Composition Measurements from ISEE-3: Fluorine through Calcium *

Richard A. Leske[1] and Mark l?. Wiedenbeck[2]
[1] California Institute of Technology, [2]Jet Propulsion Laboratory
Pasadena, California USA

ABSTRACT

Spacecraft measurements are reported of the elemental composition of galactic cosmic rays with $9 < Z \leq 20$ at energies ~ 220 MeV/nucleon. In addition, for the elements with $16 \leq Z \leq 20$ isotopic composition results are reported. The measured composition is found to be in generally good agreement with that expected from a propagated solar-like source.

1. INTRODUCTION

Studies of the composition of nuclei heavier than helium in galactic cosmic rays have revealed a pattern of source abundances which are remarkably similar to those found in the solar system, taking into account fractionation effects correlated with first ionization potential. Several exceptions to this pattern have been found in the form of enhanced abundances of a small number of specific isotopes, most notably ^{22}Ne. This previous work has focused primarily on the charge range up through silicon and on the iron group, because these elements are the most abundant and are expected to have sizable primary components.

To look for evidence of further compositional differences between the solar system and the cosmic ray source we have studied elements in the intermediate range $9 \leq Z \leq 20$. Our observations were made with the high energy cosmic ray experiment aboard the ISEE-3 spacecraft during the period 1978 August to 1981 April. These low energy data also serve to test models of cosmic ray propagation at energies below 1 GeV/nucleon where previous measurements are very limited. The analysis techniques employed have been described in detail by Leske (1993).

2. ELEMENTAL ABUNDANCES

Our measurements of elemental abundances relative to silicon are listed in Table 1. In Figure 1 these abundances (filled circles) are compared with previously reported observations. over a broad range of energies. Above 1 GeV/nucleon the energy dependence of these elemental ratios has been relatively well defined by the measurements from the HEAO-C2 experiment (Engelmann *et al.* 1990). However, below 1 GeV/nucleon the data are very limited. Previous spacecraft observations at energies ~ 100 to 200 MeV/nucleon have been reported from IMP-8 (Garcia-Munoz and Simpson 1979) and Voyager (Ferrando *et al.* 1991 a,b) but the derived abundance ratios have relatively large uncertainties. For several elements (e.g., F, Na, Al) discrepancies between the two data sets are apparent, although with the large uncertainties on the measurements the significance of some individual differences is no more than two standard deviations. However, the differences appear to follow a pattern in which the Voyager abundances are in most cases lower than those from IMP-8. Our data, which have significantly smaller uncertainties, generally indicate values closer to those reported from Voyager.

The solid curves shown in Figure 1 are the results of a calculation of propagation and solar modulation effects using parameters previously found to give reasonable agreement for the secondary-to-primary ratios B/C and Sc+Ti+V/Fe (Leske 1993). No adjustments have been made to the model to improve the fit in the range $15 \leq Z \leq 20$, and it is clear that there are some significant discrepancies. At energies $\lesssim 400$ MeV/nucleon

* Part of the work described herein was performed by the Jet Propulsion Laboratory of the California Institute of Technology under contract with the National Aeronautics and Space Administration. Early parts of this work were carried out at the University of Chicago with support from NASA grant NAG 5-308.

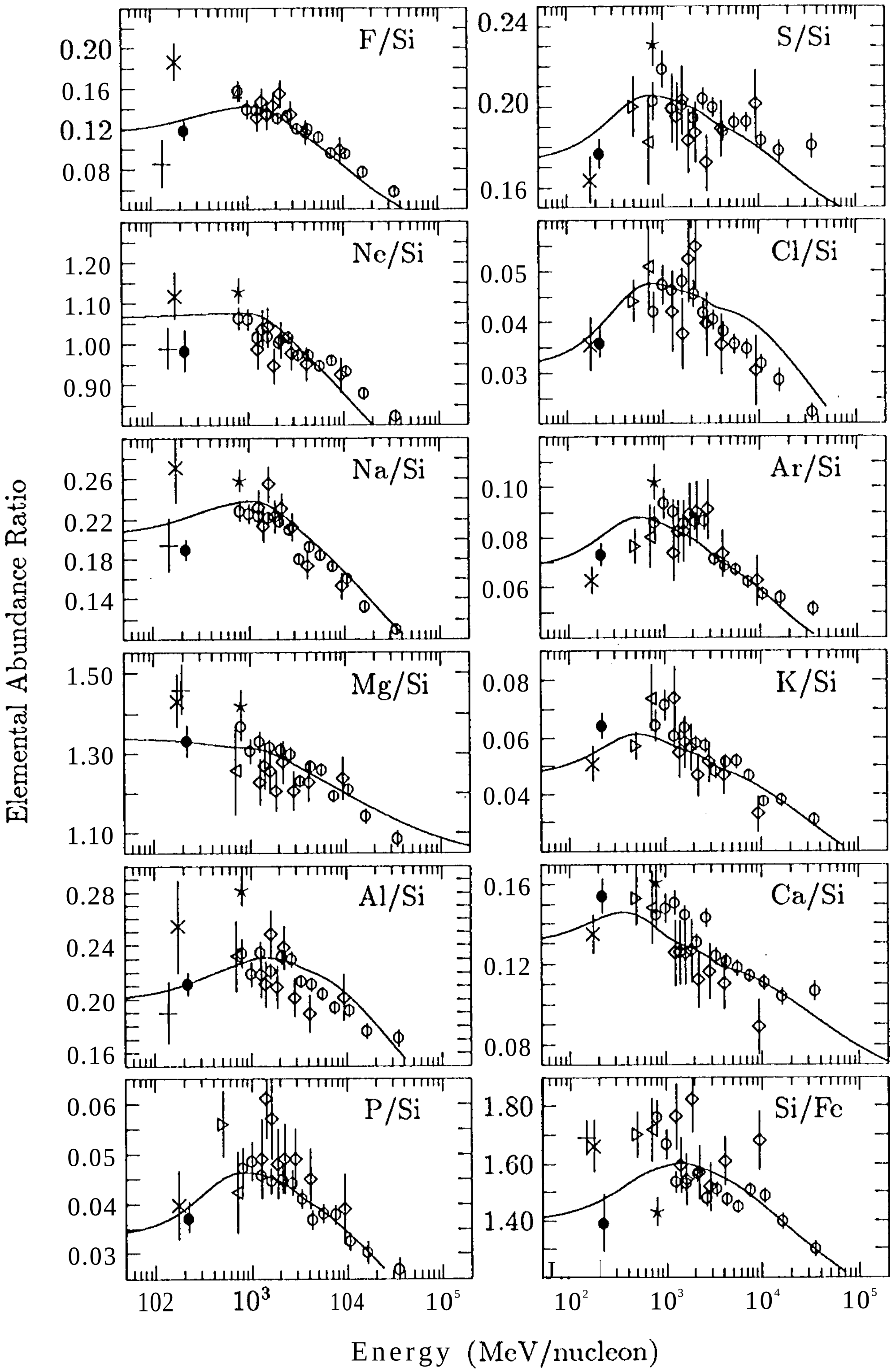

Fig. 1: Measured elemental abundance ratios (points) compared with results of a propagation calculation (smooth curves). Satellite measurements: . this work; x Garcia-Munoz *et al.* (1979); + Ferrando *et al.* (1991 a, b); o Engelmann *et al.* (1990). Balloon measurements: ▹ Minnesota; o Chicago; ⋆ New Hampshire; a GSFC/Siegen.

the models indicate that the ratios plotted should decrease with decreasing energy. Our data tend to support this prediction, but more extensive and more precise low energy observations are needed to adequately test the propagation and solar modulation model.

3. ISOTOPIC COMPOSITION

We have previously reported isotopic composition measurements from ISEE-3 for the elements Nc, Mg, Al, and Si, and will not repeat those here.

For the intermediate-mass elements 15< Z ≤ 20 the mass resolution of the ISEE-3 instrument was not sufficient to resolve individual isotopes, and the abundances of these elements arc sufficiently low that one cannot use data cuts to select a high resolution subset of the data while still retaining adequate statistical accuracy. Rather, looser cuts were used to obtain the mass distributions shown in Figure **2,** and the isotope fractions were derived by fitting peaks whose shapes were obtained from previous studies of the instrument response over a broad range of elements, extending both below and above the range discussed here. Comparing the mass distribution for P, which should consist of the single stable isotope ^{31}P, with those of the heavier elements one sees that the resolution is sufficient to reliably derive abundances of the major isotopes.

Table 2 shows the isotopic composition derived for each element. These values include small corrections for the differences between the energy intervals over which the various nuclides are measured, and for differences in nuclear interaction 1osscs in the instrument. In Figure 3 these mass fractions are compared with previous measurements made with balloon-borne experiments, and with earlier partial results from ISEE-3. Also shown in Figure 3 (horizontal lines) arc the mass fractions predicted using the model of propagation and solar modulation mentioned above. In this calculation it was assumed that the isotopic composition of the cosmic ray source is like that of the solar system. Thus major differences between the predicted and measured mass fractions could indicate differences in isotopic composition between the cosmic ray source and the solar system. However, our observations do not indicate any such major differences. While this mainly reflects the fact that the abundances of most nuclides in this charge range are expected to be dominated by secondaries, it can be used to conclude that the dominant isotopes of S and Ca in the cosmic ray source are ^{32}S and ^{40}Ca, and to indicate that ^{36}Ar is probably the major isotope of Ar just as it is in primordial solar material uncontaminated by ^{40}Ar produced from ^{40}K decay.

TABLE 1
Measured Elemental Abundances

F	118±10
Nc	982±51
Na	189±11
Mg	1 330±40
Al	211±9
Si	≡ 1000
I'	3743
s	176±8
Cl	36±3
Ar	73±5
K	64±5
Ca	154±9
Fe	719±54

TABLE 2
Measured Mass Fractions

	A	Fraction
s	32	0.65+ 0.04
	33	0.'13 ± 0,03
	34	0.21 ± 0.03
	36	< 0.02
Cl	35	0.60* 0.07
	36	0.13 ± 0.07
	37	0.27 ± 0.07
Ar	36	0.36+ 0.06
	37	0.23+ 0.06
	38	0.37 ± 0.06
	40	$0.034^{+0.024}_{-0.017}$
K	39	0.48+ 0.06
	40	0.25 ± 0.07
	41	0.27 ± 0.06
Ca	40	0.27+ 0.04
	41	0.12 ± 0.03
	42	0.14 ± 0.03
	43	0,23 ± 0.04
	44	0.24 ± 0.04
	46	<0.012

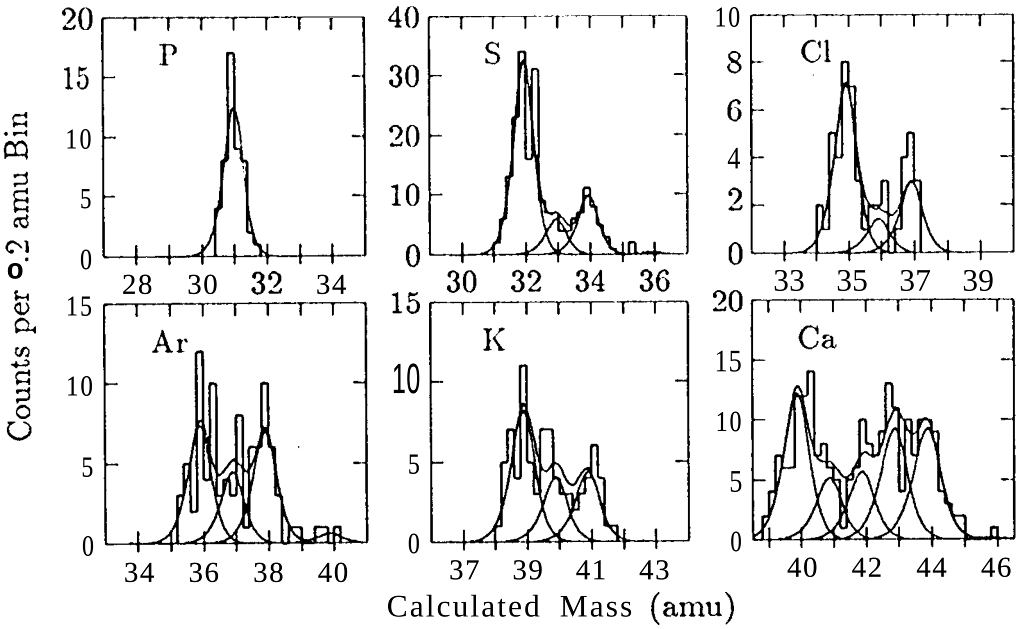

Fig. 2: Measured mass histograms. The smooth curves show the fits on which the reported abundances are based (Leske 1993). For sulfur, $\sigma_M \simeq 0.3$ amu.

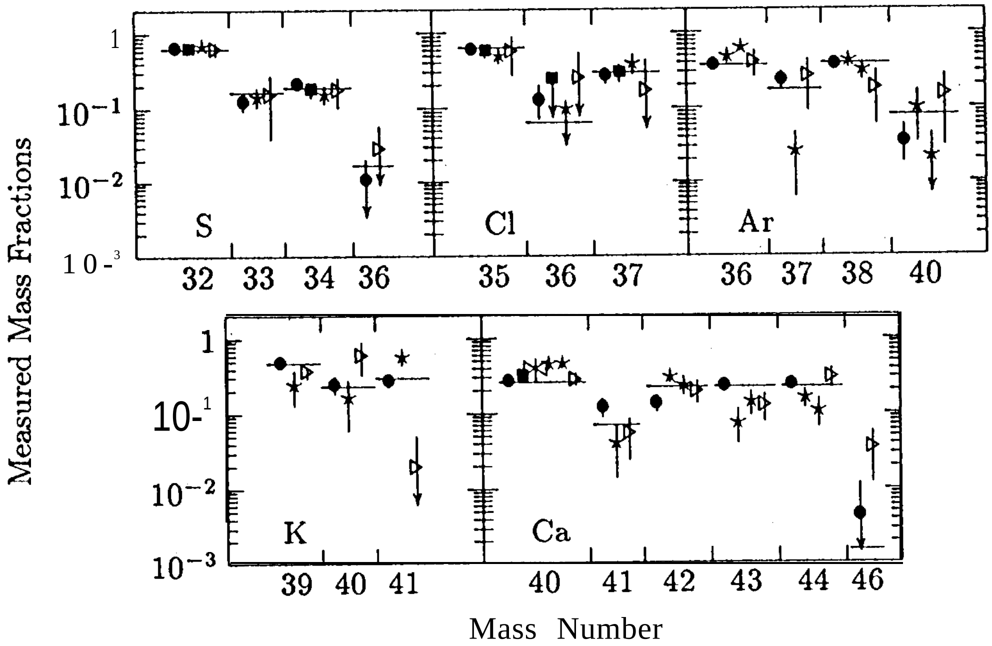

Fig. 3: Measured mass fractions compared with predictions of the propagation model (horizontal lines). ■ previous results from ISEE-3; ⋈ UC Berkeley balloon experiment; the other symbols are defined in the caption to Fig. 1.

REFERENCES

Engelmann, J.J., et *al.*: 1990, A&A, 233, 96.
Ferrando, P., *et al.*: 1991a, A&A, 247, 163.
Ferrando, P., *et al.*: 1991b, Proc. 22nd ICRC (Dublin), 1, 647.
Garcia-Munoz, M., and Simpson J. A.: 1979, Proc. 16th ICRC (Kyoto), 1, 270.
Leske, R. A.: 1993, Ap.J., 405, 567.