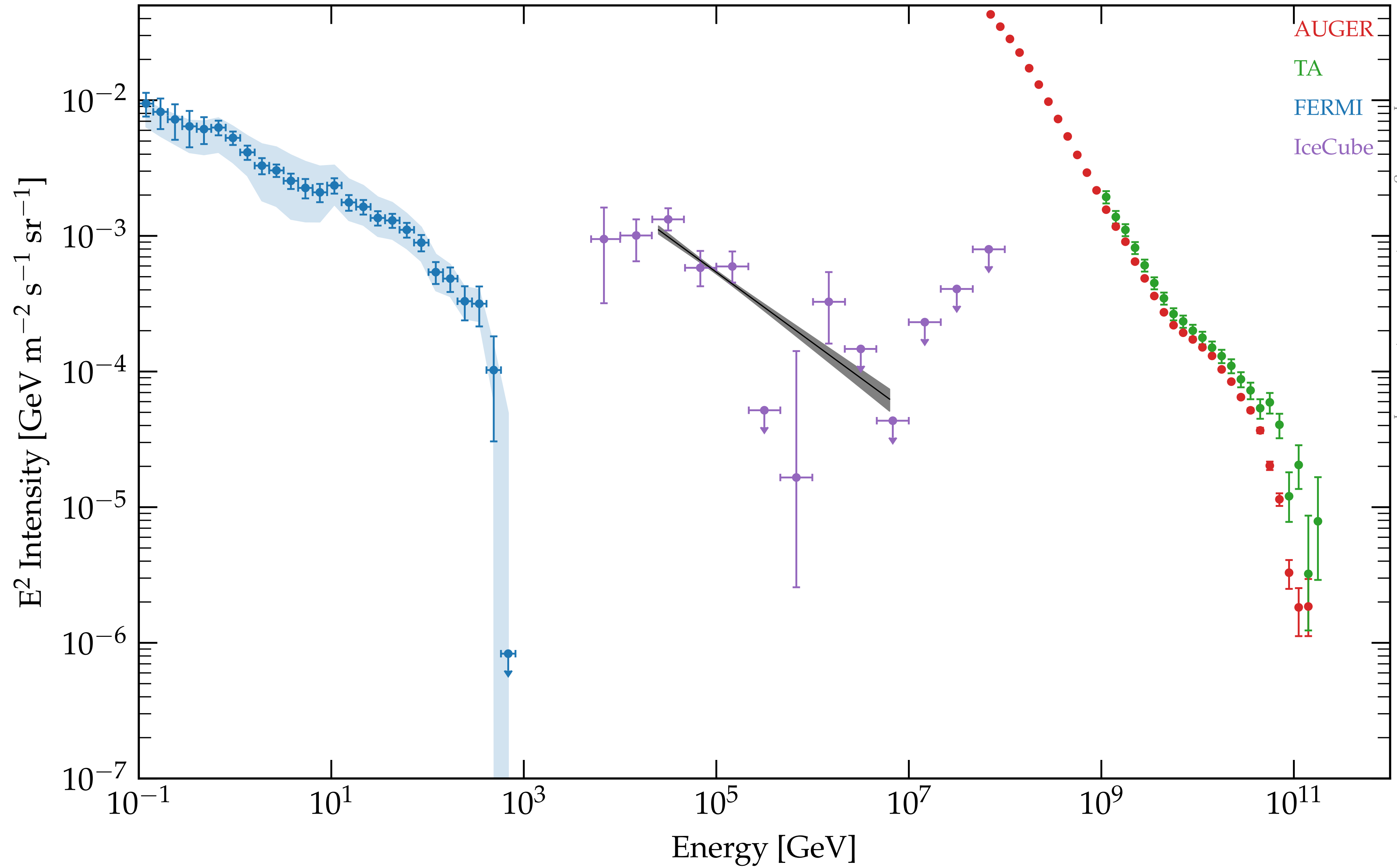


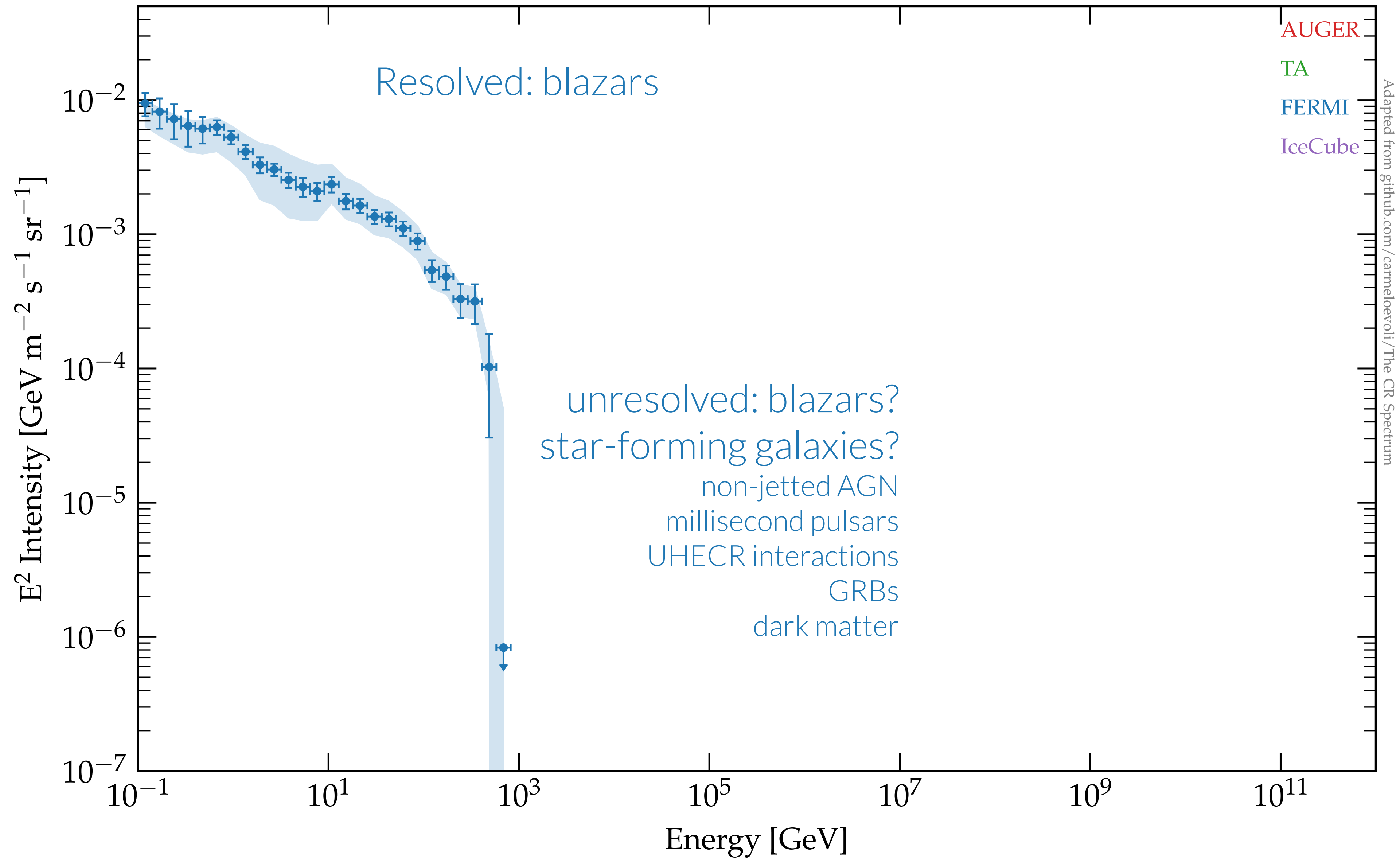
# Neutrino - $\gamma$ -ray - UHECR connection

Foteini Oikonomou

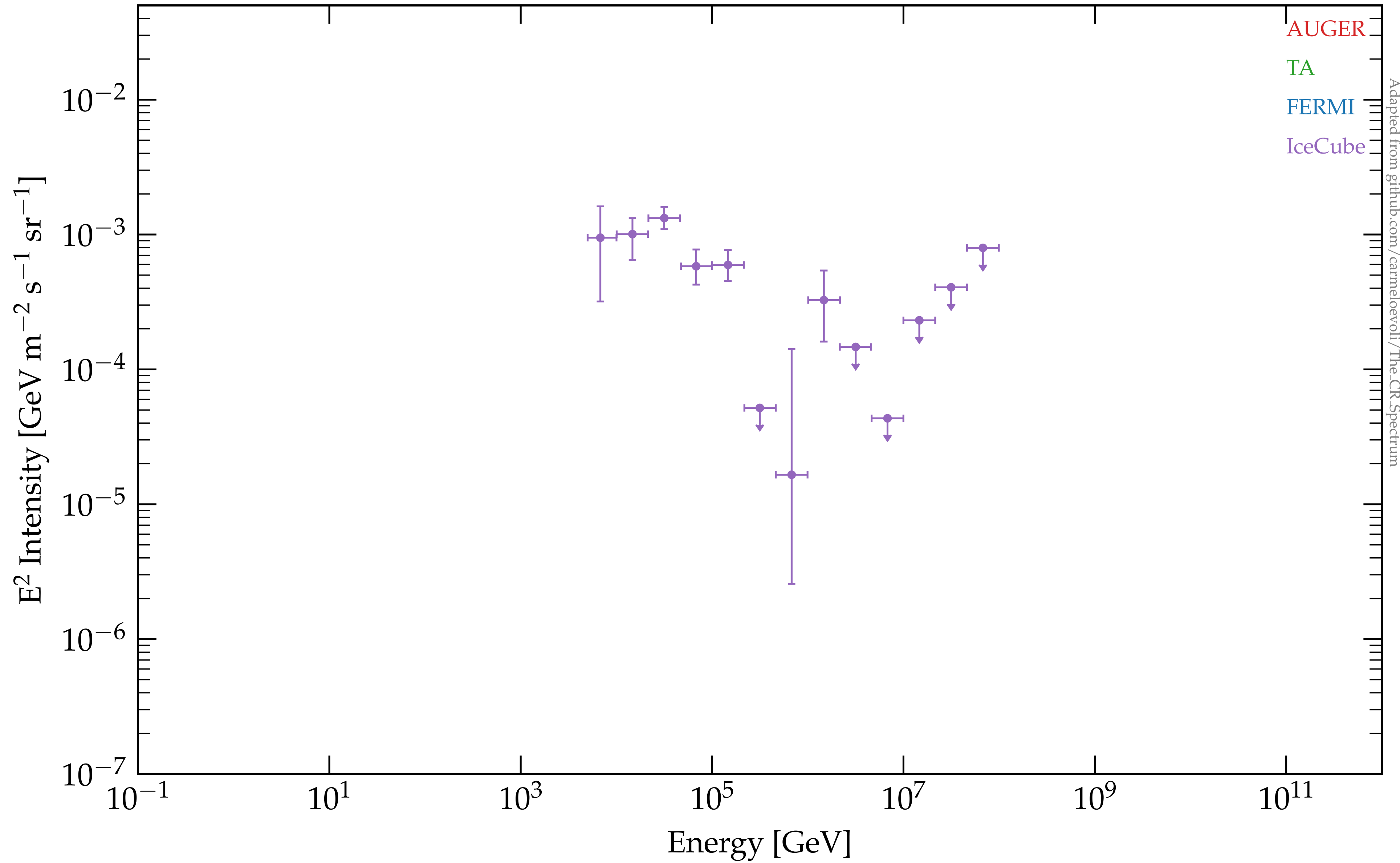
# High-energy messengers



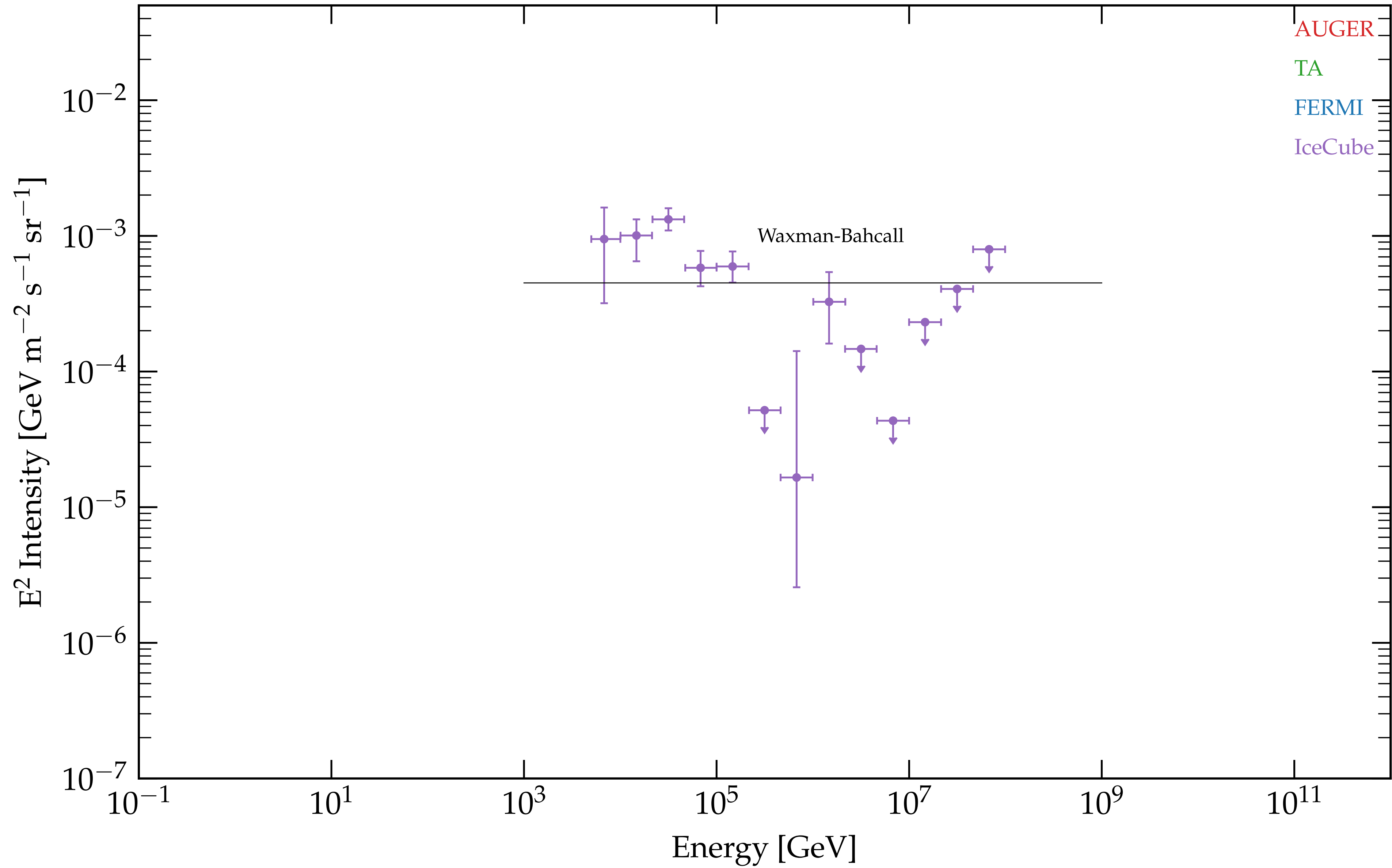
# High-energy messengers



# Neutrinos

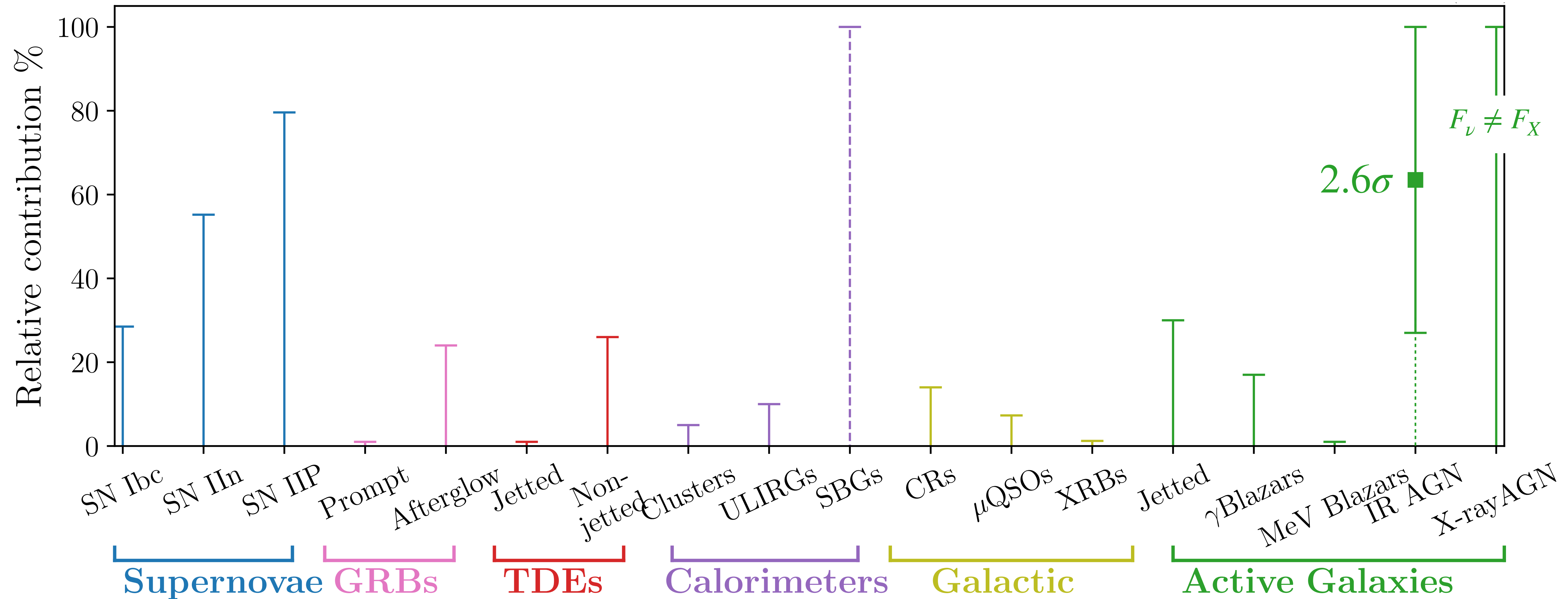


# Neutrinos

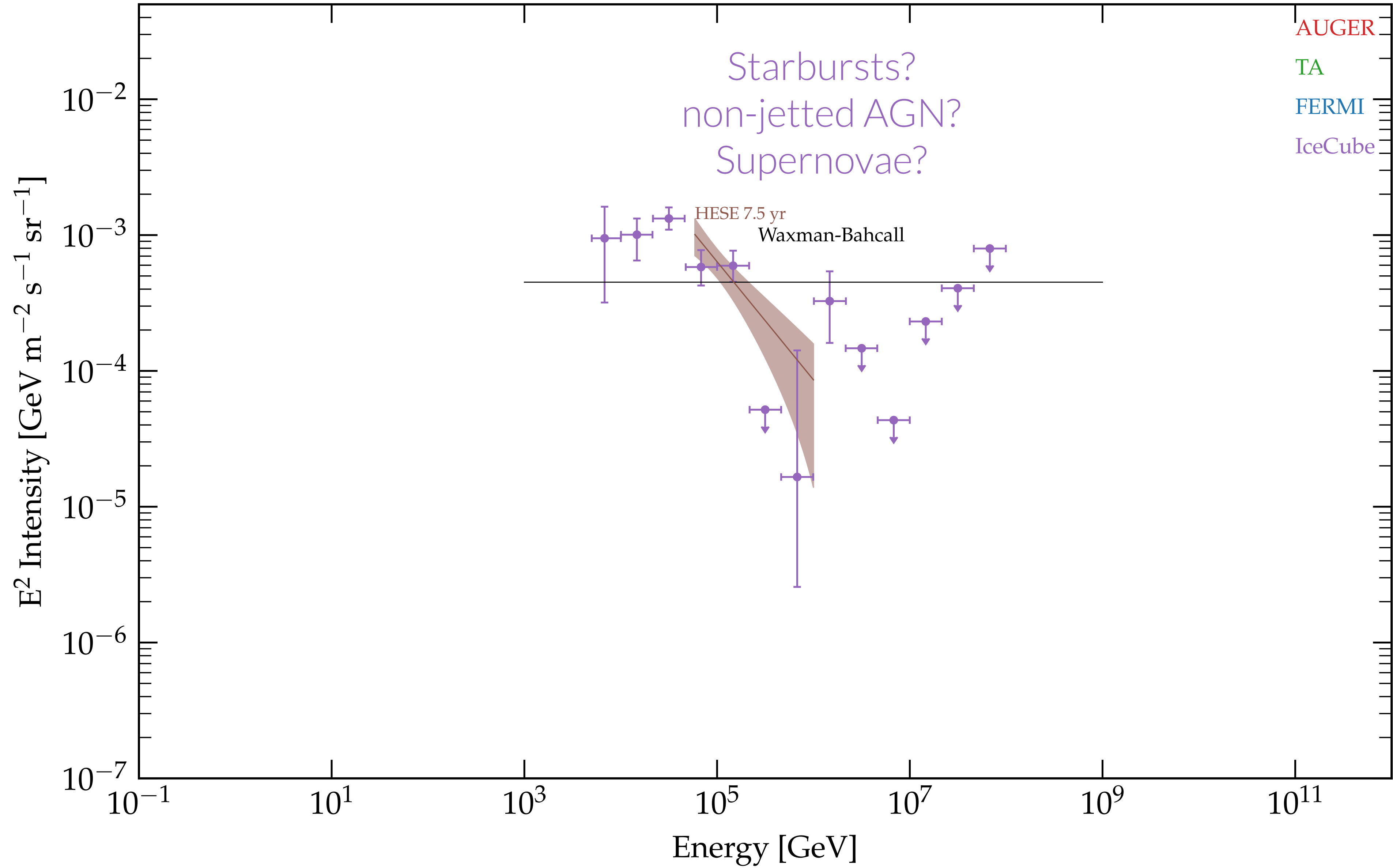


# Neutrinos: Stacking limits

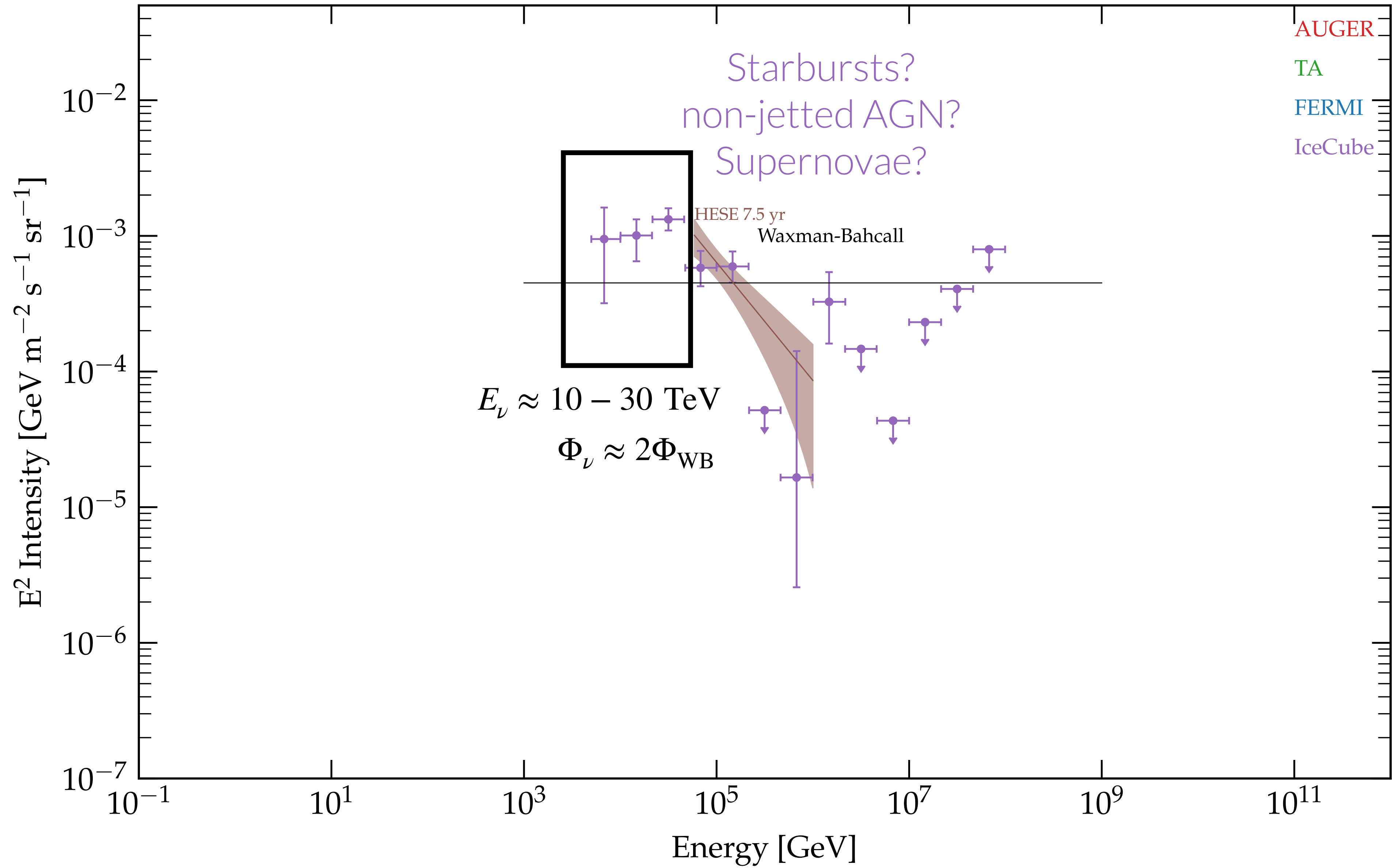
FO PoS ICRC2021 (2022) 030 (see for list of references)



# Neutrinos

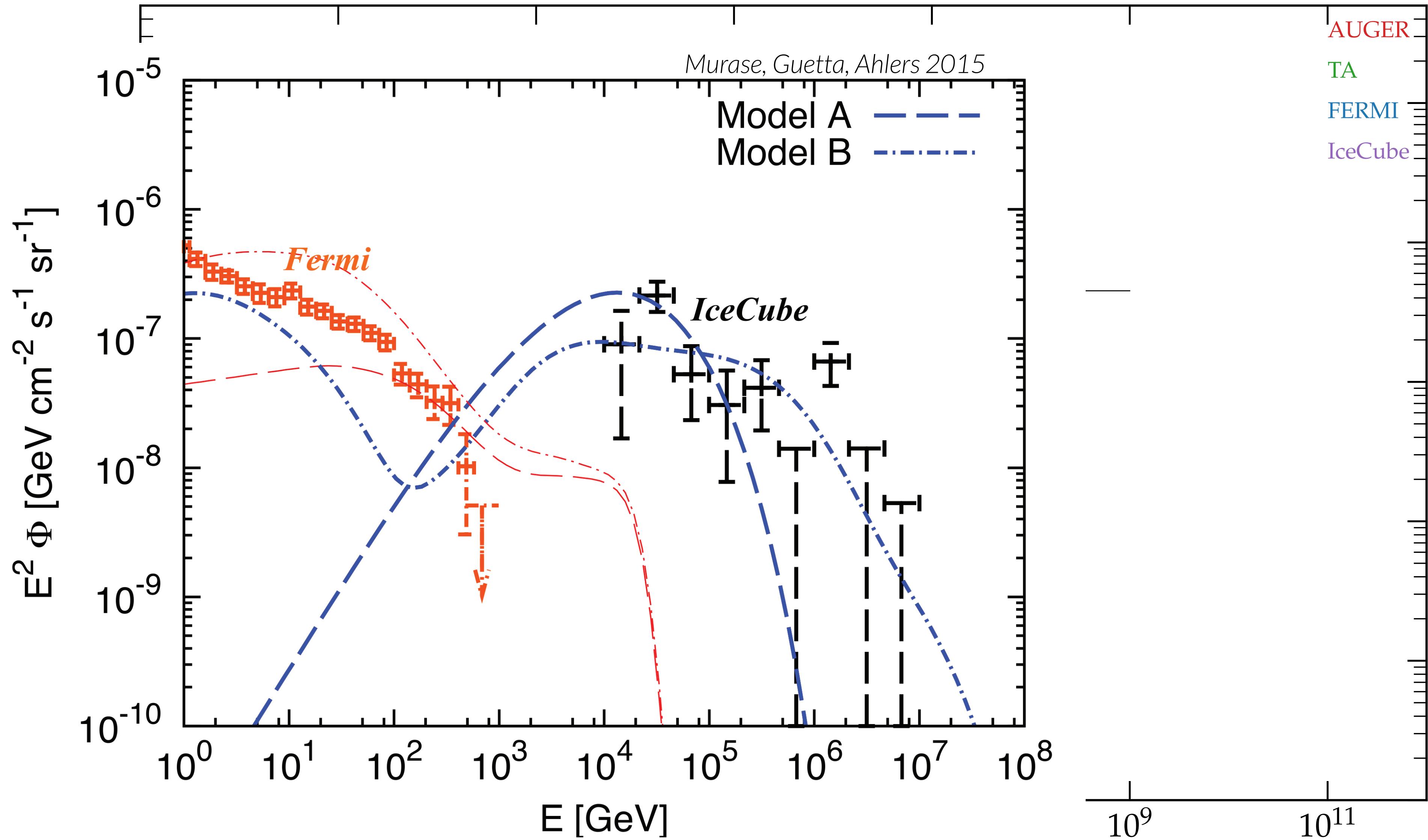


# Neutrinos

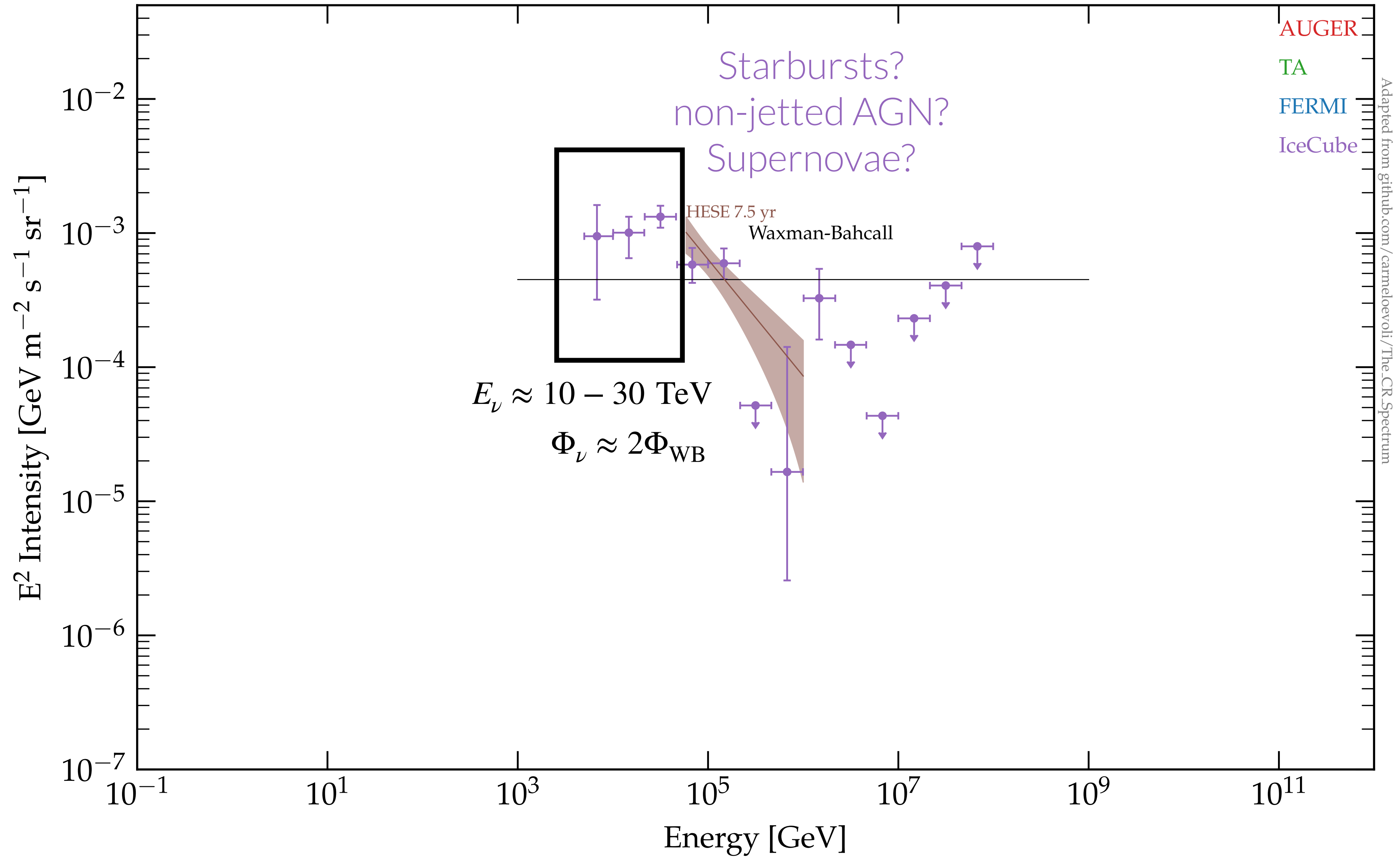




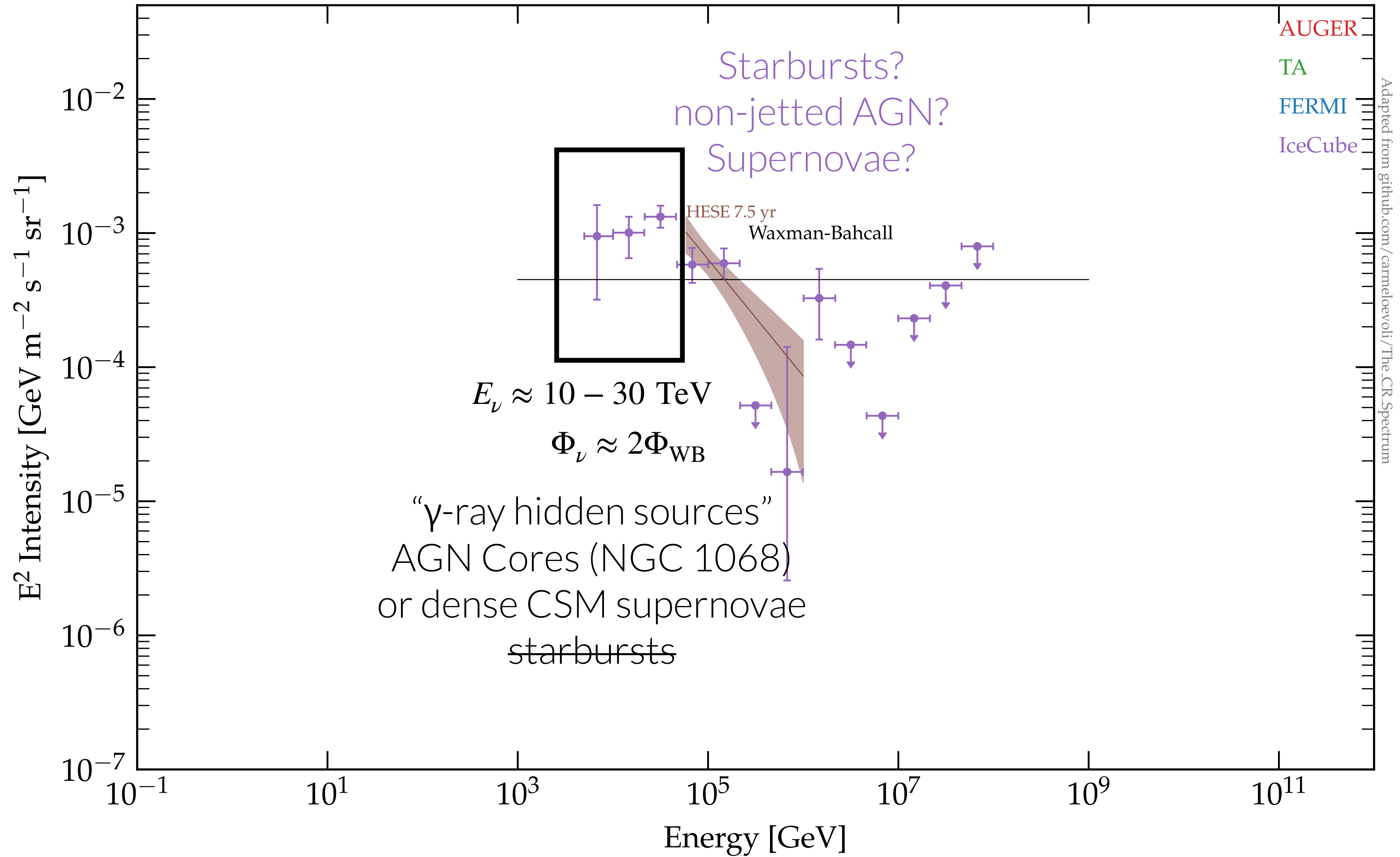
# Neutrinos



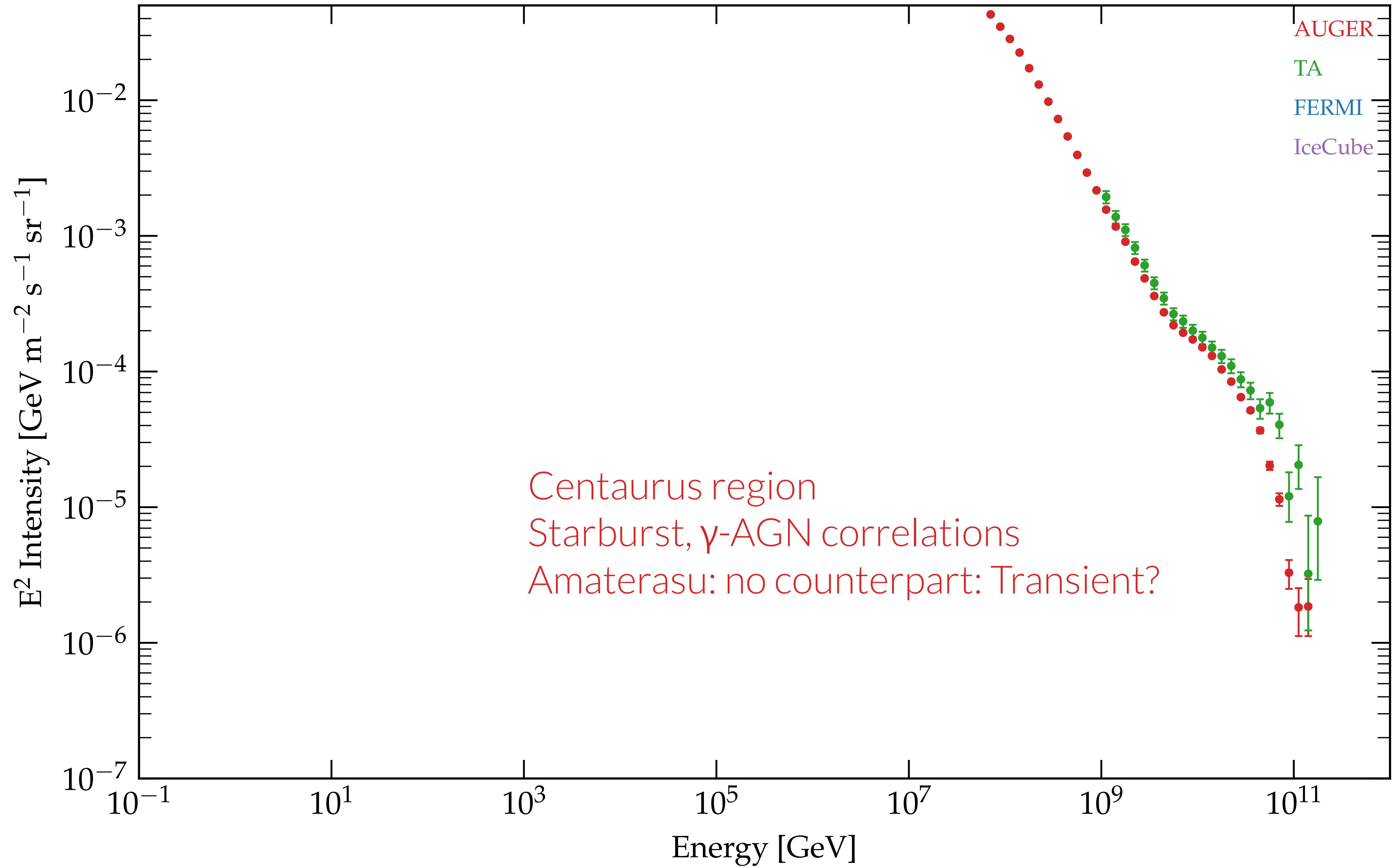
# Neutrinos



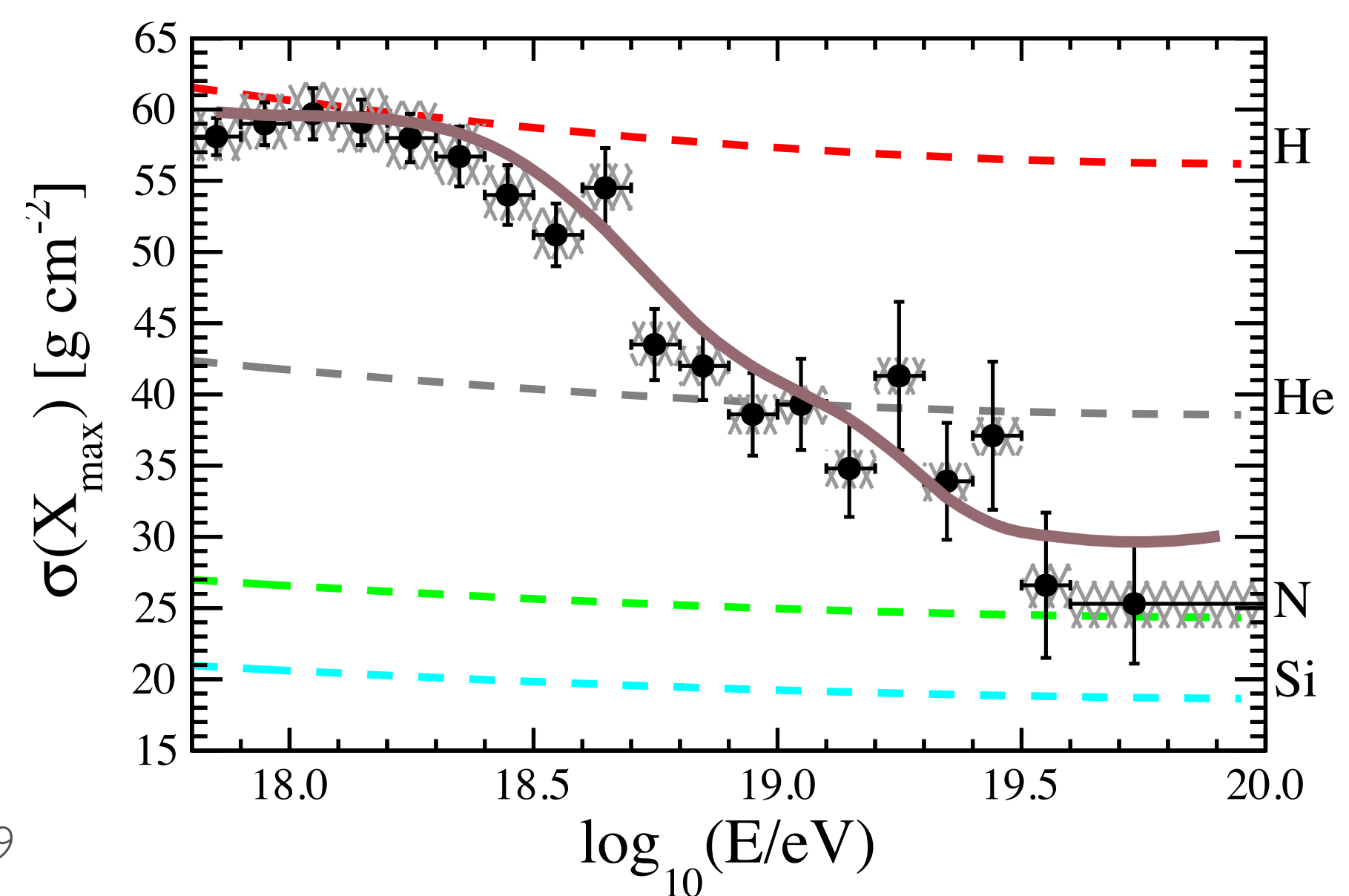
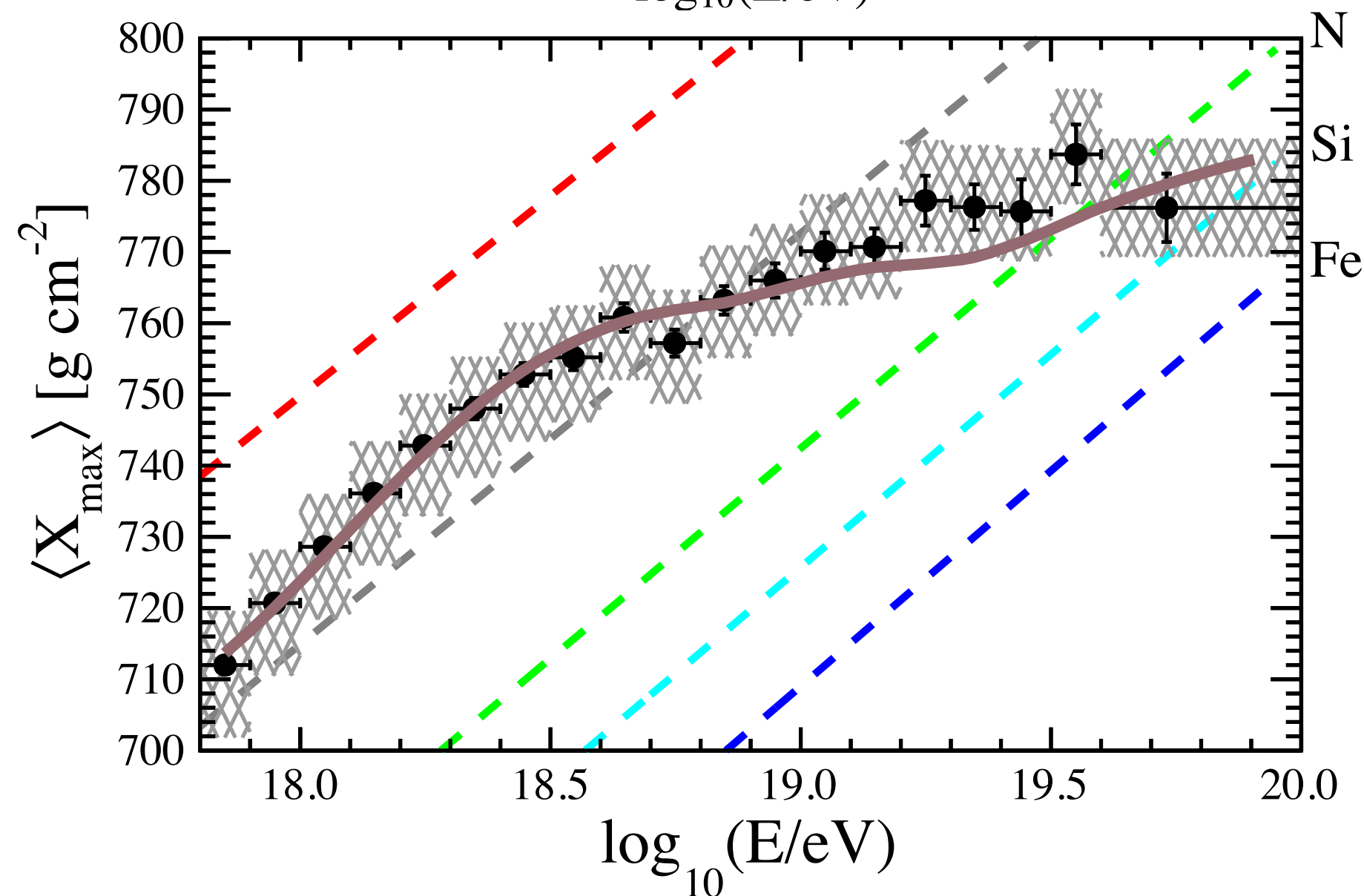
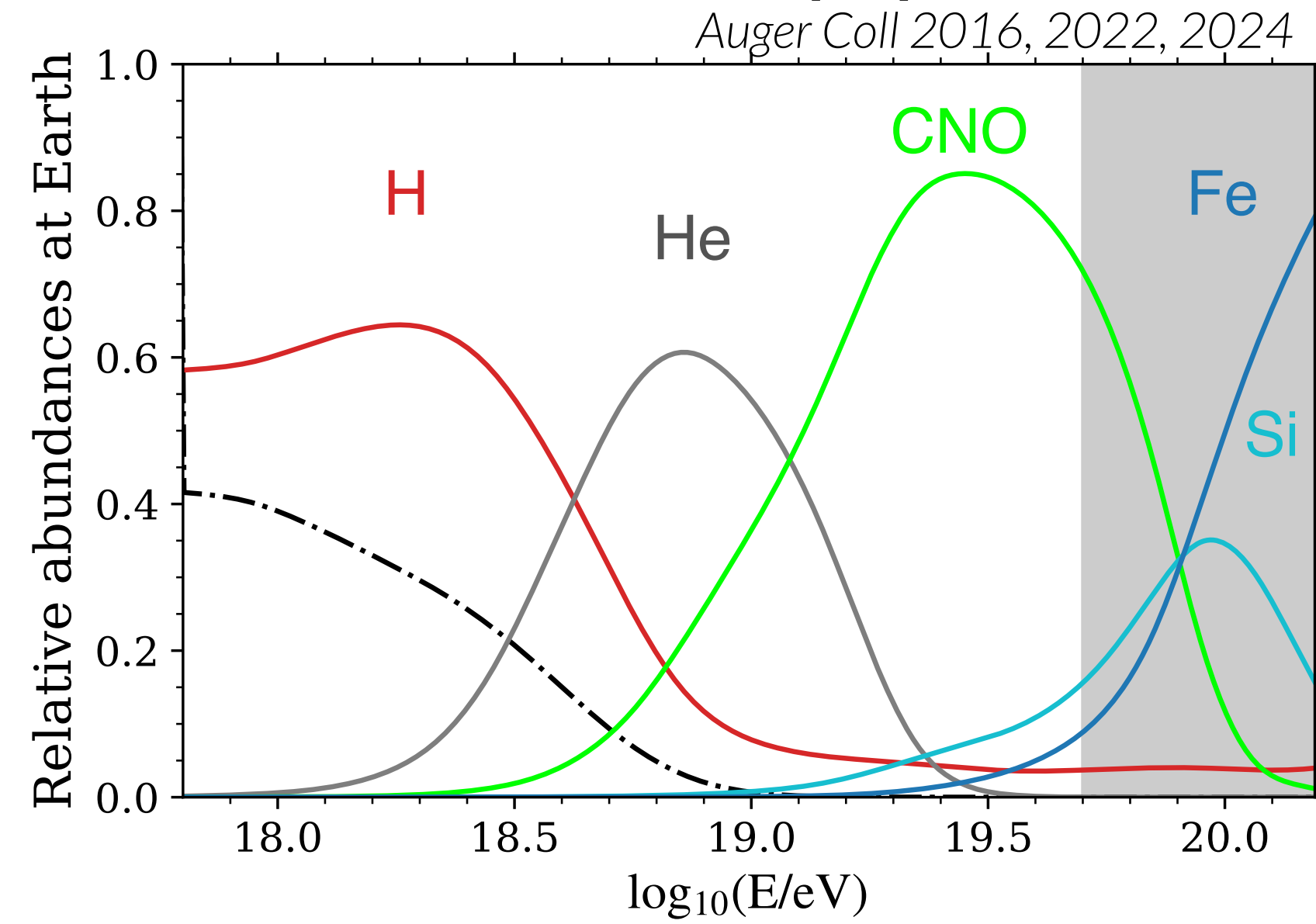
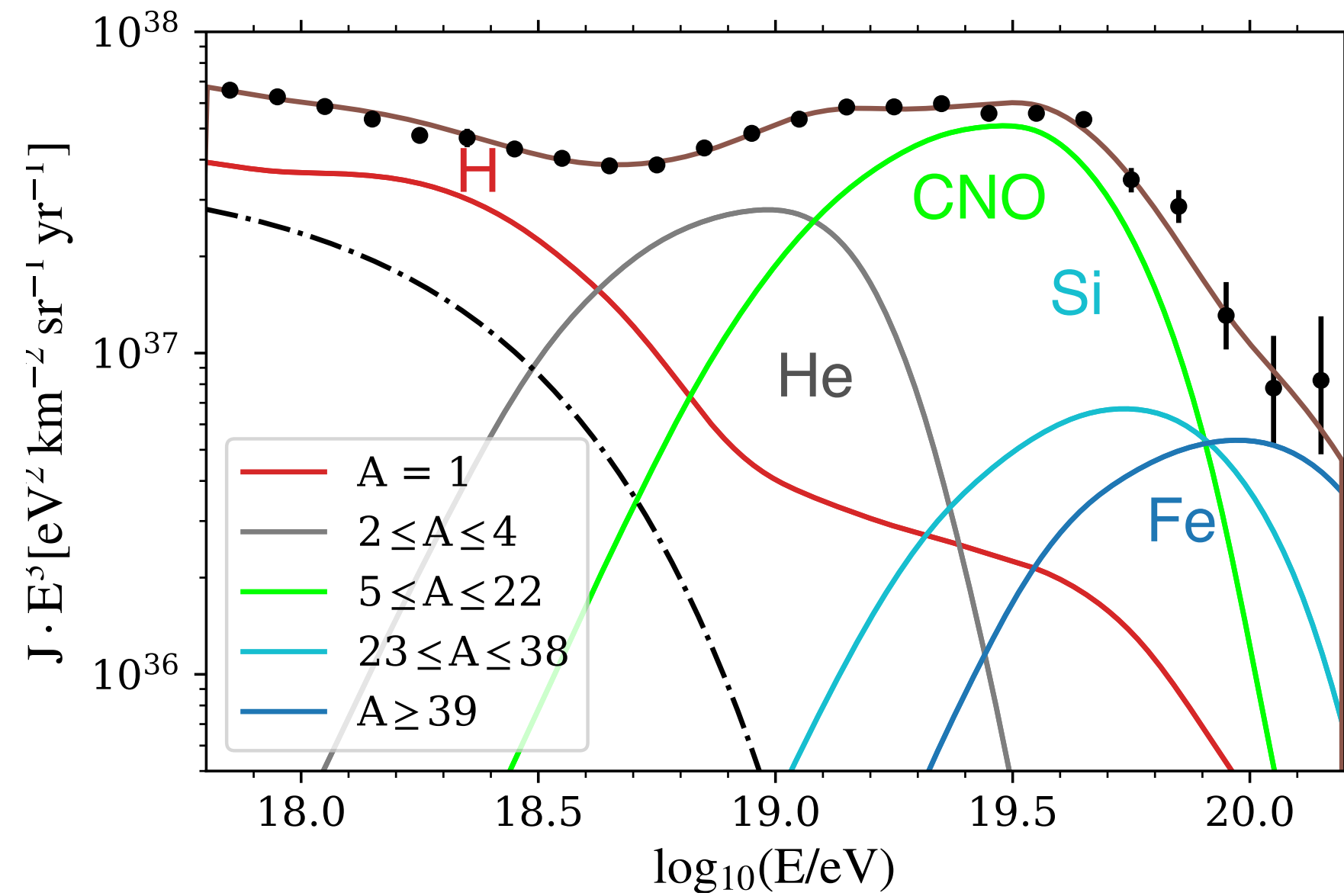
# Neutrinos



# UHECRs



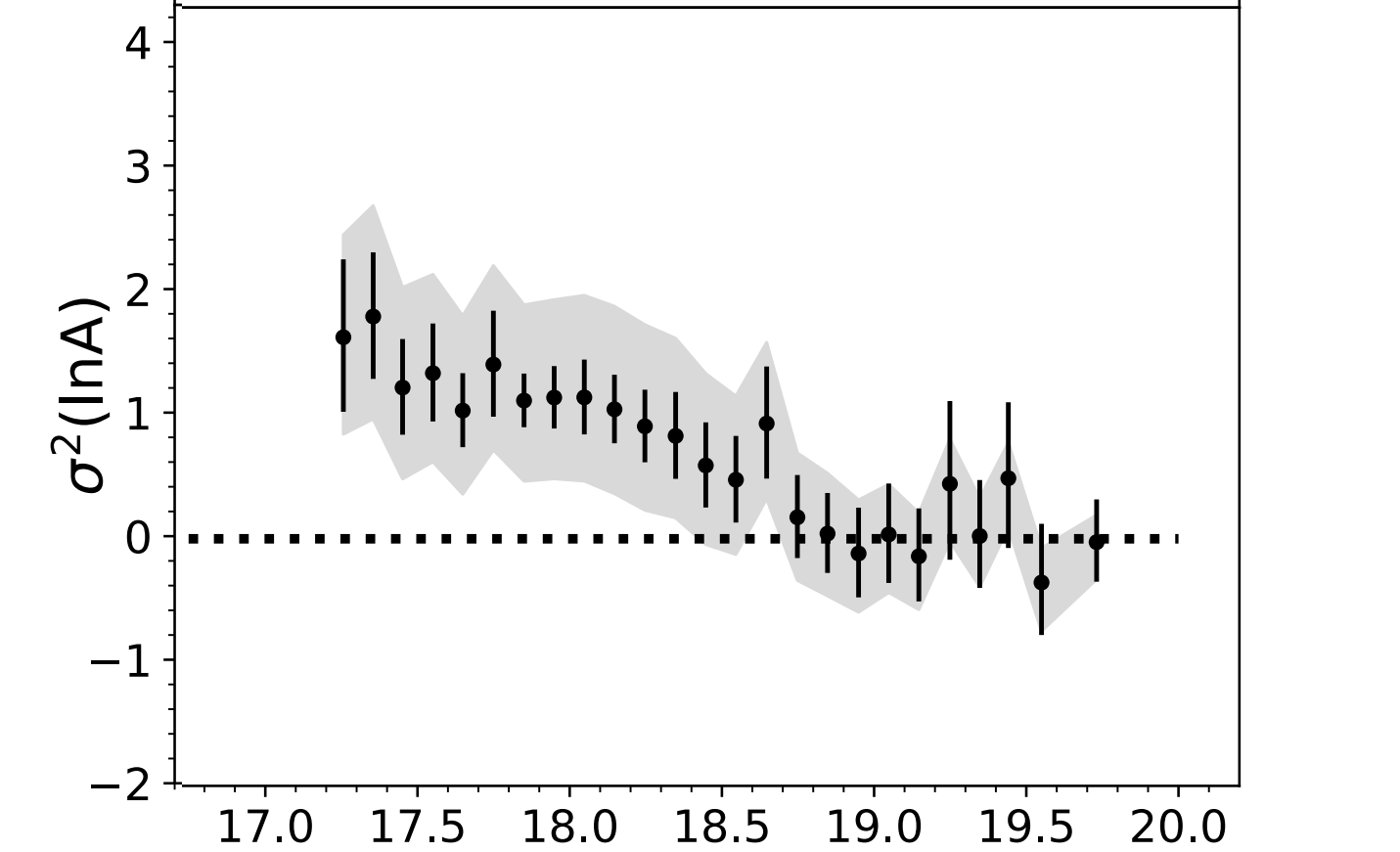
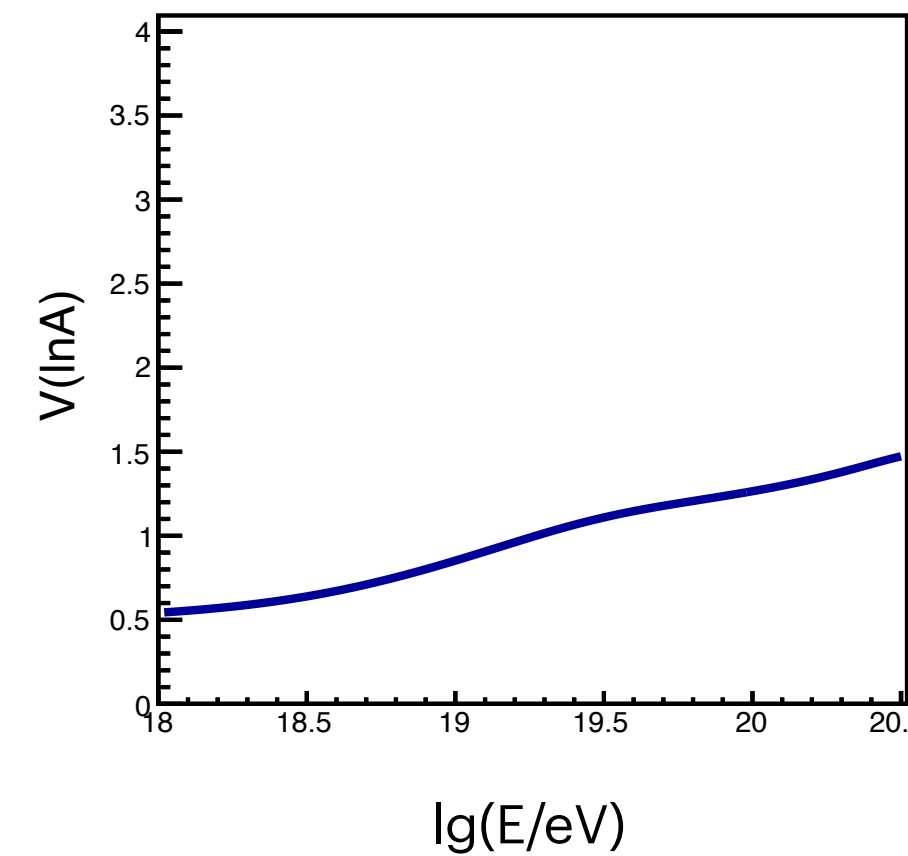
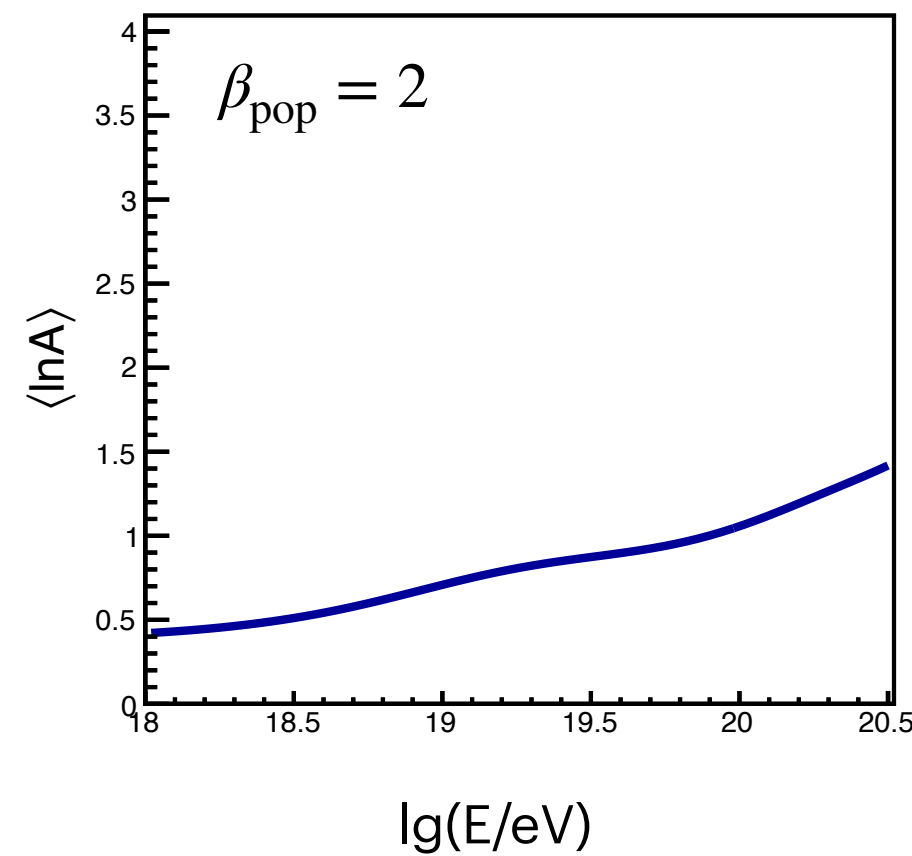
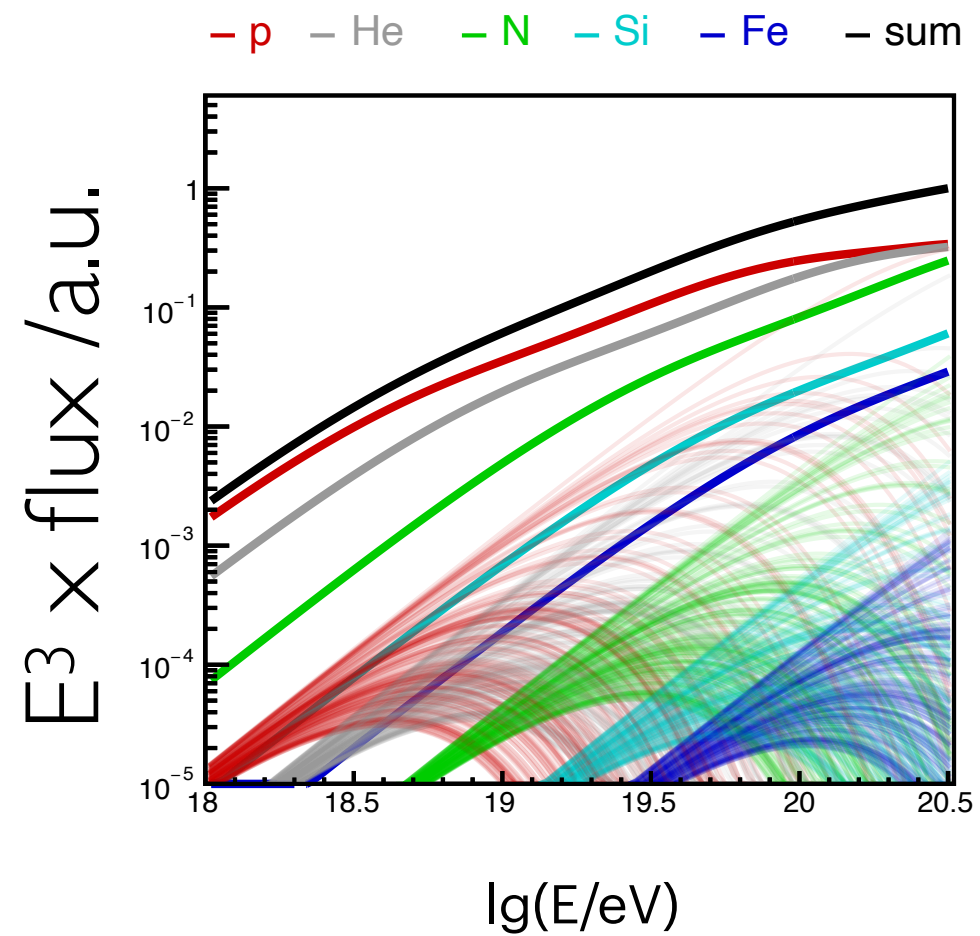
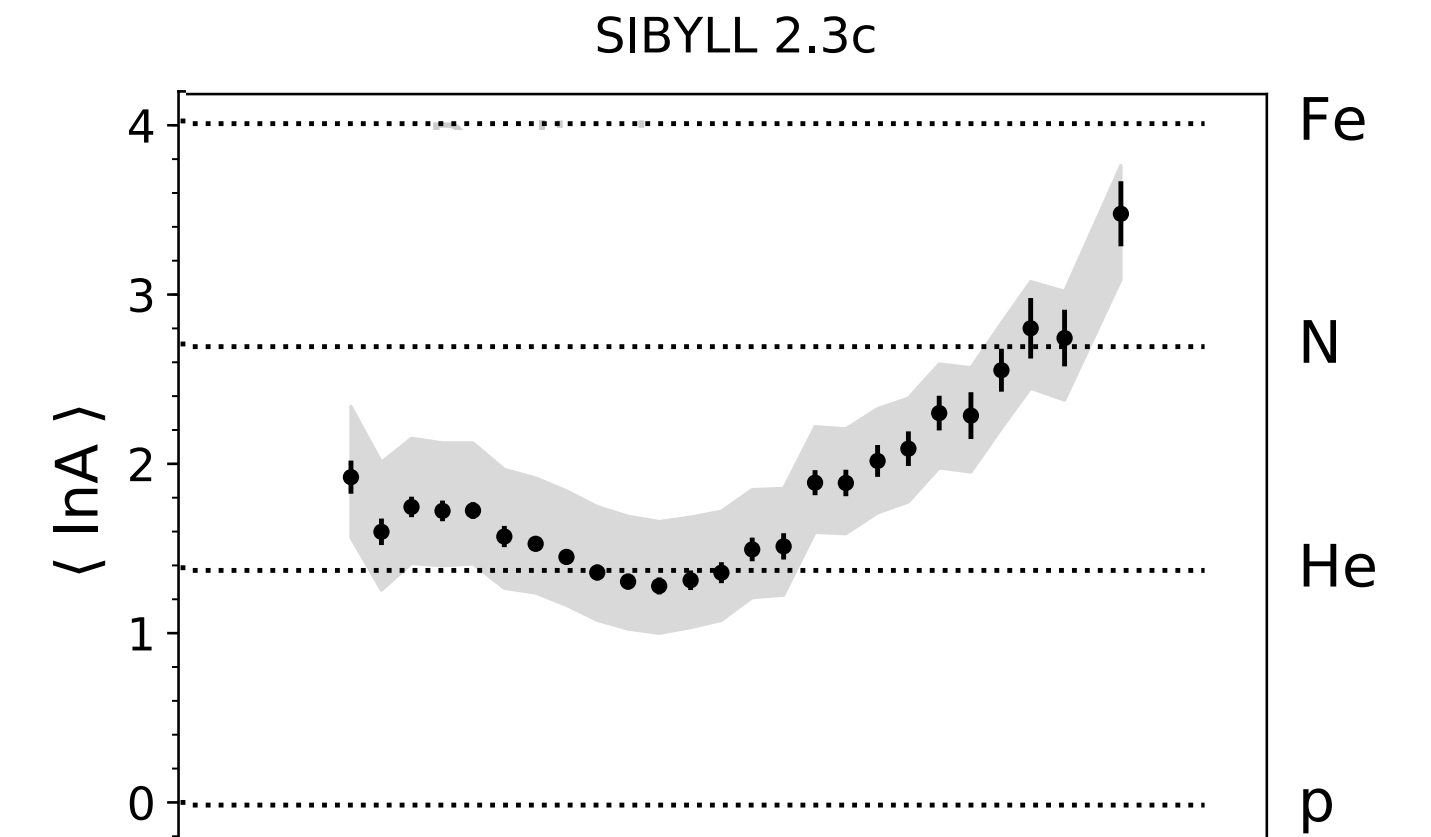
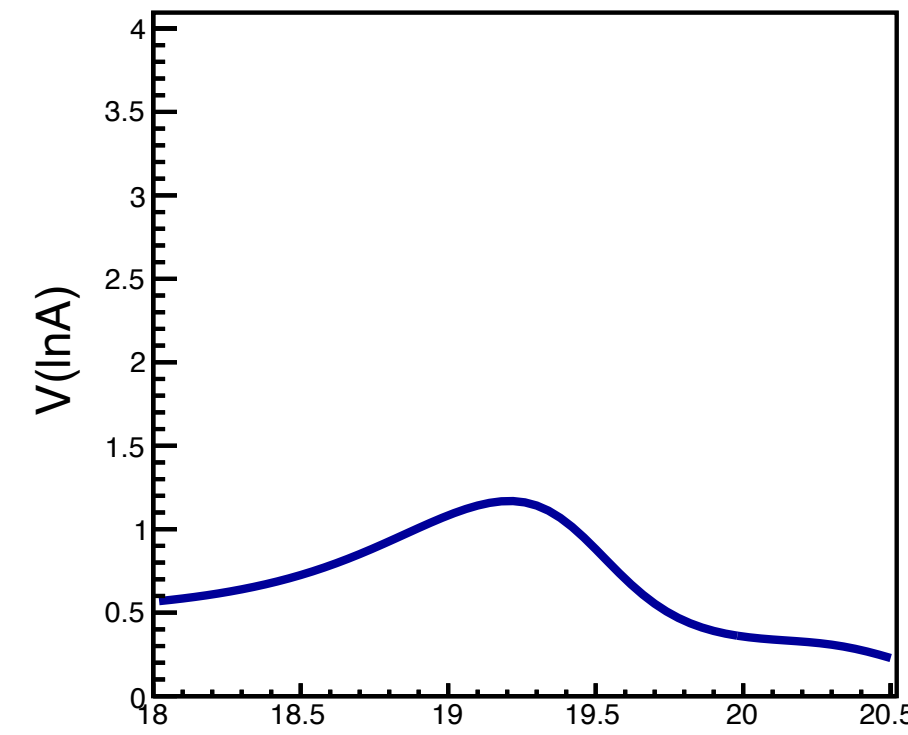
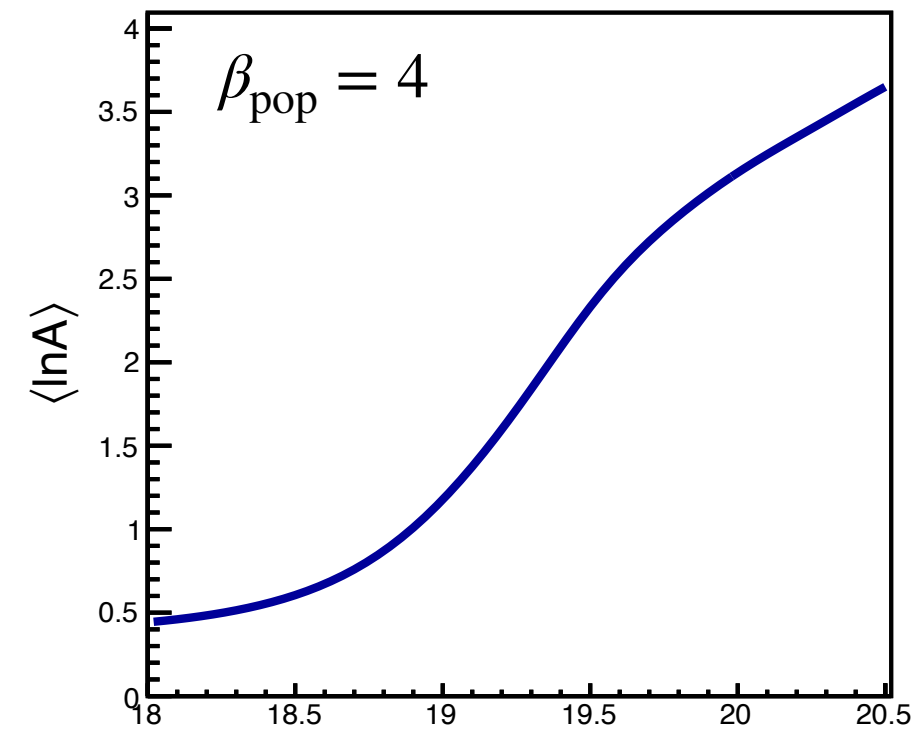
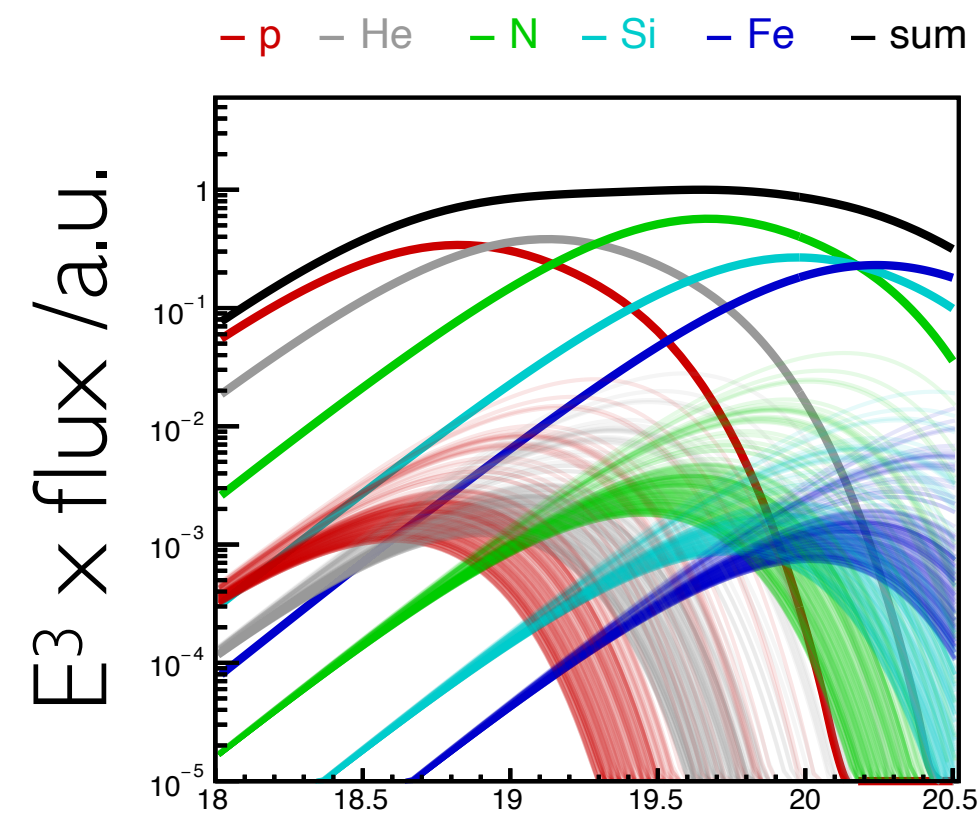
# UHECR origin: Combined-fit search approach



# Combined fit with a population of non-identical sources

Toy example with power-law distributed maximum energy  $\frac{dN}{dE_{\max}} \propto E_{\max}^{-\beta_{\text{pop}}}$

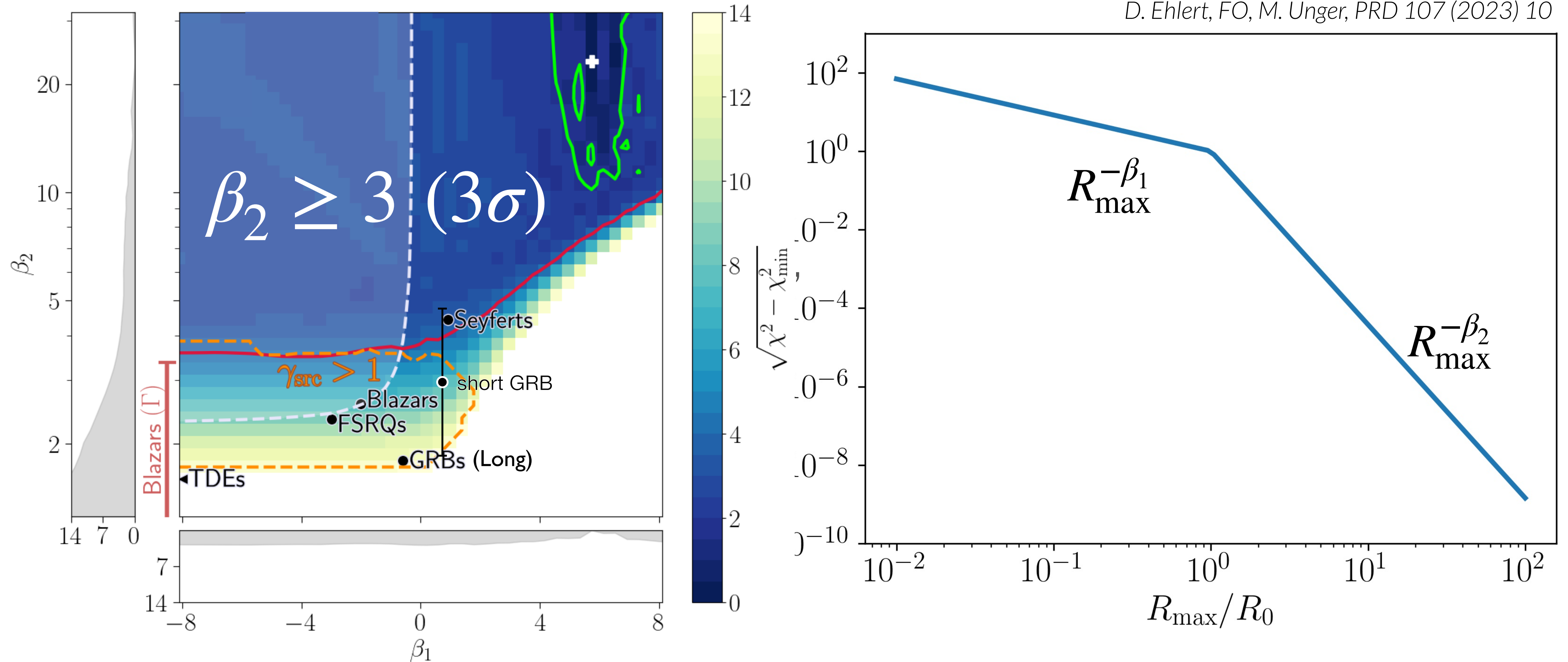
*D. Ehlert, FO, M. Unger, PRD 107 (2023) 10*



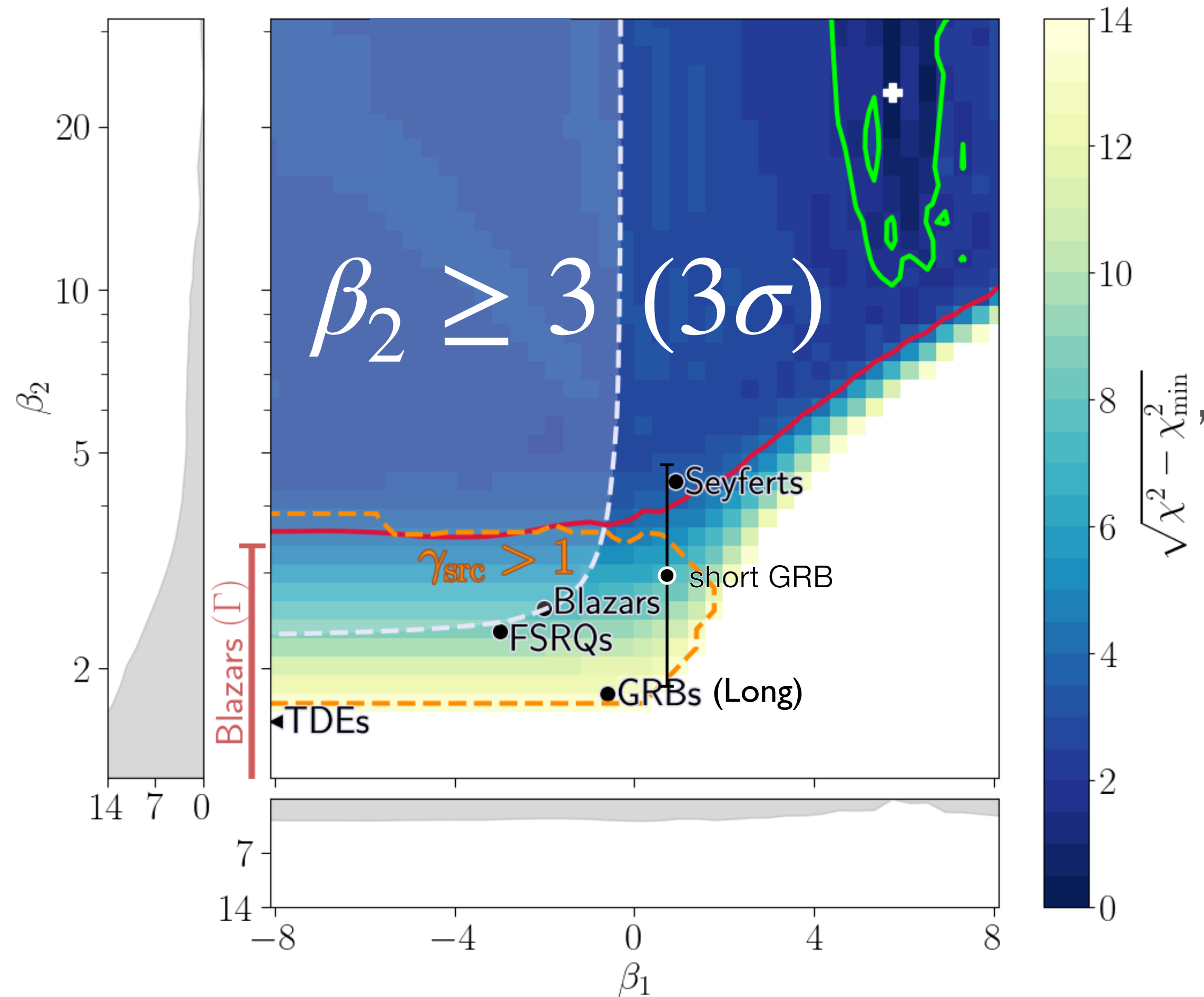
*A. Yushkov for the Auger Coll, ICRC 2019*

# A curious maximum rigidity distribution

D. Ehlert, FO, M. Unger, PRD 107 (2023) 10



# A curious maximum rigidity distribution



$$L \gtrsim L_B \sim \frac{U_B \cdot \text{Volume}}{t} \sim B^2 R^2 \Gamma^4 c$$

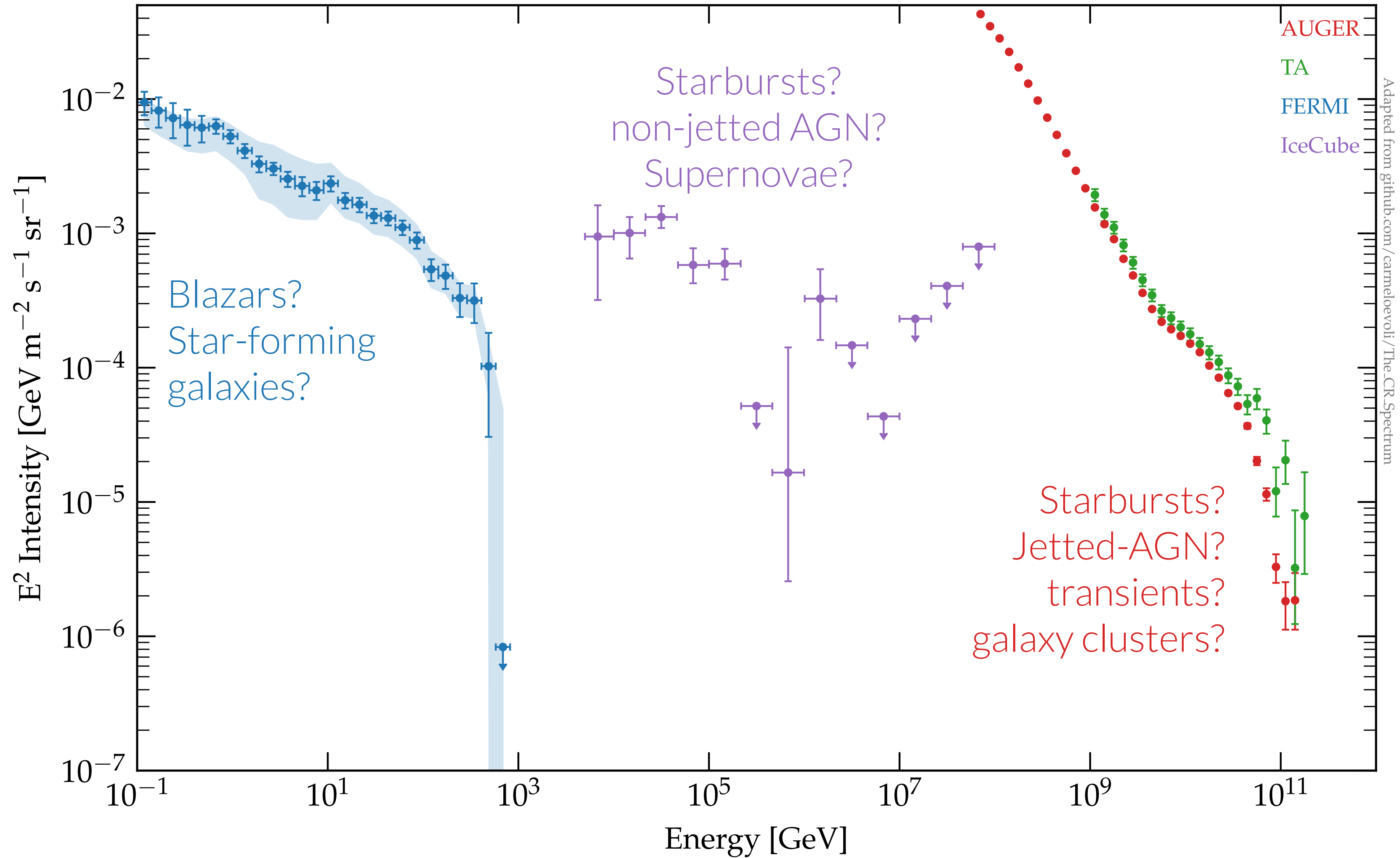
$$L_{\text{min}} \sim 10^{44.5} \text{ erg/s} \cdot \Gamma^2 \cdot \left( \frac{E}{100 \text{ EeV}} \right)^2$$

$$E_{\text{max}} \sim 100 \text{ EeV} \cdot \frac{1}{\Gamma} \cdot \left( \frac{L}{10^{45.5} \text{ erg/s}} \right)^{1/2}$$

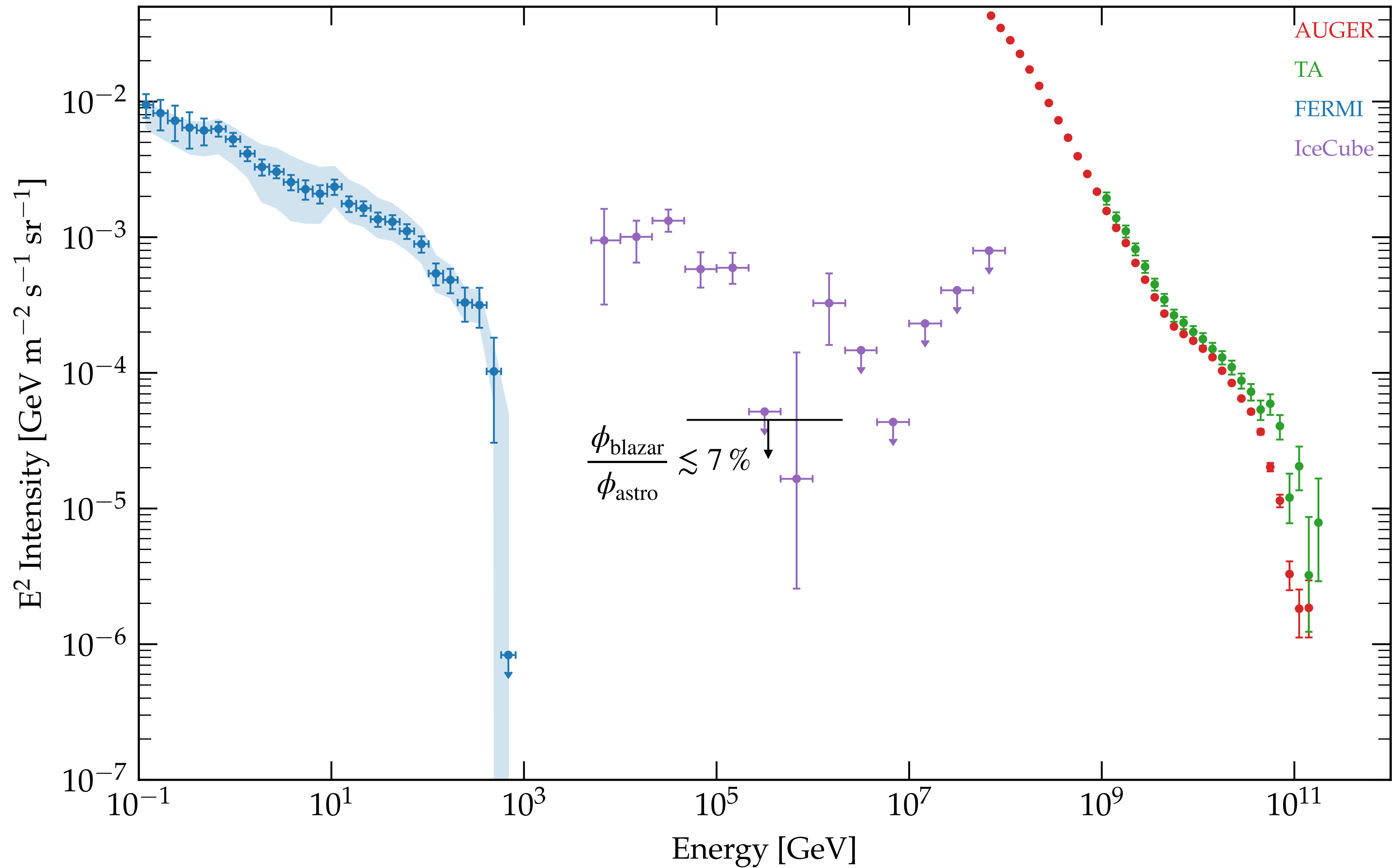
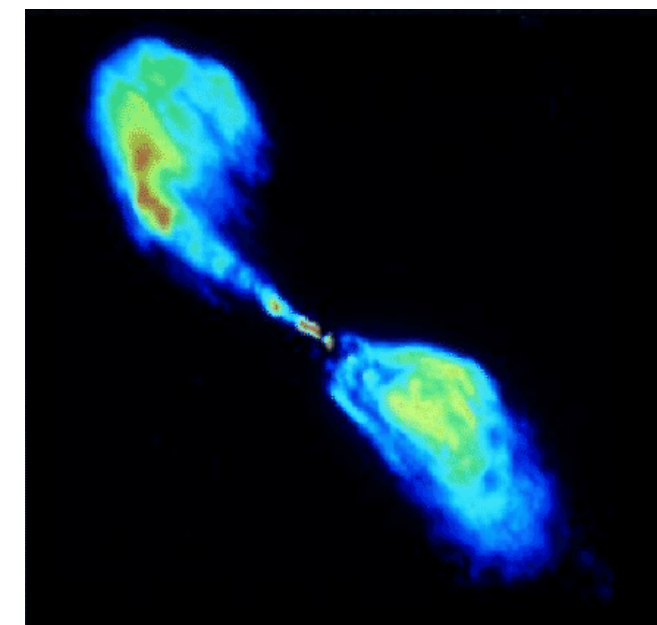
Lovelace 1976, Waxman 1995, 2001, Blandford 2000,  
Lemoine & Waxman 2009, Farrar & Gruzinov 2009



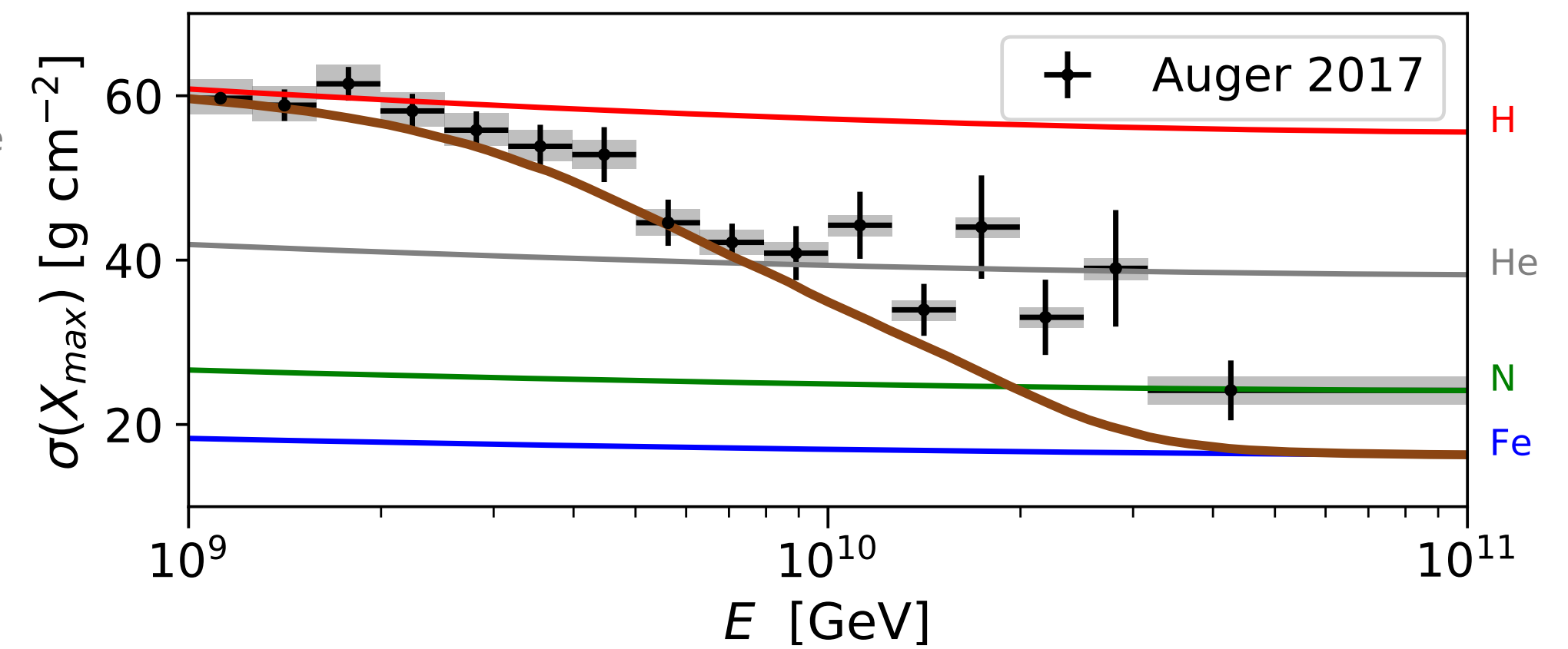
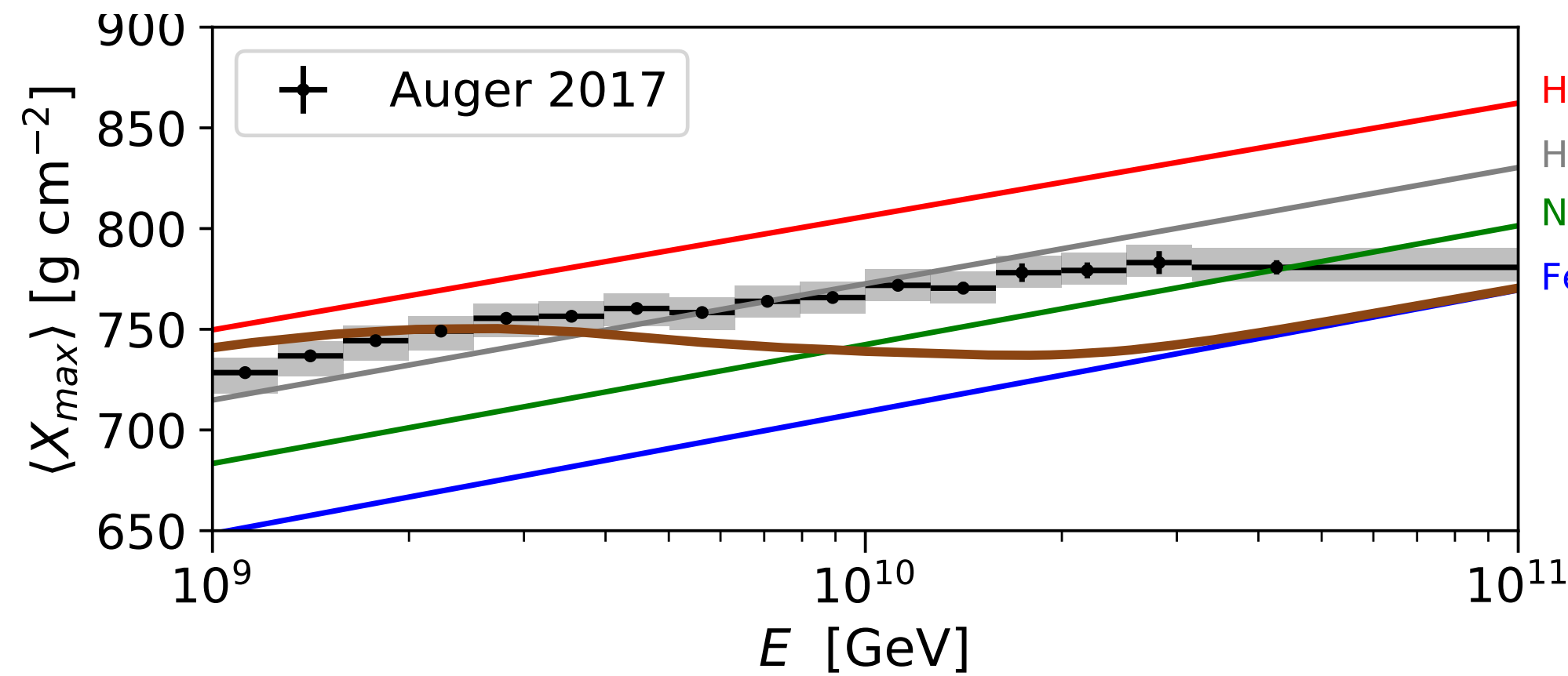
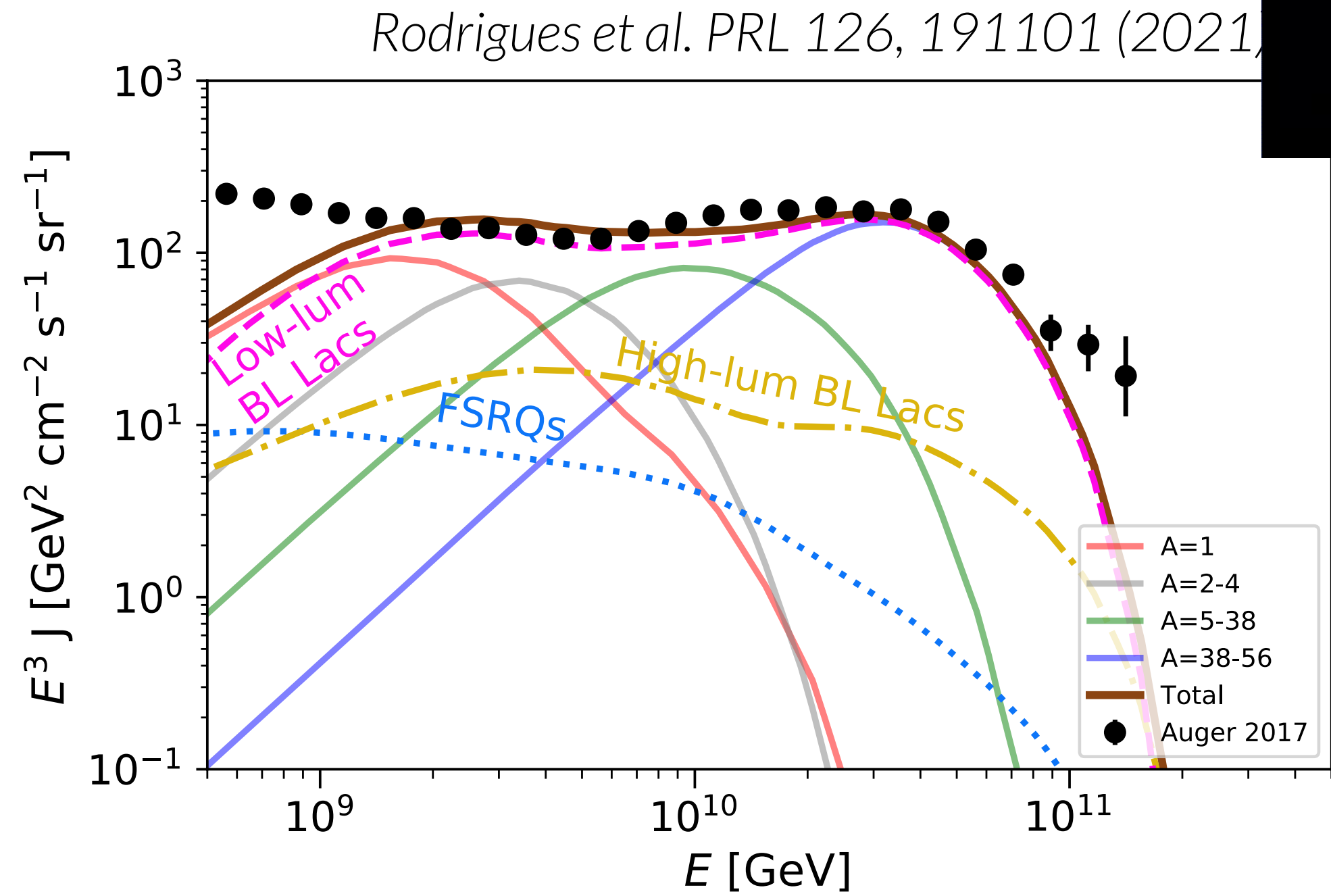
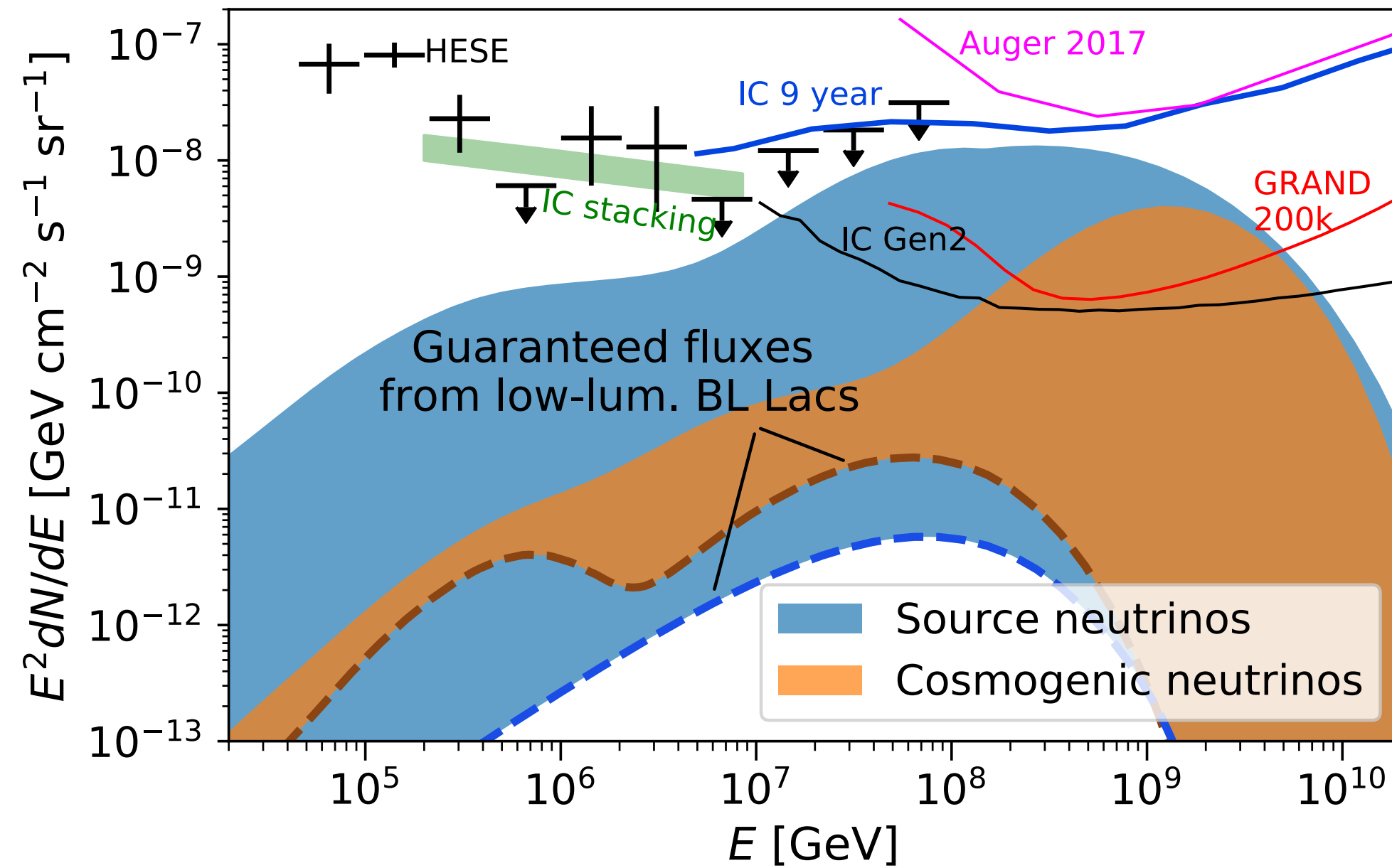
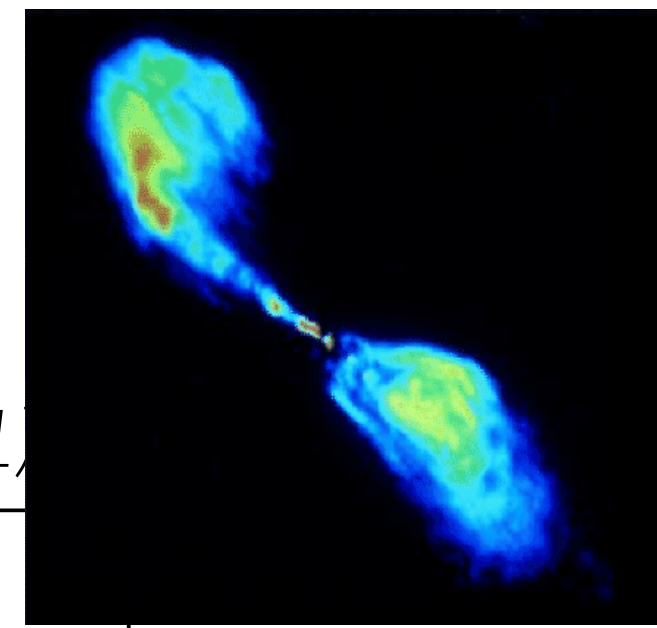
# Common origin?



# Jetted AGN?



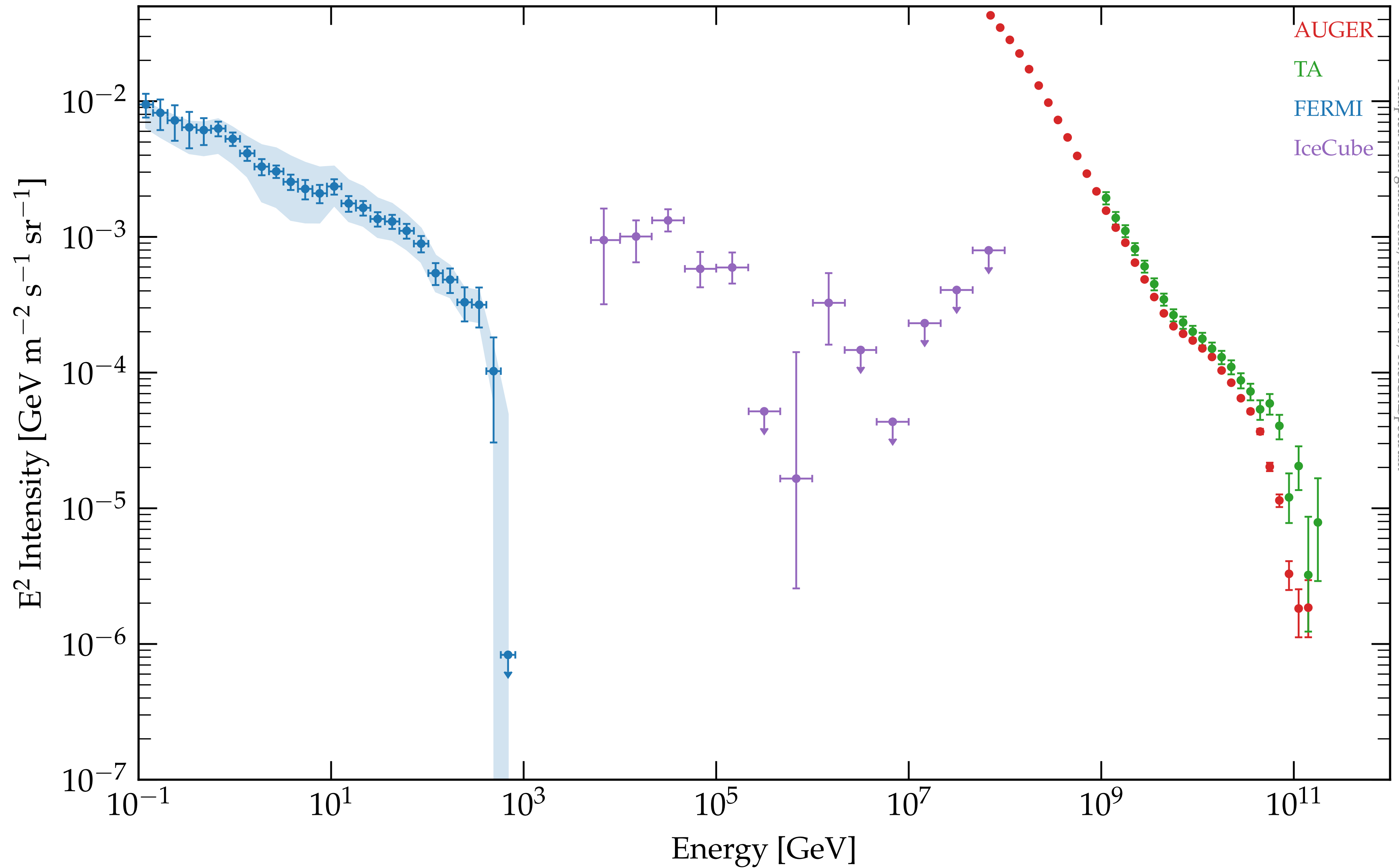
# Jetted AGN?



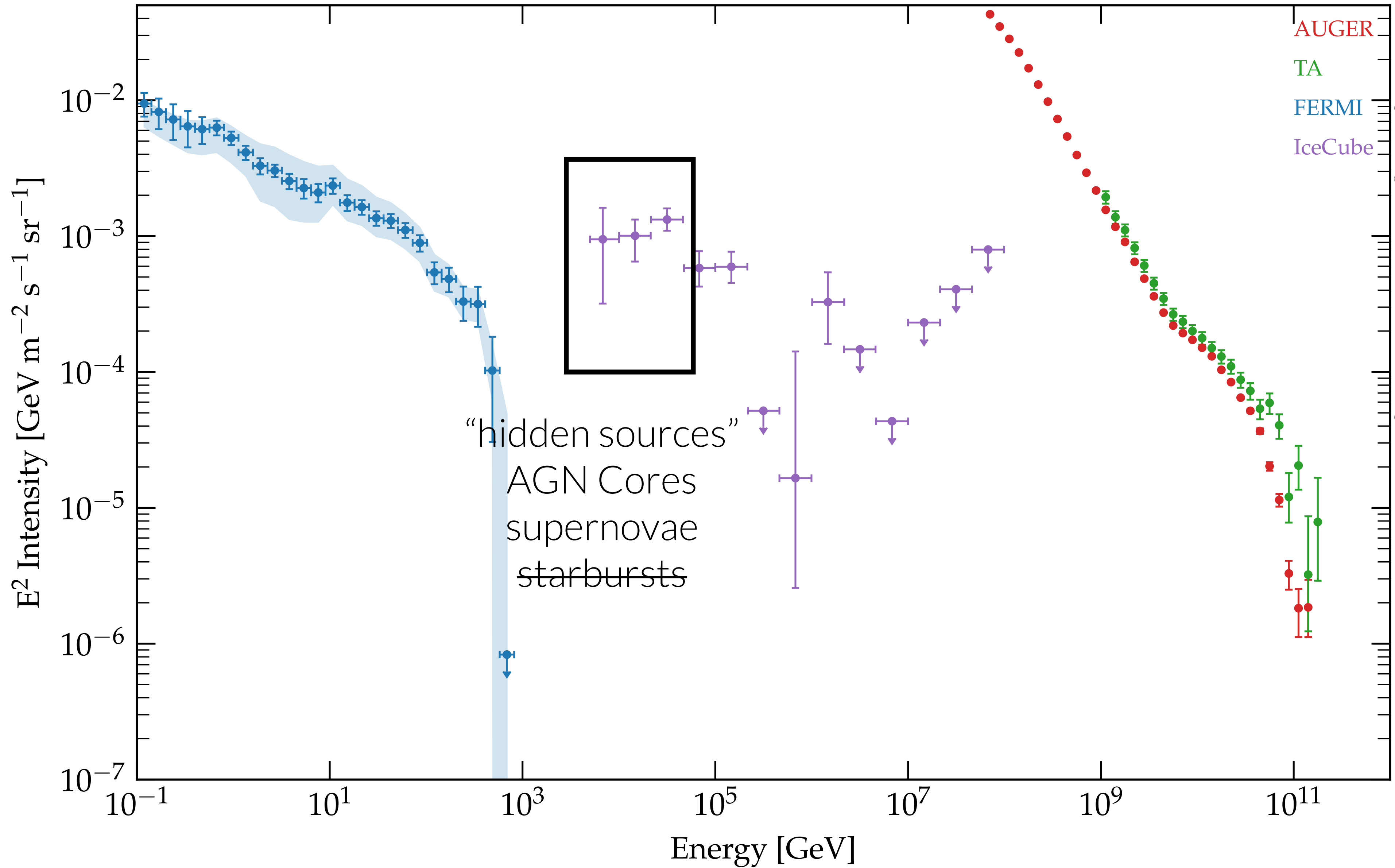
See also Murase+ 2014, Kachelriess+ 2017,  
Kimura+ 2018, Eichmann+ 2022, Zhang+ 2024

But "narrow maximum rigidity distribution" and composition a  
problem. Possible solution: Single source (Cen A)

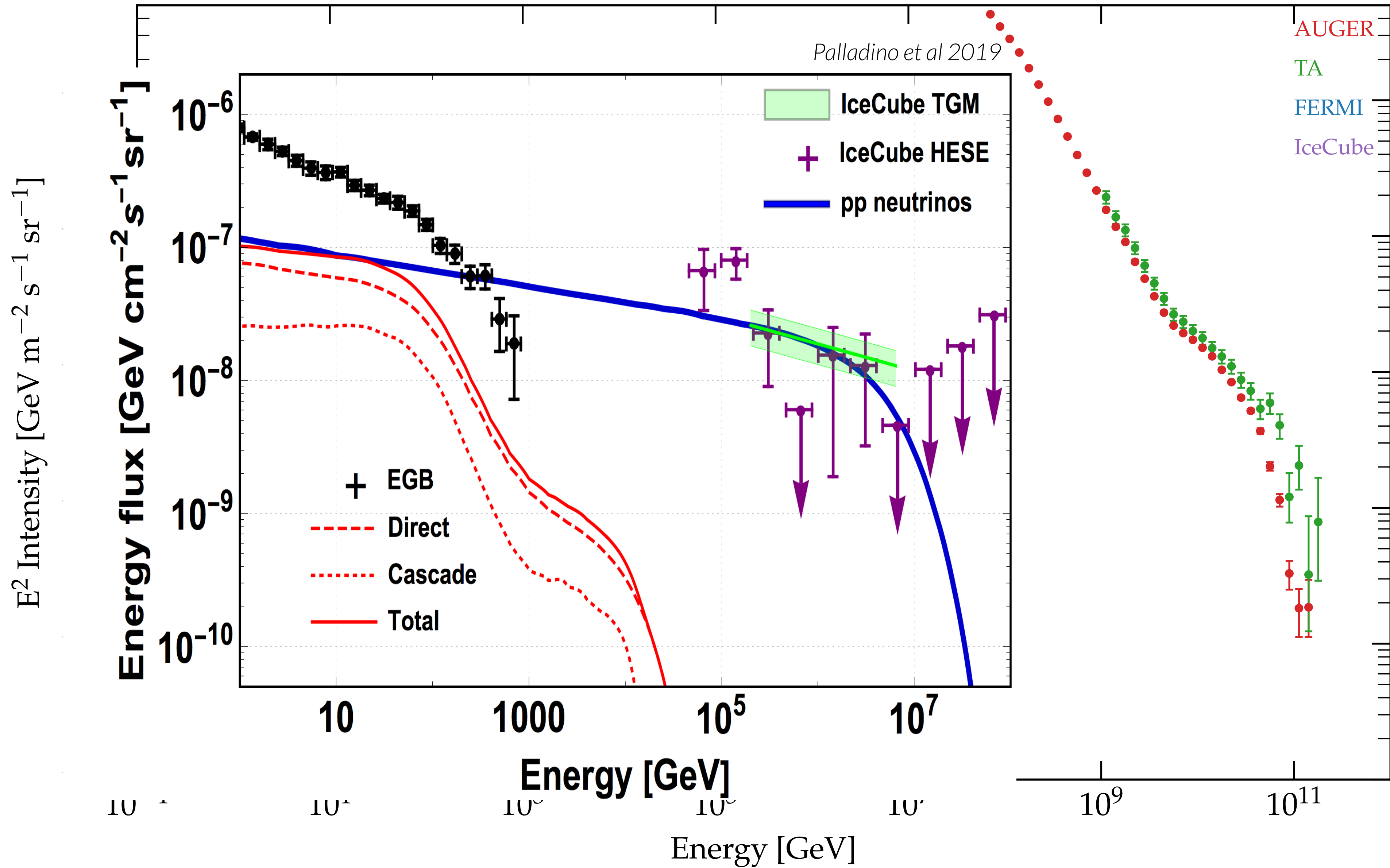
# Starbursts?



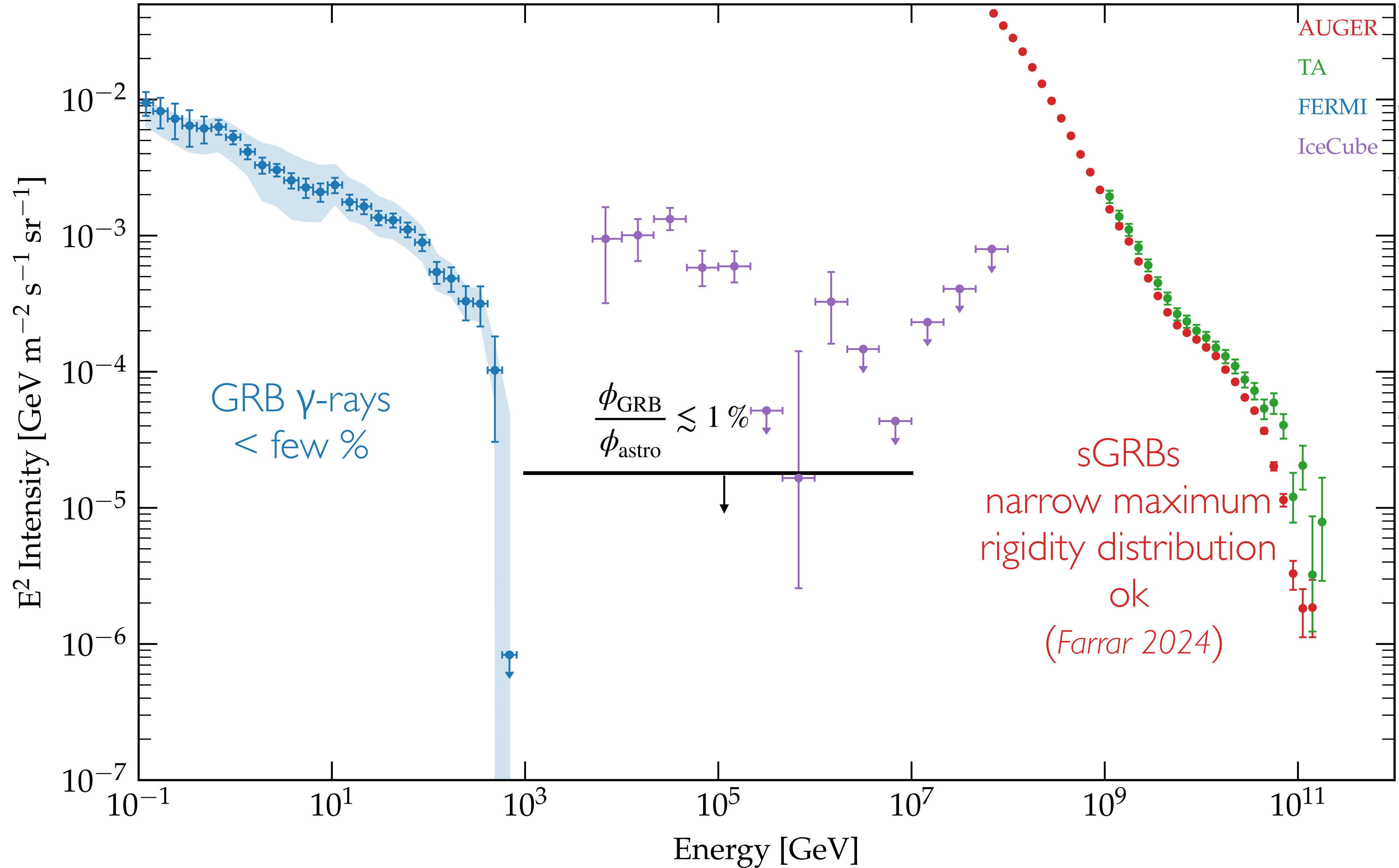
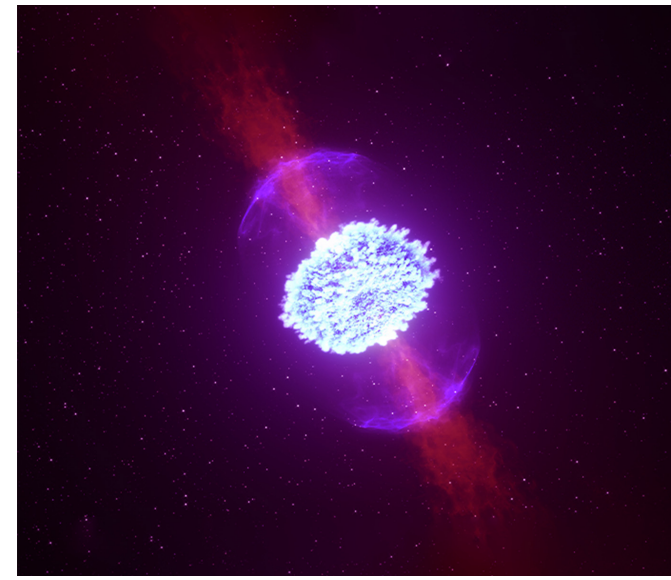
# Starbursts?



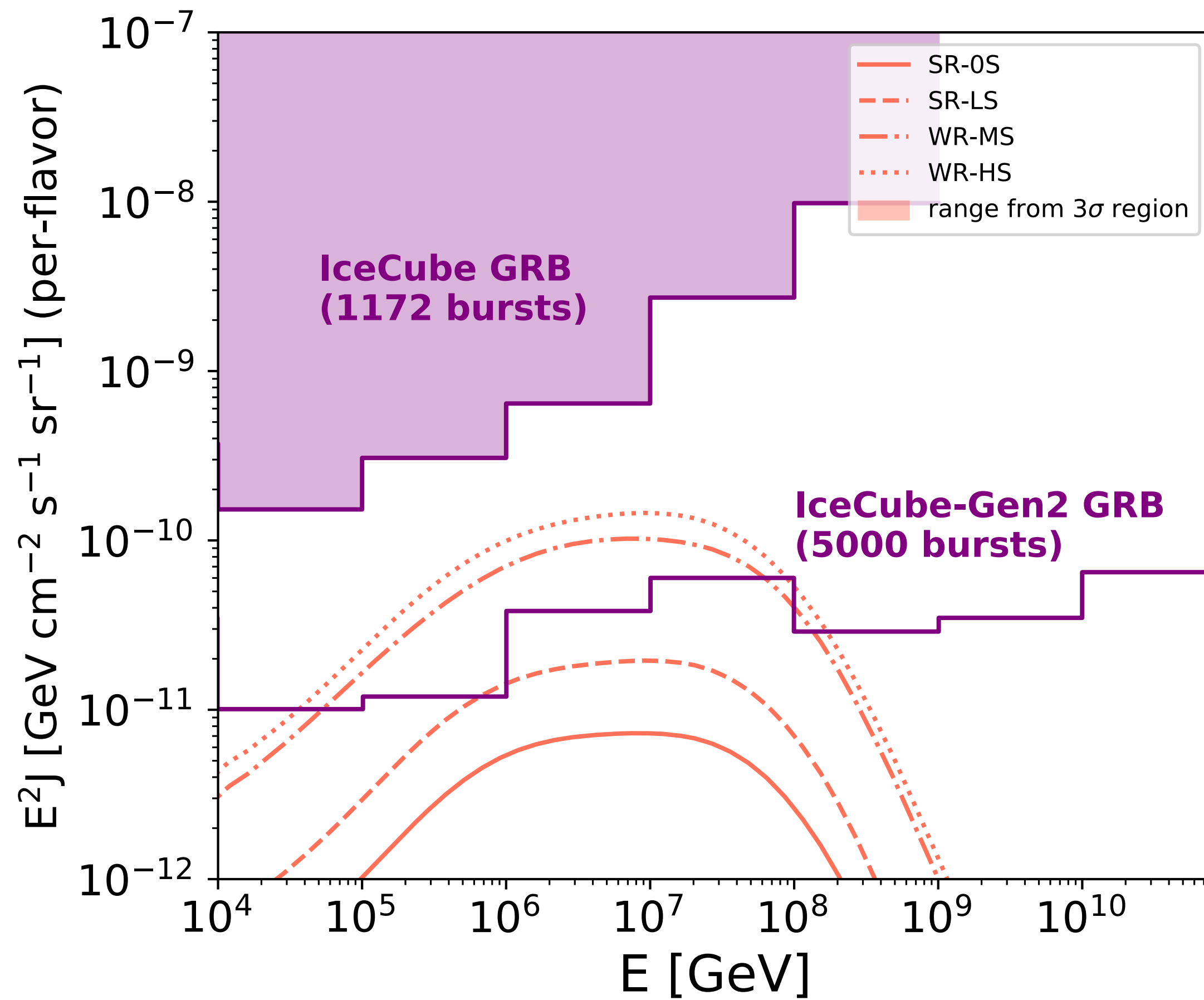
# Starbursts?



# GRBs?

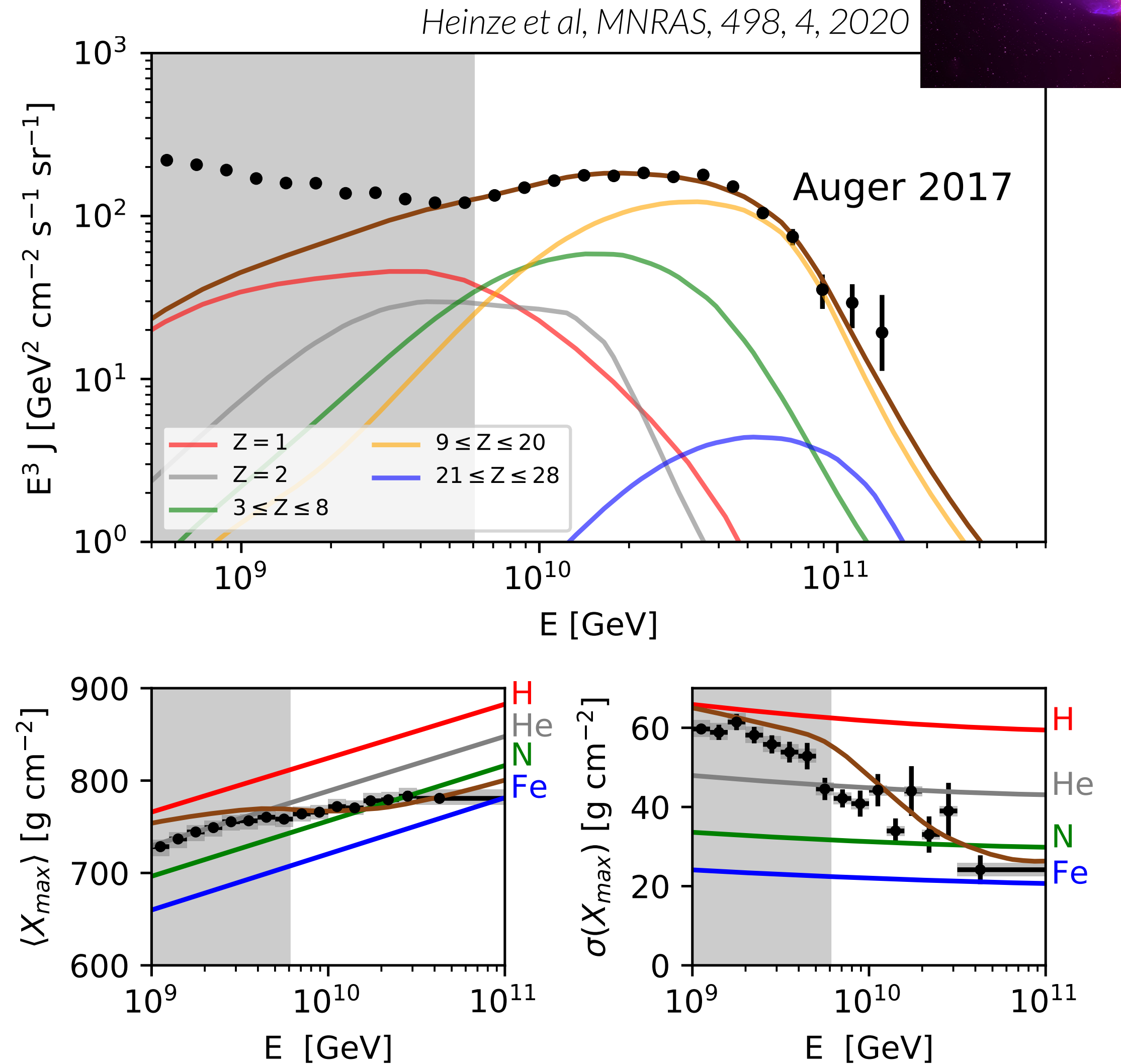
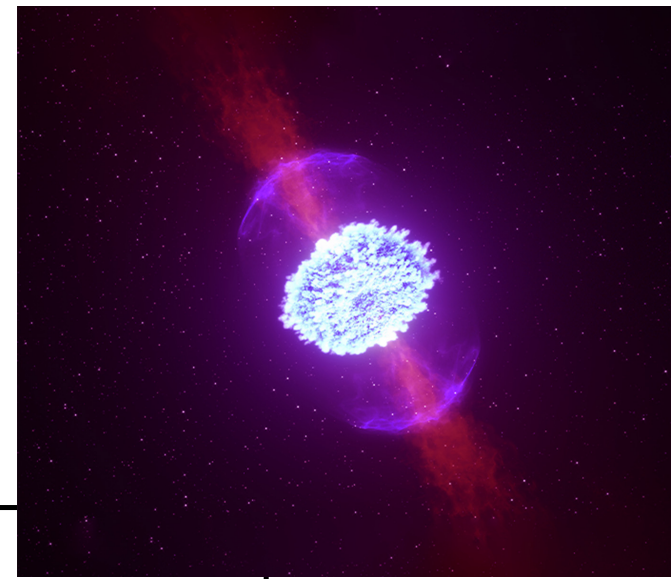


# GRBs?



Heavy injected composition:  $f_{>\text{He}} > 70\%$

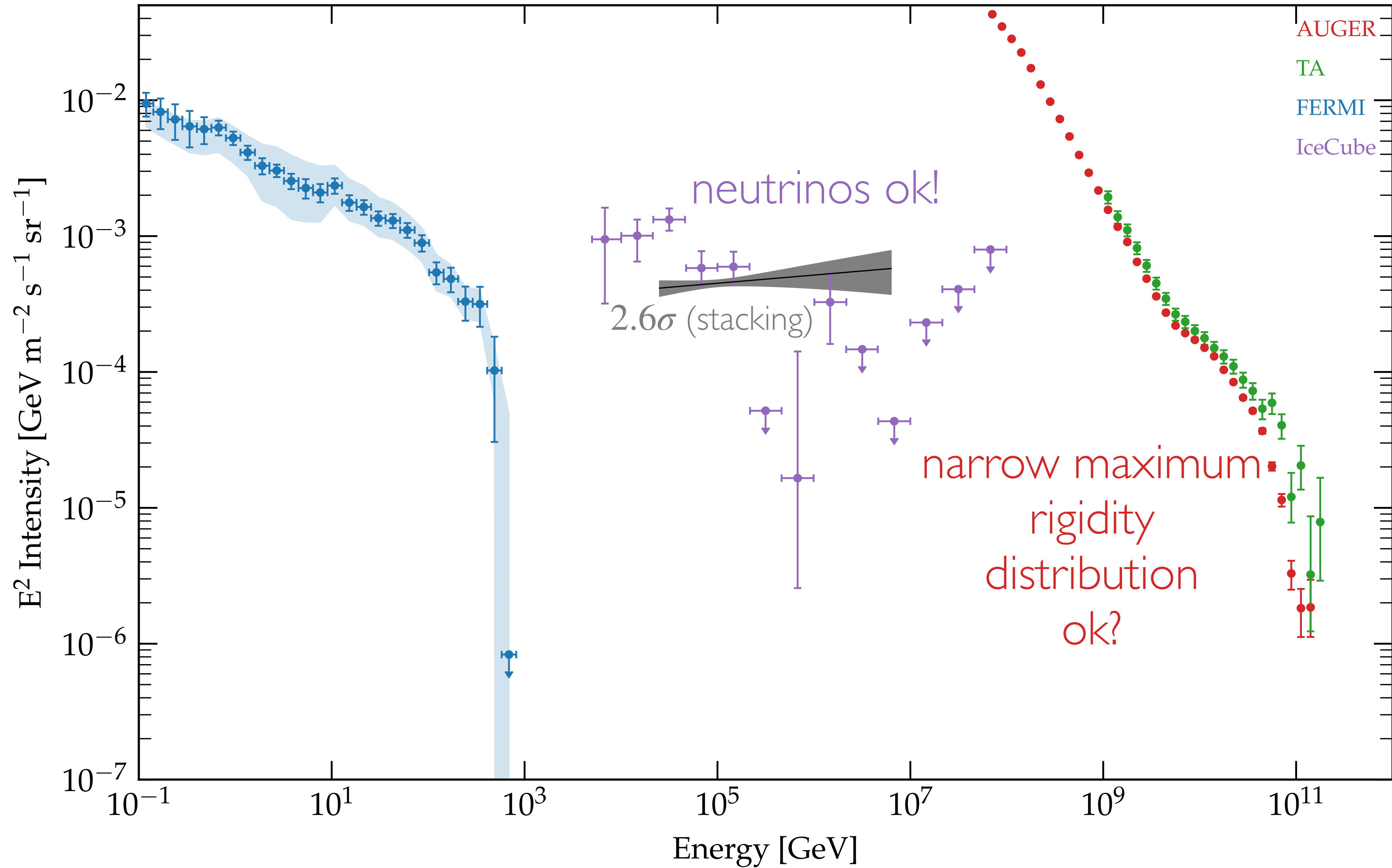
High UHECR luminosity:  $L_{\text{UHECR}}/L_{\gamma} \sim 100$



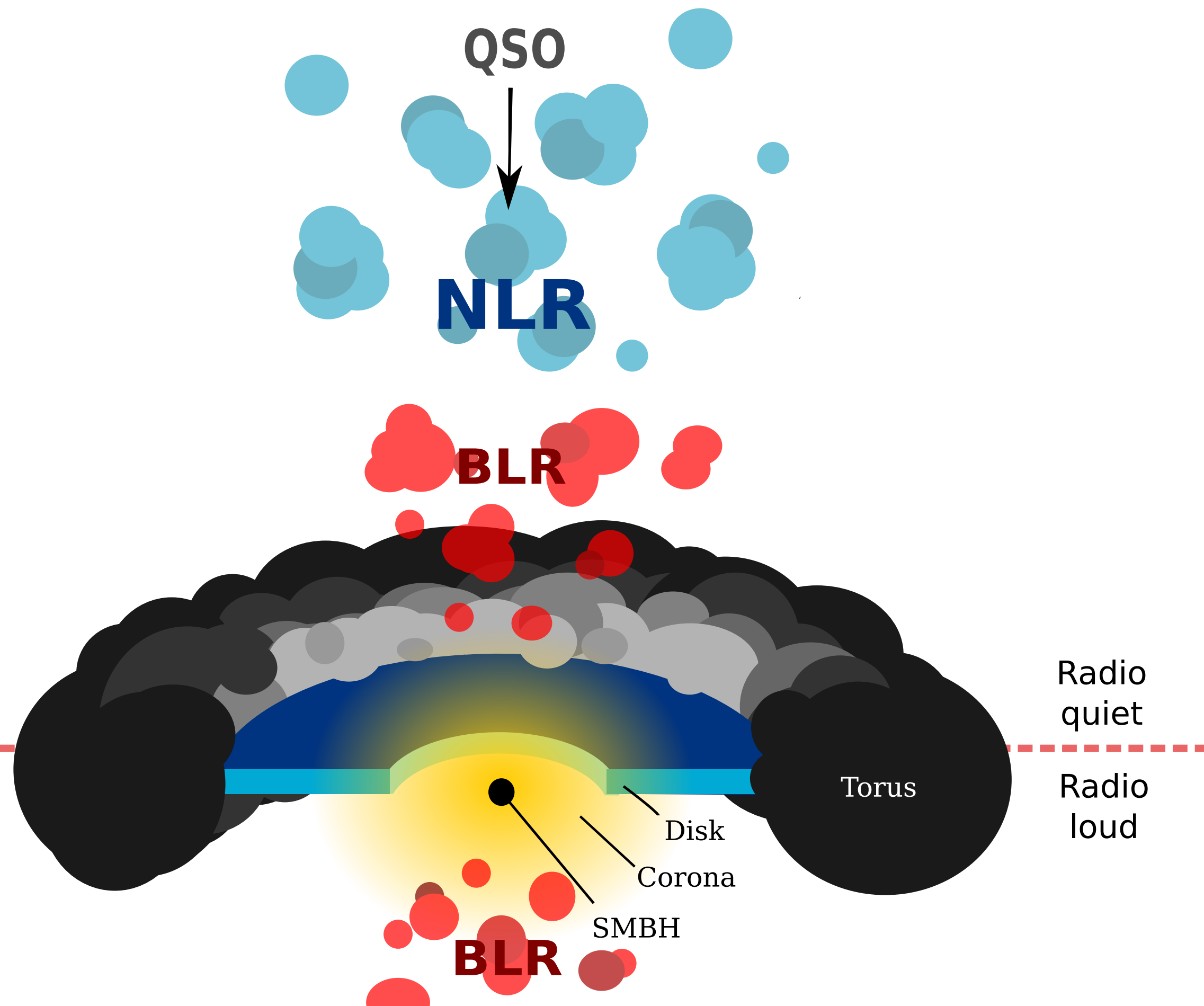
See also Globus+ 2015, Zhang+ 2018, Biehl+ 2018, Boncioli+ 2018, Rudolph+ 2019, Zhang+ 2024



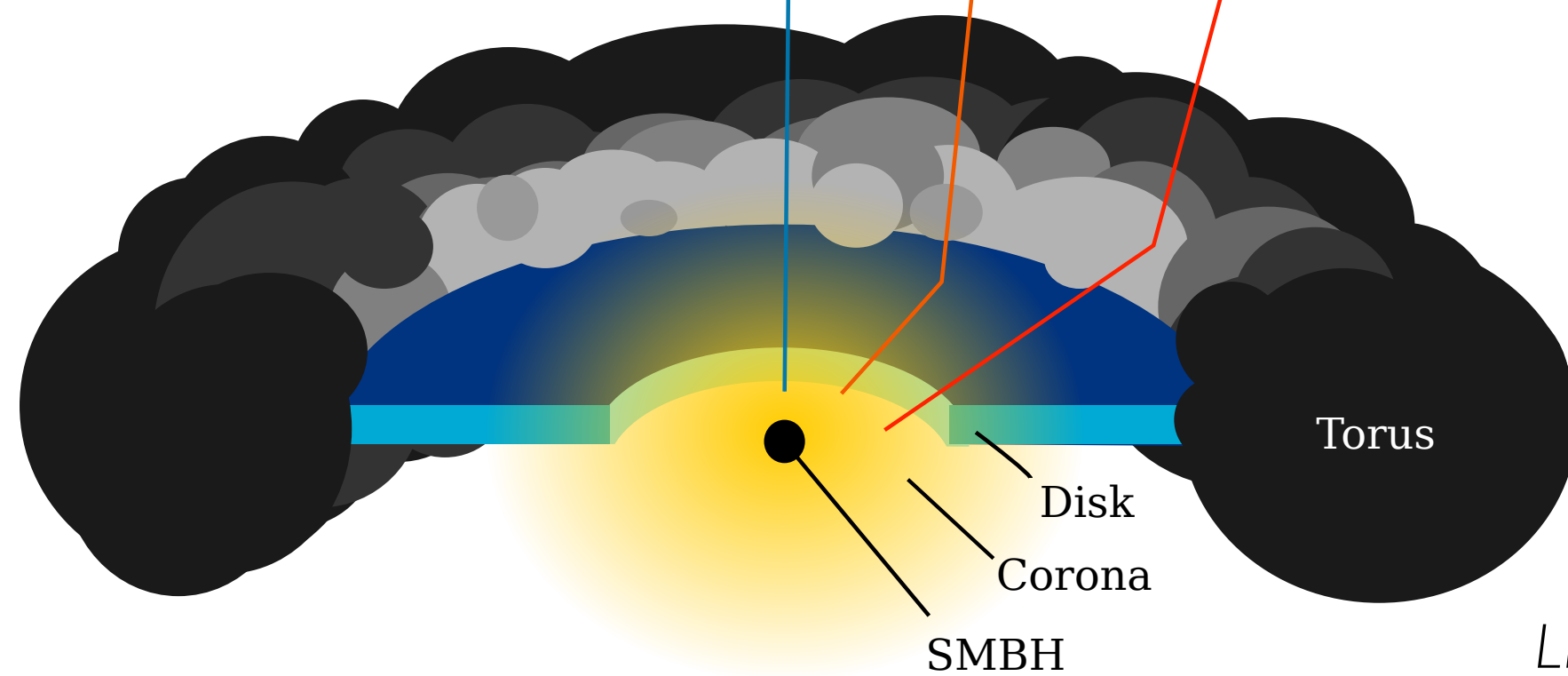
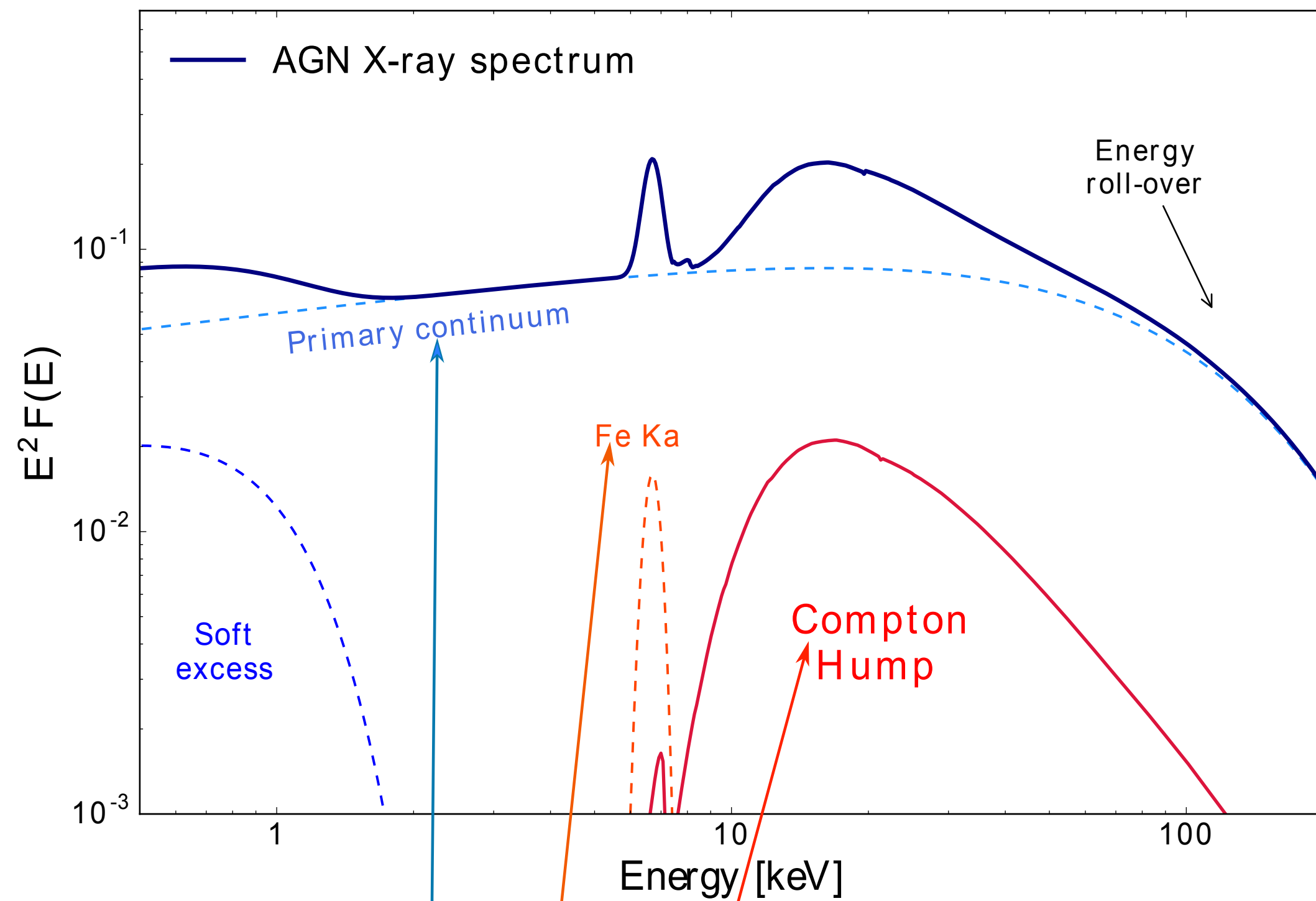
# Non-jetted AGN?



# X-ray absorbers in AGN

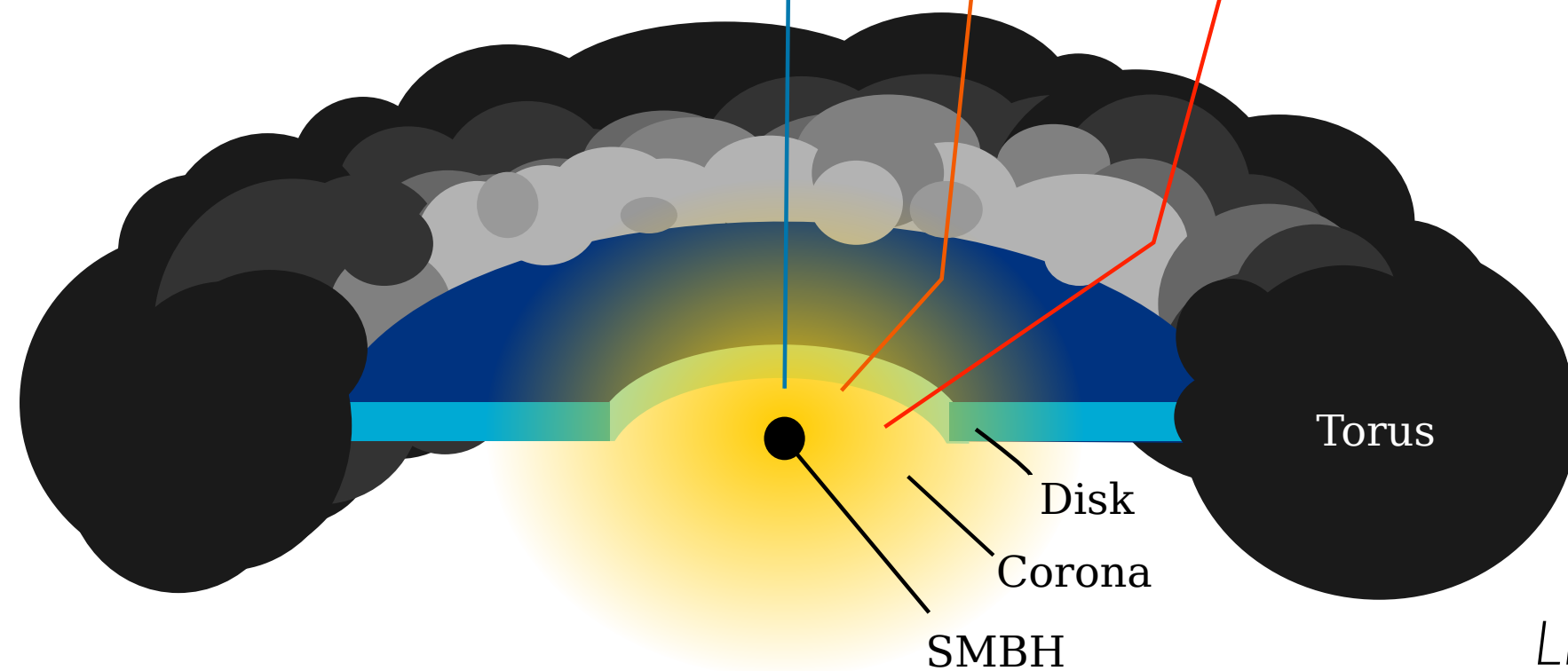
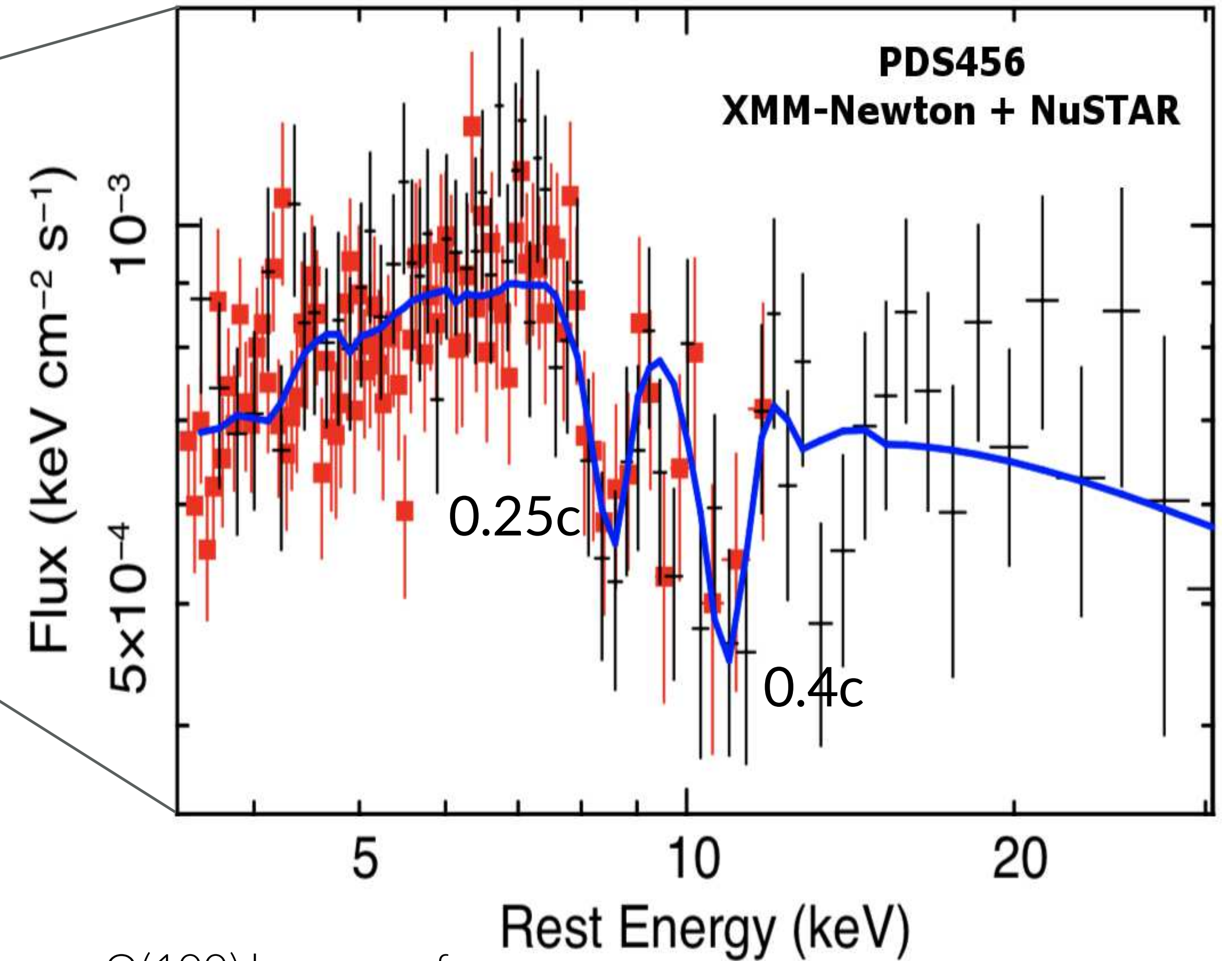
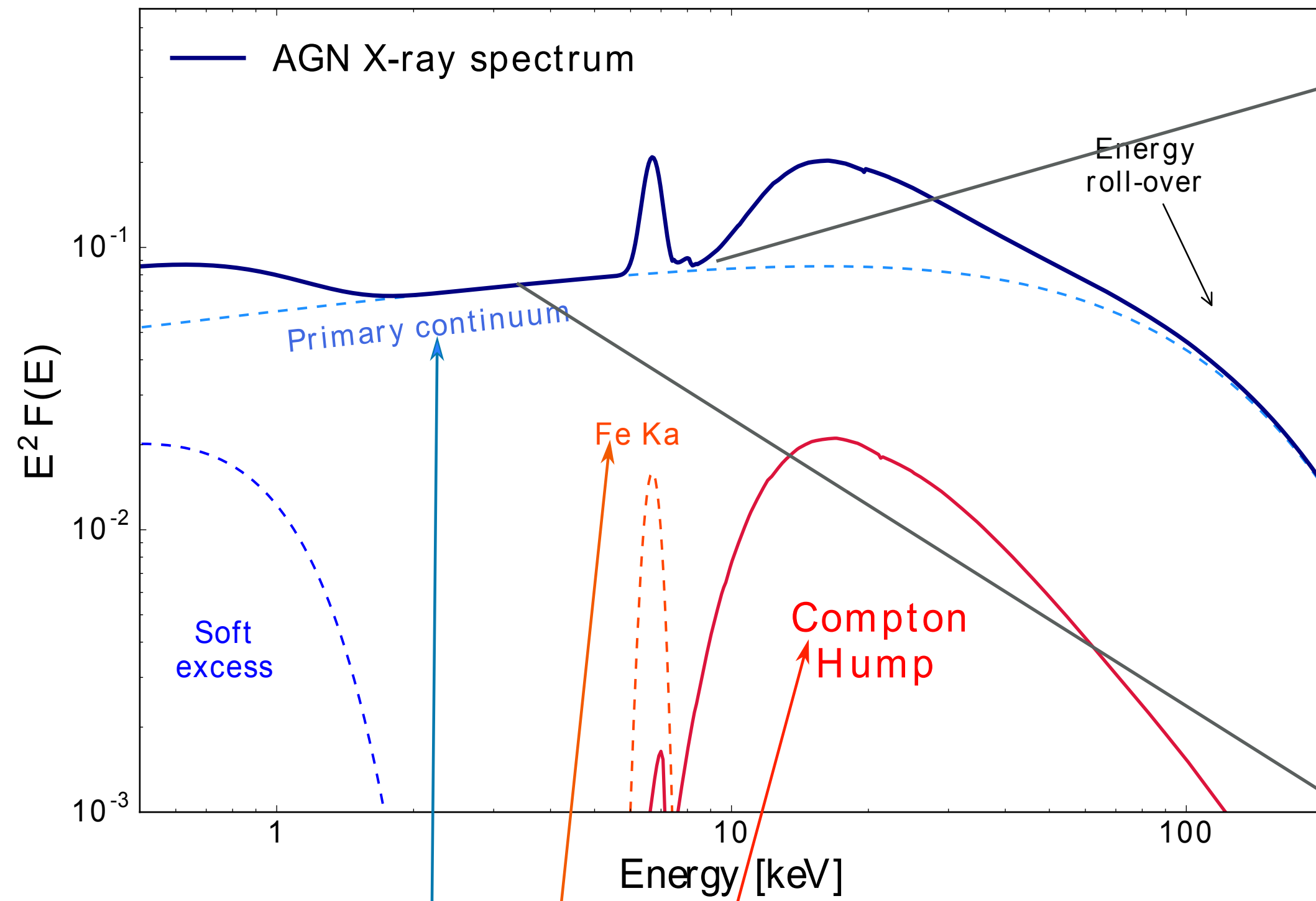


# X-ray absorbers in AGN



# X-ray absorbers in AGN

Nardini et al 2015



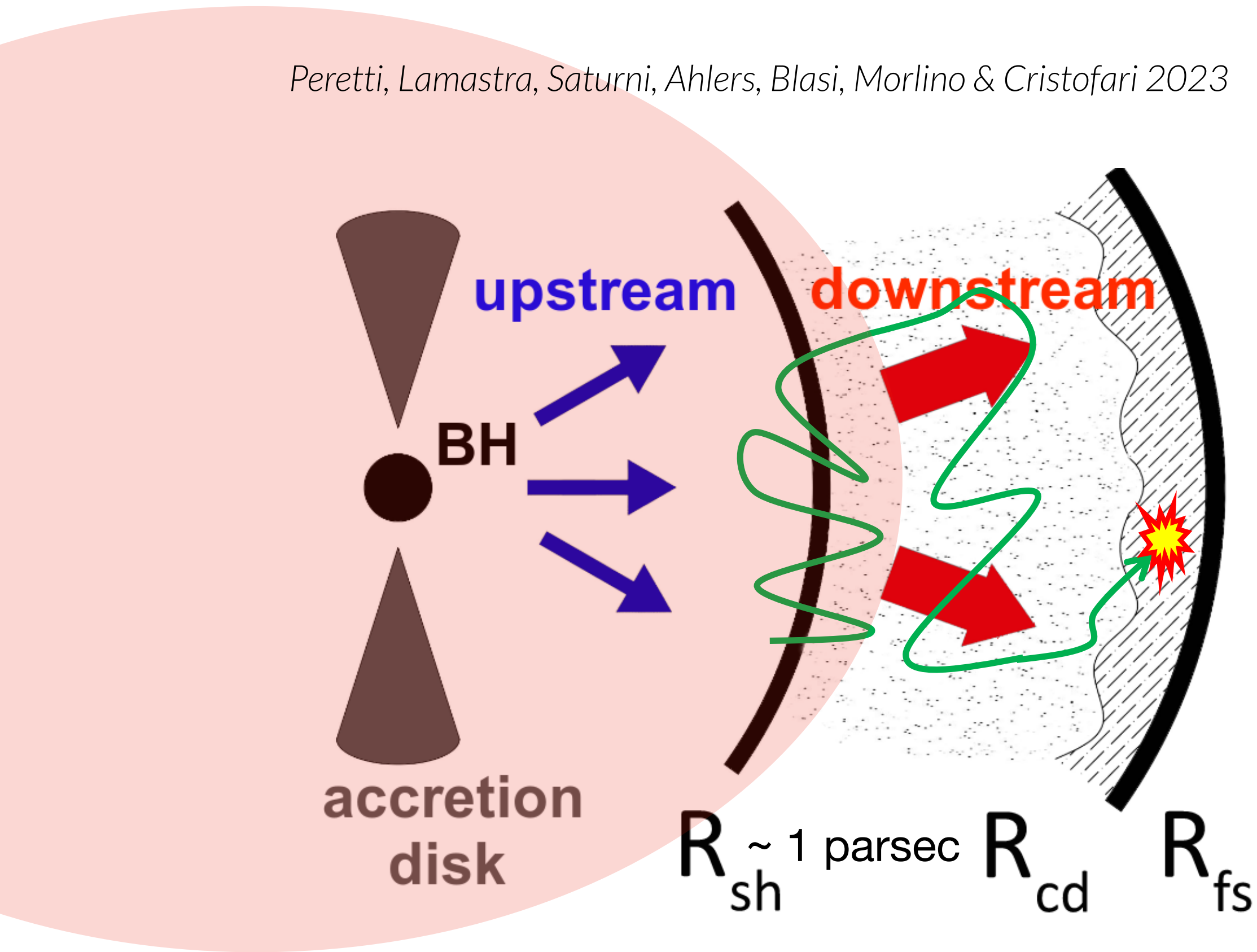
Linda Baronchelli 2020 20

O(100) known so far

Observed in ~40% of jetted and non-jetted AGN

# UHECR acceleration in UFOs?

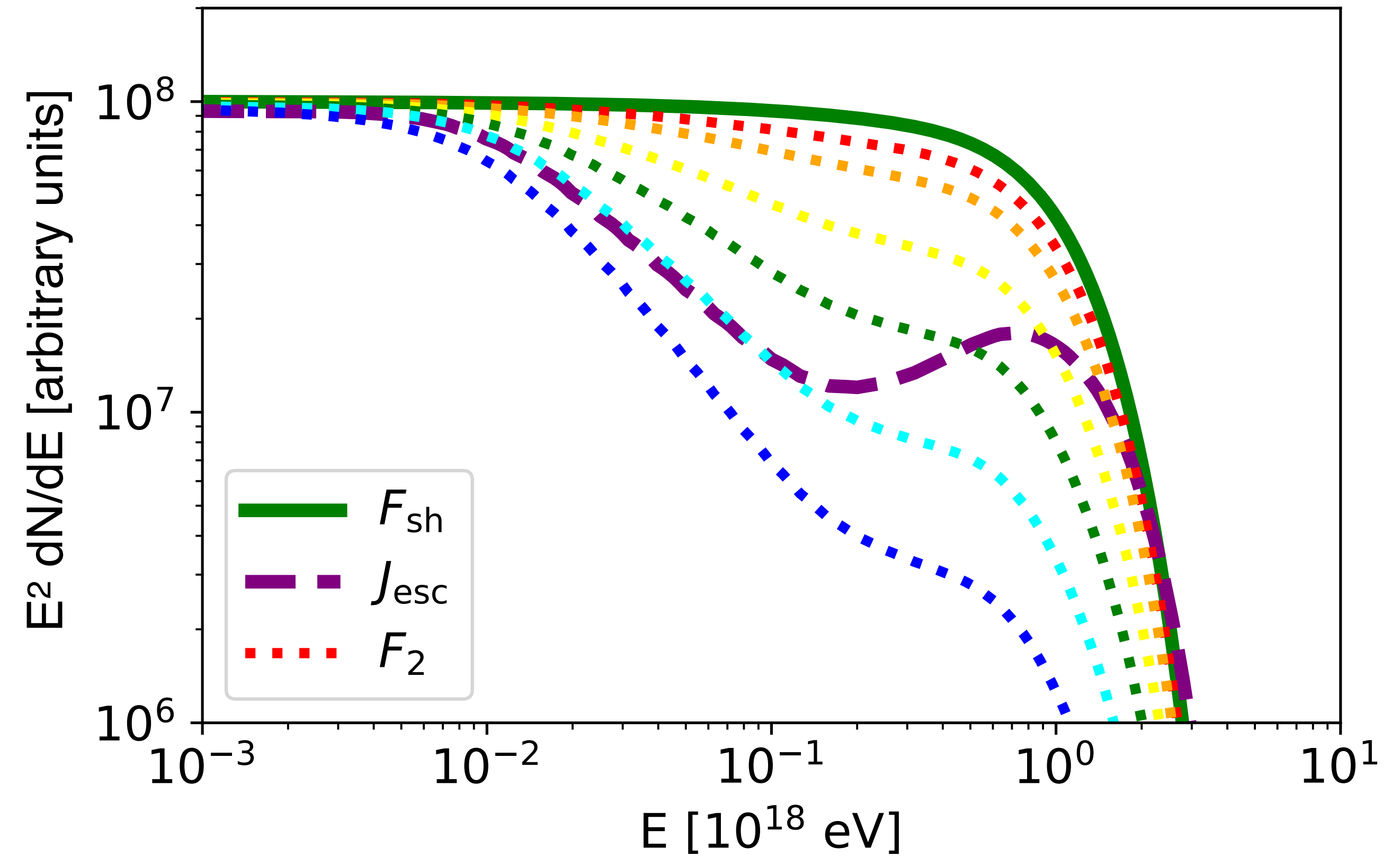
Peretti, Lamastra, Saturni, Ahlers, Blasi, Morlino & Cristofari 2023



IR torus  $L_{IR} \sim 0.5L_{disk}$

$$R_{IR} \sim 1 \text{ pc} \cdot \left( \frac{L_{disk}}{10^{45} \text{ erg/s}} \right)^{1/2}$$

Peretti, Lamastra, Saturni, Ahlers, Blasi, Morlino & Cristofari 2023



$$E_{p,max} \sim 1 \text{ EeV} \left( \frac{\dot{M}}{0.1 M_{\odot} \text{ yr}^{-1}} \frac{1 \text{ pc}}{R_{shock}} \right)^{1/2} \frac{v_{UFO}}{0.2c}$$

# UHECR nuclei in UFOs?

Spectrum at acceleration

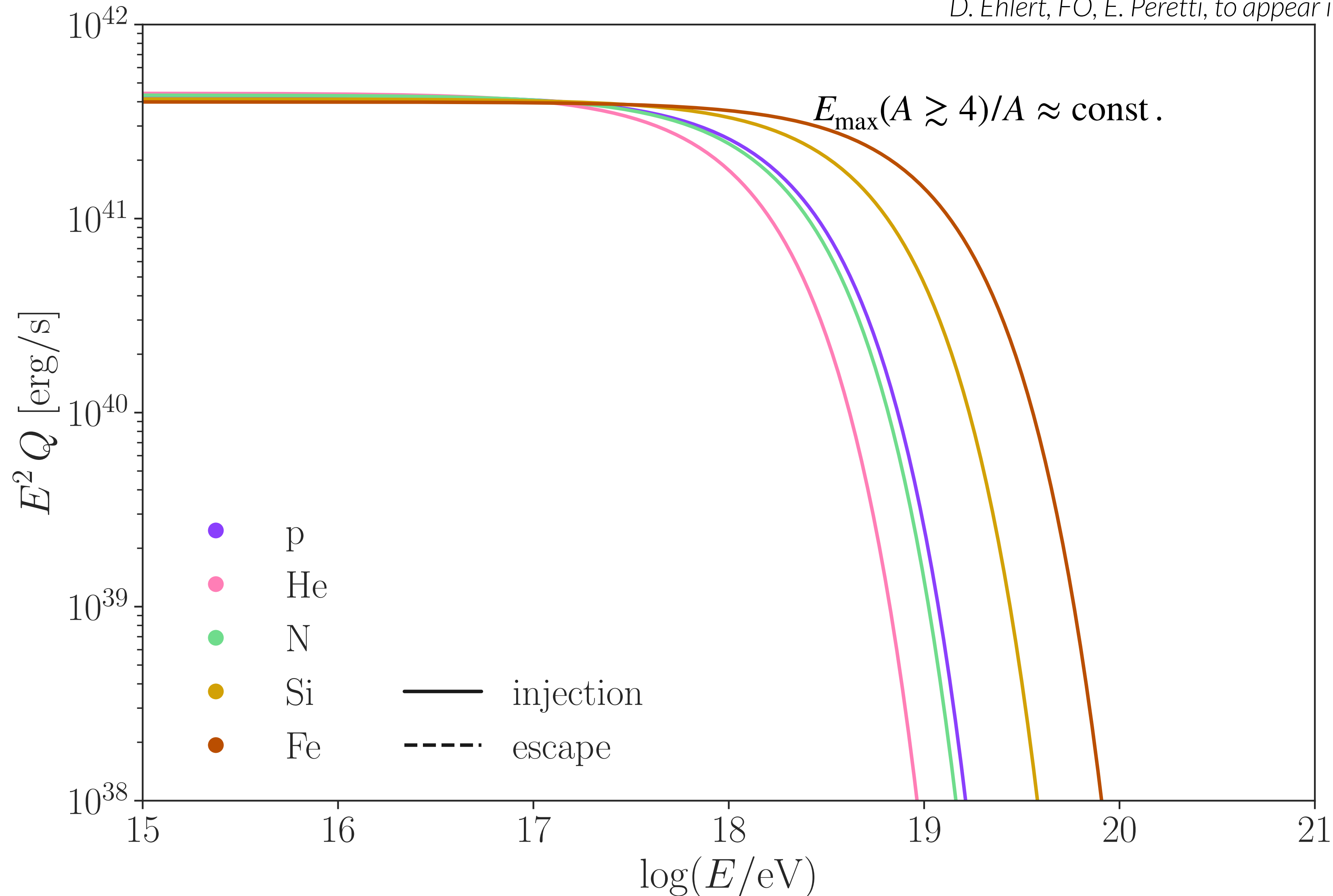
Ultra-high-energy cosmic rays from  
ultra-fast outflows of active galactic nuclei



Domenik Ehlert<sup>1</sup>, Foteini Oikonomou<sup>1</sup>, Enrico Peretti<sup>2</sup>  
<sup>[1]</sup> Institutt for fysikk, Norwegian University of Science and Technology, Trondheim, Norway  
<sup>[2]</sup> Université Paris Cité, CNRS, Astroparticule et Cosmologie, Paris, France

domenik.ehlert@ntnu.no

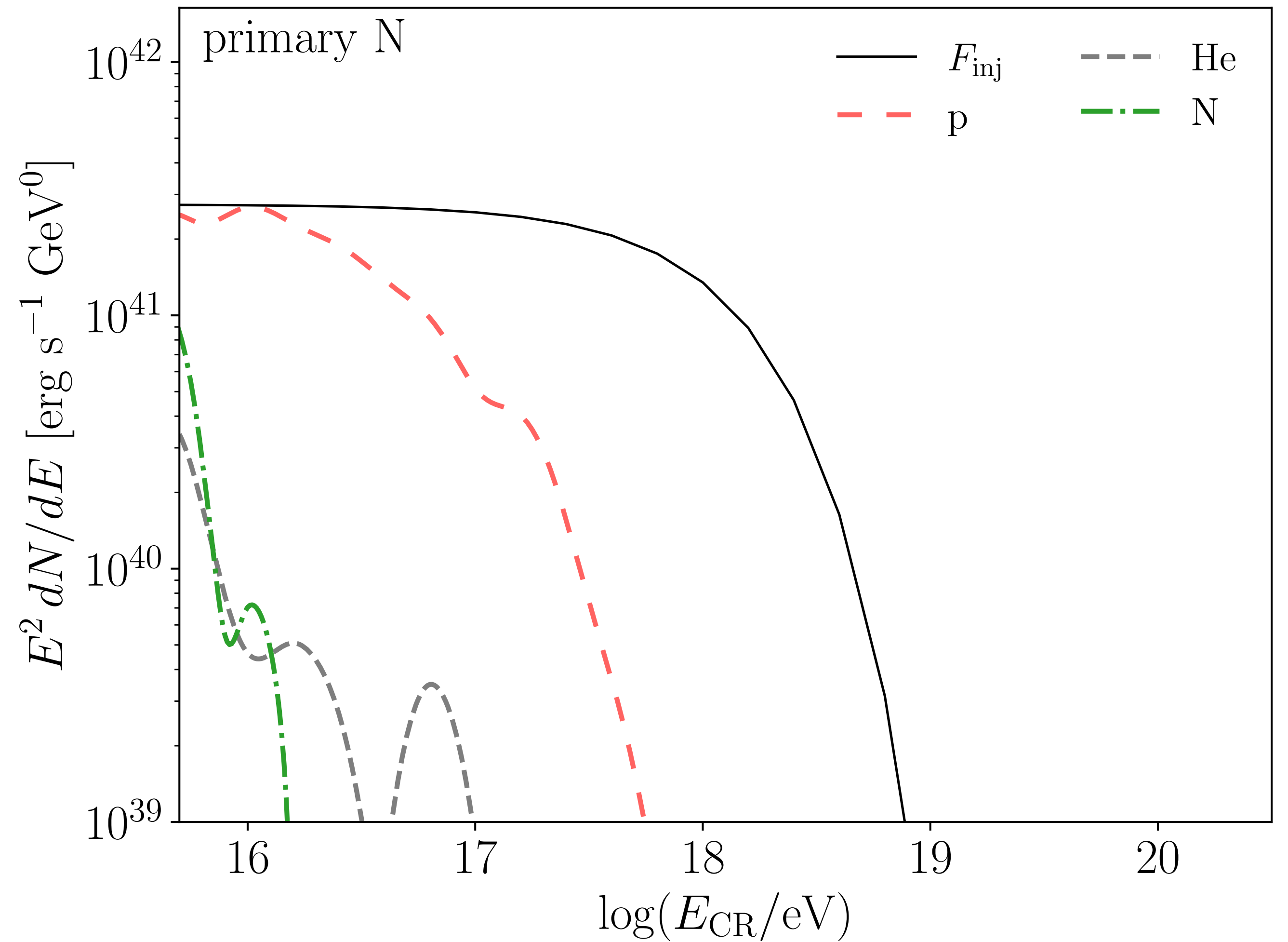
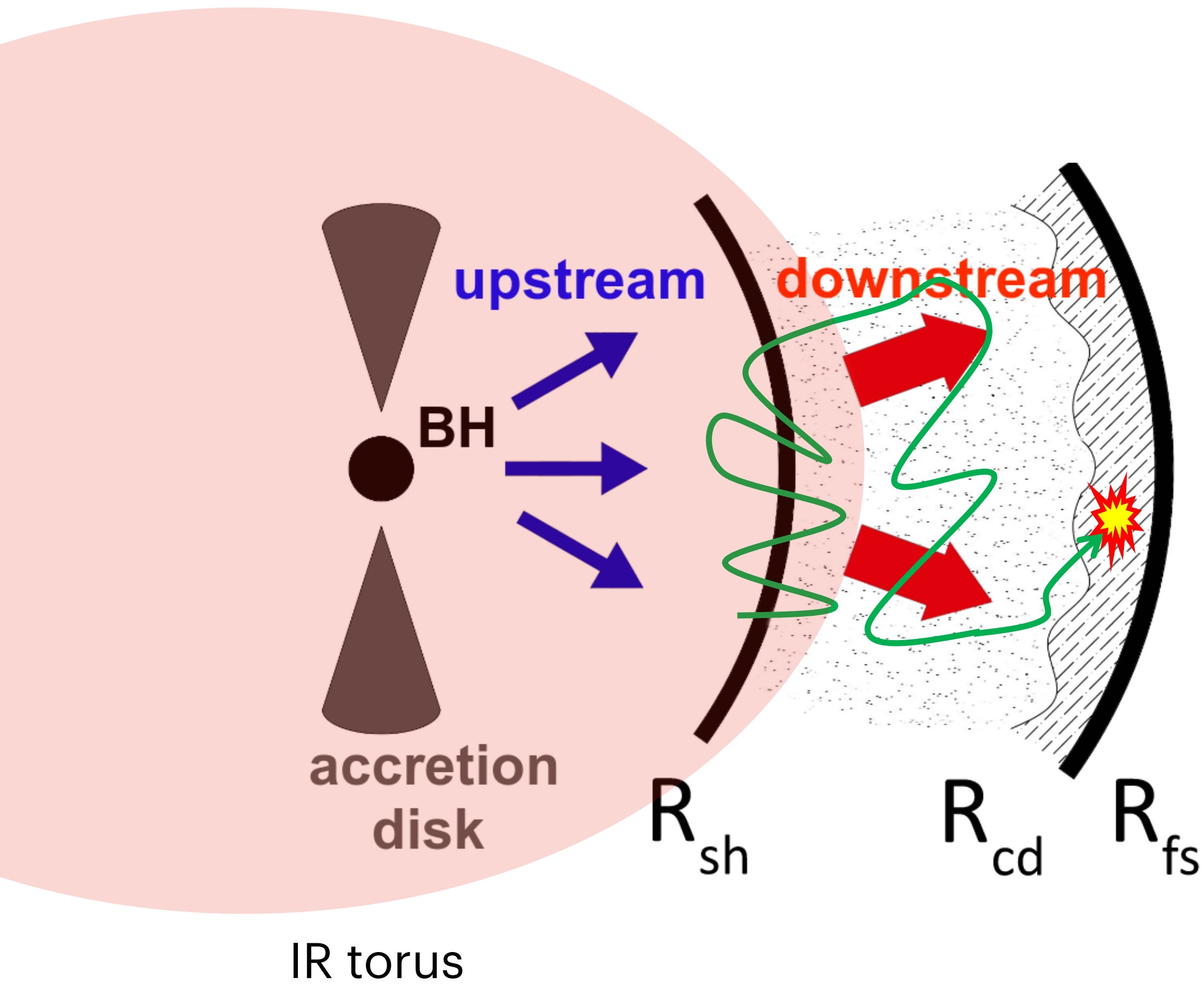
*D. Ehlert, FO, E. Peretti, to appear in MNRAS, arXiv:2411.05667*



# UHECR nuclei in UFOs?

Escaping spectrum

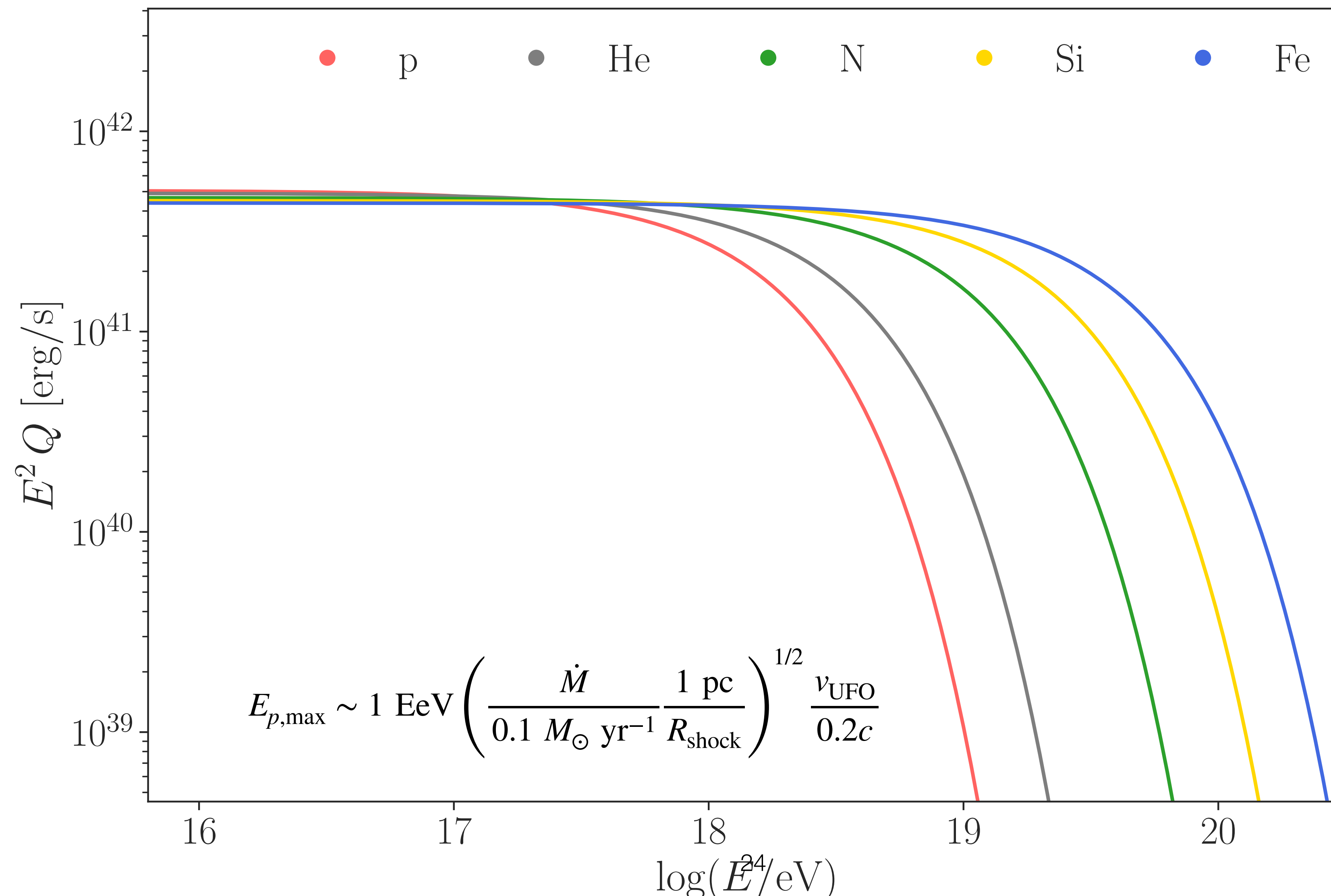
D. Ehlert, FO, E. Peretti, [arXiv:2411.05667](https://arxiv.org/abs/2411.05667)



# Extreme ultra-fast outflows

Spectrum at acceleration [ $\sim 10\%$  of our sample]

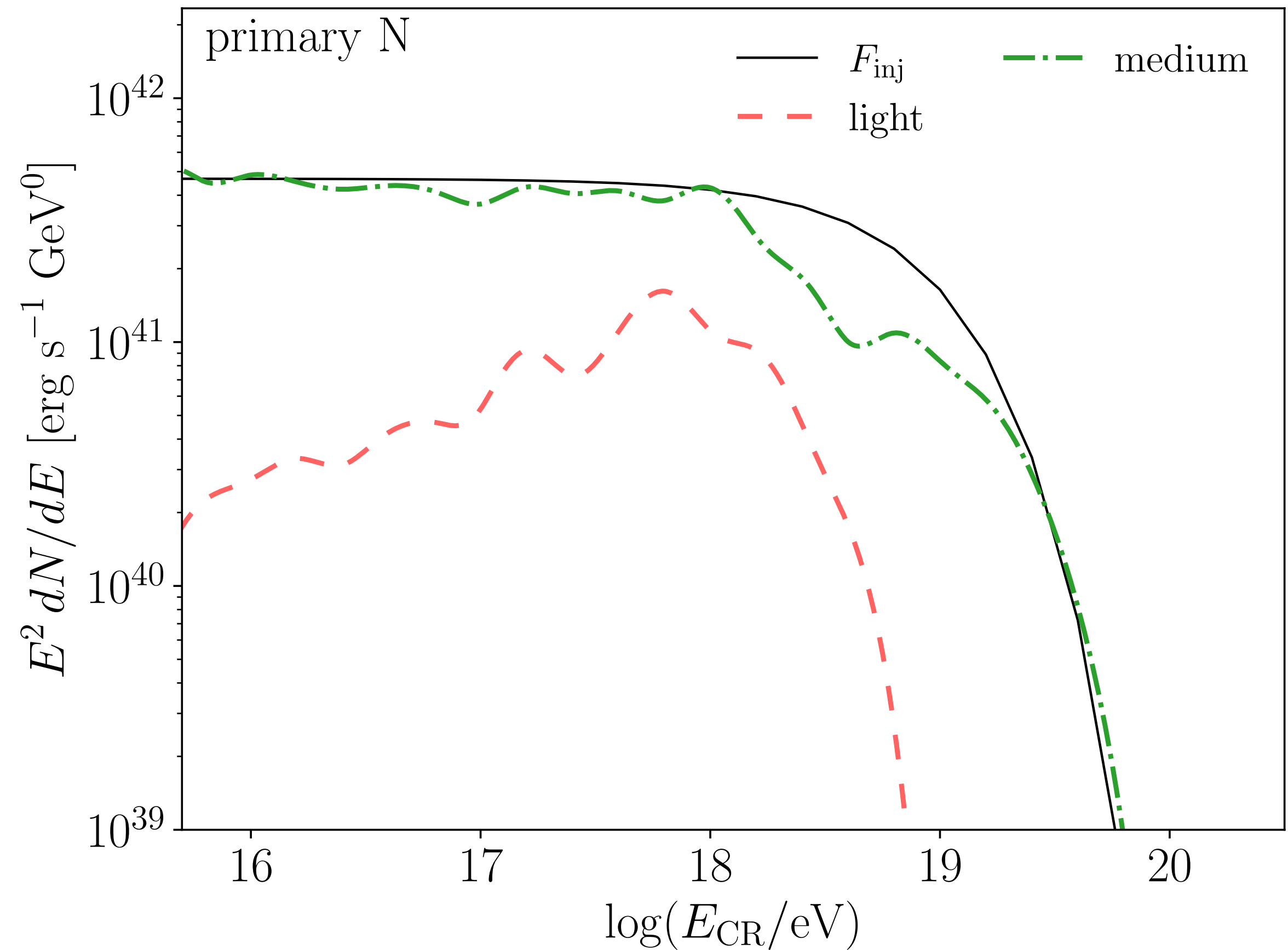
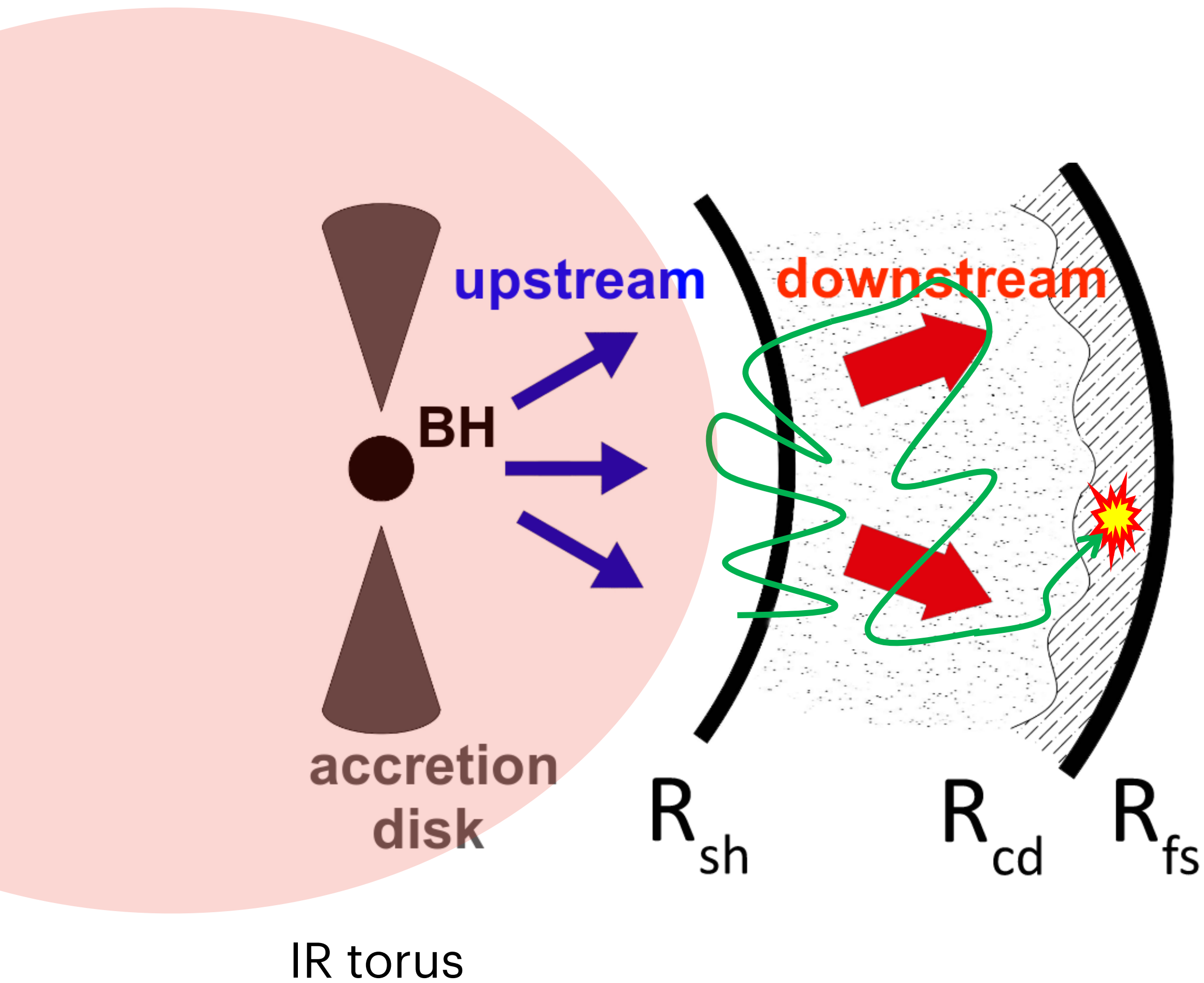
*D. Ehlert, FO, E. Peretti, to appear in MNRAS, arXiv:2411.05667*





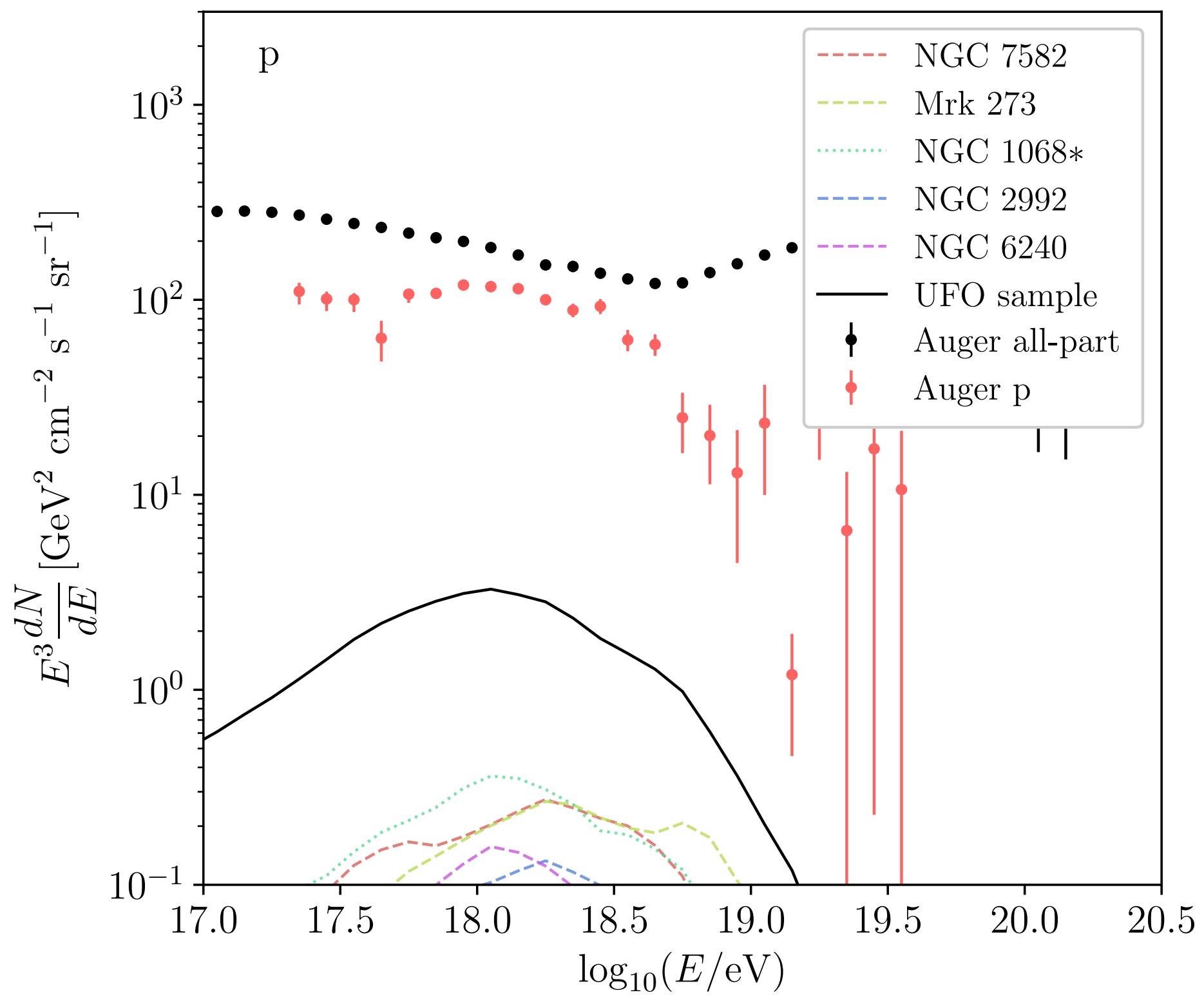
# Extreme UFOs: Intermittent sources at the highest energies

Spectrum at escape [ $\sim 5\%$  of our sample]



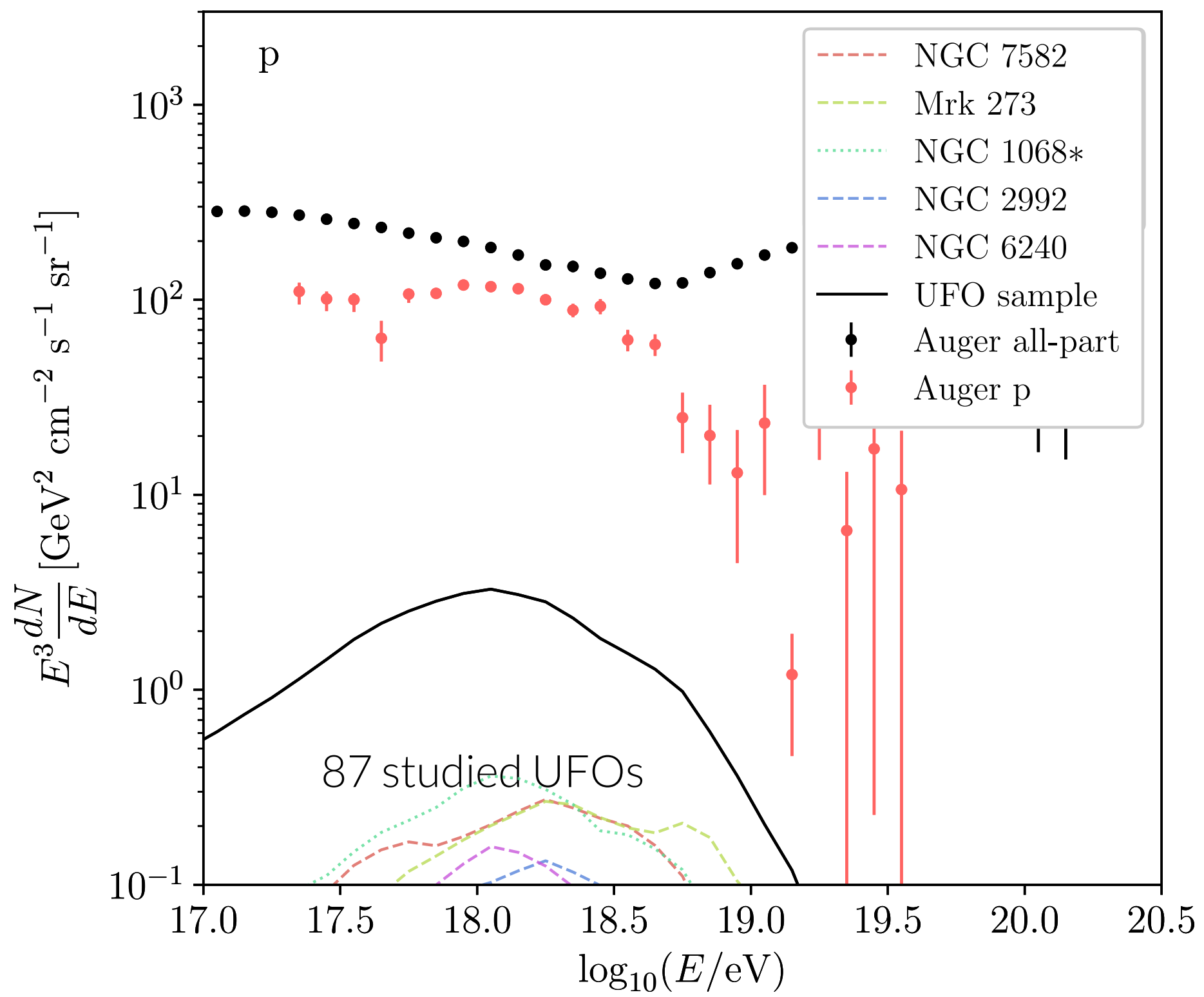
# AGN population

D. Ehlert, FO, E. Peretti, [arXiv:2411.05667](https://arxiv.org/abs/2411.05667)



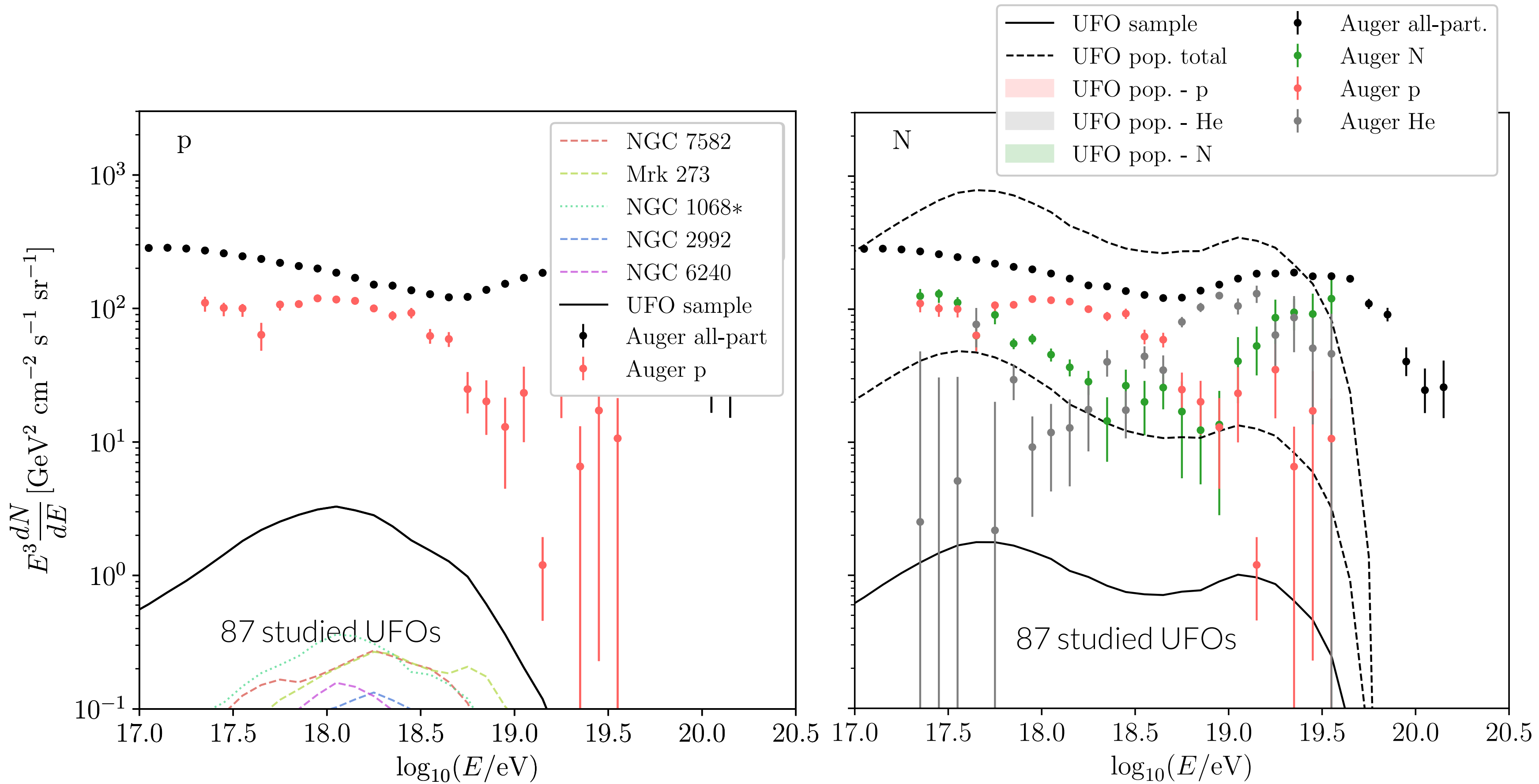
# AGN population

D. Ehlert, FO, E. Peretti, [arXiv:2411.05667](https://arxiv.org/abs/2411.05667)



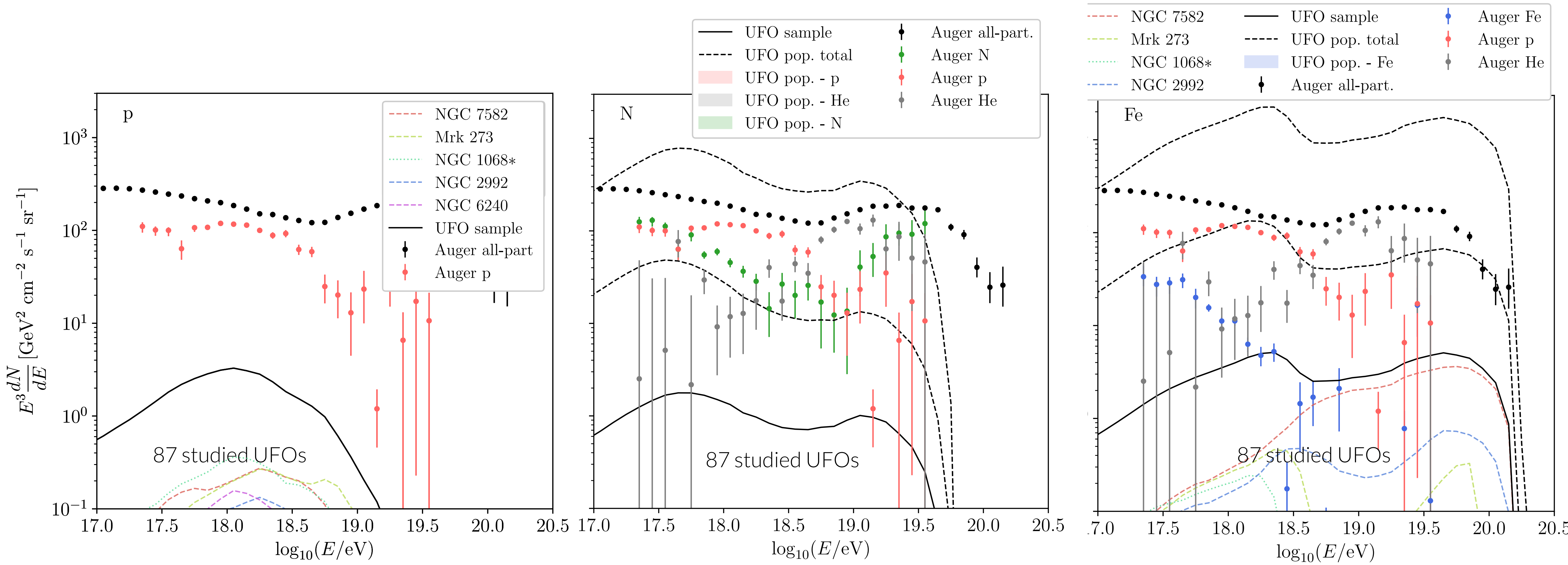
# AGN population

D. Ehlert, FO, E. Peretti, [arXiv:2411.05667](https://arxiv.org/abs/2411.05667)



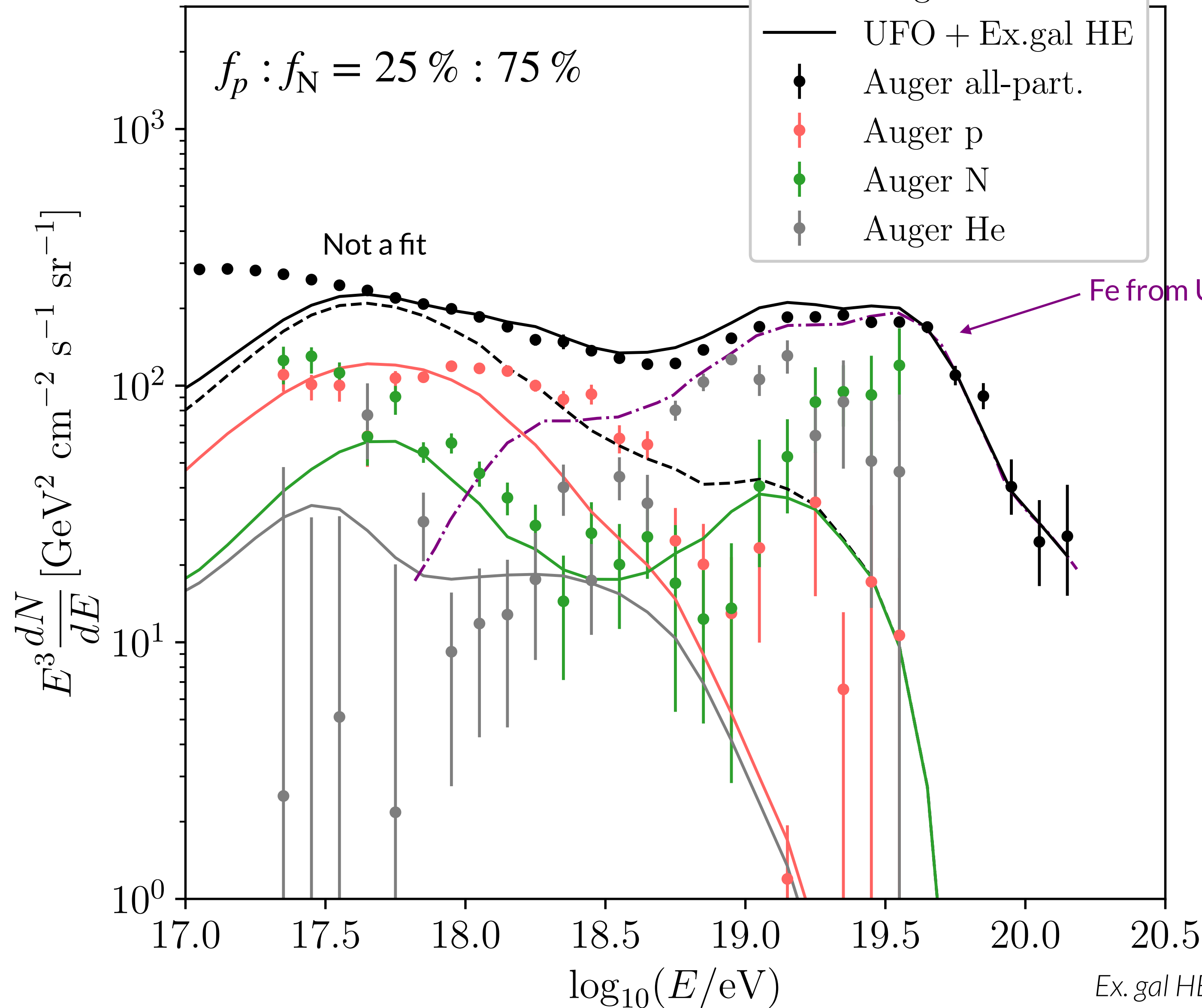
# AGN population

*D. Ehlert, FO, E. Peretti, arXiv:2411.05667*



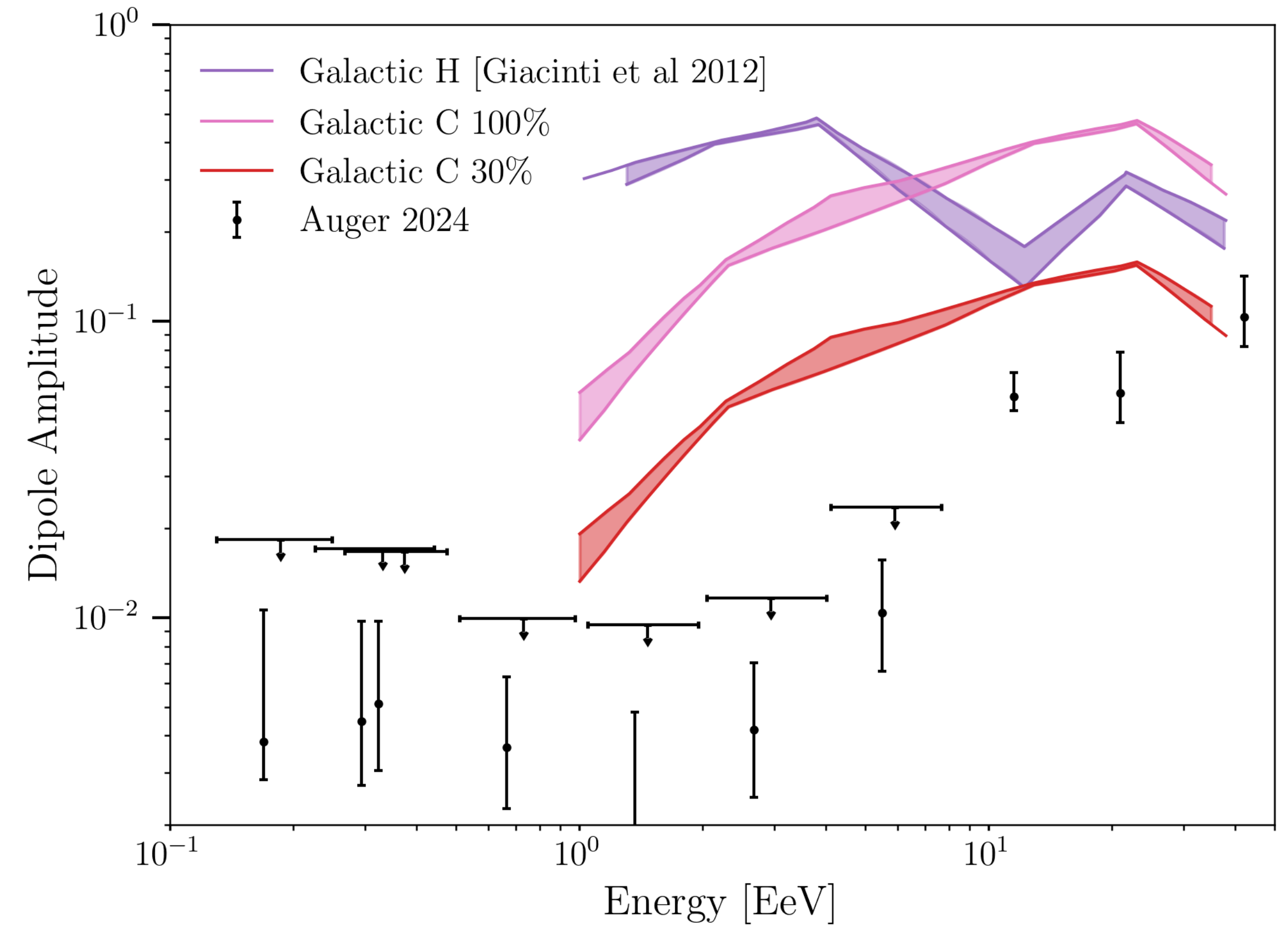
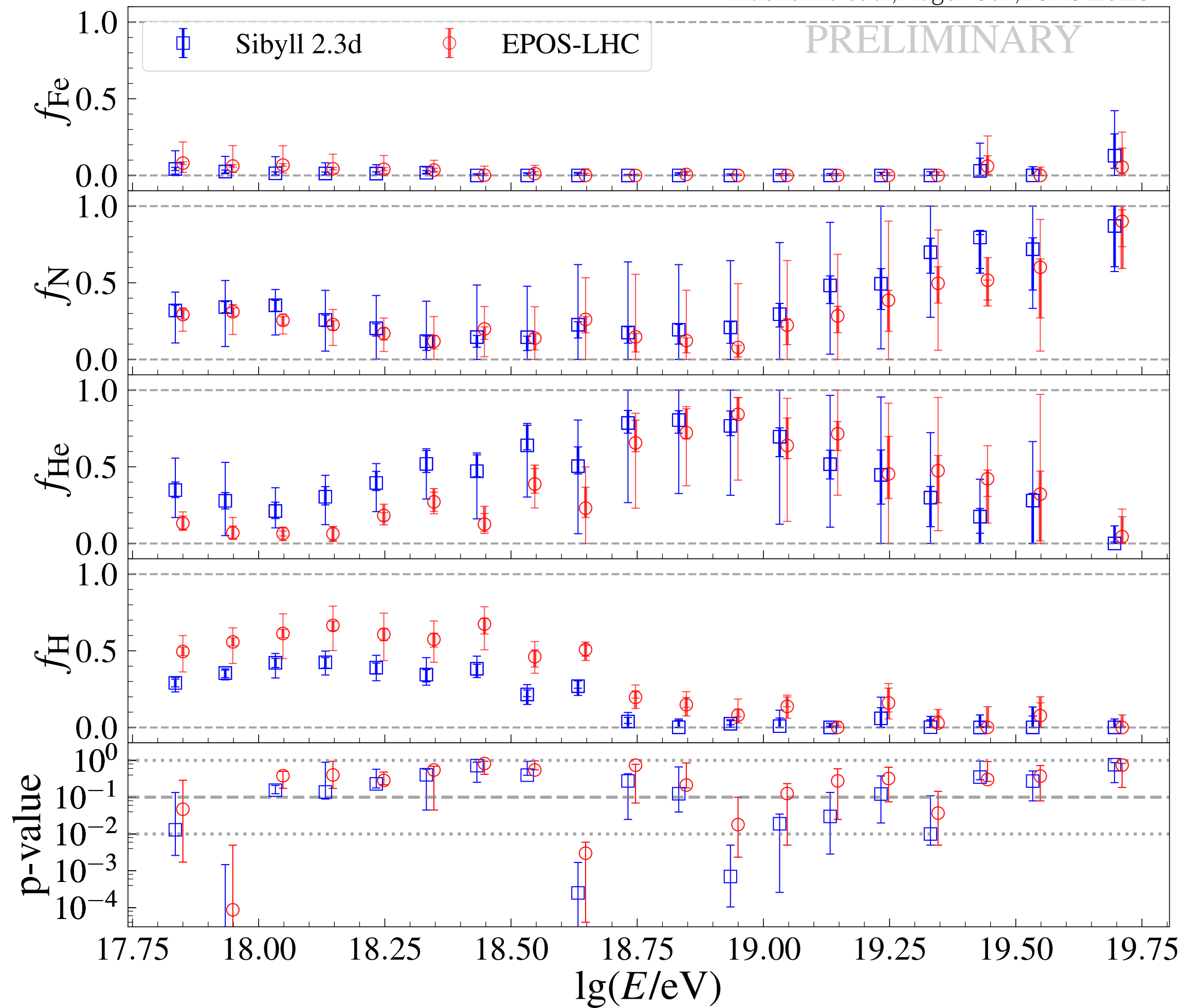
# AGN population

D. Ehlert, FO, E. Peretti, arXiv:2411.05667

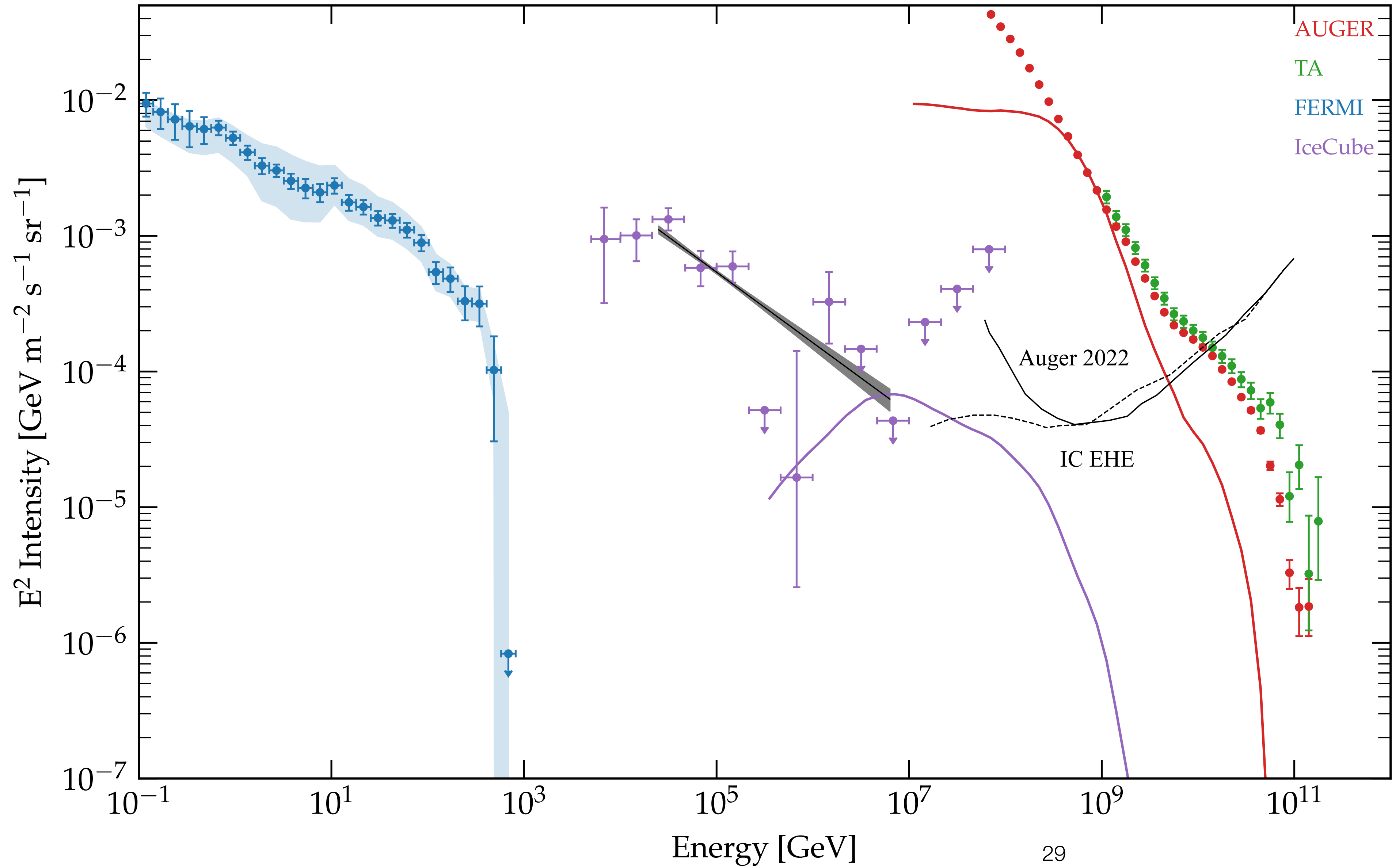


# Galactic-Extragalactic Transition

Tkachenko et al, Auger Coll, ICRC 2023

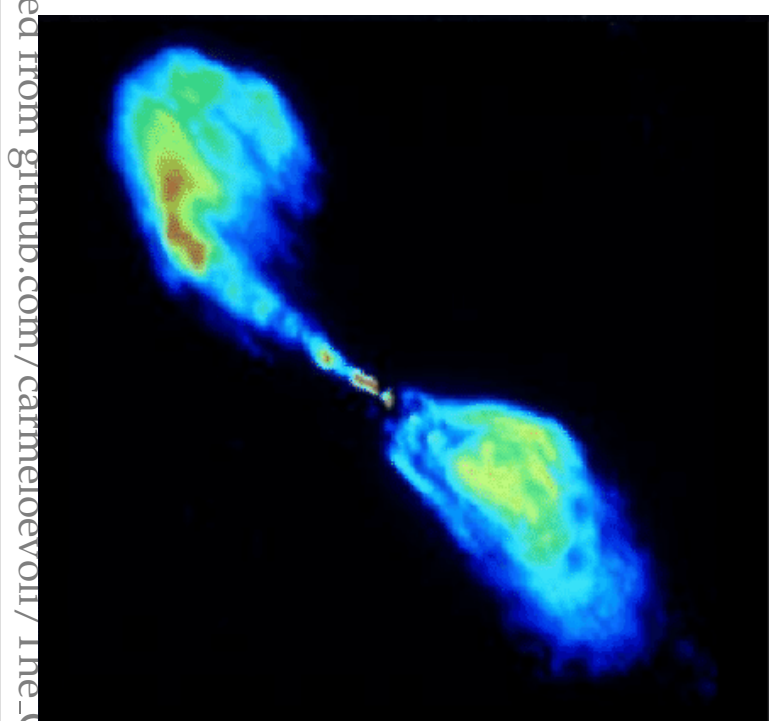
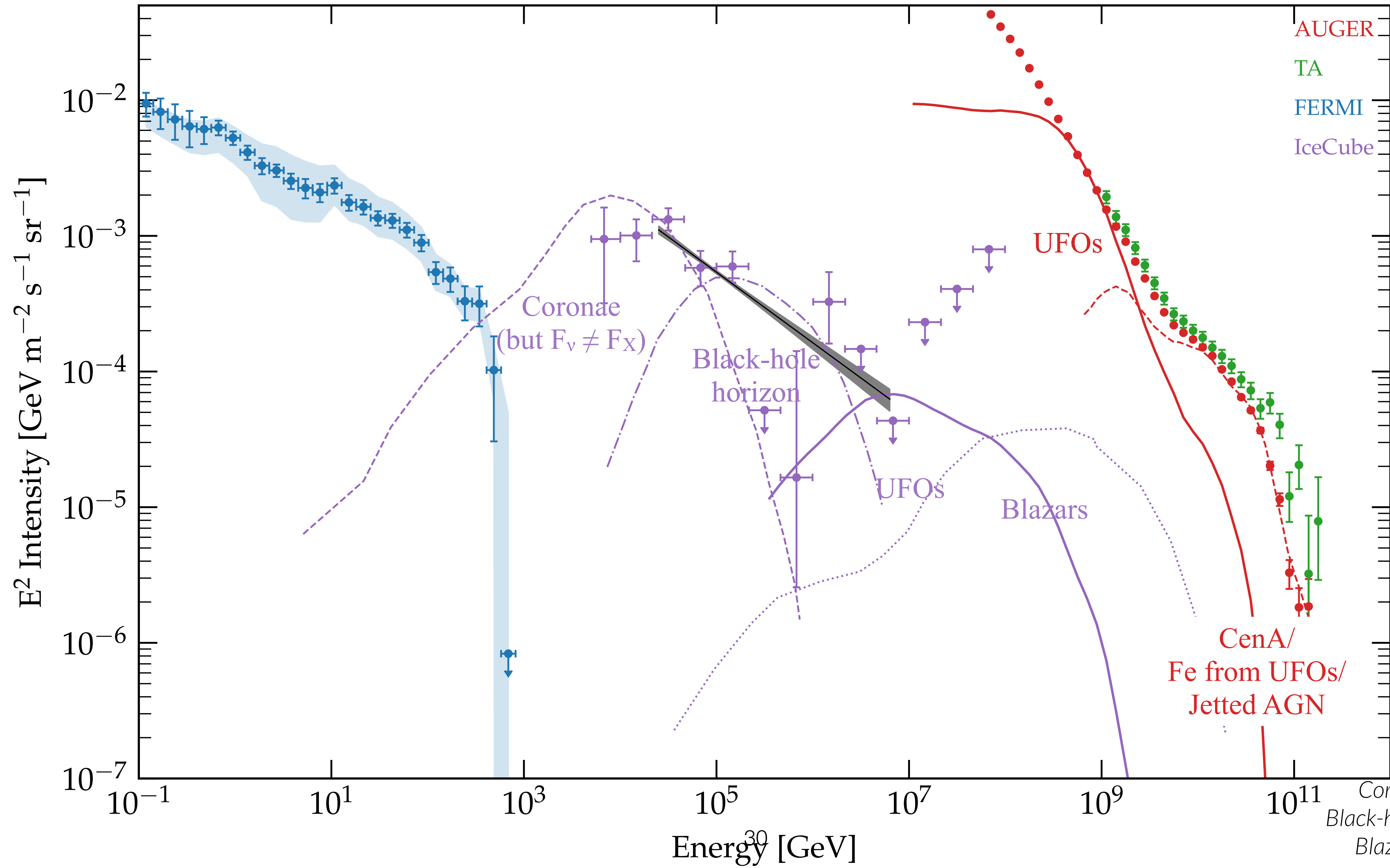


# UFO population: Diffuse neutrino flux





# Active Galactic Nuclei



Adapted from ginub.com/carnieoerovoi/Ine-CR-Spectrum

Coronae: Murase+ 2020 PRL,  
 Black-hole horizon: Kalashev+ 2015,  
 Blazars: Rodrigues+ 2021 PRL

# Summary

$\nu - \gamma - \text{UHECR}$  common origin?

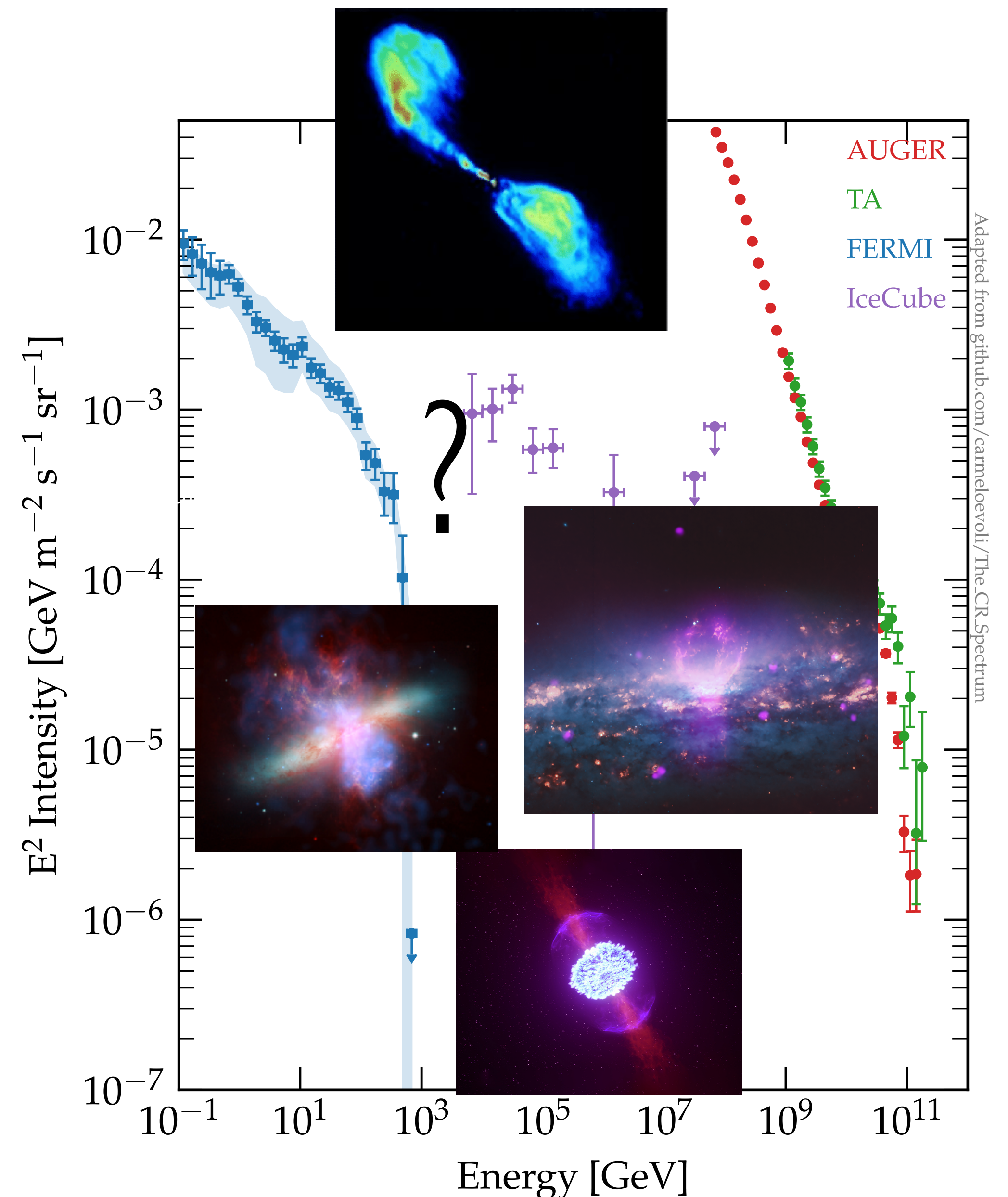
Possible for AGN – otherwise several source populations

Origin of “Component B”

AGN UFOs can fill the transition region - testable with neutrinos

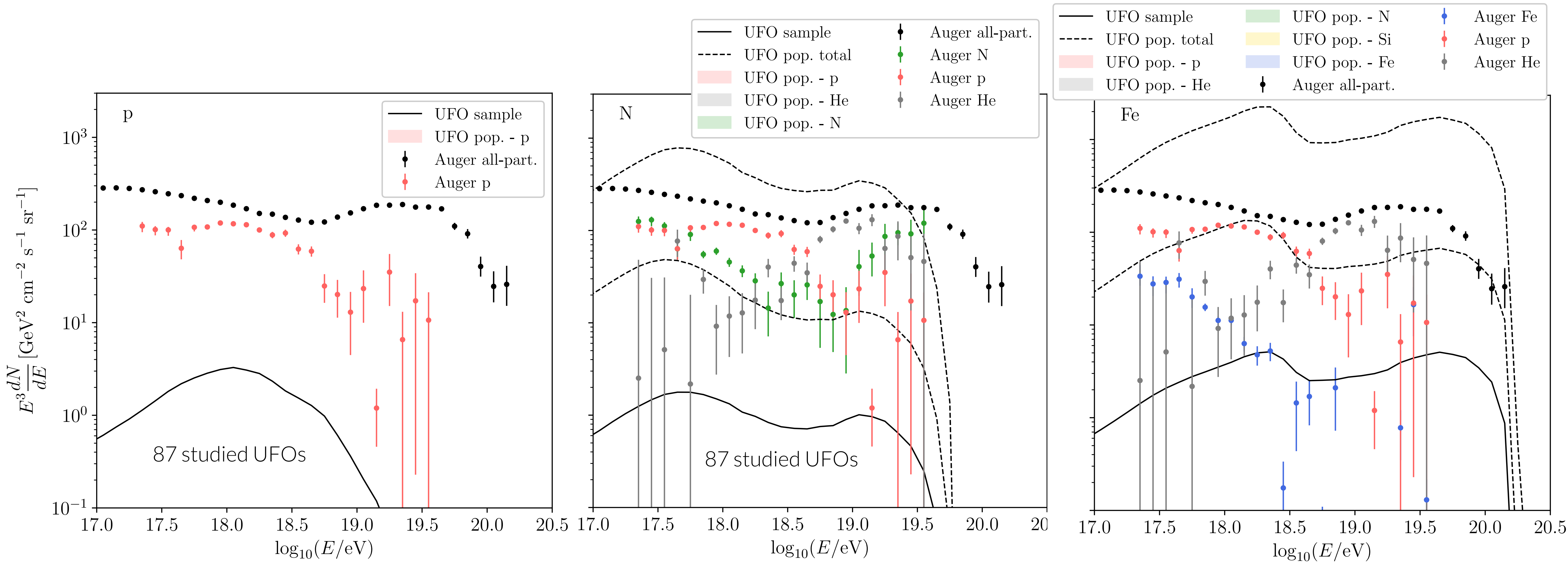
The sources are complex..

e.g. Starburst activity correlated with transients and AGN activity!



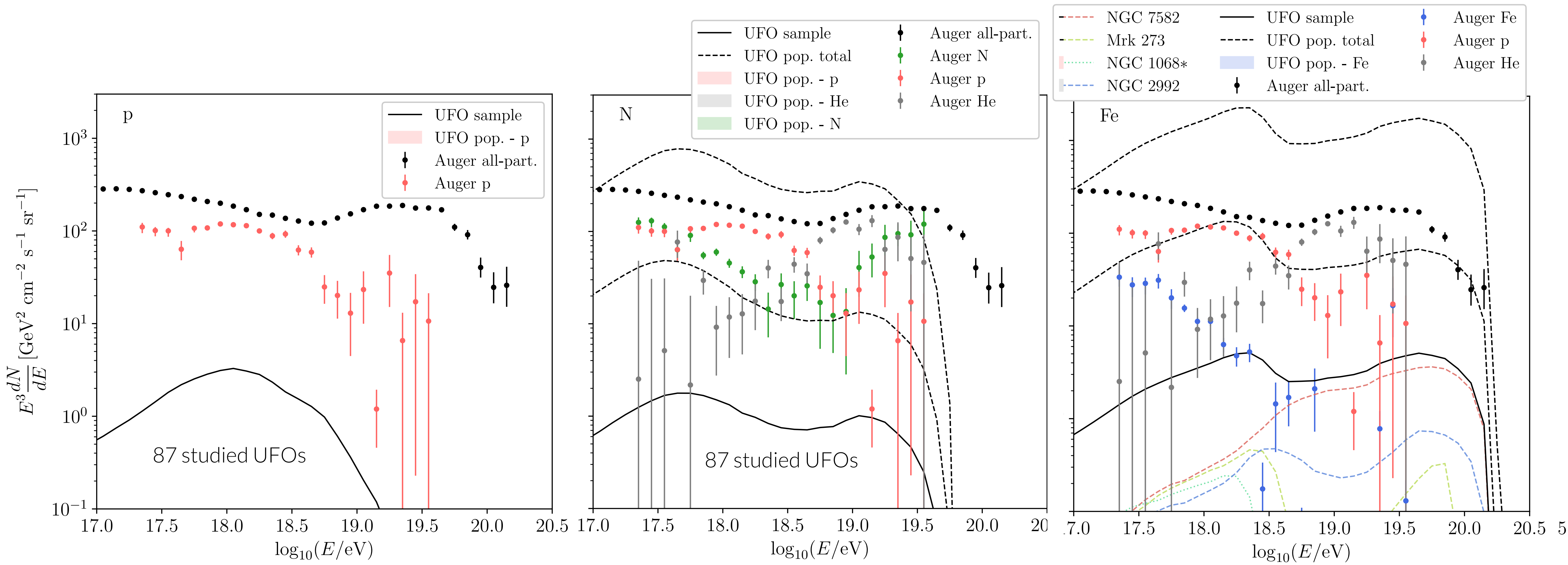
# AGN population

*D. Ehlert, FO, E. Peretti, arXiv:2411.05667*

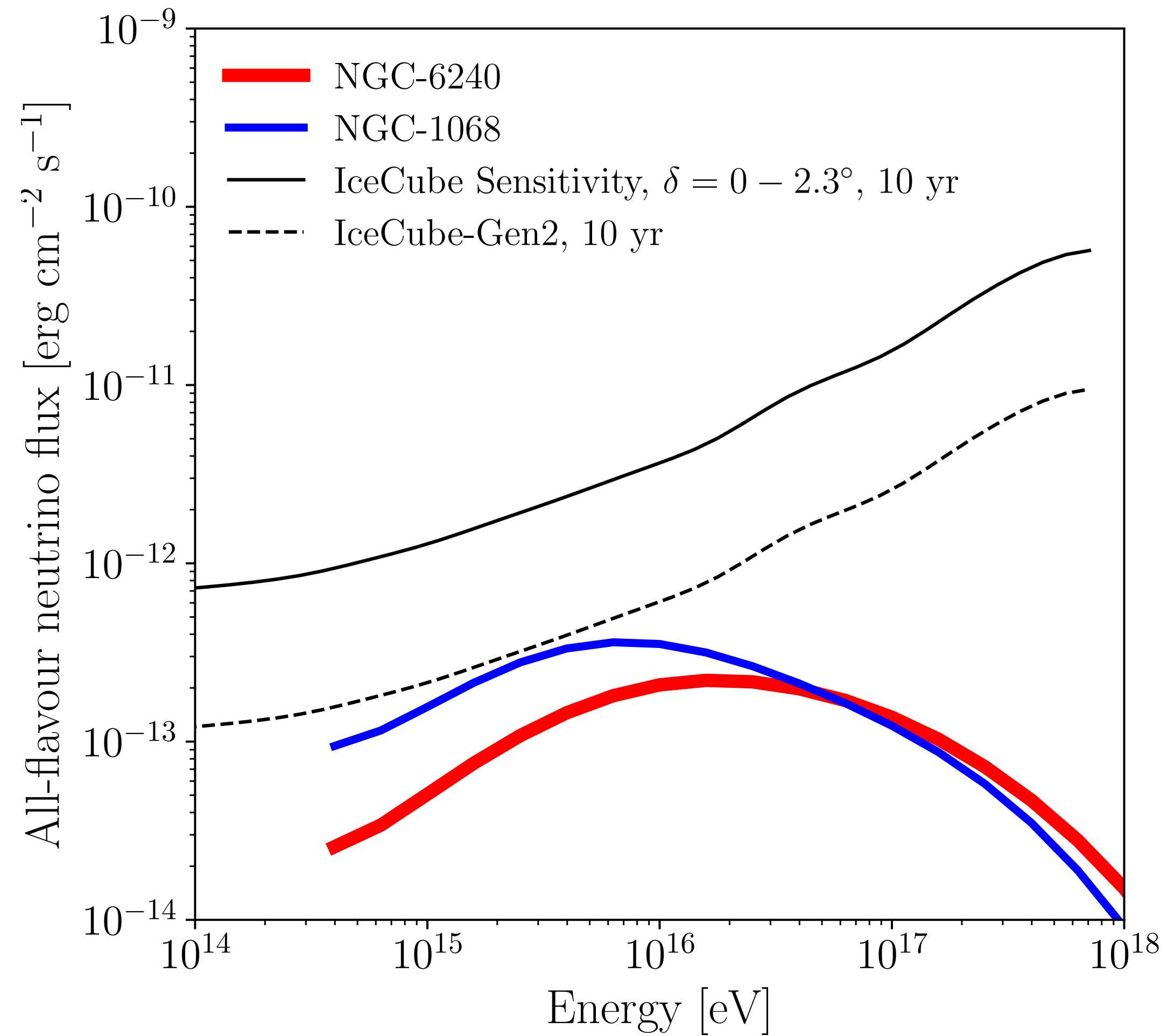


# AGN population

*D. Ehlert, FO, E. Peretti, arXiv:2411.05667*

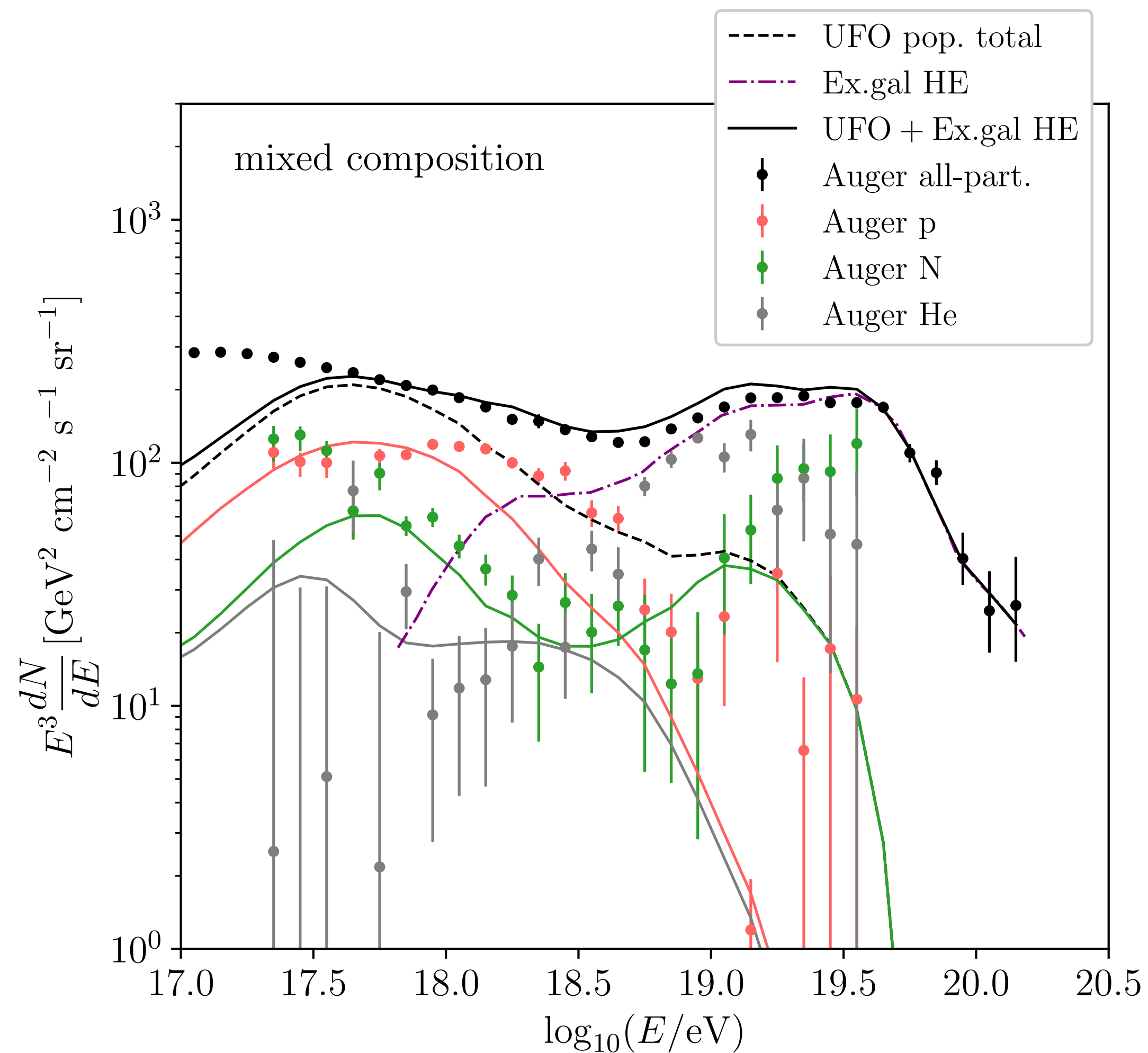


# UFO population: Point-source fluxes

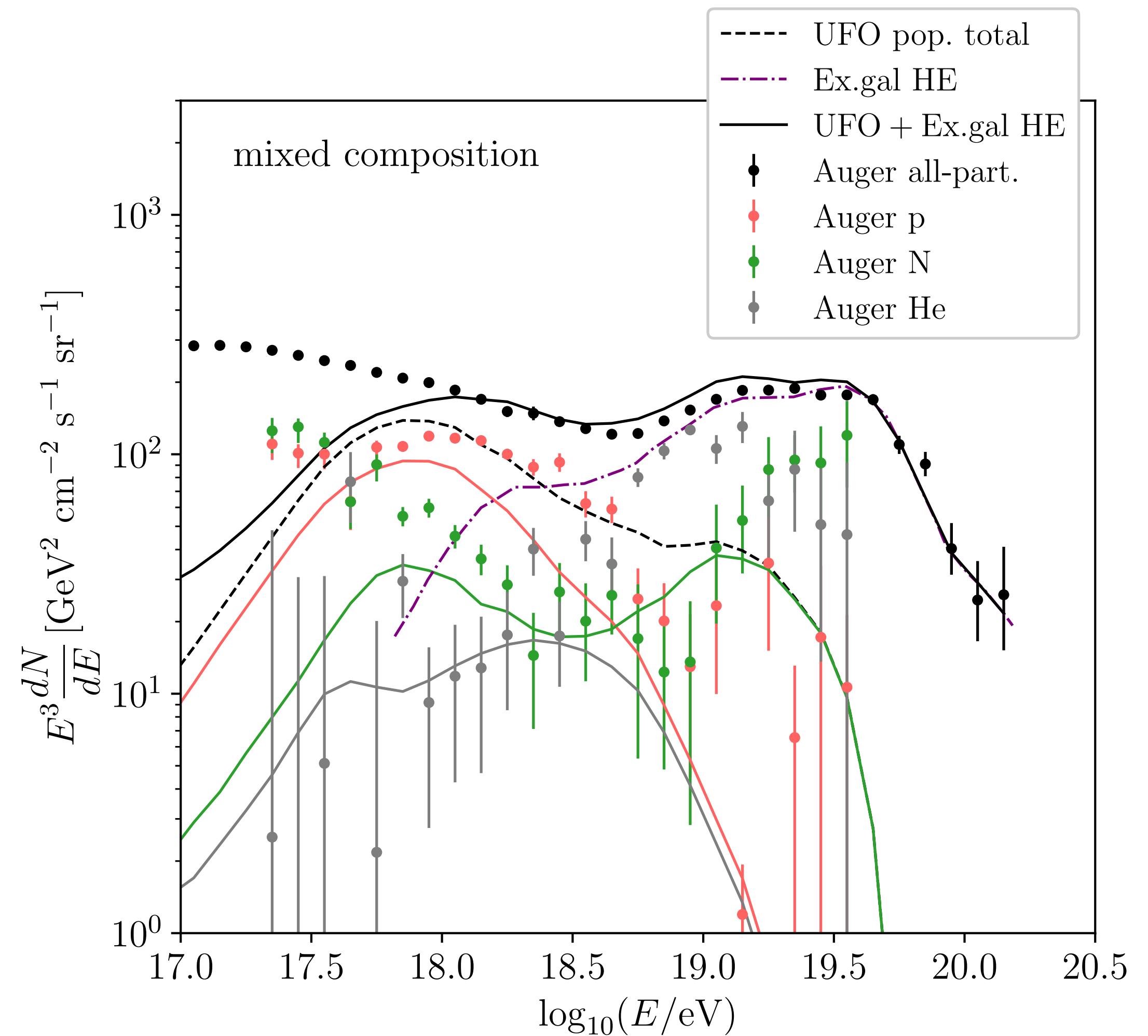


# UFO population: Magnetic Horizon

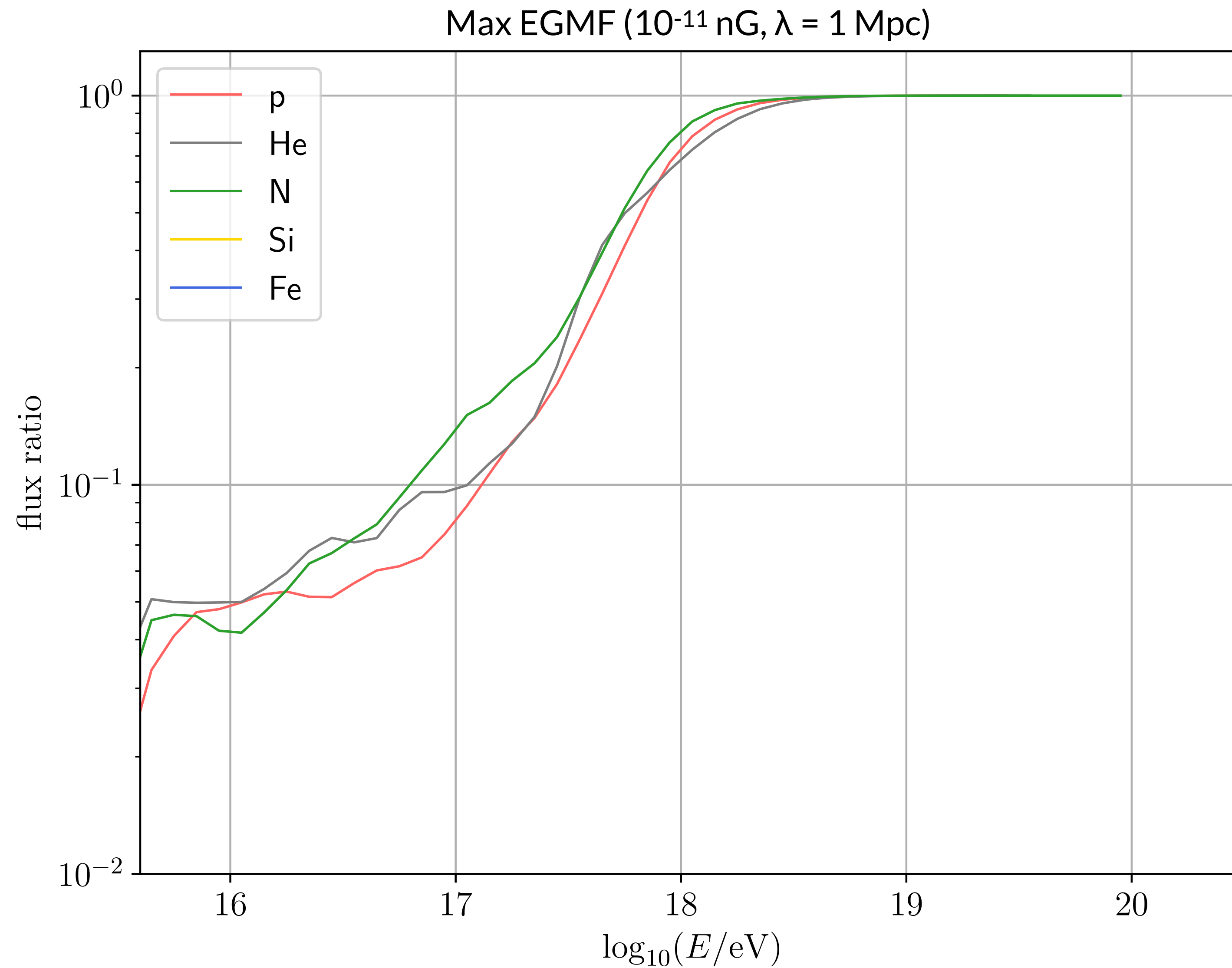
Low EGMF ( $\leq 10^{-12}$  nG)



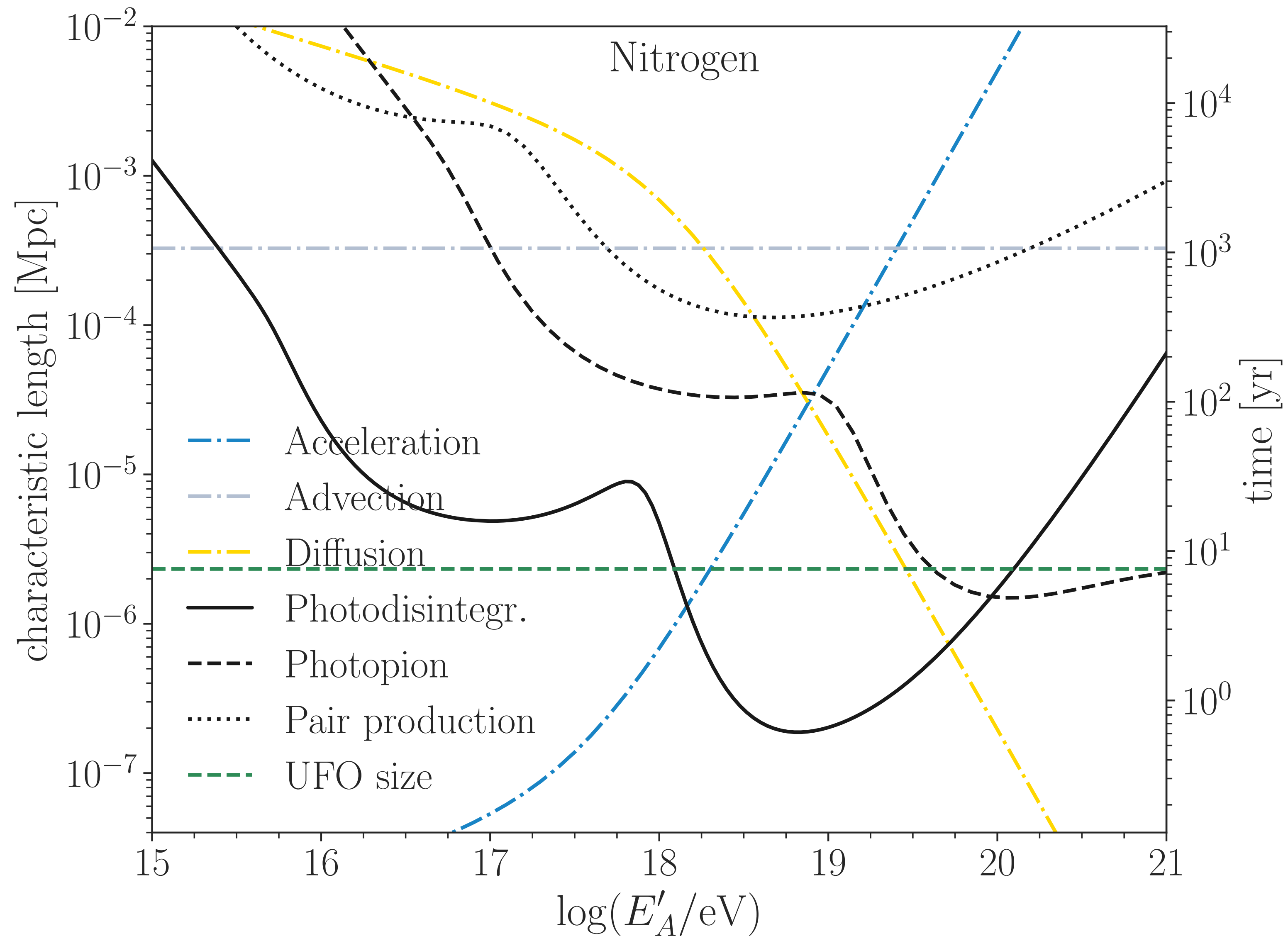
Max EGMF ( $10^{-11}$  nG,  $\lambda = 1$  Mpc)



# UFO population: Magnetic Horizon



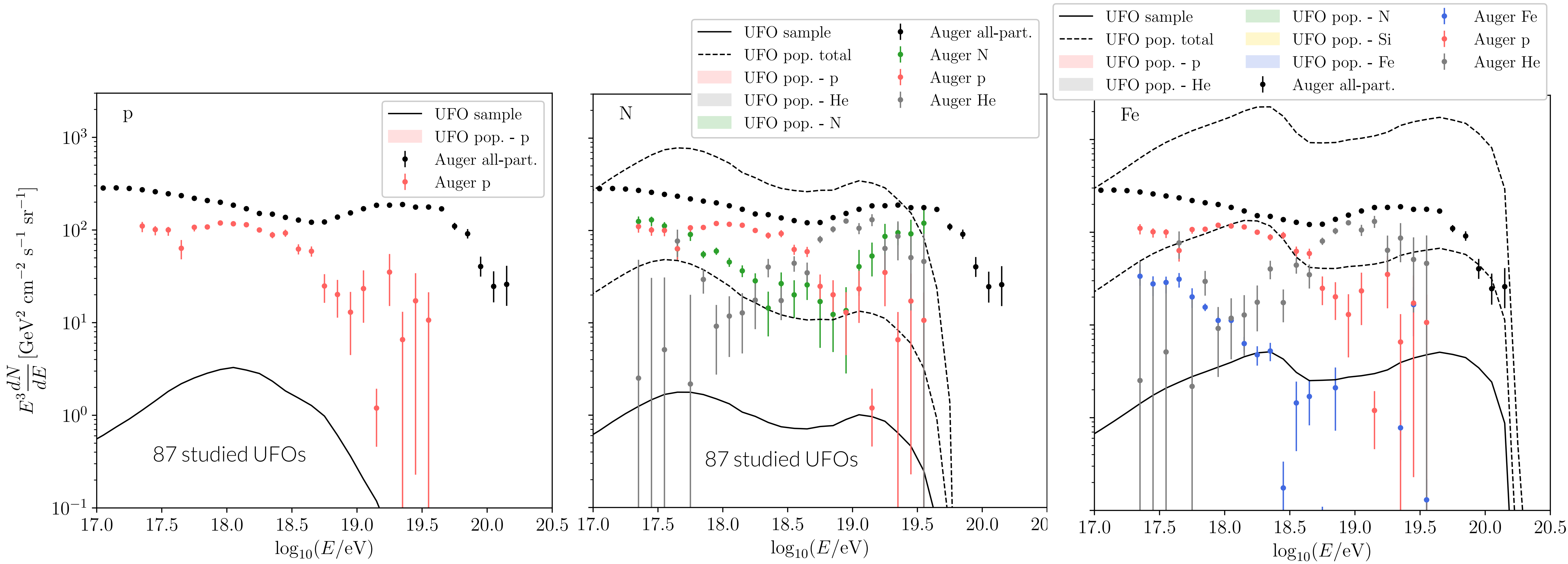
# UFOs: What limits the maximum energy





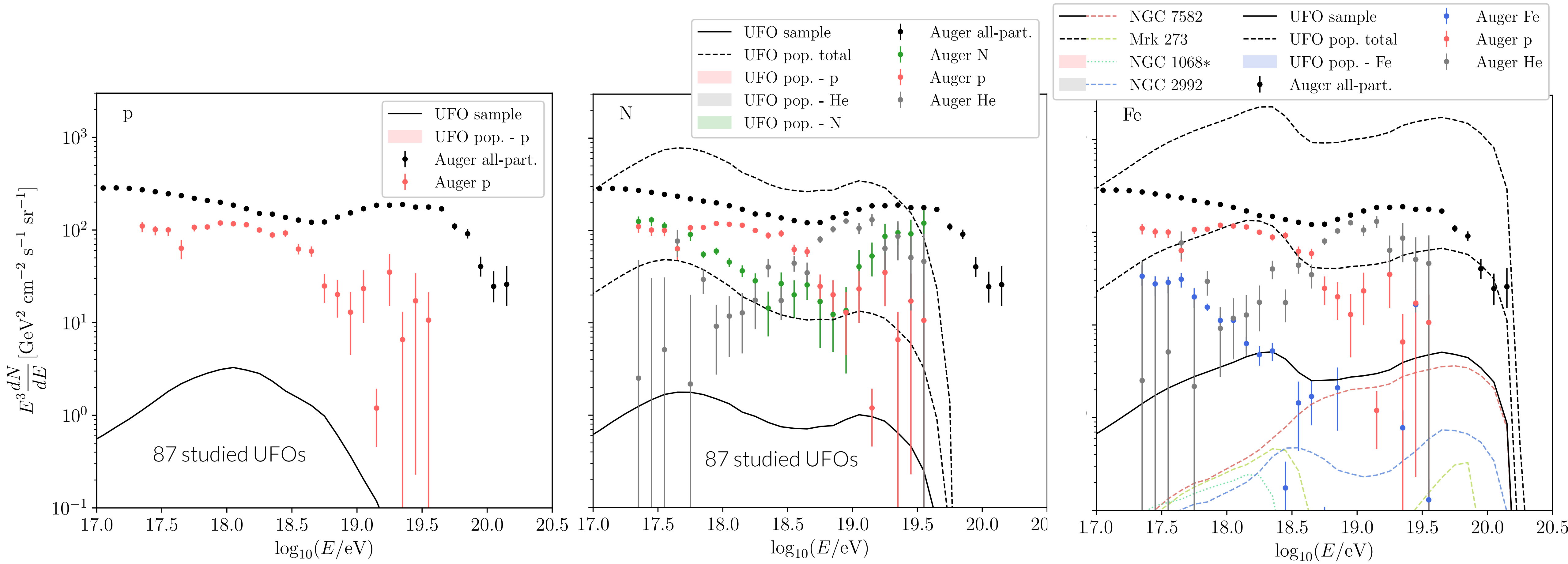
# AGN population

*D. Ehlert, FO, E. Peretti, arXiv:2411.05667*



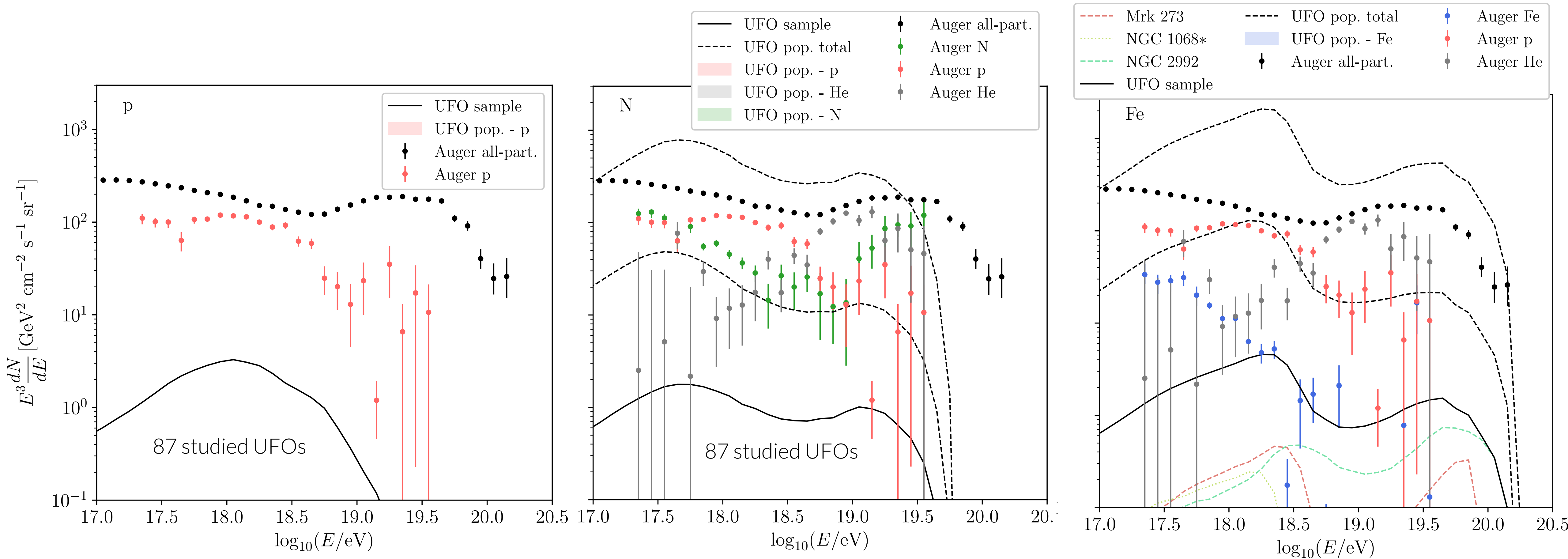
# AGN population

*D. Ehlert, FO, E. Peretti, arXiv:2411.05667*



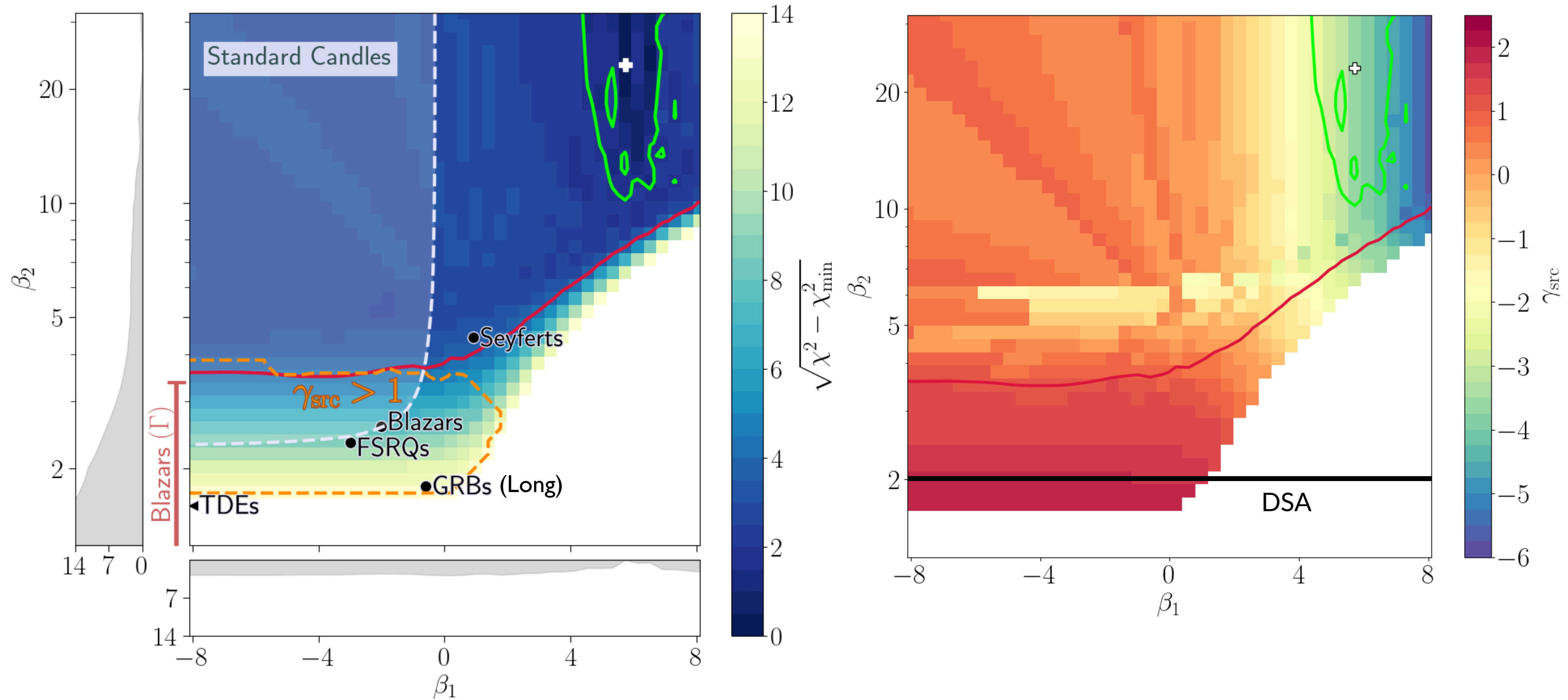
# AGN population

*D. Ehlert, FO, E. Peretti, arXiv:2411.05667*

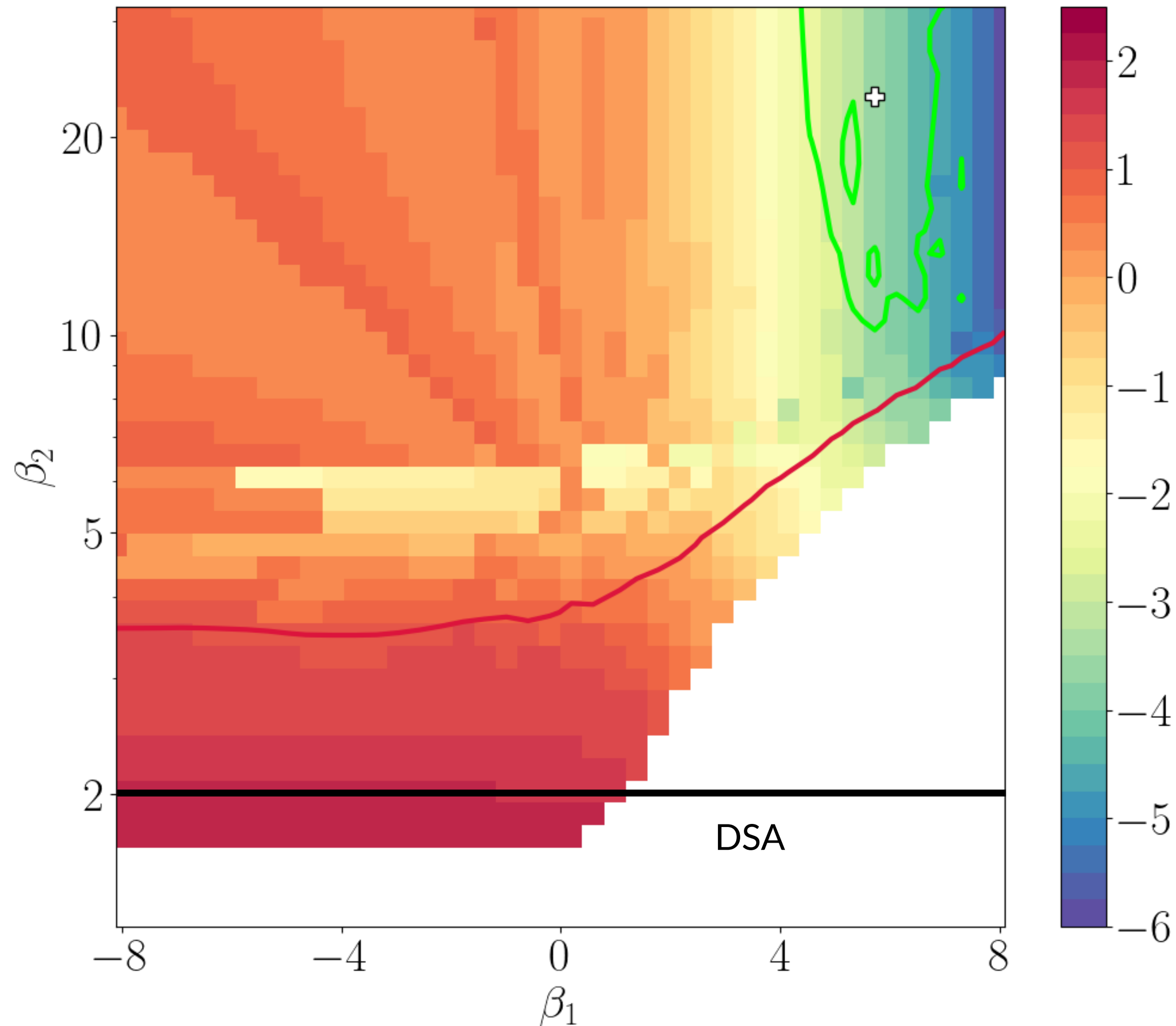


# A curious maximum rigidity distribution

D. Ehlert, FO, M. Unger, PRD 107 (2023) 10



# A comment on hard spectra



Acceleration process

Shock acceleration with synchrotron losses

*Zirakashvili & Aharonian 2006*

Relativistic turbulence

*Comisso, Farrar, Muzio 2024*

Interactions/confinement in the sources

*Globus, Allard, Mochkowitz, Parizot 2014*

*Unger, Farrar, Anchordoqui 2014*

Extragalactic magnetic horizon

*Pierre Auger Coll JCAP 07 094 2024*