Mini-RF Bistatic Observations of Copernican Crater Ejecta

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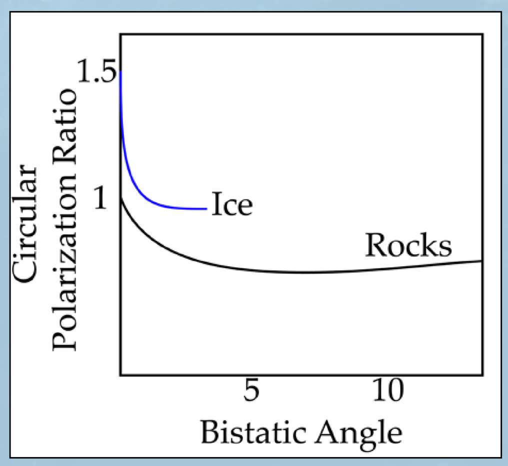
Background

Operations

- Mini-RF is a dual-frequency radar flying onboard the Lunar Reconnaissance Orbiter (LRO) and is currently operating in a bistatic configuration with Arecibo Observatory in Puerto Rico and the DSS-13 antenna at Goldstone acting as transmitters. Mini-RF receives the signal backscattered from the lunar surface.
- DSS-13 is used for the collection of X-band (7147 MHz; 4.2 cm) data
- Arecibo Observatory is used for the collection of S-band (2380 MHz; 12.6 cm) data
- Mini-RF receives orthogonal linear polarizations (H and V).
- The circular polarization ratio, CPR = $(S_1-S_4)/(S_1+S_4)$, is one Mini-RF data product (right) that it is commonly used in analyses of planetary radar data [1,2]. This ratio provides an indication of surface roughness, as determined by the distribution of surface and buried wavelength-scale scatterers (e.g., boulders).

Laboratory Analogues

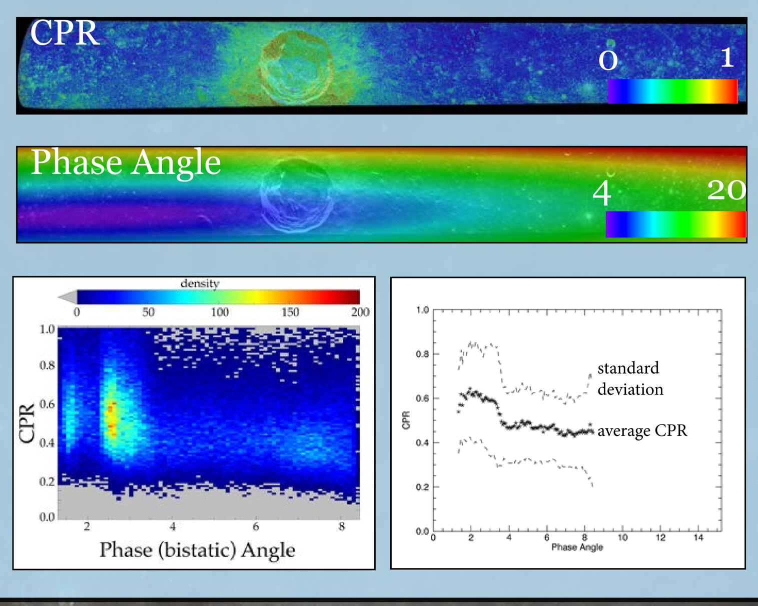


Laboratory analogues suggest both ice and rocky material will exhibit similar, though distinct, Coherent Backscatter Opposition Effects (CBOEs).

It is expected that the ejecta of young craters will exhibit a CBOE in the CPR at low bistatic angle due to the rough and blocky nature of the ejecta. This CBOE is expected to fade as ejecta blankets degrade and mature.

(left) cartoon of expected response, modified from [3,4]

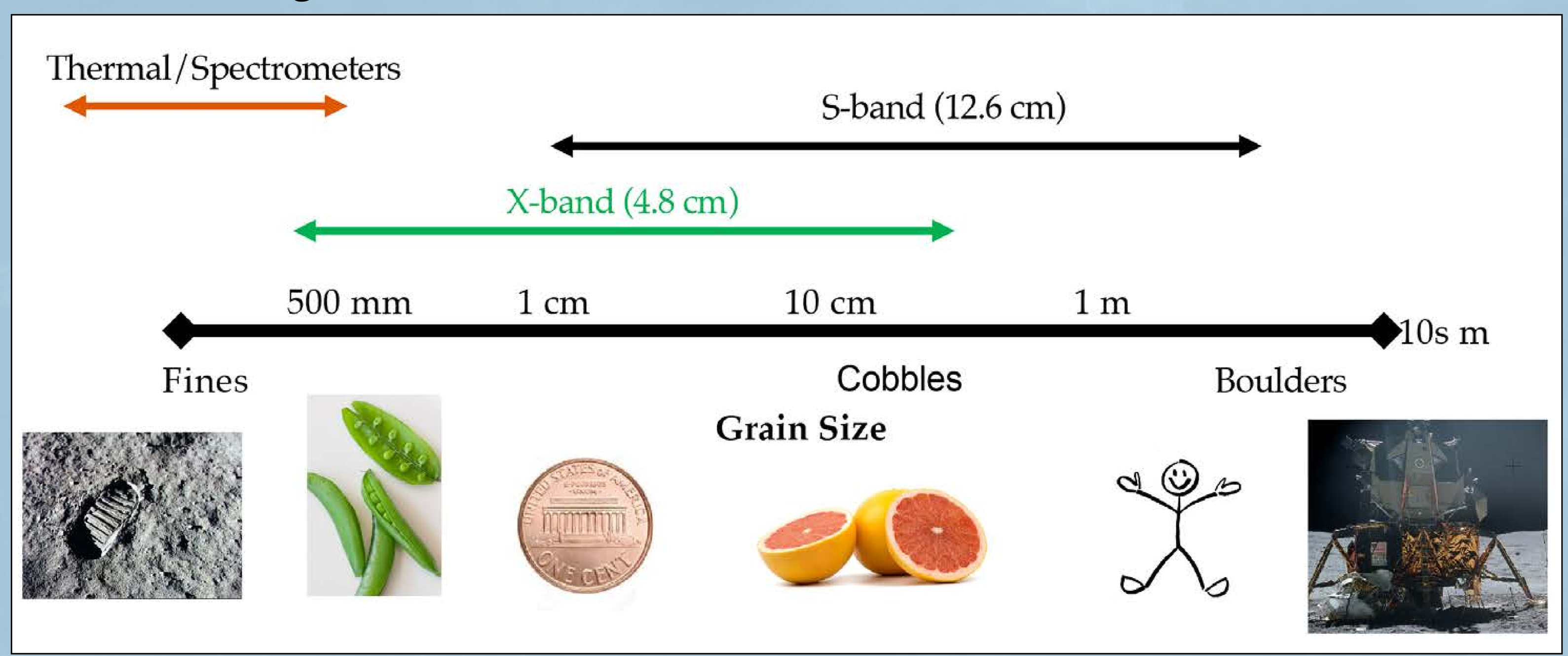
CPR as a function of bistatic angle - *Kepler Crater*



The CPR values for each pixel in an annulus encompassing the ejecta blanket are compared to the phase angle of the respective pixels. The values for every phase angle are binned (left) and averaged (right). Only phase angle bins with greater than 100 measurements are averaged.

Observations and Analysis

What Are We Observing?



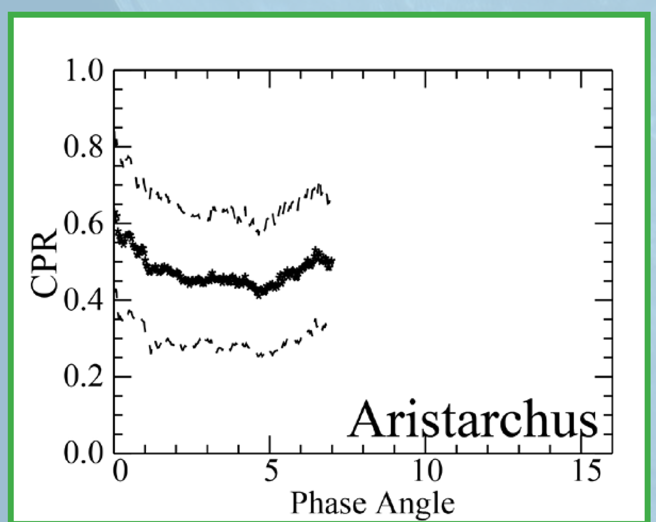
Observations using different wavelengths allow us to build up a picture of how quickly regolith weathers/breaks down on the lunar surface. These observations may be able to find finer age differentiations based on where maturity effects are seen at differing wavelengths compared to single instrument analyses.

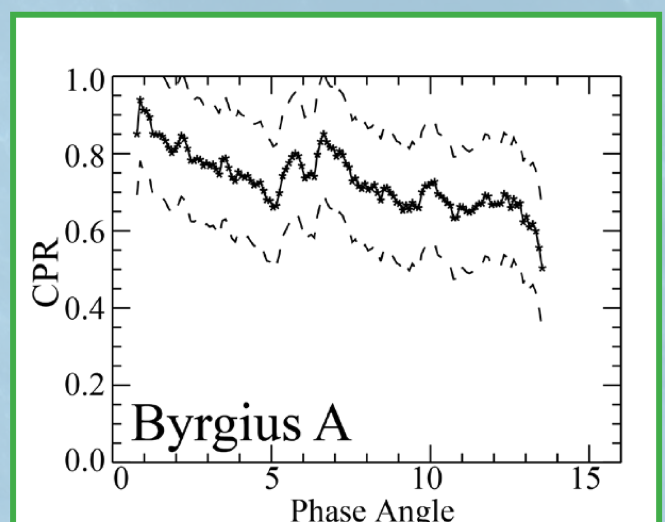
When looking within similar wavelengths, differences between signatures at craters allows relative age dating. For example, no clear opposition effect observed at Hercules crater (bottom, right). Instead, a relatively flat behavior is seen as function of phase angle. Hercules is often categorized as an Eratosthenian crater, which may explain the lack of CBOE. This may provide a baseline for examination and characterization of Copernican v. Eratosthenian craters.

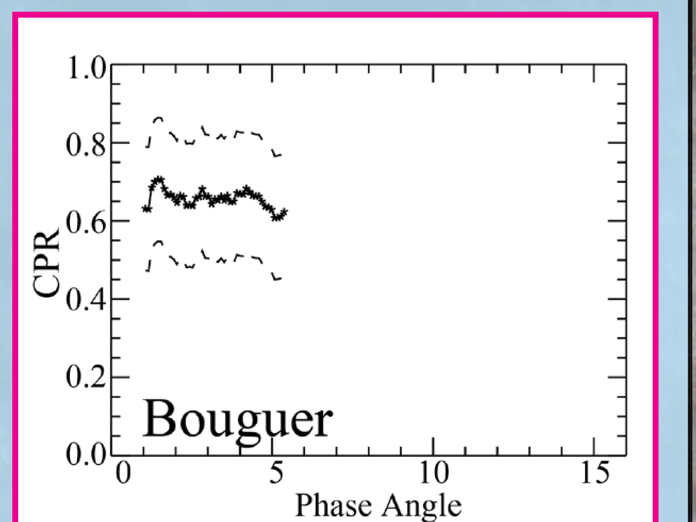
Bistatic Radar Observations of Young Lunar Craters

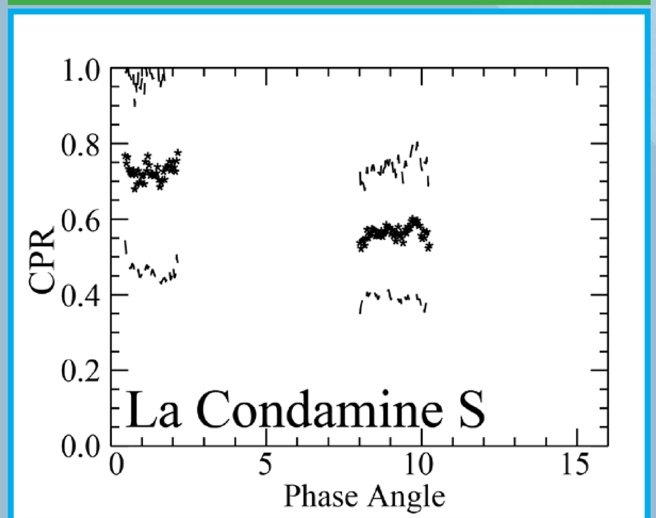
S-band Observations of Copernican craters show multiple scattering behaviors as a function of bistatic angle.

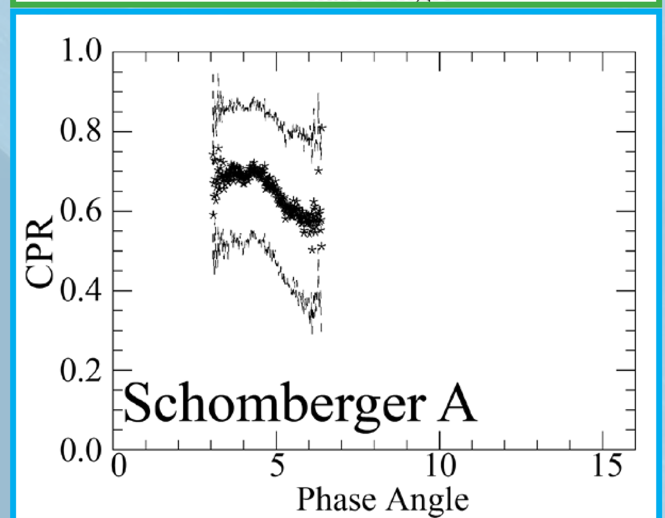
Some craters (Byrgius A, Aristarchus) exhibit a possible CBOE at low phase angles. Others (Schomberger A, Kepler, LaCondamine S?) exhibit a higher CPR at low phase, but it is different than CBOE. The rest show an approx. flat response as a function of phase angle (e.g., Bouguer, Hercules, Harpalus), suggesting older material or different scattering properties in the ejecta.

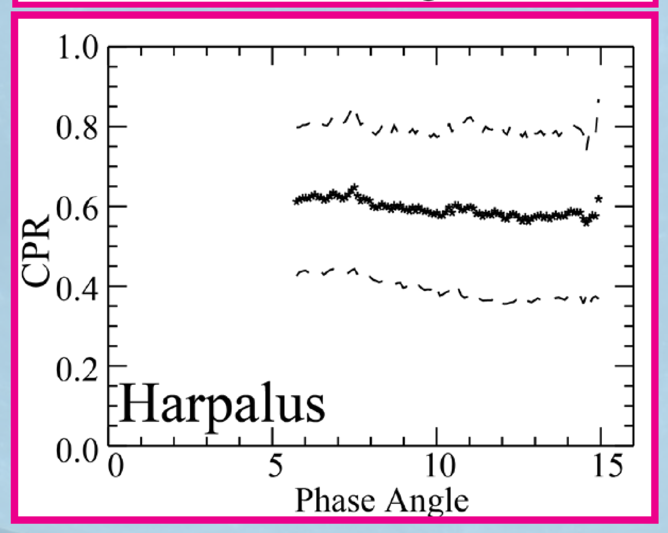






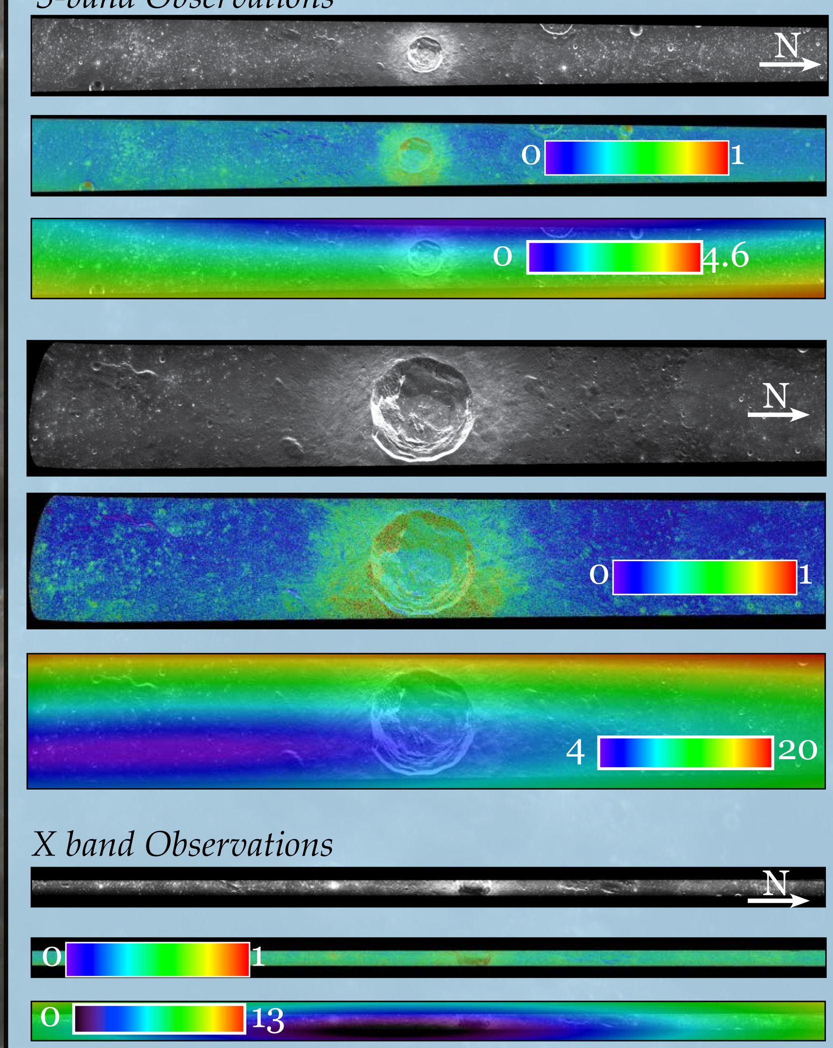


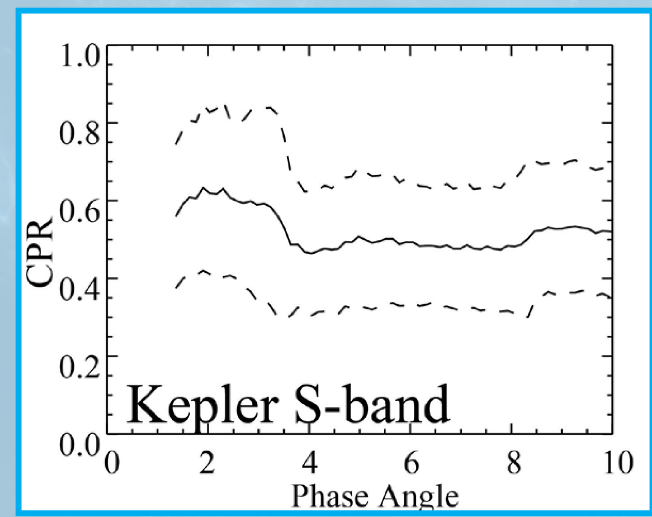


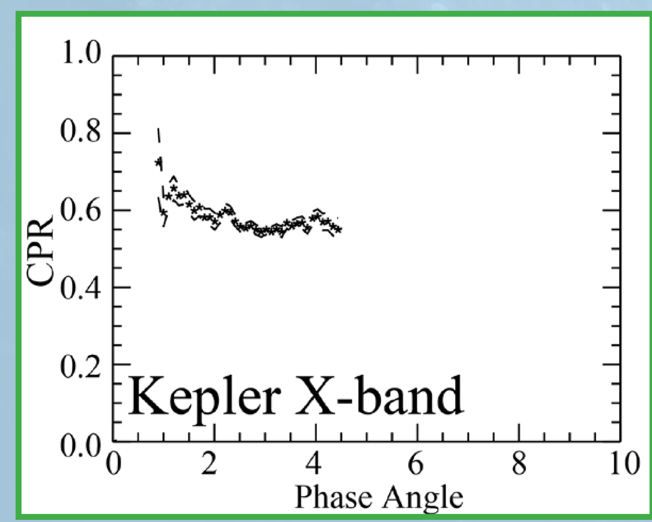


Multi-wavelength Observations

Kepler: Examining Behavior Across Wavelengths



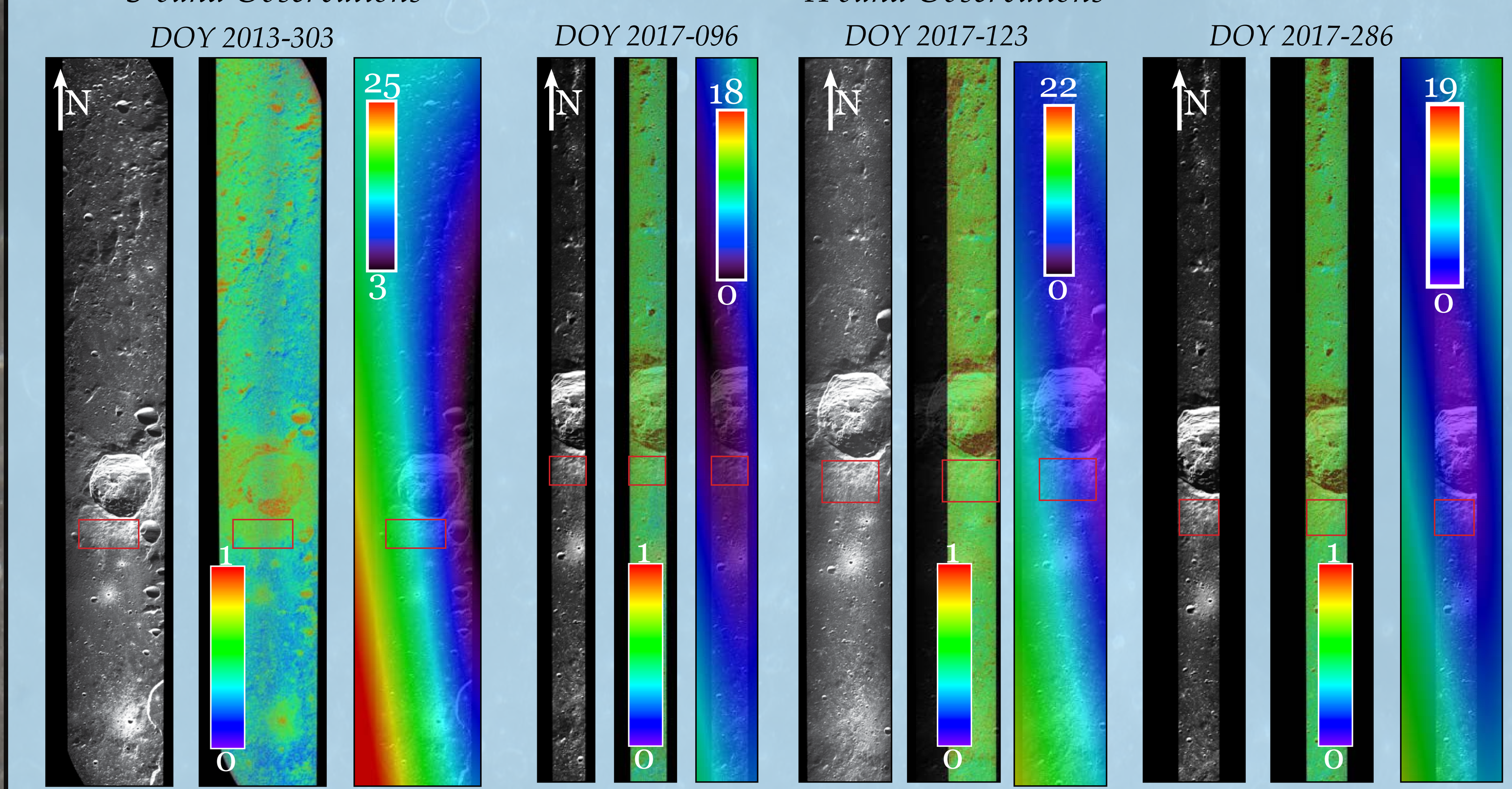




Kepler crater was examined in both S-band and X-band data. In S-band, Kepler has a unique signature with suggestions of a CBOE at low wavelengths. The flattening in the CPR response is similar to that seen in Schomberger A at S-band and is unique among other observed craters. X-band observations show a possible CBOE as well, though the upturn happens at shorter wavelengths compared to S-band. The average CPR values are consistent between wavelengths. The images (left) show the data for 3 collects over Kepler crater. For each collect: (top) S1, the total power returned to the radar, (middle) the CPR values, (bottom) observed phase angle over S1.

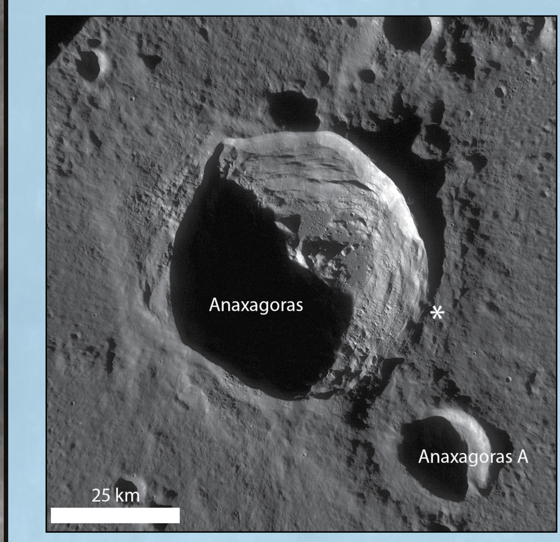
Anaxagoras: Examining Behavior Across Wavelengths

Multiple collects were aquired for Anaxagoras in both wavelengths, allowing a more complete phase space to be examined. Areas with overlapping phase space are averaged in the curves (right). The images (below) show the total power returned to the radar (S1, left), CPR (middle), and phase angle space overlaid on S1 (right) for each collect.

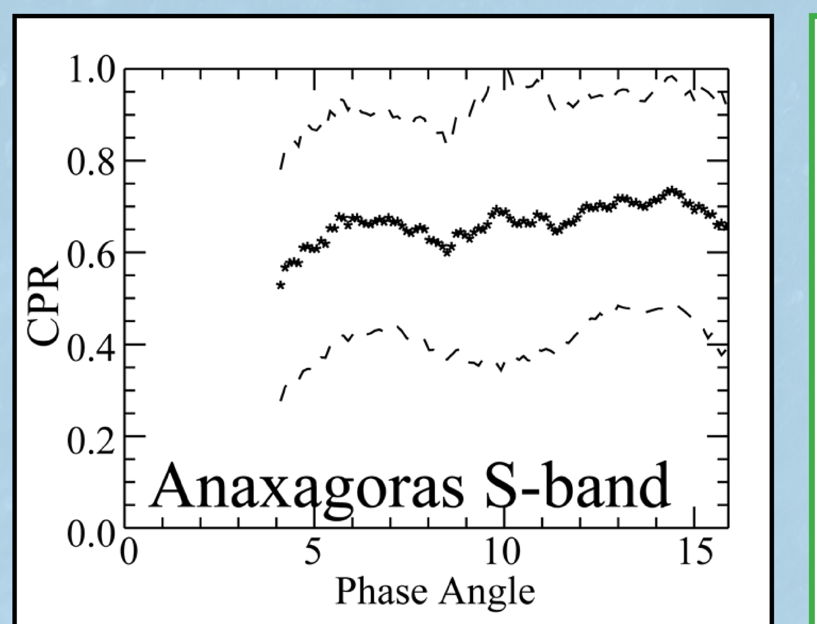


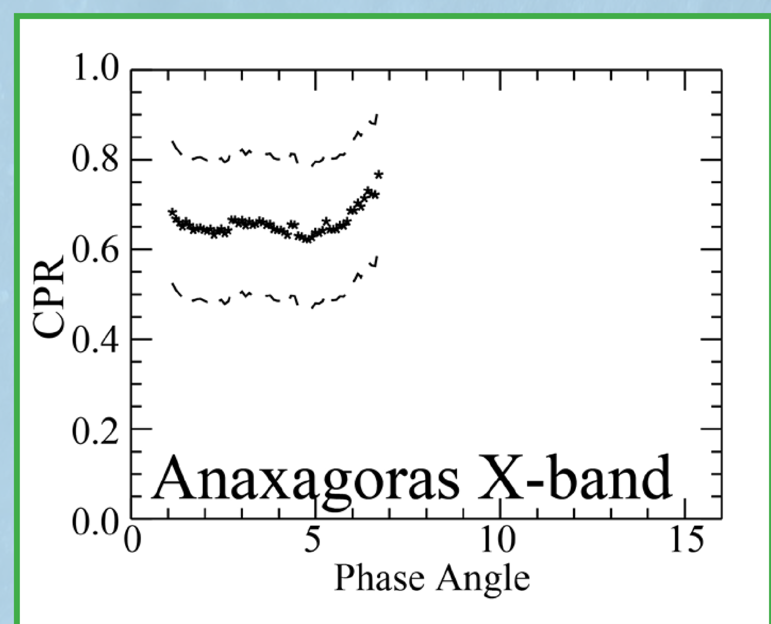
Two different collects (left) were averaged to generate CPR as a function of phase angle in S-band for Anaxagoras crater ejecta. The response across phase angles is relatively flat, and does not show clear evidence for a CBOE.

Three collects (right) were averaged to generate CPR as a function of phase angle in X-band for Anaxagoras crater ejecta. The response across moderate phase angles is relatively flat, but the CPR increases at both low and higher phase angles.



(top) S-band Mini-RF S1, CPR and phase angle images. (bottom) Lunar Reconaissance Orbiter Camera image of Anaxagoras crater. The ejecta blankets around the crater exhibit hummocky terrain in optical images, and show up as rough surfaces at radar wavelengths (12.6 cm).



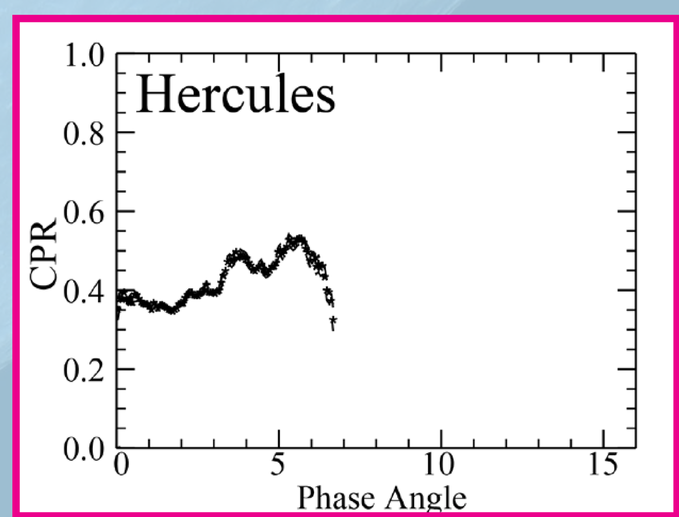


Anaxagoras was examined in both S-band and X-band data. A clear CBOE is seen in X-band data, while the CPR as a function of bistatic angle is more flat in S-band. This could be a wavelength effect or due to the range of bistatic angles currently observed. More observations are being targeted to complete the phase-angle space to resolve this discrepancy.

Summary and Discussion

- Mini-RF observations show the first ever CBOE observed on the lunar surface at radar wavelengths
- A variety of scattering characteristics are seen in Copernican ejecta blankets as a function of bistatic (phase) angle
- Multiple wavelength observations can help us constrain the rate of breakdown of rocks of varying size to understand how impacts produce regolith
- Presence (or lack) of observed CBOE may provide additional methods for relative age dating of ejecta material (e.g., Hercules, right)

Future work includes quantitatively identifying these effects and filling in phase angle space. Stay tuned!



Hercules (age: Eratosthenian) is older than others examined here. The CPR response is relatively flat across all low phase angles with some suggestion of structure at longer phase angles. This may provide a comparison of what "old" material looks like, and allow for relative ages based on CPR measurements.

[1] Campbell et al. (2010), Icarus, 208, 565-573; [2] Raney et al. (2012), JGR, 117, E00H21; [3] Hapke et al. (2012), JGR, 117, E00H15, doi:10.1029/2011JE003916; [4] Hapke and Blewett (1991), Nature, 352, 46-47