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THE CHARGE SPECTRA OF SOLAR COSMIC RAYS

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I would like to report on a different approach to measuring charge spectra of solar cosmic rays. These observations were made by a telescope that Frank McDonald, Bonnard Teegarden, and I have on the IMP 6 satellite, and they illustrate very nicely the quantum jump in capability that took place between IMP 6 and the previous IMP satellites.

In particular, we have extended the charge range beyond charge 2 right up to charge 26, and we have also extended the energy range to lower energies. There is a unique innovation in this experiment, which we refer to as our Cancro priority system, after our favorite engineer Jerry Cancro. It preferentially selects rare events above charge 2 and gives them top priority for telemetry readout, thus breaking the monopoly that protons and helium nuclei otherwise would have on the telemetry.

This effectively increases the number of nuclei that we were able to observe above charge 2 by a factor of several hundred. This factor of several hundred is all important for prior to the last few months, there simply have not been any other satellite-borne detectors that could compete with the rocket-borne emulsion technique that Don Reames just described. It must be nice to have 10 yr without competition from anybody else..

I am referring now to measurements that resolve individual charges above charge 2. With our new capability, we will be able to extend this pioneering work to lower energies and also to smaller flares, and we are hoping to try to measure the charge composition in long-lived solar particle streams as well, which simply can not be done with emulsions.

So far, we have observed two flares since the time IMP 6 was launched in March of this year. I will be reporting today mainly on a small flare that took place in April, since we are just now starting to get our teeth into the larger flare, which took place in September.

Figure 1 illustrates the telescope that we are using. It consists of a thin and a thick solid-state detector surrounded by an active anticoincidence. We analyze particles that enter the front aperture and either stop in the front detector or in the second detector but reject all those particles that intersect the anticoincidence.

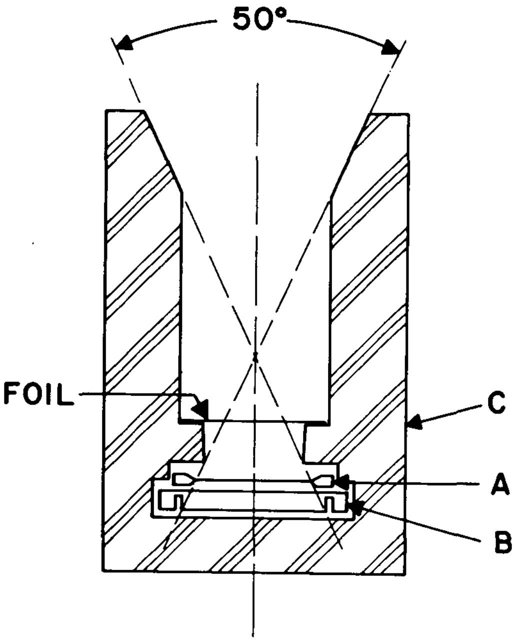

Figure 1–IMP 6 telescope. *A* is the 150-μm silicon, 300-mm^2 detector; *B* is the 3-mm silicon, 500-mm^2 detector; *C* is the plastic scintillator; and the foil is 1 mg cm^{-2} titanium.

The response for particles that stop in that front detector is shown in Figure 2. You can see that even though it is only a one-dimensional measurement, we do have some measure of charge resolution. You can distinguish electrons, protons, helium nuclei, and particles with charge Z greater than 3. The fantastic thing about these data is that they cover over 9 orders of magnitude in intensity, far more than we have been able to cover before.

Figure 3 illustrates the response of the telescope for particles that penetrate into that second detector. On the left-hand side you see over a hundred carbon, nitrogen, and oxygen nuclei from a flare on April 6. We were delighted with these data because without our priority system we would have had, say, only two of those nuclei, and we could not have done much with that. But with over a hundred particles and good charge resolution, we could make a reasonably good measurement.

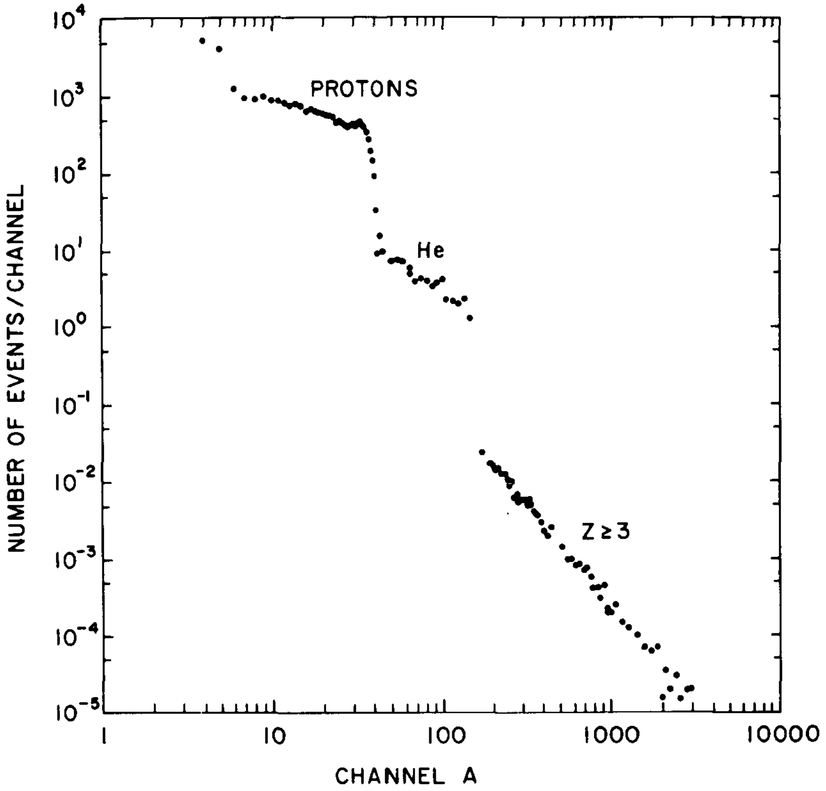

Figure 2–IMP 6 telescope response for particles stopping in detector *A*.

I might say that the priority system selected these hundred events from over 100000 protons and helium nuclei that were competing for telemetry space, and that is why if we had not had our priority system we would have only seen some two events.

On the right-hand side, you can see the comparable data taken in September and we were ecstatic with this. There are over 4000 particles on that figure, and you can see that nitrogen, which is a low-abundance nucleus, is clearly separated from the neighboring carbon and oxygen, which are much more abundant than the nitrogen.

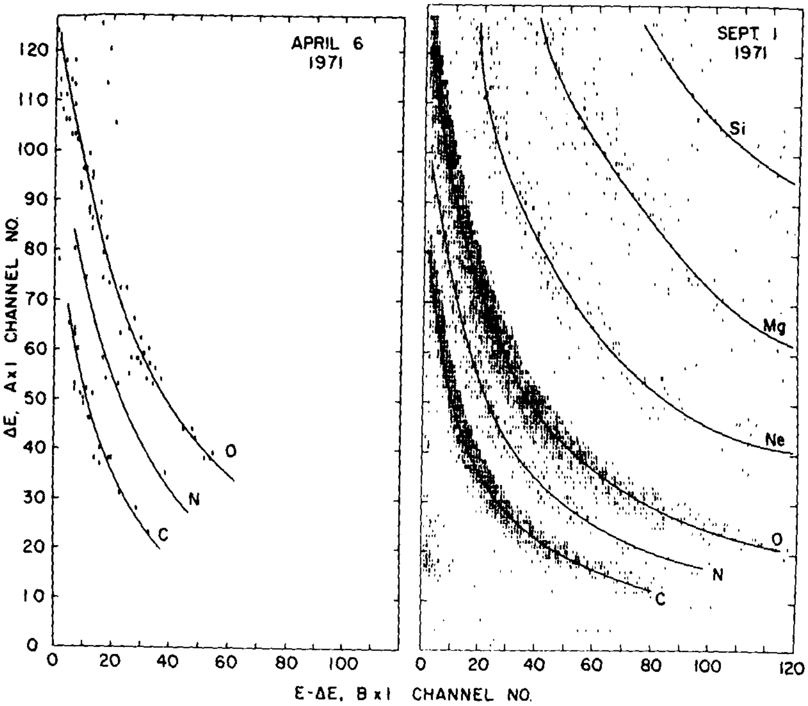

Figure 3–IMP 6 telescope response for particles stopping in detector *B*.

The background-free nature of this telescope is also evident by the fact that there is just no fluorine present here at all and you can see that we have nicely resolved neon, magnesium, and silicon. The data extend beyond those illustrated, and we can see more than 40 iron nuclei in a very nice tight band, indicating that we have good charge resolution right up to charge 26.

Table I shows some of the data that we have obtained from the April flare compared with the results of David Bertsch, Don Reames, and Carl Fichtel (Ref. 1) at higher energies from rocket-borne emulsions. The helium-to-medium ratio (He/*M*) that we observe is slightly lower than what they have, but it is constant throughout the flare, a point which they have been worried about since some people have recently claimed that it does vary. We saw it to be constant at low energies as well as at the higher energies where the emulsions are measuring.

TABLE I—IMP 6 Measurements Compared With Rocket-Borne Emulsion Results

Element ratio	IMP 6 measurements at ~1.3 to 3.7 pJ nucleon^{-1} (~8 to 23 MeV nucleon^{-1})	Emulsion measurements at ⩾3pJ nucleon $^{-1}$ (⩾20 MeV nucleon^{-1})
He/*M*	46 ± 9	58 ± 5
C/O	0.42 ± 0.11	0.56 ± 0.06
N/O	0.20 ± 0.08	$0.19 {}^{+0.03}_{-0.07}$
Ne/O	0.11 ± 0.05	0.16 ± 0.03
Mg/O	0.20 ± 0.08	0.056 ± 0.014
Si/O	0.11 ± 0.06	0.028 ± 0.01
Fe/O	0.17 ± 0.08	0.011 ± 0.003

Notice that for the low charges the agreement between the two studies is quite good. As we move to higher charges, the relative abundances are somewhat larger. It has been suggested that this might be characteristic of small flares, but I think it is too early to really say that.

Anyway, we have developed a very fine detector for this sort of observation, and we are very much excited by the data that we are getting. We should be able to come up with more complete results in the near future.

REFERENCE

1. Bertsch, D. L.; Fichtel, C. E.; and Reames, D. V.: Nuclear Composition and Energy Spectra in the April 12, 1969, Solar Particle Event. Astrophys. J., vol. 171, 1972, p. 169.