Modeling Radar Scattering from Icy Lunar Regoliths

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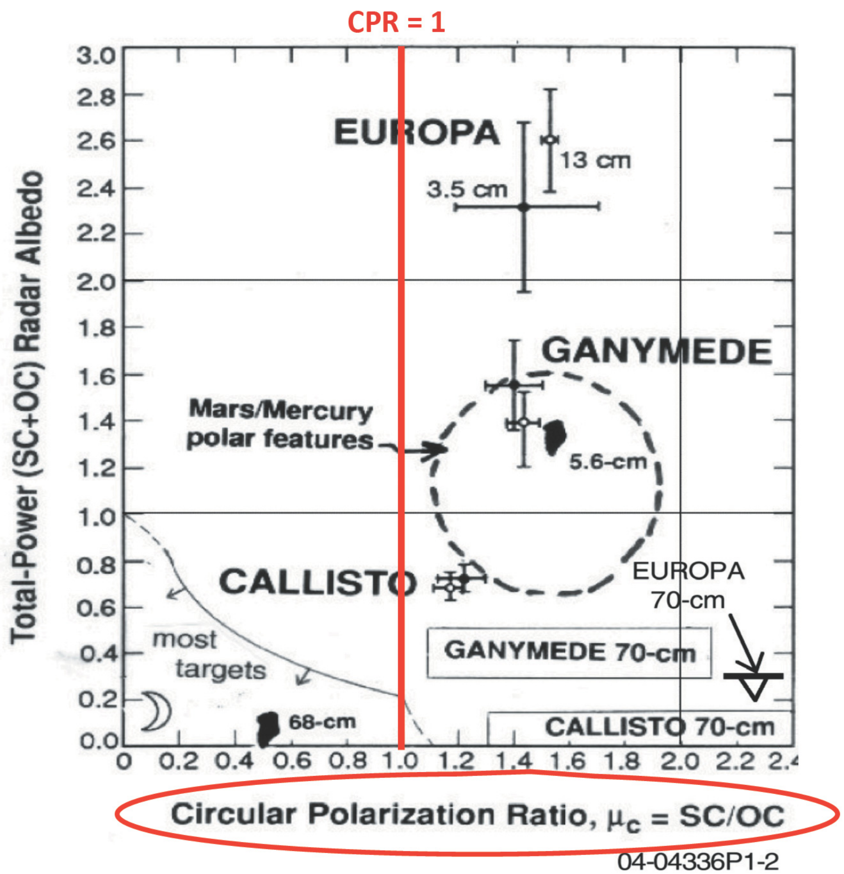
References

- ***Modeling Radar Scattering from Icy Lunar Regoliths at 13-cm and 4-cm Wavelengths, Thompson, Ustinov, and Essam Heggy, JGR, Jan, 2011***
- ***Initial Results for The North Pole of the Moon from Mini-SAR, Chandrayaan-1 Mission, Spudis et al. GRL, Vol. 37, 2010***

Rationale for Modeling



From Ostro, 2002

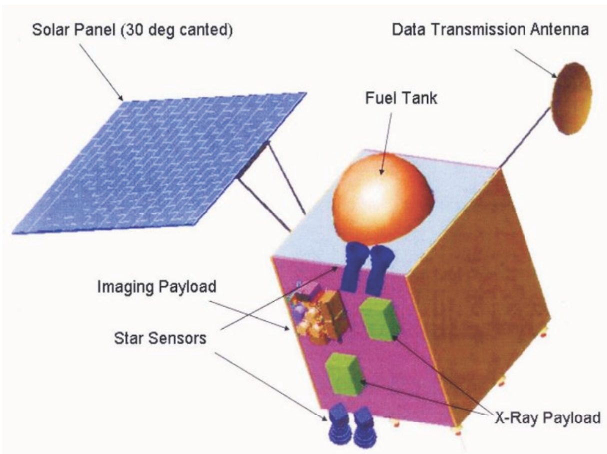
If there is ice on the Moon like that at the poles of Mercury and Mars or like the Galilean satellites, then it would have echo enhancement of 10 or more and a Circular Polarization Ration (CPR) greater than unity.

This is not yet observed on the Moon.

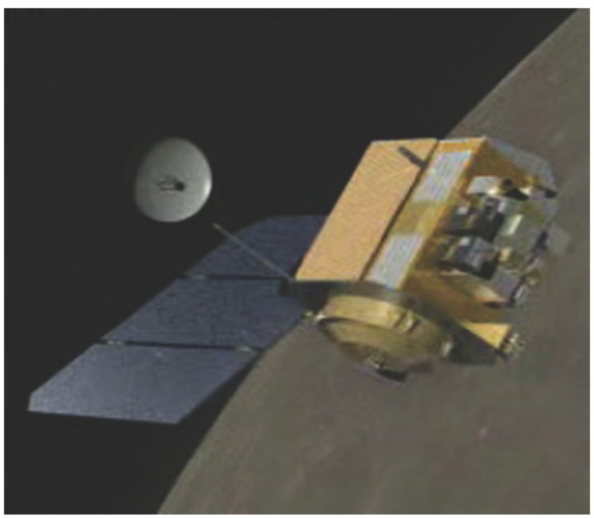
Thus, can we generate models that predict how these otherwise strong signals are muted/masked by regolith?

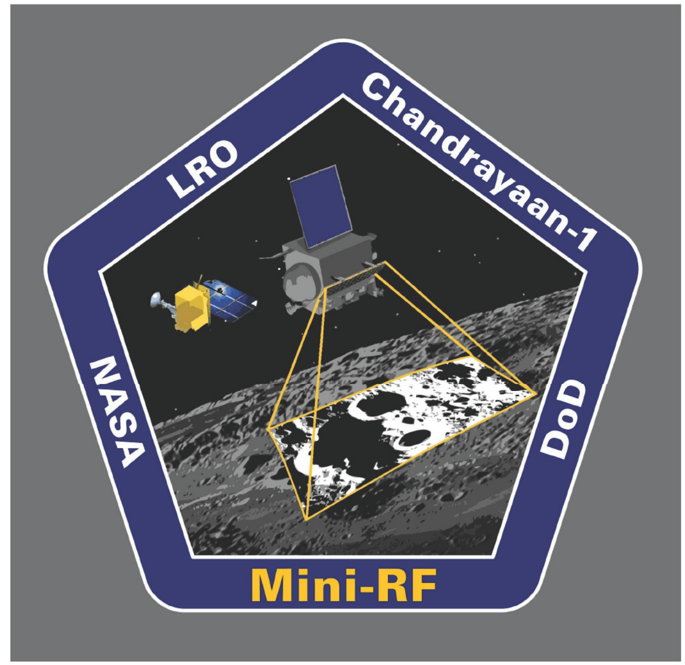
Chandrayaan-1 and LRO Mini-RF Radars

Chandrayaan-1



LRO





Chandrayaan-1 and LRO were in polar orbits thus enabling the Mini-RF observations of polar regions.

Chandrayaan-1 and LRO Mini-RF Radar Parameters

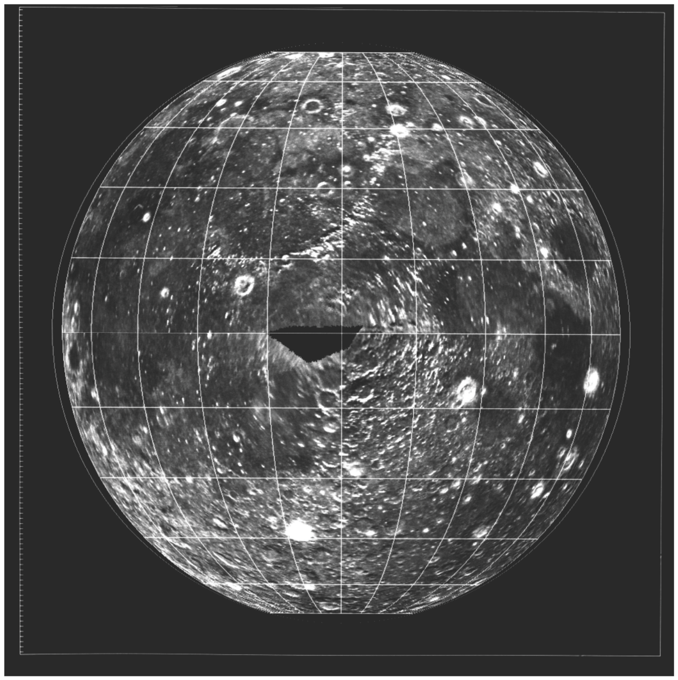
Parameter	Chandrayaan-1	LRO S-Band	LRO X-Band
Frequency	2380 MHz	2380 MHz	7140 MHz
Wavelength	12.6 cm	12.6 cm	4.2 cm
Pixel Spacing	75 m	7.5 and 75 m	7.5 and 75 m
Number of Looks	16	8 and 16	8 and 16
Swath Width	8 km	4 and 6 km	4 km
Angle of Incidence (Center-Beam)	35°	49°	49°
Antenna Beam-Width (Azimuth)	5°	6°	2°
Antenna Beam-Width (Range)	10°	10°	3.3°

Chandrayaan-1 Mini-RF Operations – October'08 – August'09

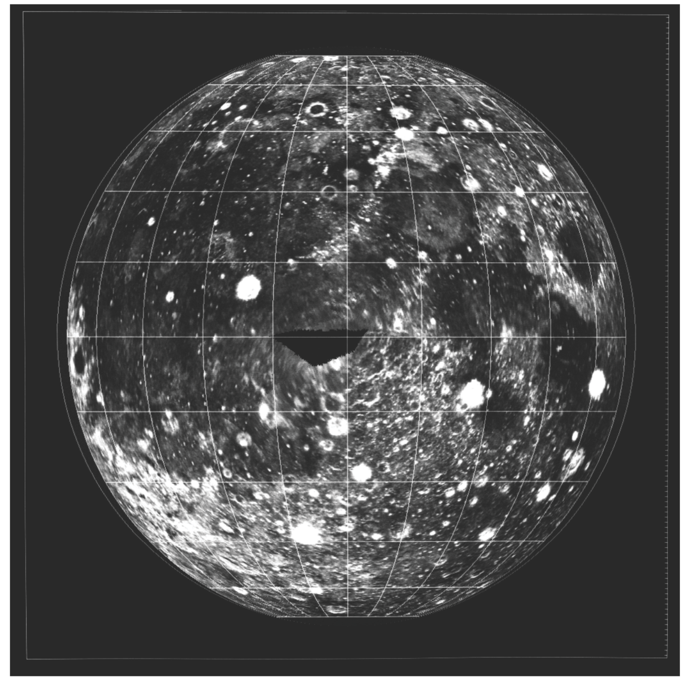
LRO Mini-RF Operations July'09 – December'10

Lunar Radar Images at 70 cm

Opposite-Sense Circular (OC)



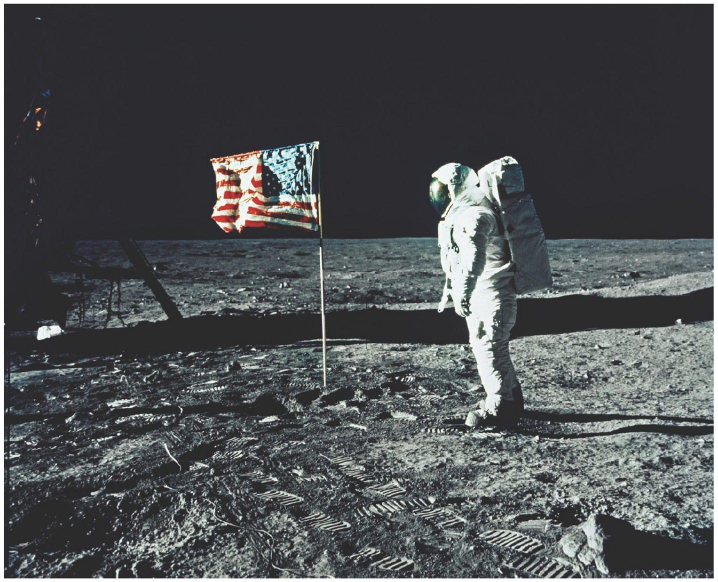
Same-Sense Circular (SC)



- Echoes are modulated by slope and roughness
- Mare-Terra differences are 2-to-4:1
- Strongest roughness deltas about 10:1

Lunar Surface Panorama

Average Lunar Surface



Apollo - Mare

Rough, Fresh Surface
Times-10 70-cm Enhancement
Times-3 3.8-cm Enhancement

Surveyor-VII - Tycho Rim

Lunar surface and regolith is a matrix of sand-like soil and rocks

Schematic of Lunar Subsurface (Apollo 17 Preliminary Science Report)

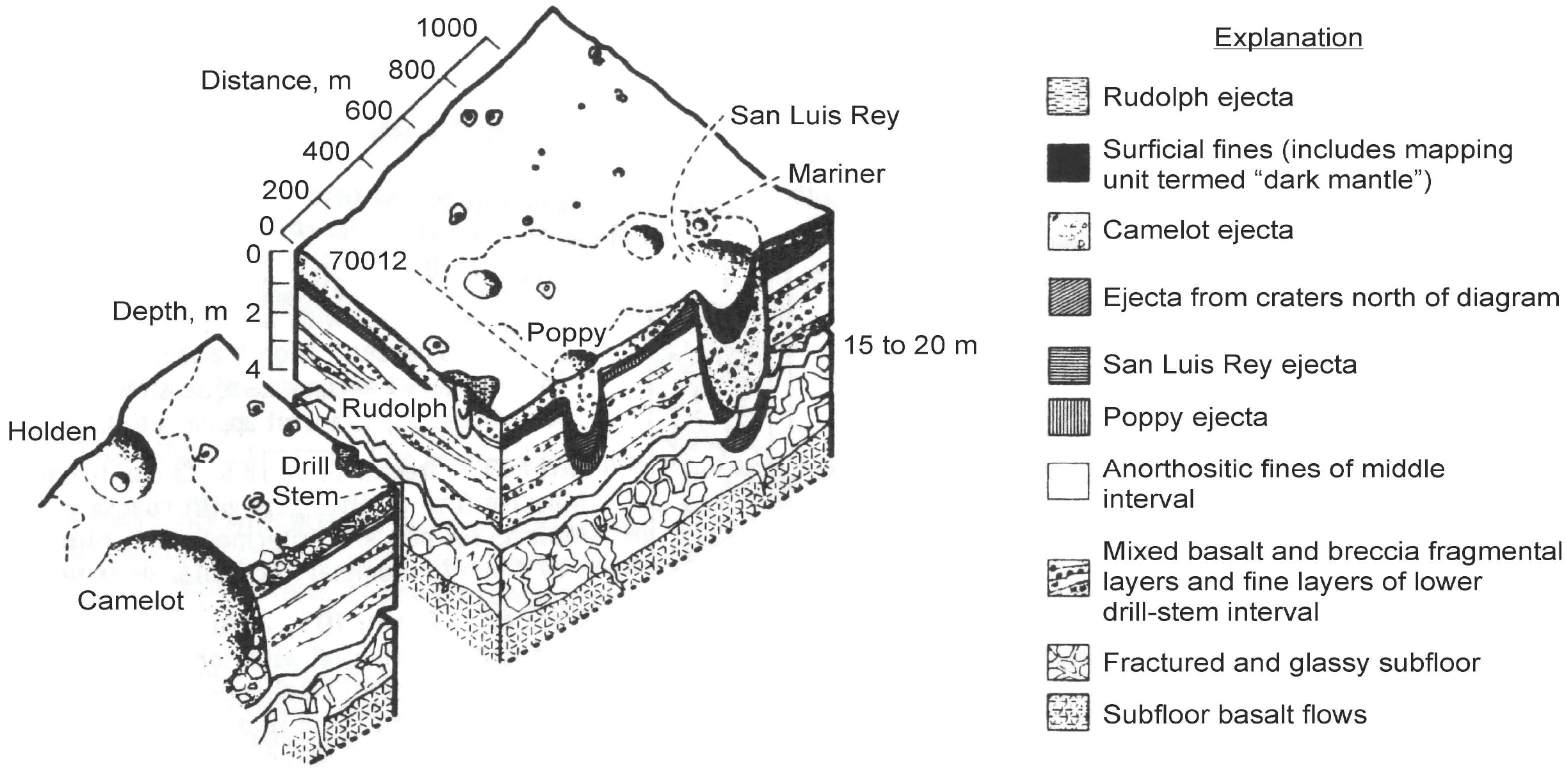


Figure 7-28. – Block diagram depicting the reconstruction of regolith history in the vicinity of deep drill string (LM area). The front face is a radial section through Camelot Crater, the drill-stem site, and the LM site; the other faces parallel the standard lunar surface grid. (Vertical exaggeration is 200x.)

Subsurface crater ejecta layers provide specular scattering

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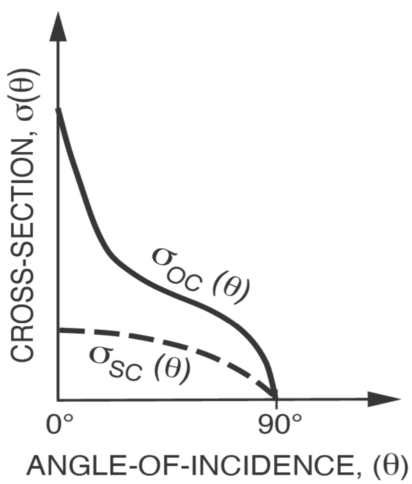
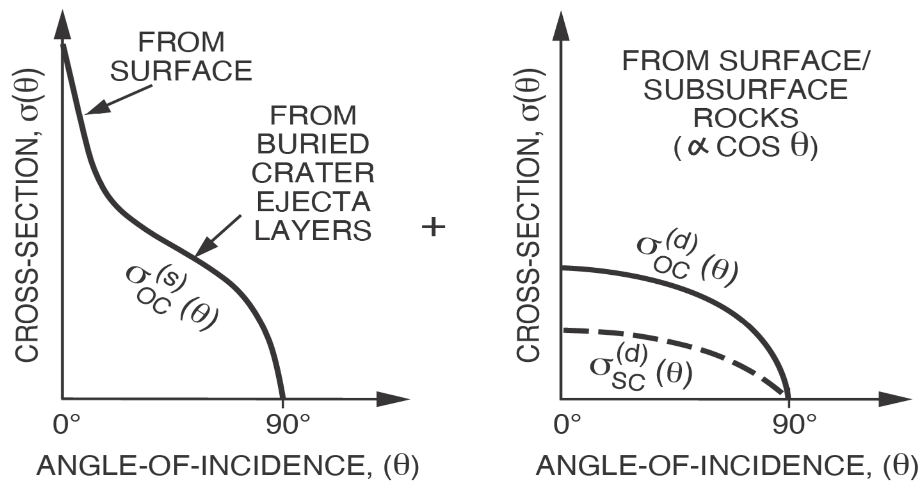
Average Lunar Radar Behavior

JPL

<table>
<tr><th><u>OBSERVATIONS</u></th><th><u>INFERRED SCATTERING MECHANISMS</u></th></tr>
<tr><td>POLARIZED (OC) + DEPOLARIZED (SC)</td><td>SPECULAR + DIFFUSE</td></tr>
<tr><td>
</td><td>
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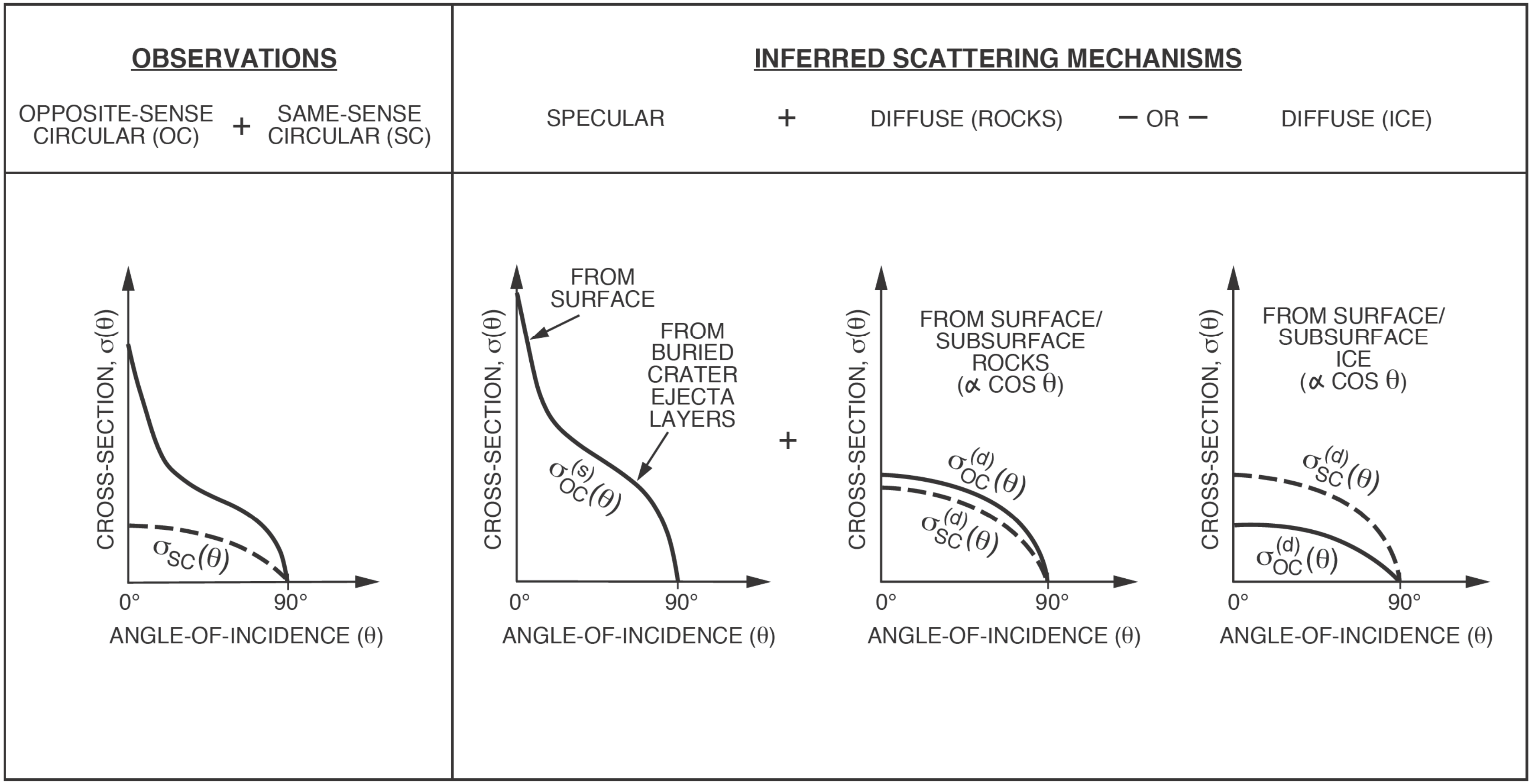
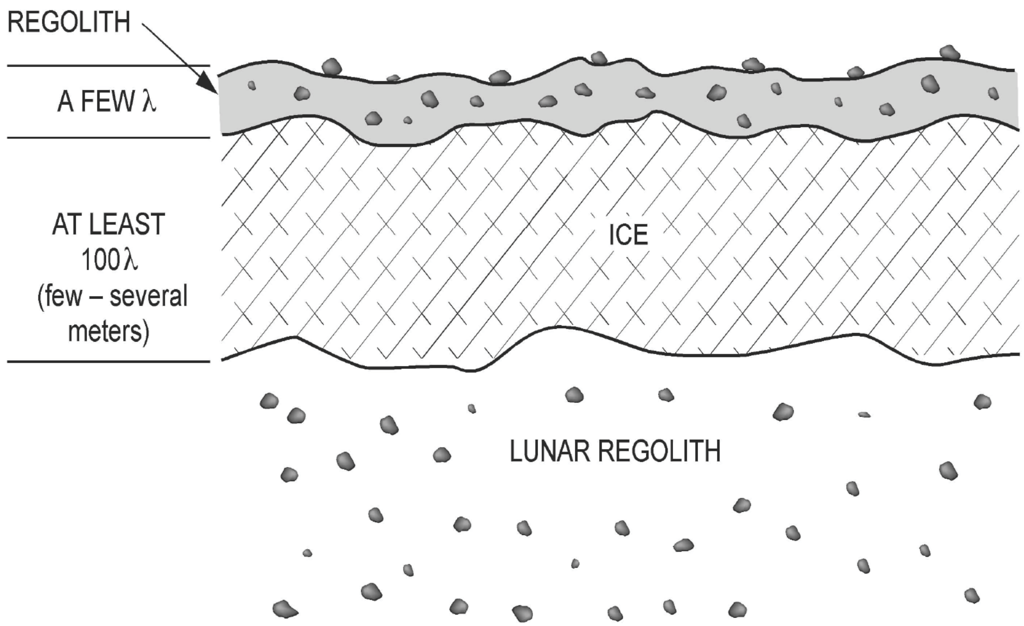
Average Lunar Radar Behavior
Diffuse and Specular Components

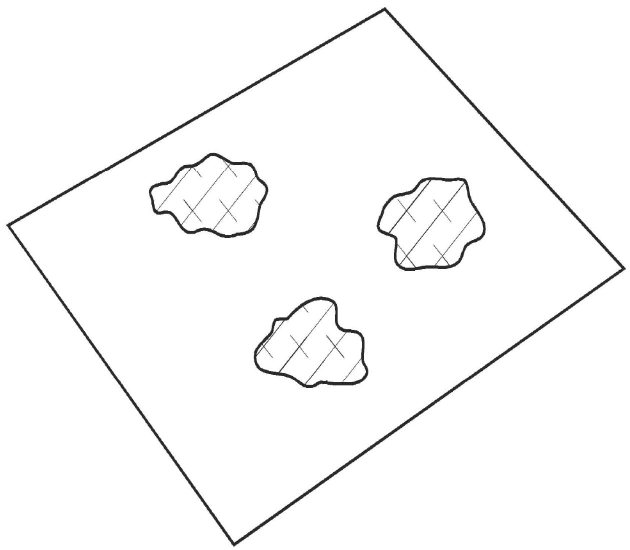


Assumed Lunar Ice Conditions

Thick (>100λ) ice lens covered with thin regolith



Ice patches inside a radar pixel



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North Pole Radar CPR Mosaic – Chandrayaan-1

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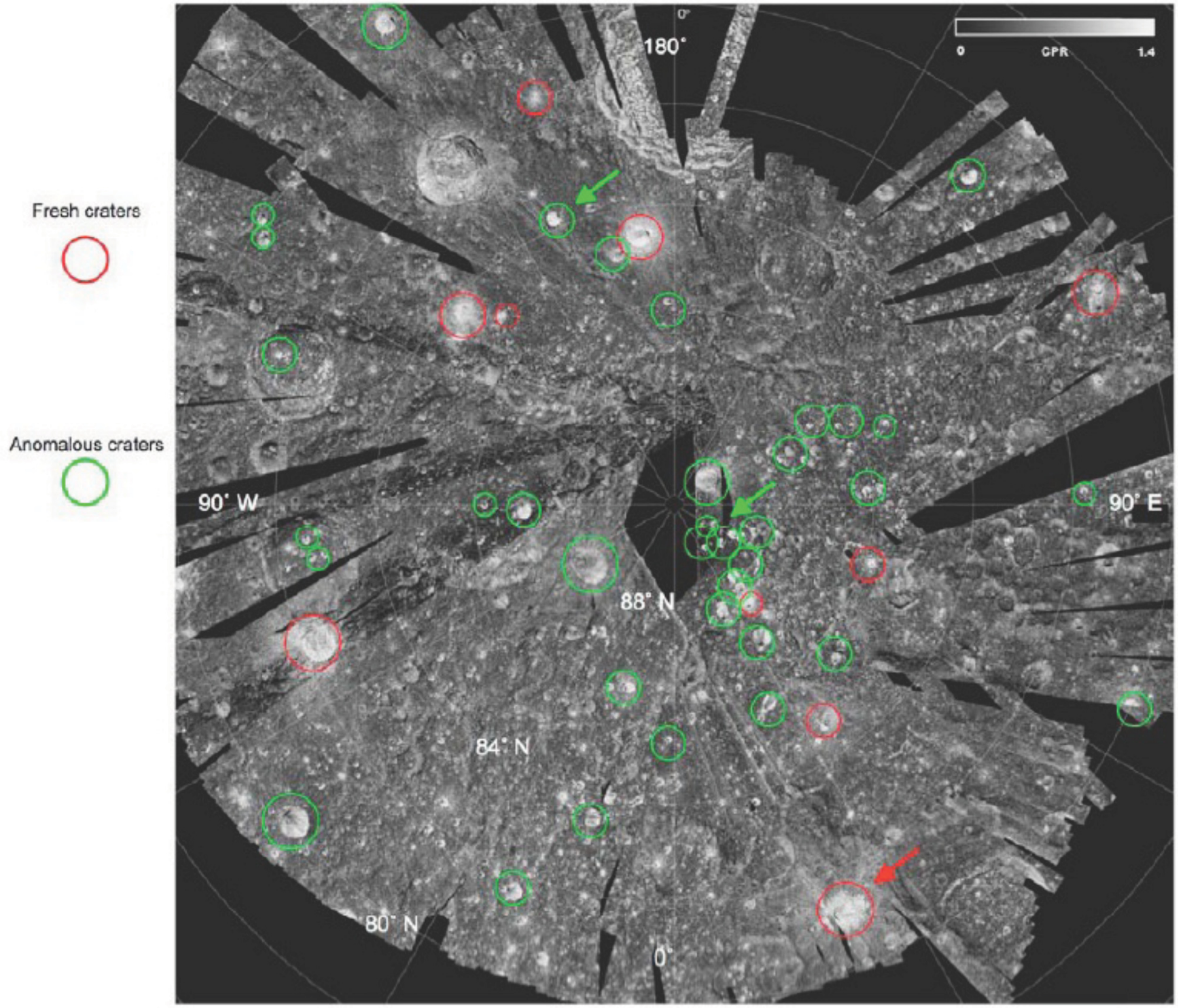
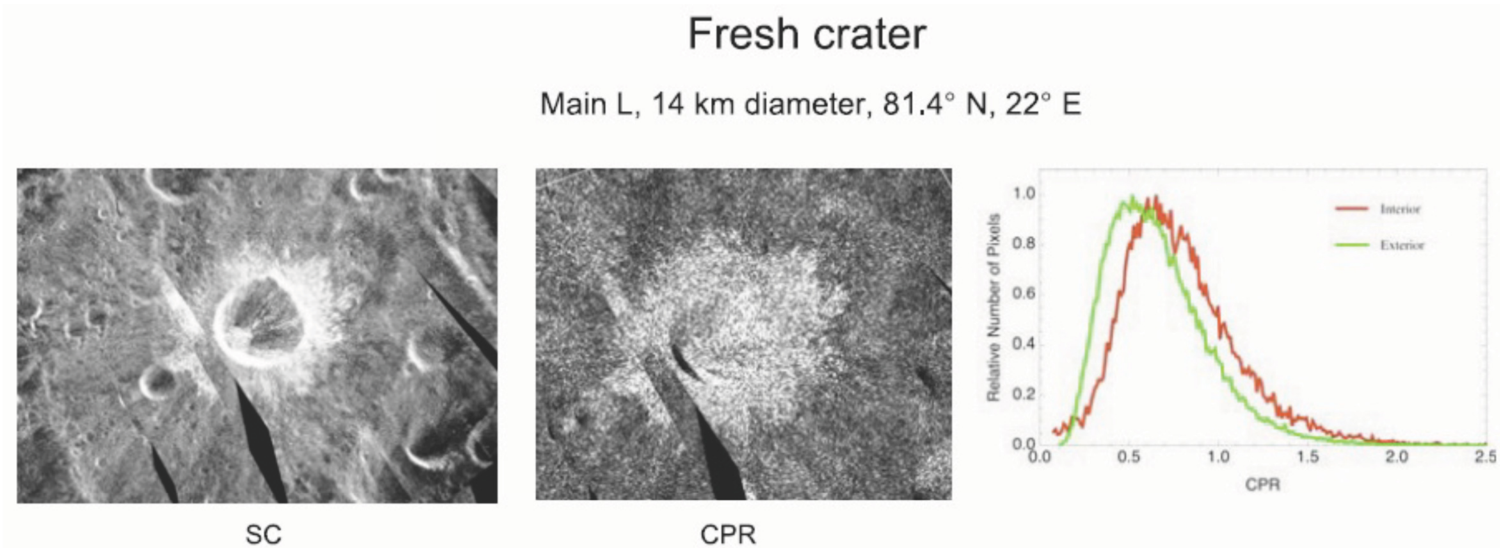
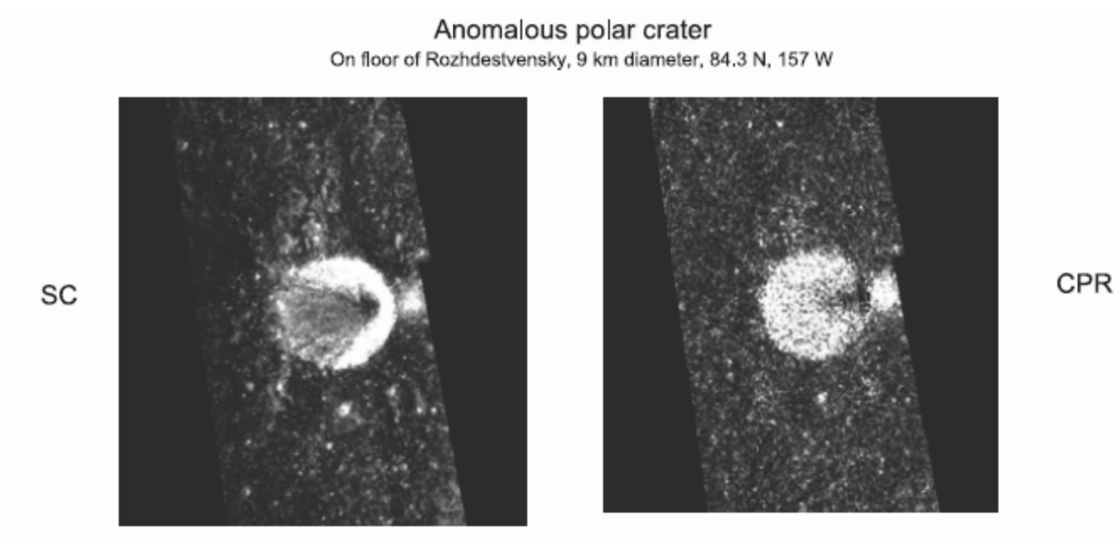


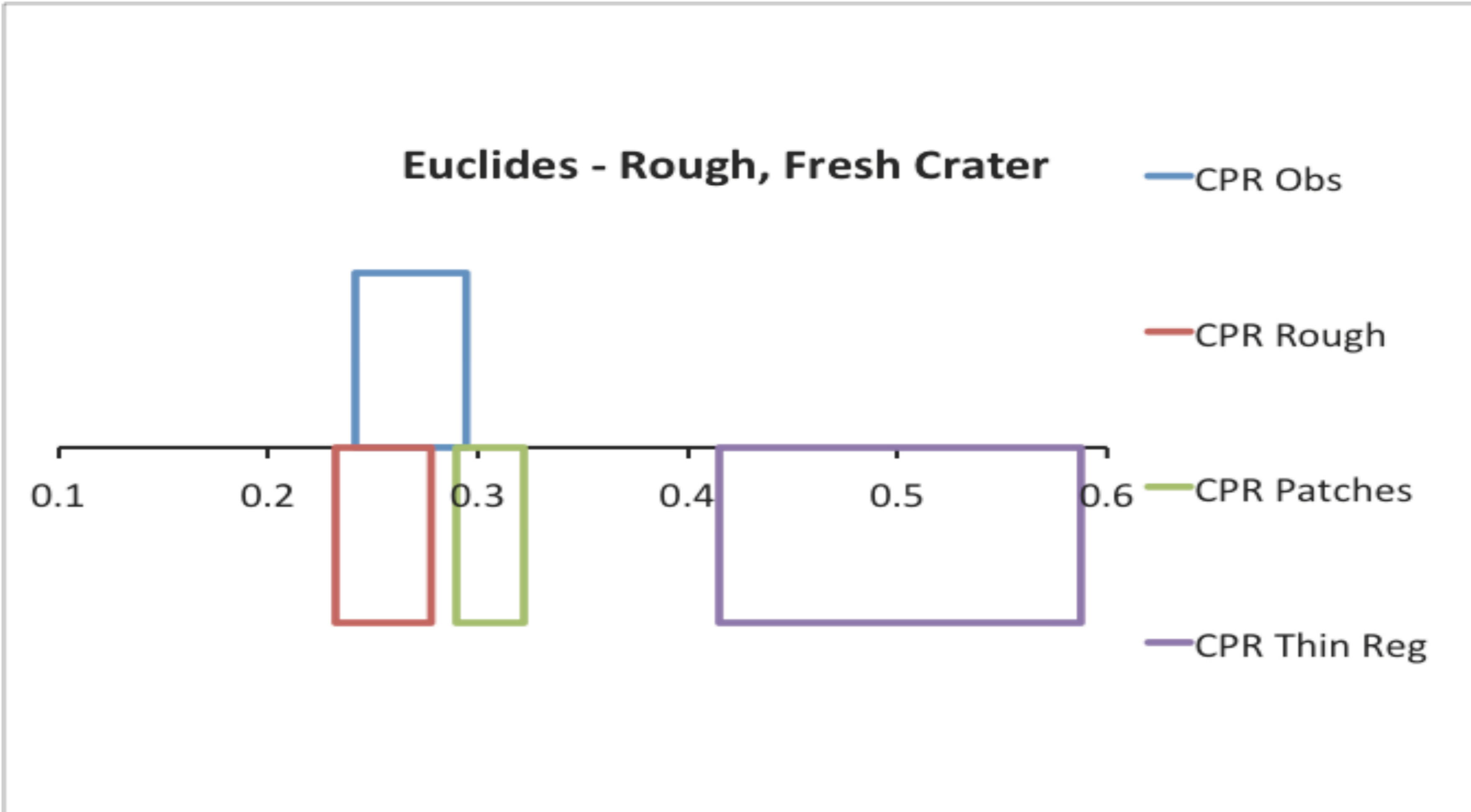
Examples of Blocky and Icy Craters



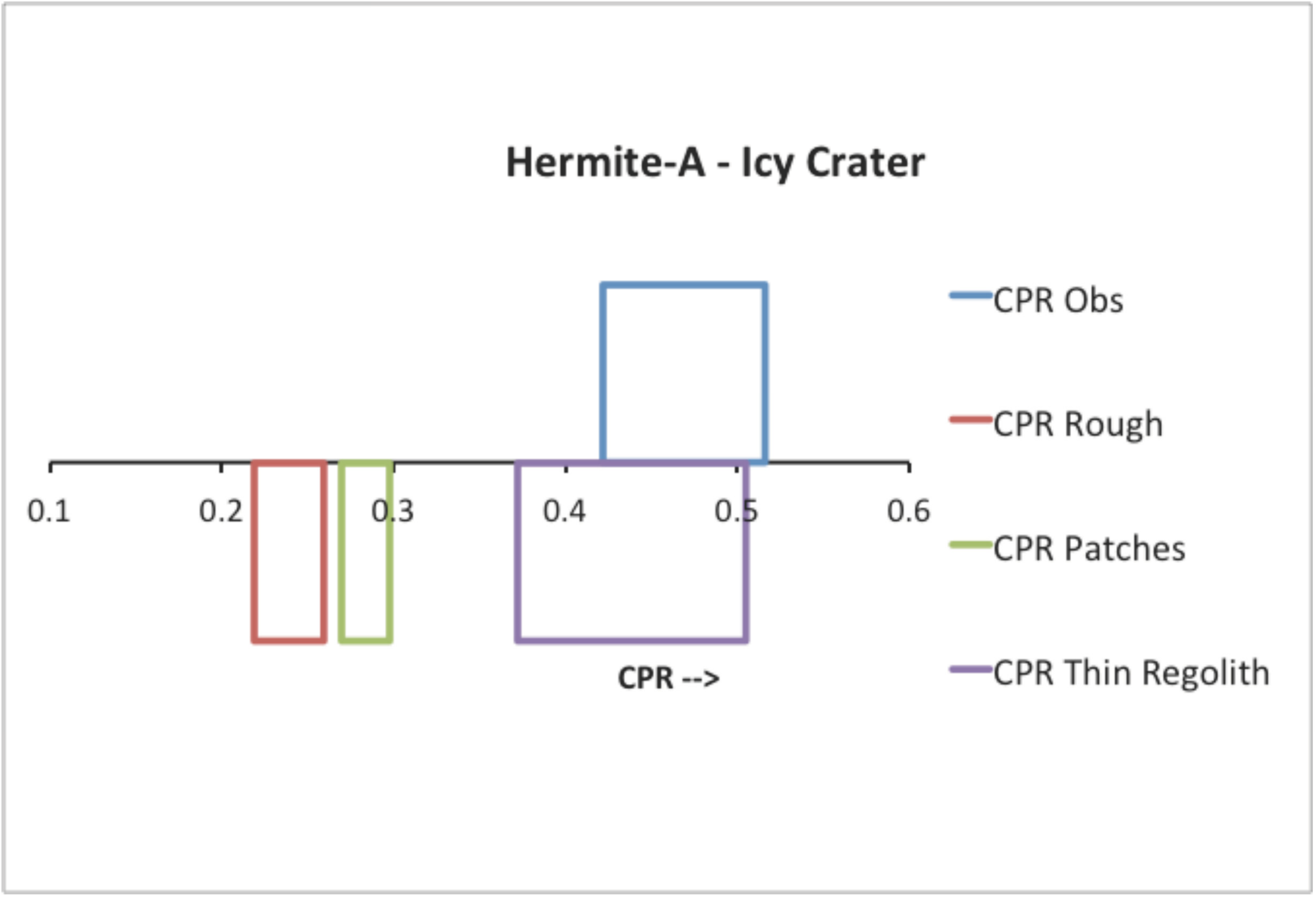


From Spudis et al., Initial results for the north pole of the Moon from Mini-SAR, Chandrayaan-1 mission, *GRL*, 2010.

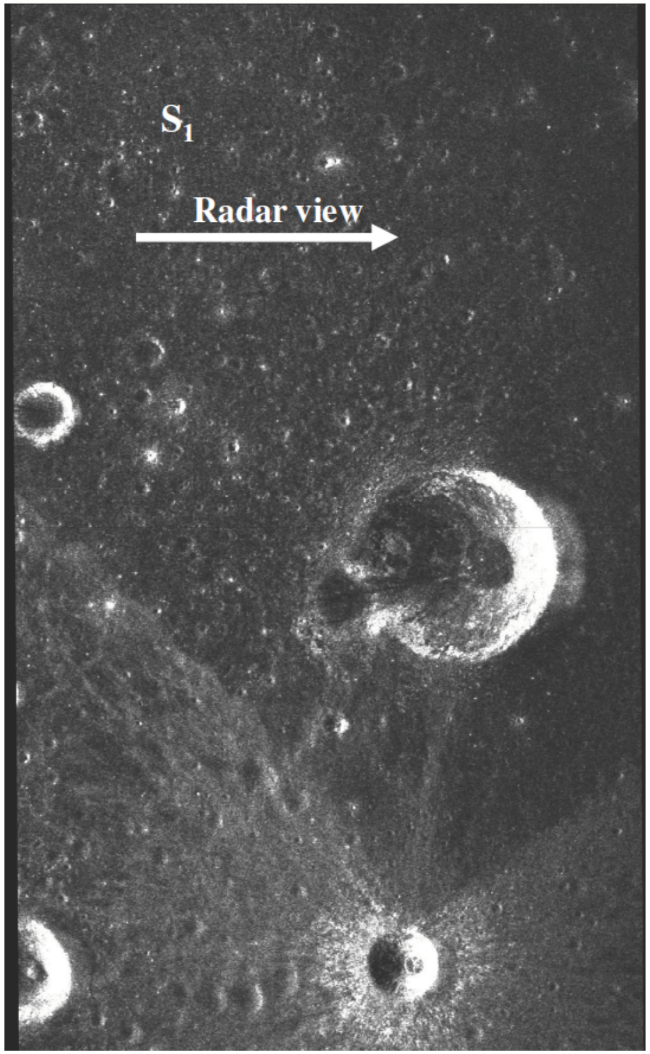
Modeling Results – Rough, Fresh Crater

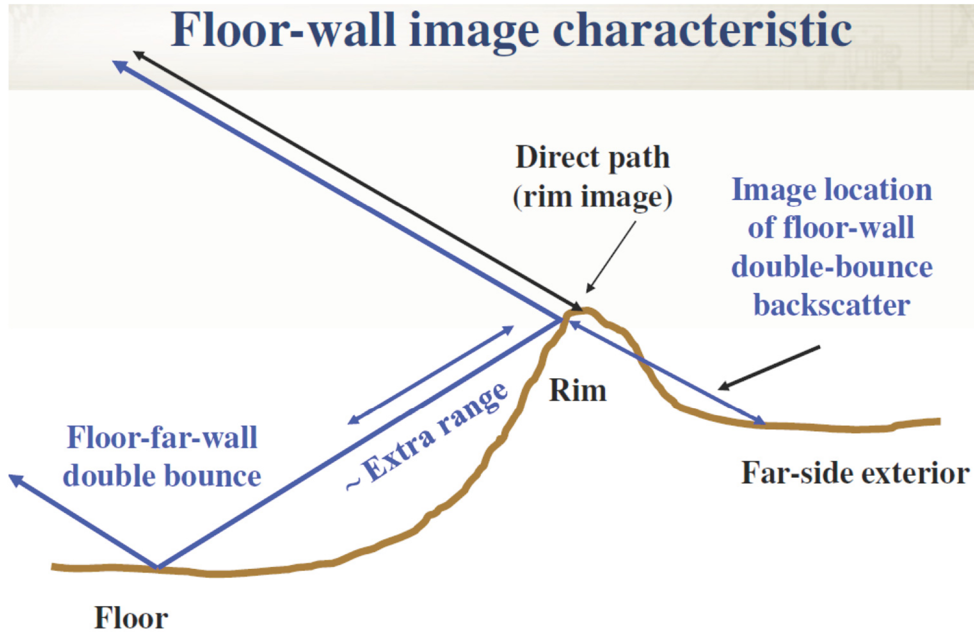


Modeling Results – Icy Crater



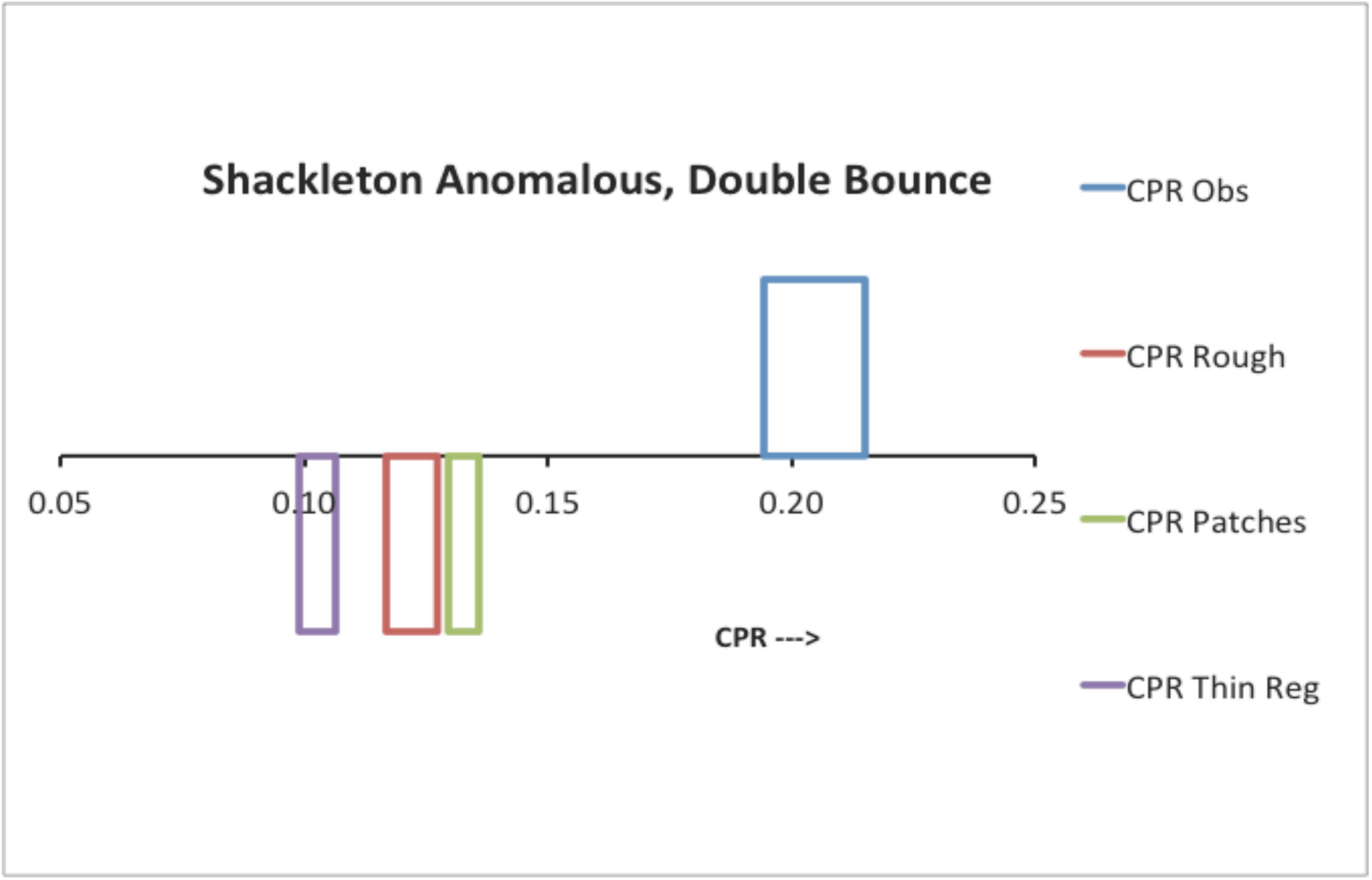
Double Bounce – Anomalous Crater





Courtesy of Keith Raney, APL, 2011

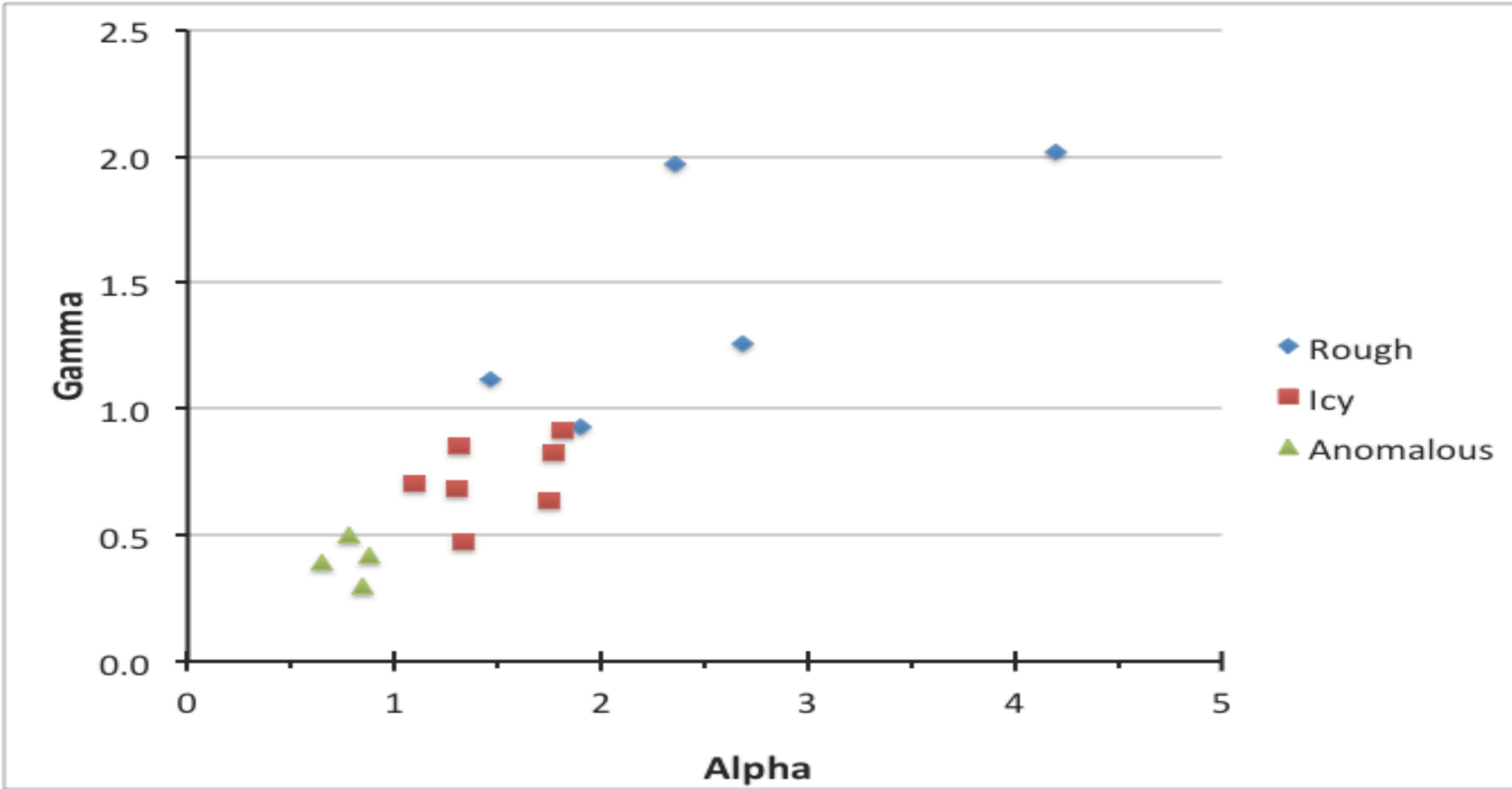
Modeling Results – Anomalous, Double Bounce Crater



Modeling Results

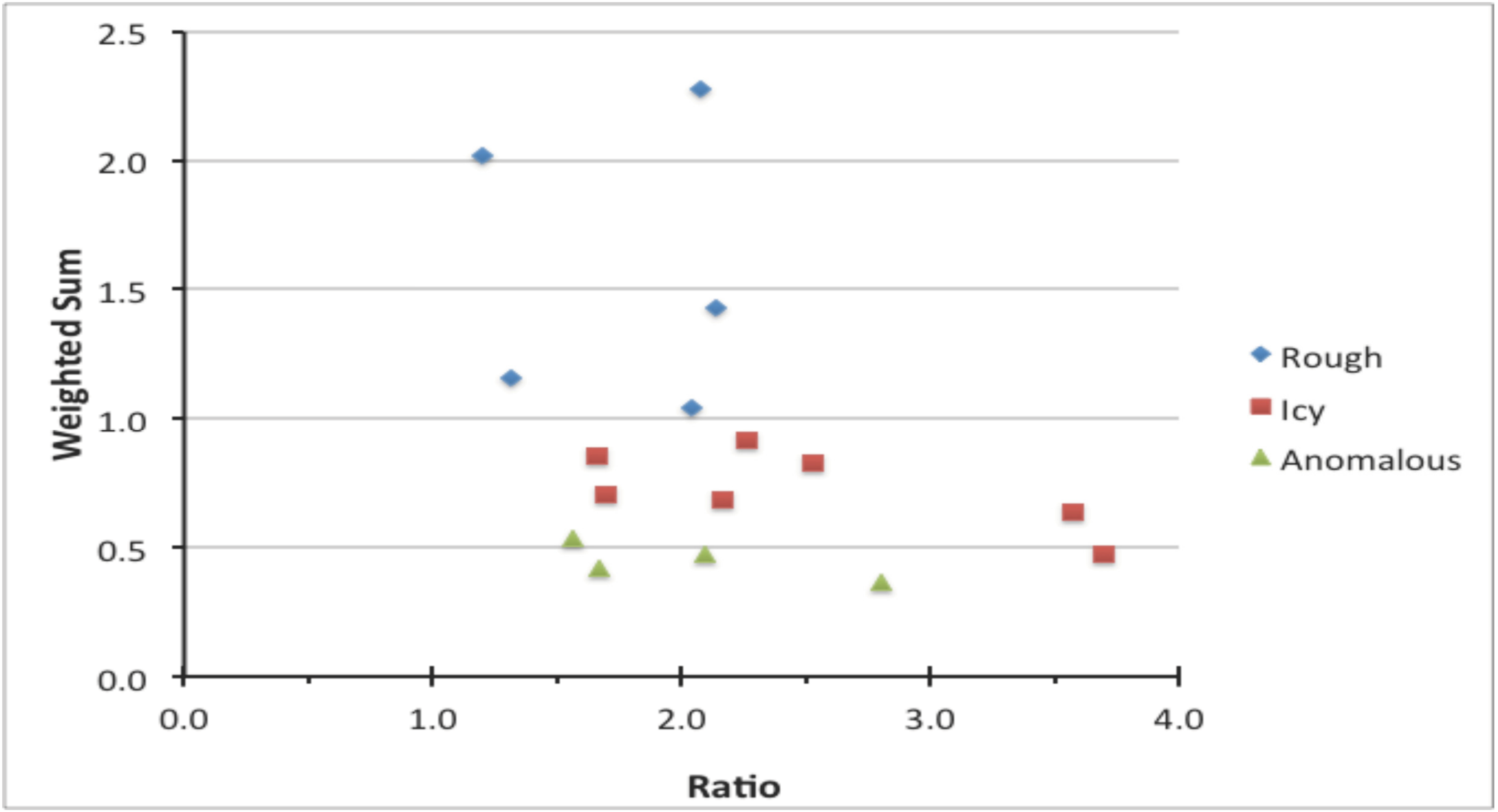
Crater	Alpha	Gamma	Ratio	Sum	Double Bounce	Model Fit
Fresh Non-Polar						
Giordano Bruno	4.20	2.02	2.1	2.27		< Rough Surface
Byrgius A	2.36	1.97	1.2	2.02		<< Rough Surface
Euclides - New	1.90	0.93	2.0	1.04		Rough - Patches
Fresh Polar						
Main L	2.69	1.26	2.1	1.43		Rough Surface
Other Rozhdestvensky	1.47	1.12	1.3	1.16		Rough Surface
Icy						
Floor ofPeary 1	1.10	0.65	1.7	0.70		Thin Regolith
Floor of Peary 2	1.81	0.80	2.3	0.92		Ice Patches
Rozhdestvensky N	1.31	0.79	1.7	0.85		Ice Patches
Floor of Hermite Cut 1	1.30	0.60	2.2	0.68		Thin Regolith
Floor of Hermite Cut 2	1.77	0.70	2.5	0.82		Ice
Hermite A	1.75	0.49	3.6	0.64		Thin Regolith
Erlanger	1.33	0.36	3.7	0.47		> Thin Regolith
Anomalous/ ? Double-Bounce ?						
Anomalous	***0.84***	***0.30***	***2.8***	0.36	***YES***	***>> All 3***
Rozhdestvensky - Floor	0.65	0.39	1.7	0.42	*LIKELY*	>> All 3
Other Rozhdestvensky - Floor	0.88	0.42	2.1	0.47	*LIKELY*	>>All 3
Shackleton	0.78	0.50	1.6	0.53	*LIKELY*	>> All 3
Anomalous Models						
No Specular - Diffuse = Ave Diffuse	1.00	0.26	3.8	0.35		
SC Diffuse = 0.8 / OC Diffuse = 1.25	0.80	0.33	2.4	0.38		
SC Diffuse = 0.8 / OC Diffuse = 1.5	0.80	0.39	2.0	0.44		

Modeling Results: Alpha vs. Gamma



Alpha = OC Enhancement / Gamma = SC Enhancement

Modeling Results: Sum vs. Ratio



Alpha = OC Enhancement / Gamma = SC Enhancement
Ratio = Alpha/Gamma
Weighted Sum = 0.12 Alpha + 0.88 Gamma = Total Power Enhancement

Concluding Remarks

- We tested our model assuming diffuse and specular scattering components by examining 13 polar and 3 non-polar craters using LRO Mini-RF data for the Lunar North Polar Region

- Results indicate that there are 3 separable classes of craters based upon their SC enhancement (Alpha) and OC enhancement (Gamma)
  – Icy
  – Rough Fresh
  – Double Bounce (Anomalous)

- Next Step: Produce North and South Polar mosaics using automated identification of Icy, Rough Fresh and Double Bounce classes of craters