

OBSERVATIONS OF WATER VAPOR IONS AT THE LUNAR SURFACE*

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Abstract. The Apollo 14 Suprathermal Ion Detector Experiment observed a series of bursts of 48.6 eV water vapor ions at the lunar surface during a 14-h period on March 7, 1971. The maximum flux observed was 10^8 ions $\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$. These ions were also observed at Apollo 12, 183 km to the west. Evaluation of specific artificial sources including the Apollo missions and the Russian Lunokhod leads to the conclusion that the water vapor did not come from a man-made source. Natural sources exogenous to the Moon such as comets and the solar wind are also found to be inadequate to explain the observed fluxes. Consequently, these water vapor ions appear to be of lunar origin.

1. Introduction

The existence of water at or beneath the lunar surface is a question of great importance in theories of formation of lunar surface features and of the Moon itself (cf. Urey, 1969 for a review). If the Moon were devoid of water now or in the past it would be unique among the terrestrial (i.e. high density) planets about which detailed information is now available. At the Third Lunar Science Conference we presented preliminary observational evidence for the occurrence of endogenous water vapor at the lunar surface (Freeman *et al.*, 1972b). In this paper we review this evidence, present a more detailed description of the event, and discuss more completely arguments pertaining to the identification of the source.

The Apollo 14 Suprathermal Ion Detector Experiment (SIDE), part of the Apollo Lunar Surface Experiments Package (ALSEP), observed ions of mass 18 amu/q during an event of approximately 14 hours duration on March 7, 1971. Because of their mass per unit charge, these ions are believed to be constituents of the water vapor group. Several gas sources associated with the Apollo 14 mission one month earlier have been suggested as possible sources of this water vapor. However, all of these appear to us to be inadequate to explain the observed phenomena.

The SIDE consists of two positive-ion detectors: the mass analyzer (MA) and the total ion detector (TID). The location of the Apollo 12 and 14 SIDEs and the concept of acceleration of ions into the instruments are illustrated in Figure 1. The MA consists of a velocity filter and an energy per unit charge (energy/q) filter followed by an ion detection system. The velocity filter and energy/q filter are sequenced through a series of steps to provide coverage of twenty mass/q ranges at each of six energy/q steps: 0.2, 0.6, 1.8, 5.4, 16.2 and 48.6 eV/q. The TID is an ion energy/q spectrometer that records ions without mass discrimination in 20 differential energy channels from

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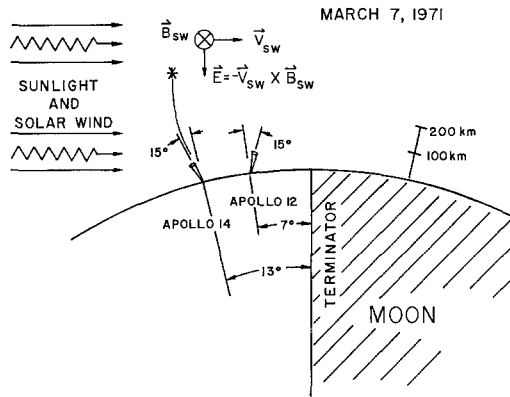


Fig. 1. Conceptual operation of the SIDE as a mass spectrometer, showing geometry of the March 7 event. Photo-ionization by solar UV and charge exchange processes with the solar wind ionize the lunar exosphere. These ions are then accelerated by the interplanetary electric field associated with the motion of the solar wind (Manka and Michel, 1970; Manka, 1972), as illustrated, or some other acceleration mechanism operating in the lunar environment. Full details of the operation of the SIDE can be found in Freeman *et al.* (1970), and Hills and Freeman (1971).

3500 eV/q down to 10 eV/q. The lowest energy channels can be used as a check on the MA data. Each SIDE has a field of view 6° square centered on a direction 15° from the local vertical. The Apollo 12 SIDE look direction is toward the west and the Apollo 14 SIDE views toward the east.

The efficacy of the SIDE system has been demonstrated by numerous observations of mass spectra associated with the LM rocket exhaust gases (Freeman *et al.*, 1972a), LM cabin venting (Hills and Freeman, 1971), and gas emission from the S-IVB and LM lunar impact events (Freeman *et al.*, 1971). The exhaust gas spectrum obtained 14 hours after the Apollo 12 LM landing exhibited a broad range of masses (Freeman *et al.*, 1972b), in good agreement with the laboratory measurements of Simoneit *et al.* (1969). As shown in Figure 2, two months later the exhaust gas ion intensities had decreased generally by an order of magnitude, but the spectrum was still very broad and readily identifiable as due to exhaust gases. There were several changes in the spectrum due to the operation of ionization, loss, dissociation, and recombination processes over the two months. Most striking was the disappearance of mass 18 ions and the appearance of a significant quantity of mass 16 ions. These mass 16 ions presumably came from the dissociation of the more massive molecules in the original spectrum; principally water vapor. For comparison, the maximum water vapor ion intensity observed by the Apollo 14 SIDE during the March 7 event is indicated in Figure 2 (see next page). It is more than *three orders of magnitude greater* than the intensity observed by the Apollo 12 SIDE 14 h after lunar landing.

2. Water Vapor Observations, March 7, 1971

The Apollo 14 MA data from the March 7 event are shown in Figure 3. The time

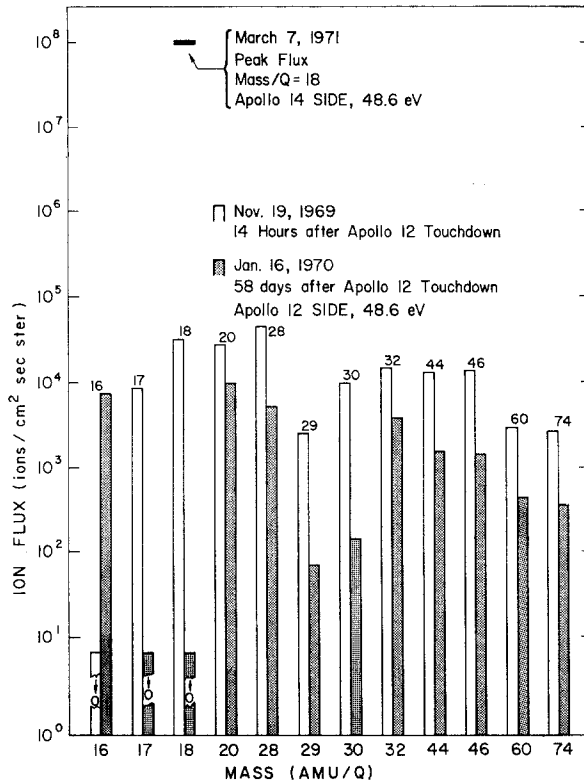


Fig. 2. Observed decrease in exhaust gas fluxes over a 58 day period. For comparison, the peak flux seen in the March 7 water vapor event is shown.

history of the events leads to a separation of the data into three parts. The mass spectra accumulated in each part are shown in the upper portion of the figure, together with the best fit to the observations, based on laboratory calibration data. In Part I, the accumulated spectrum can be fitted by a mixture of 85% mass 18 amu/q and 15% mass 16 amu/q while in Parts II and III the data is fitted well with 100% mass 18 amu/q. For Part I a fit including a percentage of mass 17 amu/q is also possible but presses the resolution of the experiment. This apparent change in the mass spectrum during the event is suggestive of the injection of fresh gas and thereby a dynamic rather than a static event.

The Apollo 14 TID recorded data consistent with that of the MA, showing sporadic bursts of low energy ions throughout the event. Figure 4 shows two successive energy spectra obtained with the TID. The broad high energy spectrum at 250–1000 eV is due to ions in the Earth's magnetosheath, and is not of interest in this event. The important feature is the high mono-energetic flux of low-energy ions (70 eV in this spectrum). The narrow low-energy portion of the spectrum occurred at various energies, but usually was observed in only one channel at a time (at 30, 50, or 70

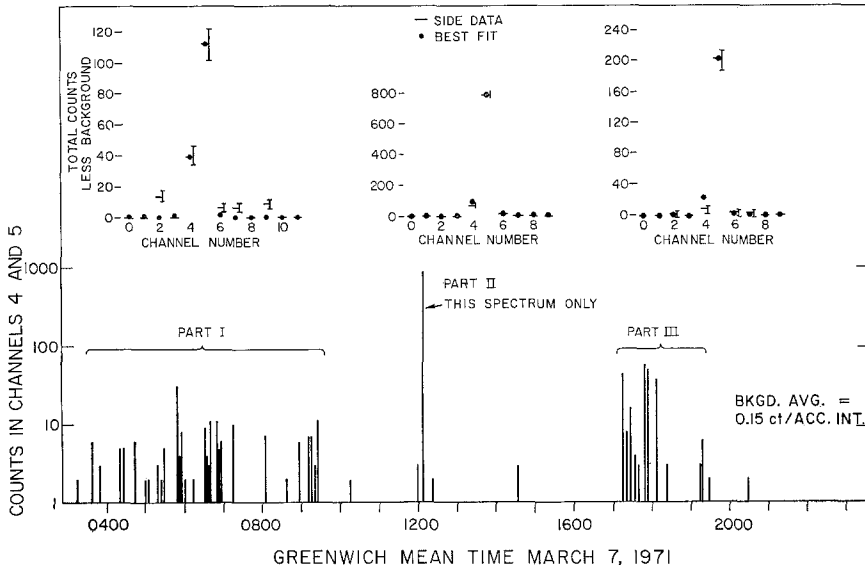


Fig. 3. Time history of the Apollo 14 Mass Analyzer data for the March 7 water vapor event. Laboratory calibrations indicate that water vapor ions are recorded primarily in channel 5 of this instrument with channel 4 recording approximately 12% as many counts. Consequently, to show the principal features of the March 7 event, the total counts in adjacent channels 4 and 5 at 48.6 eV are displayed in the lower portion of the figure. Ions were observed during the March 7 event only at the highest energy level, 48.6 eV, and not at the next lower level, 16.2 eV. Twenty-channel mass spectra at 48.6 eV were obtained in 24 s every 2.58 min. Insets display the observed mass spectra summed over each part of the event as well as a fit to the observations. One count in channel 5 corresponds to a flux of H_2O^+ of $1.2 \times 10^5 \text{ ions cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$.

eV/q). The two illustrated spectra indicate the sporadic nature of this flux.

The SIDE MA at the Apollo 12 site 183 km to the west (see Figure 1) was quite noisy at the time, so no usable mass spectra were obtained. There was, however, good correlation between the TID responses of the two instruments during the event. Both instruments detected significant fluxes starting at 0300–0400 UT on March 7. The Apollo 14 SIDE was turned off at 2100 UT on March 7, according to its scheduled cycle for thermal control. The Apollo 12 SIDE continued to detect ions until the end of the event at ~ 0400 UT on March 8. The time history of the TID data is indicated in Figure 5. The ion energies observed at the Apollo 12 site during Part I of the event were higher than those at Apollo 14, being generally in the 100 eV/q and 250 eV/q channels, whereas the energies at Apollo 14 were in the range 50 eV/q to 100 eV/q. During Part II of the event the energies observed by the Apollo 12 TID decreased to a level matching those observed at the Apollo 14 site. Again we see the suggestion of a dynamic rather than a static event. Fluxes observed by the Apollo 12 TID were typically $1\text{--}5 \times 10^5 \text{ ions cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, while the Apollo 14 TID detected typical fluxes of $4\text{--}10 \times 10^5 \text{ ions cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. Peak fluxes for each instrument were generally about 5 times greater than these typical fluxes.

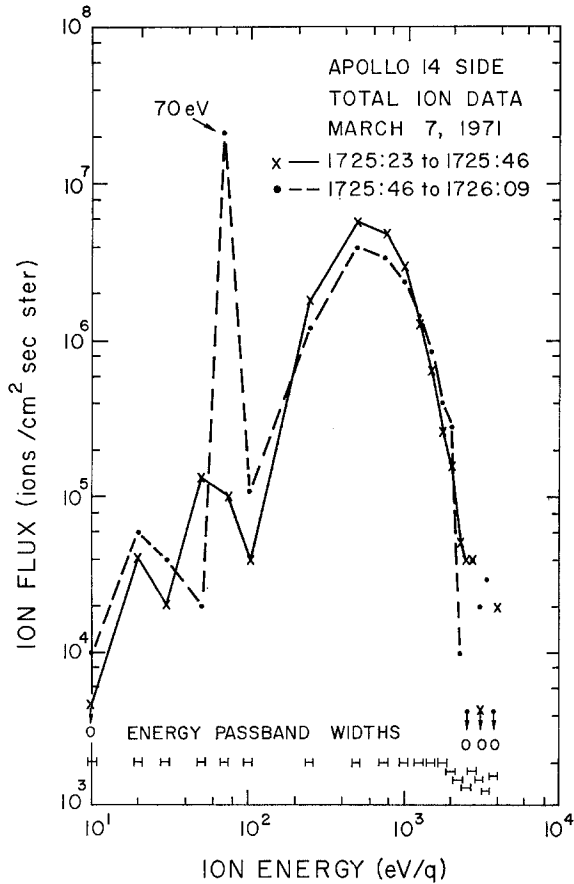


Fig. 4. Total Ion Detector data from the Apollo 14 SIDE for two successive spectra during the March 7 event. The width of an energy channel is approximately 10% FWHM. The peak at 70 eV corresponds to the water vapor ions seen in the mass analyzer. The broad spectrum peaking near 500 eV is that of magnetosheath ions and occurs independently of the water vapor ions.

Simultaneous with the SIDE observations, ions were also detected by the Charged Particle Lunar Environment Experiment (CPLÉE). The CPLÉE has two charged particle analyzers, one of which looks in a vertical direction and the other 60° west of vertical. The low energy (60–300 eV/q) detectors of both analyzers recorded an apparently isotropic flux of ions between ~0400 UT, March 7 and ~0900 UT, March 8 with maximum fluxes between 1200 UT and 1600 UT on March 7 (F. Rich and D. Reasoner, private communication). Fluxes of such low energy ions are not normally detected by CPLÉE in this portion of the lunar orbit due to the high threshold of the low energy ion channels and large angle between the magnetosheath flow direction and instrument look direction. A complete analysis of the CPLÉE data and calculations of the total flux have not yet been made.

3. Comparison with Electric Field Data

In an attempt to determine whether the sporadic nature of the March 7 event was due to either an intermittent source or simply a variability in observing conditions, the ion data have been compared with simultaneous data concerning the interplanetary electric field. The interplanetary electric field \mathbf{E} is related to the solar wind velocity \mathbf{V} and magnetic field \mathbf{B} by the expression $\mathbf{E} = -\mathbf{V} \times \mathbf{B}$. It has been shown (Manka *et al.*, 1972; Manka, 1972) that this electric field can be an important acceleration mechanism for ions produced in the lunar exosphere. The interplanetary electric field undergoes rapid temporal fluctuations in both magnitude and direction. Consequently, temporal variations in the ion observations could be a result of changes in the solar wind parameters rather than changes in the source of the ions.

The solar wind data, the MA data, and the TID data are shown in Figure 5. The solar wind magnetic field data was measured by Explorer 35 in lunar orbit and was generously supplied by Dr David Colburn. The solar wind velocity as recorded by the Apollo 14 Solar Wind Spectrometer varied between 275 and 340 km s⁻¹ during the March 7 event (Conway Snyder, private communication). Since only the magni-

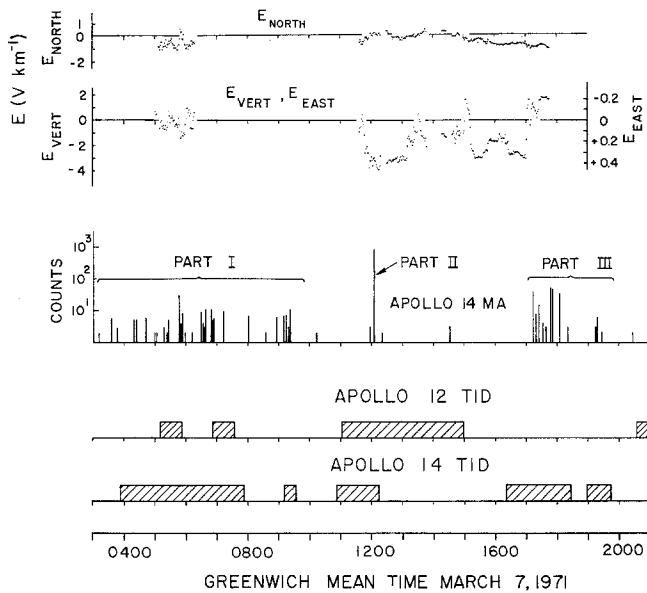


Fig. 5. Comparison of SIDE data and the interplanetary electric field on March 7, 1971. The electric field is derived from 1 min 22 s averages of the magnetic field measured by Explorer 35 in lunar orbit. The time delay between field fluctuations measured in lunar orbit and at the lunar surface is estimated to be less than one minute. Gaps in the electric field data result from unavailability of magnetometer data during these times. The three components of the electric field are given in the local coordinate system at the Apollo 14 site. A negative vertical electric field would accelerate positive ions towards the lunar surface. The MA data is the same as that shown in Figure 3. Periods when significant low-energy ion fluxes were observed in the Apollo 12 and 14 SIDEs are indicated.

tude of the electric field and not its direction is related to the solar wind speed, a uniform speed of 300 km s^{-1} has been assumed in computing the electric field components.

In the simplest model of ion acceleration by the interplanetary electric field, the field orientation most favorable for ion detection would be one in which the field is pointed directly into the instrument look angle. This requires a negative vertical component and a zero (or small) northward component.

From the data comparison we see that there is some positive correlation between the ion data and the interplanetary electric field vector. In particular, the large vertical field near 1200 UT corresponds very well with the large ion flux (Part II) observed at that time. Also, some of the sporadic ion activity in Part I correlates with times of favorable electric field orientation. However, there are periods from 1200 to 1600 UT when the field was favorable for acceleration of ions into the detectors, but no ions were detected. Also, ions were observed in the Apollo 12 instruments during the period following 1700 UT when the electric field was oriented so as to accelerate ions away from the lunar surface. This is true for all of Part III of the event for which data is available. A lack of simple correlation with the interplanetary electric field is further indicated by the fact that the observed ions were nearly monoenergetic, while acceleration of ions in an exponential atmosphere by a uniform electric field would result in a broader energy distribution (Manka, 1972). Thus, the features of the ion observations for this event are not completely determined by the interplanetary electric field vector. Numerous other examples exist in the SIDE data where the surface gas pressure is enhanced and massive ions are seen regardless of a favorable or unfavorable interplanetary electric field (Freeman *et al.*, 1972a). Until the acceleration mechanism operating in the lunar environment at that time is well understood, we will be unable to determine whether the sporadic nature of the March 7 event is due to the source or the acceleration mechanism.

Mass separation of ions may occur in the local surface magnetic fields, resulting in the apparent mass purity of an event, while in fact a mixture of ions is present. However, a preliminary estimate of such effects indicates that it would be difficult to produce a significant mass separation. Moreover, in light of the large fluctuations in the interplanetary electric field, it would be extremely difficult to maintain any mass separation for the duration of the March 7 event.

4. Quantity of Water

It is of course desirable to have some estimate of the total quantity of water represented in this event. The SIDE is an *ion* detector and determination of the quantity of *neutral* gas present requires certain assumptions. A lack of knowledge of the location and extent of the source and the details of the ionization and acceleration mechanisms precludes a precise quantitative determination. However, we have looked for a similar event where the quantity of gas released is known in order to 'calibrate' the water vapor event. In general, Apollo mission activities have resulted in counting

rates far lower than those seen on March 7. For example, the Apollo 12 LM exhaust introduced approximately 2000 kg of water into the lunar environment, yet when observed 14 h after landing resulted in an ion flux that was less than one thousandth the peak flux seen on March 7.

The only event that yielded MA counting rates as high as those during the March 7 event was the detection of the Apollo 14 LM ascent engine exhaust gases by the Apollo 12 SIDE (Hills and Freeman, 1971). The Apollo 14 SIDE was not operating at that time. The maximum counting rates for this event in both the TID and MA were within a factor of 2 of those for the March 7 event and the ion energies were comparable. However, the ion flux duration was only 2 min compared to some 14 h (intermittent) for the March 7 event. Ions were recorded starting 1 minute after the LM had passed by the minimum slant range of 27 km at an altitude of approximately 15 km. The total gas released by the LM was approximately 2200 kg (of which ~ 500 kg was water) at a constant emission rate of 5.2 kg s^{-1} (1.1 kg s^{-1} of H_2O). Therefore, if we assume equivalent ion accelerating conditions for the two events and if the water vapor source was no closer than 27 km we conclude that *at least* 500 kg of water was involved in the March 7 event. Alternatively, if an emission rate of 1 kg s^{-1} of H_2O was maintained on March 7 for a period of 14 h, a total water emission of the order of 10^4 kg is implied. The source characteristics and accelerating conditions (including ion trajectories) may be greatly different in the two events. Consequently, this estimate of the source strength may be in error. However, given a non-local source, as discussed below, these quantities serve as reasonable preliminary estimates.

5. The Apollo Lunar Module as a Possible Source

The mass spectra of LM exhaust shown in Figure 2 indicate that the exhaust spectrum is readily identifiable by its broad mass range, and does not resemble the spectrum obtained in the March 7 event. This fact, together with the unprecedented intensity of the latter event, indicates that the March 7 event was not due to LM exhaust gases. Separation of the H_2O in the LM exhaust from the other exhaust components could conceivably result from selective adsorption of the water onto the lunar surface followed by selective emission. However, such a mechanism, which could explain the purity of the event, fails to account for the more than three orders of magnitude increase between the H_2O fluxes measured 14 h after the LM exhaust release and those seen on March 7, one month after the Apollo 14 mission.

The maximum flux of water vapor ions observed at the Apollo 14 SIDE during this event was approximately $10^8 \text{ ions cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. For comparison, when the LM cabin was vented during the Apollo 14 mission prior to the 2nd EVA, the SIDE observed a short-lived (approximately one minute) flux of $4 \times 10^5 \text{ ions cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ at 50 eV. At the same time the ALSEP Cold Cathode Gauge Experiment (CCGE) measured a high neutral gas pressure (Johnson *et al.*, 1971). This is important, for it establishes that the CCGE would have seen a large neutral gas pressure rise if enough gas were liberated *locally* to cause the high counting rate seen by the SIDE on March

7. There was no such increase (Johnson *et al.*, 1972) therefore the source must have been further away than the LM or the other debris left on the surface nearby. A gas source at a great distance could lead to the production of ions which subsequently reach the SIDE, while the neutral gas density at the instrument might never be high enough to be observed by the CCGE. The simultaneous observation of the event by the Apollo 12 SIDE further implies a distant or wide-spread source.

6. The Apollo CSM as a Possible Source

The 43 kg of waste water, mostly excess H₂O from the fuel cells, (C. Staresinich, private communication) dumped from the Apollo 14 Command/Service Module (CSM) in lunar orbit one month earlier has been suggested as a possible source (F. El-Baz, private communication; Page, 1972). An attractive feature of such a source is the presumed narrow altitude distribution of gas, resulting in a narrow energy spectrum after acceleration through an electric field. However, we note that a narrow altitude distribution is not a prerequisite for the narrow energy spectrum observed, since a narrow energy spectrum seems to be a general feature of heavy mass ion events *regardless of the source*. For example, narrow energy spectra of approximately 50 eV energy have been observed during the Apollo 14 cabin vent (Hills and Freeman, 1971), in association with Apollo 12 LM exhaust (Freeman *et al.*, 1970), and also at times when the source is less obvious (Freeman *et al.*, 1972b). Furthermore, as shown in Figure 5, the interplanetary electric field strength was $\sim 3\text{V km}^{-1}$ at 1200 GMT on March 7. Thus, if the observed 50–70 eV water vapor ions seen at that time resulted from simple vertical acceleration, they were produced at an altitude of 15–25 km. This is much lower than the 100 km orbit of the CSM.

Most of the water dumped from the CSM will freeze promptly and then rapidly vaporize by sublimation. Sharma and Buffalano (1971) estimate the *e*-folding lifetime of the ice crystals to be less than 30 h. Exposure of this water vapor to the solar ultraviolet and the solar wind particles results in the production of H₂O⁺ ions as well as the dissociation of H₂O into H and OH. Later the production of OH⁺, and finally that of O⁺, will dominate as further dissociation and ionization takes place and as the quantity of H₂O becomes depleted. Figure 6 shows the calculated rates of production for these ions as a function of ultraviolet exposure time. If the event of March 7 were due to water ejected from the Apollo 14 CSM a month earlier, then ions of masses 16 and 17 would be more abundantly produced than ions of mass 18, contrary to observation. In fact, in Part I of the event there is an indication of mass 16 and possibly mass 17 ions, but only a small amount. The later parts of the event showed only mass 18 ions. As was noted earlier, this change of spectrum is suggestive of a possible injection of fresh gas during the event.

The ion flux expected at the SIDE due to the CSM water dump can be estimated as simply the total number of 50 eV ions formed in one second in the cm² column over the detector. If all of the ice had become vapor within a few days, dissociation and ionization by solar UV at a rate of 10^{-5} s^{-1} (Werner *et al.*, 1964) would reduce the

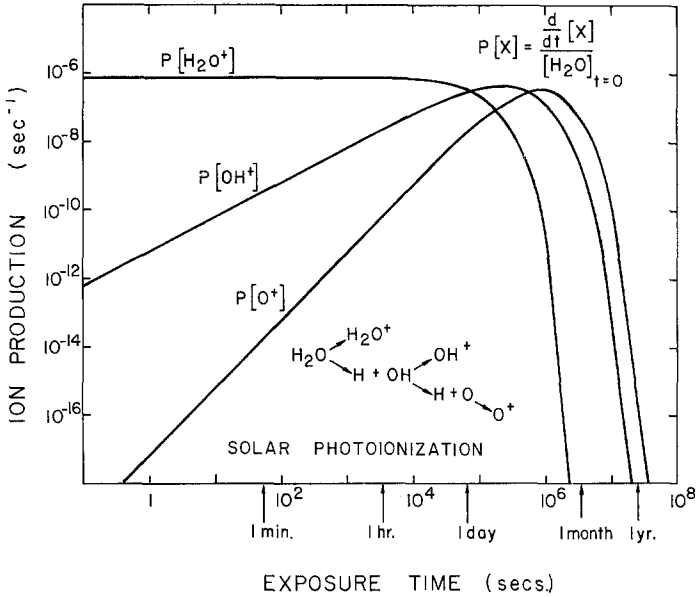


Fig. 6. Production rates of ions resulting from exposure of water to solar ultraviolet at the Moon. These curves are obtained from solution of the differential equations describing the depicted reaction chain. Production rates are normalized to the initial number of H_2O molecules; the change in production rate is due to the change in composition. The appropriate reaction rates were obtained from Hinteregger (1960), Werner *et al.* (1967), and Mukherjee and Siscoe (1973).

initial 43 kg of water to about 4×10^{15} molecules of H_2O . Also, since the counting rates in Part I of the ion event were present for longer than the 2-h orbital period of the CSM, then if the source gas was in orbit it must have been dispersed relatively uniformly throughout the orbital path. (After one month the gas cloud would be expected to be widely dispersed since the molecular sublimation velocity is about $\frac{1}{3}$ of the initial orbital velocity.) In this case the average volume rate of H_2O^+ production is simply the number of neutral molecules times the ion production rate (Mukherjee and Siscoe, 1973) divided by the volume over which the original gas has become dispersed. A conservative estimate of this volume is $4 \times 10^8 \text{ km}^3$, obtained by assuming dispersal over 100 km in altitude along the initial orbit and 10° in latitude transverse to the orbit. Finally, integration over the narrow altitude range ($\sim 1 \text{ km}$) in which the observed ions originate results in an upper limit on the flux measured by the SIDE of $4 \times 10^{-8} \text{ ions cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$, much less than the observed peak flux of $10^8 \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$.

F. El-Baz (private communication; Page, 1972) has suggested that the ice cloud remained intact for one month and then impacted the Moon due to orbital decay. We know of no way to inhibit sublimation for one month. However, even if we assume the worst case where dissociation and ionization do not begin until just at the time of observation (implying $\sim 10^{27} H_2O$ mole present), we obtain a flux of only $2 \times 10^4 \text{ ions cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. This is also an upper limit to the OH^+ or O^+ flux at any time.

Orbital decay is an additional mechanism for H₂O loss and would reduce the estimated ion fluxes, diminishing even further the possibility of the CSM being the source of the observations. Water molecules that impact the surface are equivalent to a surface source and can be ruled out as a possible source due to the small quantities involved.

We conclude that the CSM waste water dump is unlikely to be the source because it has been shown to lead to a counting rate much smaller than observed, and because consideration of the observation of the Apollo 14 LM ascent indicates a much greater quantity of water as the source. Also the appeal of the CSM as a source is diminished when it is recognized that a narrow altitude distribution for the gas is not required. Furthermore, the time history of the event suggests an impulsive injection of fresh gas during the event, long after the CSM has left the Moon.

7. The Lunokhod as a Possible Source

It has been brought to our attention (K. P. Florensky, private communication) that the Russian Lunokhod research vehicle (located approximately 1400 km from Apollo 14) occasionally vents 'a few liters' of water from its cooling system.

After a quantity of water vapor N_0 is released from the Lunokhod it will diffuse outward from the landing site. The water molecules move along ballistic trajectories in the lunar exosphere, traveling a distance L of ~ 300 km in a time τ of ~ 600 s. between contact with the surface. This diffusing cloud of water vapor will expand to a radius R of 1400 km in a time equal to $R^2\tau/L^2 \approx 4$ h (cf. Hall, 1973). An upper limit to the height-integrated density (mole cm^{-2}) at a distance R of 1400 km is given by $N_0/\pi R^2 = 1.6 \times 10^{-7} N_0$. This value is an upper limit since in such a diffusion process, the columnar density is always greater the nearer to the source point (Hall, 1973). This upper limit equals 5×10^8 mole H₂O cm^{-2} for each liter of H₂O released and is a factor 10^3 smaller than the columnar density of the ambient lunar exosphere (Johnson, 1971). It would result in a count rate for the SIDE MA of ~ 0.02 counts s^{-1} . Thus, the Lunokhod ventings are not sufficiently large enough to account for the March 7 event.

8. Comets and the Solar Wind as Possible Sources

Having considered all artificial sources we will now evaluate two natural sources which are exogenous to the Moon: comets and the solar wind.

An impact of a comet or cometary debris could be a source of water vapor in localized areas of the Moon. The impact of a solid comet of a mass of a thousand kilograms (the approximate mass of water inferred for this event) on March 7, can be firmly ruled out by the lack of any seismic activity characteristic of such an impact. Furthermore, March 7 is neither a date of known meteor showers nor a date when the Earth-Moon system is near known old comet orbits (Thornton Page, private communication). Also, comets and comet remnants contain significant quantities of other materials, such as CO₂, which were not detected during the March 7 event. Conse-

quently, it appears unlikely that a comet or cometary remnant could be the source of the observed water.

Interactions between the solar wind and the lunar material as a source of water at the lunar surface was suggested by Michel (1964). The details of such a production mechanism have been evaluated by Mukherjee and Siscoe (1973) who concluded that the maximum density of the solar wind-produced H_2O near the lunar surface would be about $6 \times 10^{-3} \text{ cm}^{-3}$, a factor of 10^7 smaller than the ambient lunar exospheric density (Johnson, 1971). Thus, the solar wind is an insufficient source for the March 7 observations.

9. The Moon as a Possible Source

Examination of the lunar samples has indicated them to be remarkably devoid of water (Lunar Sample Preliminary Examination Team, 1969, 1970). However, at least one hydrated mineral has been found in the Apollo 14 surface samples (Agrell *et al.*, 1972). Further, preliminary analysis of the Apollo 16 soil samples from the Descartes region indicates large amounts of hydrated minerals (Gregory, 1972). It has been suggested that a comet impact may have been responsible for the Apollo 16 results. However, Williams and Gibson (1972) have raised some questions regarding the chemical feasibility of such a process.

The high orders of hydrogen and oxygen in the cosmic and solar abundances of the elements lead to the expectation of water as a common constituent of the planets. Possible exceptions would occur if extremely efficient defluidization or loss processes have been operable (see Green, 1964 for a review of defluidization processes on the Moon) or if the Moon accreted inhomogeneously as an original satellite of the Earth (Anders, 1970).

There have been numerous suggestions of subsurface water on the Moon, trapped below an ice layer beneath the lunar surface (Gold, 1960; Green, 1964; Schubert *et al.*, 1970) and liberated occasionally by the flexing or fracture of the lunar crust. The so-called Lunar Transient Phenomena have been shown (Moore, 1971) to occur with a preference for times near lunar perigee passage and at likely positions for crustal stress. There were seismic signals ('swarms', not due to impact events) observed by the Passive Seismic Experiment during this event (G. Latham, private communication), although such seismic signals have been observed many times without simultaneous observations of high ion intensities. Thus there may be no meaningful relation between the seismic signals and the water vapor event. However, there is a possibility that such seismic signals are linked to a release of gas, but that the probability for the gas to be eventually detected as ions by the SIDE is quite low. If the acceleration of the ions occurs as illustrated in Figure 1 and discussed by Manka and Michel (1970), then the SIDE can detect the ions only when the interplanetary electric field points approximately antiparallel to the local vertical. This can occur only within a few days of sunrise and sunset and when the interplanetary magnetic field points nearly normal to the ecliptic plane. The magnetic field can be expected to have the correct direction less than 2% of the time (Burlaga and Ness, 1968). In addition, the

gas source must be large enough and near enough to produce observable fluxes of ions. Thus the probability that a random venting of gas will result in ions observed by the SIDE is quite low if the solar wind electric field is the only acceleration mechanism.

We emphasize that the March 7 event was an intense event of extended duration and we have not yet seen another event like it. The question of lunar venting vs. artificial sources would be more unambiguously resolved if another event similar to that of March 7 were found displaced further in time from an Apollo mission. Although there exist a few other events which may be attributable to transients in the lunar atmosphere, none of these has yet been found to include water vapor as a constituent. Since water vapor is the subject of this paper, these will be discussed in a future report.

10. Conclusions

None of the suggested artificial sources for the observed water ions appears to us to be capable of producing the observed ion fluxes. Table I lists the prominent source candidates and the objections to each. Therefore, we conclude that the only possible source is a natural source endogenous to the Moon.

TABLE I

Source	Difficulties
LM	<ol style="list-style-type: none"> 1. event duration and intensity 2. simultaneous observation at 2 sites 3. not observed by CCGE
Residual exhaust gases	<ol style="list-style-type: none"> 1. event intensity 2. exhaust spectrum maintains identity for at least 58 days, with H₂O dissociation 3. time history suggests impulsive injection of fresh gas during event
CSM waste water	<ol style="list-style-type: none"> 1. event intensity and duration 2. interplanetary electric field strength implies source altitude lower than CSM orbit 3. narrow altitude distribution not required in order to explain observed narrow energy spectrum 4. time history suggests injection of fresh gas during event
Lunokhod Comets	<ol style="list-style-type: none"> 1. event intensity 1. no known cometary impact or cometary remnant 2. event purity
Solar wind	<ol style="list-style-type: none"> 1. event intensity
Moon	????

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