The meaning of the UHECR Hot Spots

A Light Nuclei Nearby Astronomy

Daniele Fargion\textsuperscript{1,2,}a, Graziano Ucci\textsuperscript{3}, Pietro Oliva\textsuperscript{4}, and Pier Giorgio De Santis Lucentini\textsuperscript{4}

\textsuperscript{1}Physics Depart., Rome University 1, Sapienza, Ple. A. Moro 2, 00185, Rome, Italy
\textsuperscript{2}INFN, Ple. A. Moro 2, 00185, Rome, Italy
\textsuperscript{3}Engin. Depart., Niccolò Cusano University, Via Don Carlo Gnocchi 3, 00166 Rome, Italy
\textsuperscript{4}GUBKIN Uni. of Oil and Gas, Leninsky prospekt 65, Moscow, Russia.

e-mail: daniele.fargion@roma1.infn.it

Abstract. In this paper we review all the up-to-date Ultra High Energy Cosmic Rays (UHECR) events reported by AUGER, by Telescope Array (TA) and by AGASA in common coordinate maps. We also confirm our earliest (2008-2013) model, where UHECR are mostly made by light nuclei (namely He, Be, B), which explains the Virgo absence and confirms M82 as the main source for North TA Hot Spot. Many more sources, such as NGC253 and several galactic ones, are possible candidates for most of the 376 UHECR events. Several correlated map, already considered in recent years, are then reported to show all the events, with their statistical correlation values.

1 Introduction

On November 2007, AUGER \textsuperscript{1} reported, within 27 events, a rare clustering of UHECR events centered around Cen-A with a spread within $\pm 15^\circ$: a first south Hot Spot anisotropy. The later 2011 data (69 UHECR events, as well as the additional train of dozens of twin events at 20 EeV \textsuperscript{2,5}) confirmed such as UHECR Hot Spot, thus strengthening the nuclei-like (not the proton-like) UHECR composition supposition \textsuperscript{4}. Since 2011, neither the Virgo Cluster nor any Super-Galactic anisotropy (as it has been first assumed to be detectable under the UHECR protons composition assumption) were in fact detected by AUGER. On the other side, Telescope Array (TA) did found, in last few months, a comparable remarkable anisotropy (a north Hot Spot, also spread within $\pm 15^\circ$) pointing to an uncorrelated and unexpected Sky. Therefore, up to now we must take care mostly of two Hot Spots in Northern and Southern Sky. Moreover and once again unnoticed, the Virgo cluster - better viewed from TA skies - did not rise at all, even in TA data, where one would expect it to rise if, as TA claims, UHECR were protons. To make more contradictory this race in discovering UHECR Astronomy, we remind that since 2007 AUGER favored an iron composition, while TA always sticked on protons. Eventually, the very last events by TA (72 + 15 events) and the deeper and final AUGER records (231 events in the 2004-2014 period) \textsuperscript{3} offer an unique opportunity to combine their maps and test eventual sky correlations though AUGER disclaimed any possible relevant connection, out of the Cen-A Hot Spot. The AUGER and TA maps are often in a not-comparable map projections. Here we did combine both of those published (and for TA in-press) events in a known and useful coordinate system. We shall discuss and weight the clustering along these maps overlapping on different ones. We remind that we suggested, since very early 2008 \textsuperscript{4} (see also \textsuperscript{5}), that AUGER puzzle (anisotropy size and Virgo Absence) could find a solution if UHECR were mostly lightest nuclei, like helium. Such composition would indeed explain the spread angle of UHECR by random bending them along galactic fields ruling out the unique Hot Spot due to our nearest AGN: Cen-A. Moreover, the He-like nuclei are fragile by photo-nuclear dissociation by Cosmic Microwave Background: they cannot flight large GZK distances as proton do (50 – 80 Mpc), but they can fill a few smaller Universe size (3 – 4 Mpc). Because of this Cen-A could shine, Virgo could not. Lightest UHECR nuclei may also explain, we argued then and now, the remarkable earliest AUGER and recent TA result, the Virgo absence, by lightest fragility and opacity: in the same model the TA Hot Spot on North Sky must be originated by a very nearby source. Ursa Major Cluster or Virgo are too far, but a closer source such as M82 star-bust galaxy can survive the flight.

The so-called TA Hot Spot (about dozen of events) is not centered onto M82, but it is coherently bent by (15 – 20$^\circ$) in nearby North Galactic fields (see fig.\textsuperscript{2,5} and fig.\textsuperscript{14,15}). However, we recognize in the same bending tail a much near, narrower and very recent (this year) 5 event clustering, confirming such a probable coherent bending of UHECR light nuclei from M82. Such a quintuplet cluster within 100 square degree has a probability $< 10^{-3}$ to occur by chance. Moreover the oldest UHECR AGASA record on North sky (58 events) did show an unique triplet almost overlapping, making the chance prob-
ability to find such a clustering for 8 events within 150-200 square degree, as low as \((1 \div 4) \cdot 10^{-4}\). We will reconfi-
rm then that Cen-A, M82 and a few galactic sources like Vela, Cygnus X3 and SS433, could eject light or heavier UHECR nuclei, possibly radioactive ones, bent by large local magnetic fields. We were inspired by early preliminary UHECR correlation with TeV anisotropy maps discovered in the last decade by Milagro, ARGO and now by Hawk and ICECUBE in these very recent years. We claim again that such TeV-UHECR correlation might be due to the UHECR fragment nuclei by radioactive decay in flight and/or by UHECR lightest nuclei secondaries photodissociation while coming to us. We note a new interesting clustering along South Galactic Pole pointing to the main nearby star-burst galaxy NGC 253, a similar M82 object, once again within 3 Mpc distance.

1.1 Cen-A, M82 and NGC 253 as the main extragalactic UHECR sources

UHECR are clustering both within South (AUGER) and North (TA) sky in wide \(\pm 15^\circ\) Hot Spots. The nearest Galactic Cluster, Virgo, within the expected GZK opacity distance for proton (related to the apparently observed GZK cut off observed spectra by Hires, AUGER and TA) is absent and its absence is remarkable in particular in recent TA data as well as in last 231 AUGER events. The Virgo clustering absence do not fit with UHECR as nu-
cleon. The same \(\pm 15^\circ\) Hot Spot clustering cannot fix with an extra-galactic heavy nucleus composition (Fe, Ni) be-
because of their much larger charge and wider deflection an-
gle (above 90\(^\circ\)). However lightest UHECR nuclei, namely or mostly He, are fragile enough to be absorbed and hidden soon by photo-dissociation on cosmic radiation on their way from Virgo (20 Mpc) to us, thus explaining their absence. On the contrary AUGER clustering around the near-
est active AGN Cen-A (3.5 Mpc), may be caused by the random *incoherent* bending of light He nuclei along the galactic magnetic fields; Virgo missing in TA data is ex-
plained again by the UHECR He opacity. The TA Hot Spot clustering could be ejected by star-burst M82 (3.5 Mpc) as the main source, while UHECR are bent and spread by a *coherent* magnetic field either galactic at North Pole or/and extra-galactic. We want to underline here the clustering of 5 UHECR TA events nearer M82, since it might be a first UHECR trace around this main source. Such very narrow (5 events) spot almost overlap an older one: a triplet observed by AGASA in 1990-2000. The binomial probability to find 4+1 of such events inside a narrow area of \(10^2\) square degrees, within 87 TA signals, is \(< 8.2 \cdot 10^{-4}\), even ignoring the AGASA triplet. Considering also the ad-
ditional 58 AGASA events and a triplet clustering within 150\(^\circ\), the probability shrinks to \(< 10^{-4}\). These quintuplet sig-
nals are additional to the remaining (more deflected) He-
like nuclei found in wider TA hot spot (21 events within 87 in nearly 2000 square degree sky), whose probability to occur by chance is as low as \(< 2 \cdot 10^{-3}\) but their cluster-
ing is more diluted and far from M82. Additional traces might be gamma secondaries of these UHECR He photo-
dissociation in flight (or radioactive decay in flight as for He\(^6\) isotope or Be\(^7\) or more abundant and deflected Al\(^26\)) that might also paint and trace, by boosted Lorentz factor, part of these gamma anisotropy at TeV maps discovered by Milagro, ARGO, HAWK and ICECUBE. Few UHECR sources might be also galactic as the very recent multi-
plet (8 events) along Vela shows also Cygnus X3 clustering raised as a peculiar narrow multiplet as well as a much more narrow clustering event (around SS433 or Aq1) and possibly spread sources along Magellanic stream regions (LMC and SMC, or NGC 253, a second near -
3.5 Mpc - star-burst source and/or Fornax Dwarf Galaxy source), see fig. [14][15].

1.2 Bending for He UHECR and fragments at 20 EeV along Cen-A

Let us make a short remind on why choosing He-like composition: the old 2011 UHECR multiplet clustering foreseen on 2009 ([5]) and observed in 2011 ([2]) and forgot in most report by AUGER UHECR at 20 EeV energy contains just three apparently isolated trains of events which point to unknown sources (see old 69 events on IR map, see fig. [1]). However, the crowding of the two train multiplet tail fix inside a very narrow disk area focused about the Cen-A UHECR source, the fact being remarkable ([11]).

As it has been foreseen. If UHECR are made by protons (as some AUGER and TA authors believe), they will not naturally explain such a tail structure because these events do not cluster more than a few degrees, unlike the observed UHECR and the associated multiplet. He-like UHECR fit the AUGER composition traces as well as the HIRES and TA ones. The He secondaries split in half (or in fourths) as it has been foreseen recently ([11]). Indeed, the dotted circle around Cen-A containing two (of three) multiplets by a radius as small as 7° extends in an area that is as small as 200 square degrees, below or near 1% of the AUGER observation sky. The probability that two out of three sources fall inside this foreseen small area is by binomial distribution ℓ= 3 · 10⁻⁴. Moreover the same twin tail of the events is aligned almost exactly ±0.1 rad along the UHECR train of events toward Cen-A. Therefore the UHECR multiplet alignment at 20 EeV has a probability as low as P(3, 2) ≈ 3 · 10⁻⁵ of following an a priori foreseen signature ([5], [7] and [11]).

The incoherent random angle bending along the galactic plane and arms δm, while crossing along the whole Galactic disk (L = 20 kpc) in different, alternating, spiral arm fields and within a characteristic coherent length ℓc ≈ 2 kpc for He nuclei is

\[ \delta_{m-He} \approx 16° \frac{Z}{Z_{He}} \left( \frac{6 \cdot 10^{19} \text{eV}}{E_{CR}} \right) \left( \frac{B}{3 \mu G} \right) \sqrt{\frac{L}{20 \text{kpc}}} \sqrt{\frac{\ell_c}{2 \text{kpc}}} \]

The heavier (but still light) nuclei bounded from Virgo might also be Li and Be:

\[ \delta_{m-Be} \approx 32° \frac{Z}{Z_{Be}} \left( \frac{6 \cdot 10^{19} \text{eV}}{E_{CR}} \right) \left( \frac{B}{3 \mu G} \right) \sqrt{\frac{L}{20 \text{kpc}}} \sqrt{\frac{\ell_c}{2 \text{kpc}}} \]

It should be noted that the present anisotropy above GZK ([9]) energy 5.5 · 10¹⁹ eV (if extra-galactic) might leave a tail of signals: indeed the photo disruption of He into deuterium, tritium, He³ and protons (and unstable neutrons), arising as clustered events at a half or a quarter (for the last stable proton fragment) of the energy: protons being with a quarter of the energy but a half of the charge of the He parent may form a tail smeared around Cen-A at a twice larger angle ([5], [7] and [11]). We suggested looking for correlated tails of events, possibly in strings at relatively low energy ∼ (1.5 ÷ 3) · 10¹⁹ eV along the Cen-A train of events. It should be noted that deuterium fragments have one half of the energy and mass of helium: therefore D and He spot are bent in the same way and overlap into UHECR circle clusters ([11]). Deuterium is even more bounded in a very local Universe because of its fragility. In conclusion, He like UHECR may be bent by a characteristic angle as large as δm-He ≈ 16°; its expected lower energy deuterium or proton fragments at half energy (30 – 25 EeV) are also
within the observed Cen-A UHECR multiplet [2].

The hint of the Al\(^{57}\) we have noted first hint of a galactic source arising as radioactive UHECR triplet [7]. The arrival tracks of these UHECR radioactive heavy nuclei may be widely deflected accordingly at \(\delta_{\text{cm-p}} \approx 16^\circ\); the last traces of protons at a quarter of the UHECR energy, around 20 EeV energy, will be bent and spread within \(\delta_{\text{cm-p}} \approx 32^\circ\), exactly within the observed Cen-A UHECR multiplet [2].

2 TeV Gamma and UHECR

In recent updated UHECR AUGER-TA maps (fig.2, 3, 4, 5) we have noted first hint of a galactic source arising as a UHECR triplet [2]. The hint of the Al\(^{57}\) gamma map traced by Comptel somehow overlapping with UHECR events at 1-3 MeV, favors a role of UHECR radioactive elements (Al\(^{57}\)). The most prominent radioactive nuclei are the Ni\(^{56}\), Ni\(^{57}\), Co\(^{56}\) and Co\(^{56}\), made by Supernova (SN) and possibly by their collimated GRB micro-jet components, ejecta in our own galaxy. Similar radioactive traces may arise by UHECR scattering on dense gas clouds. Indeed in all SN Ia models, the decay chain Ni\(^{56}\) \(\rightarrow\) Co\(^{56}\) \(\rightarrow\) Fe\(^{56}\) provides the primary source of energy that powers the supernova optical display even days and weeks later the explosion. Ni\(^{56}\) decays by electron capture and the daughter Co\(^{56}\) emits gamma rays by the nuclear de-excitation process; the two characteristic gamma lines are at \(E_\gamma = 158\) keV and \(E_\gamma = 812\) keV respectively.

Their half lifetimes are spread from 35.6 hours for Ni\(^{57}\) to 6.07 days for Ni\(^{56}\). However there are also more unstable radioactive rates, as happens to be for Ni\(^{55}\) nuclei whose half life is just 0.212 s or Ni\(^{57}\), whose decay is 21 s. Therefore we may have an apparent UHECR, boosted by a factor \(\Gamma_{\text{Ni}^{56}} \approx 10^9\), lifetime spread from 2.12 \(\cdot\) \(10^8\) s or 6.7 years (for Ni\(^{55}\)) up to nearly 670 years (for Ni\(^{57}\)), or even 4 million years for Ni\(^{57}\). EeV and PeV radioactive UHECR or their fragment may also play role in gamma and neutrino emission (see UHECR events as in figs.5, 6, 7) with different Fermi, IR, radio maps, figs.8, 9, 15, for gamma TeV-UHECR correlation and in particular see figs.8, 9, 15, in the TeV gamma background). This consequence wide range of lifetimes guarantees a long life activity on the UHECR radioactive traces. The arrival tracks of these UHECR radioactive heavy nuclei may be widely bent, as shown below, by galactic magnetic fields. Among the excited nuclei to mention for the UHECR-TeV connection there is Co\(^{60}\) whose half life is 10.1 min and whose decay gamma line is at 59 keV. At a boosted nominal Lorentz factor \(\Gamma_{\text{Co}^{60}} \approx 10^9\), we obtain \(E_\gamma \approx 59\) TeV; note that a gamma air-shower exhibits a smaller secondary muon abundance with respect to the equivalent hadronic abundance; therefore a gamma simulates (10%) an hadronic shower (\(E_{\text{Gamma-hadron}} \approx 6\) TeV) corresponding closely to the observed ICECUBE-ARGO anisotropy [10]. The decay boosted lifetime is 19000 years, corresponding to 6 kpc distance. Therefore Co\(^{60}\) energy decay traces, lifetime and spectra fit well within the present UHECR-TeV connection for nearby galactic sources as Vela and - probably - Crab. Other radioactive scattering trace, usually at lower energy may also shine at hundreds or tens of TeV or below by Inverse Compton and synchrotron radiation. Therefore their UHECR bent parental nuclei may also shine in TeV Cosmic Ray signals. In \(\beta\)-decay processes, electrons and
neutrinos are also born, providing a new diffused gamma and PeV neutrino source. Also light nuclei, as He⁶, might decay in flight playing a radioactive UHECR-TeV role.

3 UHECR galactic bending for Ni⁵⁷

Cosmic Rays are blurred by magnetic fields. UHECR also suffer from Lorentz force deviation. This smearing could be a source of UHECR features, mostly along CentA. There are at least three mechanisms for magnetic deflection along the galactic plane, a sort of galactic spectroscopy of UHECR [4]. Magnetic bending by extragalactic fields is in general negligible in comparison with the galactic one. Late nearby (almost local) bending by turbulence and random deflection along the whole plane inside different arms:

1. The coherent lorentz angle bending $\delta_{\text{Coh}}$ of a proton (or nuclei) UHECR (above GZK [9]) within a galactic magnetic field in a final nearby coherent length of $l_c = 1 \text{kpc}$ is

$$\delta_{\text{Coh-\scriptsize p}} \approx 2.3^\circ \frac{Z}{Z_{\text{H}}} \left( \frac{6 \cdot 10^{19} \text{eV}}{E_{CR}} \right) \left( \frac{B}{3 \mu \text{G}} \right) \left( \frac{l_c}{\text{kpc}} \right).$$

2. The random bending by random turbulent magnetic fields, whose coherent sizes (tens of parsecs) are short and whose final deflection angle is smaller than others are ignored here.

3. The ordered multiple UHECR bending along the galactic plane across and by alternate arm magnetic field directions whose final random deflection angle is remarkable and discussed below. The bending angle value is quite different for a heavy nucleus such as a UHECR from Vela whose distance is only 0.29 kpc:

$$\delta_{\text{Coh-\scriptsize Ni}} \approx 18.7^\circ \frac{Z}{Z_{\text{Ni}}} \left( \frac{6 \cdot 10^{19} \text{eV}}{E_{CR}} \right) \left( \frac{B}{3 \mu \text{G}} \right) \left( \frac{l_c}{0.29 \text{kpc}} \right).$$

Note that this spread can explain the nearby Vela TeV anisotropy area (because of the in-flight radioactive emission) around its correlated UHECR triplet. There is a further extreme possibility: a Crab pulsar at a few kpc is feeding the TeV anisotropy connecting with a gate its centered disk to a wider extended region, where some UHECR are clustering. From far Crab distances the galactic bending is:

$$\delta_{\text{Coh-\scriptsize Ni}} \approx 129^\circ \frac{Z}{Z_{\text{Ni}}} \left( \frac{6 \cdot 10^{19} \text{eV}}{E_{CR}} \right) \left( \frac{B}{3 \mu \text{G}} \right) \left( \frac{l_c}{2 \text{kpc}} \right).$$

Such a spread is, again, able to explain the localized TeV anisotropy born in Crab (2 kpc), apparently extending around an area near Orion, where spread UHECR events also seem to be clustered. Such heavy iron-like (Ni, Co) UHECR, because of the big charge and large angle bending, are mostly bounded inside a Galaxy, as well as in a Virgo cluster, possibly explaining the absence of UHECR in that direction. The possible galactic component of UHECR is suggested by the correlated dark Hydrogen and dust map with the UHECR distribution as well as radio 408 MHz emission: see Figures 8-11.

4 Conclusions

It is worthwhile to remind that in an (unexpected) future where UHECR are more and more homogenous and uncorrelated with nearby GZK sources they will require far cosmic UHECR origination (as it has been the case for
Figure 13. All oldest UHECR by AGASA, AUGER, TA, in galactic Mollweide coordinate with several candidate sources with label: blue AUGER, red 72 events by TA, green last 15 by TA, 58 old AGASA cyan events for a total 376 UHECR events. Note the crowding of triplet around M82 source, the multiplet around Cygnus X3, M82, ss433, NGC253. The possible correlation between UHECR and ICECUBE UHE neutrino is still questionable. We note anyway a doublet near Vela and other marginal correlation discussed elsewhere.

Figure 14. All UHECR events superimposed to the polarized emission in Planck data by Milky Way. Note the oval contour that defines possible UHECR clustering along candidate source. Photo Credit: ESA. We added to the 376 events 14 events by Haverah Park, Fly's Eye, Yakutsk. Other events by HiRes has not been included. The map is in galactic Hammer coordinate.

GRB). In this (still not actual) frame the most reasonable candidate for UHECR are the UHE (zeV) neutrinos (considered nearly 20 years ago) by far away cosmic source edges (AGN, GRBs jets), evading the GZK cutoff; they are hitting relic neutrinos (with mass) clustered around our Galaxy halo. These scattering are leading to Z resonance and its decay in nucleon secondaries observed as UHECR [20]. A relic neutrino mass at 0.4 eV may be ideal for such resonance, even if a 0.2-0.1 eV neutrino mass may still be (better) compatible with Planck limits and comparable with atmospheric mass splitting [17]. A fourth (now on fashion, but still speculative) eV sterile neutrino, being thermalized in big bang and better clustered, it fit better the Z-showering solution. The associated tau neutrino (either by Z decay or GZK cutoff) component and its possible (yet unobserved) double bang [26], in ICECUBE or any consequent PeV-EeV Tau airshowers in TA and AUGER maybe the road map to test any UHECR and the UHE neutrino astronomy connections (see [24], [25], [27], [28], [29], [30], [32]).

Figure 15. As in fig. [14] in celestial coordinates (Mollweide), over TeVs gamma anisotropy by Hawk and IceCube detectors. Note in particular the possible asymmetric clustering on UHECR nearby Virgo as well as other oval contour for additional candidates. We added to the 376 events 14 events by Haverah Park, Fly’s Eye, Yakutsk. Other events by HiRes has not been included.

In conclusion, the two main clustering in the NORTH (HOT SPOT by TA) and in the SOUTH (HOT SPOT by AUGER) are too wide (15-20 degree, as in fig. [14] [15]) to be in debt to protons (whose bending extend just a few degree) as advocated by TA. Such Hot Spots are at the same time too narrow to be originated by cosmic UHECR heavy (Fe, Ni) nuclei (whose bending may exceed 80 degrees), as advocated by AUGER. Light or lightest nuclei may be the best compromise and the natural extragalactic UHECR carrier ([4], [5], [7], [11], [21]). They fit or coexist with AUGER and TA composition results. Also a few, very nearby galactic UHECR heavy-light nuclei may spread in few tens degree clustering spot. We tried here in present updated maps to correlate these first few clustering with their source, offering to them a name or a preliminary identity. We combined all known UHECR archives (AUGER-TA-AGASA and a few more UHECR detection) in best known usable coordinates (see fig. [2][3][11]). We overlap UHECR on Fermi gamma sky, on Radio or IR maps, (see fig. [6][10] as well as with last Planck magnetic maps and ARGO-ICECUBE TeV maps (see fig. [14][15] tracking the oval clustering mask areas. Analogous recent attempts to correlate UHECR within any wider (canonical) GZK volumes (with AGN,BL Lac sources) failed [3]. Therefore the best clustered source event is near Cen-A, in the south HOT Spot; but also M82 that might feed the observed TA clustering by light nuclei whose bending shine the NORTH Hot Spot [6]. The incoherent random bending in Cen-A, may set the source in the main clustering center; because of the horizontal spiral arms fields the spread occur in a vertical (orthogonal to the galactic plane) direction. Otherwise a coherent bending in M82 case may lead the source at the edge of the clustering Hot Spot; this occur because the unique magnetic field bends coherently positive charges in the same asymmetric way by Lorentz forces. The same coherent asymmetric bending could be responsible for Crab location at the oval edge, Fornax and NGC253 clustering, the Vela asymmetric position respect the nearby 8 events (see fig. [14][15]). The Lightest nuclei provide at the moment a natural bending angle (and a save
cut off for UHECR) from Virgo, whose distance is too far and whose central disk sky is nearly empty (see fig.14 in celestial coordinates). However as in fig.14 let us note a remarkable possible weak asymmetric clustering linking bent UHECR events to Virgo in a nearby area (see fig.15). The probability that such a clustering takes place in a thousand square degree oval by 13 events over 159 in the North sky is below 7⋅10^{−3}. This area is coincident with area C anisotropy found by ARGO (see fig.15).

The probability to observe 8 events within the nearby Vela area (see fig.14) is only 2.5⋅10^{−2}; however the corresponding clustering probability around the thin Crab oval area by 11 events is near 10^{−4}, (see fig. 15). The probability to find 7 events around Cygnus X3 is 3.1⋅10^{−3}; note that two additional HIRES events are in this Cygnus area (but their exact coordinate have not been published) leading to a remarkable correlation, as well as the ARGO anisotropy around that area. The probability to find in a very narrow oval area four UHECR (two of them are the highest ones of TA and AUGER), pointing to SS433 (or AqX1) is about 6.7⋅10^{−5}, see fig [36, 6]. The eventual clustering around the Small and Large Magellanic Clouds (SMC.LMC) are still a weak but interesting hint being as rare as 3⋅10^{−2}.

In conclusion two nearest AGN, Cen-A and M82 may explain the main strong statistical presence of two Hot Spot. REF6. The probability for the by-chance event for Cen-A (wide dashed Hot Spot) is around (1.5⋅10^{−5}), the probability for its inner smaller clustering is about (5.4⋅10^{−4}, see fig. 14, 15). We remind also for the tens EeV clustering along the same oval area (see fig. 1). The probability to have a North Hot Spot (narrow area around M82) with 8 events is 2.3⋅10^{−3} while the probability for the whole wide North Hot Spot (dashed lines in fig.14,15) is 1.3⋅10^{−4} [3, 18]. Lightest (He, Li, Be, B) UHECR nuclei may be main the natural currier. Their fragments (α, γ), by their decay, as being radioactive (or by photo disso-

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