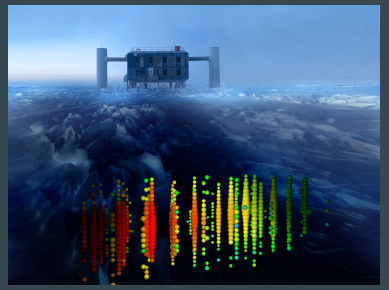
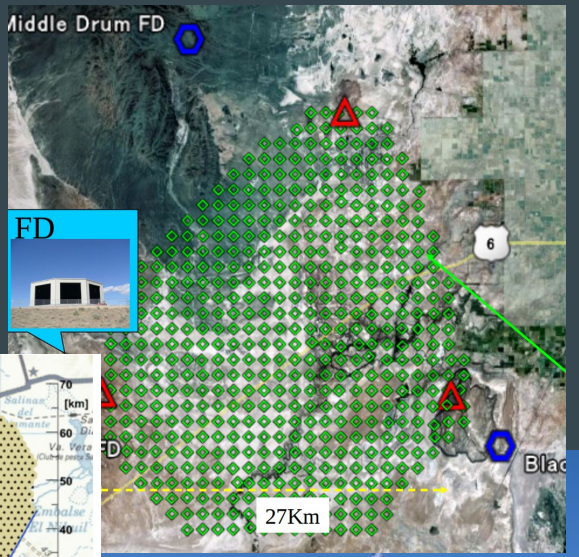
UHECR-2016 Summary

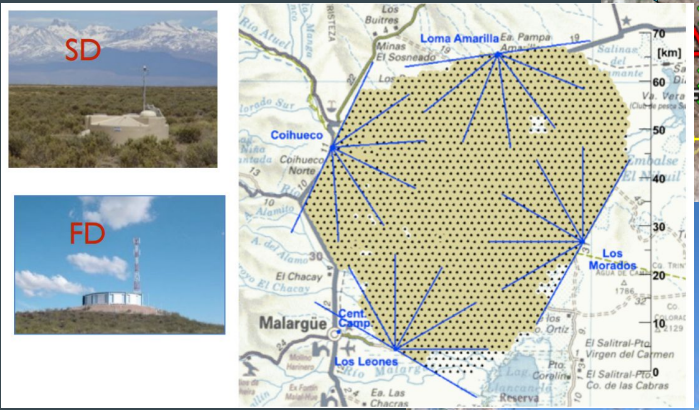
Alexander Kusenko
(UCLA and Kavli IPMU)

Interesting times!

- New data: cosmic rays, neutrinos, γs
- Exciting questions about
  - Spectrum
  - Composition
  - Sources
  - Anisotropy



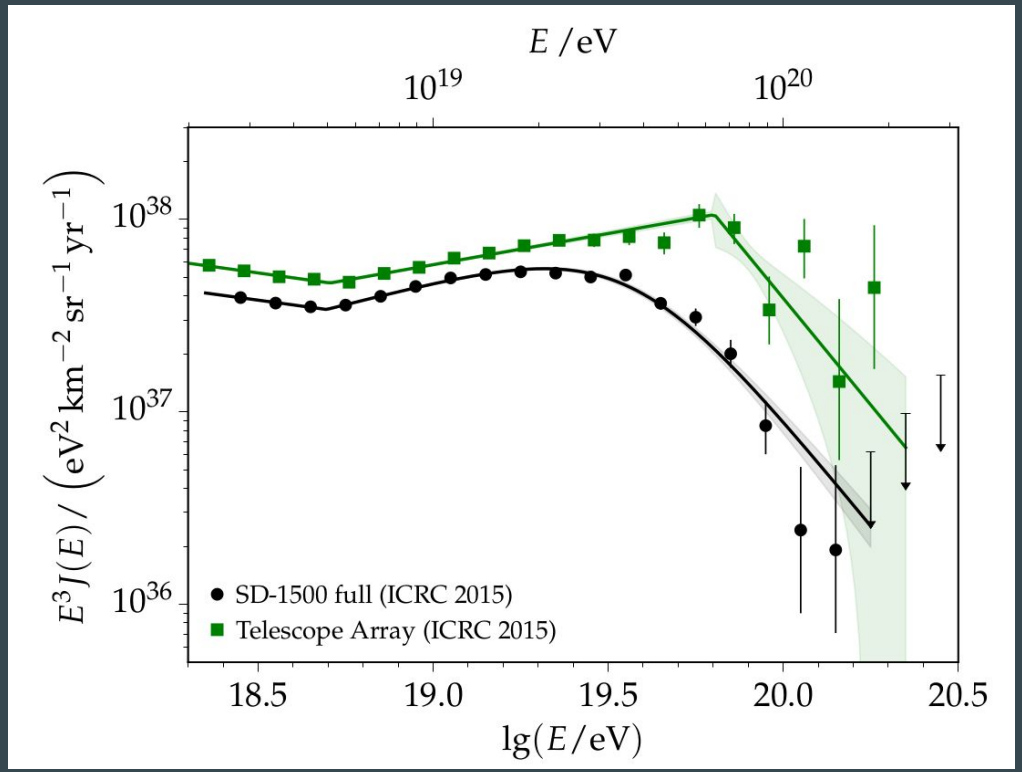




As a Chinese proverb says,
宁為太平犬，莫做亂离人

“It is better to be a dog in peaceful times than to give a conference Summary Talk in interesting times...”

Cosmic ray spectrum: PAO and TA



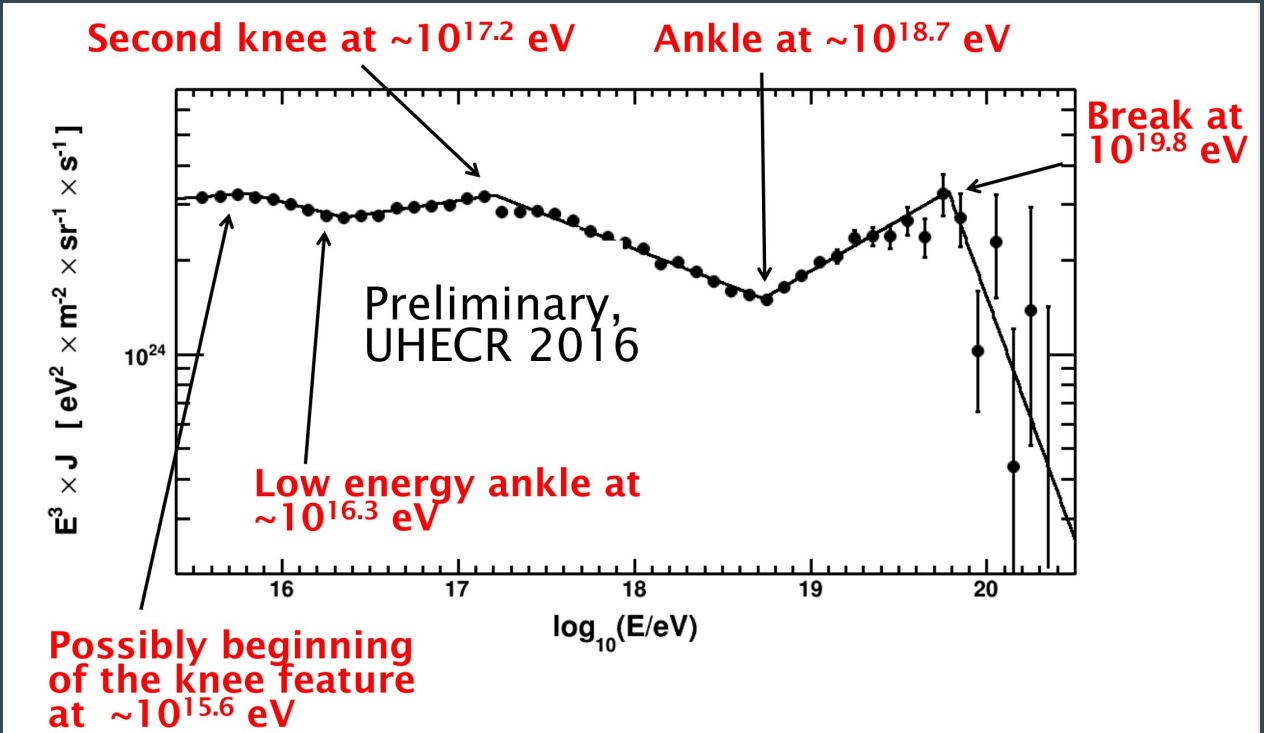
Both experiment see a cutoff, supposedly, a GZK cutoff.

A discrepancy at ~25 EeV (energy rescaling doesn't help)

Ivanov, Roth, others

on

Spectral features according to TA

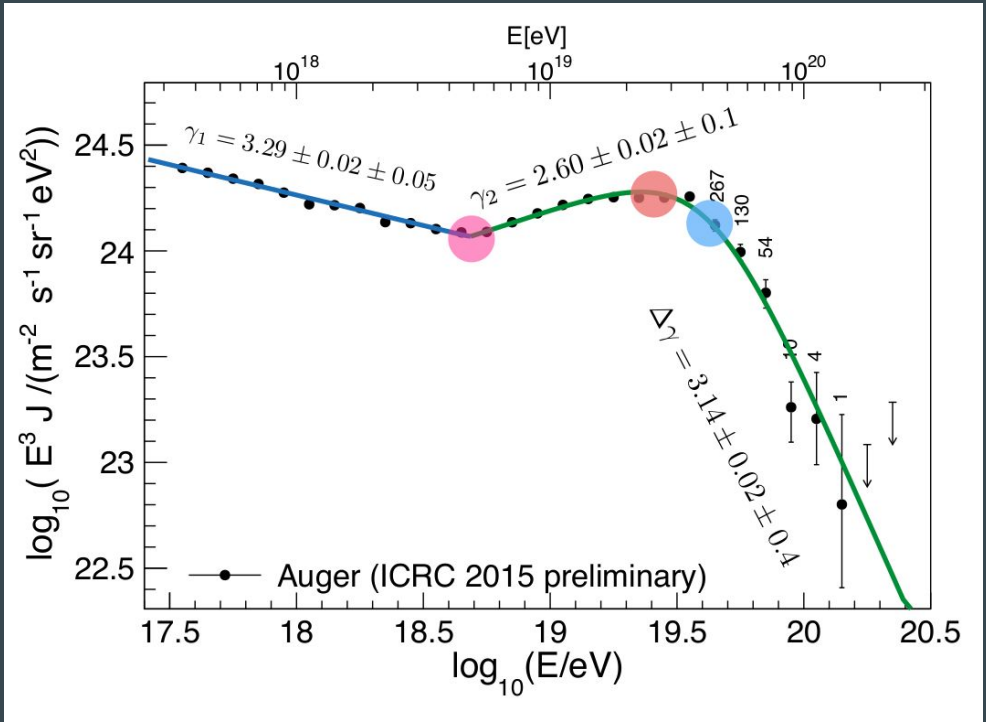


Four features:

- low-energy ankle at ~$10^{16.3}$ eV
- 2nd knee at ~$10^{17.2}$ eV
- ankle at ~$10^{18.7}$ eV
- GZK break at ~$10^{19.8}$eV

Ivanov

Spectral features according to PAO

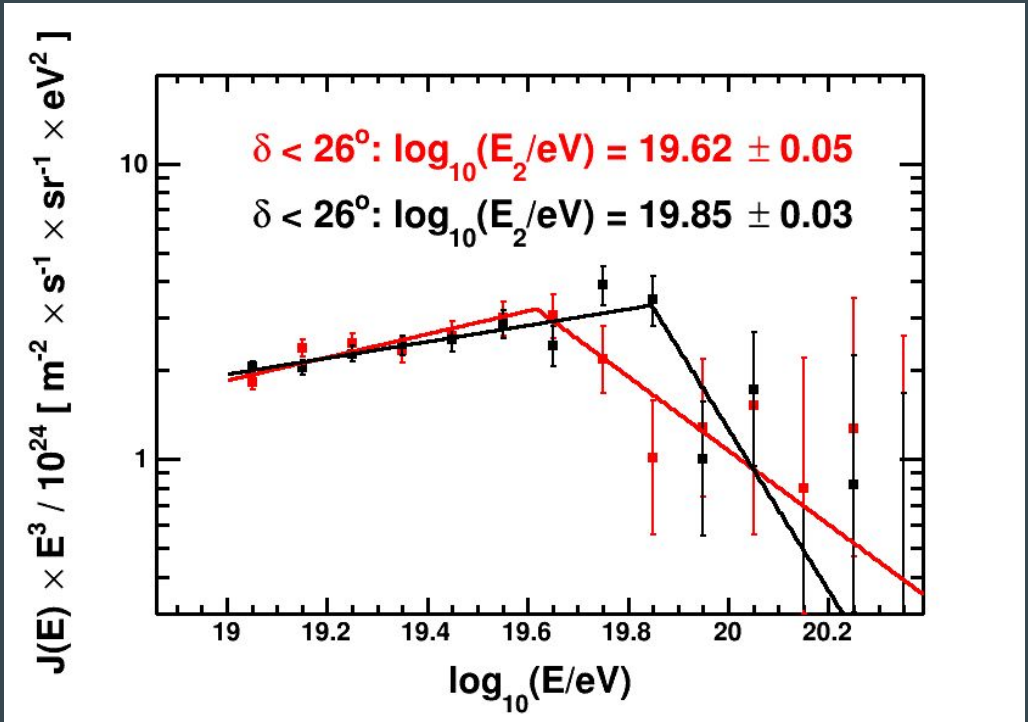


$$E_{\rm ankle} = 4.8 \pm 0.1 \pm 0.8\ {\rm EeV}$$
$$E_{\rm s} = 42.1 \pm 1.7 \pm 7.6\ {\rm EeV}$$
$$E_{1/2} = 24.7 \pm 0.1^{+8.2}_{-3.4}\ {\rm EeV}$$

For comparison,
TA ankle: 5 EeV;
TA suppression: 63 EeV

Roth

Declination dependence according to TA

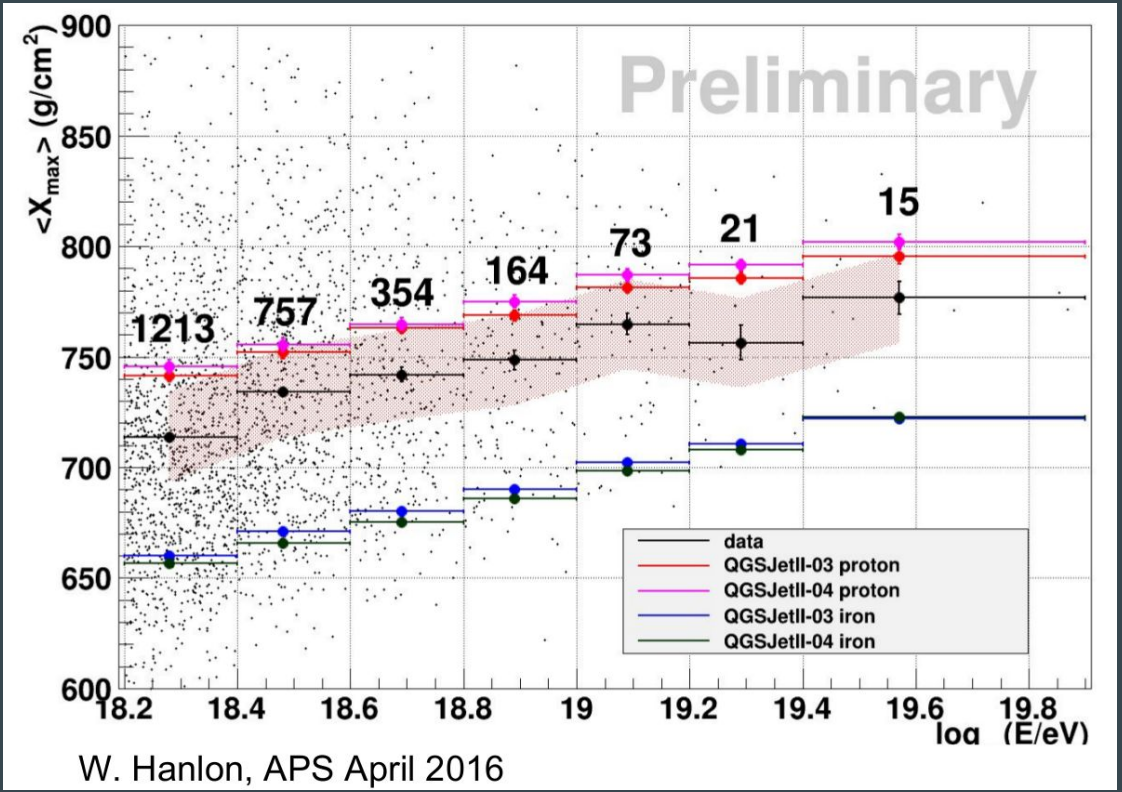


Declination dependence (3.9σ)
In the TA data sample with zenith angle up to 55 degrees.

PAO (Roth): TA/Auger discrepancy shows no significant indication of variation in 4 declination bands

Ivanov

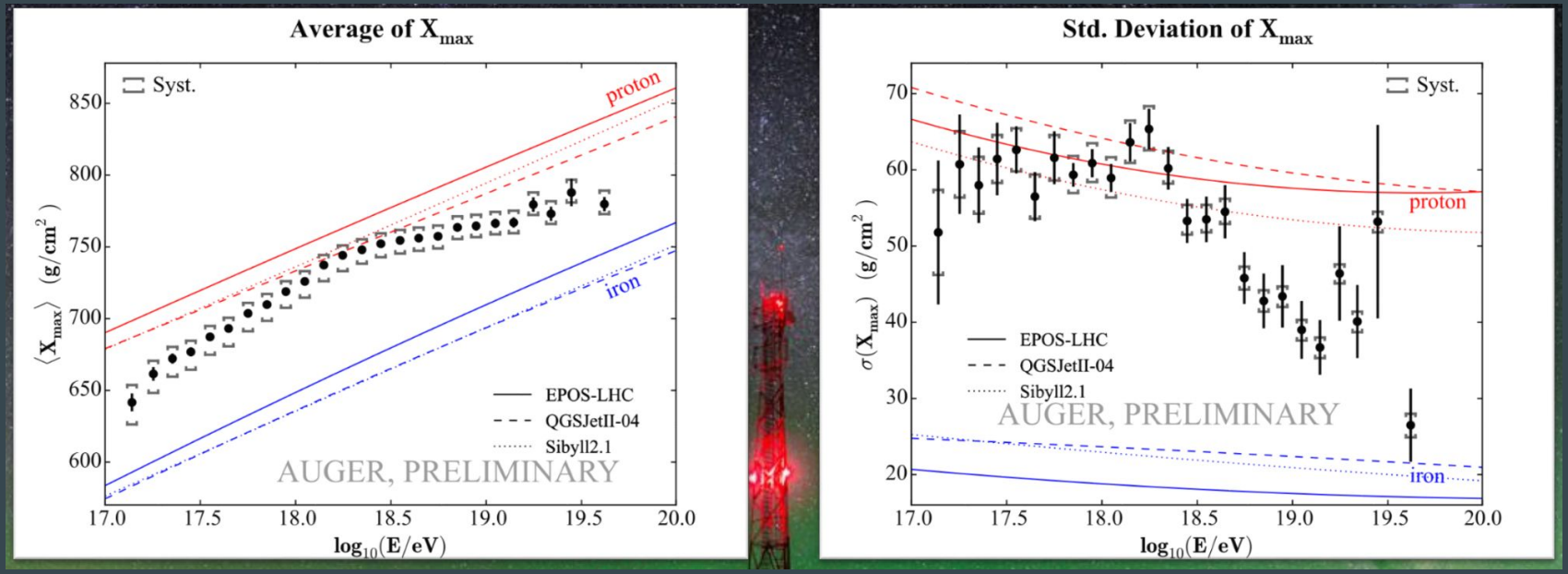
Composition: TA results



"Light composition"
(=not iron) is favored

Belz, Hanlon

Composition: Pierre Auger results

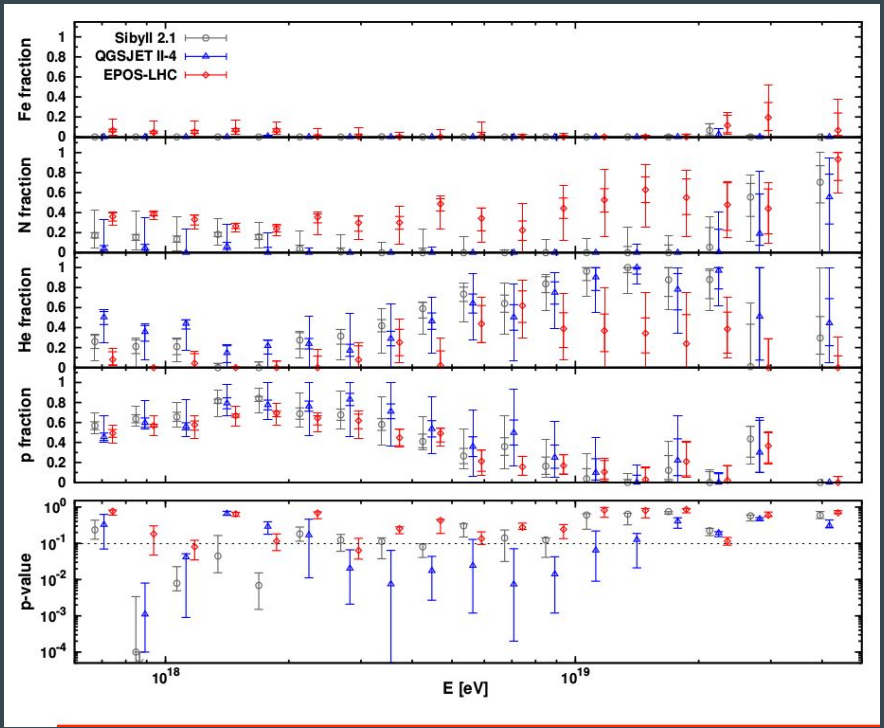


Significant change in the composition at 2 EeV.

Peculiar energy dependence in $\sigma(X_{max})$.

Plum

Composition: Pierre Auger results

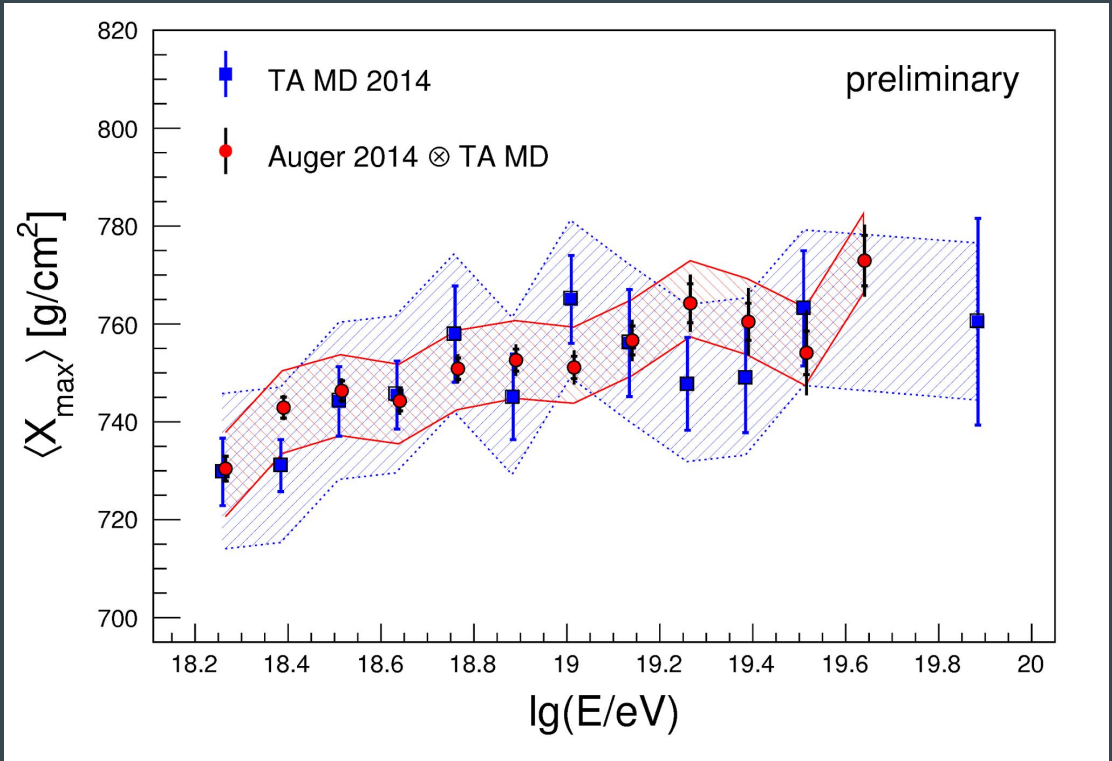


Disfavor pure protons

Favor mixed composition with significant fraction of He, and A>4 nuclei (N)

Fits with mixed composition (based on assumptions about the injection spectra) represent the ankle, other features

Auger - TA composition working group: encouraging



For an assumed mixed composition, the two experiments would have given ***consistent*** results.

Significant progress

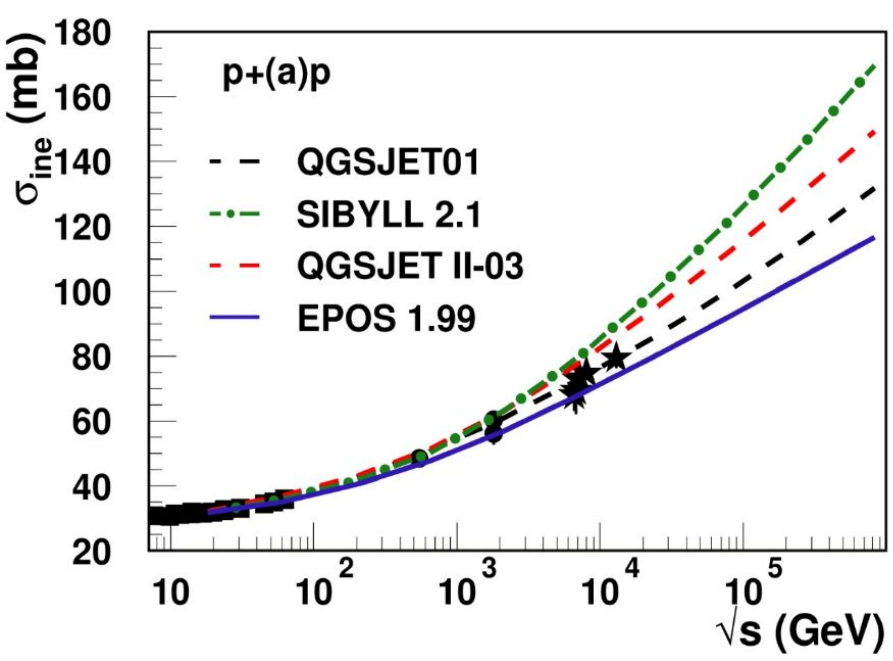
Hanlon

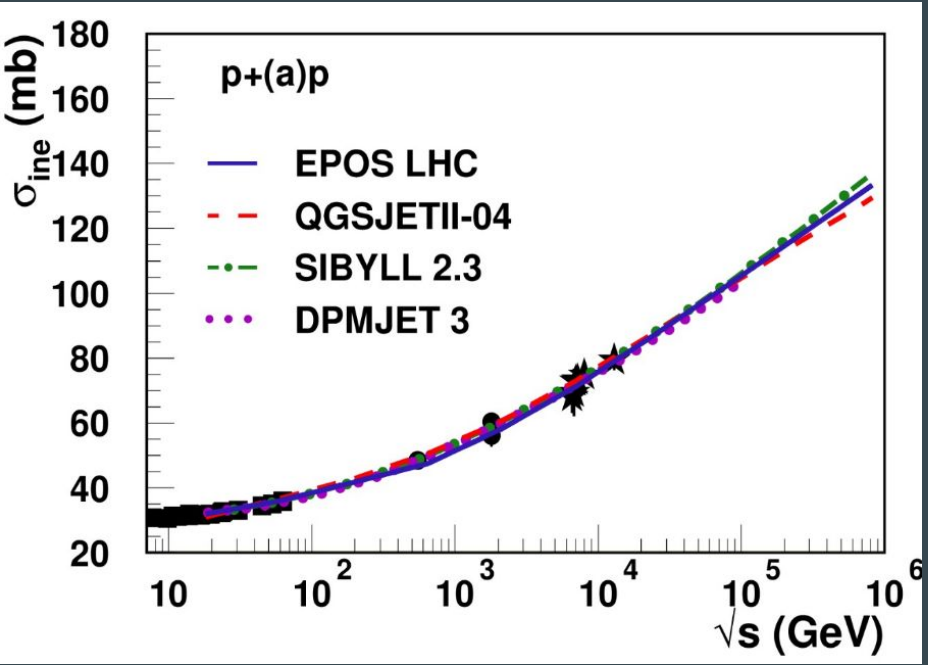
Convergence of Pierre Auger and TA results

- General agreement, but differences in spectral features
- Progress in understanding the composition
- Anisotropy features differ between the two experiments

Rivers Rhone and Arve:
converging, but still distinctly different

Progress in simulations: before and after the LHC





Pierog

Progress in simulations, but puzzles remain

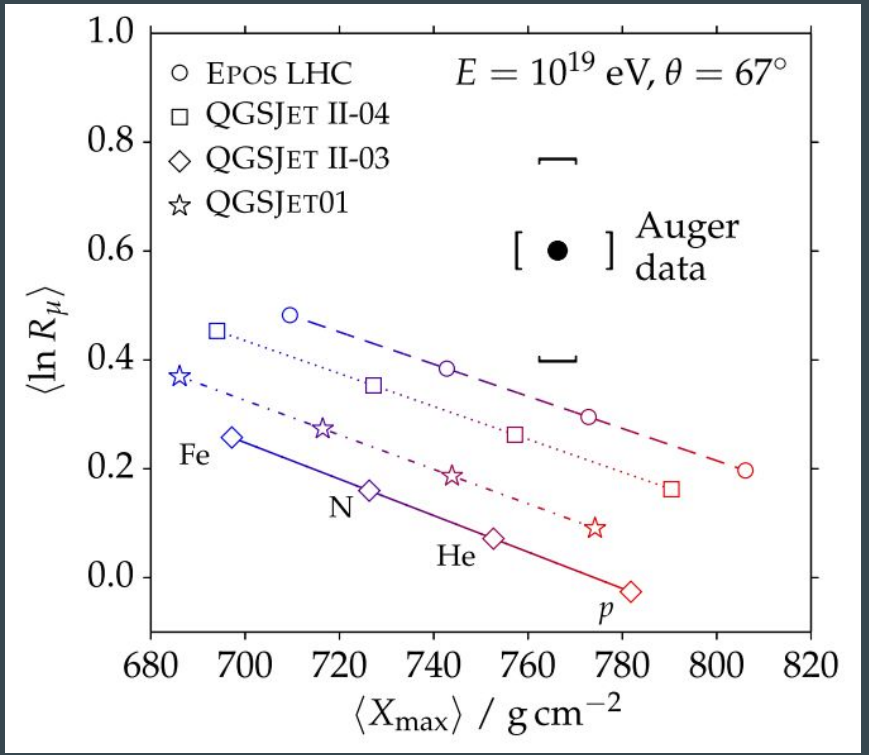
Inclined showers are very muon rich.

$$R_\mu \equiv \frac{N_\mu^{\text{data}}}{N_\mu^{\text{MC}}}$$

A solution may be around the corner. [Pierog]

Encouraging!

Muons invaluable for composition! [Engel]



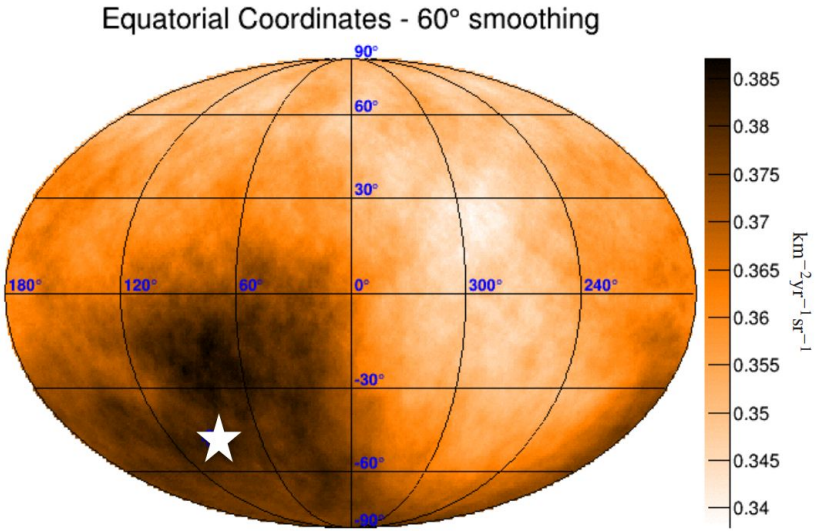
Anisotropy: large-scale anisotropy according to PAO '15

Auger data set : ≈ 70000 events with E>4 EeV and $\vartheta < 80°$, 85% sky coverage

Modified Raleigh or East-West analysis
on 1500 m and 750 m arrays dataset

Auger/TA : ≈ 17000 Auger events , ≈ 2500 TA events with E>10 EeV , Full sky coverage

Spherical harmonic analysis



AUGER/TA

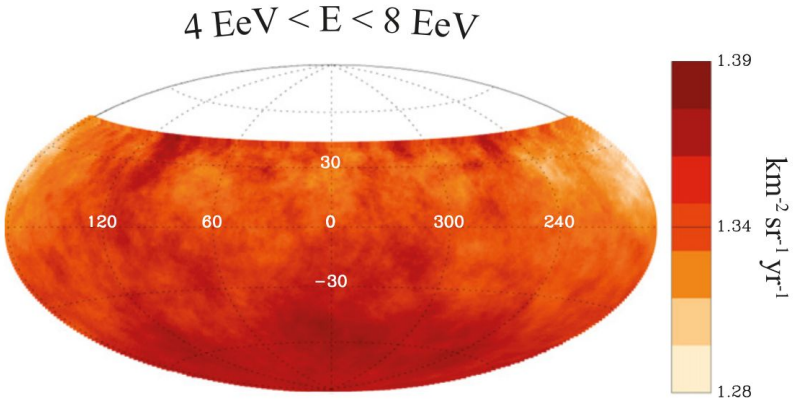
Dipole Amplitude: 6.5 ± 1.9%

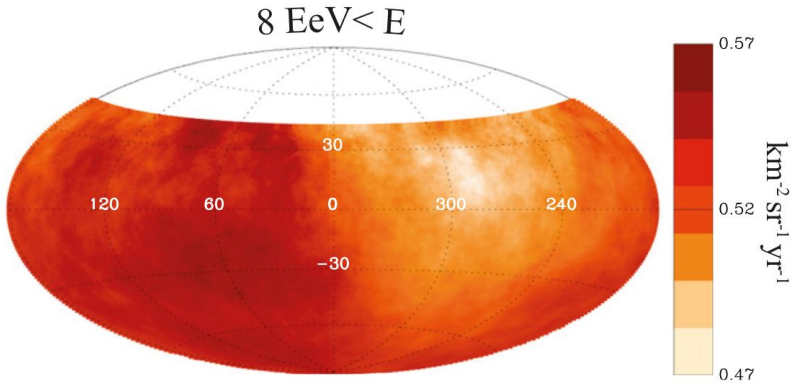
($p=5\times10^{-3}$)

Pointing to (a, d) =
(93°±24°, -46°±18°)

Lhenry-Yvon, TeVPA 2015

Auger: a dipole anisotropy (significance: >4σ)





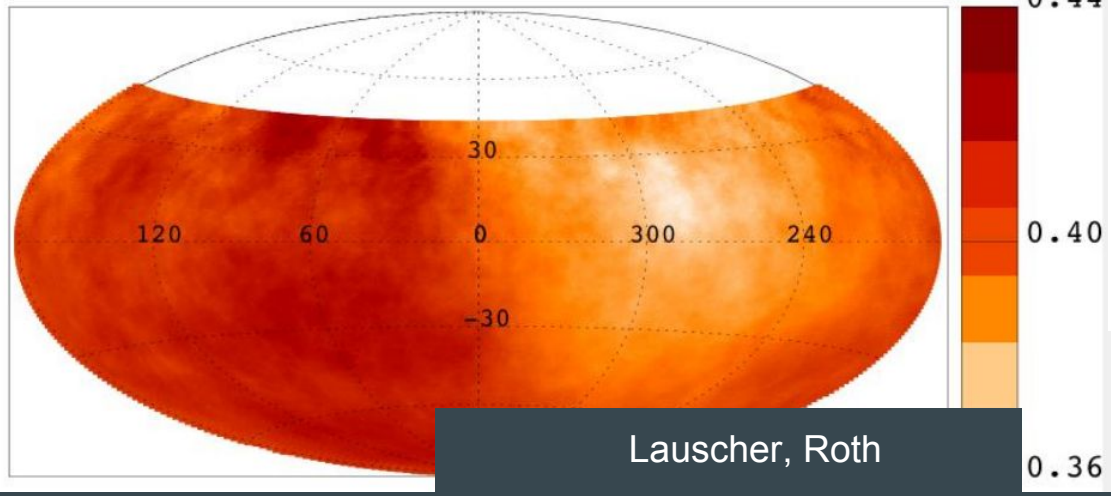
E [EeV]	d	d_d	a_d
4-8	(2.7±1.2)%	-81°±17°	15°±115°
>8	(7.3±1.5)%	-39°±13°	95°±13°

Roth

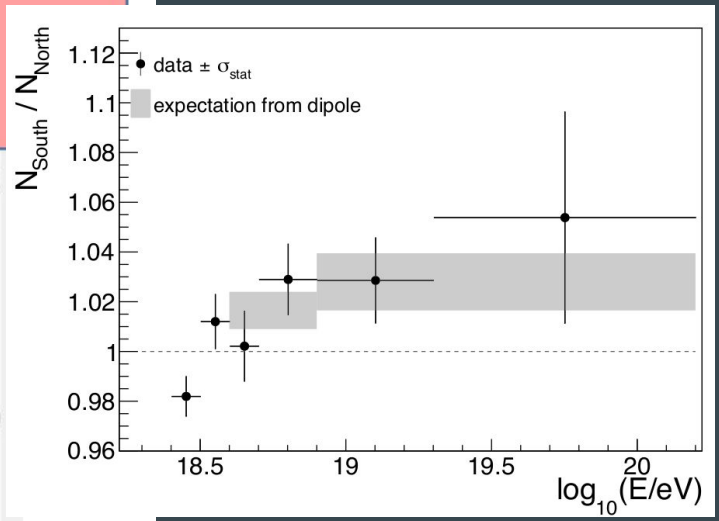
Large-scale anisotropy: dipole

$E > 8$ EeV ($P(\geq r^{\alpha}) = 6.4 \times 10^{-5}$ (4σ))

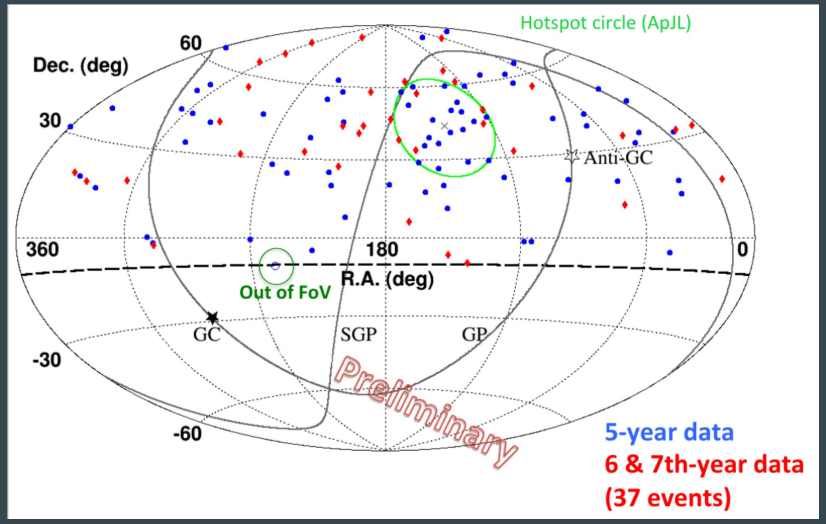
- Total amplitude $d = 7.3\ \% \pm 1.5\%$
- Location $(\alpha,\delta) = (95 \pm 13, -39 \pm 13)^{o}$

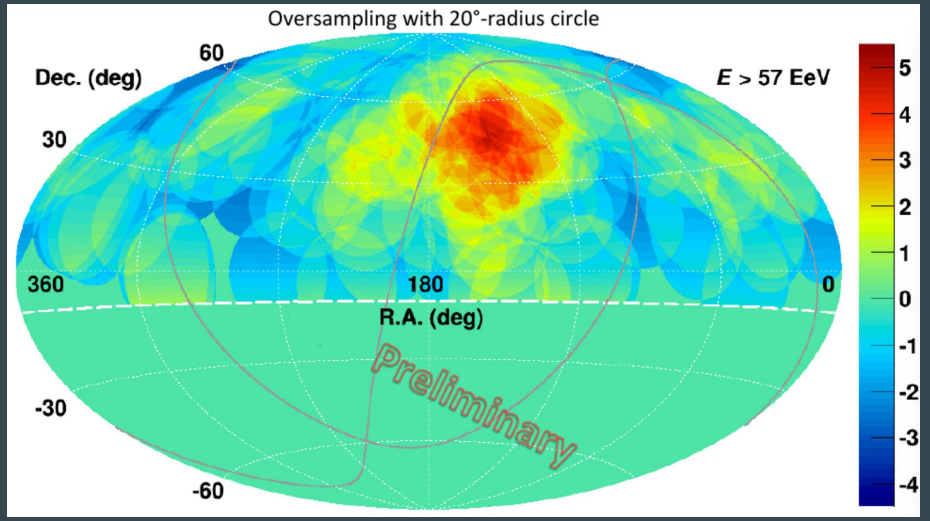


Lauscher, Roth



TA hot spot (7 years data)





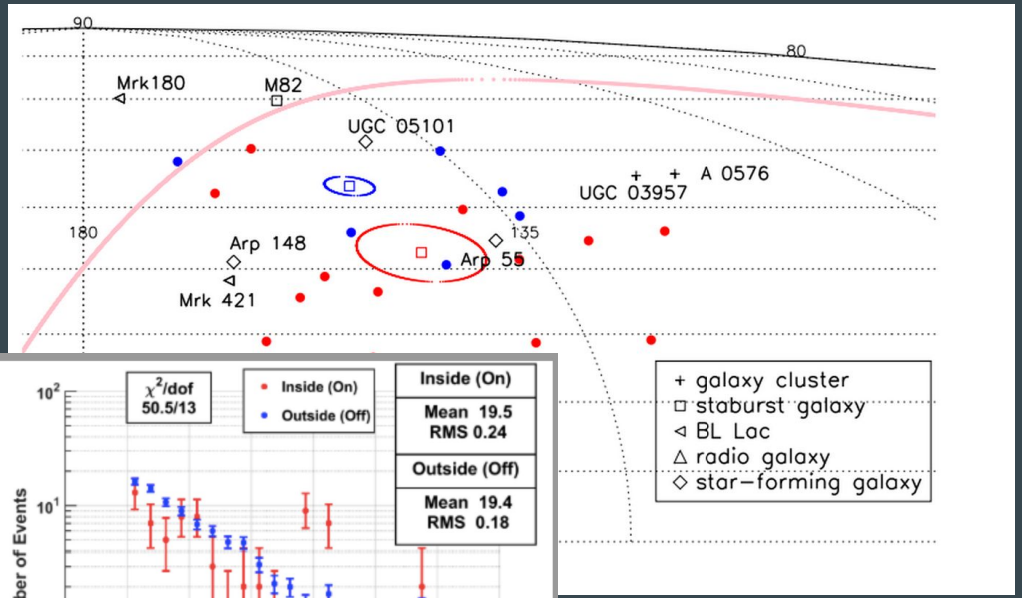
Chance probability to exceed 5.1σ in the exposure: 3.4σ (0.037 %) post-trial

Tinyakov

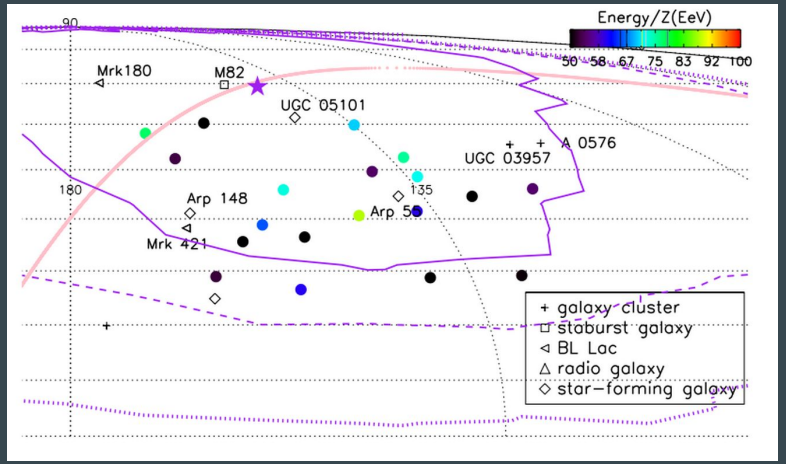
TA hotspot: a single source?

Blue: Events with > 75EeV (High Rigidity).

Red: Events with < 75EeV (Low Rigidity). Circles represent the mean Positions of the events. Consistent with magnetic deflections from a single source in the Supergalactic plane.

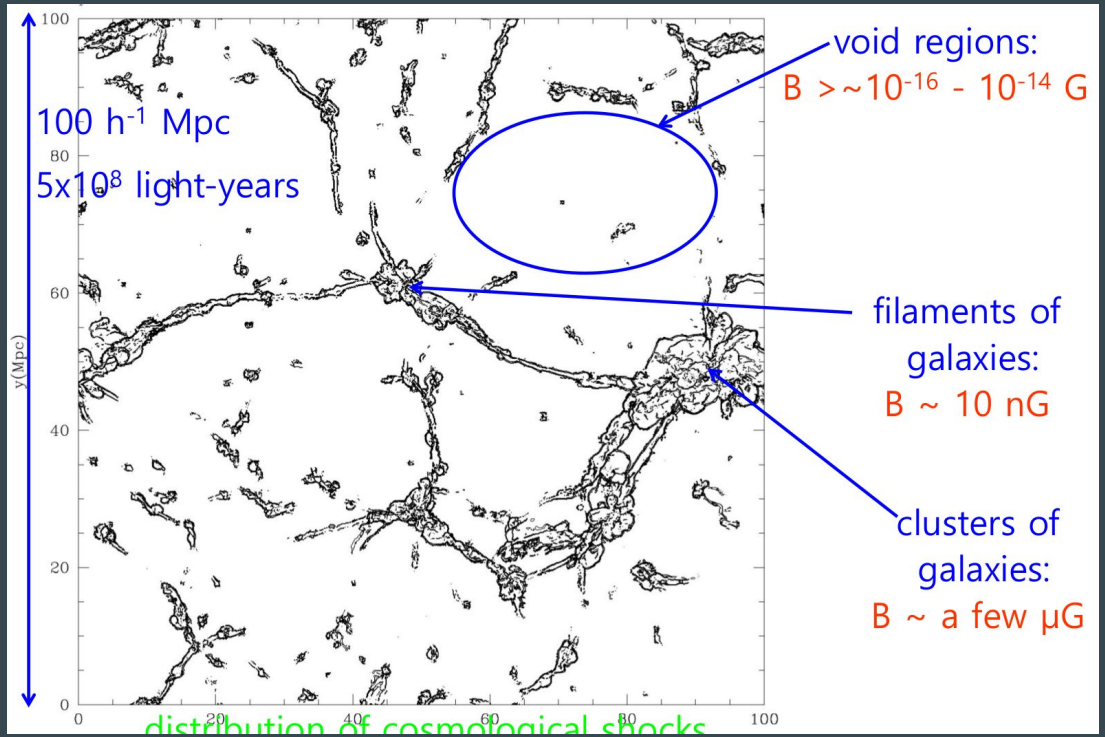


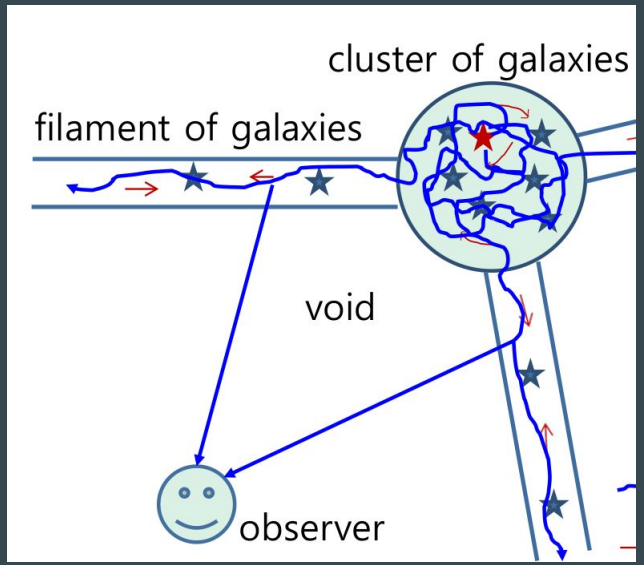
He



The highest energy point suggestive of a nearby source. M82?

Applied UHECR physics: probing the magnetic fields





Ryu, Tinyakov, van Vliet

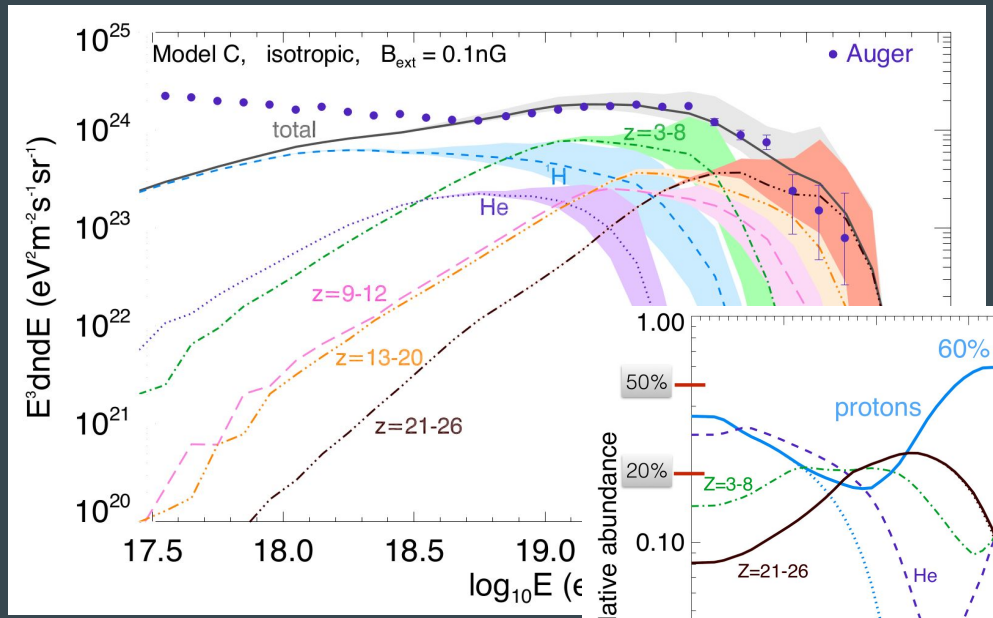
Sources: the unknowns

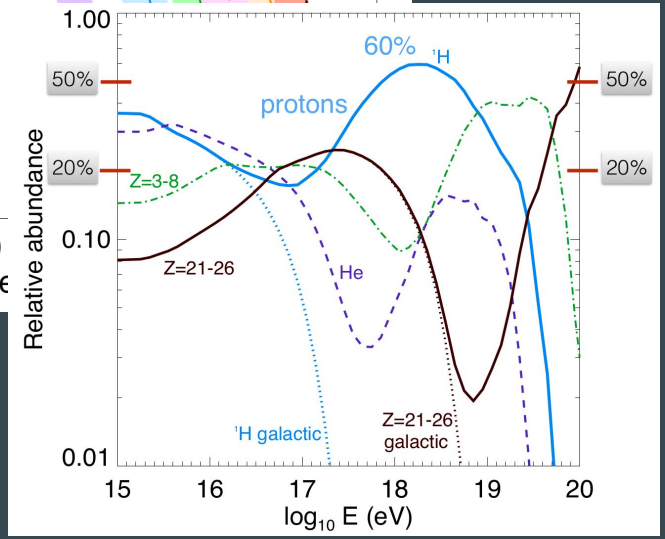
- What are they?
  - AGN, GRB, pulsars, etc. are among the candidates. Blazars (AGN) appear to accelerate protons to at least $10^{17\text{-}18}$ eV as evident from gamma ray observations [Essey et al.]
  - Steady or transient? [Fang,Kotera]
  - Possibly, different classes contribute at the same time
- Where are the sources?

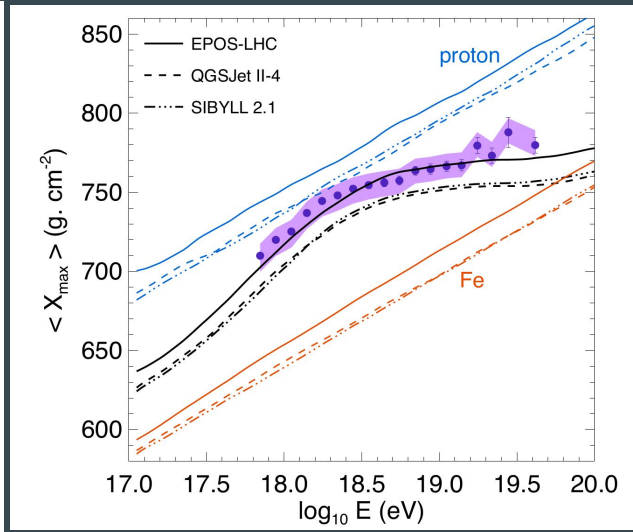
  A transition from galactic to extragalactic is expected at “high energy”, but
  - The transition may be and should be composition dependent
  - Transient sources of nuclei in our own galaxy can complicate matters

Different philosophies: with emphasis on simplicity, or with emphasis on description of all the data.

Modeling composition, galactic-extragalactic transition

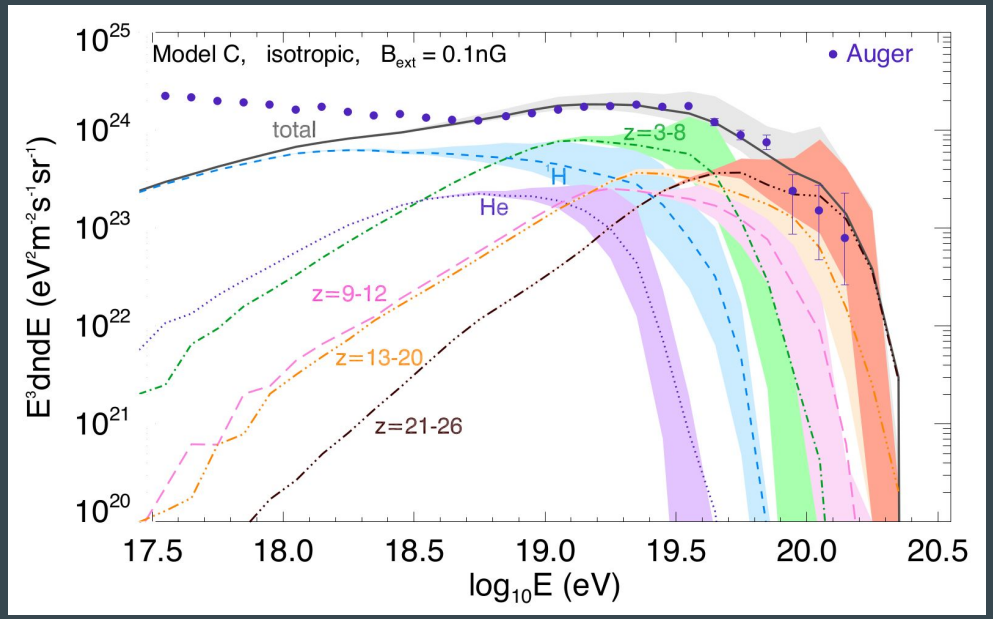






Parizot: GRB (or other sources).
Composition based on low-energy.
Fits the spectrum and composition.

Modeling composition, galactic-extragalactic transition



Parizot: GRB (or other sources). Composition based on low-energy. Fits the spectrum and composition.

Is it natural?

Yes, if it is part of Nature

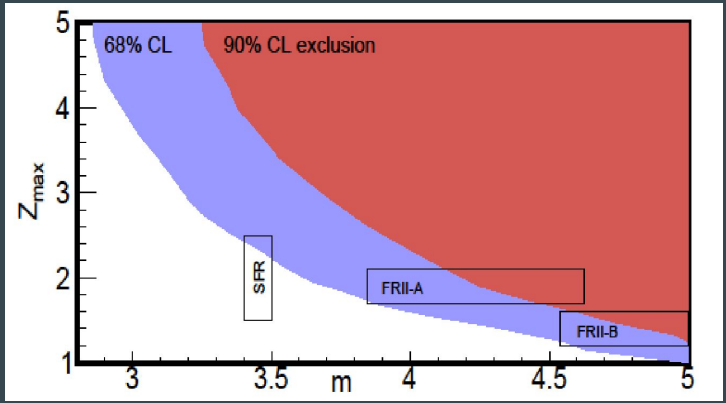
Multimesenger signals

- IceCube begins to constrain models of cosmogenic neutrinos
- Gamma rays provide evidence of UHECR acceleration in AGNs
- Links between IceCube PeV neutrinos and UHECR?

IceCube constraints on cosmogenic neutrinos

Ishihara

For proton UHECR, amount of fluxes in 60PeV-10EeV region can be expressed as a function of **m** and $\mathbf{z_{max}}$



evolution function of UHECR source is parameterized as $\psi(z)=(1+z)^m$ for $z \leq z_{max}$

Assumptions

- only CMB is target field (small IR/O contribution in the current energy range)
- the photo-pion production is single pion from Δ-resonance only

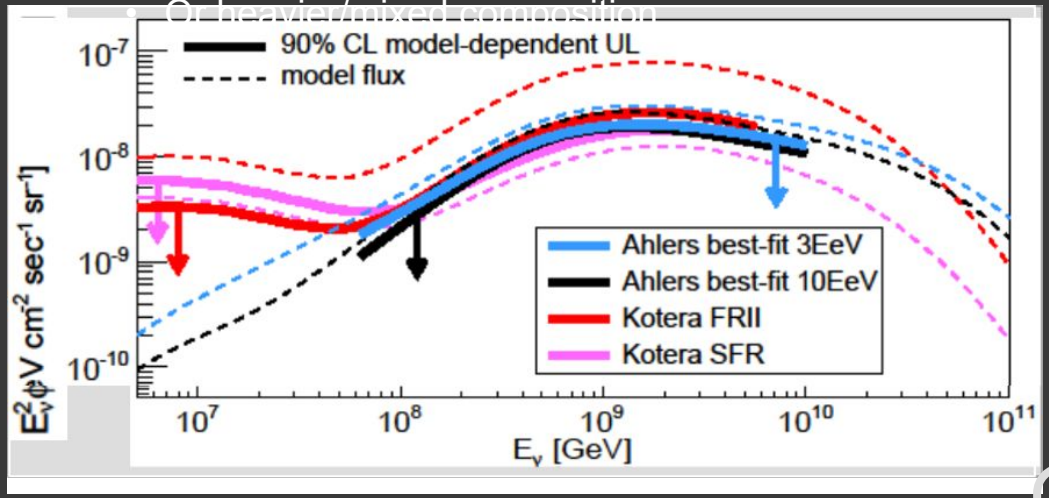
➡ Underestimates flux below 100 PeV

SFR: Hopkins and Beacom 2006
FRII-A: Inoue and Totani 2009
FRII-B: Ajello et al 2012

UHECR sources evolve more slowly than SFR

IceCube cosmogenic model constraints [Ishihara]

- Expect 4-5 events from SFR models
- UHECR sources evolve more slowly than SFR
- Or heavier/mixed composition



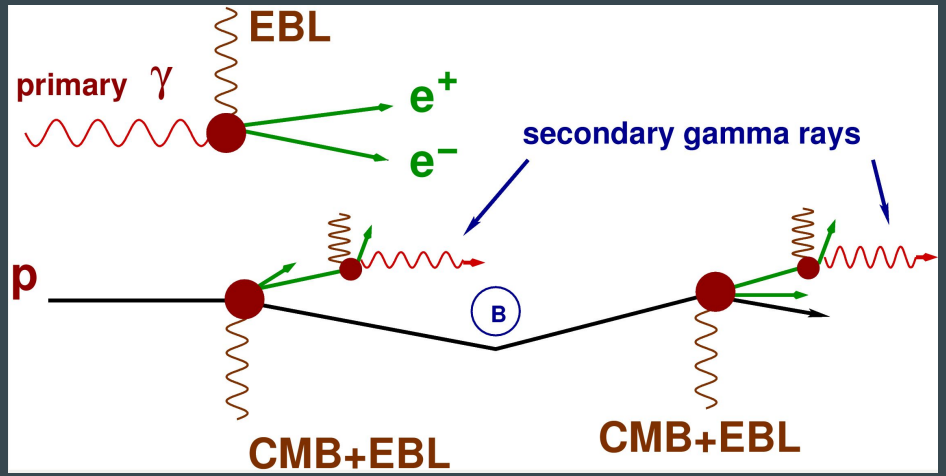
models to describe the origin of observed diffuse gamma-ray as cosmogenic, measured UHECRs

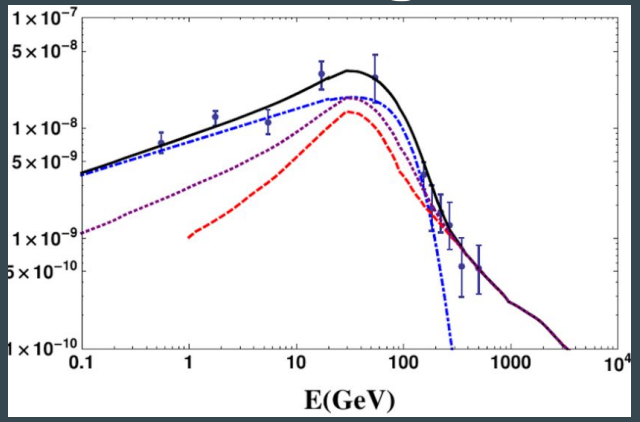
model	Event rate in 2426-d	p-value
Kotera et al SFR	3.6	22.3
Kotera et al FRII	14.7	<0.1%
Aloisio et al SFR	4.8	7.8%
Aloisio et al FRII	24.7	<0.1%
Ahlers 3EeV m=4.1 z_{max}=2	4.4	2.2%
Ahlers 10EeV m=4.6 z_{max}=2	5.3	0.7%

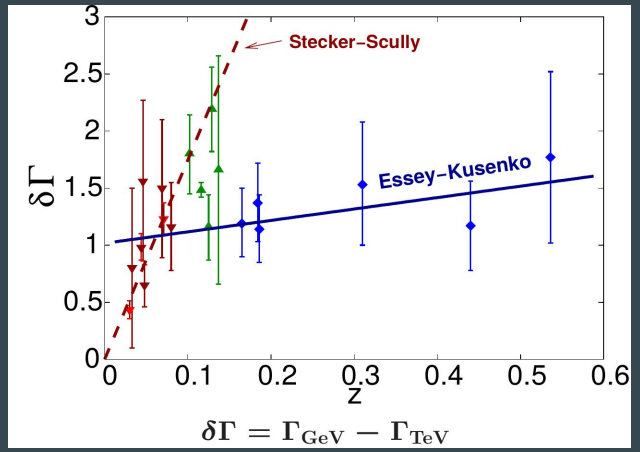
First evidence that AGN emit UHECR ($E \gtrsim 10^{17\text{-}18}$ eV or higher)

Gamma-ray data provide evidence that AGN are accelerated in AGN.

Blazar spectra demand a cosmic ray contribution. [AK]







The future

- Auger Upgrade
- TA x 4
- TALE
- TAIGA
- IceCube Gen-2
- JEM-EUSO
- TUS
- ARA
- ARIANNA

- Understanding the spectrum and composition
- Charged particle astronomy
- Neutrino astronomy

Let us thank Sagawa sensei and all the organizers!

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