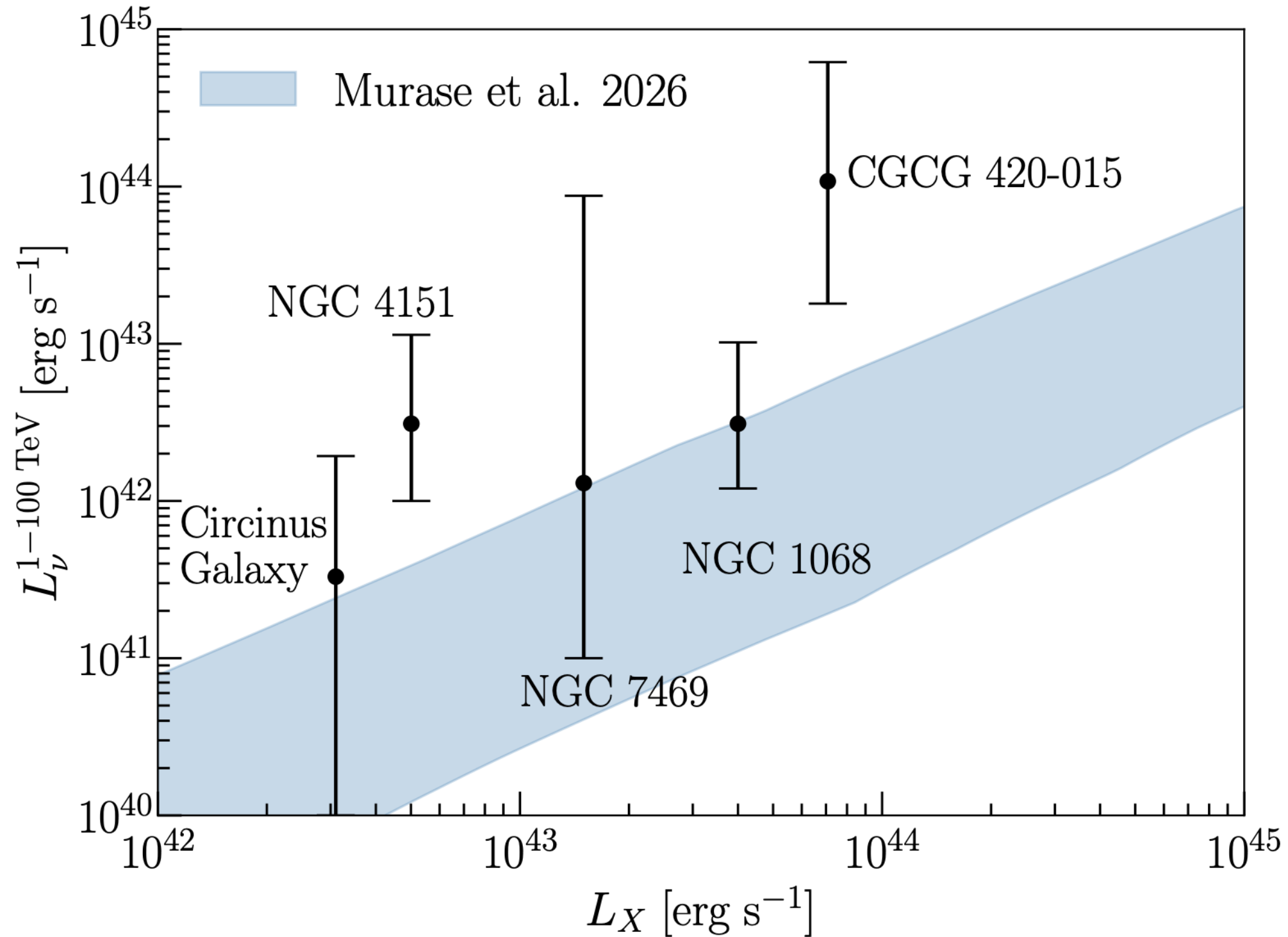
- The GeV γ -rays are explained by the starburst activity.
- The inclusion of sub-GeV measurements restricts the maximum energy of neutrinos.

Multimessenger Input



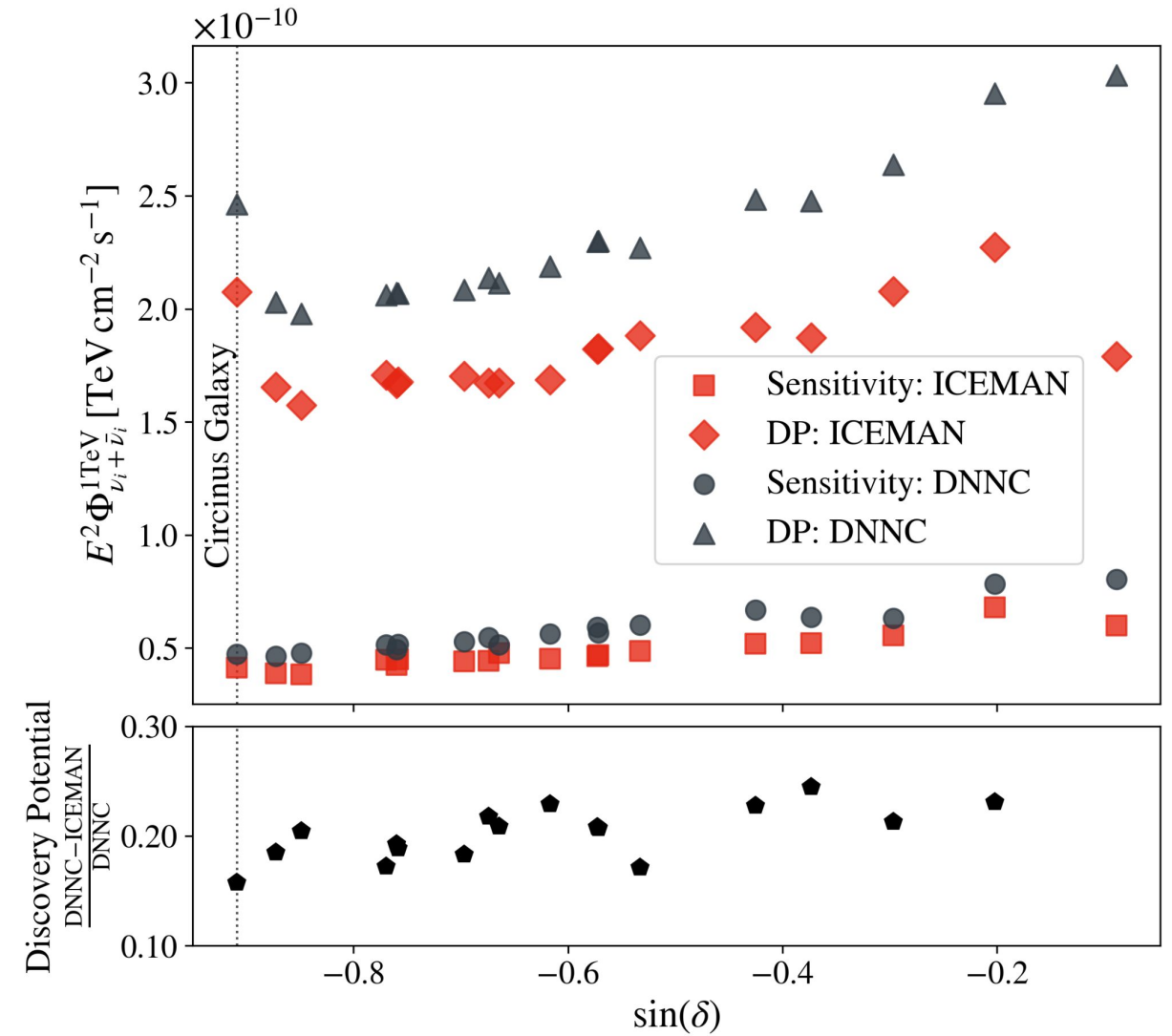
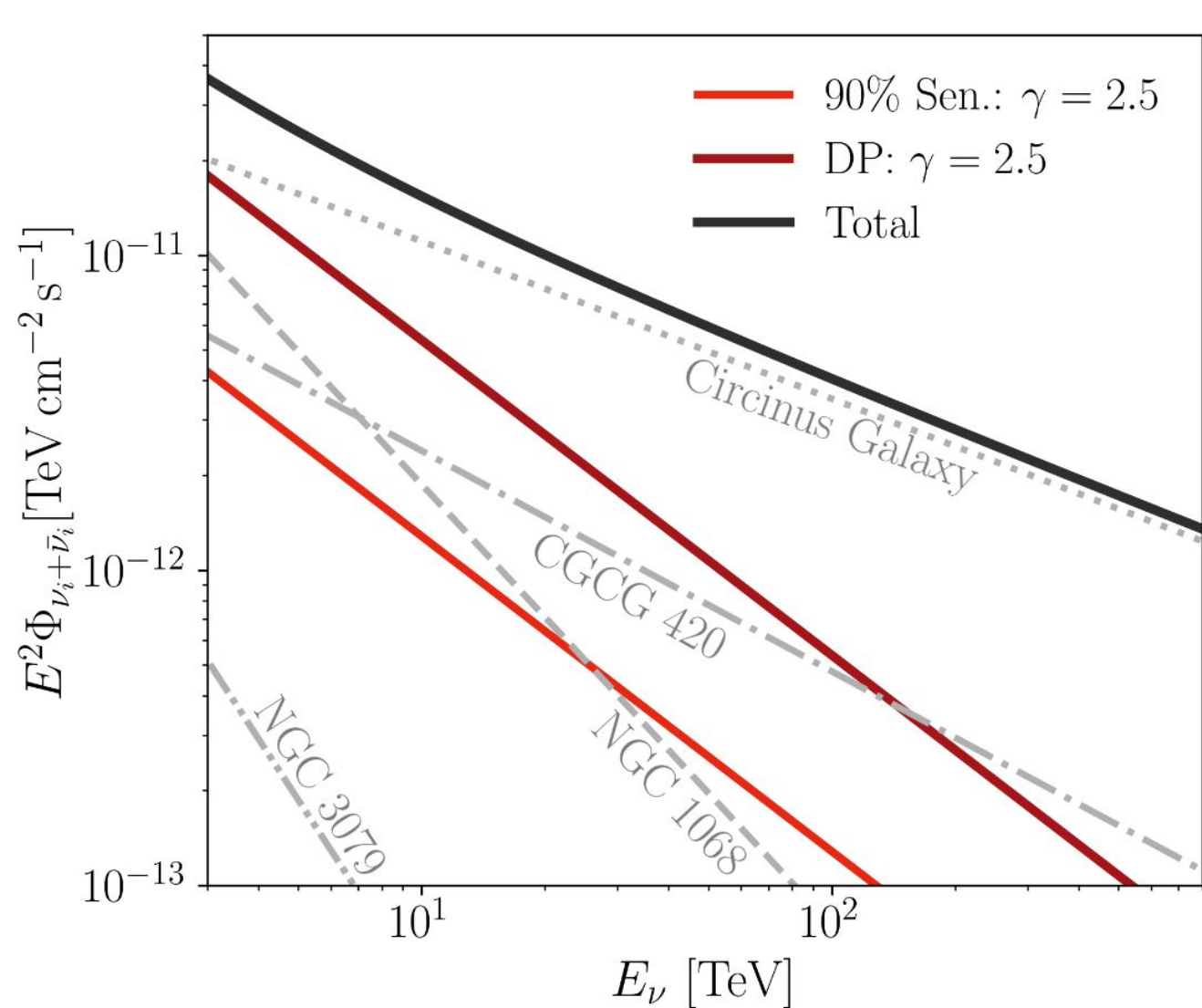


Emerging X-ray - Neutrino Connection



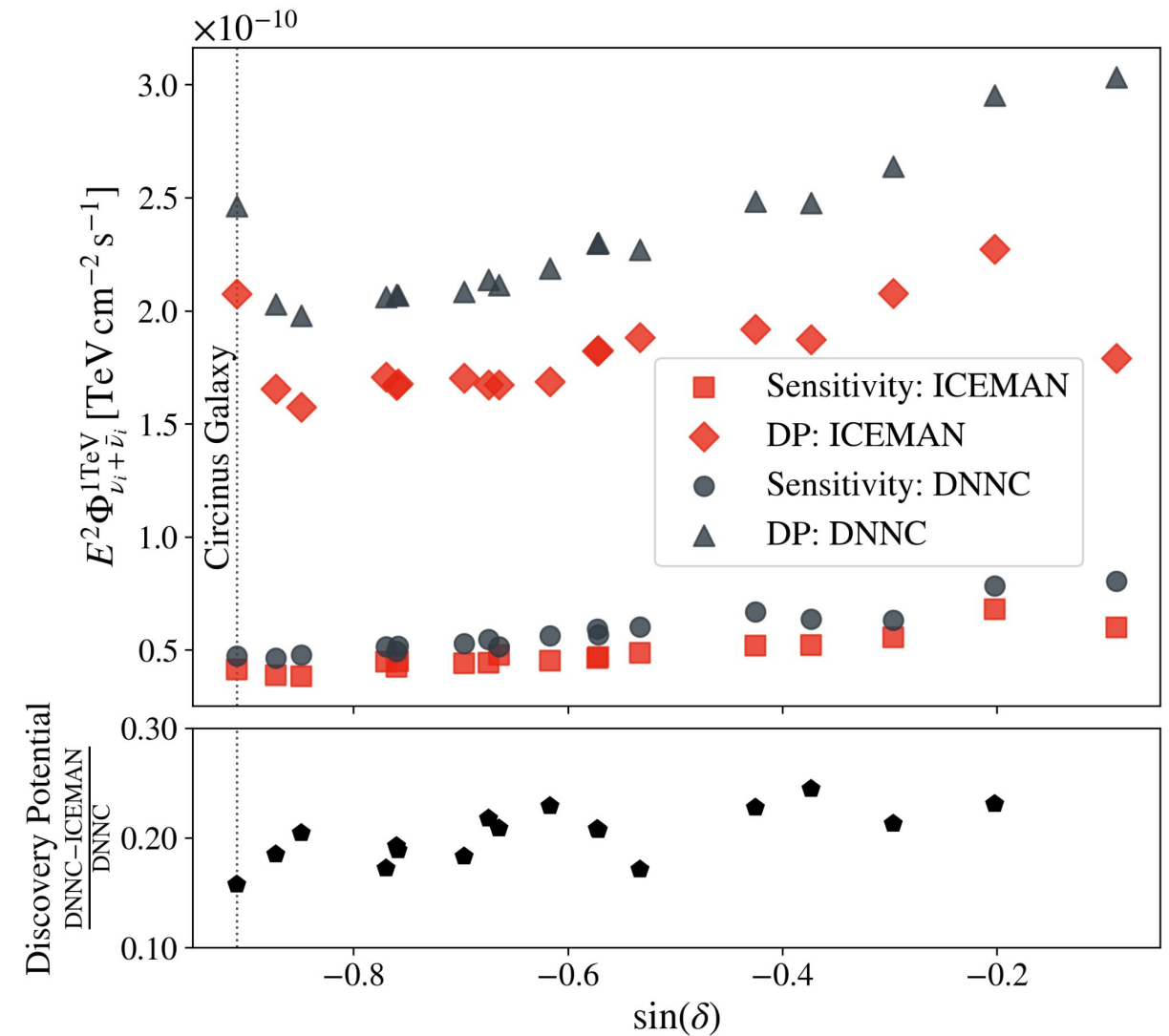
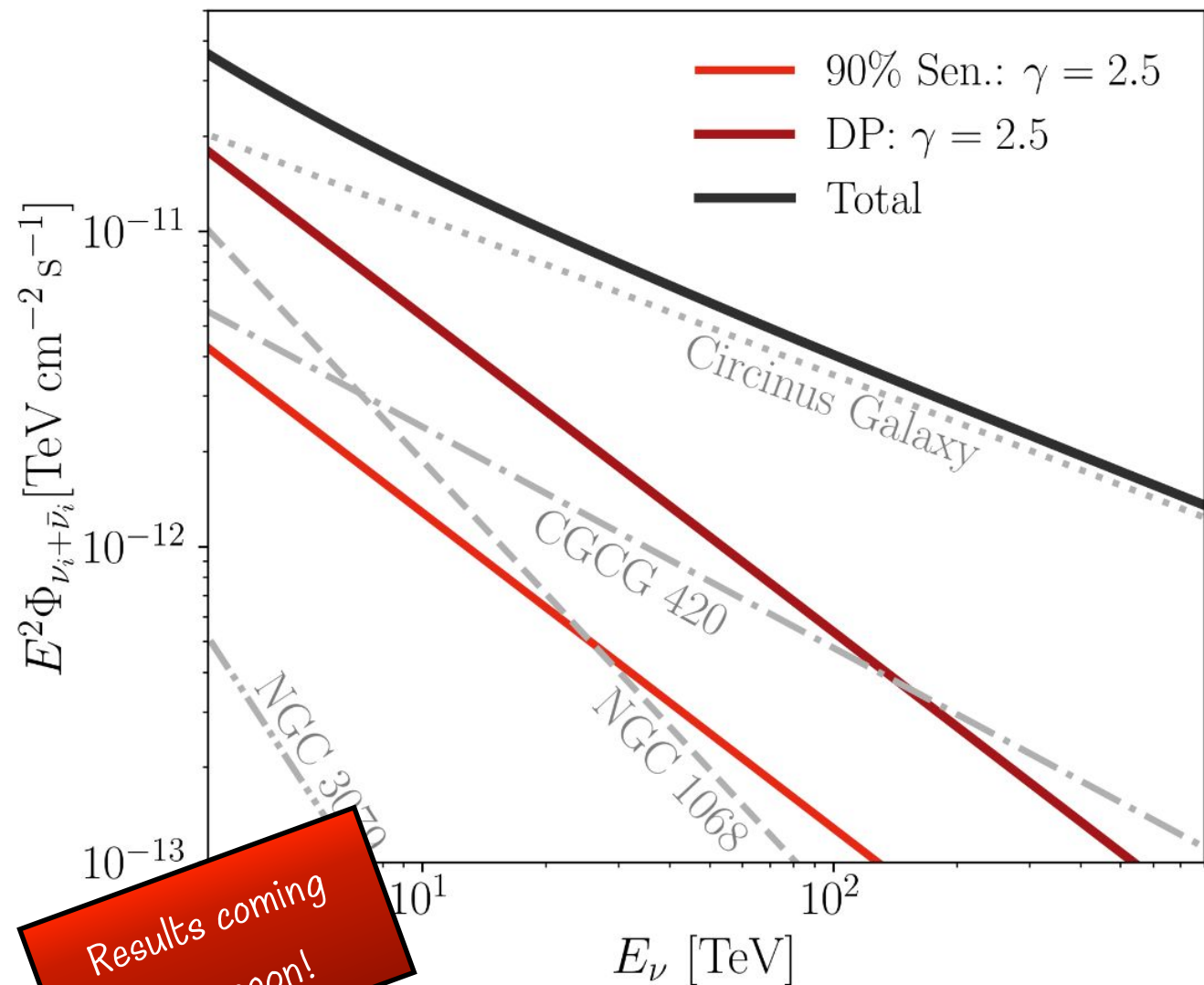
Carpio, AK, Murase, ApJ 2026

All flavor search for CTAGN



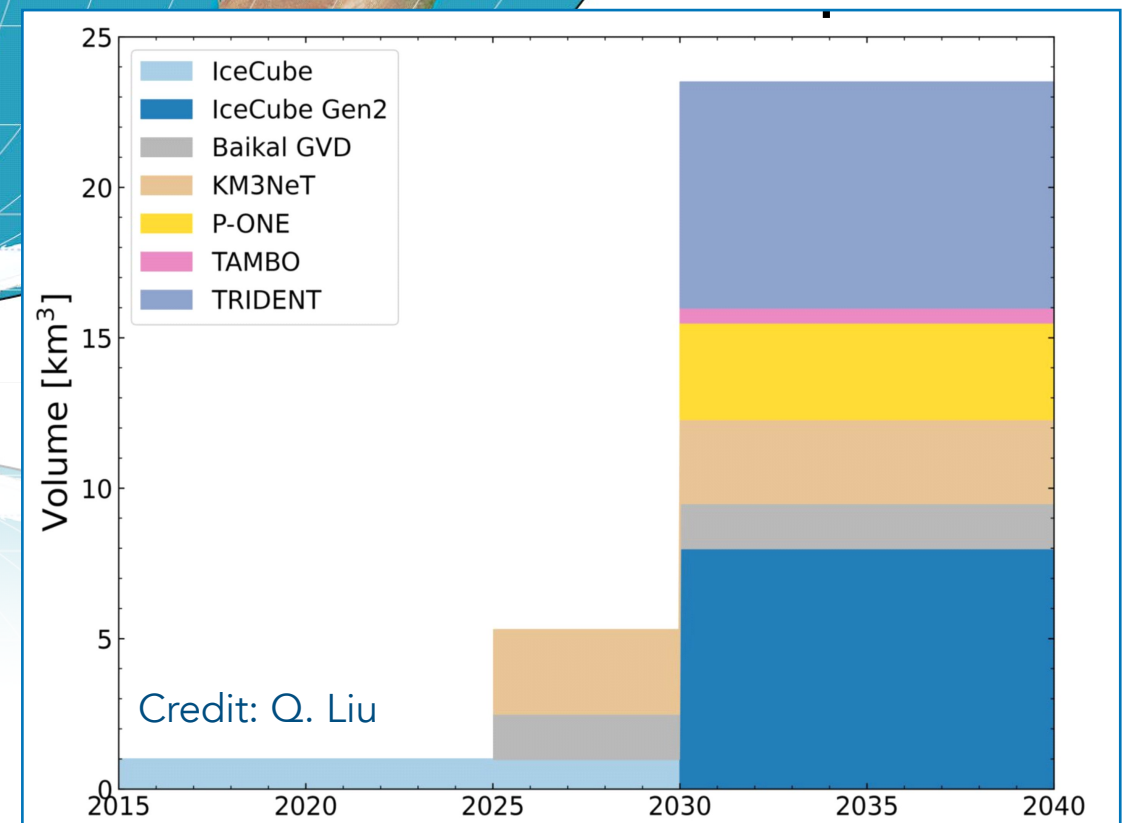
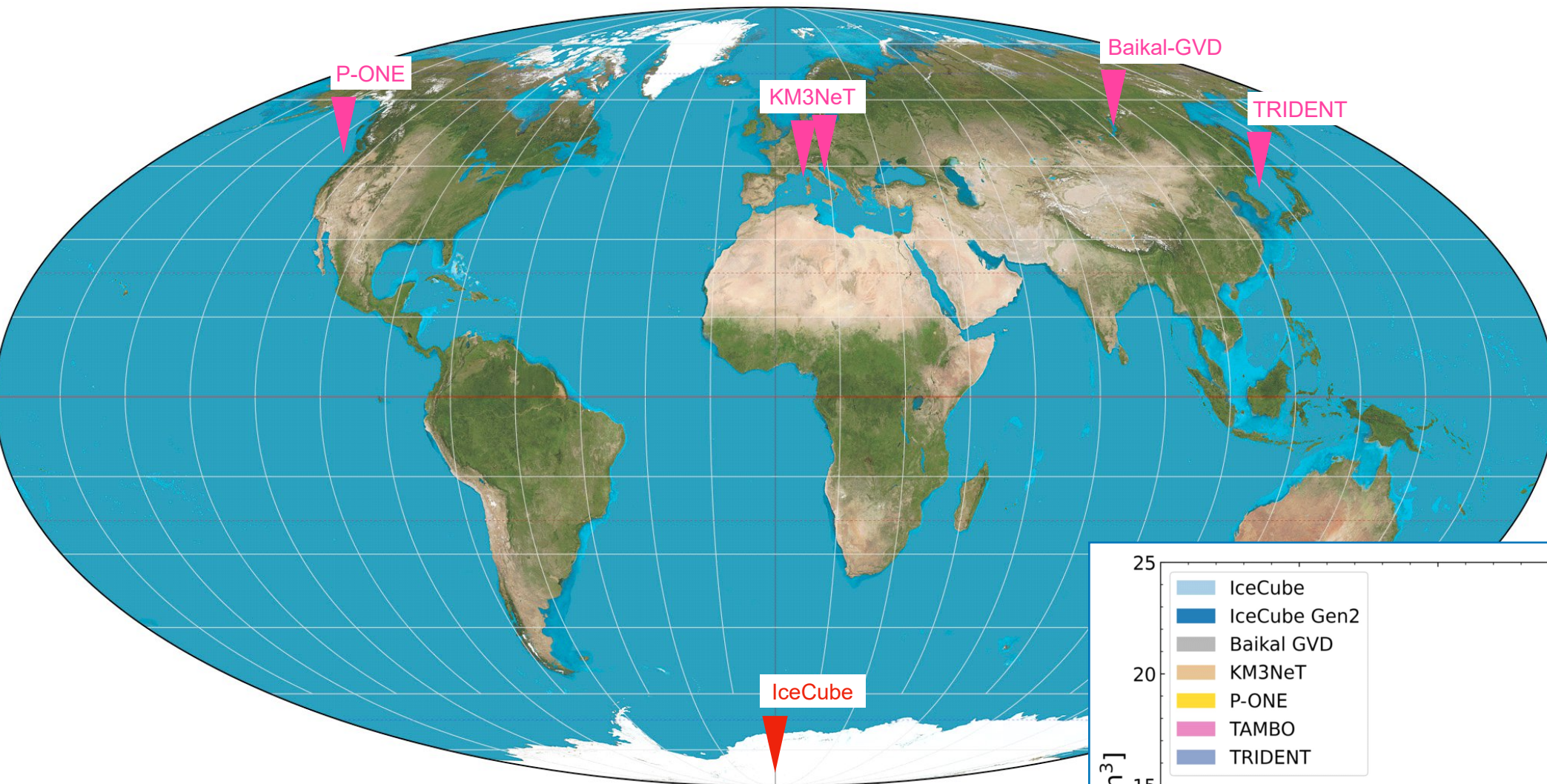
- All flavor search by combining DNNCascade (12 yr), Northern Tracks (13 yr), and ESTES (~10 yr)
 - *Obtaining the best accessible all-sky sensitivity*
- Using the most up-to-date and comprehensive study of obscured AGN cores

All flavor search for CTAGN



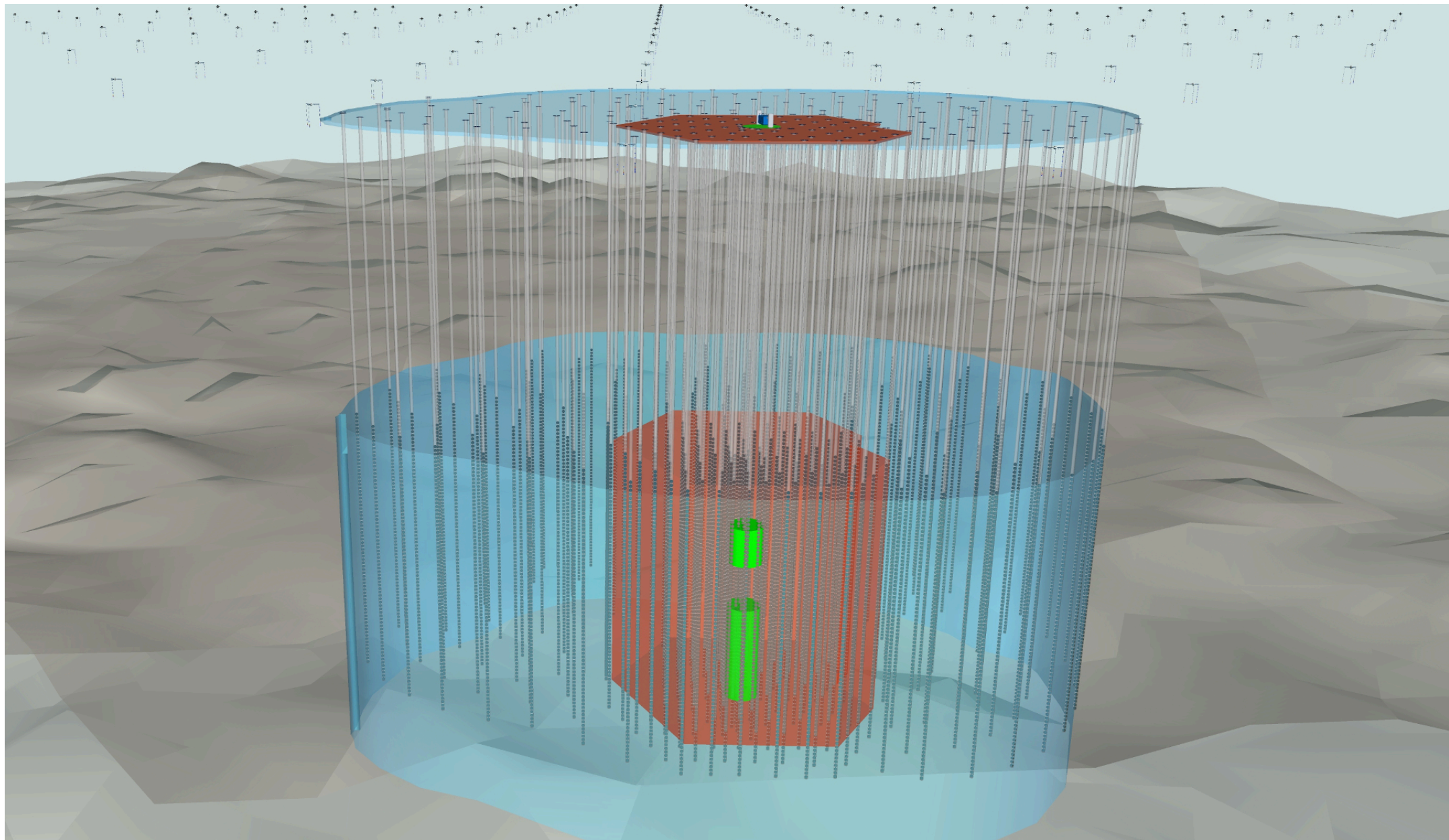
- All flavor search by combining DNNCascade (12 yr), Northern Tracks (13 yr), and ESTES (~10 yr)
 - *Obtaining the best accessible all-sky sensitivity*
- Using the most up-to-date and comprehensive study of obscured AGN cores

Neutrino Astronomy Landscape



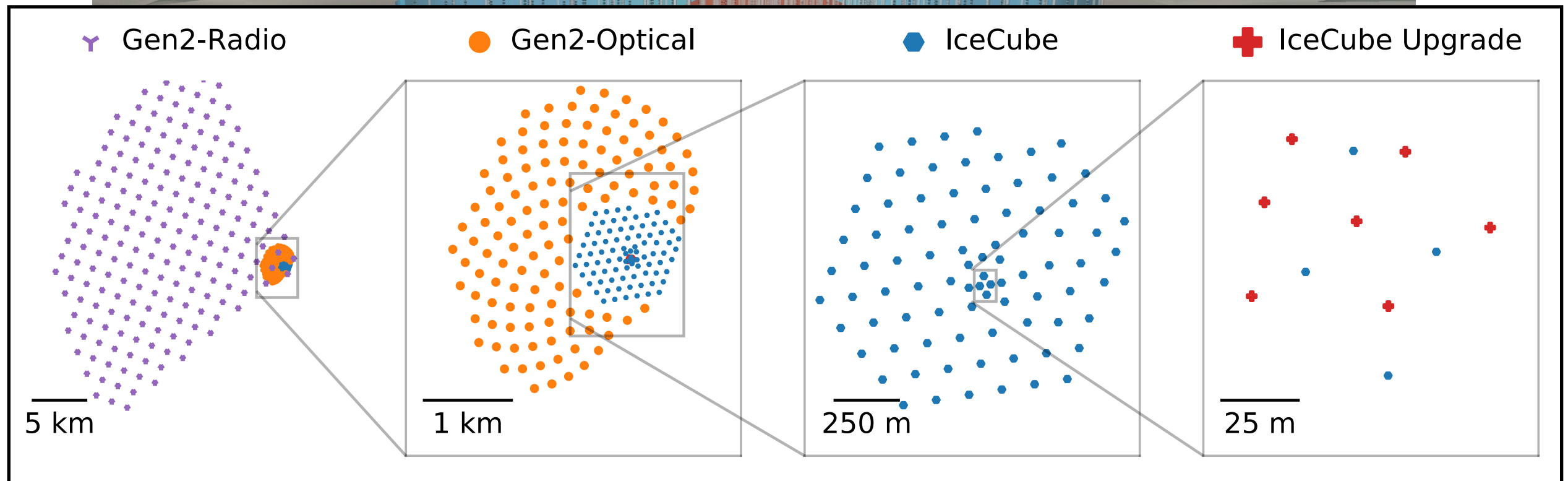
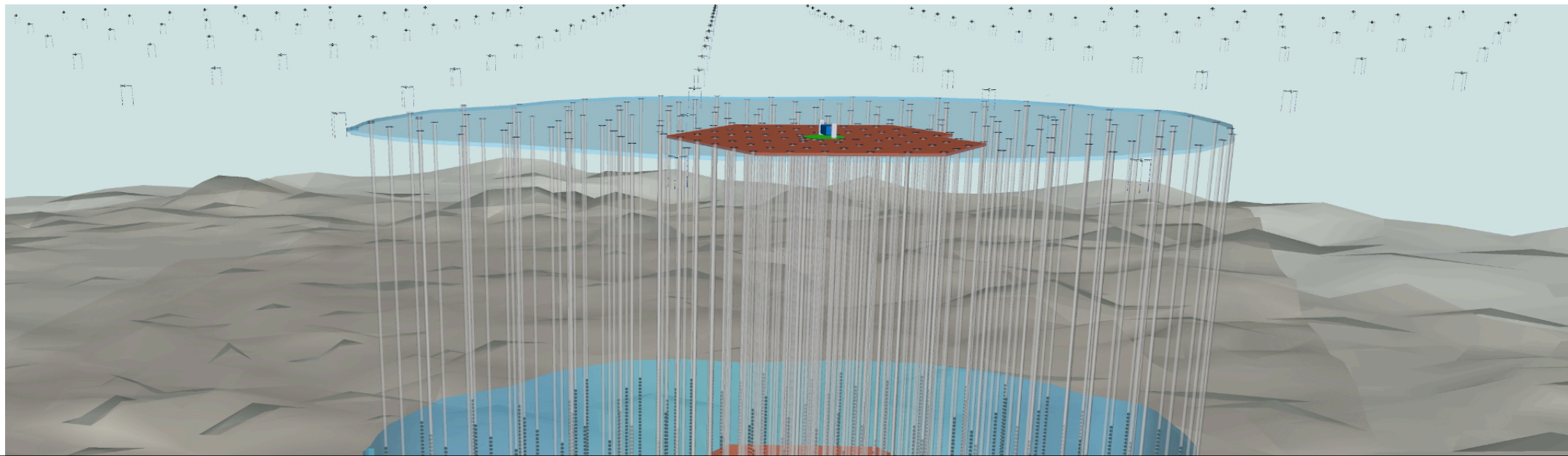
IceCube-Gen2

Near 10 times larger, reaching to energies of EeV



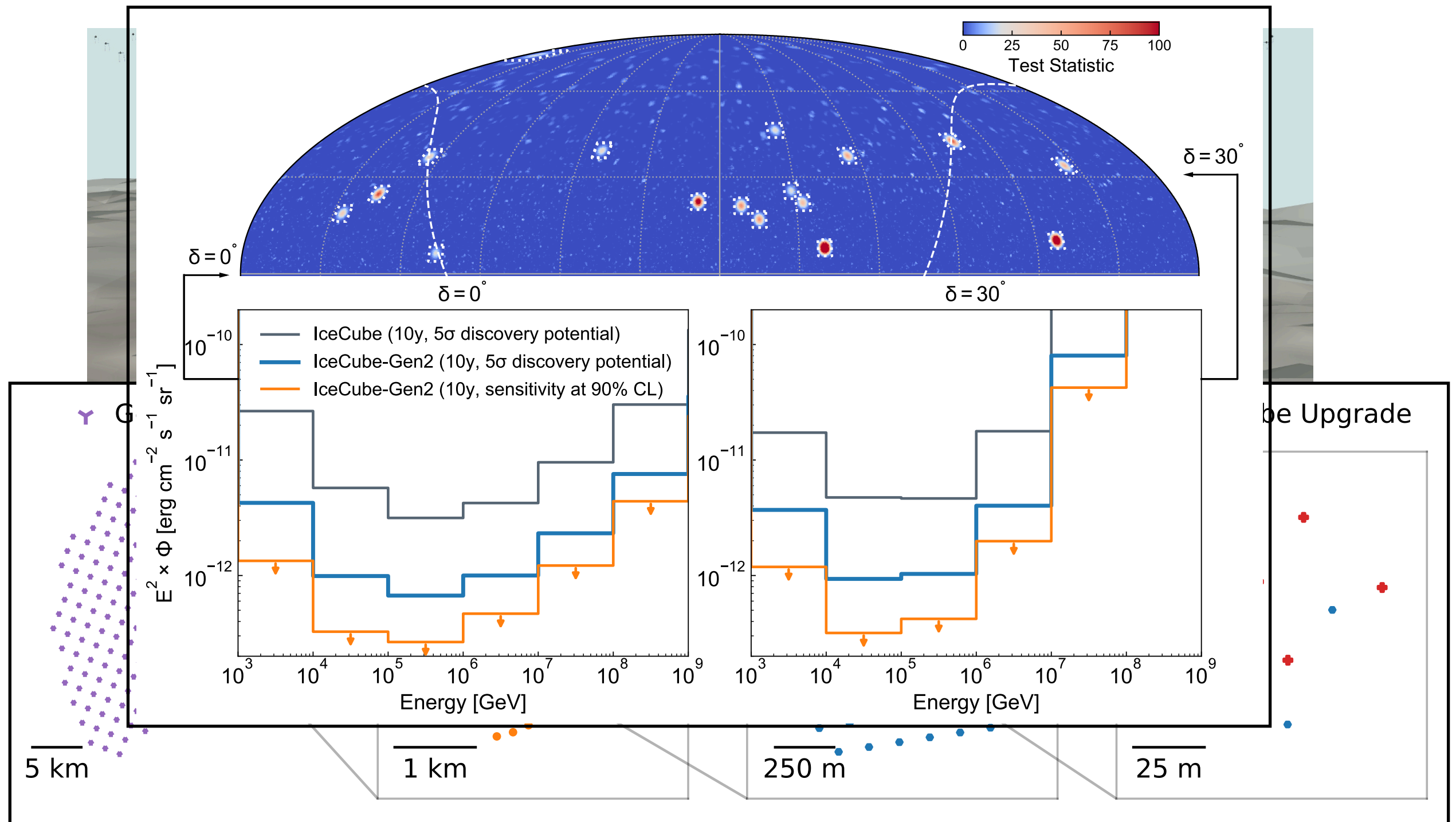
IceCube-Gen2

Near 10 times larger, reaching to energies of EeV



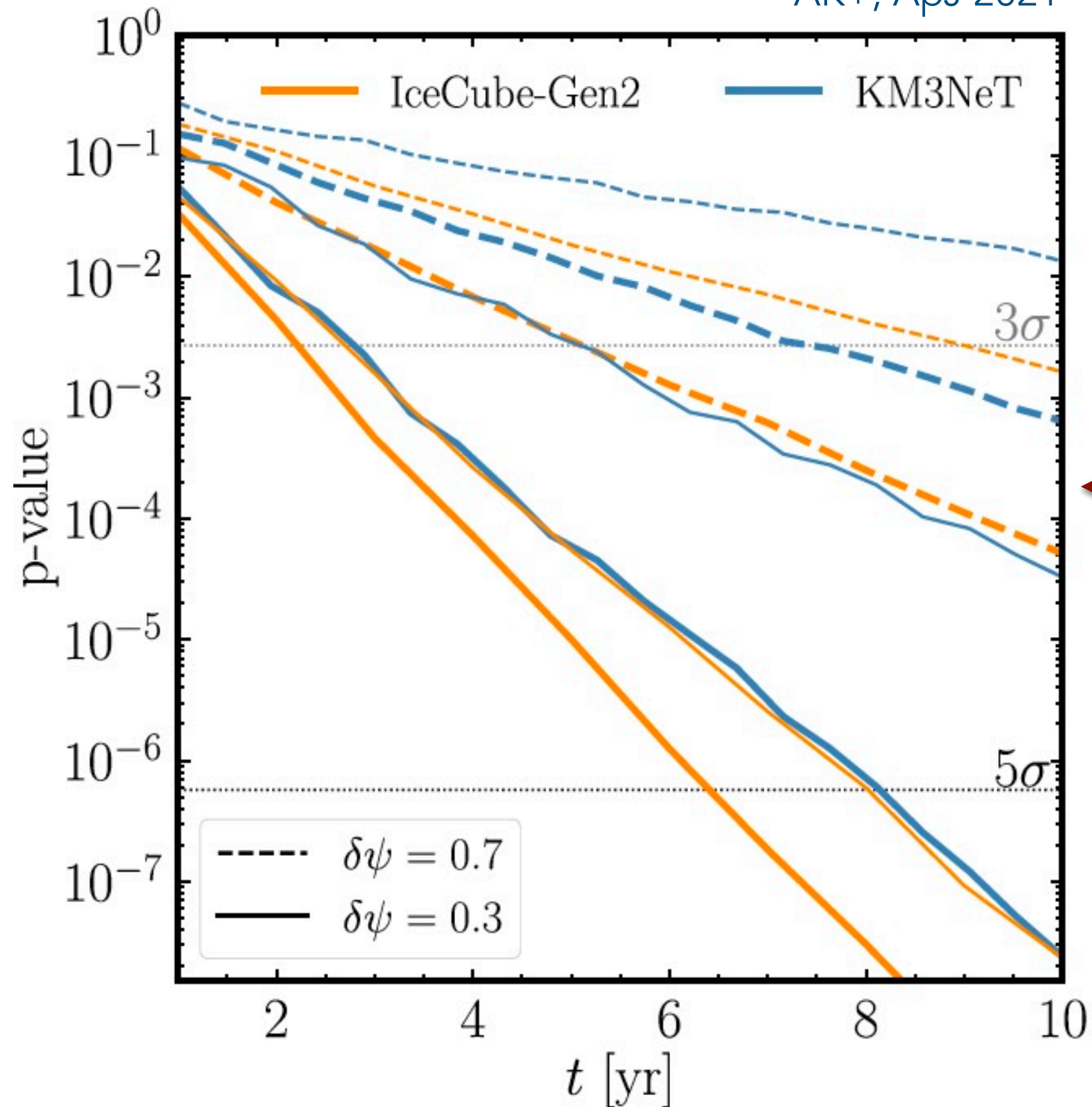
IceCube-Gen2

Near 10 times larger, reaching to energies of EeV



Prospects for future experiments

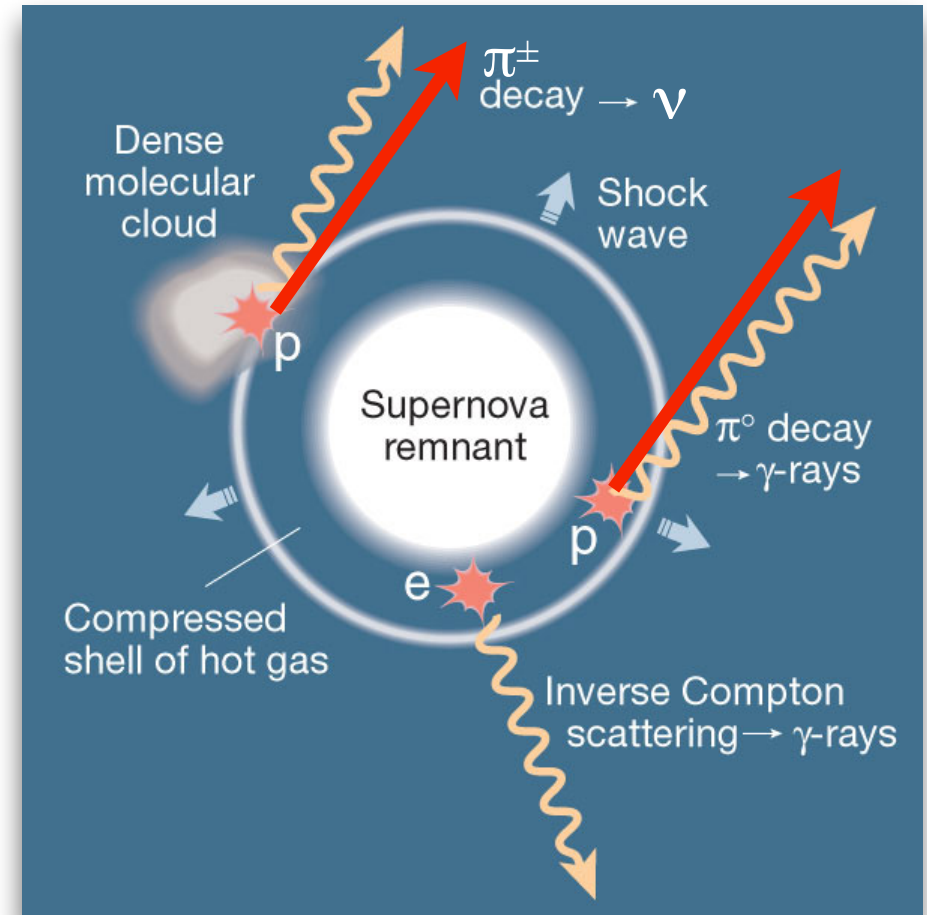
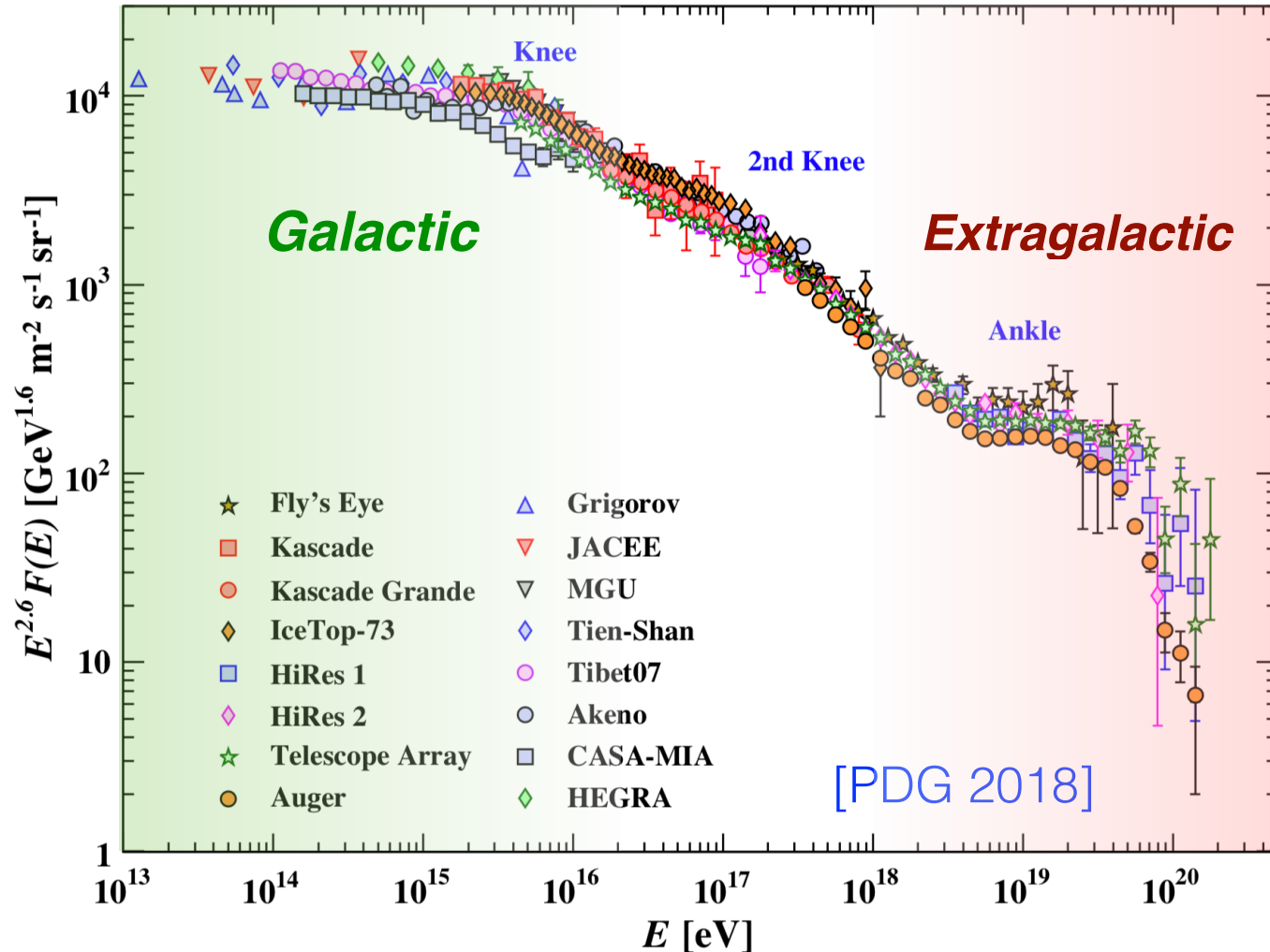
AK+, ApJ 2021



Modest CR
Pressure Scenario

Galactic Cosmic Ray Accelerators

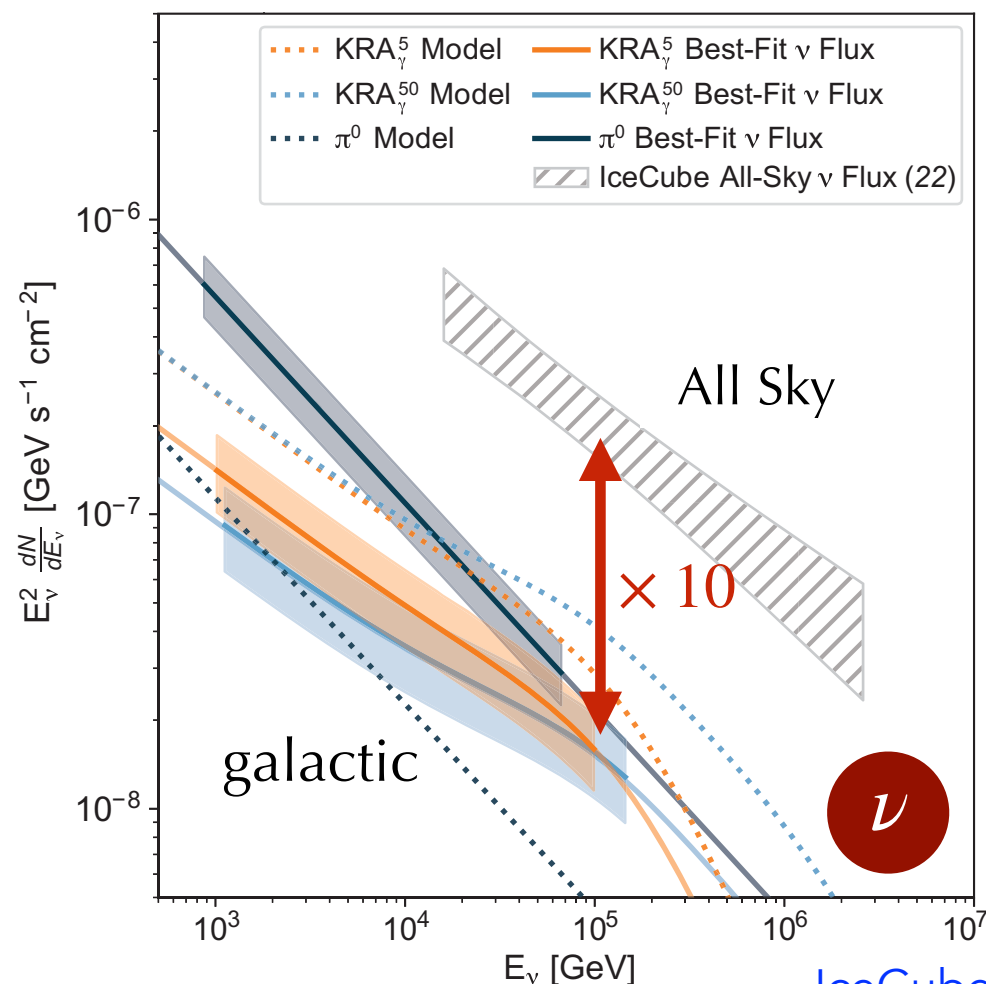
- The search for Galactic cosmic neutrino sources concentrates on the search for “Pevatrons” which have the required energetics to produce cosmic rays up to the knee in the spectrum.
- “Pevatrons” will produce pionic γ -rays whose spectrum extends to several hundred TeV without cut-off.
- Supernova remnant meet such condition.
- TeV γ -rays should be accompanied by TeV neutrinos, observable at IceCube.



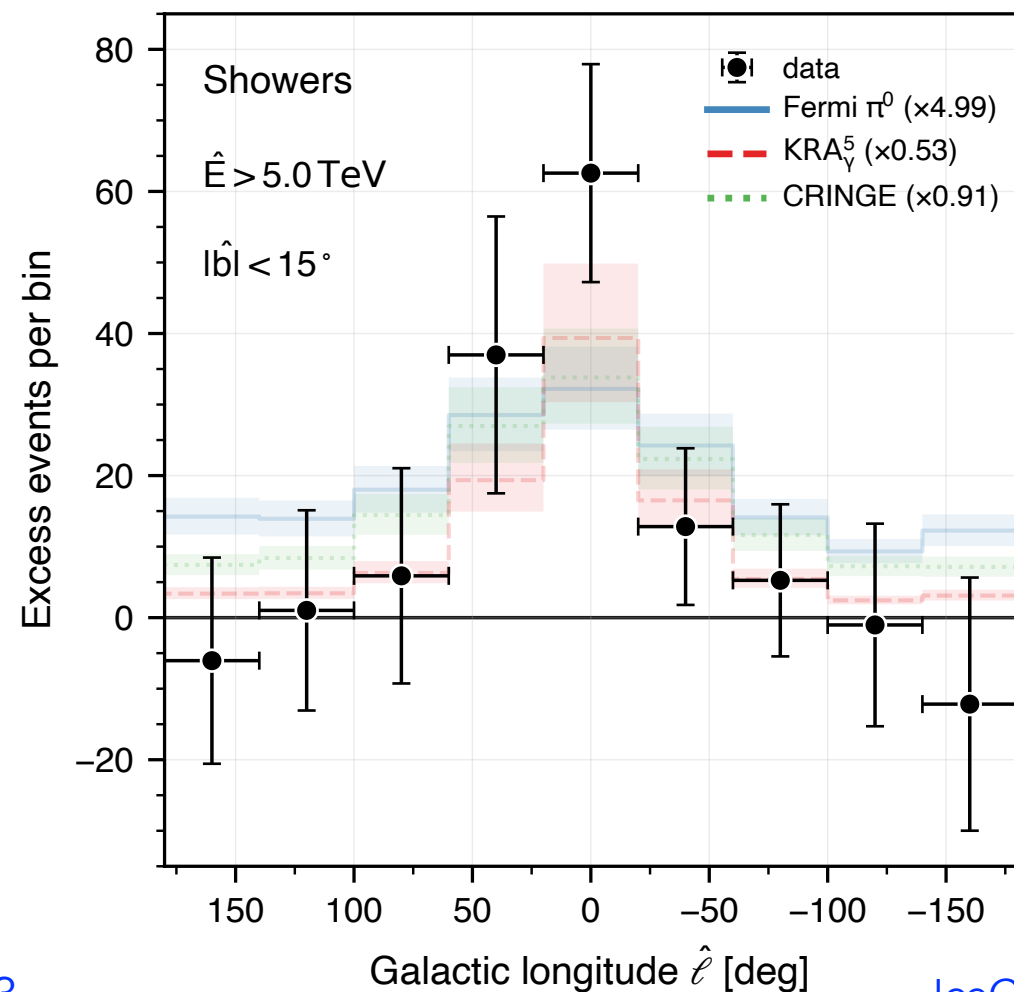
Galactic Neutrino Emission

Cascades boost IceCube sensitivity to extended emission in the Southern sky.

- ▶ New analysis with additional years, combined dataset, and improved systematics rejects the no Galactic hypothesis at 5.7σ significance
- ▶ Current analyses reject no Galactic component hypothesis but cannot distinguish between models
- ▶ The nature of Galactic neutrinos (source vs diffuse) remains an open question



IceCube, Science 2023



IceCube 2026

Potential Galactic Sources

SN 1054

Supernova Remnants

Credit: ESA/Hubble

Pulsar Wind Nebulae

Credit: NASA/CXC/SAO

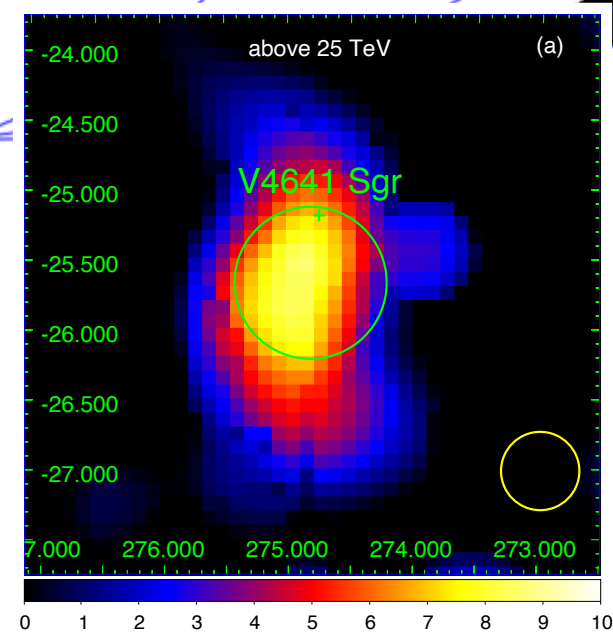
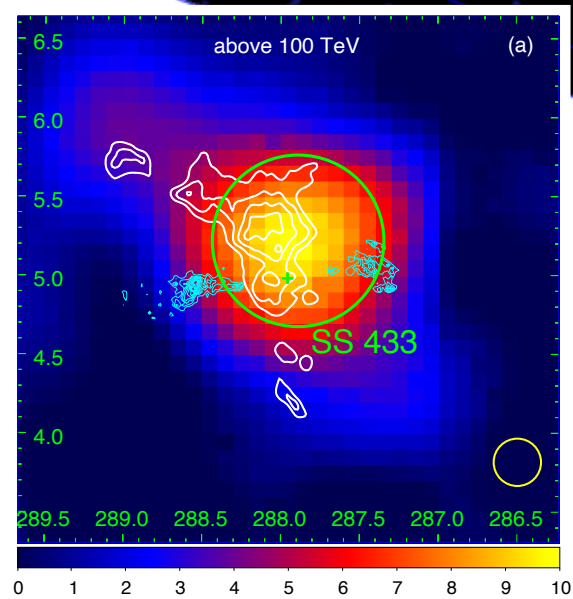
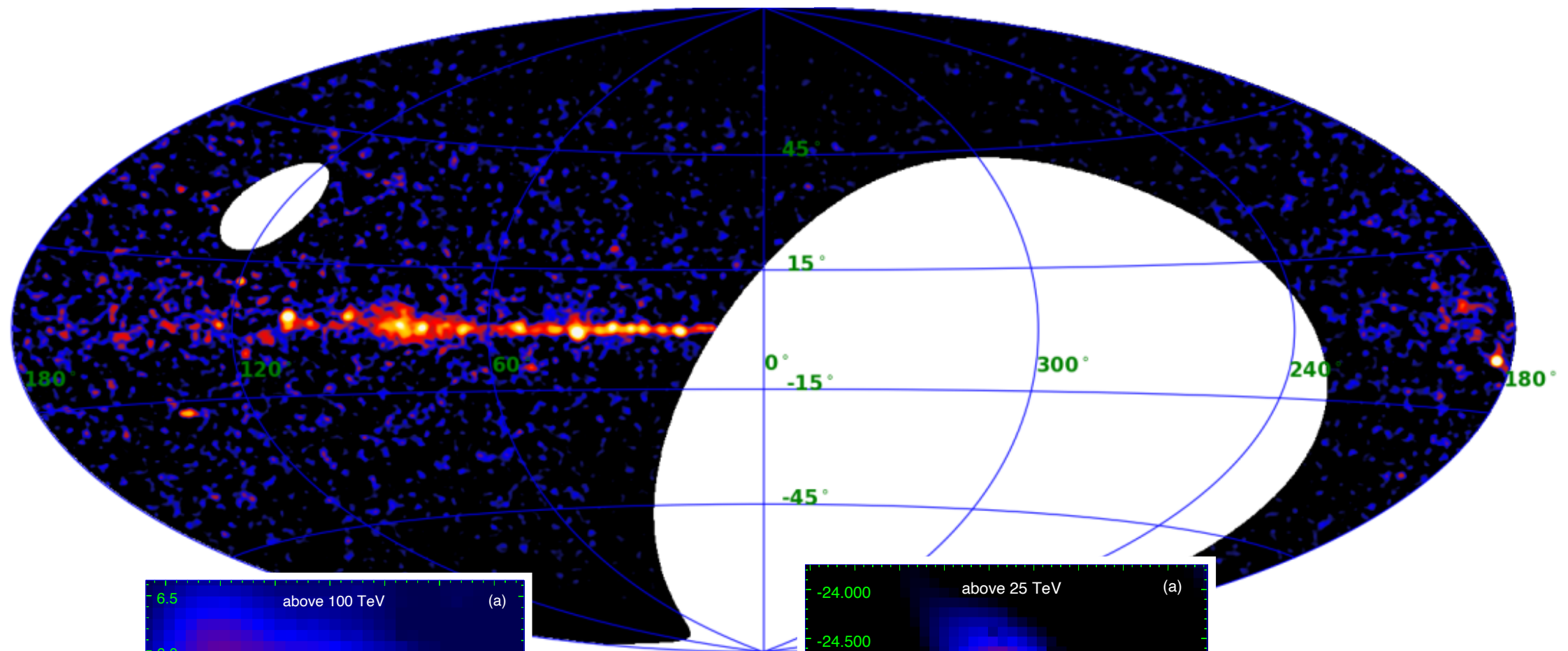
Binaries

Credit: NASA

Diffuse Galactic Emission

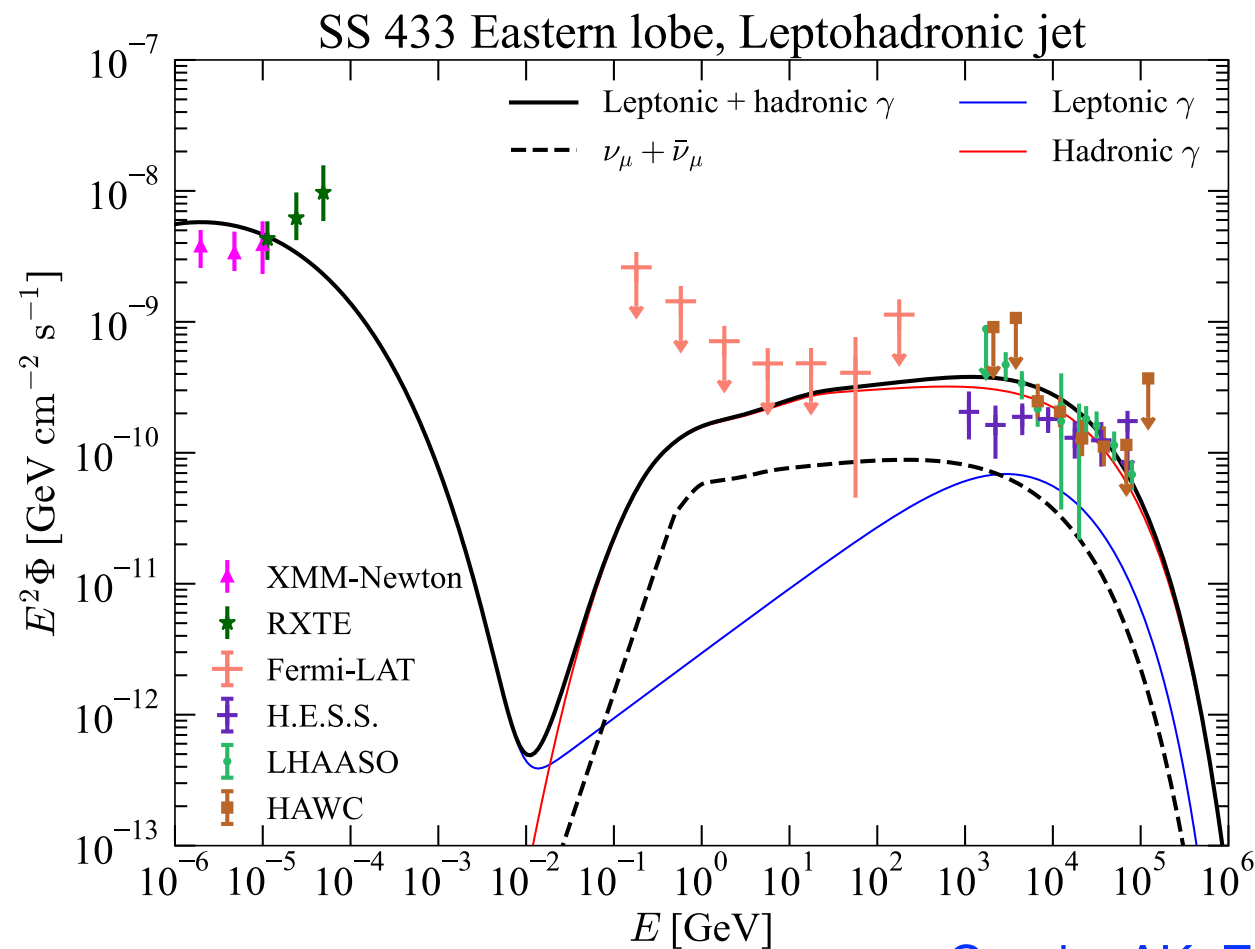
ESA/Planck Collaboration

LHAASO & VHE γ -ray sky

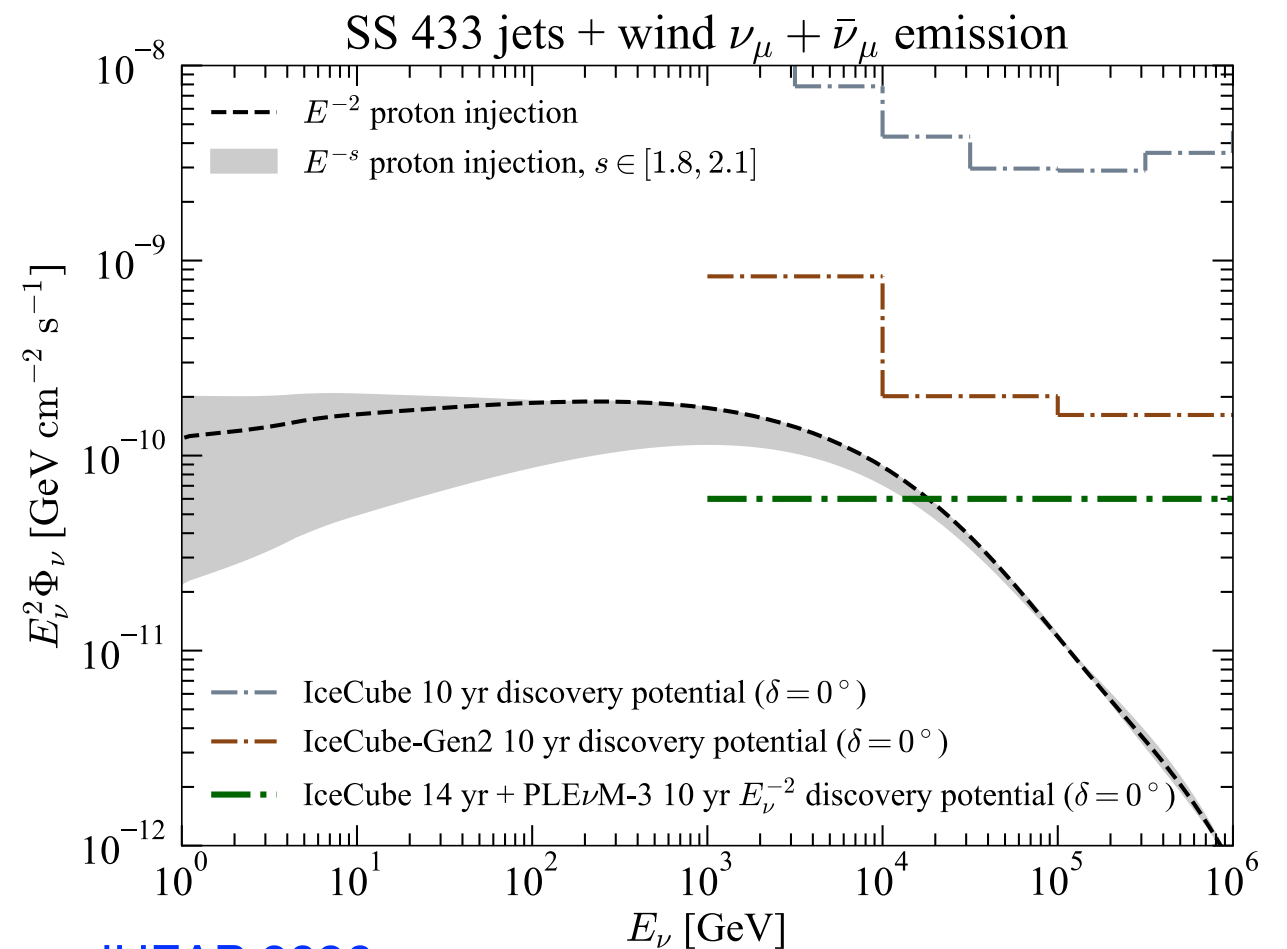


LHAASO 2024

VHE emission from Microquasars

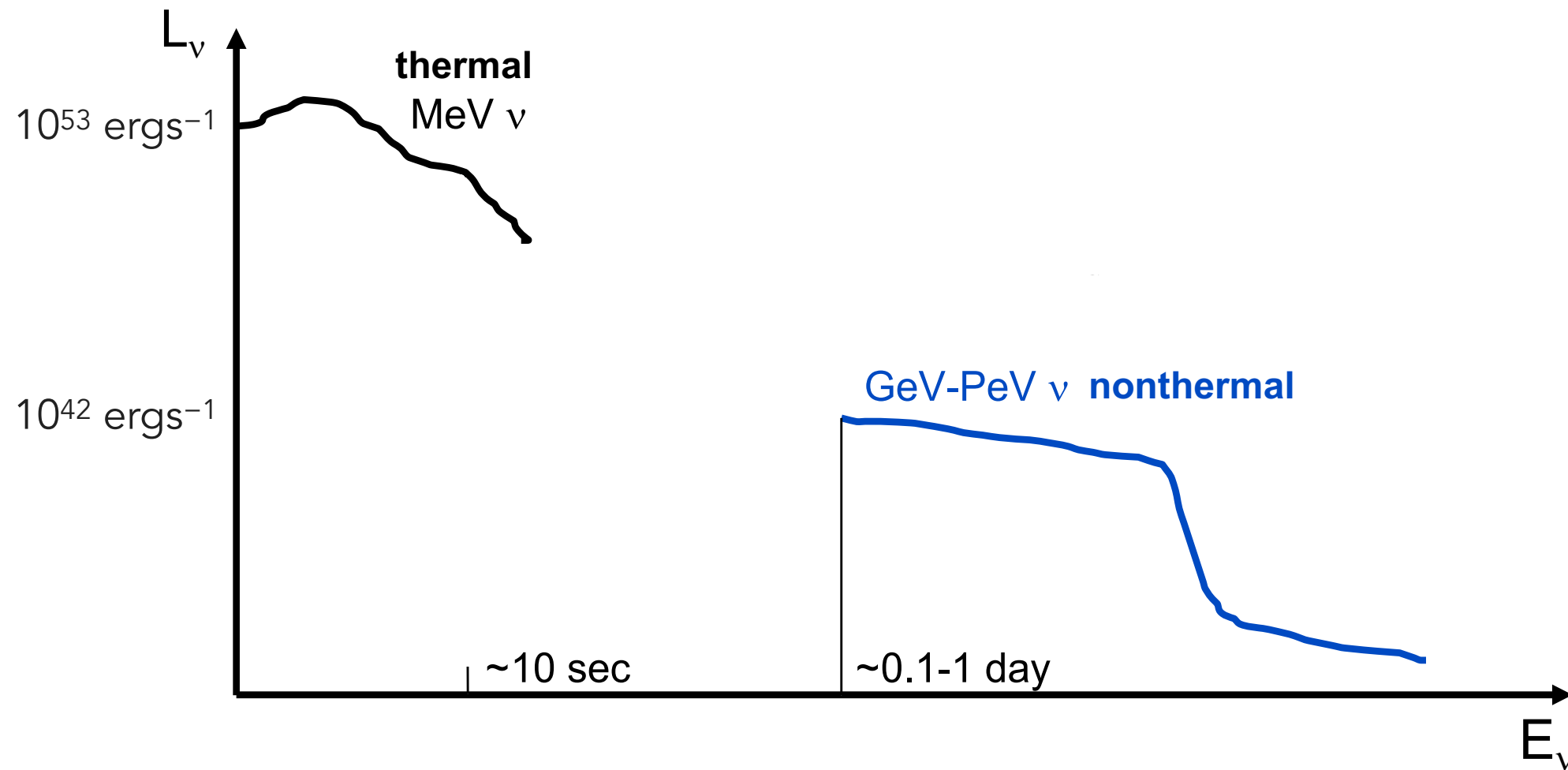


Carpio, AK, Zhang, JHEAP 2026

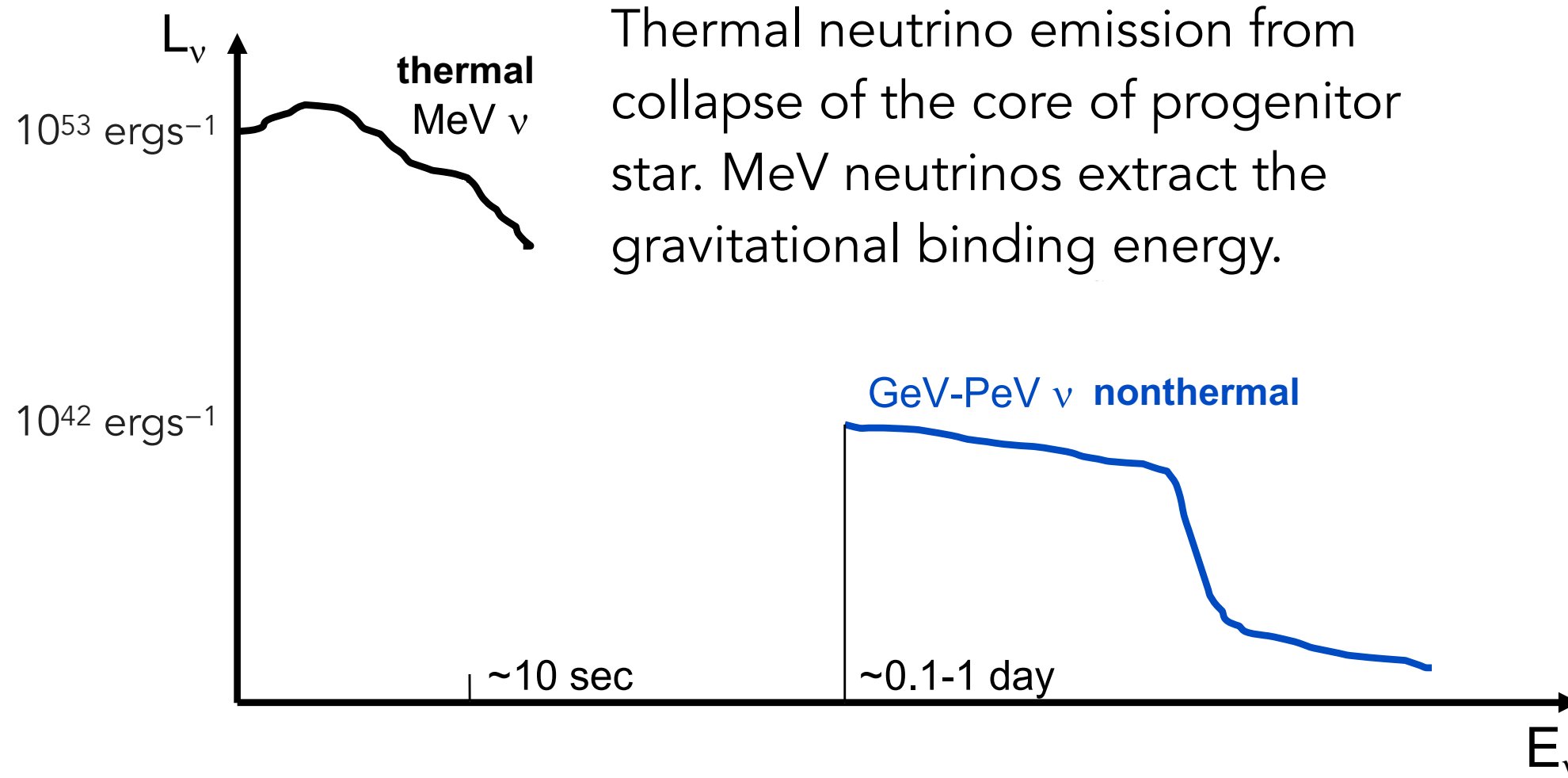


- Hadrons play a major role in the γ -ray emission from these sources.
- The level of flux not high enough to be identified in current experiments.

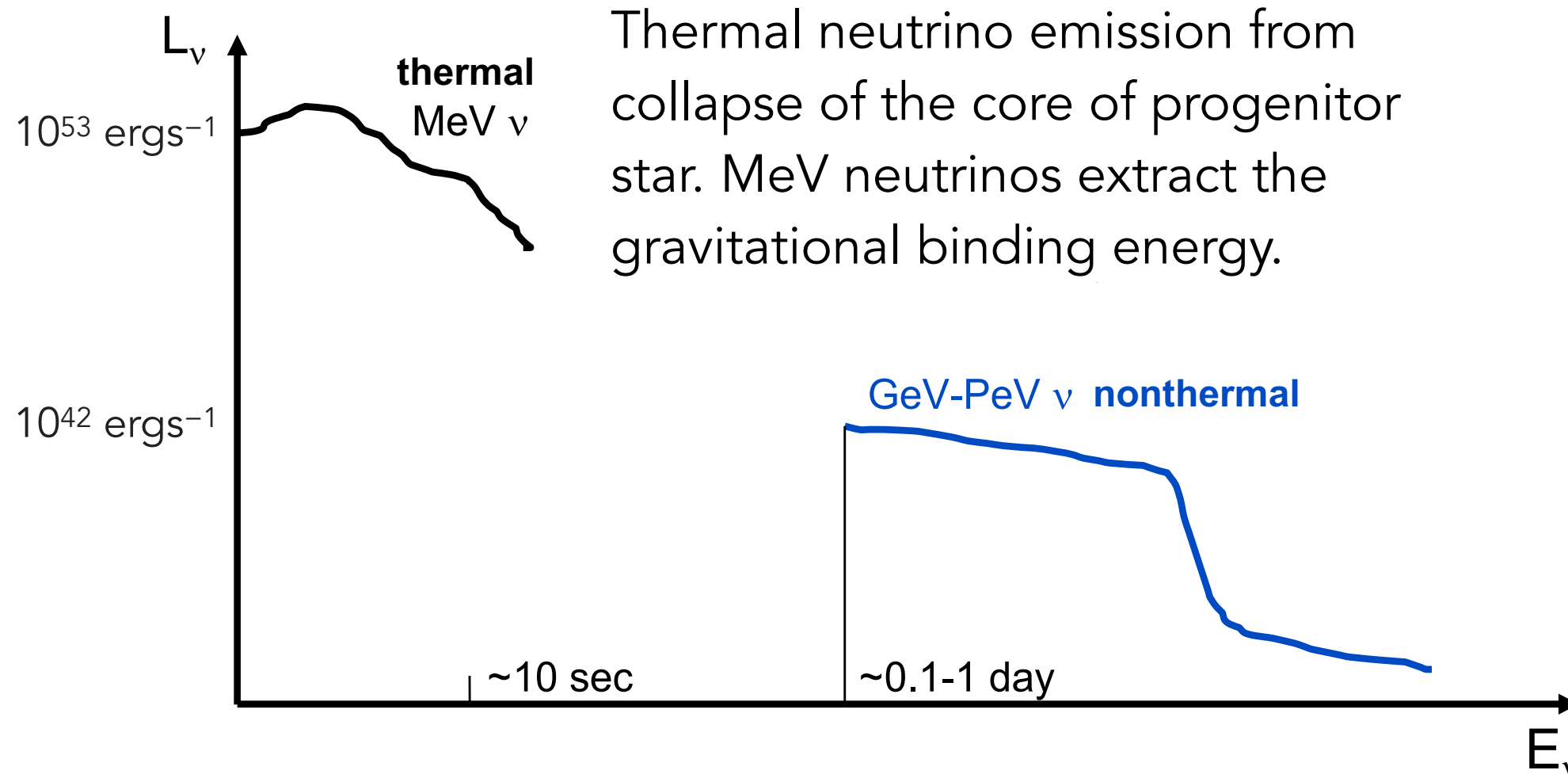
Neutrinos from Core Collapse Supernovae



Neutrinos from Core Collapse Supernovae

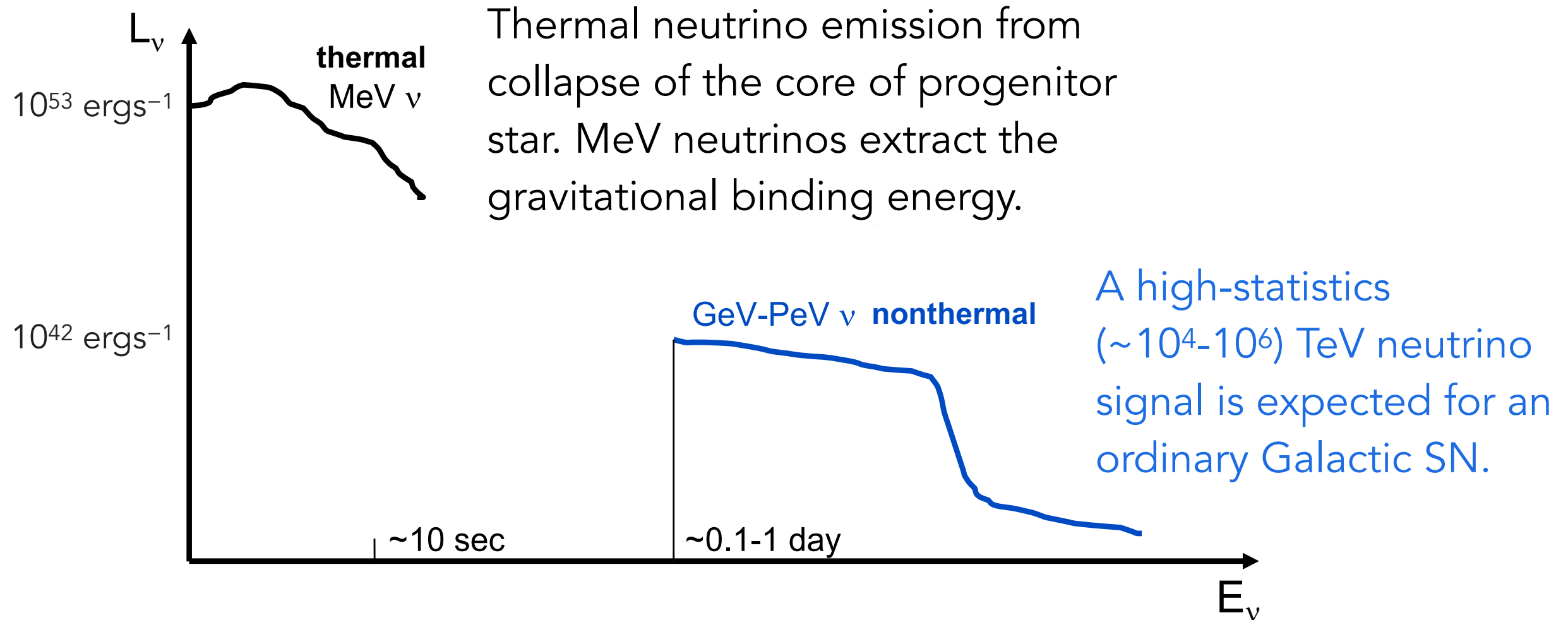


Neutrinos from Core Collapse Supernovae



- Observation of extragalactic SNe showed rapid significant mass loss in SN progenitor which leads to shock interaction with dense circumstellar material (CSM).
 - ▶ Shock interaction with CSM results in production of HE neutrinos!

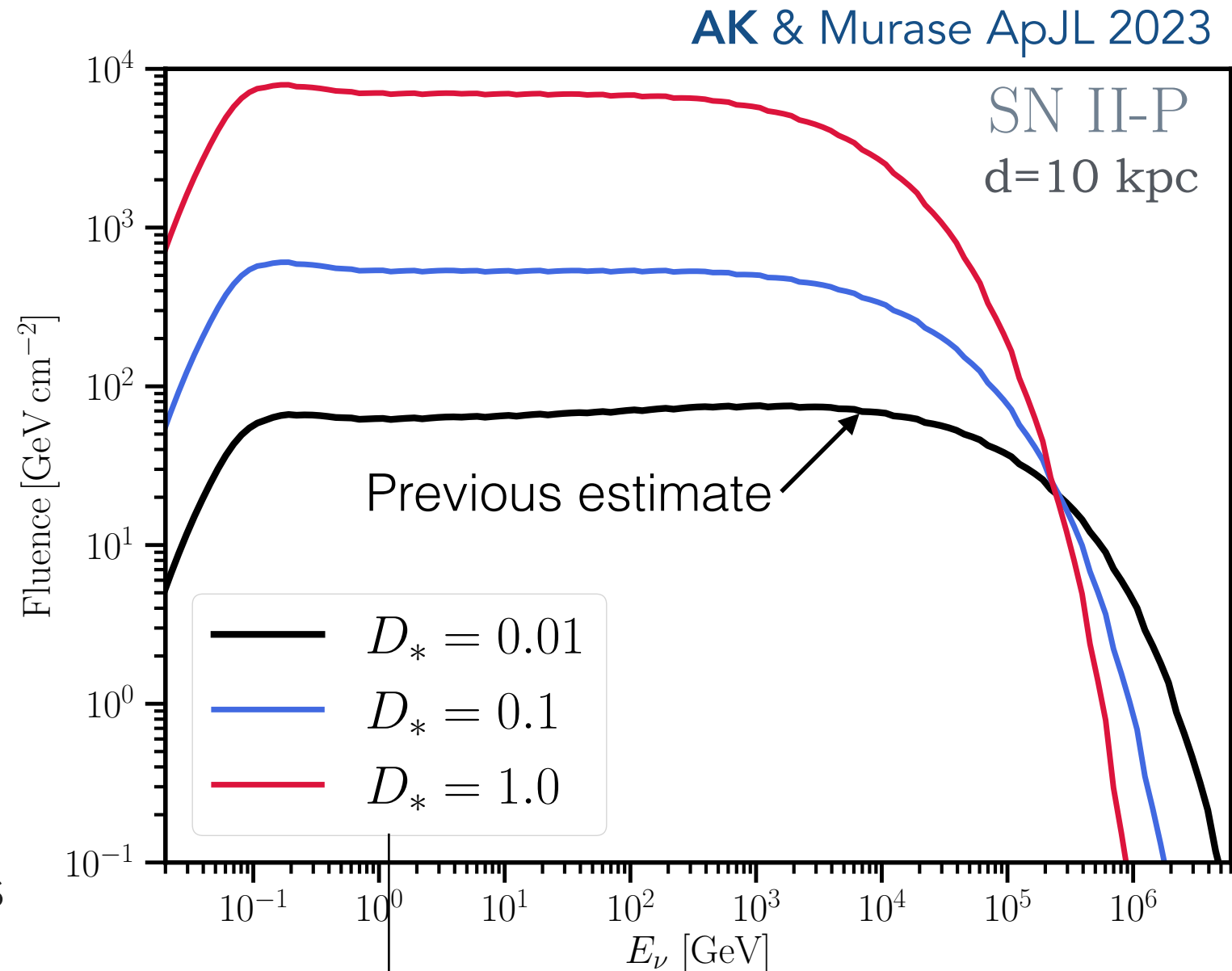
Neutrinos from Core Collapse Supernovae



- Observation of extragalactic SNe showed rapid significant mass loss in SN progenitor which leads to shock interaction with dense circumstellar material (CSM).
 - ▶ Shock interaction with CSM results in production of HE neutrinos!

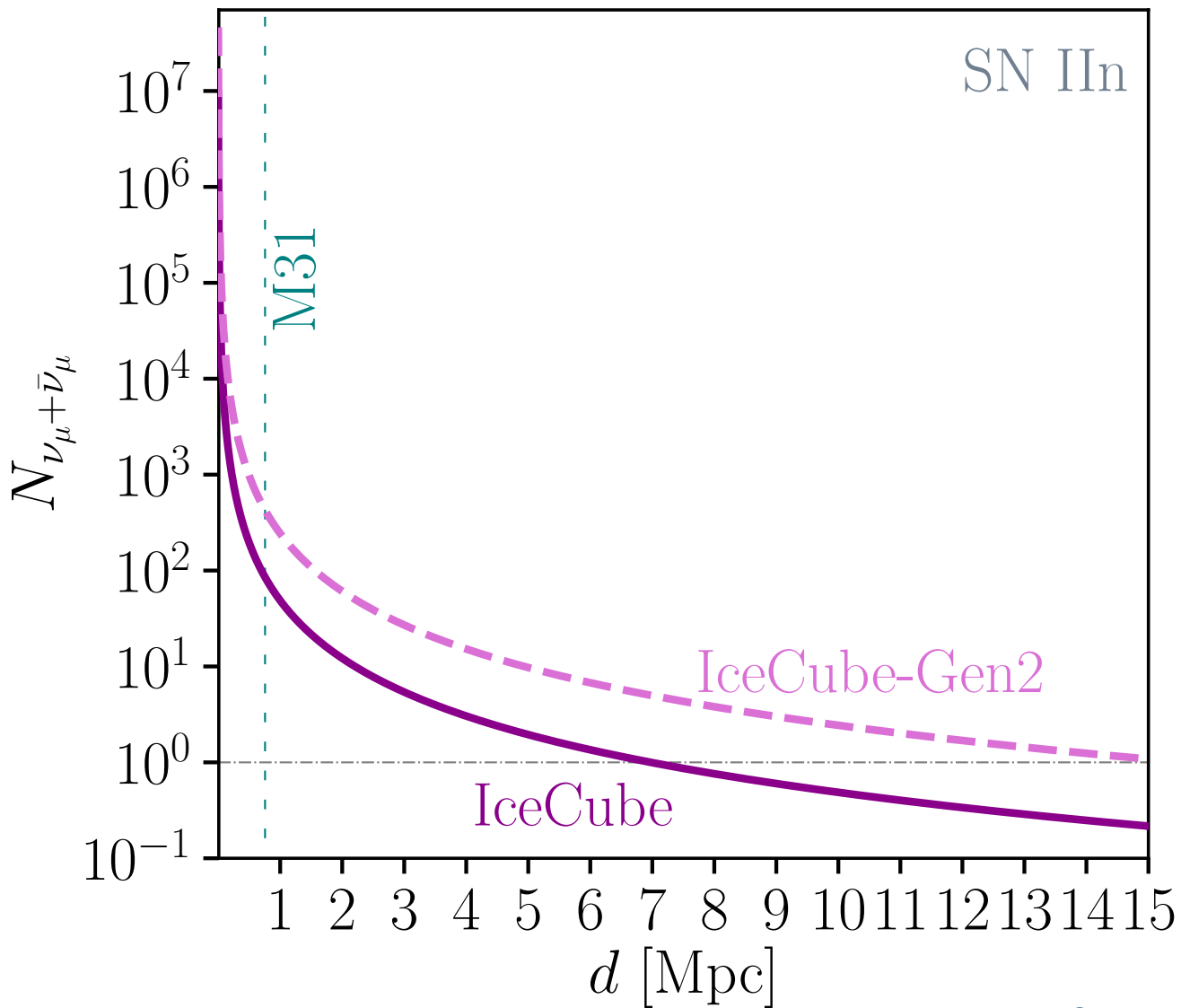
HE Neutrinos from SN II-P

- SN II-P is the most common type of core-collapse SN
- Progenitors are Red Super Giants.
- The level of the neutrino emission is generally lower than SN II_n but the higher rate increases the chance for observation.
- Recent observations suggests more efficient neutrino production [MOROZOVA+2018].
 - ▶ *Observation is more likely!*

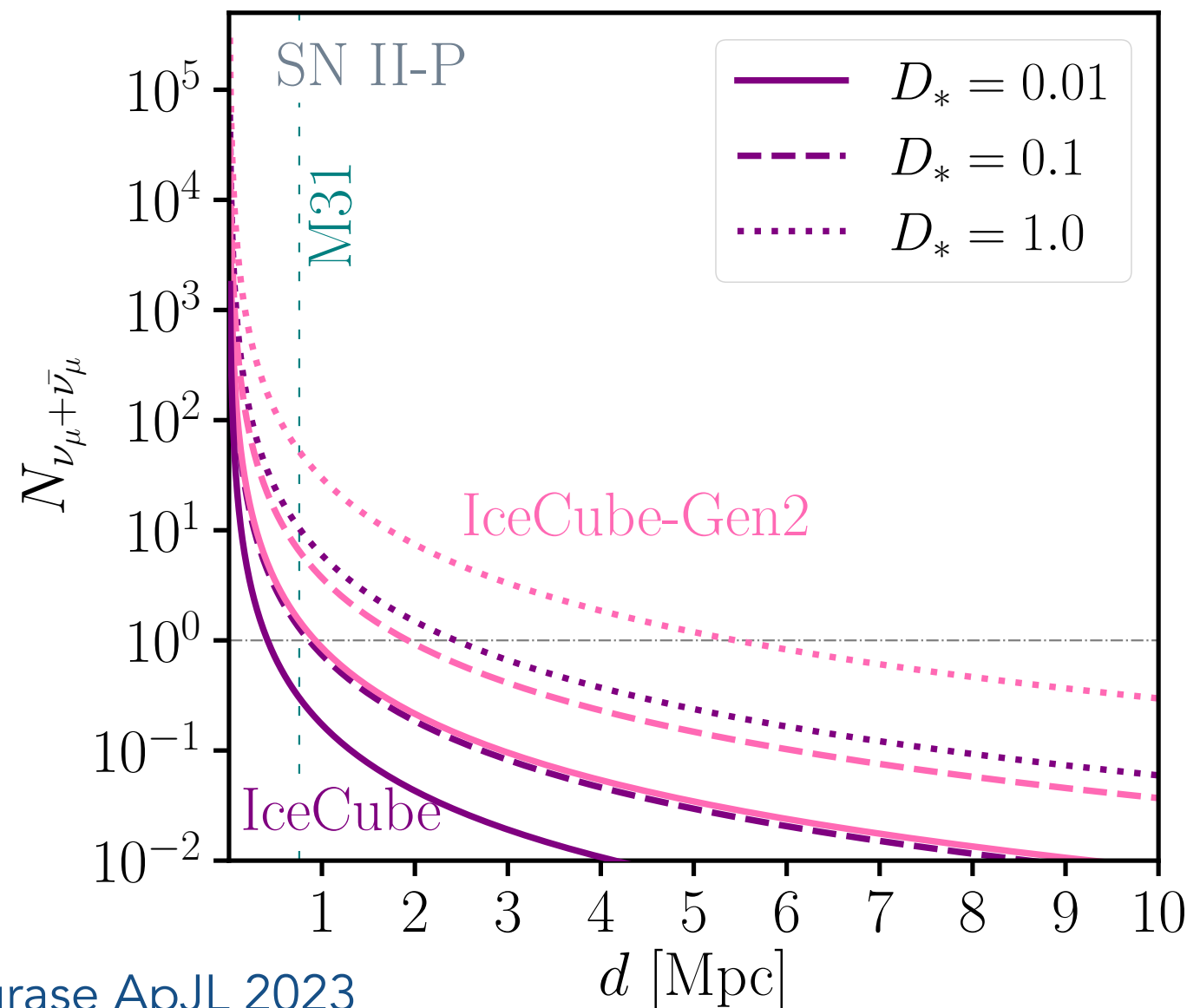


D^* parameterizes mass loss rate and wind velocity and is directly correlated with neutrino emission.

HE Neutrino Emission from CCSNe



AK & Murase ApJL 2023



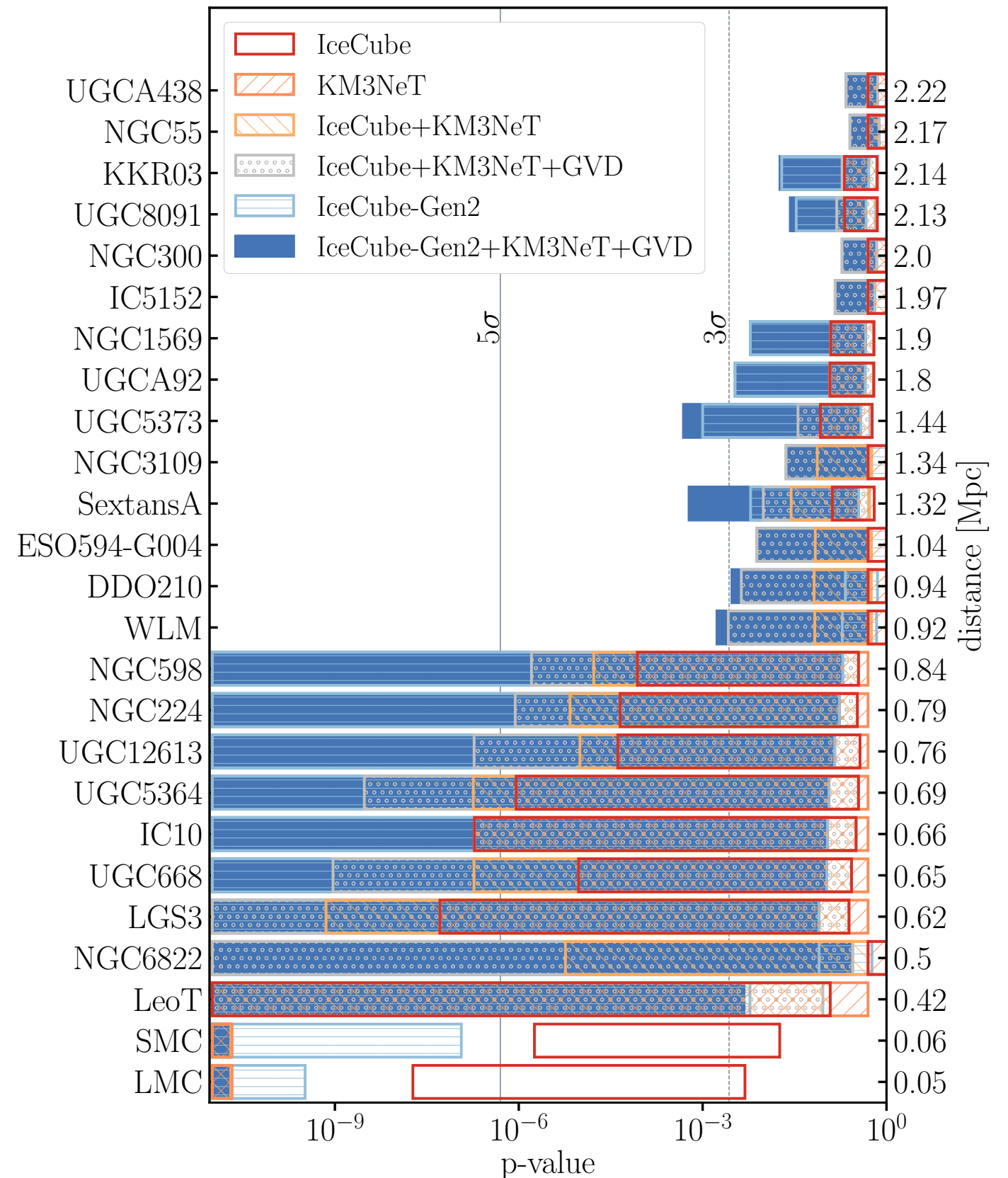
- Occurrence of SNe inside Milky Way would overwhelm neutrino telescopes with $> 10^7$ neutrinos within a year.
- The horizon for observation of neutrinos from SNe extends beyond our Galaxy.

HE Neutrino emission from SN II-P

► Local Galaxies

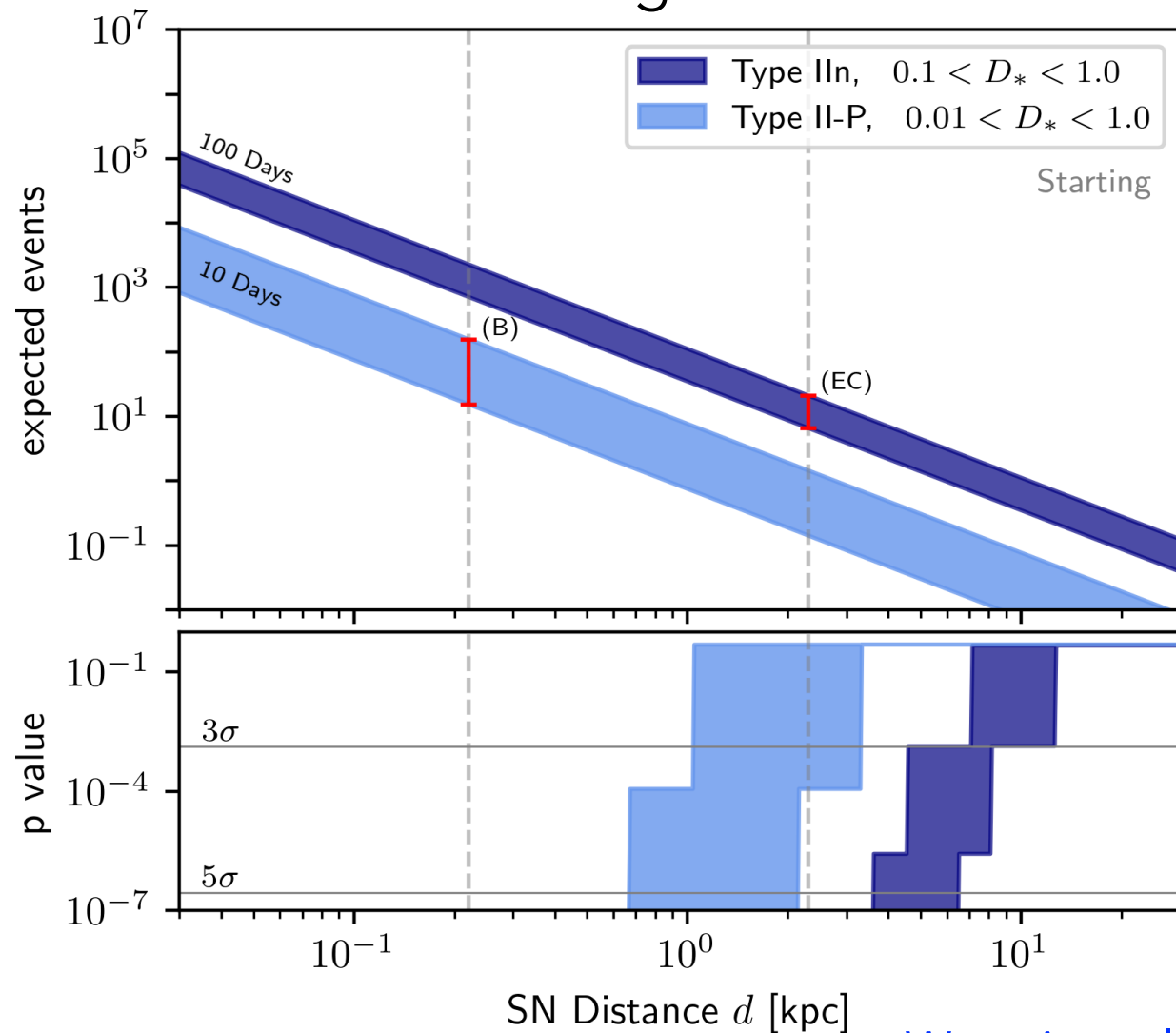
- HE neutrinos from close by sources (e.g. LMC & SMC) can be identified in current detectors.
- Joint analysis of data from upcoming neutrino telescopes in the Northern hemisphere will boost the sensitivity.
- Next generation of neutrino telescopes will push the horizon for identification of HE neutrinos from SN II-P to more than 2 Mpc.

AK & Murase ApJL 2023

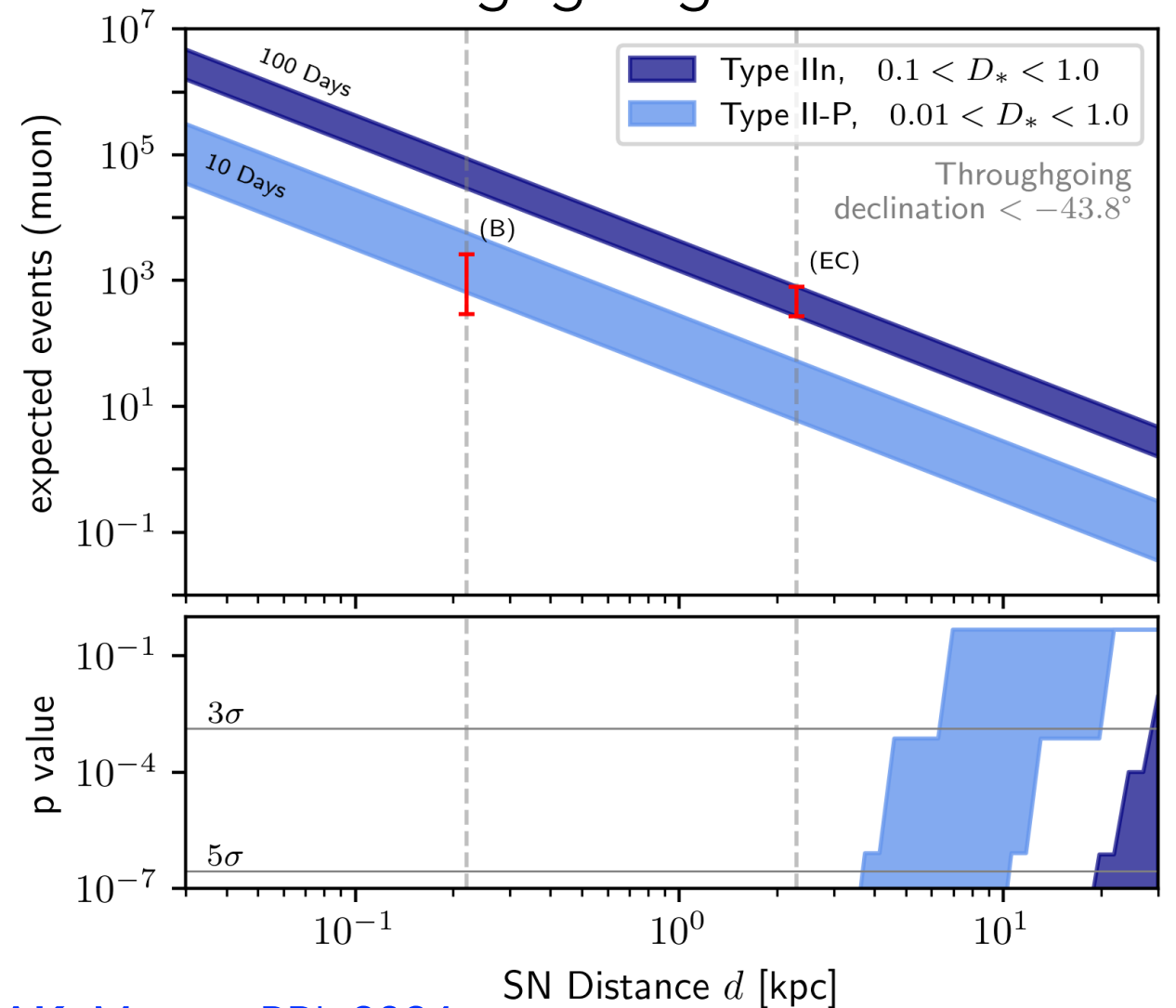


HE Neutrinos from SNe in ATLAS

Starting Events



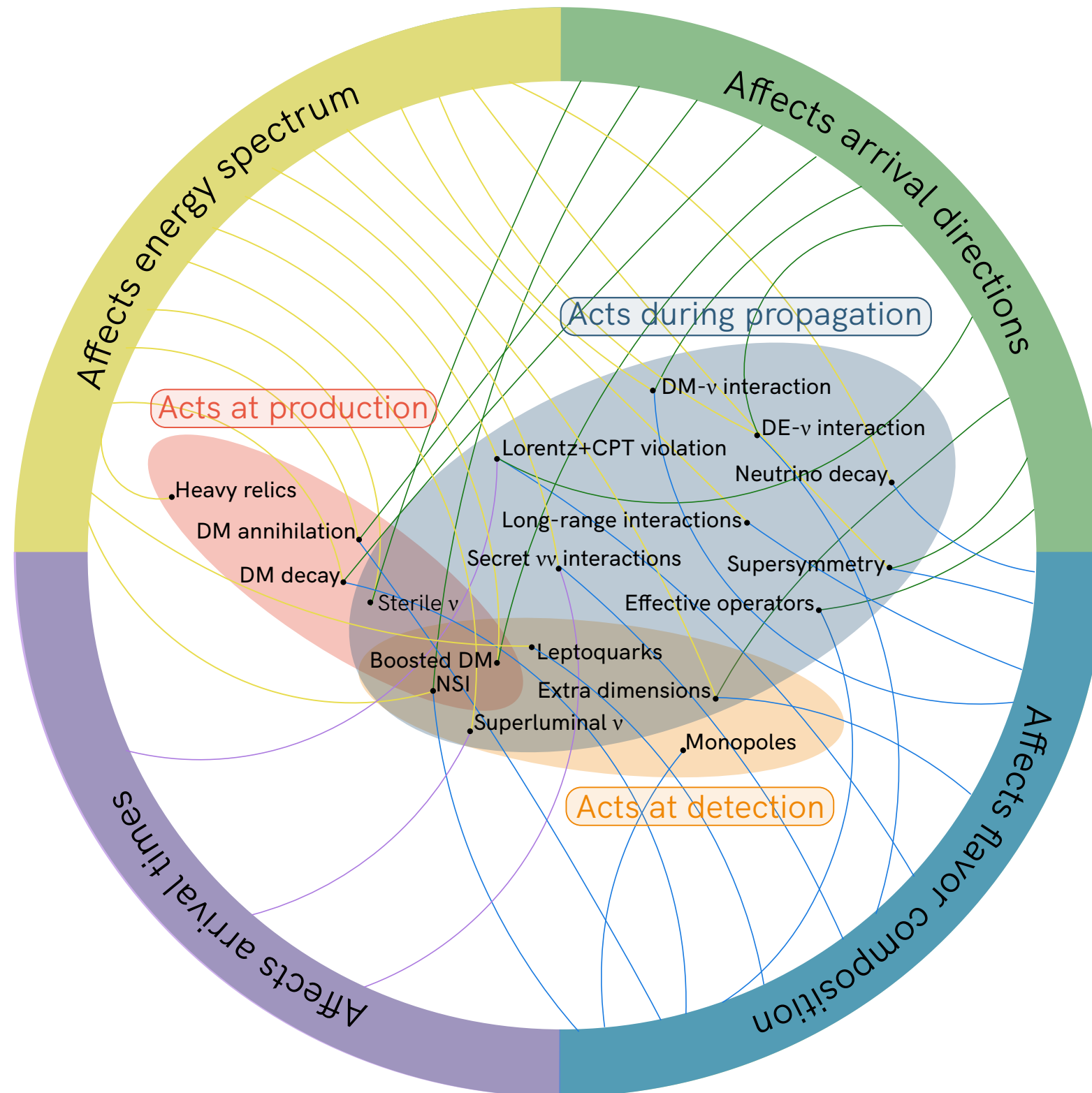
Throughgoing events



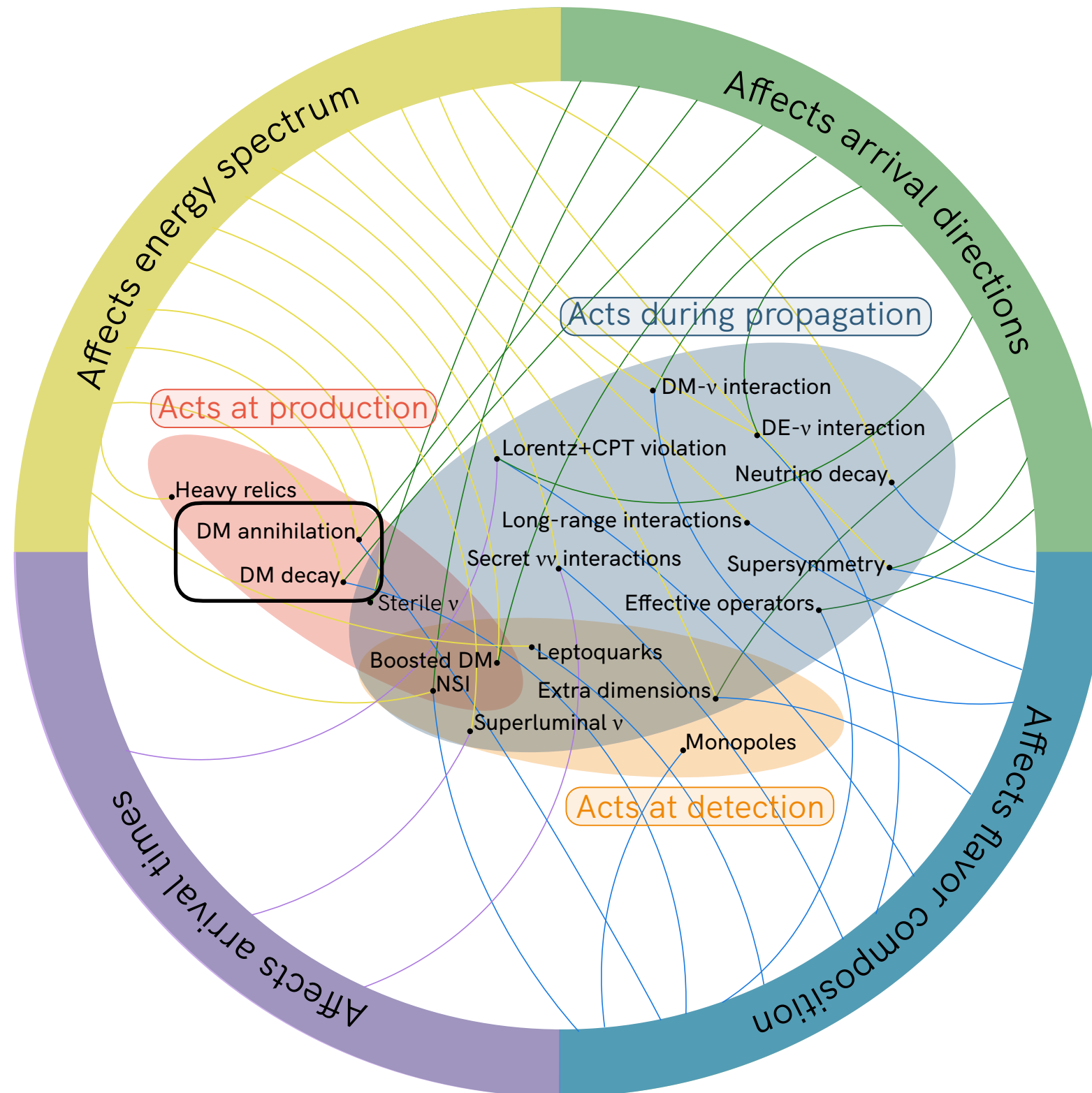
Wen, Arguelles, **AK**, Murase PRL 2024

- ▶ The high-level of neutrino flux from a Galactic Core-Collapse offers the opportunity to observe neutrinos in dense particle detectors.
- ▶ The precision of particle detectors yields a unique opportunity to study flavor physics.

New Physics and HE Cosmic Neutrinos



New Physics and HE Cosmic Neutrinos

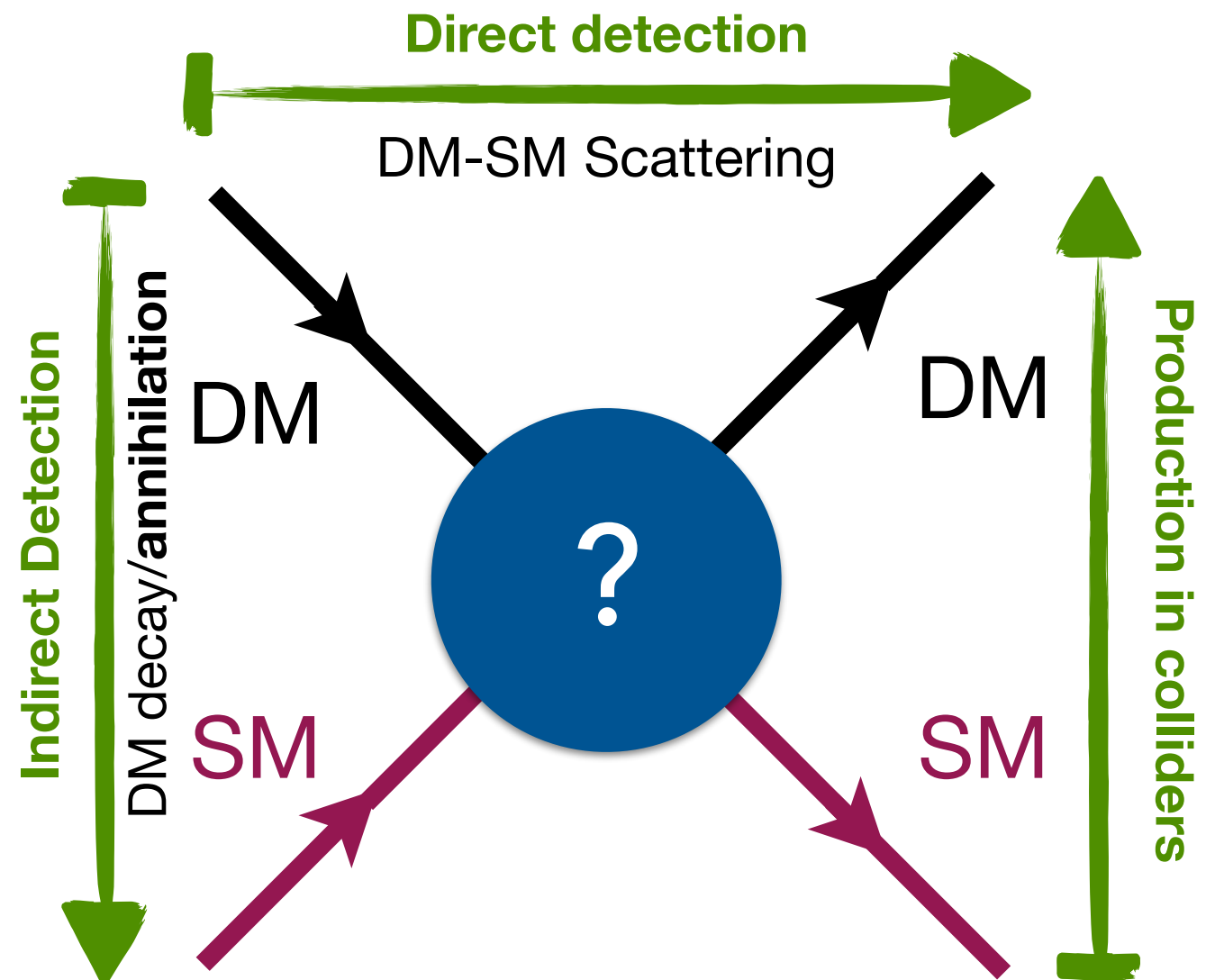


Why study new physics with HE neutrinos?

- 1 They have the highest energies (TeV-10s of PeV)
 - Probe physics at new energy scales
- 2 They have long baseline (diameter of the Earth-~Gpc)
 - Tiny effects can accumulate and become observable
- 3 They are weakly interacting & have unique quantum number (flavor)
 - Powerful tool to probe for new effects
- 4 High Statistics and complementarity

Neutrino Portal to Dark Matter

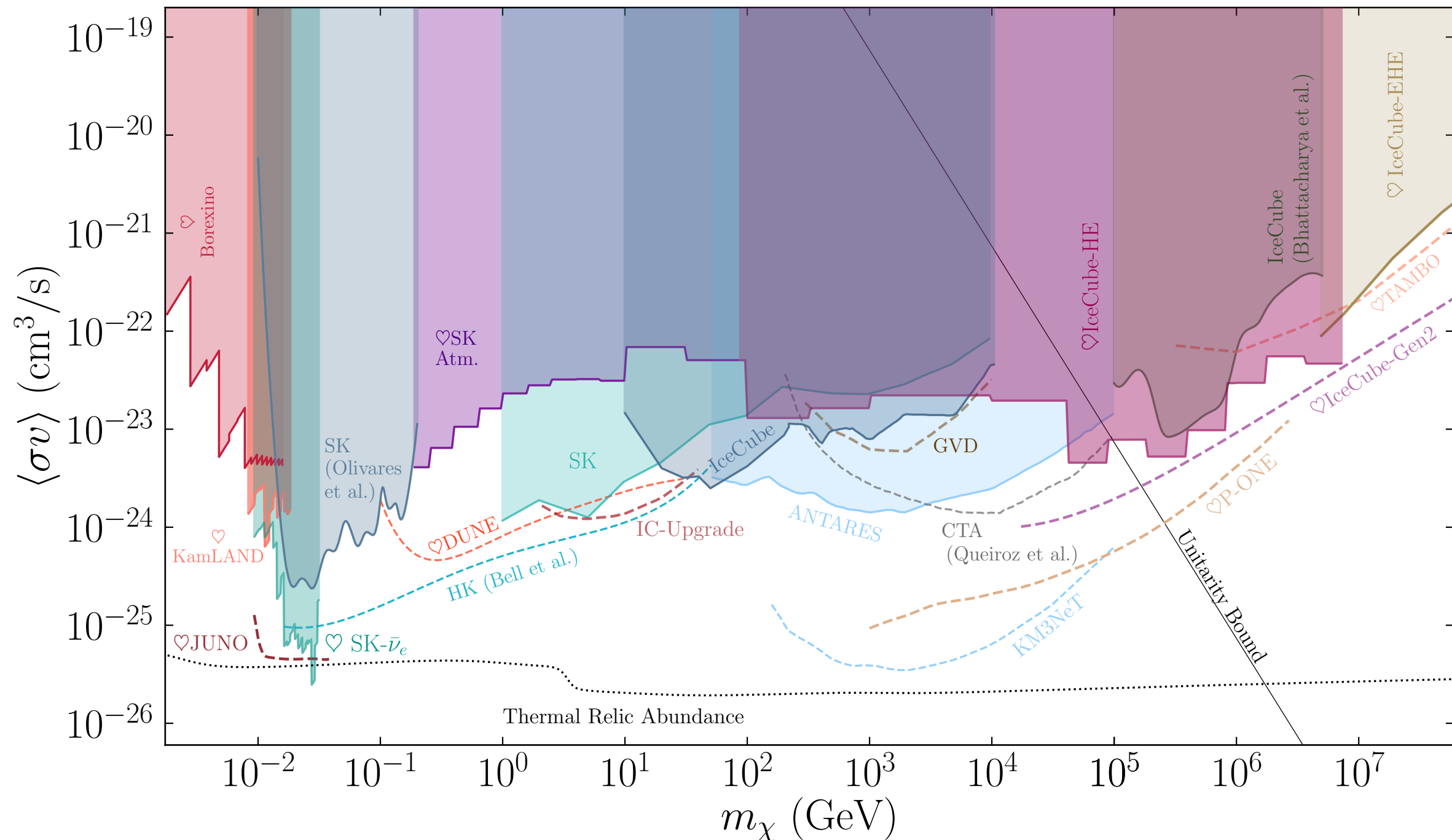
- Thermal production of WIMPs in early Universe implies possible ongoing self-annihilation of DM.
- Strongest constraints are in place from the absence of any signal in X-ray & gamma-rays from the Milky Way.
- Neutrino portal: *the most invisible channel*, hardest to detect, difficult to rule out!



Indirect Search for Dark Matter

► Dark Matter Annihilation

Argüelles, Diaz, AK +, Rev.Mod. Phys. 2022.

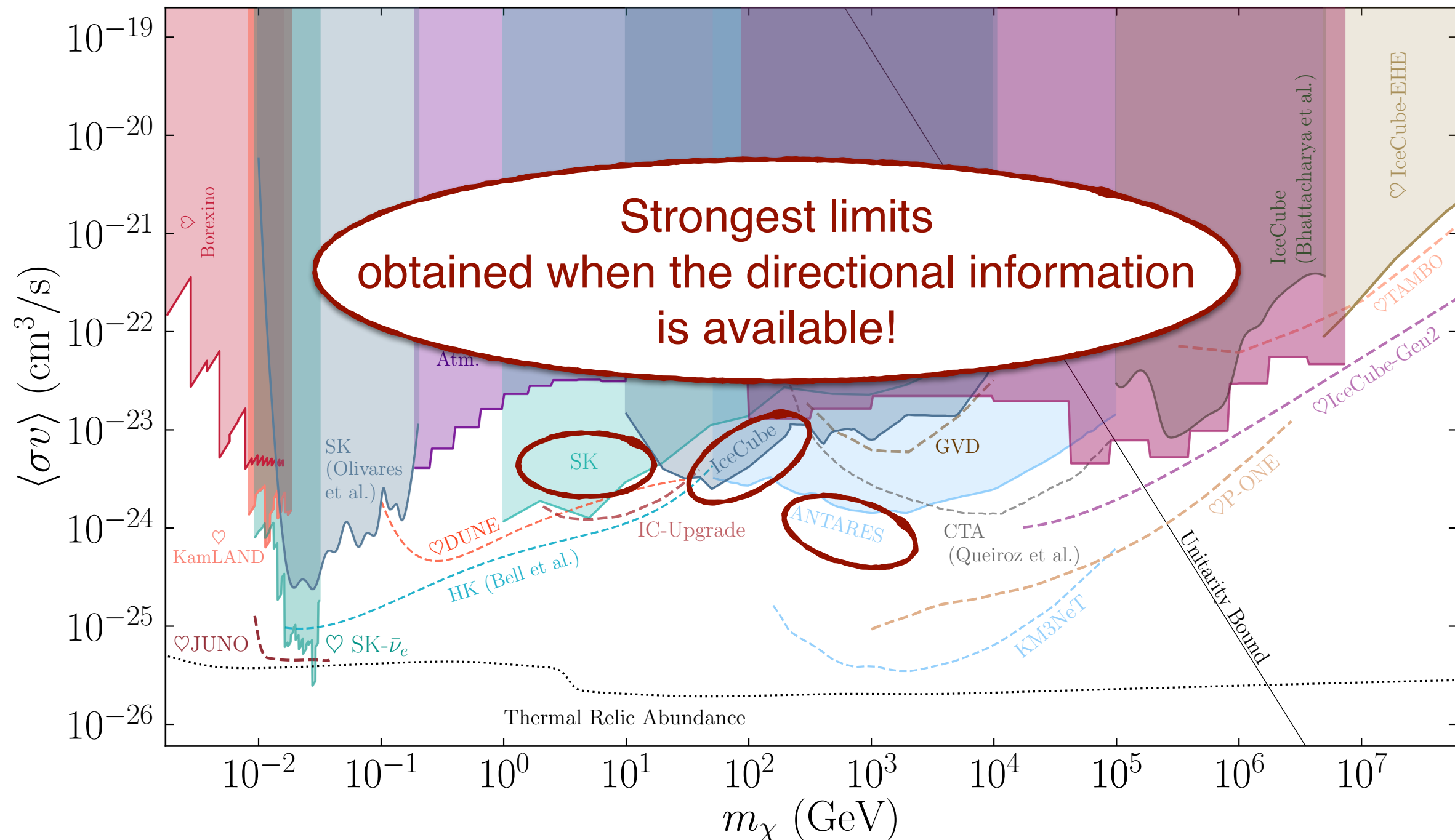


Upper limit on DM annihilation to neutrinos serves as an upper bound to DM annihilation to SM [Beacom+2007].

Indirect Search for Dark Matter

► Dark Matter Annihilation

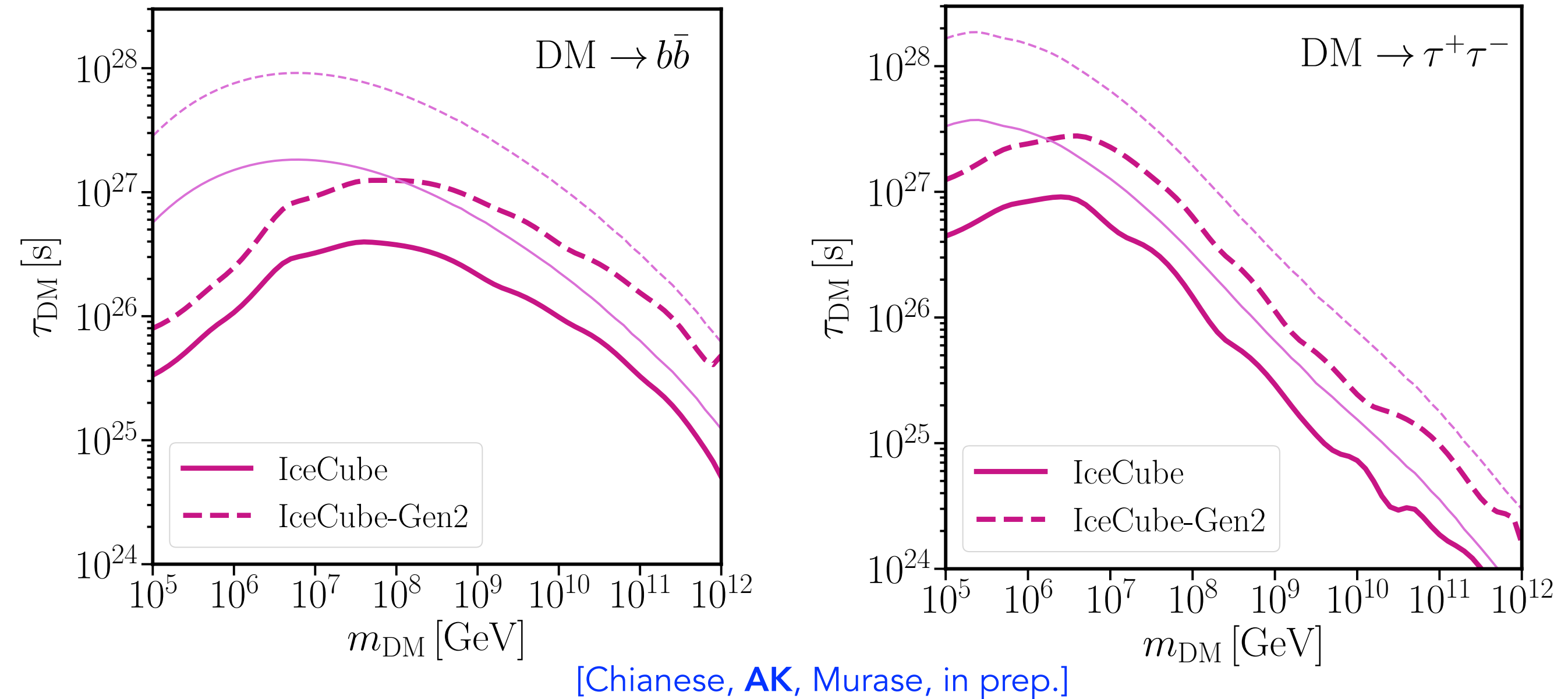
Argüelles, Diaz, AK +, Rev.Mod. Phys. 2022.



Upper limit on DM annihilation to neutrinos serves as an upper bound to DM annihilation to SM [Beacom+2007].

DM Signal from Galaxy Clusters

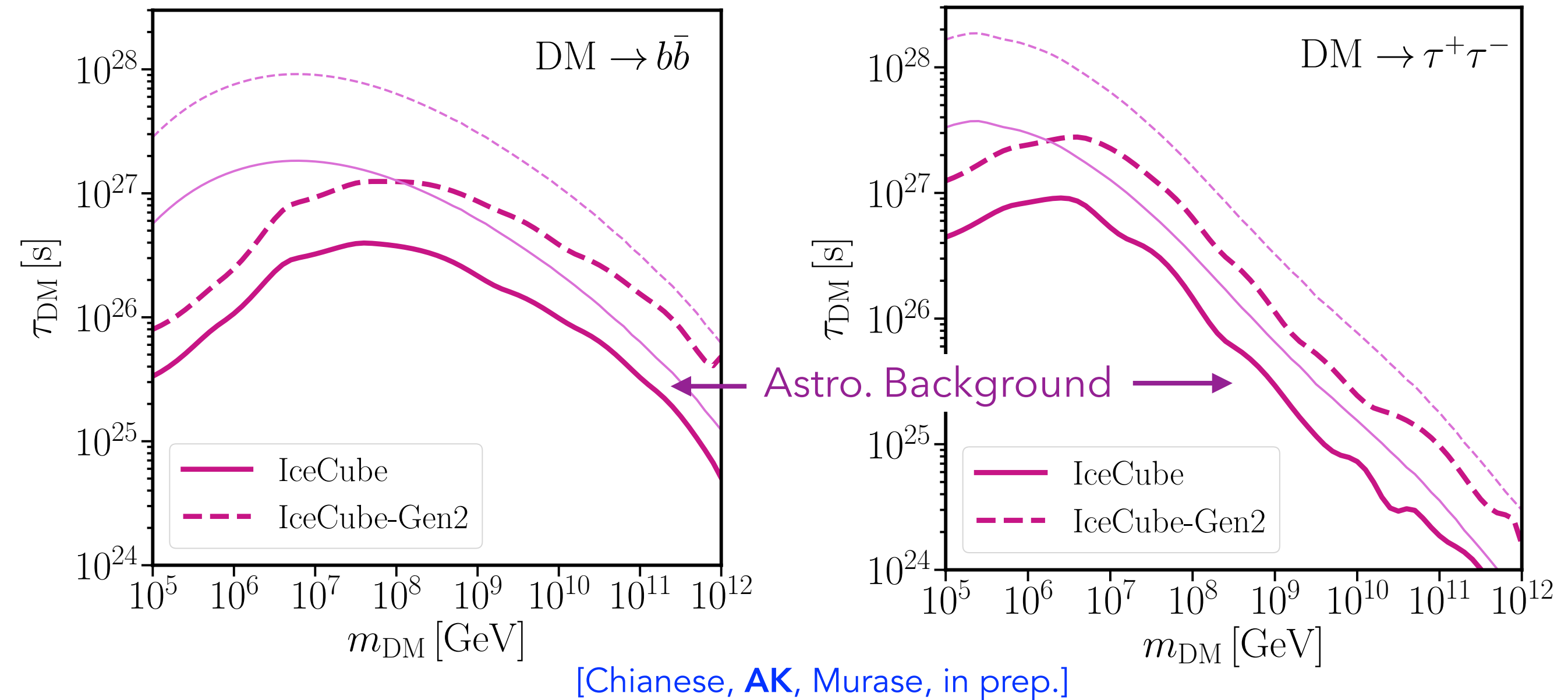
► Virgo Cluster



In the Gen2-era, stacking with more clusters can overcome diffuse limits.

DM Signal from Galaxy Clusters

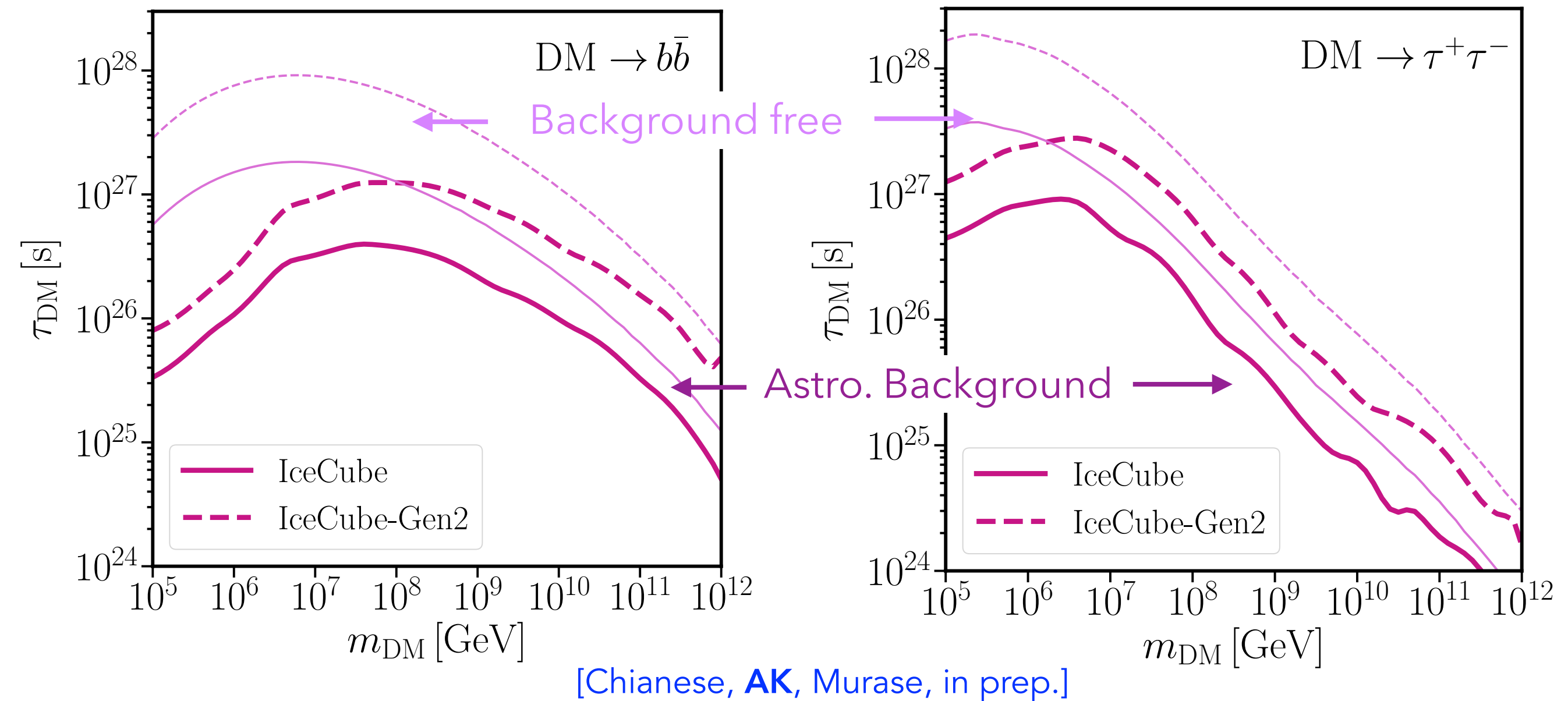
► Virgo Cluster



In the Gen2-era, stacking with more clusters can overcome diffuse limits.

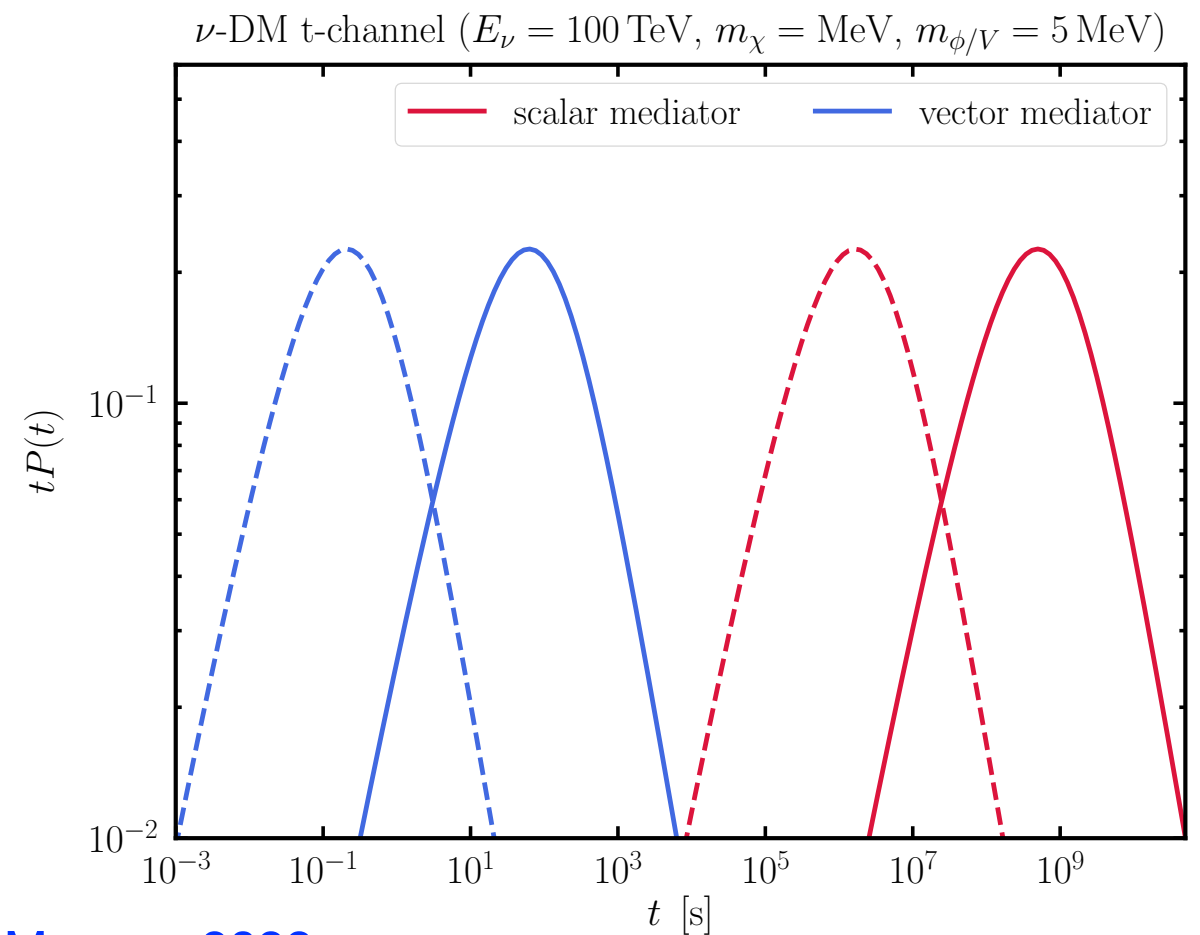
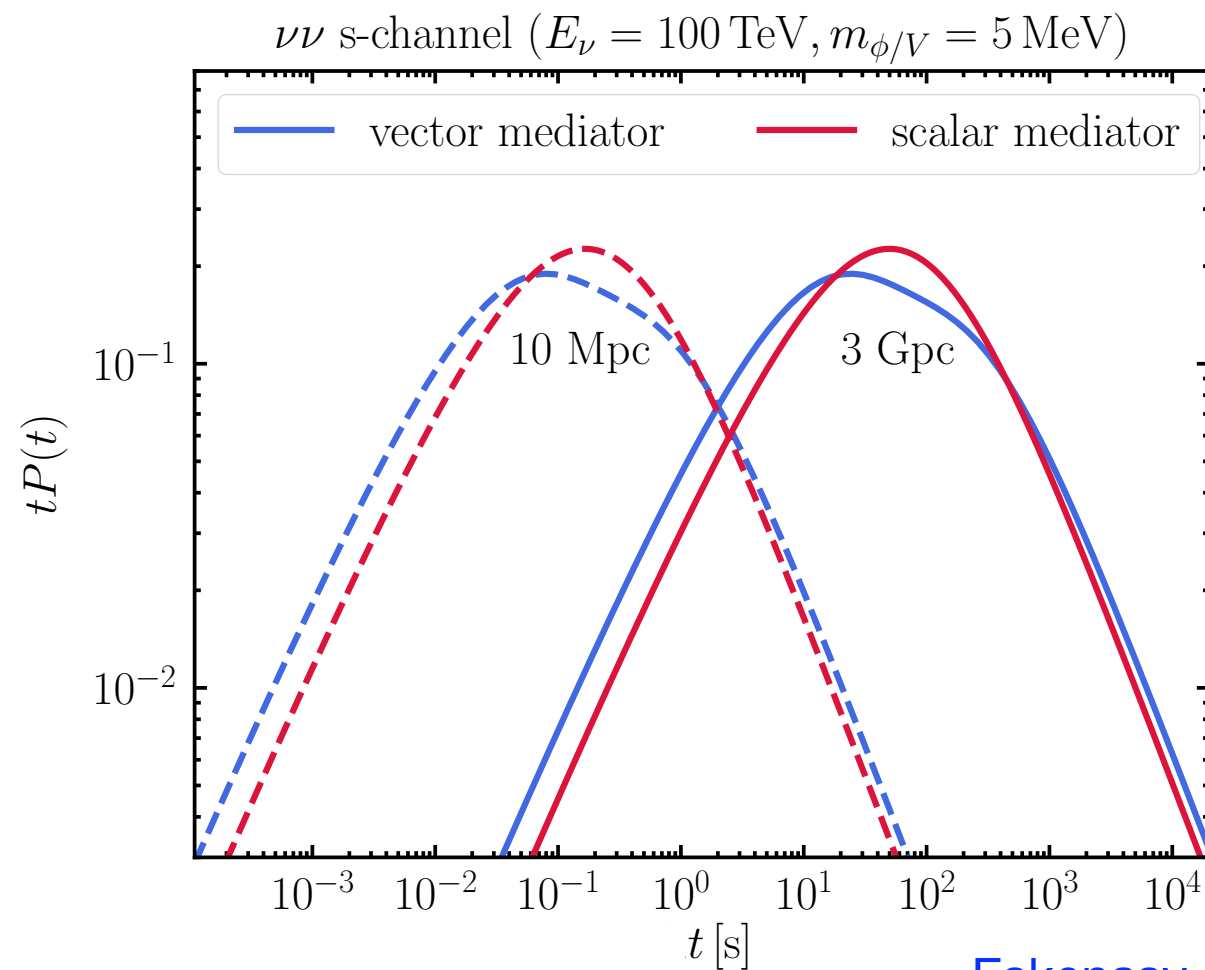
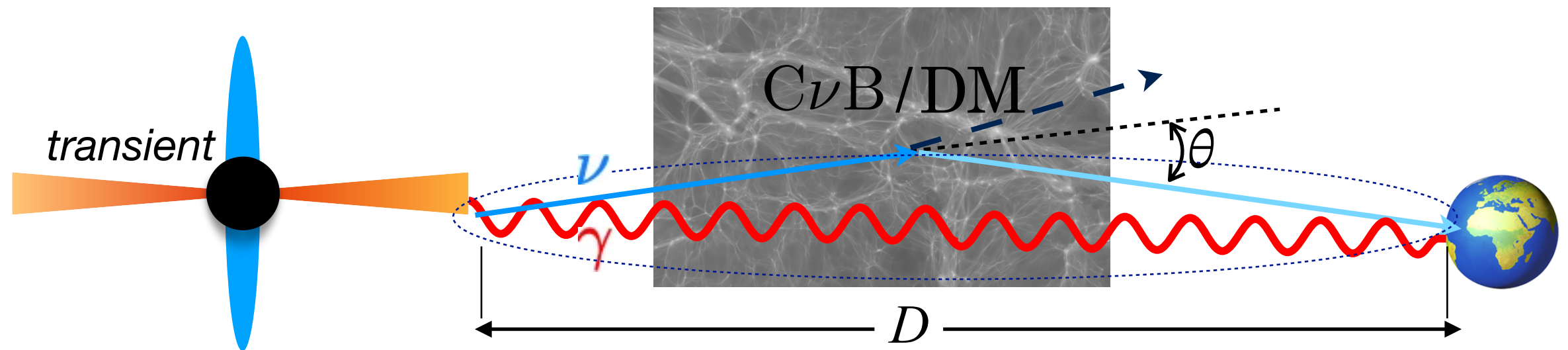
DM Signal from Galaxy Clusters

► Virgo Cluster



In the Gen2-era, stacking with more clusters can overcome diffuse limits.

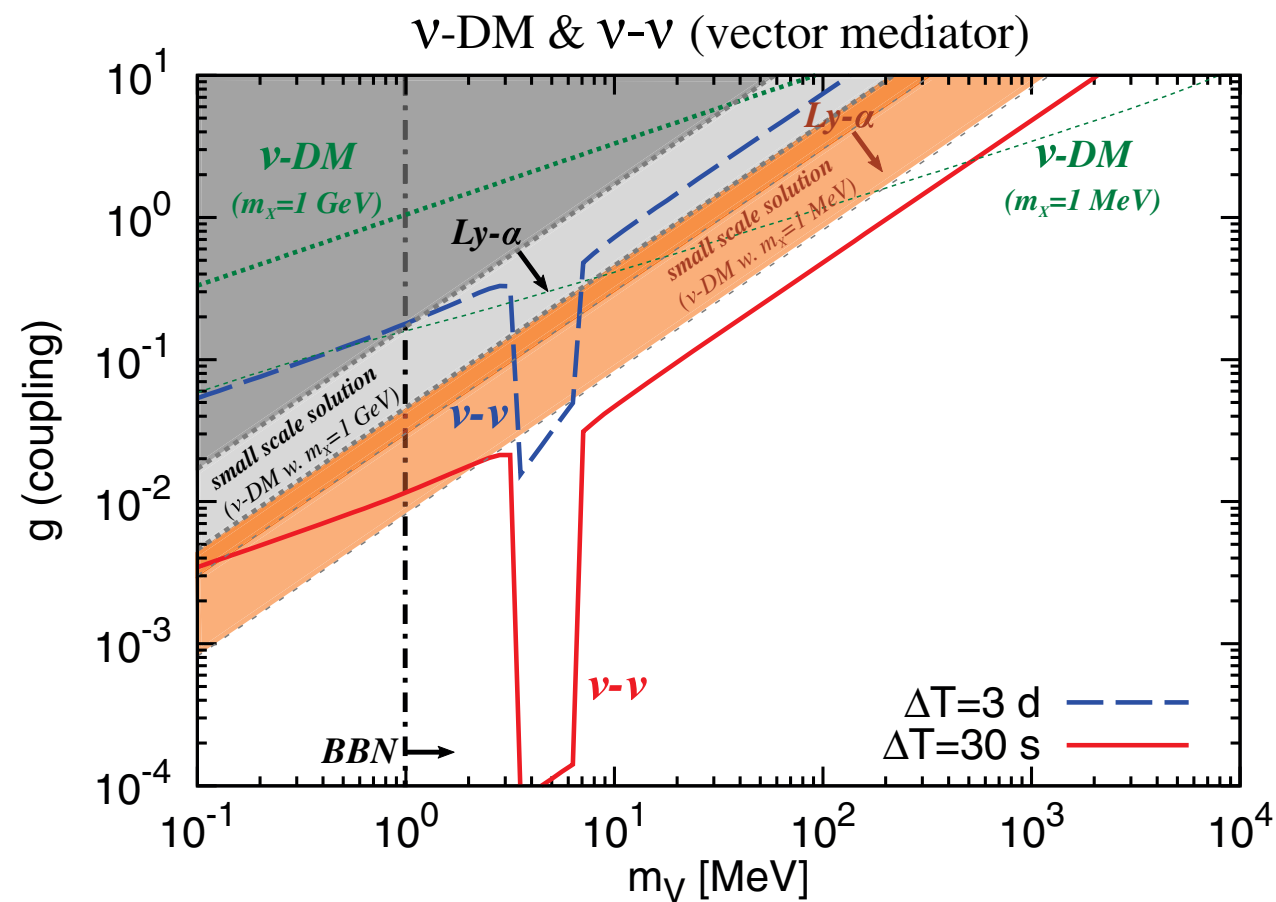
BSM-induced Time Delay



Eskenasy, AK, Murase, 2022

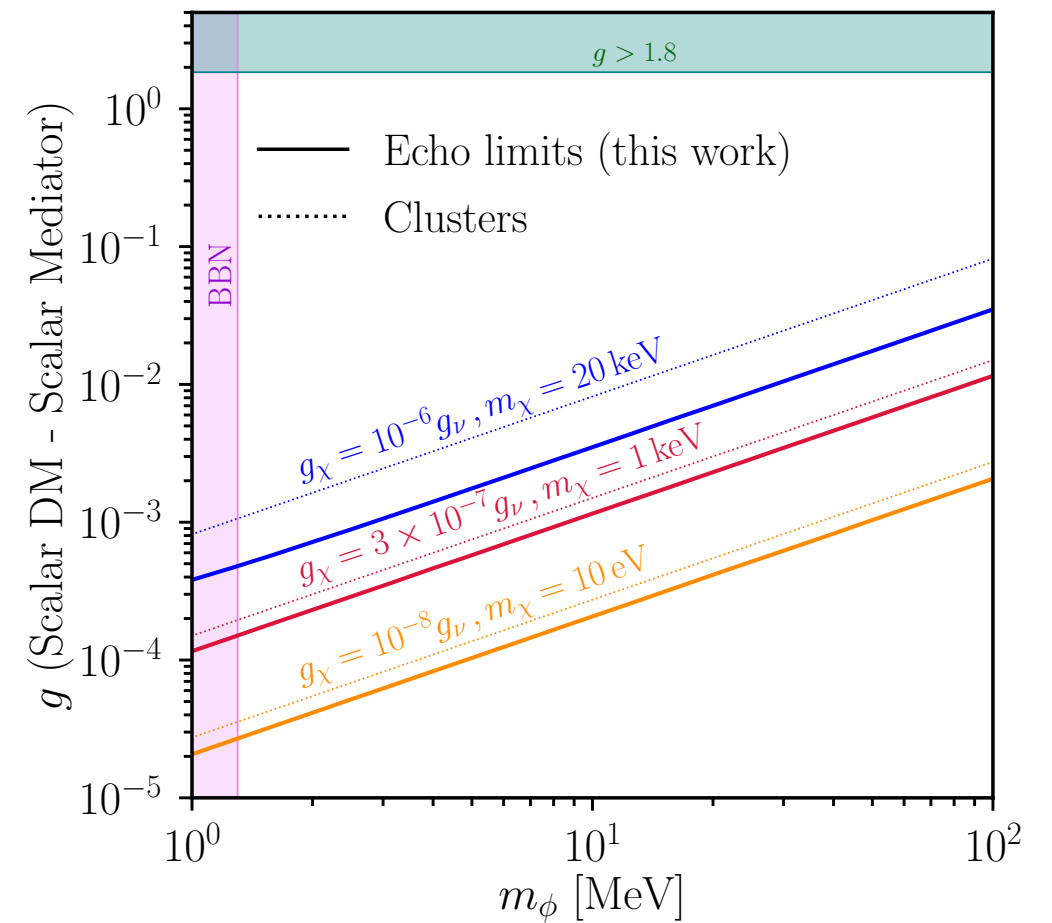
Constraining ν interactions

Blazar flares
100 TeV neutrinos
IceCube



Murase & Shoemaker 2019

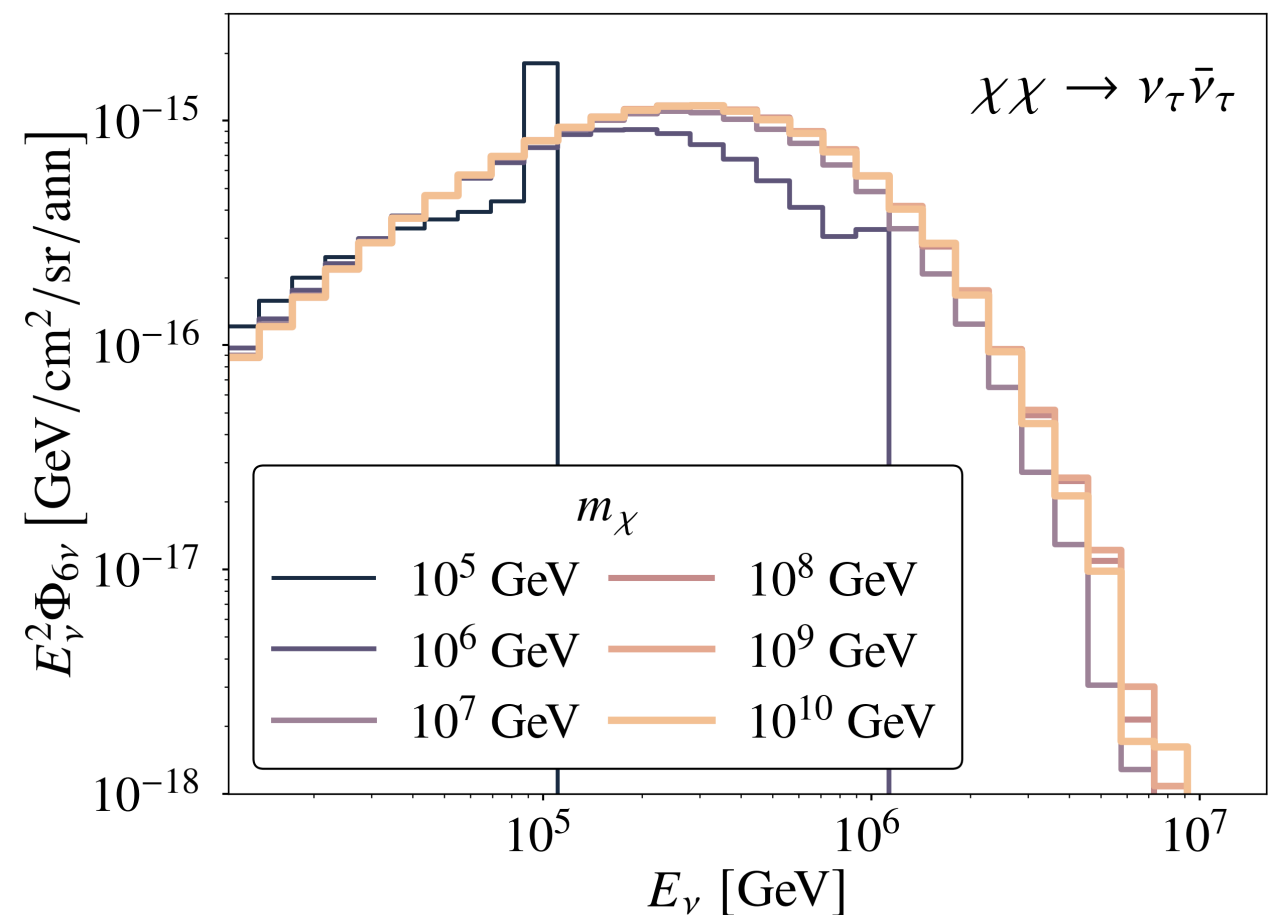
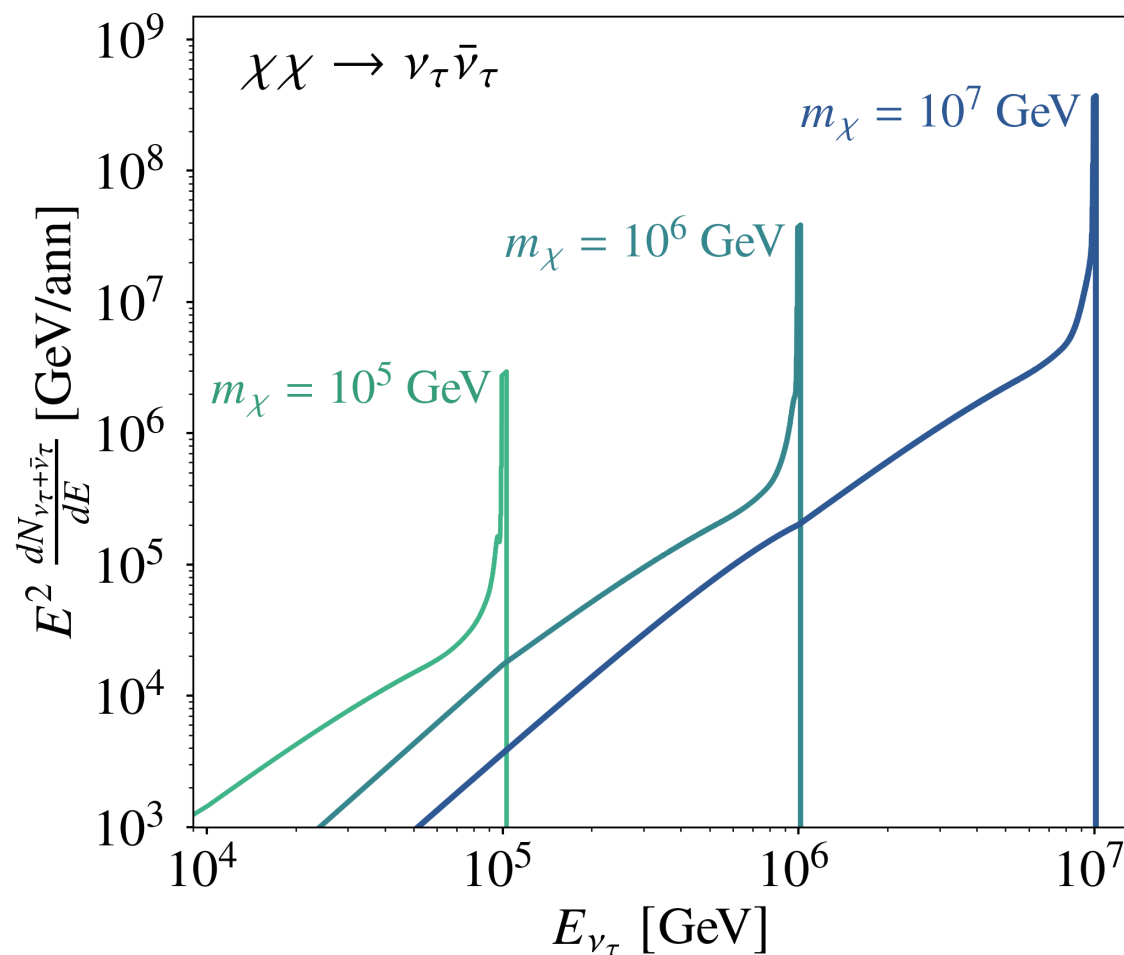
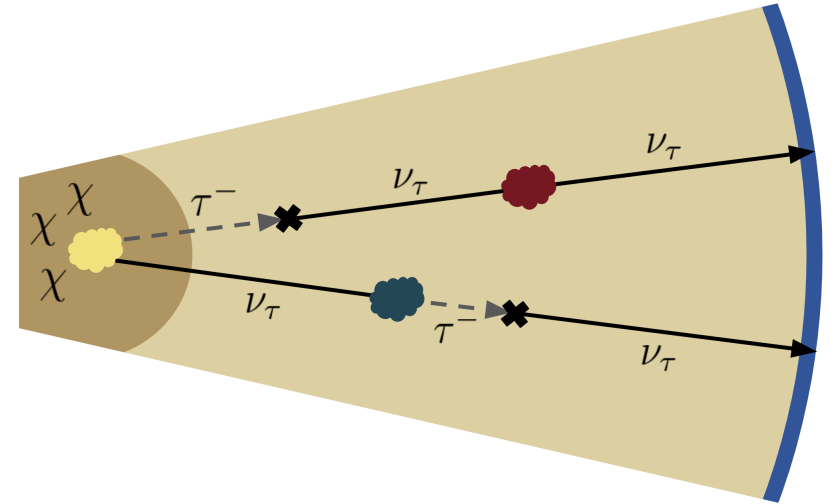
Core Collapse SN
15 MeV neutrinos
Hyper-K



Carpio, AK, Murase JCAP 2022

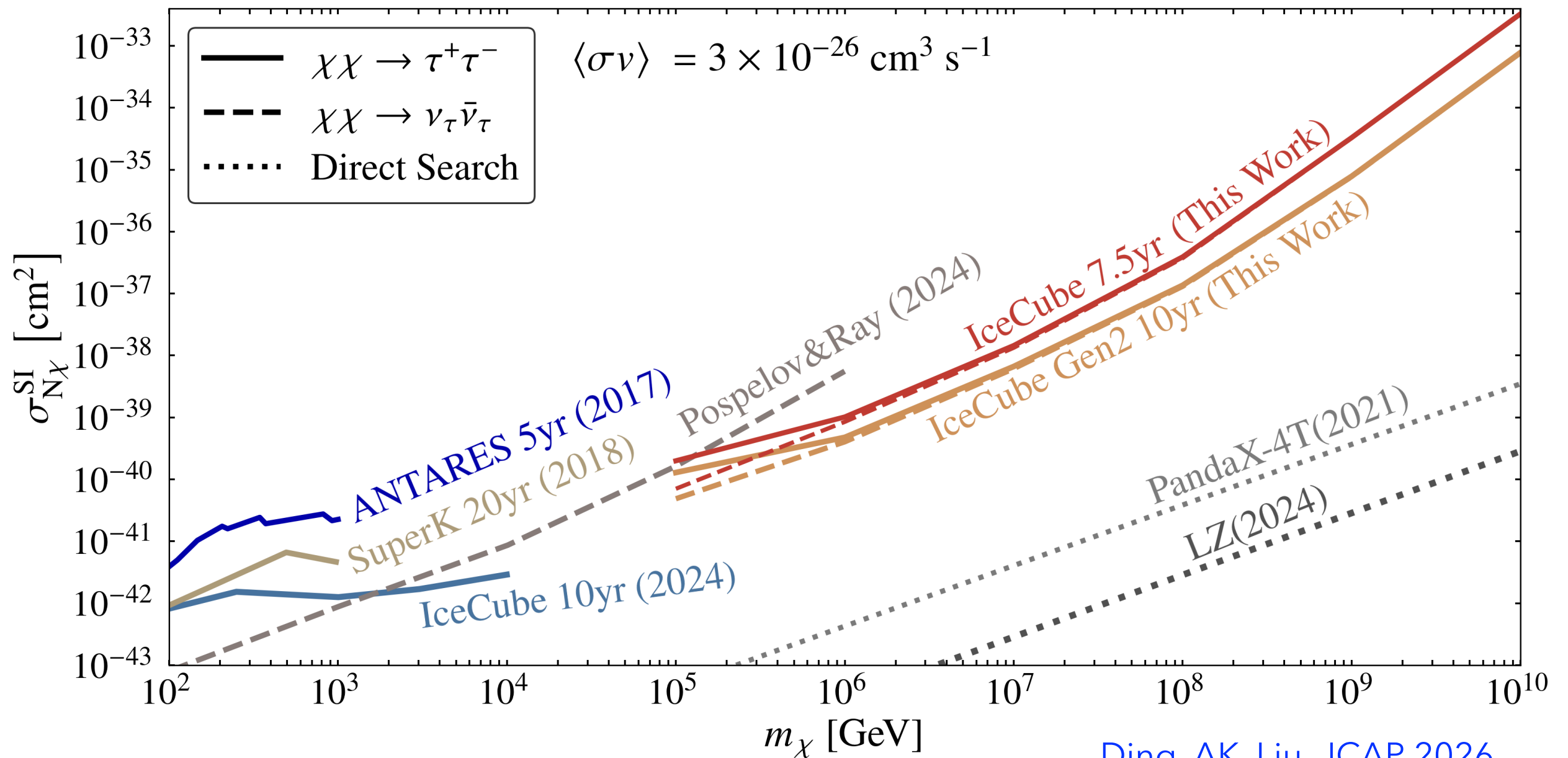
Tau neutrinos & VHDM in the Earth

- ▶ The Earth becomes opaque to very-high-energy neutrinos, limiting neutrino searches for DM from Earth to 10 TeV.
- ▶ At $> \text{PeV}$ energies, tau regenerations produces a pile up of events at TeV—PeV energies.



Tau neutrinos & VHDM in the Earth

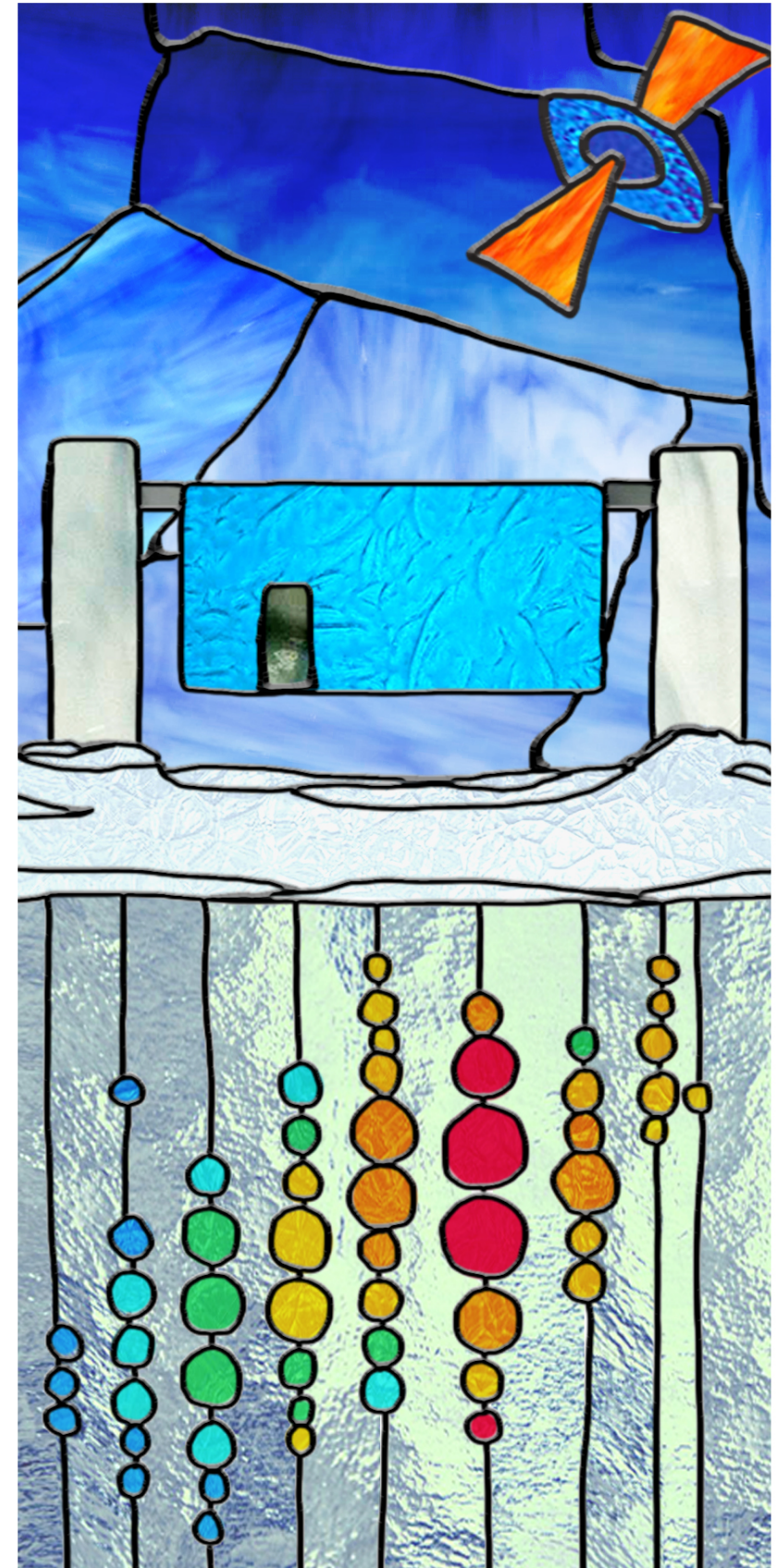
- Neutrino telescope operating in $> \text{TeV}$ energies can probe VHDM, providing indirect search for Earth DM.



Ding, AK, Liu, JCAP 2026

Summary

- After a decade of observation, signs of anisotropy are emerging in IceCube data.
 - ▶ Early indications points to AGN as primary source of high-energy cosmic neutrinos.
 - ▶ Features in the measured cosmic neutrino flux point to different population of sources contributing at medium and high-energies
 - ▶ Neutrino Telescopes are closing in on the Galactic sources of HE neutrinos.
 - ▶ Core collapse supernovae can contribute to the cosmic neutrino flux and identification of HE neutrinos from them can provide realtime probe of particle acceleration.
 - ▶ Identification of the origin of HE neutrinos offers new opportunities in understanding dark matter and physics beyond the Standard Model

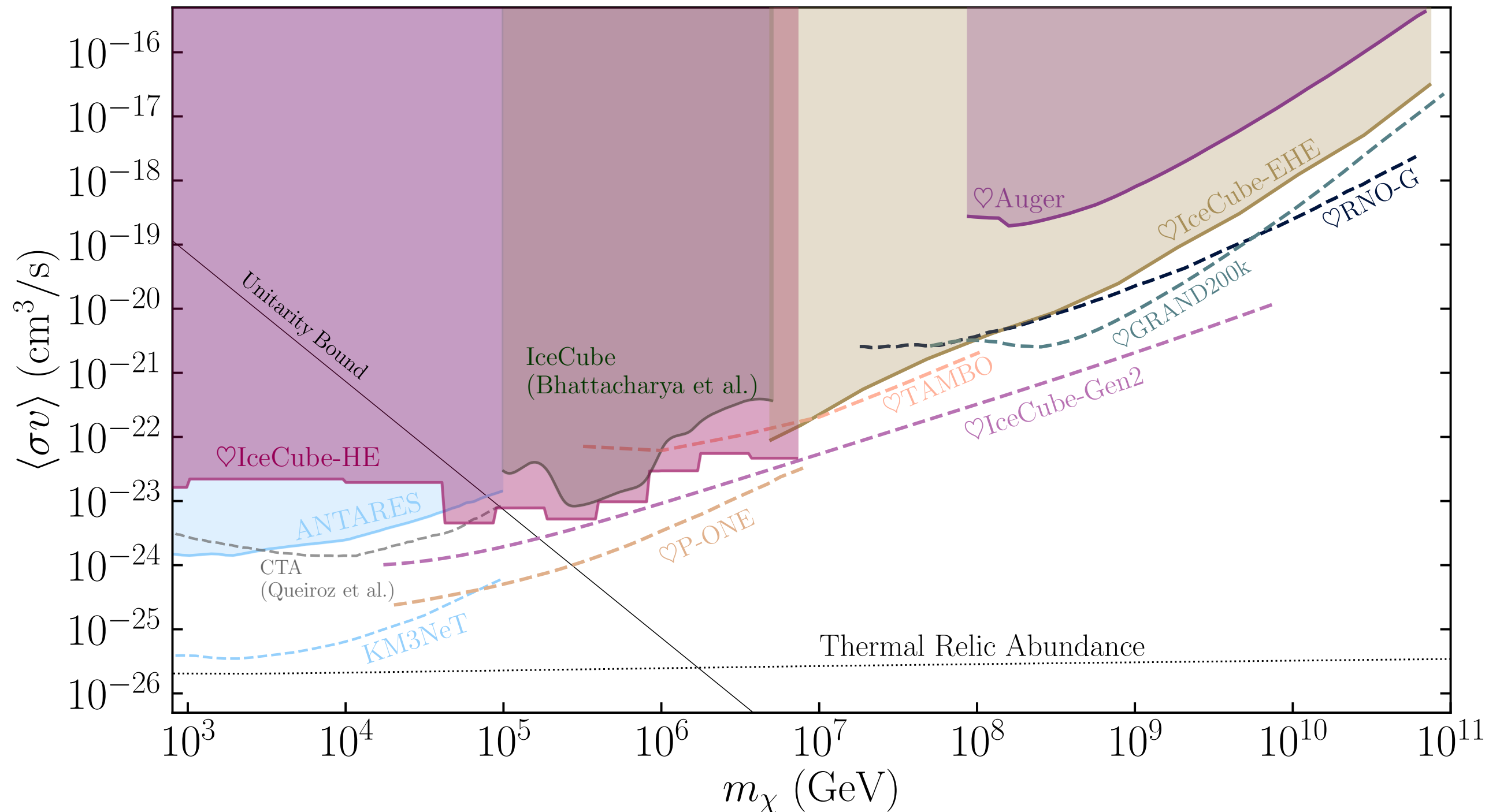


Thanks!

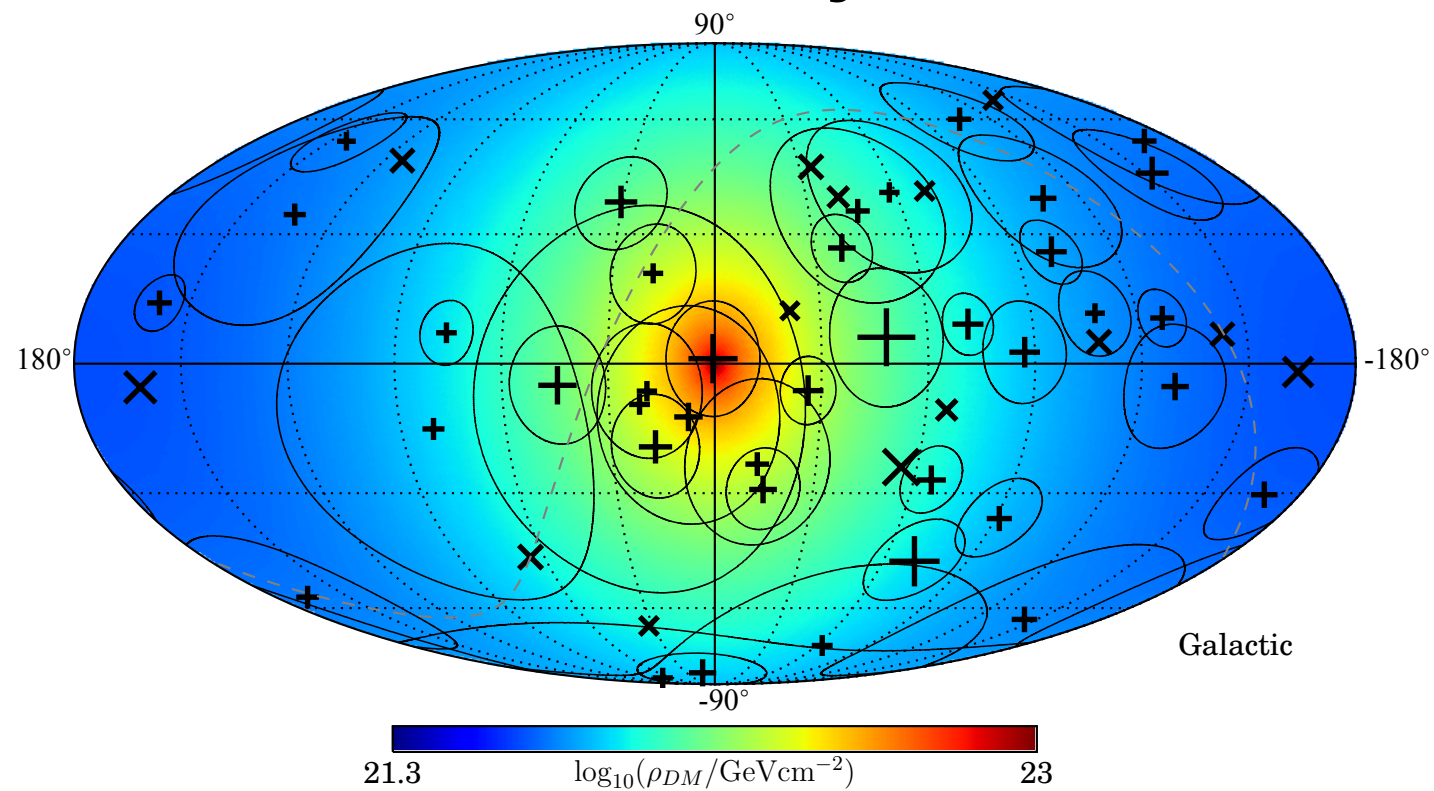
Back up Slides

Constraining the DM parameter space

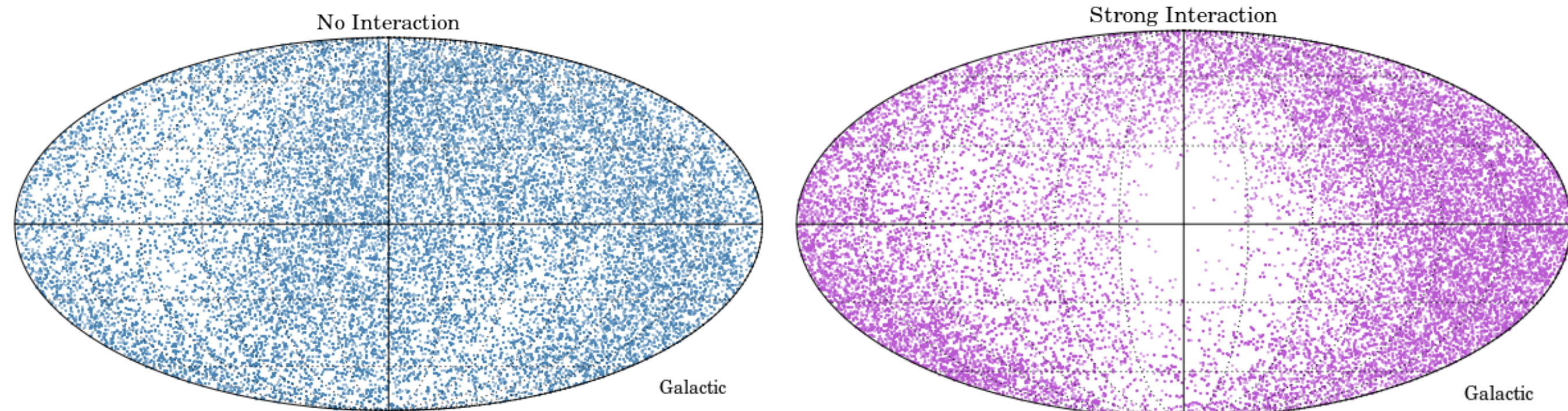
- High Mass (only accessible to neutrinos)



Dark matter column density* seen from Earth

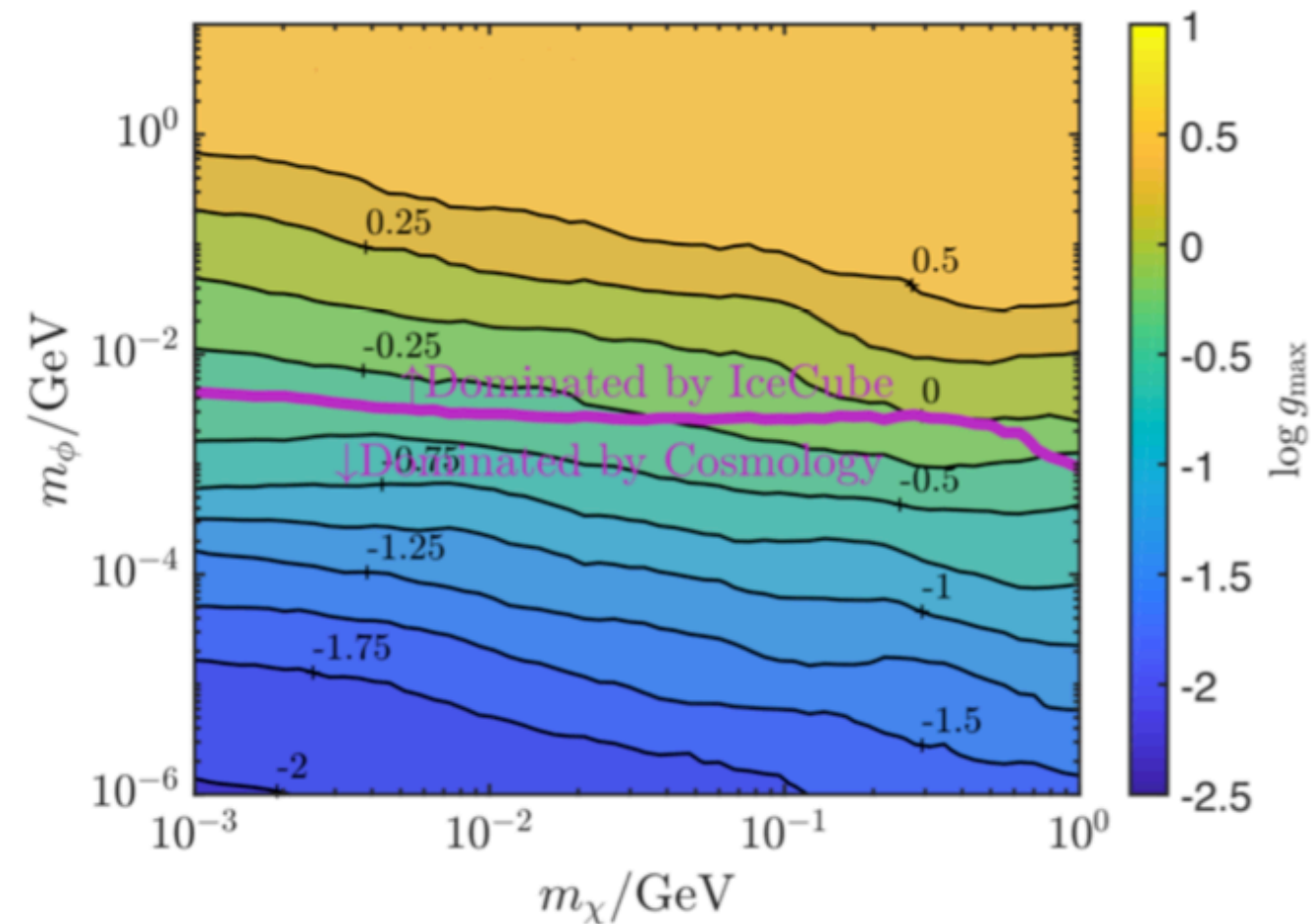


Simulation including effects of detector, Earth

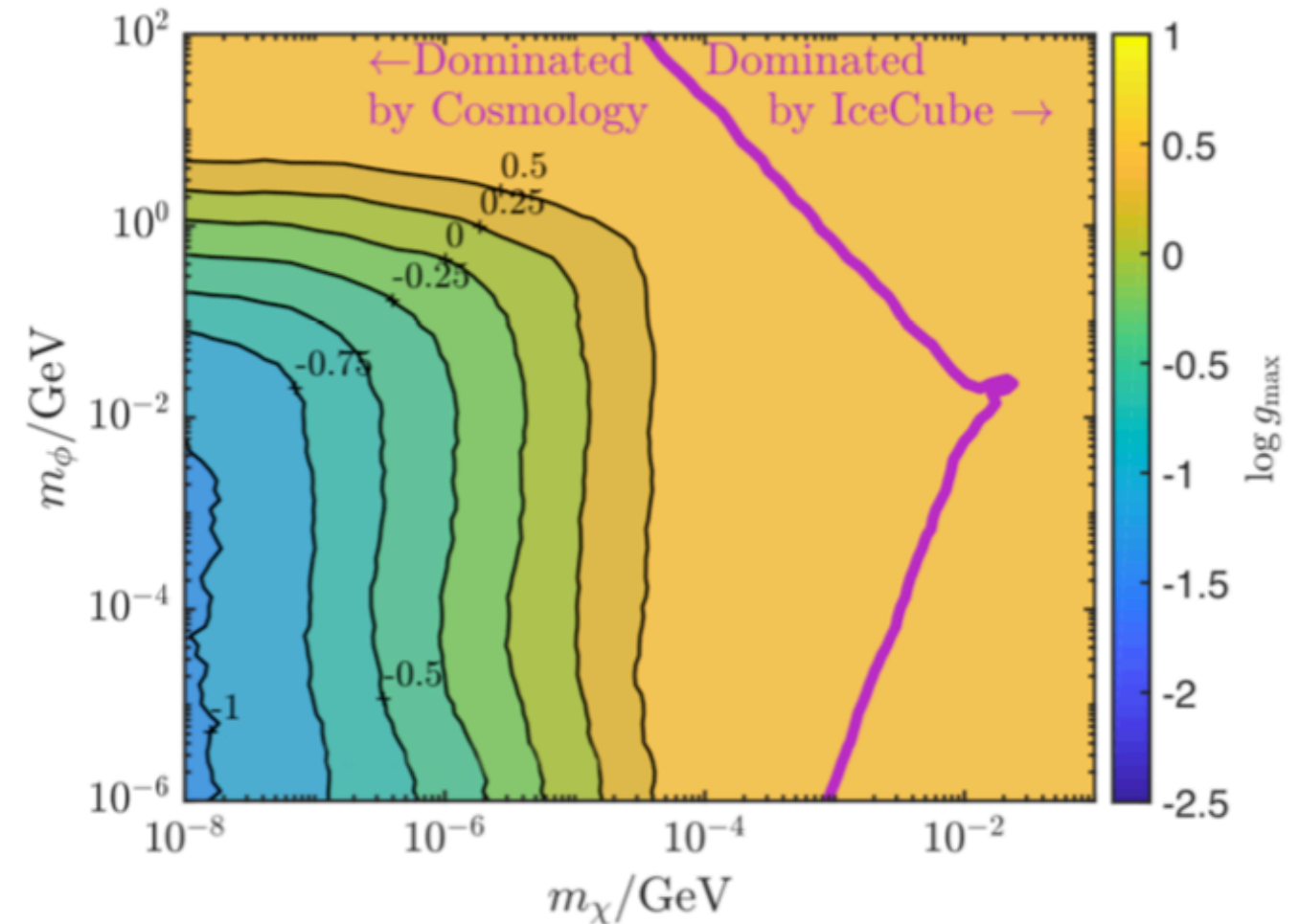


Constraints on DM-Nu Interaction

Fermionic DM
Vector Mediator



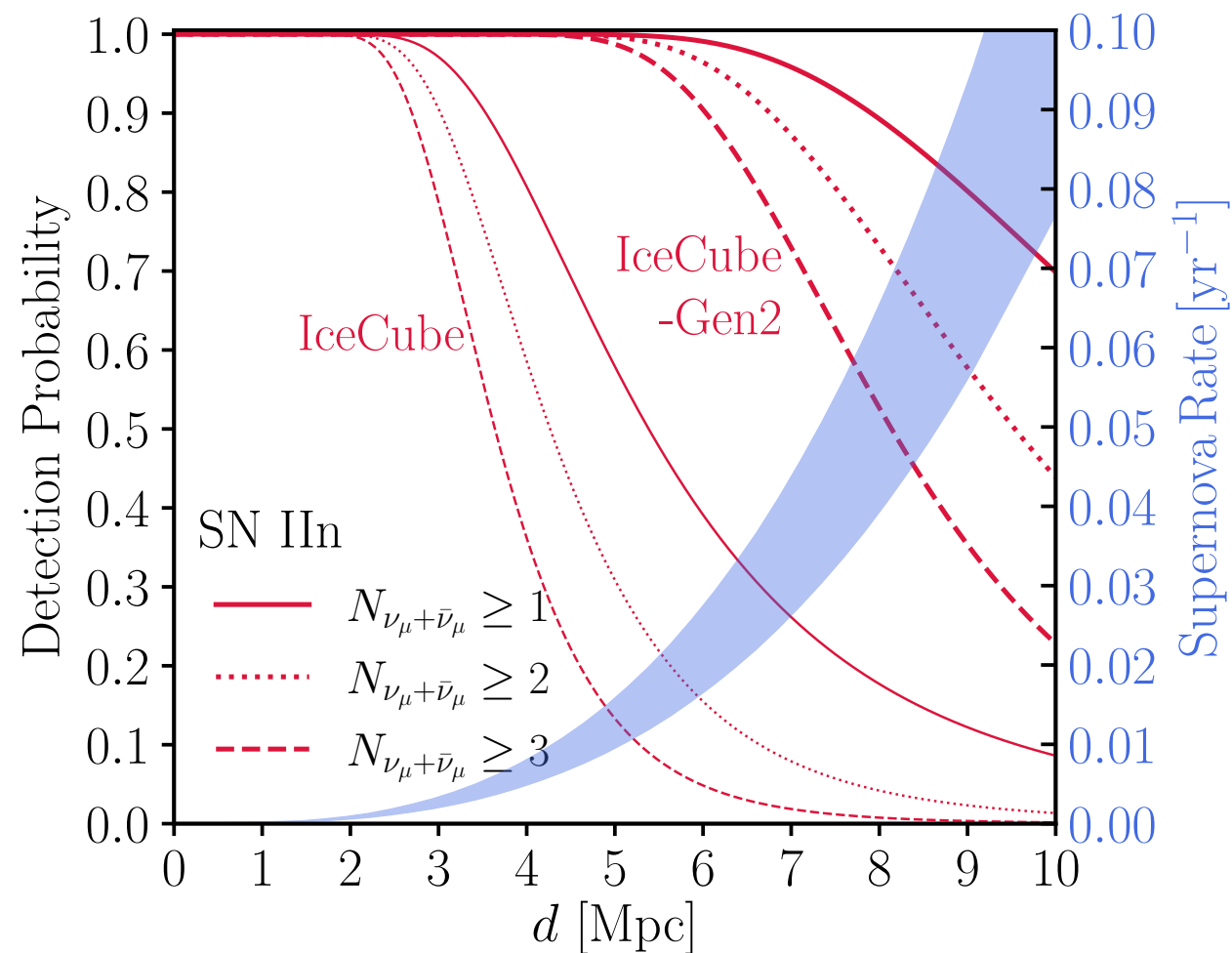
Scalar DM
Fermionic Mediator



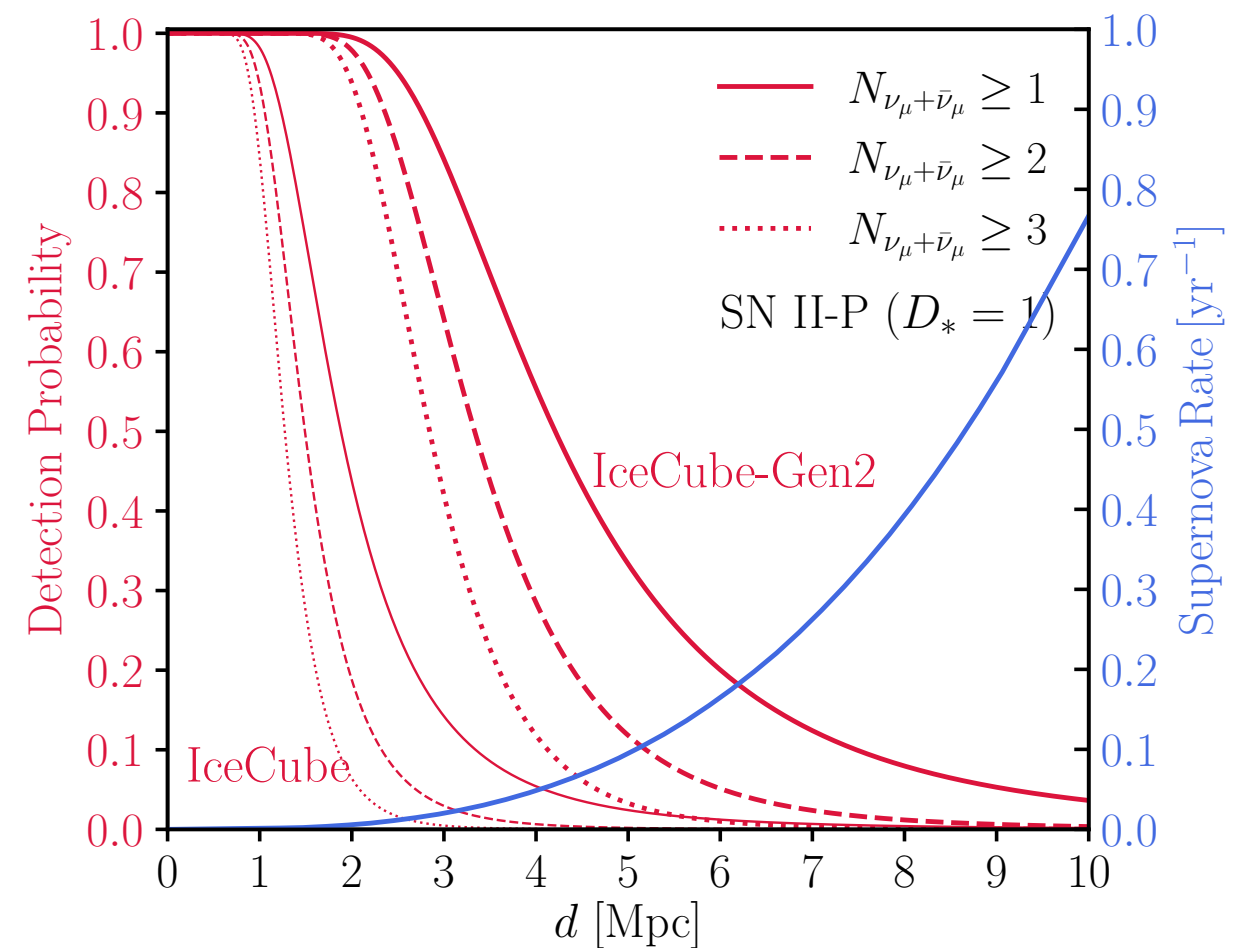
Competitive limits compared to cosmological constraints!

[Argüelles, AK, Vincent, PRL 2017, IceCube JCAP 2022]

HE Neutrinos from CCSNe

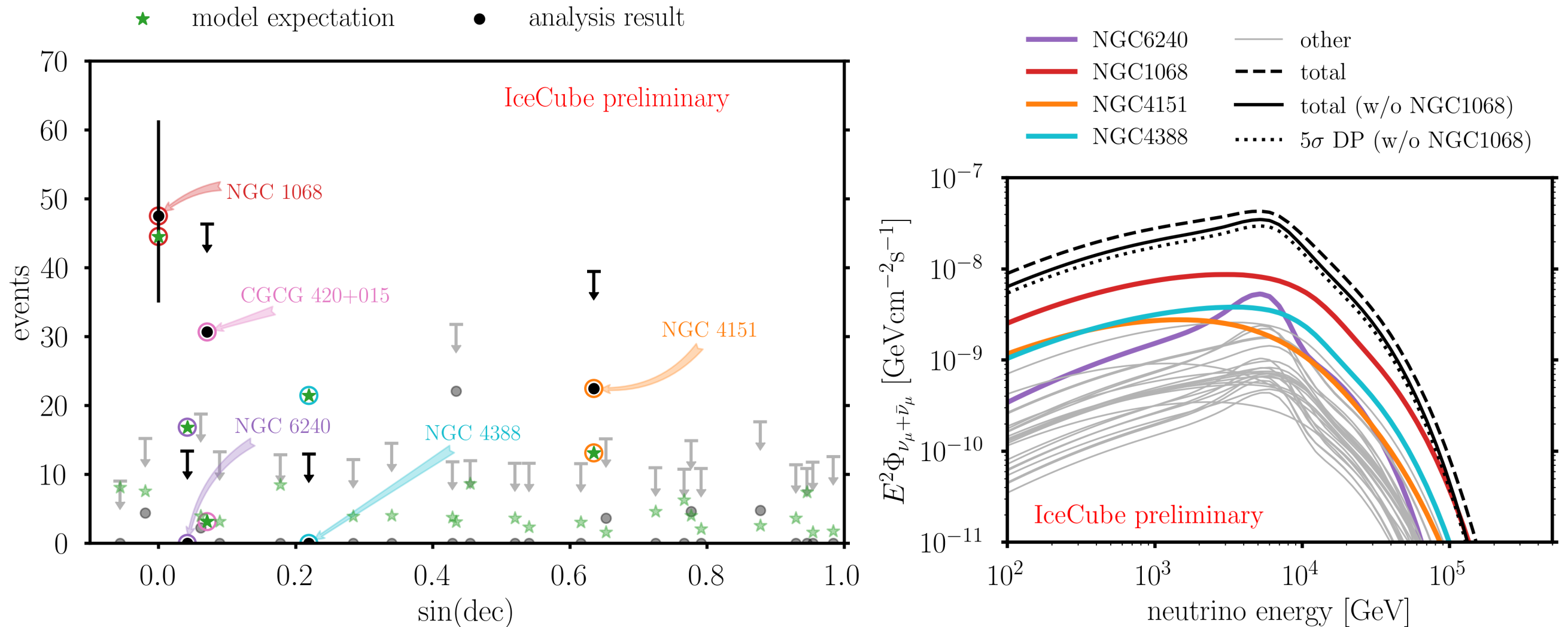


AK & Murase ApJL 2023



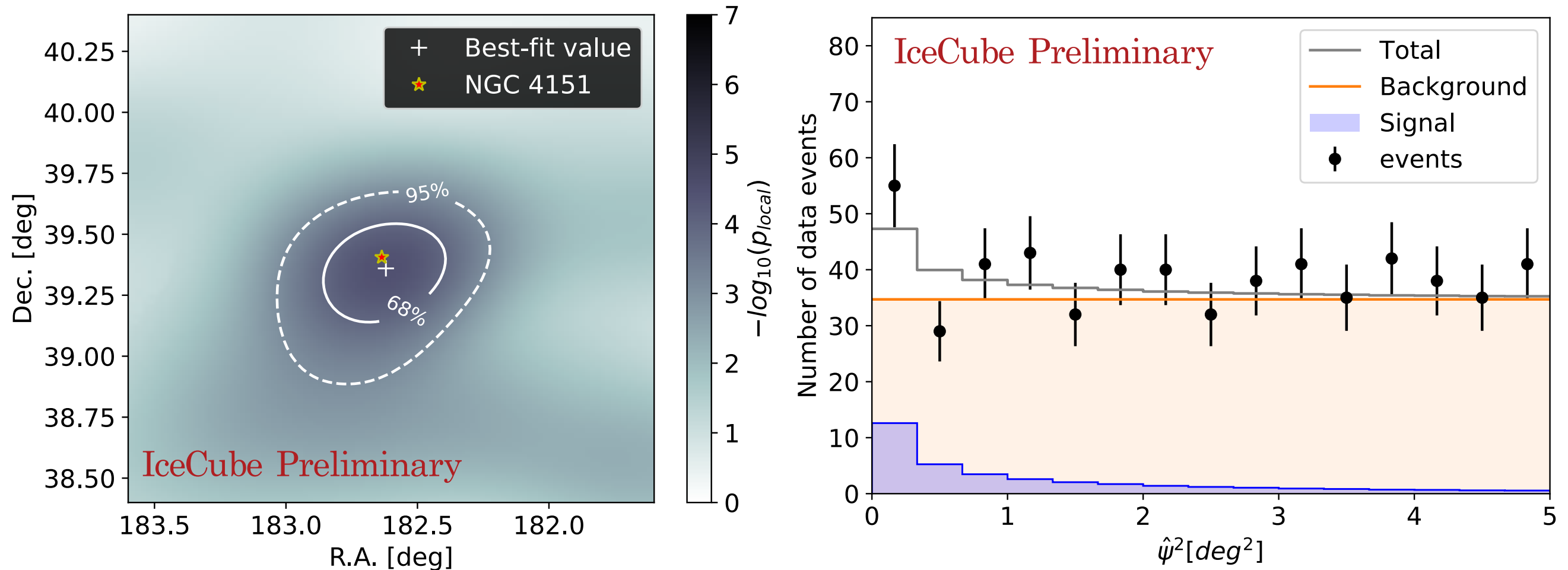
The next generation of neutrino telescopes will extend the horizon for observation of multiple neutrinos from extragalactic SN IIn.

Neutrinos from Bright Seyferts



- ▶ Selecting sources based on the intrinsic X-ray flux (as a proxy for neutrino production)
- ▶ Catalog search finds excess in the direction of 2 sources in addition to NGC 1068
 - ▶ Binomial p-value study finds CGCC 420-15 and NGC 4151 at 2.7σ (Posterior p-value with NGC 1068 yields 4σ)

NGC 4151 — 2.9σ



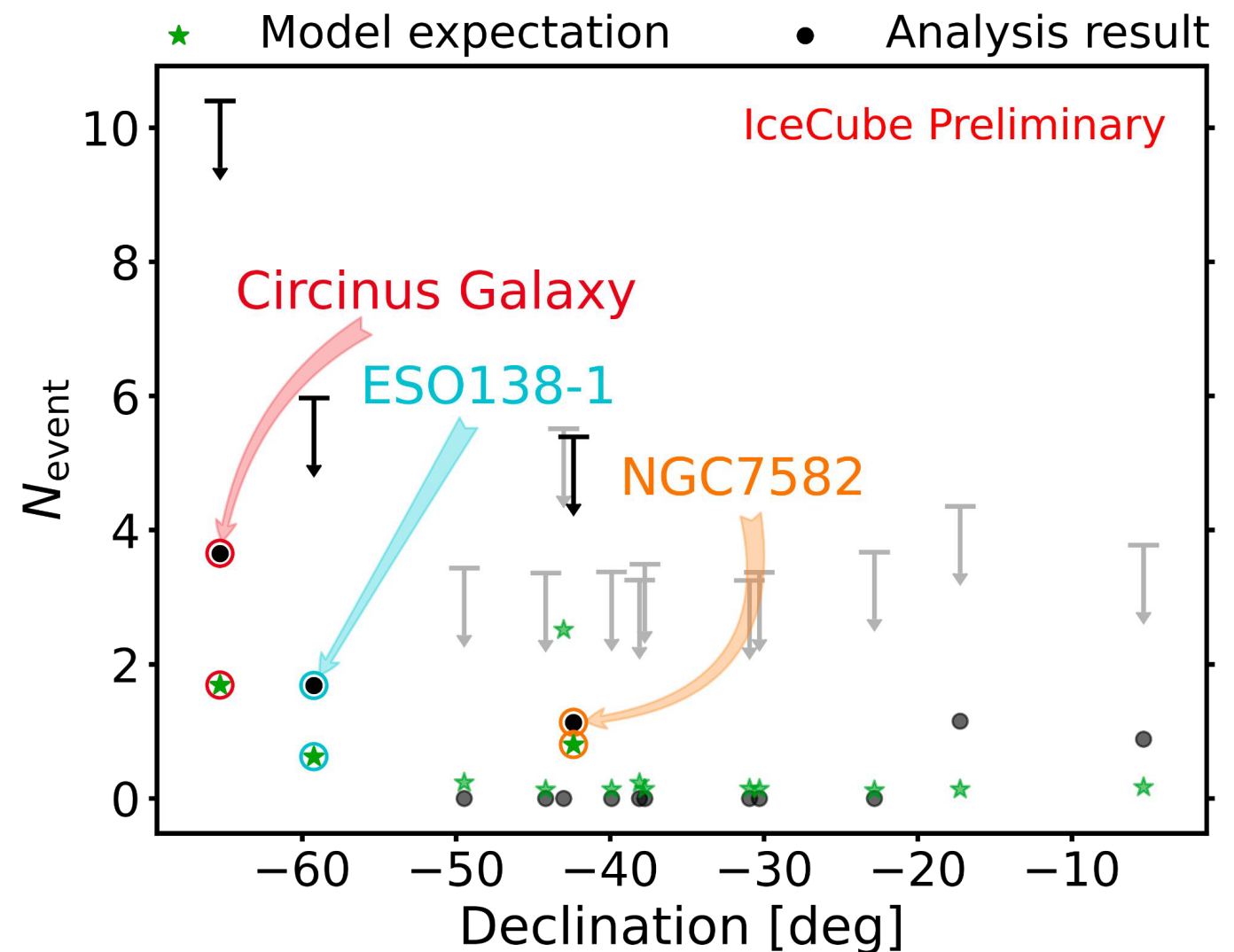
- ▶ NGC 4151 appears at 2.9σ (global significance)
- ▶ The second most significant steady source in IceCube

New Results from the Southern Sky

- ▶ The majority of bright nearby Seyfert galaxies are in the Southern Hemisphere
- ▶ IceCube has **sufficient sensitivity** with Enhanced Starting Events to search for emission from prominent sources in the Southern Hemisphere.

- Best p-value for the source in the Southern sky:
 - ▶ **Circinus Galaxy**
 - ▶ 3.6 neutrino events at 2.8σ local significance (1.8σ post trial)
- 2 additional sources with excess:
 - ▶ ESO 138-1
 - ▶ NGC 7582.

- Stacking analysis:
 - ▶ **6.7 events**



Yu, AK+, IceCube, ICRC 2023