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CORRELATION OF SOURCE ABUNDANCES OF ULTRAHEAVY COSMIC RAYS WITH FIRST IONIZATION POTENTIAL – RESULTS FROM HEAO-3

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ABSTRACT

The cosmic-ray-source abundances inferred from HEAO-3 observation by the Heavy Nuclei Experiment for $30 < Z < 60$ generally follow the correlation with first-ionization potential which has previously been observed for $Z < 30$. However the low Ge abundance suggests that the elemental "volatility" may be an organizing factor.

1. Introduction

The relative abundances of elements at the cosmic ray source are broadly similar to the abundances found in the solar system, but with distinct quantitative differences. Cassé and Goret (1978) demonstrated that the ratio of cosmic-ray-source (CRS) to solar system (SS) abundances shows a strong correlation with the first-ionization potential (FIP) of the element, with elements of high FIP having a lower CRS/SS ratio. While the data available to Cassé and Goret were confined to elements of $Z \leq 28$ (where Z is atomic number), preliminary result from the HEAO-3 Heavy Nuclei Detector (Binns et al. 1981) indicated that the same correlation extended to the even-Z elements of $Z \leq 40$. At higher charge, Binns et al. (1983) showed that the observed relative abundances among the four even-Z elements Sn, Te, Xe, Ba ($50 \leq Z \leq 56$) were roughly consistent with what would be expected for a cosmic-ray source of solar-system abundances, modified by the same FIP correlation.

An alternative to FIP as an organizer for the CRS/SS ratio is elemental volatility, since among the elements for which good cosmic-ray source abundances have been determined those with high FIP are volatile, and those with low FIP are refractory (Cesarsky and Bibring, 1980; Epstein, 1980, Tarafdar and Apparao, 1981; Bibring and Cesarsky, 1981). Meyer (1981) has summarized the elements which might be used to distinguish between the effects of volatility and FIP. In particular the volatile elements with low FIP which have substantial primary components at earth are ${}_{32}$Ge, ${}_{50}$Sn, and ${}_{82}$Pb.

2. Data

New results from the HEAO-3 Heavy Nuclei Experiment in the interval $32 \leq Z \leq 42$ (Binns et al., OG1-16) give data from a significantly larger period of time than previously reported, so better statistical accuracy is achieved. Also the new data report a lower abundance of ${}_{32}$Ge than before, because some Fe events which had previously been misidentified as Ge have now been recognized and eliminated.

In the interval $50 \leq Z \leq 58$, Krombel et al. (OG1-21) report relative abundances of the even-Z elements from the same instrument. We have used a carefully selected set of events in this charge interval and a correspondingly selected set of Fe to determine that the abundance of the group $50 \leq Z \leq 58$ is 22 ± 4 per 10^6 Fe. This normalization permits us to place these elements on the usual CRS/SS vs FIP plot.

We have propagated our observed abundances back to the cosmic-ray source using the propagation of Margolis (OG5.2-8). Table 1 gives our observed abundances and the source abundances which result from propagation back to the source in three propagation models, a 5.5 g/cm^2 leaky box, a 6.5 g/cm^2 leaky box, and a path length distribution with linear rise to 1.0 g/cm^2 followed by 6.5 g/cm^2 exponential decay. The error bars on the source abundances are the result of the error bars on the observations after propagation back to the source; they represent the one-sigma source uncertainty owing to the one-sigma uncertainty of observation of all the elements which affect that source abundance. These error bars do not include any effect of uncertainty in the nuclear interaction cross-sections or in the path-length distribution. The differences among the source abundances from the propagations listed here demonstrates the lack of sensitivity to propagation details for most of these elements, because most of them do not have major secondary contribution. However, the source abundances for $_{36}$Kr, $_{50}$Sn, and to a lesser degree $_{52}$Te are in the fact quite sensitive to the propagation, because of the substantial secondary Kr contribution from $_{38}$Sr and the secondary Sn and Te contributions from $_{54}$Xe and $_{56}$Ba. (Source abundances inferred from a propagation by Brewster et al. (1983) agree with those of the Margolis propagation used here.)

Table 1. Abundances Relative to 10^6 Fe

Z	Observed		Inferred Source					
			5.5 g/cm^2		6.5 g/cm^2		(1 + 6.5 g/cm^2)*	
Ge 32	91	$^{+12}_{-8}$	81	$^{+14}_{-9}$	81	$^{+14}_{-9}$	79	$^{+14}_{-9}$
Se 34	43	$^{+9}_{-6}$	32	$^{+11}_{-6}$	32	$^{+11}_{-6}$	30	$^{+11}_{-7}$
Kr 36	23	$^{+8}_{-5}$	13	$^{+9}_{-5}$	12	$^{+10}_{-5}$	9	$^{+10}_{-6}$
Sr 38	34	$^{+10}_{-6}$	33	$^{+12}_{-7}$	33	$^{+12}_{-7}$	33	$^{+13}_{-7}$
Zr 40	13	$^{+5}_{-4}$	14	$^{+6}_{-4}$	14	$^{+6}_{-4}$	14	$^{+7}_{-5}$
Mo 42	8	$^{+2}_{-2}$	7	$^{+3}_{-3}$	7	$^{+3}_{-3}$	7	$^{+3}_{-3}$
Sn 50	5.5	±1.6	3.0	±2.2	2.8	±2.2	2.1	±2.4
Te 52	3.3	±1.1	2.5	±1.6	2.5	±1.6	2.1	±1.8
Xe 54	3.4	±1.1	3.7	±1.6	3.0	±1.6	2.8	±1.8
Ba 56	6.0	±1.5	7.0	±2.1	7.1	±2.1	7.5	±2.3
Ce 58	2.7	±1.0	3.5	±1.5	3.6	±1.6	4.0	±1.8

*Linear rise to 1 g/cm^2 followed by 6.5 g/cm^2 exponential.

Figure 1 plots the CRS/SS ratio for $Z > 30$ from our results and for $Z \leq 30$ from Perron et al. (1981). Our data are plotted for the 6.5 g/cm^2 leaky box; approximately the same propagation was used for the C2 results. The plotted error bars on CRS/SS include the solar system uncertainties.

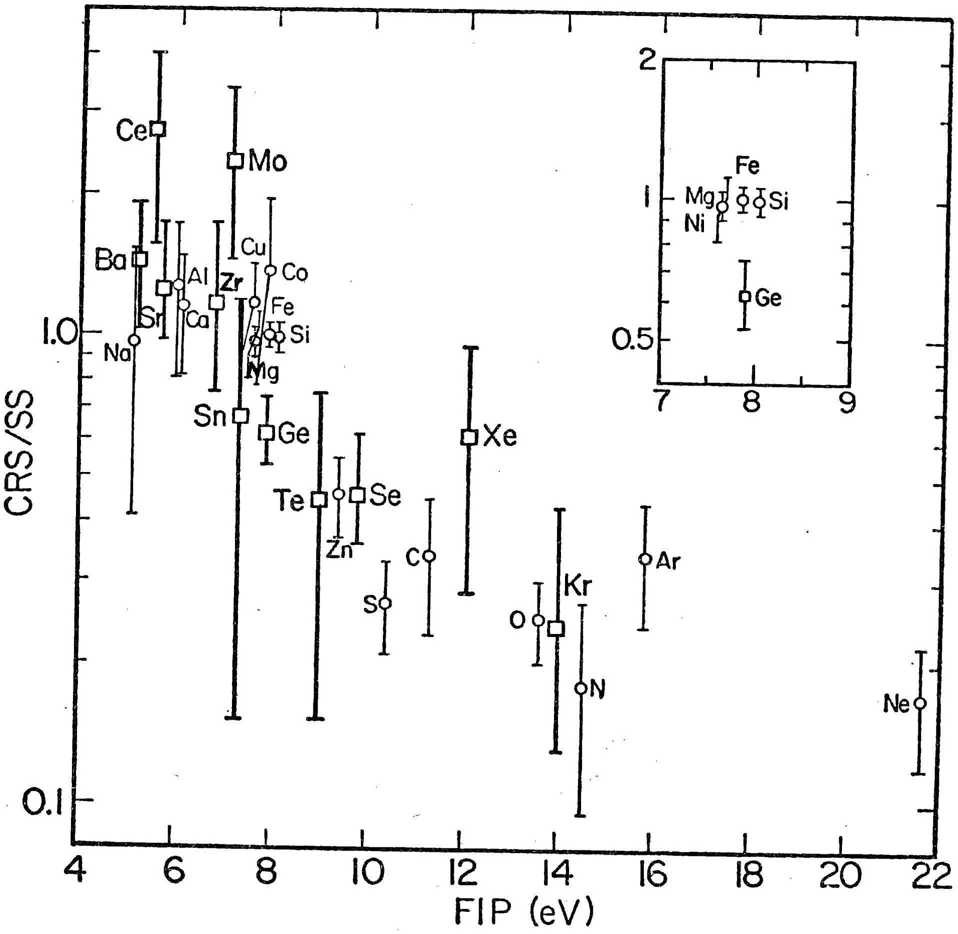

Figure 1. Ratio of cosmic-ray-source (CRS) abundances to solar-system (SS) abundances (Anders and Ebihara, 1982) versus the first ionization potential (FIP) of the elements. Squares use our CRS data. Circles use CRS data of Perron et al. (1981).

3. Discussion

Figure 1 demonstrates that the elements with well-defined source abundances in the $32 \leq Z \leq 58$ interval generally follow the same correlation of CRS/SS vs FIP as do the elements of $6 \leq Z \leq 30$. However, we note (see insert) that Ge falls nearly a factor of two below the very well determined points for Mg, Ni, Fe, and Si which have nearly the same FIP. This difference suggests that volatility may indeed be a significant factor. The Sn result is consistent with the importance of volatility, but the large uncertainty in its source abundance makes Sn inconclusive in distinguishing the effects of volatility from those of FIP.

If indeed abundances of volatile elements are suppressed below those expected from a FIP model, then the low abundance of Pb relative to Pt which has been observed in our HEAO experiment (Fixsen et al. OG1-22) could be at least partially explained by the volatility of Pb, and it may not be necessary to invoke a depletion of s-process nuclei in the Pt-Pb region.

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