OG 1.3.01

Mass Composition above 10^{17}eV

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Abstract

A new analysis has been made of the constituent masses of primary cosmic ray nuclei using data from the Fly's Eye experiment (Bird et al., 1993) and a new air shower analysis by one of us (Wibig, 1998). The 'usual' Extragalactic (EG) component has been identified, but it is contended that this contains a significant fraction of heavy nuclei, right up to about 2.10^{19} eV, where the data cease. The implication is that perhaps as many as 50% of the EG particles start off as heavy nuclei (Fe?) and fragment on the radiation fields, as proposed by Tkaczyk et al. (1975).

The idea militates against exotic massive particles being the source of the EG particles.

1 Introduction:

It is conventional wisdom that the Extragalactic ultra high energy cosmic rays (UHECR) are protons. However, as we pointed out nearly 25 years ago (Tkaczyk et al, 1975), it is not unlikely that there is a significant admixture of heavier nuclei. Such an idea would be valuable - if true- from the standpoint of the difficulty, so far, of locating specific extragalactic sources. The presence of a mixture of masses (or, more significantly, charges) would cause a greater dispersion of arrival directions at earth of the UHECR.

The method adopted here is not a new one, in that it uses the spread of depth of shower maximum (and the means), as a function of energy, but what is new is the adoption of a (hopefully) more accurate interaction model than hitherto. The model is from the work of Wibig (1999), to be referred to as I.

2 The Analysis

The most comprehensive data on shower maxima appear to be those from the Fly's Eye detector (Bird et al., 1993). The results on the mean values are given in Figure 1; also given there are the predictions from I for the masses indicated. It is immediately evident that there is evidence for non-protons even above 10^{19} eV, where it is commonly believed that extragalactic particles predominate.

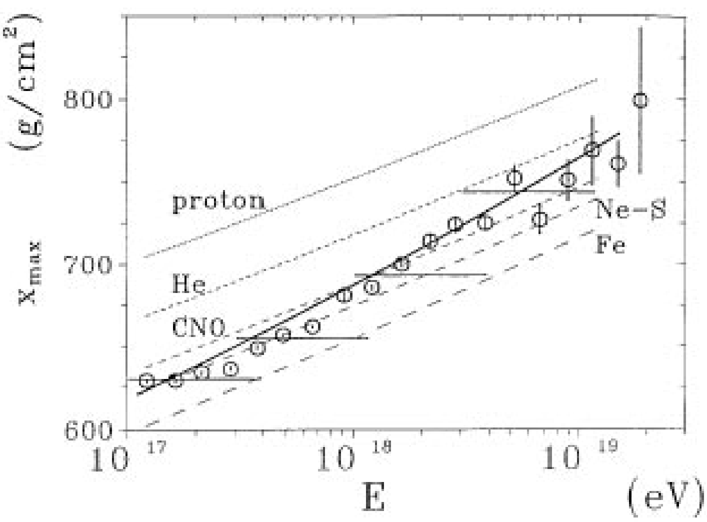

Figure 1. Depth of shower maximum versus energy from Fly's Eye (Bird et al., 1993) in comparison with our predictions for various nuclear masses (from I).

Elsewhere, (Wibig and Wolfendale, 1999, to be denoted II), we have estimated the fraction of light nuclei (<Z>~2) from Galactic sources which would be consistent with the anisotropy analysis of Chi et al. (1994) and this is given as GL in Figure 2 (it is similar to that derived from the anisotropy analysis described by Wolfendale et al. in these Proceedings). An estimate of the Galactic heavy nucleus flux (<Z> = 15) is also given in Figure 2. The results from Figure 1 are transposed to the points in Figure 2 assuming that there are just the two components (L and H).

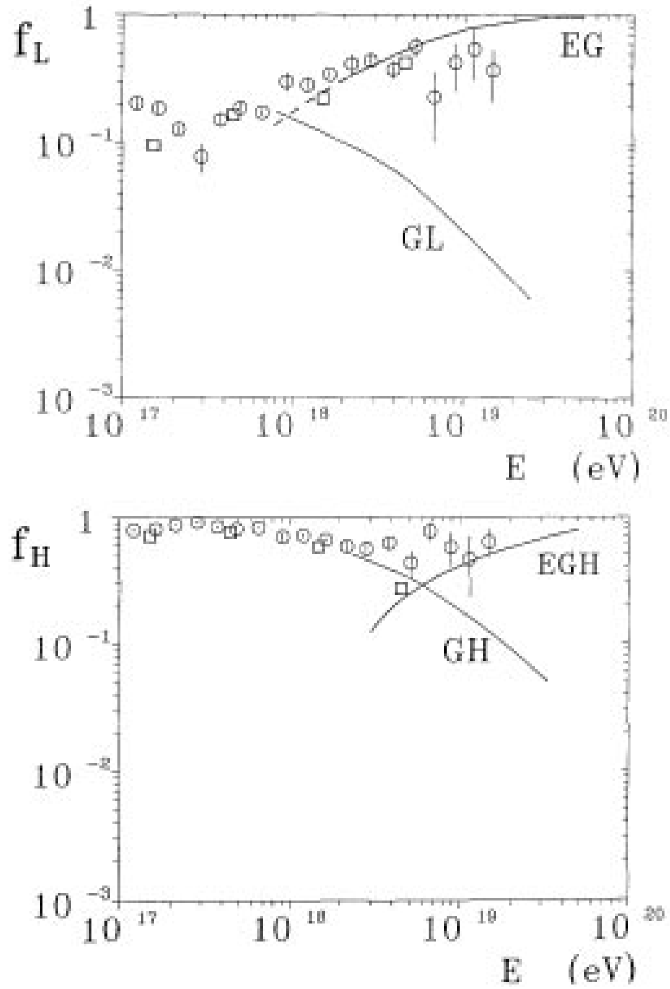

Figure 2. Division of the Galactic (G) and Extragalactic (EG) nuclei between Light (<Z> = 2) and Heavy (<Z> = 15).

A more detailed analysis has been given by us in II of the fluctuation results from Fly's Eye for the data divided into four energy bands: (1-3)10^{17}eV, (3-10)10^{17}eV, (1-3)10^{18}eV and (3-10)10^{18}eV. In each case fits have been made for various numbers of mass components, from 1 to 5; these are: P alone, Fe alone, P + Fe, P + CNO + Fe and P + He + CNO + (Ne - S) + Fe. In every case chi-squared fits show that the P alone and Fe alone situations are unacceptable at all energies. The situation for the other 3 mixtures is that increasing the number of components usually improves the chi-squared (per degree of freedom), although not markedly so. Nevertheless, if a mixture is required then it is rather unphysical that it should be simply P and Fe.

Figure 3 shows the situation for the highest energy groups.

A remark can be made with regard to the validity of the method, and the important conclusion that the EG component has a mixed composition. This is that there is virtually no latitude for systematically displacing the $f(X_{max})$ values (Fig. 3) so as to negate the presence of Fe; the f-values rise too rapidly at the lower X_{max} values.

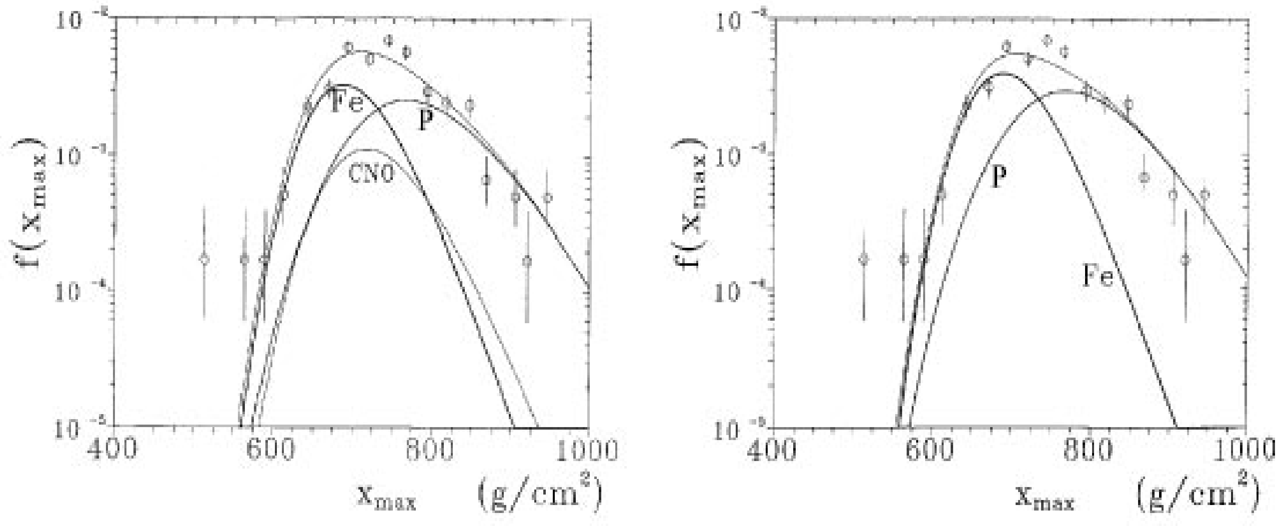

Figure 3. Frequency distribution of the depth of maximum values from the Fly's Eye experiment (Bird et al., 1993) in comparison with our prediction for two situations as to primary masses: P + Fe + CNO, and P + Fe. The energy range is the highest available: $(3\text{-}10)10^{18}$ eV.

3 Conclusions:

There is evidence for nuclei heavier than protons at all energies considered, including those above 3.10^{18}eV where EG particles predominate (Figure 2). An approximate analysis (see II), using the EG propagation calculations of Tkaczyk et al. (1975), indicates that some 50% of the EG particles of UHE could have started off as iron nuclei; the result is then protons plus fragmentation products of the interactions.

References

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