Angela V. Olinto
The University of Chicago

Extensive Air Showers

1937: Pierre Auger

~ 10^{15} eV

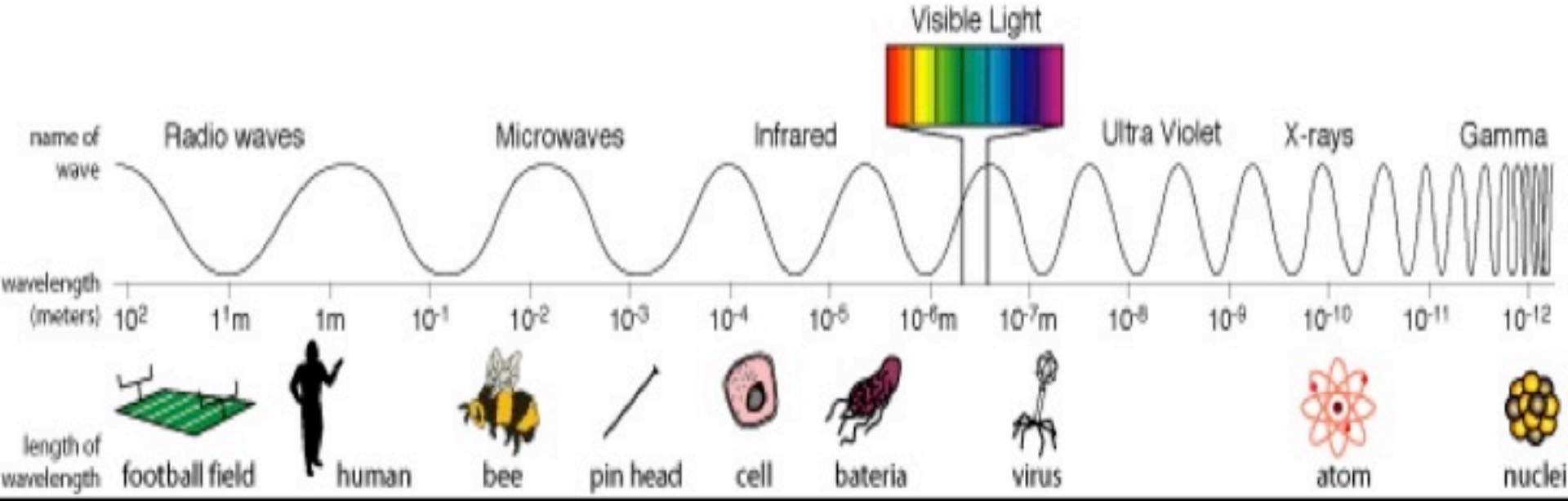
CERN

Ultra High Energy Cosmic Rays

1962 John Linsley

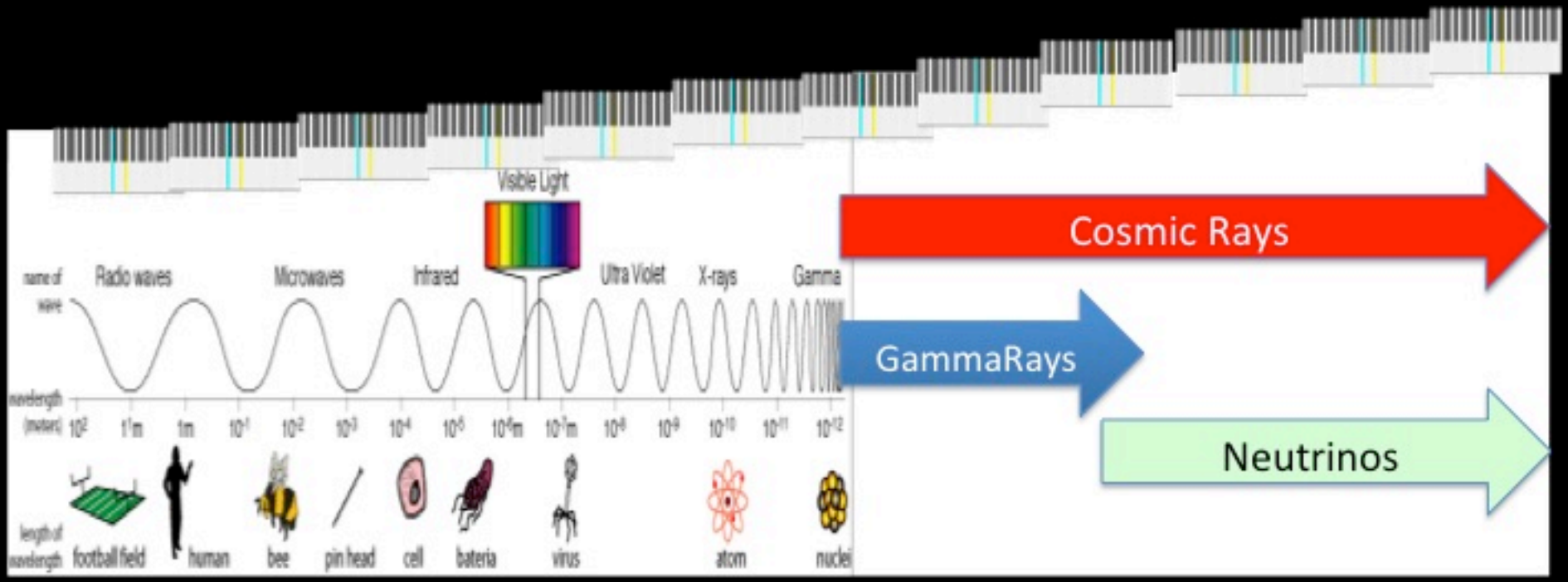
~10^{20} eV event

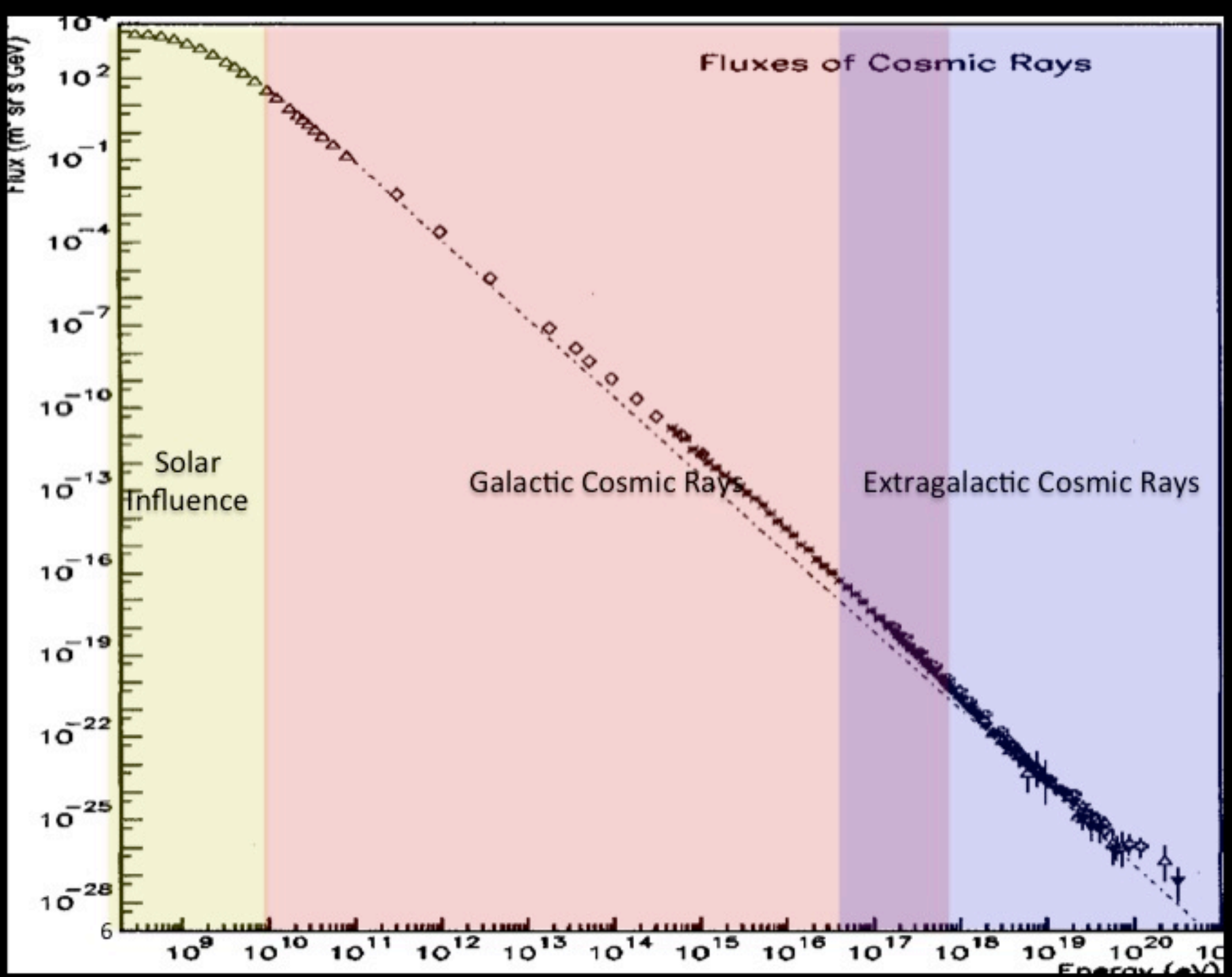
Photon "energy range"

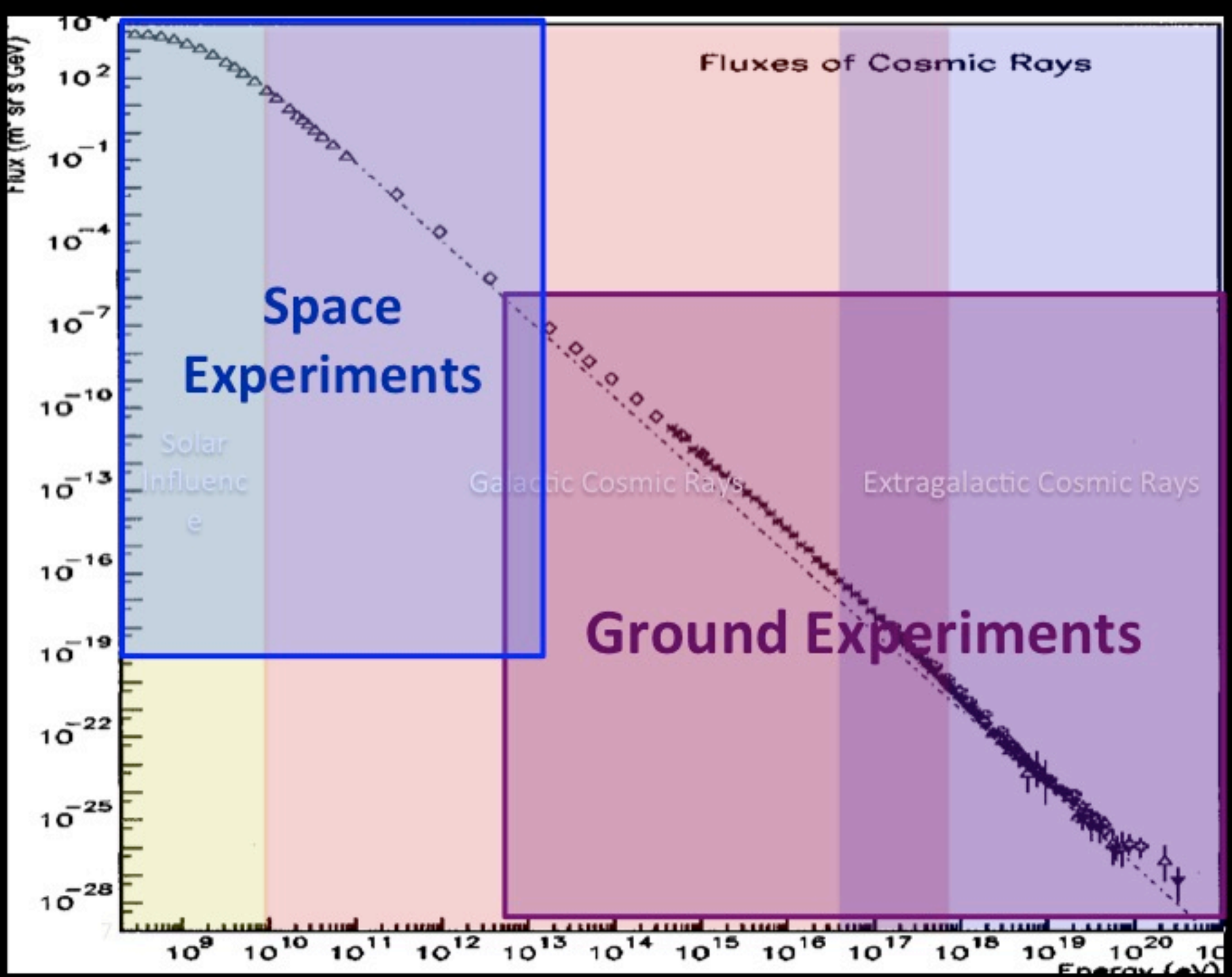


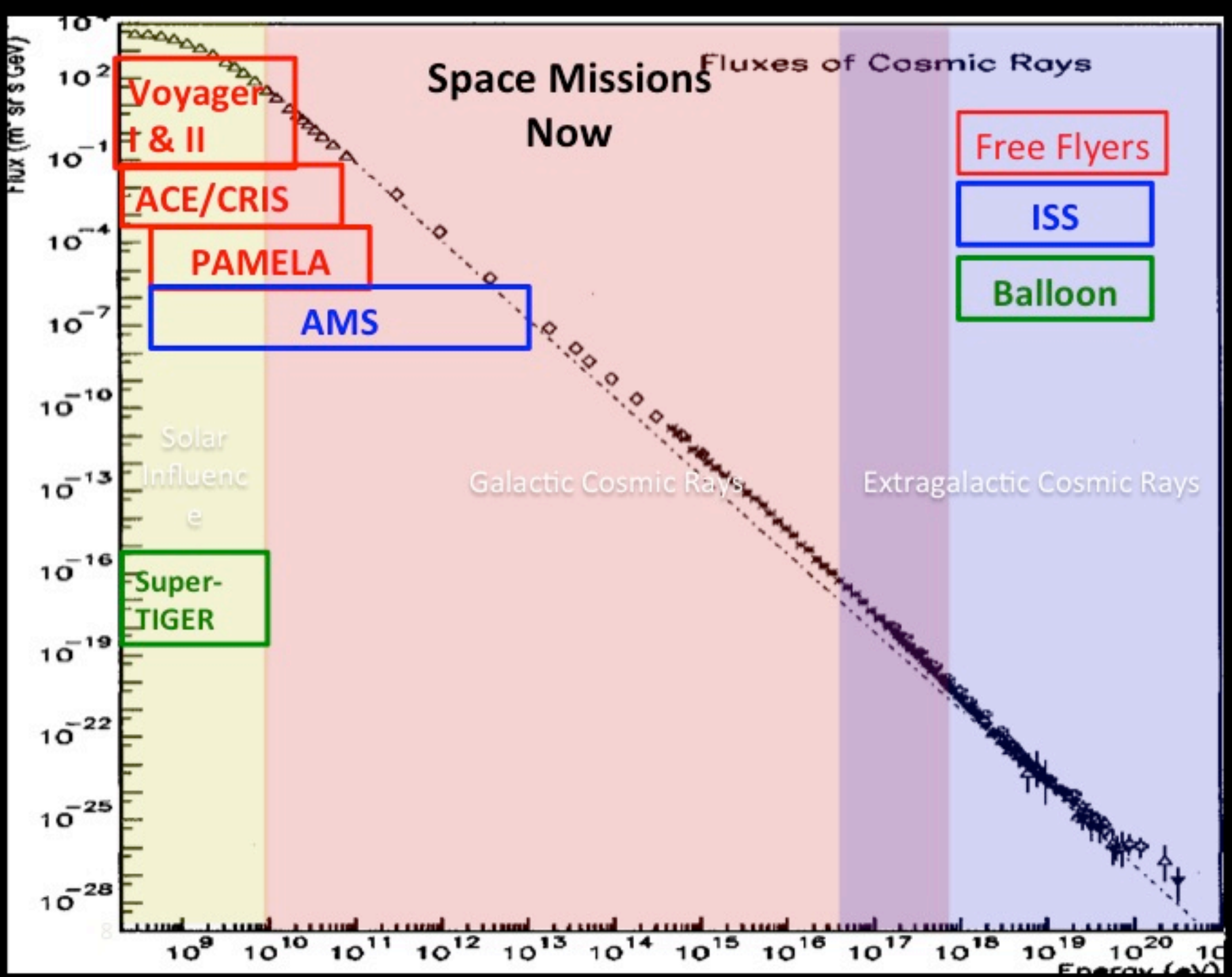
High Energy Particles

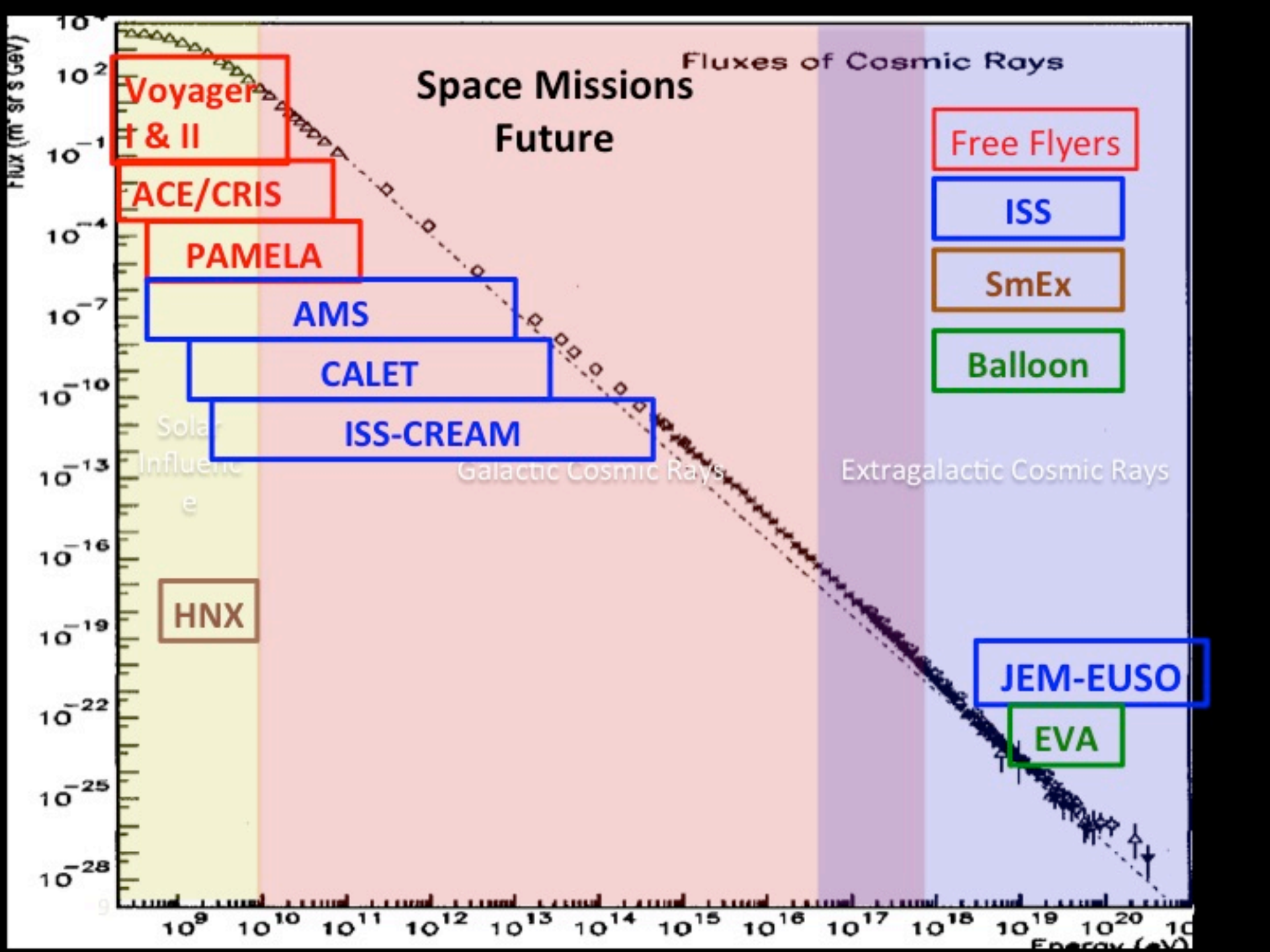
~ double the energy range for Astrophysics

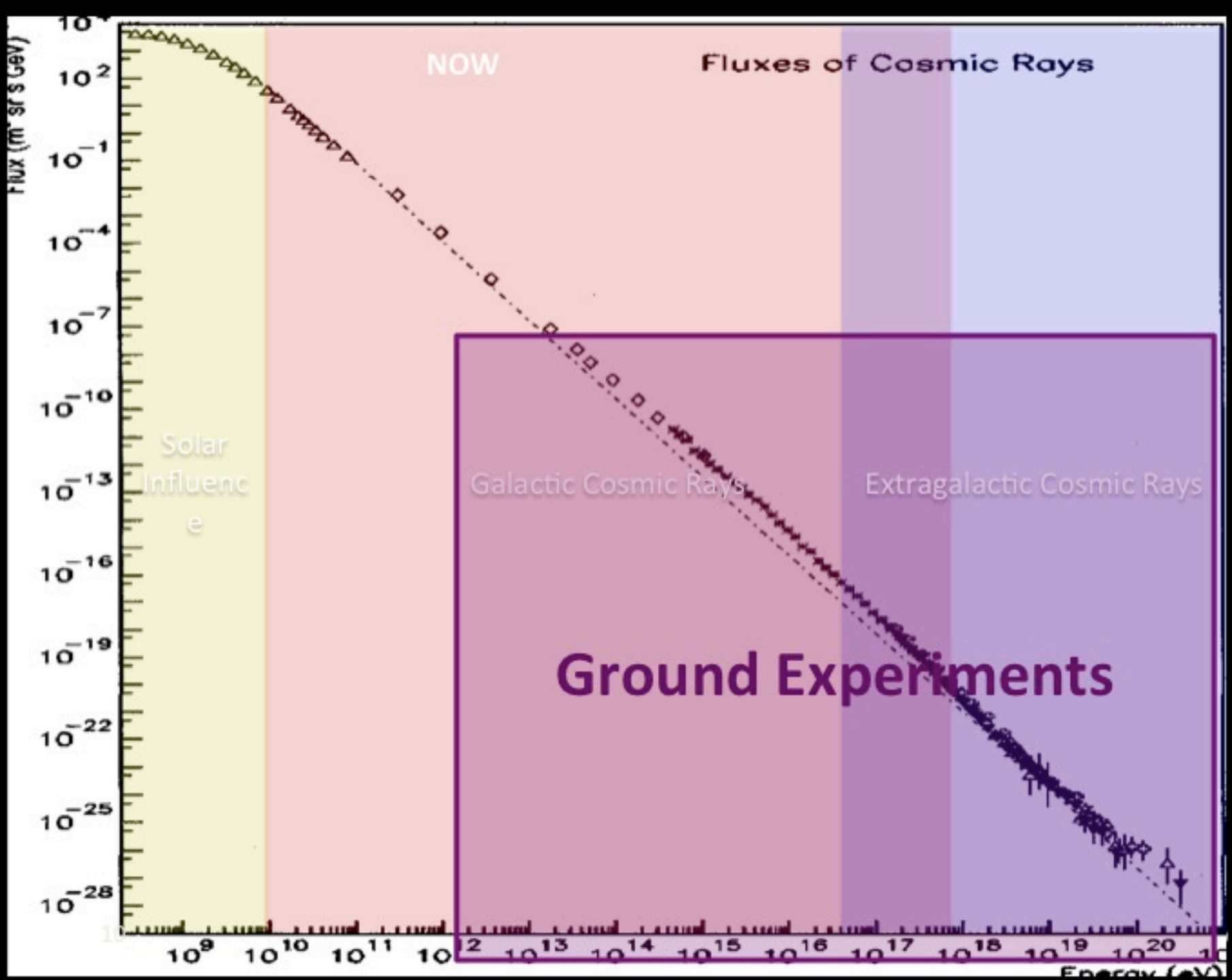


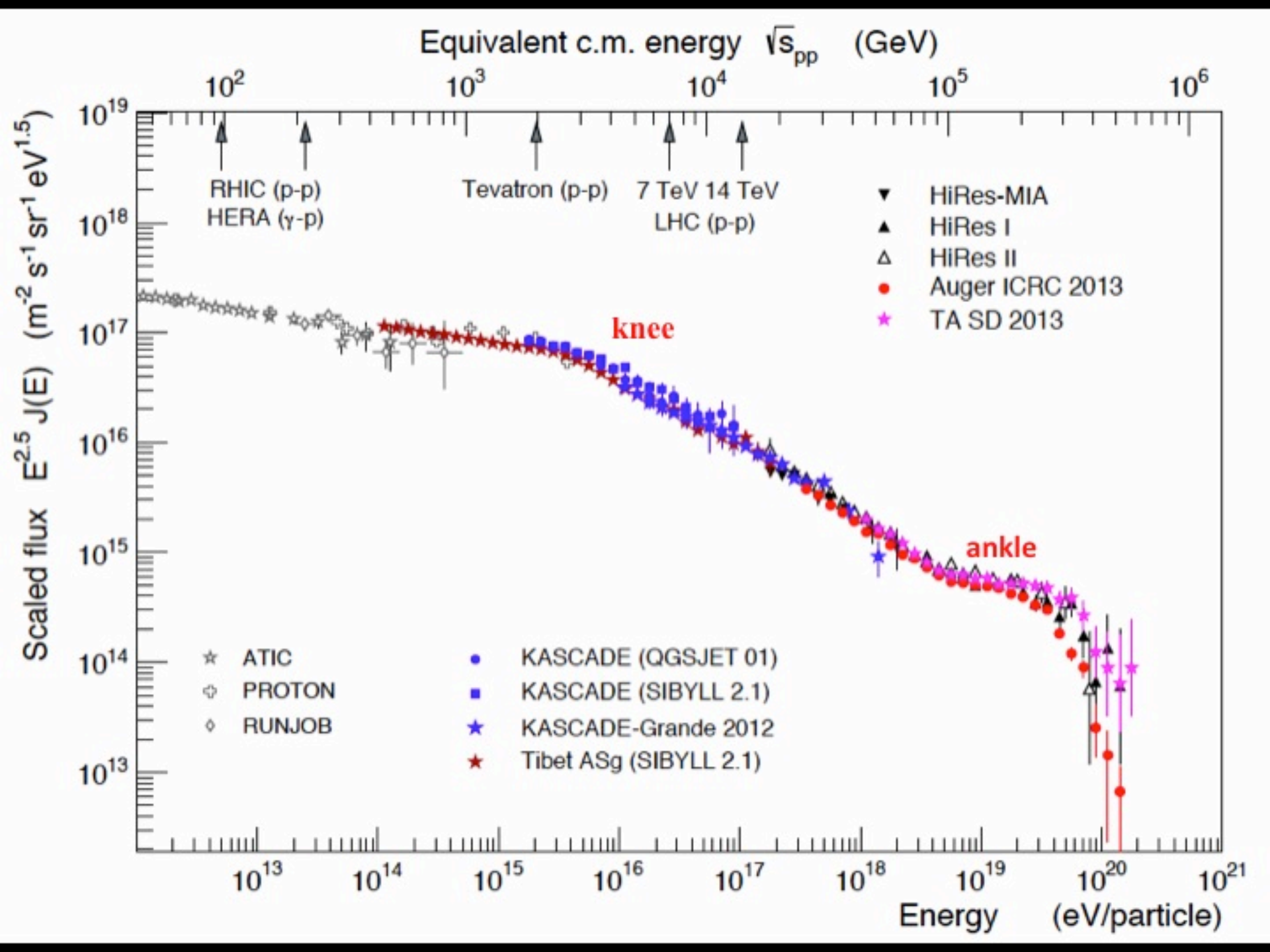

Fluxes of Cosmic Rays
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays

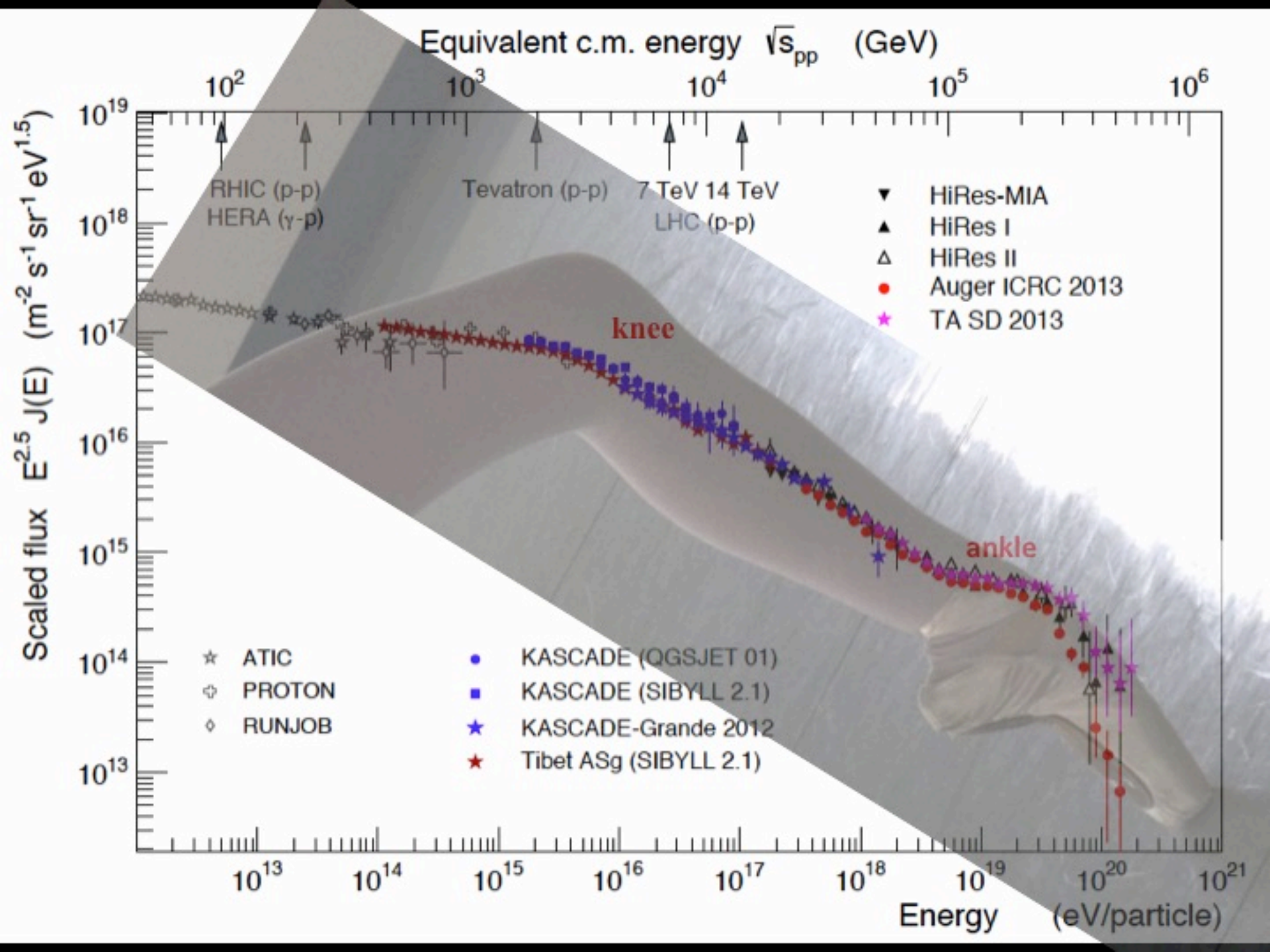

Fluxes of Cosmic Rays
Space Experiments
Ground Experiments
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)

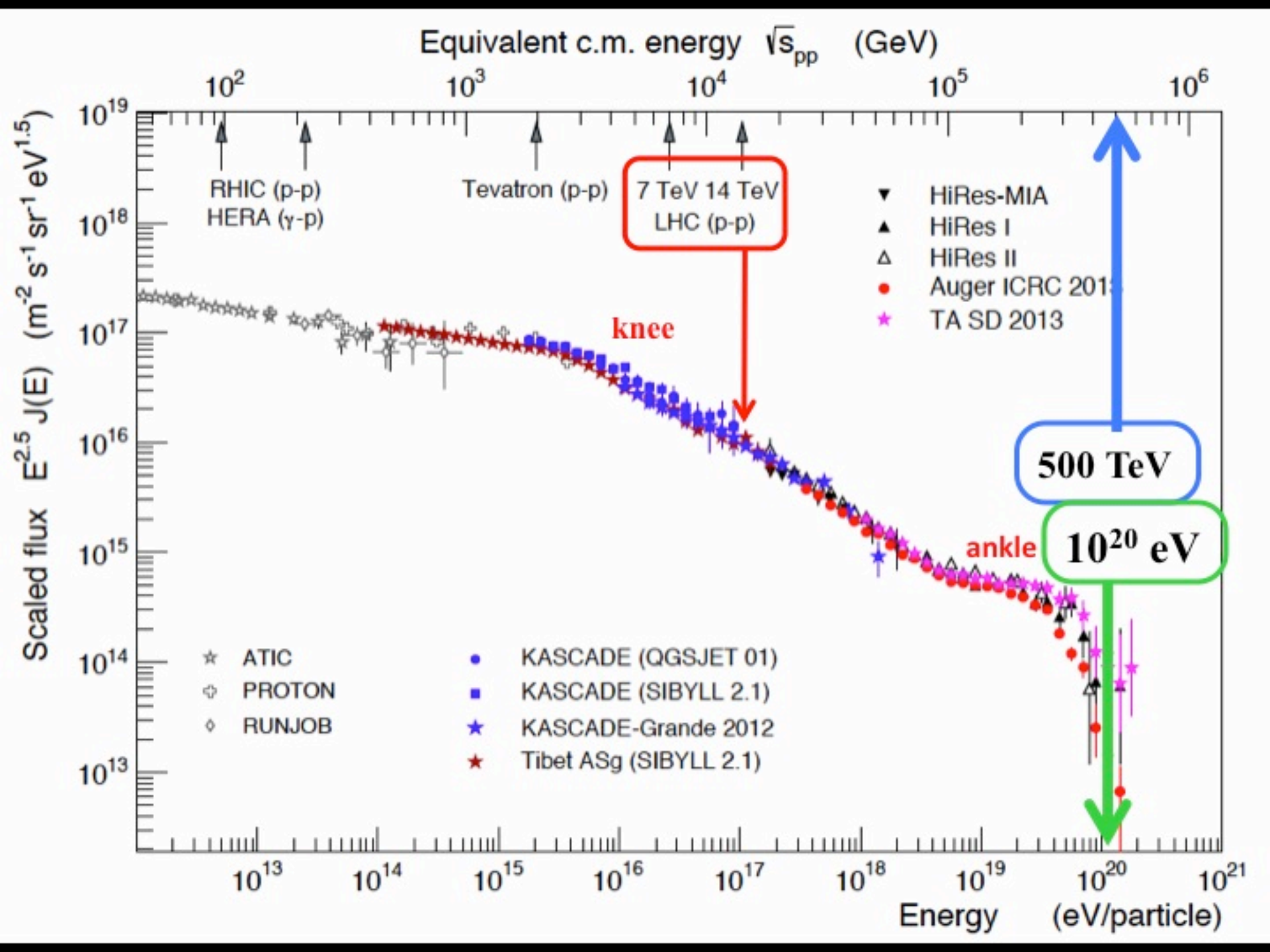

Space Missions
Now
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
Super-TIGER
Free Flyers
ISS
Balloon
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)

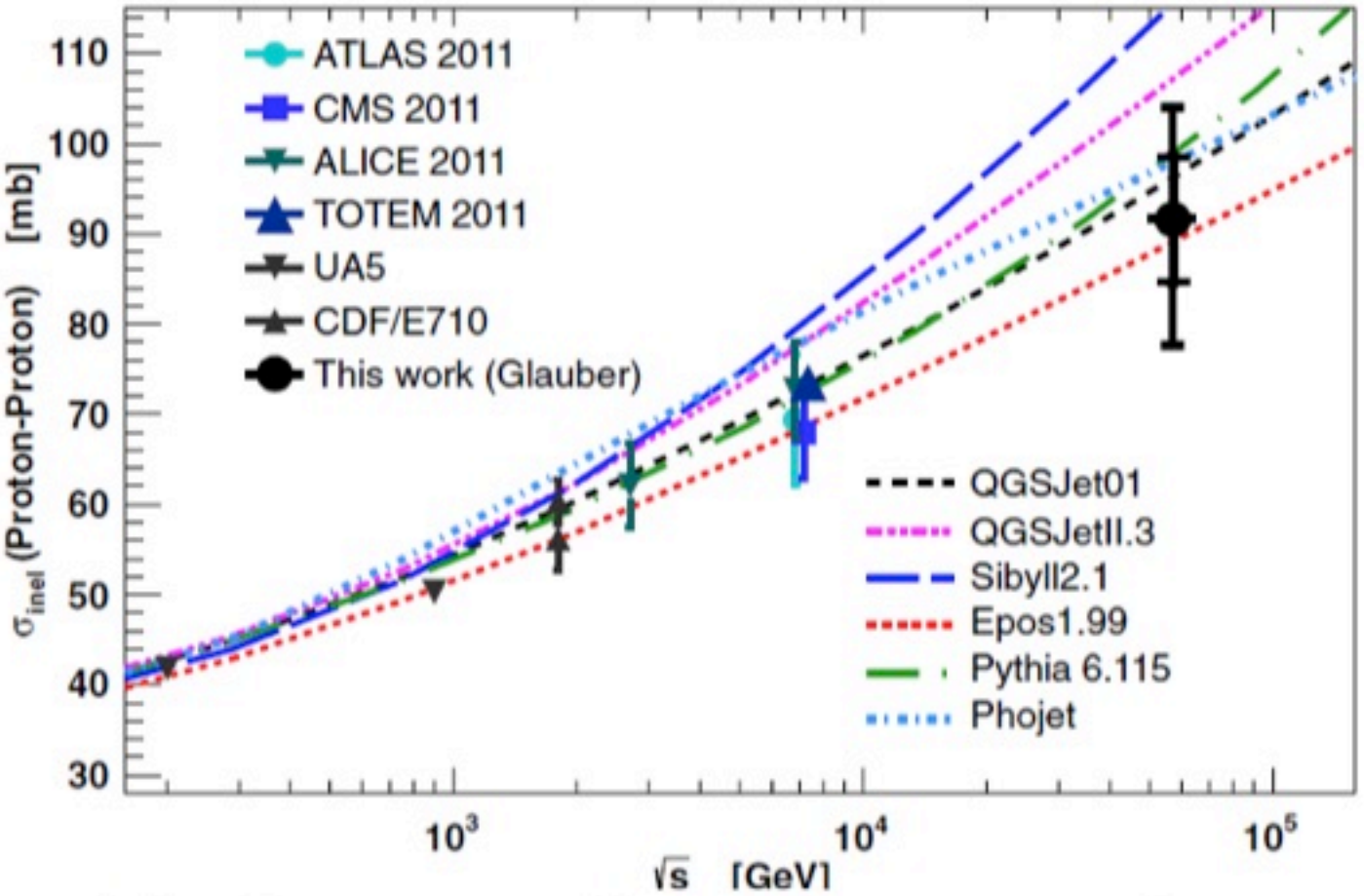

Fluxes of Cosmic Rays
Space Missions
Future
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM
HNX
Free Flyers
ISS
SmEx
Balloon
JEM-EUSO
EVA
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)


Fluxes of Cosmic Rays
NOW
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
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
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

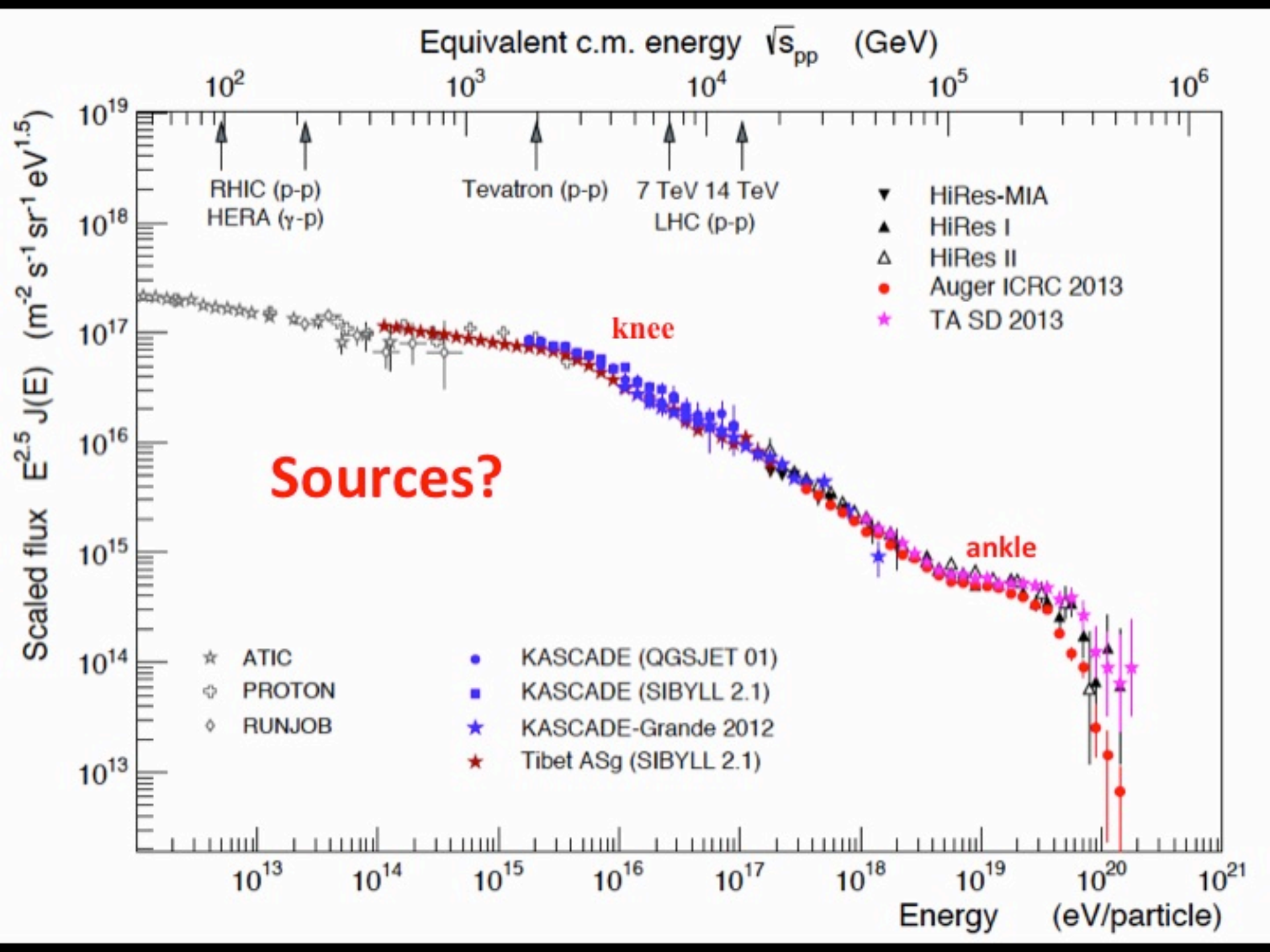

Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
ankle
Scaled flux E^2.5 J(E) (m^-2 s^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
ATIC
PROTON
RUNJOB
KASCADE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

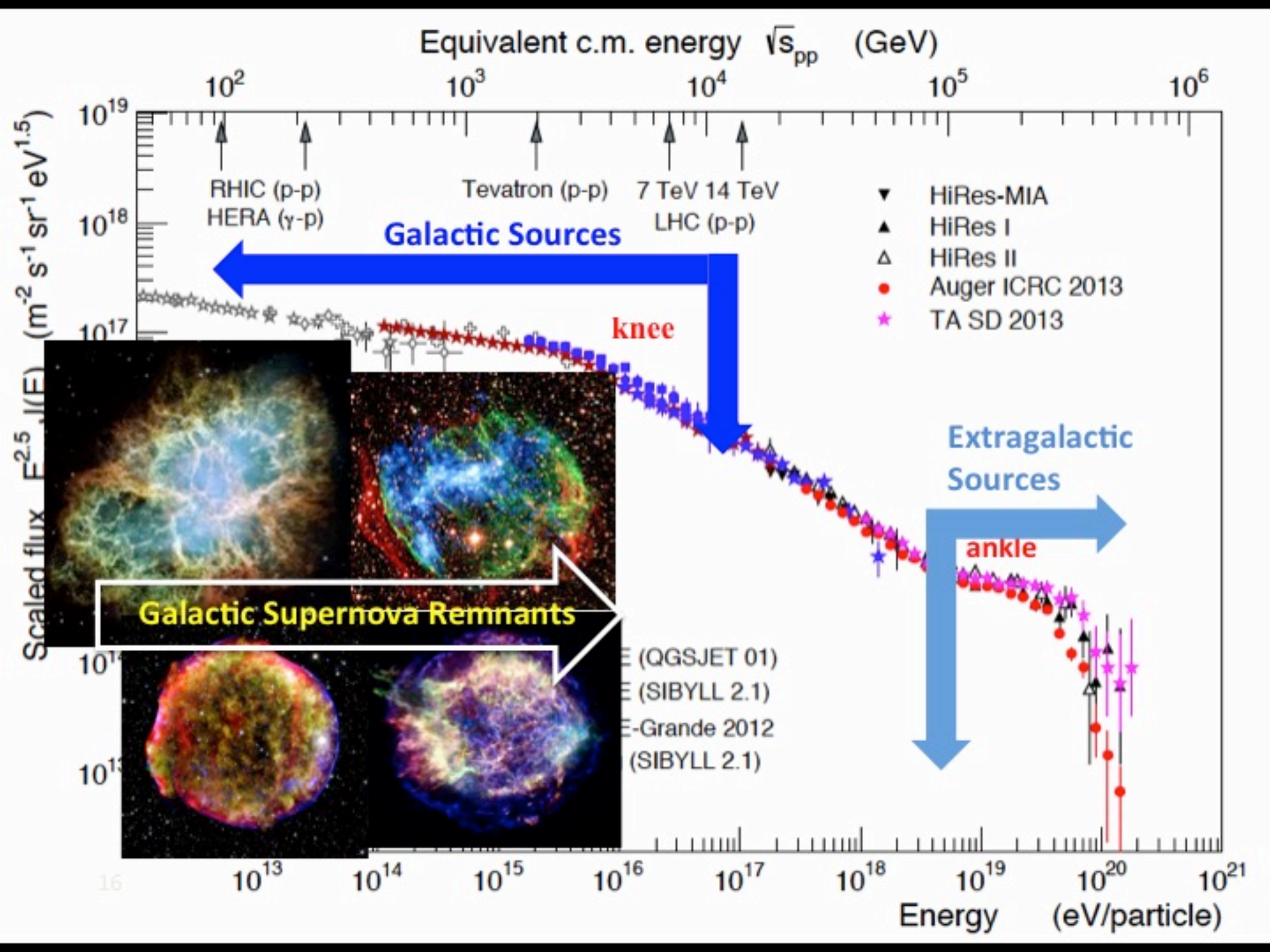

Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 201
TA SD 2013
knee
ankle
500 TeV
10^20 eV
Scaled flux E^2.5 J(E) (m^-2 s^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

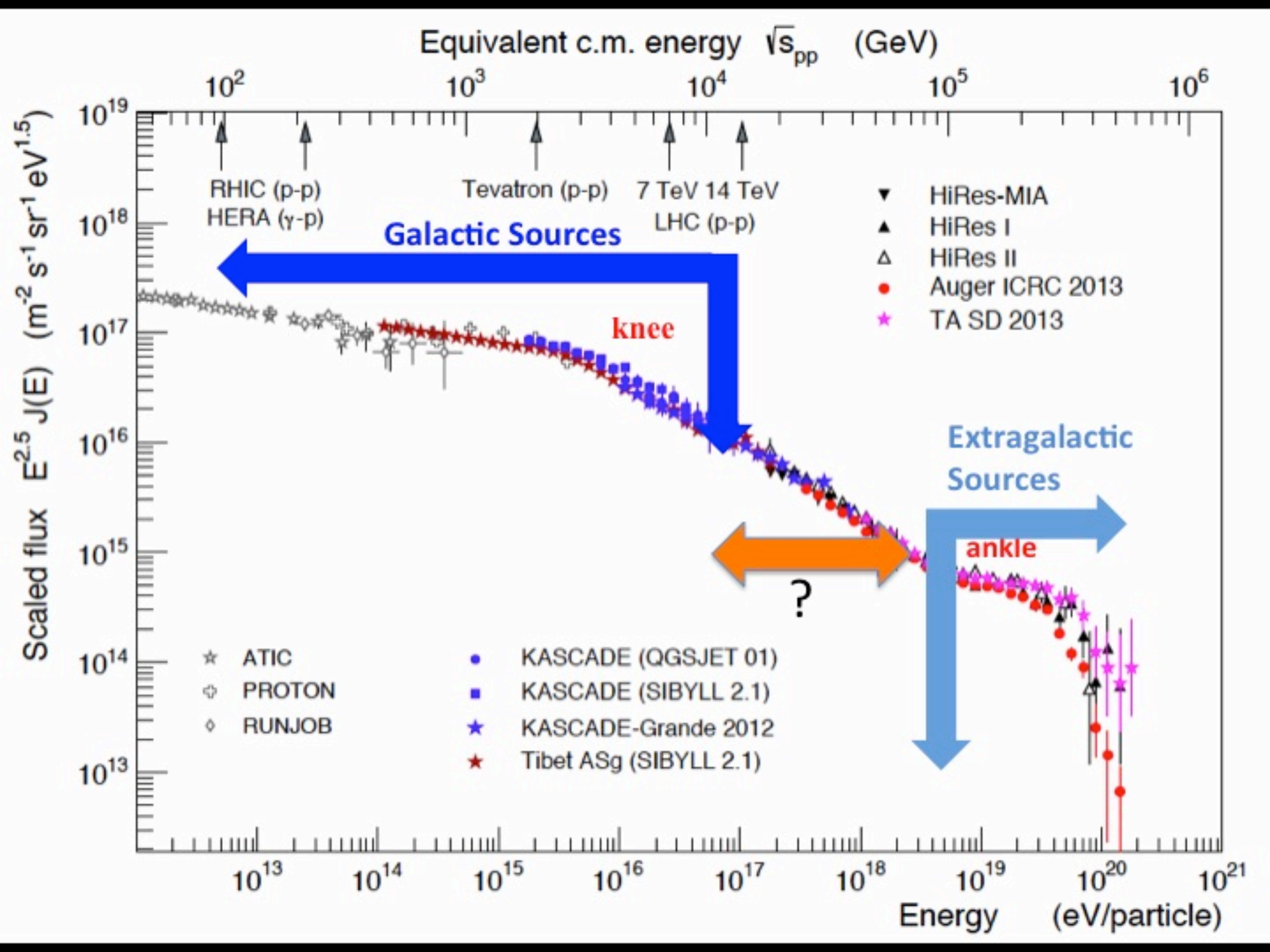


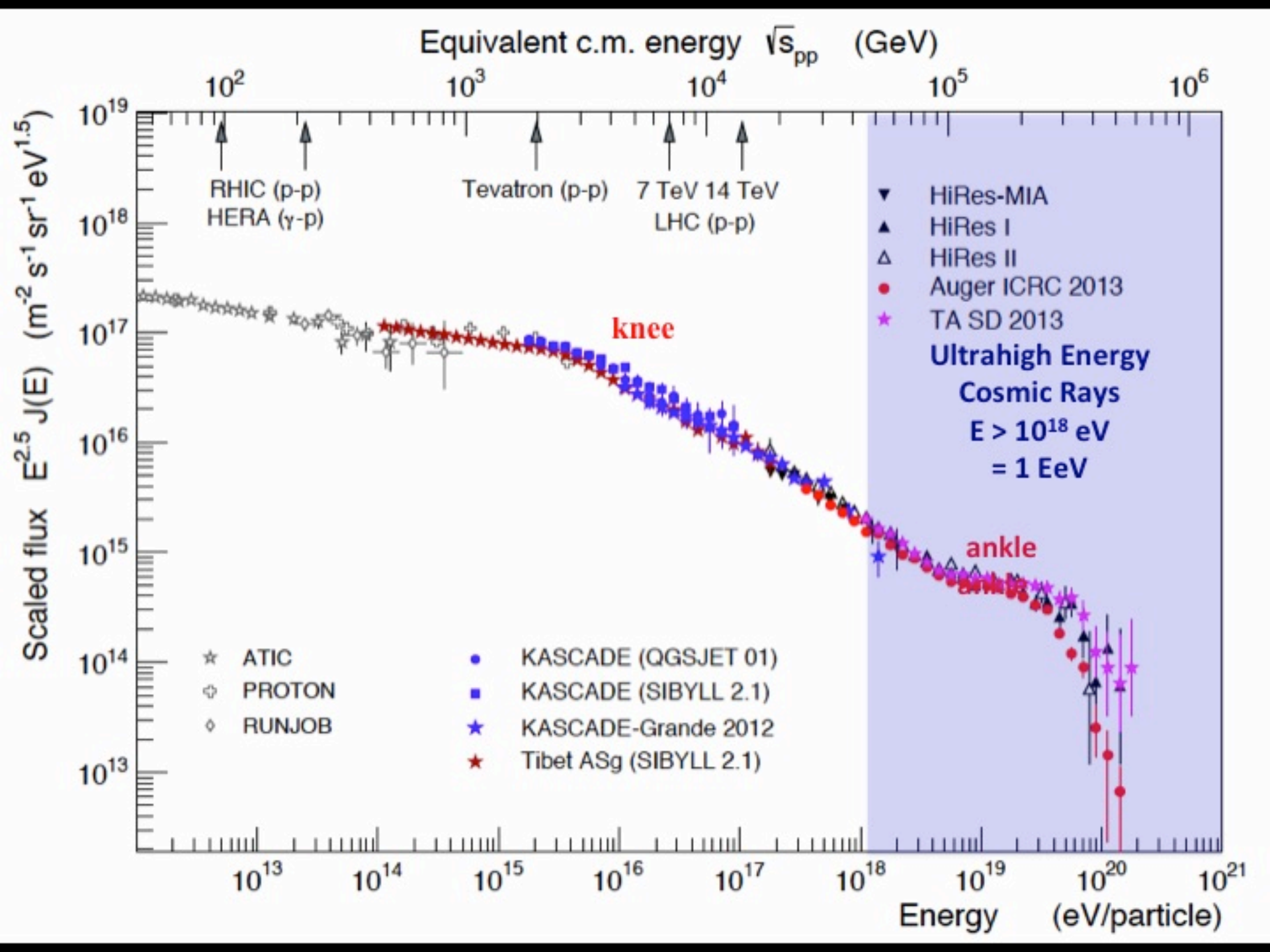
$$\sigma_{pp}^{\text{inel}} = [92 \pm 7(\text{stat})^{+9}_{-11}(\text{syst}) \pm 7(\text{Glauber})] \text{ mb},$$

$$\sigma_{pp}^{\text{tot}} = [133 \pm 13(\text{stat})^{+17}_{-20}(\text{syst}) \pm 16(\text{Glauber})] \text{ mb}.$$

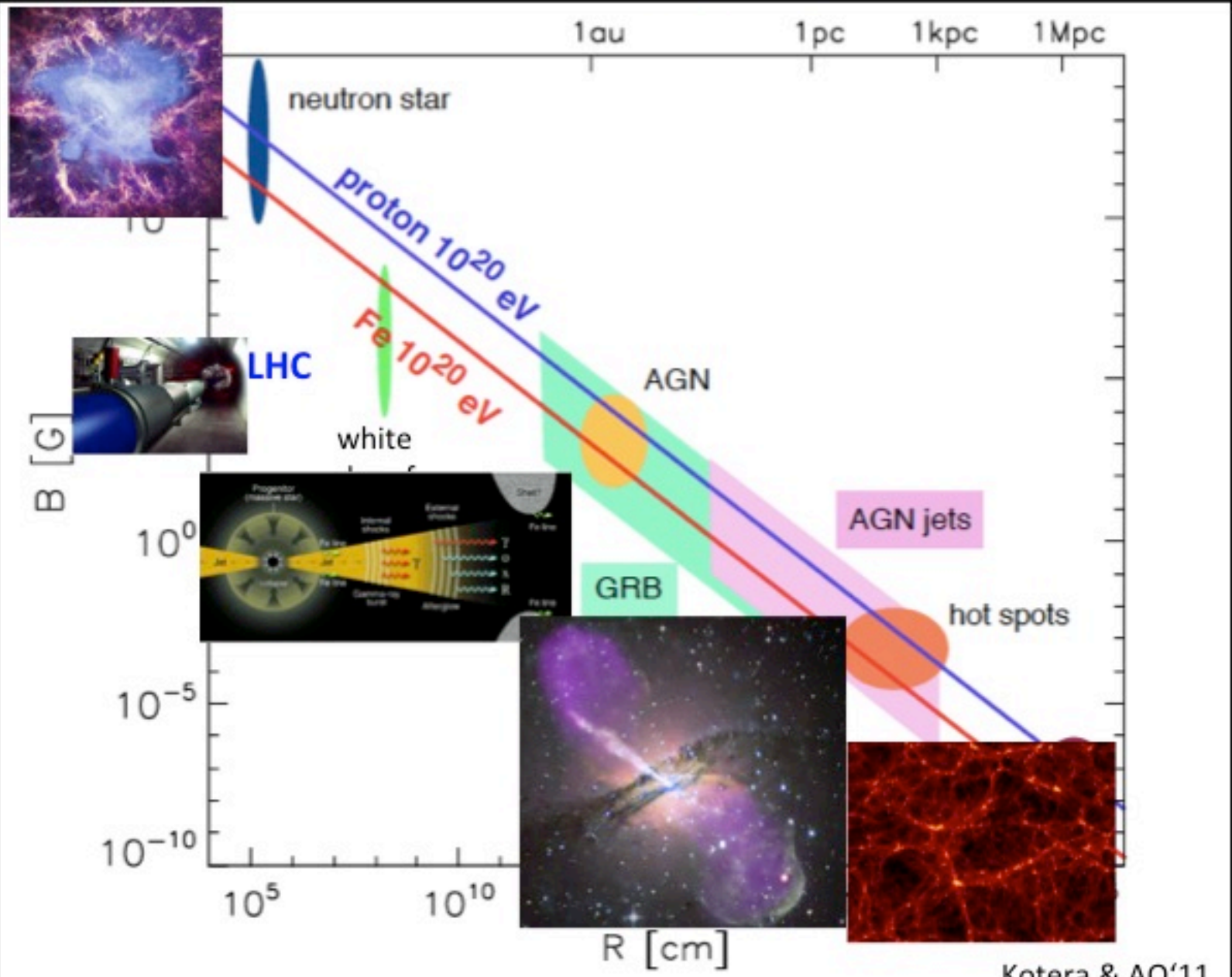

Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
knee
ankle
Sources?
Scaled flux E^2.5 J(E) (m^-2 s^-1 sr^-1 eV^1.5)
10^19
10^18
10^17
10^16
10^15
10^14
10^13
ATIC
PROTON
RUNJOB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

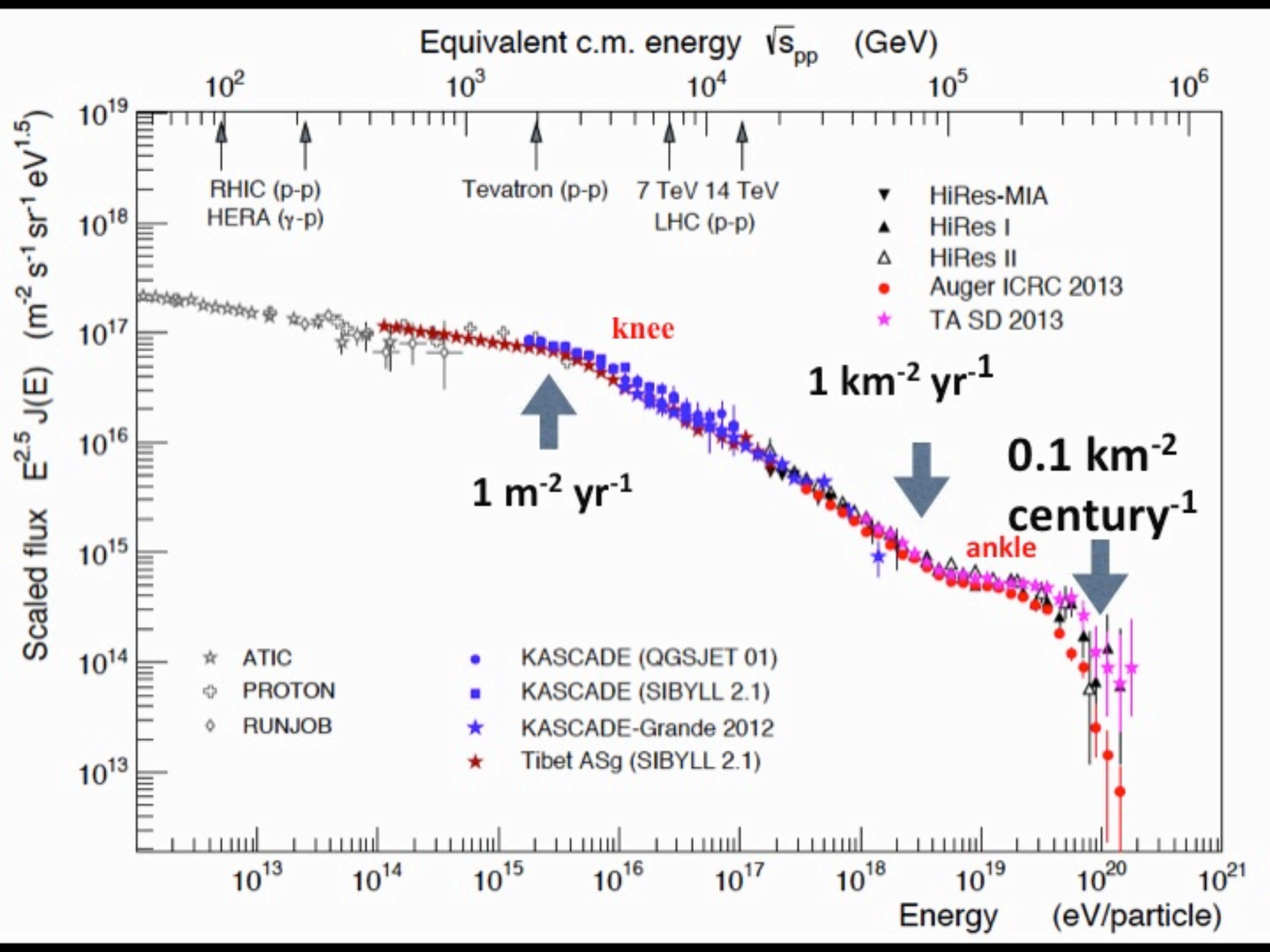

Equivalent c.m. energy √s_pp (GeV)
10^2
10^3
10^4
10^5
10^6
RHIC (p-p)
HERA (γ-p)
Tevatron (p-p)
7 TeV 14 TeV
LHC (p-p)
Galactic Sources
knee
Extragalactic
Sources
ankle
?
HiRes-MIA
HiRes I
HiRes II
Auger ICRC 2013
TA SD 2013
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande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

Hillas Plot: E_{max} required



Kotera & AO'11


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
1 km^-2 yr^-1
1 m^-2 yr^-1
0.1 km^-2 century^-1
ankle
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
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

Current Observatories of Ultrahigh Energy Cosmic Rays

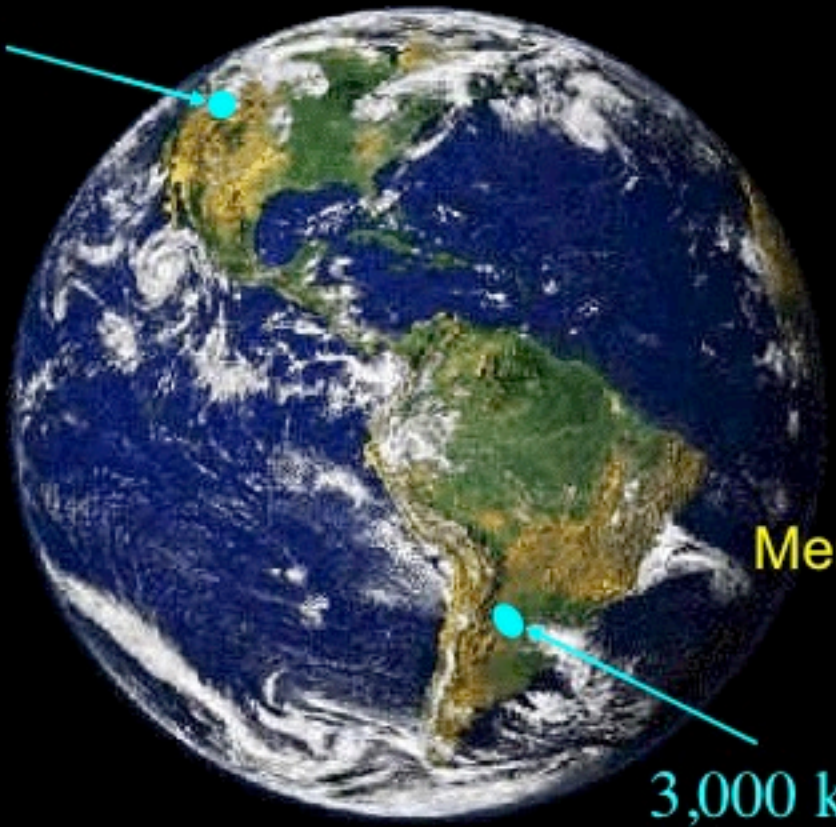
Telescope Array

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

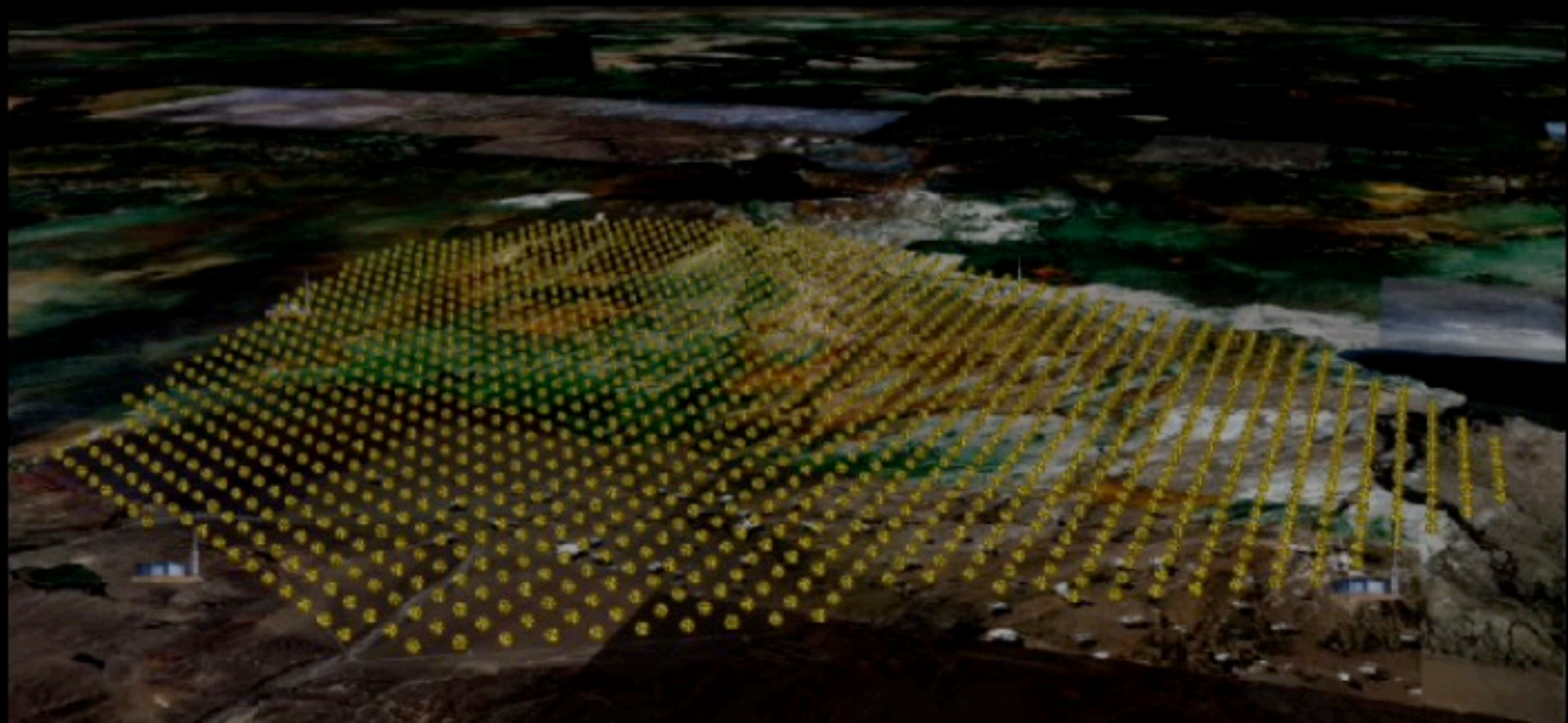
4 fluorescence telescopes

Pierre Auger Observatory

3,000 km² water cherenkov detectors array

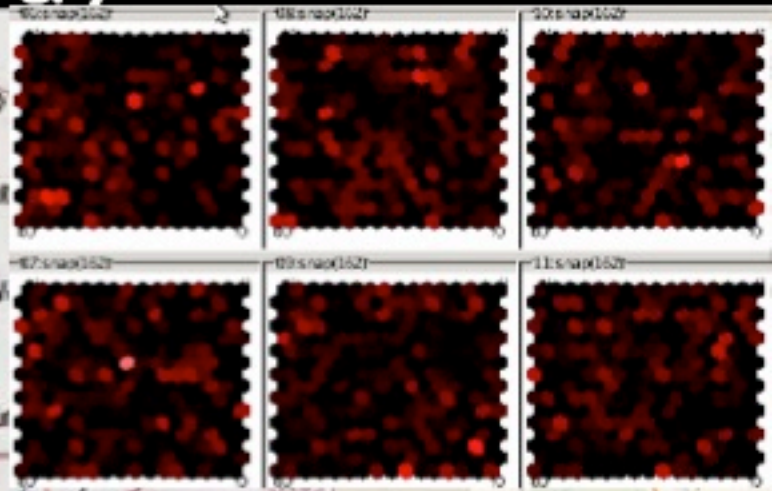
4 fluorescence Telescopes, Malargue, Argentina

~ 500 Scientists, 19 Countries



Telescope Array

Belgium
Japan
Korea
Russia
USA



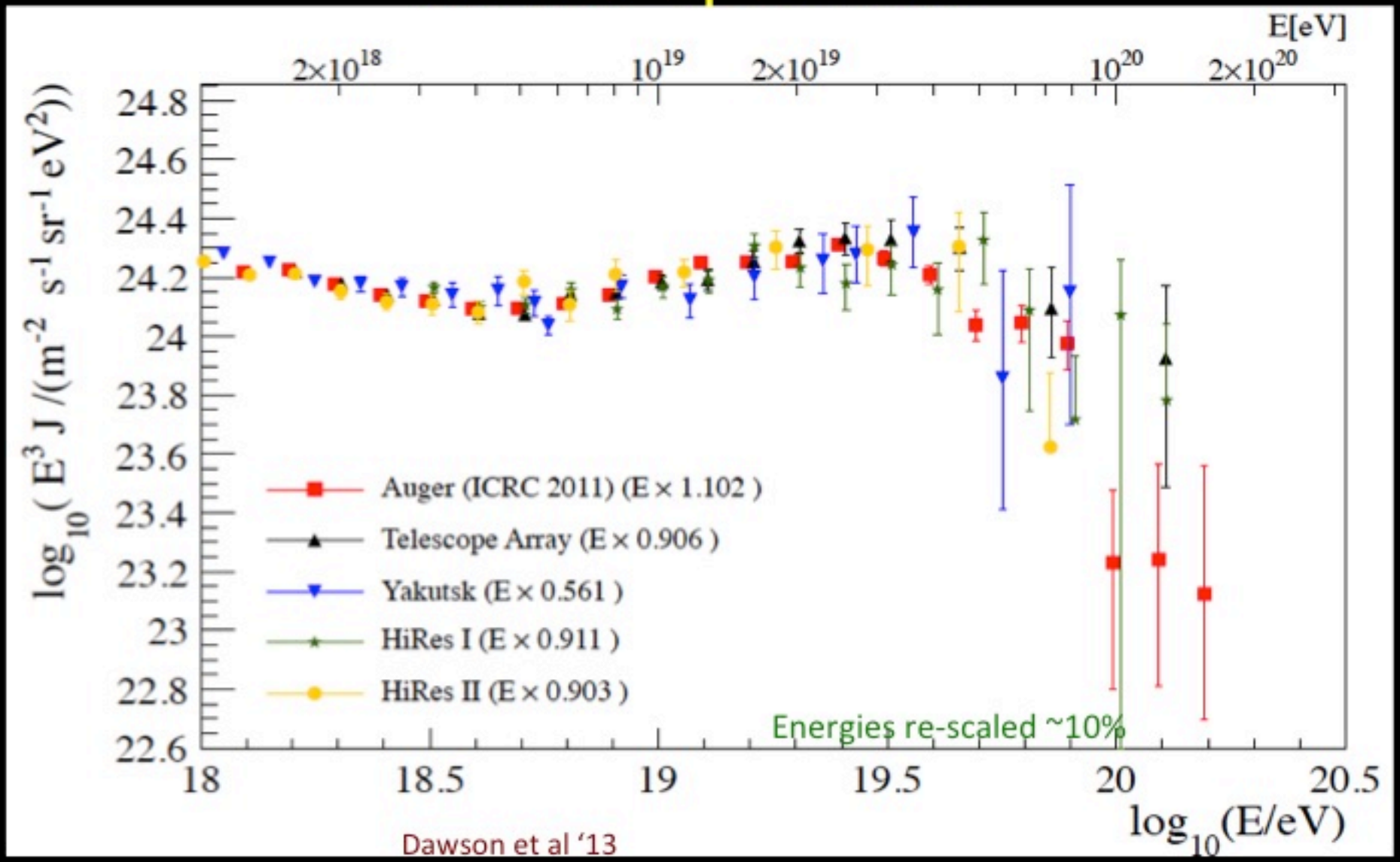
Area: 700 km^2

3 FD stations overlooking an array of

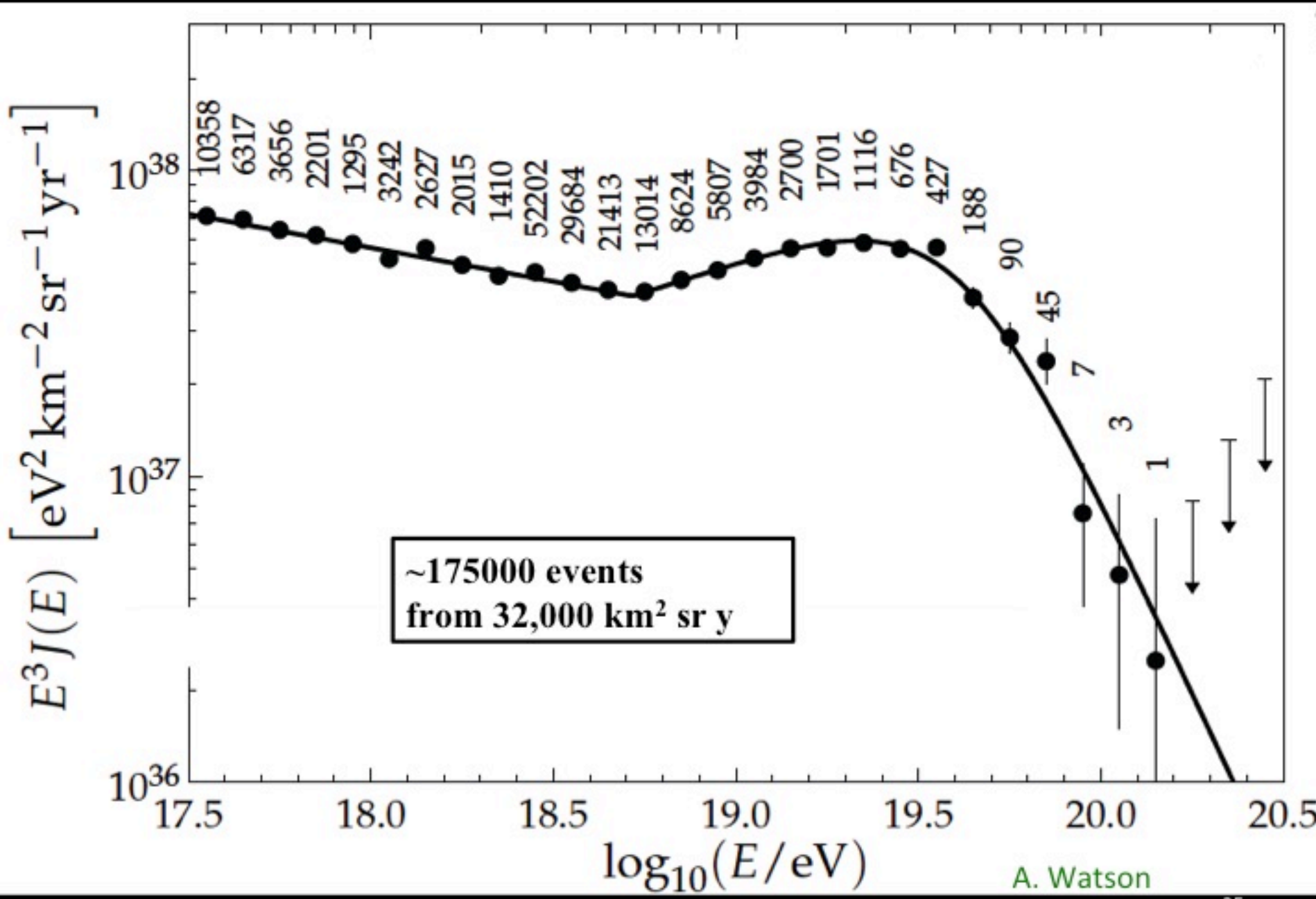
507 scintillator surface detectors (SD)

CERN UHECR 2012 Working Group

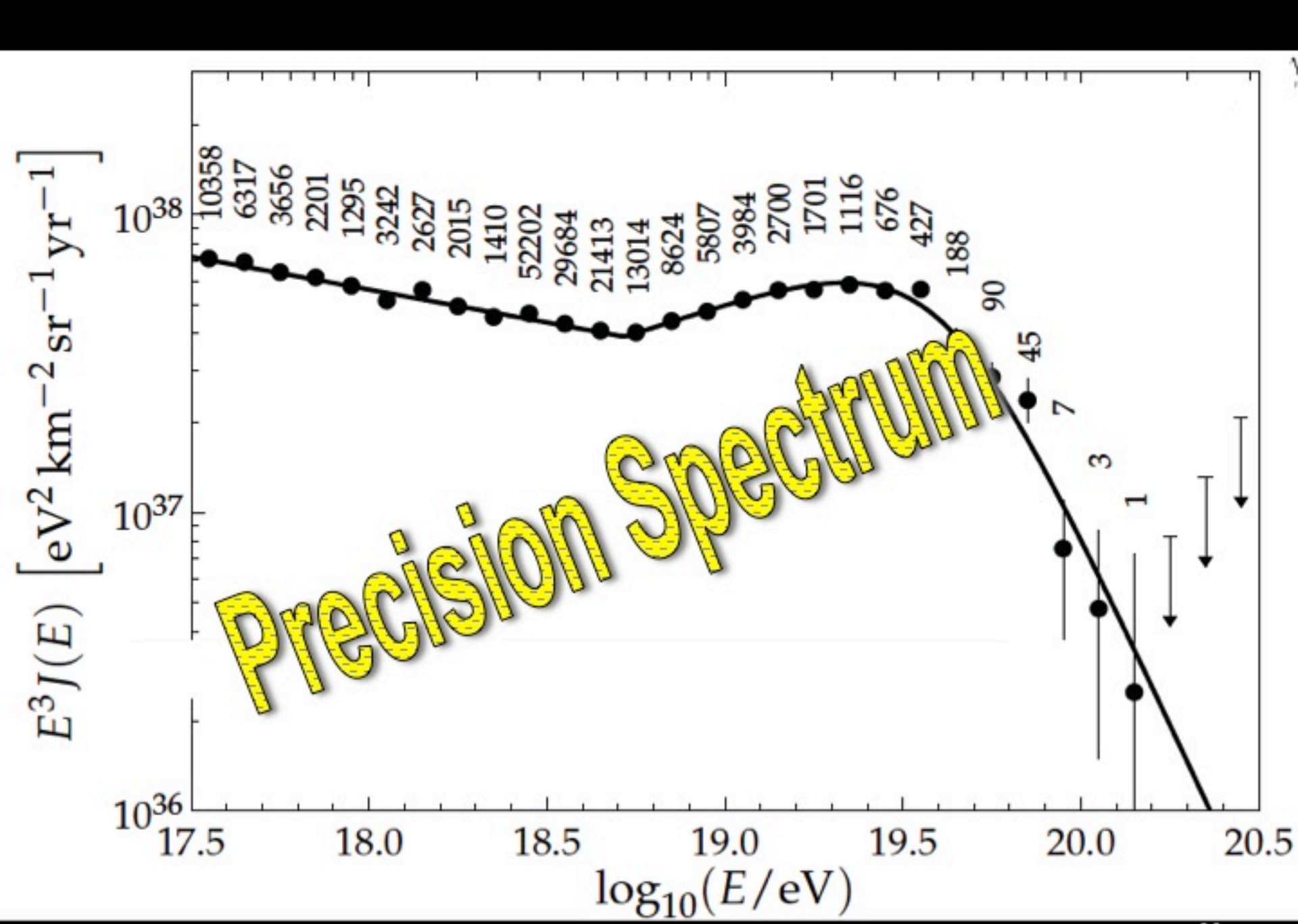
Unified Spectrum

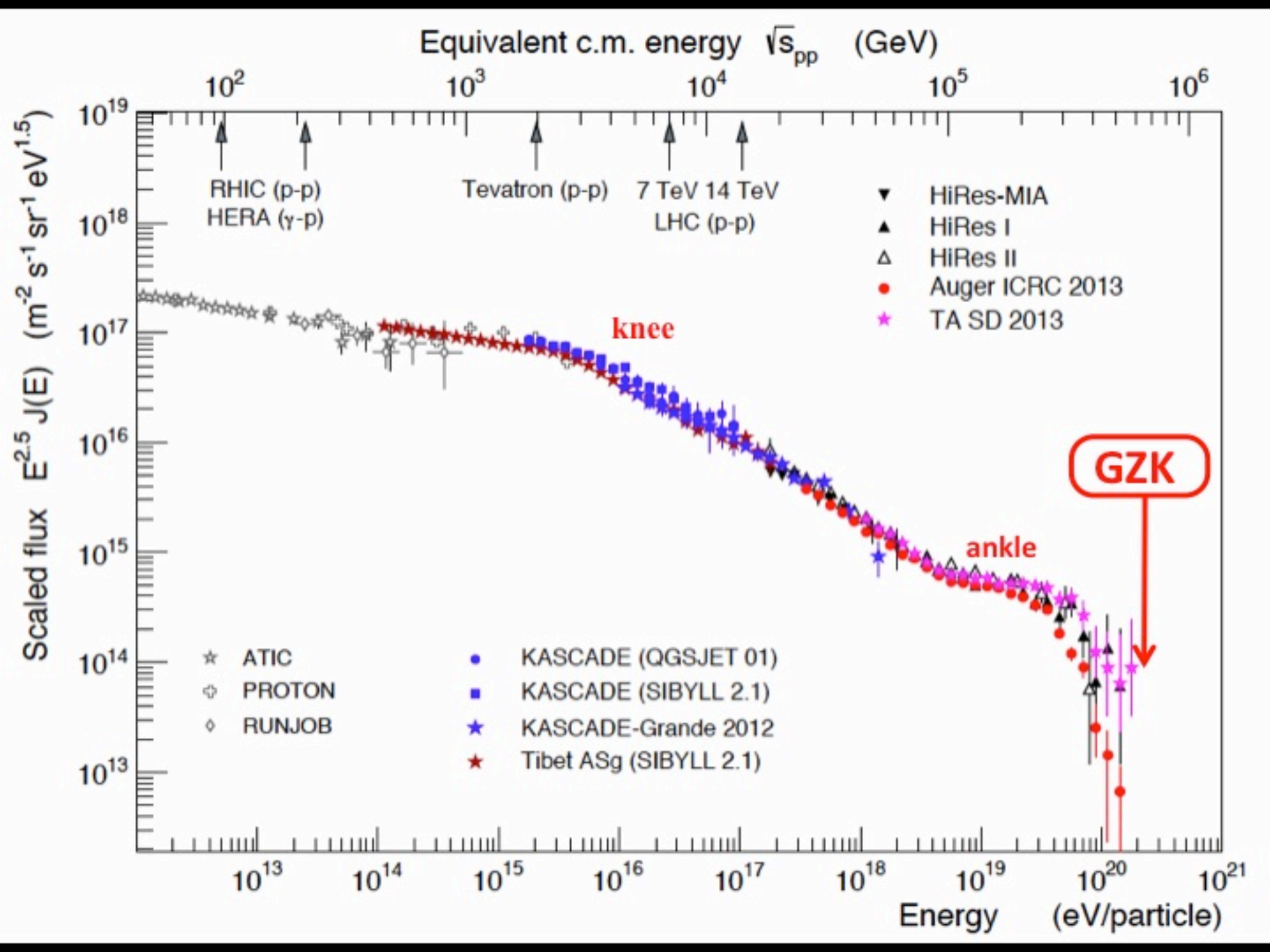


Dawson et al '13

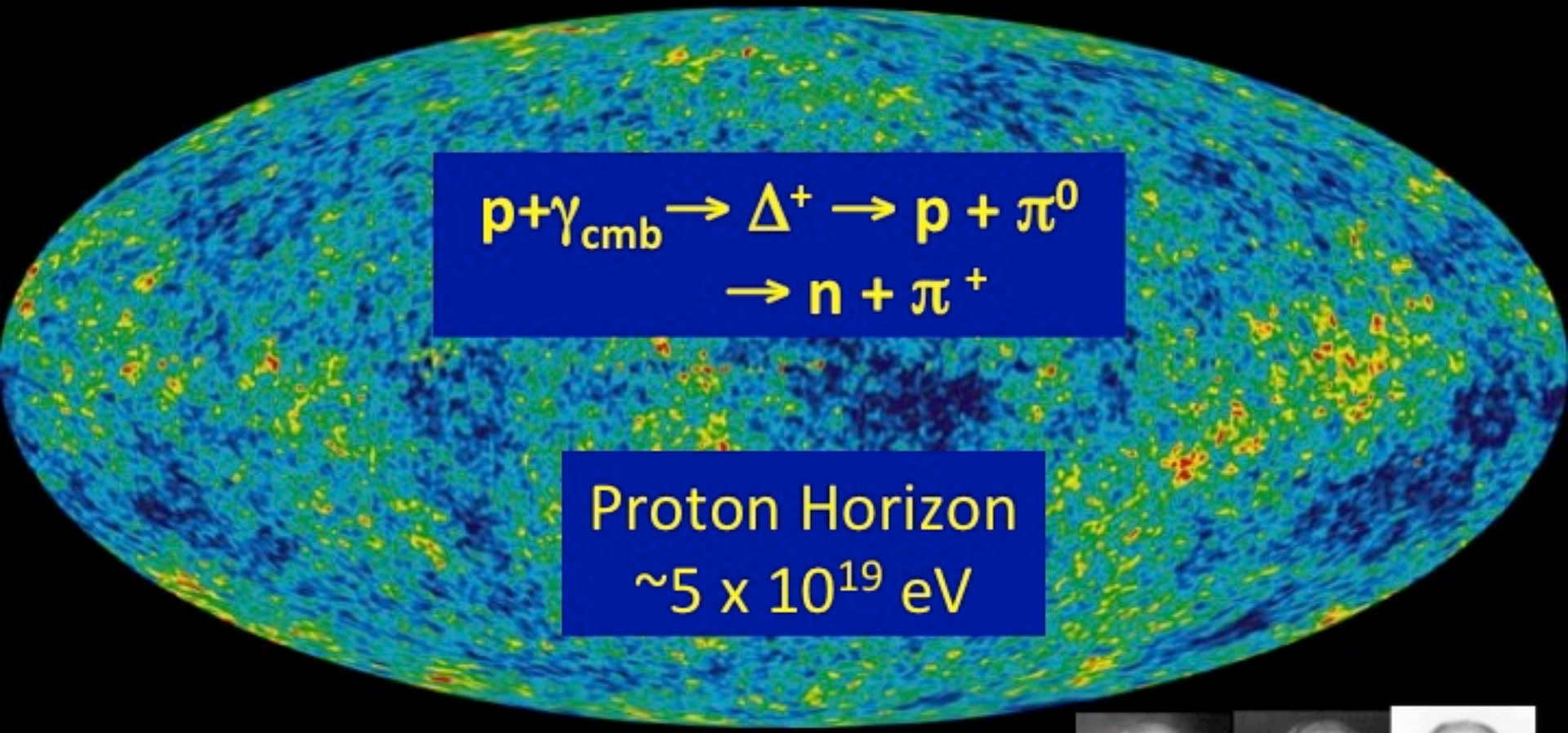

$E^3 J(E)$ $\left[\mathrm{eV}^2\,\mathrm{km}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{yr}^{-1}\right]$
10^{38}
10^{37}
10^{36}
10358
6317
3656
2201
1295
3242
2627
2015
1410
52202
29684
21413
13014
8624
5807
3984
2700
1701
1116
676
427
188
90
45
7
3
1
~175000 events
from 32,000 km² sr y
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$\log_{10}(E/\mathrm{eV})$

A. Watson


Precision Spectrum
$E^3 J(E)$ $\left[\mathrm{eV}^2\,\mathrm{km}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{yr}^{-1}\right]$
10^{38}
10^{37}
10^{36}
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
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$\log_{10}(E/\mathrm{eV})$


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
GZK
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)

"Cosmologically Meaningful Termination"



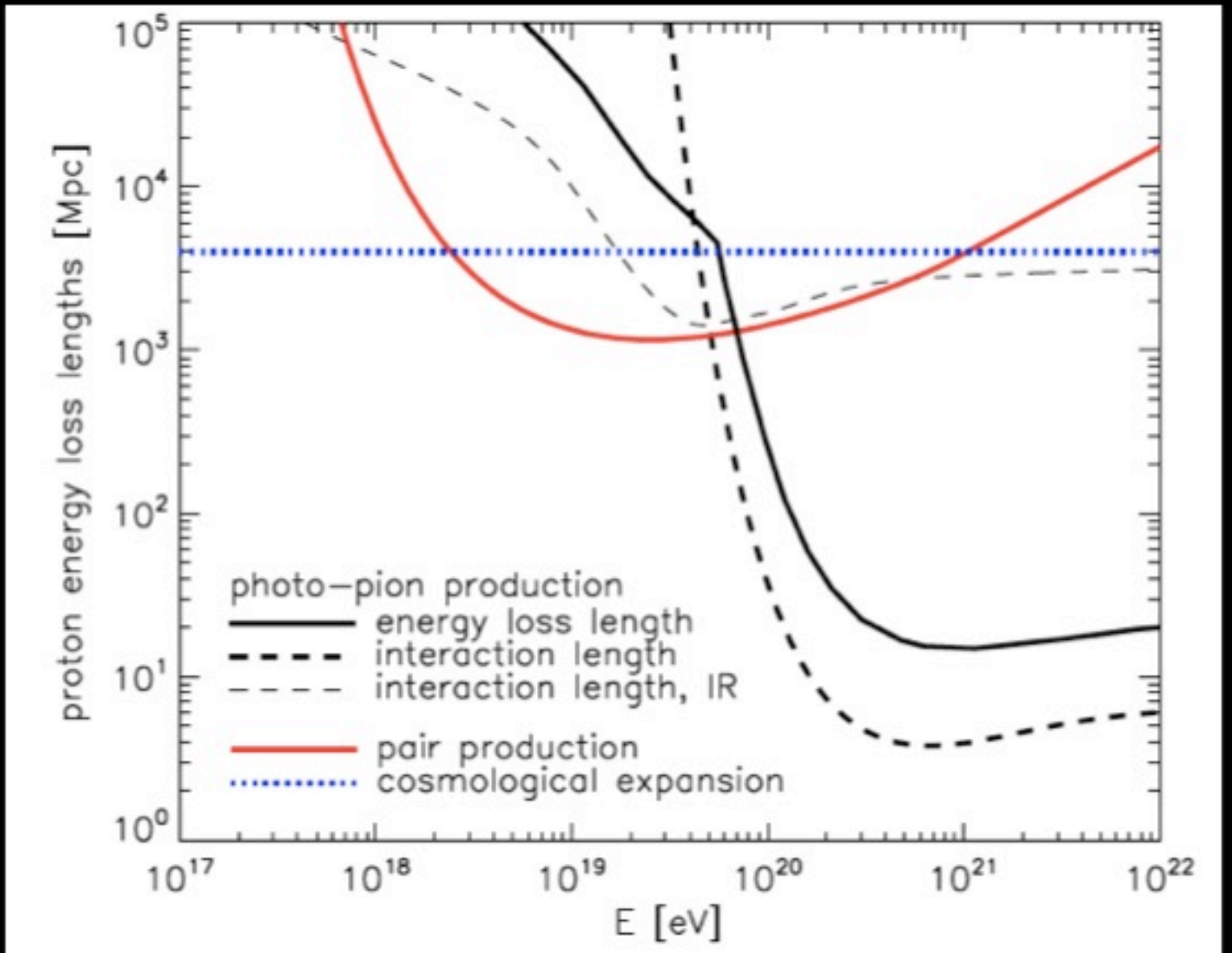
$$p + \gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0}$$
$$\rightarrow n + \pi^{+}$$

Proton Horizon
~5 x 10^{19} eV

GZK Cutoff

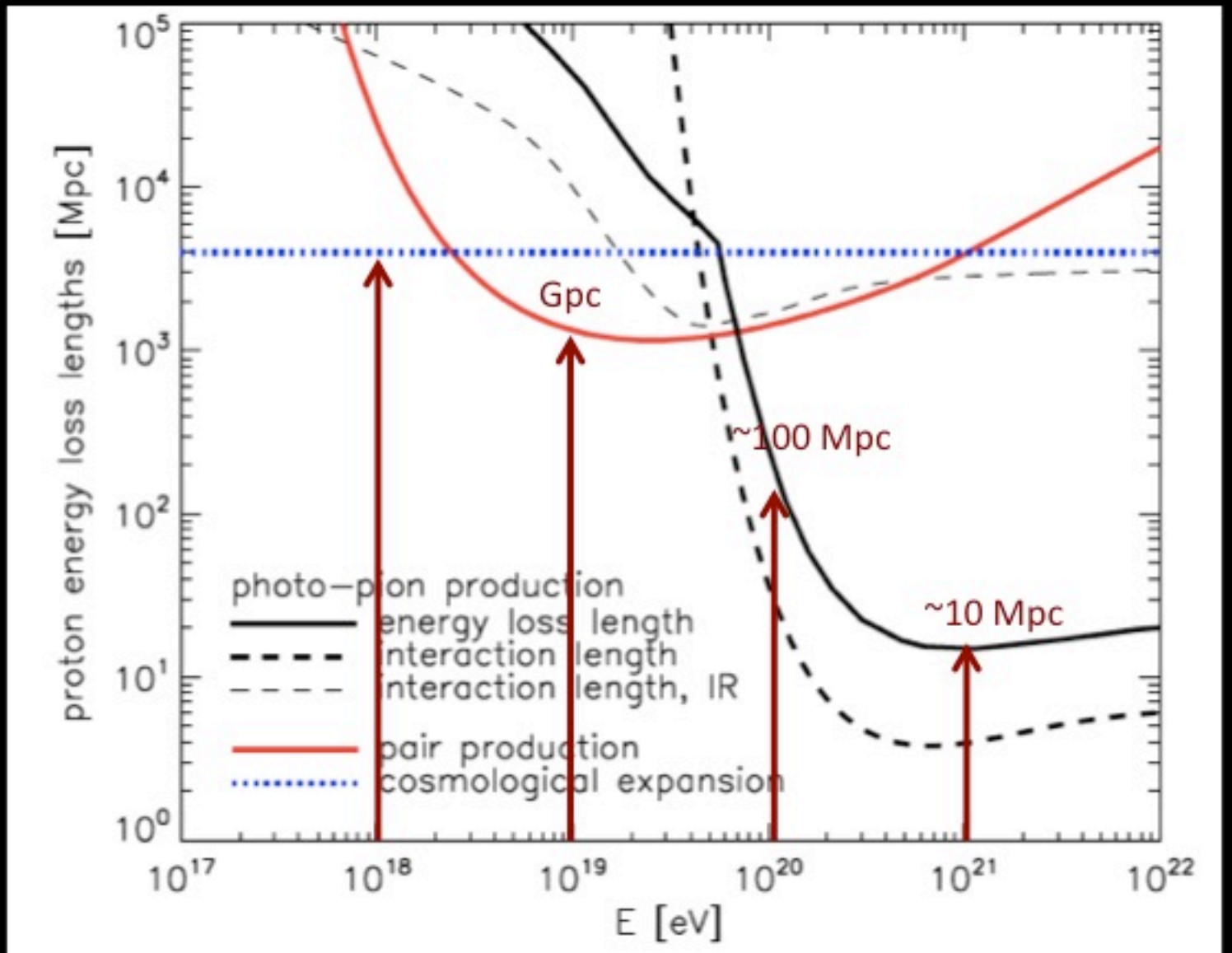
Greisen, Zatsepin, Kuzmin 1966

Greisen-Zatsepin-Kuzmin effect

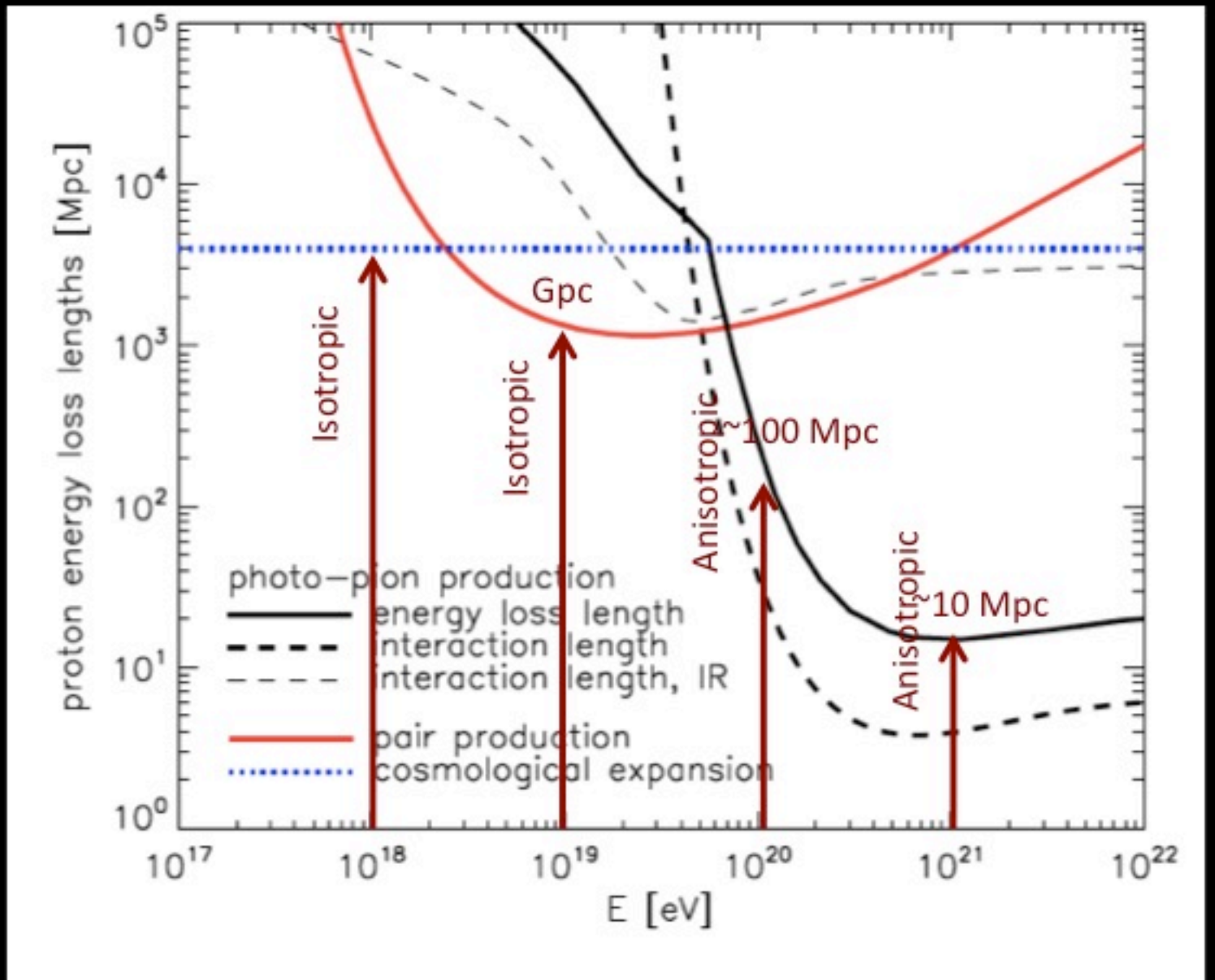


Kotera & AO 11

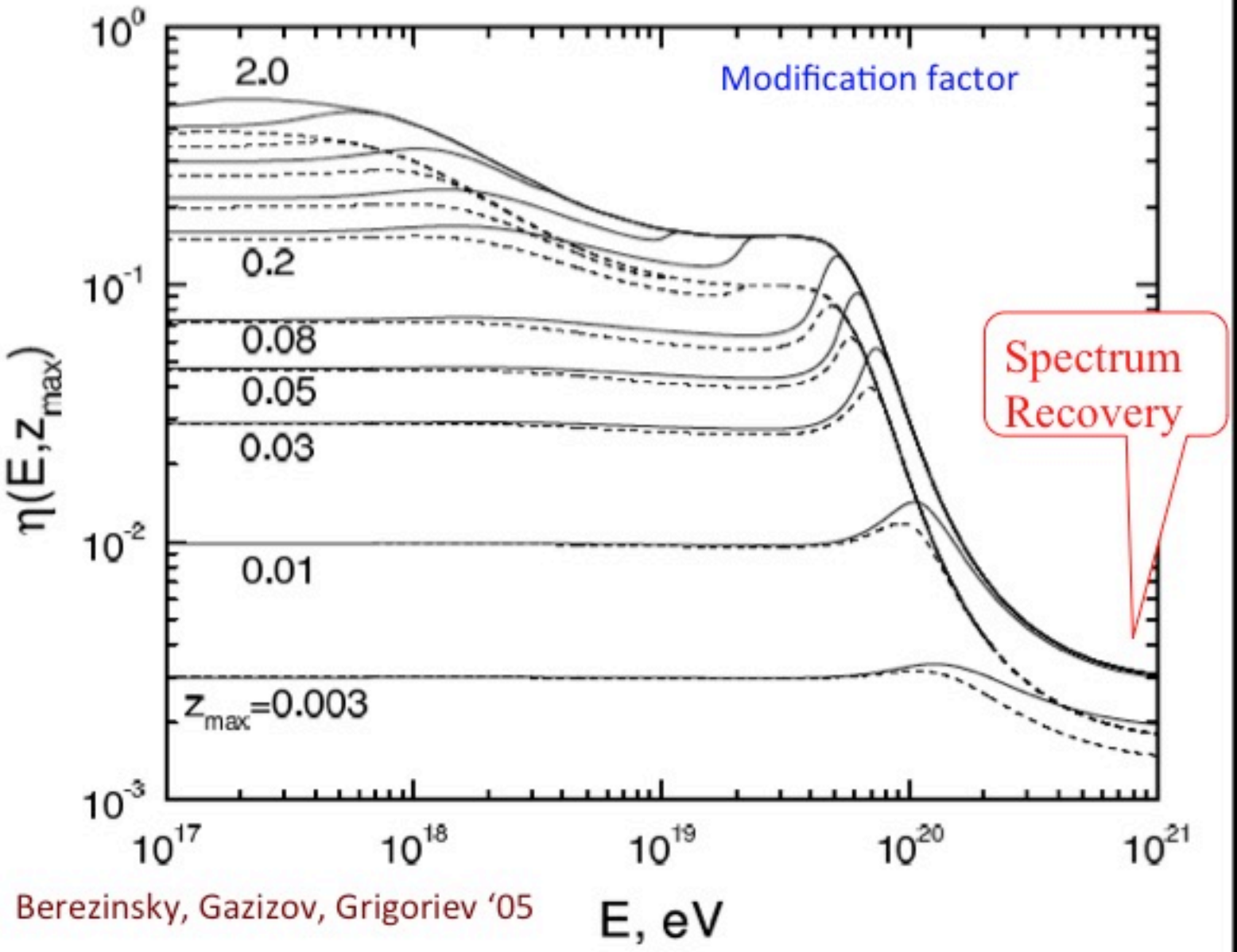
Greisen-Zatsepin-Kuzmin effect



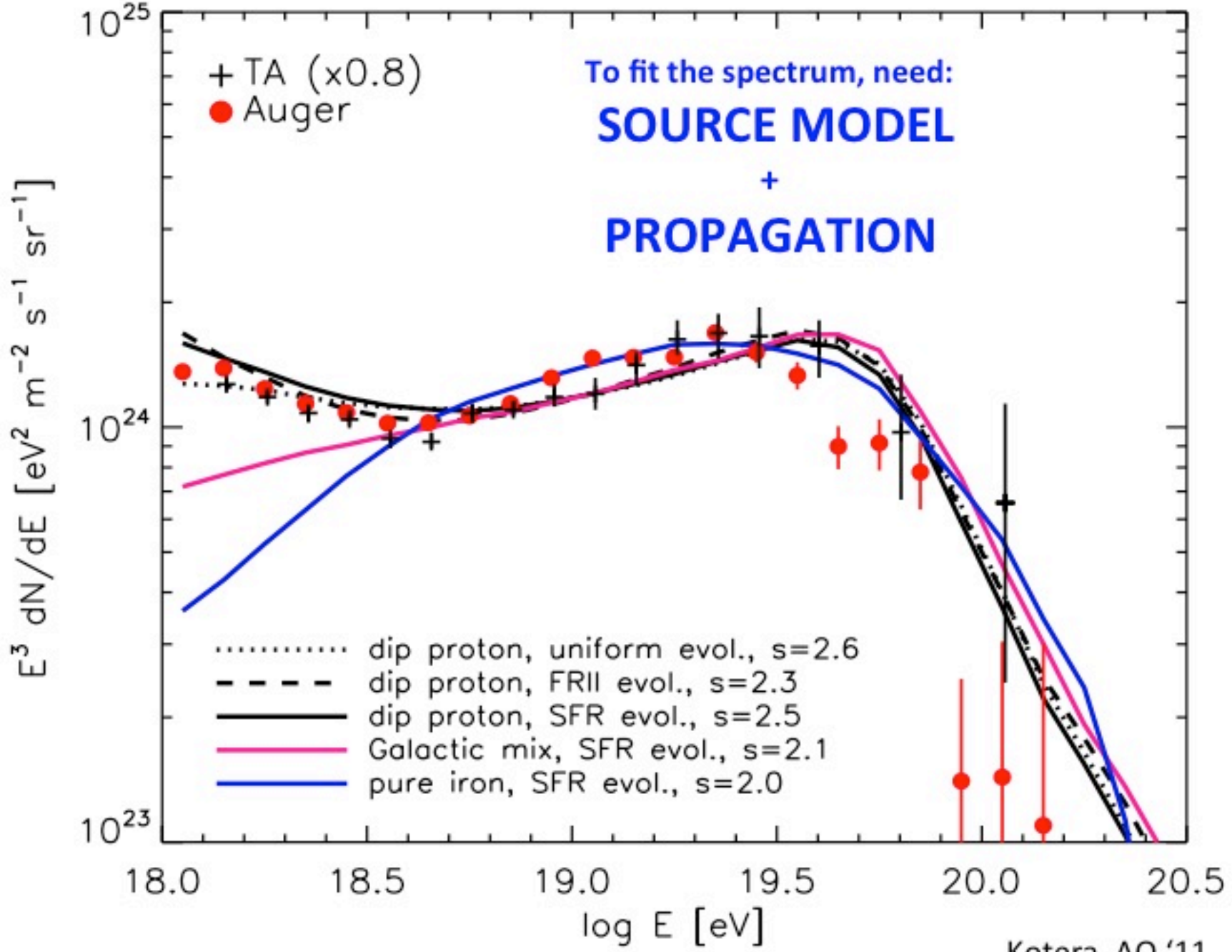
Greisen-Zatsepin-Kuzmin effect



Propagation of UHE protons

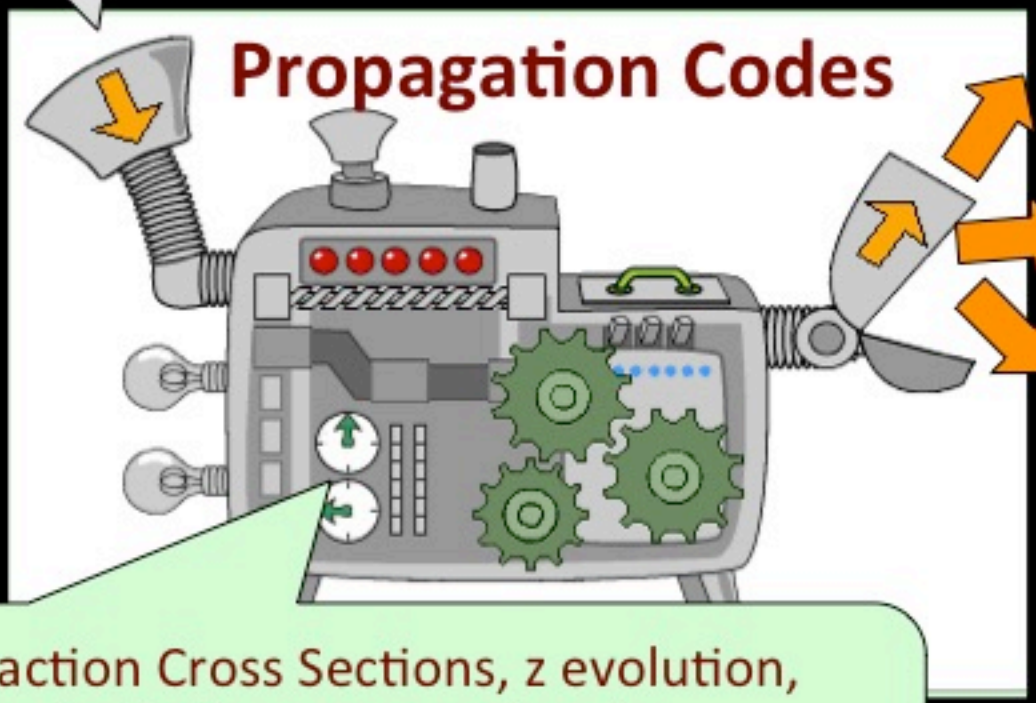


Berezinsky, Gazizov, Grigoriev '05


+ TA (x0.8)
● Auger
To fit the spectrum, need:
SOURCE MODEL
+
PROPAGATION
dip proton, uniform evol., s=2.6
dip proton, FRII evol., s=2.3
dip proton, SFR evol., s=2.5
Galactic mix, SFR evol., s=2.1
pure iron, SFR evol., s=2.0
E^3 dN/dE [eV^2 m^{-2} s^{-1} sr^{-1}]
10^{25}
10^{24}
10^{23}
18.0
18.5
19.0
19.5
20.0
20.5
log E [eV]
Kotera, AO '11

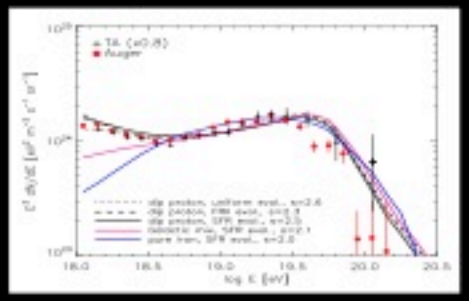
Source Model:

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

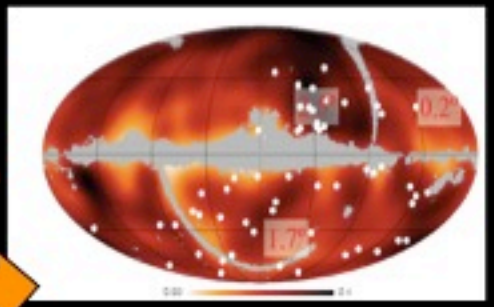


Interaction Cross Sections, z evolution, Intergal B fields, CMB, UV/Opt/IR background, Primary, Secondary nuclei, nucleons, e+e-, gamma-rays, neutrinos,...

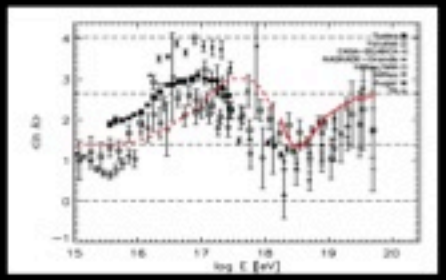
Spectrum



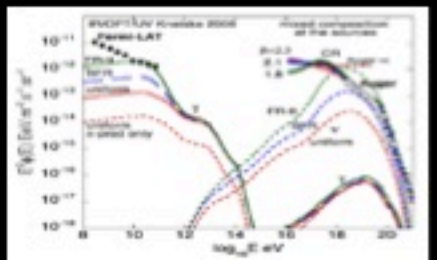
Anisotropies

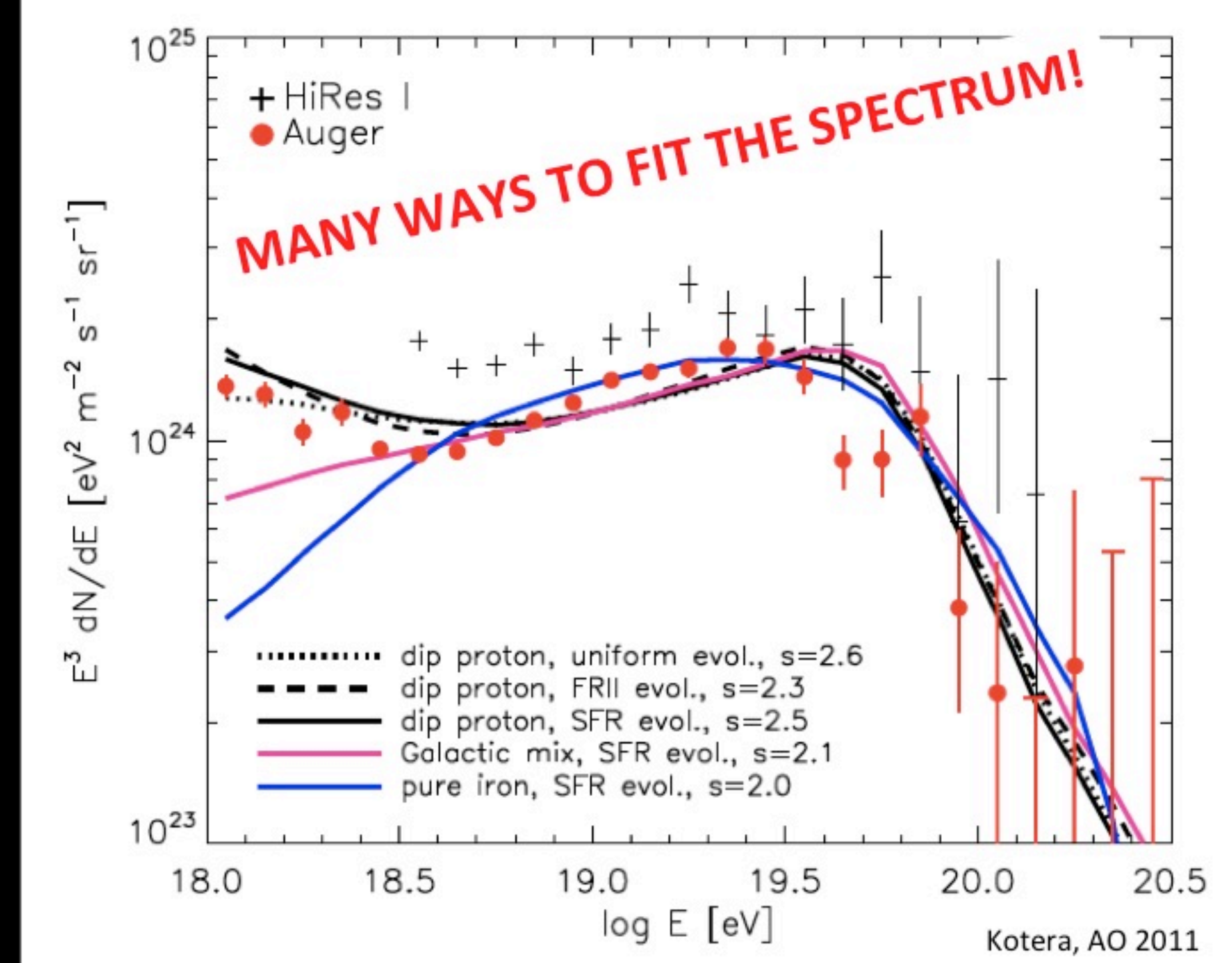


Composition



Multi-messengers




MANY WAYS TO FIT THE SPECTRUM!
HiRes I
Auger
dip proton, uniform evol., s=2.6
dip proton, FRII evol., s=2.3
dip proton, SFR evol., s=2.5
Galactic mix, SFR evol., s=2.1
pure iron, SFR evol., s=2.0
E^3 dN/dE [eV^2 m^{-2} s^{-1} sr^{-1}]
10^{25}
10^{24}
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18.5
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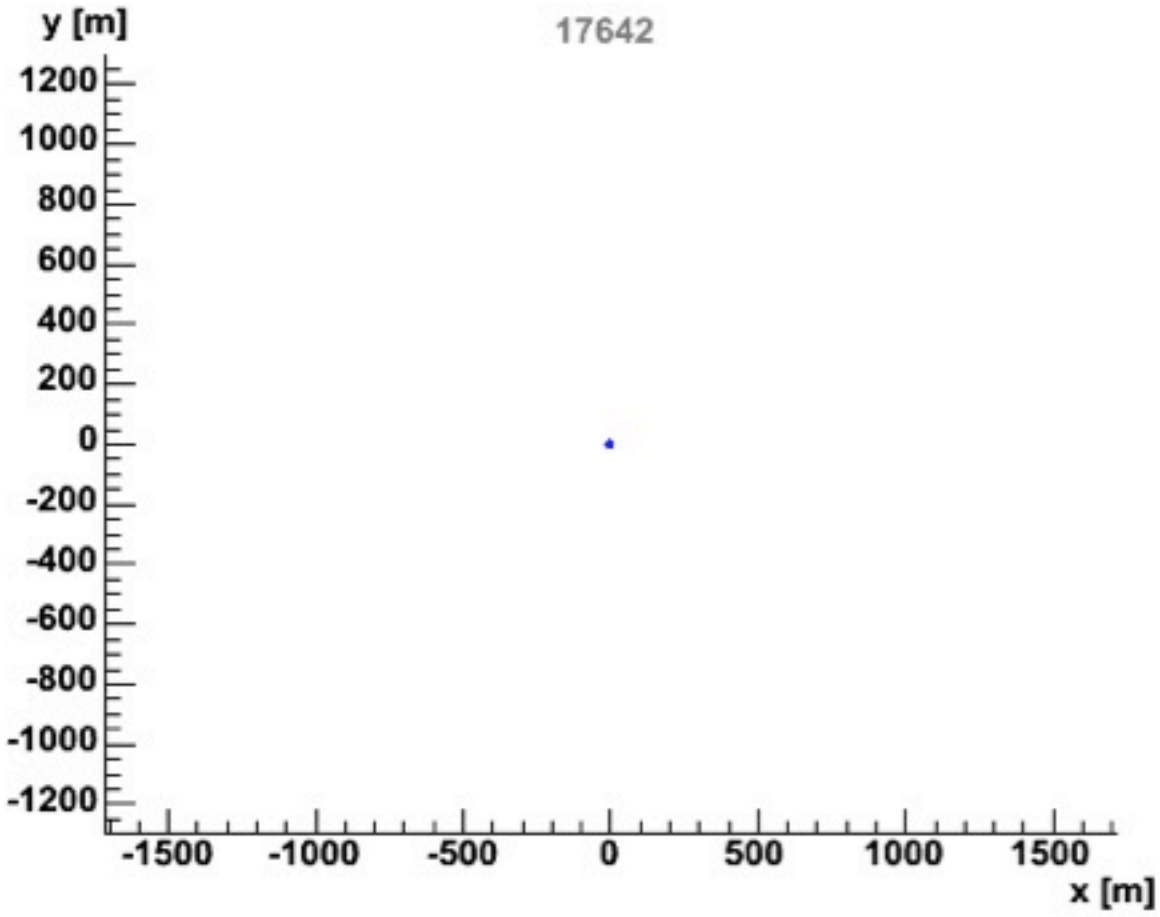
19.5
20.0
20.5
log E [eV]
Kotera, AO 2011

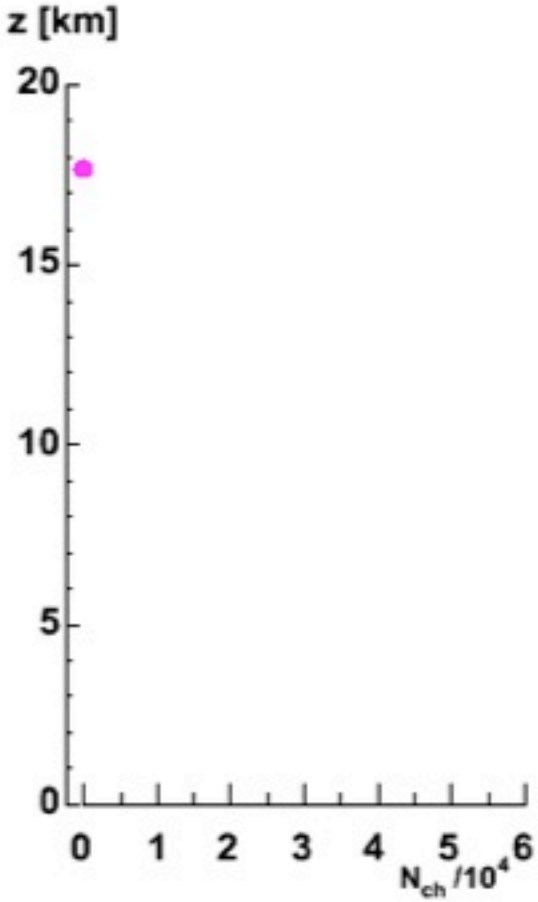
UHECRs Current Status

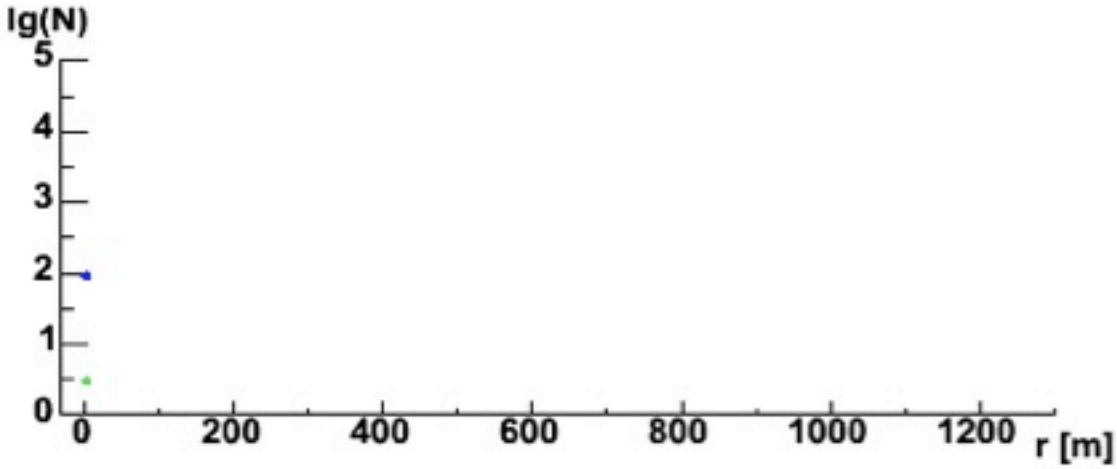
Leading Observatories: Auger & Telescope Array agree on the shape of the spectrum

Energy scale: ~10% difference

Composition?







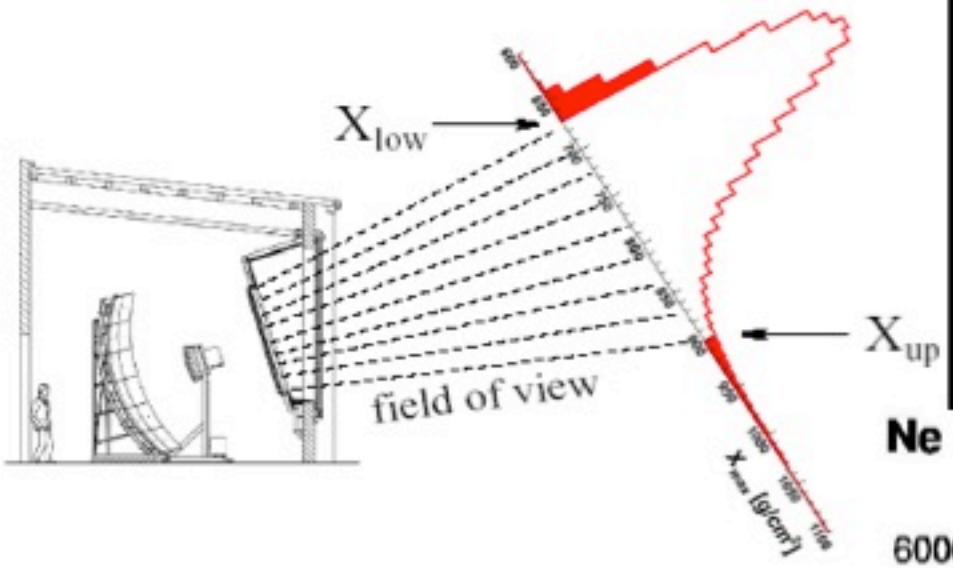
Proton 10^{14} eV

h^{1st} = 17642 m

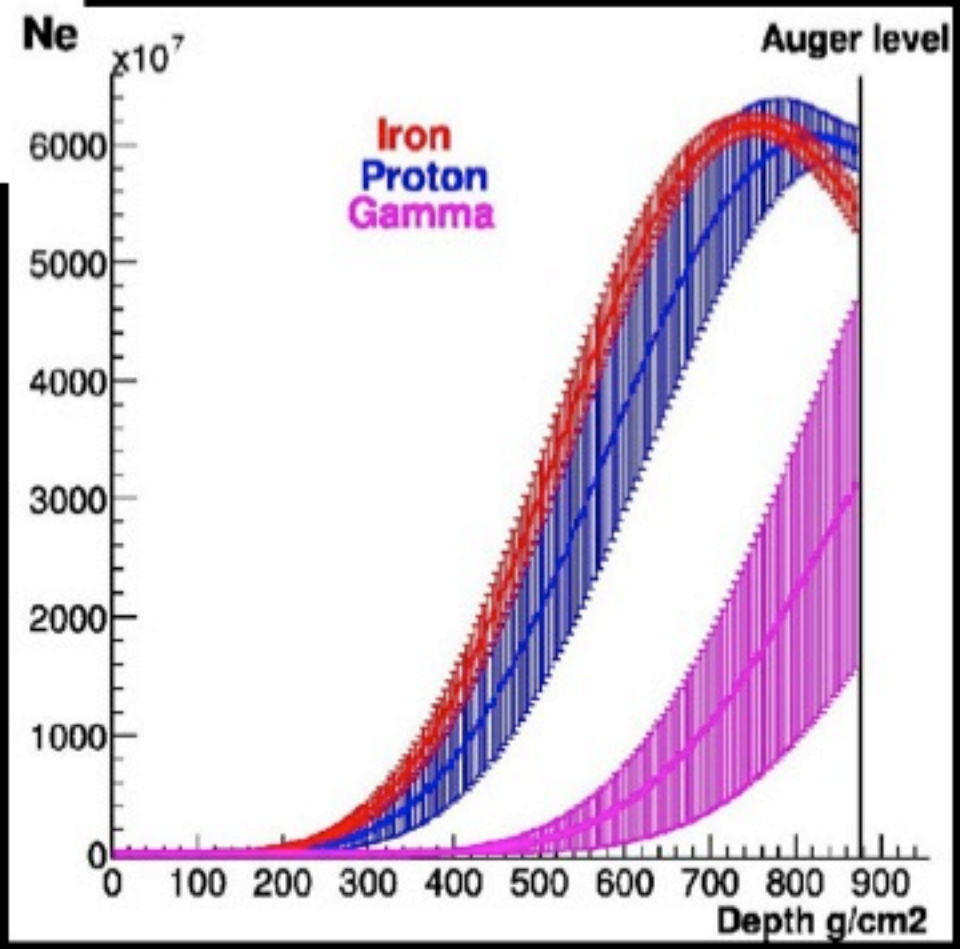
hadrons muons

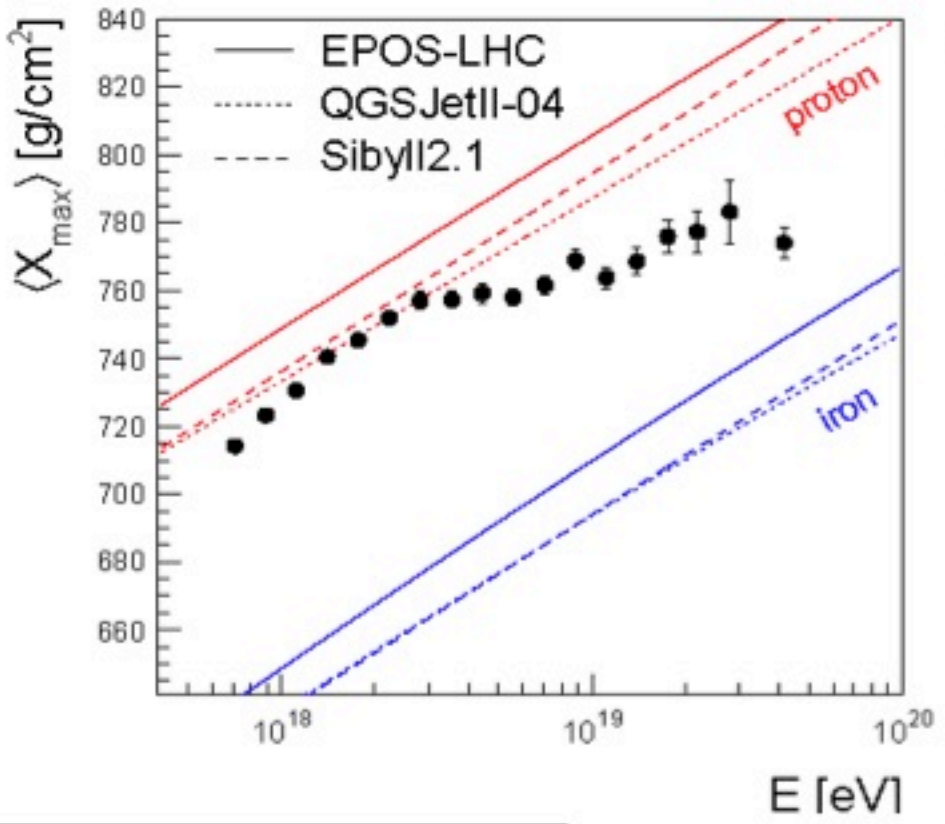
neutrons **electrs**

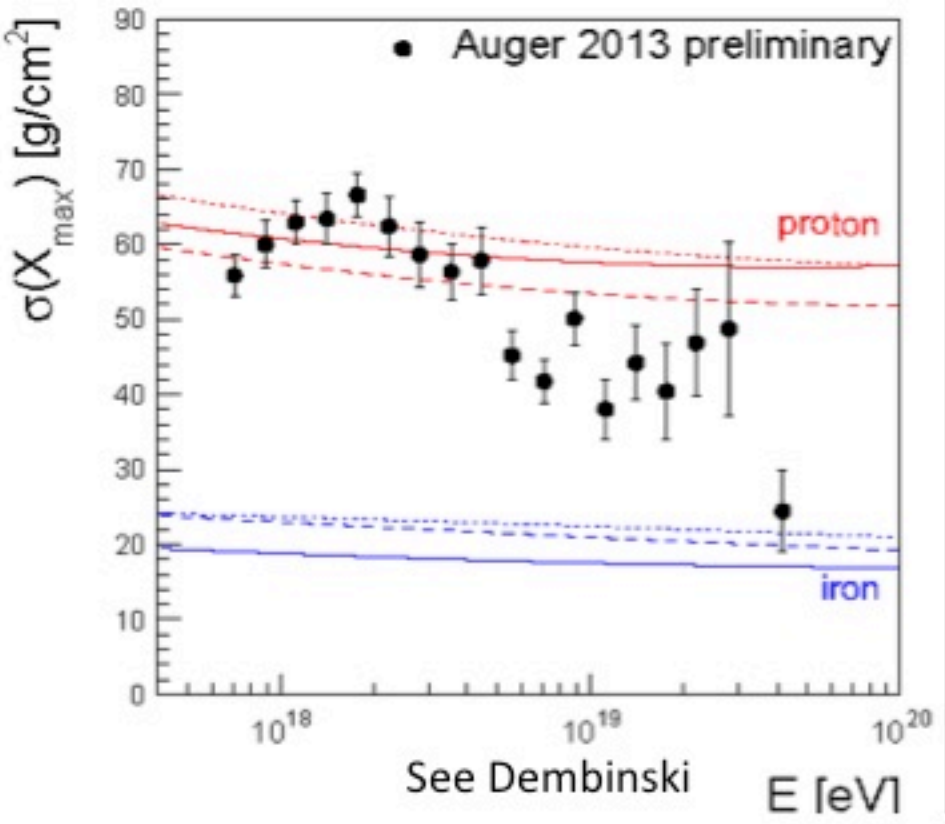
J.Oehlschlaeger,R.Engel,FZKarlsruhe



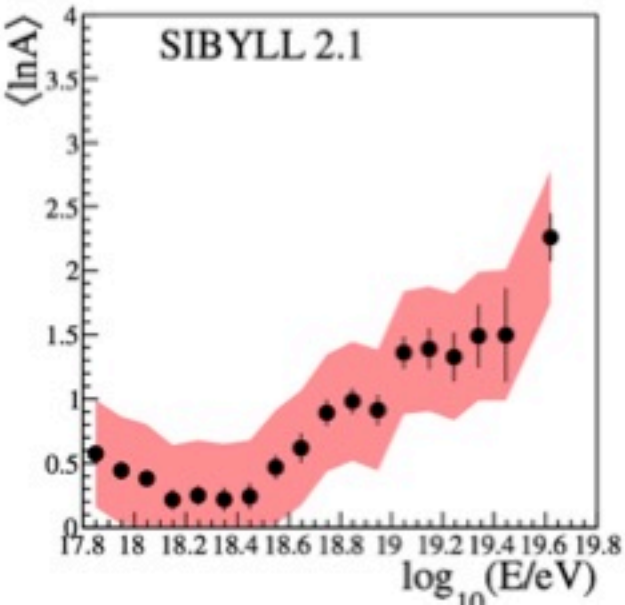
Composition observable: shower maximum average and fluctuations

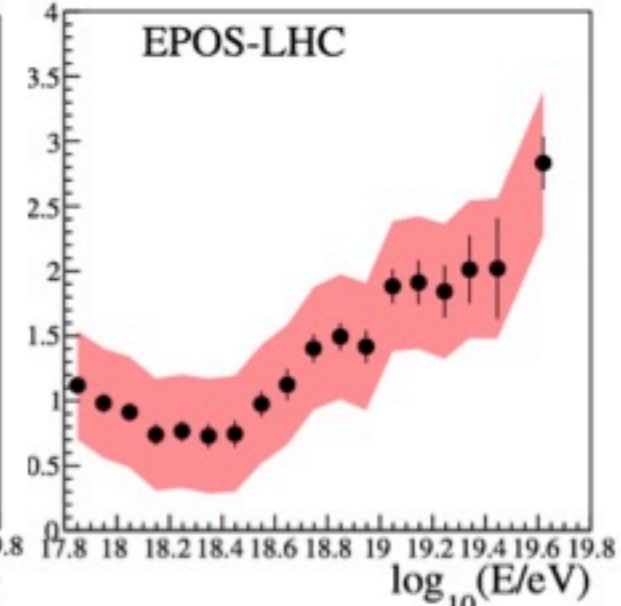


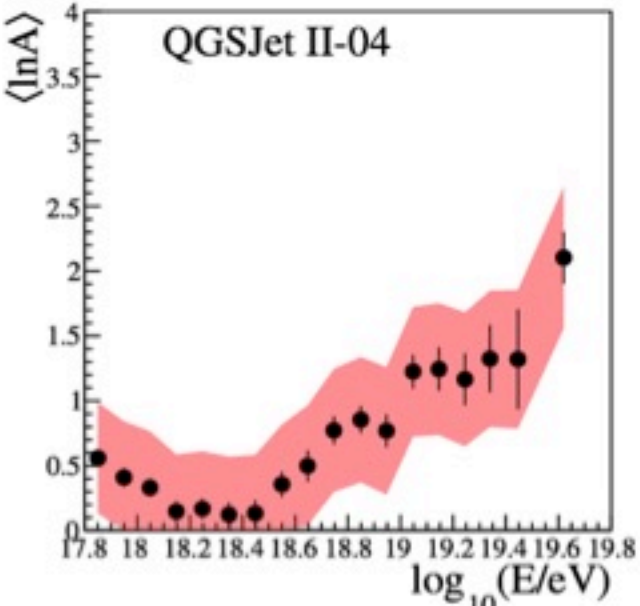


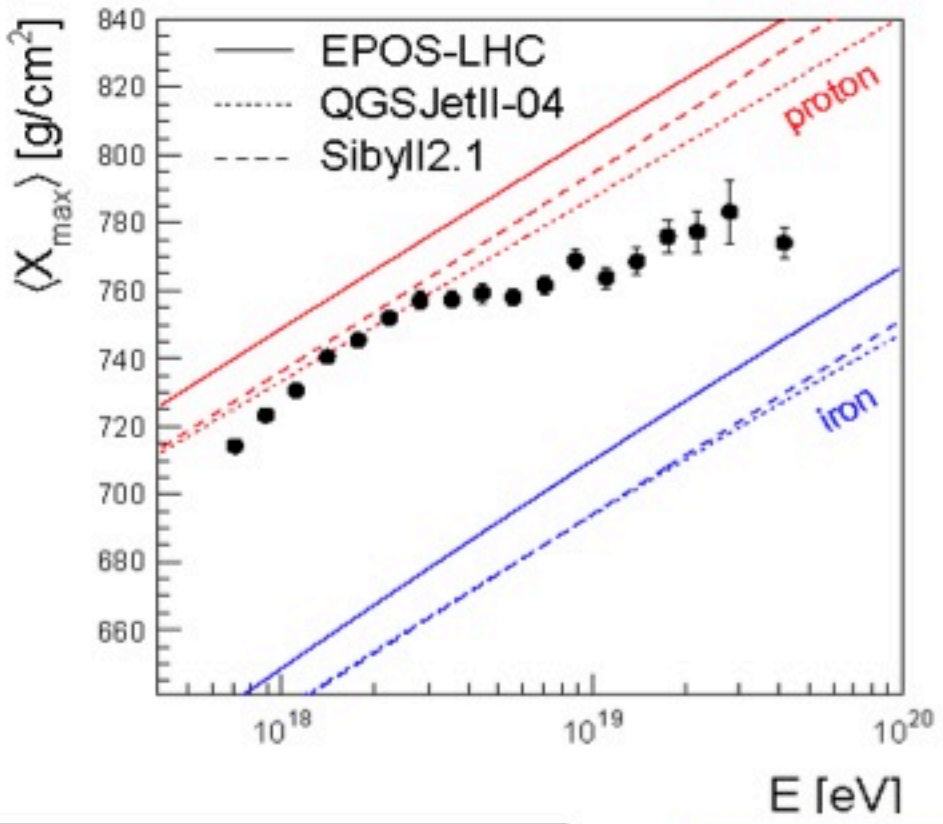


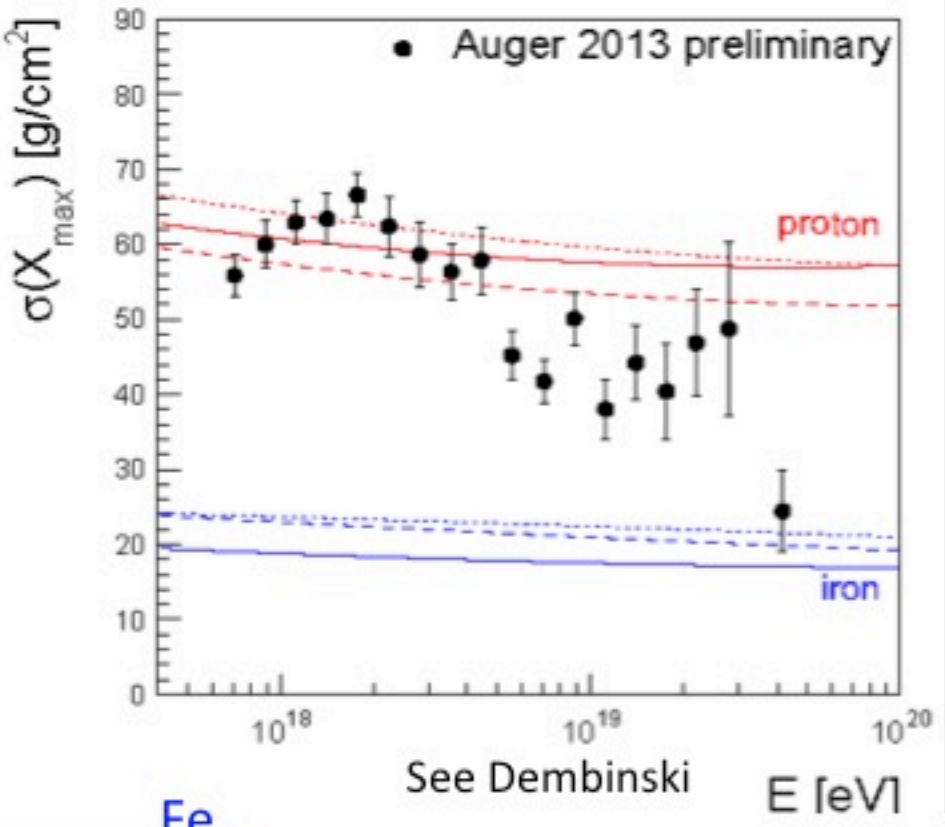
See Dembinski



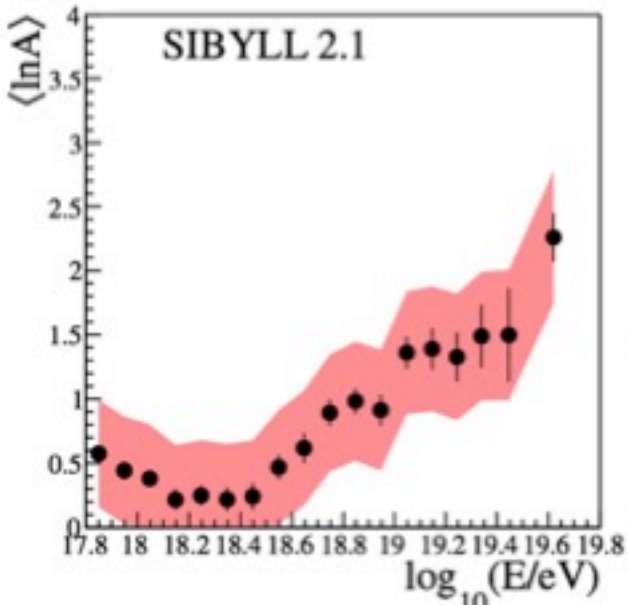


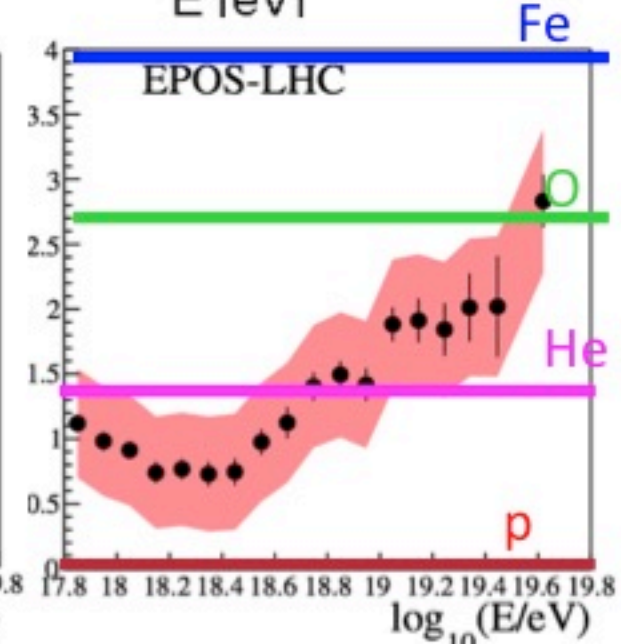


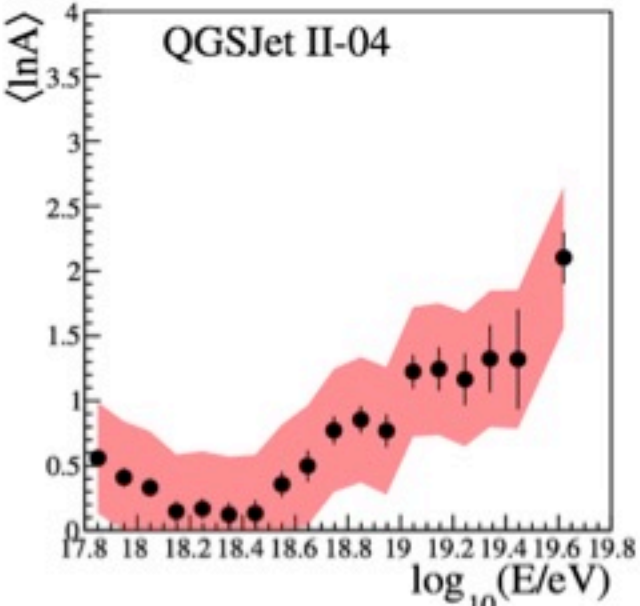


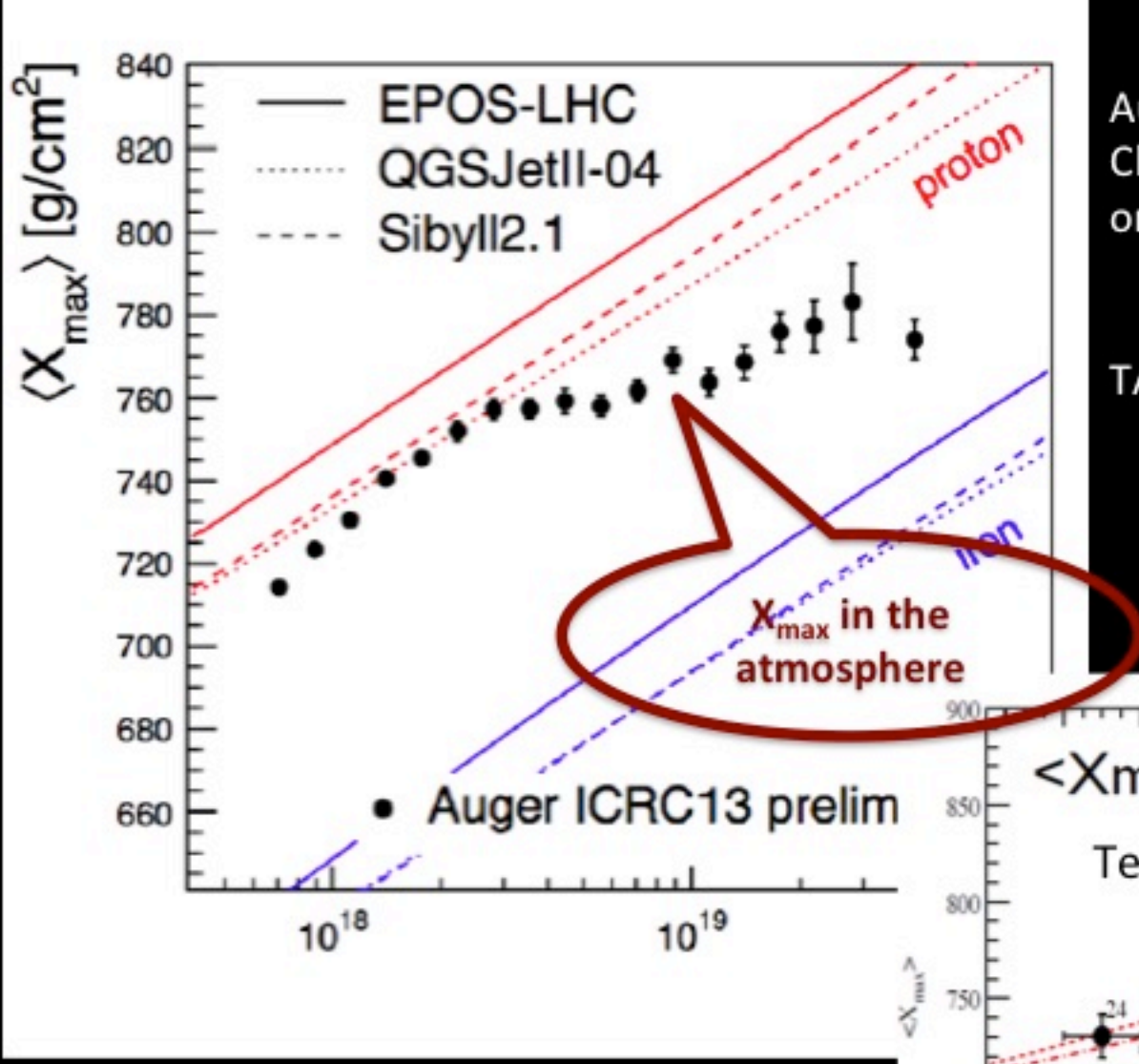


See Dembinski



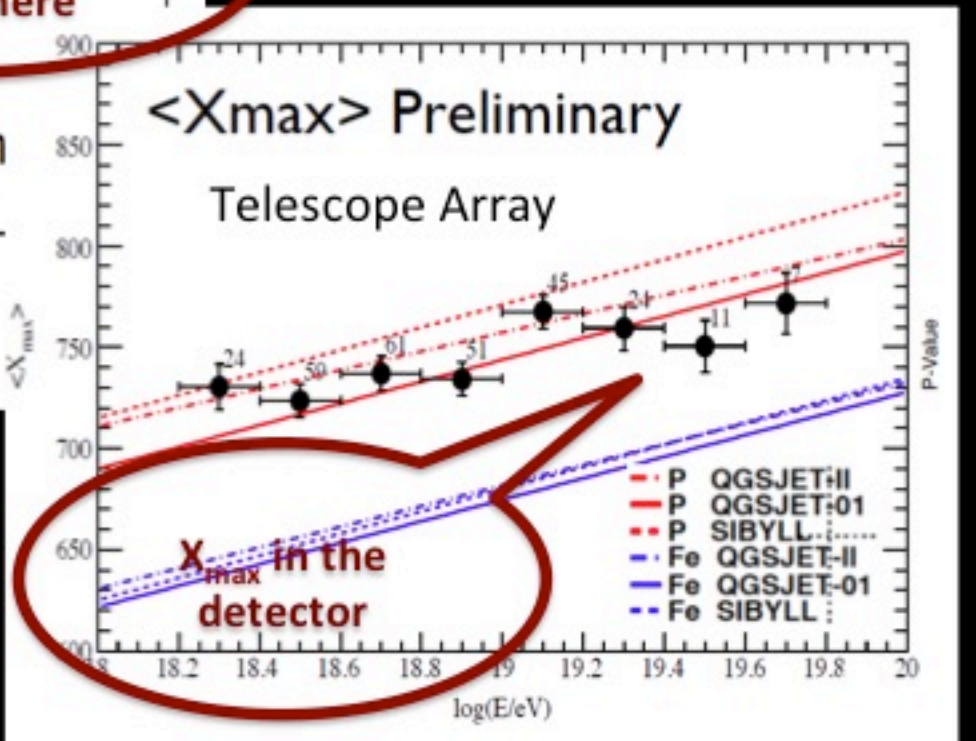




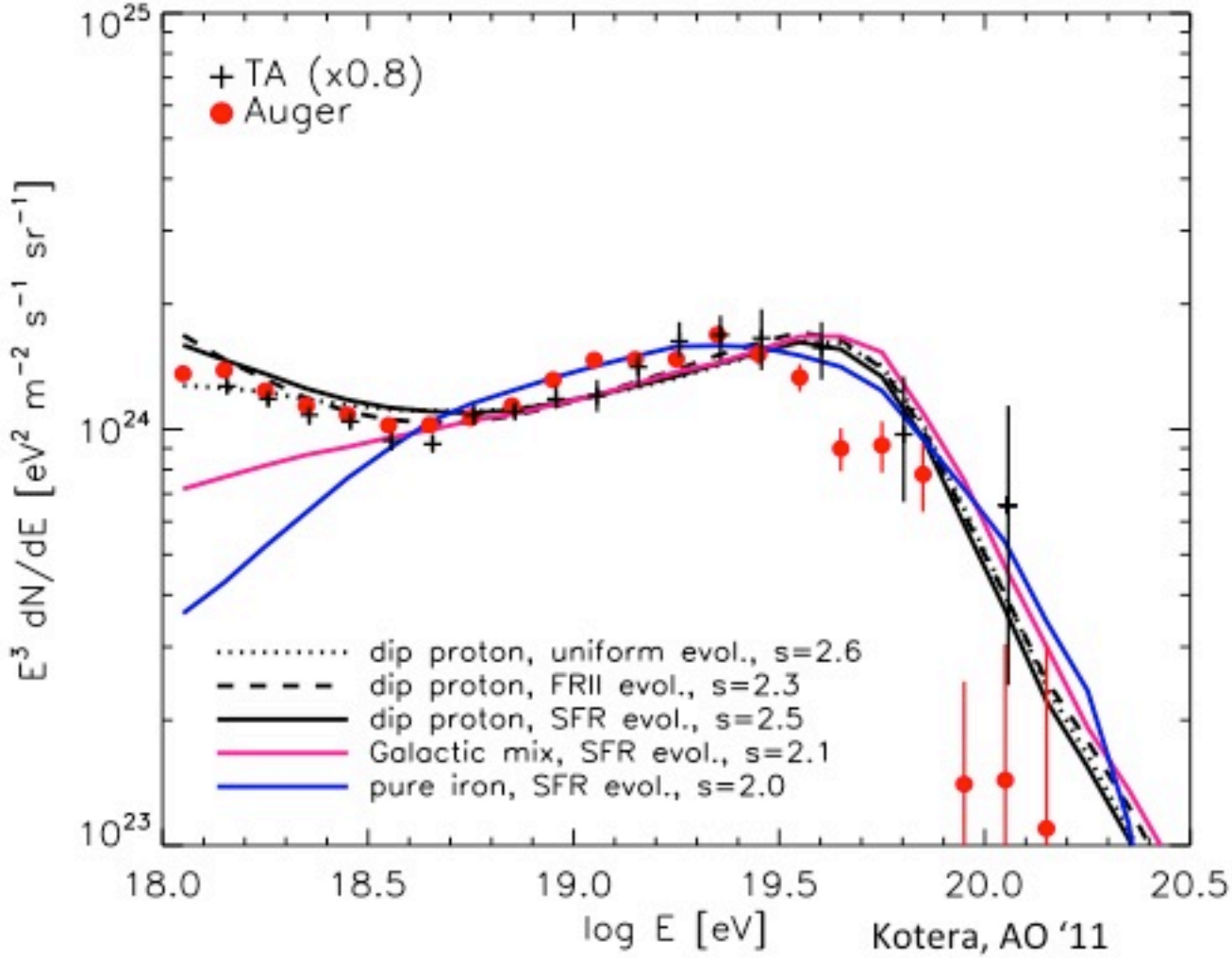


Auger sees change slope:
Change in Composition
or interactions

TA: not confirmed yet



GZK ?


+ TA (x0.8)
● Auger
dip proton, uniform evol., s=2.6
dip proton, FRII evol., s=2.3
dip proton, SFR evol., s=2.5
Galactic mix, SFR evol., s=2.1
pure iron, SFR evol., s=2.0
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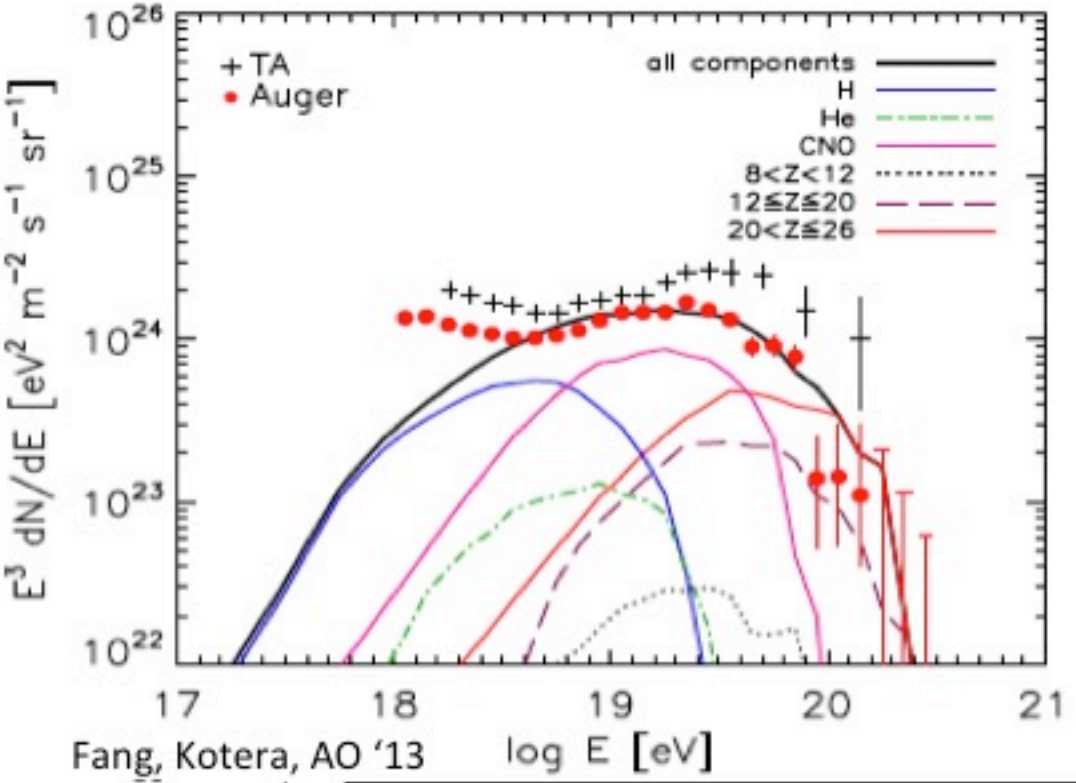
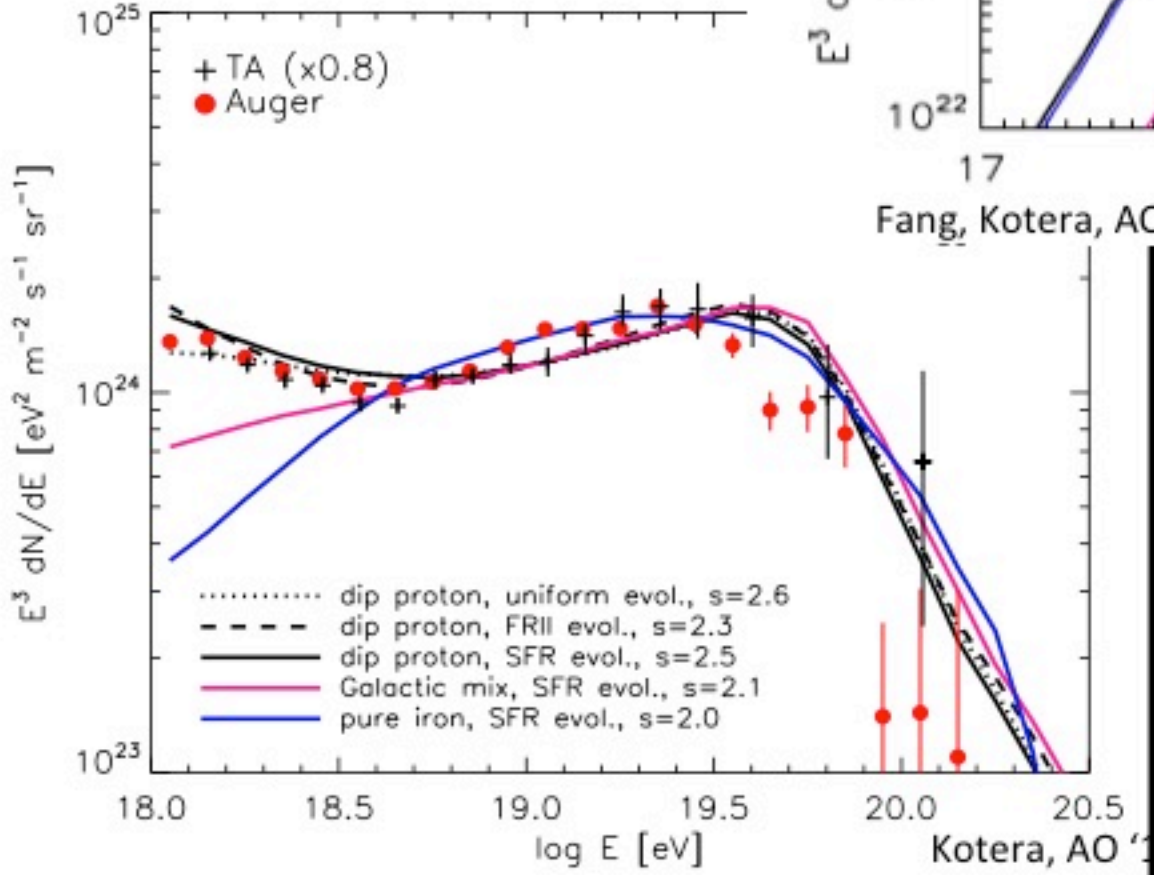
E^3 dN/dE [eV^2 m^{-2} s^{-1} sr^{-1}]
18.0
18.5
19.0
19.5
20.0
20.5
log E [eV]
Kotera, AO '11

GZK or E_{max}?

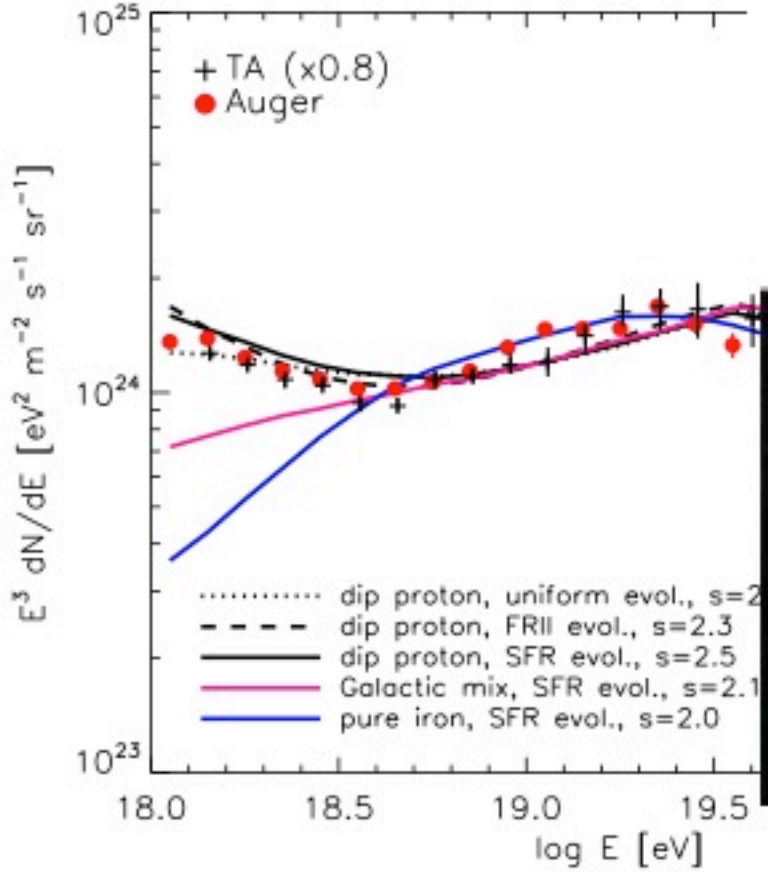


Fang, Kotera, AO '13

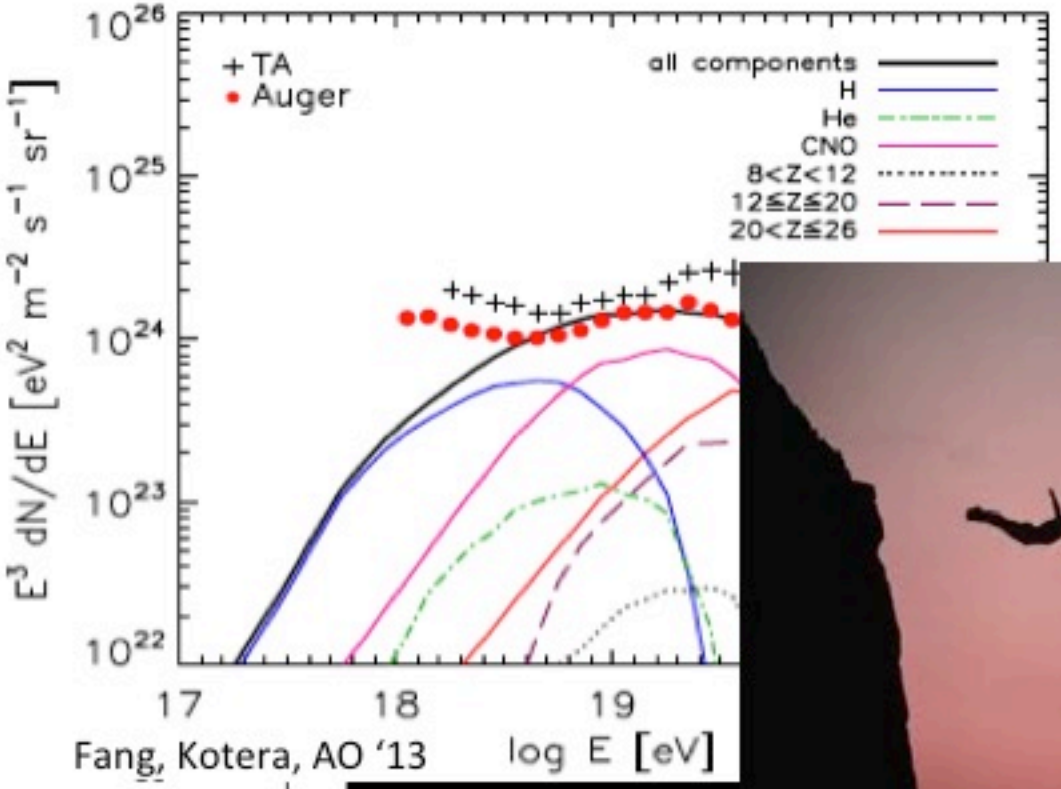


Kotera, AO '1

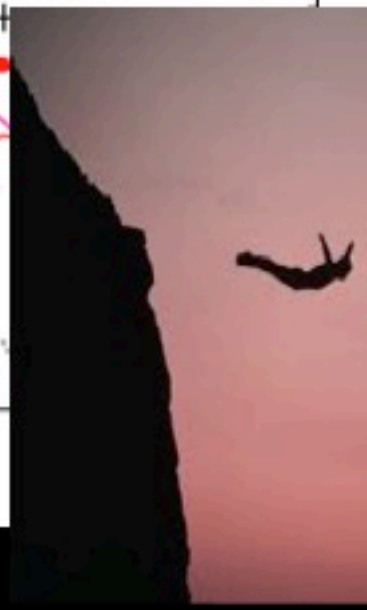
GZK vs E_{max}

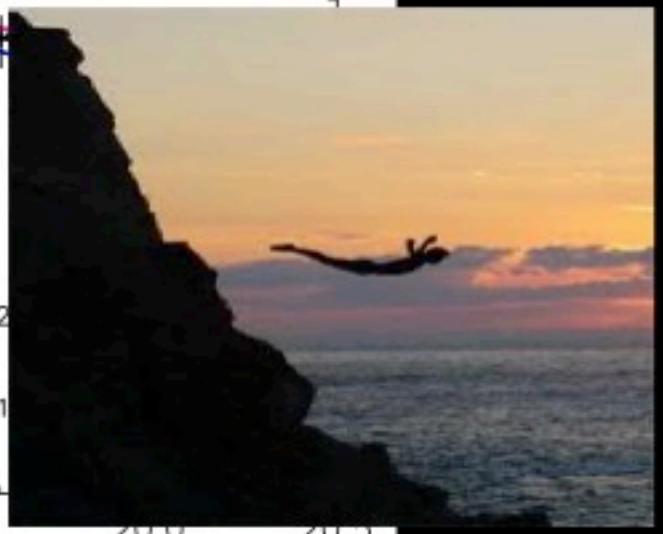


Kotera, AO '11

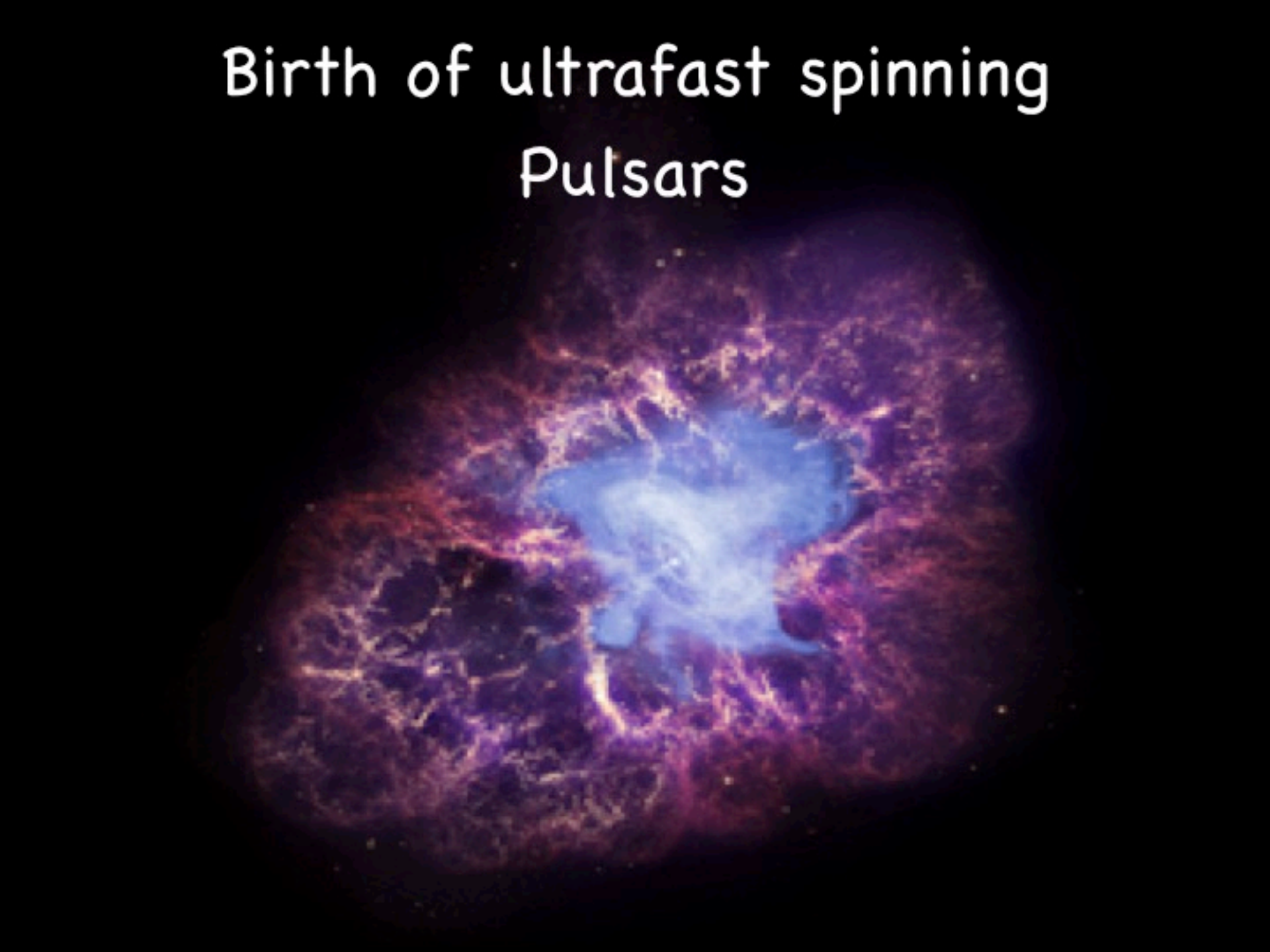


Fang, Kotera, AO '13

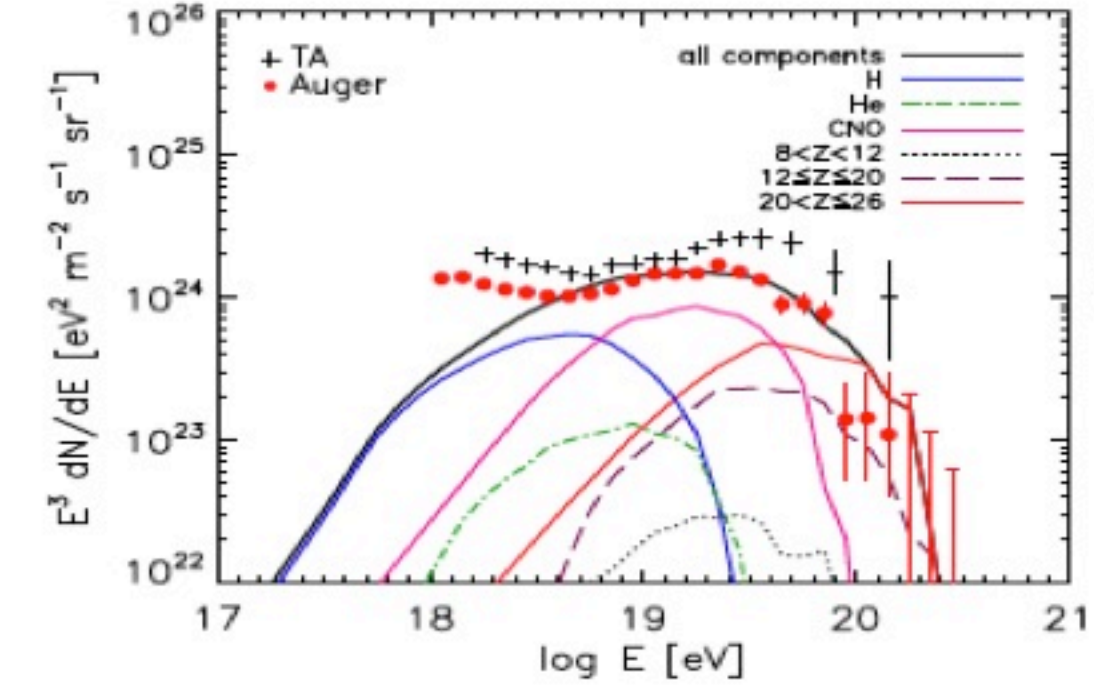


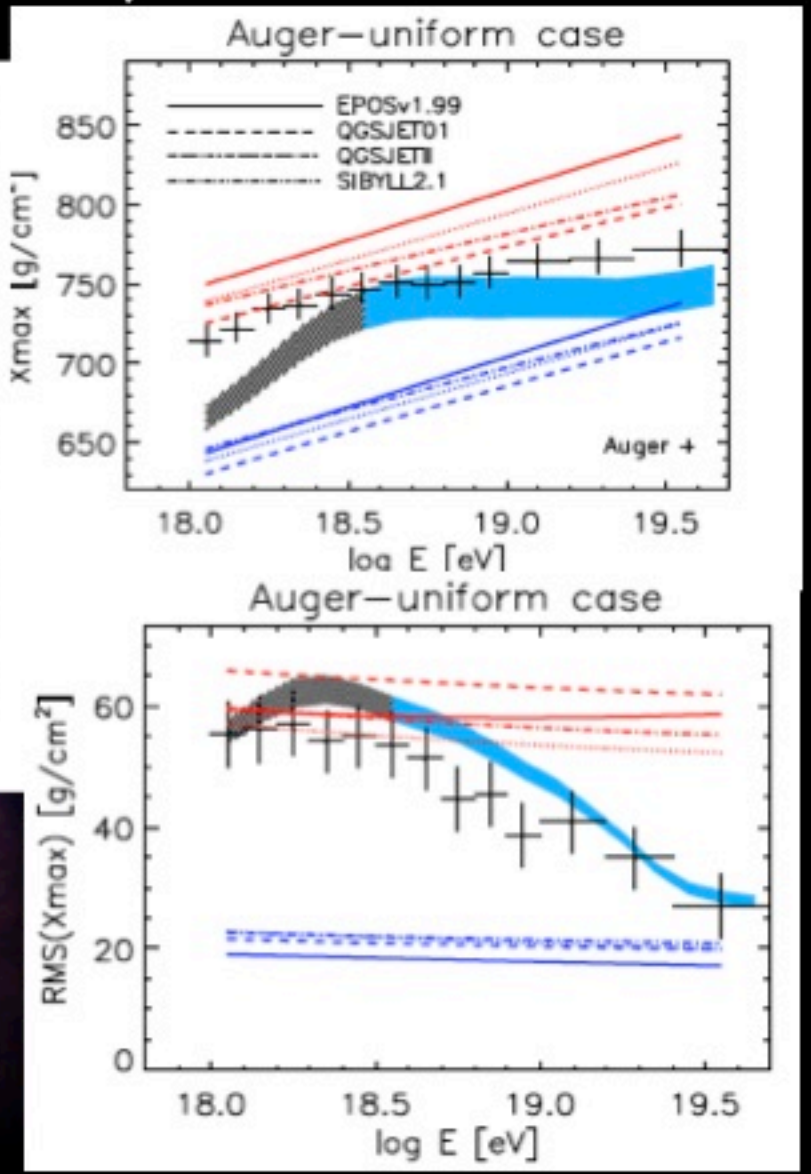


Birth of ultrafast spinning Pulsars



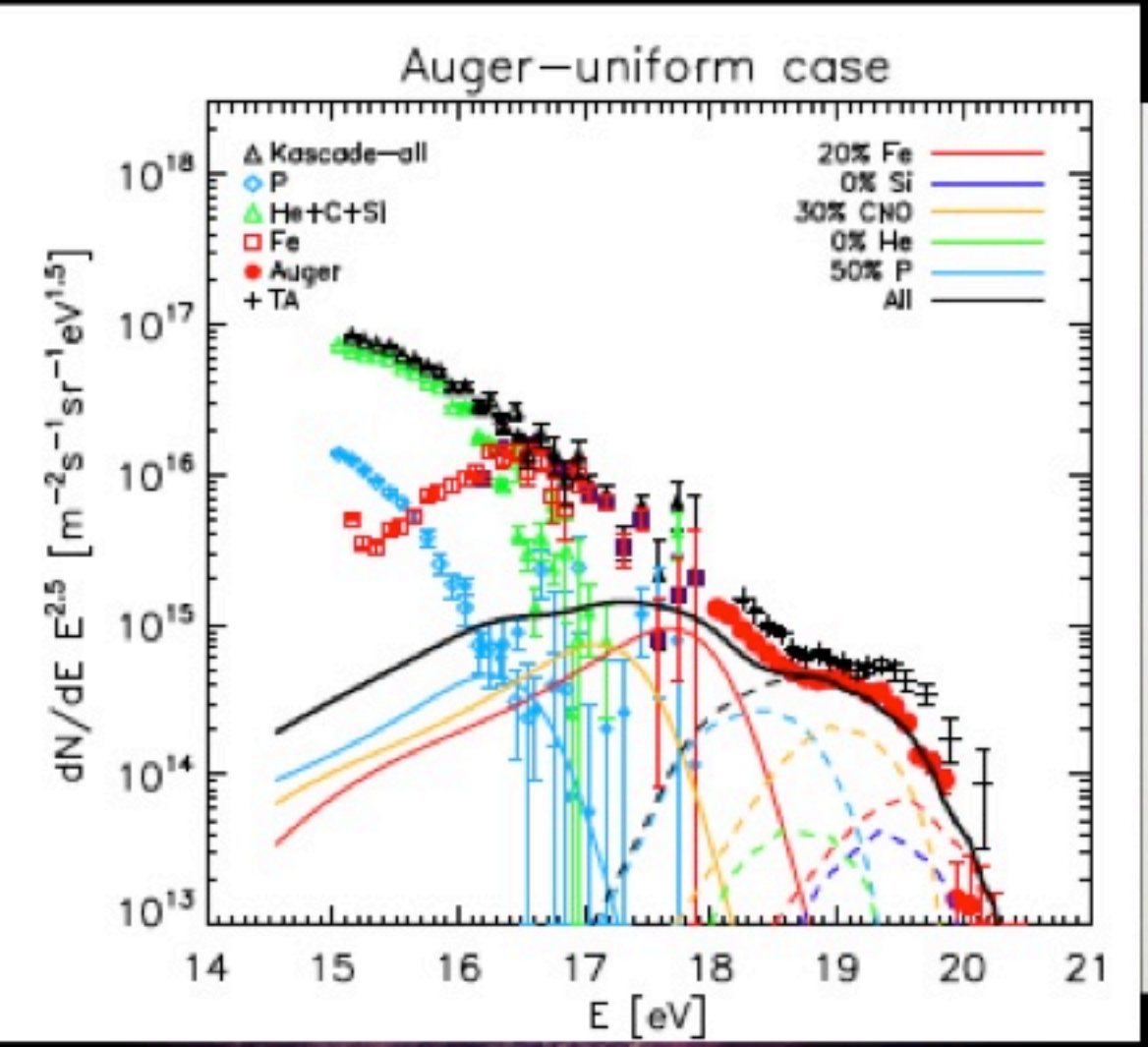
Fast Spinning Newborn Pulsars fit Spectrum & Auger Composition !

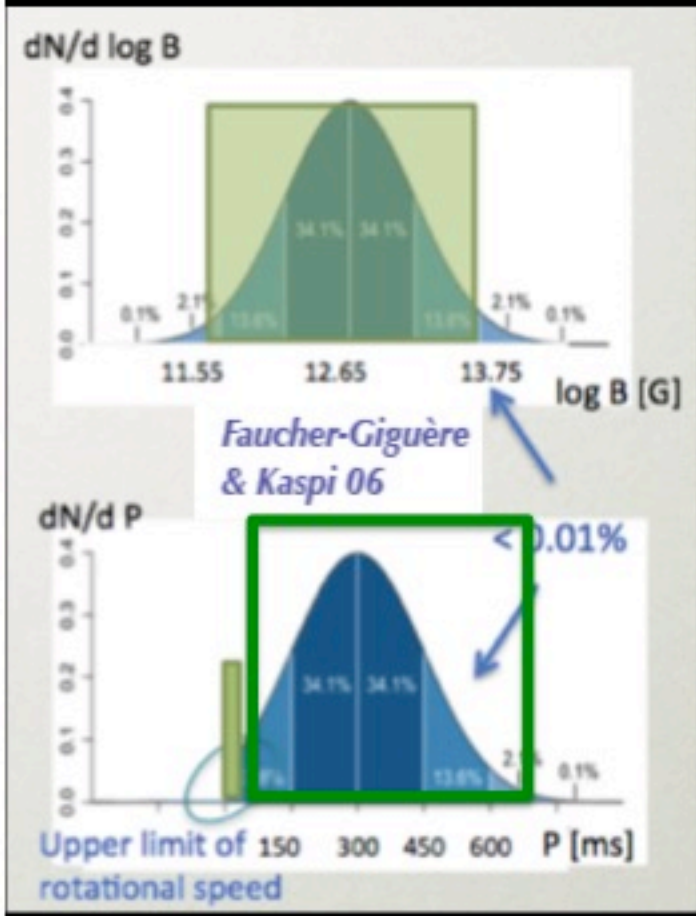




Fang, Kotera, AVO '13

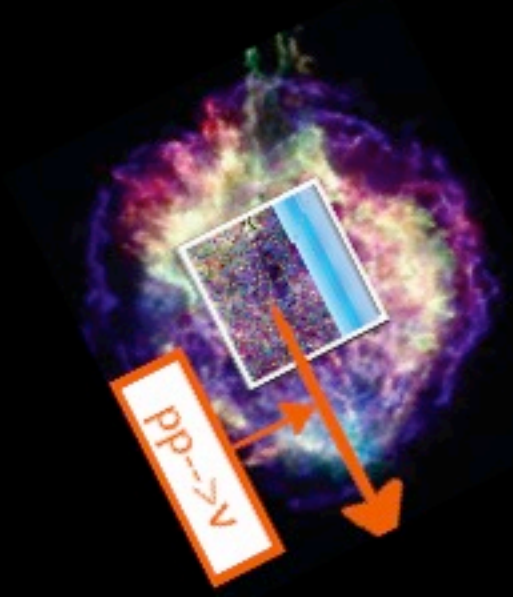
Galactic Newborn Pulsars?

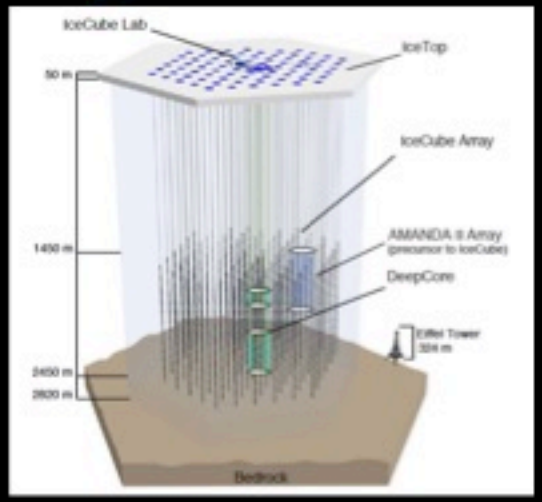


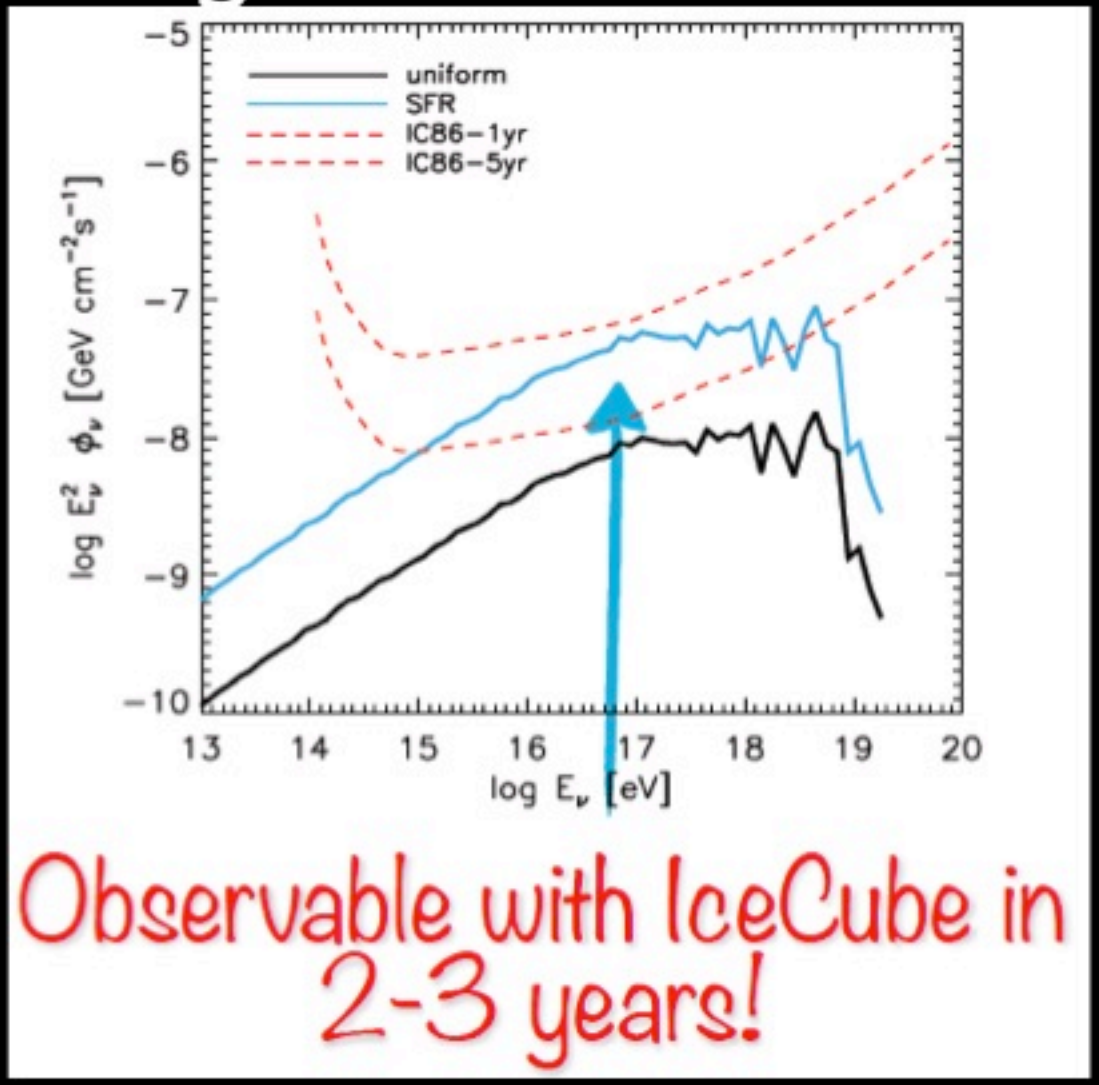


Fang, Kotera, AVO '13

Multi-messenger Predictions







Observable with IceCube in 2-3 years!

Fang, Kotera, Murase, AVO '13

UHECRs Current Status

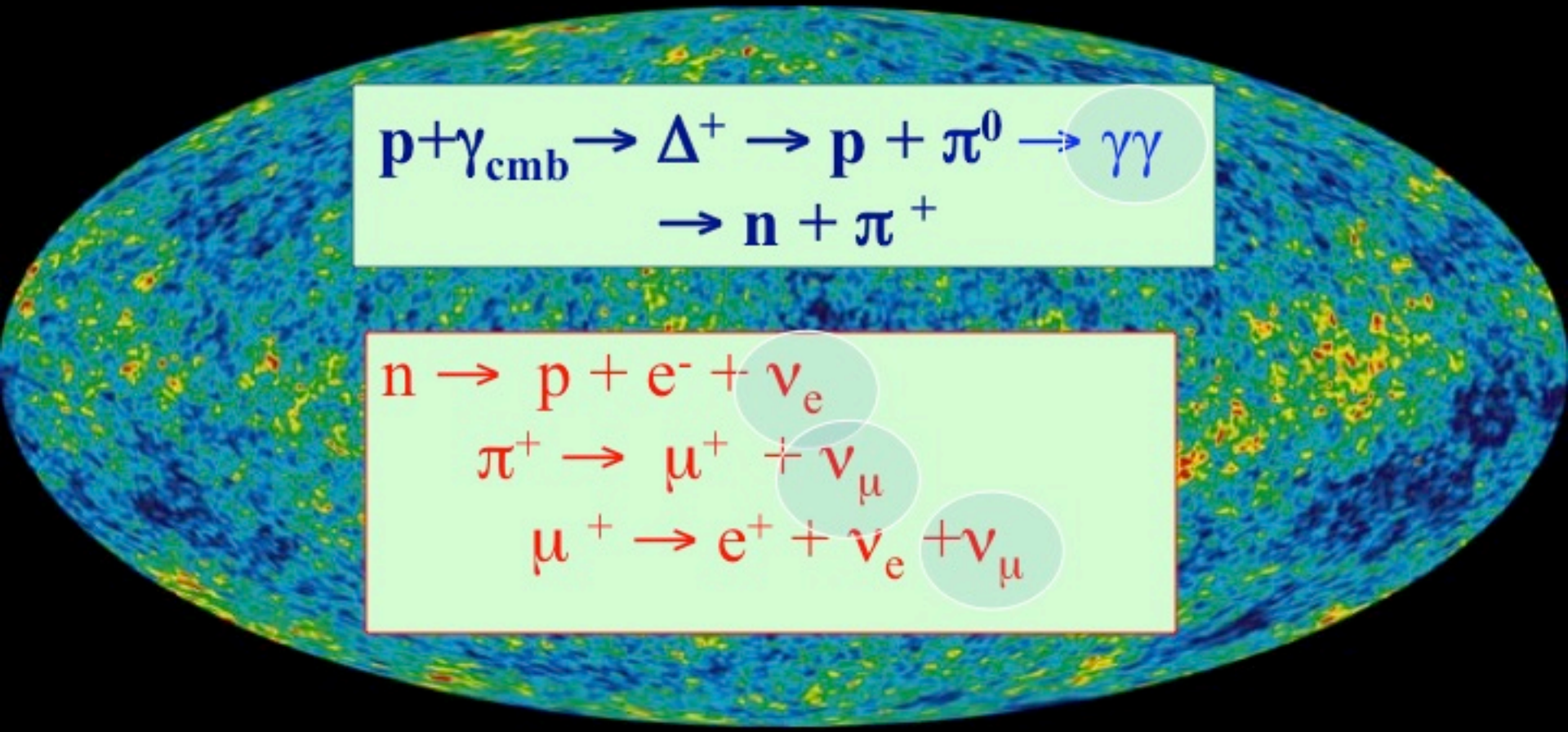
Leading Observatories: Auger & Telescope Array agree on the shape of the spectrum

Energy scale: ~10% difference

Composition: controversial

Multi-messenger clues

Cosmogenic (GZK, BZ*) Neutrinos & Photons



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

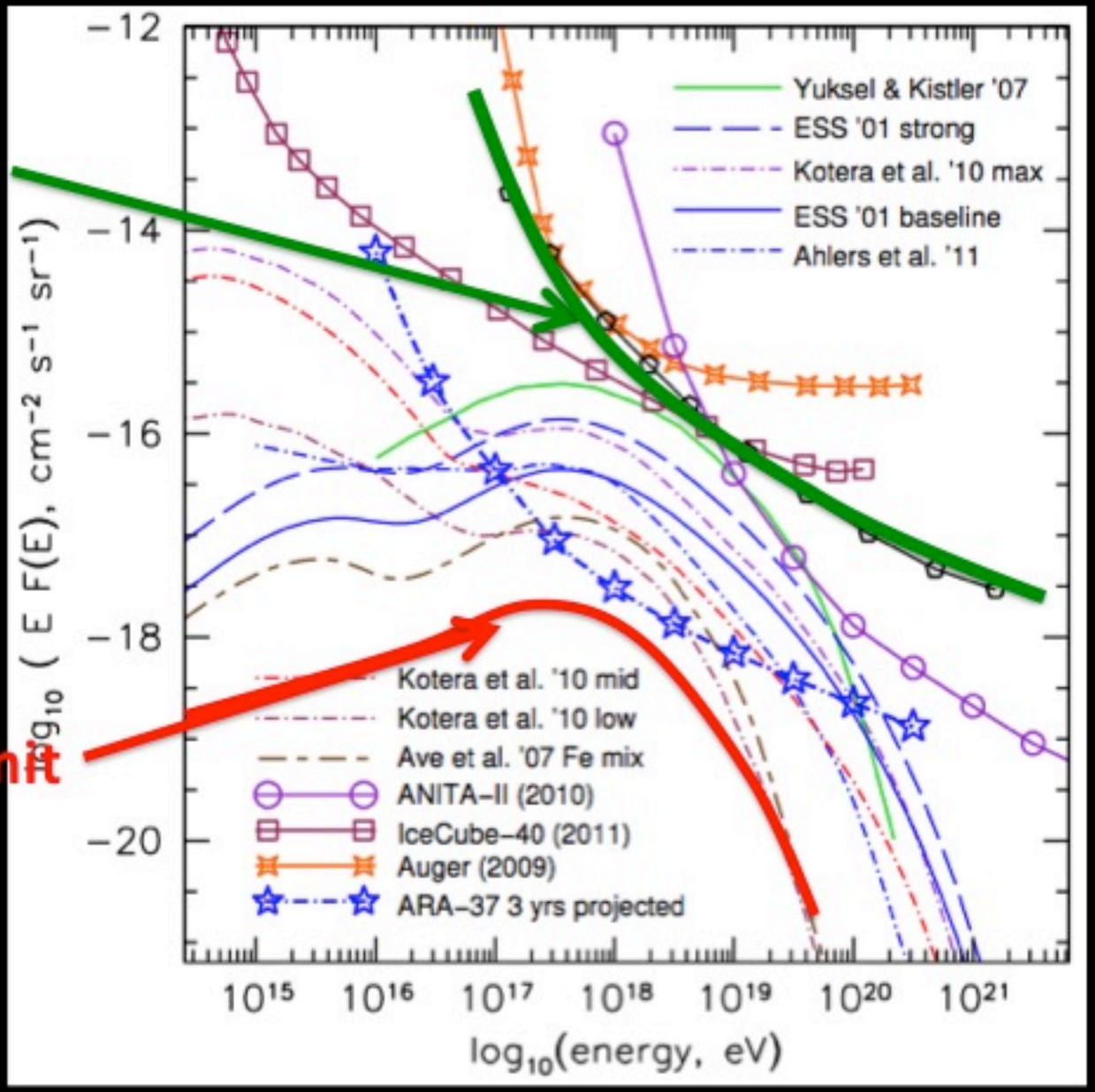
$$n \rightarrow p + e^{-} + \nu_{e}$$
$$\pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$
$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \nu_{\mu}$$

Berezinsky & Zatsepin '69

Neutrino Detectors

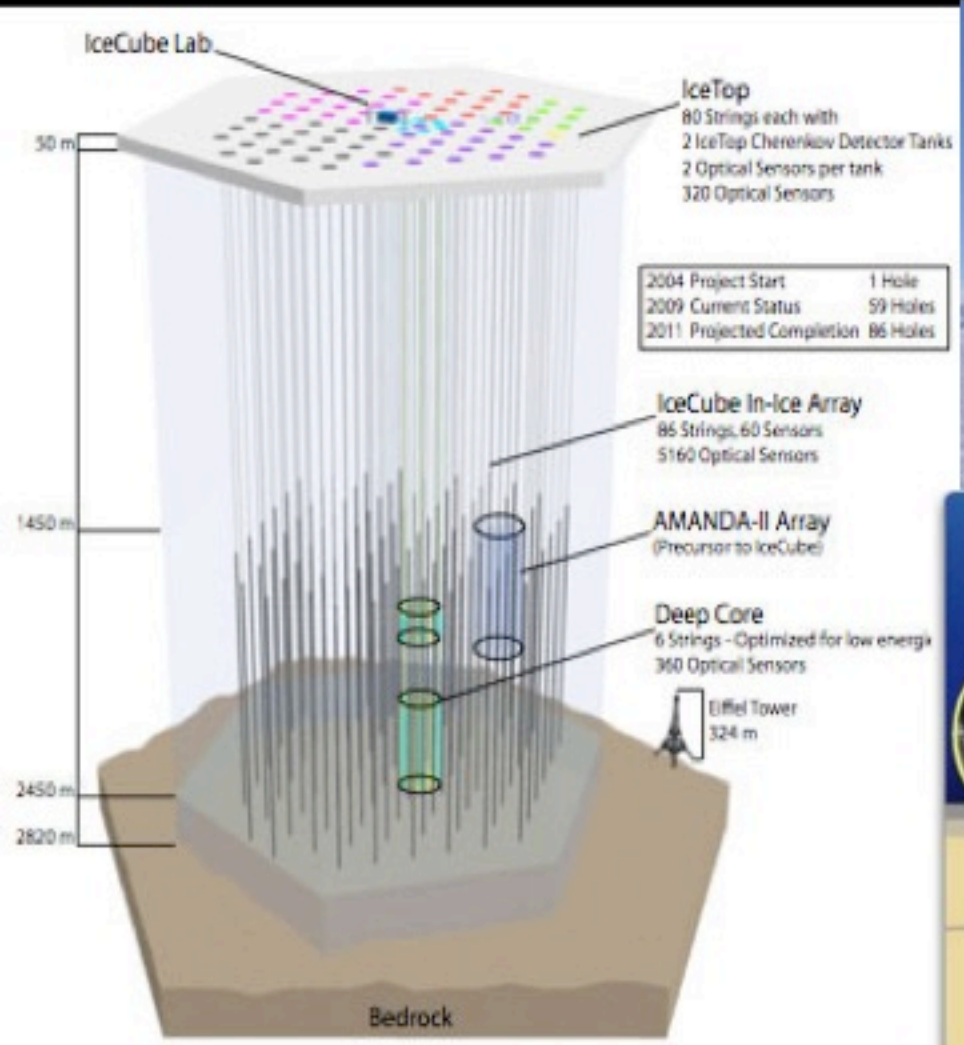
Current Limits

Flux Lower Limit

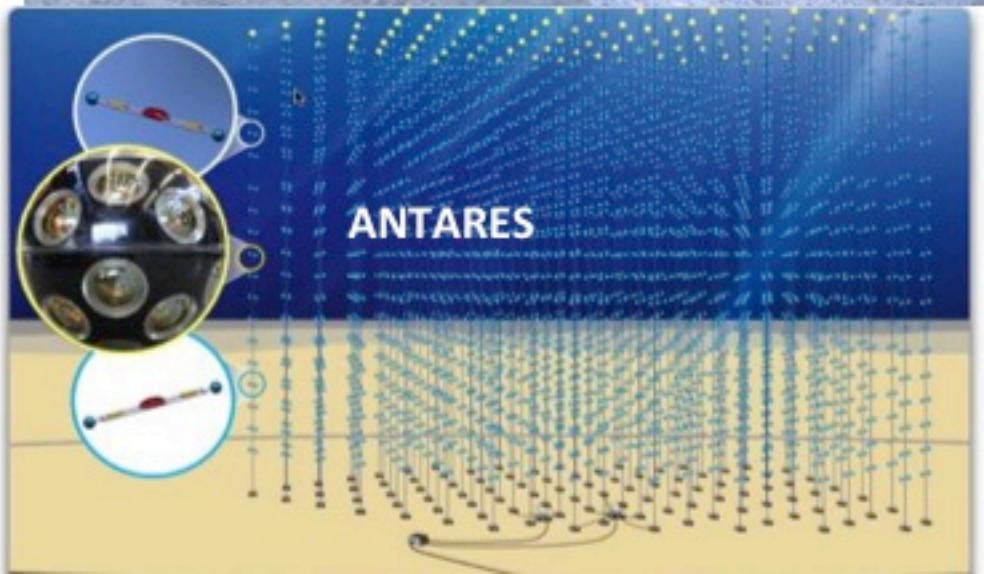


Highest Energy Neutrino Observatories

IceCube



ANITA

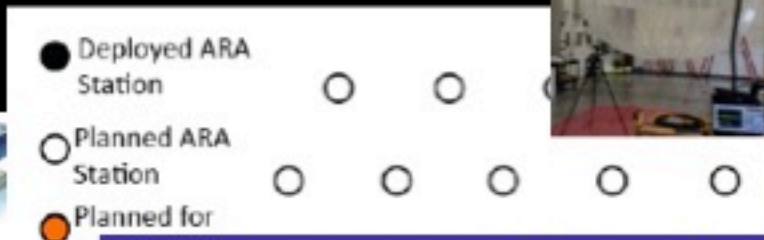


Next Generation UHE neutrinos

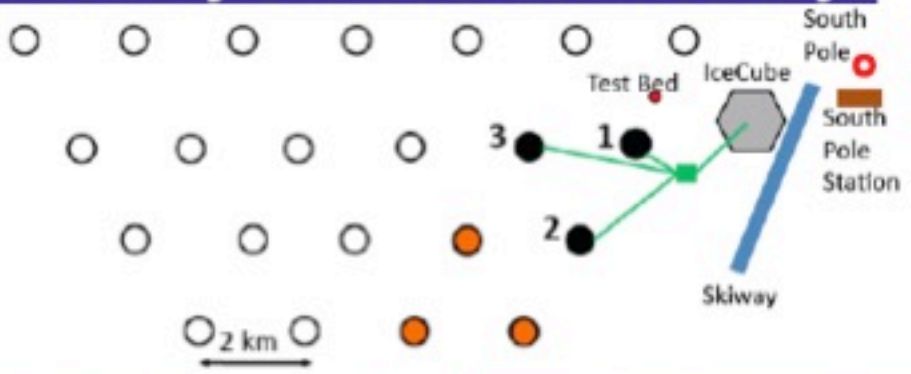
ExaVolt antenna

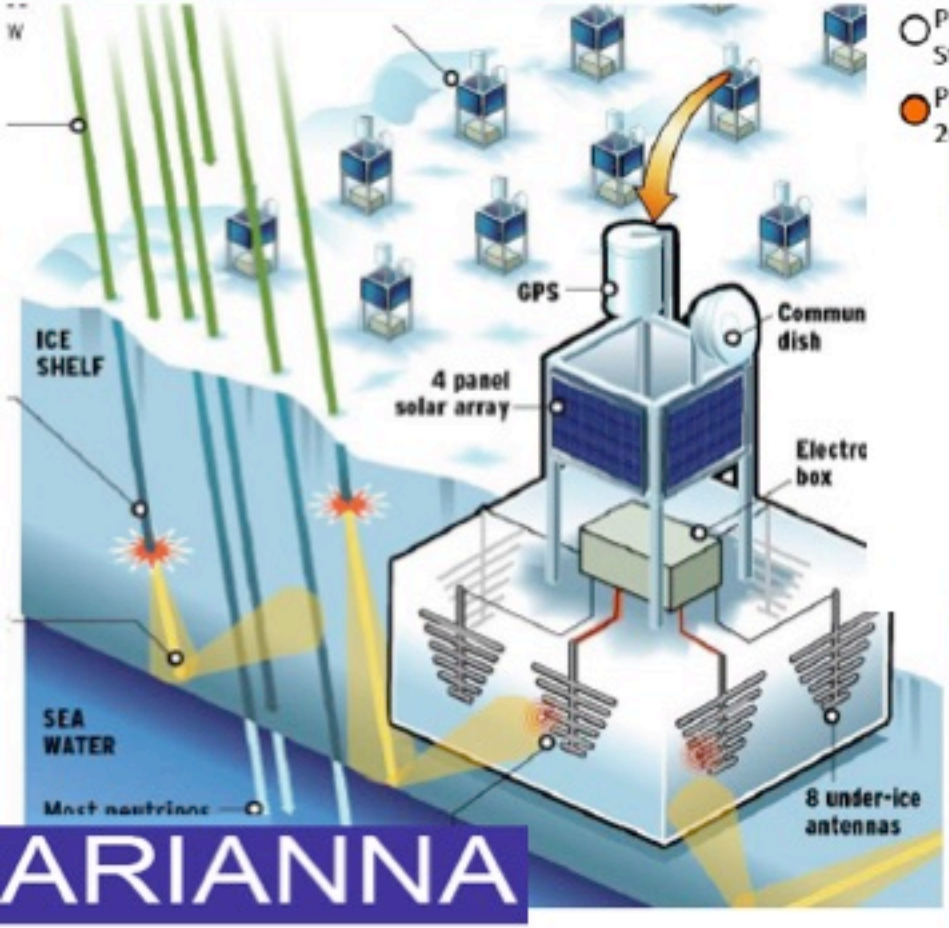
P. Gorham (EVA)

Wallops: successful 1/20th scale model test,



ARA: Askaryan Radio Array





ARIANNA

ARIANNA Coll. See arXiv:1207.3846

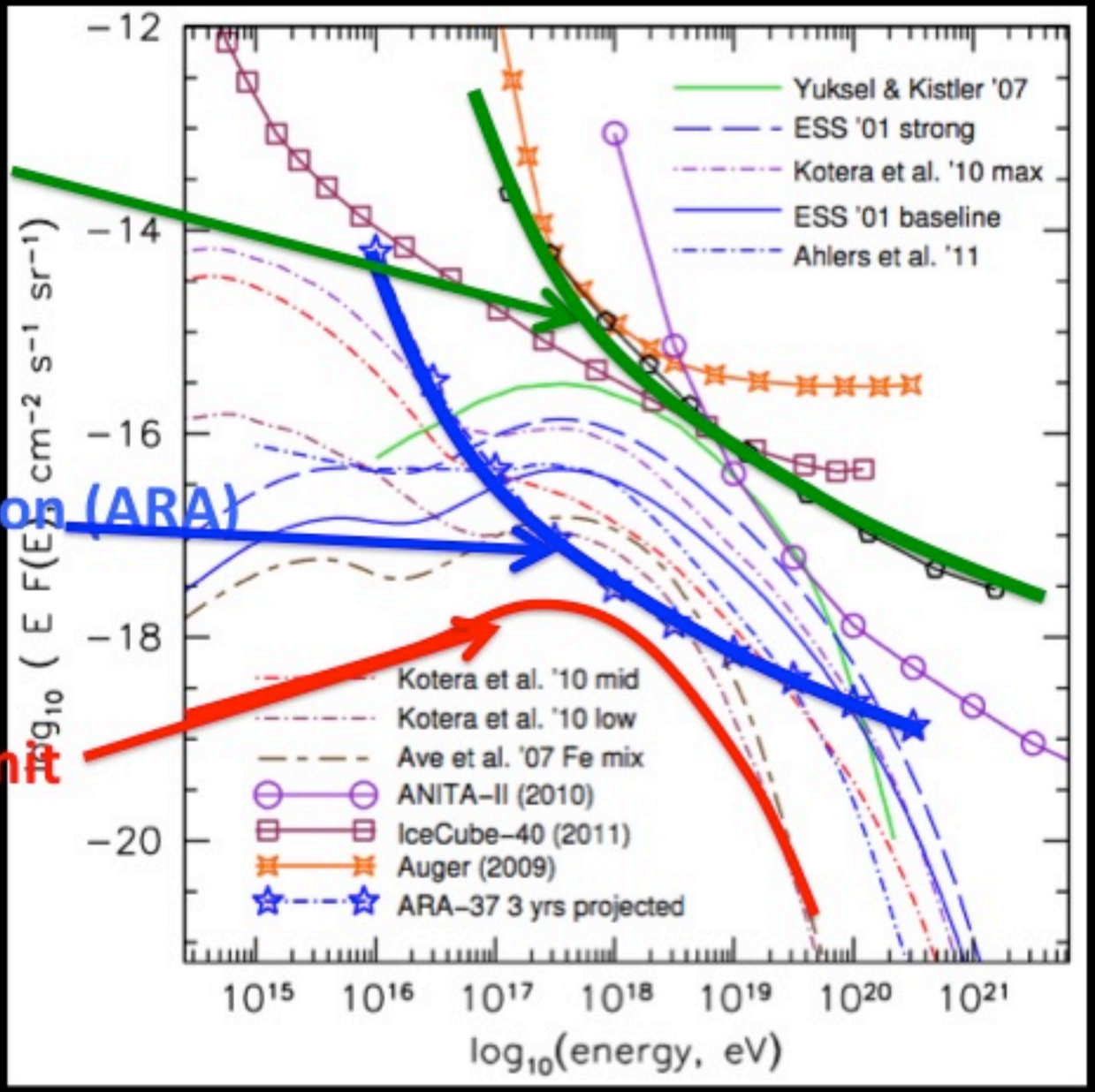
from Vieregg CSS13

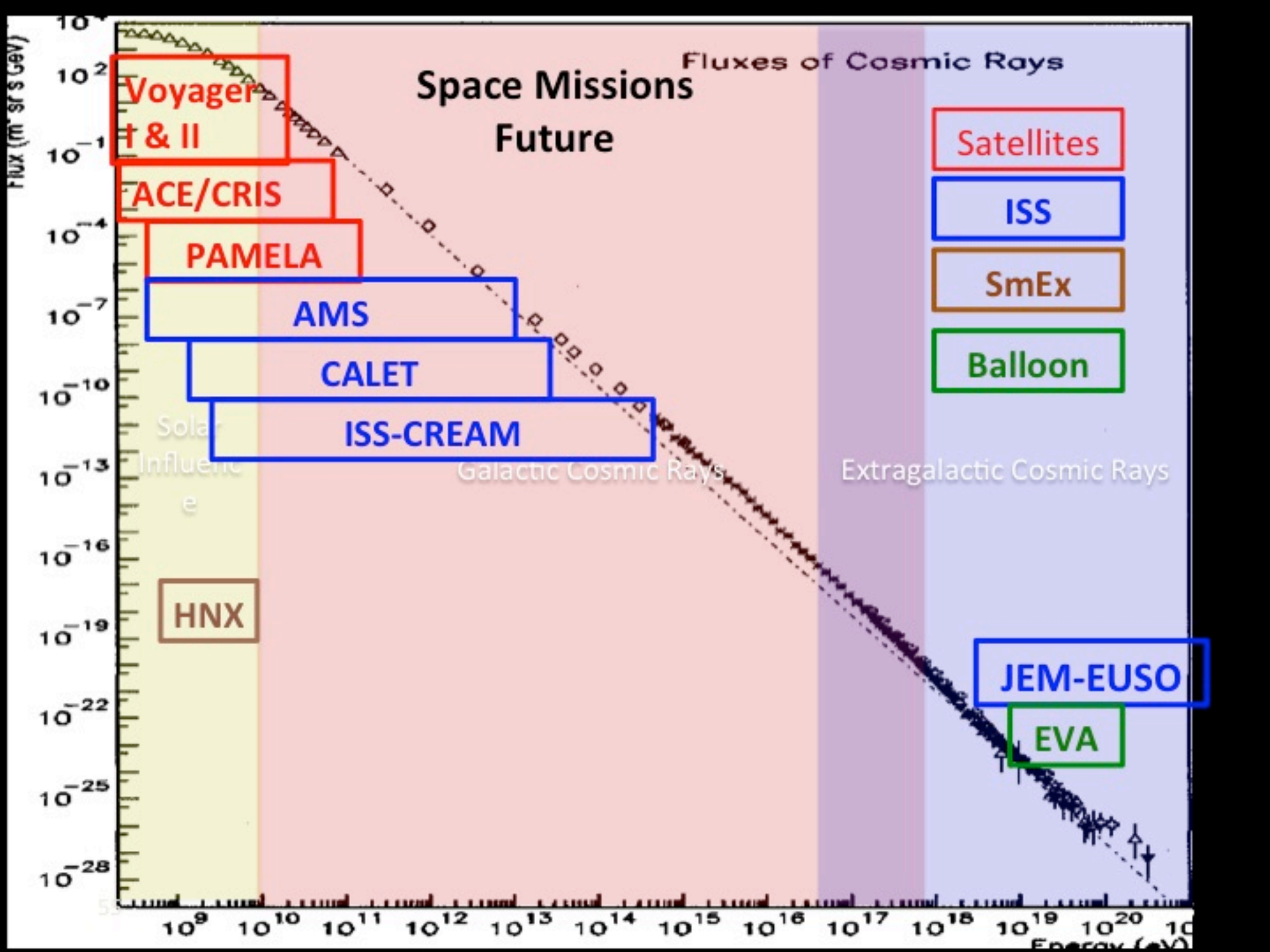
Neutrino Detectors

Current Limits

Next Generation (ARA)

Flux Lower Limit




Space Missions
Future
Fluxes of Cosmic Rays
Voyager I & II
ACE/CRIS
PAMELA
AMS
CALET
ISS-CREAM
HNX
Satellites
ISS
SmEx
Balloon
JEM-EUSO
EVA
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
Flux (m² sr s GeV)
Energy (eV)

UHECRs Current Status

Leading Observatories: Auger & Telescope Array agree on the shape of the spectrum

Energy scale: ~10% difference

Composition: controversial

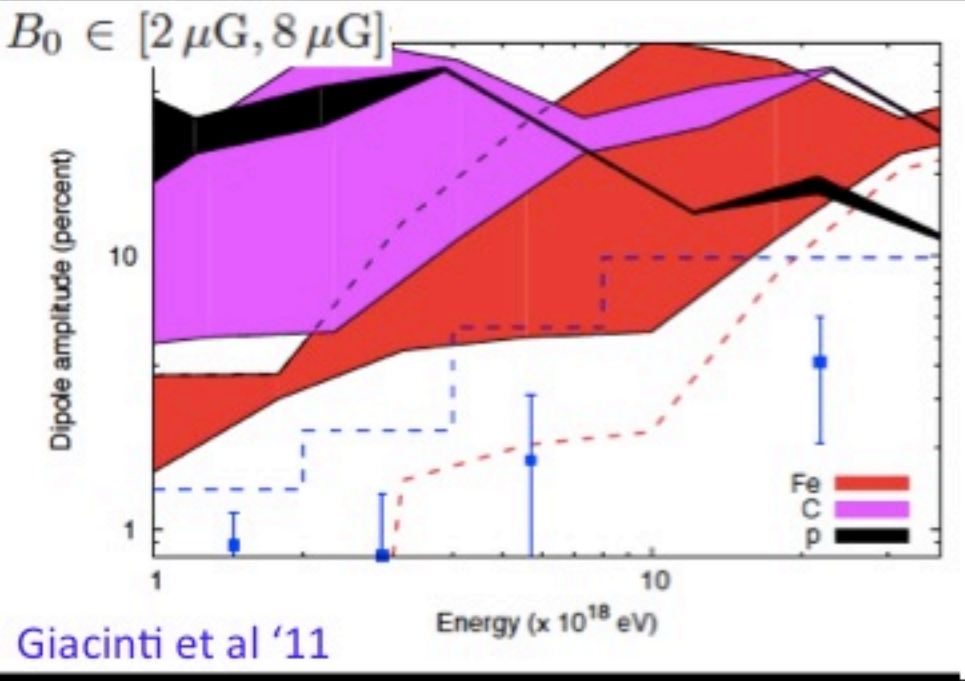
Multi-messenger clues: not yet

Anisotropies?

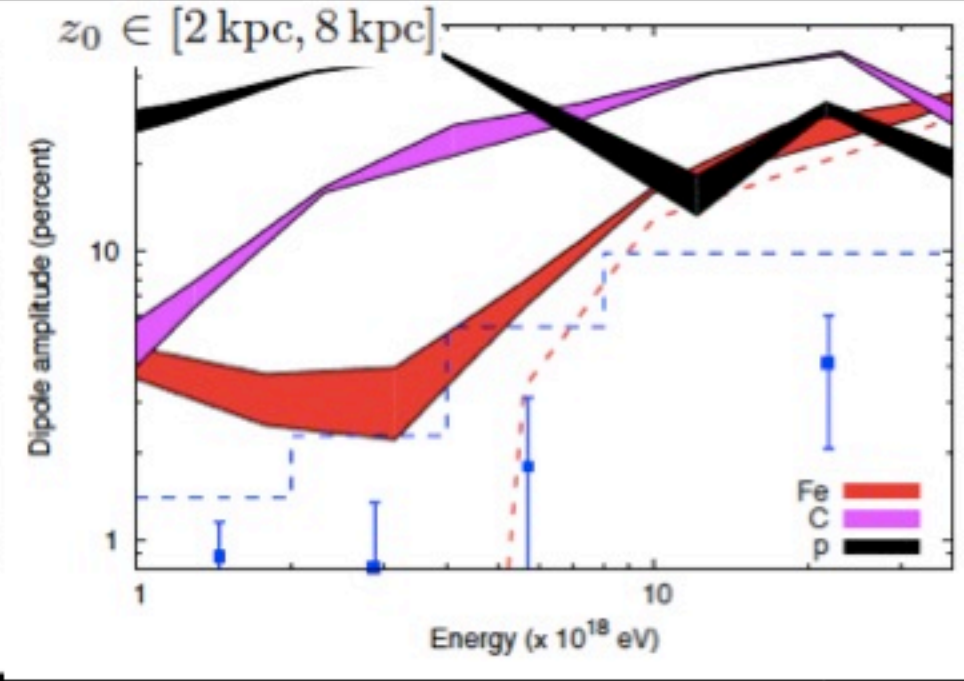
E>20 EeV Cosmic Rays are EXTRAGALACTIC

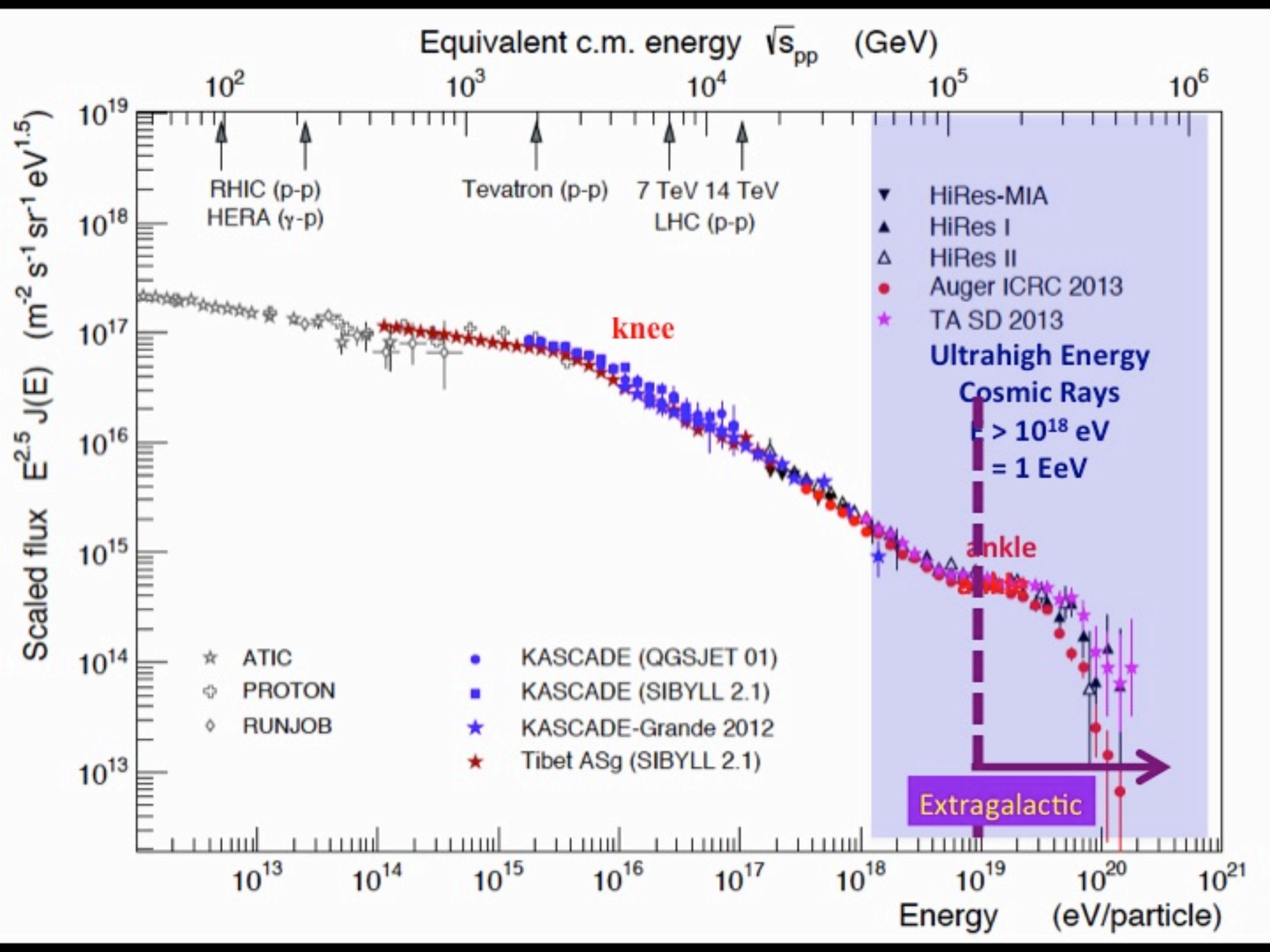
No Galactic Plane Anisotropy

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 √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
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
ATIC
PROTON
RUNJOB
KASCADE (QGSJET 01)
KASCADE (SIBYLL 2.1)
KASCADE-Grande 2012
Tibet ASg (SIBYLL 2.1)
Extragalactic
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
Energy (eV/particle)

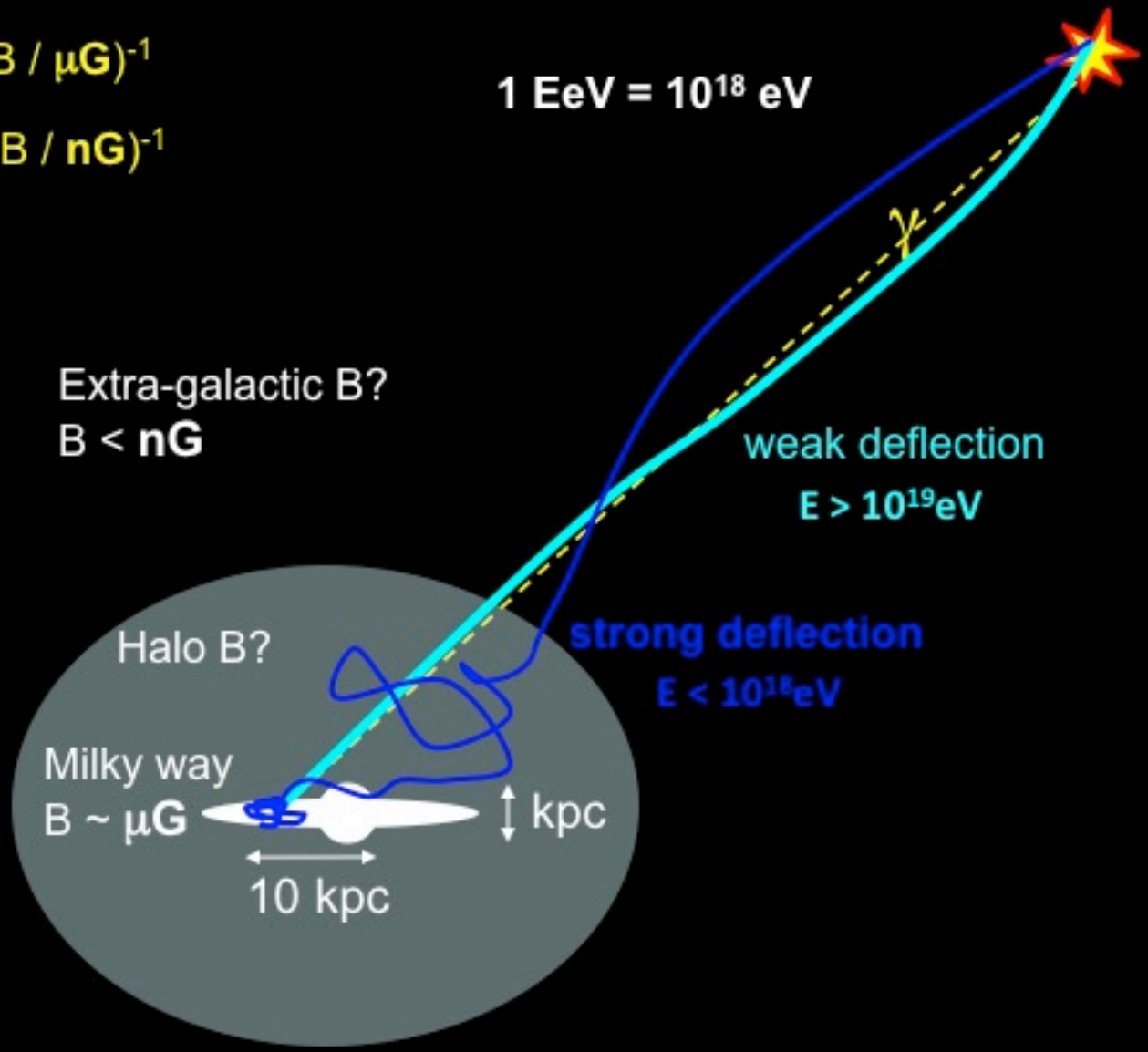
"Known unknown"

Cosmic Magnetic Fields

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

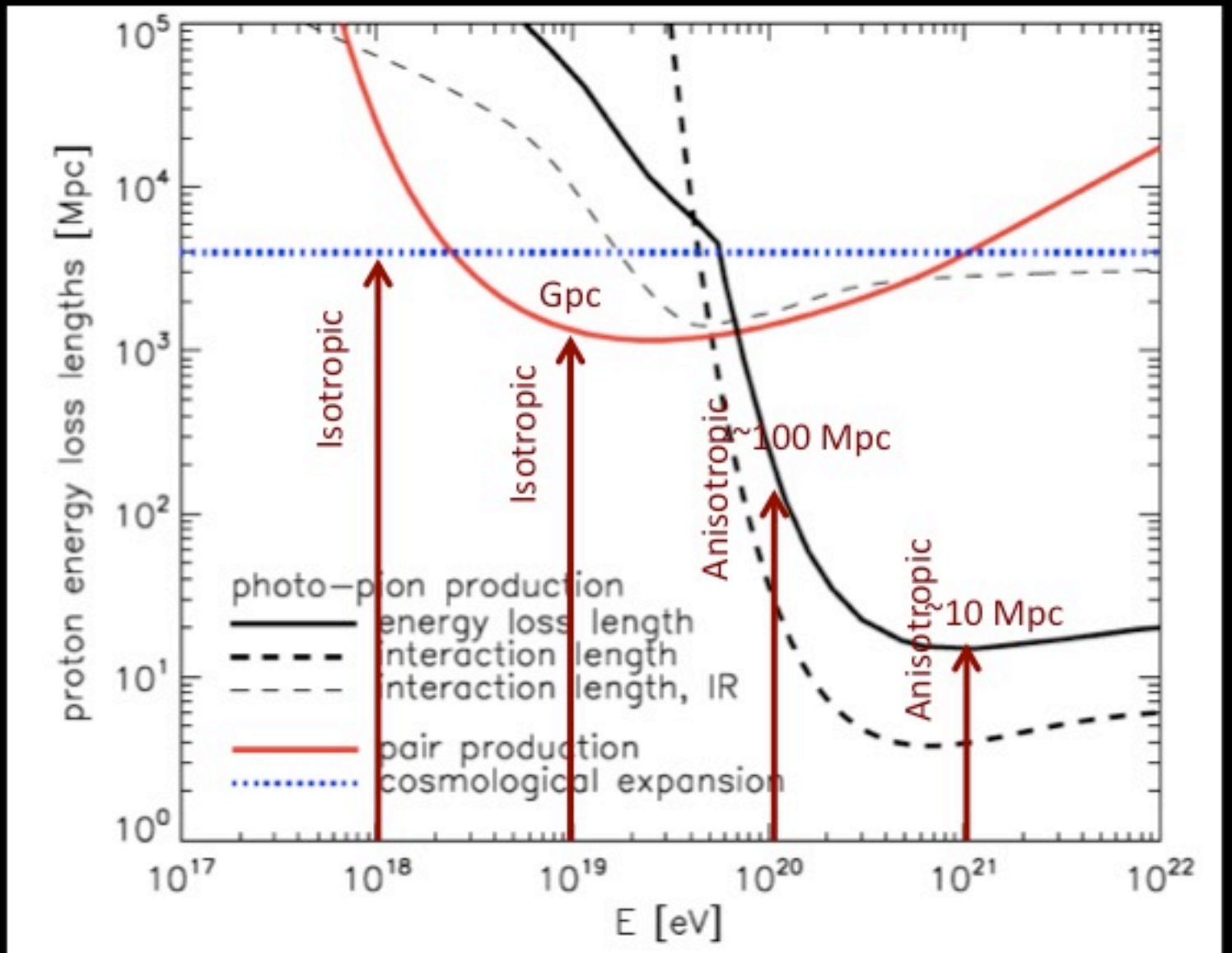
R_L = **Mpc** Z^{-1} (E / EeV) (B / **nG**)$^{-1}$

1 EeV = 10^{18} eV

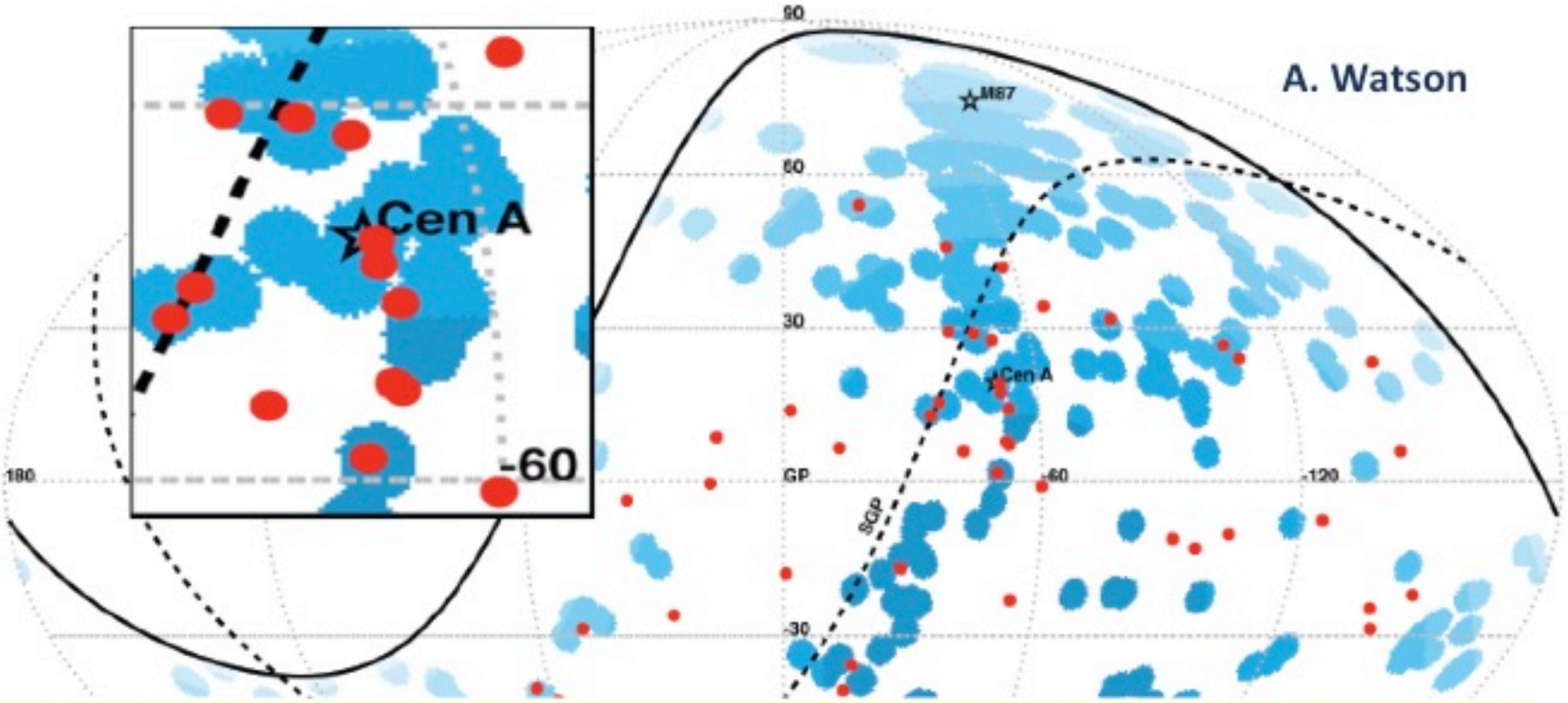


Galactic B deflection
<< 10^o Z (40 EeV/E)
anisotropic in sky

Greisen-Zatsepin-Kuzmin effect



Where do UHECRs come from?



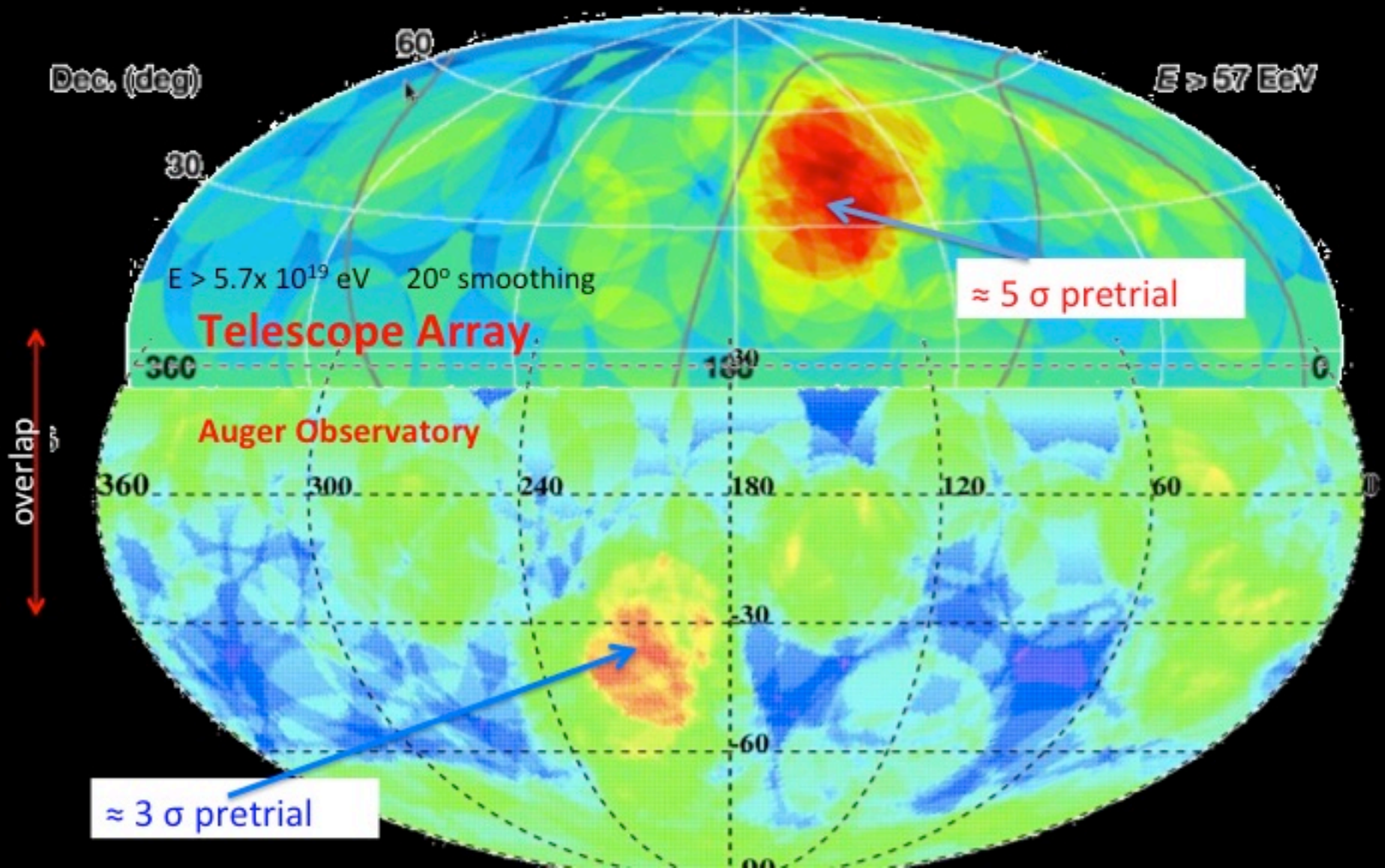
Correlation has fallen from ~ 68% to ~ 28% (2007 –> 2014) compared with 21% for isotropy: about 1.4% probablity

Cen A may be a source: in 13° circle around: 12 seen/1.7

A clear message from the Pierre Auger Observatory:-

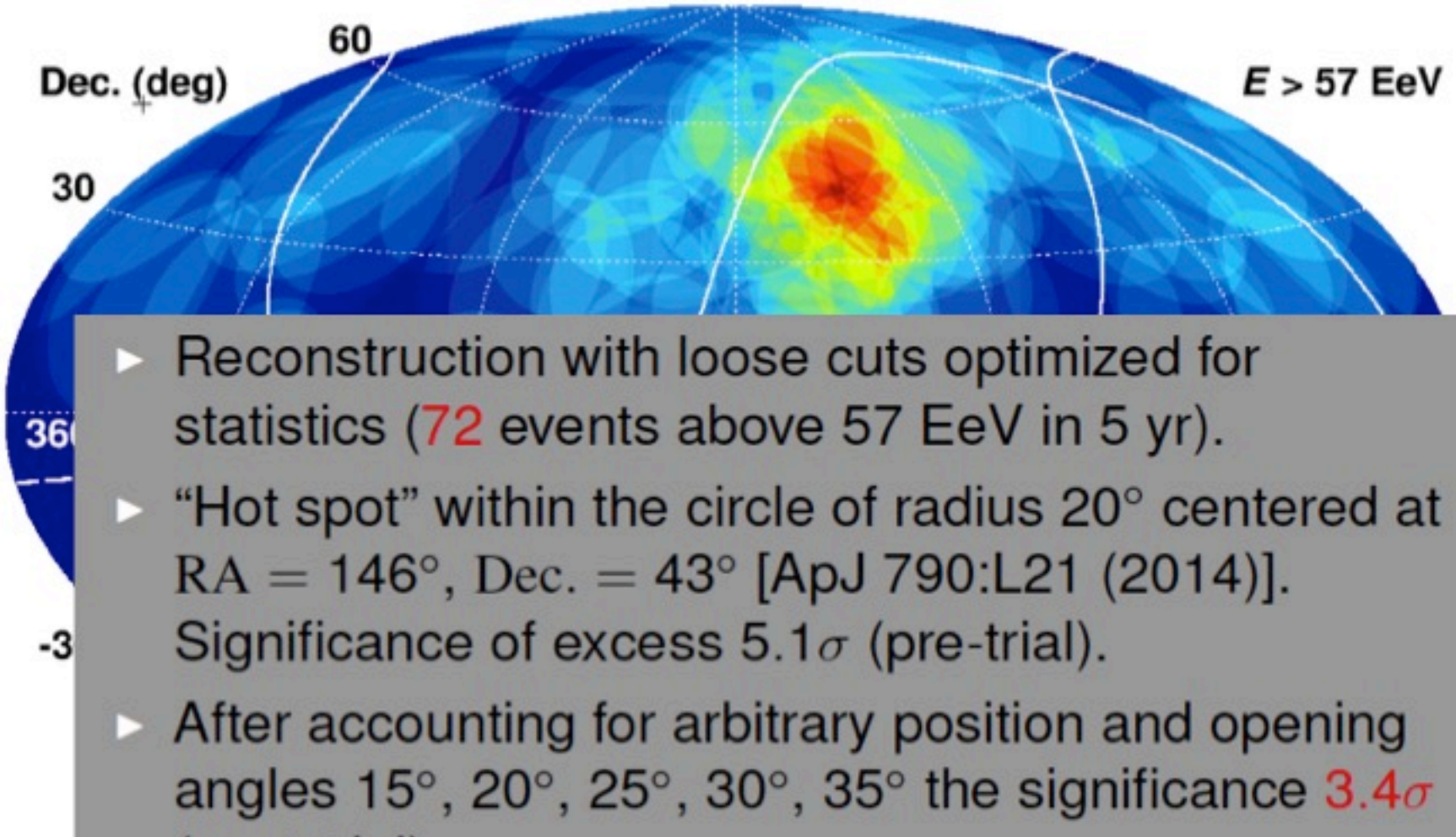
We made it too small (2 per month at energy of interest)

Anisotropy Hints > 60 EeV



Anisotropy Hints > 60 EeV

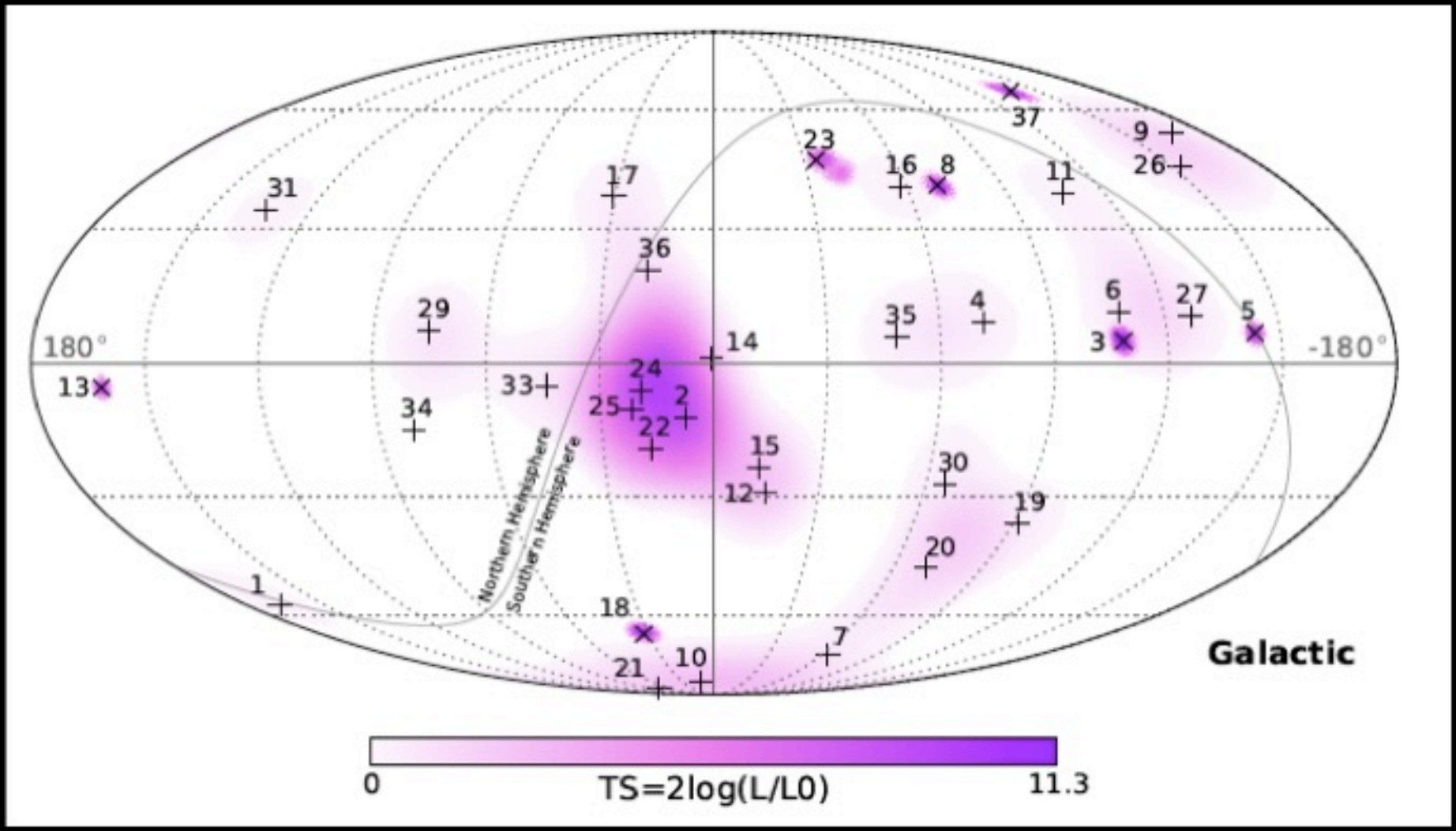
Oversampling with 20°-radius circle



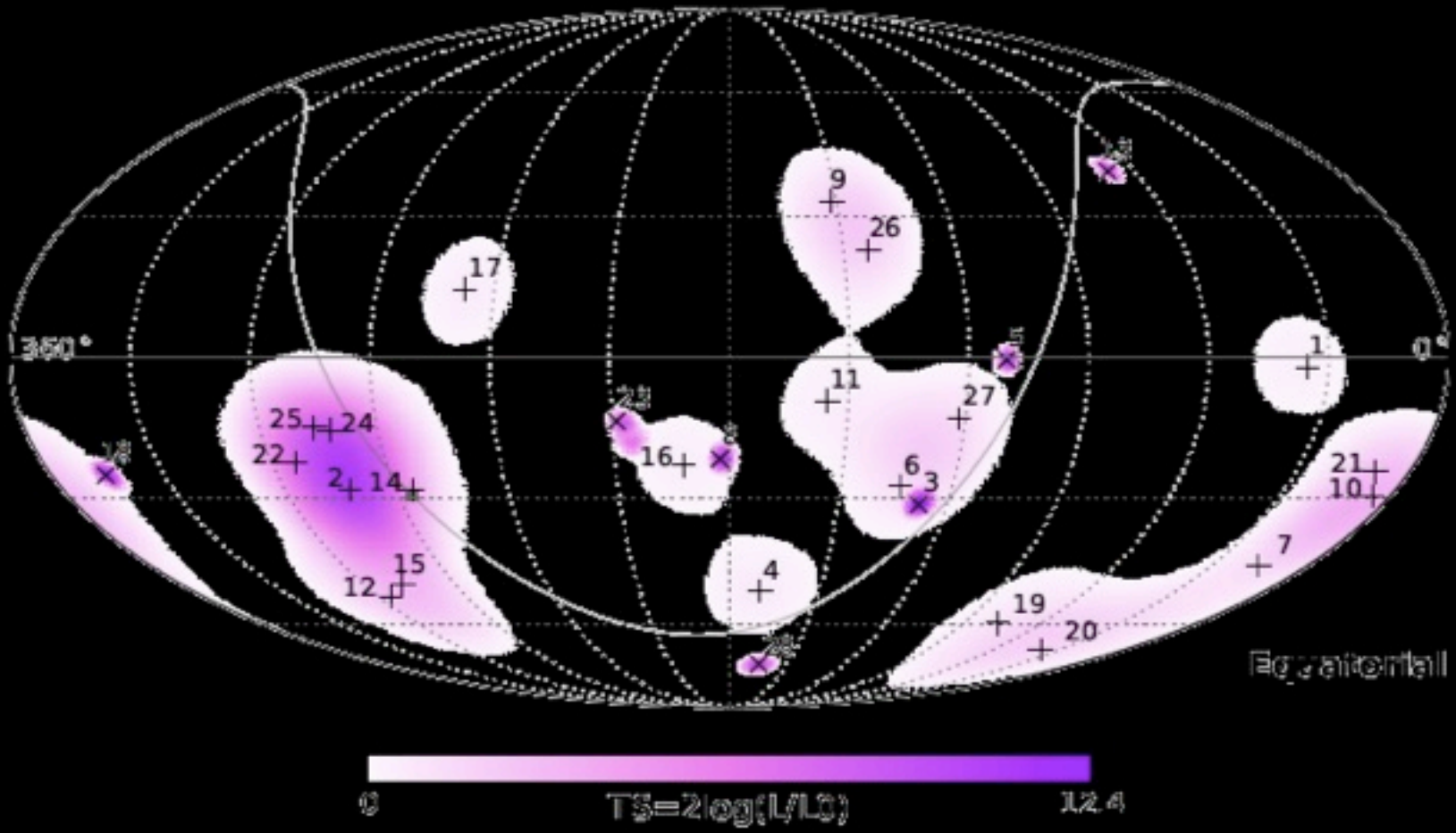
- Reconstruction with loose cuts optimized for statistics (72 events above 57 EeV in 5 yr).
- "Hot spot" within the circle of radius 20° centered at $\mathrm{RA} = 146°$, $\mathrm{Dec.} = 43°$ [ApJ 790:L21 (2014)]. Significance of excess 5.1σ (pre-trial).
- After accounting for arbitrary position and opening angles 15°, 20°, 25°, 30°, 35° the significance 3.4σ (post-trial).

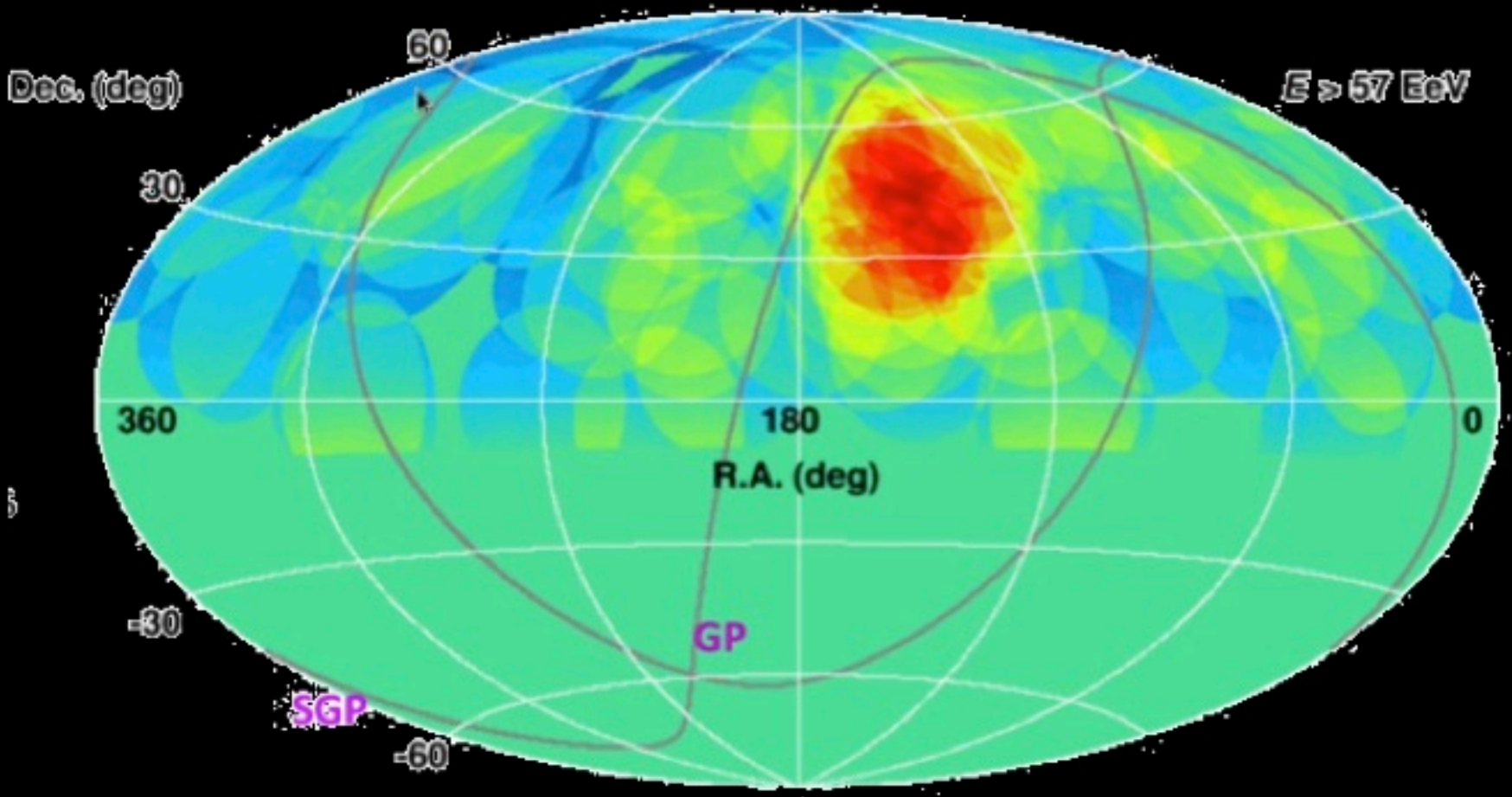
IceCube 37 Events

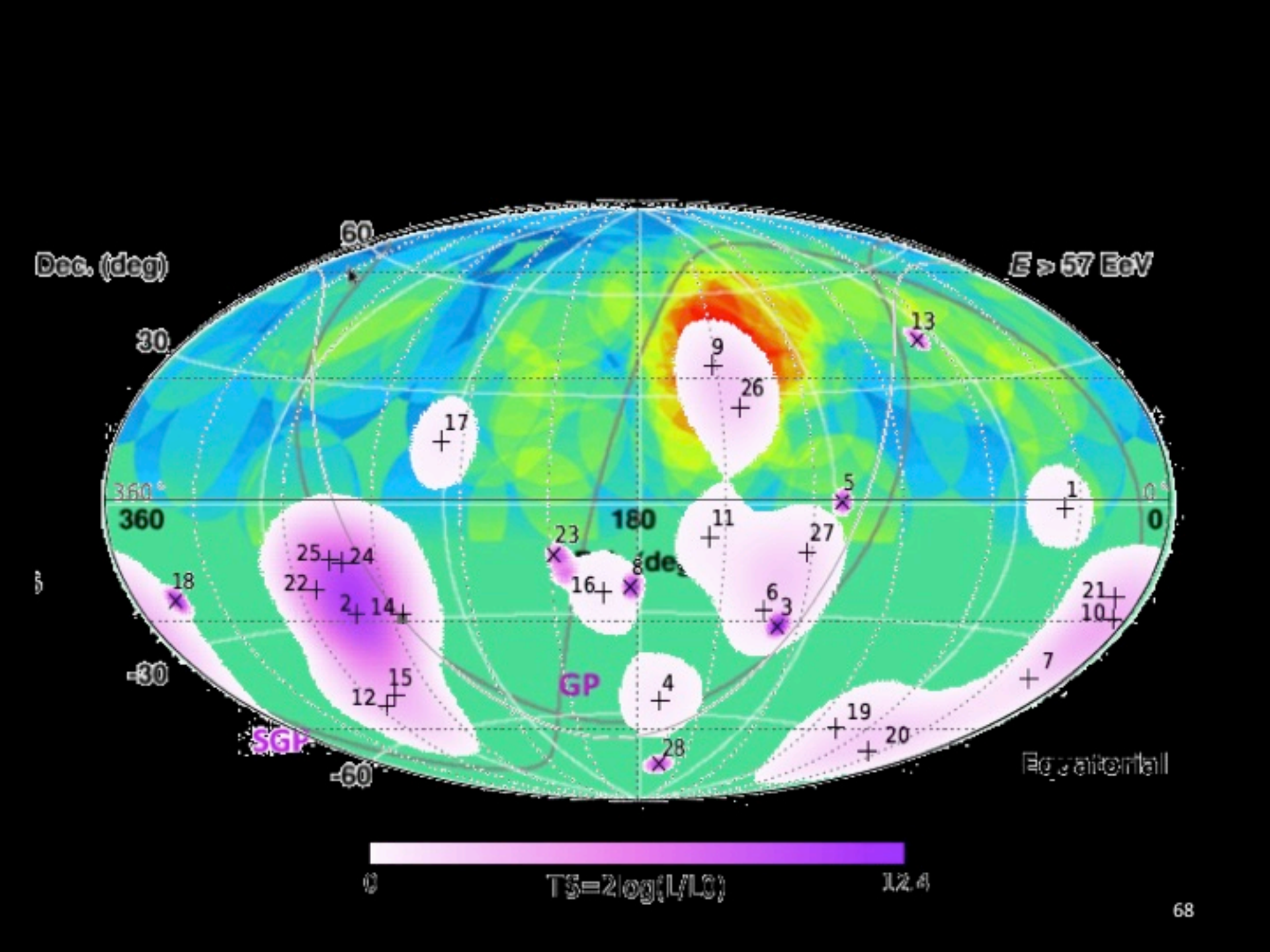
3 yr data; 30 TeV to 2 PeV



Phys. Rev. Lett. 113, 101101 (2014)


360°
0°
9
26
17
1
11
27
25
24
22
2
14
16
6
3
21
10
7
15
12
4
19
20
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
360
180
0
360°
0°
E > 57 EeV
GP
SGP
Equatorial
0
TS=2log(L/L0)
12.4
1
2
3
4
5
6
7
8
9
10
11
12
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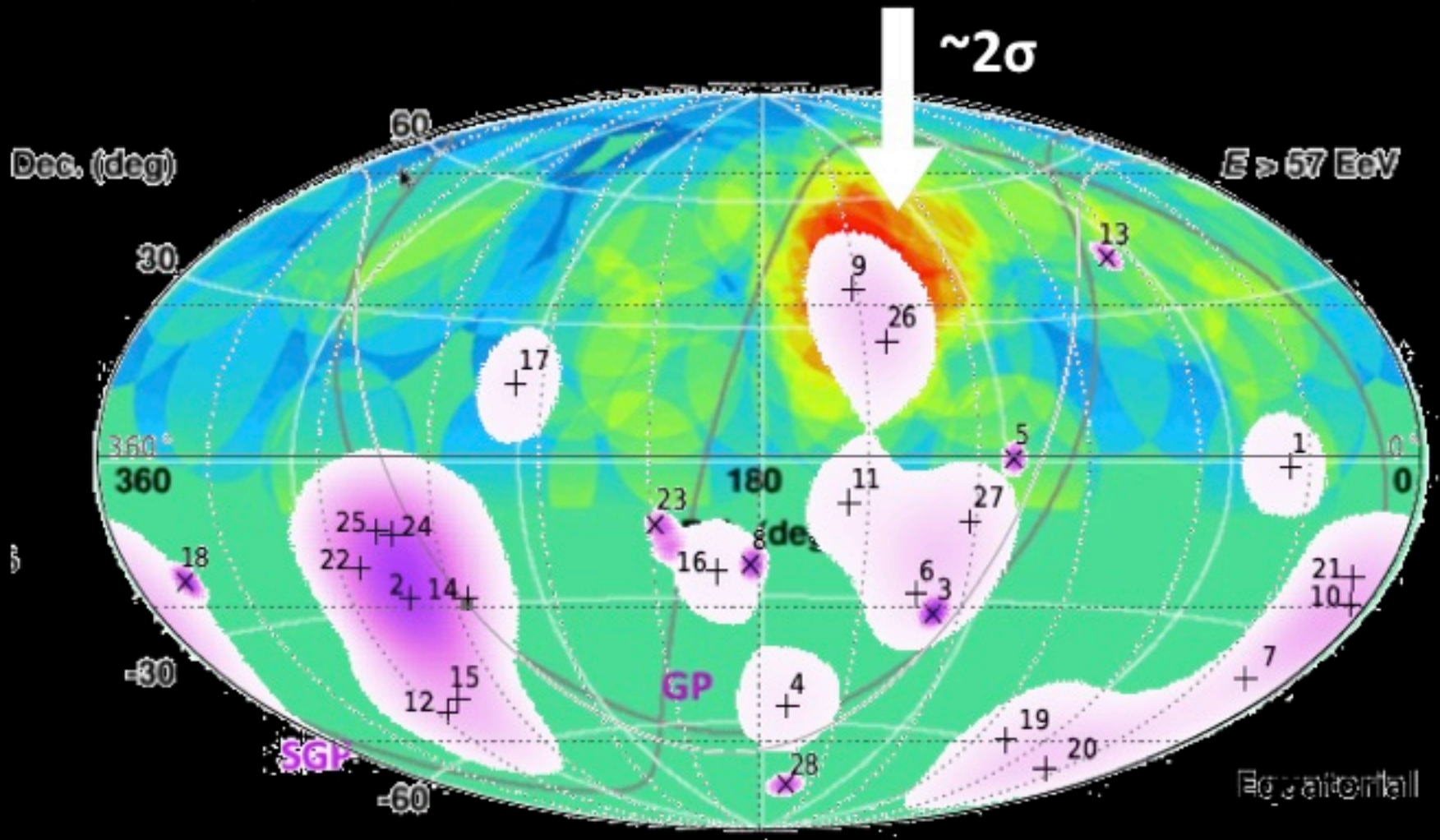
27
28

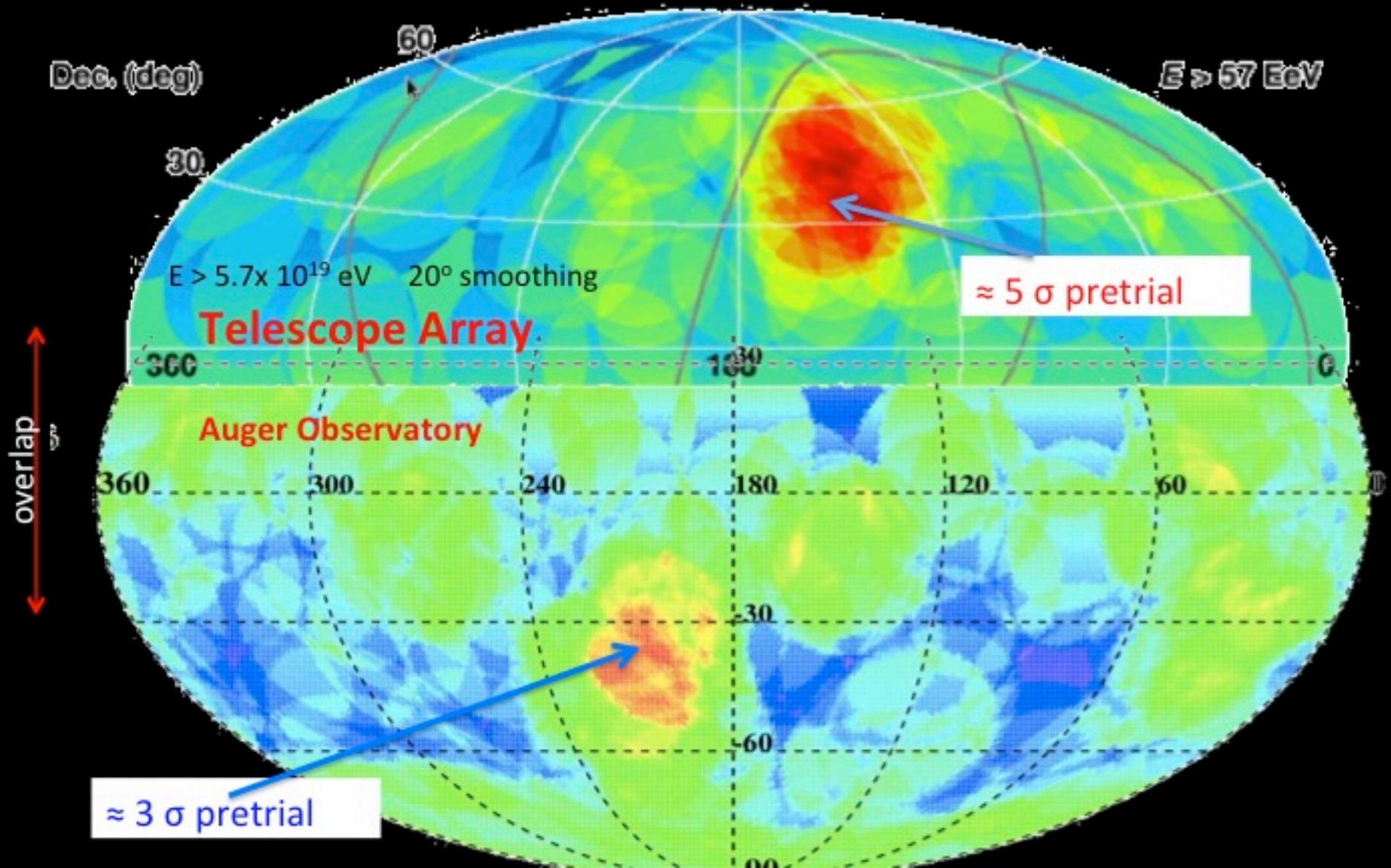
Neutrino & UHECR Coincidence



Fang, Fujii, Linden, AO '14

Anisotropy Hints > 60 EeV

Statistically limited

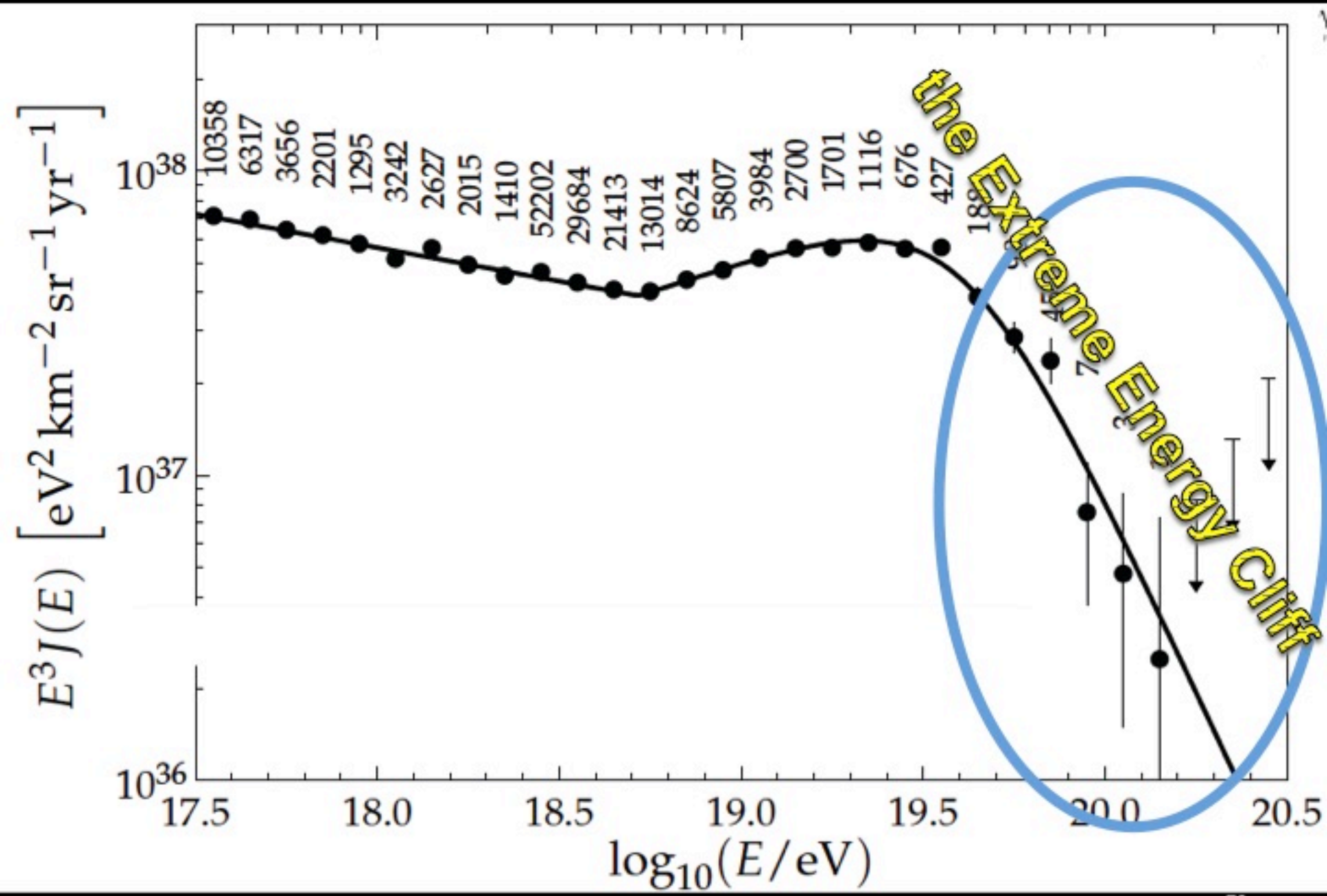


Anisotropy Hints > 60 EeV

Statistically limited

A clear message from the Pierre Auger Observatory:-
We made it too small (2 per month at energy of interest)

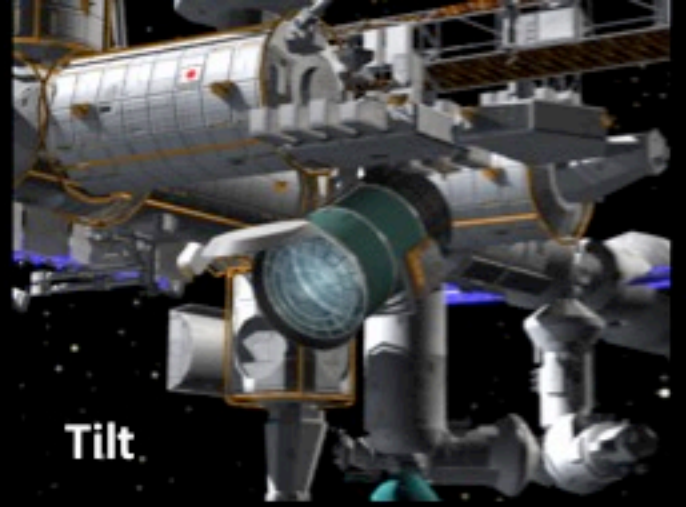
A. Watson

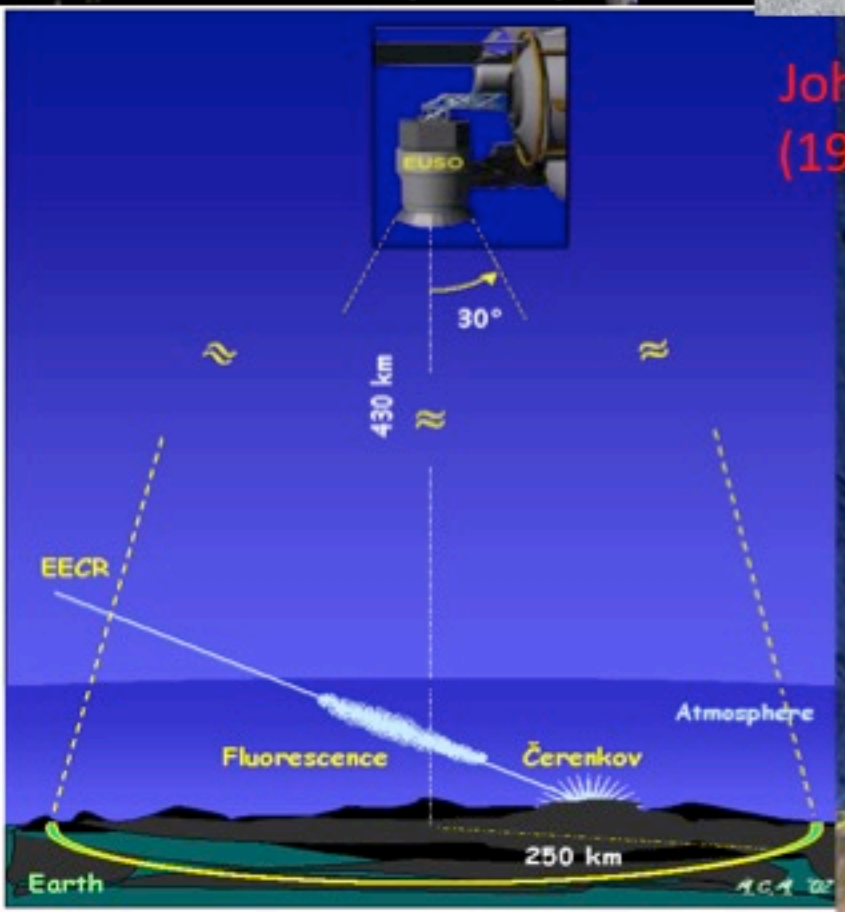

the Extreme Energy Cliff
$E^3 J(E)$ $\left[\mathrm{eV}^2\,\mathrm{km}^{-2}\,\mathrm{sr}^{-1}\,\mathrm{yr}^{-1}\right]$
10^{38}
10^{37}
10^{36}
10358
6317
3656
2201
1295
3242
2627
2015
1410
52202
29684
21413
13014
8624
5807
3984
2700
1701
1116
676
427
182
17.5
18.0
18.5
19.0
19.5
20.0
20.5
$\log_{10}(E/\mathrm{eV})$

Off the Extreme Energy Cliff

Fluorescence from SPACE

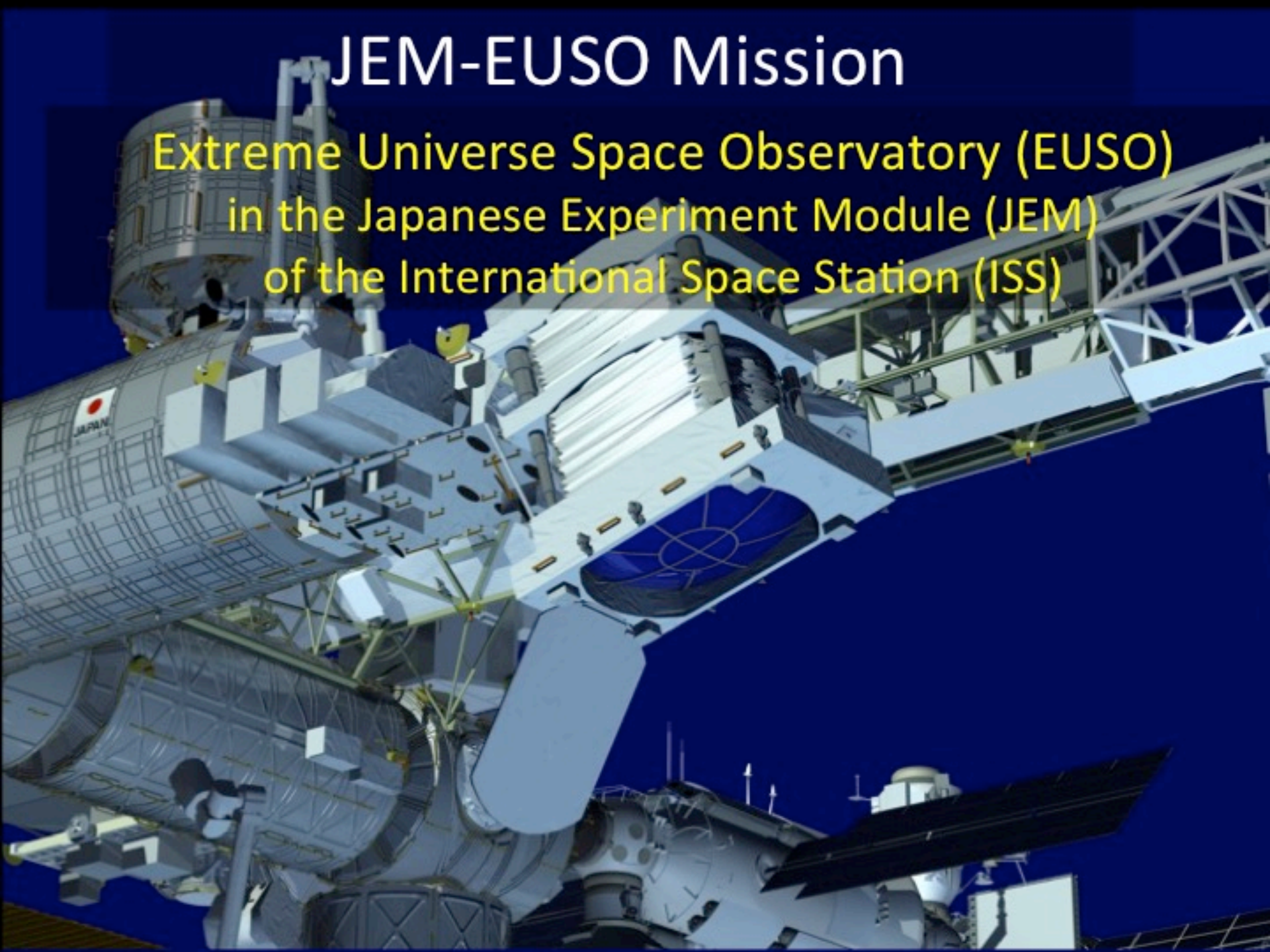
John Linsley
(1925-2002)





JEM-EUSO Mission

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

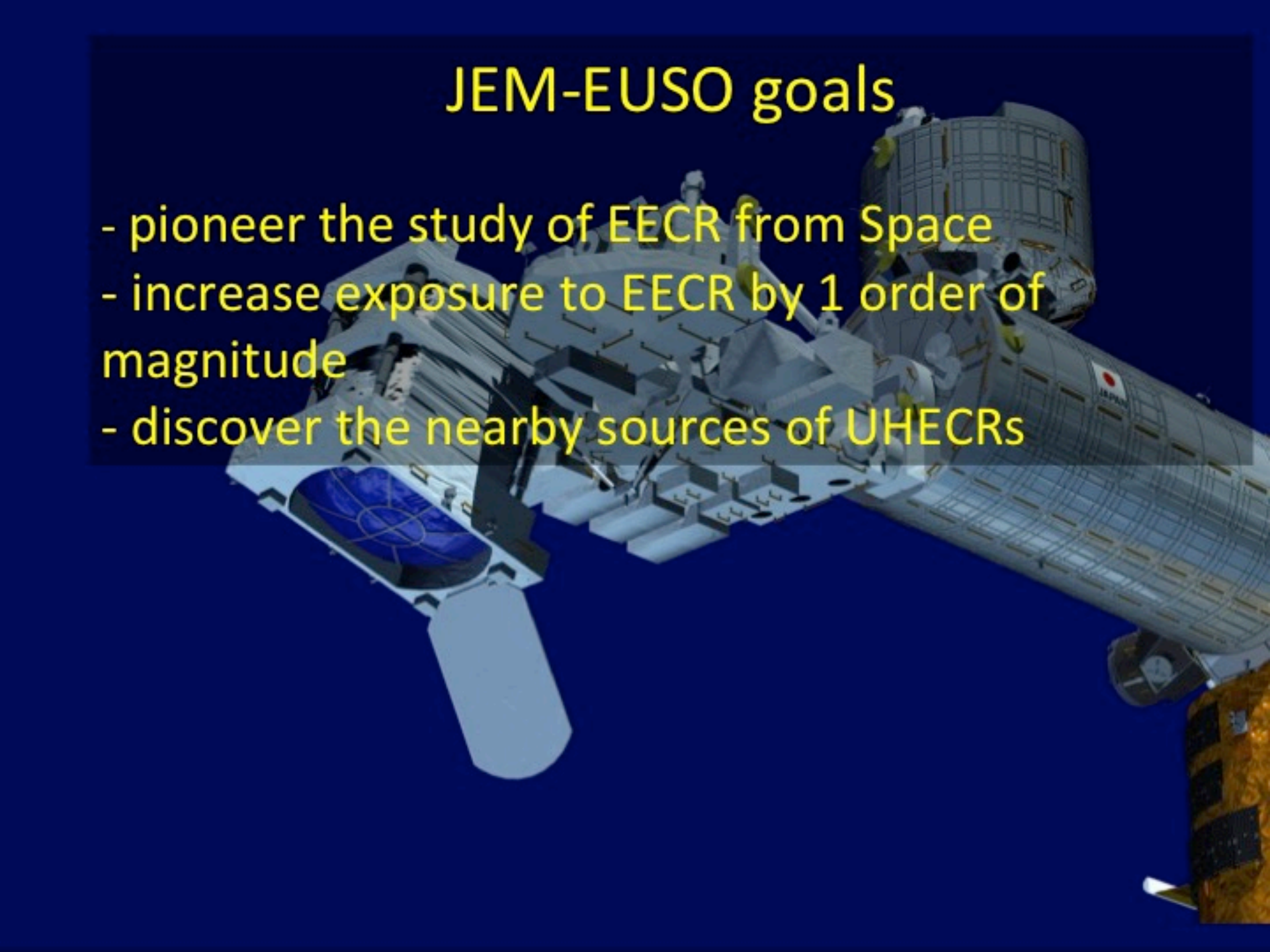


JEM-EUSO

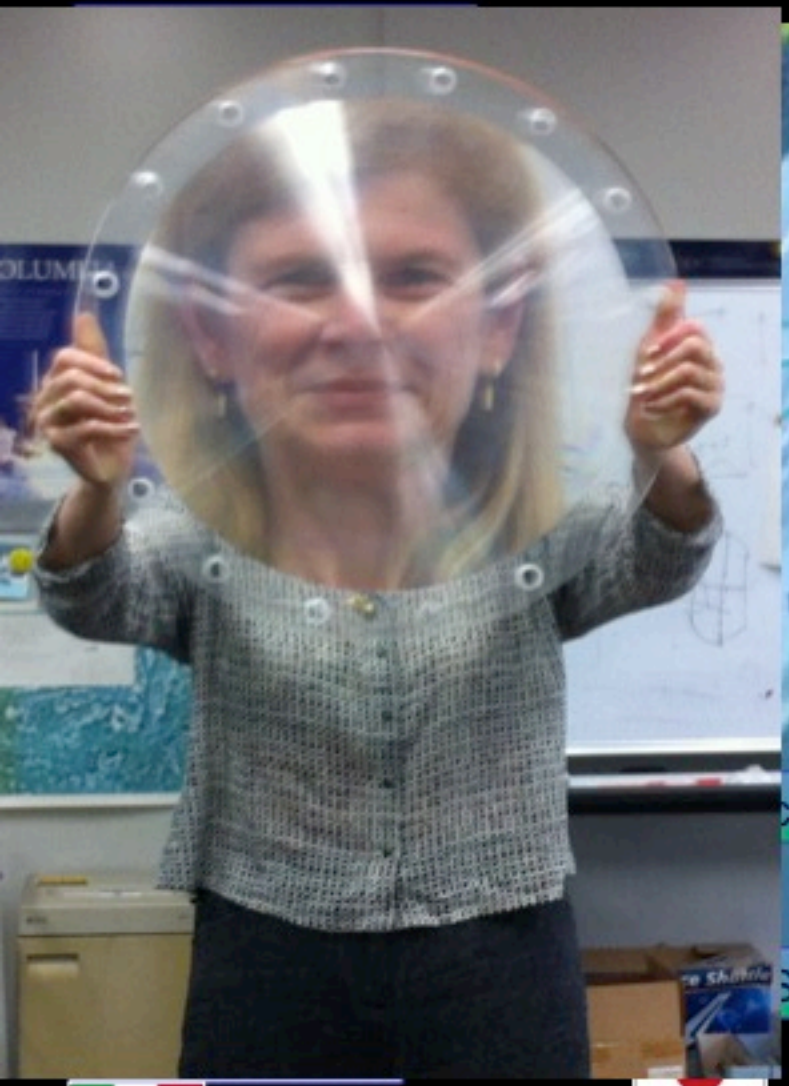
Japan, USA, Korea, Mexico, Russia, Algeria
Europe: Bulgaria, France, Germany, Italy, Poland, Slovakia, Spain, Switzerland, Sweden
16 Countries, 300 researchers

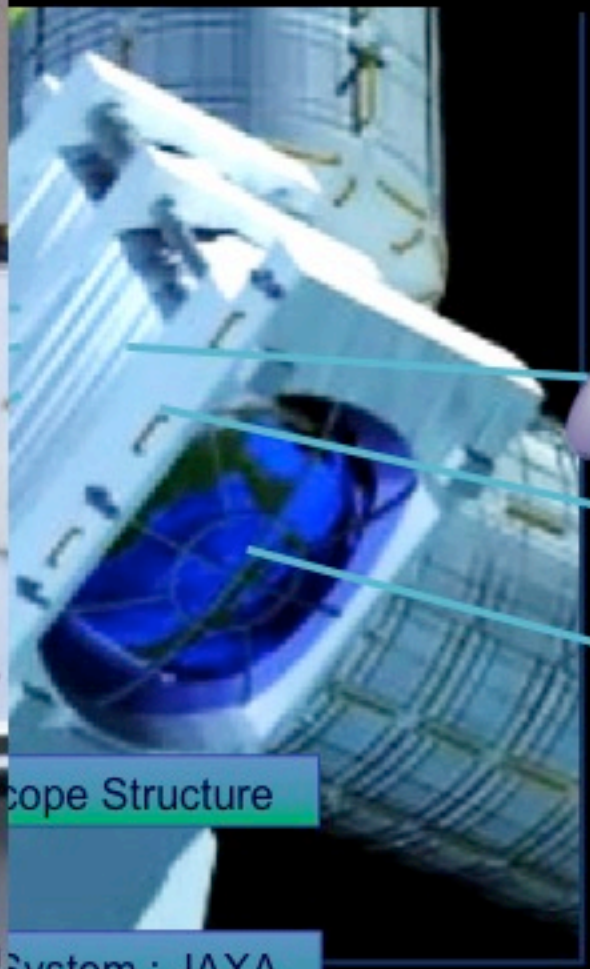
JEM-EUSO goals

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



Payload





Optics

Rear Fresnel Lens

Precision Fresnel lens

Iris

Front Fresnel lens

cope Structure

On-board Calibration

System : JAXA

Ground Based Calibration

Ground Support Equipment

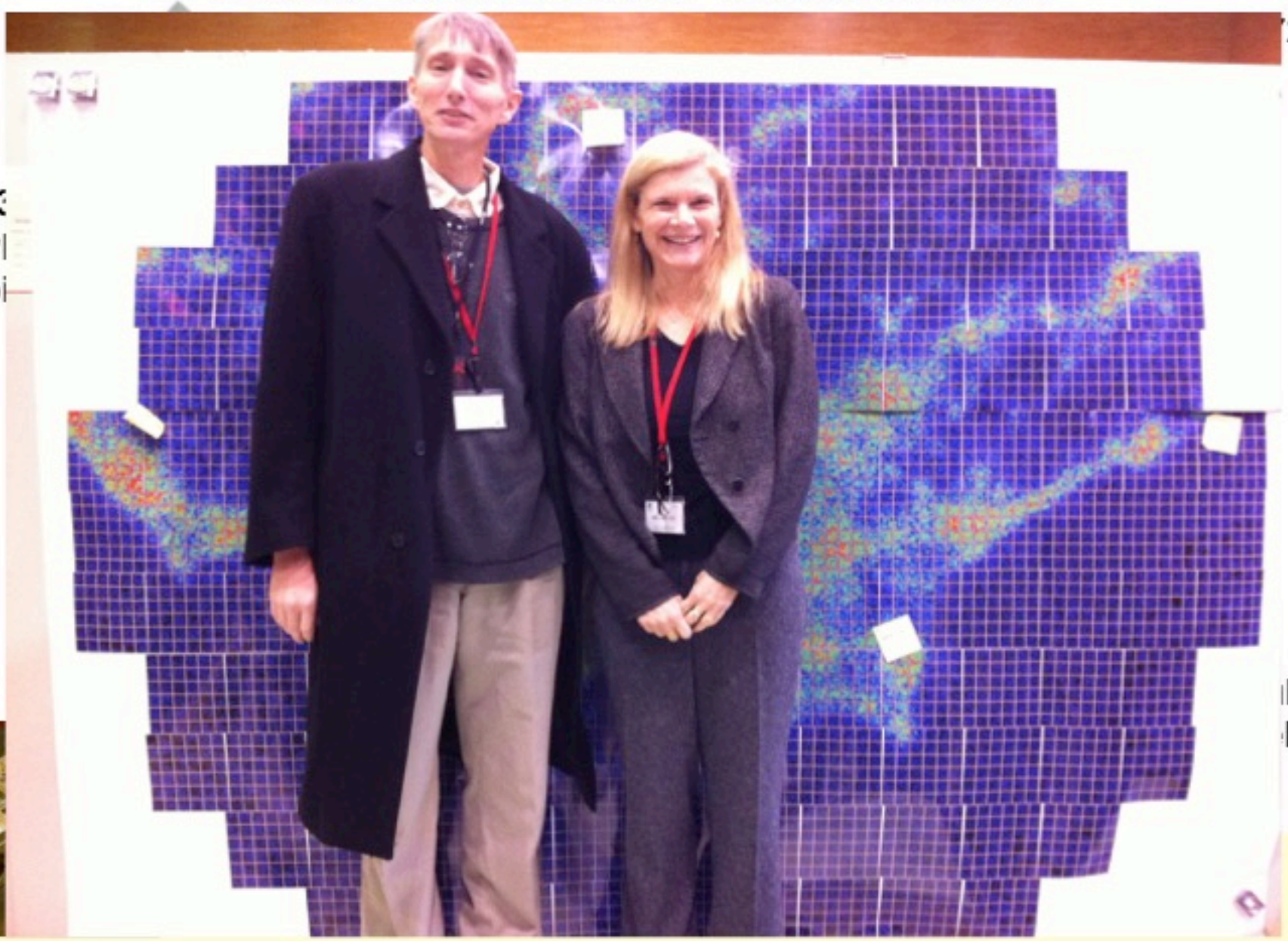
Atmospheric Monitoring

Simulation : Worldwide

Science Instrument

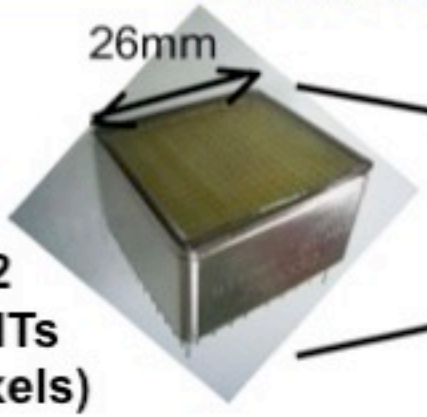
tics

Focal Surface Detector

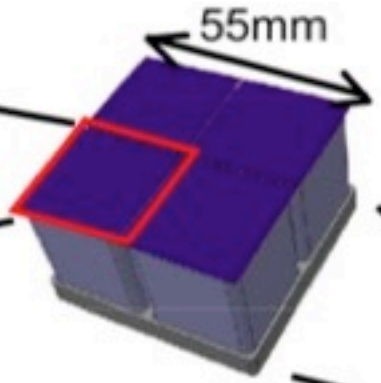


Focal Surface Detector

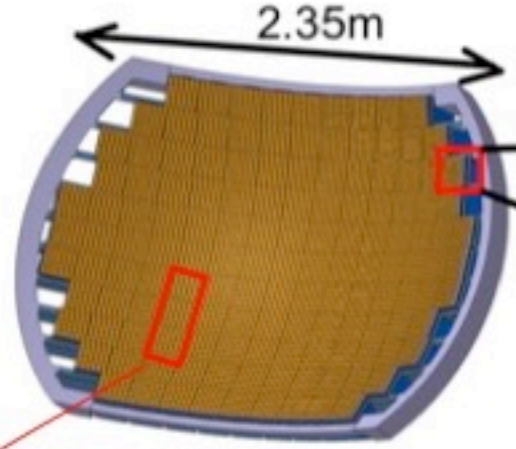
Y. Kawasaki, ID 0472
M. Ricci, ID 0335

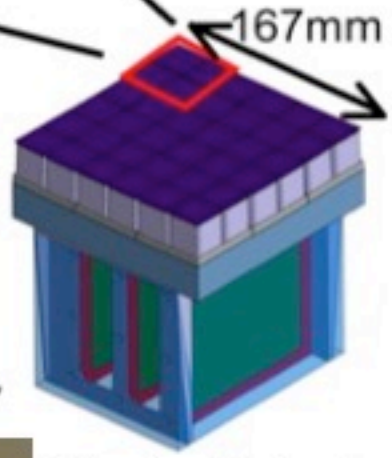


4932
MAPMTs
(8x8 pixels)



Elementary Cell
(2x2 PMTs = 256 pixels)





Focal Surface detector
137 PDMs
= 0.3M Pixels

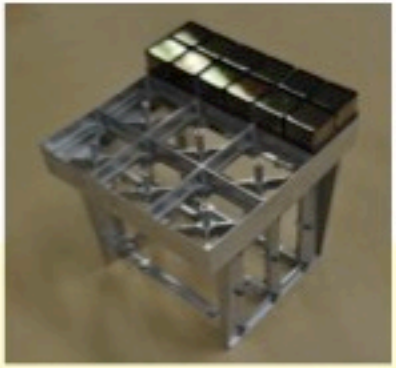
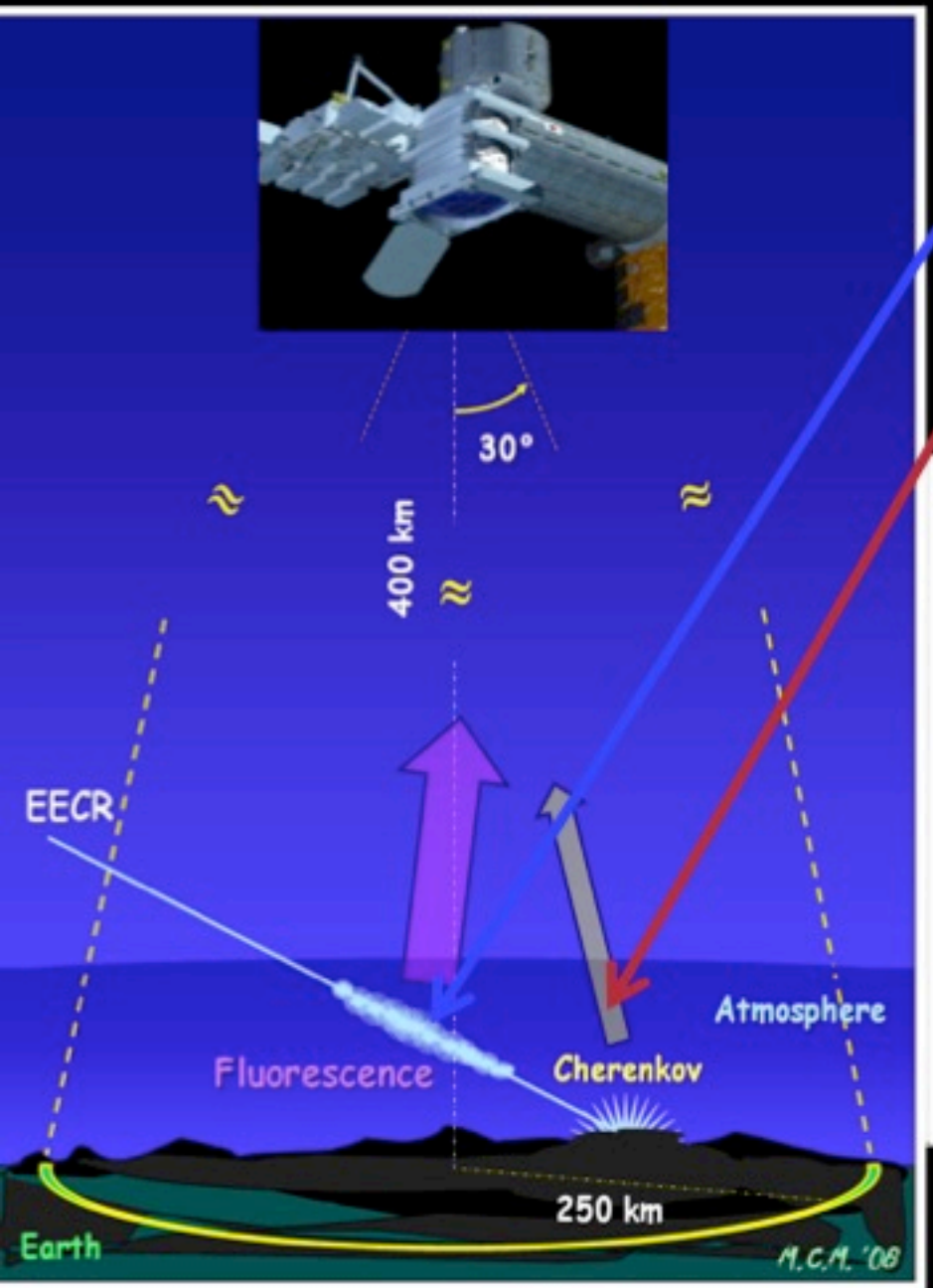


Photo-Detector Module
(3x3 ECs = 2,304 pixels

1 High Voltage / PDM

Fluorescence from SPACE

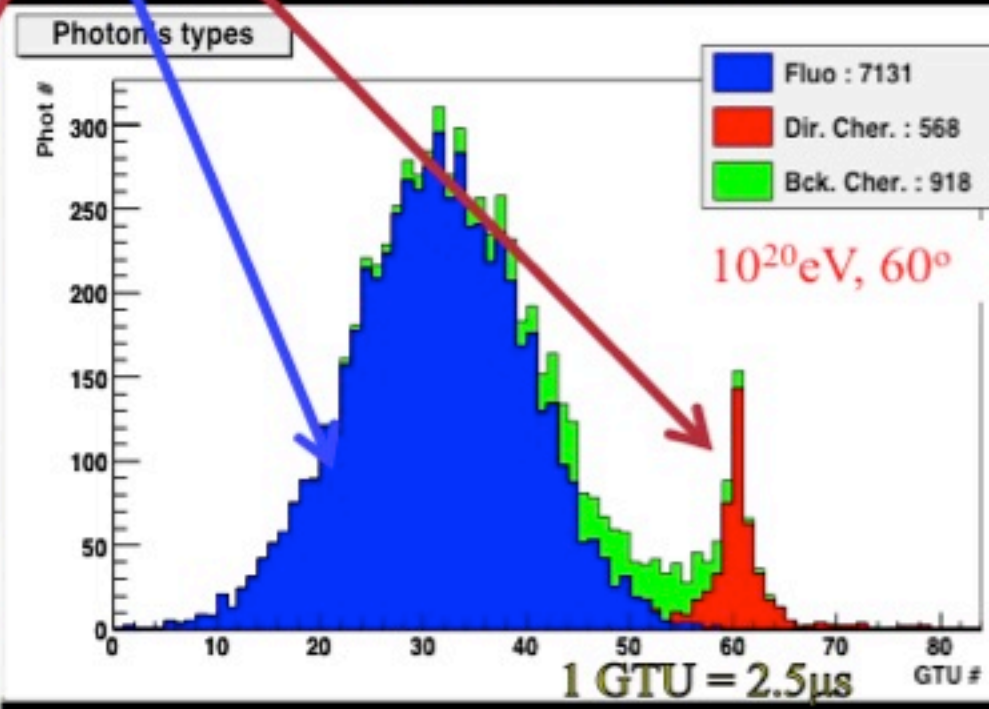


Fast Signal: 50 -150 μs

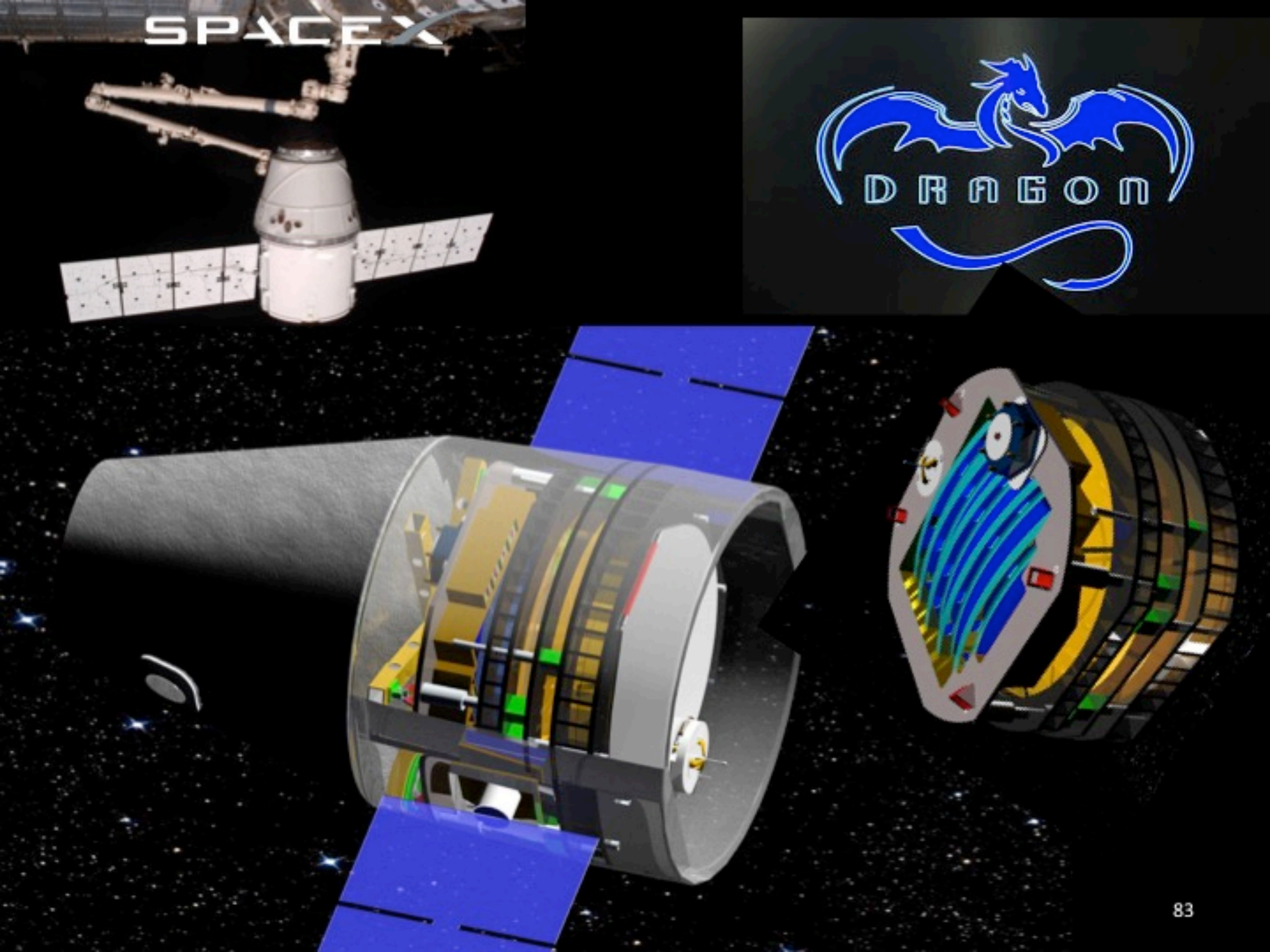
a) Fluorescence

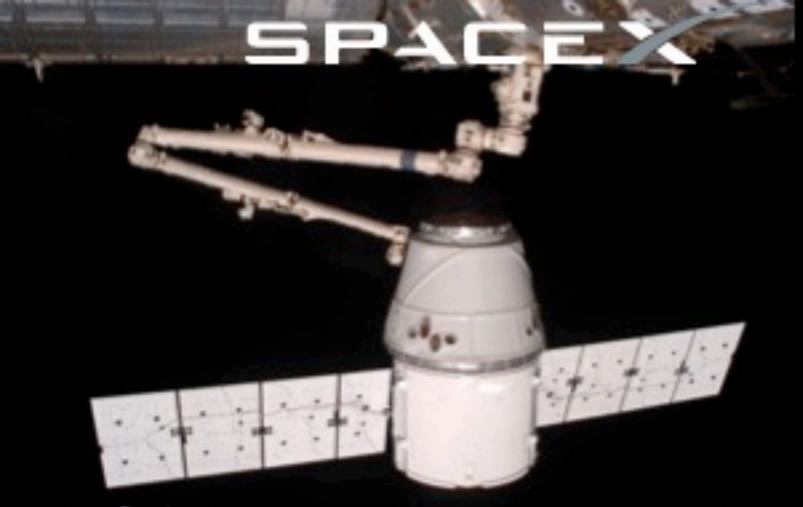
b) Scattered Cherenkov

c) Direct (reflected Cherenkov)

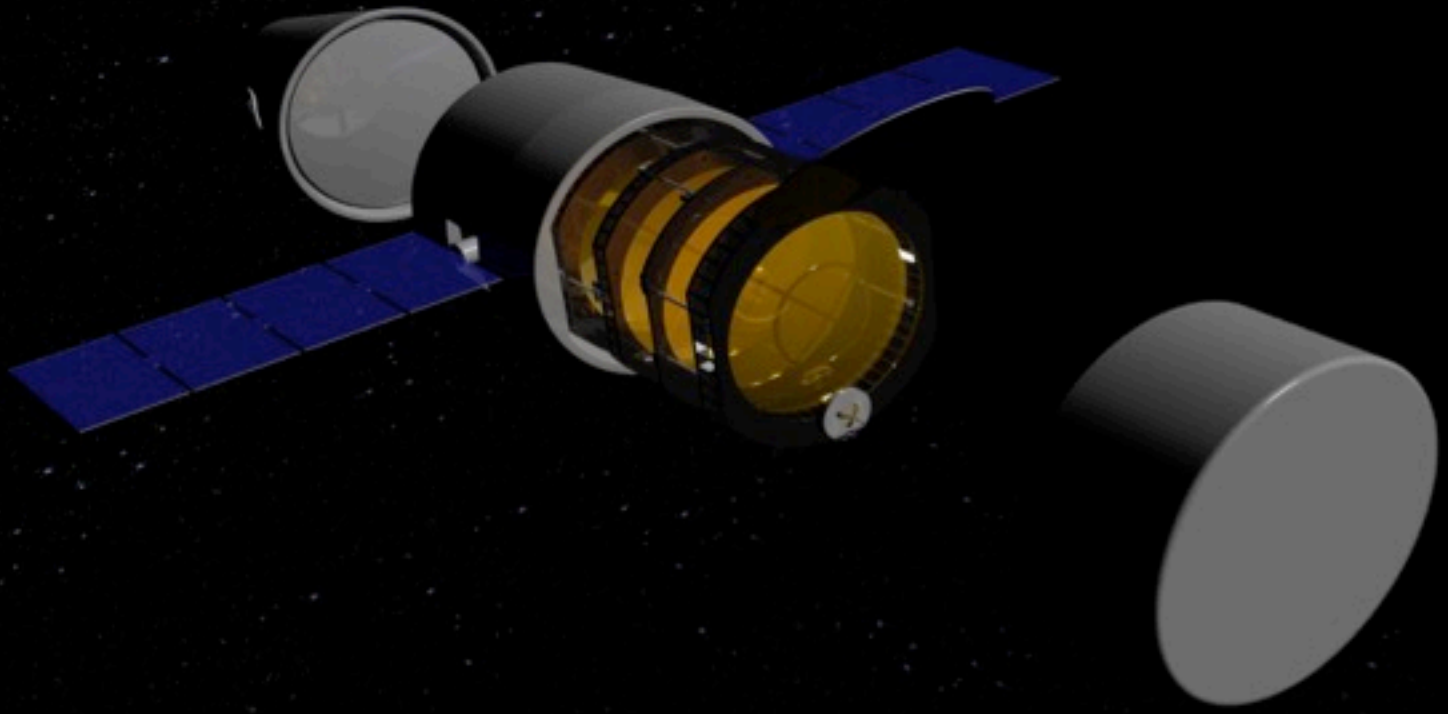


Background: 500 /m^2 sr ns


SPACEX
DRAGON



DRAGON



Full Sky Coverage

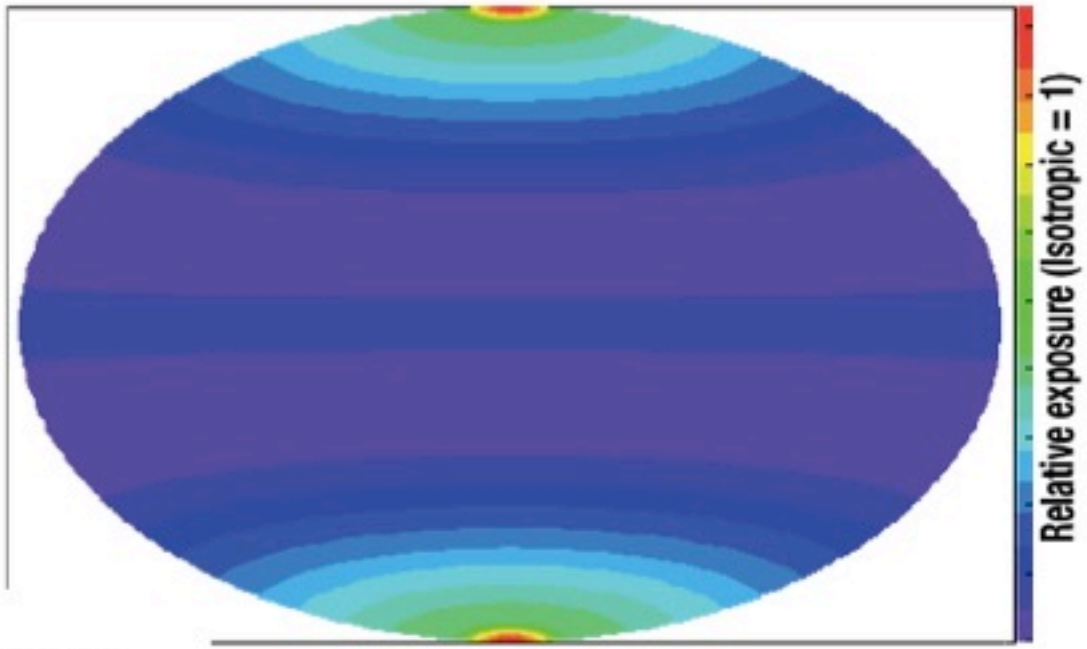
with nearly uniform exposure

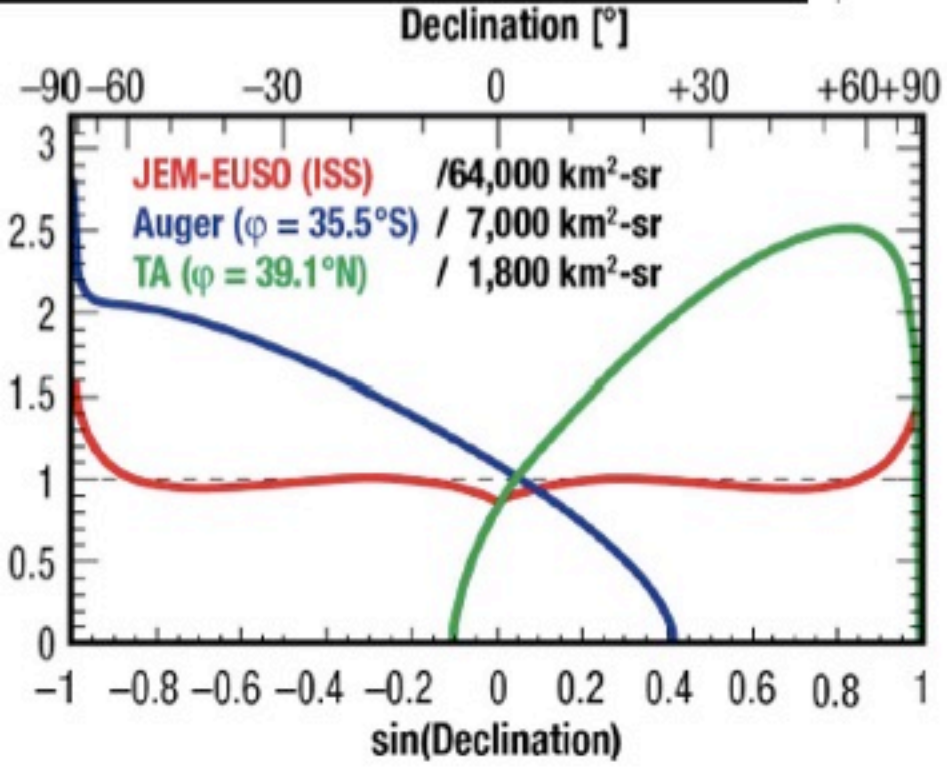
The ISS ORBIT

Inclination: 51.6°
Height: ~400km

JEM-EUSO

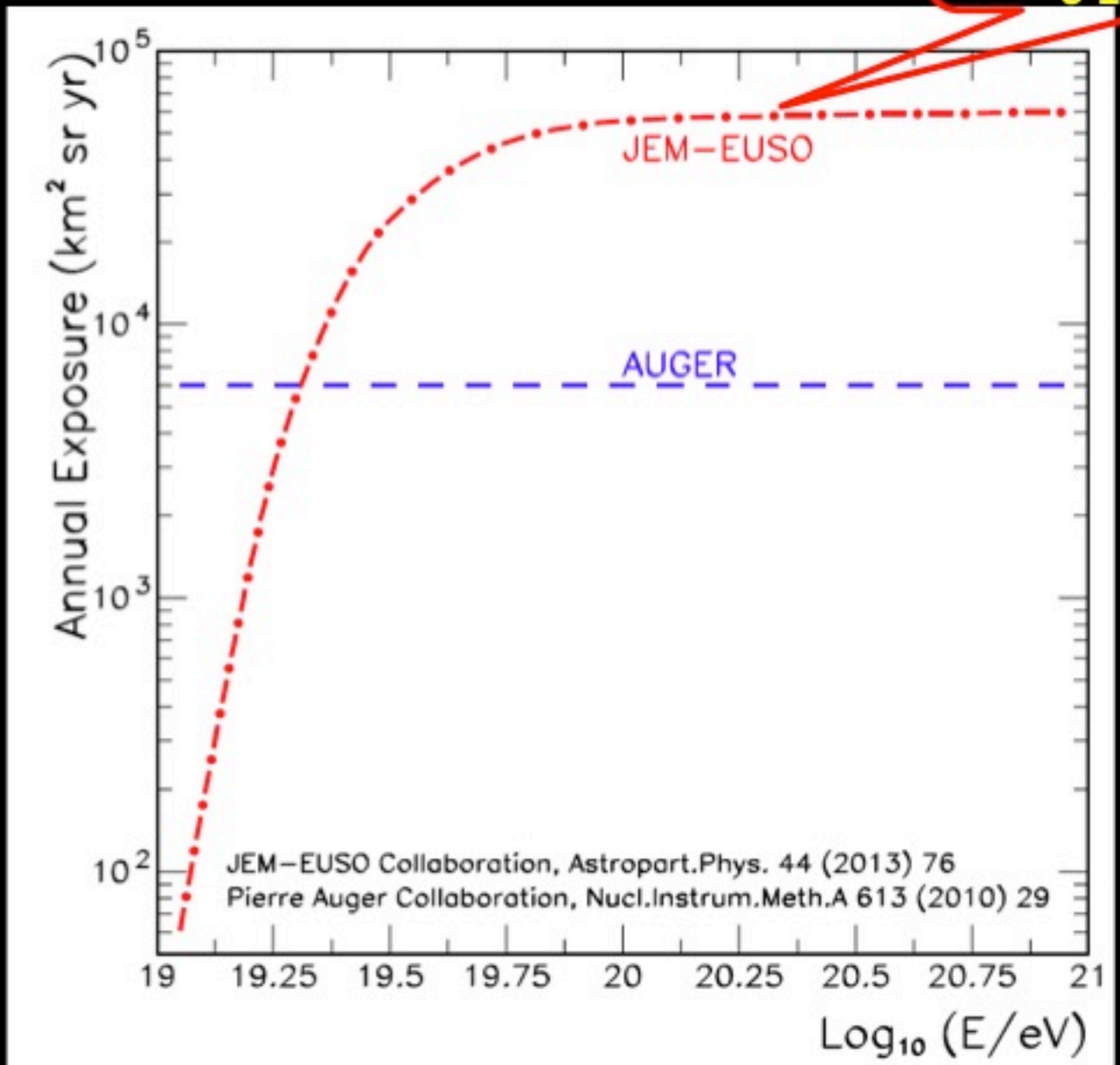
Sky Coverage



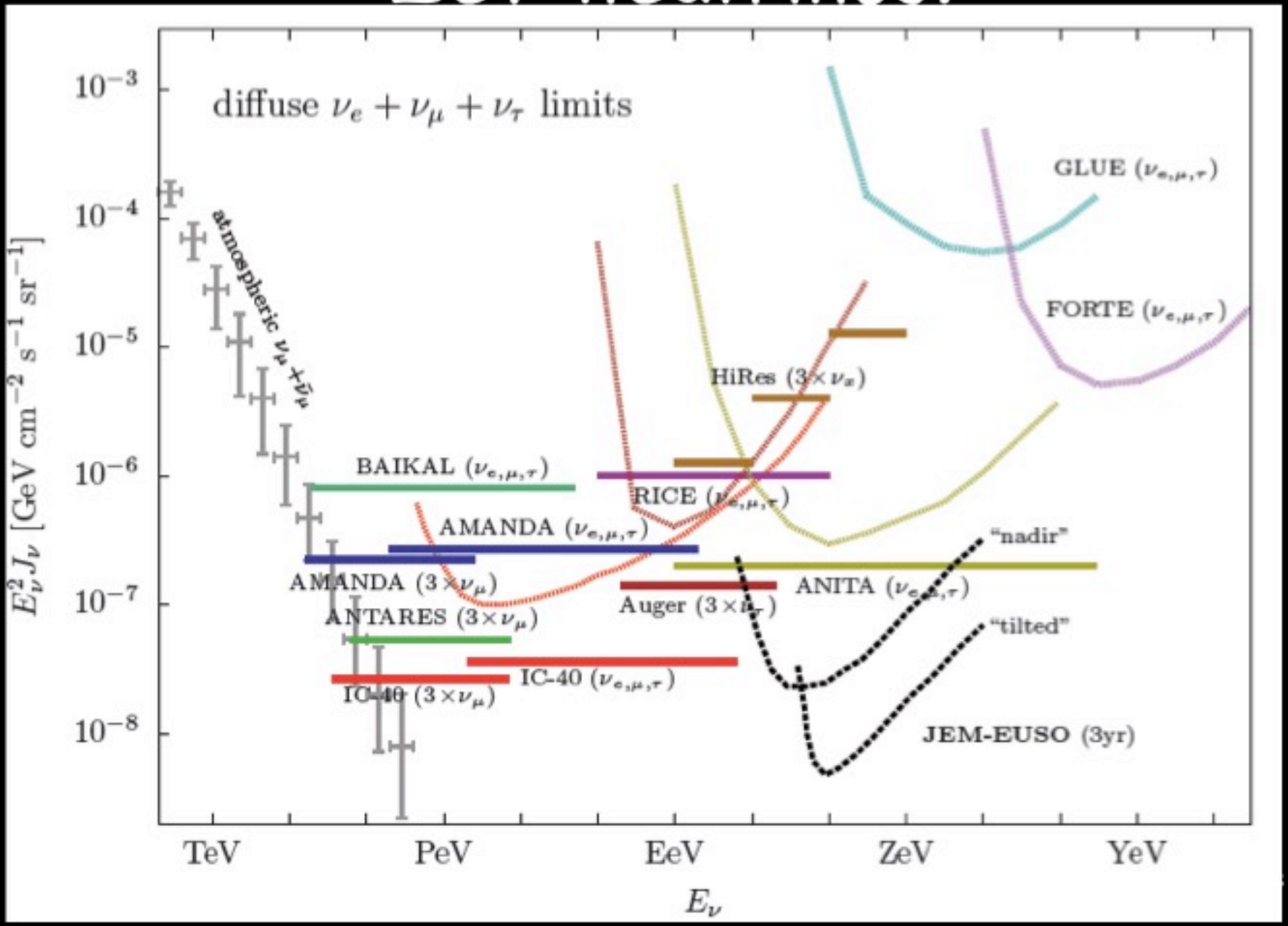


JEM-EUSO

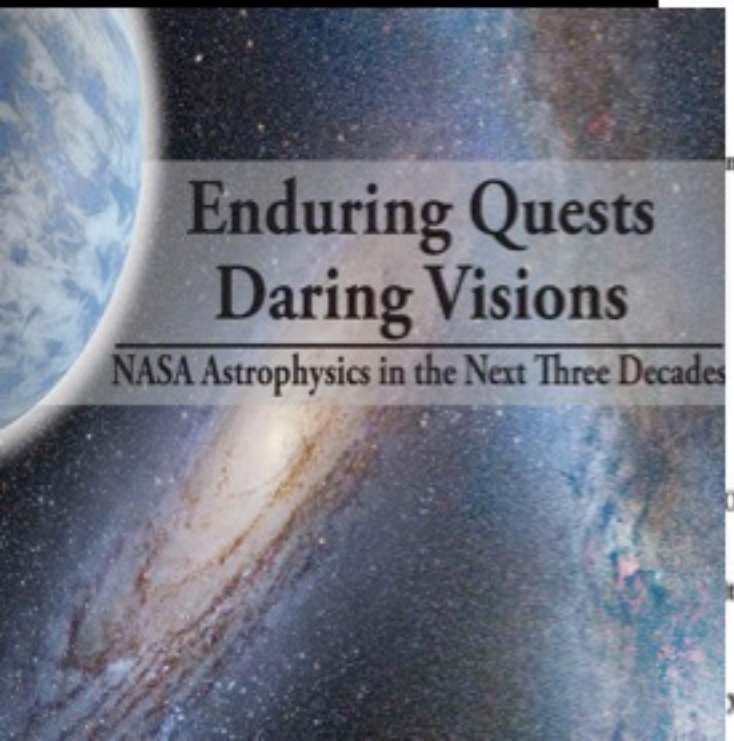
annual exposure =
10 x Auger
$6\ 10^4$ km^2 sr yr



ZeV neutrinos?



NASA Astrophysics Roadmap 2014

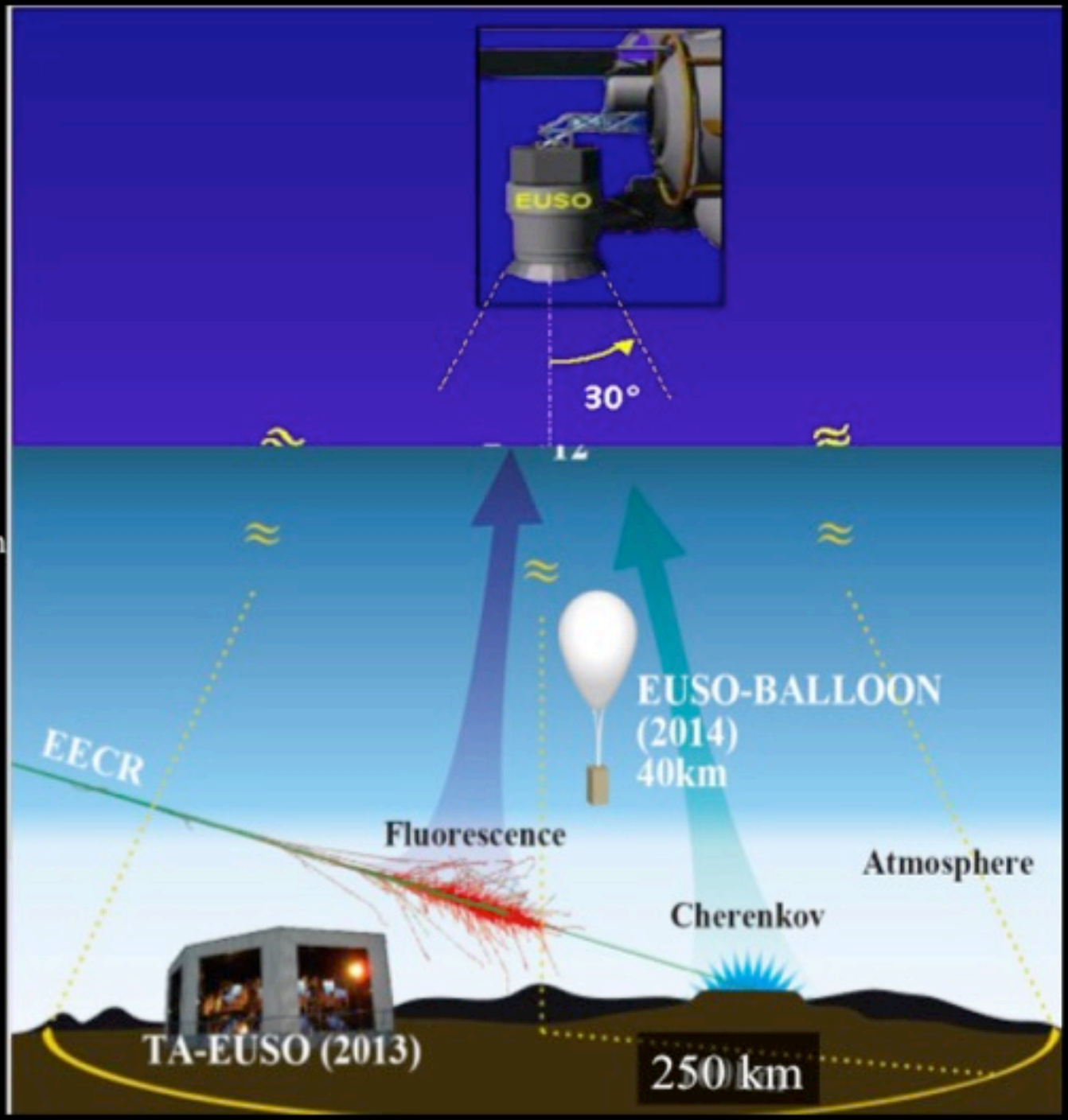


	Near-Term	Formative	Visionary
Gravitational Waves		Gravitational Wave Surveyor	Gravitational Wave Mapper
Cosmic rays	JEM-EUSO		
Radio			Cosmic Dawn Mapper
Microwaves		CMB Polarization Surveyor	
Infrared	JWST	Far IR Surveyor	
Optical	WFIRST-AFTA, Euclid, TESS, Gaia	LUVOIR Surveyor	ExoEarth Mapper
Ultraviolet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

The EUSO program

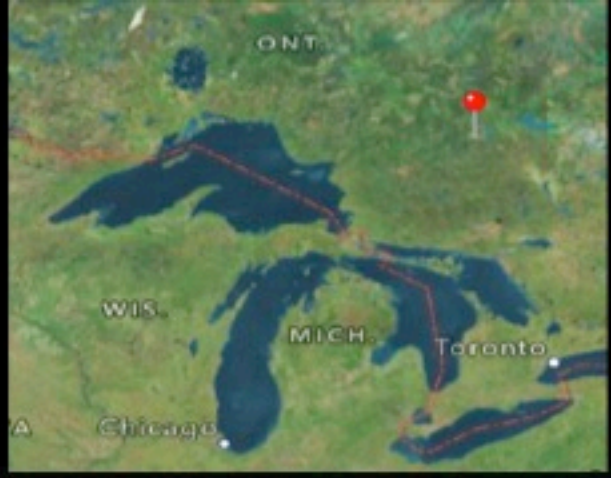
1. EUSO-TA:
Ground detector at
Telescope Array site: 2013

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

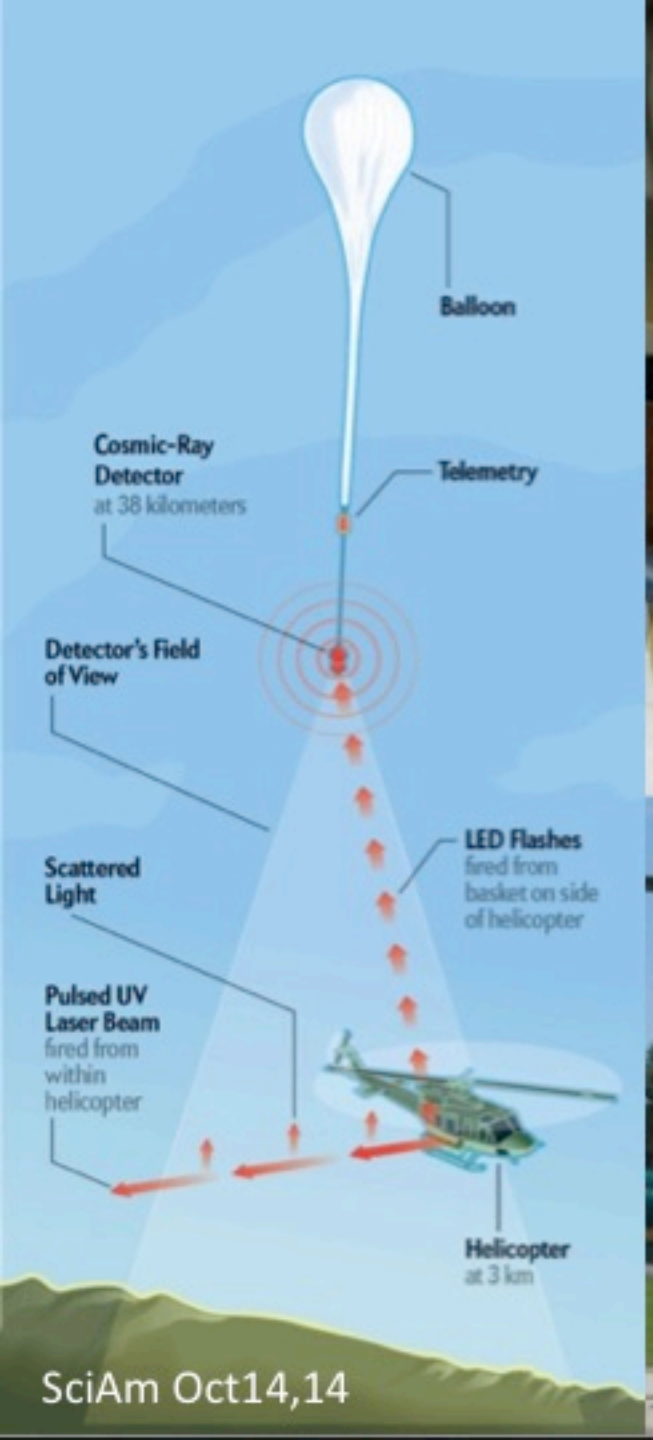


EUSO – Balloon

1st flight from Timmins, Canada (CNES)
August 24-25, 2014



EUSO Balloon:
1st flight and first light on 24-25.8.2014

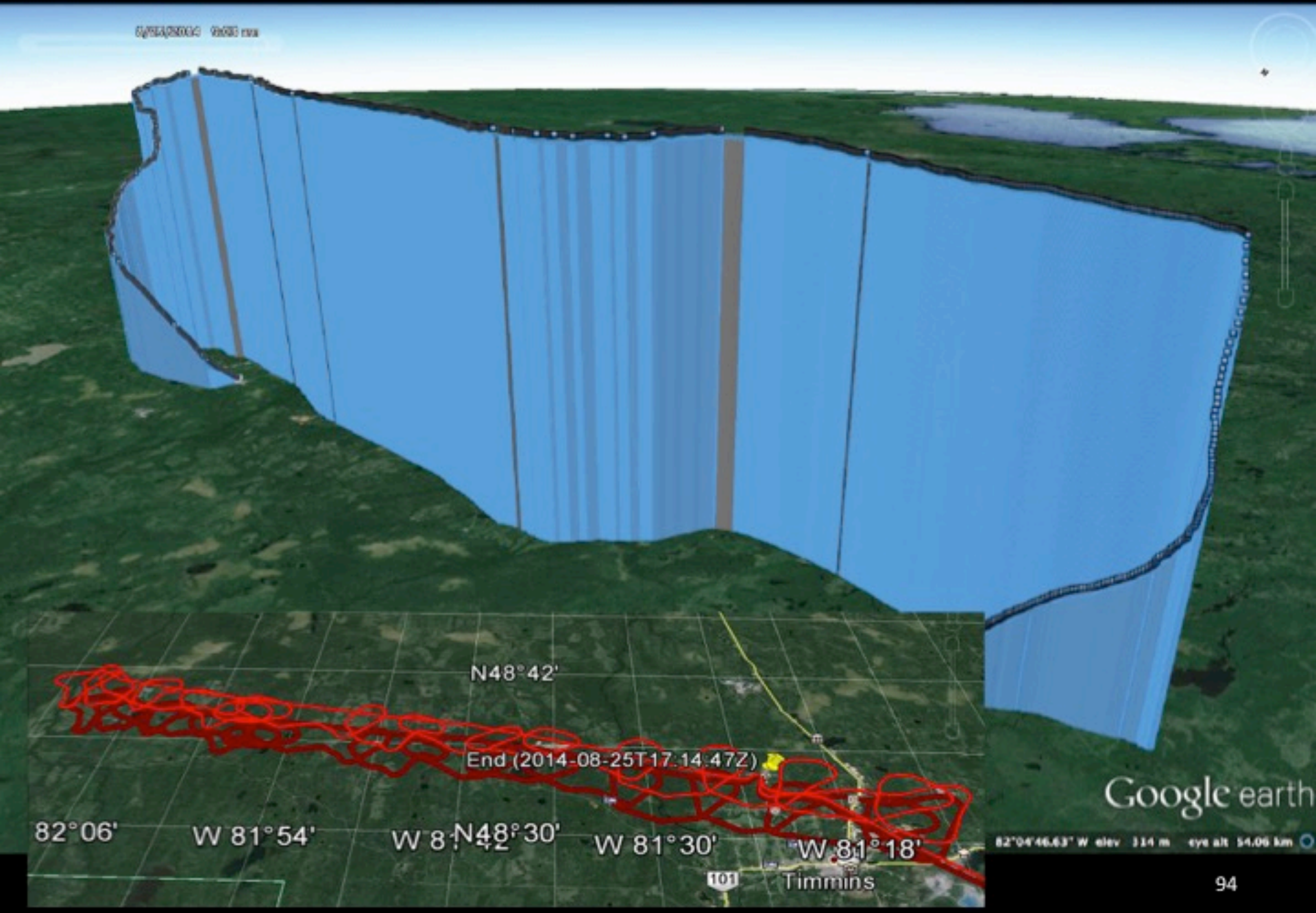


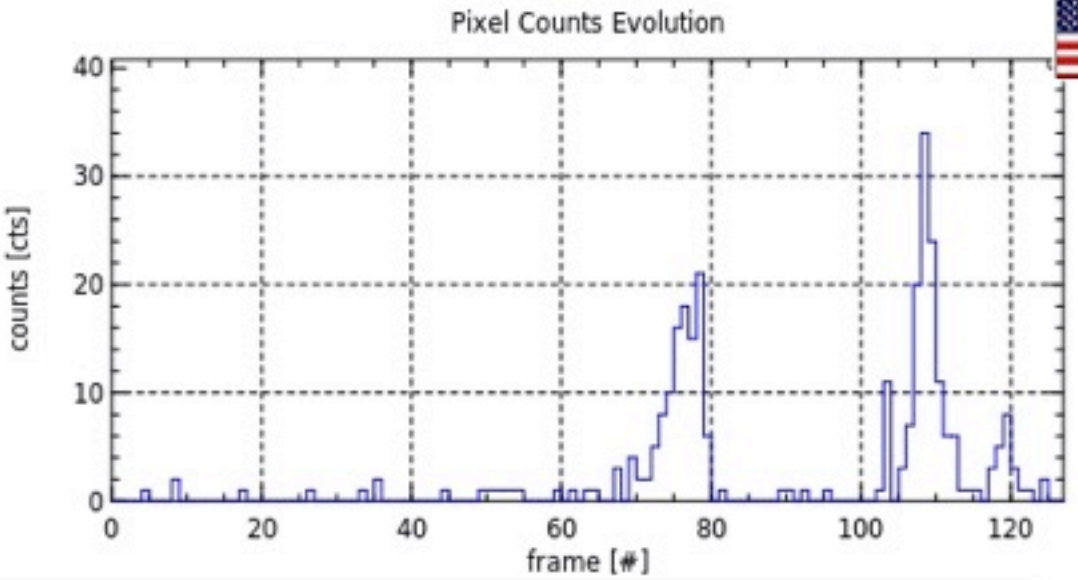
SciAm Oct14,14

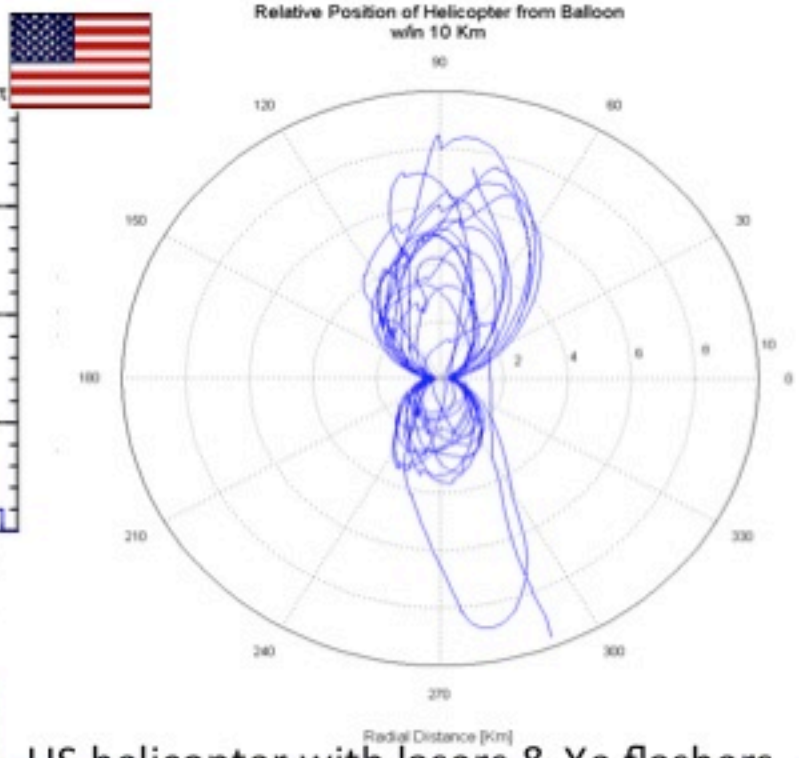
Xenon Flasher

Laser System

UV LED Flasher


N48°42'
End (2014-08-25T17:14:47Z)
82°06'
W 81°54'
W 81°42'
N48°30'
W 81°30'
W 81°18'
101
Timmins
Google earth





US helicopter with lasers & Xe flashers tracked the balloon

> 5hrs of data

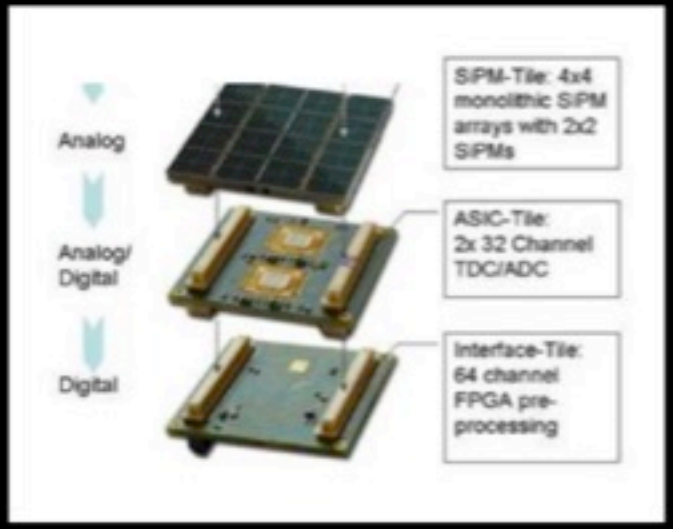
Observed flashes, Laser shots

Low energy CRs with Geiger counter + IR camera cloud cover

"Lake Euso" - the site of eusobalioon's splashdown;

the instrument booth floating above the waterline

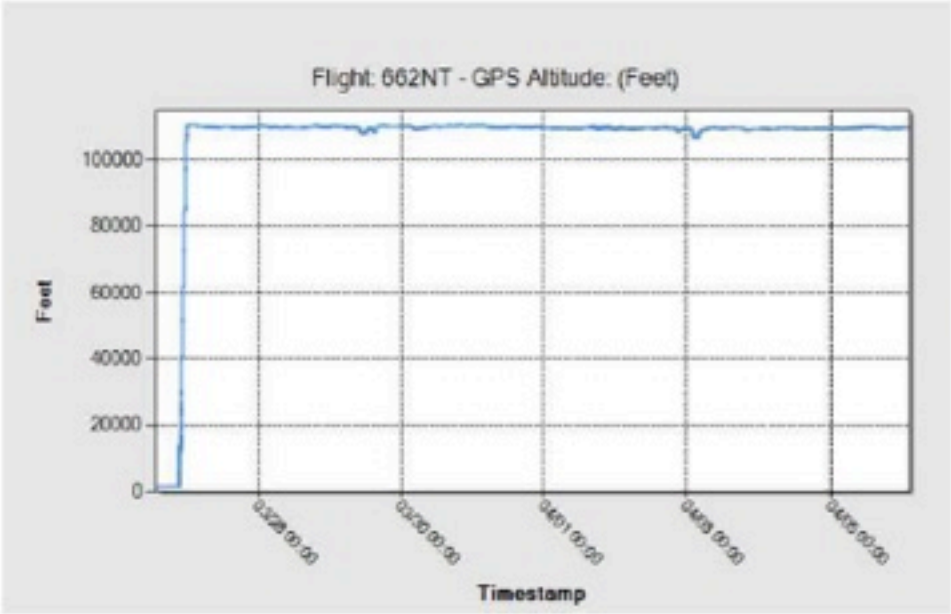
Next steps: **EUSO-SPB**
Super Pressure Baloon (SPB)
Ultra Long Duration flight
- first observations of UHECRs from space
- test SiPM focal surface

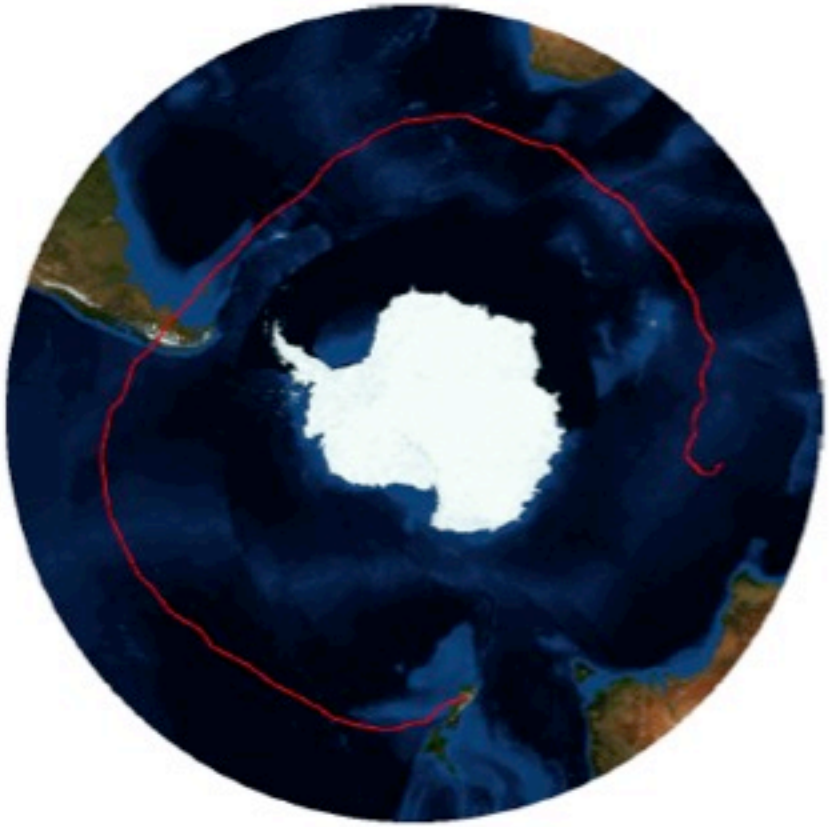


Astrophysics Division

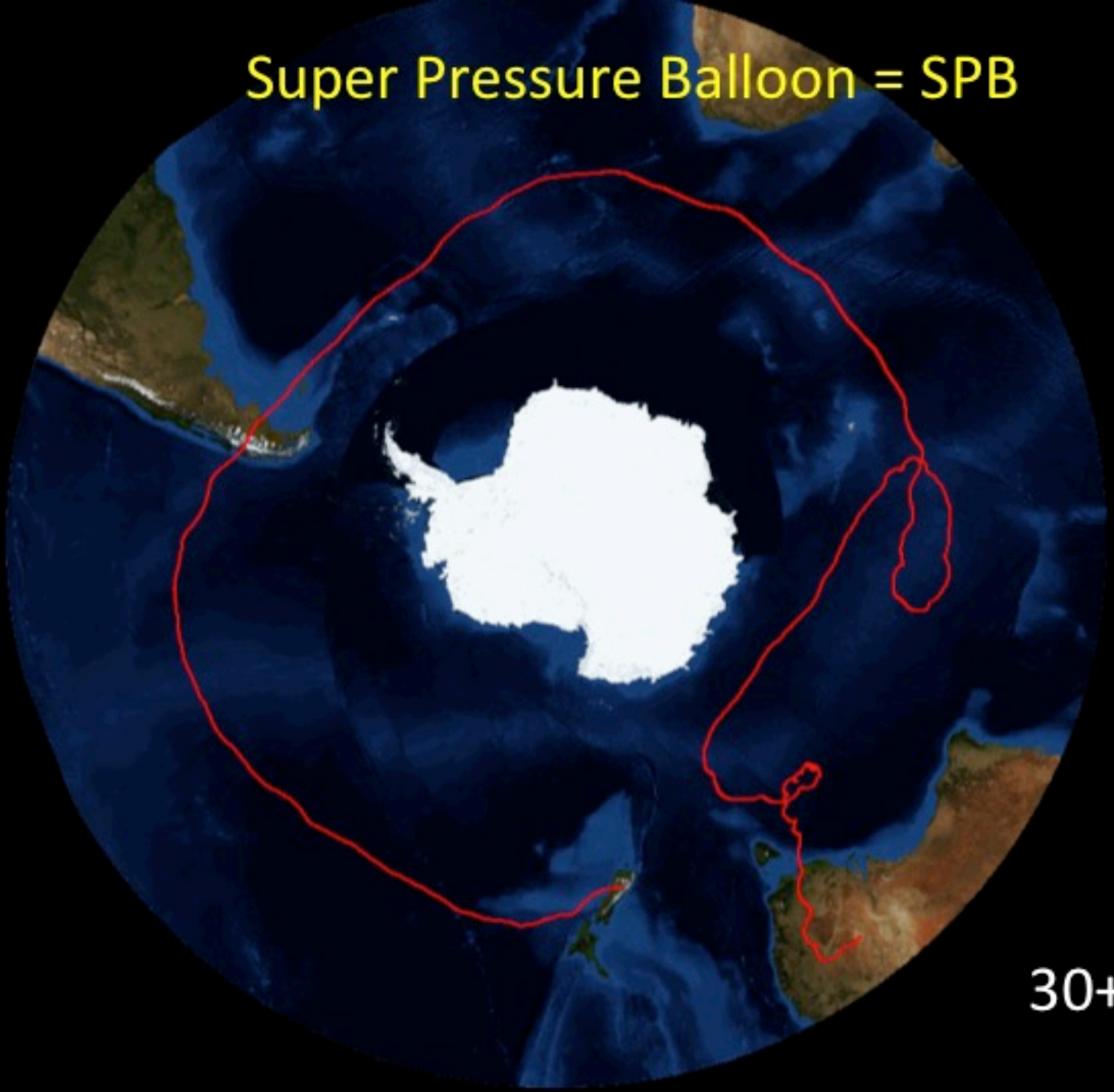
First NASA Balloon Launched from Wanaka, NZ

- Launched from Wanaka, NZ on morning of 3/27/15.
  - ✓ Afternoon of 3/26/15 EST.
- Balloon remains healthy 4/9/15 >14 days into the flight!
  - ✓ Floating at nearly altitude around 109,000 – 110,000 ft.

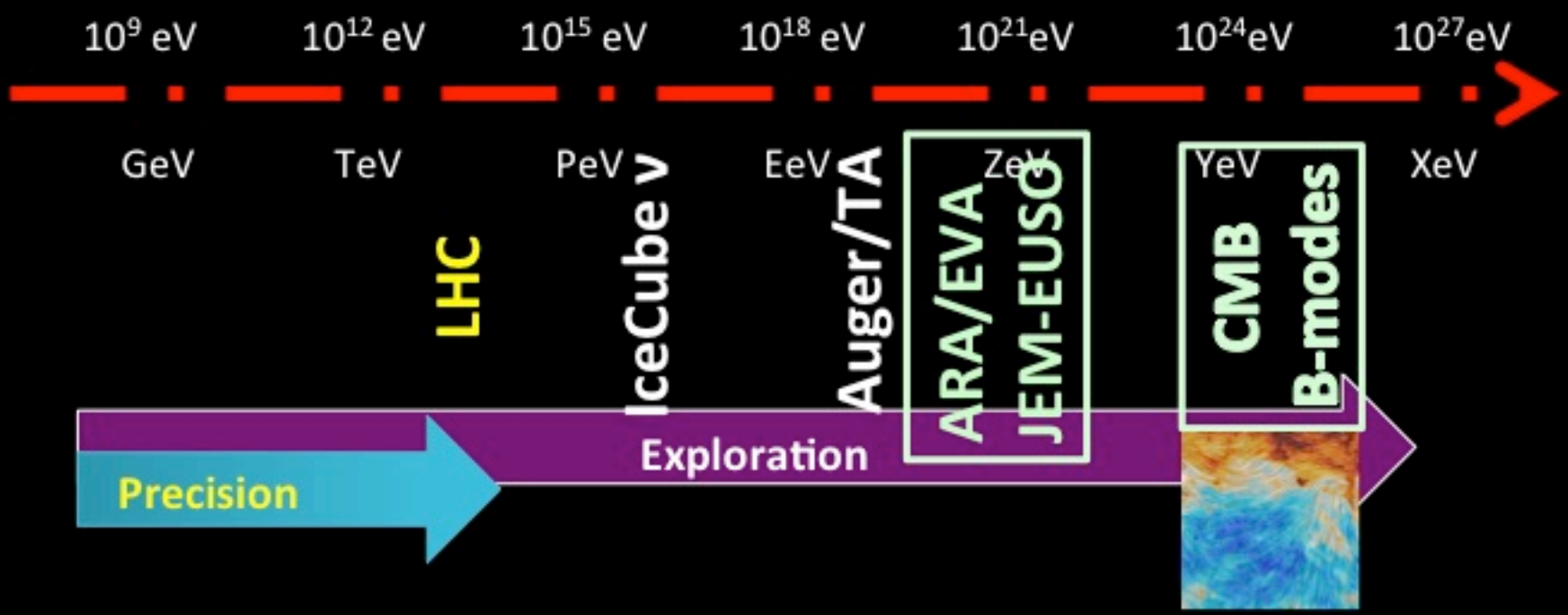




Super Pressure Balloon = SPB



30+ days


10^9 eV
10^{12} eV
10^{15} eV
10^{18} eV
10^{21}eV
10^{24}eV
10^{27}eV
GeV
TeV
PeV
EeV
ZeV
YeV
XeV
LHC
IceCube ν
Auger/TA
ARA/EVA
JEM-EUSO
CMB
B-modes
Precision
Exploration

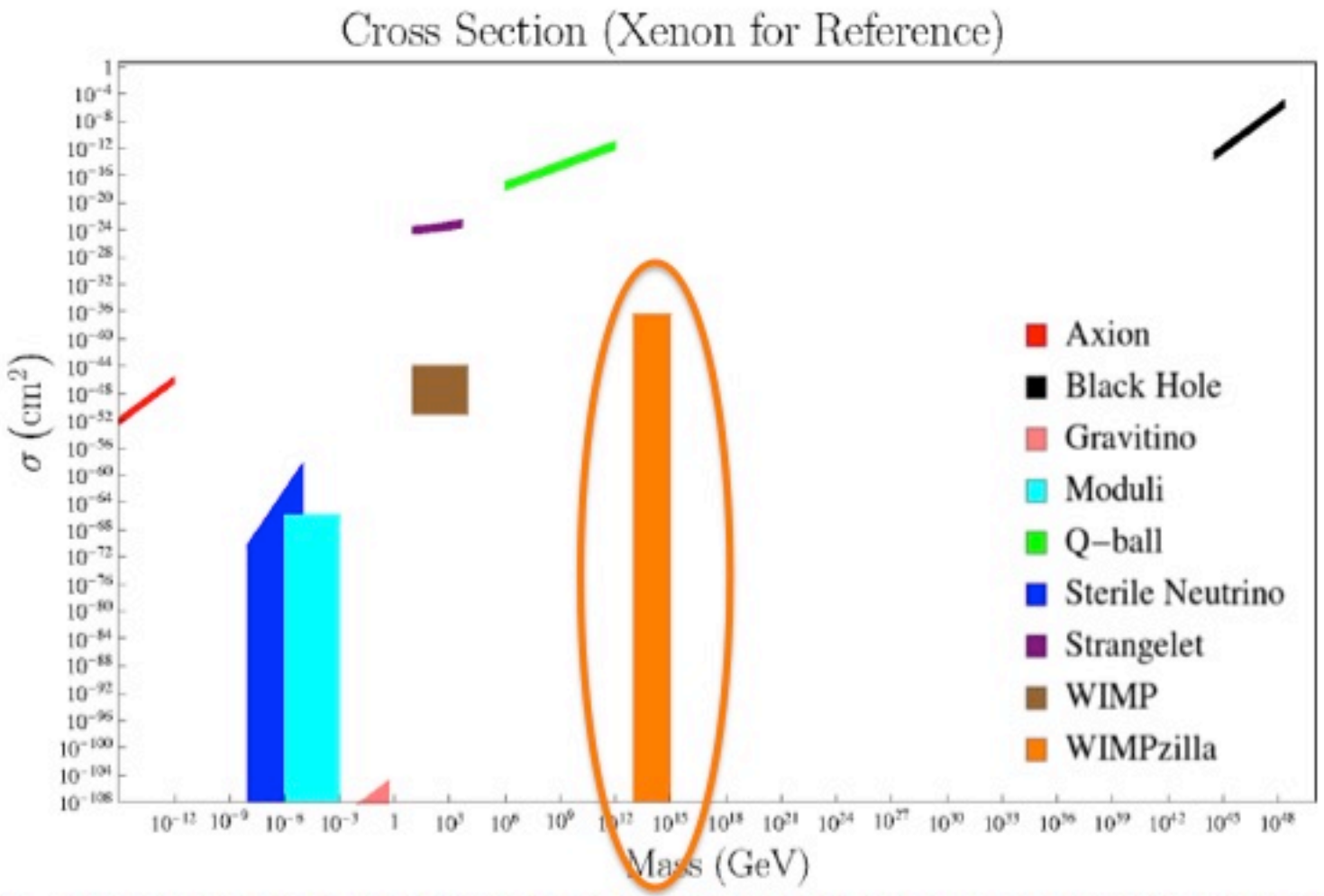
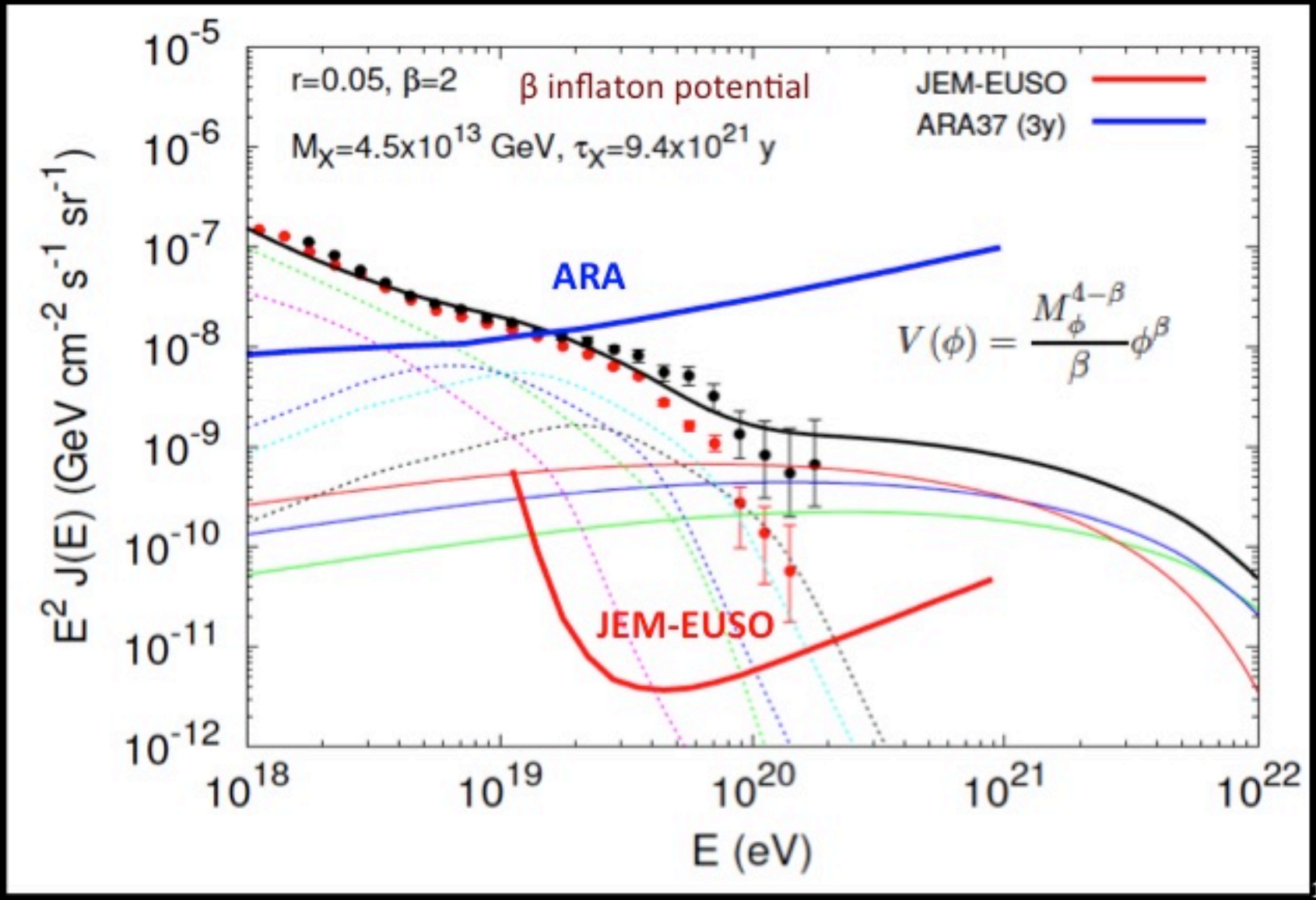


Figure 4-8. *The range of dark matter candidates' masses and interaction cross sections with a nucleus of Xe (for illustrative purposes) compiled by L. Pearce. Dark matter candidates have an enormous range of possible masses and interaction cross sections.*

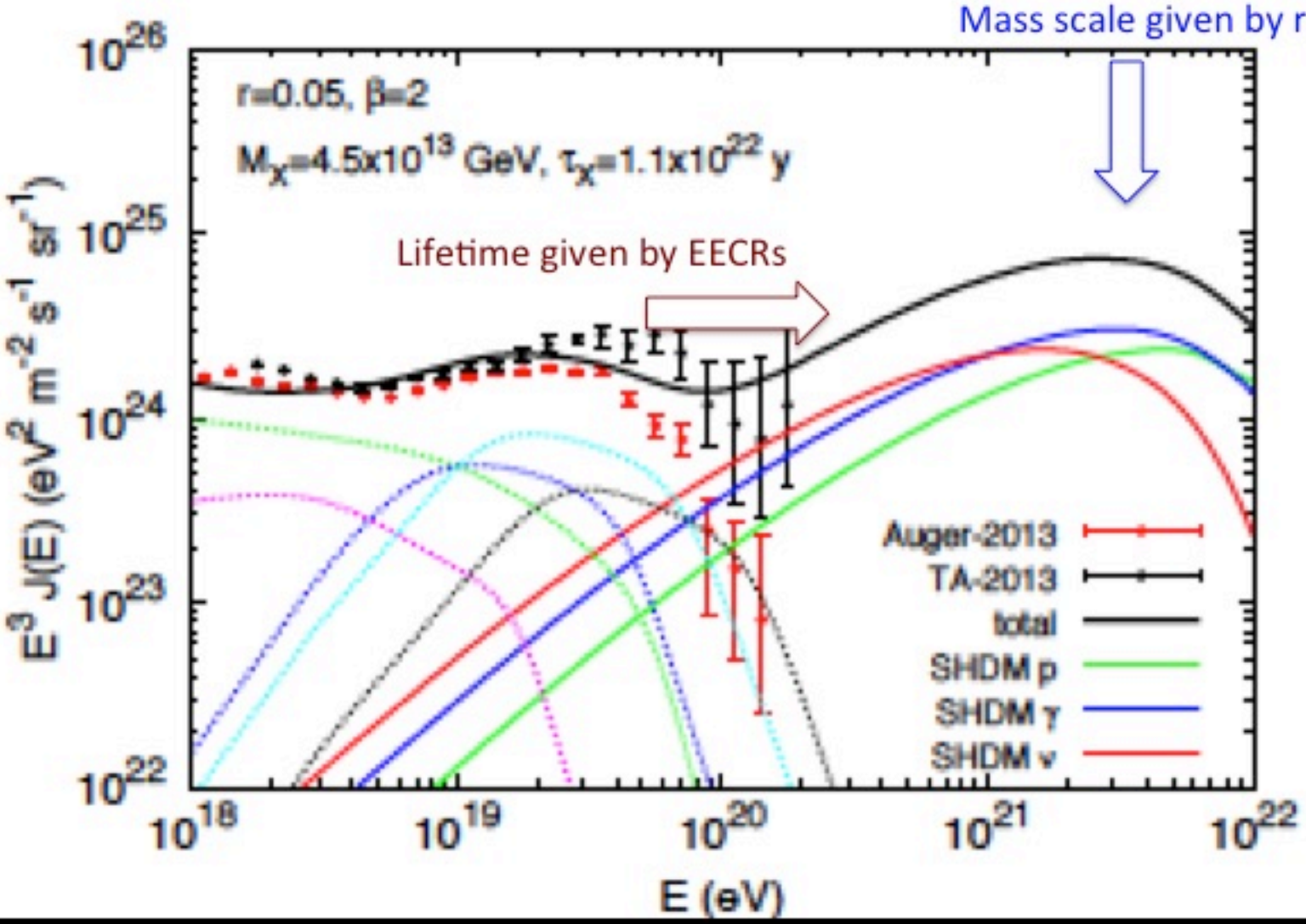
Super Heavy Dark Matter

Aloisio, Matarrese, AO '15



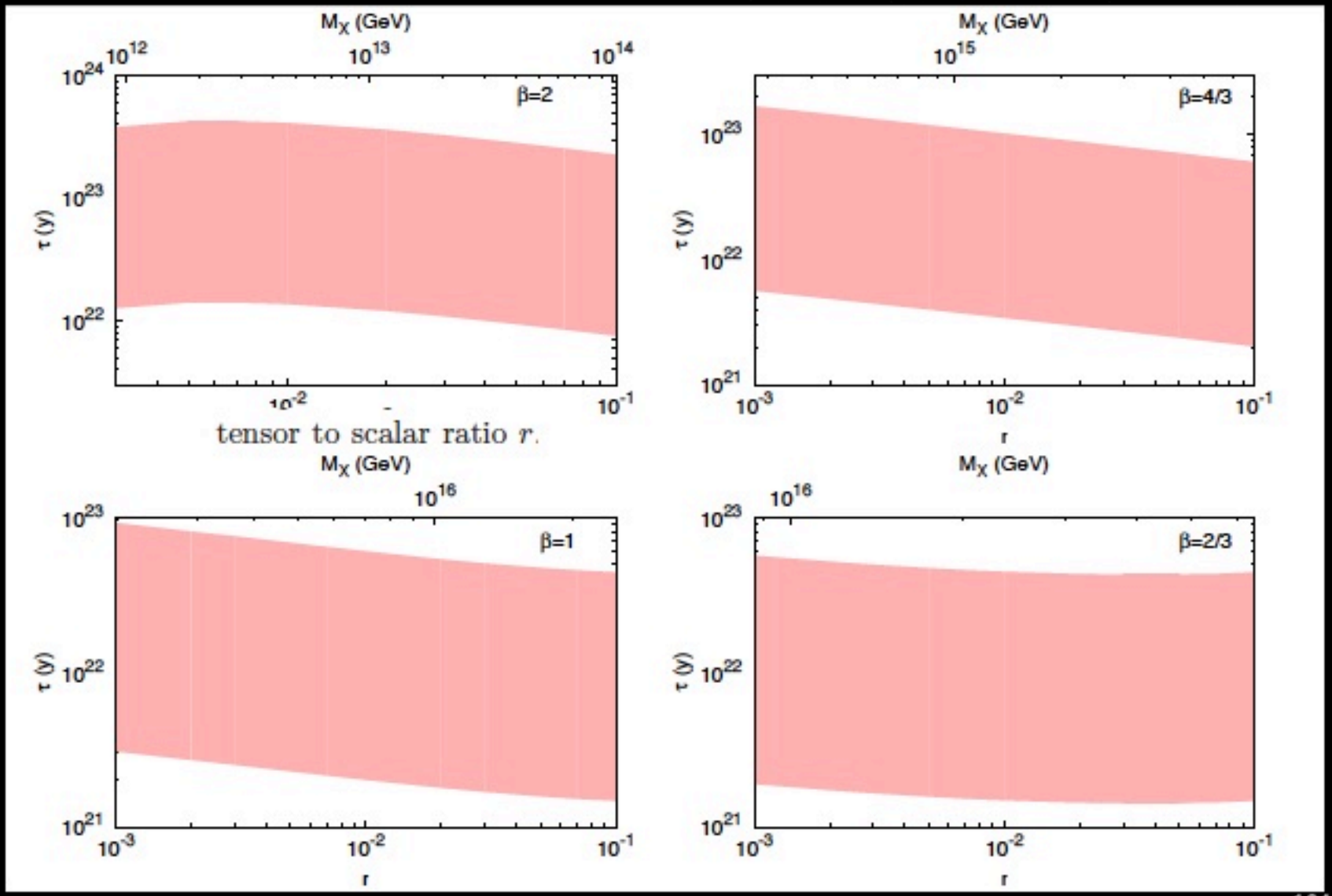
SHDM

Aloisio, Matarrese, AO '15



Super Heavy Dark Matter

Aloisio, Matarrese, AO '15



How many UHECRs > 60 EeV?

Auger + TA ~30 events/yr

JEM-EUSO

~200 events > 60 EeV/y

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/y

4 o.o.m to go!

Earth surface ~ 5 10^8 km^2

~3.4 10^6 events/yr

Extreme Energy Frontier Mysteries to be Resolved from Space!

Thanks!


Extreme Energy Frontier
Mysteries to be
Resolved from Space!
Thanks!