DATING FRESH LUNAR CRATERS WITH MINI-RF. S. W. Bell,[1] B. J. Thomson,[2] M. D. Dyar,[3] and D. B. J. Bussey.[2] [1]Amherst College, Amherst, MA 01002 (swbell11@amherst.edu), [2]Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723, [3]Dept. of Astronomy, Mount Holyoke College, South Hadley, MA 01075.

Introduction: Attempts at dating individual craters on the Moon too small for traditional crater counting analysis have thus far met with only limited success. The Trask (1971) dating system used a qualitative assessment of crater morphology from optical images to place craters into one of six age classes [1]. Swann and Reed (1974) used cosmic ray exposure ages of samples collected from the Apollo missions to calibrate the relative dating system for small Copernican craters [2]. Here we present an improved dating system for small fresh craters using new data from the Mini-RF (Radio Frequency) instrument on NASA's Lunar Reconnaissance Orbiter.

Mini-RF is a lightweight, synthetic aperture radar (SAR) with a primary wavelength in the S band at 12.6 cm and a resolution of 30 m/pixel [3]. One of the principal factors affecting total radar backscatter is the roughness on the scale of the wavelength of the radar, so Mini-RF can detect ejecta even when impact gardening has muted the optical signature of the ejecta.

Our method focuses on the bright halos that encircle craters in radar images. Using Earth-based 3.8 cm radar, Thompson et al. (1981) determined that these halos represent the ejecta lingering around fresh craters, ejecta that have yet to be erased by micrometeorite, solar wind, and cosmic ray bombardment [4]. Applying established crater counting techniques, they derived a lifetime of 40(+16/-12) Ma for halos around craters of 4 km in diameter [4]. However, the 2 km resolution of the radar dataset used limited their ability to fully assess the radar properties of these craters, especially for smaller craters and those with fainter halos [4]. Taking advantage of new high-resolution radar coverage from Mini-RF, we have created a methodology for dating individual craters based on the extent of their gradually degrading radar-bright halos.

Methods: Craters were observed using the S1 data product, which gives a map of total radar backscatter (S1 is the sum of the horizontal and vertical polarization channels). To give as complete a picture as possible, all craters with definitive halos were identified, though some analyses (see below) were restricted to craters larger than 500 m in diameter. Overall, 177 craters with diameters ranging from 0.15 km to 3.5 km were observed. The initial survey of radar-bright crater halos included Mini-RF radar swaths from orbits 2250, 2251, 2252, 2253, 2254, 3124, and 3125. This set of images coincides with a portion of the nearside that overlaps the region studied previously with ground-based radar [4], and also included a previously unstudied portion of the farside.

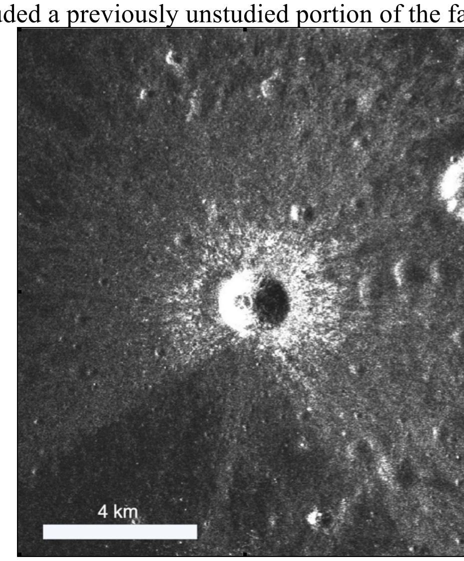

Figure 1: Mini-RF S1 image of a bright halo crater with a clear zone of avoidance. PDS tag: LSZ_01776_2S1_EKU_31S334_V1 (25.77˚S, 26.18˚W)

Results: Fig. 1 gives an example of a radar-bright halo crater. A notable feature of this halo is a wedge-shaped gap in the ejecta, known as a zone of avoidance, that forms when an impact strikes the surface at an angle <20˚ [5].

In the region studied, 177 distinct halo craters were identified, yielding an average crater density of 5.95×10^{-4} craters per km^2. Craters with the highest ratios of ejecta diameter to crater diameter were found to have the brightest radar halos; these craters also exhibited the sharp rims used by Trask (1971) [1] to identify fresh craters (Fig. 1).

Average lifetimes of halos on the lunar surface were estimated following the methods of [6]. Craters were binned by diameter into six logarithmically increasing bins between 0.5 and 4.0 km. For each bin, the frequency of craters in the bin was estimated by calculating the *R* parameter:

$$R = \frac{\overline{D}^3 N}{A\left(D_{\max} - D_{\min}\right)},$$

where $\overline{D}$ represents the geometric mean of the crater diameters in the bin, *N* the number of craters in the bin, *A* the area, and D_{max} and D_{min} the edges of the bin. Plots of the common logs of the *R* values against the common logs of the means of the diameters in the bins were used to compare the data to measured crater distribution of the Apollo 12 site in Oceanus Procellarum, which has been dated to 3.3 Ga (Fig. 2) [7].

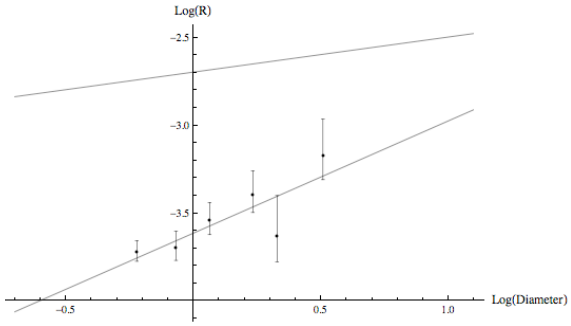

Figure 2: An R plot of crater frequency (log(R)) vs. the log of the mean diameter in km of craters in each bin. The upper line gives the crater distribution for Oceanus Procellarum, log(R)=0.2log(d)-2.7 [6]. The lower line shows the best fit line through our data, log(R)=0.64log(d)-3.6 with an R^2 *of 0.67.*

The ratio of our *R*-value model to the Oceanus Procellarum *R*-value model was multiplied by 3.3 Ga to extract an approximate estimate of the halo lifetimes as a function of crater diameter from these data. The resulting lifetime function, which assumes a constant cratering rate over the past 3.3 Ga, is given in Fig. 3.

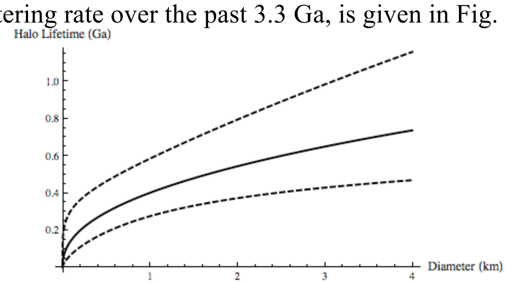

Figure 3: A plot of halo lifetime vs. crater diameter. The dotted lines represent 1σ statistical errors.

From these estimated halo lifetimes, the ages of each halo crater were quantified using ratios of halo diameter (D_h) to crater diameter (D_c), assuming that the craters with the highest ratios are the freshest. For a particular ratio, the fraction of the craters with higher ratios was multiplied by the expected lifetime of the halo. With this analysis, the age of a particular halo crater can be estimated from just two parameters: the crater diameter and the halo diameter. Craters with diameters under 500 m were excluded due to resolution effects, The outer edges of the halo are found to fade much more quickly than the inner regions (Fig. 4).

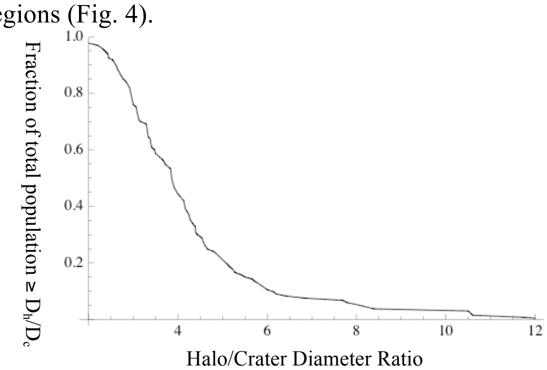

Figure 4: Cumulative distribution of the ratio of halo diameter (D_h) to crater diameter (D_c).

Discussion: Previously estimated lifetimes of X-band (3.8 cm wavelength) halos around craters with a diameter of 4-32 km are 40+16/-12 Ma [4]. Our extrapolated estimated lifetime for S-band halos of these craters was 730+690/-270 Ma. Despite the large error bars, it is clear our estimated lifetimes are longer. This is most likely due to two factors. First, the Mini-RF data have much higher resolution, allowing detection of fainter halos, and second, Thompson et al. (1981) used the X-band, where the halos fade more quickly [4]. They also observed considerably larger halo diameters (up to 15-30 crater diameters), indicating that finer radar-bright ejecta (i.e., ejecta that appears bright at 3.8 cm wavelengths) are originally emplaced further out than bright ejecta detectable with 12.6 cm radar wavelengths.

There are a number of assumptions made in our age analysis that may introduce some uncertainty into our analysis. It is possible that micrometeorite bombardment rates (and hence the erosion rate) may differ with latitude [8], longitude [9], and time [10]. Brightness and the extent of halos may differ depending on obliquity and the sharp decrease in velocity for secondary impacts. An additional problem for age quantification is the slow rate at which a dim halo fades below the detection limit, so the difference between, for example, a 300 Ma and a 500 Ma halo around a 1 km diameter crater may be exceptionally slight. Many of these concerns will be addressed in future work that will expanding our study to larger craters using radially averaged brightness profiles to better quantify halo brightness.

Conclusions: Our results clearly demonstrate the potential of Mini-RF for detailed studies of ejecta morphology of fresh lunar craters. Rocks with 12.6 cm sizes are present in fresh lunar ejecta, originally emplaced out to an average of 11±1 crater radii. The rate of degradation of the radar signature of lunar craters decreases as the ejecta blanket becomes more eroded. The lifetime of the 12.6 cm halos have been characterized, and a preliminary system for dating individual craters has been developed.

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