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The Ankle in the UHE Cosmic Ray Spectrum

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Abstract: We have examined a variety of models for the origin of Extragalactic Cosmic Rays in order to see if it is possible to explain the ankle in the observed high energy spectrum as a property of EG protons alone. We find that it is not, a variety of effects smearing out the ankle due to the e^+e^- transition. We see no evidence to doubt our original contention that the ankle marks the cross-over from mainly Galactic to mainly EG sources. For 'exotic' EG sources such as AGN and quasars, the energy requirements are very severe and we wonder now if more normal galaxies are responsible in the sense that many galaxies generate particles of energy to 10^{20} eV but our own does not, at present.

Introduction

Uncertainty about the important 'demarkation energy, E_c' - the value at which the Galactic (G) and Extragalactic (EG) intensities are equal - comes from a variety of factors.

Firstly, although we have argued [1] that G-particles persist up to at least $3.10^{18}\ eV$ from a detailed analysis of directional anisotropies, favouring the Galactic Plane (which would indicate Galactic particles), we have to admit that these arguments rest, inevitably, on rather imprecise observations.

Secondly, a similar situation arises for the primary mass composition. The observations of the depth of shower maximum, the usual indicator of average primary mass, have been analysed by us [2], and others, to show that a significant fraction of heavy nuclei persist, even up to the highest energies. If so, then, as we have demonstrated [3], the ankle would not be explainable in EG terms alone, because of various smearing effects. However, not only do experimental problems arise but, importantly, the high energy interaction models are imprecise because of the inevitable need to extrapolate accelerator results to higher energies. Thus, in principle at least, the particles could be protons alone, right up through the ankle in energy.

The above is not to say that the EG-p scenario (i.e. all EG particles are protons and the ankle is a property of EG particles alone ,e.g. [4]) is likely. Nevertheless, it needs taking seriously. In passing, it can be remarked that, if true, the effect on the two factors described above would be serious, and interesting.

Analysis for EG-protons

The method is to adopt a variety of extragalactic source models, with their different spatial distributions and follow the CR protons through the CMB to their destination at earth. The ensuing energy spectrum is then compared with observation and conclusions drawn.

As is well known, there is no concensus as to the nature of the source(s) of EGCR. Even in the Galaxy itself, at least above the 'knee' - where supernova remnants (SNR) probably 'give out' - there is uncertainty. Thus, it is necessary to consider a number of possibilities.

The models are as follows:

1. Uniform density of identical sources. This unphysical situation is adopted as a datum, against which the more physically acceptable models can be compared.

2. Non-uniformity of the density of sources. Here we adopt as an indication the surveys of galaxy 'densities' by Dudarewicz et al. [5] and Medina-Tanco [6].

3. Colliding galaxies. A promising model has been put forward by Al Dargazelli et al. [7], based on an apparent coincidence of the arrival directions of some UHECR with 'nearby' colliding galaxies. Unfortunately, identifications of the galaxies are only secure to about 40 Mpc.

4. Galaxy clusters. In some senses this distribution can be taken as a proxy indicator of strong Active Galactic Nuclei (AGN). There are, however, some subtleties with regard to CR from Clusters [8], and these will be taken separately.

5. Quasars. Two distributions have been adopted here, but both are derived from the same basic data [9]. In one, Q1, only quasars intrinsically brighter than a particular value ($M_B = -24$) are assumed relevant. In the other, Q2, the integrated quasar luminosity is computed for each distance range (i.e. z-range) and adopted. Insofar as we need a mean magnitude and a density we adopt $M_B = -22$ for the former.

6. CDM. A 'long-shot' is the spatial distribution of dark matter estimated by us from a variety of sources. Inevitably, with its strong z-dependence its outcome is not very different from that for quasars.

Table 1 gives the basic data for the various models.

The calculations are made, as usual, using a continuum of sources with the appropriate source density versus radial distance. However, sources are not discrete and, when the mean density is low (but mean energy output high), an important phenomena appears, related to the distance to the nearest sources: there is an increasing loss of low energy particles the greater this distance is. This is illustrated in Figure 1a, for the datum situation of a constant density of sources, with a minimum distance of 50 Mpc. This distance corresponds to a spatial density of order 10^{-5} Mpc^{-3}, i.e. a factor 1000

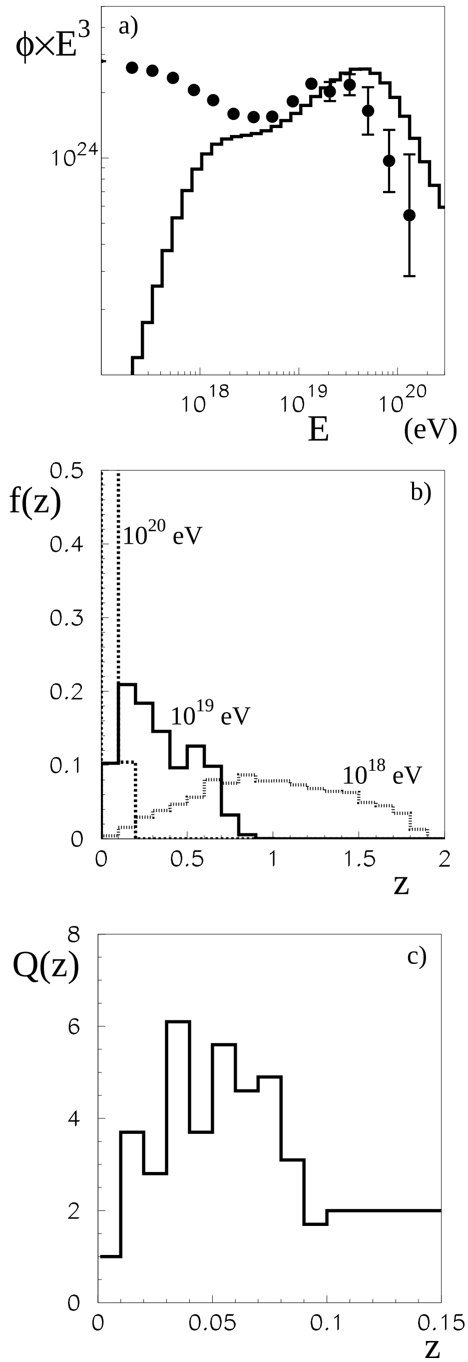

Figure 1: Results for the adopted galaxy cluster distribution (similar to that of AGN).
a) The derived spectrum.
b) The distribution of propagation times
c) Modification factor (source density divided by the local value) versus z.

Model Title	Median distance (Mpc)	Density (Mpc^{-3})	$< M_B >$	η
Uniform	650	10^{-2}	-20	10^{-3}
Galaxy Clusters (AGN)	300	3×10^{-5}	-20	0.3
Medina-Tanco	650	10^{-2}	-20	10^{-3}
Dudarewicz et al.	550	10^{-2}	-20	10^{-3}
Colliding galaxies	550	10^{-5}	-	1
Quasars (Q1)	1500	3×10^{-7}	-24	1
Quasars (Q2)	1400	3×10^{-6}	-22	0.1
CDM	850	-	-	-

Table 1: Parameters of the models

smaller than the spatial density of ‘normal galaxies’. Such a value is typical for likely EG sources.

The magnetic properties of the IGM are taken, following our earlier work, i.e. a mean field of 4 nG and a mean reversal length of 1 Mpc (4 nG corresponds to near equipartition of energy between the EG magnetic field and EGCR). These values are not critical.

The Results for EG-protons

An example of the results is shown in Figure 1 and Figure 2 shows a summary of the spectral shapes for all the models.
Inspection of Figure 2 shows that none of the spectra are satisfactory. Insofar as the standard input spectrum having $\gamma = 2.0$ has been adopted a steeper one could be taken such as to give a fit for case (h) (CDM) or, perhaps case (g) (Quasars, Q2). However, an artificial truncation would have to be included below 10^{18} eV to avoid too dramatic an energy input.

Discussion and Conclusions

It is evident that no model has been tried which gives consistency with the idea that all the UHECR above 10^{18} eV are EG protons and that the well-known ‘ankle’ is a property of the EG spectrum alone. When it is borne in mind that various phenomena, not considered here in detail - such as the likely intermittent nature of EG sources - would give rise to further distortions of the ankle, such a model seems to be ruled out, at least for the scenarios listed in Table 1.
Continuing with a discussion of source efficiency, as remarked earlier ‘normal’ galaxies give reasonable efficiencies (10^{-3}) but our own Galaxy does not, apparently, give particles of high enough energy. A way forward would be to assume that our Galaxy is unusual in this respect and that most ‘normal’ galaxies (say more than 50%) do have CR extending to 10^{20} eV. Such a situation, although not ideal, is probably the best one at the present time.
Our preferred model is still that the ankle represents the transition from mostly Galactic to mostly EG but the problem of just what the EG sources are, remains.

References

[1] Wibig T. and Wolfendale A.W., 1999a, J.Phys.G., **25**, 2001.
[2] Wibig T. and Wolfendale A.W., 1999b, J.Phys.G., **25**, 1099.
[3] Wibig T. and Wolfendale A.W., 2005, J.Phys.G., **31**, 255.
[4] Berezinsky V.S. et al., 2004, Astropart. Phys. **21**, 617.
[5] Dudarewicz A. and Wolfendale A.W., 1994, MNRAS **268**, 609. (basic data given in Chincarini G. et al., 1992 NATO. ASI. C. Vol. 366 ‘Clusters and Superclusters of Galaxies, Kluwer Dordrecht (ed. A.C.Fabian) 253).
[6] Medina-Tanco, G., 1998, Astrophys. J., **510**, L91.
[7] Al-Dargazelli, S.S. et al., 1996, J. Phys. G., **22**, 1825.
[8] Bahcall, N.A., 1988, Ann. Rev. Astron. and Astrophys., **26**, 631.
[9] Croom, S.M., 2004, Mon. Not. Roy. Astron. Soc. **349** 1397.

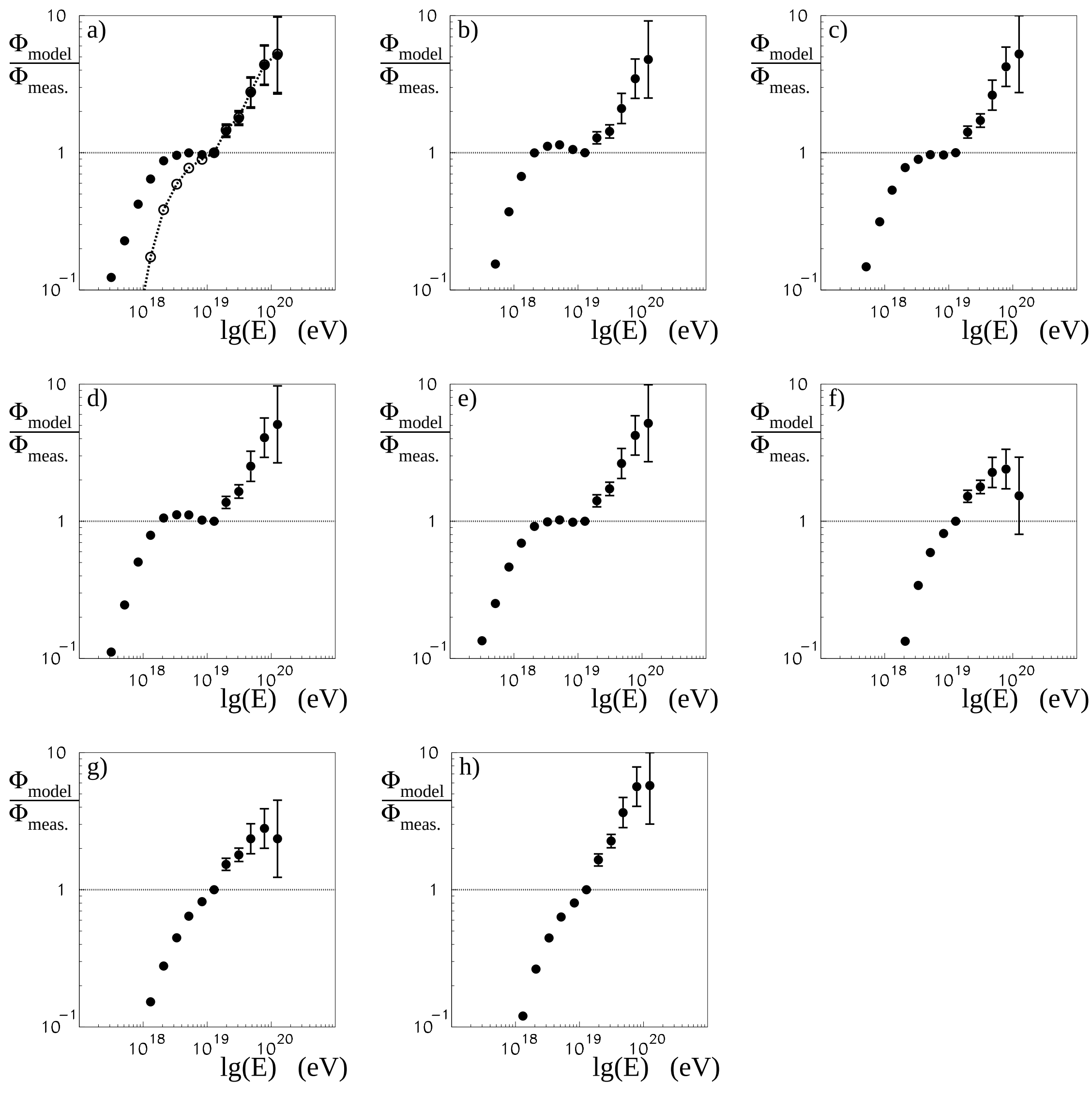

Figure 2: Ratios of predicted intensities to those measure from our previous summary, with the 'low' energy normalization for the models summarized in Table 1. In (a) the situation is also shown for there being no sources within 50 Mpc - dotted.