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Search for a Galactic Enhancement of the Ultra-High-Energy Cosmic Rays Using the HiRes Stereo Data

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Previous reports from the AGASA collaboration have indicated evidence for an enhancement from the Galactic plane in a relatively narrow energy band between 1 and 2 EeV. If correct this would be the most direct evidence to date for Galactic sources of ultra-high-energy cosmic rays. Analysis of ~4.3 years of stereo data taken with the High Resolution Fly's Eye Experiment (HiRes) shows no indication of an enhancement from the direction corresponding to the Galactic plane. Analysis of the entire dataset also shows no indication of an enhancement from the Galactic plane.

1. Introduction

The anisotropy of ultra-high energy cosmic rays may hold clues to their origin. The AGASA collaboration has reported an anisotropy associated with the Galaxy over a narrow energy band [1]. Selecting events with energies between 1 and 2 EeV, AGASA observed a 20% excess from a direction near the Galactic center and somewhat smaller enhancement from the Cygnus region (Galactic longitude ~80 degrees). In the same data set they observed a ~10% deficit from the Galactic anti-center. Their data show a strong dipole nature in equatorial coordinates, with right ascensions between 0 and 200 degrees showing large deficits relative to right ascensions between 200 and 360 degrees. These results have not yet been confirmed by an independent experiment. Several hypothesizes have been put forth to explain these results. One theory invokes the leaky box model of cosmic-ray propagation and requires the proton spectrum to steepen near 10^{18} eV. The other model assumes that the anisotropy is due to cosmic-ray neutrons. At 10^{18} eV neutrons have a decay length of about 10 kpc, however this would require a rather sharp cutoff in the neutron energy spectrum above $10^{18.5}$ eV to account for the lack of anisotropy at higher energies.

The High Resolution Fly's Eye Experiment is a stereoscopic air fluorescence detector sensitive to cosmic rays with energies above ~2×10^{17} eV. The two detector stations are separated by 12.6 km. The HiRes-I site consists of 21 5.1m^2 mirrors which view zenith angles between 73 and 87 degrees. At the HiRes-II site there are 42 mirrors that cover the zenith angle range from 59 to 87 degrees. Each mirror is viewed by an array of 256 photomultiplier tubes (PMTs), each with a field-of-view of 1 degree. Further details of the detector may be found in [2, 3]. The data set presented here begins on 29 September 1999 and ends on 15 February 2004. A total of 4651 events that survived a set of standard quality cuts (goodness of geometrical and energy fit, zenith angle less than 70 degrees, weather) are used in the analysis.

2. Data Analysis

To search for sources of ultra-high-energy cosmic rays it is necessary to compare the actual number of detected events in some region of the sky, with an estimate of the background in the same region of the sky. The estimate of the background is normally carried out under the assumption that the cosmic rays are isotropic. The problem then is reduced to determining the sensitivity of the detector to cosmic rays as a function of the local coordinates (zenith and azimuth) and the exposure of the detector to different regions of the celestial sky. Here we follow the method developed in [4] (known as "direct integration") to estimate the background. The background estimate N_{bkg} for a given region of right ascension (ra) and declination (δ) is given by:

$$N_{bkg}[ra,\delta_0] = \iint E(ha,\delta)R(t)\varepsilon(ha,ra,t,\delta,\delta_0)dtd(ha)d\delta$$

Where $E(ha,\delta)$ is the probability that a given event came from the direction (ha,δ), where *ha* is hour angle and δ is declination, $R(t)$ is the event rate in the detector at time *t*, and $\varepsilon(ha,ra,t,\delta,\delta_0)$ is one if the hour angle and sidereal time are such that event falls within the right ascension, declination bin of interest and zero otherwise. In the above equation we have assumed that $E(ha,\delta)$ is independent of time over the integration interval. In [4] a 2-hour integration interval was selected, however due to the low event rate in HiRes single integration interval was used for the entire dataset. It has been found that $E(ha,\delta)$ is stable over the entire dataset. As an example Figure 1 shows the hour angle distribution of events taken during the summer and winter months. The data in the figure have been normalized to ease comparison as there is 2.3 times as much data taken during the winter months as during the summer months.

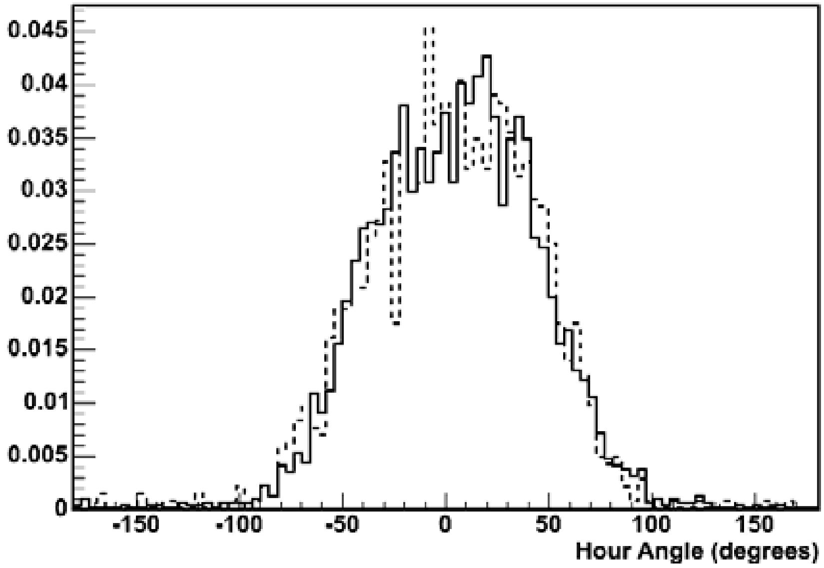

Figure 1 Summer (dashed) and winter (solid) hour angle distribution of events. The data have been normalized so the area under each histogram is unity.

Since the AGASA results are not well defined (definite coordinates for the regions of excess and deficit are not given, different publications give slightly different energy intervals [1, 5]) we have adopted a somewhat more general approach to search for an enhancement from the Galaxy. Based upon the AGASA results a region that includes Galactic longitudes between 0 and 100 degrees was examined. This region includes both the Galactic center (where there is little exposure due to the latitude of the HiRes experiment) and the Cygnus region, where there is good exposure. Both a ±5 degree (R1) and ±10 degree (R2) region around the Galactic equator have been searched for enhancements. In both regions two different energy ranges are examined: the first coinciding with the reported narrow-band enhancement from AGASA between 1-2 EeV (1438 events) and the other includes events of all energies (4651 events).

3. Results

Figures 2 and 3 show the longitudinal distribution (in Galactic coordinates) of the number of excess events along the Galactic equator for regions R1 and R2 (respectively) in the AGASA energy band between 1 and 2 EeV. Table 1 summarizes the results for both regions and both energy intervals. No significant excess is observed in any of the analyses. The resulting 90% c.l. upper limits are between 15% of the background for all energies and 27% of the background for events between 1 and 2 EeV.

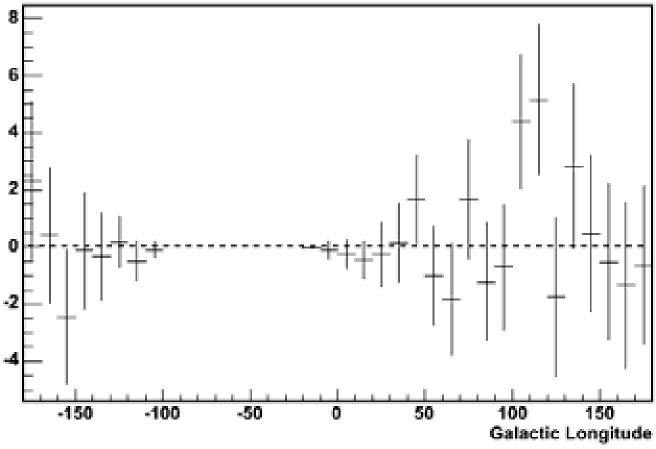

Figure 2. The number of excess events as a function of Galactic longitude for region R1, a ±5 degree region around the Galactic equator.

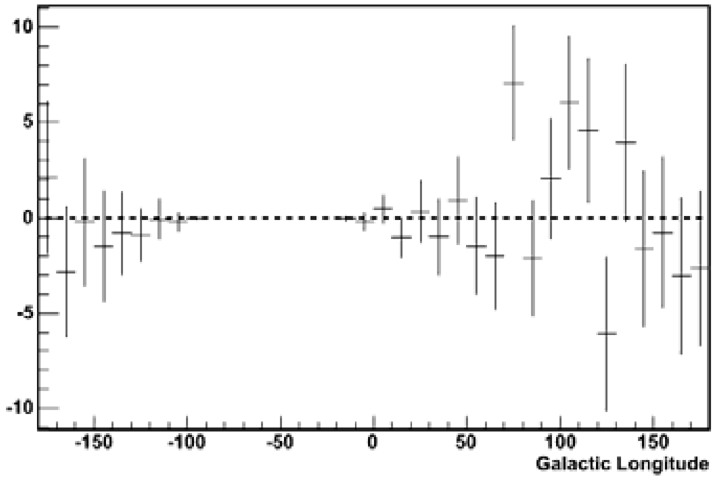

Figure 3. The number of excess events as a function of Galactic longitude for a region R2, a ±10 degree region around the Galactic equator.

Table 1 Results of search for an enhancement of ultra-high energy cosmic rays between Galactic longitude 0 and 100 degrees.

Region & Energy	**On Source**	**Off Source**	**Excess**	**90% c.l. Upper Limit (Events)**
±5/All Energy	89	88.8	0.2	15.6
±10/All Energy	196	187.3	8.7	28.5
±5/1-2 EeV	24	26.3	-2.3	7.1
±10/1-2 EeV	59	55.8	3.2	14.4

4. Conclusions

The AGASA collaboration has previously reported an enhancement of cosmic rays in a narrow energy band between 1-2 EeV from regions near the Galactic center and the Cygnus region. In the same analysis they reported a deficit of cosmic rays in the same energy band from the Galactic anti-center. Roughly 4.3 years of stereo data from the HiRes experiment has been searched for a similar enhancement. No evidence of an enhancement of cosmic rays in the same energy band as AGASA reports nor from all HiRes events from the region of the Galactic plane that includes the Galactic center and the Cygnus region has been observed. The 90% c.l. upper limits on the fractional excess from the Galactic plane between Galactic longitude 0 and 100 degrees are between 15% and 27% depending upon the width in Galactic latitude and the energy range of the selected events.

5. Acknowledgements

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