

# **Pierre Auger as a multi-messenger observatory**

## **A template for CREDO?**

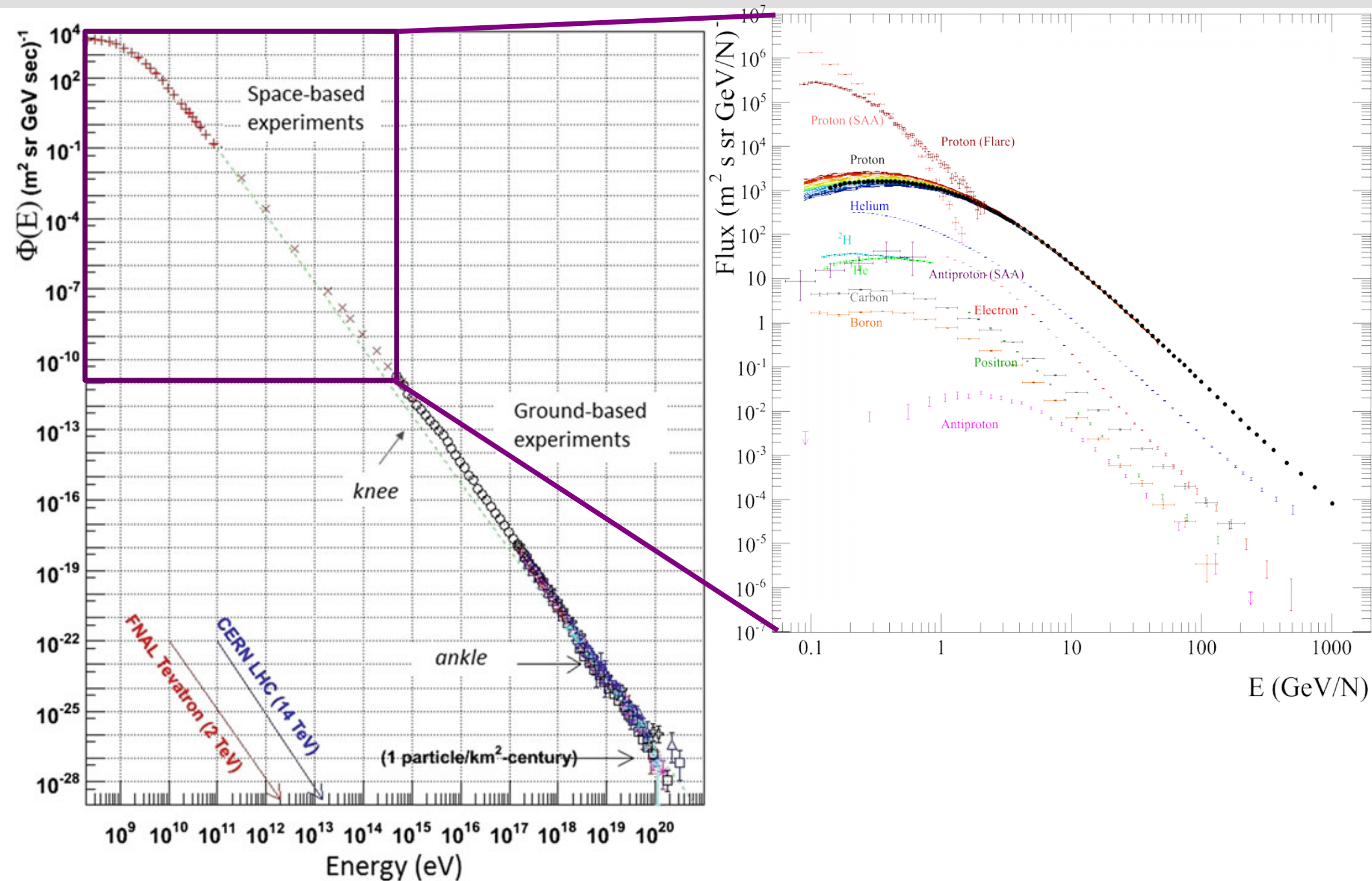
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**Thomas Bretz**

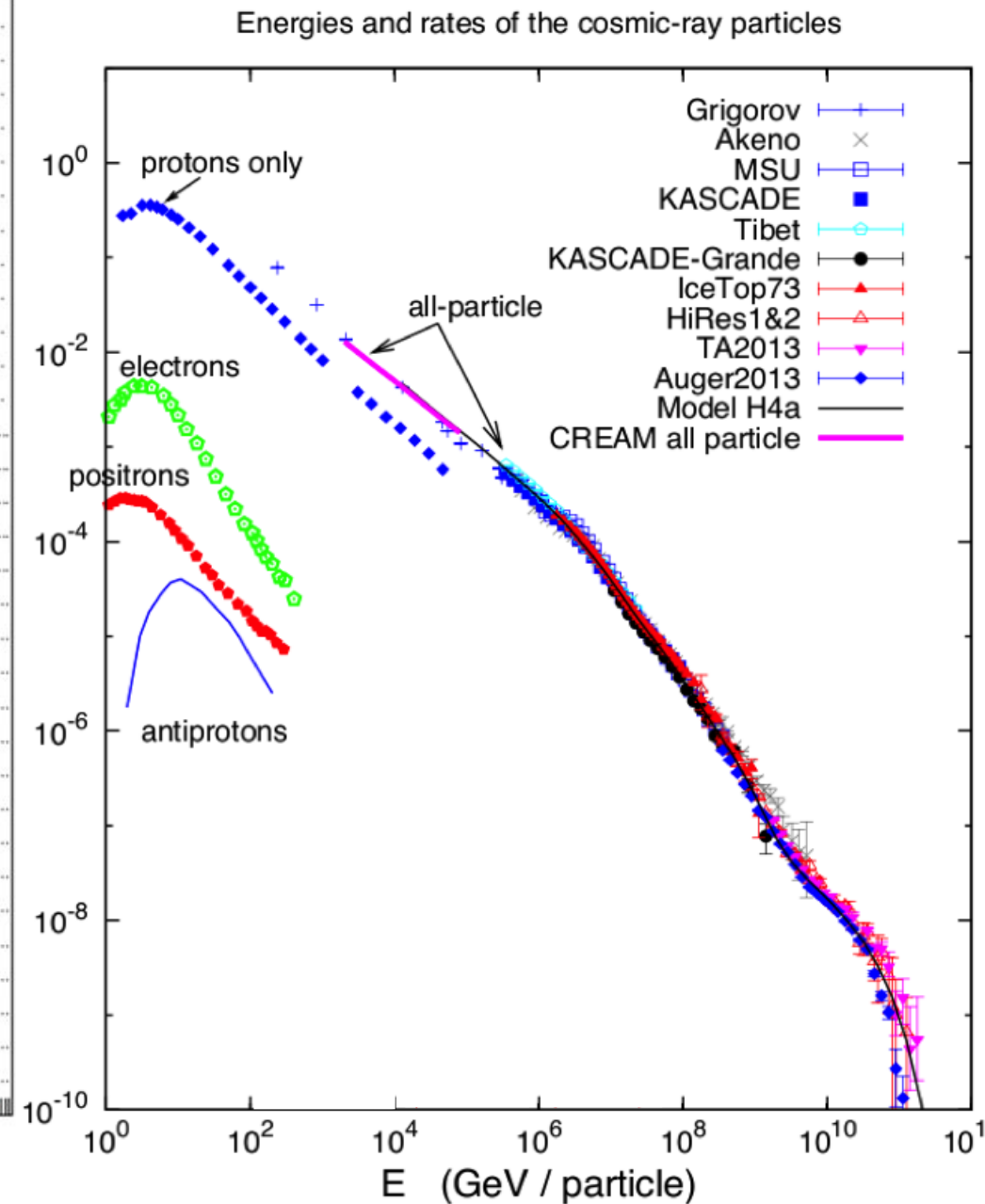
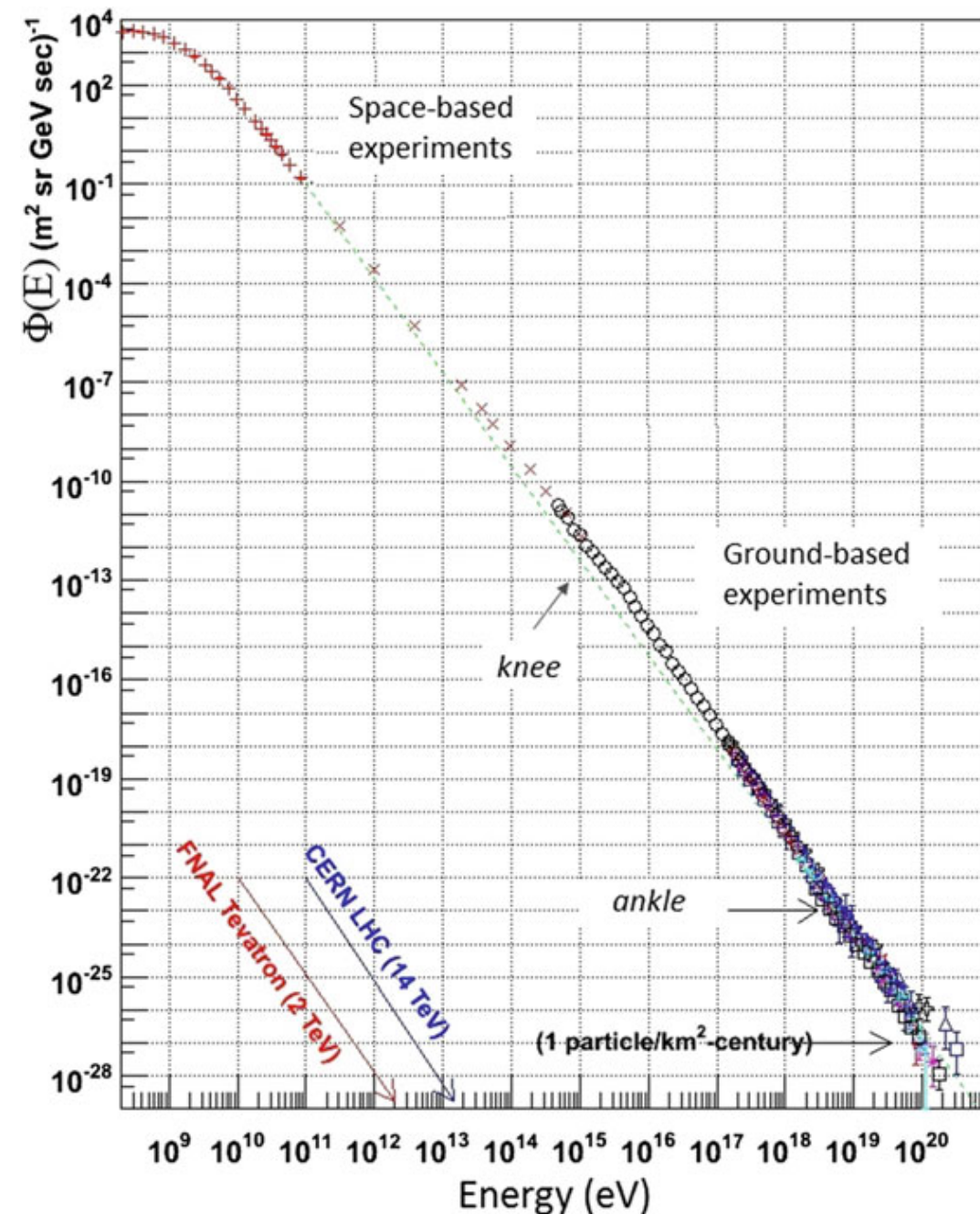
**RWTH**AACHEN  
UNIVERSITY

**What is the origin of cosmic-rays?**

# Cosmic-ray energy spectrum

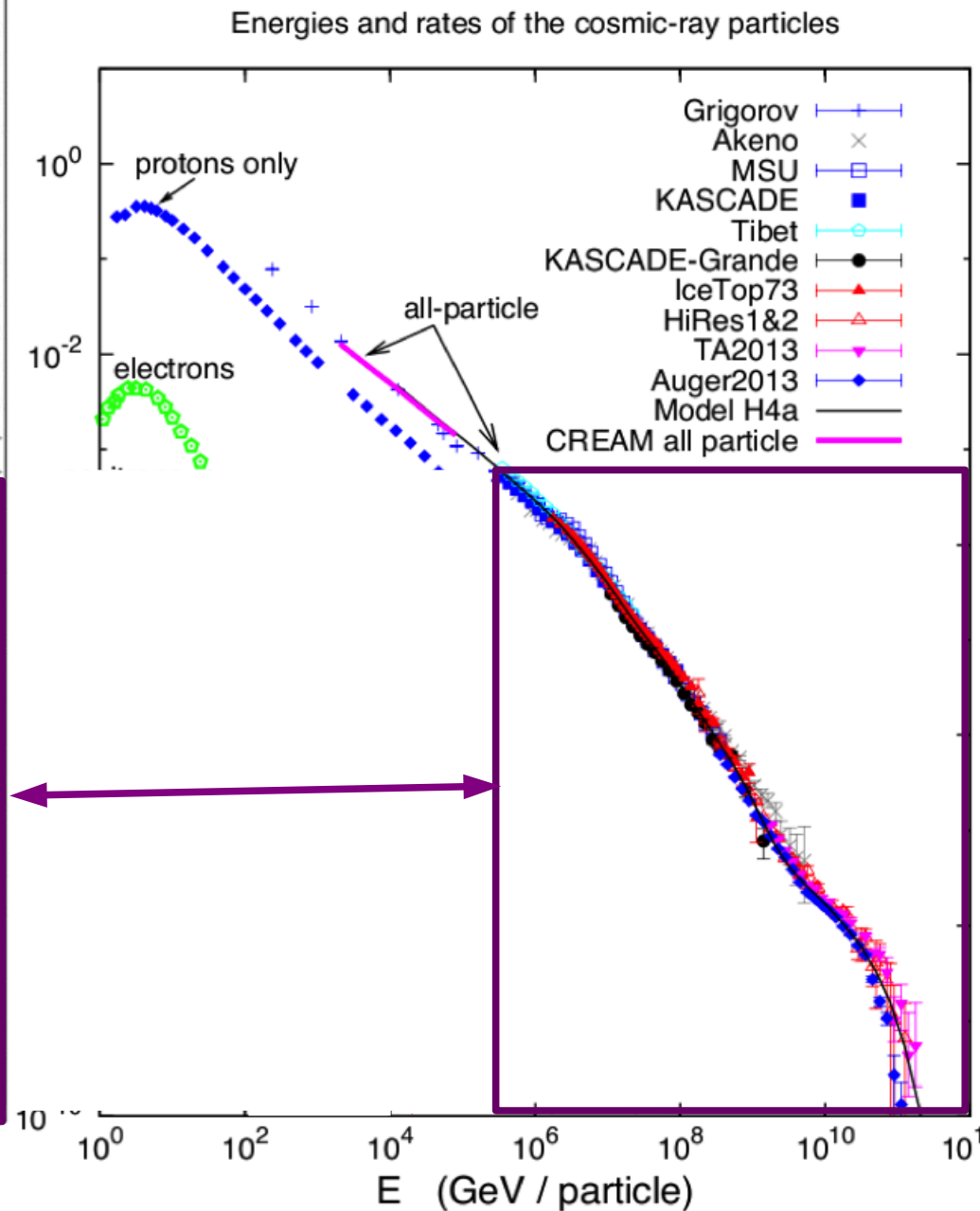
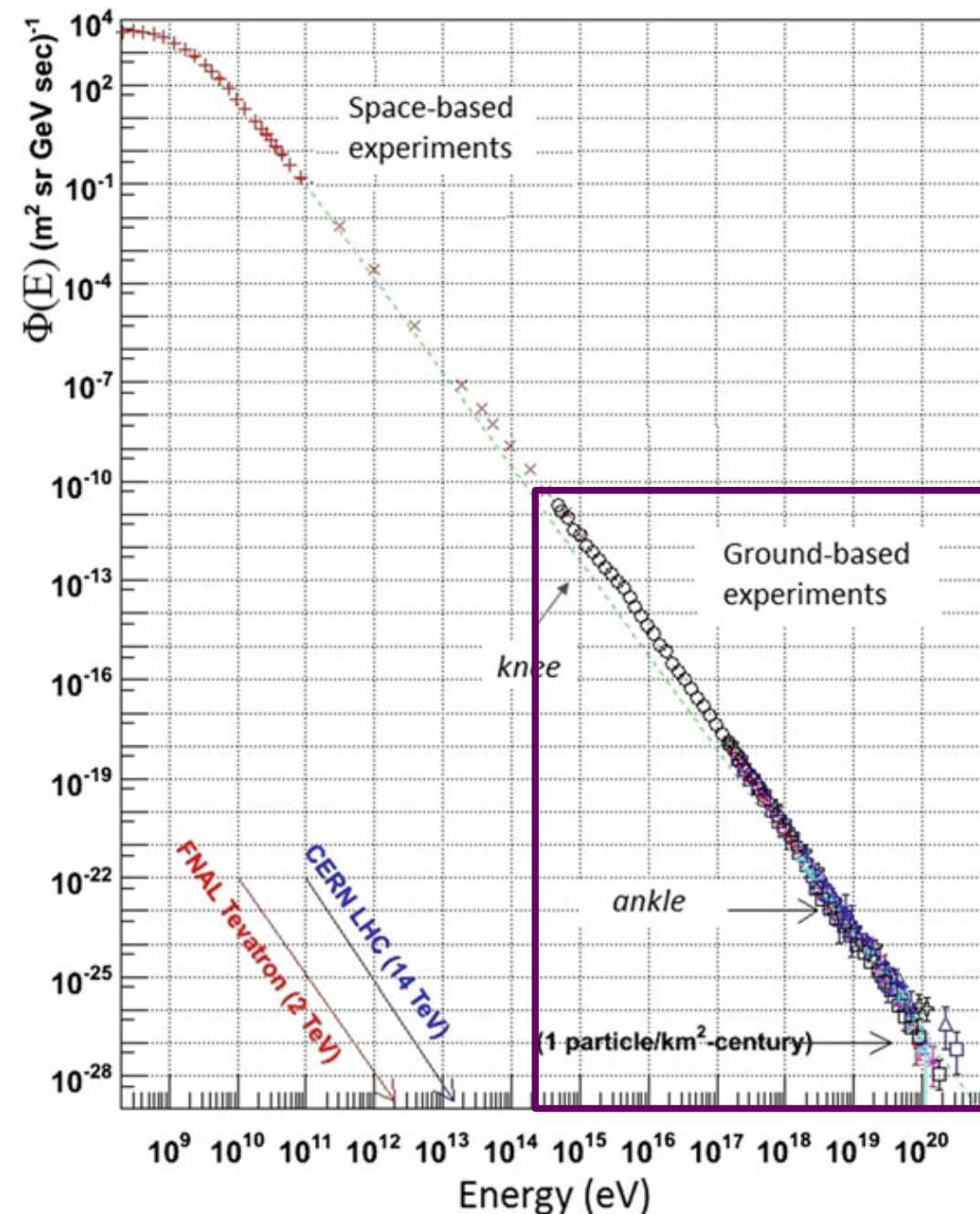


# Cosmic-ray energy spectrum

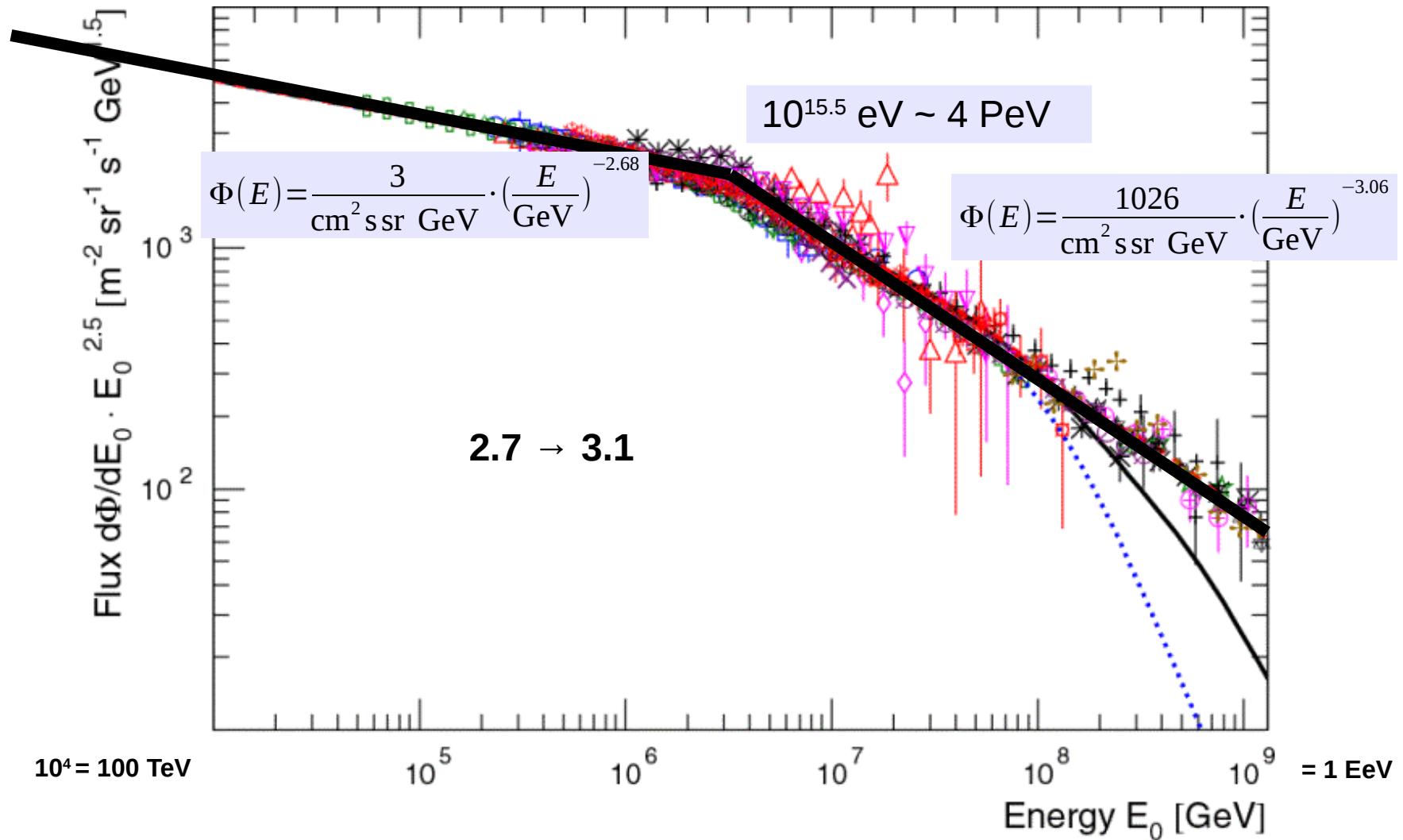




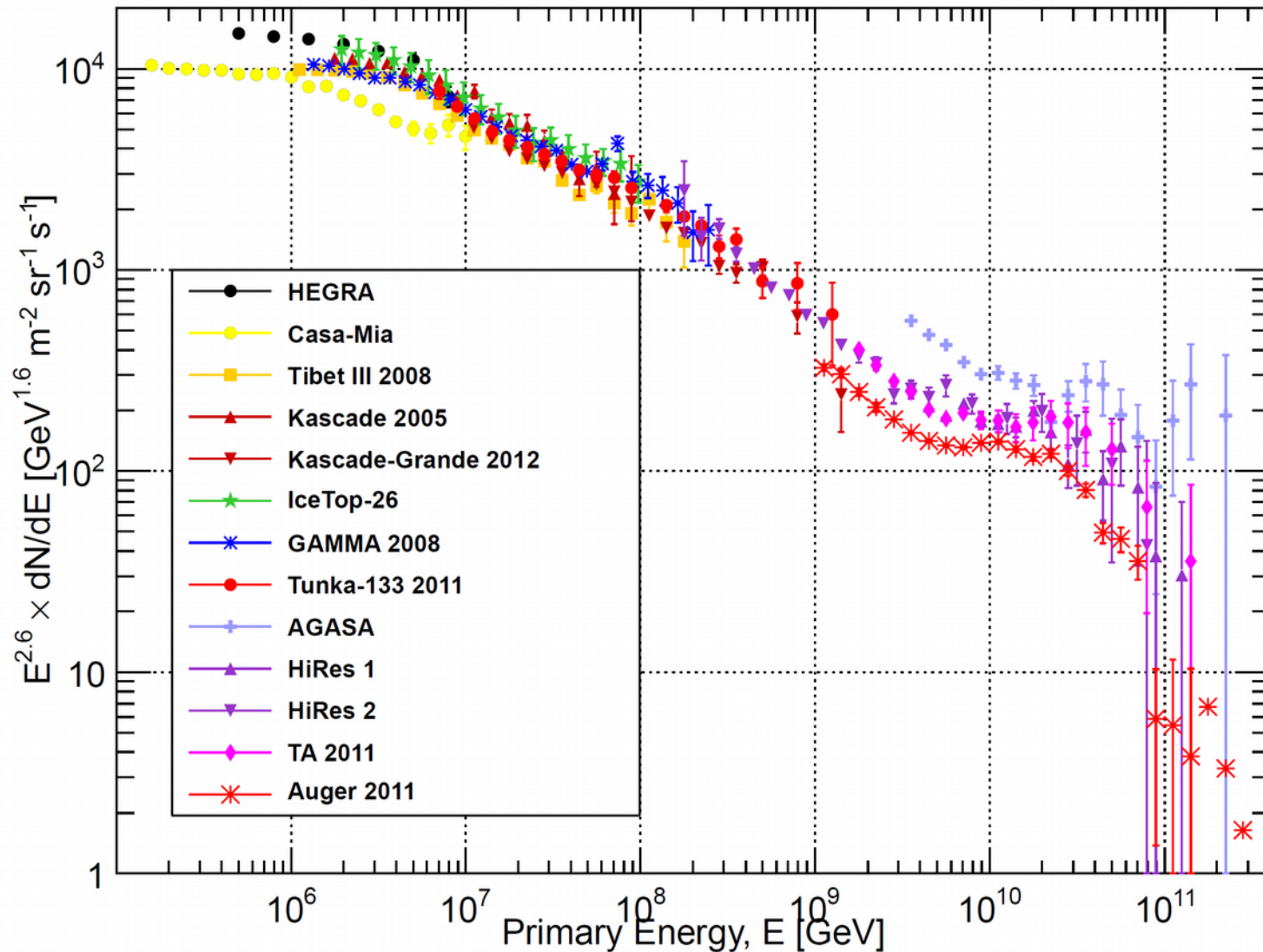
# Cosmic-ray energy spectrum



# Classical view around the knee

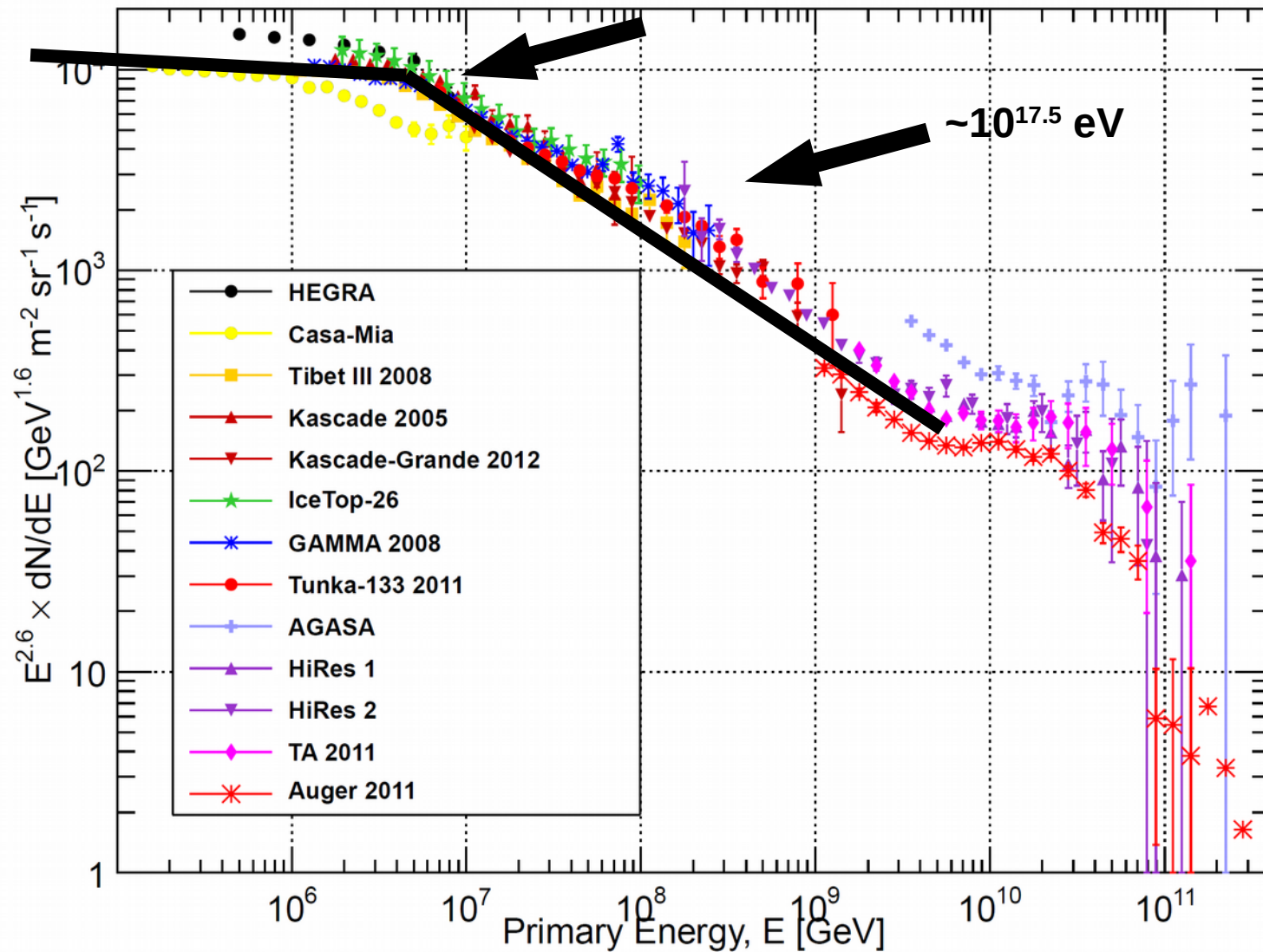


arXiv:1303.3565



Indications for structures above the knee

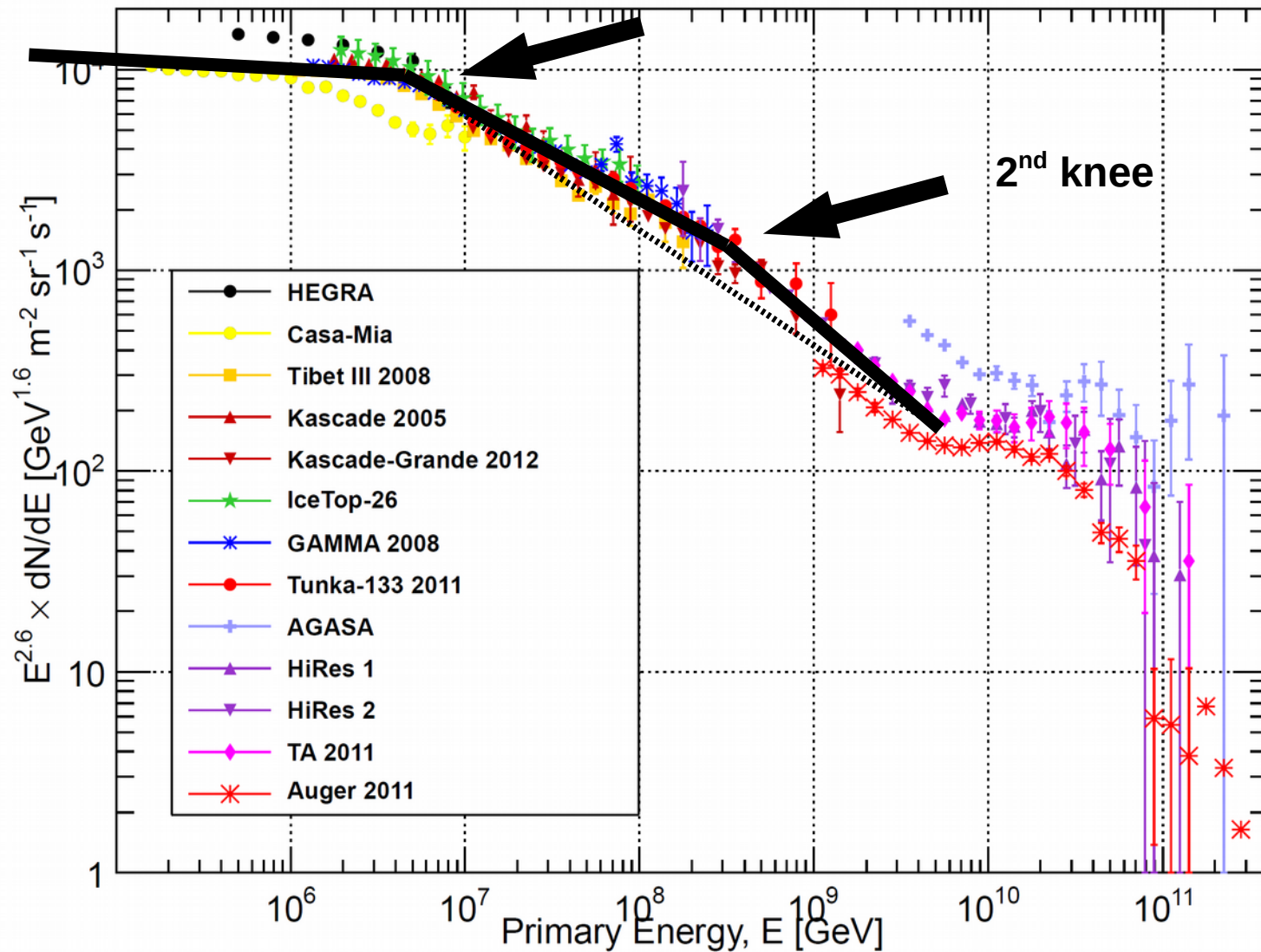
arXiv:1303.3565



Indications for structures above the knee

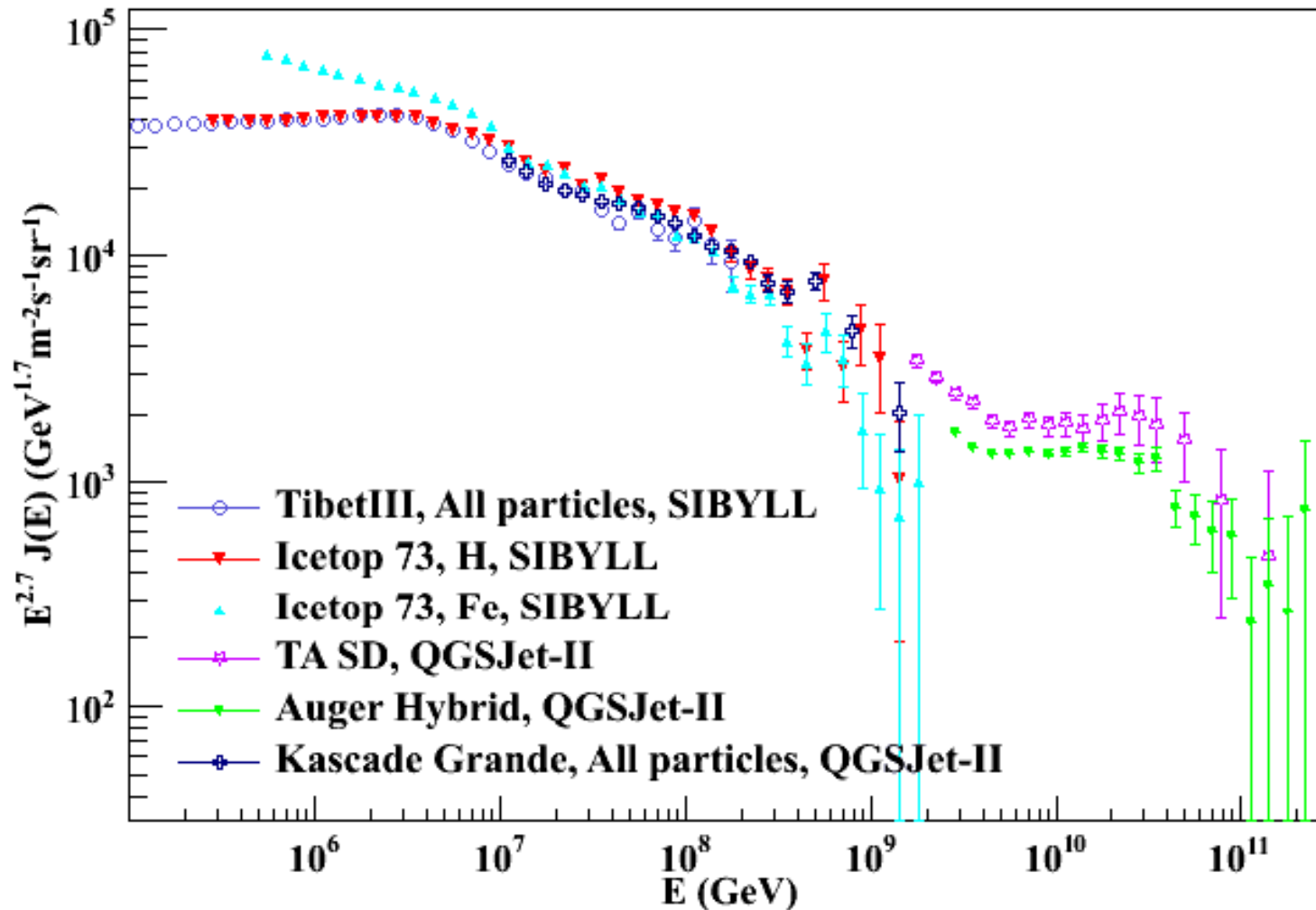


arXiv:1303.3565

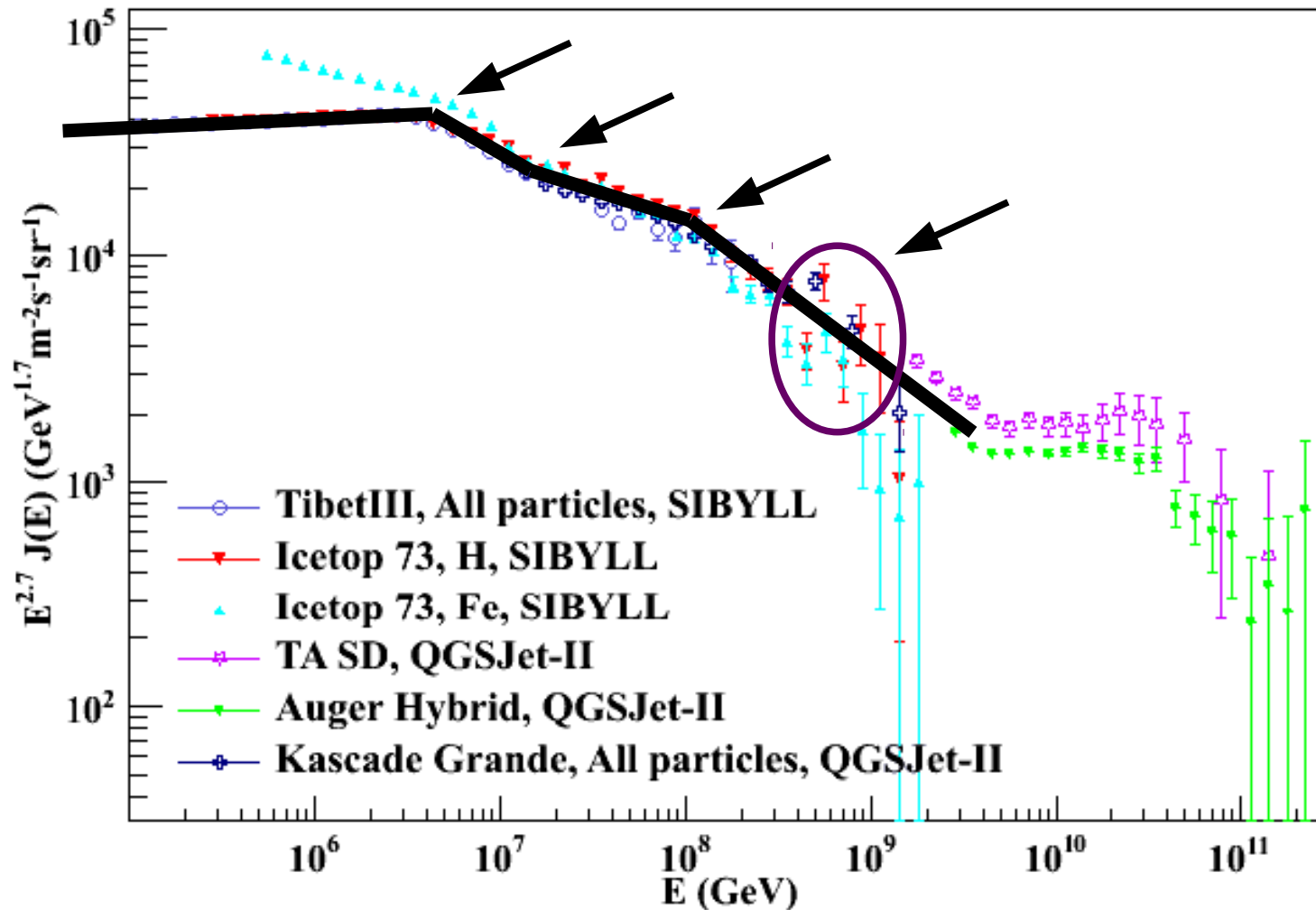


Indications for structures above the knee



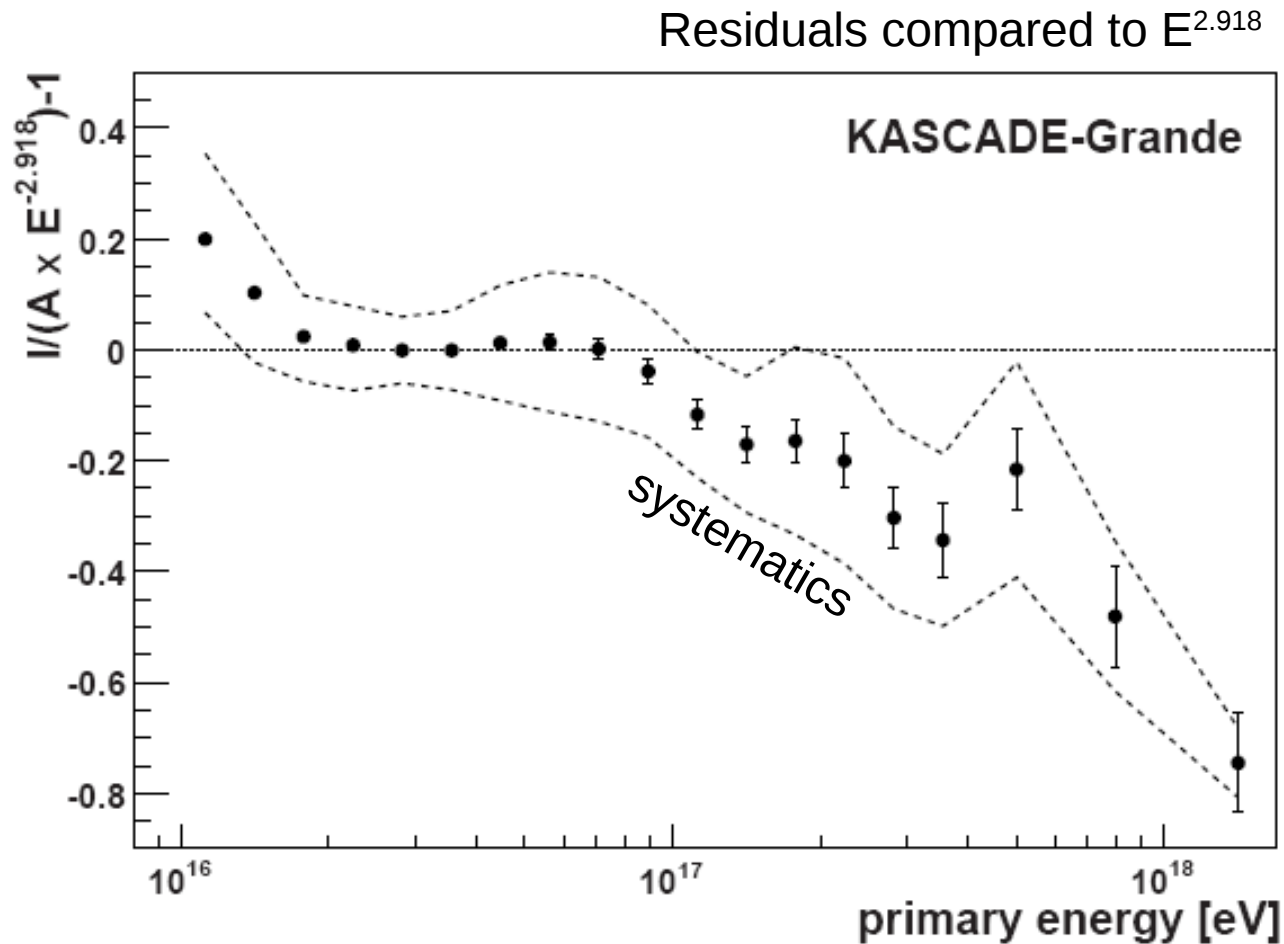


Indications for structures above the knee  
 $\Rightarrow$  few local accelerators?

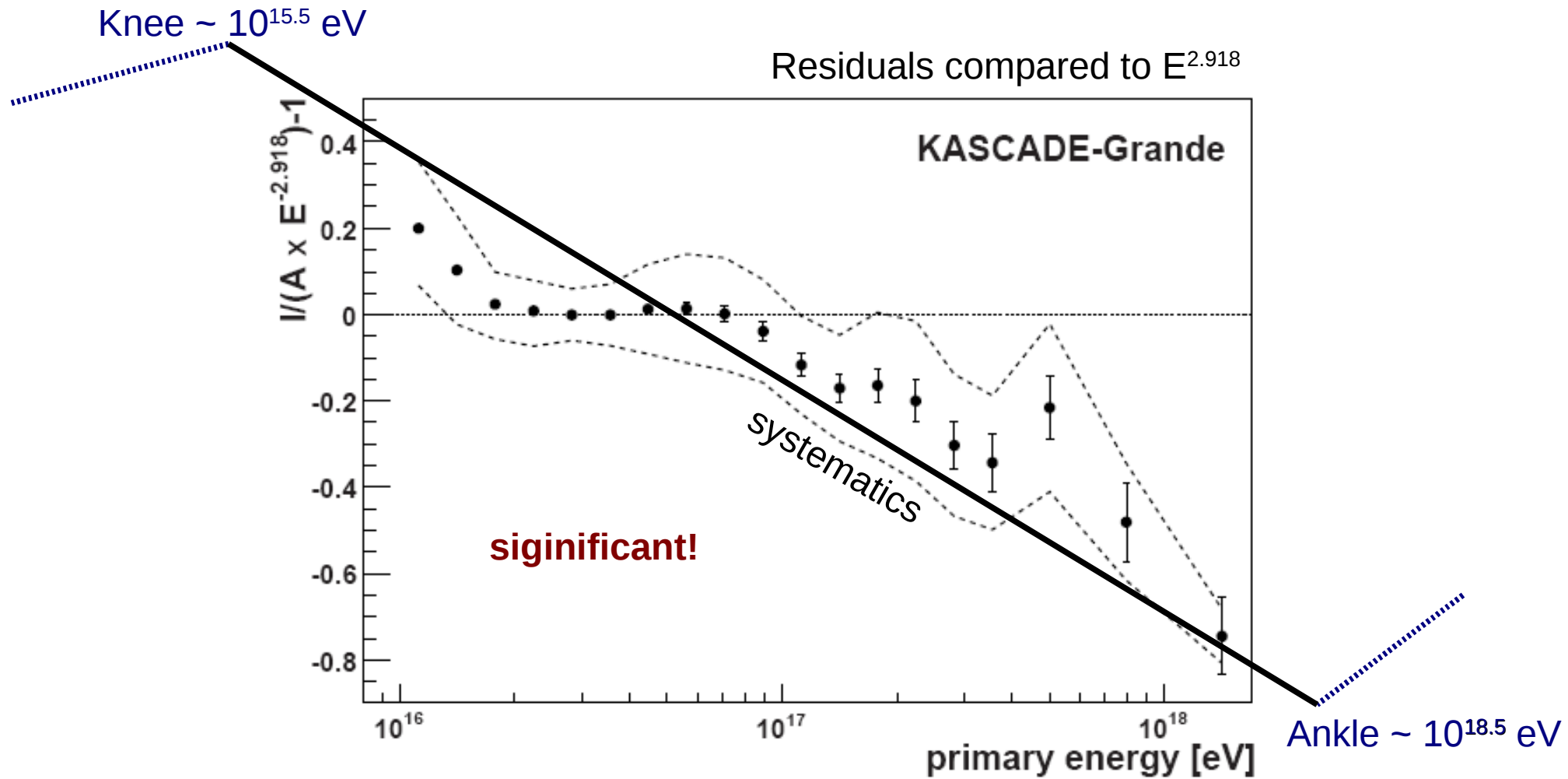


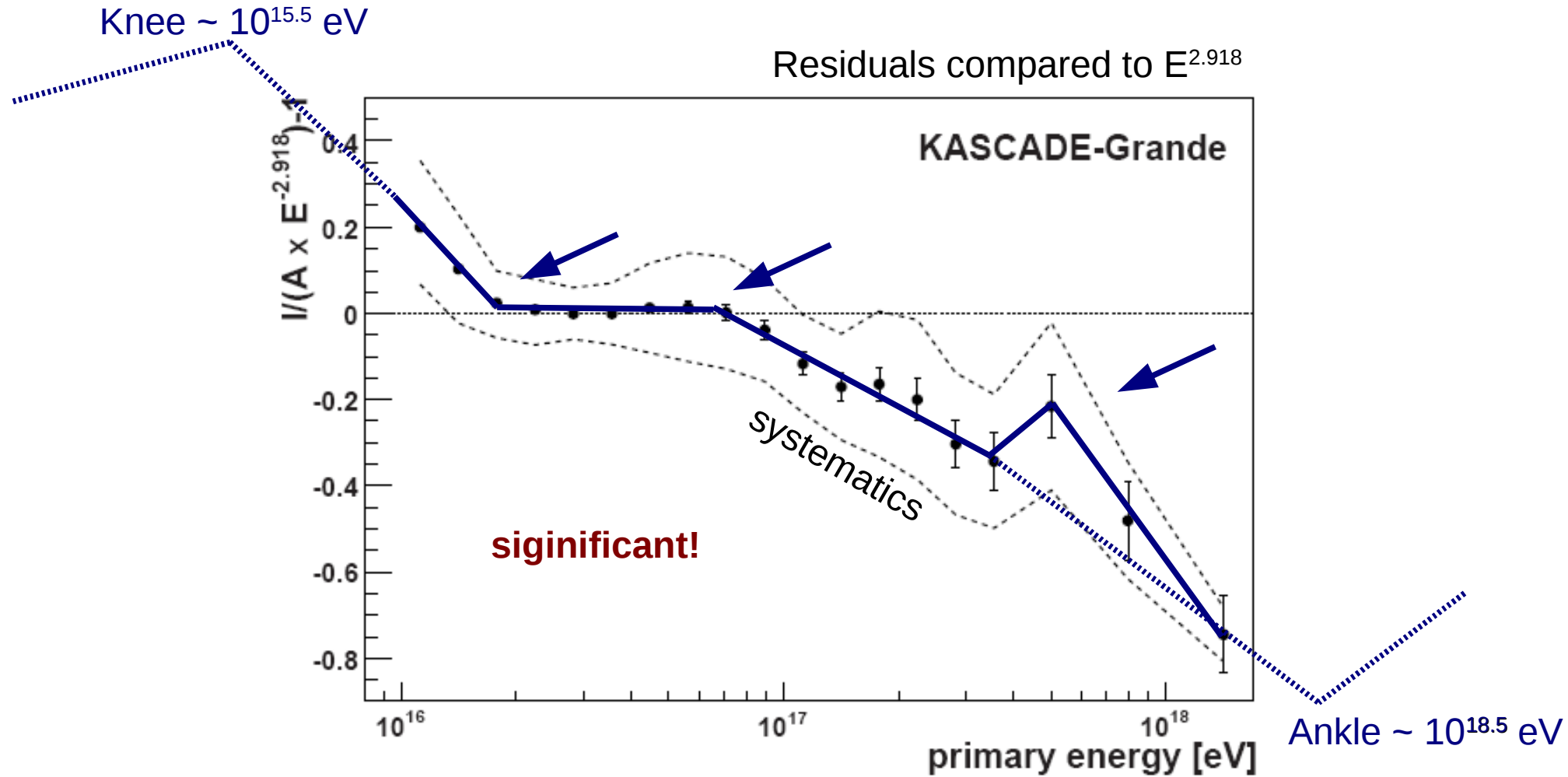
Indications for structures above the knee  
 $\Rightarrow$  few local accelerators?

Knee  $\sim 10^{15.5}$  eV

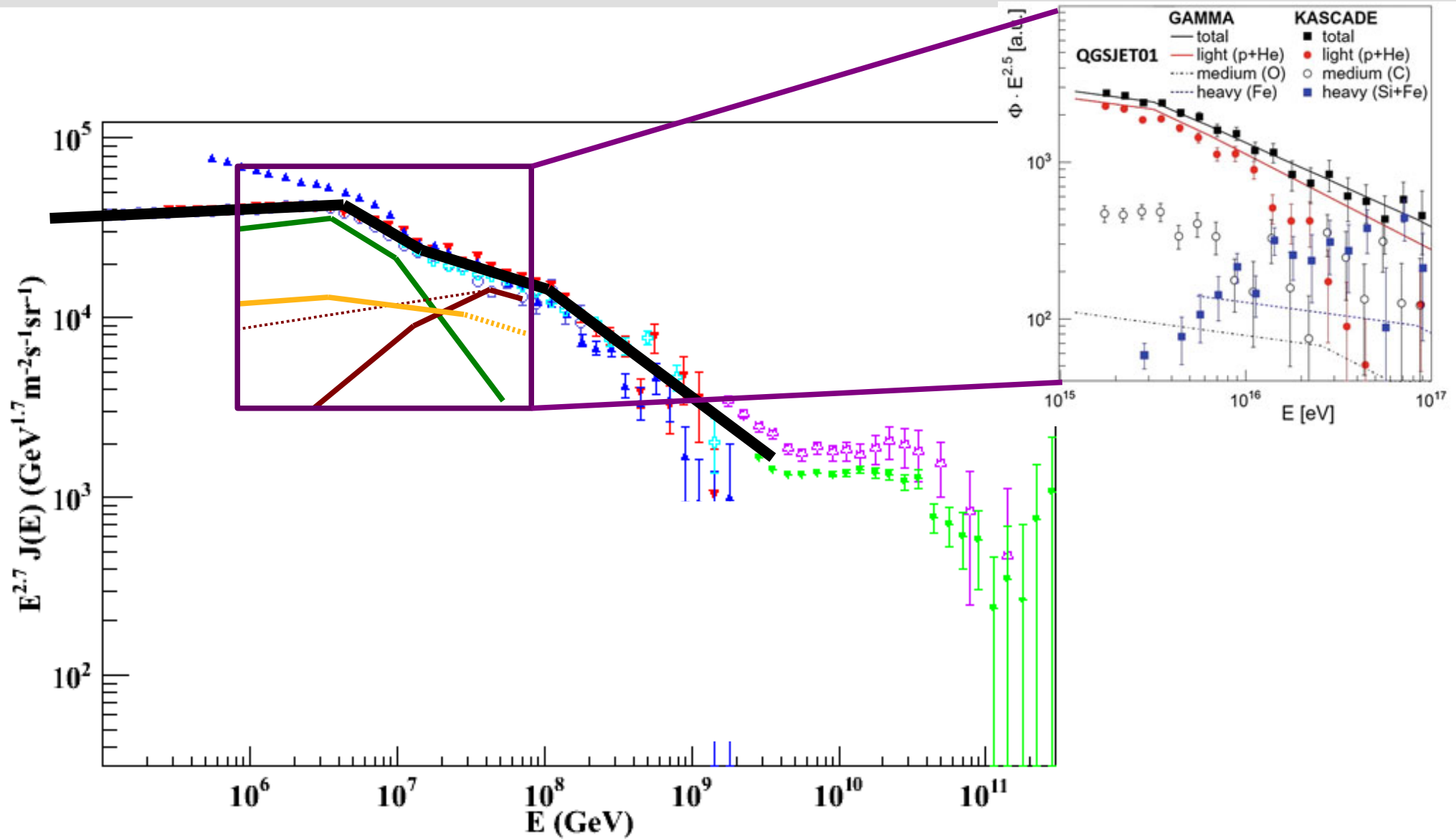


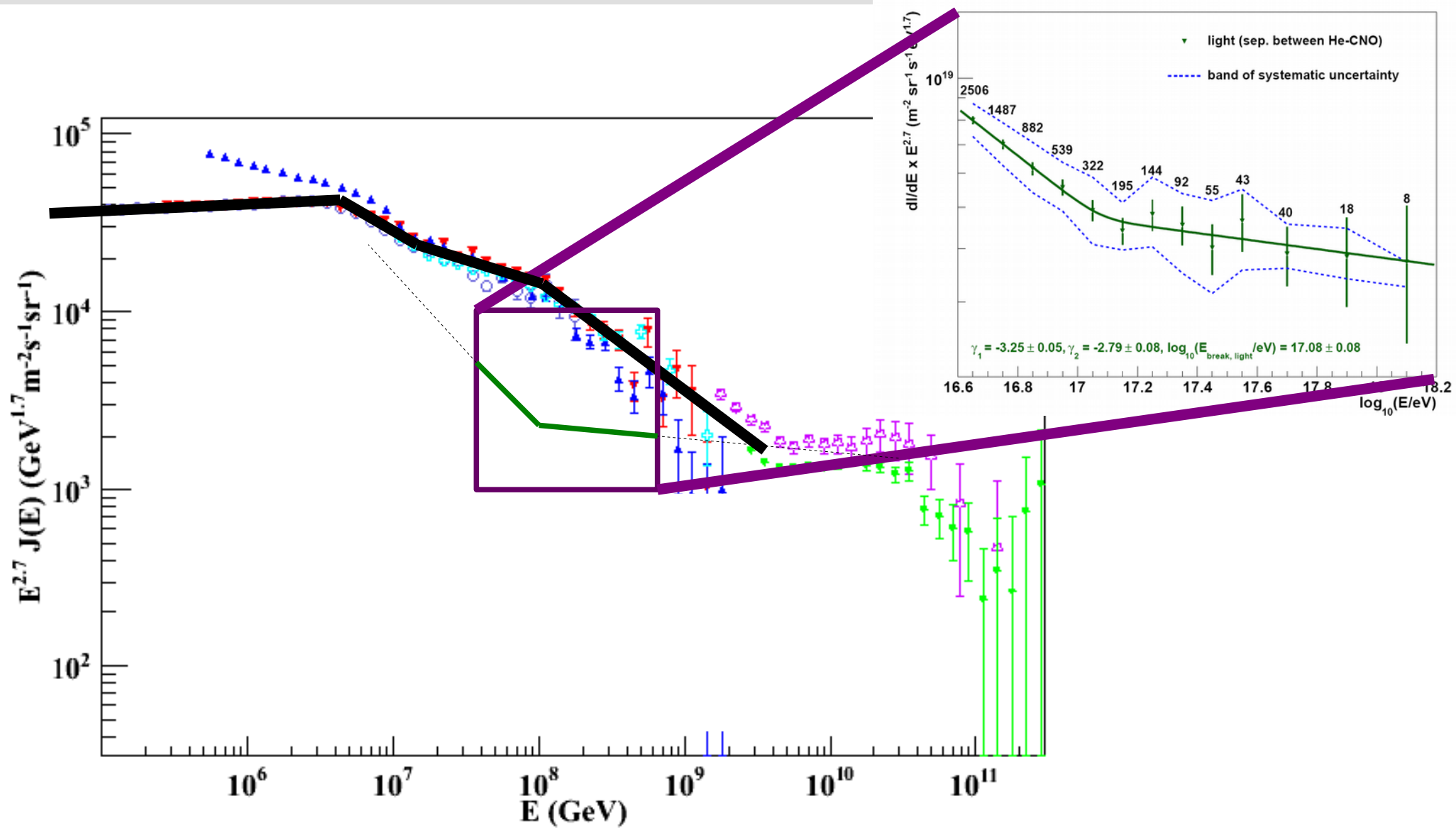
Ankle  $\sim 10^{18.5}$  eV



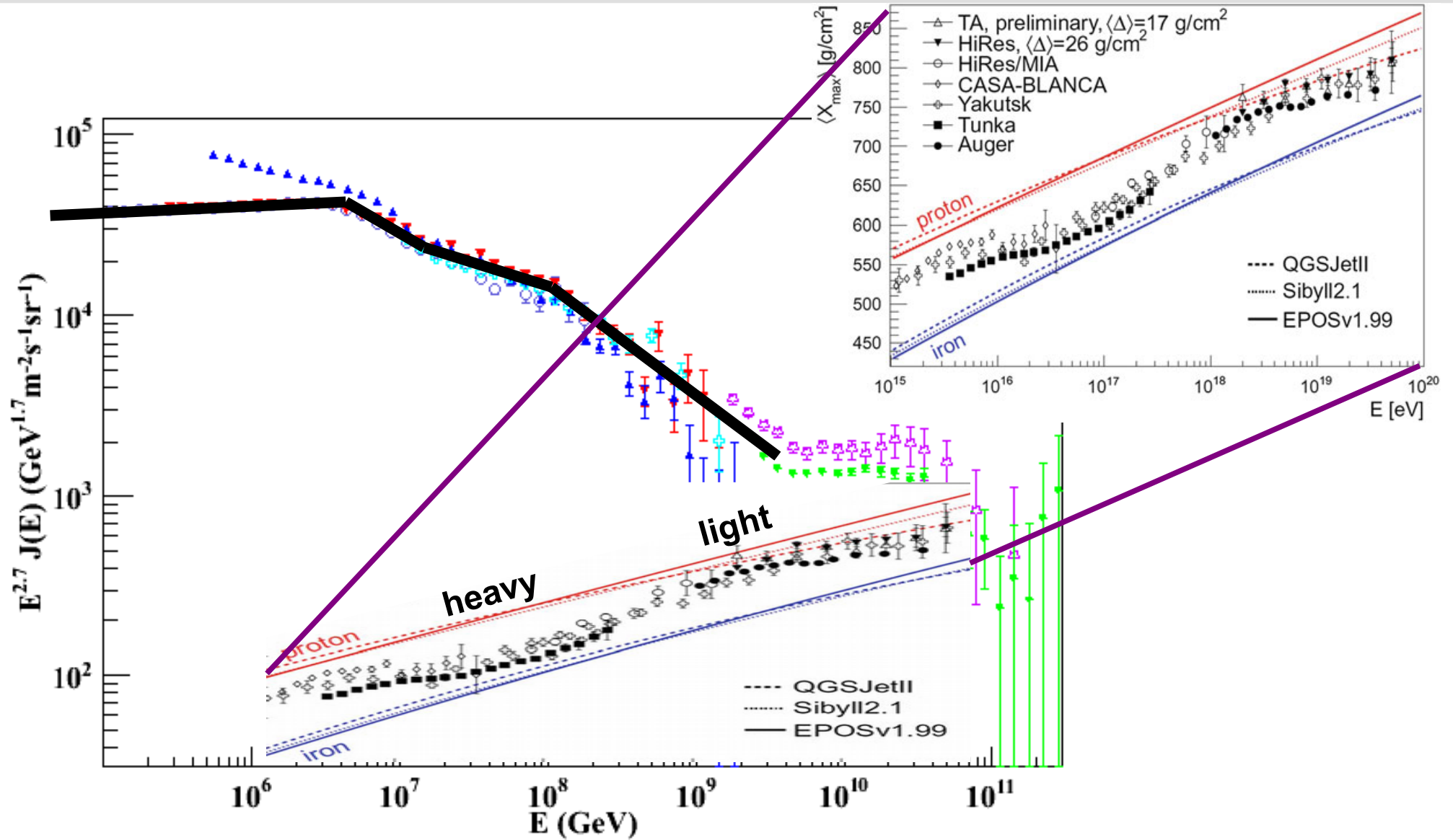


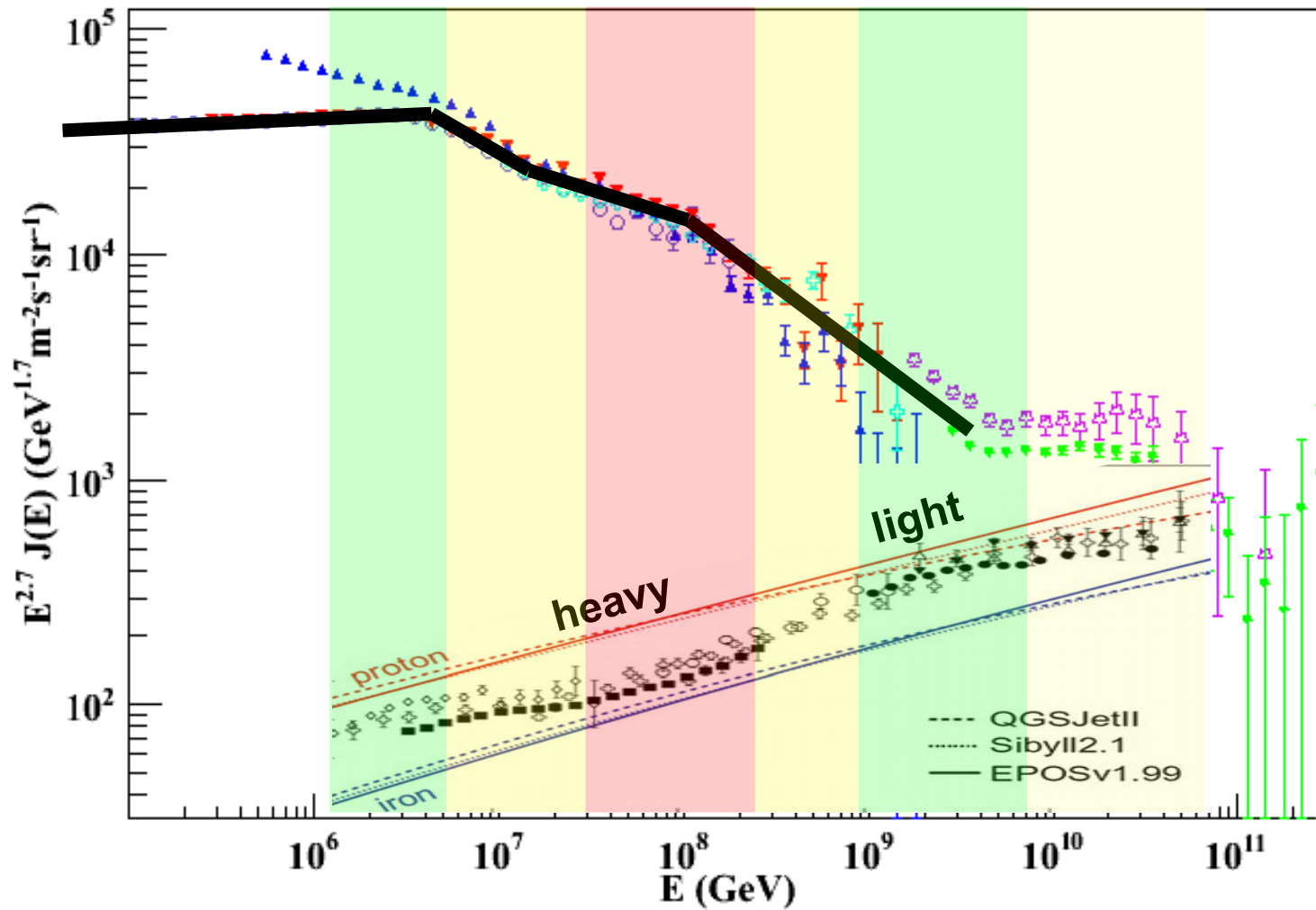


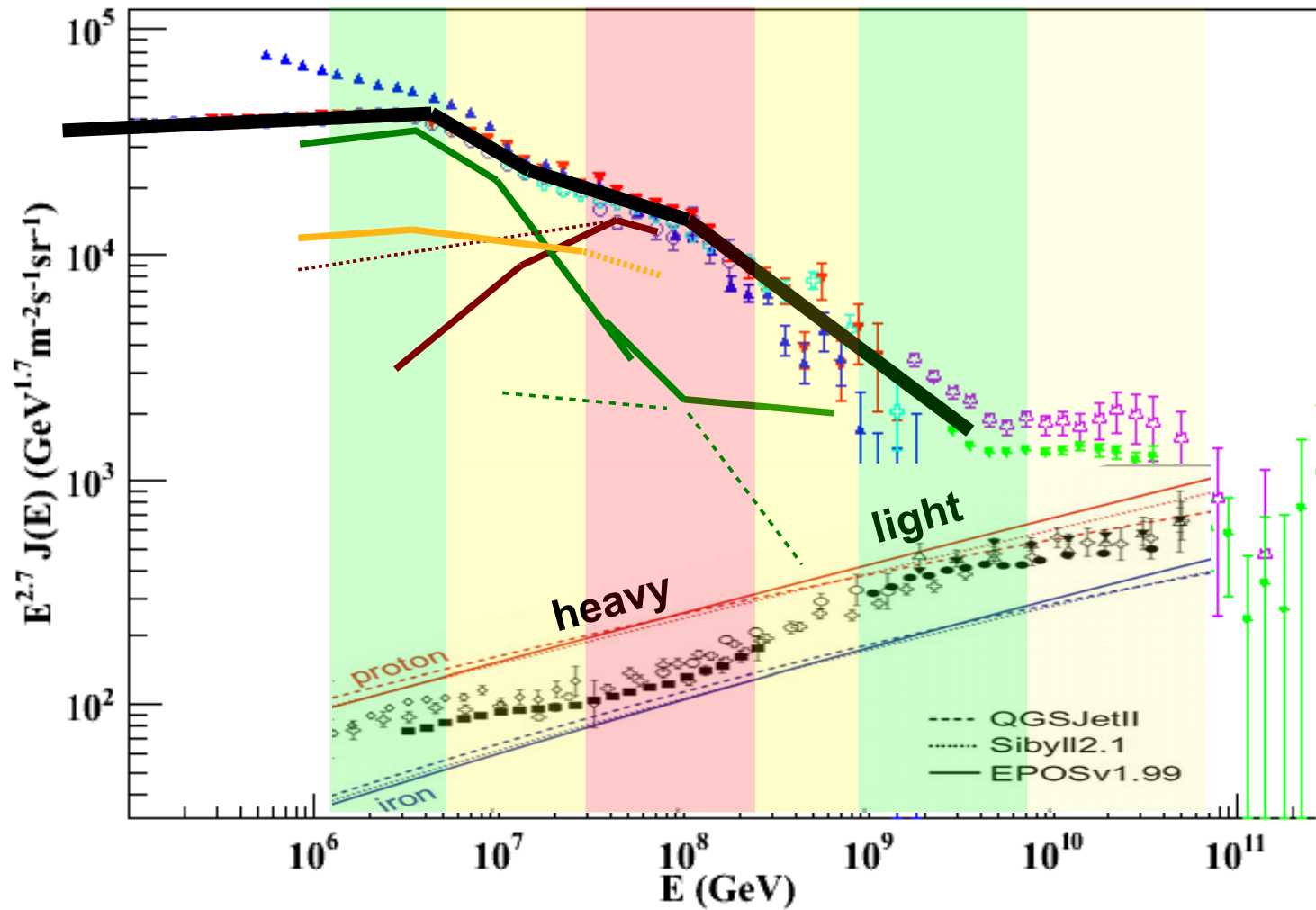




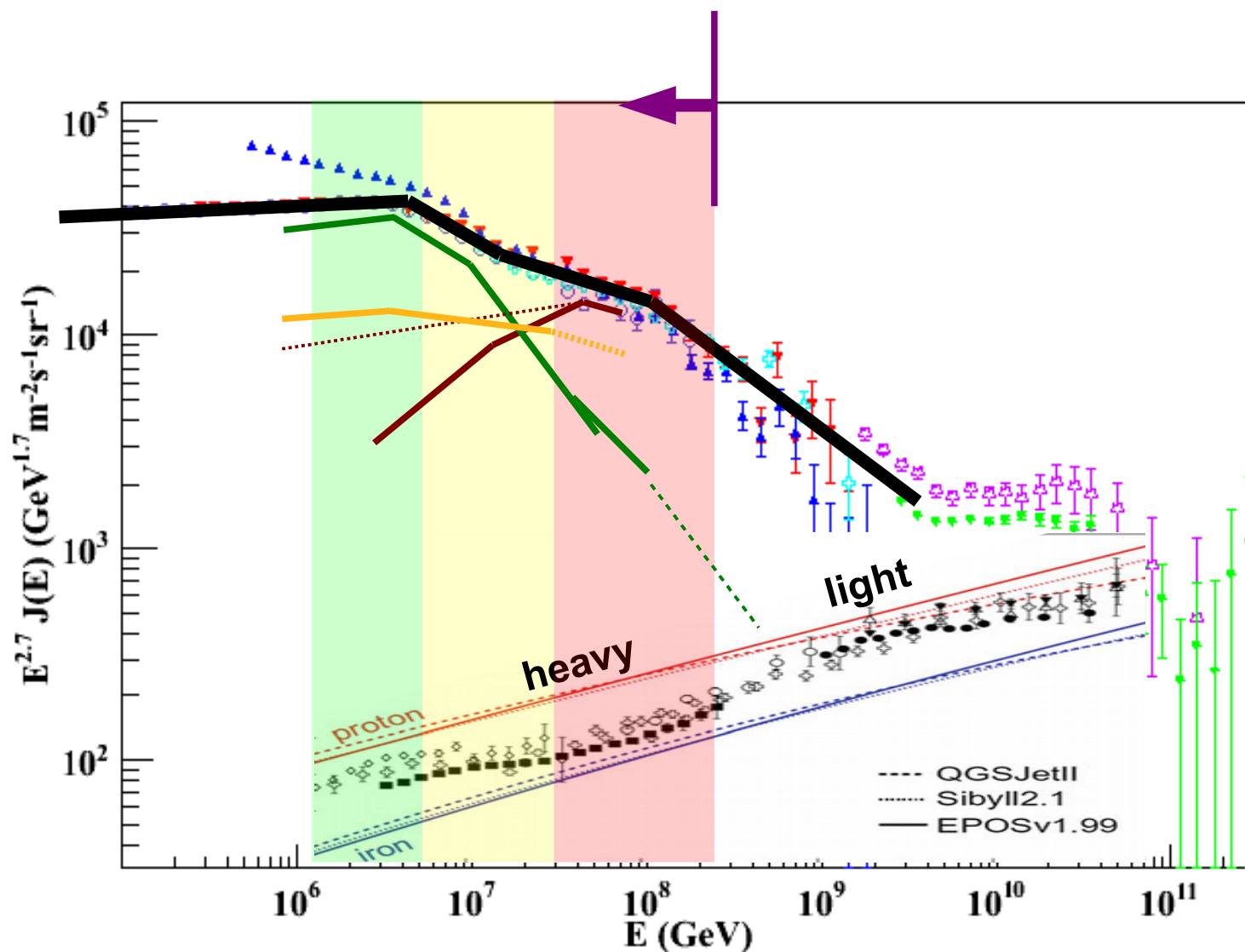
# UHECR (Pierre Auger)









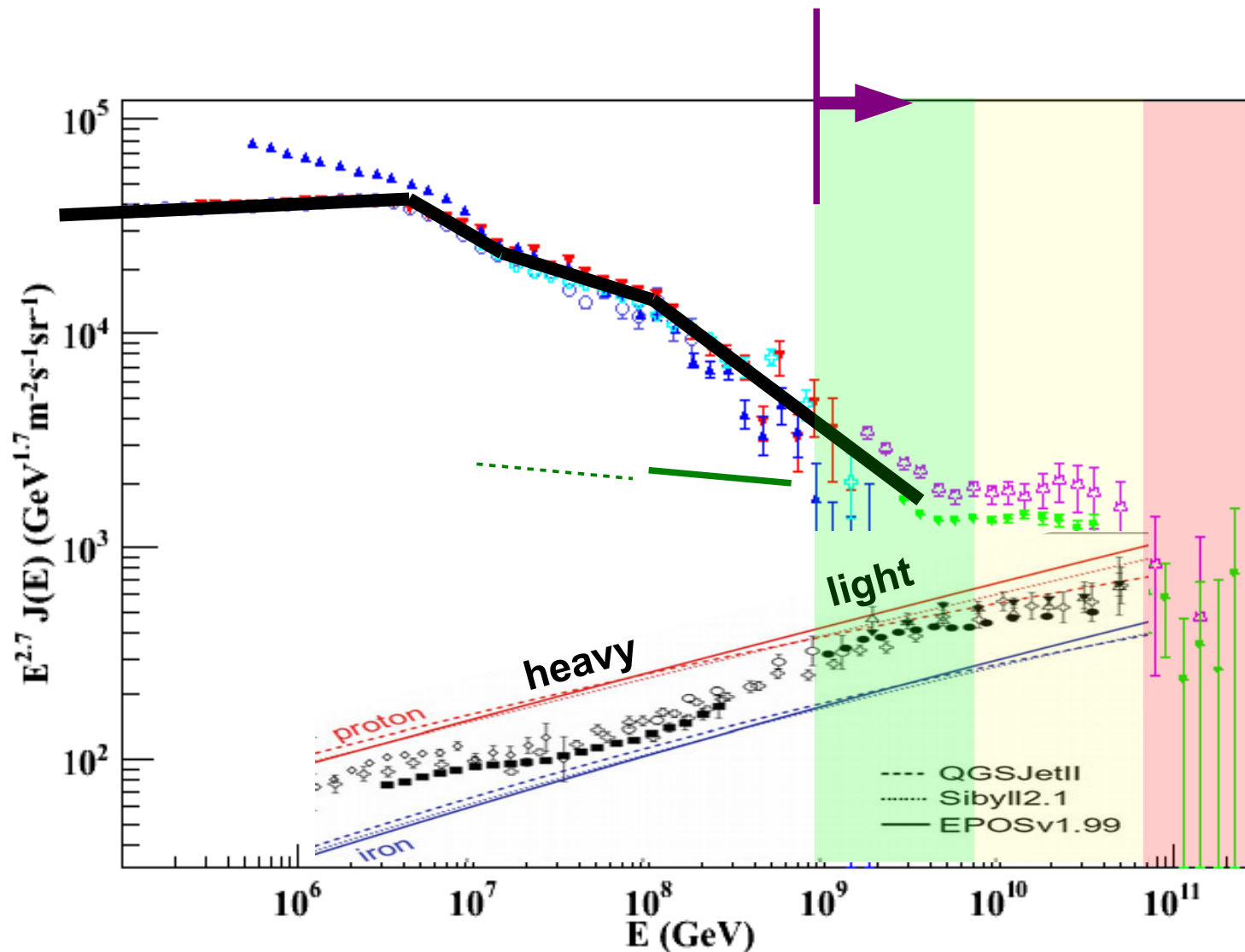


- Cut-off above the knee
- Galactic?
  - mainly due to reasonable agreement with expectations from SN
- life-time
- max. power
- number count
  - no direct evidence!

Not really the physics case for CREDO

- how low can CREDO go?

**BUT:** We have **not** yet identified **A SINGLE** Super Nova with the required acceleration properties!



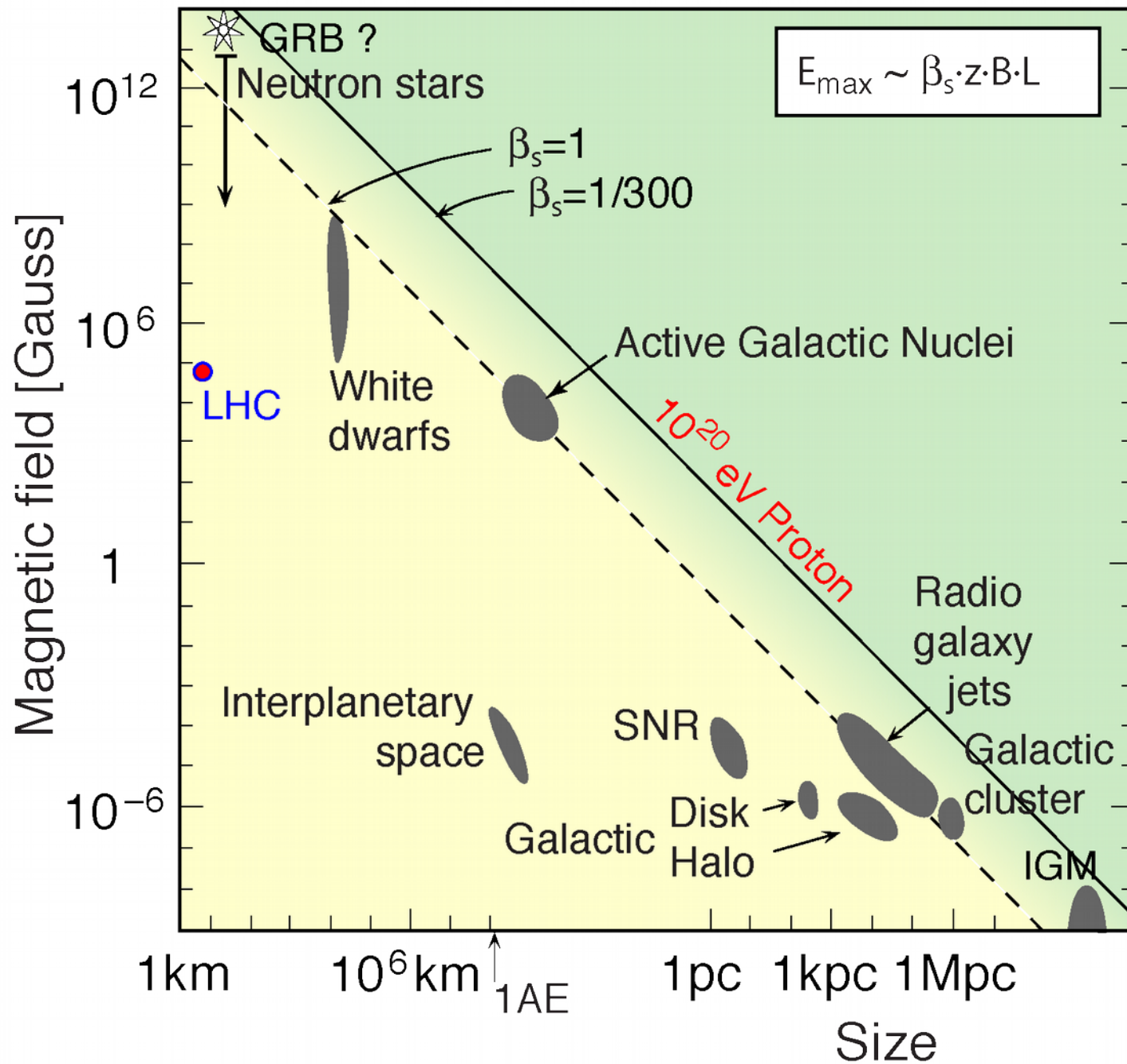
- Onset of a non-galactic component (extra-galactic!)

→ What are the sources?

**BUT:** We have **not** yet confirmed **A SINGLE** extra-galactic source as an emitter of charged CR!

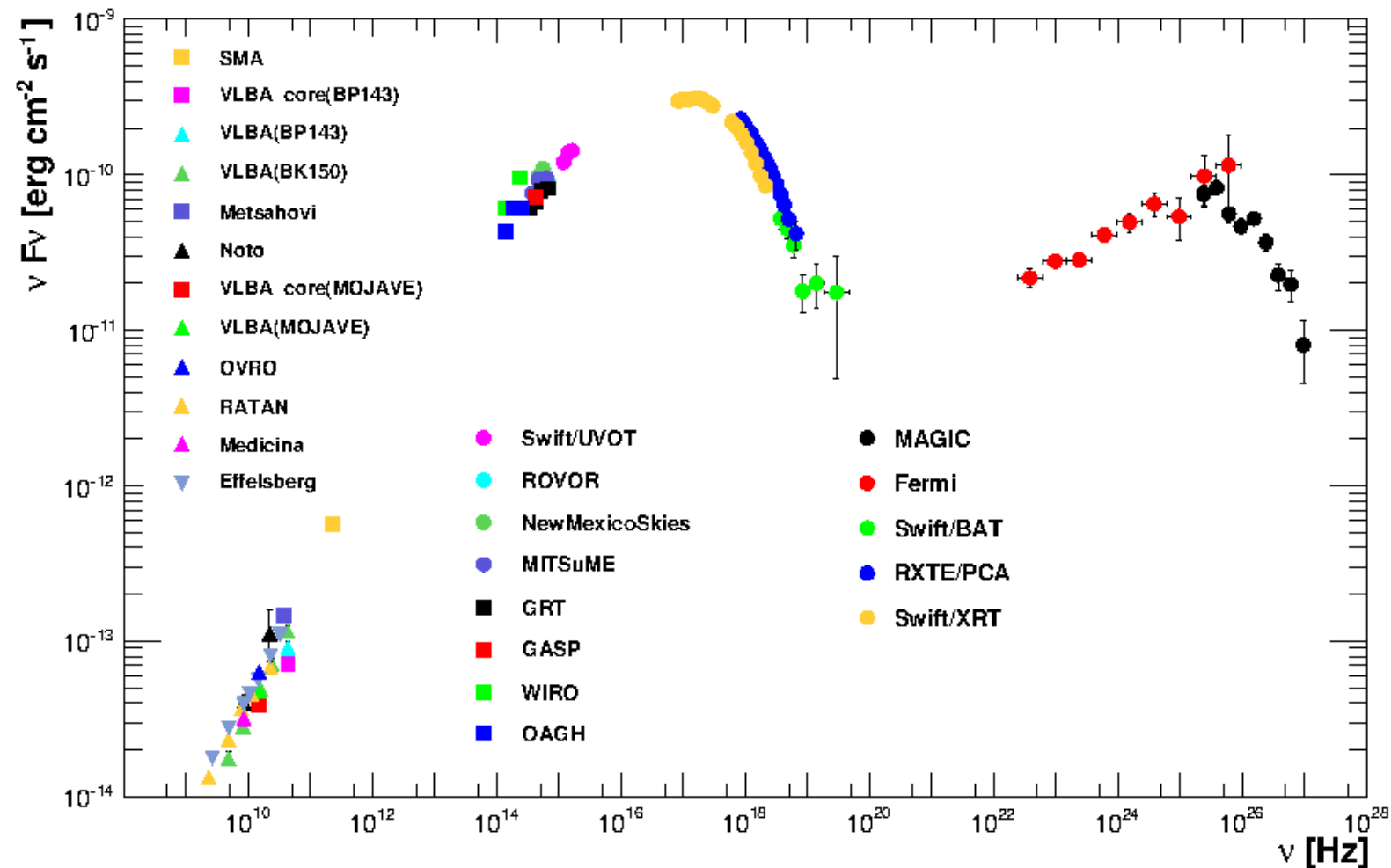
Maybe TXS 0506+056 ??

# What are the sources?



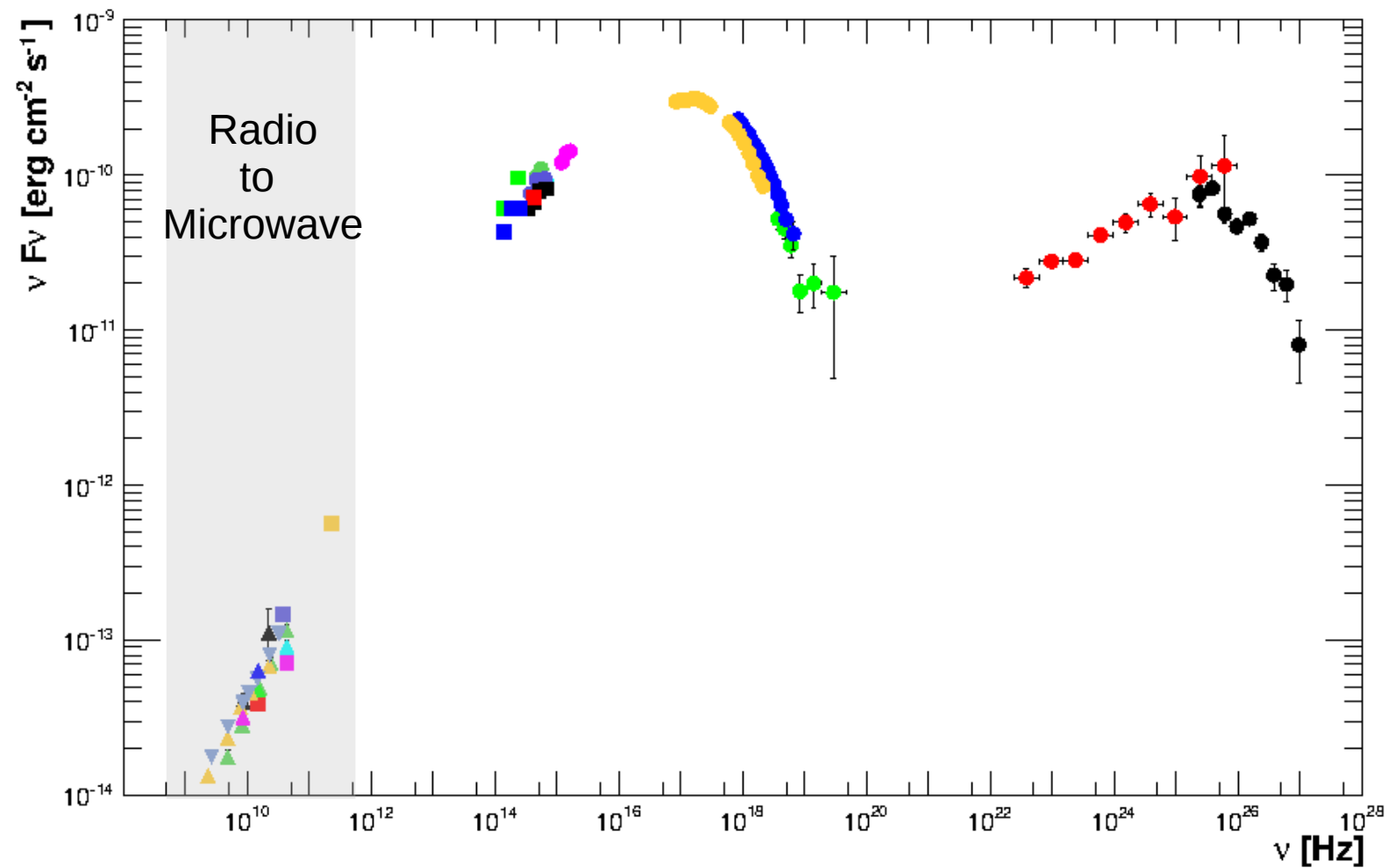
# Spectral Energy Distribution

## Mrk 421



# Spectral Energy Distribution

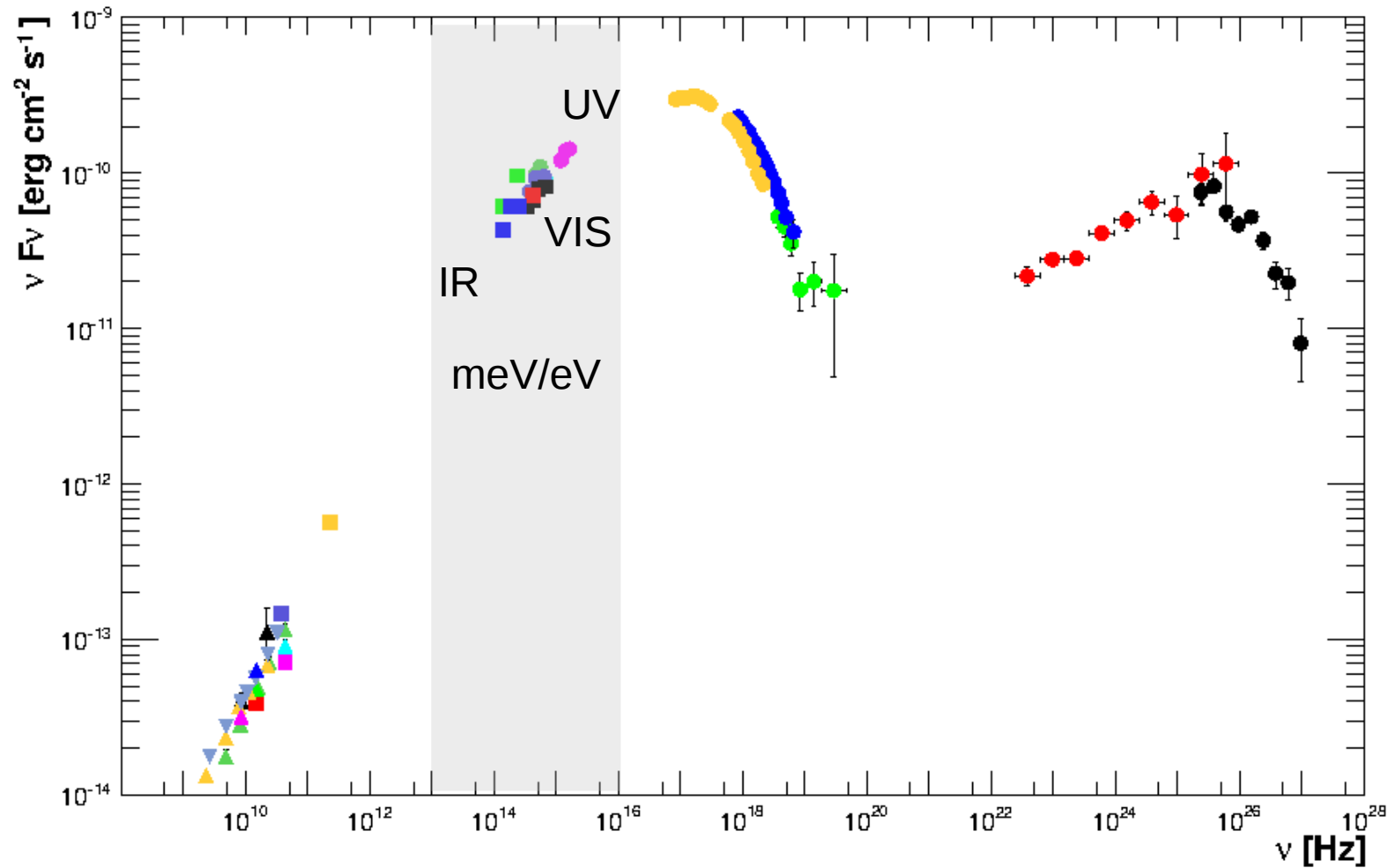
## Mrk 421





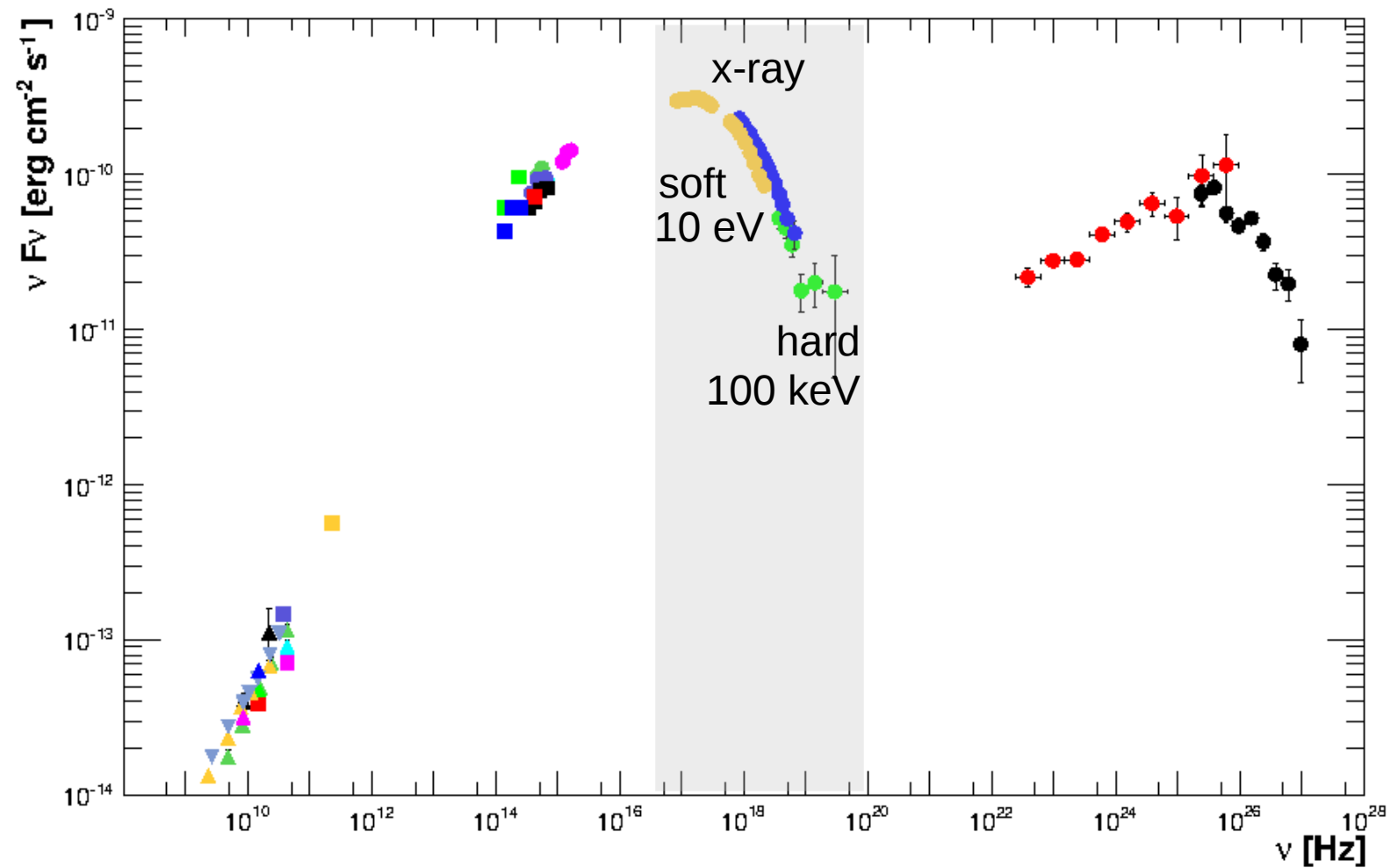
# Spectral Energy Distribution

## Mrk 421



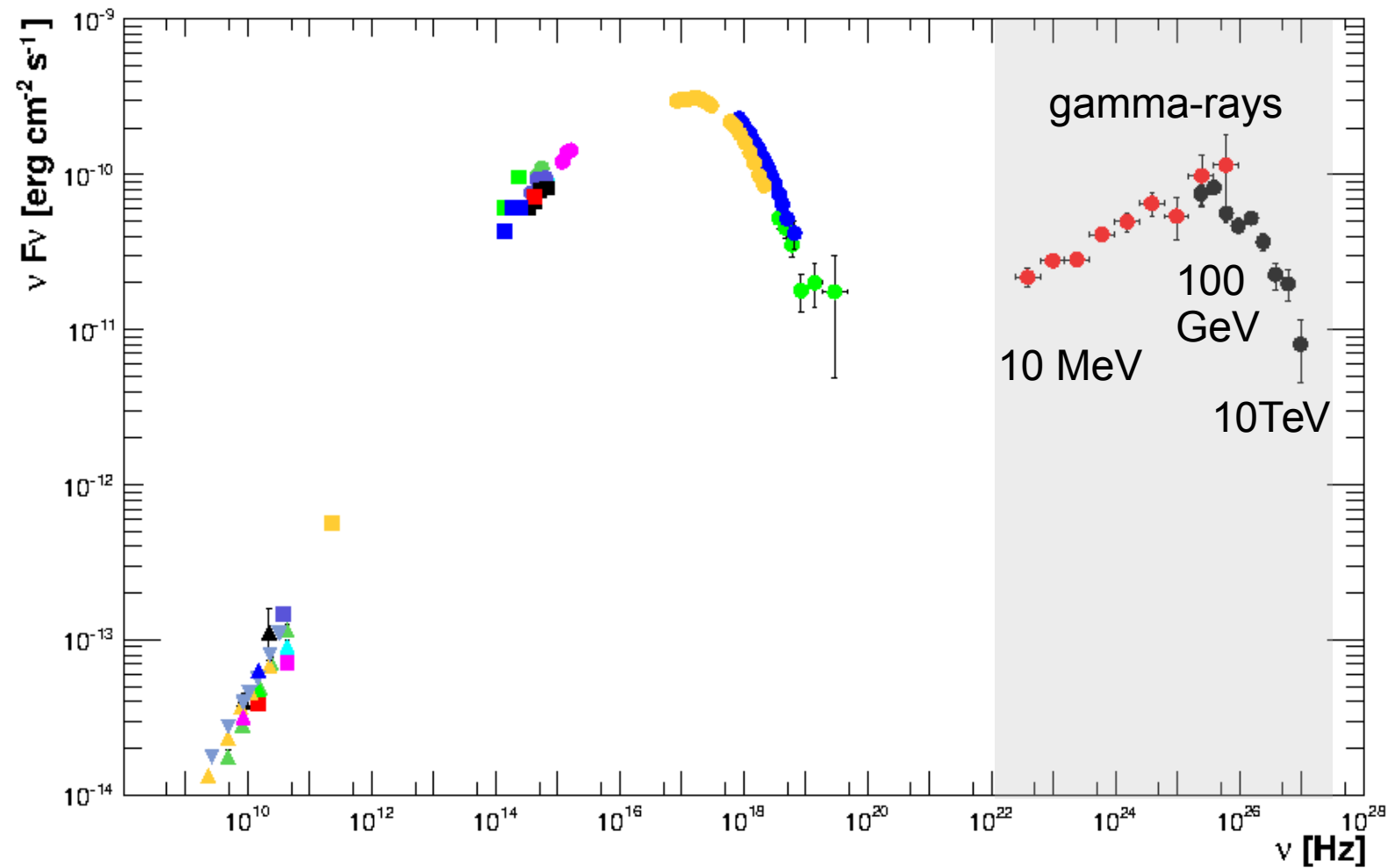
# Spectral Energy Distribution

## Mrk 421



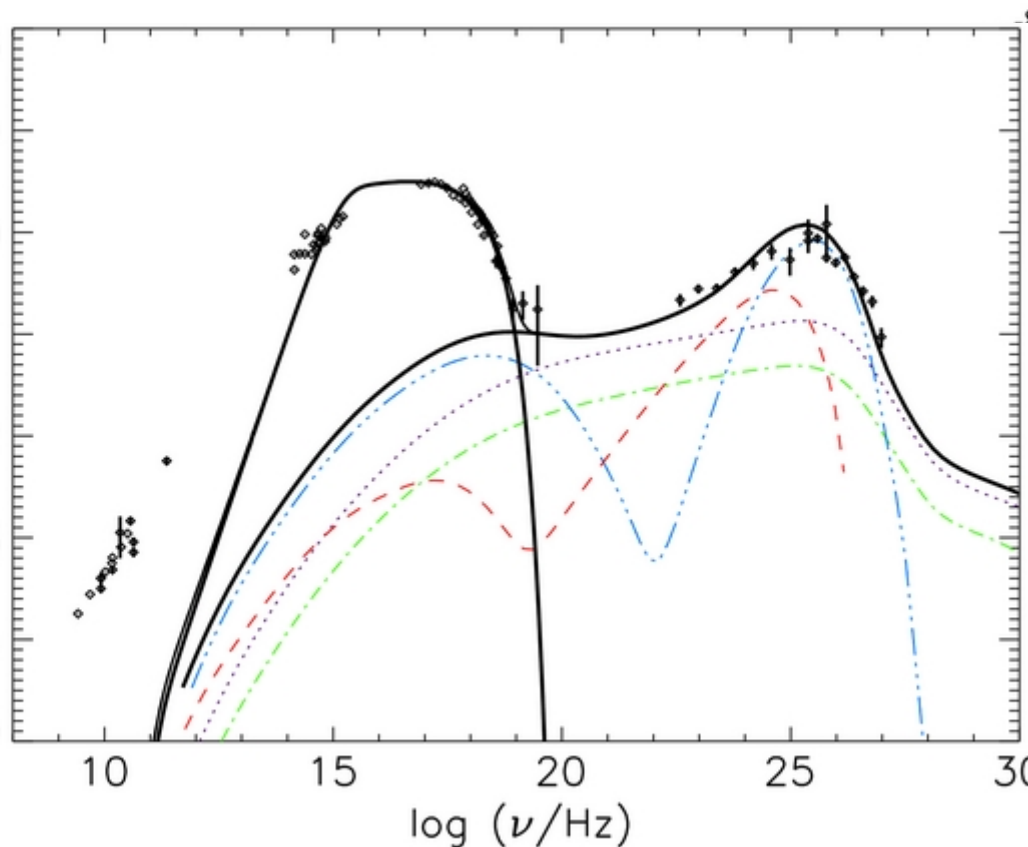
# Spectral Energy Distribution

## Mrk 421

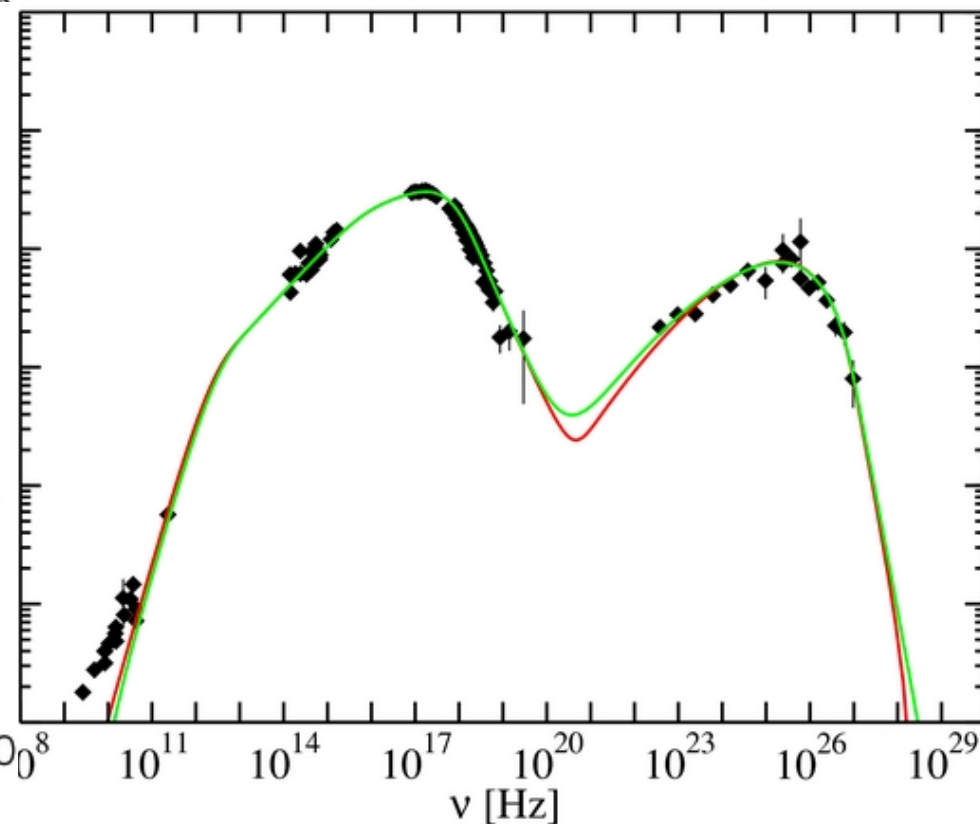


# 4.5 month quasi-synchronous

Hadronic acceleration



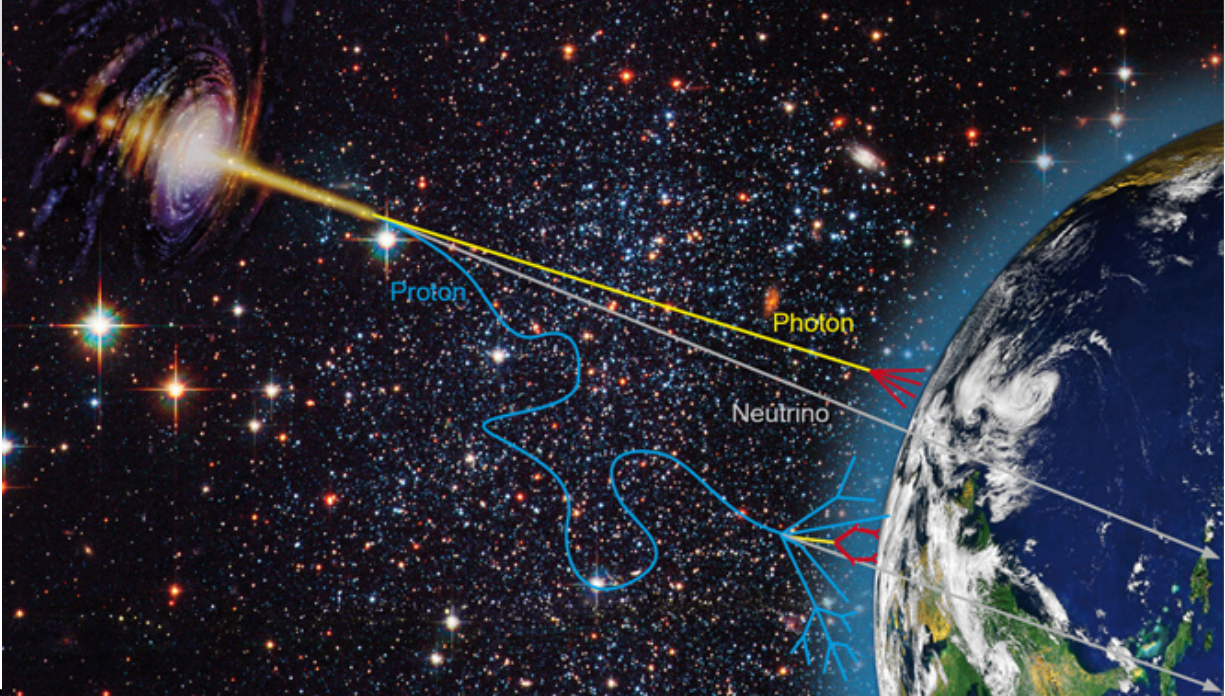
Synchrotron self-compton



Fits with typical  $>10$  free parameters

Magnetic field:	50 G	$\sim 50$ mG	taken from observations
Variability time scale:		$\sim 100$ h	
Comoving emission region:	30 AU	$\rightarrow 300$ AU	

# Multi-Messenger



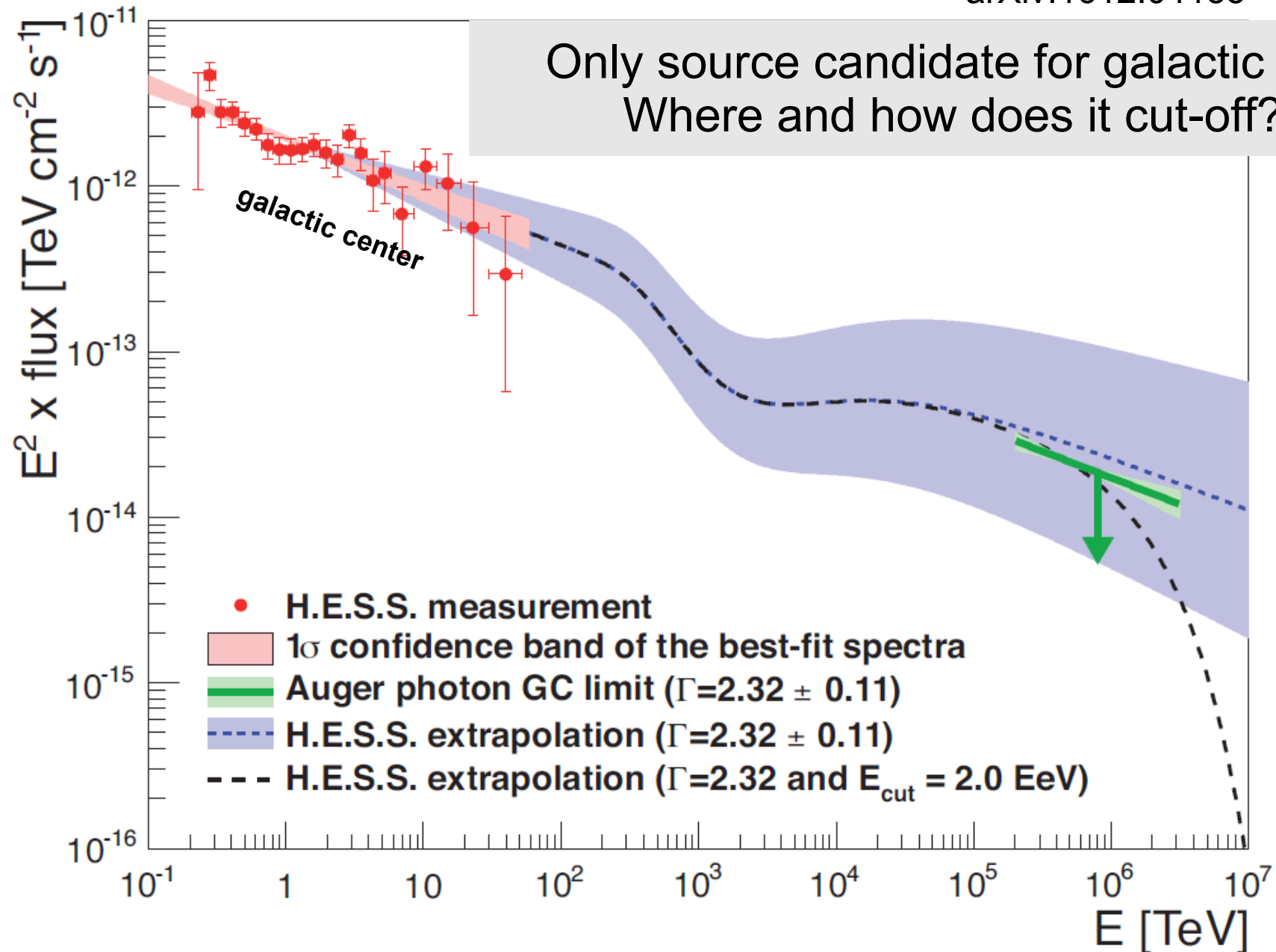
Doug Cowen, TAUP

Messenger	Sample size	Straight trajectory	Pointing resolution	Penetrating
$\gamma$			$\ll 1^\circ$	$E_\gamma < 50 \text{ TeV}$ ( $\gamma + \gamma_{\text{IR}} \rightarrow e^+e^-$ )
$\nu$	$\sigma_{\nu, \text{matter}} \ll 1$		$\sim 1^\circ$	
p, nuclei		<b>B</b> fields	$\sim 1^\circ$	$E_p < 30 \text{ EeV}$ (GZK cutoff)
Grav. waves			$\sim 1000 (^\circ)^2$ (only 2 detectors)	

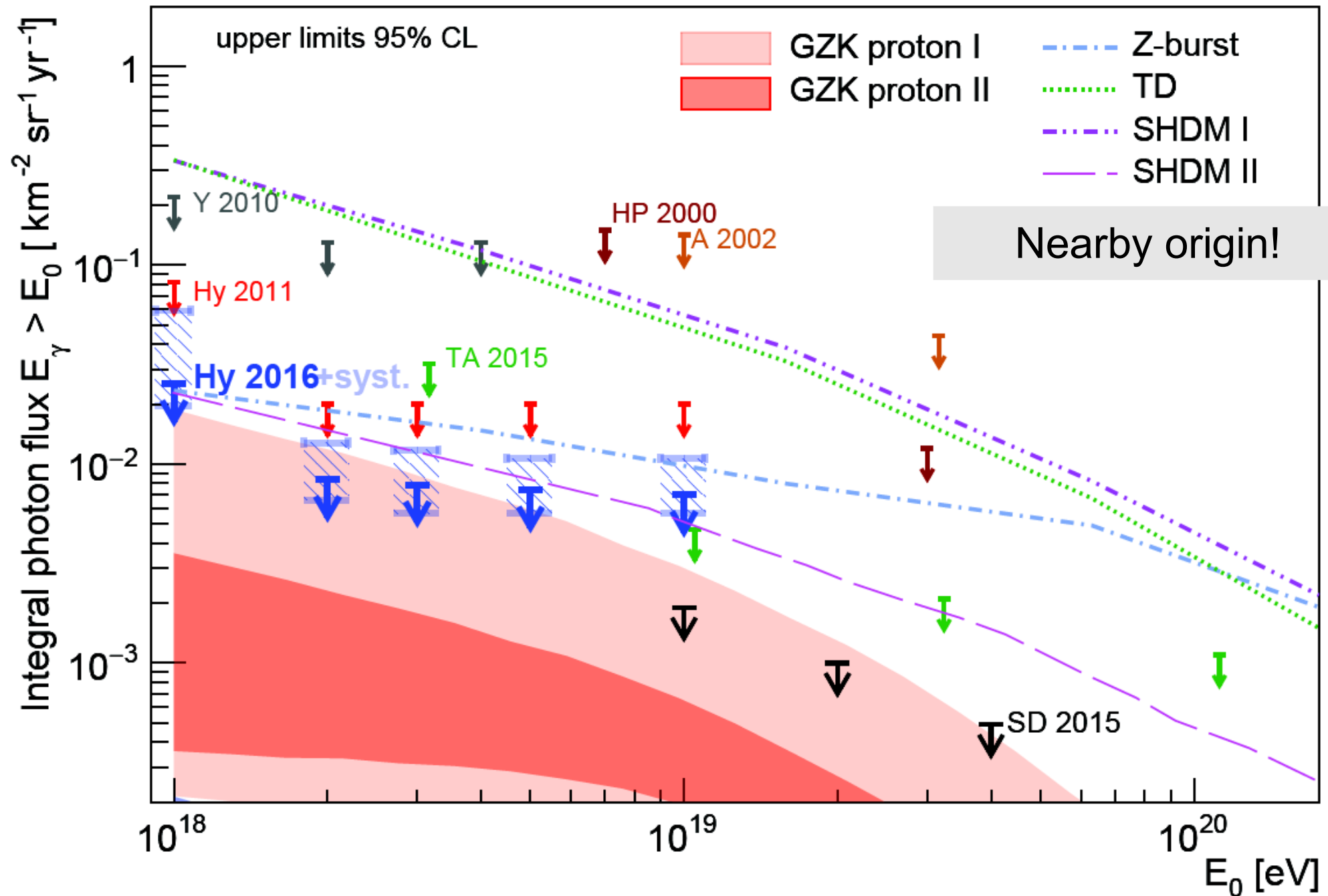
- Maybe they are not visible?
- Maybe they don't emit neutrinos?
- Mostly deflected, too low statistics.
- Only from exception source states.

# Point source limit on UHE photons

arXiv:1612.04155

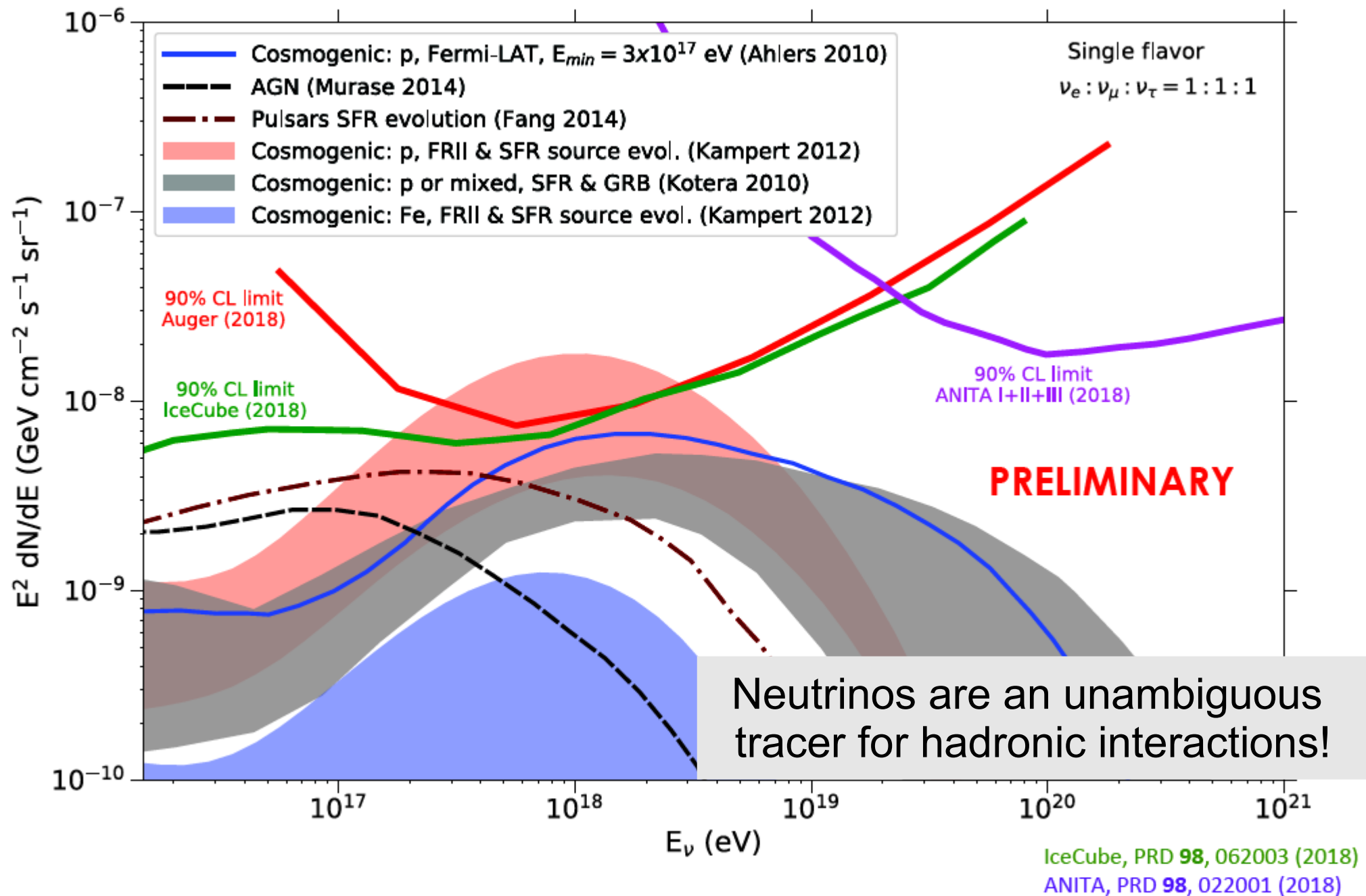


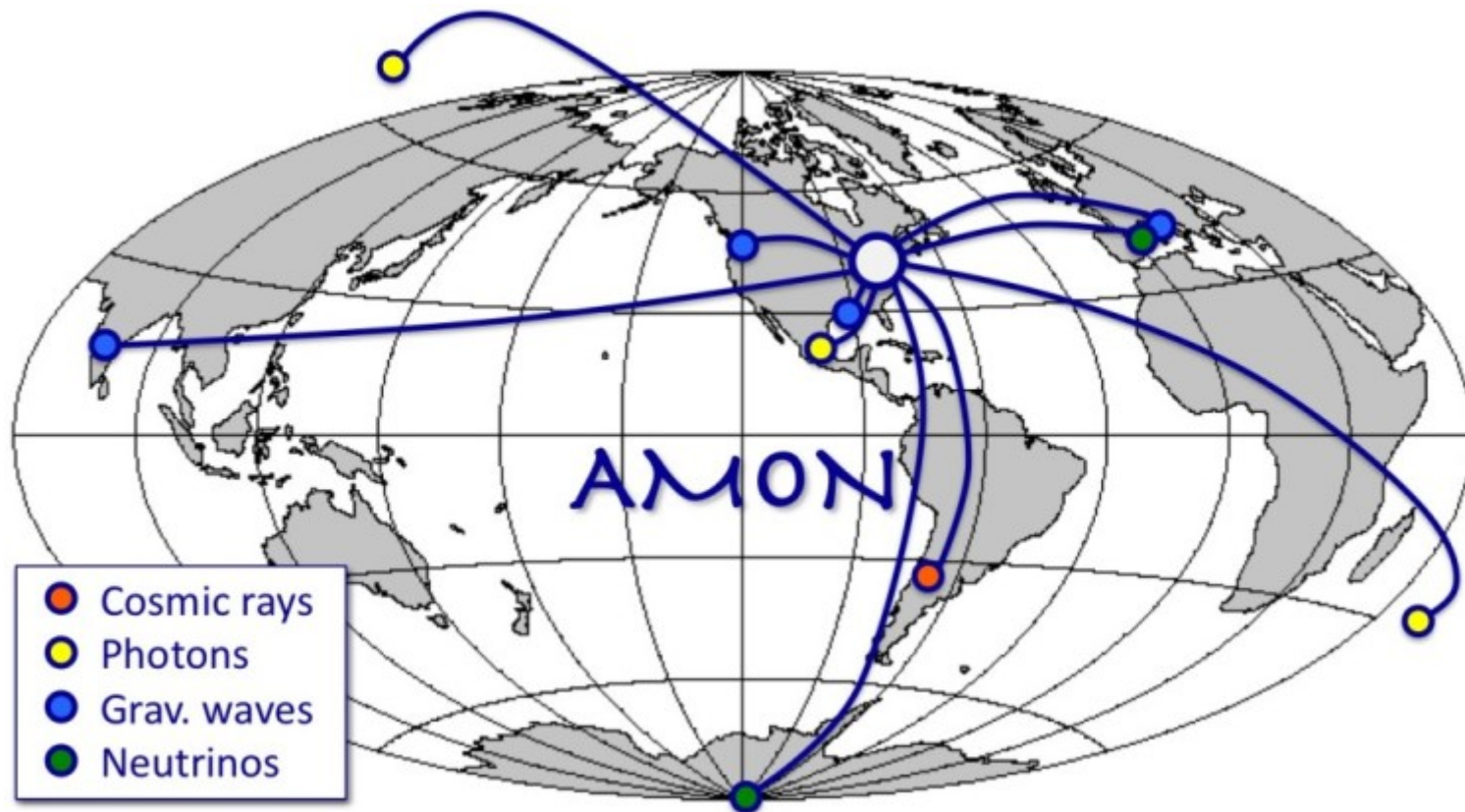
# Diffuse UHE photon limits



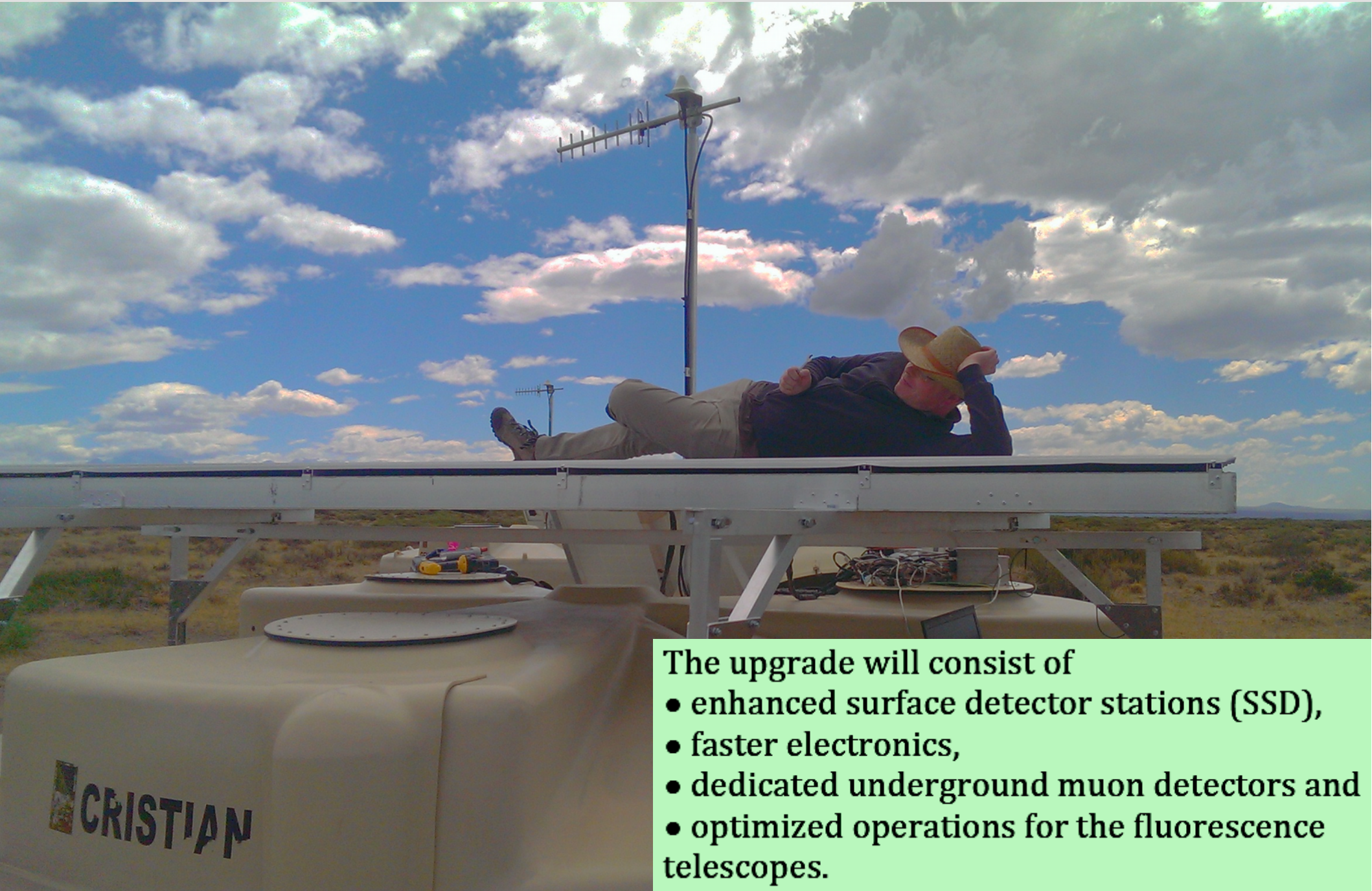


# Diff. limits on diffuse UHE neutrinos









The upgrade will consist of

- enhanced surface detector stations (SSD),
- faster electronics,
- dedicated underground muon detectors and
- optimized operations for the fluorescence telescopes.

## Members and Prospective Members

OBSERVATORY/ CONTACT	LETTER OF COLLABORATION	MOU SIGNED
<b>ANTARES</b> Juergen Brunner	Yes	Yes [MoU]
<b>FACT</b> Adrian Biland		Yes [MoU]
<b>Fermi</b> Julie McEnery	Yes	
<b>HAWC</b> Ignacio Taboada	Yes	Yes [MoU]
<b>IceCube</b> Doug Cowen	Yes	Yes [MoU]
<b>Large Millimeter Telescope</b> Alberto Carraminana	Yes	Yes
<b>LCOGT</b> Todd Boroson		Yes [MoU]
<b>LIGO</b> Gabriela Gonzalez	Yes	
<b>MASTER</b> Vladimir Lipunov		Yes [MoU]
<b>Palomar Transient Factory</b> Tom Prince	Yes	
<b>Pierre Auger</b> Miguel Mostafa	Yes	Yes [MoU]
<b>Swift</b> Scott Barthelmy	Yes	Yes [MoU]
<b>VERITAS</b> Abe Falcone	Yes	Yes
<b>MAGIC</b> Konstancja Satalecka		Yes [MoU]

# AMON

# RWTH AACHEN UNIVERSITY

Neutrino

TeV Gamma

GeV Gamma

TeV Gamma

Neutrino

Radio

Optical

GW

Optical

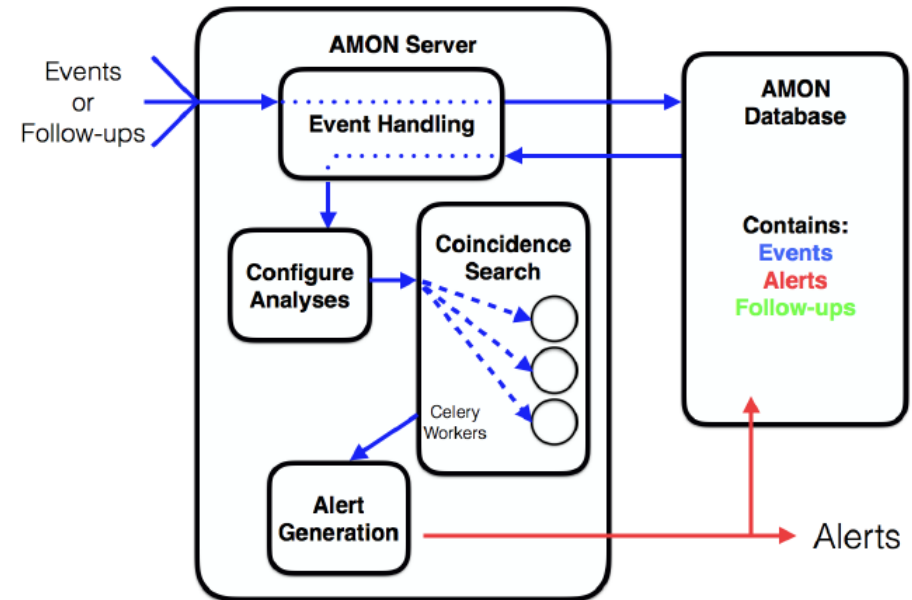
Optical

UHECR

X-ray UV/opt.

TeV Gamma

TeV Gamma



# Why is the relevant for CREDO?

- Assume that you measure an increase in detection rate, but you do not see any event or coincidence...
- Assume you are connected to AMON (or anything similar) or have any kind of multi-messenger sensitivity
  - You might be able to find something in the sub-threshold data in coincidence e.g. with IceCube or gamma-telescopes



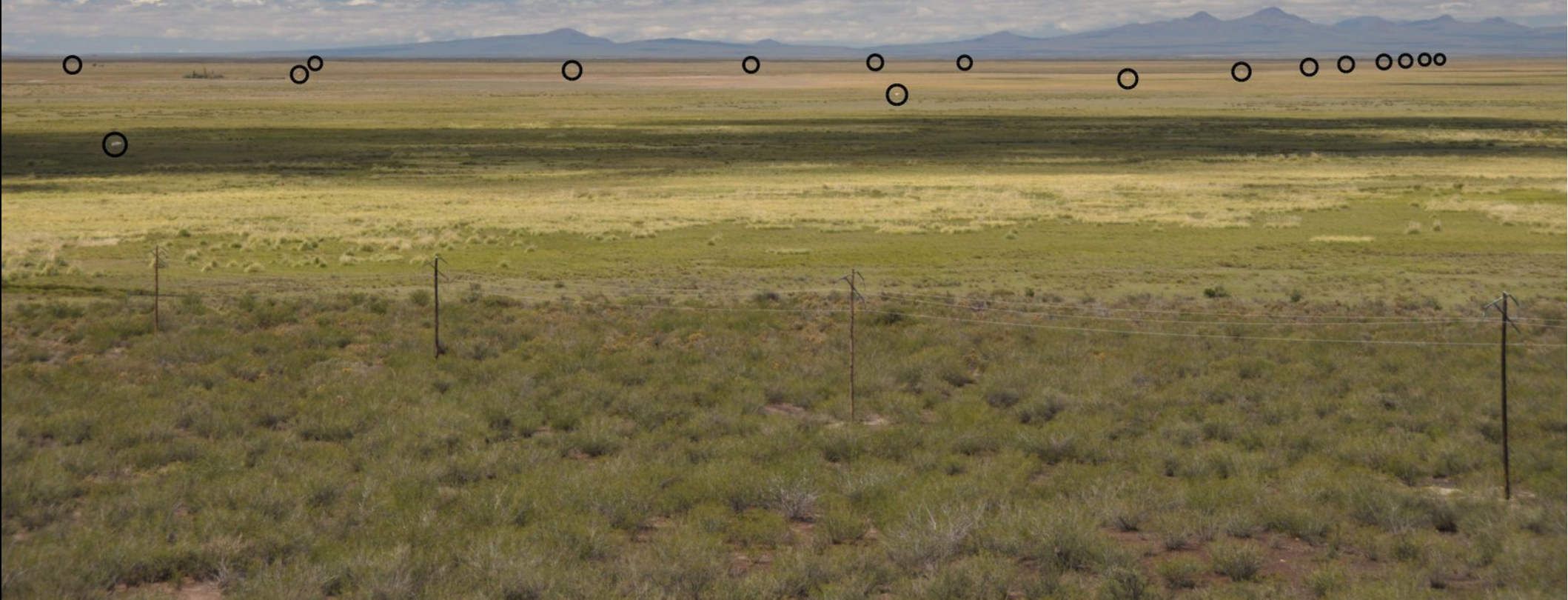
# Pampa Amarilla, Argentina

?





# Pampa Amarilla, Argentina





# PAO vs. CREDO vs. AMON

- You can think of CREDO as an extended Pierre Auger with a dynamic layout and a wide distribution of stations
- You can also think of CREDO as thousands of experiments participating in AMON
  - Can AMON (or similar) create sub-threshold sensitivity with CREDO?