



credit: Yuya Makino

Cosmogenic neutrinos from the high-redshift universe

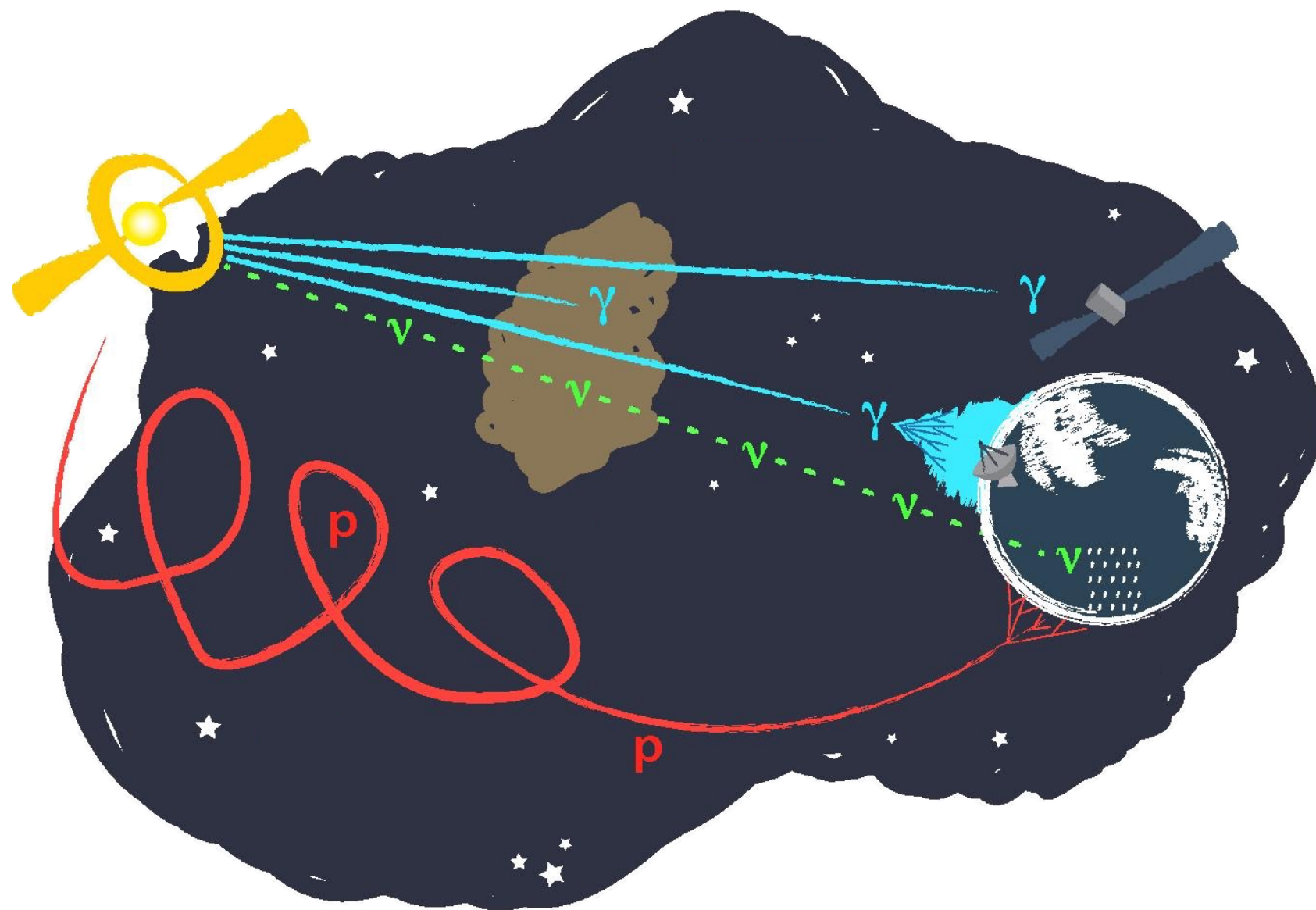
TeVPA 2026

Maximilian Meier, Shigeru Yoshida

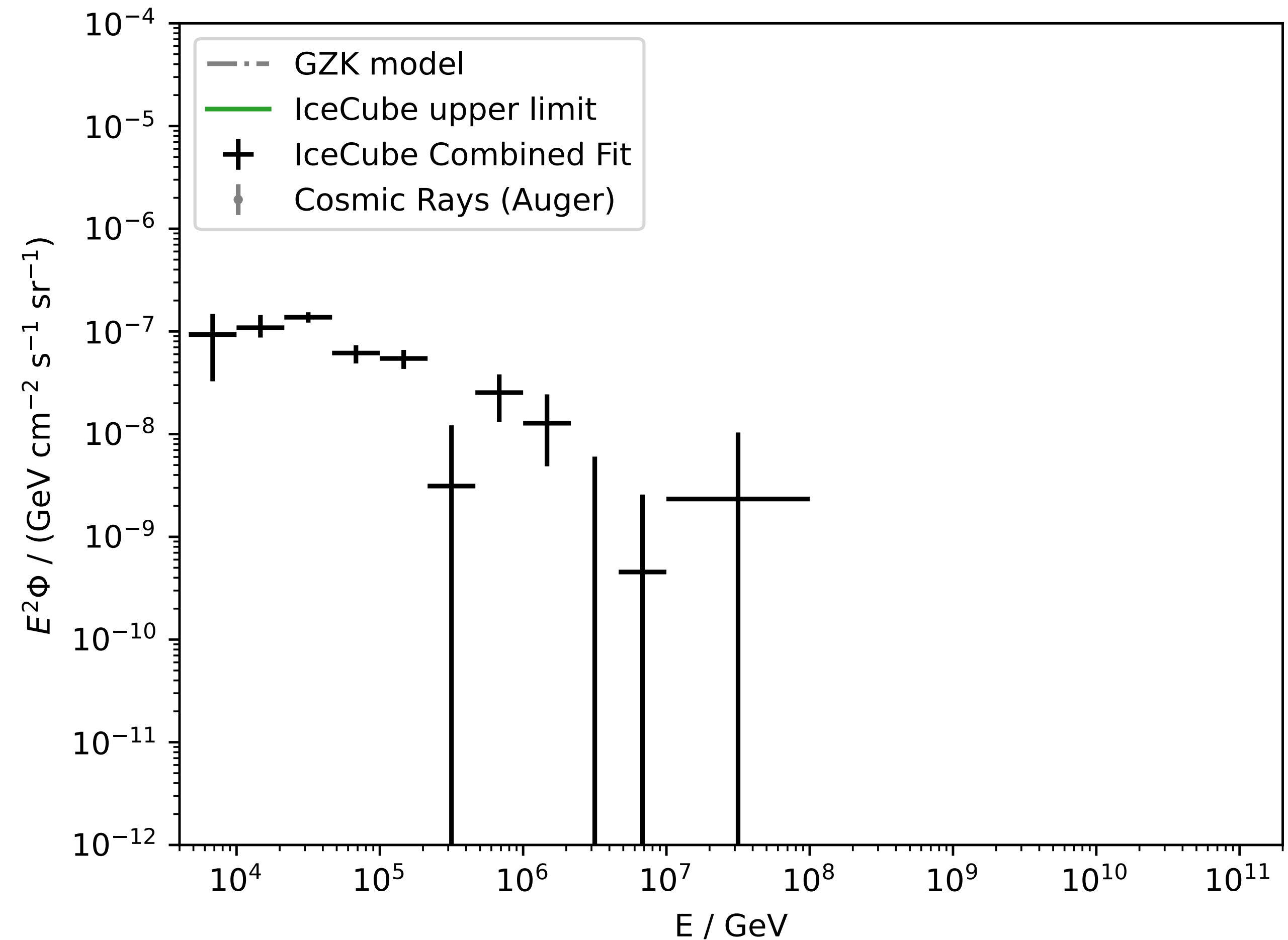
2026.09.02

High-energy neutrino landscape

- Diffuse high-energy neutrino flux is getting characterised in more detail by IceCube
- Astrophysical neutrinos described well by a broken power law from **5 TeV** to **10 PeV** with a break around $\sim 30 \text{ TeV}$

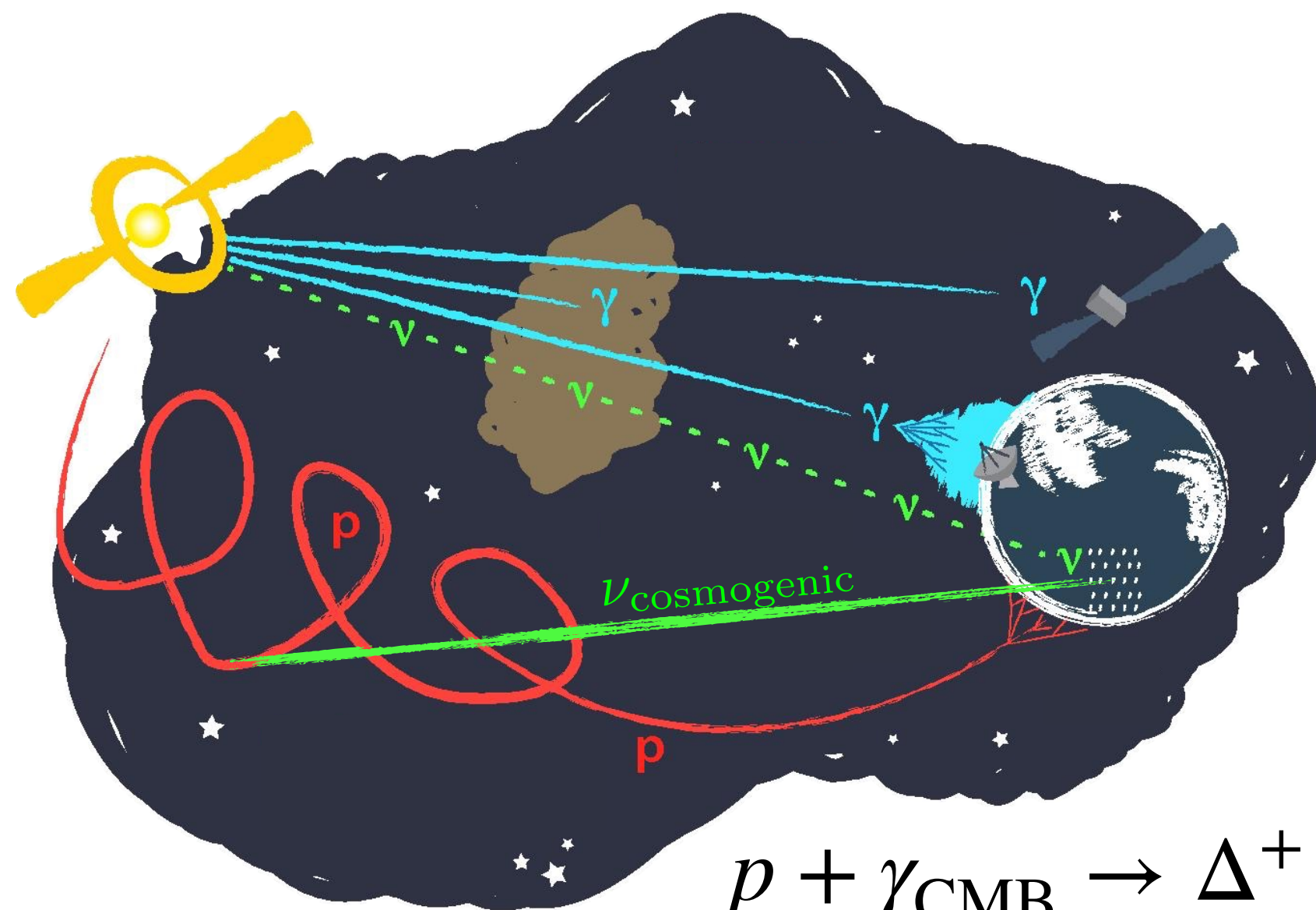


IceCube Combined Fit: Phys.Rev.Lett. 136 (2026) 121002

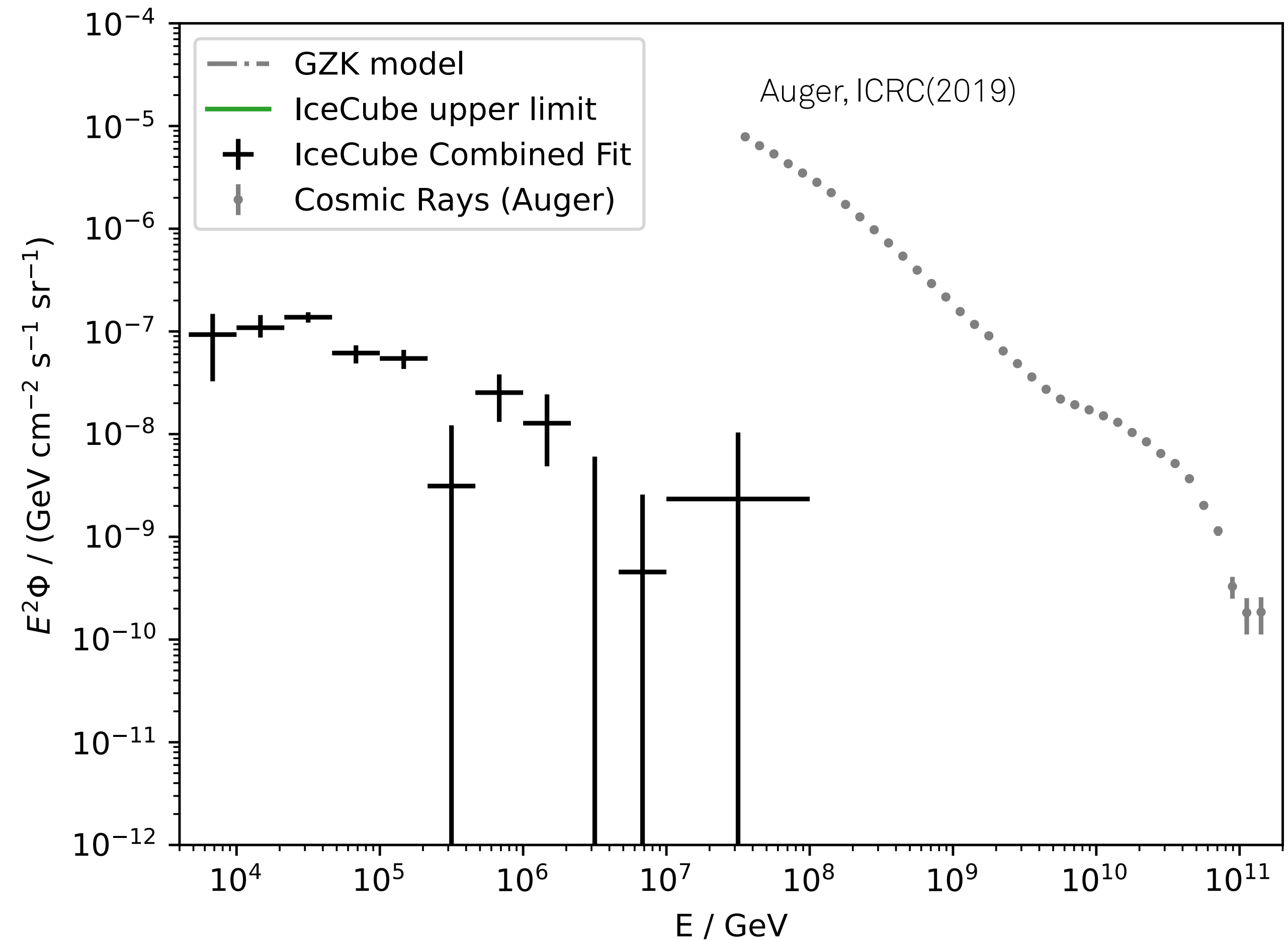


High-energy neutrino landscape — Cosmogenic neutrinos

- Distinct component expected to arise from interactions between ultrahigh-energy CRs and background photons in the universe
- Required conditions
 - Substantial proton fraction f_p at $E_{p,\text{max}} \gtrsim E_{\text{GZK}}$
 - Many distant sources contribute to a large flux



$$p + \gamma_{\text{CMB}} \rightarrow \Delta^+ \rightarrow \nu + X$$

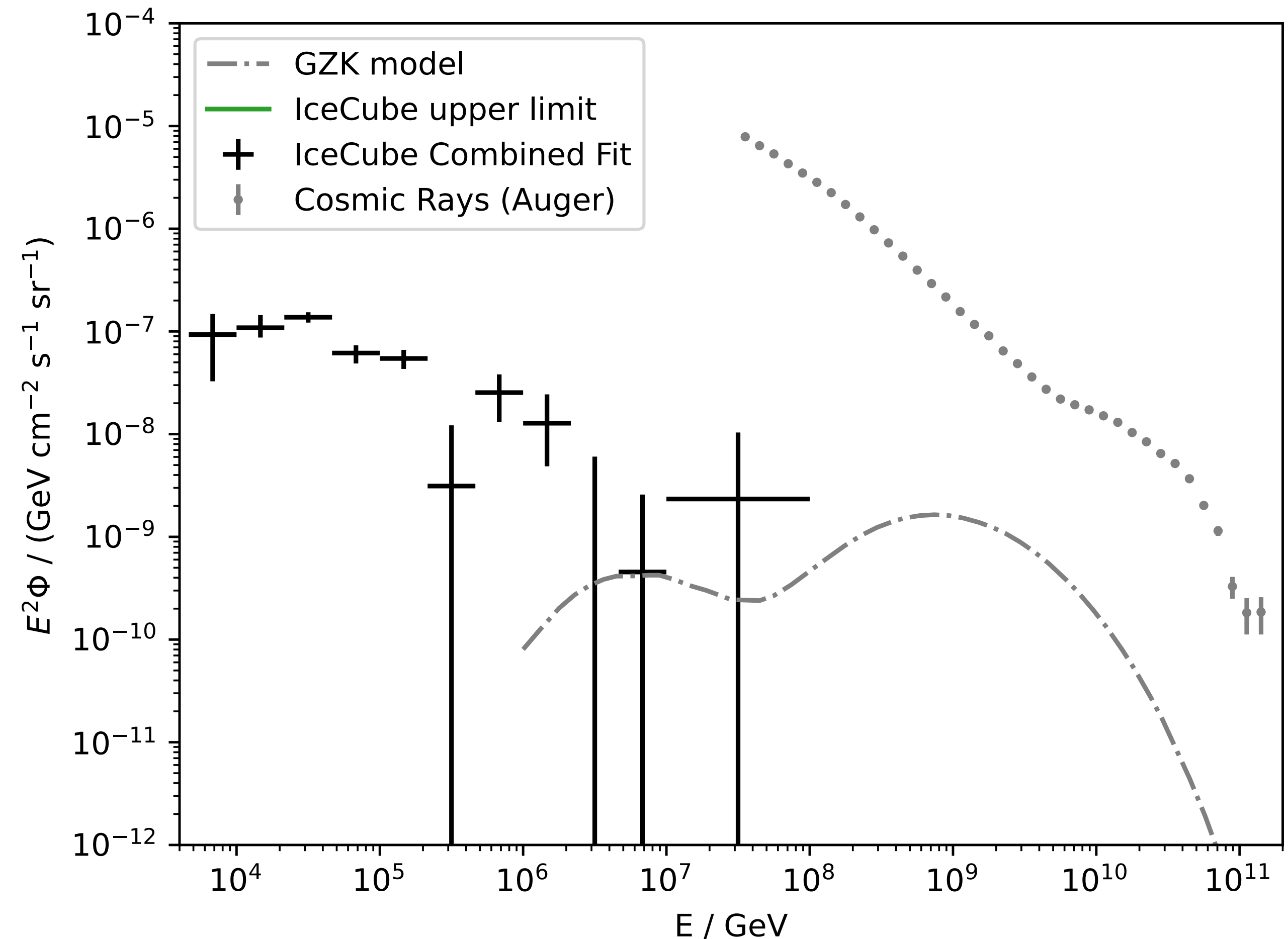
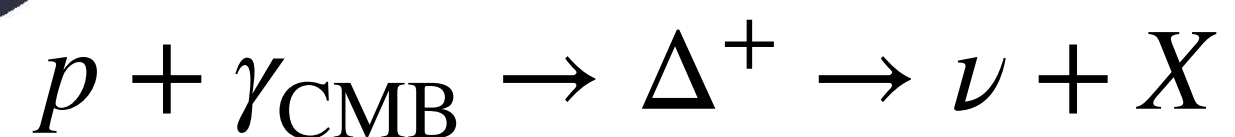
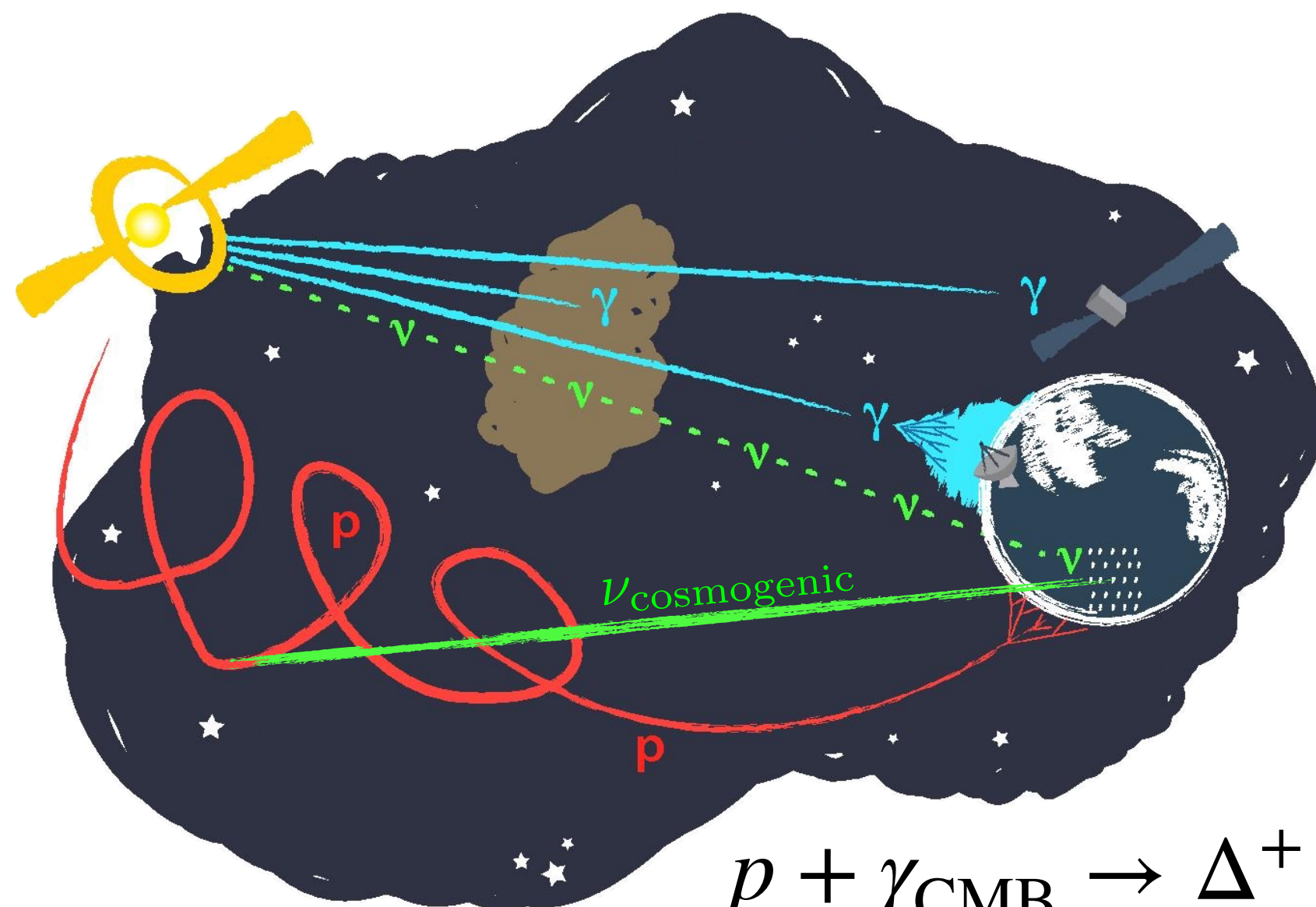


High-energy neutrino landscape — Cosmogenic neutrinos

GZK model from [van Vliet et al. \(2019\)](#)

$$f_p = 0.1, m = 3.4, E_{p,\max} = 10^{20} \text{ eV}, \alpha = 2.5$$

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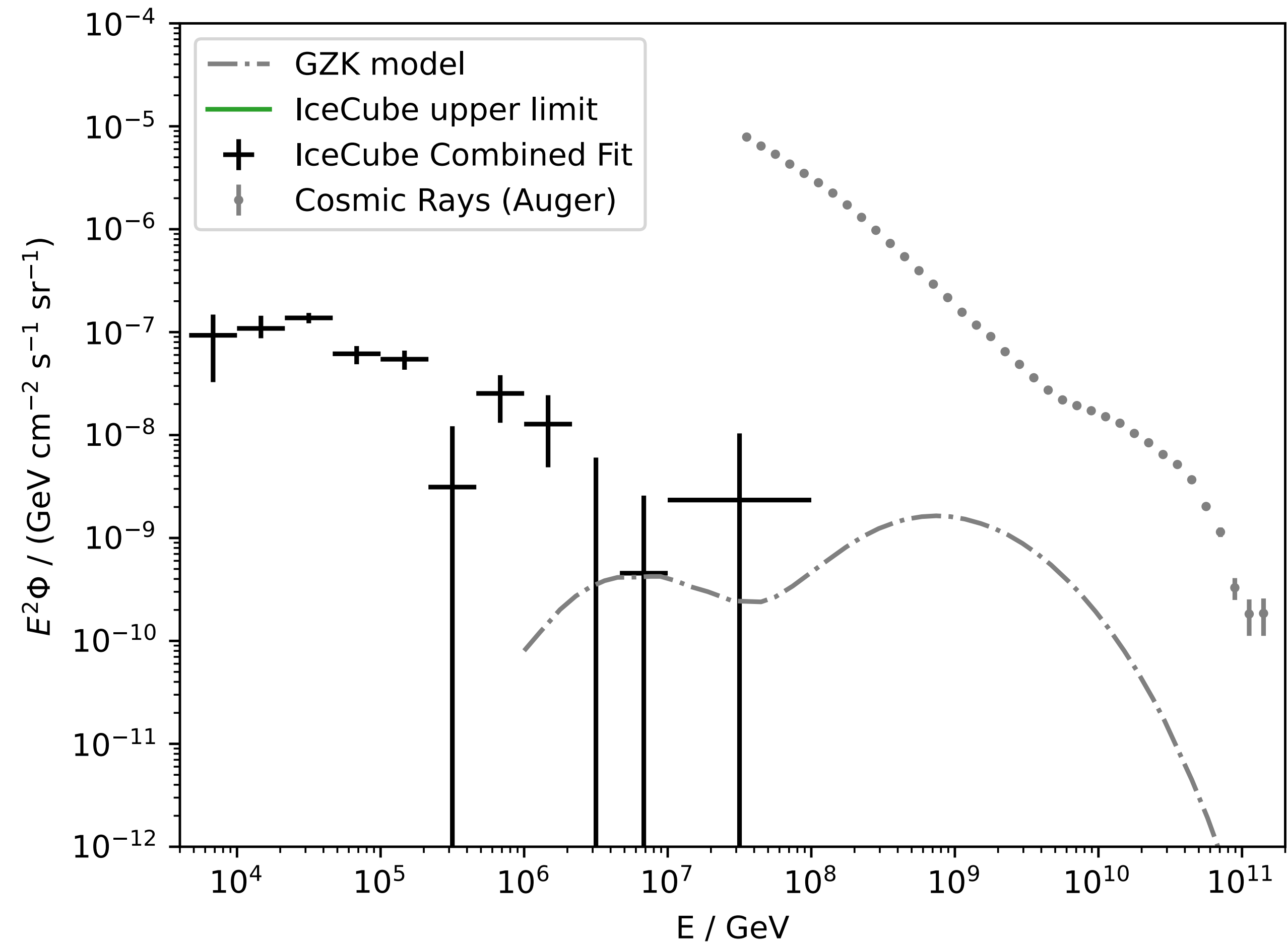
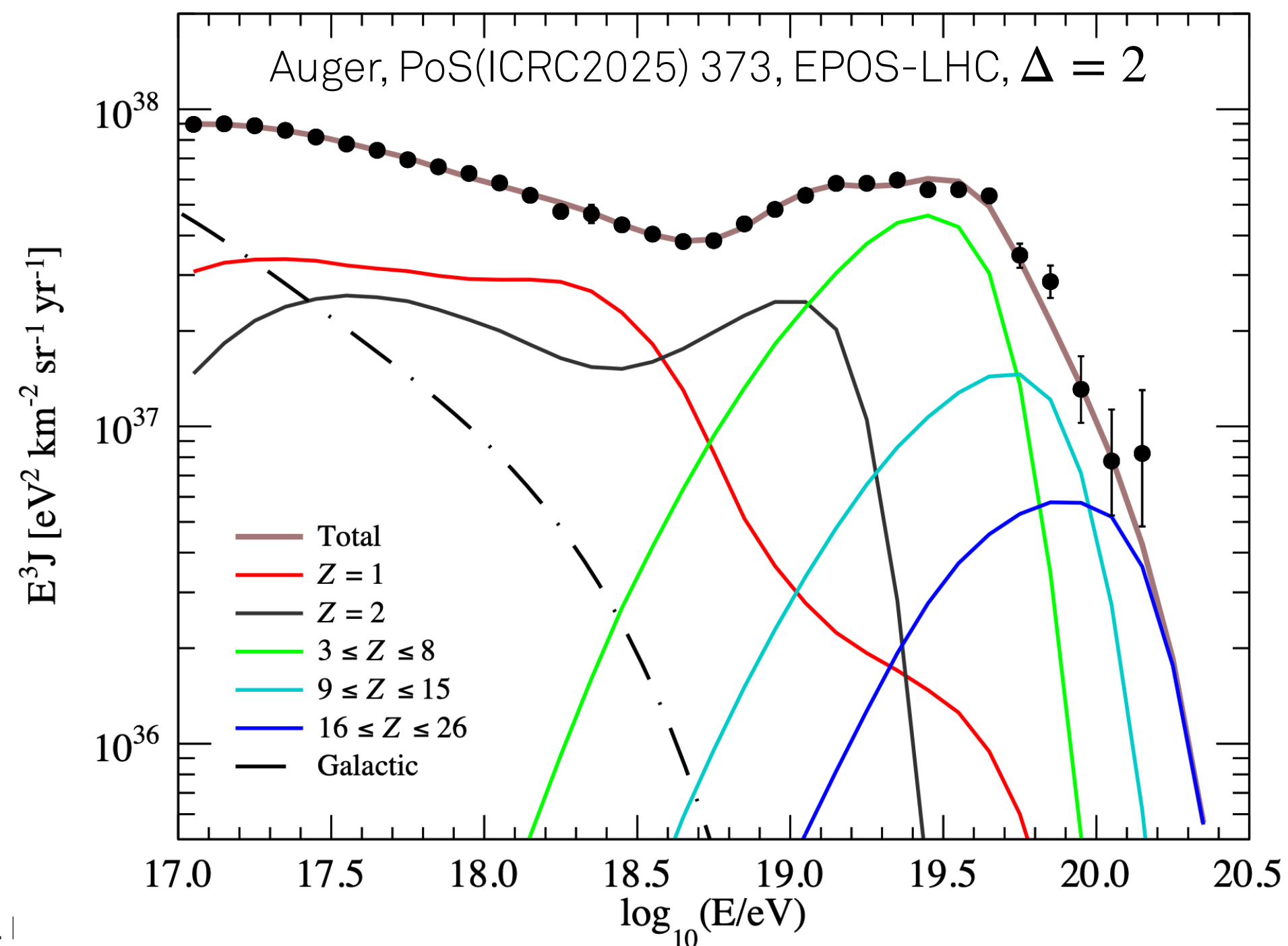


High-energy neutrino landscape — Cosmogenic neutrinos

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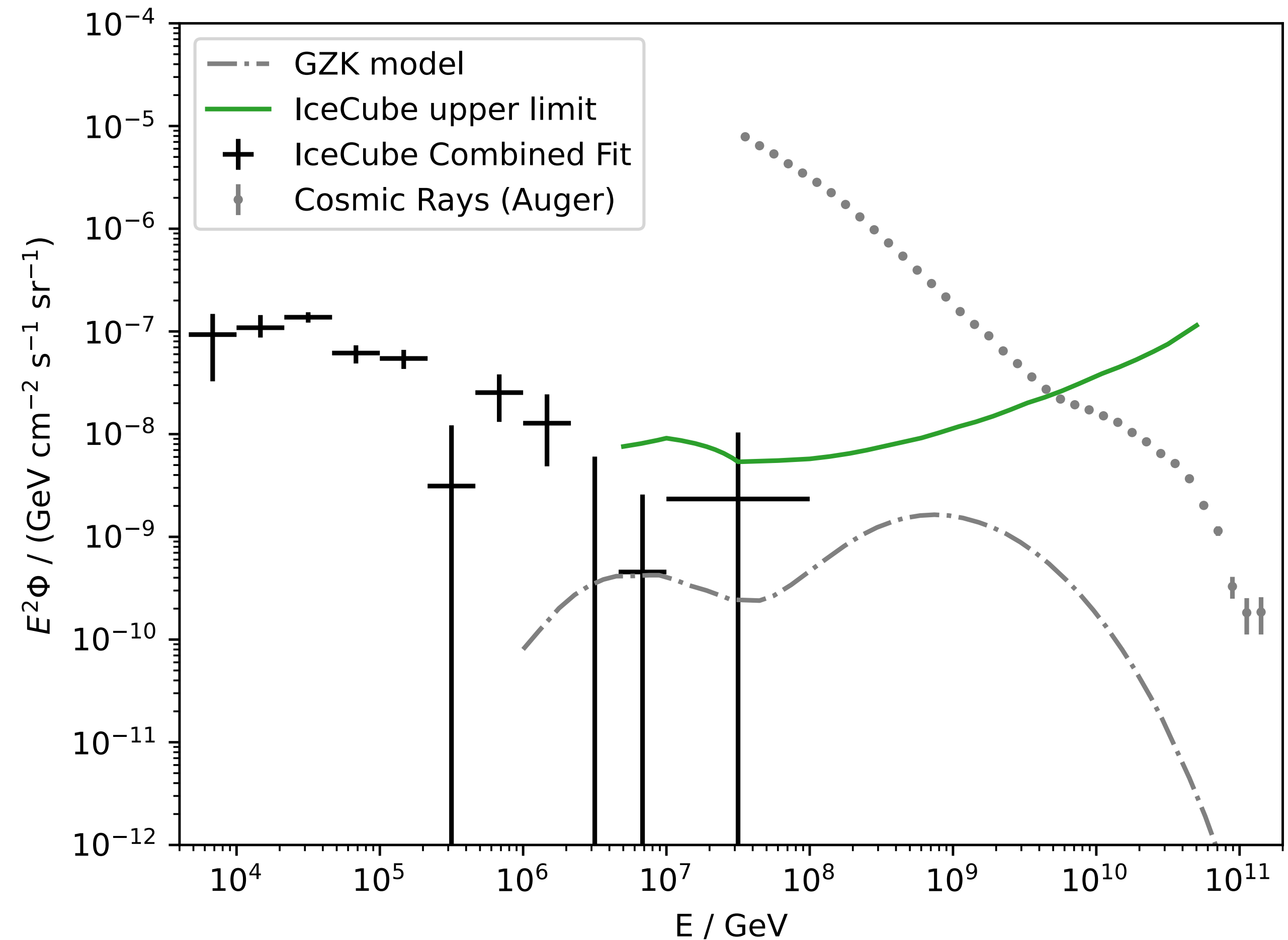
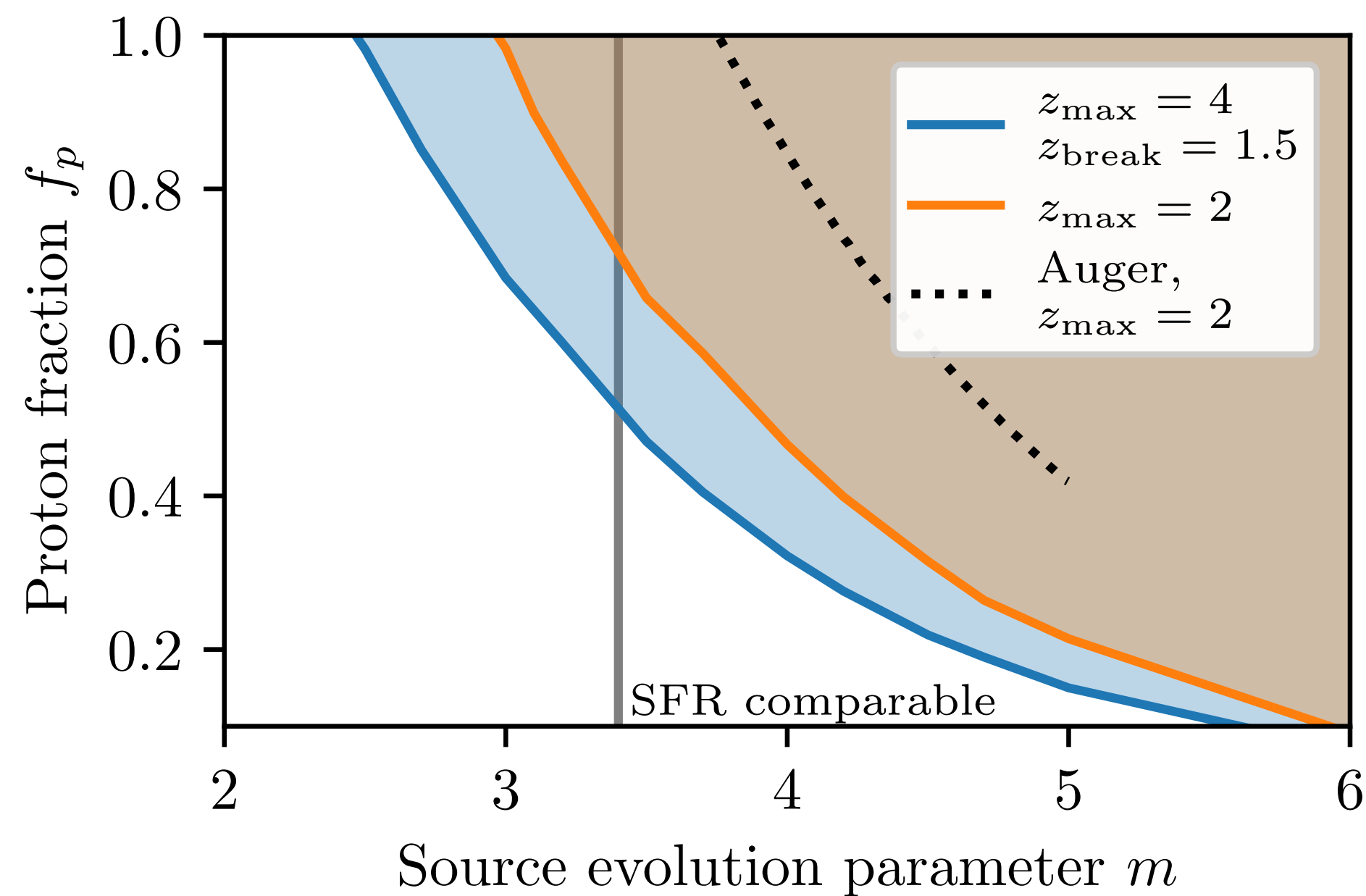
- Challenges for cosmogenic neutrinos
 - Cosmic ray data suggests heavy composition at highest energies $f_p \ll 1$
 - $E_{p,\max} \not\gg E_{\text{GZK}}$ (rigidity dependent $E_{\max}$)



High-energy neutrino landscape — Cosmogenic neutrinos

IceCube EHE limit, Phys. Rev. Lett. 135, 031001 (2025)

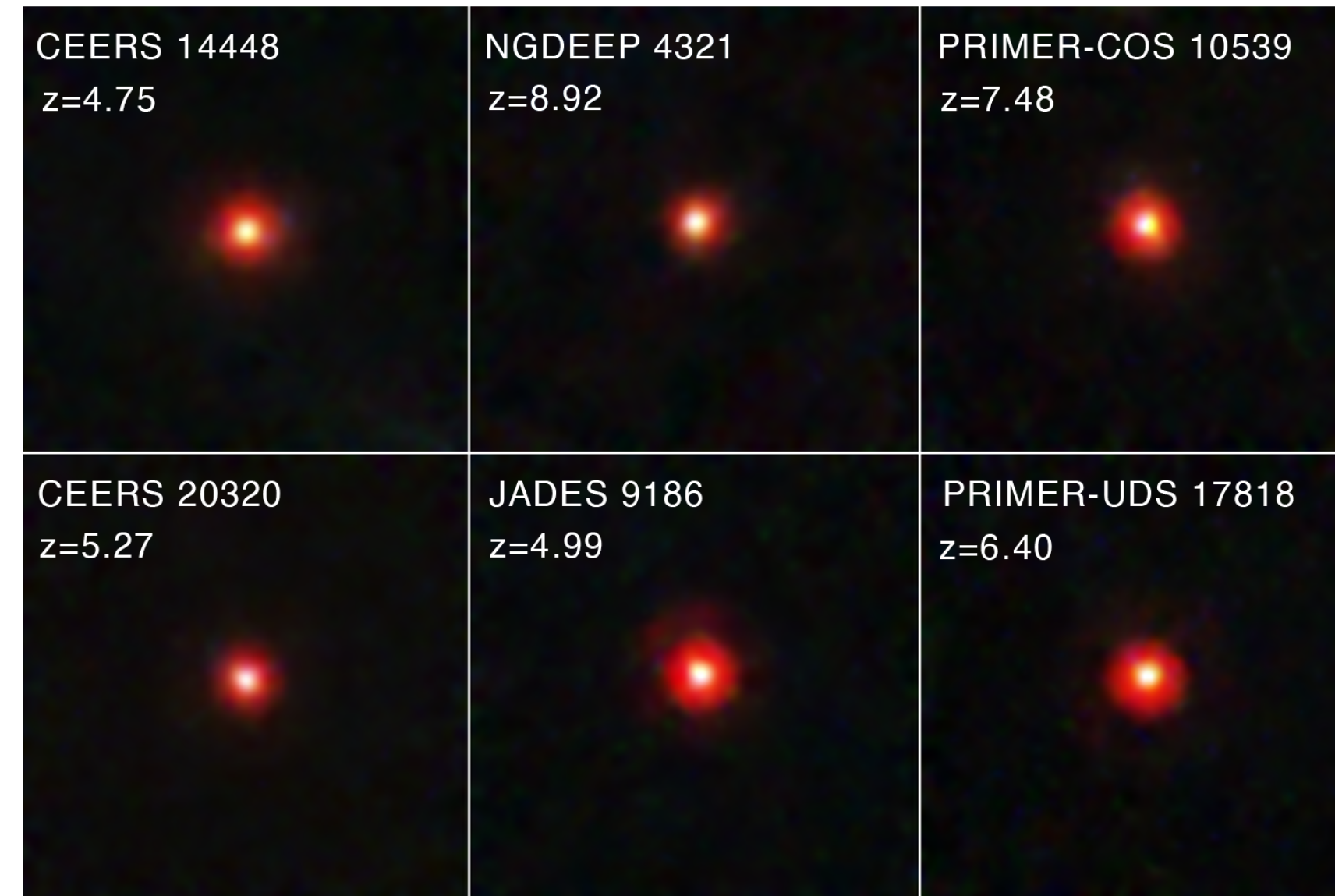
- Flux of neutrinos above **5 PeV** constrained by IceCube
- Also constrains $f_p < 1$ for large portion of source evolution phase space



Little Red Dots

- Large population of AGN in the high redshift universe ($z > 5$) discovered in JWST data
- Appear as compact red objects
→ Little red dots
- Bolometric luminosity in infrared band
 $L_{\gamma, \text{bol}} \sim 10^{43-46} \text{ erg/s}$
- From Hillas criterion:
LRDs may be able to accelerate CR protons up to

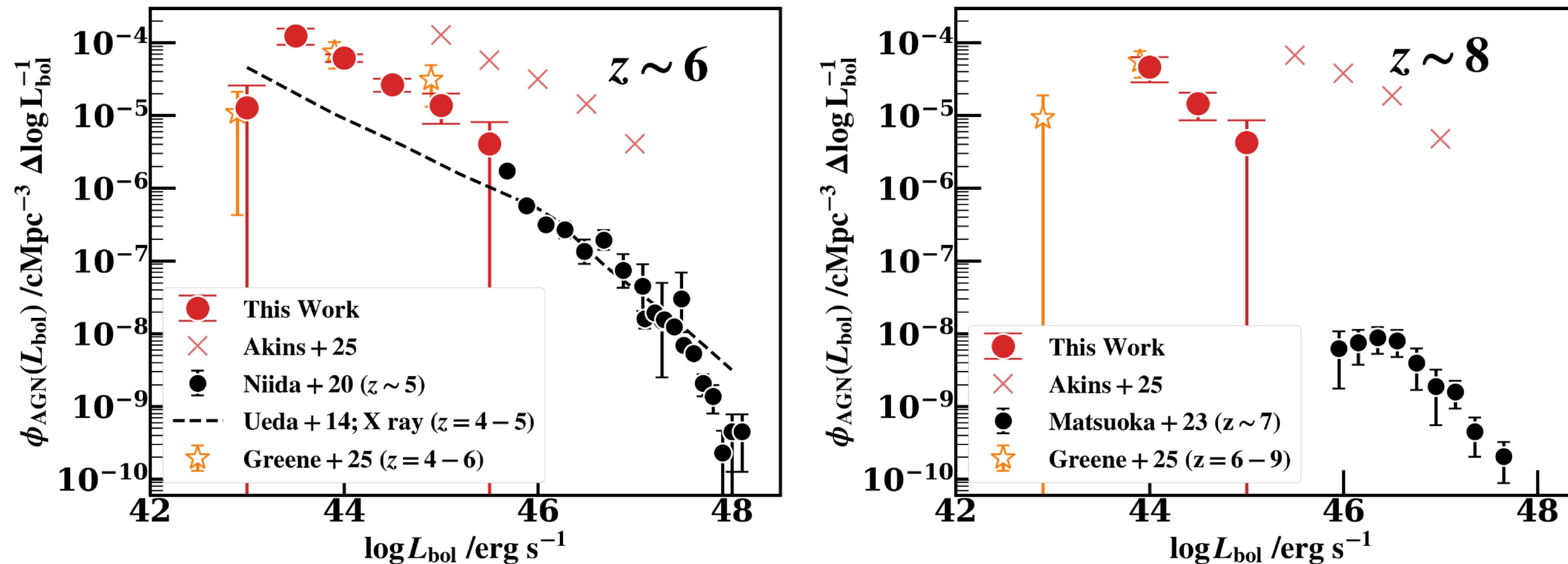
$$\varepsilon_{p, \text{max}} \simeq 8 \cdot 10^{10} \text{ GeV} \left(\frac{L_{\gamma}}{10^{45} \text{ erg/s}} \right)^{1/2} (\xi_B)^{1/2}$$



Little Red Dots

■ Luminosity function of LRDs

Umeda et al 2026 ApJ 999 183



Based on
JWST data

■ Interesting properties for cosmogenic neutrinos

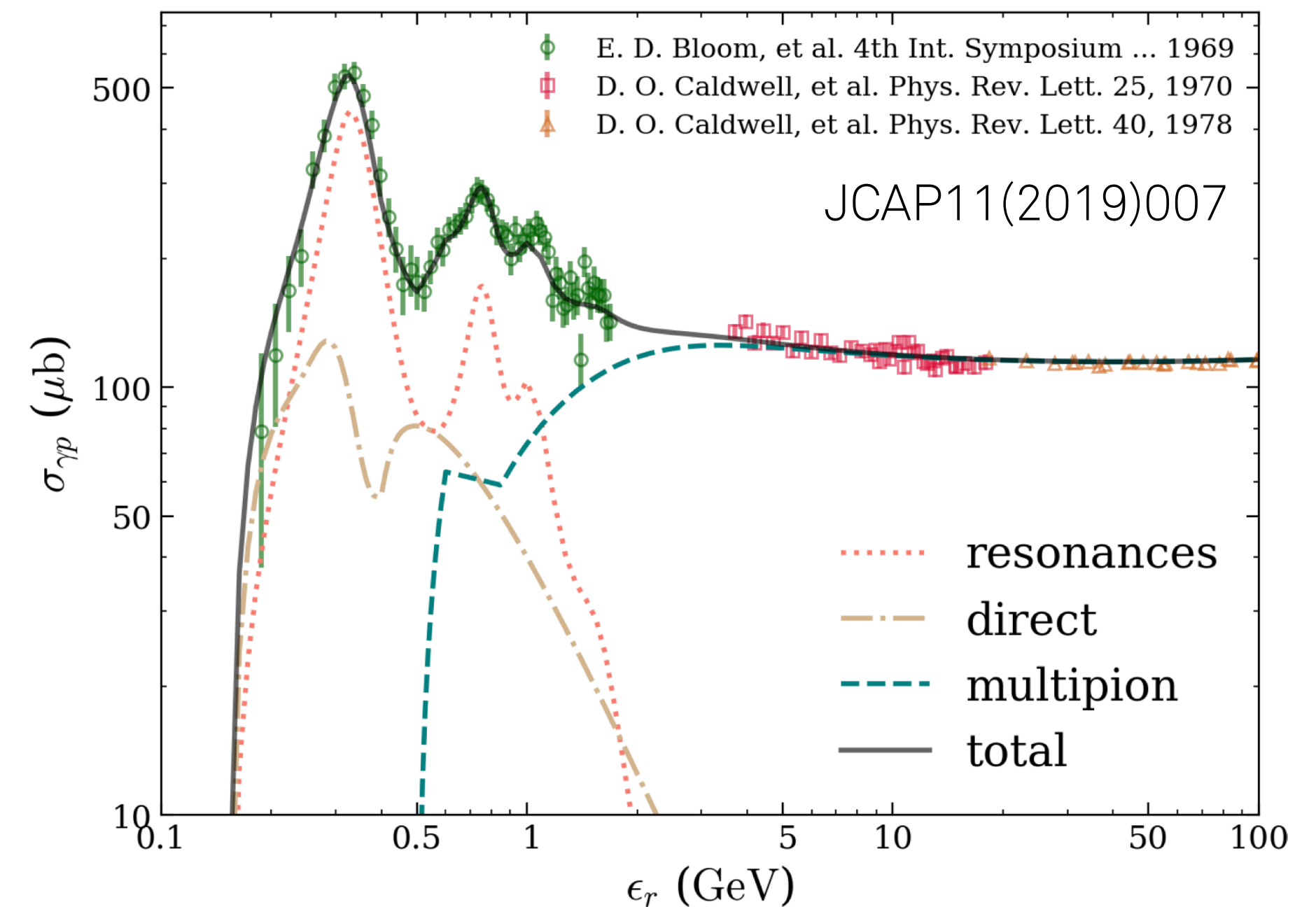
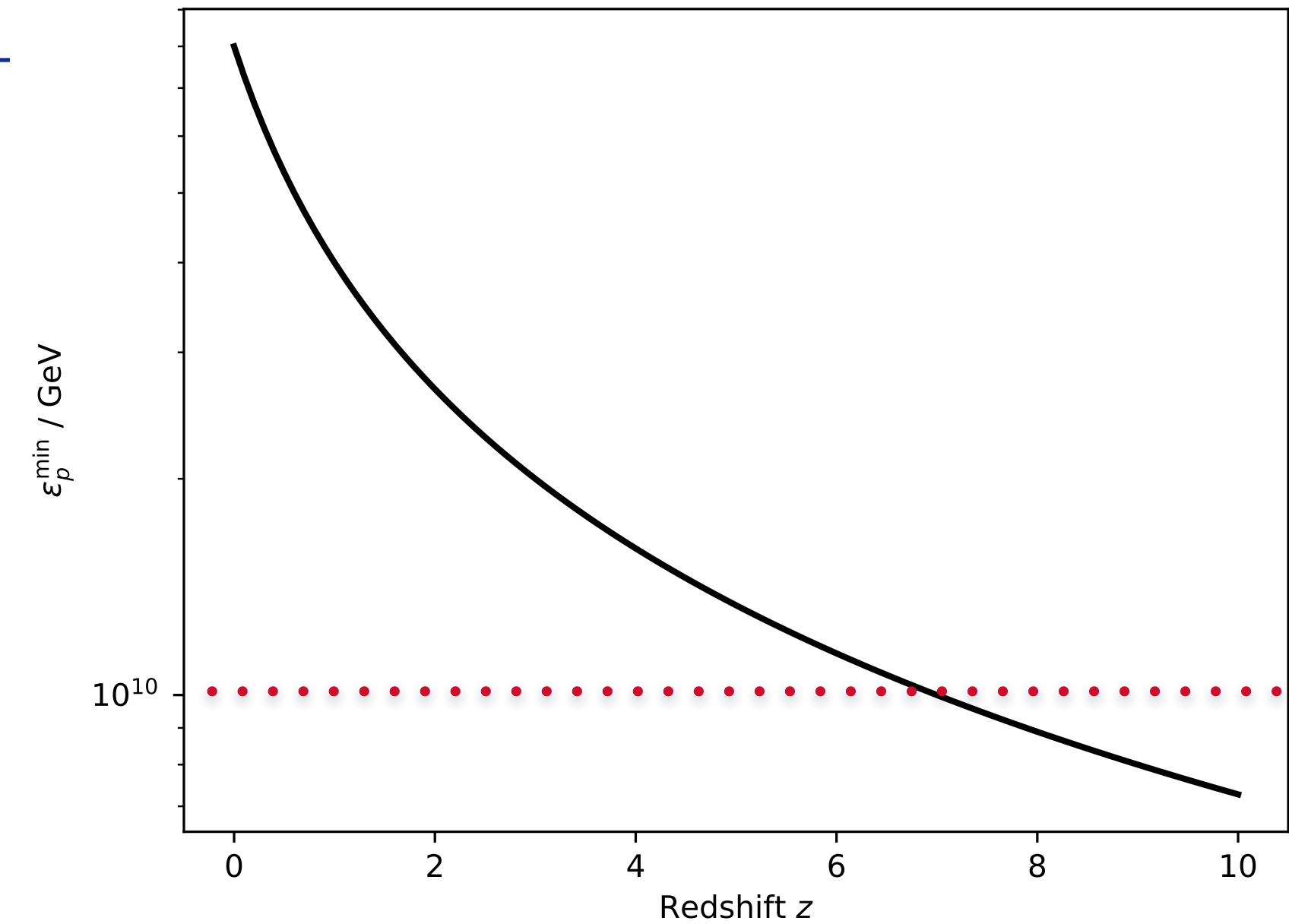
- Low metallicity $\rightarrow$ plausible to produce a proton dominated flux of CRs
- High-redshift CMB is hotter than in the present universe $\rightarrow$ Lower energy threshold for photo-pion production

Cosmogenic neutrinos from the high- z Universe

- High-redshift CMB is hotter than in the present universe
→ Lower energy threshold for photo-pion production

$$\epsilon_p^{\min} \gtrsim \frac{8 \cdot 10^{10}}{1+z} \text{ GeV}$$

- Allows for cosmogenic neutrino production from the early universe with lower energies protons
- Producing a neutrino bump at lower energies compared to „local cosmogenic neutrinos“

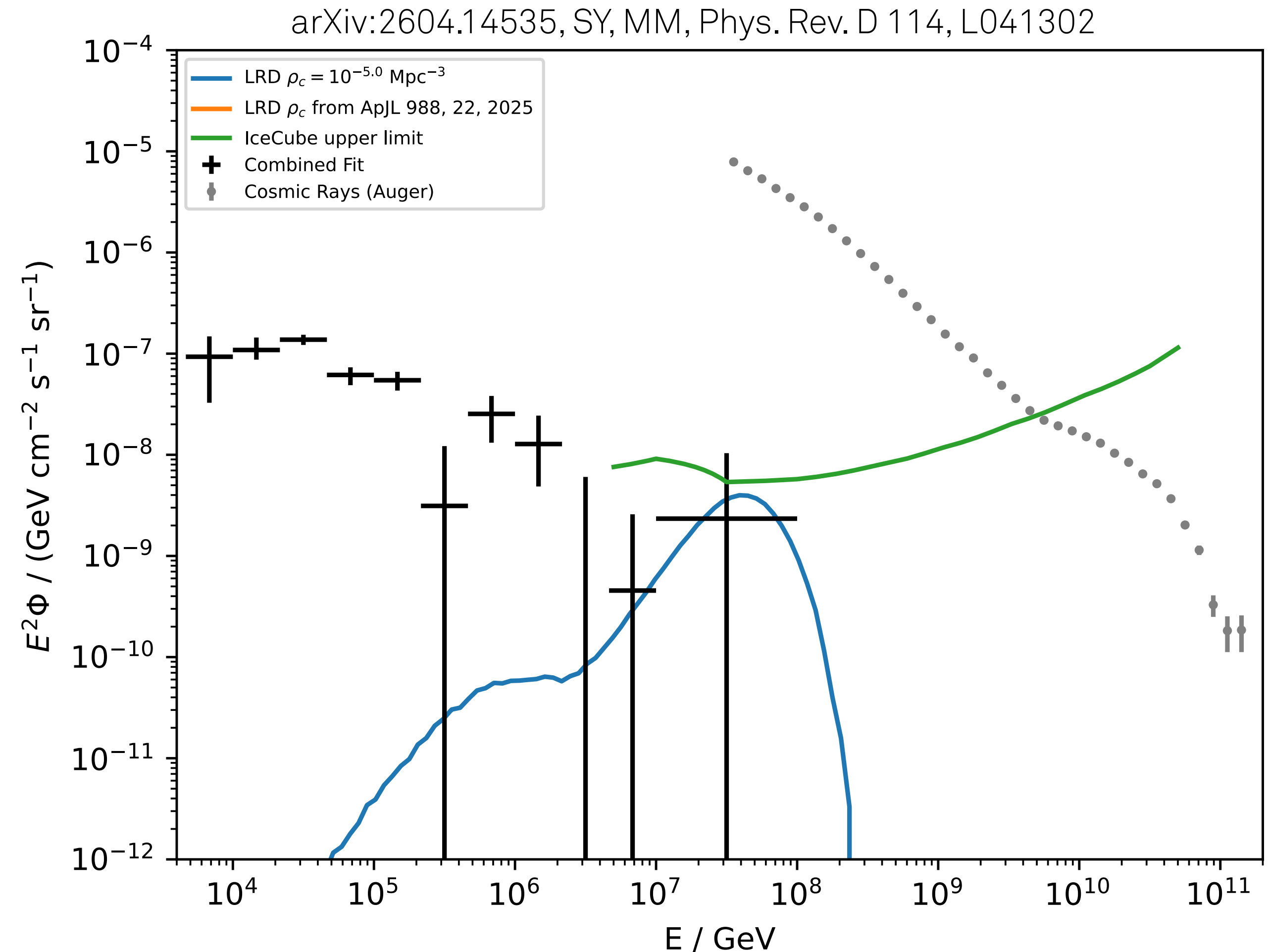


Cosmogenic neutrinos from LRDs

- Using CRPropa, we simulated the production of cosmogenic neutrinos from potential high energy protons from LRDs
- Assuming
 - Luminosity density:

$$n_0 \cdot L_{\text{CR}} \sim 10^{-5} \text{ Mpc}^{-3} \times 10^{45} \text{ erg/s}$$
 - Proton emission with:

$$\varepsilon_{p,\text{max}} \sim 10^{10} \text{ GeV}, \gamma = 2$$
- Without fine-tuning, find a ν flux consistent with IceCube measurements above 10 PeV

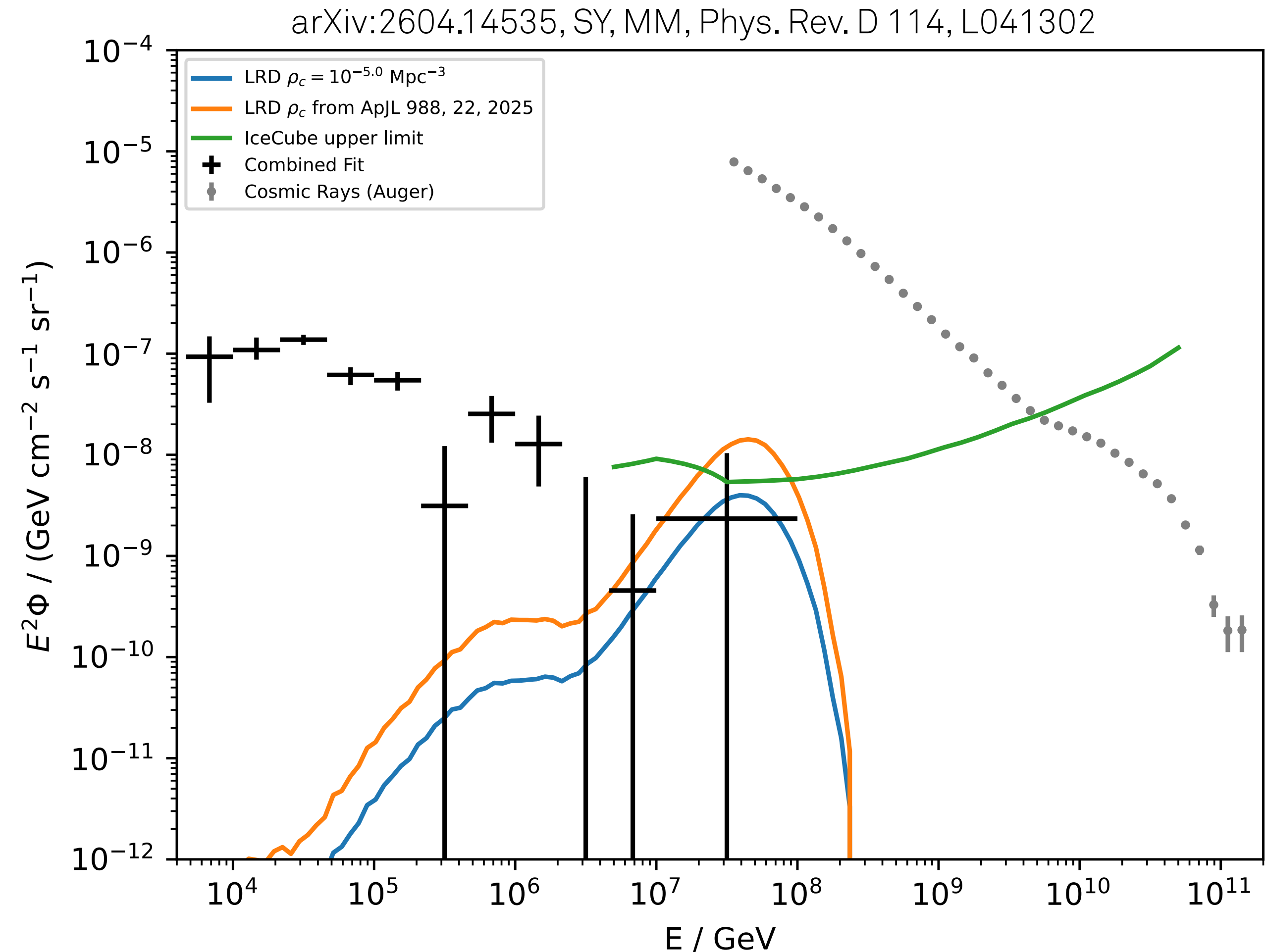


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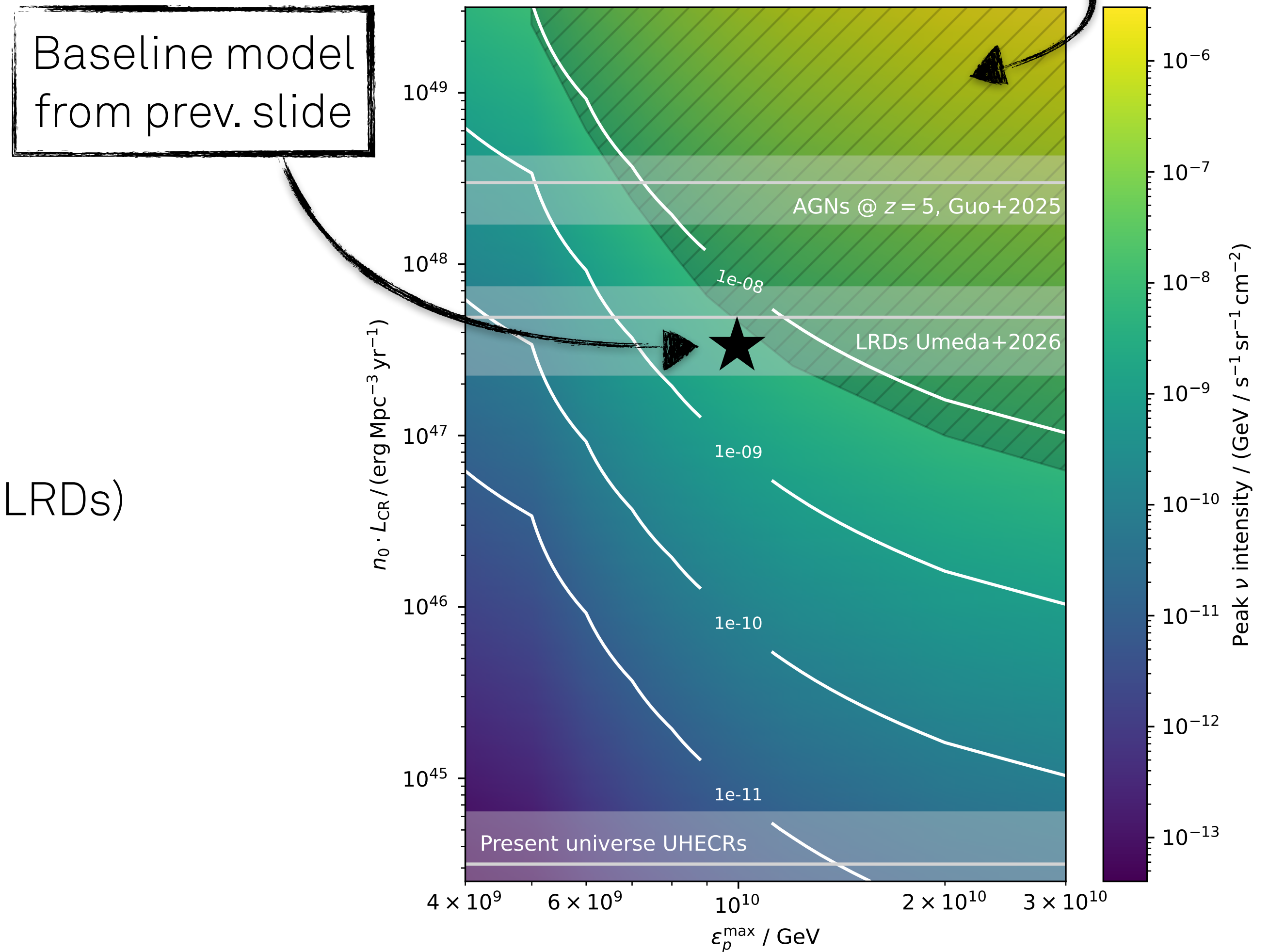
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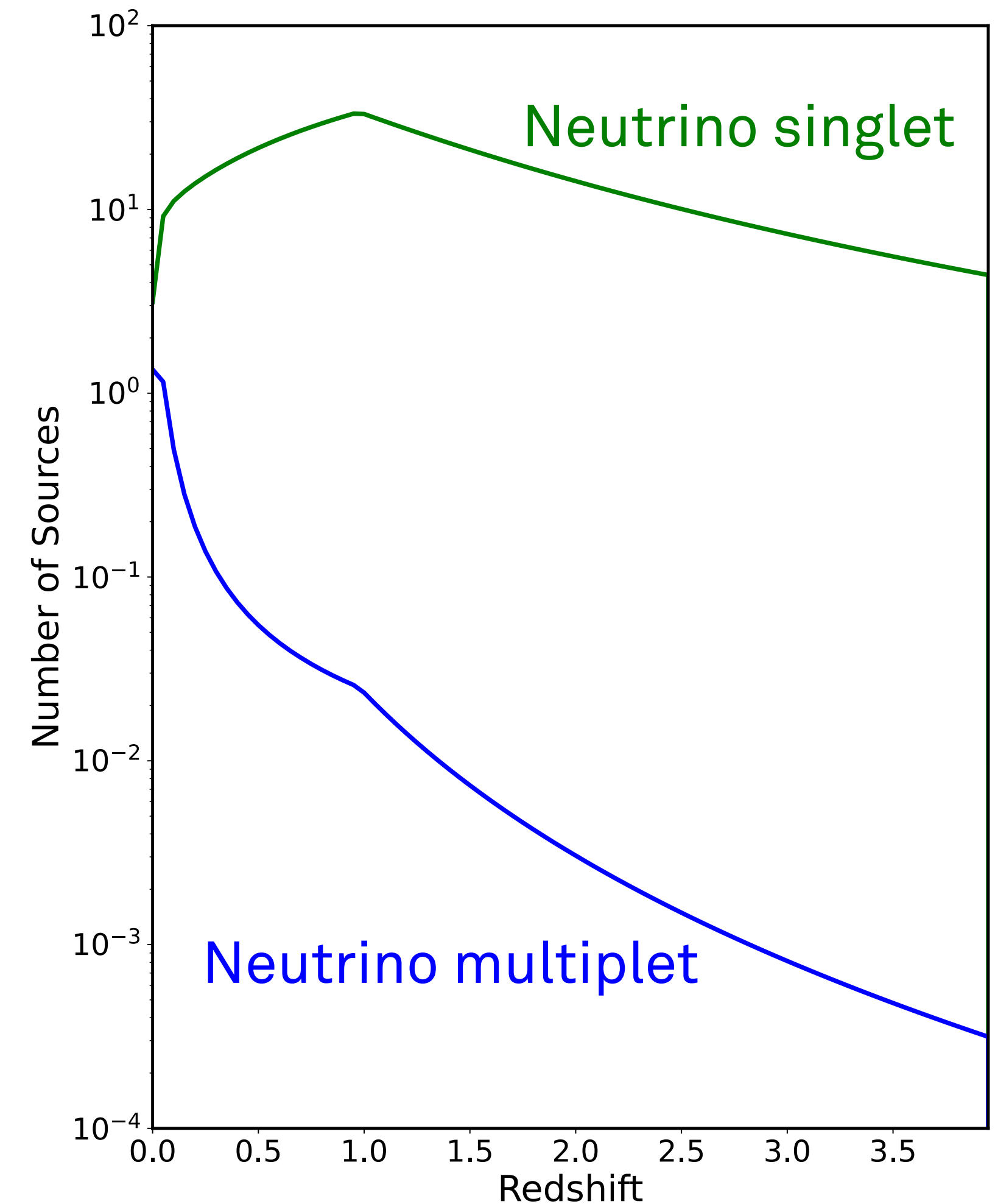
Cosmogenic neutrinos from LRDs

- Strong dependence on the maximum energy near photo-pion production threshold
- Population of broad-line AGNs may also be capable of emitting high-energy protons
 - Fainter bolometric luminosities (compared to LRDs)
 - Higher number density



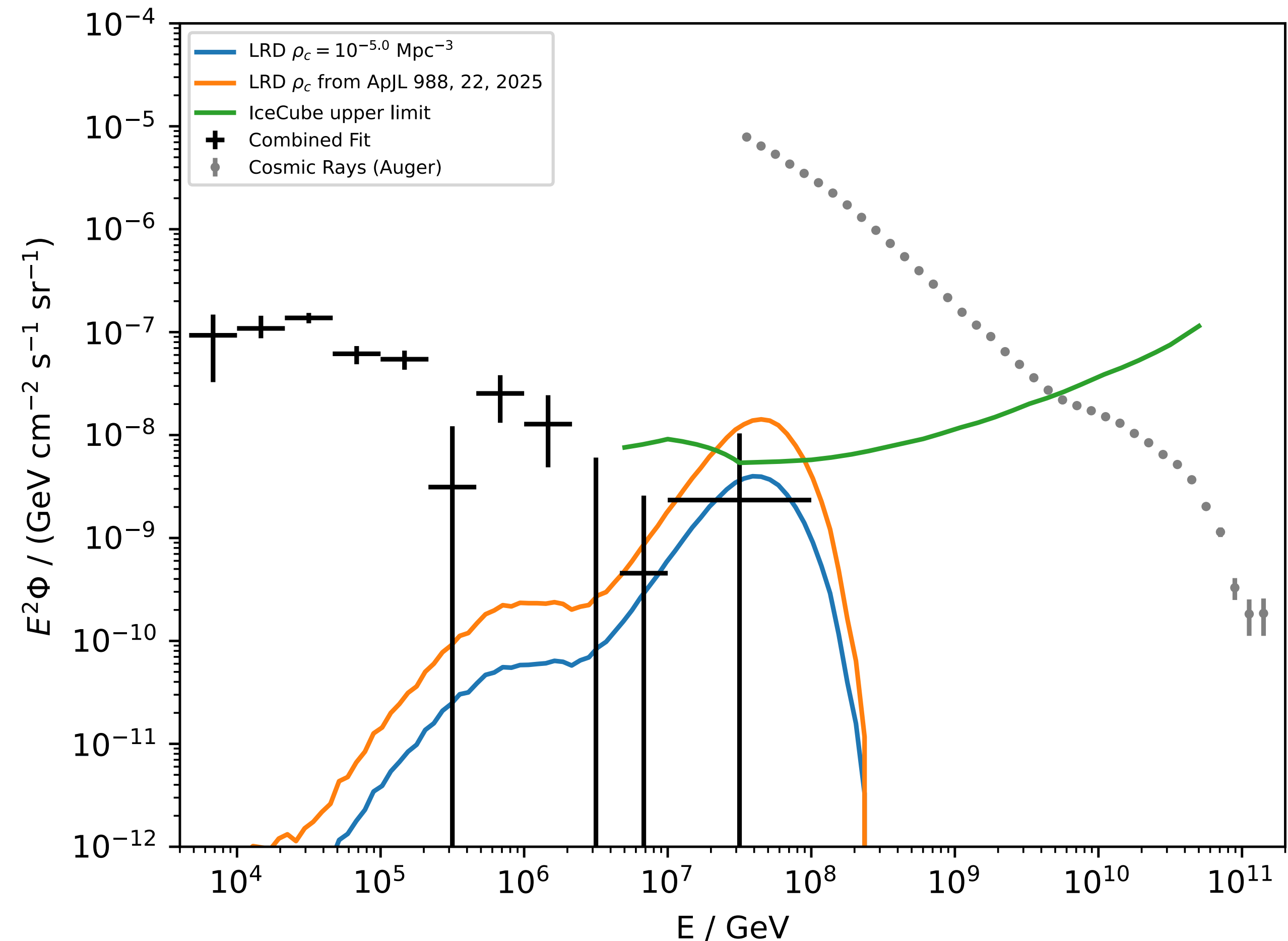
Experimental verification

- Scenario where nearby ($z \lesssim 1$) sources produce a similar neutrino intensity that can explain the 50 PeV bump
- Neutrino detector with enough exposure $\sim 1\text{ k „IceCube years“}$
- About 4-5 sources would yield detectable PeV+ multiplet signals
→ Signature of small-scale anisotropy
- If no nearby sources of high-energy neutrinos can be identified
→ Growing indication for origin from high-redshift universe

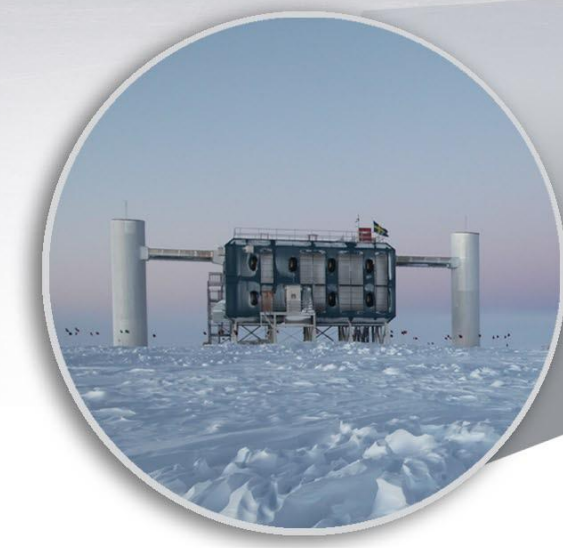


Summary

- JWST data shows large populations of AGNs in the early, high-redshift universe
- Nature of these objects is still a very active research field and not yet well constrained
- Within the allowed parameter space it is conceivable that they
 - Accelerate protons to high energies
 - Produce a flux of cosmogenic neutrinos with a distinct bump around 50 PeV
 - Potentially explain IceCube neutrinos above 10 PeV
- Could reveal UHECR emission from the early universe!



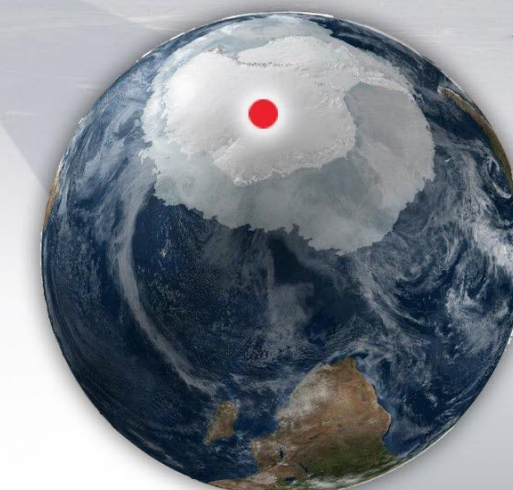
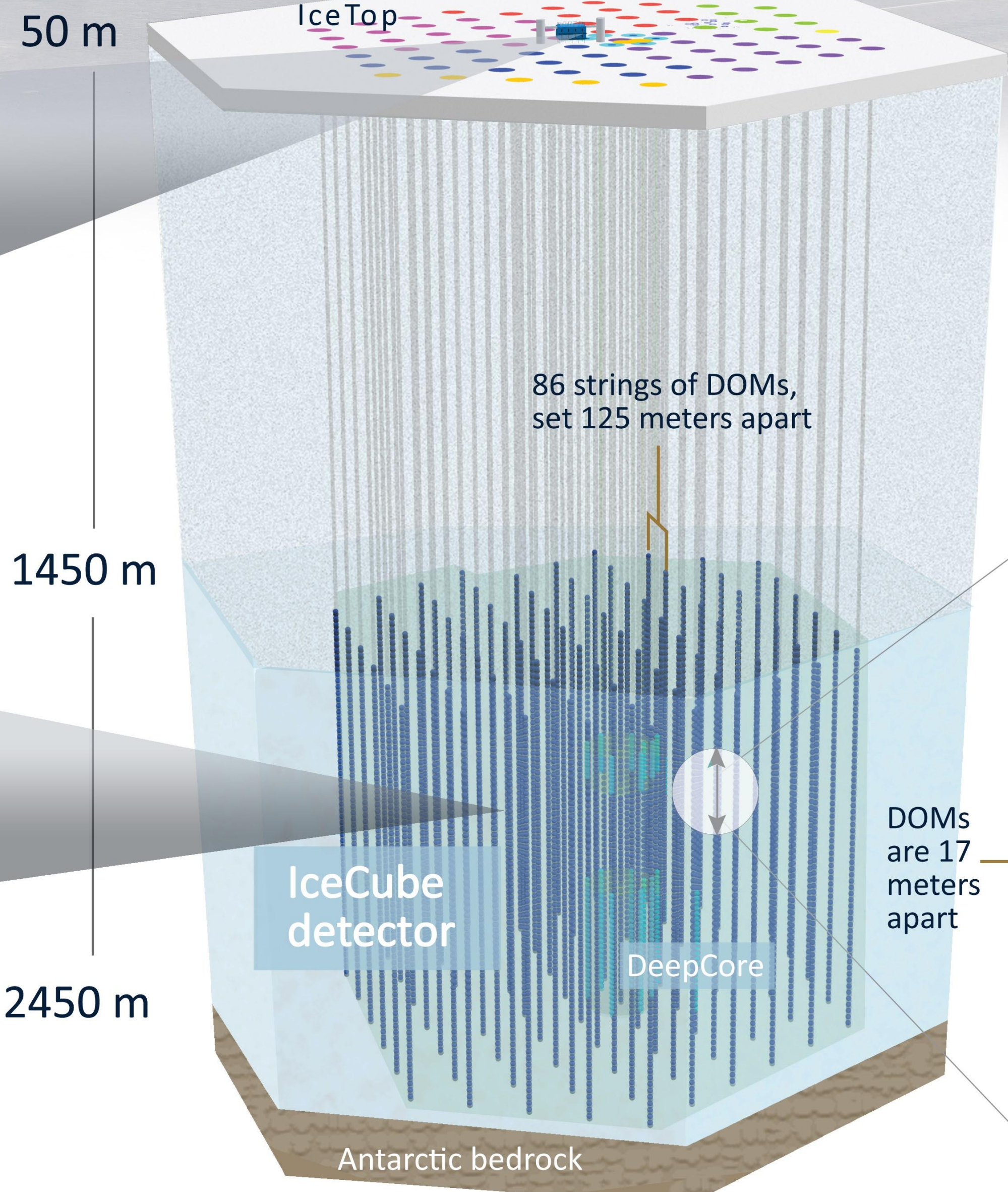
Backup



IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison



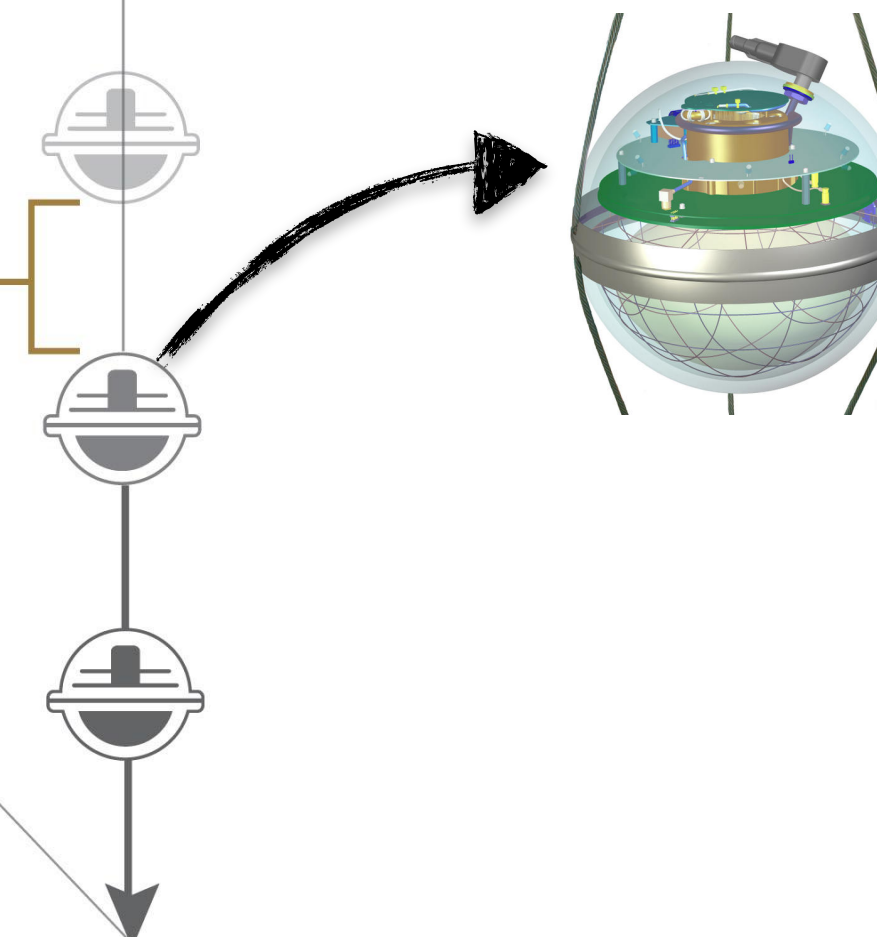
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice



Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility

60 DOMs on each string

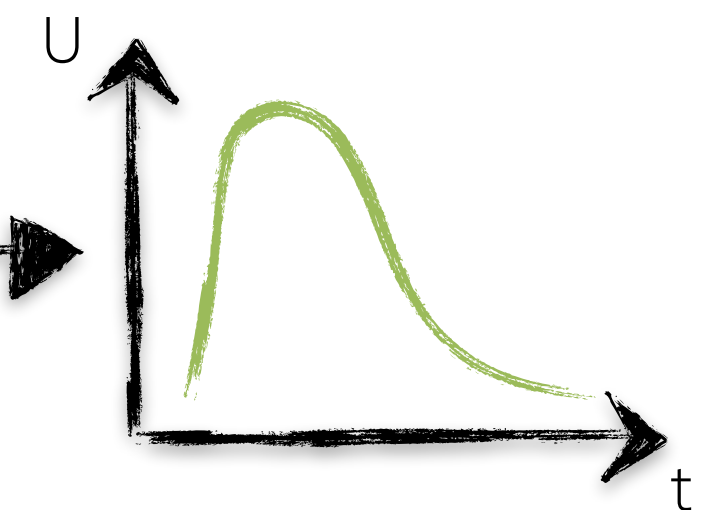
DOMs are 17 meters apart



Detector Design

-  1 gigaton of instrumented ice
-  5,160 light sensors, or digital optical modules (DOMs), digitize and time-stamp signals
-  1 square kilometer surface array, IceTop, with 324 DOMs
-  2 nanosecond time resolution
-  IceCube Lab (ICL) houses data processing and storage and sends 100 GB of data north by satellite daily

Waveform



128 Samples
300 MHz sampling rate

Cosmogenic neutrinos from LRDs

- Comparison between simulated results and analytical approximation
- Bump is slightly narrowed due to neglecting Bethe-Heitler pair production
- Bump intensity is underestimated due to threshold effects such as direct pion production

