THE MINI-RF RADAR: POLARIZATION PERFORMANCE AND COMPARISON WITH PRIOR RADAR DATA.

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Introduction: The Mini-RF radar, launched on the Lunar Reconnaissance Orbiter (LRO), imaged 66% of the lunar surface and 99% of the lunar poles (upwards of 70°). The radar is hybrid-polarimetric, transmitting one circular polarizations and receiving linear H and V polarizations which are then converted into Stokes polarization parameter images [1]. The transmitter ceased to function in Dec. 2010 and the radar receiver is currently being used along with a transmitter at Arecibo Observatory for bistatic observations of near-side targets [2].

Calibration: Mini-RF had both pre-launch calibration tests and subsequent transmit and receive tests using ground-based telescopes [1,3]. The processing of the monostatic primary mission data set used SPECAN ScanSAR algorithm software (as was used for Magellan) produced by the company VEXCEL, a Microsoft subsidiary. The processing of data from the current bistatic operation of Mini-RF uses software developed by Sandia National Labs. In the VEXCEL processor, the azimuth beam calibration is incorporated as part of the processing to avoid artifacts. The elevation beam pattern and channel calibrations are incorporated after the complex H and V images have exited the VEXCEL software. These calibration values [1,3] are currently included in the data released to the Planetary Data System; however, there are still some remaining inconsistencies with the polarimetry products which the Mini-RF team is currently documenting for publication. Two of these are described below.

Range-direction gradient: There is an observable gradient in the range (horizontal) direction of some Mini-RF data that is clearly an artifact not removed with current calibration parameters. This gradient is most prominently observed in Circular Polarization Ratio (CPR) products (Fig. 1) and varies from image to image, with CPR magnitude variations of up to ~0.2-0.3. While the magnitude of CPR at a given location on a surface can vary significantly, as a function of incidence angle, the Mini-RF team determined early on that this effect does not contribute significantly to the gradient observed in the data. More specifically, given the 50 km orbit of LRO and the ~15 km strip width of Mini-RF images, the change in incidence angle across an image is ~6° (slightly variable depending on the exact on incidence angle and orbit). Prior lunar data sets (e.g. [4,5]) demonstrate this would not be enough to generate the observed effect. Subsequent work has

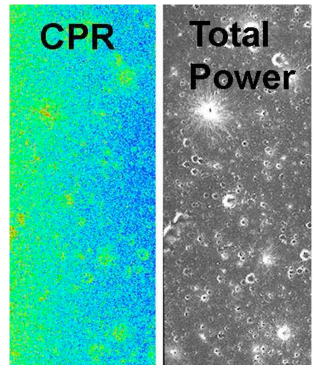

Fig. 1: An example of a CPR gradient across Mini-RF image LSZ_02067_ 2S1_EKU_09N033_V1. The width of each strip is ~12 km. The CPR values are a rainbow scale stretched between 0 (blue) and 1.0 (red).

revealed that, at least in some cases, the sampling of the radar range gates did not capture the center of the radar beam on the surface of the Moon. Outside the 3 dB main beam, there is lower signal-to-noise, which causes the CPR values to increase.

We are currently investigating the cause of this discrepancy and so far have verified that the choice of range gate applied to a given target region in the Mini-RF planning software (and the topographic data used to inform that choice) was not the source of this issue. When present in Mini-RF data, this artifact is clearly observable and its effect on scientific analysis can be mitigated by avoiding these regions of the radar image. It is possible that radar images affected by this artifact will be reprocessed at a later date to include more range bins than the VEXCEL processor initially output, such that the 3 dB beam information can be properly excerpted from the larger-range image. Doing so would come with a resolution penalty for some parts of the image, however. For the global products (100 m/pixel), the data is averaged sufficiently that the gradient is usually no longer noticeable.

Comparison with ground-based radar data: Lunar radar data have also been acquired using a bistatic combination of the Arecibo radar transmitter and the Green Bank Telescope (GBT) receive system. The Arecibo/GBT data are processed using a range-Doppler algorithm with subsequent focusing and were calibrated using standard radio sources and measurements of the noise in each channel [4]. Data are acquired at 80 m/pixel and polarimetry is produced at

~120 m/pixel to decrease speckle noise. For lunar targets where the viewing geometry is the nearly the same in both Mini-RF and Arecibo/GBT data, the polarimetry should be very similar. However, we have discovered that there is considerable difference in CPR values between the two datasets, especially for the brightest targets (Fig 2). There are multiple possible causes of this discrepancy. We have primarily used the Aristarchus data set as a test case due to the similar viewing geometry and broad range of CPR values in this region.

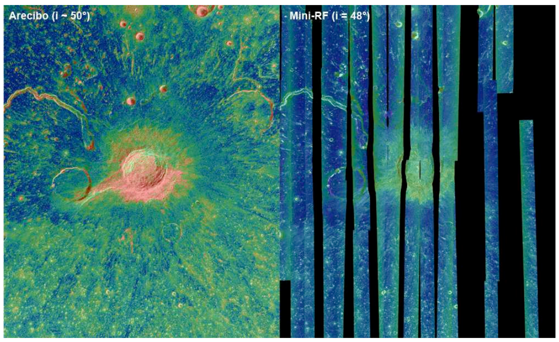

Fig. 2: Differences in CPR are clearly visible between Arecibo (left) and Mini-RF data (right) of Aristarchus crater. In this case, the Arecibo incidence nagle is ~50° and the Mini-RF incidence angle is ~48°. CPR has been stretched from 0 (purple) to 1.2 (red) in both images.

One possible cause of a non-linear CPR difference is cross-talk between the two Mini-RF polarization channels. To test this theory, we altered the raw voltages from the Arecibo/Green Bank data to incorporate different levels of cross-talk, reprocessed the data, and compared to Mini-RF. Fig. 3 shows how the CPR values change as cross-talk is added to the data. In order to reproduce the Mini-RF CPR values, we would need to add an unrealistic amount of cross-talk (-3 dB, i.e. 50%). None of the calibration tests suggest that this could be a possibility for Mini-RF, which had a measured cross talk of about -20 dB [1]. The cross-talk of the GBT receive system and Arecibo radar transmitter are well-characterized and very low (e.g. -30 dB).

Another possible cause for the differing CPR values is a reduction in dynamic range due to sampling. The Arecibo data are sampled at 4 bits, whereas the Mini-RF "zoom" (15x30 m/pixel) data are downconverted to 2 bit data using a optimum threshold block-adaptive quantization algorithm. The lower-resolution "baseline" (150 m/pixel) data were sampled at 8 bits [1]. Histograms of the exact same areas observed in both of these Mini-RF modes show small changes in the peak CPR values that do not match the magnitude of what is observed between Arecibo and Mini-RF. This suggests that the Mini-RF bit-reduction strategy is not the major cause. We have also considered the possibility that the 4-bit sampling at the Green Bank Telescope could be insufficient to measure the noise floor. However, examination of the Doppler power spectrum for these observations shows that the noise floor decreases, levels off, and appears sidelobe-free at the edges of the spectrum where the noise is measured.

There is also a difference in the transmitted polarizations between Mini-RF and Arecibo: Mini-RF has an transmit axial ratio of 2.5 dB [1], which means that the polarization state of the echos will be different than for a pure circular case. However, modeling of this effect has demonstrated that it is again much less than the differences between the Arecibo and Mini-RF CPR values [1].

Currently, our search for an explanation is focusing on the different processors used for each type of data. If the differences are due to processing or applied calibration values in one of the data sets, it will be possible to reprocess the data set and obtain consistent CPRs. If the difference is due to instrument parameters or sampling limitations, it will be very difficult to "correct" either data set to match the other and maintain independent measurements of scattering properties. This is because the problem is non-linear, and because the transmitted power (and usually the viewing geometry) are different between Mini-RF and Arecibo. However, relative values within each data set can still be compared due to a very consistent mosaicking for both Mini-RF and the ground-based data.

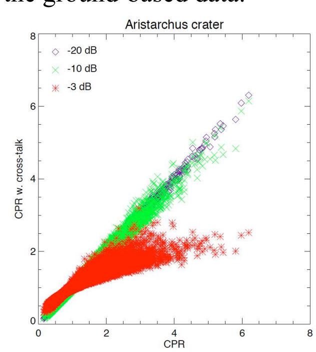

Fig. 3: As the cross-talk between the two radar receive channels increases (red is the most cross-talk), the CPR values level off relative to what they would be with no cross talk (x-axis). Note that small cross-talk does not substantially alter CPR values.

References: [1] Raney, R. K. et al. (2011) *Proc. IEEE, 99,* 808-823. [2] Bussey et al. (2013) 44th LPSC, #2816. [3] McKerracher, P. L. et al. (2010), LPSC , abstract #1533 [4] Campbell, B. A. et al. (2010) *Icarus, 208*, 565-573. [5] Carter, L. M. et al. (2009) *JGR, 114,* E11004, doi:10.1029/2009JE003406.