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The meaning of the UHECR Hot Spots: A Light Nuclei Nearby Astronomy

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Abstract. We update all the recent UHECR events reported by AUGER, Telescope Array as well as by AGASA in common coordinate maps. We confirm our earliest (2008-2013) model where UHECR are mostly light nuclei (He,Be,B), explaining the Virgo absence and confirming M82 as the main source of North TA Hot Spot. Many more sources , as NGC 253 and galactic ones, are possibly source of most of the 376 UHECR events. Several correlated map, already considered in recent years, are shown with all the events

1 Introduction

On November 2007 AUGER [3] has shown within 27 events a rare clustering (spread within $\mp 15^o$) of UHECR events centered around Cen A, a first Hot Spot anisotropy. The later 2011 data (69 UHECR events), as well additional train of dozen of twin events at 20 EeV [4]) confirmed a such UHECR Hot Spot as well as reinforced a nuclei (not a proton) UHECR composition. The AUGER composition derived by UHECR slant depth signature. Since 2011 AUGER didn't detect Virgo Cluster nor any Super-Galactic anisotropy as it has been first assumed, if UHECR were protons. Telescope Array (TA) in last few months did found a comparable remarkable anisotropy (a Hot Spot, also spread within $\mp 15^o$) pointing in an (uncorrelated) unexpected Sky. Therefore , up to now we face mostly two Hot Spot in North and South Sky. Moreover, once again un-noticed, the Virgo cluster, within a better view of TA sky, didn't rise at all also in TA data, as one would expect, if, as TA claim, UHECR are protons. To make more contradictory the race in UHECR Astronomy we remind that since 2007, AUGER favored an iron composition while, as mentioned, TA preferred an UHECR proton. Finally the very last events by TA, $(72+15$ events) and the deep and final AUGER records (2004-2014, 231 events) [5], offer an unique case for combine their maps and test eventual sky correlation. AUGER disclaimed any possible relevant connection, out the Cen A, Hot Spot. The AUGER and TA maps are often in not comparable map projection. Here we did combine both of those published (and TA in press) events in known and useful coordinate. We shall discuss and weight their clustering along these maps overlap on different ones. We remind that we suggested since very early 2008 [28] that AUGER puzzles (anisotropy size, Virgo Absence) could found solution if UHECR were mostly lightest nuclei, like Helium. Indeed their spread angle by random bending along galactic fields will explain the unique Hot Spot due to our nearest AGN: Cen-A. Indeed 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 just few smaller Universe size($3-4$ Mpc). Therefore Cen A could shine, Virgo not. Lightest UHECR nuclei may 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 more nearby source as M-82 Star-bust Galaxy [17] 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 $(15-20^o)$ in nearby North Galactic fields. However we recognize in the same bending tail a much near, more narrow and very recent (this year additional events) 5 event clustering, confirming such a probable coherent bending of UHECR light nuclei from M82. Such a quintuplet cluster within (100^o square degree) has the probability below $< 10^{-3}$ to occur by chance. Moreover the additional oldest UHECR AGASA record on North sky (58 events) did show an unique triplet almost overlapping, making the chance probability to find such a clustering within ($150^o - 200^o$ square degree, 8 events) as low as $(1\cdot 10^{-4} - -4\cdot 10^{-4})$. Therefore we reconfirm that Cen A, M82 [17] and a few galactic sources, as Vela, Cygnus X3, SS433 could also eject light or heavier UHECR nuclei, possibly radioactive nuclei bent by large local magnetic fields. We were inspired by early preliminary UHECR correlation with TeV anisotropy maps discovered last decade by Milagro, ARGO and now by Hawk and ICECUBE in very recent years. We reconfirm that such TeVs-UHECR correlation might be indebt to the UHECR fragment nuclei by radioactive decay in flight and or by UHECR lightest nuclei photo-dissociation secondaries 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

Ultra High Energy Cosmic Rays (UHECR) are clustering both within South (AUGER) and North (Telescope Array, TA) sky in wide $\pm 15^o$ 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, in particular in recent TA data as well in last AUGER 231 events. The Virgo clustering absence do not fit UHECR as nucleon. The same $\pm 15^o$ clustering Hot Spot cannot accomodate with an extragalactic heavy nucleous composition (Fe,Ni), because of their much larger charge and wider (above 90^o degrees) deflection angle. However lightest UHECR nuclei, namely or mostly He, are fragile enough to be soon absorbed and hidden by photo-dissociation on Cosmic radiation on their way from Virgo (20 Mpc) to us, explaining their absence. On the contrary AUGER clustering around nearest active AGN (3.5 Mpc) Cen A, maybe indebt to bent light (He) nuclei spread by random *incoherent* bending along the spiral galactic magnetic fields; Virgo missing in TA data is explained again by the UHECR He opacity. The TA Hot Spot clustering may be ejected by Star-burst M82 (3.5 Mpc) as a main source, while UHECR are bent and spread by a *coherent* magnetic field either galactic at North Pole (and-or extragalactic). We underline here the clustering of 5 UHECR TA events much nearer M82. They might be a first UHECR trace around this main source (the nearest Star-Burst Galaxy M82). Such very narrow (5) spot almost overlap an oldest one, a triplet observed by AGASA on 1990-2000. The binomial probability to find 4 (+1) of such events inside a narrow area of 10^2 square degree, within 87 TA signals, is within $< 8.2 \cdot 10^{-4}$, even ignoring the AGASA triplet. Considering also the additional 58 AGASA events and a triplet clustering within 150^o, the probability reduces to 10^{-4}. These quintuplet signals 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 $< 2 \cdot 10^{-4}$, but their clustering 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 multiplet (8) along Vela shows, Cygnus X3 clustering, a peculiar narrow triplet event (SS433 or Aq1) and possibly spread sources along Magellanic stream regions, LMC and SMC, or as NGC 253, a second nearest (3.5Mpc) Star-Burst source or a and Fornax D (Dwarf Galaxy) source.

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

Let us make a short remind for choosing He like composition: the *old* 2011 UHECR multiplet clustering published on 2011 [4] (and forgot in most report) by AUGER UHECR at twenty EeV energy contains just three apparently isolated trains of events. They apparently point to unknown sources (see old 69 events on IR map). However, the crowding of the two train multiplet tail centers inside a very narrow disk area focused about the rarest Cen A UHECR source as it has been foreseen is remarkable, [16]. If UHECR are made by protons (as some AUGER and TA author 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 as well as the HIRES and TA composition traces. The He secondaries split in half (or a fourth) energy fragments along the Cen A tail the presence of which has being foreseen, in recent years[30],[16]. Indeed, the dotted circle around Cen A containing two (of three) multiplets by a radius as small as 7.5^o extending 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. *simeq*$3 \cdot 10^{-4}$. 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 twenty EeV has an a priori probability as low as $P(3,2) \simeq 3 \cdot 10^{-5}$ of following an a priori foreseen signature[16].

The incoherent random angle bending (2) along the galactic plane and arms, δ_{rm}, while crossing along the whole Galactic disk $L \simeq 20 \cdot kpc$ in different (alternating) spiral arm fields and within a characteristic coherent length $l_c \simeq 2 \cdot kpc$ for He nuclei is $\delta_{rm-He} \simeq$

$$\simeq 16^\circ \cdot \frac{Z}{Z_{He^2}} \cdot (\frac{6 \cdot 10^{19} eV}{E_{CR}})(\frac{B}{3 \cdot \mu G}) \sqrt{\frac{L}{20 kpc}} \sqrt{\frac{l_c}{2 kpc}}$$

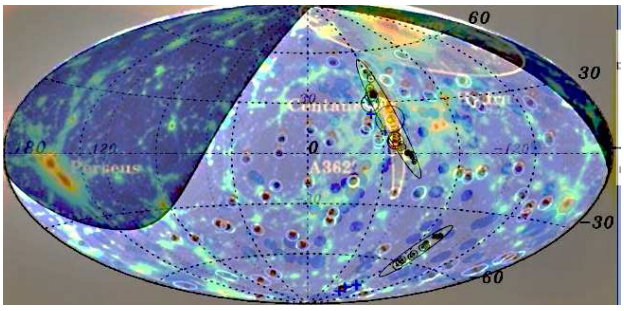

Figure 1. An earliest (2011) UHECR AUGER data above GZK cut by 69 Auger events and 20 EeV clustering on Infrared background: Note the Virgo absence and the Cen A clustering [30],[13]

The heavier (but still light) nuclei bounded from Virgo might also be Li and Be: $\delta_{rm-Be} \simeq$

$$\simeq 32^\circ \cdot \frac{Z}{Z_{Be^4}} \cdot (\frac{6 \cdot 10^{19} eV}{E_{CR}})(\frac{B}{3 \cdot \mu G}) \sqrt{\frac{L}{20 kpc}} \sqrt{\frac{l_c}{2 kpc}}.$$

It should be noted that the present anisotropy above GZK [10] energy $5.5 \cdot 10^{19} eV$ (if extragalactic) might leave a tail of signals: indeed the photo disruption of He into deuterium, tritium, He^3 and protons (and unstable neutrons), arising as clustered events at a half or a quarter (for the last most 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* [16]. We suggested looking for correlated tails of events, possibly in strings at low $\simeq 1.5 - 3 \cdot 10^{19} eV$ 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* [16]. Deuterium is even more bounded in a very local Universe, because of its fragility (explaining the absence of Virgo). In conclusion, He like UHECR may be bent by a characteristic angle as large as $\delta_{rm-He} \simeq 16^\circ$; its expected lower energy Deuterium or proton fragments at half energy ($30 - 25 EeV$) are also deflected accordingly at ($\delta_{rm-p} \simeq 16^\circ$); the last traces of protons at a quarter of the UHECR energy, around twenty EeV energy, will be bent and spread within ($\delta_{rm-p} \simeq 32^\circ$), exactly within the observed Cen A UHECR multiplet.

2 TeV Gamma and UHECR

In recent UHECR maps we have noted first hint of a galactic source arising as a UHECR triplet [13]. The hint of the Al^{26} gamma map traced by Comptel somehow overlapping with UHECR events at 1-3 MeV favors a role of UHECR radioactive elements (as Al^{26}). The most prompt radioactive nuclei are the Ni^{56}, Ni^{57} (and Co^{56}, Co^{60}), made by Supernova (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 rspectively. Their half lifetimes are spread from 35.6 h for Ni^{57} and 6.07 d. for Ni^{56}. However there are also more unstable radioactive rates, as for Ni^{55} nuclei whose half life is just 0.212 s or Ni^{67}, whose decay is 21 s. Therefore we may have an apparent boosted UHECR ($\Gamma_{Ni^{56}} \simeq 10^9$) lifetime spread from $2.12 \cdot 10^8$ s or 6.7 years (for Ni^{55}) up to nearly 670 years (for Ni^{67}) or 4 million years for Ni^{57}. EeV and PeV radioactive UHECR or their fragment may also play role in gamma and neutrino emission. This consequent 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 is Co_m^{60} whose half life is 10.1 min and whose decay gamma line is at 59 keV. At a boosted nominal Lorentz factor $\Gamma_{Co^{60}} = 10^9$, we obtain $E_\gamma \simeq 59$ TeV ; note that a gamma air-shower exhibits a smaller secondary muon abundance with respect to the equivalent hadronic abundance; therefore a gamma simulates a (10%) hadronic shower ($E_{gamma-hadron} \simeq 6$ TeV) corresponding closely to the observed ICECUBE-ARGO anisotropy [26]. The decay boosted lifetime is 19000 years, corresponding to 6 kpc distance. Therefore Co_m^{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 He 6, might decay in flight playing a radioactive UHECR-TeV role.

3 UHECR galactic bending for Ni^{57}

Cosmic Rays are blurred by magnetic fields. UHECR also suffer from Lorentz force deviation. This smearing maybe a source of UHECR features, mostly along Cen A. There are at least three mechanisms for magnetic deflection along the galactic plane, a sort of galactic spectroscopy of UHECR [28]. Magnetic bending by extragalactic fields is in general negligible in comparison with galactic bending. Late nearby (almost local) bending by a nearest coherent galactic arm field, and random bending by turbulence and random deflection along the whole plane inside different arms:

(1) the coherent Lorentz angle bending δ_{Coh} of a proton (or nuclei) UHECR (above GZK [10]) within a galactic magnetic field in a final nearby coherent length of $l_c = 1 \cdot kpc$ is:

$\delta_{Coh-p}. \simeq 2.3^\circ \cdot \frac{Z}{Z_H} \cdot (\frac{6 \cdot 10^{19} eV}{E_{CR}})(\frac{B}{3 \cdot \mu G})\frac{l_c}{kpc}$

(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: $\delta_{Coh-Ni} \simeq 18.7^\circ \cdot \frac{Z}{Z_{Ni^{28}}} \cdot (\frac{6 \cdot 10^{19} eV}{E_{CR}})(\frac{B}{3 \cdot \mu G})(\frac{l_c}{0.29 kpc})$

Note that this spread is able to explain the nearby Vela TeV anisotropy (because of the radioactive emission in flight) area around its correlated UHECR triplet. There is an ex-

treme possibility: that 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:
$\delta_{CohNi} \simeq 129^\circ \cdot \frac{Z}{Z_{Ni^{28}}} \cdot (\frac{6 \cdot 10^{19} eV}{E_{CR}})(\frac{B}{3 \cdot \mu G})(\frac{l_c}{2kpc})$
Note that such a spread is 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 radio 408 MHz emission: see Figures below.

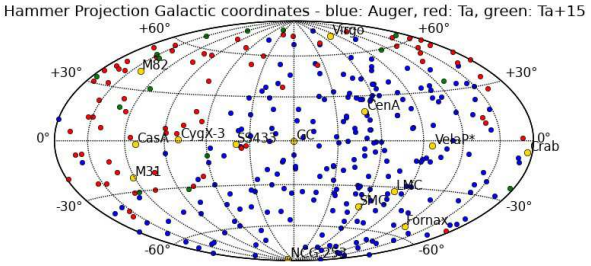

Figure 2. Hammer Projection, Galactic Coordinate map for last 231 AUGER UHECR with additional 72+15= 87 last TA records, in a total of of 318 events. Few potential sources are labeled

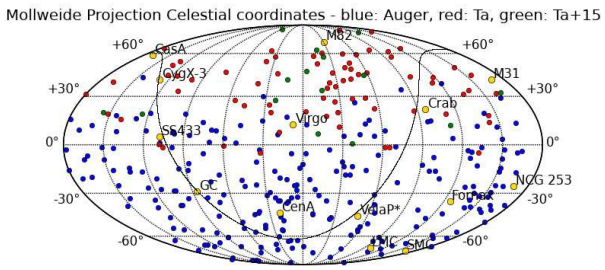

Figure 3. Mollweide Projection, Celestial Coordinate map for last 231 AUGER UHECR with additional 72+15= 87 last TA records. Few potential sources are labeled

4 Conclusions

The recent AUGER report on 231 UHECR recorded in a decade as well as the 87 Telescope Array events of last 6 record time have been shown in common coordinate system and in different projection. Moreover the AGASA 58 events have been also added in order to enrich the North sky with all available data. These maps have been overlap on different background confirming earlier correlation (clustering along Cen-A), first suggestions (triplet around Vela that grew to several train of events), clustering along Cygnus X3 (both by early and late TA data), remarkable clustering toward M82, convincing triplet (with highest AGASA-TA UHECR overlap) along SS433 (or Aq X1), an unique train of events along brightest gamma Pulsar Vela, a few possible clustering mostly within galactic Radio and relic dust. We also note a rare triplet nearby M81, our nearest Andromeda galaxy. Moreover the highest TeV gamma anisotropy are partially correlating with UHECR in a remarkable way, suggesting radioactive UHECR spray of secondaries (gamma, electron paies, alfa, neutrons) along their flight. Such a gamma and electromagnetic showering might also feed the recent TeV positron flux observed by AMS2. Lightest nuclei (He,D,T,Li,Be,B and maybe C) might play a key role as currier of UHECR. Also Ni, Co or Al might play a role from nearest sources as we did suggest since a few years (2008) in several articles [16].

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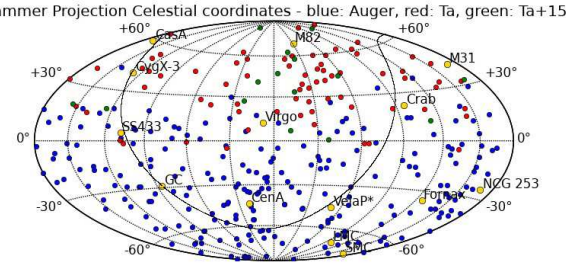

Figure 4. Hammer Projection, Celestial Coordinate map for last 231 AUGER UHECR with additional 72+15= 87 last TA records. Few potential sources are labeled as well as the galactic plane

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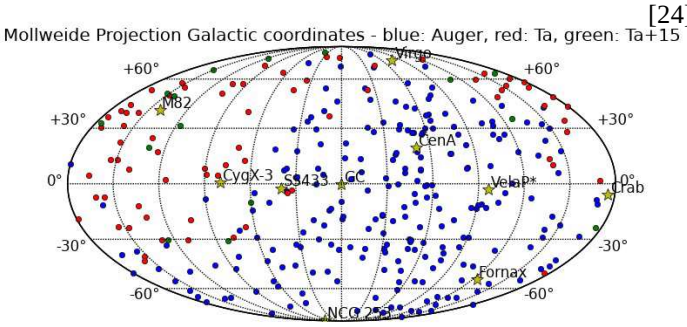

Figure 5. As above, in Mollweide Projection, Galactic Coordinate map for last 231 AUGER UHECR with additional 72+15= 87 last TA records with additional . Few potential sources are labeled

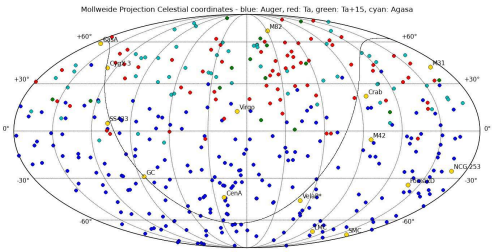

Figure 7. All oldest and last UHECR events by AGASA, AUGER, TA, in Celestial Malloweide coordinate with several candidate sources with label for a total 376 UHECR events, over the Fermi map of MeV-GeV energies. There are clear signal around Vela and Cygnus and other galactic sources, as well around Cen A, M82, Magellanic Clouds sources

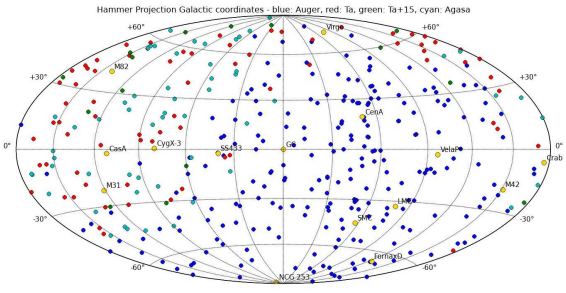

Figure 6. All oldest UHECR by AGASA, AUGER, TA, in galactic Hammer coordinate with several candidate sources with label: blue AUGER, red 72 events by TA, green last 15 by TA, 58 old AGASA cyan events for a total 376 UHECR events

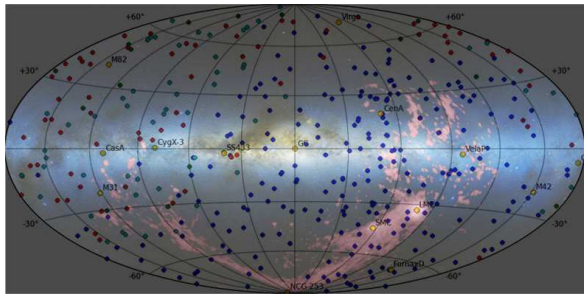

Figure 8. All oldest and last UHECR events by AGASA, AUGER, TA, in galactic Hammer coordinate with several candidate sources with label for a total 376 UHECR events; the whole map is overlap on the Magellanic Stream in nearby galactic volume

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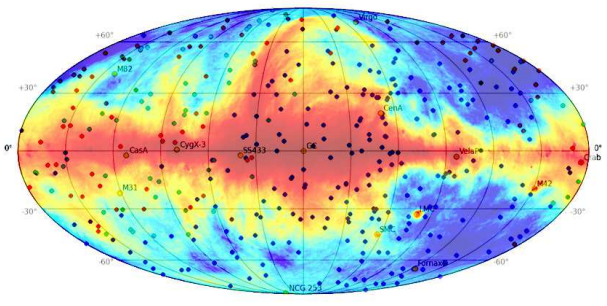

Figure 9. All oldest and last UHECR events by AGASA, AUGER, TA, in galactic Malloweide coordinate with several candidate sources with label for a total 376 UHECR events, overlap on the galactic radiation at 408 MHz: it is remarkable that most of the events are located where there is synchrotron radio emission, possibly reinforcing a large galactic UHECR origination or a key role of UHECR shining into 408MHz radio sky

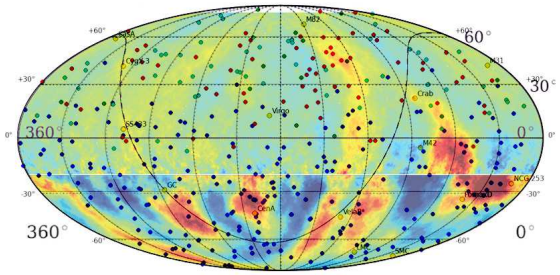

Figure 10. All oldest and last UHECR events by AGASA, AUGER, TA, in galactic Hammer coordinate with several candidate sources with label for a total 376 UHECR events, over the gamma TeV background (2 TeV on the North, 20 TeV on the South), signals found on the North sky by ARGO on Tibet and at South by ICECUBE. Note that ARGO detector is recording both gamma and Cosmic Ray at once, keeping memory (partially) of a small galactic plane anisotropy toward Cygnus X3

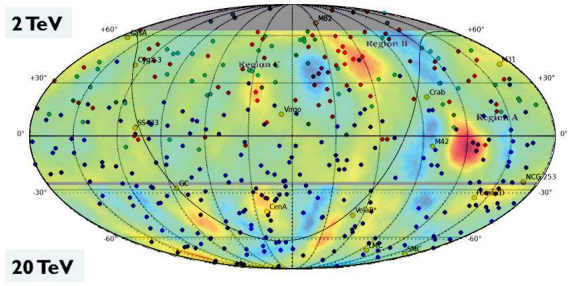

Figure 11. All oldest and last UHECR events by AGASA, AUGER, TA, in galactic Hammer coordinate with several candidate sources with label for a total 376 UHECR events, over the gamma TeV background (2 TeV on the North, 20 TeV on the South), signals found by Hawk on North and at South by ICECUBE. Note that Hawk, like older Milagro detector is recording mostly Cosmic Ray (not gamma) ; therefore they do not see (clearly as ARGO, figure above) the galactic anisotropy toward Cygnus X3

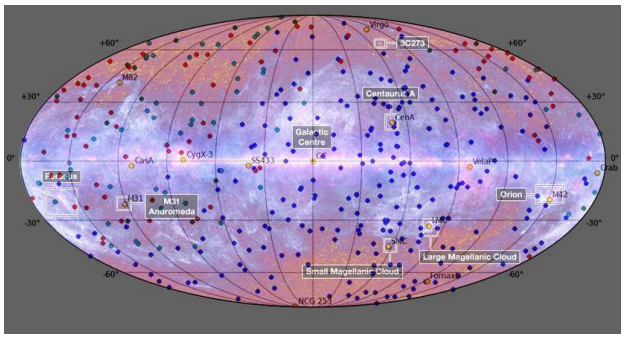

Figure 12. All oldest and last UHECR events by AGASA, AUGER, TA, in galactic Hammer coordinate with several candidate sources with label for a total 376 UHECR events, over the Planck map of infrared due to dust. Again there is a remarkable signal in the absence of dust where there are also none or few UHECR events

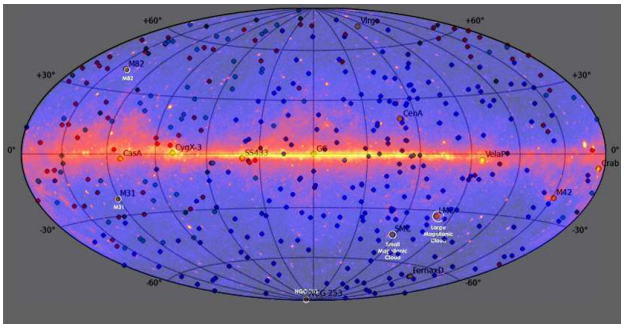

Figure 15. All oldest and last UHECR events by AGASA, AUGER, TA, in galactic Hammer coordinate with several candidate sources with label for a total 376 UHECR events, overlapping the Fermi map of MeV-GeV energies. There are clear signal around Vela and Cygnus and other galactic sources, as well around Cen A, M82, Magellanic Clouds sources

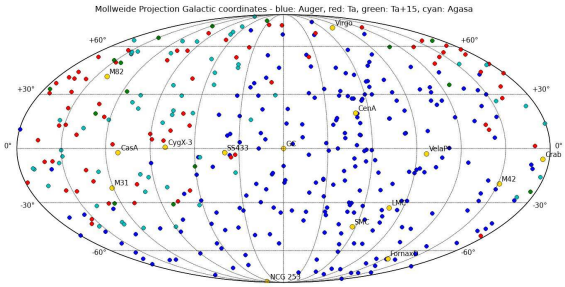

Figure 13. As above, in Mallwoide Projection, Galactic Coordinate map for last 231 AUGER UHECR with additional 72+15= 87 last TA records. Few potential sources are labeled

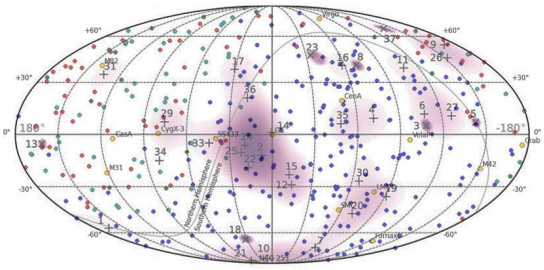

Figure 16. All oldest UHECR by AGASA, AUGER, TA, in galactic Mollweide coordinate with several candidate sources with label: blue AUGER, red 72 events by TA, green last 15 by TA, 58 old AGASA cyan events for a total 376 UHECR events. Note the crowding of triplet around M82 source, the multiplet around 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

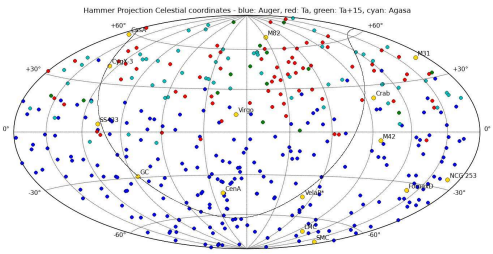

Figure 14. All oldest and last UHECR events by AGASA, AUGER, TA, in celestial Hammer coordinate with several candidate sources with label for a total 376 UHECR events, with the galactic plane curve