Preliminary Results from Multi-band Polarimetric Observations of the Lunar Surface. Minsup Jung[1], Sungsoo S. Kim[1], Kyoung Wook Min[2], Ho Jin[1], Ian Garrick-Bethell[1,3], Mark Morris[4], [1]School of Space Research, Kyung Hee University, Korea (msjeong@ap4.khu.ac.kr), [2]Dept. of Physics, Korea Advanced Institute of Science and Technology, [3]Dept. of Earth & Planetary Sciences, University of California, Santa Cruz, [4]Dept. of Physics & Astronomy, University of California, Los Angeles

Introduction: We carried out multi-band (U, B, V, R, and I passbands) polarimetric observations of the whole near side of the moon from the Lick observatory using a 15-cm reflecting telescope. Polarization of the light scattered by the lunar surface contains information on the mean particle size of the lunar regolith, which gradually decreases by continued micro-meteoroid impact over a long period and thus is an age indicator of the surface. We have constructed a map of mean particle sizes for the whole near side of the moon. We also found that the mean particle sizes of Renier Gamma are somewhat dissimilar to those predicted by OMAT (optical maturity) values, which may be a clue to understanding the nature and formation mechanism of the swirls.

Background: The sunlight scattered on the lunar surface is partially linearly polarized [1]. The polarized light contains information on the lunar regolith, such as its mean particle size, composition and so on. Particularly, the mean particle size is an important parameter when designing lunar rovers and making artificial regolith for laboratory experiments. In addition, the mean particle size can be an indicator of maturity for the lunar regolith because micro-impacts make particle sizes smaller and have constantly occurred on the lunar surface [2, 3]. The mean particle size can be measured from the observations of the maximum polarization and albedo [4, 5, 6]. However, monochromatic polarimetry and photometry provide limited information regarding the properties of the regolith because the regolith consists of various minerals. Therefore, multi-band polarimetry provides more informative data for understanding the polarization properties of lunar regolith.

Observations and Data Processing: We conducted multi-band polarimetry at Lick observatory from July 14th to Aug 1st. We used a 15-cm aperture reflecting telescope and a 3.3k X 2.5k CCD with band-pass filters (U, B, V, R and I) and a polarization filter. Spatial resolution is 1.84km/pixel at the lunar center. Polarization degree highly depends on phase angle. One has to obtain as many phase angle data as possible to obtain a more precise measure of the polarization maximum. The phase angle coverage is from 36.80° to 120.96°, and the number of obtained phase angles is 30. The polarimetry accuracy is estimated to be ~0.5%p.

The maximum polarization degree for the central region of the lunar disk cannot be directly obtained from ground-based observations because the polarization degree approaches the maxium value when the phase angle is close to 100°. For this reason, we fit our polarization values with a model polarization curve,

$$P_\alpha = \frac{(sin^2(\alpha - \Delta\alpha))^w}{1 + cos^2(\alpha - \Delta\alpha) + depol} \quad (1)$$

where α is the phase angle, $\Delta\alpha$ is the shift parameter and *depol* is the de-polarization parameter [7].

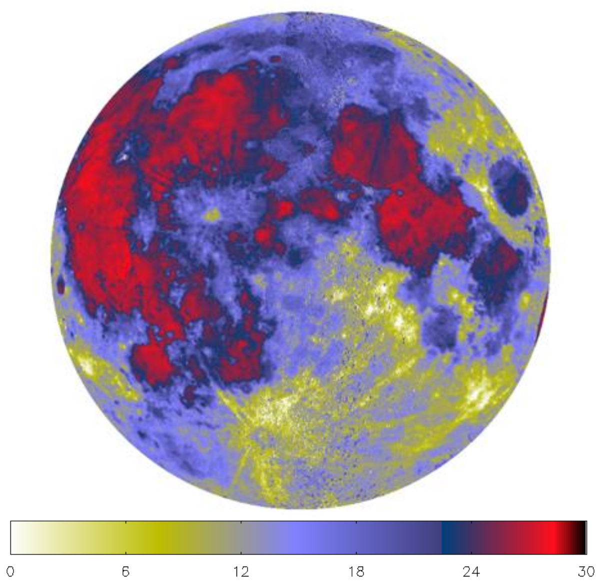

Figure 1. The map of the polarization maximum from the V band. The color bar is in units of percent.

Figure 1 is a map of the maximum polarization degree from our method. The map shows a general trend of the lunar polarization properties (maria have higher polarization values then highlands) [1].

Mean Particle Size: The mean particle size accounts for the maturity of the lunar surface: the larger the mean particle size, the fresher the lunar soil. We estimate the mean particle size from our multi-band polarimetry and Clementine albedo data using the relation.

$$P_{max} = C_1(\overline{d})A^{-1.37} \quad (2)$$

where P_max is the maximum polarization, $C_1(\overline{d})$ is the mean particle size parameter, and A is the albedo [6]. The degree of polarization is a function of phase angle, and the maximum polarization among all phase angles depends on the albedo and the mean particle size [4, 5, 6]. Then, the mean particle size $\overline{d}$ can be obtained from Dollfus's equation,

$$C_1(\overline{d}) = (0.021\overline{d} + 1.76) \times 10^{-3} \quad (3)$$

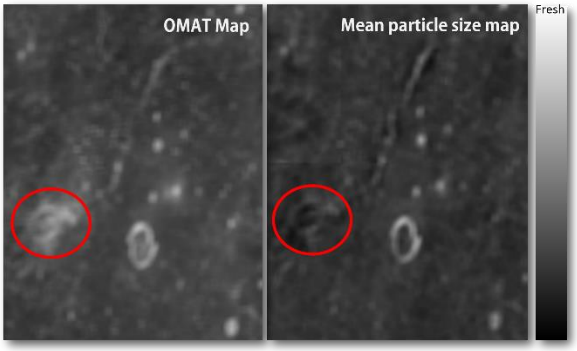

Figure 2. OMAT and mean particle size maps. Red circles mark the location of Reiner Gamma swirl. Brighter color indicates fresher soil in the OMAT map, and larger particle size in the mean particle size map.

We compared the mean particle size we measured and OMAT, a well-known maturity index [8], from the Clementine data. As **Figure 2** shows, OMAT values and our mean particle sizes generally have good correlation—the larger the mean particle size, the fresher the soil. However, we found that the two values are inconsistent in the swirl region—the OMAT map indicates that the Reiner Gamma swirl is fresher (brighter in the map) than its neighbor while the mean particle size map shows that the swirl is as mature (smaller particle sizes) as its neighbor. This implies that the properties of Reiner Gamma regolith can be different from the regolith of other fresh craters, and appears to support the dust transport model [9] of swirls. According to the dust transport model, swirls are formed by accumulating levitated small dust, which can be smaller then few microns [10]. The inconsistency between the OMAT and the mean particle size can be explained if the regolith in the swirl region is mainly composed of fine, but fresh particles.

However, it is difficult to rule out the alternative explanation that the unique properties of swirls are entirely a product of solar wind deflection by the underlying magnetic field [11]. In this case, the reduced solar wind flux would cause the fresh appearance, while micrometeroids, unimpeded by the magnetic field, would produce fine grain-size regolith over billions of years.

Wavelength Dependencies: To further understand the properties of the regolith, we compared the albedo and polarization ratios between adjacent bandpasses. In **Figure 3**, blue, black and red symbols are for maria, Reiner Gamma swirl, and highlands, respectively. Albedo ratios have very narrow ranges regardless of the region, but P_{max} ratios have relatively wider ranges and are quite different between maria and highlands. P_{max} vs. P_{max} ratio relations (middle column) show that the spectro-polarimetric properties of the swirl region is closer to that of maria than highlands. The spectral dependencies of the polarization degree is not well known

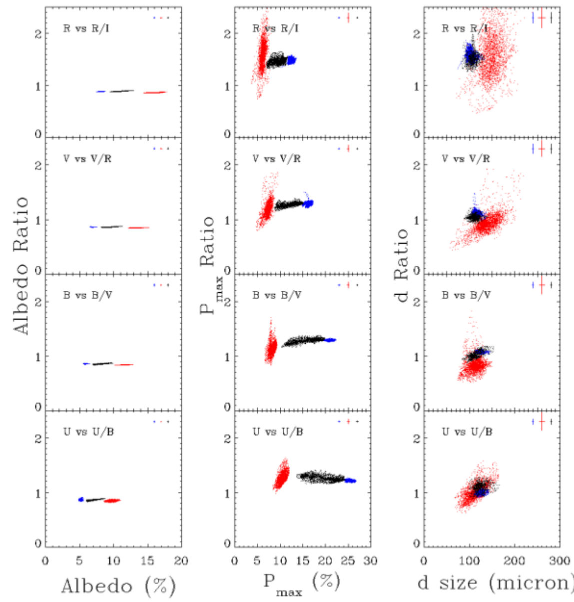

Figure 3. Wavelength dependencies of the albedo, polarization maximum, and mean particle size for maria (blue), Reiner Gamma swirl (black), and highlands (red).

yet, and our data are a good resource for advancing studies in this field. In the future, we plan to conduct lab experiments and computer simulations to understand our spectro-polarimetric data of the lunar surface. Ultimately, this may help resolve some of the open questions about the properties of swirls.

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