DETECTION AND CHARACTERIZATION OF PRESENT DAY LUNAR IMPACT CRATERS WITH MINI-RF/GOLDSTONE X-BAND BISTATIC OBSERVATIONS.

J.T.S. Cahill[1], G.W. Patterson[1], F.S. Turner[1], G.A. Morgan[2], A.M. Stickle[1], E.J. Speyerer[3], R. Espiritu[1], B.J. Thomson[4], and the Mini-RF team. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD (Joshua.Cahill@jhuapl.edu), [2]National Air and Space Museum, Smithsonian Institution, Washington, D.C., [3]Arizona State University, Tempe, AZ, [4]University of Tennessee, Knoxville, TN.

Introduction: A multi-look temporal imaging survey by Speyerer et al. [1] using the Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) has detected over 220 new resolvable impacts of at least 10 meters in diameter since NASA's Lunar Reconnaissance Orbiter (LRO) entered orbit around the Moon, at a flux that is substantially higher (33%) than anticipated from previous studies [2]. Speyerer et al. [1] also observed secondary cratering processes that they estimate churn the top two centimeters of regolith more than a hundred times faster than previous models estimated from meteoritic impacts (ten million years). This has significant implications toward an assessment of hazards for any robotic and human exploration on the surface of the Moon. It also has implications for the interpretation of crater-based chronology of the lunar surface.

The Miniature Radio Frequency (Mini-RF) instrument aboard LRO is a hybrid dual-polarized synthetic aperture radar (SAR) that now operates in concert with the Arecibo Observatory (AO) and the Goldstone deep space communications complex 34-meter antenna DSS-13 to collect S- and X-band bistatic radar data of the Moon, respectively. Here we targeted some of the larger (>30 m) craters identified by Speyerer et al. [1] and executed bistatic X-band radar observations both to search for and, if observed, characterize the spatial extent and distribution of cm-scale scatterers in their ejecta relative to visible wavelengths. Data acquired during Mini-RF monostatic operations, when the transmitter was active, show no available coverage of the regions in question before or after two of the new impacts occurred. This makes Mini-RF and Earth-based bistatic observations all the more valuable for examination of these fresh new geologic features.

Method: Collecting bistatic radar data involves AO and/or DSS-13 illuminating the lunar surface at S-band (12.6 cm) or X-band (4.2 cm) wavelength, respectively, with a circularly polarized, chirped signal and tracking the Mini-RF antenna boresight intercept on the surface of the Moon. Transmitted pulses from AO and/or DSS-13 are 100 to 400 µs in length and the Mini-RF receiver operates continuously, separately receiving the horizontal and vertical polarization components of the signal backscattered from the lunar surface. The resolution of the data is ~100 m in range and ~2.5 m in azimuth but can vary from observation to observation, as a function

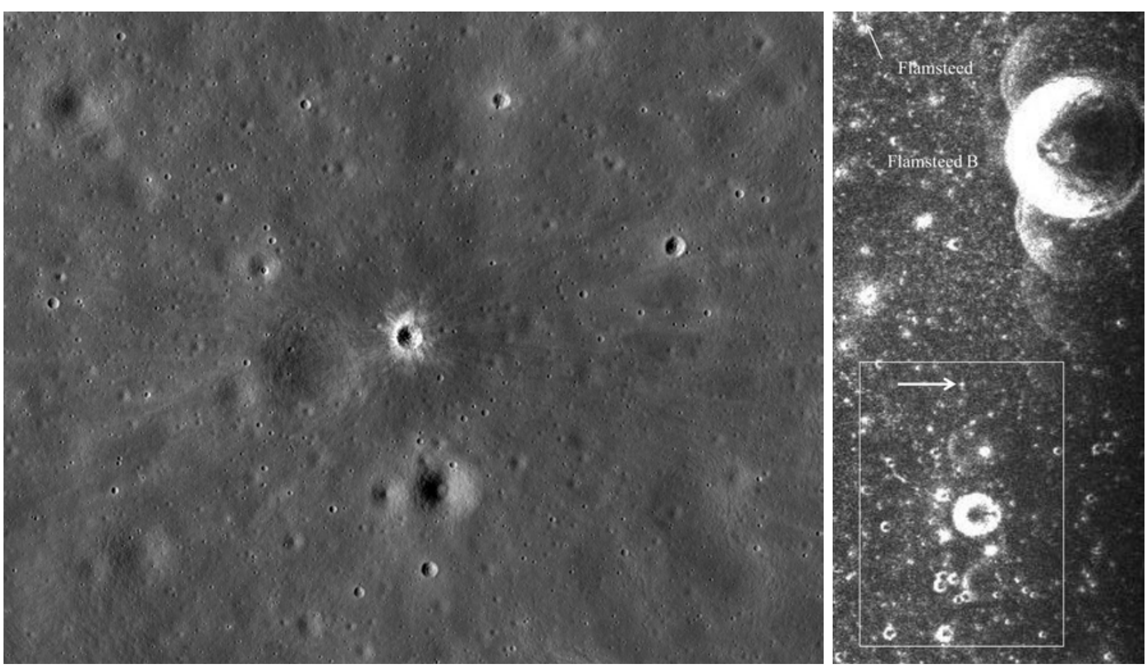

***Figure 1**: (Left) LROC NAC coverage at 0.5 m/pix of a 50 m diameter crater near Flamsteed and Flamsteed B craters. (Right) Mini-RF bistatic S_1 image (100 m/pix); arrow denotes crater detection.*

of the viewing geometry. For analysis, the data are averaged in azimuth to provide a spatial resolution of 100 m. This yields an ~40-look average for each sampled location in an observation and an average $1/N^{1/2}$ uncertainty in the backscattered signal of ±16%. In theory, this should also enable a modest improvement in along track resolution, but processing for that effort has not yet been attempted.

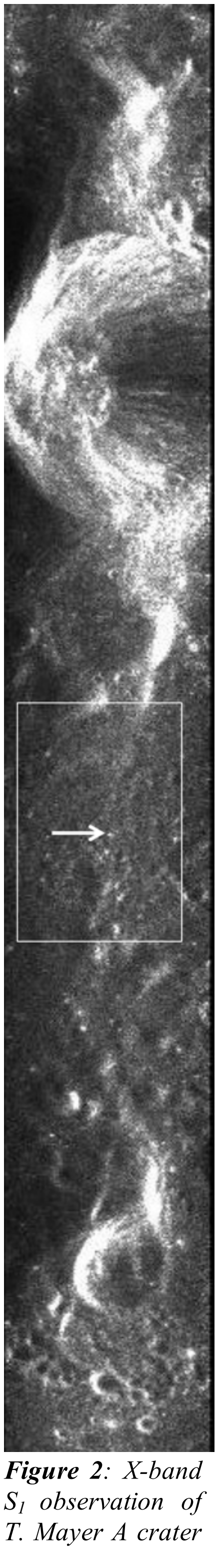

Figure 2: X-band S_1 observation of T. Mayer A crater region. Arrow denotes a new 43 m diameter crater.

In a somewhat analogous fashion to a photometric analysis, we are using Mini-RF's bistatic configuration to make targeted collects of X- and S-band data at a range of phase angles. To date, we have collected one observation of the 50 m crater near the Flamsteed and Flamsteed B (Fig. 1) and two observations of the 43 m crater near T. Mayer A (Fig. 2-3).

To examine crater ejecta properties over this phase space we primarily take advantage of two basic radar parameters, the first Stokes parameter, S_1 (i.e., total backscattered power), and the circular polarization ratio, CPR, which are commonly used in analyses of planetary radar data [3-5]. Each of these parameters offer a measure of surface roughness at the wavelength scale of the radar. Surfaces that are smooth at the wavelength scale will have lower S_1 and CPR values and surfaces that are more rough will have higher S_1 and CPR values. In this way, we intend to measure the extent of new crater ejecta observable in Mini-RF data as compared to NAC visible imagery. Average ejecta profile analyses of each are being constructed to aid in this study.

Observations: While preliminary analyses of Arecibo/Greenbank and Mini-RF/Goldstone bistatic observations are unable to resolve the new crater cavities at these localities, they do confirm lunar surface roughness changes occurred between 2008 and 2017. For example, Earth-based Arecibo/Greenbank observations (100 m/px) do not show the new 43 m crater during the early part of the LRO mission within 2013. However, Mini-RF/Goldstone bistatic observations have discerned them in 2017 (Fig. 2 and 3). It is therefore plausible some combination of Earth-based and Mini-RF orbital collects may contribute toward narrowing the timing of these occurences in the future.

Mini-RF X-band (4.2 cm) observations of these craters indicate the presence of newly emplaced material at radial distances of 100-300 meters from each impact. Detectability at X-band further implys the proximal ejecta of these impacts contain a high proportion of scatterers in the ~0.5 to 50 cm size range.

Summary and On-Going Work: Mini-RF will continue to examine these and other new craters to characterize the physical properties of their ejecta and constrain them temporally.

References: [1] Speyerer et al. (2016) Nature, 538, 215. [2] Neukum et al. (2001) SSR, 96, 55. [3] Campbell et al. (2010) Icarus, 208, 565. [4] Raney et al. (2012) JGR, 117, 1. [5] Campbell (2012) JGR, 117, 10.1029/2012JE004061.

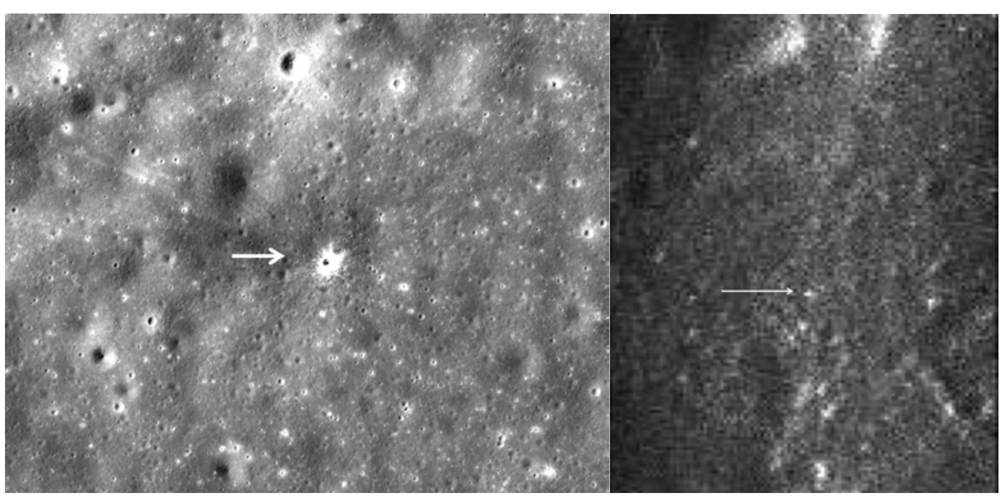

***Figure 3**: (Left) LROC NAC coverage at 0.5 m/pix of a 43 m diameter crater south of crater T. Mayer A. (Right) X-band S_1 detection of 43 m crater ejecta (100 m/px).*