

Space Observatories for the Highest Energy Cosmic Particles

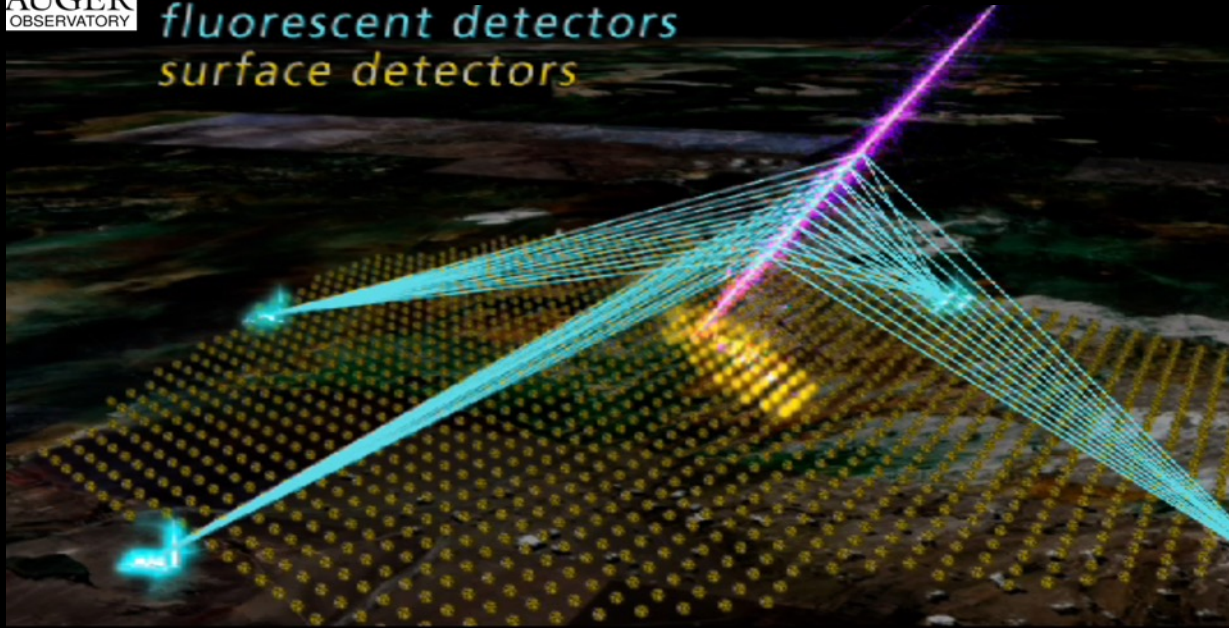
Cosmic Rays and Neutrinos

POEMMA & EUSO-SPB



PIERRE
AUGER
OBSERVATORY

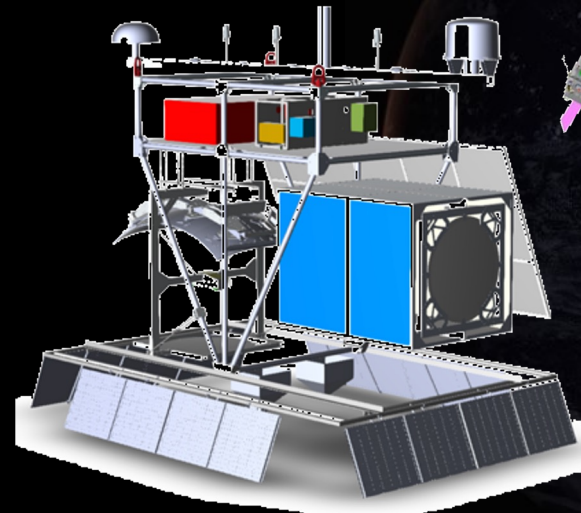
fluorescent detectors
surface detectors



EUSO-SPB₁



EUSO-SPB₂



POEMMA



INPE,

September 19, 2023

Angela V. Olinto



THE UNIVERSITY OF
CHICAGO

The Multi-Wavelength Sun

radio waves

microwave

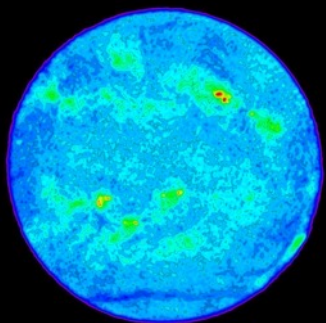
infrared

visible light

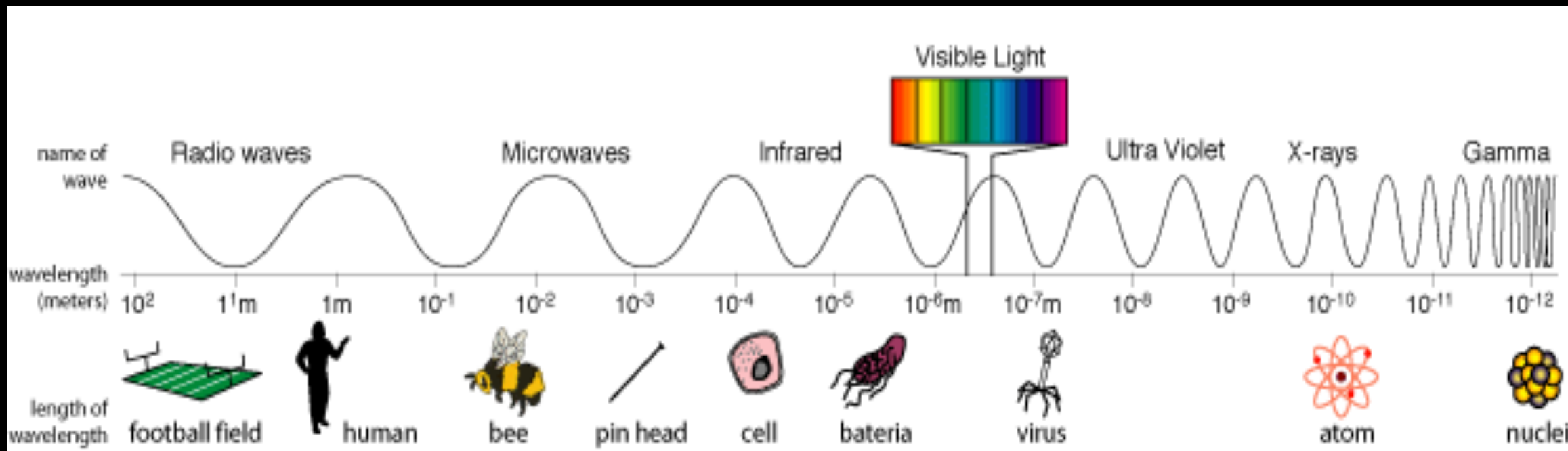
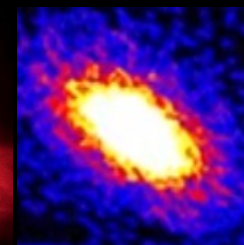
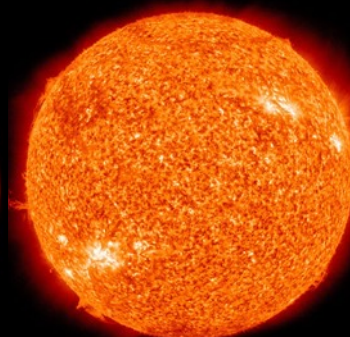
ultraviolet

x-rays

gamma rays



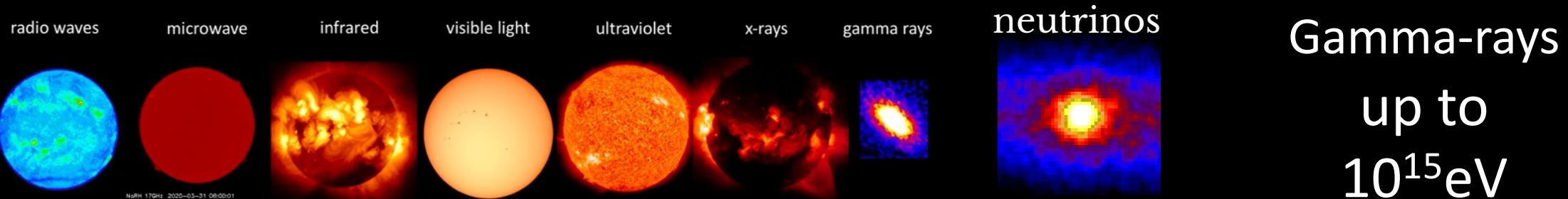
NoRH 17GHz 2020-03-31 06:00:01



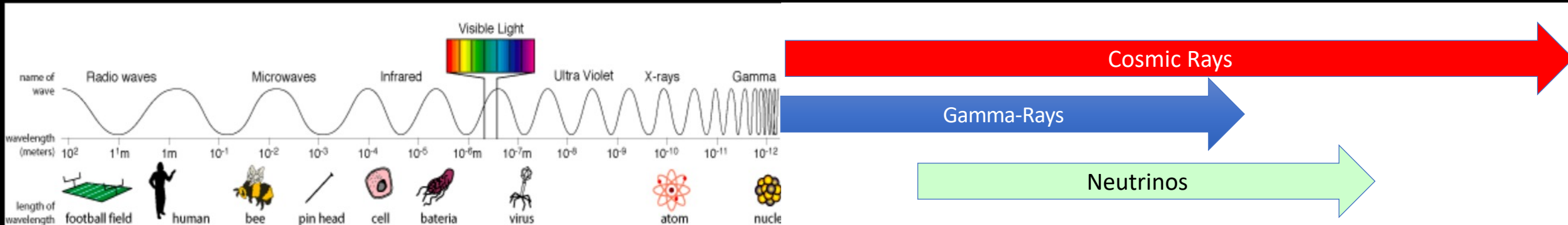
Cosmic Particles

~ double the reach for Astrophysics

The Multi-Wavelength Sun



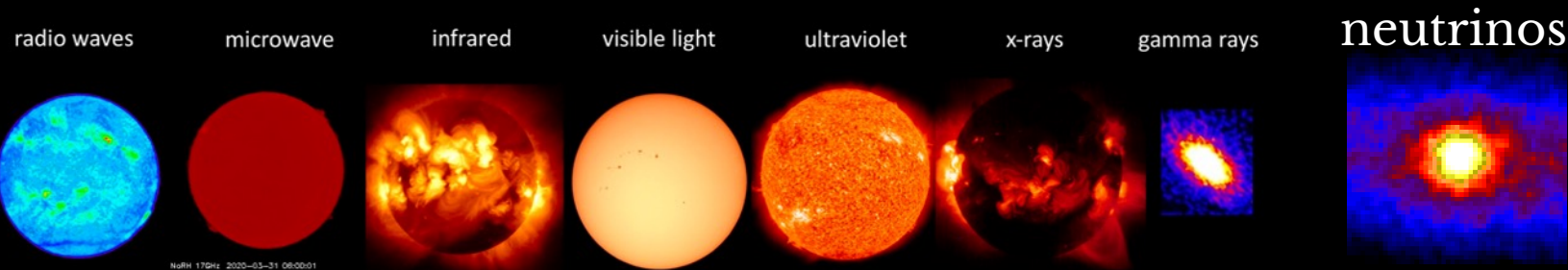
Gamma-rays
up to
 10^{15} eV



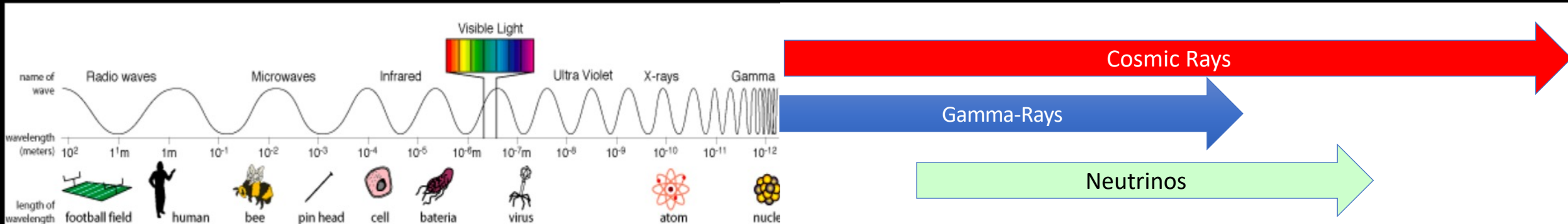
Cosmic Particles

~ double the reach for Astrophysics

The Multi-Wavelength Sun

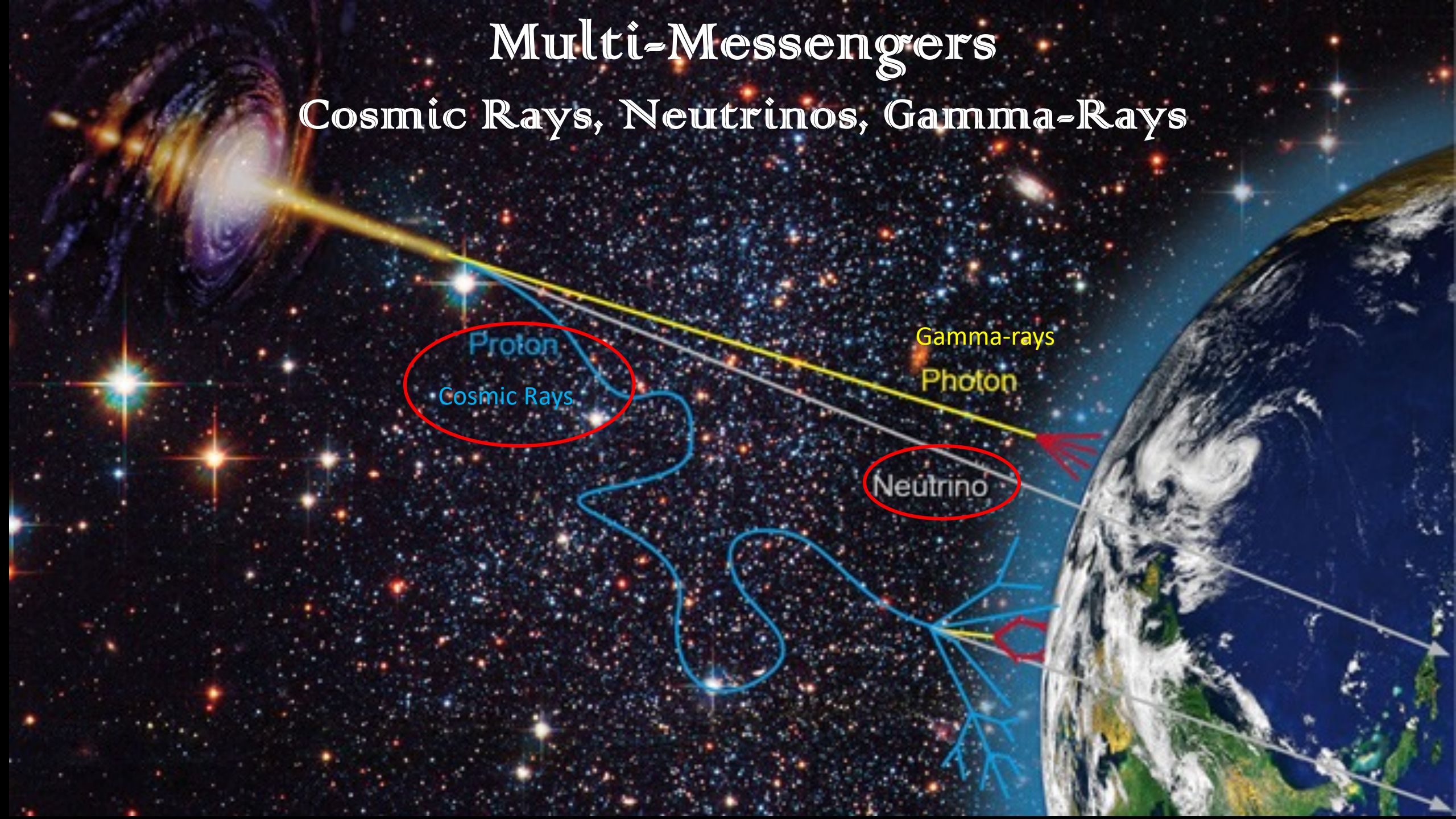


Cosmic Rays
up to
 10^{20} eV



Multi-Messengers

Cosmic Rays, Neutrinos, Gamma-Rays



Cosmic Rays

Group → ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
Lanthanides				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Neutrinos

Quarks

u up	c charm	t top
d down	s strange	b bottom
e electron	μ muon	τ tau
ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino

Leptons

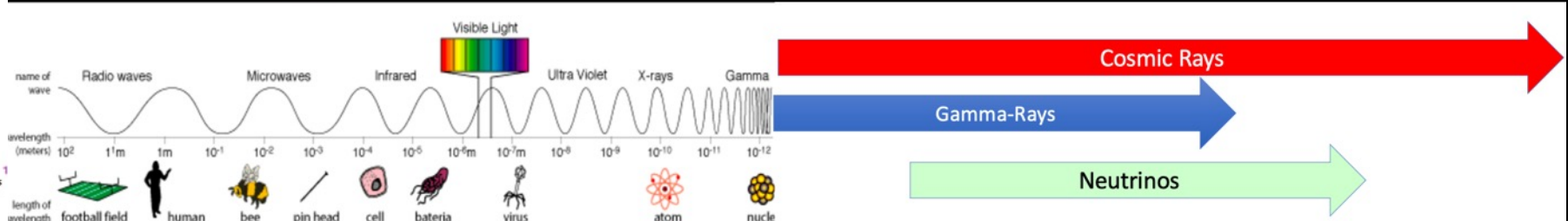
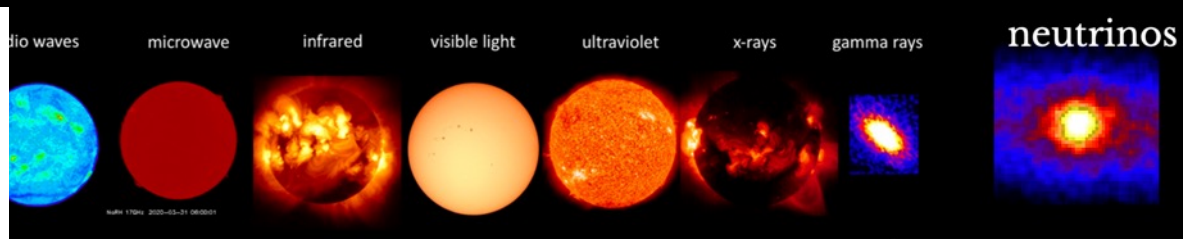
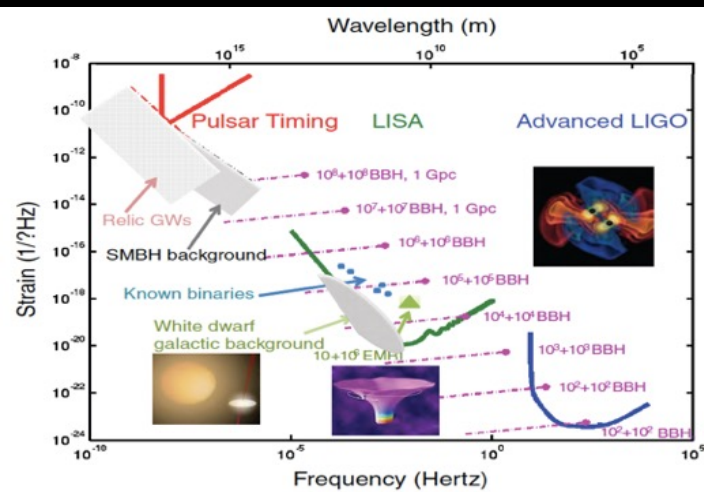
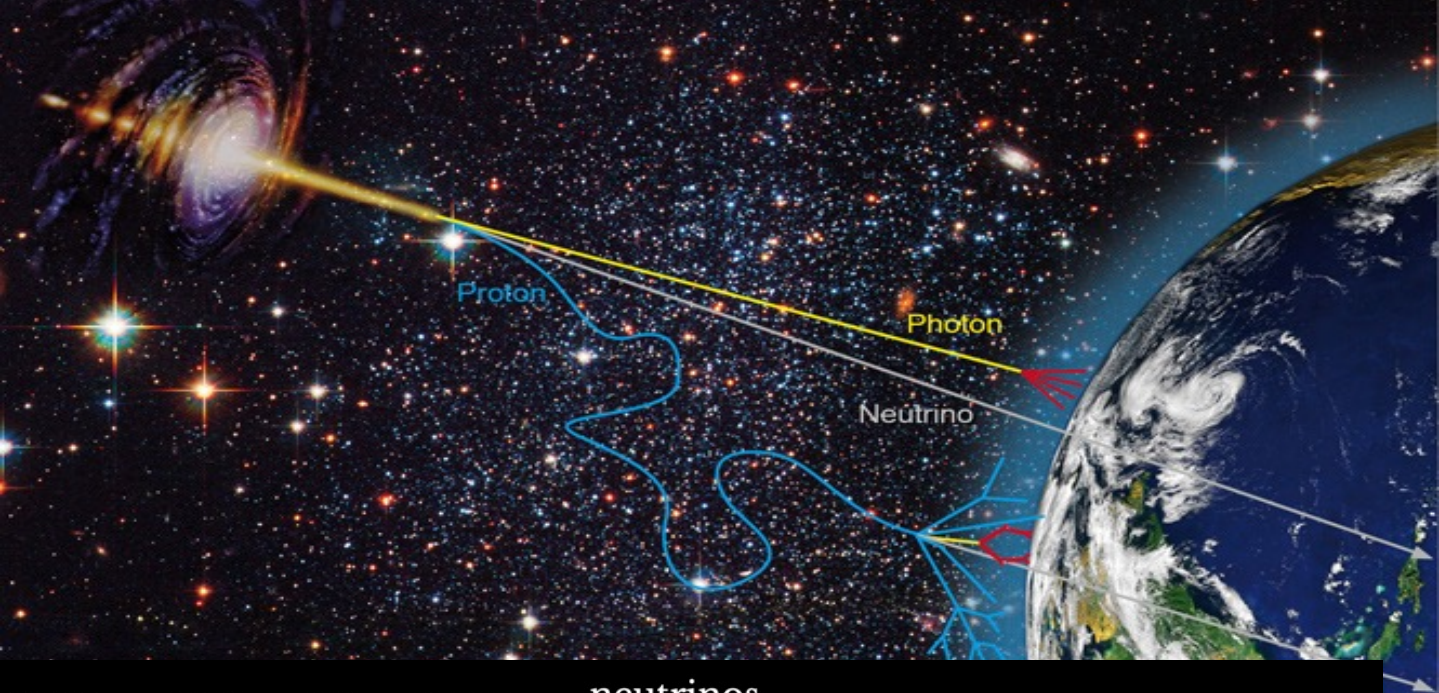
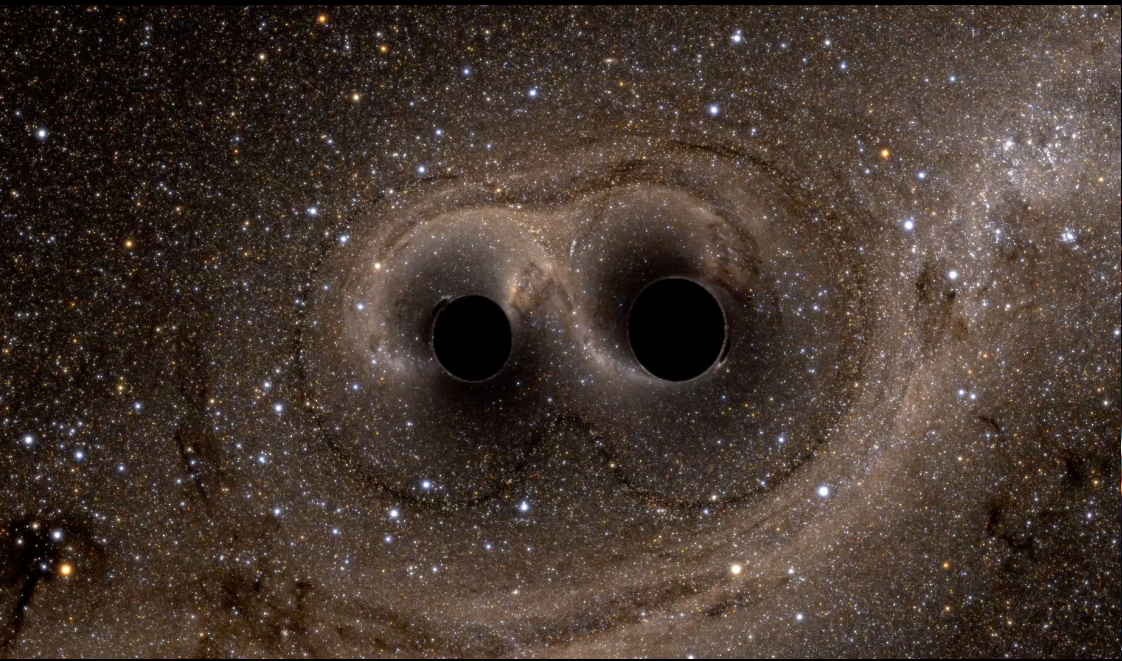
Forces

Z Z boson	γ photon
W W boson	g gluon



Multi-Messengers

~ Triple the reach for Astrophysics – 40 orders of magnitude



Gravitational Waves

Electromagnetic Waves

Cosmic Particles

Astroparticle Physics Open Questions:

What are the sources of the **Ultra-High Energy Cosmic Rays** (UHECRs)?

What are the sources of **Astrophysical Neutrinos**?

Outline:

1. What are the sources of the **Ultra-High Energy Cosmic Rays** (UHECRs)?

Cosmic rays with energy above $1 \text{ EeV} = 10^{18} \text{ eV}$

- ~ What is the spectrum of UHECRs?
- ~ What is the composition of UHECRs?
- ~ What is the sky distribution of arrival directions?
- ~ Neutrino and gamma-ray secondaries?
- ~ What physical processes do UHECRs probe?

2a. What are the sources of **Astrophysical Neutrinos**?

2b. Future Outlook

Submitted to the US Community Study
on the Future of Particle Physics (Snowmass 2021)

Ultra-High-Energy Cosmic Rays

The Intersection of the Cosmic and Energy Frontiers

Abstract: The present white paper is submitted as part of the “Snowmass” process to help inform the long-term plans of the United States Department of Energy and the National Science Foundation for high-energy physics. It summarizes the science questions driving the Ultra-High-Energy Cosmic-Ray (UHECR) community and provides recommendations on the strategy to answer them in the next two decades.

arXiv:2209.11726v1 [hep-ph] 23 Sep 2022

Report of the Topical Group on Cosmic Probes of Fundamental Physics for for Snowmass 2021

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High-Energy and Ultra-High-Energy Neutrinos: A Snowmass White Paper

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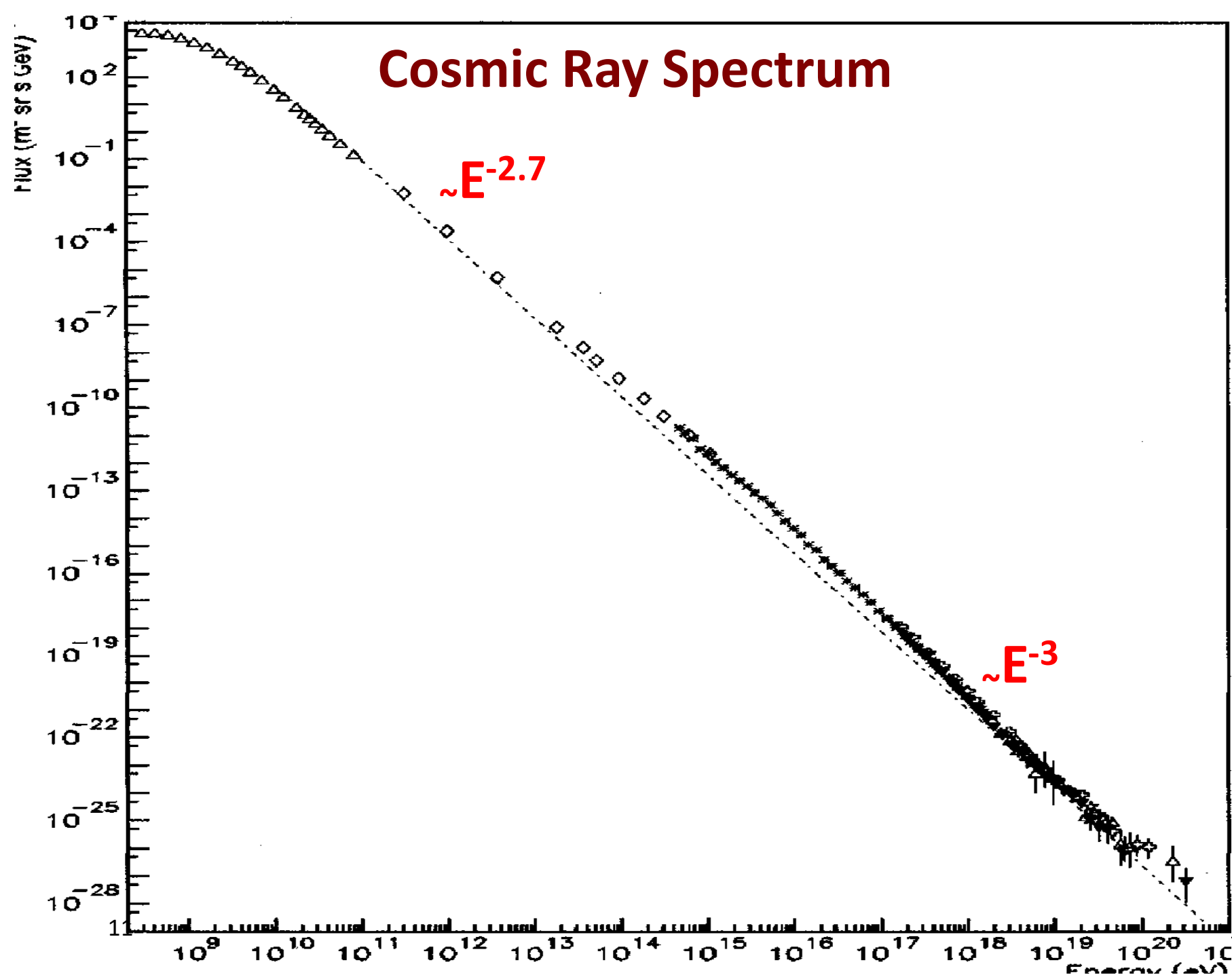
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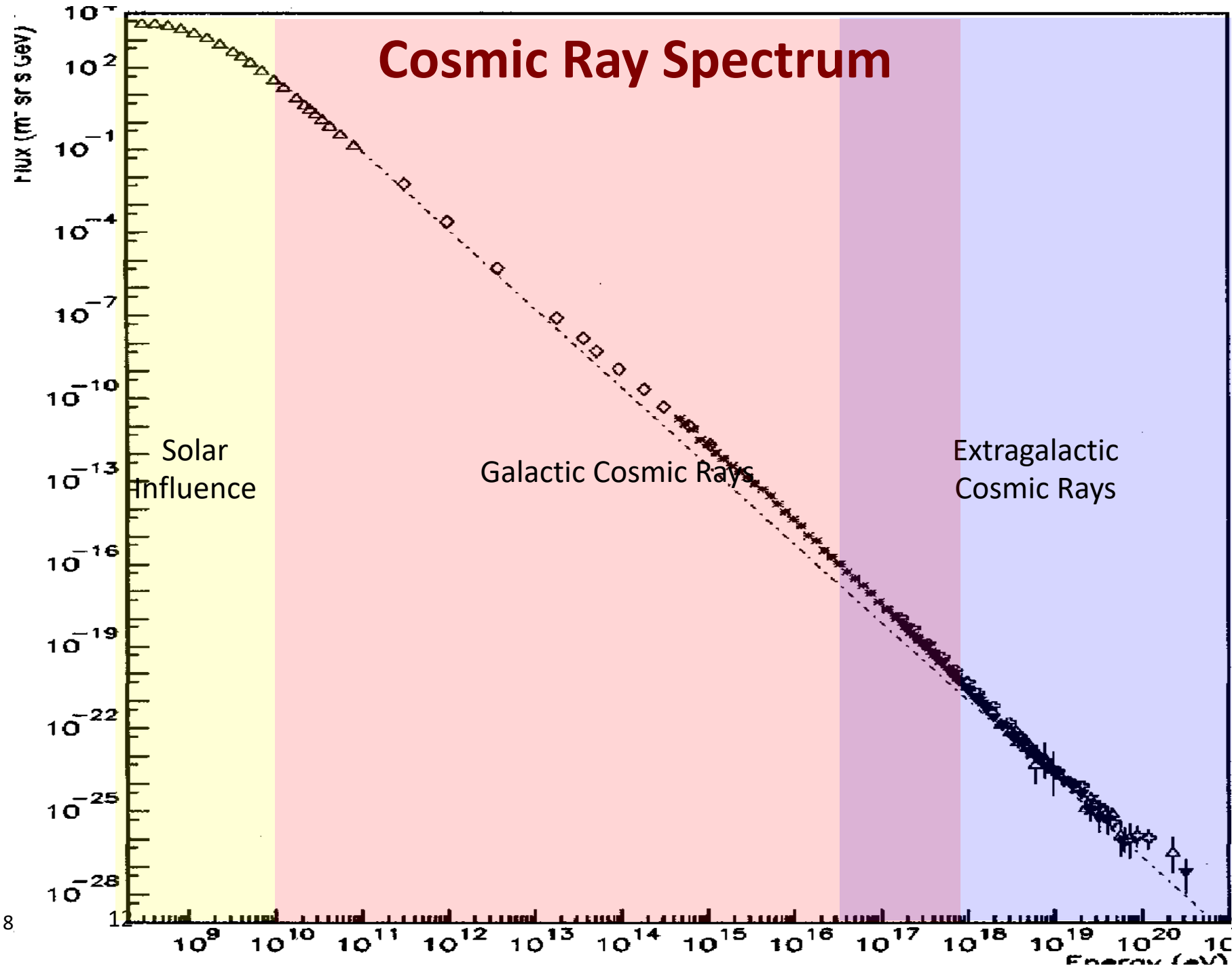
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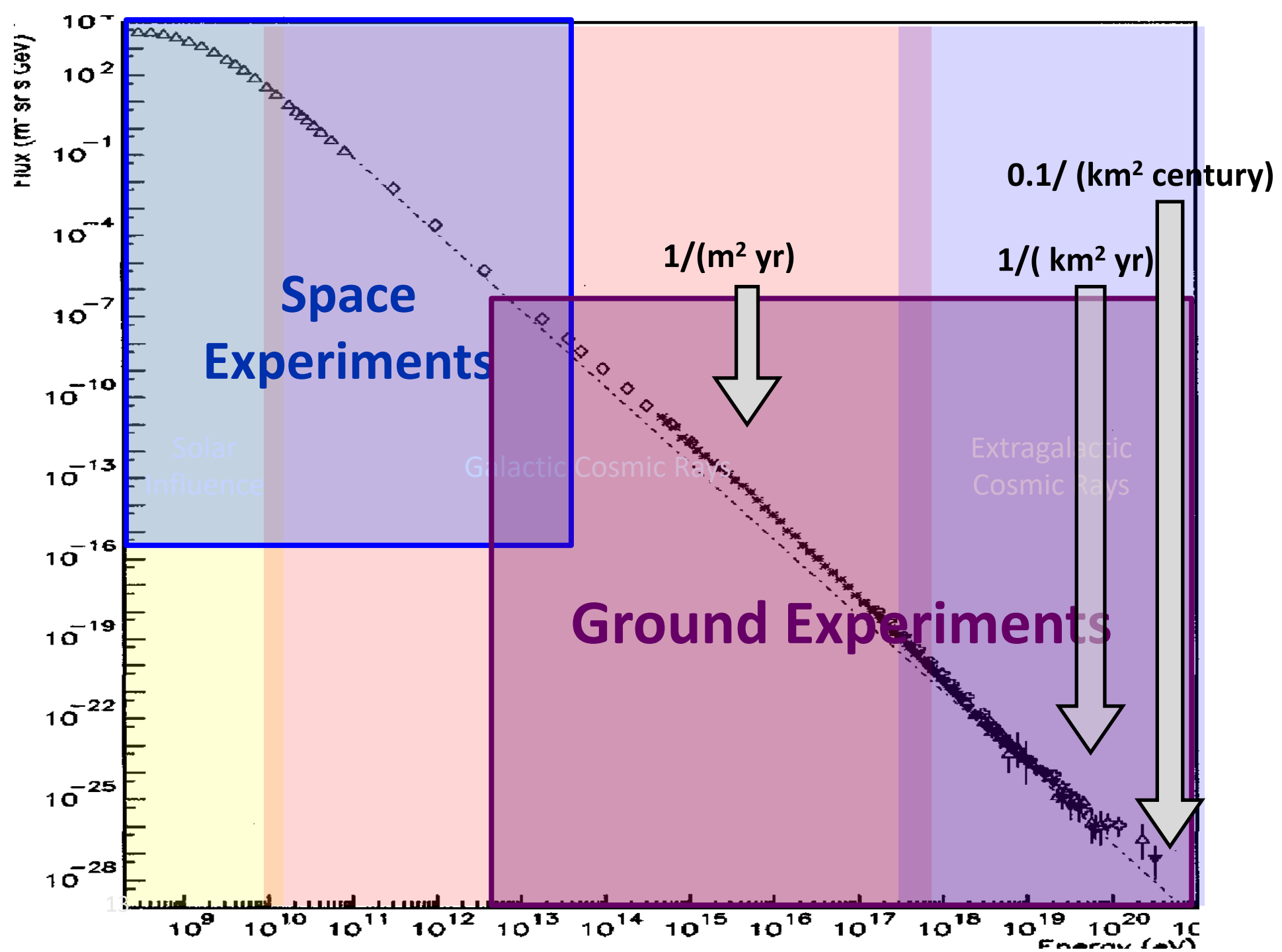
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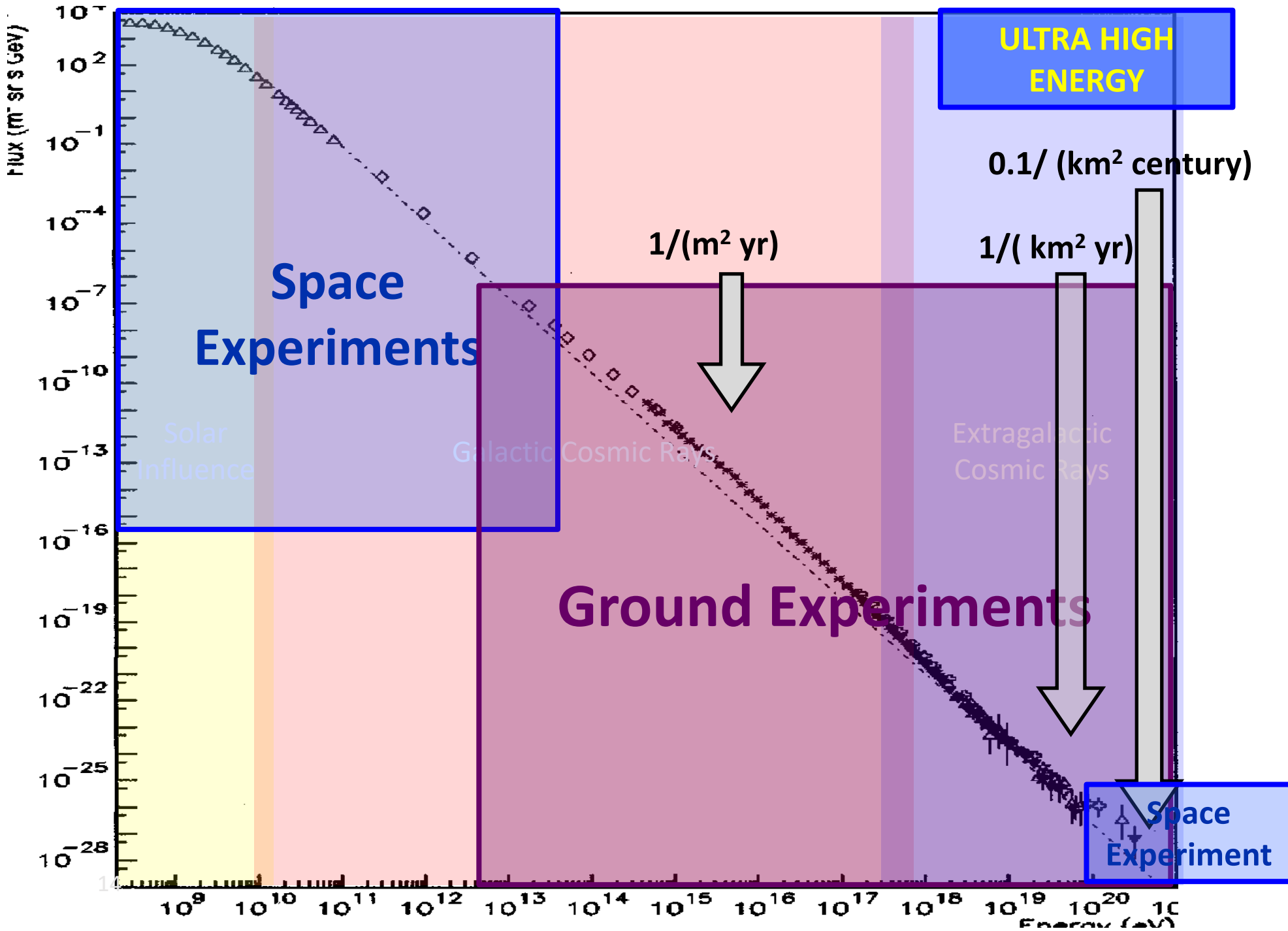
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^f steph.wissel@desy.de

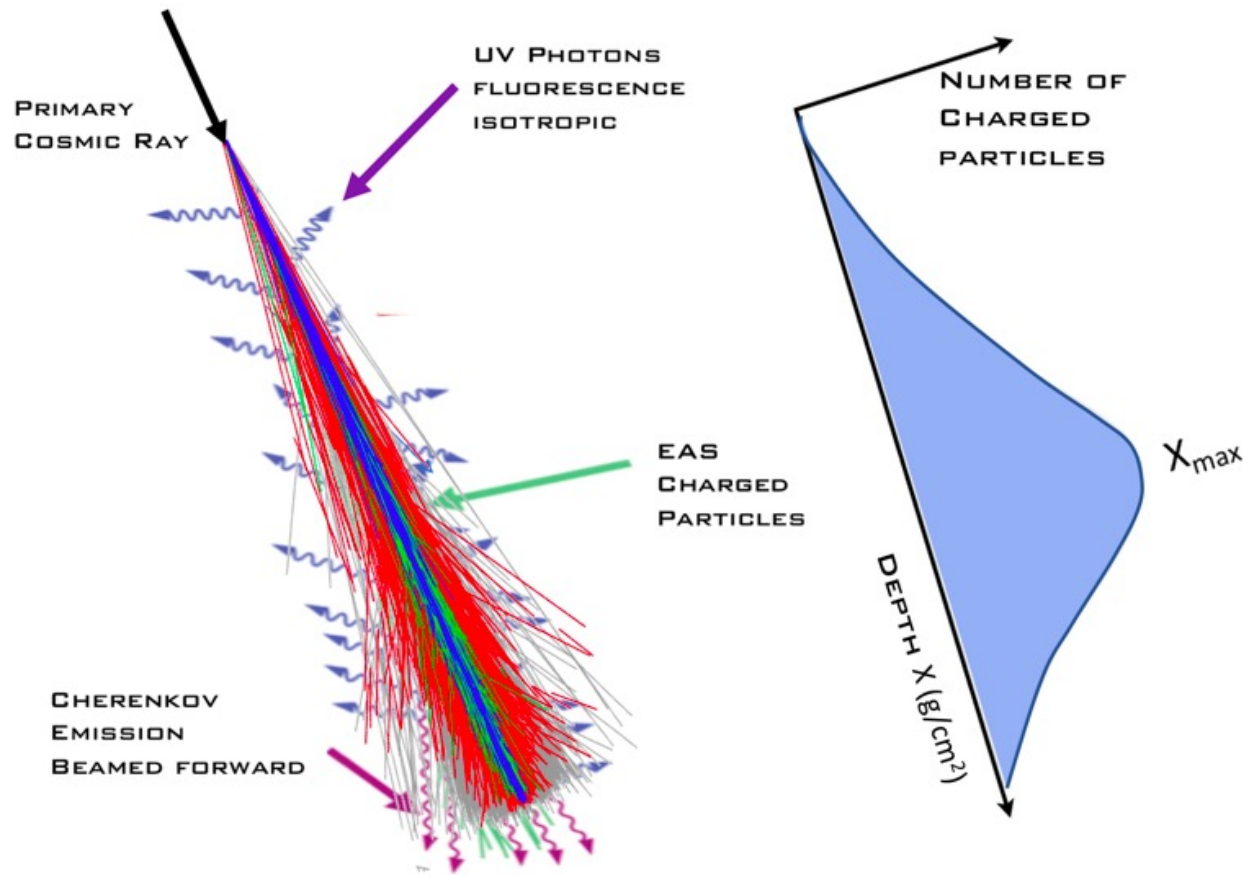
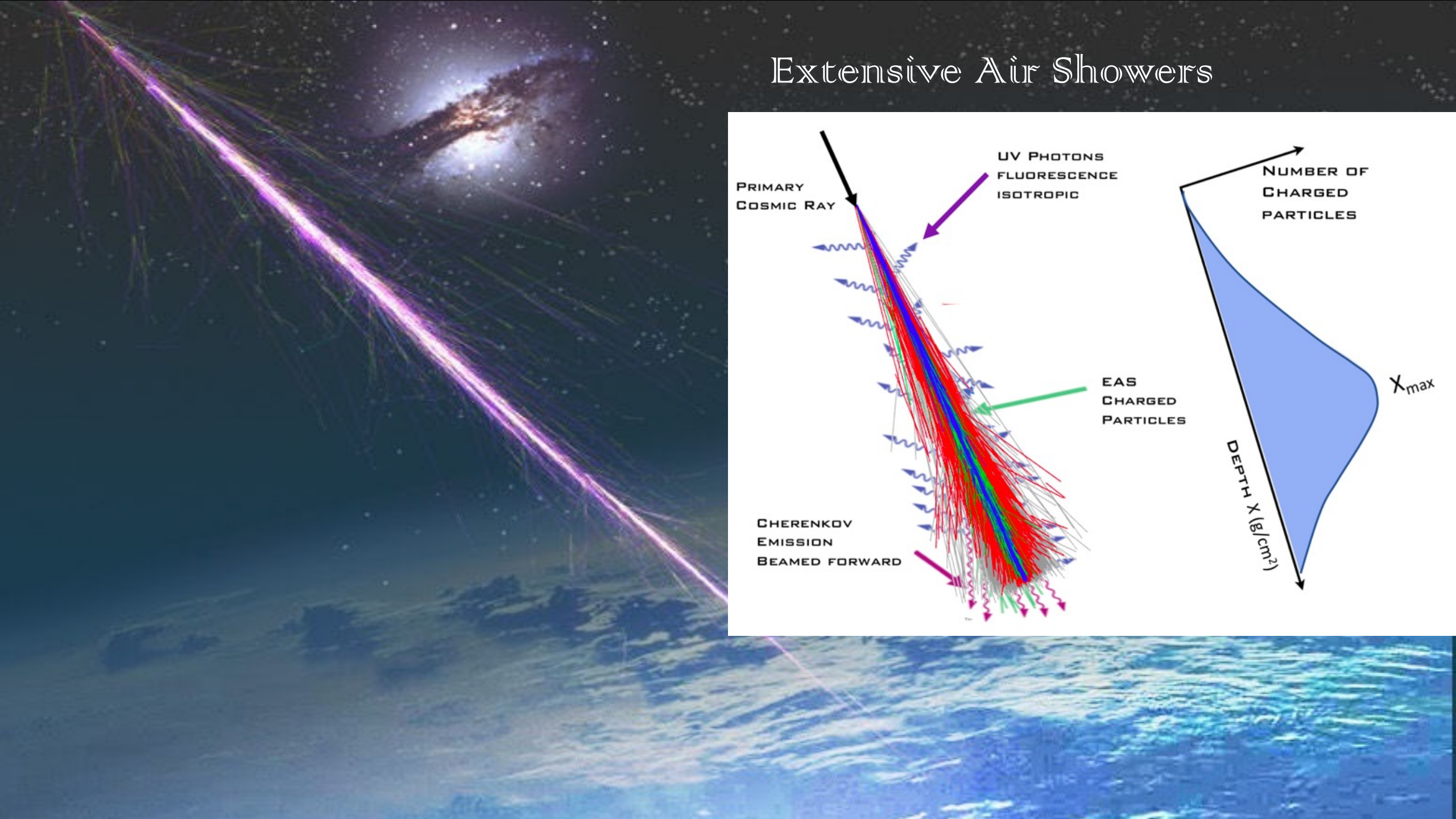


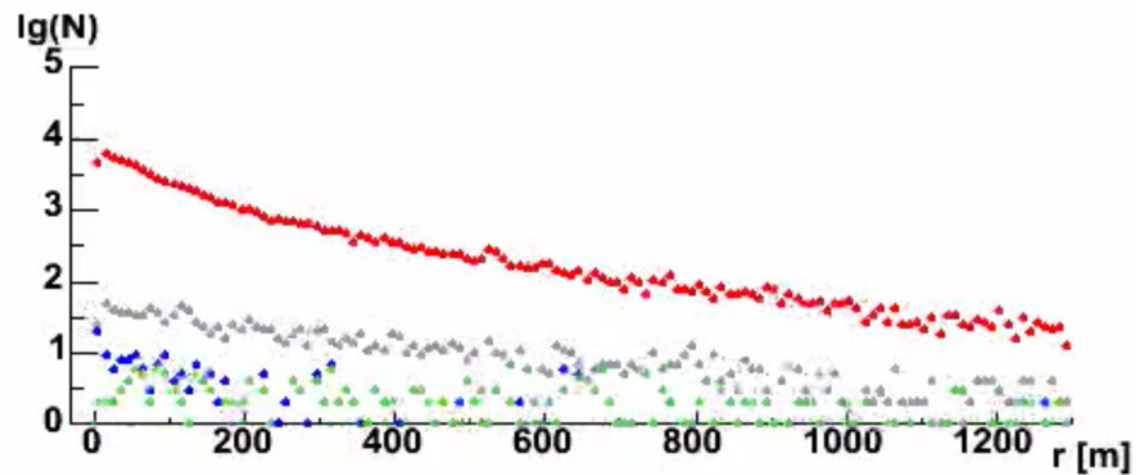
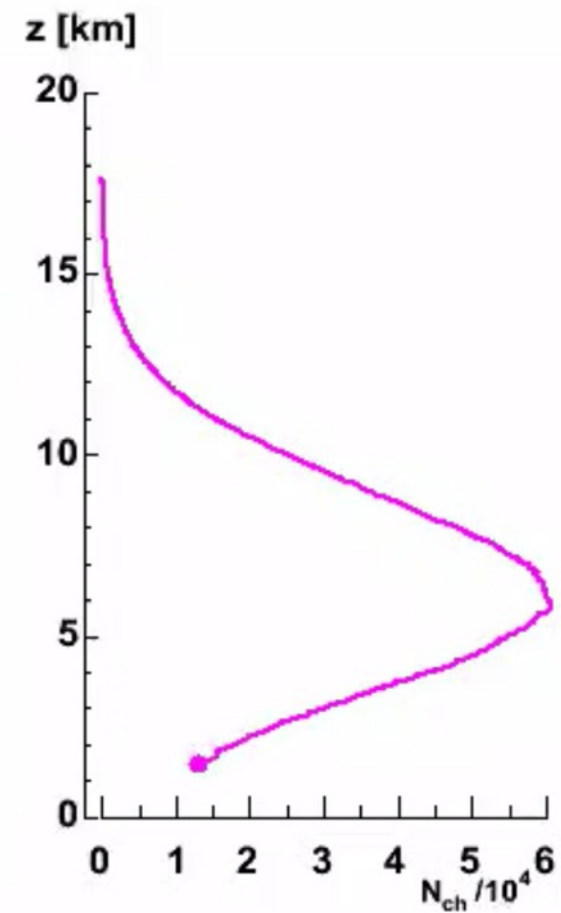
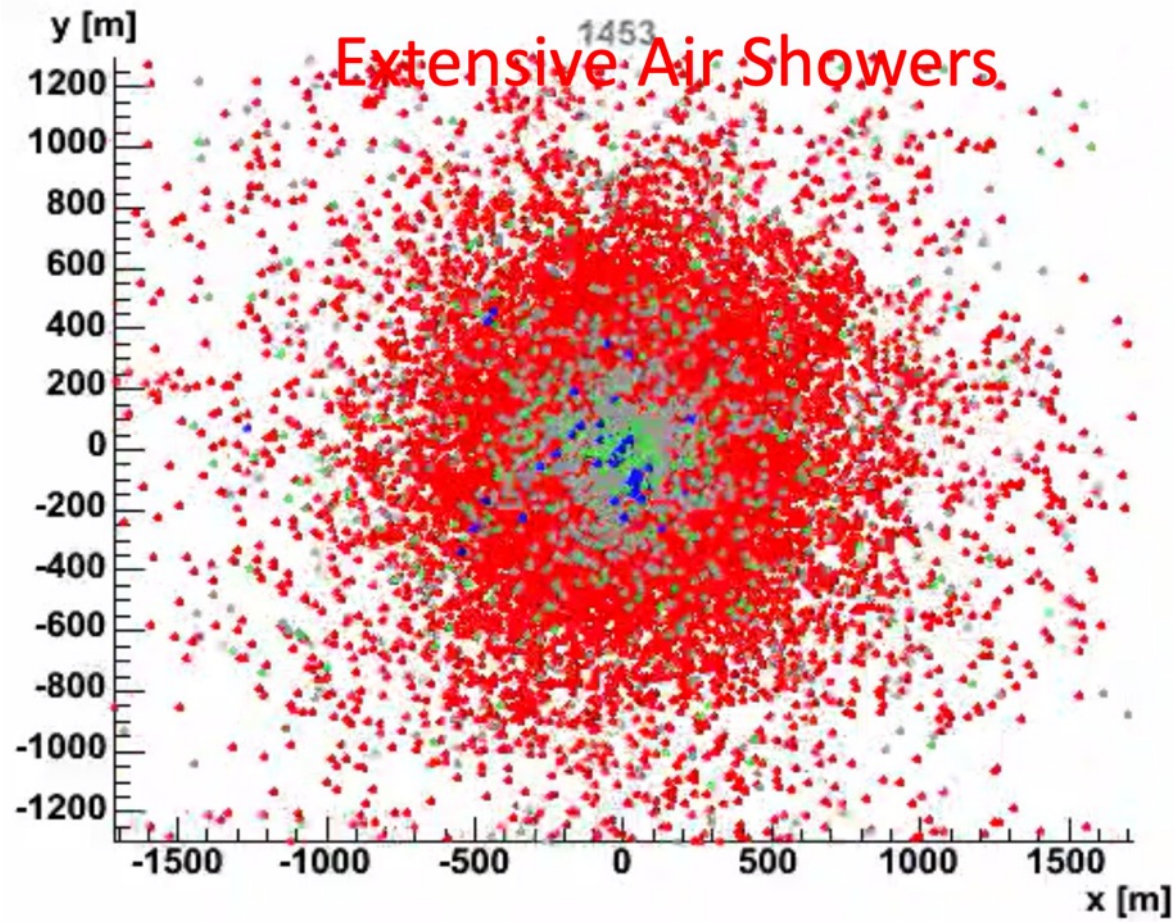






Extensive Air Showers





Proton 10^{14} eV

$h^{1st} = 17642$ m

hadrons muons

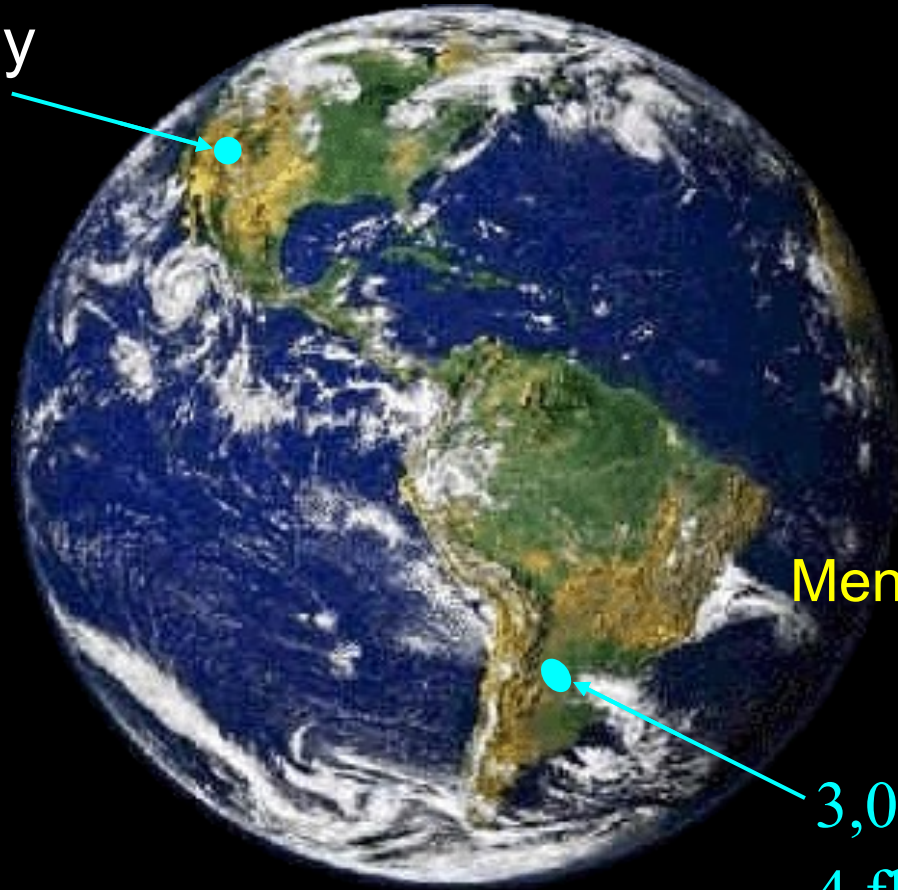
neutrons electrs

Leading Observatories of Ultrahigh Energy Cosmic Rays

Telescope Array

Utah, USA
(5 country
collaboration)

700 km² array
3 fluorescence
telescopes

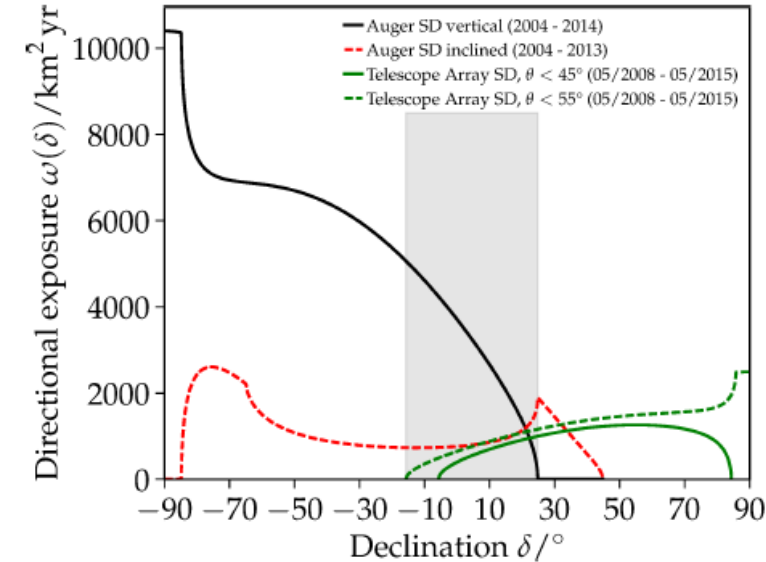


Pierre Auger
Observatory

Mendoza, Argentina
(19 country
collaboration)

3,000 km² array
4 fluorescence telescopes

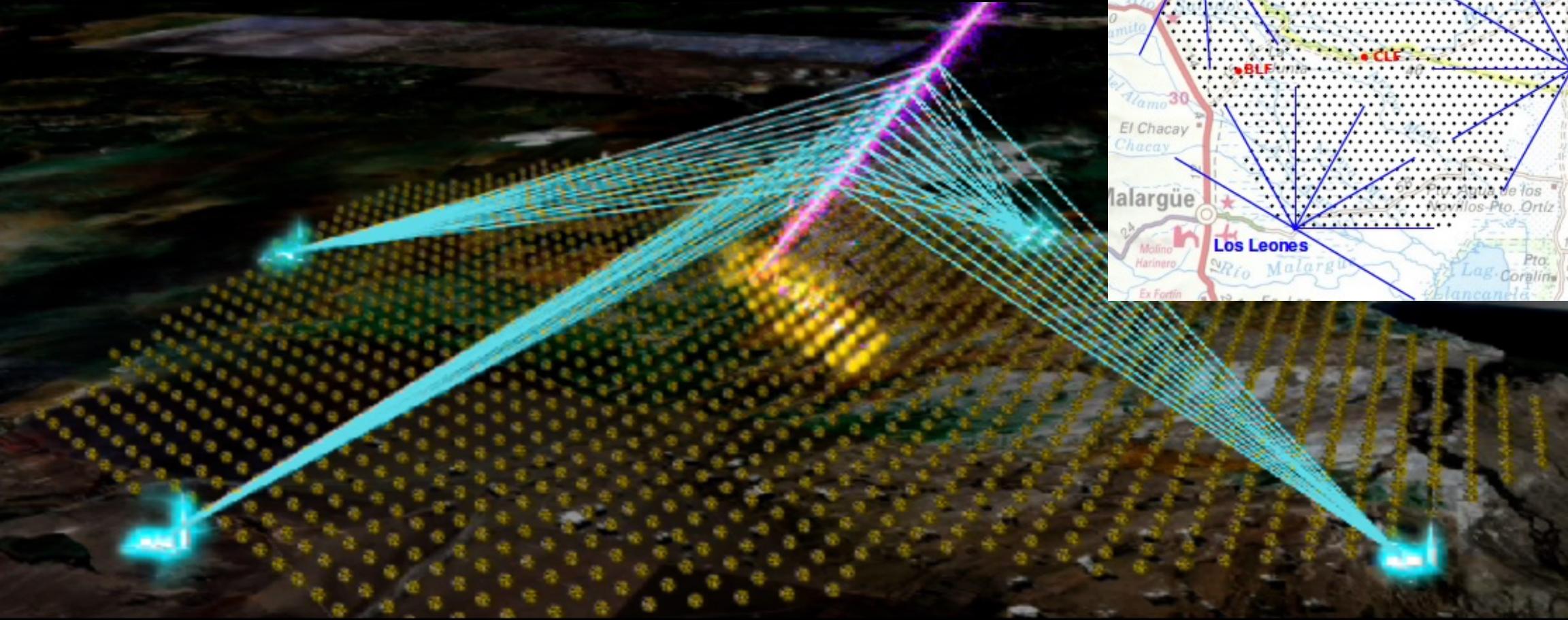
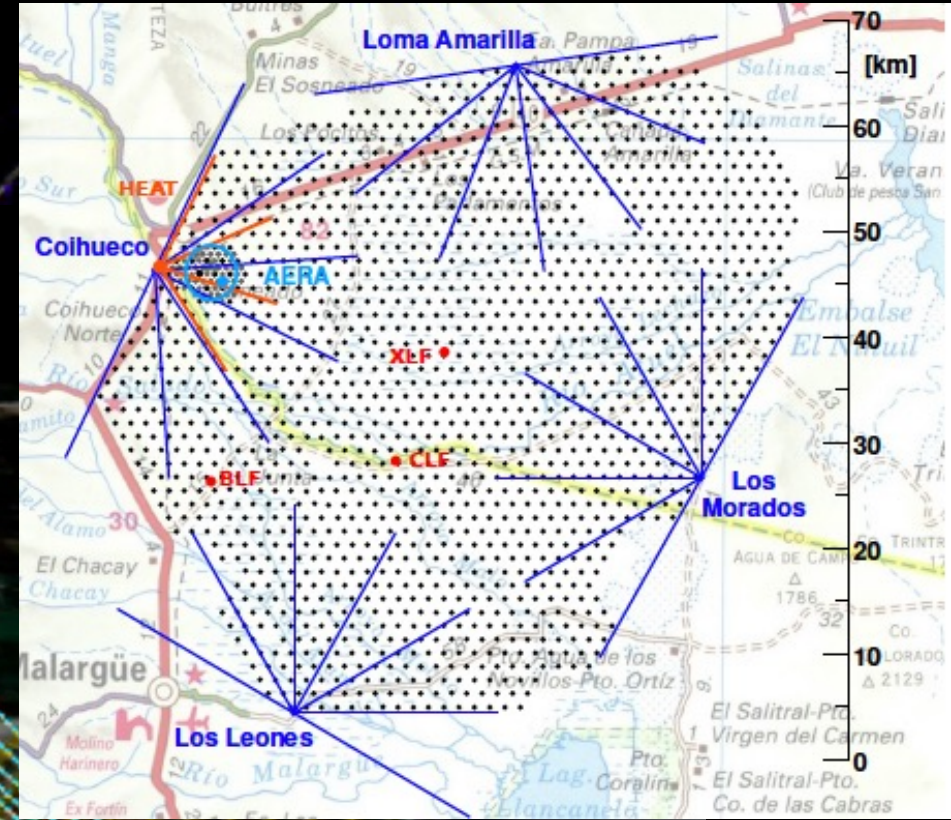
Together full sky coverage



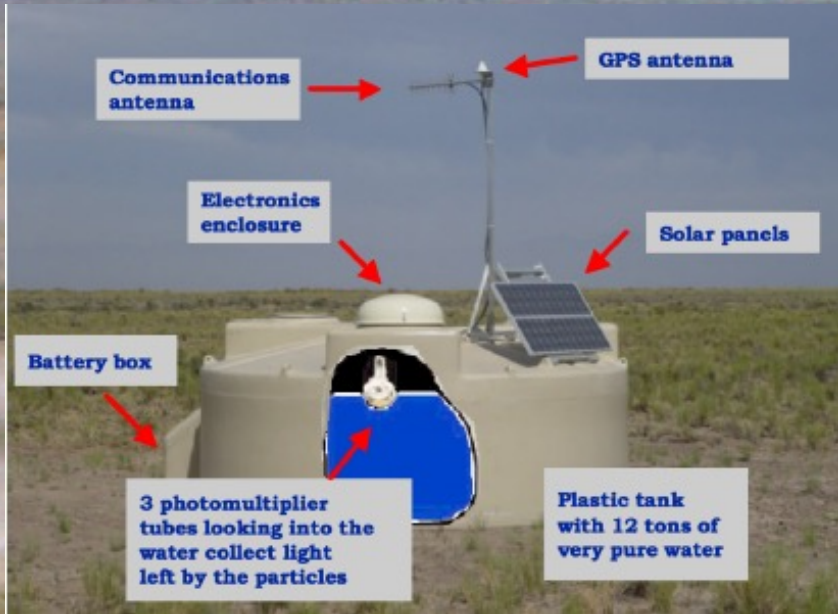


Pierre Auger Observatory

3,000 km² surface array=1665 water Cherenkov tanks
4 Fluorescence telescopes



3,000 km² array of 1665 water Cherenkov tanks with 1.5 km distancing



4 Fluorescence telescopes
overlooking the site



Telescope Array

Middle Drum: based on HiRes II



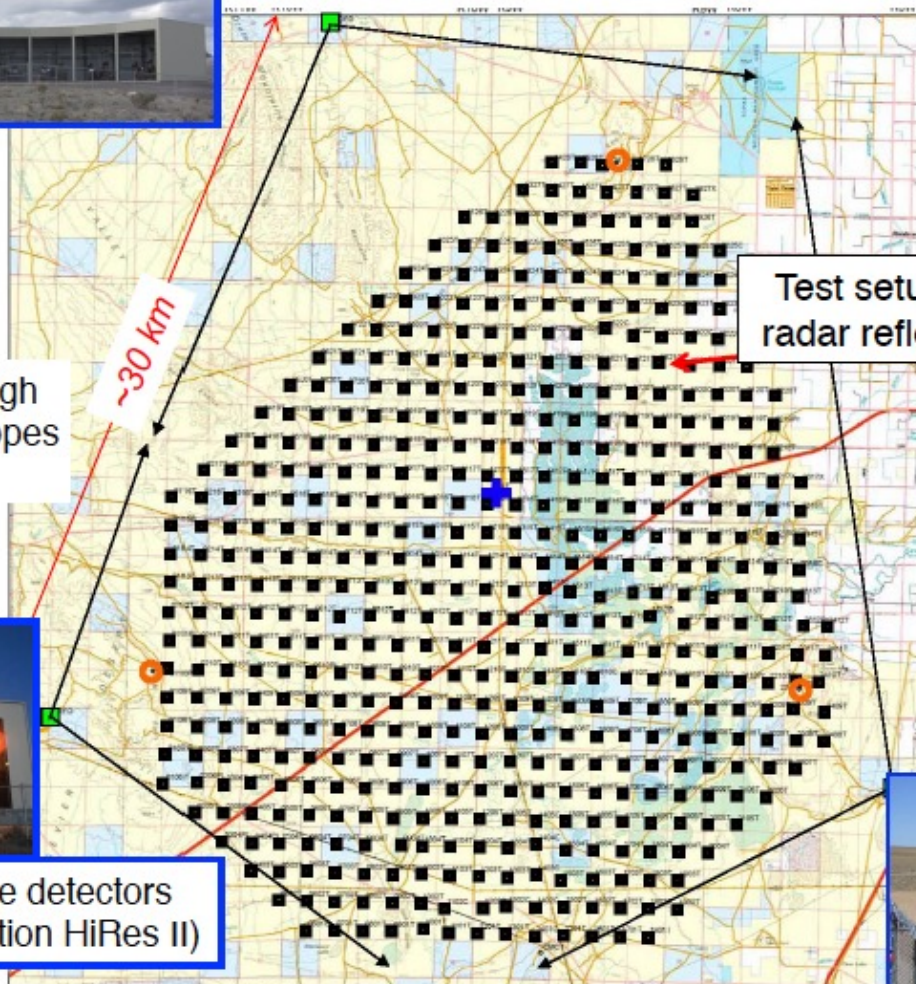
LIDAR
Laser facility

Infill array and high
elevation telescopes



3 fluorescence detectors
(2 new, one station HiRes II)

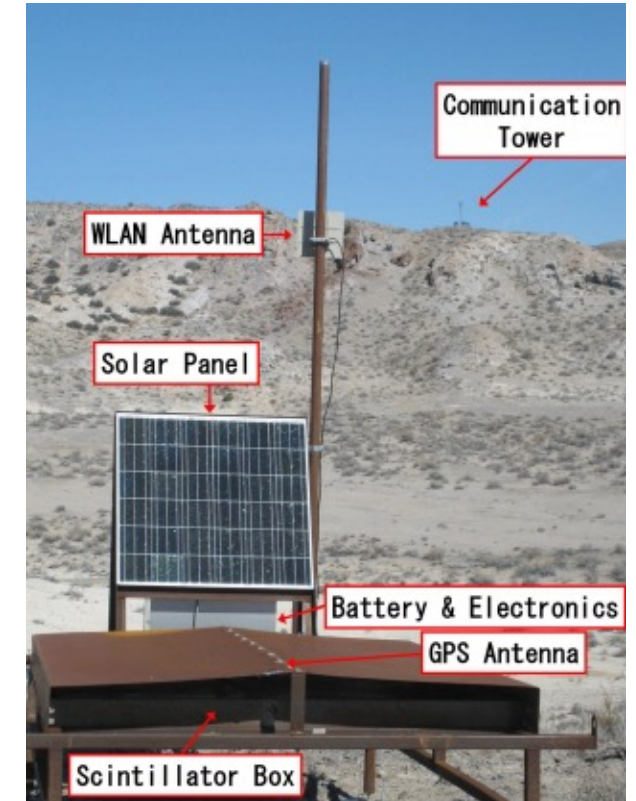
TALE (TA low energy extension)



Test setup for
radar reflection

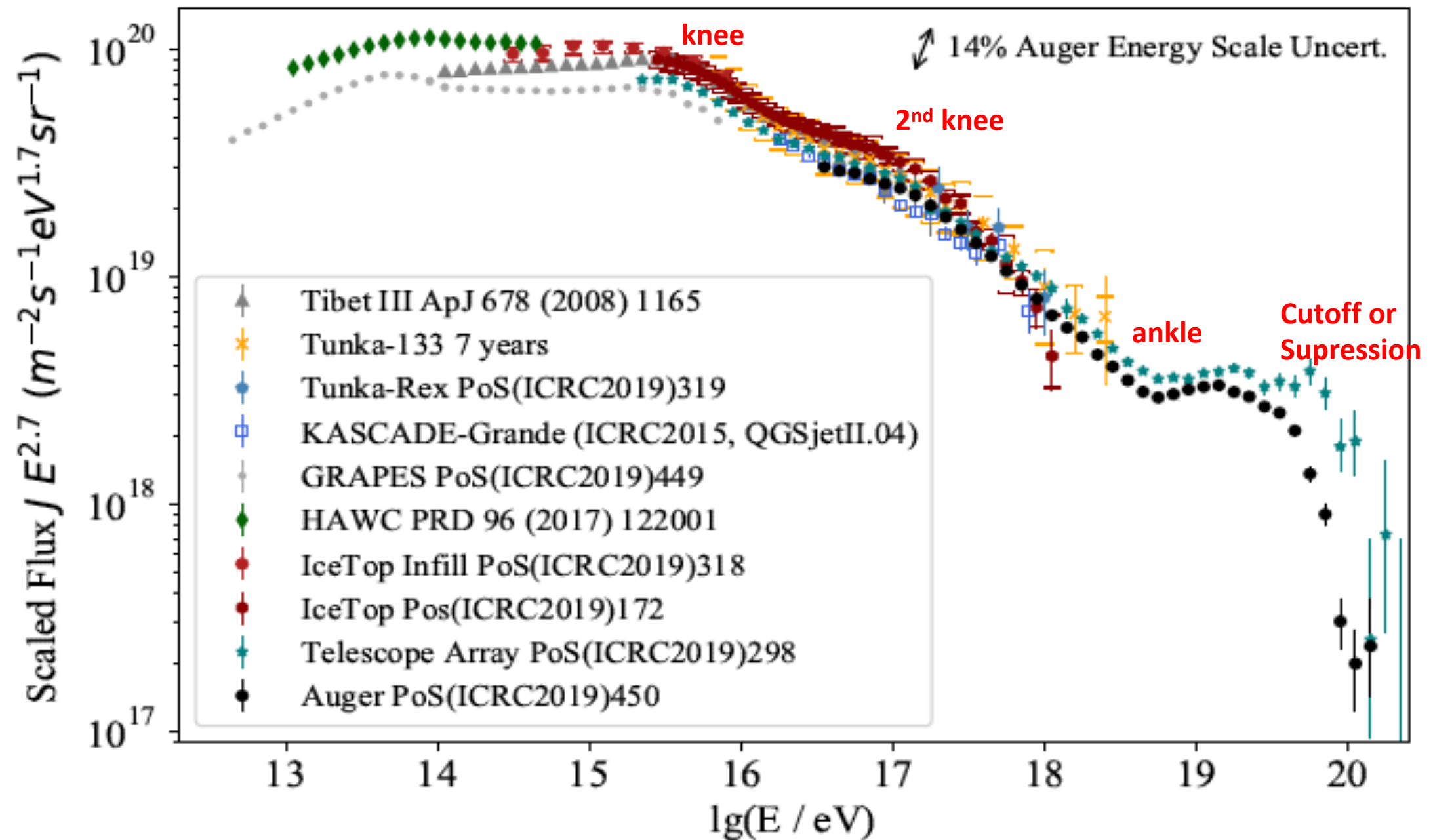
Electron light
source (ELS):
~40 MeV

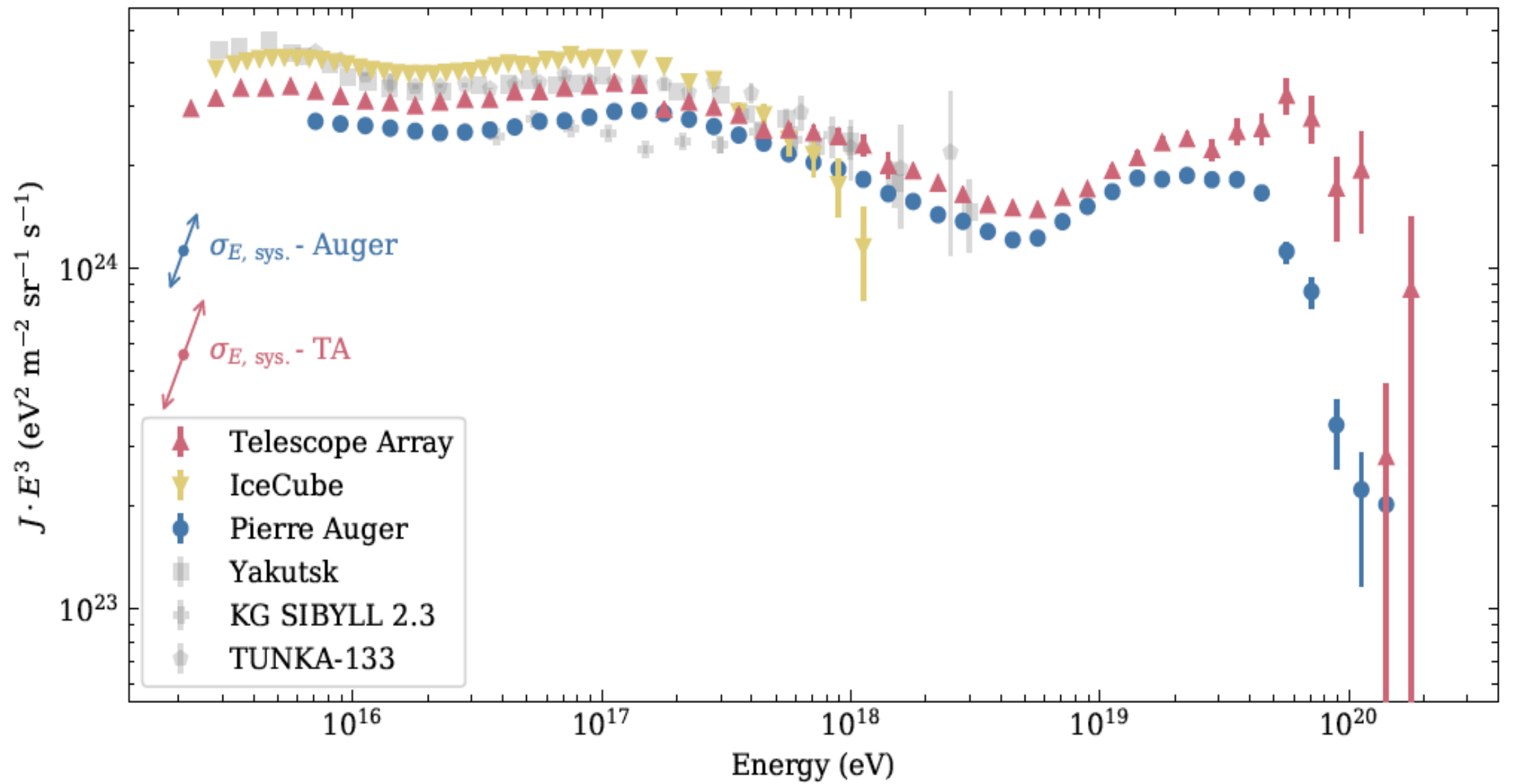
Northern hemisphere: Utah, USA

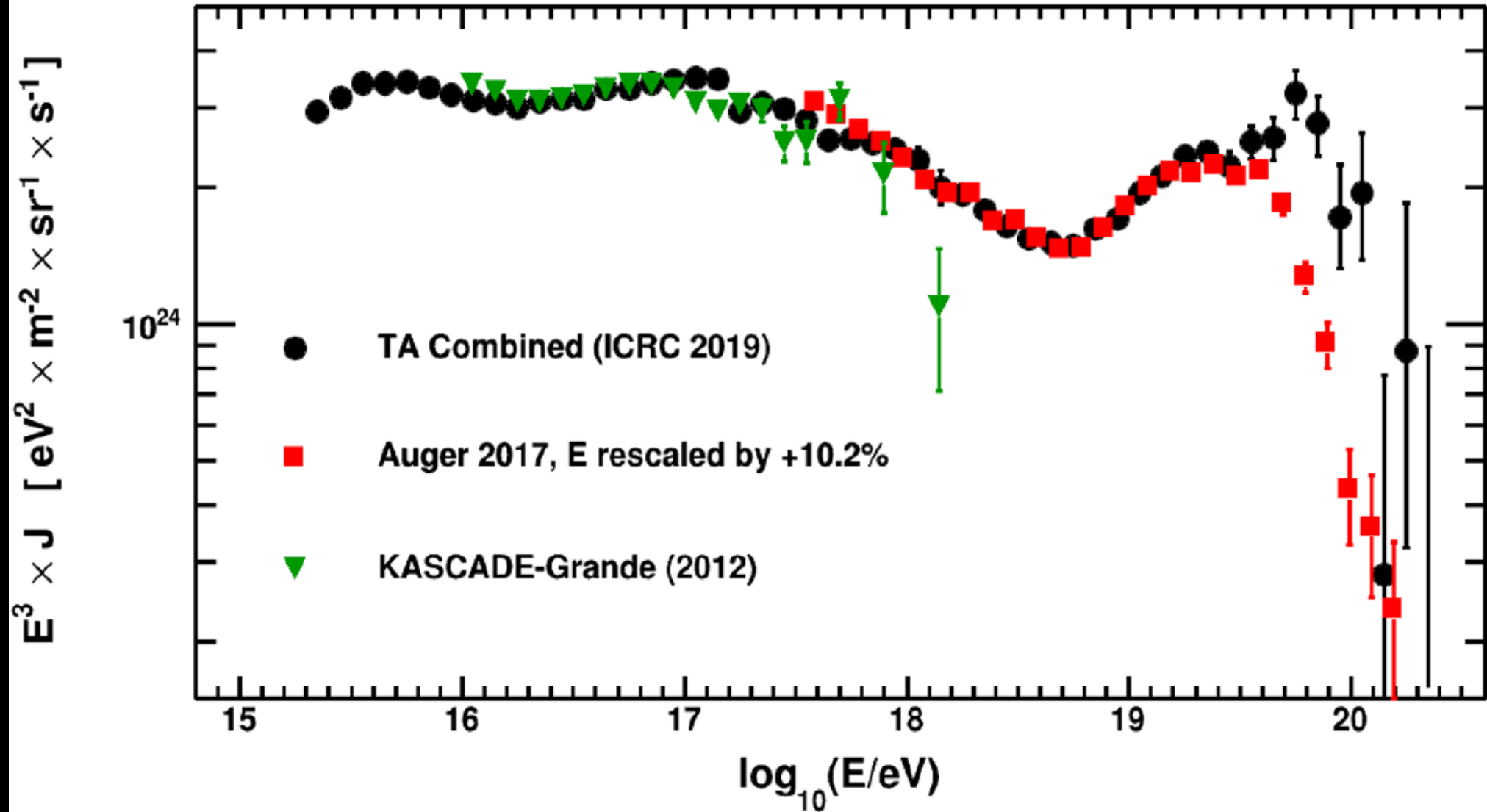


507 surface detectors:
double-layer scintillators
(grid of 1.2 km, 680 km²)

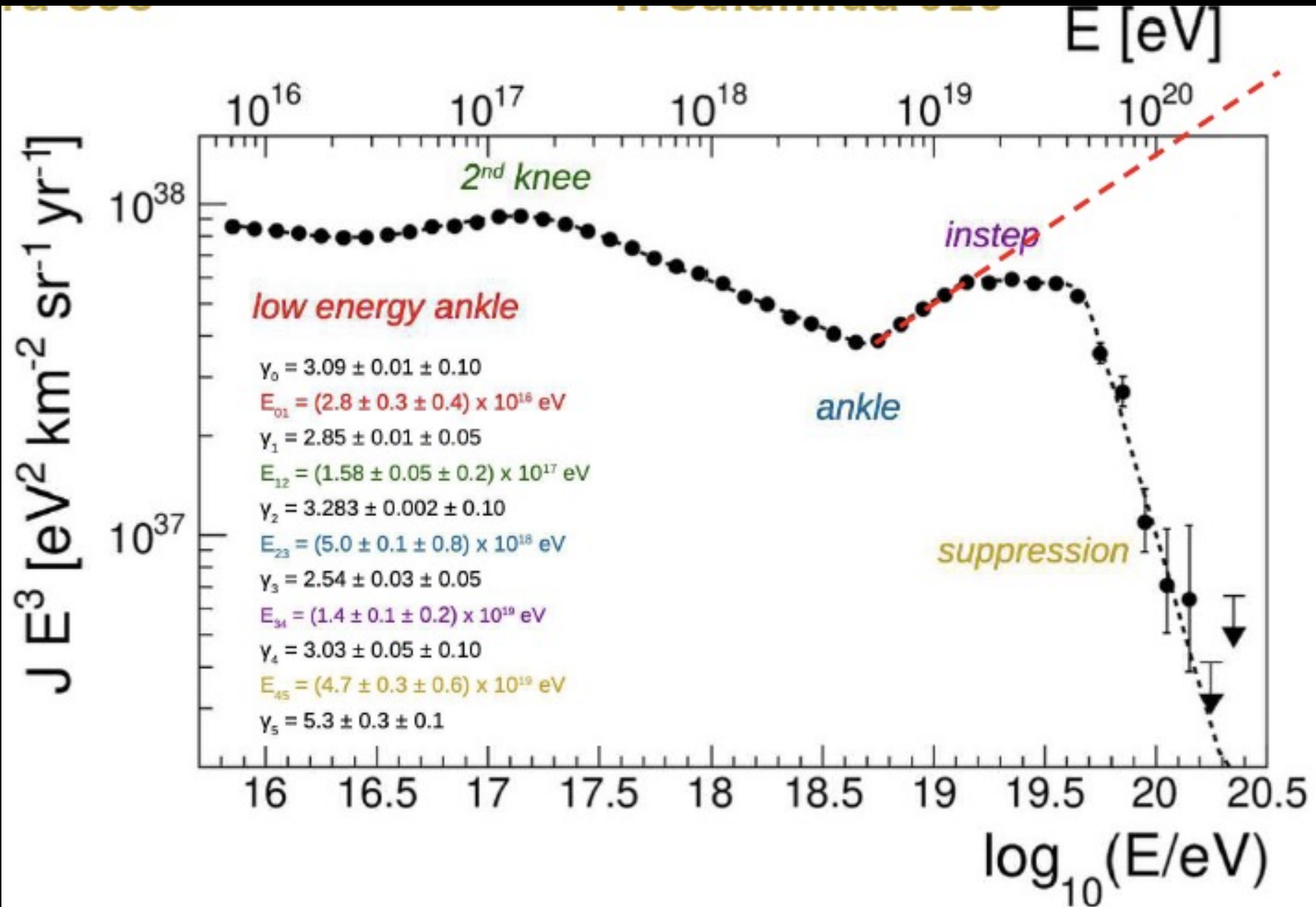
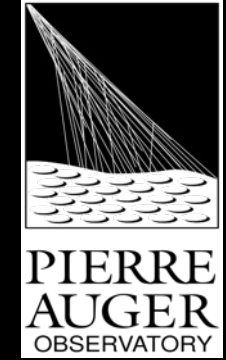
What is the spectrum of UHIECRs?



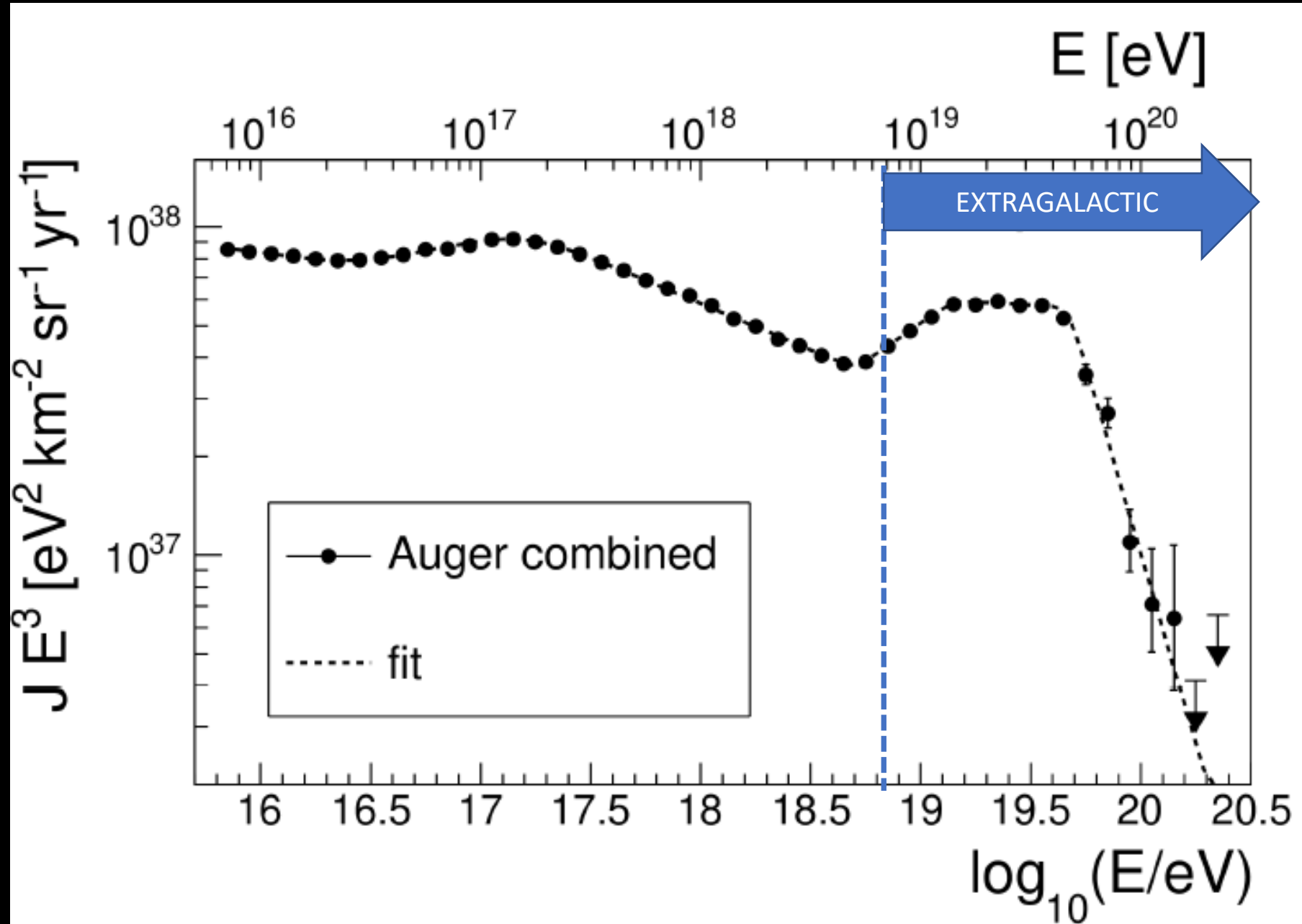




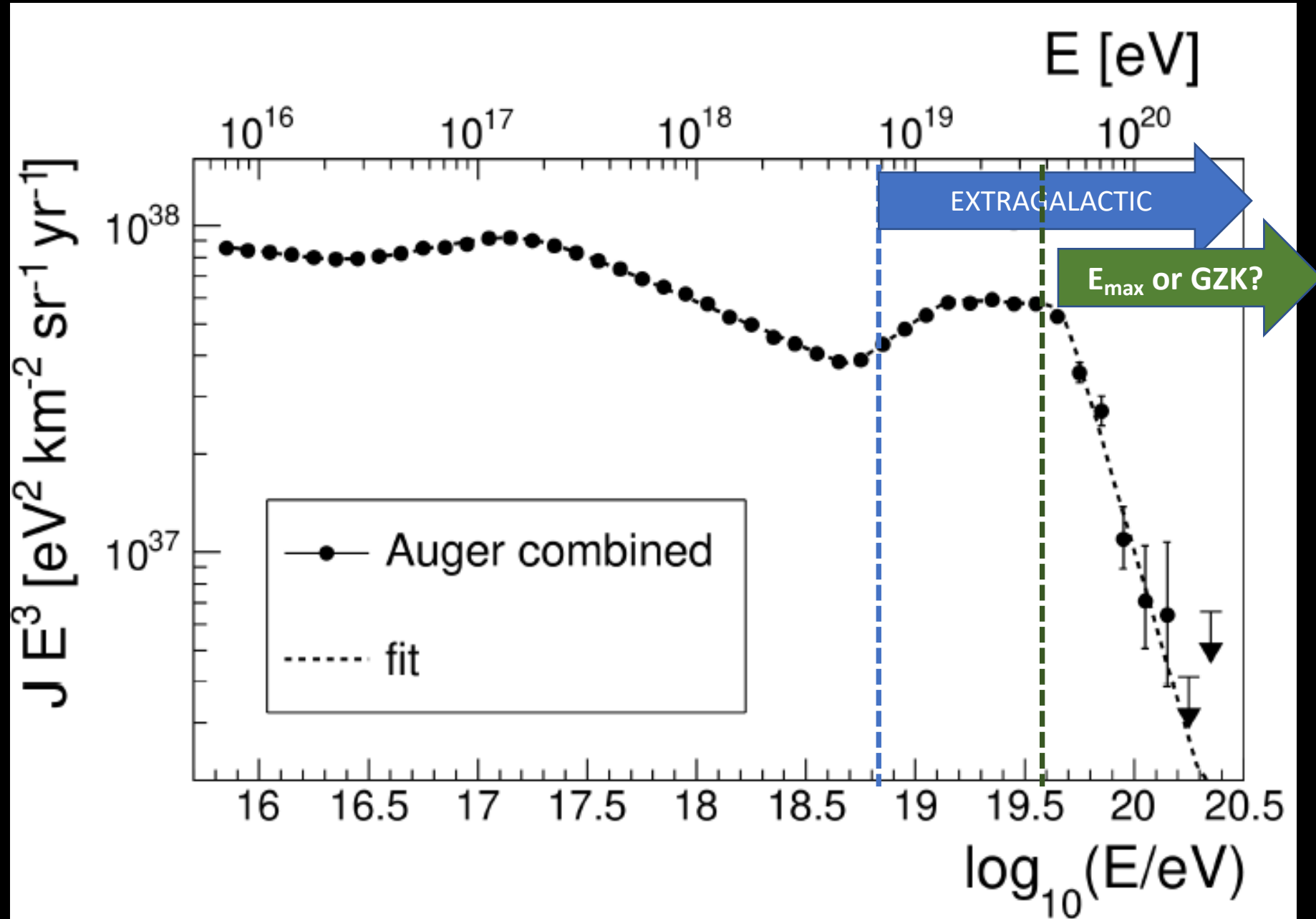
Auger Spectrum ICRC 2023



Auger Spectrum ICRC 2021



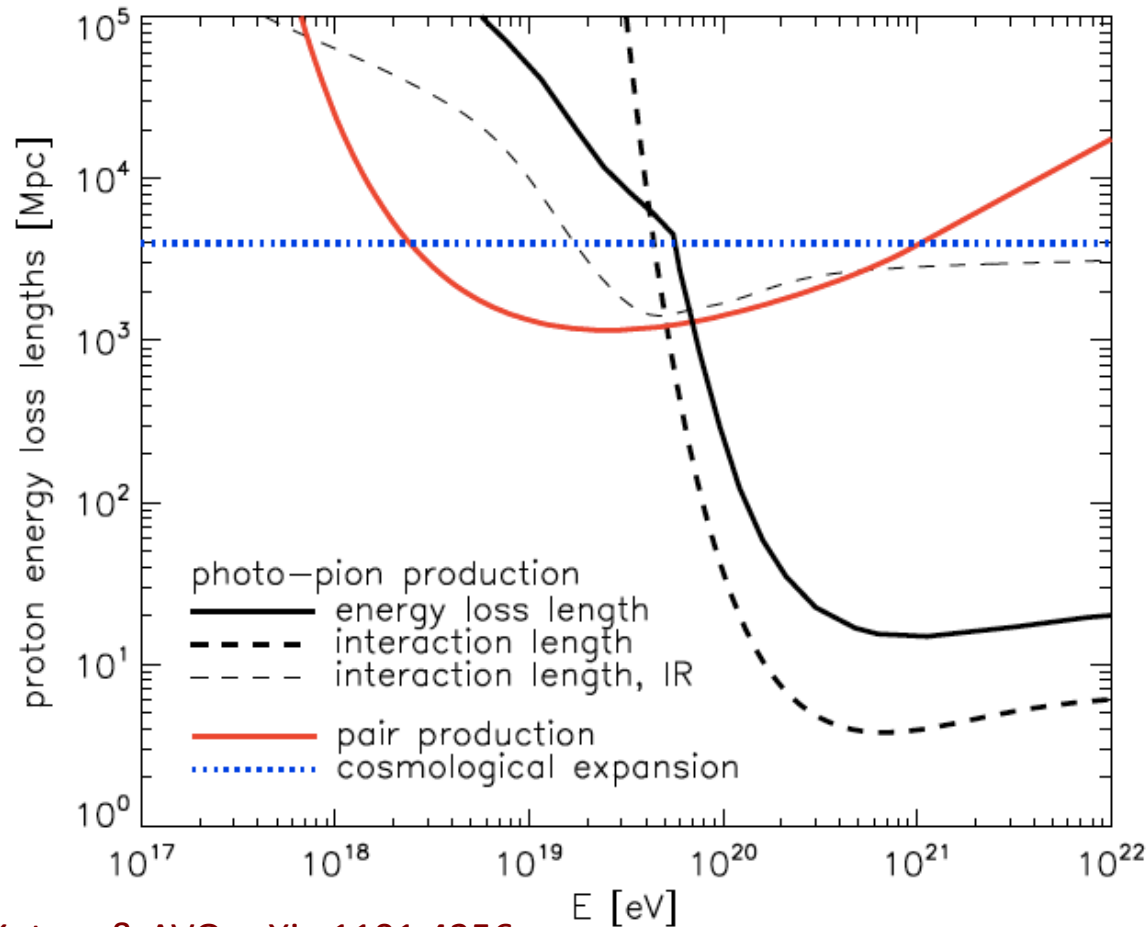
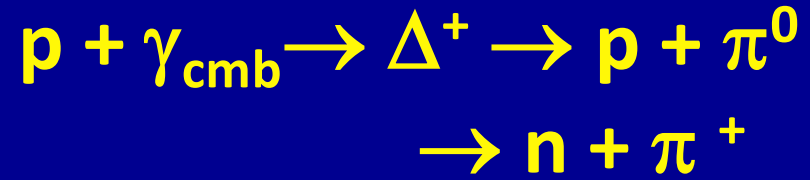
Auger Spectrum ICRC 2021



GZK Cutoff

Greisen,
Zatsepin, Kuzmin
1966

Greisen-Zatsepin-Kuzmin Effect

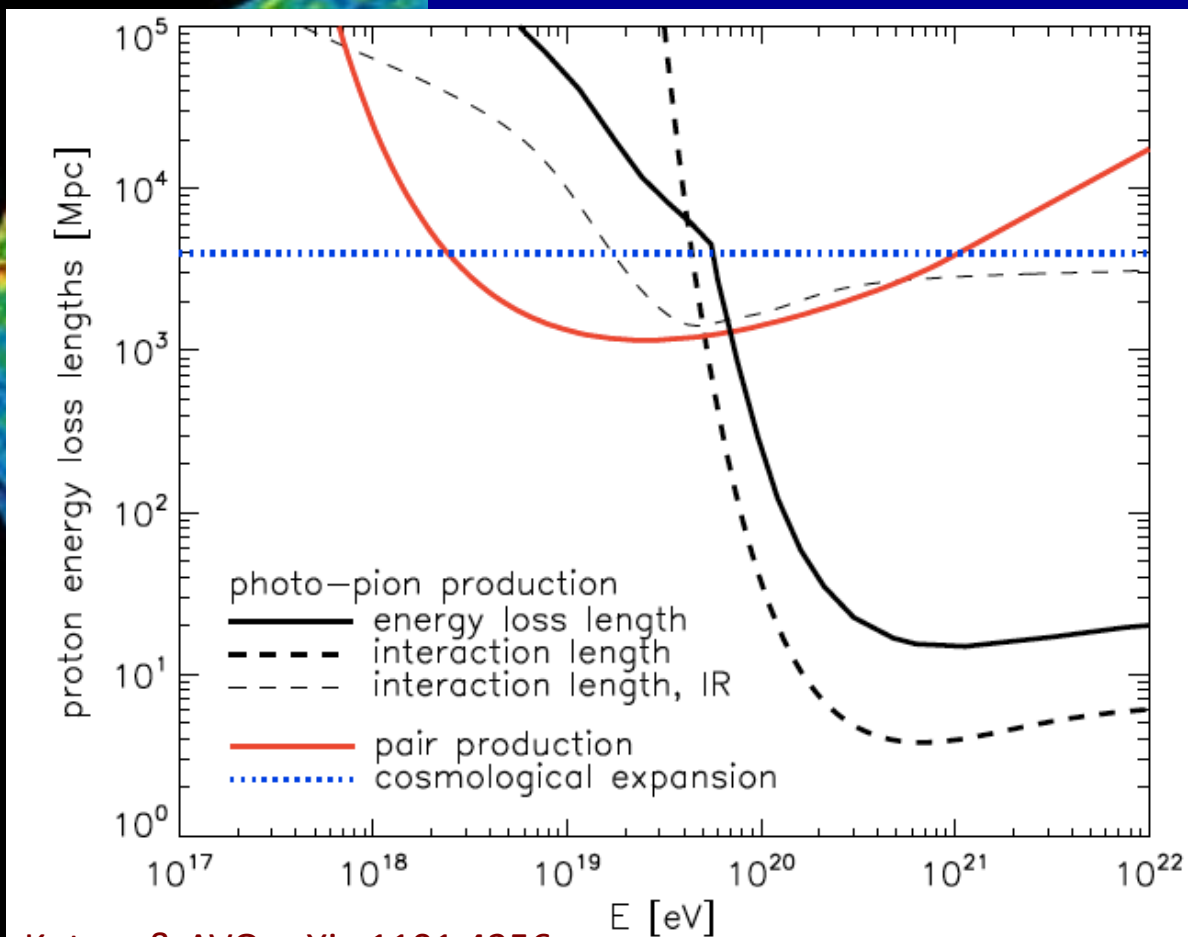
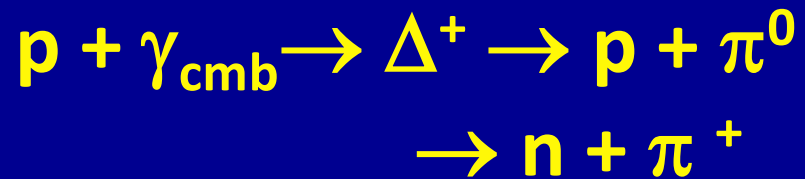


Kotera & AVO arXiv:1101.4256

GZK Cutoff

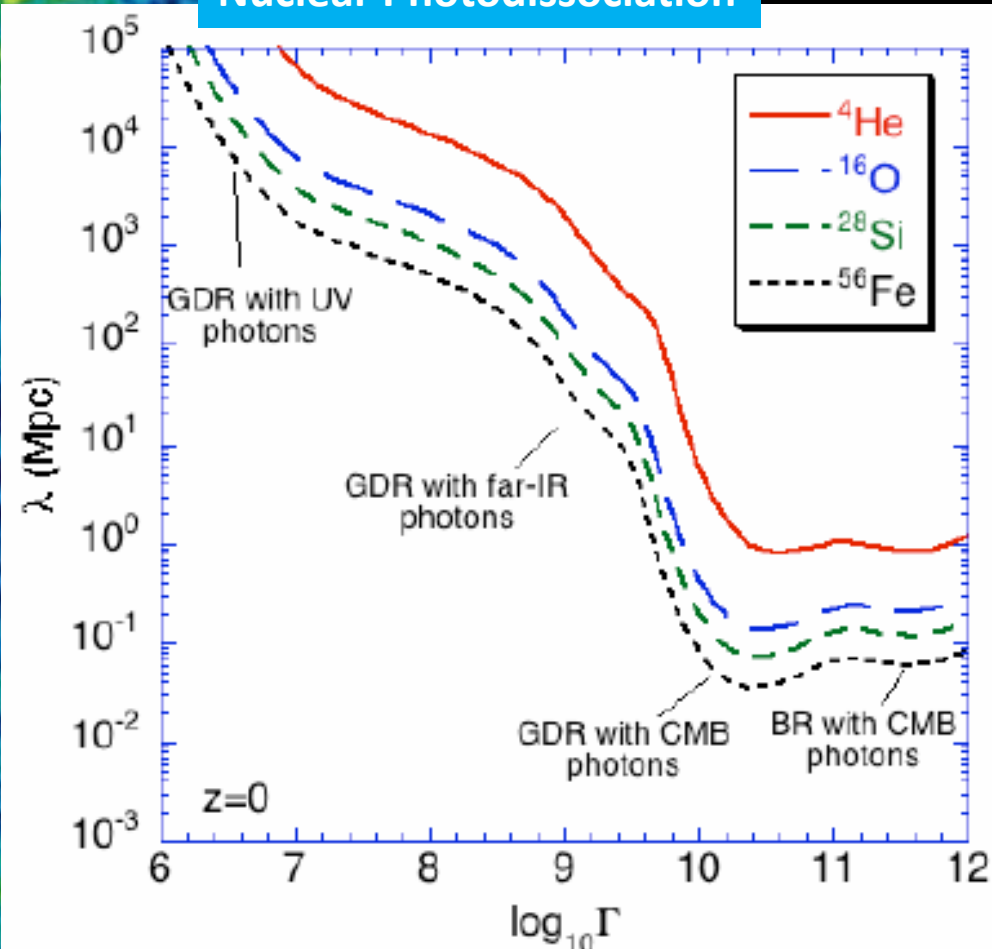
Greisen,
Zatsepin, Kuzmin
1966

Greisen-Zatsepin-Kuzmin Effect



Kotera & AVO arXiv:1101.4256

Nuclear Photodissociation

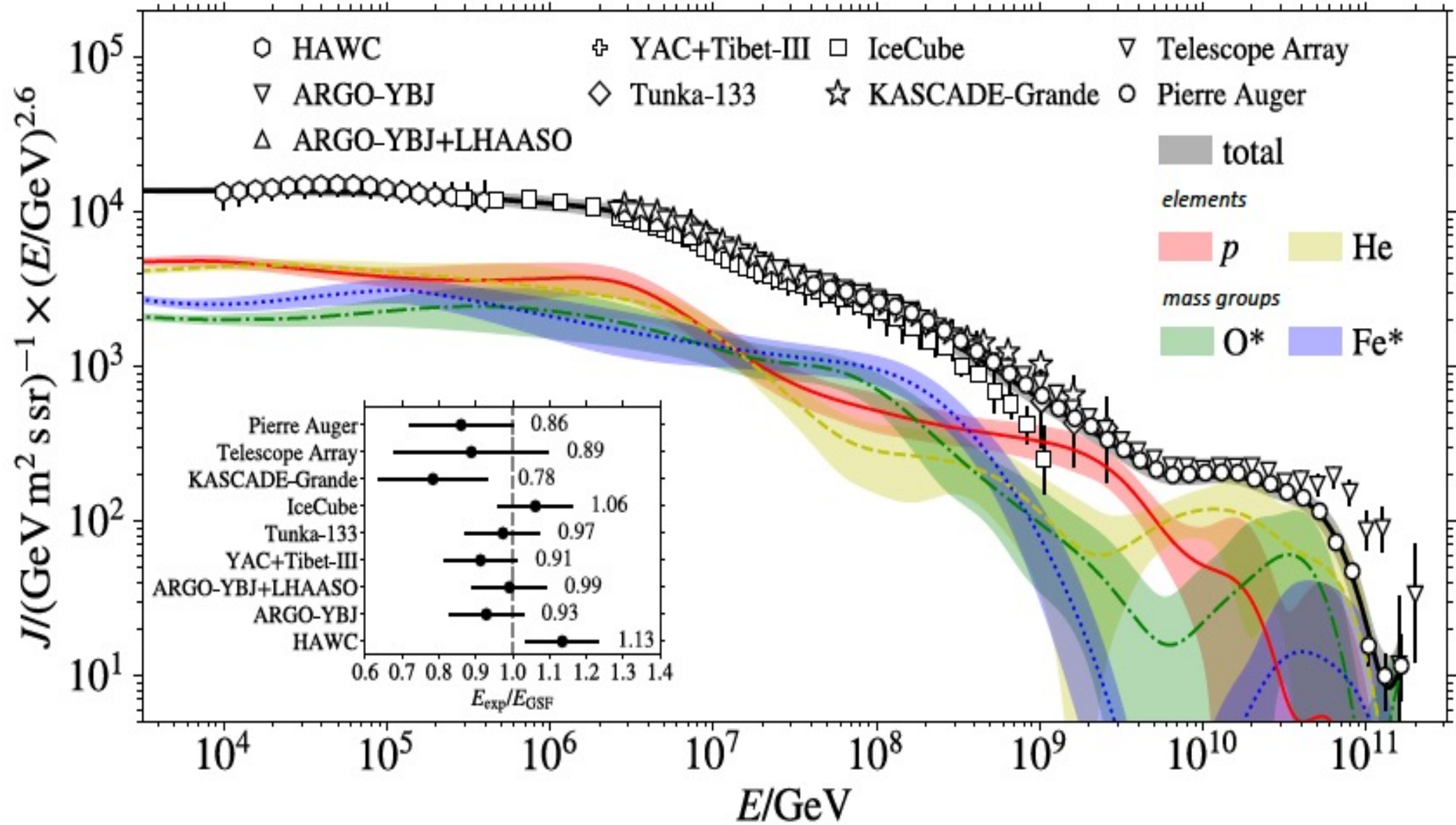


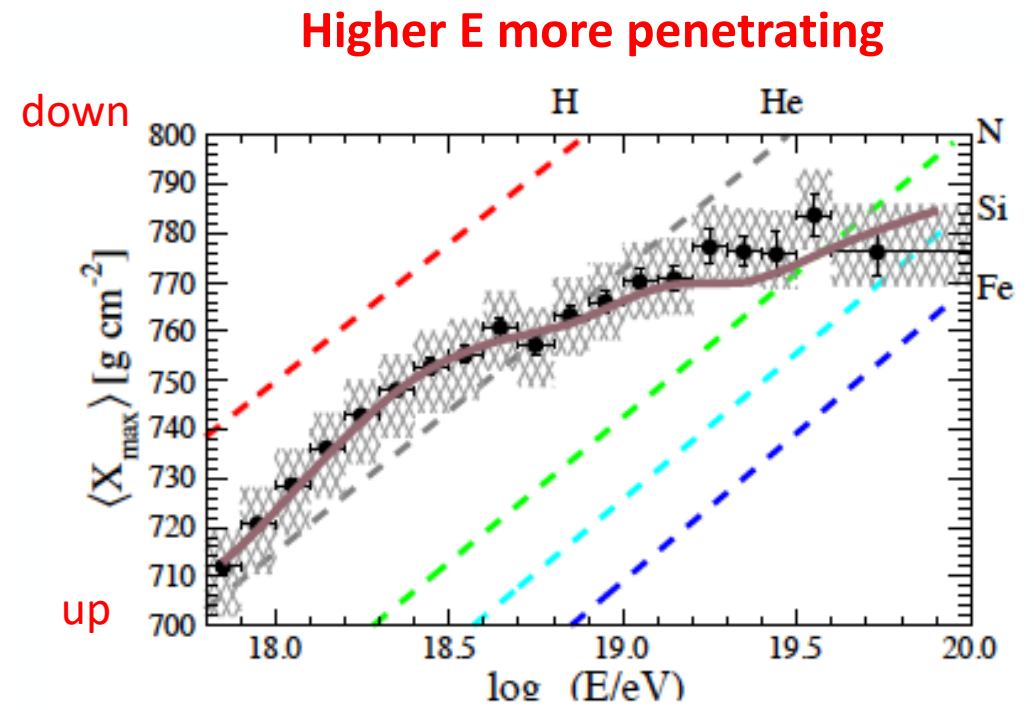
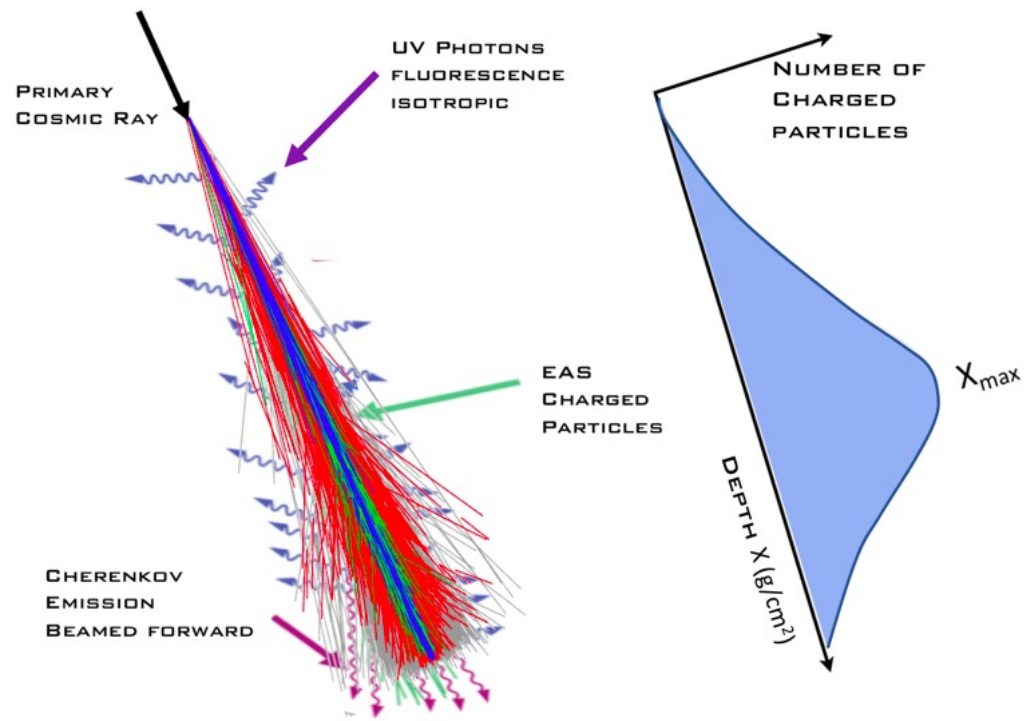
Allard, Busca, Deceprit, AVO, Parizot arXiv:0805.4779

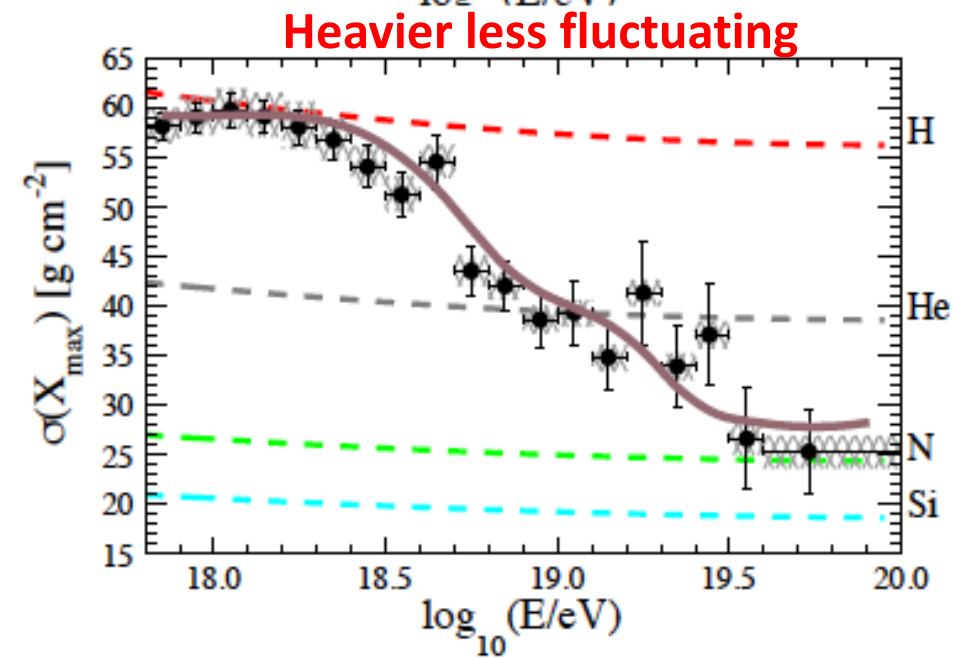
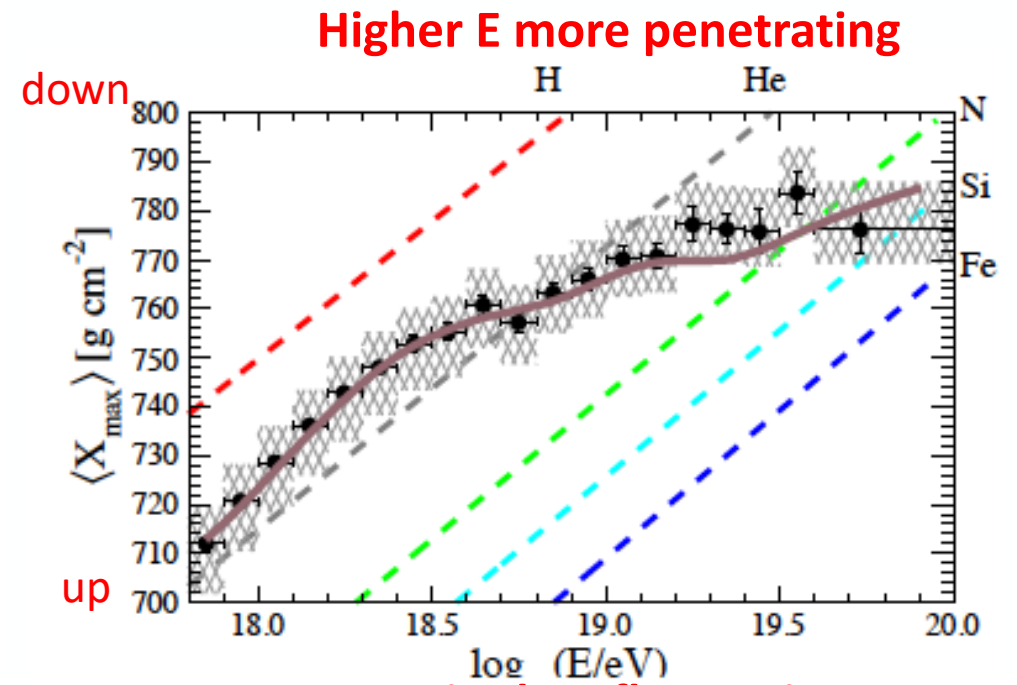
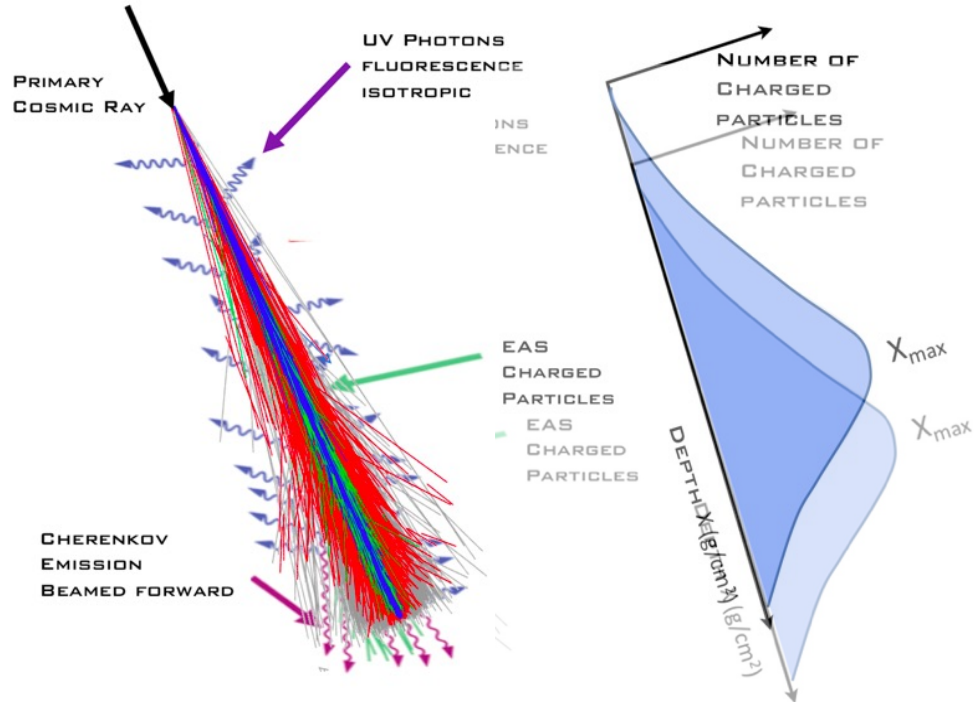
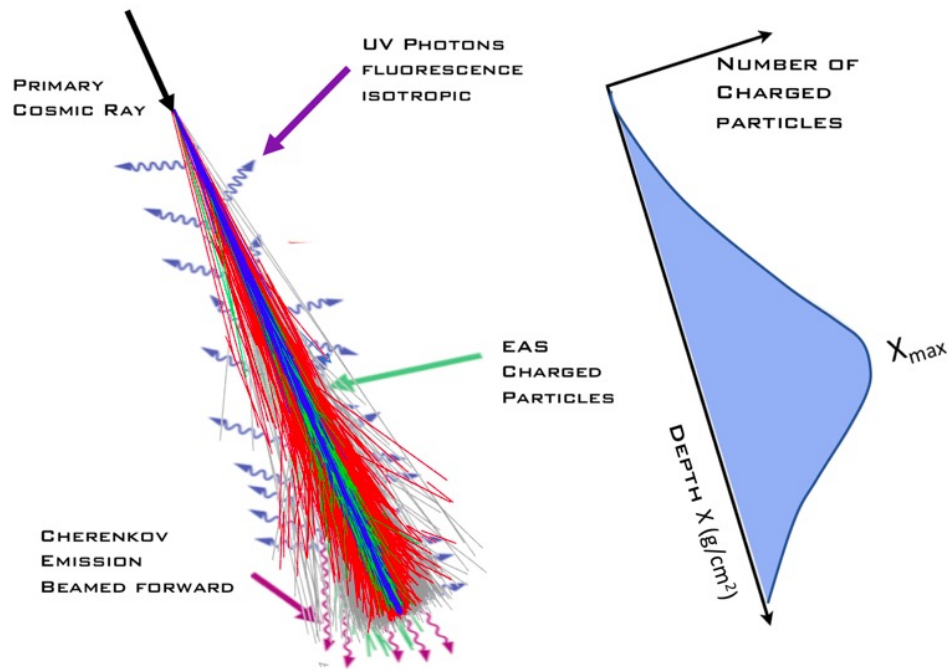
GDR: Giant Dipole Resonance

BR: Baryonic Resonances

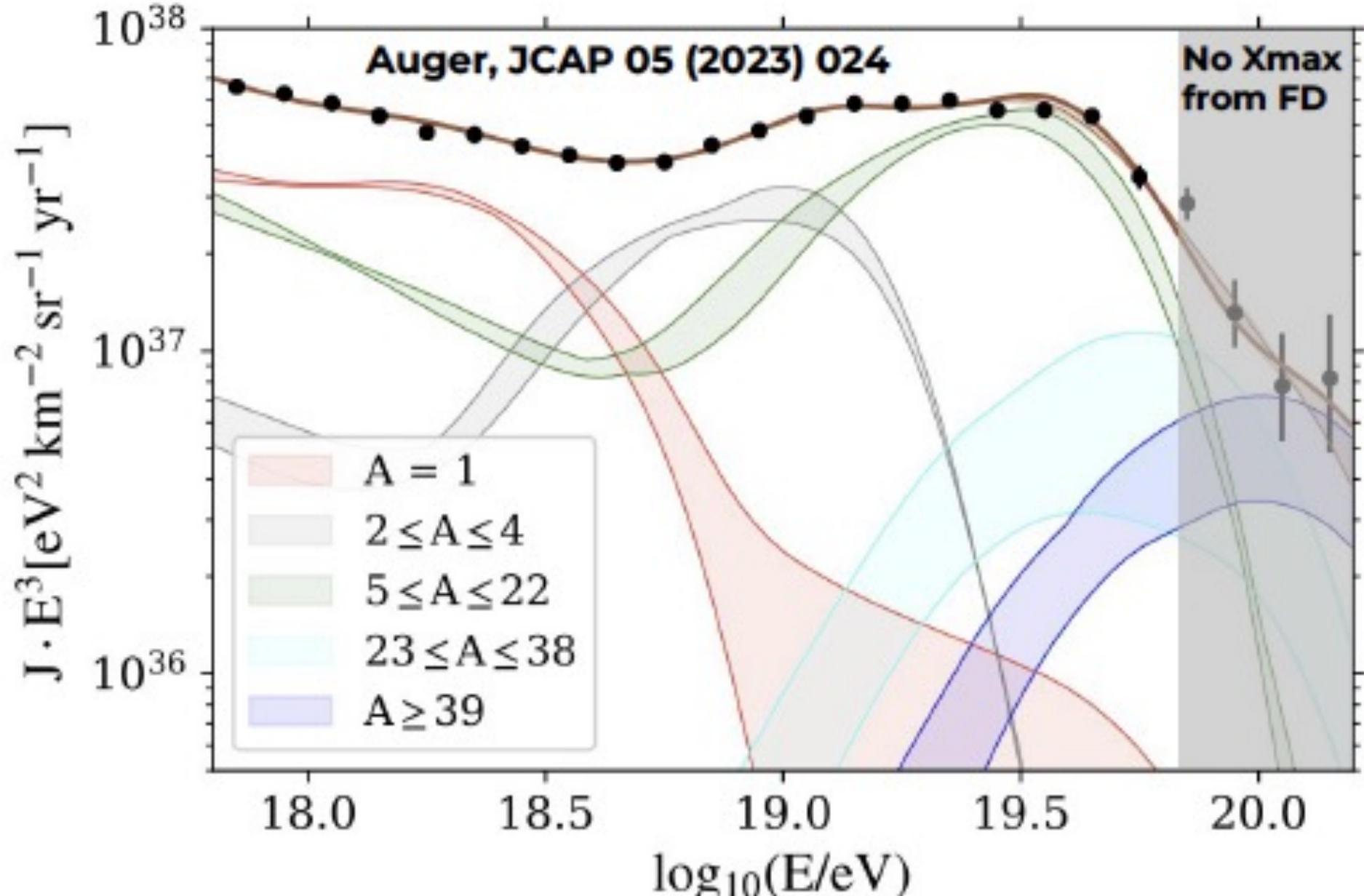
What is the composition of UHNECRs?



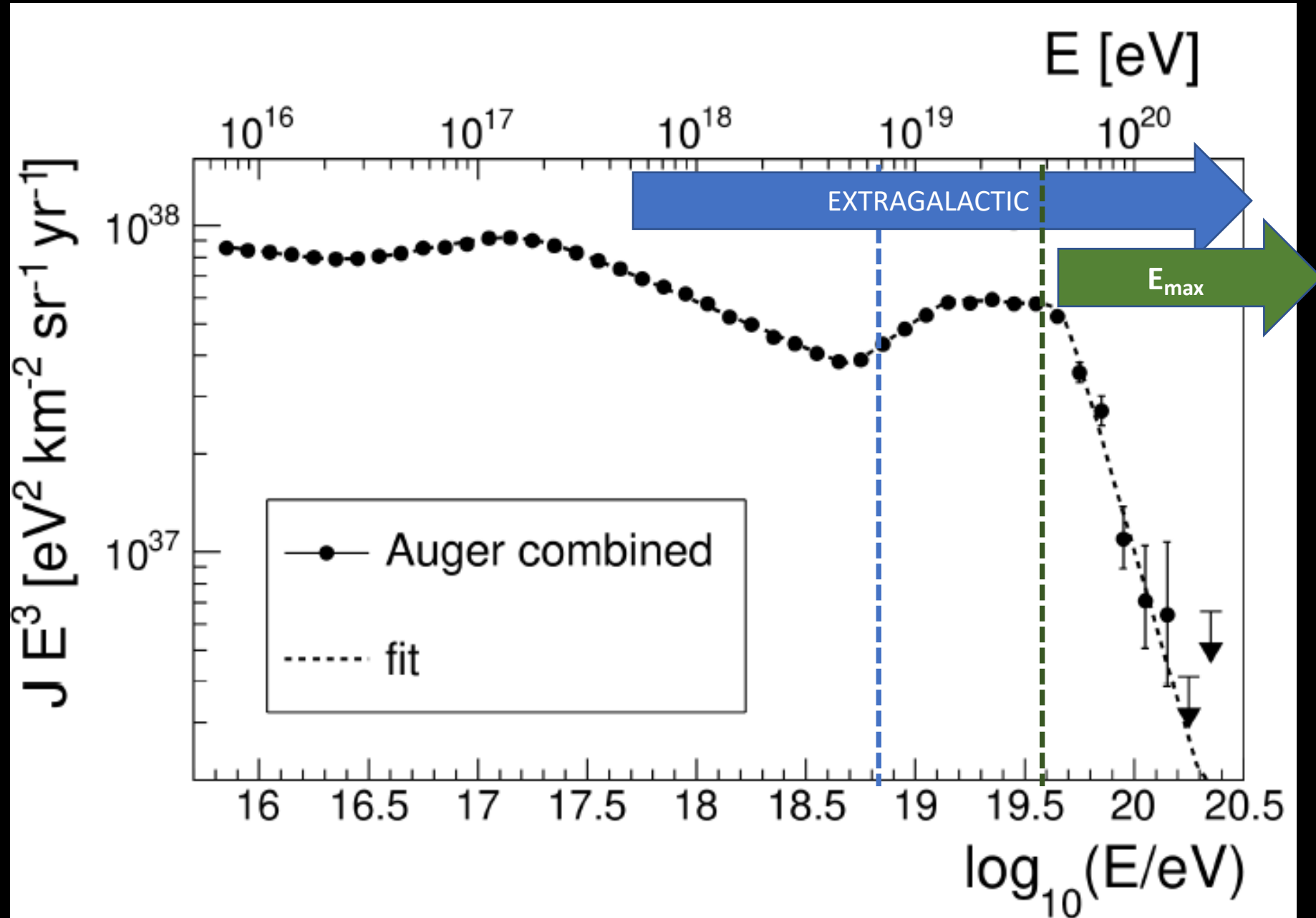




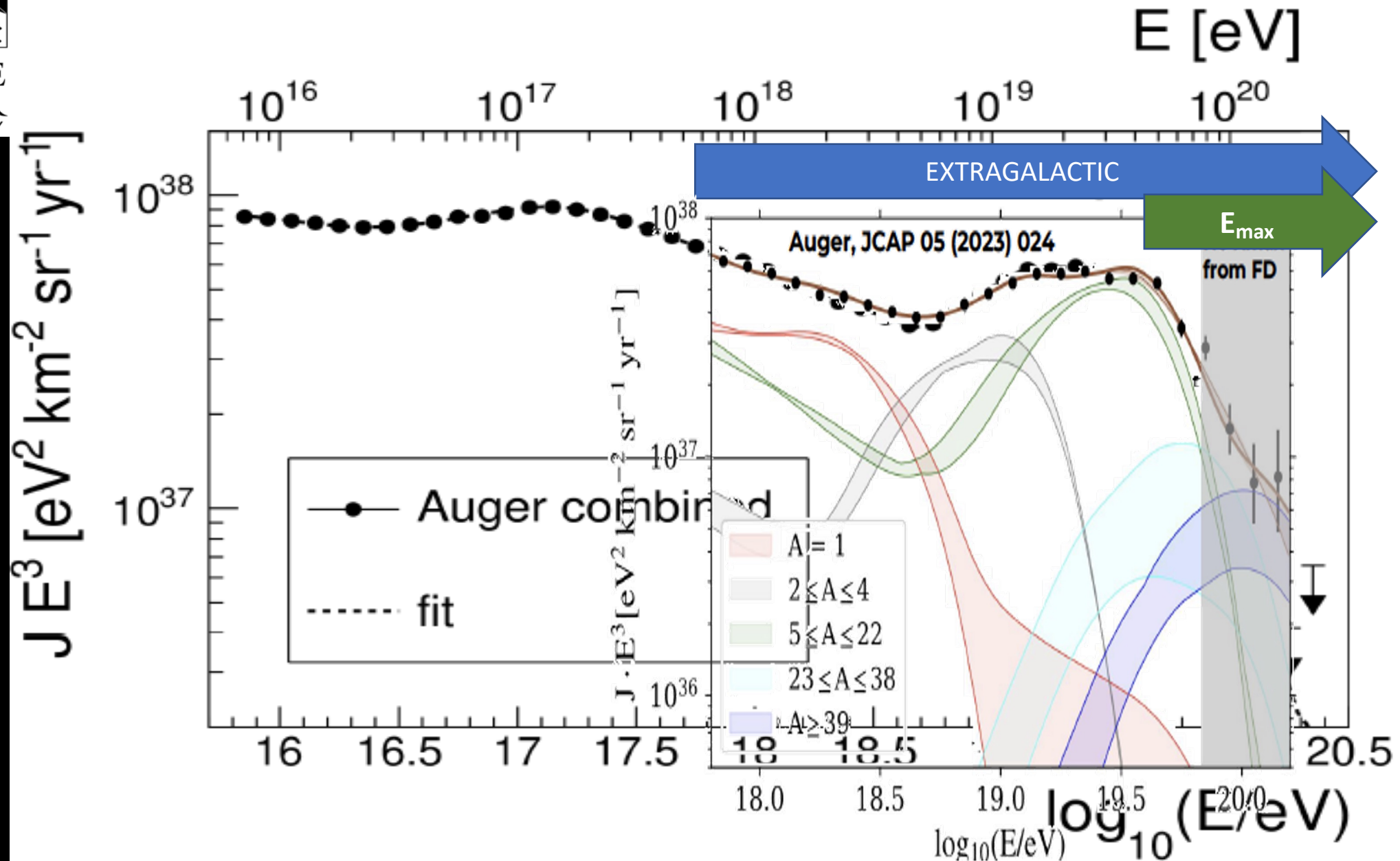
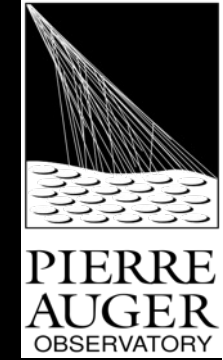
Auger Composition ICRC 2023



Auger Spectrum ICRC 2021



Auger Spectrum+Composition ICRC 2021

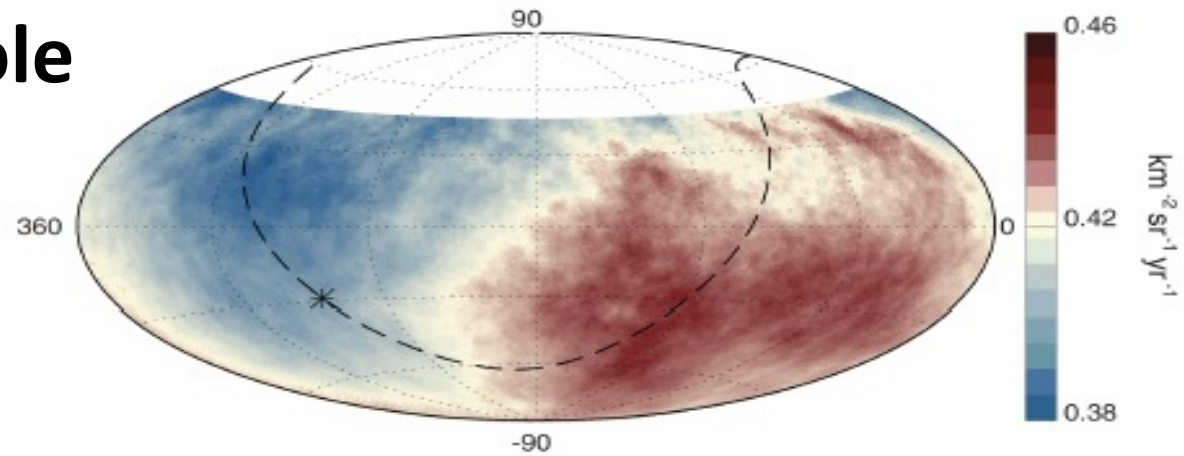


What is the sky distribution of arrival directions?

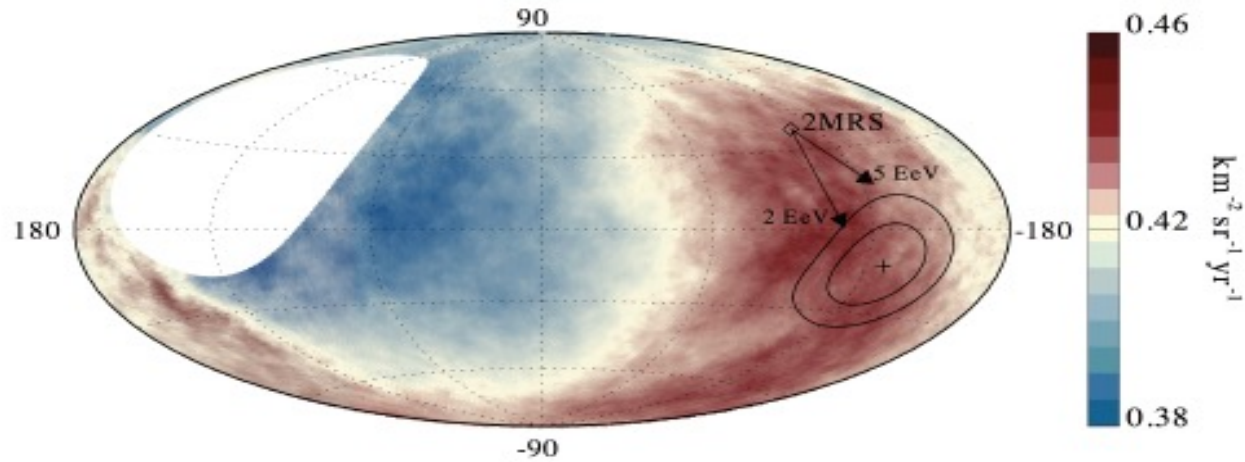
Auger Dipole

$E > 8 \text{ EeV}$, 6.5%

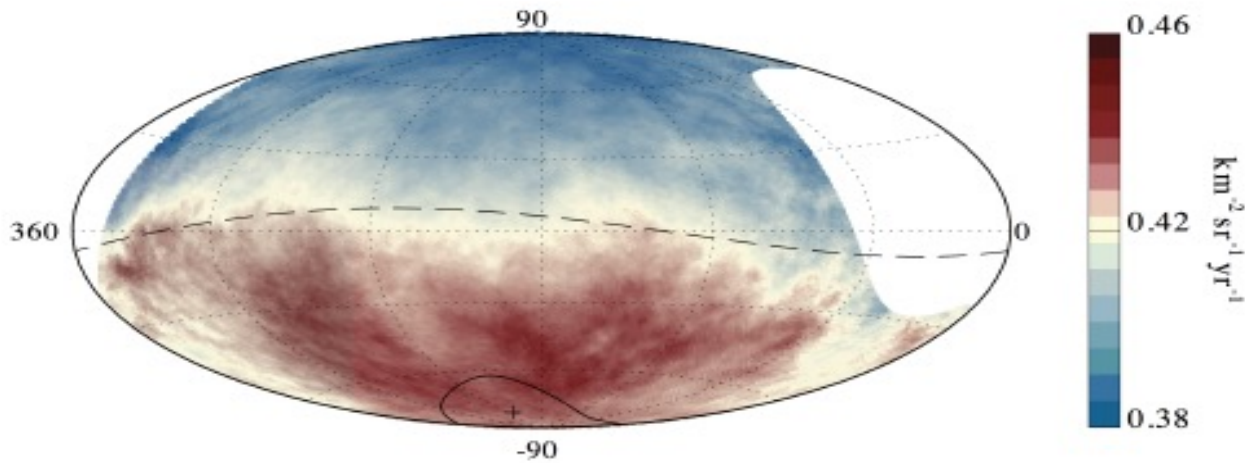
Equatorial



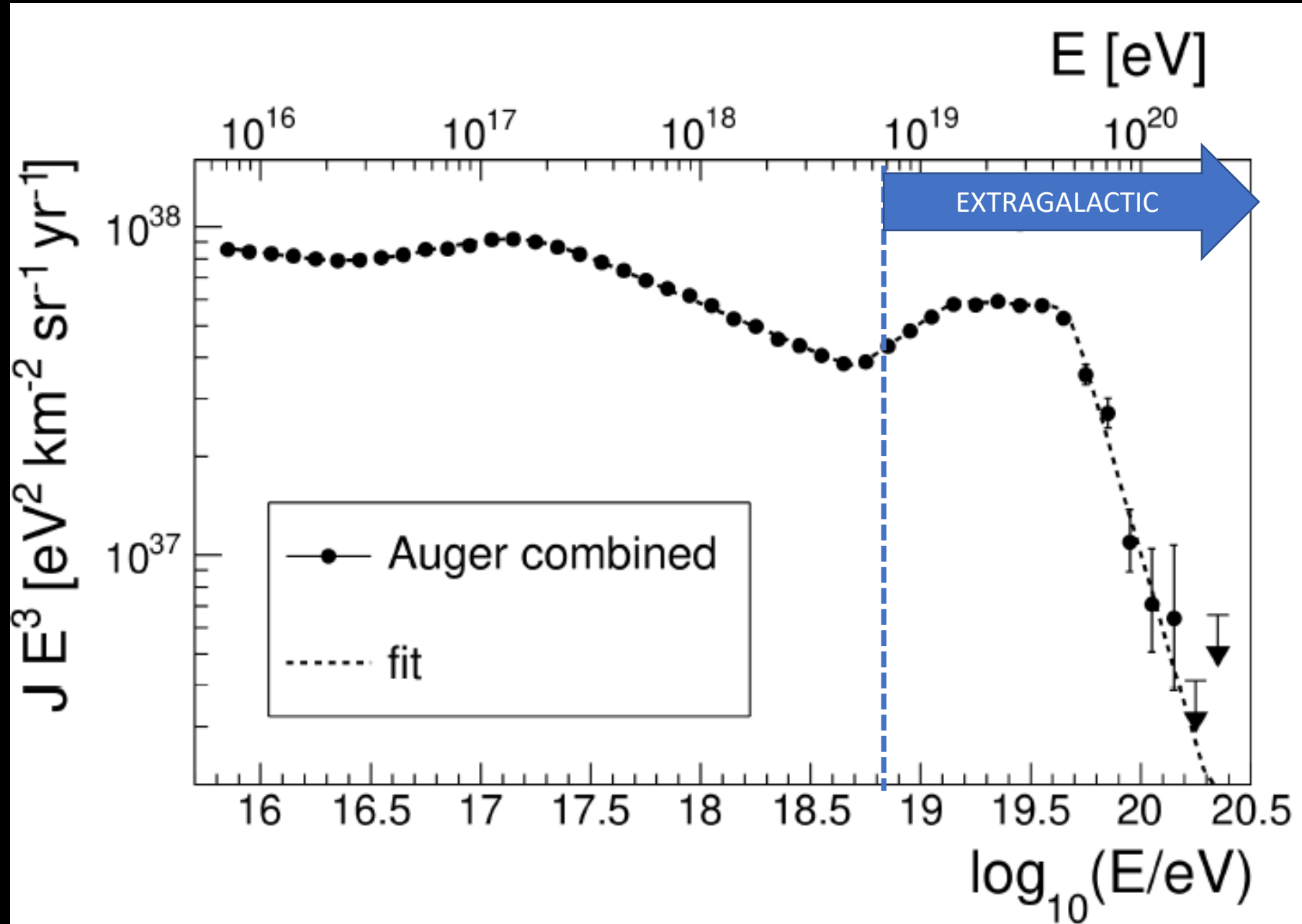
Galactic



Super Galactic



Auger Spectrum ICRC 2021



Where are the neutrino and gamma-ray secondaries?

Cosmogenic (GZK, BZ*) Neutrinos & Photons

$$\begin{aligned} p + \gamma_{\text{cmb}} &\rightarrow \Delta^+ \rightarrow p + \pi^0 \rightarrow \gamma\gamma \\ &\rightarrow n + \pi^+ \end{aligned}$$

$$\begin{aligned} n &\rightarrow p + e^- + \nu_e \\ \pi^+ &\rightarrow \mu^+ + \nu_\mu \\ \mu^+ &\rightarrow e^+ + \nu_e + \nu_\mu \end{aligned}$$

*Berezinsky & Zatsepin '69

Cosmogenic Messengers

