Bull. Astr. Soc. India (1993) **21**, 387-390

Observations of sub-iron (Sc-Cr) to iron (Fe) abundance ratios in the low energy (30-300 MeV/N) galactic cosmic rays in Spacelab-3 experiment and their implications

S. Biswas, N. Durgaprasad, R. K. Singh, M. N. Vahia and J. S. Yadav
Tata Institute of Fundamental Research, Bombay 400 005

A. Dutta and J. N. Goswami
Physical Research Laboratory, Ahmedabad 380 009

Abstract. The Spacelab-3 cosmic ray experiment Anuradha was used to measure the sub-iron (Sc-Cr) to iron abundance ratios in the low energy galactic cosmic rays. Measurements made at four different depths of the detector yielded the (Sc-Cr)/Fe ratios of 0.8 to 1.2 in 30 to 300 MeV/N. These are in agreement with results from Skylab and Soyuz-6 experiments and establishes that this abundance ratio is about 1.0 inside the magnetosphere. It is seen that this abundance ratio is about a factor of two higher than values of about 0.5 measured in space crafts in interplanetary space. It is shown that the enhancement of the ratio is probably due to the geomagnetic transmission effects and the degree of ionization of the low energy Sc to Cr and Fe ions in galactic cosmic rays. Further studies are needed to fully understand the phenomena and their implications.

Key words : cosmic ray—abundance ratio—space craft

1. Introduction

The measurements of abundance ratios of sub-iron (Sc-Cr) to iron ions in Galactic Cosmic Rays (GCR) have been used for over two decades as the sensitive indicators of amount of material traversed by cosmic rays in the interstellar medium, as it is well known that the sub-iron ions are produced by the fragmentation process of iron nuclei in collisions with the interstellar matter.

We present here, the recent results obtained by us on the (Sc-Cr)/Fe abundance ratios in low energies (E = 30-300 MeV/N) in Spacelab-3 cosmic ray experiment and discuss their new implications. It is found that the new value of about (1.0), obtained from the measurements at low energies, agrees well with that obtained in satellite experiments conducted inside the magnetosphere in Skylab, Spacelab-3 (preliminary results) and Soyuz-6. On the other hand, spacecraft measurements of the ratios in low energy range of about 80-400 MeV/N in interplanetary medium on IMP-8, ISEE-3 and Voyager-2 are consistent with one another and yield the ratio of about 0.5. This apparently large difference has been a puzzling problem.

In this paper, (i) we establish the reliability of the enhanced ratios by a number of new measurements; (ii) we suggest the possible hypothesis which will be able to resolve the apparent anomaly of the difference in the ratios, inside and outside the magnetosphere. It is noted that the future experiments with large statistics will be able to confirm the validity of the picture.

2. Experiment and results

The details of the detector used and the experimental procedure used are as follows. One hundred and forty nine sheets of CR-39 detector, each of nominal thickness of about 0.25 mm and 40 cm diameter were exposed to cosmic rays in the Anuradha experiment in Spacelab-3 mission of NASA, USA. The plates were scanned in pairs for double cones produced by cosmic ray events. The pairs of plates selected for the present study were 1-0 & 1-1, 1-2 & 1-3, 1-14 & 1-15, and 2-50 & 2-51 to allow the dynamic range of energy between (30-300 MeV/N) for the iron group of nuclei. These cones were then followed through till the end of their paths in the stack for the determination of their energies and their nuclear charges. This was done using the technique of energy loss rate versus the residual energy. The charge resolution of identification was $\sigma_z = 0.3$ for $Z = 22\text{-}26$. In table 1, we give the abundance ratios obtained in this experiment.

Table 1. Sub-iron (Sc-Cr) to Fe abundance ratios in Spacelab-3. Corrected ratio refers to the fragmentation correction. The number of events used refer to those in overlapping energy intervals

Sr. No.	Scan plates	No. of events	Energy (MeV/N)	Measured (Sc-Cr)/Fe	Corrected (Sc-Cr)/Fe
1	1-0, 1-1	28	22-80	1.20 ± 0.45	1.20 ± 0.45
2	1-2, 1-3	44	54-80	1.00 ± 0.30	1.00 ± 0.30
3	1-14, 1-15	21	90-170	1.18 ± 0.52	1.15 ± 0.51
4	2-50, 2-51	29	190-280	1.07 ± 0.40	0.98 ± 0.37

In figure 1 we show the results obtained so far on the ratios in the energy range 30-10,000 MeV/N, together with our results.

In order to understand the enhancement of the low energy abundance ratios, we suggest the following scenario, which is consistent with the standard model of cosmic ray origin and propagation.

1. GCR heavy ions such as Fe ions originate from galactic sources e.g. SN, SNR etc.
2. These are injected with some initial acceleration into the ISM.
3. Interaction with matter in ISM results in the fragmentation of iron particles into sub-iron. This process, at low and intermediate energies, (500-10,000 MeV/N), gives a path length of about 8-10 $g{\cdot}cm^{-2}$ of interstellar matter.
4. Energy loss of these GCR heavy ions in ISM reduce the energies to 1-10 MeV/N for some particles.
5. These low energy ions are in partially ionized states (equilibrium charge distribution), get accelerated to medium energies through supernova remnant shock fronts in the ISM or accelerated in heliospheric shock fronts.

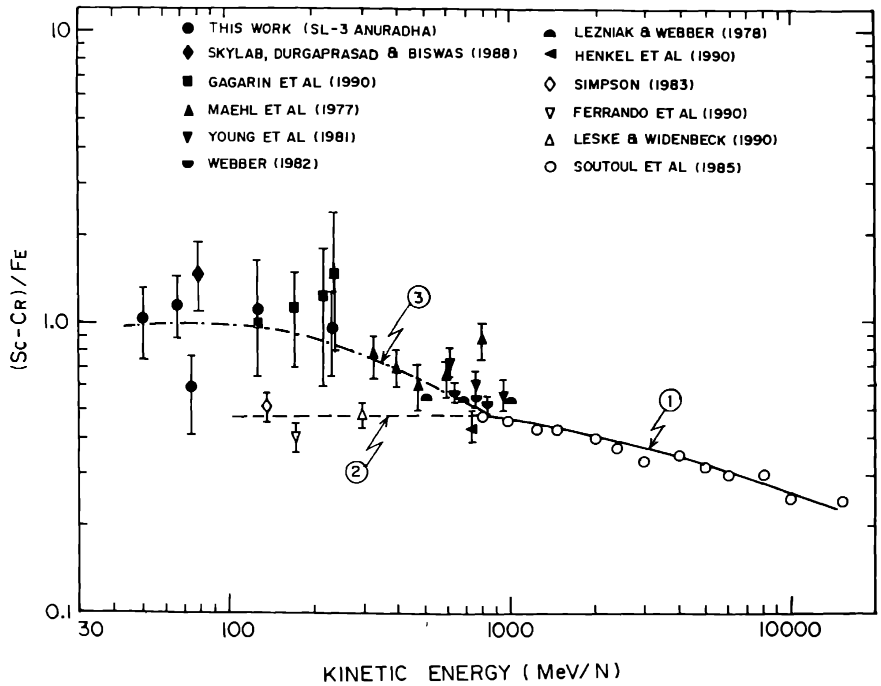

Figure 1. Abundance ratios of (Sc-Cr) to Fe versus energy/N measured in this experiment and compared with other investigators. Closed symbols show data within the magnetosphere in Skylab, Spacelab-3 and Soyuz-6 as well as several balloon experiments. Open symbols refer to values obtained outside the magnetosphere in IMP-8, Voyager-2 and ISEE-3 spacecrafts. The solid line in the figure is a functional fit given by Soutoul *et al.* for HEAO-3 data. The dashed and dashed-dotted lines are merely meant to guide the eyes.

6. These particles propagate in the interplanetary medium where they maintain their charge states.
7. The ratio gets enhanced within the magnetosphere by about a factor of 2—wholly or partly due to geomagnetic transmission effects (see table 2).

In table 2, we give the calculated and measured ratios of (Sc-Cr)/Fe in the geomagnetosphere. Mean degree of ionization, Z^*/Z, is according to the charge states measured by Dutta *et al.* (1993). The effective exposure factor (EEF) is according to Biswas *et al.* (1988). Calculated enhancement factor (CEF) is due to the EEF. The measured enhancement factor (MEF) is the ratio of the measured flux inside the geomagnetosphere to that measured outside the geomagnetosphere as obtained from figure 1.

Table 2. Calculated and measured ratios of (Sc-Cr)/Fe in the geomagnetosphere

Ion	Z^*/Z (Upper limit)	Av. Mom. PC (GeV)	EEF (Upper limit)	CEF (Lower limit)	MEF
Sc-Cr	0.71	0.37	0.091	1.2	2.2
Fe	0.80	0.37	0.079	1.0	1.0

3. Future work

We suggest that, (i) in future, cosmic ray detectors to detect sub-iron and iron particles at low energies be flown in spacecrafts inside the magnetosphere and in the interplanetary space at the same period of time; (ii) the results, therefrom, can provide information on the mean ionization state of these elements; (iii) these, in turn, will help to understand the electron capture and reacceleration processes in the interstellar medium, as well as the transmission effects in the interplanetary medium and in the magnetosphere.

References

Biswas S., Durgaprasad N., Singh R. K., Vahia M. N., Yadav J. S., Dutta A., Goswami J. N., 1988, Astrophys. Space Sci., 149, 357.

Durgaprasad N., Biswas S., 1988, Astrophys. Space Sci., 149, 163 and references cited therein.

Dutta A., Goswami J. N., Biswas S., Durgaprasad N., Mitra B., Singh R. K., 1993, ApJ (in press).

Ferrando P., Lal N., McDonald F. B., Webber W. R., 1990, 21st ICRC, 3, 40.

Gagarin Yu. F., Dvoryanchikov Ya. V., Lyagruchin V. I., Ovchinnikova A. Yu., Solovyev A. V., Khilyutta I. G., 1990, 21st ICRC, 3, 11.

Henkel M., Acharya B. S., Heinbach U., Heinrich W., Hesse A., Koch Ch., Luzietti B., Noll A., Simon M., Tittel H. O., Esposito J. A., Streitmatter R. E., Ormes J. F., Balasubrahmanyan V. K., Chistian E. R., Barbier L. M., 1990, 21st ICRC, 3, 15.

Leske R. A., Wiedenbeck M. E., 1990, 21st ICRC, 3, 57.

Simpson J. A., 1983, in : Composition of Origin of Cosmic Rays, ed. M. M. Shapiro, D. Reidel, Dordrecht, Holland, p. 1.