ELEMENTAL ABUNDANCE DIFFERENCES BETWEEN NUCLEI ACCELERATED IN CIR SHOCKS AND SOLAR FLARES

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ABSTRACT. By measuring the ratios of nuclear abundances H/He, CNO/Fe-group and the Fe-group/HE for 51 passages of Corotating Interaction Regions (CIRs) at 1 AU, and also by measuring these ratios from 620 solar flares in the energy range 0.6 to 4 MeV per nucleon, it is concluded that CIR shock acceleration alone does not change significantly these ratios from the values they have for solar system abundances or the solar wind. On the other hand, the solar flare ratios continue to reflect strong biases in the abundances, consistent with requirements for multi-stage acceleration processes at the Sun.

1. **Introduction.** It was discovered that hydrogen and helium nuclei are accelerated in the interplanetary medium in association with corotating interaction regions (CIRs) mainly beyond 1 AU (McDonald et al. 1976; Barnes and Simpson 1976) and that the corotating shocks associated with the CIRs are the site of the acceleration process (e.g. Barnes and Simpson 1976; Pesses et al. 1978). McGuire et al. (1978), Gloeckler et al.(1979) and Scholer et al. (1979) then showed that at 1 AU, CIRs accelerate nuclei over the element range of hydrogen to iron with relative abundances that tend to be different from typical abundance distributions observed at low energies in solar flare accelerated nuclei.

The evidence by Tsurutani et al. (1982) that CIR shock acceleration of ions is due to quasi-perpendicular shocks mainly beyond 1 AU now provides the opportunity to investigate further; 1) the origin of the local (interplanetary) "seed" ion population which is accelerated by CIRs, and; 2) the question of whether an interplanetary quasi-perpendicular shock can reproduce the kinds of preferential enhancements of abundances frequently observed for solar flare accelerated nuclei. This latter question has a strong bearing on whether, in solar flares, shocks alone can account for the observed enhancements, or whether, for example, the ions in the solar flare site undergo a preliminary stage of injection which biases the relative abundances. Our investigation includes the measurement of selected abundance ratios (e.g., H/He, CNO/Fe, and Fe/He) for 51 passages of CIRs at 1 AU during the period 1973-79. We also have determined these abundance ratios for 620 solar flares observed during 1973-84, of which a subset of 100 flares are observed to be ^{3}He-rich.

2. **Experimental Aspects.** Because the spectra of CIR accelerated nuclei have steep negative slopes and are restricted to energies below a few MeV per nucleon, their measurement by means of single dE/dx parameter analysis is difficult (e.g. McGuire et al. 1978). These difficulties are reduced in the case of the IMP 7 and IMP 8 Low Energy Telescope (LET; Simpson et al., 1974) which, in addition to a thin dE/dx detector has: a) a second yes/no detector providing particle range information, and; b) a 256 channel pulse height analyzer that spans the range H to Fe (which is in saturation). Pulse discriminator levels are set for fluxes of four

major nuclear groups, mainly H, He, CNO and Mg-Fe. The latter group, dominated by the iron flux will be referred to as the Fe-group ("Fe") in this report. The pulse height analysis enables us: 1) to independently measure the energy spectrum of He nuclei; 2) to evaluate any contamination of low Z particles by higher Z nuclei (which is an insignificant factor for the CIR composition measurements) and; 3) to normalize the fluxes of H, He, CNO, and "Fe" to abundance ratios for the same energy per nucleon. For CIRs the principal source of error in the "Fe" group abundances is statistical fluctuations, however for the CNO group and He abundances, the largest errors are systematic (i.e. from uncertainties in the count rate discriminator levels, the spectral slope, and uncertainties of range-energy relations at these low energies). For solar flares the "Fe" contamination appearing in the CNO fluxes is the most significant factor. Since the same instrument and method of analysis are employed in obtaining both CIR and solar flare abundances, the systematic errors mostly cancel when determining the ratios of abundances. Further details on the analysis will be published elsewhere.

The identification of intervals for CIR passage were mainly based on CIRs identified in previous publications (see e.g., Christon and Simpson, 1979; Tsurutani _et al_., 1982) with the constraints that: 1) the flux for the He at low energy must reach a factor 6 above the prevailing background counting rate of 0.0015 He/s; 2) the magnetic field and solar wind measurements confirmed the presence of a CIR; and 3) a recurrence period of 27 days could be identified. Our investigations with IMP 7 and 8 at 1 AU assume, as do the reports of McGuire _et al_. (1978), Gloeckler _et al_. (1979), and Scholer _et al_. (1979) that the 1 AU observations of CIR abundances are the result of the inward flow of the ions (e.g. Marshall and Stone, 1977) from the CIRs beyond 1 AU.

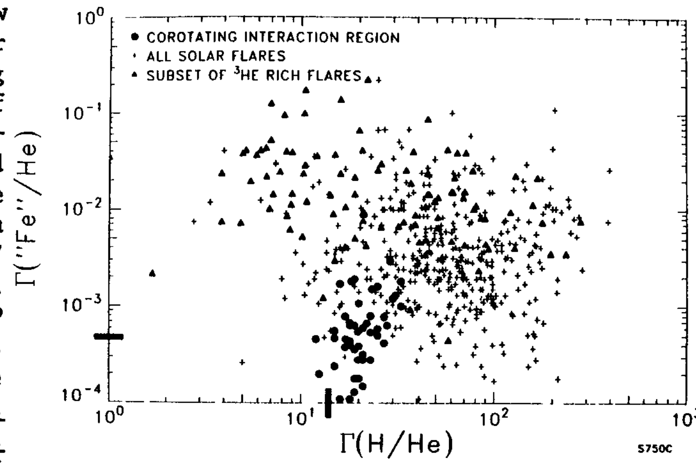

Figure 1

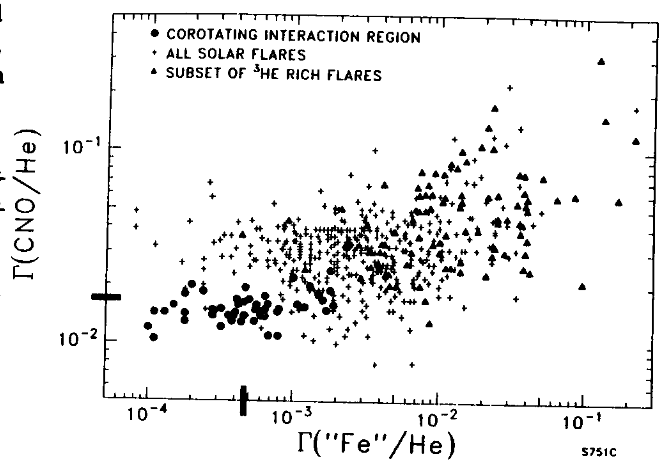

Figure 2

3. <u>Comparison of CIR and Solar Flare Accelerated Nuclei</u>. The abundance ratios of "Fe"/He versus H/He in the energy interval 0.6-4 MeV/n are plotted in Figure 1 for CIRs, all solar flares, and the subset ^{3}He-rich solar flares. Figure 2 is the corresponding plot for "Fe"/He versus CNO/He. The data from Figures 1 and 2 have been used to prepare the histograms in Figures 3 and 4. These plots reveal: 1) The range of variations for all 3 measured abundance ratios for CIRs (including experimental error) is seen in Figs. 1 and 2 to be small compared to that for the range of solar flare abundance ratios (i.e., the dynamic range of variation for CIRs is only a factor ~2 for H/He and CNO/He and factor 30 for "Fe"/He, whereas the dynamic ranges for solar flare abundance ratios are 3000, 40, and 3000 for H/He, CNO/He and "Fe"/He, respectively). From the number distributions of the CIR H/He and "Fe"/He ratios in Figs. 3 and 4 we note the narrower distribution for the CIRs compared with the corresponding solar flare distributions. Unlike the case for solar flares, we have found no examples of large deviations from the mean abundance ratios for CIRs; 2) the mean H/He, CNO/He and "Fe"/He ratios for CIRs are 20, 0.015, and 0.00048 respectively, while the corresponding H/He, CNO/He and "Fe"/He ratios for flares are 52, 0.030, and 0.0028, respectively. The CIR average abundance ratios are close to the universal abundance ratios (Cameron, 1982) (marked as bars on the axes of Figs. 1 and 2) except the H/He ratio which is in somewhat better agreement with fast solar wind values. Average solar flare "Fe"/He abundances at 2-4 MeV/n are seen to be enhanced by a factor of six to seven over photospheric abundances, and He is seen to be depleted in solar flares relative to both H and CNO. In Fig. 1 and 2, very few solar flares ratios appear in the plot area occupied by the CIR data.

We have compared our results for the H/He, CNO/He and Fe/He ratios of CIR accelerated particles with previously reported abundance ratios in Table 1. We have converted published He/O ratios to a CNO/He ratio by using the the published CIR C/O ratios. Clearly our survey, when averaged over many CIRS, confirms the earlier published work based on relatively few CIRs and flares.

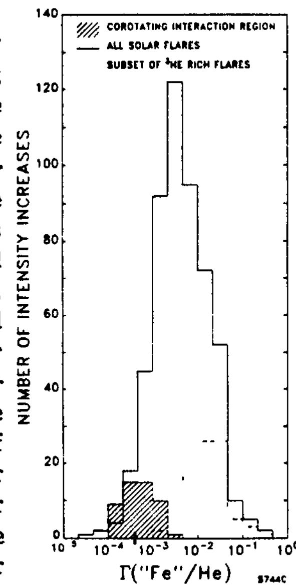

Figure 3

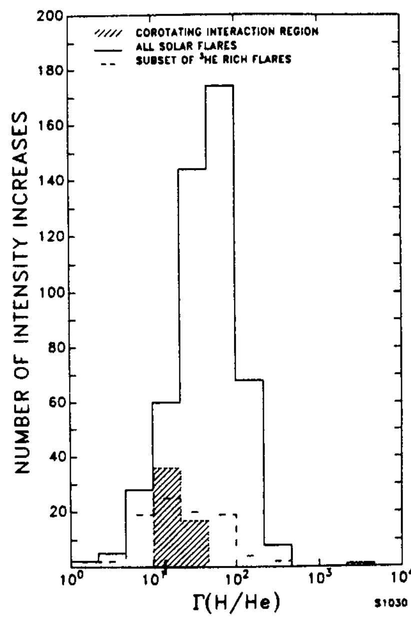

Figure 4

4. **Conclusions.** We find that: 1) for nuclei accelerated in corotating interaction region shocks the average values of the abundance ratios are close to the solar system abundances and are not inconsistent with the abundance ratios for the solar wind; 2) The variability of the abundance ratios for CIRs is more than an order of magnitude less than the variability observed in solar flares confirming McGuire et al. (1978); 3) there is no evidence for preferential enhancements of nuclear abundances in any CIR events.

From the above evidence we conclude that the "seed" nuclei for the CIR shock acceleration mechanism are ambient ions in the interplanetary medium with a composition which is simila_ to the solar system abundances. However, for solar flare nuclei we find, as reported by several

TABLE 1

Reference	Energy Range (MeV/n)	C/O	CNO/He x 100	Fe/He x 10000	p/He	Number of CIRs	Years
(7)	3.4 - 23.	0.8 ± .2	1.48 ± .45^{+}	NA	22. ± 5.*	6	1973-1976
(9)	0.6 - 1.0	0.91 ± .03	0.98 ± .045^{+}	7.1 ± .6	11.9 ± 0.2	4	1974
		0.90 ± .07	0.80 ± .084^{+}	1.8 ± .6	11.2 ± 0.2	5	1976
(4)	0.3 - 5.0	1.05 ± .19	1.25 ± .42^{+}	5.5 ± 2.	16.6 ± 3.5	9	1974,1976
This Work	0.6 - 4.0	NA	1.5 ± .25	5. ± 3.	20. ± 2.	51	1973-1979
(2)		0.60	1.67	4.7	14.		

+ Ratios and errors calculated from C/O and He/O ratios and errors quoted in each paper.
* Average of 17 events at 1.6-8.8 MeV/n

investigations, that the ambient source of nuclei reflects biases in the relative abundances of accelerated nuclei - i.e., preferential enhancements of some abundances. Thus, if shocks accelerate nuclei in solar flares, they probably represent the second stage of acceleration. The small variation in the CIR abundance ratios suggests that only shock acceleration is involved in the interplanetary medium, whereas the extreme variability of the solar flare ratios from solar flares points to a complex, multiple acceleration process.

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