MINI-RF AND THE CURIOUS CASE OF CABEUS CRATER.

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Introduction: The Mini-RF instrument aboard NASA's Lunar Reconnaissance Orbiter (LRO) is currently acquiring bistatic radar data of the lunar surface in an effort to understand the scattering properties of lunar terrains as a function of bistatic (phase) angle. Previous work, at optical wavelengths, has demonstrated that the material properties of lunar regolith can be sensitive to variations in phase angle [1-3]. This sensitivity gives rise to the lunar opposition effect and likely involves contributions from shadow hiding at low phase angles and coherent backscatter near zero phase [1]. Mini-RF bistatic data of lunar materials indicate that such behavior can also be observed for lunar materials at the wavelength scale of an S-band radar (12.6 cm). Among the terrains observed thus far, we have found the response of materials associated with the floor of the crater Cabeus to be particularly interesting.

Bistatic Operations: Radar observations of planetary surfaces provide important information on the structure (i.e., roughness) and dielectric properties of surface and buried materials [4-7]. These data can be acquired using a monostatic architecture, where a single antenna serves as the signal transmitter and receiver, or they can be acquired using a bistatic architecture, where a signal is transmitted from one location and received at another. The former provides information on the scattering properties of a target surface at zero phase. The latter provides the same information but over a variety of phase angles. NASA's Mini-RF instrument on the Lunar Reconnaissance Orbiter and the Arecibo Observatory in Puerto Rico are currently operating in a bistatic architecture (the Arecibo Observatory serves as the transmitter and Mini-RF serves as the receiver). This architecture maintains the hybrid dual-polarimetric nature of the Mini-RF instrument [8] and, therefore, allows for the calculation of the Stokes parameters (S_1, S_2, S_3, S_4) that characterize the backscattered signal (and the products derived from those parameters).

Observations: A common product derived from the Stokes parameters is the Circular Polarization Ratio (CPR),

$$\mu_C = \frac{(S_1 - S_4)}{(S_1 + S_4)} \qquad (1).$$

CPR information is commonly used in analyses of planetary radar data [4-7], and is a representation of surface roughness at the wavelength scale of the radar (i.e., surfaces that are smoother at the wavelength scale will have lower CPR values and surfaces that are rougher will have higher CPR values). High CPR values can also serve as an indicator of the presence of water ice [9].

As part of the Mini-RF bistatic observation campaign, CPR information for a variety lunar terrains is being collected. The crater Kepler, and the mare deposits that surround it, offer an example of what this information can tell us about the phase angle reponse of lunar materials at the transmitted wavelength of the radar (12.6 cm). Data for this particular region has been acquired on multiple occasions (i.e, Oct. 2, 2012 and Mar. 14, 2013) and cover a phase angle range of 0° to 22°. Isolating the response of Kepler's ejecta blanket from the surrounding mare deposits (Fig. 1), it is clear that the mare deposits have an nearly uniform CPR for phase angles < ~17° while materials associated with the ejecta blanket show a steady and significant increase in CPR for phase angles < ~5°. The difference in the response of these two terrains is likely related to the size and distribution of scatterers present in the material. In other words, the size and distribution of radar scatterers in the ejecta blanket are such that an opposition effect involving contributions from shadow hiding and coherent backscatter is observed.

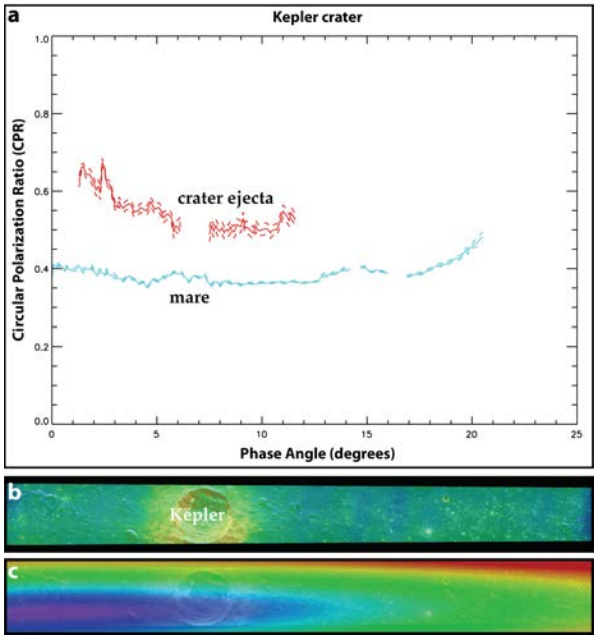

Fig. 1. (a) Plot of CPR vs. phase angle for crater ejecta and mare materials associated with Kepler crater (8.1°N, 38.0°W, dia. 32 km). Mini-RF images of CPR (b) and phase angle (c) – each overlain on S_1 data.

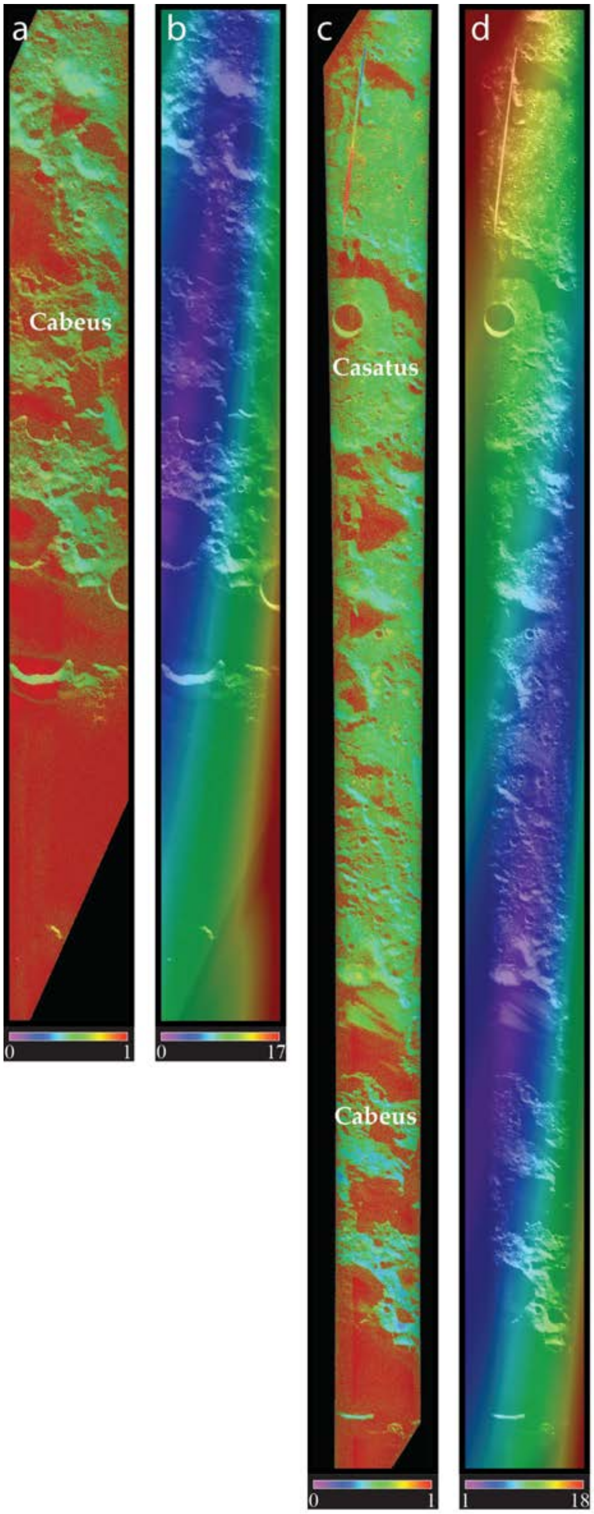

Fig. 2. Mini-RF images of CPR (a) and phase angle (b) for Cabeus (84.9°S, 35.5°W, dia. 98 km) collect acquired on Aug. 7, 2012 – each overlain on S_1 data. Mini-RF images of CPR (c) and Phase angle (d) for Cabeus collect acquired on May 7, 2013 – each overlain on S_1 data.

The south polar crater Cabeus is another example. Data for this particular region has also been acquired on multiple occasions (Fig. 2) and cover a phase angle range of 0° to 18°. When viewed at near zero phase (Fig. 2a,b), the floor of Cabeus crater shows an enhancement in CPR with respect to surrounding materials of ~10%. This is not apparent in data acquired of Cabeus crater when Mini-RF operated in a monostatic mode [10]. Further, when viewed at phase angles of several degrees (Fig. 2c,d), the floor of Cabeus crater shows a suppression of CPR with respect to surrounding materials of ~10%. The reason for the difference in the response of this terrain with respect to surrounding materials is not clear but the grazing incidence (~85°) at which the region is viewed by Mini-RF when operating in a bistatic mode plays a role. Additional data of this region has been acquired (i.e, June 30, 2013 and Dec. 12, 2013) and analysis is ongoing.

Summary: Mini-RF is currently acquiring bistatic radar data of the lunar surface to understand the scattering properties of lunar terrains as a function of phase angle at S-band wavelengths (12.6 cm). Observations of lunar crater ejecta appear consistent with theoretical and experimental work performed at optical wavelengths [1-3]. This information is providing insight into to the relative contributions of coherent backscatter and shadow hiding to the lunar opposition effect – at radar wavelengths. Observations of the south polar crater Cabeus indicate anomalous scattering behavior associated with crater floor materials (behavior not observed with monostatic data). It is probable that the incidence angle at which the data was acquired plays a role in the differences observed between bistatic images and with the monostatic data. It is also possible that the source of these differences may prove to be unique to materials present at the lunar poles.

References: [1] Hapke et al. (1998), *Icarus*, 133, 89-97; [2] Nelson et al. (2000), *Icarus*, 147, 545-558; [3] Piatek et al. (2004), *Icarus*, 171, 531-545. [4] Campbell et al. (2010), *Icarus*, 208, 565-573; [5] Raney et al. (2012), *JGR,* 117, E00H21; [6] Carter et al. (2012), *JGR,* 117, E00H09; [7] Campbell (2012), *JGR*, 117, E06008; [8] Raney, R. K. et al. (2011), *Proc. of the IEEE*, 99, 808-823; [9] Black et al. (2001), *Icarus*, 151, 167-180; [10] Neish et al. (2011), *JGR*, 116, E01005.