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Detection of anisotropies in the arrival directions of 600 GeV–10 TeV cosmic rays with the ARGO-YBJ experiment

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Summary. — ARGO-YBJ is an RPC "carpet" aimed to the detection of extensive air showers induced by charged cosmic rays and gamma-rays in the energy range GeV–PeV. The data-set collected since November 2007 has been analyzed and very significant anisotropies (more than 10 standard deviations), with relative intensity of the order of 10^{-3} have been found. The observation is not explained with the current models of galactic magnetic field and propagation of cosmic rays in the Galaxy.

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1. – Introduction

In 2007, modeling the large scale anisotropy of TeV cosmic rays, the Tibet-ASγ Collaboration ran into a "skewed" feature in the excess region known as "tail in" [1]. They modelized it with a couple of intensity excesses in the hydrogen deflection plane, each of them 10°–30° wide. Afterwards the Milagro Collaboration claimed the discovery of two localized regions of excess 10 TeV cosmic rays [2]. Regions "A" and "B", as they were named, are positionally consistent with the "skewed feature" observed by Tibet-ASγ and were parametrized with r.a.-dec. rectangles in celestial coordinates. Both detectors and methods of data analysis were quite different and only the Milagro Collaboration excluded the hypothesis of a gamma-ray–induced effect. The excesses are 10°–30° wide and no interpretation holds leaving the standard model of cosmic rays and that of the local galactic magnetic field unchanged at the same time. In fact, the gyroradius of cosmic rays in the local galactic magnetic field is about $r_{a.u.} = 100\,R_{\mathrm{TV}}$, where $r_{a.u.}$ is in astronomic units and R_{TV} is in TeraVolt.

The ARGO-YBJ experiment [3, 4] is a wide field-of-view air shower array located at the YangBaJing Cosmic Ray Laboratory (Tibet, P.R. China, 4300 m a.s.l., 606 g/cm^2). It reports here the observation of the region "A" and "B" with unprecedented detail,

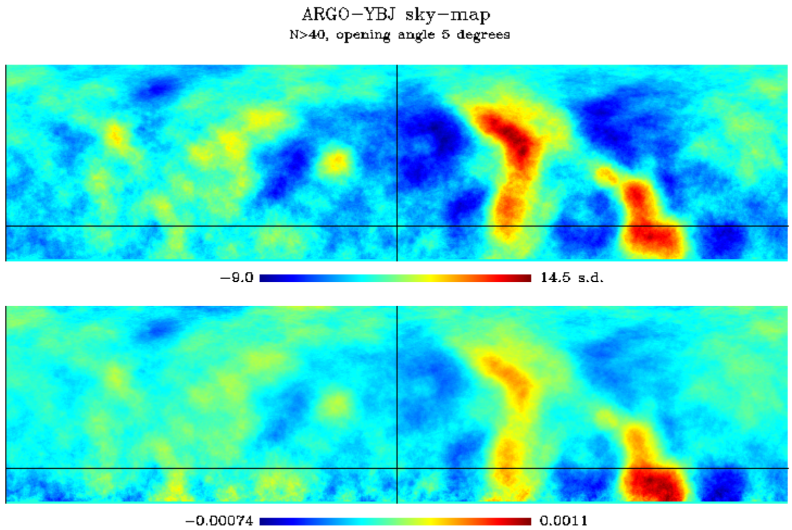

Fig. 1. – ARGO-YBJ sky-map in celestial coordinates. Opening angle 5°. Upper plot: significance of the observation. Lower plot: relative excess with respect to the estimated background.

giving important information on their shape and their extension. Moreover several substructures have been found and new weaker few-degree excesses throughout the sky region $195° \leq r.a. \leq 315°$.

2. – Data analysis and results

The data used for the present analysis have been taken from November 2007 to November 2010. All events with more than 40 particles in the central carpet have been used. Among them, only those with reconstructed zenith angle less than or equal to 50° were used to fill the maps. The triggering showers that passed the selection above were 1.27×10^{11}. The zenith cut selects the declination region $\delta \sim -20° \div 80°$. The isotropic background of cosmic rays has been estimated with methods based on time average [5].

Figure 1 shows the ARGO-YBJ sky map in celestial coordinates, as obtained from all events analyzed as mentioned in the previous paragraph. The upper plot shows the significance of the observation while the lower the intensity relative to the estimated background. They look slightly different because the efficiency of ARGO-YBJ is not uniform along the declination. The most evident features rest in the right side of the map and coincide spatially with regions "A" (the largest and weakest one) and "B" (the other one). Region "B" appears to be made of two distinct hot spots and those of region "A" do not seem so different in size (see the on-line color version). On the left side of the maps, several new extended features are well visible, though less intense than those aforementioned. Together with that of regions "A" and "B", the observation of these structures may open the way to an interesting study of the TeV cosmic-ray sky. To figure out the energy spectrum of the excesses, data have been divided into five independent multiplicity sets, according to the number of strips they fired on the central carpet. Figure 2 shows the evolution of the anisotropies with the multiplicity of the detected showers. In the left plot, the upper map shows the map of the relative

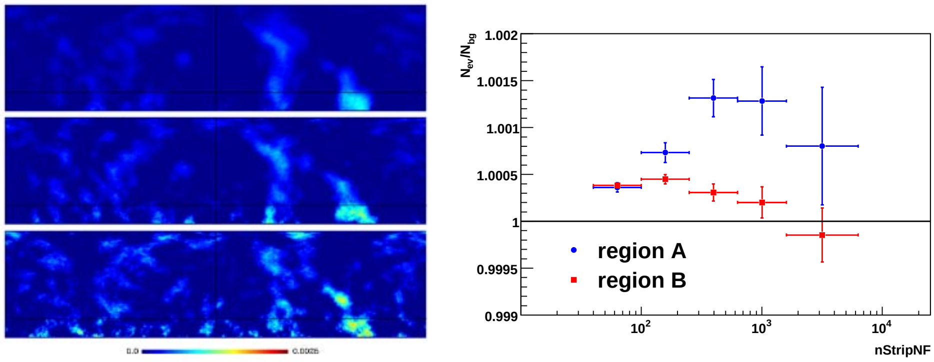

Fig. 2. – Left plot: evolution of the cosmic-ray intermediate scale features with the energy. The color scale spans from 0 to 10^{-3}. See the text for details. Right plot: energy spectrum of the region "A" and "B" excesses. The horizontal axis represents the number of fired strips. The vertical axis represents the ratio between the events collected and the expected background.

intensity for $40 \leq N_{strip} < 99$, the intermediate for $100 \leq N_{strip} < 249$ and the lower for $250 \leq N_{strip} < 629$. The opening angle is still 5°. What is worth noting is that the excess intensity increases with the energy for all regions under consideration. Moreover, the highest energy (*i.e.* the highest rigidity) map suggests the excesses lay on angular scale of 5°–10° and what appears to be merged at lower energies seems to be well separated a factor 10 above (see region "A" for instance).

As a preliminary result, we computed the energy spectrum of the two most intense excesses, for which we used the parametrization introduced by the Milagro Collaboration [2]. The result is shown in the right plot of fig. 2. Region "A" seems to have spectrum harder than isotropic cosmic rays and a cutoff around 600 fired strips (proton median energy $E_p^{50} = 8\,\text{TeV}$). On the other hand, the excess hosted in region "B" is less intense and has a spectrum well distinguished from that of isotropic cosmic rays, harder from 100 fired strips on ($E_p^{50} = 2\,\text{TeV}$). Moreover, there is a hint of flattening at lower multiplicites.

3. – Conclusions

Thanks to the operational stability, the high duty-cycle, as well as the very good angular resolution, the ARGO-YBJ experiment detected several few-degree cosmic-ray excesses in three years of data acquisition. If the explanation of these phenomena is really related to the emission from nearby sources, few-degree anisotropies may reveal as an effective tool to probe the accelerated emission of cosmic rays at sources.

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