POLARIMETRIC BEHAVIOUR OF VARIOUS LUNAR IMPACT CRATERS DERIVED FROM CHANDRAYAAN-2 DUAL-FREQUENCY SAR FULL-POL L-BAND ACQUISITIONS.

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Introduction: The L&S-band Dual-Frequency Synthetic Aperture Radar (DFSAR) onboard Chandrayaan-2 orbiter, is the first fully polarimetric (FP) SAR system in lunar orbit [1]. L-band FP data has been shown to be effective to differentiate lunar impact craters based on their degradation stage [2]-[4]. Hence, DFSAR observations can contribute significantly towards understanding the origin and evolution of lunar impact craters. Fresh, partially and fully degraded craters can be easily differentiated using radar parameters [2], but understanding difference in polar and non-polar anomalous craters is crucial from water ice context (where anomalous refers to different CPR behaviour internal and external to a crater). Here, we exhibit results obtained from DFSAR L-band FP observations towards understanding radar scattering properties of different impact craters, with special emphasis on polar and non-polar anomalous craters.

Study Area and Data Used: L-band FP SAR observations obtained at ~26° incidence angle over various lunar impact craters situated in north pole (Peary crater), south pole (Haworth and Cabeus crater) and mid-latitude (Byrgius C and Gardner crater) are analysed. These impact craters are categorized into fresh (3 Nos.), polar anomalous (7 Nos.), non-polar anomalous (5 Nos.) and degraded craters (4 Nos.).

Methods: A methodology based on full-polarimetry descriptors was evolved to analyze DFSAR data, as described below:

i. Covariance Matrix: The complex co-polarized (HH and VV) and cross-polarized (HV and VH) backscattering elements are used to generate covariance matrix (C3) [5]. The derived C3 elements are multilooked (ML factor ~38) to generate squared pixels with reduced speckle noise. The multilooked C3 elements are georeferenced and orthorectified using LOLA DEM [6] to obtain image resolution of 25 m.

ii. Circular Polarization Ratio (CPR): The orthorectified C3 matrix is converted to C2 matrix corresponding to hybrid-pol scattering elements [7] in left circular transmission and linear reception mode. The resultant complex LH and LV backscattering elements are used to compute Stokes parameters and CPR [8].

iii. Single-bounce Eigenvalue Relative Difference (SERD): Allain et al. [9] derived eigenvalue-based single-bounce eigenvalue relative difference (SERD) to characterize natural media. This parameter is derived from the coherency matrix [T3] under reflection symmetry condition. SERD is surface roughness indicator [10], where low SERD denote rough surface, whereas high SERD corresponds to smooth surface.

iv. Ratio: The Ratio of the elements of coherency matrix [(T22+T33)/T11] is independent on the surface roughness and depends only on the dielectric constant of the surface and the incidence angle [11]. Thus, the ratio is used to assess variation in dielectric properties in different lunar craters. Previous results suggest that with increase in the dielectric constant, the ratio value increases [11].

Figure 1: Scatter plots showing average CPR (top), SERD (middle) and Ratio (bottom) values of interior and exterior part of various group of lunar impact craters. Error bar corresponds to one standard deviation of the mean values.
Results and Discussion: We investigate the CPR, SERD and Ratio value of the interior and exterior part of the lunar impact craters to characterize their physical properties. Fresh and degraded craters show equivalent CPR, SERD and Ratio values in interior and exterior part (Figure 1), indicating similar roughness and dielectric composition. However, the magnitude of these polarimetric parameters between fresh and degraded craters significantly varies. Fresh craters hold rocky ejecta in interior and exterior part leading to enhanced roughness. In contrary, interior and exterior of degraded craters consist of weathered and fragmented ejecta and regolith leading to smooth surface. Besides, fresh rocky surface holds higher dielectric values compared to weathered and disintegrated rocks or soil of similar composition due to change in density and particle size. Non-polar anomalous craters have distinct variation in polarimetric behaviour in interior and exterior. The interior parts are characterized by low SERD and high CPR and Ratio values compared to exterior part. Hence, the crater interiors consist of higher roughness and dielectric materials compared to their exteriors. Possibly the presence of fresh rock boulders in the interior part are responsible for relatively higher dielectric and roughness compared to regolith dominated exteriors. The polarimetric trend of non-polar anomalous craters is parallel to 1:1 line in the scatter plots (Figure 1). The interior parts of the non-polar anomalous craters hold same polarimetric values of the interiors of fresh crater, indicating that they retained the roughness conditions formed during the crater formation process.

Polar anomalous craters also exhibit distinct difference in polarimetric properties in interior and exterior part. However, the polarimetric values have no clear trend with the 1:1 line. The CPR, SERD and Ratio values in the interior of the polar anomalous craters are similar to degraded craters. However, there are elevated CPR, SERD and Ratio values in the interior part, but not equivalent to the non-polar anomalous craters. We propose two hypotheses to interpret these observations:

1st Hypothesis: Differential weathering in the crater interior and exterior parts can result in exponential changes in polarimetric behaviour allied with crater degradation. After crater formation, the fresh ejecta in the exterior part would have experienced enhanced space weathering and fragmentation compared to interior part, leading to decline in roughness and dielectric constant. Whereas, interior part of the crater retains similar physical behaviour as fresh crater due to sluggish degradation rate. This stage can be exemplified using non-polar anomalous craters. Further, the weathering in the exterior part reaches the matured stage, where, the rock particle reaches minimum grain size to form lunar regolith equivalent to degraded crater. However, due to slow degradation rate, interior part contains rock blocks and ejecta. Polar anomalous craters possibly belong to this stage, where interior part is having higher polarimetric values, but not similar to non-polar anomalous craters. Besides, due to freezing temperature, thermal cracking on the interior walls of the craters trigger additional degradation. Hence, the degradation rate in polar anomalous craters can be faster compared to non-polar anomalous craters.

2nd Hypothesis: The polar anomalous craters are similar to degraded crater holding water ice inclusions, which in turn leading to enhancement in the CPR, SERD and Ratio parameters. Figure 2 reveals, equivalent radar intensity enhancement in fresh and degraded craters and in close range to unity, due to similar physical behaviour in the interior and exterior regions. However, the intensity enhancement ranges from twice to five times for non-polar anomalous craters, because of significantly different physical behaviour in interior and exterior parts. Interestingly, for polar anomalous craters the intensity enhancement is also in close vicinity to unity. Possibly polar anomalous craters belong to degraded crater group. However, their interiors are characterized by some exceptional behaviour due to some additional factor leading to enhancement in the CPR, SERD and Ratio values. We suggest that this additional factor is probably water ice, which is triggering enhancement in the polarimetric behaviour of the polar anomalous craters. However, due to less abundance and small particle size of water ice the intensity enhancement is not significant.

Figure 2: Differential polarimetric behaviour of various group of lunar impact craters due to variability in the physical properties. Intensity enhancement denotes the ratio of total scattered radar intensity (Span: HH+HV+VH+VV) in interior and exterior parts. The colour groups for different set of craters are same as shown in Figure 1.