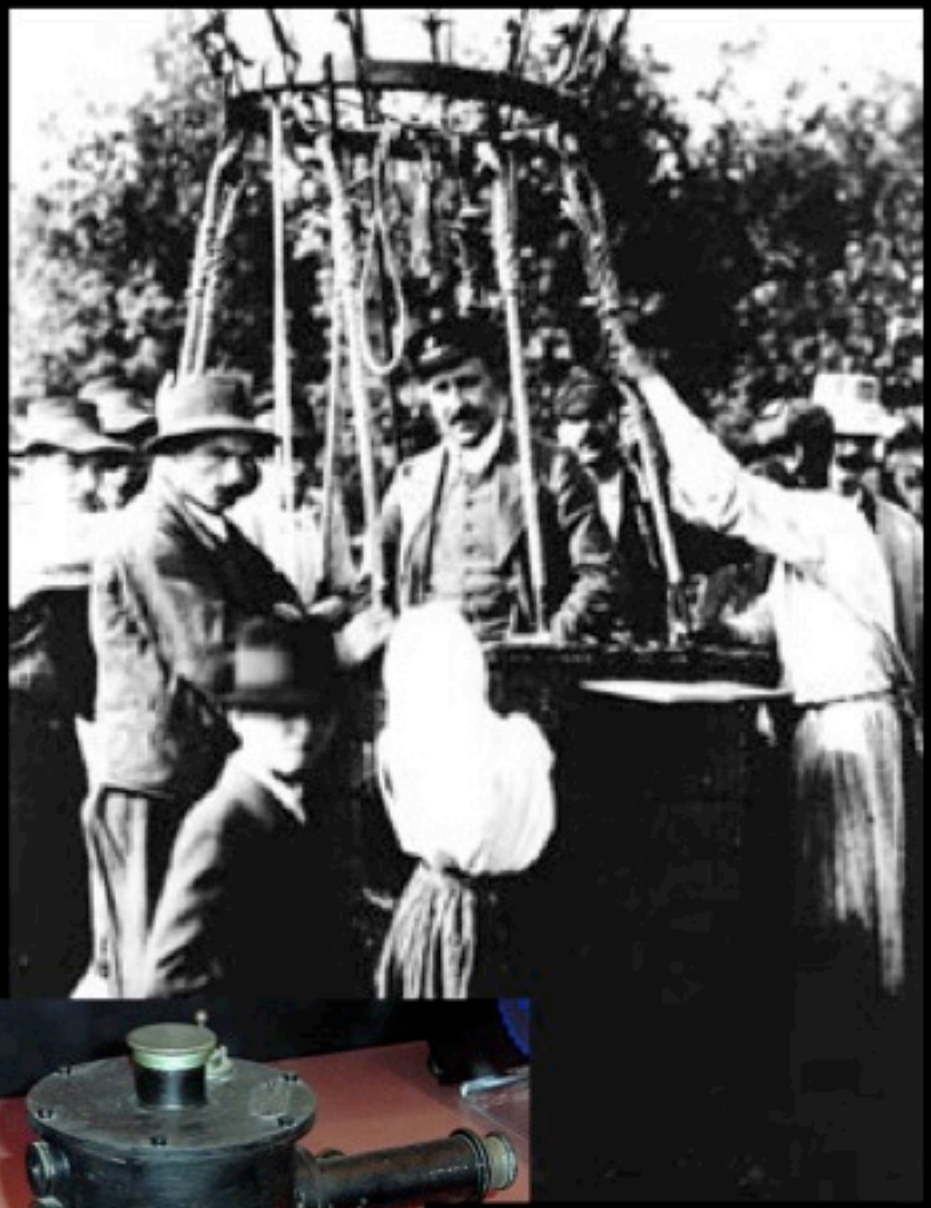
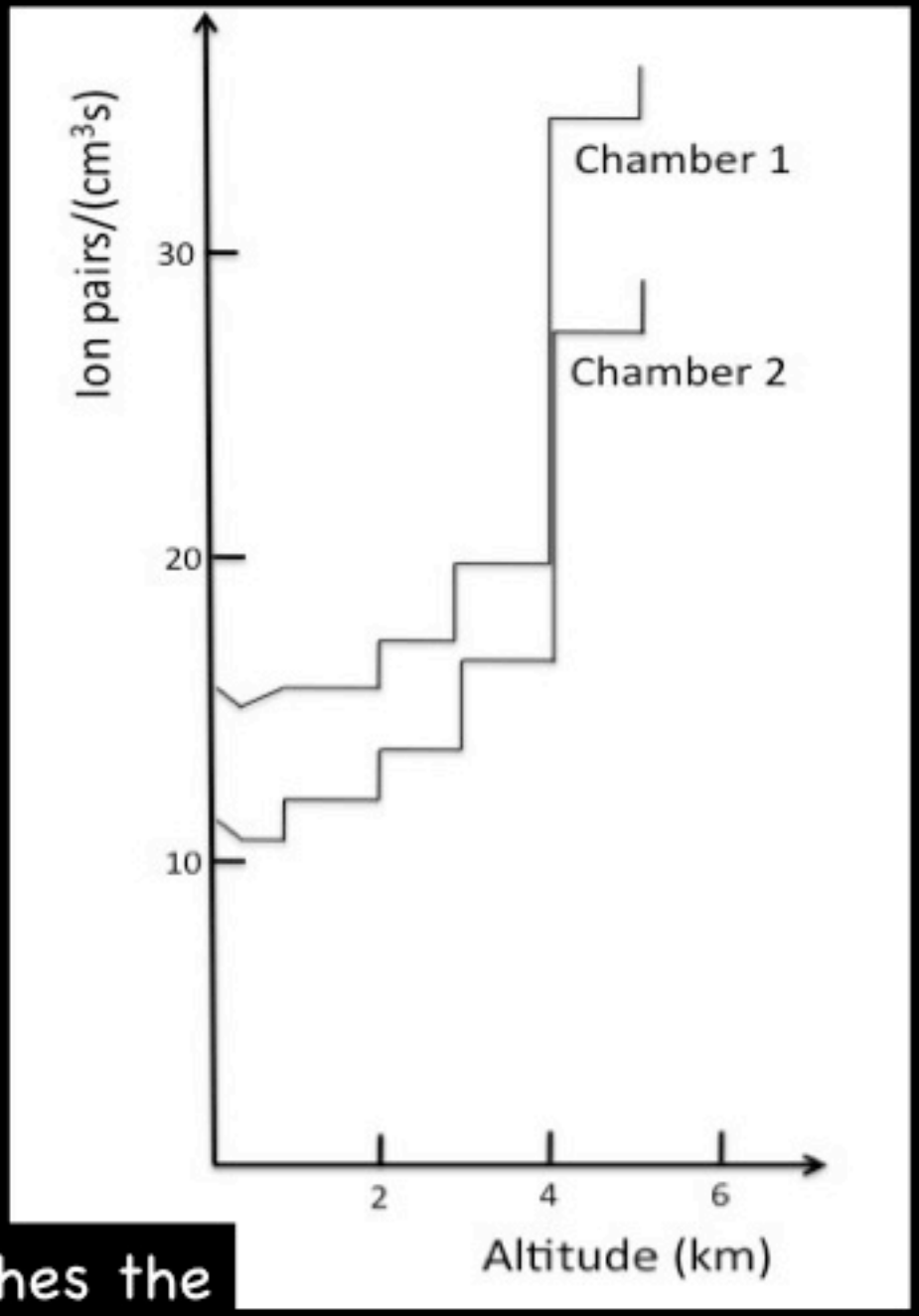
News from the Extreme Energy Cliff!

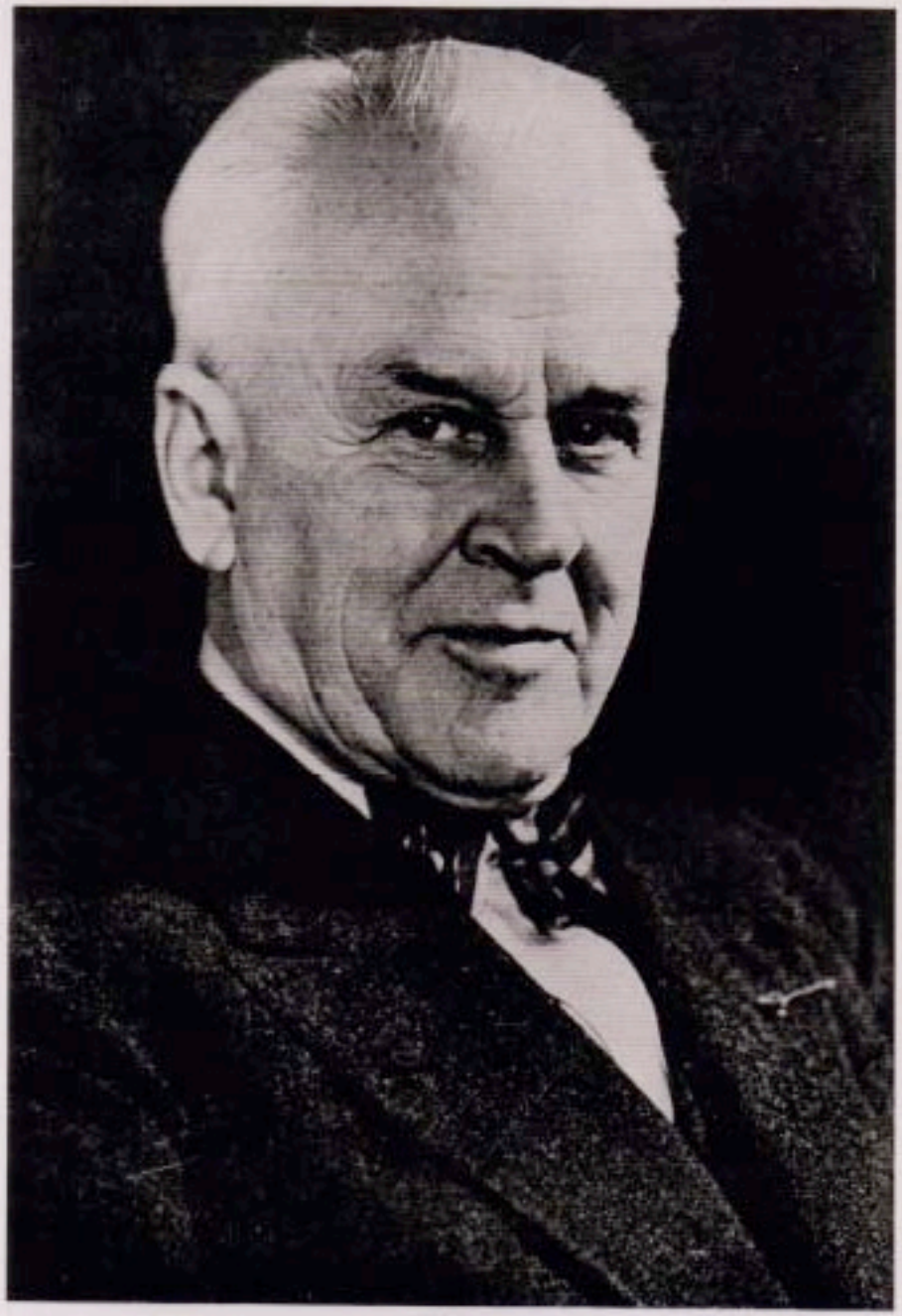
Angela V. Olinto
The University of Chicago

1912



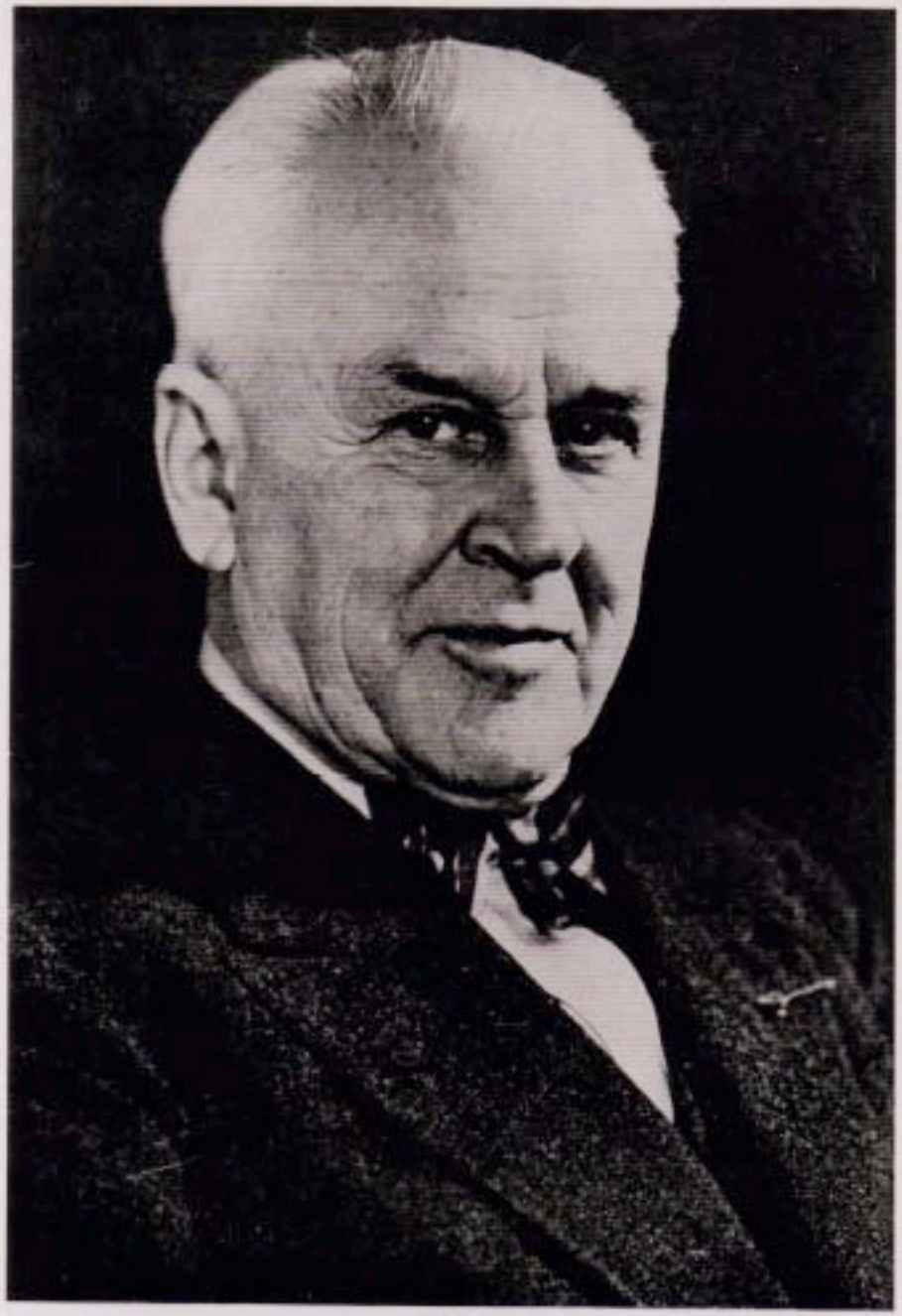


Victor Hess establishes the cosmic nature of ionizing radiation



ROBERT A. MILLIKAN

Millikan:
Cosmic Rays



ROBERT A. MILLIKAN

Compton:

Cosmic Rays = ***Charged Particles***

Millikan:

Cosmic Rays = Gamma-rays

The New York Times

VOL. LXXXI...No. 27,370. December 31, 1932

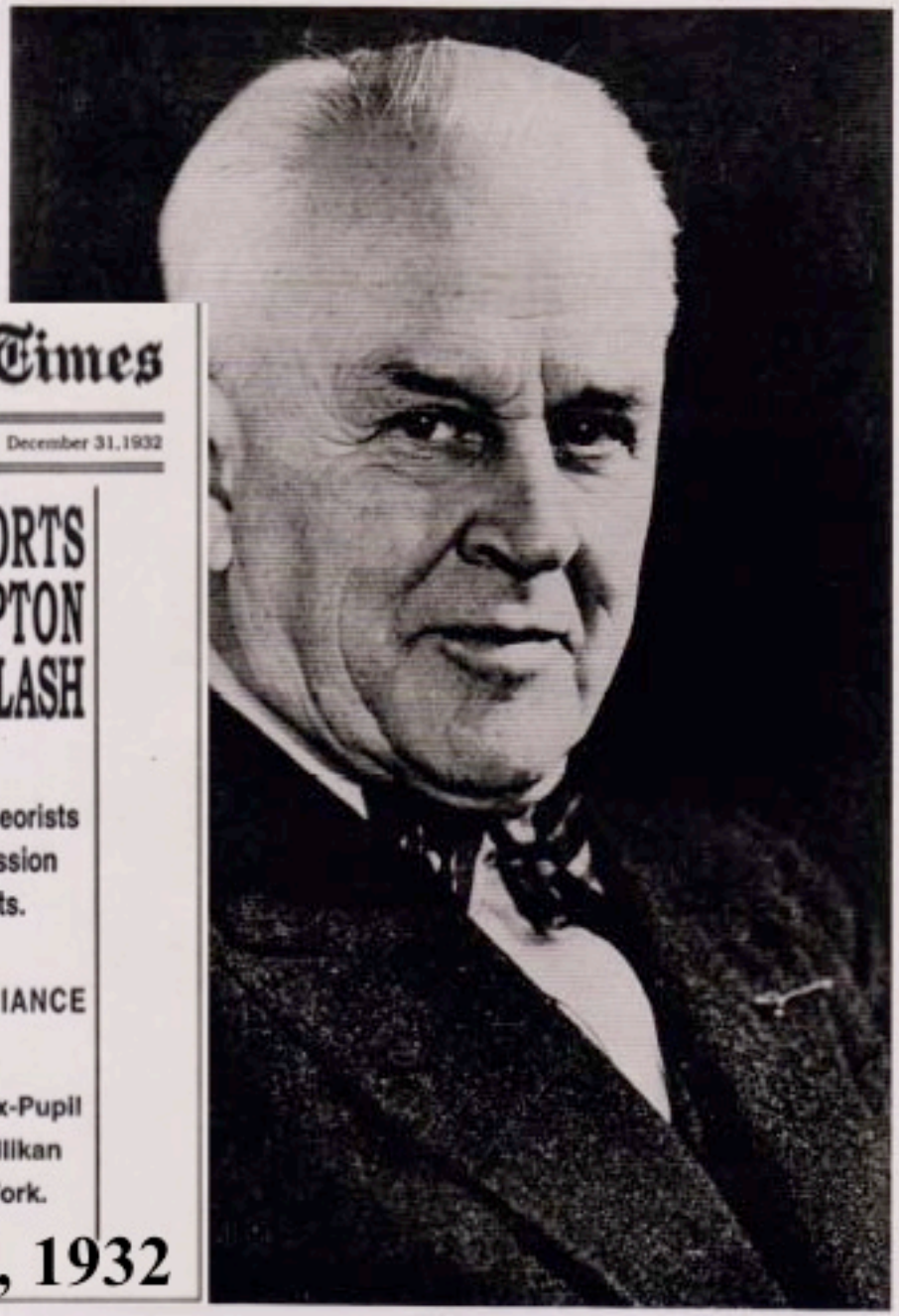
MILLIKAN RETORTS HOTLY TO COMPTON IN COSMIC RAY CLASH

Debate of Rival Theorists Brings Drama to Session of Nation's Scientists.

THEIR DATA AT VARIANCE

New Findings of His Ex-Pupil Lead to Thrust by Millikan at 'Less Cautious' Work.

NYT: December 31, 1932

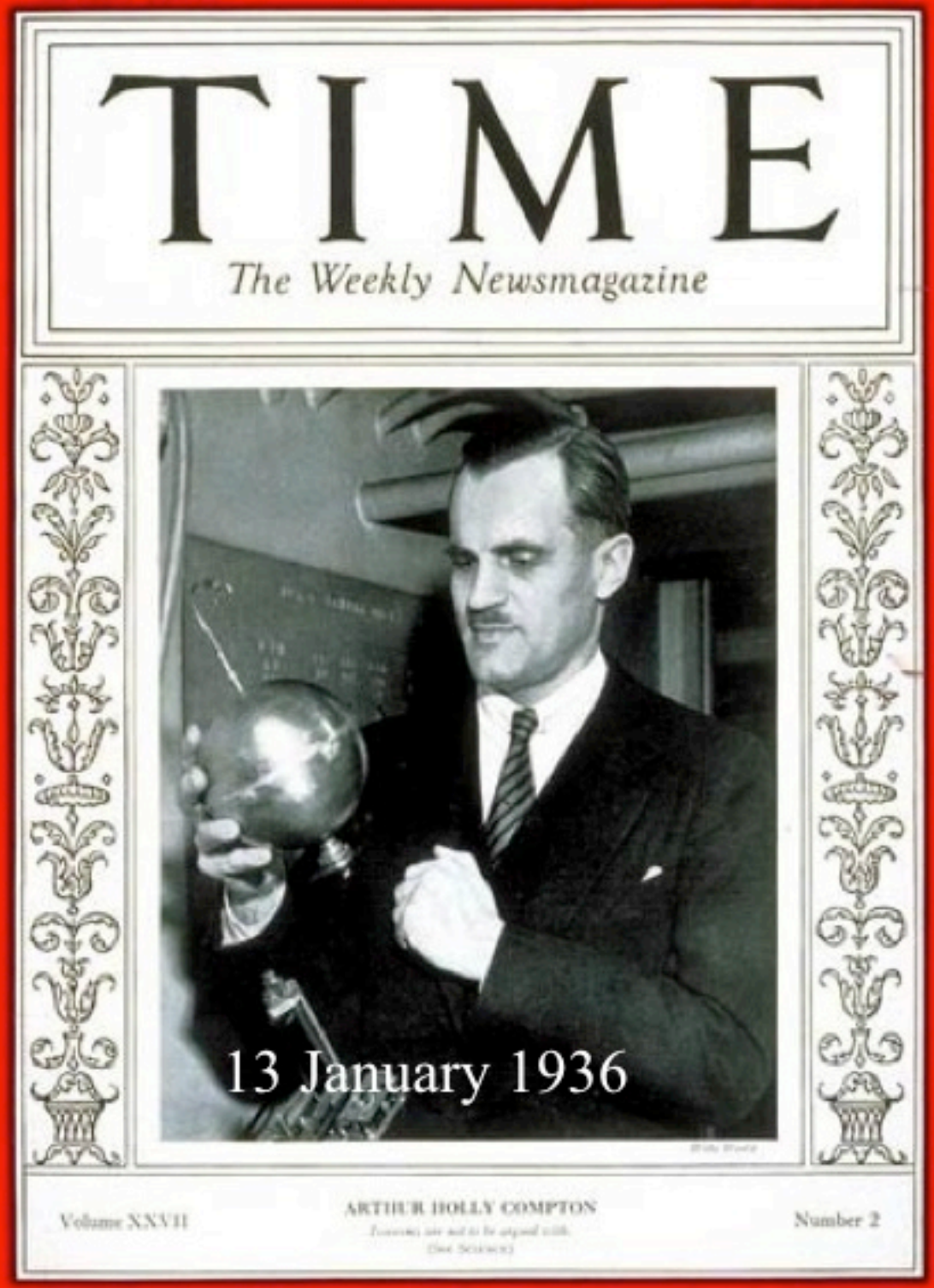


ROBERT A. MILLIKAN

Compton:
Cosmic Rays = Charged Particles

Millikan:
Cosmic Rays = Gamma-rays

NYT: D



Compton:

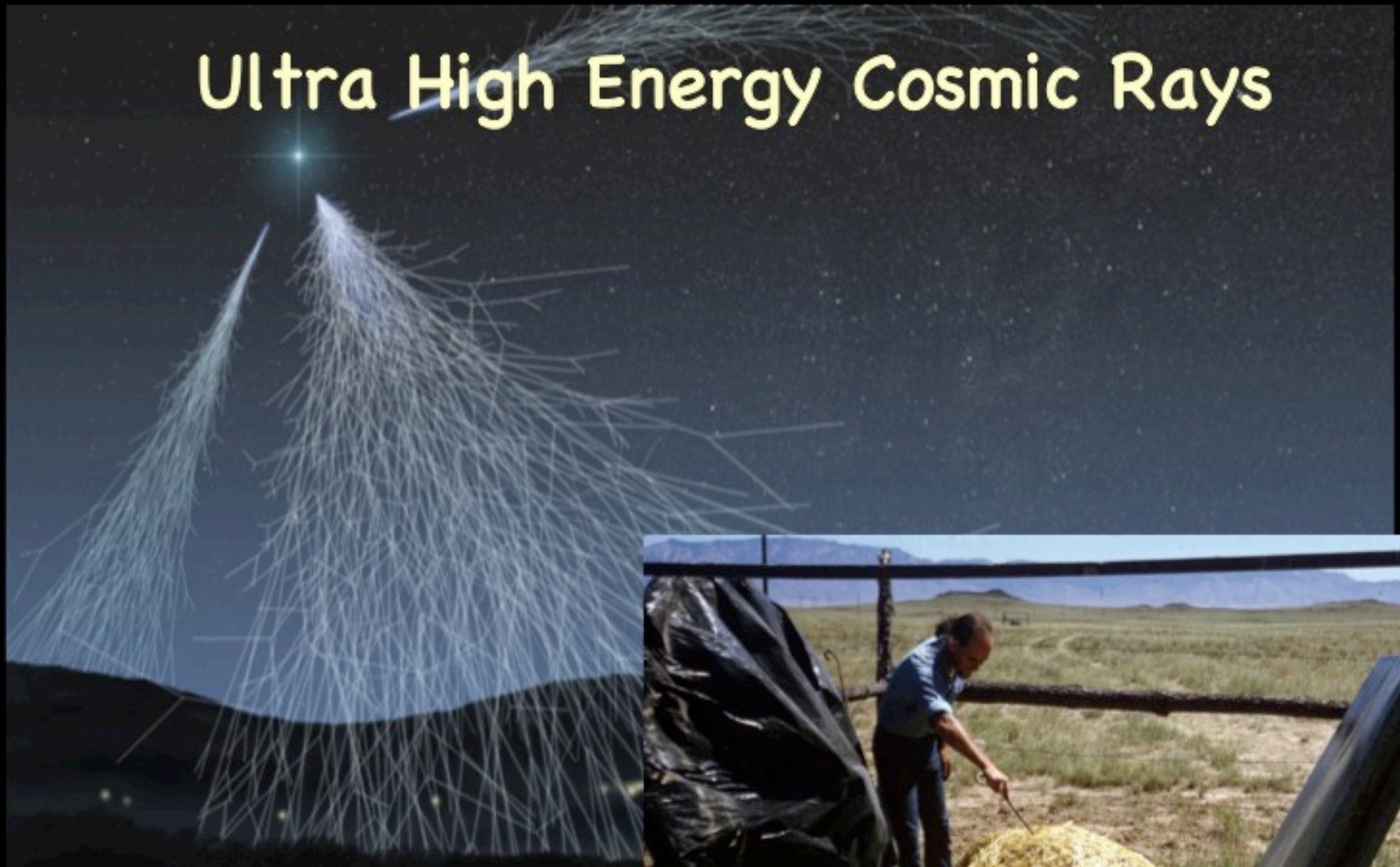
Cosmic Rays = Charged

Extensive Air Showers

1937: Pierre Auger

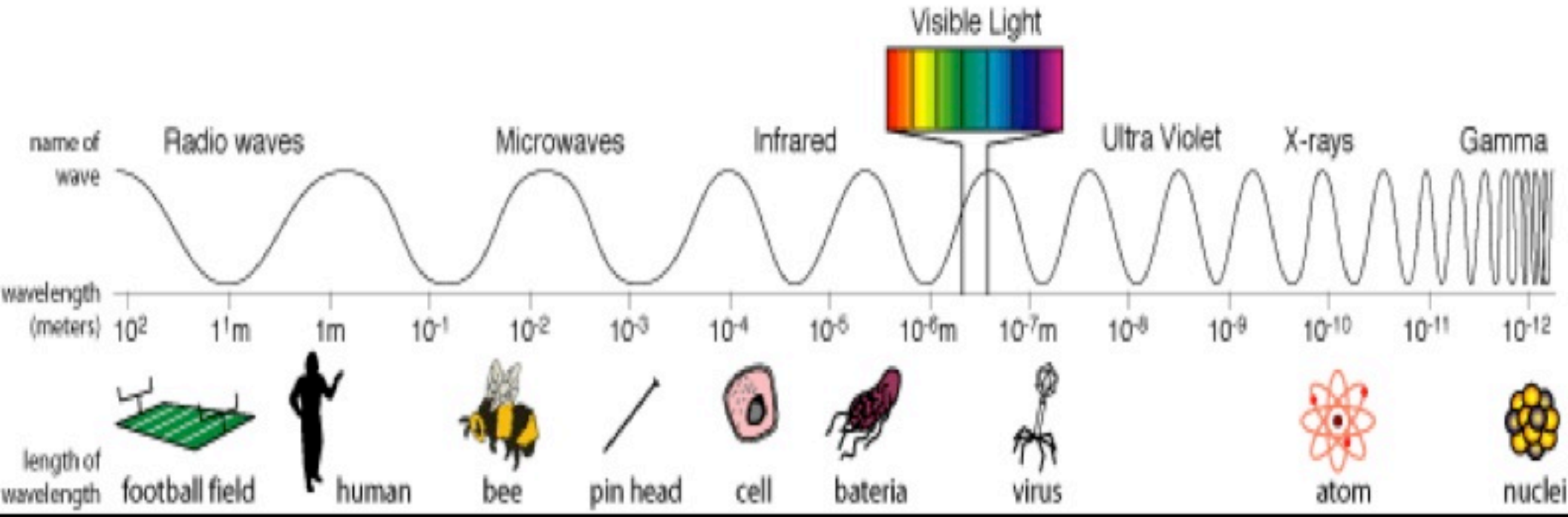
~ 10^{15} eV

Ultra High Energy Cosmic Rays



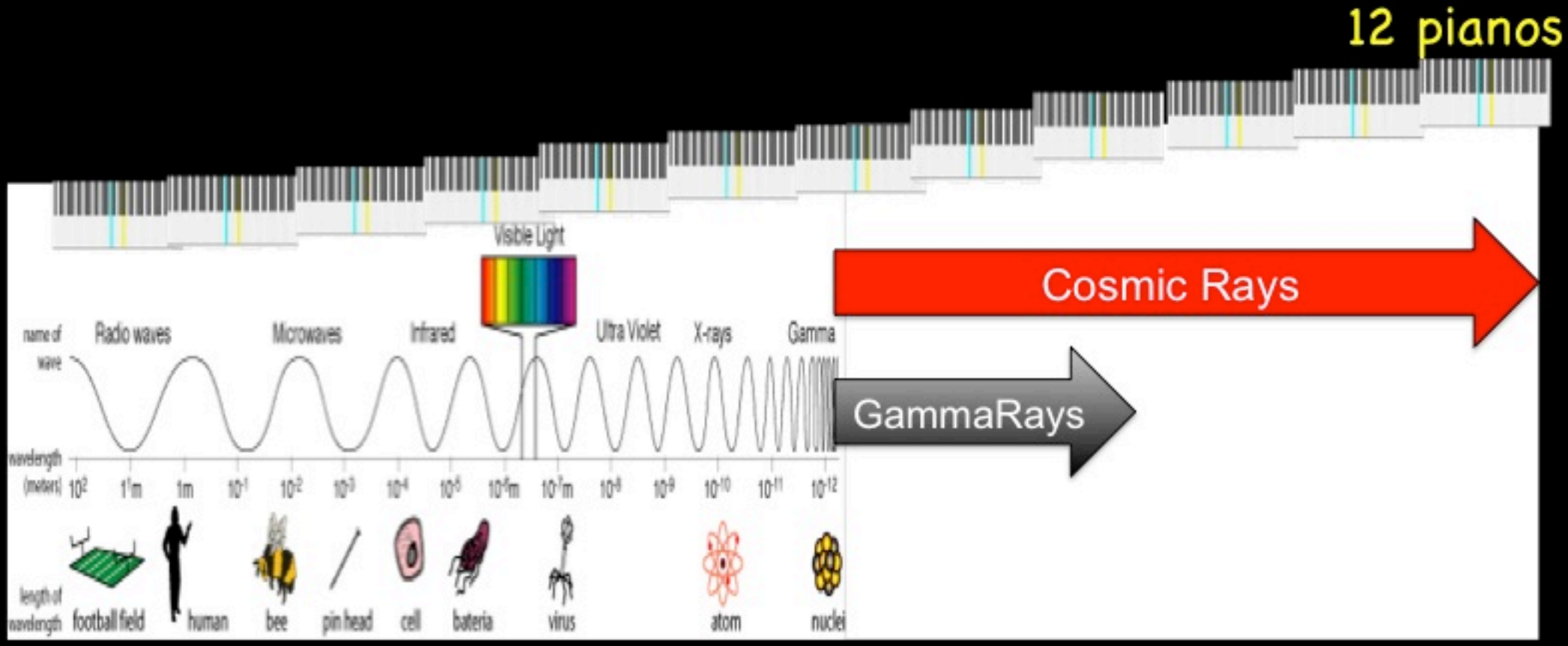
1962 John Linsley
10^{20} eV event

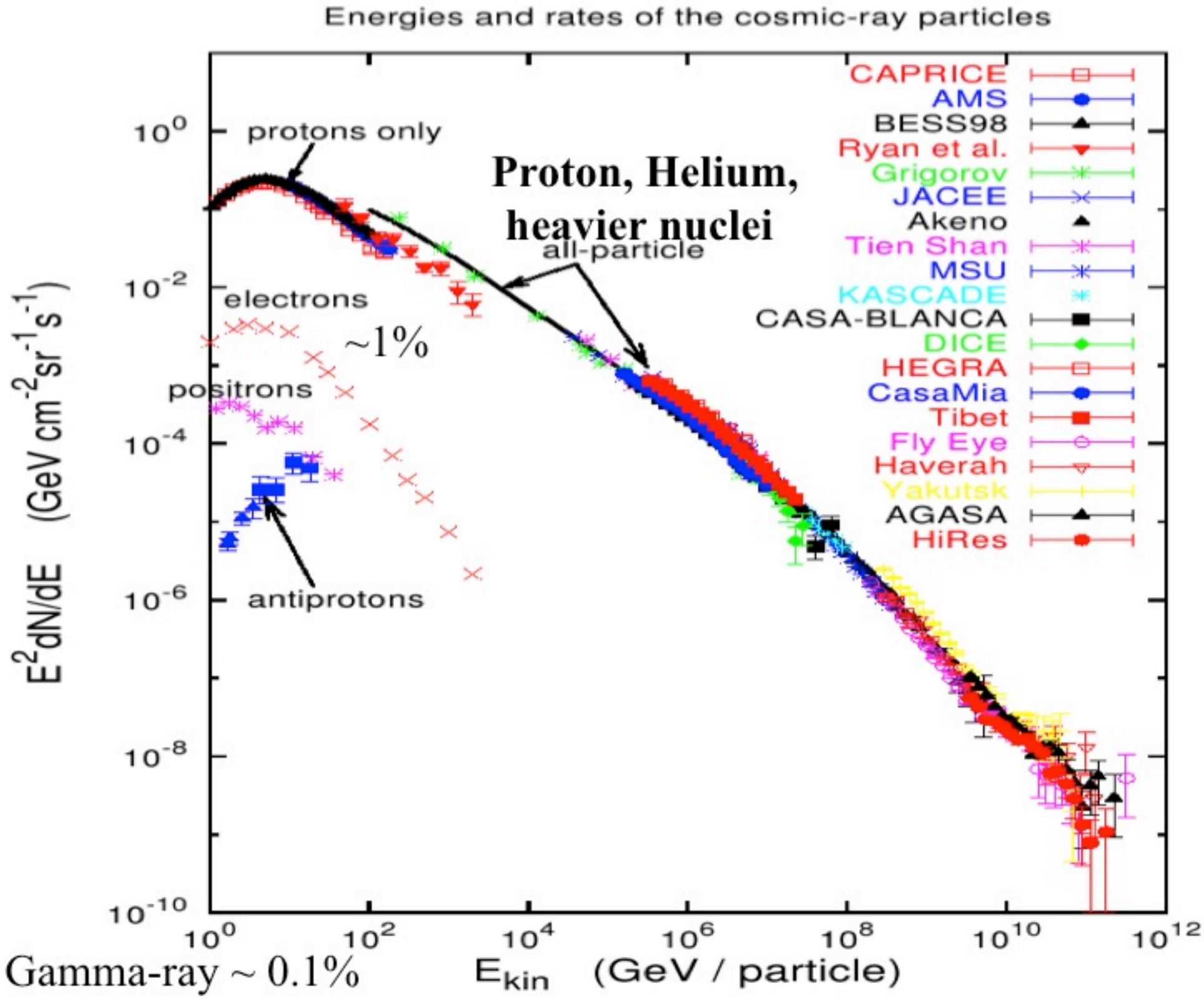
Photon "energy range"

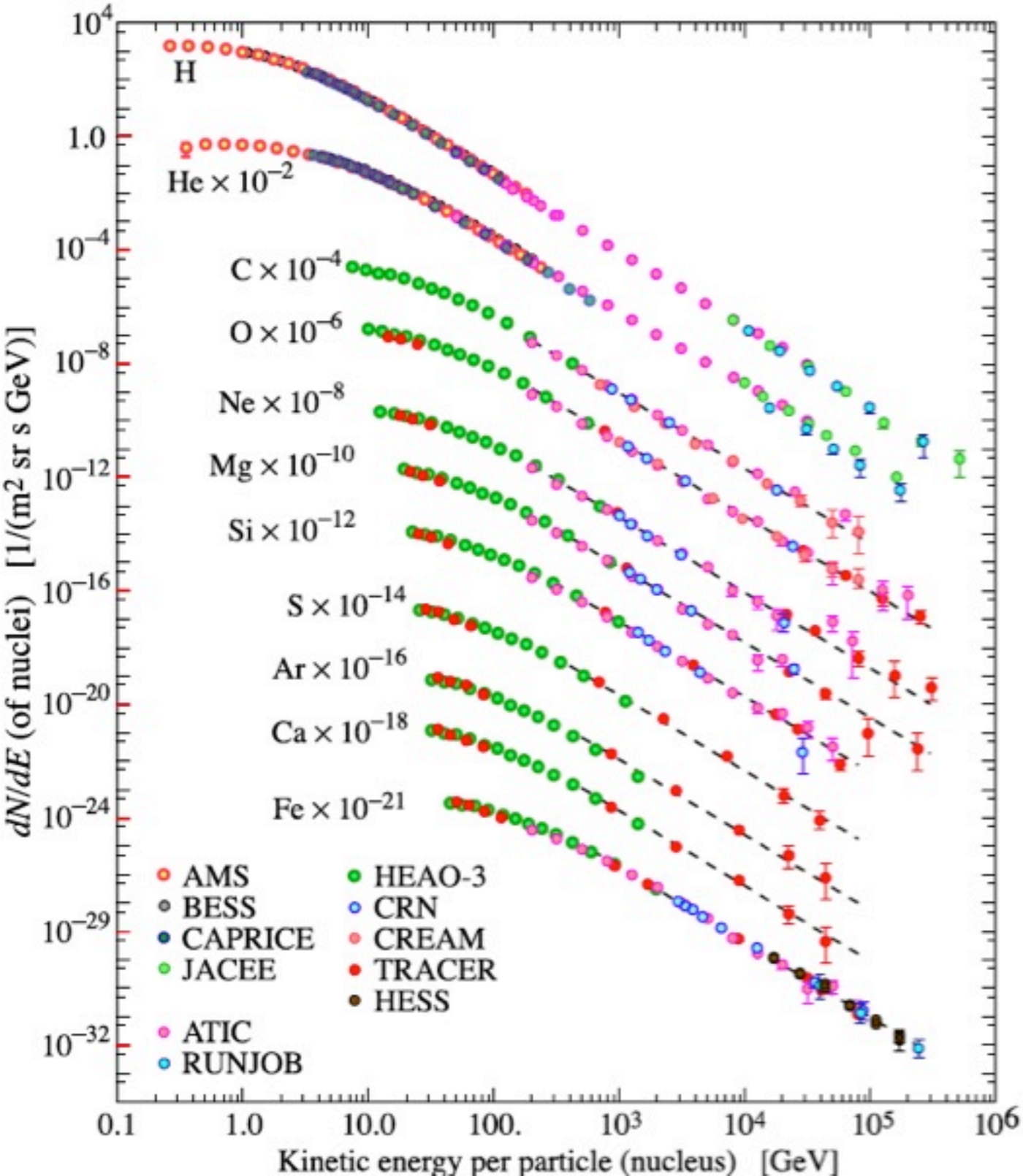


Energy range of Cosmic Rays

+ 12 orders of magnitude
from 0.1 GeV to 0.3 ZeV or from 10^8 to 10^{20} eV




Energies and rates of the cosmic-ray particles
protons only
Proton, Helium,
heavier nuclei
all-particle
electrons
~1%
positrons
antiprotons
CAPRICE
AMS
BESS98
Ryan et al.
Grigorov
JACEE
Akeno
Tien Shan
MSU
KASCADE
CASA-BLANCA
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
Yakutsk
AGASA
HiRes
$E^2 dN/dE$ (GeV cm^{-2}sr^{-1}s^{-1})
E_{kin} (GeV / particle)
Gamma-ray ~ 0.1%

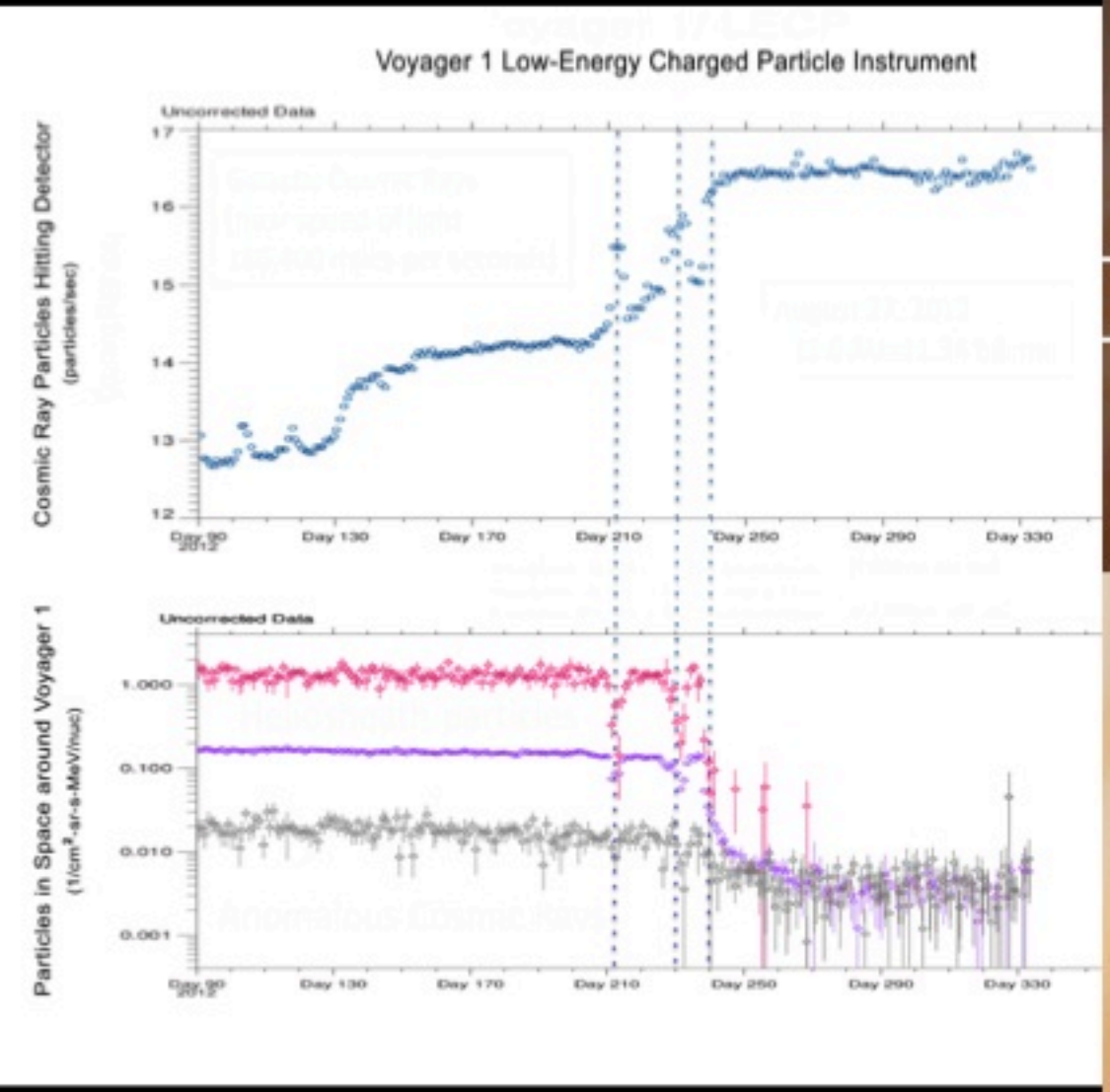

H
He × 10^−2
C × 10^−4
O × 10^−6
Ne × 10^−8
Mg × 10^−10
Si × 10^−12
S × 10^−14
Ar × 10^−16
Ca × 10^−18
Fe × 10^−21
AMS
BESS
CAPRICE
JACEE
ATIC
RUNJOB
HEAO-3
CRN
CREAM
TRACER
HESS
dN/dE (of nuclei) [1/(m² sr s GeV)]
Kinetic energy per particle (nucleus) [GeV]

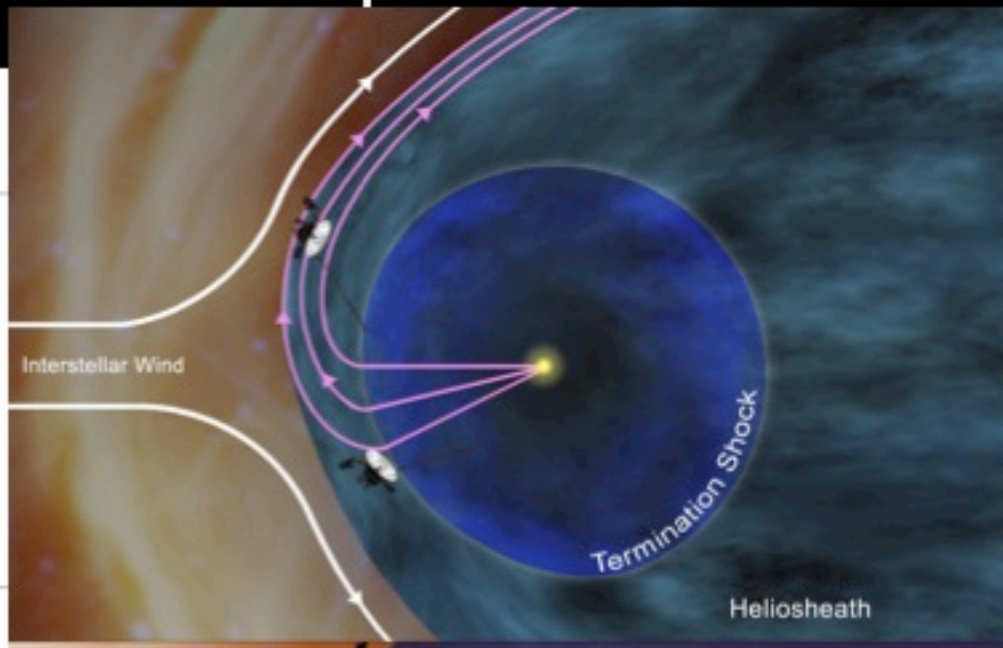
Recent Highlights at lower energies

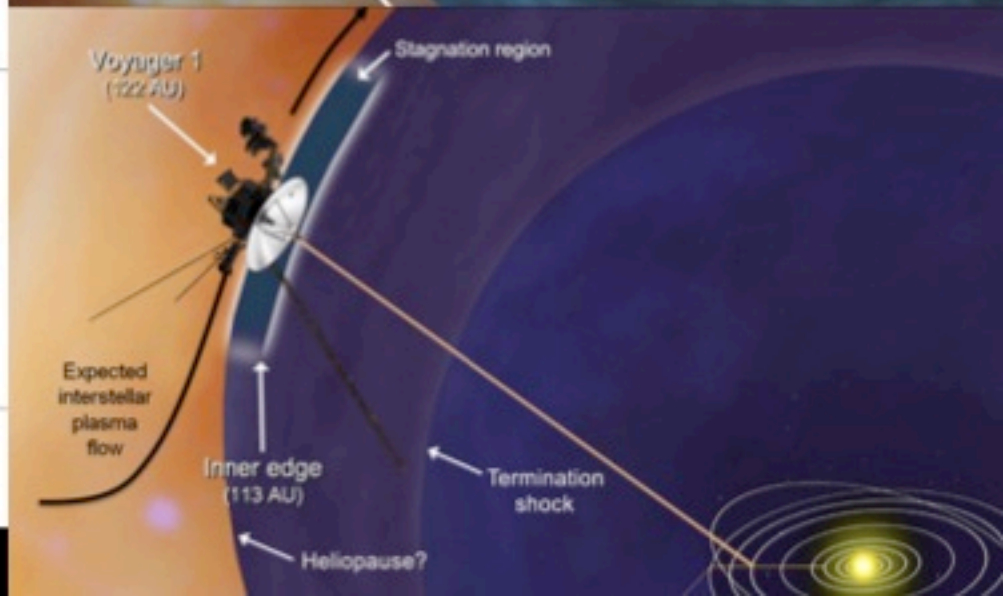
Voyager 1 (Dec. 2012)

reached 'the magnetic highway'

on its way to interstellar space







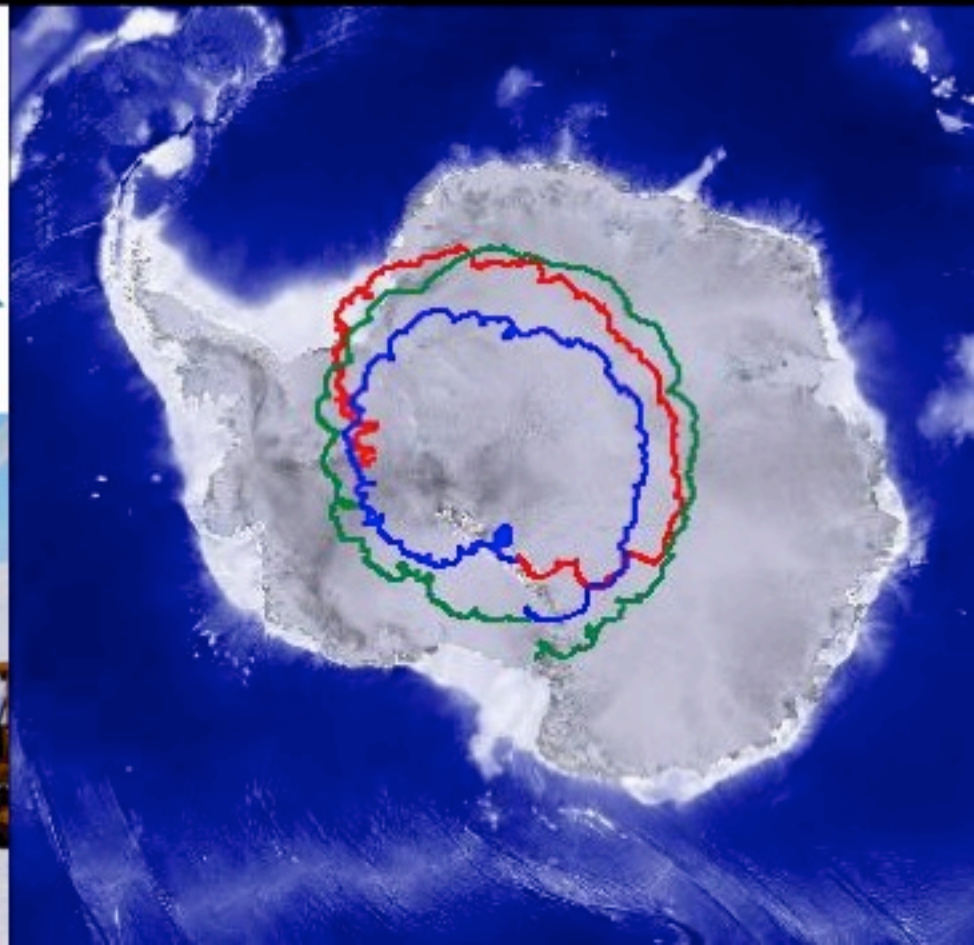
Super-TIGER (Feb. 2013)

Trans-Iron Galactic Element Recorder

breaks flight duration record: 55 days @ 127,000ft

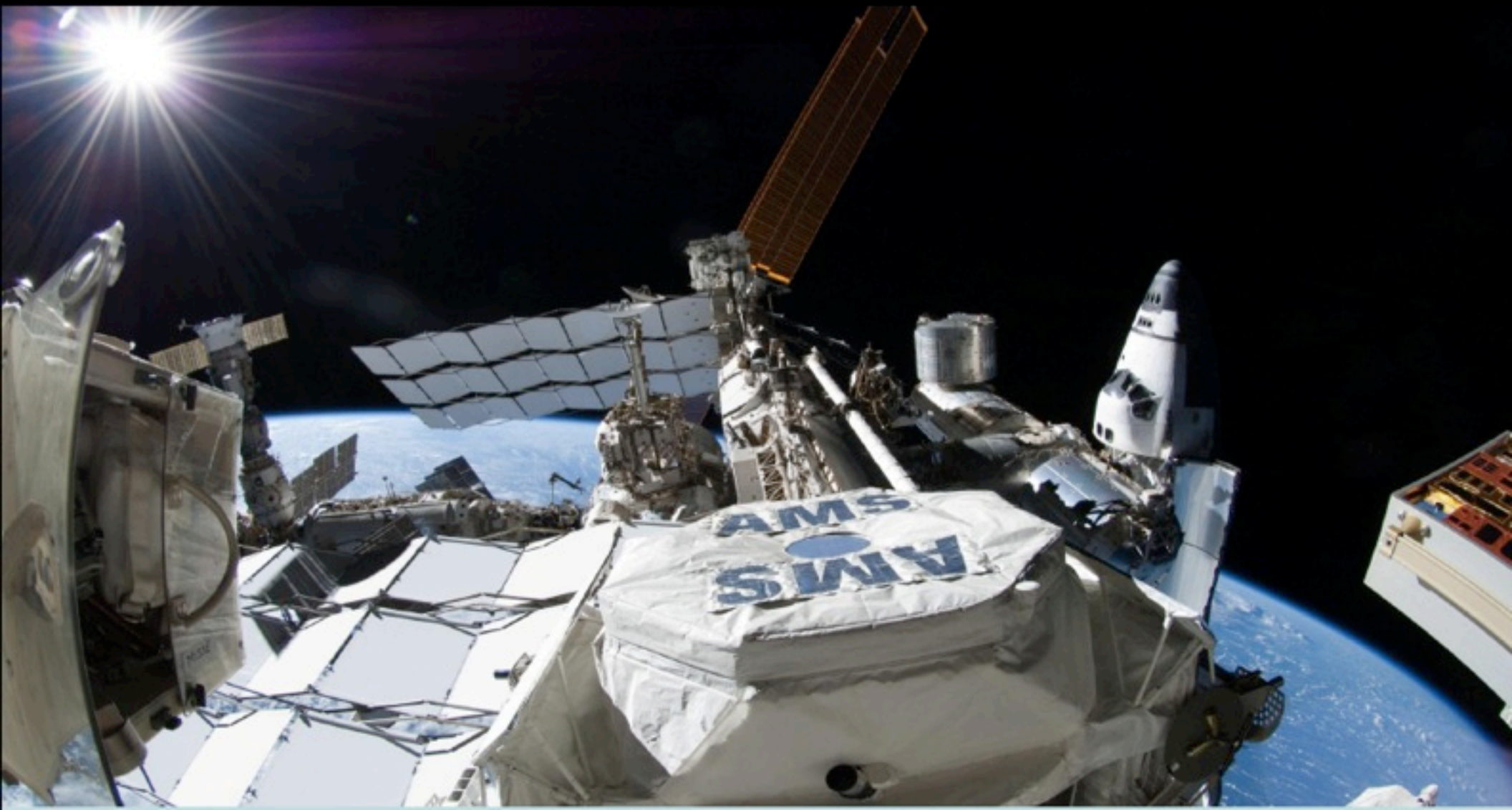
UltraHeavy Nuclei 10 x sensitivity

study composition and origin of Galactic Cosmic Rays



Alpha Magnetic Spectrometer (Mar. 2013)

AMS on the ISS announces first results



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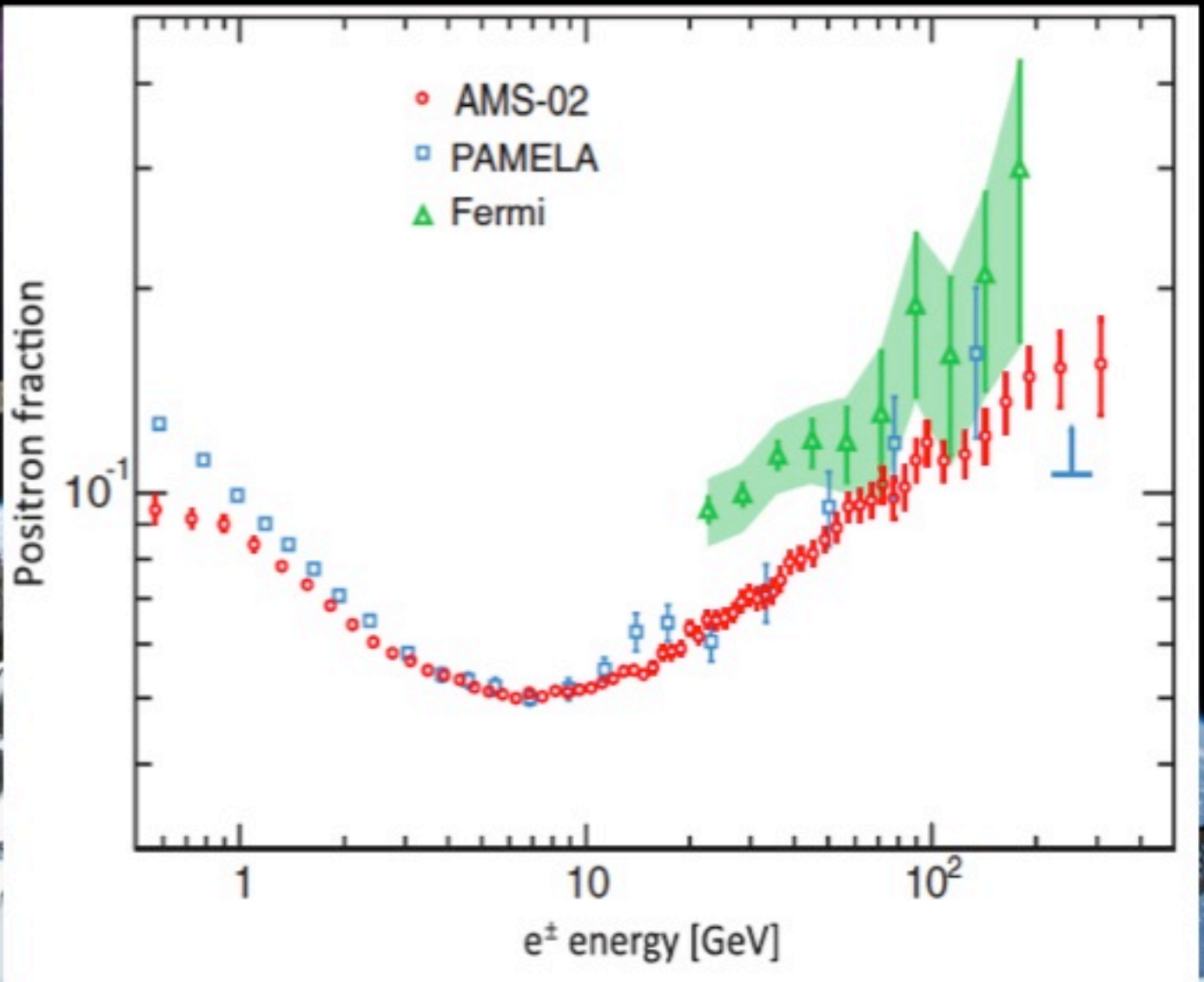


International Space Station

International Space Station

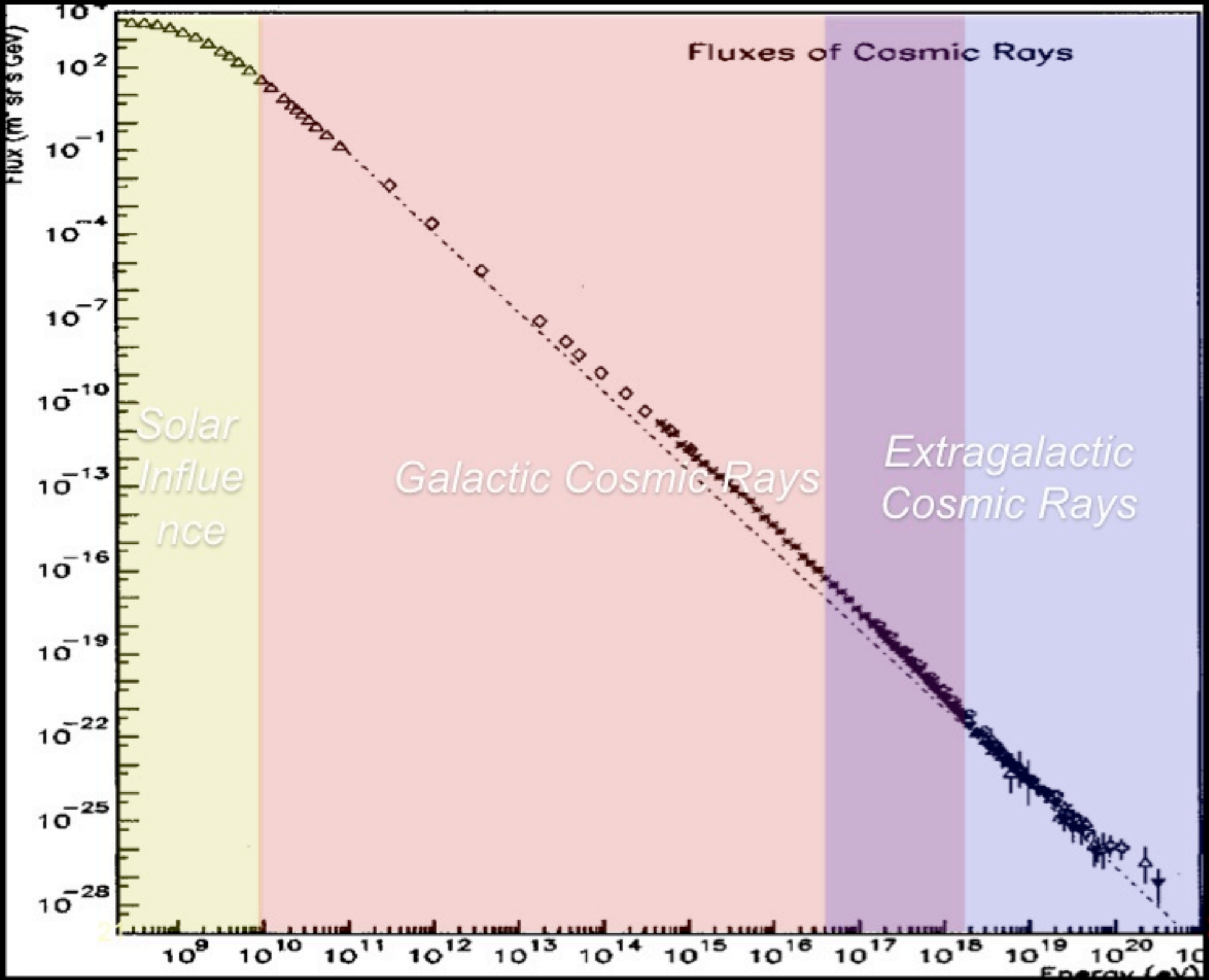
International Space Station

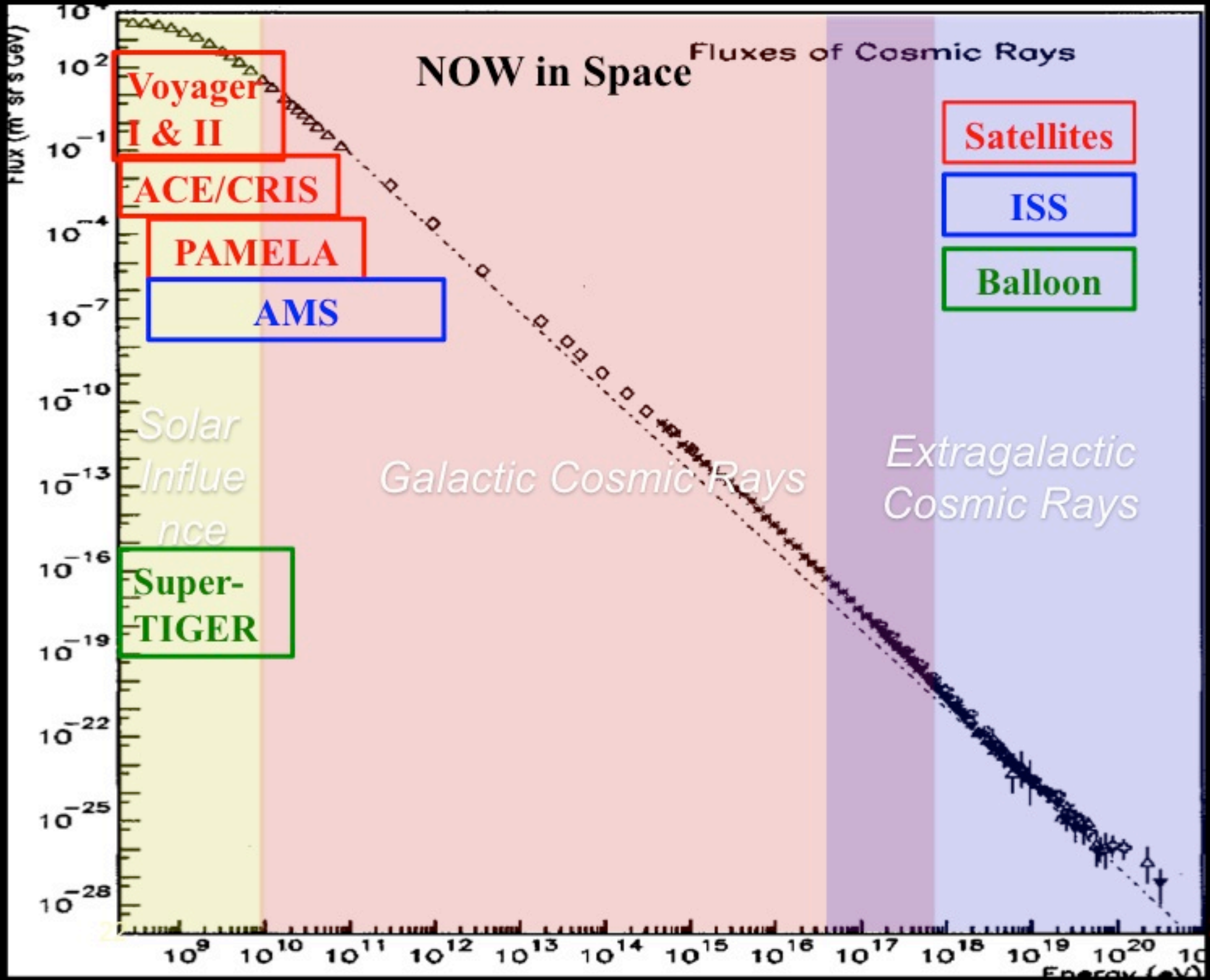
2015

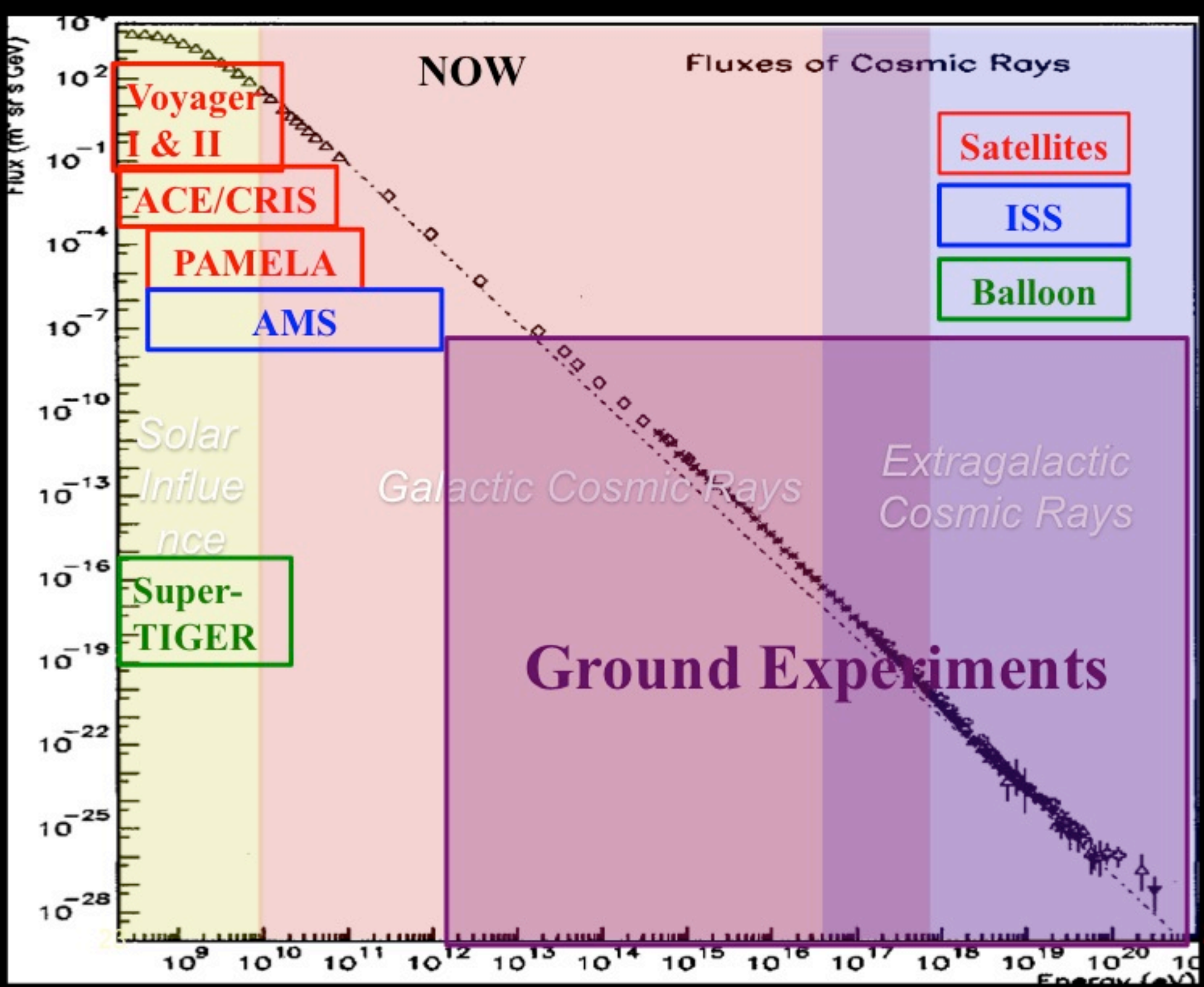
Japanese Experiment Module
(JEM)

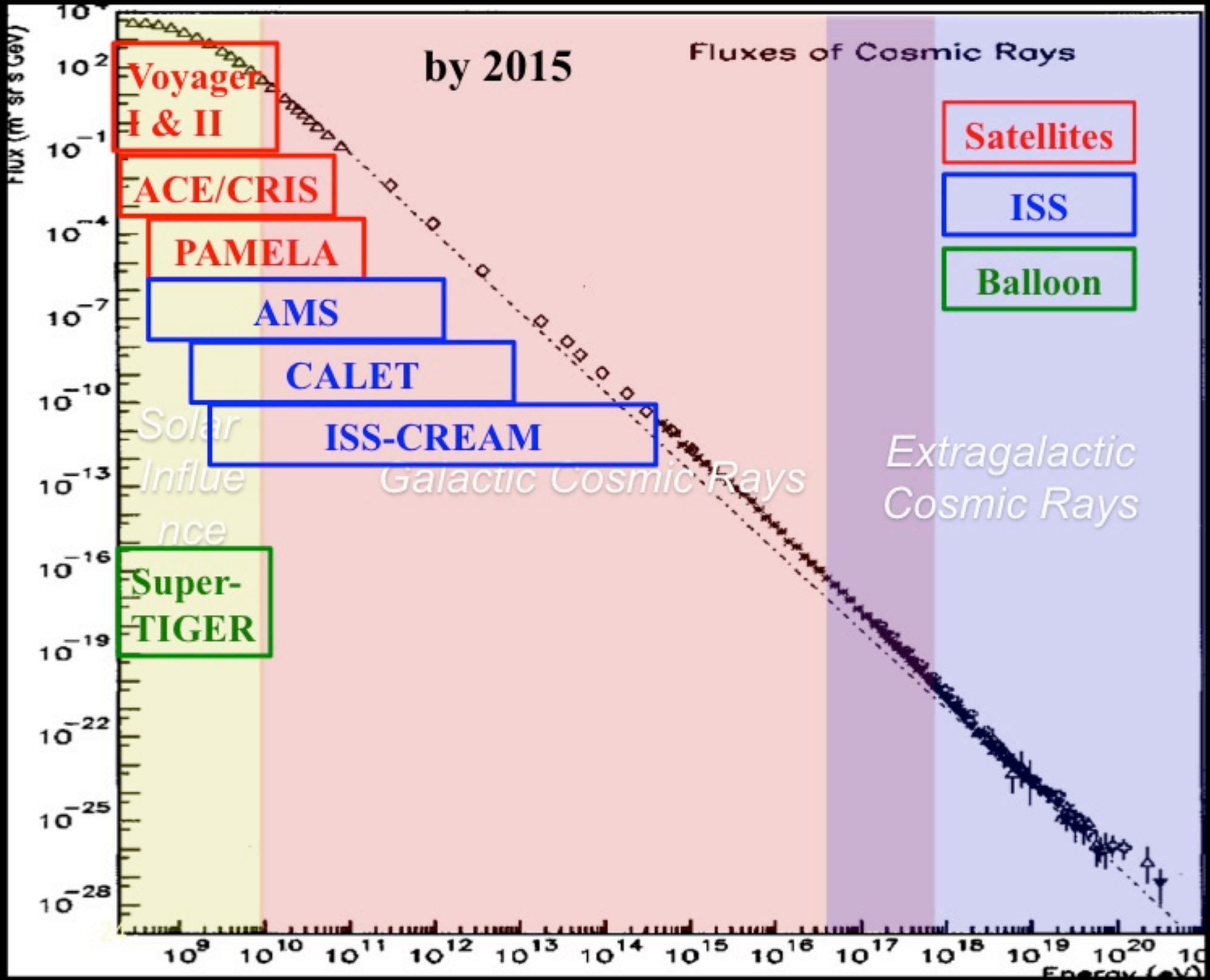
International Space Station

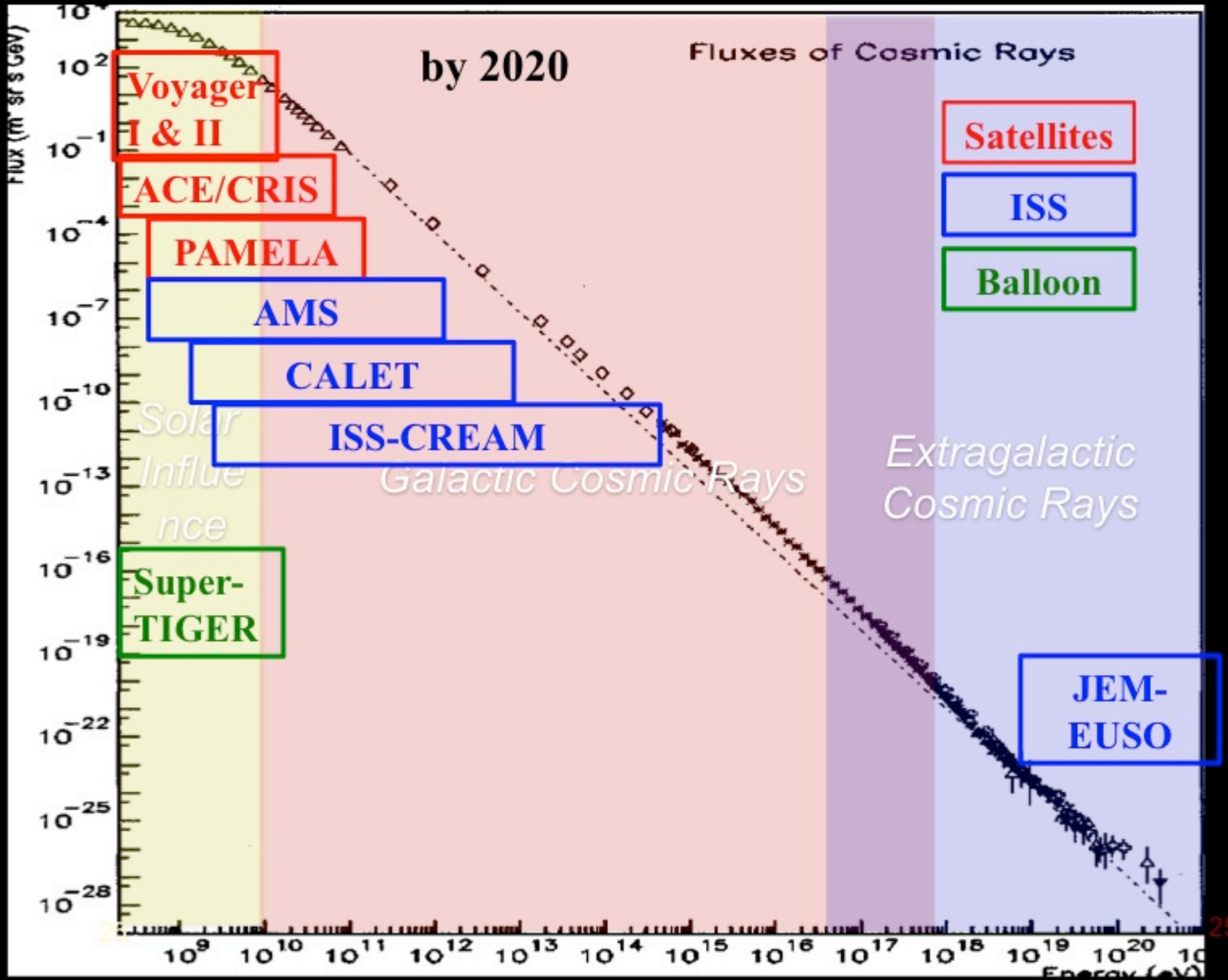
2020


Fluxes of Cosmic Rays
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)


NOW in Space
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
Super-TIGER
Satellites
ISS
Balloon
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)


NOW
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
Satellites
ISS
Balloon
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Super-TIGER
Ground Experiments
Flux (m² sr s GeV)
Energy (eV)


by 2015
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM
Super-TIGER
Satellites
ISS
Balloon
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)


by 2020
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM
Super-TIGER
Satellites
ISS
Balloon
JEM-EUSO
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)

Main Open Questions in CR Science

Origin of Galactic Cosmic Rays (GCR):

- What are the accelerators?
- What are they accelerating?
- How do they propagate in the Galaxy?
- Where is the Transition between Galactic & ExtraGalactic CRs?

Origin of ExtraGalactic Cosmic Rays (XGCR):

- What are the accelerators?
- What are they accelerating?
- How do they propagate to Earth?
- At what Energy COSMIC RAY ASTRONOMY begins?

How do Cosmic Rays Affect the Earth and its Biosphere, the Solar System, the Galaxy, other Galaxies, and the formation of Stars and Galaxies?

Questions Related to CR Science

Indirect Dark Matter Searches

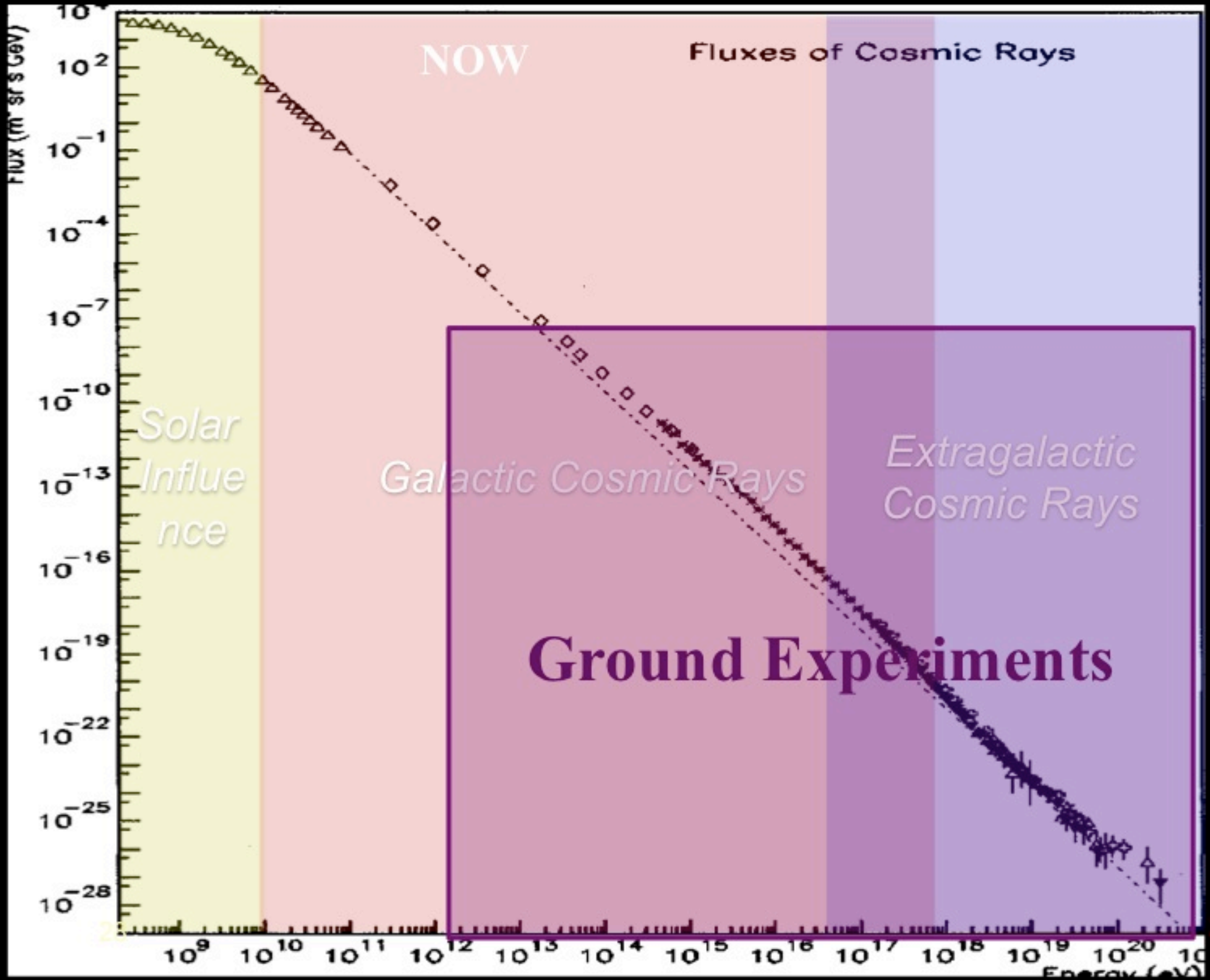
- in the Galactic Halo: e+, e-; p, anti-p, γ, ν ...

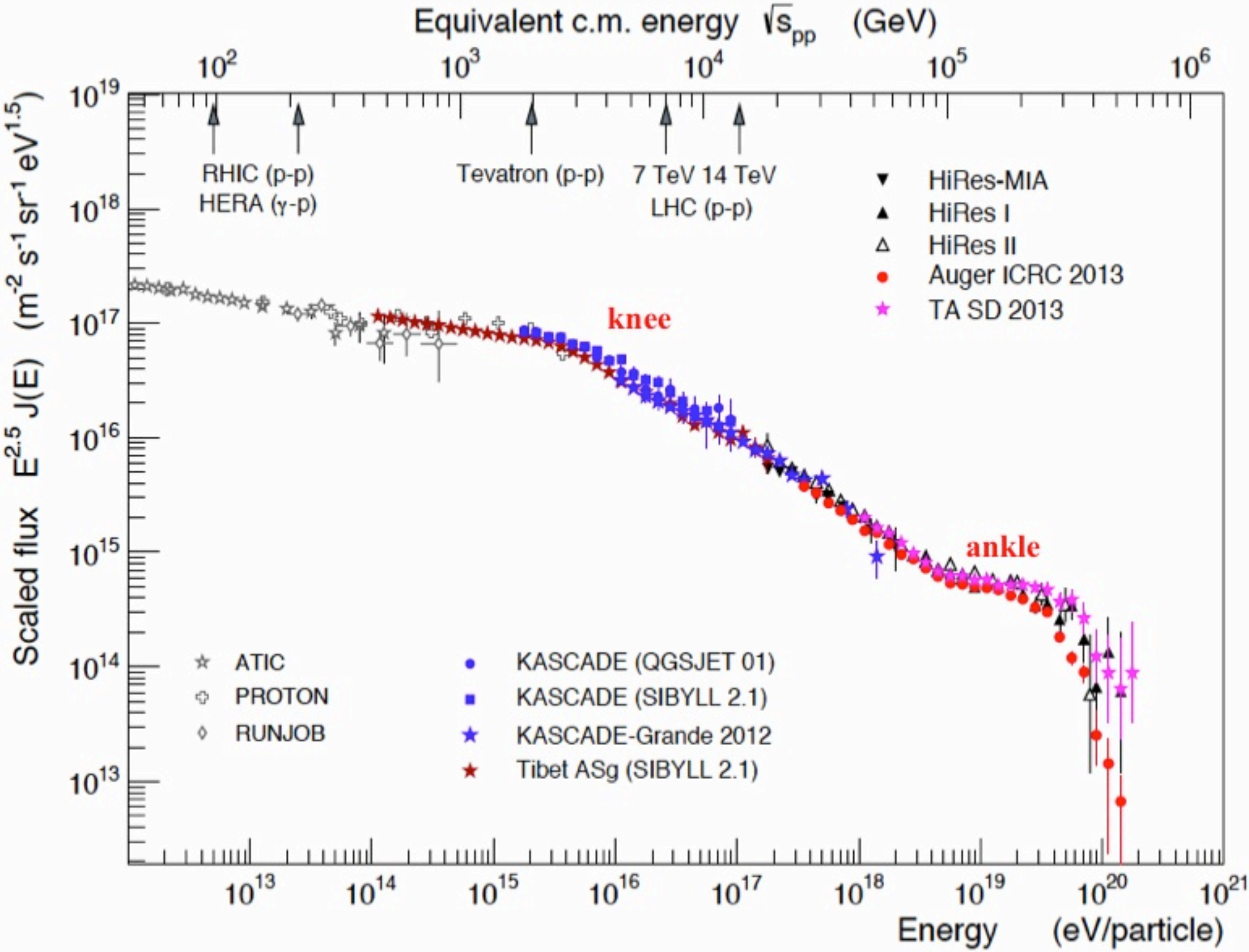
Probe of Particle Interactions above LHC energies

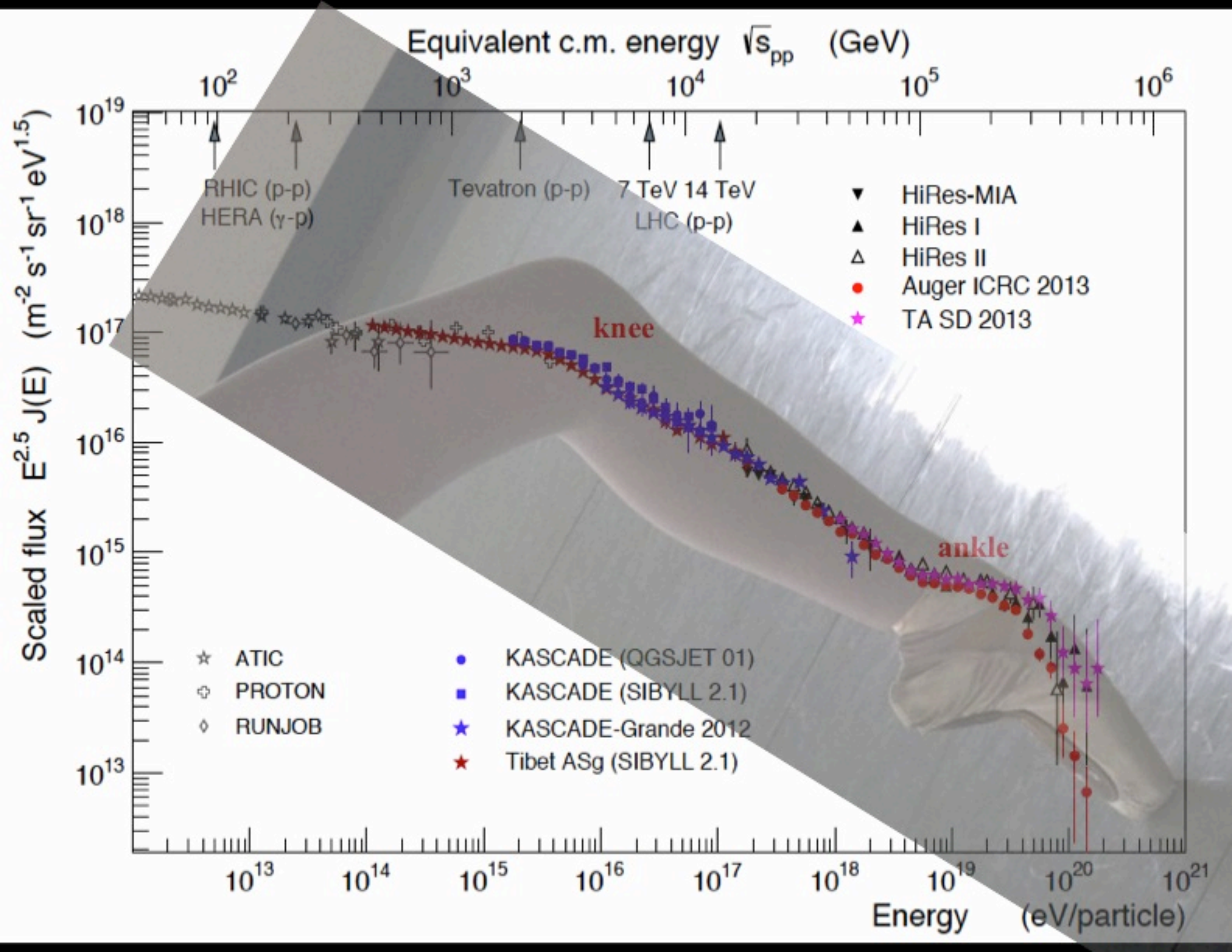
- Ultrahigh Energy Cosmic Rays (UHECR) E_{cm} > 100 TeV
- Ultrahigh Energy Neutrinos

Searches for Exotic Components of Matter:

- antinuclei
- strangelets
- primordial black holes


NOW
Fluxes of Cosmic Rays
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Ground Experiments
Flux (m² sr s GeV)
Energy (eV)


Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
ankle
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
Scaled flux E^2.5 J(E) (m^-2 s^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)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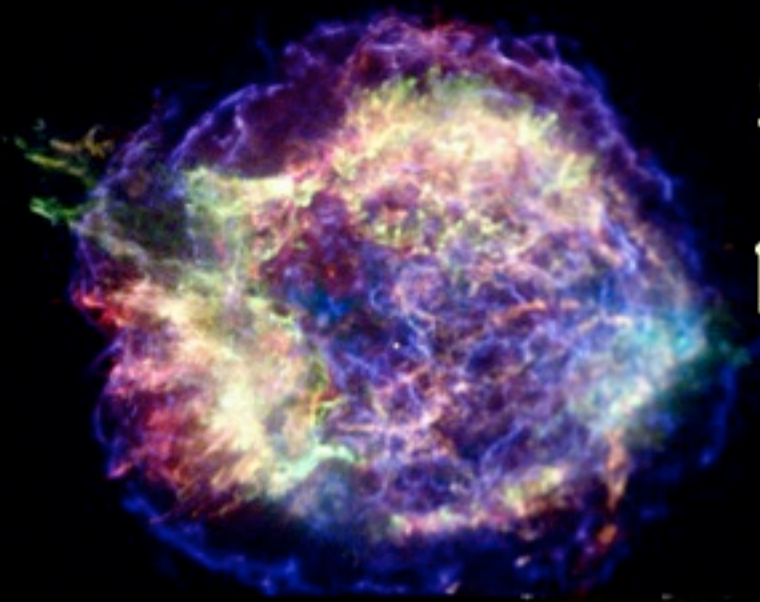
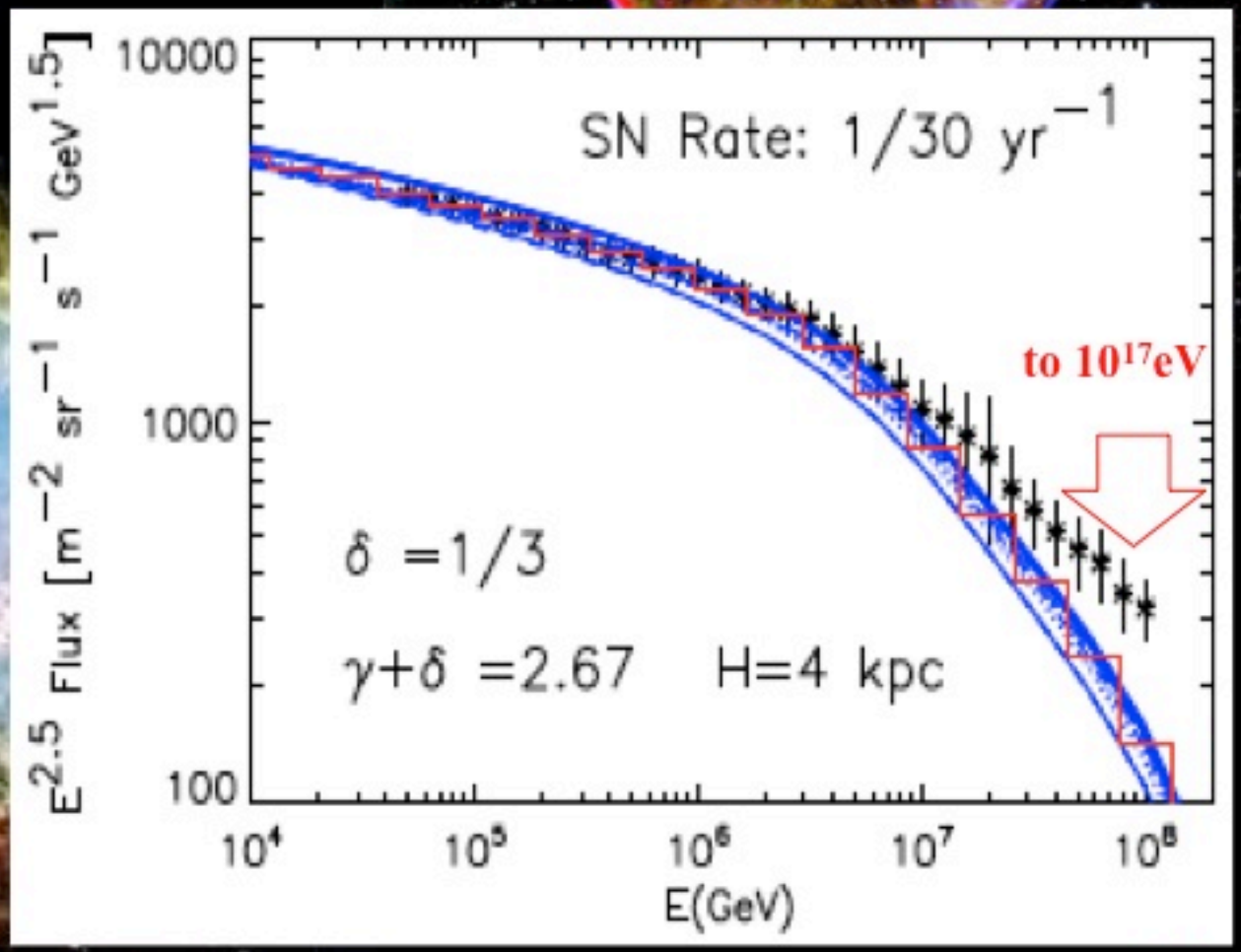
10^14
10^13
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

Super-novae

Cosmic Rays from Super-novae
Baade & Zwicky (1934)

Supernova Remnants



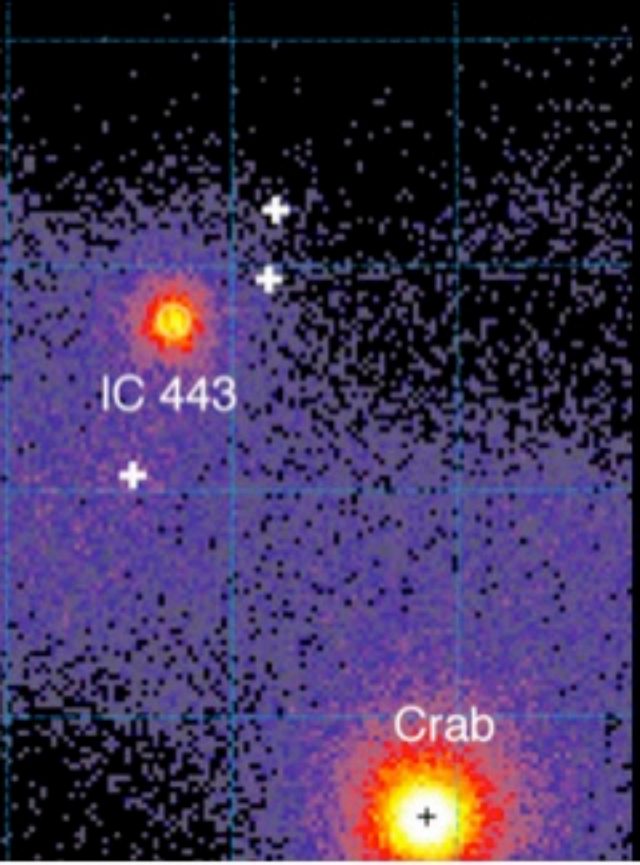


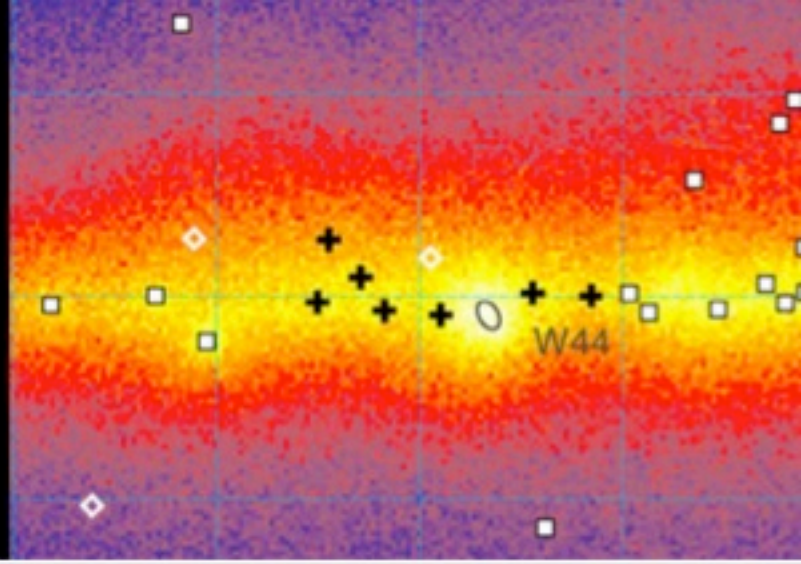
Blasi & Amato 2012

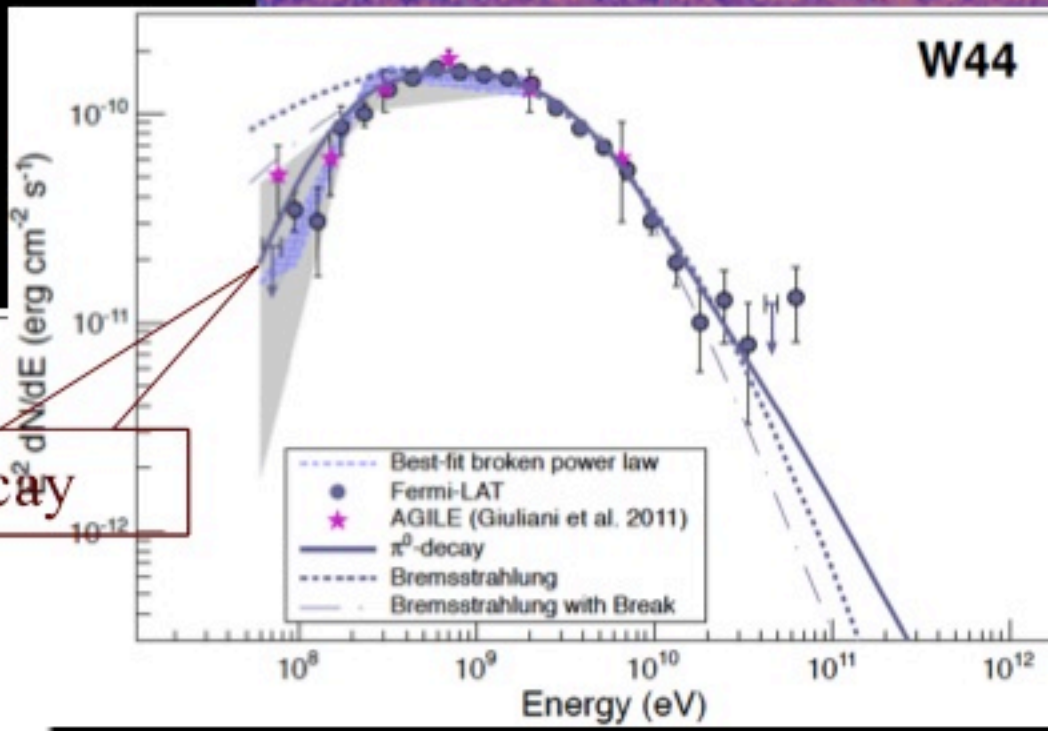
π^0 decay!

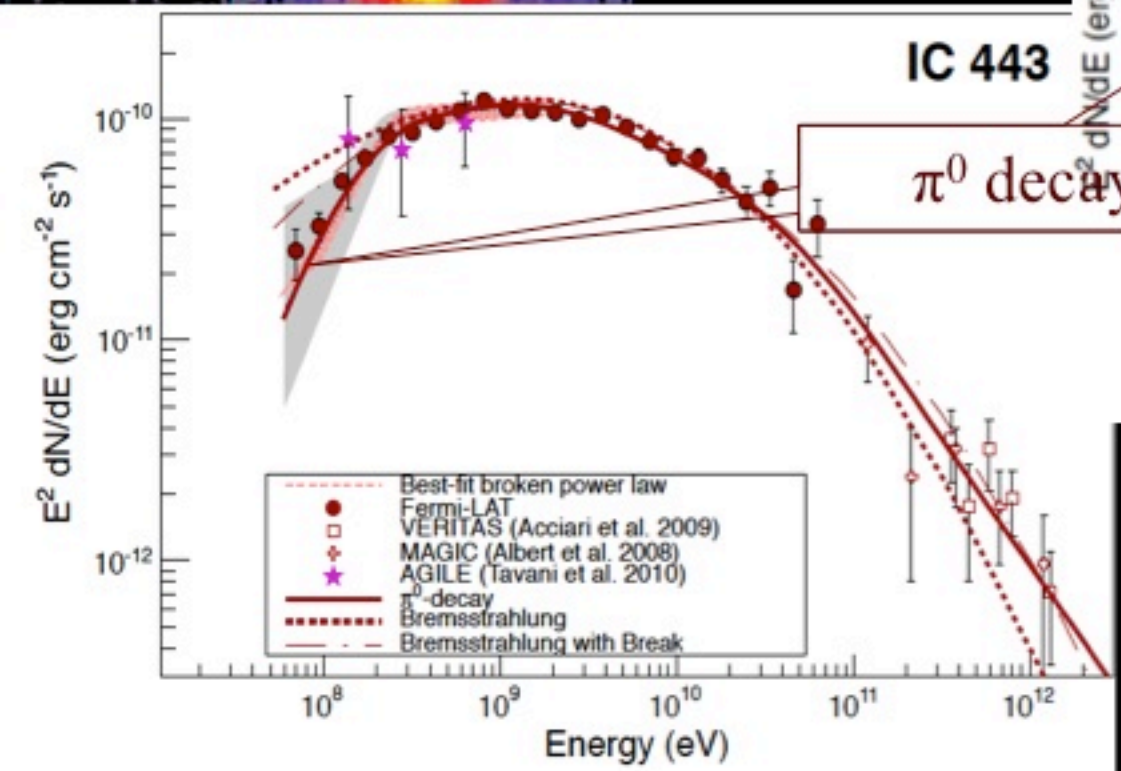
IC 443 & W44

Fermi & AGILE

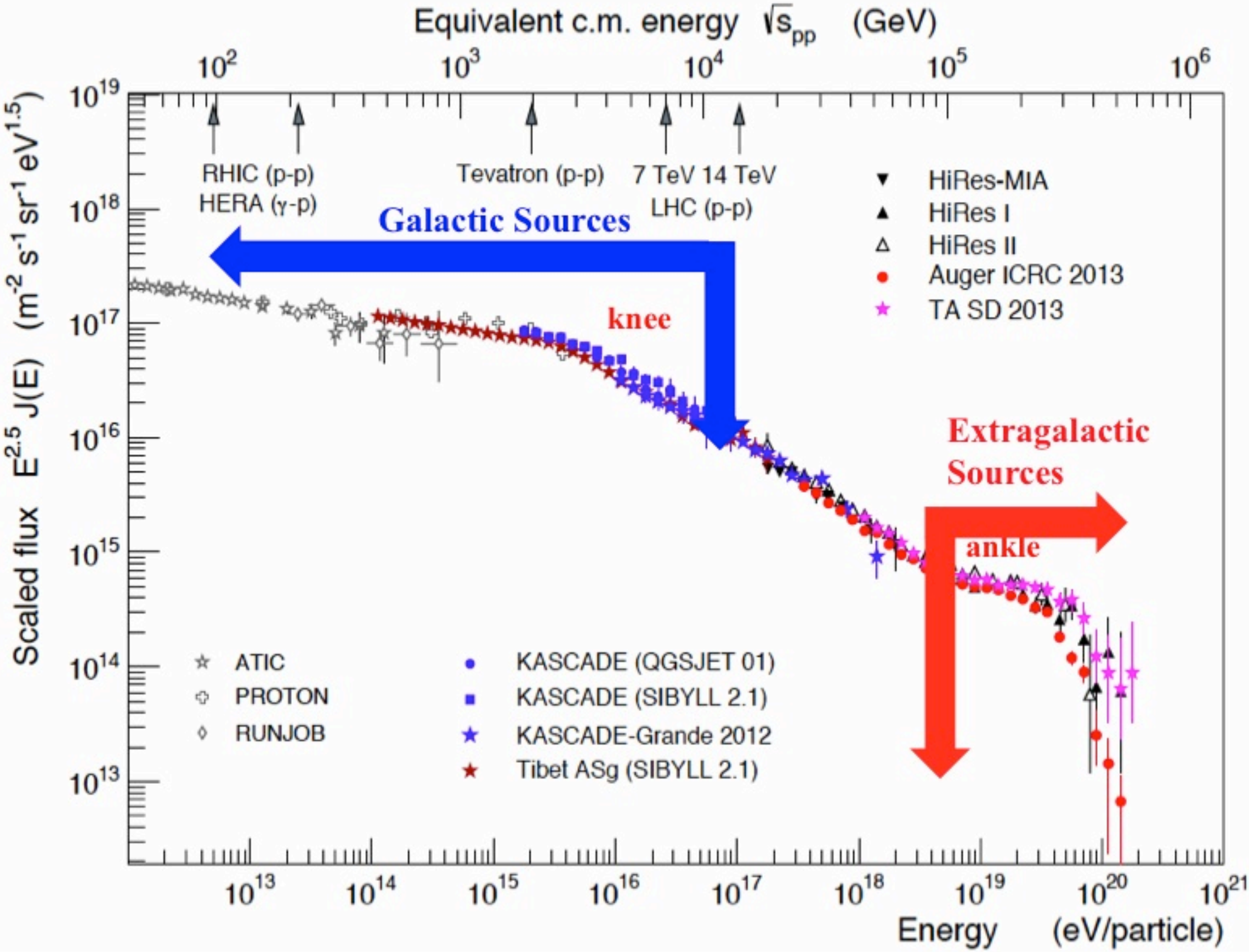








Ackermann et al (Fermi Collab) '13
arXiv:1302.3307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10^2
10^3
10^4
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10^6
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HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
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Galactic Sources
knee
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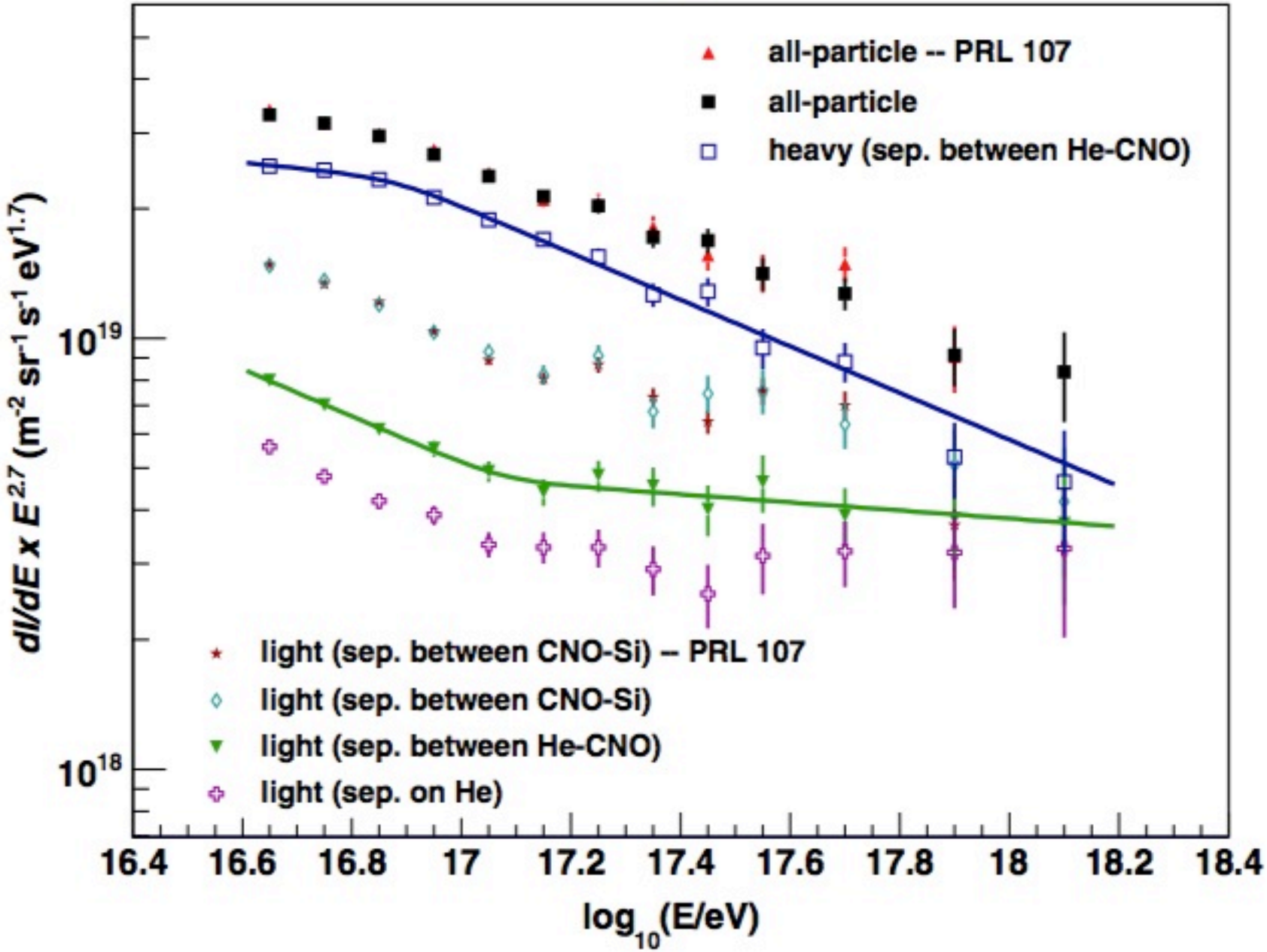
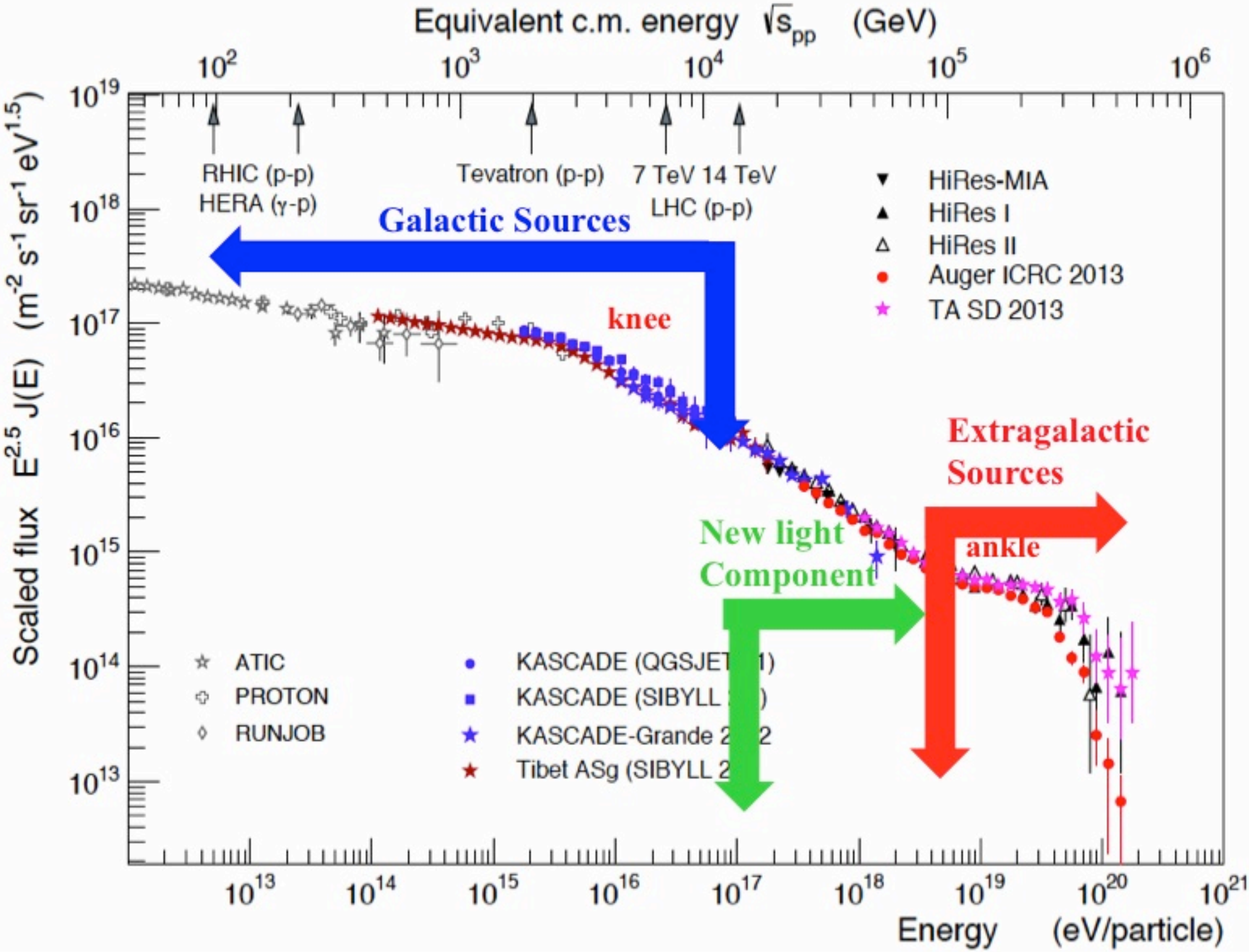
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)

Galactic – Extragalactic Transition



KASCADE coll. PHYSICAL REVIEW D 87, 081101(R) (2013)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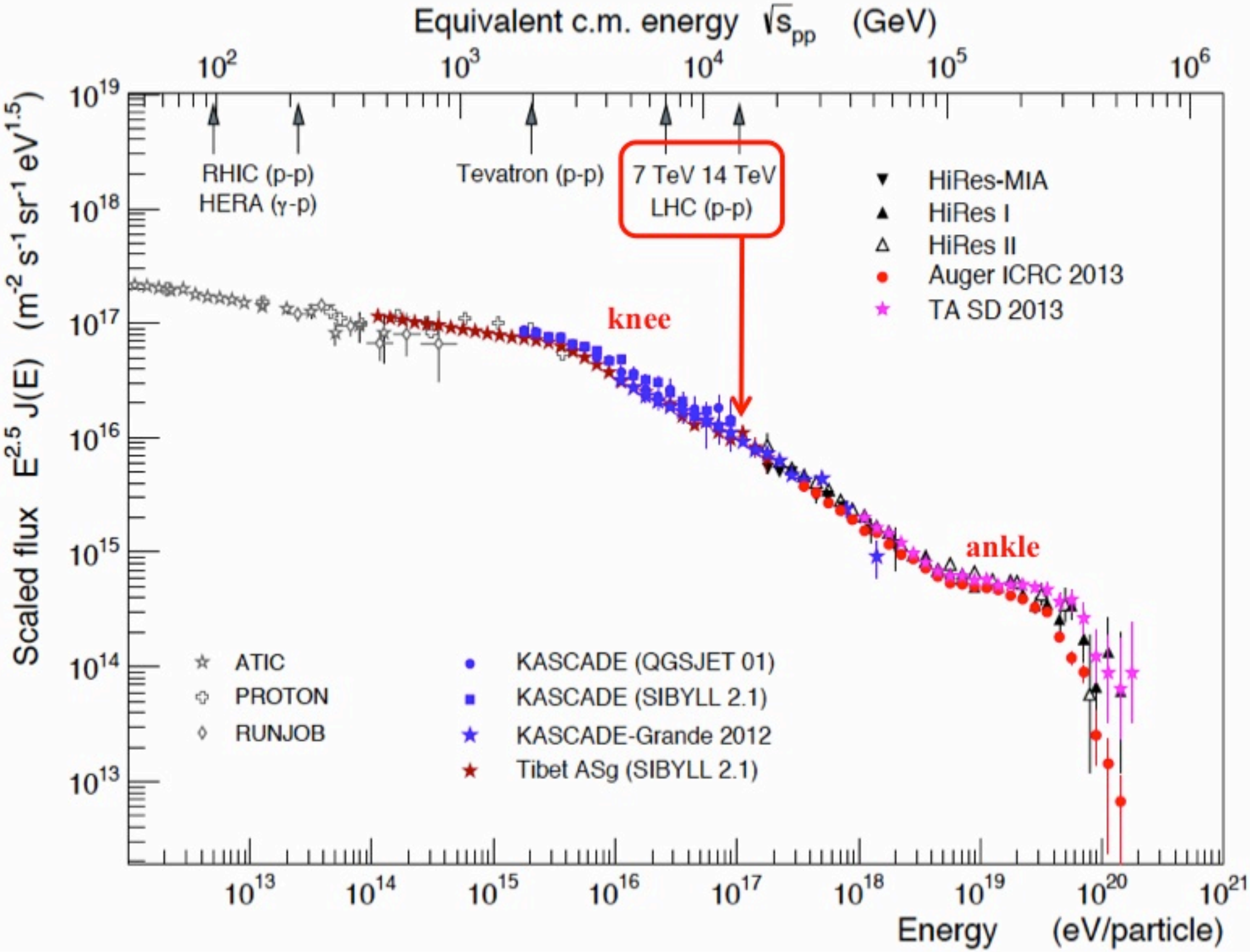
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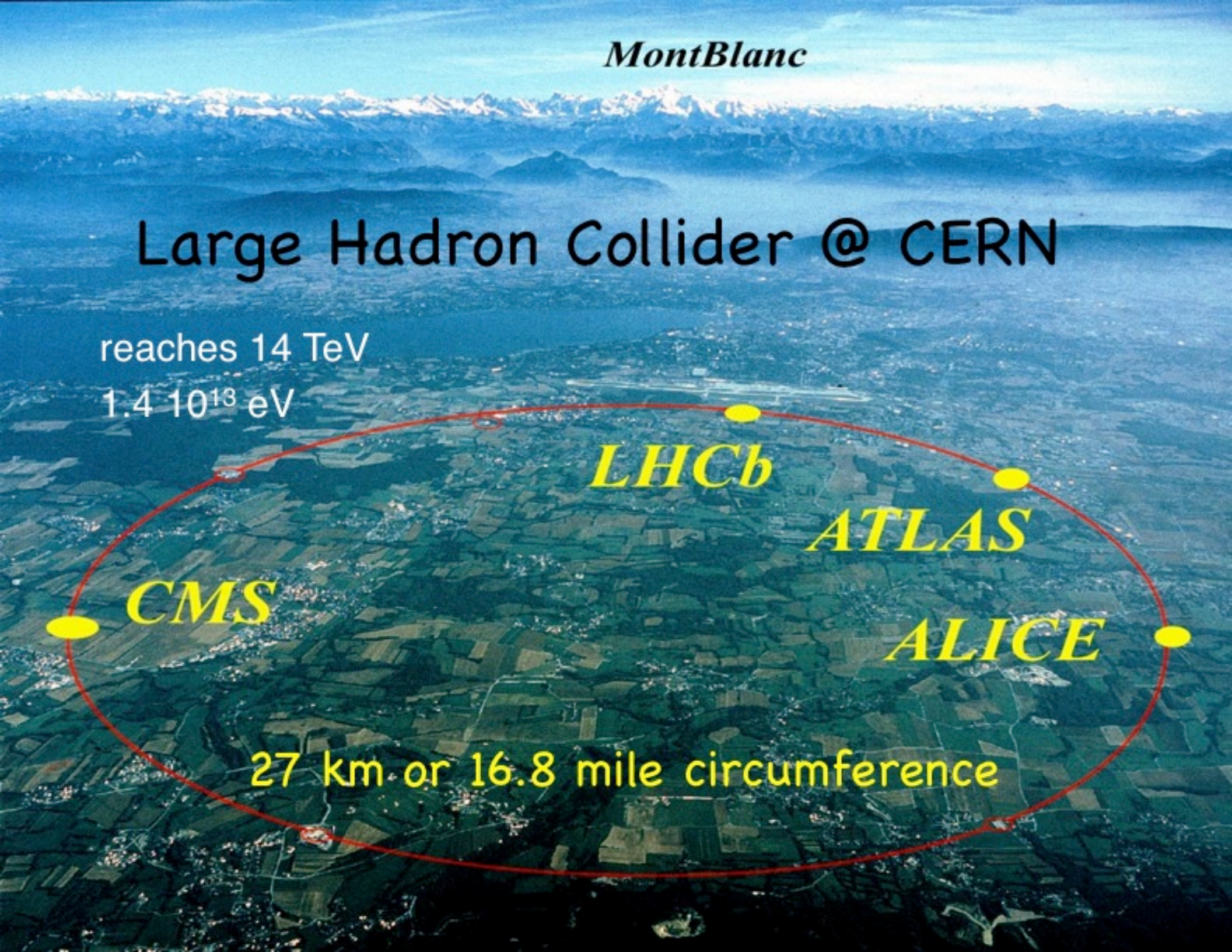
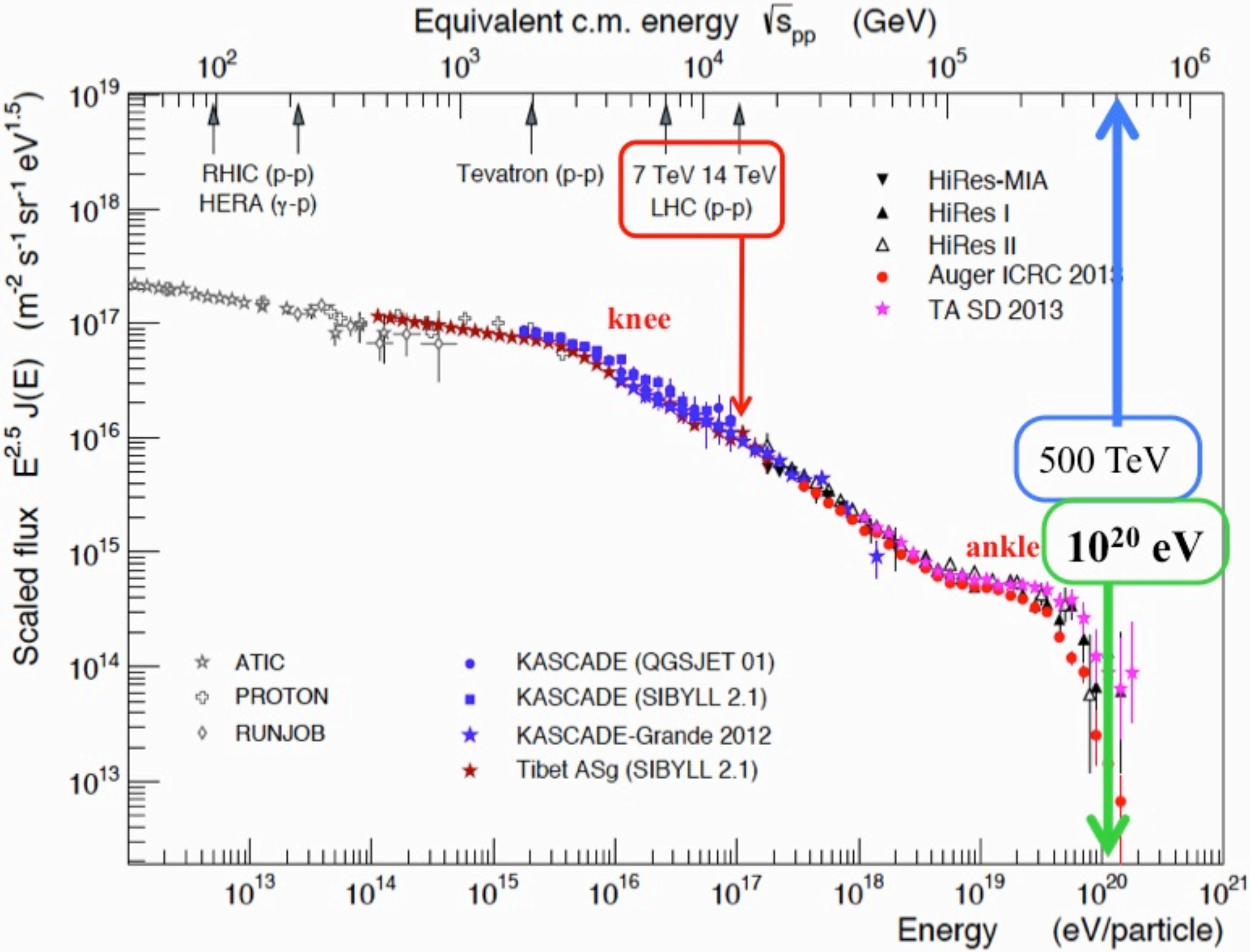

MontBlanc
Large Hadron Collider @ CERN
reaches 14 TeV
1.4 10¹³ eV
LHCb
ATLAS
CMS
ALICE
27 km or 16.8 mile circumference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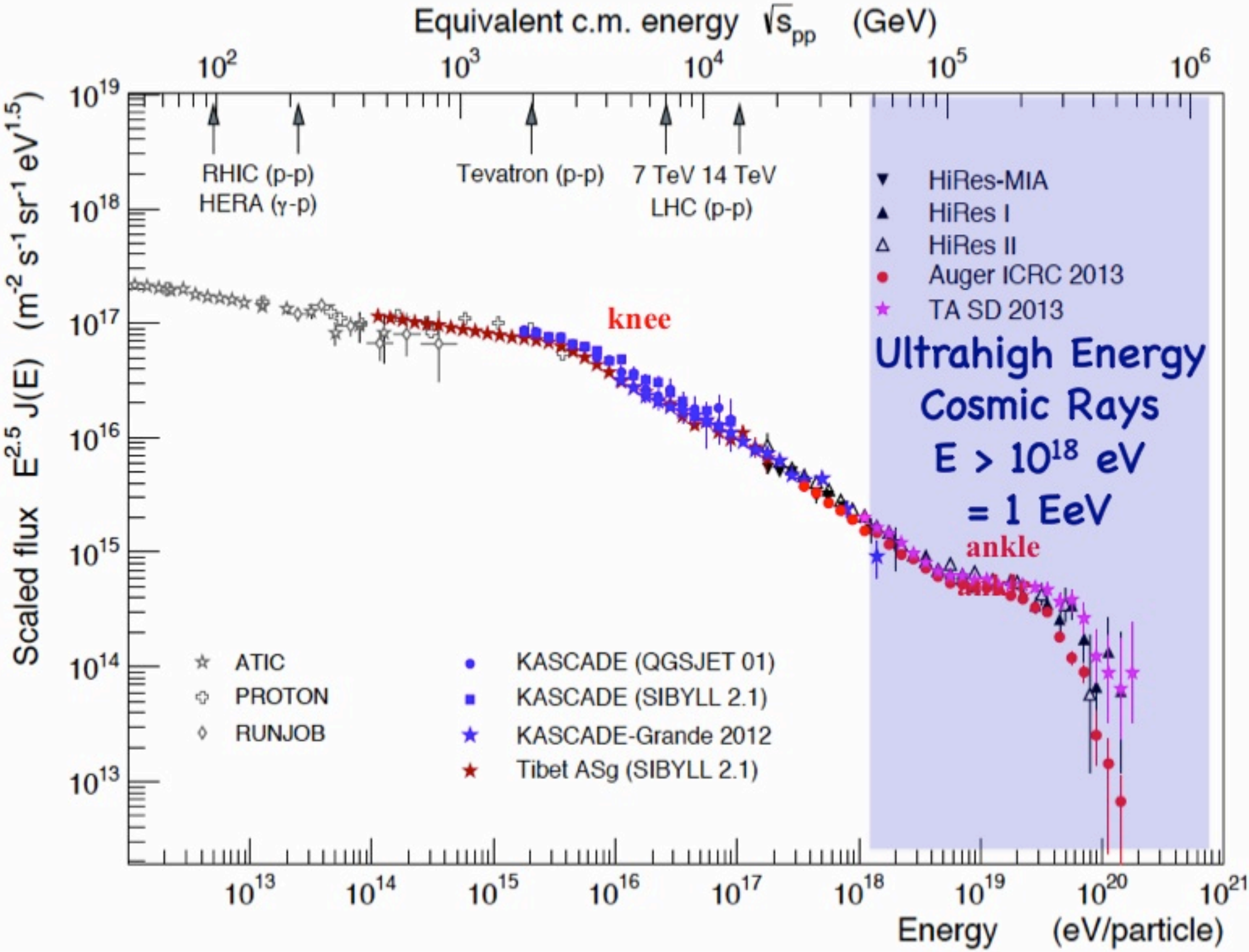
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
ankle
500 TeV
10^{20} eV
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
Scaled flux $E^{2.5}$ J(E) (m^{-2} s^{-1} sr^{-1} $eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)


Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
Ultrahigh Energy
Cosmic Rays
E > 10^{18} eV
= 1 EeV
ankle
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
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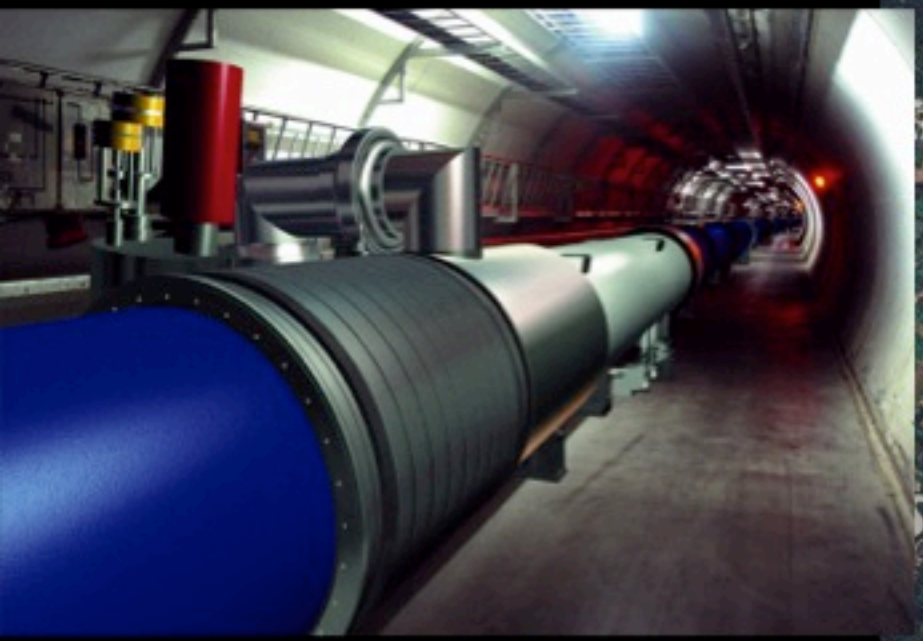
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)

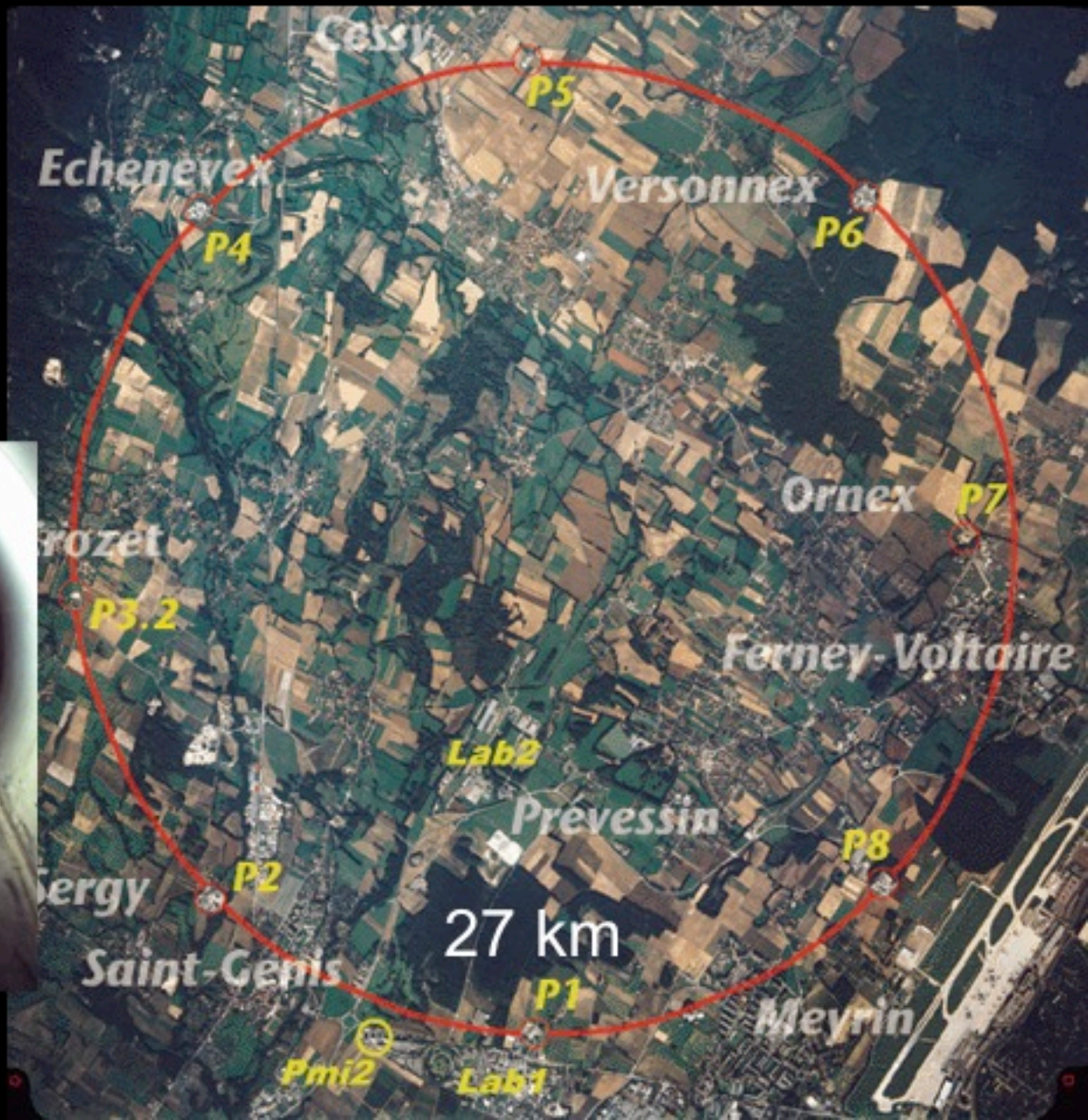
Large Hadron Collider

reaches 14 TeV

1.4 10^{13} eV



8.4 Tesla

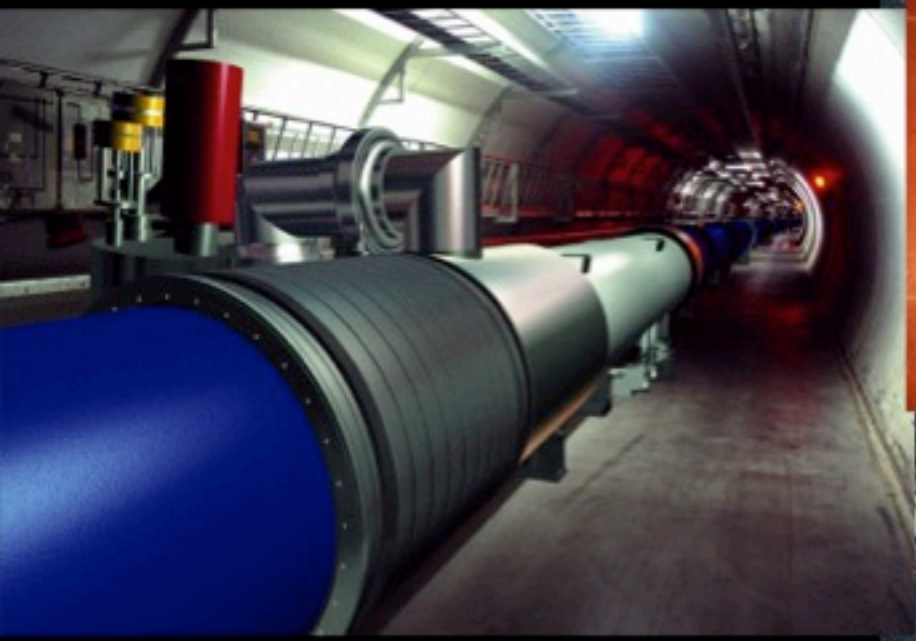


Challenging Accelerators

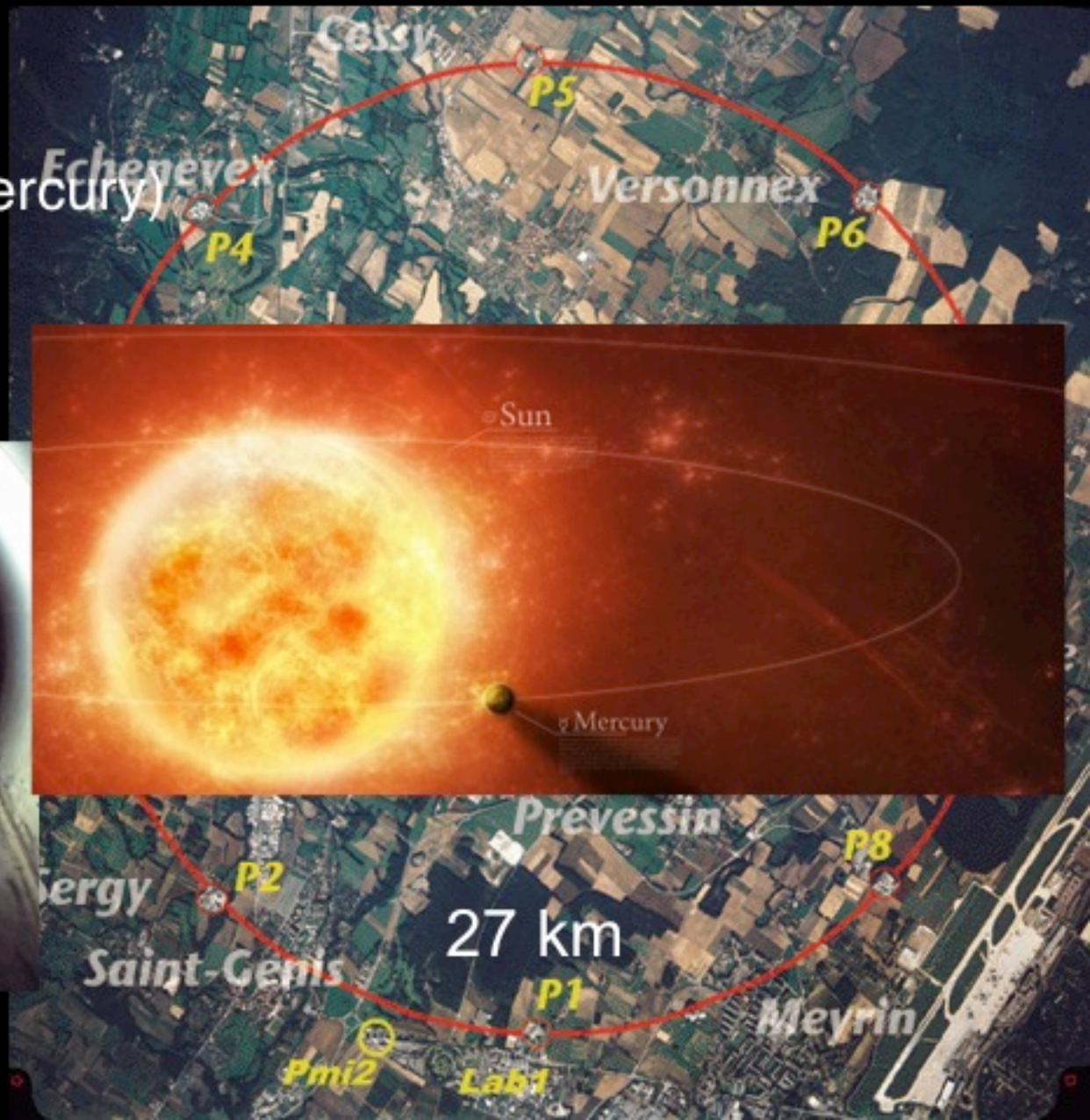
to reach 10^{20} eV

with LHC magnetic field,
radius ~ 10^7 km (Sun – Mercury)

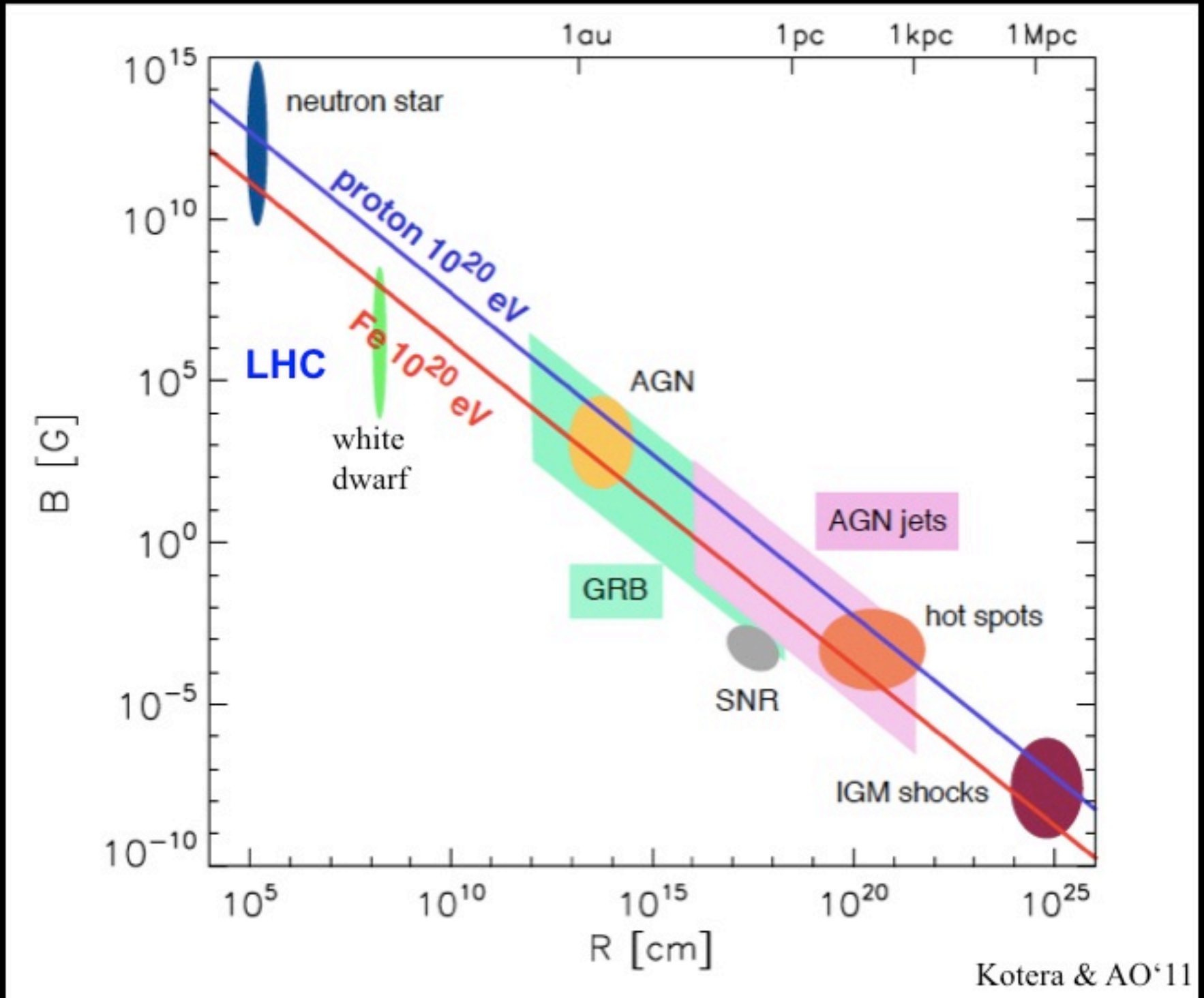
or **10 GT** magnets!

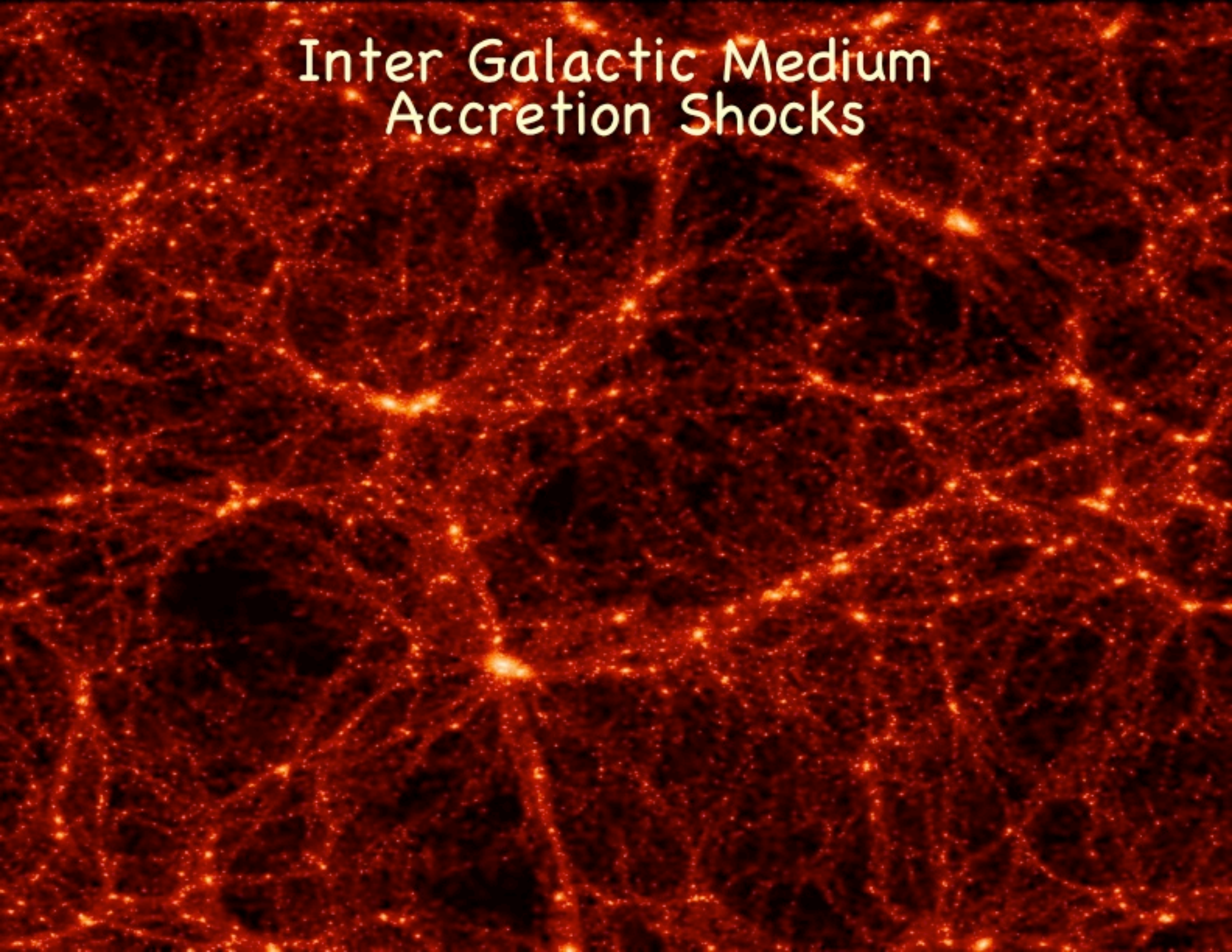


8.4 Tesla

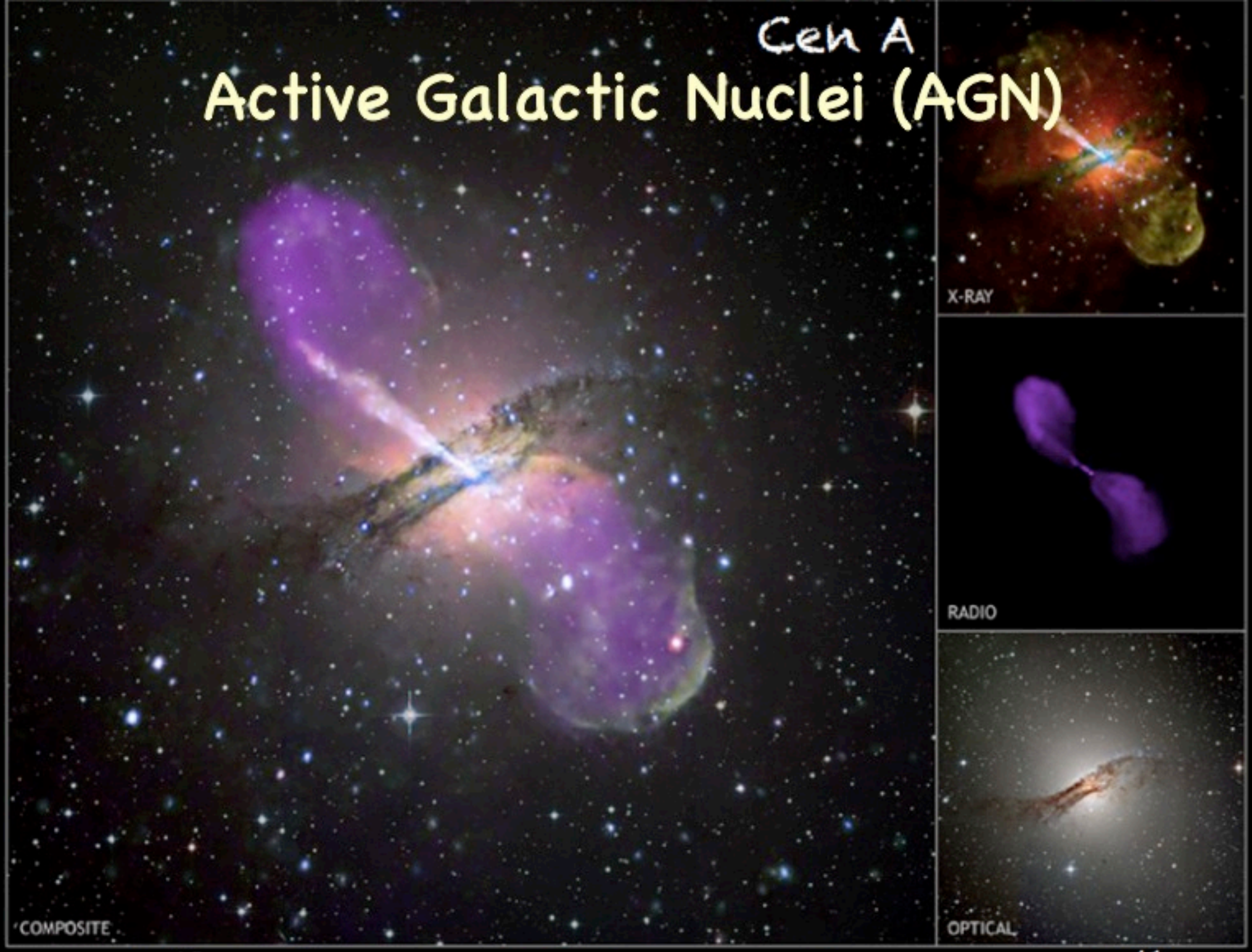


Hillas Plot: E_{max} required



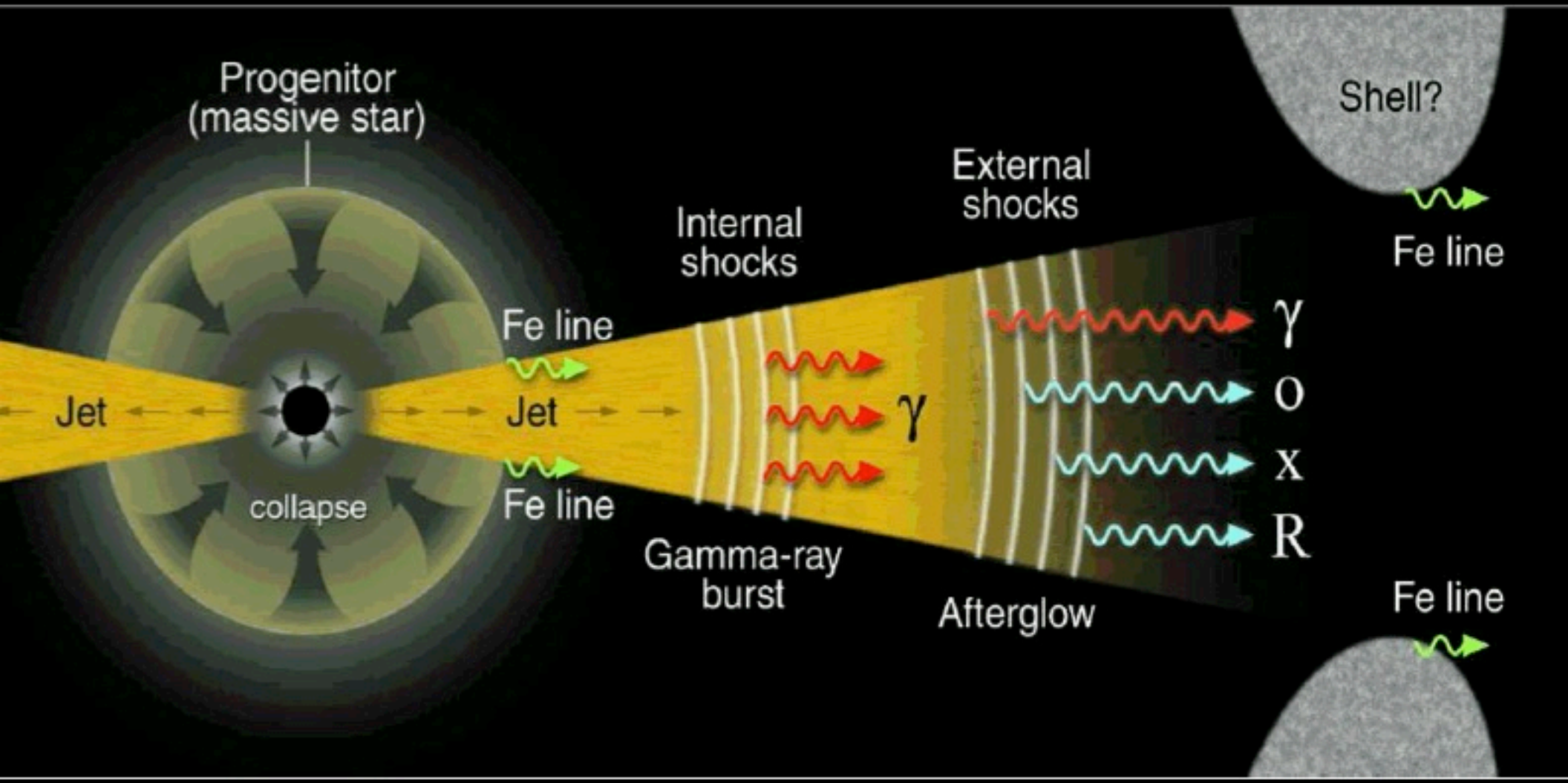

Inter Galactic Medium
Accretion Shocks

Active Galactic Nuclei (AGN)



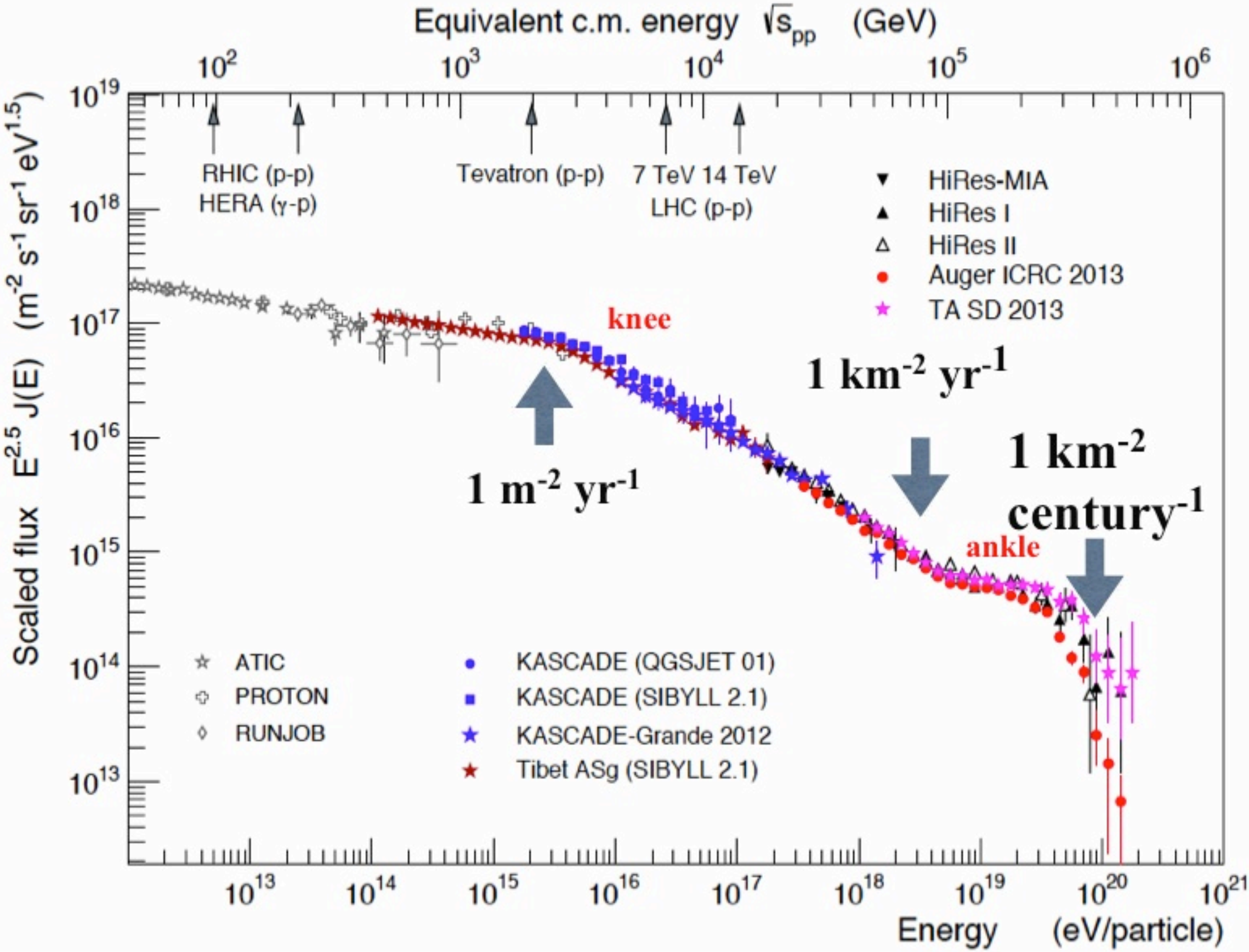
$L_{\rm bol} = 10^{43}$ erg/s $\quad d = 3.4\,{\rm Mpc}$ $\quad L_{\gamma>100{\rm MeV}} \approx 10^{41}$ erg/

Gamma-ray Bursts



Meszaros '01

Newborn Pulsars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10^5
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RHIC (p-p)
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Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
1 km^-2 yr^-1
1 m^-2 yr^-1
1 km^-2 century^-1
ankle
ATIC
PROTON
RUNJOB
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KASCADE (SIBYLL 2.1)
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Scaled flux E^2.5 J(E) (m^-2 s^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
10^20
10^21
Energy (eV/particle)

Current Observatories of Ultrahigh Energy Cosmic Rays

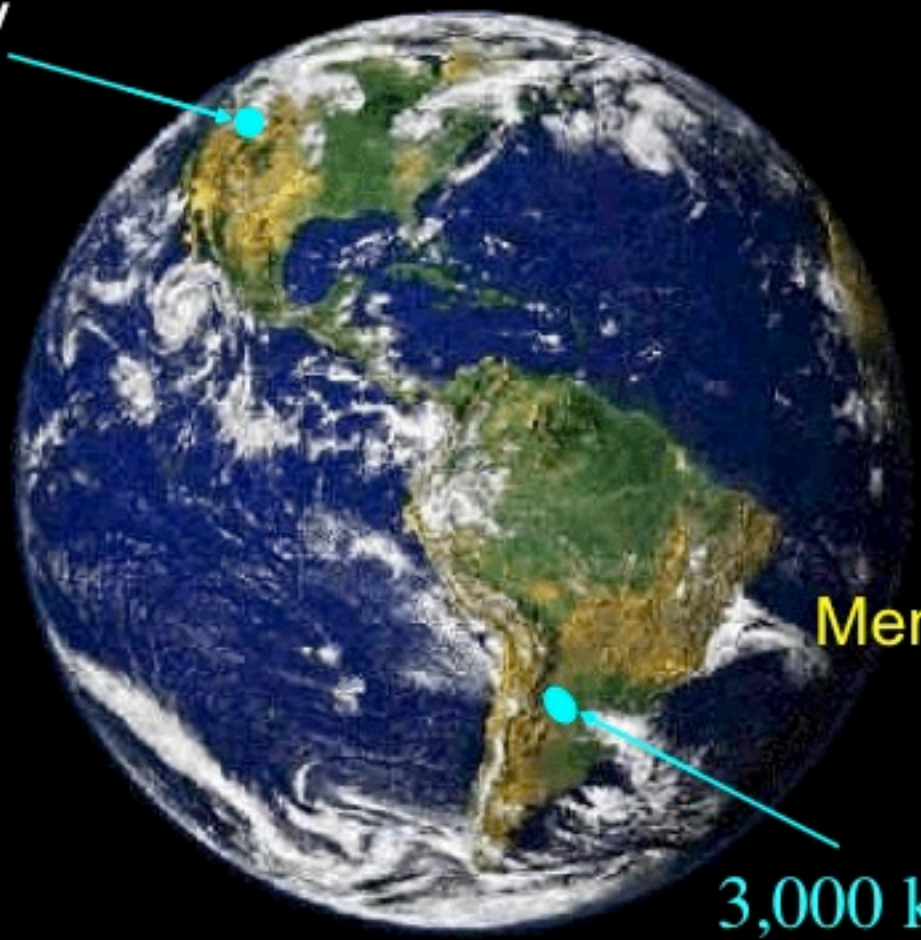
Telescope Array

Utah, USA

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes



Pierre Auger Observatory

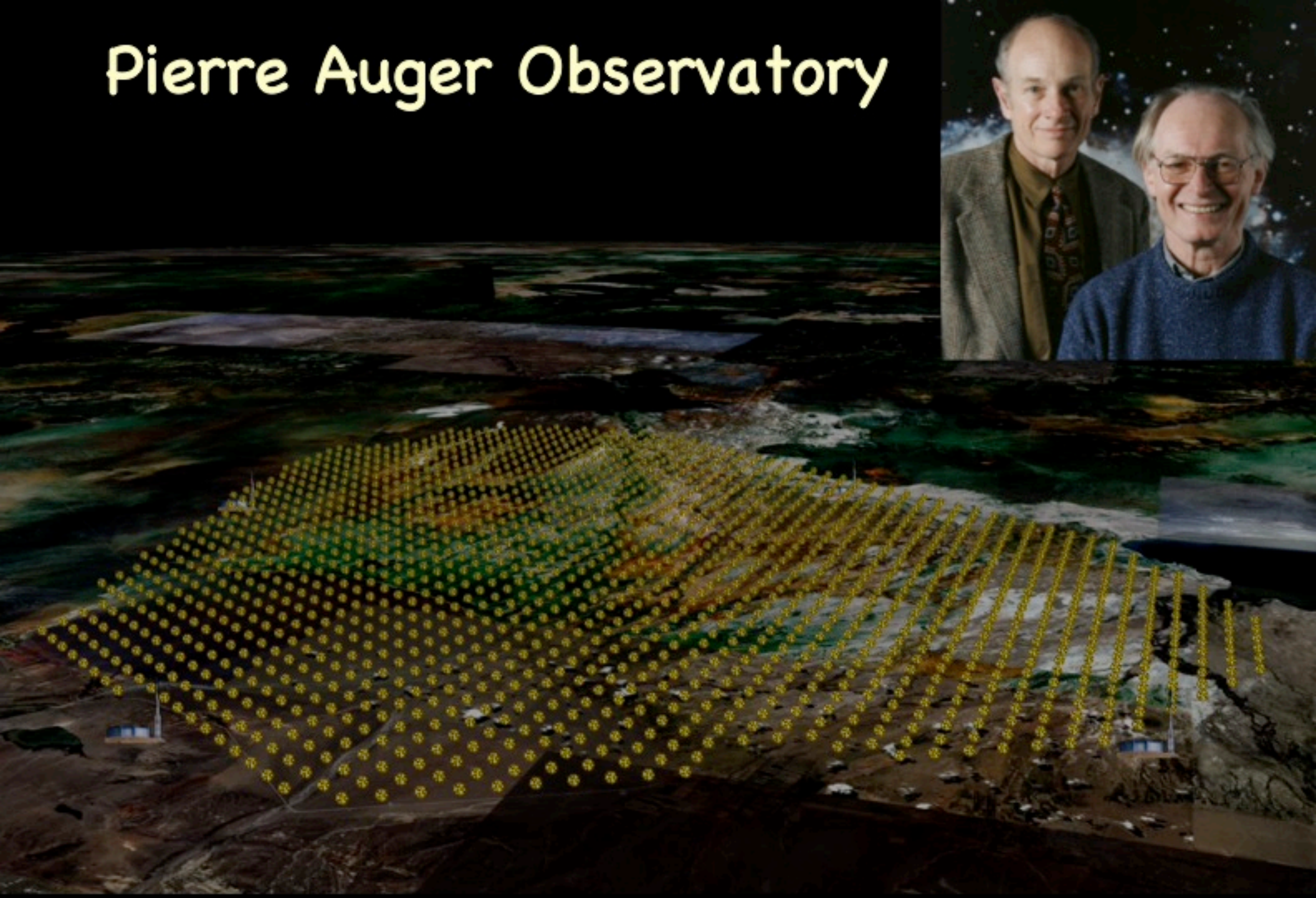
Mendoza, Argentina

(19 country collaboration)

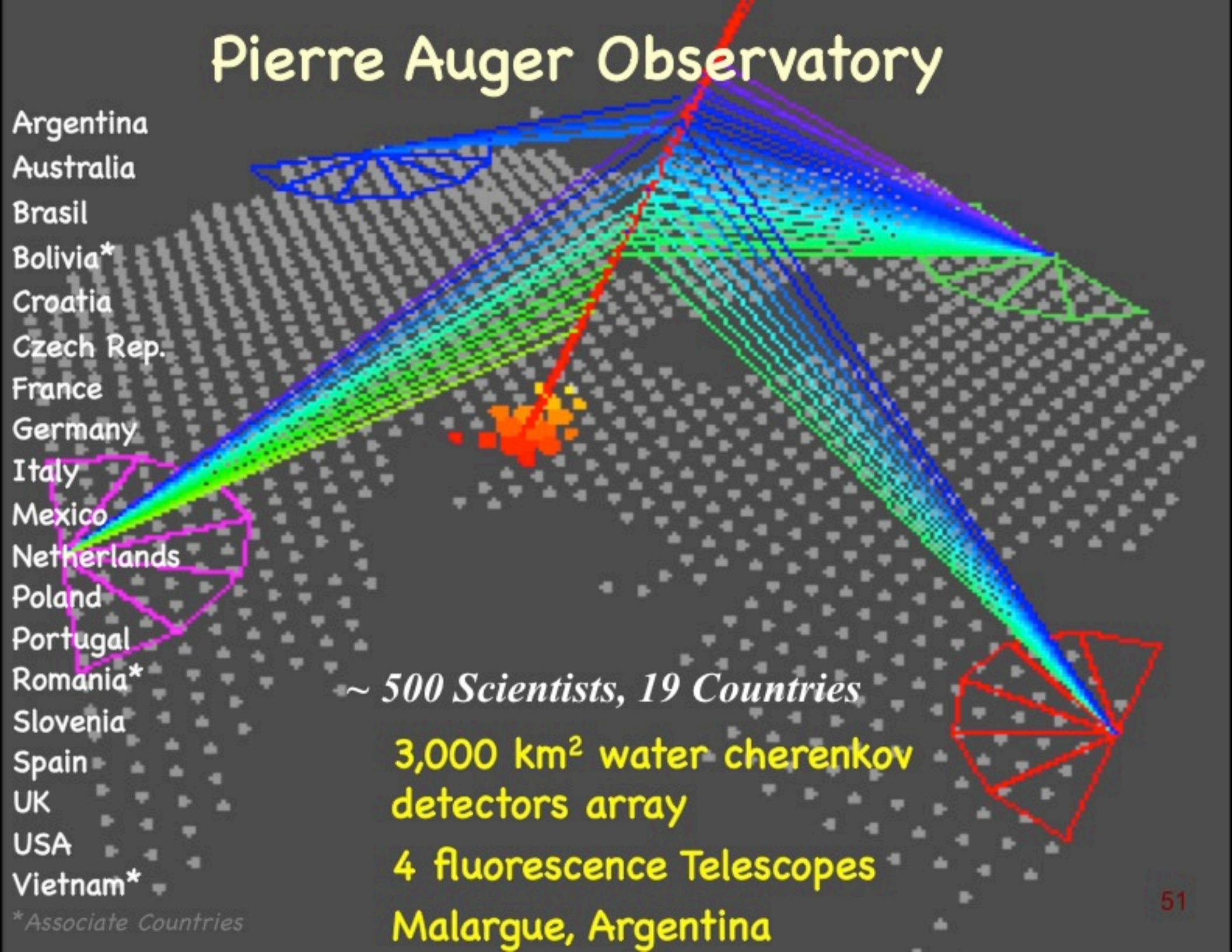
3,000 km^2 array

4 fluorescence telescopes

Pierre Auger Observatory



Pierre Auger Observatory



Argentina
Australia
Brasil
Bolivia*
Croatia
Czech Rep.
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Romania*
Slovenia
Spain
UK
USA
Vietnam*

*Associate Countries

~ 500 Scientists, 19 Countries

3,000 km^2 water cherenkov detectors array

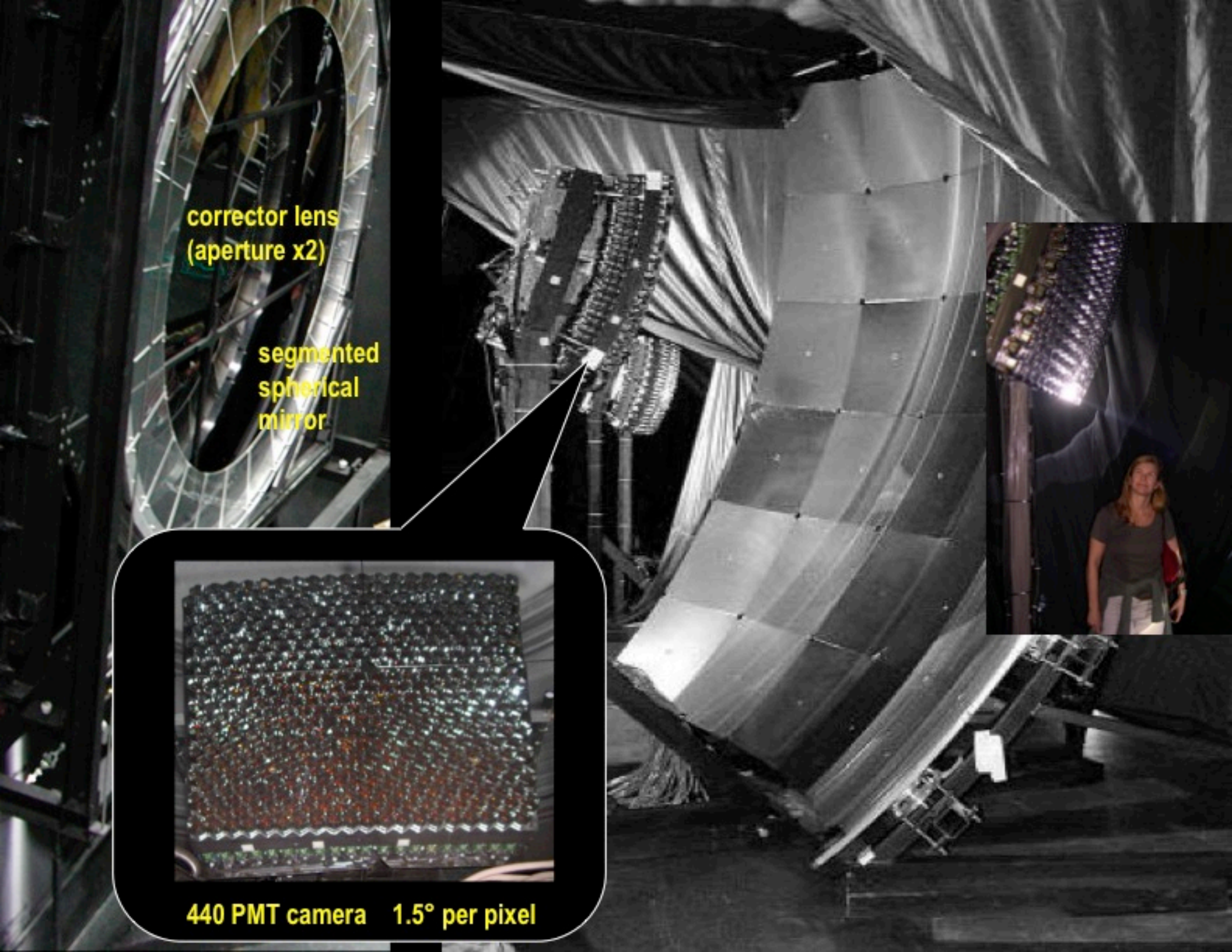
4 fluorescence Telescopes

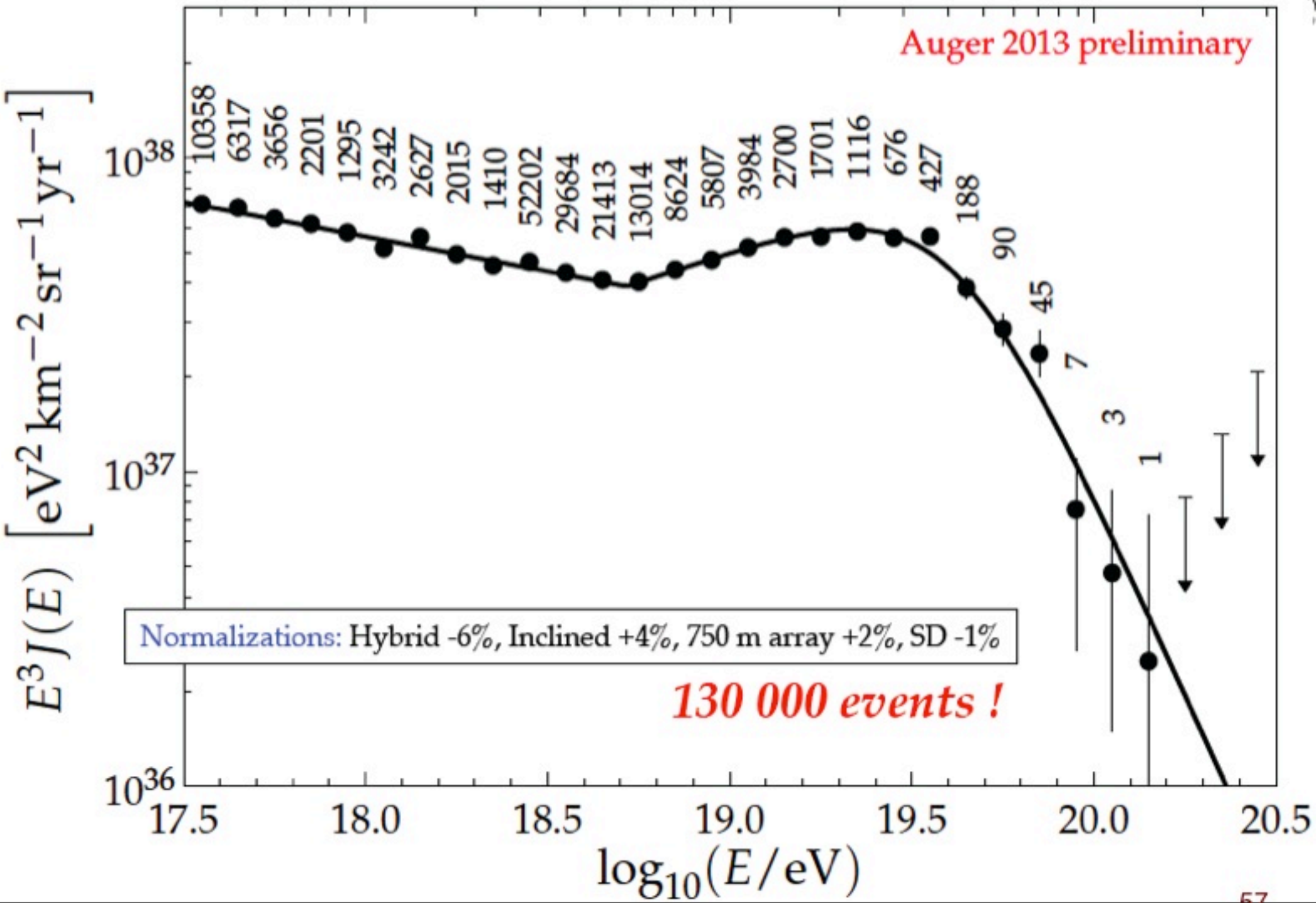
Malargue, Argentina

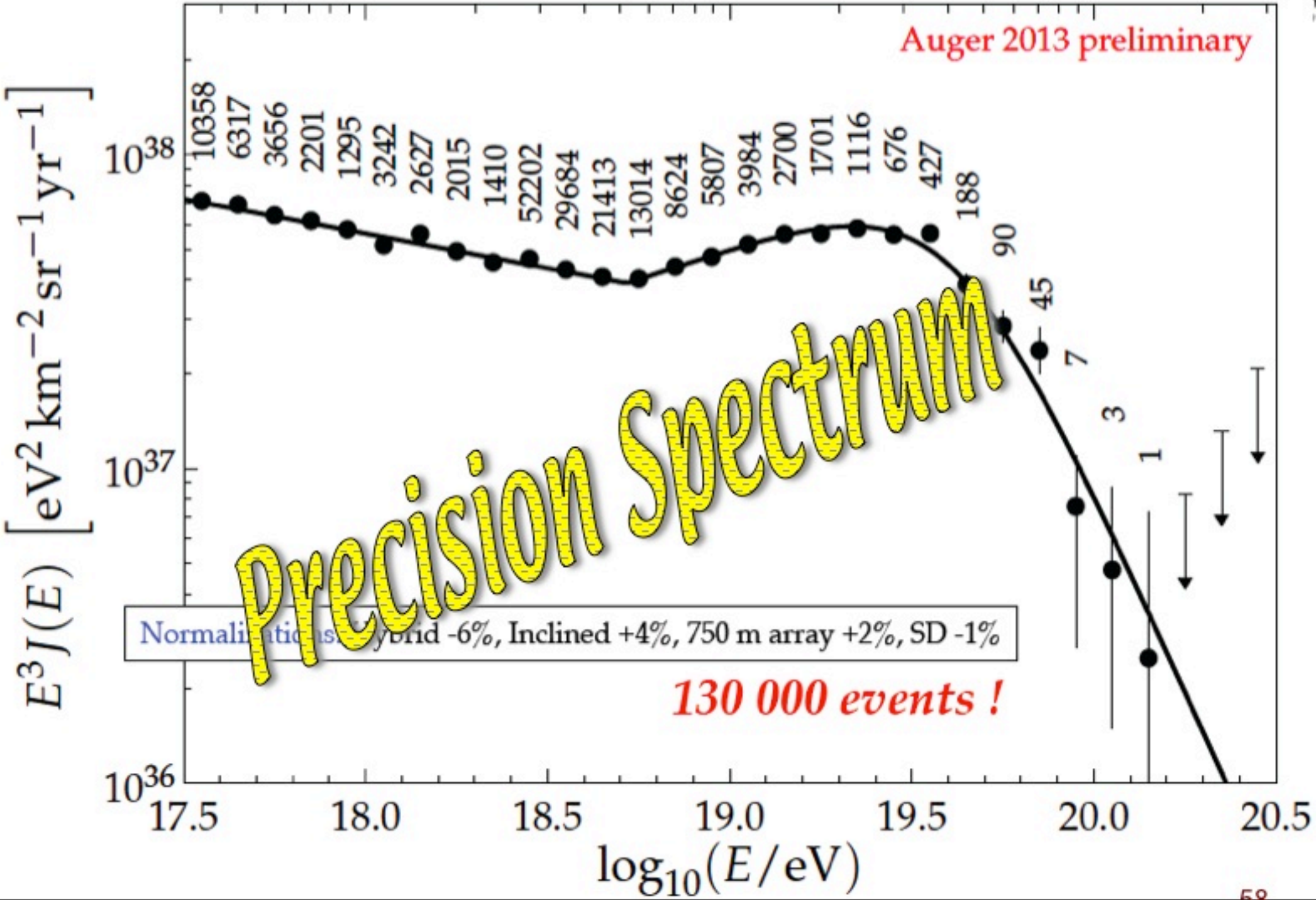
surface detector


array of tanks

4 times 6 telescopes overlooking the site


corrector lens
(aperture x2)
segmented
spherical
mirror
440 PMT camera 1.5° per pixel


Auger 2013 preliminary
10358
6317
3656
2201
1295
3242
2627
2015
1410
52202
29684
21413
13014
8624
5807
3984
2700
1701
1116
676
427
188
90
45
7
3
1
10^{38}
10^{37}
10^{36}
$E^3 J(E)$ $[\mathrm{eV}^2\,\mathrm{km}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{yr}^{-1}]$
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$\log_{10}(E/\mathrm{eV})$
Normalizations: Hybrid -6%, Inclined +4%, 750 m array +2%, SD -1%
130 000 events !


Auger 2013 preliminary
Precision Spectrum
130 000 events !
Normalization: Hybrid -6%, Inclined +4%, 750 m array +2%, SD -1%
$E^3 J(E)$ $[\mathrm{eV}^2\,\mathrm{km}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{yr}^{-1}]$
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90
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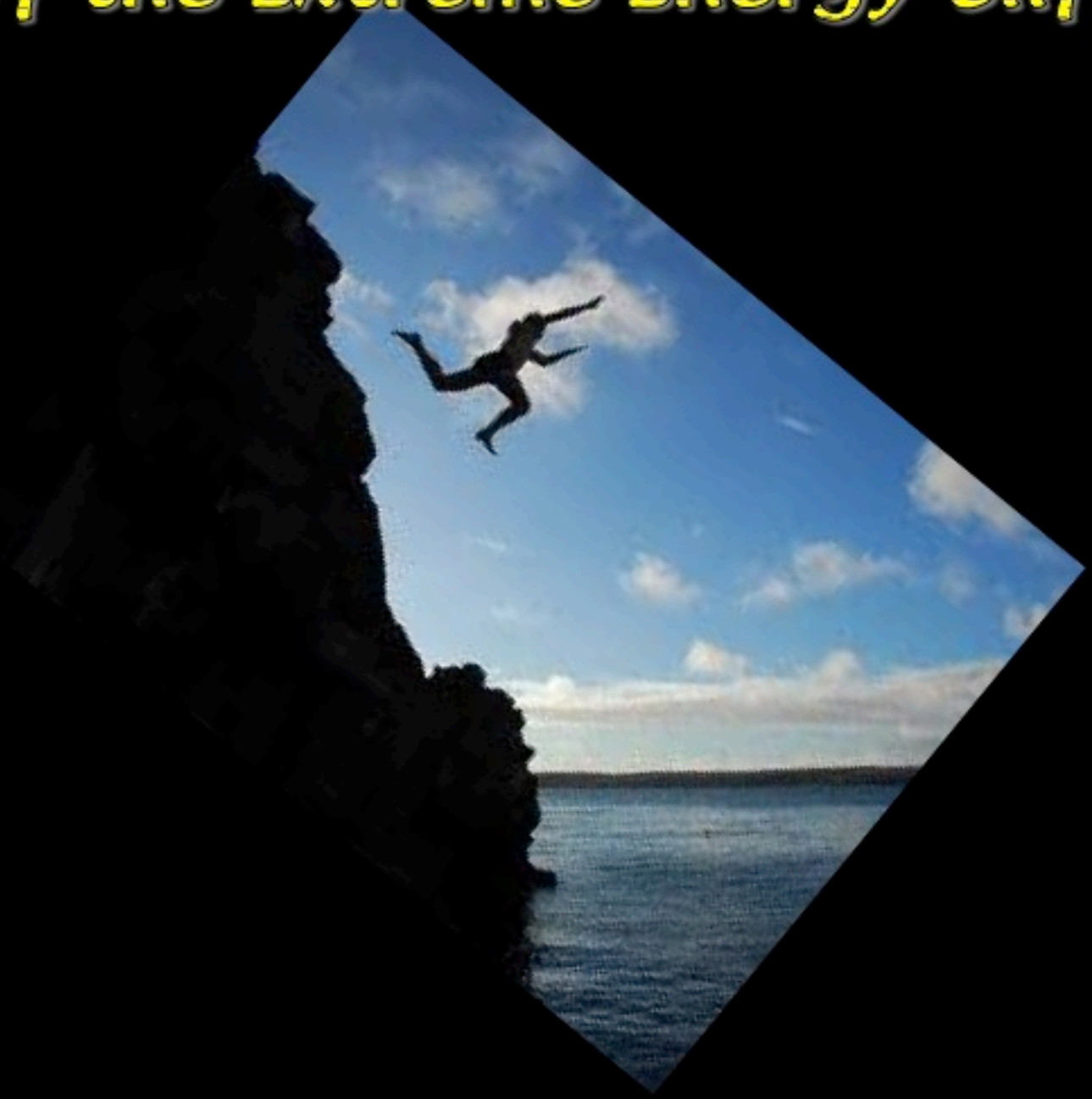
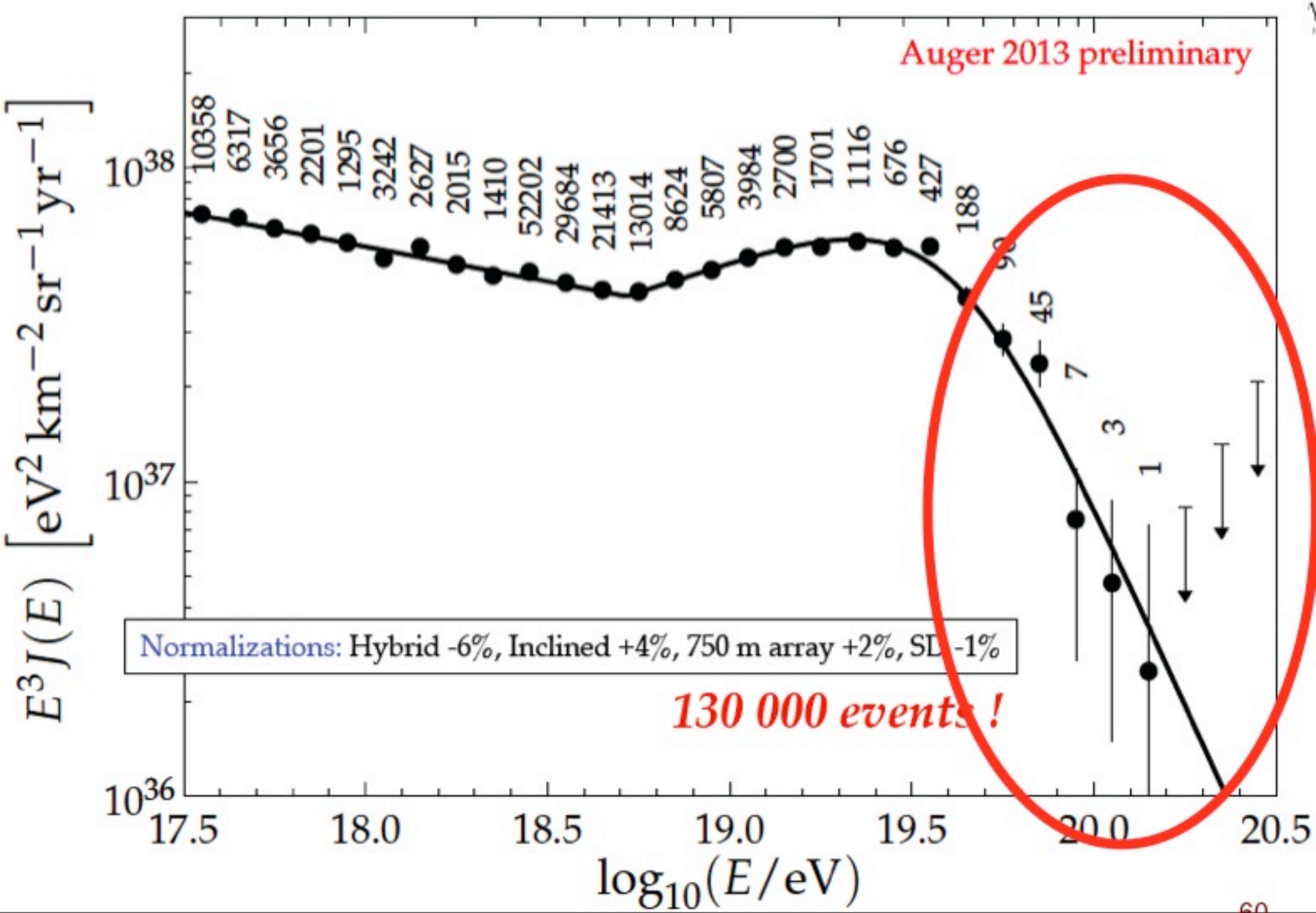
3
1
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$\log_{10}(E/\mathrm{eV})$

Off the Extreme Energy Cliff




Auger 2013 preliminary
$E^3 J(E)$ $[\mathrm{eV}^2\,\mathrm{km}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{yr}^{-1}]$
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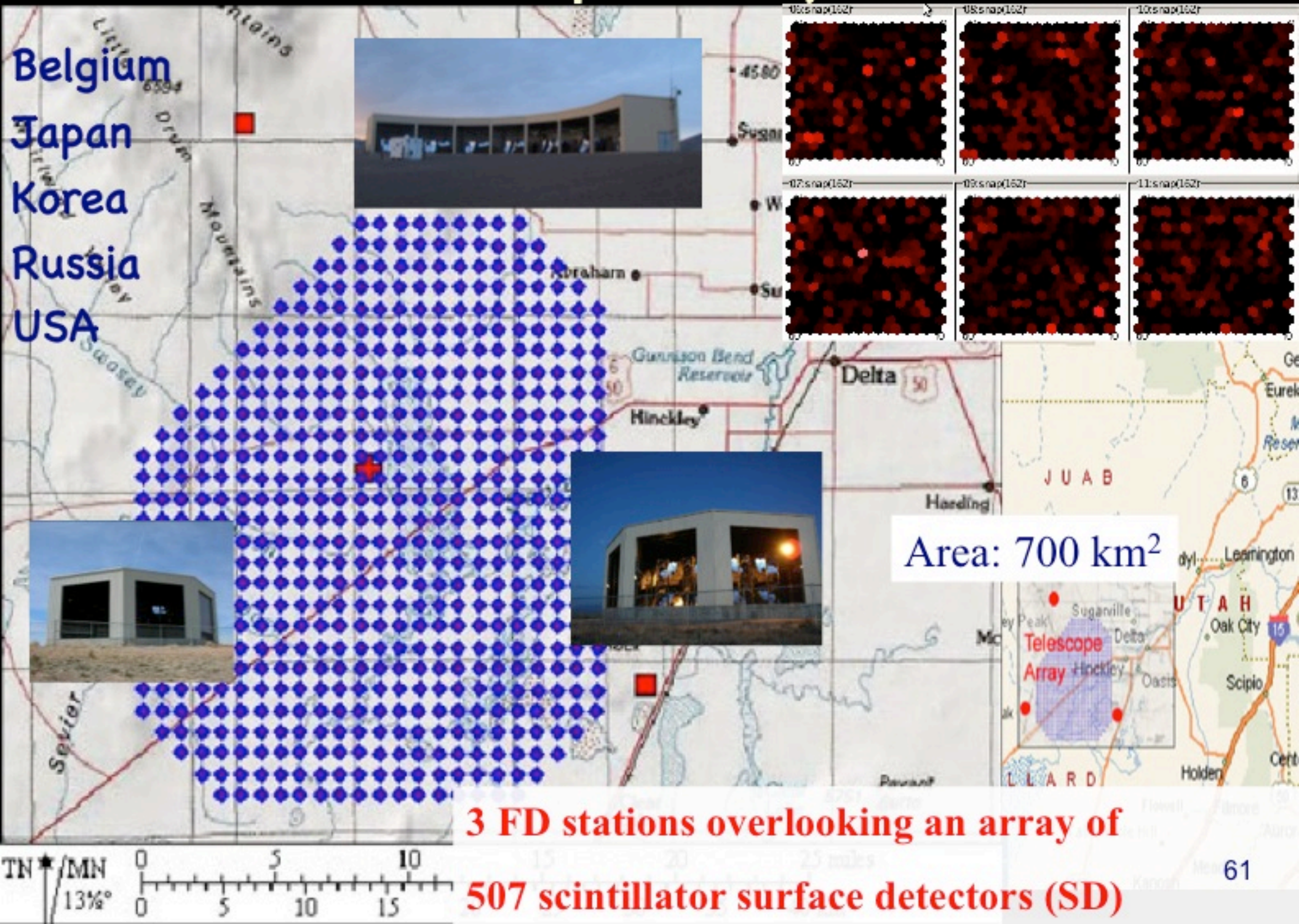
130 000 events !
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$\log_{10}(E/\mathrm{eV})$

Telescope Array



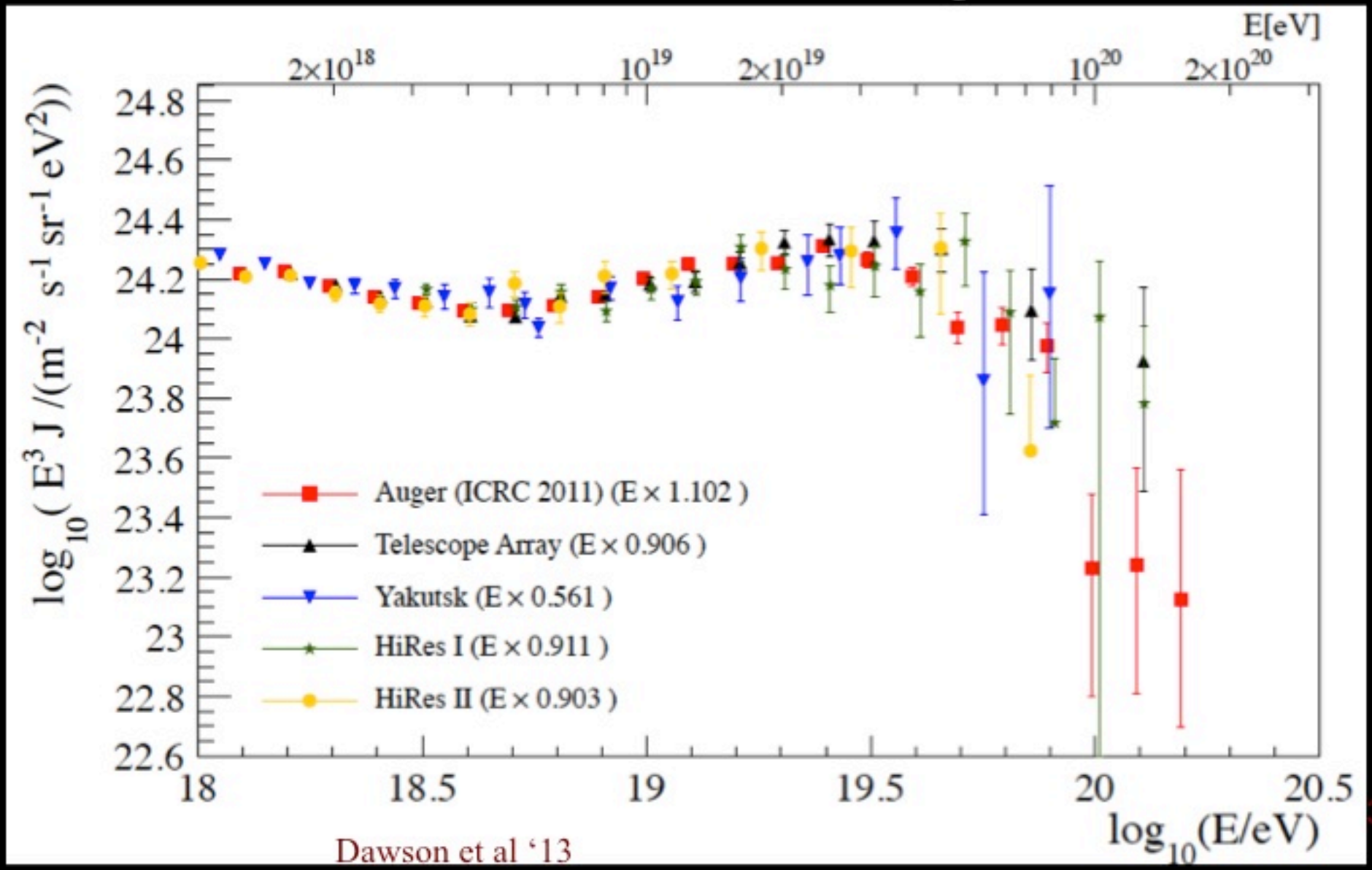
3 FD stations overlooking an array of 507 scintillator surface detectors (SD)

Deployment (up to 50/day) 485
SDs: 10/2006 - 3/2007

2012 CERN Working Group

Unified Spectrum

Energies re-scaled ~10%



Dawson et al '13

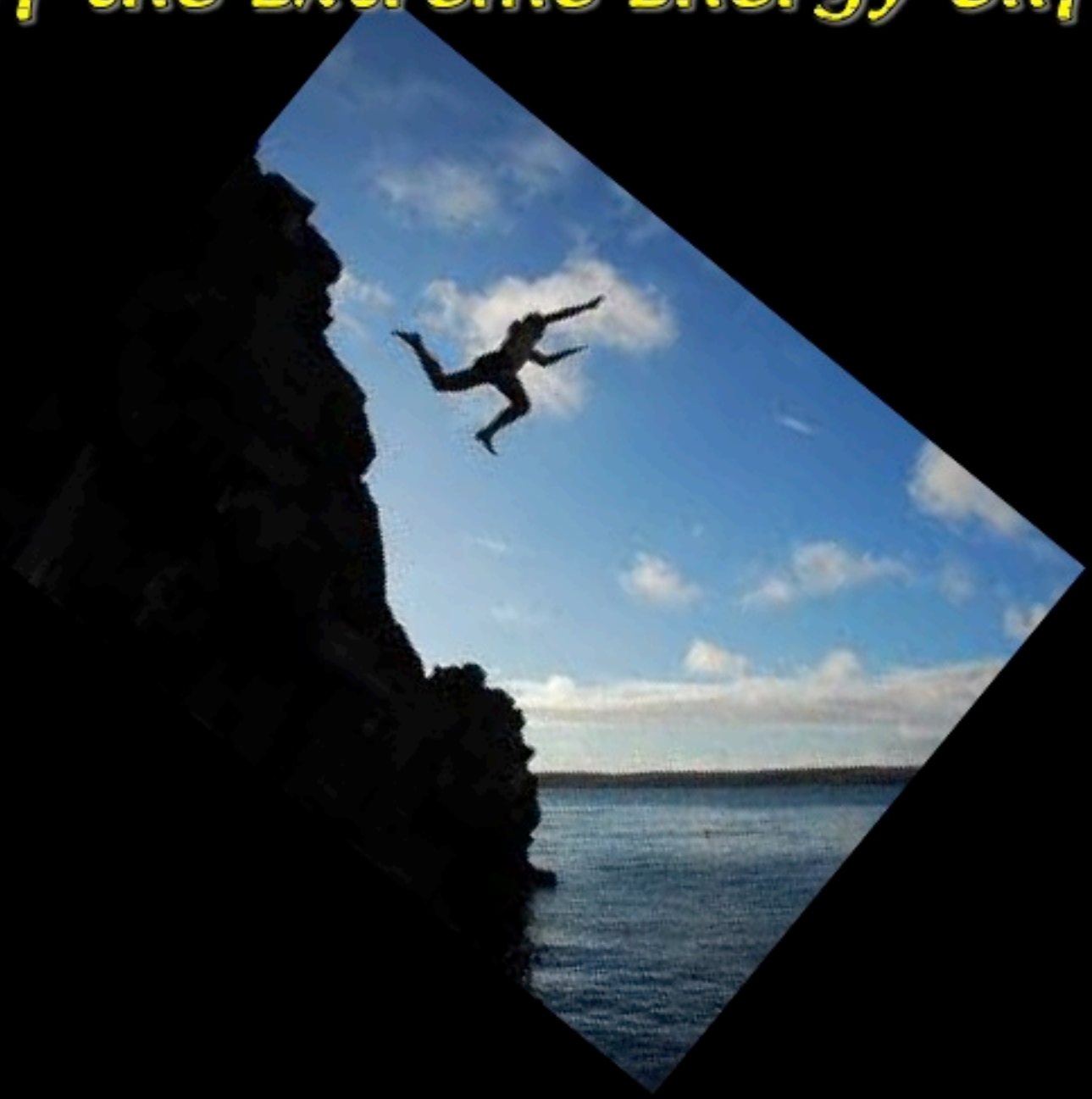
UHECRs Current Status

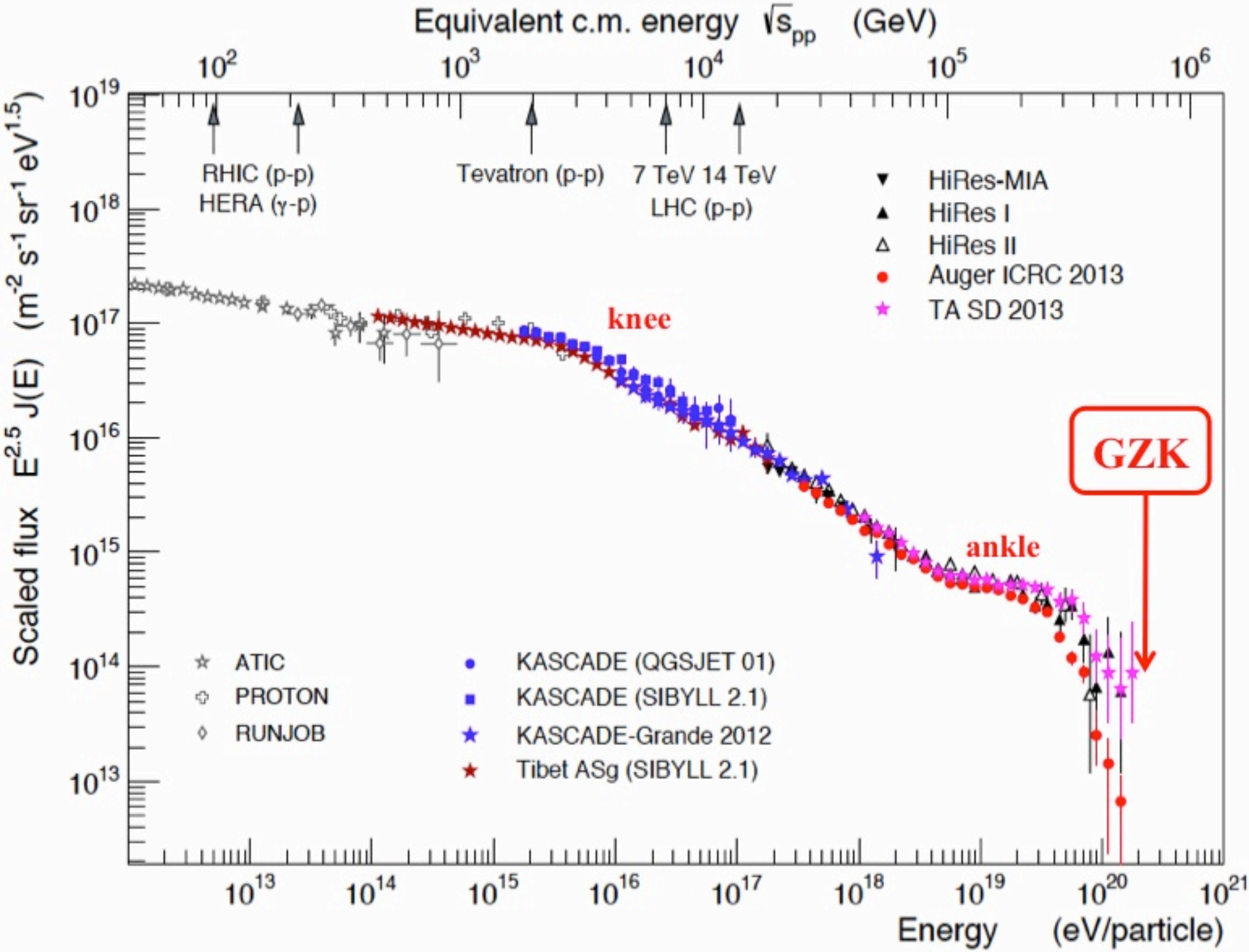
Leading Observatories: Auger & Telescope Array

Agree on the shape of the spectrum

Energy scale: ~10% difference

Off the Extreme Energy Cliff




Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
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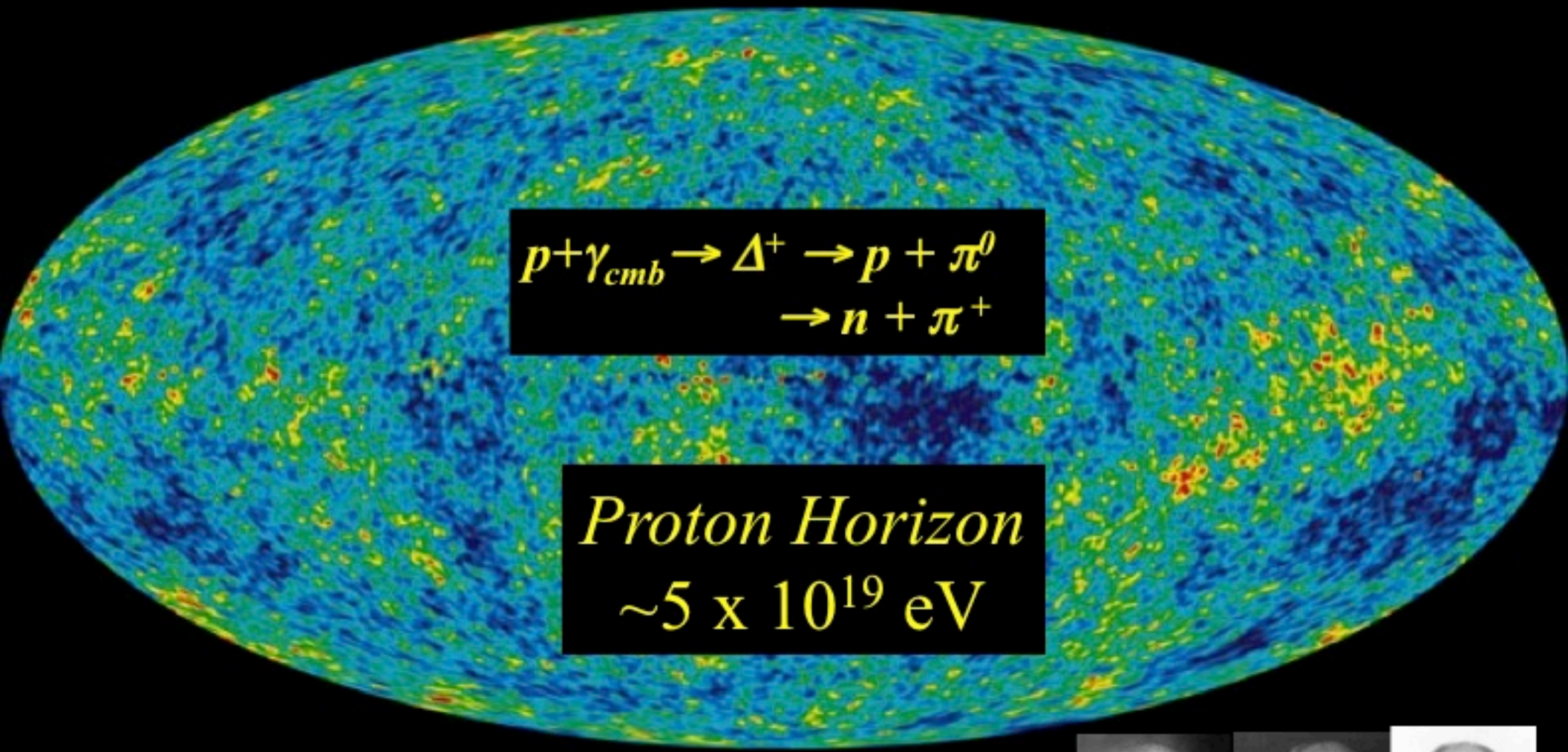
10^13
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

"Cosmologically Meaningful Termination"



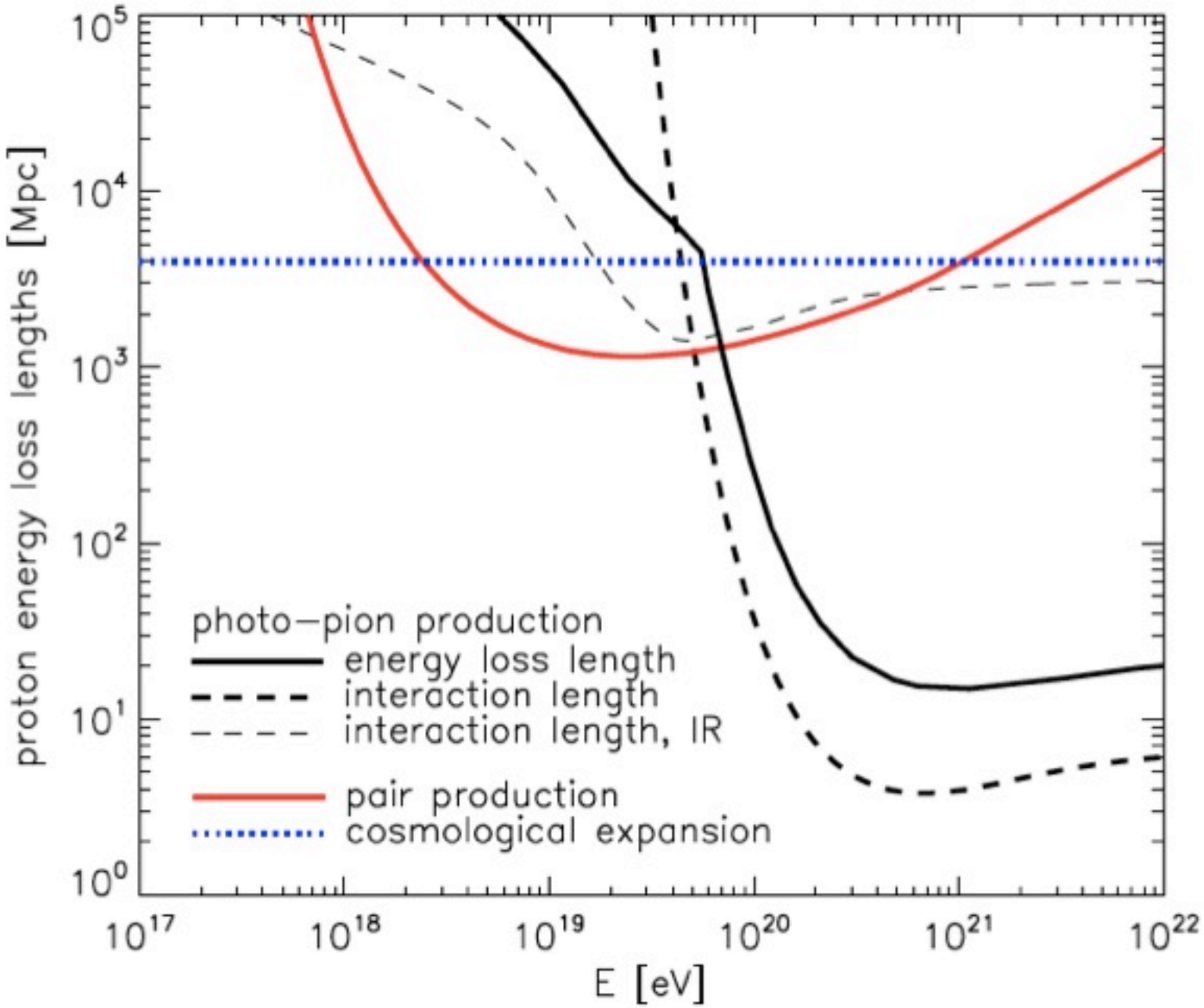
$$p + \gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0}$$
$$\rightarrow n + \pi^{+}$$

Proton Horizon
~5 x 10^{19} eV

GZK Cutoff

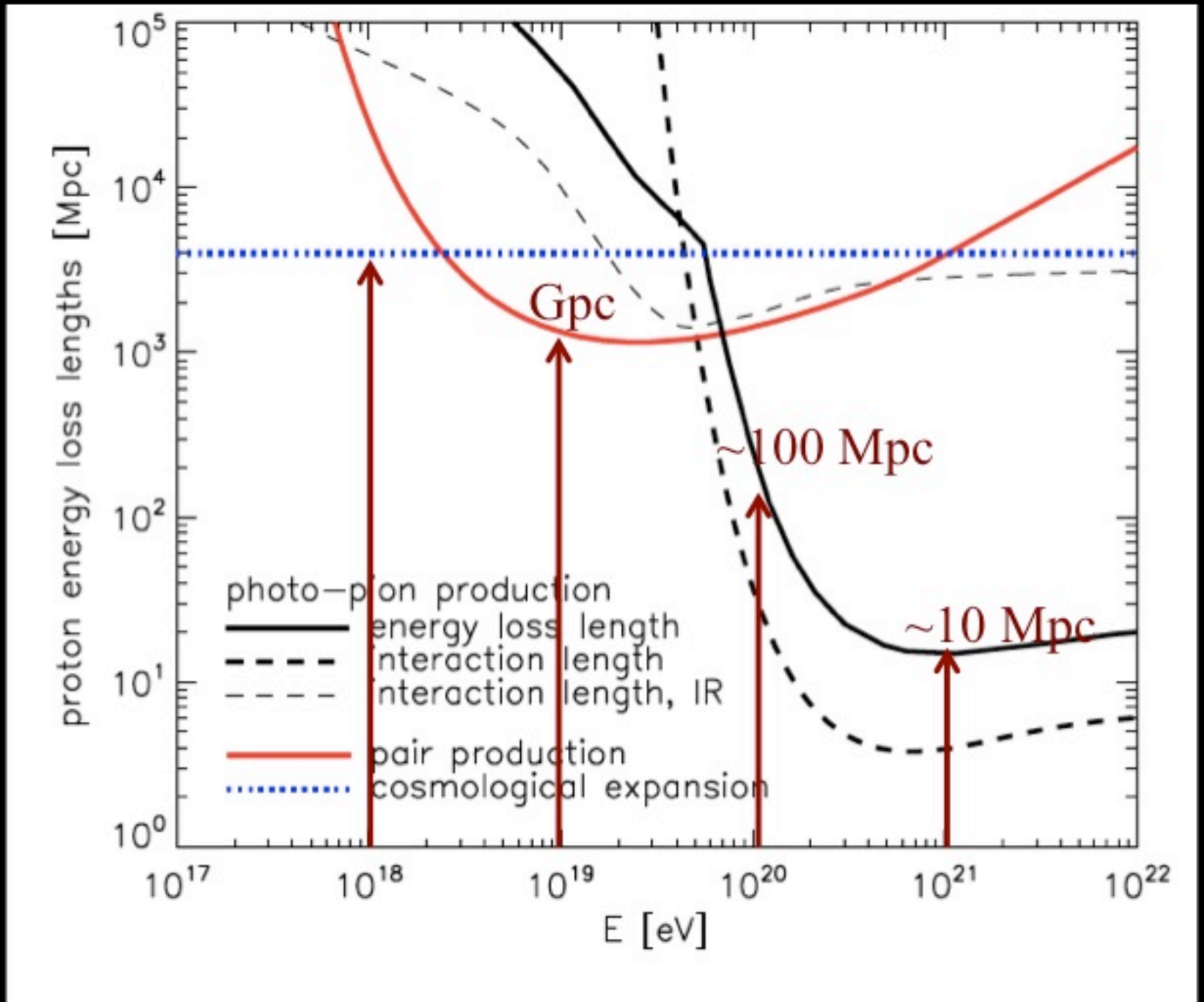
Greisen, Zatsepin, Kuzmin 1966

Greisen-Zatsepin-Kuzmin effect

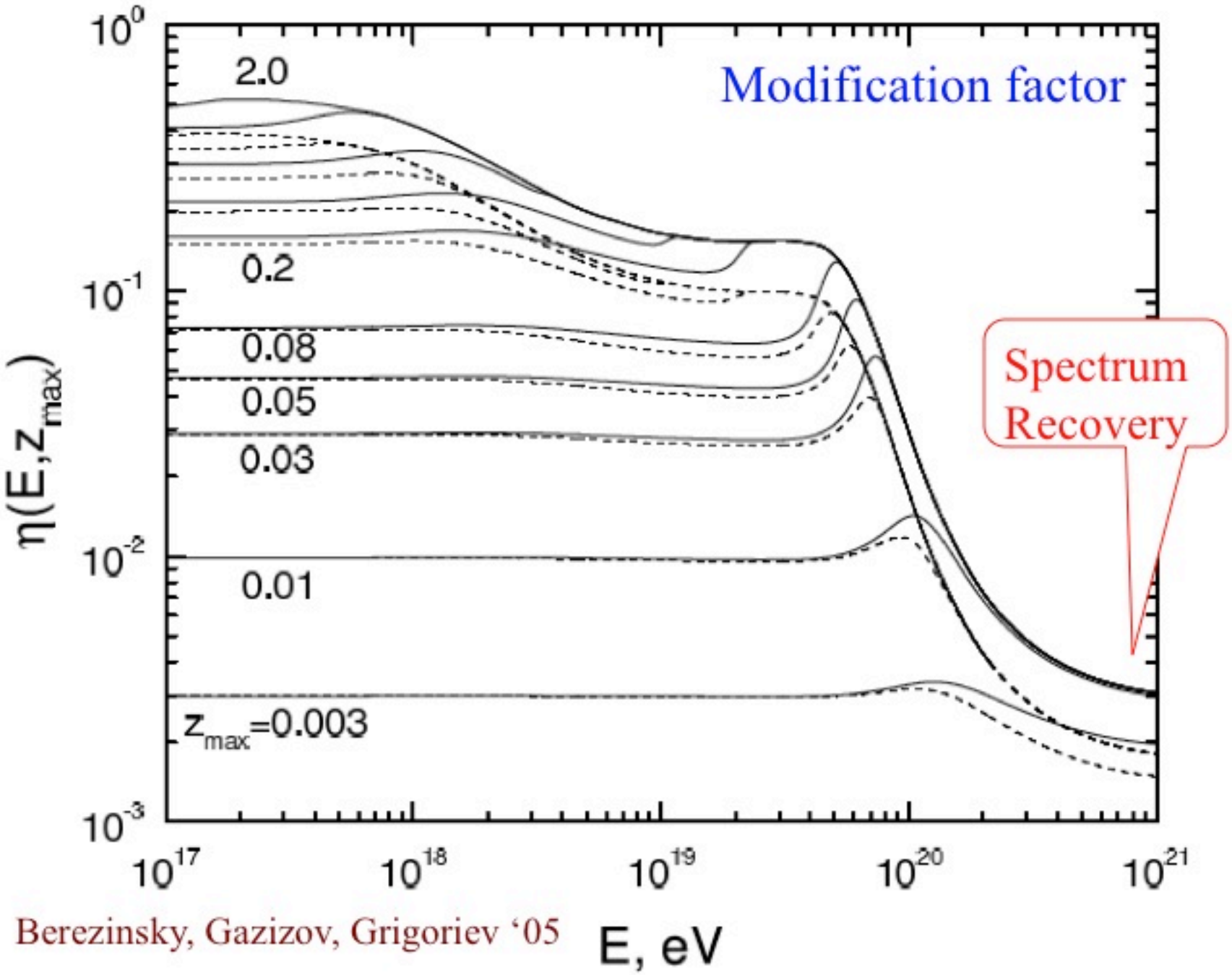


Kotera & AO 11

Greisen-Zatsepin-Kuzmin effect



Propagation of UHE protons



Berezinsky, Gazizov, Grigoriev '05

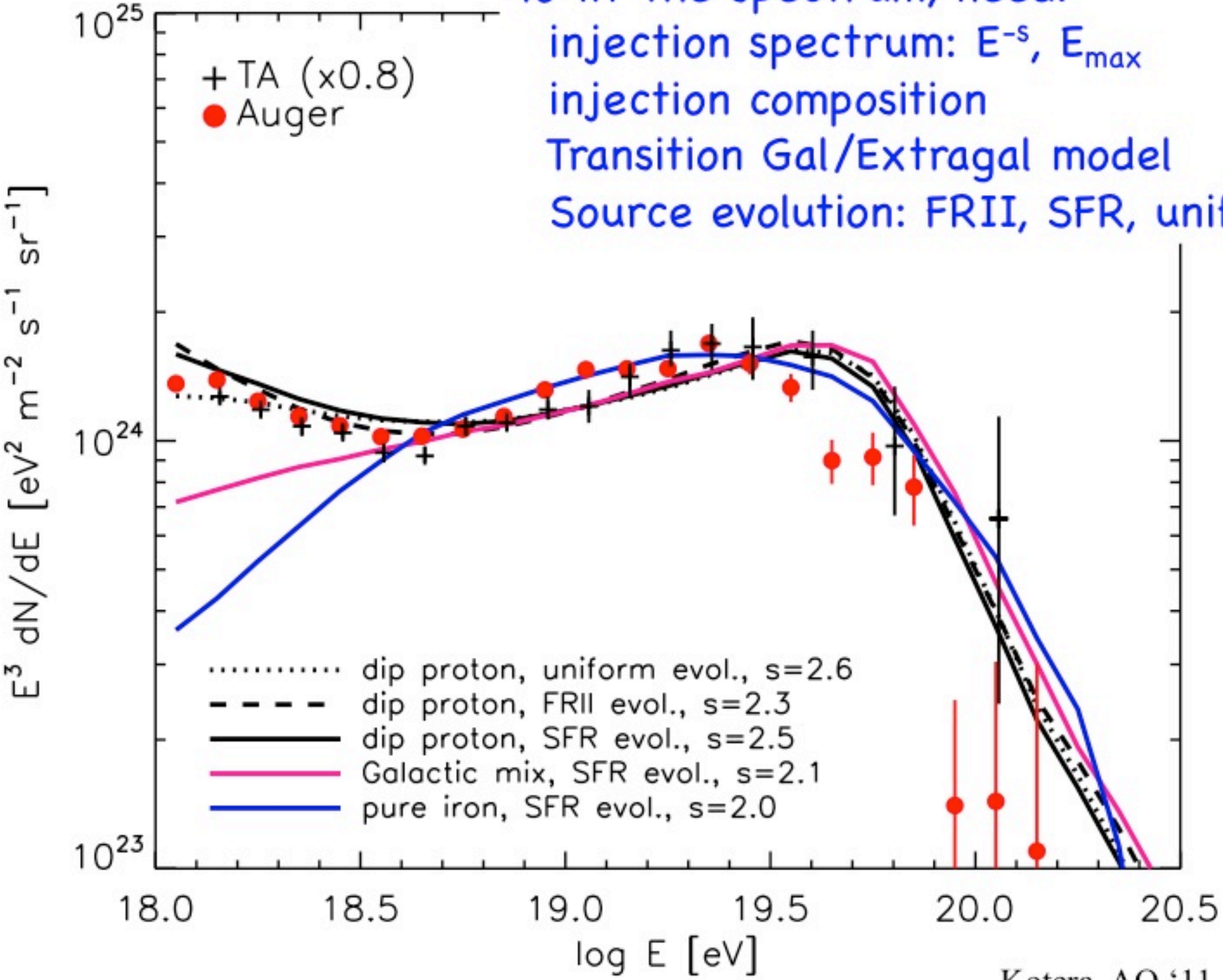
To fit the spectrum, need:

injection spectrum: E^{-s}, E_{max}

injection composition

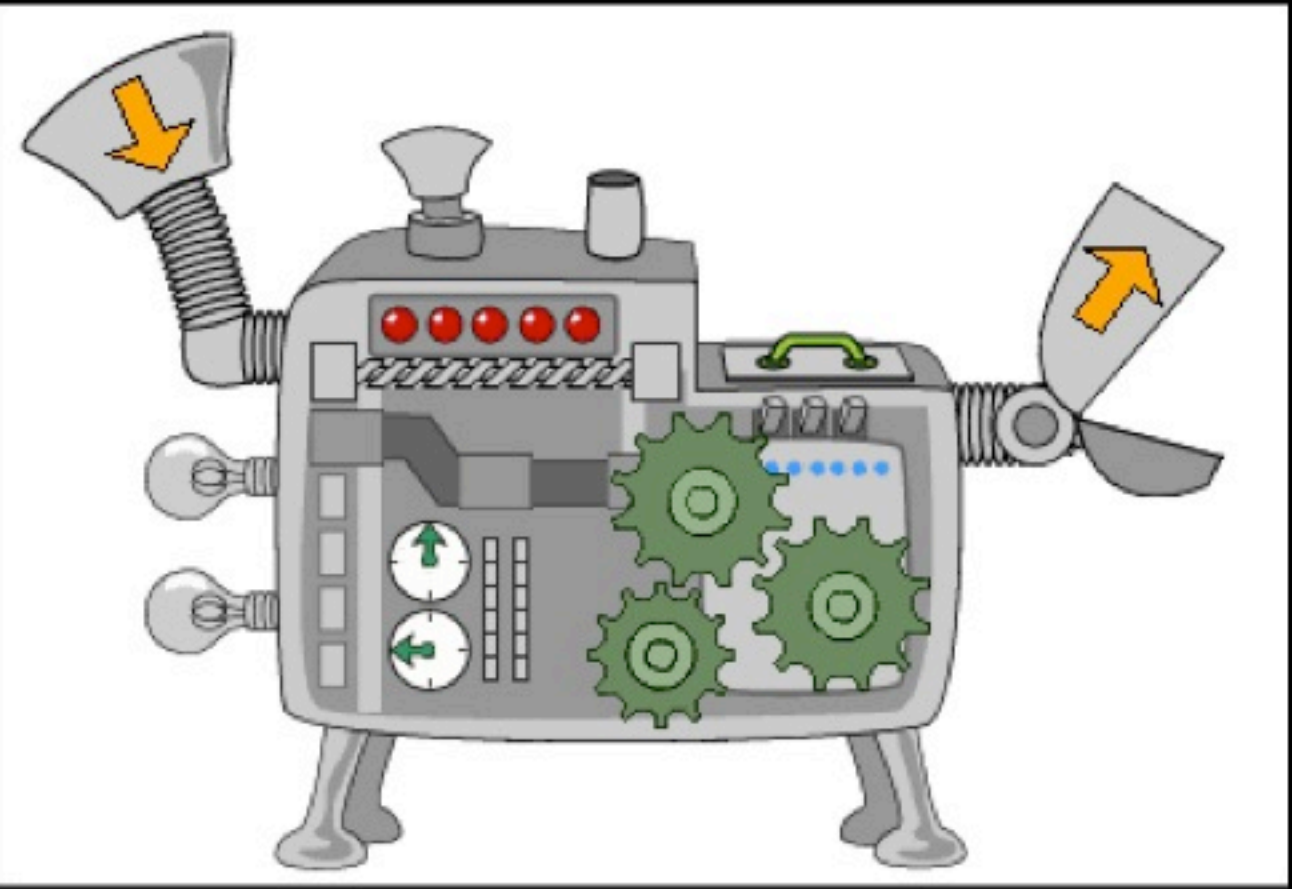
Transition Gal/Extragal model

Source evolution: FRII, SFR, uniform



Kotera, AO '11

Modern Propagation Codes



Public:

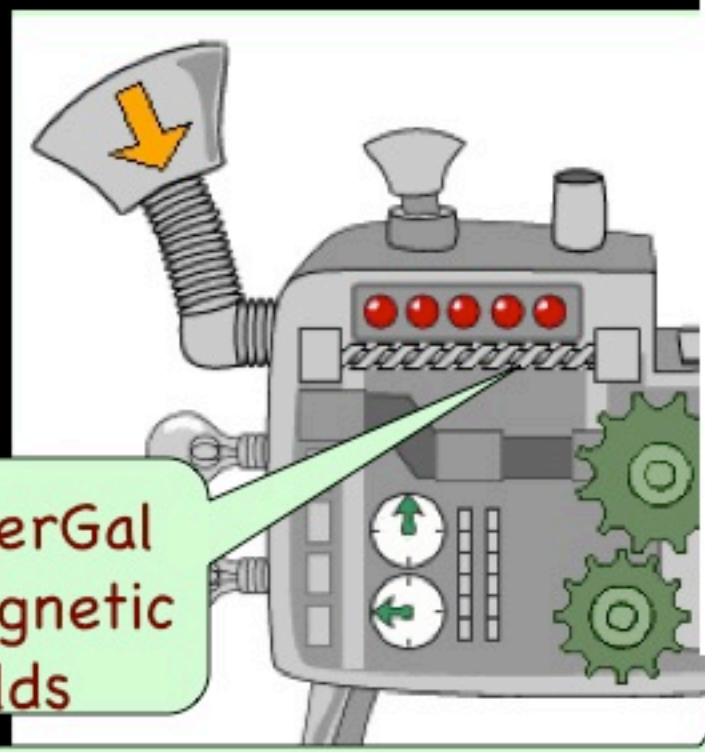
CRPropa
1.0 Armengaud et al '06
2.0 Kampert et al. '12
3.0 Alvez Batista et al '13

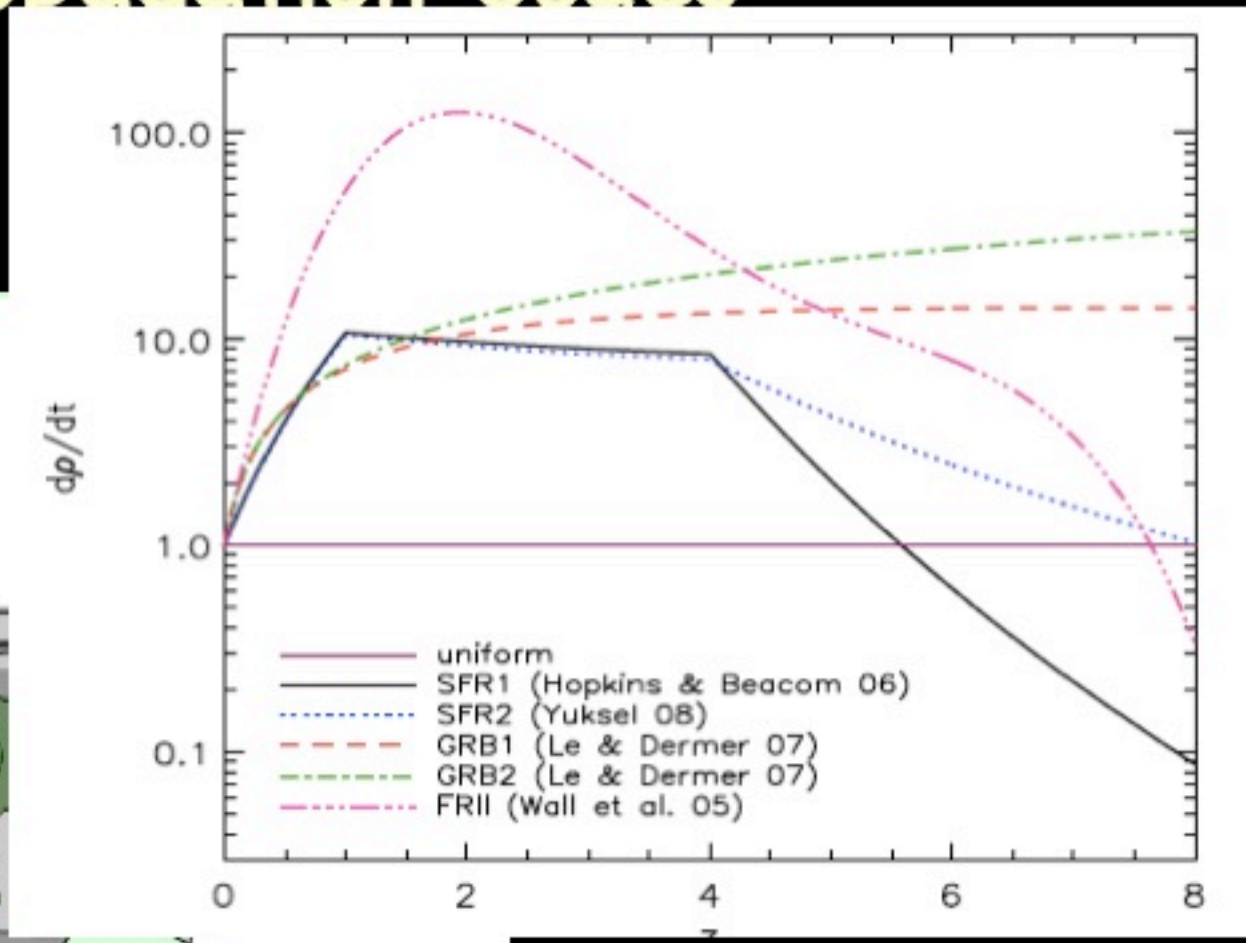
SimProp
Aloisio et al '12

Private:

Allard et al '04
Taylor '07
Ahlers '10
others...

Modern Propagation Codes



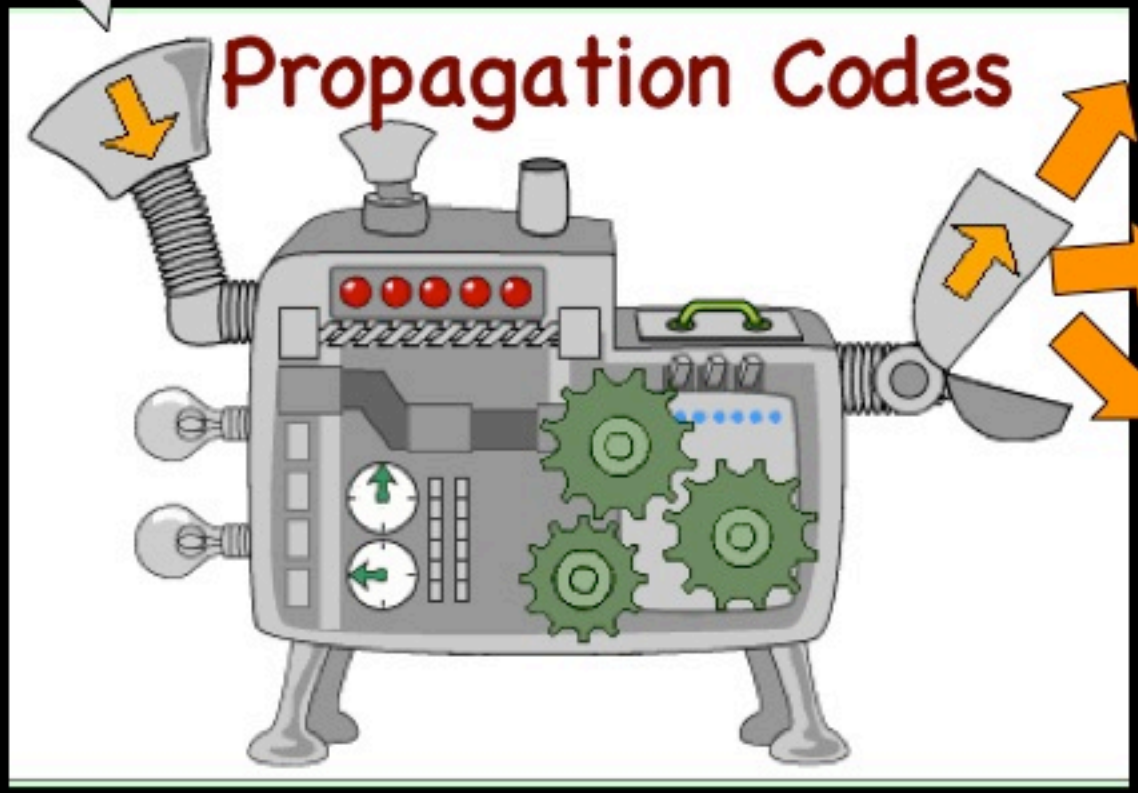


InterGal Magnetic Fields

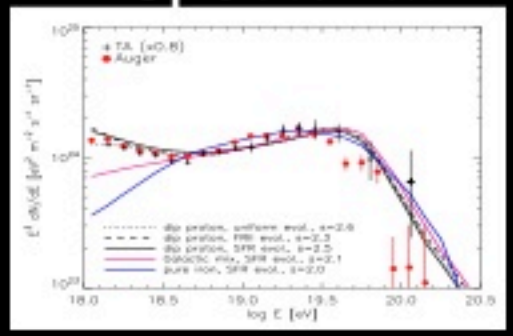
Interaction Cross Sections, z evolution
Background Fields: CMB, UV/Opt/IR
Primary, Secondary nuclei, nucleons,
e+e-, gamma-rays, neutrinos,...

Source Model:

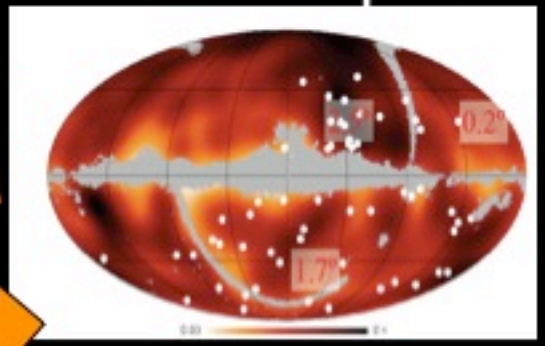
- injection spectrum: E^{-s}
- injected composition
- redshift distribution



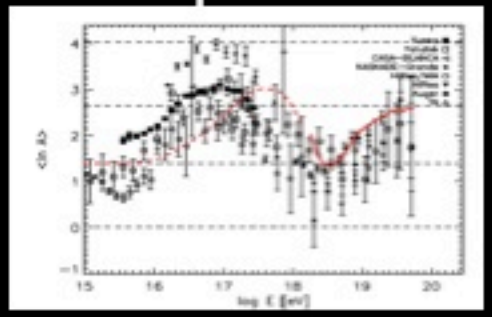
Spectrum



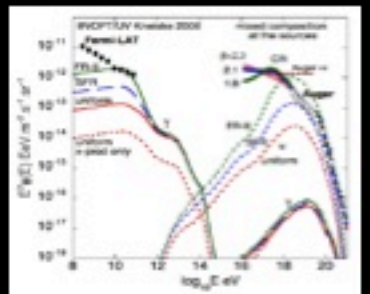
Anisotropies

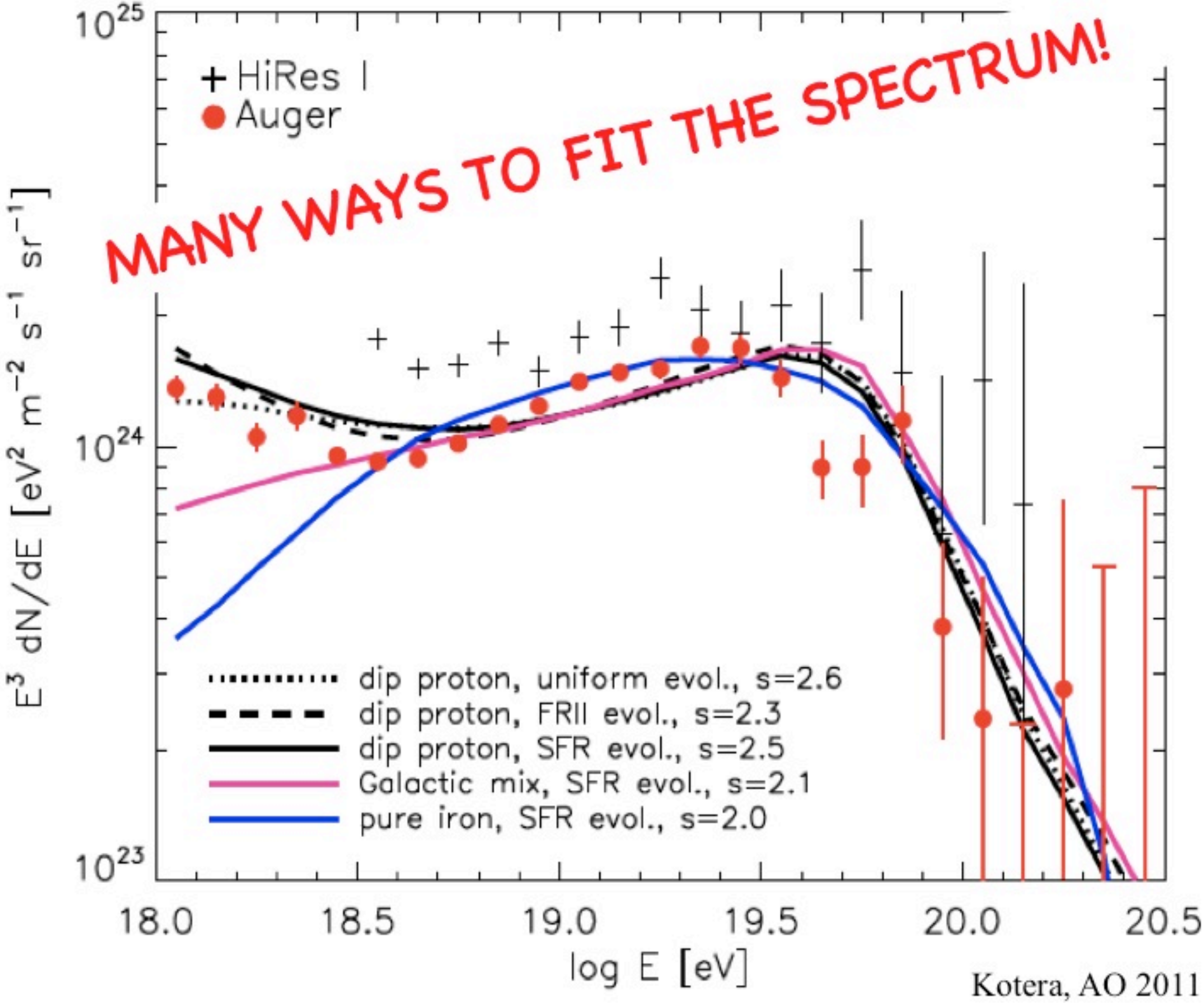


Composition



Multi-messengers





Kotera, AO 2011

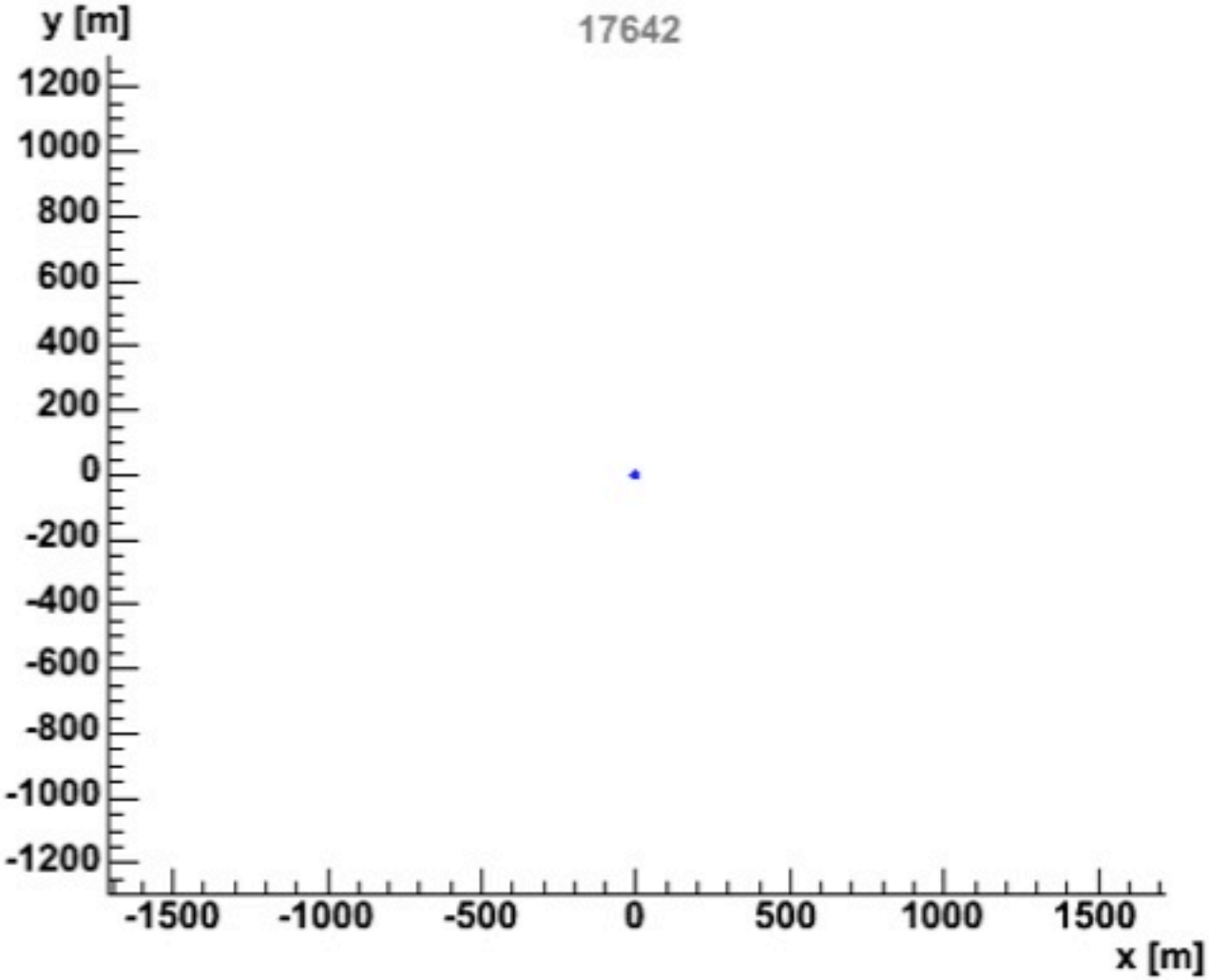
UHECRs Current Status

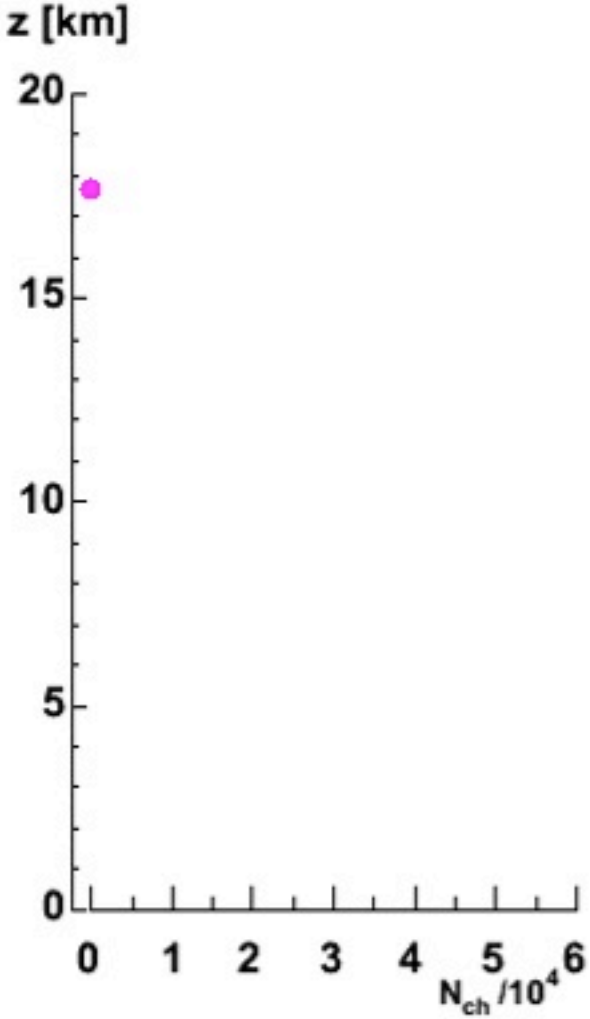
Leading Observatories: Auger & Telescope Array

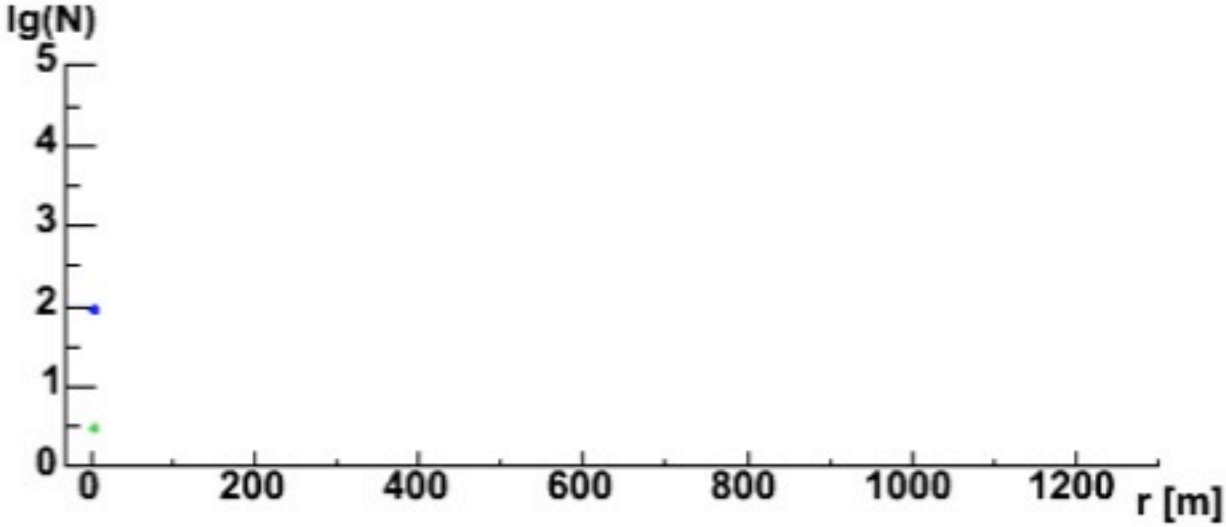
Agree on the shape of the spectrum

Energy scale: ~10% difference

Composition?







Proton 10^{14} eV

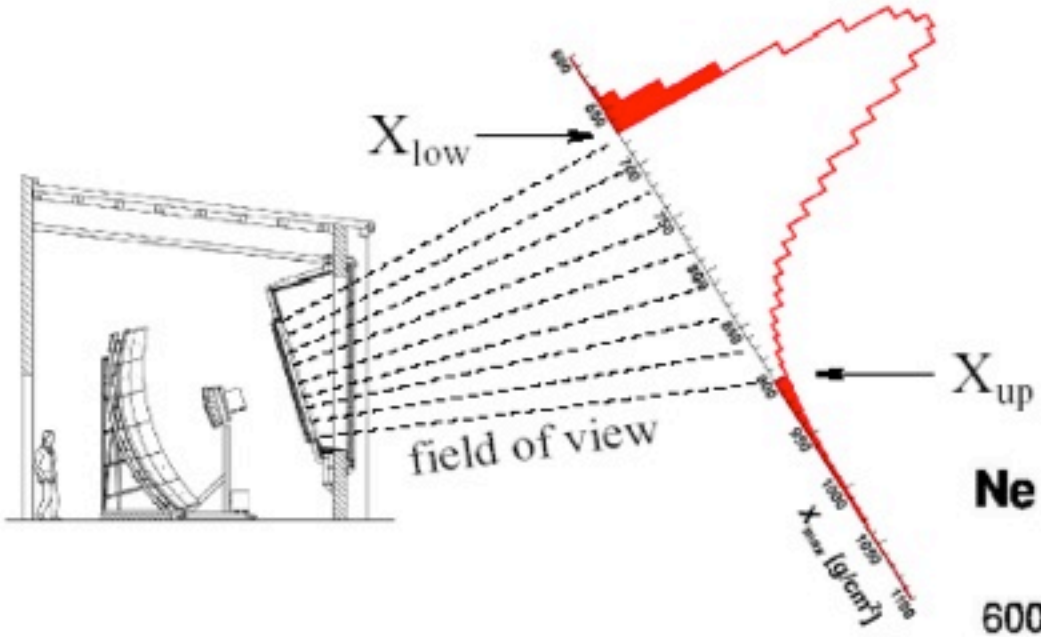
h^{1st} = 17642 m

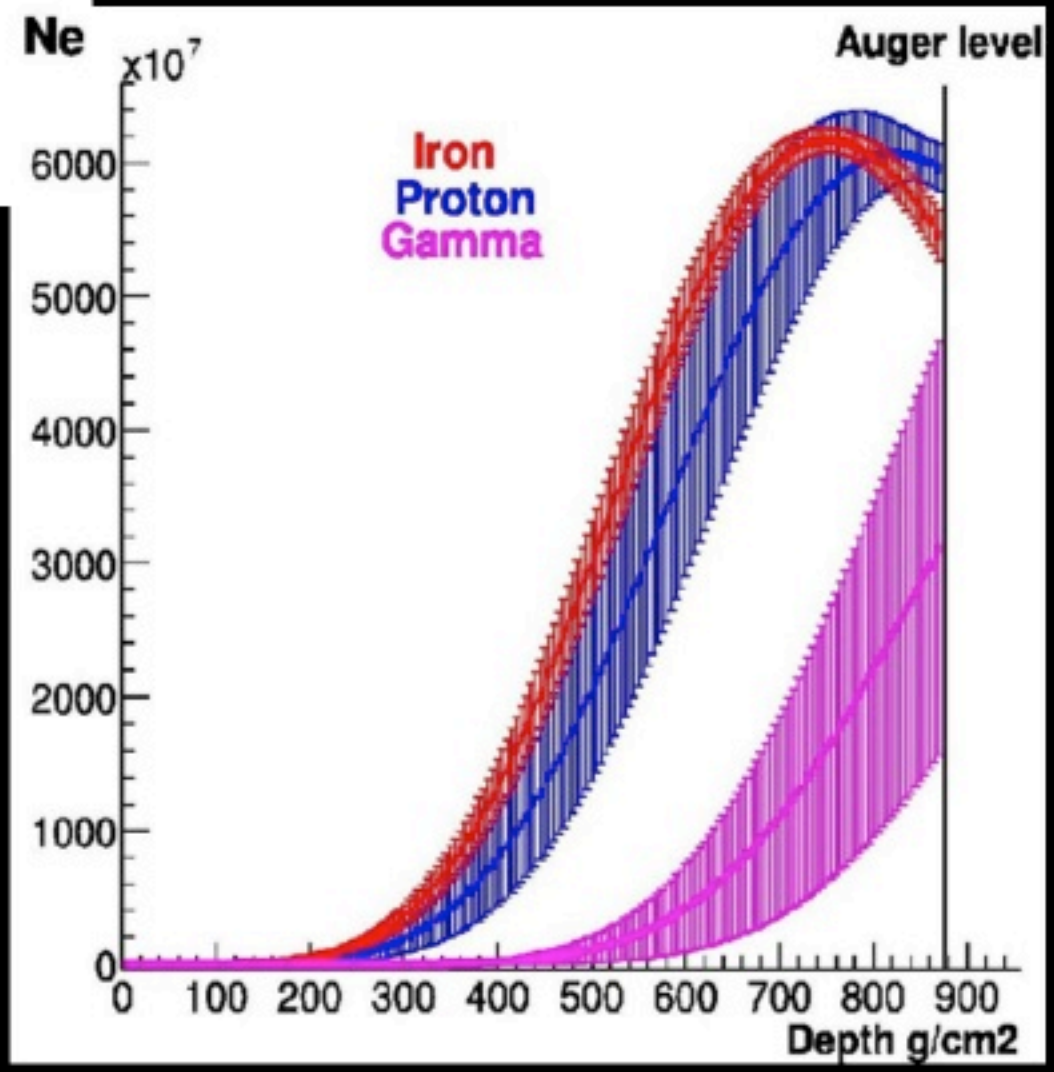
hadrons muons

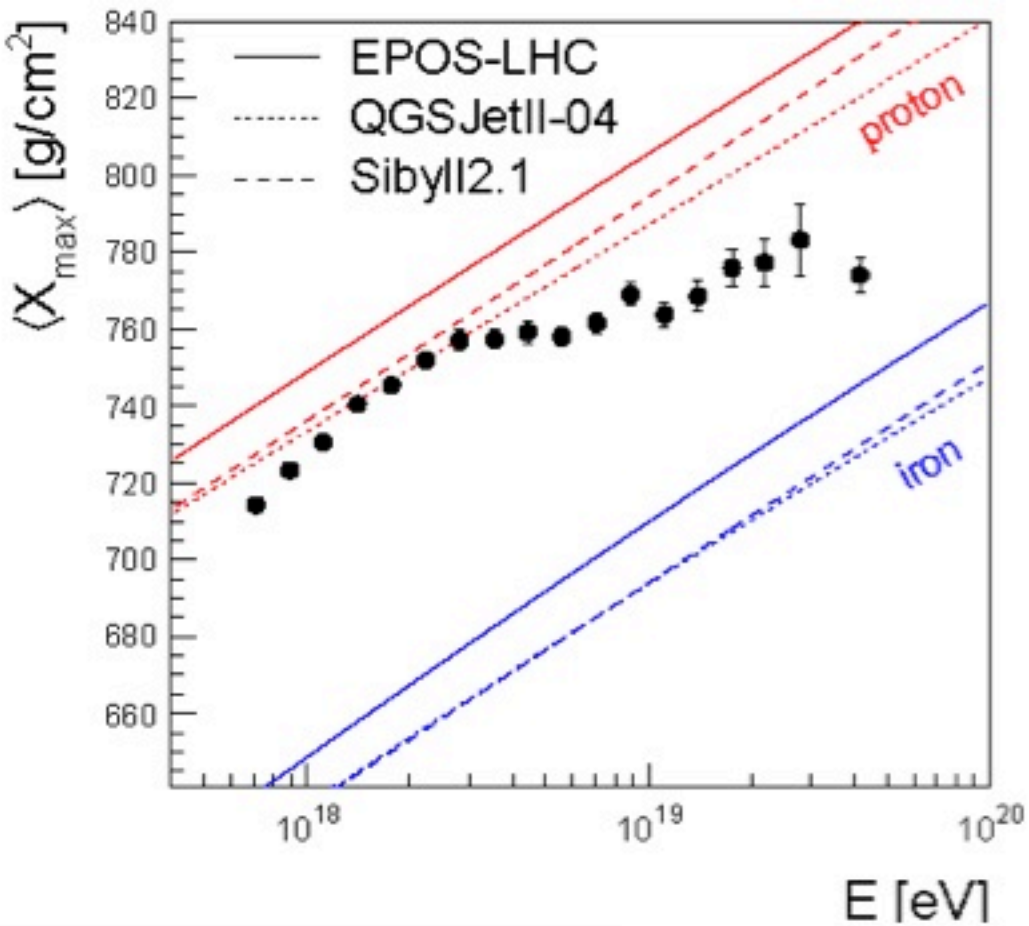
neutrons **electrs**

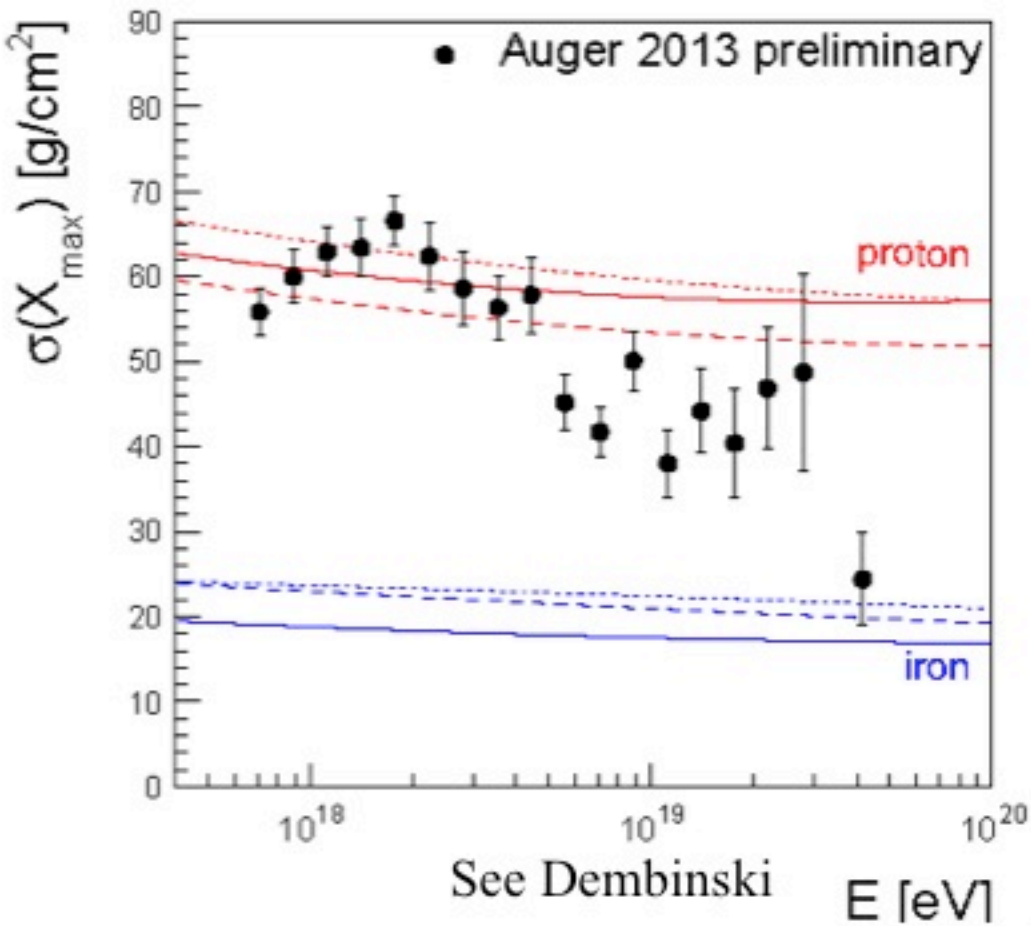
J.Oehlschlaeger,R.Engel,FZKarlsruhe

Composition observable: shower maximum

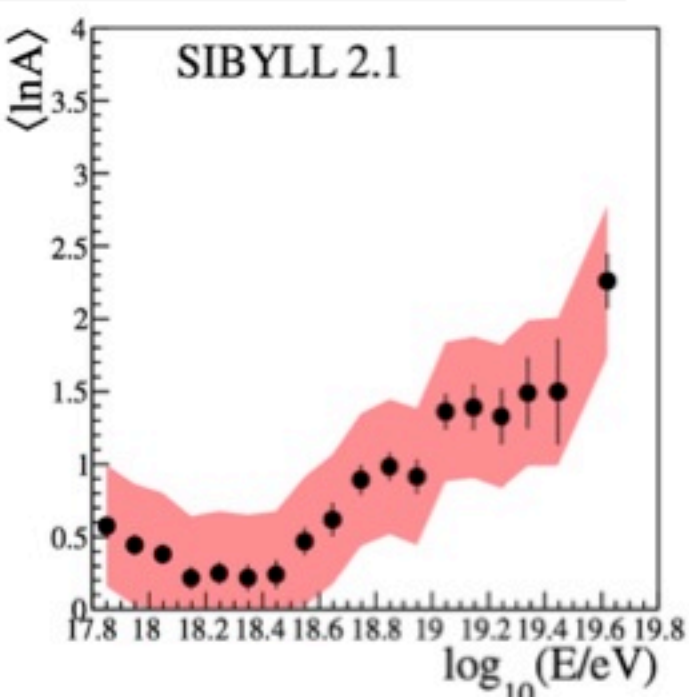


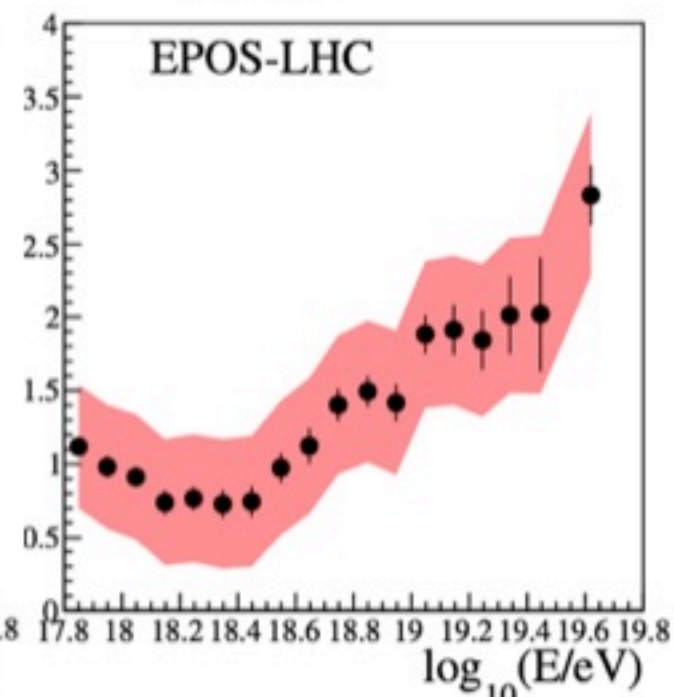


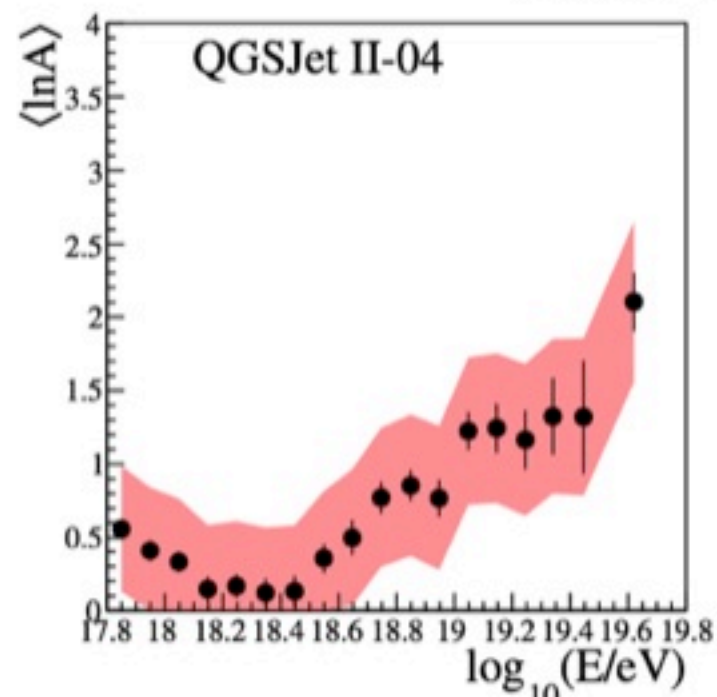


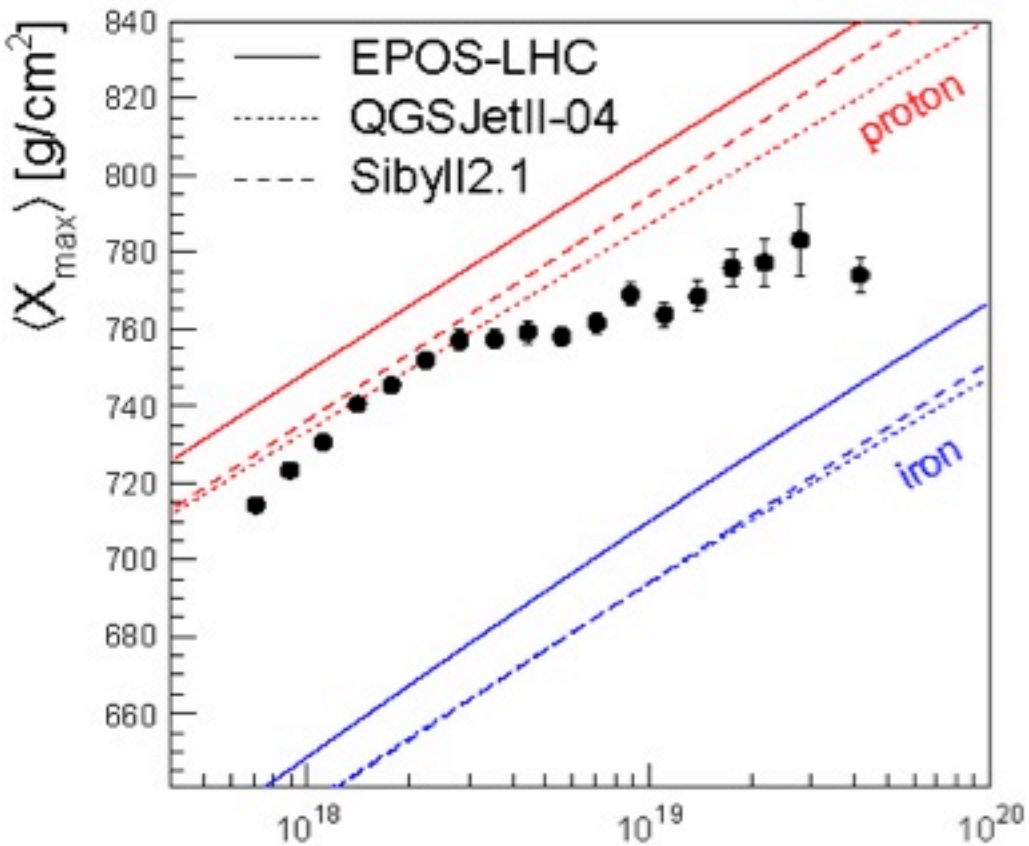


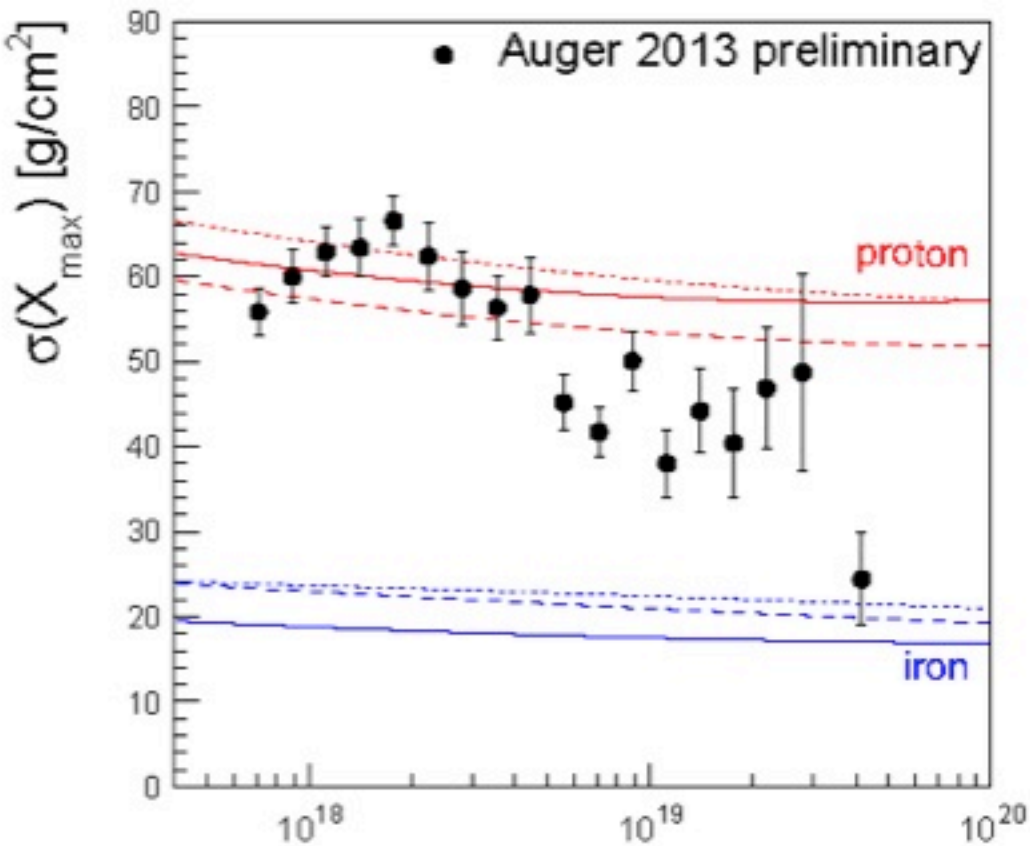
See Dembinski



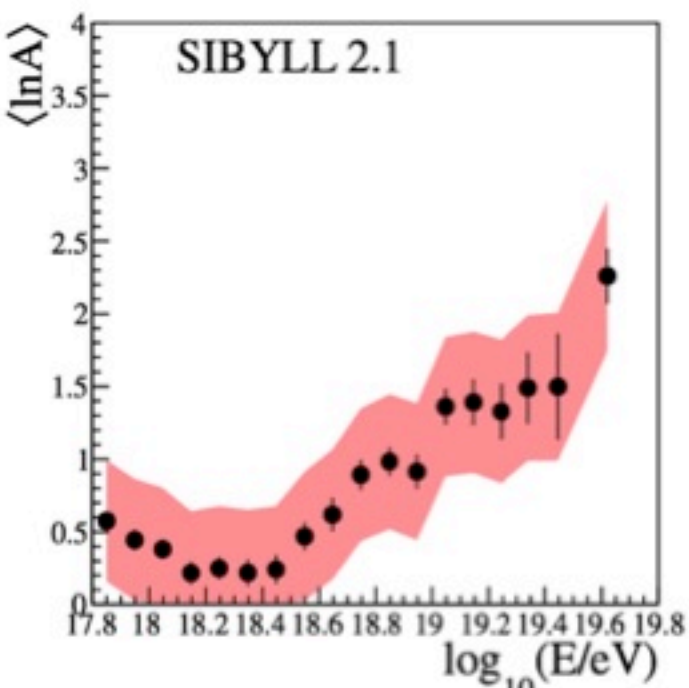


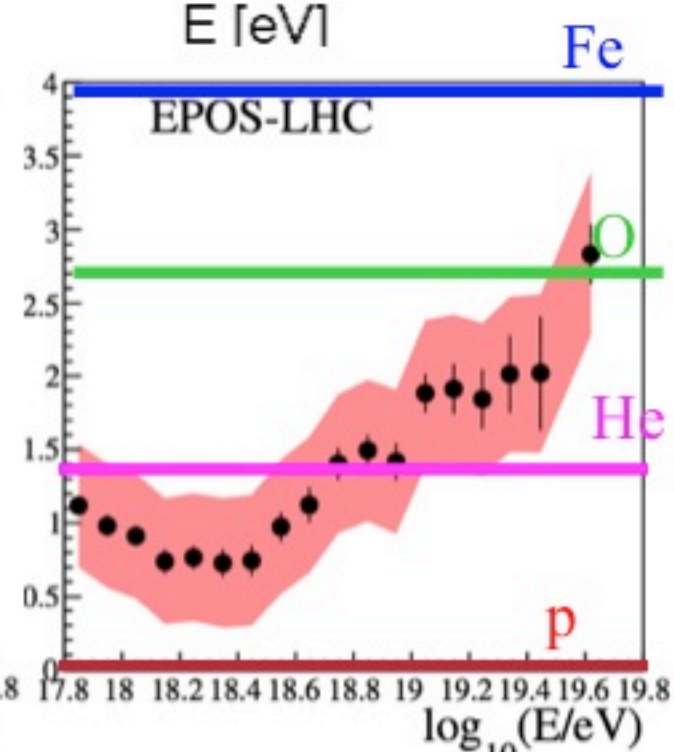


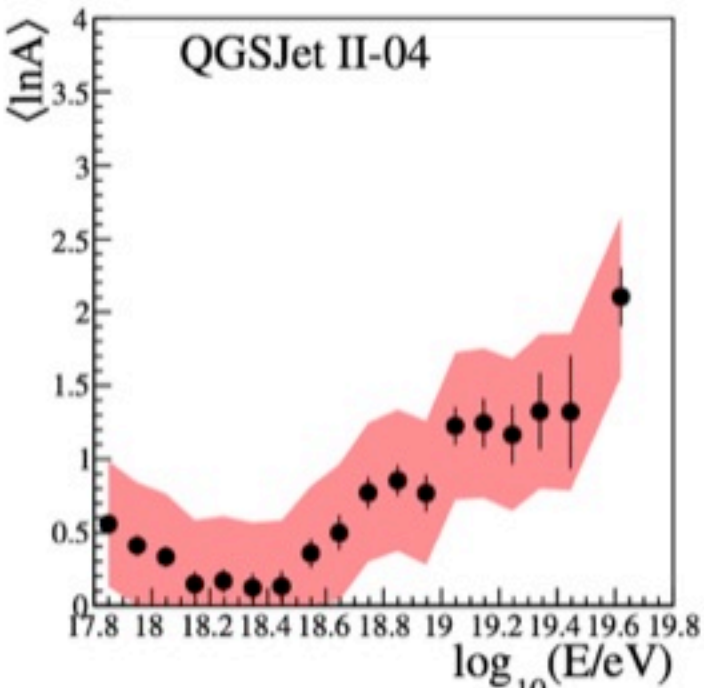


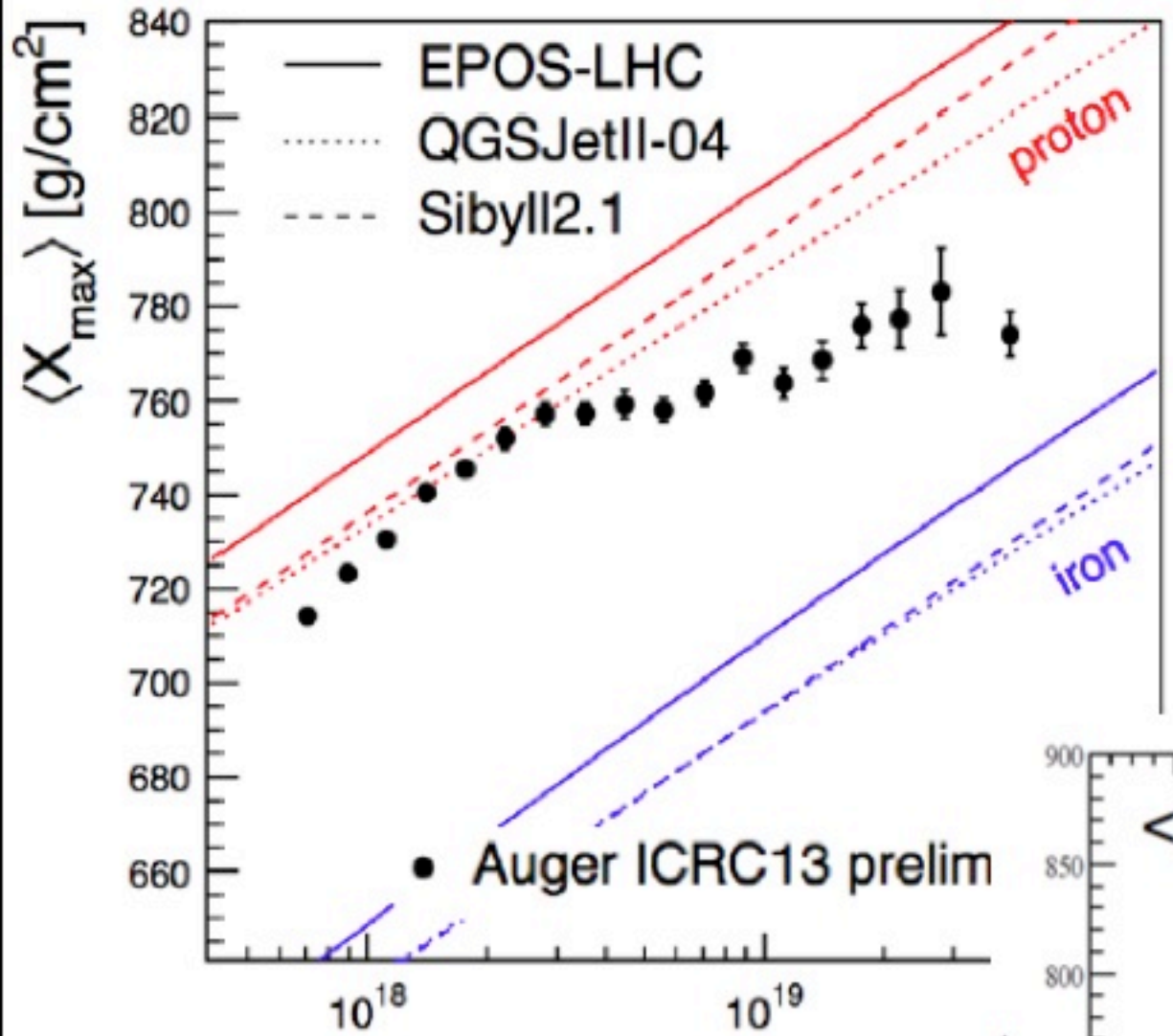


See Dembinski



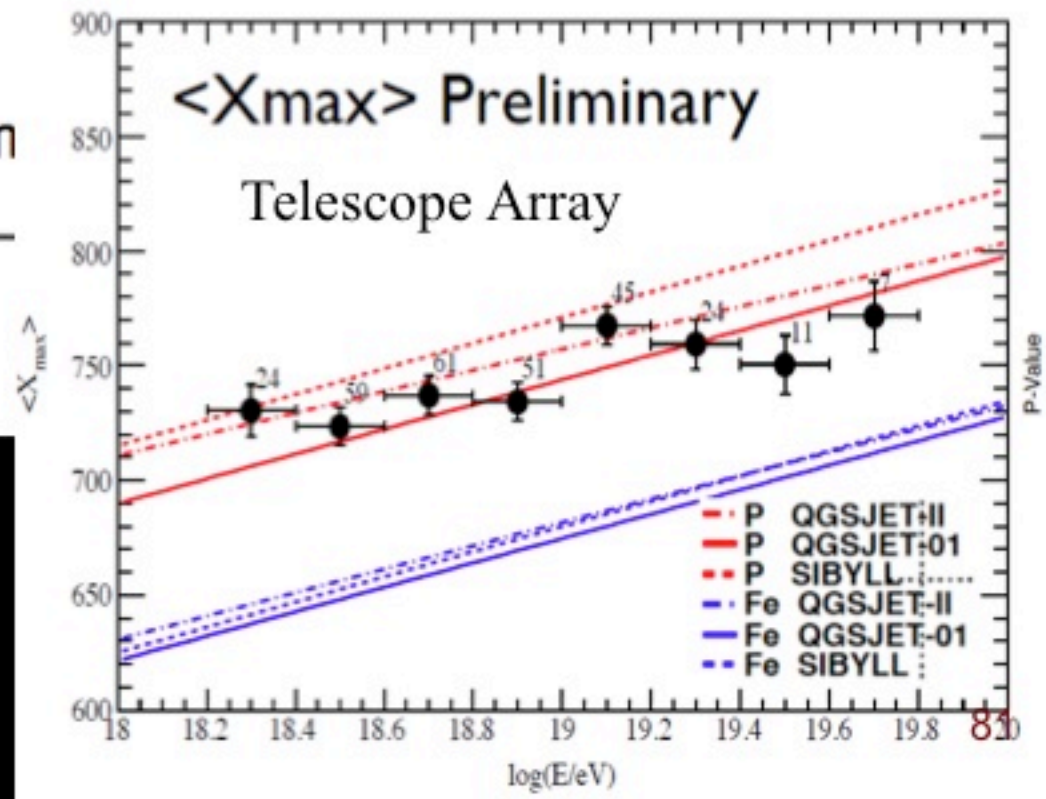


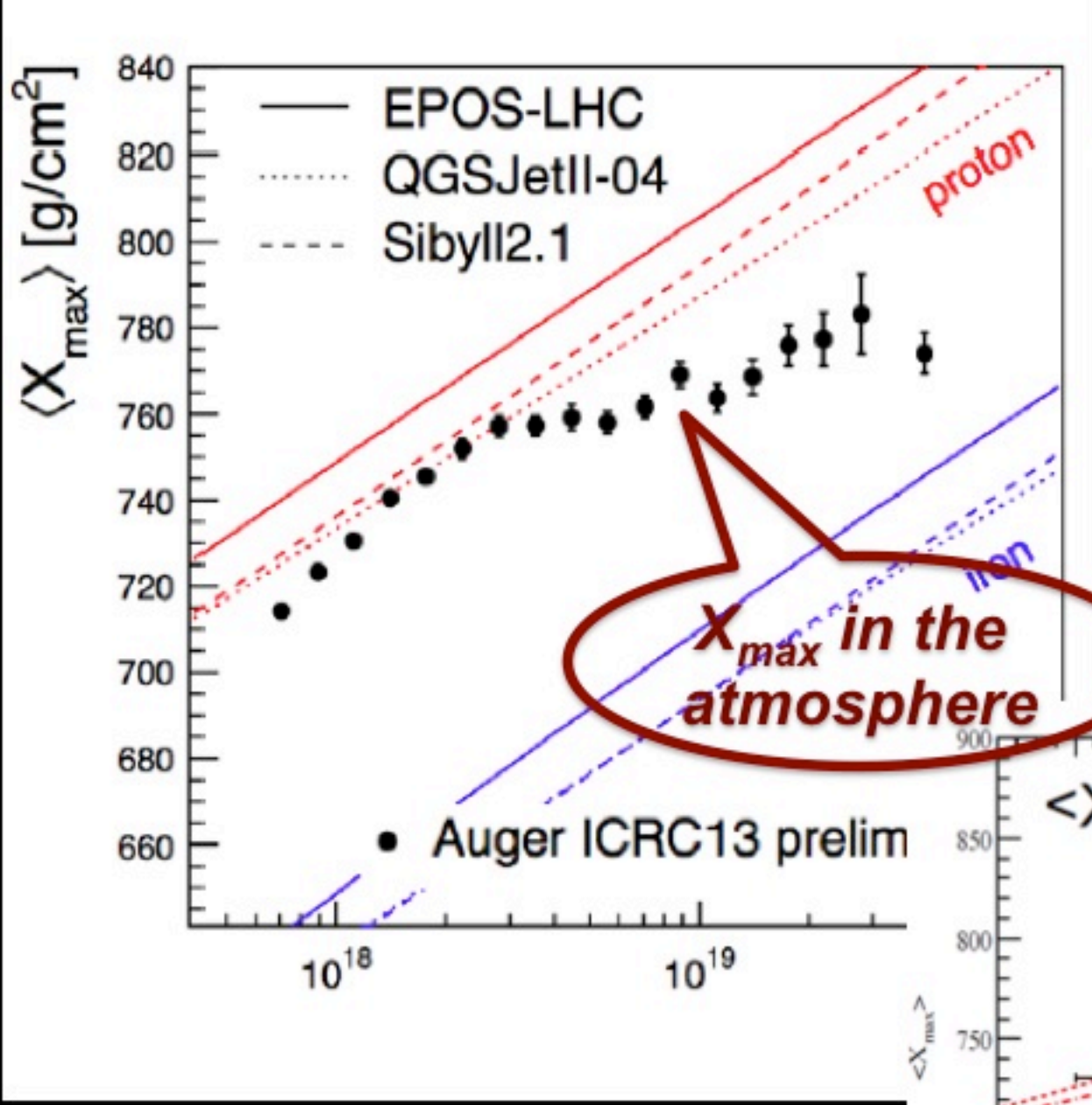




Auger sees change slope: Change in Composition or interactions

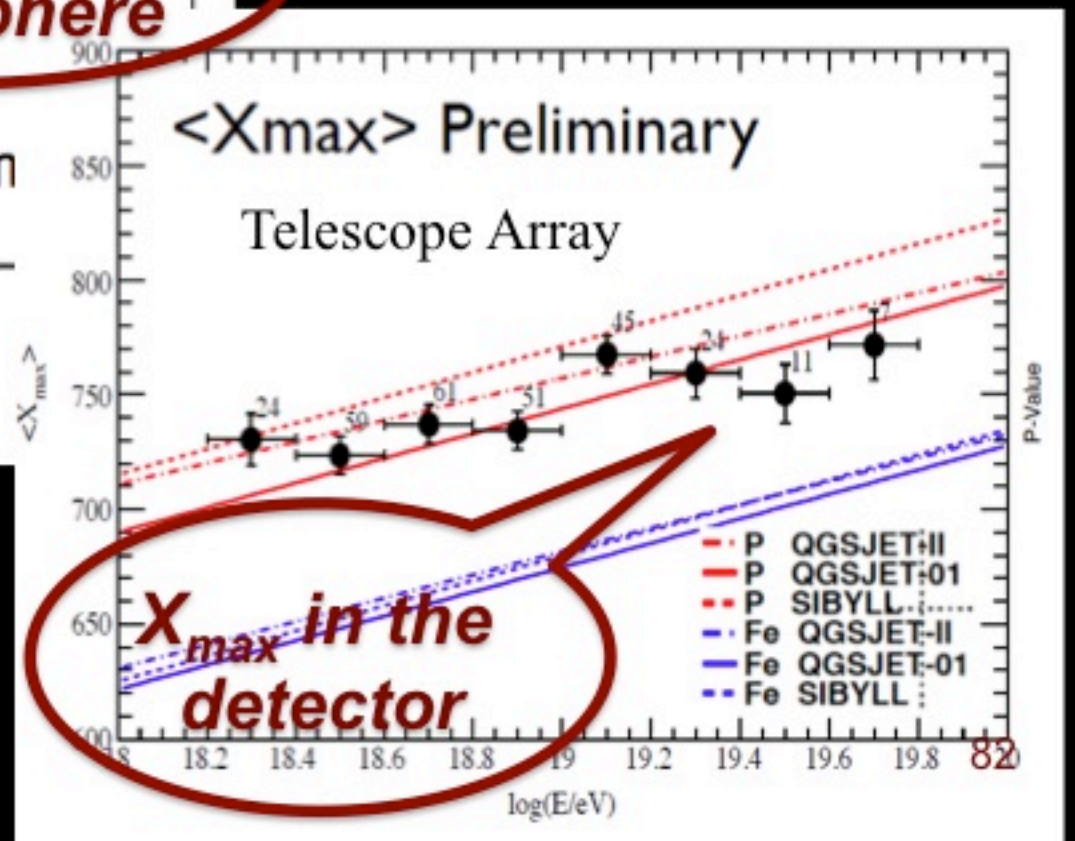
TA: not confirmed yet



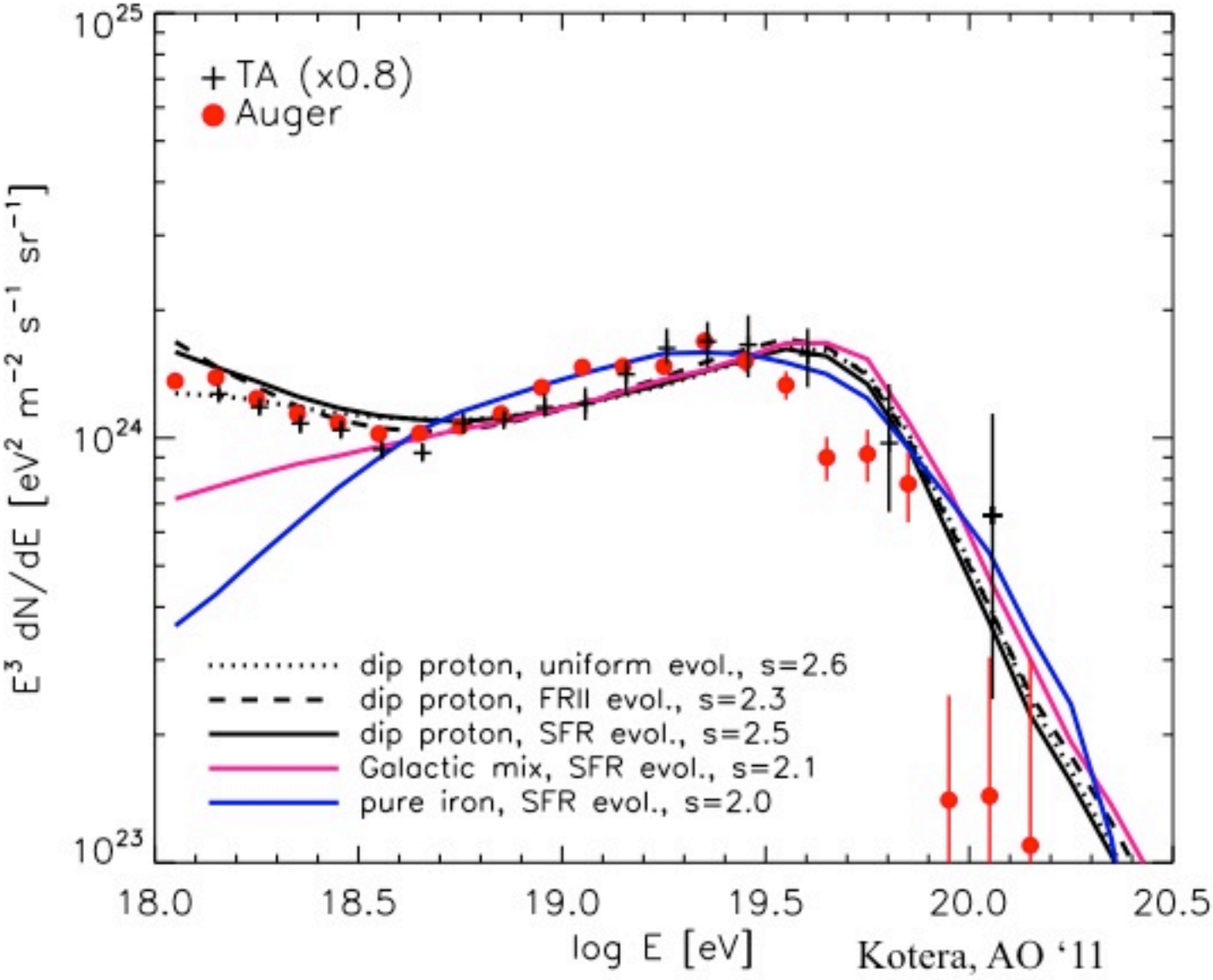


Auger sees change slope: Change in Composition or interactions

TA: not confirmed yet

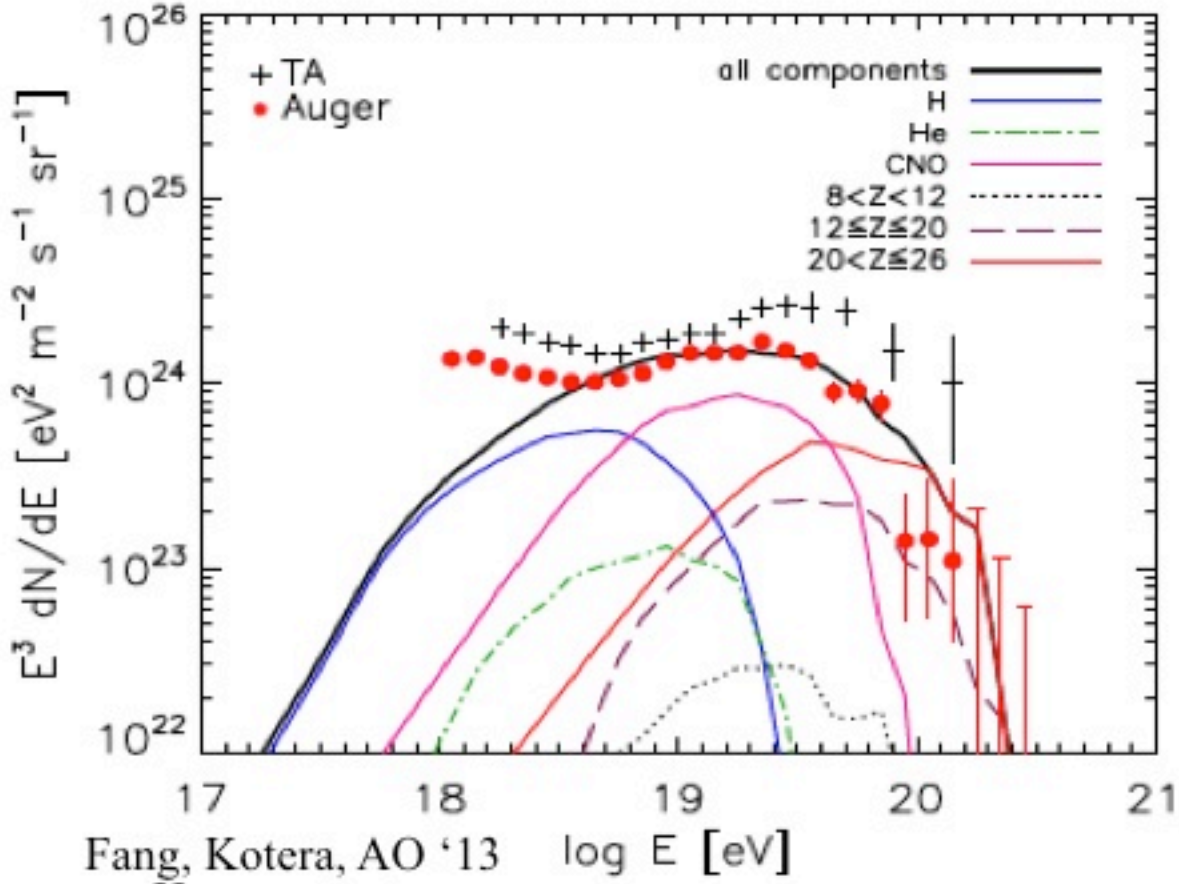


GZK

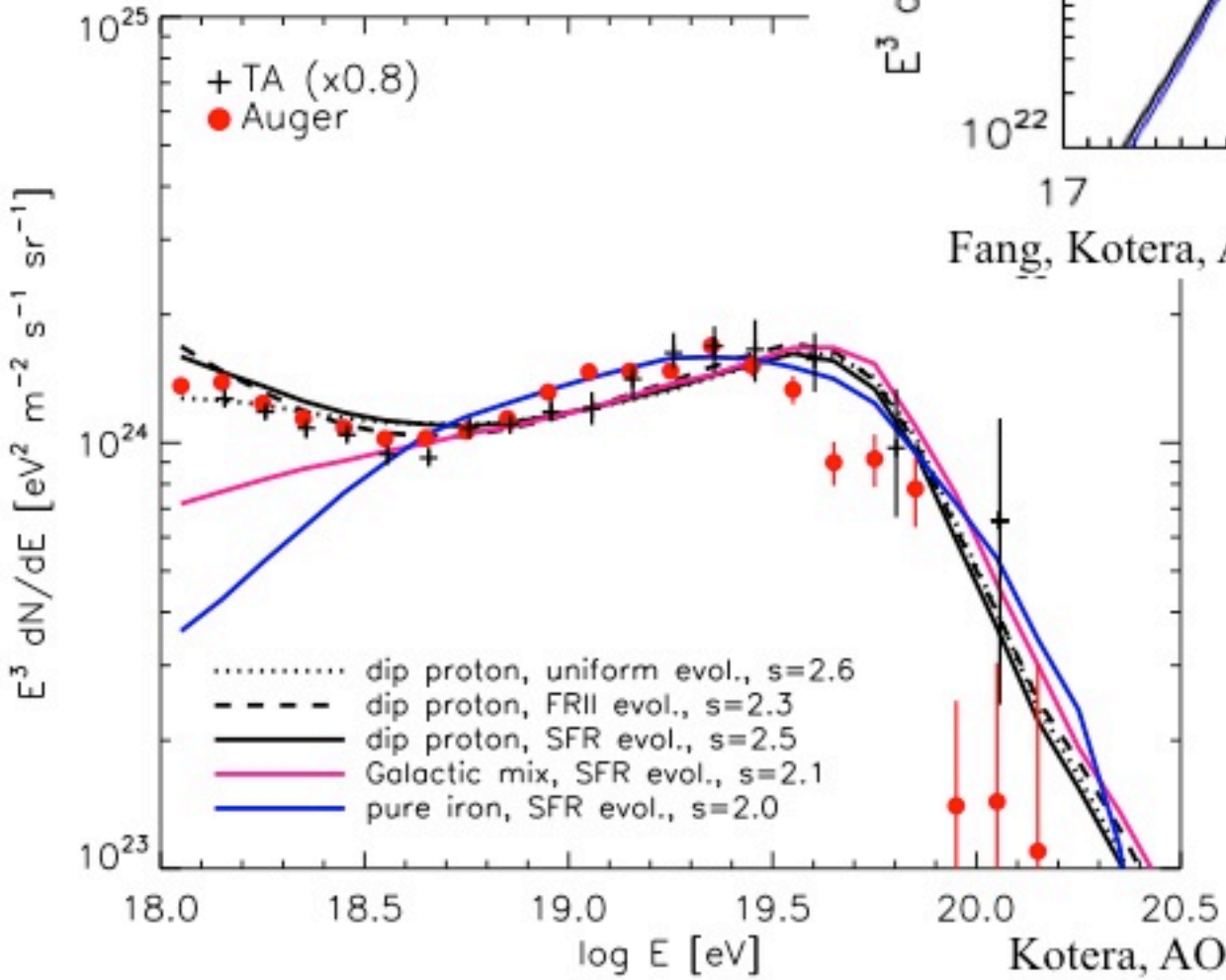


Kotera, AO '11

GZK or E_{max}?

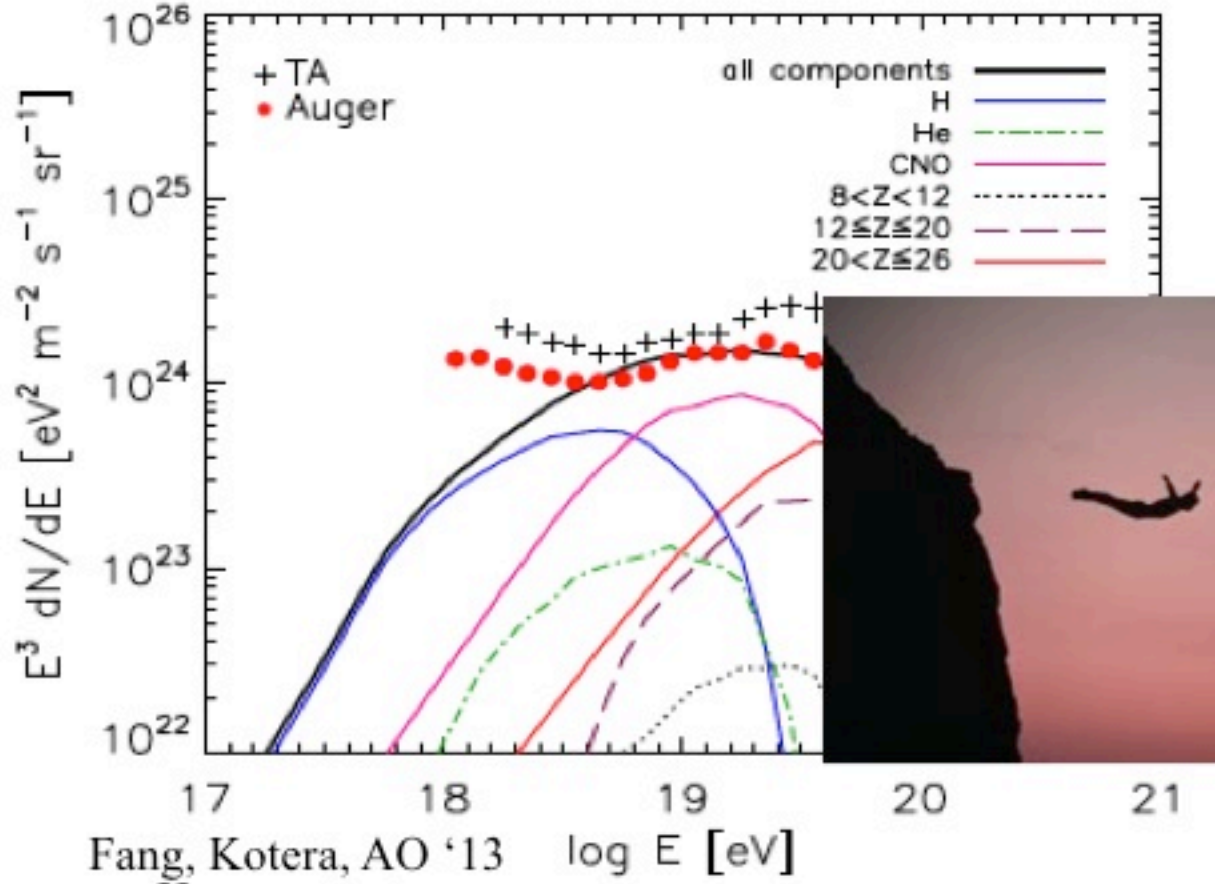


Fang, Kotera, AO '13

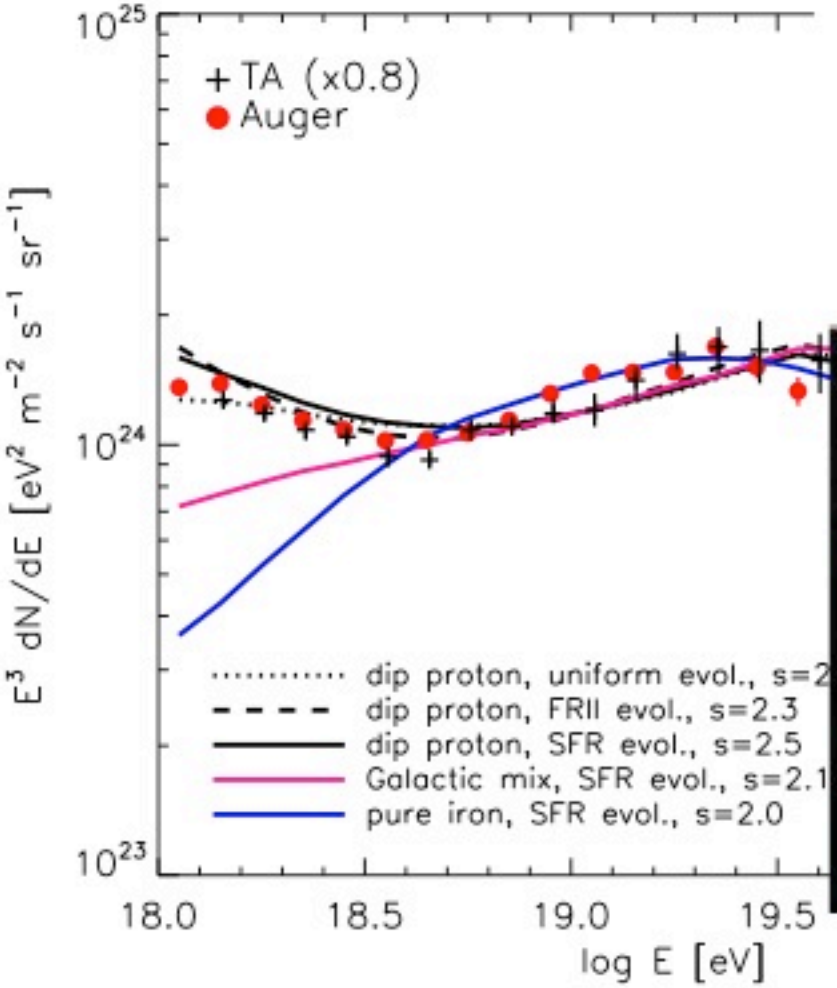


Kotera, AO

GZK vs E_{max}



Fang, Kotera, AO '13



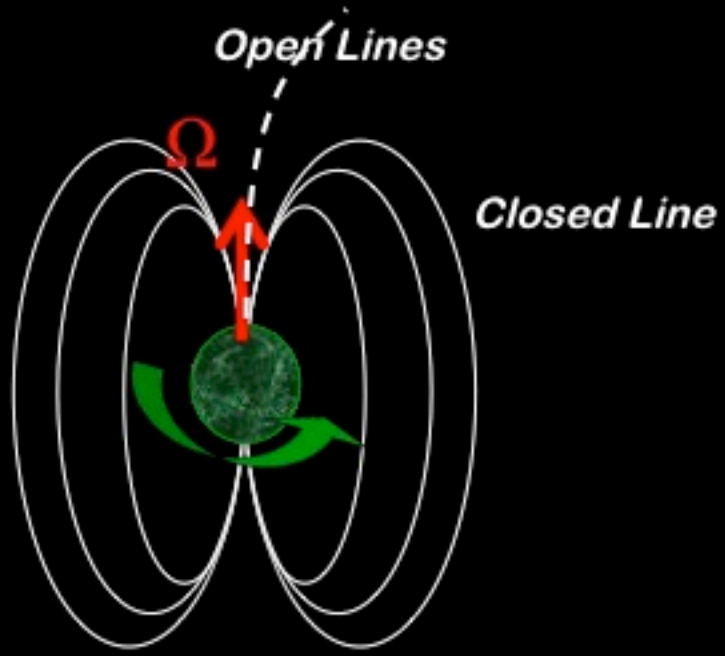
Kotera, AO

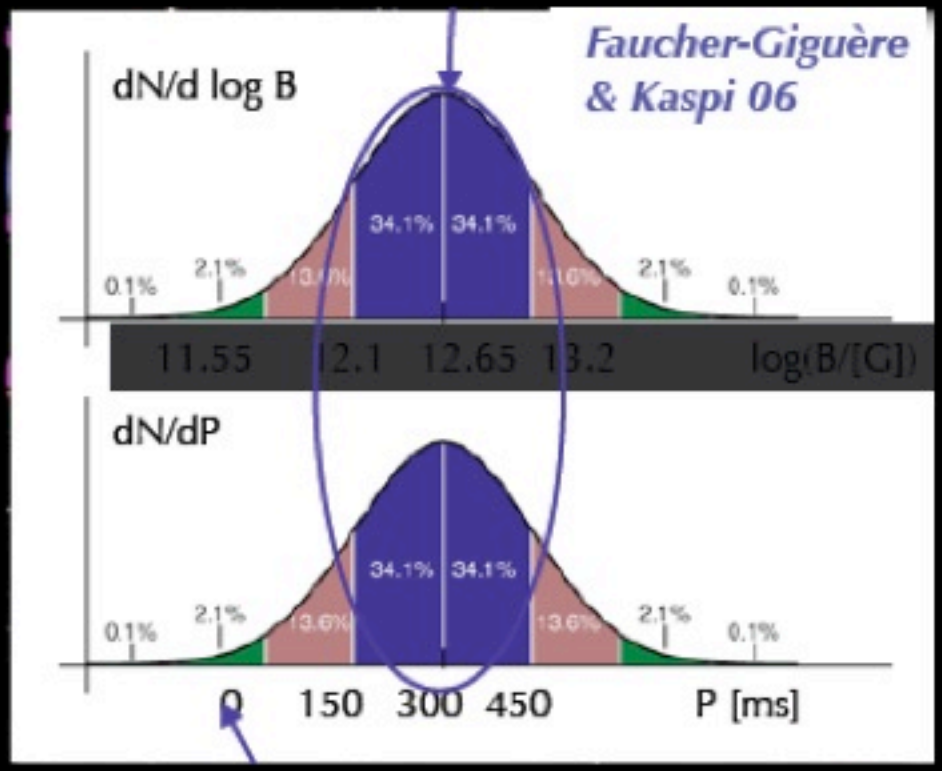
Specific Source Model

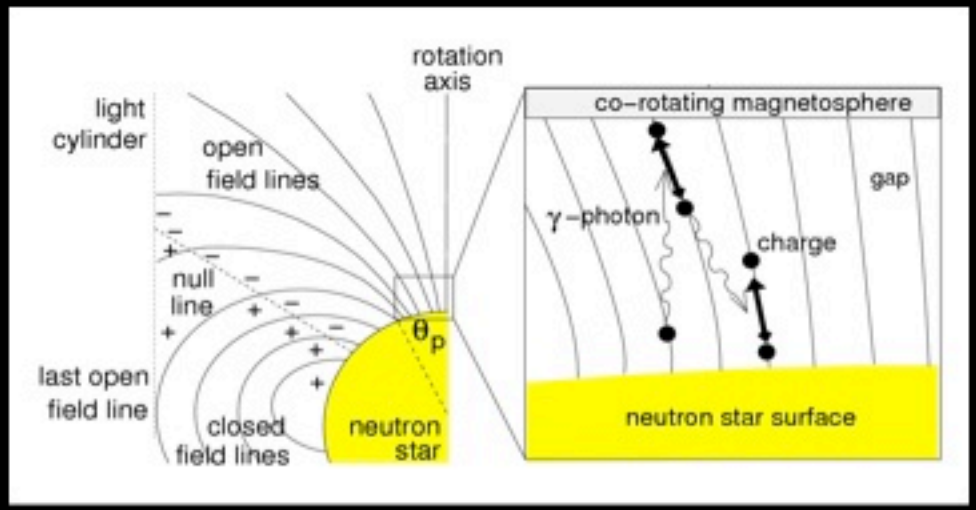
Birth of ultrafast spinning Pulsars

Young Neutron Stars & Magnetars

M ~1 M_{solar} R~10km compact stars
Born Fast spinning (P<< 300 ms)
– slows down due to magnetic breaking
(and gravitational radiation early one)
Born B ~ $10^{12\text{-}13}$ G







Blasi, Epstein & AVO '00, Arons '03

Birth of ultrafast Pulsars

Newborn Pulsar with: $B_S \equiv 10^{13} B_{13}$ G $\quad Z_{26} \equiv Z/26 \quad \Omega_{3k} \equiv \Omega/3000$ rad s^{-1}

At the light cylinder: $R_{lc} = 10^7 \Omega_{3k}^{-1}$ cm $\qquad n_{GJ} = 1.7 \times 10^{11} B_{13} \Omega_{3k}^4 / Z$ cm^{-3}

Magnetic wind can accelerate particles up to $\qquad E_{cr} \simeq B_{lc}^2 / 8\pi n_{GJ}$

$$E_{max} = \frac{Ze\, B_{lc} R_{lc}}{c} \simeq 8 \times 10^{20} Z_{26} B_{13} \Omega_{3k}^2 \text{ eV}$$

$$E_{cr} \simeq 4 \times 10^{20} Z_{26} B_{13} \Omega_{3k}^2 \text{ eV}$$

Maximum Energy? ✔

Spectrum too hard:

The predicted UHECR flux at the Earth is

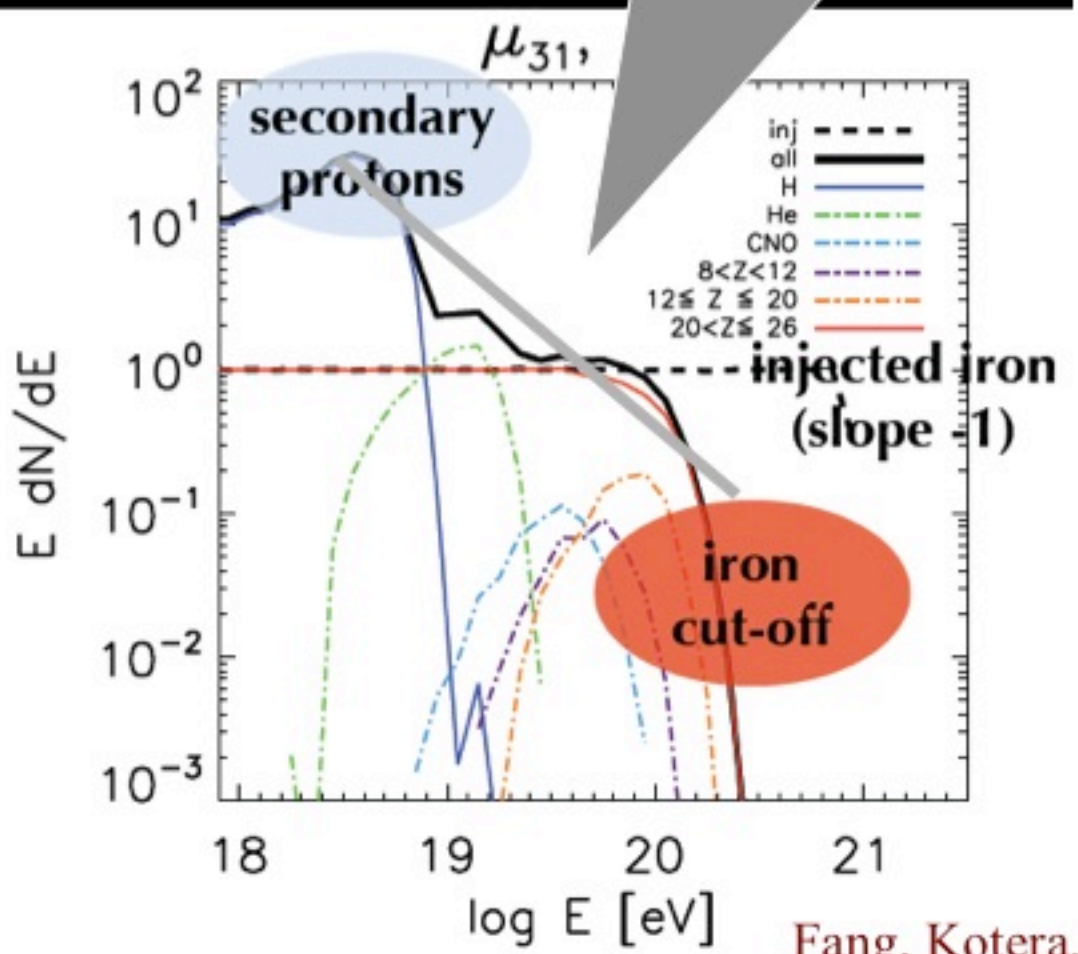
$$F(E) = 10^{-24} \frac{\xi \epsilon Q}{\tau_2 R_1^2 B_{13} E_{20} Z_{26}} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$$

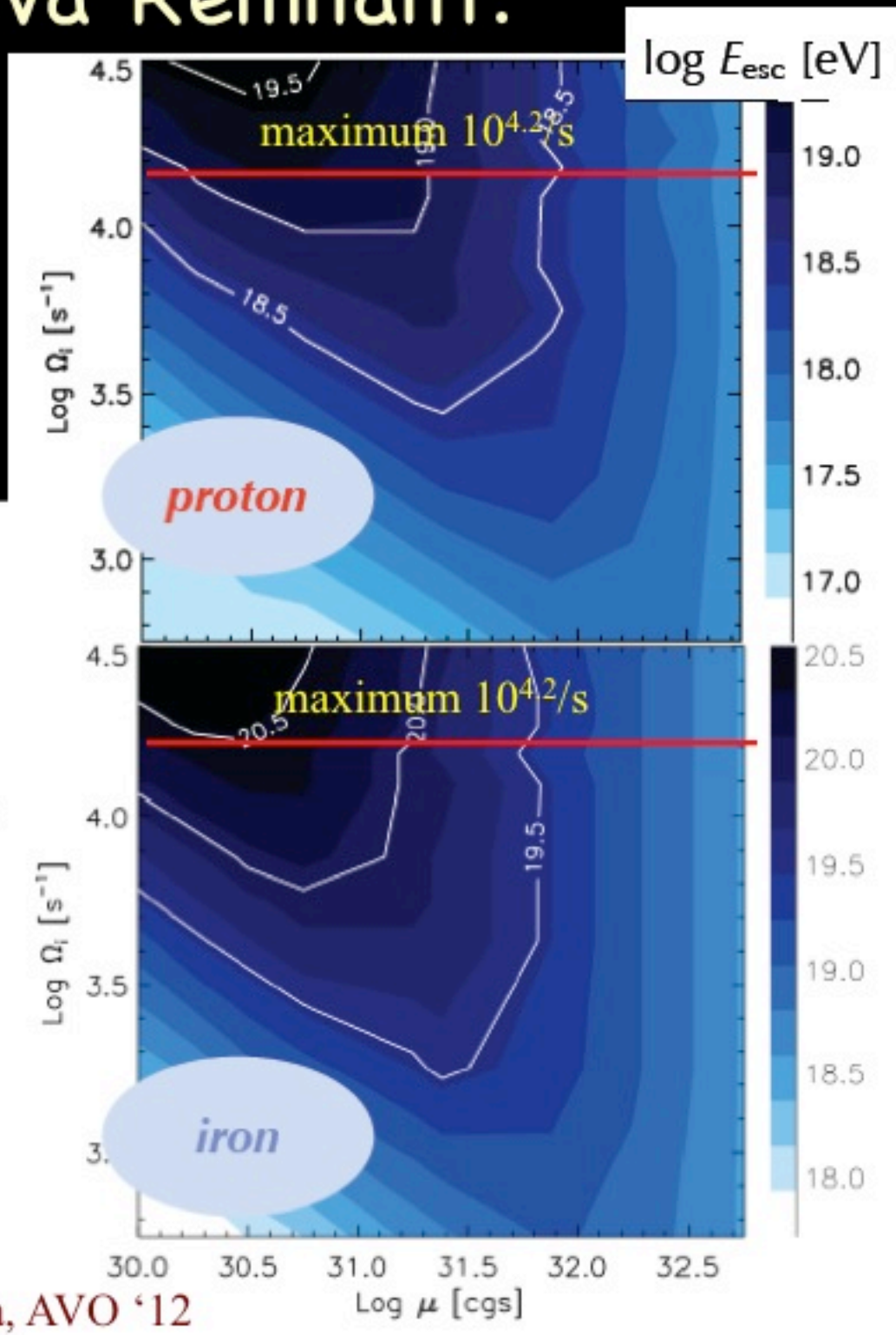
Spectrum is hard ~ E^{-1}

Blasi, Epstein, AVO '00

Escape from Supernova Remnant:

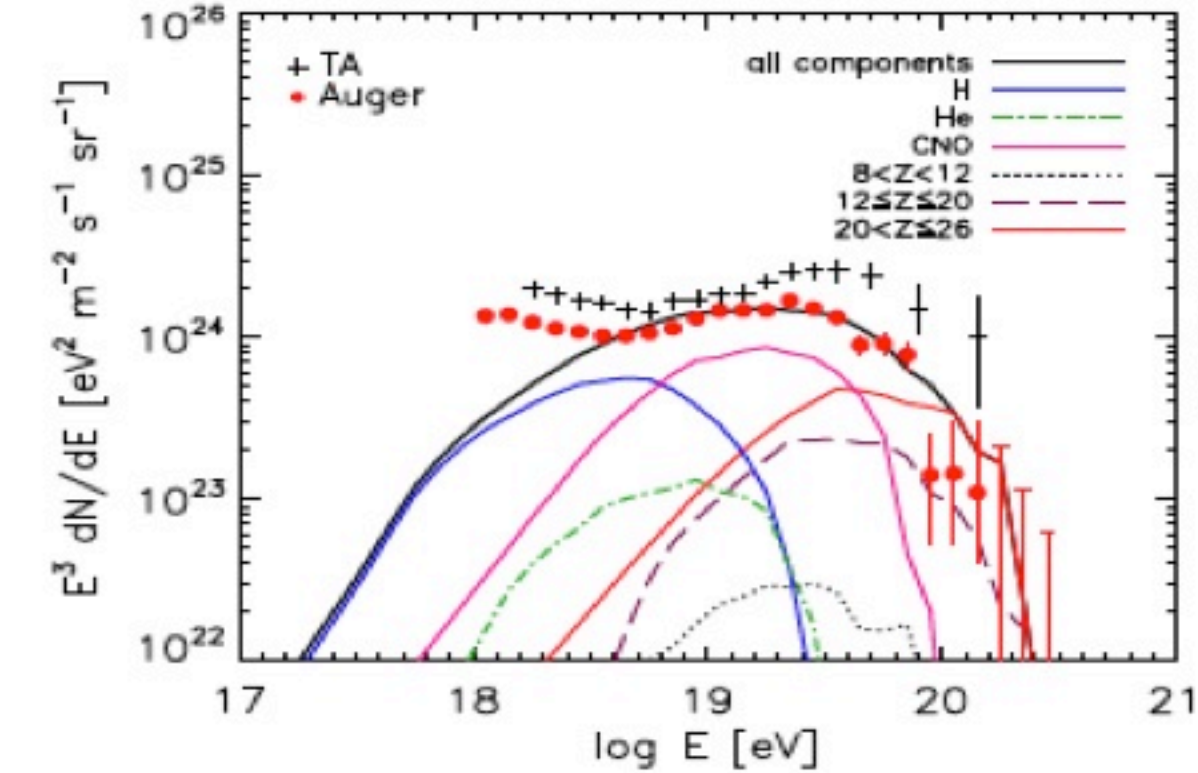
softens the spectrum between protons and iron + pulsar distribution & propagation

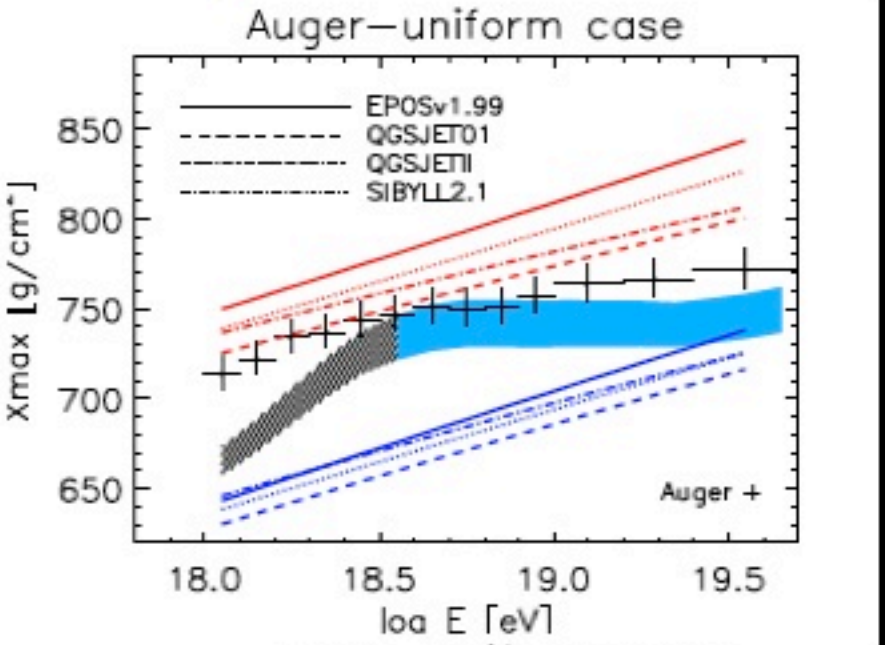


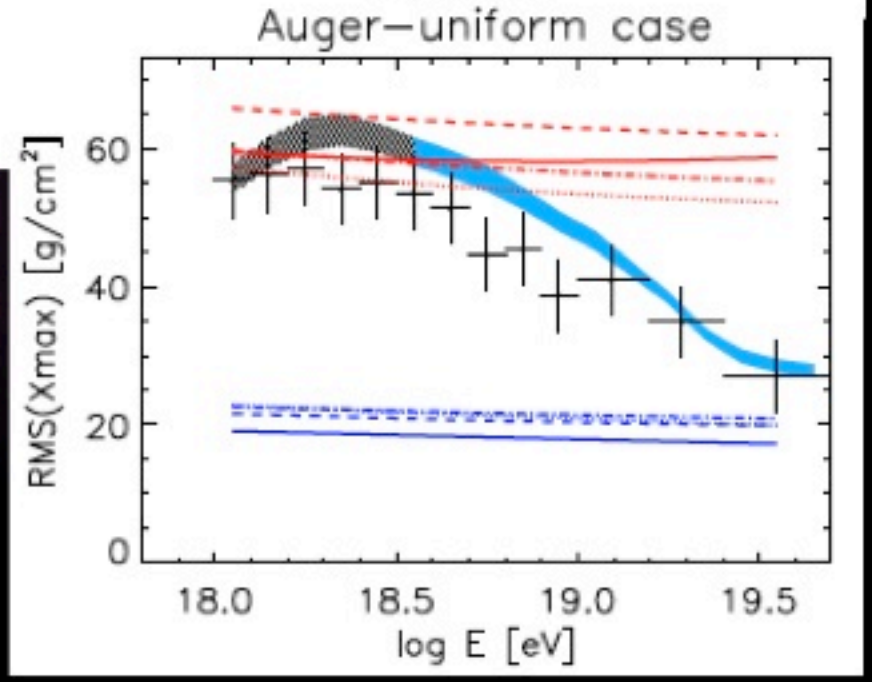


Fang, Kotera, AVO '12

Newborn Pulsars fit Spectrum & Auger Composition !

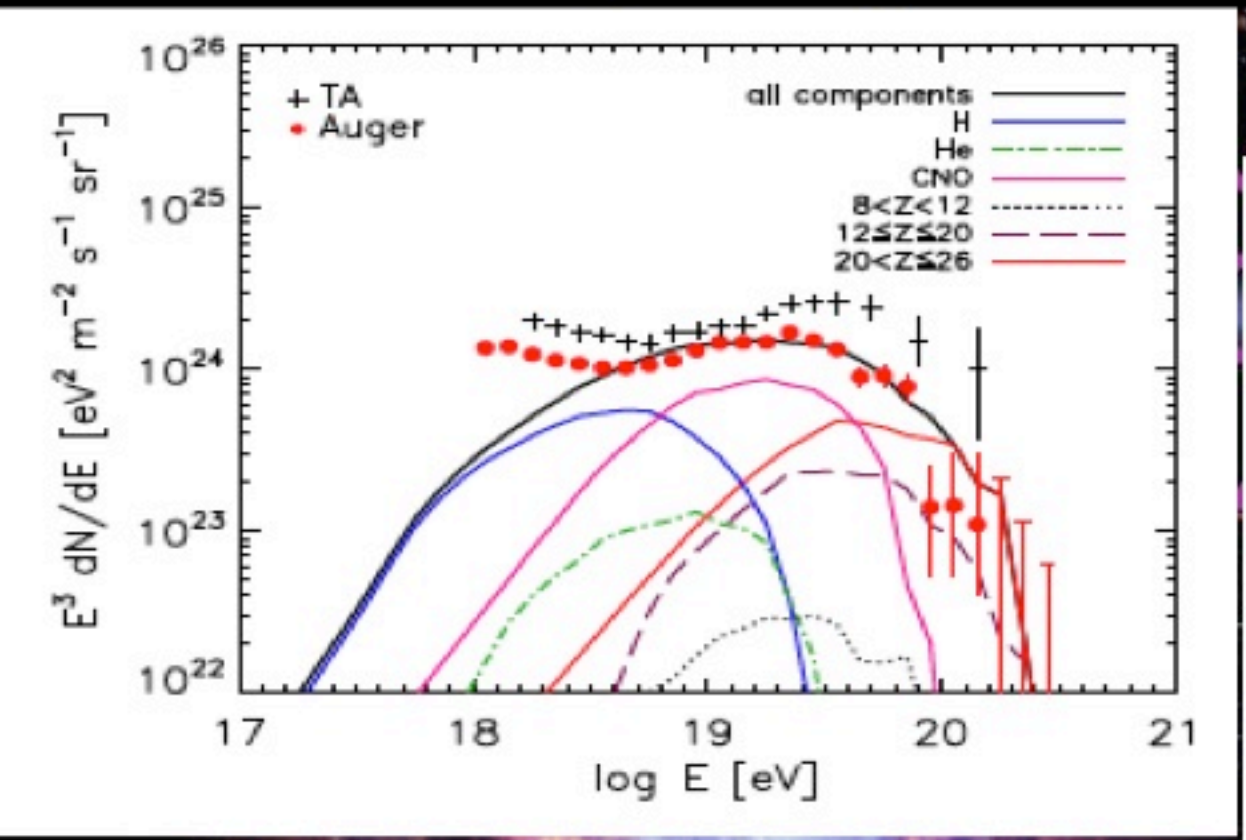


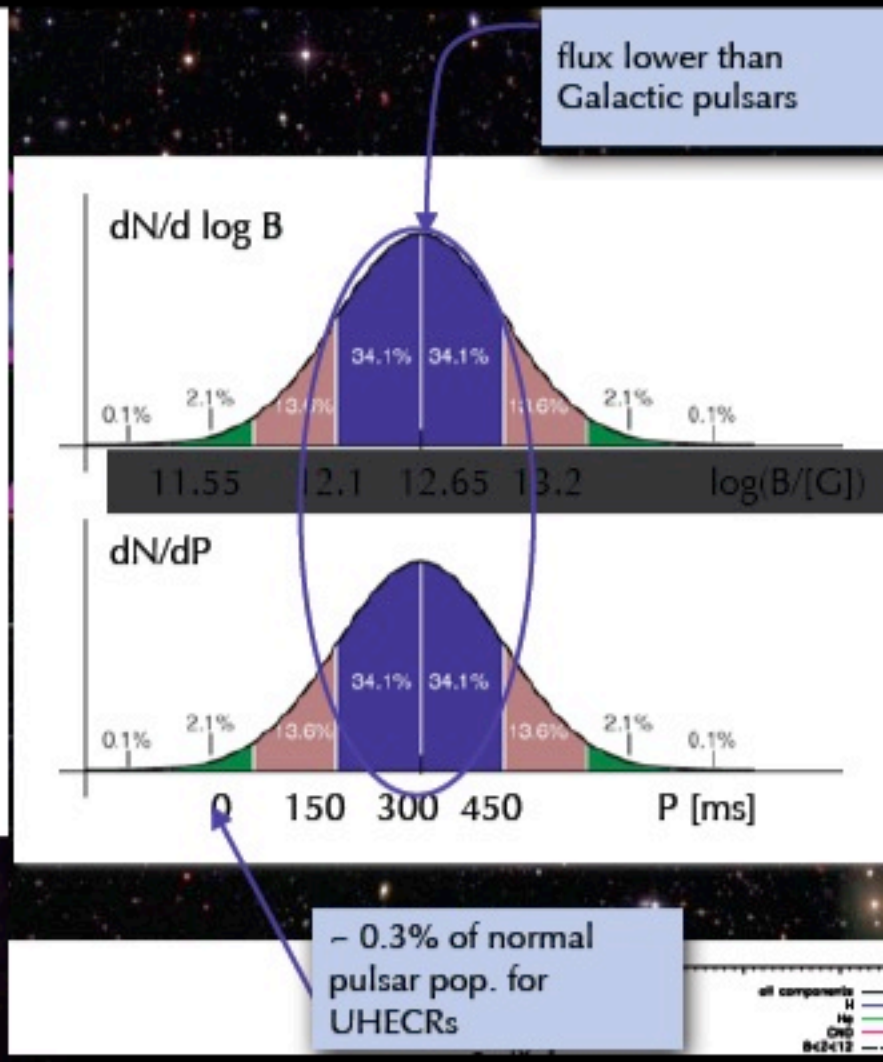




Fang, Kotera, AVO '13

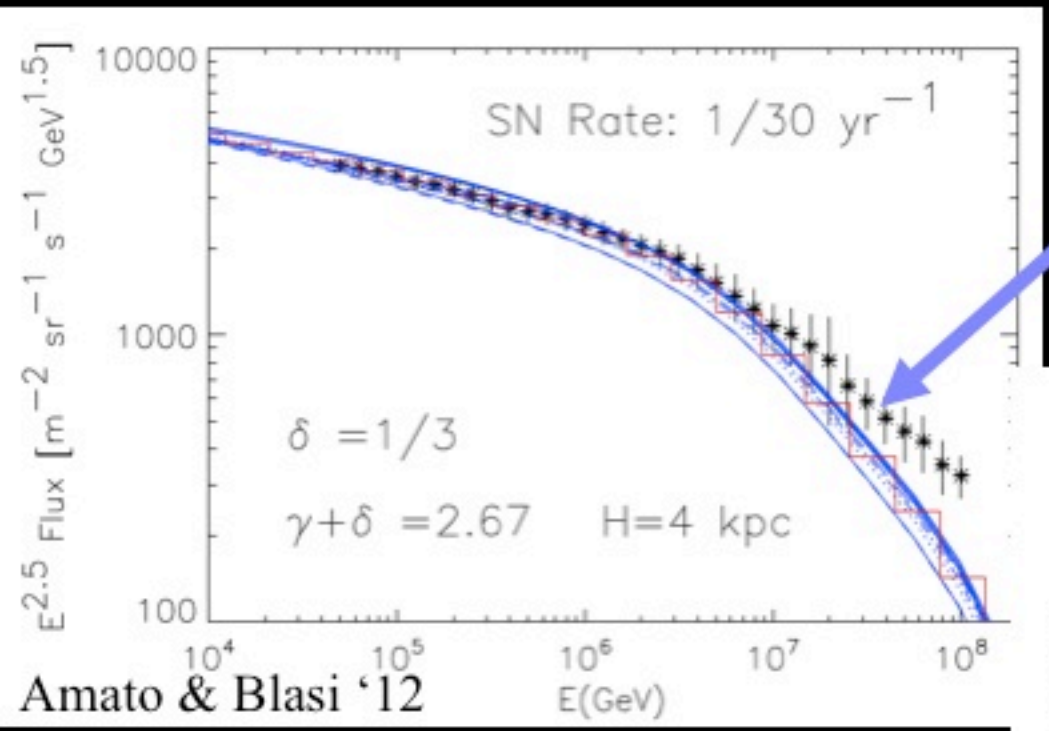
Fast Spinning Newborn Pulsars !





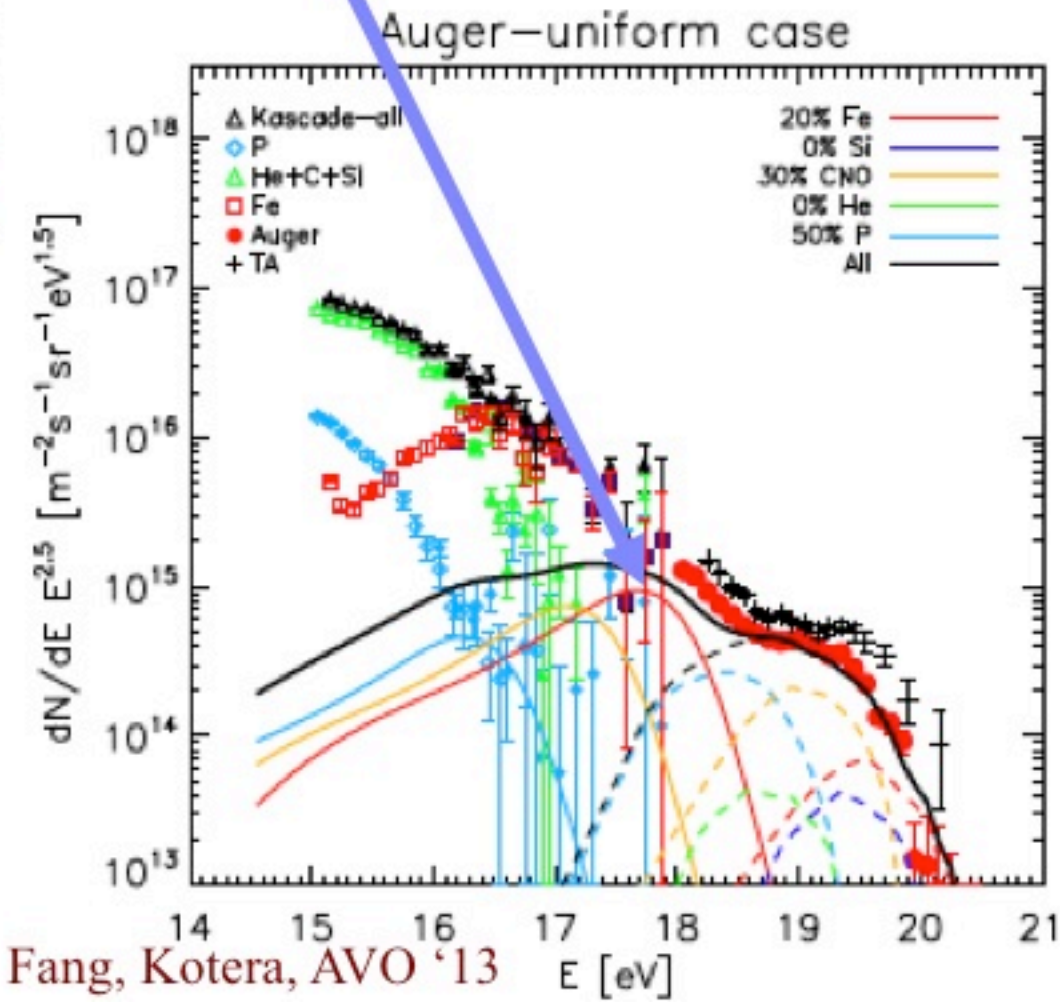
Fang, Kotera, AVO '13

Galactic Cosmic Rays



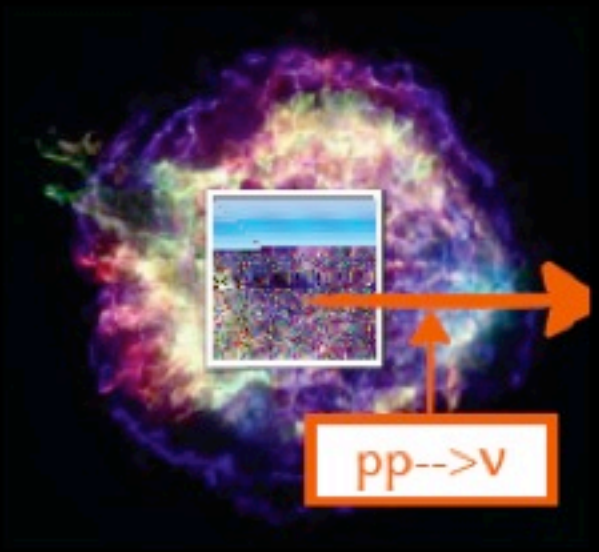
Amato & Blasi '12

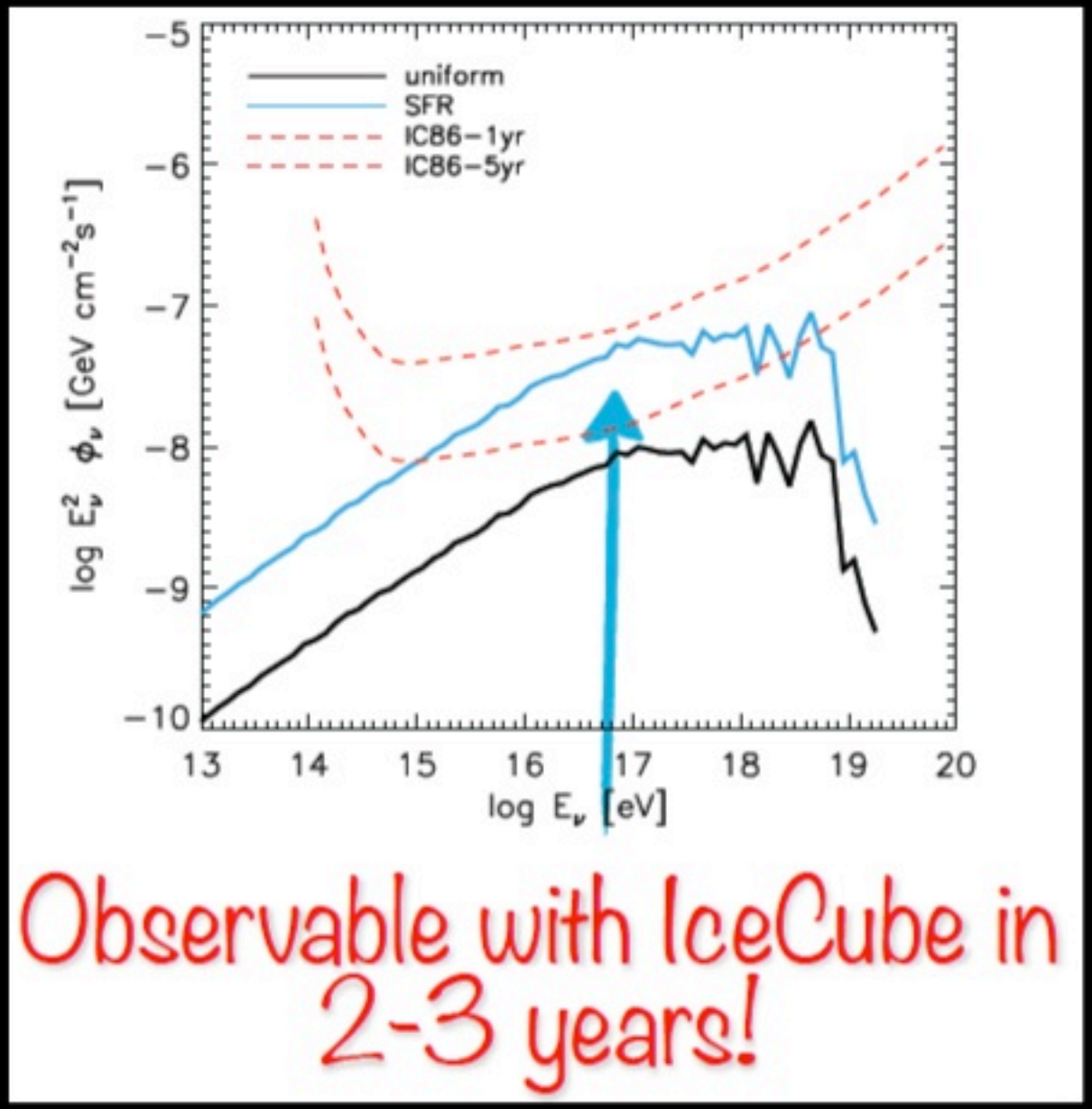
fill the gap



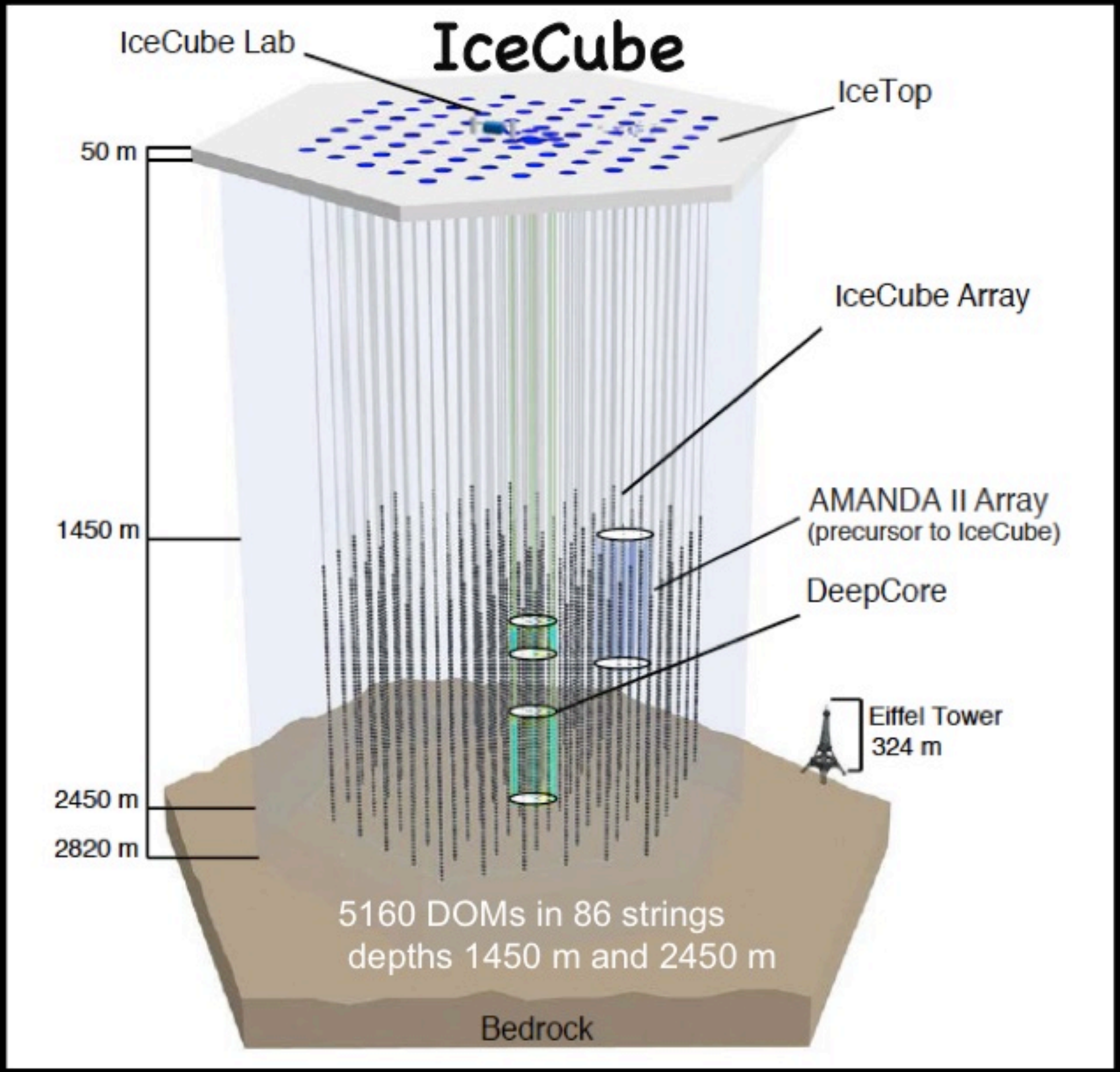
Fang, Kotera, AVO '13

Multimessenger Predictions



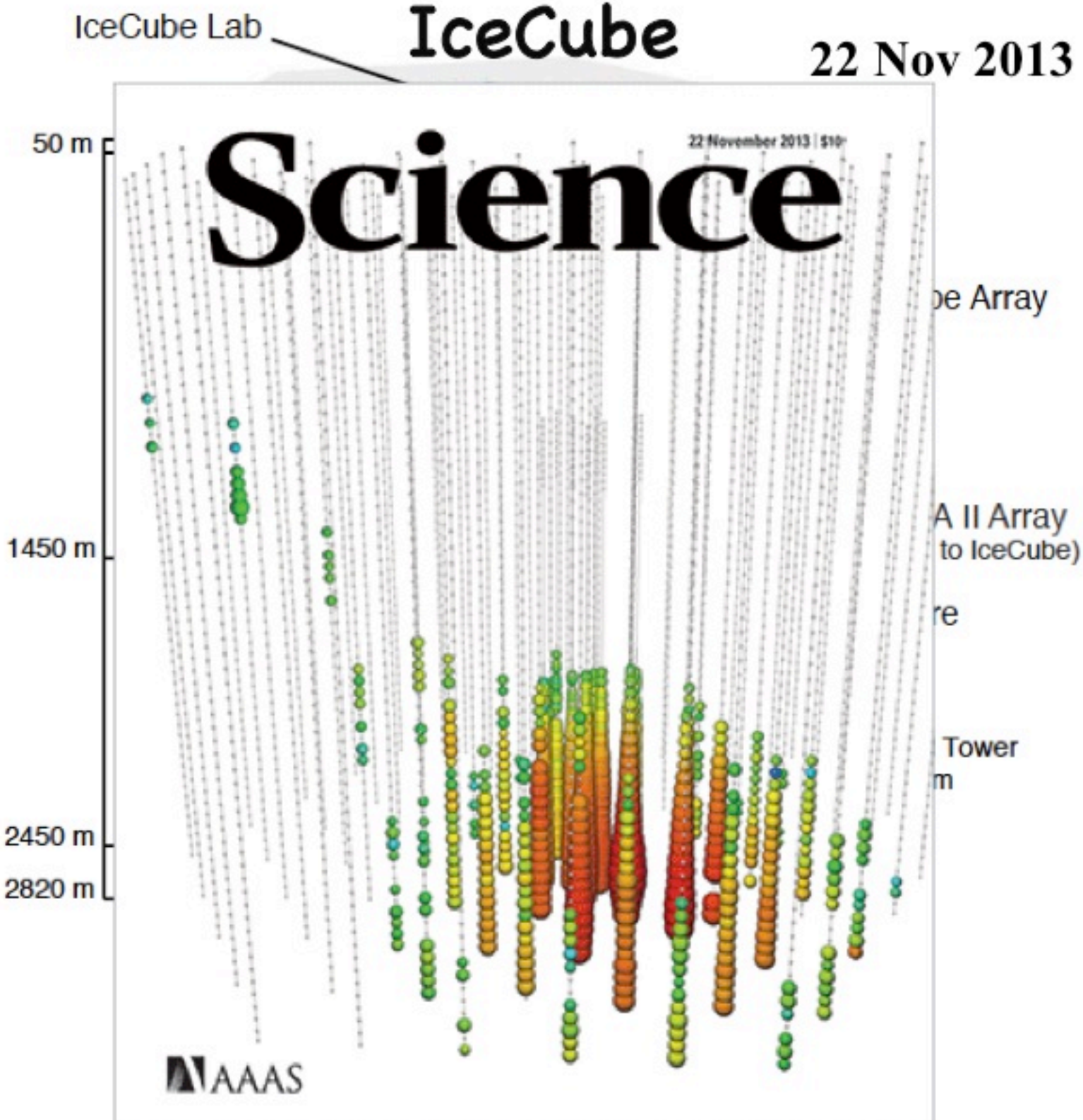


Fang, Kotera, Murase, AVO '13


IceCube
IceCube Lab
IceTop
50 m
IceCube Array
AMANDA II Array
(precursor to IceCube)
1450 m
DeepCore
Eiffel Tower
324 m
2450 m
2820 m
5160 DOMs in 86 strings
depths 1450 m and 2450 m
Bedrock

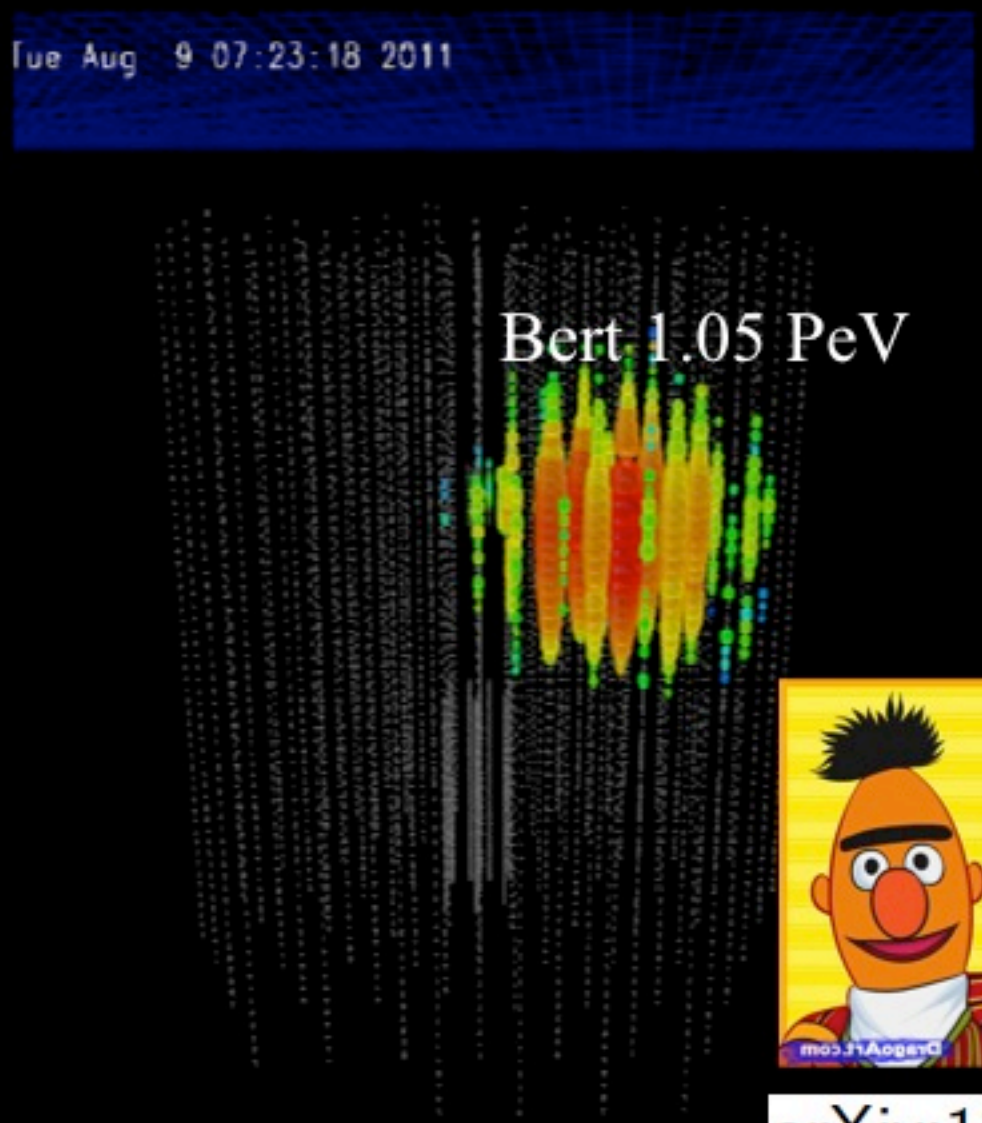
IceCube

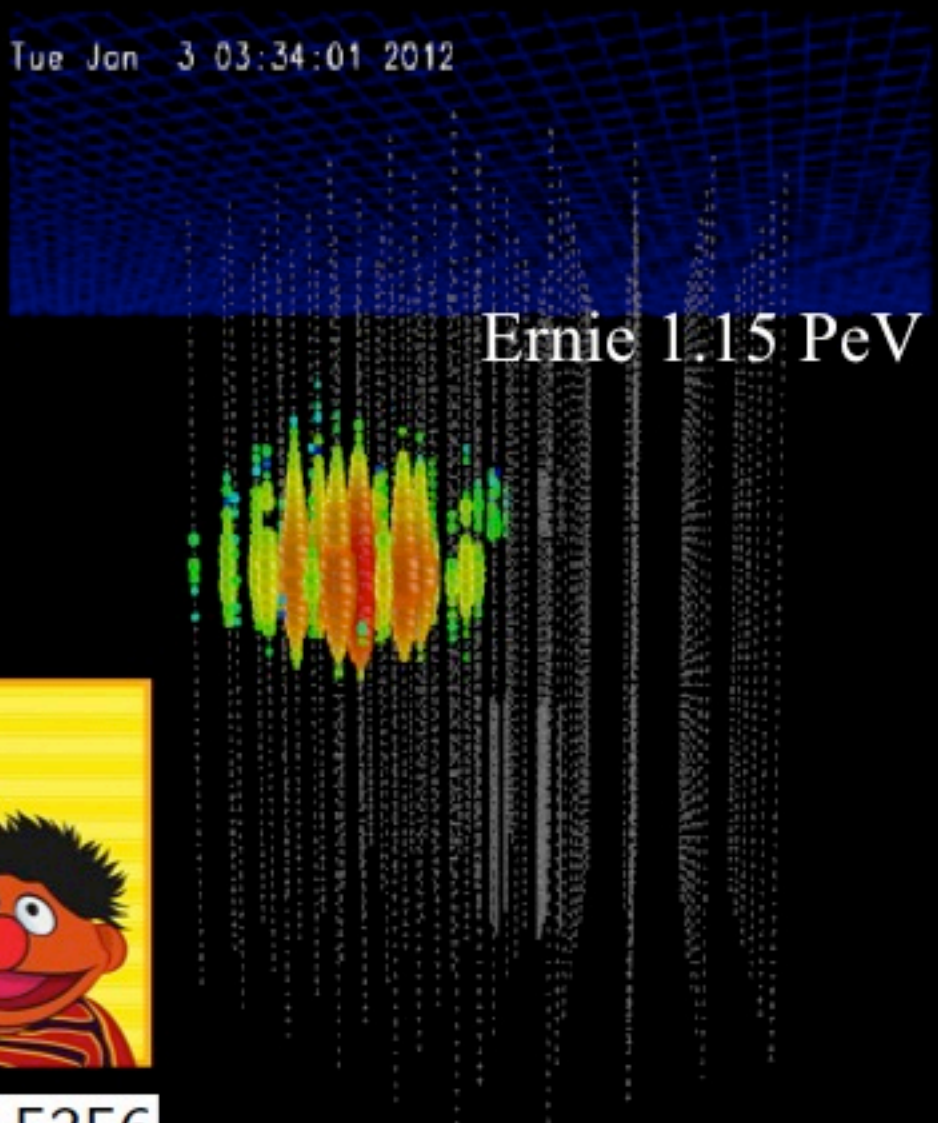
22 Nov 2013



Neutrino Astronomy Begins

PeV neutrinos first observed by **IceCube** (Apr'13)

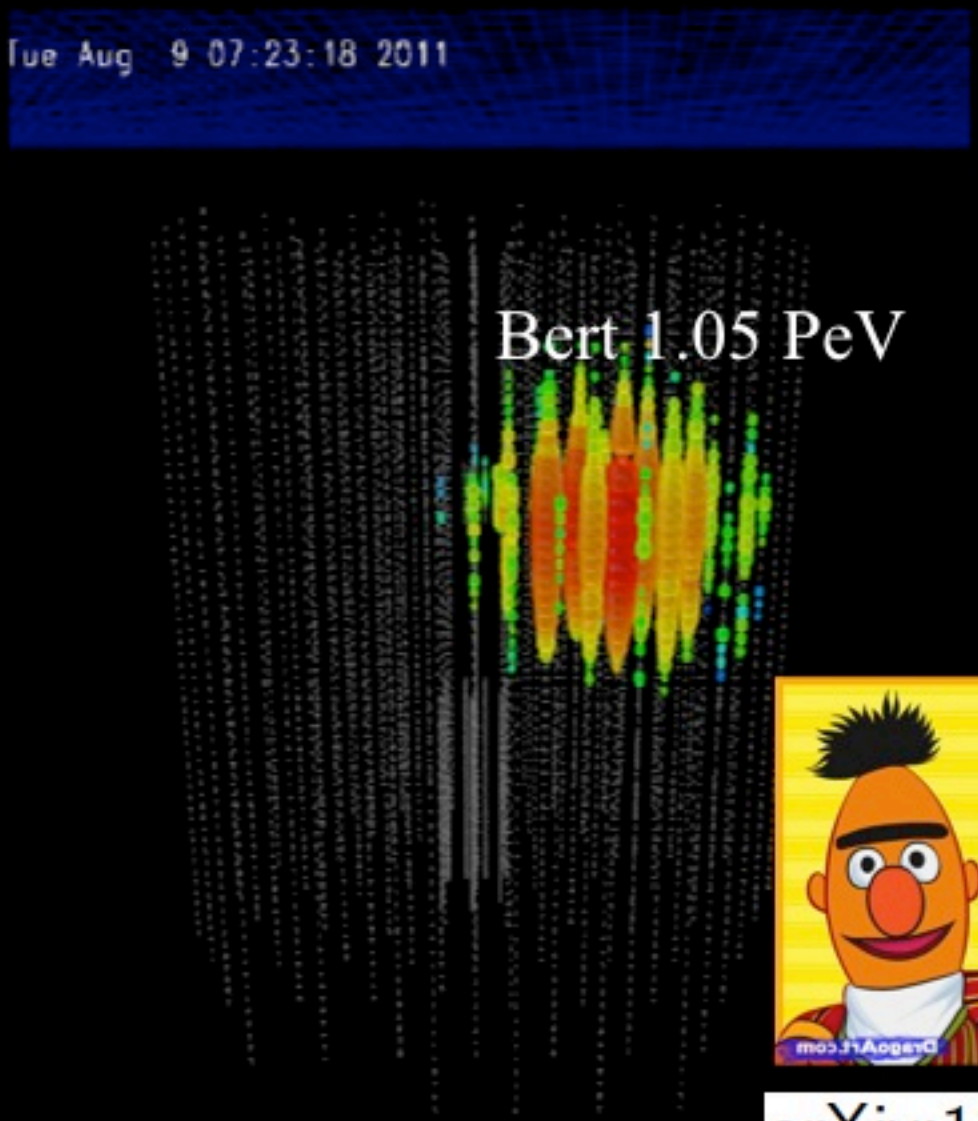


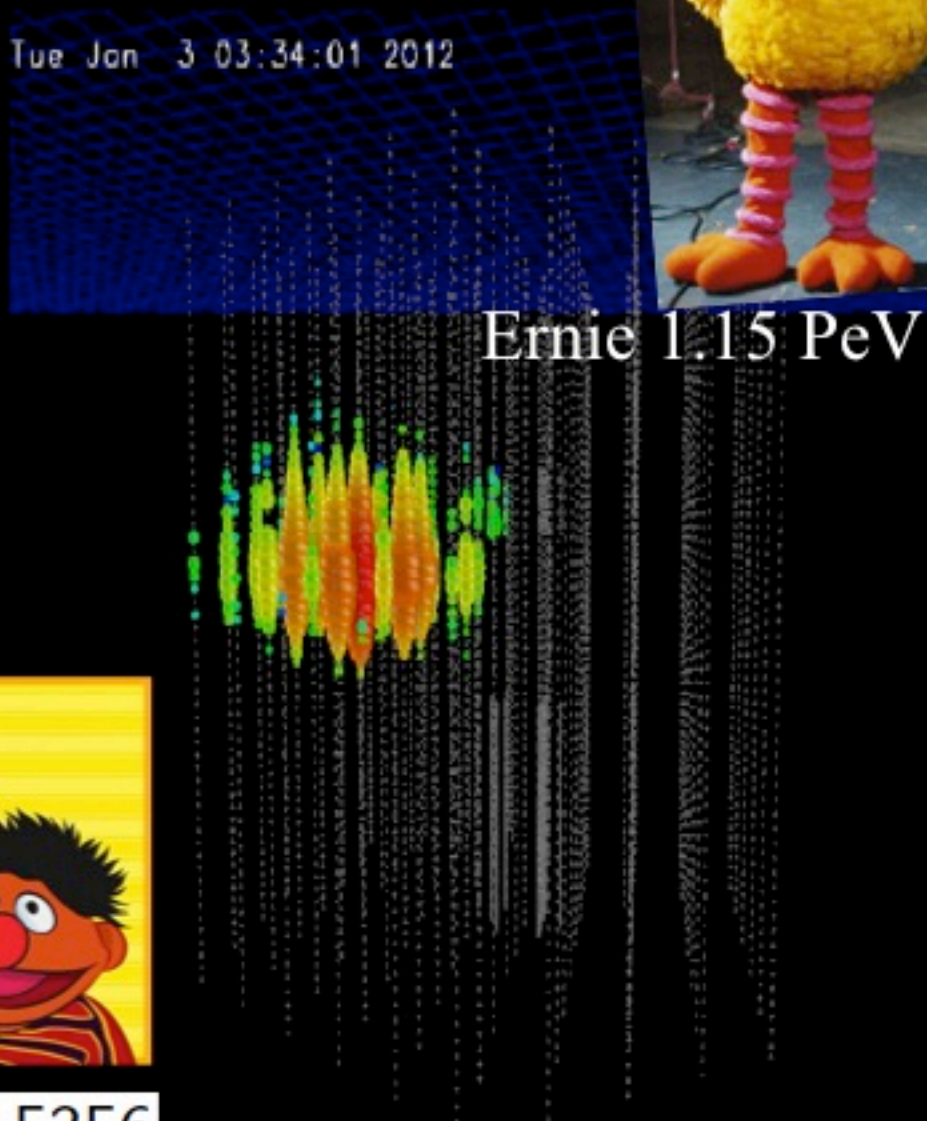


arXiv:1304.5356

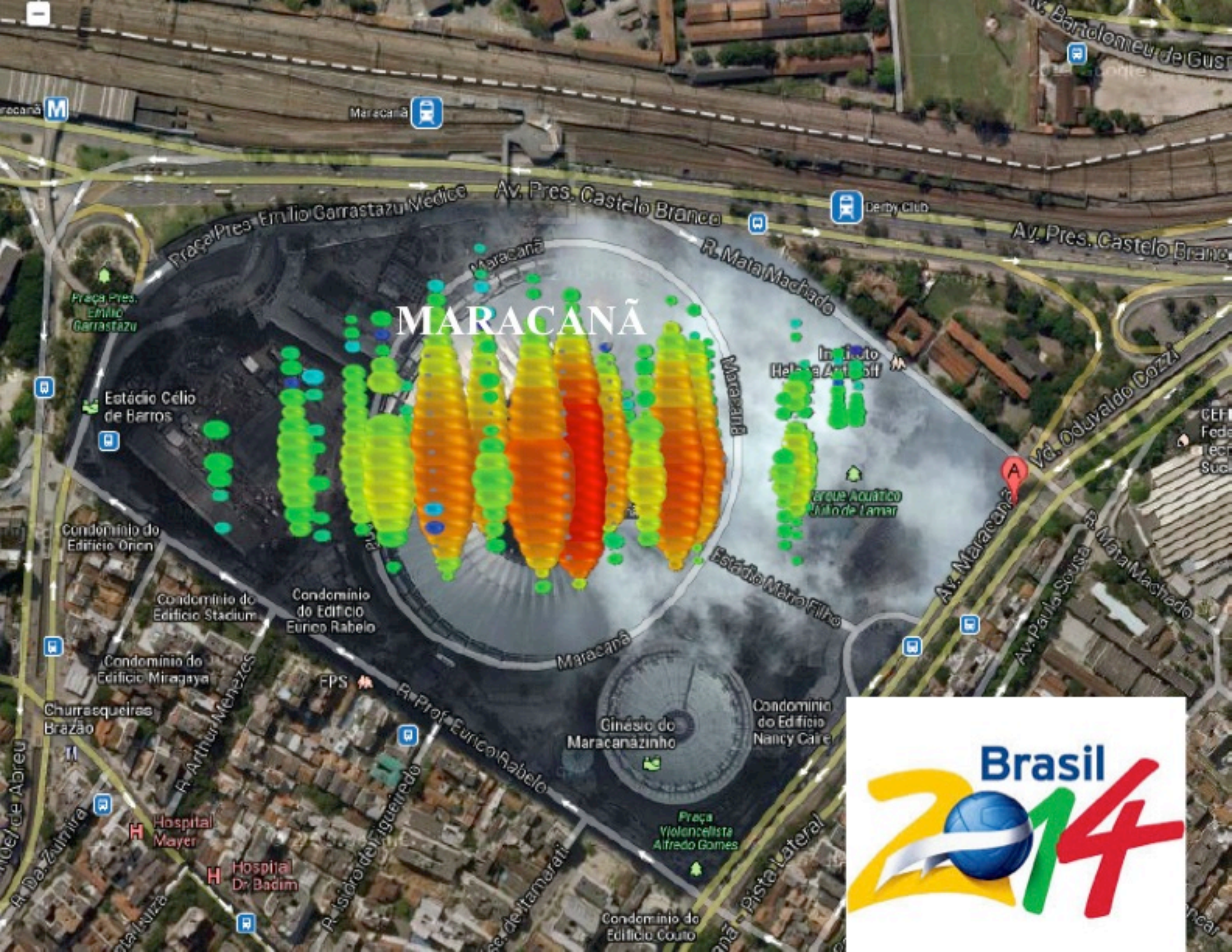
Neutrino Astronomy Begins

PeV neutrinos first observed by **IceCube** (Apr'13)

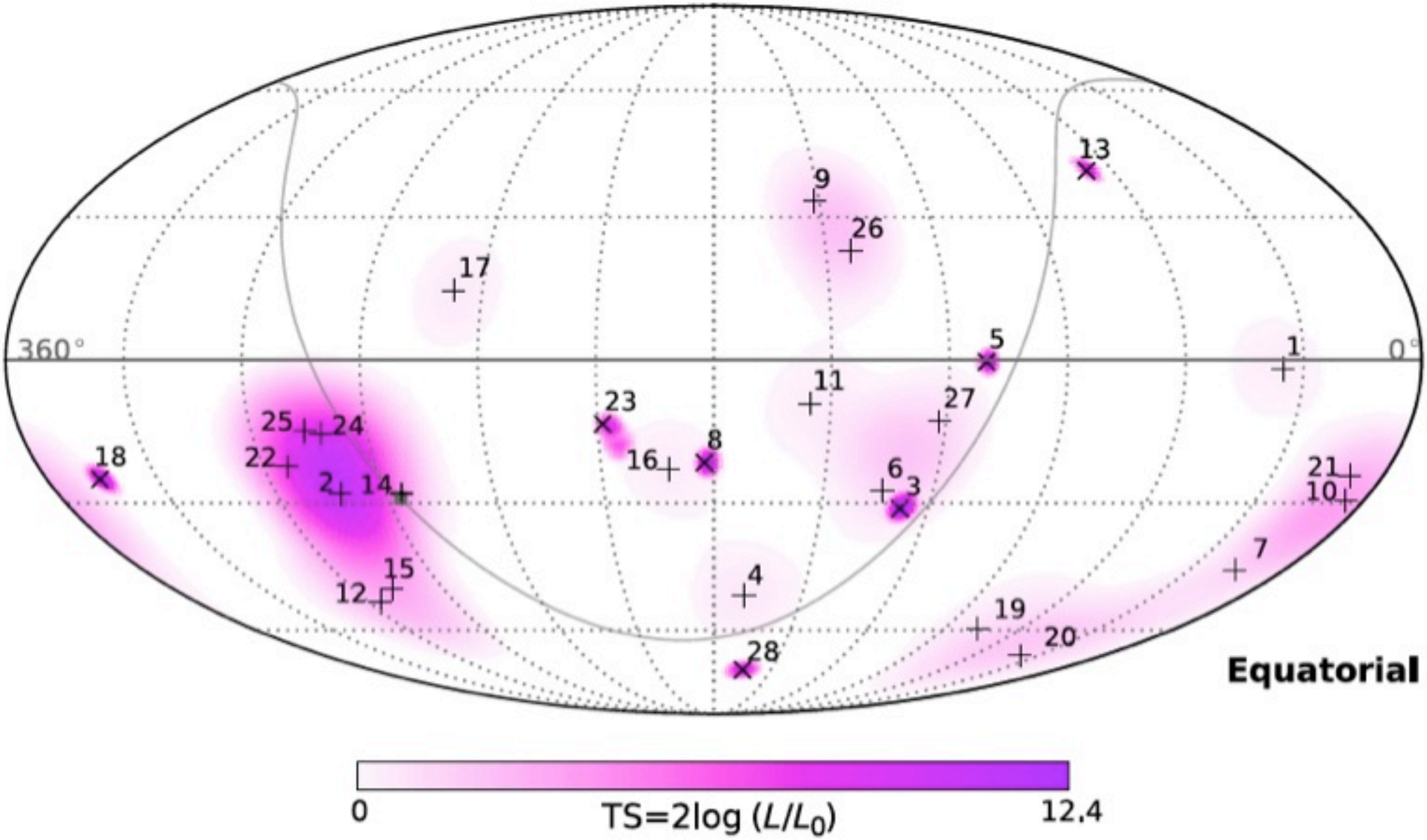




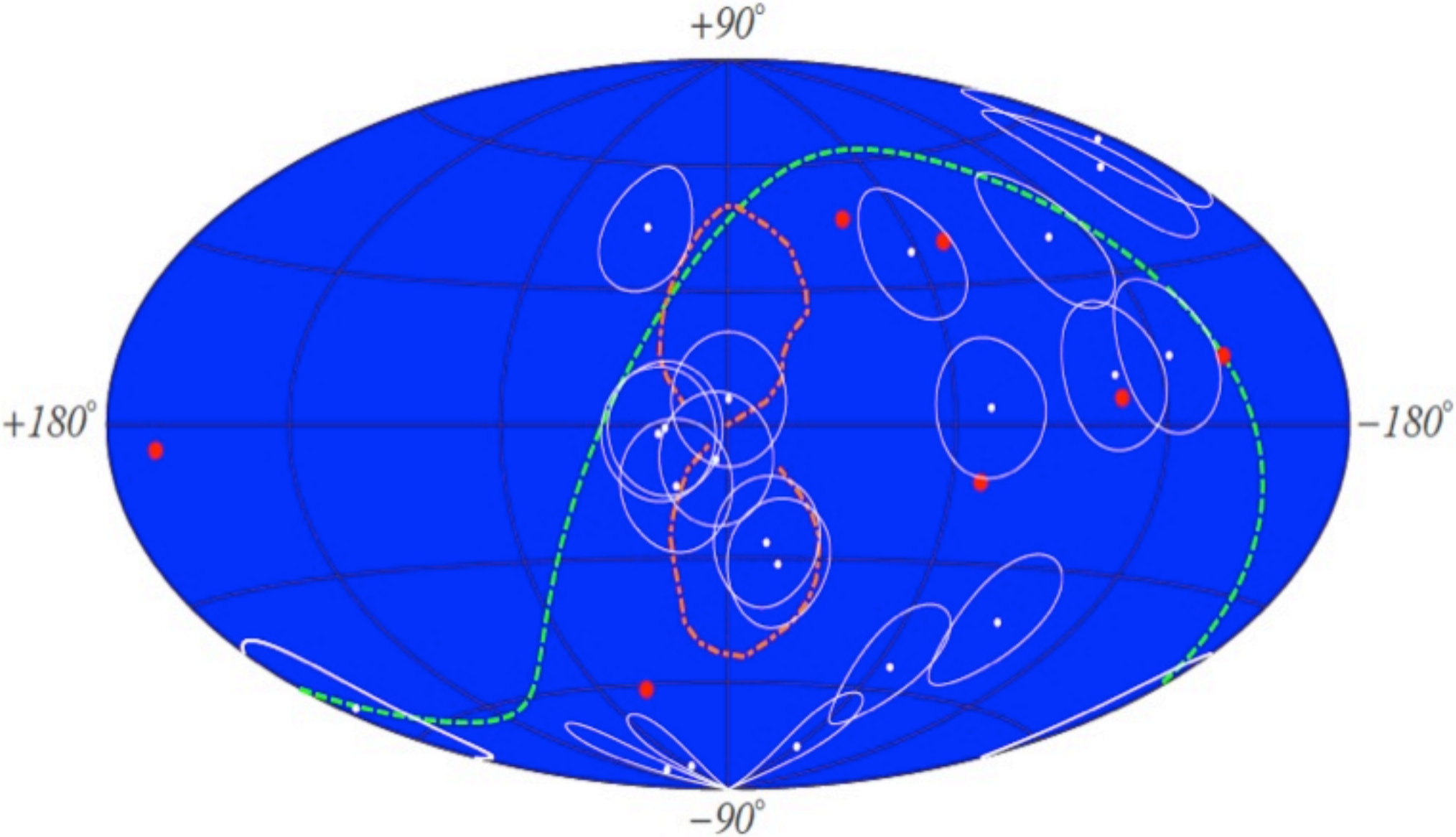
arXiv:1304.5356


MARACANÃ
Av. Pres. Castelo Branco
Praça Pres. Emílio Garrastazu Médici
R. Mata Machado
Maracanã
Estádio Célio de Barros
Condomínio do Edifício Orion
Condomínio do Edifício Stadium
Condomínio do Edifício Eurico Rabelo
Condomínio do Edifício Miragaya
Churrasqueiras Brazão
FPS
R. Prof. Eurico Rabelo
Ginásio do Maracanãzinho
Condomínio do Edifício Nancy Caire
Estádio Mário Filho
Av. Maracanã
Vd. Odyvaldo Cozzi
Av. Paulo Sousa
Hospital Mayer
Hospital Dr. Badim
Praça Violoncelista Alfredo Gomes
Condomínio do Edifício Couto
Pista Lateral
Brasil 2014

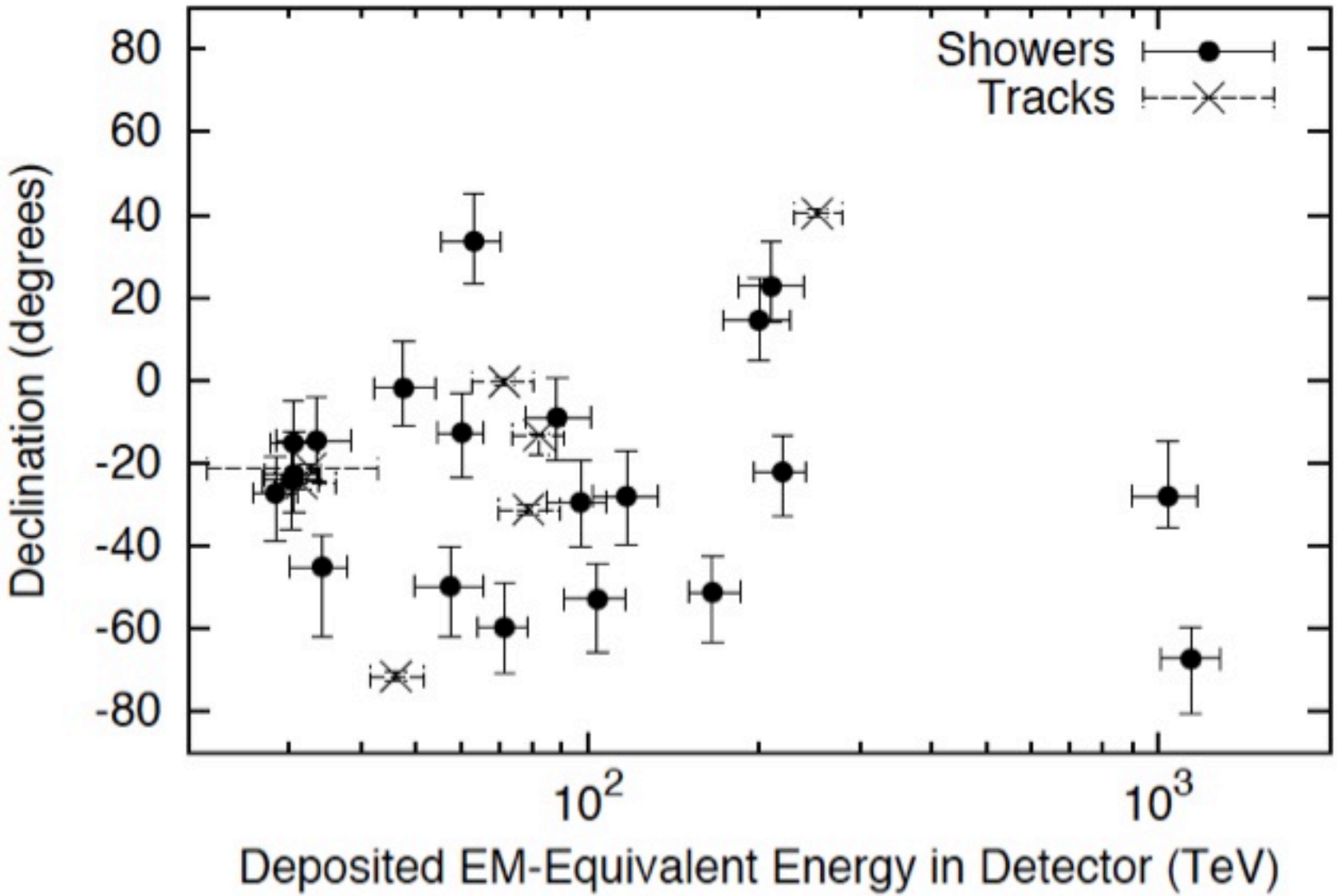
28 IceCube Events



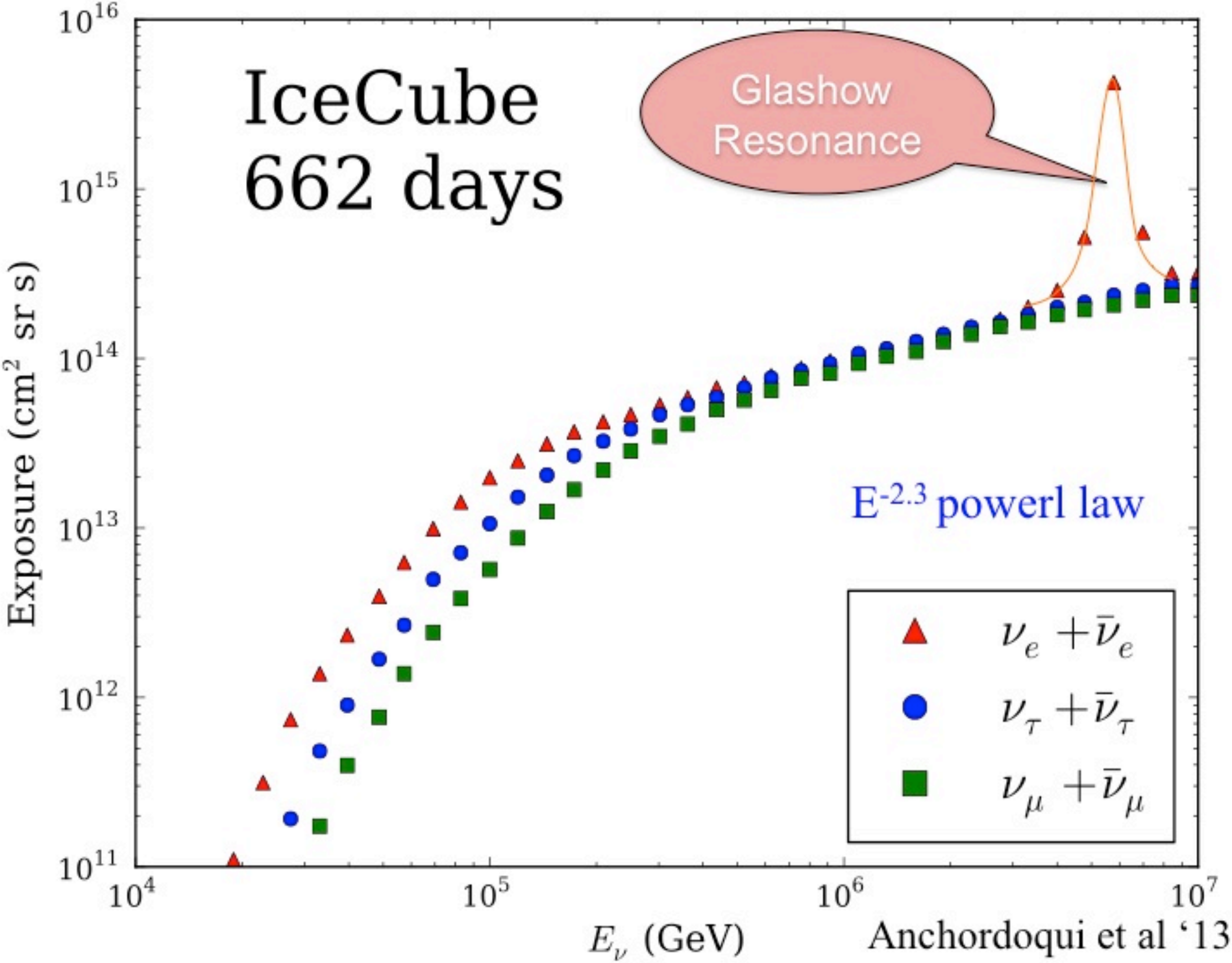
Galactic Coordinates



IceCube 28 neutrino-like events (4.3σ)

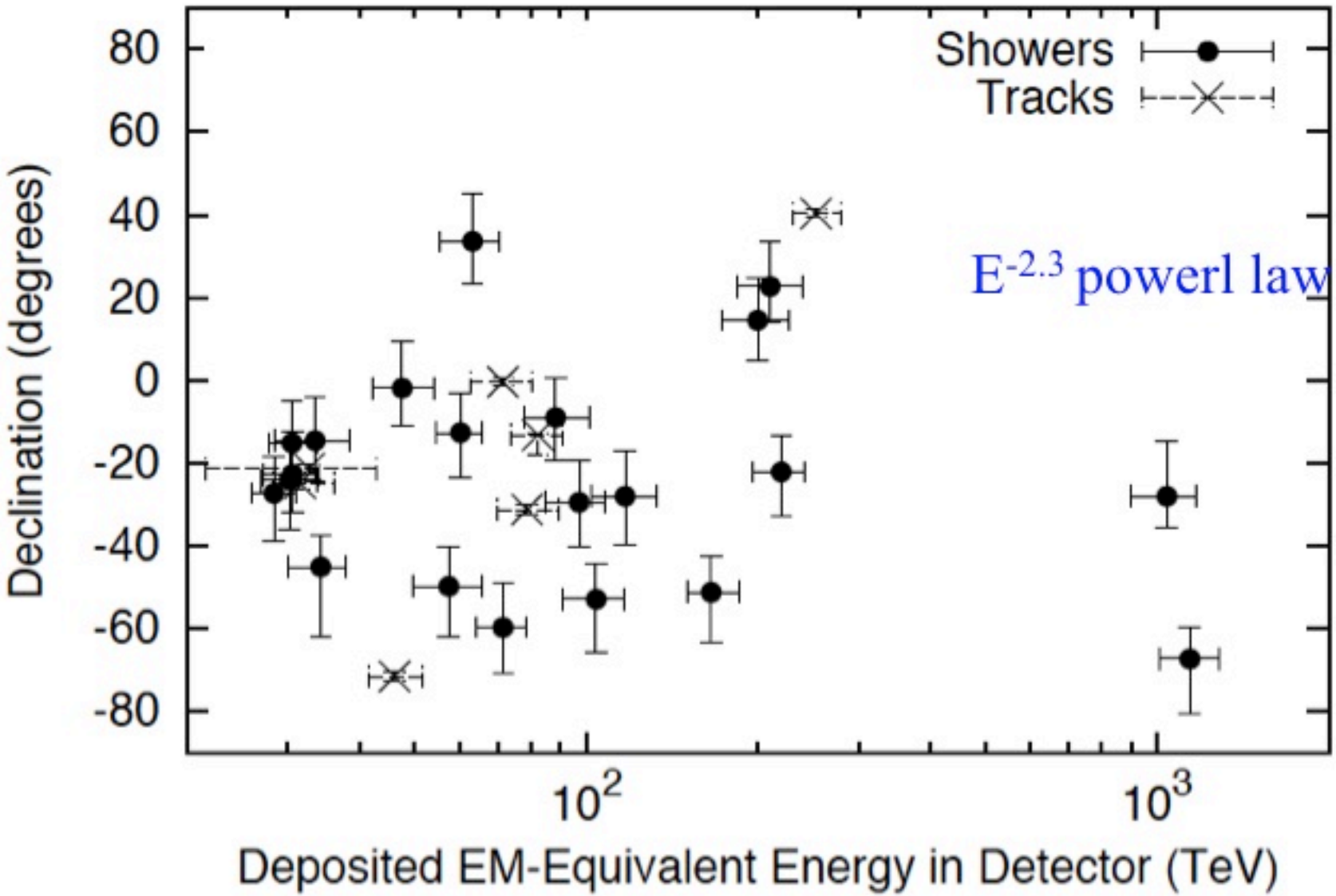


28 events (7 with visible muons, 21 without) on background of $10.6^{+4.5}_{-3.9}$ (12.1 ± 3.4 with reference charm model)



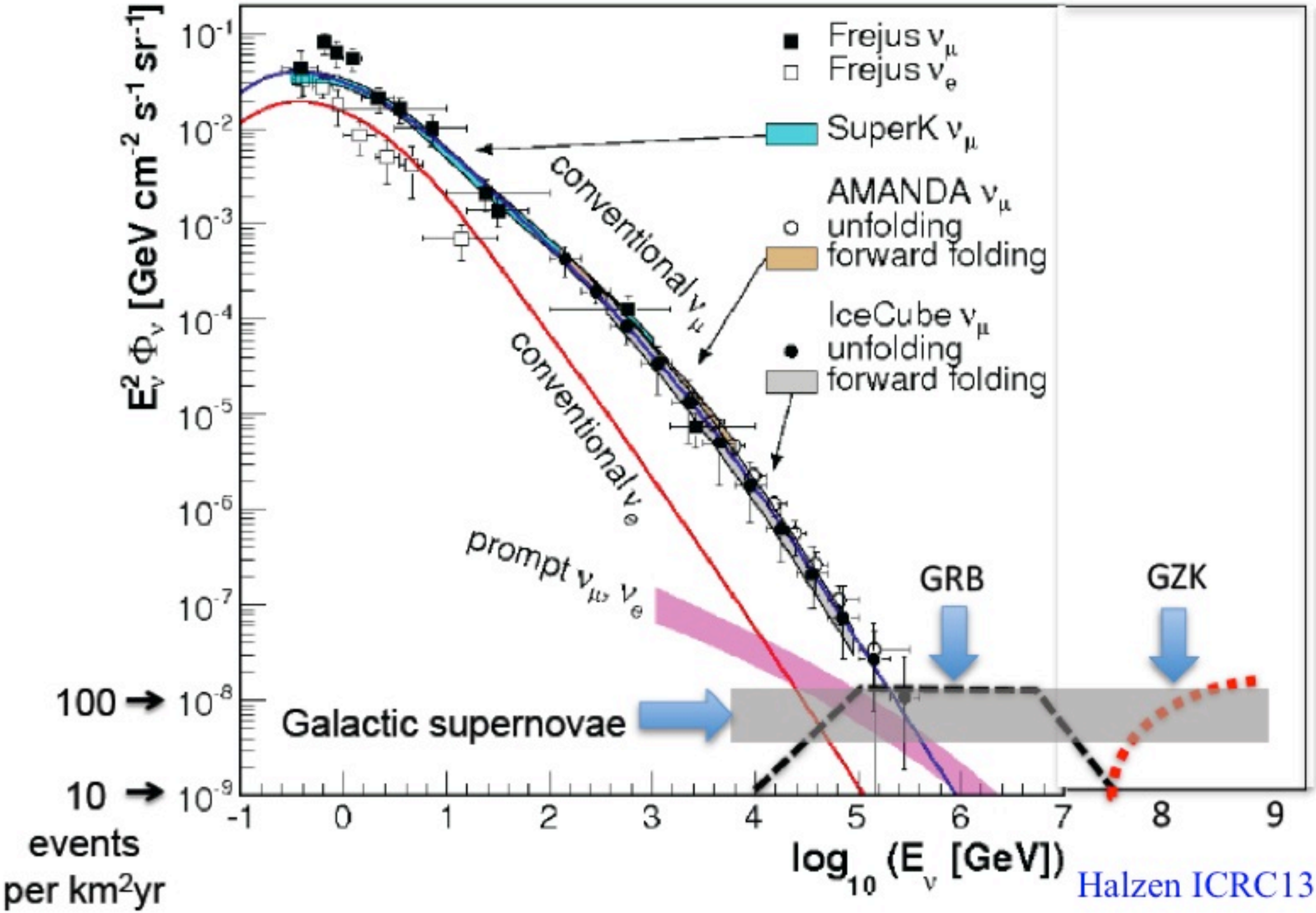
Anchordoqui et al '13

IceCube 28 neutrino-like events (4.3σ)



28 events (7 with visible muons, 21 without) on background of $10.6^{+4.5}_{-3.9}$ (12.1 ± 3.4 with reference charm model) Anchordoqui et al '13

Galactic CRs?



Halzen ICRC13

UHECRs Current Status

Leading Observatories: Auger & Telescope Array

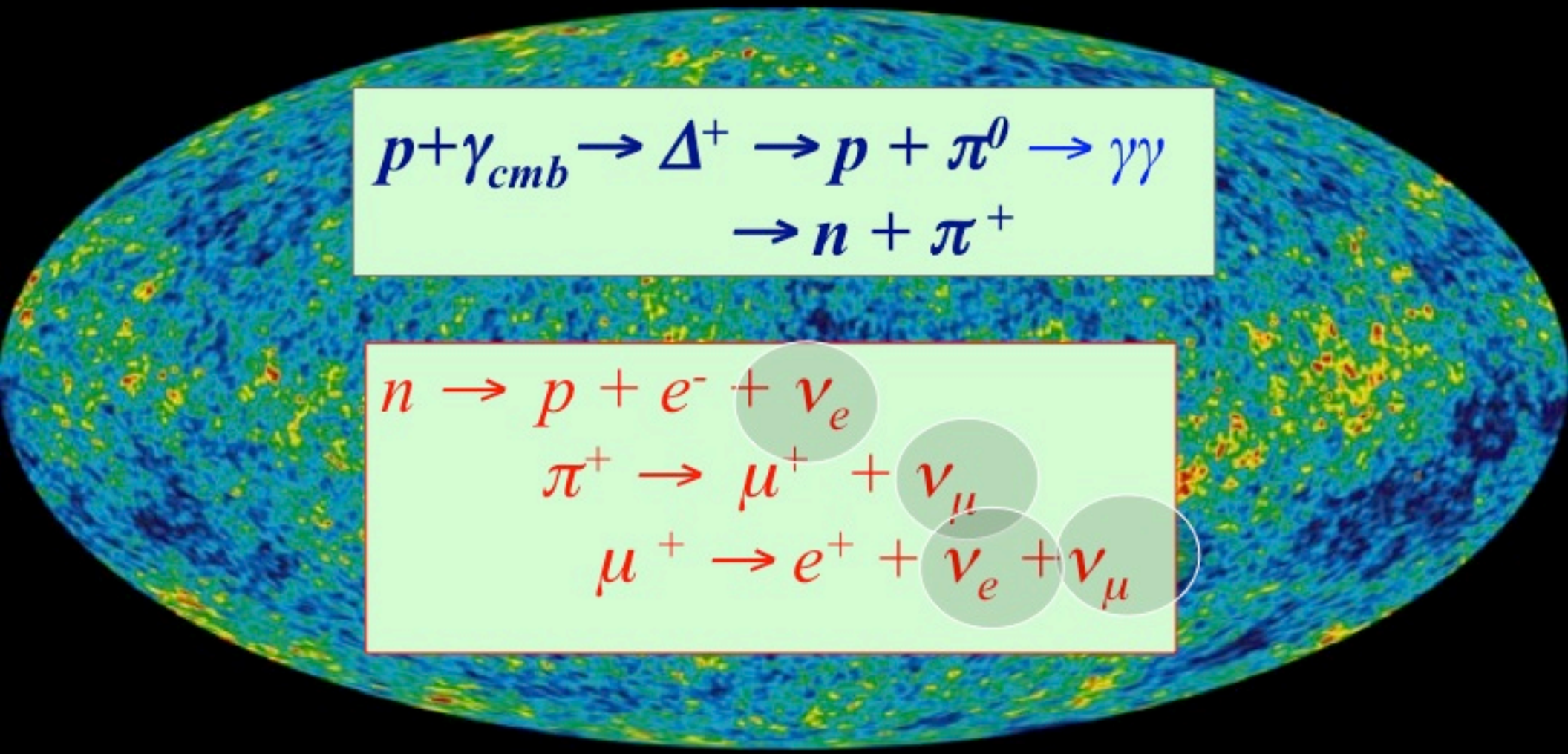
Agree on the shape of the spectrum

Energy scale: ~10% difference

Composition: controversial

Multi-messenger clues

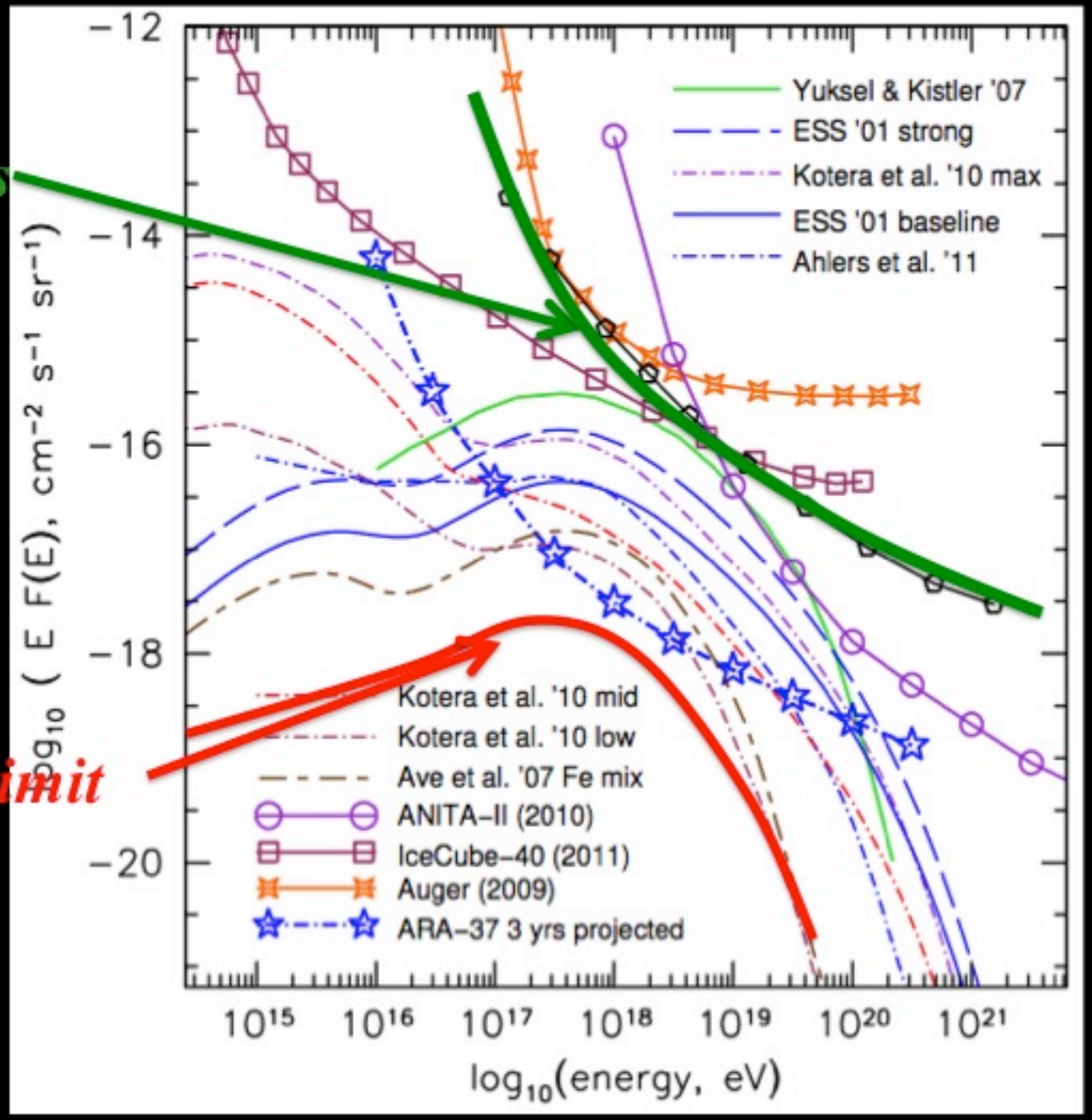
Cosmogenic (GZK, BZ) Neutrinos & Photons



$$p + \gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0} \rightarrow \gamma\gamma$$
$$\rightarrow n + \pi^{+}$$

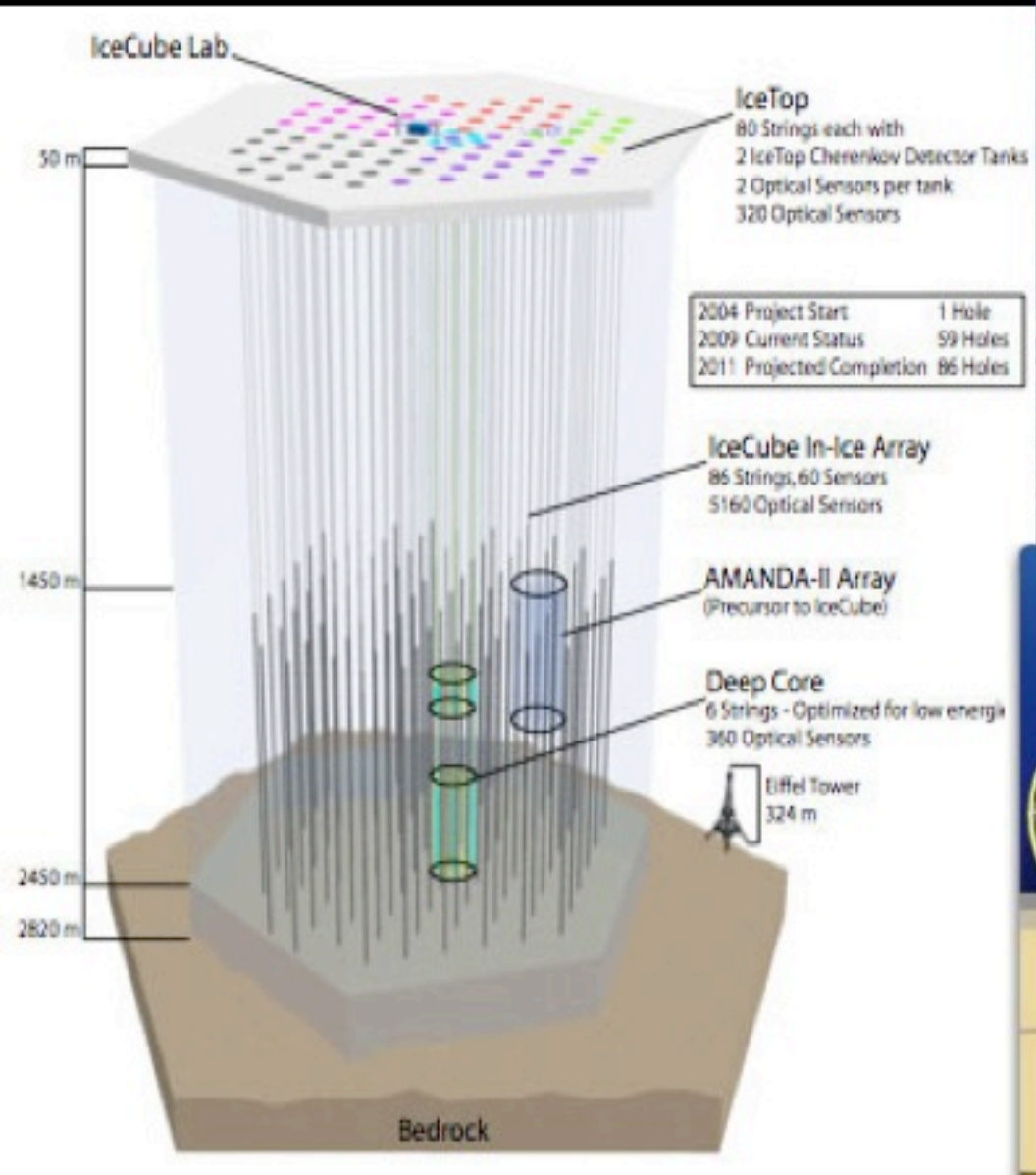
$$n \rightarrow p + e^{-} + \nu_{e}$$
$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$
$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \nu_{\mu}$$

Neutrino Detectors

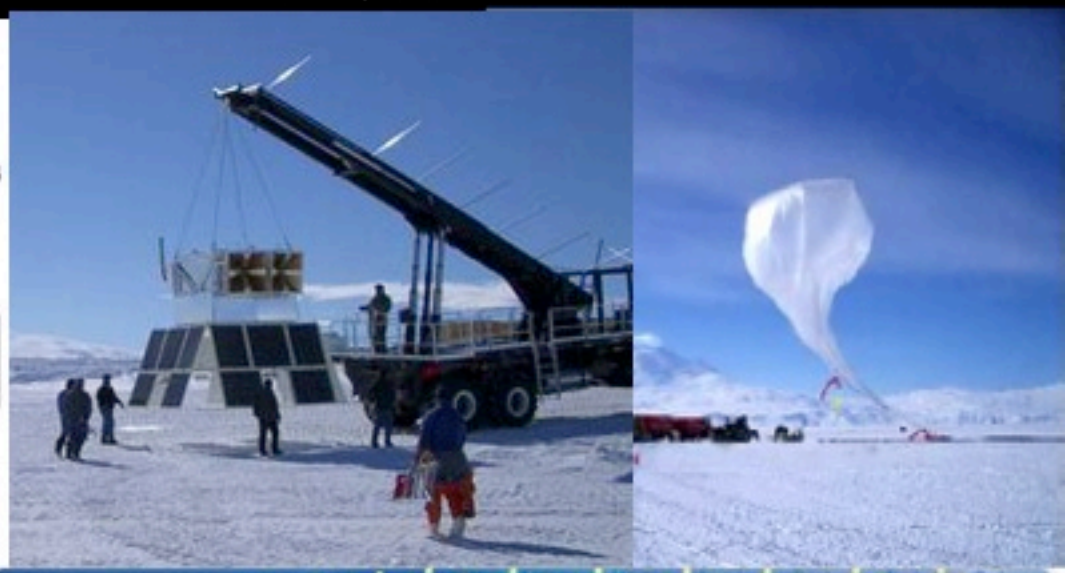


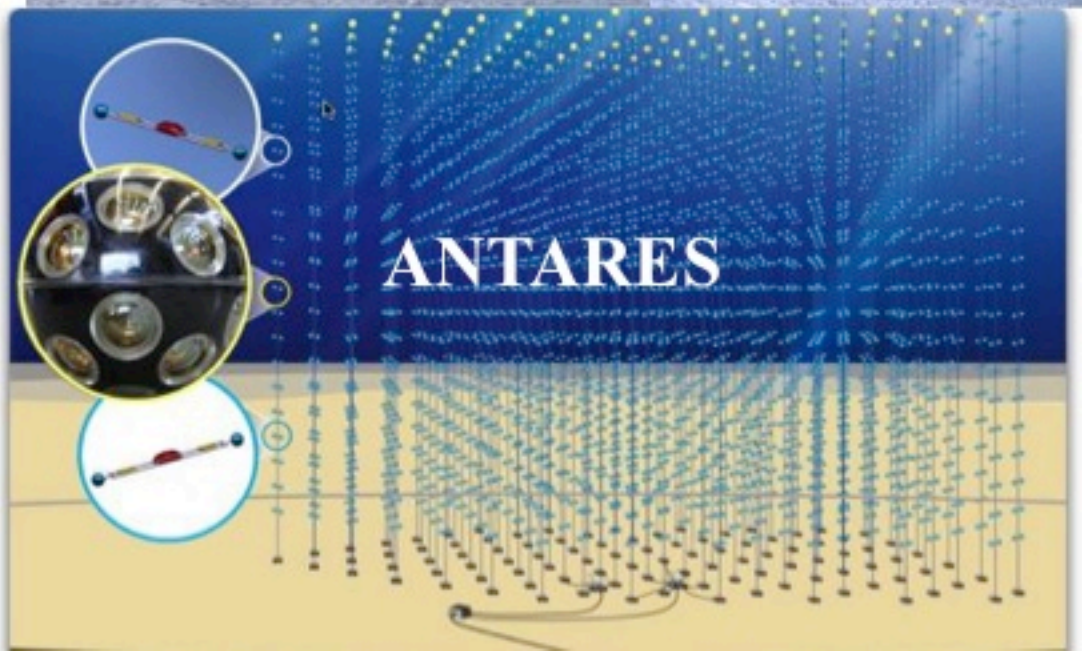
Highest Energy Neutrino Observatories

IceCube



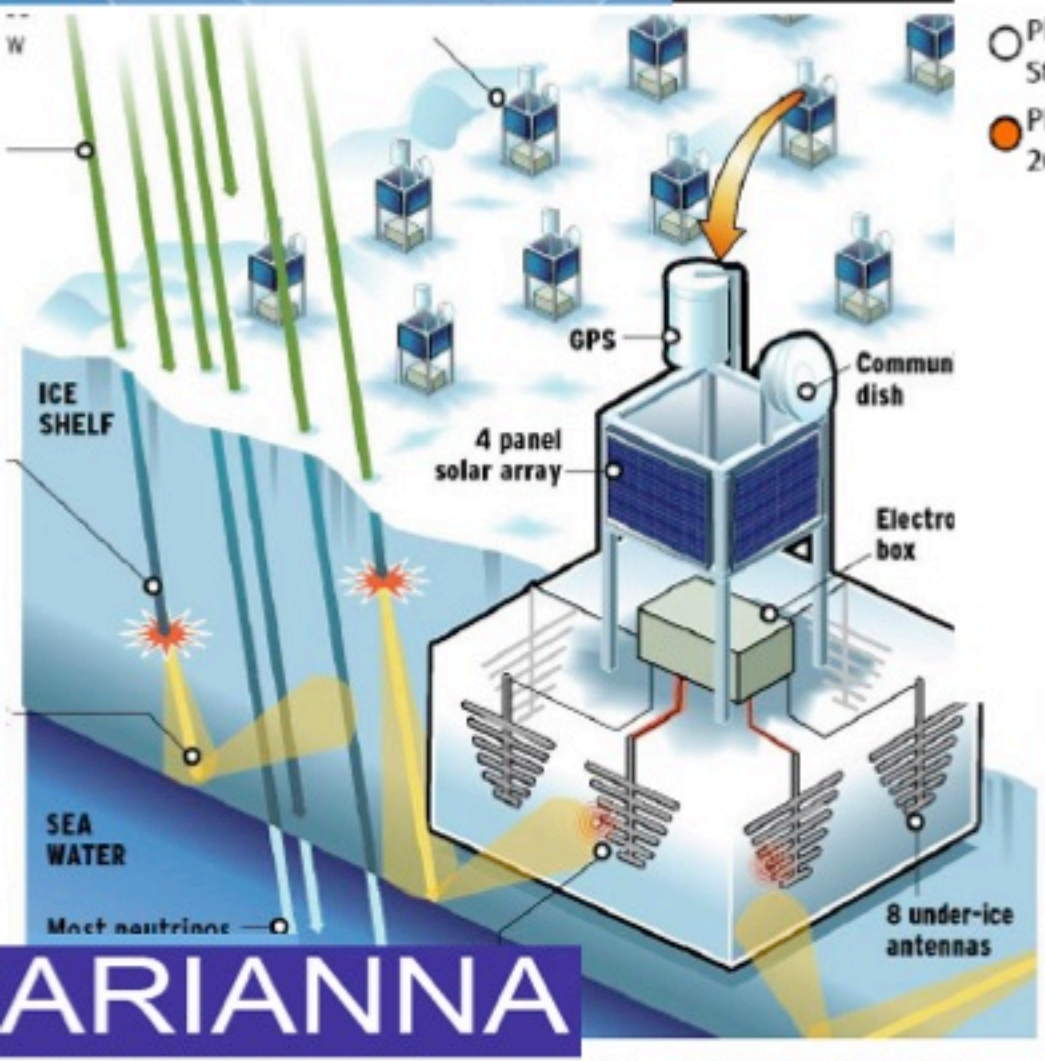
ANITA



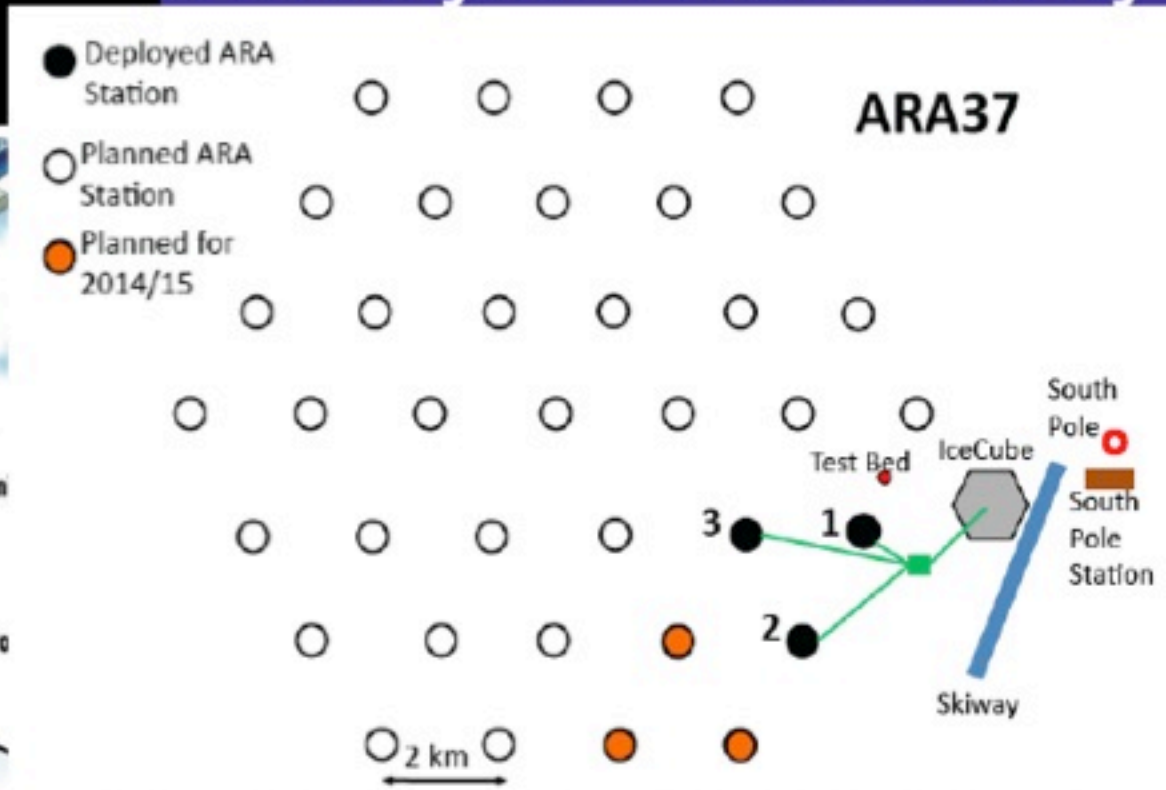


Next Generation

ARA: Askaryan Radio Array

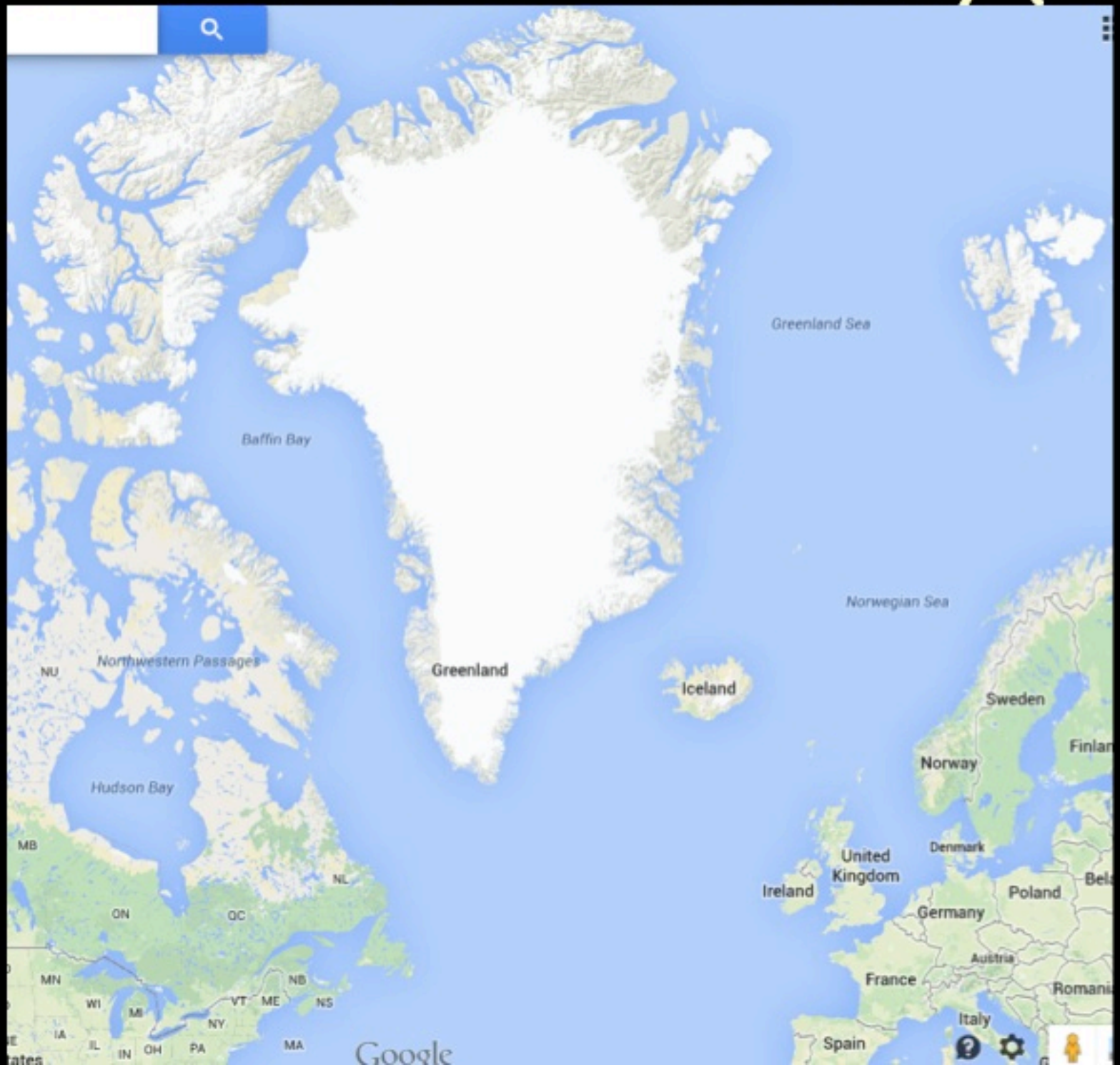


ARIANNA

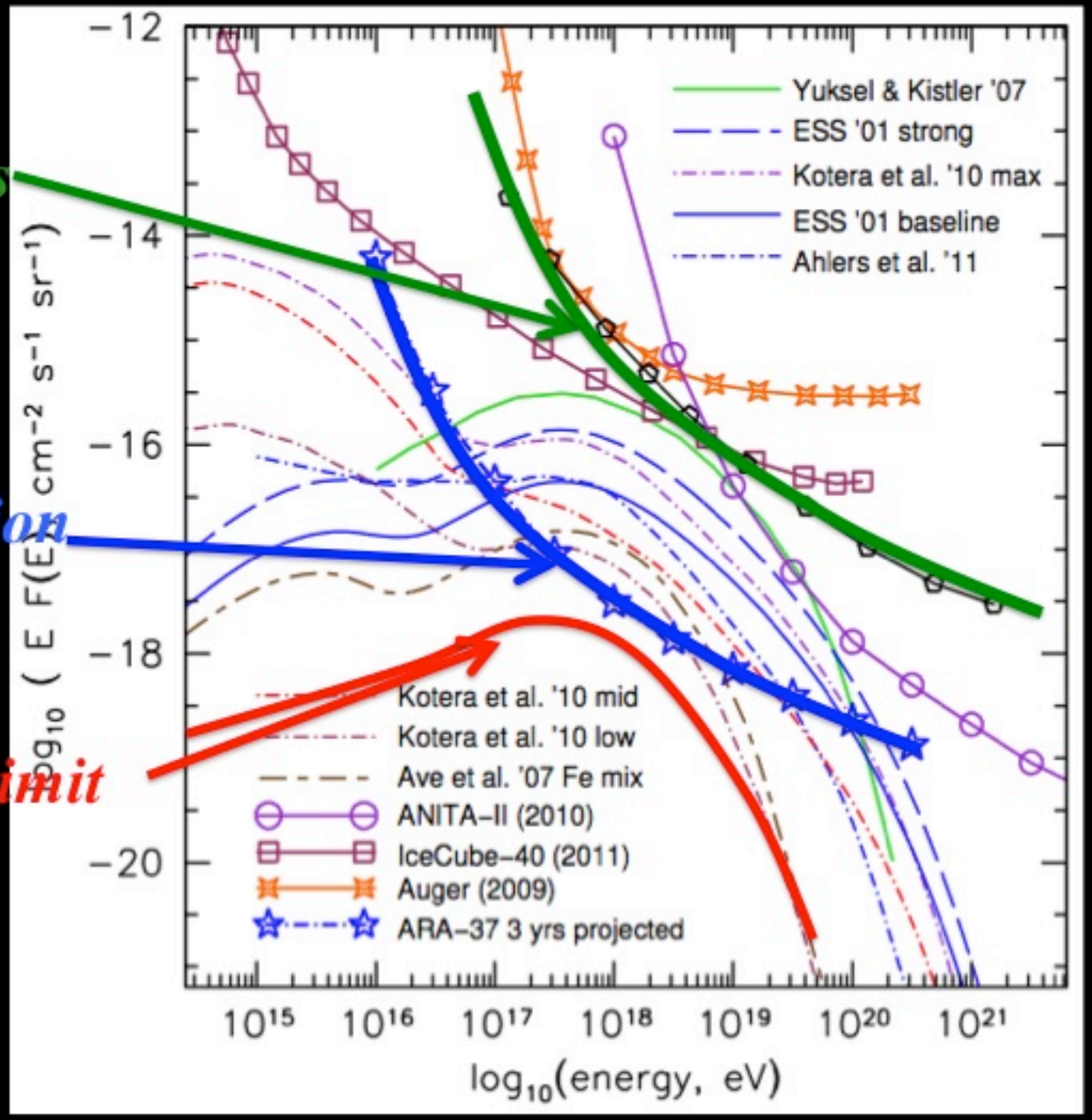


ARIANNA Coll. See arXiv:1207.3846

Greenland Neutrino Observatory (GNO)



Neutrino Detectors



UHECRs Current Status

Leading Observatories: Auger & Telescope Array

Agree on the shape of the spectrum

Energy scale: ~10% difference

Composition: controversial

Multi-messenger clues: not yet

Anisotropies?

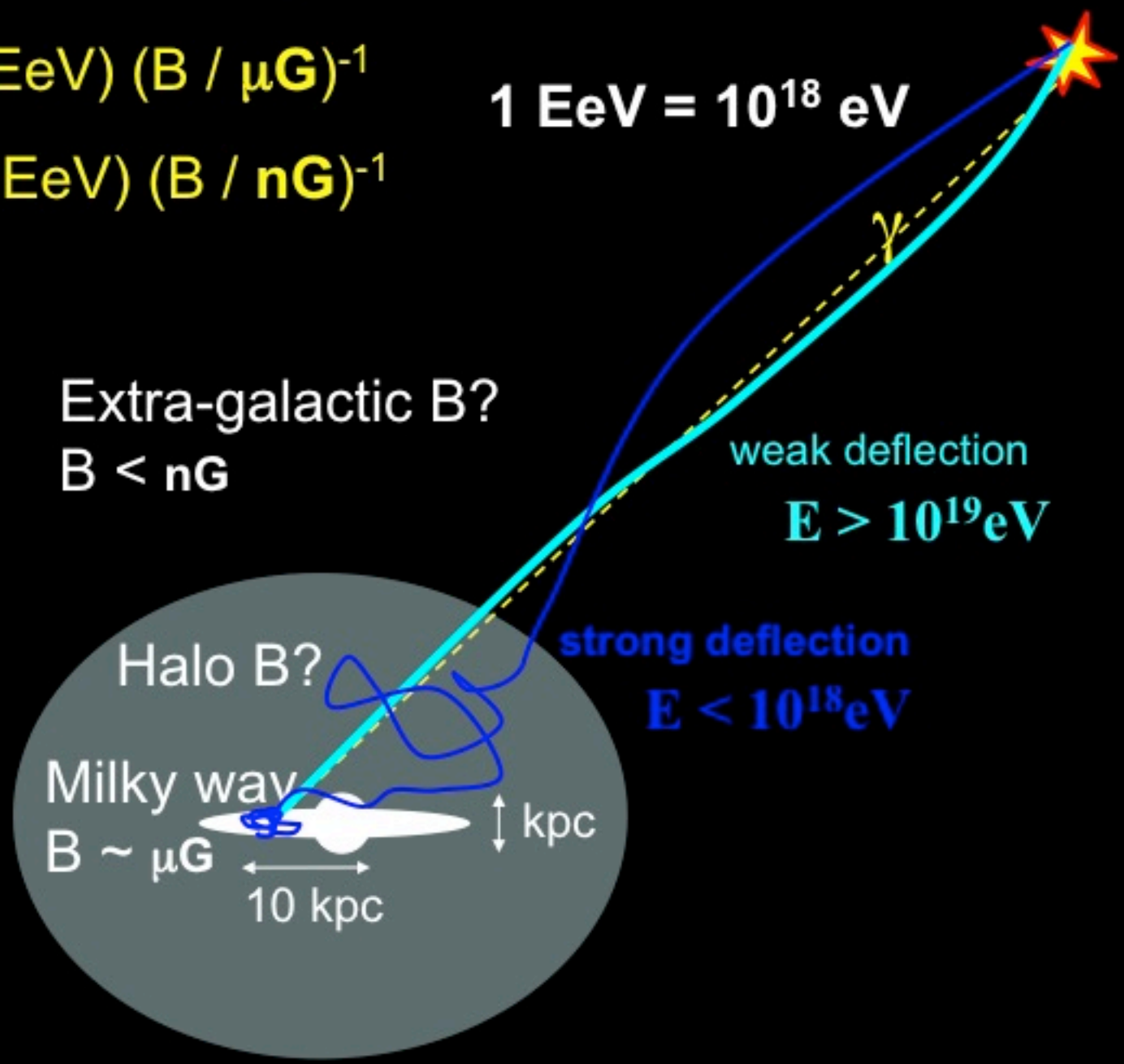
"Known unknown"

Cosmic Magnetic Fields

R_L = **kpc** Z^{-1} (E / EeV) (B / **μG**)$^{-1}$

R_L = **Mpc** Z^{-1} (E / EeV) (B / **nG**)$^{-1}$

1 EeV = 10^{18} eV



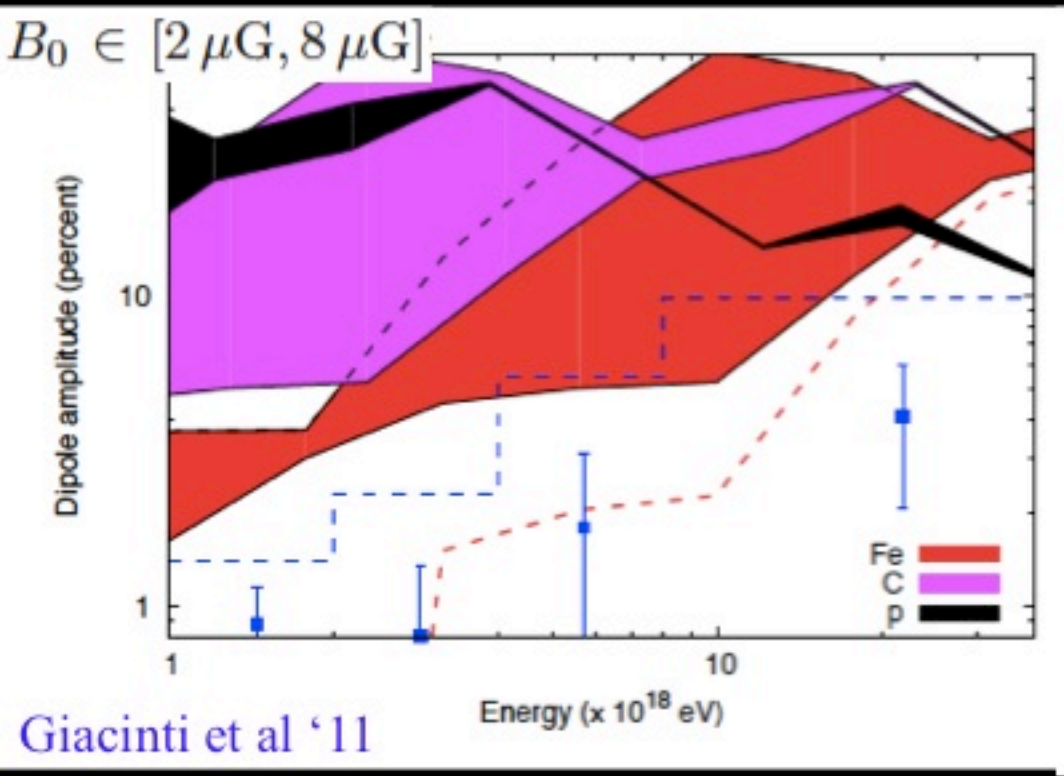
Extra-galactic B?
B < **nG**

Galactic B deflection
<< 10° Z (40 EeV/E)
anisotropic in sky

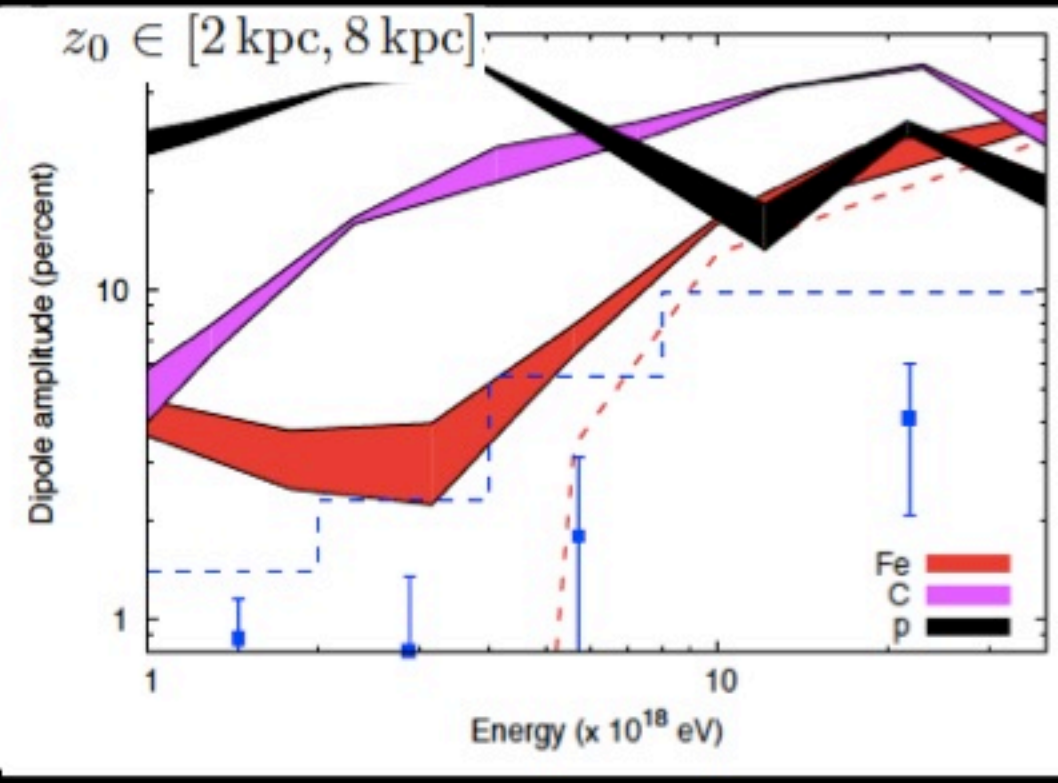
No Galactic Plane Anisotropy

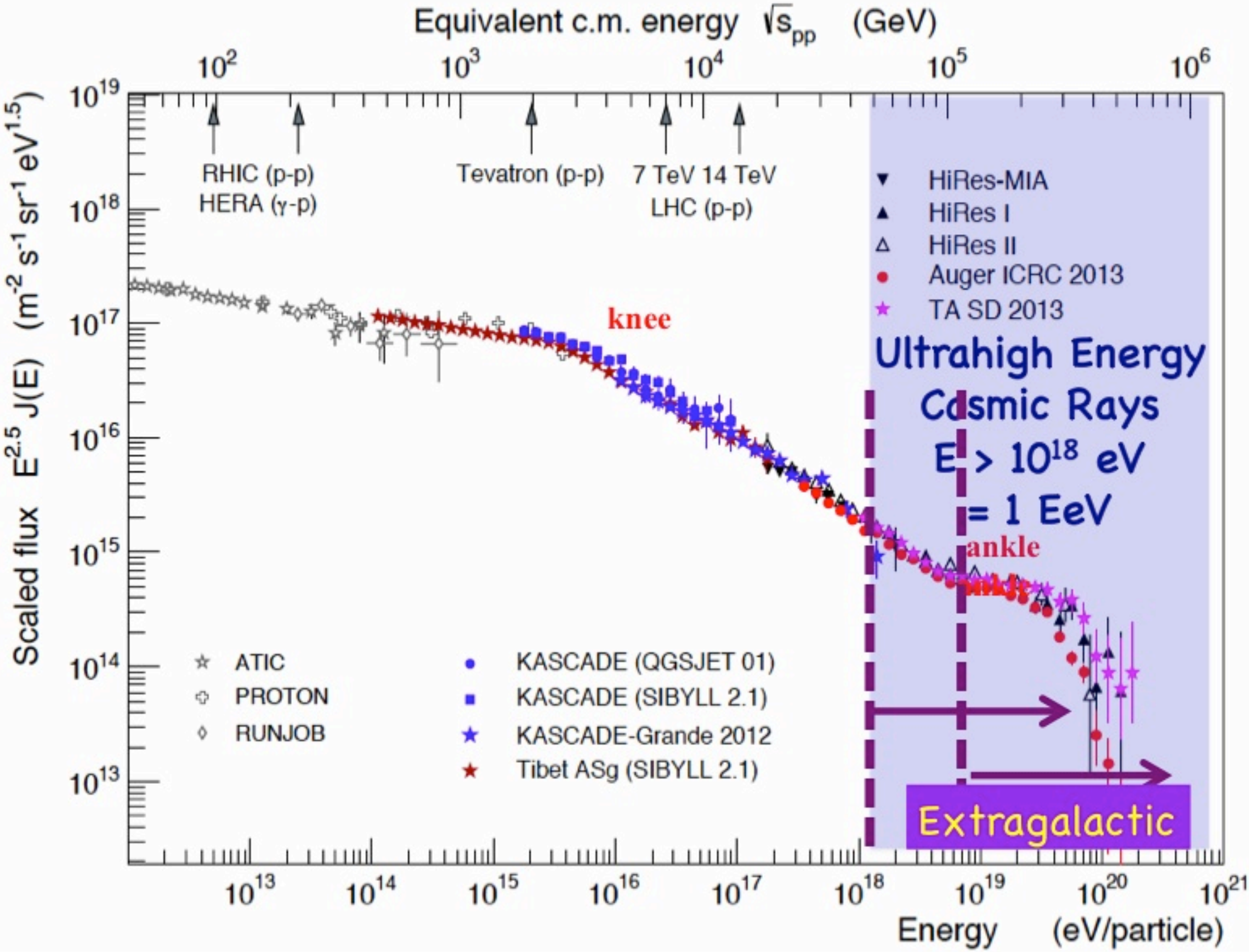
E>20 EeV Cosmic Rays are EXTRAGALACTIC

Auger Anisotropy limits: rule out Galactic protons to CNO as dominant CR component **E > 1 EeV** and Fe above **20 EeV**

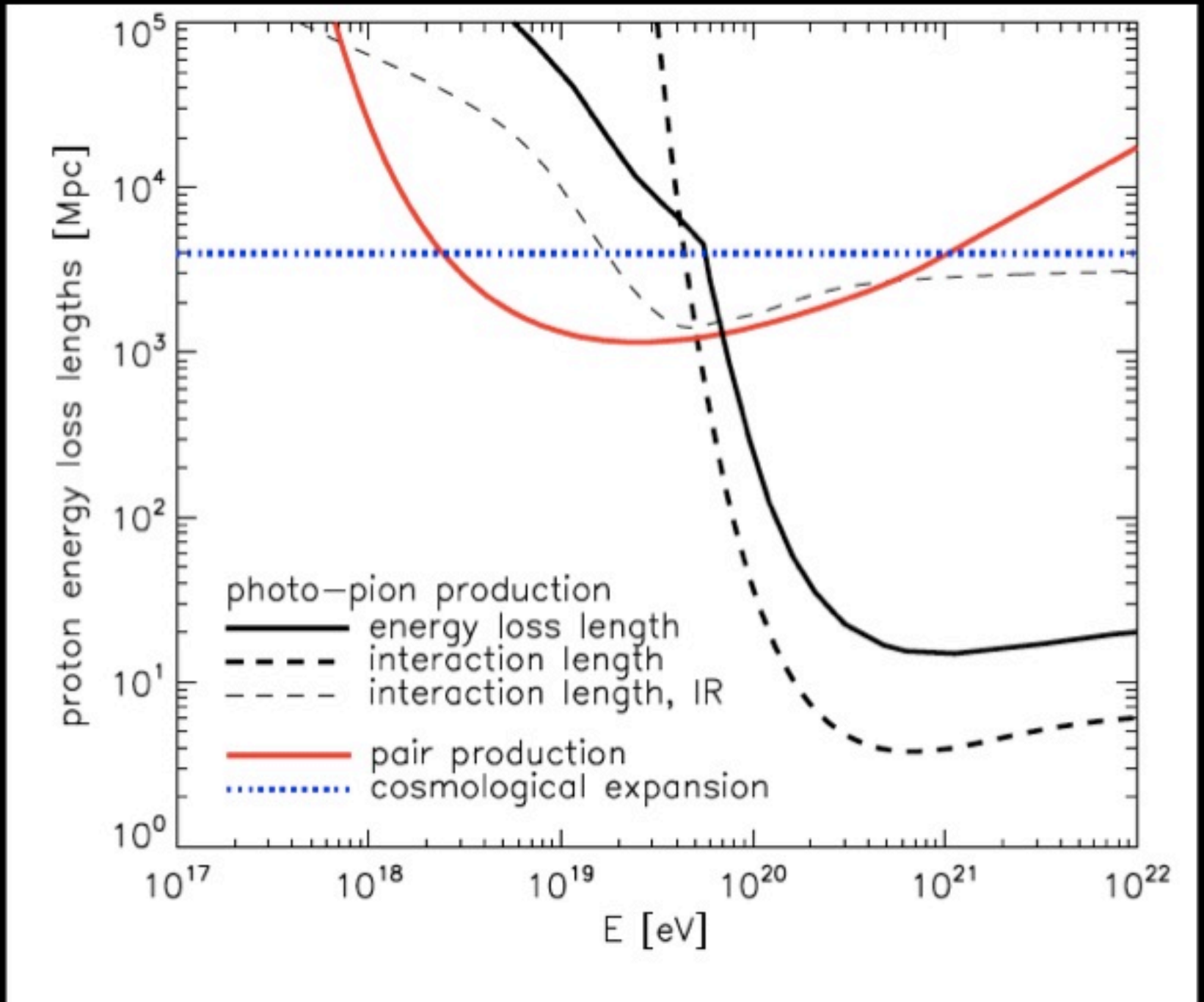


Giacinti et al '11

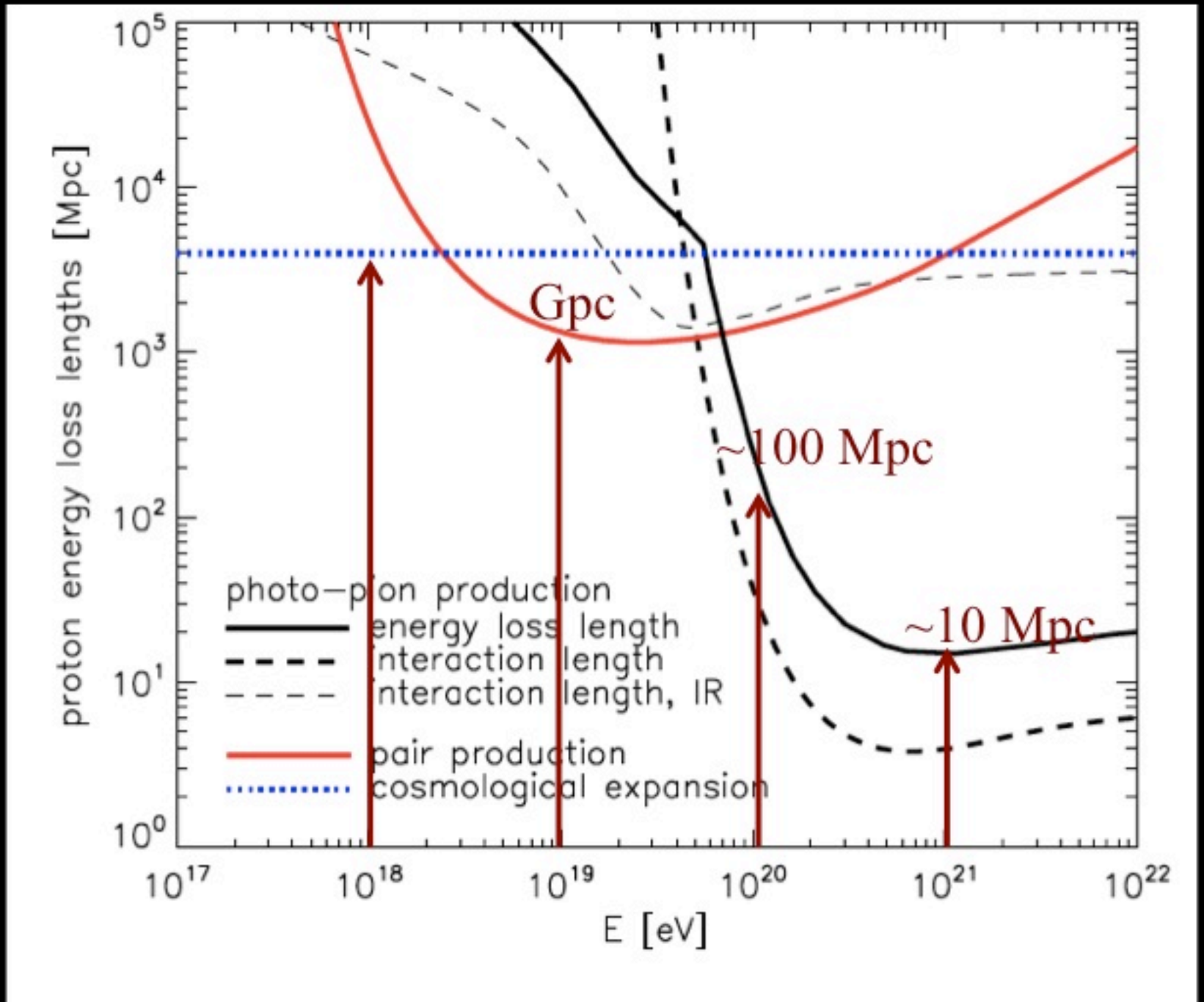



Equivalent c.m. energy $\sqrt{s_{pp}}$ (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
Ultrahigh Energy
Cosmic Rays
E > 10^{18} eV
= 1 EeV
ankle
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
Extragalactic
Scaled flux $E^{2.5}$ J(E) (m^{-2} s^{-1} sr^{-1} $eV^{1.5}$)
10^{19}
10^{18}
10^{17}
10^{16}
10^{15}
10^{14}
10^{13}
10^{13}
10^{14}
10^{15}
10^{16}
10^{17}
10^{18}
10^{19}
10^{20}
10^{21}
Energy (eV/particle)

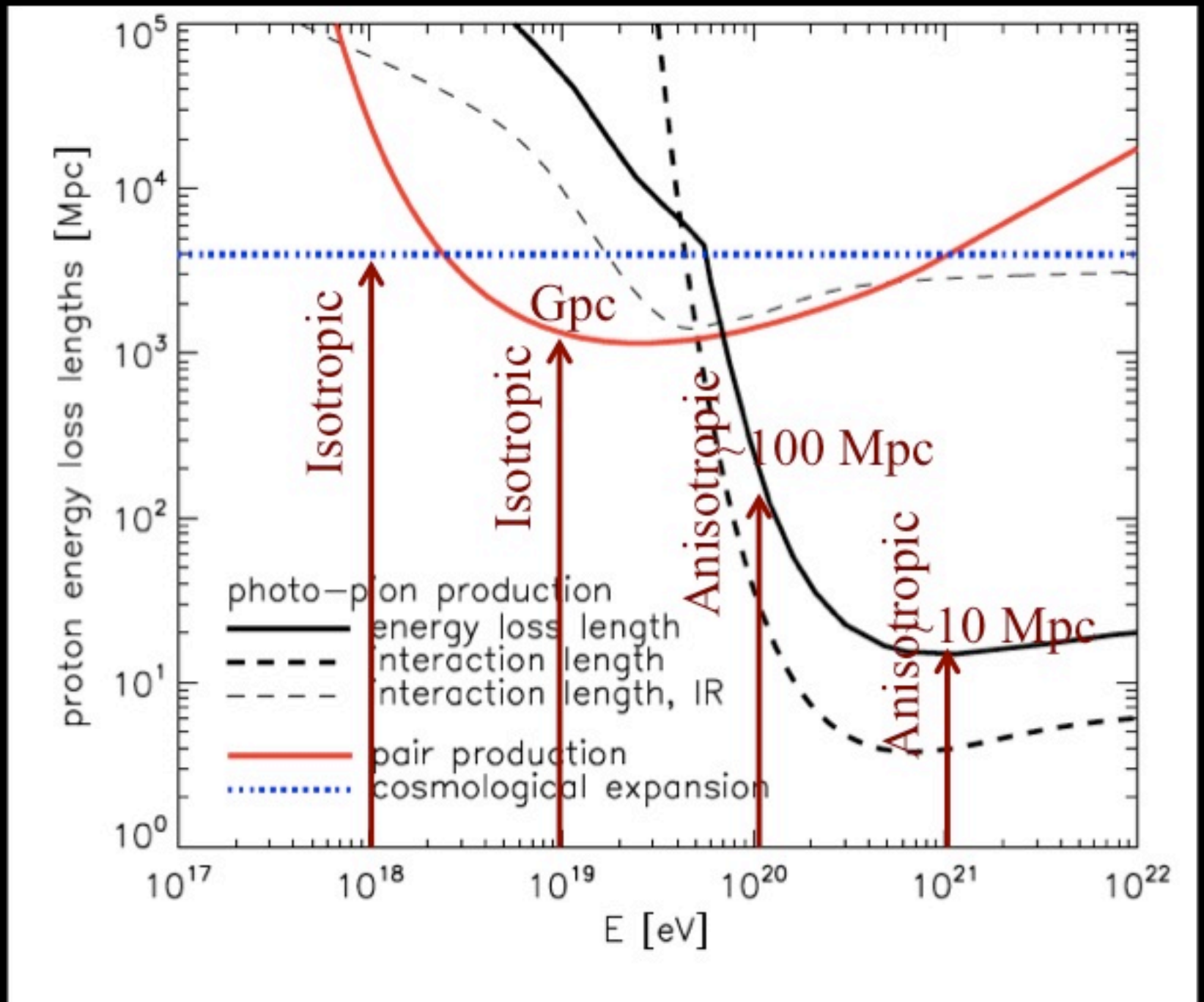
Greisen-Zatsepin-Kuzmin effect



Greisen-Zatsepin-Kuzmin effect



Greisen-Zatsepin-Kuzmin effect

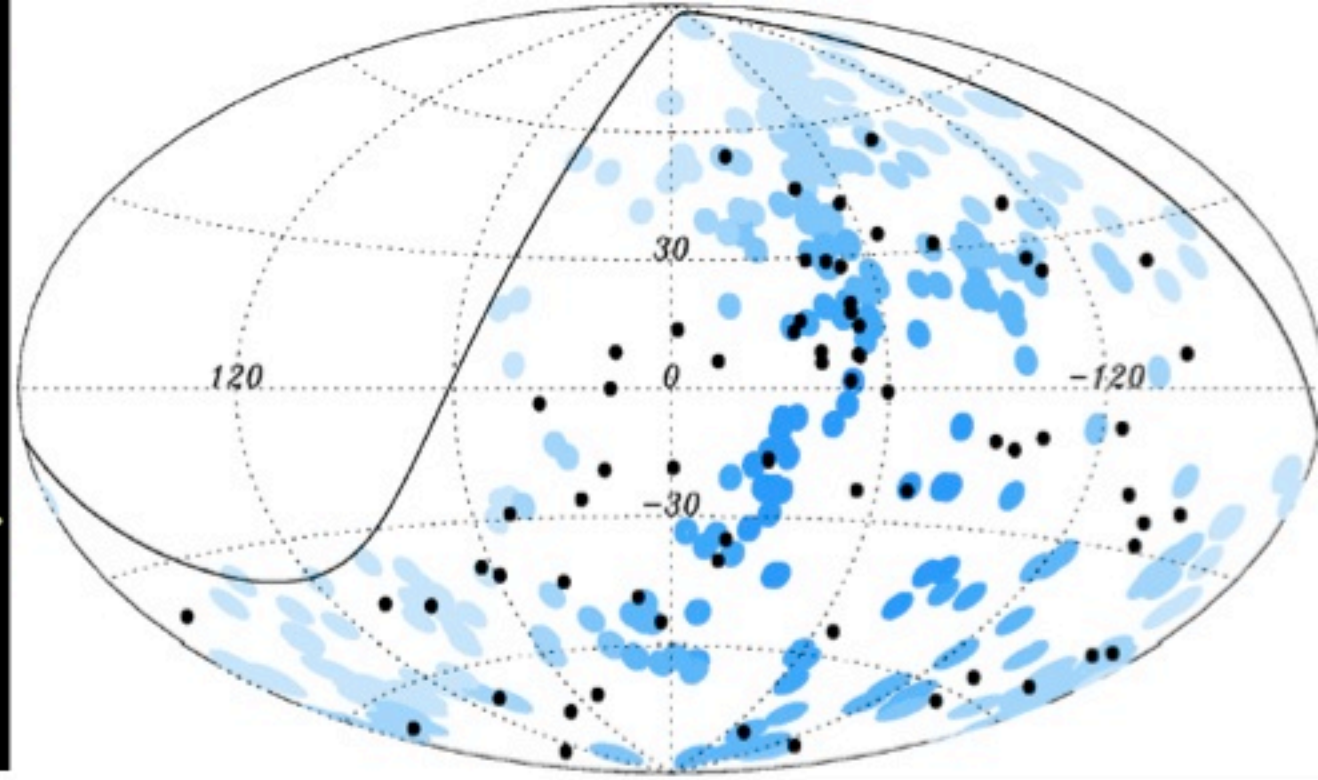


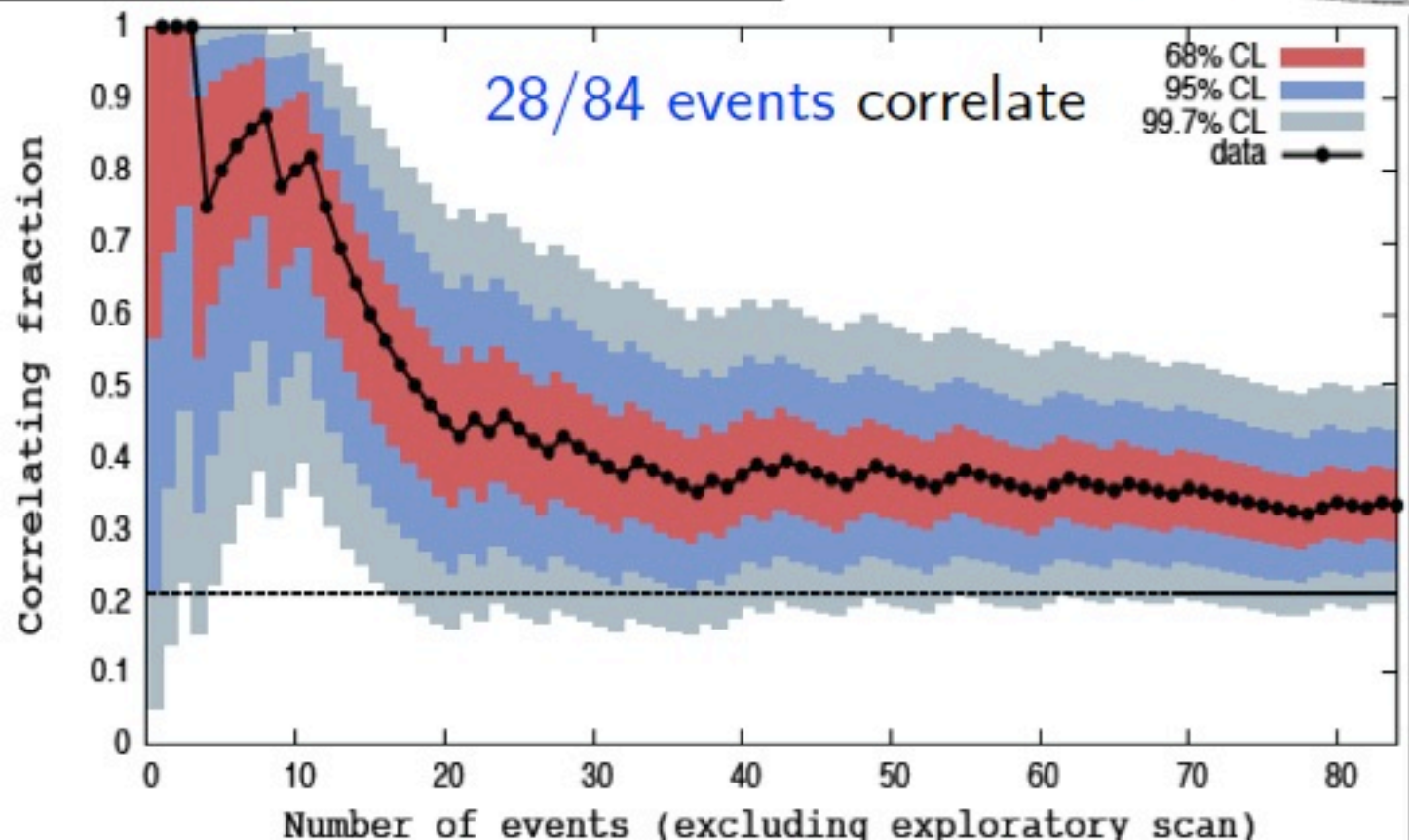

Where do UHECRs
come from?

Auger: consistent with Anisotropy

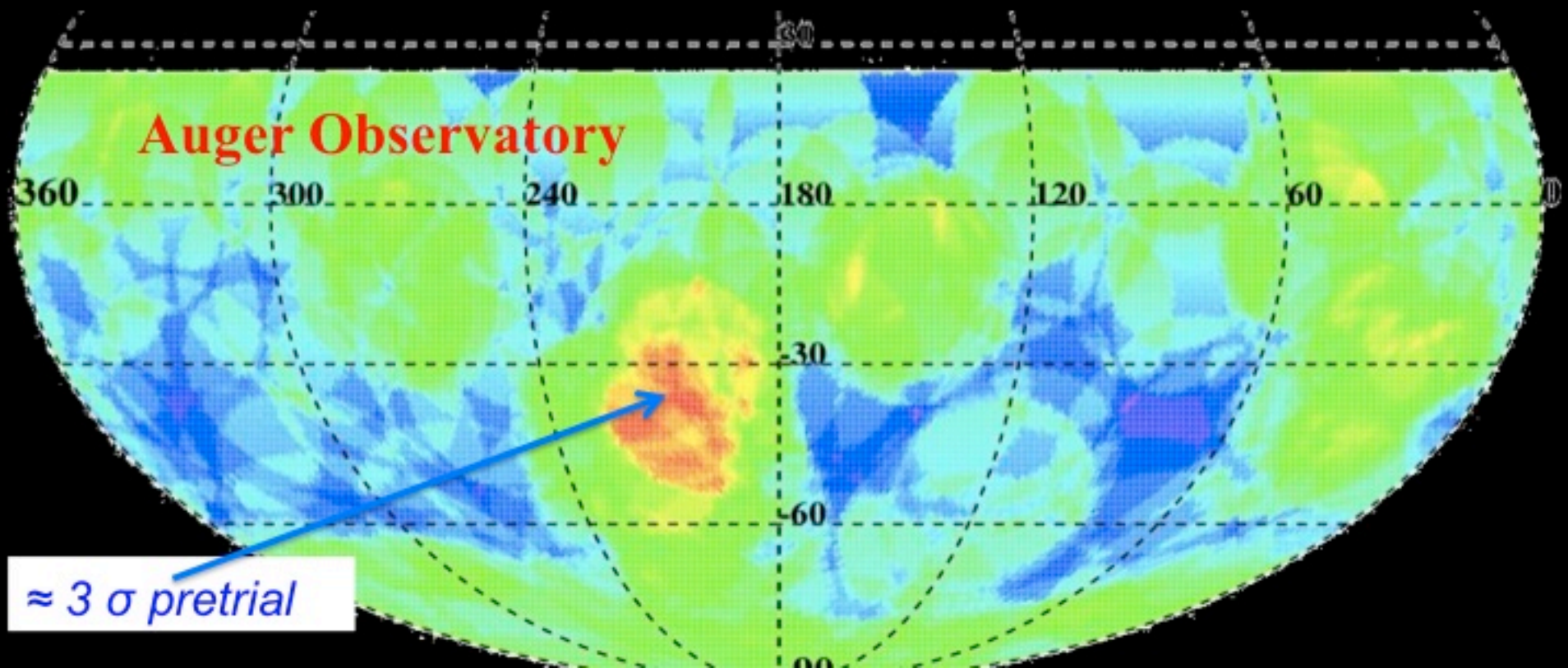
> 60 EeV

AGN catalog test

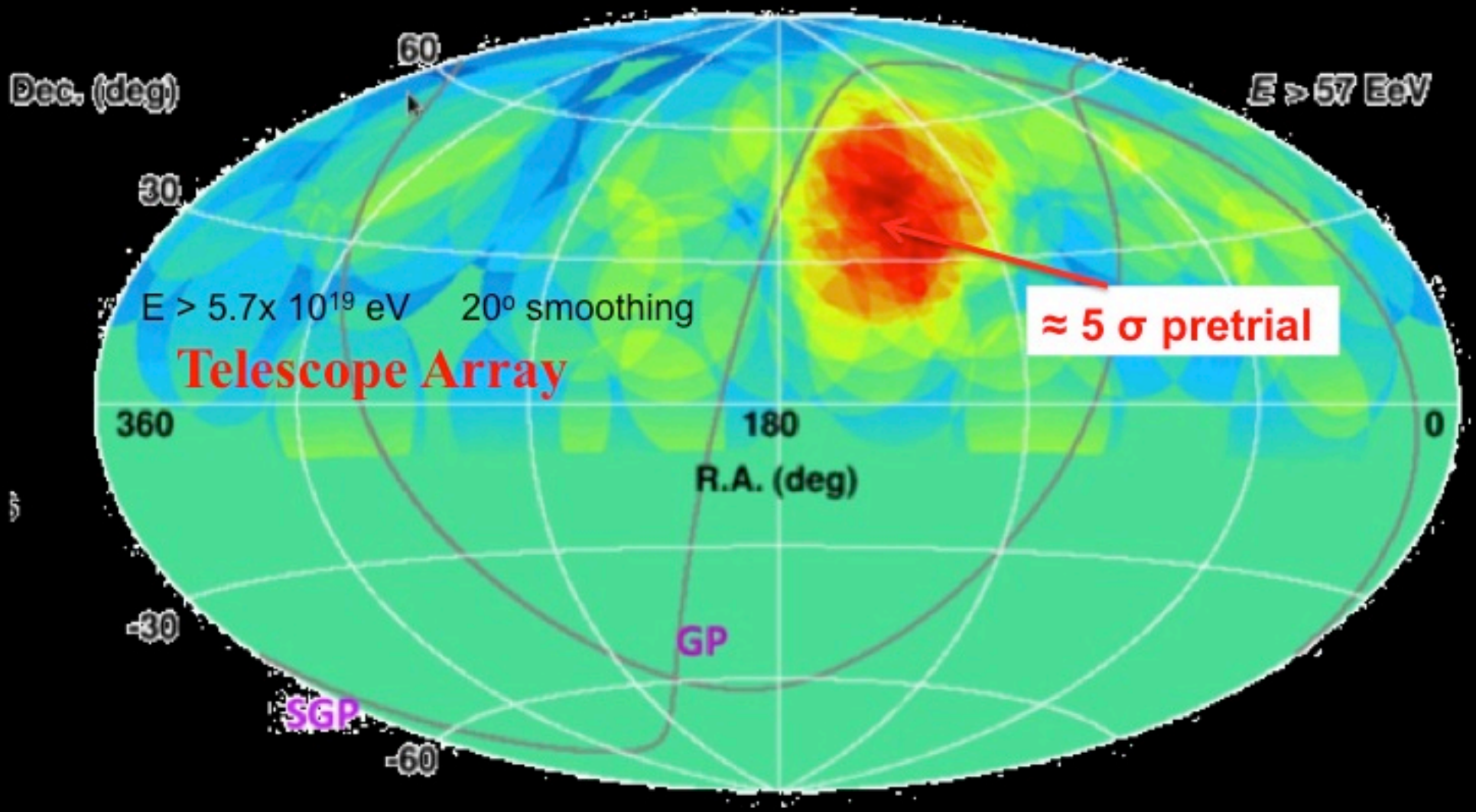




Anisotropy Hints > 60 EeV

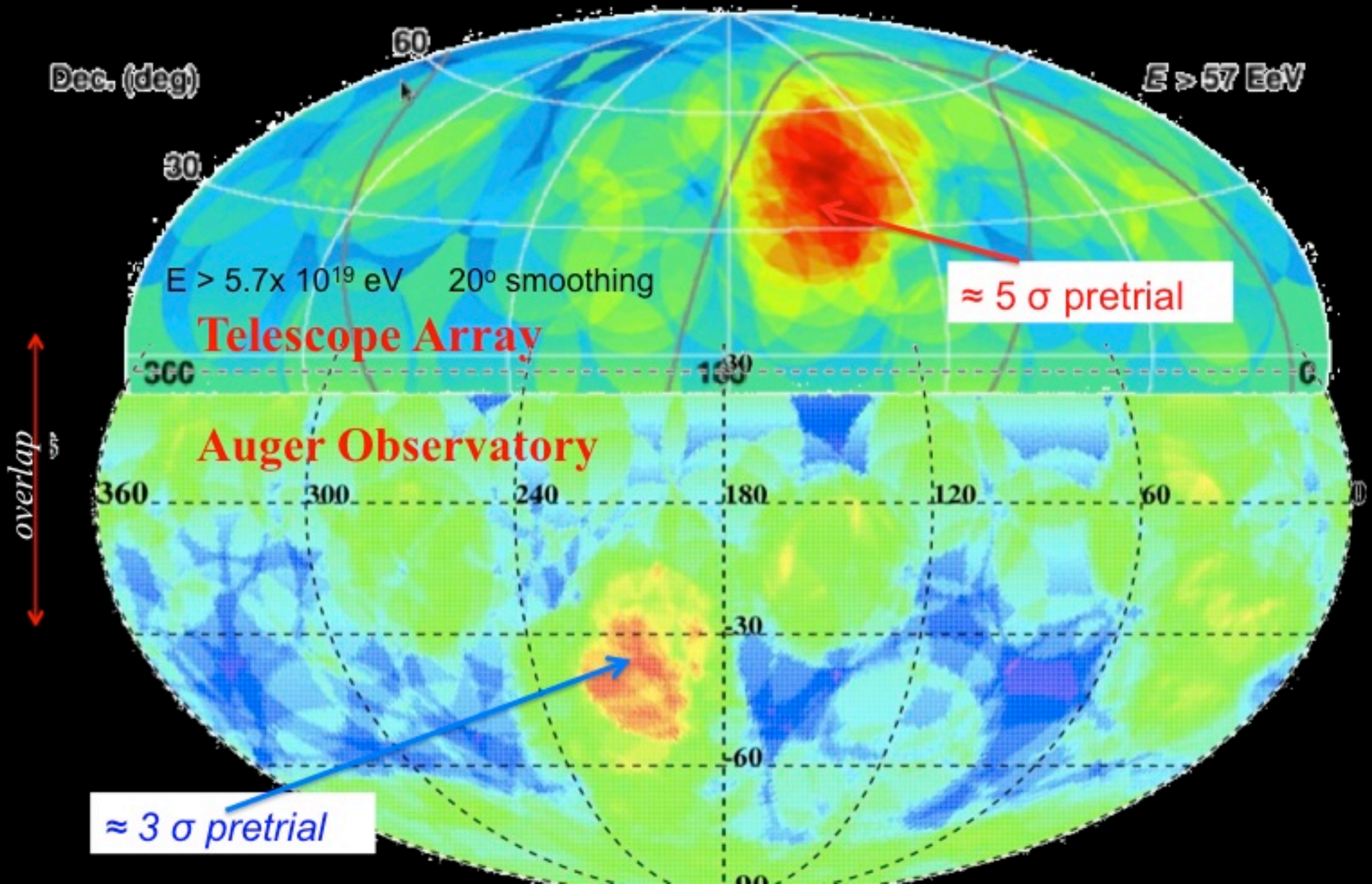


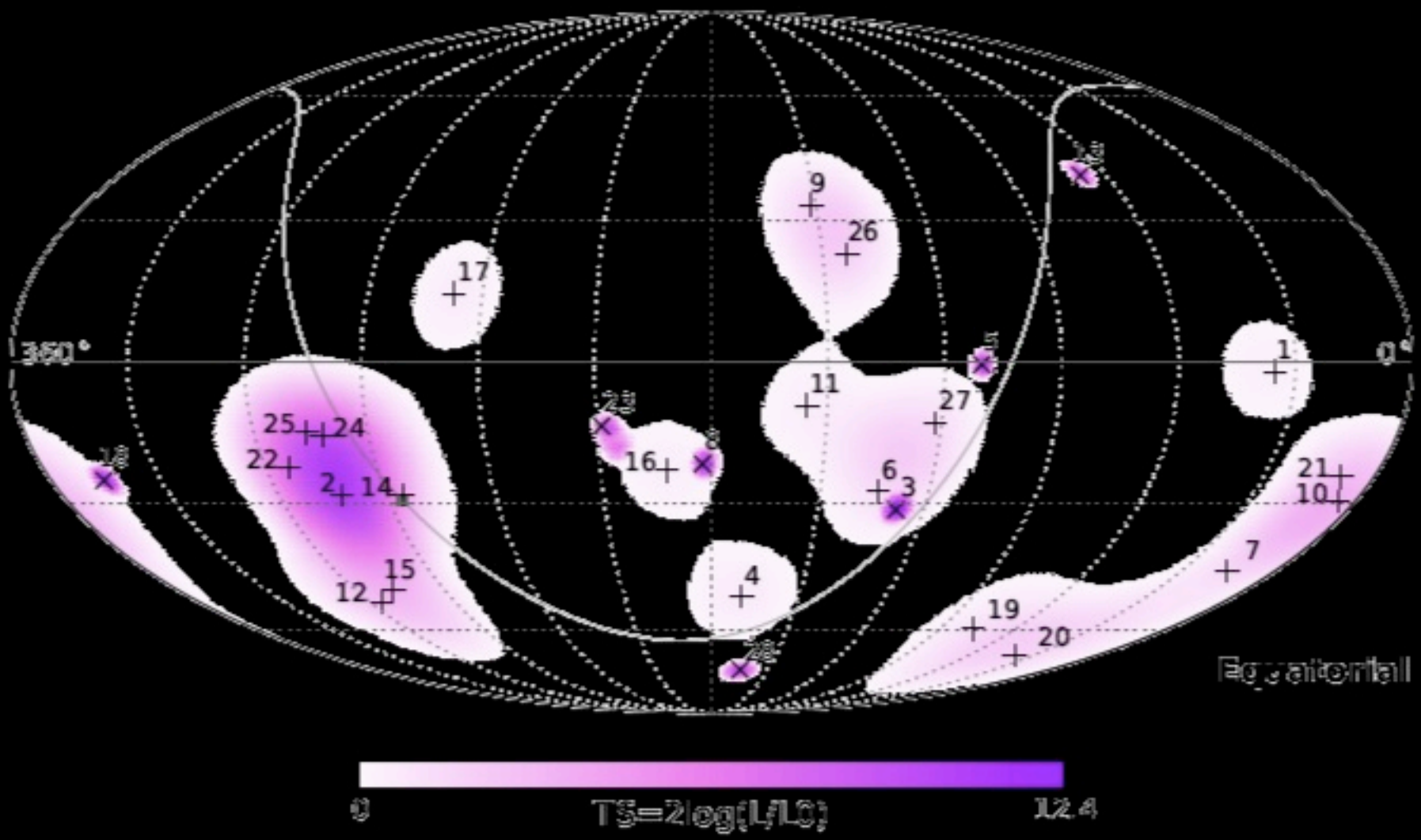
Telescope Array
Anisotropy Hints > 60 EeV

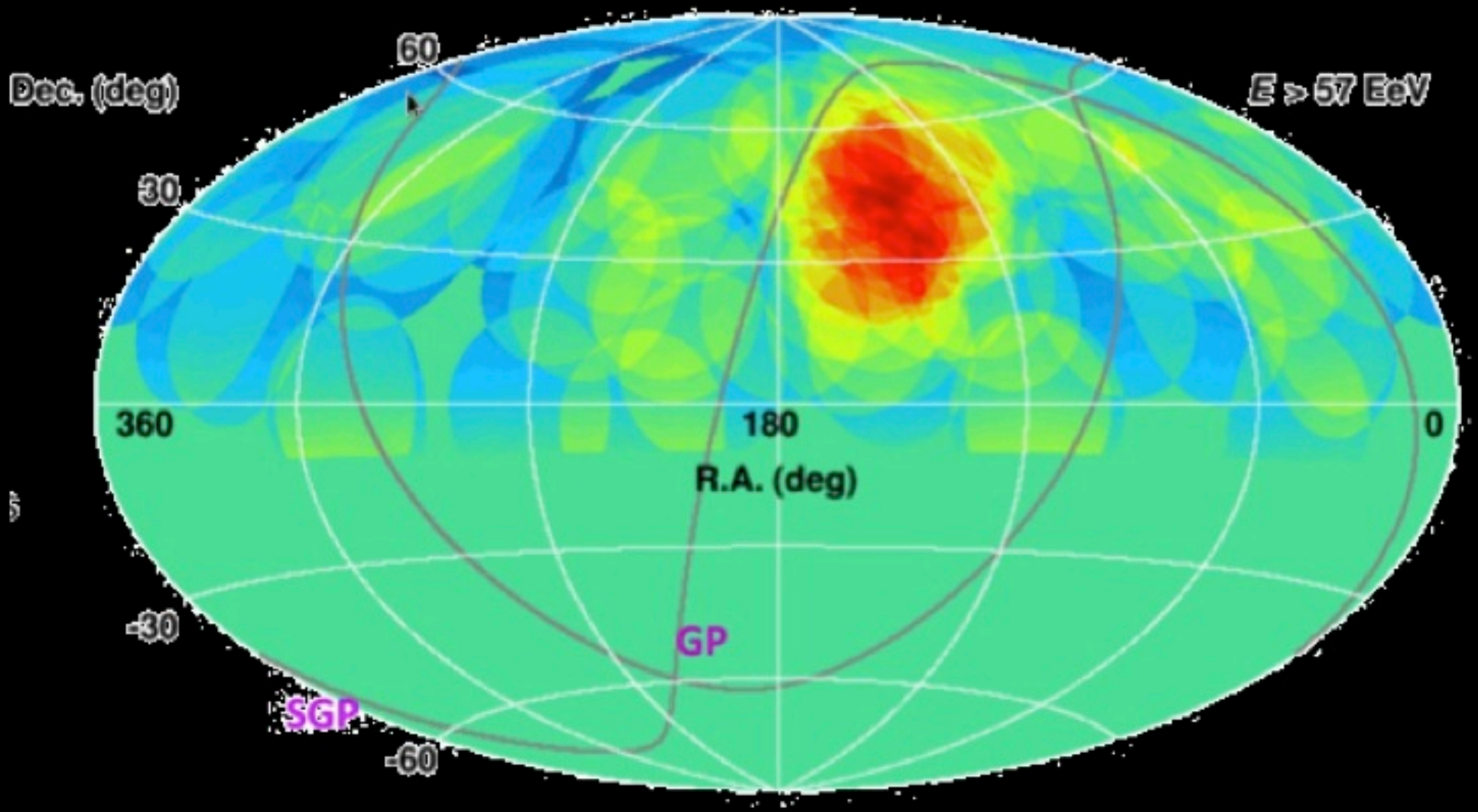


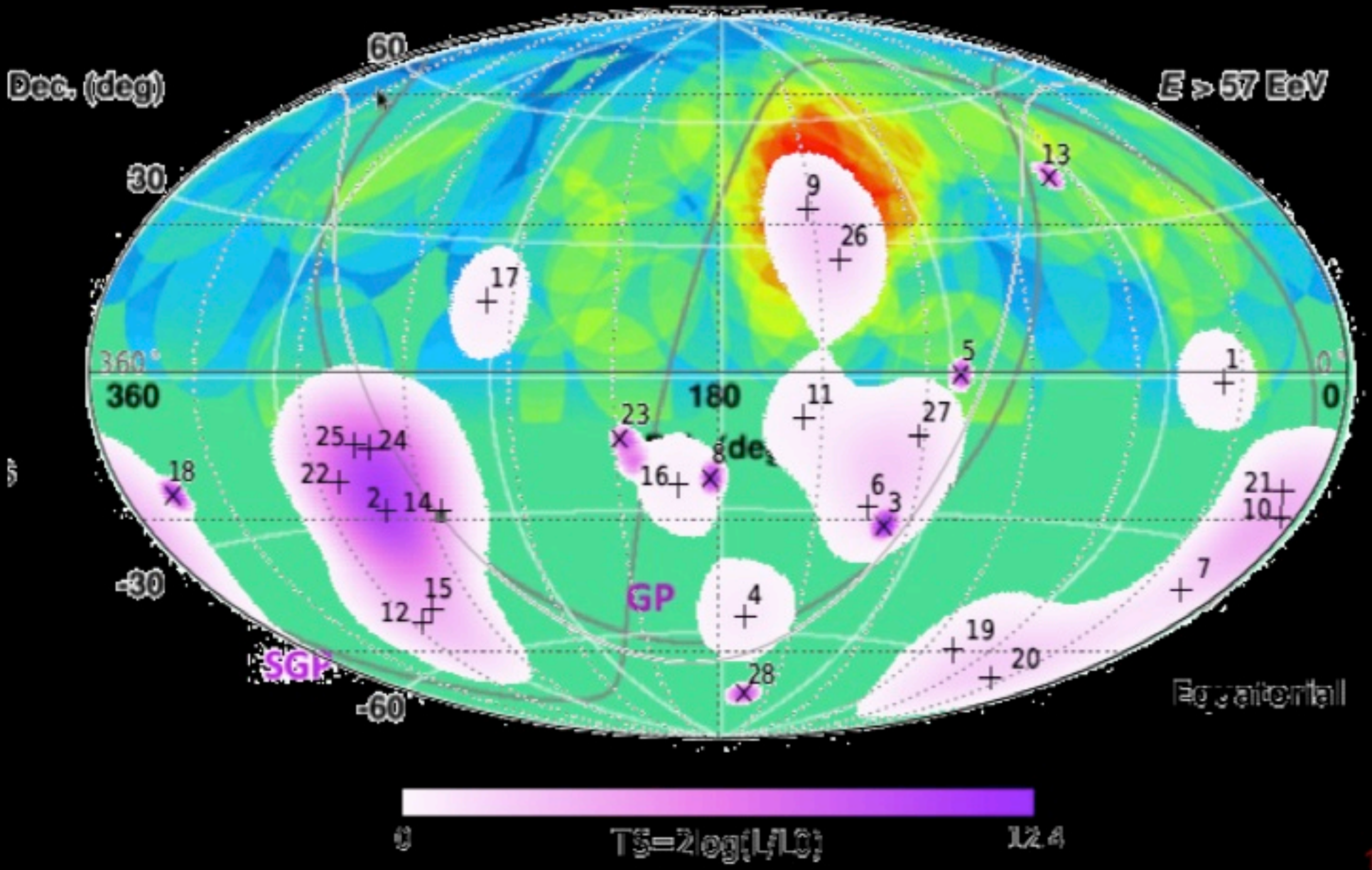
Soon to be announced!

Anisotropy Hints > 60 EeV

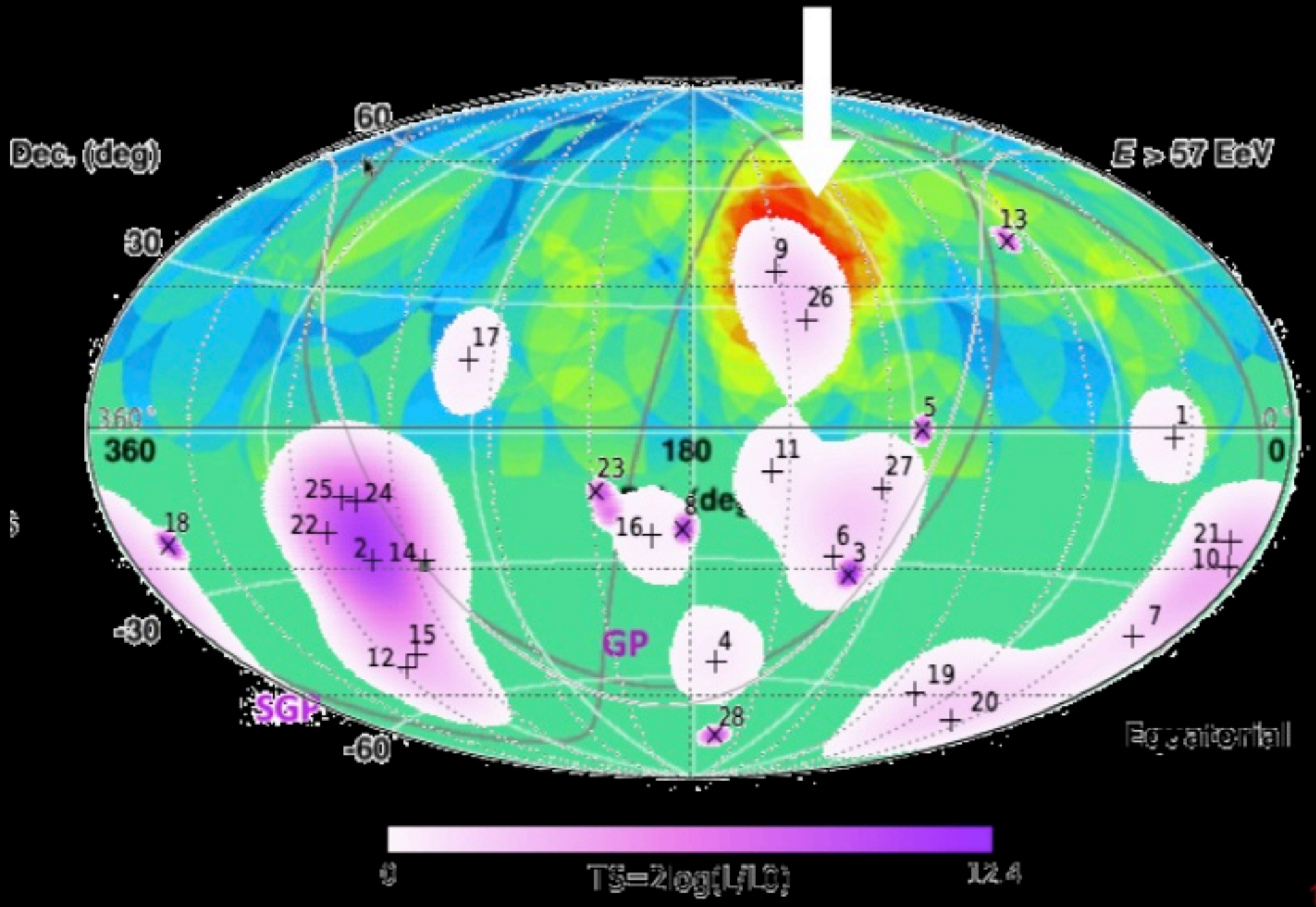



360°
0°
Equatorial
0
TS=2log(L/L0)
12.4


Dec. (deg)
60
30
-30
-60
E > 57 EeV
360
180
0
R.A. (deg)
GP
SGP


Dec. (deg)
60
30
-30
-60
E > 57 EeV
360°
360
180
0°
0
GP
SGP
Equatorial
0
TS=2log(L/L0)
12.4

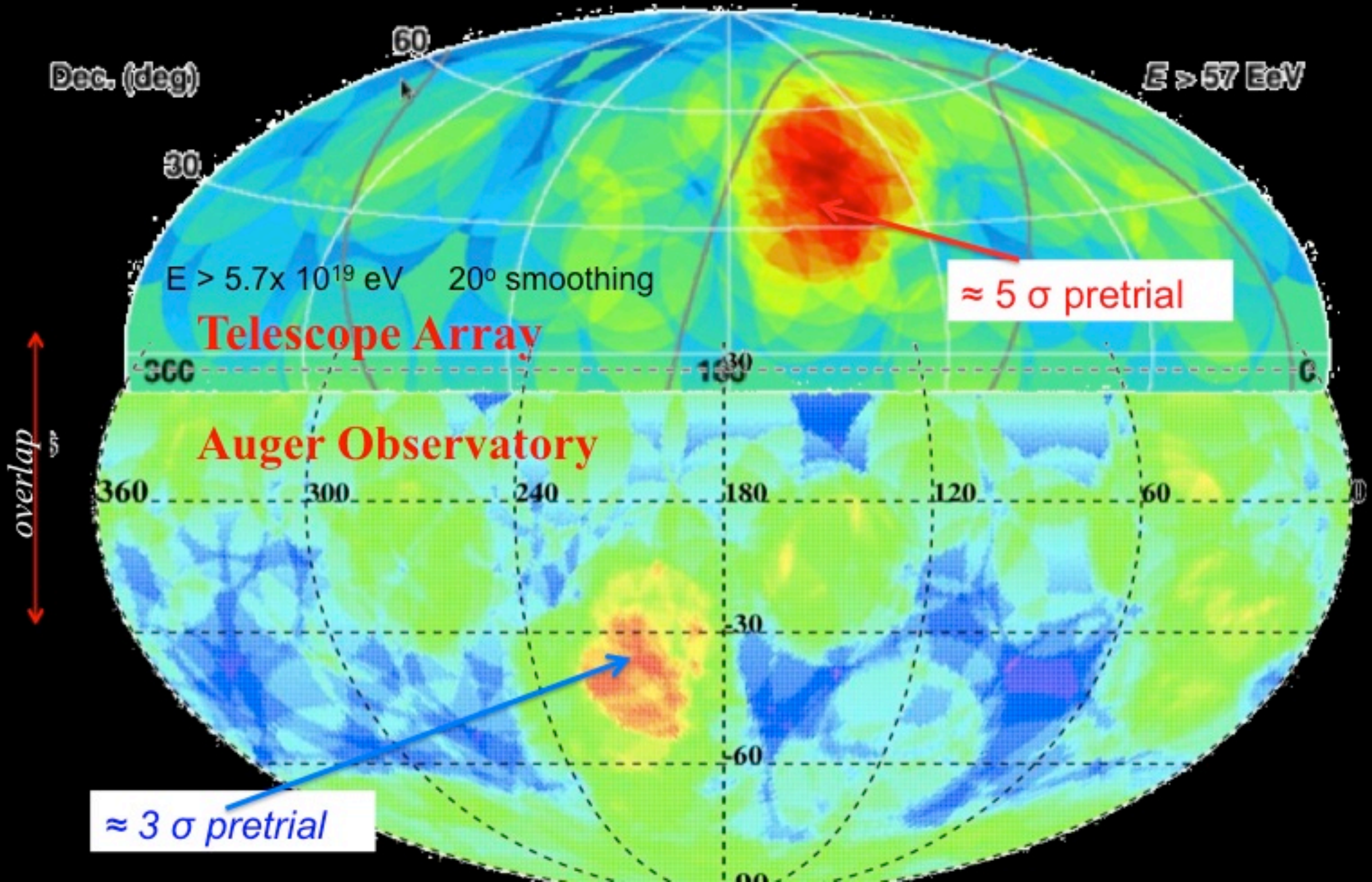
Neutrino & UHECR Coincidence



Off the Extreme Energy Cliff

Anisotropy Hints > 60 EeV

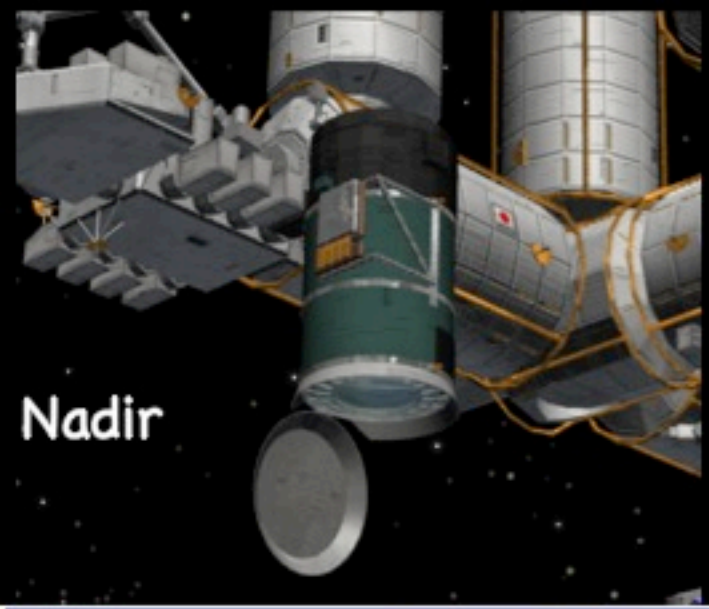
Statistically limited



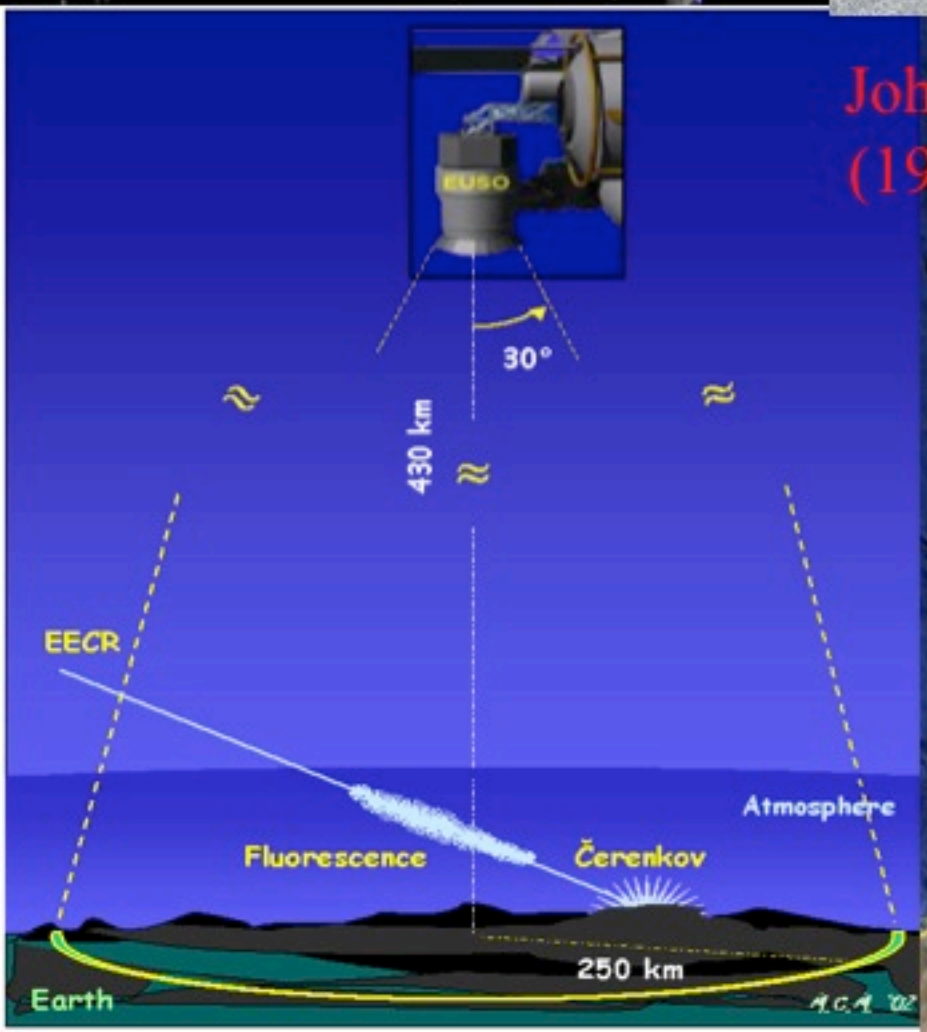
Anisotropy Hints > 60 EeV

Statistically limited

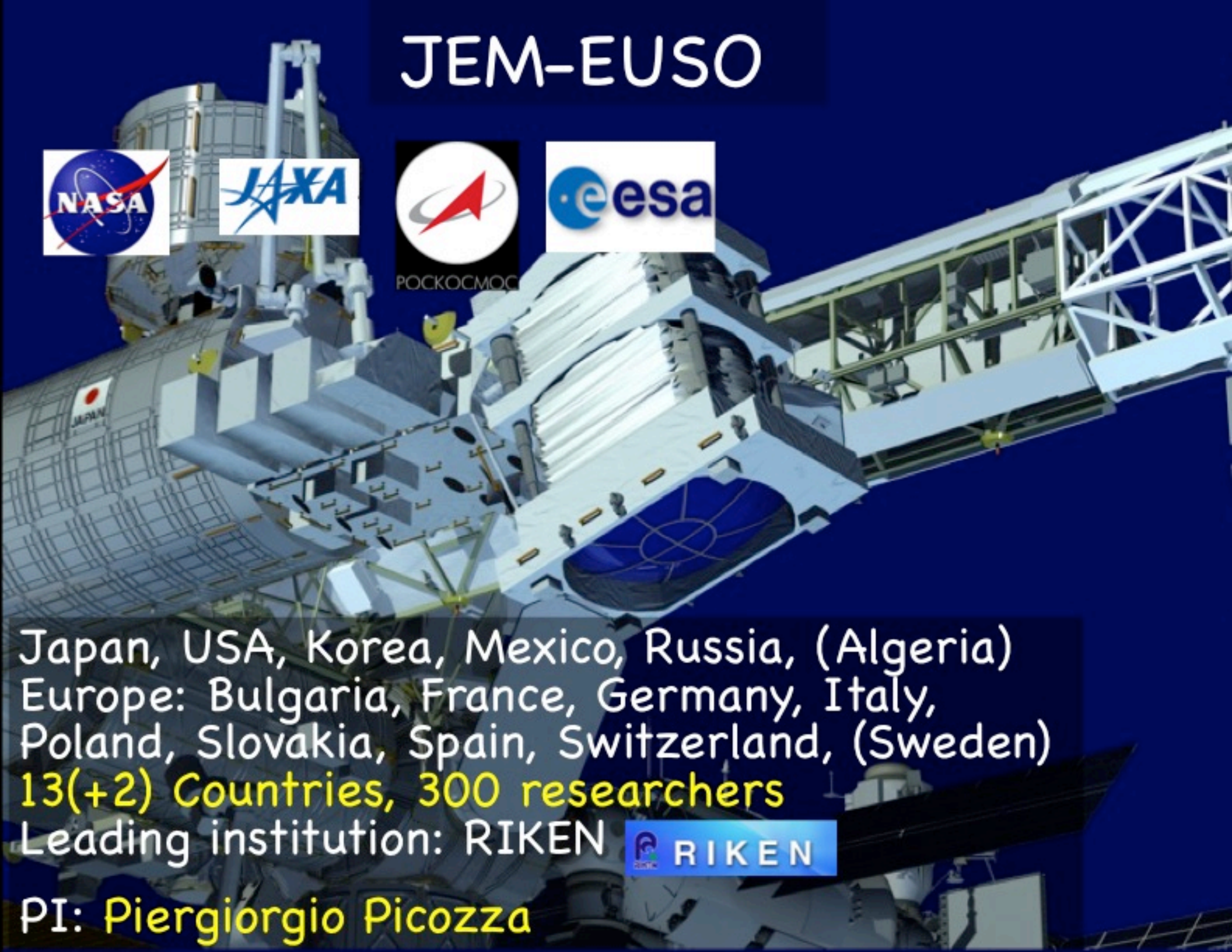
Fluorescence from SPACE



John Linsley
(1925-2002)



JEM-EUSO

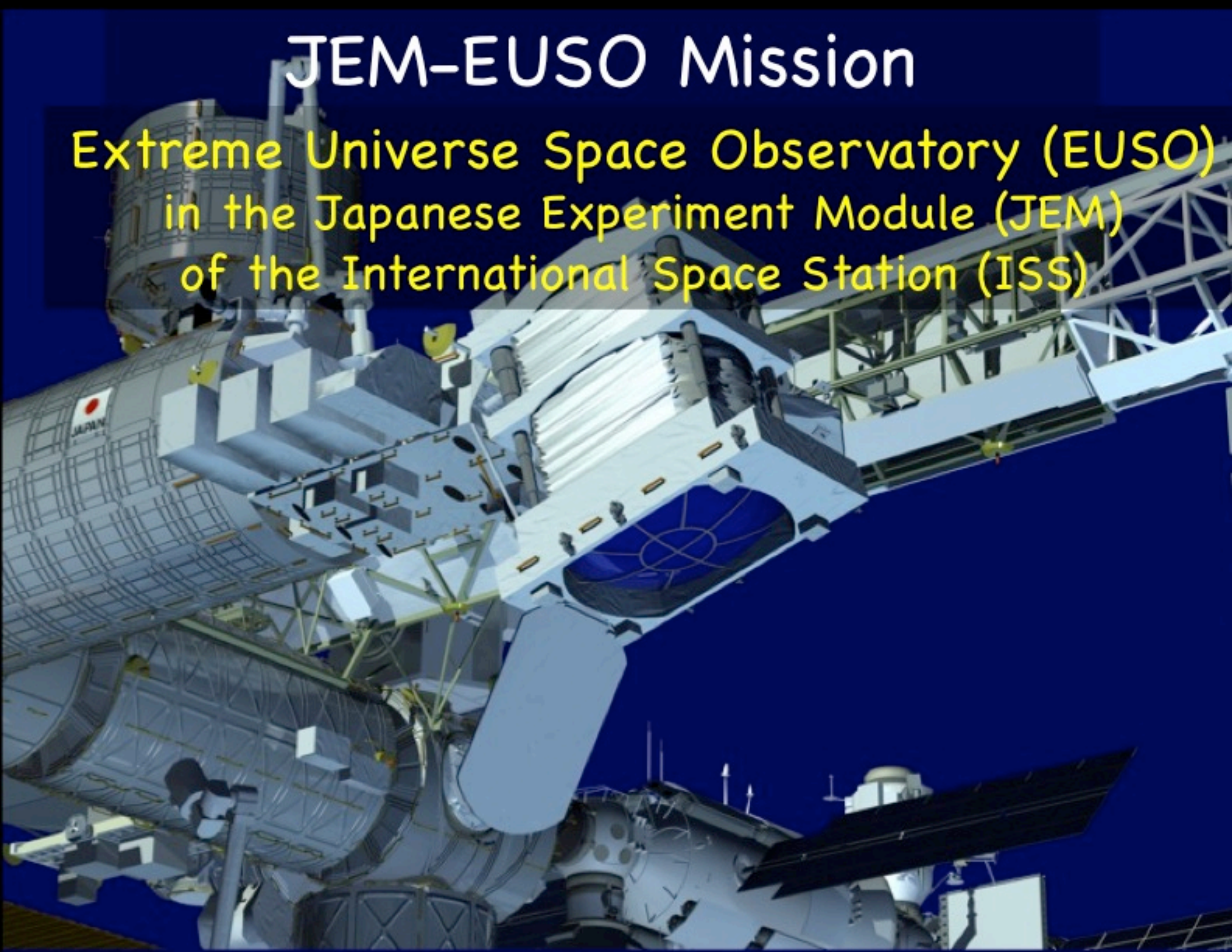


Japan, USA, Korea, Mexico, Russia, (Algeria)
Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland, (Sweden)
13(+2) Countries, 300 researchers
Leading institution: RIKEN

PI: Piergiorgio Picozza

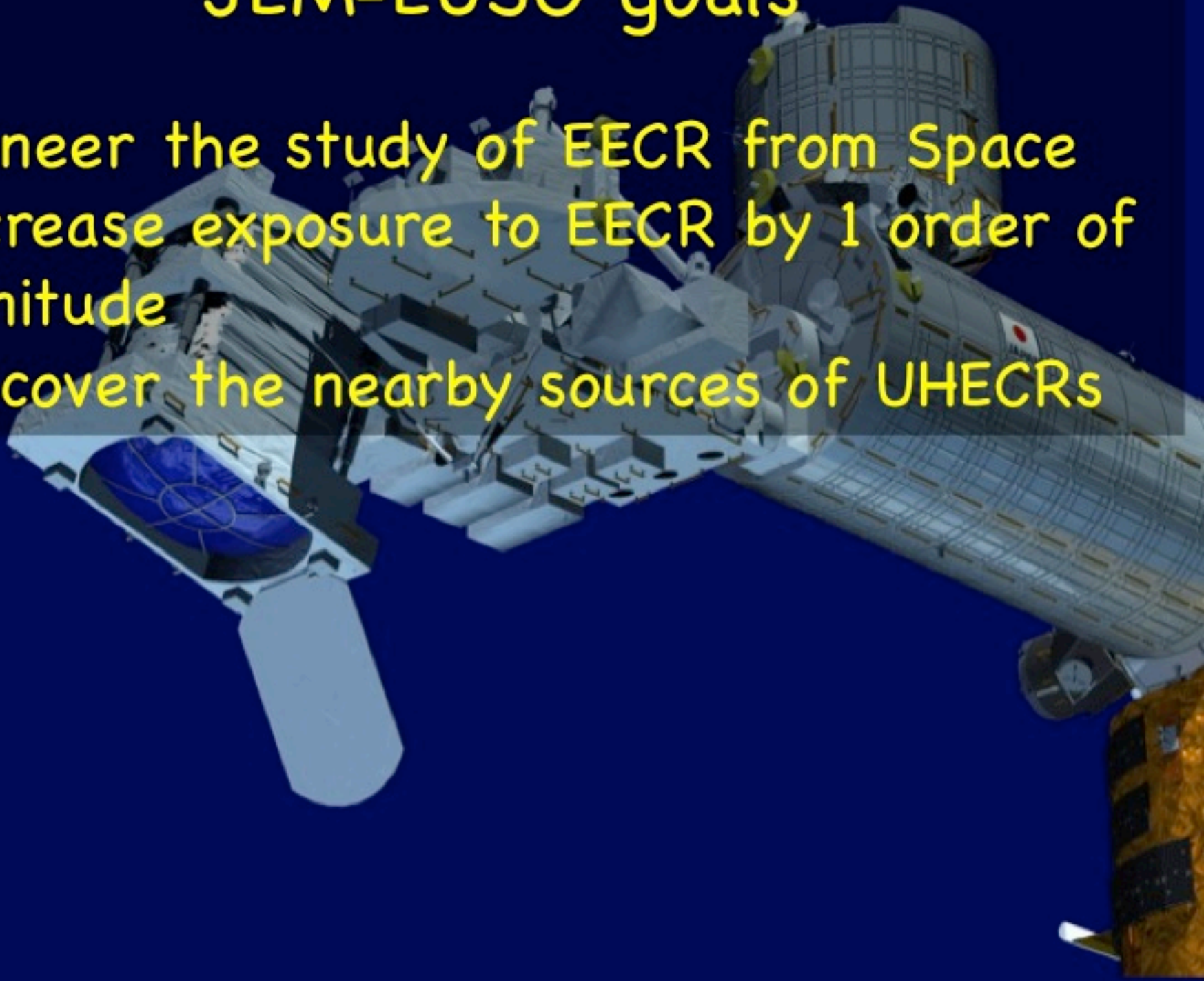
JEM-EUSO Mission

Extreme Universe Space Observatory (EUSO)
in the Japanese Experiment Module (JEM)
of the International Space Station (ISS)

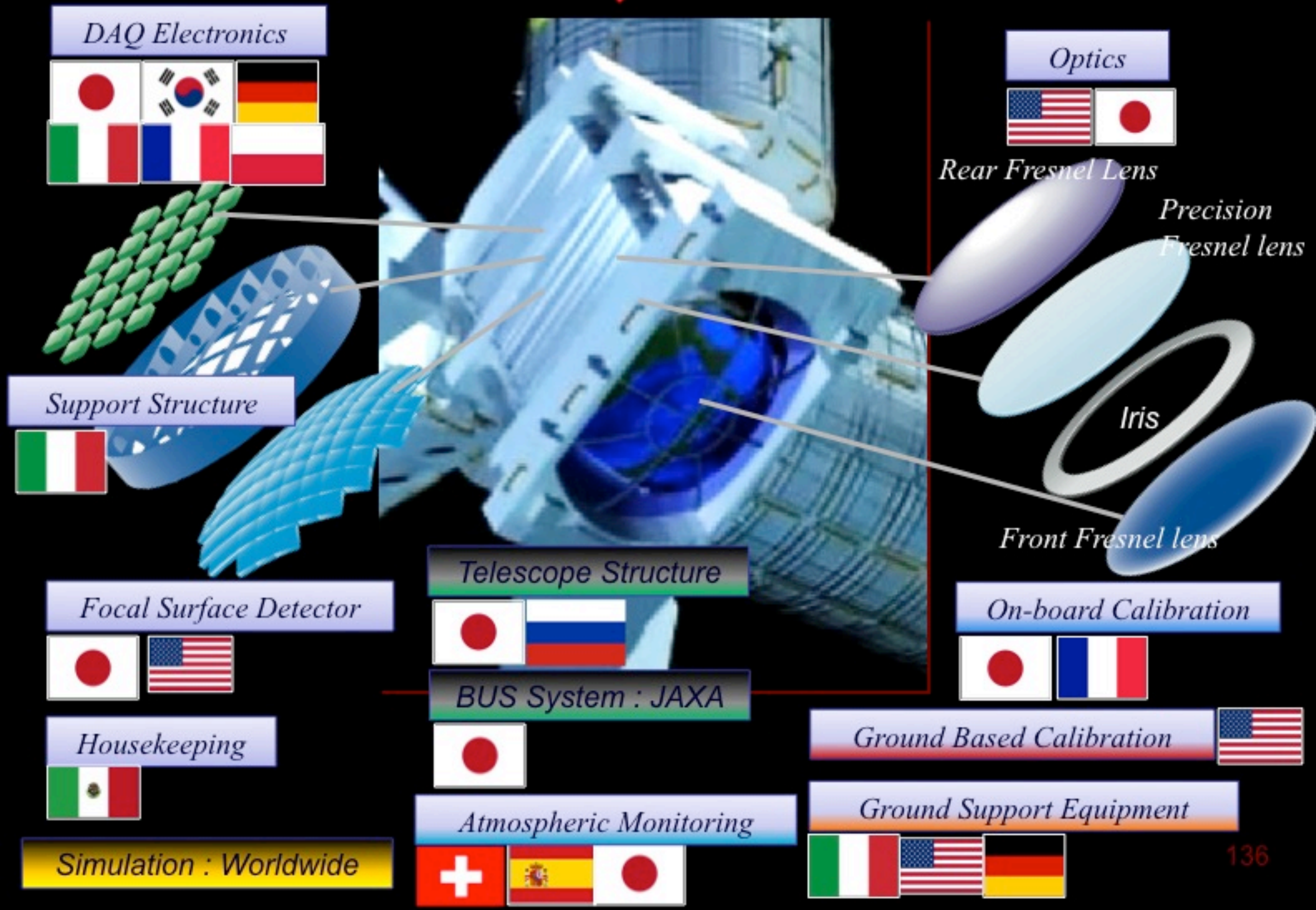


JEM-EUSO goals

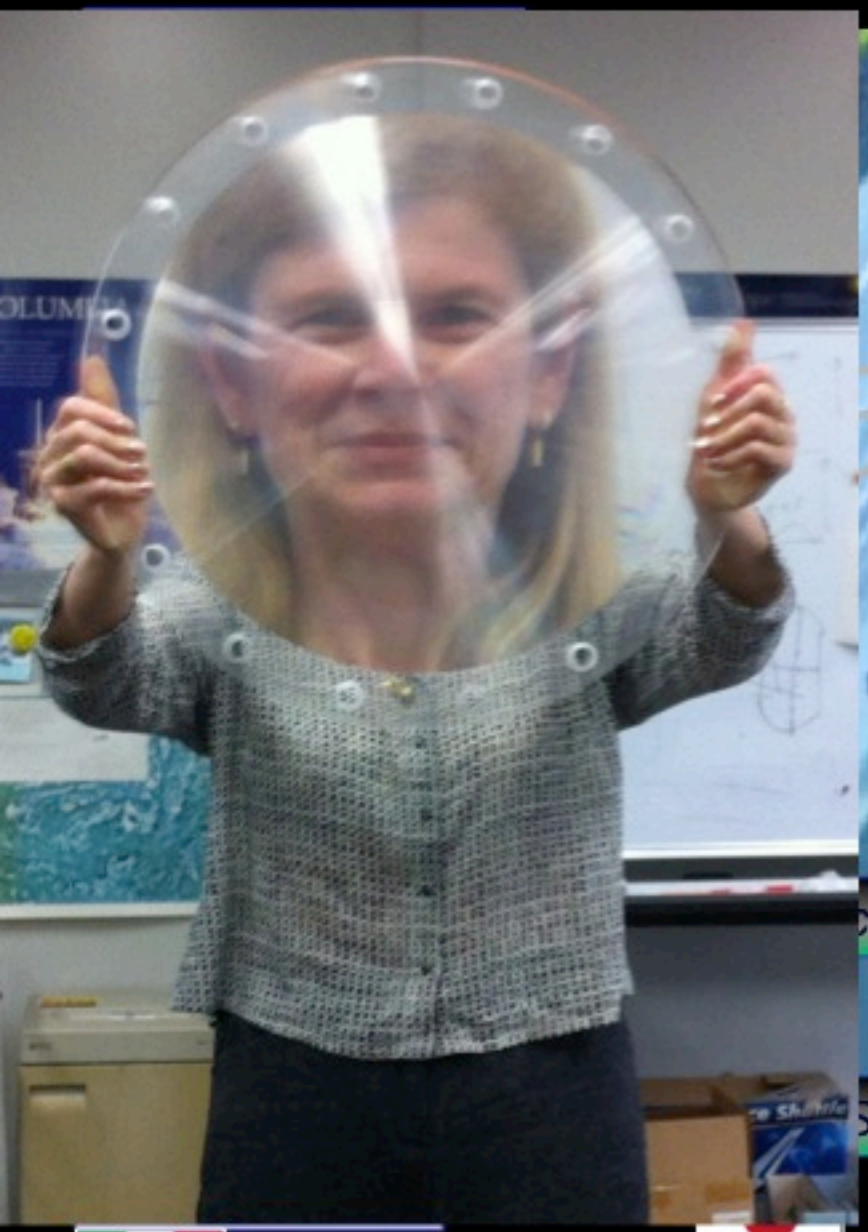
- pioneer the study of EECR from Space
- increase exposure to EECR by 1 order of magnitude
- discover the nearby sources of UHECRs



Payload


DAQ Electronics
Optics
Rear Fresnel Lens
Precision Fresnel lens
Support Structure
Iris
Front Fresnel lens
Telescope Structure
Focal Surface Detector
On-board Calibration
BUS System : JAXA
Housekeeping
Ground Based Calibration
Ground Support Equipment
Atmospheric Monitoring
Simulation : Worldwide

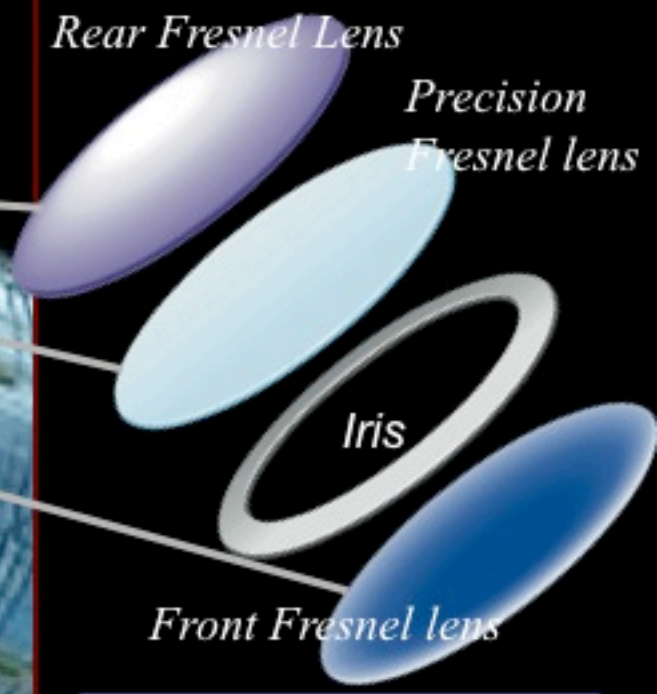
Payload



cope Structure

System : JAXA

Optics



On-board Calibration

Ground Based Calibration

Ground Support Equipment

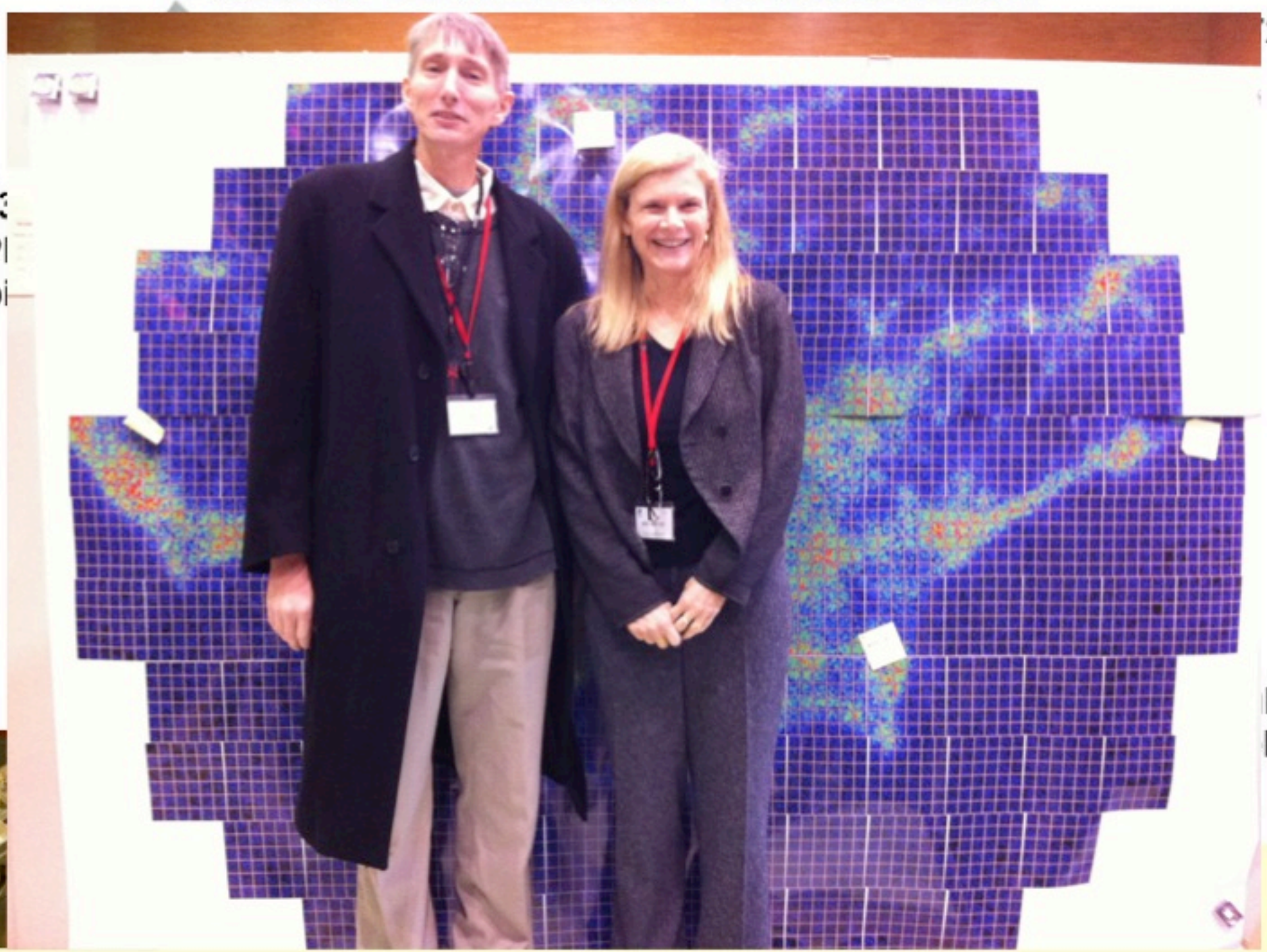
Atmospheric Monitoring

Simulation : Worldwide

Science Instrument

tics

Focal Surface Detector

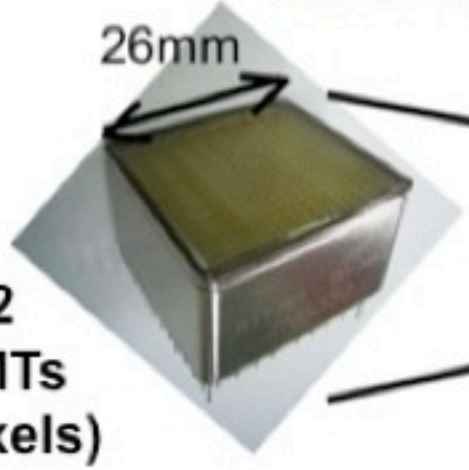


493
MAP
(8x8 pi

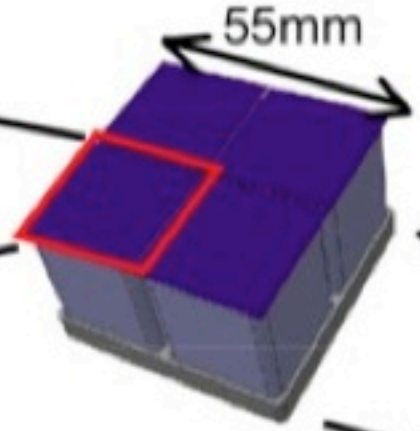
le
ls

Focal Surface Detector

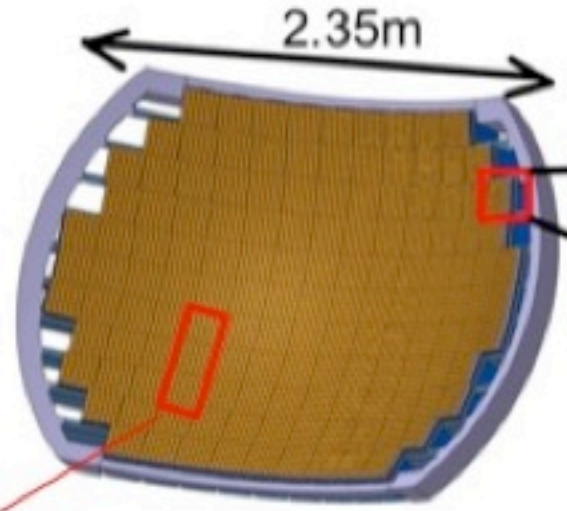
Y. Kawasaki, ID 0472
M. Ricci, ID 0335

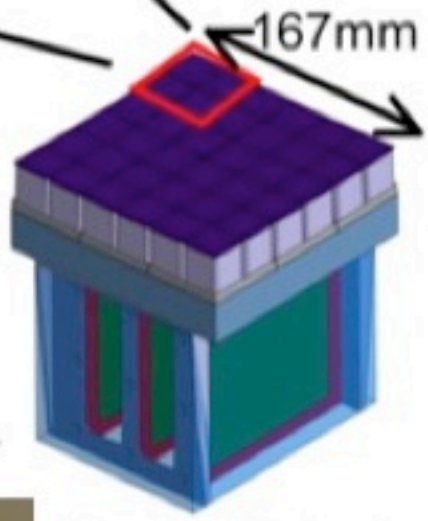


4932 MAPMTs (8x8 pixels)



Elementary Cell (2x2 PMTs = 256 pixels)





Focal Surface detector
137 PDMs
= 0.3M Pixels

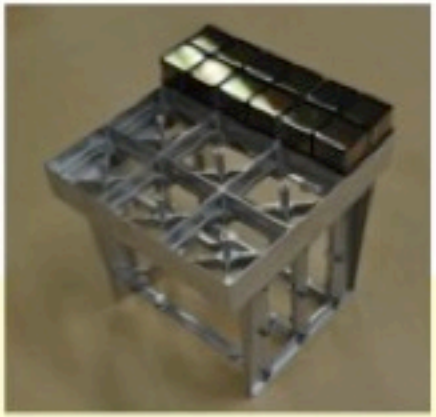
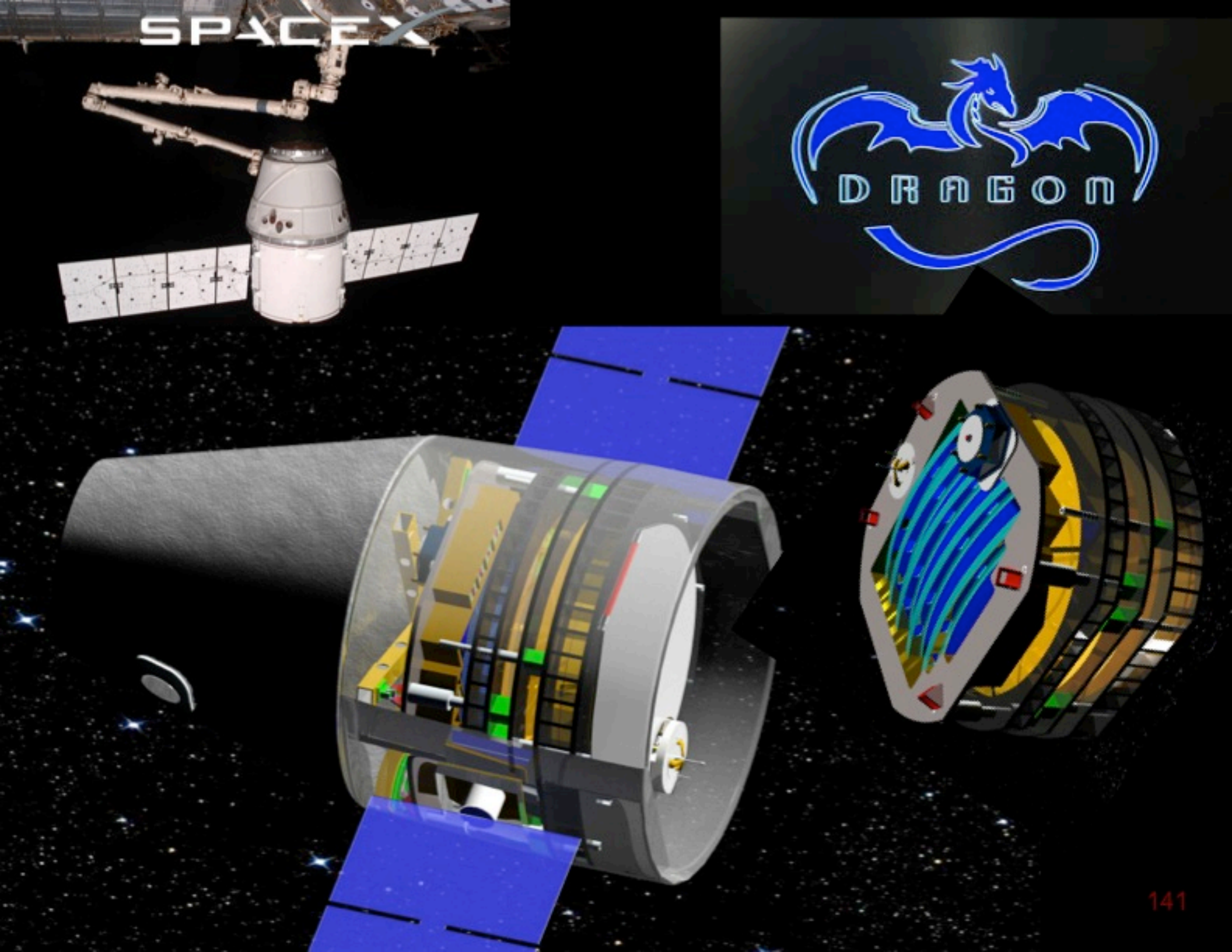
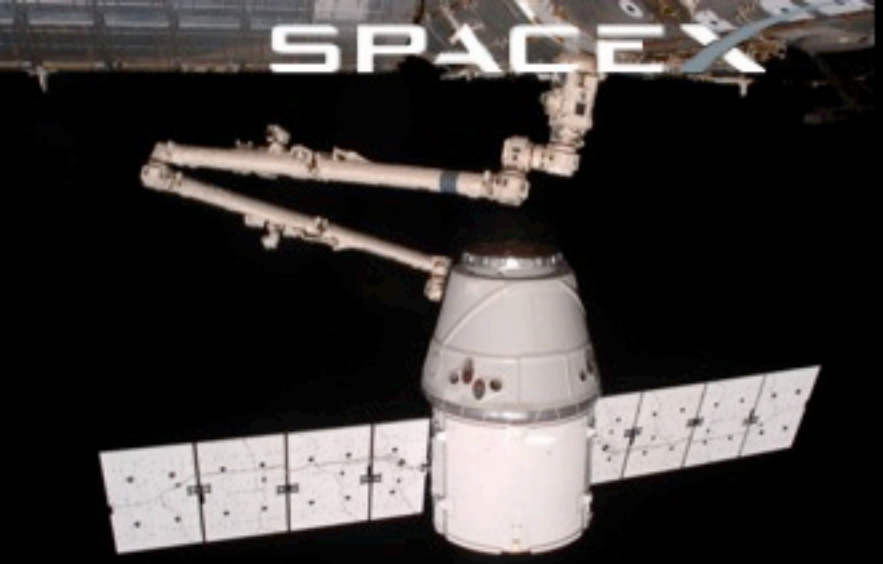


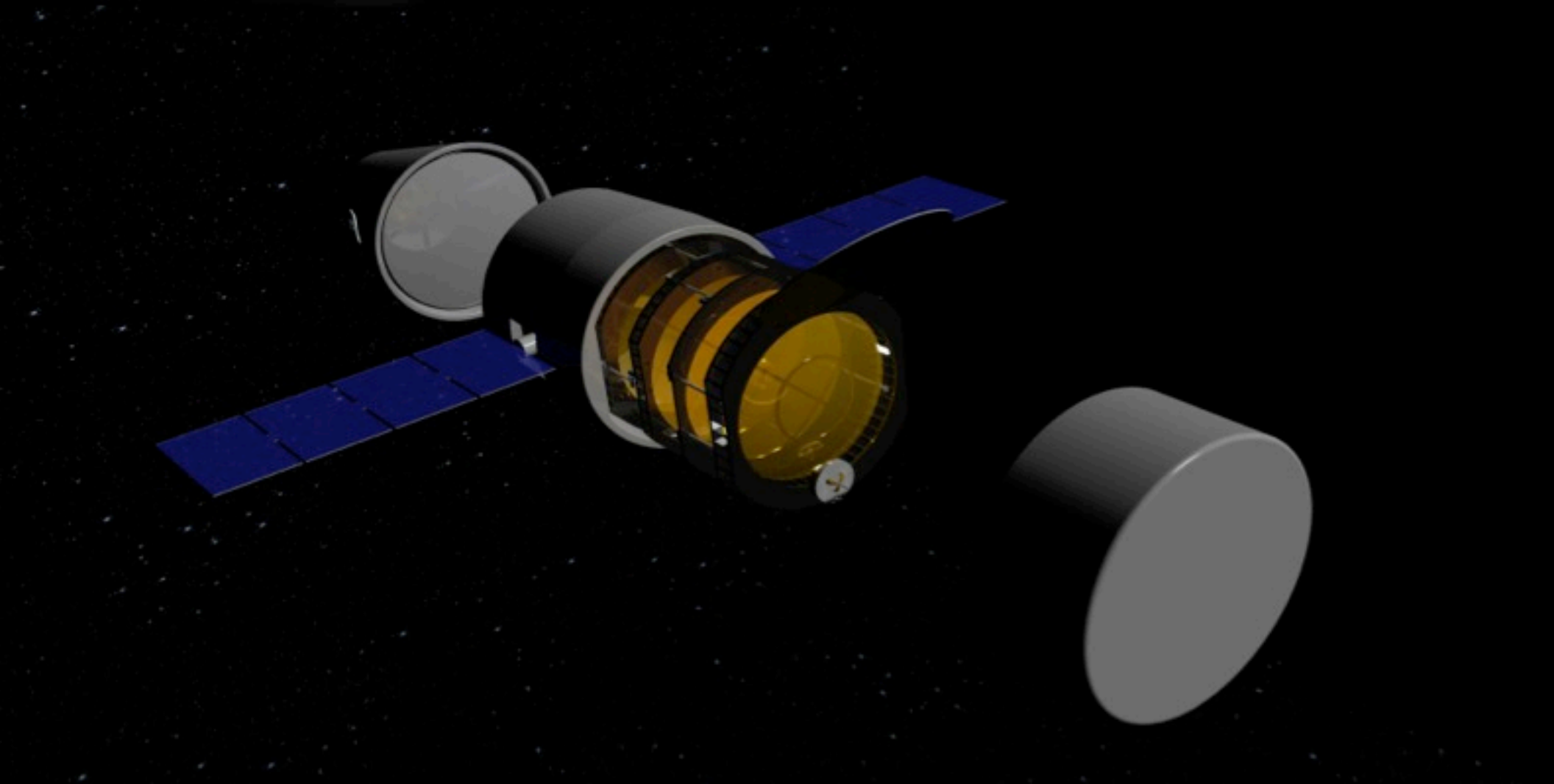
Photo-Detector Module (3x3 ECs = 2,304 pixels

1 High Voltage / PDM


SPACEX
DRAGON

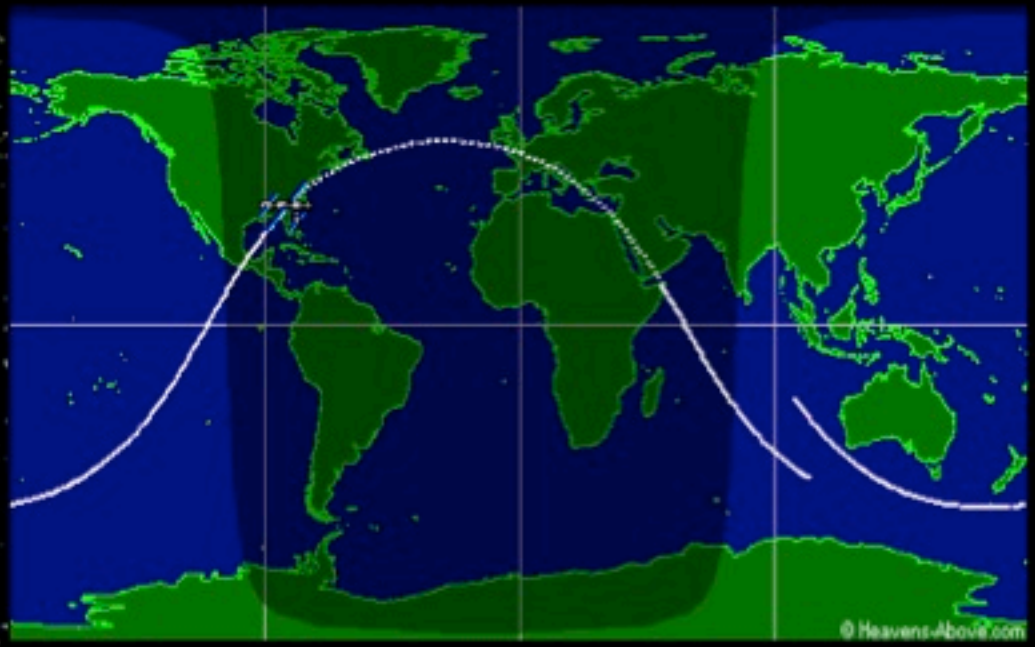

SPACEX


DRAGON



Full Sky Coverage
with nearly uniform exposure

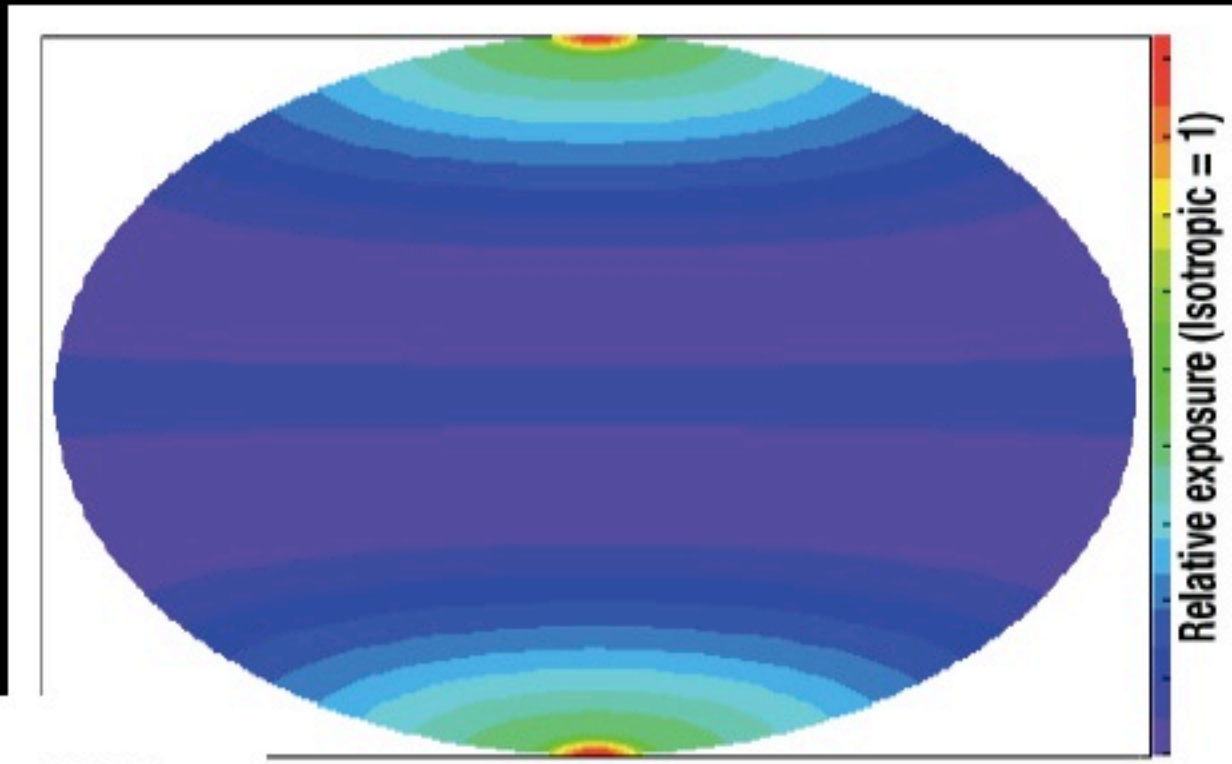
The ISS ORBIT

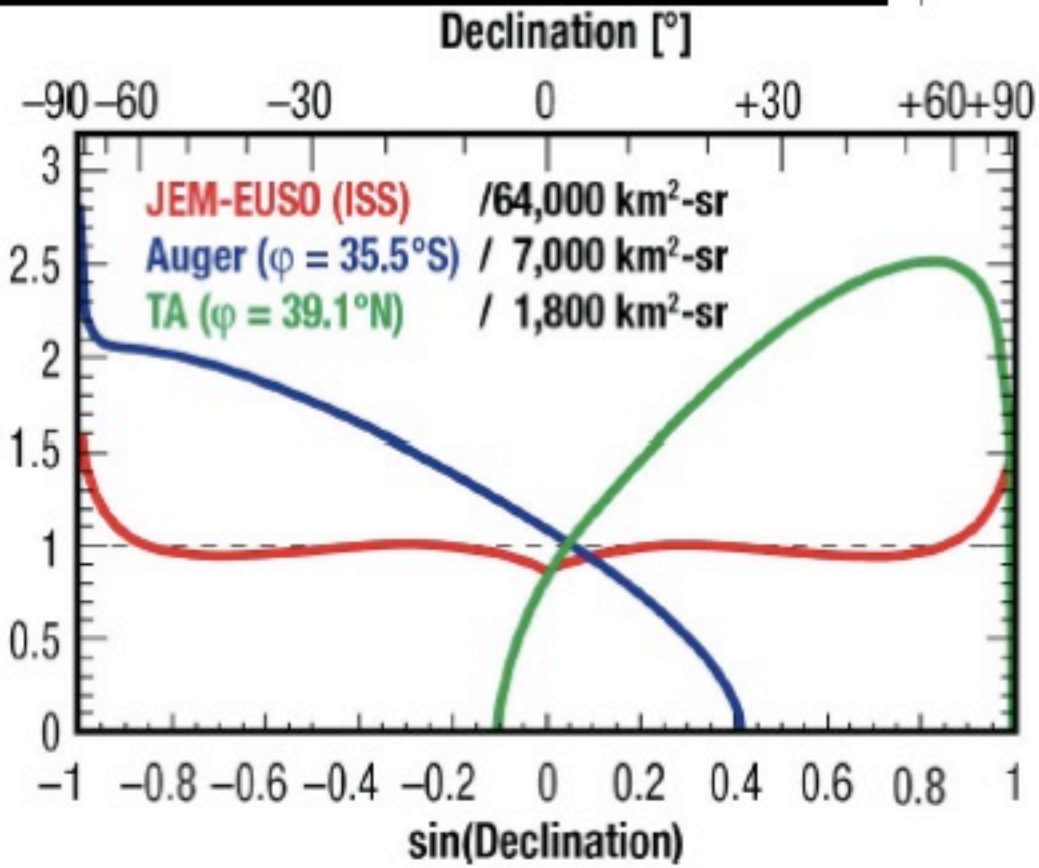


Inclination: 51.6°
Height: ~400km

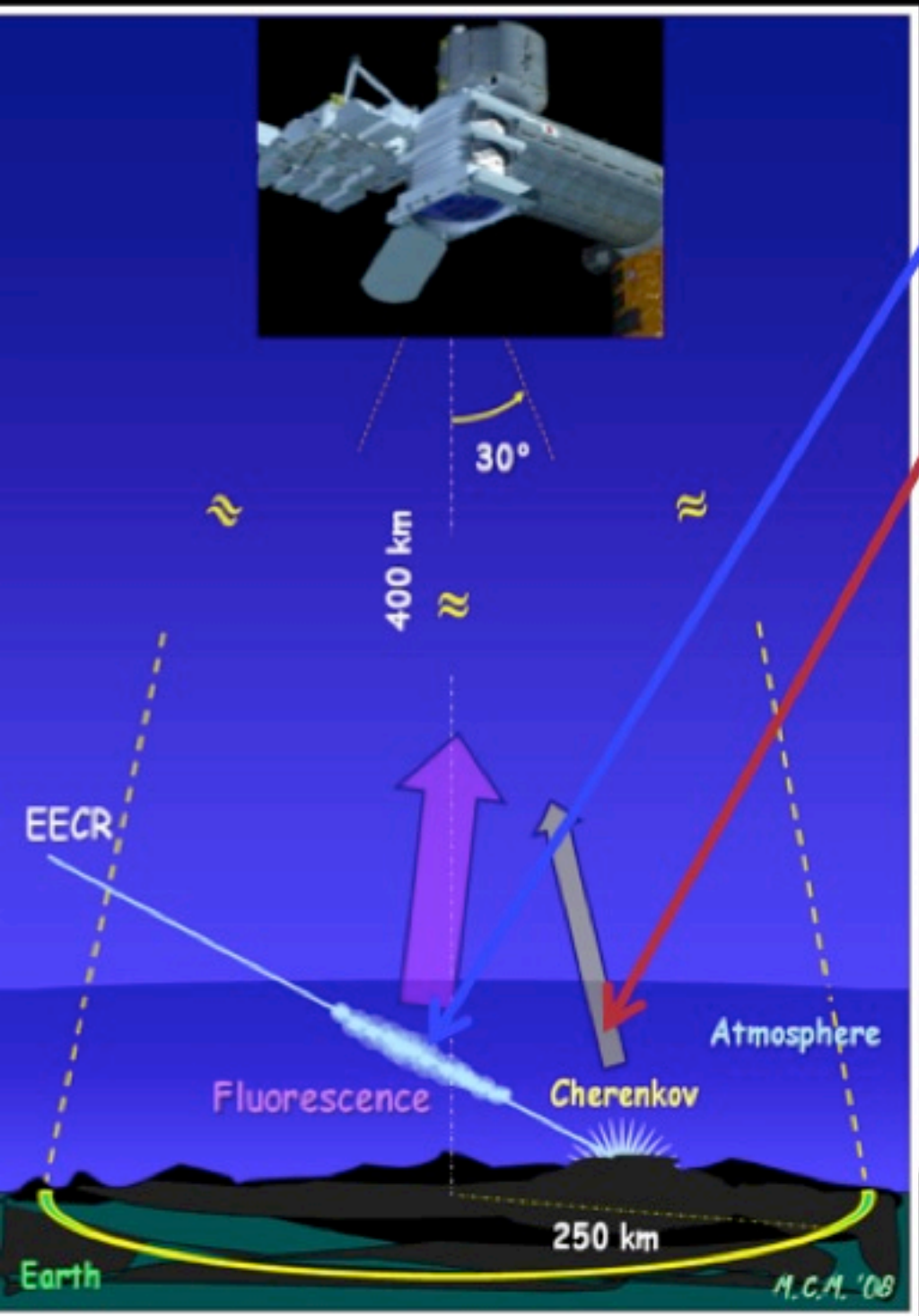
JEM-EUSO

Sky Coverage





Fluorescence from SPACE

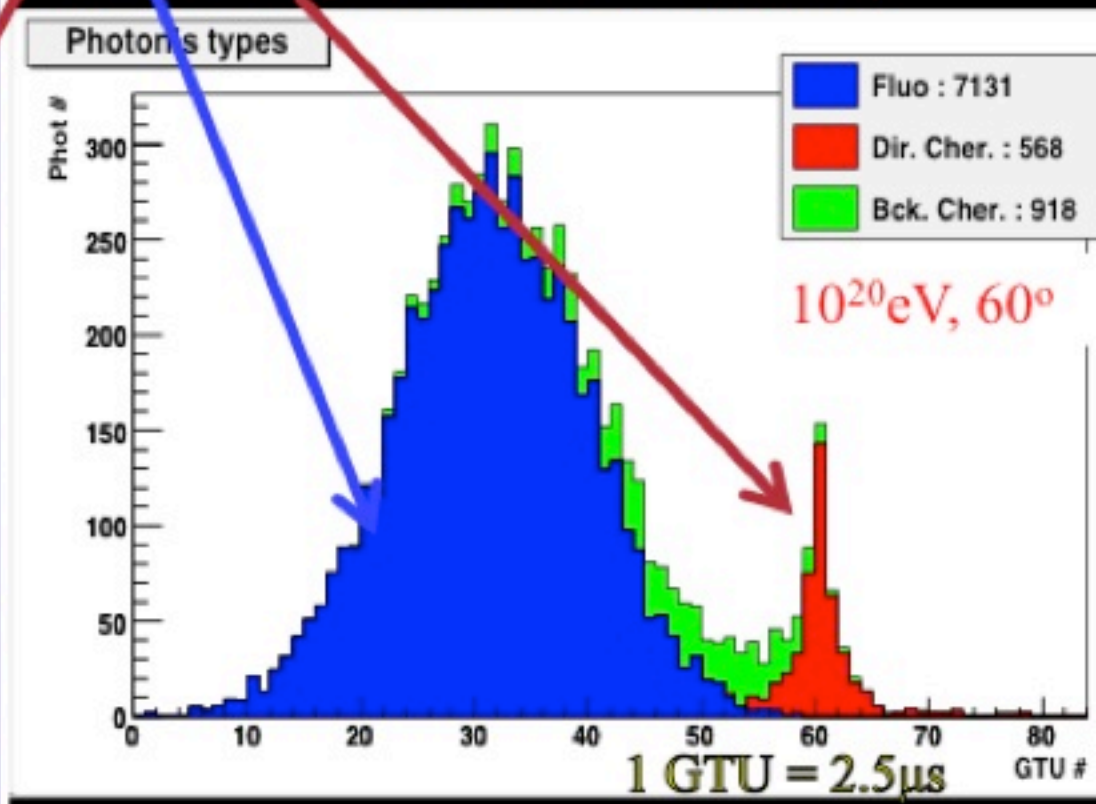


Fast Signal: 50 -150 μs

a) Fluorescence

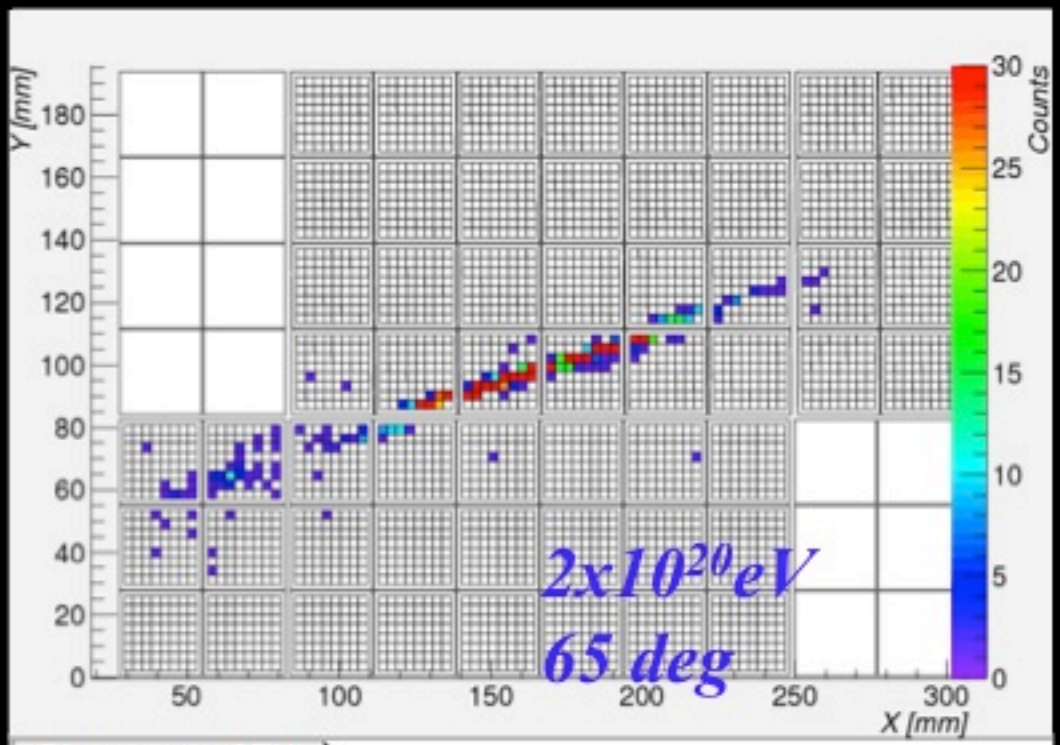
b) Scattered Cherenkov

c) Direct (reflected Cherenkov)

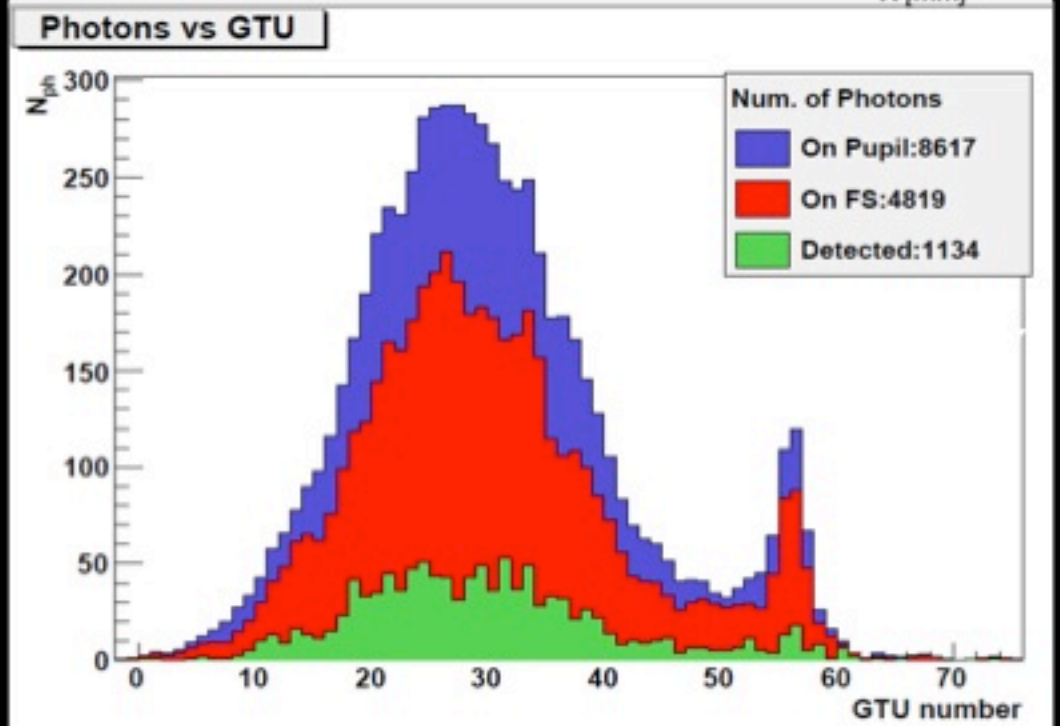


Background: 500 /m^2 sr ns

Shower Simulation



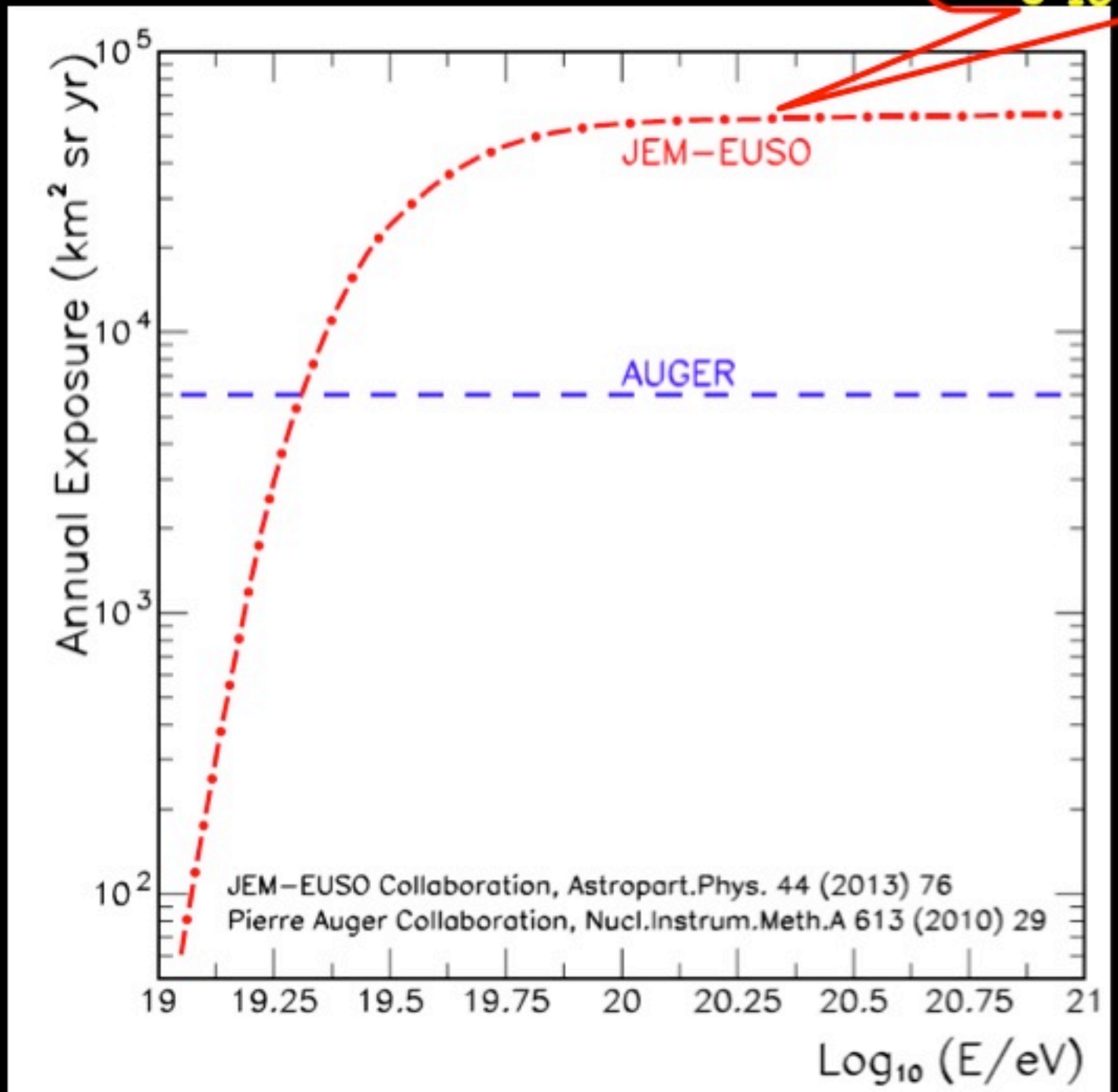
Simulated air shower image on the focal surface detector.



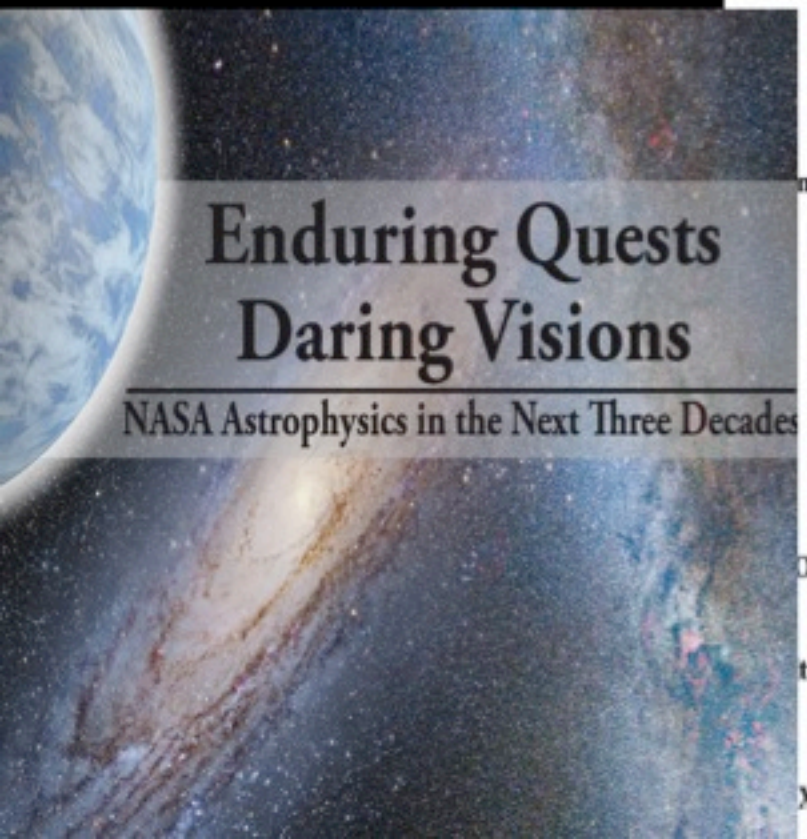
Detected photoelectrons are recorded every Gate Time Unit (GTU) of 2.5μs continuously.

JEM-EUSO

annual exposure =
10 x Auger
6 10^4 km^2 sr yr



NASA Astrophysics Roadmap 2014

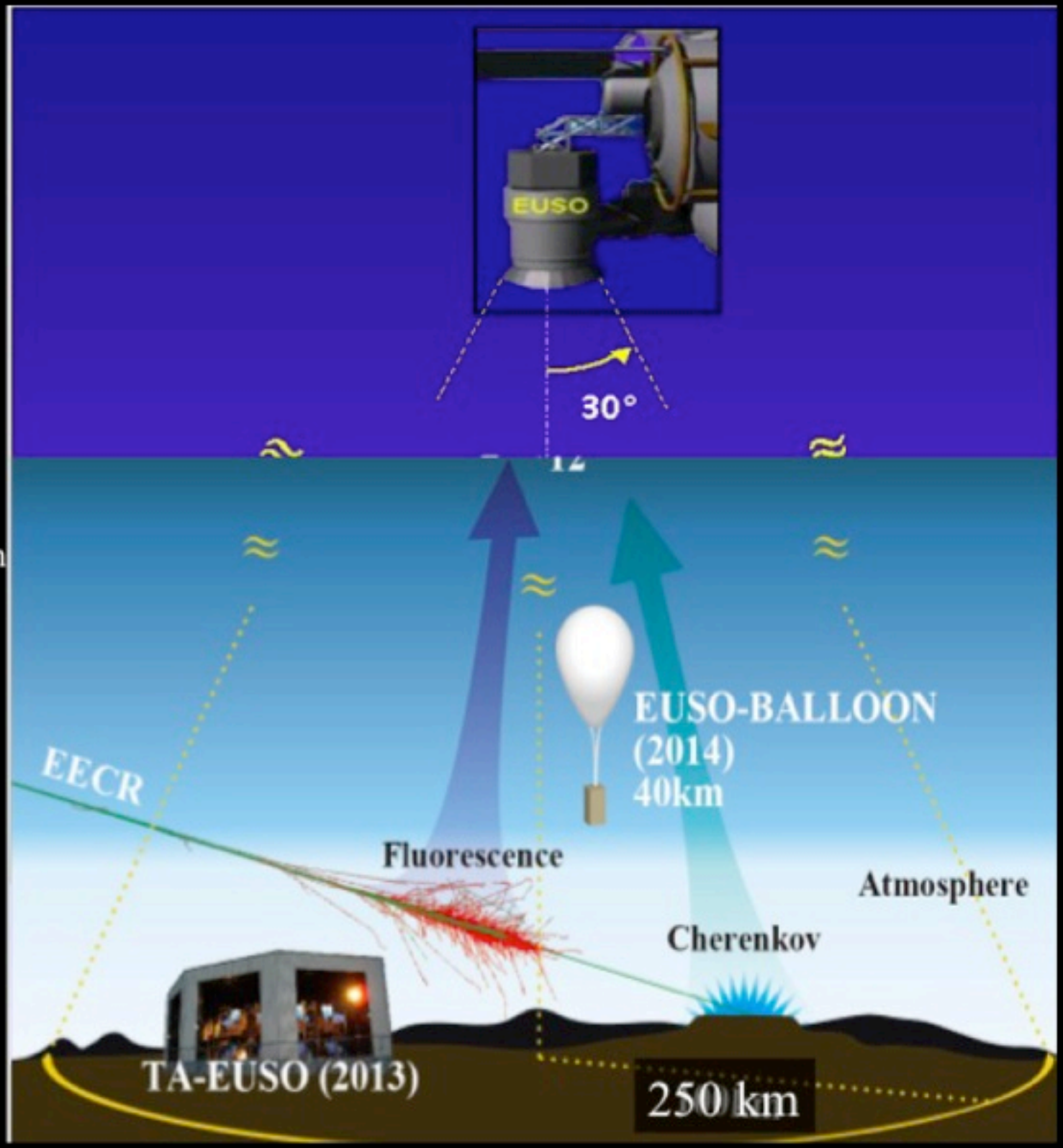


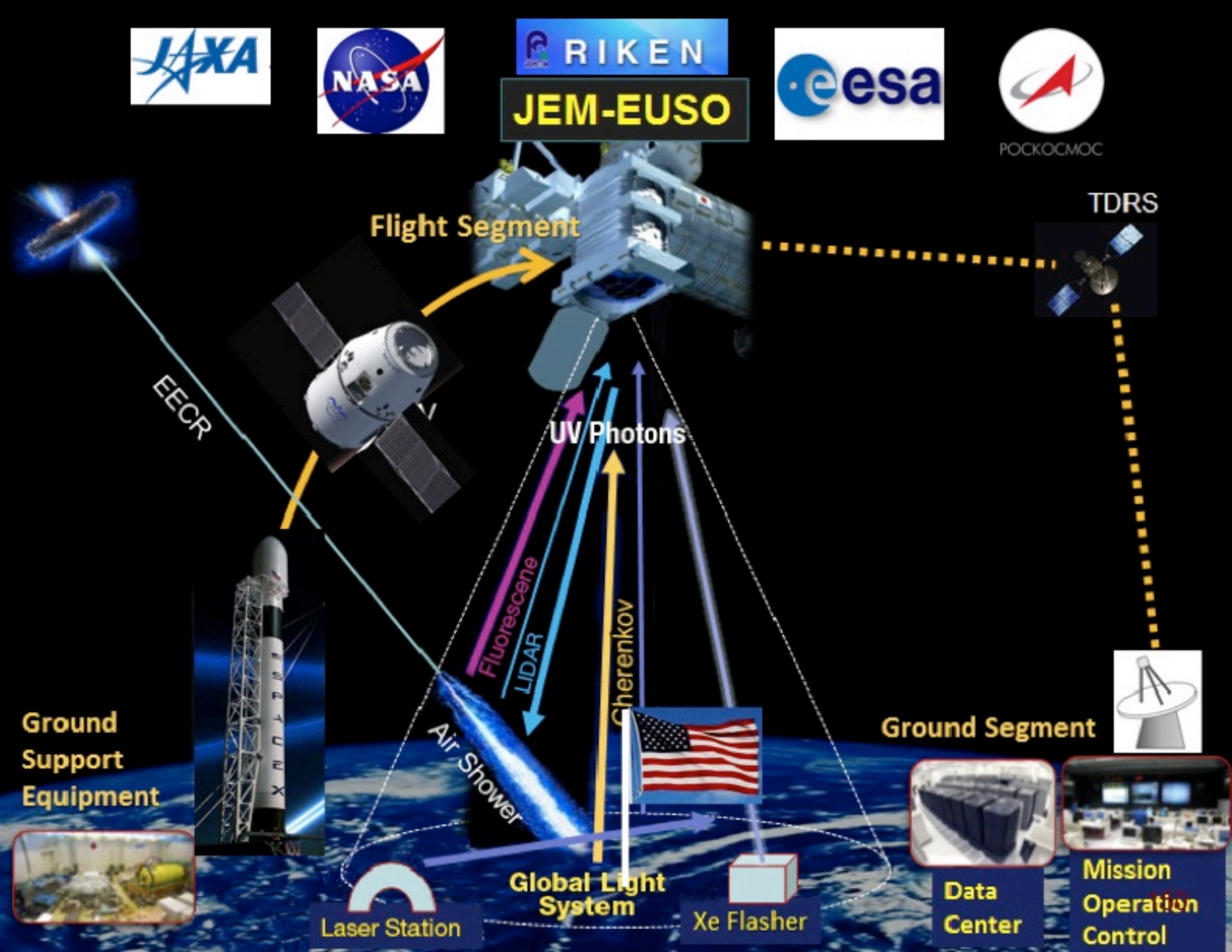
	Near-Term	Formative	Visionary
Gravitational Waves		Gravitational Wave Surveyor	Gravitational Wave Mappe
Cosmic rays	JEM-EUSO		
Radio			Cosmic Dawn Mapper
Microwaves		CMB Polarization Surveyor	
nfrared	JWST	Far IR Surveyor	
	WFIRST-AFTA, Euclid	LUVOIR Surveyor	ExoEarth Mapper
Optical	TESS, Gaia		
traviolet			
X-rays	NICER, Astro-H		

The EUSO program

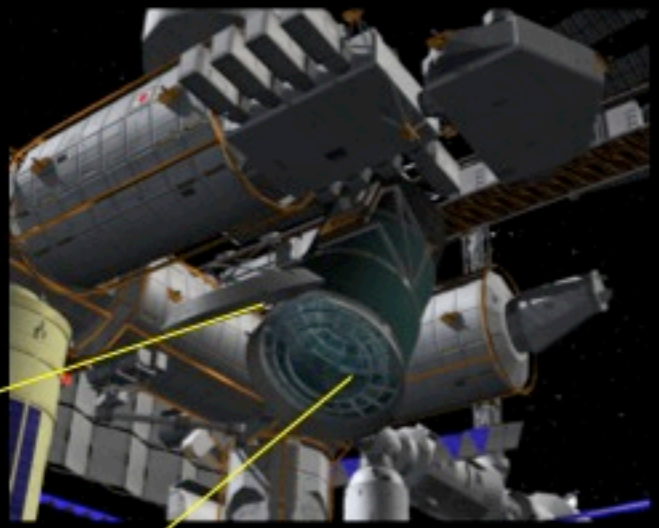
1. EUSO-TA:
Ground detector at
Telescope Array site: 2013

2. EUSO-BALLOON:
3 Balloon flights; 1st from
Timmins, Canada 2014
CNES
(French Space Agency)




JAXA
NASA
RIKEN
JEM-EUSO
esa
POCKOCMOC
TDRS
Flight Segment
EECR
UV Photons
Fluorescene
LIDAR
Cherenkov
Air Shower
Ground Support Equipment
Ground Segment
Laser Station
Global Light System
Xe Flasher
Data Center
Mission Operation Control

Global Light System

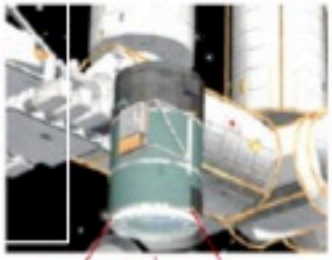


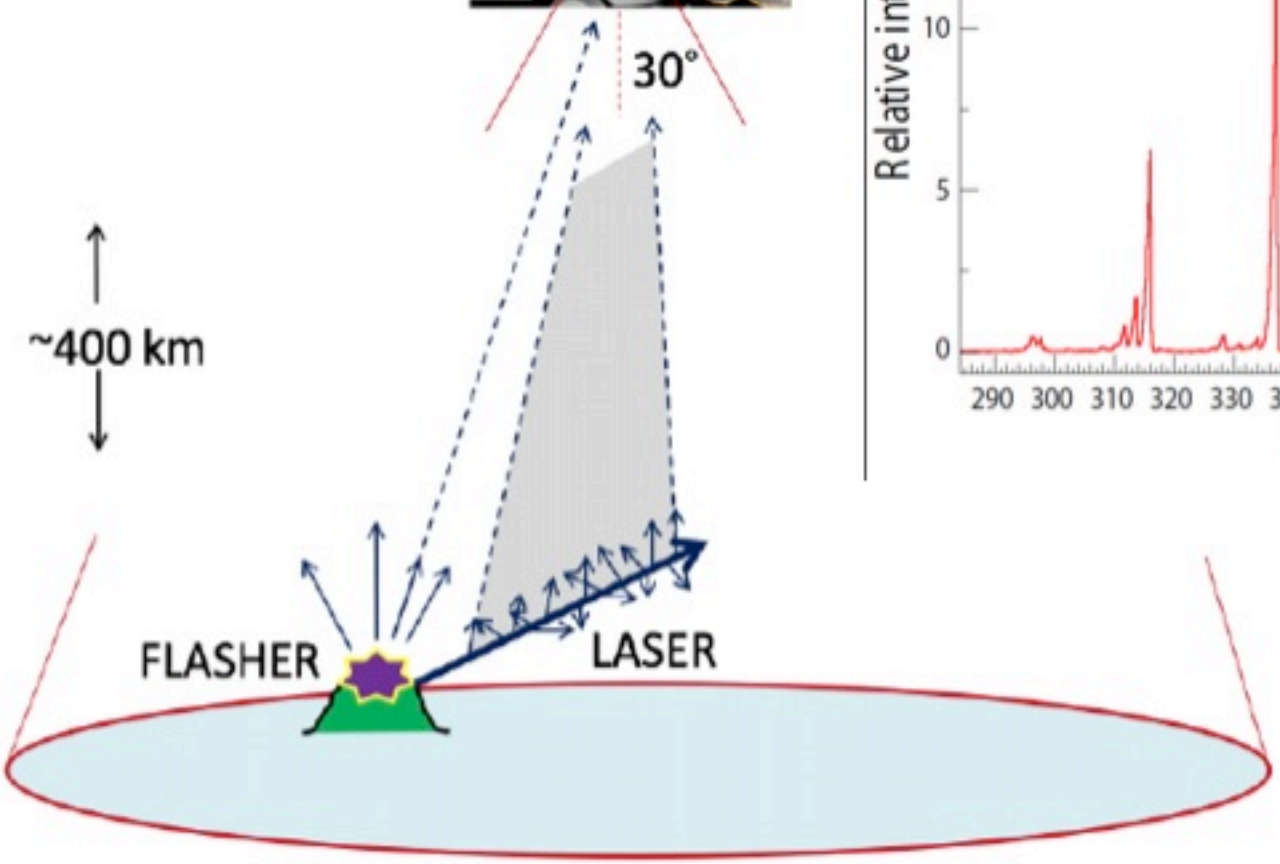
JEM-EUSO
detector

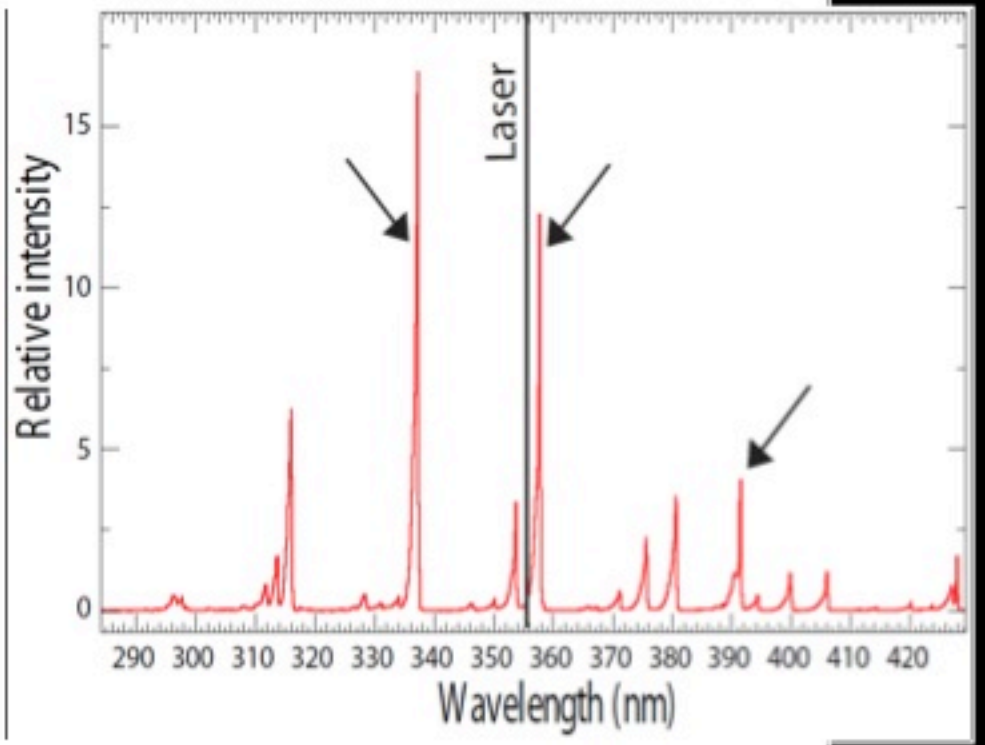
Laser Beam

GLS

12 stations:
- *12 with Xe Flashlamps*
- *6 with Steered Lasers*
- *1 airborne System*



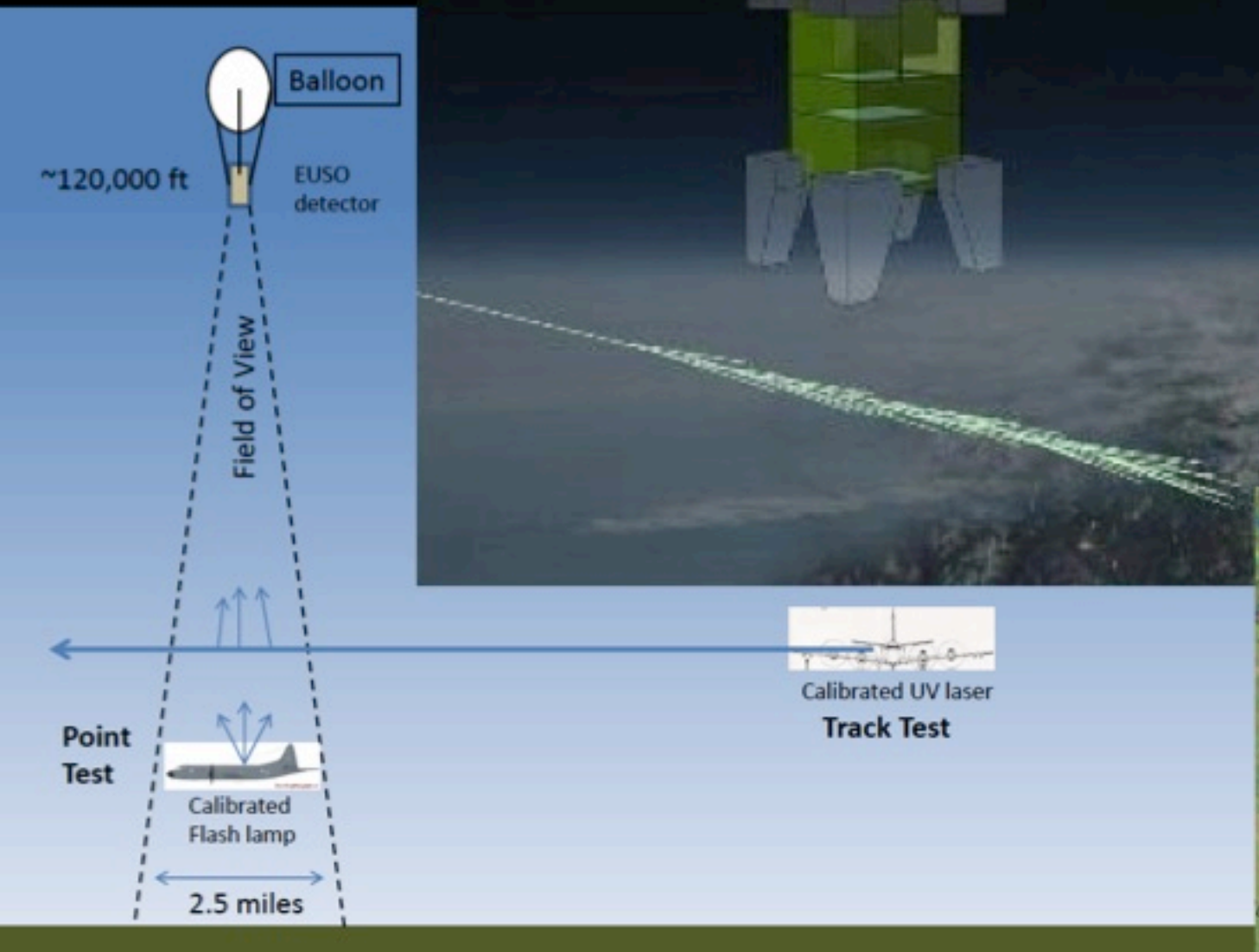


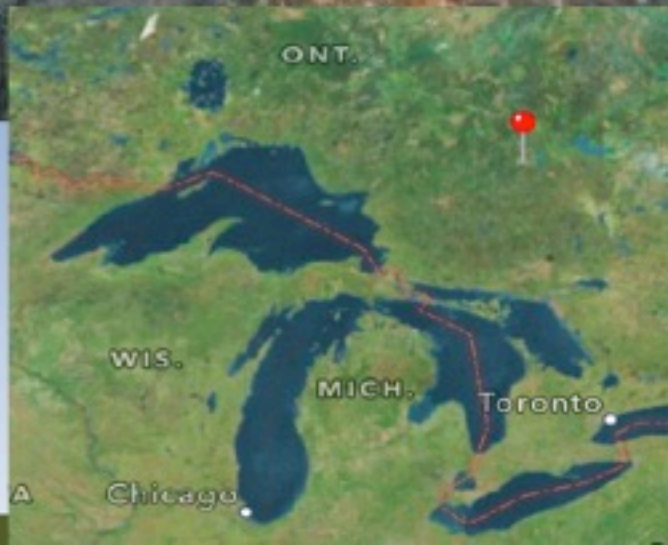


a pathfinder mission for JEM-EUSO

EUSO-BALLOON

PI: P. von Ballmoos
Phase C/D
Flight in Fall 2014





How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/yr

Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/yr

4 0.0.m to go!

Earth - surface ~ 5 10^8 km^2

~3.4 10^6 events/yr


Extreme Energy Frontier
Thanks!