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Characterization of Lunar Crater Ejecta Deposits Using *m−chi* Decompositions of Mini-RF Radar Data

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Abstract

Impact cratering is the dominant weathering process on the surface of the Moon and is largely the determining factor of material distribution on the lunar surface [1]. Radar data provide unique information on both the horizontal and vertical distribution of impact deposits [*2*]. We introduce a new technique for analysis of polarimetric radar astronomical data, *m-chi*, derived from the classical Stokes parameters. Analysis of the crater Byrgius A demonstrates how *m-chi* can more easily differentiate materials within ejecta deposits and their relative thicknesses.

1. Introduction

In traditional optical remote sensing studies, lunar impact crater materials that are considered to be immature or recently disturbed are optically bright relative to their surroundings. Over time this signature can be subdued due to space weathering in the upper microns of the surface, where optical data is sensitive. Radar can image these same deposits at depths scaled to the radar's longer wavelength. This information can be conventionally expressed using derived products such as the circular polarization ratio (CPR), which can be ambiguous when characterizing ejecta blankets. The Mini-RF radar aboard NASA's Lunar Reconnaissance Orbiter (LRO; 2009-) is hybrid dual-polarimetric [3], a form of compact polarimetry [4] and specifically designed to further differentiate contexts such as these.

Mini-RF, together with its precursor, Mini-SAR, on India's lunar Chandrayaan-1 satellite [5] (2008-9), are the first polarimetric synthetic aperture radars (SAR) outside of Earth orbit. These radars offer the same suite of polarimetric information from lunar orbit as Earth-based radar astronomy [6]. These data are represented through the classical Stokes parameters [7].

2. Method

In traditional radar astronomy, the four Stokes parameters (S_1, S_2, S_3, S_4), can be use to derive daughter products [2] that are used individually for surface analysis. CPR and the degree of linear polarization are well known examples [8]. In contrast, the same four Stokes parameters support matrix decomposition techniques that to date are relatively unknown in radar astronomy, although they are well established analysis tools in Earth-observing 3x3 (or 4x4) polarimetric data [9]. We adapt this method to our 2x2 matrix data.

Decomposition depends on identifying two (or more) variables which when used together classify backscattering characteristics of the observed scene. This method leads to unambiguous differentiation of single bounce, double bounce, or randomly-polarized backscatter. The Mini-RF team has adopted the *m−chi* decomposition as an analysis tool. In this formulation the key inputs are the degree of polarization, *m*, and the degree of circularity, χ

$$\sin 2\chi = -\, S_4/mS_1 \qquad (1).$$

The *m−chi* decomposition may be expressed through a color-coded image, where

$$\begin{aligned} R &= [mS_1(1 + \sin 2\chi)/2]^{1/2} \\ G &= [S_1(1 - m)]^{1/2} \\ B &= [mS_1(1 - \sin 2\chi)/2]^{1/2} \end{aligned} \qquad (2)$$

Here, Red corresponds to double-bounce, , Green represents the randomly polarized constituent, and Blue indicates single-bounce (and Bragg) backscattering.

2. Analysis

LROC Wide-Angle Camera (WAC) image data suggest that the 19 km diameter crater Byrgius A has an ejecta blanket that extends up to 300 km beyond its rim (Fig. 1a). Derived CPR data clearly show an increase in surface roughness associated with the continuous and discontinuous portions of the Byrgius A ejecta (Fig. 1b). An *m-chi* decomposition of the crater and its surroundings reveals the higher degree of double bounce backscatter and volumetric scattering associated with its ejecta (Fig. 1c). However, beyond the continuous portion of the ejecta blanket, we observe portions of surface covered by discontinuous ejecta in visible imagery that shows a predominance of Bragg scattering. This is not expected for ejecta material and is instead more indicative of the surrounding mature lunar regolith. The implication is that Mini-RF is detecting material beneath the ejecta of Byrgius A. This suggests that the thickness of the ejecta, for radial distances > ~10 km, is on the order of a meter or less, since the backscattered wave's penetration can be no more than about ten wavelengths (12.6 cm at S-band). This is in contrast with thickness estimates of ~15 meters for that radial distance, based on scaling relationships [10].

6. Conclusions

The Mini-RF instrument on LRO is among the first polarimetric imaging radars outside of Earth orbit. Stokes information returned from the instrument can be used to create derived products such as CPR and an *m-chi* decomposition. The latter is a new technique, for radar astronomy. Using CPR data and the *m-chi* decomposition parameter as a tool to examine lunar craters we demonstrate the ability to differentiate materials within ejecta deposits and their relative thicknesses.

References

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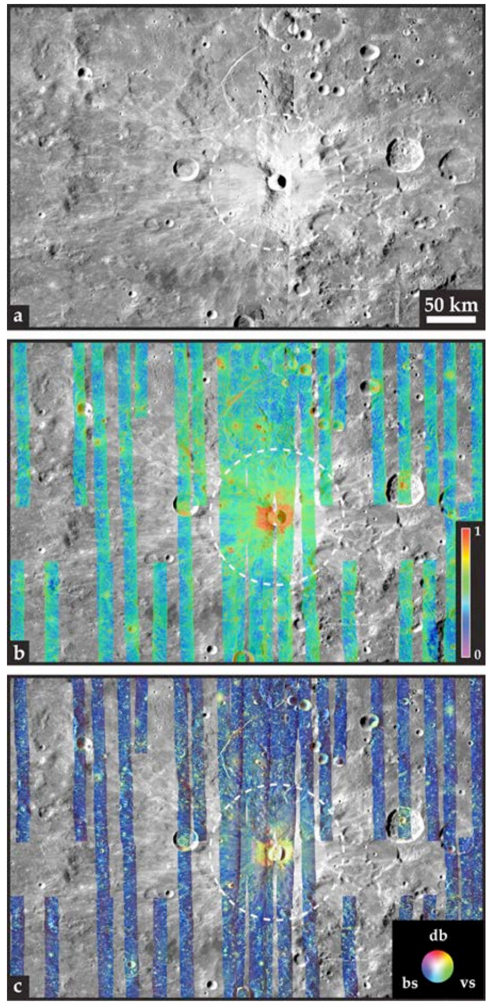

Figure 1. The crater Byrgius A is 19 km in diameter and located at 24.5°S, 63.7°W; (a) 100 m/pixel simple cylindrical LROC WAC image [11] of the crater; (b) CPR information overlain on LROC WAC (bottom left); (c) *m-chi* decomposition overlain on LROC WAC. The color wheel highlights the colors for each *m-chi* scattering regime (red: double bounce, *db*; blue: single bounce, *bs*; green: volume scattering, *vs*) and combinations of these regimes that may appear visually.