ABUNDANCES OF 'SECONDARY' ELEMENTS AMONG THE ULTRAHEAVY COSMIC RAYS - RESULTS FROM HEAO-3

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ABSTRACT

The HEAO-3 Heavy Nuclei Experiment has measured elemental abundances of ultraheavy cosmic rays near earth. The elements with atomic number (Z) in the intervals $44 \lesssim Z \lesssim 48$ and $62 \lesssim Z \lesssim 74$ arriving at earth are expected to have significant secondary components. However, their source abundances are unlikely to be low enough to warrant treating them as pure secondaries. Our results are consistent with solar system abundances modified for first ionization potential with possibly some enhancement of the r to s ratio.

Introduction

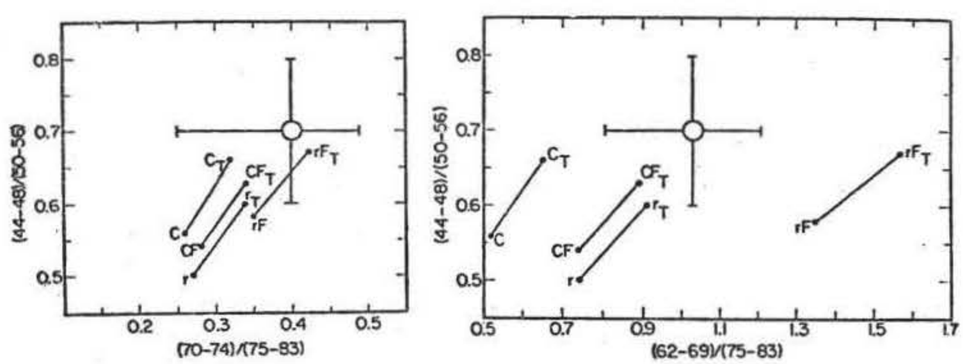
The overabundance in the cosmic radiation of nuclei with $3 \lesssim Z \lesssim 5$ and $21 \lesssim Z \lesssim 25$ relative to their solar system abundances has long been attributed to fragmentation in the interstellar medium. Comparison of the matter traversed implied by the overabundance of the light nuclei with that implied by the sub-iron elements has led to the conclusion that there is a distribution of traversed pathlengths. The conventional model assumes an exponential distribution which is equivalent to escape from a 'leaky box'. Some evidence for the need to remove short pathlengths from such a distribution has been advanced and in response several models of 'truncation' have been suggested including that of a 'nested leaky box' of Cowsik and Wilson(1973,1975). The ultraheavy elements provide a test for the need for truncation. Their interaction mean free path is much shorter than that of the lower charge nuclei subjecting them to an increased amount of fragmentation for the same path length.

Experiment

The HEAO-3 Heavy Nuclei Experiment was designed to measure the abundances of the heavier nuclei in the cosmic radiation (Binns et al 1981). This is the first report of results on those charge groups most likely to have a bearing on models of propagation. Because of limitations on statistics and resolution we will restrict ourselves to charge group ratios. The elements with $44 \lesssim Z \lesssim 48$ have solar system abundances which are significantly less than their neighbors with $50 \le Z \le 56$. A similar situation exists with respect to the groups $62 \le Z \le 69$ and $70 \le Z \le 74$ when compared to $75 \le Z \le 83$. Thus the ratios of these charge groups provide information on the nature of cosmic ray propagation.

For the charge range $40 \le Z \le 60$ the data are those used in Stone et al (OG 1-21). The data in the range $62 \le Z \le 83$ are from Fixsen et al (OG 1-22). Both data sets are for particles with an energy greater than 1 Gev/amu with a mean energy substantially above this lower limit. The data were selected to exclude interactions in the Cherenkov radiators or in the material material surrounding them. This was done by requiring agreement between the ion chamber signals on either side, whenever possible, otherwise agreement between the signals in the Cherenkov and the ion chamber was required. Interactions in the entrance window could not be detected.

The abundance ratios have not been corrected for events lost due to interactions in the detector. The decrease in interaction mean free path with increasing charge increases the number of interactions of higher charges but the broadening of charge resolution reduces the chance of rejecting those interactions in which only a few charges were lost. These two effects nearly cancel each other in this experiment. A rough calculation showed that interactions in the entrance window to the detector would reduce the ratios observed here by about 5%. This is a negligible correction considering the uncertainties in the calculation and in our experimental data.



Figures 1 and 2: Observed abundance ratios compared to predictions of various source and propagation models.
o = Experimental point.
C = solar system abundances (Cameron 1982a).
r = r component of solar system (Cameron 1982b).
F = FIP correction (Brewster et al 1983).
T = nested leaky box escape lengths: 1 and 4.5 g/cm^2 H.
All others single leaky box with escape length 5.5 g/cm^2 H.

Results

In figures 1 and 2 our experimental results are compared to several propagation calculations of Brewster et al.(1983). Our numerical results are:

$$S40 = \frac{44 \leq Z \leq 48}{50 \leq Z \leq 56} = .70 \pm .10$$

$$S60 = \frac{62 \leq Z \leq 69}{75 \leq Z \leq 83} = 1.03 \begin{smallmatrix} +.18 \\ -.22 \end{smallmatrix}$$

$$S70 = \frac{70 \leq Z \leq 74}{75 \leq Z \leq 83} = .40 \begin{smallmatrix} +.09 \\ -.15 \end{smallmatrix}$$

It is evident that neither the ratio S40 nor the ratio S70 is very sensitive to the assumed source composition, whereas the ratio S60 is. The ratio S40 suggests a truncation of short path lengths. The ratio S60 suggests a source differing from the FIP corrected solar system by a larger r to s ratio.

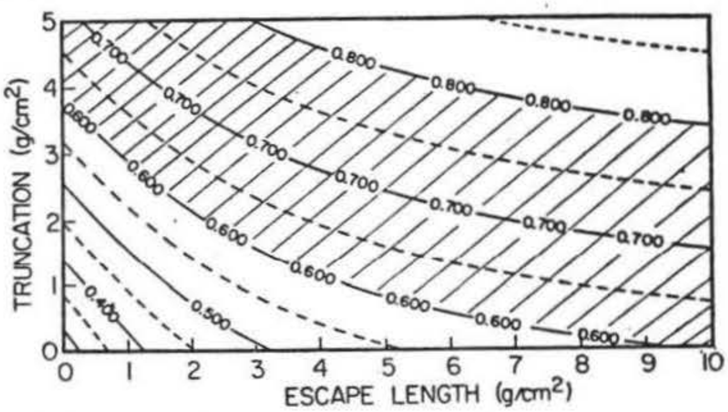


Figure 3: (44-48)/(50-56) with FIP (see text)

A different method to assess the effect of truncation in short pathlengths was described by Margolis in OG 5.2-8 and is shown in figure 3. Contours of the ratio S40 are plotted after propagating a solar system source (Anders and Ebihara 1982) modified for a first ionization potential correlation through the interstellar medium. Every point on the figure corresponds to the calculated ratio after propagation through hydrogen with a mean free path distribution rising linearly from zero to the desired 'truncation' (in g/cm^2), then falling exponentially with the given 'escape length'. The shaded area indicates the $\pm$ 1σ limits on our observed value for this ratio. The figure points out that this ratio is in fact not very sensitive to the parameters used in the propagation model. Again our result suggests the need for some truncation but it differs by only 1.3σ from the point at 6.5 g/cm^2 escape length with zero truncation.

Our results are thus compatible with plausible sources and current propagation models of the cosmic rays.

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