THE UNIVERSITY OF CHICAGO

Ultra-High-Energy Cosmic Rays and Neutrinos from Relativistic Jets of Active Galactic Nuclei

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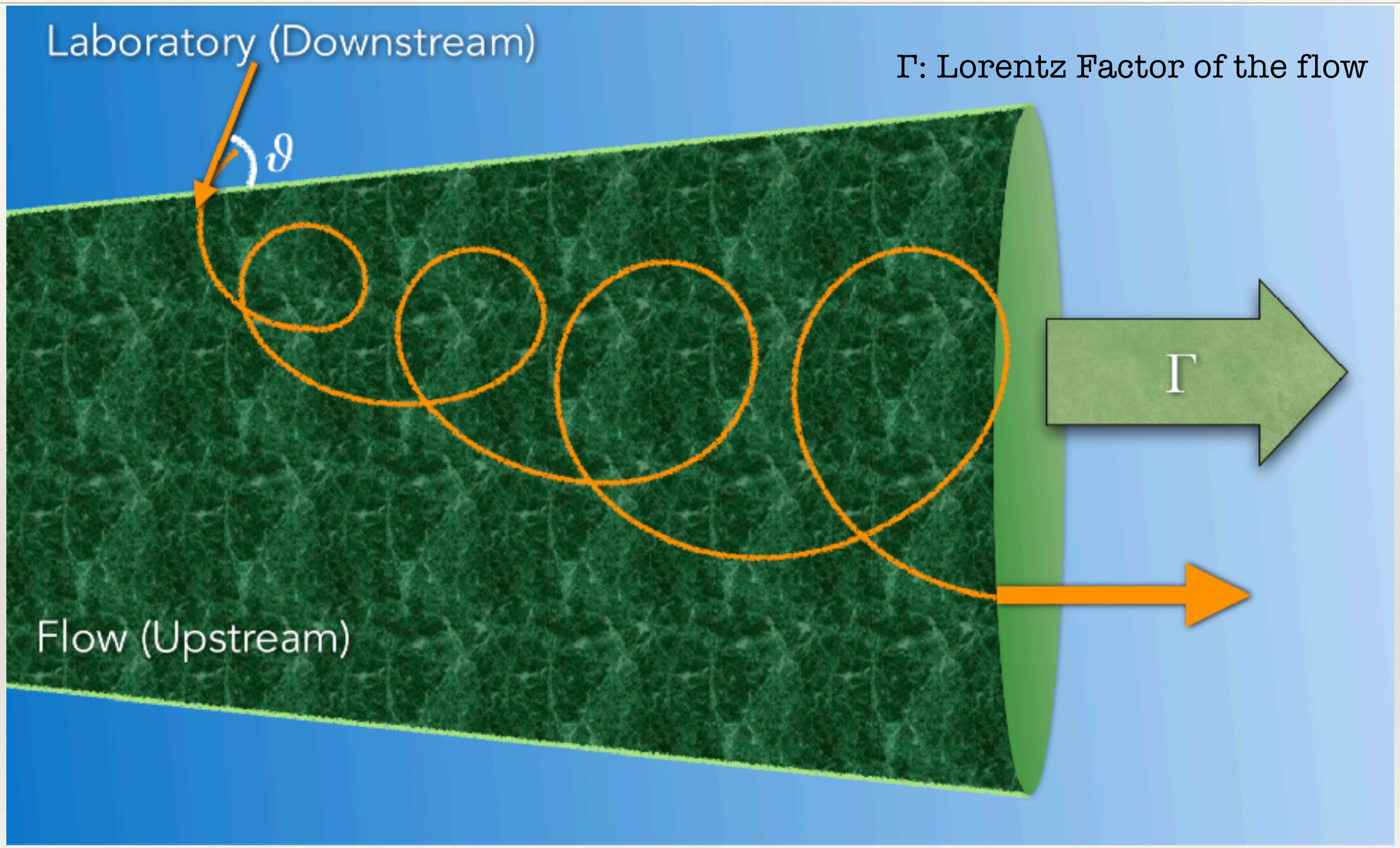
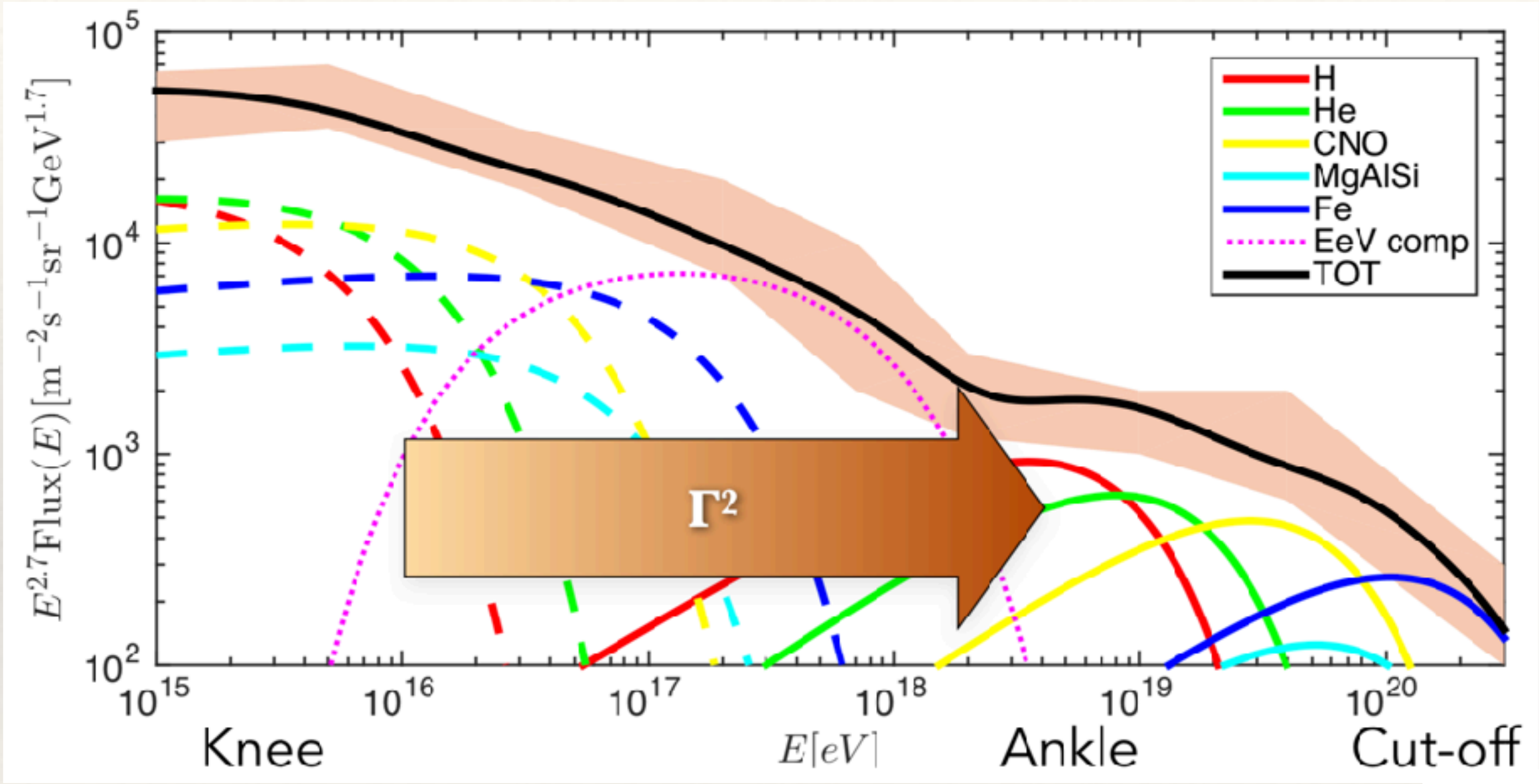
The *espresso* mechanism: A brief Introduction



To get UHECRs: **SEEDS: galactic CRs** with energies up to ~ 3Z PeV

STEAM: AGN jets with Lorentz factors Γ up to ~ 20-30

The *espresso* mechanism and the chemical composition



Caprioli 2015

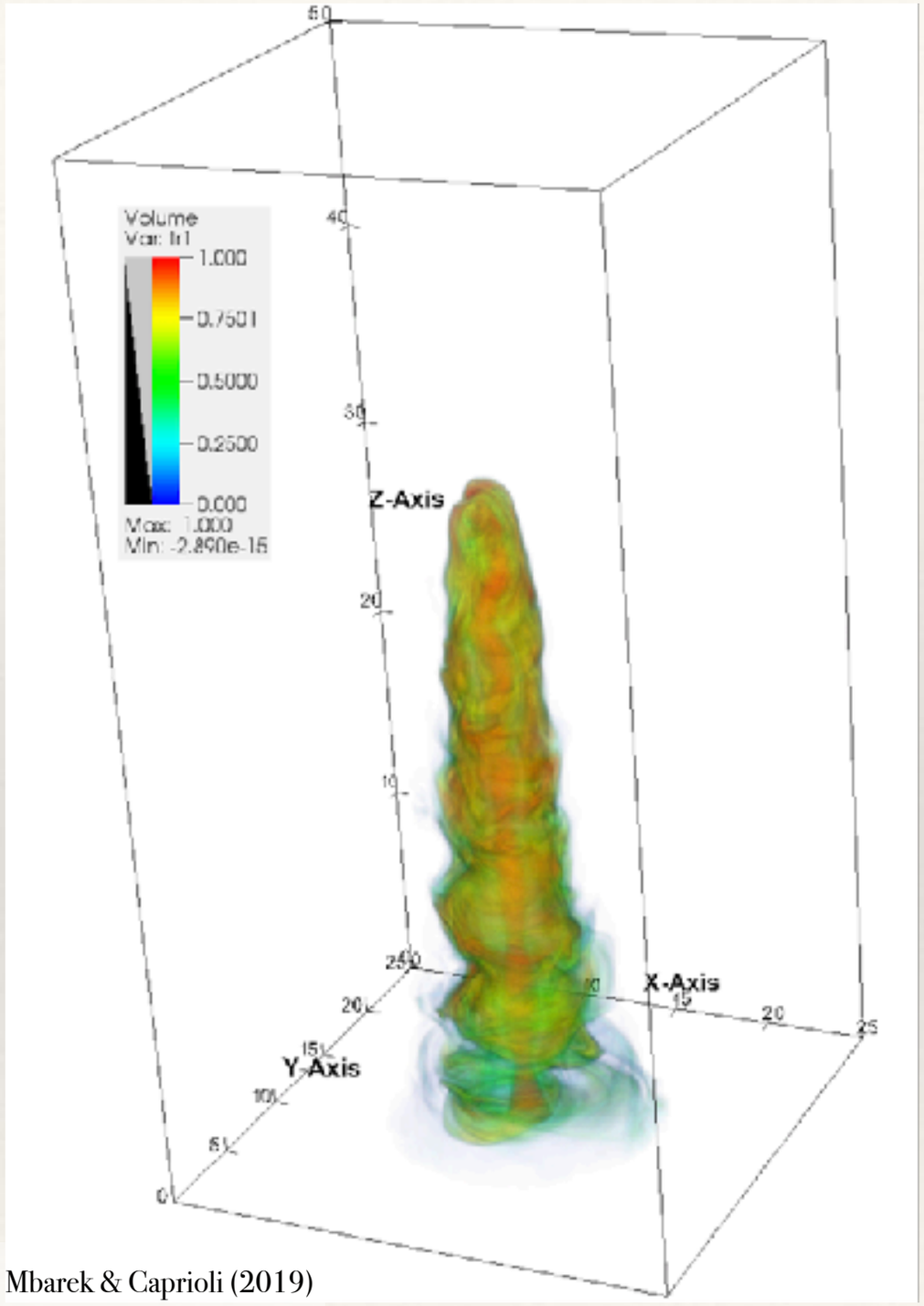
Fluxes and chemical composition above 10^{15} eV from *espresso* model compared with UHECR data.

Consistent with results from the Auger collaboration (2017)

Espresso in relativistic MHD Jet Simulations

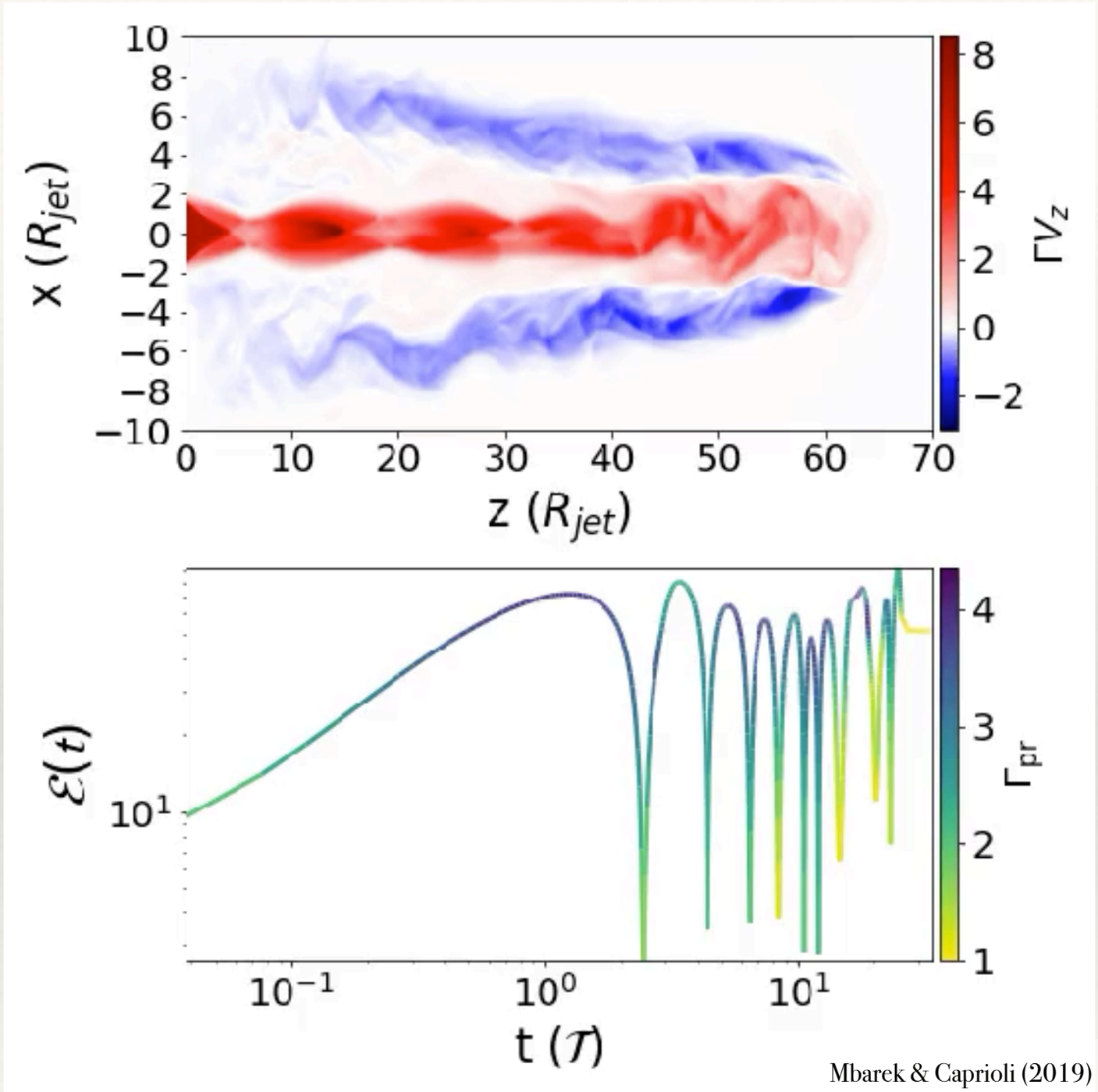
3D Simulation with PLUTO (Mignone et al. 2010)

Jet is initialized with $\Gamma = 7$, but the effective value $\Gamma_{\rm eff} = 3.2$



Mbarek & Caprioli (2019)

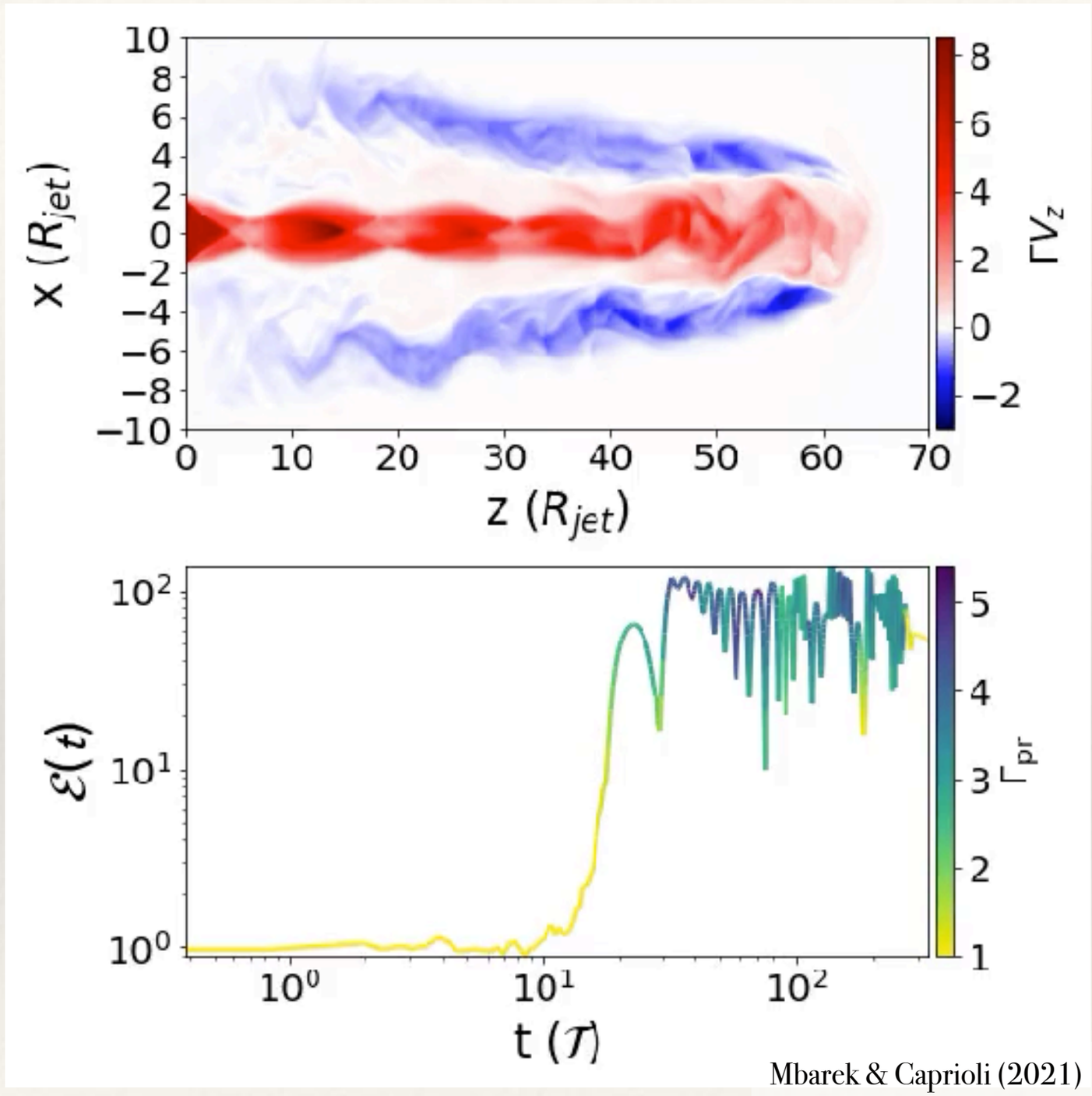
2D slice of Particle Trajectories



Mbarek & Caprioli (2019)

2D slice of Particle trajectory in MHD jet simulation

Particle Trajectories with subgrid magnetic fluctuations



Mbarek & Caprioli (2021)

With Bohm diffusion

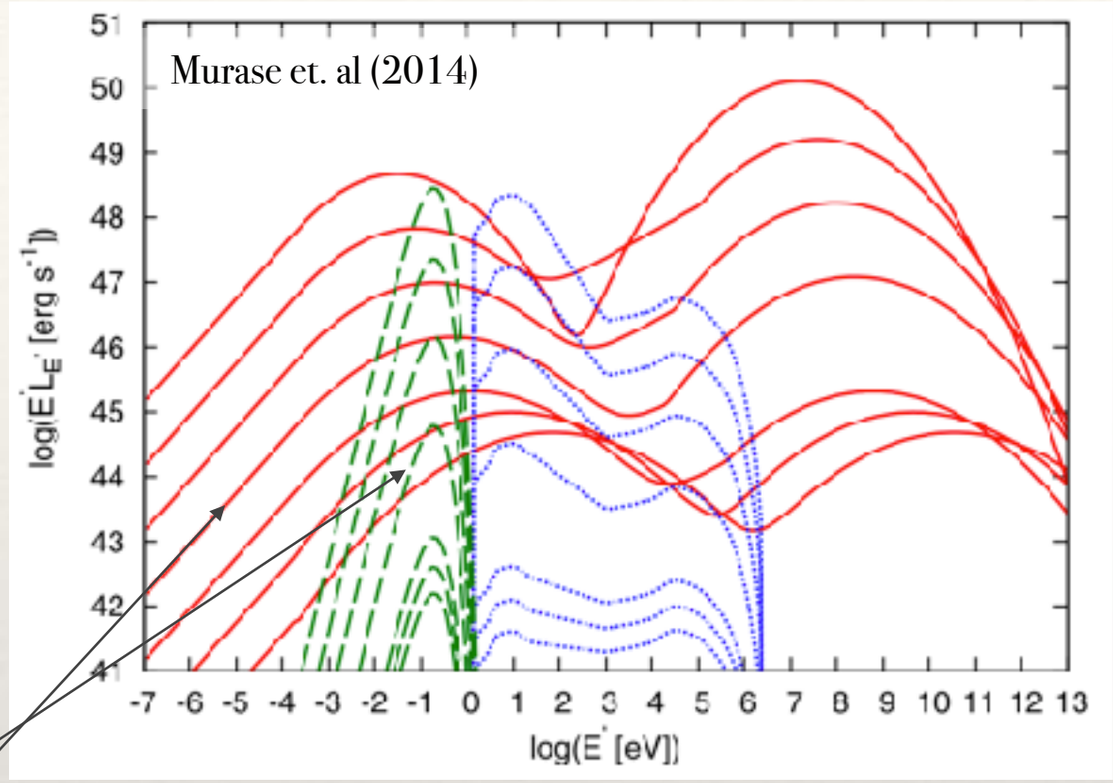
In Mbarek, Caprioli & Murase (2021 in prep.):

- We examine the following questions:
  - What are the effects of losses on accelerated particles?
  - What is the expected spectrum of UHE neutrinos produced by a typical AGN?
  - If AGNs are the sources of UHECRs, can they be responsible for the IceCube flux?
  - What are the implications for multimessenger astronomy ?

Photon Field Prescription and Neutrino Production routes

	neutrino Production mechanism	Energy fraction
p	$p + \gamma \rightarrow 3\nu$	p:$\nu \sim$ 20:1
	$p + p \rightarrow 3\nu$	p:$\nu \sim$ 20:1
N	$N + \gamma \rightarrow \pi^{\pm} \rightarrow 3\nu$	N:$\nu \sim$ 20A:1
	$N + \gamma \rightarrow n \rightarrow \bar{\nu}_e$	N:$\nu \sim 10^3$A:1

SED emission components for different AGN jets



Chosen Photon fields from a quite powerful jet: $L_{\rm bol} = 10^{48} erg/s$

Dusty Torus IR

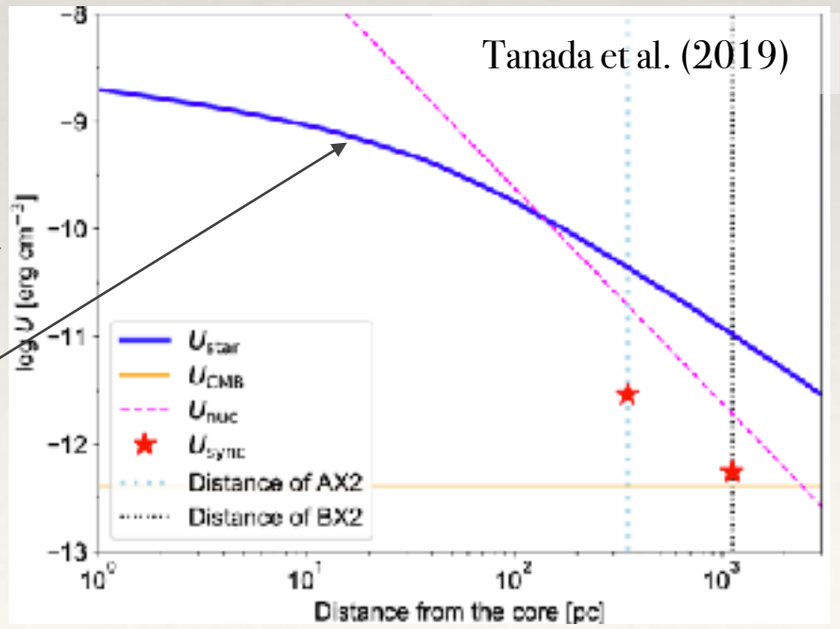
Broad Line Region

Nonthermal Emission

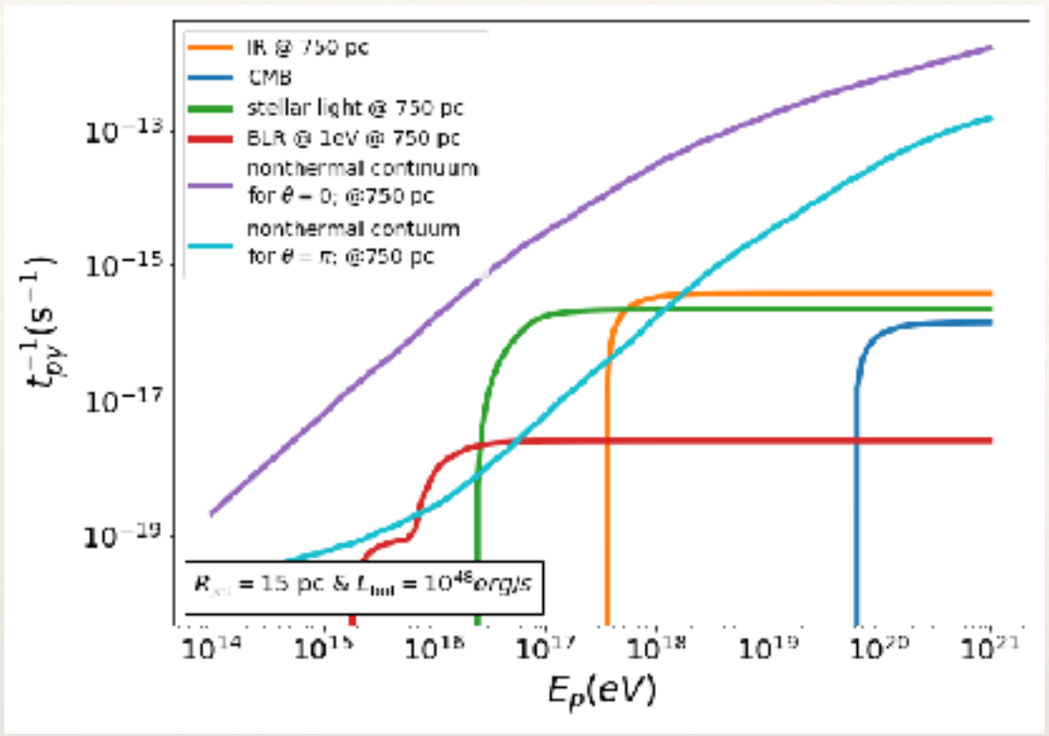
Other considered fields:

stellar light

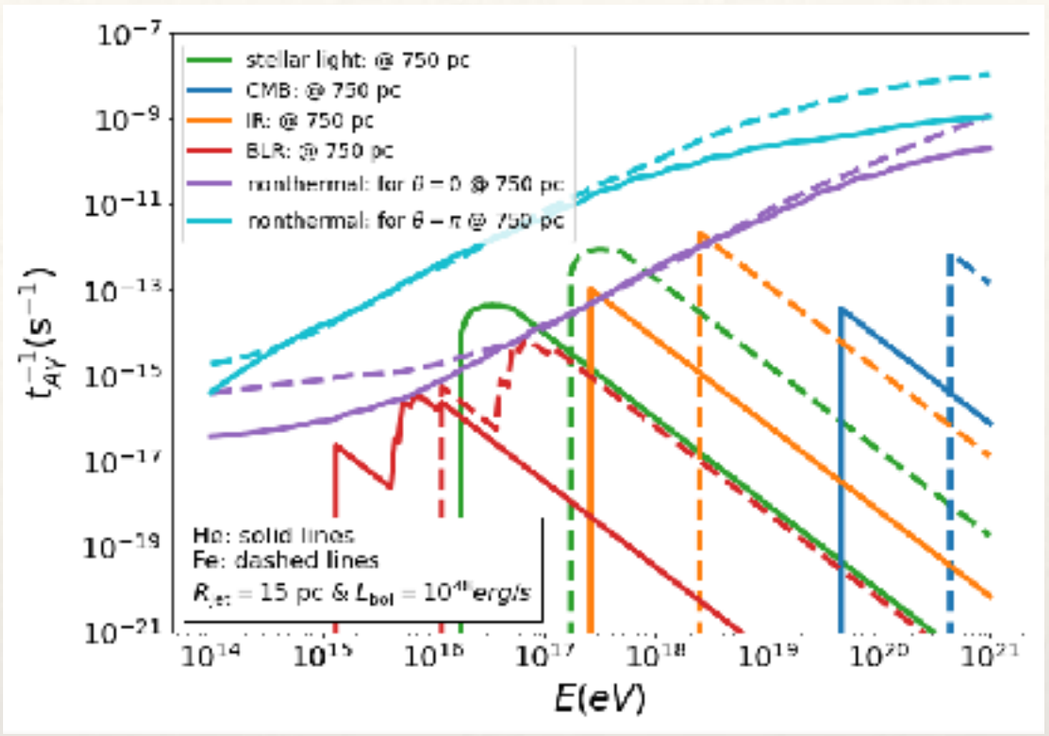
CMB



Proton and Nucleus Interactions

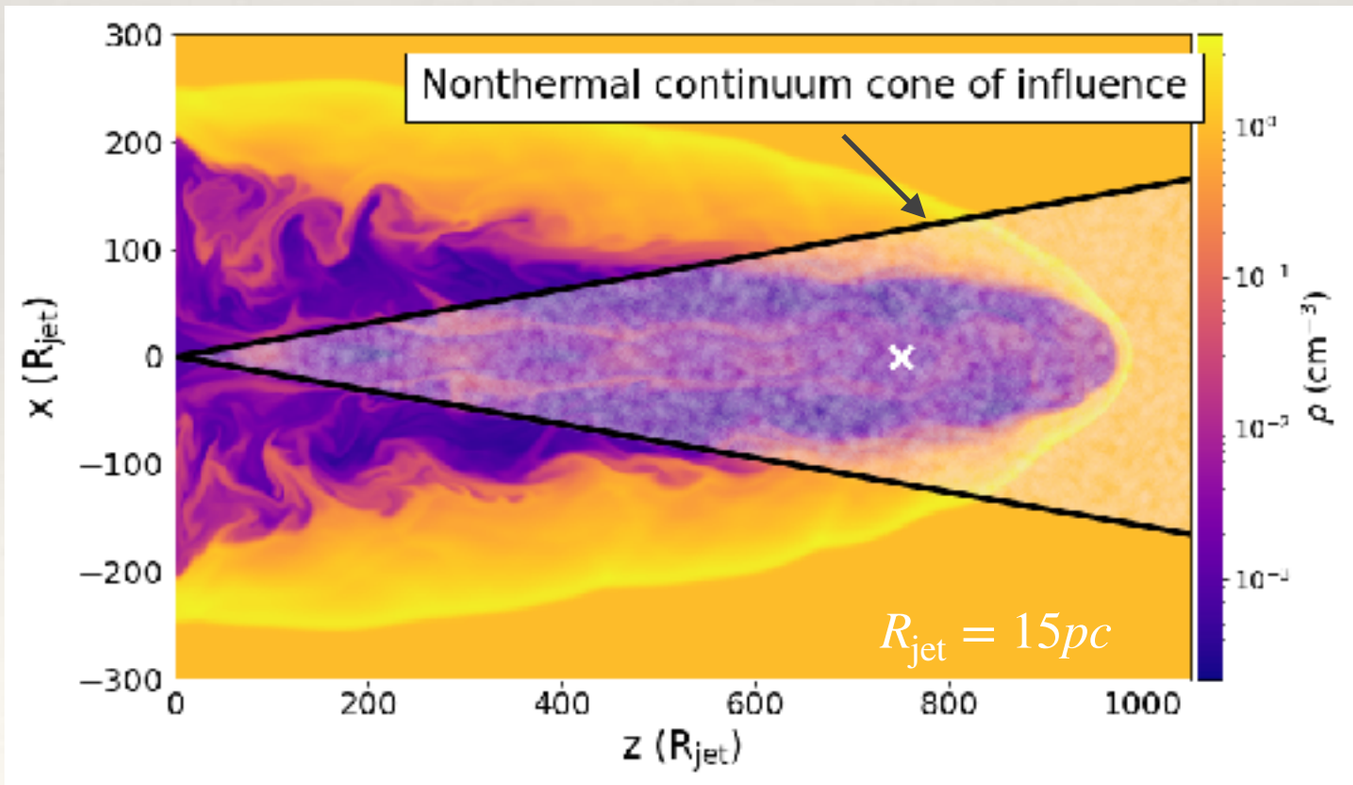


Photomeson Interactions

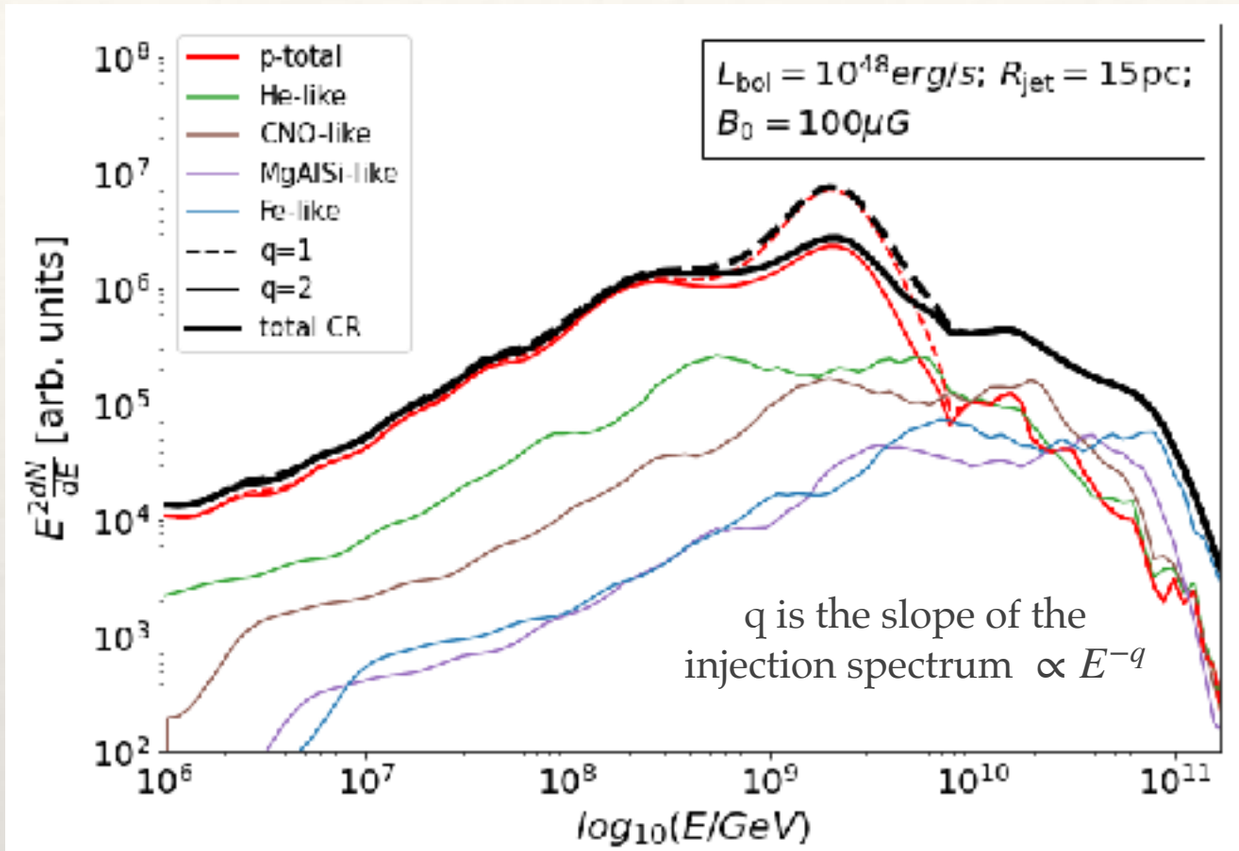


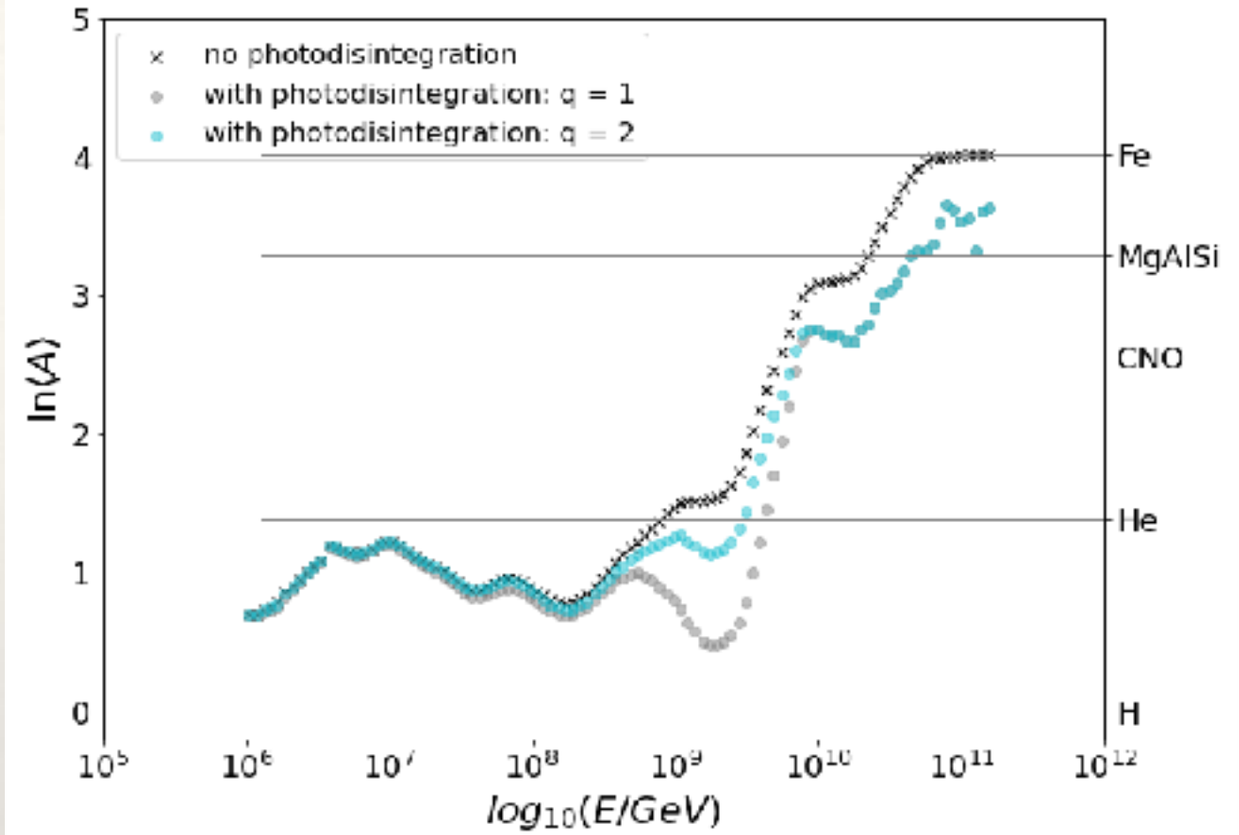
Photodisintegration Interactions

2D slice of the Jet density map with the nonthermal continuum cone of influence (angle $1/\Gamma_{eff}$)



Effects of losses on UHECR spectrum

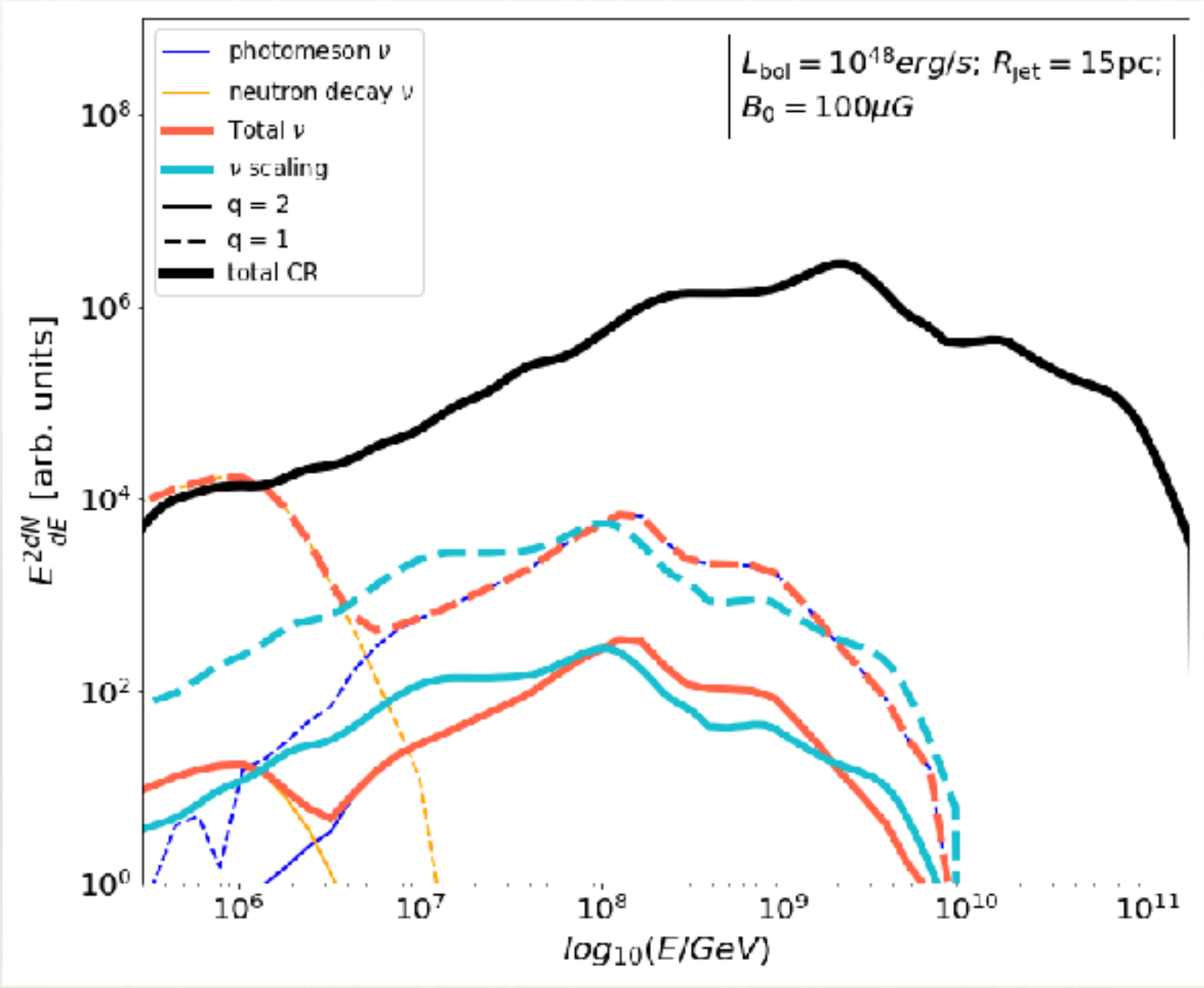




- **Takeaway messages:**
  - Photodisintegration effects are not significant (Consistent with Auger results)
  - UHECR spectrum still heavy at highest energies (Consistent with Auger results)
  - Peak at 10^{18} eV is associated with reaccelerated secondary protons (More prominent for q = 1)

Neutrino Spectra

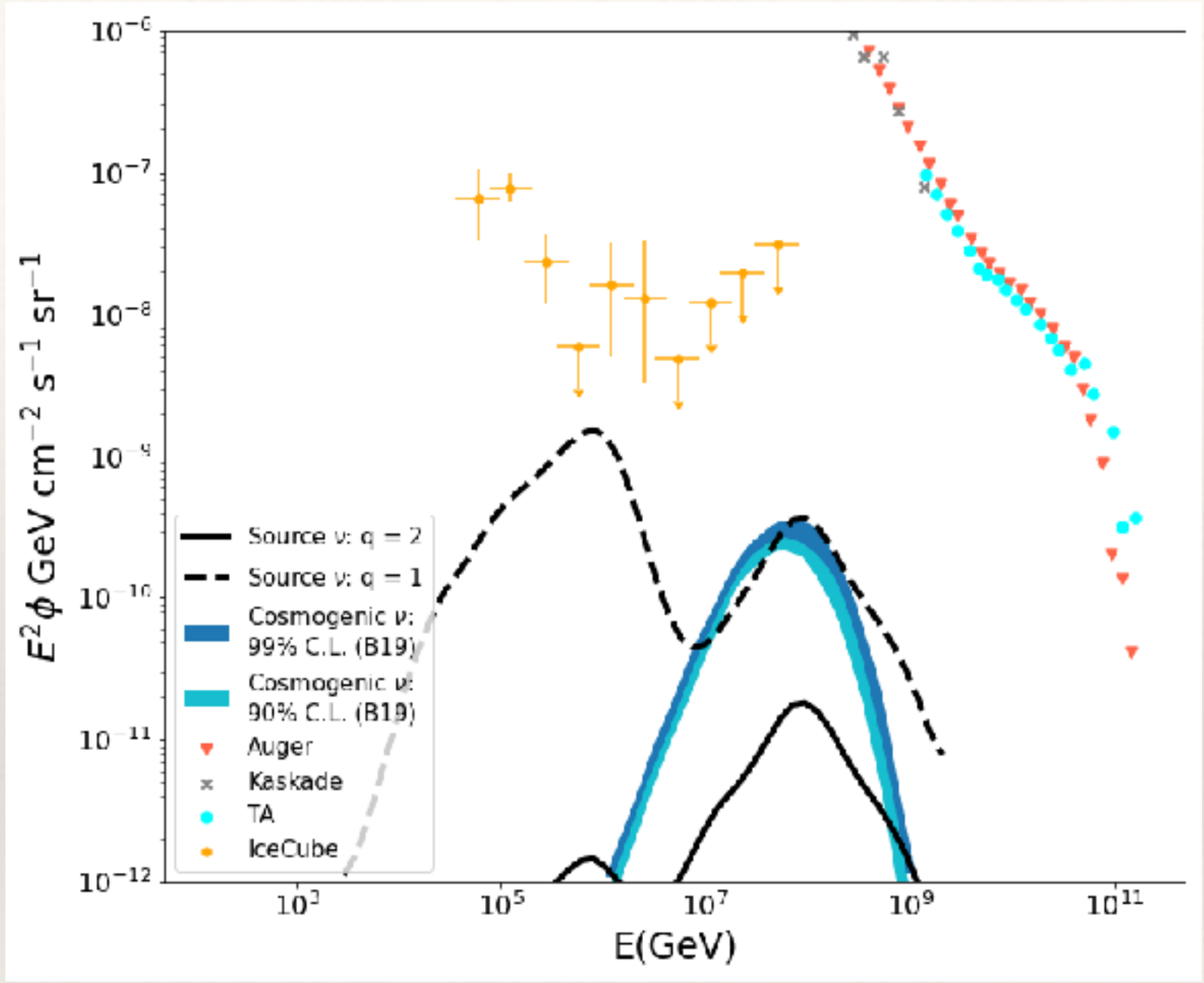
- **Takeaway messages:**
  - Source neutrinos could be significant
  - Can estimate the source neutrino flux contribution based on the relative normalization with the UHECR flux
  - Neutrinos from neutron decay are more prominent at lower energies for q=1



q is the slope of the injection spectrum $\propto E^{-q}$

Source vs. Cosmogenic Neutrinos

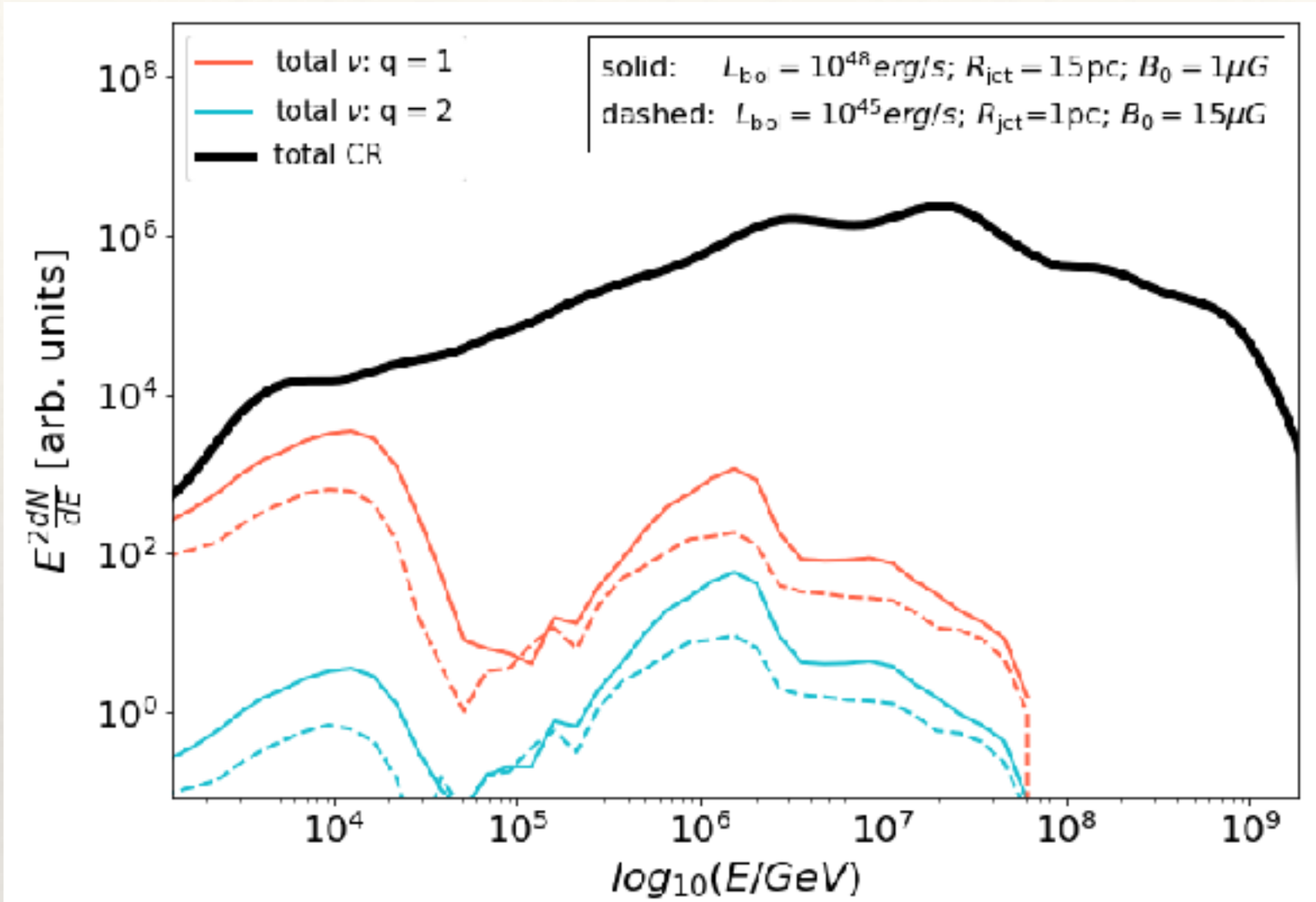
- Takeaway message:
  - Source neutrinos have a comparable flux to that of cosmogenic neutrinos
  - For flatter injection spectra, neutron decay neutrinos are significant



Cosmogenic neutrinos calculations are taken from Batista et al. (2019) modeled based on an AGN source evolution with different confidence levels

IceCube neutrinos?

- **Takeaway message:**
  - The AGN jet stationary neutrino spectrum **cannot** explain the IceCube neutrino flux
  - Neutrinos could correlate with flares since nonthermal contribution dominates (ν and γ-ray flare from TXS 0506+056 possibly correlated)



Different magnetic field and radius prescriptions

Conclusions

- Our framework is a self-consistent bottom-up approach for studying the multi-messenger connection between UHECRs and neutrinos
- AGN jets cannot explain the whole of IceCube's neutrino spectrum, **BUT** neutrinos should correlate with flares
- The source neutrino flux with energies $> 10^{17}$eV could be comparable to cosmogenic neutrinos
- Our predictions are testable with a well-studied particle acceleration theory behind all of our predictions