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Search for Intermediate-Scale Anisotropy by the HiRes Experiment

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Abstract: The HiRes collaboration has searched for intermediate-scale anisotropy of ultrahigh energy cosmic rays in two ways: first a search for variation with declination of the flux of cosmic rays, and second in their arrival directions. The data of the HiRes-II detector was used in the search.

Introduction

The High Resolution Fly's Eye (HiRes) experiment [1] is a fluorescence experiment to study ultrahigh energy cosmic rays. In this paper we describe three searches for anisotropy at intermediate angular scales using the HiRes-II detector.

The first search is for a variation with declination of the flux of cosmic rays. The purpose of this is to investigate a possible implication of the recent measurement of the cosmic ray flux by the surface detector of the Pierre Auger experiment in the southern hemisphere [2]. At energies above the "ankle", they found a power law index of -2.6, where all previous experiments, in the northern hemisphere, have found a value of -2.8 [3].

The second search is for anisotropy in cosmic rays' arrival directions. In such a search one calculates what an isotropic distribution would be and compares it with the data. We find a deficit of events near the direction of the galactic anticenter which is similar to that seen by the Akeno and AGASA experiments [4].

The third search is for an excess of events along the galactic plane. Again we compare the data, binned in galactic latitude, b, with the expectation of an isotropic sky.

One of HiRes' two detectors, the HiRes-II detector was located atop Camel's Back Ridge on the U.S. Army Dugway Proving Ground in Utah. The detector consisted of 42 mirrors and clusters of phototubes that observed the sky from 3° to 31° in elevation and almost the whole azimuth. The mirrors collected cosmic ray showers' fluorescence light and focused it on 16 x 16 arrays of phototubes. Pulse height and timing information were saved for later analysis.

Using this information, the geometry of the shower can be determined, the profile of the shower development in the atmosphere can be obtained, and the energy and direction of travel of the primary cosmic ray measured. Cosmic rays of energy above about $10^{17.2}$ eV can be seen by the HiRes-II detector. The upper limit of event energies is determined by the GZK suppression [5] at about $10^{19.8}$ eV. The average energy of events seen by HiRes-II is about $10^{18.0}$ eV.

In this paper we use the monocular reconstruction of the HiRes-II data set collected from December, 1999, through April, 2006. This data set contains about 12,000 events. The energy resolution is typically about 18%. The angular resolution is about ±5° in the plane defined by the detector and shower axis, and about ±0.5° in the normal direction. The elongated shape of events' error ellipses complicates searches for point sources somewhat, but searches for extended structure are not impeded by this factor.

Declination-dependence of the Cosmic Ray Flux

The spectrum measurement for this study is that of reference [6]. Figure 1 shows a histogram of the declination of events, and that the median is about 20°. In dividing the sky into two parts, one obtains the best statistical power by choosing a declination (δ) value that gives equal statistics in the two parts. Hence we will form the ratio of fluxes of δ<20°/δ>20°.

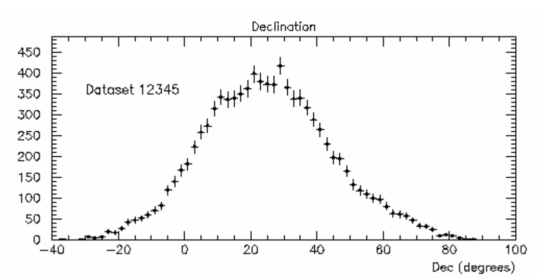

Figure 1: Histogram of the declination of events seen in the HiRes-II data set.

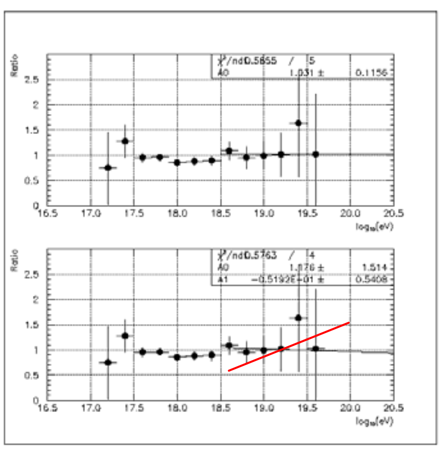

Figure 2: The ratio of the spectrum for declination less than 20 degrees, to the spectrum for declination greater than 20 degrees. No hint of a difference is apparent in these data. The red line indicates what a spectral power law index of -2.6 would look like.

The flux ratio is shown in Figure 2. The upper part of the figure shows the data plus a fit to a horizontal line, and the lower part the fit is to a line whose slope is allowed to vary. The fitting program chooses a slope of -0.05±0.5, i.e., no significant slope. We conclude that no hint of a variation on the sky of the spectral power law index is apparent in these data.

Intermediate-Scale Pointing Anisotropy

A Deficit near the Galactic Anti-center

The first task to complete in a search for pointing anisotropy is to calculate how an isotropic sky would appear. We do this using the "hour-angle" method [7]. In our experiment the distribution of events in hour angle and declination is independent of month of the year, even though the number of events varies due to the different length of nights. Figure 3 shows a two-dimensional scatter plot of hour angle vs. declination, and Figure 4 shows a comparison of summer and winter hour angle and declination histograms with an all-year histogram.

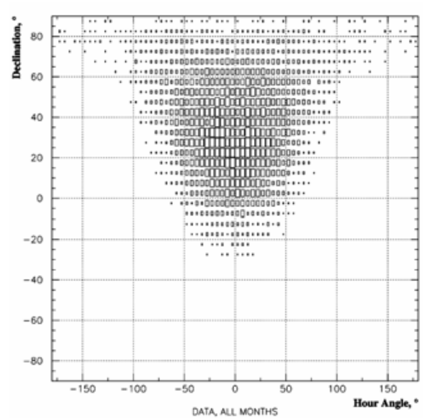

Figure 3: Hour angle vs. declination for all months of the year.

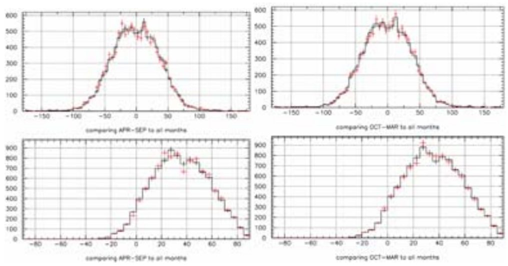

Figure 4: Hour angle and declination comparisons between summer data (left panel), and all-year, and winter data (right panel) and all-year.

After calculating the isotropic background, normalizing it to the data, forming the data - background difference, and dividing by the standard deviation of the ratio, the result is shown in Figure 5. No significant excess appears on this plot. The most significant deviation from anisotropy is a deficit of events near the galactic anticenter. This resembles a deficit previously seen by the Akeno and AGASA experiments.

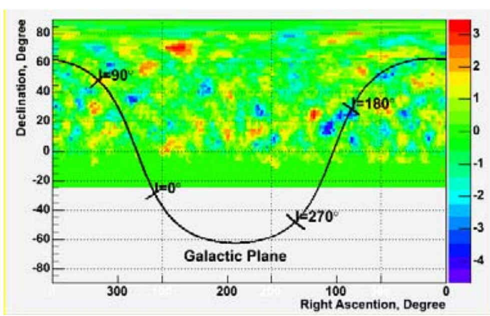

Figure 5: Significance plot of the pointing directions of events from 17.5 < log(E,eV) < 18.5, integrated over 5 degree circles.

In the analysis of their deficit the AGASA collaboration integrated their sky plot over 20° circles, and used an energy range 17.8 < log(E,eV) < 18.3. Figure 6 shows AGASA's significance plot. To make a better comparison we integrated the HiRes-II data over 20° circles, and we show the resulting sky plot in Figure 7.

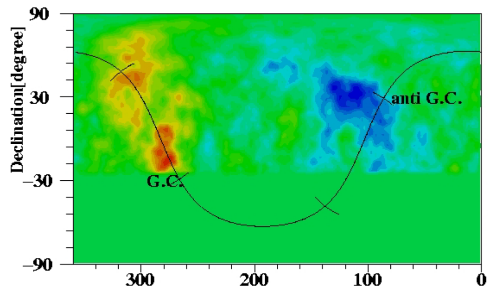

Figure 6: Significance plot of the Akeno and AGASA data, integrated over 20 degree circles.

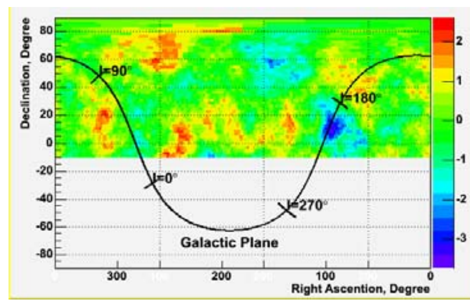

Figure 7: HiRes sky plot, with data integrated over 20 degree circles. The deficit near the galactic anti-center appears at right ascension 95°, declination 10°.

To quantify a comparison of the sky plots shown in Figures 6 and 7, we use two statistics: the maximum significance of the HiRes deficit and the χ^2 of the shape of the deficit between Akeno-AGASA and HiRes. The combined chance probability of a random data set having a significance the same as or larger than the HiRes deficit and having a χ^2 of the shape of the deficit the same or lower than the data is 0.0014. This corresponds to 3.2 standard deviations from isotropy.

Since this is less than 5 standard deviations we cannot claim observation of a new effect. This deficit must be examined by future experiments in the northern hemisphere. We expect that the Telescope Array experiment will confirm or reject this as a source of anisotropy.

Search for Anisotopy along the Galactic Plane

We performed a search for anisotropy along the galactic plane by forming a histogram of the data in galactic latitude, b. We compared this histogram to that expected from our simulated isotropic background. The result is shown in Figure 8.

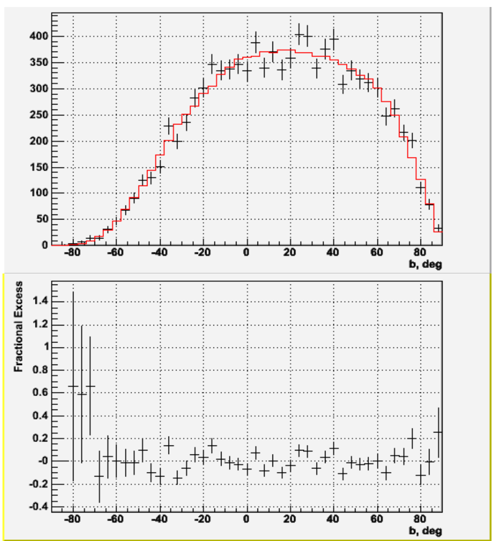

Figure 8: Upper panel: histogram of galactic latitude, b, for the data, and (in red) for the expectation of an isotropic data set. Lower panel: ratio of data to simulation. No excess is observed. The data is shown for energies 17.5 < log(E,eV) < 18.5

These data can be used to place upper limits at 90% confidence level of an excess along the galactic plane are 9% for |b|<5°, and 7% for |b|<10°.

Summary

We have searched for two form of anisotropy in the arrival directions of ultrahigh energy cosmic rays. Data collected by the HiRes-II detector was used for these searches. First we searched for a declination dependence of the spectrum of cosmic rays. In particular we wanted to look for evidence that at lower declinations the spectrum at higher energies than the ankle might show a power law index of -2.6, rather than the value of -2.8 seen by previous northern hemisphere experiments. We see no evidence for a declination dependence of the spectral power law index.

Second we searched for intermediate-scale anisotropy in the energy range 17.5 < log(E,eV) <18.5. The most significant effect is a deficit of events, from the way an isotropic sky distribution is expected to appear, which is located near the galactic anti-center. This deficit is quite similar to one seen previously by the Akeno and AGASA experiments. We calculated the chance probability of the HiRes deficit to be 0.0014, which corresponds to 3.2 standard deviations.

Finally we searched for an excess of events along the galactic plane. None appears above the expectations of an isotropic data set. 90% confidence level upper limits are: 9% for |b|<5°, and 7% for |b|<10°.

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