Mapping the Moon in P_{min}

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Abstract

At small phase angles the Moon reveals a wide negative polarization branch whose inversion angle is 22° and whose average amplitude is 1%. We present results of polarimetric mappings of the Moon in $P_{\min}$ at a phase angle near 11°. The observations in the red and blue spectral bands were carried out with the Kharkov 50-cm telescope at the Maidanak Observatory (Middle Asia) using a Canon-350D camera and polarizing filter. A thorough calibration of the camera array (flat field and so on) allows for the reliable detection of significant variations of $|P_{\min}|$ over the lunar surface, from 0.2 to 1.6 %. Smallest $|P_{\min}|$ are characteristic of young bright craters; the parameter $|P_{\min}|$ is the highest for the lunar highland and bright mare areas.

1 Introduction

The lunar surface is illuminated by solar radiation that is not polarized. Upon scattering the radiation becomes polarized and the polarization degree P varies with the phase angle α. In particular at small phase angles the wide negative polarization branch with $|P_{\min}| \approx 1$ %, $\alpha_{\min} \approx 11°$, and inversion angle equal 22° is observed [1-3] ($P = \frac{I_\perp - I_\parallel}{I_\perp + I_\parallel}$, where $I_\parallel$ and $I_\perp$ are intensities measured, respectively, at parallel and perpendicular orientations of the analyzer axis with respect to the scattering plane). The negative polarization is observed for different particulate surfaces, an example of which is the lunar regolith.

Telescope polarimetric observations of the Moon are still rare. One of the reasons for this is the lack of motivation due to poor interpretation of previous lunar polarimetry. There are only three large surveys [1,2,4,5] of discrete polarimetric measurements. Results in imaging lunar polarimetry also are meager, though recently it was shown that this method suggests at large phase angles an effective diagnostic tool for determination of compositional heterogeneity of particles of the lunar surface [6]. There has been only one attempt to carry out imaging polarimetry of the Moon at small phase angles where the polarization degree is negative [7]. That investigation [7] has shown noticeable variations of $|P_{\min}|$ over the lunar surface, approximately from 0.2 to 1.8 %. Although the diagnostic meaning still remains unclear, we further develop the approach of [7] using more accurate maps of $|P_{\min}|$ whose initial images have higher spatial resolution.

2 Observations

The observations in the red and blue spectral bands were carried out with the Kharkov 50-cm telescope at the Maidanak Observatory (Middle Asia) using a Canon-350D camera and polarizing filter. The Observatory is characterized with very good astro-climate conditions, many nights of clear sky and very small atmosphere turbulence. The polarimetric measurements were made at a phase angle near 11° that is close to α_{min} for the Moon. The flat fields of the system "camera array + filters + telescope" at two spectral channels (red: λ_{eff} = 0.63 μm and blue: λ_{eff} = 0.48 μm) were measured and then taken into account. A thorough calibration allows the reliable detection of significant variations of $|P_{min}|$ over the lunar surface, which are in quantitative agreement with our previous discrete and mapping measurements [2,4,7]. We present results of our polarimetric measurements of the Moon in P_{min} for several areas of the lunar nearside. Figures 1-4 present images of albedo, $|P_{min}|$ in blue light, and the ratio $|P_{min}|_{red}$ / $|P_{min}|_{blue}$ for 4 areas of the lunar nearside. The higher the parameter $|P_{min}|$, the brighter the details of the $|P_{min}|$ map. All variations of the parameter $|P_{min}|$ correspond to specific morphological features of the lunar surface, which is a strong argument that we are studying a real physical effect and not an artifact. The $|P_{min}|_{red}$ / $|P_{min}|_{blue}$ ratio is higher for mare surface. Bright highland craters do not show up on the $|P_{min}|_{red}$ / $|P_{min}|_{blue}$ images. This probably is related to the fact that the lunar highland is more spectrally neutral, than mare regions.

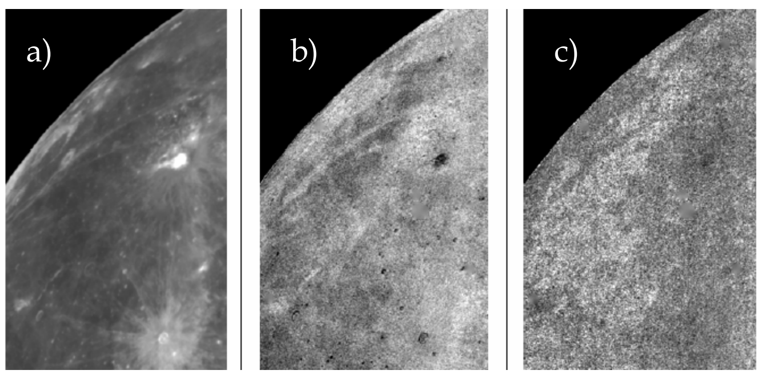

Figure 1: Images of a) albedo, b) $|P_{min}|$ in blue light, and c) ratio $|P_{min}|_{red}$ / $|P_{min}|_{blue}$ for the northwestern portion of the lunar disk. The bright spot on right side of the albedo image is the crater Aristarchus.

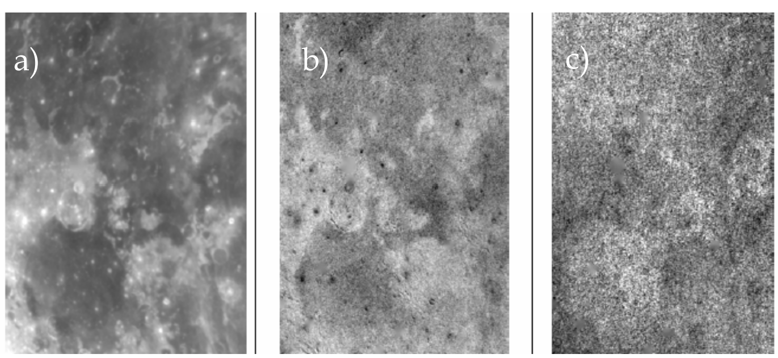

Figure 2: Images of a) albedo, b) $|P_{min}|$ in blue light, and c) the ratio $|P_{min}|_{red}$ / $|P_{min}|_{blue}$ for the southwestern portion of the lunar disk including Mare Humorum.

3 Results and discussion

Comparing the albedo and $|P_{min}|$ images in Fig. 1-4, one can see that for the low albedo domain there is a direct correlation between $|P_{min}|$ and albedo (the brighter the lunar detail, the higher its $|P_{min}|$), while for bright lunar areas (young craters) the correlation is inverted. Unfortunately, the interpretation basis for the $|P_{min}|$ variations is not sufficiently developed to explain these observations. From laboratory experiments we know that the wide negative polarization branch values of $|P_{\min}|$ is a function of particulate surface albedo and particle size [3,8,9]. The brighter the particulate surface, the higher, the incoherent multiple scattering, hence, the lower $|P_{\min}|$ should be. On the other hand, the smaller the particle size, the deeper the negative polarization branch, i.e. higher $|P_{\min}|$. Thus the inverse correlation between albedo and $|P_{\min}|$ can be attributed to the multiple scattering reducing $|P_{\min}|$ as well as the fact that young (bright) craters are composed of particles coarser than those of the mature regoliths. It is more difficult to interpret the direct correlation at the low albedo domain. This correlation exists regardless of the effect of multiple scattering. An explanation of the direct correlation can be related to the scattering properties of single particles. Using the DDA method we calculated the polarization phase curves (Fig. 4, left panel) for aggregated particles (Fig. 4, right panel) averaged over orientation at different values of the imaginary part (Im(m)) of the refractive index m. As can be seen $|P_{\min}|$ increases with decreasing absorption Im(m). Many different series of such calculations show the same. We suppose that this effect could be responsible for the direct correlation between albedo and $|P_{\min}|$ in the low-albedo domain, when multiple scattering is small.

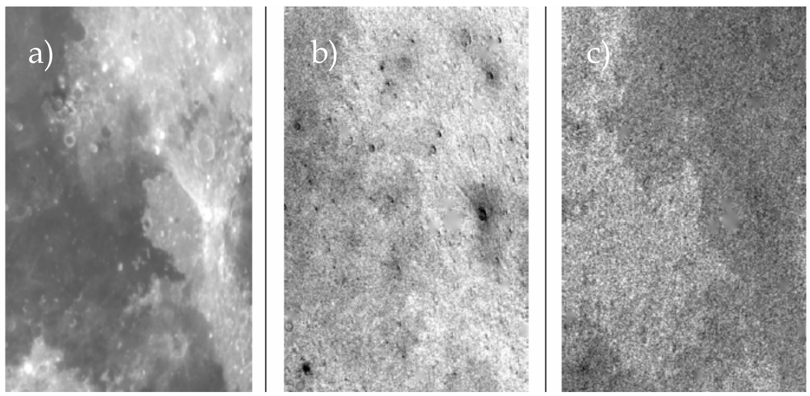

Figure 3: Images of a) albedo, b) $|P_{\min}|$ in blue light, and c) the ratio $|P_{\min}|_{red}$ / $|P_{\min}|_{blue}$ for the eastern portion of the lunar disk. The bright spot on the right side of the albedo image is the crater Proclus.

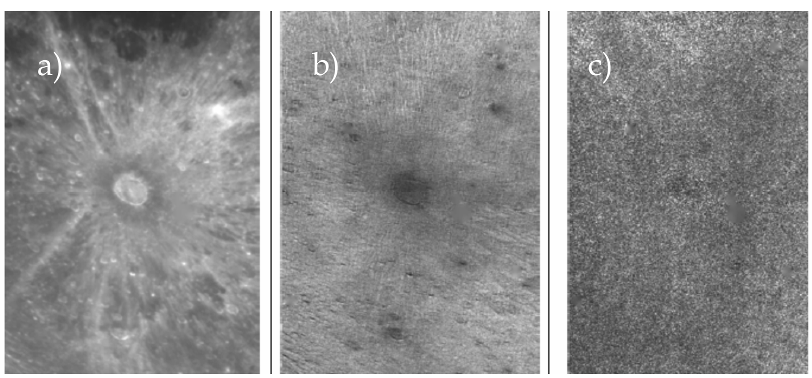

Figure 4: Images of a) albedo, b) $|P_{\min}|$ in blue light, and c) the ratio $|P_{\min}|_{red}$ / $|P_{\min}|_{blue}$ for the southern portion of the lunar disk. In the center of the albedo image one can see the crater Tycho.

The northwestern portion of the lunar nearside that includes the craters Aristarchus and Kepler is shown in Fig. 1. The crater Aristarchus reveals a low polarization degree, as small as 0.6 % in blue light. Unexpectedly the Reiner gamma formation (left lower corner) shows up as a unit with relatively high $|P_{\min}|$. Figure 2 presents albedo and polarimetric images for the southwestern portion of the lunar disk including Mare Humorum (left lower portion of the frame). Two low $|P_{\min}|$ areas can be seen in the frame, near the upper edge and again a bit to right and below the center. These areas are not peculiar in albedo. For the image in Fig. 2 the border between highlands and maria is clearly seen in the $|P_{\min}|$ image. The eastern portion of the lunar disk is presented in Fig. 3. The crater Proclus and its ray system conspicuously show up on this scene, $|P_{\min}|_{blue} \approx 0.4$. No trace of the crater and rays may be found on the image $|P_{min}|_{red}$ / $|P_{min}|_{blue}$. The same is observed for the crater Tycho (Fig. 4). We note that in many cases nearby young craters with the same albedo reveal very different values of $|P_{min}|$.

4 Conclusion

We have presented the first results of our polarimetric measurements of the Moon at a phase angle near 11°. The observations in the red and blue spectral bands were carried out with the Kharkov 50-cm telescope at the Maidanak Observatory using a Canon-350D camera and polarizing filter that provides reliable detection of significant variations of $|P_{min}|$ over the lunar surface, from 0.2 to 1.6 %. The smallest $|P_{min}|$ are characteristic of young bright craters; the parameter $|P_{min}|$ is highest for highland and bright mare areas. In many cases bright young craters with the similar albedo reveal very different values of $|P_{min}|$.

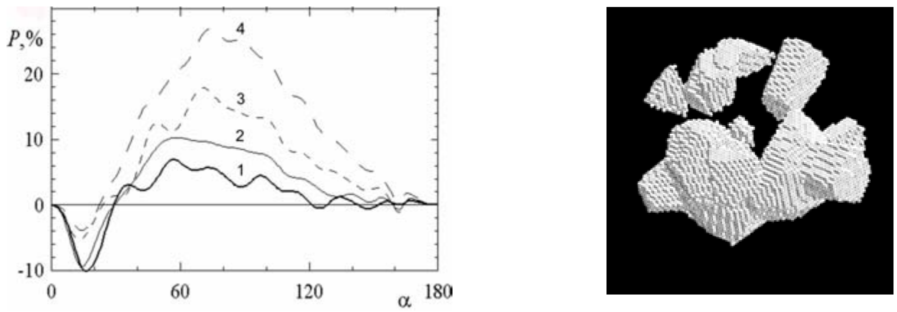

Figure 5: Polarization phase curves (left panel) calculated for aggregate particles (right panel) at Re(m) = 1.5, $X = 2\pi r/\lambda = 10$, where r is the radius of circumscribed sphere and λ is the wavelength. Curves 1-4 correspond to Im(m) = 0, 0.02, 0.05, and 0.1, respectively.

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