A GONIOMETRIC SYSTEM TO MEASURE THE INCOMPLETE MUELLER MATRICES OF PACKED LAYERS. Hao Zhang[1], Weidong Jin[1], Weibiao Xu[2], Ziwei Wang[1], Yazhou Yang[1], Ye Yuan[1] and Hui Sun[1]. [1]Faculty of Earth Science, China University of Geosciences, Wuhan, China (zhanghao@cug.edu.cn), [2]Purple Mt. Observatory, Chinese Academy of Sciences, Nanjing, China.

Introduction: Light reflection from solar system bodies may provide a wealth of compositional and morphological information of the regolith grains. In contrast with the more extensively used conventional visible and NIR spectroscopy, qutitative directional spectroscopy has gained more popularity only in recent years. For example, the phase ratio imagery method [1][2] has been found to be able to manifest the lunar surface roughness and thus may complement the color ratio imagery method [3]. Furthermore, based on Earth based observations, multi-anglular polarization spectroscopy has been found very useful in lunar regolith size and porosity determinations [4].

Another interesting issue is the relationship between the polarization ratios and the opposition surge. The degree of linear polarization (DOLP), circular polarization ratio (μ_C) and two linear polarization ratios ($\mu_{//}$ and $\mu_\perp$) used by the remote sensing community (e.g. [5]) may be defined as:

$$DOLP = \frac{I_\perp - I_{//}}{I_\perp + I_{//}}, \quad (1)$$

$$\mu_C = \frac{I_{CS}}{I_{CO}}, \quad (2)$$

$$\mu_{//} = \frac{I_{ps}}{I_{pp}}, \quad (3)$$

and

$$\mu_\perp = \frac{I_{sp}}{I_{ss}}. \quad (4)$$

In eqs. (1)-(4) “C” stands for circular polarization, “O” and “S” stand for the opposite and same helicity, respectively; “p” and “s” labels the electric field component of light parallel and perpendicular to the scattering plane, which is the plane containing the incident and viewing directions, respectively. For example, I_{ps} stands for scattered light polarized in the s-direction with incident light polarized in the p-direction, and so forth.

For many airless bodies, the DOLP defined by eq. (1) has been found to have strong phase angle dependence. Near the opposition, the strong intensity surge exhibited by the Moon and many asteroids is accompanied by the appearance of negative values of the DOLP. The polarization ratios defined in eqs. (2)-(4), though impossible to measure in passive remote sensing and is still debateble, have been found to have different behaviours towards the opposition in laboratory lunar sample measurement.

To investigate the many open questions in polarized multi-angular remote sensing, we have set up a polarized light scattering goniometer capable of measuring the incomplete Mueller matrices of particulate surfaces. We envision that in the near future polarized multi-angular spectroscopy, both passive and active, should find more applications in planetary remote sensing and may eventually be implemented to some mission payload.

Methodology: We assume that a packed surface composed of non-spherical particles with no symmetry planes would have the most general form of a Mueller matrix:

$$M_{ij} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \\ M_{41} & M_{42} & M_{43} & M_{44} \end{bmatrix}, \quad (5)$$

and the quantities given in eqs. (1)-(4) may be expressed in terms of the matrix elements as :

$$DOLP = -\frac{M_{21}}{M_{11}}, \quad (6)$$

$$\mu_C = \frac{M_{11} + M_{14} + M_{41} + M_{44}}{M_{11} + M_{14} - M_{41} - M_{44}}, \quad (7)$$

$$\mu_\perp = \frac{M_{11} - M_{12} + M_{21} - M_{22}}{M_{11} - M_{12} - M_{21} + M_{22}}, \quad (8)$$

$$\mu_{//} = \frac{M_{11} + M_{12} - M_{21} - M_{22}}{M_{11} + M_{12} + M_{21} + M_{22}}. \quad (9)$$

Obvisously, measurements of the 7 Mueller matrix elements M_{11}, M_{12}, M_{21}, M_{22}, M_{14}, M_{41} and M_{44} would be sufficient in obtaining the polarization ratios defined in eqs. (1)-(4).

The polarized goniometer system: The light source of the system consists of three high power lasers: a He-Ne laser at 633 nm and two diode-pumped solid state lasers operating at 532 and 473 nm, respectively. After exiting the laser head, light is inserted into an optic fiber and directed to the end of a rotatable bar carrying the illumination optics. A collimator with appropriate numerical aperture is used to collimate the light exiting the fiber and provides uniform illumination onto the sample surface. The scattered light is collected by the collection optics mounted on another rotatable bar driven by a computer-controlled servo motor. With such a configuration, reflectance measurements at various viewing zenith angles at a fixed incident zenith can be measured automatically. Both of the rotatable bars are 2m long which ensures the collection optics to have a high angular resolution (0.6° full angle). Such a resolution gurantees the detection of any subtle angular strutures such as rainbow features in well-sorted samples in controlled measurements [6][7]. The configurations of the system allow reflectance measurements be made at incident and viewing zenith angles from 0-80° and a minimum phase angle of 0.6°.

Two methods are used to measure the Mueller matrix elements needed in eqs. (6) through (9). As shown in Fig. 1, the first method uses two precision linear polarizers and two zeroth order quarter wave plates with appropriate wavelengths as polarization elements. By properly rotating these polarizers the desired matrix elements or their linear combinations can be obtained. In the second method, the quarter wave plate in incident optics is replaced by a liquid crystal retarder (LCR). The LCR's fast axis has a fixed orientation with respect to the linear polarizer. By varying the voltage applied to the LCR a retardance δ

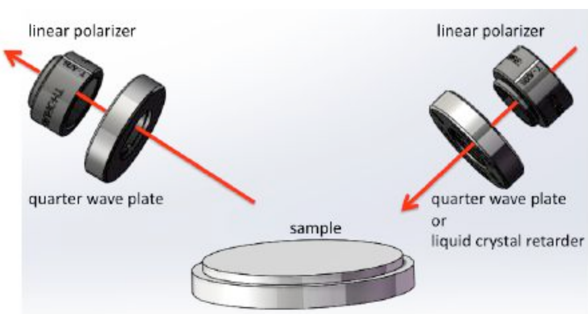

Fig. 1. Schematics of the incident and the collection polarization elements. The linear polarizer in the detection optics has a fixed orientation with the detector.

Fig. 2. The goniometric system with the sample hoder in the front.

is generated and the intensities reaching the detector can be expressed as:

$$I_{detector} = M_{11} + M_{12}\cos\delta + M_{14}\sin\delta - M_{41} - M_{42}\cos\delta - M_{44}\sin\delta \quad (10)$$

and

$$I_{detector} = M_{11} + M_{12}\cos\delta + M_{14}\sin\delta + M_{41} + M_{42}\cos\delta + M_{44}\sin\delta \quad (11)$$

In eqs. (10) and (11), the M_{42} element is unwanted while the needed M_{21} and M_{22} elments are missing. To get M_{21} and M_{22}, the quarter wave plate in the collection optics is removed and the intensity measured. To eliminate any possible polarization dependent sensitivities of the detector (currently a Si photodiode for brighter surfaces and a photomultiplier for very dark samples), the last polarizing element (the linear polarizer in the collection optics) has a fixed orientation with respect to the detector in all measurements.

The reason that we choose a LRC instead of other more accurate polarization modulation devices is that the LCR has relatively a smaller volume and weight. This is crucial in reaching a smaller minimum phase angle in measurement as this value is determined by the size of the collection optic tube assembly. To ensure the accuracy of the measured values, we use these two methods to cross-check each other and compare with published values of some popular samples such as the Labsphere Spectralon plaque. More details and data will come as measurements continue.

Conclusions: The light scattering facility described here is part of our continuing efforts of building laboratory devices necessary for the proper interpretations of spectroscopic data measured from various airless planetary bodies. We expect that such laboratory data would help improve our quantitative undertandings of polarized reflectance and may eventually turn polarization-enabled sensors into future's payload concepts.

Ackowledgement: We thank K. Voss, S. Kaasaleinen, O. Munoz, C. Liu and J. Rao for helpful discussions. Supports from NSFC (41071229 and 41276180) are acknowledged.

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