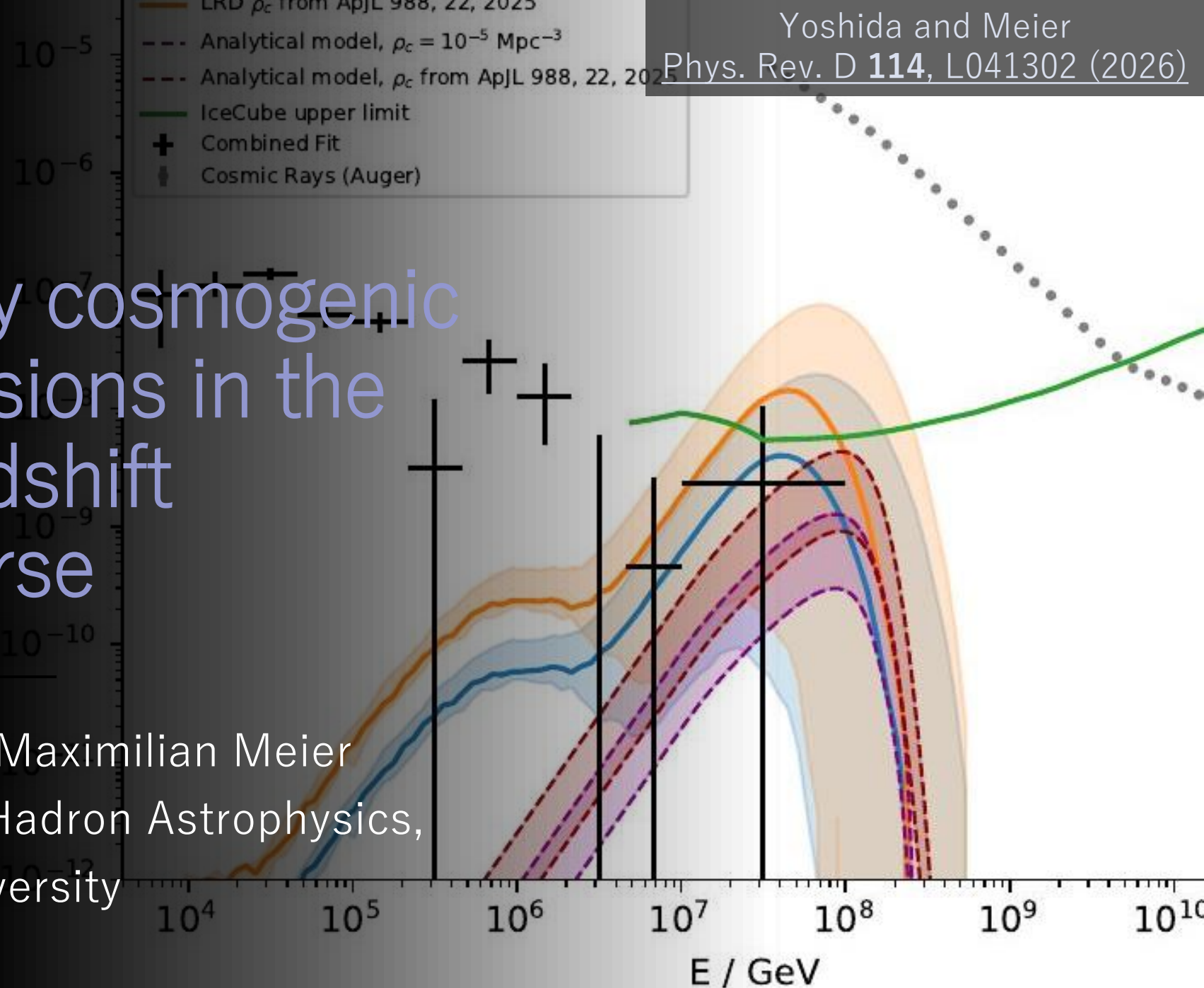


Ultrahigh-energy cosmogenic neutrino emissions in the high-redshift universe

Shigeru Yoshida and Maximilian Meier
 International Center for Hadron Astrophysics,
 Chiba University

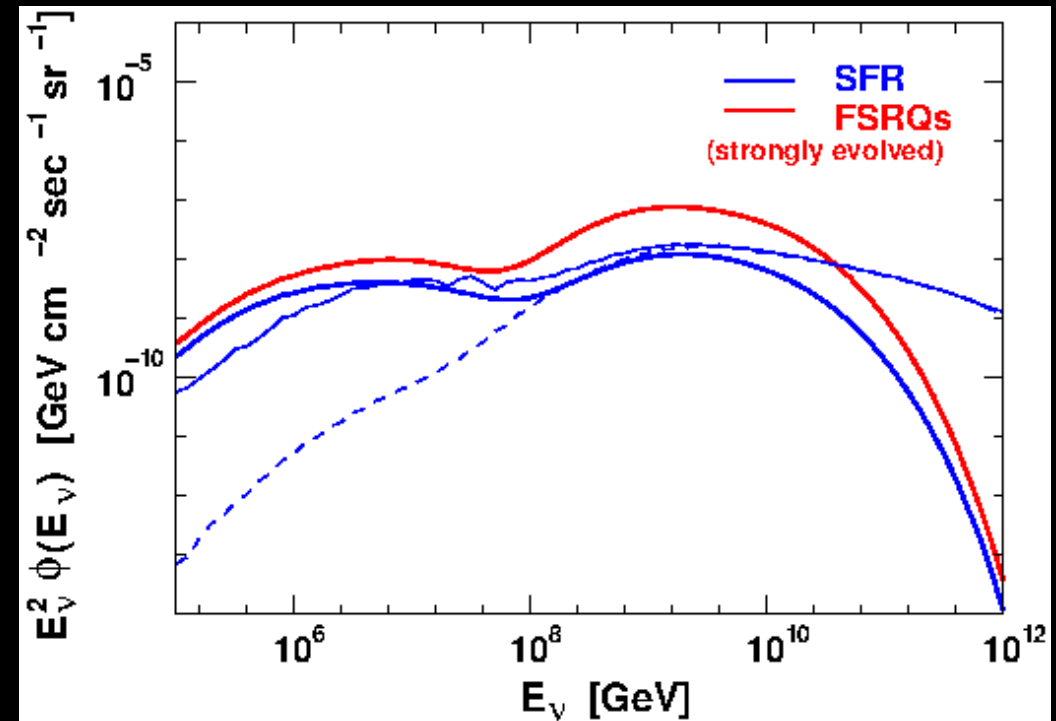
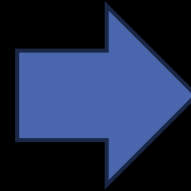
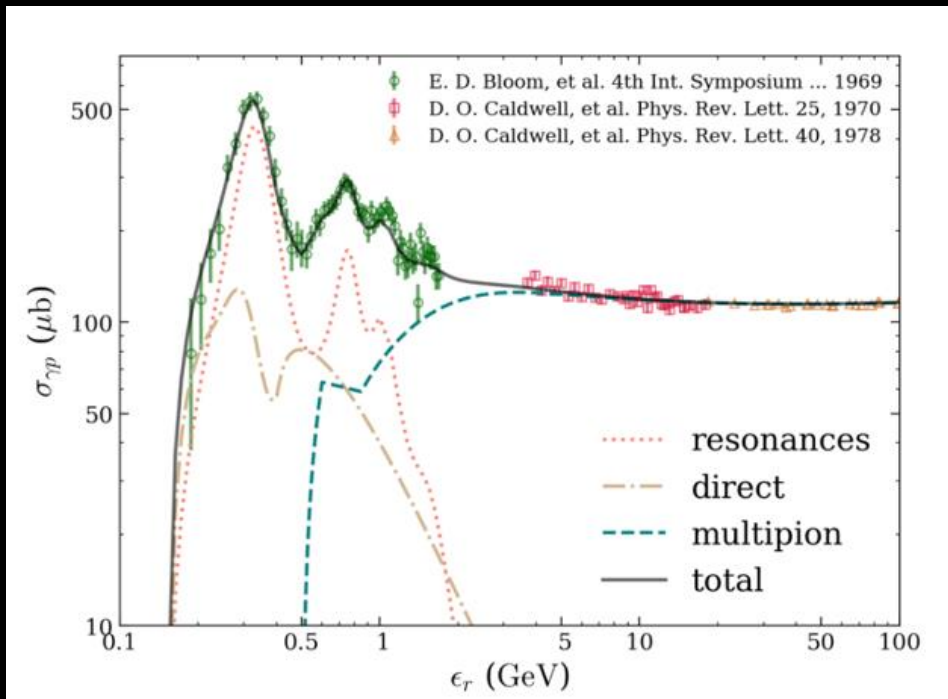


Cosmogenic (GZK) Neutrinos

Photohadronic interactions

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

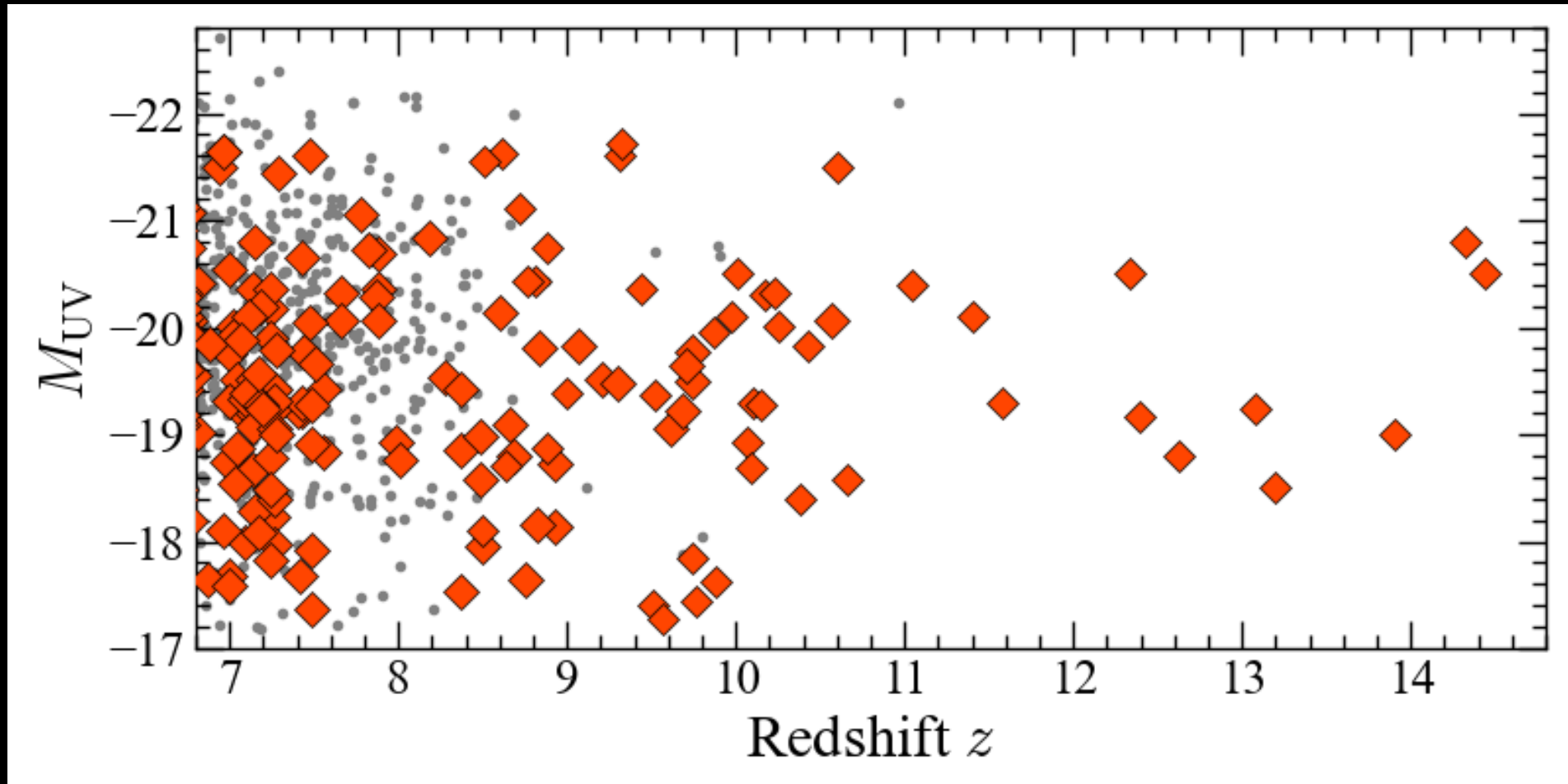
Neutrinos in **EeV (10⁹ GeV)** range



AGNs in high-redshift space

JWST has discovered a new large population of *high-z* AGNs

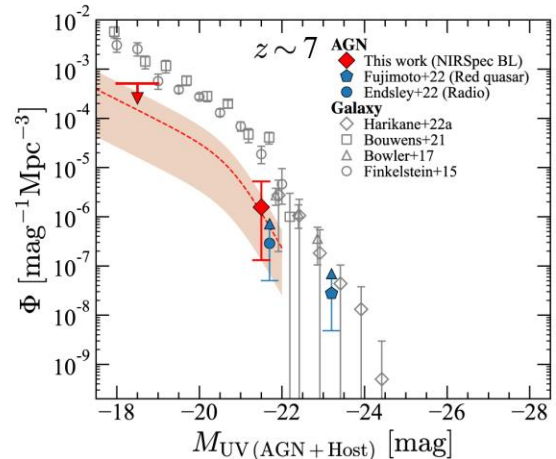
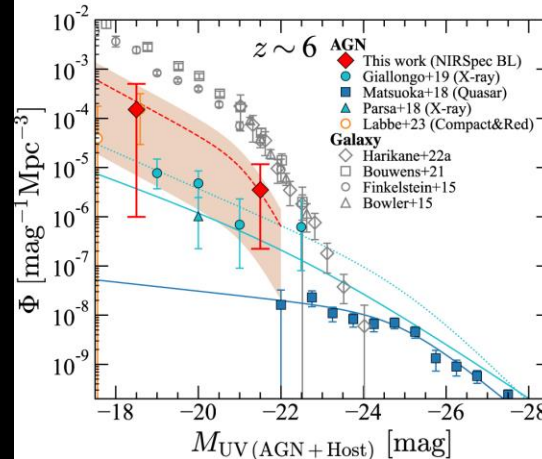
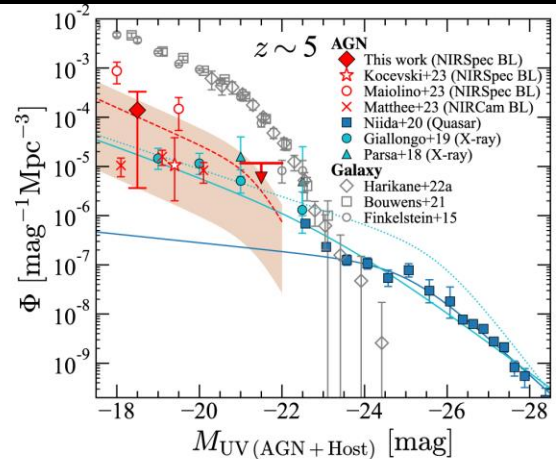
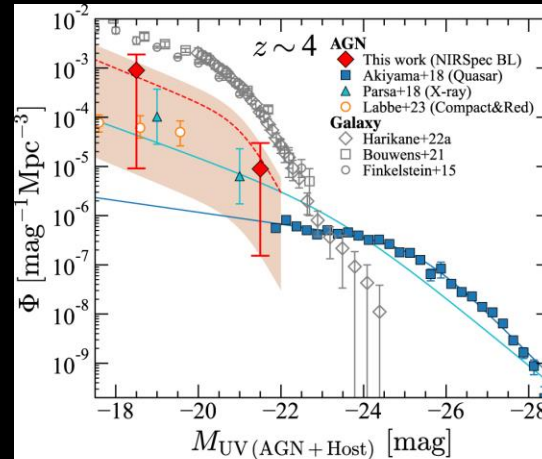
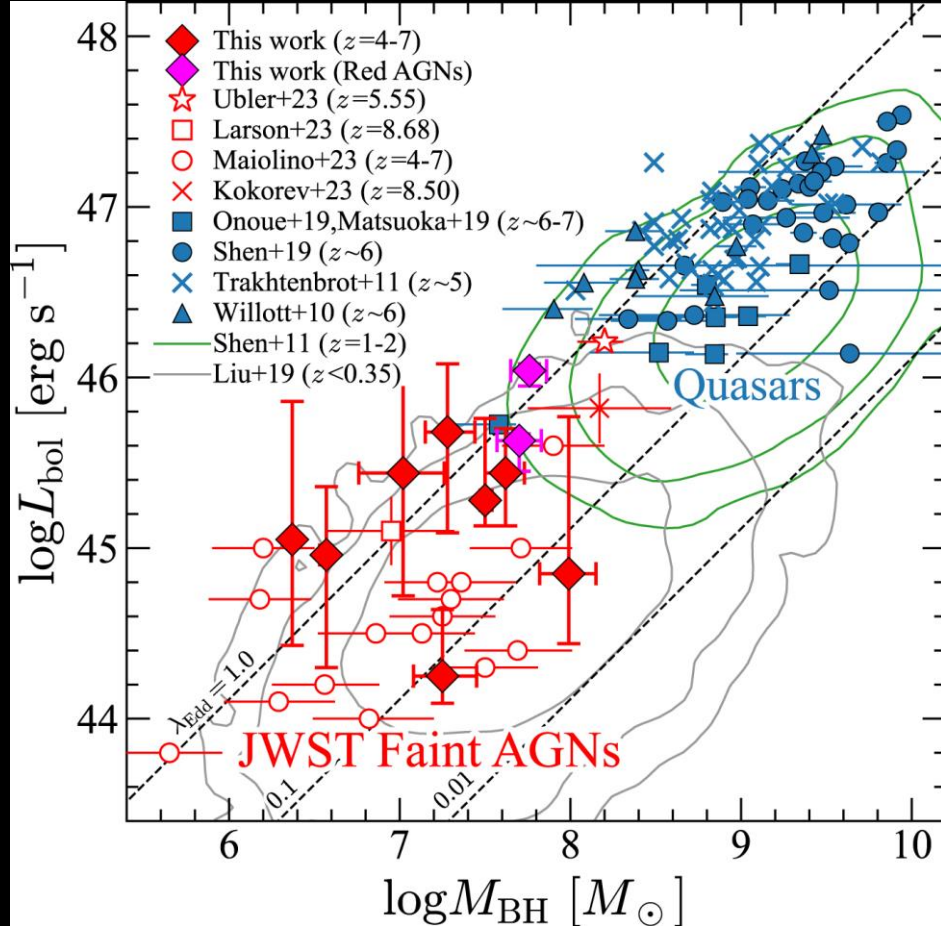
Harikane+ ApJ 2023



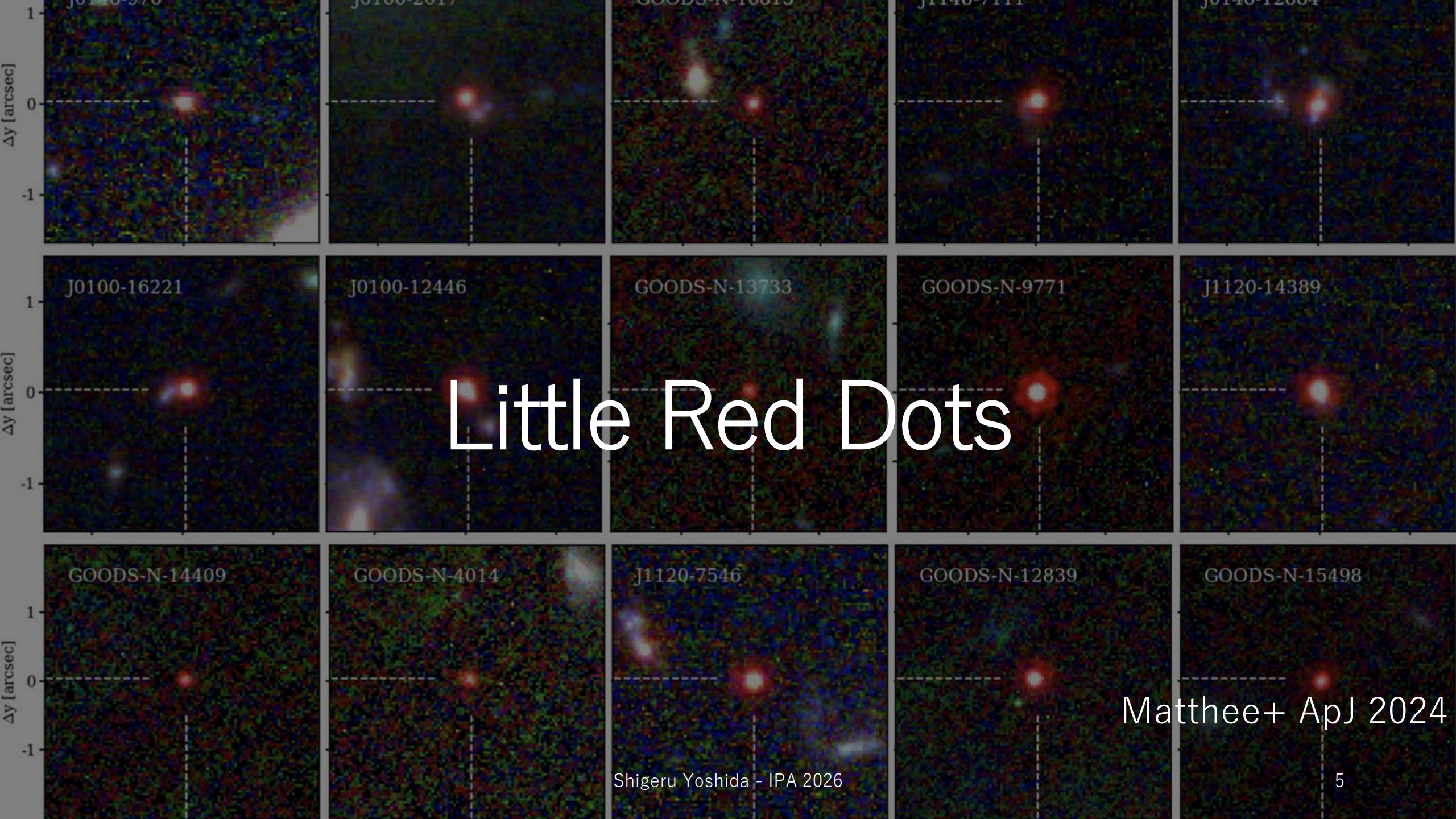
AGNs in high-redshift space

JWST has discovered a new large population of *high-z* AGNs

Harikane+ ApJ 2023



fainter, but lots more than expected in $z = 5 \sim 10$



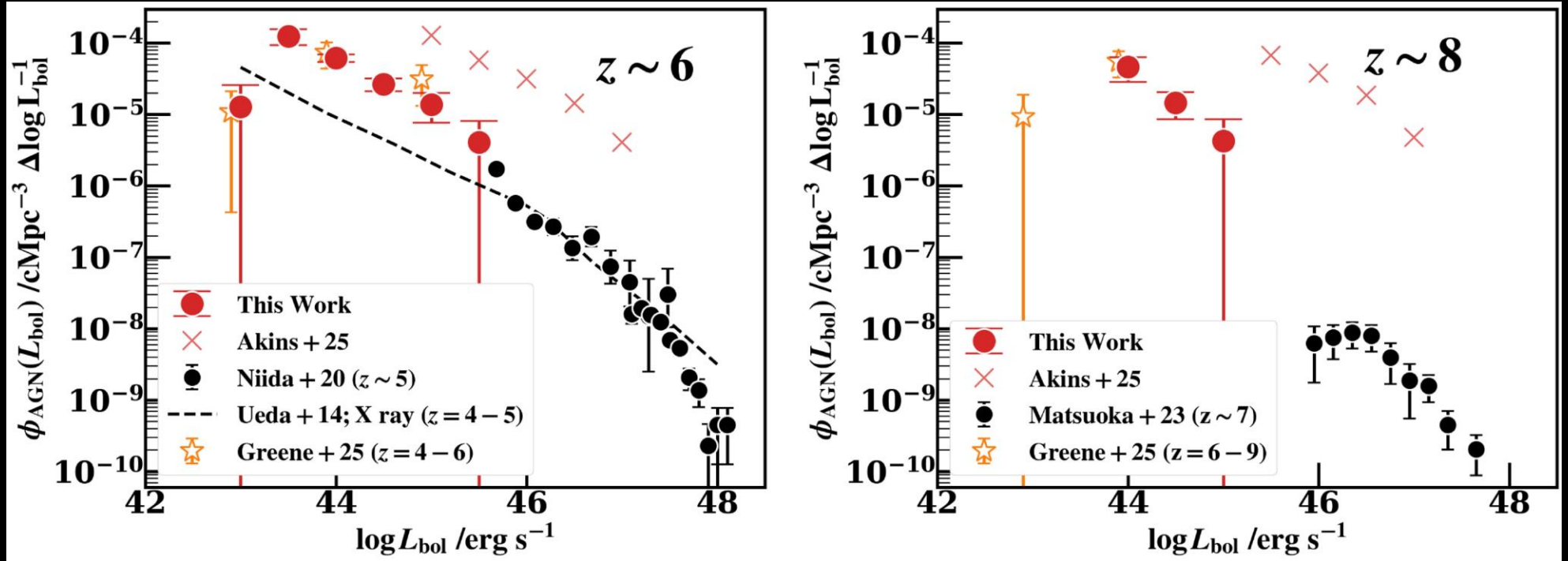
Little Red Dots

Matthee+ ApJ 2024

AGNs in high-redshift space

JWST has discovered a new large population of *high-z* AGNs

Umeda+ ApJ 2026



$$L_{\text{bol}}^{\gamma} \sim 10^{45} \text{ erg/s}$$

$$n_0 \sim 10^{-5} \text{ Mpc}^{-3}$$

$$L_{\text{bol}}^{\gamma} = 10^{45} \text{ erg/s}$$

The Hillas Condition

$$\varepsilon_{\text{p}}^{\text{max}} \simeq 8 \times 10^{10} \left(\frac{L^{\gamma}}{10^{45} \text{ erg/s}} \right)^{1/2} \xi_{\text{B}}^{1/2} \text{ GeV}$$

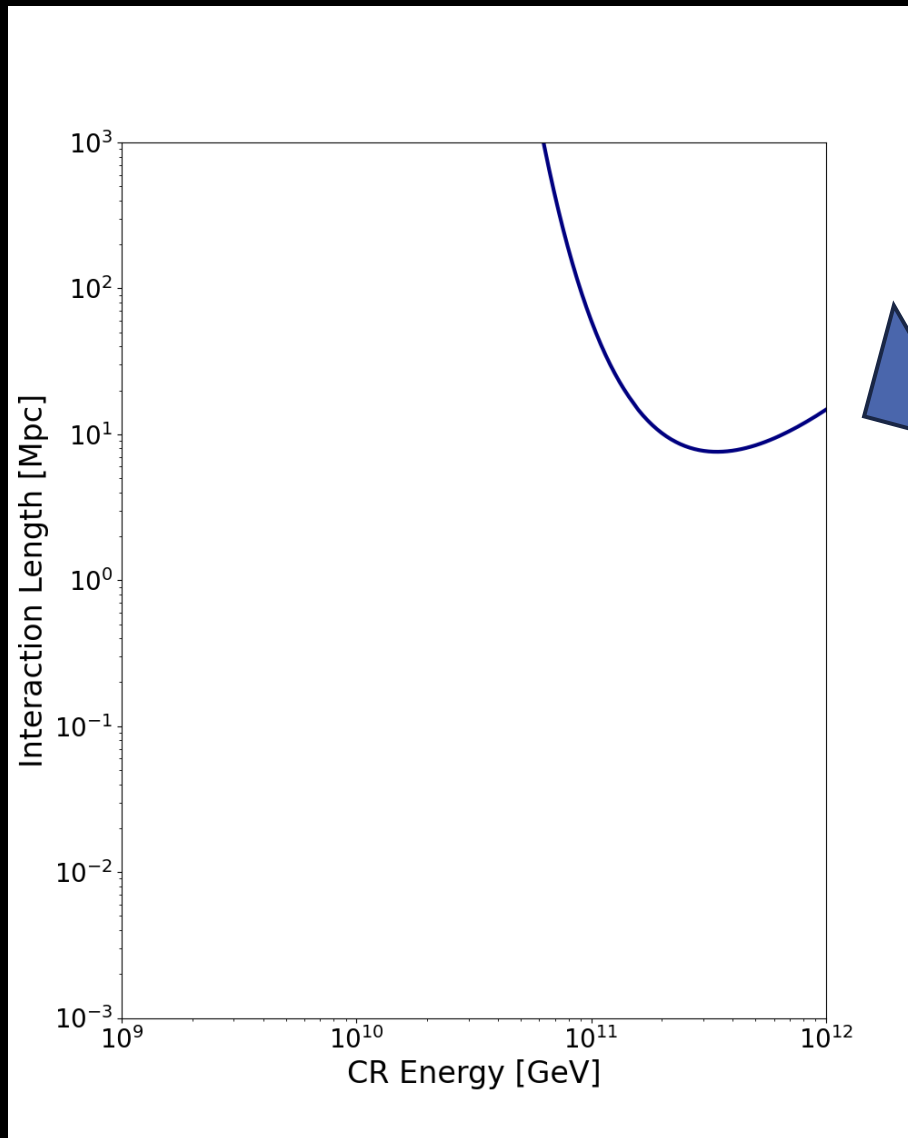
LRDs (or AGNs in high- z space) may be emitting protons with $\sim 10^{10}$ GeV (10^{19} eV).

Then the emitted protons **inevitably** collide with CMB!!

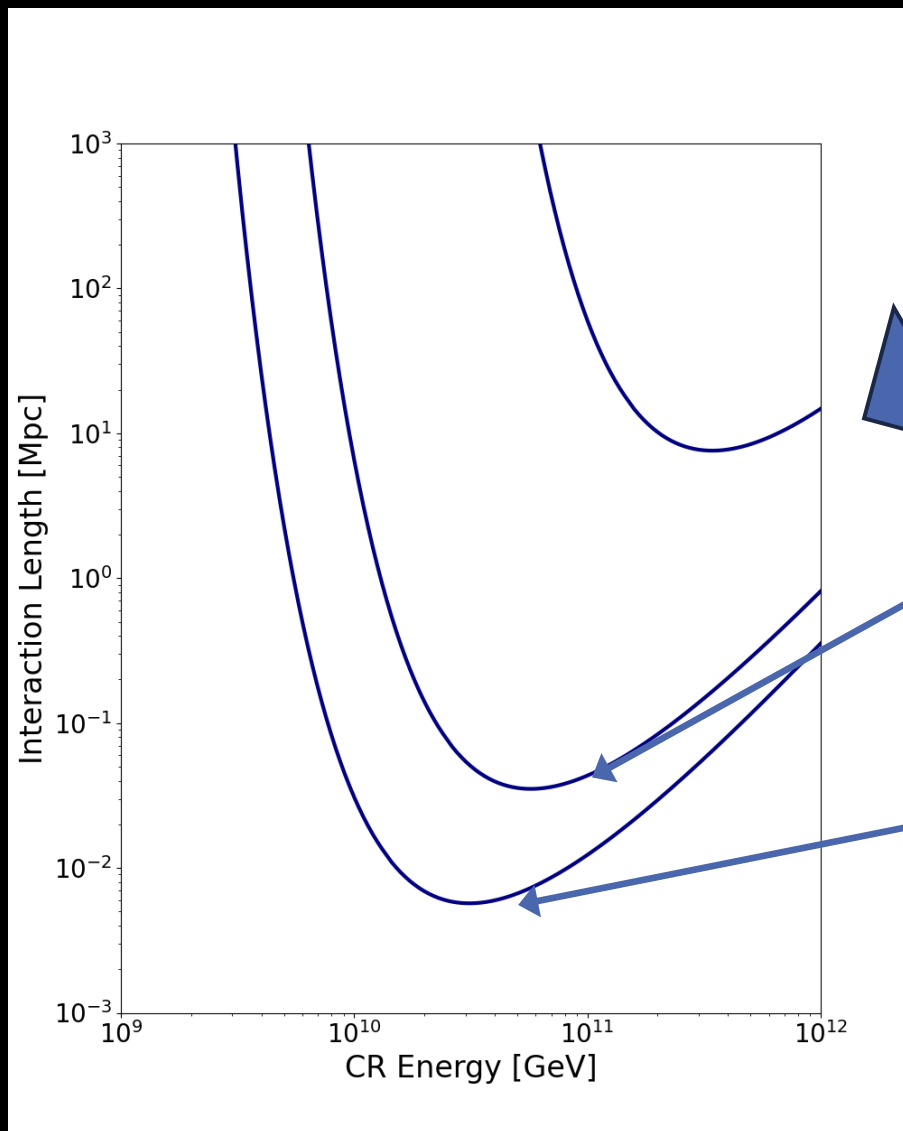
Interaction length of $p\gamma_{\text{CMB}}$

$z = 0$ (present Universe)

$\lambda_{p\gamma} \sim 5 \text{ Mpc}$ at $\varepsilon_{\text{CR}} \sim 3 \times 10^{11} \text{ GeV}$



Interaction length of $p\gamma_{\text{CMB}}$



$z = 0$ (present Universe)

$$\lambda_{p\gamma} \sim 5 \text{ Mpc} \quad \text{at} \quad \varepsilon_{\text{CR}} \sim 3 \times 10^{11} \text{ GeV}$$

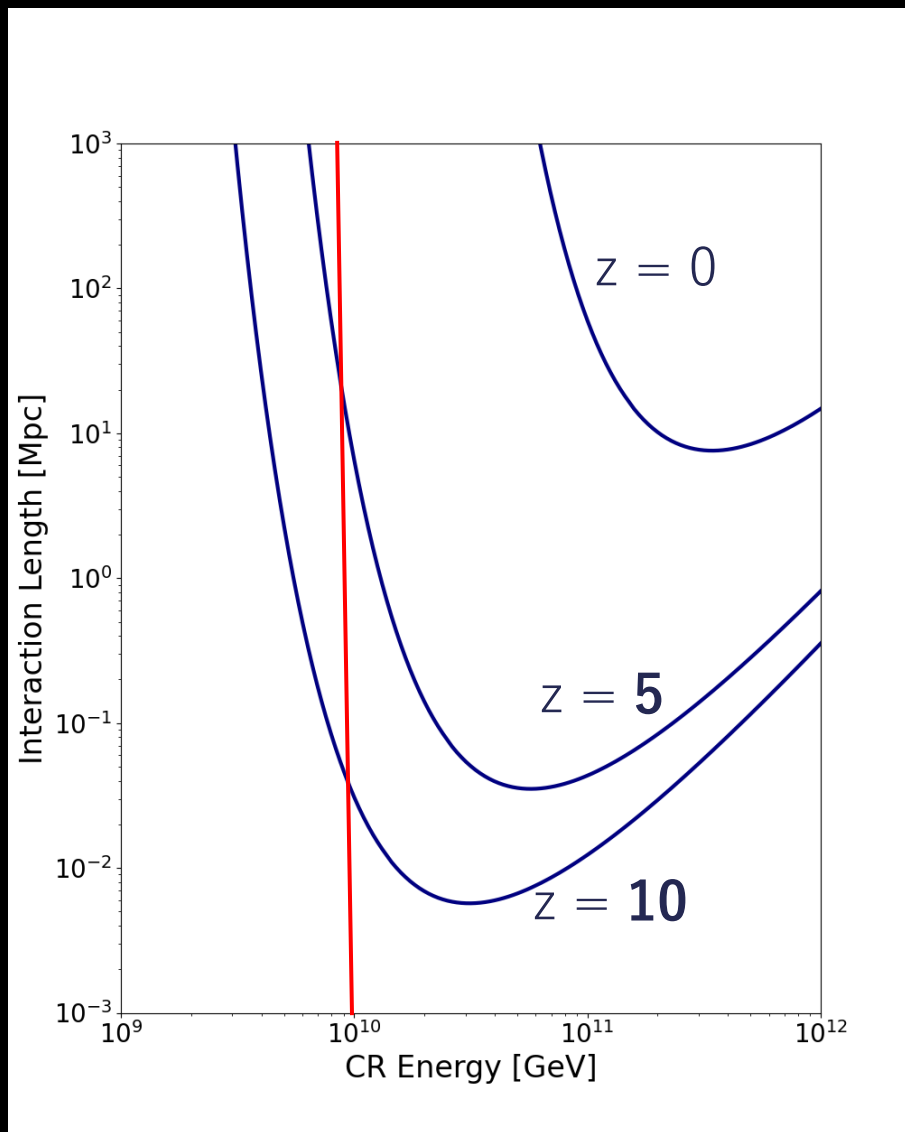
$z = 5$

$$\lambda_{p\gamma} \sim 30 \text{ kpc} \quad \text{at} \quad \varepsilon_{\text{CR}} \sim 5 \times 10^{10} \text{ GeV}$$

$z = 10$

$$\lambda_{p\gamma} \sim 5 \text{ kpc} \quad \text{at} \quad \varepsilon_{\text{CR}} \sim 3 \times 10^{10} \text{ GeV}$$

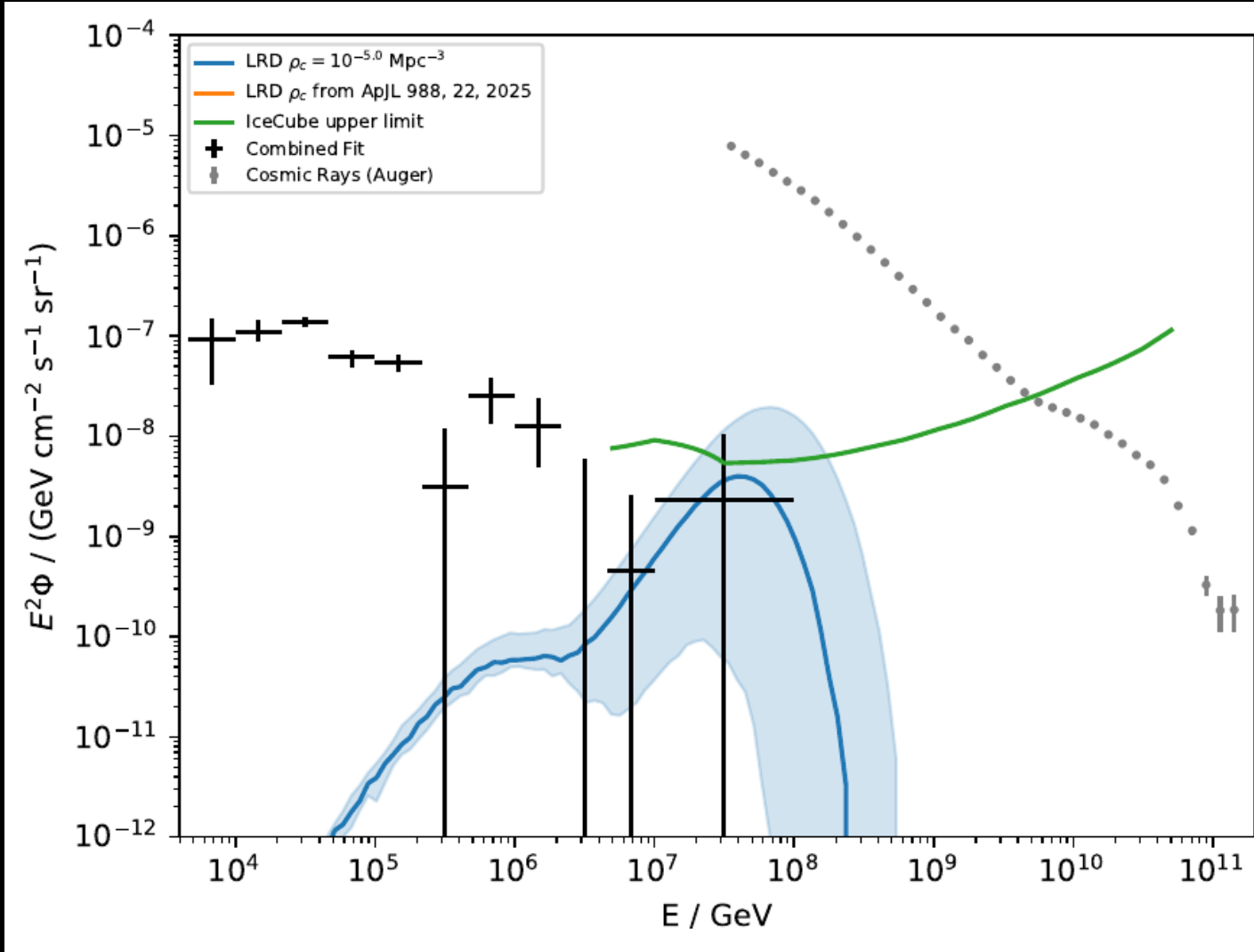
Interaction length of $p\gamma_{\text{CMB}}$



$$\varepsilon_{\text{CR}} \lesssim 10^{10} \text{ GeV}$$

would result in substantial
cosmogenic ν productions

Cosmogenic Neutrino Flux from LRDs



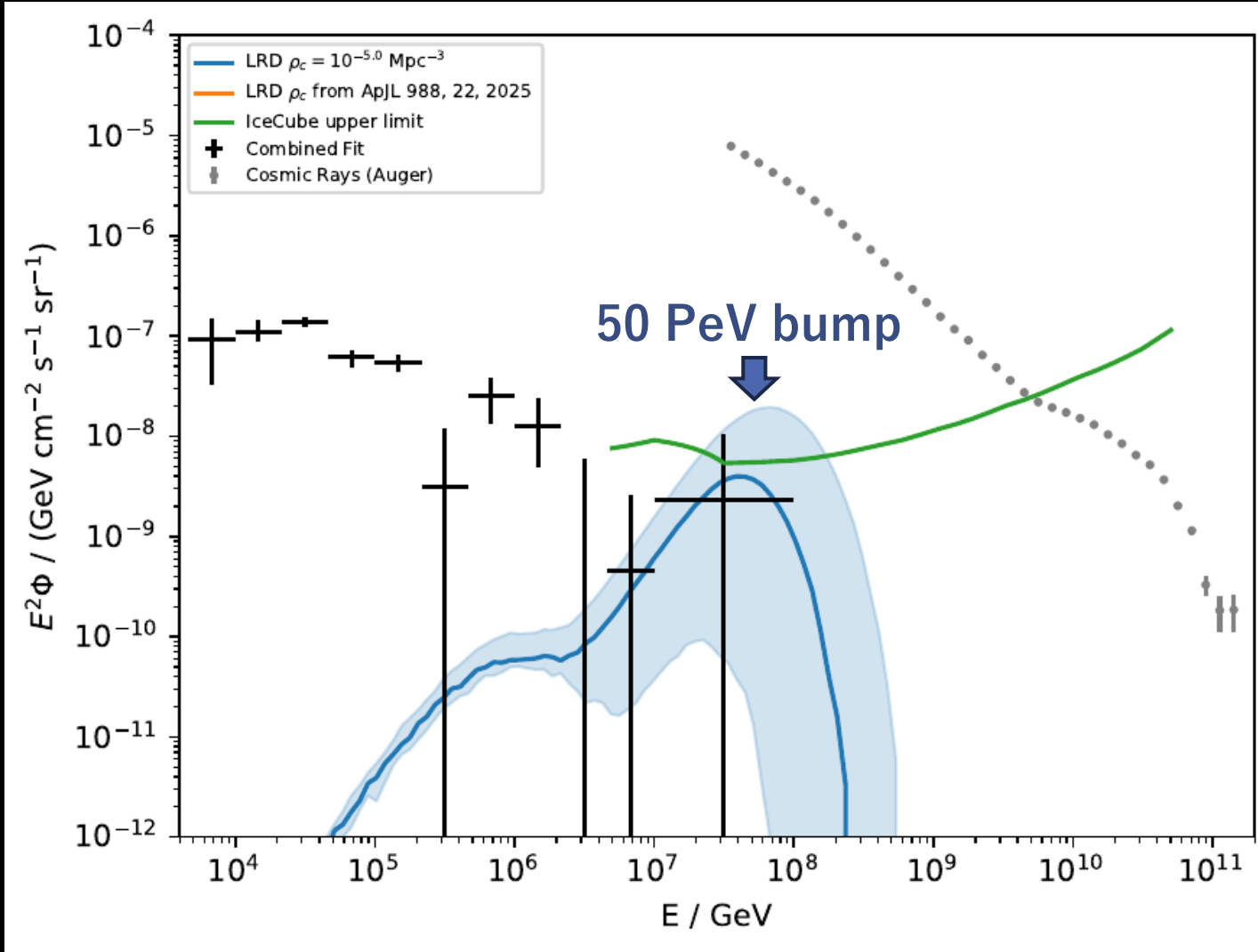
Based on the JWST observations

$$\left[\begin{array}{l} 5 \leq z \leq 10 \\ n_0 = 10^{-5} \text{ Mpc}^{-3} \\ L_{\text{bol}}^p = 10^{45} \text{ erg/s} \end{array} \right.$$

Our assumptions

$$\varepsilon_{\text{CR}} \lesssim 10^{10} \text{ GeV}$$

Cosmogenic Neutrino Flux from LRDs



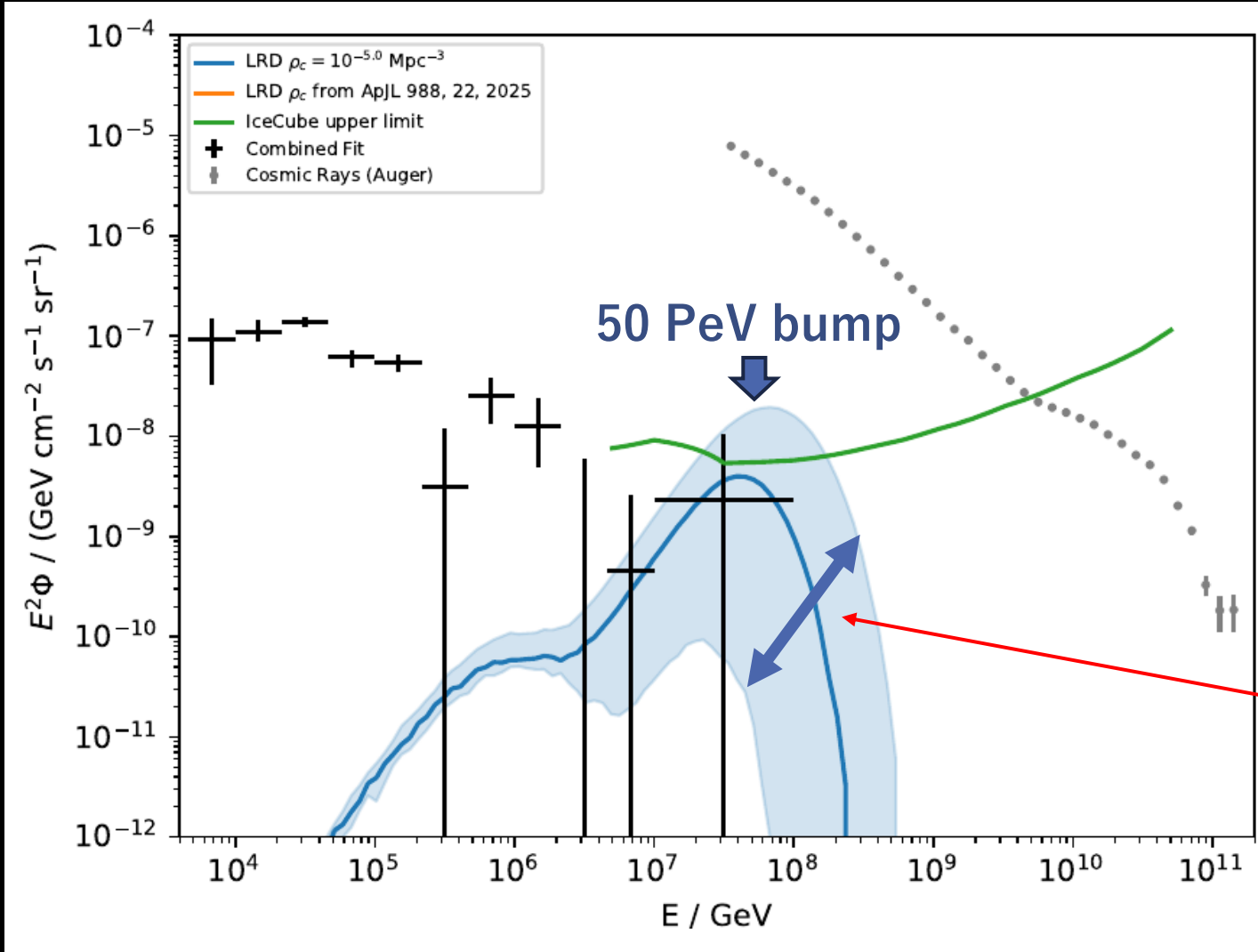
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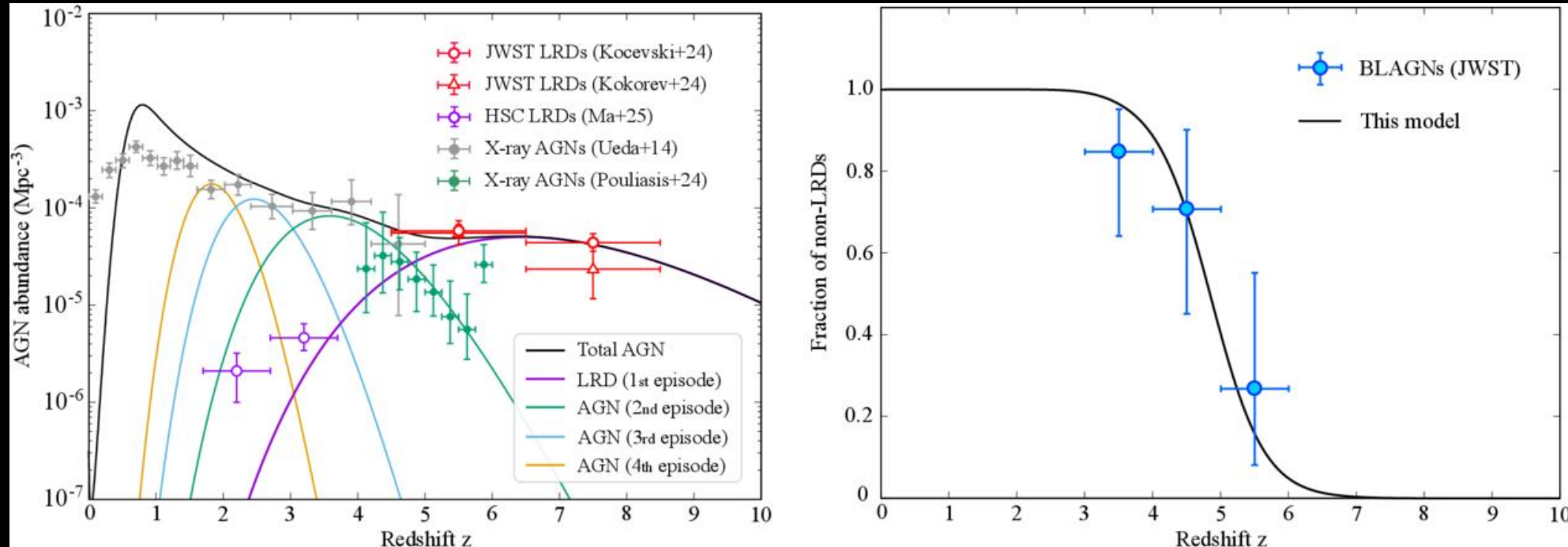
Our assumptions

$$\varepsilon_{\text{CR}} \lesssim 10^{10} \text{ GeV}$$

when varying $\varepsilon_{\text{CR}}^{\text{max}}$ by a factor 2

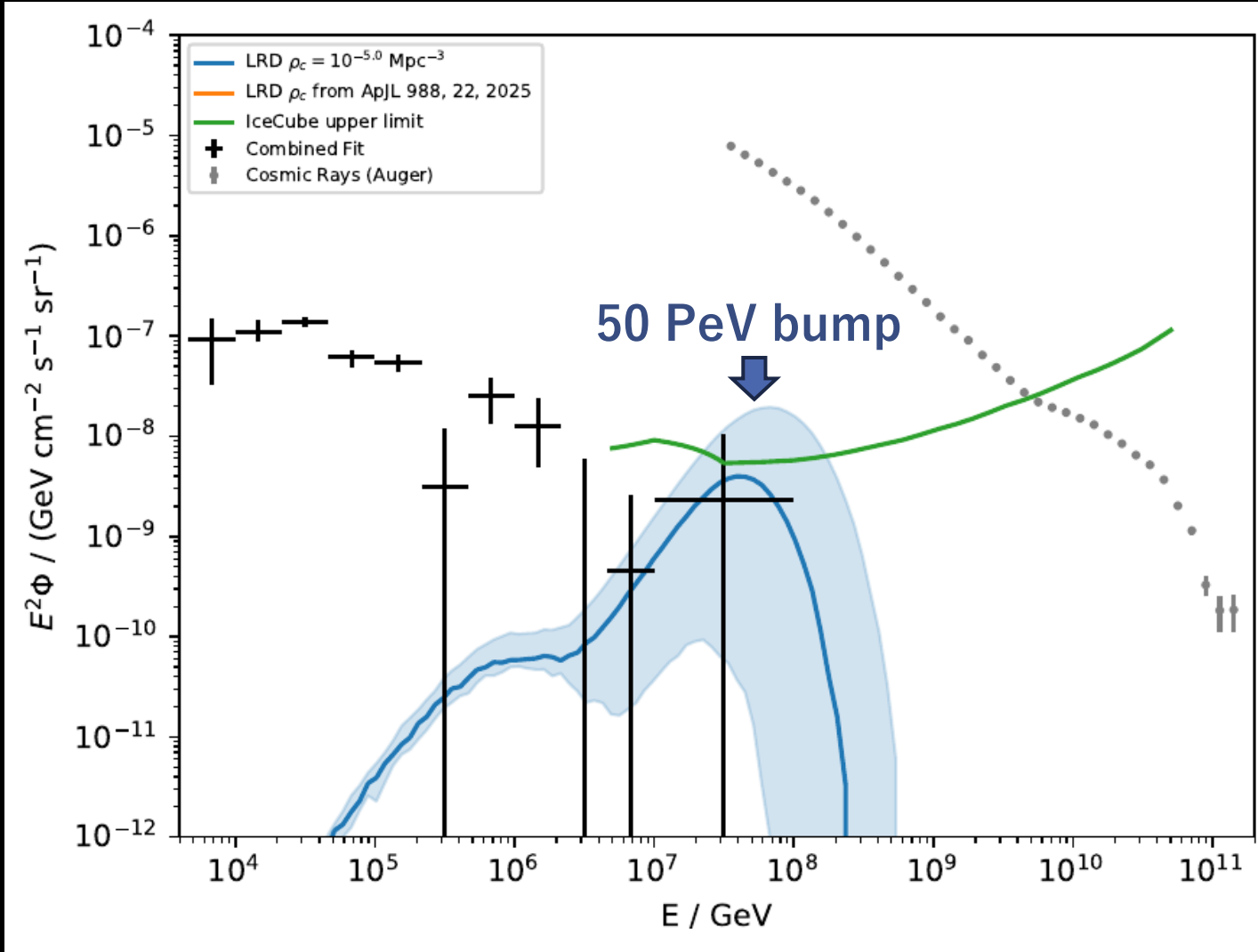
LRDs are cosmologically evolved?

Maybe



Inayoshi+ ApJ 2025

Cosmogenic Neutrino Flux from LRDs



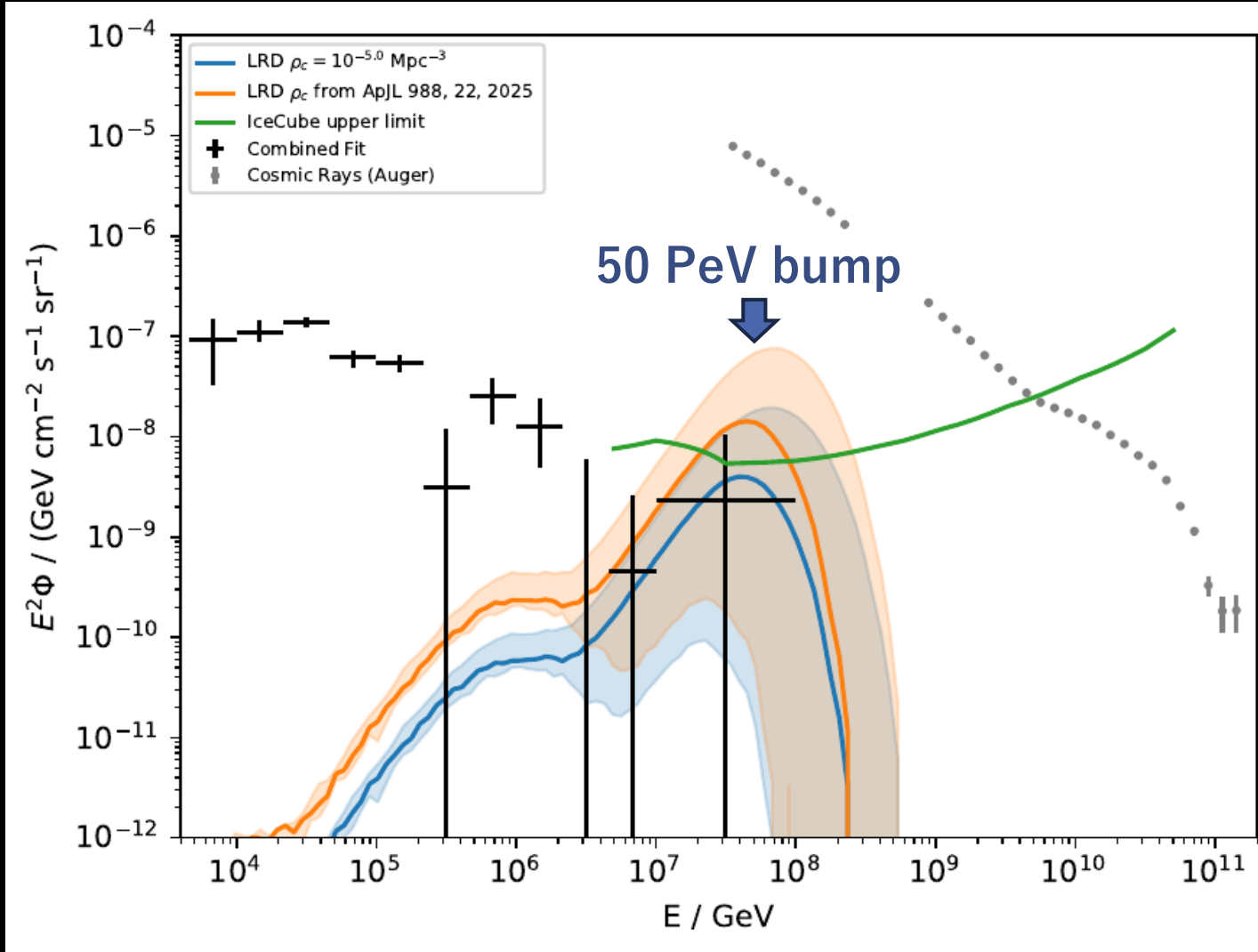
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Our assumptions

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Cosmogenic Neutrino Flux from LRDs



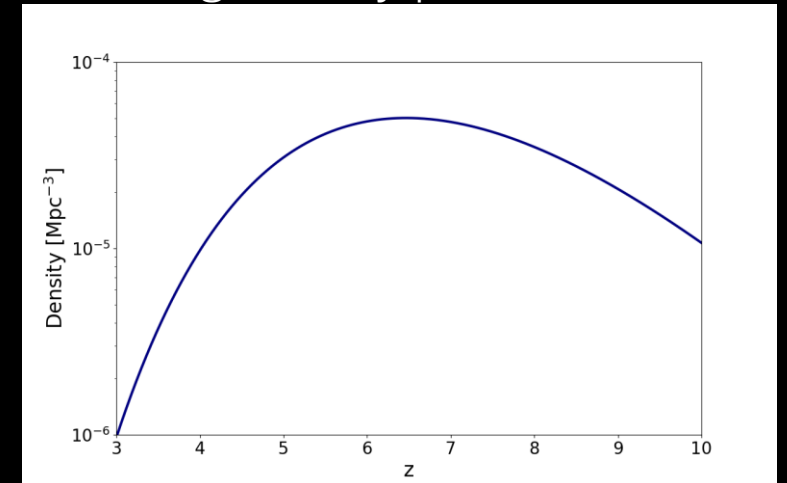
Based on the JWST observations

$$\left[\begin{array}{l} 5 \leq z \leq 10 \\ n_0 = 10^{-5} \text{ Mpc}^{-3} \\ L_{\text{bol}}^p = 10^{45} \text{ erg/s} \end{array} \right.$$

Our assumptions

$$\varepsilon_{\text{CR}} \lesssim 10^{10} \text{ GeV}$$

co-moving density profile

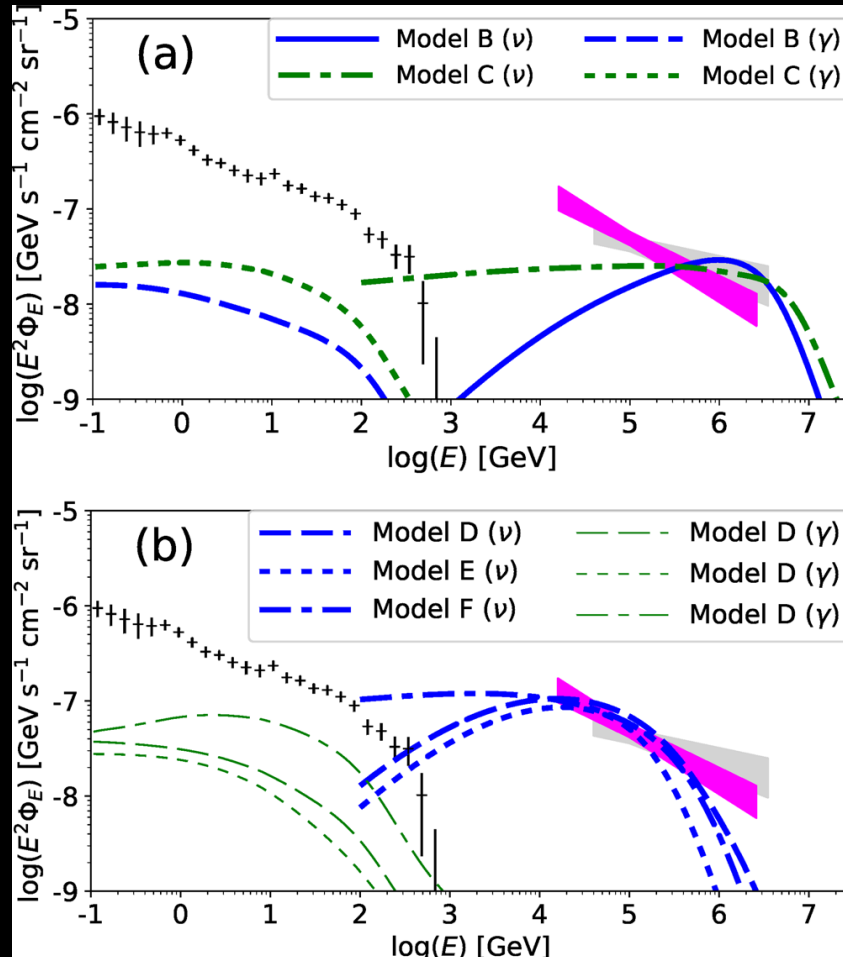


The 50 PeV bump

It is **unlikely** that any other scenario produces a 50 PeV bump.

Kimura+ Nature Comm. 2021

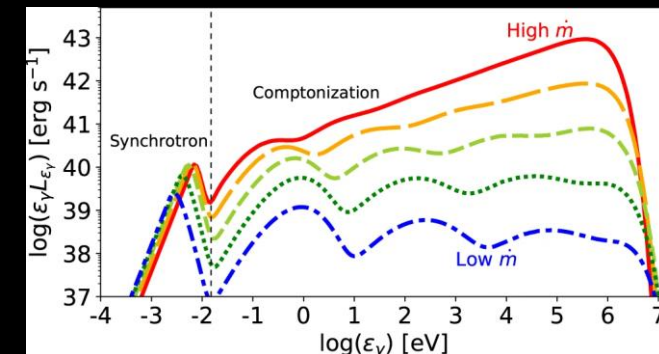
Why not?



10PeV bump

100 TeV bump

1. muons (and pions) are cooled by synchrotron radiation in the B-field that is needed to accelerate protons
(c.f. [Yoshida & Murase PRD 2020](#))
2. No enough supply of long-wavelength infrared (~ 0.1 eV) to produce 50 PeV neutrinos through proton collisions.



Take-away messages

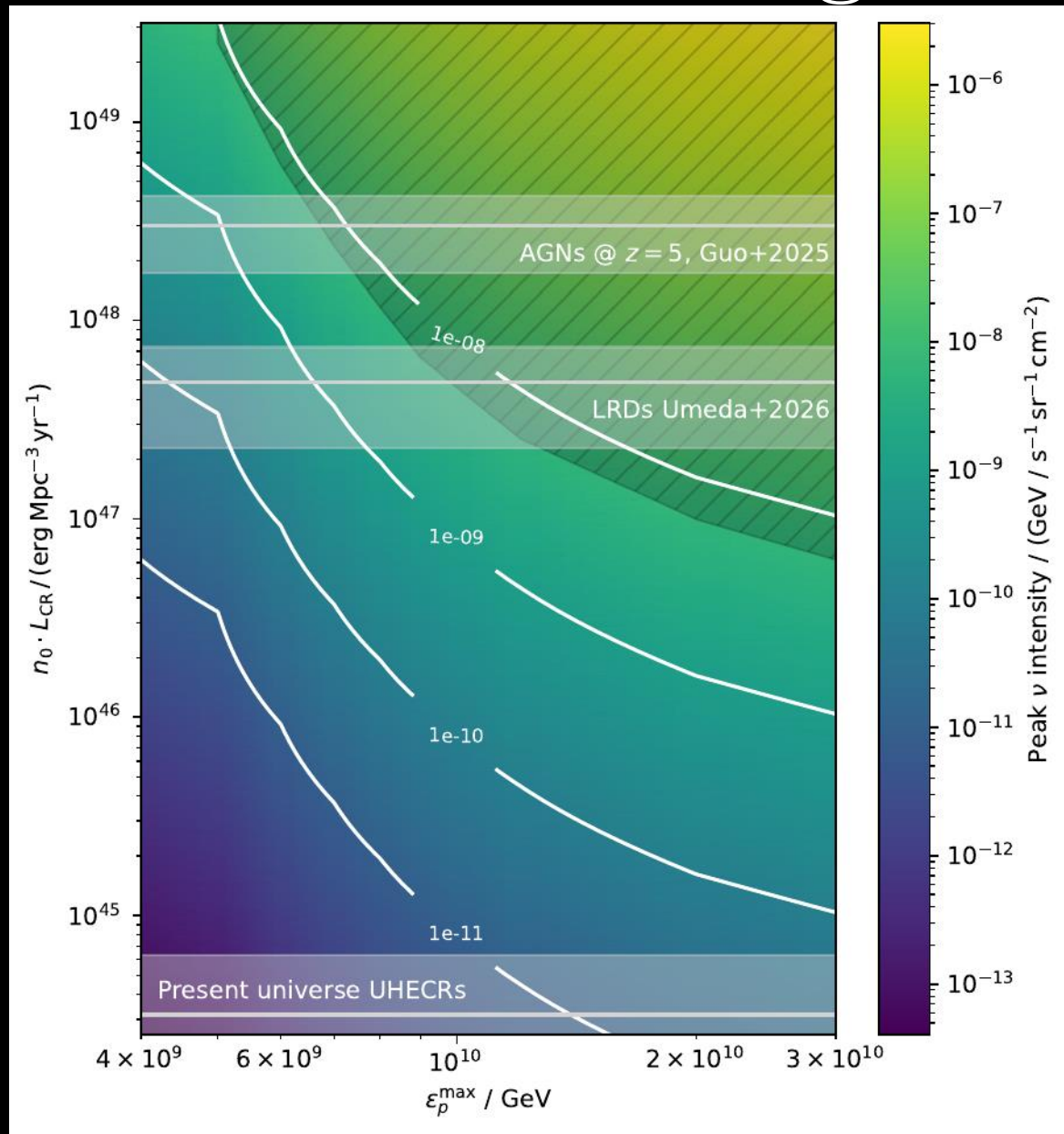
Look for a 50 PeV bump in neutrino spectrum

The 50 PeV bump will infer **UHRCR emissions**
in the high-redshift universe

backup

Energetics

Cosmic Ray Luminosity Density



ruled out by
IceCube EHE ν limit (PRD 2025)

Comparisons to analytical estimates

