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Title: Global Distributions of Gas & Dust in the Lunar Atmosphere from Solar Infrared Absorption Measurements with a Fourier Transform Spectrometer

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GLOBAL DISTRIBUTIONS OF GAS & DUST IN THE LUNAR ATMOSPHERE FROM SOLAR INFRARED ABSORPTION MEASUREMENTS WITH A FOURIER TRANSFORM SPECTROMETER

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Summary

This white paper addresses the critical need for measurements of **global vertical distributions of dust & gas density** in the lunar environment in accordance with the NRC recommendations of goals for Exploration of the Moon. The lunar surface is mostly covered with a layer of micron/sub-micron size dust grains formed by meteoritic impact over billions of years. Theoretical models indicate that the dust grains on the lunar surface are charged by the solar UV radiation as well as the solar wind plasma, and are levitated and transported over long distances on the lunar surface, as exhibited by a horizon glow and transient dust clouds during the Apollo missions [e.g., McCoy, et al., 1974; Rennilson et al., 1974; Pellizari et al., 1978; Zook et al., 1991; Horanyi et al., 1998; Stubs et al., 2003; O'Brien, 2009). In addition to the dust, the Moon has a tenuous atmosphere with evidence for the existence of very-low-density CH_4, CO_2, NH_3, along with some rare gases (see, e.g., Johnson et al., 1992; SDT report on Lunar Atmosphere and Dust Environment Explorer Study Report, 2008). The possibility of out-gassing of H_2O in the lunar polar-regions also exists. Definitive information on dust/gas distributions in the global lunar environment is currently unavailable and is essential for addressing a variety of issues dealing with lunar environment.

Since the abundance of dust on the Moon's surface with its observed highly adhesive characteristics has the potential of severe impact on human habitat and operations of mechanical equipment for Moon-based scientific investigations, a high priority should be to determine the global dust & gas distributions in the lunar environment. This information is essential for understanding the lunar environment in order to develop appropriate mitigating strategies for carrying out all investigations on the Moon.

The above critical need has been recognized by the National Research Council in its report on the Scientific Context with recommendations of the following investigations and Science Goals for Exploration of the Moon (2007):

(i) ***Scientific study of the processes involved with the atmosphere and dust environment of the Moon while the environment remains in a pristine state.***

(ii) ***Determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity.***

The need to determine the GLOBAL dust & gas density and its time variability is clearly emphasized in the NRC committee's recommendations. Although the above recommendations appear to have a lower priority in terms of the merits of basic scientific interest, the committee recognizes its importance by recommending its implementation at the earliest opportunity, as it would impact all other investigations from the Moon.

In this white paper, we bring to the attention of the lunar science community, a well developed technique that is the most suitable and most sensitive means for achieving the objective of measurements of very tenuous global distributions of dust & gas in the lunar environment. The proposed technique is based on solar infrared absorption measurements in the limb observation mode with a Fourier transform spectrometer in the middle infrared spectral region (~ 4-50 μm; 200-2500 cm^{-1}) with variable spectral resolution of ~ 1-10 cm^{-1}. Infrared solar absorption measurements of the Moon in the limb observation mode, offers the capability to provide highest sensitivity measurements of most tenuous atmospheres such as that of the Moon with densities as low as ~ 0.1 cm^{-3} and volatiles gases such as H_2O, CH_4, CO_2, and NH_3 with particle densities of ~ 10^5- 10^7 cm^{-3} .

I. Current Lunar Dust/Gas Measurement Instruments

The techniques for measurements of lunar dust/gas distributions that have been employed or currently being considered, involve both in-situ and remote sensing instruments from the lunar surface and a lunar orbiter. These include:

1. **Mass spectrometers**, may provide accurate time varying values of dust/gas densities with: (a) Measurement from the lunar surface: Near surface measurement of dust/gas densities at specific sites of the surface based instruments.

(b) Measurements from a lunar orbiter: Dust density measurement at specific altitudes corresponding to the orbiter heights. The mass spectrometer instruments have the potential of providing high accuracy dust/gas density measurements at specific instrument sites and altitudes. The broader and more general level of understanding of understanding of the nature and variability of understanding of the lunar dust/gas will not be provided by such limited in-situ instruments.

2. **Remote sensing UV-Vis spectrometers:** Currently proposed UV-Vis spectrometer Instruments will measure scattered optical emissions from the lunar dust and line emissions from exospheric gases. Analytical models based on radiation from lunar exospheric dust and gas, employing Mie theory calculations are expected to provide dust and gas distributions in the lunar environment. UV-Vis spectrometers are expected to be carried aboard the LADEE mission for measurements or lunar dust and gas distribution measurements (e.g., Glenar et al., 2008).
The UV-Vis spectrometer may provide some useful limited information about the lunar dust, but in view of its low sensitivity and low spatial resolution, it will not fulfill the requirement of adequately measuring the global vertical distribution of dust and gases in the lunar environment.

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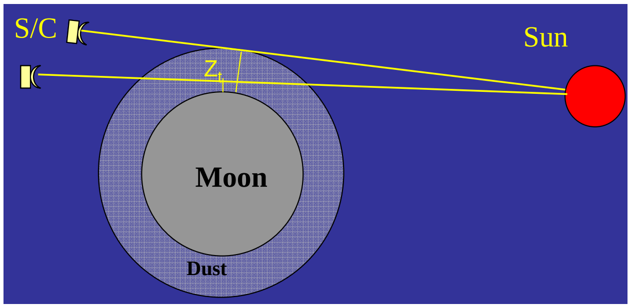
II. Global Lunar Dust/Gas Measurements Solar Infrared Absorption of Lunar with a Fourier Transform Spectrometer

The measurement and instrument concept presented in this white paper is based on the observation of solar infrared absorption spectra of dust/gas abundances in the lunar limb viewing mode (Fig. 1) over a range of angles and tangent heights that would provide the following unique advantages over

Fig. 1



all other remote sensing techniques of trace gases/dust absorbers in planetary atmospheres.

1. An extremely high detection sensitivity of the gas/dust absorptions spectra in the solar occultation mode spectra over long paths
2. Limb viewing mode of observation provides high spatial resolution with sharply peaked contributions functions, with a true remote sensing capability of acquiring global vertical distributions of gas and dust.
3. A Fourier transform spectrometer would provide broad-band high spectral resolution spectra exhibiting absorption spectra of lunar dust as well as spectral lines of any detectable volatile gases.
4. The proposed measurements will fulfill a critical need to acquire the **global distribution of dust and gas in the pristine lunar environment.**

The observed infrared absorption dust spectra may be analyzed to retrieve the vertical distribution of dust/gas densities by utilizing the spectral inversion techniques well developed for infrared remote sensing of the Earth and planetary atmospheres [Abbas, et al., 1984-2004]. Information about the dust size distribution will be obtained with parallel laboratory measurements of the extinction coefficients of individual micron or submicron size dust grains.

Fourier transform spectrometer: With the primary objective of broadband dust measurements, a Fourier transform spectrometer with a spectral resolution of ~ 1- 10 cm^{-1} in the 200-2500 cm^{-1} (4-50 um) region would provide absorption spectra suitable for retrieval of lunar dust/gas distributions. The following Fourier transform spectrometers would serve as models for the lunar based spectrometer: (1) (CIRS-*lite*), which is a newly developed significantly advanced version of the IR instrument aboard the Cassini spacecraft for observations of the Saturnian system. This spectrometer incorporates numerous advanced features that include: light weight, variable high spectral resolution (0.125-10cm^{-1}); broad band-pass, high sensitivity with a superconductor bolometer; and a smaller telescope (15 cm), etc. This instrument would be ideal for remote sensing of global dust and gas distributions in the lunar atmosphere for solar infrared absorption measurements. There is no known technique better than the one considered here to fulfill the critical need of measurements of the **global dust/gas distributions** in the lunar atmosphere. (2) ATMOS/JPL middle infrared solar absorption spectrometer by Gunson et al. [13] flown on Spacelab 3 and Atlas/Shuttle missions or measurement of trace gas species in the Earth's upper atmosphere. (3) TES (Mars Global Surveyor mission), and Mini-TES (Mars Rover), thermal emission Fourier Transform spectrometers, employed for Mars exploration

The design for the lunar spectrometer will incorporate features suitable for lunar dust/gas measurements by solar absorption mode, involving a sun-tracker, fore-optics, interferometer, and electronics.

Analytical Techniques

Vertical Dust/Gas Distribution Measurements

Some selected model calculations for retrieval of lunar dust distributions from solar infrared dust absorption spectra using an algorithm employed in infrared remote sensing of the Earth's and the planetary atmospheres

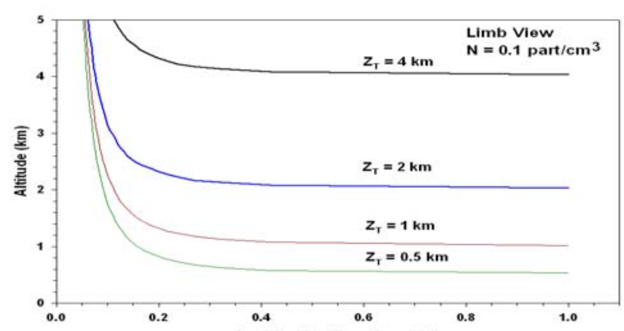
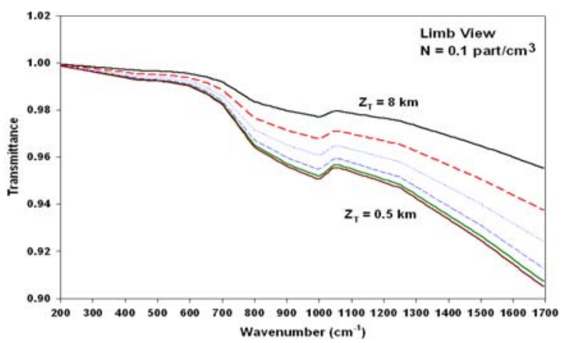


Fig. 2. Contribution functions for limb-view paths with tangent-heights of 0.5, 1, 2, and 4 km.

[e.g., Abbas et al., 1991-2004] were carried out with assumed dust density and infrared extinction data. The extinction coefficients in the middle infrared spectral region (200-1700 cm^{-1}) are assumed to be the similar to those for planetary dust/aerosol for particles of all size. The dust content is specified by number density cm^{-3} with uniform distribution at all altitudes.

Numerical calculations for the limb-viewing mode of observations with plots of the contribution functions and transmittances for a few tangent heights are shown in Figs. 3a, b.



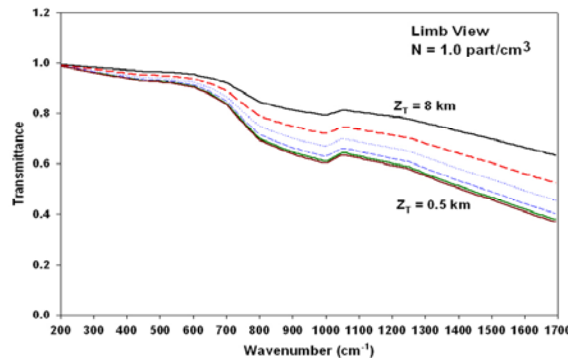


Fig. 3a, b. Calculated dust transmittances for limb-view paths with tangent-heights of 0.5, 1, 2, 4, and 8 km, assuming uniform dust density of 0.1 and 1.0 cm^{-3}.

The infrared dust/gas spectra observed under solar occultation mode may be analyzed to retrieve the vertical dust/gas density distributions by utilizing radiative-transfer and spectral inversion techniques well developed for infrared remote sensing of the Earth and planetary atmospheres [e.g., Abbas et al., 1984-2009]. Information about the dust size distribution will be obtained with parallel laboratory measurements of the extinction coefficients of individual micron or submicron size dust grains.

Conclusions

The measurement technique presented here is based on limb viewing infrared absorption spectra of lunar dust and gases in solar occultation mode over a range of observation angle and limb tangent heights with a Fourier transform spectrometer. This white paper recommends it as the most useful and a highly sensitive technique for remote sensing of global distributions of both lunar dust /gas of the lunar environment.

Expected Impact for NASA:

The measurements with the proposed technique will provide lunar dust/gas distributions in close conformity with the **recommendations** and Concept in the **Final Report of NRC-Committee** on the Scientific Context for Exploration of the Moon (2007, p.43, Concept 8), expressed as:

8a: “**Determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity.”**

8b: “**Determine the size, charge, and spatial distribution of electrostatically transported dust grains** and assess their likely effects on lunar exploration …”

Expected Impact outside NASA

The proposed measurements will fulfill a critical need to understand the nature of the lunar atmosphere, global gas and dust distributions. This will have an impact on development of satisfactory mitigating strategies from an engineering perspective, in order to resolve the issues of harsh lunar environment, and help open the doors of lunar exploration for a vast range of commercial enterprises.

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