Light nuclei solving the AUGER puzzles: the Cen-A imprint

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Abstract
Ultra-high-energy cosmic rays’ (UHECR) maps at 60 EeV have been found recently by the AUGER group to be spreading anisotropy signatures in the sky. The results have been interpreted as a manifestation of AGN sources ejecting protons at GZK (Greisen–Zatsepin–Kuzmin) edges, around or below 80 Mpc distances, mostly from Supergalactic (SG) plane. The result is surprising due to the lack of correlation with the much nearer Virgo cluster. Moreover, early GZK cutoff in the spectra may be better reconciled with light nuclei (than with protons). In addition, a large group (of nearly a dozen) of events cluster suspiciously along Cen-A. Finally, proton UHECR composition nature is in sharp disagreement with the earlier AUGER claim of a heavy nuclei dominance at 40 EeV, within 13 extreme events ($\ln A = 2.6 \pm 0.6$). Therefore, we interpret here the signals as mostly UHECR light nuclei (He, Be, B, C and O) ejected from nearest Cen-A, smeared by galactic magnetic fields, whose random vertical bending is overlapping with SG arm. The (possible) AUGER misunderstanding took place because of a rare coincidence between the SG plane (arm) and the smeared (randomized) signals from Cen-A, bent orthogonally to the galactic fields. Our derivation verifies the consistency of the random smearing angles for He, Be, B, C and O range, respectively, $\gtrsim 2.7^\circ$–$11^\circ$ in reasonable agreement with the AUGER main group event around Cen-A. Only a few other rare events are spread elsewhere: The more collimated from Cen-A, the lighter ($\ln A_{He} \leq 2$). The more spread, the heavier ($\ln A \geq 2$). Consequently, Cen-A is probably one of the best candidate UHE neutrinos at tens–hundreds of PeVs. This solution may be tested soon by future (and may even have already been recorded) clustering around the Cen-A barycenter, events smeared by vertical galactic magnetic forces on the lightest nuclei.

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(Some figures in this article are in colour only in the electronic version.)

1. Introduction: puzzled by AUGER puzzle

The last AUGER report [1], confirmed in a more recent [2] paper, surprised us by its conflicting fragments in the growing ultra-high-energy cosmic rays (UHECR) puzzle. The expected GZK (Greisen–Zatsepin–Kuzmin) cutoff took place, as in HIRES [3] spectra, at much earlier energy edges ($6 \times 10^{19}$ eV) than those expected for protons or iron ($1$–$2 \times 10^{20}$ eV), in order to be confined within a local universe (100 Mpc) versus the much larger proton (500 Mpc). Why protons at all, if the previous composition at 40 EeV (12 extreme events) leads to heavy nuclei ($\ln A = 2.6 \pm 0.6$)? Indeed, we note here, there are other UHECR candidates whose GZK cutoffs occur at earlier energies (fitting an earlier cutoff), but are nuclei: they are the light ones, which are bound by fast photo-dissociation in low energy (of a few tens of exa-electron volts (EeV)) and nearby volume (ten or a few tens of megaparsec (Mpc)), keeping partial directionality. Their allowed volumes are therefore quite local, as shown in figure 1, compatible with Cen-A spread group. This AGN (active galactic nucleus) source, because of the distance, is also the brightest. Much farther sources are diluted by distance and suppressed at the largest edges by light nuclei cutoff. The very absence of the rich nearby Virgo AGN is indeed still
puzzling [5]: its presence might be hidden in earlier AGASA (Akeno giants air shower array) and Haverah Park [6] and references therein; let us note that a marginal signal (3 events) from near Fornax cluster arose already. A Virgo comparable one is awaited. In my opinion, the very dominant presence of a much nearer Cen-A AGN source coincident with a few doublets (or even a multiple dozen clustering at wider solid angles) suggests a key role for nearby sources over distant ones; but Virgo and M87, I believe, should rise too, perhaps spread. Why (following AUGER) should the apparent farther sources from Cen clusters or even the Shapley concentration (figure adapted from [4]): beryllium, helium and boron are among the lightest nuclei that suffer a more drastic cutoff (see figure above) bounding them at nearest cosmic volumes. This may better explain their allowed arrival from Cen-A (4 Mpc), their collimation a few degrees from the source and the apparent absence from more distant Virgo (16 Mpc). Three events from Fornax may still reconcile with heavier (C, O) nuclei. A single bent event from Virgo may be present in large galactic latitude.

more diffused noise suggest a few or no presence of Fe and p candidates. At the present stage and at 60 EeV edges, we believe the sky UHECR is ruled by Cen-A light nuclei and a few scattered sources around.

The galactic magnetic field present in the galactic disk is organized in a spiral way. The lines are frozen inside the galactic plane. The consequent Lorentz forces are orthogonal, with opposite sign, to it. Consequently, the lines are placed from left to right in the plane; the bending of the UHECR charges takes place to and fro in a vertical manner (as shown in figure 5) in a random way (filling the SG arm). The average deflecting angle is approximately:

\[ \delta_{\text{lim}} \gtrsim 1.33^\circ \times Z \left( \frac{6 \times 10^{19} \text{ eV}}{E_{\text{CR}}} \right) \left( \frac{B}{\mu \text{G}} \right) \sqrt{\frac{L}{10 \text{kpc}}} \sqrt{\frac{l_c}{l_{\text{kpc}}}}. \]  

(1)

The following values are respectively, for He, Be, B, C and O:

\[ \delta_{\text{He}} \gtrsim 2.7^\circ, \delta_{\text{Be}} \gtrsim 5.3^\circ, \delta_{\text{B}} \gtrsim 6.7^\circ, \delta_{\text{C}} \gtrsim 8^\circ \text{ and } \delta_{\text{O}} \gtrsim 10.7^\circ. \]

These values are only approximate and might be enhanced by a factor probably above 2–3. Indeed, the galactic magnetic field on the plane is quite a bit larger (two to four times at least) than the halo one, and the distances from Cen-A cross twice the galactic size; therefore,

\[ \delta_{\text{lim}} \gtrsim 3.76^\circ \times Z \left( \frac{6 \times 10^{19} \text{ eV}}{E_{\text{CR}}} \right) \left( \frac{B}{2 \mu \text{G}} \right) \sqrt{\frac{L}{20 \text{kpc}}} \sqrt{\frac{l_c}{\text{kpc}}}. \]  

(2)

These values are respectively for He, Be, B, C and O:

\[ \delta_{\text{He}} \gtrsim 7.5^\circ, \delta_{\text{Be}} \gtrsim 11.2^\circ, \delta_{\text{B}} \gtrsim 18.9^\circ, \delta_{\text{C}} \gtrsim 22.6^\circ \text{ and } \delta_{\text{O}} \gtrsim 30.2^\circ. \]  

In this view, it may well be possible that not all of the UHECR are light nuclei, but just the lightest ones (He, Be), whose propagation distance is just smaller than the Virgo distance. This solution may best explain the puzzling absence of a Virgo signal. These bending angles are indeed well compatible with the observed angular spread (see oval

Figure 1. Energy losses and nuclei range: while light nuclei are bounded in the local universe, the heavier ones (iron nuclei) and protons are not so suppressed at energy \( E = 5.6 \times 10^{19} \text{ eV} \) edge. The ‘p’ and ‘Fe’ must arrive from a wide, almost homogeneous, universe \((R \gtrsim 500 \text{ Mpc})\). Therefore, light nuclei may explain an earlier GZK cutoff and the observed nearby inhomogeneity (figure adapted from [4]).

Figure 2. Energy losses and lightest nuclei ranges (adapted from [7]): beryllium, helium and boron are among the lightest nuclei that suffer a more drastic cutoff (see figure above) bounding them at nearest cosmic volumes. This may better explain their allowed arrival from Cen-A (4 Mpc), their collimation a few degrees from the source and the apparent absence from more distant Virgo (16 Mpc). Three events from Fornax may still reconcile with heavier (C, O) nuclei. A single bent event from Virgo may be present in large galactic latitude.
and interpretation with AGN at 80 Mpc in far SG volumes. The red oval clustering overlap with SG plane led to a possible bent by random galactic fields and by different nuclei composition. within the red oval. They could be the spread signals by UHECR position is marked by the arrow, while the ten events around are vertical spread (in galactic coordinate) took place, as shown (in this way explaining the early energy GZK steepness). The GZK cutoff makes them bounded in their local source nearby the nearest distance and by light nuclei courier, whose small by nearby source Cen-A: its shine (as observed) comes from Our solution foresees that the UHECR near the Earth are ruled 2. Testing the present solution

Figure 3. UHECR event in the nearest (redshift z > 0.01) local universe map shows the Virgo cluster absence, though Fornax cluster is mildly observable owing to few events. This contradicting argument has been well underlined recently [5]. The Cen-A position is marked by the arrow, while the ten events around are within the red oval. They could be the spread signals by UHECR bent by random galactic fields and by different nuclei composition. The red oval clustering overlap with SG plane led to a possible mis-interpretation with AGN at 80 Mpc in far SG volumes.

Figure 4. Radio polarization (2.4 GHz), observed by Wmap over the UHECR AUGER events: the polarization is due to interstellar charges and galactic magnetic lines. These signatures imply spiral magnetic line morphology (see figure 5). These lines also would lead to UHECR deflections orthogonal to the galactic disk for charged nuclei emitted by Cen-A.

in figure 3) of the UHECR around Cen-A. Most heavy iron nuclei are widely spread: δ²⁶Fe ≥ 33.8° or δ²³⁰Fe ≥ 95°, losing most of the arrival–source link. The absence of diffused events disfavors such a composition, contrary to [1] iron–proton hybrid composition assumption. At lower energies, the bending of heavy nuclei pollutes and spreads homogeneously the UHECR (ten or a few tens of EeV) map. Therefore, just a few light nuclei may spread the main clustering group (almost a dozen) around Cen-A. We do not consider here the less relevant extragalactic magnetic bending, because our main proposal leads to a very local source volume, mostly ruled out by nearby last galactic deflections.

above, because of the disk’s horizontal spiral magnetic lines (figures 4 and 5). Incidentally, this axis overlaps part of the SG plane, leading to some confusion. The UHECR at 60 EeV are dominated neither by protons nor by iron whose larger ranges would naturally offer a clearer trace of nearby (Virgo) or a little more far Universe. AUGER present UHECR events, we believe, are blazed by light nuclei, or even the lightest ones, probably secondaries of heavier ones. The fragmentation (or even the inner AGN jet nucleo-synthesis) occurs possibly by photon-dissociation taking place near the AGN jet source via self-light interactions. At 40 EeV, the heavy nuclei and protons may still be present and pollute the Universe isotropically at tens of EeV spectra, traveling from wider Universe volumes. At higher energy, above 60 EeV, we believe mostly or just light or even lightest nuclei may arrive. The nearly on-axis event from Cen-A (2–5°) is (probably) the imprint of the lightest ones (He), whereas the more spread events at larger angles (8–10°) may be the secondaries (Be and B), whose propagation range is, nevertheless, much more bounded than the proton or iron one, best explaining the missing Virgo. Consequently, we foresee the crowding of future events in a cluster vertically around the Cen-A source, it being the real barycenter of the UHECR spread group, and no longer the far away SG plane. This model explains the lack of Virgo (whose signal might nevertheless rise soon): indeed a single event not far from Virgo could be a very deflected Be, B one or rare C, O nuclei. The model agrees with a modest signal of the Fornax cluster. The rarest single iron UHECR or protons, but even better C, O nuclei, may be responsible for a few remaining spread events. The very rare overlapping doublet below the galactic disk may be related to a nearby source. The consequent signature of our proposal, compatible with the one offered just recently [8], is that events at the extreme random angles (δsm ≥ 8–10°) far from Cen-A must share a heavier composition than the more collimated ones (δsm ≃ 2–5°), being lighter (for comparable energy). This must be manifest by their airshower elongation value: ln A₁₆ ≤ 1.38, ln A₂₂ ≤ 2.2 and ln A₂₃ = 2.38; as we mentioned, we also consider eventually ln AC = 2.485 and ln AO = 2.77. These values conform well with the AUGER claim at 40 EeV of a dominant heavy nuclei composition (ln A = 2.6 ± 0.6).
These values differ drastically from $\ln A_p = 0$ for proton or $\ln A_{Fe} = 4$ implied by the claim of [2] and they might be soon tested in the UHECR length trace (slant depth) observed at best in fluorescence detectors (FD). Also, the most deflected events from Cen-A (at the same energy range) should exhibit richer muon composition in surface detectors (SD) than the less deflected ones in axis to Cen-A.

3. Conclusions

The AUGER discovery of UHECR anisotropy has been a great achievement, that needs a longer time record. Its interpretation was probably hurried up and confusing because of an accidental coincidence between the SG contour and the galactic Lorentz force bending of light nuclei. If the AUGER interpretation ($R_{GZK} \simeq 80$ Mpc range) is true, then the expected UHE neutrino secondaries’ fluency (from observed UHECR energy fluency $\phi_{UHECR_{GZK}} \simeq 1$ eV cm$^{-2}$ s$^{-1}$ sr$^{-1}$) extended to the whole Universe’s size ($R_{Hubble} \simeq 4$ Gpc range) would have already reached detectable values: indeed the secondary $\phi_\nu$ energy fluency approximates to

$$\phi_\nu + \phi_{\bar{\nu}} \simeq \frac{1}{6} \phi_{UHECR_{GZK}} \left( \frac{R_{Hubble}}{R_{GZK}} \right)^3,$$

$$\phi_\nu + \phi_{\bar{\nu}} \simeq 60 \text{ eV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}.$$ 

This value enhanced by the redshift power factor might imply a fluency at the edge (or above) of the AUGER bound [9, 10]. Also some EeVs gamma showers from the SG plane might already be clustering and might have been recorded by AUGER. Our proposal is somehow of minor impact for neutrino astronomy, offering a lower GZK rate, but it clarifies the role of the lightest nuclei in nearby UHECR astronomy (mostly from our main Cen-A source). The consequence in UHECR neutrino astronomy is nevertheless relevant: Cen-A might soon become a major UHE neutrino source to be observed (with some difficulties, depending on the exact source of photo-pion and photo dissociation) by the AUGER future records via horizontal air showers [9, 10], induced by EeV UHE $\nu_\tau$, via their secondary $\tau$ decay in air, and by their final horizontal air shower, as well as by Magic telescope [11], looking for such skimming blazing $\nu$ air showers at horizon edges. Because of the lower UHE neutrino secondaries’ energy expected from the lightest nuclei dissociation, the UHE tau air showers will be better revealed at tens to hundred PeV range in AMIGA smaller sized array detector and/or by high-elevation telescopes (HEAT) to be deployed in future AUGER inner (Coihueco) enhanced area [12].

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References

[1] Pierre Auger Collaboration 2007 Science 318 939–43 (Preprint 0711.2256)
[2] Pierre Auger Collaboration 2007 Preprint 0712.2843
[3] Sokolsky P 2007 (Hires Collaboration) Preprint 0706.1248
[4] Dermer C 2007 ICRC07 (Preprint 0711.2804v2)
[5] Gorbunov D, Tinyakov P, Tkachev I and Troitsky S 2007 Preprint 0711.4060v1
[6] Staney T et al 1995 Phys. Rev. Lett. 75 3056–9
[7] Hooper D, Sarkar S and Taylor A M 2007 Astropart. Phys. 27 199–212
[8] Wibig T and Wolfendale A W 2007 Preprint 0712.3403v1
[9] Pierre Auger Collaboration 2007 Preprint 0712.1909v1
[10] Fargion D et al 2008 JHEP Conf. Ser. 110 062008 (Preprint 0711.2326)
[11] Fargion D 2007 Frascati Phys. Ser. XLV 289–97 (Preprint 0708.3645)
[12] Fargion D et al 2004 Astrophys. J. 613 1285–301
[13] Fargion D 2002 Astrophys. J. 570 909–25
[14] Fargion D et al 2007 Preprint 0710.3805, 0711.2326
[15] Fargion D 2006 Prog. Par.-Nucl. Phys. 57 384
[16] Etchegoyen A (Pierre Auger Collaboration) Preprint 0710.1646v1