THE GALACTIC COSMIC RAY ENERGY SPECTRA AS MEASURED BY THE FRENCH-DANISH INSTRUMENT ON HEAO-3

E. Juliusson, J.J. Engelmann, J. Jorrand, L. Koch-Miramond, P. Masse, N. Petrou

Service d'Astrophysique, Centre d'Etudes Nucléaires de Saclay, France

N. Lund, I.L. Rasmussen, M. Rotenberg

Danish Space Research Institute, Copenhagen, Denmark

ABSTRACT

We report measurements of the energy spectra of the galactic cosmic rays from Beryllium to Nickel made between 0.7 and 30 GeV/nuc with the French-Danish instrument on board the HEAO-3 satellite.

1. Introduction

The HEAO-3 french-danish instrument with its three Cerenkov detectors can measure the cosmic ray spectra over a wide energy range, as discussed in another paper at this conference (Engelmann et al., 1983, hereinafter : paper I), which also discusses the problem of combining measurements made by different counters with different resolution.

One problem which immediately arises when measuring the absolute spectra rather than the relative composition is that the geomagnetic field does not transmit particles with rigidity below a certain cut off value. During the flight, this cut off value constantly changes, which does not affect the relative abundances at any particular energy, but distorts the measured spectra, since very high energy nuclei are collected all the time, while low energy nuclei are collected only when the cut off value is sufficiently low.

2. Cut off corrections

How we correct for this cut-off variation is shown in figure 1. This is a scatter plot of log momentum (P) versus log rigidity cut-off (R), showing well the location of the cut-off around R/P = 2.15 (the A/Z value). We discard the nuclei too close to the cut off, that is where $R/P > 1.20 = \alpha$ and collect the momentum spectra N'(P) and cut-off spectra M'(R) for the remaining nuclei. These spectra are of course drastically affected by the sharp cut-off condition $R/P \geq \alpha$. The undistorted spectra N(P) and M(R), free from magnetic filtering can now be calculated. As one can quickly see by looking at the figure :

$$M(R) = M'(R) \sum_0^\infty N(P)dP / \sum_{R/\alpha}^\infty N(P)dP \qquad (1)$$

$$N(P) = N'(P) \sum_0^{\infty} M(R)dR / \sum_0^{\alpha P} M(R)dR = N'(P).CORR(P)$$

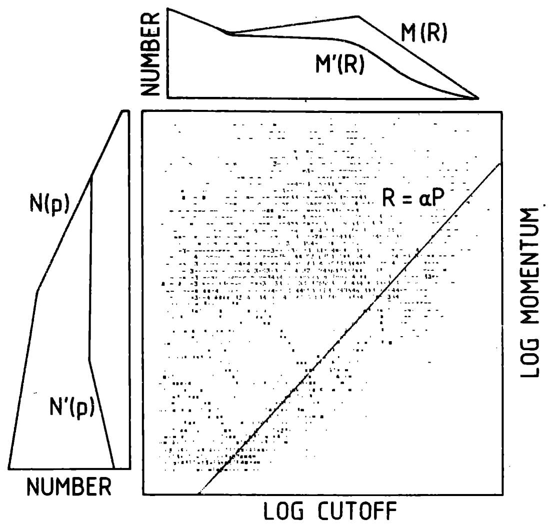


Fig.1: Scatter plot of log momentum (P) versus log rigity cut off (R)

these coupled equations can be solved in a few iterations giving the correction factors CORR(P) and the undistorted spectra in momentum and cut off, i.e. the time spent at the different cut offs during the flight.

The measured momentum spectra N'(P) are here obtained using the method explained in paper I, but that method is used here only for obtaining the correction factor CORR(P). For the absolute spectra we want to use a more physical method showing better up to which energy we can make measurements with the instrument.

3. Measurement of the momentum spectra

We made a Monte Carlo simulation of the signal response of the three Cerenkov counters, starting from an input spectrum $N_G(P)$ chosen as a powerlaw in total energy sufficiently close to the true spectrum N(P). This gives us calculated signal spectra $F_G(Si)$ which can be compared to the measured signal spectra $F_M(Si)$, where Si is the i th. channel of the spectrum. In the calculation of $F_G(Si)$, the cut off correction given by (1) is taken into account as an entrance probability T(P) =1/CORR(P). The other corrections for interaction, efficiency and selection by the instrument are included in the same way in the simulation, which takes also into account the slowing down of the nucleus in the instrument and some non linearities or departure of the Cerenkov response from the ideal form $S = 1 - P_c^2/P^2$. A random signal fluctuation is included both geometrical (proportional to S) and statistical (also inversely proportional to Z) and a background signal with geometrical and statistical fluctuation is added. The simulation reproduces well the actual distribution, except for the long tail apparent in the observed signal distribution, especially for the light nuclei, due to some unknown background.

At the same time the simulation calculates the average momentum P_i of the particles within each signal channel Si. How this average is calculated is not critical, but one can show, that for power law spectra the geometrical mean (exp ($\langle$ Log P $\rangle$)) is the most representative average and it will therefore be used here.

We then define the measured flux at momentum P_i to be :

$$N_M(P_i) = N_G(P_i) \cdot F_M(Si)/F_G(Si) \quad (2)$$

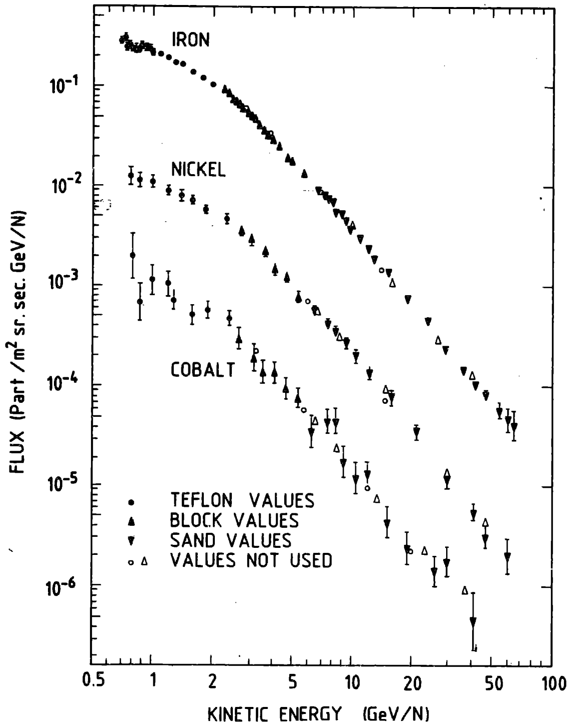


Fig. 2 : Energy spectra of Fe, Ni, Co nuclei obtained independently with the three Cerenkov detectors.

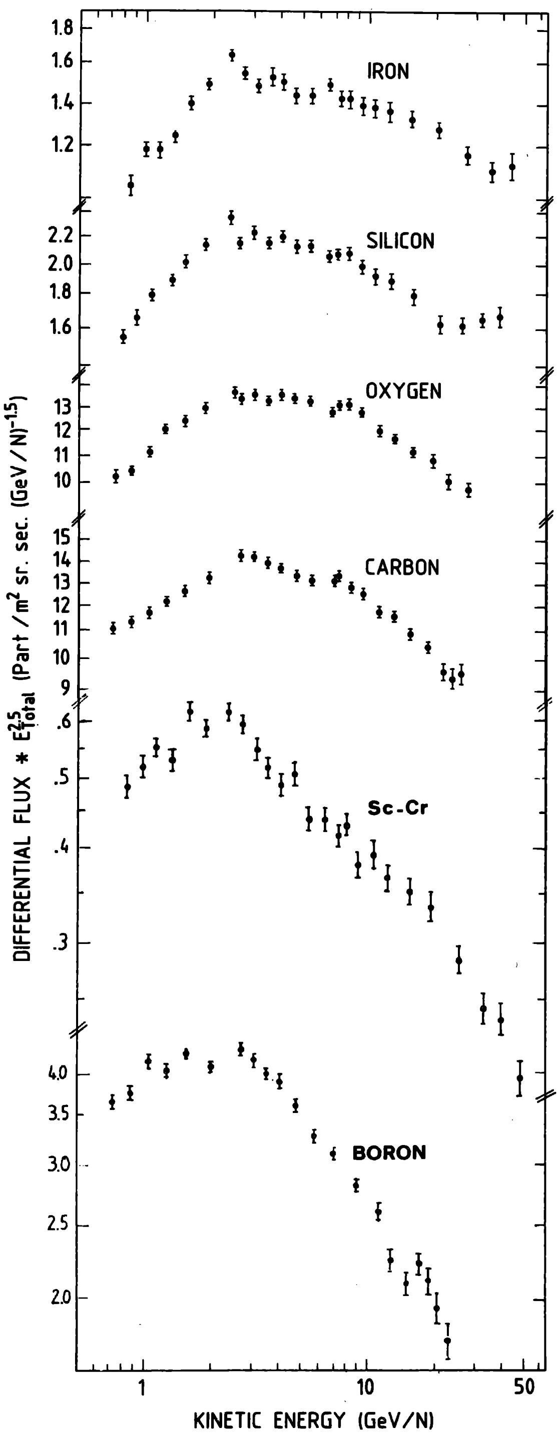
The resulting spectra for the Iron group nuclei are shown in figure 2. This figure shows teflon, block and sand spectra, obtained independently from each other, as explained in paper I. By most standards of comparison the agreement between the individual spectra is excellent. This agreement to within a few percent up to the very high energy, at least for the heavier elements, is a powerful argument for believing that the systematic errors on the final spectra are very small, or at most a very few percent. However, with our minute statistical errors associated with the millions of events collected, the systematic errors, although small, are in many cases still limiting the accuracy. The limiting factors are the final accuracy with which we know the resolution of the instrument, the thresholds of the counters, non linearities in the instrument response, efficiencies of the hodoscope and cut off corrections. The final values for all of these factors are derived from the data itself.

4. Results

At least at this stage, we cannot derive the absolute flux, so we normalize all results to :

FLUX (OXYGEN) AT 4 GeV = 0.25 per m^2 Sr.S. GeV/nuc. in agreement with Webber (1982).

A full table of fluxes $N(P_i)$ with errors for all the elements cannot be included here, but figure 3 shows the spectra measured for some of the cosmic ray nuclei. These spectra have been flattened by multiplication by $(E_{TOTAL})^{2.5}$ to show more clearly the details of the spectra. All the spectra are quite smooth and the separation between the points in figure 3 is larger than or comparable to the energy resolution below 10 GeV/nuc., so any irregularity even narrow should be clearly visible.



This is no longer true above 10 GeV/nuc., where only broad irregularities or spectral changes can be considered significant.

References

Engelmann, J.J. et al. (1983), paper OG 1-9 this Conf.

Webber, W.R. (1982), Int. School of Cosmic Rays Astrophysics, Erice.

Fig. 3 : Flattened spectra of primary and secondary nuclei obtained by multiplying the differential flux by $E^{2.5}_{total}$