UHECR Anisotropy from Luminous Infrared Galaxies - Predictions for the Pierre Auger Observatory

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Abstract

We consider the hypothesis that luminous infrared galaxies (LIRGs) are sources of the UHECRs. By associating the AGASA triplet with the Arp 299 galaxy we obtain reasonable values for Galactic and extragalactic magnetic fields. We predict what the southern sky, to be seen by the Auger experiment, should look like, so that the LIRG hypothesis could be verified soon.

1. Introduction

In the quest for the origin of the ultra high energy cosmic rays (UHECR) various methods have been pursued, where the most promising one is to look for the particle point sources. Some directional correlations with quasars have been found [4,8] but we are rather sceptical about considering these very distant objects as sources of UHECR particles, because of the GZK effect. This paper is partly a continuation of our previous hypothesis that UHECRs may come from luminous infrared galaxies (LIRGs) [6]. These objects have IR emissivities larger by an order of magnitude than normal galaxies. Being mainly colliding galaxies they may constitute favourable conditions for high energy particle acceleration (see also [1]). In [6] we have shown that there is quite a reasonable directional correlation between $(4-8)\times10^{19}eV$ AGASA showers and LIRGs on the northern sky. In particular, the AGASA triplet [7] coincides well with the brightest (up to 70 Mpc) extragalactic IR source, Arp 299, 42 Mpc away. Here, we analyse further the possibility of Arp 299 being the source of the triplet particles, allowing for their changing directions in extragalactic and Galactic magnetic field. We also predict what the southern sky would look like in the highest energy cosmic particles, as measured by the Pierre Auger Observatory in Argentina [3].

2. AGASA triplet from Arp 299 ?

The positions of the three shower directions of the AGASA triplet, together with the direction towards Arp 299 are shown in Fig 1.. The particle energies are

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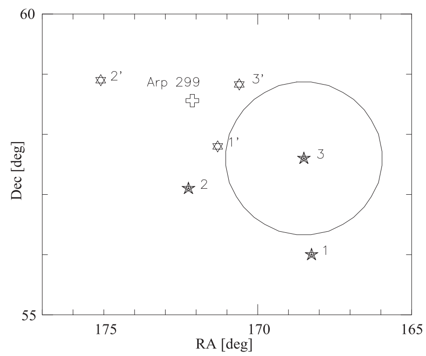

Fig. 1. Close look at the sky near Arp 299 (cross). Dark stars denote AGASA triplet, open stars - particle directions before entering the Galaxy. Circle shows uncertainty of shower direction $\sim 1.5^\circ$ above 5×10^{19}eV.

54, 55 and 78 EeV correspondingly for shower 1,2 and 3. As the distance to Arp is 'only' about 42 Mpc, let us assume that these particles may have arrived from this source with negligible energy losses and follow the consequences.

As all three particles are shifted more or less in similar directions away from the source it may be that it is the Galactic magnetic field responsible for that. One can find such a value of the integral $\int B_\perp dl$ (along the line of sight) that the combined occurence of the remaining particle deflections in the extragalactic chaotic fields is most probable. Let us denote the deviation of the particle arrival direction from that towards the source by $\vec{r'}$. If it is caused by multiple independent small deviations in the extragalactic magnetic field, then the probability that three particles will have deviations $\vec{r'_1}$,$\vec{r'_2}$ and $\vec{r'_3}$, each within a small solid angle $d\Omega_1$,$d\Omega_2$ and $d\Omega_3$, equals:

$$dp(\vec{r'_1}, \vec{r'_2}, \vec{r'_3}) = \prod_{i=1}^{3} \frac{1}{\sigma_i^2}\, exp\Big(- \frac{\vec{r'^2_i}}{\sigma_i^2}\Big) d\Omega_i \tag{1}$$

where σ_i is the r.m.s. of r'_i and equals: $\sigma_i = \sqrt{2}\, q_i B_{rms} \sqrt{lD}/(3E_i)$ (for a model with magnetic cells of size l), and D is the distance to the source.

The Galactic field shifts the particle arrival directions by:

$$\vec{g_i} = \frac{q_i}{E_i} \int \vec{B} \times \vec{dl} = \frac{0.53^\circ}{\epsilon_i} \int \vec{B_6} \times \vec{dl} \equiv \frac{\vec{a}}{\epsilon_i} \tag{2}$$

where $\epsilon_i = E_i/10^{20}eV$, $B_6 = B/10^{-6}G$ and q_i is the particle charge. We assume here that all particles have the same charge $q = 1e$. If the *observed* deviations from the source are $\vec{r_i}$ then $\vec{r'_i} = \vec{r_i} - \vec{g_i}$. Introducing all this into (1) we obtain the probability dp as a function of $\vec{a}$ and $\sigma_{1,2,3}$. We want to find such a vector $\vec{a}$ for which the probability dp has a maximum value. Differentiating (1) with respect to the two coordinates a_x and a_y (where x corresponds to declination and y to right ascension) and putting the derivatives equal to zero we obtain:

$$a_x = \frac{1}{3} \sum_{i=1}^{3} \epsilon_i \Delta x_i \quad and \quad a_y = \frac{1}{3} \sum_{i=1}^{3} \epsilon_i \Delta y_i \tag{3}$$

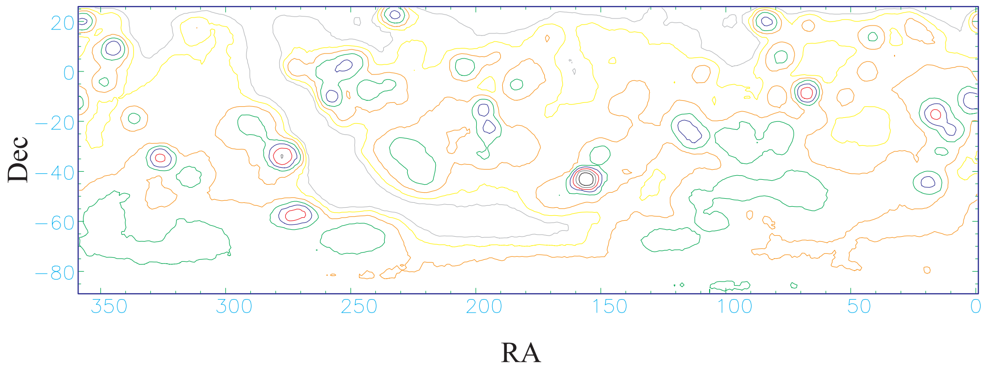

Fig. 2. UHECR sky (energy above 40 EeV) predicted for Auger. Isolines (flux per unit solid angle) spaced with factor 0.5.

where Δx_i and Δy_i are the components of $\vec{r_i}$ Adopting the particular values of Δx_i and Δy_i for the AGASA triplet with Arp 299 as the source we find that $\int B_\perp dl \simeq 2.4\mu G \cdot kpc$. This value does not look unreasonable for the Galactic latitude $\simeq 56°$.

The particle new directions, after shifting by $-\vec{a}/\epsilon_i$, are shown in Fig 1. by the open stars. The remaining deviations $\vec{r_i'}$ depend on the parameter $b = B_{rms}\sqrt{l}$, which can be found by maximizing again the combined probability (1). So far we have neglected the experimental uncertainties of the shower directions. For the AGASA triplet, however, $\sigma_i \leq \sigma_{exp}$, so that at this stage any conclusions about $B_{rms}\sqrt{l}$ have large uncertainty. Nevertheless for $r' \leq 1°$ one gets $b \leq 0.3\, nG\, Mpc^{1/2}$, a value consistent with the current knowledge.

One can go even further and assume that all particles in the multiplet were emitted at the same time i.e. the time interval of their emission is much smaller than the time interval of their arrivals. If the latter ($\simeq 3$ yrs) is compared to the r.m.s. of the arrival time differences

$$\sigma_{\Delta t} \simeq 1.25 \times 10^4 yrs \cdot (D/30Mpc)^2 \cdot (b/1nG\, Mpc^{1/2})^2 \cdot \epsilon^{-2} \tag{4}$$

then $b \simeq 10^{-2}\, nG\, Mpc^{1/2}$. It is much smaller than that estimated from the above analysis of the deviation angles, if σ_{exp} are neglected.

3. UHECR sky predicted for the Auger experiment

Assuming that LIRGs are the UHECR sources one can predict the angular distribution of the shower directions as would be observed by the southern site of the Pierre Auger Observatory. We assume that the cosmic ray production rate of a LIRG is proportional to its IR emissivity. We adopt the production energy spectrum $\propto E^{-2}dE$ up to $E_{max} = 10^{21}eV$. In the extragalactic space

Table 1. Mean number of doublets and triplets (within separation angle $\leq 2.5°$) predicted for Auger for LIRG and isotropic sky ($E > 4 \times 10^{19} eV$).

N_{events}	$< N_{doub} >$ LIRG/Iso	$< N_{trip} >$ LIRG/Iso
100	4.7/3.5	1.5/0.18
200	14/12.5	5.6/1.3
300	25/25	21/8.3

the particles are being scattered by the magnetic fields such that $B_{rms} \cdot \sqrt{l} = 1\, nG\, Mpc^{1/2}$. The Auger exposure corresponds to that calculated with purely geometrical considerations, which for $E > 4 \times 10^{19} eV$ is probably not far from the truth. The result is presented in Fig 2.. Galactic field has not been taken into account. The most conspicuous object is the galaxy NGC 3256. It is a merging system - "super starburst" galaxy [5] in a very vigorous episode of star formation, also the most luminous X-ray starburst galaxy currently known. If the Arp 299 in the northern hemisphere is responsible for the three events then Auger could register about 4 showers from NGC 3256 for each 100 events above $4 \times 10^{19} eV$. The expected number of doublets and triplets to be registered by Auger for the LIRG hypothesis and isotropic sky is shown in Table 1 for 100, 200 and 300 total events. For higher number of showers it is looking for individual sources rather than counting multiplets what will be a better way of analysis.

4. Conclusions

The Auger experiment will soon see the southern sky with unprecedented sensitivity (see eg.[2]), so that the hypothesis of the luminous infrared galaxies as to be responsible for UHECR particles (and for the AGASA triplet) will probably be verified. The accuracy of the shower direction determination in this experiment will be below one degree. So, if any point-like excess is visible, its correlation with an object could be analysed by finding the best Galactic and extragalactic magnetic fields, as presented here.

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1. Al-Dargazelli S.S. et al, 1996, J.Phys. G 22, 1825
2. Bluemer J. for Auger Collaboration, 2003, 28th ICRC, Tsukuba
3. Cronin J., 1997, Pierre Auger Design Report, http://www.auger.org
4. Farrar G.R. and Biermann P.L., 1999, Phys. Rev. Lett. 83, 2472
5. Joseph R.D. and Wright G.S., 1985, MNRAS, 214, 87
6. Smialkowski A., Giller M. and Michalak W., 2002, J. Phys. G, 28, 1359
7. Takeda M. et al, 1999, ApJ, 522, 225
8. Tinyakov P.G. and Tkachev I.I., 2002, Astropart. Phys., 18, 165