Frascati, ***24 September,*** ***Daniele Fargion,***

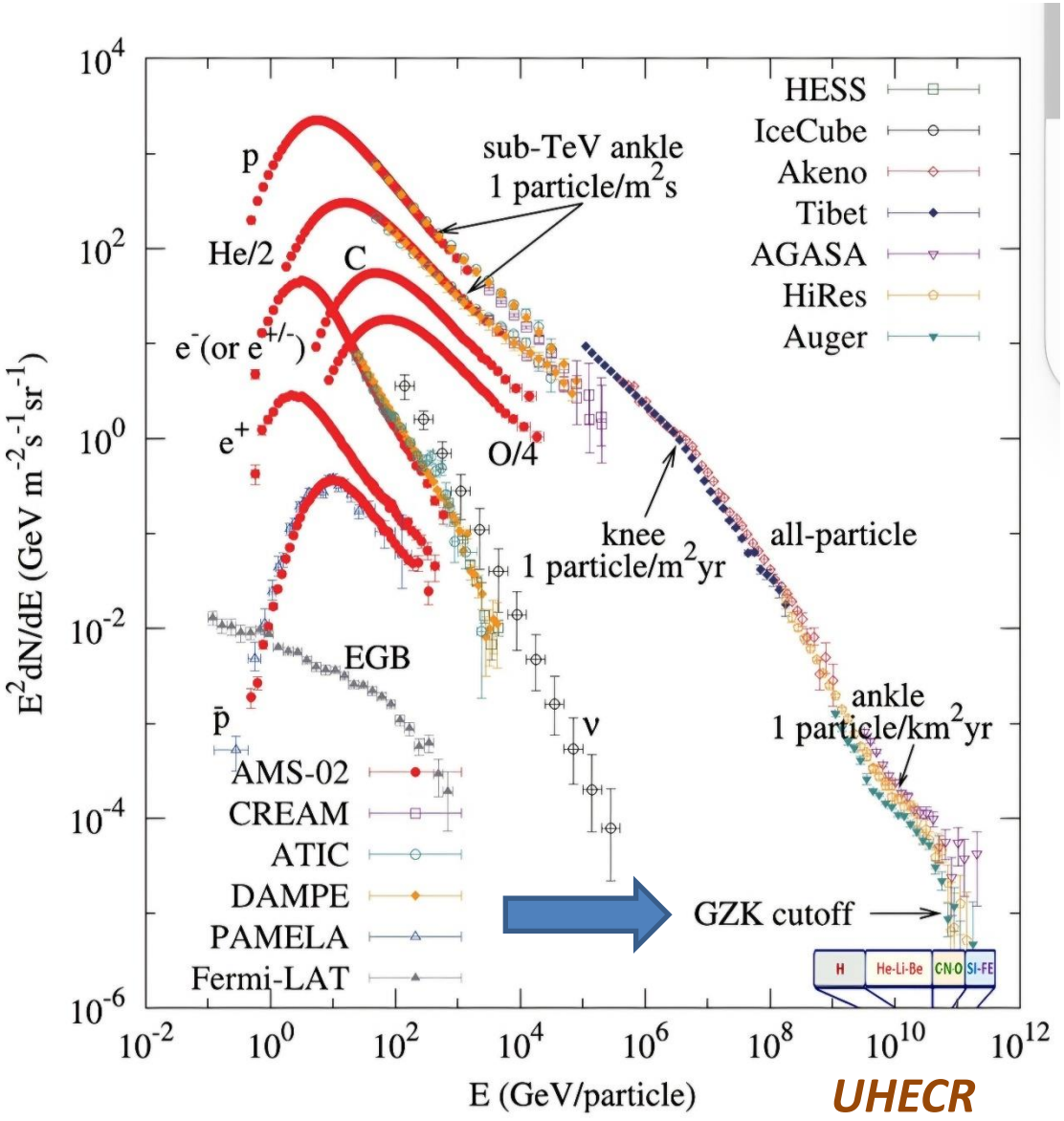
RICAP 2024

On Cosmic Rays Puzzle

*A century of **Cosmic Ray deflections**:*

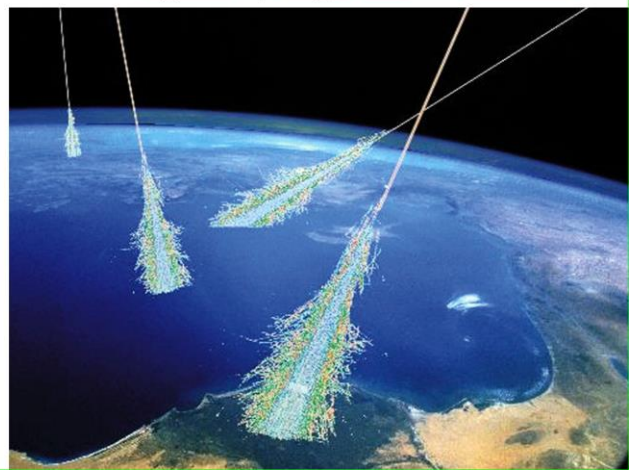
Any good reason for a never ending, « blind man's fly» ?

A brief Summary of «Cosmic Rays»



UHECR

UHECR signals by huge tree-air-showers

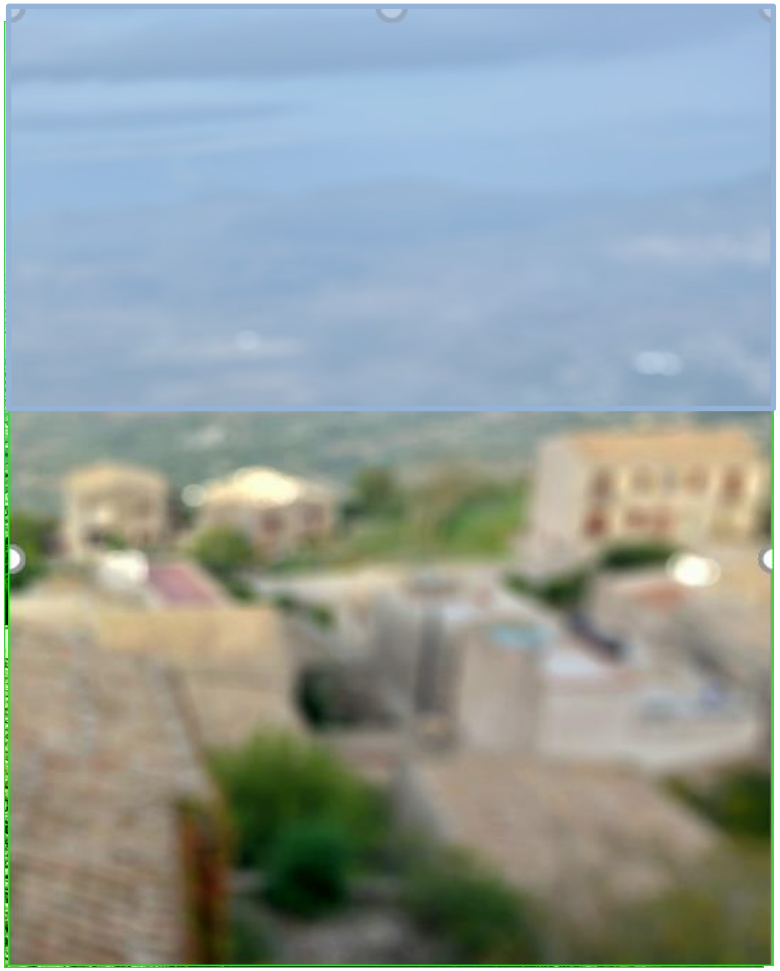


UHECR

Cosmic Rays, Charged, Bent and ***much Smeared.***

But, ***UHECR, are less smeared , more bounded:***

A new UHECR (> tens EeV) « Astronomy» ?



The Two different nuclear cut off to UHECR by relic

1:photons: GZK: Greisen, Zatzepin,Kuzmin

2:and GDR : Giant Dipole Resonance

GZK photopion cutoff occur at tens EeV, it makes UHECR constrained near,

……40 Mpc (1% Cosmic radius)

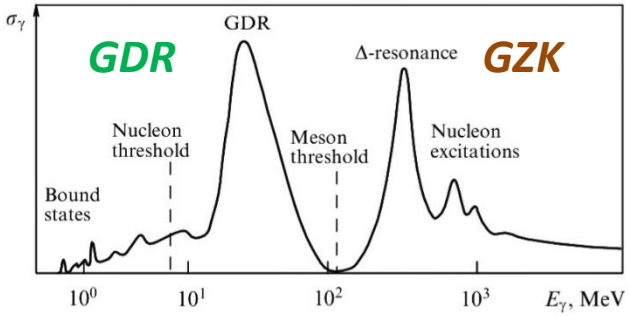
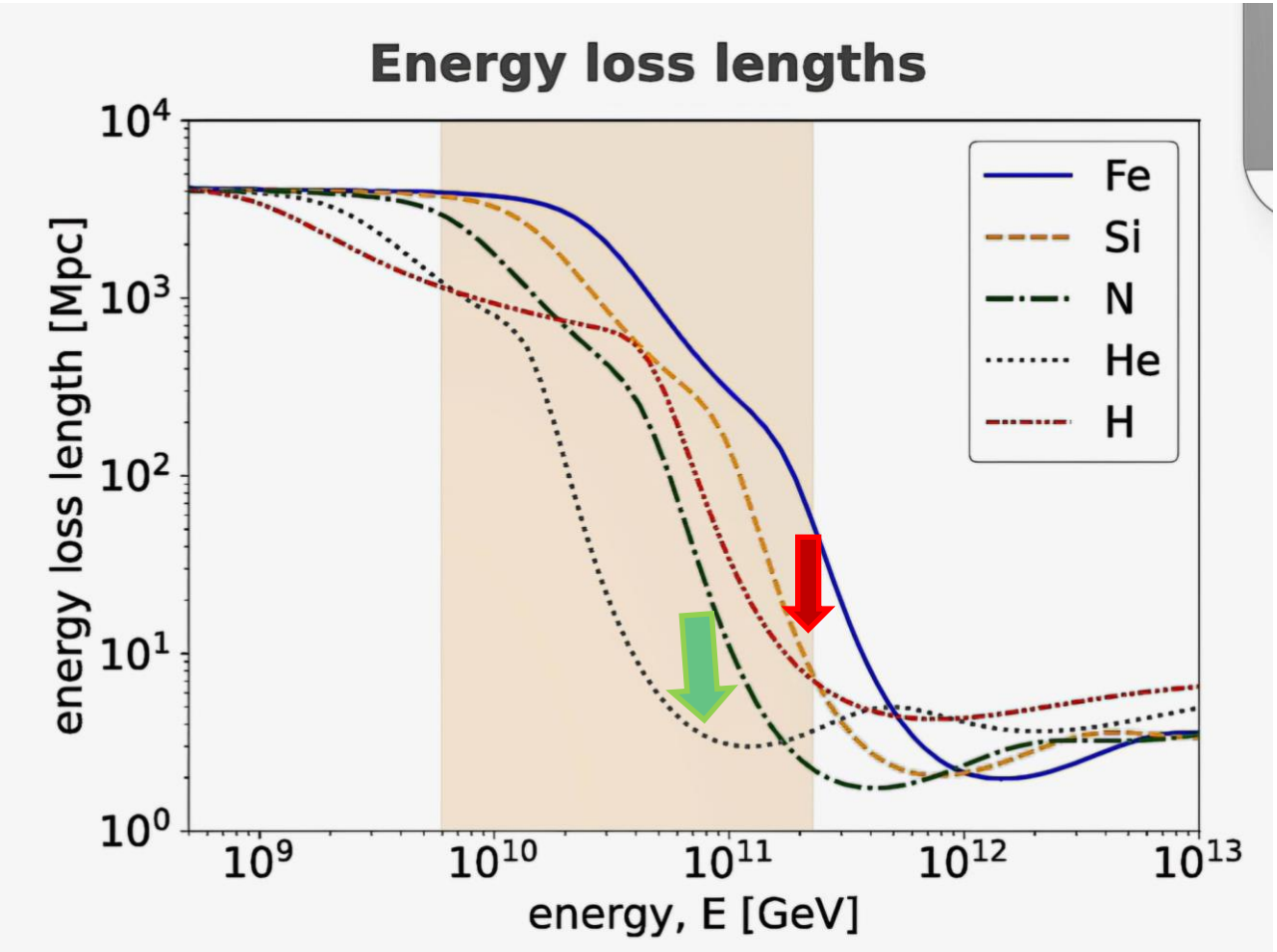


Figure 1. Schematic dependence of the cross section of photon absorption by atomic nuclei and free nucleons on the photon energy.

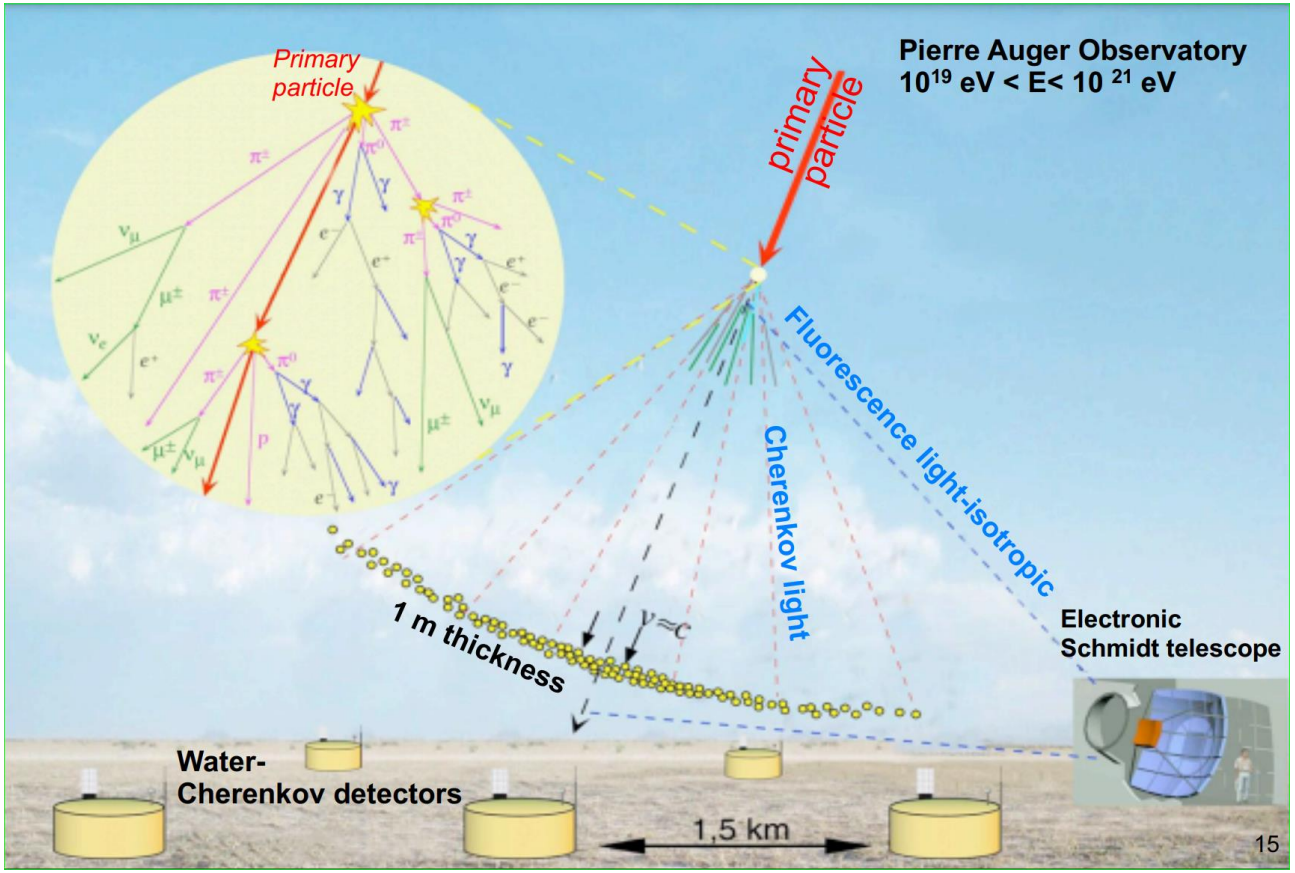
- GDR = photonuclear dist e
- makes (to lightest nucle.) a severe cut off at tens EeV ,
- constrained in a nearer, …… 4 Mpc (0.1% Cosmic radius)

UHECR bounded by GZK (p) and GDR (He) cut off *both* in energy and distances



Rare Air Shower detection for ***UHECR,*** *energy and composition. Largest (3000 km square)*

Auger *arrays (South) and* ***TA*** *(600 km square) (North)*



Lightest to Heavy nuclei confined in Nearest Universe

by

Daniele Fargion,

see also

UHECR Clustering: Lightest Nuclei from Local Sheet Galaxies

https://doi.org/10.3390/universe10080323

Bending charges , nucleon, nuclei in UHECR at GZK: for Proton <-> 9°, for He-> 18° Therefore: Who and Where are the sources ?

- *Random Galactic and Extra Galactic bending*

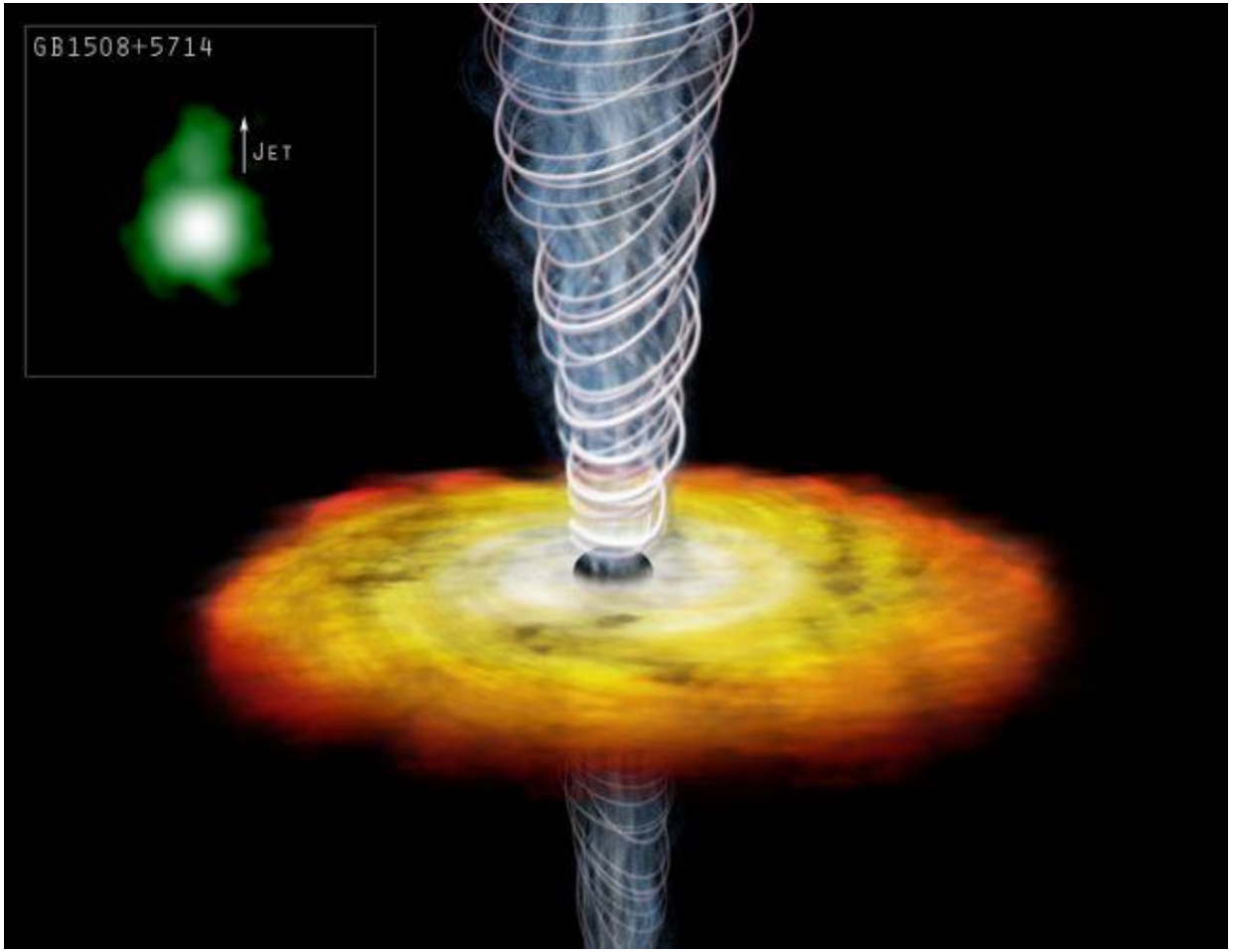
$$\alpha^{p}_{\mathrm{G_{rm}}} = 5.65^{\circ}\left(\frac{Z}{Z_p}\right)\left(\frac{E}{6\cdot 10^{19}\,\mathrm{eV}}\right)^{-1}\left(\frac{D}{20\,\mathrm{kpc}}\right)^{1/2}\left(\frac{d_c}{\mathrm{kpc}}\right)^{1/2}\left(\frac{B}{3\mu G}\right). \quad (5)$$

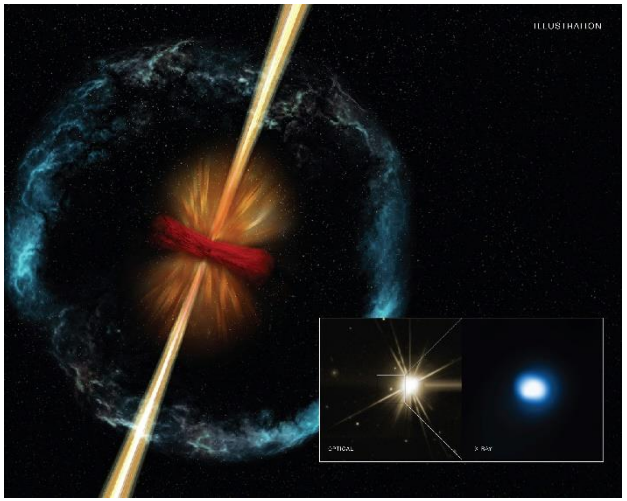
The angular separation between observed UHECRs smeared anisotropy Hot Spot and Cen A is about 18°. Assuming for Cen A a distance of 4 Mpc and an average magnetic field B of about 3 nG for the extragalactic path, the angle as a function of energy can be rewritten as

$$\alpha^{p}_{\mathrm{E_{rm}}} = 3.5^{\circ}\left(\frac{Z}{Z_p}\right)\left(\frac{E}{6\cdot 10^{19}\,\mathrm{eV}}\right)^{-1}\left(\frac{D}{4\,\mathrm{Mpc}}\right)^{1/2}\left(\frac{d_c}{\mathrm{Mpc}}\right)^{1/2}\left(\frac{B}{1\,\mathrm{nG}}\right). \quad (6)$$

The total bending angle for a proton is therefore the sum of both two angle galactic and extragalactic component , or = 9.15°. Indeed, the Helium bending will be just twice, and as large as the observed 18° Hot Spot along Cen A. Quite close to the observed one.

AGN and GRB Jets: BH+Accretion disk Ideal smoking gun sources for UHECR!





Virgo Absence

THE GZK cut off UNIVERSE

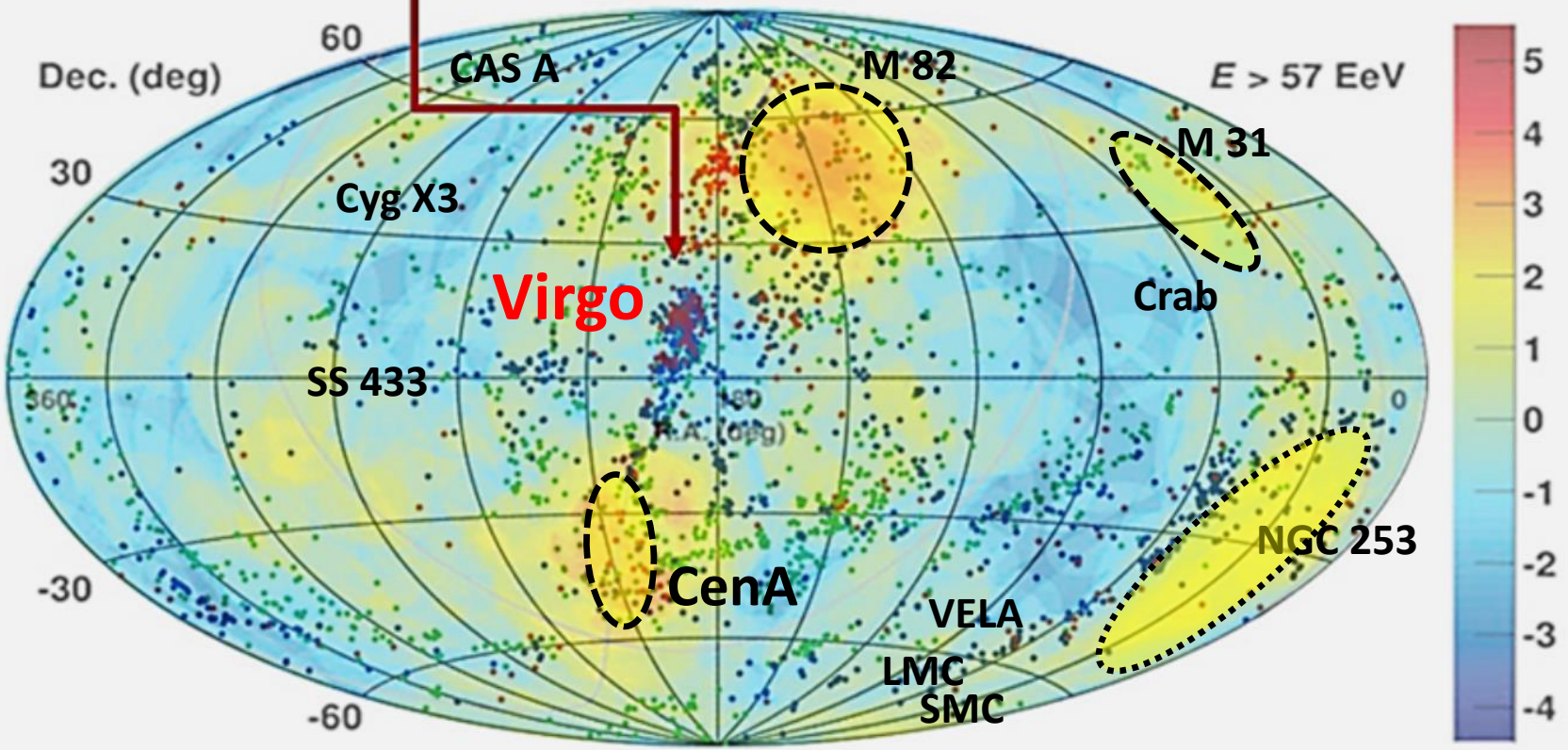
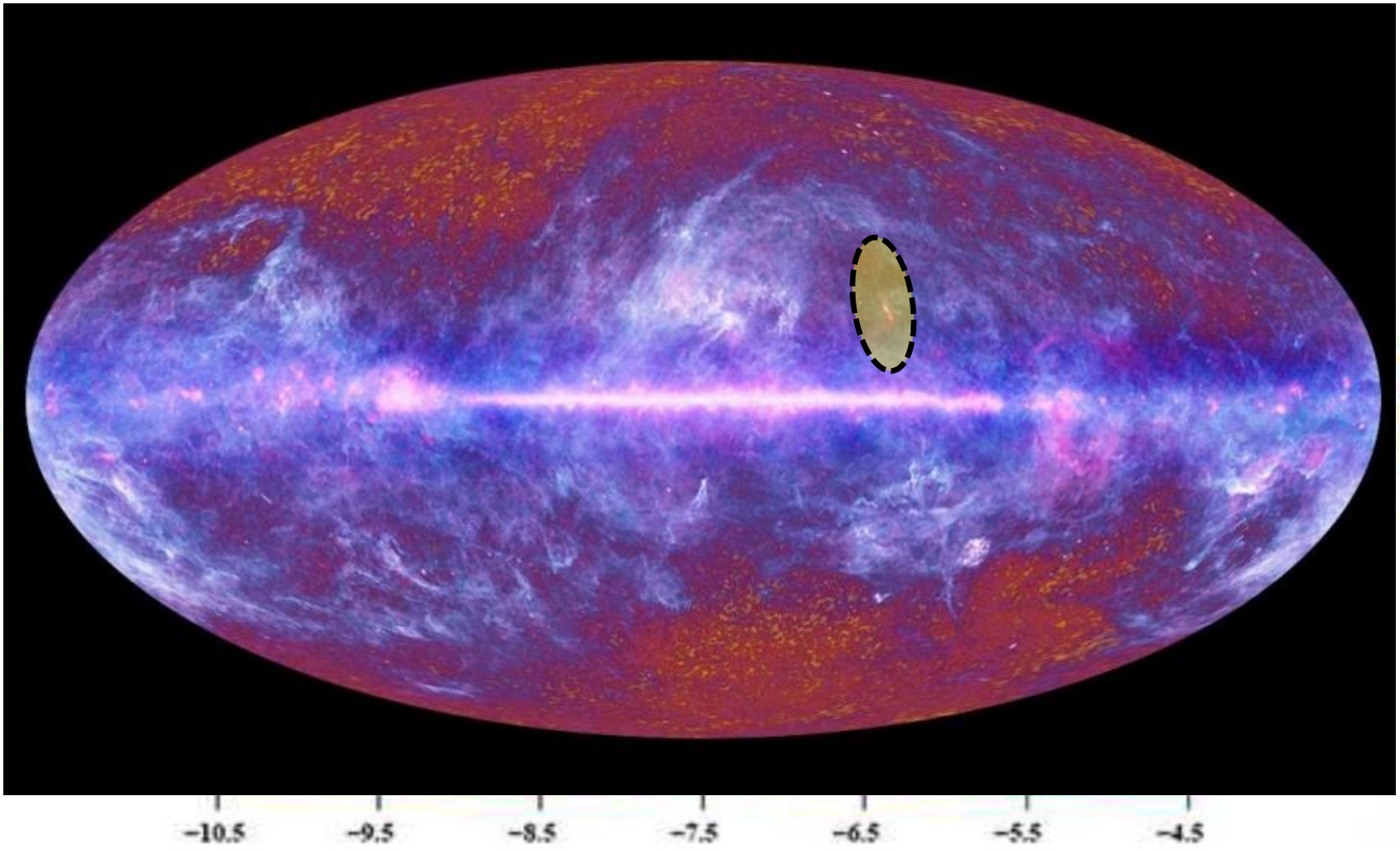


Figure 15. 2MASS galaxies inside the 3000 km s^{-1} sphere in equatorial coordinates (centered at R.A. = 0° and following the convention of R.A. increasing to the left). Heliocentric velocities are color coded with red, blue, and green representing bins of increasing redshift/distance. Red for $V_h < 1000$ km s^{-1}, blue for $1000 < V_h < 2000$ km s^{-1}, and green for $2000 < V_h < 3000$ km s^{-1}.

AGAIN: expected VIRGO CLUSTER DOMINANCE (40 Mpc):

GALACTIC COORDINATE : but, only 1 clustering-→ Cen A



How to make Virgo opaque, while only Cen A observable?

- *if **Proton** are the UHECR, than **Virgo** should shine at **GZK cut off , 40 Mpc**… (but it doesn't)*

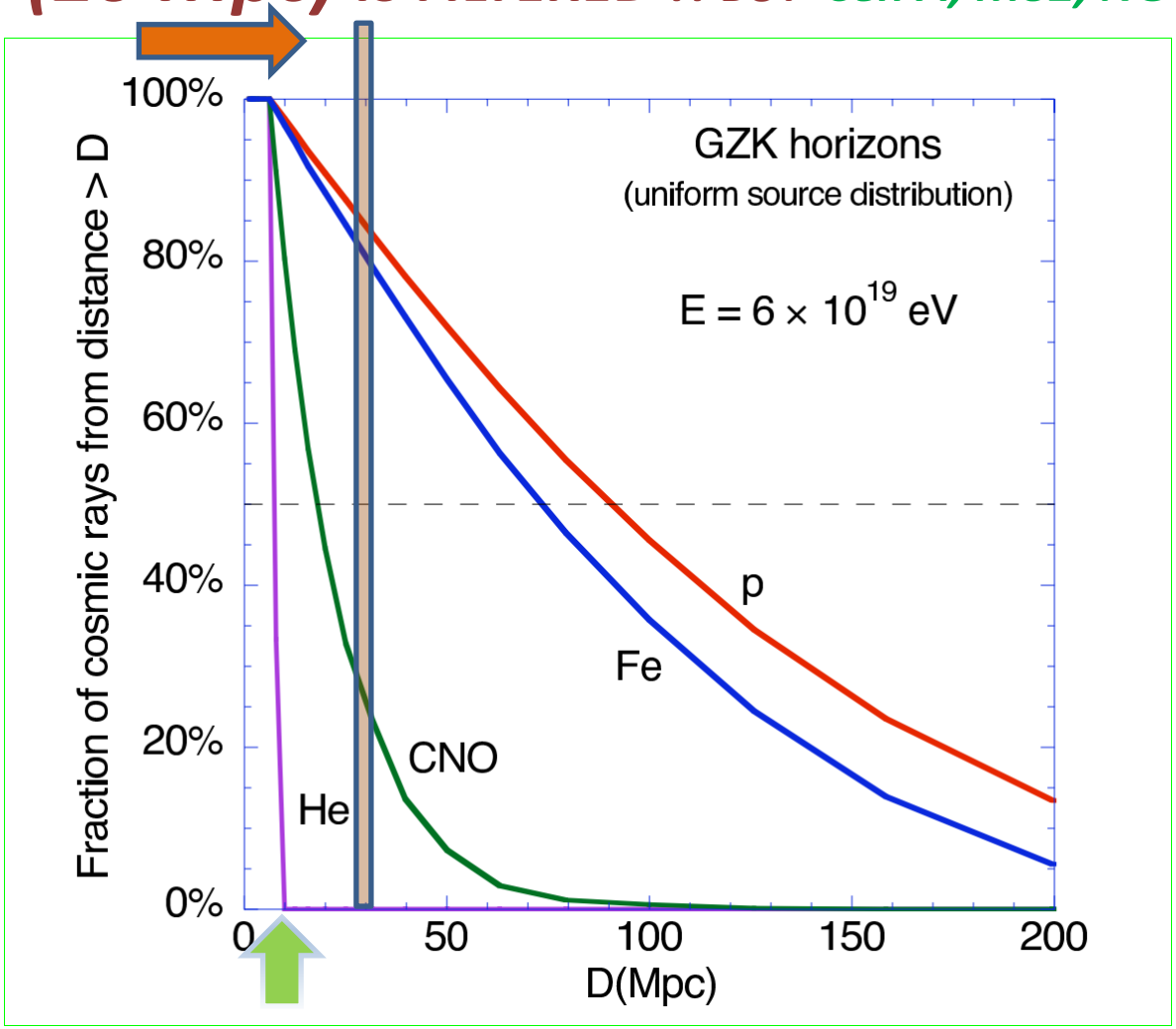
- ***But,** if UHECR are (He,..**Lightest nuclei)**,*
- ***They should shine at a GDR cut off,** much smaller, ……**4 Mpc**,…therefore….:*

- ***Virgo is absent (as it is far),***
- ***but, Cen A, not: it is within 4 Mpc.***

Distances flight for lightest UHECR Nuclei:

D-He-Li-Be, very narrow→ ***4 Mpc cut off***

VIRGO (20 Mpc) IS FILTERED !! BUT Cen A, M82, NGC 253, NOT!!.



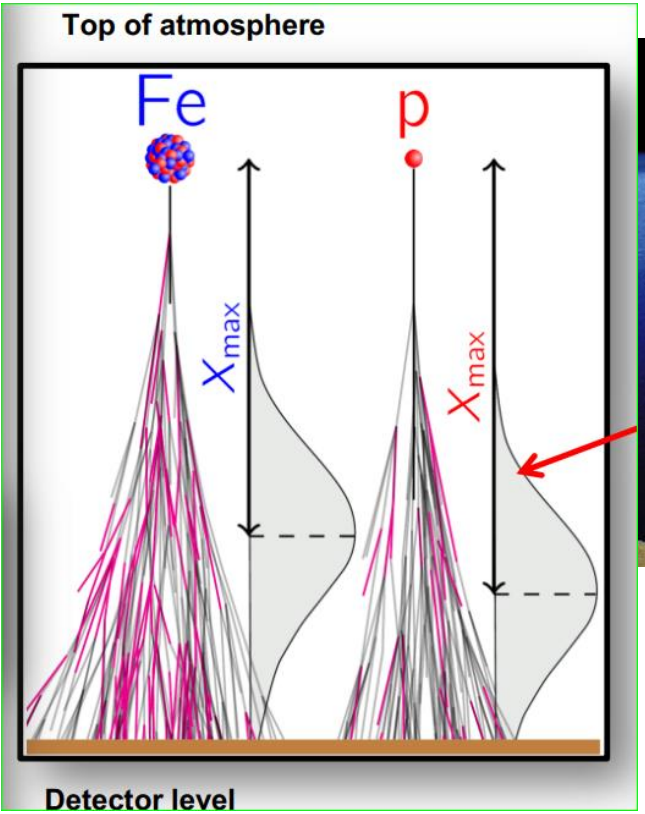
A different way to verify the COMPOSITION : A Test for UHECR observed by their huge tree-air-showers.

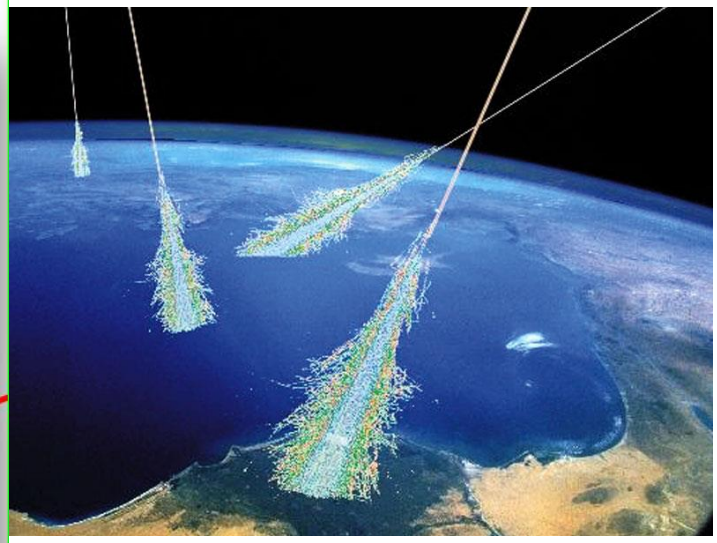
AUGER JCAP 2018: arxiv:1612.07155

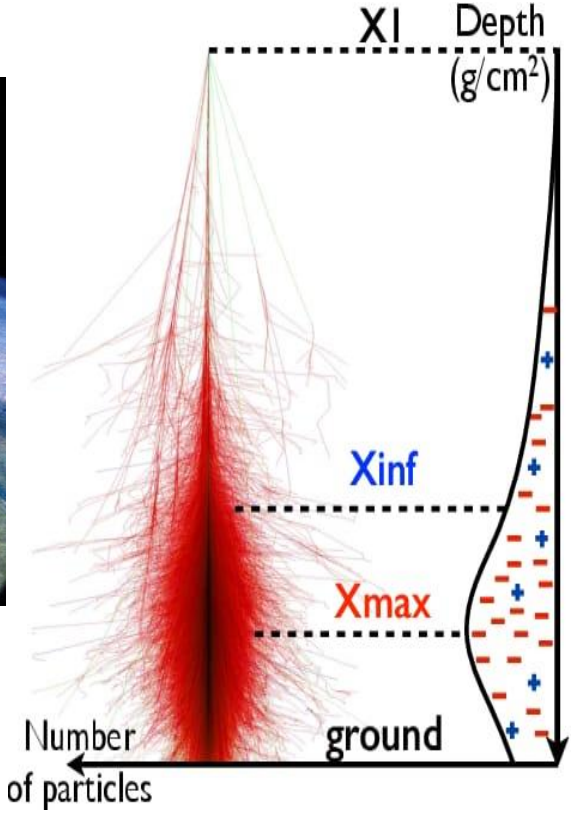
*Their air shower «three» structure = **Slanth Depth** <=> is the imprint.*

The lightest, less cross section, more penetrating, lower altitude

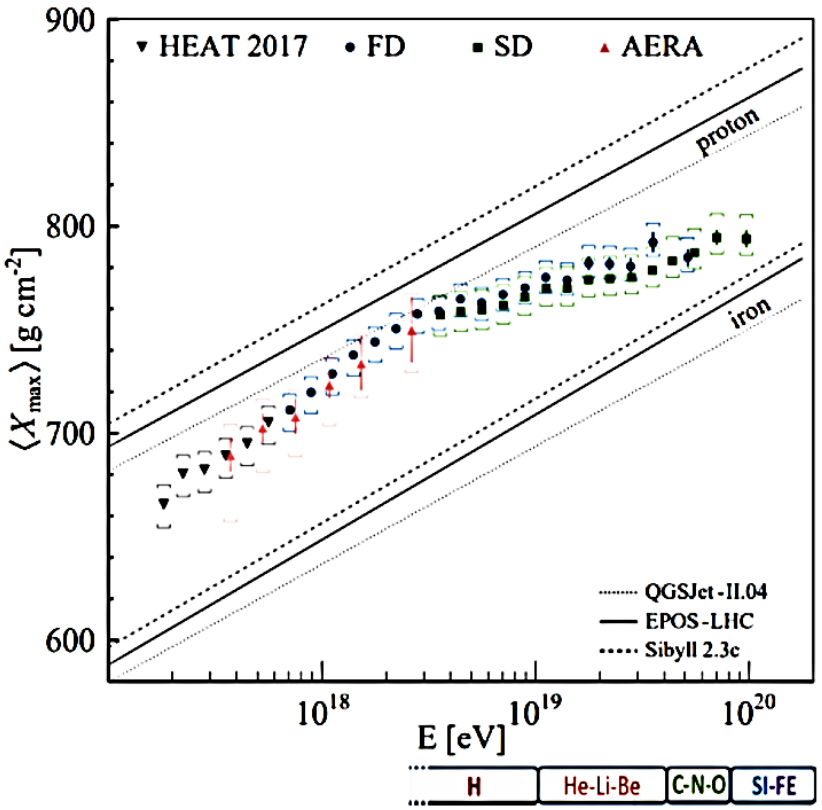
The heavier**,larger cross section, less pennetrating, **higher altitude

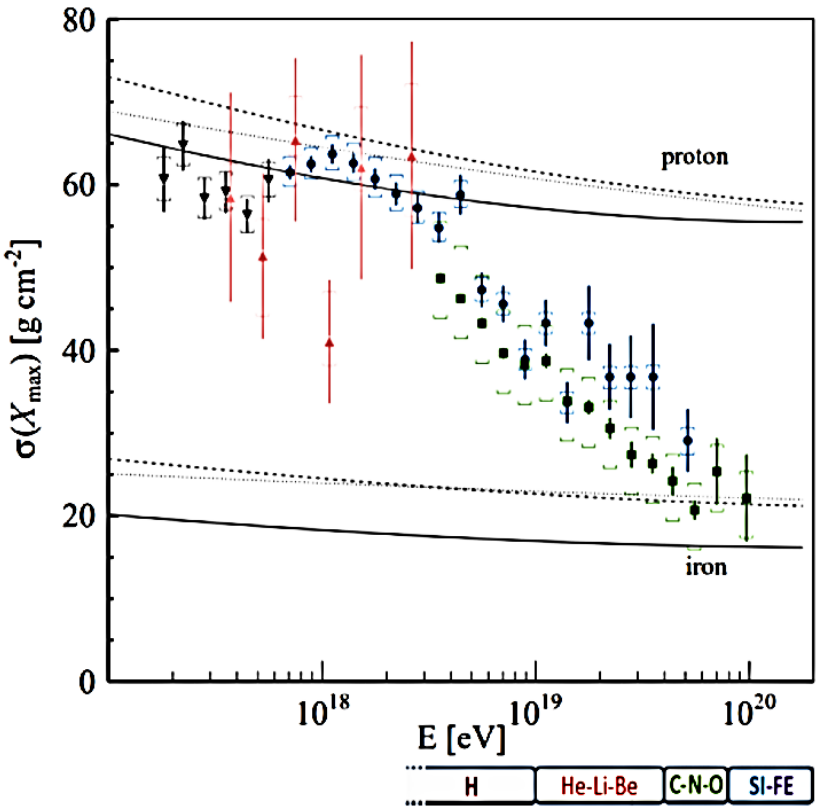




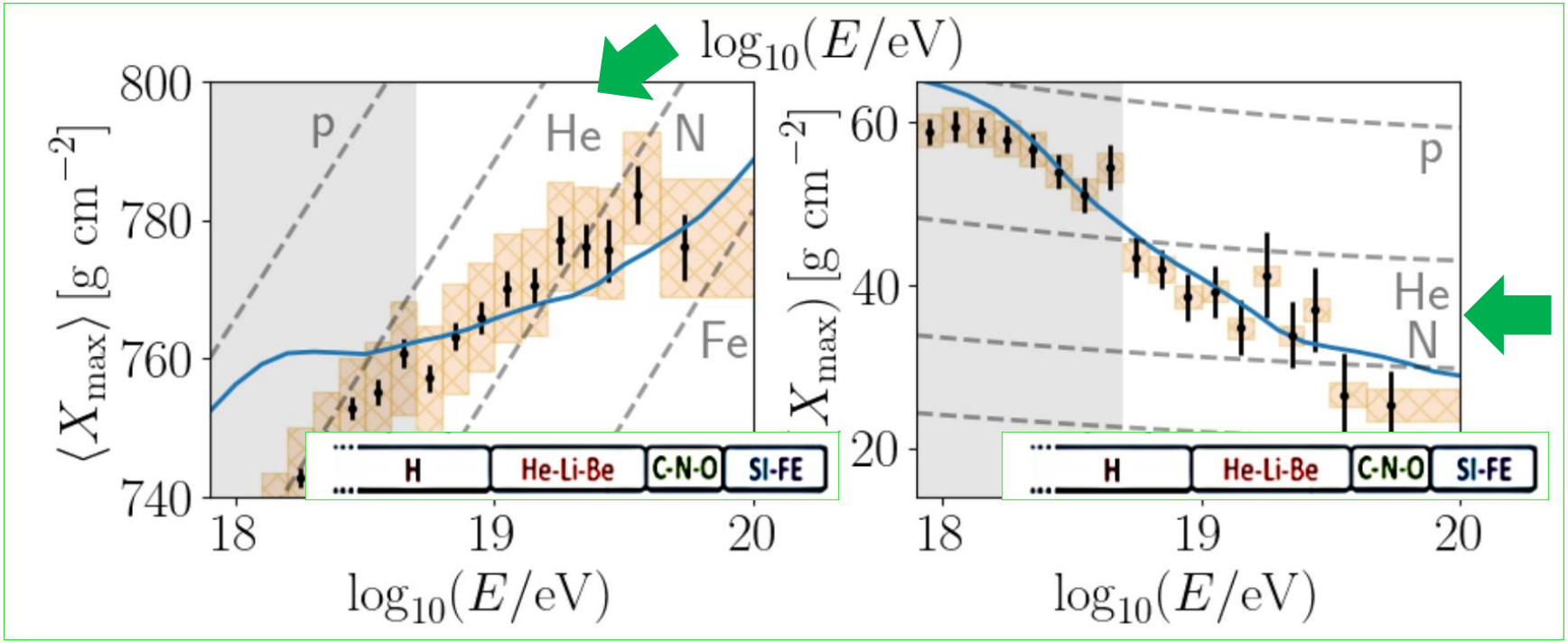


Composition evolution : from lightest to heavy nuclei with UHECR energy growth

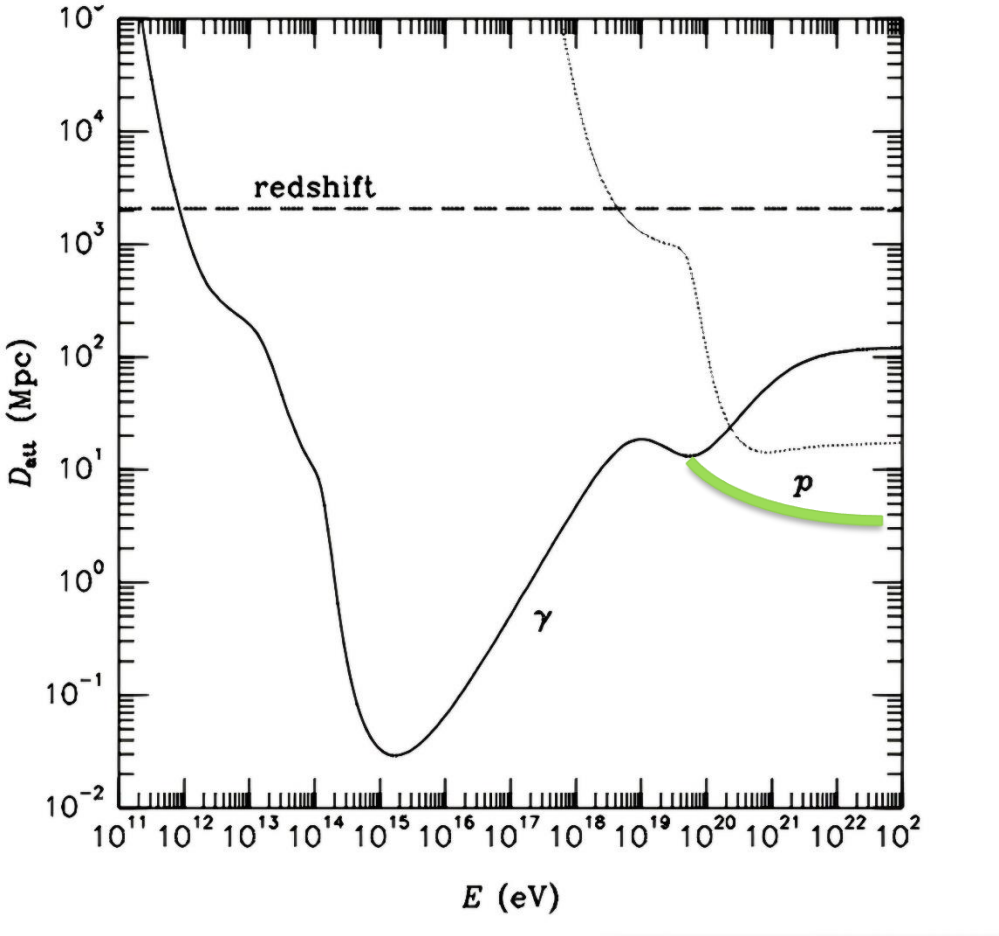




Composition evolution with UHECR energy growth by Slanth Depth, Xmax :He-Be dominant from ten EeV up to 40 – 50 EeV



Photon Astronomy versus UHECR (by proton or ***Lightest Nuclei***)



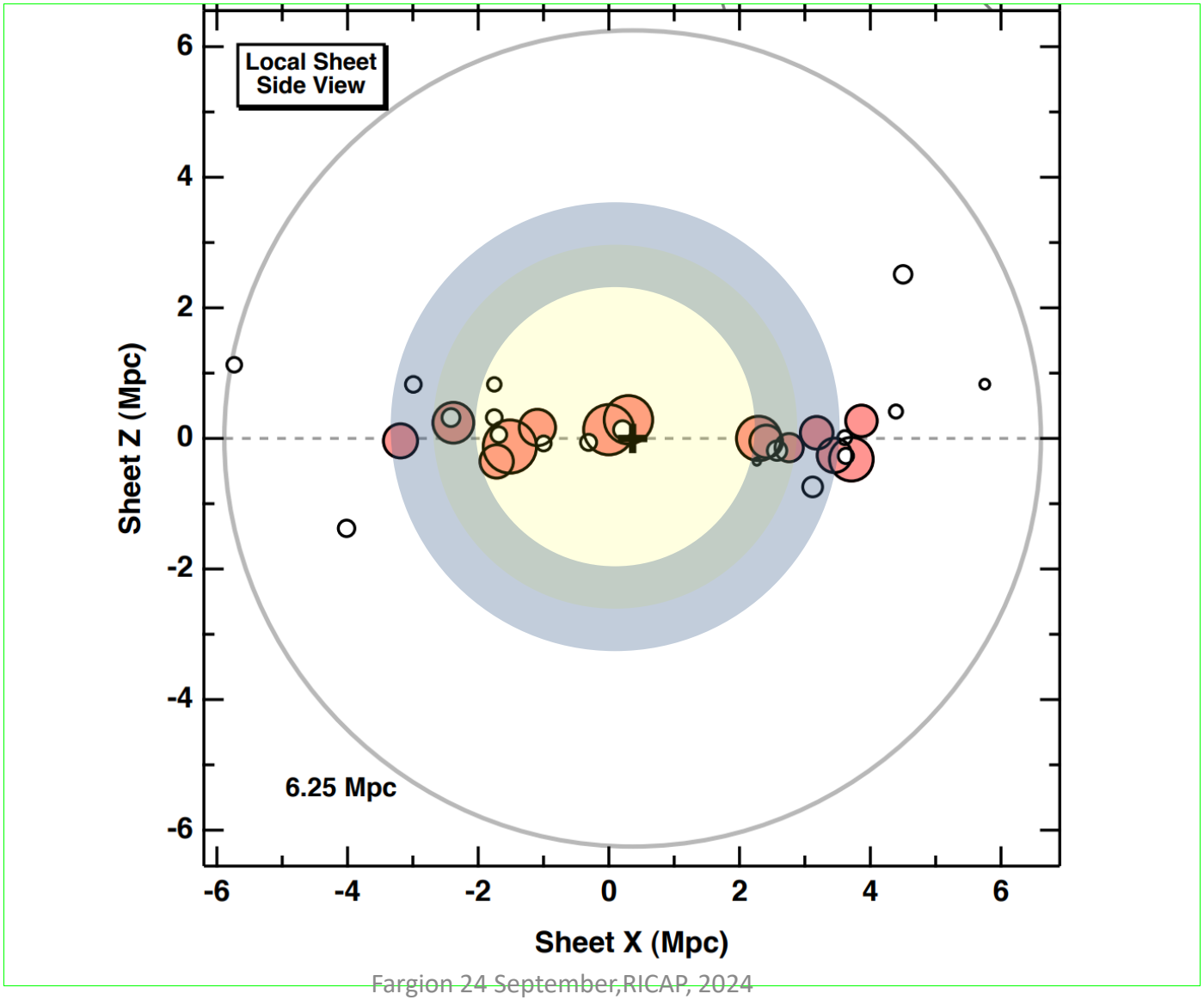
UHECR clustering + associated sources: all within 4 Mpc: observations up 2024

- ***Cen A,(AUGER) 2007,***
- ***M82 (Telescope Array) 2009,***
- ***NGC 253 (D:F: and AUGER) 2014***

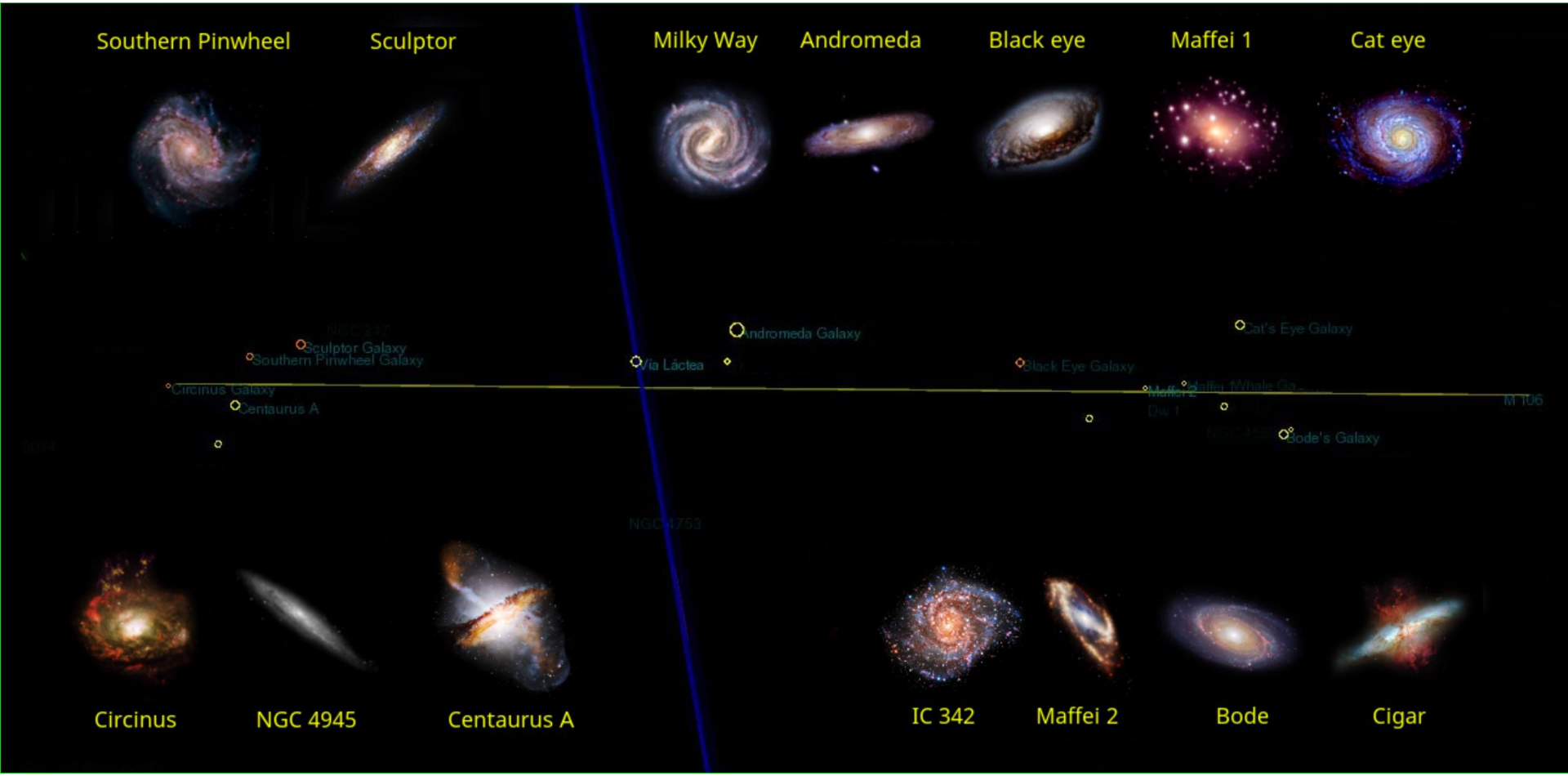
- ***Other, not yet widely accepted***
- *LMC (DF) , Cas A, Cyg X3 , (2012-2024)*
- *SS 433 (DF) (2014-2024)*
- *M31 (DF) (2018-2024),*
- *Maffei Galaxies (Taylor, DF), (2023-2024)*
- ***LOCAL SHEET GALAXIES (2023-2024)***

2014 :the Council of Giants at Local Sheet

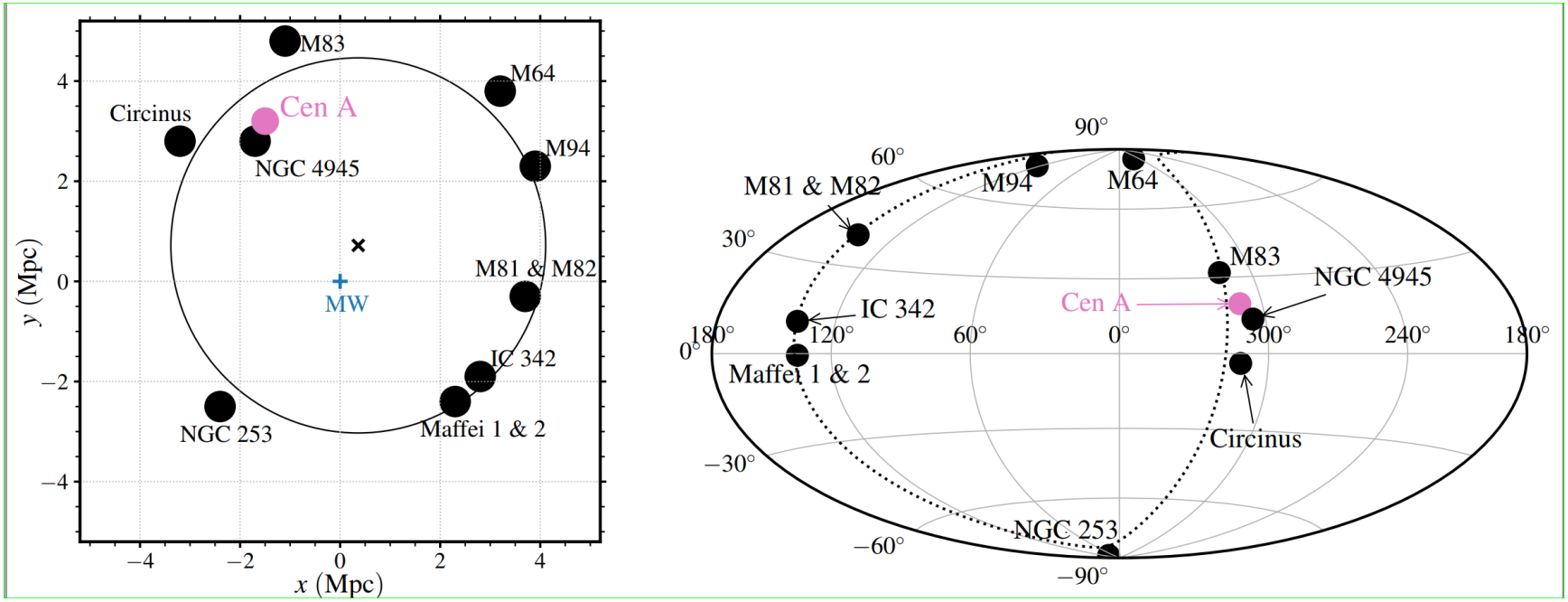
Within the GDR cut off



*Council of **Giants**: just a dozen of objects*

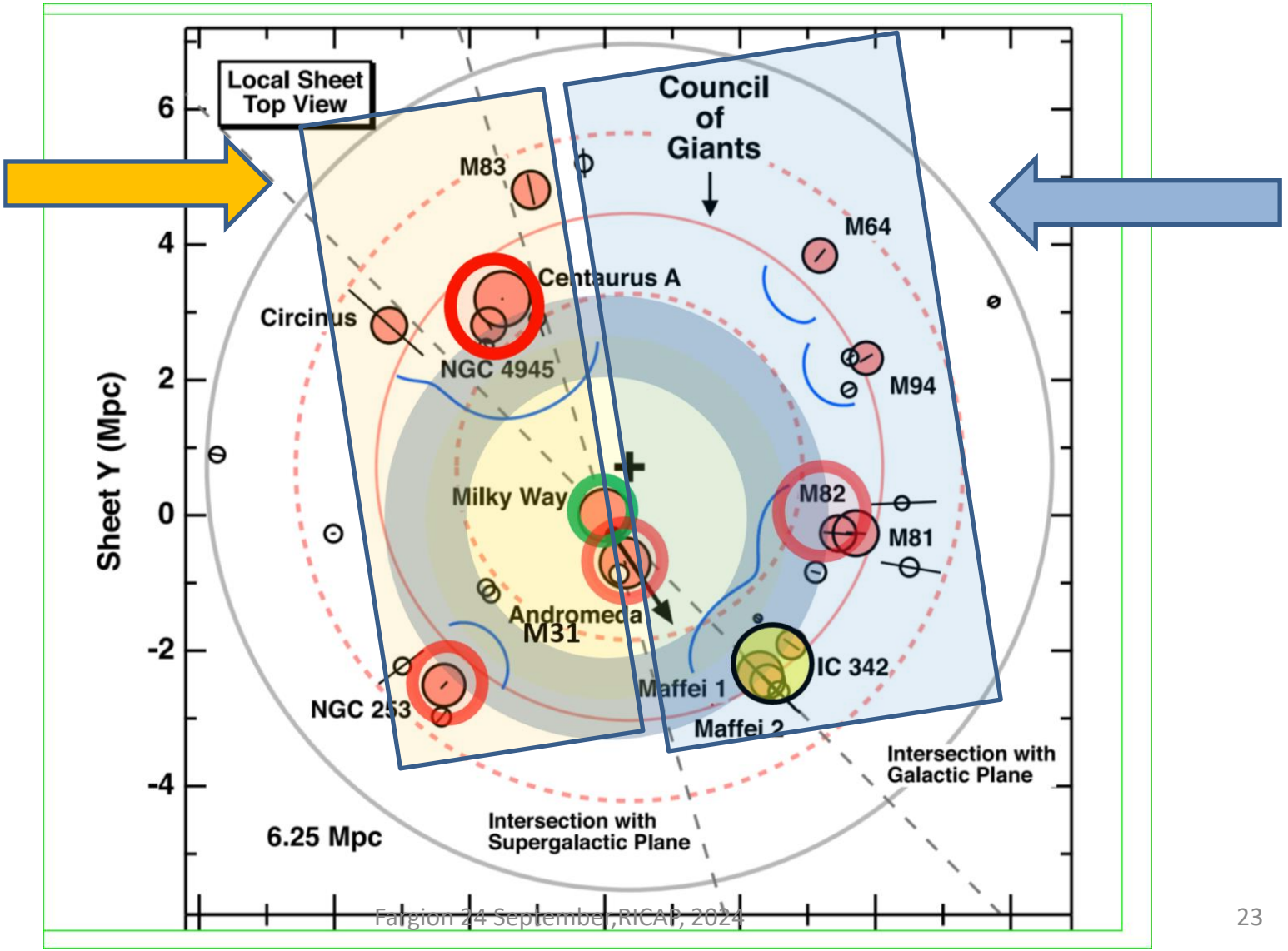


The Local Sheet Galaxies, or the Council of Giants map, galactic coordinate



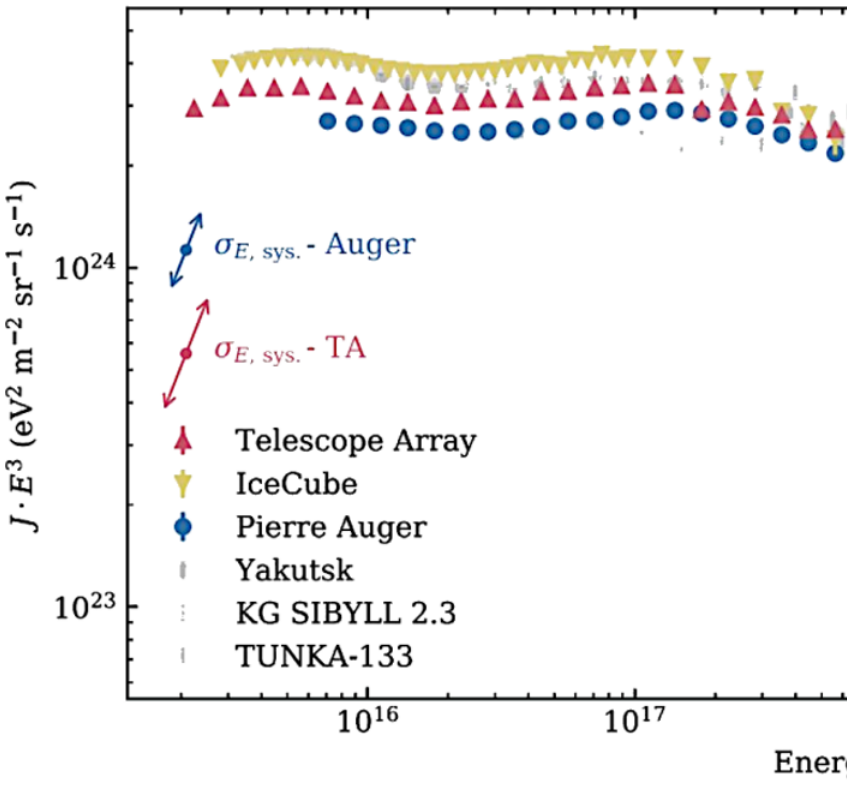
The Local Sheet- A Few Mpc distances

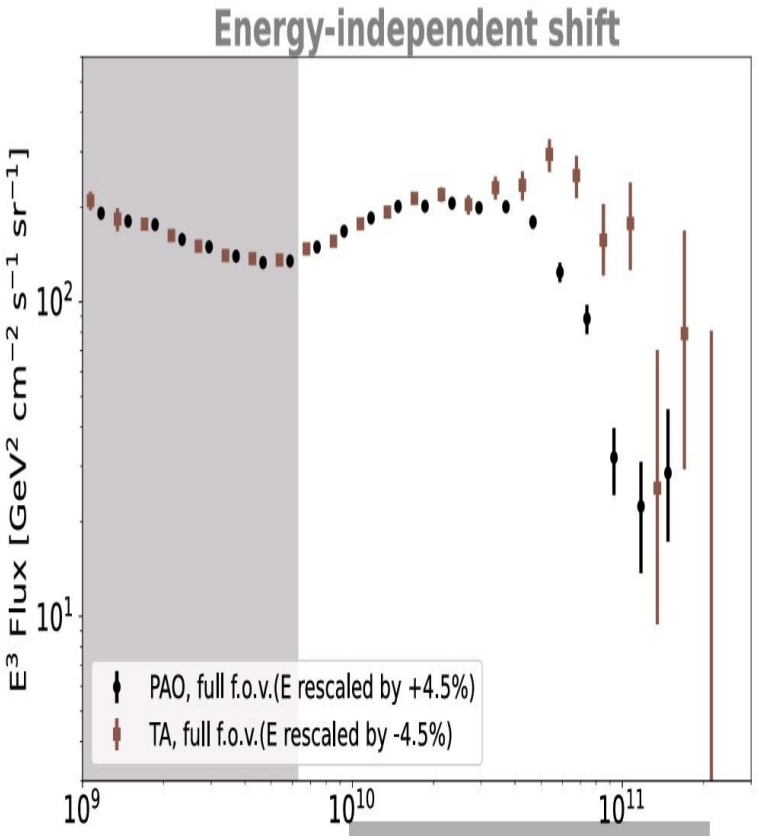
South-North UHECR sky asymmetry



North versus South , AUGER-TA sky puzzling asymmetry along the UHECR GZK cut off

Plotko et a





Galactic Coordinate: Hot Spots and Local Sheet Sources++ Multiplets

https://arxiv.org/pdf/2302.06489

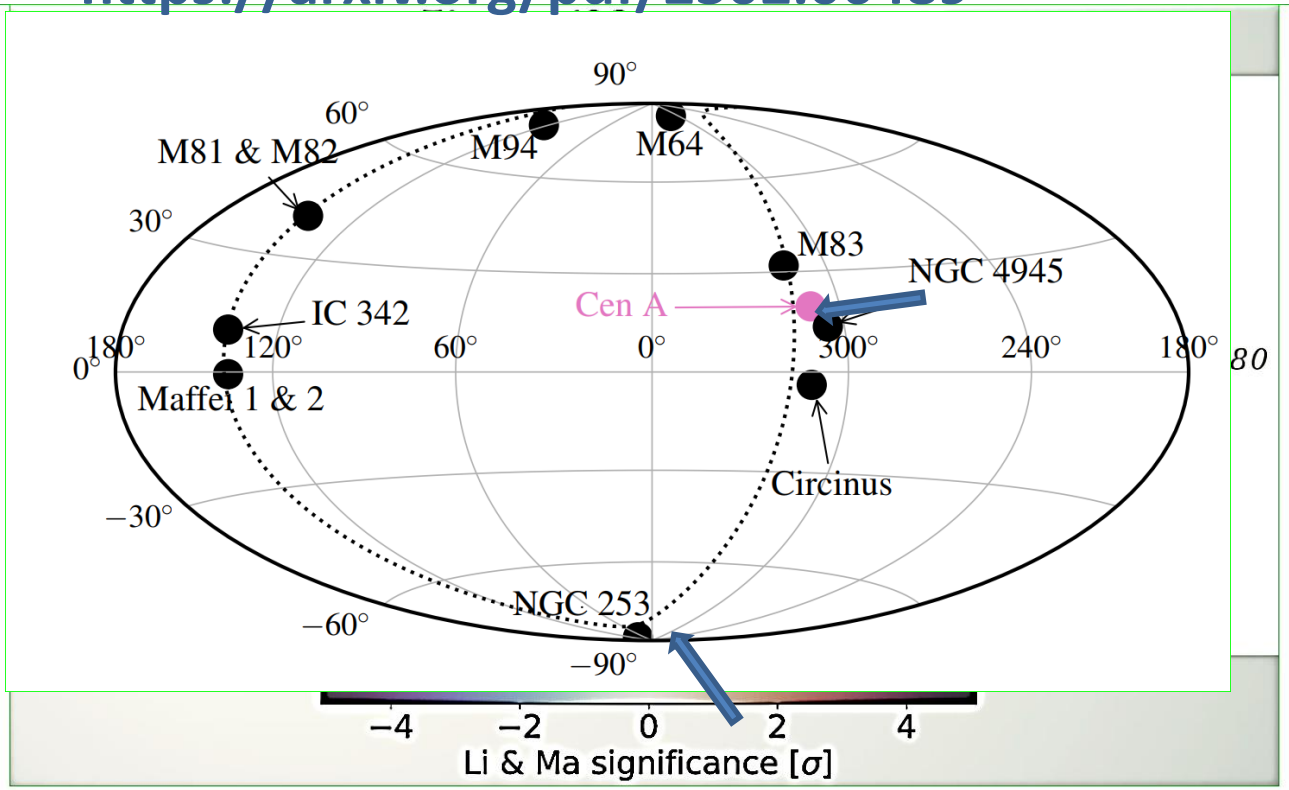
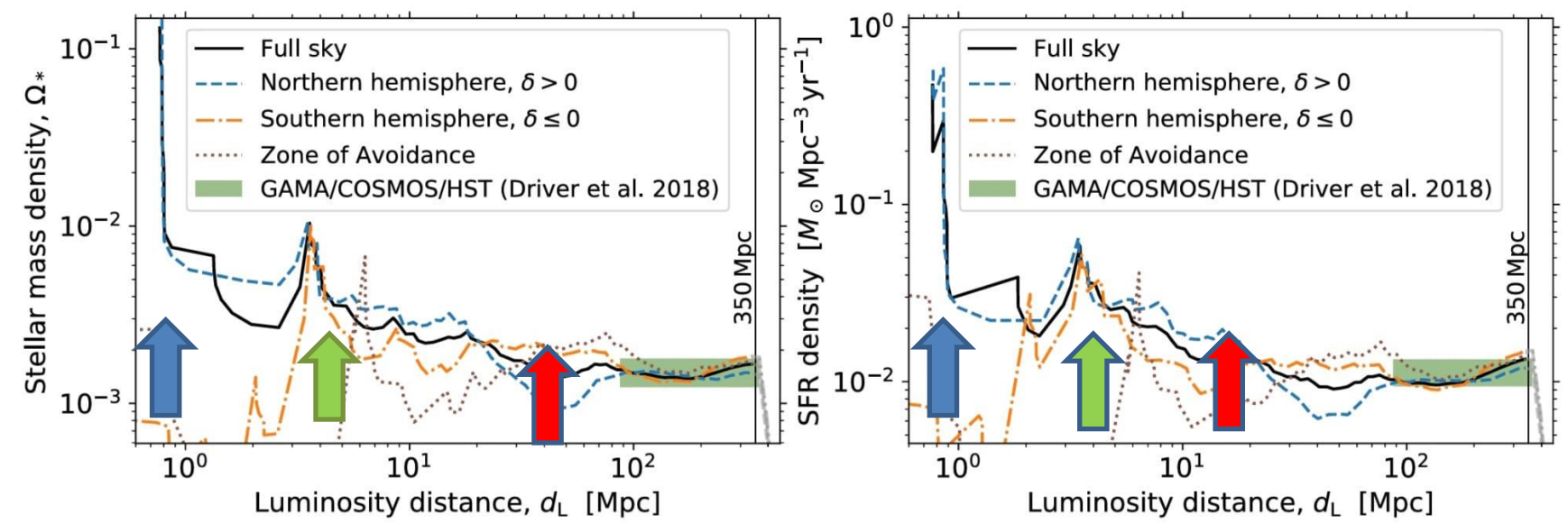


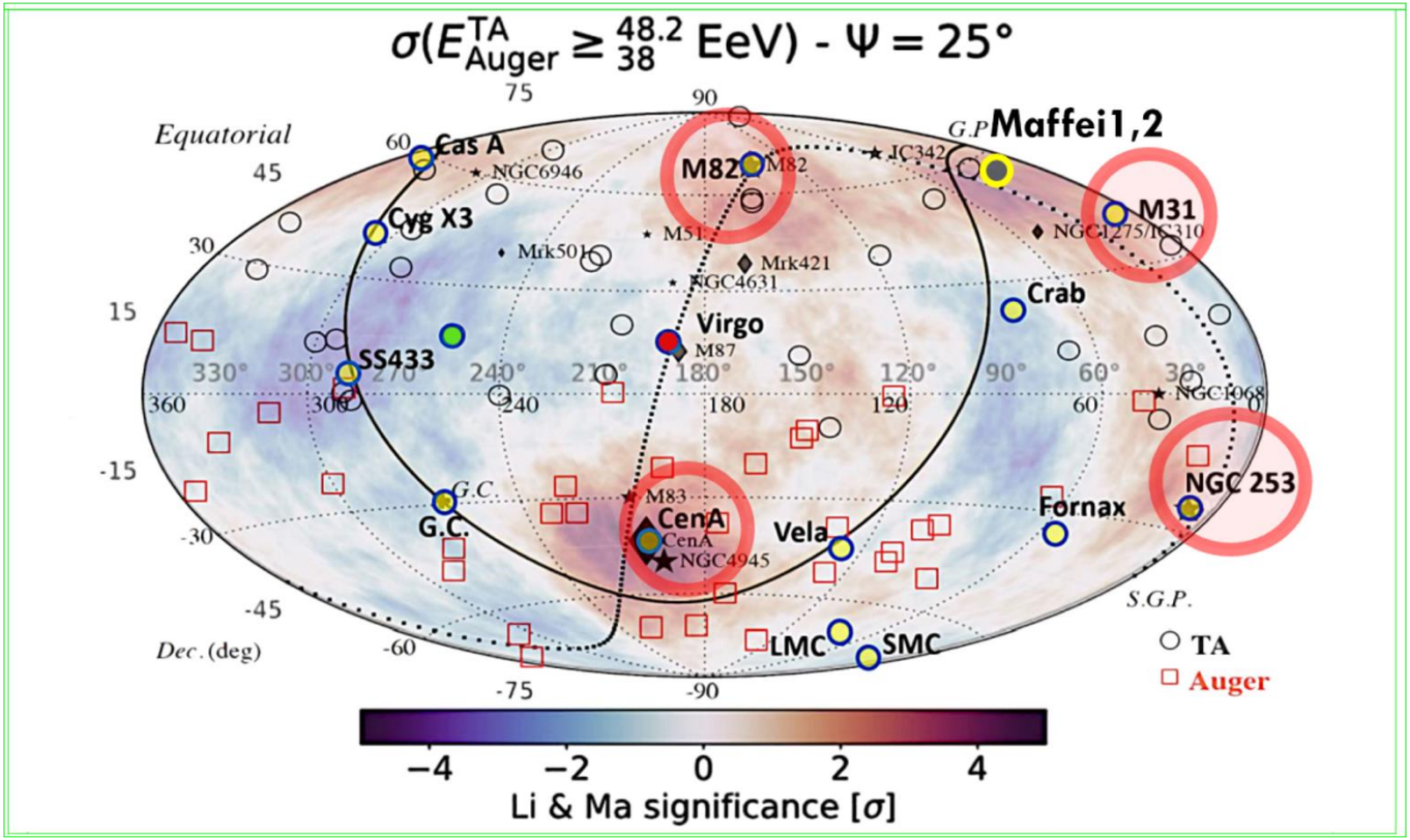
Figure 9. The clustering and the main sources with earliest multiplets in galactic coordinate. Several nearest SNR and Star Burst Galaxies within 2 – 3 Mpc: Cen A, M 82, NGC 253, Cas A. The last is a nearby irregular Starburst galaxy located on galactic plane, also in axis with its SNR at Milky Way plane. The three UHECRs multiplets [31,32], are estimated to come from the few candidate sources, marked by the blue "+", two toward Cen A, one toward NGC 253, that are overlapping a most recent clustering map based on TA and AUGER data [43].

Stellar Mass and Star Formation Rate within a Billion Light-years, by Jonathan Biteau 2021

the Andromeda-Local Sheet-VIRGO mass distribution

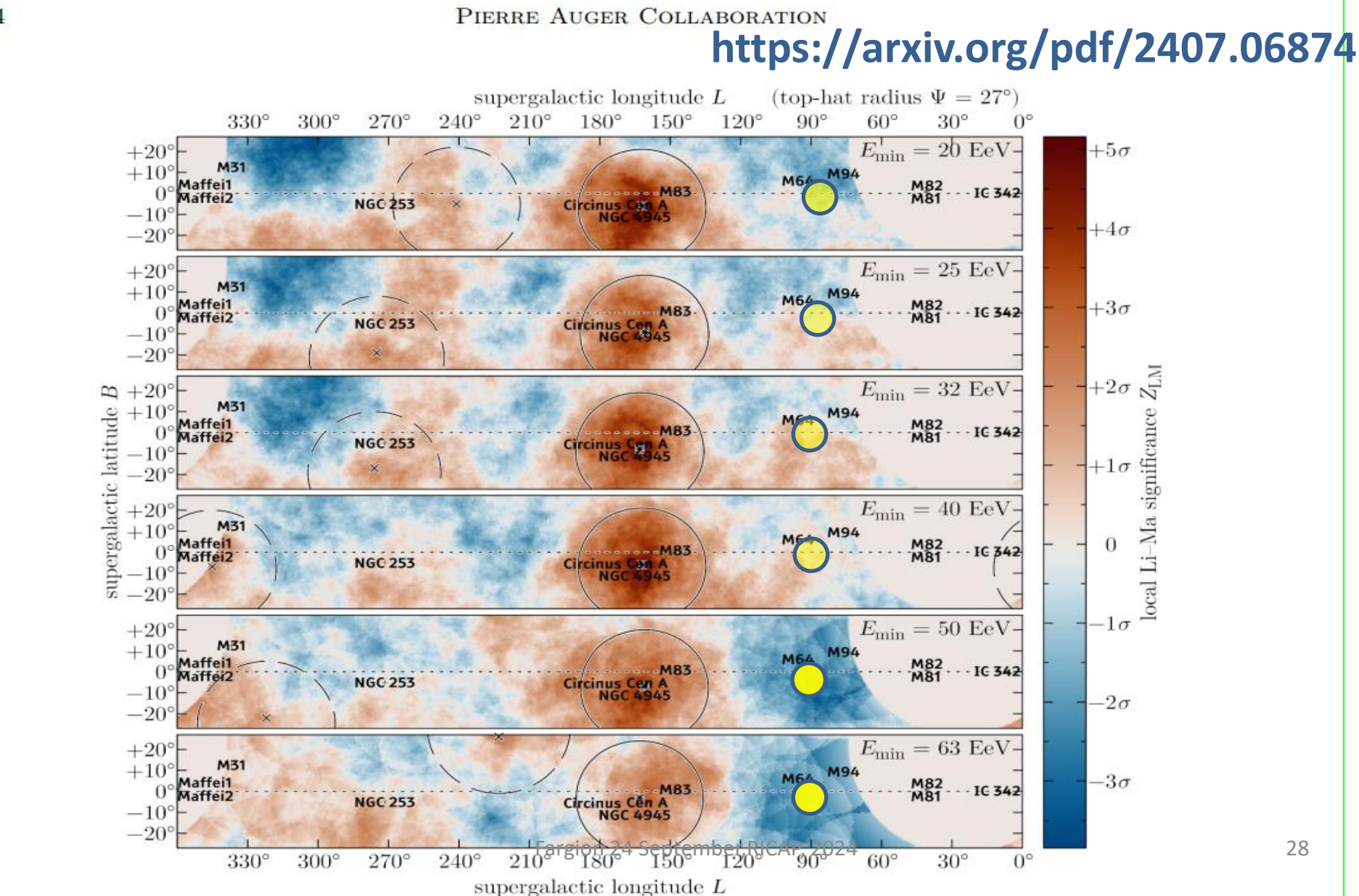


2024, Celestial Coordinate Hot Spots and Amaterasu

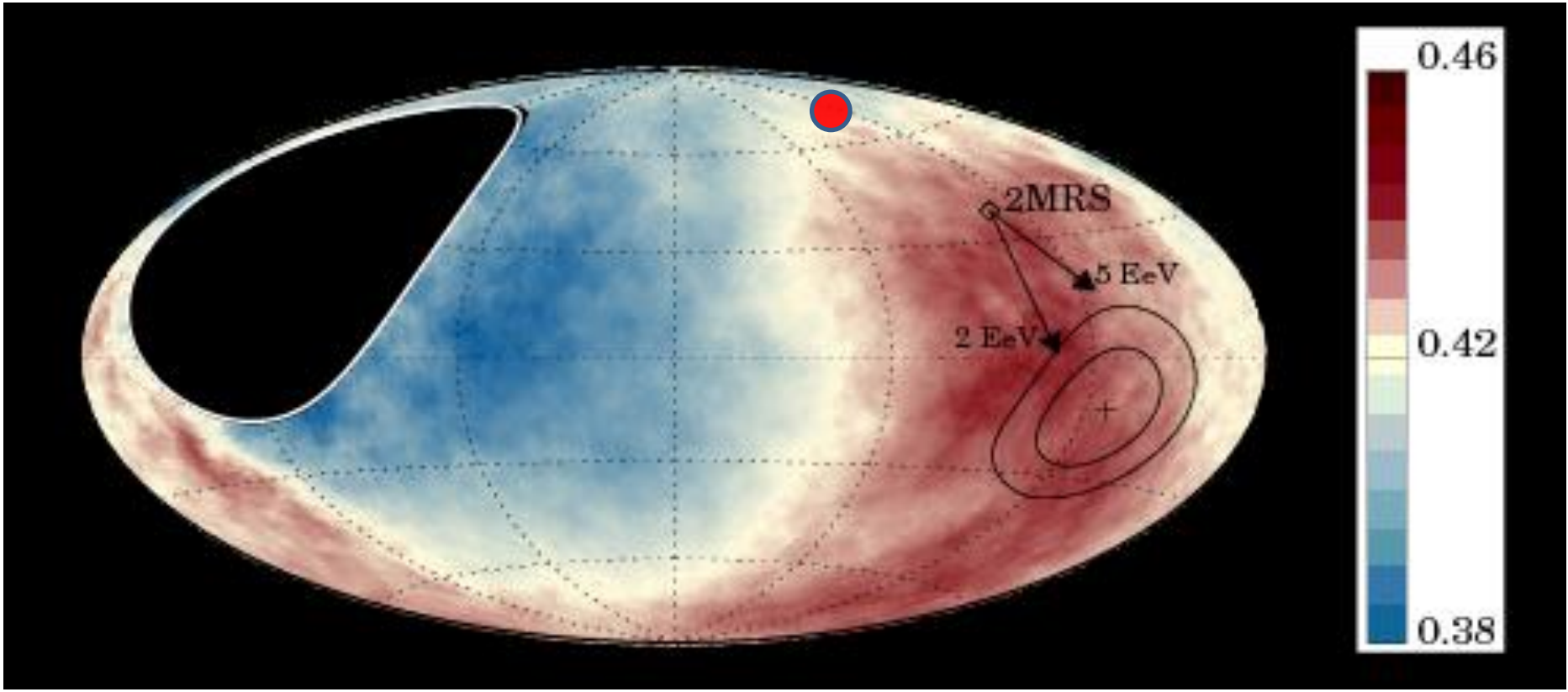


AUGER : the Supergalactic versus LOCAL SHEET= Plane , July 2024 ,

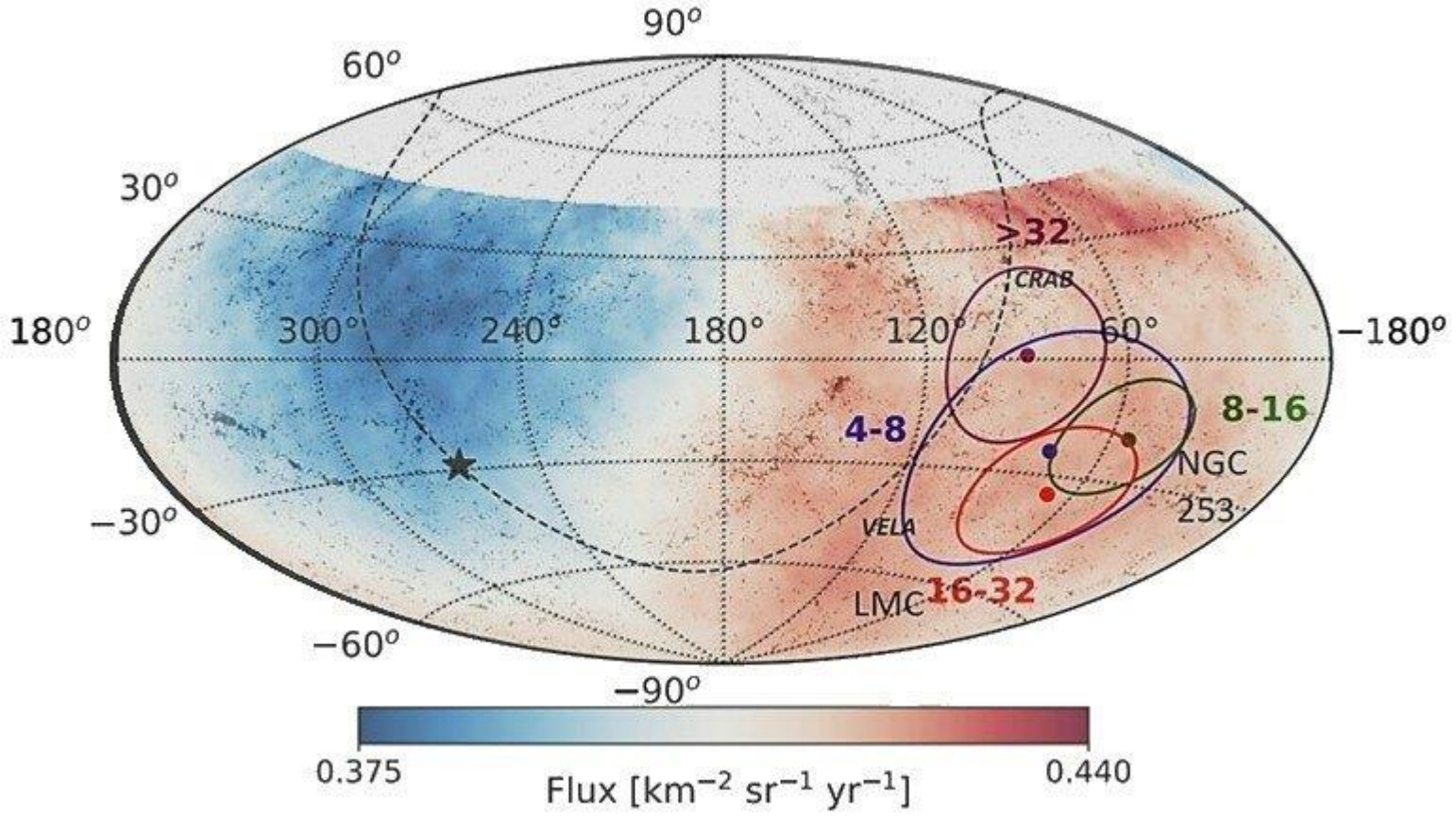
A very missing Virgo



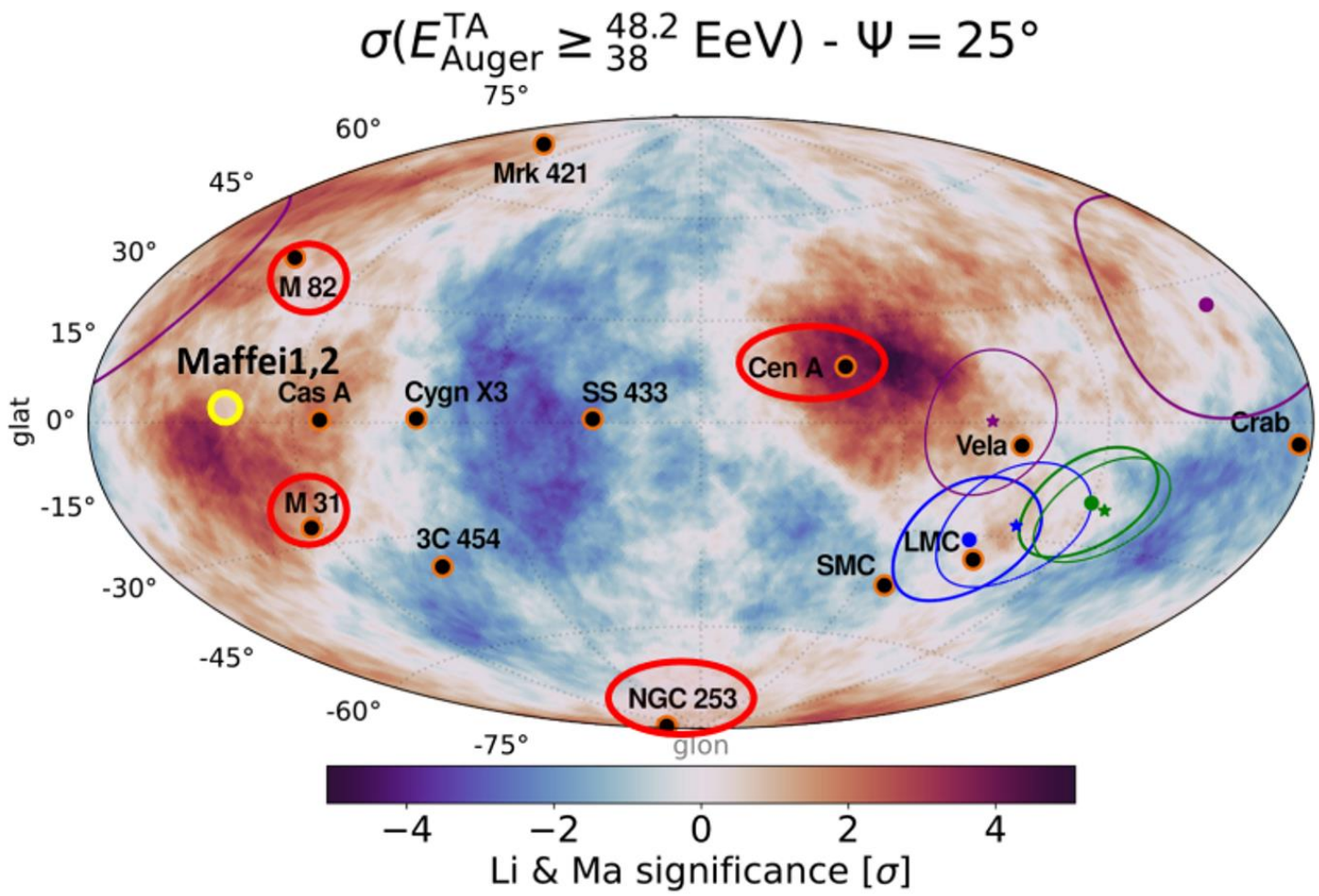
UHECR DIPOLE: Different direction and SIZE of EeV AUGER anisotropy respect to the cosmic big bang dipole-Virgo-- Great Attractor-and the galactic speed



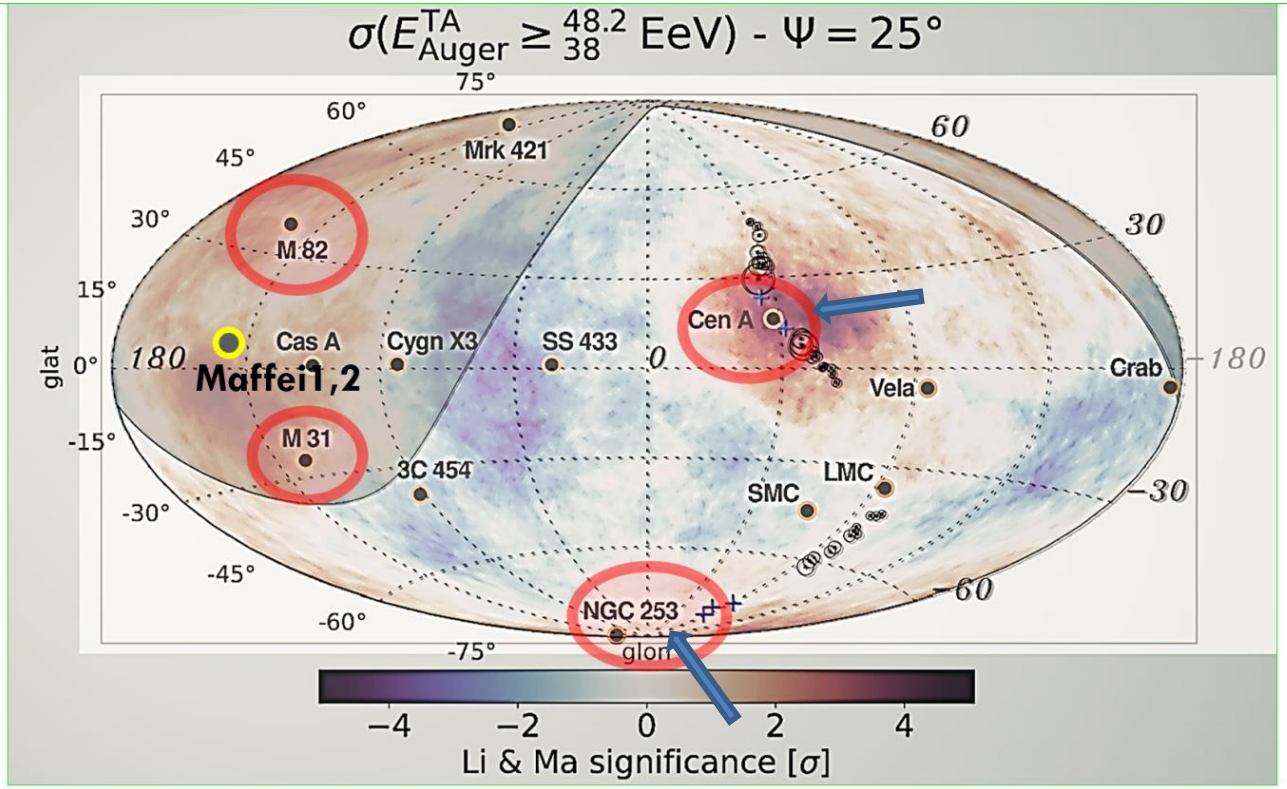
Auger Dipole at 4-8, 8-16, 16-32, >32 EeV



Galactic coordinate—AUGER Dipole Anisotropy-Hot spots- Local Sheet Sources



Galactic Coordinate: Hot Spots and Local Sheet Sources++ Multiplets



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Additional Multiplets and puzzling clustering at 3C454

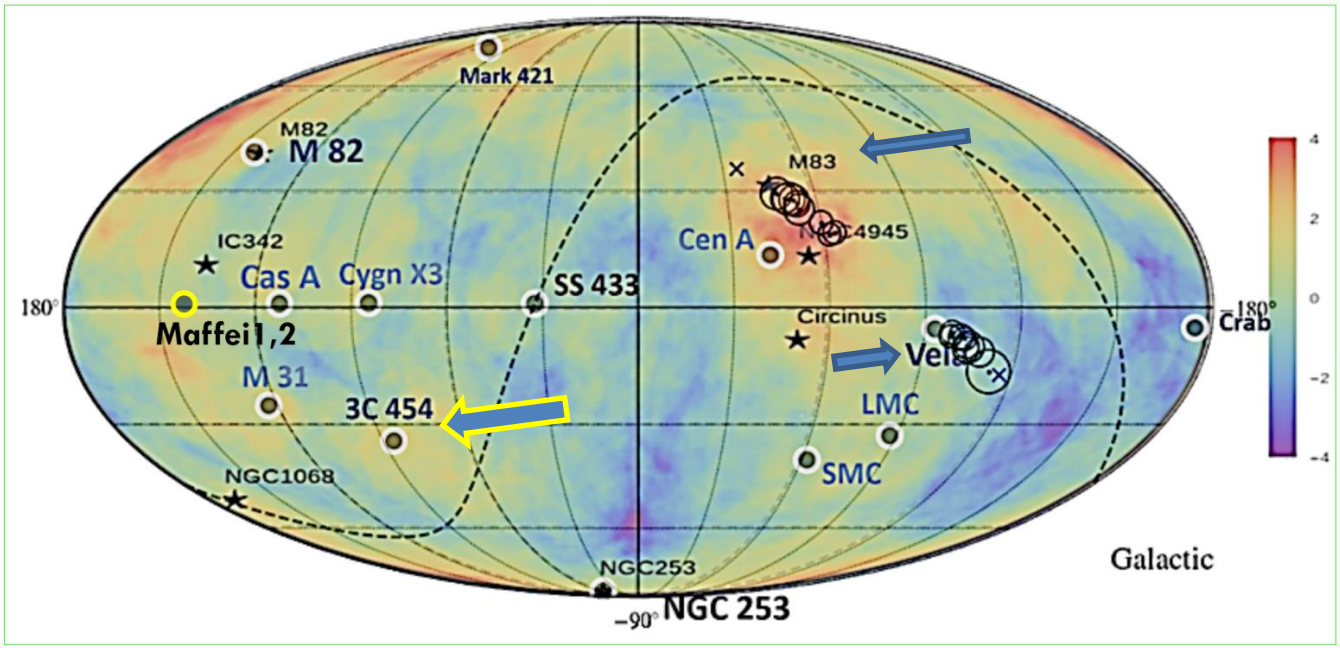
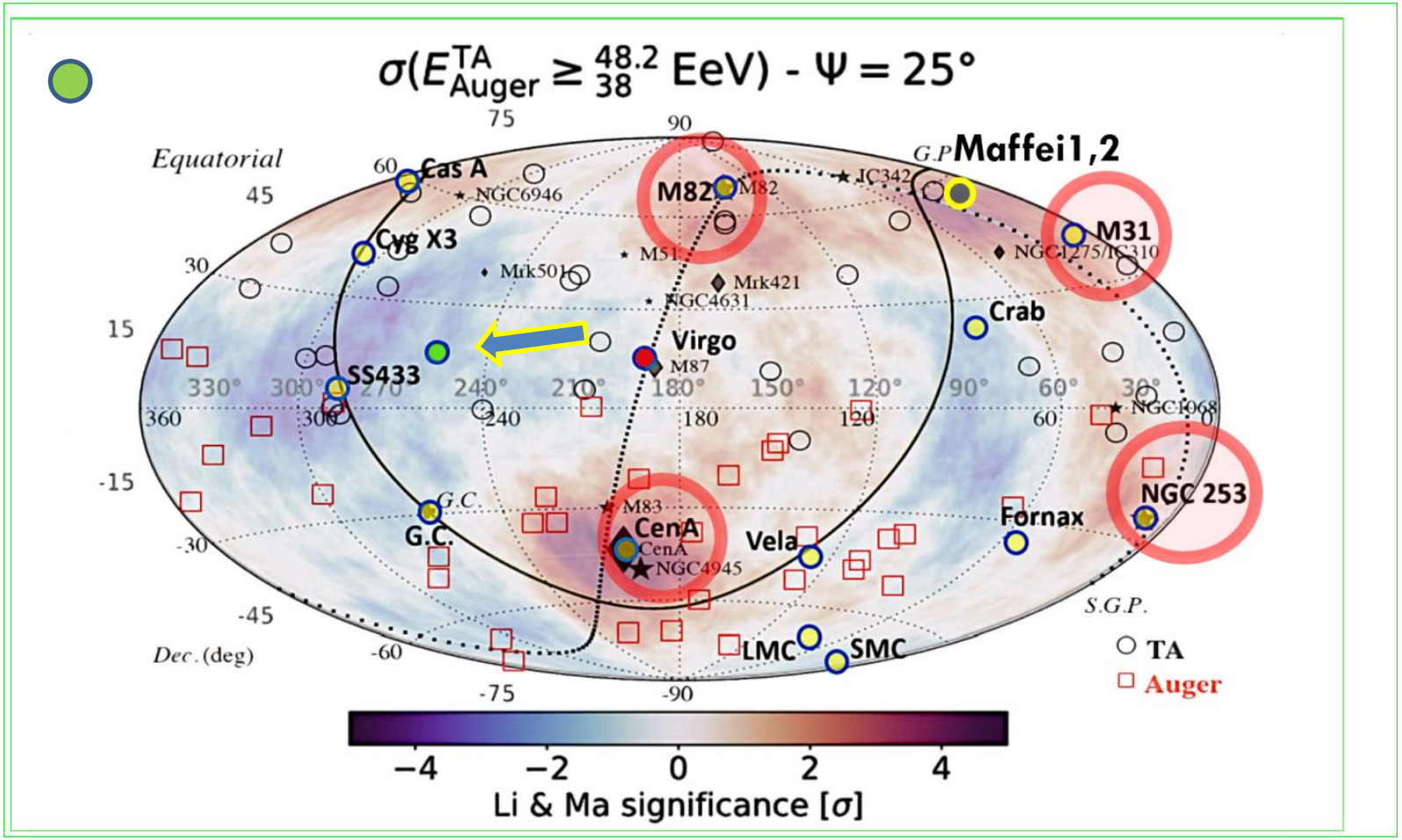


Figure 10. The most recent multiplet clustering in galactic coordinate [57]. Several nearest SNR and Star Burst Galaxies within 2 – 3 Mpc: Cen A, M 82, NGC 253, Cas A. Note the upper multiplet is pointing toward the Cen A hot spot, possibly to a more distant Star Burst source, M83, at 5 Mpc distance. Additional clustering lay along Vela SNR, not in a successful overlapping. Indeed a few UHECR composition differences, might invert the direction arrow of the multiplet clustering. The Vela, with the LMC role, could be important to feed the wide spread AUGER dipole anisotropy. These multiplets, again, are shown over the UHECRs map clustering considered by early authors. [21]. .

Amaterasu, most recent TA 220 EeV UHECR: a SS433 heavy bent Ni UHECR?



Conclusions

- ***UHECR clustering are mostly due to lightest nuclei: D,H,Be,Li***
- ***UHECR are mainly made by GRBs and AGN jets***
- ***Such UHECR are bounded within 4 Mpc in Local Sheet Galaxies***
- ***The first clustering : Cen A, M82, NGC 253 are found and confirmed; M31, Maffei Galaxies, Cas A, also start to arise.***
- ***Multiplets from Cen A and NGC 253 have been foreseen/observed.***
- ***UHECR Asymmetry North South made by few Local Sheet masses asymmetry in sky***
- ***UHECR AUGER Dipole fed by NGC 253 and , possible LMC, Vela, Crab***
- ***If Mrk os 3C454 AGN and UHECR cluster correlate more with time, and their composition is mainly nucleon like,..then .. Z burst model based on ZeV-relic neutrino scattering, overcome the puzzle: A Great neutrino discover***

2008-2024: UHECR Lightest nuclei Model evolution

- **arXiv:2408.07172 , UHECR Clustering: Lightest Nuclei from Local Sheet Galaxies**
- **arXiv:2303.08922 , UHECR Signatures and Source➔……**
- **arXiv:1412.1573, The meaning of the UHECR Hot Spots: A Light Nuclei Nearby Astronomy ➔…….**
- **arXiv:0908.2650, Coherent and random UHECR Spectroscopy of Lightest Nuclei along CenA…**

arXiv:0801.0227

Light Nuclei solving Auger puzzles. The Cen-A imprint

Thank You for your Ultra High Energy ***attention***

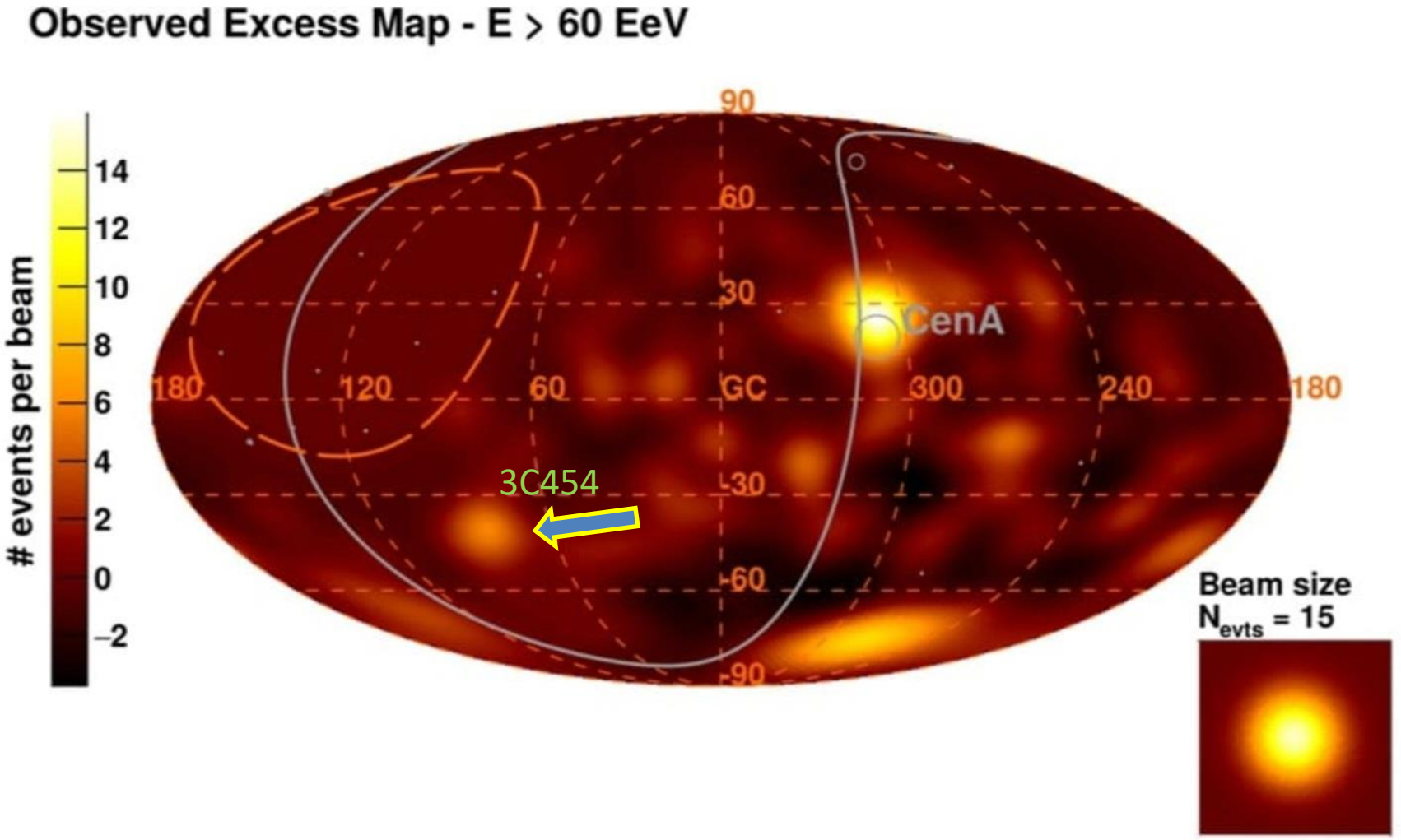
Summary 2 (2014, ten years ago)

- Same message in earliest time:

A possible solution to Virgo absence by GZK light nuclei dissociation cut off

- Physica Scripta Volume 78 Number 4
- D Fargion 2008 *Phys. Scr.* **78** 045901 :
- **Light nuclei solving the AUGER puzzles: the Cen-A imprint**
- **Virgo absent because He UHECR are absorbed**

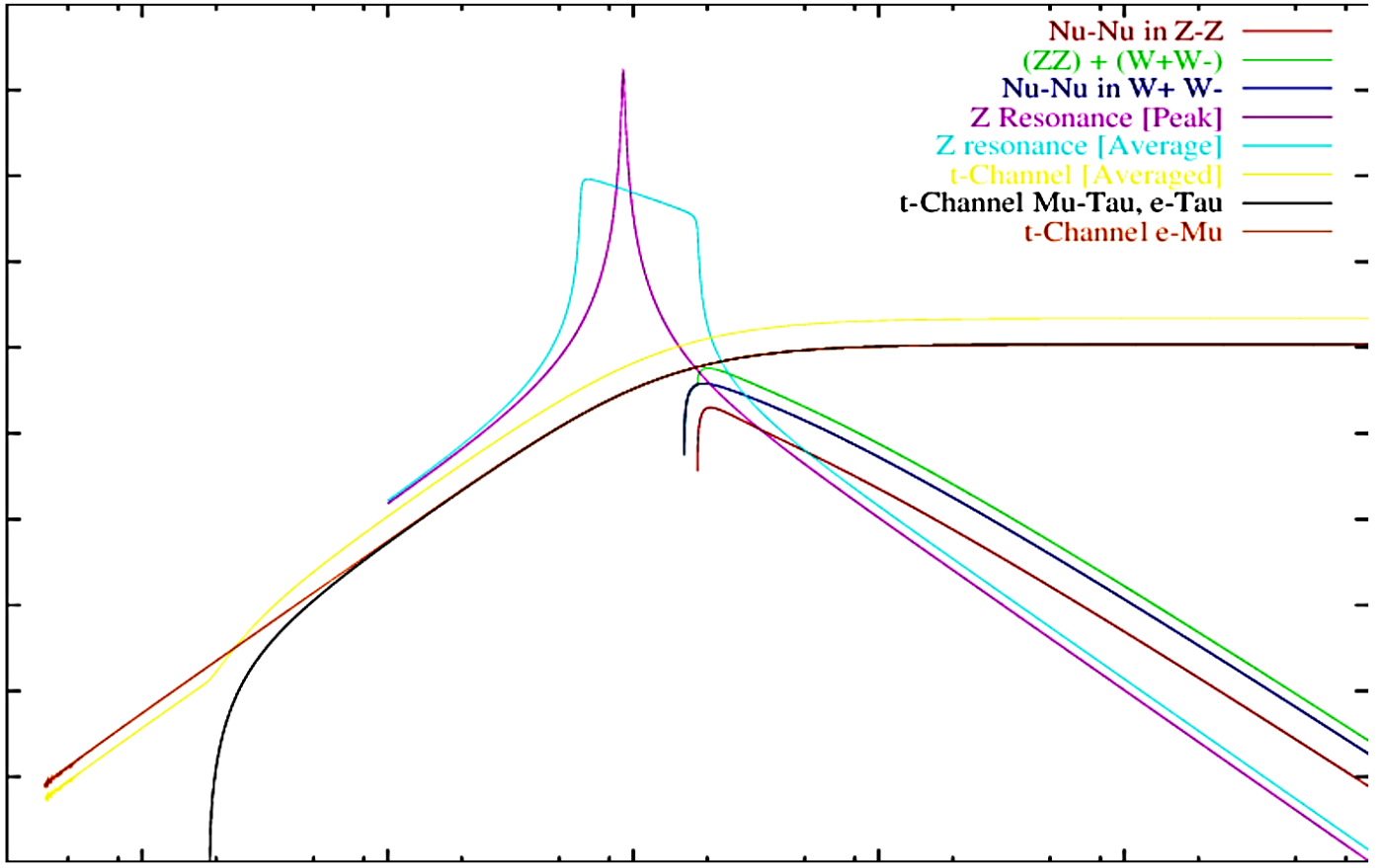
Z-resonance on 3C454 : neutrino-neutrino relic in UHECR puzzle?



Far AGN correlating UHECR and UHE ZeV neutrino scattering on relic eV ones

- **arXiv:2310.19227 [pdf, other]**
- **The unprecedented flaring activities around Mrk 421 in 2012 and 2013: The test for neutrino and UHECR event connection**
- **Authors:** Nissim Fraija,et al

Uhe ZeV neutrino scattering on relic ones (about 1-0.2 eV mass)



The $\nu \bar{\nu} \rightarrow Z, W^+ W^-, ZZ$, T-channel, cross sections as a function of the center of mass energy in $\nu\bar{\nu}$. These cross-sections are estimated also in average (Z) as well for each possible t-channel lepton pairs. The averaged t-channel averaged the multiplicity of flavours pairs $\nu_l, \bar{\nu}$□ respect to neutrino pair annihilations into Z neutral boson.

Conclusion 2

- ***Ten EeV dipole is fed by NGC 253 AGN and by the local Vela, Crab. LMC and possibly, also, by Andromeda, Fornax D.***

- **Puzzling 3C454 clustering , Amaterasu, if a real one, might be related to UHE ZeV neutrino scattering onto relic ones in a hot, dark halo.**
- **THE Z-BURST lead to *nucleon-composition***
- **Heavy galactic nuclei lead to *Ni-like composition***

A UHECR heaviest nuclei CR connection? Most energetic UHECR much bent

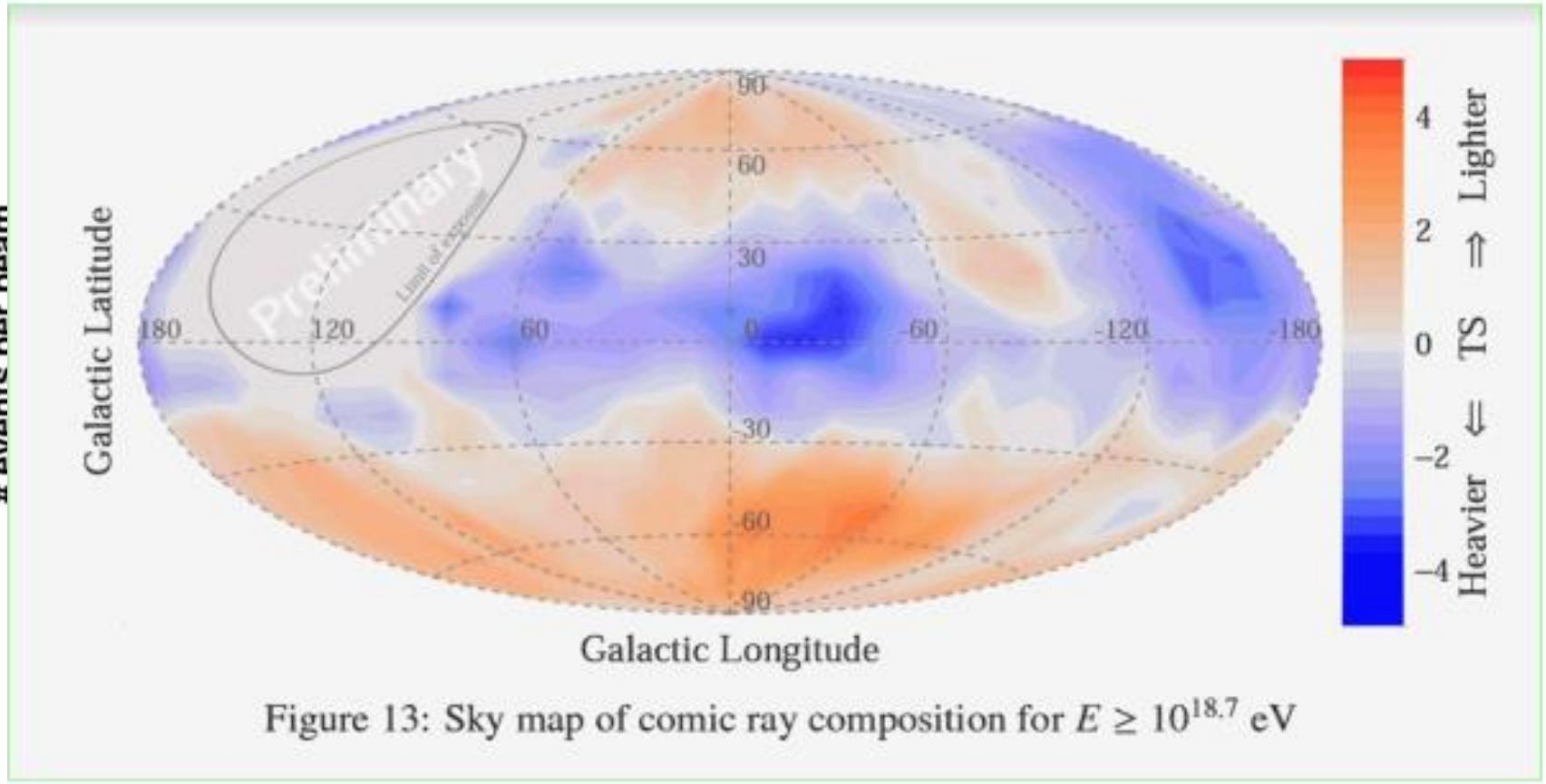
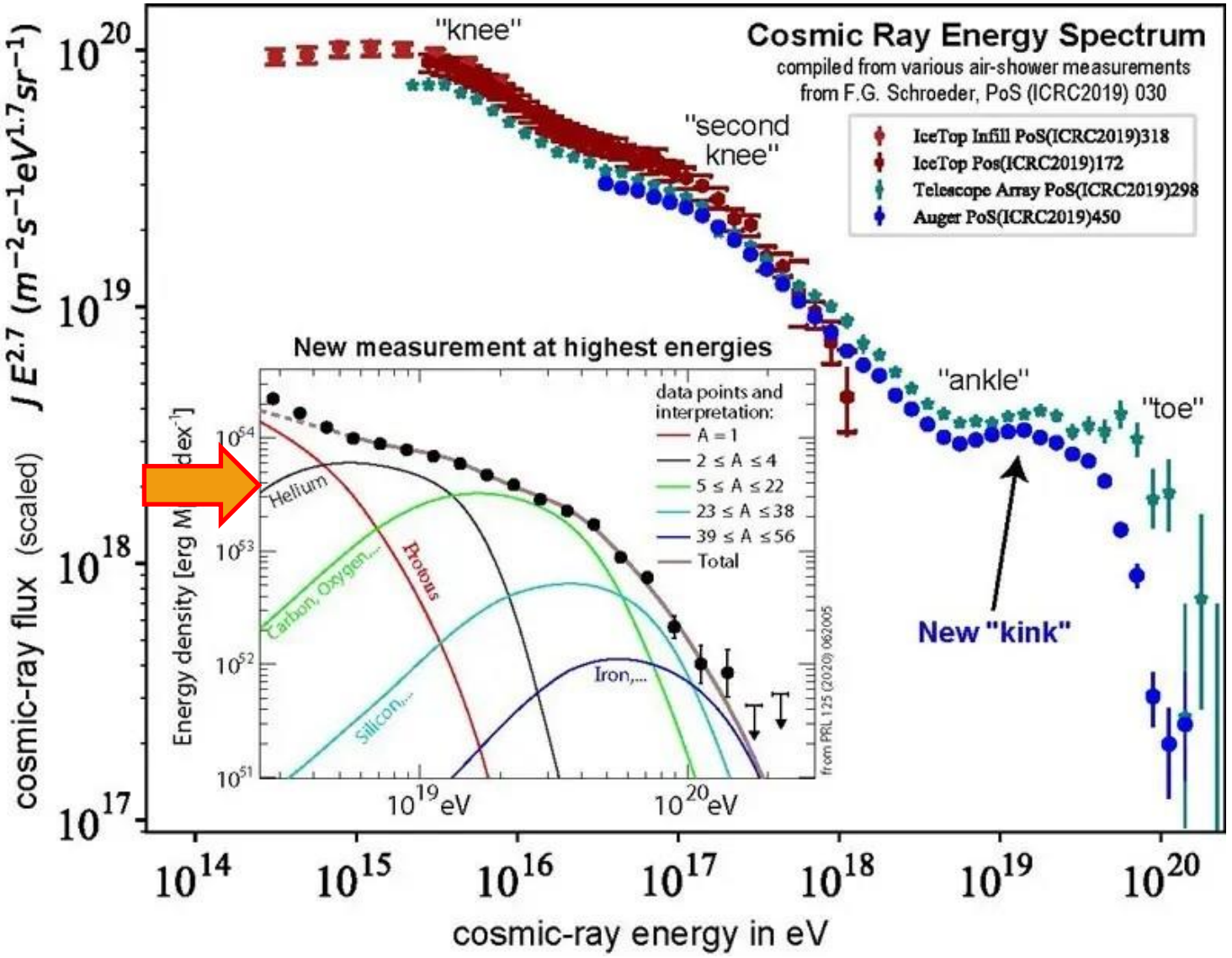


Figure 13: Sky map of comic ray composition for $E \geq 10^{18.7}$ eV

UHECR spectra evolution: 2019 composition models



10 years ago

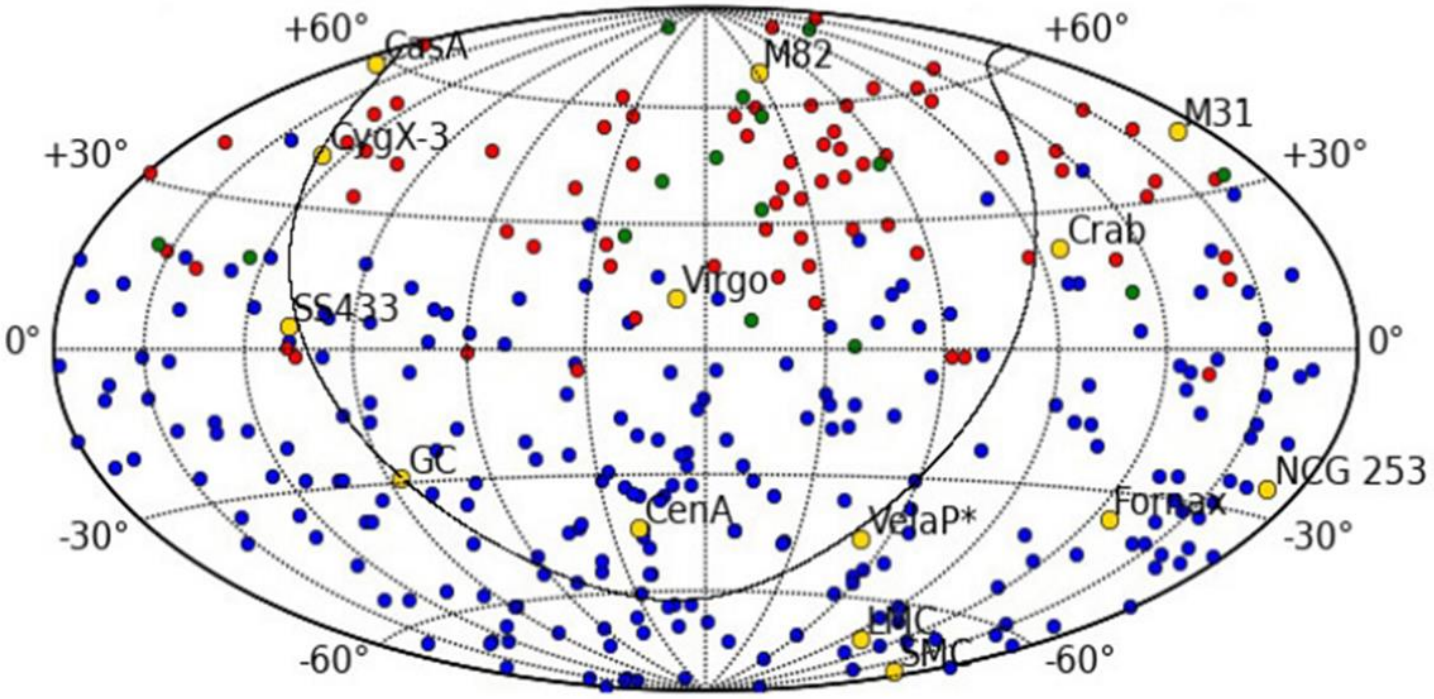


Figure 4. Hammer Projection in Celestial coordinate for the latest 231 AUGER UHECR (blue) with additional 72+15=87 latest TA (72 red and 15 green) records. A few potential sources are labeled as well as the galactic plane.

SD
No

Bending charges in magnetic fields

- **The TeVs CR Lunar and Solar Shadows bending**

Larmor radius R_L is

$$R_L = 33360km \cdot (E/TeV) \cdot (B/Gauss)^{-1}$$

Let us remind here the ideal case for a coherent bending of geomagnetic field for the Moon shadow.

The Earth magnetic dipole field decay as a cubic law with the distance. Therefore the deflection is being mostly ruled (while being displaced to west side, because nucleons are positives) by the nearest geomagnetic dipole, in a very narrow Earth size, by an approximated formula as:

$$\delta_{G_{Moon}} = 1.27^{\circ}\left(\frac{Z}{Z_p}\right)\left(\frac{E}{T\,\mathrm{eV}}\right)^{-1}\left(\frac{D}{4000km}\right)\left(\frac{B}{0.2G}\right) \quad (3)$$

These bending are used to calibrate TeV-PeV cosmic ray resolution in CR detector array. The solar shadows does suffer of a comparable bending, even if one includes an additional deflection that is related to the solar interplanetary influence in the far CR flight:

$$\delta_{G_{Sun}} = 1.15^{\circ}\left(\frac{Z}{Z_p}\right)\left(\frac{E}{T\,\mathrm{eV}}\right)^{-1}\left(\frac{D}{1.5\cdot 10^{8}km}\right)\left(\frac{B}{5\mu G}\right) \quad (4)$$

Different incoherent bending expressions, the random ones, will be useful and will be

Amaterasu Highest event: From SS433?

That event had been observed at the highest UHECRs energy, $E = 2.44 \cdot 10^{20}$ eV, nearly four times larger than the energy considered in expression above. Therefore, one may derive respectively the light and heavy nuclei deflection for the *Amaterasu* energy as follows:

$$\alpha^{Si}_{\mathrm{G_{rm}}} = 22.7^{\circ} \left(\frac{Z}{Z_{Si}}\right) \left(\frac{E}{2.4 \cdot 10^{20}\,\mathrm{eV}}\right)^{-1} \left(\frac{D}{5\,\mathrm{kpc}}\right)^{1/2} \left(\frac{d_c}{\mathrm{kpc}}\right)^{1/2} \left(\frac{B}{3\mu G}\right). \tag{8}$$

$$\alpha^{Ni}_{\mathrm{G_{rm}}} = 45.5^{\circ} \left(\frac{Z}{Z_{Ni}}\right) \left(\frac{E}{2.4 \cdot 10^{20}\,\mathrm{eV}}\right)^{-1} \left(\frac{D}{5\,\mathrm{kpc}}\right)^{1/2} \left(\frac{d_c}{\mathrm{kpc}}\right)^{1/2} \left(\frac{B}{3\mu G}\right). \tag{9}$$

Or, simply, $\alpha^{Si} = 22.7^{\circ}$. $\alpha^{Ni} = 45.5^{\circ}$. These angular deflections for the light nuclei Si are marginally consistent with the SS433-Amaterasu angular distance. The heavy nuclei Ni bending is well compatible with the observed SS433-Amaterasu angular distance nearly of $35^{\circ} - 40^{\circ}$, see Fig.4.

The same heavy nuclei Ni-like UHECR can be coherently deflected [46] by the nearby Vela SNR, 0.29 kpc, by an angle comparable to the observed displaced clustering. The same train of events might feed the UHECRs EeVs dipole clustering in AUGER events: 18.7°.

Apparent GZK cut off at 100 EeV in UHECR led to models based on photopion opacity =

- *Most preferred protons as UHECR*

These UHECR protons could fly almost undeflected, 40 Mpc , at hundred EeV energy

- *Within such «GZK distances» Virgo cluster should shine bright*

However

- ***UHECR the clustering observed by AUGER since 2007 is showing on a mysterious VIRGO absence….***

- ***IF UHECR were proton than…***
  VIRGO at 20 Mpc, it had to rise bright

The UHECR suffer of photo-pion opacity: ***the GZK cut off***

(and ***also*** *photo nuclear disruption by* ***G****iant* ***D****ipole* ***R****esonance,* ***GDR****)*