RICE UNIVERSITY

RECURRING ION EVENTS AT THE LUNAR SURFACE

by

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ABSTRACT

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Rice University's Suprathermal Ion Detector Experiment (SIDE) has been deployed on three Apollo missions (XII, XIV, and XV). This thesis presents the results of the Apollo XII SIDE, Total Ion Detector, for the first six months of nighttime data. During this time ion events were observed to occur at certain points in the lunar orbit. These events are classified according to their time histories and their energy spectral characteristics into five types. Type I has a single peaked differential energy spectrum with its peak energy ranging from 2000 to 3500 eV. Type II has a double peaked differential energy spectrum with its high energy peak ranging from 2000 to 3500 eV and its low energy peak ranging from 30 to 250 eV. Type III has a narrow, single peaked energy spectrum in the range 250 to 750 eV. Type IV has a broad, single peaked energy spectrum in the range 50 to 100 eV. Type V has a single peaked energy spectrum in the range 1000 to 1750 eV. An example of each type is described and possible sources for each are given. Along with these events, Short Intense Bursts are also observed. These bursts are defined and discussed in a similar manner.
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CHAPTER 1 - INTRODUCTION

1.1 HISTORY AND SCIENTIFIC OBJECTIVES

The Suprathermal Ion Detector Experiment (SIDE) was designed and built by Time Zero Corporation under the supervision of Rice University to achieve the following scientific objectives (Freeman et. al., 1970):

A. Provide information on the energy and mass spectra of the positive ions close to the lunar surface that result from solar ultraviolet or solar wind ionization of gases from any of the following sources: residual primordial atmosphere of heavy gases, sporadic outgassing such as volcanic activity, evaporation of solar wind gases accreted on the lunar surface, and exhaust gases from the lunar module descent and ascent motors and the astronauts' portable life-support equipment;

B. Measure the flux and energy spectrum of positive ions in the Earth's magnetotail and magnetosheath during those periods when the Moon passes through the magnetic tail of the Earth;

C. Provide data on the plasma interaction between the solar wind and the Moon;

D. Determine a preliminary value for the electric potential of the lunar surface.

Three of these instruments have been successfully deployed as part of the Apollo Lunar Surface Experiments Package. The first was deployed by the Apollo XII astronauts on November 19, 1969 in the Ocean of Storms. The second was deployed by the Apollo XIV astronauts in the Fra Mauro Region, and the third instrument was deployed on the lunar surface during the Apollo XV mission. All instruments are presently operating satisfactorily.

1.2 INSTRUMENT

Each instrument consists of two separate detectors: the Total Ion Detector (TID) and the Mass Analyzer (MA). The TID
utilizes a cylindrical electrostatic analyzer and a channel-electron multiplier to measure the energy per unit charge of all ions entering into a narrow square solid angle $6^\circ$ on a side (see Figure 1). The voltage on the electrostatic analyzer is stepped so that ions in the energy range $10 - 3500$ eV/q are detected in twenty energy channels ($10, 20, 30, 50, 70, 100, 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2250, 2500, 2750, 3000, 3250, 3500$ eV/q). The energy band width of each channel is $\pm 5\%$ of the center energy, thus only the high energy channels (above 2250 eV) overlap. The channel-electron-multiplier is a Bendix Funneltron operated as an ion counter (energy is obtained from the voltage on the electrostatic analyzer not from the pulse height). The funneltron is biased at its input end at $-3500$ V thereby boosting the ion's energy, after being analyzed in the electrostatic analyzer to yield high detection efficiencies. The geometric factor for the Apollo XII SIDE is approximately $10^{-4}$ cm$^2$ ster.

The MA utilizes a Wein Velocity Filter with a cylindrical electrostatic analyzer and a Bendix Funneltron to measure both the mass per unit charge and the energy per unit charge of the ions entering into a narrow square solid angle $6^\circ$ on a side. The electrostatic analyzer is stepped through six voltages so that ions in the energy range 0.2 to 48.6 eV/q are detected in the six energy channels ($0.2, 0.6, 1.8, 5.4, 16.2, 48.6$ eV/q). At each energy level the Wein Velocity Filter is stepped through twenty mass per unit charge channels. For the Apollo XII MA these channels cover the range 10 - 1000 AMU/q. The Bendix Funneltron is utilized and biased in the same manner as the Funneltron used in the TID.
The SIDE is programmed to execute one complete cycle every 2.55 minutes. This cycle consists of 128 frames, 1.2 seconds per frame. The TID completes one spectrum (10-3500 eV/q) in twenty frames and thus obtains six complete spectra each SIDE cycle. The MA requires 120 frames to obtain twenty mass steps for each of six different energies. The remaining eight frames are used for calibration of both detectors. This calibration adds to the reliability of the data. The accumulation interval for each step of the TID and MA is 1.13 ± .025 seconds not 1.2 seconds. This allows time for readout and for transients to die between frames.

To compensate for a potentially large (tens of volts) lunar surface potential a wire screen is deployed on the lunar surface beneath the SIDE. This screen is connected through a stepped voltage supply to a grid mounted in front of the ion entrance apertures for the TID and MA (see Fig. 1.) The voltage supply varies between 27.6 and -27.6 volts in 24 steps.

The entrance aperture of the instrument stands 20 inches above the lunar surface. Both detectors have fields of view canted 15° from the local vertical.

For a thorough description of the SIDE refer to Freeman et. al. (1970).

1.3 APOLLO XII SIDE

This thesis presents the results of the first six months of nighttime data from the TID of the Apollo XII SIDE. This instrument was deployed such that its look direction is
pointed $15^\circ$ west of the vertical and in the plane of the ecliptic. Figure 2 shows the look directions (arrows) in an earth-sun fixed coordinate system at various points in the lunar orbit. Sunrise, noon, sunset and midnight refer to the Apollo XII Alsep location.

It was found during operation, that the background rates for both the TID and MA are extremely sensitive to the temperature. Figure 3 plots the average background counts per SIDE frame for the TID for 12 hour intervals during the lunar night. These background rates are obtained by grounding the electrostatic analyzer and monitoring the Funneltron's output. This is done twice every SIDE cycle during calibration frames. The values shown represent an average over the first four months of data. The error bars indicate the upper and lower monthly values for each point during this period and the small numbers indicate the number of months available for the average. If no number is shown background rates for all four months were used in the average.

Also due to the high temperatures, it was necessary to operate on a limited duty cycle such that the SIDE be turned off by ground command two days after sunrise and turned on again two days before sunset. In the daytime the SIDE is turned on at certain times for several hours. The daytime data obtained in this manner is not discussed in this report but has been presented in such papers as Fenner et. al. (1971) and Garrett et. al. (1971). Figure 4 shows the periods for which data is available and has been analyzed for this report. This figure does not show all the times in the six month period during which the SIDE was turned on.
The periods which show either magnetosphere, magnetosheath, or bow shock data have been deleted. The SIDE has also detected at least one interplanetary storm. Results from this event have been presented by Medrano et. al. (1971).
CHAPTER 2 - DATA

2.1 DATA ANALYSIS

The SIDE data as received from the Manned Spacecraft Center are on magnetic computer tape in a compact format. Utilizing Rice University's Burroughs 5500 this data was checked for quality and outputted on other magnetic tapes in a format acceptable to the SDS 910. The SDS arranged the data in matrix form such that one spectrum (20 data points) was printed on one line with each successive spectrum on the following lines. The data points were still given in terms of counts per SIDE frame. This format made the high count-rates stand out visually and thus greatly enhanced the author's ability to scan large quantities of data to obtain results given below. The individual events were recorded and re-analyzed on the SDS 910. The differential flux and integral flux were obtained for each cloud.

2.2 OVERVIEW

The first six months of data (November 19, 1969 to May 16, 1970) have been analyzed in this manner. The natural ion clouds during this time have been classified according to their time histories and their average differential fluxes into 5 types. Four of these types recur at certain points in the lunar orbit. The fifth type shows a less certain correlation. Along with these clouds, other shorter events have been observed which also show no definite correlation with positions in the lunar orbit. These events shall be referred to as short intense events (SIE). The results in this paper are based only on the TID data. The MA data is presently being analyzed.
2.3 ION EVENT: TYPE I

Type I consists of a high energy peak ranging from 2000 - 3500 eV/q. These events last from 2 to 25 minutes. A 20 minute cloud observed on January 3, 1970 is presented in Table 1 and Figures 5, 6, 7, and 8.

Figure 5 shows the general characteristics of this particular event. The activity in counts per SIDE frame has been grouped into 5 categories as shown on the scale and then plotted for each energy channel. Each vertical column represents one TID spectrum (approximately 24 seconds). The time axis indicates the time at which the spectrum began. Note that this is slightly discontinuous since 8 calibration frames (9.6 seconds) occur after every 6 TID spectra. This figure clearly shows that almost all of the activity occurs in the energy channels above 1750 eV. Note the characteristic burst type structure. This event is not composed of a continuous stream of ions but rather short bursts of ions. This may be due to the narrow field of view of the detector rather than to the intrinsic properties of the event.

The spectra marked with a bar over them are shown in more detail in Table 1. The counts per SIDE frame are shown in the same format as the data after initial analysis by SDS 910. Each line corresponds to one TID spectrum with successive spectra following. The intermittent temporal structure and the high degree of activity in the higher energy channels are evident. Note also the decay of energy for this initial burst. This energy decay is also very characteristic of this type of event. The second half of the table shows data from later in the event.

The energy channel having the peak average flux for this
TABLE 1

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SIGNS

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FRAMES

| Frame | 163 | 157 | 181 | 15  | 1   | 0   | 0   | 2   | 0   | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   |

EVE

| Eve  | 0   | 1   | 0   | 0   | 0   | 0   | 0   | 0   | 1   | 0   | 1   | 0   | 4   | 0   | 0   | 0   | 1   | 0   | 0   |
event was 3000 eV/q. The counts per SIDE frame for this channel are plotted versus time for the whole event on Figure 6.

Figure 7 plots the energy channel having the maximum counts (10 or more) for each TID spectrum versus time. The arrows represent TID spectrum in which no counts exceed 10. As can be seen, the peak energy varies quite rapidly but with a tendency towards decreasing energies during each burst.

Figure 8 plots the average differential flux versus energy for the entire event. Also shown is standard deviation of the background when averaged over a corresponding length of time ($\sigma/\sqrt{n}$) to show the statistical significance of the measured values. For this period of time $\sigma/\sqrt{n}$ corresponds to a count rate of 113 counts per SIDE frame. The flux has already been corrected for the background reading.

Figure 9 is a histogram showing the number of occurrences of a type 1 event in twelve hour intervals for this six month period versus days after sunset. An event can be defined as sustained activity (at least 2 minutes) with a substantial number of counts greater than 5$\sigma$ above background. Activity which begins at least 40 minutes after the last event ended is considered as a new event.

Note the great abundance of occurrences around and especially after sunset with only minor activity at sunrise. Recall that the SIDE is usually turned off about 2 days after sunrise and turned on again about 2 days before sunset with only sporadic look periods (lasting about 2 hours) in between. However these short look periods show no activity above background.
2.4 **ION EVENT: TYPE II**

Type II has a double peaked energy spectrum. The high energy peak is in every way identical to Type I having an energy range of 2000 – 3500 eV and a duration of 2 to 25 minutes. The low energy peak has an energy range of 30 – 250 eV and its onset can lag behind the initial high energy burst by as much as 1 to 15 minutes.

On February 2, 1970, 0650 GMT, a 10 minute type I event was observed which was followed by relatively minor activity in the higher energy channels (sporadic peaks in the range 2000 – 3500 eV). At 0739 GMT another burst of high energy particles occurred accompanied by peaks in the 70 and 100 eV/q channel. This is shown on Figure 10. The initial part of this event is shown in more detail in Table 2. Note that the higher energy counts have a lower magnitude than those shown for Type I. This is not a general characteristic of Type II events.

The counts per SIDE frame for both the high energy peak (2250 eV) and the low energy peak (100 eV) are plotted versus time in Figure 11.

Figure 12 plots the low energy channel having the maximum counts per SIDE frame in each spectrum versus time. As can be seen, the energy of the low energy peaks is very stable whereas the count rates for both high and low energy peaks are highly variable and exhibit the burst structure as observed in Type I.

Figure 13 plots the average differential flux versus energy for the entire event shown in Figure 10 and Figure 14 plots the number of occurrences of Type II events in 12 hour intervals versus position in the orbit. Once again the majority of observations occur at sunset, however the total number
**TABLE 2**  
**TYPE II ION CLOUD**

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of occurrences is much less than the total number of occurrences of Type I (see figure 9).

It might be argued that Type II is the result of two simultaneous but independent phenomena and should not be regarded as a separate type of event. In this light consider Figures 15 and 16. For the Type II event described above, all the high energy counts (1500 - 3500 eV) were summed for each spectrum and the low energy counts (30 - 500 eV) were likewise summed. To remove needless complications due to the short burst structure of these events, these sums were then averaged over four successive spectra. These average integral counts were plotted versus time on Figure 15. A similar cloud observed 0921 GMT, April 30, 1970 was processed in a similar manner and plotted on Figure 16. Note the excellent correlation between the first large high and low energy peaks. In both cases there was essentially no activity in the low energy channels for several hours preceding these events and at least one hour following these events. This correlation would be difficult to explain in terms of two completely independent phenomena.

2.5 ION EVENT: TYPE III

Type III events have a peak energy in the range 250 - 750 eV and a duration of 5 minutes to 2 hours. These events usually, but not always, have two phases. The first phase consists of a very narrow energy spectrum with significant counts in only one or two energy channels. It is this phase that characterizes a Type III event. The second phase consists in a broader energy spectrum with the peak energy moving to higher energy channels. This latter phase usually occurs during the last few minutes of the cloud and has a
## TABLE 3
TYPE III ION CLOUD

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<th>ENERGY (keV/q)</th>
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much shorter duration than the first phase. The shorter events generally do not exhibit a second phase whereas the longer events may have several alternating first and second phases with the initial phase composing most of the event.

A 14 minute event observed on January 2, 1970 is shown in Figure 17. A section of both the first phase and the second phase is shown in greater detail in Table 3.

The characteristics of both phases can really be seen in Figures 18 and 19. The peak average differential flux for this event is in energy channel 250 eV. The counts per SIDE frame for this channel are plotted versus time in Figure 18. Although the count rates are highly variable, this event shows much more temporal continuity than either Type I or Type II. This may indicate either that Type III is a continuous stream of ions and Types I and II are intermittent streams or Type III is more isotropic and Types I and II are more unidirectional flows.

The energy channel having the maximum counts in each SIDE spectrum is plotted in Figure 19. The two phases are quite evident on this plot. Figure 20 plots the average differential flux for the total event. Figure 21 plots the number of occurrences versus position in orbit. Observe the overwhelming correlation with sunrise and sunset with maximum occurrence 3 days before sunrise. This is a totally different lunar orbit distribution from Types I and II.

2.6 Ion Event: Type IV

Type IV is characterized by a very broad energy spectrum for the average differential flux and a peak energy in the range 50 - 100 eV. These clouds may have a duration anywhere between 5 minutes and 2 hours. They often exhibit the
**TABLE 4**

**TYPE IV ION CLOUD**

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two phase structure as seen in Type III but to a lesser extent. The energy channel having maximum counts remains fairly constant during the first phase though the energy spectrum is very broad. During the second phase the peak energy varies rapidly but with the overall tendency to move to higher energy channels.

Several Type IV clouds were observed on January 16, 1970, one of which is discussed below. A 25 minute section of a 90 minute cloud is shown in Figure 22. The wide spectrum is evident in this plot. Sections of the first and second phases are shown in Table 4.

The peak energy for this event was 70 eV. The counts per SIDE frame for this channel are plotted on Figure 23. The energy channel having the maximum counts in each spectrum is plotted on Figure 24. The second phase shown in Table 4 begins at 12 minutes on this figure. A larger second phase begins at 20 minutes. Figure 25 plots the average differential flux versus energy for the entire 90 minute cloud. Figure 26 plots the number of occurrences versus position in orbit.

It is interesting to compare these figures with the corresponding figures for Type III clouds. The rather long bursts and two phase structures are recognizable in both types. Also the excellent correlation of frequency of occurrence versus position in orbit is apparent. Note however that Type IV tend to peak closer to the terminators than Type III. The major differences between these types are the lower peak energies of Type IV and the much broader spectrum exhibited by the average differential flux of Type IV.

For further discussion of a string of Type III and IV events see Freeman et. al. (1970).
2.7 **ION EVENT: TYPE V**

The average differential flux for a Type V event has a single peaked energy spectrum in the range 1000 - 1750 eV. These events have a very short duration, 2 to 10 minutes, but can have very high counts. A four minute cloud observed on February 2, 1970 is shown in Figure 27 and Table 5. The sporadic activity beginning at approximately 11 minutes is not a general characteristic of a Type V event. It is interesting to note that even these short events exhibit the intermittent burst structure observed in Types I and II, however there is no tendency towards energy decay.

The counts per SIDE frame for the energy channel having the peak average flux (1000 eV) are plotted in Figure 28. The energy channel having the maximum counts in each spectrum is plotted in Figure 29. The average differential flux is plotted on Figure 30, and the number of occurrences is plotted on Figure 31.

Unlike any of the previous 4 types, Type V does not seem to correlate with position in lunar orbit using sunrise and sunset as the references points. Two successive sunrises are approximately 30 days apart whereas two successive peri¬gees are only 28 days apart. Figure 32 plots number of occurrences versus days after perigee. This correlation does not indicate a definite relationship with perigee crossings as has been found for the ALSEP Passive Seismic Experiment (Latham et. al. 1970).

2.8 **SHORT INTENSE BURSTS**

These bursts are very similar to Type V in structure but are much shorter. Approximately 75% of the statistically significant counts occur within 3 or 4 seconds. Thus these
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bursts are not events as defined for Types I through V since they do not exhibit sustained activity. They seem to occur randomly through the night and can have a peak energy in any energy channel. One such burst was observed on March 15, 1970, 12:37 GMT. This event is shown in Table 6. Note the minor activity which occurs about 3 minutes (7 SIDE spectra) after the major event. This is typical for a SIB.

2.9 THEORETICAL DISCUSSION

The purpose of the SIDE is to determine what plasma phenomena are operative near the lunar surface. In this light it is helpful to consider the particles and fields in this region.

Possible sources of charged particles in the lunar environment are listed below:

A. Solar Wind

B. Lunar Atmosphere
   1. Ambient Lunar Atmosphere
   2. Subsurface and Surface Outgassing
   3. Impacts
      a. Lunar Vehicles
      b. Meteorites
   4. Contaminant Gases

C. Earth's Bow Shock

The properties of the solar wind have been the subject of a great deal of investigation. These properties are amply discussed in a multitude of works such as Brandt (1970) and Hundhausen (1970).

The ambient lunar atmosphere though extremely tenuous can be ionized either by incident solar photons or incident solar wind and subsequently accelerated to produce a steady
stream of ions. Subsurface outgassing, impacts, and contaminant gases (such as rocket fuel) will produce expanding gas clouds. On the sunlit side some of these particles will be ionized. If the detector and the source are in close proximity, the detector will measure the motion of the cloud as the cloud passes over it. However, if the detector and the source are greatly separated, the gas cloud will blend with the neutral atmosphere and be indetectable as a cloud.

Satellite data (Asbridge et al., 1968) have shown that particles having energies of several keV can be ejected by the Earth's bow shock and propagate upstream along interplanetary magnetic field lines. When these field lines connect the Moon with the bow shock one can expect these particles to be incident on the lunar surface.

The various fields which might influence these particles are listed below:

A. Magnetic Fields
   1. Interplanetary Magnetic Field
   2. Constant Local Fields
   3. Induced Magnetic Fields

B. Electric Fields
   1. Electrostatic Lunar Surface Field
   2. $\vec{V} \times \vec{B}$ Field

The interplanetary magnetic field has also been extensively investigated. For an adequate treatment of these results see Chapters 3 and 5 of Brandt (1970) and the references contained therein.

Dyal et al. (1970) have reported that the Lunar Surface Magnetometer (LSM) which was also deployed by the Apollo XII astronauts has shown that a constant local field of 36±5 γ
exists in the vicinity of the SIDE. This field is directed
towards the south east. If it is assumed to be a dipole
field with its source on the surface, then the source must
be located at least 0.2 km. from the magnetometer.

Along with this constant field, the LSM in conjunction
with the Explorer 35 magnetometer indicates a strong lunar
inductive response to external magnetic fields. At the
present time it is not known whether the whole Moon or a
part of the lunar material near the Apollo XII landing site
partake in this inductive response.

The electrostatic lunar surface potential has been the
subject of much debate in the last few years. Some estimates
give the potential in tens of volts. Recent calculations by
Grobman and Blank (1969) place the potential at the subsolar
point for typical solar wind conditions at +3 volts. Under
plausible limits of the pertinent parameters, the potential
at the subsolar point may vary from +0.6 to 10.2 volts.

If the solar wind can be assumed to have infinite con¬
ductivity, the electric field in the rest frame of this med¬
ium must be zero. This is due to the fact that for the cur¬
rent (j) given by
\[ j = \sigma (E + \vec{v} \times \vec{B}) \]
to remain finite in a medium having infinite conductivity
the sum (E + \vec{v} \times \vec{B}) must vanish. Thus an ion in motion with
respect to the solar wind will see an electric field given
by the expression
\[ \vec{E} = -\vec{v} \times \vec{B} \]
where \( \vec{v} \) is the velocity of the ion with respect to the solar
wind and \( \vec{B} \) is the value of the field at the position of the
ion. If \( \vec{v} \) is taken as 400 km/sec and the perpendicular com¬
ponent of the magnetic field is 5\( \gamma \) (these are typical values
for the solar wind velocity and interplanetary magnetic field) then $E = 2 \text{ volts/km}$.

2.10 APPLICATIONS TO THE PRESENT DATA

Types I and II are similar in that they have a high energy peak and therefore will be treated together. These clouds occur predominately one or two days after sunset as can be seen in Figure 33. This figure merely repeats previous data for ease of comparison. Assuming a garden hose angle of $45^\circ$, the nose of the bow shock will be connected to the lunar orbit at this position. A proton with energy $3000 \text{ eV}$ has a velocity of $750 \text{ km/sec.}$ and requires 7 minutes to travel from the bow shock to the lunar orbit. During this time the field lines are being convected at the solar wind velocity. The vector sum of the initial velocity ($750 \text{ km/sec.}$) along the garden hose angle of $45^\circ$ and the solar wind velocity ($400 \text{ km/sec.}$) in the antisolar direction yields the direction of propagation of the particle. For the conditions given above this direction is $70^\circ$ from the Earth-Sun line. This trajectory intersects the lunar orbit 2 days after sunset rather than 3 as mentioned above.

These comments on the interplanetary magnetic field may be misleading. Even though the direction of the field averages at the garden hose angle, the field itself can vary rapidly in direction and magnitude. At any given time all that is required is that the field lines along which the particles are propagating connect with the Moon when the particles reach the lunar orbit. Under these conditions it is possible for bow shock particles to be observed at any time during the lunar night. However, the probability of observing these particles is greatest 2 days after sunset.
This agrees with the data for Types I and II.

Asbridge et. al. (1968), Montgomery et. al. (1970), and Scarf et. al. (1970) have reported energy ranges of these ejected ions as determined by satellite data of 2 to 7 keV and these ions are predominately protons. This agrees with energies of the high energy peaks for Types I and II which is 2.0 to 3.5 keV. Ions with energies above 3.5 keV cannot be detected by the SIDE.

Next consider the low energy peak of Type II events. Fairfield (1969) reported the observation of wave trains (varying amplitude sinusoidal variations of the magnetic field lasting up to tens of minutes) with frequencies 0.01 to 0.05 Hz in the rest frame of the satellite propagating upstream in the solar wind. Scarf et. al. (1970) have shown conclusively that these wave trains are generated by bow shock ejected particles mentioned above. Recently Russell et. al. (1971) have reported discrete wave packets (regular variations of the magnetic field lasting tens of seconds) at frequencies near 0.4 Hz in the rest frame of the satellite. These packets are related to the wave trains and thus by inference to the ejected particles. The 0.4 Hz wave packets occur in the midst of the 0.01 - 0.05 Hz wave trains 89% of the time, however the reverse is not true. These packets have peak amplitude of 4γ and may last 7.5 to 22.5 seconds and usually propagate in groups. The authors, using a small amplitude plasma treatment, associate these packets with waves having right hand polarization and a wave frequency of 2 to 4 times the proton gyrofrequency in the rest frame of the solar wind. A proton can resonate with these waves in two different manners. The first method requires that the proton propagate faster than the packet such that the anom-
alous Doppler shifted wave frequency corresponds to the proton gyrofrequency. This means that a proton circling a magnetic field line sees an electric field which is spinning at the same rate. This is called cyclotron resonance. For the wave packets being considered here, the proton's energy parallel to the magnetic field must be approximately 150 eV. The second method requires that the proton velocity parallel to the field must equal the wave phase velocity parallel to the field. Under these conditions the proton will see a constant field in both magnitude and direction. This is called Landau resonance. For the above packets, the proton energy parallel to the field would be approximately 20 eV.

Russell et. al. (1970) report that these packets have been observed at a distance of 24 $R_e$ from the Earth in the interplanetary medium. It seems likely that they also exist at the lunar orbit. It is interesting to note that these low energy particles (20 -150 eV) have not been reported in the solar wind at distances of 24 $R_e$. Assuming that these packets are associated with the low energy peak in Type II events, these ions may have their source very close to the Moon. The above considerations present a possible though not conclusive explanation for Type II events. The intrinsic uncertainty in Russell et. al. (1971) treatment of the wave packets may explain the observed energy spread (30-250 eV) rather than two spikes at 20 and 150 eV.

Due to the similarities in Types III and IV these events will be treated together. The peak energies (250-750 eV) for Type III events include the medium to low energy solar wind. The energy spectra for Type III are usually very narrow which is also characteristic of the solar wind. On the other hand the peak energies (50-100 eV) for Type IV events
lie below the solar wind energies and the energy spectra for Type IV are usually very broad. Unlike the solar wind, both Types III and IV are observed when the look directions of the SIDE are 75° (at sunset) and 105° (at sunrise) from the sun.

An interesting comparison can be made with the data for February 14, 1970 beginning 0536 UT (35.7 hours or 18.0° before photoelectron sunrise) and ending 1637 UT (25.2 hours or 12.8° before photoelectron sunrise). During this period Clay et. al. (1971) have reported that large fluxes of particles were measured by the Apollo XII Alsep Solar Wind Spectrometer (SWS). At this time OGO 5 in earth orbit measured an average solar wind velocity of 430 km/sec. (approximately 950 eV for protons) and a density of 2 protons/cc.

The SWS results are consistent with such a flow if it is assumed that the flow was coming from a direction 5° above the horizon. The SIDE meanwhile was pointing approximately 120° from the sun and 100° from the bulk flow as measured by the SWS.

The SIDE data for this period is given below. Note that the SIDE data begins at 0420 UT, 1 hour and 16 minutes before the SWS data. Evidently the initial portion of the flow was below the sensitivity of the Faraday cups used as detectors in the SWS.

0420 - 0629 Isolated peaks no structure;
0629 - 0709 Type III. event, peak energy beginning at 250 eV and shifting to 750 eV;
0709 - 0845 Isolated peaks;
0845 - 0905 Type IV event, peak energy 100 eV;
0905 - 0952 Isolated peaks;
0952 - 1010 Type III event, peak energy 500 eV;
1010 - 1634 Isolated peaks.
At 1634 GMT an intense burst of ions occurred stretching from 250 to 3500 eV and then the data suddenly becomes very quiet. This agrees with the abrupt end of the SWS data at 1637 GMT.

This is the only period during which the SWS observes such a flow up to 36 hours before sunrise. However, Figure 25 shows that Type III and IV events are often observed 3 and 4 days before sunrise. Clay et. al. (1971) suggest a local magnetic field $7^\circ$ to the north of east of the ALSEP site as the mechanism which deflects solar wind ions $15^\circ$ around the lunar surface. If all Type III and IV events are associated with the deflection of the solar wind then it is possible to conclude the following:

A. These flows are frequent but usually have magnitudes below the sensitivity of the SWS;

B. The deflection mechanism is much stronger than that proposed by Clay et. al. since now it must deflect solar wind ions $40^\circ$ around the lunar surface;

C. This deflection mechanism must be operative at both the sunrise and sunset terminators.

It is possible that all Type III and IV events are associated with solar wind flows. Consider other possible sources. It has been suggested that the vents of the propellant tanks in the LM descent stage which were opened by the astronauts prior to liftoff may periodically freeze and inhibit the escaping fuel. If this fuel were the source of these ion events, one would expect that the frequency and intensity of these events would decrease over the six month period being considered. Since this is not the case, the escaping fuel does not seem to provide a plausible source.

The only other possible source is the Moon itself. Consider first the neutral atmosphere. The Cold Cathode Ion Gage
Experiment (CCIGE) deployed as part of the Apollo XIV mission has shown that the ambient neutral atmosphere at the lunar surface contains $10^6$ particles/cc at the lunar noon and $10^5$ particles/cc at lunar midnight (D. Evans private communication). This indicates an exosphere type condition exists in which neutral particles travel in ballistic trajectories uninterrupted by collisions with other gas molecules. On the sunlit side these particles are continually being ionized and subsequently being accelerated by various mechanisms. Manka and Michel (1971) have discussed ion trajectories under $\vec{v} \times \vec{B}$ acceleration process and shown that under normal conditions initial flow of ions will be either north or south depending on $\vec{B}_{s.w.}$. Such a flow cannot be detected by the SIDE since its look direction is in the plane of the ecliptic. However, under unusual conditions i.e. the component of $\vec{B}_{s.w.}$ perpendicular to $\vec{v}_{s.w.}$ is directed totally out of the ecliptic, then the initial flow will be in the ecliptic plane. Since the solar wind varies $\pm 10^\circ$ with a $5^\circ$ abberation angle, this initial flow can vary from $75^\circ$ to $105^\circ$ with respect to the Sun. Type III and IV events are observed when the SIDE has these look directions (approximately 1.5 days after sunrise and 1.5 days after sunset) but not exclusively at these times. It now remains for Explorer 35 magnetometer data to determine the direction of $\vec{B}_{s.w.}$ during these events.

The acceleration of thermal ions in the vicinity of the Moon is actually very complex. A thorough treatment must include not only the interplanetary magnetic field, but also all the local magnetic fields, the induced magnetic fields, and possibly the electrostatic lunar surface potential. Such a problem lies beyond the scope of this thesis.

Another possible source of these ion events is ions
trapped in an expanding gas cloud. Such gas clouds could be caused by subsurface outgassing or impacts of large meteorites. Subsurface outgassing on the sunlit side would result in part of the cloud being ionized. However on the dark side there is no obvious ionization mechanism thus the clouds would go undetected. In conjunction with the seismic data it is interesting to note that there is no correlation between the occurrence of Type III and IV ion events and perigee. Only in one month during this six month period was perigee on the sunlit side. There was no unusual activity at this time. However due to the constraints mentioned above, the periods during which the SIDE would be able to see the resulting ions is small.

An impact of large meteorites could produce a gas cloud and ions at impact. Therefore such events could be detected on either the sunlit or dark side of the Moon. Several impacts of manmade vehicles with the lunar surface have already occurred. These events have been discussed by Freeman et. al. (1970), and Snyder et. al. (1971). Though these impacts produced ions in the same energy ranges as Type III and IV events the time histories of these events are radically different from these types of ion events.

Type V events encompass the upper solar wind energies (1000 - 1750 eV) and are generally short (2 - 10 minutes). They show slightly better correlation with apogee and perigee than they do for sunrise and sunset. This might indicate a source associated with the lunar seismic activity which peaks just before perigee. However it seems strange that these 1000 eV events are results of subsurface outgassing. Furthermore how could these particles be ionized when these events occur on the dark side?
When plotted versus sunset and sunrise these events appear to occur randomly. This suggests a random source such as meteoritic impact; however the time history of these events also differs radically from the man produced impacts.

Another possible source is deflected solar wind particles. This would place even more stringent conditions on the deflection mechanism since now the ions have a higher energy and must be deflected up to $90^\circ$ around the lunar surface.

A final source for these events may be bow shock particles which have lost some of their energy in transit. In this case one would expect a frequency of occurrence distribution similar to Types I and II. Figure 33 shows this is not so.

Thus the source of Type V events remains undetermined.

An SIB can occur at any time and at any energy. They can be distinguished from transmission noise by an analysis of the engineering data during the event. This analysis is part of the routine data quality check performed on the Burroughs 5500.

Mirtov (1968) suggests that micrometeorites having masses of $10^{-6}$ to $10^{-7}$ grams and colliding with the Moon at the rate $5 \times 10^{-3}$ impacts/m$^2$/sec may provide a major contribution to the tenous lunar atmosphere. Assuming that the meteorites have a velocity of 15 km/sec and $10^{-4}$ of the total energy is spent in ionization, one would expect $10^{13}$ ions to be produced per impact. It is conceivable that SIDE could detect impacts within a short range. A statistical study of these events is required to test this hypothesis.
CHAPTER 3 - SUMMARY

The data analysis may be summarized as follows:

Type I
1. Single peaked, average energy spectrum in the range 2000 to 3500 ev
2. Intermittent burst type structure
3. Energy decay for each separate burst
4. Maximum occurrence one day after sunset

Type II
1. Double peaked average energy spectrum with higher energy peak in the range 2000 to 3500 ev and the lower energy peak in the range 30 to 250 ev.
2. Intermittent burst type structure
3. High energy peak similar to type I
4. Low energy peak is stable in energy
5. Maximum occurrence at sunset

Type III
1. Single peaked average energy spectrum in the range 250 to 750 ev
2. More temporal continuity than in types I or II
3. Two phase structure
4. First phase has stable peak energy and narrow energy spectrum
5. Second phase has increasing peak energy and broad energy spectrum
6. Occurrences at sunrise and sunset with maximum 3 days before sunrise
Type IV

1. Single peaked average energy spectrum in the range 50 to 100 eV.
2. More temporal continuity than in types I or II
3. Two phase structure
4. First phase has stable peak energy and wide energy spectrum
5. Second phase has increasing peak energy and wide energy spectrum
6. Occurrences at sunrise and sunset with maximum one day after sunrise

Type V

1. Single peaked average energy spectrum in the range 1000 to 1750 eV
2. Short duration, 2 to 10 minutes
3. Occurrences seem random throughout the night
4. No correlation with perigee

SIB

1. Single peaked energy spectrum in any energy channel
2. Short duration, 3 to 4 seconds
3. Occurrences seem random throughout the night
CHAPTER 4 - CONCLUSION

As is often the case, the analysis of any finite quantity of data in a new area raises more questions than it answers. Nevertheless, some conclusions can be drawn and some ideas concerning what direction to pursue in further analysis can be obtained. These are discussed below:

A. Types I and II seem to be associated with the ejected protons from the Earth's bow shock.

B. The low energy peak of Type II may be due to wave-particle interactions with the wave packets discussed by Russell et. al. (1970). Possible correlation with OGO - 5 magnetometer data may yield some information concerning this low energy peak.

C. At least some of the Type III and IV clouds can be attributed to a deflection of the solar wind. Further correlation with SWS data, Apollo XIV CPLEE and SIDE and possibly Apollo XV SIDE data may greatly increase our knowledge.

D. Some of the Types III and IV clouds may be associated with ionization and subsequent acceleration of local ions. A thorough analysis of the SIDE Mass Analyzer data should provide many answers concerning this hypothesis. Analysis of the magnetometer data will test Manka and Michel's (1971) treatment of possible acceleration mechanisms.

E. Type V clouds seem to provide the greatest challenge. If a correlation with the Lunar Passive Seismic Experiment proves fruitless then possible correlation with solar wind velocities may yield some results.
F. A thorough statistical study of Short Intense Bursts may yield the necessary information to test the micrometeorite hypothesis.
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FIGURE CAPTIONS

Figure 1. Schematic diagram of the Suprathermal Ion Detector Experiment.

Figure 2. Moon's position relative to Earth - Sun line using sunset at ALSEP location as day zero. The arrows indicate the look direction of the instrument.

Figure 3. Twelve hour average background rate versus day after sunset for the TID during the first four months of operation of the Apollo XII SIDE. The error bars indicate the variation of the individual background rates during this period and the numbers indicate the number of months, if less than four, in which data was obtained for this time.

Figure 4. Times for which data has been analyzed for this report.

Figure 5. Counts per SIDE frame for all energy channels for a Type I event observed January 3, 1970.

Figure 6. Counts per SIDE frame of the peak energy channel versus time for a Type I ion event observed January 3, 1970.

Figure 7. Channel having maximum counts for each TID spectrum versus time for a Type I ion event.

Figure 8. Average differential flux versus energy for Type I ion event. The standard deviation of the background averaged over n TID spectra (σ/√n) is shown to indicate the statistical significance of the data points.

Figure 9. Frequency of occurrence versus days after sunset in twelve intervals for Type I events.
Figure 10. Counts per SIDE frame for all energy channels for a Type II event observed February 2, 1970.

Figure 11. Counts per SIDE frame of the peak energy channel versus time for a Type II ion event observed February 2, 1970.

Figure 12. Channel having maximum counts for each TID spectrum versus time for a Type II ion event.

Figure 13. Average differential flux versus energy for a Type II ion event. The standard deviation of the background (σ) is also shown.

Figure 14. Frequency of occurrence versus days after sunset in twelve hour intervals for Type II ion events.

Figure 15. Average integral counts versus time for a Type II ion event observed February 2, 1970.

Figure 16. Average integral counts versus time for a Type II ion event observed April 30, 1970.

Figure 17. Counts per SIDE frame for all energy channels for a Type II event observed January 2, 1970.

Figure 18. Counts per SIDE frame of the peak energy channel versus time for a Type II ion event observed January 2, 1970.

Figure 19. Channel having maximum counts for each TID spectrum versus time for a Type III ion event.

Figure 20. Average differential flux versus energy for a Type III ion event. The standard deviation of the background is also plotted.

Figure 21. Frequency of occurrence versus days after sunset in twelve hour intervals for Type III ion events.

Figure 22. Counts per SIDE frame for all energy channels for a Type IV event observed January 16, 1970.
Figure 23. Counts per SIDE frame of the peak energy channel versus time for a Type IV ion event observed January 16, 1970.

Figure 24. Channel having maximum counts per TID spectrum versus time for a Type IV ion event.

Figure 25. Average differential flux versus energy for a Type IV ion event. The standard deviation of the background is also shown.

Figure 26. Frequency of occurrence versus days after sunset in twelve hour intervals for Type IV ion events.

Figure 27. Counts per SIDE frame for all energy channels for a Type V event observed February 2, 1970.

Figure 28. Counts per SIDE frame of the peak energy channel versus time for a Type V ion event observed February 2, 1970.

Figure 29. Channel having maximum counts for each TID spectrum versus time for a Type V ion event.

Figure 30. Average differential flux versus energy for a Type V ion event. The standard deviation of the background is also shown.

Figure 31. Frequency of occurrence versus days after sunset in twelve hour intervals for Type V ion events.

Figure 32. Frequency of occurrence versus days after apogee for Type V ion events.

Figure 33. Average differential flux versus energy and frequency of occurrence versus days after sunset for all 5 types of ion events.
MOON POSITIONS RELATIVE TO EARTH - SUN LINE

TYPICAL LUNAR ORBIT
POSITIONS ARE GIVEN IN DAYS AFTER SUNSET
ARROWS INDICATE DETECTOR LOOK DIRECTION

Figure 2
12 HOUR AVERAGE BACKGROUND RATE VS. TIME FOR TID

Figure 3
AVAILABILITY OF SIDE DATA FOR MOON IN INTERPLANETARY MEDIUM
NOVEMBER 19, 1969—MAY 16, 1970

SIDE TURNED ON NOVEMBER 19, 1969 (1918 UT)

DATA AVAILABLE Figure 4
TYPE ION EVENT
JANUARY 3, 1970

COUNTS/SIDE FRAME

TIME (MINUTES)

CLOUD BEGINS (15:07 GMT)

Figure 6

PEAK ENERGY (eV)

TIME (MINUTES)

Figure 7
TYPE I ION EVENT
JANUARY 3, 1970

Figure 8

Figure 9
TYPE II ION EVENT
FEBRUARY 2, 1970

COUNTS/SIDE FRAME

ENERGY (eV)

LOW ENERGY PEAK

CLOUD BEGINS (07:39 GMT)

TIME (MINUTES)

Figure 11

Figure 12
TYPE II ION EVENT
FEBRUARY 2, 1970

Figure 13

Figure 14
Figure 15

TYPE II ION EVENT

FEBRUARY 2, 1971 (07:39 GMT)

HIGH ENERGY SUM
LOW ENERGY SUM

TIME (MINUTES)

AVERAGE INTEGRAL COUNTS
Figure 16

TYPE II ION EVENT
APRIL 30, 1970 (0921 GMT)

- HIGH ENERGY SUM
- LOW ENERGY SUM

TIME (MINUTES)

AVERAGE INTEGRAL COUNTS
TYPE III
JANUARY 2, 1970

Figure 17
TYPE III ION EVENT
JANUARY 2, 1970

Figure 18

CLOUD BEGINS (20:25 GMT)

TIME (MINUTES)

COUNTS/SIDE FRAME

ENERGY (eV)

PEAK

250 e.v.

Figure 19
TYPE III ION EVENT
JANUARY 2, 1970

Figure 20

Figure 21
TYPE IV
JANUARY 16, 1970

TIME (MINUTES GMT)

T.D. ENERGY CHANNELS (6/4)
TYPE IV ION EVENT
JANUARY 16, 1970

TIME (MINUTES)

(23:16 GMT)

COUNTS/FRAME

ENERGY (eV)

PEAK
TYPE IV ION EVENT
JANUARY 16, 1970

Figure 25

**Figure 26**


days after sunset
TYPE V
FEBRUARY 2, 1970

EVENT BEGINS (11:44 GMT)

Figure 27
TYPE V ION EVENT
FEBRUARY 2, 1970

Figure 30

Figure 31
Figure 32

TYPE Y10N EVENTS

PERIGEE

APOGEE

DAYS AFTER APOGEE

NUMBER OF OCCURRENCE

0 4 8 12 16 20 24 28 32

0 4 8 12 16 20 24 28 32
LOG$_{10}$ AVERAGE DIFFERENTIAL ENERGY FLUX (#/cm$^2$-sec-ster-ev)

ION EVENTS
NOV. 19, 1969 - MAY 16, 1970

Figure 33