From SMART-1 to future lunar exploration

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ESTEC/SRE-S

ILEWG Executive Director

Smart-1 Lunar Mission

First ESA lunar orbiter

Test new technologies

- Solar Electric Propulsion

- instrument miniaturisation

- Faster, cheaper, smarter

Science goals:

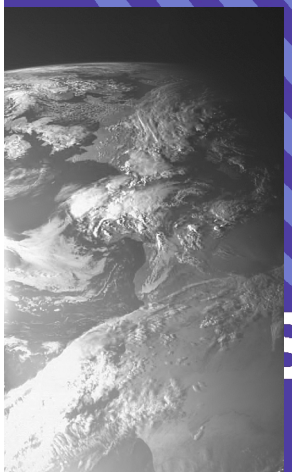
First X-ray global map of lunar elements

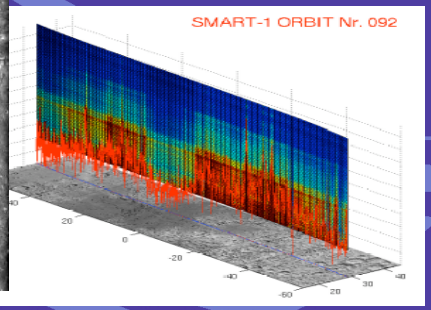
First mapping of minerals in infrared

Launch date: **27 Sept 2003, Ariane 5**

Lunar capture: 15 Nov. 2004

Lunar science orbit 15 March 2005





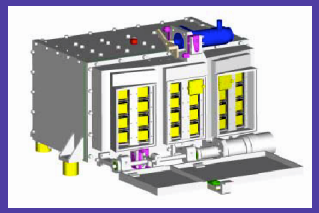
Mission: **6 months nominal lunar orbit operations + 1 year extension until Impact 3 Sept 2006**

Launch mass: **370 kg**

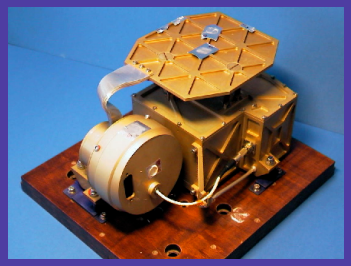
Payload: 19 kg

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

European Technologies
Success of Mini-Instruments (19 kg)



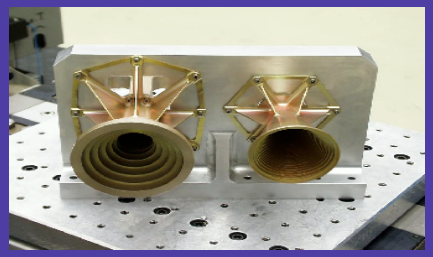
- D-CIXS Compact Imaging X-ray Spectrometer (UK, 5.2 kg)
- + XSM solar X-ray Monitor (SF)



- SIR IR Spectrometer (D, 2.3 kg)

- AMIE High Resolution micro-Camera (CH, 2.1 kg)

- SPEDE Spacecraft Potential Electron Dust Exp. (SF, 0.8 kg)
- EPDP Electric Propulsion Diagnostics Package (I, 2.4 kg)



- KATE Deep Space X- Ka Communications (D/ESA, 6.2 kg)
- RSIS radio science (I)

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From gateway to lunar capture

- 11 Nov 10:30 UT SMART-1 crossed fuzzy Earth-Moon gravity gateway
- 12 Nov lunar approach images of north pole far side from 60000 km
- 15 Nov 17h48 UT 1st Perilune at 5000 km

28 Oct from
600,000 km

12 Nov from
60,000 km

SMART-1 Technology, Science and Exploration Themes

TESTING NEW TECHNOLOGIES AND NEW METHODS

SOLAR ELECTRIC PROPULSION, MINIATURISATION, LOW COST

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

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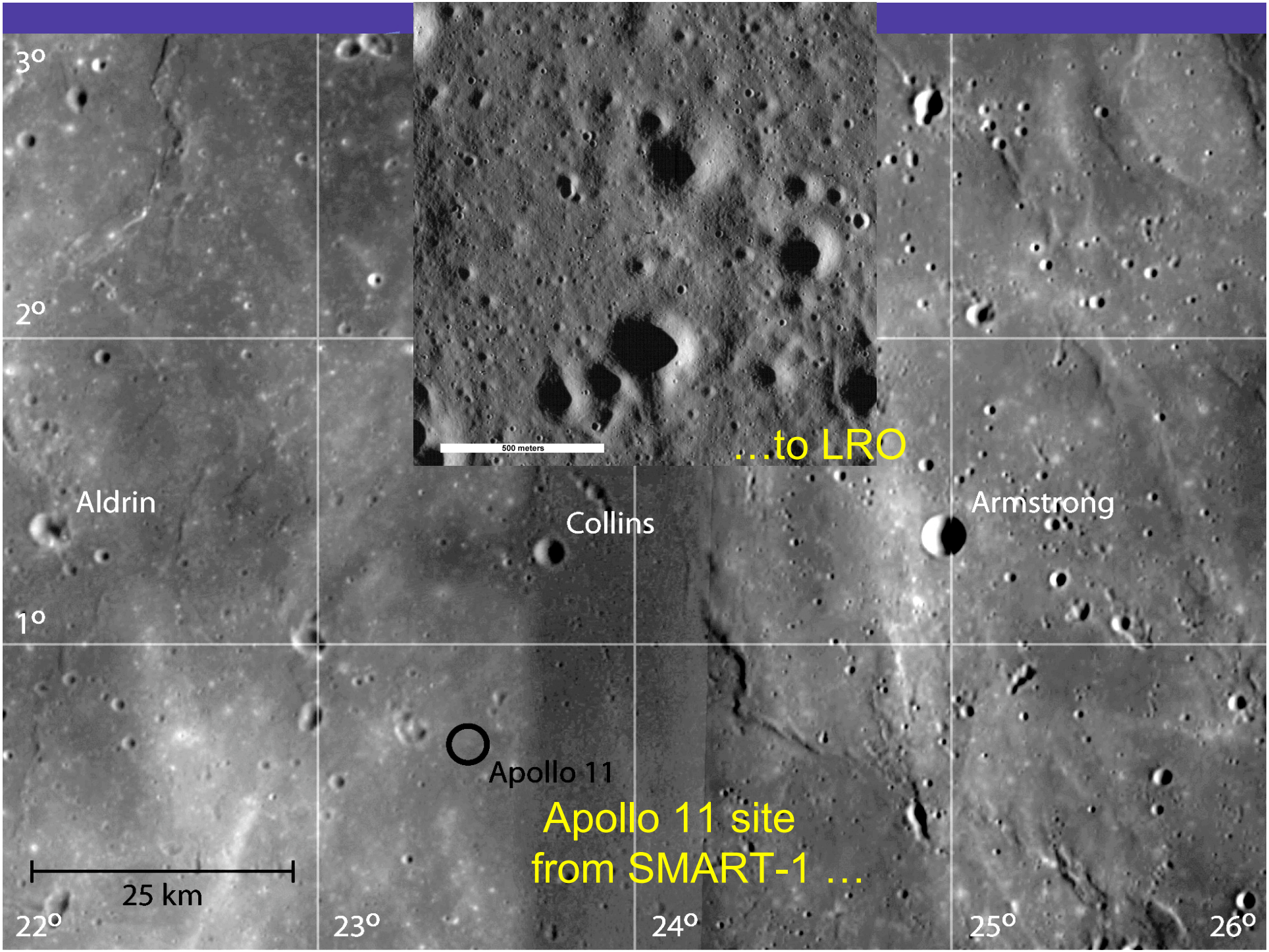
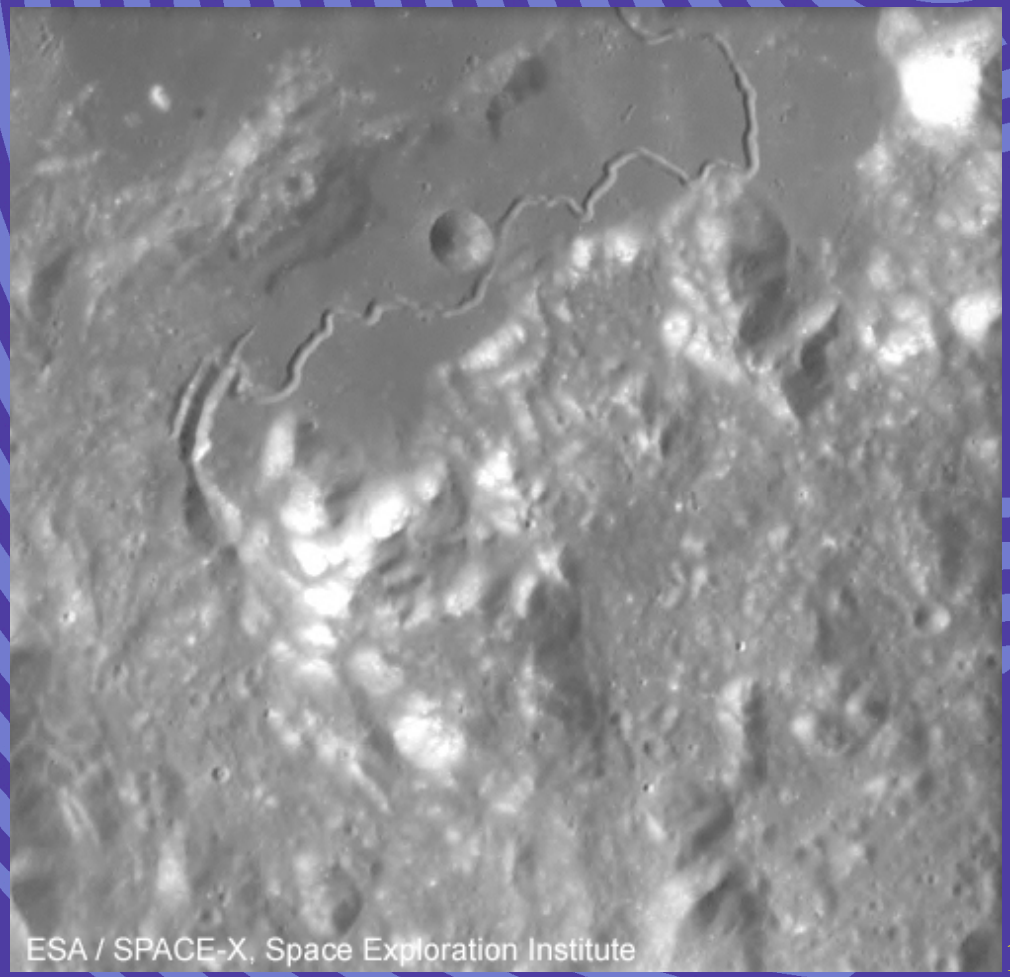
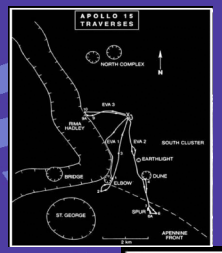
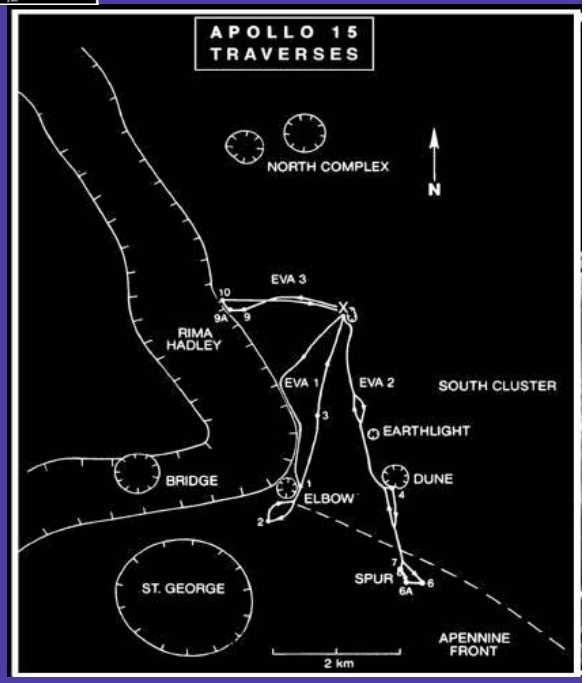

3°
2°
1°
500 meters
…to LRO
Aldrin
Collins
Armstrong
Apollo 11
Apollo 11 site
from SMART-1 …
25 km
22°
23°
24°
25°
26°

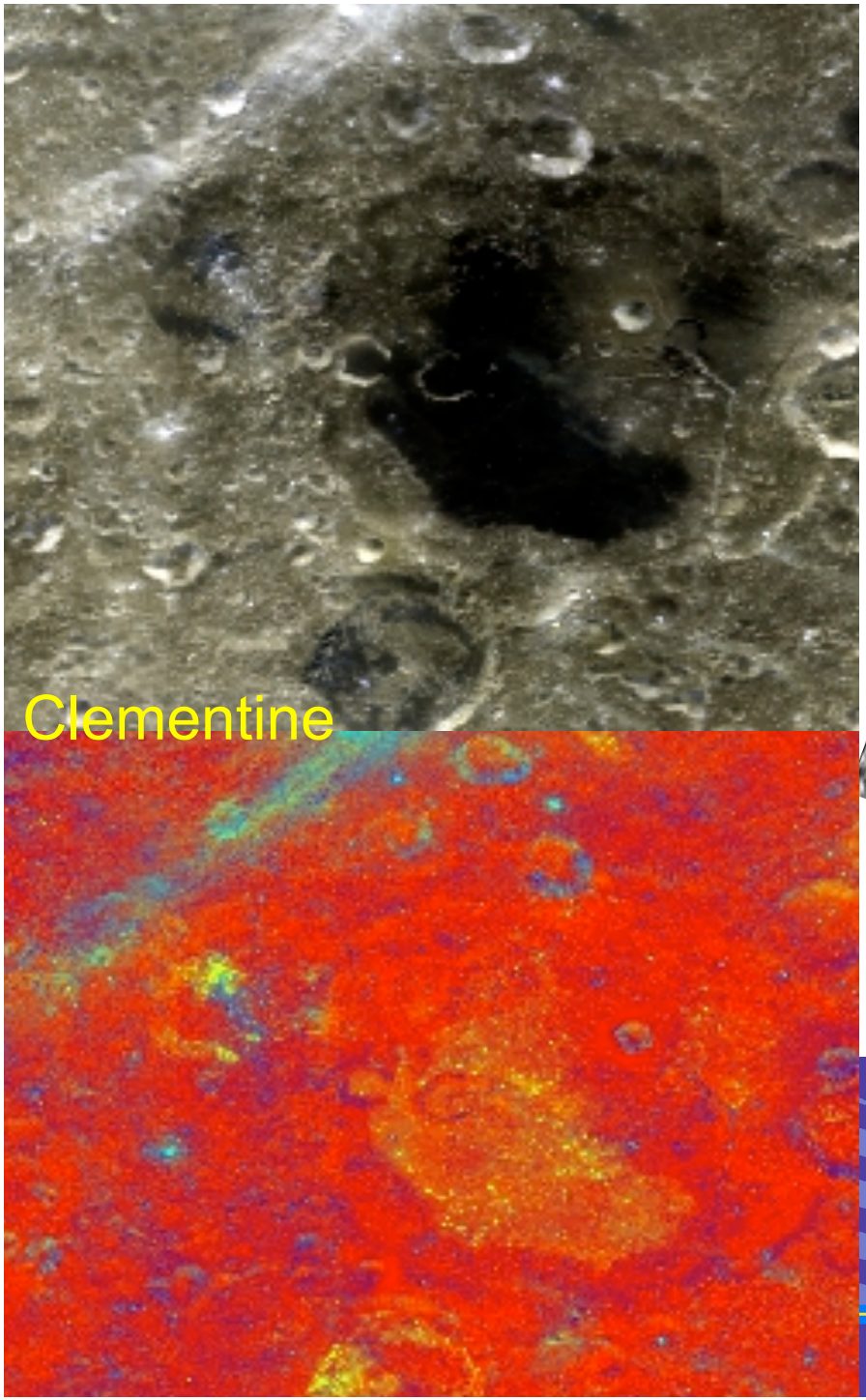
SMART-1 view of Hadley Rille near Apollo 15 landing site

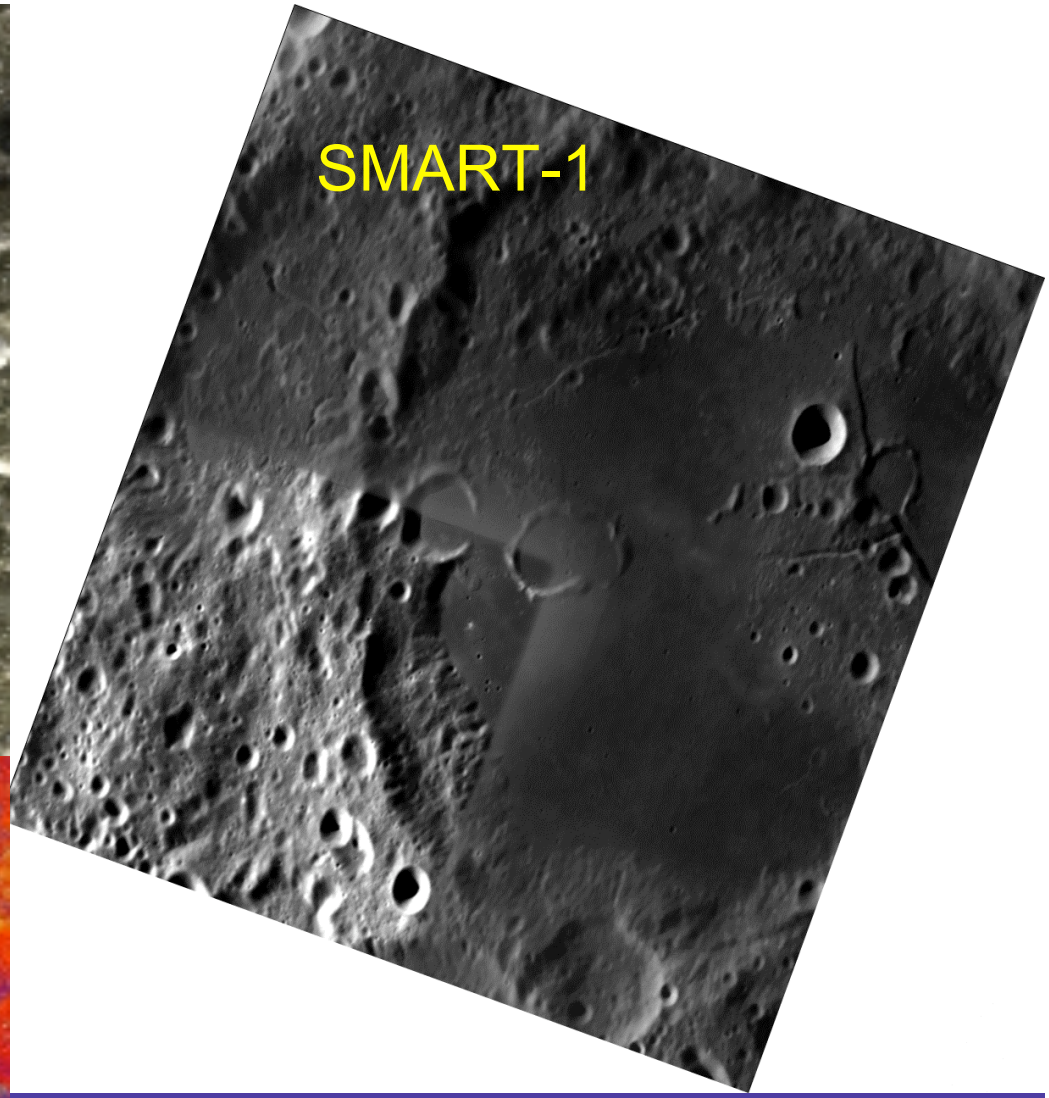






100 km field



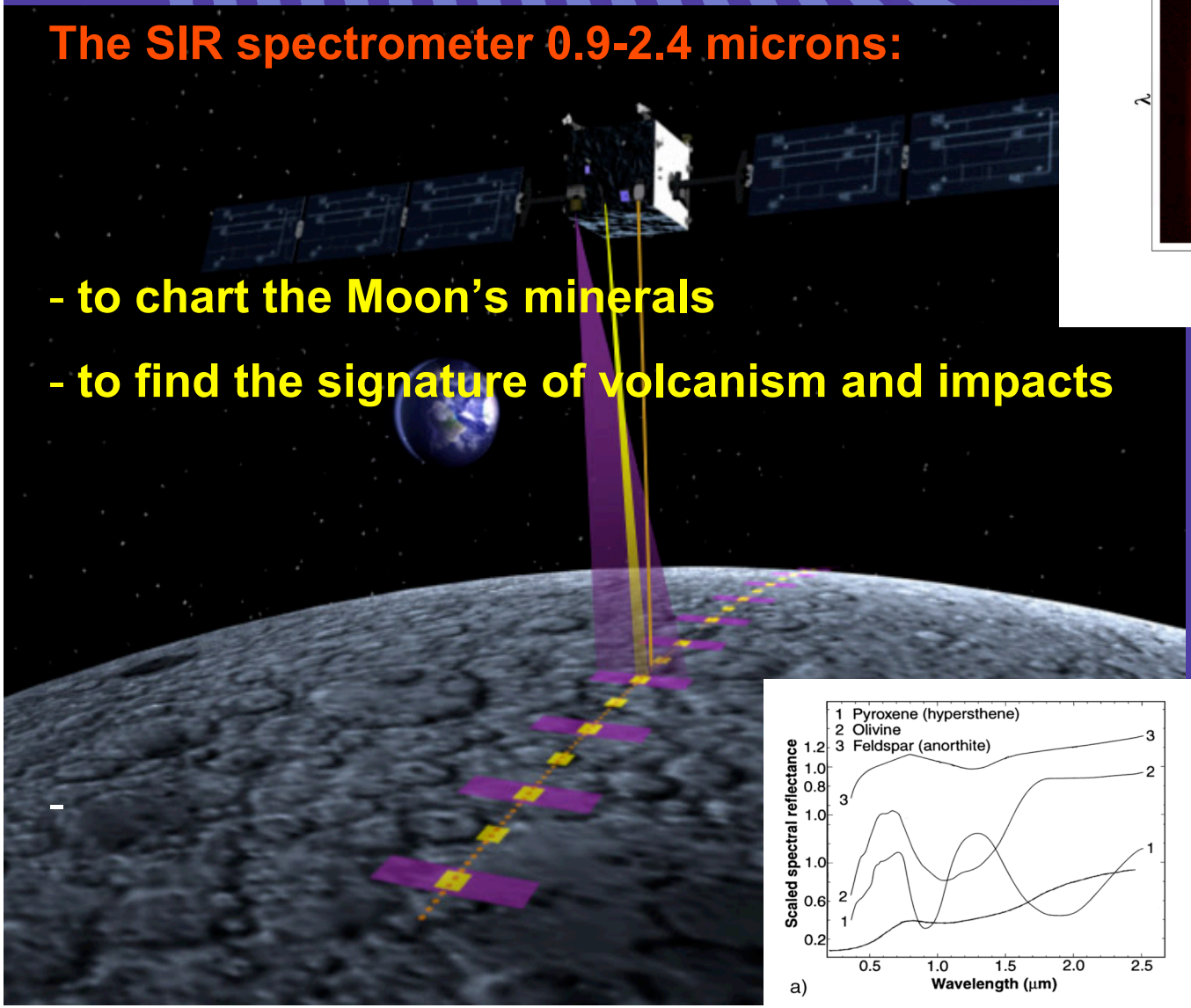


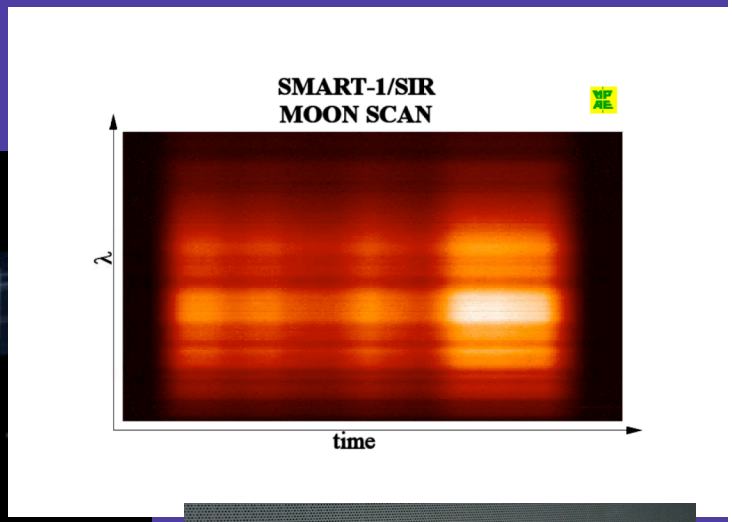
Jules Verne crater: Volcanism in South Pole-Aitken Basin

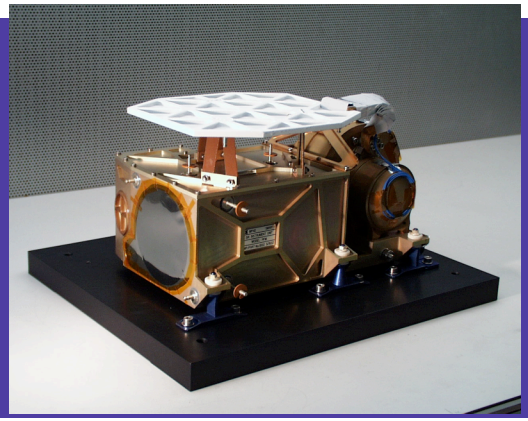
Smart-1/SIR & the infrared Moon: minerals

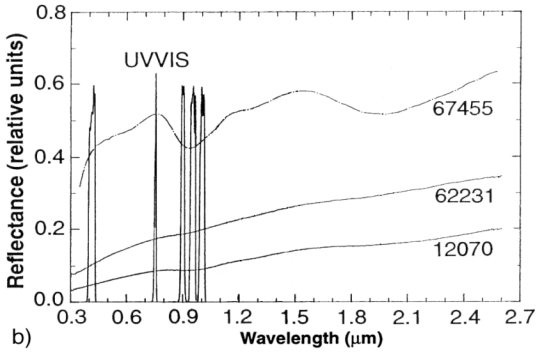
The SIR spectrometer 0.9-2.4 microns:

- **to chart the Moon's minerals**
- **to find the signature of volcanism and impacts**

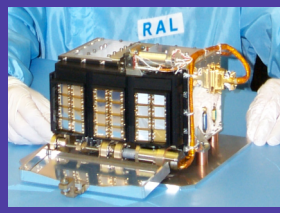








SMART_1 D-CIXS & the X-ray Moon: tracing violent Earth-Moon beginnings

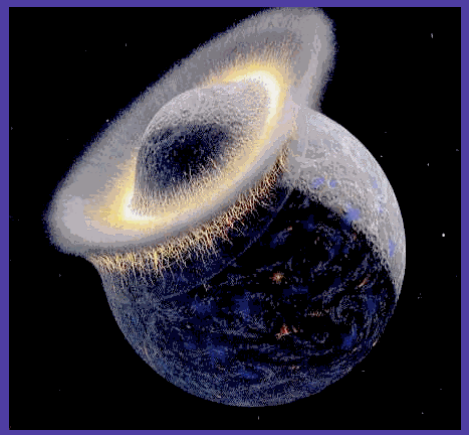


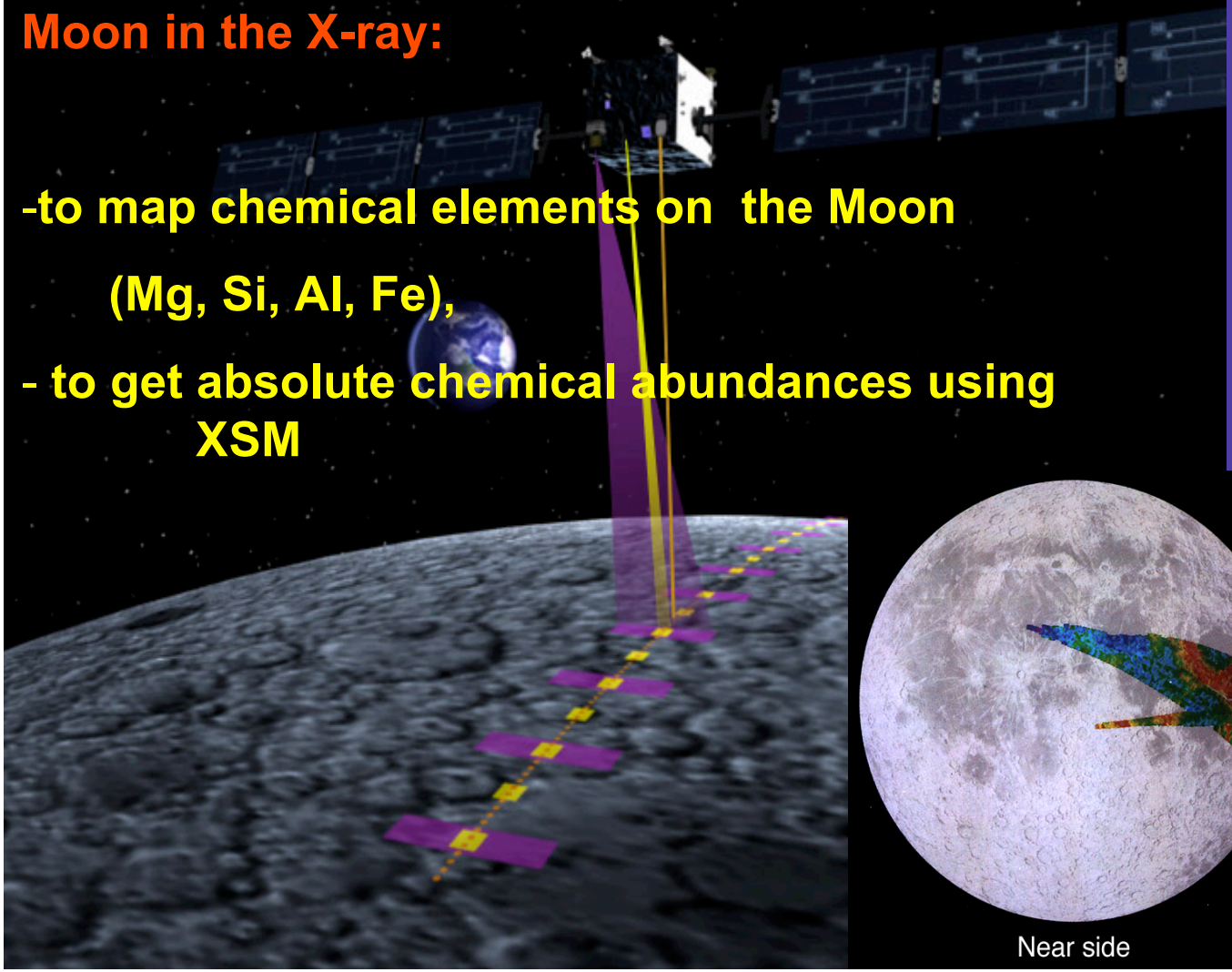
The D-CIXS spectrometer looked at the "invisible" Moon in the X-ray:

-to map chemical elements on the Moon

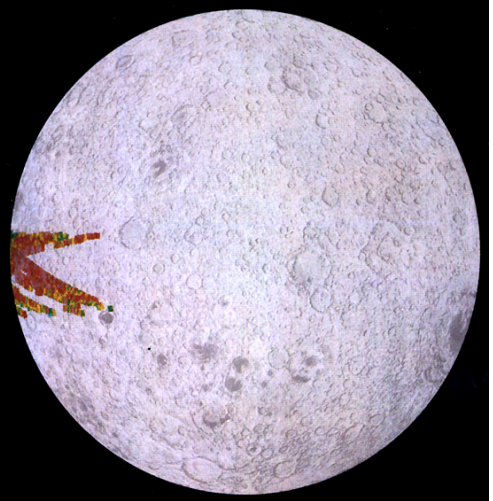
(Mg, Si, Al, Fe),

- to get absolute chemical abundances using XSM



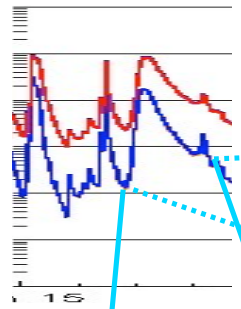


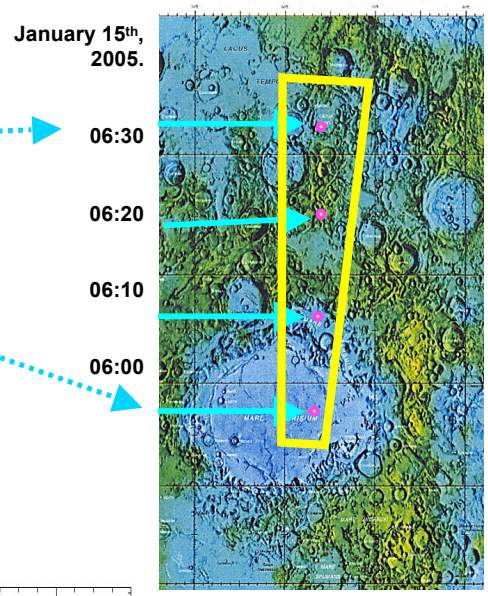
Near side



Far side

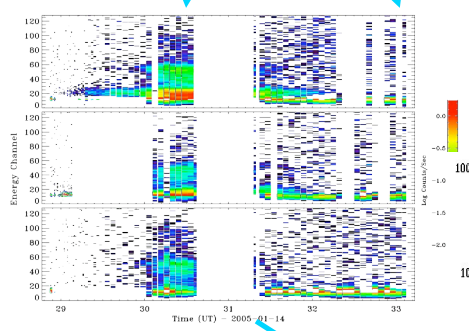
The Sun shines X-rays

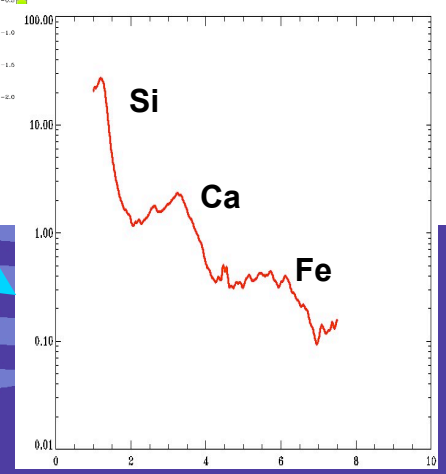




The Moon glows

-> D-CIXS





Derived elemental composition

1st detection of Calcium, Magnesium (Grande et al 2007), Titanium (Swinyard et al 2009)

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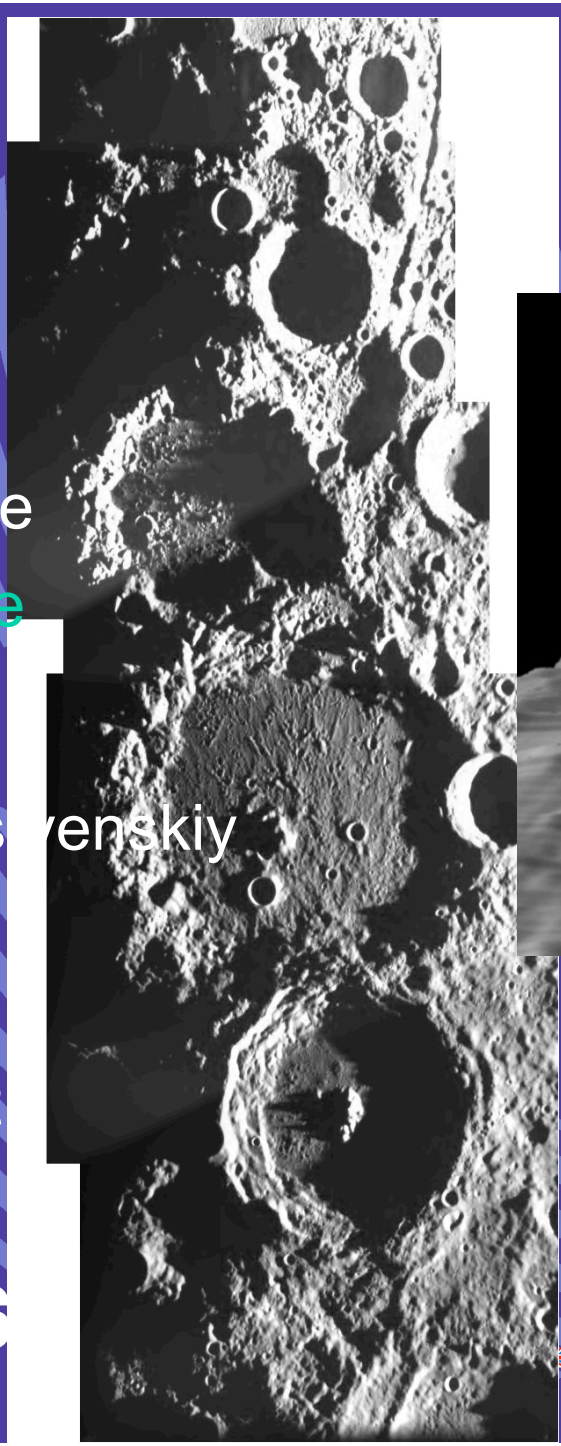
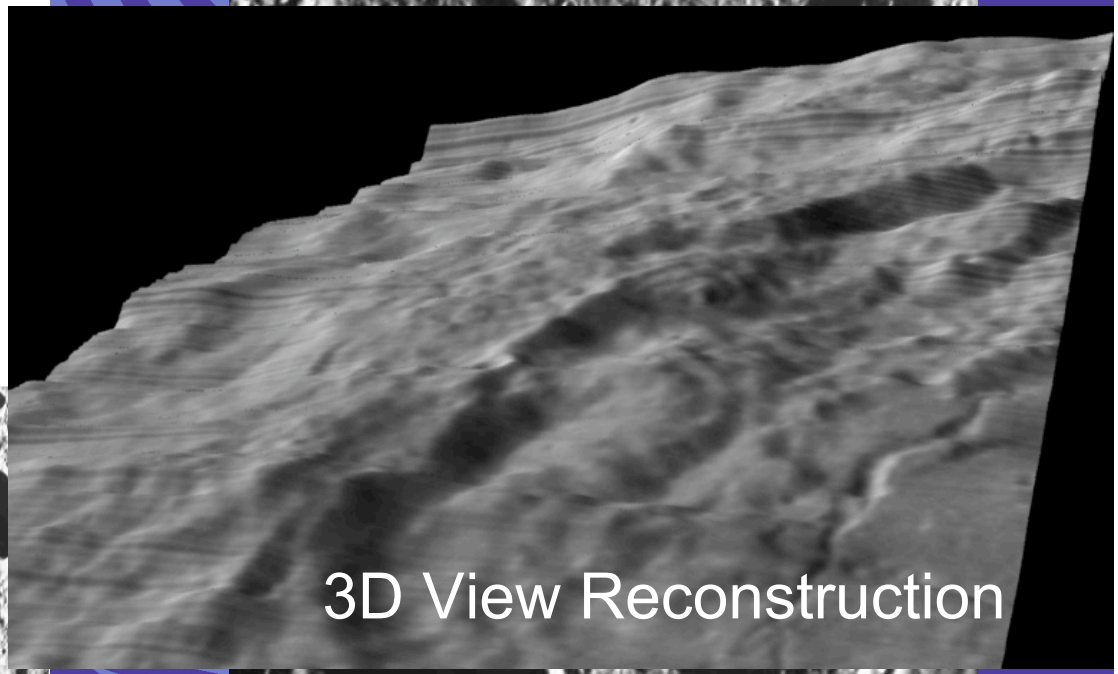
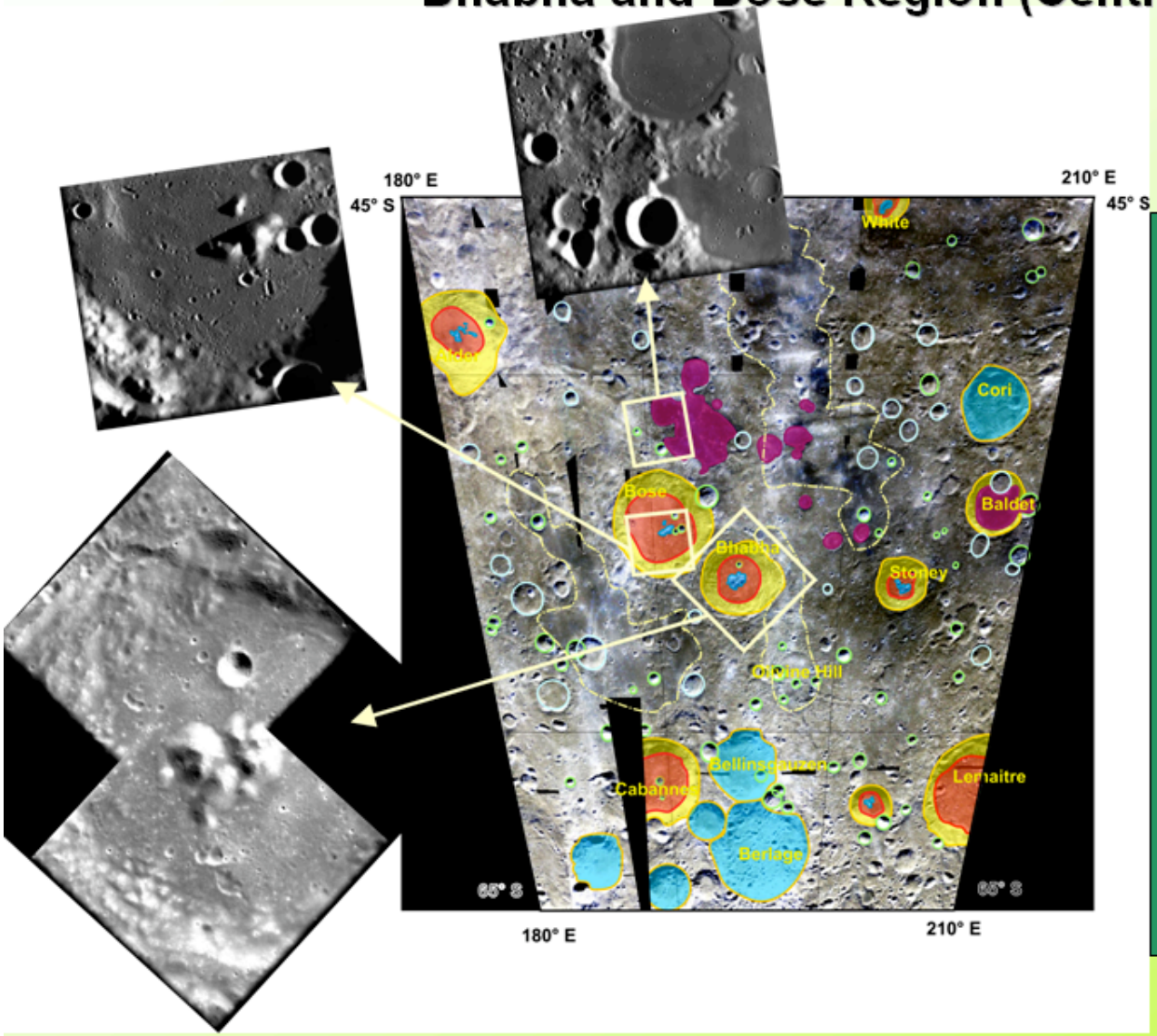

Hermite
North Pole
Rozhdes venskiy
Plaskett


3D View Reconstruction

Geological mapping

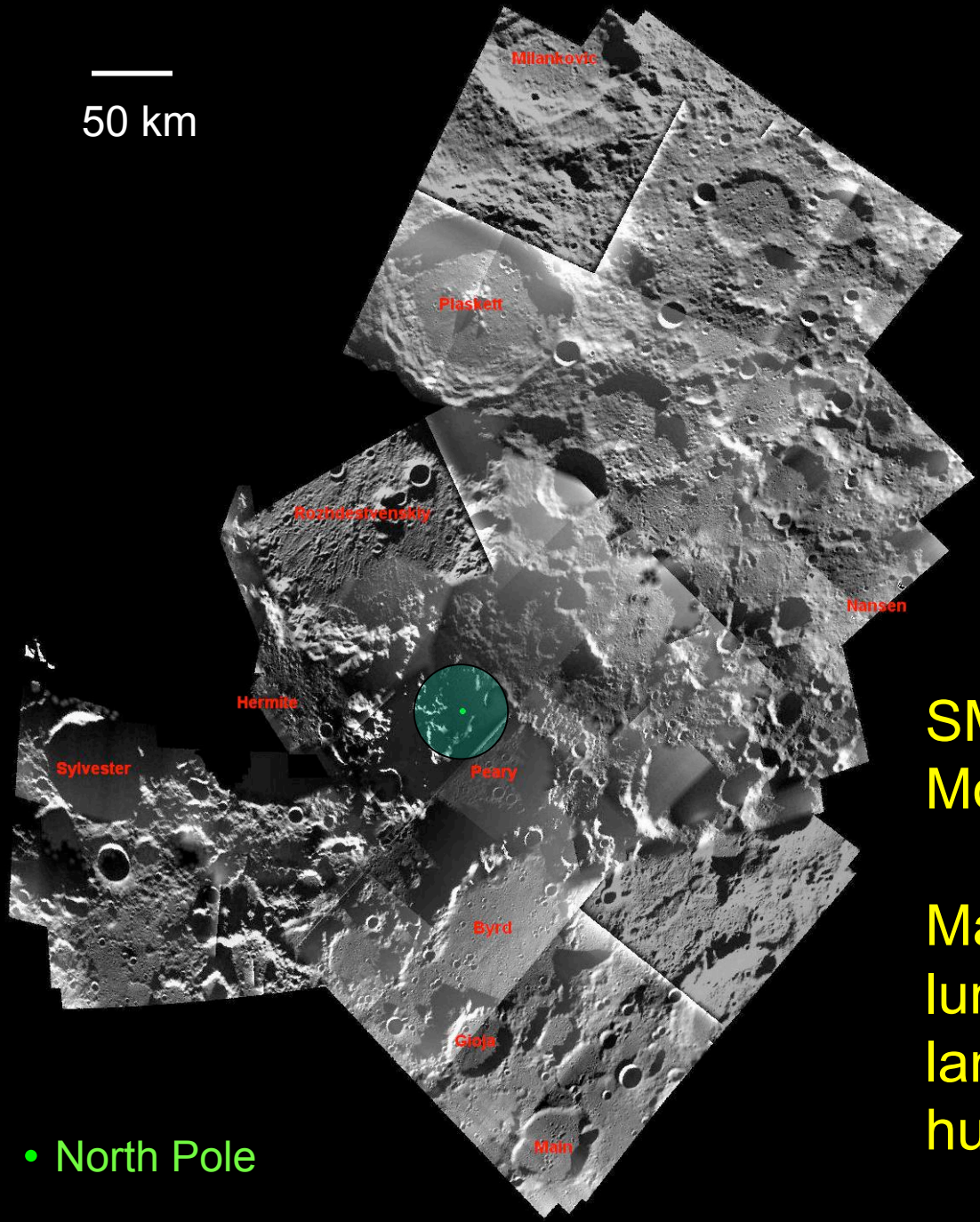
Bhabha and Bose Region (Central SPA)



Units

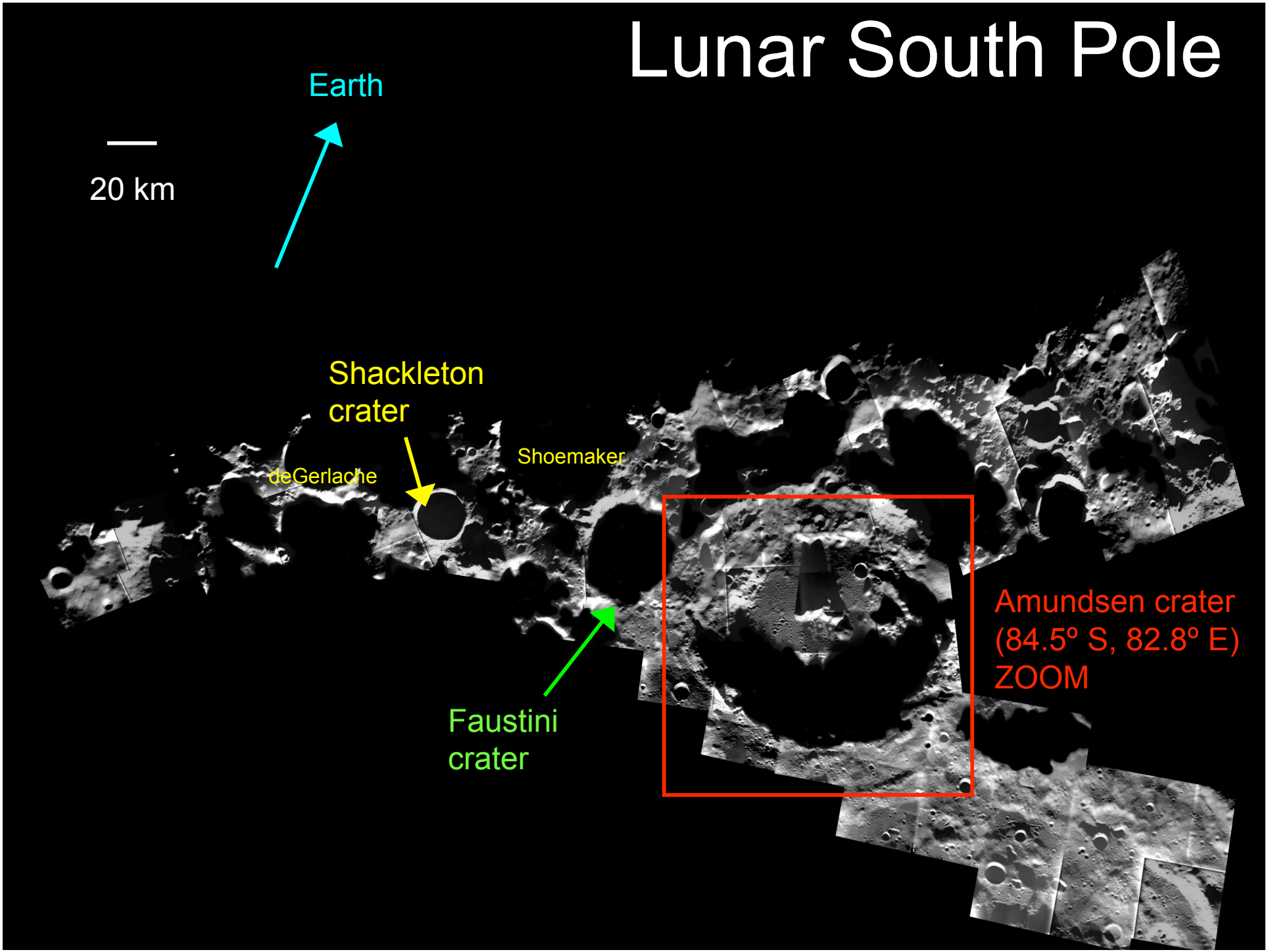
- Crater wall; freshly exposed materials
- Crater floor; weathered, smooth surface with impact melt
- Central peak; uplifted material
- Volcanism; young mare basalt
- Dashed Areas; geochemically different regions, possible impact melt sheet or cryptomaria
- Old craters
- Young simple craters

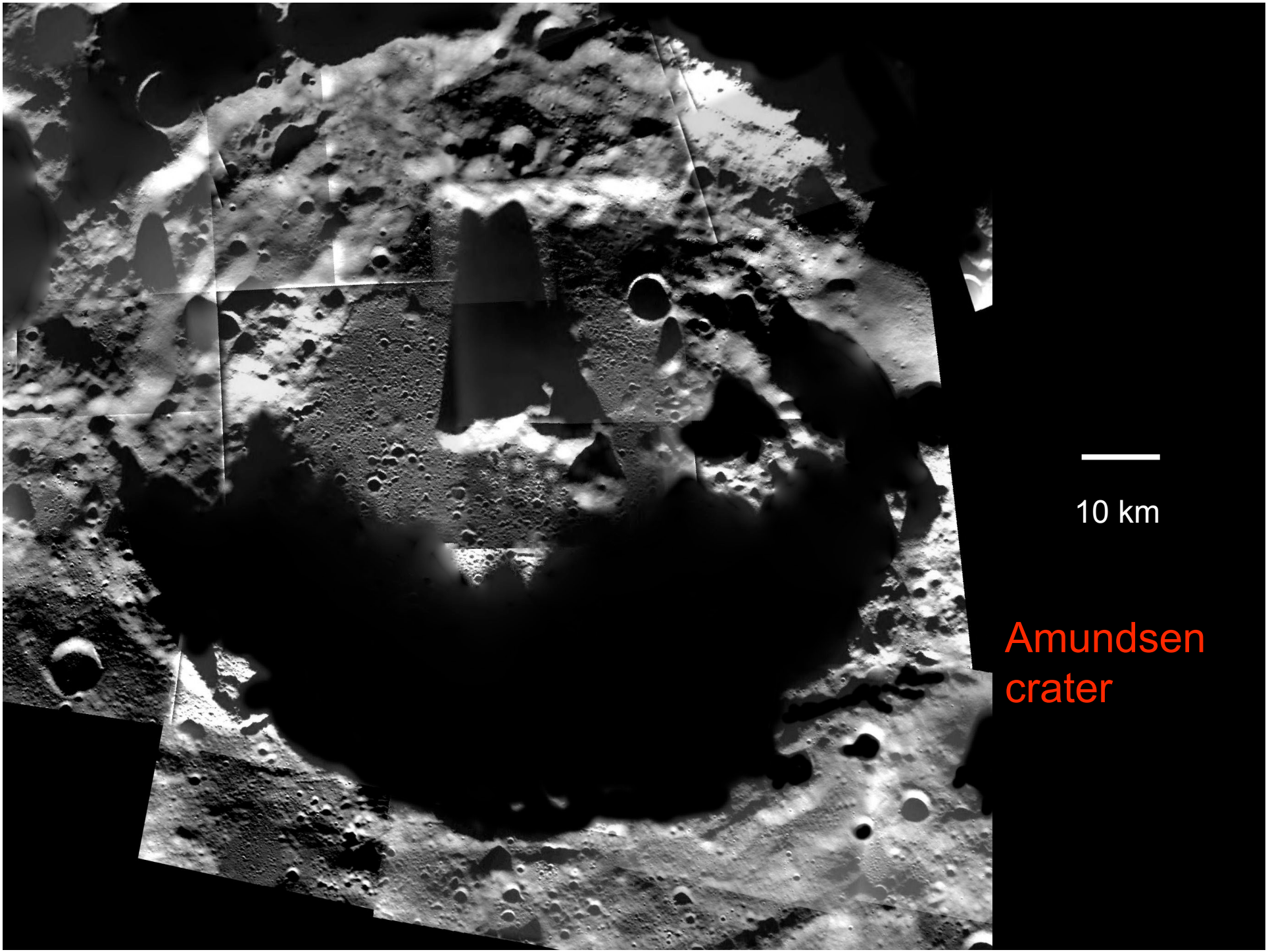
Geomorphological map overlain on Clementine (UV/VIS) real color image.
High resolution images of geomorphology from SMART-1, AMIE.
(A.M. Borst en F. Bexkens, 2008)



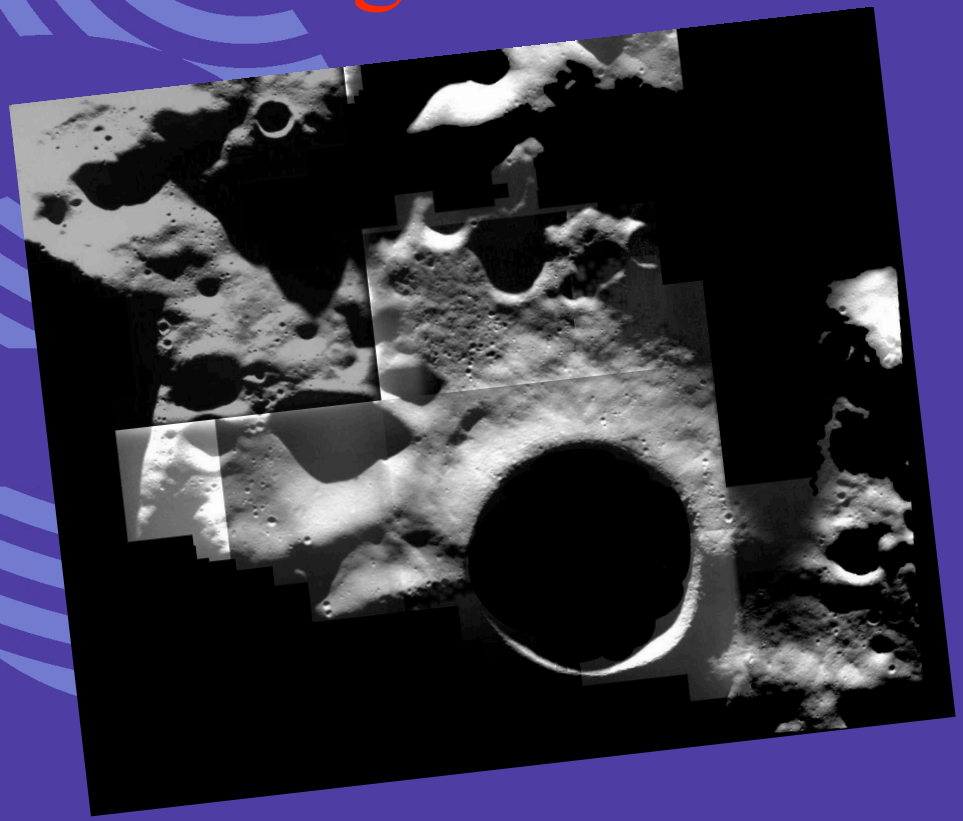
SMART-1
Mosaic of North polar region

Mapping support to future lunar exploration: landers, rovers and human bases

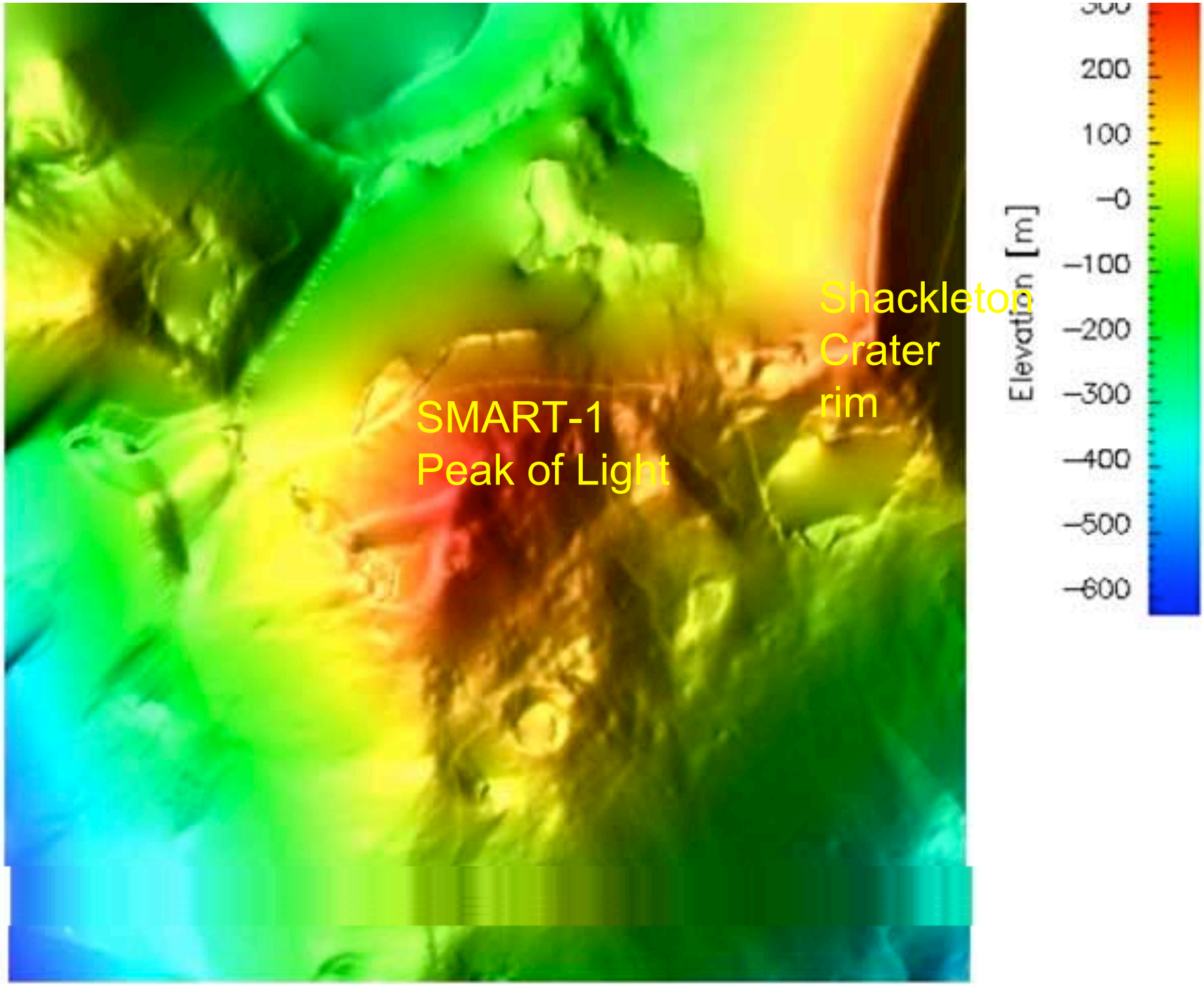

Lunar South Pole
Earth
20 km
Shackleton crater
deGerlache
Shoemaker
Faustini crater
Amundsen crater
(84.5º S, 82.8º E)
ZOOM

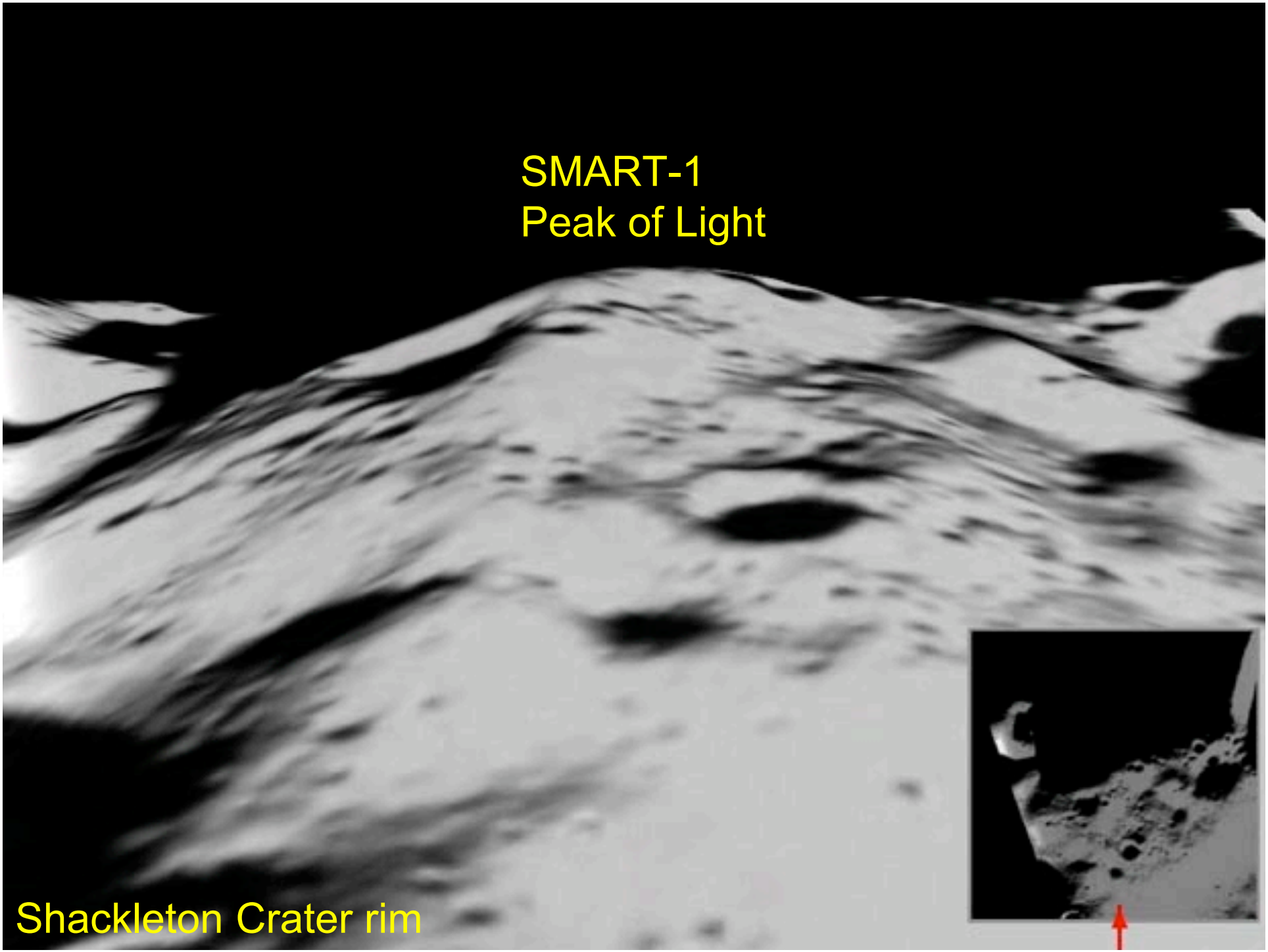

10 km
Amundsen
crater

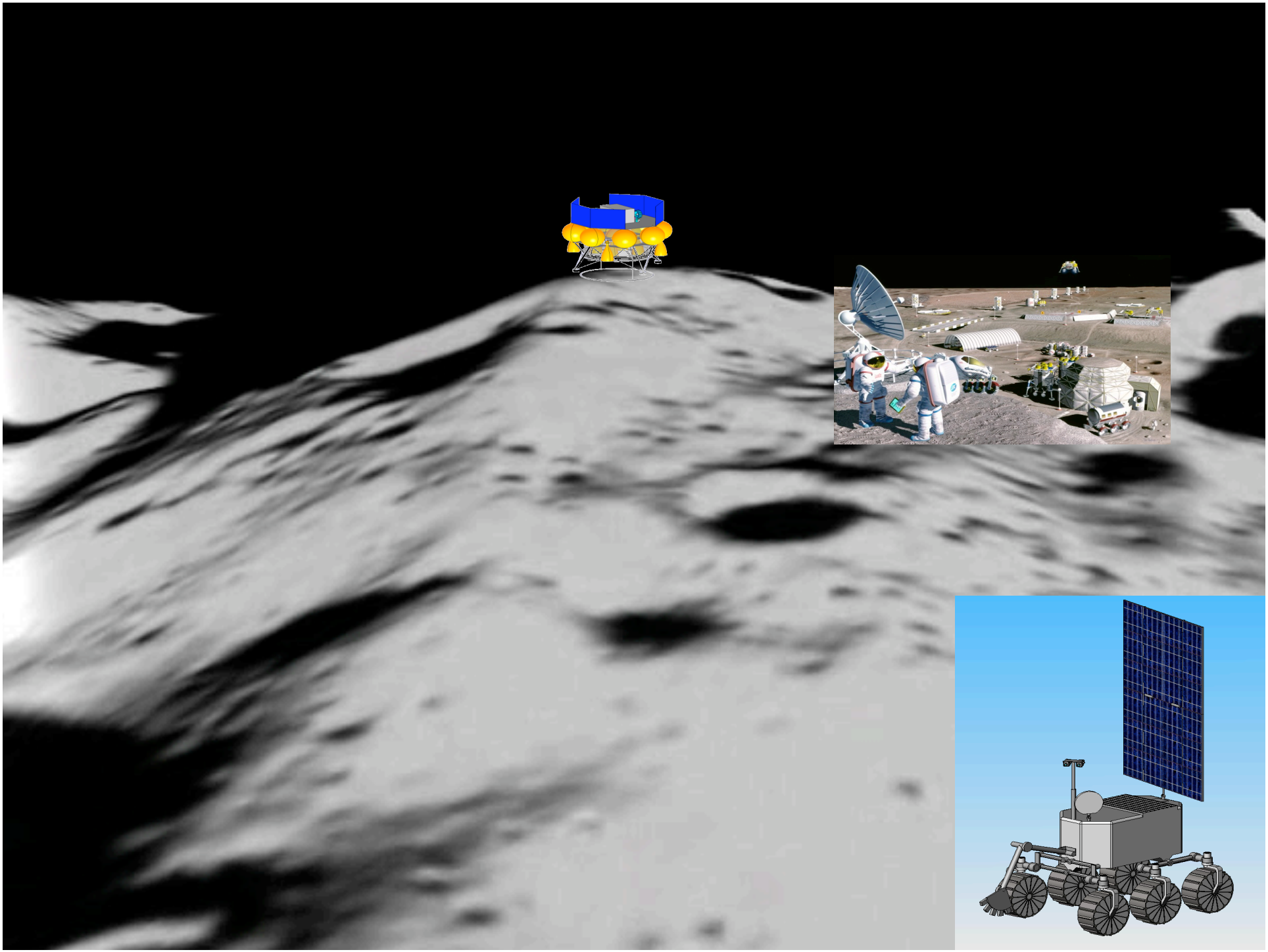
Rotational and Seasonal illumination changes



143 images point to peak of eternal light

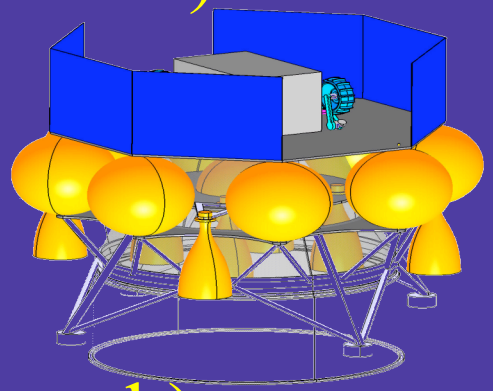

Shackleton
Crater
rim
SMART-1
Peak of Light
Elevation [m]
200
100
0
−100
−200
−300
−400
−500
−600


SMART-1
Peak of Light
Shackleton Crater rim



Possible lander concepts

- Impactors (SMART-1 and LCROSS)
- Penetrators (UK Moonlite)
- Google Lunar X-Prize class
- Mid-class landers (Soyuz Class launchers)
  - LES-3 Lunar Exploration Study
  - Moon-NEXT
  - Shared Ariane 5 class
- Logistics Cargo Lander (Ariane 5 launch)



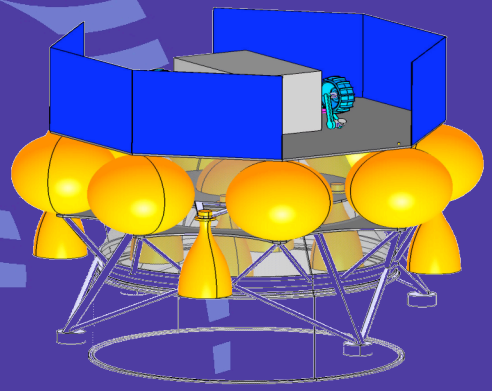
SMART-1 flash and debris cloud (CFHT)
-> “dry run” for LCROSS

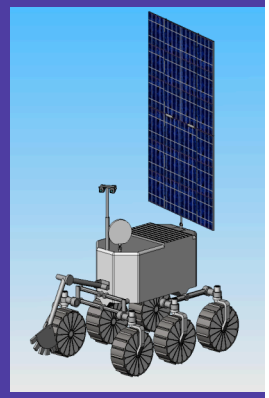
< 40 km >

European Lunar Polar Lander Concept

1) Precise Landing on the Moon
2) Preparation of future exploration & sample fetcher
3) Geochemical study of polar regions
4) Ice Search/ characterisation

Cost 300 Meuro





- Lander station element
- Rover element
- Robotic challenge
- Orbiter and relay infrastructures

- Opportunities for Students, education, outreach, cultural, artistic experiments

- Part of global robotic village with Chang-E2, Selene 2, and supporting International Lunar Network…

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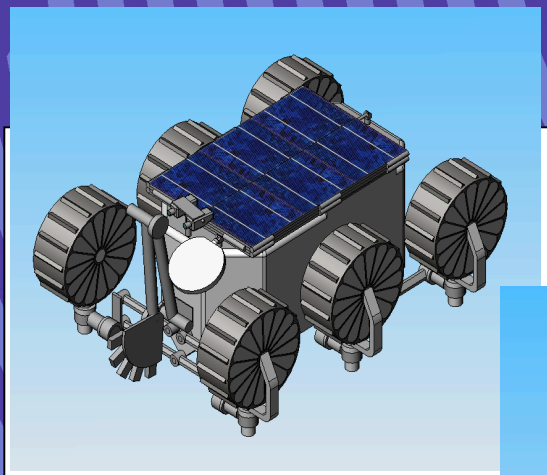
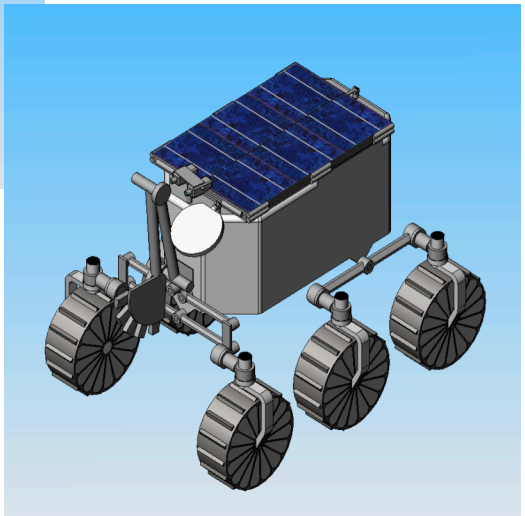
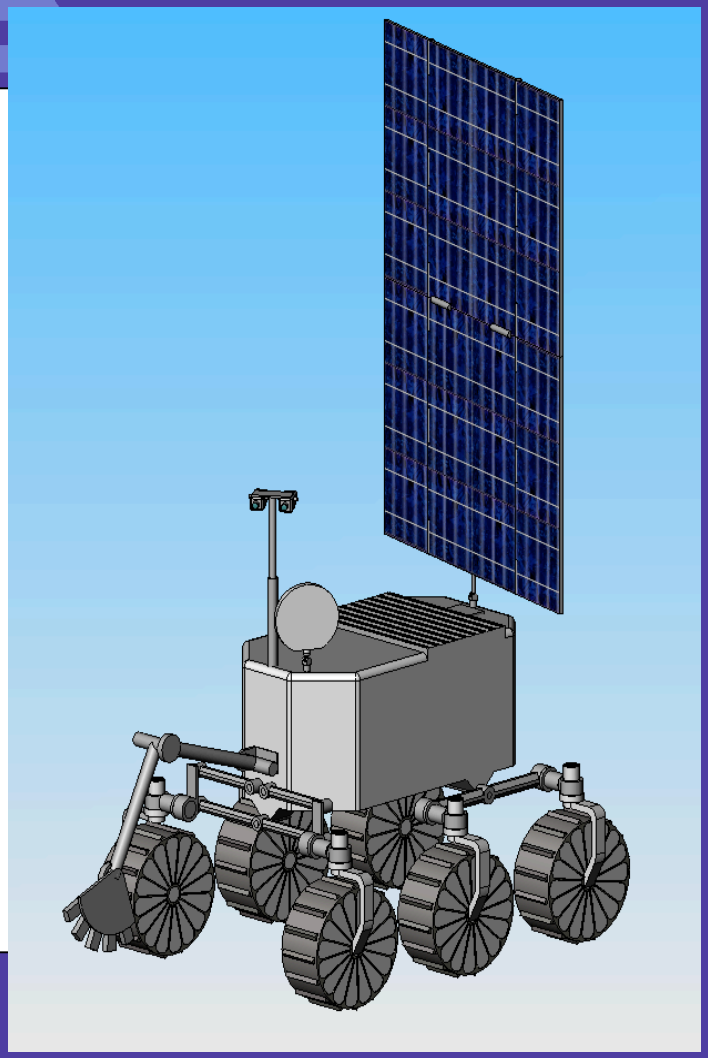
Conceptual design for lunar regional ExoMoon rover inherited from ExoMars



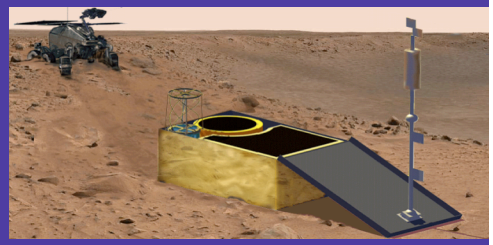


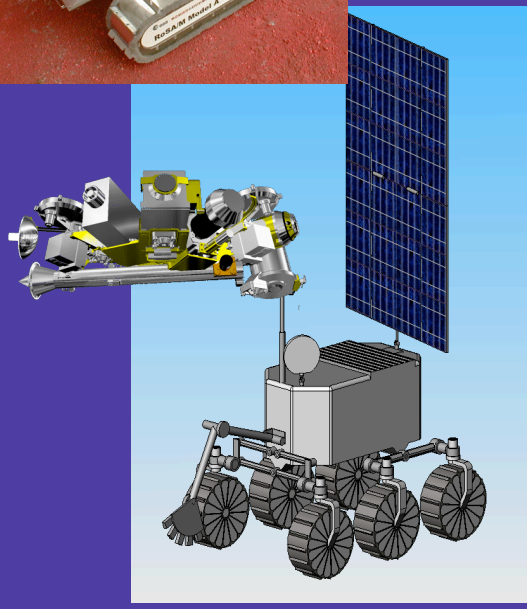


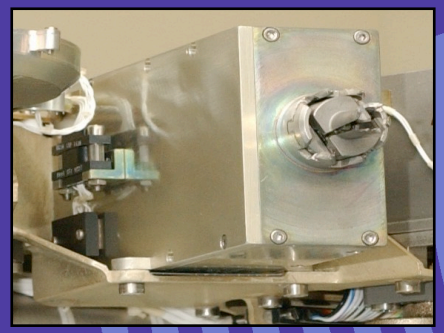
Instruments for Moon landers (100-180 kg):

- ELP European Lunar Geophysics package: 15-20 kg
  - Seismometer, Geodesy and laser , Heat flux, Magnetometer (coordinated with Intl Lunar Network)
- Lander instruments: 10 kg
  - Cameras: Descent, Pan Cam, Stereo, SRC
  - Local sample analysis (GCMS), permittivity
- Life science/environment experiments : 7 kg
  - Radiation/ environment/planetary protection studies
  - Melissa bacteria precursor, plants on the Moon
- Close proximity Rover: 5 kg
  - Neutron spectrometer, APX , Close up camera
  - Electromagnetic sounder, Ground penetrating radar
- ExoMoon Regional rover : 120 kg
  - Navigation and hazards avoidance, inspection cam,
  - Robotic arm (PAW like), drill and mole , Active seismic,
  - LIBS, Fluorescence, Thermal IR fluorescence
  - Dust lifting measurement device, QCM or cube piezo
- Lunar robotic challenge to access ice in dark: 15 kg

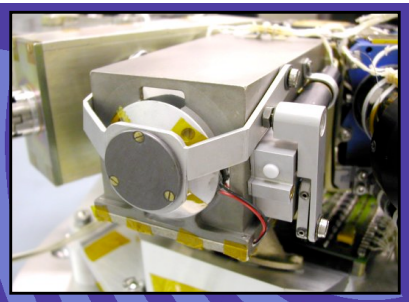
  nanorover, harpoon, impactor, …



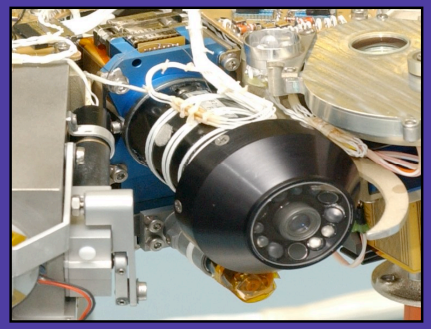




Rock Corer
Hong Kong Polytechniq

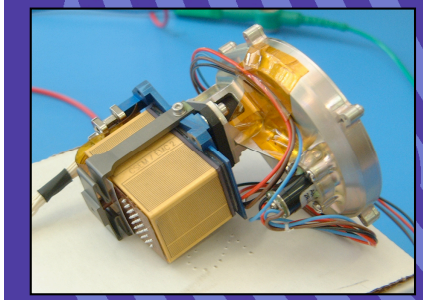


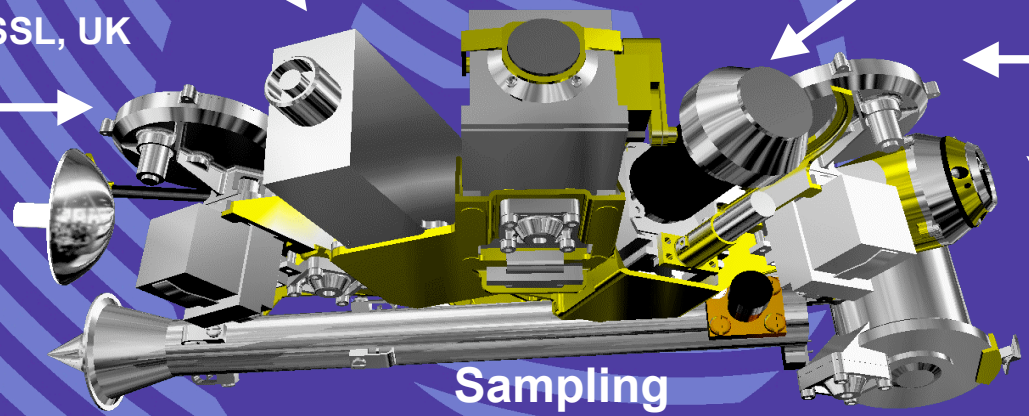
Mössbauer Spectrometer
University of Mainz, Germany



Microscope
Switzerland, MPEA Germany

Stereo Camera
MSSL, UK

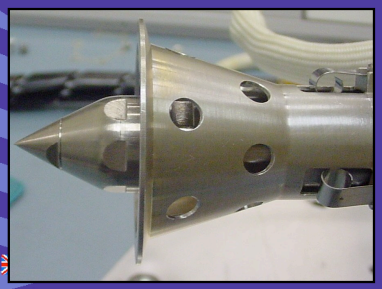


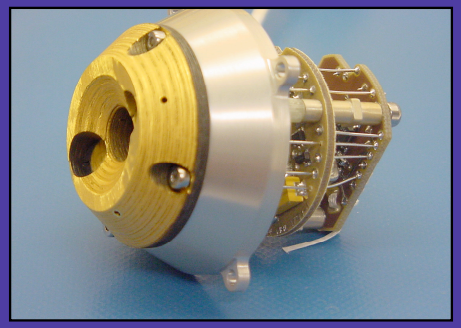


Stereo Camera

X-Ray Spectrometer
University of Leicester, UK

Sampling Mole
DLR, Germany





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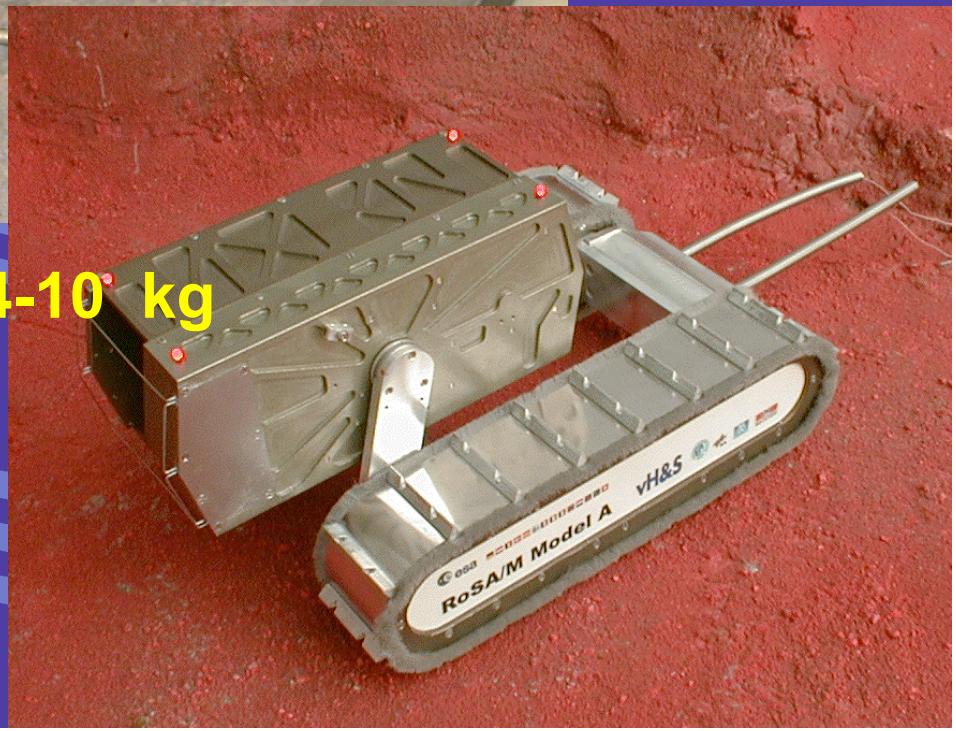
PAW Courtesy M. Sims Leicester U.

Tethered small rovers 4-10 kg



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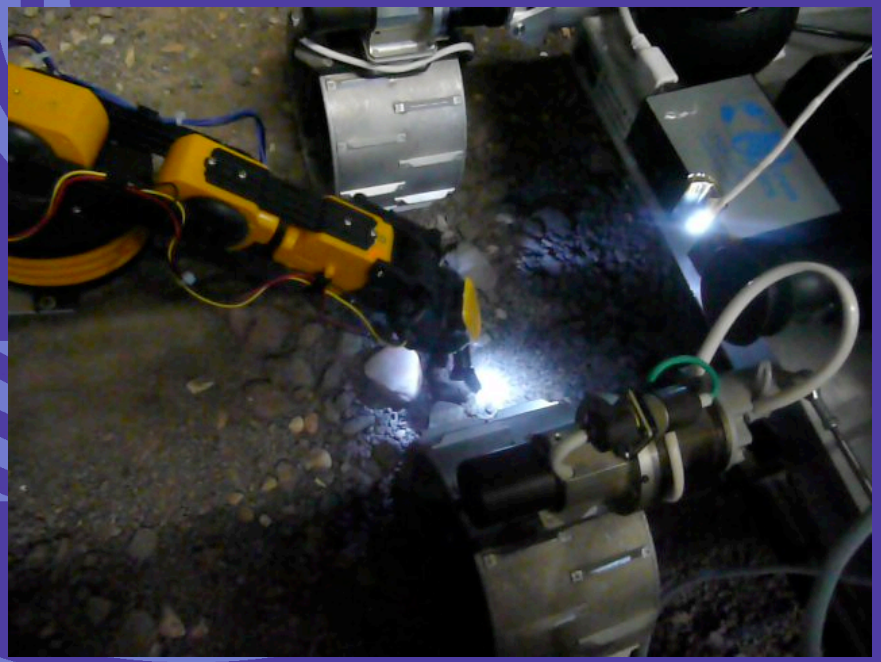
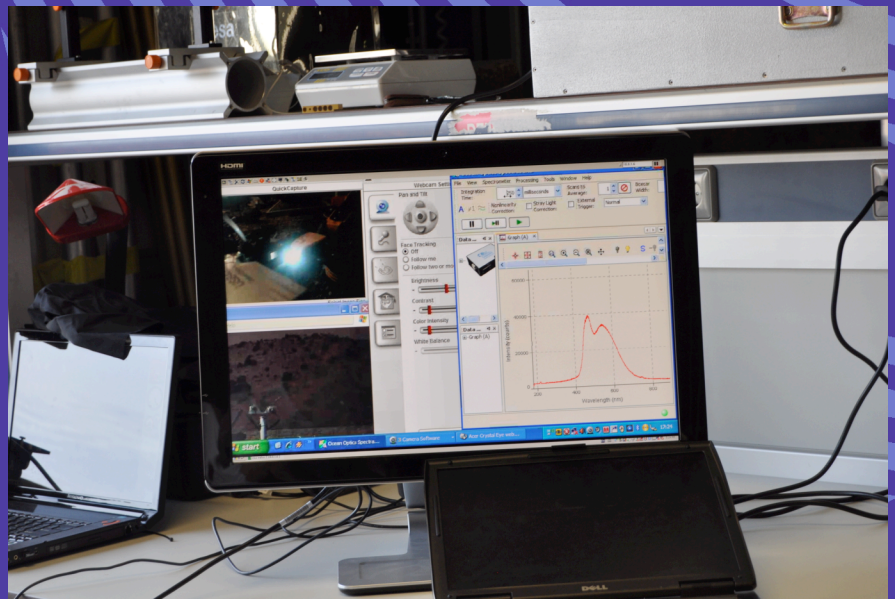
Sample handling, analysis & Cooperative robotic village

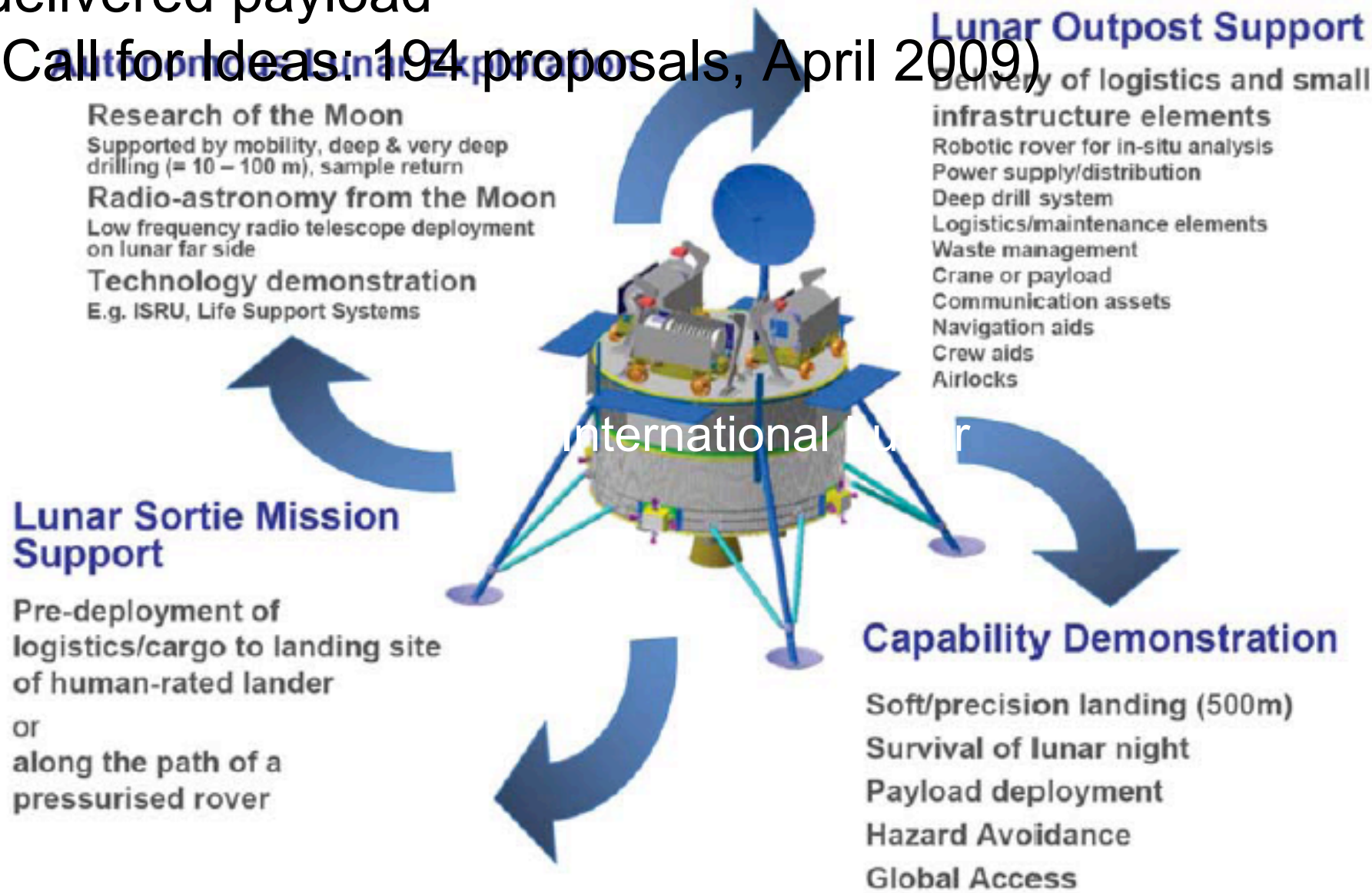
- Rover 1: Base rover with Raman analysis
- Rover 2: Rover equipped with robotic arm

Rover ExoGeoLab demo

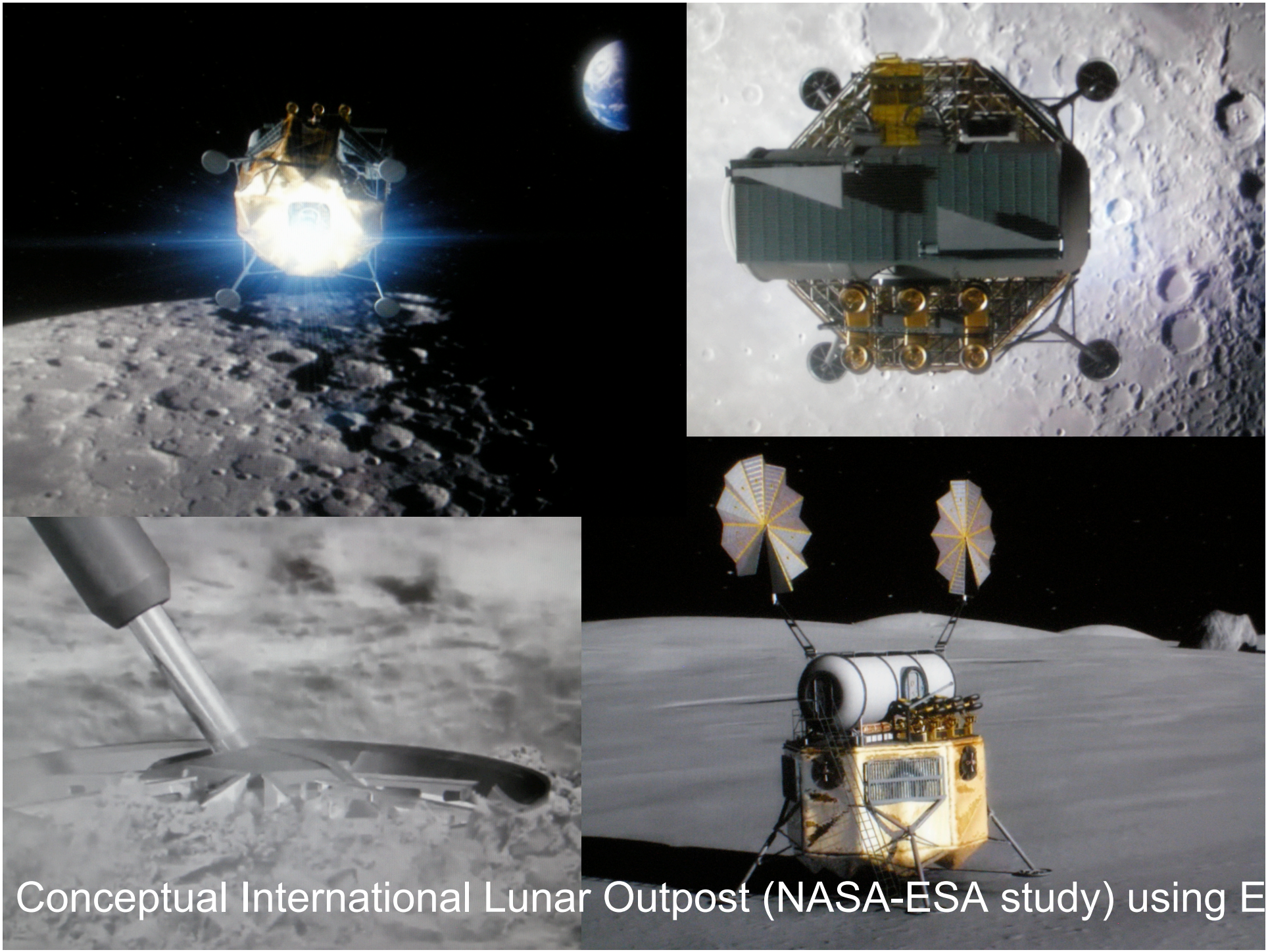




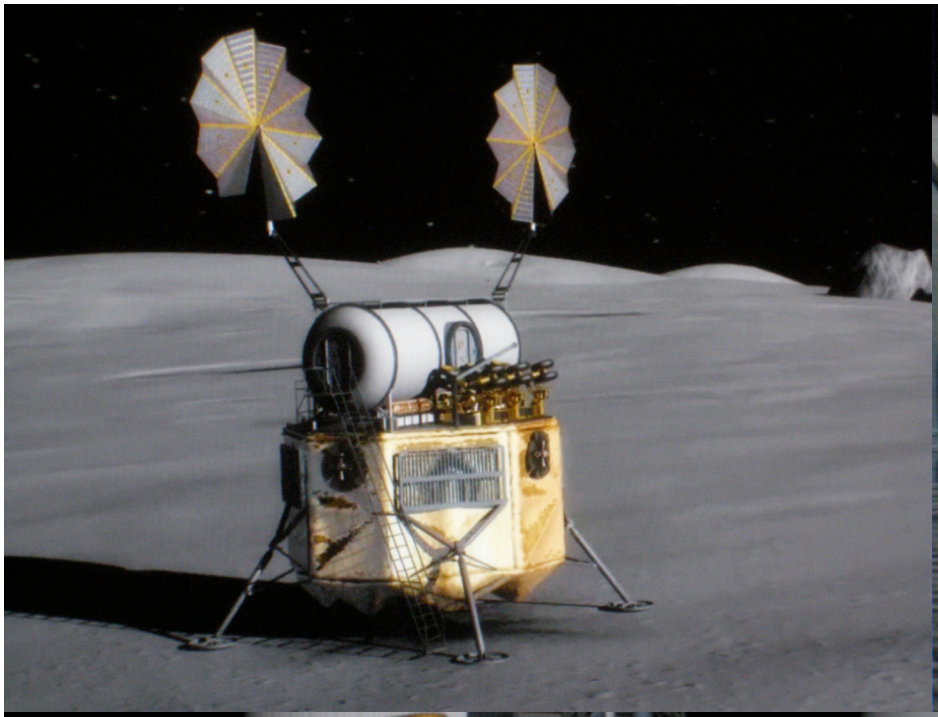
ESA Lunar Cargo Lander, Ariane V launch, 1-1.5 ton delivered payload
(Call for Ideas: 194 proposals, April 2009)



Lunar Lander Mission Scenario



Conceptual International Lunar Outpost (NASA-ESA study) using E



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JV-2

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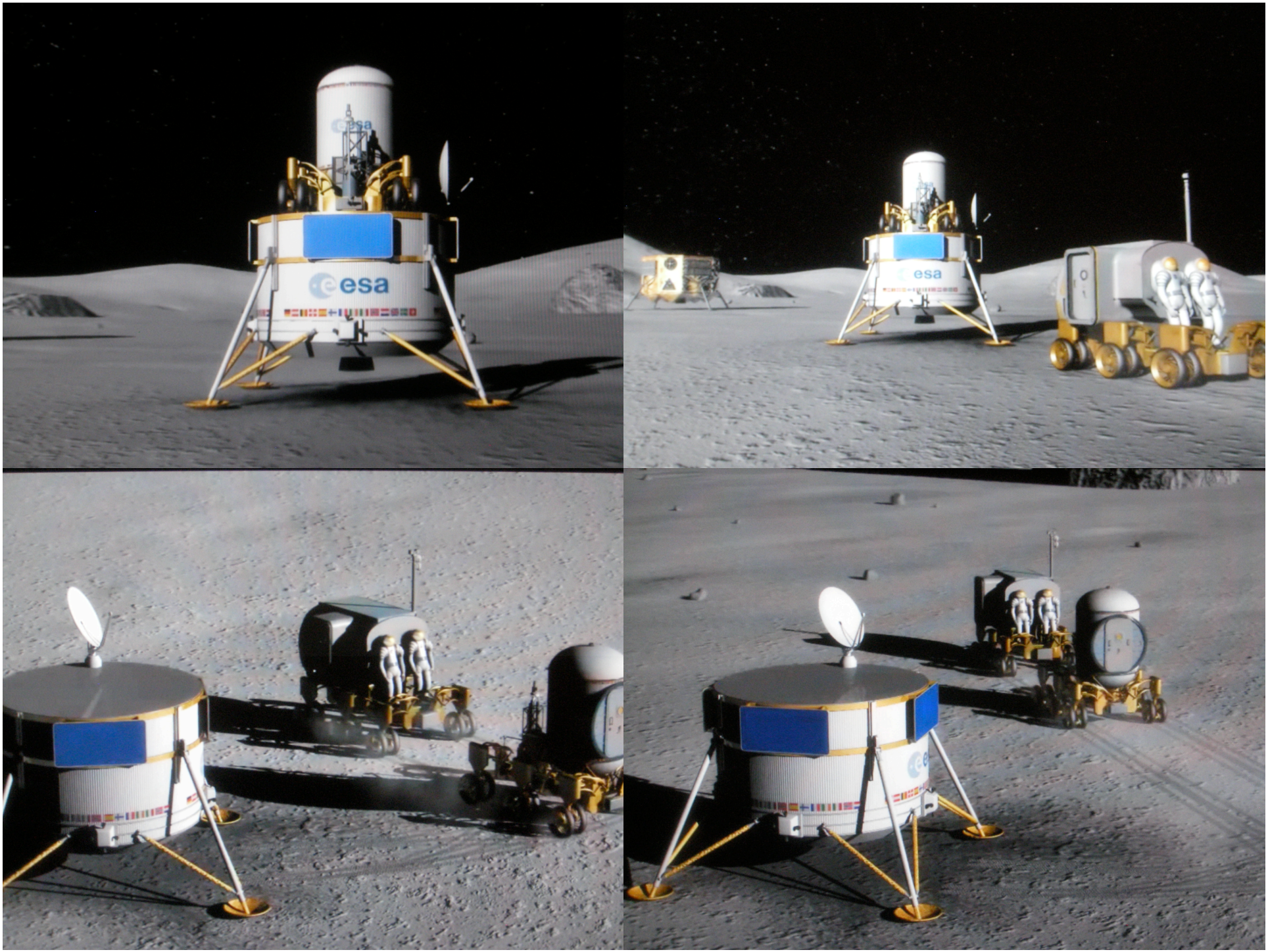
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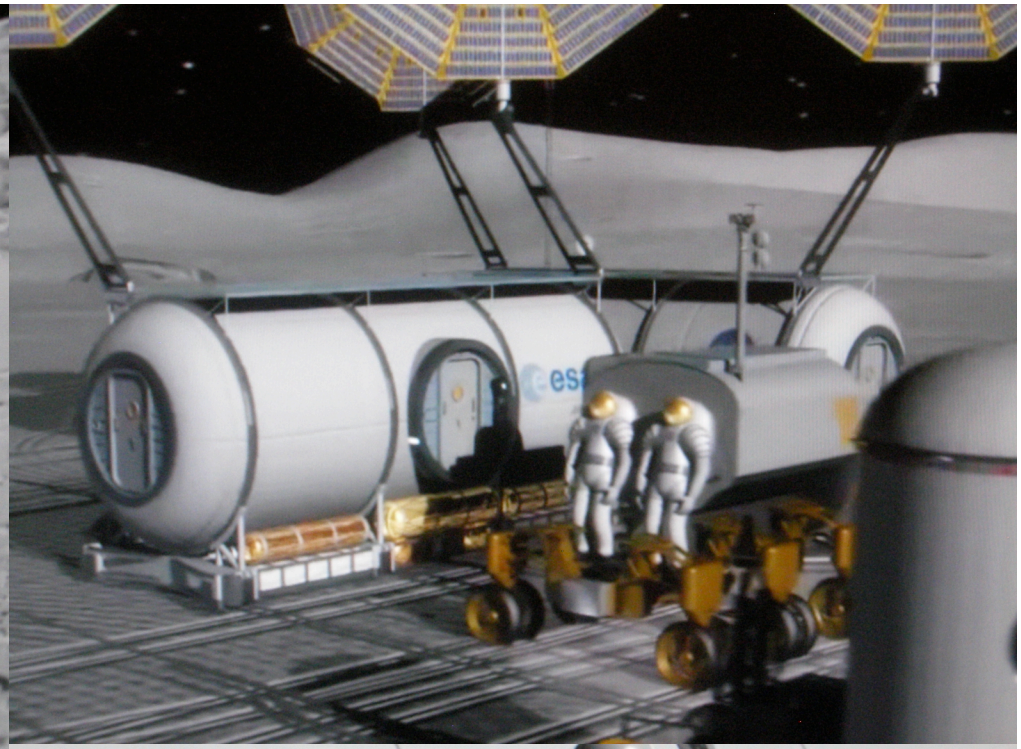

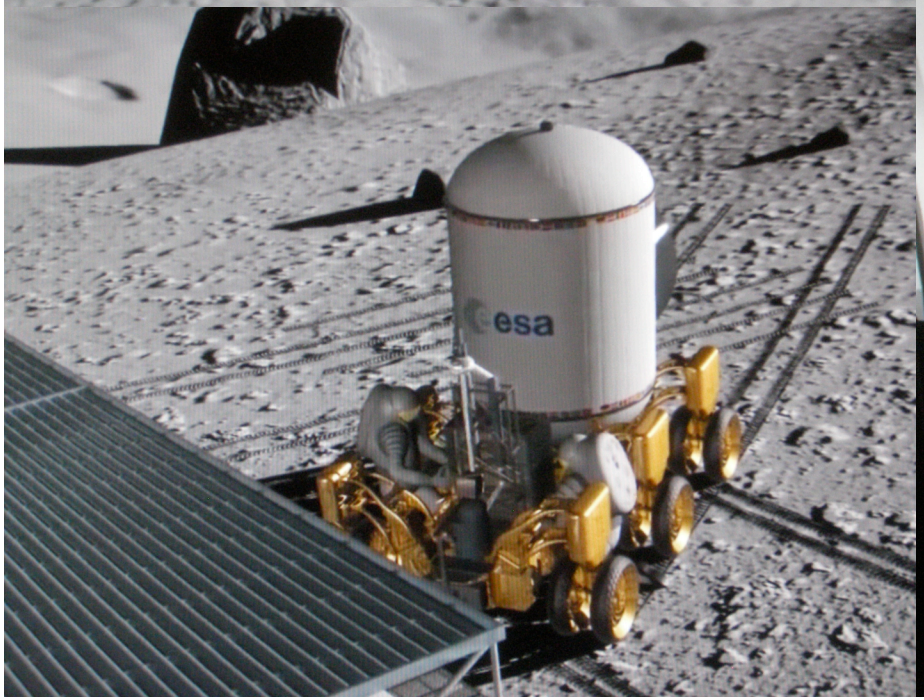
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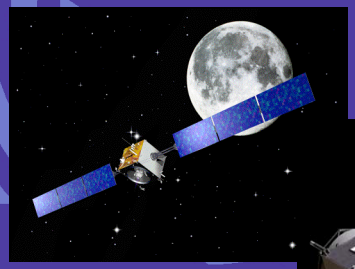
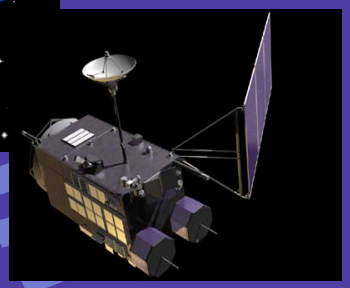
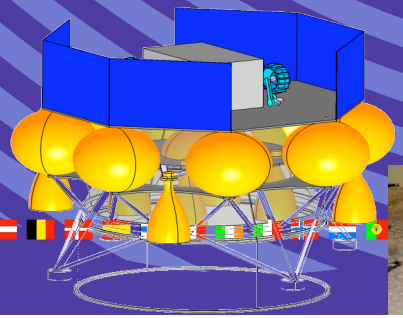
Towards Robotic Village and International Lunar Bases

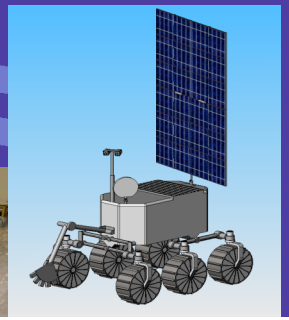
Data analysis & Interpretation
Technology Lessons Learned
Science & Exploration Results
Preparation for human lunar missions





2003-06 SMART-1 technology mission
2007-09 JAXA Selene Kaguya (science results)
2007-09 Chinese Chang'e 1 (ESA ground station)
2008 ISRO Chandrayaan-1 (ESA SIR2, C1XS, SARA +2 US)
2009 LRO & LCROSS (reconnaissance, survey, impact, outreach)
2011- Orbiters (GRAIL+LADEE, LEO, ESMO, BW, ASI)
2012- Landers, Rovers & Robotic village
(GLXP, Chang'e2, Selene2, India, Lunaglob, UK Moon Lite)
2014-2016 International Lunar Network, ESA Moon-NEXT
2017- ESA Logistics Cargo lander, Sample return: Chang'e 3, Selene3
2020- Human missions
2024 International Lunar Bases





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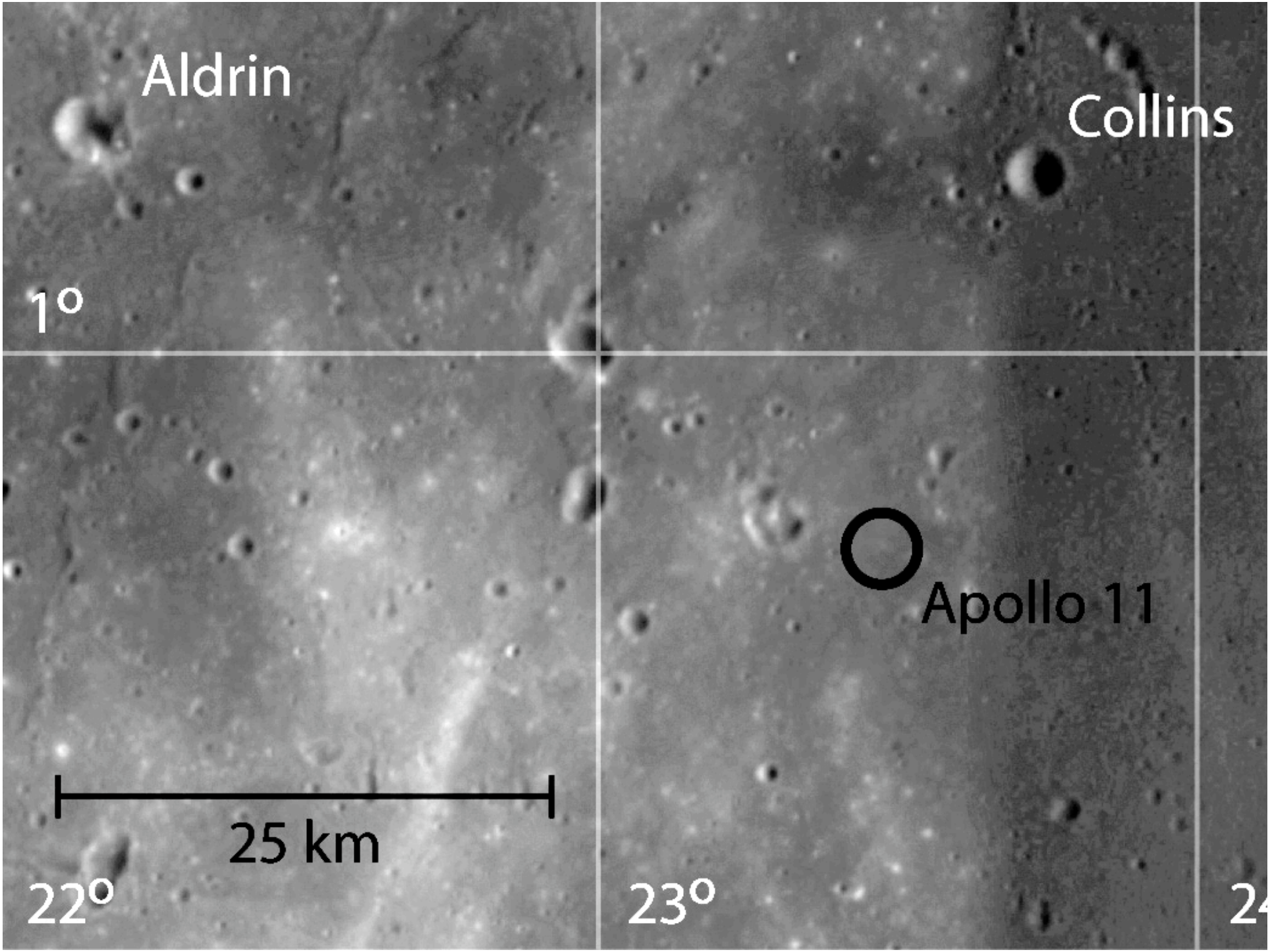
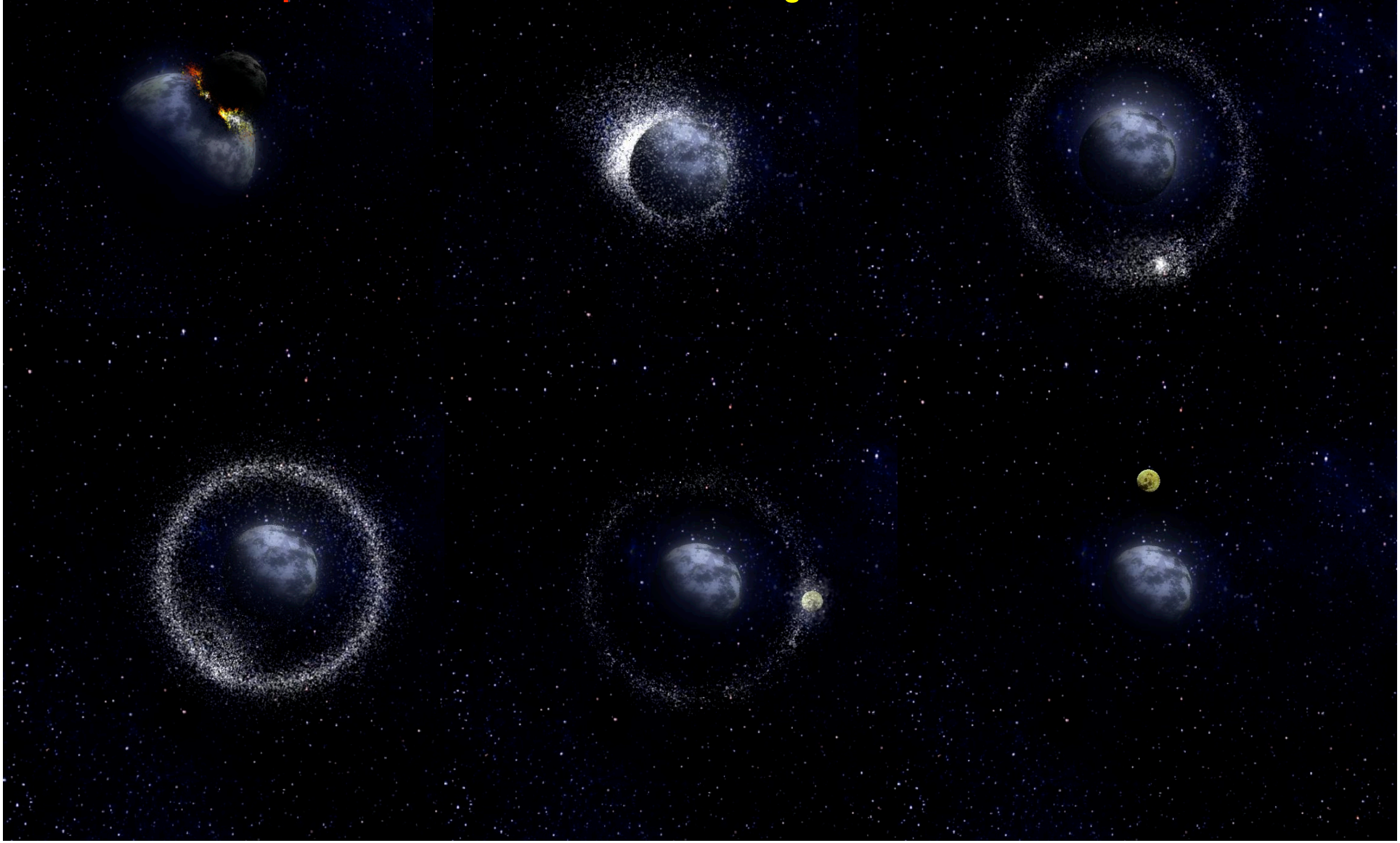

Aldrin
Collins
1°
Apollo 11
25 km
22°
23°

How did the Moon form?

Global composition **Al, Mg, Si, (Fe), olivines/pyroxenes**

Bulk crustal composition **Constrain theories of origin and evolution of the Moon.**