Solar Coronal and Photospheric Abundances from Solar Energetic Particle Measurements

H. Breneman and E C Stone

California Institute of Technology
Pasadena, California 91125 USA

1. Introduction

Solar energetic particle (SEP) elemental abundance data from the Cosmic Ray Subsystem (CRS) aboard the Voyager 1 and 2 spacecraft (Breneman and Stone 1985) are used to derive unfractionated coronal and photospheric abundances for elements with $3 \le Z \le 30$. We find that the ionic charge-to-mass ratio (Q/M) is the principal organizing parameter for the fractionation of SEPs by acceleration and propagation processes and for flare-to-flare variability, making possible a single-parameter Q/M-dependent correction to the average SEP abundances to obtain unfractionated coronal abundances. A further correction based on first ionization potential allows the determination of unfractionated photospheric abundances

2. Results

The composition of individual flares relative to the average SEP composition can be described by a function that is roughly monotonic in Z but variable in magnitude from flare to flare (Cook et al 1979, 1984, McGuire et al 1979, Meyer 1981,

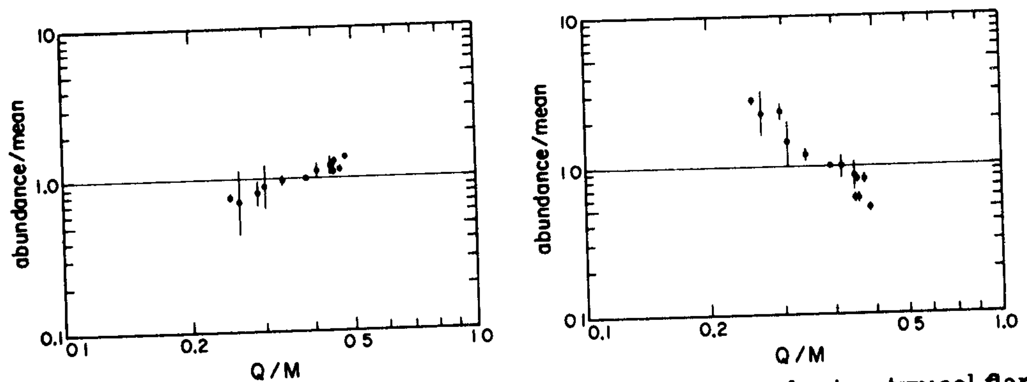

Fig. 1. Abundances relative to the mean SEP abundance for two typical flares, plotted vs. Q/M.

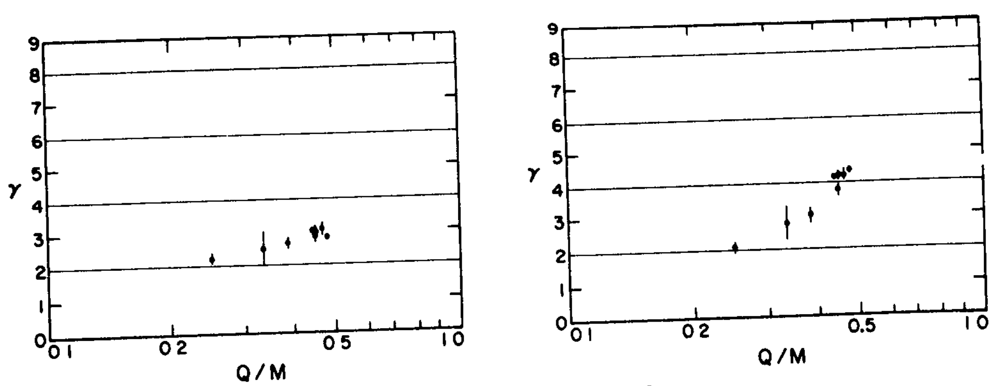

Fig 2 Spectral index γ vs. Q/M for two typical flares.

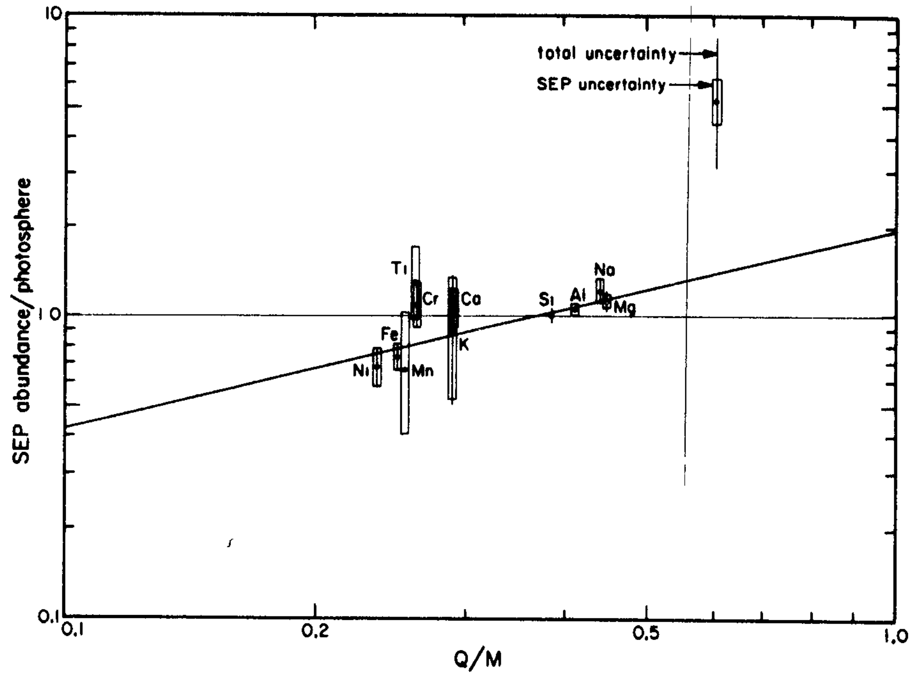

Fig 3 Mean SEP abundance relative to the photosphere (Grevesse 1984) for the low-FIP elements, plotted vs. Q/M. The best-fit power-law has a reduced χ^2 of 1.0.

1985) Using the recently reported SEP ionic charge states (Luhn et al. 1984), we find that this compositional variability exhibits a monotonic dependence on the ionic charge-to-mass ratio Q/M of the particles, as illustrated in Fig 1 Such a dependence is not unexpected for acceleration and propagation effects The spectral indices of the elemental differential energy spectra for a given flare also tend to be ordered by Q/M (Fig 2) Thus we derive an unfractionated coronal composition by applying a Q/M-dependent correction to the average SEP abundances.

3. Discussion

The correction factor has been determined by comparing the SEP abundances of elements with low first ionization potential (FIP), which display no FIP-dependent fractionation (Breneman and Stone 1985), to the photospheric spectroscopic abundances (Grevesse 1984) (see Fig 3) The derived correction function, which is a power-law in Q/M with a slope of 0.66 ± 0.17, may be applied to the SEP abundances for *all* elements, resulting in SEP-derived coronal abundances (see Table I) As Fig 4 shows, they agree well with coronal abundances obtained by XUV/X-ray spectroscopy, but have much higher precision and are available for many more elements.

The derived coronal abundances can also be corrected for the FIP-dependent fractionation suggested by the dynamical ionization model of Geiss and Bochsler (1984). In this model, the high-FIP elements such as N, O, F, Ne, Cl and Ar are depleted because their ionization times are longer than the time individual atoms spend in a rising spicule. Thus, their abundances are corrected by the depletion factor of oxygen in SEPs relative to the photosphere (4.03 ± 0.26), P and S are corrected by the depletion factor of sulfur (1.89 ± 0.17), C is corrected by the mean of the oxygen and sulfur depletion factors, since its proper depletion factor is uncertain, and the low-FIP elements, which are quickly ionized, are left

Table I. SEP-derived coronal and photospheric abundances relative to silicon

Z	SEP-derived corona	SEP-derived photosphere	Z	SEP-derived corona	SEP-derived photosphere
6	2350^{+250}_{-230}	6490^{+280}_{-270}	19	$3.9^{+2.1}_{-1.6}$	$3.9^{+2.1}_{-1.6}$
7	$700.^{+52}_{-49}$	2775^{+53}_{-50}	20	$82.^{+14}_{-12}$	$82.^{+14}_{-12}$
8	5680^{+360}_{-340}	22900	21	$(0.31^{+0.55}_{-0.31})$*	$(0.31^{+0.55}_{-0.31})$*
9	$(0.28^{+0.29}_{-0.28})$*	$(1.1^{+1.2}_{-1.1})$*	22	$4.9^{+1.6}_{-1.3}$	$4.9^{+1.6}_{-1.3}$
10	$783.^{+84}_{-77}$	3140^{+205}_{-195}	23	$(0.48^{+0.69}_{-0.48})$*	$(0.48^{+0.69}_{-0.48})$*
11	$67.0^{+6.8}_{-6.2}$	$67.0^{+6.8}_{-6.2}$	24	$18.3^{+3.9}_{-3.3}$	$18.3^{+3.9}_{-3.3}$
12	$1089.^{+84}_{-82}$	1089^{+84}_{-82}	25	$6.8^{+3.9}_{-2.7}$	$6.8^{+3.9}_{-2.7}$
13	$83.7^{+4.2}_{-4.0}$	$83.7^{+4.2}_{-4.0}$	26	1270^{+170}_{-150}	1270^{+170}_{-150}
14	1000	1000	27	< 18.1	< 18.1
15	$4.89^{+0.66}_{-0.72}$	$9.24^{+1.46}_{-1.54}$	28	$46.5^{+8.1}_{-7.4}$	$46.5^{+8.1}_{-7.4}$
16	$242.^{+10}_{-9}$	$460.^{+42}_{-39}$	29	$(0.57^{+0.87}_{-0.57})$*	$(0.57^{+0.87}_{-0.57})$*
17	$2.38^{+0.84}_{-0.80}$	$9.6^{+3.5}_{-3.3}$	30	$1.61^{+0.87}_{-0.76}$	$1.61^{+0.87}_{-0.76}$
18	$24.1^{+4.2}_{-3.6}$	102^{+20}_{-17}			

* Based on fewer than 5 particles and highly uncertain

unchanged The resulting SEP-derived photospheric abundances (Table I) involve fewer modeling parameters than spectroscopic determinations and are available for some elements (e g , C, N, Ne, Ar) that cannot be observed spectroscopically The main differences (Fig 5) are a significantly higher abundance of Cr (and possi-

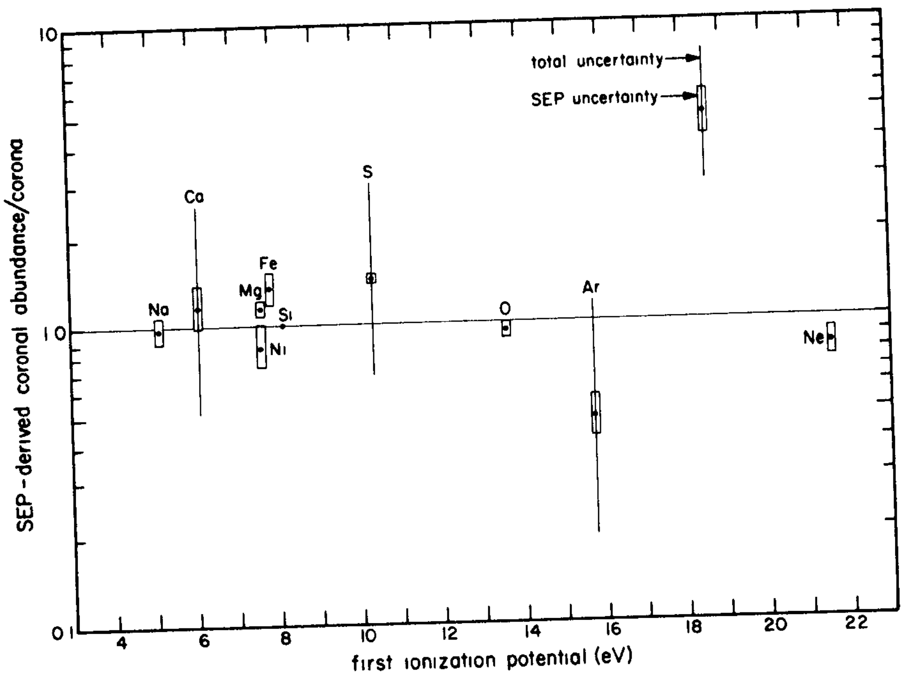

Fig 4 SEP-derived coronal abundances relative to spectroscopically-derived coronal abundances (Veck and Parkinson 1981), plotted vs FIP

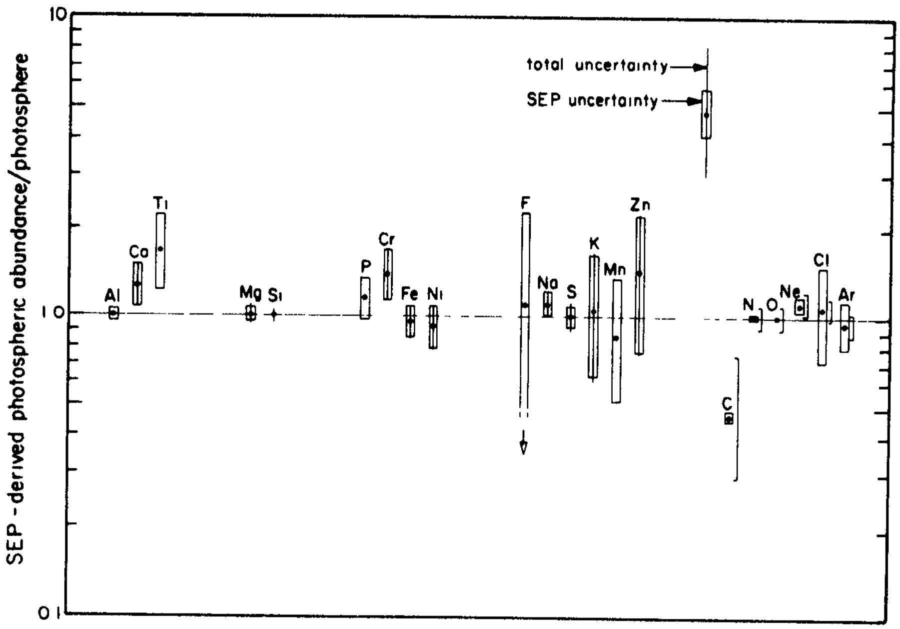

Fig 5 SEP-derived photospheric abundances relative to spectroscopically-derived photospheric abundances (Grevesse 1984) The estimated uncertainty in the FIP fractionation correction is indicated by the vertical brackets

bly Ca and Ti) and a C abundance that is about half of the commonly assumed solar abundance The SEP-derived Fe/Si ratio is in agreement with the recent photospheric value (Grevesse 1984), which is 50% larger than the meteoritic value

4. Acknowledgements

This work has been supported in part by the National Aeronautics and Space Administration under contract NAS7-918 and grant NGR 05-002-160

References

Breneman, H, and Stone, E C 1985, *Proc 19th Int Cosmic Ray Conf* (La Jolla), paper SH 2 1-4

Cook, W R, Stone, E C, Vogt, R E, Trainor, J H, and Webber, W R 1979, *Proc 16th Int Cosmic Ray Conf* (Kyoto), **12**, 265

Cook, W. R, Stone, E C, and Vogt, R E 1984, *Ap J* **279**, 827

Geiss, J, and Bochsler, P 1984, International Conference on Isotopic Ratios in the Solar System, Paris

Grevesse, N 1984, *Physica Scripta* **T8**, 49.

Luhn, A, Klecker, B, Hovestadt, D, Gloeckler, G, Ipavich, F M, Scholer, M, Fan, C Y, and Fisk, L A 1984, *Adv Space Res* **4**, No 2-3, 161

McGuire, R E, von Rosenvinge, T T, and McDonald, F B 1979, *Proc 16th Int Cosmic Ray Conf.* (Kyoto), **5**, 61

Meyer, J-P 1981, *Proc 17th Int. Cosmic Ray Conf* (Paris), **3**, 145

Meyer, J-P 1985, *Ap J Suppl.* **57**, 151