MINI-RF OBSERVATIONS IN SUPPORT OF LCROSS. C.D. Neish[1], D.B.J. Bussey[1], P. Spudis[2], B. Thomson[1], G.W. Patterson[1], L. Carter[3], and the Mini-RF Science Team [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, 20723 (catherine.neish@jhuapl.edu), [2]Lunar and Planetary Institute, Houston, TX, 77058, [3]Smithsonian Institution, Washington, DC, 20560.

Abstract: On October 9, 2009 the LCROSS spacecraft impacted Cabeus crater, located near the south pole of the Moon. Prior to that impact, the Mini-RF instrument on ISRO's Chandrayaan-1 and NASA's Lunar Reconnaissance Orbiter (LRO) obtained S-Band (12.6 cm) SAR images of the impact site at 150 and 30 m resolution, respectively. These observations show that Cabeus has a circular polarization ratio (CPR) comparable to or less than the lunar average. This is not consistent with the presence of thick deposits of water ice within a few meters of the lunar surface.

Background: Equipped with its own active source, a synthetic aperture radar (SAR) is one of few instruments that can "see in the dark". This allows it to view areas of permanent shadow near the poles of the Moon, which may harbour volatiles such as water ice [1]. Thick deposits of water ice have a unique radar signature that would be observable with such an instrument. Normally, radar is backscattered off an interface, causing a change in the polarization of the beam. This leads to a return with more of an "opposite sense" (OC) polarization than a "same-sense" (SC) polarization. However, in weakly absorbing media (such as water ice) the radar beam can be deflected 180° by a series of forward scattering events off small imperfections in the material, each of which preserves the polarization properties of the signal [2]. Those portions of the wavefront that are scattered along the same path in opposite directions can also combine coherently to produce an increased intensity in the radar return [3]. These two effects lead to large returns in the same sense (SC) radar return and values for the circular polarization ratio (CPR = SC/OC) which can exceed unity. This effect has been observed on the Galilean satellites [4], Mars' polar ice caps [5], and the polar regions of Mercury [6].

In November 2008, the Indian Space Research Organization (ISRO) launched the Chandrayaan-1 spacecraft carrying a Mini-SAR instrument [7]. This instrument (dubbed "Forerunner") was capable of obtaining SAR images at 150 m resolution in the S-Band (12.6 cm). Before the spacecraft's untimely demise in August 2009, Forerunner acquired nearly complete (>90% coverage) mosaics of both polar regions of the Moon [8]. In June 2009, NASA launched the Lunar Reconnaissance Orbiter (LRO) carrying the Mini-RF technology demonstration. This instrument has the ability to obtain SAR images in the S- and the C-Band (4.2 cm), at resolutions of 150 (baseline) and 30 m (zoom) at both wavelengths.

Observations: A calibrated mosaic of the south pole was obtained at 150 m resolution by Forerunner during its first imaging season (February-April 2009). Uncalibrated mosaics of the LCROSS target sites were obtained at 30 m resolution during LRO's commissioning phase between June-September 2009. Both mosaics show Cabeus crater to have an average or lower than average CPR (Figures 1, 2). In the Chandrayaan-1 mosaic, Cabeus had a mean CPR = 0.24 ± 0.12, compared to the mean for the entire south polar mosaic, CPR = 0.31 ± 0.17. Only 0.06% of the pixels in Cabeus had CPR > 1. A single S-Zoom observation was also obtained of the impact site post-impact, though no obvious changes were detected (Figure 3). An interferometric SAR (InSAR) observation was acquired by LRO prior to impact, but a second and third pass will be required to derive topography of the impact site. The InSAR data has a spatial resolution of ~ 1 x 15 m.

Discussion: Early reports from the LCROSS team indicate a discovery of water in Cabeus [9]. The Mini-RF observations provide constraints on the form of that water. For example, is the water in the form of a thick deposit of ice, small grains of ice mixed into the regolith, or a layer of water adsorbed onto mineral grains?

If we assume the LCROSS impactor made a final crater ~20 m in diameter [9], then the transient crater diameter was D_t = 0.84D = 17 m, and the excavation depth was H_{exc} ~ 1/10 D_t ~ 2 m [10]. Mini-RF can penetrate several meters into the lunar regolith, so it too has sampled materials at depth. The penetration depth of the radar signal is dependent on the illuminating wavelength, λ, the loss tangent of the regolith, tan δ, and the real dielectric constant of the regolith, ε' [11]. To first order, the penetration depth d is:

$$d = \frac{\lambda}{2\pi\sqrt{\varepsilon'}\tan\delta}$$

The loss tangent of highlands material range from 0.01 to 0.001, and the regolith has a dielectric constant of ~3 [12]. This gives a penetration depth of ~1-10 m for S-Band radar. Given that we see no CPR enhancements with Mini-RF at the LCROSS impact site, if the regolith in Cabeus has material properties similar to the lunar highlands, there can be no thick deposits of water ice in this region. The water discovered by

LCROSS would therefore be in the form of small pieces of ice mixed into the regolith, or water adsorbed onto minerals. Such a form of water would not exhibit large CPR values, though it could be responsible for the decrease in epithermal neutron counts observed by Lunar Prospector, which probed to depths of ~1 m [13]. It is also possible that there are thick deposits of ice buried deeper than the radar penetration depth. Such deposits could have been shocked by the impact, and water vapour expelled through pore spaces in the regolith.

The full story of water ice at the lunar poles will only be revealed by multiple observations by a diverse suite of instruments. Mini-RF on Chandrayaan-1 and LRO has provided, and will continue to provide, an important chapter of that story.

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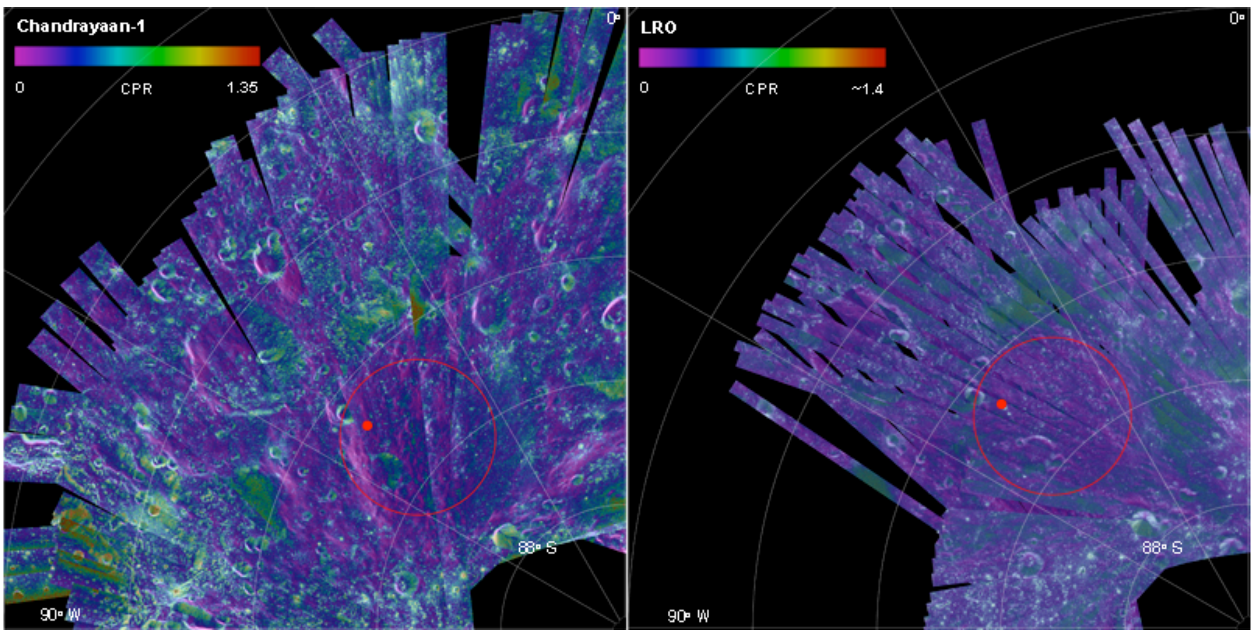

Figure 1: Circular polarization ratio (CPR) overlaid on same sense (SC) S-Band radar mosaics of Cabeus crater taken by the Mini-RF instrument on Chandrayaan-1 (left) and LRO (right). The red circle indicates the location of Cabeus crater, and the red disk represents the approximate location of the LCROSS impact. Note the relatively low values of CPR in the region of the impact.

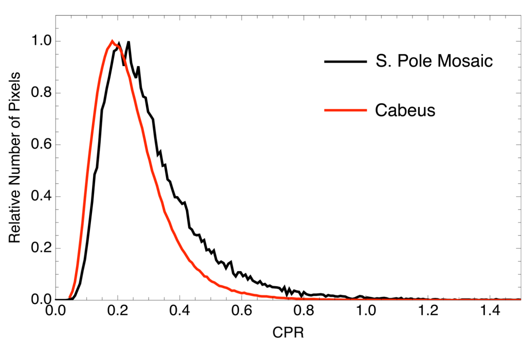

Figure 2: CPR values for Cabeus crater compared to the entire Chandrayaan-1 south polar mosaic. The mean CPR for Cabeus, 0.24 ± 0.12, is lower than that of the south polar mosaic, 0.31 ± 0.17.

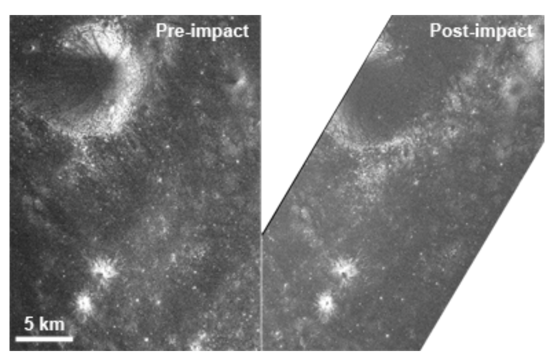

Figure 3: S-band SC images of the LCROSS impact site taken prior to impact (look direction from left) and after impact (look direction from right). No obvious changes were detected at 30 m resolution.