**MINI-RF ON LRO AND ARECIBO OBSERVATORY BISTATIC RADAR OBSERVATIONS OF THE MOON.**
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**Introduction:** NASA's Mini-RF instrument on the Lunar Reconnaissance Orbiter (LRO) and the Arecibo Observatory (AO) in Puerto Rico have been operating in a bistatic architecture (AO serves as the transmitter and Mini-RF serves as the receiver) over approx. a 2.5 year period in an effort to understand the scattering properties of lunar terrains as a function of bistatic (phase) angle. In that time, 28 observations of the surface have been acquired for the lunar nearside and poles (Fig. 1). These observations include mare materials, highland materials, pyroclastic deposits, and a variety of craters (polar and non-polar). The primary motivation for acquiring these data is to characterize the opposition response of lunar materials at S-band wavelengths (12.6 cm). A purpose for doing so is to differentiate the Circular Polarization Ratio (CPR) response of materials that are rough from surfaces that harbor water ice.

**Background:** The transmitter for Mini-RF bistatic observations is the 305 m Arecibo Observatory radio telescope in Puerto Rico. For each observation, the antenna is pointed at a target location on the moon and illuminates a large fraction of the lunar surface around that location with a circularly polarized, S-band (2380 MHz) chirped signal that has a fixed peak power of 200 kw. The data returned provide information on the structure (i.e., roughness) and dielectric properties of surface and buried materials within the penetration depth of the system (up to several meters for Mini-RF) [1-4]. The bistatic architecture allows examination of the scattering properties of a target surface for a variety of bistatic (phase) angles.

Laboratory data and analog experiments, at optical wavelengths, have shown that the scattering properties of lunar materials can be sensitive to variations in bistatic angle [5-7]. This sensitivity manifests as an opposition effect and likely involves contributions from shadow hiding at low angles and coherent backscatter near 0° [5]. Analog experiments and theoretical work have shown that water ice is also sensitive to variations in phase angle, with an opposition effect that it is tied primarily to coherent backscatter [8-10]. Differences in the character of the opposition response of these materials offer an opportunity to differentiate between them, an issue that has been problematic for radar studies of the Moon that use a monostatic architecture [11,12].

**Observations:** CPR information is commonly used in analyses of planetary radar data [1-4], 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 [13]. We use CPR as a function of bistatic angle to explore the opposition response of lunar materials at S-band wavelengths (Fig. 2).

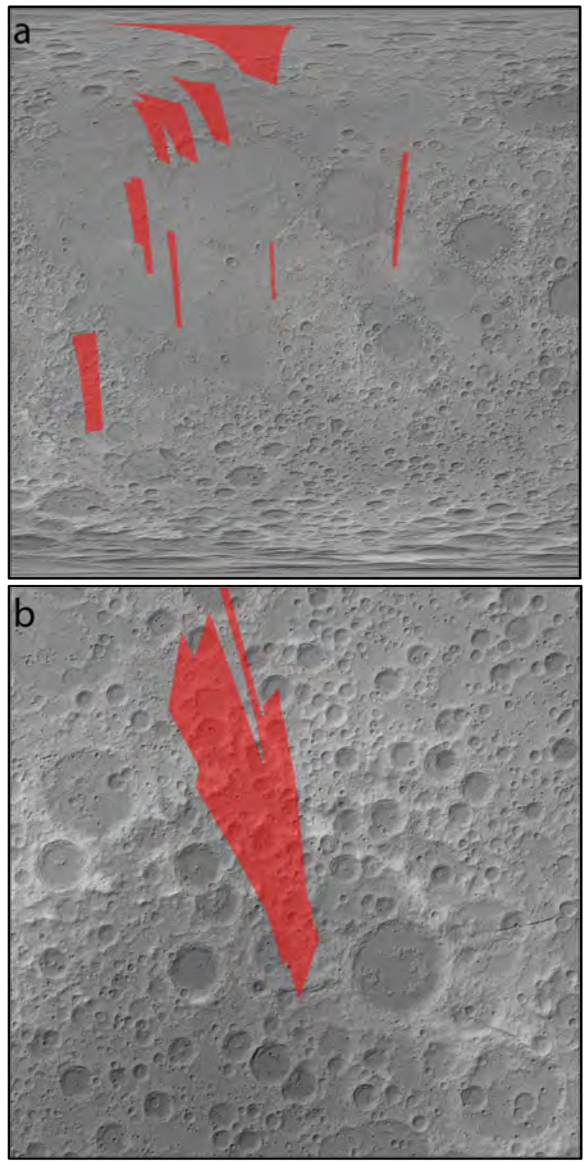


Fig.1. Bistatic radar coverage of the lunar (a) nearside (90°W to 90°E) and (b) south pole (60°S to 90°S).

Data of mare materials, highland materials, pyroclastic deposits, and a variety of craters (polar and non-polar) have been acquired over the course of Mini-RF bistatic operations. Observations of mare materials and pyroclastic deposits show an essentially uniform CPR response for bistatic angles < 10° (Fig. 2a). Apparent variations between deposits are likely related to the incidence angle/latitude at which they were acquired but may also indicate heterogeneity in material properties and/or composition. Observations of crater ejecta show variations in CPR, as a function of bistatic angle, that are not uniform for Kepler and Byrgius A or consistent from crater-to-crater (Fig. 2b). The response of Kepler and Byrgius A is suggestive of an opposition effect. The inconsistency from crater-to-crater may be related to the age of the deposit and/or target material properties. Observations of the floor of Cabeus crater show variations in CPR, as a function of bistatic angle, that are also indicative of an opposition response.

**Results:** Mini-RF has acquired a significant amount of bistatic radar data of the lunar surface in an effort to understand the scattering properties of lunar terrains as a function of phase angle at S-band wavelengths (12.6 cm). This information is providing insight into variability in the scattering properties of a number of primary lunar terrains.

Observations that include mare materials, highland materials, and pyroclastic deposits have not shown an opposition response over for bistatic angles of ~0.1° to 10°. In contrast, observations of the ejecta blankets of young, fresh craters have shown an opposition response but the character of the response varies for each crater. Observations of portions of the floor of the south polar crater Cabeus also show an opposition respone. The character of the radar response from the crater, as a function of bistatic angle, appears unique with respect to all other lunar terrains observed.

**References:** [1] Campbell et al. (2010), *Icarus*, 208, 565-573; [2] Raney et al. (2012), *JGR,* 117, E00H21; [3] Carter et al. (2012), *JGR,* 117, E00H09; [4] Campbell (2012), *JGR*, 117, E06008; [5] Hapke et al. (1998), *Icarus*, 133, 89-97; [6] Nelson et al. (2000), *Icarus*, 147, 545-558; [7] Piatek et al. (2004), *Icarus*, 171, 531-545. [8] Hapke and Blewett (1991), Nature, 352, 46-47; [9] Mishchenko (1992), Astrophysics and Space Science, 194, 327-333; [10] Mishchenko (1992), Earth, Moon, and Planets, 58, 127-144; [11] Spudis P.D. et al. (2010) *GRL* [12] Spudis et al. (2013), *JGR 118*, 1-14; [13] Black et al. (2001), *Icarus*, 151, 167-180.

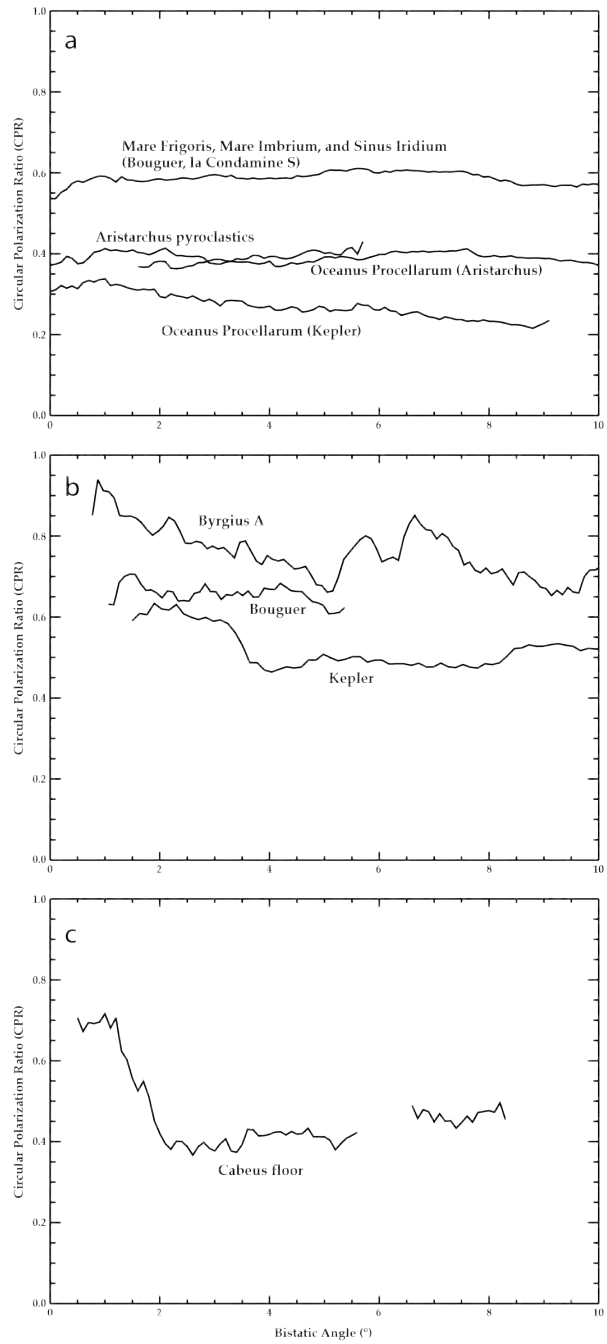


Fig. 2. Plots of CPR vs. bistatic angle for (a) mare materials that range in latitude from ~0° to 60°N, (b) Several prominent craters in the diameter range ~20 to 30 km, and (c) floor materials of the south polar crater Cabeus.