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SOLAR PARTICLE COMPOSITION MEASUREMENTS

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For some time now our group at Goddard had been engaged in studying the compositon of solar particle events; that is, the relative abundance of different elements, using nuclear emulsion detectors flown on board sounding rockets. More recently we have been able to extend these observations to elements as heavy as iron.

Figure 1 shows some of the earlier work. Here we are looking at the energy spectra or energy per nucleon spectra (energy per nucleon being related to the particle velocity) for helium nuclei (the open figures), and for carbon, nitrogen, and oxygen combined (the solid figures), here multiplied by a "magic" factor of 58. We see that for the several events and observation times plotted, the spectra of these different nuclei are very similar.

We have been able to understand this phenomenon by the model in which the particles in a flare are stripped of electrons in the high temperature of a flare region, and subsequently are accelerated presumably by magnetic fields. These particles, stripped of electrons, have the same charge-to-mass ratio and therefore are indistinguishable to electric and magnetic fields; therefore, if we compare the abundances of different particles of the same velocity, we would expect to find an abundance that is directly related to that in the source, in this case in the flare region or the Sun itself. So these particle measurements appear to provide a direct measure of solar abundances themselves in these intense events.

Figure 2 shows a more detailed comparison, element by element for the combined result. The solar cosmic ray results (our results – shown in solid figures) are compared with photospheric and coronal abundances for the elements, where comparisons are possible.

In general we see that the agreement is reasonably good with the photospheric abundances, where those are available (all abundances are normalized to oxygen). Note particularly the carbon-to-oxygen ratio and the abundances of neon, magnesium, and silicon.

As we look toward iron, we begin to worry somewhat as to whether the assumptions, the necessary criteria, are met, since iron, even when fully stripped, has a charge-to-mass ratio that differs by about 8 percent from

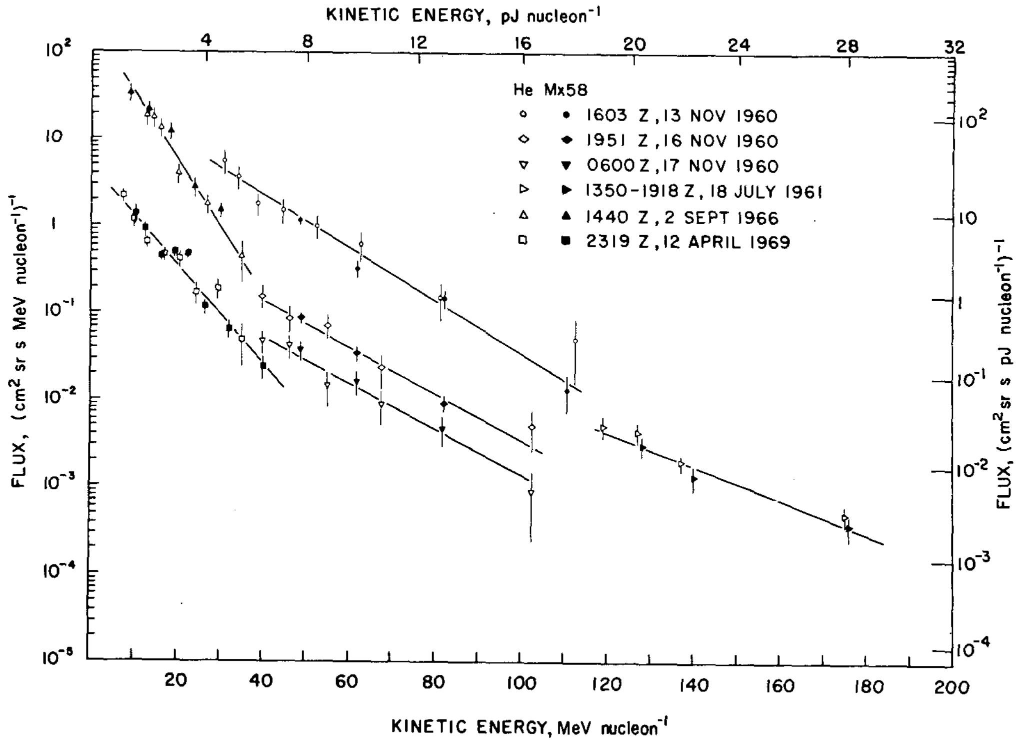

Figure 1–Energy per nucleon spectra.

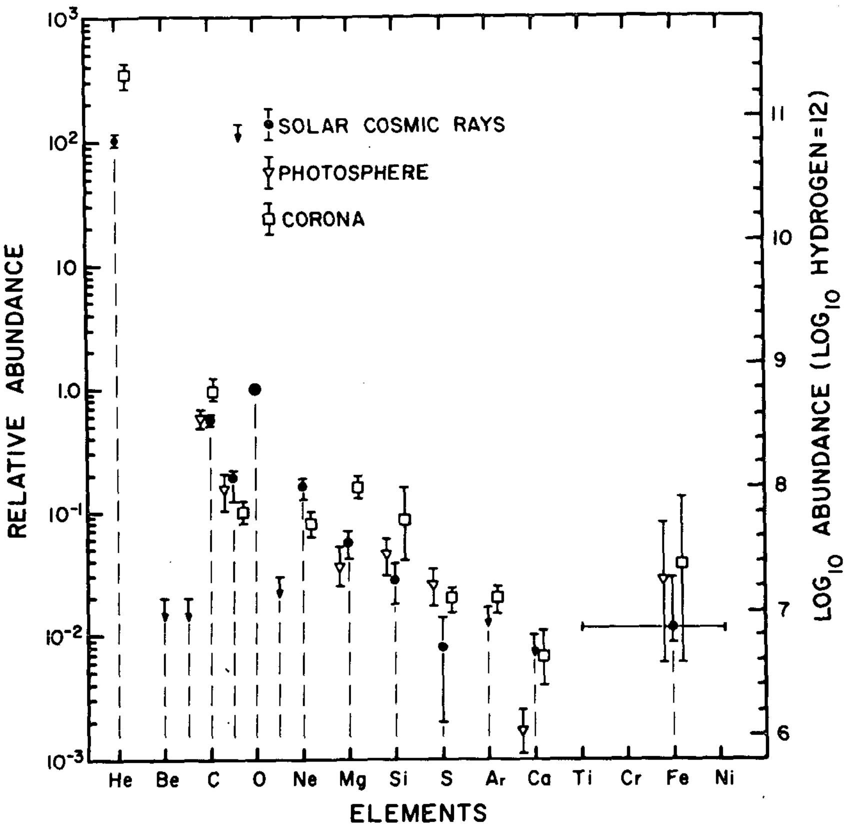

Figure 2—Comparison of solar cosmic ray, photospheric, and coronal abundances for the elements.

those of the lighter species. We know quite well that in cases where the charge-to-mass difference is large, in comparing hydrogen and helium, for instance, we see enormous differences in flux with time and with energy during the events. So we are somewhat concerned that the abundance of iron does not fluctuate in a similar manner.

Table I shows the results. Our first measurement, the first observation of iron in September 1966, was about 1 percent of oxygen. In the event in January of this year, we were able to obtain a second preliminary measurement which seems to agree quite well statistically with the earlier results.

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TABLE I. Iron Abundance.

Solar particle events	Percent of oxygen
Nov. 12, 1960	<2
Sept. 2, 1966	1.1±0.3
Apr. 12, 1969	<3
Jan. 24, 1971	1.3±1.2
Solar photosphere (Ref. 1)	2.5±1.2

For comparison, I have shown one of the more recent photospheric abundances. These are somewhat subject to interpretation, and earlier estimates differ by perhaps as much as an order of magnitude.

So it seems that even in the case of iron one can make measurements that relate to the abundance of the element in the Sun.

In these events and a subsequent event in September of this year that has not yet been analyzed, we also flew some plastic detectors for the University of California and hope to make cross comparisons of iron from the two different types of detectors. The plastic detectors observe at somewhat lower energy and can be more directly related then to observations in lunar samples to extend measurements of this kind over large ranges of history.

Also, in the near future we will be increasing our observation area in order to observe the less intense events where some of the conditions for invariant abundances might not be met. By observing changes in composition we might learn something more about the acceleration mechanism. Of course, in addition, we will be able to observe less abundant elements with the increased area.

REFERENCE

1. Aller, L. H.: Paper presented at 12th Int. Conf. Cosmic Rays (Hobart, Tasmania, Australia), 1971.