(Memo-75-003) ELECTROSTATIC DUST TRANSPORT AND ITS CONSEQUENCES FOR THE LUNAR RANGING EXPERIMENT (Texas Univ.) 23 p HC $3.25 CSCL 03B

N75-20185

Unclas
G3/91 14657

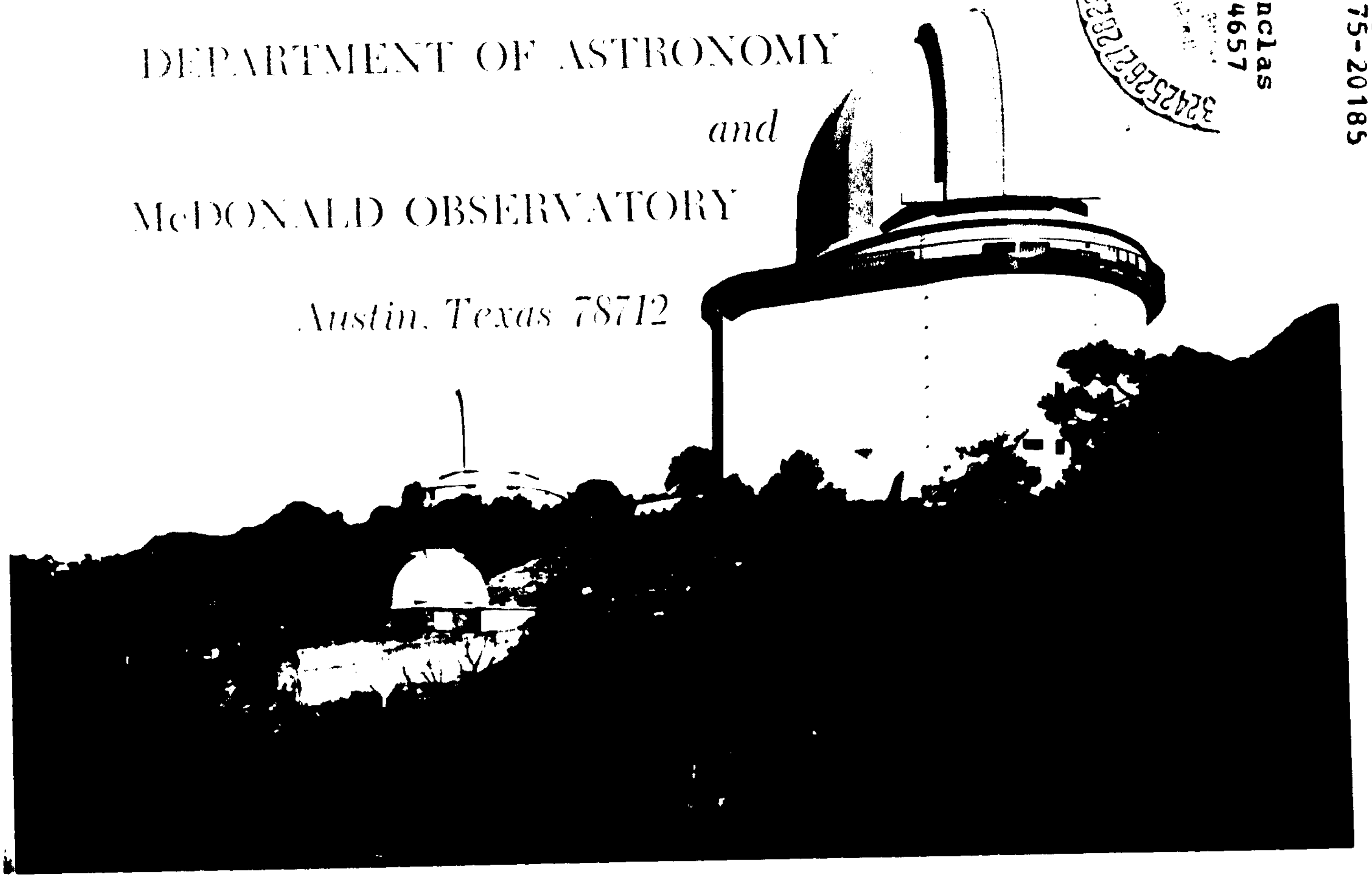
THE UNIVERSITY OF TEXAS AT AUSTIN

DEPARTMENT OF ASTRONOMY

and

McDONALD OBSERVATORY

Austin, Texas 78712



ELECTROSTATIC DUST TRANSPORT

AND ITS CONSEQUENCES

FOR THE LUNAR RANGING EXPERIMENT*

by

E. C. Silverberg

The University of Texas McDonald Observatory

Fort Davis, TX 79734

Research Memorandum in Astronomy #75-003

March 1975

*This work supported by NASA Grant NGR 44-012-165

ABSTRACT

This research note attempts to qualitatively model the available data concerning the electrostatic transport of dust on the lunar surface. Charged dust grains, held in place by adhesive forces, are shot into space at velocities of hundreds of meters per second. Larger particles, because of their greater charge, are quickly decelerated in the nearby fields, while the smaller grains travel in ballistic trajectories for hundreds of kilometers. Flux estimates indicate that there is little danger to the optical corner reflectors for the next few decades.

PREFACE

Several months ago Gary Latham brought to my attention the possibility that the lunar dust flux might be high enough to be noticed by the lunar ranging experiment. In the hope of silencing that fear, and armed with recent publications by Berg and Criswell, I began an attempt to calculate the hazard. It soon became apparent that much was still to be learned about the character of the dust transport. In particular, consequences of an adhesive force in the lunar regolith had apparently been neglected. My elementary attempts to add the effects of adhesion seem to have uncovered more questions than they have answered. Knowing that definite solutions, deserving of a formal publication, are quite far removed, I offer this progress report in the hopes that it will disseminate these preliminary thoughts to the appropriate audience.

My grateful thanks to O. Berg, D. Criswell and J. Lindsay for their very helpful advice, and in one case (O. B.) the discussion of considerable unpublished data.

10 March 75

E. C. Silverberg

ELECTROSTATIC DUST TRANSPORT AND ITS CONSEQUENCES FOR THE LUNAR RANGING EXPERIMENT

INTRODUCTION

The lunar ranging experiment has been in operation since the summer of 1969 when the first of several quartz retroflector packages was deployed by the Apollo 11 crew.[1] Since that time more than three quarters of a million laser shots have been fired at the lunar surface for the purpose of very accurate range determinations.[2] These range measurements have been used to gain considerable knowledge of the moon's orbit and its librations.[3] Recently, the data has expanded its impact into the fields of general relativity and the rotation of the Earth.[4] Ultimately it is hoped that the technique will play a major role in monitoring the Earth's rotation and pole wander and provide numerous measurements of continental drift.[5]

In order for the experiment to fully participate in its stated goals, it is imperative that the lunar retroreflectors enjoy a lengthy and unaltered existence on the lunar surface. At the onset of the experiment this was little in doubt. The lack of an appreciable atmosphere was thought to limit erosive effects on the lunar surface to those caused by the influx of micrometeorites. Earlier space vehicles placed this flux level well below that which was thought to be important to the lunar ranging experiment, even over a period of many centuries.

The accumulation of data from the many lunar landing vehicles has greatly changed our view of the lunar erosive processes. It now appears that a major factor in the lunar erosion is caused by the buildup of electrostatic charge during the passage of the terminators across the lunar surface. These electrostatic effects are undoubtedly responsible for considerable mass transport and result in a dust flux in the vicinity of the surface many times higher than that expected from the interplanetary micrometeorites. The purpose of this paper is to review the evidence for lunar dust flux caused by electrostatic effects, model these data, and determine their effect on the lifetime of the lunar ranging experiment.

THE DATA

Although electrostatic dust transport was anticipated even before the first lunar landing vehicles,[6,7] the extent of its importance in the lunar erosive processes was not generally anticipated. The direct study of the dust with a sensor was not initiated until the last of the Apollo flights, after its existence had been confirmed through a number of indirect observations.[8] Whereas the lunar ranging retroreflectors will be affected by the cumulative effects of the entire population of particles, no other measurements are available to date which refer to but a small percentage of either the velocity or size spectrum of the particle population. We are, therefore, at a considerable disadvantage in interpreting the available observations of dust with regard to their implications for the optical retroreflectors. Nonetheless, the wide range of available observations permits a very good qualitative, if not yet quantitative, view of the situation.

The lines of evidence which are available are the following: 1. the horizon glow observations of the Surveyor space craft;[9,10] 2. the terminator events recorded by the Apollo 17 dust sensor;[11] 3. the Surveyor 3 dust contamination as recorded by the Apollo 12 examination team;[12] 4. sunrise effects while in lunar orbit reported by the Apollo astronaut teams;[13] 5. visual effects implying rapid sedimentation, such as half buried rocks and hummock-like structures at the base of long slopes;[14] and 6. the apparent albedo changes in some of the ALSEP experiment packages.[8,15]

Horizon glow: The horizon glow phenomenon, which was seen by the Surveyor 6 and 7 landers, concerns the apparent levitation of dust particles by some tens of centimeters above the surface following sunset. The phenomenon was most fully studied in a paper by Rennilson and Criswell

(1974)[10] complimented by several other references.[9,16,17] The suggestion is made that dust particles of some 5 to 6 microns in radius are levitated above the lunar surface at sunset by kilovolt potentials which develop along the shadow lines at the terminator. Particles smaller than five microns are thrown into much larger regions of space and thus do not contribute to the visual effects at sunset.[9]

The Apollo 17 Sensors: Berg, et al. (1974) report an enhanced lunar dust flux which is in phase with the synodic cycle of the moon. Coincidence dust sensors, which can be activated by any particle with an energy in excess of 0.6 ergs and a velocity in excess of 800 meters per second, show an enhanced flux as much as 40 hours before sunrise at the landing site with another enhancement following sunset. The orientation of these sensors on Apollo 17 favors the interpretation of westward moving particles at sunrise and eastward moving particles at lunar sunset. In addition there is a longer duration of "front film" dust detections in phase with the synodic cycle which can occur at energies of only 0.1 ergs. While the particle charge may be an important aspect of these events,[18] the characteristics of the plasma detectors greatly favor the high velocity tail of any lunar flux distribution. Thus, they are a measure of an entirely different end of the population than that indicated by the ground-hugging horizon glow.

Lunar Orbiter Observations: Visual reports by the orbiting Apollo crews indicate a pre-sunrise enhancement of the sky brightness which is interpreted as a high altitude distribution of lunar dust.[13,19,20] If so, the brightness of the phenomenon is another measure of the high velocity and hence high altitude dust distribution indicated by the Apollo 17 sensors.

Surveyor 3: One of the goals of the Apollo 12 flight was to return with samples of the Surveyor 3 hardware to evaluate the effects of 950 days on the lunar surface.[12] The most interesting observation from our standpoint is the uniform coverage of material on one of the screwheads and washers indicating that some 15% of the area was affected by particles smaller in size than 4 microns radius. While this degree of coverage can not be typical, since it would have been noticed by the lunar ranging experiment some time ago, it is interesting to note that the size cut-off corresponds to some degree with Criswell's evaluation of the horizon glow.

ALSEP Packages: Albedo changes in the ALSEP packages on several of the Apollo flights has been inferred by a raise in temperature of the experiment packages by some 2 degrees per year. If we imply that ½ of the albedo change is due to dust coverage on the packages, we can infer an upper limit to the dust flux as that which can cover about one percent per year of the surface. This upper limit will not be relevant after we have had a closer look at the other data types.

Visual Effects: Visual effects, such as half-covered rocks, hummock-like structures at the base of hills and the sediment-like structure of the lunar core drillings, are additional evidence for the phenomenon we are seeking. It is doubtful that such observations will ever shed much information with regard to the lifetime of the lunar ranging package; but they are, nonetheless, supporting evidence for the high erosion rates which are implied by the other lines of evidence.

THE INTERPRETATION

The geometry of the horizon glow events seen on the Surveyor lander and caused by the so-called "levitation of dust particles" has been studied in some detail. There seems to be no reason to doubt that the basic mechanism proposed in the literature is a correct interpretation of the phenomena. Electrons are ejected from the lunar soil by photo emission due to the solar ultra-violet. When this occurs in isolated sunlit regions along the terminator, the positive field which builds up in the area tends to draw the electrons back towards their point of origin. Some of these electrons fall into the nearby unilluminated reaching an energy given by

$$E = qV. \tag{2}$$

Using these basic physical constraints we must in some manner explain the development of two populations of particles: the long range ballistic particles seen by Apollo 17 and the orbiting astronauts; as well as the ground-hugging population of 5 and 6 micron particles discovered in the Surveyor horizon glow observations. We believe that this dual population can be explained if the ejected particles are separated according to their charge and velocity much like the mechanism of a mass spectrograph. Large, low velocity particles traveling in the nearby fields are curved quickly back to the surface near their ejection point. Smaller particles, having sufficient velocity to cross the field without a great deal of energy loss, attain ballistic trajectories of hundreds or even thousands of kilometers.

The physical constraints which dictate the character of the solution are as follows.

1) Particles must be able to break short range forces of adhesion before leaving the surface (equation 1).

2) The energy of those particles which attain long range trajectory must approximate the product of their charge times the original accelerating voltage (equation 2). In addition this energy must be at least great enough to

be detected by the front film sensors on the Apollo 17 dust experiment and in some cases exceeds 0.6 ergs which is the threshold sensitivity of the coincidence detectors on that experiment. The lack of time-of-flight measurements of the Apollo 17 experiments, however, rule out energies in excess of 2 ergs.

$$2 \text{ ergs} \geq E = qV_o \geq 0.2 \text{ ergs} \qquad (3)$$

3) Some of the particles travel at least hundreds of kilometers to the Apollo 17 sensor and are seen at altitudes greater than one hundred kilometers above the lunar surface. They will not be measured if they exceed the escape velocity of the moon.

$$2.8\text{km/sec} > v > 1\text{km/sec} \qquad (4)$$

The average flux of particles within these velocity limits is approximately $2 \times 10^{-6}\text{cm}^{-2}\text{sec}^{-1}$.[11]

4) For horizon glow particles in the five to six micron range, the field gradient over the nearby lunar regolith is large enough to limit their height to approximately 30 centimeters.

$$E = Fd = q \cdot \nabla V' \cdot h \qquad (5)$$

where: $h \doteq 30\text{cm}$ and E is constrained by equation 3.

Let us investigate the consequences of these limitations in the case where the charge in the particles is proportional to their area and that adhesive forces are approximately constant (and equal to 0.5 dynes) for particles whose radius lies between 1 and 10 microns (rough, irregular particles will have few points of contact and will increase their adhesive forces more slowly than their physical dimensions). The first and second requirements mentioned earlier will lead to the conclusion that

$$|E| \sim |F| \text{ cgs} \tag{6}$$

i.e. the characteristic scale of the electrostatic field must be on the order of centimeters. Thus we can confirm Criswell's evaluation of the scale from on independent point of view. If we limit q to about 10^6 electrons per particle, V must exceed 3100 volts per centimeter. If $|V_0| = |2\nabla V|$ (cgs), this particle would have an energy upon ejection of approximately 1 erg. A silicate particle having this energy and traveling at a median velocity of 1.5 kilometers per second should have a radius of approximately 2 microns. It could travel in a ballistic arc which might exceed a thousand kilometers in length. Submicron particles which possess similar energy would be likely to exceed escape velocity. This leads to the expectation that the lunar regolith would be deficient in particles below micron size, regradless of crushing strength arguments (a fact which may have been noticed by at least one lunar investigator).[22]

The field gradients will undoubtedly be greatest along the narrow line between the sunlit electron source and the nearby dark region. Thus, particles will tend to leave this region traveling, in most cases, over an oppositely charged plate. With the geometry shown, positive particles would tend to leave in an eastward direction, traveling over the negatively charged dark plate, while the negative particles would launch in the opposite direction. If the lunar regolith particles collect electrons at a rate which is proportional to their area, they will be able to break the adhesive forces at different field gradients. Larger particles will be able to collect enough charge to attain the adhesive limits at voltages of only hundreds of volts per cm. However, unless the <u>scale</u> of the electrostatic fields is highly dependent on their magnitude all particles, regardless of size, will tend to have simiiar energies (equation 6). Thus, a 6.3 micron particle carrying a charge which is an order of magnitude larger than its 2 micron counterpart will have an equal energy.

The particles which are released will lose a percentage of their vertical energy over the nearby oppositely charged region which is roughly proportional to their charge. A 6.3 micron particle having a 10^7 electron charge leaving the surface at a 45^o angle would lose all of its vertical momentum at a height of approximately 30 centimeters <u>if</u> the average field gradient is 100 volts per centimeter. It is extremely unlikely, of course, that the gradient is constant throughout a region which is a meter in size. Thus, the particle would probably spend most of its energy close to the surface leaving a smaller and smaller residual energy as it gains height. Note that a 2 micron particle which was ejected along the same path would only lose ten percent of its energy due to the smaller charge. Thus an ejection mechanism involving nearly an equal adhesive force and a particle charge proportional to area could provide the mass separation necessary to produce two populations of particles implied by the Surveyor 7 and Apollo 17 results.

One of the consequences of adding an adhesive force to the electrostatic processes is that it implies that the particles in the horizon glow events will be traveling at considerable velocity. Rennison and Criswell extimate the column density in the line-of-sight of the Surveyor 7 horizon glow to be approximately fifty particles per centimeter squared, or, on the order of one particle per cc.[10] If we can estimate the velocity of these particles we can, in turn, imply a flux. An upper limit to the particle flux would be given by that model which predicts the maximum velocity. A maximum velocity model would assume that the particles are decelerated uniformly in a constant field gradient. Uniform deceleration implies average velocities on the order of 100m/sec for the six micron particles. This would imply a transported mass on the order of 40 micrograms sec^{-1} for each centimeter of horizon glow parallel to the terminator line. If the shadow line moves in longitude approximately five centimeters during an hour of horizon glow activity, our upper limit would affect a thickness of lunar regolith which is approximately 100 microns in thickness. Since only the smallest particles would be affected and that these would be tossed back and forth over the same locations during each terminator passage, the net mass transport over the duration of a year is probably considerably less than these figures would indicate.

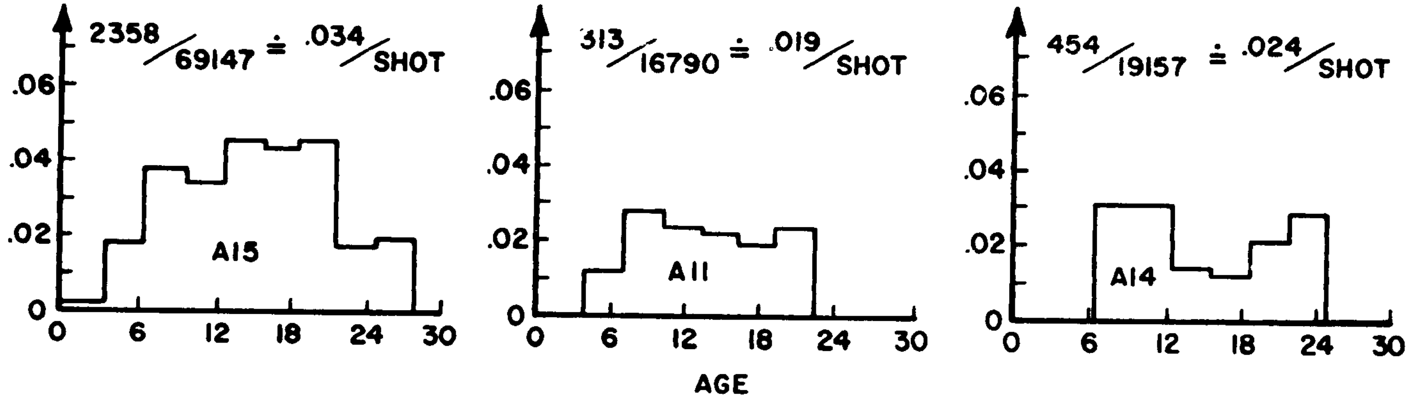
Whether or not the horizon glow flux estimates can be linked to the ballistic flux measurements of the Apollo 17 sensors depends to what degree these sunset horizon glows relate to the apparently much stronger sunrise events.[11] Let us use the horizon glow data to estimate a particle flux of approximately 10^5 particles/sec/cm along a line parallel to the terminator. The particles in the lunar regolith have a relatively shallow size spectrum by interplanetary standards. The number of particles per unit size varies approximately as $r^{-1.3}$.[23] Thus, this six micron particle flux should free approximately four times as many one to three micron particles to participate in long range ballistic trajectories. If the smaller particles are spread out over some thousand kilometers in longitude, as indicated by the duration of the Apollo 17 events, we would expect the long range dust flux to peak at approximately 4×10^{-3} particles cm^{-2}. This upper limit to the flux is over three orders of magnitude higher than the average observed by Apollo 17, but cannot be considered in disagreement with those measurements. The entire terminator line will probably not participate in horizon glow events. Furthermore, the Apollo 17 sensors are not sensitive to the entire distribution of particles. We expect the latter to measure a flux considerably lower than that estimated by these means. In addition, we note that the density of two micron particles would be on the order of 10^{-8} per cc up to 100km altitude. This number density may be high enough to account for the anomalous sunrise events reported by the orbiting astronauts. In short, a model comprised of electrostatic and adhesive forces coupled with basic geometric considerations proposed by Criswell may be able to explain the bulk of the lunar dust observations.

THE CONSEQUENCES:

Even though the integrated <u>flux</u> of the terminator events is only an order of magnitude higher than the interplanetary flux, the integrated <u>area</u> carried by these particles dominates the interplanetary components by several orders of magnitude. It will, therefore, dominate the dust coverage on the lunar retroreflectors. The particle flux in the lunar surface will be highly variable and depend on whether or not you are in the local region where the horizon glow occurs. Inasmuch as the retroreflectors were all placed in rather smooth areas, and since they are all still functioning, we shall assume that they were not placed in active horizon glow locations. This being the case they will be primarily affected by the long range ballistic particles; that is, those which are smaller in size than 5 microns but not so small that they will reach escape velocities.

Let us split the difference between the upper limit calculated from the horizon glow data and that measured near Apollo 17 and assume a particle flux of 8×10^{-5} cm^{-2} sec^{-1}. In other words, assume that the limited population seen by Apollo 17 sensor represents 1/40th of the total distribution. If such a flux dominates for approximately 40 hours per month and the average particle size is 3 microns, we would anticipate a coverage of approximately 4×10^{-5} $year^{-1}$. Even in the unlikely case that each particle damages an area which is 10 times its own cross section, we would still anticipate a lifetime for the retroreflectors in excess of many decades. Only in the unfortunate event that a retroreflector is close enough to a horizon glow source to be affected by larger particles

SIGNAL vs PHASE BETWEEN 24 DEC. 1973 12 DEC. 1974



SIGNAL vs YEAR (p.e./SHOT)

	FY71	FY72	FY73	FY74	FY75 (to Jan)
11	.027	.027	.026	.030	.019
14	.023	.029	.037	.034	.032
15	—	.051	.039	.040	.047

EVIDENCE FOR THE LACK OF APPRECIABLE DUST COVERAGE would we expect any appreciable coverage over the course of a century.

So far the lunar ranging data bears witness to this optimistic view for the lifetime of the retroreflectors. Table I tabulates the average signal from each of the three Apollo corner reflectors over the last 4½ years of operation. Although there are large fluctuations from year to year, depending on weather conditions, there is no evidence of any degradation in the overall performance. We admit, however, that this test is extremely insensitive due to the difficulty of maintaining the lunar ranging system in anywhere near a state of relative calibration.

Knowing something about the character of the electrostatic dust transport, we believe that we have at our disposal a much more sensitive test than the overall signal. Most of the dust carried by the electrostatic transport mechanism will be in a generally East-West motion. The Apollo 15 retroreflector is at a 30° angle to the surface and faces due South. Each of the quartz retroreflectors is recessed by half its diameter in the face of an aluminum panel. It is impossible to believe that dust in ballistic trajectories will coat the recessed retroreflectors in anywhere near a uniform manner. It is critical that the retroreflectors be maintained in an isothermal environment. A non-uniform dust coat over even one percent of the surface of the quartz retroreflectors should be immediately apparent as a depressed signal at full moon (i.e. when the sun is shining directly down at the quartz corner cubes).[24] The table shows the performance of the Apollo 15 retroreflectors as a function of phase. As you can see there is no evidence for a depressed signal at full moon caused by non-uniform heating of the quartz corner cubes.

In conclusion: the available evidence for lunar electrostatic dust transport indicates that it is not an immediate danger to the performance of the lunar ranging experiment, a conclusion which is born out by the ranging data obtained to date.

REFERENCES (abbreviated list)

1. C. O. Alley et al., Science 167 458, (1970)

2. P. L. Bender et al., Science 182 228, (1973)

3. J. G. Williams et al., The Moon 8 469, (1973)

4. P. L. Bender et al., Trans. AGU 55, 1105, (1974)

5. P. L. Bender & E. C. Silverberg, Proced. Int. Symp. on Recent Crustal Movements, Zurich Aug. 1974 (to be published in Techtrophysics)

6. T. Gold, Mon. Not. Royal Astron. Soc. 115 #6, 585 (1955)

7. S. F. Singer & E. H. Walker, Icarus 1 112, (1962)

8. O. Berg et al., Apollo 17 Prelim. Science Report 16-1, (1973)

9. D. R. Criswell, Photon and Particle Interactions with Surfaces in Space, R. Grard (ed.), D. Reidel, Holland (1973), P. 545

10. J. J. Rennison & D. R. Criswell, The Moon 10 121, (1924)

11. O. Berg et al., Geophys. Res. Lett 1, 289 (1974)

12. R. E. Benson et al., Apollo 12 Prelim. Science Rep. 217, (1970)

13. J. E. McCoy & D. L. Criswell, Proceedings of the Fifth Lunar Science Conference, Geochemica et Cosmochemica Acta 3 2671, (1972)

14. T. Gold & C. J. Williams, Photon and Particle Interactions with Surfaces in Space, R. Grard (ed.), D. Reidel, Holland (1973), P. 557

15. G. Latham, Private Communication

16. D. R. Criswell, Lunar Science Institute Contrib. #195 100, (1974)

17. D. R. Criswell, Proceedings of the Third Lunar Science Conference, 2671, (1972)

18. O. Berg, private communication

19. J. E. McCoy & D. R. Criswell, Lunar Science Institute Contrib. #195 104, (1974)

20. J. E. McCoy et al., Proceedings of the Sixth Lunar Science Conference (preprint)

21. J. A. Ryan, JGR 71 4413, (1965)

22. J. Lindsay, private communication

23. Apollo 15 Prelim. Exam. Team, Science 175 363, (1972)

24. J. E. Faller et al., Apollo 15 Prelim. Science Report 14-1, (1971)