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UHECR multiplets versus Hot spots clustering in Auger sky: the forgotten signals

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Two main UHECR hotspots have been found in the Auger sky, clustering towards NGC253 and CenA, our nearby AGN sources: their presence is still controversial, as well as the additional AUGER dipole at ten Eev. A first data (2009-2012) sample in Auger was related to three chains of multiplets with energy of tens of EeV, clustered around the more energetic UHECR clusters. These multiplet trails, nearly a dozen of events each, were pointing to the main well-defined directions in the sky: Cen A and NGC 253. These secondaries signals, probably fragments of high-energy UHECR primaries, have been forgotten or neglected. Such additional information, in our opinion, is capable of accurately disentangle and confirm the nature of the UHECR candidate hot spot sources. For different reasons UHECR are imagined mostly located in our nearby (one or few Mpcs) Local Group universe.

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1. Introduction:UHECR and the Virgo missing

Cosmic rays are a century old puzzle in physics. We do not know, a priori, either where they come from, or who their main sources are, or what their nuclear nature is, or what are the accelerating processes capable of ejecting them as Cosmic Rays at such extreme Ultra High Energy (E > EeV edges). This confusion is mainly due to the fact that CR charges get smeared by the cosmic magnetic fields bending.

We may remind that the same CR smeared puzzle is somehow related to persistent galactic or magnetic fields along galactic or cosmic distances and to the connected misterious absence in our Universe of magnetic monopoles. UHECRs, above few or tens EeV energies, being so energetic, have been expected, for decades, to fly almost straight on, retaining finally memory of their sources in the sky. Offering a new UHECR Astronomy. Nevertheless UHECR might be suffering of a partial bending: their arrival could lead both to a wide clustering or to a narrow spot in sky possibly correlated with their original sources. The UHECR energy, its composition and the Galactic and Cosmic magnetic fields bending are therefore, the main parameters that rule the understanding of any UHECR Astronomy. Highets energy photons are constrained by photon-photon pair production altready at tens TeV or even at PeV energy, bounded at hundred Kiloparsec radius. There is also an additional parameter on UHECR trajectory: a proton above 60 EeV, while flying along hundred Mpc, interact with cosmic relic photons, leading, by photo-pion interactions, to the Delta resonance. Therefore they are bounded both in energy and in distances. Less than a hundred Mpc or $1-3\%$ of the whole Universe radius. Less than a millionth volume of the cosmos.

Other UHECR nuclei may behave differently with the cosmic relic photons, leading to different signatures and cut-off. The proton UHECR opacity, as we just mentioned, was foreseen as soon as the Black Body Spectra was discovered, on early 1966. The consequent typical cut-off (the so called GZK one) above 60 EeV energy had been suggested and searched. This cut-off had been surprisingly not observed by earliest and smaller size, Fly's Eye or AGASA, array detectors, on early $1990-2000$ years. Nevertheless later on, larger arrays, as Hires, AUGER and Telescope Array confirmed an UHECR cut off, almost comparable with a proton expected one. Therefore such a GZK cut off discover had convinced most authors to believe that UHECR were mainly protons. In this nuleon currier models the bending is minimal (due to the proton single charge), and the expected clustering had to be quite sharp; nearly one or a few degrees at hundred EeV energy. Within such a nearest GZK sky, Virgo cluster (thousands of galaxy at 20 Mpc), was expected to shine as the brightest, narrow, spot in UHECR sources. Indeed all infrared galaxies are shining at best toward toward this Virgo cluster. But Virgo was and is absent.

Indeed AUGER, largest, 3500 km square, array detector, revealed a first clustering in the South sky, on late 2007 . It was not showing any sharp (few degrees) cluster in the sky, as proton should do, toward Virgo. The AUGER revealed a quite mild spread (ten-twenty degrees) group of events, a first "hot spot" cluster, toward an unique AGN (a nearest one) source: Cen A: a natural nearest candidate source. Additional clustering events observed by TA were also forming a large hot spot (twenty degree) cluster toward an additional, North sky, nearest AGN (Star Burst Galaxy): M82.

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2. Virgo Absence and the Lightest nuclei

However the Virgo Cluster (the nearest, 20 Mps , best population candidate), was the key missing presence. This absence, in our view, was and remains the main key mistery: a message survived in all UHECR last records.

On the other side, there was also a remarkable tendency, (noted mainly by A. Watson at Auger group) [1], in UHECR airshowering composition due to their average slanth depth evolution with the increase of their energy, from EeVs to tens EeVs ones. The imprint was pointing, above ten EeV, from a proton main composition to the rise and the rule of a new lightest (or light) nuclei, (not iron nor proton one).

These two discoveries, lightest nuclei and Virgo absence, in the maps and UHECR spectra, were forcing us to suggest that UHECR above a few tens EeV, were ruled, not longer by proton (or by light or heavy nuclei), but, mainly, by lightest (fragile) ones, as D, He, Li, Be. Indeed, because lightest nuclei fragility, their flight from Virgo will be severely filtered and bounded. Within a much severe distances than GZK size. A processes, photo-nuclear distruption, able to contain , such lightest He-like UHECR, in a very short (one-two Mpc) Universe size. This explained at once the mysterious Virgo absence both in the AUGER or TA sky. These lightest, He (or D,Li, Be) charges , also explained their wider spot (than proton ones) spread at ten or two tens degree.

Moreover, we noted, that Cen A and M82, (as well as a more recent discovered third Hot Spot, around NGC253, in AUGER sky), being above $2 - 3$ Mpc distances, had anyway to suffer of a partial photo-nuclear-distruption during their distant flight. These distruption and their fragment secondaries, had also to be located along the main harder UHECR events chain of traces in their parental hot spots. These consequences, the fragment trail, were foreseen on early 2009 [2] , as a possible chain of lower energetic UHECR nearby Cen A source.

Soon later data (2010-2012) AUGER collaboration discovered [3], such fragment clustering, three chains of multiplets, nearly a dozen events each, at energy of $(10 - 20$, EeV). These multiplets were pointing (by their energy chain tails) to the main AUGER hot spot, Cen A, in the sky. The multiplets bending indeed were aligned with their growing energy, because of the magnetic field Larmor radiuses, with growing energy. The coherent bending with energy, converged to a main source: Cen A : but also, surprisingly, toward the second brightes and nearest AGN , NGC 253. See Fig.1. We underline the importance of their correlation both with their main, central, CenA (the two converging multiplets), as well as toward the more recent hot spot, NGC 253 (a third multiplet). These signals (at $15 - 20$ EeV) , since a decade, have been somehow "forgotten" or unnoticed. Such fragments,therefore could be able to pinpoint and confirm their common hot spot parental origin. Such sources are located in a billionth of our Universe volume: our very Local Group (Mpcs) sky. Their presence overlap on AUGER recent UHECR maps as in Fig.3.

2.1 Multiplet probability to converge on CenA and NGC 253 sources

The multiplet chain trails are pointing and ending as shown by mark + .The solid angle of each of the three small disk (a circle toward CenA, of a disk of radius about $7^o - 8^o$, one twin ellipse of comparable areas, toward NGC253) is below or near of 1% of the whole AUGER observable sky: therefore the probability $P_{2\ Cen_A}$ to have at least twice a clustering toward Cen A, the choosen source a priopri, within three trials , following binomial distribution, is: $P_{2\ Cen_A} = 3 \cdot 10^{-4}$.

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The presence of a second clustering into the second hot spot in the AUGER sky, became evident not on early 2007, but much later. On 2015 we noticed the possible role of NGC 253 as the source of the new, growing or clustering, hot spot in the south AUGER sky. Therefore the three multiplets clustering along the two known (in AUGER) hot spots, considering their whole area in solid angle (nearly 2% of the whole sky) is: $P_{3\ Cen_A} = 8 \cdot 10^{-6}$. Assuming a wider disk areas, by a factor B, ($B > 1$, to better include the source and the multiplet edge), the results will scale and reduce, respect to the previous ones , as follows:$P_{2\ Cen_A} = 3 \cdot B^2 \cdot 10^{-4}$, $P_{3\ Cen_A} = 8 \cdot B^3 \cdot 10^{-6}$. For example , for B=1.5 , disk radius about 10 degrees, the corresponding probability reduces to: $P_{2\ Cen_A} = 6.75 \cdot 10^{-4}$, $P_{3\ Cen_A} = 2.7 \cdot 10^{-5}$.

Naturally we had not noticed, in early 2009 the NGC253 as a possible UHECR source, and we didn't foresee this third clustering. However, even a posteriori, this third additional correlated result is quite a remarkable one. The role of such multiplets pointing to their main sources, Cen A and NGC 253, may be an additional tool in discovering the UHECR origin.

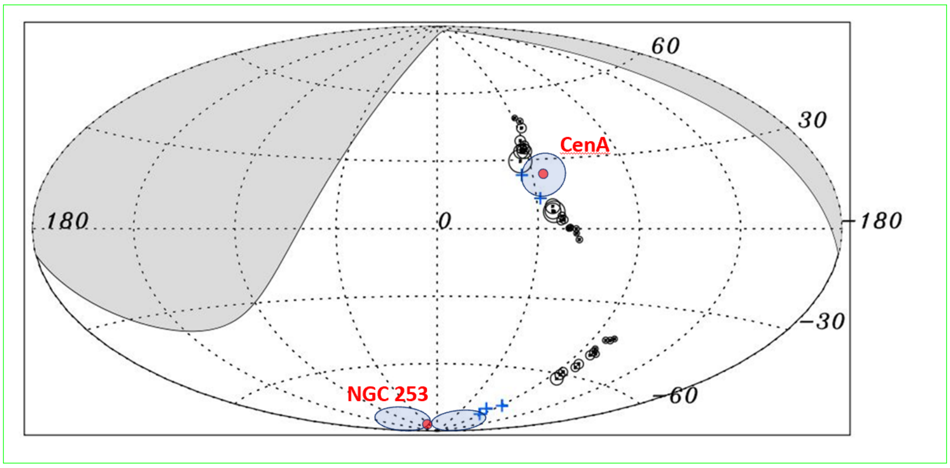

Figure 1: Observed multiplets with 10 or more events in galactic coordinates. The size of the circles is proportional to the energy of the event. Blue plus "+", signs indicate the final locations of a potential sources for each multiplet as indicated by the AUGER team in 2012 [3]. In red the names corresponding to the AGN or Star burst sources attributable to the same source as marked on the figure, above Cen A, below, NGC253. The solid line represents the border of the field of view of the Southern Observatory for zenith angles smaller than 60° and the grey shaded area is the region outside the field of view. The Auger sky area is nearly two third of the whole sky.

3. UHECR and the Dipole Anisotropy

The remarkable large AUGER dipole anisotropy may find a first understanding by the same NGC 253 main role in UHECR clustering in South Pole sky. Indeed the same multiplets toward NGC 253 , shown in figure 3, are able , in principle, to pollute the main power energy component of the dipole. Also Local sources , as LMC, SMC, or even Crab and Vela, might be able to add polluted EeV energy components. Anyway there is not any reasonable way to reach such a large AUGER EeV dipole anisotropy (6 – 7%) by any kinematic motion , as for our known cosmic dipole

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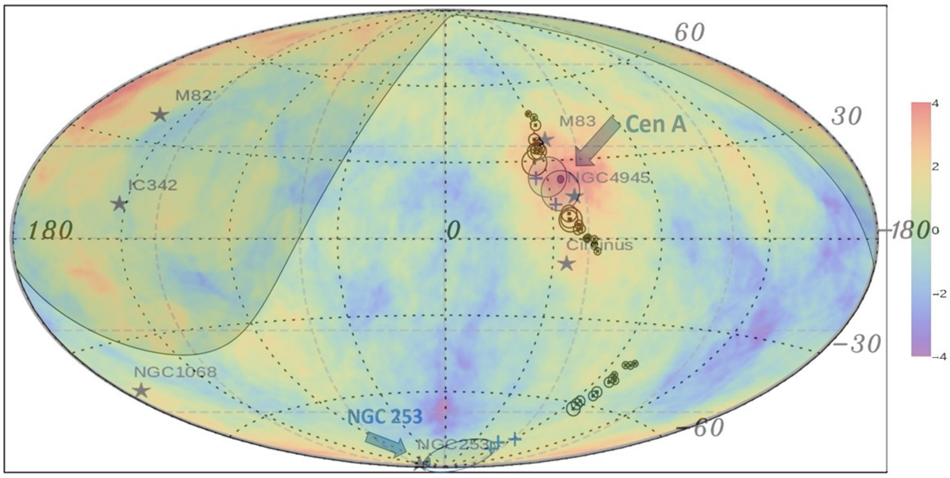

Figure 2: As above,the solid line represents the border of the field of view of the Southern Observatory for zenith angles smaller than 60° and the grey shaded area is the region outside the field of view. Note that the eventual clustering of UHECR fragments toward M82 (North sky), its eventual multiplets have not been known or published, and consequently we will not consider it here.

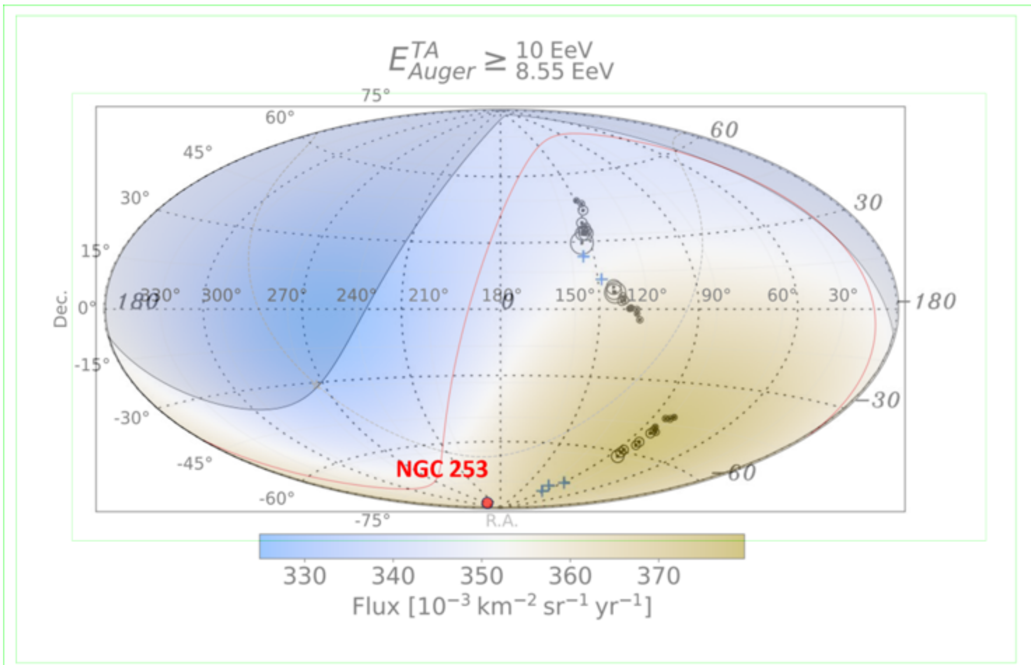

Figure 3: The Dipole anisotropy for the most recent TA and AUGER map [4], overlapped by the NGC multiplets about ten EeV energy. The chain of deflected UHECR events from NGC 253 might be the main feeding ones of the central UHECR dipole anisotropy. Additional local sources (LMC, SMC, Crab, Vela, or galactic ones) may also be partially a present contribute to such a large EeV dipole anisotropy.

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Doppler signature at (0.2%) level. Such a large UHECR dipole, nealy 30 times larger than the cosmic (kinematic) one, the absence of any large galaxy cluster in that anisotropy direction, is a key test of the local UHECR origination, (as by NGC 253) source. The absence of any large galactic plane at $40 - 60$ EeV energies, imply that the UHECR ejection are short life events, and their local memory as well as the shorth distance from the episodic event, is more relevant than any other persistent mass distribution clustering .

4. The UHECR Composition along EeV-ZeV energies : from light nuclei to protons and later, lightest, light, heavy nuclei

In recent years the UHECR composition, evolving with the energy increase, had shown a behavior summirized as follows: from a dominant, light nuclei, at EeV energy toward a proton dominated one at ten EeV. However, at few tens EeV, once again UHECR , are made by lightest nuclei up or near $30 - 60$ EeV. At higher energies, > 60 EeV, UHECR light or even heavy nuclei rise their role, ruling at $70- > 100$ EeV energy edges. These changes may explain the complex evolution in UHECR clustering [5, 6]. The absence of proton at UHECR at 40 EeV, explain the absence of narrow angle hot spot clustering, and justify the mysterious missing of Virgo. The presence of lightest nuclei imply also a very narrow cut off, (2-3 Mpc), much near than any hundred Mpc GZK one; the consequence is an opacity of Virgo, as well as a wider hot spot clustering angle. The UHECR fragmentation in multiplets ,forseen for lightest nuclei before the observations, toward two main AGN sources is an obvious confirm of this scenario. The presence at edge energies of heavy (like Ni, Co, Fe) nuclei, might explain , by their largest bending, (originated mostly within our galaxy), bending able to smear and uncorrelate UHECR -to their sources events, possibly in correlation with tens TeV anisotropy sky [7] [5].

5. Conclusions

The missing of Virgo, the fragments of Cen A UHECR, were inspiring the lightest nuclei UHECR model [8], [2], [9], [3]. These first candidate sources, as well as NGC 253, have been discussed since 2015 [10], [11]. In particular we noted the growing signals around , LMC, SMC and Crab in nearby sky, possibly explained, (now, also or mainly) by NGC 253 multiplets, that are feeding the low energy dipole Auger anisotropy [5]. There is, nevertheless, still much attention and suggestions for a far (> hundred Mpc) UHECR candidature. We noticed that the AGN time-limited life is uncorrelated with such far sources [12]. There are, however, some additional minor clustering finding an answer to some different,(early and very speculative) proposal [13]. Indeed the extreme powerful gamma source, 3C 454, shows such a minor clustering of UHECR. The role of such 3C 454 clustering may be relevant only if the narrow clustering will be more enhanced with more data. The 3C 454 is too far in GZK distance unity to be explained via any directional UHECR nuclear event. It can be, therefore, an UHECR secondary source created by an UHE neutrino courier: an eventual UHE ZeV neutrino signal, whose hitting and scattering onto the relic cosmic neutrino background, with a tiny mass, in a hot wide halo [13], is leading to the Z boson resonance, whose decay is finally capable to feed UHECR nucleon (nucleons and anti nucleons) from 3C 454, signals that are hitting the Earth, leading to the observed UHECR. Such relic cosmic neutrinos might be possibly,

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in a mass range of 1.6 eV mass, as the most recent candidate sterile; or common ones (lighter, at $0.4 - 0.1$ eV mass). If in future, their discovery , their masses and flavors[14, 15] will verified in this spectacular way, it will be the most revolutionary test able to verify at once cosmology, astrophysics and particle physics. In conclusion, two major UHECR hotspots have been found in the Auger sky, clustering towards NGC253 and CenA, our nearby AGN or star burst sources: AUGER found three chains of multiplets secondaries (energy of tens of EeV). These multiplets, nearly a dozen events each, pointed to both the well-defined directions (the Hot Spot) in the sky. These multiplets, in our opinion, favor the lightest nuclei model, the Local Group UHECR origination, as well as the main role of NGC 253 in feeding also the AUGER remarkable large, dipole anisotropy.

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