INVESTIGATING THE EFFECT OF CRATER EVOLUTION PROCESS ON THE RADAR SCATTERING BEHAVIOUR OF THE LUNAR CRATERS USING CHANDRAYAAN-2 DUAL-FREQUENCY SAR DATA. Tathagata Chakraborty*, Deepak Putrevu, Sriram S. Bhiravarasu, Anup Das, Dharmendra Kr. Pandey, V.M. Ramanujam, Raghav Mehra and Pragya Arora, Space Applications Centre, Indian Space Research Organization, Ahmedabad, India *(tathagata@sac.isro.gov.in)

Introduction: The earlier flown radar instruments on lunar orbit have paved the path to characterize physical behaviour of the lunar surface targets especially impact craters using radar polarimetry. However, as these radars were configured for hybrid or compact polarimetry (CP) operations the studies were limited majorly to radar echo strength and Circular Polarization Ratio (CPR) based characterization **[1-8]**. However, to comprehensively characterize the lunar geological features, enhanced set of measurements as provided by a fully-polarimetric (FP) radar is required. Dual-Frequency Synthetic Aperture Radar (DFSAR) onboard Chandrayaan-2 orbiter is the first SAR with full-polarimetric capability in a lunar orbit, and therefore, meets the above expectations of measurements **[9-10]**. Hence, DFSAR observations can contribute significantly towards understanding the origin and evolution of lunar impact craters.

Methods: In this study DFSAR L-band fully-polarimetric observations obtained at ~26º incidence angle over 25 impact craters (fresh:5 nos., polar anomalous: 13 nos., non-polar anomalous: 3 nos. and degraded craters: 4 nos.) have been analysed towards understanding their radar scattering properties. In conjunction with the conventional CPR, we explore the unique full-polarimetric child parameters such as Single-bounce Eigen value Relative Difference (SERD) and T-ratio (involving diagonal elements of coherency matrix, T3) which are sensitive to surface roughness and dielectric constant, respectively **[11]**. The results present distinct physical behaviour of various categories of the impact craters.

Radar Polarimetric behaviour of craters: We observe that fresh and degraded craters exhibit similar CPR, SERD and T-ratio values in interior and exterior parts (Fig. 1, red and green data points), indicating similar roughness and dielectric composition in both the parts. However, the magnitude of these polarimetric parameters between fresh and degraded craters varies significantly. Fresh craters hold rocky ejecta in both interior and exterior regions leading to enhanced roughness, in contrast to weathered fine grained regolith of degraded craters. Besides, fresh rocky surface results in higher T-ratio (dielectric constant) values compared to weathered and disintegrated rocks or soil of degraded crater due to change in density and particle size. Non-polar anomalous craters have distinct variation in polarimetric behaviour in interior and exterior. The interior of these craters are characterized by low SERD along with high CPR and T-ratio values compared to their exteriors (Fig. 1, yellow data points). Possibly the presence of fresh rock boulders in the interiors are responsible for relatively higher dielectric and roughness compared to regolith dominated exteriors. The interior parts of the non-polar anomalous craters hold strong similarity with the 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 their interior and exterior parts. The CPR, SERD and T-ratio values in the exterior of the both polar and non-polar anomalous craters are similar to degraded craters. Interestingly, equivalence in polarimetric values is observed in the interiors of the polar anomalous craters and exteriors of the fresh craters. These polarimetric observations overall indicate that polar anomalous craters hold centimetre-decimetre scale surface roughness.

Relationship of Polarimetric behaviour with craters degradation: Our results, based on the overall polarimetric behaviour of different category of craters, imply crater degradation process as a major controlling factor for the observed polarimetric signatures of the craters. Therefore, to further establish the fact, we have investigated relationship between the obtained polarimetric parameters (CPR, SERD and T-ratio) with the depth-to-diameter ratio (as a proxy to the crater degradation) of the craters. On the Moon, fresh young craters have prominent crater boundary (rim) and high depth-to-diameter ratio. Due to crater degradation in the form of mass wasting from the steep wall slope or interior wall collapse, the large pieces of ejecta get fragmented to small particles and accumulate in the floor of the crater. Therefore, with accumulation of thick fine grained regolith material on the floor, the depth of the crater gradually decreases. Hence, crater degradation leads to reduction in the depth-to-diameter ratio of the crater.

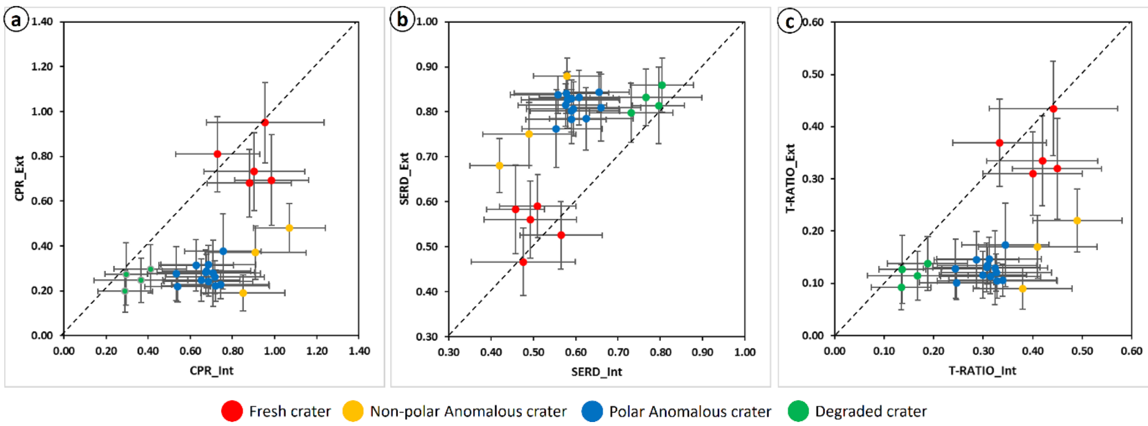

Figure 1: Scatter plots showing (a) average CPR, (b) SERD and (c) T-ratio values of interior and exterior parts of various groups of lunar impact craters. Error bar corresponds to one standard deviation of the mean values.

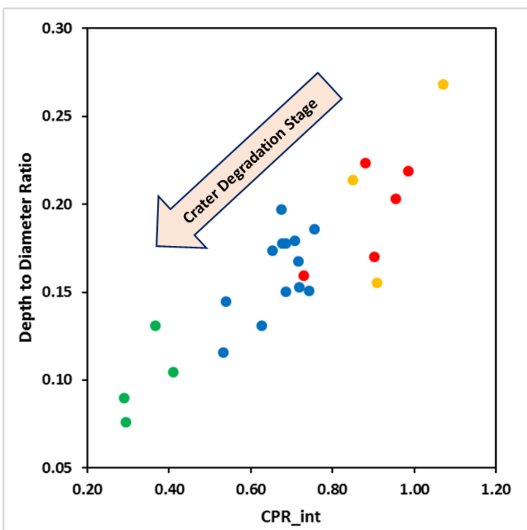

Figure 2: Scatter plots showing average CPR values of interior of various groups of lunar impact craters with reference to Depth to Diameter ratios of the craters.

Figure 2 showcases the relationship of the depth-to-diameter ratio with the overall CPR values obtained from interior part of different categories of craters. The CPR values are showing a good linear correlation with the depth-to-diameter ratio of the craters. The CPR values reduce from fresh to degraded craters as a function of depth-to-diameter ratio. Thus, the crater degradation is leading to the reduction in the surface roughness and dielectric constant of the craters, and thereby, leading to CPR reduction. Further, the co-occurrence of fresh and non-polar anomalous craters in the plot, indicate that interior of the non-polar anomalous craters suffered minimal crater degradation, leading to retention of the physical properties from the crater formation stage.

However, still we cannot confirm the absence of water ice in the polar anomalous craters. In the present study, we mainly focused on overall polarimetric behaviour of the different category of craters. It is obvious that the dominant physical behaviour of the scatterers controls the overall polarimetric signature of the entire crater in study. Hence, crater degradation process overall controls the polarimetric behaviour of the impact craters.

References: [1] Carter et al., J. Geophys. Res., doi:10.1029/2009JE003406 (2009); [2] Spudis et al., J. Geophys. Res., Planets, https://doi.org /10.1002/jgre.20156 (2013); [3] Neish et al., J. Geophys. Res., https://doi.org/10.1029/2010JE-003647 (2011); [4] Campbell, J. Geophys. Res., doi:10.1029/2012JE004061 (2012); [5] Saran et al., PSS, 71, pp. 18-30 (2012); [6] Fa and Cai, J. Geophys. Res., doi:10.1002/jgre.20110 (2013); [7] Cahill et al., Icarus, https://doi.org/10.1016/ j.icarus.2014.07.018 (2014); [8] Fa and Eke, J. Geophys. Res., Planets, https://doi.org/10.1029/ 2018JE005668 (2018); [9] Putrevu et al., 2016, Adv. Space Res., 57, 627-646; [10] Putrevu et al., 2020, Current Science, 118, 226; [11] Putrevu et al., 2022, 53rd LPSC, Abstract#1916.