Identification of the anomalies in the lunar regolith structure with the phase-ratio imagery

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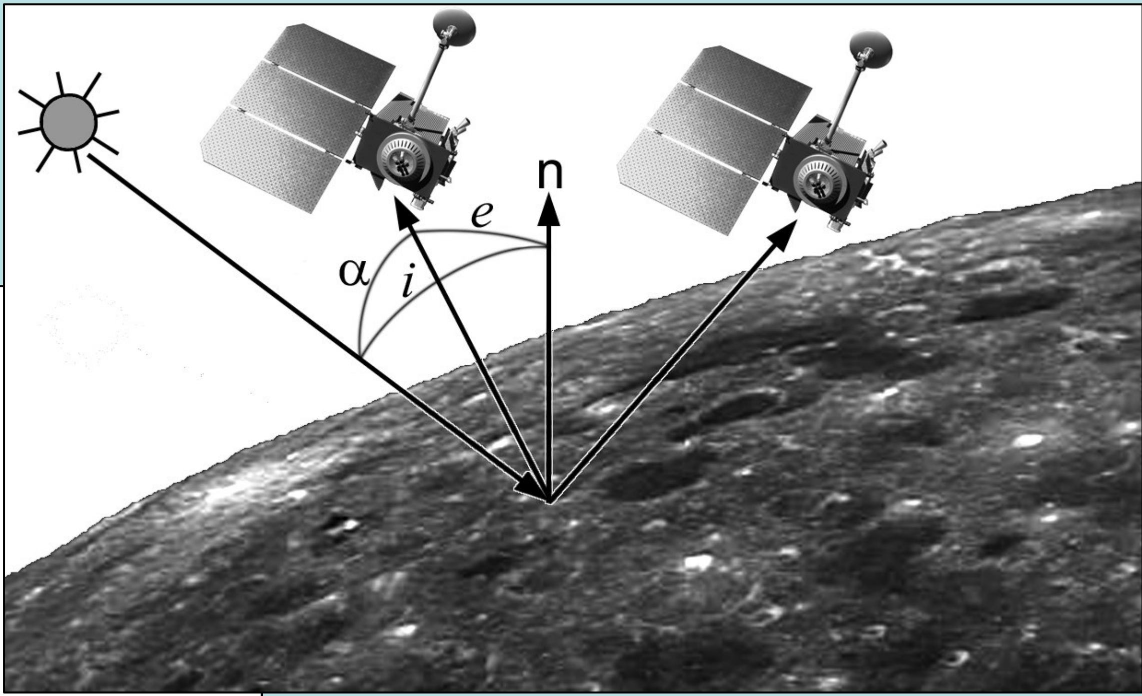
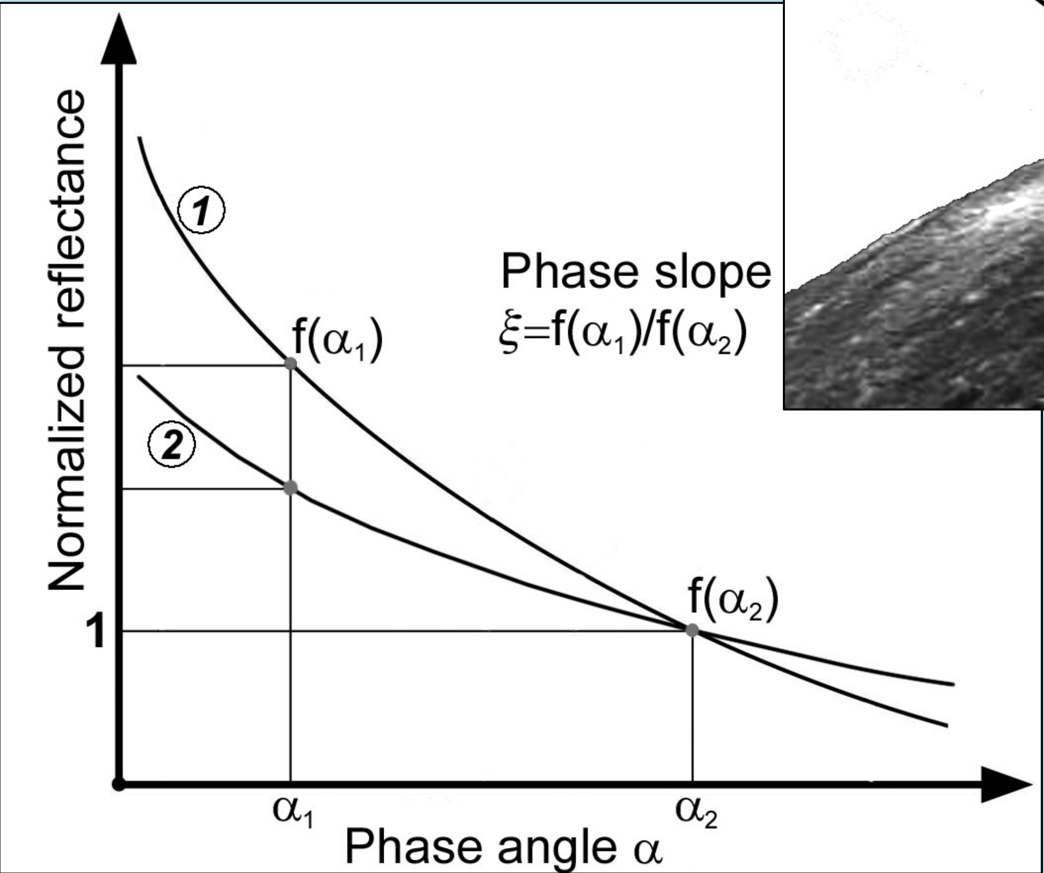
Regolith on SSB, Meudon, 1-3 Dec., 2010

Phase function

- Photometric function *F*: $R(i,\varepsilon,\varphi) = R_0 F(i,\varepsilon,\varphi)$,
  i -incidence, ε -*emission* , φ -azimuth angle,
  R – bidirectional reflectance , $R_0 = R(0,0,0)$
- Factorization of photometric function *F*:
  $F(\alpha,\beta,\gamma) = f(\alpha)\cdot D(\alpha,\beta,\gamma)$, where
  α,β,γ – phase angle, luminance longitude, luminance latitude,
  $f(\alpha)$ - ***phase function***
  $D(\alpha,\beta,\gamma)$ - disk function (brightness trend “limb-terminator”, sphericity of the planet)
- $f(\alpha) \rightarrow$ optical properties of the lunar surface

Phase ratios: measurements of phase function





Phase slope
$\xi = f(\alpha_1)/f(\alpha_2)$

Phase function: Physical effects

The interaction of light with the regolith:

√ single-particle scattering
√ incoherent multiple scattering between particles
√ mutual shadowing of particles coherent multiple
√ coherent backscatter enhancement at opposition
√ macroscopic surface roughness

Relative contribution of all those effects:

controlled by the physical properties of the regolith (the transparency, shape and compaction of regolith particles)

Phase function: Physical effects

- $1^\circ < \alpha < 5^\circ$ – coherent backscatter enhancement and shadow-hiding effect in the regolith are important
- $5^\circ < \alpha < 40^\circ$ – the shadow-hiding effect and contribution of single-particle scattering are major
- $\alpha > 40^\circ$ – the shadow-hiding effect on all roughness scales, including the scales of surface topography, becomes significant

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* Shadow-hiding effect in regolith: also the multiple light scattering *within and between particles* → secondary illumination of shadows weakening their effect.

Albedo-related variations of ξ

- The general ***inverse correlation* of *steepness* ξ with *albedo:***

increase of single-particle albedo →
surface albedo enhancement →
growth of the illumination of the shadowed areas with diffusely scattered light →
growth of multiple scattering contribution →
weakening shadow-hiding effect

Anomalies of phase function

- The general ***inverse correlation* of *steepness*** ξ **with *albedo***

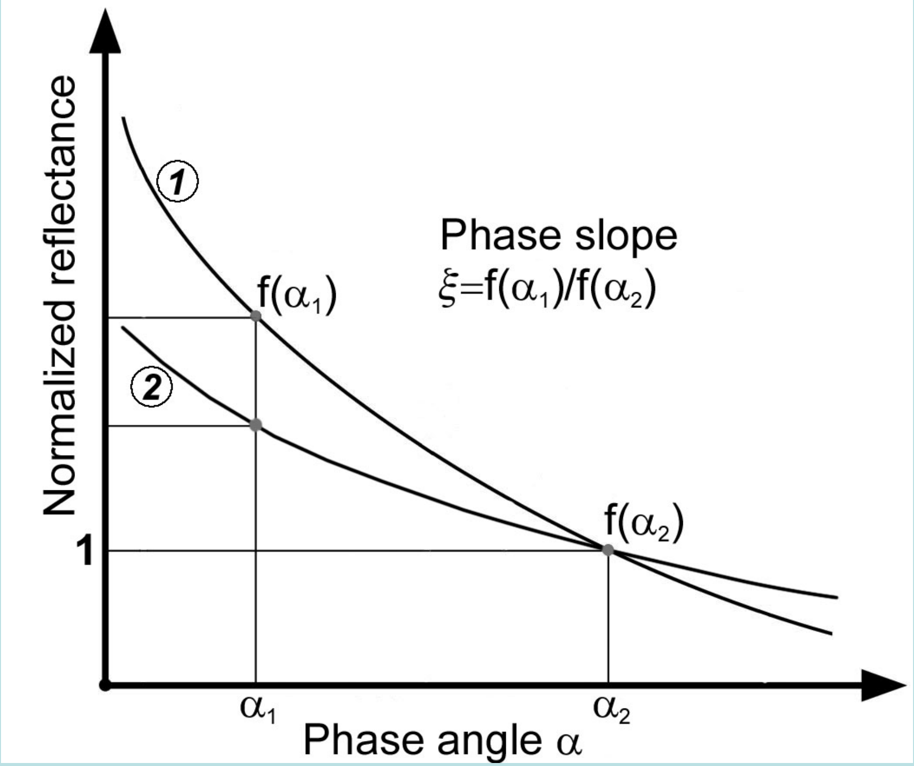
- Significant deviations from the
  "***inverse correlation"*** rule:

<u>possible anomalies in the lunar regolith structure</u>

- Low-ξ **"negative"** photometric anomalies
  (*smooth phase function*)

- High-ξ **"positive"** photometric anomalies
  (*steep phase function*)

Phase-ratio imagery: qualitative estimates of regolith structure variations

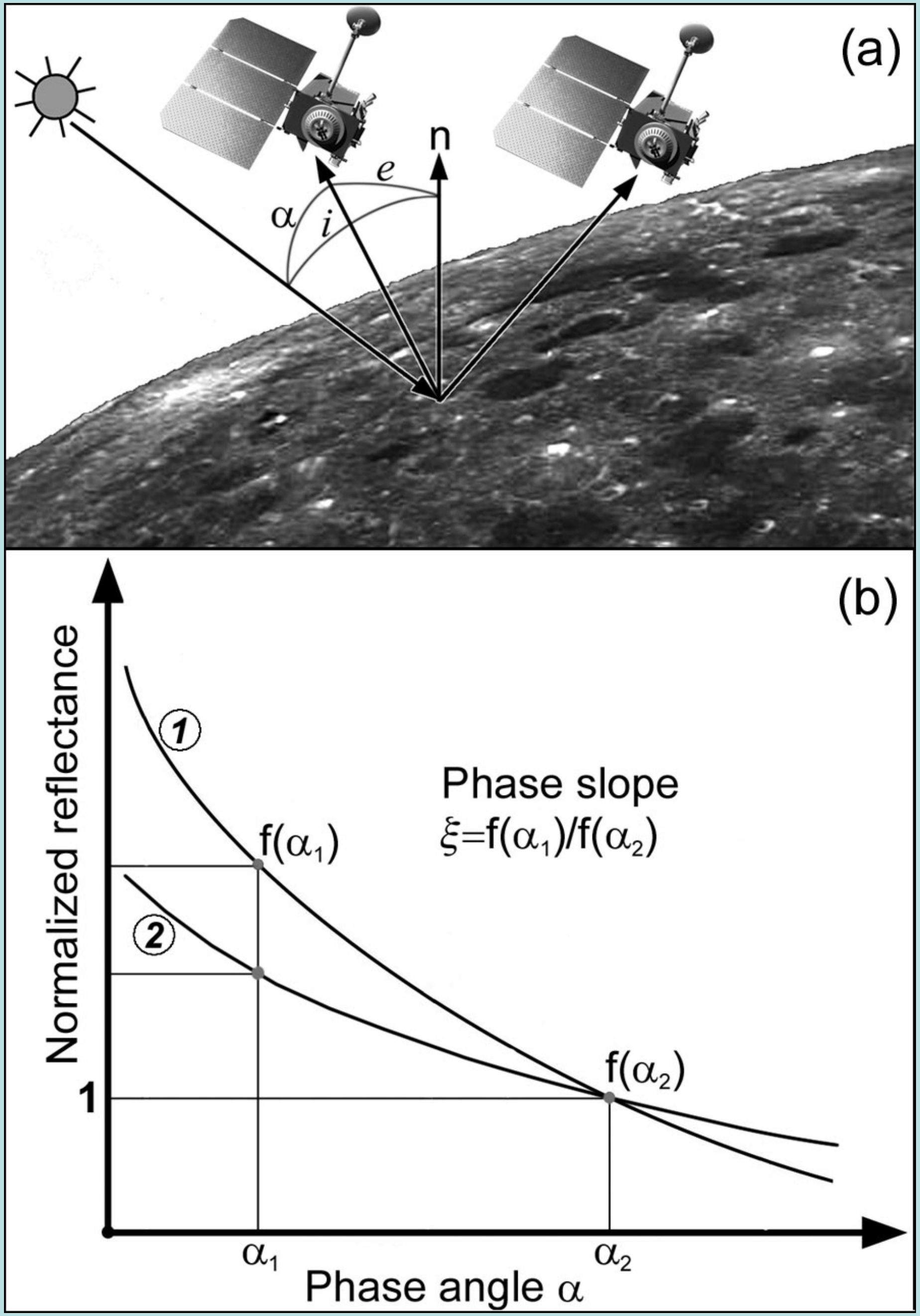


The phase slope is when	steeper	smoother
the *surface* is	dark	bright
grains are	coarse	fine
and *packed*	loosely	tightly
there are	many boulders	few boulders

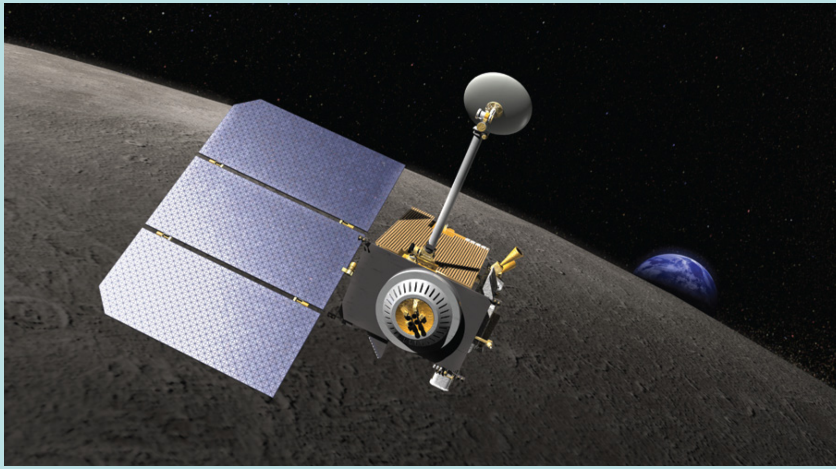
Test of the phase-ratio method: imagery of the Apollo landing sites

(1) Regolith properties have been studied *in situ*

(2) Documented changes of the regolith structure



PHOTOMETRIC ANOMALIES IN THE APOLLO LANDING SITES



- NASA Lunar Reconnaissance Orbiter (**LRO**), launched 18 June 2009
- Lunar Reconnaissance Orbiter Camera (**LROC**), includes two monochrome Narrow Angle Cameras (**NAC**s).
- The spatial resolution of the LROC NAC from the 50-km orbit is **50 cm/pixel**.
- LROC NAC image calibration pipeline :
  raw signal → radiance units of $\mu W/(cm^2\ sr\ nm)$→
  radiance factor (exposure time, dark image, and flat field).

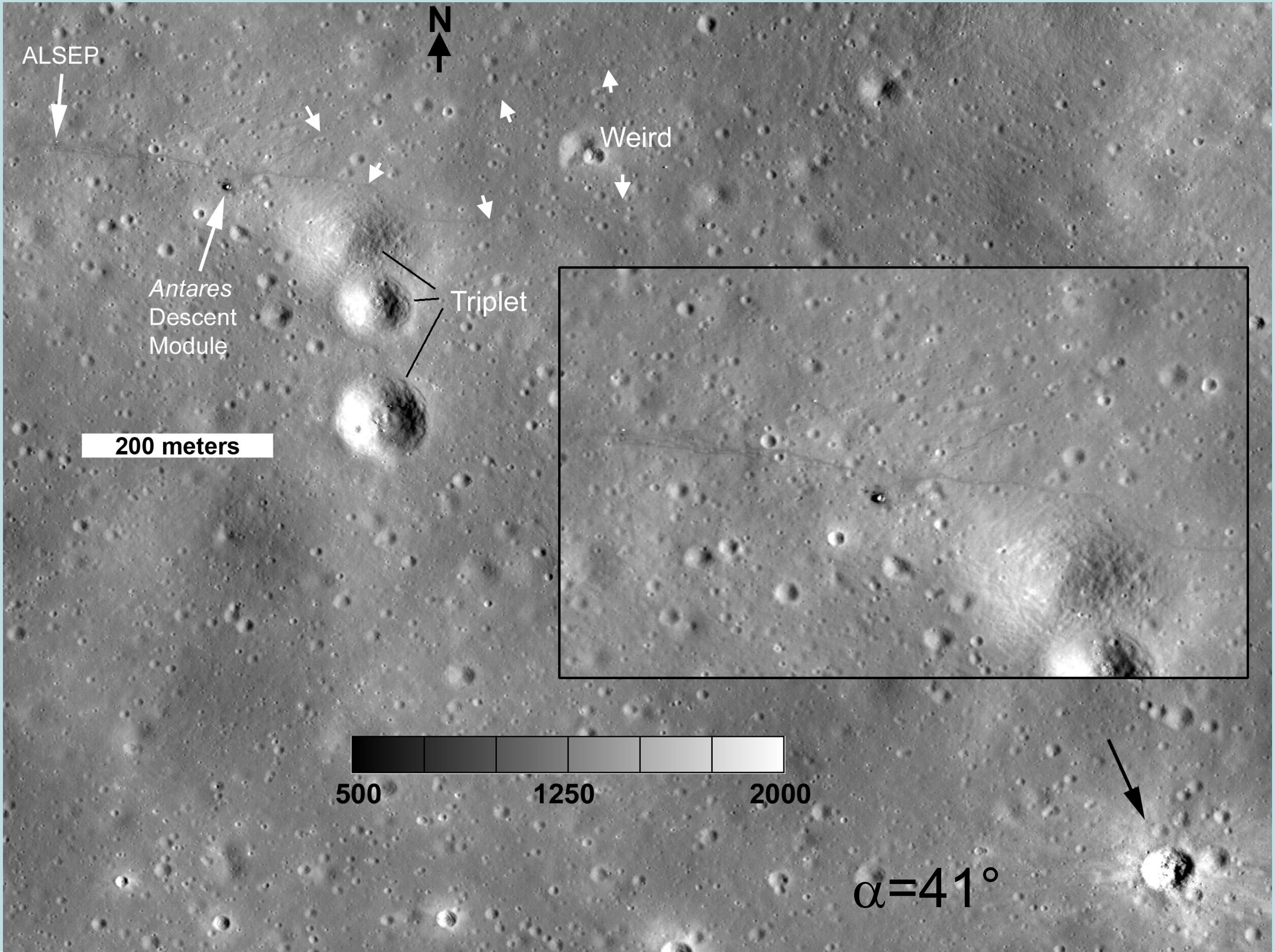
Phase-ratio imaging by LROC NAC

- Coregistration of the low- and high-phase-angle frames with subpixel accuracy
- Using a rubber-sheet geometric transformation
- Maximizing the local correlation between overlapping images (the formal accuracy of the co-registration is 1/10 pixel)

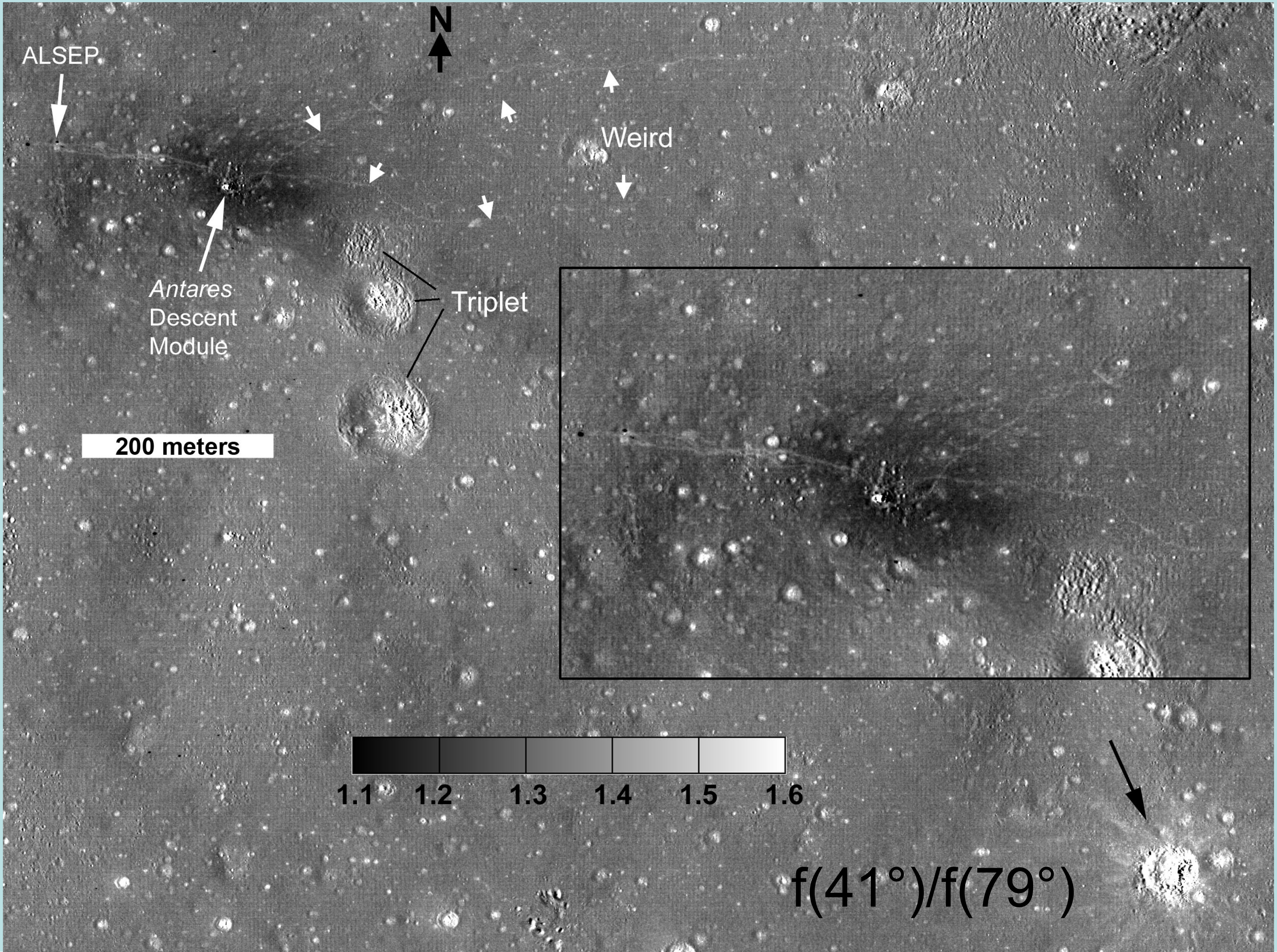
Phase-ratio imaging by LROC NAC

Landing site	Image ID	**Resolution, m/pix**	**Emission angle, deg.**	**Incidence angle, deg.**	**Phase angle, deg.**
Apollo 14	M114064206LC	0.525	16.71	57.86	41.16
	M114071006LC	0.534	22.23	56.94	79.16
Apollo 15	M111571816LC	0.522	12.19	38.55	30.24
	M111578606LC	0.546	22.26	37.91	56.18
Apollo 17	M113751661LC	0.525	18.86	56.73	38.80
	M113758461RC	0.515	14.88	55.72	70.17

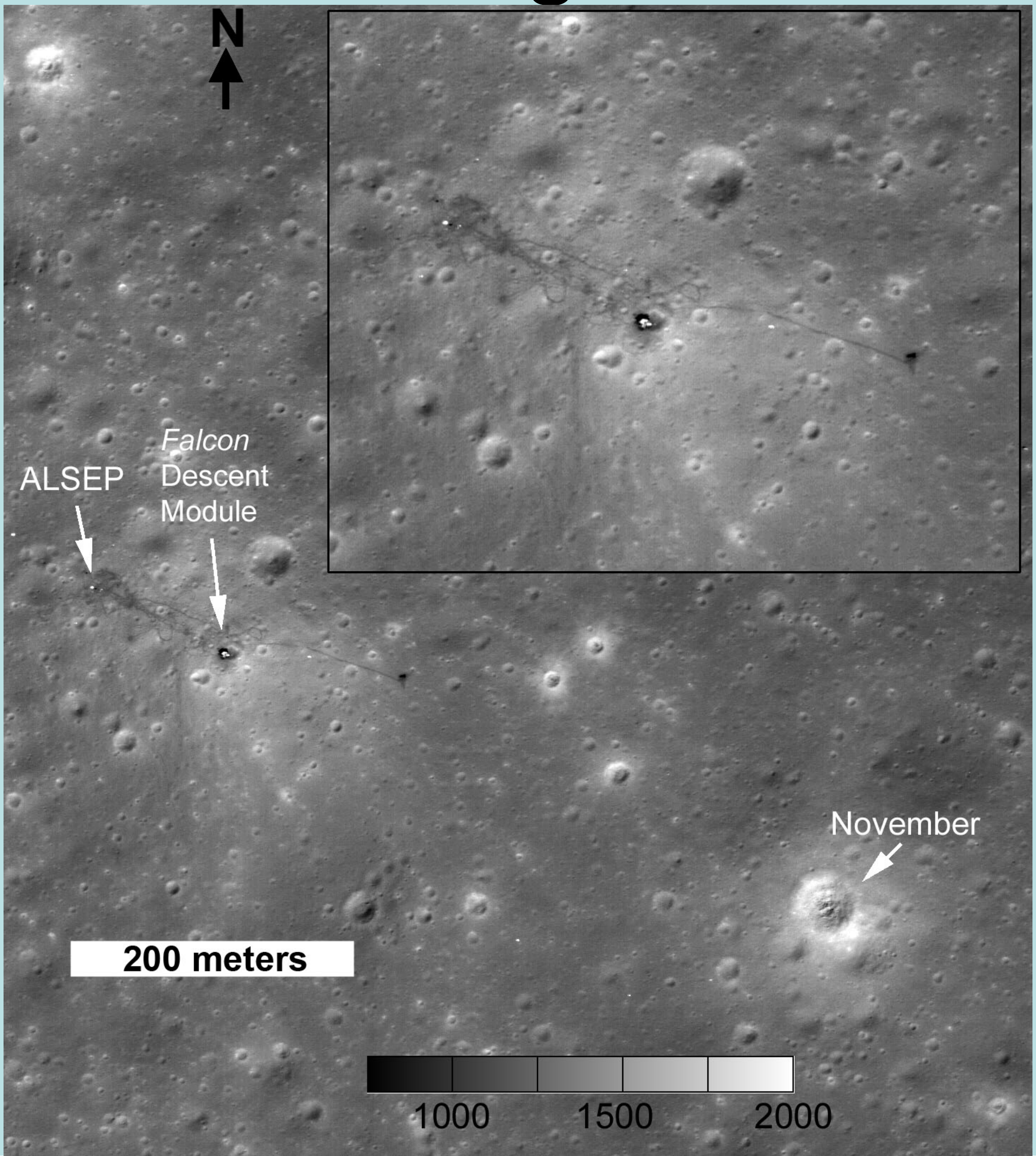
Apollo-14 landing site: reflectance



Apollo-14 landing site: phase ratio

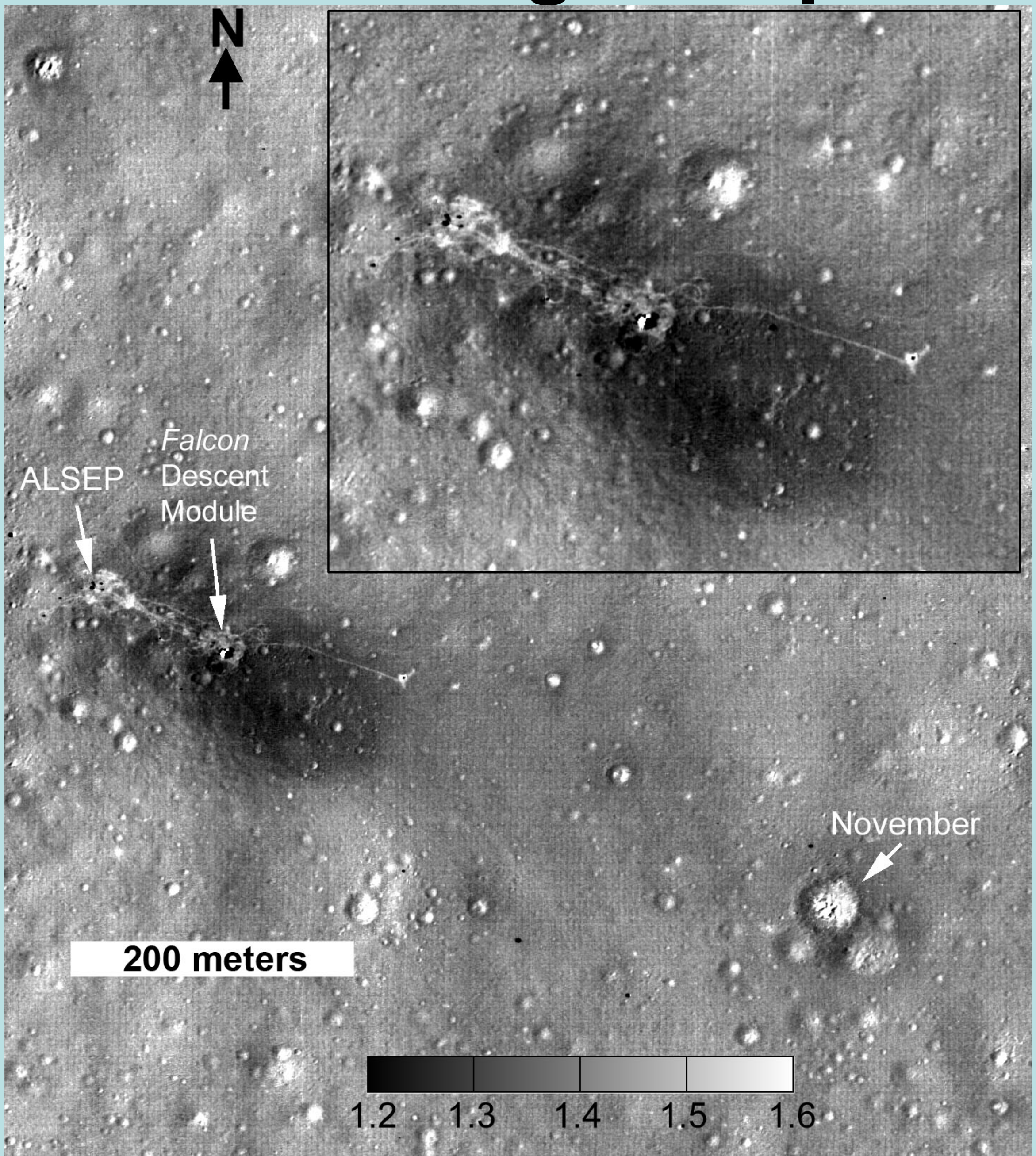


Apollo-15 landing site: reflectance



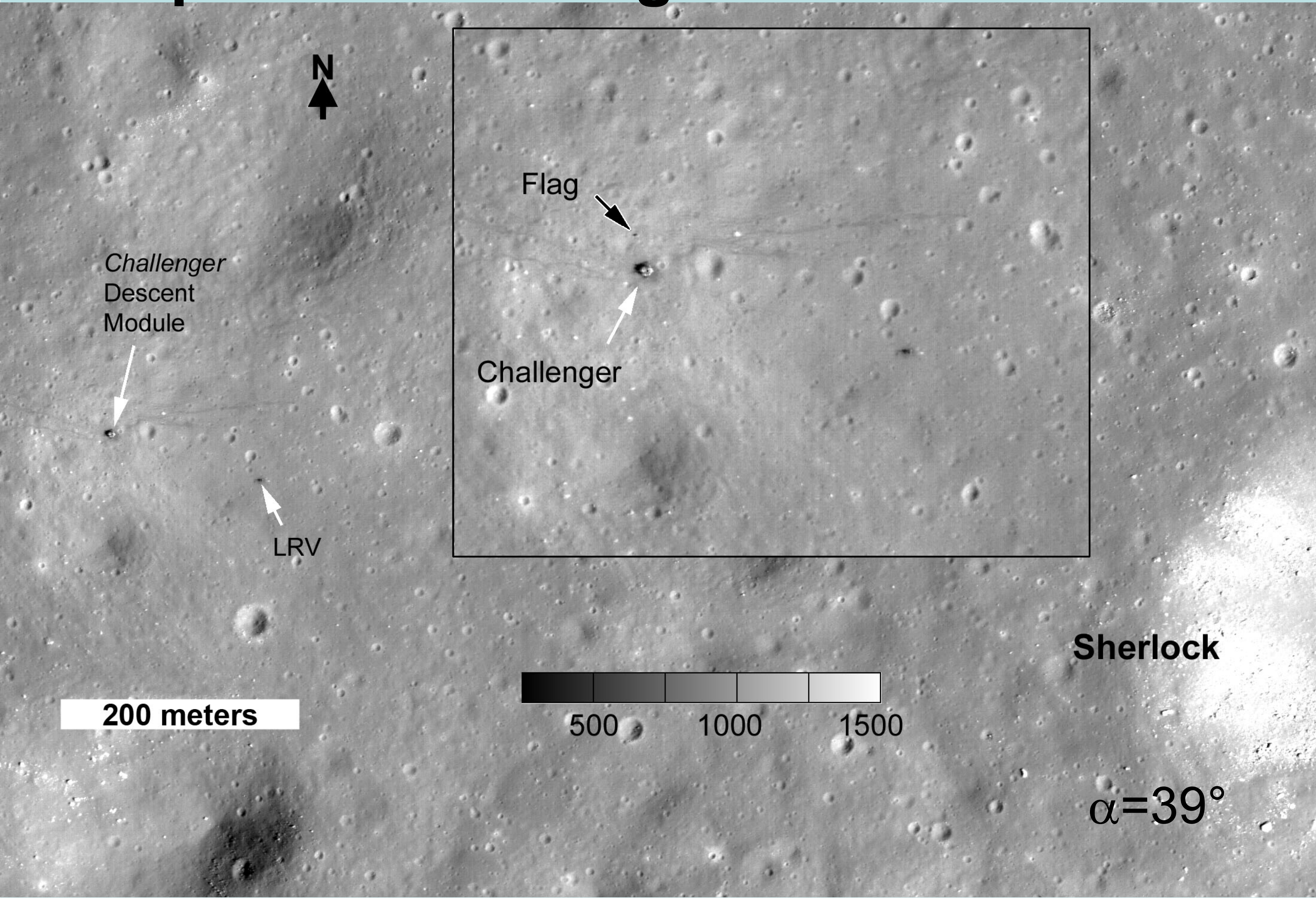
α=30°

Apollo-15 landing site: phase ratio

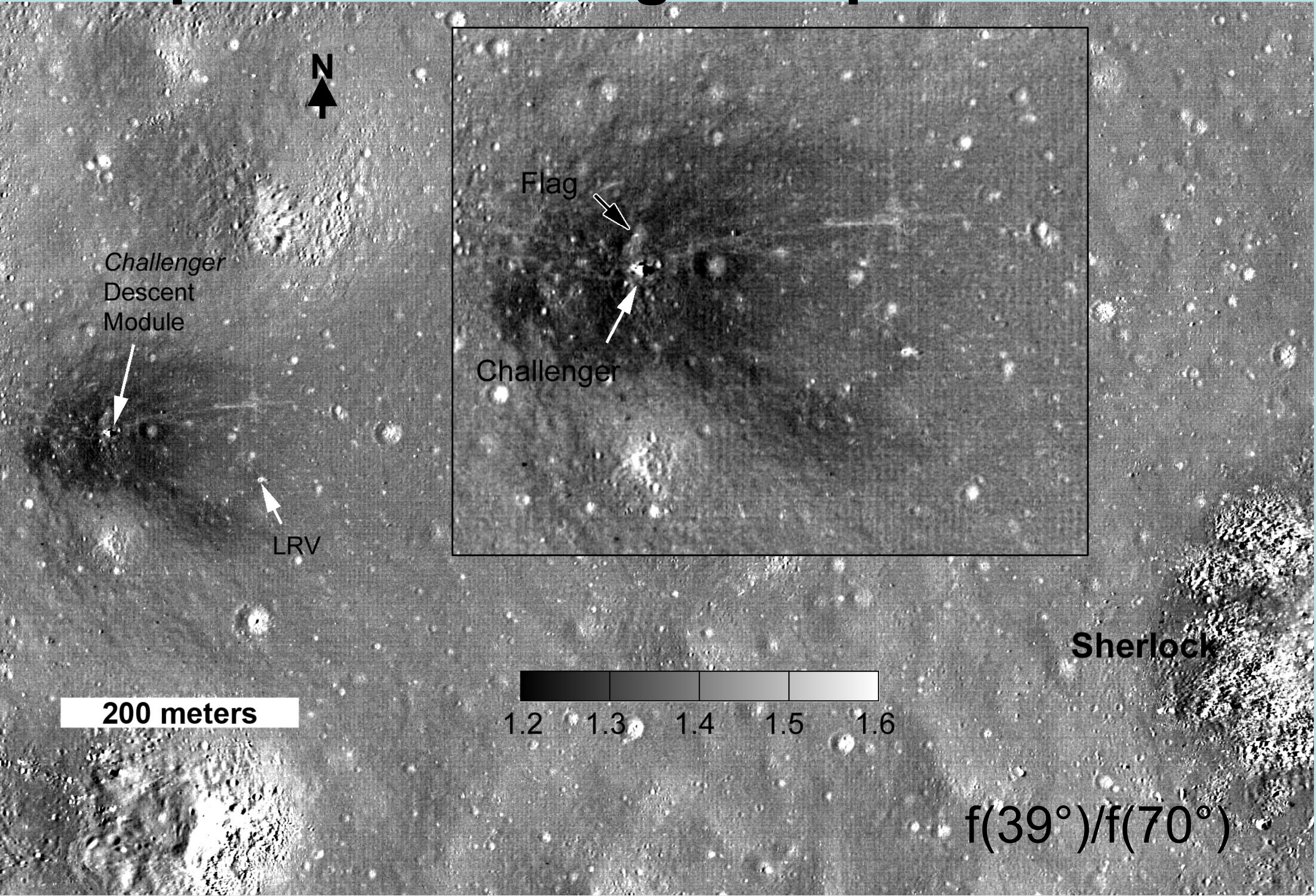


f(30°)/f(56°)

Apollo-17 landing site: reflectance



Apollo-17 landing site: phase ratio



PHOTOMETRIC ANOMALIES IN THE APOLLO LANDING SITES

- Landing sites reveal photometric anomalies (lower values of the phase-function steepness).
- Reason: Smoothing of the surface microstructure caused by the engine jets of the landing modules
- Another type of anomaly – higher phase-function slopes for tracks left by astronaut boots and the wheels of the MET and LRV, soil loosening.
- <u>Quantitative estimate</u>: 10-15% of phase slope = disturbances on <u>mm-cm</u> scales
- Method allows an identification of naturally altered or artificially disturbed surface structure

* Kaydash et al., Icarus, 2010. 10.1016/j.icarus.2010.08.024