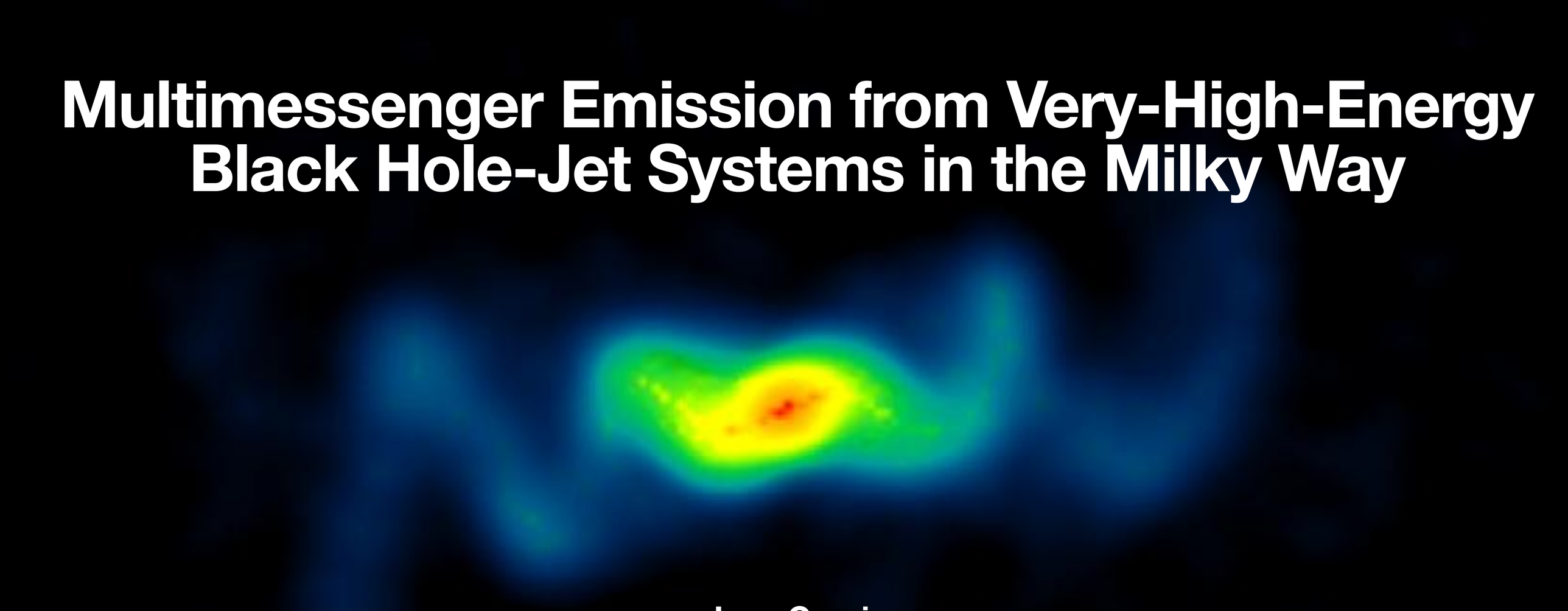
Multimessenger Emission from Very-High-Energy Black Hole-Jet Systems in the Milky Way



Jose Carpio
University of Nevada Las Vegas / Niels Bohr Institute

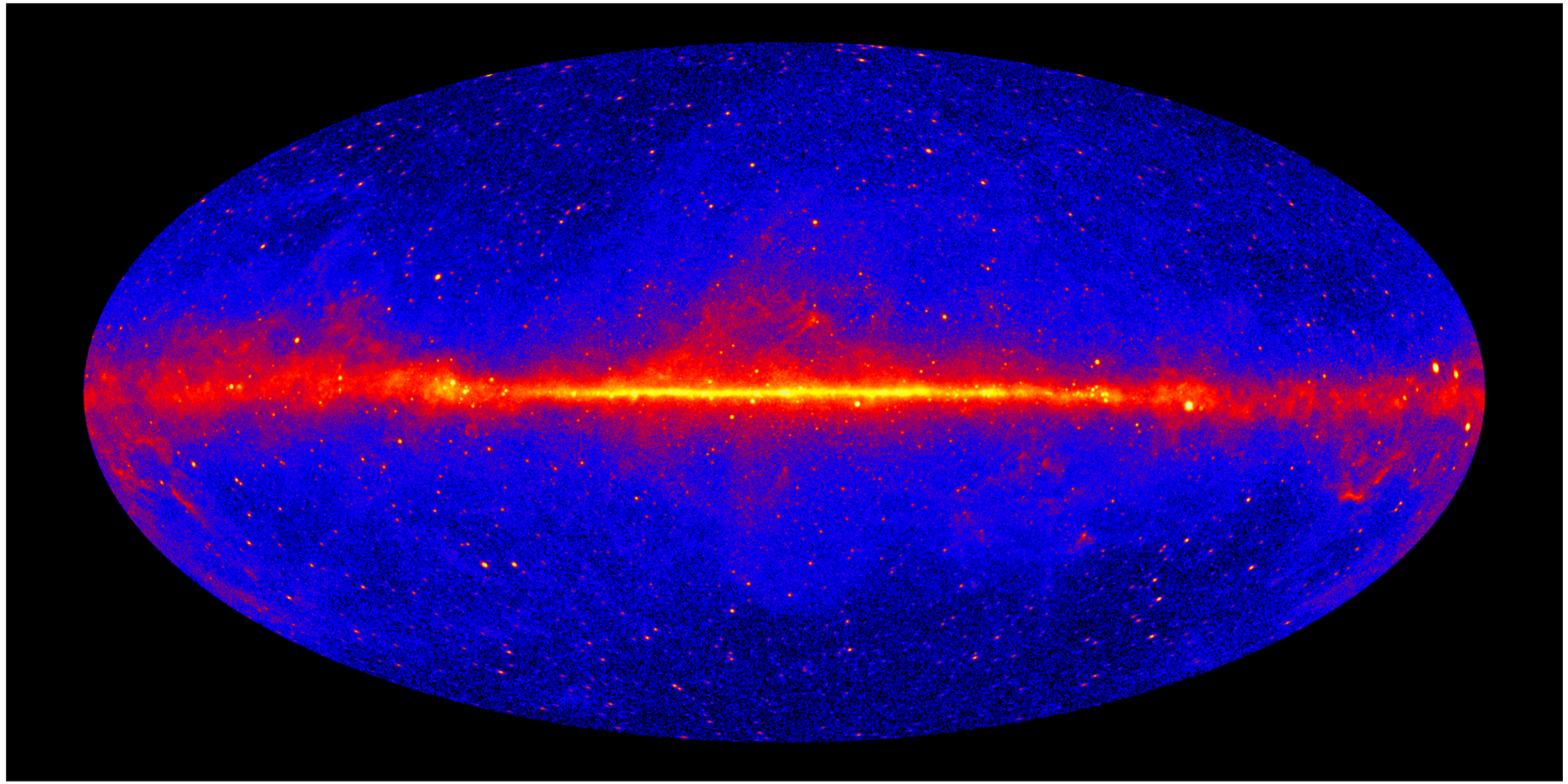
TeVPA 2026, August 31st 2026

Collaborators: Ali Kheirandish and Bing Zhang

JHEAP 51, 100538 (2026)

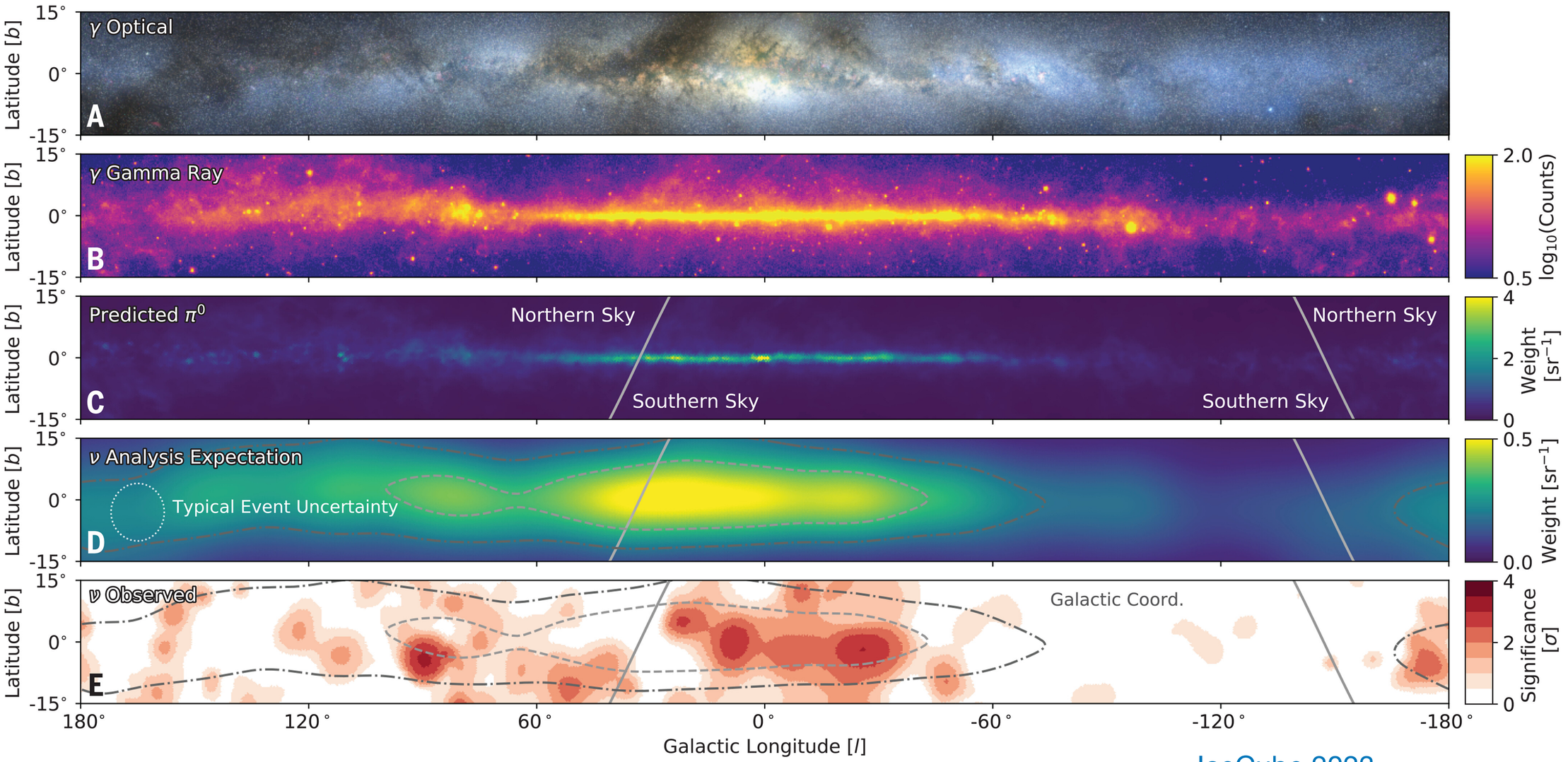
The Galactic γ-ray sky

- γ-ray observations point to powerful non-thermal processes in the Galaxy.
- While individual sources can be resolved, γ-rays alone cannot identify the underlying particles undergoing acceleration (i.e. leptonic vs hadronic)



Neutrinos from the Galactic plane

For galactic sources, IceCube has observed neutrino emission from the Galactic plane



IceCube 2023

Neutrinos from the Galactic plane

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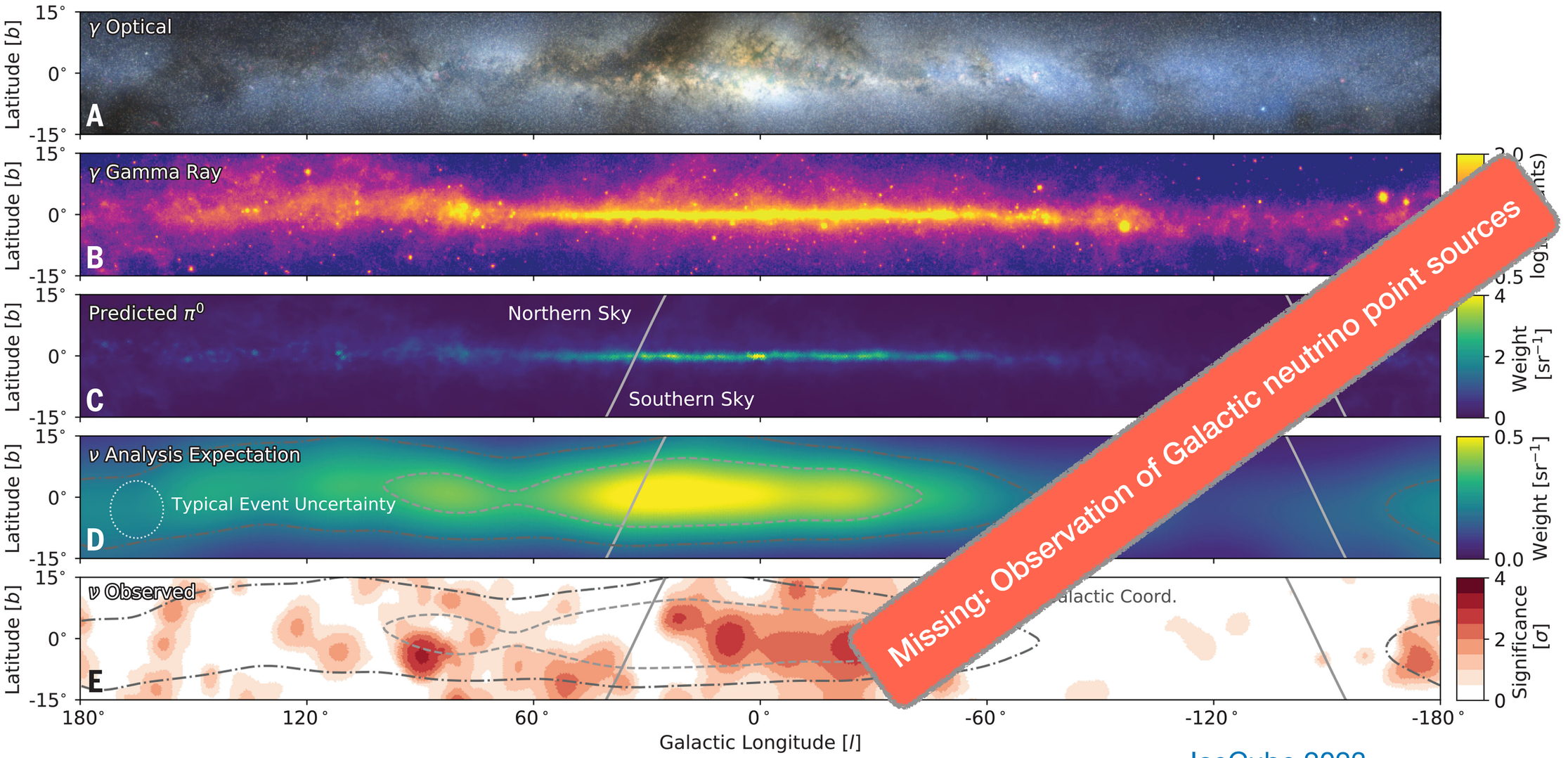
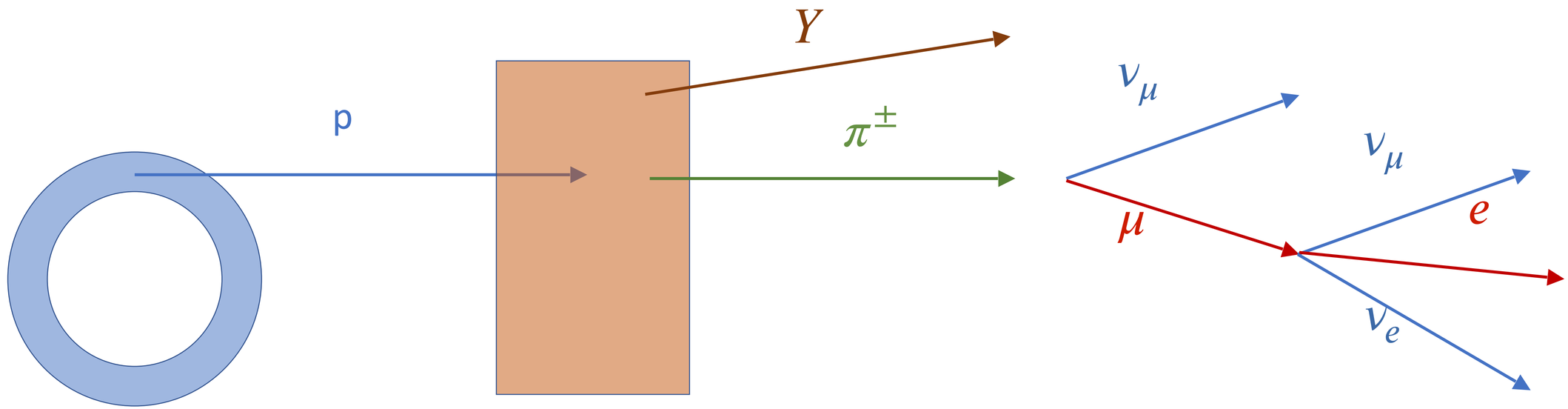


IceCube 2023

Neutrino emission in microquasars

Neutrino emission is evidence of **hadronic particle acceleration**



Cosmic accelerator
>100 TeV protons

Target: Photons in ev-keV can clear the π production threshold

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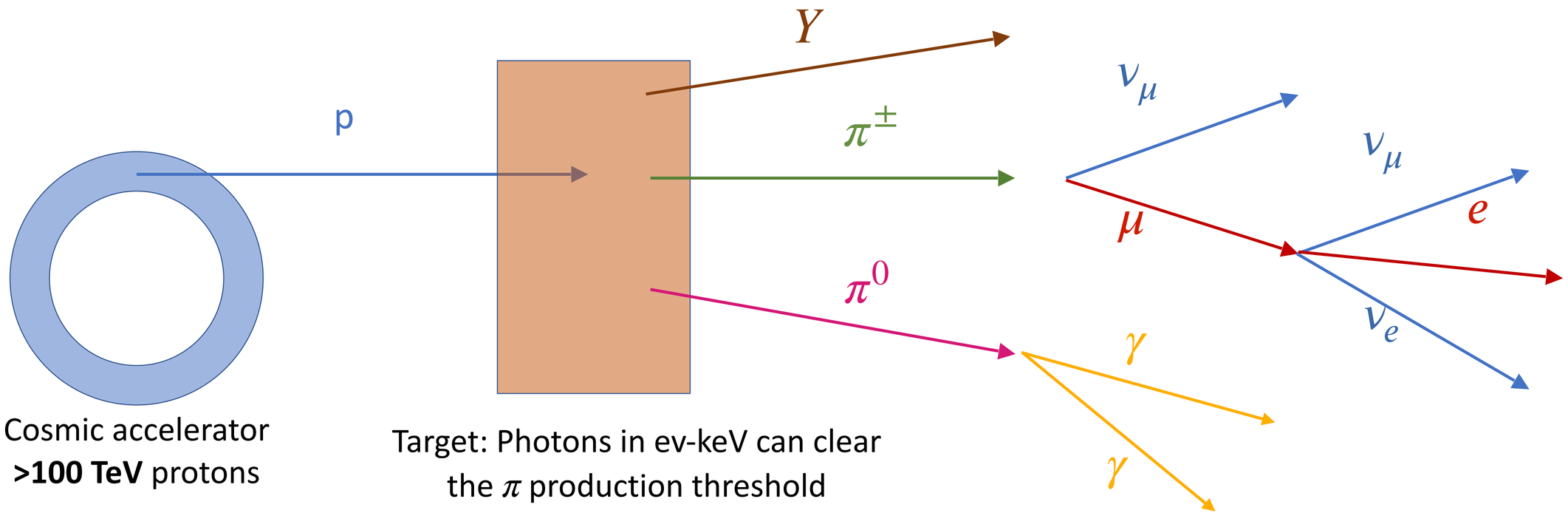

Cosmic accelerator
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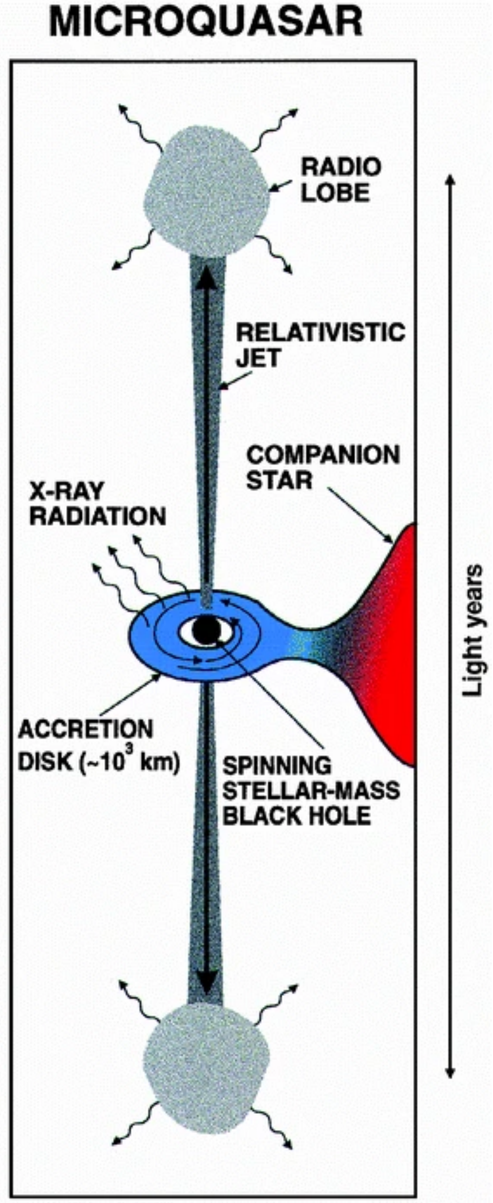
Target: Photons in ev-keV can clear the π production threshold

γ-rays are co-produced with neutrinos

Galactic neutrino source candidate: microquasars



Mirabel & Rodriguez 1998

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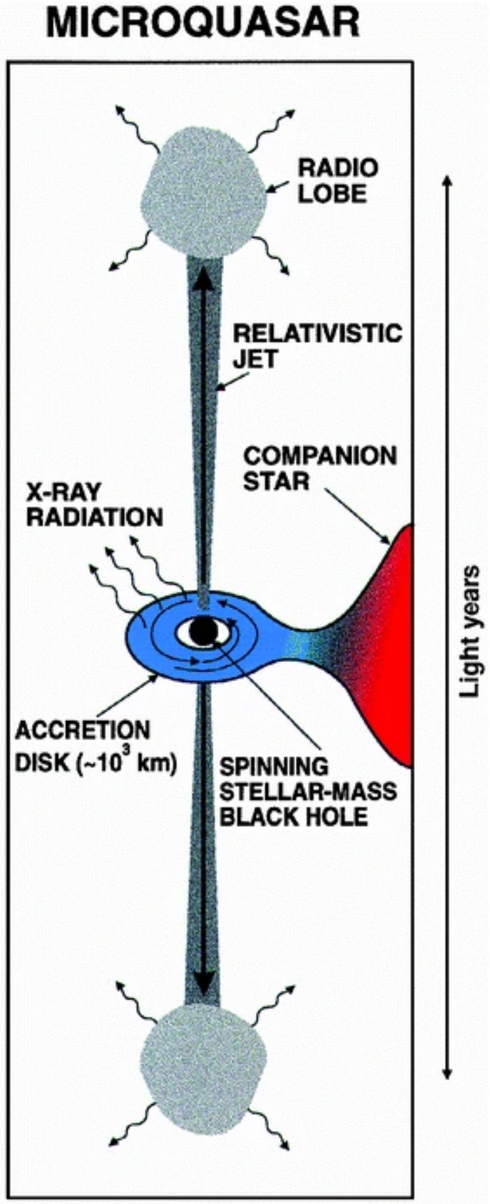

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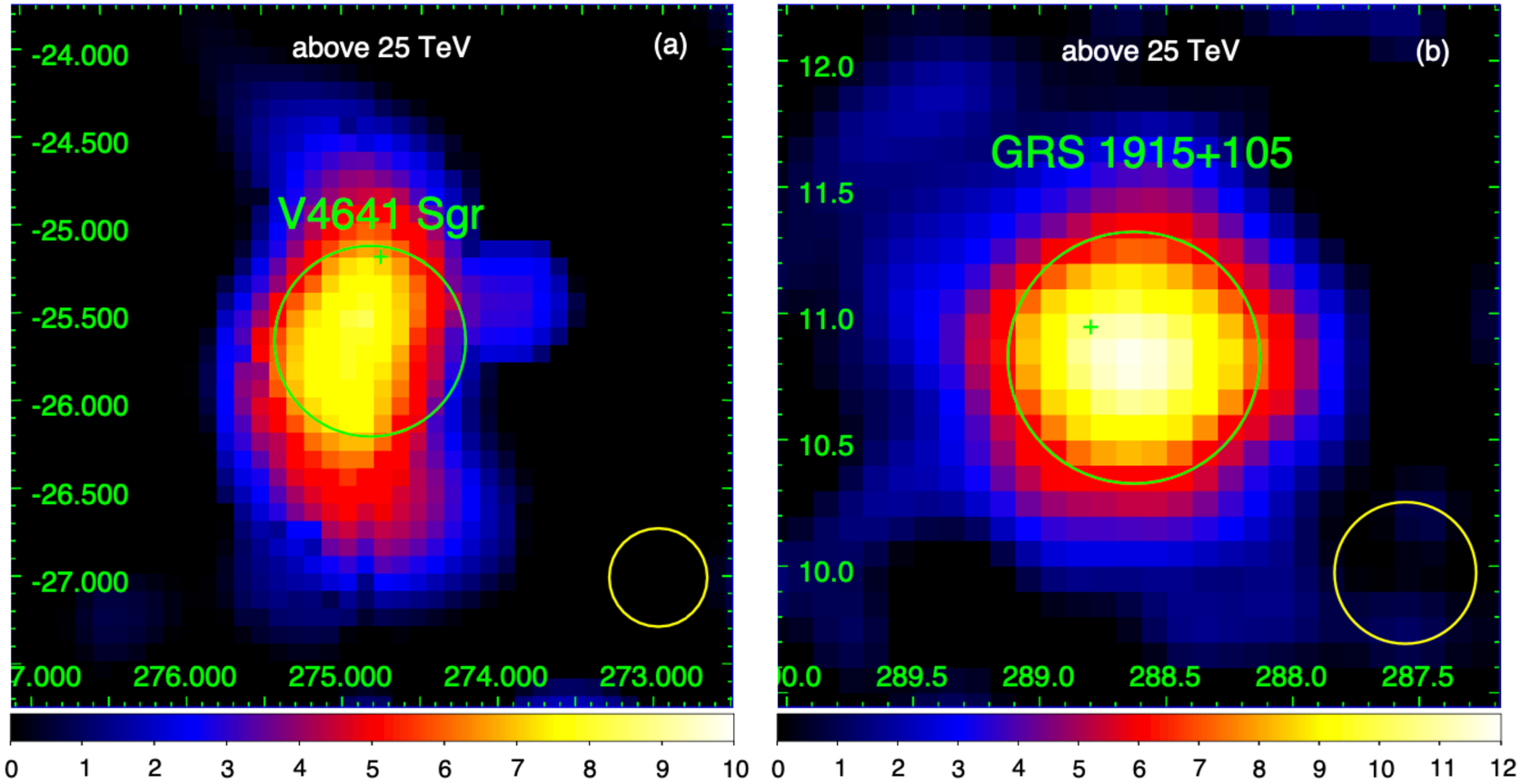
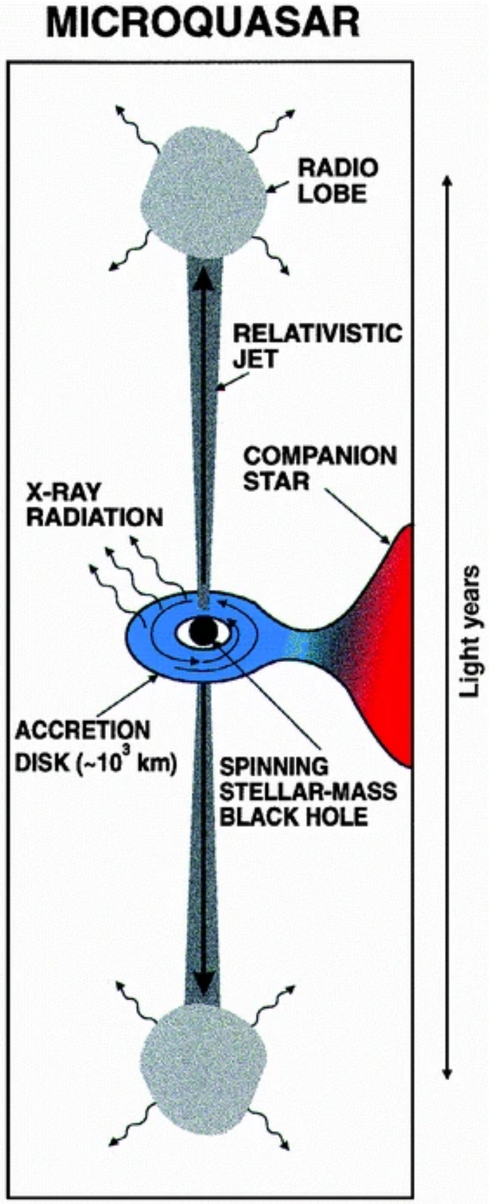
LHAASO found >25 TeV γ-rays from microquasars



LHAASO 2024

Galactic neutrino source candidate: microquasars



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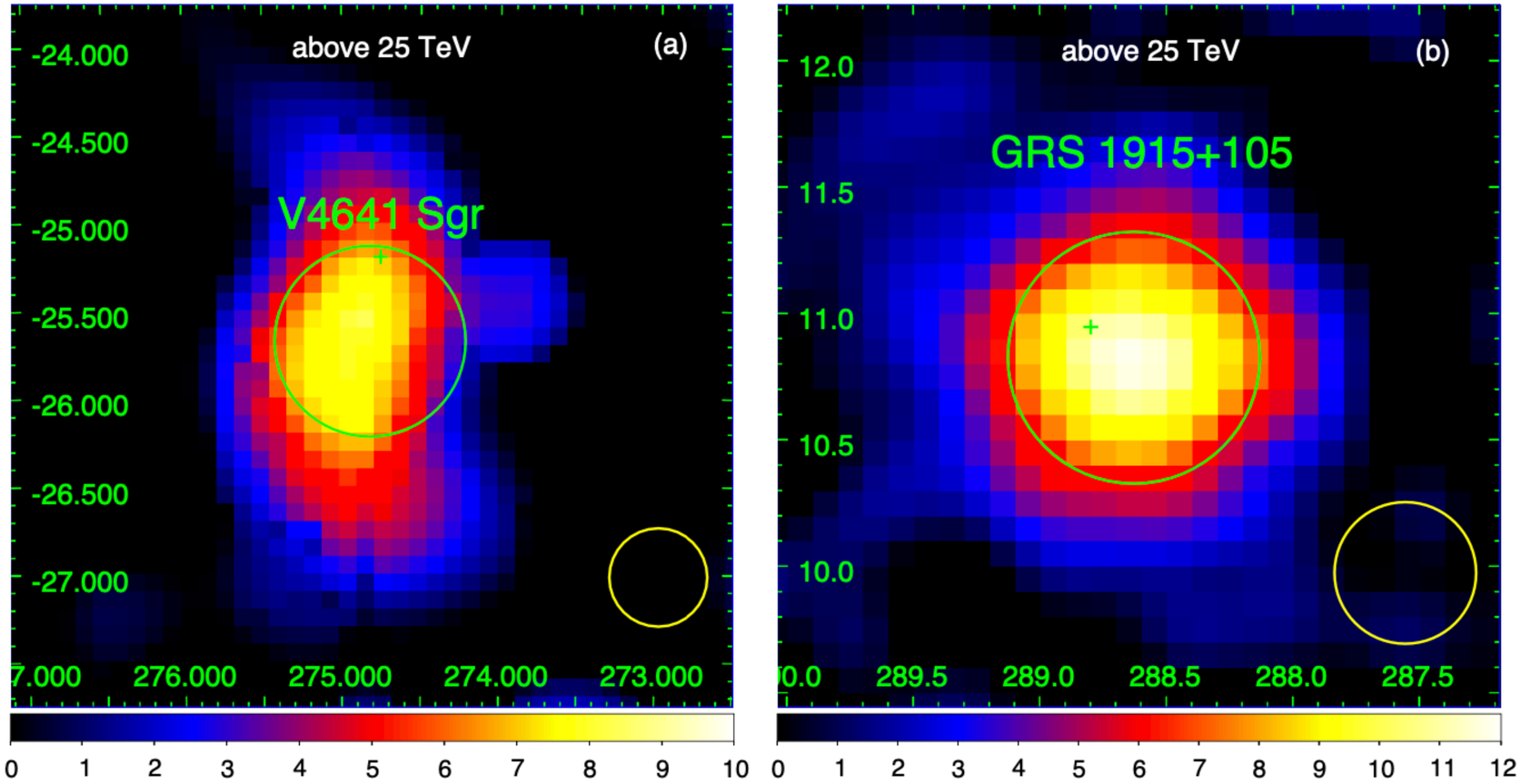
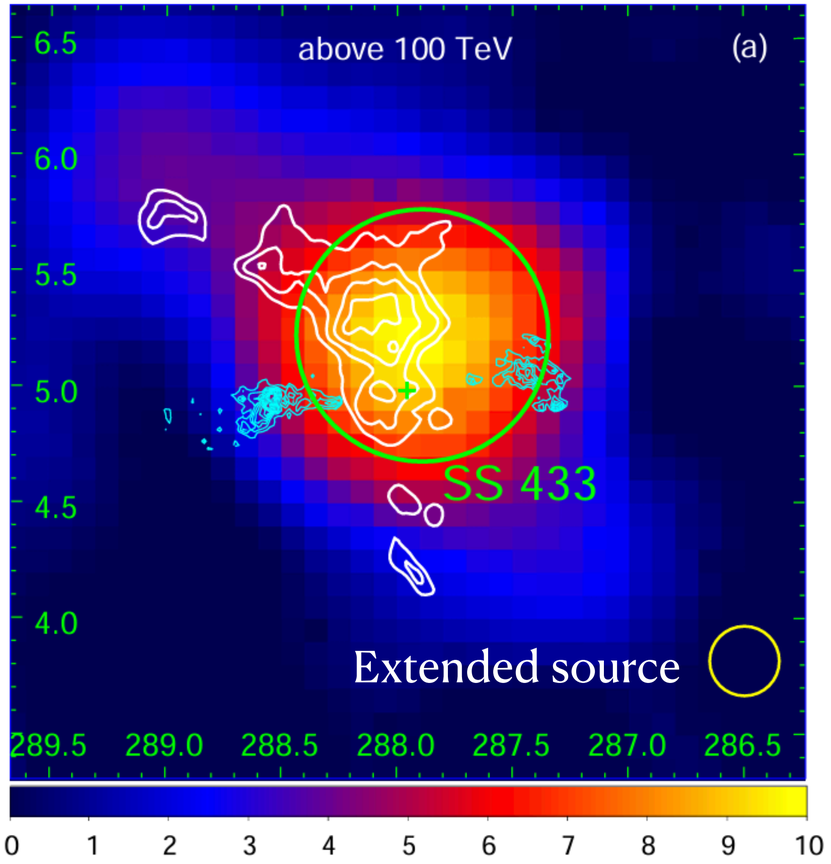


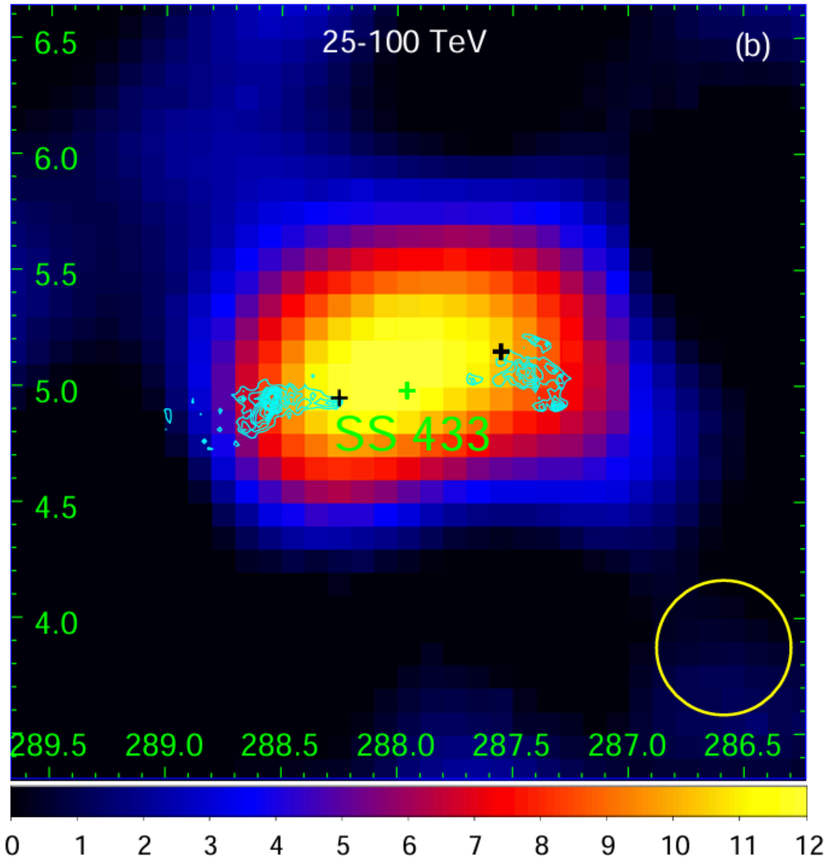
LHAASO 2024

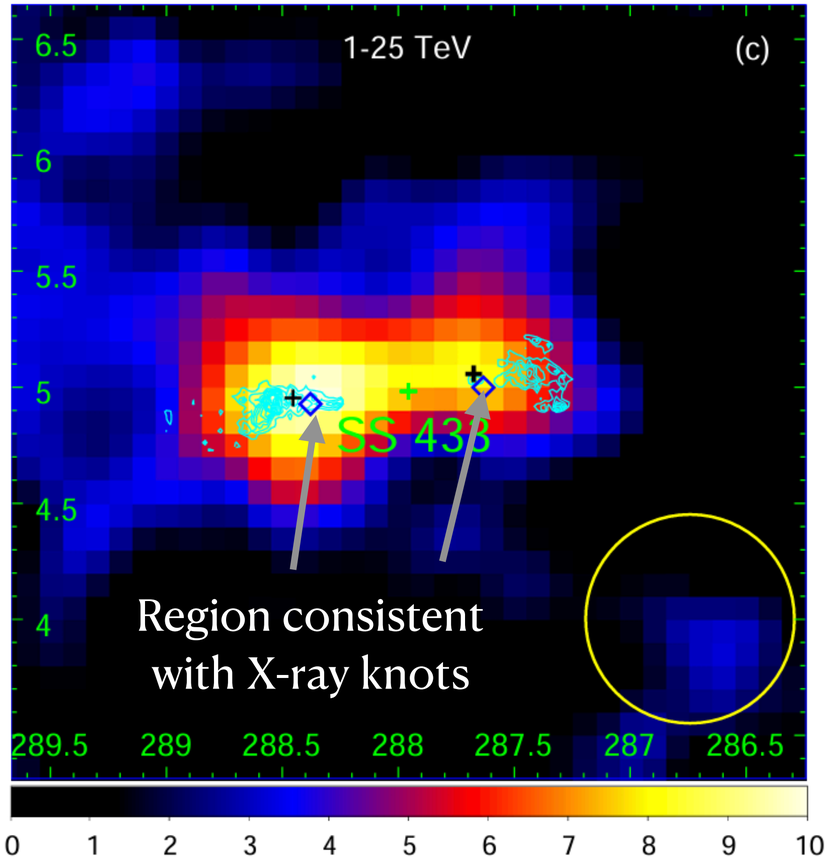
Works on cosmic ray, γ-ray and/or neutrino emission in microquasars:

C. Tong+ 2026, Z. Curtis-Ginsberg+ 2026, B.T. Zhang & S. Yu 2026, Y. Wei+ 2025, M. Kleimenov+ PRD 2026, B. Paul+ 2025, A.M. Bykov+ PRD 2025, B.T. Zhang+ PRD 2025,

SS433: Most significant LHAASO source







Extended wind with a hadronic component only

Large-scale jet where X-rays are produced

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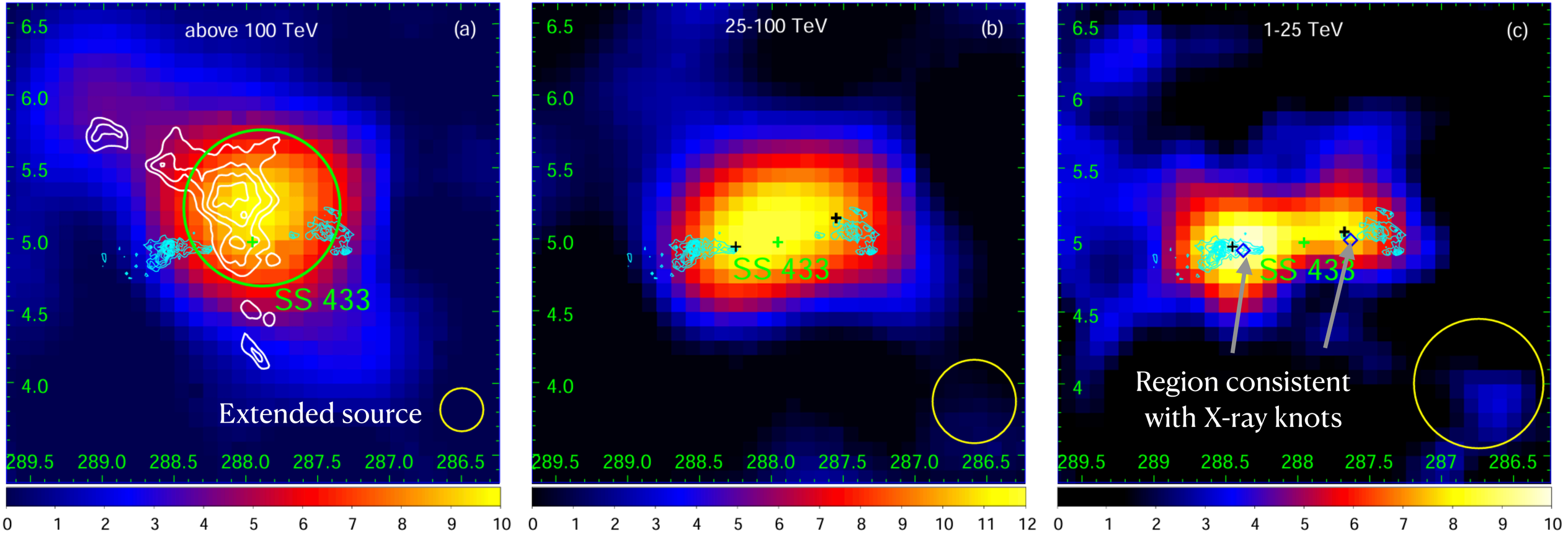
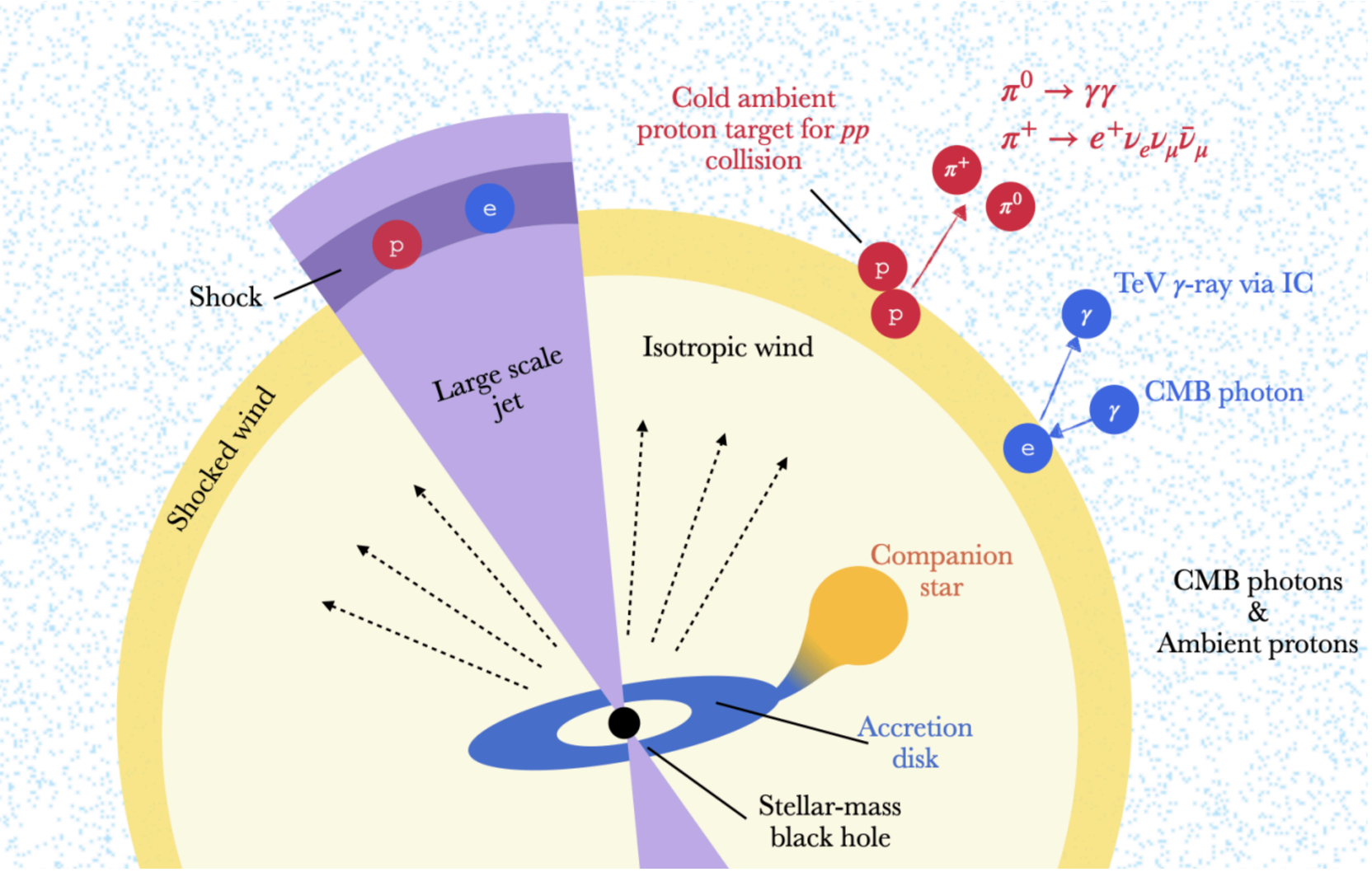


Extended wind with a hadronic component only

Large-scale jet where X-rays are produced

A two-zone model may explain this source

High-energy multimessenger emission



Particle acceleration at shocks

Carpio, Kheirandish & Zhang 2025

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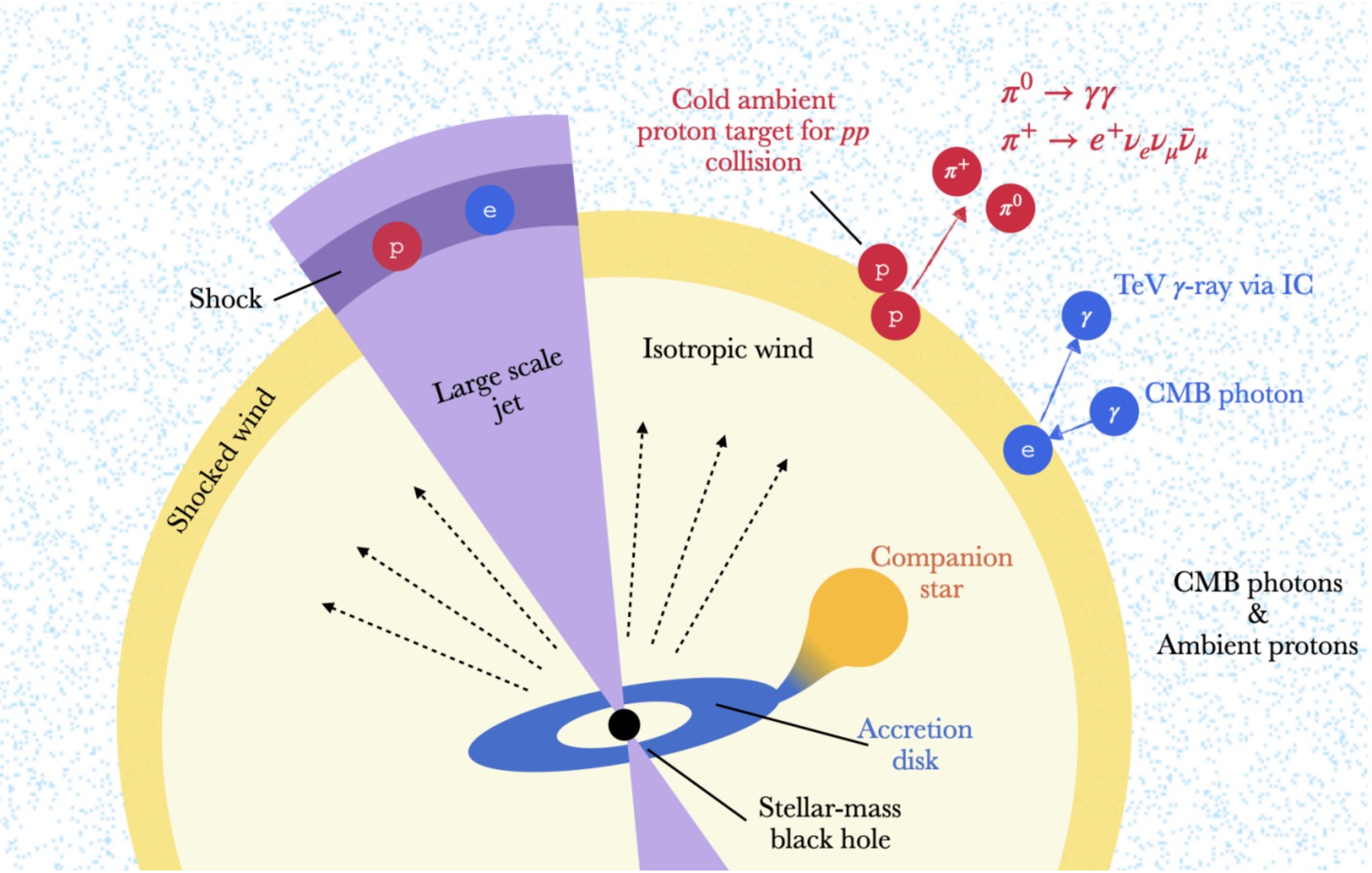

Particle acceleration at shocks

Important model parameters

- Magnetic field B
- Acceleration region size R
- Jet/wind luminosity L
- Energy injected to e, p

Carpio, Kheirandish & Zhang 2025

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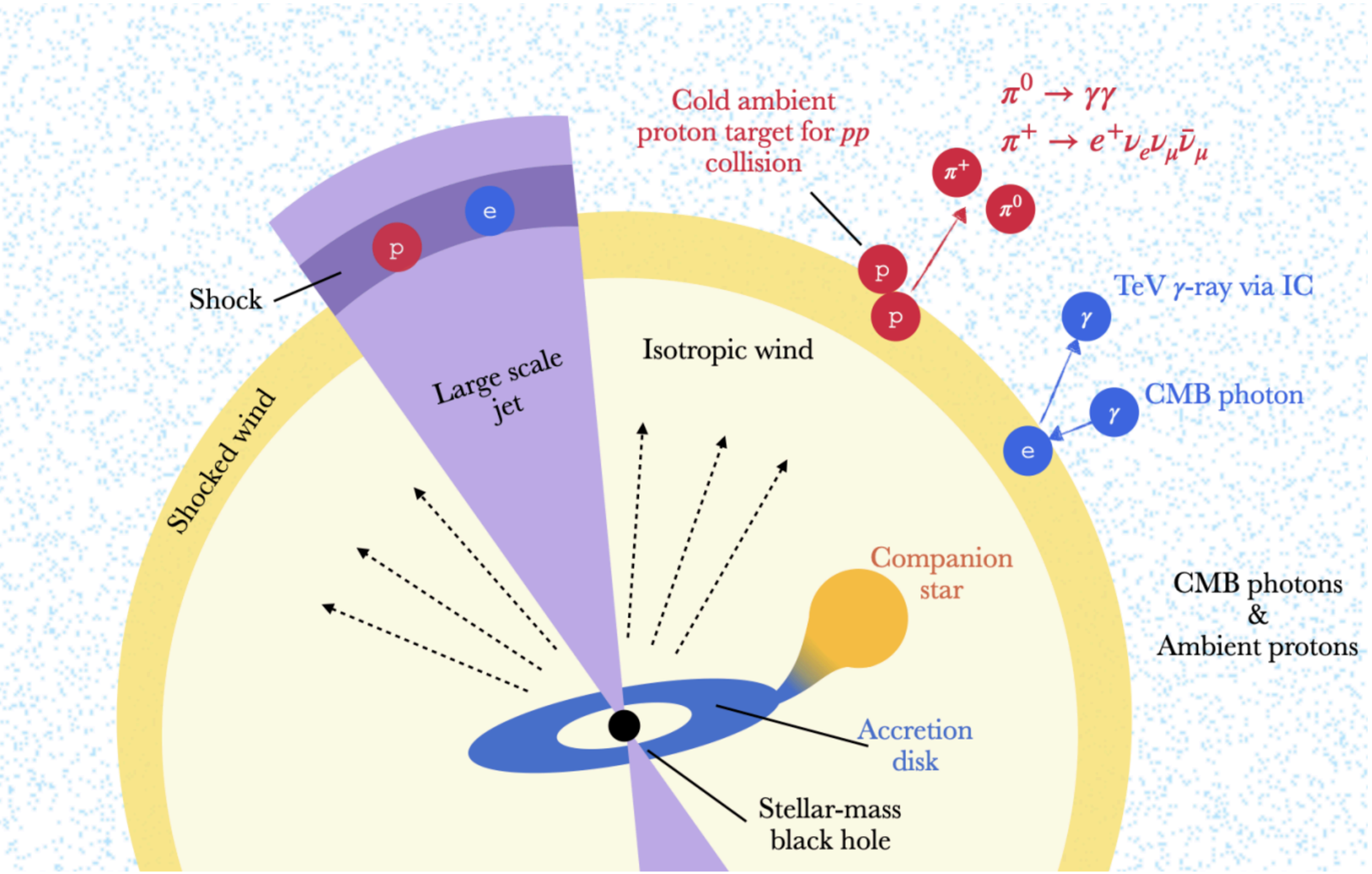

Carpio, Kheirandish & Zhang 2025

Particle acceleration at shocks

Important model parameters

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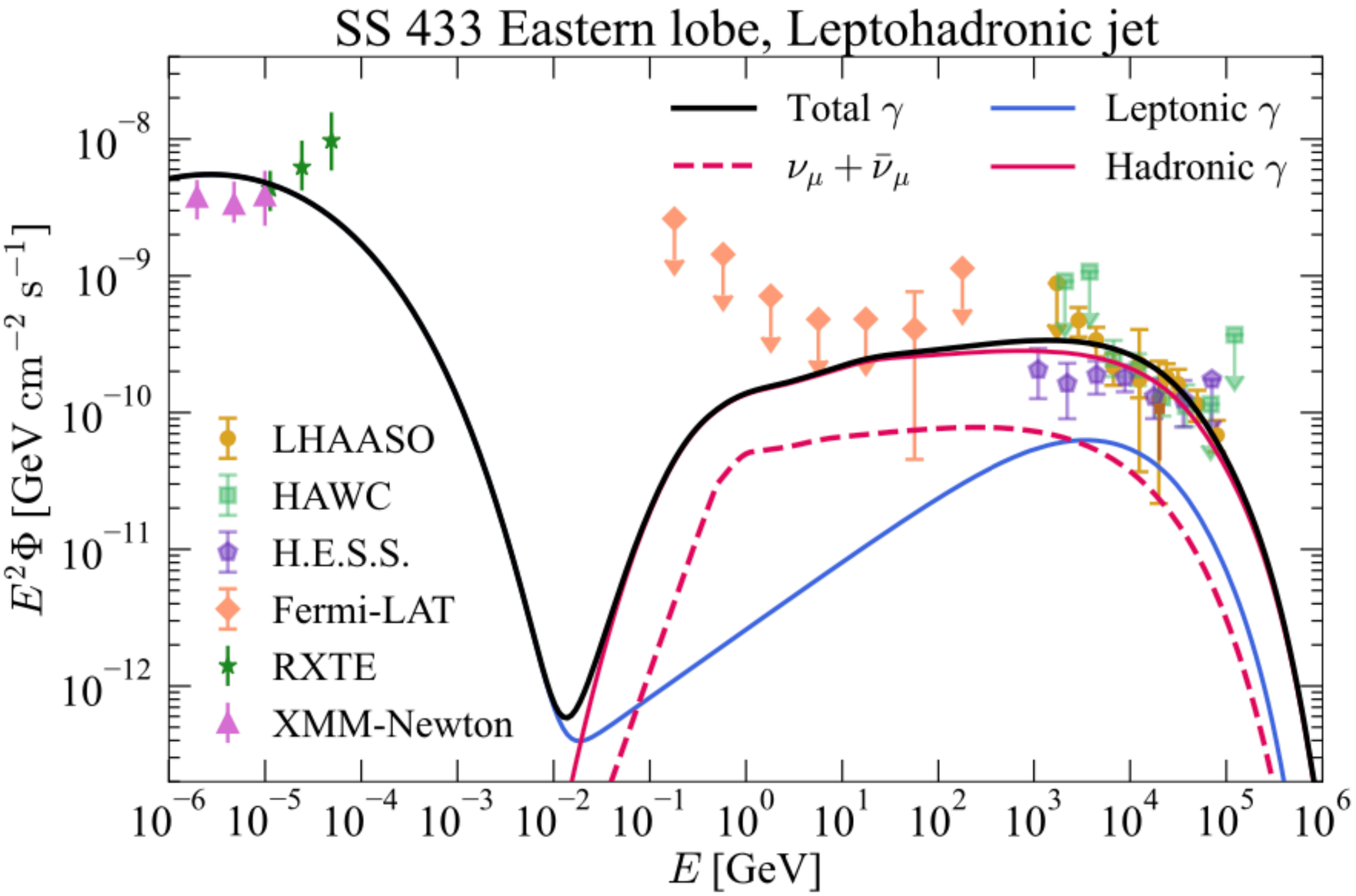
Main question

Is the observed emission hadronic (from p) or leptonic (from e) ?

SS 433 Eastern lobe



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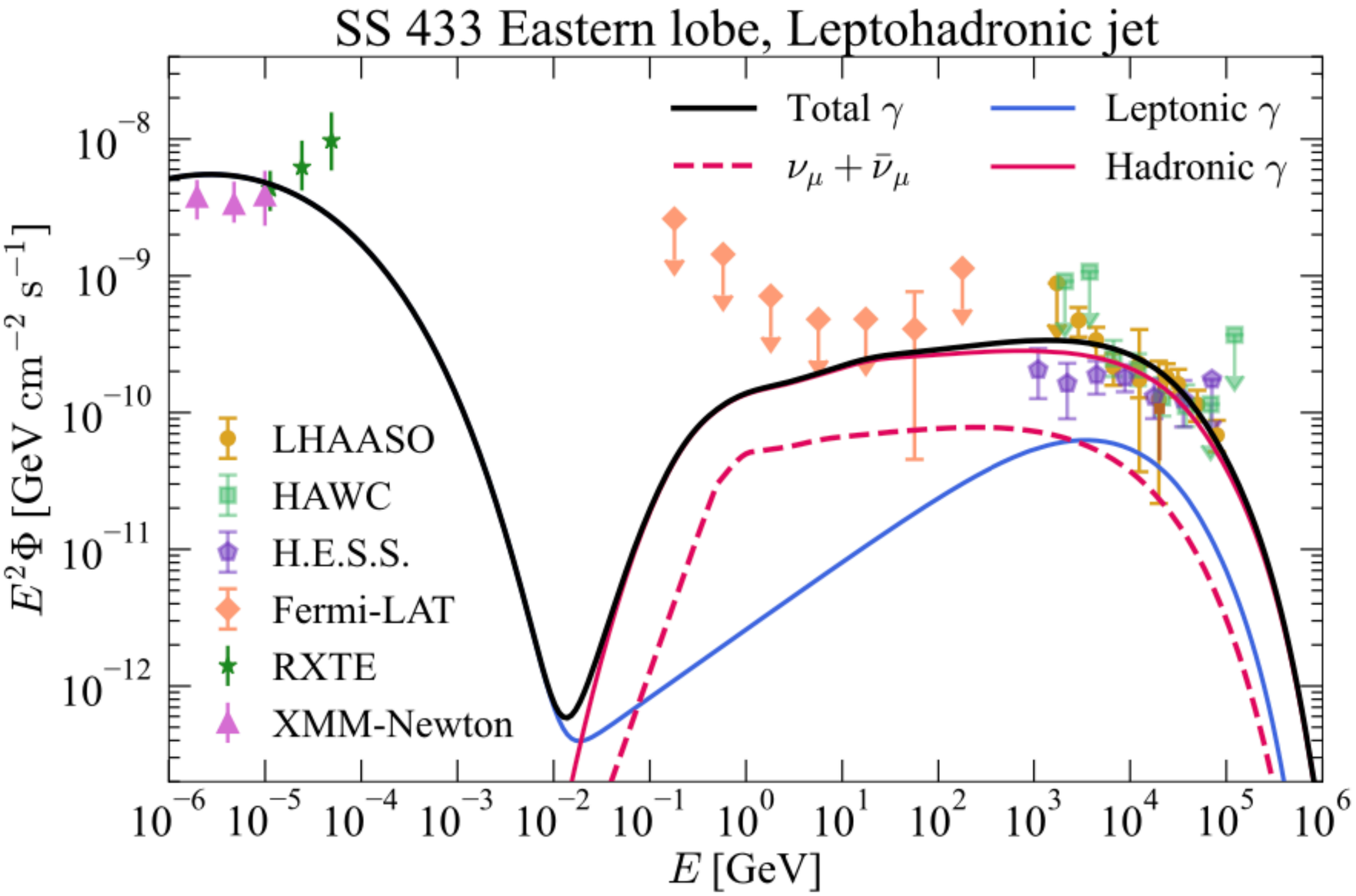


E^{-2} injection spectrum

Jet luminosity: 2×10^{39} erg s^{-1}

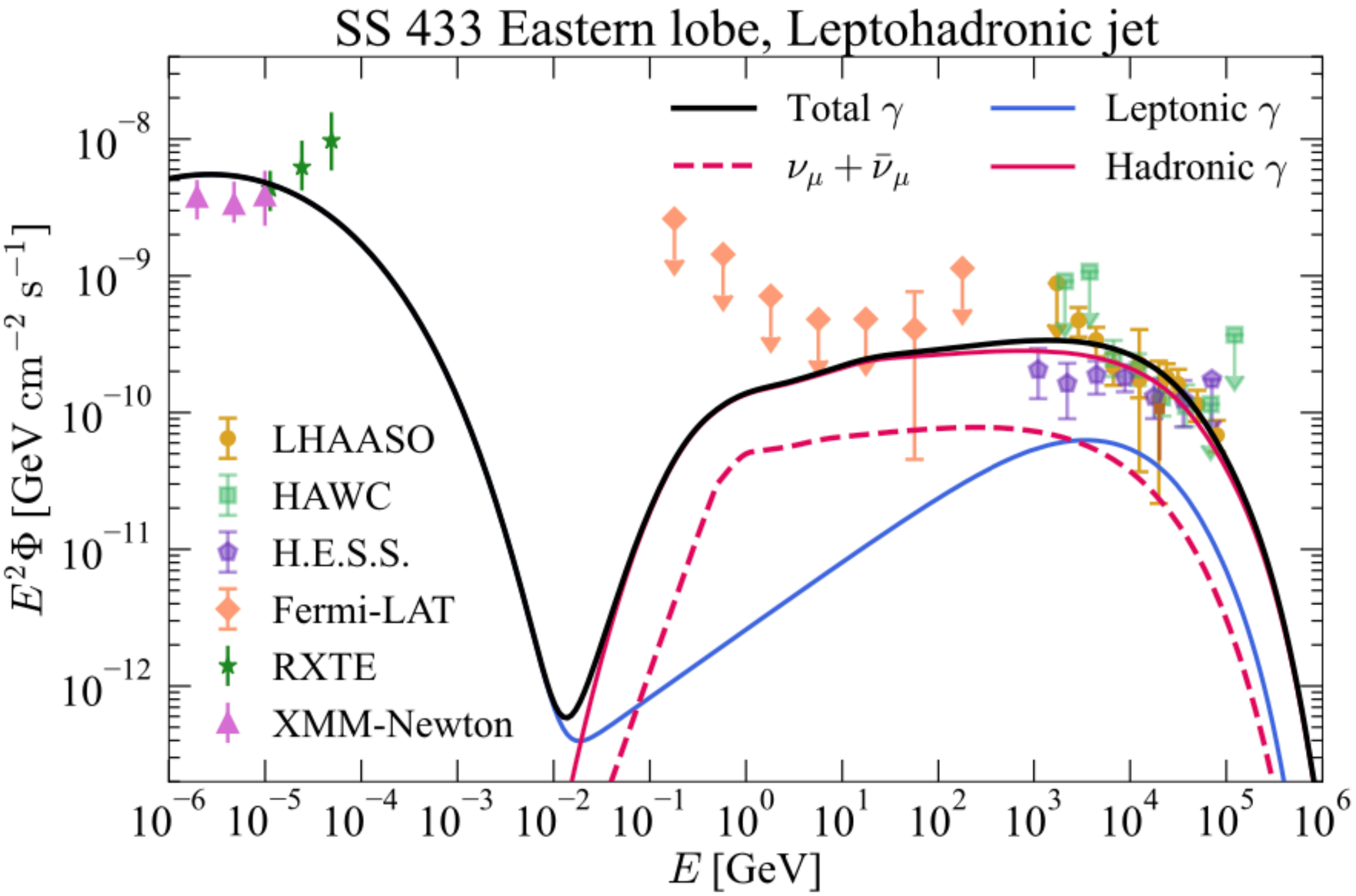
$B = 25\ \mu$G, $R = 8.1$ pc

10% of the energy to protons

0.2% to electrons

Ambient proton density: 30 cm^{-3}

SS 433 Eastern lobe



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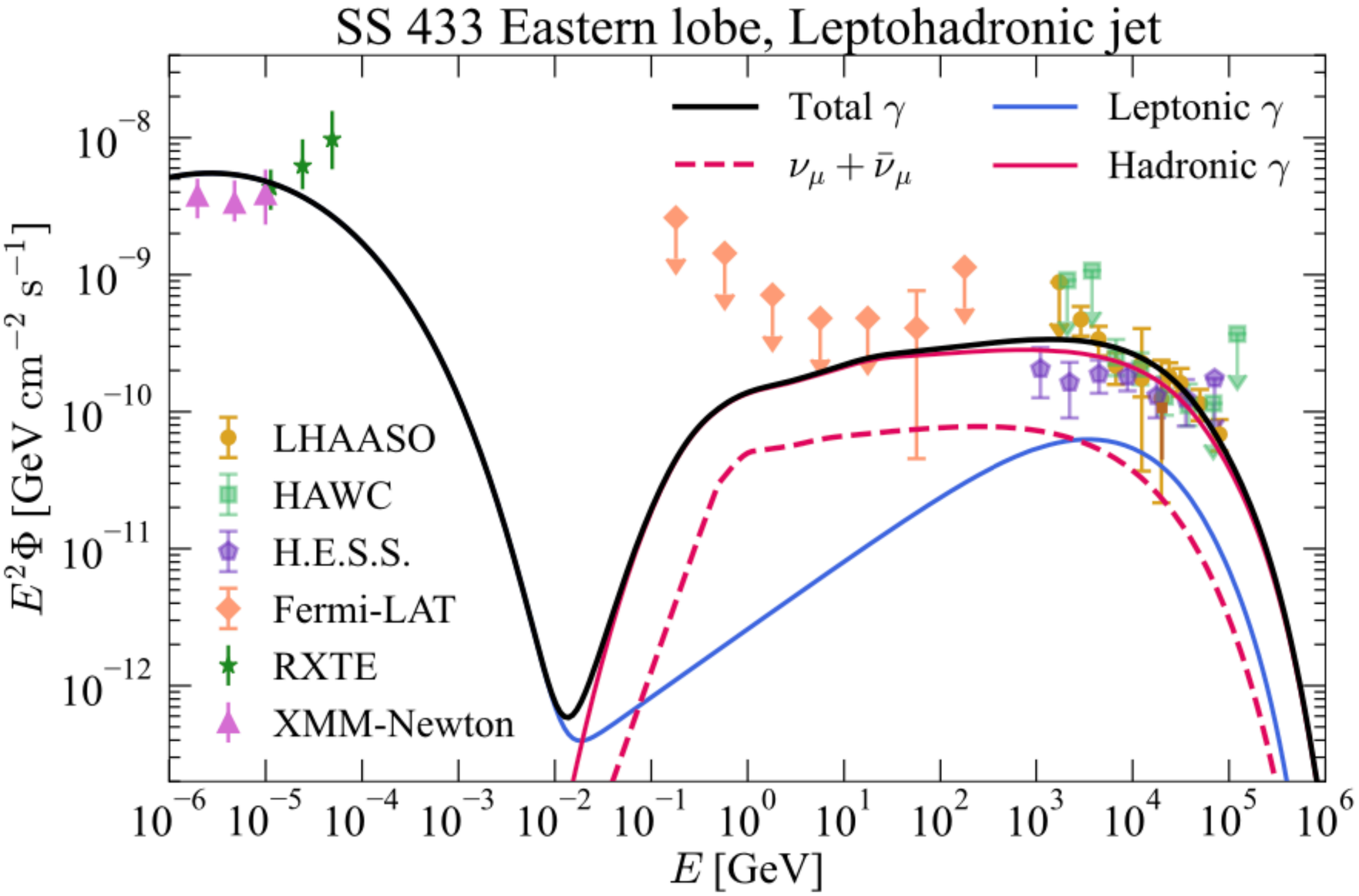

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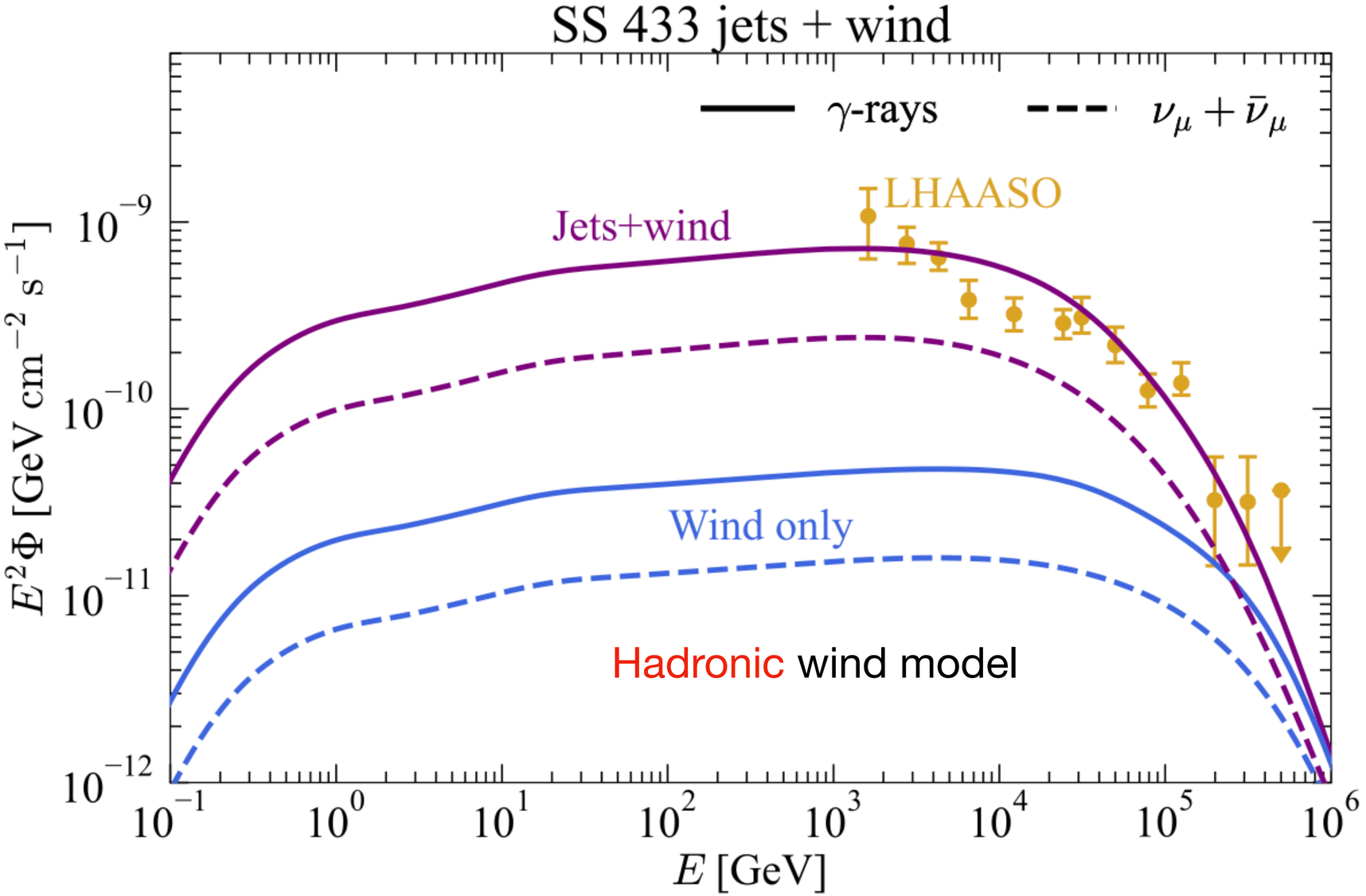
Hadronic γ-rays extend down to GeV energies

SS 433 jets + wind

Combined contributions from east/west lobes and isotropic wind



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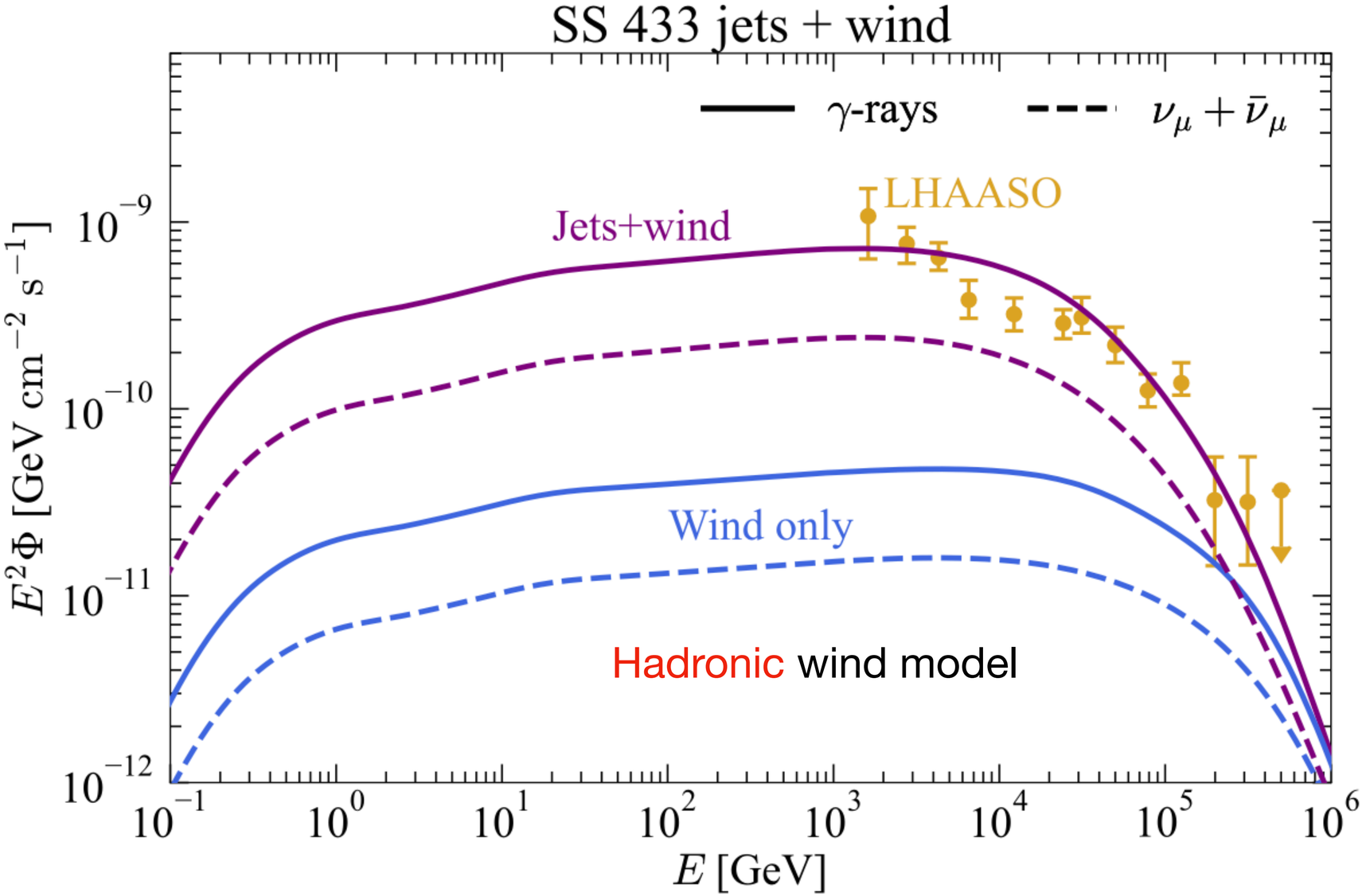

E^{-2} injection spectrum

Wind luminosity: 10^{39} erg s^{-1}

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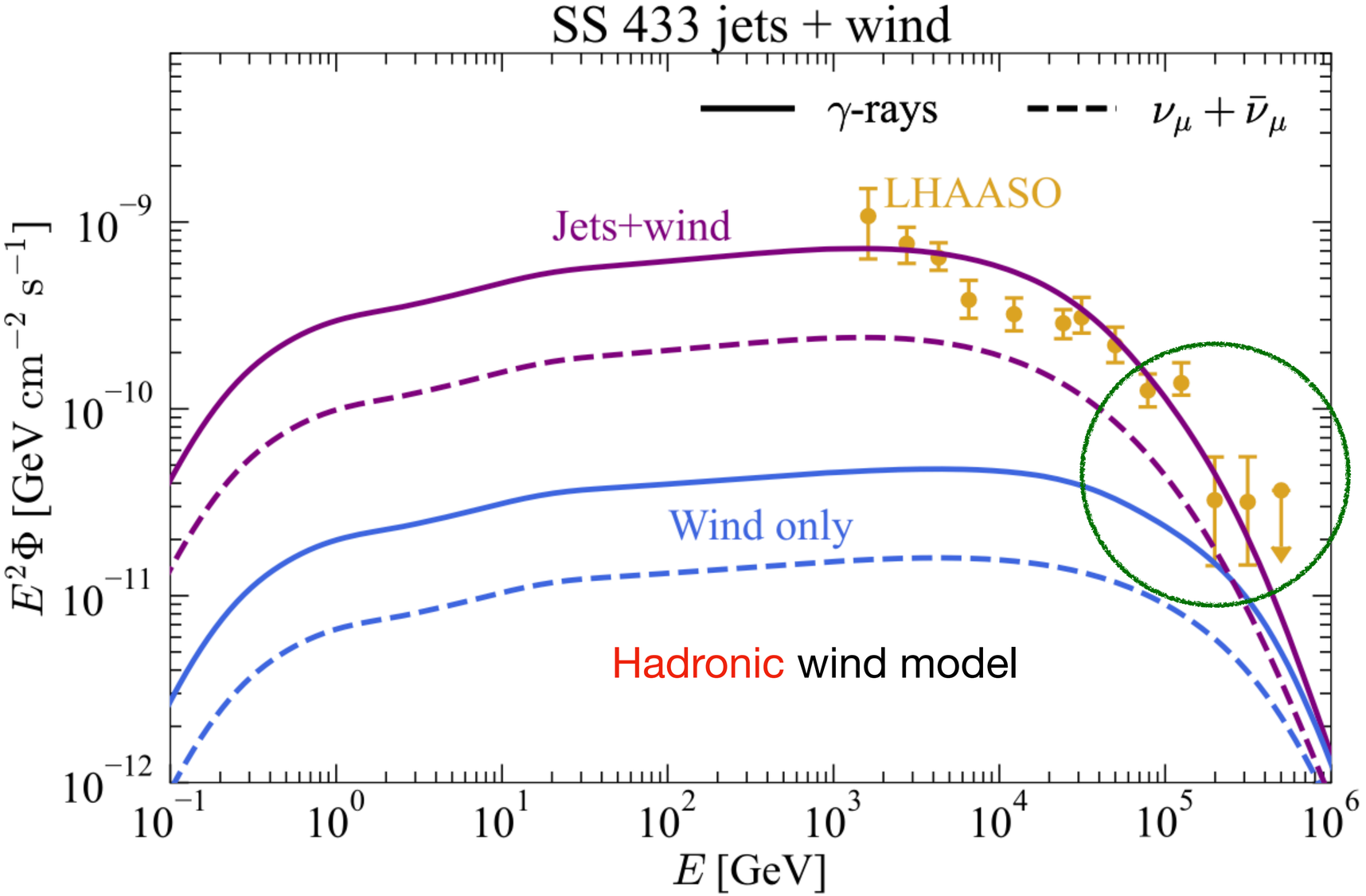
10% of the energy to protons

Ambient proton density n_p: 2 cm^{-3}

SS 433 jets + wind

Combined contributions from east/west lobes and isotropic wind



E^{-2} injection spectrum

Wind luminosity: 10^{39} erg s^{-1}

$B = 25\ \mu$G, $R = 100$ pc

10% of the energy to protons

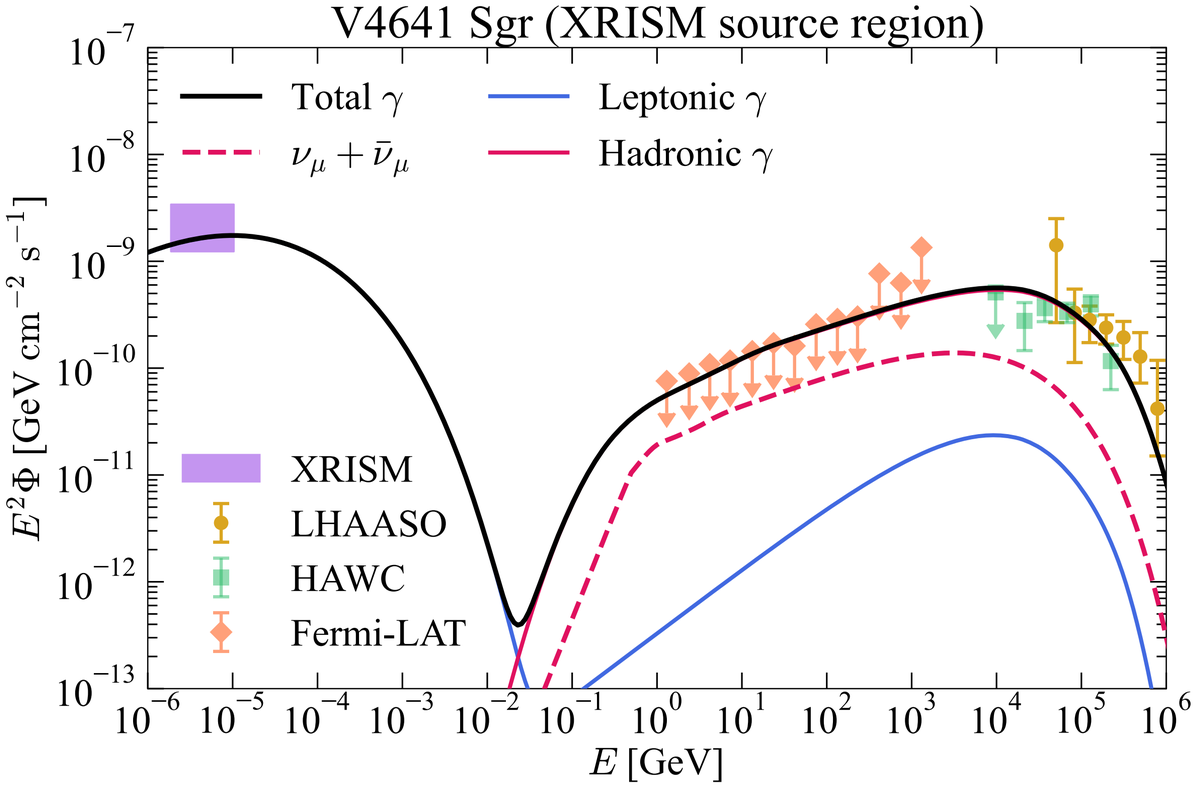
Ambient proton density n_p: 2 cm^{-3}

Wind contributes > 50 TeV γ-rays

Lower n_p reduces the number of γ-rays

V4641 Sgr

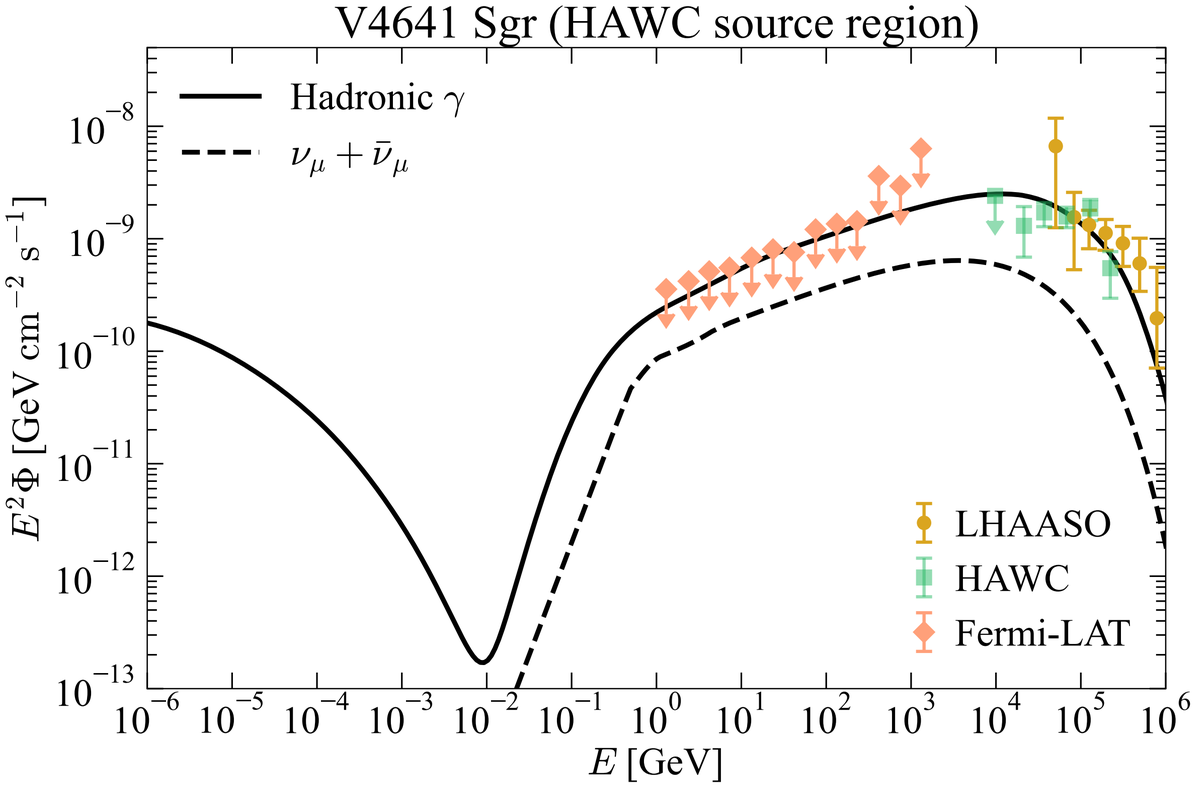
Applying our model to the emission regions observed by XRISM and HAWC ($E^{-1.8}$ spectrum)



Leptohadronic model

$B = 25\ \mu\mathrm{G}$
$R = 16$ pc

Ambient proton density n_p: 20 cm^{-3}



Hadronic model

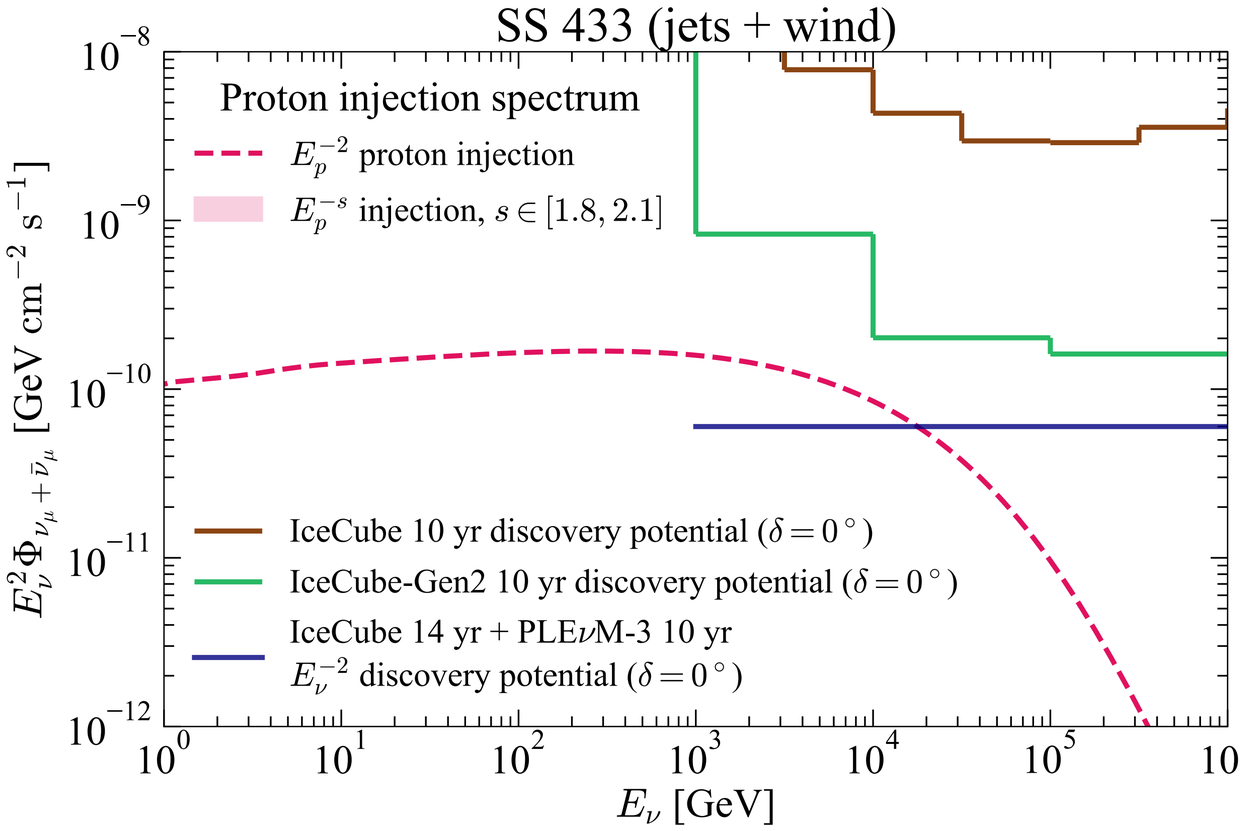
$B = 25\ \mu\mathrm{G}$
$R = 60$ pc

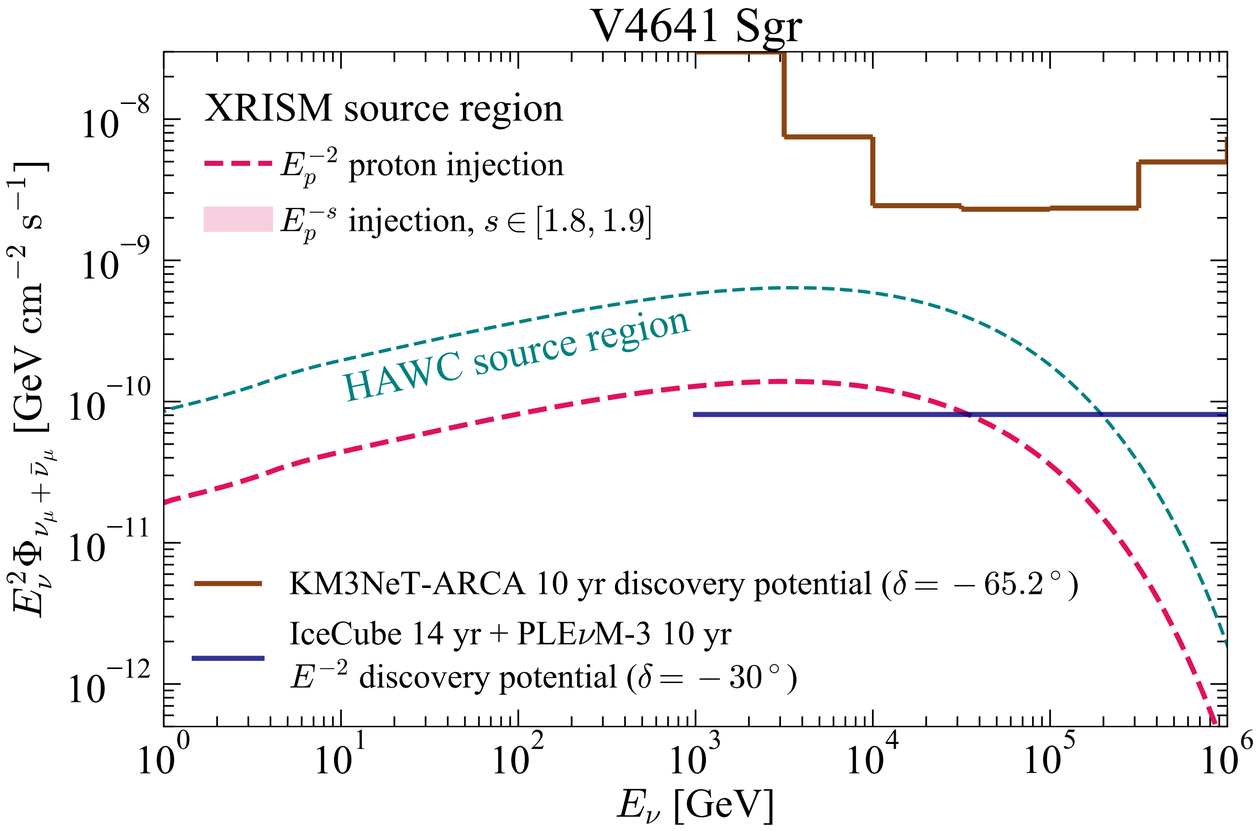
Ambient proton density n_p: 8 cm^{-3}

Neutrino emission

Neutrino detection is a smoking gun for hadronic particle acceleration.

Focus on $\nu_\mu + \bar{\nu}_\mu$ due to improved angular resolution





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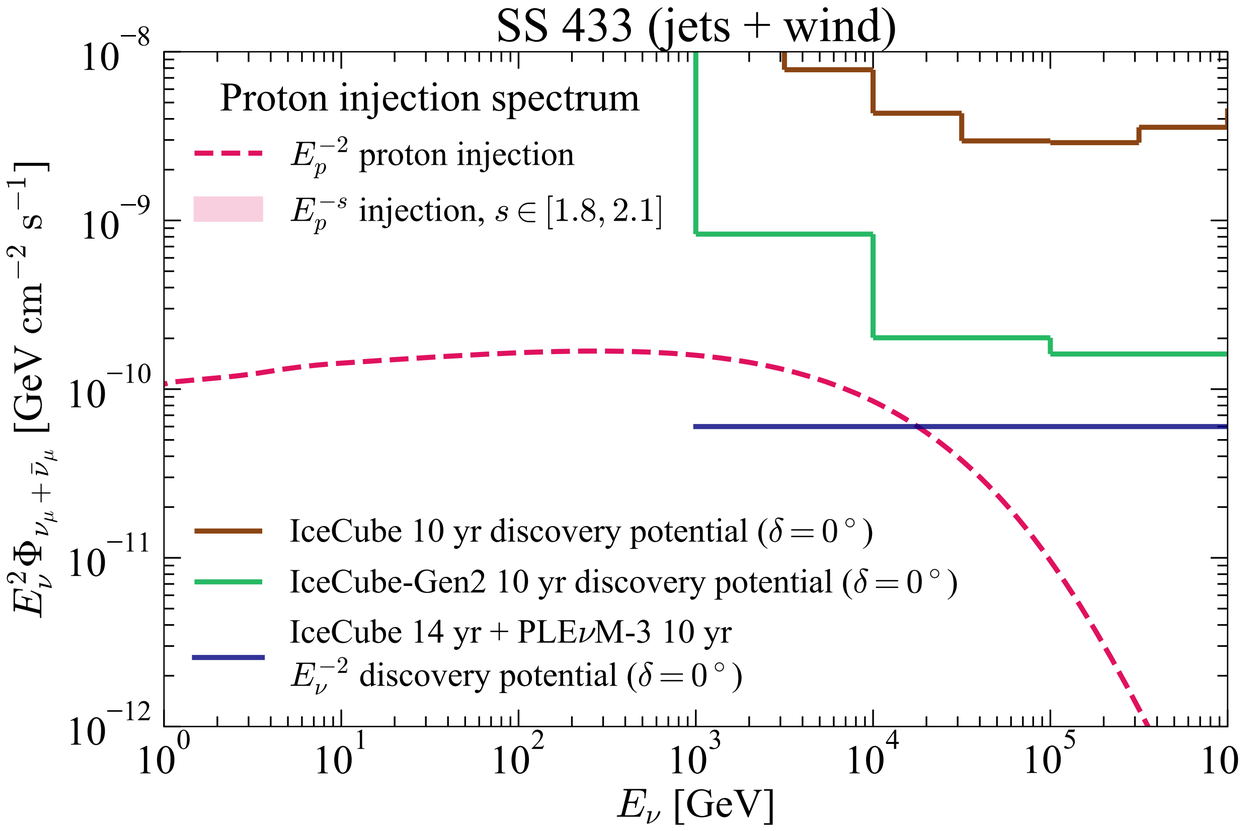

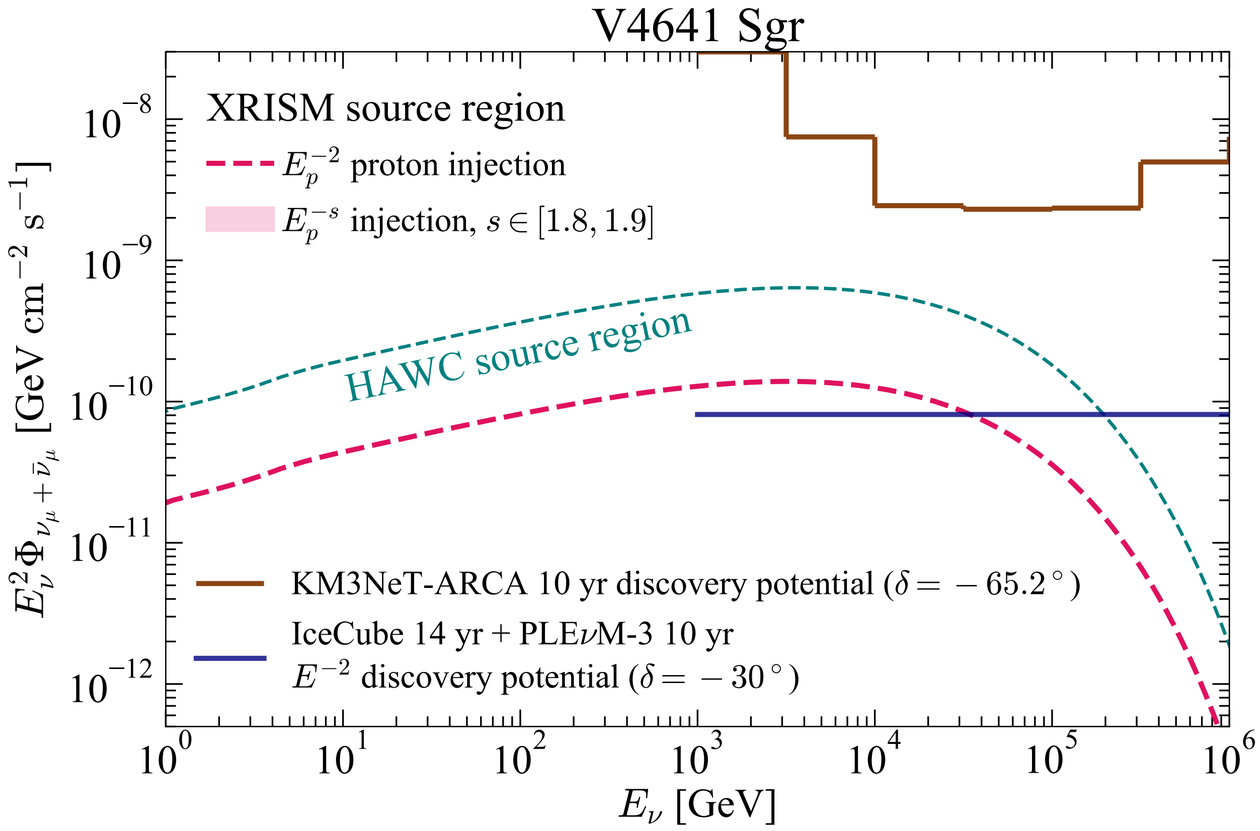

- Next-generation experiments are, individually, unlikely to discover a neutrino signal
- A combined measurement from multiple experiments may lead to a discovery

Summary and outlook

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- Emission of > 100 TeV γ-rays requires particle acceleration
- Neutrino detection prospects are not highly encouraging, and may require multiple next-gen detectors
- X-ray emission limits the total electron energy

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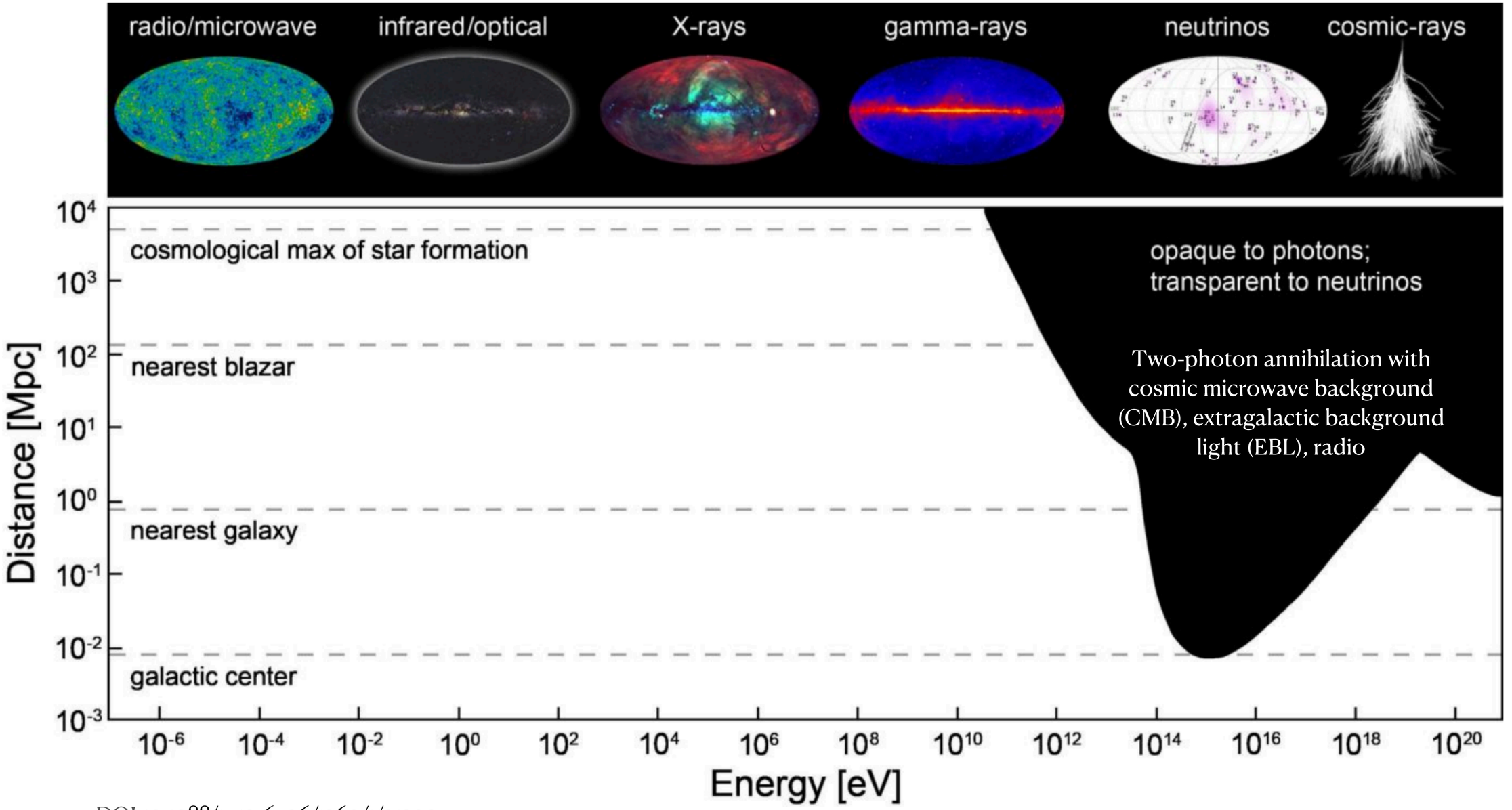
Outlook

- Further GeV measurements can constrain hadronic models
- Additional 10 TeV - >100 TeV data useful to identify γ-ray cutoffs and implications for maximum hadron/lepton energies

The photon horizon



DOI:10.1088/1742-6596/1269/1/012005

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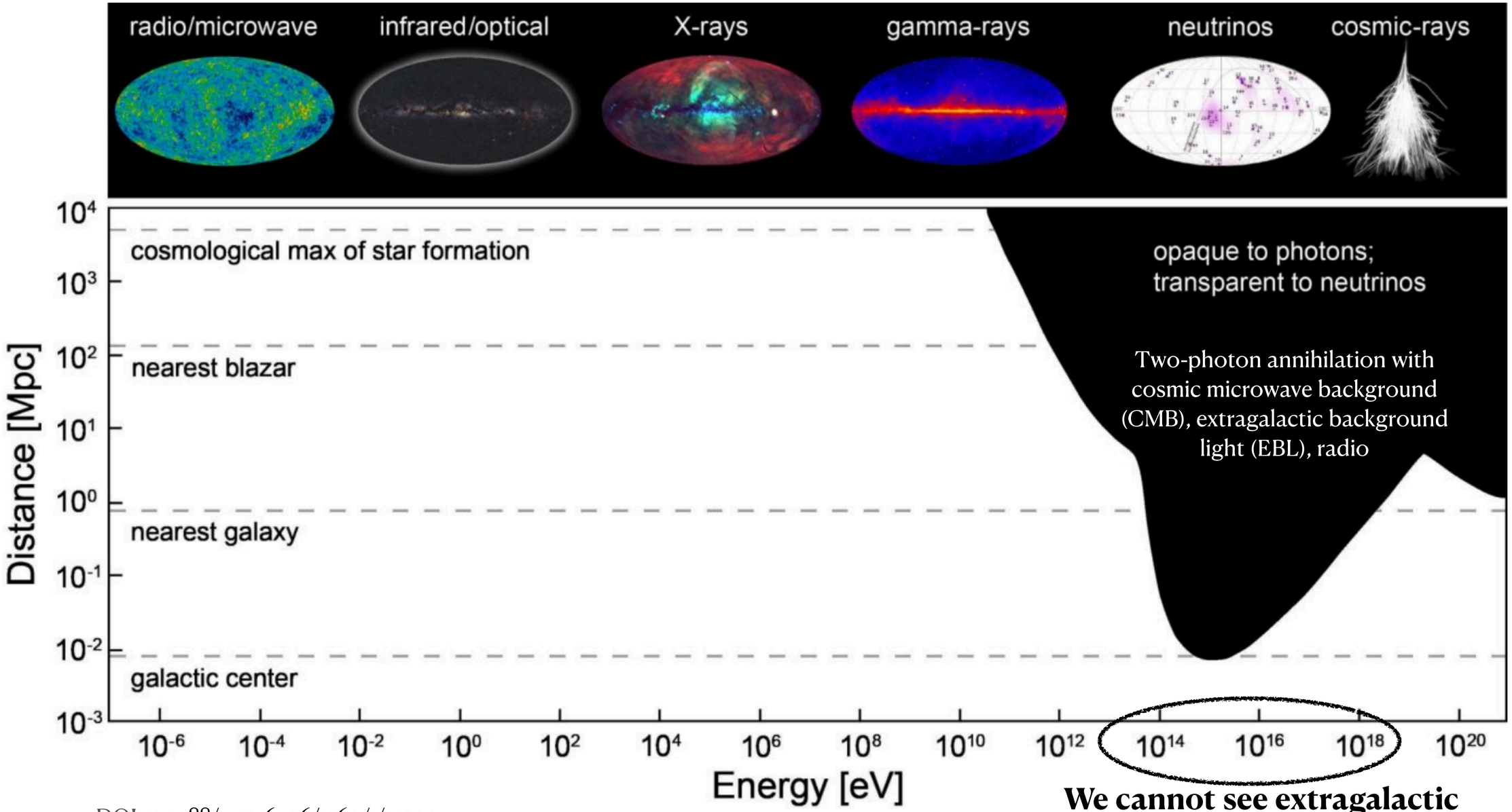

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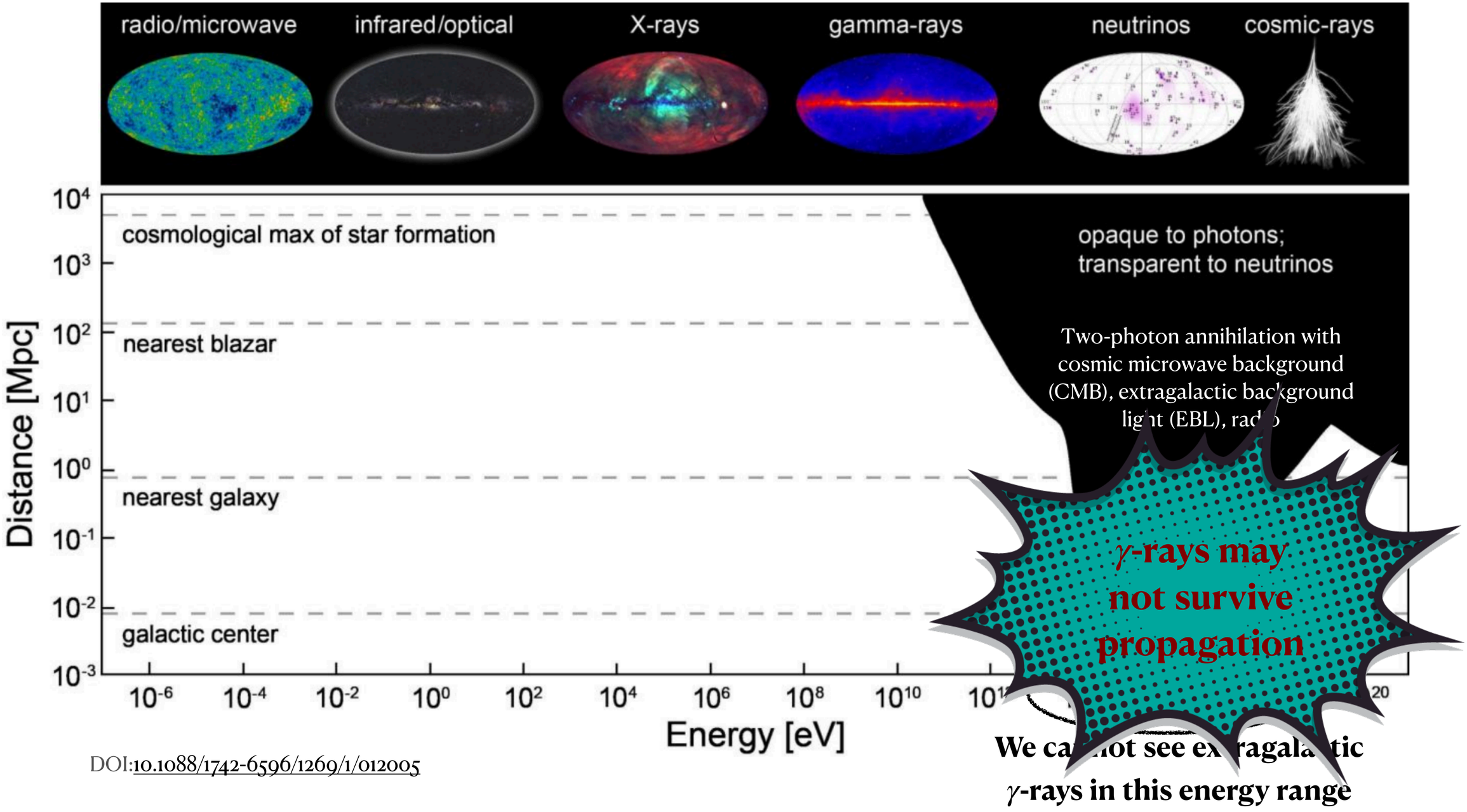
We cannot see extragalactic γ-rays in this energy range

The photon horizon



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