Search for anisotropies of UHECRs with the Pierre Auger Observatory

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Abstract. The Pierre Auger Observatory for Ultra High Energy Cosmic Rays in Malargüe, Argentina is nearly complete. Four searches for anisotropy on data taken between January 2004 and March 2007 are presented. No significant deviation from isotropic arrival directions has been found.

1. Introduction

The distribution of the arrival direction of Ultra High Energy Cosmic Rays (UHECRs) encodes valuable information about their nature and origin as well as information about the galactic and intergalactic magnetic fields. The largest observatory for UHECRs is the Pierre Auger Observatory (Auger) in Malargüe, Argentina. Its surface detector (SD) consists of 1600 water Cherenkov counters on a 1.5 km triangular grid covering 3000 km$^2$. The SD is overlooked by an air fluorescence detector (FD) of 24 Schmidt telescopes located at the periphery of the SD array. The combination of the two detection techniques provides a unique handle for precision energy calibration and the understanding of reconstruction uncertainties of direction and energy of the cosmic rays [1].

Due to an uptime close to unity the SD delivers the highest statistics data set for anisotropy searches. The arrival direction of the cosmic ray is derived from the arrival time of the shower particles at the Cherenkov counters. The energy of the shower is derived from the particle density distribution at the ground. The accuracy of the reconstructed direction is about 1.2 degrees for showers of $\geq 3$ EeV and 4 or more stations and 0.9 degree for showers of $\geq 10$ EeV. The uncertainty of the energy estimation is 10\% due to reconstruction and 22\% due to systematics [2].

While the end of construction is expected early in 2008 a set of data has already been collected which corresponds to an exposure of about one year of observation with the full Auger SD array. A variety of searches for anisotropy have already been conducted. We report the results of four different search strategies based on data taken between January 2004 and March 2007.

2. Anisotropy searches

2.1. Search for flux excess around the Galactic Centre

The Galactic Center (GC) is a primary target for anisotropy searches at EeV energies ($1\text{EeV} = 10^{18}\text{eV}$). It hosts a massive black hole associated with the radio source Saggittarius A and the supernova remnant Saggittarius A East. There have been reports about an excess of cosmic rays
from the GC (4.5σ) by the Akeno Giant Air Shower Array (AGASA) as well as the SUGAR experiment (2.9σ) [4]. Besides that the highly significant observation of TeV γ rays from the GC by H.E.S.S. [3] confirms the GC as a potential accelerator of cosmic rays.

The exposure accumulated by Auger in the direction of the GC by far exceeds that of previous experiments. In order to compare with previous observations we used exactly the same search directions and bin sizes. For the AGASA-like search we observed 2116 events with 2169.7 expected from an isotropic flux. For the SUGAR-like search we obtained 286 events with 289.7 expected, i.e. no excess was observed in Auger data. For details of the analysis see [5].

Figure 1 shows the significance map for overdensities of cosmic rays with energies between 0.8 and 3 EeV in a search window of 5° radius. The galactic plane is indicated by a solid line with the GC (cross). Also shown are the search bins used by AGASA and SUGAR.

2.2. Search for large scale structure
The transition from galactic to extragalactic cosmic rays is expected to occur in the energy range of 1 to 10 EeV. This transition may cause an anisotropy on large scales such as the size of the galaxy. Such a large scale structure was reported by the AGASA experiment as a 4% amplitude modulation in right ascension for the energy range 1-2 EeV [4].

The sensitivity of large scale anisotropies strongly depends on the reliability of the background estimation called the coverage map. For our analysis a semianalytical method was used which exploits the azimuthal symmetry of the detector and almost uniform acceptance in sidereal time. The acceptance in zenith is derived from the observed zenith distribution of the data set. Effects such as array growth, seasonal variations and dependencies of the trigger rate on air temperature and air pressure are taken into account by a time dependent zenith distribution.

The coverage map can be compared with the observed distribution of arrival directions in many ways. A common estimator is the Rayleigh analysis. We performed a scan over energy of the Rayleigh amplitude, phase and probability. No significant modulation was found throughout the scan. By comparison of the observed modulation intensity with simulated random samples upper limits were derived on a 95% confidence level. For an energy range window of 1 to 3 EeV an upper limit on a dipole amplitude of 0.7% was derived. For details see [6].

2.3. Search for correlation with active galactic nuclei
Another class of anisotropy searches concerns correlations of UHECRs with active galactic nuclei, especially BL Lacs. Significant correlations have been reported in [7]. Analyses based on another data set did not confirm the reports, however, that analysis found significant correlation with different search parameters [8]. We use events with 10 EeV or more recorded by the Auger SD to test the reported excesses. This set contains 1672 events, i.e. about 6 times the number of events included in any of the previous reports. The strength of the correlation is given by the number of events with an arrival direction less than a given angular distance from any of the candidate point sources. The chance probability to observe k or more out of N events which correlate is given by the cumulative binomial distribution $P = \sum_{j=k}^{N} \binom{N}{j} p^j (1-p)^{N-j}$, where $p$ is the probability for a individual event from an isotropic flux to correlate. The significance of $P$ strongly depends on the search parameters, such as the angular scale, energy threshold and the selection of candidate sources. In order to test the previously reported excess correlations without any bias we build four tests with identical search parameters. The selection of sources candidates is based on magnitude, red shift, radio loudness, gamma ray emission and/or optical polarization. Note, however, that the field of view of the southern Pierre Auger Observatory differs from the one of the data sets used before, i.e. the source samples are not identical.

All four tests gave results consistent with an isotropic flux of UHECRs. For details of the analysis see [9].
2.4. Search for clustering of UHECR above 10 EeV

Clustered arrival directions of UHECRs would suggest that they are accelerated in celestial objects and provide a handle to identify them. The expectation for clustering increases with energy because the range of UHECRs gets smaller due to the GZK effect while the magnetic deflection decreases. So above 60 EeV a few nearby sources should dominate the flux and clustering should become significant.

There has been a claim of significant clustering by the AGASA-experiment. Auger has collected 62 events with energies above 40 EeV, which we used to search for clustering. However, since there is no a priori choice of energy threshold and angular separation, we do not choose a particular combination, but scan through all combinations within reasonable limits and account for the number of trials [11]. For any combination we count the number of pairs and estimate the chance probability from comparison with simulated isotropic samples.

In figure 2 we show the result for Auger data. For the cut combination used by AGASA (40 EeV, 2.5°) we obtain 2 pairs were 1.5 were expected from isotropy, i.e. our data do not confirm the AGASA report. The minimum of our scan is located at ≈60 EeV and 7° where 8 pairs are observed while 1 was expected ($P_{\text{min}} = 10^{-4}$). However, the chance probability to obtain that from a isotropic distribution with a scan is $P \approx 2 \times 10^{-2}$. So with the present statistics of Auger it is only marginally significant. For details of the analysis see [10] and references therein.

3. Conclusion

Four anisotropy searches based on data recorded with the Auger surface detector between January 2004 and March 2007 have been presented. No significant deviation from isotropy was found in these searches. Note that Auger will double its data set within one year.

4. References

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