INVESTIGATION OF THE CAPABILITY OF H-α DECOMPOSITION OF COMPACT POLARIMETRIC SAR DATA WITH APPLICATION TO LUNAR SURFACE. Sriram Saran, Anup Das, Dharmendra Pandey, Space Applications Centre (ISRO), Ahmedabad 380015, India (saran@sac.isro.gov.in)

Introduction: Compact polarimetry (CP) is a technique that indicates the possibility of reducing complexity, cost, mass, and data rate of a SAR system and encompasses those options that fall between dual-polarized and quad-pol SARs [1-3]. The Mini-SAR and Mini-RF instruments (jointly called as the Mini-RF radars) flown on the Chandrayaan-1 and Lunar Reconnaisance Orbiter (LRO) respectively are a class of radars with an innovative hybrid dual polarimetric architecture [3, 4], a form of compact polarimetry [2]. These radars offer the same suite of polarimetric information from lunar orbit as Earth-based radar astronomy [4, 5], since both types of radars measure the 2x2 covariance matrix of the backscattered field. In this paper we investigate the capabilities of CP data obtained from the Mini-SAR to distinguish different physical scattering mechanisms through *H-α* (Entropy-Alpha) decomposition [6]**.** The entropy maps of polar regions of the Moon are then compared with the most often used Stokes child parameter circular polarization ratio (*CPR*) which is defined as the ratio of the same sense (SC) relative to the opposite sense (OC) polarized returns.

Scientific Context: In traditional radar astronomy, the four Stokes parameters lead to child products which are used individually, of which CPR and the degree of linear polarization are widely used to understand geophysical properties of the surface [5, 7, 8]. Apart from the Stokes child paremeters, polarimetric analysis of the data received from the Mini-RF radars involves signal decomposition, in which two or more suitably selected parameters are used jointly to classify fundamental characteristics of the observed field [8]. This method leads to unambiguous differentiation of single bounce, double bounce, or randomly-polarized backscatter.

In most analyses of CP data, the decomposition methods are based on relating the obtained Stokes parameters to the properties of the propagating wave as well as the scattering coefficients of the medium. Three of such well-known techniques are the m-delta [3], m-*chi* [8] and m-alpha [9] where m, delta (δ), *chi* and alpha referes to the degree of polarization, relative phase between received H and V, ellipticity of the scattered wave and the scattering mechanism parameter (0<alpha<90°) respectively. Theses methods permit a rigorous quantification of surface/subsurface scattering properties [e.g. 9, 10].

The *H-α* decomposition proposed by Cloude and Pottier [6] is one of the most common decomposition theorems used to identify the physical scattering mechanisms and their properties. It is based on the analysis of eigenvalue and eigenvector of the coherency matrix *T* and has several properties such as rotation invariance, irrelevance to specific probability density distributions, and covering the whole scattering mechanism space. In this study, *H-α* decomposition [6] is applied to the Hybrid-pol Mini-SAR data and the results are compared with the CPR, which is one of the most useful indicators of surface roughness.

Method: Conventional approach of deriving Cloude-Pottier entropy and *α*-angle parameters from CP data is based on the construction of pseudo quad-pol data from them [e.g. 1, 2]. Such methods employ radar scattering models that assume reflection symmetry and a relationship between the linear coherence and the cross-polarization ratio to construct a full reflection symmetric polarization matrix from the 2×2 covariance data. In our analysis, *H-α* decomposition is performed with the original data without any transformation to pseudo quad-pol space since expanding the basic 2x2 matrix of the observed field into a 3x3 matrix cannot elucidate further information. Further, if a 3x3 matrix is compressed by some argument into a 2x2, there is no way that information about the scattering can survive, beyond that is carried by the observed backscattered field.

The polarimetric scattering entropy (H) and *α*-angle are calculated using the expressions given in [6]. Also, there exists a is a nonlinear relationship between H and the degree of polarization P given by [11] as

$$H=-\frac{1}{2}\left\{(1+P)\log_2\left[\frac{1}{2}(1+P)\right]+(1-P)\log_2\left[\frac{1}{2}(1-P)\right]\right\}$$

The Mini-SAR has collected S-band SAR images for over 90% of both lunar poles [12]. The datasets corresponding to both the poles are phase-corrected [4, 13] and later mosaiced using ISIS software. A 2×2 scattering matrix is generated using the 4 Stokes parameters and then imported into the PolSARpro (v 5.03) environment for generating Entropy and *α*-angle mosaics (from C2 matrix).

Analysis and Discussion: Figure 1 shows the entropy (H) maps (60 m/pixel) for both polar regions of the Moon. The H values are almost well correlated with the corresponding CPR values except near few regions.

Crater	Mid Location	Interior		Exterior	
		H	CPR	H	CPR
Whipple	89.13°N, 120.01°E	**0.51± 0.3**	**0.67± 0.19**	**0.06± 0.17**	**0.3± 0.13**
Peary	Mutiple (Secondaries)	**0.57± 0.34**	**0.74± 0.27**	**0.12± 0.23**	**0.34± 0.16**
Main L	81.7°N, 23.2°E	**0.69± 0.24**	**0.8± 0.28**	**0.58± 0.3**	**0.69± 0.27**
Sylvester	82.65°N, 81.21°W	**0.14± 0.24**	**0.34± 0.13**	**0.11± 0.21**	**0.33± 0.13**
Rozhdestvensky N	84°N, 156.5°W	**0.73± 0.23**	**0.82± 0.31**	**0.5± 0.27**	**0.58± 0.27**
Plaskett	81.63°N, 176.71°E	**0.12± 0.24**	**0.32± 0.16**	**0.19± 0.28**	**0.41± 0.18**
Gioja	83.34°N, 1.76°E	**0.06± 0.15**	**0.3± 0.1**	**0.07± 0.17**	**0.29± 0.11**
Byrd	85.42°N, 10.07°E	**0.04± 0.13**	**0.25± 0.1**	**0.11± 0.21**	**0.32± 0.13**
Amund-sen	84.44°S, 83.06°E	**0.13± 0.25**	**0.35± 0.17**	**0.12± 0.23**	**0.14± 0.2**
Wiechert J	85.20°S, 177.63°W	**0.12± 0.23**	**0.32± 0.15**	**0.06± 0.16**	**0.3± 0.11**
Haworth	87.45°S, 5.16°W	**0.2± 0.28**	**0.4± 0.17**	**0.08± 0.19**	**0.3± 0.15**
Unnamed	Multiple	**0.47± 0.32**	**0.65± 0.24**	**0.18± 0.26**	**0.45± 0.2**

Table 1 Mean Entropy (H) vs Mean CPR for some prominent polar craters. Standard deviation (σ) is indicated after the mean value.

Table 1 gives the mean values of Entropy and CPR values for some of the prominent craters in the lunar poles, analyzed in this study. The craters in blue denote the anomalous craters that are found in permanently shadowed regions as reported in previous observations [e.g. 13, 14]. H values show a positive correlation with CPRs near such regions. Near the radar facing rim of impact craters where the CPR values are very low, H values tend to almost zero and we can extract the dominant scattering mechanism in such regions. Very high H values in the range of 0.85 are observed in distal ejecta regions of some young craters near both the poles where CPR values are relatively low (~0.7).

There are many possible explanations for such a breakdown in the correlation between H and CPR values, with physical basis being the foremost. High H values indicate that the target is depolarizing and we can no longer consider it as having a single equivalent scattering matrix [6]. Although many such features have high entropy as observed from Figure 1, there exist several distinct areas of degraded craters and regolith which have low entropy. This implies the possibility of reliable classification and parameter extraction from the polarimetric response of such targets. Since the total CPR is not a simple addition of the component CPRs, but is rather the ratio of the entire depolarized radar echo to the polarized radar echo, changes in corresponding CPR values are observed.

In case of the α-angle parameter, it is observed that dihedral scattering and surface scattering (polarized part of the received field) yield the same result, i.e α = ~45° so that each scattering mechanism cannot be distinguished.

Conclusion: The capability of CP SAR data to discriminate among different scattering mechanisms via H-α decomposition has been investigated and applied it to Mini-SAR data of lunar polar region. The entropy parameter indicates that it is an apparent proxy for scattering entropy, as used in the full polarimetric H/α decomposition. However, we need to try and relate this entropy to scattering physics in the medium, and not just viewing it as a wave property. Also, H may be used for unsupervised classification of CP SAR data obtained from the Mini-RF radars, as a first stage process before attempting inversion of the data, based on physical models. Also, using the α-angle parameter generated in this study the physical scattering mechanisms of targets cannot be discriminated.

References:. [1] Souyris, J. C. et al. (2005) *IEEE Trans. Geosci. Remote Sens., 43 (3)*, 634-646. [2] Nord, M. E. et al. (2009) *IEEE Trans. Geosci. Remote Sens., 47*, 174-188. [3] Raney, R. K. (2007) *IEEE Trans. Geosci. Remote Sens., 45 (11)*, 3397-3404. [4] Raney, R. K. et al. (2011) *Proc. IEEE 99 (5)*, 808-823. [5] Carter, L. M. et al. (2004) *JGR 109*, E06009. [6] Cloude, S. R. and Pottier, E. (1997) *IEEE Trans. Geosci. Remote Sens., 35 (1)*, 68-78. [7] Carter, L. M. et al. (2006) *JGR,111*, E006005. [8] Raney, R. K. et al. (2012) *JGR, 117*, E00H21. [9] Cloude, S. R. (2012) *IEEE Remote Sens. Lett.*, 9(1), 28-32. [10] Lawrence, S. J. et al. (2013) *JGR 118*, 1-20. [11] Zhang et al. (2014) *IEEE Geosci. Remote Sens. Lett., 11 (4)*, 868-872. [12] Spudis, P. D. et al. (2010) *LPSC XLI*, Abstract 1224. [13] Mohan, S. et al. (2011) *Current Science* 101 (2), 159-164. [14] Spudis, P. D. et al. (2013) *JGR 118*, 1-14.

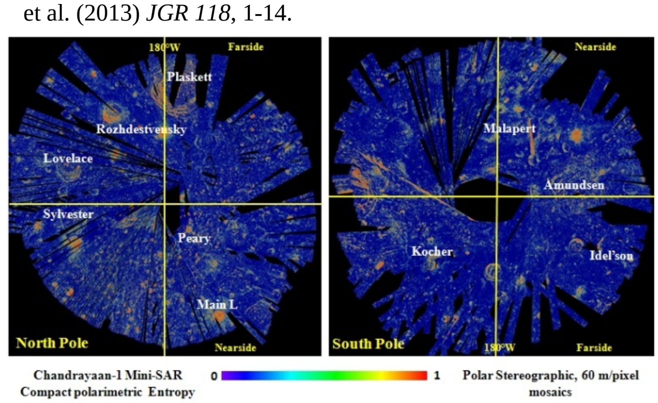

Figure 1 Entropy maps of lunar poles generated from Mini-SAR data