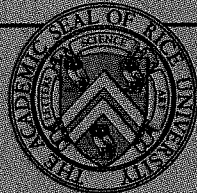


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LUNAR SURFACE: APOLLO XII OBSERVATIONS

by

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DEPARTMENT OF

SPACE SCIENCE



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Abstract

An experiment designed to measure the differential energy spectrum and a coarse mass spectrum of ions near the lunar surface was deployed by the Apollo XII astronauts. This experiment has yielded evidence for a general mechanism which accelerates originally thermal ions up to several hundred electron volts.

Acceleration of Thermal Ions at the Lunar

Surface: Apollo XII Observations

The Suprathermal Ion Detector Experiment, hereafter called SIDE, provides information on the energy and mass spectra of low energy (0.2 to 48.6 eV) positive ions close to the lunar surface resulting from UV or solar wind ionization of gases possibly due to the following sources: A residual primordial atmosphere of heavy gases; outgassing of the moon, e.g., due to volcanic activity; evaporation and sputtering of solar wind gases accreted on the lunar surface; exhaust gases and outgassing from the Lunar Module. Furthermore, SIDE measures the flux and the differential energy spectrum of higher energy (10-3500 eV) positive ions in the magnetotail, the magnetosheath and the interplanetary space, thus providing data on the interaction between the solar wind and the moon.

Figure 1 shows a schematic diagram of the SIDE. It consists of a pair of positive ion detectors. The first of these, the total ion detector, employs a cylindrical curved plate analyzer followed by a channel-electron-multiplier operated as an ion counter. The total ion detector measures the differential positive ion energy spectrum from 3500 down to 10 eV in twenty energy steps. The accumulation time for one energy step is 1.2 seconds. The second detector, the mass analyzer, is provided with a crossed electric and magnetic field velocity filter

(or Wien filter) and a curved plate analyzer. The requirement that an ion pass through both filters to reach the input of the channel-electron-multiplier and be counted allows a determination of its mass per unit charge. The mass analyzer takes mass spectra at six energy levels: 48.6, 16.2, 5.4, 1.8, 0.6, and 0.2 eV. For the Apollo XII instrument, twenty mass channels span the mass range from approximately 10 to 1000 AMU/q. The accumulation time per mass channel is again 1.2 seconds. In 2.58 minutes a complete mass spectrum at all six energies and a calibration cycle of eight frames is obtained. At the same time the total ion detector scans through six energy spectra and a calibration cycle. The flux of ions below 10 AMU/q which is not obtained from the mass analyzer can, in principle, be obtained by subtracting the integrated mass spectrum flux from the total ion flux obtained by the total ion detector at similar energy steps. The energy pass-band is $\pm 5\%$; the field of view is roughly a square solid angle 6° on a side for both detectors. The sensitivities of the total ion detector and the mass analyzer are respectively 5×10^{17} and 10^{17} counts per second per ampere of entering ion flux.

In order to compensate for a possibly large lunar surface potential a wire screen is deployed on the lunar surface beneath the SIDE. The potential between this screen and instrument ground and a grounded grid mounted immediately above the ion entrance apertures can be changed in 24 steps from 0 to 27.6 volts positive and negative. An automatic mode is available where this voltage changes by one step after a complete energy and mass scan of the mass analyzer (i.e., every 2.58 minutes). This so-called ground plane stepper may function

in either of two possible ways: The effect of a positive lunar surface potential is counteracted allowing the low energy ions to reach the instrument with their intrinsic energy. On the other hand, at near zero lunar potential, thermal ions may be accelerated into the SIDE.

The Suprathermal Ion Detector was deployed on the moon on November 19, 1969, as part of the Apollo XII Lunar Surface Experiments Package (ALSEP). It stands approximately 50 feet from the ALSEP central station in a southwesterly direction. The top surface is 20 inches above the lunar surface. The sensors' look directions include the ecliptic plane and the look axes are canted 15° from the local vertical and to the west. Since the turn-on of the instrument, on November 19, 19:18 GMT, the SIDE has performed well. All temperatures and voltages have been nominal. Only two significant anomalies have been noted. Beginning at sunrise of the second lunar cycle, the background of the mass analyzer became high and erratic during lunar daytime. Until this erratic behavior is understood or subsides, no daytime mass analyzer spectra are available after December 18, 1969. Secondly, high pressures presumably associated with the high temperatures at lunar noon have caused us to drop from a 100% to a 15% operation duty cycle for several days either side of lunar noon.

Shortly after turn-on of the instrument (November 19, 1969) several low energy events (20-100 eV) were detected in the total ion detector. These ions appeared to come in clouds which remained up to approximately 10 minutes. Some were accompanied at the outset by higher energy ions (250-750 eV). At least one arrival of such a cloud was coincident with a variation in the ALSEP magnetometer

data indicating the passage of a current sheet nearby (1). Further comparison of our data with those of the magnetometer is planned. At the time the low energy ions were seen by the total ion detector the mass analyzer detected ions in the 48.6 eV range (SIDE frames 0-19). Figure 2 shows the total ion detector counts and the mass analyzer counts of a typical event. Four such events were detected during the operating period of the first lunar day. They all originate in the period shortly after turn-on and they all show similar characteristics with a mass analyzer peak between SIDE frames 2 and 6, corresponding to a mass range of 18 to 50 AMU/q. Hydrogen and helium, which are not covered by the mass analyzer, are not the main components of these clouds as estimated by comparing total ion detector and mass analyzer data. We think that the most likely sources for these ions are Lunar Module outgassing and exhaust products. We feel, however, that the interesting part of these data is not so much the identification of the source but the fact that we have not detected any very low energy ions (< 20 eV). This is evidence for a general acceleration mechanism which energizes originally thermal ions to tens of electron volts. Further evidence for such a mechanism is presented in the following paragraphs.

On November 20, 1969, the Lunar Module impacted the moon about 70 km east-southeast of the ALSEP site. 52 seconds after the impact a statistically significant ion flux was detected in the 500 and 250 eV channels of the total ion detector. This flux was still apparent in the next spectrum but had vanished still another spectrum later (Figure 3a).

On April 15, 1970, the Apollo XIII S-IVB rocket stage impacted the moon 140 km west of the ALSEP site. These two impact events were observed also by the ALSEP Passive Seismic Experiment (2). Figure 3b shows how this event was registered by the total ion detector (50 to 100 eV channels) and the mass analyzer (48.6 eV) simultaneously. This time the first significantly increased ion flux was observed 22 seconds after the impact. The mass spectrum shows ions from 10 to 80 AMU/q. The relative heights of the peaks do not represent the relative abundances of the different masses in the ion cloud as the flux is changing very rapidly during the scanning of the mass spectrum. However, it is safe to say that at least 10% and perhaps as much as ~100% of the ions have masses greater than 10 AMU/q.

There is no doubt that the ions detected by the SIDE are related to the two impacts. It is known that such high velocity impacts can vaporize material (3) and it is likely that part of such vapor is ionized. But if the detected ions had received their energies (~500 eV and ~70 eV for the LM and S-IVB events, respectively) at the locations of the impacts they should have arrived at the ALSEP site after a few seconds, depending on their mass. The relatively long delay times of the arriving ions (~52 seconds and ~22 seconds) suggest that they were created (e.g., by solar UV), and then accelerated after a neutral or partly ionized cloud had expanded from the impact point to a location from which ions had ready access to the SIDE detectors.

We think that the same acceleration mechanism is responsible for the energization of the ions of all events described here. The most likely mechanism is $(\vec{E} \times \vec{B})$

drift acceleration by the solar wind. Manka and Michel (4) have calculated trajectories for ions created at the lunar surface or in a lunar atmosphere. Their results show that such ions would, in general, impinge on the lunar surface at a relatively shallow angle, and hence be measured by our instrument only with low efficiency if at all. Detailed studies of the interplanetary field conditions and possible influences of local fields are in progress to determine if the proposed ($\vec{E} \times \vec{B}$) acceleration can explain the presence of the suprathermal ions detected by the SIDE. If not, an alternative acceleration mechanism will be required.

Numerous other energetic ion phenomena have been detected by the Apollo XII SIDE, but these are not thought to have originated from local thermal gas (5,6).

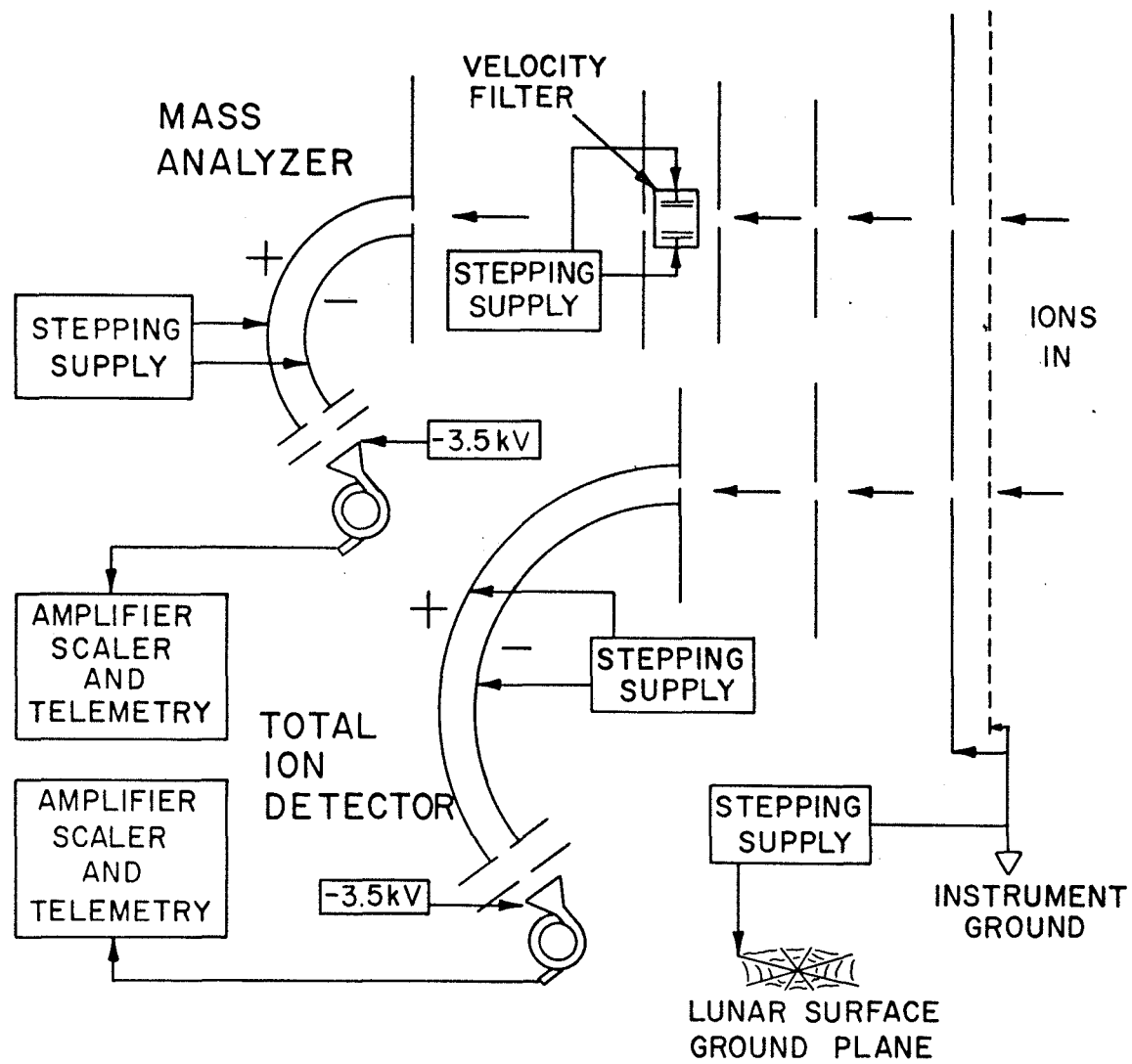
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References and Notes

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7. Supported in part by NASA under contract NAS 9-5911. One of us, H.B., is an ESRO/NASA International Post-Doctoral Fellow.

Figure Captions

- (1) Schematic diagram of the Suprathermal Ion Detector Experiment.
- (2) Samples of the simultaneous total ion detector and mass analyzer data for November 19, 1969. The total ion detector 20 channel energy spectrum repeats each 20 frames except for a calibration cycle. The mass analyzer sweeps through a mass spectrum at each energy in 20 frames.
- (3a) Total ion detector spectra at LM impact. The background counting rate at this time (shortly after deployment) is high due to initial outgassing as the temperature rises. Simultaneous data (not shown) from the mass analyzer, which has an energy range well below that of the ions in this event, indicate only a low background rate.
- (3b) Total ion detector and mass analyzer spectra at S-IVB impact. The ALSEP site is in lunar night about 18 hours prior to sunrise. The very low background counting rates are typical of the night-time data.



SUPRATHERMAL ION DETECTOR EXPERIMENT

FIGURE 1

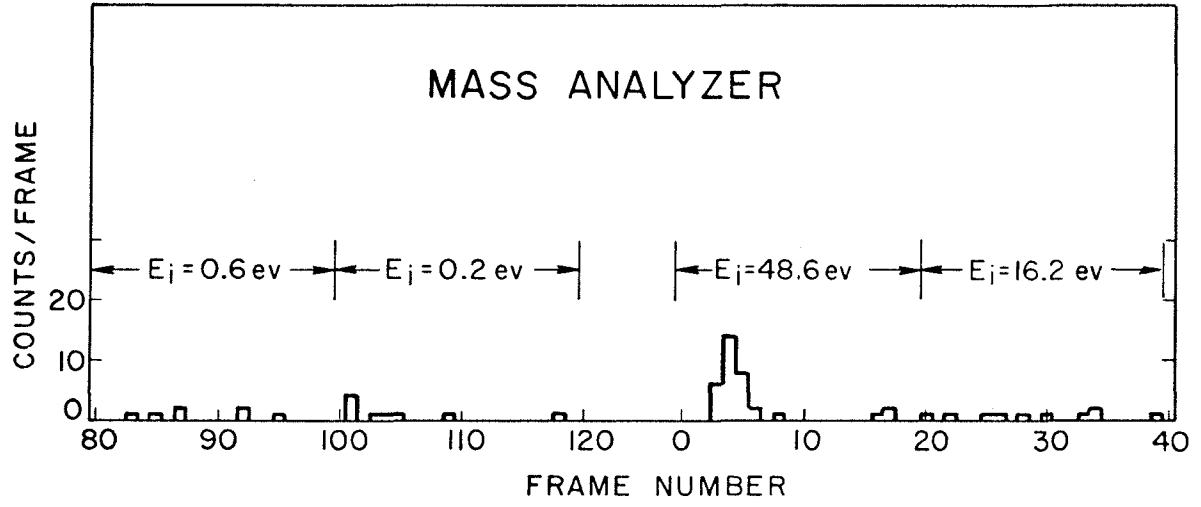
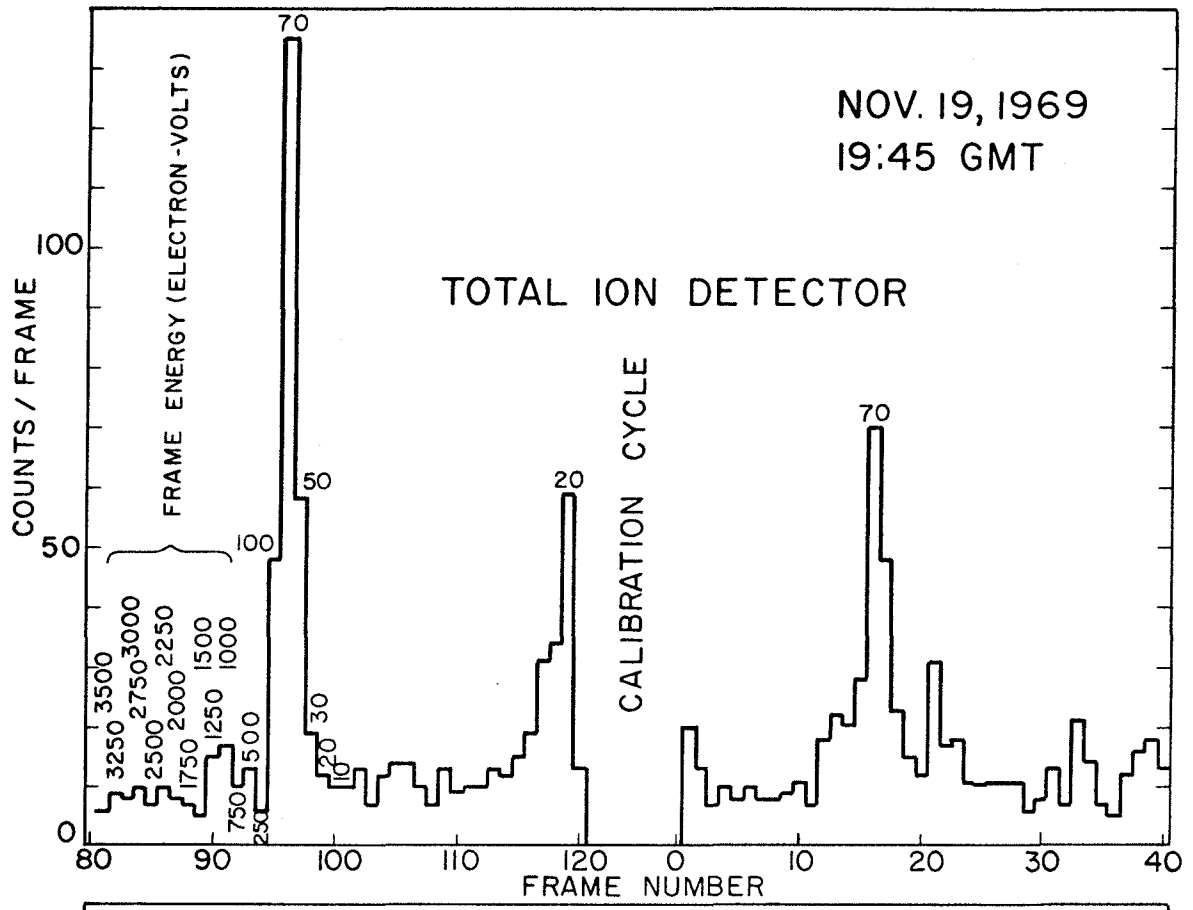


FIGURE 2

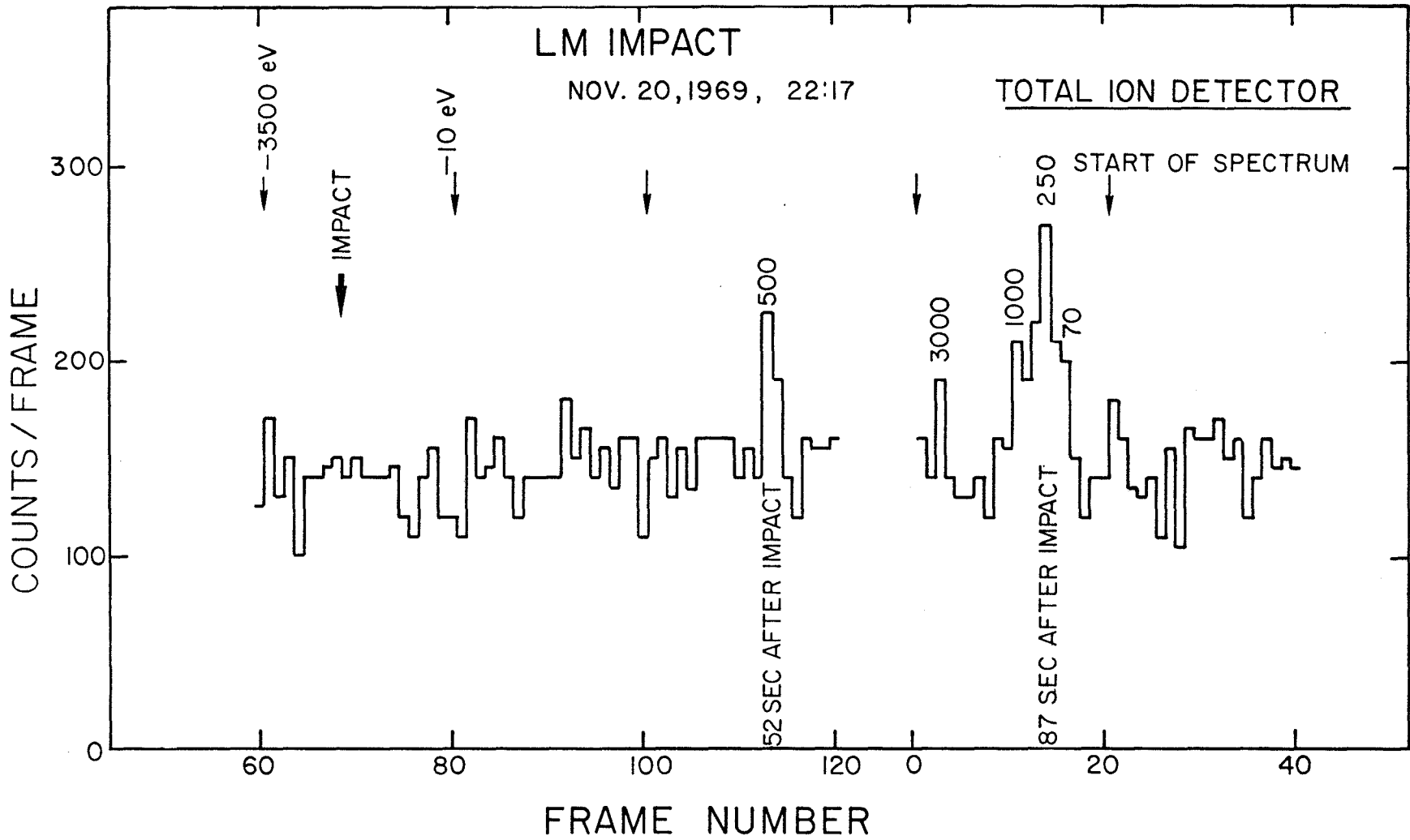


FIGURE 3a

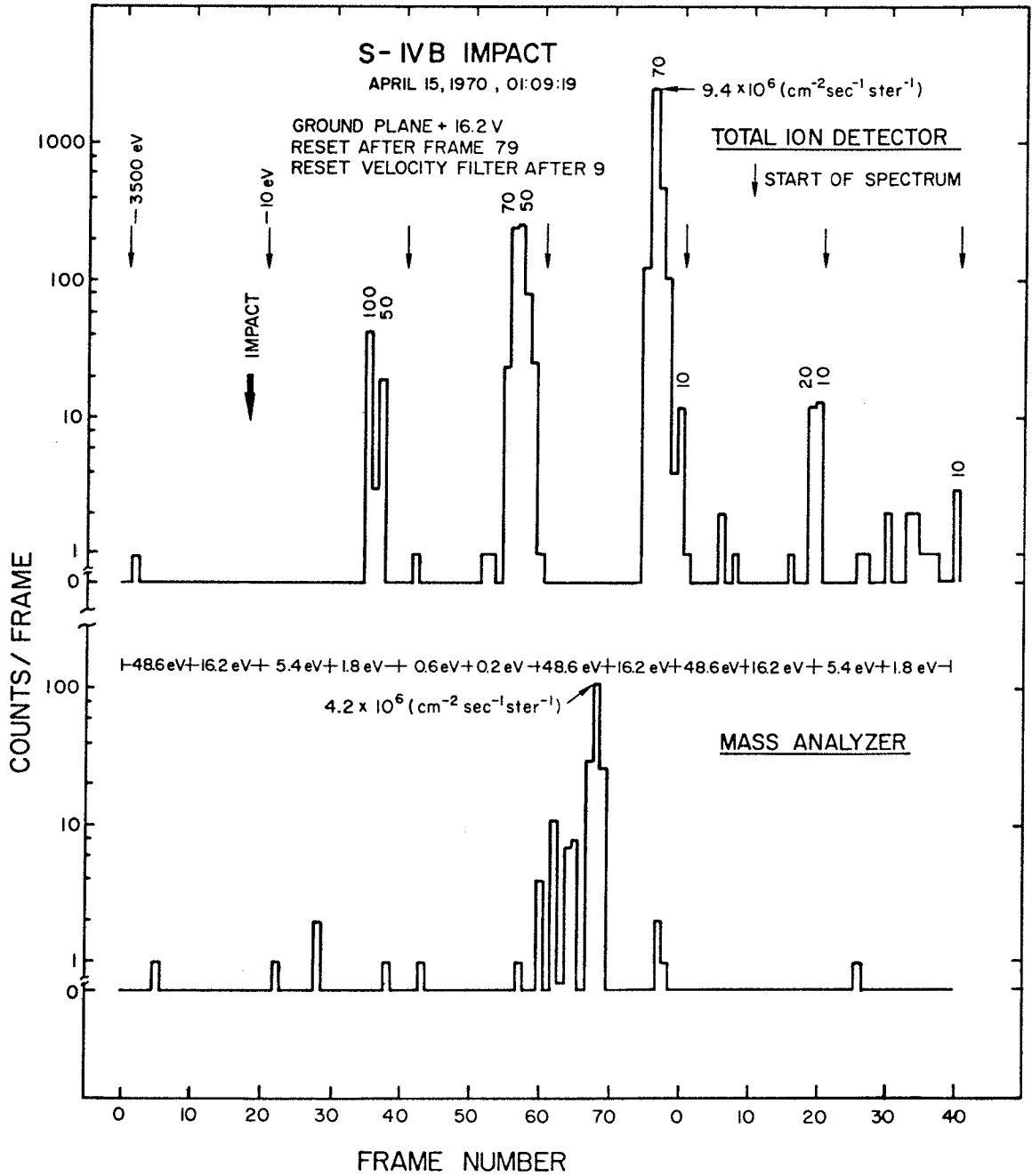


FIGURE 3b