MINI-RF/AO BISTATIC OBSERVATIONS OF THE FLOOR OF CABEUS CRATER AND THEIR IMPLICATIONS FOR THE PRESENCE OF WATER ICE. G.W. Patterson[1], A.M. Stickle[1], F.S. Turner[1], J.R. Jensen[1], D.B.J. Bussey[1], P. Spudis[2], R.C. Espiritu[1], R.C. Schulze[1], D.A. Yocky[3], D.E. Wahl[3], M. Zimmerman[1], J.T.S. Cahill[1], M. Nolan[4], L. Carter[5], C.D. Neish[6], R.K. Raney[1], B. J. Thomson[7], R. Kirk[8], T. W. Thompson[9], B.L. Tise[3], I.A. Erteza[3], C.V. Jakowatz[3], [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD (Wes.Patterson@jhuapl.edu), [2]Lunar and Planetary Institute, Houston, TX, [3]Sandia National Laboratory, Albuquerque NM, [4]Lunar and Planetary Laboratory, Tucson AZ, [5]NASA Goddard Space Flight Center, Greenbelt MD, [6]University of Western Ontario, Ontario Canada, [7]Boston University, Boston MA, [8]USGS, Astrogeology Science Center, Flagstaff AZ, [9]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA.

Introduction: The Miniature Radio Frequency (Mini-RF) instrument on NASA's Lunar Reconnaissance Orbiter (LRO) is a hybrid dual-polarized synthetic aperture radar (SAR) that operated in concert with the Arecibo Observatory (AO) to collect bistatic radar data of the lunar nearside from 2012 to 2015. The purpose of the bistatic campaign was to observe the scattering characteristics of the upper meter(s) of the lunar regolith, as a function of the bistatic angle, and to search for a coherent backscatter opposition response indicative of the presence of water ice. A variety of lunar terrains were sampled over a range of incidence and bistatic angles. An opposition response was observed for the floor of the south-polar crater Cabeus and the character of the response appears unique with respect to all other lunar terrains sampled. Analysis of data for this region suggests that the unique nature of the response may indicate the presence of near-surface, wavelength scale (12.6 cm) or larger, deposits of water ice [1].

Background: The Mini-RF instrument operated in concert with the Arecibo Observatory (AO) to collect bistatic radar data of the lunar nearside from 2012 to 2015 [1]. Mini-RF operated as the receiver for bistatic operations and AO operated as the transmitter. This architecture maintained the hybrid dual-polarimetric nature of the Mini-RF instrument [2] and, therefore, allowed 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). The goal of the Mini-RF bistatic campaign was to observe the scattering characteristics of the upper meter(s) of the surface and search for a coherent backscatter opposition response indicative of the presence of water ice. Experimental work at optical wavelengths has demonstrated that water ice and lunar regolith can produce an opposition response [3-6]. For the experiment involving simulated water ice [3], a relatively narrow optical opposition response was observed for circular polarization ratio (CPR) data at phase angles ≤ ~1°. (Phase angle at optical wavelengths is termed the bistatic angle at radar wavelengths). A broader opposition response, involving phase angles ≤ ~5°, was observed for CPR data of dry lunar regolith [4].

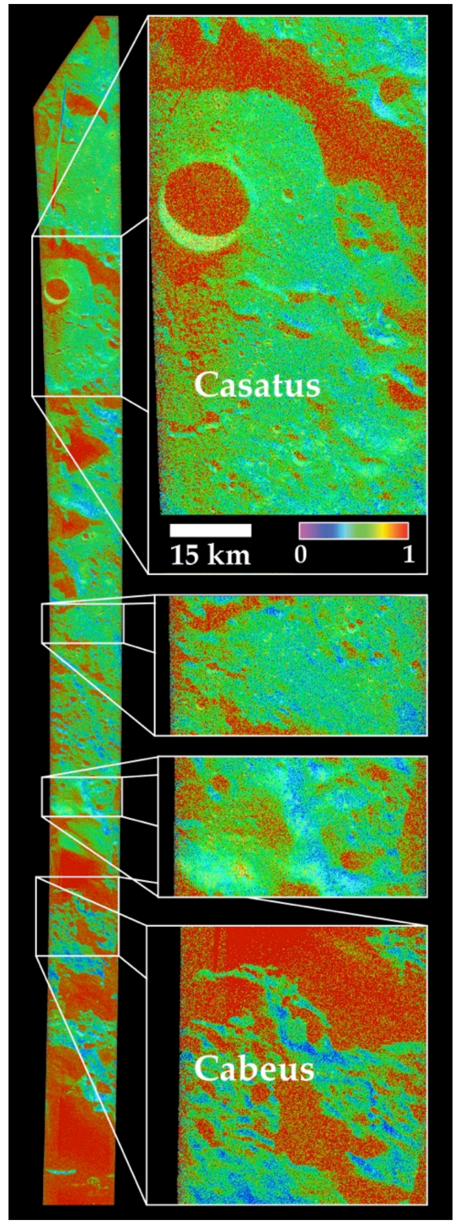

Fig. 1. CPR data for bistatic observation 2013-127. Insets show examples of regions sampled for analysis: (top) the floor of the 111 km diameter crater Casatus; (top middle) highland inter-crater plains material; (bottom middle) radar-facing slopes; and (bottom) the floor of Cabeus crater (98 km in diameter).

Analysis: The data necessary to detect and characterize the opposition response of various lunar terrains were drawn from the S_1 (equivalent to total power), CPR, and bistatic angle information of a given bistatic observation (Fig. 1). The spatial resolution of the data varied from one observation to another,as a function of the viewing geometry, but averaged ~100 m. Regions within an observation that were representative of a specific lunar terrain were sampled and the CPR response of the regions were plotted against the range of bistatic angles observed (Fig. 2). Each terrain was sampled multiple times within an observation and often in multiple observations of the same terrain. The sampled data were then combined for analysis. CPR values were binned in 0.1° bistatic angle intervals and the mean value for each bin was determined. The number of CPR measurements per bin averaged 1000. Bins with < 100 CPR measurements were excluded from consideration.

Results: The floor of Cabeus was observed on 5 occasions over the course of the Mini-RF bistatic campaign [1]. The observations covered bistatic angles of 0.5° to 8.6° for incidence angles ranging from 82.4° to 86.6°. The mean CPR peaks at ~0.7 for bistatic angles of 0.5° to 1.3° and then drops to 0.39 at a bistatic angle of 2.2° (Fig. 2). The CPR remains at an average of ~0.4 through to 3.5° and then climbs steadily to an average of ~0.47 for bistatic angles > 6.5°. This response is characteristic of an opposition effect and is markedly different from the response of surrounding materials. Comparison of the response with experimental and theoretical analyses of the opposition response of particulate materials at optical wavelengths [5-10] suggests that the bistatic observations of the floor of Cabeus crater are consistent with the presence of wavelength scale (12.6 cm) or larger deposits of water ice. However, the measured CPR of the floor of Cabeus for bistatic angles < 0.5°, gathered by Mini-RF monostatic [11] and ground-based [e.g., 12] observations, are not consistent with CPR measurements at similar bistatic angles for other known icy materials [e.g,, 13-15]. To address this discrepancy and further characterize the bistatic scattering characteristics of the lunar poles, Mini-RF is currently proposing a second bistatic campaign to image additional polar targets at 12.6 cm (S-band) wavelengths and to begin acquiring bistatic observations at 4.2 cm (X/C-band) wavelengths.

References: [1] Patterson et al., *Icarus*, submitted; [2] Raney et al. (2011) *Proc. IEEE*, 99, 1-6; [3] Hapke and Blewett (1991) *Nature*, 352, 46-47; [4] Hapke et al. (1998) *Icarus*, 133, 89-97; [5] Nelson et al. (2000) *Icarus*, 147, 545-558; [6] Piatek et al. (2004) *Icarus*, 171, 531-545; [7] Hapke (1986) *Icarus*, 67, 264-280; [8] Hapke (2002) *Icarus*, 157, 523-534; [9] Mishchenko et al. (2007) Optics Express, 15(6), 2822-2836; [10] Mishchenko (2008) *Rev. Geophys.*, 46, 2007RG000230; [11] Neish et al. (2011) *JGR*, 116, E01005; [12] Campbell et al. (2006) *Icarus* 180, 1–7; [13] Ostro et al. (1992) *JGR*, 97, 18,227-18,244; [14] Harmon et al. (1994) *Nature*, 369, 213-215; [15] Black et al. (2001) *Icarus,* 151, 167-180.

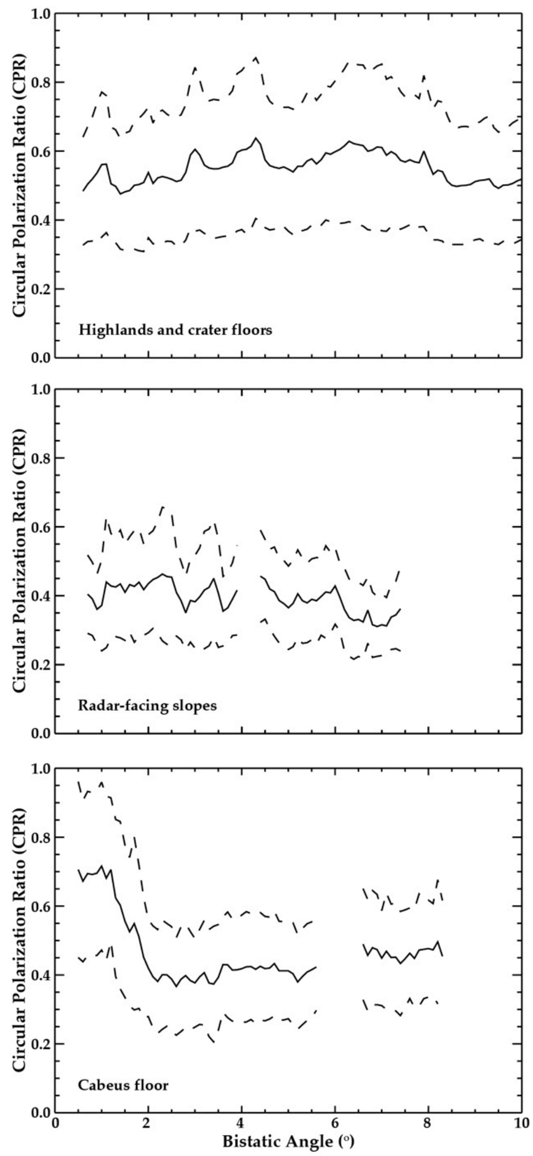

Fig. 2. Plots of mean CPR (solid lines) versus bistatic angle for (top) highland materials observed at incidence angles ranging from 64° to 81.5°, (middle) radar-facing slopes observed at incidence angles ranging from 76.5° to 82°, and (bottom) Cabeus floor materials sampled in 5 bistatic observations targeting Cabeus at incidence angles ranging from 82.4° to 86.6°. Uncertainty is represented by the standard deviation of the measurements (dashed lines).