DETERMINATION OF MAXIMUM POLARIZATION AS A PRIOR STUDY OF KPLO/POLCAM. S. A. Hong[1], M. Jeong[2], and C. K. Sim[1], [1]Kyung Hee University, Yongin, South Korea. (sbhong@khu.ac.kr), [2]Korea Astronomy and Space Science Institute, Daejeon, South Korea.

Introduction: The sunlight reflected by the lunar surface is partially polarized by the ensemble of the grains of various size and composition, and the microstructure of the regolith [1, 2]. In order to study the surface of the Moon by means of polarimetry, the maximum polarization (P_{max}) should be constructed since the degree of polarization is dependent on the phase angle α. Then, the median grain size can be estimated using polarimetric and photometric data, which will be useful to study the space weathering on the Moon and to determine the landing site for a future lunar mission [1, 3].

Despite the usefulness of polarization on the lunar surface, the polarimetric observations from the lunar orbit have never been performed so far. As a prior study for successful mission of the Polarimetric Camera (PolCam) which will be onboard the Korea Pathfinder Lunar Orbiter (KPLO), we investigate the accuracy of P_{max} determination in a limited phase-angle coverage case using the ground-based polarimetric data [3]. Following the empirical formula to fit the polarimetric phase curve with a three-parameter proposed by Korokhin & Velikodsky [4], we intensively deal with the "positive" branch of polarization.

The P_{max} map of the lunar nearside has been constructed from the polarimetric data obtained at the phase angles (α) ranging from 40° to 120° from the ground [3]. Then, we investigated the reliability of P_{max} obtained assuming a sparse distribution of α. We found that the fitting formula of the polarization curve by Korokhin and Velkodsky is indeed a one-parameter function in the positive polarization regime (α > 40°), implying that P_{max} can be reliably obtained from a limited number of P observations (α > 90°) in the positive polarization regime. Thus, we expect that constructing the P_{max} map of the Moon from the space mission can be completed even the case of a sparse and/or scarce distribution of α.

Data and Method: The P observations were made in 2013 July 14 to August 1 using a 15-cm reflecting telescope at the site of Lick Observatory with the best seeing at 1″ for the whole near-side of the Moon. The phase angles range from 40° to 120° [3]. The P_{max} was constructed using the empirical formula provided by Korokhin & Velikodsky (2005) to the observed P,

$$P(\alpha) = \frac{(sin^2(\alpha-\Delta\alpha)^W)}{1+cos^2(\alpha-\Delta\alpha)+D} \qquad (1)$$

where α is the phase angle, $\Delta\alpha$ is the shift in α_{max} from 90°, W is the width of the curve, and D is the amount of depolarization. The P_{max} was obtained by fitting the above equation to the observed P using the χ^2 minimization as a downhill simplex method[5].

First, since we focus on the positive branch, we optimized the equation (1) by reducing the number of free-parameters keeping $\Delta\alpha$ and/or W constant and analyzed the results of $P_{max}|_W$ or $P_{max}|_{\Delta\alpha}$ as a function of the two parameters ($\Delta\alpha$ and D or W and D) and the $P_{max}|_{\Delta\alpha,W}$ as a function of an one parameter (D). Second, we investigated the effect of α coverage on the P_{max} assuming a limited phase-angle coverage case.

Results and Conclusions: We have studied the characteristics of the polarimetric phase curve for the Moon to completely construct the polarimetric map considering the future space mission. First, the maps of P_{max}, α_{max}, and W for the whole near-side Moon were constructed fitting the phase curve as a function of three parameters ($\Delta\alpha$, W, and D, Fig. 1). The region with longitudes less than ±15° has been excluded because the α-limitation of a ground-based observations causes a large uncertainty on the P_{max} estimation [3].

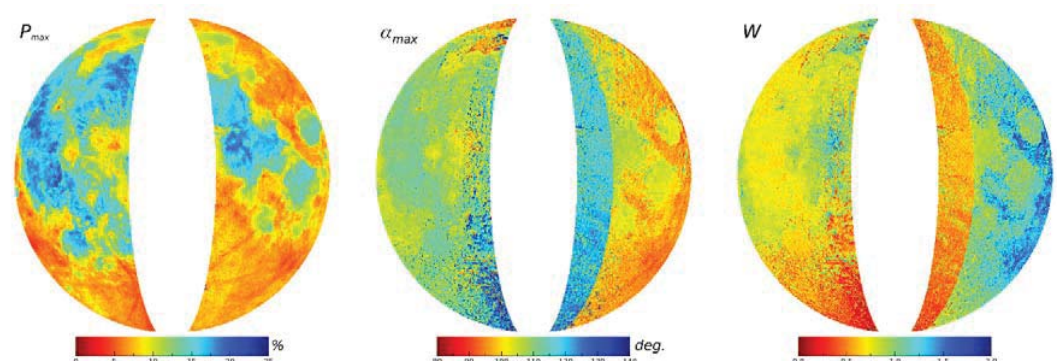

Fig. 1: Maps of P_{max}, α_{max}, and W in B-band. The region with longitudes ≲ ±15° has large uncertainty, so that has been excluded from quantitative analyses throughout this work. The color scales are in unit of %, degree, and arbitrary, respectively.

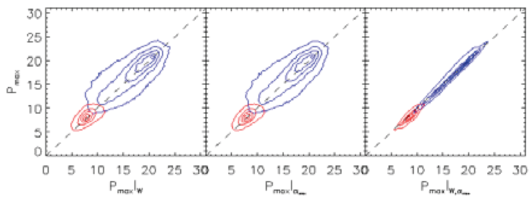

Fig. 2: Correlation between $\boldsymbol{P}_{max}$ and $\boldsymbol{P}_{max}|_W$, $\boldsymbol{P}_{max}|_{\Delta\alpha}$, $\boldsymbol{P}_{max}|_{\Delta\alpha,W}$, where $\boldsymbol{P}_{max}$ are results from fitting the formula with three parameters ($\Delta\boldsymbol{\alpha}$, $\boldsymbol{W}$, and $\boldsymbol{D}$), $\boldsymbol{P}_{max}|_W$ or $\boldsymbol{P}_{max}|_{\Delta\alpha}$ are results from that with fixed $\boldsymbol{W}$ or $\Delta\boldsymbol{\alpha}$, and $\boldsymbol{P}_{max}|_{\Delta\alpha,W}$ are results from that with fixed $\Delta\boldsymbol{\alpha}$ and $\boldsymbol{W}$. The red color indicates highlands, while the blue color indicates the maria. The contours are for the 5th, 25th, 50th, 75th, and 95th percentiles. The dashed lines indicate the one-to-one.

The $\boldsymbol{\alpha}_{max}$ and $\boldsymbol{W}$ maps have discontinuities around the longitudes of ±30° which are also due to limitations of the ground-based observations that observe the eastern and western regions on the Moon at different days. Despite these discontinuities on the maps of $\boldsymbol{\alpha}_{max}$ and $\boldsymbol{W}$, the $\boldsymbol{P}_{max}$ map had continuous values because the $\boldsymbol{\alpha}_{max}$ and $\boldsymbol{W}$ were complements of each other.

Second, the phase curve of the empirical formula was simplified with an average of value either $\Delta\boldsymbol{\alpha}$ or/and $\boldsymbol{W}$ ($\boldsymbol{P}_{max}|_W$, $\boldsymbol{P}_{max}|_{\Delta\alpha}$, and $\boldsymbol{P}_{max}|_{\Delta\alpha,W}$). The comparison of between $\boldsymbol{P}_{max}$ and $\boldsymbol{P}_{max}|_W$, $\boldsymbol{P}_{max}|_{\Delta\alpha}$, and $\boldsymbol{P}_{max}|_{\Delta\alpha,W}$ indicated that the $\boldsymbol{P}_{max}$ can be obtained from a single parameter function (Fig. 2). A single parameter function was comparable to the Umov law[6]. In addition, the validation of a single parameter function were examined in terms of the fixed value and effects of outliers. The variation on the fixed value had little affect on the results of $\boldsymbol{P}_{max}$ and $\boldsymbol{P}_{max}|_W$, $\boldsymbol{P}_{max}|_{\Delta\alpha}$, and $\boldsymbol{P}_{max}|_{\Delta\alpha,W}$. The outliers from the relationship between $\boldsymbol{P}_{max}$ and $\boldsymbol{P}_{max}|_{\Delta\alpha,W}$ were defined to be 10% smaller or larger than the differences between them, which caused the mean absolute biases of 0.45% and 0.54% for the maria and highlands, respectively.

Third, we assumed a limited phase-angle case due to the high-latitudes of the observing side or fault observations due to a mal-function of the mission instrument. We calculated the $\boldsymbol{P}_{max,limited}$ when the phase angles were limited to be less than 80°, 90° or 100°. The comparison between $\boldsymbol{P}_{max}$ and $\boldsymbol{P}_{max,limited}$ confirmed that the $\boldsymbol{P}_{max}|_{\Delta\alpha,W}$ calculated from a single parameter function by keeping $\Delta\boldsymbol{\alpha}$ and $\boldsymbol{W}$ constant works well when the largest phase angle is over 90° (Fig. 3). Therefore, we would have to get the data when the $\boldsymbol{\alpha}$ is greater than at least 90° in order to complete the map of $\boldsymbol{P}_{max}$ for the entire lunar globe from a space mission.

In conclusion, the $\boldsymbol{P}_{max}$ could be satisfactorily estimated from the Polarimetric Camera (PolCam) onboard Korea Pathfinder Lunar Orbiter (KPLO). Polarimetric data from the lunar orbit will provide important information on the characteristics of the lunar regolith allowing us to understand the effect of the space weathering on the airless body.

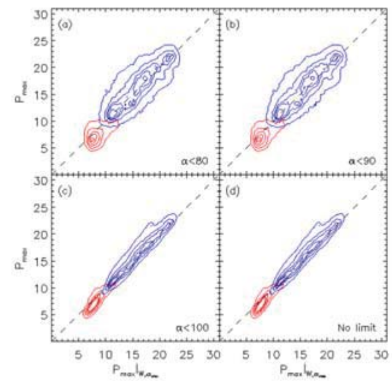

Fig. 3: Correlation between $\boldsymbol{P_{max}}$ and $\boldsymbol{P_{max}^{\alpha<80}}|_{\Delta\alpha,W}$, $\boldsymbol{P_{max}^{\alpha<90}}|_{\Delta\alpha,W}$, $\boldsymbol{P_{max}^{\alpha<100}}|_{\Delta\alpha,W}$, and $\boldsymbol{P_{max}}|_{\Delta\alpha,W}$, where $\boldsymbol{P_{max}}$ are results from fitting the formula with phase angles from 40 to 120°. $\boldsymbol{P_{max}^{\alpha<80\ or\ 90\ or\ 100}}|_{\Delta\alpha,W}$ are results from that with limited phase angles by 80°, 90°, 100°, respectively. The dashed lines indicate the ono-to-one. The color and contour are the same as Fig. 2.

References: [**1**] Shkuratov, Y. G., & Opanasenko, N. V. (1992) *Icarus*, 99, 468-384. [**2**] Dollfus, A. 1998, *Icarus*, 136, 69-103. [**3**] Jeong, M. et al. (2105) ApJS, 221, 16-33. [**4**] Korokhin V. V., & Velikodsky, Y. I. (2005) *SoSyR*, 39, 45-53. [**5**] Nelder, J. A., & Mead, R. (1965) *The Computer Journal*, 7, 308-313. [**6**] Umov, N. (1905) *ZPhy*, 6, 674.