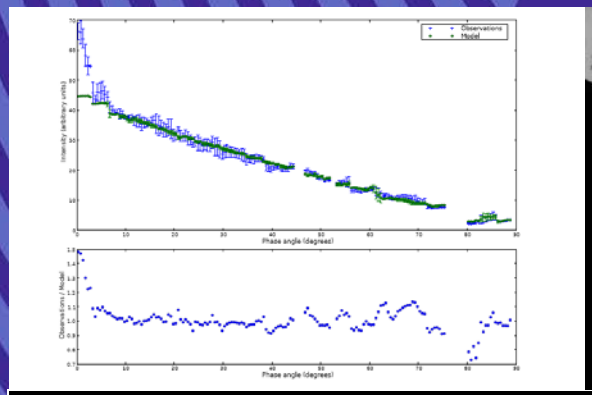
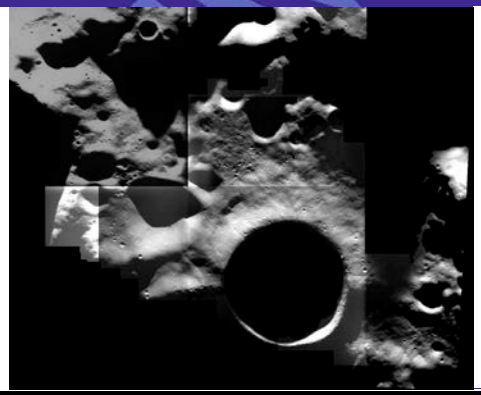
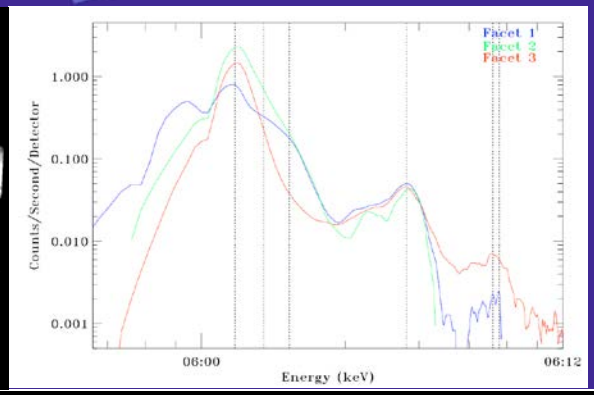
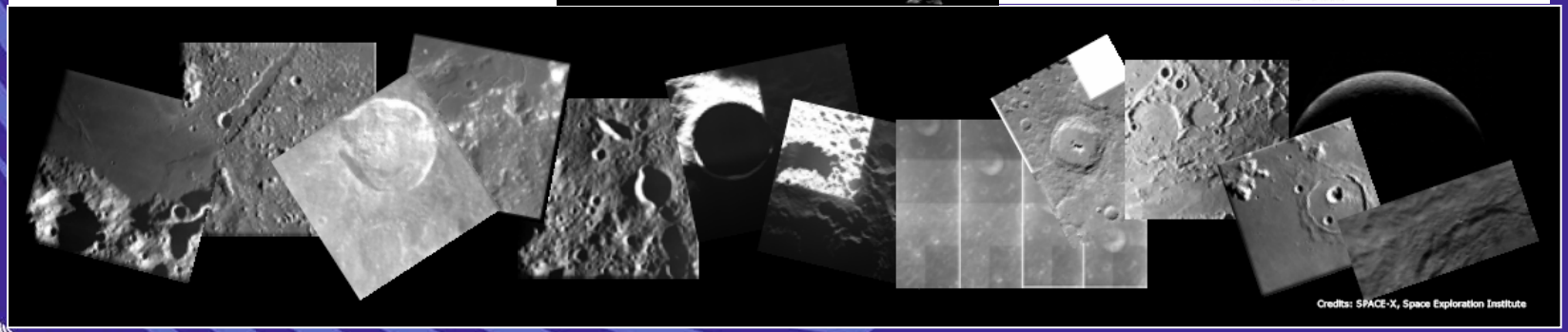
Constraints on Moon Evolution & Planetary Processes using SMART-1

Bernard H. FOING* & SMART-1 Team









http://sci.esa.int/smart-1/

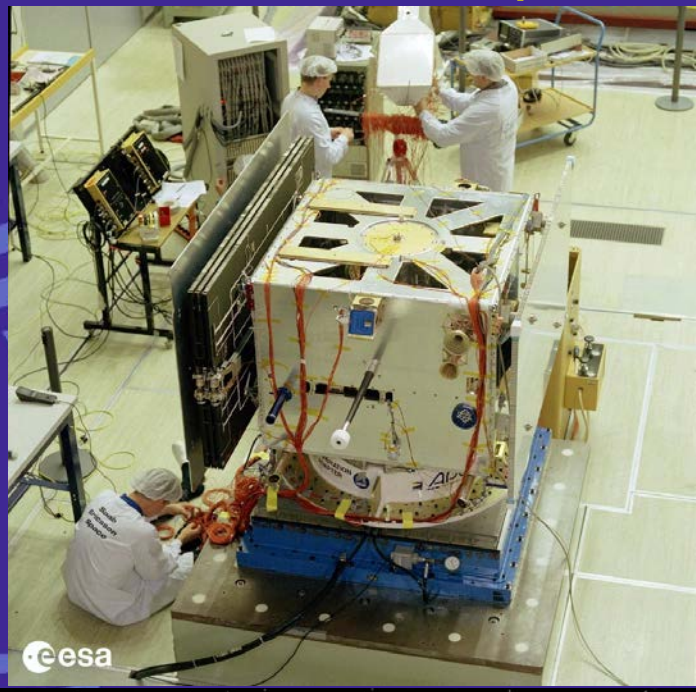
http://sci.esa.int/ilewg

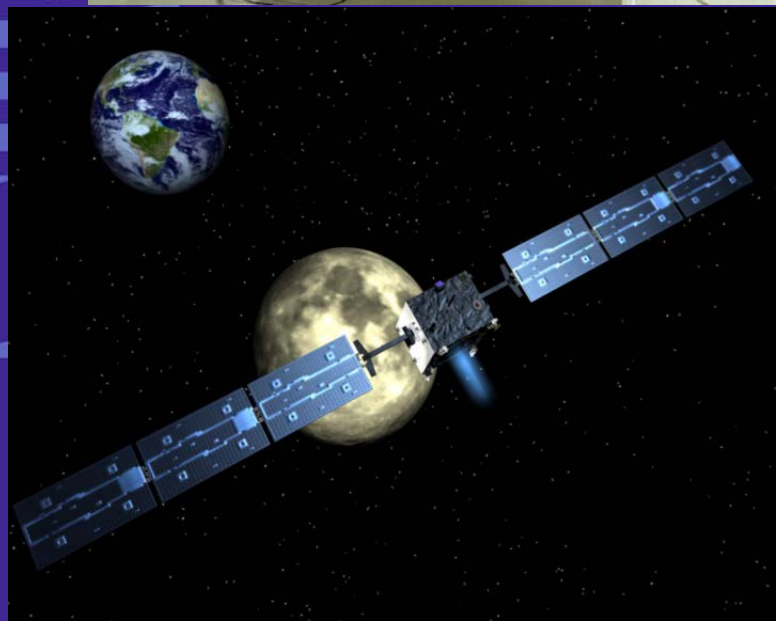
SMART-1 Mission (http://sci.esa.int/smart-1/)

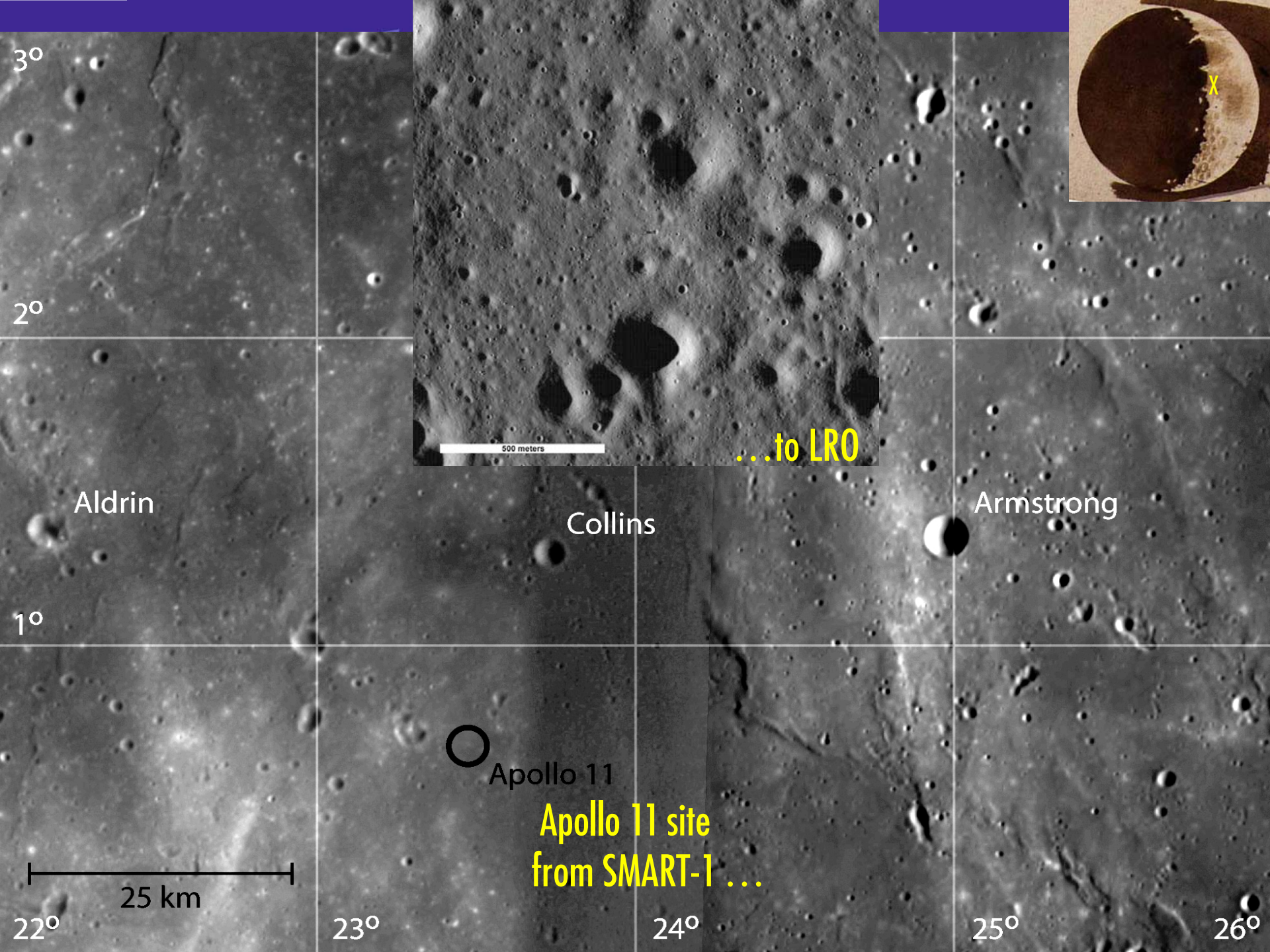
- Small Mission for Advanced Research in Technology
  - Spacecraft & payload technology demonstration for future cornerstone missions
  - Management: faster, smarter, better (& harder)
  - Early opportunity for science & exploration

SMART-1 Solar Electric Propulsion to the Moon

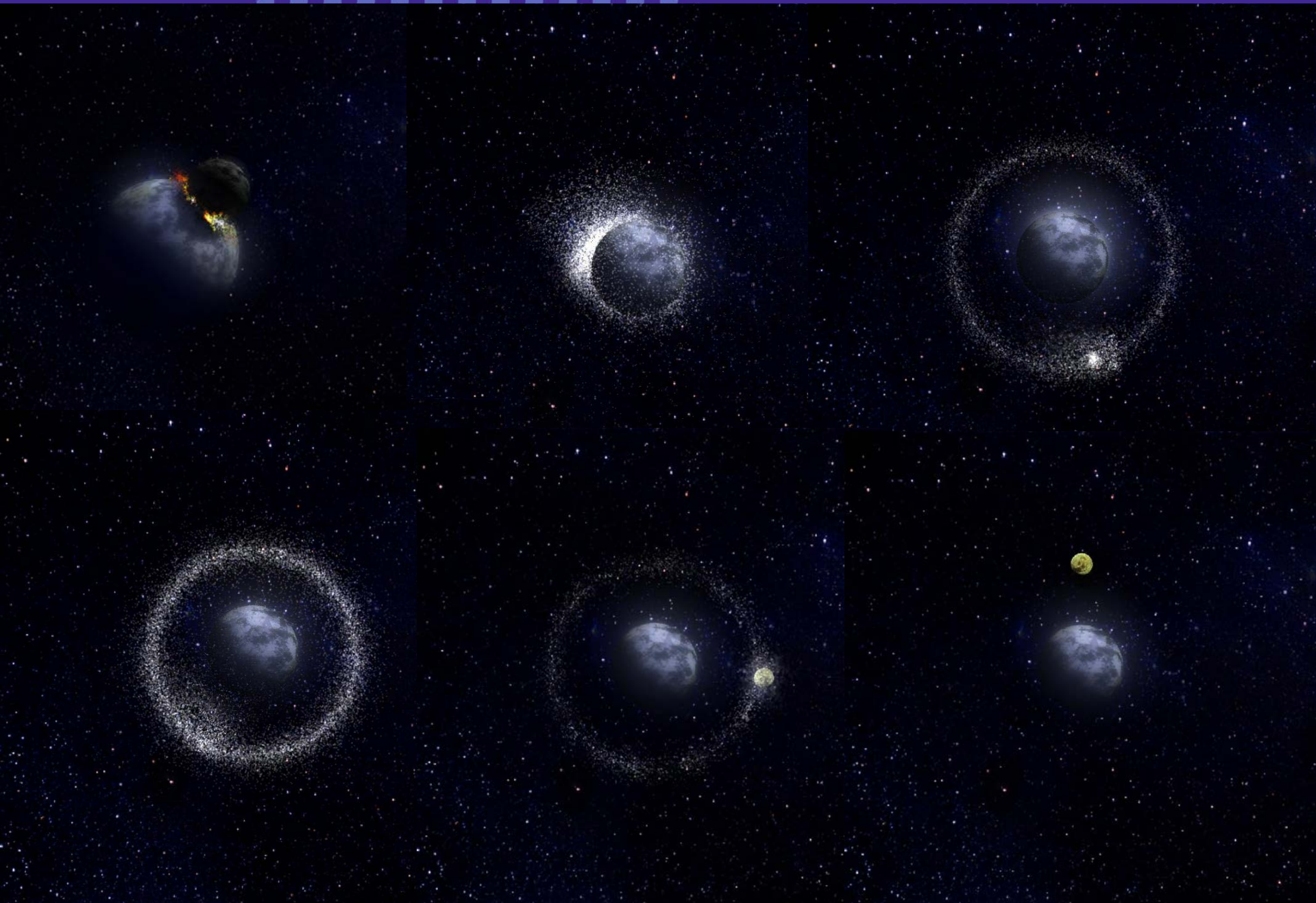
- Test for Bepi Colombo & future missions
- Mission approved 99, built in 2.5 years
- 19 kg payload, 370 kg spacecraft, 60 l fuel
- launched Ariane 5 on 27 Sept 03, Kourou
- 18 month cruise, 6+12 month in science orbit
- controlled grazing impact 3 sept 2006
- results (76 R, 320 C&T) & PSA data archives






3°
2°
1°
22°
23°
24°
25°
26°
Aldrin
Collins
Armstrong
Apollo 11
25 km
500 meters
. . . to LRO
X
Apollo 11 site
from SMART-1 . . .

Constraining Moon formation scenarios

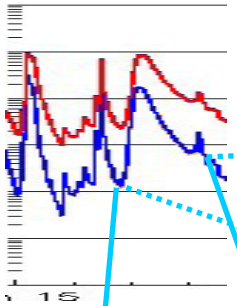


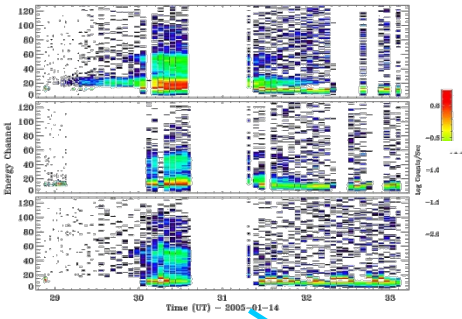
The Sun shines X-rays

The Moon glows

-> SMART-1

D-CIXS





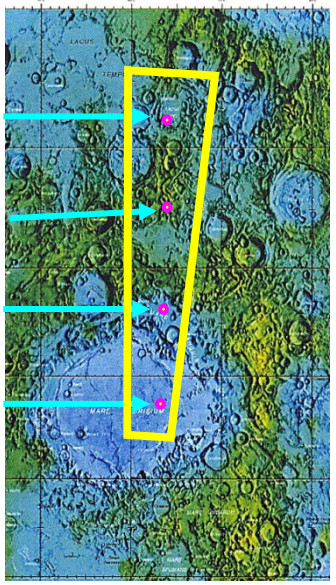
January 15th, 2005.

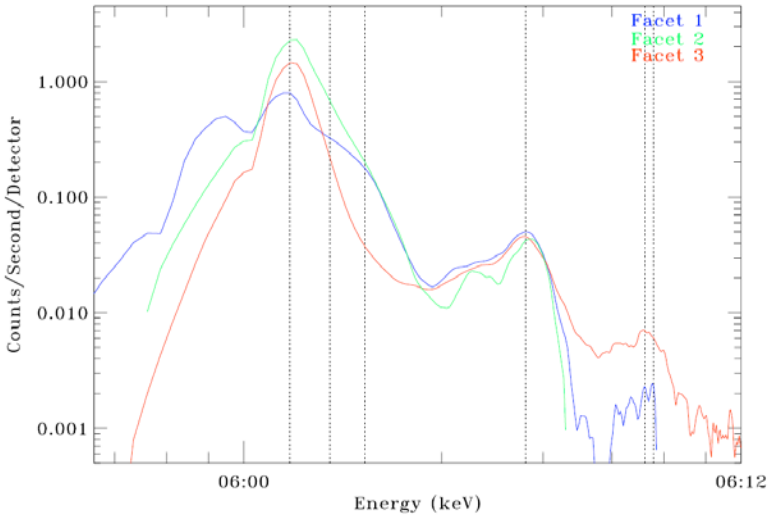
06:30

06:20

06:10

06:00





Derived elemental composition

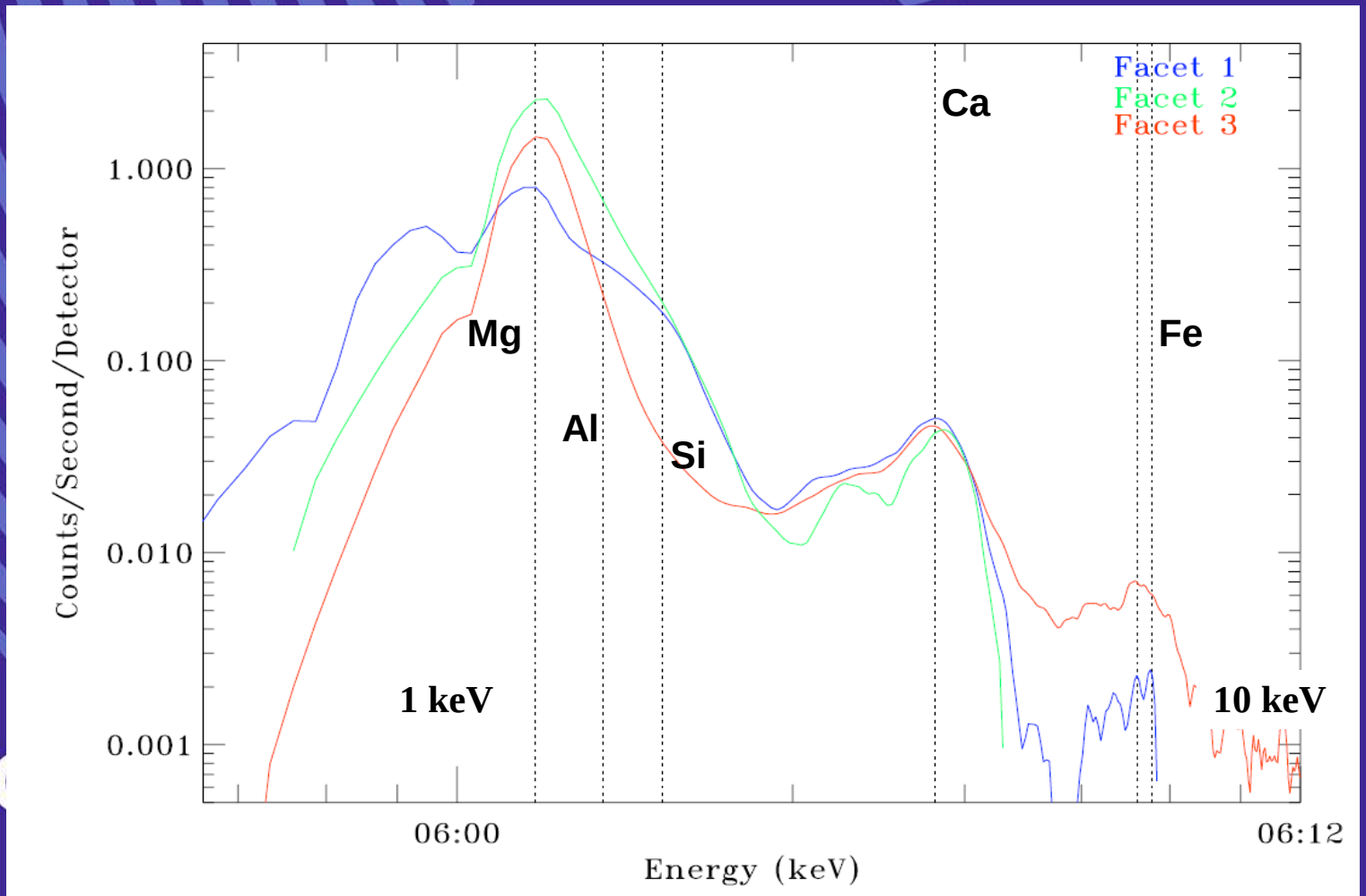
1st detection of Calcium and Magnesium

esa

X-ray signatures of Chemical Elements

First ever remote sensing measurements of Ca at the Moon

Highlands vs Crisium Mare variations Mg Al Si, not for Ca



Titanium on the Moon (DCIXS Farside / Nearside)

No Ti on
Far side
A11 G
A12 B
QUE93069 R

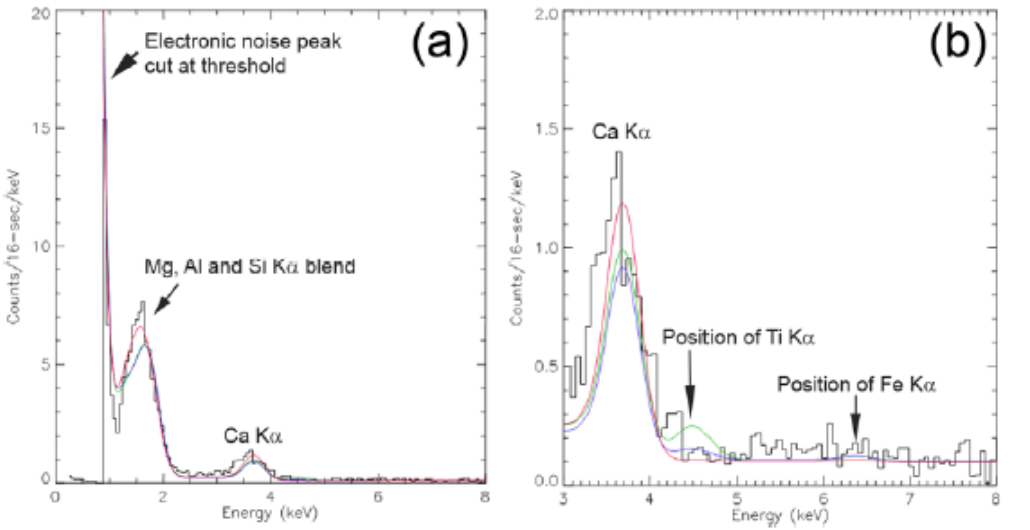
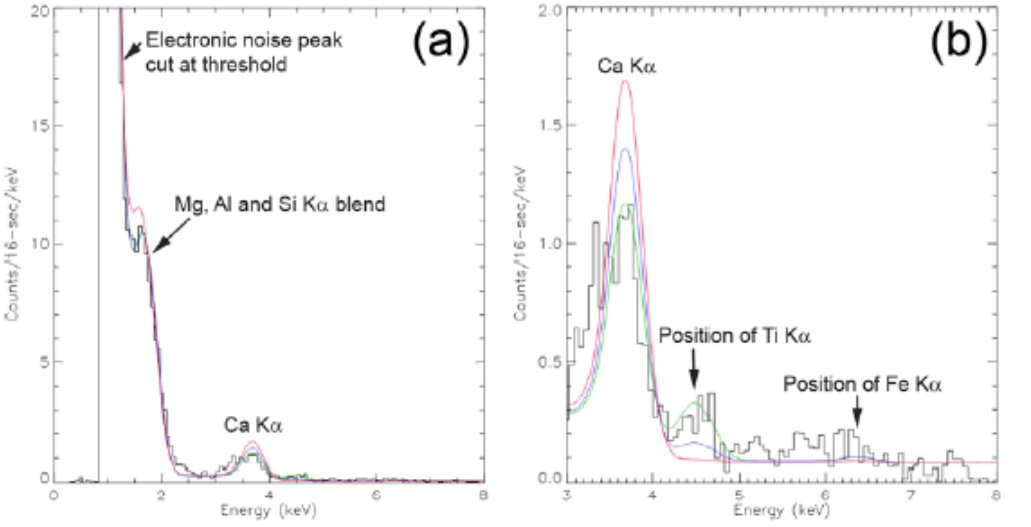
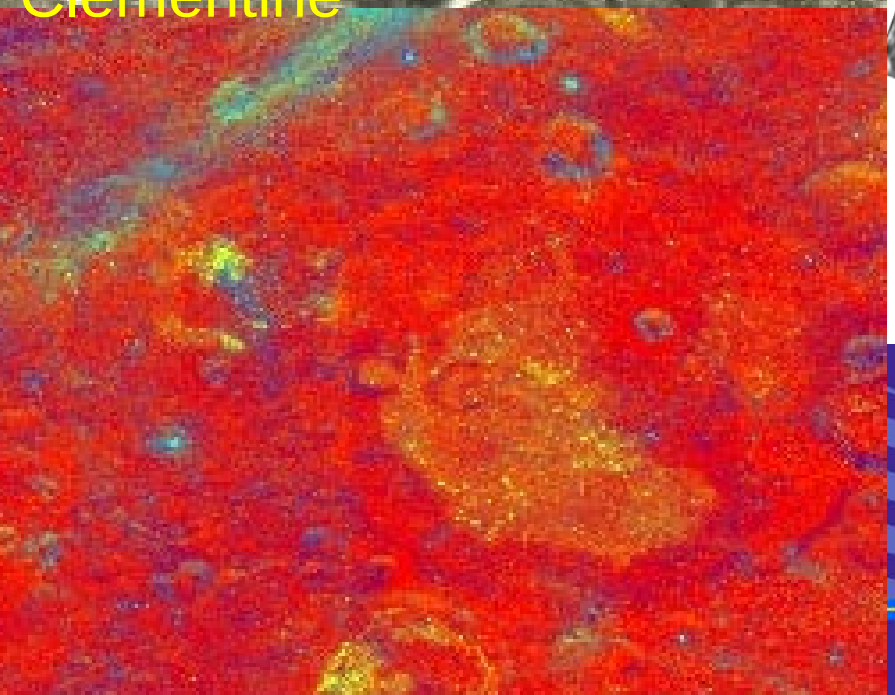


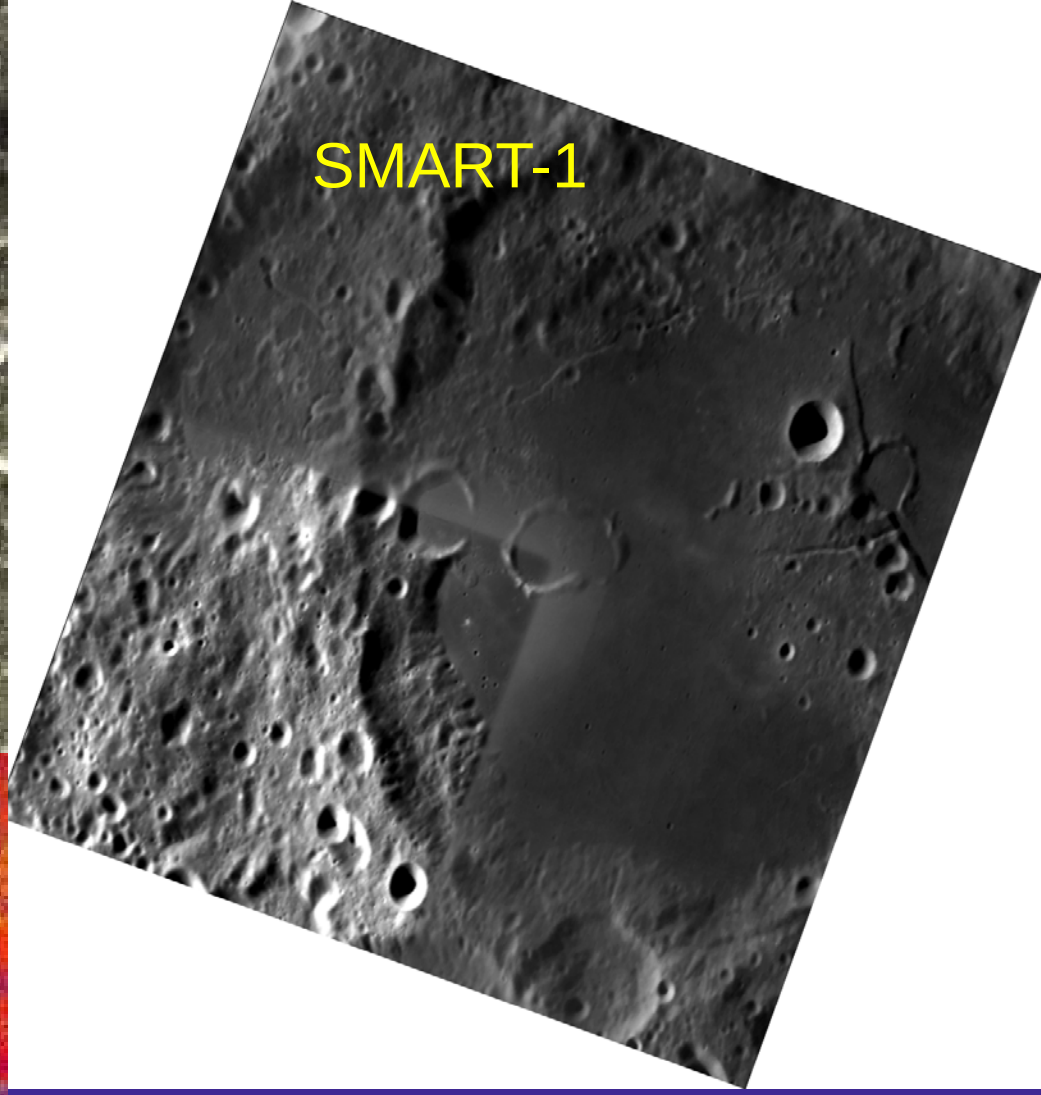
Figure 2.

Ti on
Near side Mare
A11 G
A12 B
A16 R



Swinyard et al 2009
Planetary Space Science





Jules Verne crater: Volcanism in South Pole-Aitken Basin

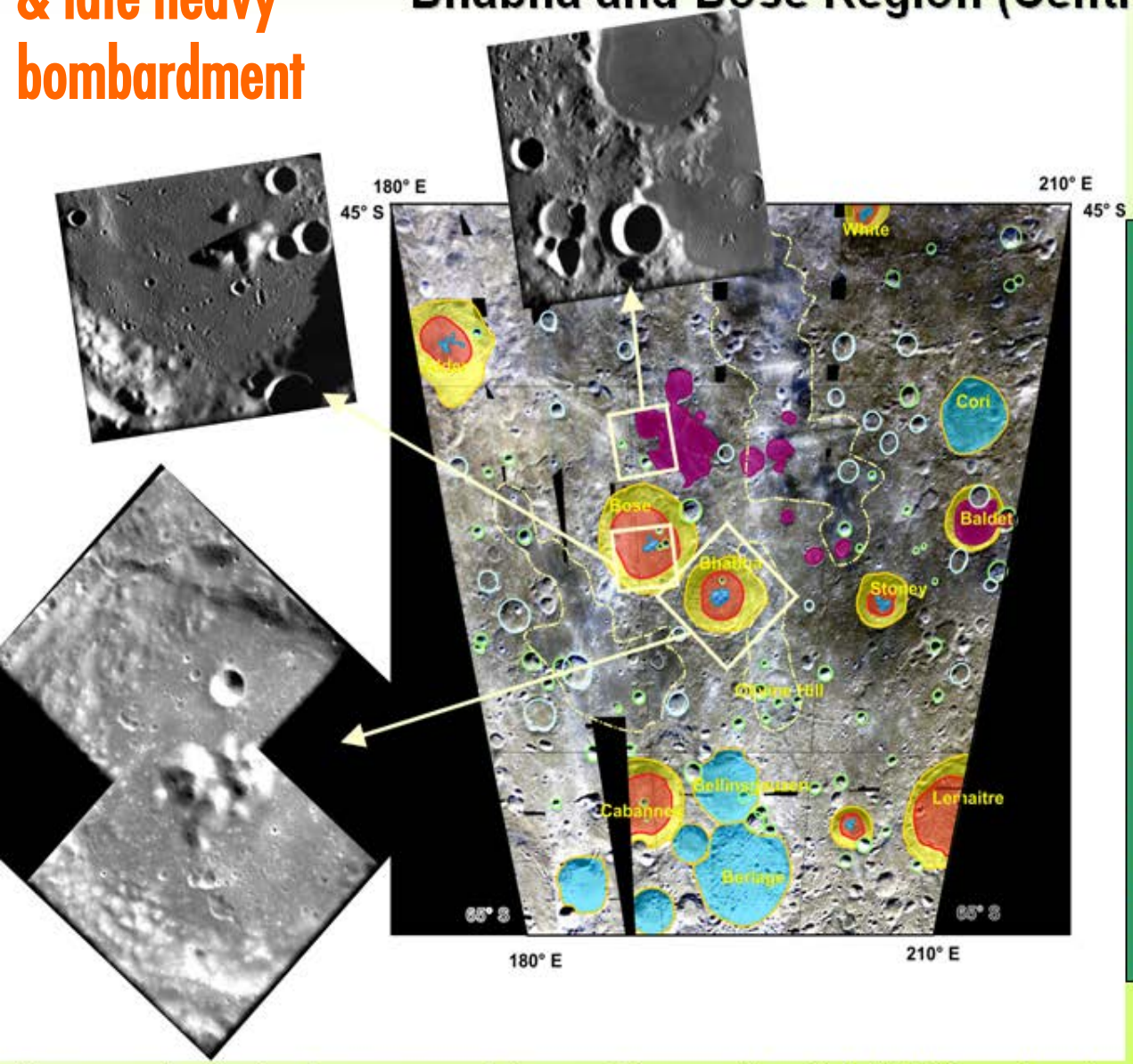
South Pole-Aitken Basin & late heavy bombardment

Geological mapping

Borst, Foing et al 2012

Bhabha and Bose Region (Central SPA)

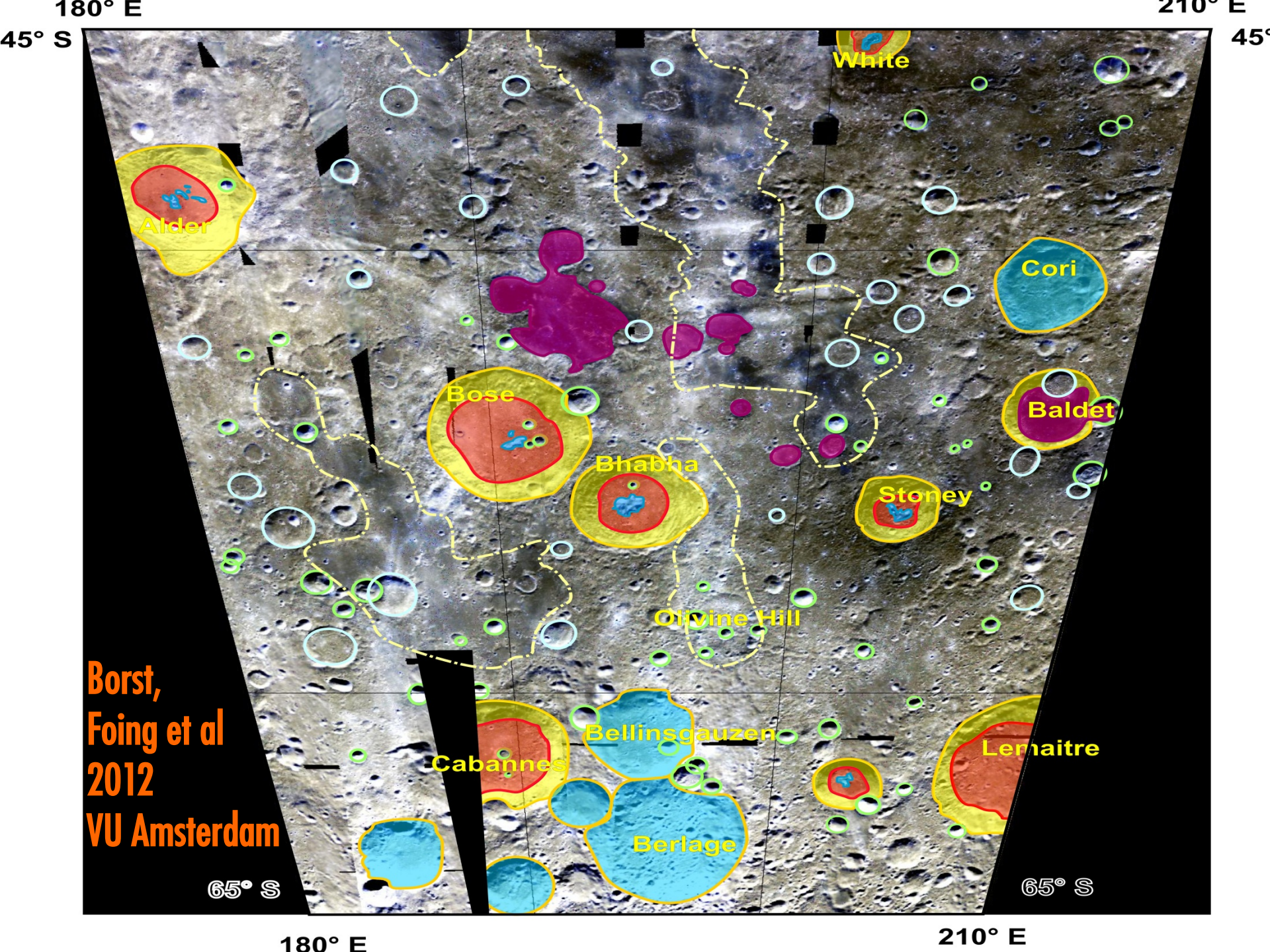
-> support to farside sample return



Units

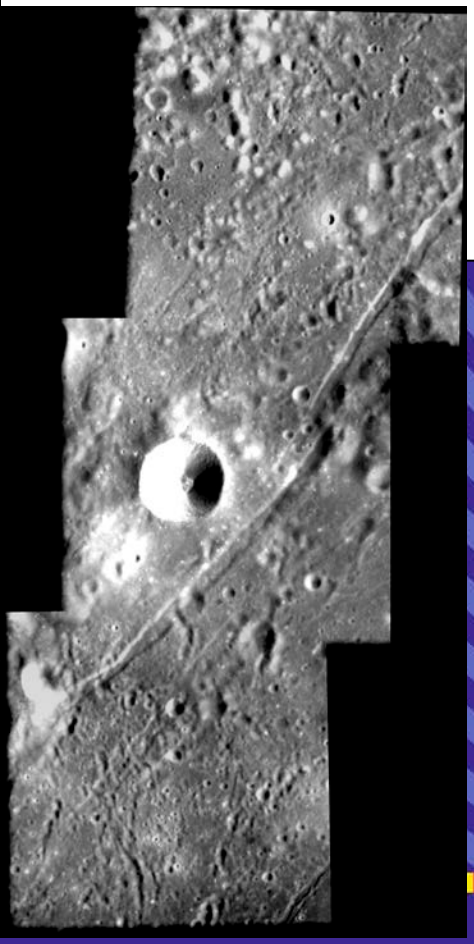
- Crater wall; freshly exposed materials
- Crater floor; weathered, smooth surface with impact melt
- Central peak; uplifted material
- Volcanism; young mare basalt
- Dashed Areas; geochemically different regions, possible impact melt sheet or cryptomaria
- Old craters
- Young simple craters

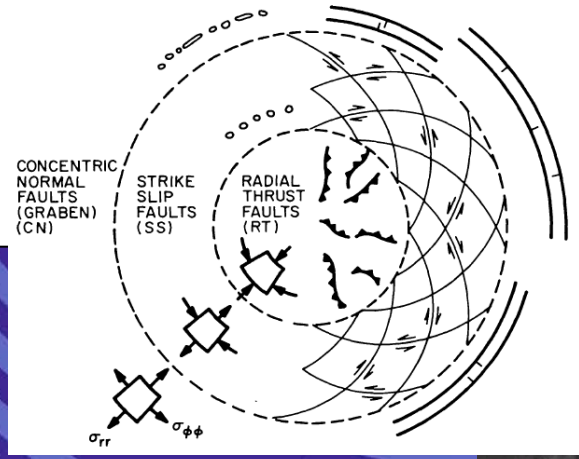
Geomorphological map overlain on Clementine (UV/VIS) real color image.
High resolution images of geomorphology from SMART-1, AMIE.

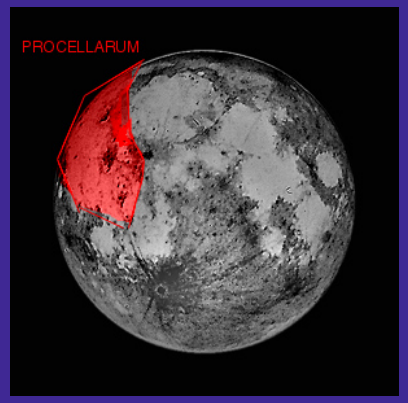

180° E
210° E
45° S
45°
White
Alder
Cori
Bose
Baldet
Bhabha
Stoney
Olivine Hill
Borst,
Foing et al
2012
VU Amsterdam
Bellinsgauzen
Cabannes
Lemaitre
Berlage
65° S
65° S
180° E
210° E

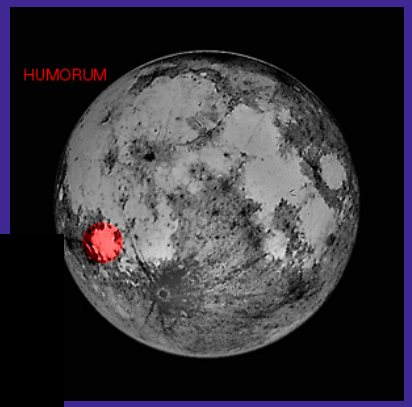
Coupling impacts, tectonics & volcanism

- Humorum: Multiringed impact basin
- Procellarum: Irregular basin
- Tectonics of mascon loading



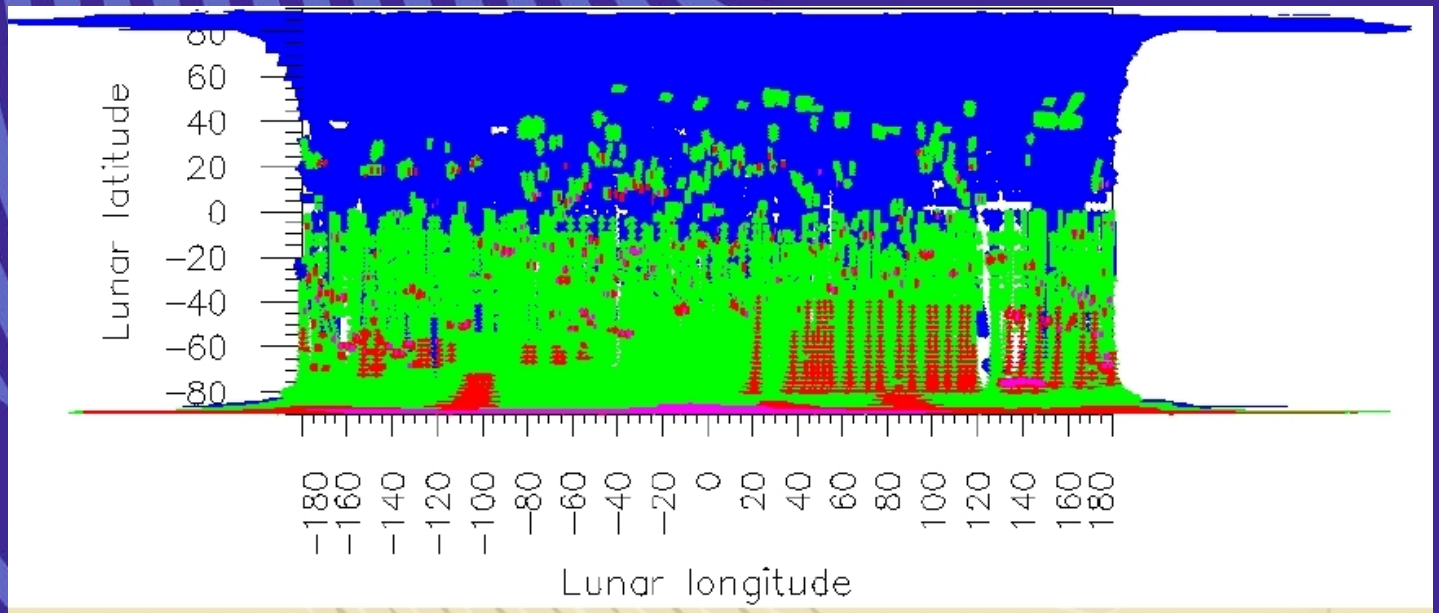


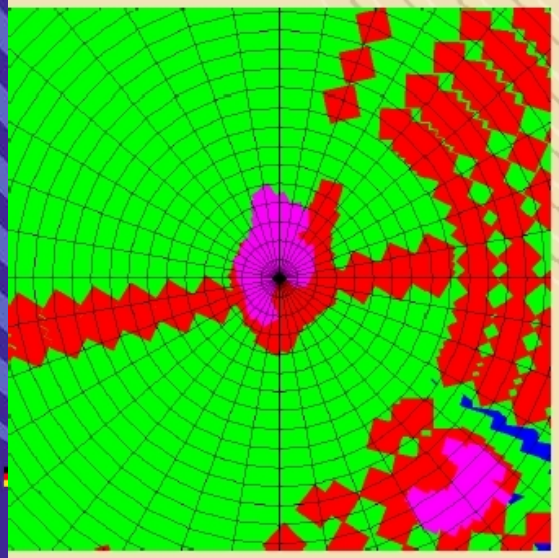




Peters Foing et al (VU Amsterdam)

SMART-1 Camera lunar coverage





- Better than 250 m/pixel
- Better than 100 m/pixel
- Better than 50 m/pixel
- Better than 35 m/pixel

Planetary Regolith properties: (Muinonen et al 2011) Multi-angular SMART-1 AMIE photometry

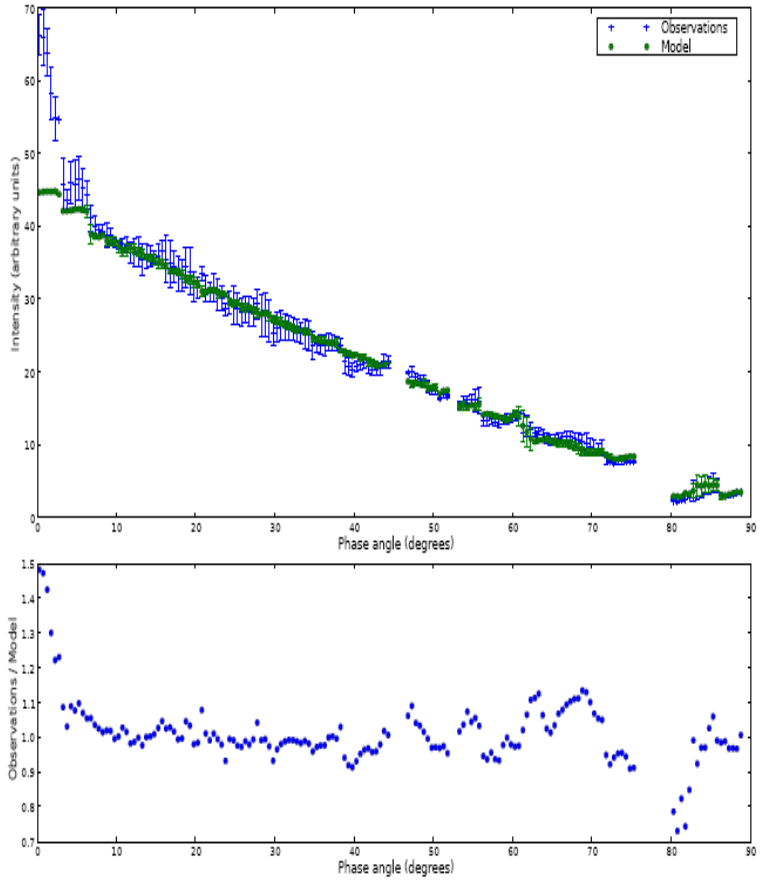


Figure 7: The multiangular AMIE photometry of the mare regions depicted in Fig. 1 fitted using the fBm-particulate-medium model with $H = 0.4$, $\sigma = 0.06$, and $v = 0.35$ (upper plate). After extracting the stochastic geometry from the photometry, we obtain the lunar mare volume-element scattering phase function (lower plate). The resulting phase function shows pronounced enhancement towards the backward scattering direction (opposition).

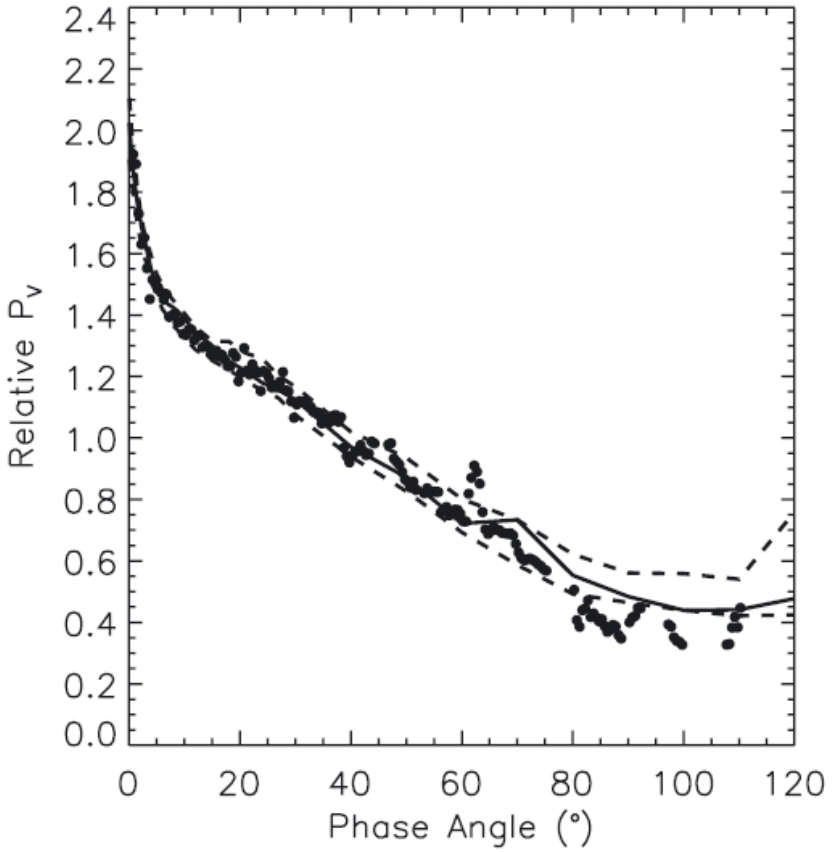
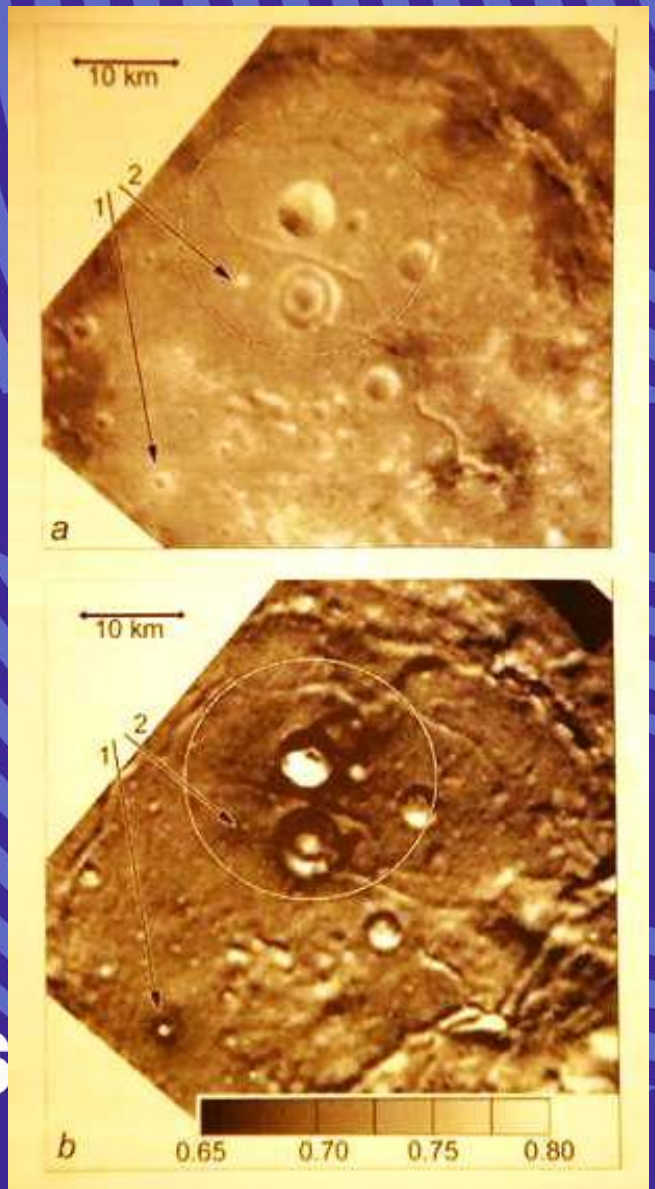


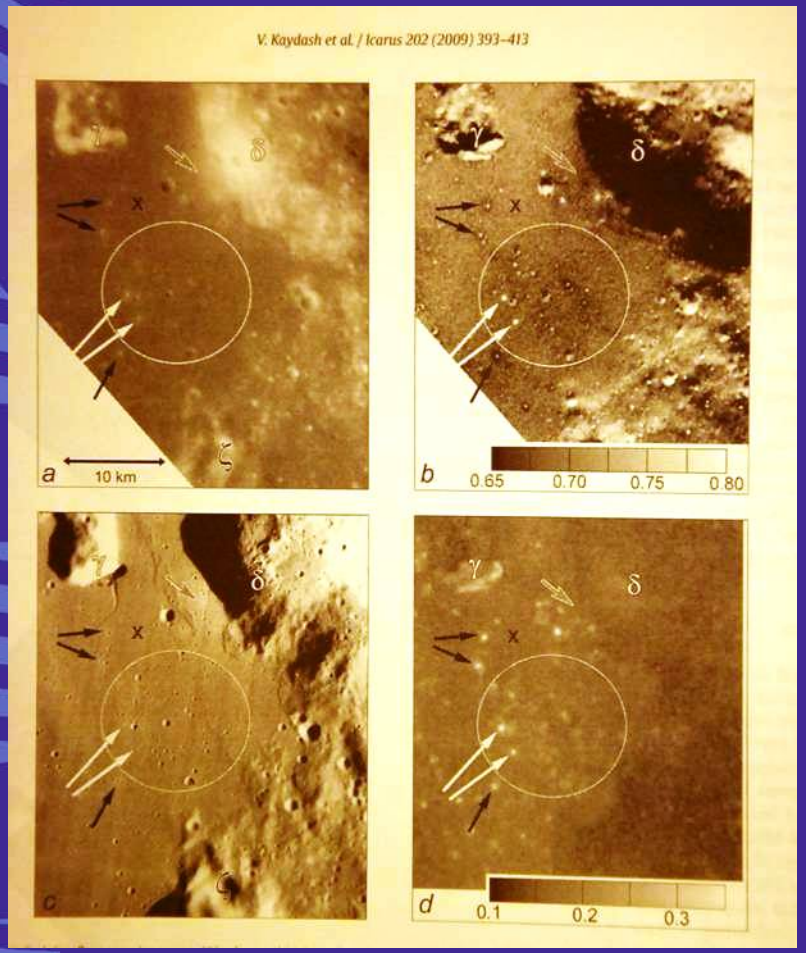
Fig. 7. The binned lunar mare volume-element phase function with the corresponding coherent-backscattering modeling including a variation envelope. Double H-G single-scattering phase functions for the fundamental scatterers give rise to coherent-backscattering peaks capable of matching the observations. For the largest phase angles, there is a deviation between the model and the observations potentially due to simplified modeling.

Photometric anomalies of lunar surface with SMART-1 AMIE
Ratios of images from different illumination phase angle
Kaydash et al Icarus 202 (2009) 393

Lavoisier

- 45 deg
- steepness





Gruithuisen dome

42 deg

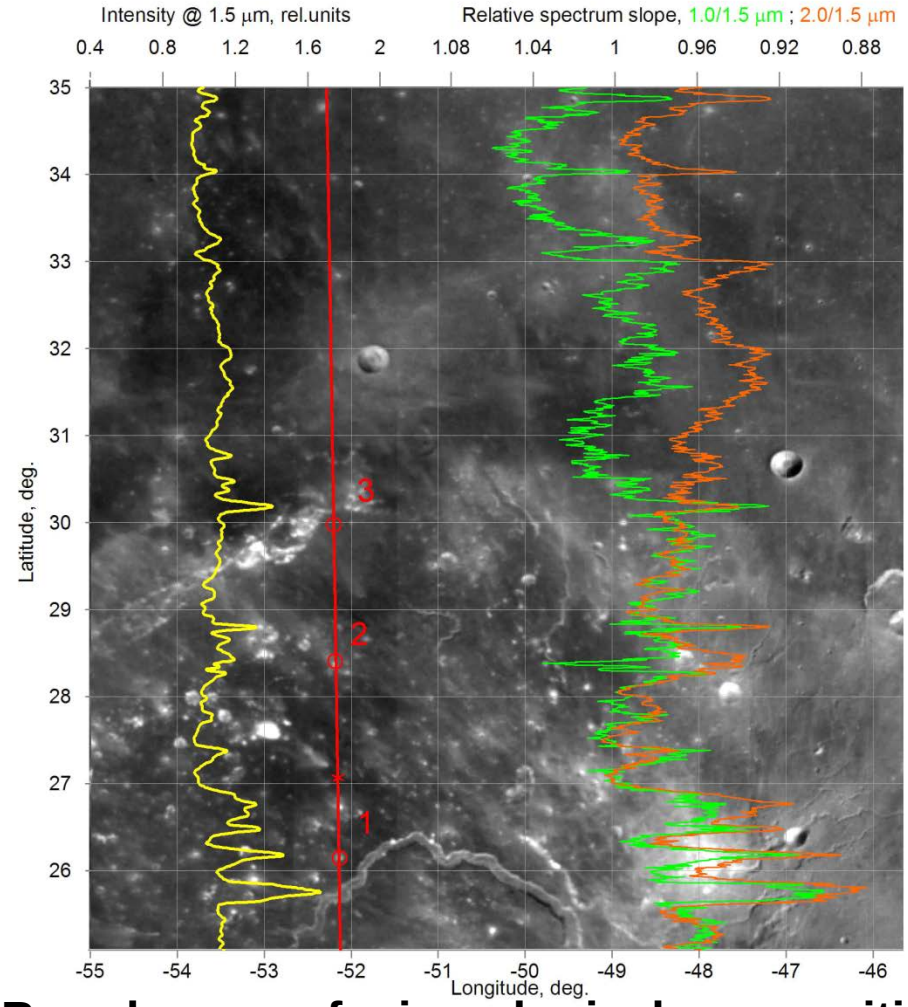
High res LO

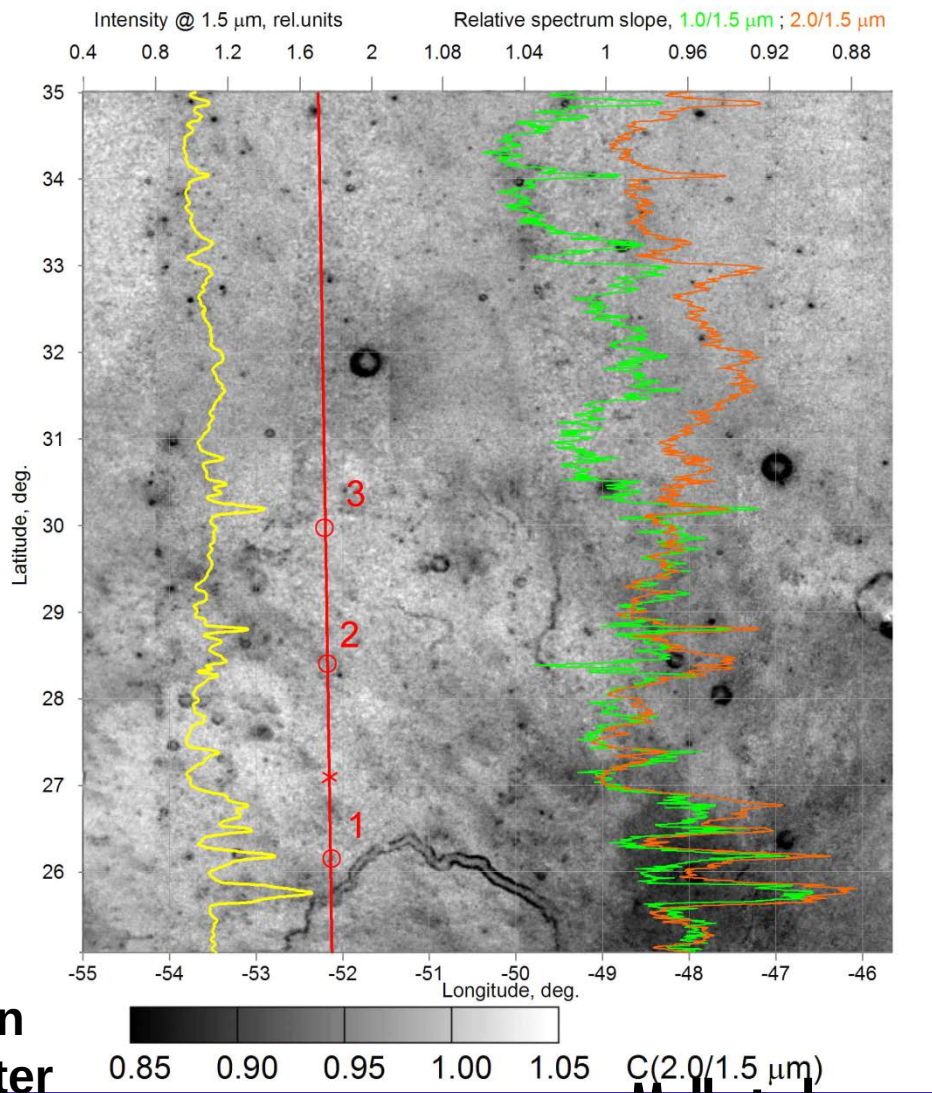
steepness

optical maturity Clem

MAPPING THE SPECTRAL PROPERTIES OF SELECTED LUNAR REGIONS

Aristarchus Plateau and Northwest of Procellarum

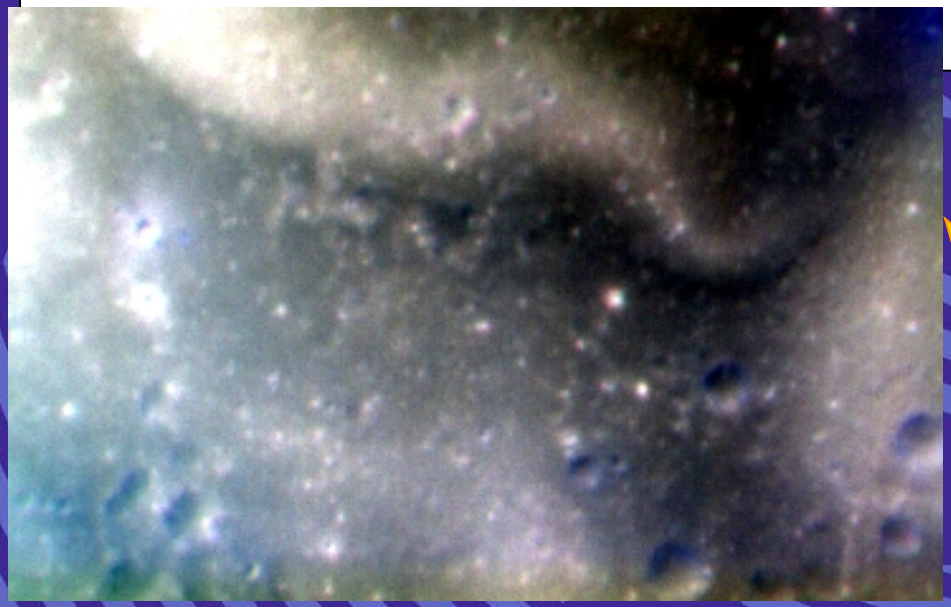




Broad range of mineralogical composition and maturity studied with SIR spectrometer

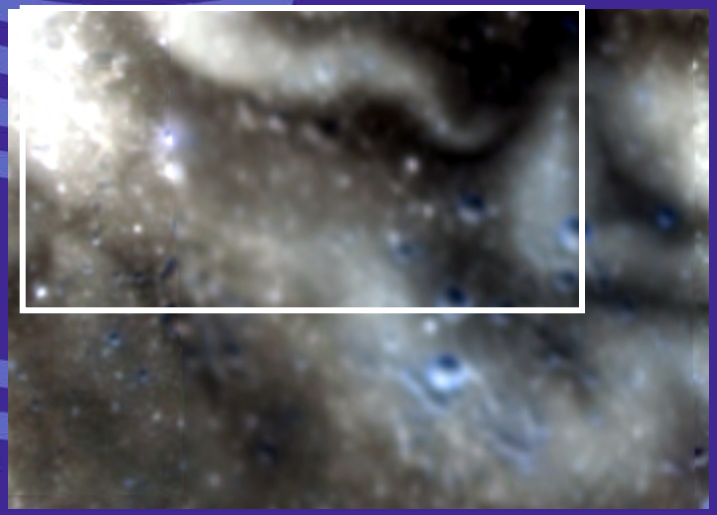
Mall et al

AMIE SMART-1 High Res Colour



Clementine

AMIE colour image Orbit 1438

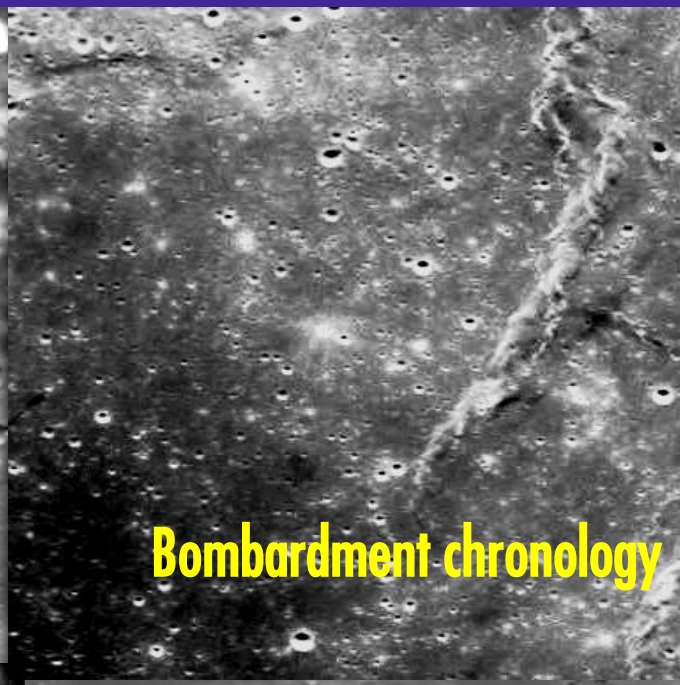


Reiner gamma
Magnetic shield
(Cerroni et al)

What shapes rocky planets?

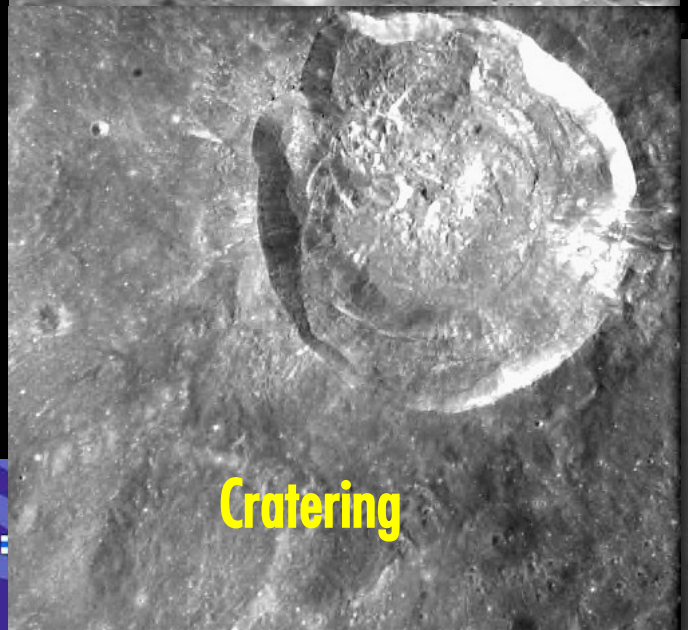
Polar regions

Tectonics



Bombardment chronology

SMART-1 impact

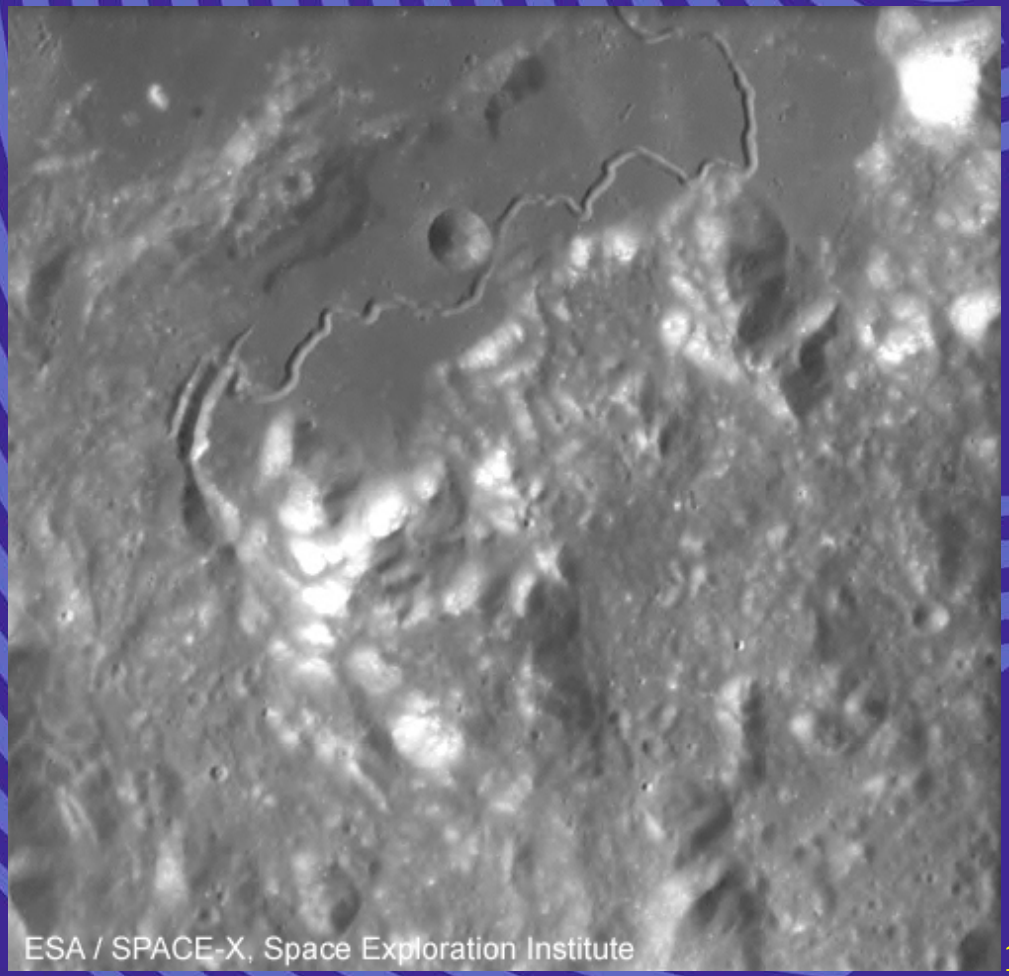


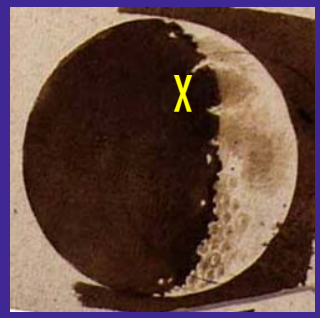
Cratering

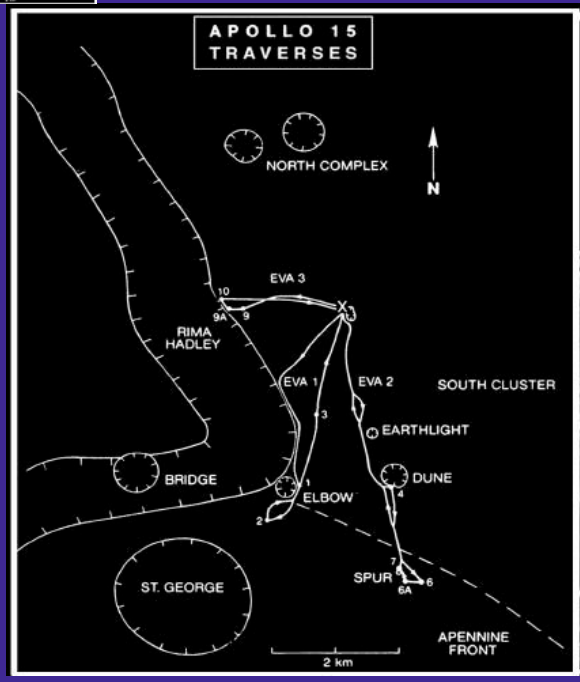
Volcanism

esa

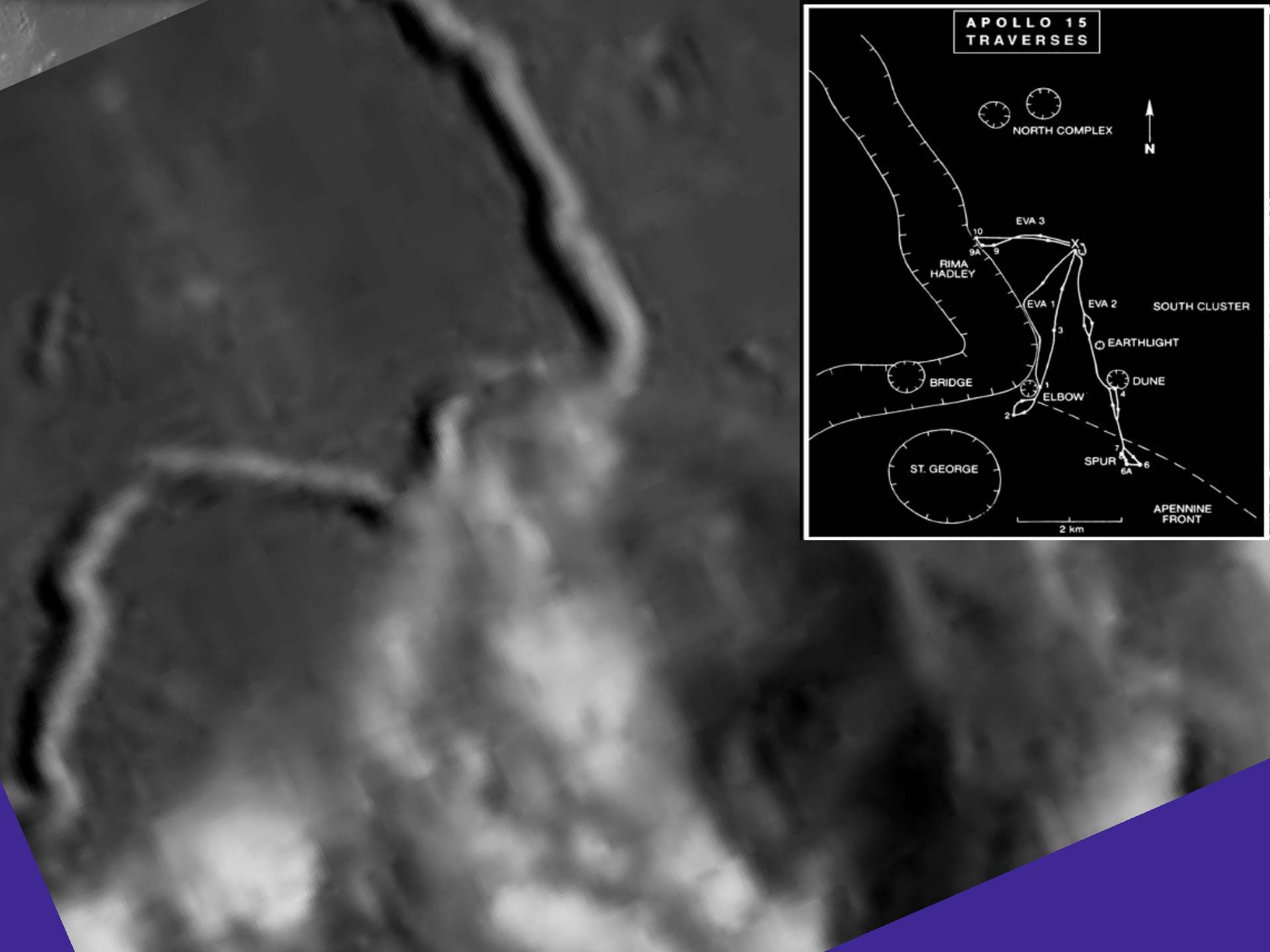
SMART-1 view of Hadley Rille near Apollo 15 landing site (mountains, volcanic plain, giant lava tube)



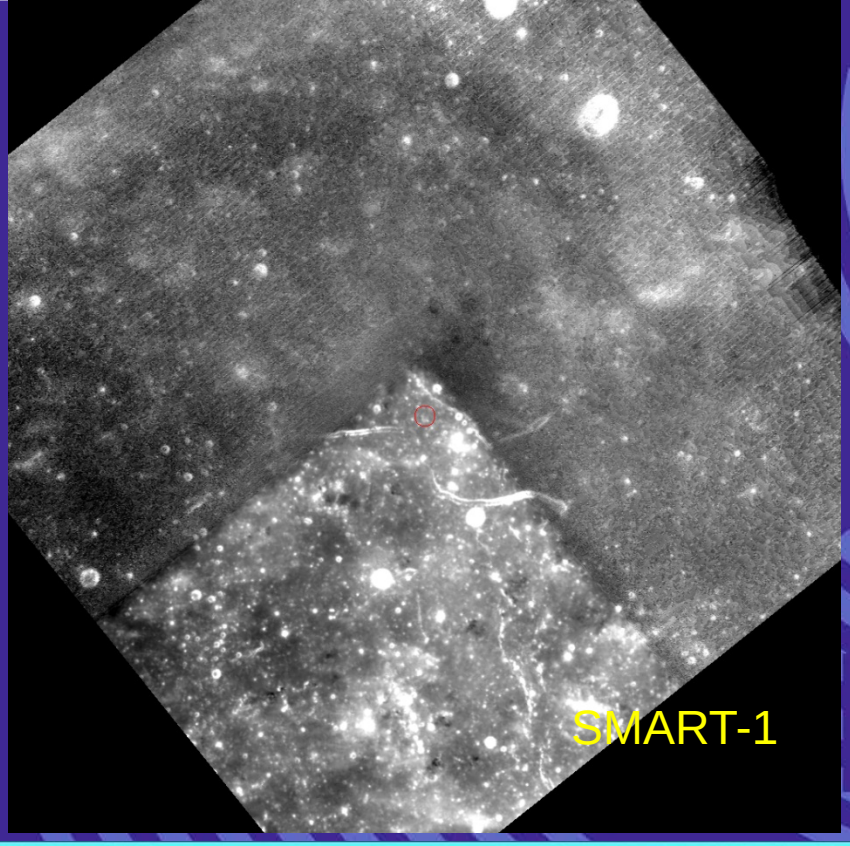


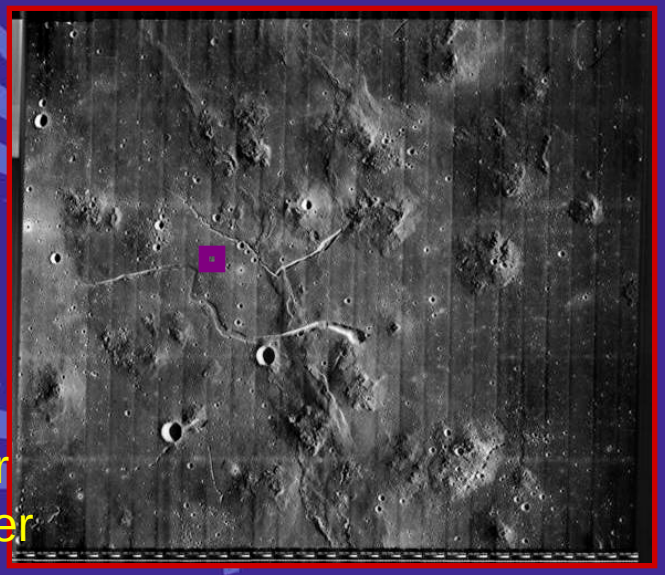


100 km field


APOLLO 15
TRAVERSES
NORTH COMPLEX
N
EVA 3
10
9A
9
RIMA
HADLEY
EVA 1
EVA 2
SOUTH CLUSTER
3
EARTHLIGHT
BRIDGE
DUNE
1
ELBOW
4
2
7
SPUR
6A
6
ST. GEORGE
APENNINE
FRONT
2 km

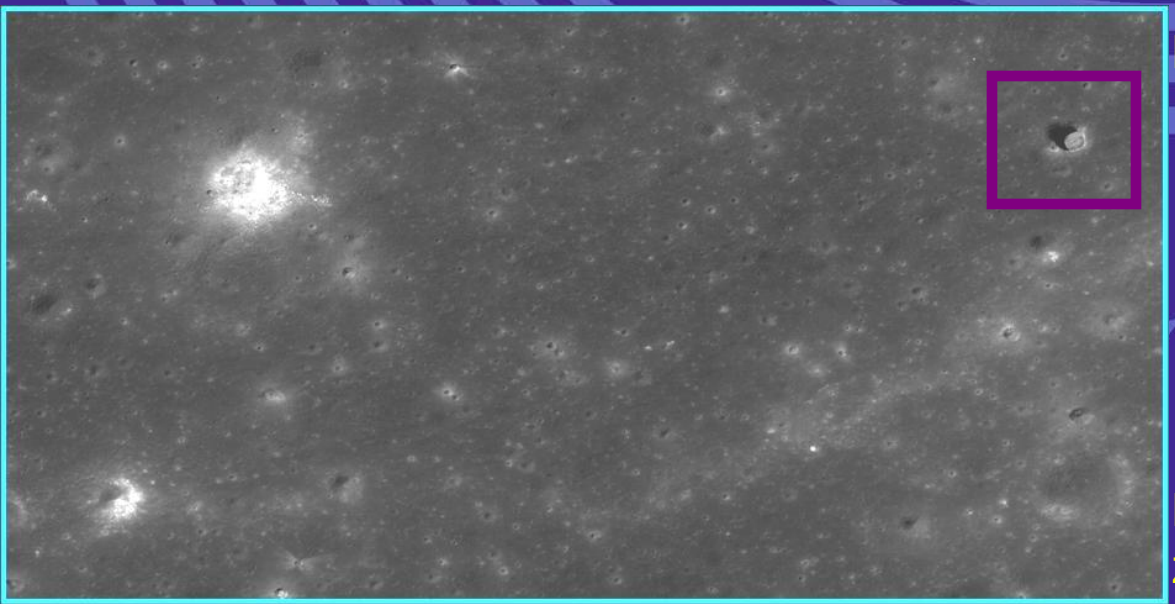
Marius Hill





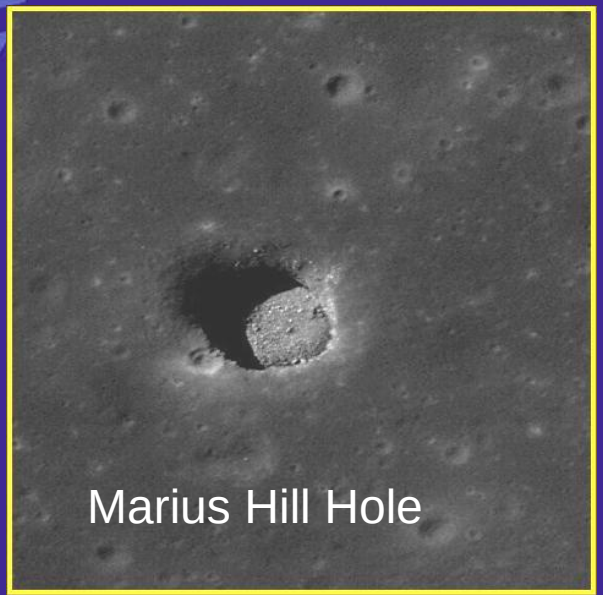
Lunar Orbiter

Foing et al , Martellato et al 2012



LRO

LRO zoom



SMART-1 maps its own landing site

Lake of Excellence

46.2 W 34.4 South

Highest resolution

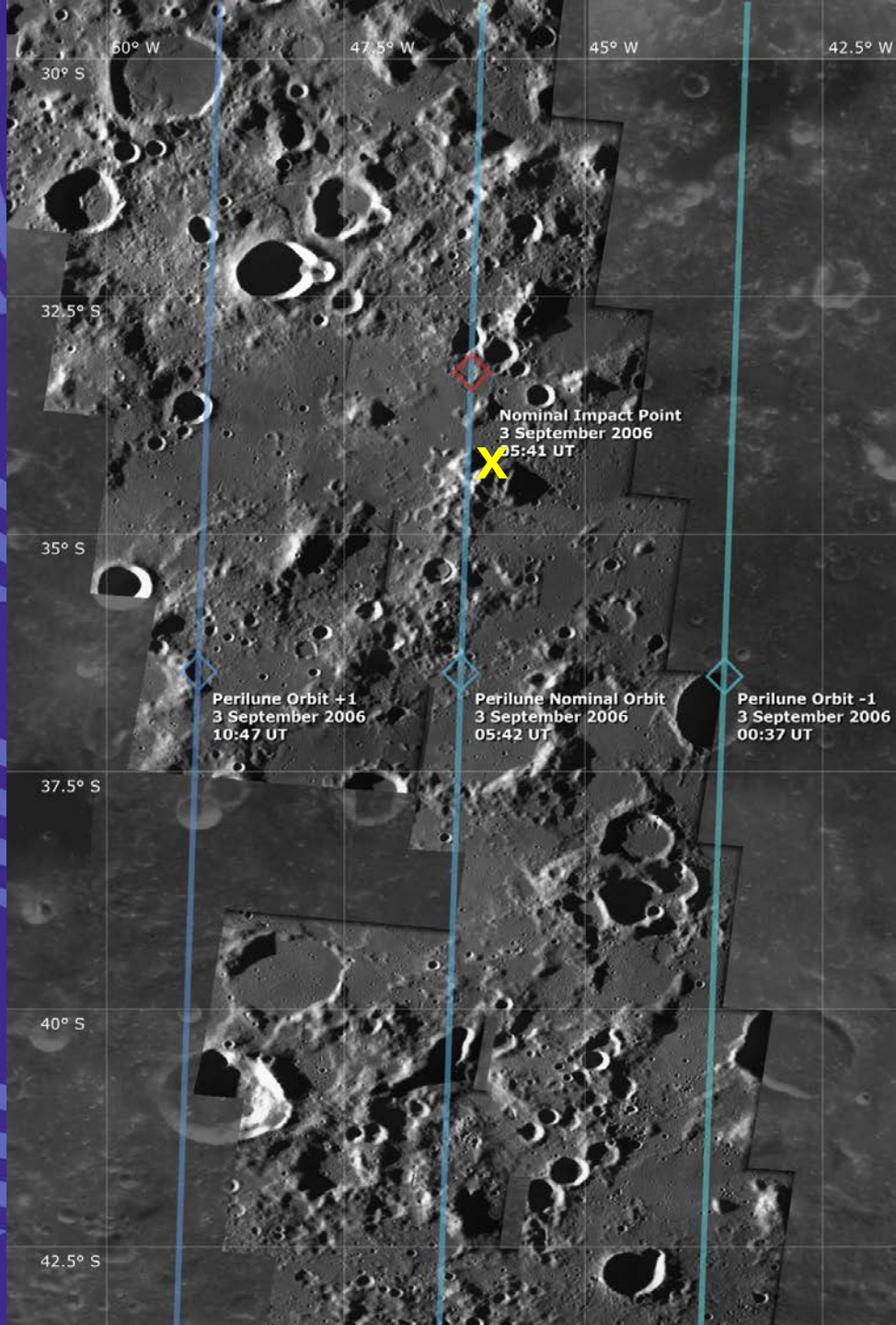
Reference for future

Crater/ ejectas detection

Historical site for GLXP

Impact time: 3 sept 5h42:21.7 UT

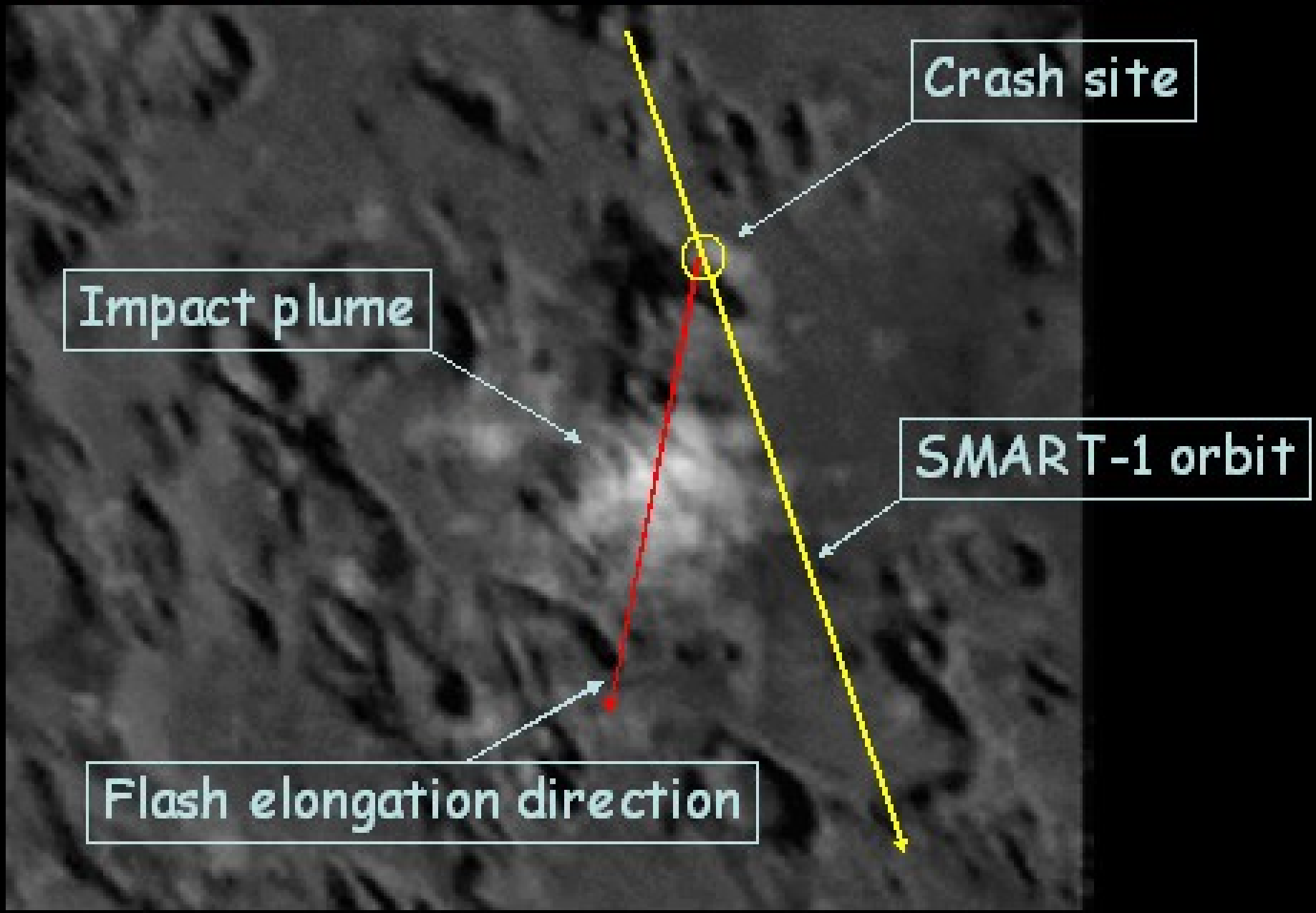
(within 1 s of prediction)



SMART-1
impact

SMART-1 flash and debris cloud (CFHT , C. Veillet)

< 40 km >


Post-flash exposure: ~10s to 20s after impact
Crash site
Impact plume
SMART-1 orbit
Flash elongation direction

Grazing Moonlets & elongated craters: Lab simulation & Modelling of SMART-1 impact (Burchell, Robin-Williams, Foing 2010 Icarus)

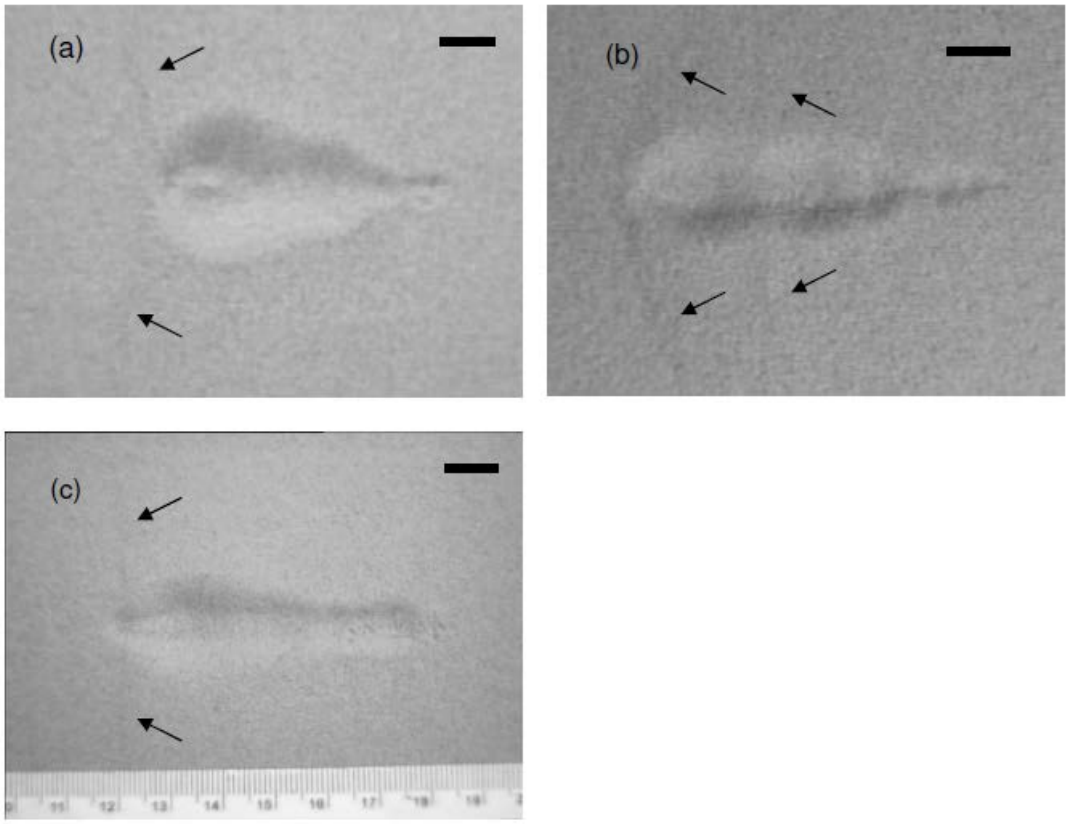
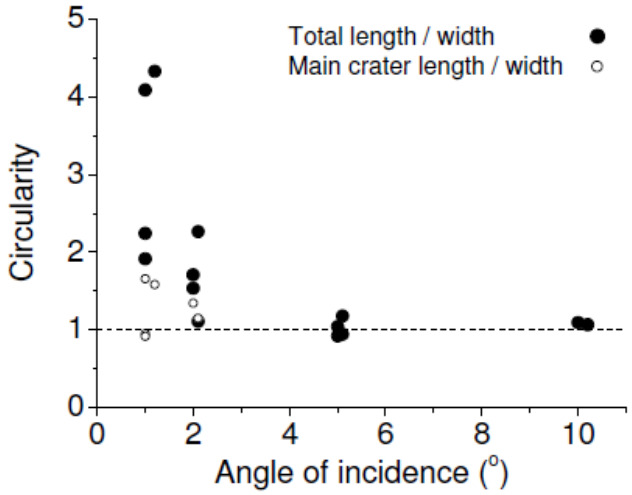
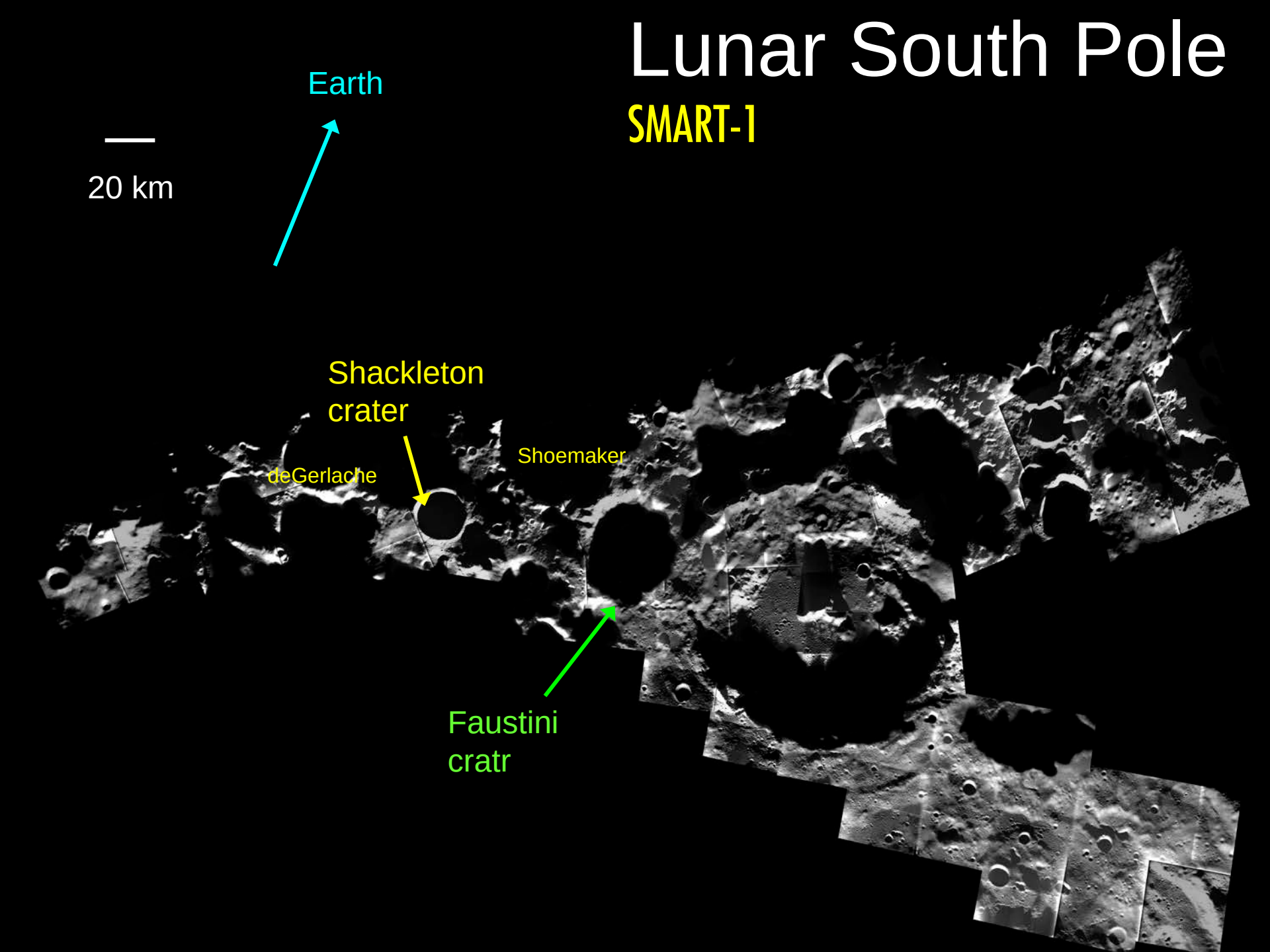


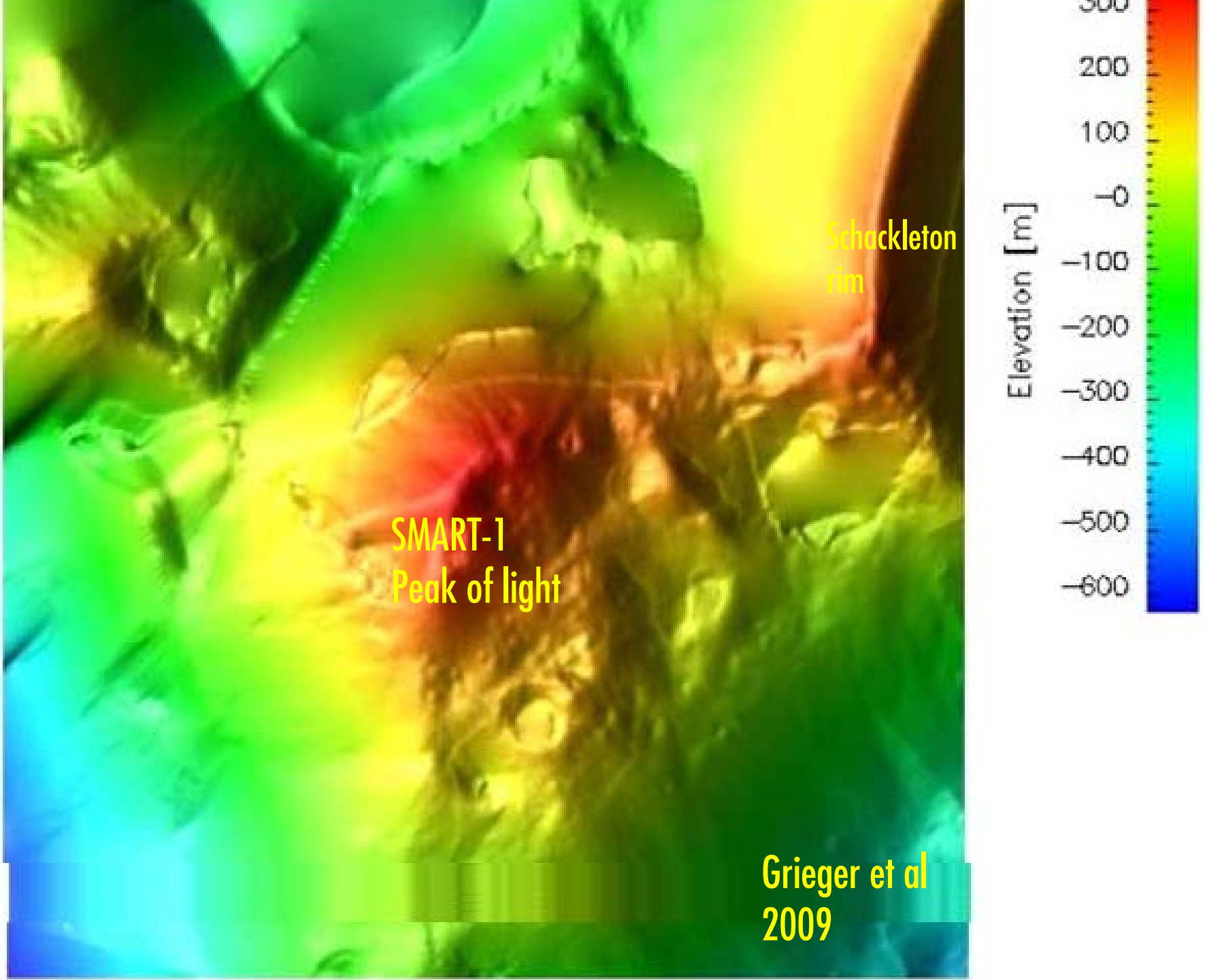
Figure 3: Crater shape at shallow incidence in the laboratory. (a) 1° incidence (b) 1° incidence (c) 1.2° incidence. Impacts are from the left and 1 cm scale bars are shown. Multiple craters are seen along the flight direction. Shock waves in the sand targets are just visible radiating transversely from the upstream edge of the craters (shown arrowed).



Lunar South Pole

SMART-1




Schackleton
rim
SMART-1
Peak of light
Grieger et al
2009
Elevation [m]
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100
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−100
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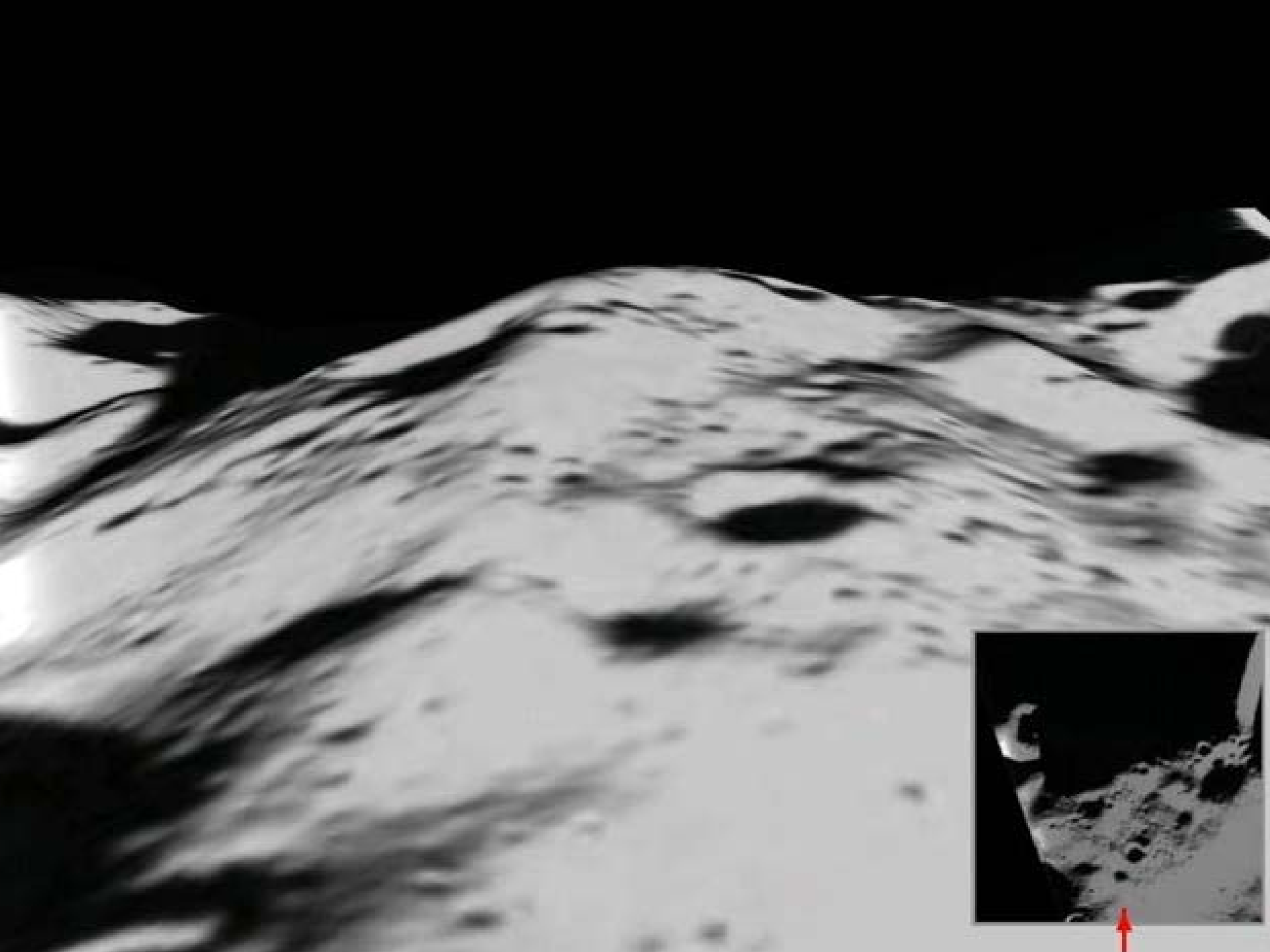
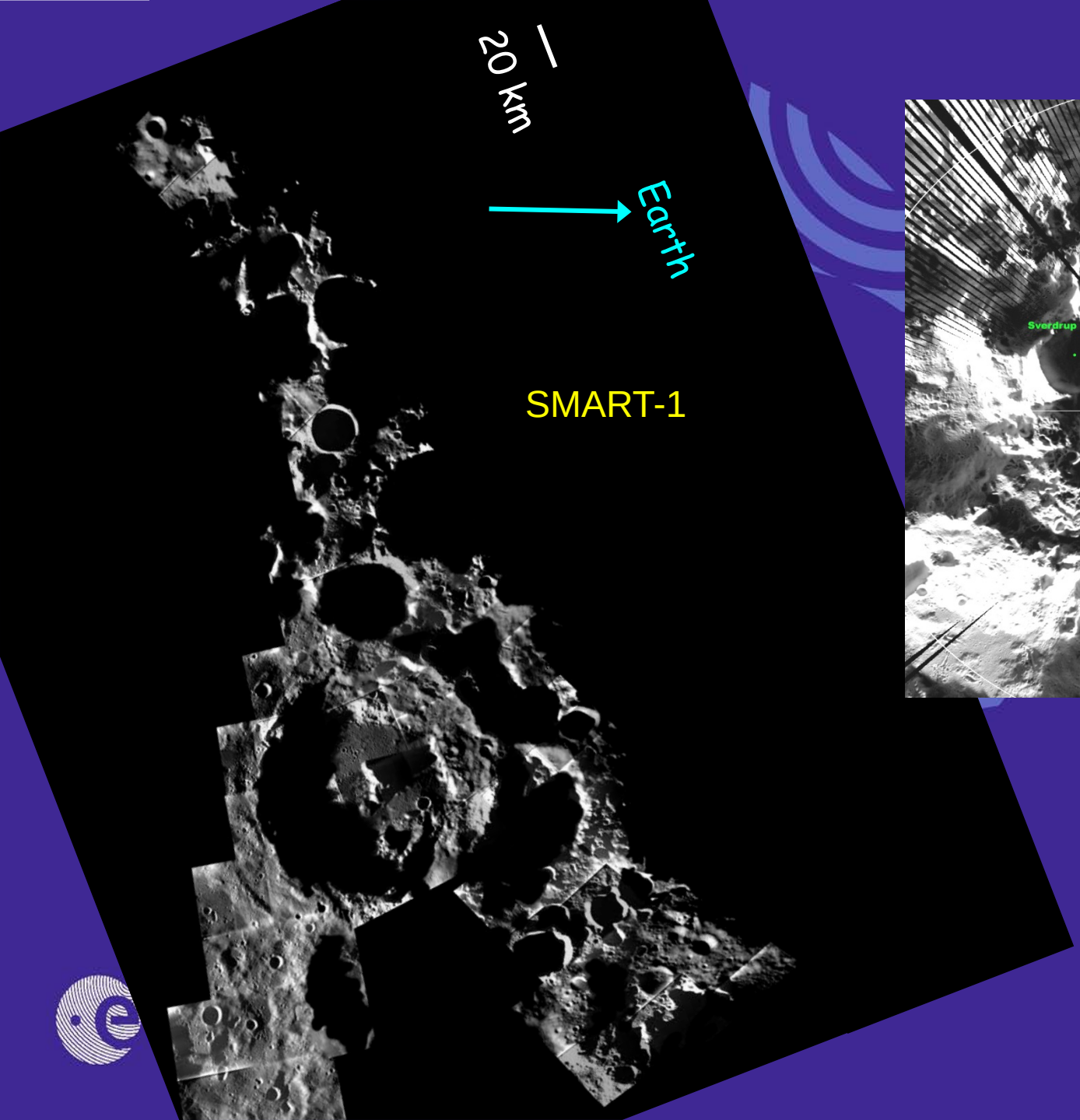
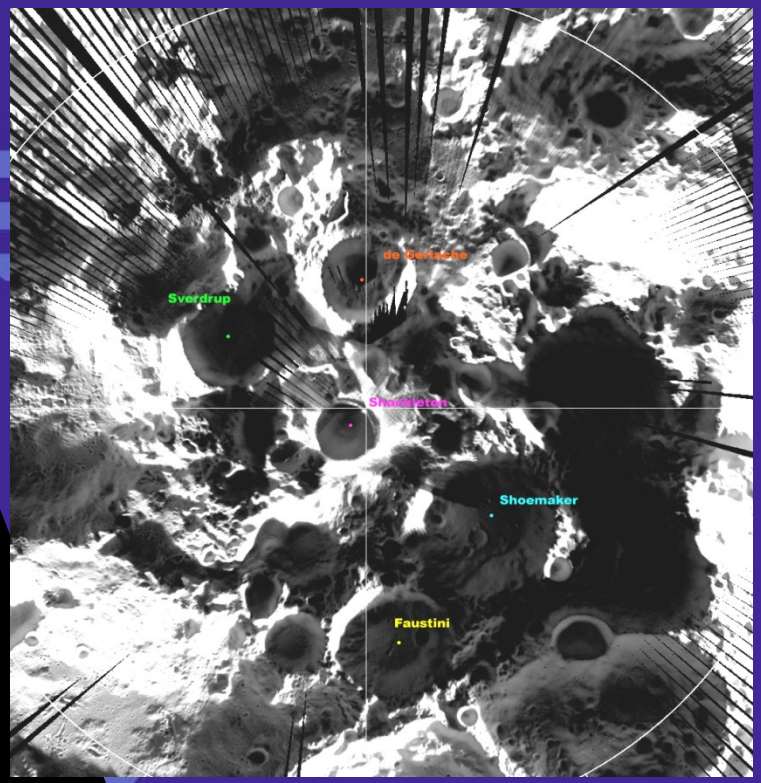
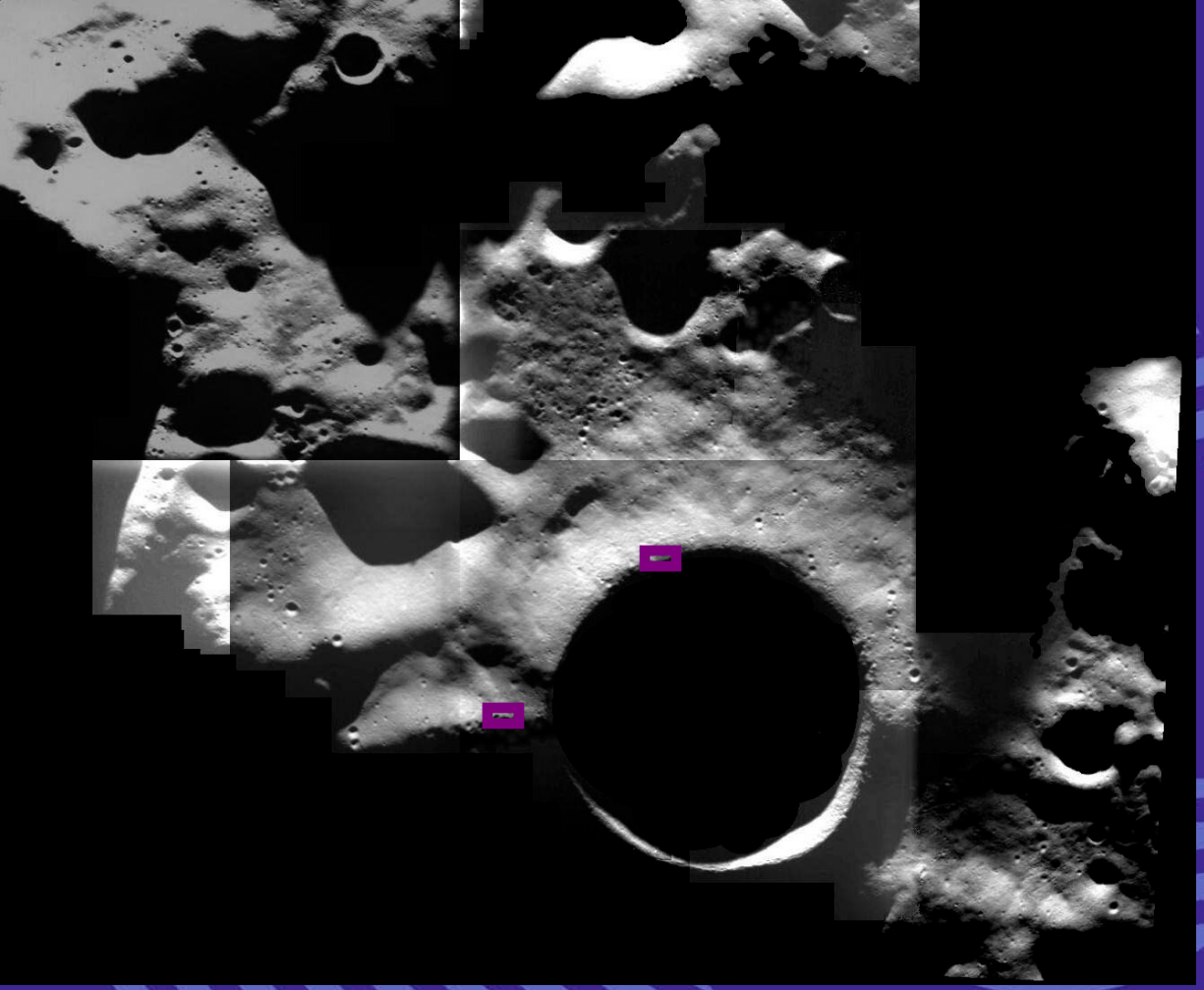



20 km
Earth
SMART-1


Sverdrup
de Gerlache
Shackleton
Shoemaker
Faustini

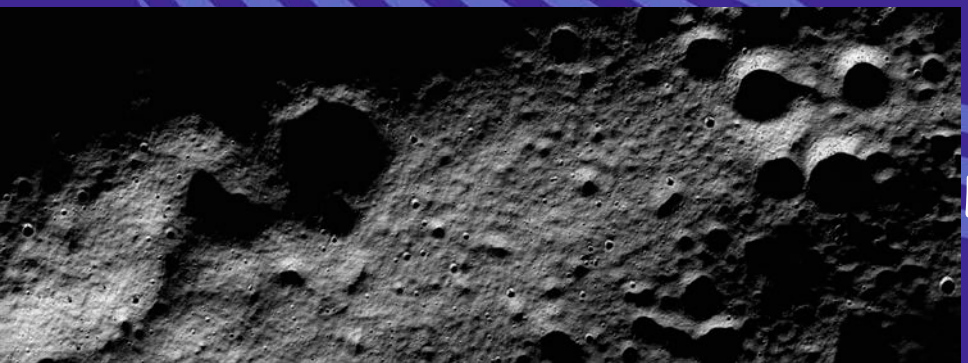
LRO



SMART-1

SMART-1 peak of light

Shackleton rim



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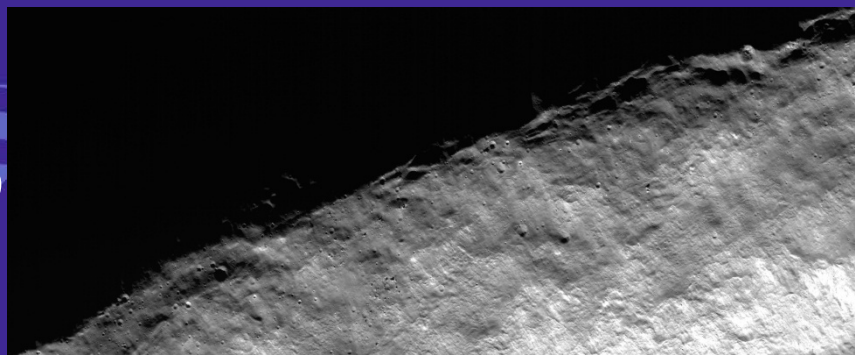


The Moon for Technology, Science and Exploration

TESTING NEW TECHNOLOGIES AND NEW METHODS

PROPULSION, MINIATURISATION, ROBOTICS, INSTRUMENTS

HOW DO EARTH-LIKE PLANETS WORK?

GEOPHYSICS: volcanism, tectonics, craters, erosion, space weather , ices

HOW DO ROCKY PLANETS FORM AND EVOLVE?

GEOCHEMISTRY: chemical composition, Earth-Moon origin, Moon evolution, accretion, collisions, giant bombardment

PREPARING FUTURE LUNAR/PLANETARY EXPLORATION

LUNAR RESOURCES SURVEY (minerals, volatiles, illumination)

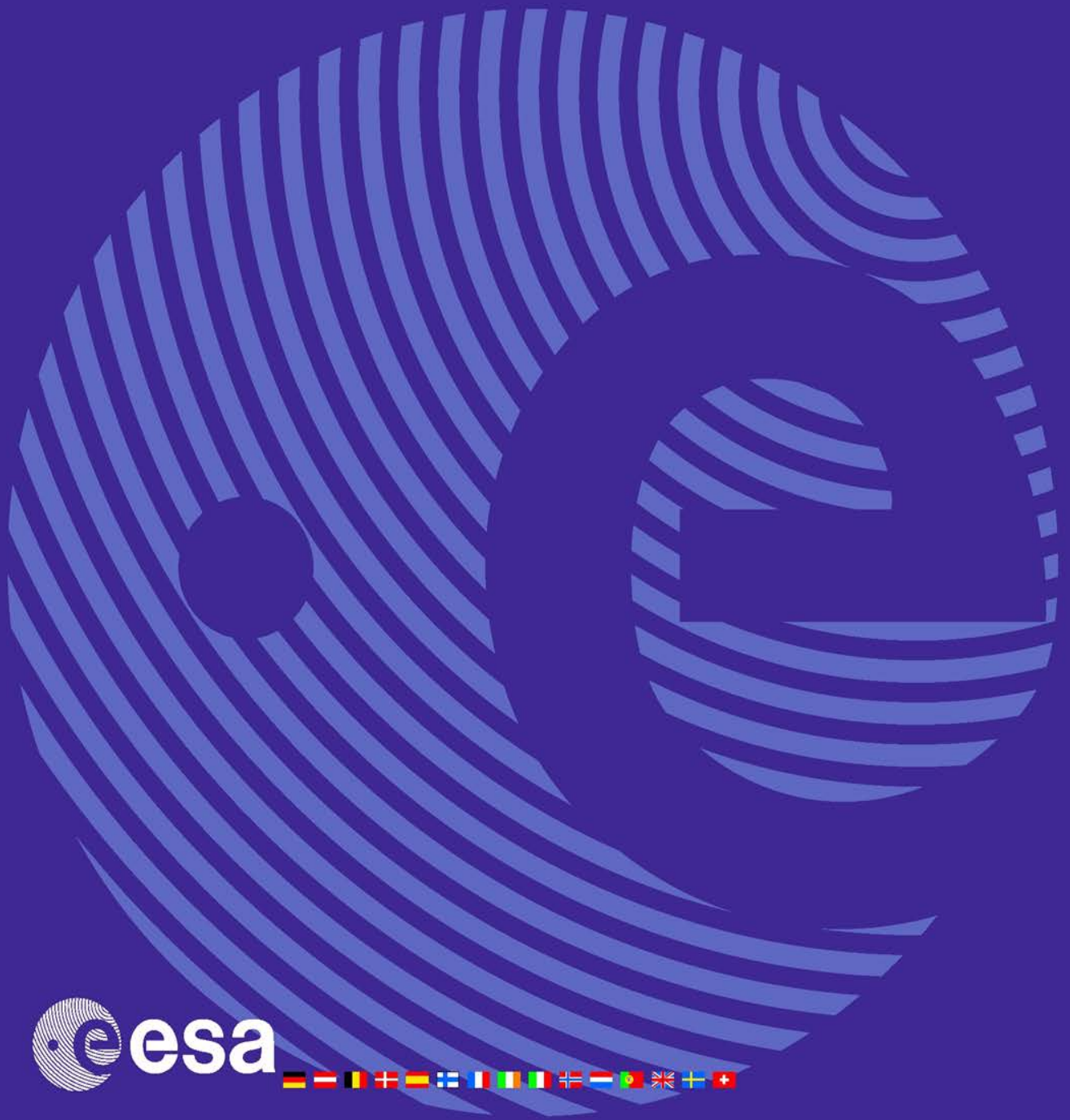
HIGH RESOLUTION MAPS: for future LANDING SITES and OUTPOSTS

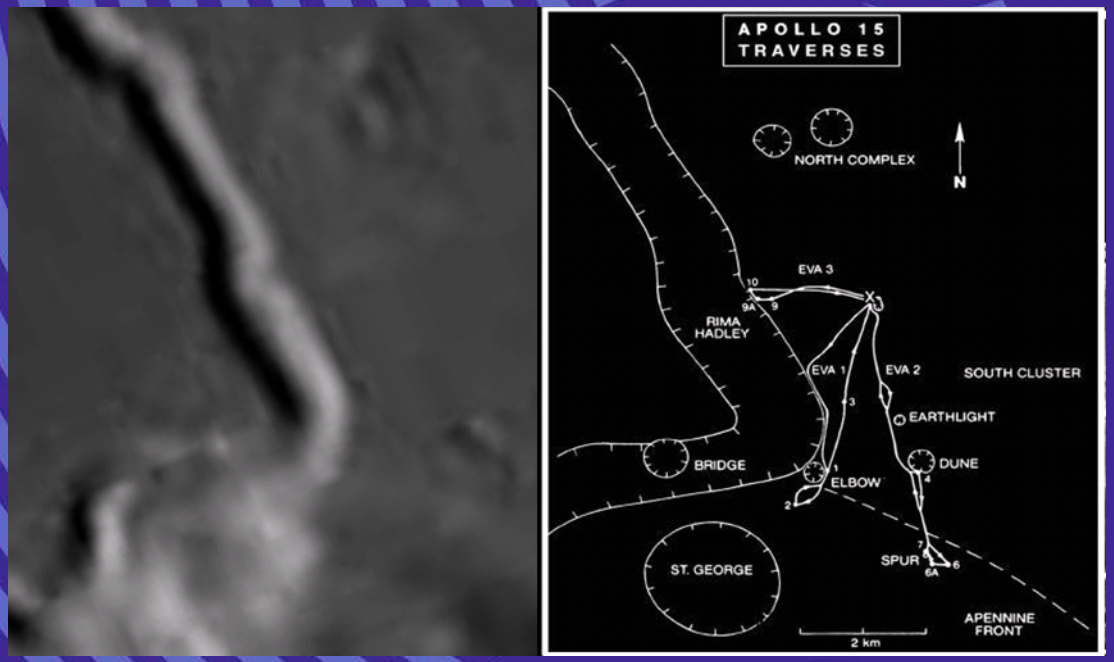
SUPPORT TO FUTURE MISSIONS AND EXPLORATION

PUBLIC OUTREACH, INSPIRATION AND EDUCATION

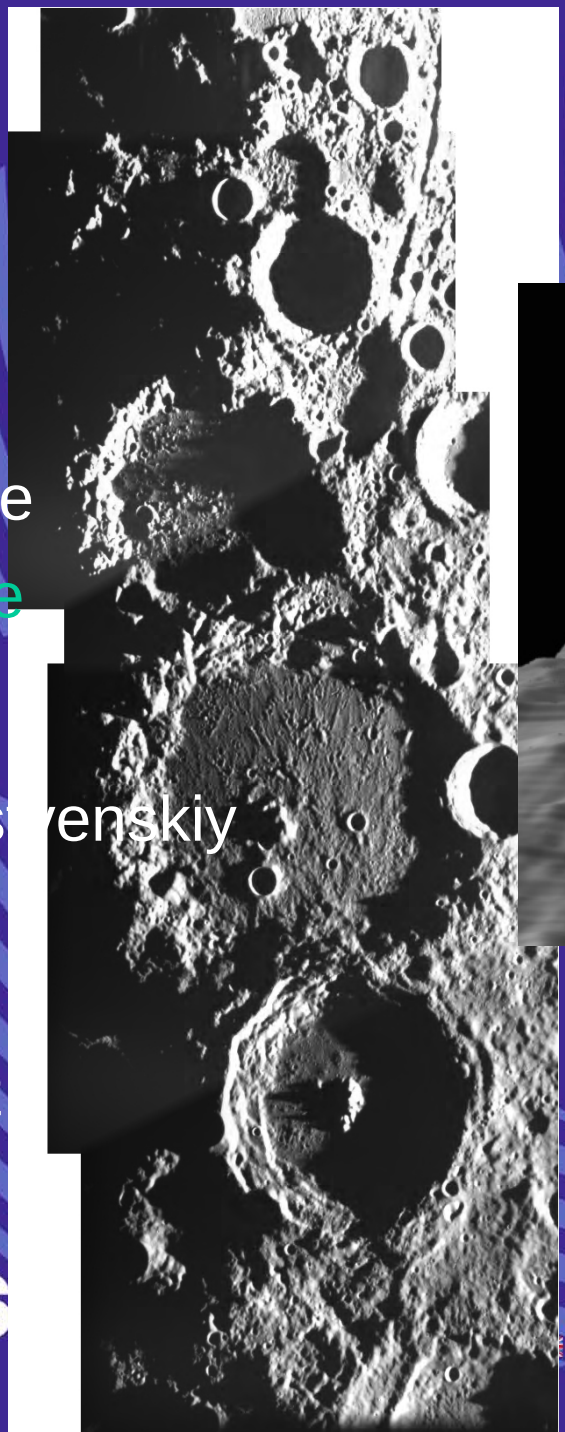
YOUNG LUNAR & GALILEAN EXPLORERS

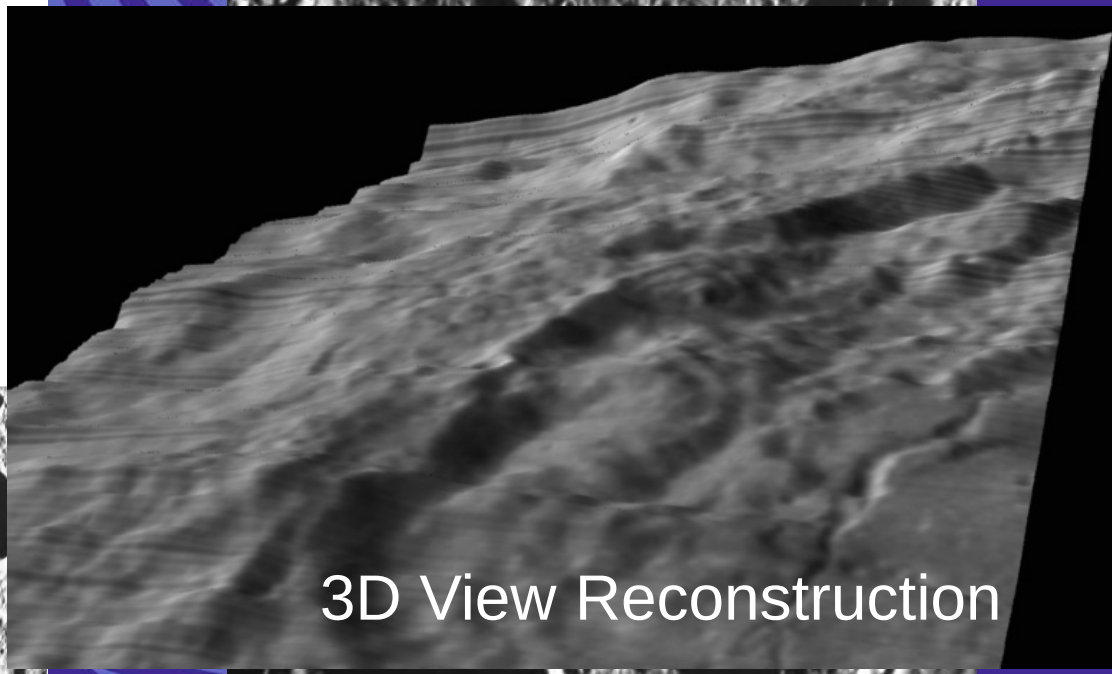
esa

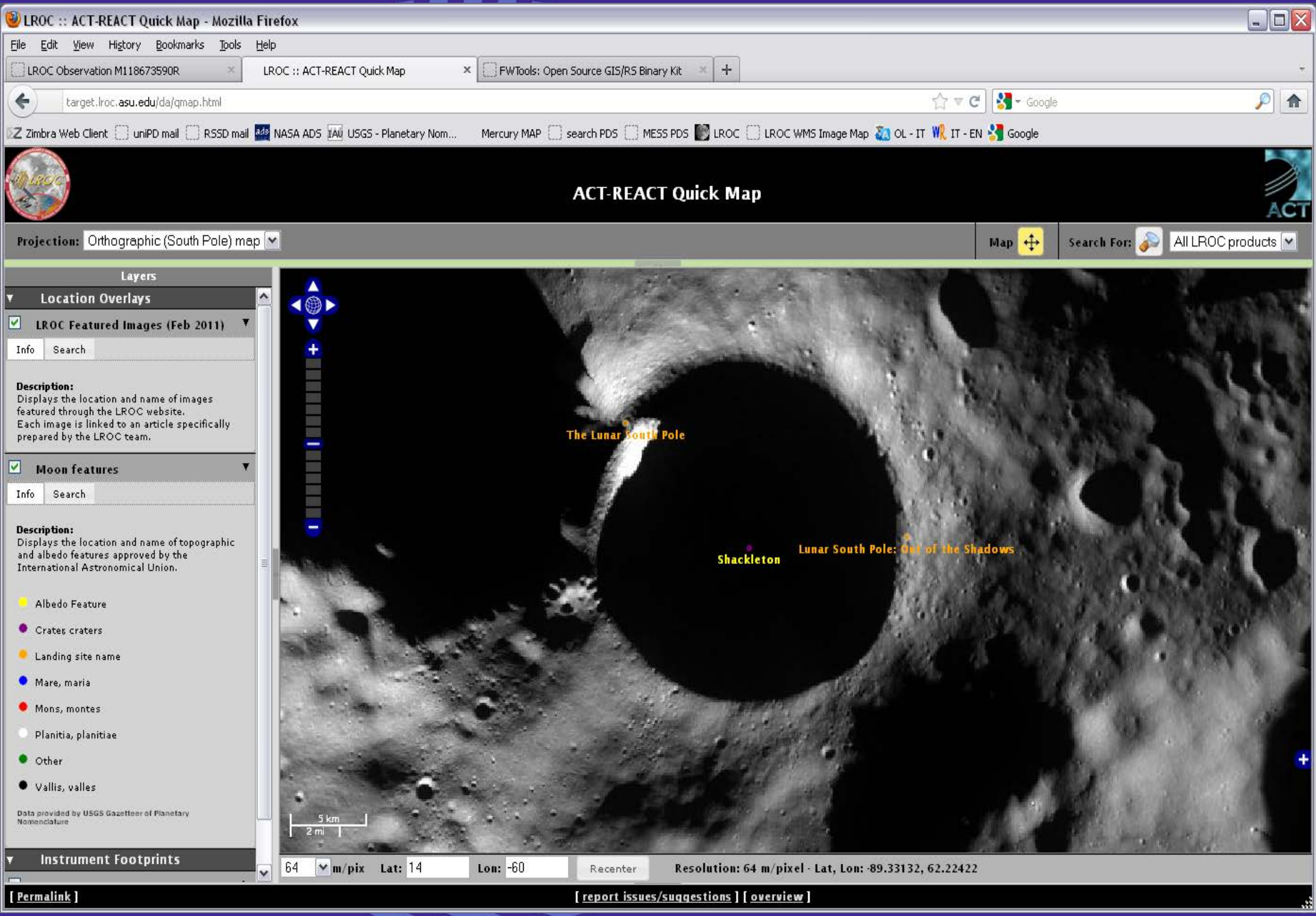

esa


APOLLO 15
TRAVERSES
NORTH COMPLEX
N
EVA 3
10
9A
9
RIMA
HADLEY
EVA 1
EVA 2
SOUTH CLUSTER
3
EARTHLIGHT
BRIDGE
DUNE
ELBOW
2
4
7
SPUR
6A
6
ST. GEORGE
APENNINE
FRONT
2 km

Polar craters






LROC :: ACT-REACT Quick Map - Mozilla Firefox
File Edit View History Bookmarks Tools Help
LROC Observation M118673590R
LROC :: ACT-REACT Quick Map
FWTools: Open Source GIS/RS Binary Kit
target.lroc.asu.edu/da/qmap.html
Zimbra Web Client
uniPD mail
RSSD mail
NASA ADS
USGS - Planetary Nom...
Mercury MAP
search PDS
MESS PDS
LROC
LROC WMS Image Map
OL - IT
IT - EN
Google
ACT-REACT Quick Map
Projection: Orthographic (South Pole) map
Map
Search For:
All LROC products
Layers
Location Overlays
LROC Featured Images (Feb 2011)
Info
Search
Description:
Displays the location and name of images featured through the LROC website.
Each image is linked to an article specifically prepared by the LROC team.
Moon features
Info
Search
Description:
Displays the location and name of topographic and albedo features approved by the International Astronomical Union.
Albedo Feature
Crater, craters
Landing site name
Mare, maria
Mons, montes
Planitia, planitiae
Other
Vallis, valles
Data provided by USGS Gazetteer of Planetary Nomenclature
Instrument Footprints
The Lunar South Pole
Shackleton
Lunar South Pole: Out of the Shadows
5 km
2 mi
64
m/pix
Lat: 14
Lon: -60
Recenter
Resolution: 64 m/pixel · Lat, Lon: -89.33132, 62.22422
[Permalink]
[report issues/suggestions] [overview]

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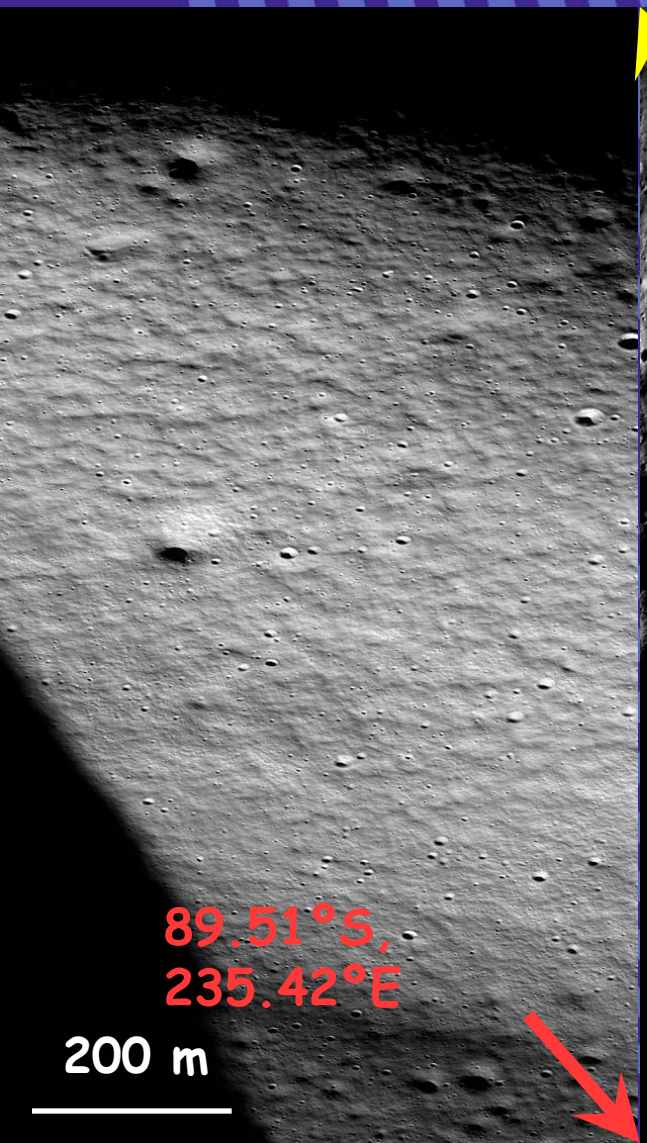
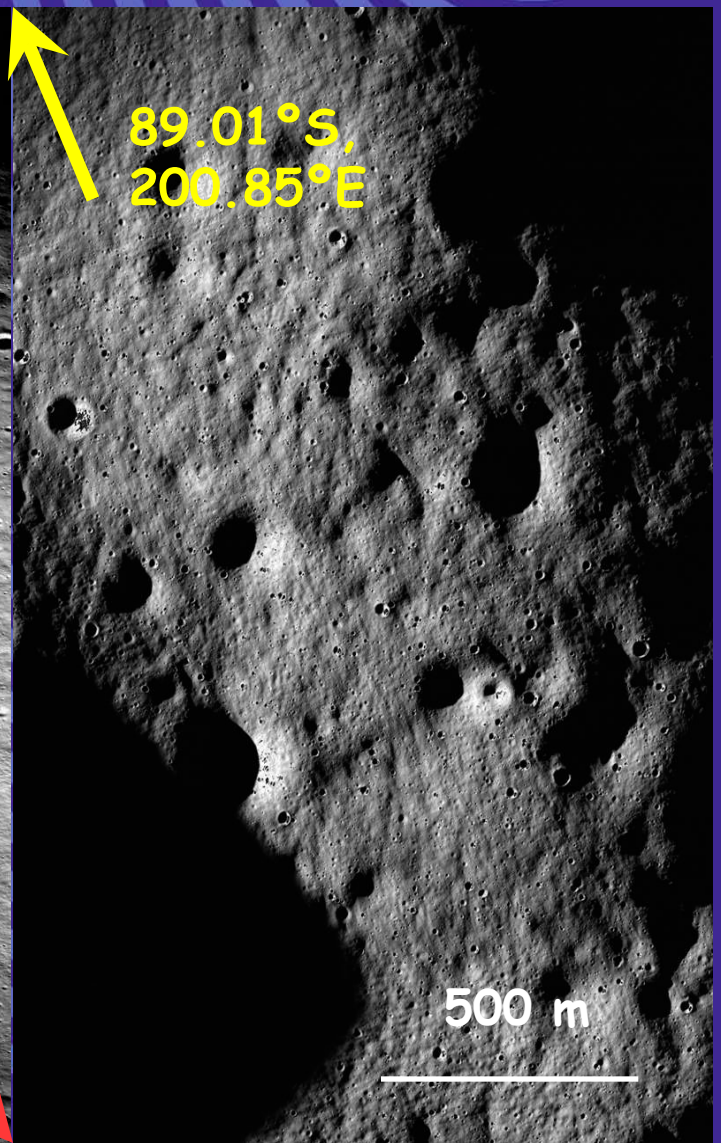
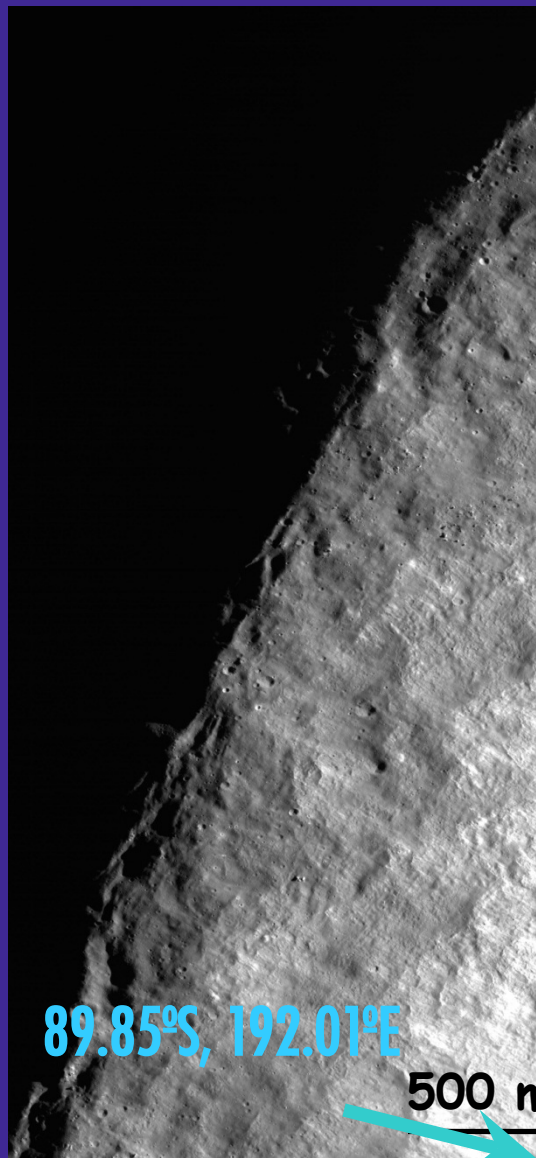
M118673590RC

M133799601RC







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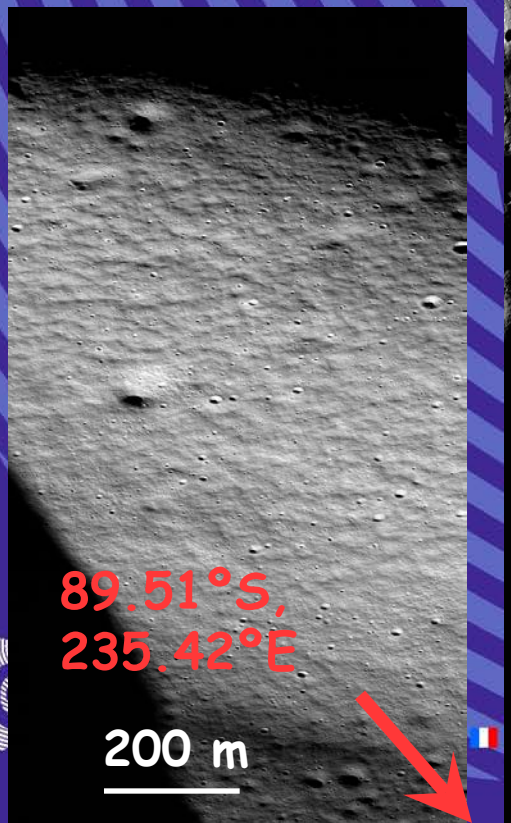

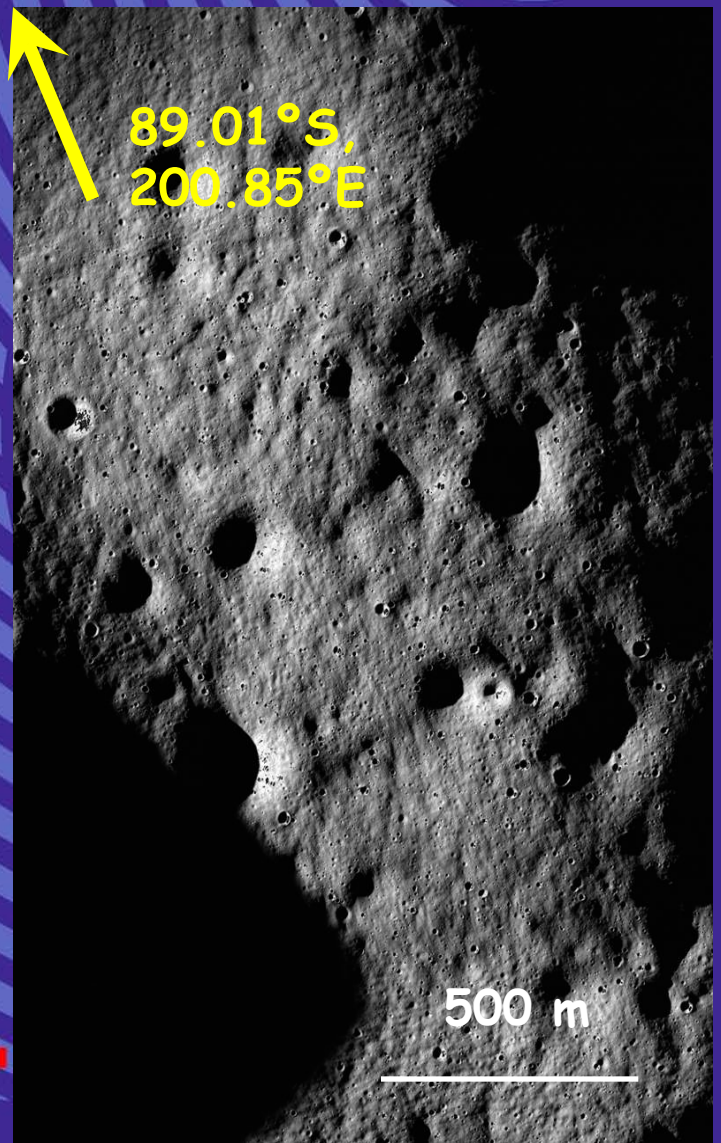

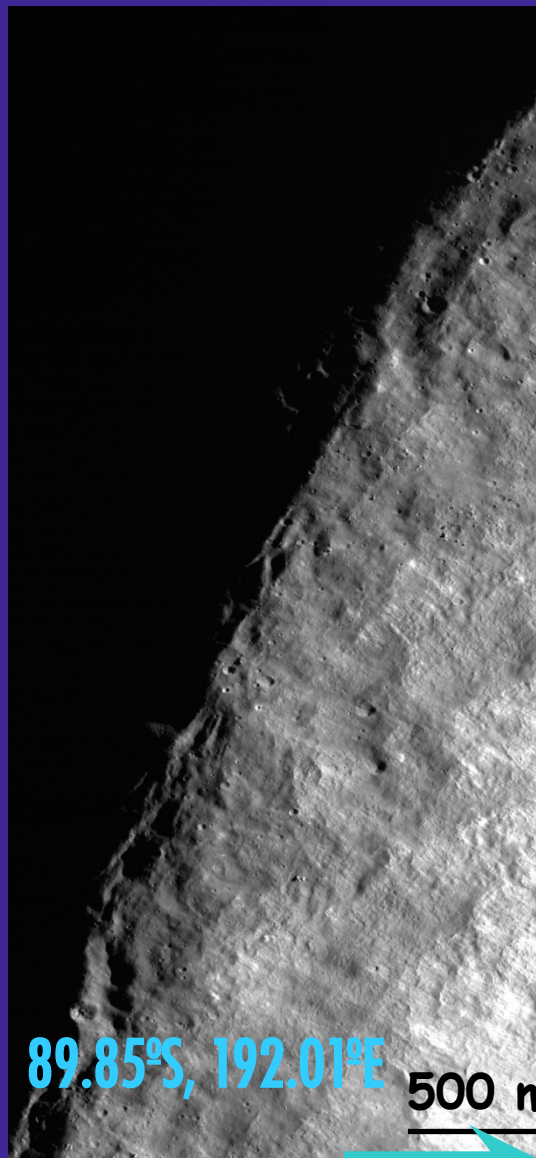

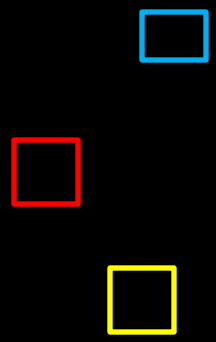

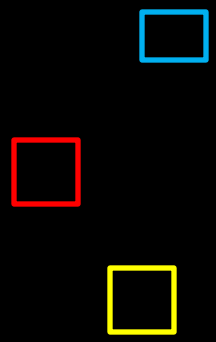

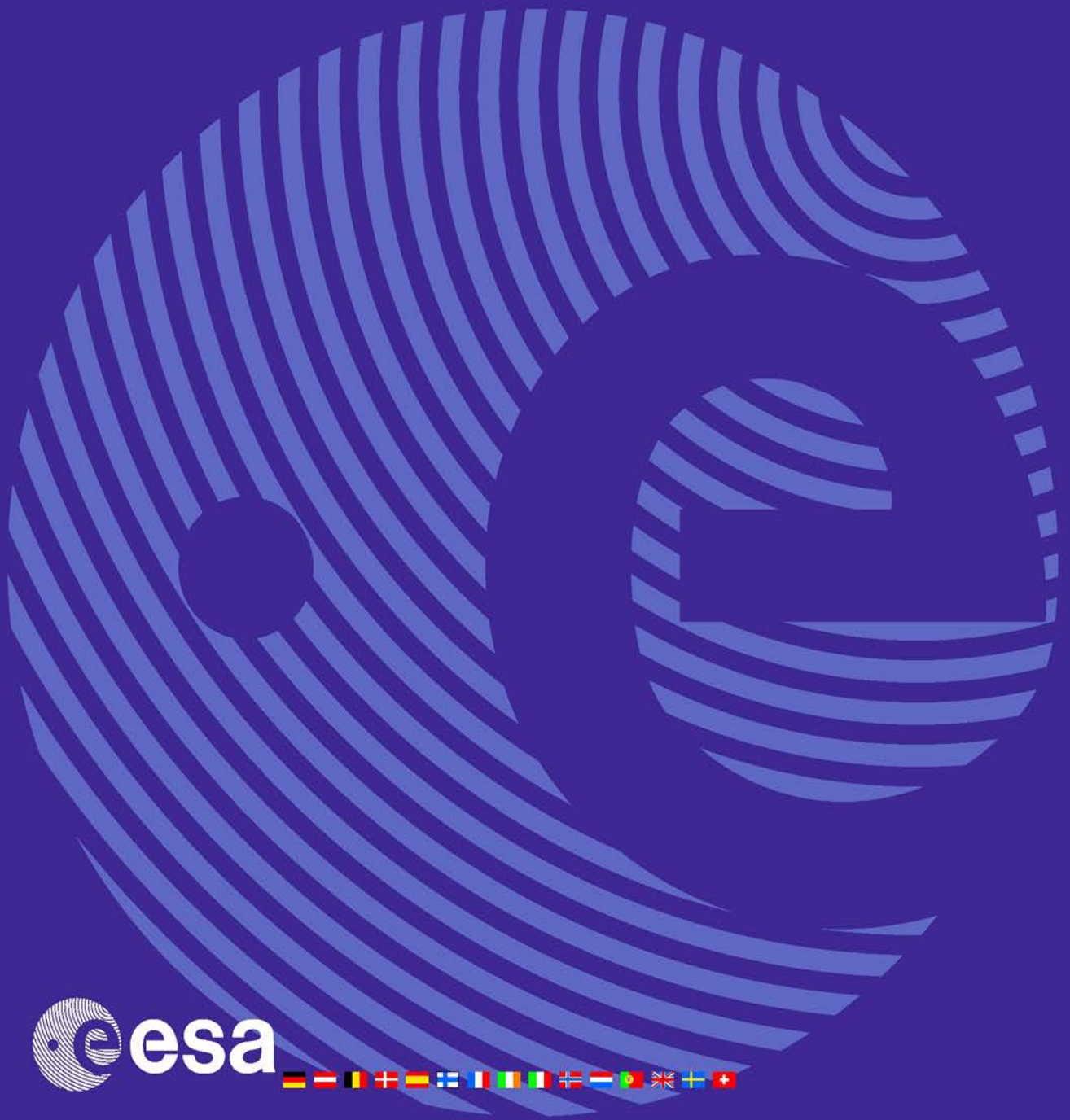
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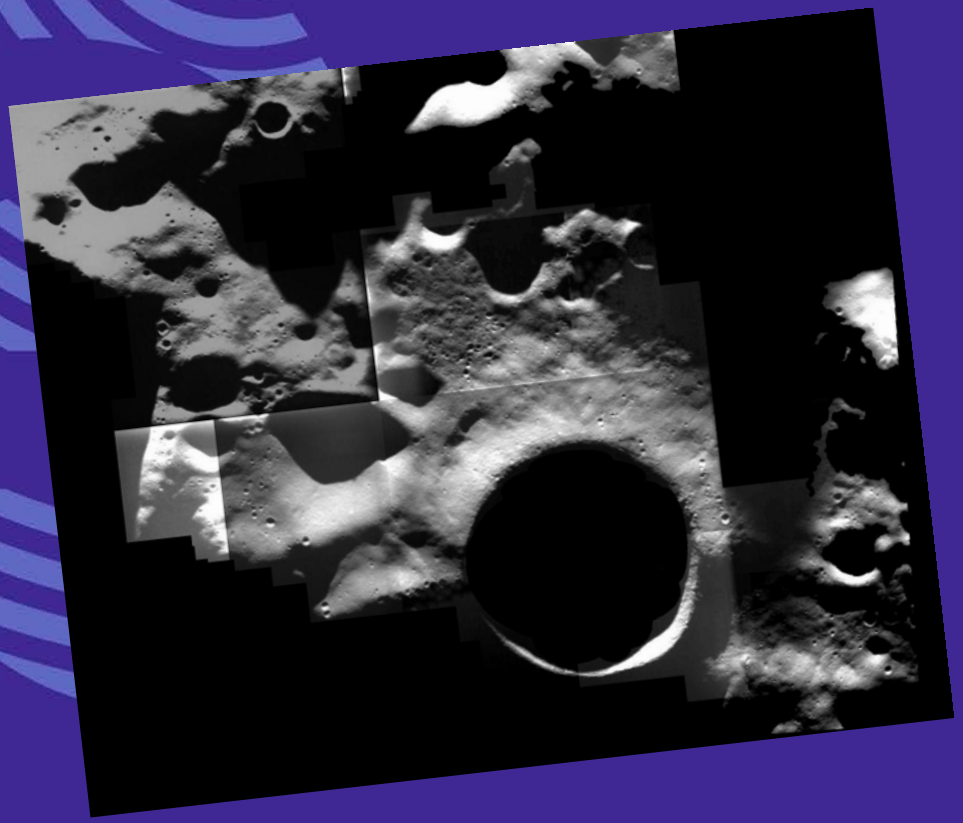
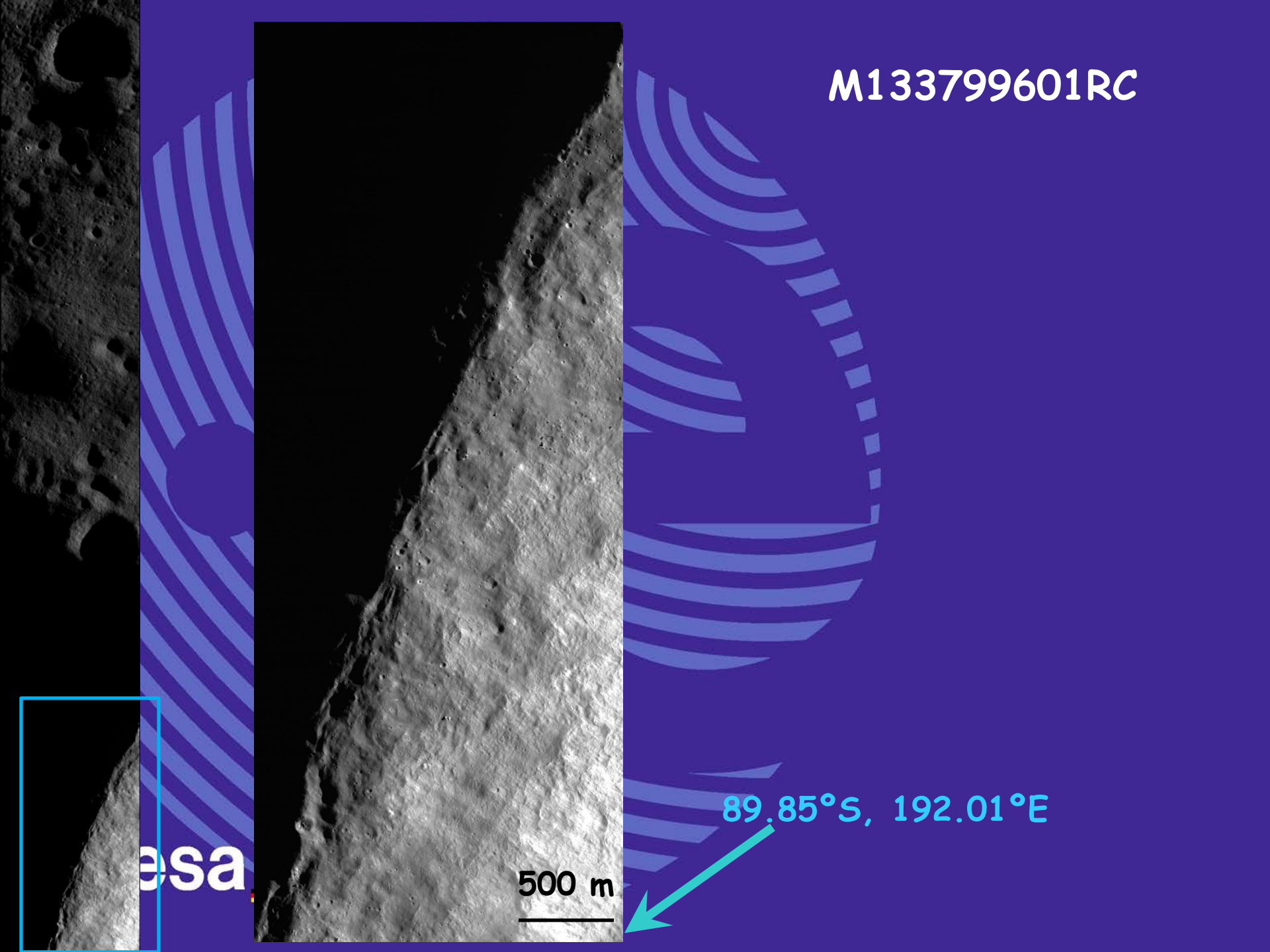


SMART-1
2 of 133 images of
Shackleton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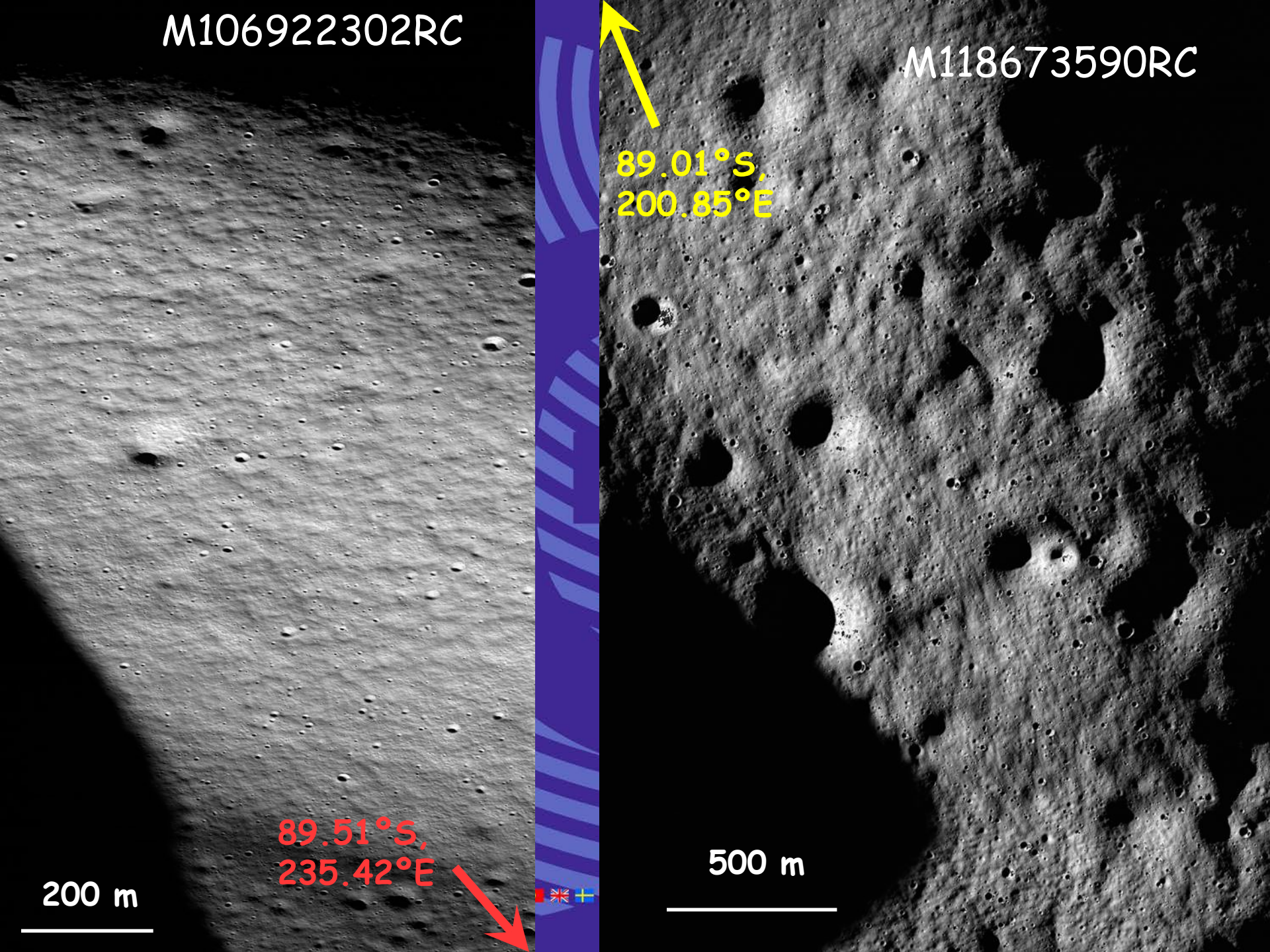
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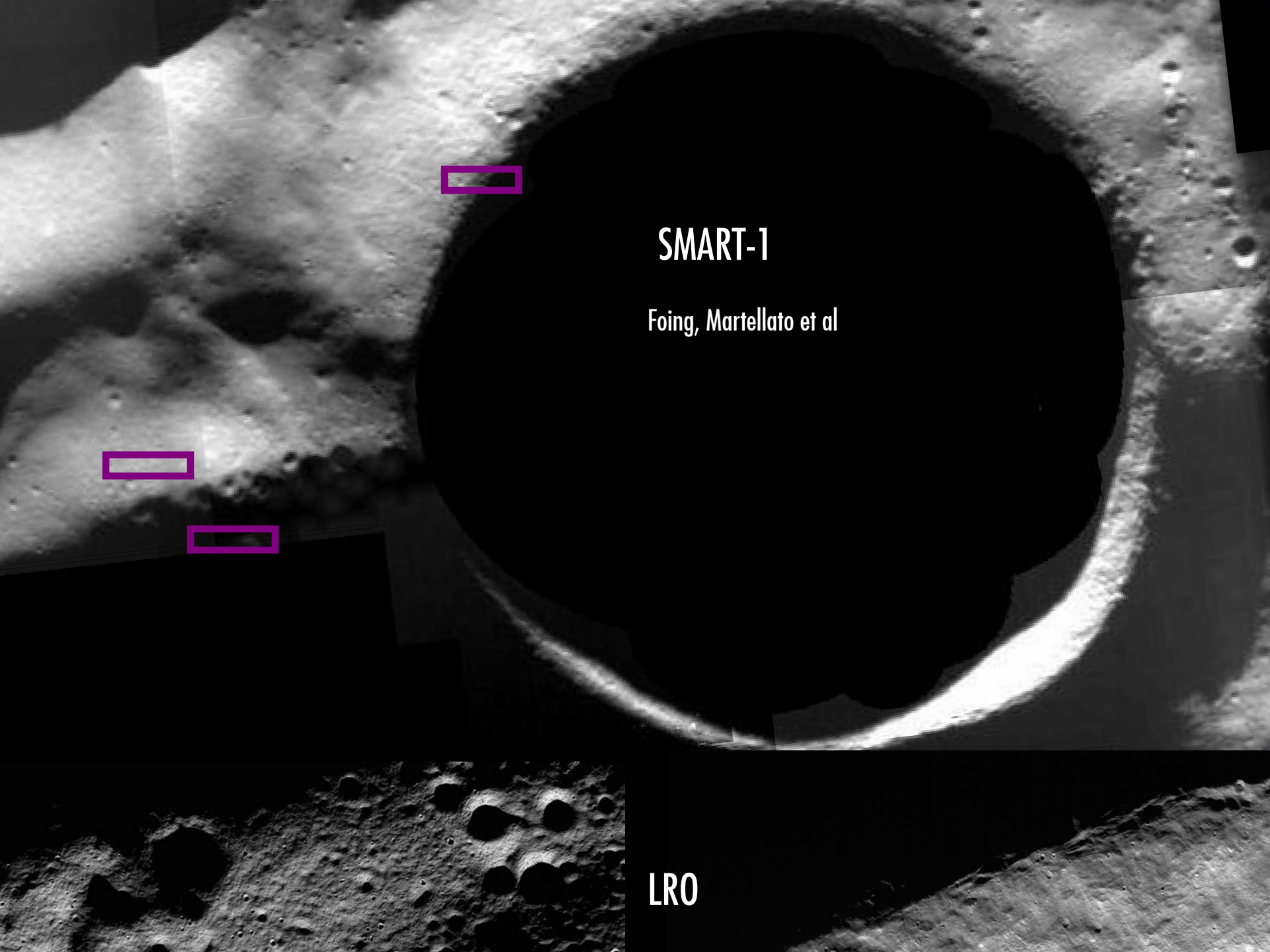
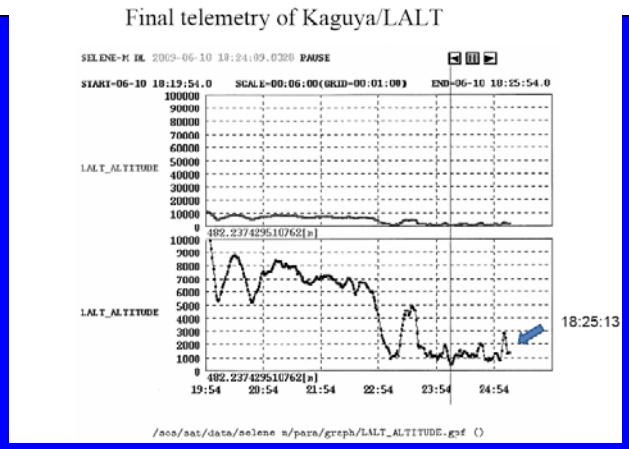

SMART-1
Foing, Martellato et al
LRO

Kaguya impact and flash

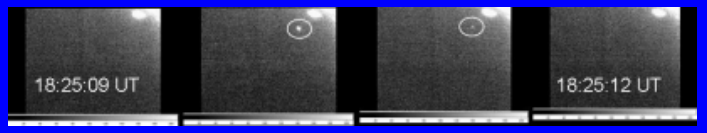


Kaguya altimetry

Kaguya team

SMART-1 images

AAT, Australia



Mt Abu, India

LROC :: ACT-REACT Quick Map - Mozilla Firefox

File Edit View History Bookmarks Tools Help

LROC Observation M118673590R | LROC :: ACT-REACT Quick Map | FWTools: Open Source GIS/RS Binary Kit

target.lroc.asu.edu/da/qmap.html

Zimba Web Client | uniPD mail | RSSD mail | NASA ADS | USGS - Planetary Nom... | Mercury MAP | search PDS | MESS PDS | LROC | LROC WMS Image Map | OL - IT | IT - EN | Google

ACT-REACT Quick Map

Projection: Orthographic (South Pole) map | Map | Search For: All LROC products

Layers

Location Overlays

LROC Featured Images (Feb 2011)

Info | Search

Description:
Displays the location and name of images featured through the LROC website.
Each image is linked to an article specifically prepared by the LROC team.

Moon features

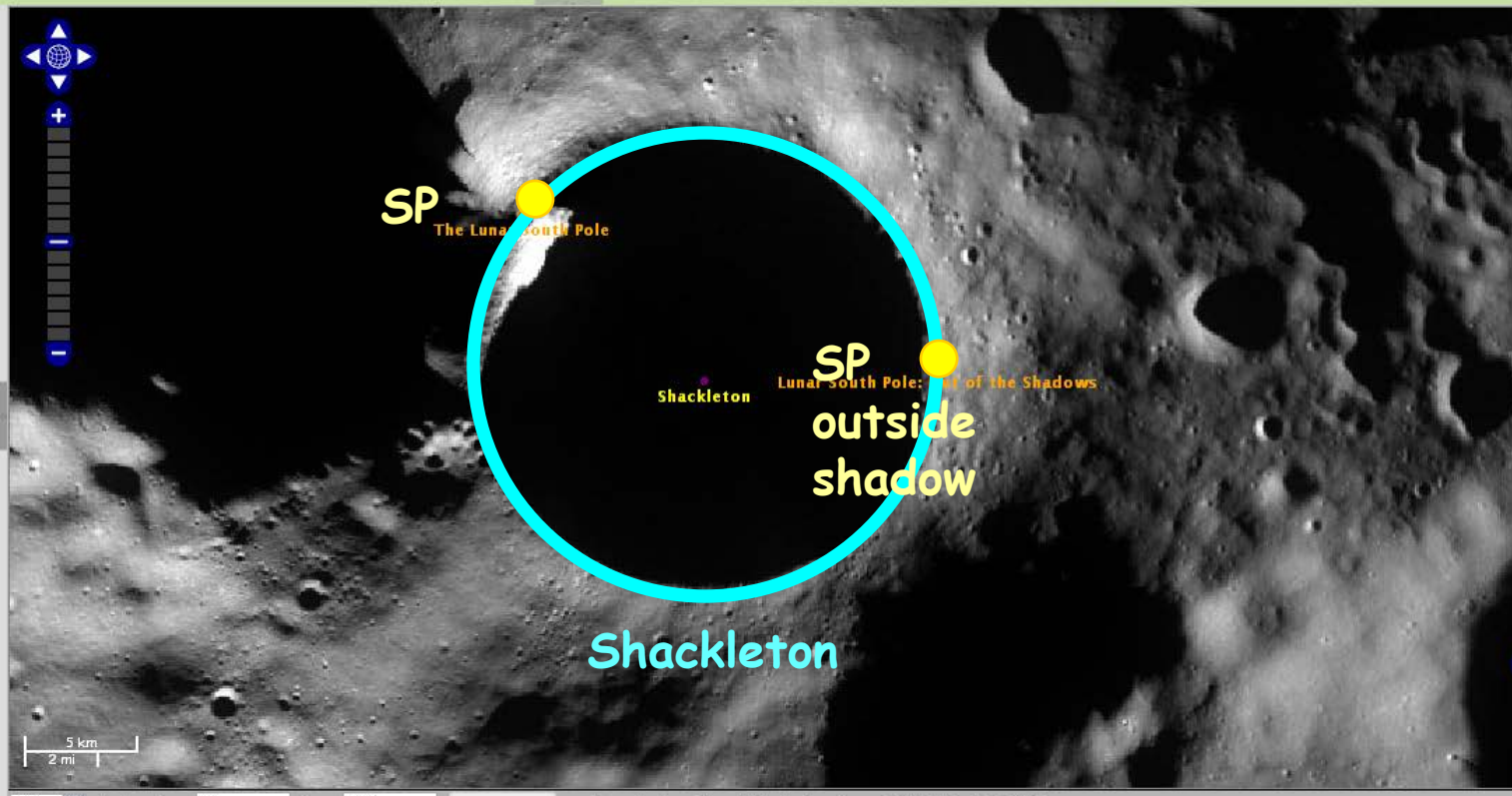
Info | Search

Description:
Displays the location and name of topographic and albedo features approved by the International Astronomical Union.

- Albedo Feature
- Crater craters
- Landing site name
- Mare, maria
- Mons, montes
- Planitia, planitiae
- Other
- Vallis, valles

Data provided by USGS Gazetteer of Planetary Nomenclature

Instrument Footprints



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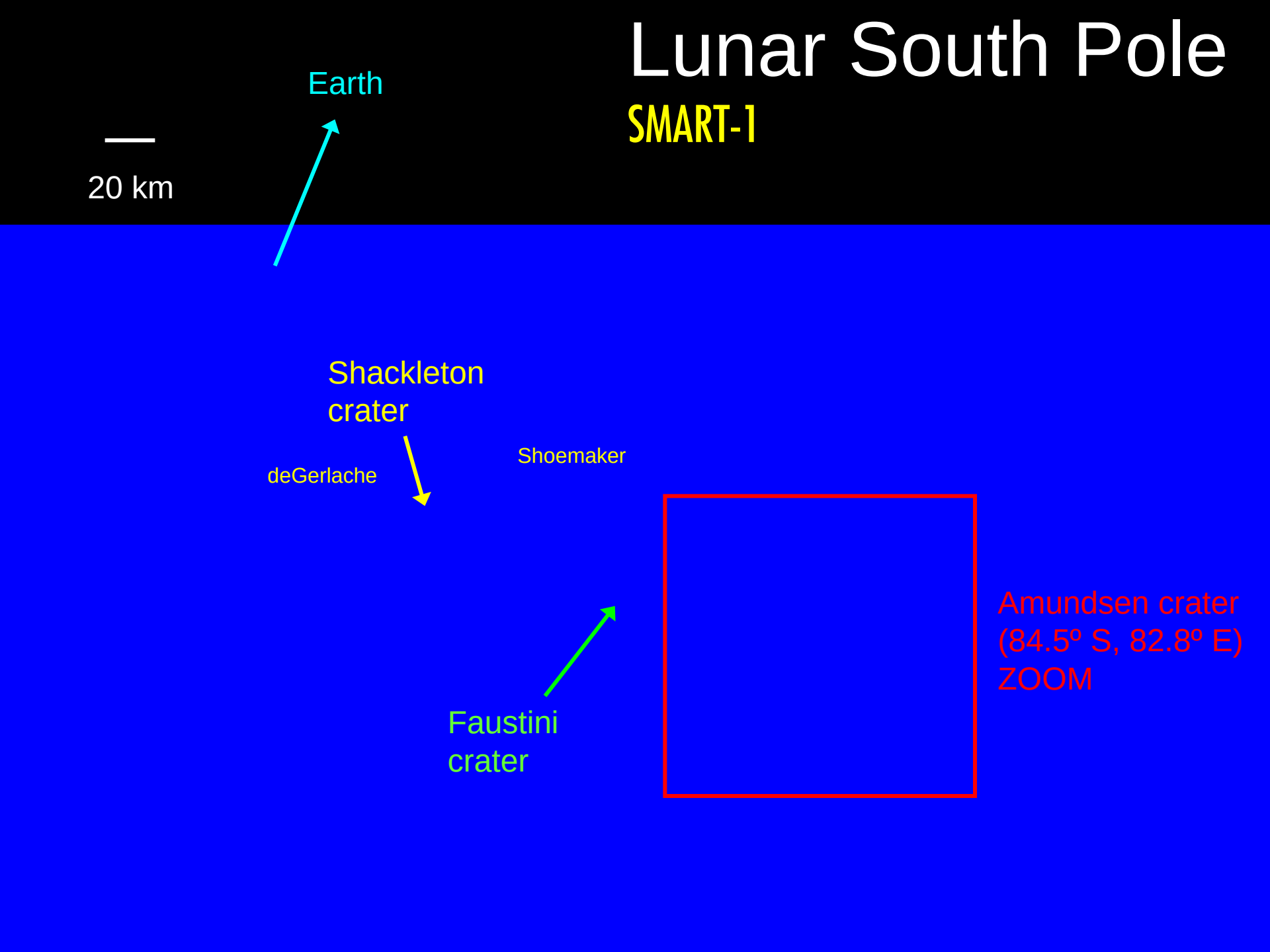
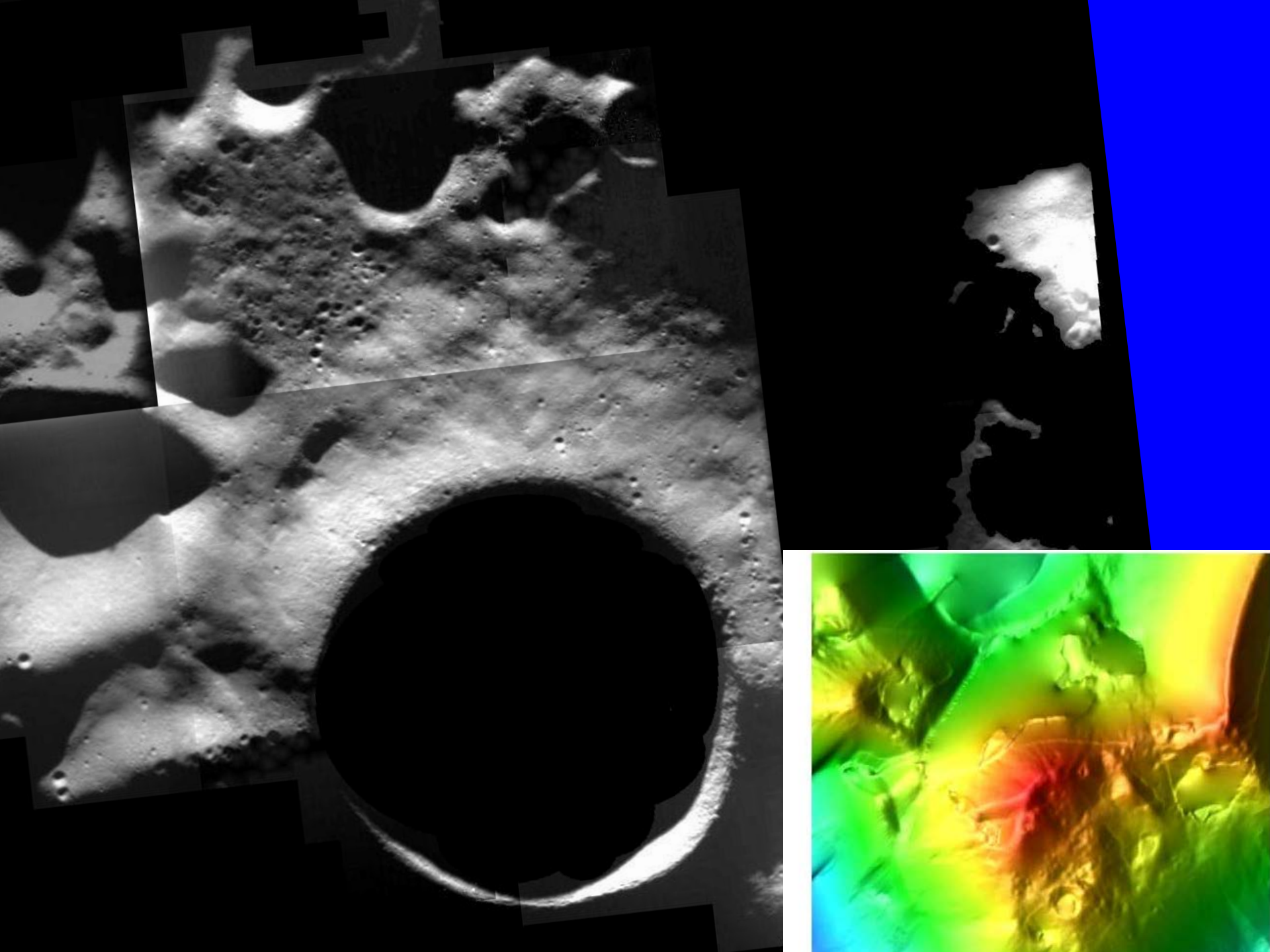
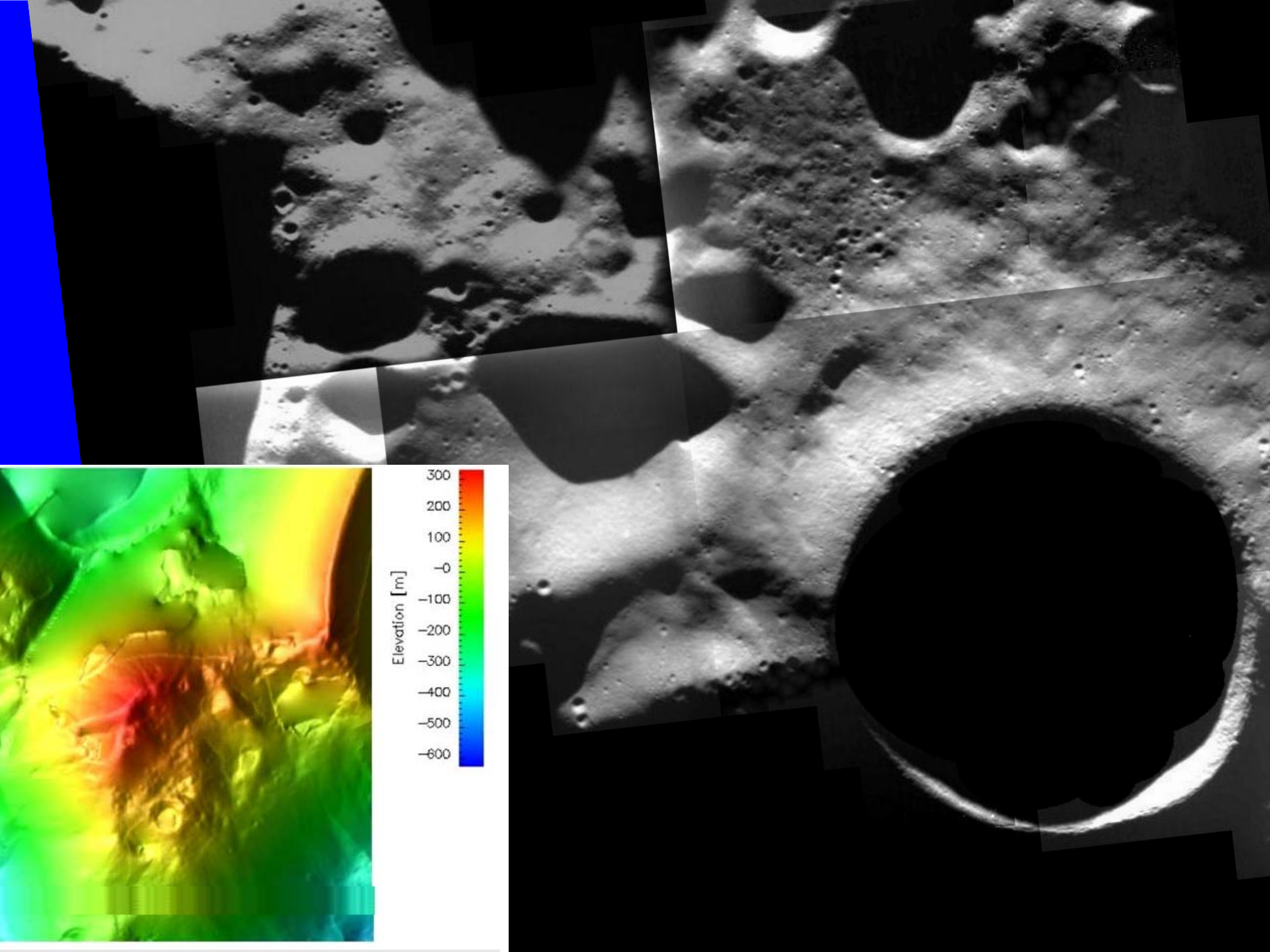
[Permalink] [report issues/suggestions] [overview]

Lunar South Pole

SMART-1



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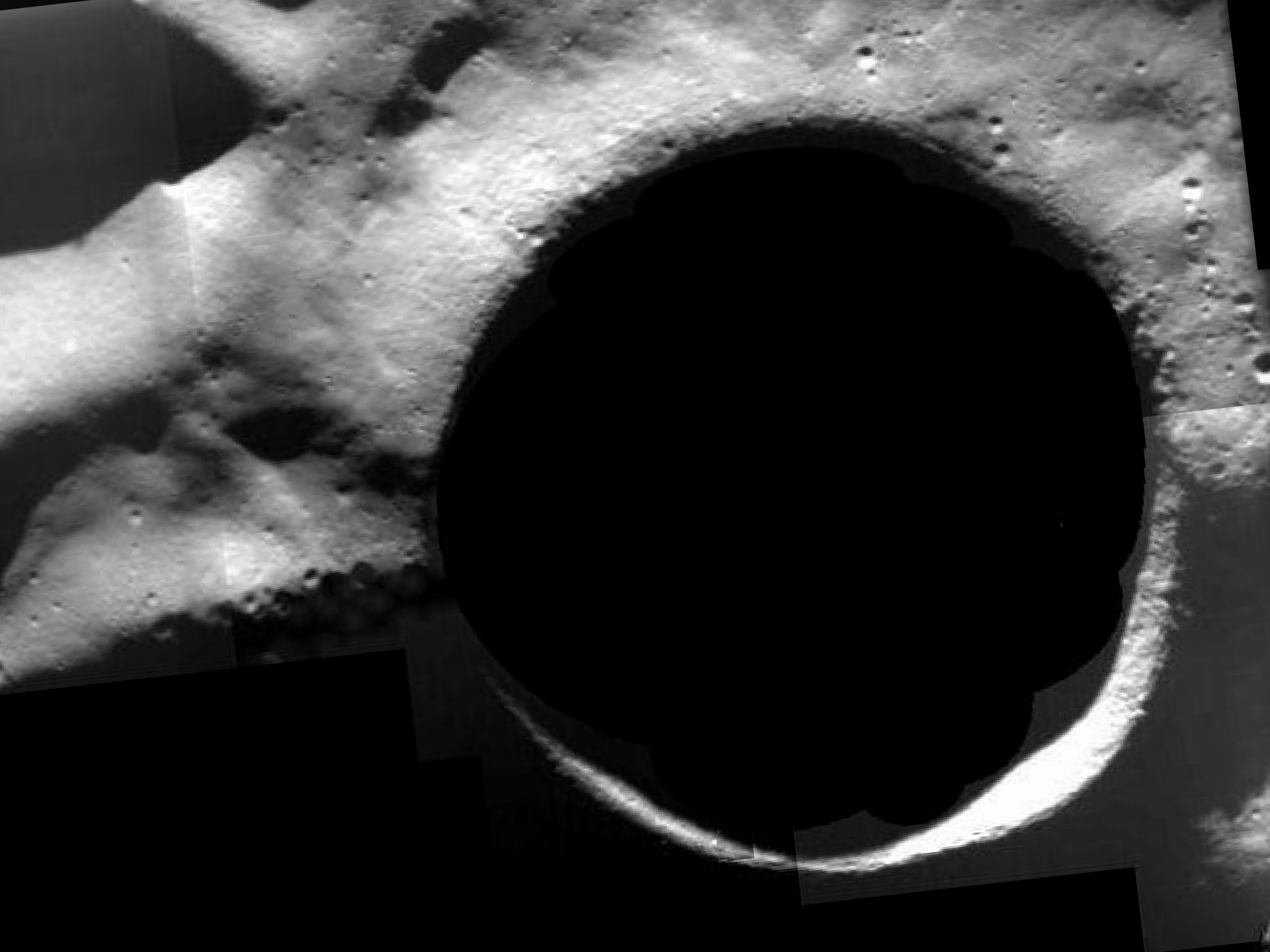
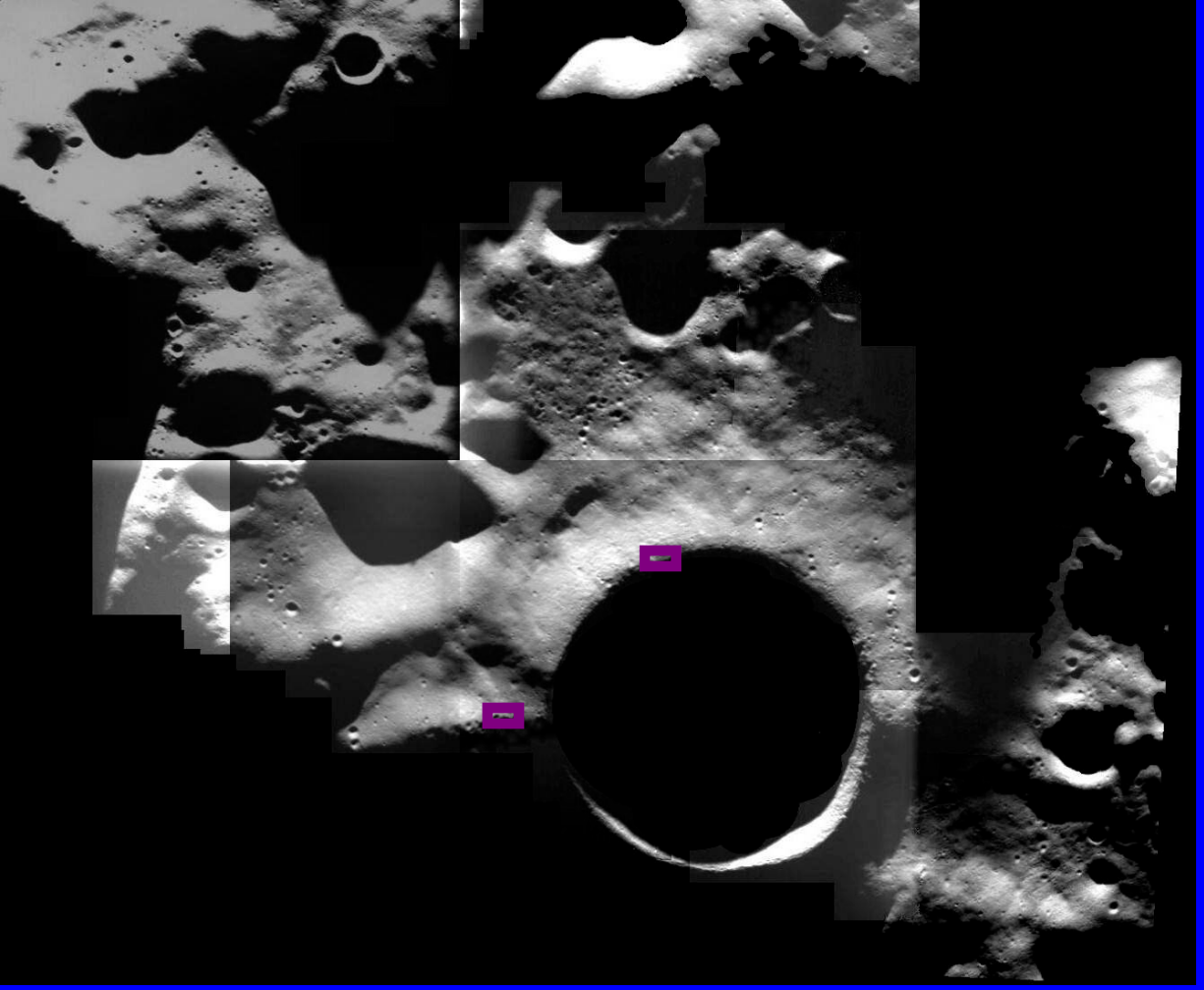
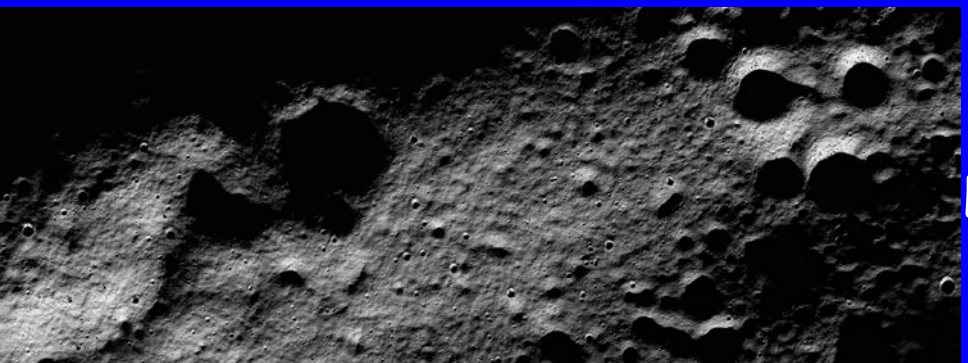
Elevation [m]





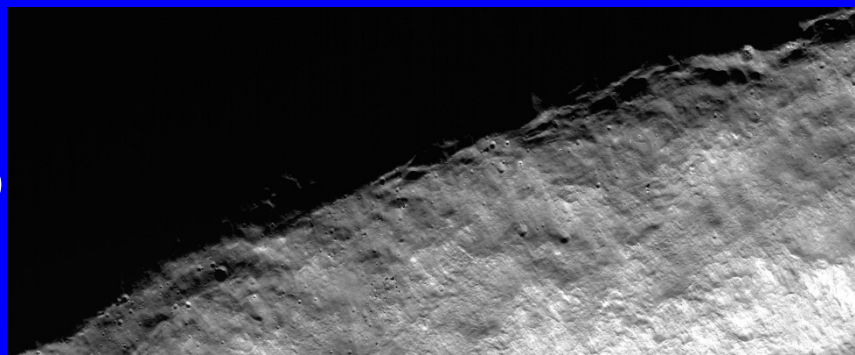
SMART-1

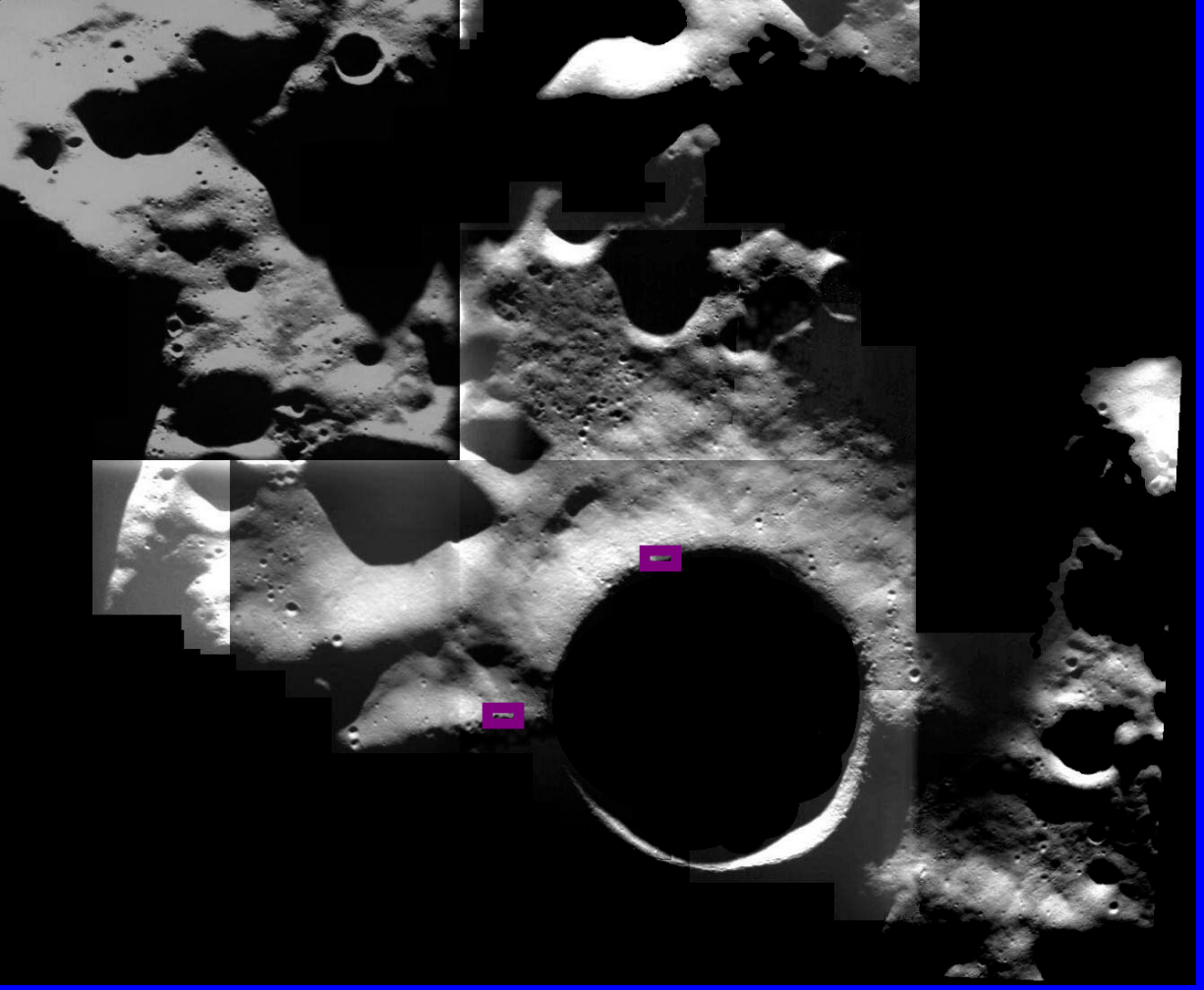
SMART-1 peak of light



LRO

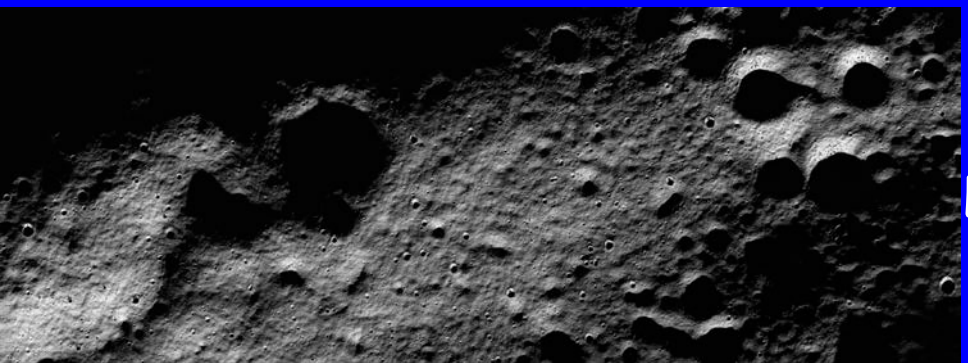
Shackleton rim





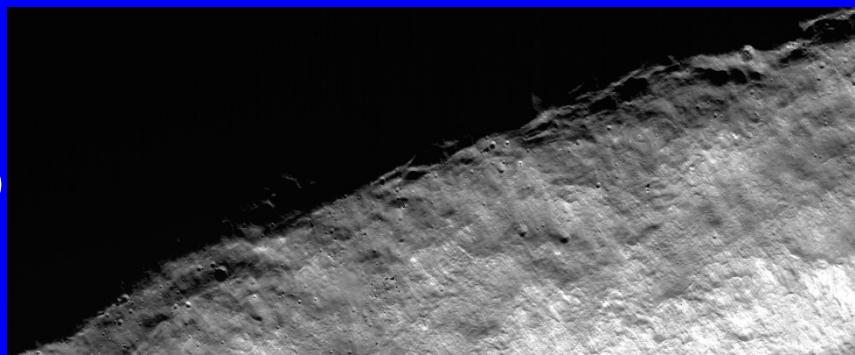
SMART-1

SMART-1 peak of light



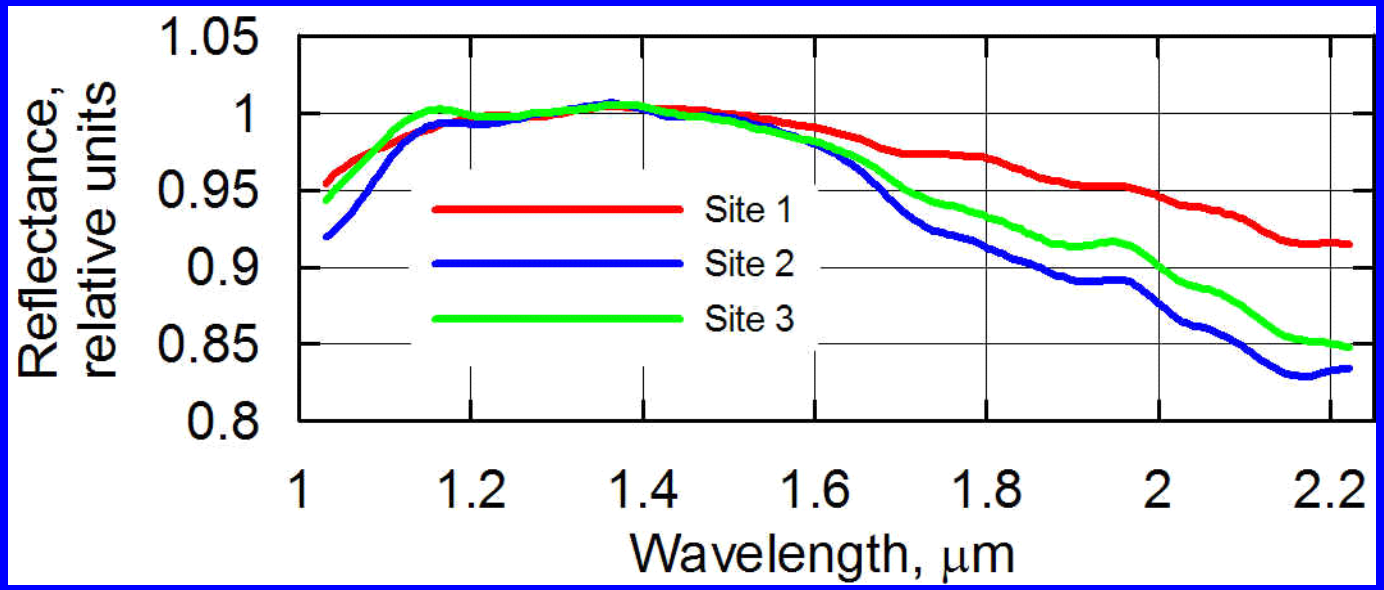
LRO

Schackleton rim



MAPPING THE SPECTRAL PROPERTIES OF SELECTED LUNAR REGIONS *Reiner-Gamma Swirl (RGS)*

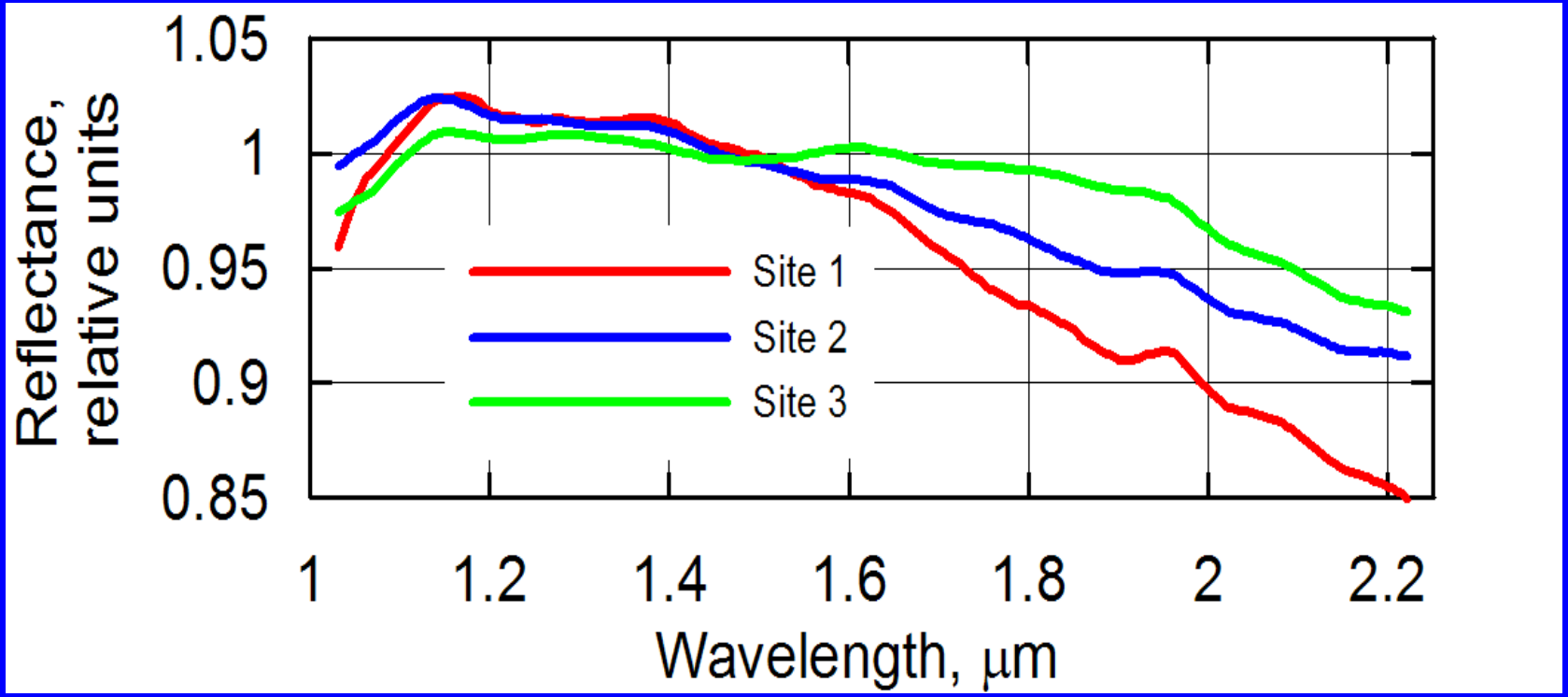
SIR team



Relative reflectance spectra for lunar sites:
~ small mare crater south from the RGS core (area 1),
~ the diffuse swirl feature at the northern part of RGS (area 2)
~ the Reiner-Gamma feature itself (area 3)

MAPPING THE SPECTRAL PROPERTIES OF SELECTED LUNAR REGIONS

Aristarchus Plateau and Northwest of Procellarum



Relative reflectance spectra for lunar sites:

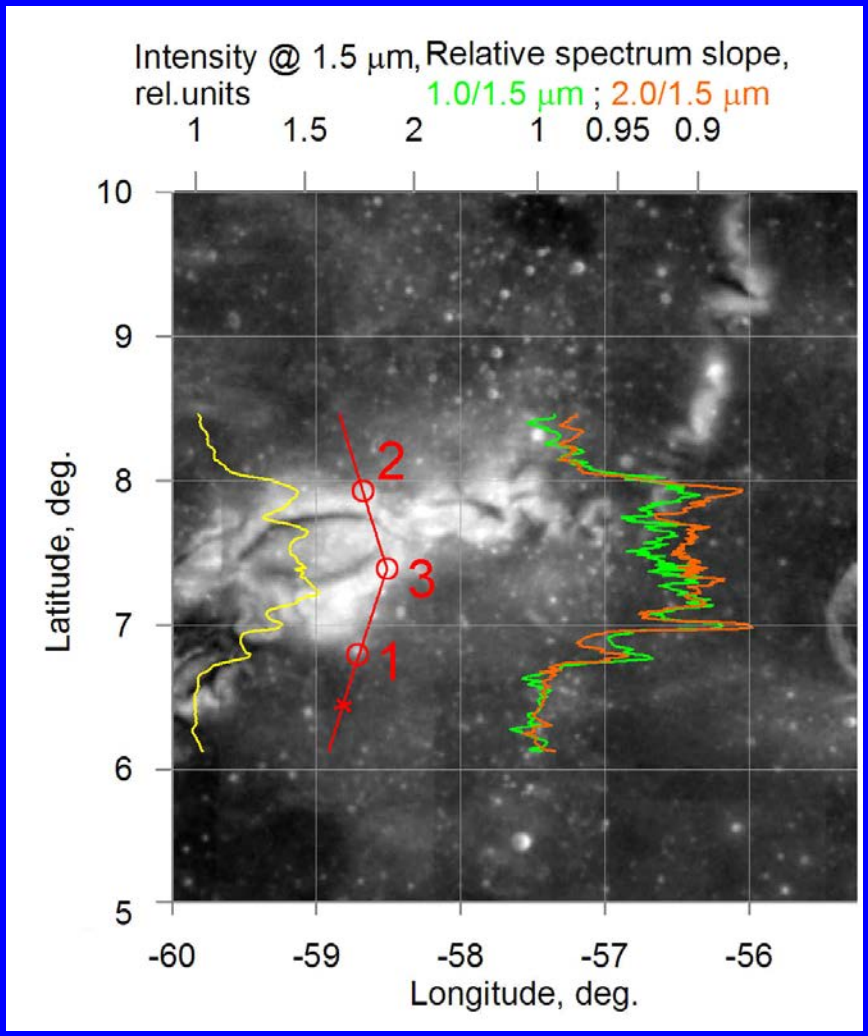
SIR team

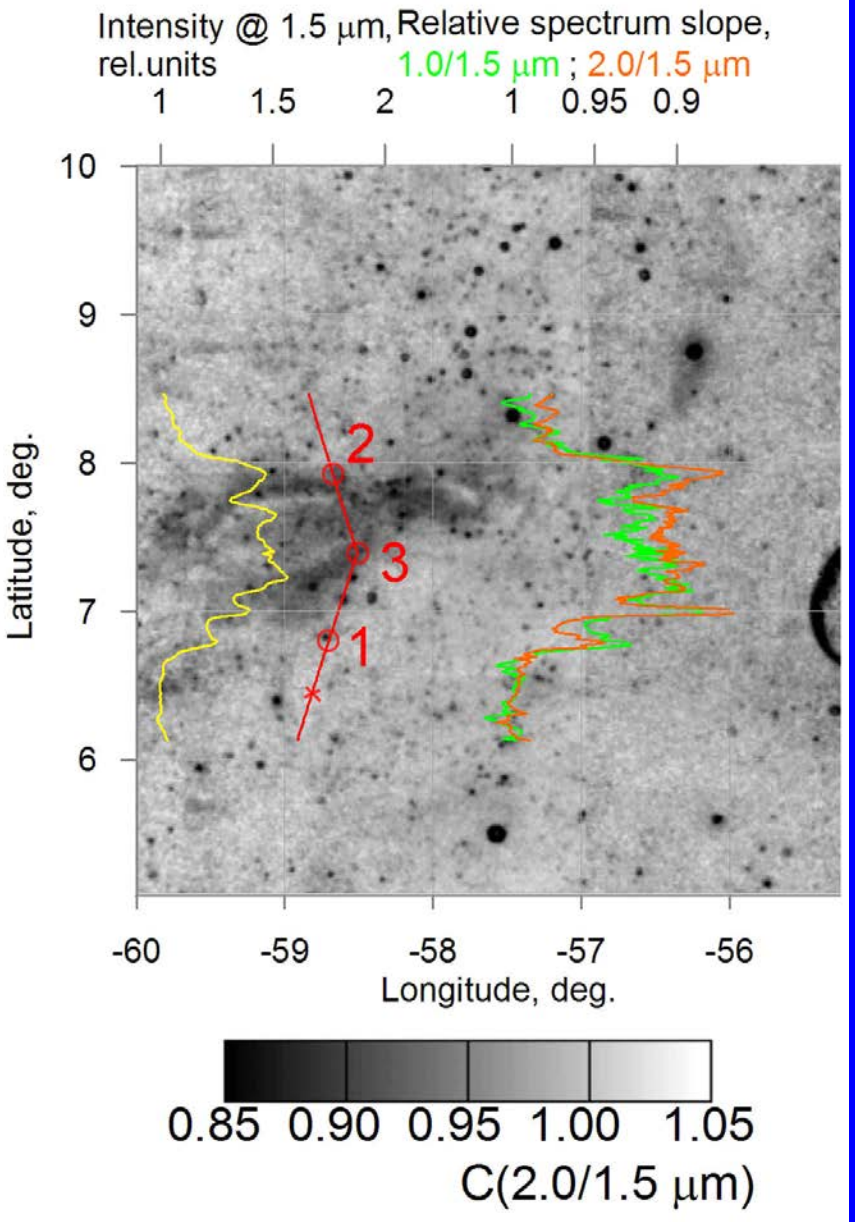
~ small mare crater close to the Schroter Valley (area 1)

~ the Aristarchus ejecta material (area 2)

~ and the site in the northern part of Plateau (area 3)

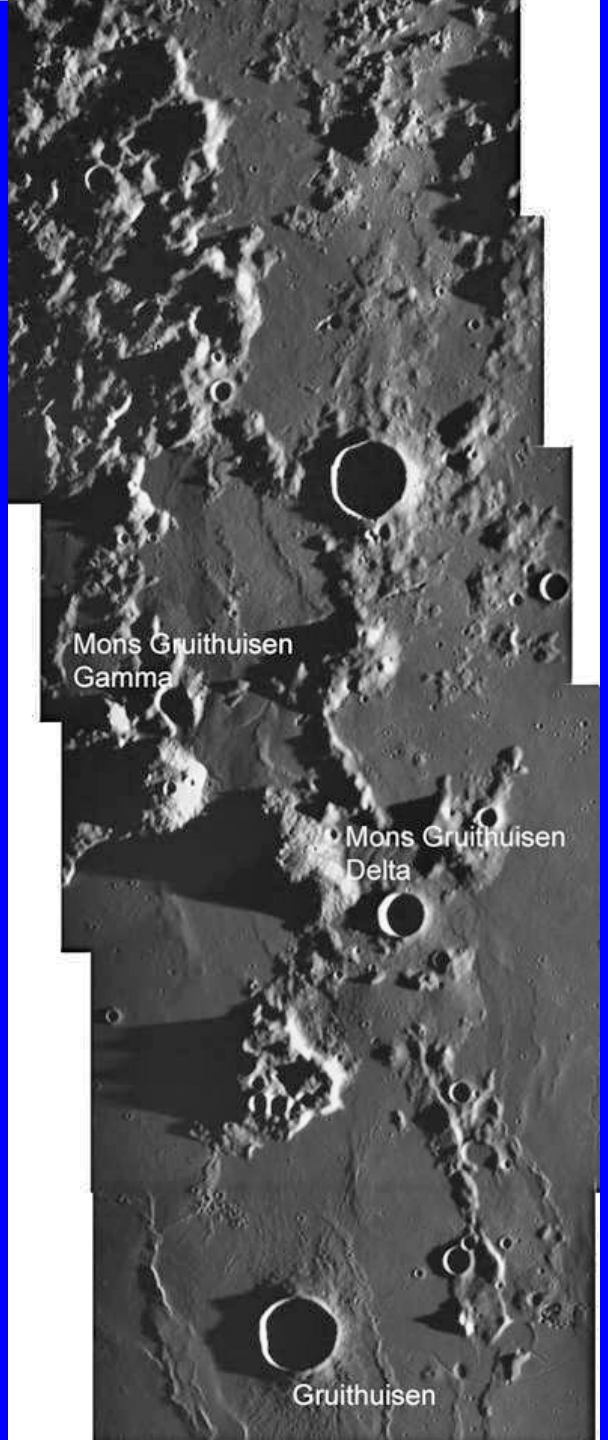
MAPPING THE SPECTRAL PROPERTIES OF SELECTED LUNAR REGIONS (*Reiner-Gamma Swirl (RGS)*)





Volcanism

Gruithuisen domes



Marius Hill