N93-26059

DATA ANALYSIS AND INTERPRETATION OF LUNAR DUST EXOSPHERE

Final Report

NASA/ASEE Summer Faculty Fellowship Program--1992

Johnson Space Center

Prepared By:	George A. Andrews Jr.
Academic Rank:	Assistant Professor of Physics
University & Department:	LeTourneau University Division of Natural Sciences Longview, Texas 75607

NASA/JSC

Directorate:	Space and Life Sciences
Division:	Solar System Exploration
Branch:	Space Science
JSC Colleague:	Andrew Potter, Ph.D.
Date Submitted:	August 21, 1992
Contract Number:	NGT-44-005-803

ABSTRACT

The lunar horizon glow observed by Apollo astronauts and captured on film during the Surveyor mission is believed to result from the scattering of sunlight off lunar fines suspended in a dust layer over the lunar surface. For scale heights on the order of tens of kilometers, it is anticipated that the size of the dust particles will be small enough to admit Rayleigh scattering. Such events would result in scattered light which is polarized to a degree which is a function of observation angle and produce spectra containing large high frequency components ("bluing"). Believing these signatures to be observable from ground based telescopes, observational data has been collected from McDonald Observatory and the task of reduction and analysis of this data is the focus of the present report.

INTRODUCTION

Evidence for electrically charged lunar fines existing and migrating above the moon's surface was recorded by the LEAM experiments conducted on the Moon [Berg et al., 1976]. In these experiments, charged particles were detected by three detectors with peak activity occurring with the passage of the terminator. In addition, the Surveyor photographs taken at sunset [Rennilson and Criswell, 1974] and the Lunokhod-2 detection of "lunar twilight" brightness [Severny at el., 1974], as well as observations sketched and reported by astronauts just before sunrise, provide powerful evidence for the existence of light-scattering dust particles in the vicinity of the terminator.

For particles possessing a greater size than the wavelength of the incident light (tenths of a micron), the scattering is independent of wavelength and is classified as Mie or Tyndall scattering. However, if the scattering particle has a size that is smaller than the incident wavelength, the intensity of the scattered light has a functional dependance on wavelength and is classified as Rayleigh scattering. For Rayleigh scattering, the intensity of the scattered light is inversely proportional to the forth power of the wavelength; hence, shorter wavelength (blue) light will be preferentially scattered. Such a "bluing" of light collected across the moon's terminator would reveal itself in the light's spectra and thus provide evidence for dust in the vicinity of the terminator. In this report, we summarize the results and analysis of observations taken at four different lunar latitudes using the 82 inch reflecting telescope at the McDonald observatory. These spectra were obtained when the moon was at first quarter on the thirteenth and fourteenth of December 1991.

REDUCTION & ANALYSIS

The Signal

Light arriving at the telescope from the moon's surface consists of three components: 1) sunlight scattered directly off the surface, 2) "earthshine" back-scattered off the moon's surface and 3) luminescence from the lunar soil. While the magnitude of the luminescent light can be substantial [Kopal 1966], its occurrence is transient in nature and tends to be confined both in locality and to emission of photons possessing longer wavelengths; hence, in our hunt for dust, we can reasonably ignore this source.

The spectrum of the back-scattered earthshine was obtained by analyzing an approximate 200km region of the slit that was positioned within the dark side of the terminator. This spectrum was then subtracted from the signal across the entire 370km slit leaving only the scattered sun light as a source of illumination.

From the before-mentioned probes and observations, as well as possible solar wind effects, the dust particles causing lunar horizon glow (LHG) would be expected to have a maximum density between 50km to 100km from the terminator in the anti-sun (dark side) direction. Thus, within this region, any relative increase in the intensity and in the degree of polarization of light possessing wavelengths below 4000A compared to longer wavelengths can be taken as indicative of the probable existence of submicron dust. However, due to the extremely small signal-to-noise ratio, conclusive evidence based on present data can not be expected. Estimates of the brightness of the "bluing" were produced by Herbert Zook and were found to be compatible with the brightness of the LHG reported by the astronauts (Zook and McCoy, 1991, and private communication).

The Data

All representative plots in this report were referenced to a fiducial spectrum. This reference spectrum was obtained from a position on the bright moon found at 41 degrees latitude. Also, all plots reveal the averaged spectral lines of a 64km region just past the apparent terminator. That is, each plot was created by averaging over 20 pixels beginning approximately 12km from the terminator with each pixel equal to 3.2km on the moon.

Finally, a conspicuous intensity "spike" centered around 4300A appears in all spectral plots (see for example figure 2-b.) It has been determined to be an artifact of the data acquisition procedure; therefore, it can be ignored. The fact that it did not cancel out in the "flat-fielding" procedure may indicate a need for further analysis.

Data Analysis

The IRAF software package (developed by NOAO for analysis of astronomical CCD image data) was used to analyze the image data. The CCD images were analyzed by the following steps:

(1) Subtraction of CCD chip bias.
(2) "Flat-fielding" the image by dividing the image by an image of blue sky. This step corrected the data for varying pixel responses.
(3) Registration of blue and red ends of the spectra. This step was necessary to correct for geometrical misalignment of the chip and for atmospheric refraction effects.
(4) Ratioing of the registered image to "fiducial" spectrum of the lunar surface. This step removed the filter transmission and spectral response curves from the data.
(5) Subtraction of the earthshine and scattered moonlight from the image data.

The data after this last step represented the spectra of any residual light in the region just beyond the terminator. This is where we expected to find evidence for a suspended dust layer.

Discussion

It is hypothesized that the higher latitude sites should produce greater scattering due to an optical depth increase. To this end, data was collected at four different northern latitudes along the terminator which bisected the moon at 2 degrees west longitude. Of course, lunar terrain differences must be kept in mind; for as is well known, different chemical composites of lunar soil, topographical changes and albedo differences result in variance of spectra.

Site 1

Figure 1 reveals the data obtained for two different transmission axis angles of the polarization analyzer for the lunar site having coordinates 78 degrees north latitude. These angles are measured with respect to the scattering plane so a perpendicular setting allows maximum transmission of the scattered light. For our purposes, only relative measures of polarization are necessary; hence the ordinate reflectance intensities are in arbitrary units. Wavelengths, in units of Angstroms, are plotted as abscissae.

In this figure, 1-a reveals the spectrum of light having its polarization plane perpendicular to the scattering plane and 1-b depicts the spectrum of light produced after the analyzer has been rotated by 45 degrees. In 1-b, the intensities of all wavelengths suffer a decrease but careful examination of wavelengths below 5000A (ignoring the range of wavelengths 4100A< x <4500A as previously warned) does in fact reveal a greater degree of polarization than at longer wavelengths.

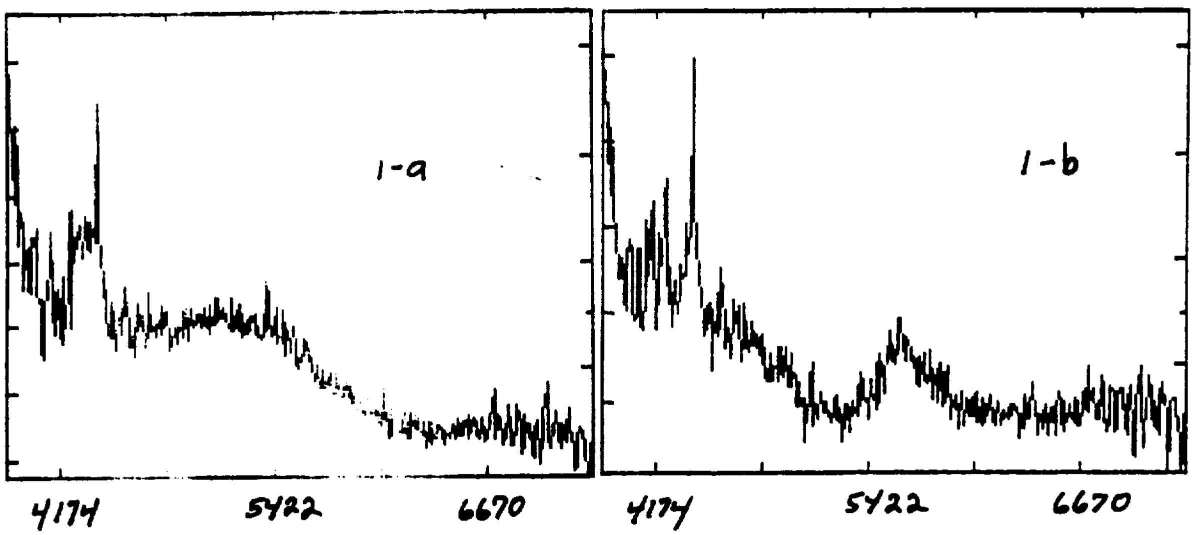

FIGURE 1. - Averaged spectrum of a 60km region of the moon just past the terminator for the 78 degree north latitude site.

When the analyzer is again rotated an additional 45 degrees (not shown), the intensities of all wavelengths actually increase to levels even greater than the intensities associated with the perpendicularly oriented analyzer. This negative polarization occurs in all cases and has been well documented by others in their lunar observations (Kopal, 1966.)

A note of caution must be sounded for this site. While compensating for terrestrial atmospheric effects, it was discovered that this site did not exhibit the expected dispersion and hence, did not need the required numerical correction as did the other sites studied. This is a curiosity that is still in need of an explanation.

Site 2
Figure 2 reveals the spectra of light captured from the region on the moon having coordinates of 60 degrees north latitude and 2 degrees west longitude. In figure 2-a, the perpendicular angle, the intensity is maximum for wavelengths below 4100A. In figure 1-b, the analyzer has been rotated 45 degrees with the evident consequence of a sharp decrease in the relative intensity of wavelengths of light below 5000A with the maximum decrease occurring for wavelengths less than 4100A! As mention in the introduction, such an increase of relative polarization of "blue" over "red" can be interpreted as a signature of Rayleigh scattered light. The forewarned artificial spike around 4300A is most evident in this plot.

The analyzer was rotated an additional 45 degrees so as to be parallel to the scattering plane but no further relative decrease for lower wavelengths was observed. However, as before, there is an actual increase in intensity of all wavelengths as well as the appearance off additional albedo structure not shown in this report and may serve to conceal the expected small signal that is indicative of dust.

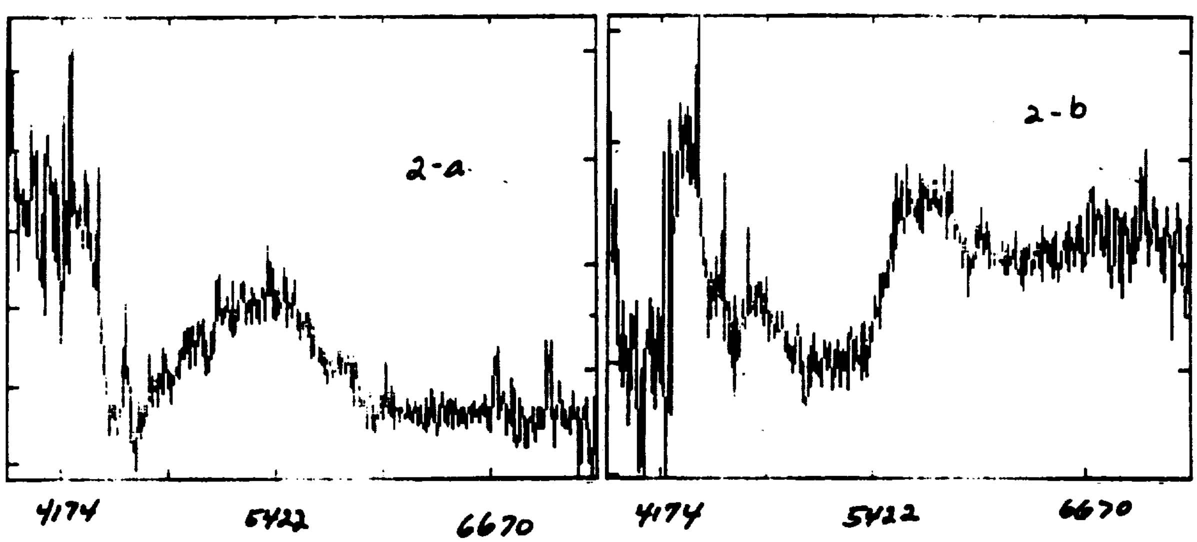

FIGURE 2. - Averaged spectrum of a 60km region of the moon just past the terminator for the 60 degree north latitude site.

Site 3
The next observational data came from a lunar region located 41 degrees north latitude. The resulting spectral plots are shown in figure 3. As in Figure 2, Figure3-b is the spectrum for the analyzer angle at 45 degrees and 3-a is for the perpendicular case; again polarization effects for wavelengths less than 5000A are evident. However, close examination of the wavelengths less than 4100A reveal less of a relative change than the 60 degree case. One possible interpretation is a decrease in scatterers do to a decrease on optical depth.

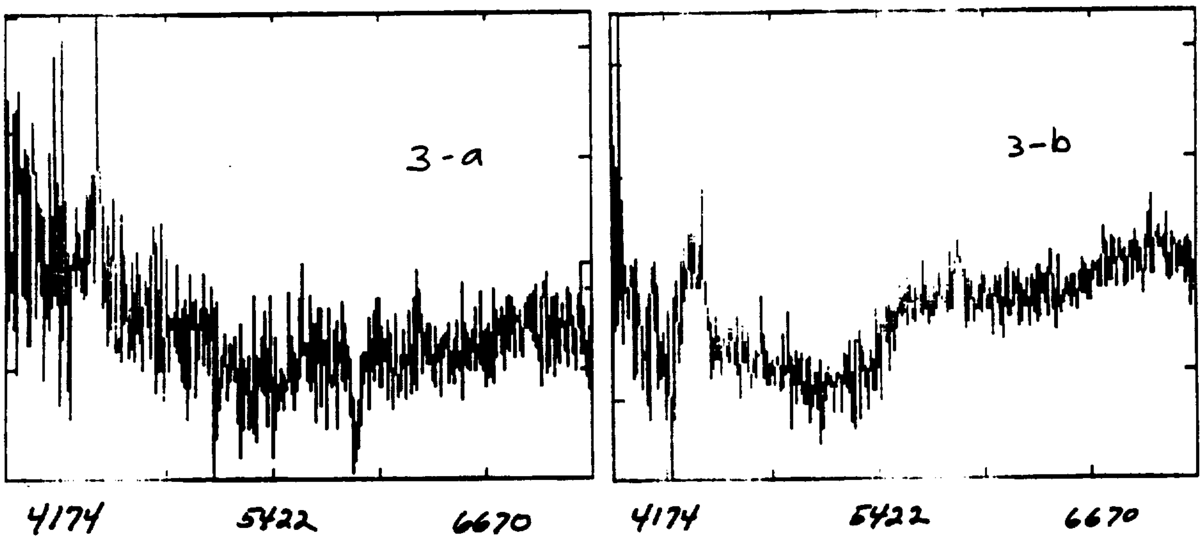

FIGURE 3. - Averaged spectrum of a 60km region of the moon just past the terminator for the 41 degree north latitude site.

Site 4
Our final data set comes from a location on the lunar surface close to the equator. The coordinates of this site are 2 degrees north latitude and 2 degrees west longitude. This region is in Sinus Medii and possesses the lowest albedo of all previous sites. Figure 4 displays the spectral data for this site and analysis reveals that there is a very slight *increase* in lower wavelengths as the polarizer is rotated. This increase is anomalous in that it is the only site in which it occurs and is counter-intuitive if dust is the cause. It must be recalled however, that the signal to noise ratio is expected to be lowest here at small latitudes do to optical depth. This fact then precludes any conclusive interpretation at this point.

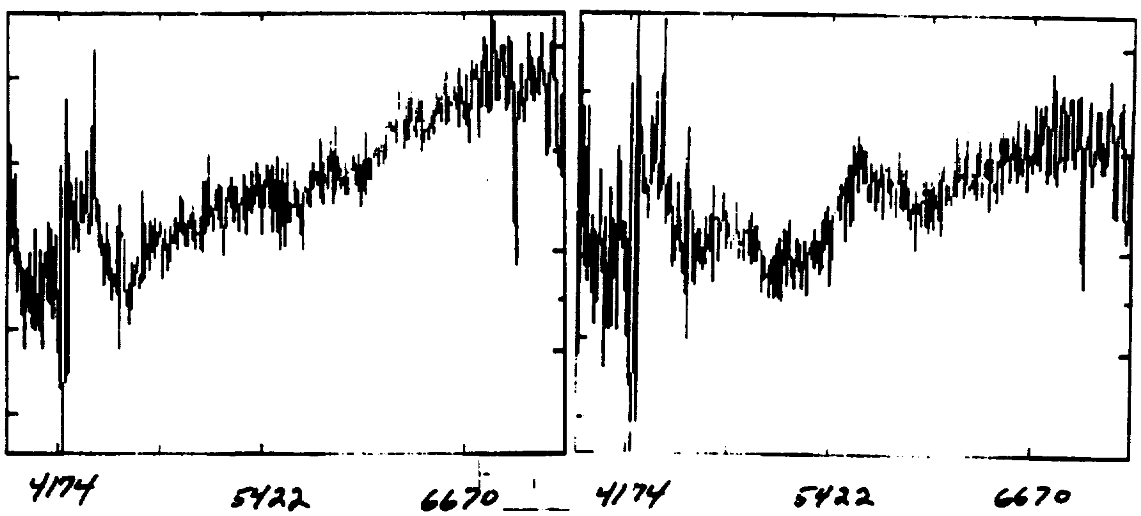

FIGURE 4. - Averaged spectrum of a 60km region of the moon just past the terminator for the 2 degree north latitude site.

When the perpendicular spectra for each site are compared against each other, an increase in intensity of lower wavelengths from site to site is observed with increasing latitude,i.e. the spectra shift to the blue. Such a comparison is shown in figure 5. Ignoring other parameters concerning geography, the case for lunar dust particles is substantiated by such a comparison.

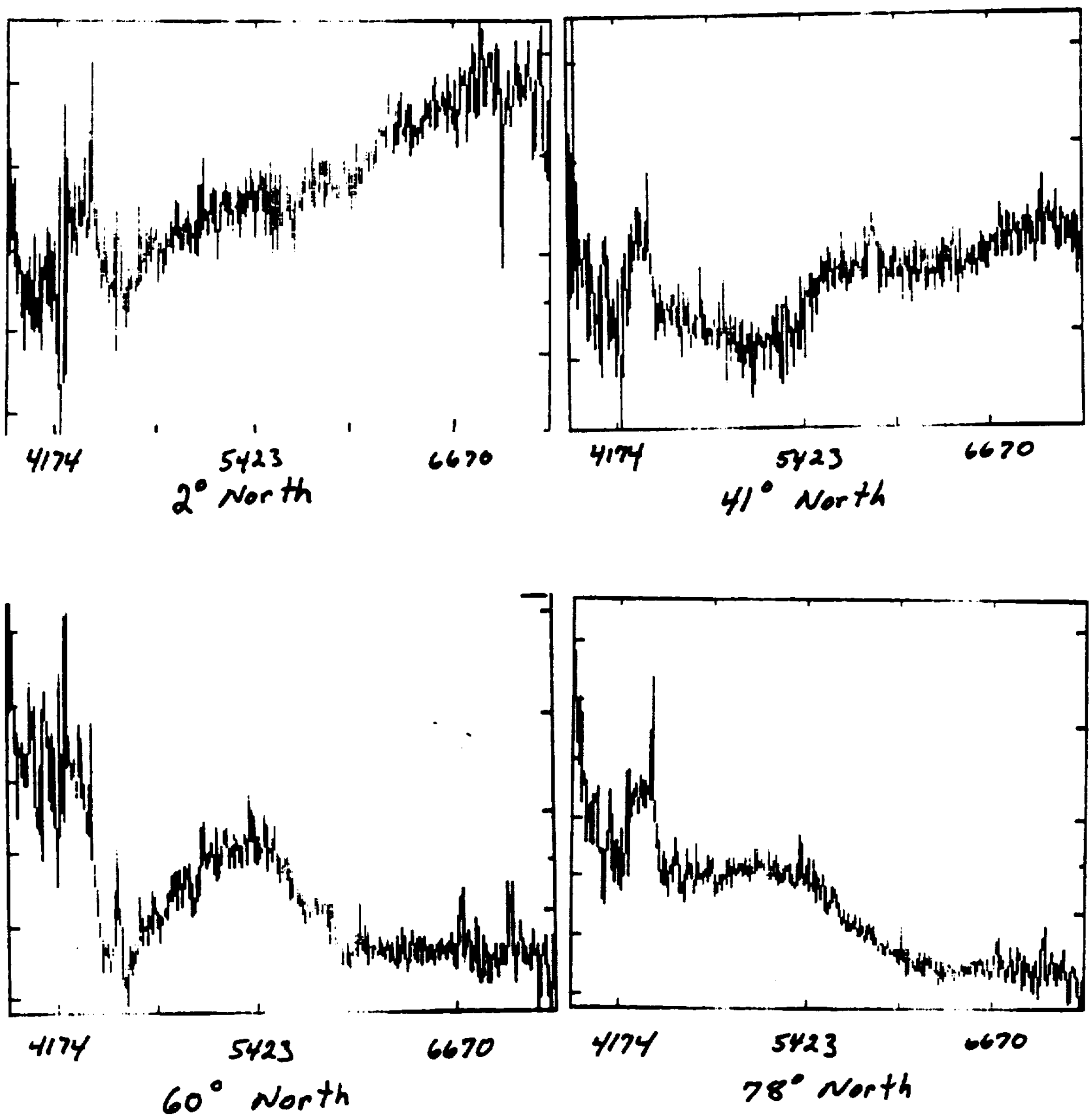

FIGURE 5 Comparison of spectra from all latitudes studied.

Summary and Conclusion

In this report, it has been shown that the degree of polarization of reflected light scattered off of the surface of the moon is greater for wavelengths residing at the blue end of the visible spectrum than for the longer wavelength red. In addition, the functional dependance of the intensity change with analyzer angle is in accord with that expected from Rayleigh scattering of light. This dependance is observed to have the expected direction (i.e., intensity increases with analyzer angle) in all cases except the one closest to the equator. It has also been demonstrated that the color of the spectra shifts toward the blue with increasing latitude; a fact which is also in agreement with The Rayleigh hypothesis in that with increased latitude there is an accompanying increase of scatterers.

REFERENCES

Berg,O.E.,H.Wolf, and J.Rhee, Lunar soil movement registered by the Apollo 17 cosmic dust experiment., *Interplanetary Dust and Zodiacal Light* (H.Elsasser and H.Fechtig, eds.), Springer-Verlag, New York, 233-237, 1976.

Kopal,Z , Astrophysics and Space Sciences Library, *An Introduction to The Study of The Moon* **4**, D.Reidel, New York, 1966.

Rennilosn,J.J. and D.R.Criswell, Surveyor observations of lunar horizon glow, *The Moon* **10**, 121-142, 1974.

Severny,A.B., E.I.Terez, and A.M.Zvereva, The measurements of sky brightness of Lunokhod-2, *The Moon* **14**, 123-128, 1975

Zook,H.A. and McCoy,J.E., Large Scale Horizon Glow and a High Altitude Lunar Dust Exosphere, *J. Geophys. Res.* **18**, 2117-2120, 1991