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Anisotropies at Ultra High Energies and the Galactic Halo

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Abstract

A measure of consistency is appearing in measurements of the anisotropy of arrival directions above 10^{17} eV and these show a Galactic Plane Enhancement and a S-N excess, to about 3.10^{18} eV. The implication is that Galactic particles predominate here. At higher energies, where an Extragalactic origin is preferred, a contender for the 'sources' is exotic dark matter particles. However, an analysis of the anisotropy at the highest energies, or, rather, the lack of it, makes this interpretation highly unlikely. Instead, 'bottom-up' acceleration, in galaxy-systems is preferred; the likely mass mixture of the primaries, above 10^{18} eV, helps to explain why strong clustering of arrival is not observed.

1 Introduction:

This paper addresses two, related, problems: the evidence for anisotropies in the arrival directions of cosmic rays above 10^{17} eV and their relevance to claims that exotic dark matter in the Galactic Halo may be the source of particles of the very highest energies.

It is particularly timely to examine the world's data on anisotropies in view of the forthcoming Auger Project which will provide data - initially in the Southern Hemisphere - on particles above 10^{18} eV, or so. A datum from the rest of the world is useful for two reasons: firstly, these data relate to lower energies than will be covered by Auger and will also provide an overlap in energy; secondly, there are suggestions that the anisotropy may differ from one Hemisphere to the other.

The search for evidence for ultra-high energy cosmic rays (UHECR) from exotic dark matter candidates will clearly be carried out more expeditiously when more data are available at the very highest energies but we contend that it is already clear that all such UHECR cannot be generated in this way.

2 The World Survey of Anisotropies:

In a recent paper (Wibig and Wolfendale, 1999) we have taken all the available data and analysed it in terms of the updated Wdowczyk and Wolfendale (1994) 'Galactic Plane Enhancement' (G.P.E.) formula:

$$R(b) = 1 - f + 1.43f(\exp -b^2) + g\,b$$

R(b) is the ratio of the intensity at Galactic latitude b to that expected for isotropy, f is the G.P.E. and g is a N-S anisotropy. The origin of f and g can be understood rather well in terms of the trajectory calculations by Chi et al. (1993a, b, c, 1994) and Dudarewicz et al. (1994).

Table 1 gives the data used and Figure 1 gives the derived values of f and g. A detailed study of the dispersion of the points about the means (for bins of energy) leads to the conclusion that the data are consistent.

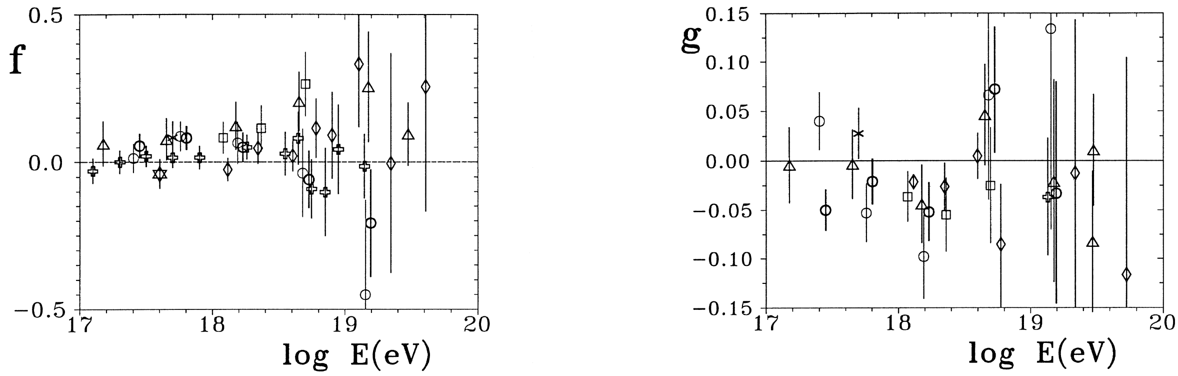

Figure 1: Galactic Plane Enhancement factor, f, and N/S Anisotropy factor, g, versus energy from data given by the authors listed in Table 1.

Array	Symbol	Latitude	Reference	Comments
Fly's Eye	○ **O**	40°N	Bird et al., (1999)	Stereo and Mono used; the data are very nearly independent.
Sydney	△	30°S	Bell et al., (1974), Winn et al., (1986)	Reanalysis by Chi et al., (1993b,c) below 10^{19} eV.
Akeno	⊕	36°N	Hayashida et al., (1999)	(1-2) 10^{18} eV - analysis by us from the contours given.
AGASA	⊕	36°N	Hayashida et al., (1997)	(1-10) 10^{17} eV - analysis by the authors themselves.
Haverah Park	□	54°N	Astley et al., (1981)	Analysis by us.
Yakutsk	◊	62°N	Ivanov (1998)	Errors increased so as to be consistent with other data (for the same particle number).
Chacaltaya	×	16°S	Anda et al., (1981)	Analysis by Wdowczyk and Wolfendale (1984).
Composite	✡		Wdowczyk and Wolfendale (1984)	Summary of world's data in terms of harmonic analysis for E < 10^{18} eV.
Composite	Δ		(see Chi et al., 1992 for catalogue references)	Analysis by us of the world's data > 10^{19} eV using Catalogue data.

Table 1: Sources of data for the results given in Figures 1 and 2

A valuable feature of the results is that there is a rough, negative, correlation of f and g, as expected from the Galactic trajectory calculations.

The average values are given in Figure 2. Also shown there are predictions for contributions from Light nuclei ('L', < Z> = 2) and Heavy ('H' <Z> = 15) according to the model of Wibig and Wolfendale (1999). The fit is not good but magnetic field model changes allow agreement to be reached.

Briefly, the results are consistent with the fraction of light Galactic nuclei being ~ 10% at 10^{18} eV and less than 1% at 5.10^{18} eV.

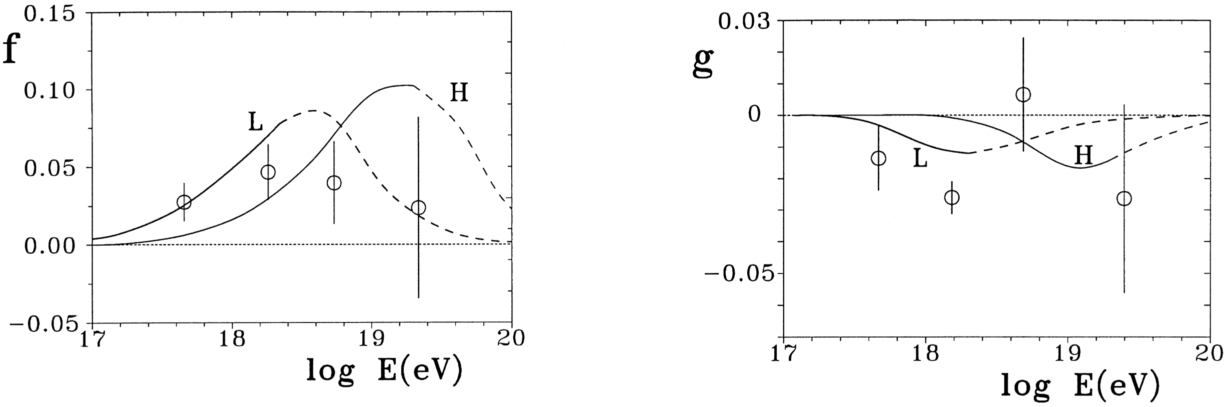

Figure 2: Average values of f and g from the data given in Figure 1 in comparison with expectation from a particular Galactic origin model (see text).

3 The Dark Matter Halo Model

A number of authors (e.g. Berezinsky et al., 1997, Birkel and Sarker, 1998) have suggested that the dark matter halo surrounding the Galaxy may contain 'cryptons' which decay into UHECR. Clearly, if the cryptons follow the 'ordinary' dark matter - for which the spatial distribution is thought to be known - then the expected anisotropies of arrival directions can be determined. We ourselves (Benson et al., 1999) have adopted a DM distribution of the form shown in Figure 3 and derived the expected anisotropy.

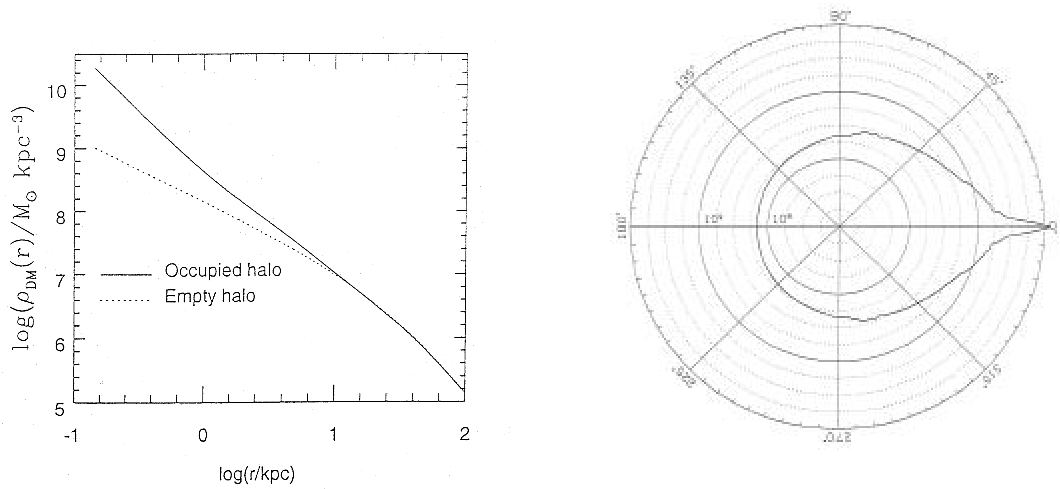

Figure 3: (Left) Density distribution versus Galactocentric distance r for an assumed spherically symmetrical halo. The ‘occupied halo’ curve is the correct one to use; in it the ordinary matter adds to the gravitational potential

(Right) The column density of dark matter seen from Earth (assuming a Galactocentric distance of 8.5 kpc) in units of solar masses per kpc^2 as a function of angle measured from the line $l = 0^o$. The results refer to zero latitude.

Two main comparisons have been made. Firstly, for <E> = 2 EeV and $|b| = 45^o$, and secondly for <E>

= 100 EeV and |b| $\simeq$ 0°. If, as would be likely for a DM model, all particles with <E> = 100 EeV were of DM origin then, for a reasonable spectrum, only 30% will be produced in this way at <E> = 2 EeV. Allowance has been made for this fact in what follows.

The resulting anisotropy factors from the data are, for 2 EeV, $R_1 - 1 = 0.04 \pm 0.04$, to be compared with an expectation of 0.8 ± 0.1. For 100 EeV the values are: (observed) $R_2 - 1 = -0.1 \pm 0.6$ and (expected) $5.3 ^{+3}_{-1}$. It is evident that there is no support for the DM model at all.

A strong argument supporting this conclusion is the non-observation of an excess from the 'nearby' Andromeda galaxy. The DM round Andromeda should give a mean UHECR intensity over a 10° radius of observation of ~ 4x. In fact, the data (from, e.g. Akeno) yields an excess of <15%, when allowance has been made for the Galactic contributions (at 2 EeV).

There is yet another reason which militates against the DM model and this concerns the unlikelihood of the DM being spherically symmetrical (B. Moore, private communication). It seems that an oblate spheroid with axial ratio of perhaps as much as 2, is preferred. Equally 'bad for the cause' is the fact that it is not yet known in which direction the axis is to be found.

The outlook for the DM model looks very bleak indeed.

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