Note on the Arrival Directions of the Highest Energy Cosmic Rays

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Abstract

The arrival directions of cosmic rays with derived energies above 10^{20}eV are examined. Those directions are fitted to celestial planes and are found to be a good fit to a combination of the galactic and supergalactic planes alone. That conclusion follows from applying both northern and southern data independently.

1. Introduction

The origins of the highest energy cosmic rays are unknown. However, at the highest energies, it is usual to expect that the propagation of those particles (probably protons) will be approximately linear and that their arrival directions would then give directional clues to their origins.

Attempts have been made to correlate the directions of such particles with the galactic and supergalactic planes. This met with some success using a compilation of northern hemisphere data [5] in which evidence was found for clustering towards the supergalactic plane. However, a similar analysis was inconclusive when applied to southern data from the Sydney University SUGAR array [4].

More recently, there has been the remarkable claim that cosmic rays at 10^{18}eV have at least one observable source direction, roughly 10° from the direction of the centre of our galaxy. That observation, first made by the AGASA group [3], was supported using data from the SUGAR array [1] which was the only cosmic ray array to have the source direction clearly within its field of view. The observation was important in itself but it also provided two further major pieces of information. It supported the idea that out galaxy can accelerate cosmic rays at least to 10^{18}eV, well above the limits of theoretical models. This is consistent with our picture of the energy spectrum being dominated by galactic particles up to the ankle. It also confirms that the SUGAR array provides data, on an event by event basis, which have adequate energy and directional information. Difficulties with photomultiplier afterpulsing had led to some uncertainty on that matter.

There is thus reason for treating the directions and energies of the highest energy events in the SUGAR catalogue as serious astronomical data within their known energy and directional uncertainties. I have therefore revisited the

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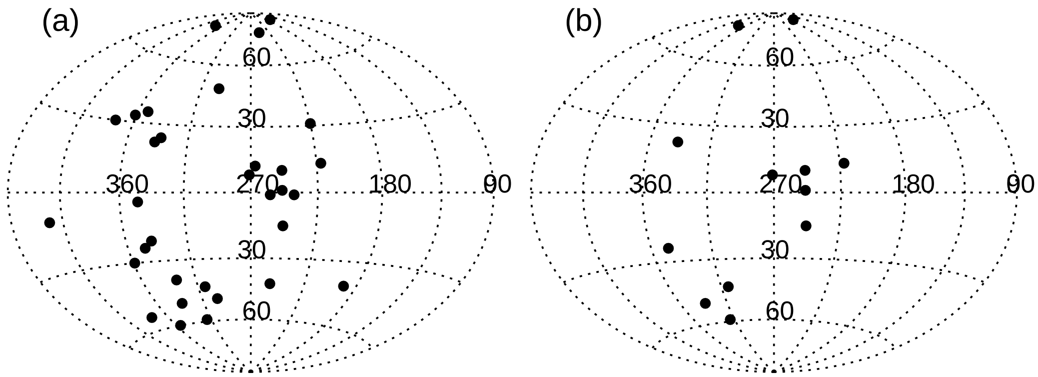

Fig. 1. Distribution in galactic coordinates of SUGAR events with energies (a) above 6×10^{19}eV and (b) 8×10^{19}eV.

directional properties of the worldwide cosmic ray dataset, including SUGAR.

It is clear from published sky maps that, despite clustering towards its direction, the highest energy cosmic rays (above 10^{20}eV) do not all come from the direction of the supergalactic plane [2,4,5]. On the other hand, despite the southern data not showing an overall rms angular deviation from the supergalactic plane which is less than expected on a random basis, in both the northern and southern maps there is a subjectively visible component which could well be said to follow that plane. For the SUGAR data, this is clear in data such as figure 1. This figure, in galactic coordinates, shows many data which are apparently in a line at a large angle to that plane, cutting it at a longitude of about 340°, plus remaining directions close to the galactic plane. The supergalactic plane cuts the galactic plane at a large angle at approximately a longitude of 320° and the data do suggest a supergalactic plane component in the SUGAR data. The lack of a significant rms clustering in the dataset is due to the remaining event directions.

The questions are, is this purely a subjective effect and, if the supergalactic plane is present, what is the meaning of the other arrival directions?

I have taken the southern (SUGAR, 8 events) and northern (Stanev *et al.* compilation, 8 events) data separately and determined the TWO planes which, in combination, give the lowest rms angular deviation of the data points from EITHER plane. In other words, I determined, for both the southern and northern data, the two best planes such that the cosmic ray arrivals would be associated with one or the other. This was achieved with a simple Monte Carlo process which determined the directions of the poles of the two planes. In galactic coordinates, those poles (b,l) were a. for the SUGAR fit $(84°, 8°)$ and $(8°, 243°)$ and b. for the northern fit $(84°, 3°)$ and $(0°, 205°)$. These independently determined planes are very similar to each other and are also very close to the galactic

$((90°, indeterminate)$ and supergalactic $(6°, 47°$ or $6°, 227°)$ planes. (A fit to the combined northern and southern datasets gives $(87°, 20°)$ and $(2°, 37°)$.) The SUGAR array has a characteristic angular uncertainty of about 5° and the rms angular deviation of its fit to the planes was 7°. It is unlikely that there is further remaining variance apart from the intrinsic angular widths of the two planes, also of the order of several degrees.

As a check on the compatability of the northern and southern data, I have taken the planes determined using the northern data and determined the rms deviation of the eight SUGAR directions from one or other of those planes. I then took the SUGAR dataset as a whole (over 15000 events) and selected, at random, 1400 groups of eight directions. When testing those 1400 groups, only four were better fits than the real SUGAR high energy data. If I had taken the accepted directions of the galactic and supergalactic planes, no randomly selected group would have been a better fit than the real SUGAR data.

2. Discussion

There is strong evidence (at the 4 parts in 1400 confidence level) that the northern and southern cosmic ray directional data above derived energies of 10^{20}eV are compatible in terms of being describable by two planes alone for the complete dataset. One of those planes is close to the galactic plane, within 6°, and the other is close to the supergalactic plane, within 20°. Considering the angular uncertainty of several degrees in the arrival direction determination of cosmic rays, and the diffuse nature of the galactic and (particularly) the supergalactic planes, those planes could well be the planes represented by the cosmic ray data. It would be a perverse coincidence if the two *a priori* planes fitted the data and were not the physical source planes.

3. Acknowledgements

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4. References

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