Statistical tests applied to the study of the anisotropy of the highest energy cosmic rays.

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Abstract
This undergraduate research project aimed to analyze the arrival directions of the highest energy cosmic rays, looking for a possible sign of anisotropy. For this purpose, the data acquired by the Pierre Auger Observatory and made available for the public were studied. The data analysis was focused on the application of two statistical tests, the two-point angular correlation test and the Rayleigh test. The results of both tests for the available data until 2014 did not show any significant evidence of anisotropy.

Key words: cosmic rays, isotropy, Monte Carlo.

Introduction

The main aim of this project was to analyze the distribution of the arrival directions of cosmic rays with energies above 5.5x10^19 eV measured by the Auger Observatory in Argentina. The performed analysis may indicate a possible anisotropy, i.e., the possibility of one or more preferential arrival directions, indicating their possible sources.

The study was based on the application of two well-known statistical tests to analyze directional data on spherical surfaces: the Rayleigh test\(^1\) and the two-point angular correlation test\(^2\).

Results and Discussion

The two proposed statistical tests were applied to the cosmic rays measured at the Auger Observatory until the end of 2014 and that are publicly available\(^3\). For comparison, the same tests were applied to sets with the same number of directions in the sky obtained from Monte Carlo simulation assuming that these directions are isotropically distributed on the sky.

As the Auger Observatory has a partial view of the celestial sphere, the generation of the simulated directions took into account the relative exposure of the Observatory, which depends on the declination.

The Rayleigh and the two-point angular correlation tests were applied to the 140 measured cosmic ray directions and also to 10000 sets of 140 directions that were simulated by Monte Carlo. Each direction in the sky is characterized by a unit vector. For the Rayleigh test, the quantity \(3R^2/N\) is calculated, where \(N\) represents the number of cosmic ray directions (140 in this case) and \(R^2\) represents the square of the magnitude of the vector sum of the \(N\) directional vectors. The value obtained for \(3R^2/N\) with the real directions was compared with the distribution of the corresponding values for the 10000 simulated sets. The comparison result did not reveal any significant sign of deviation of isotropy, since the value of \(3R^2/N\) for the data resulted consistent with the mean value of the same quantity for the simulated sets.

For the two-point angular correlation test, the same number of 10000 sets of 140 directions was generated under the hypothesis of isotropy. For the measured set of directions as well as for each of the simulated sets, the angular separation between all pairs of directions was calculated. The resulting distributions were compared, and revealed to be consistent with each other, indicating the absence of significant evidence of anisotropy.

Conclusions

With this project it could be noticed that the arrival directions of the highest energy cosmic rays measured by the Auger Observatory until 2014 did not reveal any significant evidence of anisotropy under the applied tests, being consistent with an isotropic distribution. These results leave open the search for the possible sources of these highest energy particles.

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