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# Ions from the lunar atmosphere

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**Abstract**—The ionization of neutral atoms in the lunar atmosphere produces an ionosphere around the moon. These ions are accelerated by the interplanetary electric field and local surface fields to energies of 10 to 500 eV. The Suprathermal Ion Detector Experiment (SIDE) has been observing these ions from the lunar atmosphere. The observations have been divided into four categories based on the acceleration mechanism.

## INTRODUCTION

THE LUNAR atmosphere is being constantly ionized by the solar UV and the solar wind. These ions are then accelerated by the local and interplanetary electric fields. Thus the observation of these ions formed from the lunar atmosphere should provide information concerning both the neutral atmosphere and the electric and magnetic fields operating near the moon. A significant observation of $H_2O^+$ ions over a 14 hour period has already been reported by Freeman *et al.* (1972). We here report more extensive observations of ions from the *ambient* lunar atmosphere.

## INSTRUMENT

The Suprathermal Ion Detector Experiment (SIDE) consists of two positive ion detectors: the Total Ion Detector (TID) and the Mass Analyzer (MA). A schematic representation of the TID and MA are shown in Fig. 1. The TID measures the energy per unit charge of all ions in the energy range 10 to 3500 eV. The MA measures the mass per unit charge in six energy levels: 0.2, 0.6, 1.8, 5.4, 16.2, and 48.6 eV. The mass range and mass resolution varies between each instrument. Three SIDEs have been deployed during Apollo missions 12, 14, and 15. The 14 MA has a mass resolution ($\Delta m/m$) of about 0.1 in the mass range 4 to 200 amu. The 15 MA has a mass resolution of 0.07 in the mass range 1 to 130 amu.

Both the TID and MA have a narrow field of view, about a 6° square solid angle, which is canted 15° from the local vertical.

For more information concerning the SIDE refer to Freeman *et al.* (1970).

## OBSERVATIONS

This paper presents a summary of one phase of the analysis being performed on the SIDE data. Due to various considerations (Manka and Michel, 1970) the

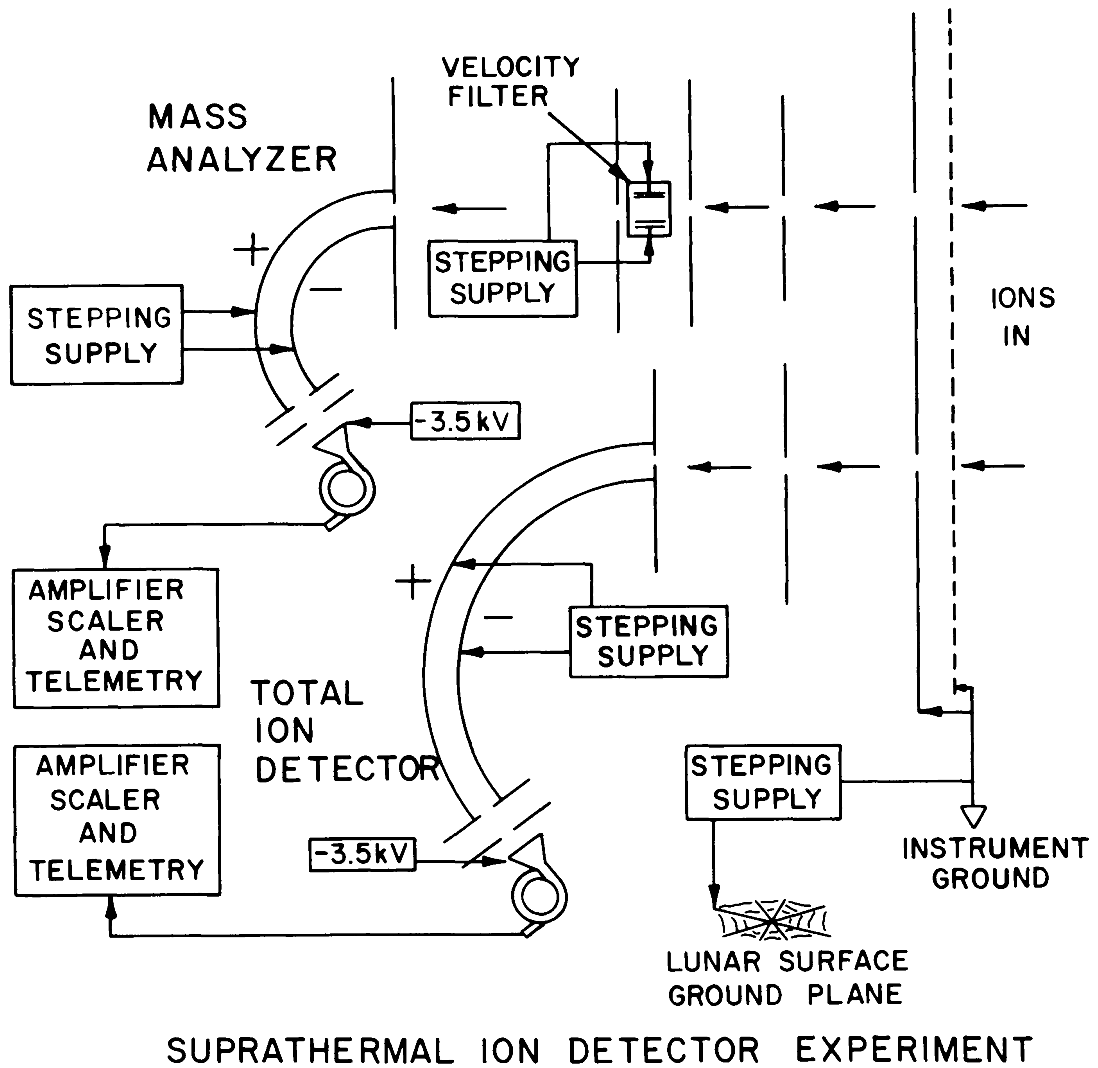


Fig. 1. Schematic diagram of SIDE showing both the Mass Analyzer and the Total Ion Detector.

ions from the lunar atmosphere were expected predominantly to have energies below 100 eV. Thus, a scan of 5 months (August–December, 1971) of TID data from the 14 and 15 SIDEs was conducted to see when low energy (10–100 eV) ions were being observed. Figure 2 shows the periods when these low energy ion were observed. The horizontal lines indicate the periods which the 14 and 15 instruments were on. The blocks show the periods during which the low energy ions were detected. The letters SW, M, and T on the top line indicate solar wind, magnetosheath, and tail respectively.

The low energy ion events can be divided into four types or categories: resonant lunar surface potential event, nonresonant lunar surface potential event, $\underline{v \times B}$ event, and the geomagnetic tail event. These are discussed below.

The first category of low energy ion events is shown by the open blocks in Fig. 2. This event depends on a resonant effect between the lunar surface potential and the internal voltages of the SIDE to accelerate ions into the instrument. A

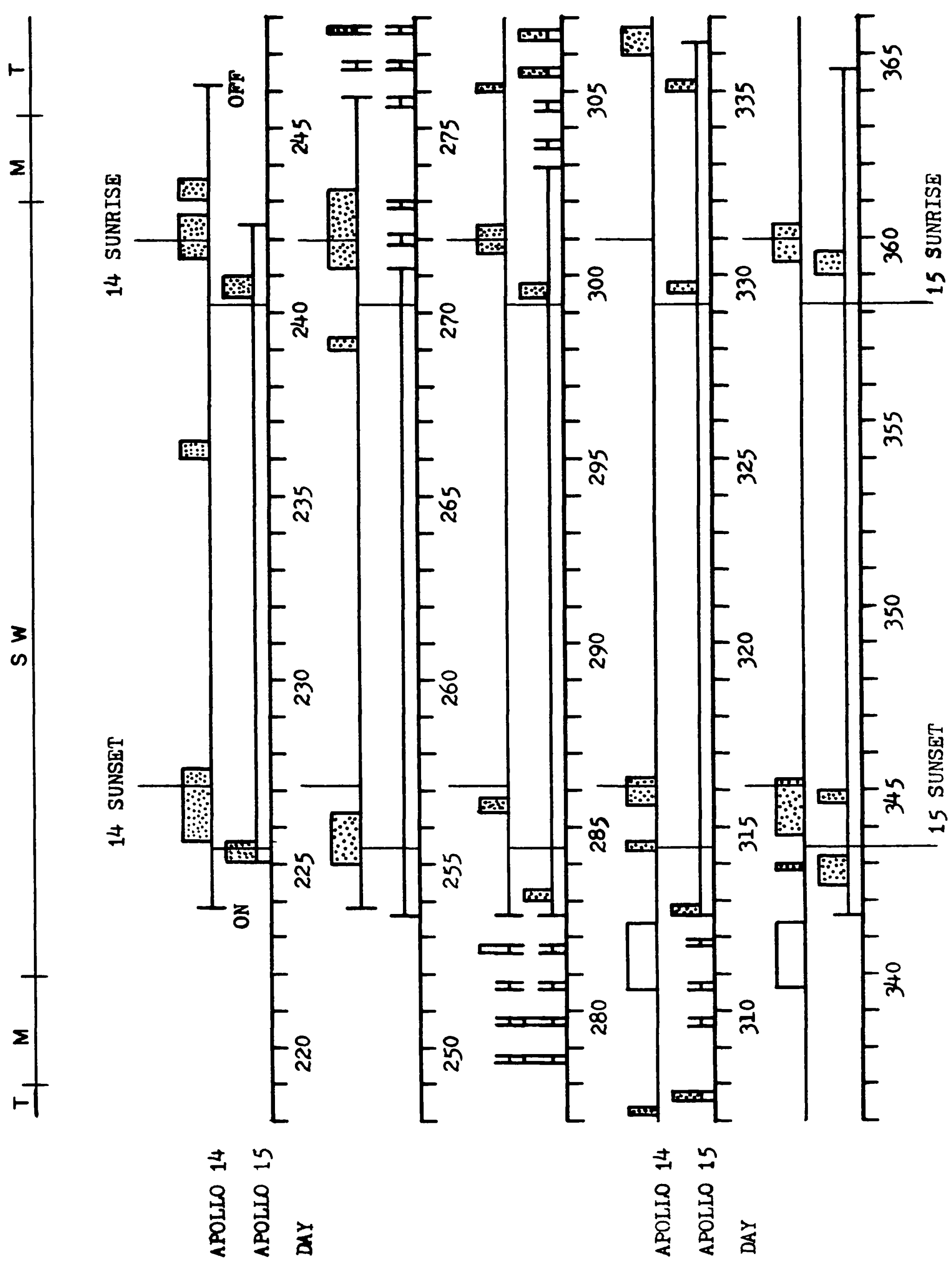


Fig. 2. Low energy (10–100 eV) activity for 5 months (August–December, 1971) of data for both the 14 and 15 TID. The letters SW, M, and T indicate that the moon was located in the solar wind, magnetosheath, or tail respectively.

thorough discussion of these events has been given by Fenner *et al.* (1973). These observations indicate a surface potential of + 10 volts for solar zenith angles of 20° to 45°.

The second type of event relies on a negative surface potential to accelerate positive ions into the instrument. However, no resonance is required between the surface potential and the internal voltages. These events account for most of the activity near the terminators as shown in Fig. 2. This correlation is due to the fact that the surface potential is positive over most of the sunlit hemisphere and becomes negative only near the terminators.

The Apollo 14 data from 5 sunsets crossings are given in Fig. 3. This figure plots the energy channel which contained the maximum flux for each half hour average vs. days before sunset. Note the steady increase in energy of the ions until sunset when the ion energy reaches a steady value of 100 eV. A linear regression analysis of these data is shown in Fig. 4. The sunset data indicate that the lunar surface potential is − 10 V about 1.5 days before sunset and attains a value of − 100 V at sunset. A study of the instrument potential shows that it is near the lunar surface potential in the terminator regions (Lindeman, 1973).

The sunrise data shown in Fig. 4 show much more scatter than the sunset data partially because of the various positions of the bow shock as shown in the figure.

The third type of event utilizes the interplanetary electric field ($\underline{E}_{IP}$) to drive ions into the instrument. This electric field is set up by the convection of the interplanetary magnetic field ($\underline{B}_{IP}$) past the moon at the solar wind velocity ($\underline{V}_{SW}$) and has a value of $\underline{E}_{IP} = -\underline{V}_{SW} \times \underline{B}_{IP}$. When the SIDE is looking perpendicular to $\underline{V}_{SW}$ (15° from the terminators) and $\underline{B}_{IP}$ is pointing out of the ecliptic plane, then the SIDE should be able to observe ions accelerated by this electric field. Correlation of SIDE observations with the direction of the interplanetary electric field has been previously reported by Manka (1972).

Since the SIDE must be about 15° from the terminator, these events are often observed simultaneously with the type 2 events. Types 2 and 3 can be differentiated in two ways. Type 2 has a narrow energy spectrum and can last for several days, while type 3 has a wide energy spectrum and lasts only a few hours. Type 3 also has a strong correlation with the component of $B_{IP}$ out of the ecliptic plane. Type 2 shows no correlation with this component of $B_{IP}$.

Four $V \times B$ events have been compared to Explorer 35 magnetometer data. Only 1 event had flux confined to a narrow cone with a half angle of 10°. The other 3 events had flux in a cone with a half angle of about 60°.

A typical energy spectrum is shown in Fig. 5. The peaks at 10 and 250 eV are common in all four events. Also shown in Fig. 5 is the predicted energy spectrum for single particle dynamics (Manka and Michel, 1970). Since the MA observed a mass of about 20 amu and the surface temperature was about 310°K, a scale height of 80 km is obtained. Note however, that a scale height of 125 km fits the observed data above 250 eV much better than the 80 km. This discrepancy has yet to be adequately explained.

Figure 2 shows that even though the SIDEs were initially cycled off and on for thermal control during the lunar day, both the 14 and 15 instruments regularly

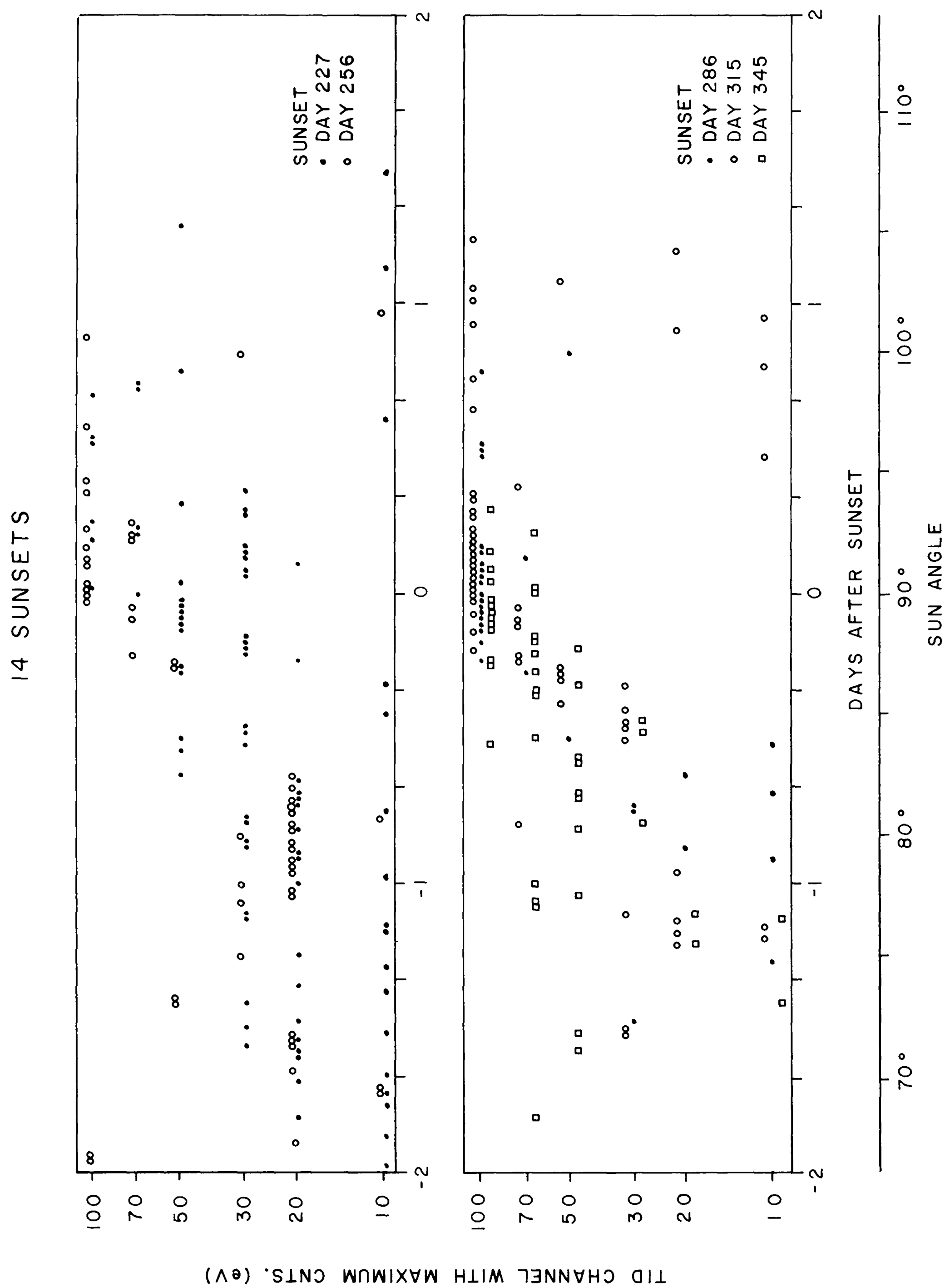


Fig. 3. TID energy channel having maximum counts per frame in a given half-hour period vs. days after sunset for the Apollo 14 SIDE.

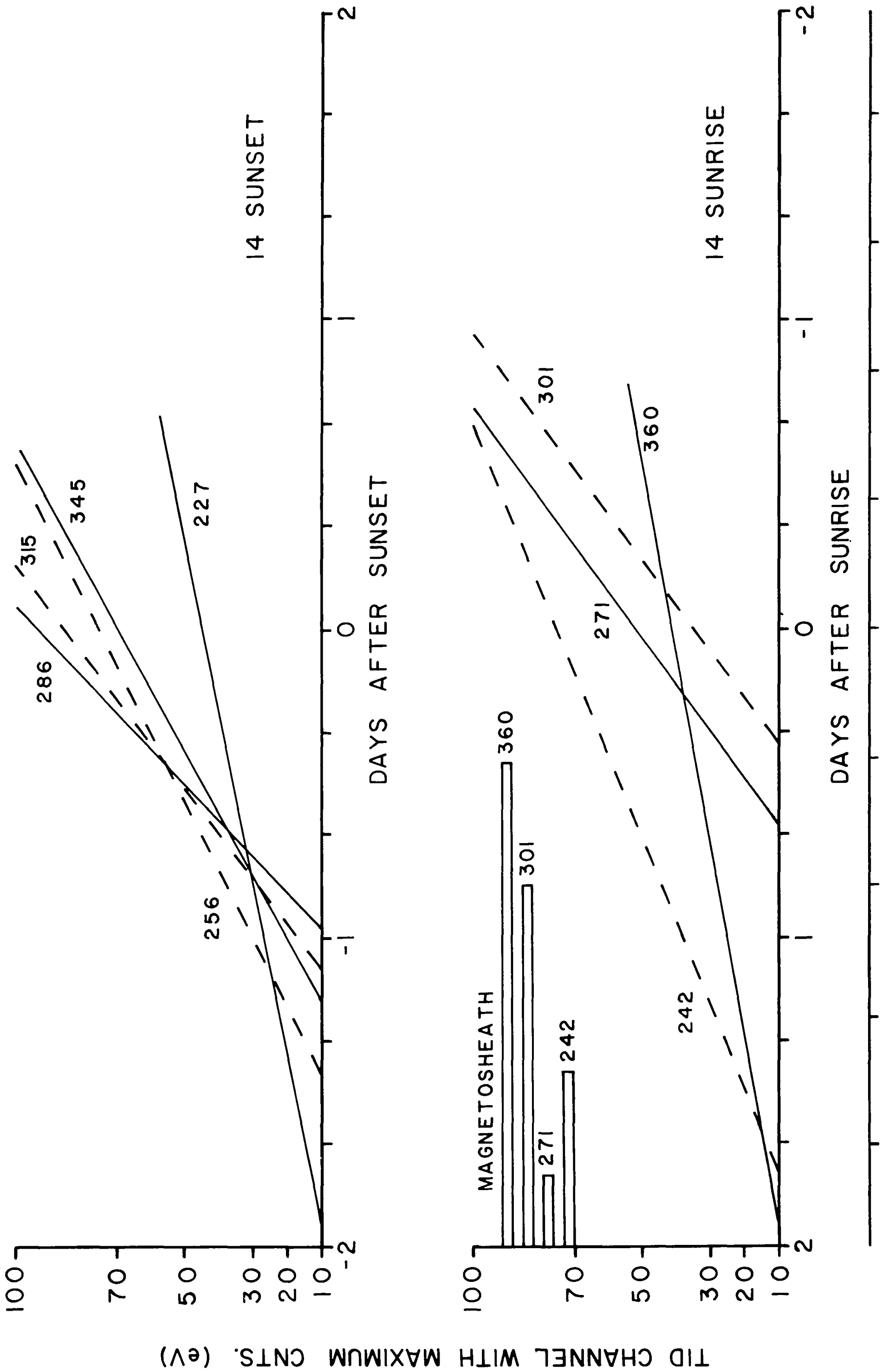


Fig. 4. Linear regression analysis for the Apollo 14 sunrise and sunset events.

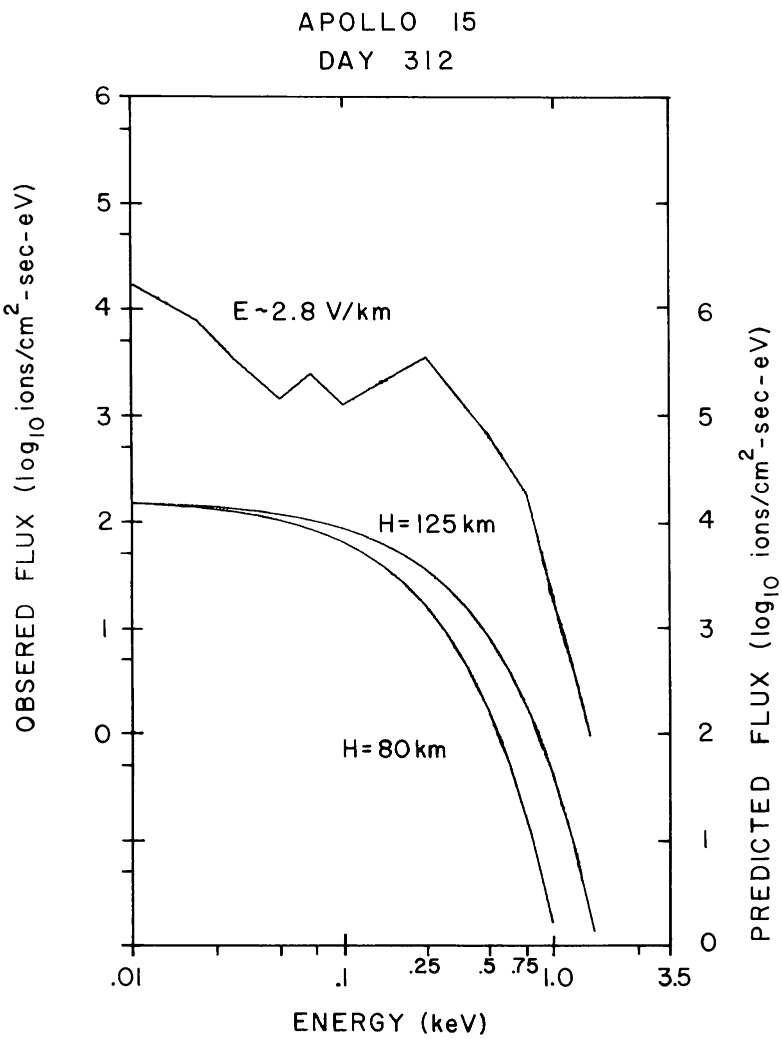


Fig. 5. Predicted and observed differential energy flux for the Apollo 15 event on day 312.

observe low energy ions in the geomagnetic tail. At present the major problem in interpreting these data is determining the origin of these ions. If they are magnetospheric in origin and are assumed to be isotropic they have a number density of 20/cm$^3$. The energy of the ions varies from 10 to 500 eV. This presents the problem of how such a dense low energy plasma could accumulate since these ions are observed both near the plasma sheet and in the high latitude tail.

The more likely answer is that these ions are from the lunar atmosphere. However, we then have the problem of identifying the acceleration mechanism. In the high latitude tail the surface potential may be greater than +200 volts (Reasoner and Burke, 1972). Thus the ions require at least 200 eV just to reach the detector. The cross-tail magnetospheric electric field is pointing almost 90° with respect to the detectors' field of view. As a result it probably has little to do with observations.

Regardless of the origin these tail events may provide a great deal of information concerning the plasma dynamics deep in the tail. If the plasma is magnetospheric in origin then it may provide the clue to the origin of the plasma sheet. If the ions are lunar in origin then we have a good opportunity for determining small scale electric fields deep in the tail.

## Ion Mass

Data are available from the mass analyzer for a number of the events described herein. These data are all consistent with the noble gases neon or argon serving as the parent atoms. A puzzle that remains is that the SIDE never indicates the presence of ions from both gases simultaneously. We suspect a mass spectrometer effect associated with local electric and magnetic fields and the narrow field of view of the SIDE detectors. An understanding of this effect is essential to a determination of the absolute quantities of the gases present.

## Conclusions

The SIDE observes ions from the lunar atmosphere in a variety of situations. This paper presents a brief summary of the observations. More detailed results will be published in future papers.

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