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Arrival Directions of Ultra-High Energy Cosmic Rays within The HiRes–I Monocular Dataset: A Search for Overlaps with the Reported AGASA Clusters

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We consider a six-source hypothesis for the arrival directions of ultra-high energy cosmic rays within the HiRes–I monocular dataset. This model assumes events originate from the directions of the six AGASA clusters, comprising a total of thirteen events above 4×10^{19} eV and observed in a dataset of comparable statistics to the HiRes-I sample. We determine the number of HiRes events consistent with arriving from the cluster directions, and place upper limits on the flux from these pointlike sources. Using a Monte Carlo technique, we find the expectation for these arrival directions given an isotropic background distribution. We then evaluate the likelihood that the same set of pointlike sources accounts for both the HiRes dataset and the AGASA signal.

1. Introduction

Determining the sources of ultrahigh energy cosmic rays will be a crucial observational contribution to the field of particle astrophysics. These particles may undergo only minor bending in the intergalactic magnetic fields, which could result in a strong correlation between the event arrival directions and the source locations. To date however searches for anisotropy in arrival directions have yielded inconclusive results. In this paper, we evaluate a particular model for pointlike sources of cosmic rays using the monocular dataset collected by the High–Resolution Fly's Eye (HiRes). This paradigm is inspired by the observations of the Akeno Giant Airshower Array (AGASA). The HiRes data provide the first opportunity to perform a statistically independent test of this hypothesis.

In 1996, AGASA first reported the observation of clustering in the arrival directions of cosmic ray events with energies above 4×10^{19} eV [7]. A cluster is defined as two or more events within a separation angle of $2.5°$. AGASA currently reports observing a total of six clusters — five doublets and one triplet — in a sample of 59 ultra–high energy cosmic ray events in the northern hemisphere [11, 12]. The locations of these clusters are estimated by taking a weighted average of the locations of the constituent events [8, 3]. We follow the AGASA convention [10] of naming these clusters C1 through C7. (Cluster C5, a doublet including an event with energy 3.89×10^{19} eV[8], has been omitted in more recent publications and is thus not considered in the present paper.) We treat these observations as the basis for a six-source hypothesis, in which the AGASA cluster directions represent six constant–intensity sources of ultrahigh energy cosmic rays.

In this paper we do not address the statistical significance of the AGASA result itself. A recent paper has commented on the significance of the AGASA clusters [6]. Here, we take at face value the assertion that 13 events above 4×10^{19} eV arrive from the direction of six pointlike sources. We do consider the effect of random clustering in the AGASA cluster signal. We also note that the relative number of events above 4×10^{19} eV observed by HiRes and AGASA disagrees with the expectation from the stated exposures of the two experiments. This fact may be due to differing absolute energy scales [1], but it bears on the present analysis and is addressed below.

The HiRes-I monocular dataset consists of 2,820 detector hours of data, collected between May 1997 and

February 2003. A total of 31 events above 4×10^{19} eV were observed during this time. The monocular reconstruction of airshowers observed with the nitrogen fluorescence technique by "profile–constrained" fitting has recently been described in the literature [1]. A feature of the monocular reconstruction is orientation–dependent (elliptical) uncertainties in the airshower arrival directions [2].

The arrival directions of HiRes–I monocular events above 4×10^{19} eV are plotted in Figure 1. Superimposed on this plot are the six AGASA cluster positions for comparison.

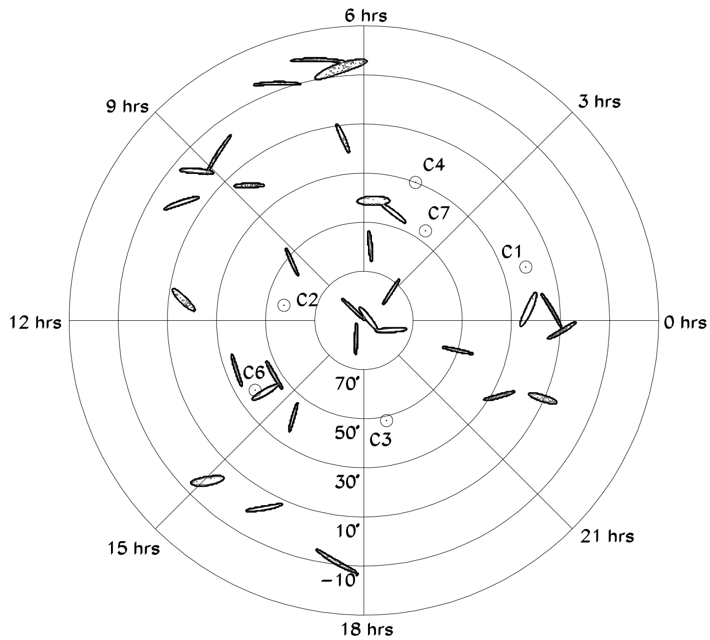

Figure 1. Arrival directions of HiRes–I monocular events above 4×10^{19} eV, plotted in polar projection, equatorial coordinates. One sigma error ellipses are shown for each event. AGASA clusters are identified as points with $2.5°$ radius circles, labeled C1 through C7 (C5 excluded).

2. Background and Point Source Monte Carlo; Flux Upper Limits

We use a library of simulated events, generated by an air shower simulation using the CORSIKA [9] code followed by a full detector simulation and reconstructed using the profile–constrained reconstruction program to determine the expected degree of overlap between the HiRes–I dataset and the AGASA clusters [2]. For this library, an isotropic distribution is assumed for events possessing the spectrum and composition reported by the stereo Fly's Eye experiment [4, 5]. A detector runtime database is used to randomly assign a time from detector "on" periods to each event in the isotropic background dataset. A total of 1,000 isotropic datasets with the same sky exposure as the HiRes–I monocular dataset were generated for comparison studies.

To calculate the detector exposure for point sources of events above 4×10^{19} eV at the positions of the six AGASA clusters, events are generated at the cluster positions, assigned a time from the distribution of HiRes detector ontimes, and projected towards the detector aperture. Local coordinates and times are determined, then the event is paired with a shower from the Monte Carlo event library having similar local coordinates. An attempt is then made to reconstruct the Monte Carlo events with the profile–constrained fitting technique. The exposure, defined as the fraction of events reconstructed multiplied by the detector aperture (area) and time, can then be used to determine flux upper limits for each of the six arrival directions.

3. Consistency of the Two Datasets

The previous section addresses the question of the consistency of the HiRes data with the expectation from an isotropic background. We next consider the question of whether the HiRes–I signal is also consistent with the six–source hypothesis. There are difficulties however in quantifying the consistency of the AGASA and HiRes–I monocular datasets.

The HiRes–I detector exposure for the present dataset is 2×10^3 km^2 sr yr for events above 4×10^{19} eV. AGASA reports an exposure of 1.3×10^3 km^2 sr yr in the same energy range [8]. These results contradict the observed event counts above 4×10^{19} eV; 31 events were observed by HiRes, 59 events are included in the AGASA sample.

A second and likely related discrepancy in the two datasets lies in the comparison of the energy spectra of the two experiments [1]: A shift in the energy scale of roughly 30% is necessary to bring the differential flux spectra into agreement. We choose to address these complications by selecting different energy cutoffs for the two experiments, consistent with the energy shift indicated in the spectral results.

4. AGASA Cluster Positions Interpreted as Sources of HiRes Events

Assuming that both AGASA and HiRes are observing sources located at the six AGASA cluster positions, we can estimate from the measured fluxes the likelihood that the two experiments are sampling a set of sources of constant intensity. For increased statistical power, we test the ensemble of observations rather than considering the six potential sources individually.

The method is as follows: Let $P_\mu(n)$ be the Poisson probability for observing n events from a distribution with a mean of μ. Let N_H represent a given number of HiRes events, and N_A a given number of AGASA events. The product

$$Q_\mu(N_H, N_A) = P_\mu(N_H) \times P_\mu(N_A) \tag{1}$$

tells us the joint probability of a single Poisson distribution with mean μ yielding the results reported by the two experiments. The value of μ with the largest Q_μ corresponds to the most likely mean value of the parent Poisson distribution.

For the most likely parent distribution, we then ask for the probability of observing $\leq N_H$ and $\geq N_A$ events. The product of these probabilities

$$R_\mu(N_H, N_A) = \left(\sum_{n=0}^{N_H} P_\mu(n) \right) \times \left(\sum_{n=N_A}^{\infty} P_\mu(n) \right) \tag{2}$$

is a measure of the fluctuation required for a single source to lead to observations of both N_H and N_A events in independent experiments.

The number N_H of events observed in HiRes is dependent on the assumed background level. Thus it is necessary to evaluate R_μ for the different background expectations. Finally, it is necessary to consider the impact of likely backgrounds in the AGASA signal. We include this effect by using their published estimate of 1.7 random doublets [12], which we interpret as a Poisson distributed background with a mean of 3.4 events. Repeating the above calculations, now performing a weighted average over all the HiRes and AGASA background hypotheses, we determine the weighted average probability that a single set of sources produced both the AGASA and HiRes signals.

5. Conclusions

The results of the studies described in this paper will be presented at ICRC2005.

6. Acknowledgements

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References

[1] R. U. Abbasi *et al.* 2004a, Physical Review Letters **92** 151101.
[2] R. U. Abbasi *et al.* 2004b, Astroparticle Physics **21** 111.
[3] AGASA web page, 2003,
http://www-akeno.icrr.u-tokyo.ac.jp/AGASA/
[4] D. J. Bird *et al.* 1993, Proceedings 23^{rd} International Cosmic Ray Conference (ICRC), Calgary **2** 38.
[5] D. J. Bird *et al.* 1994, Astrophysical Journal **424** 491.
[6] C. B. Finley and S. Westerhoff 2004, Astroparticle Physics **21** 359.
[7] N. Hayashida *et al.* 1996, Physical Review Letters **77** 1000.
[8] N. Hayashida *et al.*, 2000 astro-ph/0008102.
[9] D. Heck *et al.* 1998, CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers, Forschungzentrum Karlsruhe, Wissenschaftliche Berichte FZKA 6019.
[10] M. Takeda *et al.* 1999, Astrophysical Journal **522** 225.
[11] M. Takeda *et al.* 2001, Proceedings 27^{th} International Cosmic Ray Conference (ICRC), Hamburg, 345.
[12] M. Teshima *et al.* 2003, Proceedings 28^{th} International Cosmic Ray Conference (ICRC), Tsukuba, 437.
[13] Y. Uchihori *et al.* 2000, Astroparticle Physics **13** 151.