SOLAR PROTON, HELIUM, AND MEDIUM NUCLEI ($6 \leq Z \leq 9$)

OBSERVED FROM THE IMP-VI SATELLITE

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Abstract

Proton, helium, and medium nuclei energy spectra have been measured from the IMP-VI satellite for a recent solar flare. Above 2 MeV/nucleon these spectra are based upon single and dual parameter pulse height analysis in addition to threshold rate counting. Pulse height analysis of medium nuclei is assigned a high priority for telemetry readout so that telemetry does not become saturated by the high proton intensity. In this manner the number of pulse height analyzed medium nuclei has been increased by a factor of ~ 200. Individual medium nuclei have been resolved in the energy interval 8 - 23 MeV/nucleon.

1. Introduction

Fichtel and coworkers (for example, Bertsch, et al., this conference [1]) have emphasized the point of view that the relative abundances of solar flare particles with charge $Z \geq 2$ are constant as a function of velocity from flare to flare and represent the relative abundances before acceleration. In this view, the relative abundances of various elements in the sun which cannot be obtained from spectroscopic data alone can be obtained by the addition of flare particle data. An important example of this is the abundance ratio of solar hydrogen and helium which cannot be determined at the flare location by either technique alone. Also, spectroscopic determinations are often difficult for other elements [2] so it is desirable to have an independent measure of relative abundances from flare particles.

Possible deviations from the above picture have been the subject of theoretical speculation in the past (e.g. [3]) and have been recently reported as having been observed at low energies ($\lesssim$ 10 MeV/Nucleon) by Price, et al. [4] for iron nuclei and by Armstrong and Krimigis [5], Krimigis [6], and Beedle, Van Allen, and Webber [7] for the helium to $Z \geq 3$ ratio. Whether or not these latter measurements are inconsistent with the results of Fichtel and coworkers above ~ 20 MeV/nucleon is currently a matter of dispute [8] and will be discussed later. Price, et al. [4] found that the Fe spectrum becomes considerably steeper below ~ 10 MeV/nucleon. Fleischer, et al. [9] however, found a constant spectral exponent down to ~ 1 MeV/nucleon. These two experiments were nearly identical, both involving the study of tracks etched in glass from the Surveyor 3 spacecraft (exposed on the moon for over two and one half years).

It is interesting to note that only five solar events since 1960 have been intense enough for a detailed study of flare particle composition to be made using rocket-borne emulsion techniques. No comparable measurement (i.e. individual charges resolved above charge 2) has been previously reported from satellite-borne detectors. This paper will report the first such measurement.

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2. Description of the Experiment

The present experiment utilizes the low energy detector (LED) illustrated in Fig. 1. This telescope consists of a thin (146μ x 300 m^2) silicon surface barrier detector (detector A) and a thick (3mm x 500 mm^2) Li drifted detector (detector B) surrounded by an active anti-coincidence shield (detector C). Detector A acts as a total energy detector for particles stopping in A and as the dE/dx element of a dE/dx by E telescope for particles stopping in detector B. The response matrix for this telescope is also illustrated in Fig. 1. The dashed line on this matrix separates protons and helium nuclei from nuclei with charge greater than two. Below the dashed line the signals are analyzed in a high gain mode, while above the dashed line the signals are attenuated by a factor of 10 before being analyzed. The pulse height analyzers are linear over more than 400 channels, giving a total dynamic range of ~ 4000.

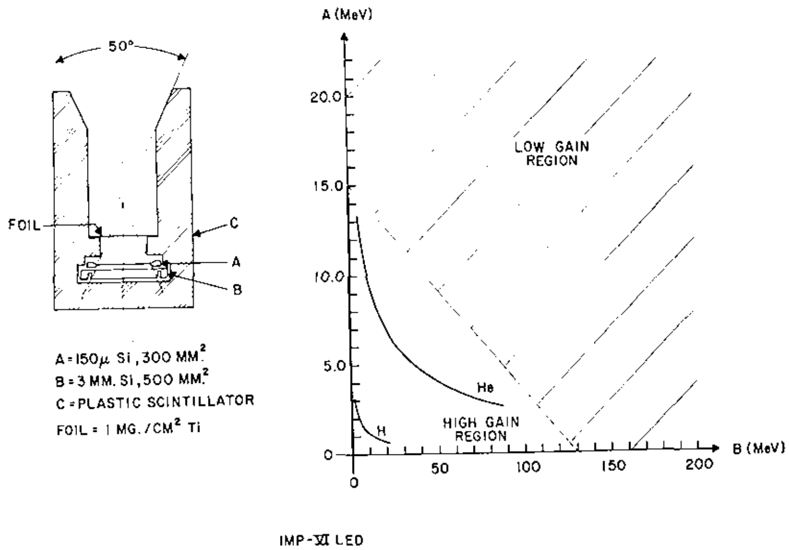

Fig. 1 - The IMP-VI Low Energy Detector and its response matrix.

The unique feature of this experiment is its priority system. Because of a limited telemetry data rate, only one analyzed event may be read out every 0.64 seconds whereas many particles will enter the telescope in this sample time. To prevent the telemetry from being saturated by protons, rare events are given a higher priority for readout. In this manner the number of pulse height analyzed medium nuclei above 1.5 MeV/nucleon has been increased by a factor of ~200 over conventional systems.

Four different event types are identified: 1. Particles with charge greater than 2 stopping in detector B; 2. Particles with charge less than or equal to 2 stopping in detector B; 3. Particles with charge greater than 2 stopping in detector A; and 4. Particles with charge less than or equal to 2 stopping in detector A. Thus the gain change boundary described earlier also separates event types 1. and 3. from event types 2. and 4.. During any given sample time the priority system then works as follows. The first event to occur is always accepted and its event type recorded. Subsequent events of the same type or types having lower priority are then rejected, while a higher priority event will be analyzed and the corresponding pulse heights replace those measured for the earlier (lower priority) event. Rates counters keep count of each particle detected for each event type irrespective of whether the particle is pulse height analyzed and read out. These counters thus provide the information for renormalization to actual intensities. In practice, the priority for each event type is changed cyclically to prevent any one event type from saturating telemetry read-out.

Prior to launch of IMP-VI on March 13, 1971, the LED telescope and its associated electronics were calibrated at the Naval Research Laboratory Cyclotron using protons from 2.5 to 30 MeV. No observable gain changes have taken place.

3. Experimental Results

The particles reported upon here originated in a class M5 flare of importance 1B. This flare occurred at S18W80 on the sixth of April at 0935 UT. Particle onset was observed at IMP-VI 1.5 hours later as illustrated in Fig. 2, which shows particle counting rates versus time. Velocity dispersion is clearly evident in this figure. The curve labeled .6-4 MeV shows an irregular rise to maximum owing to the contribution of electrons which peaked early in the event.

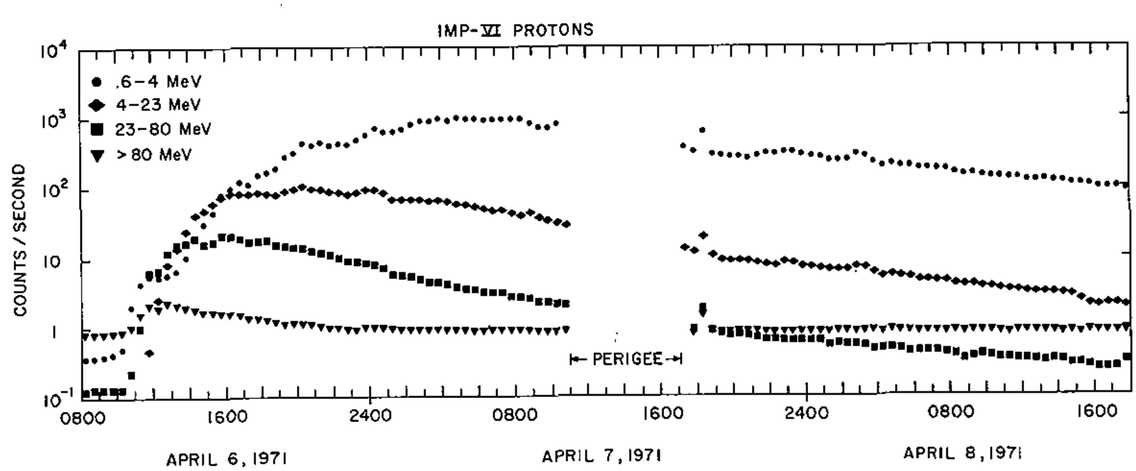

Fig. 2 - Particle counting rates versus time for various energy intervals.

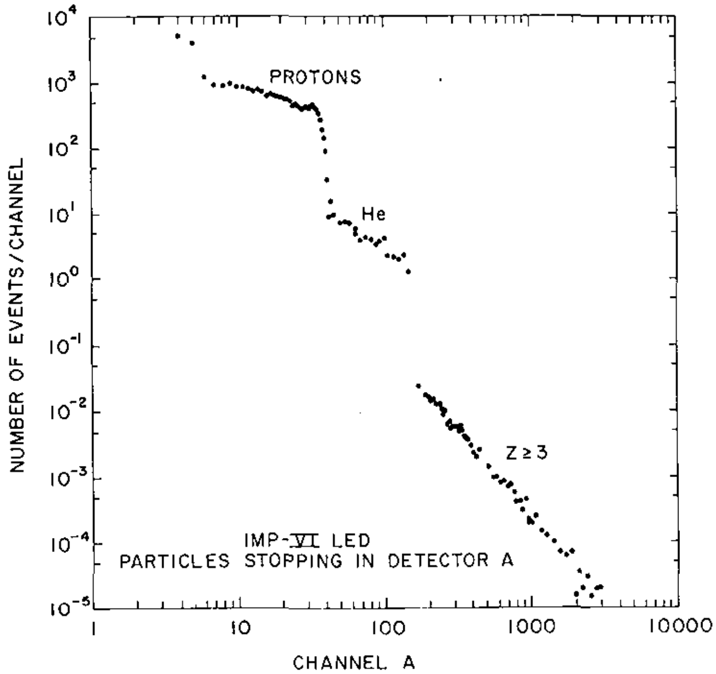

Fig. 3 - Example of a one-dimensional pulse height distribution in channel A for particles stopping in detector A.

The one dimensional pulse height distribution in Channel A for particles stopping in detector A (B pulse height = 0) is a composite response to all particles. Some measure of charge resolution is possible, however, as is illustrated in Fig. 3. The sharp transitions in the distribution are due to protons and helium nuclei above 4 MeV/nucleon entering the B detector. They provide a useful internal calibration. This distribution was accumulated over ~ 21 hours from the start of the flare and spans some nine decades in intensity. The active anti-coincidence detector (detector C) is a critical element for making measurements of intensity over such a broad range.

It may be noted that a fixed band of pulse heights in the Z ≥ 3 region of Fig. 3 corresponds to different energy bands for particles with differing charges. For example, the band of pulse heights which corresponds to oxygen nuclei between 1.56 and 4 MeV/nucleon corresponds to Fe nuclei between .61 and 1.45 MeV/nucleon [10]. If the spectra are steep then clearly Fe nuclei will be present in this band of pulse heights disproportionately to their relative abundance. It may, in fact, be possible for them to contribute a non-negligible amount to the total Z ≥ 3 intensity. An attempt to estimate the contribution of Z > 9 particles to this pulse height band will be mentioned later.

Two dimensional pulse height matrices for the same 21 hour period are illustrated in Fig. 4. From the high gain matrix we can qualitatively observe the absence of background events. Over one hundred thousand events are represented on this matrix. The low gain matrix illustrates clearly the distinct separation of C, N, and O nuclei. Some 101 particles appear here, all in the approximate energy interval of 8 - 23 MeV/nucleon. This matrix represents the first two dimensional measurement by an electronic counter of flare particles with charge greater than two.

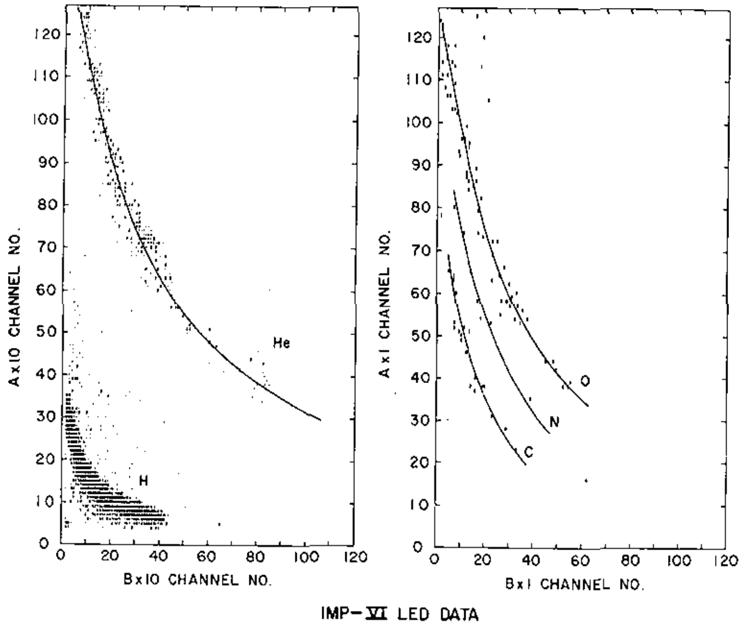

Fig. 4 - Examples of the high gain and the low gain two-dimensional pulse height distributions.

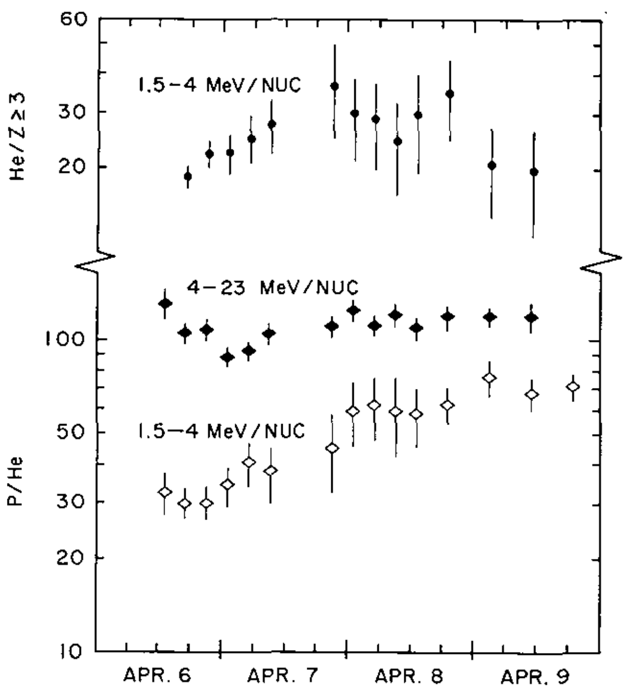

Fig. 5 - The P/He ratio and the He/Z ≥ 3 are illustrated as a function of time for the energy interval 1.5-4 MeV/nuc., as well as the P/He ratio for the interval 4-23 MeV/nucleon.

In Fig. 5 we illustrate the behavior of the proton to helium ratio with time for the energy ranges 1.5-4 MeV/nucleon and 4-23 MeV/nucleon. For the first of these energy ranges the proton to helium ratio increases with time, while for the second it is essentially constant at a rather higher value.

Also shown in Fig. 5 is the He to Z ≥ 3 ratio versus time measured using particles stopping in detector A. The resulting values are similar to those obtained in other events by Armstrong and Krimigis [5] using a single detector, a passive collimator, and two threshold levels. The bands of pulse heights used for the present measurement correspond to equal intervals in energy/nucleon for He and oxygen nuclei (1.56-4 MeV/nucleon). There is some indication that the resulting ratio increases slightly early in the event, but it is sensibly constant. On this basis we will assume that the He to medium nuclei ratio is also constant in the 8-23 MeV/nuc. region (large statistical fluctuations in the measured values mask possible time variations). Using this assumption, we present in Table 1 values for various ratios integrated over the event.

The measured He to medium nuclei ratio of 46 ± 9 in the interval 8-23 MeV/nuc. is lower than (but consistent with) the value 58 ± 5 obtained by Fichtel and co-workers above about 20 MeV/nucleon. It

	1.5-4 MeV/NUC	8-23 MeV/NUC	FICHTEL, et al ≥ 20 MeV/NUC
He/M	37±5	46±9	58±5
C/O	—	.42±.11	.56±.06
N/O	—	.20±.08	$.19^{+.03}_{-.07}$

Table 1 - Summary of various ratios obtained by integrating over most of the event.

should be realized that the value 58 ±5 is an average over ten separate measurements for 5 different solar events. The value 46 ±9 is very typical of these 10 separate measurements. The C/O and N/O ratios measured in the 8-23 MeV/nuc. interval are in excellent agreement with those of Fichtel and co-workers.

The He to medium nuclei ratio (He/M) of 37 ±5 quoted in Table 1 for the energy interval 1.5-4 MeV/nuc. has been estimated from He to Z ≥ 3 ratio of Fig.5. It has been assumed that the spectral index for each charge above charge 3 is the same and independent of energy. Under these assumptions a spectral index has been derived and the abundances of nuclei above charge 9 measured by Fichtel and co-workers have been used to deduce the quoted He/M ratio. We find that the He to Z ≥ 3 ratio must be multiplied by ~ 1.35 to obtain the He/M ratio. The quoted error of ±5 does not include an estimate for the error in this factor. The final result of 37 ±5 is decidedly lower than the result 58 ±5 of Fichtel and co-workers. Possible interpretations are (1) the He/M ratio is truly different at low energies than it is at high energies; (2) the correction factor of 1.35 is incorrect, either because the abundances used for nuclei with charge > 9 are incorrect or because the spectra of these nuclei become steeper at low energies in accordance with the results of Price, et al. [4]. We hope to be able to select between these alternatives after further study of this and subsequent events.

4. References

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