Lunar Reconnaissance Orbiter Camera: Targeting Update

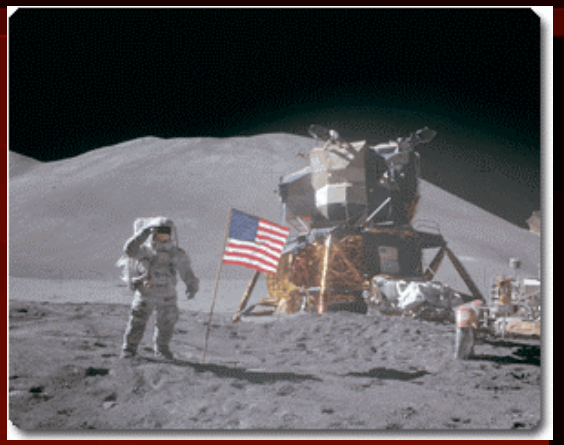
Samuel Lawrence and Mark Robinson
School of Earth and Space Exploration, Arizona State University

Bradley Jolliff
Washington University in St. Louis

Today's Talk

- Instrument Overview
- LROC Status
- LROC Instrument Capabilities
- LROC Investigation goals
- LROC data products
- NAC Exploration Mission Phase Targeting
- Exploration Target Methodology
- Public targeting interface

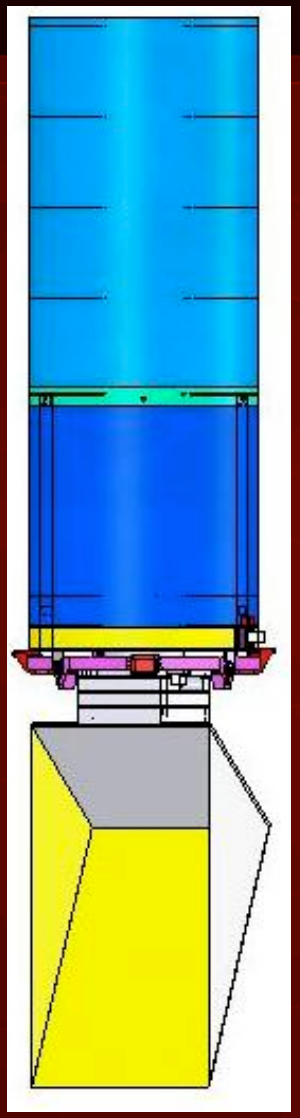
LROC Measurement Requirements/Objectives



- Landing site identification and certification (0.5 m/pixel)
- Mapping of permanent shadow and sunlit regions (WAC)
- Meter-scale mapping of polar regions (NAC)
- Overlapping observations to enable derivation of meter-scale topography (NAC photometric & geometric stereo)
- Global multispectral imaging (WAC, 7-band, high sun)
- Global morphology base map (WAC, 1-band, low sun)
- Characterize regolith properties (NAC)
- Determine current impact hazards (NAC)

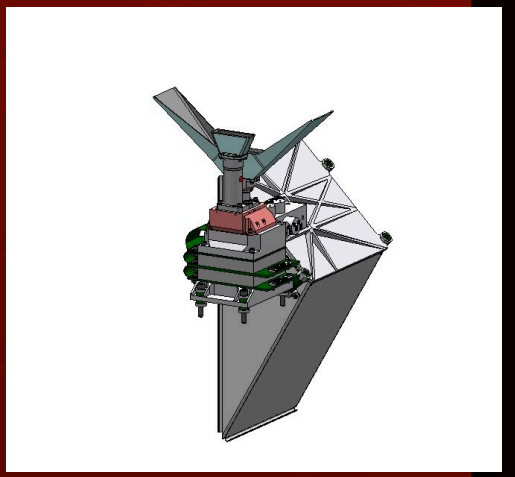
LROC System Components

- Wide Angle Camera (WAC) subsystem
  - Dual optics (UV and visible), multi-spectral imager with 100m/pixel visible resolution with a 90° FOV and 400m/pixel UV resolution with a 60° FOV
- Narrow Angle Camera (NAC) subsystem
  - Two 0.5m/pixel telescopes with a total 5.7° FOV
- Sequence and Compressor System (SCS) – electronics for commanding, receiving data from all cameras, contains power and data (SpaceWire) interfaces with the spacecraft



NAC

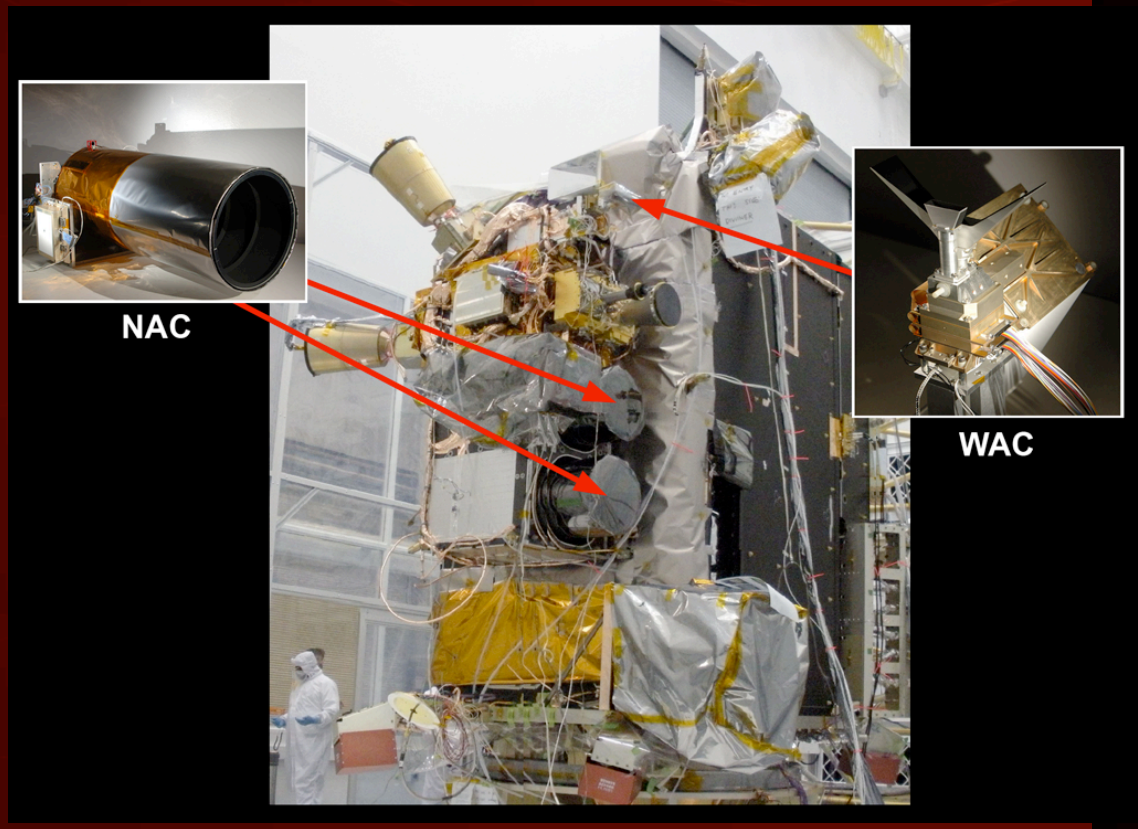
SCS



WAC

LROC Instrument Status

- LROC is integrated!
- System-level Lab Calibration Data Collection Complete
- SOC preparations proceeding smoothly
  - Tour and software demo after talk
- LRO s/c TVAC complete



LROC Observation Overview: Exploration Mission Phase

- WAC
  - Every orbit, image each pole
    - Monochrome, 100 m/p, 80° to 90° S/N latitude
  - Global monochrome 100 m/p > 50° incidence coverage
  - Global 7-color (100 VIS/400 UV m/p) observations, 10° to 40° incidence
  - Special Observations (context imaging, photometric phase experiments)
- NAC
  - Thousands of potential landing site observations 0.5 m/p
  - Polar mosaics (85.5° to 90°) @ 1 m/p
  - Conventional and photometric stereo observations for 5 to 2 m/p topography, respectively
  - Only the NAC observations require specific targeting

LROC Project Requirements (from Chin et al., 2007)

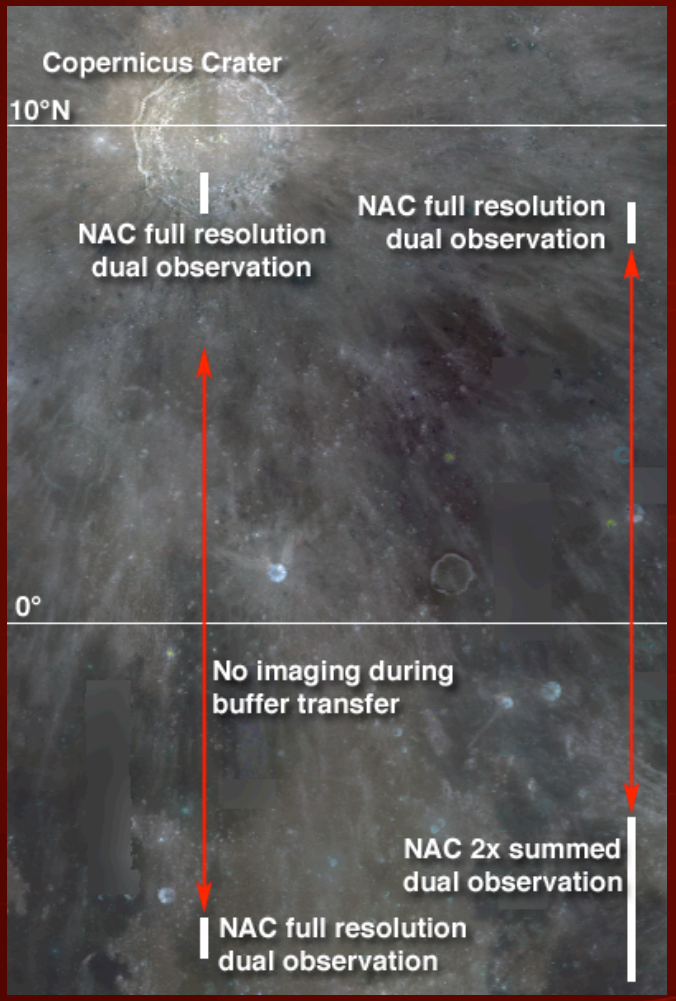
- For targets of high interest, collect multi-look NAC data reducible to 5m and 2m scale DEMs for 100 km^2 areas
- Acquire 100 m/pixel global stereo imaging reducible to 1 km/pixel global topography in EDR format
- Provide up to 50 mosaics of selected potential landing sites with 1m-scale resolution
- Provide crater size density and size distribution maps of up to 10 potential landing sites (100 km^2/site)
- Provide uncontrolled illumination movies of north and south lunar poles over the course of 1 lunar year
- Provide 1m-scale resolution uncontrolled summer mosaics of lunar poles
- 10 uncontrolled demonstration multi-spectral mosaics for high-priority areas

LROC Observation Overview: Science Mission Phase

- Proposed transition orbit enables expanded equatorial NAC coverage
  - ~20x200km which evolves into ~100 x 150 km orbit and back, with periapse migrating from equator to pole and back to equator
- Subsequent 33 x 216 km stable frozen orbit enables global 2m/pixel mosaic using NAC images at high and low Sun angles in ~4 years of observations
  - Sum 2x in southern hemisphere (0.7 to 1.0 m/p) (to increase coverage)
  - Nominal imaging northern hemisphere (1.0 to 2.2 m/p)
    - Much of north polar region covered at 50 cm to 1 m/p during nominal mission

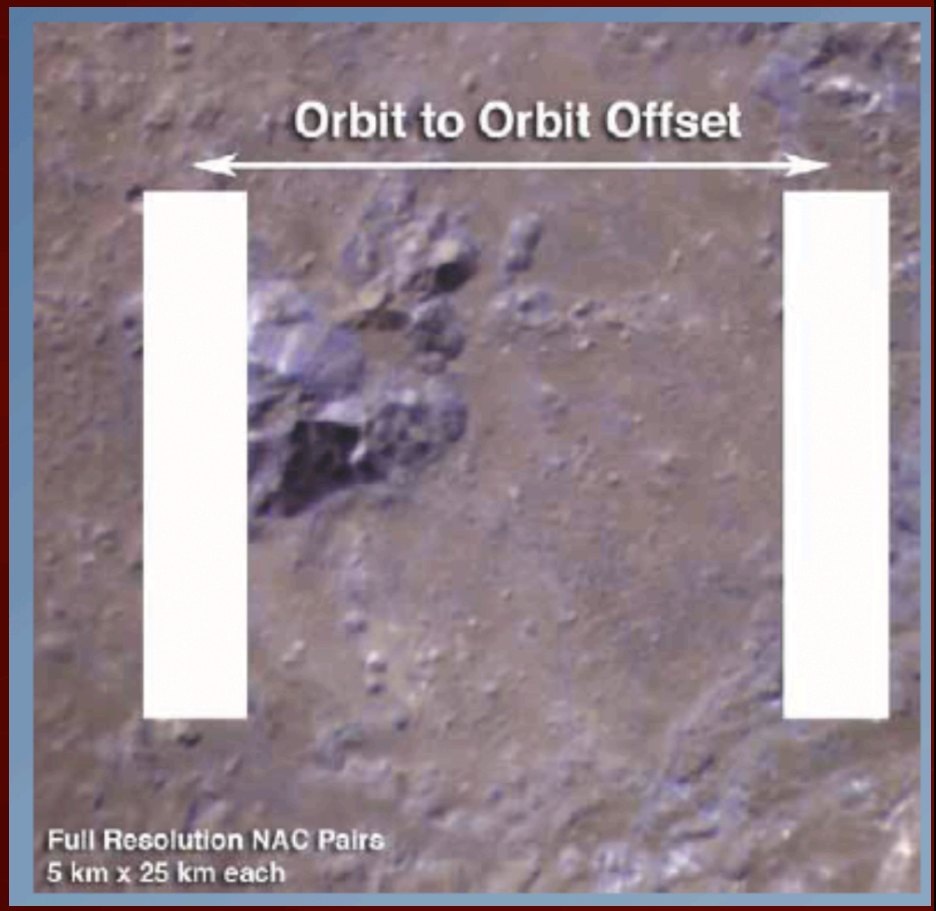
LROC NAC Observations

- Full Resolution Mode:
  - Continuous imaging for 50,000 lines
  - Fills the 256 Mbyte buffer
    - 15 seconds to acquire image
    - 25 km downtrack coverage (0.8° latitude)
- 2x Summed Mode
  - Continuous imaging for 100,000 lines, expose twice as long downtrack
  - More than double SNR
    - 60 seconds
    - 100 km downtrack coverage, 3.3° latitude
- Buffer transfer to spacecraft requires ~220 sec (10° latitude "shadow zone") for both NACs, no imaging during transfer
- Can take ~180 NAC pairs a day



LROC NAC Observations

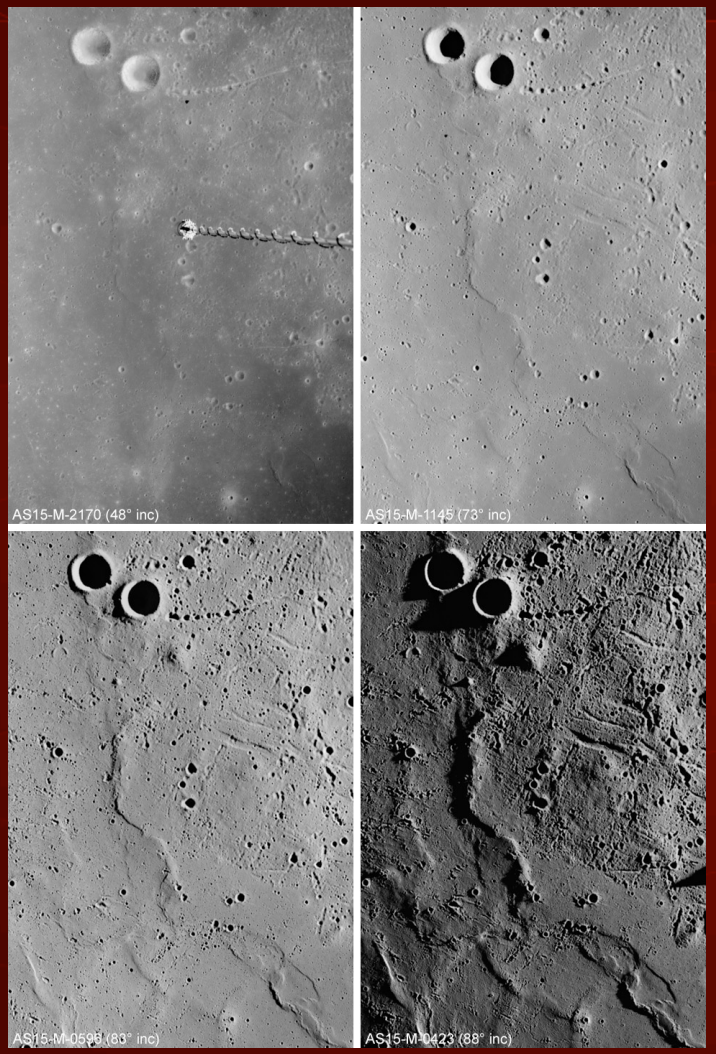
- Single Observation (50 km orbit)
  - Regular Mode:
    5 km by 25 km (0.5 m/p)
  - 2x Summed Mode:
    5 km by 100 km (1 m/p)
- Multiple nadir observations for photometric stereo (increasingly difficult near equator)
- Multiple nadir observations for areal coverage (same equatorial problem plus lighting offsets)
- Off nadir observations for stereo (20°) and areal (1° to 20°) coverage



Equatorial orbit-to-orbit offset ~ 31 km, oblique view mosaic requires 30° off point

Value of Repeat Observations

- Slow rotation of Moon precludes Sun-synchronous orbit, lighting changes over time
- Presents problems for creating mosaics with consistent lighting
- Provides opportunity for repeat coverage with different lighting enhancing site analysis



Apollo metric repeat coverage

LROC Targeting Action Team

- LROC Targeting Action Team reviews existing LROC targets and monitors progress
- Brad Jolliff, Lisa Gaddis, Brent Garry, Tom Giguere, B. Ray Hawke, Harry Hiesinger, Laszlo Keszthelyi, Sam Lawrence, Mike Malin, Mark Robinson, Julie Stopar, Shane Thompson, Livio Tornabene, Zibi Turtle
- All LROC Science Team members responsible for entering targets

LROC NAC Target Priorities

Priority 1: Requested by NASA CxP

Priority 2: LROC Measurement Requirements

Priority 3: Other Co-I or LRO Science

Priority 4: Outside science requests

Priority 5: Public requests

- Public web interface will be available 2 months before launch

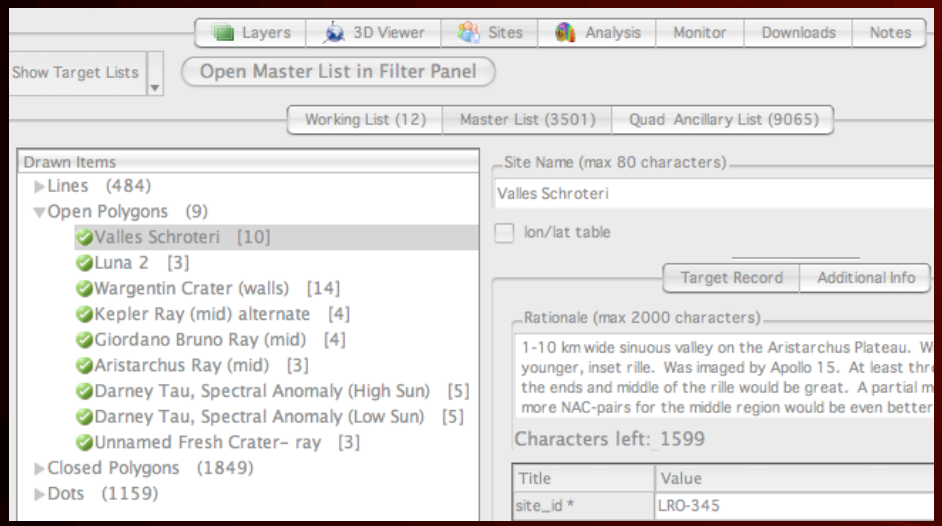
Science Targets in the Exploration Mission Phase

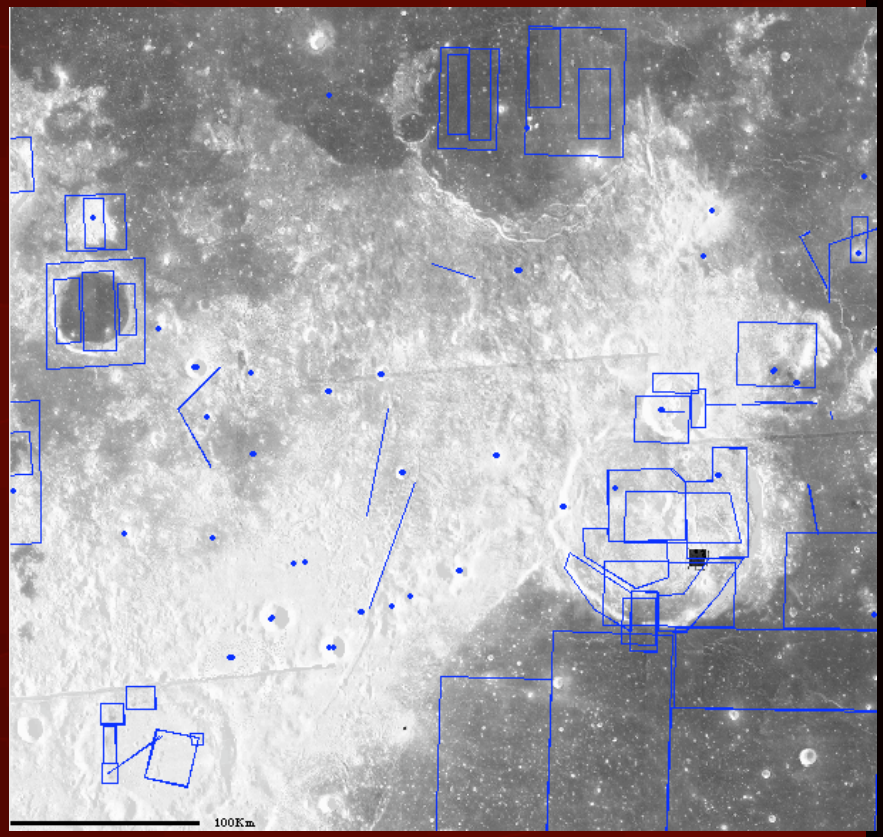
- NAC targeting addresses multiple objectives
  - LROC proposed measurement objectives
    - Regolith properties, impact rate and hazards, landing site certification …
  - Research objectives proposed by LROC Participating Scientists
  - Exploration-related targeting has first priority during Exploration phase of LRO mission
    - Dedicated science observations scheduled "around" Exploration targets
- All Science targets are potential Exploration targets!
  - LRO will make major discoveries that influence where we want to send explorers
  - High-resolution imagery of as many science targets on Moon as possible will play vital role in future lunar exploration and development

LROC NAC Targeting Progress

As of 20 January 2008:

- Master List: 4627 targets
  - Lines: 601
  - Open Polygons: 10
  - Closed Polygons: 2083
  - Dots: 1933





100 km

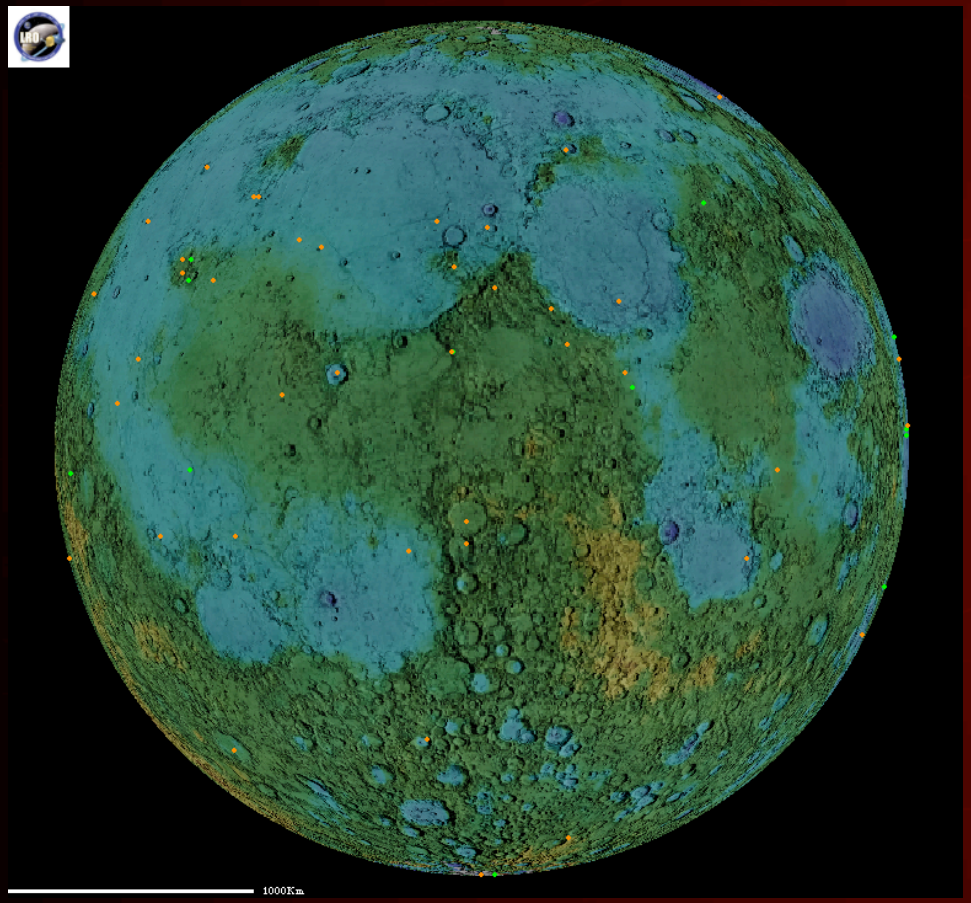
LROC Exploration NAC Targets: Sources and Provenance

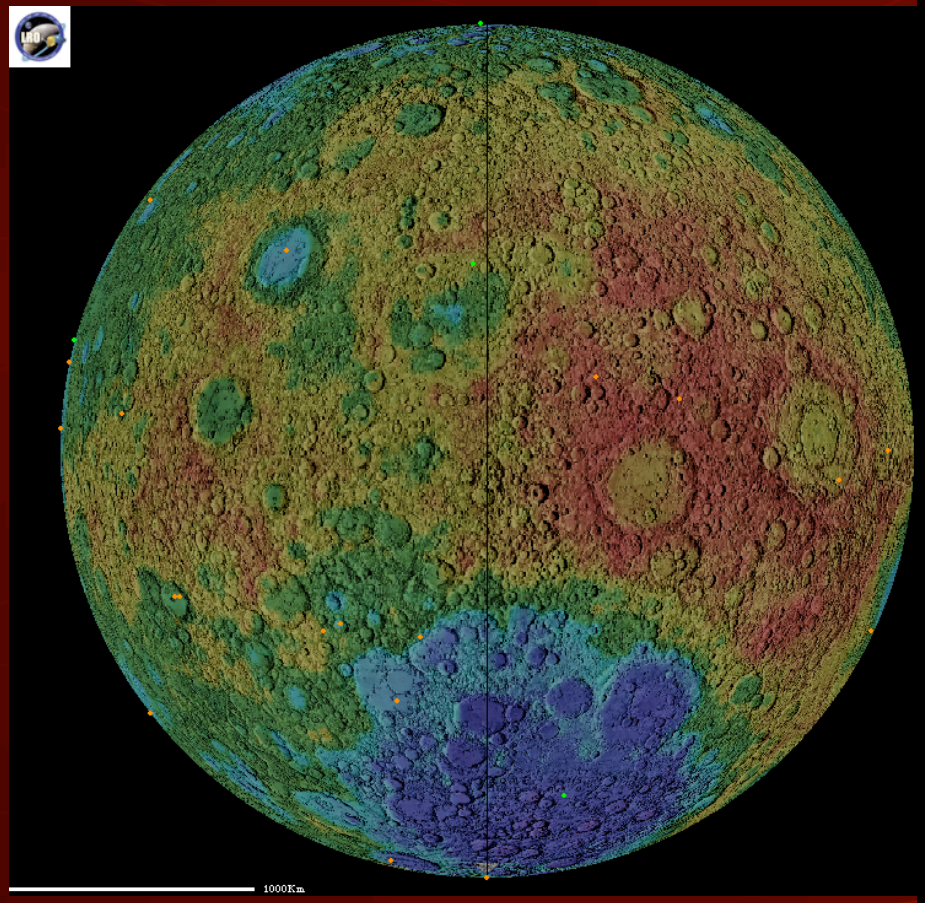
- **Provided by Constellation**
  - **NASA's Exploration Systems Architecture Study (ESAS) Report, Nov. 2005**
    - Lunar Outpost "design reference sites"
  - **Geoscience and a Lunar Base (GLB), 1990**
    - A Comprehensive Plan for Lunar Exploration (Taylor and Spudis, report of 1988 Workshop)
    - 59 sites proposed for automated sample return and human exploration
  - **Proposed First Lunar Outpost (FLO) Sites**
    - A Site Selection Strategy for a Lunar Outpost: Science and Operational Parameters Report, 1990
    - Six sites proposed for First Lunar Outpost
      - Some overlap with ESAS list
  - These lists overlap to some degree (e.g., 7 ESAS sites are on GLB list) and were extensively vetted during SEI [1988-1993]!
- **International Calibration Standard Areas**
  - Pieters et al. (L-ISCT)
  - Approx 12 sites

Exploration Target Sources Examples, con't.

- Sites considered for Apollo missions 18-20 and the Apollo Applications Program
  - NASA "grey literature" from Apollo era
- Anthropogenic sites (~50 targets)
  - e.g. Apollo landing sites, S-IVB impacts, LEM upper stages, Luna, Surveyor, etc.
- Known spectral anomalies (~25 targets)
- Possible lava tubes (~100 targets)
  - Possible permanent human habitation sites
- Mini-RF target list (TBD)
- Chandrayaan target list (TBD)
- LCROSS support imagery (TBD)

Distribution of Exploration Targets





SCIENTIA FACULTAS EXPLORATIONIS

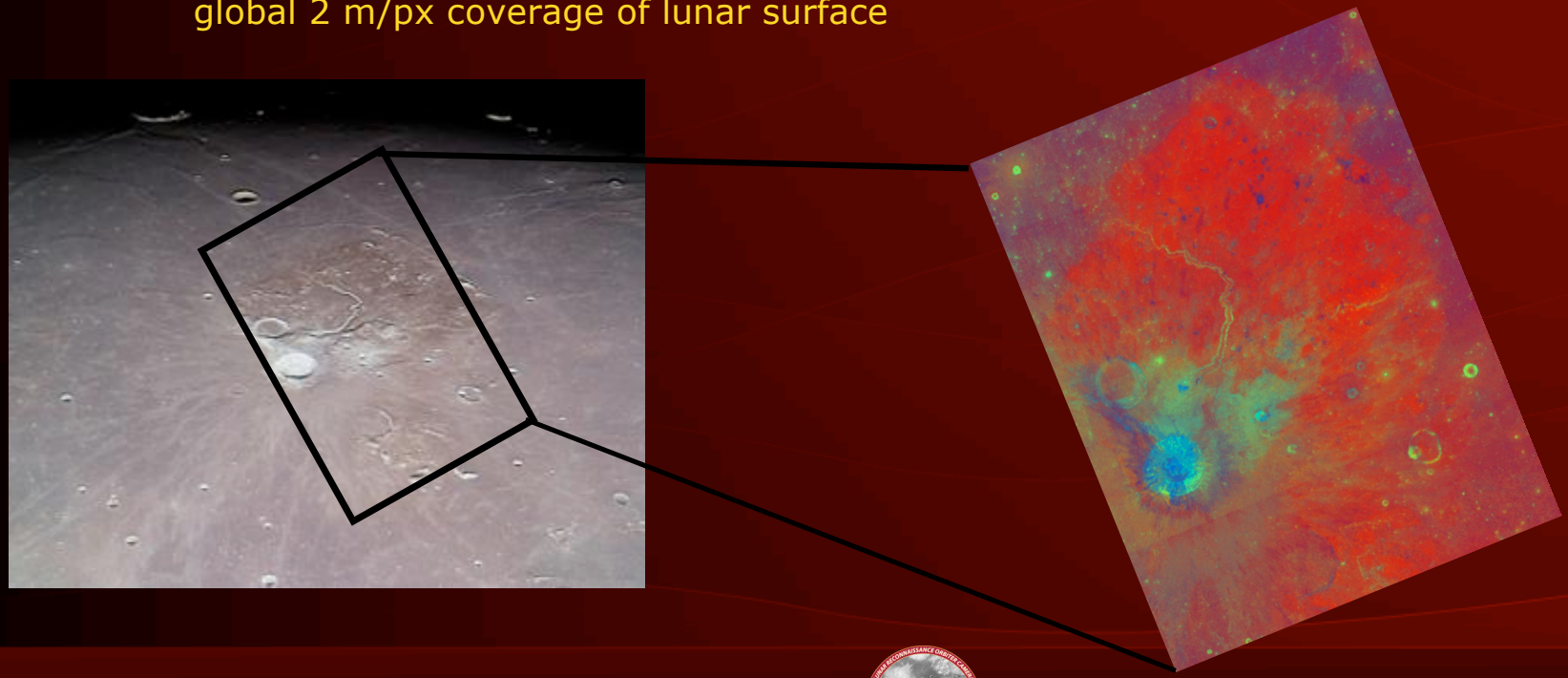
EXPLORATIO FACULTAS SCIENTIAE

LROC NAC Targeting: Mosaic Size Constraints

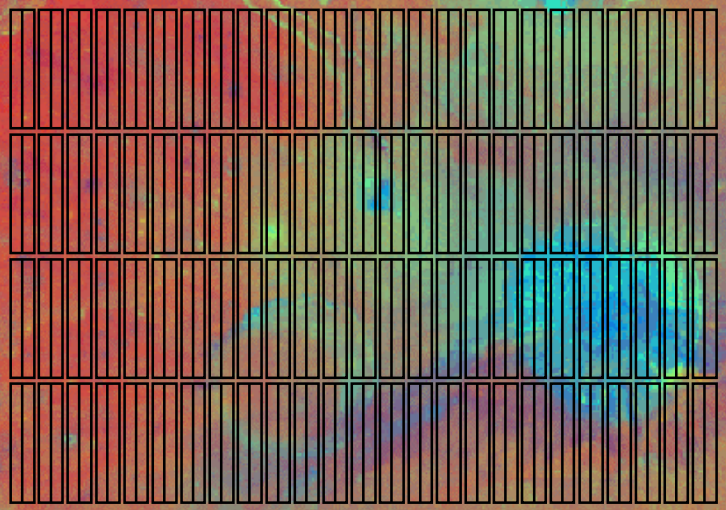
- Factors affecting LROC NAC targeting include
  - Orbital dynamics
  - LRO pointing
  - LROC NAC data transfer rates
  - Areal size of target request
  - Location of target on Moon
- These factors place important constraints on the areal extent and completeness of mosaics and stereo coverage
- These constraints must be considered when planning NAC mosaics and stereo observations
  - Can perform target coverage simulations using mission ephemeris data

Unrealistic First-Year Targeting Example: Whole Aristarchus Plateau at 50cm/px

- Example: Aristarchus Plateau (23°N, 48 °W)
  - Complete areal coverage of large targets in Equatorial and mid-latitude regions is challenging
  - LROC NAC coverage in Exploration mission phase located in large, very important regions like the Aristarchus Plateau will have to be carefully placed because complete coverage will not be possible during Exploration mission
  - Reinforces absolute necessity of LRO extended mission in stable frozen orbit to ensure global 2 m/px coverage of lunar surface



100 NAC contiguous pairs--which is unachievable at latitudes <53° at a single target during the LRO Exploration mission phase -- can only cover a portion of the Aristarchus Plateau. In addition, we would also want repeat coverage for topography and morphology which will further limit areal extent. Each double rectangle represents one NAC pair (5 km x 25 km).

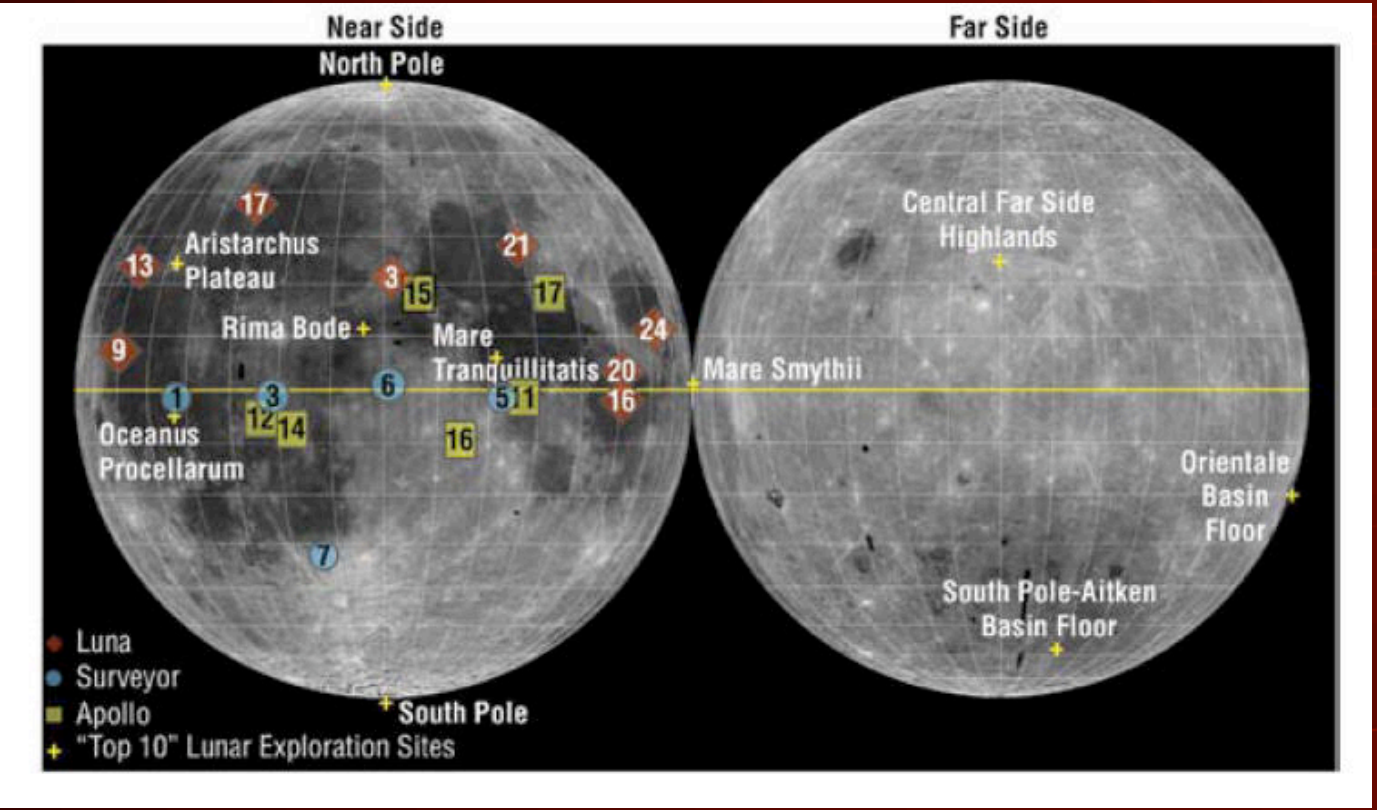


Courtesy John Gruener

ESAS Design Reference Targets

- South Pole
- SPA Floor
- Aristarchus
- Rima Bode
- W/NW Tranquillitatis
- North Pole
- Oceanus Procellarum
- Central Farside Highlands
- Orientale Basin Floor
- Mare Smythii

- Design reference sites, meant to cover a range of high-priority areas and different locations on the Moon of both ISRU and scientific interest
- ESAS sites are Priority-1 targets in LROC master target list

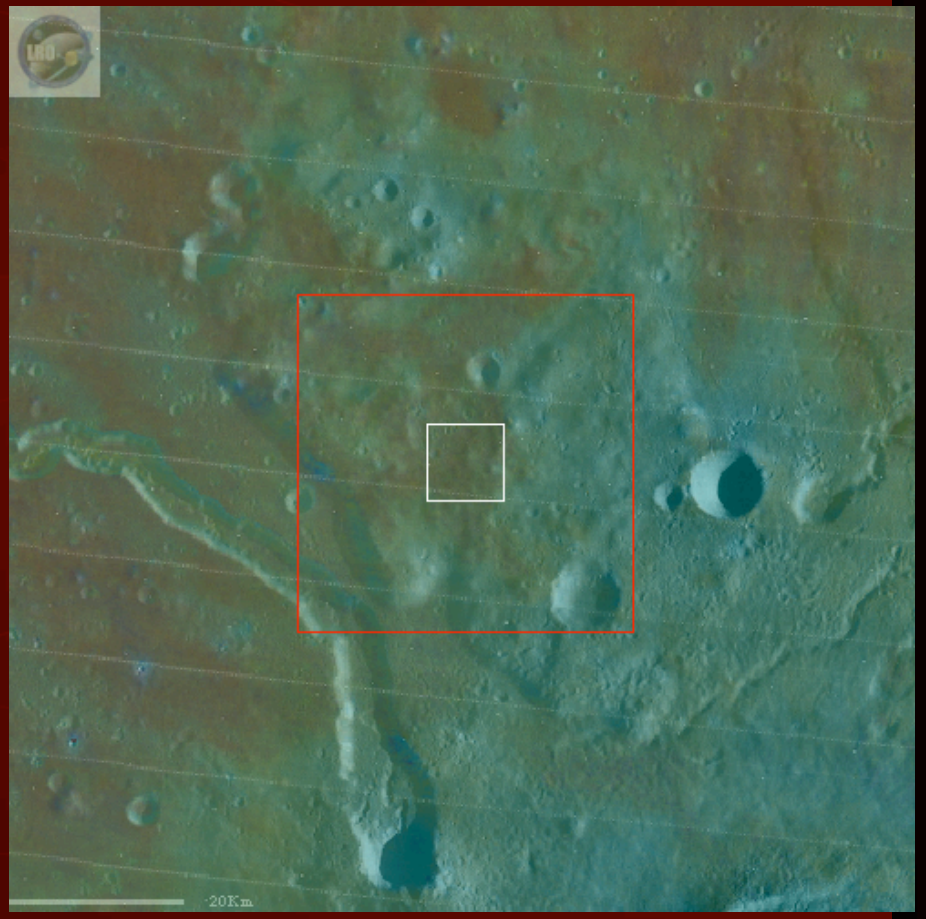


LROC
Exploration Target Methodology

- During the one year nominal LRO Exploration Mission it is difficult to acquire complete high-resolution coverage (incl. stereo) of areas larger than 10x10 km near the equator
- LROC ESAS/Priority 1 Target Methodology
  - 3 Primary ROIs defined for each ESAS target
    - Priority 1: Photometric stereo
      - 10 x 10 km ROI
    - Priority 1: Geometric Stereo
      - 10 x 10 km ROI
    - Priority 3, 20 x 20 km "best-effort" stereo data product ROI
    - Priority 4, 40 x 40 km "best-effort" monoscopic mosaic ROI
      - Images within Priority 2 box collected at every opportunity
      - Provide additional local high-resolution coverage

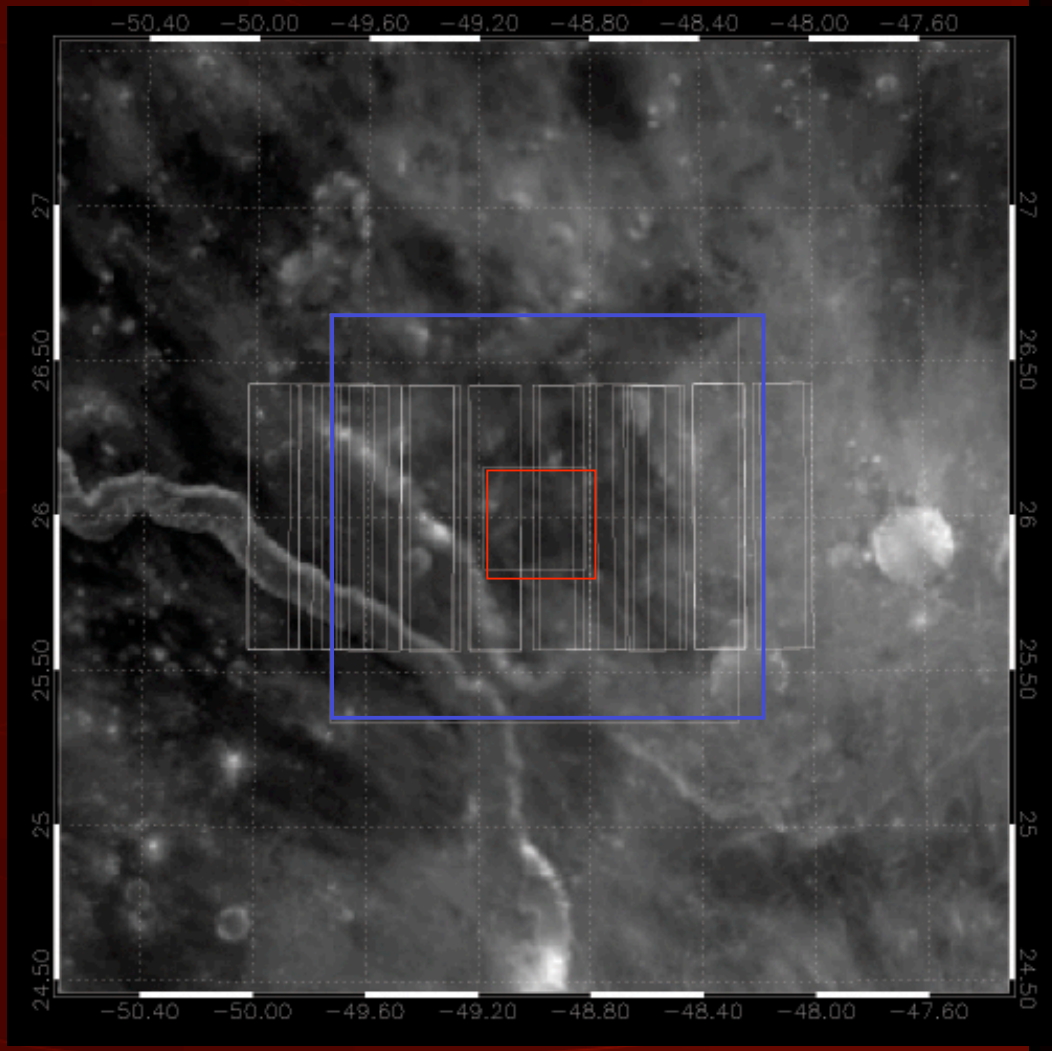
LROC NAC Targeting: Some Realistic Examples

- Simulated image campaign for the Exploration target on the Aristarchus Plateau (26°N, 49°W)
  - 100km^2 region centered on proposed landing site for photometric and geometric stereo
  - 40 x 40 km "best effort" region centered on the proposed landing site for a regional mosaic to aid mission planning
- Requirements:
  - Maximal areal coverage
  - No photometric constraints
  - Does not account for "shadow zones" from other observations
    - 11° north and south of site
  - No off-nadir spacecraft rolls
    - Only 3 off-nadir rolls allowed per day!



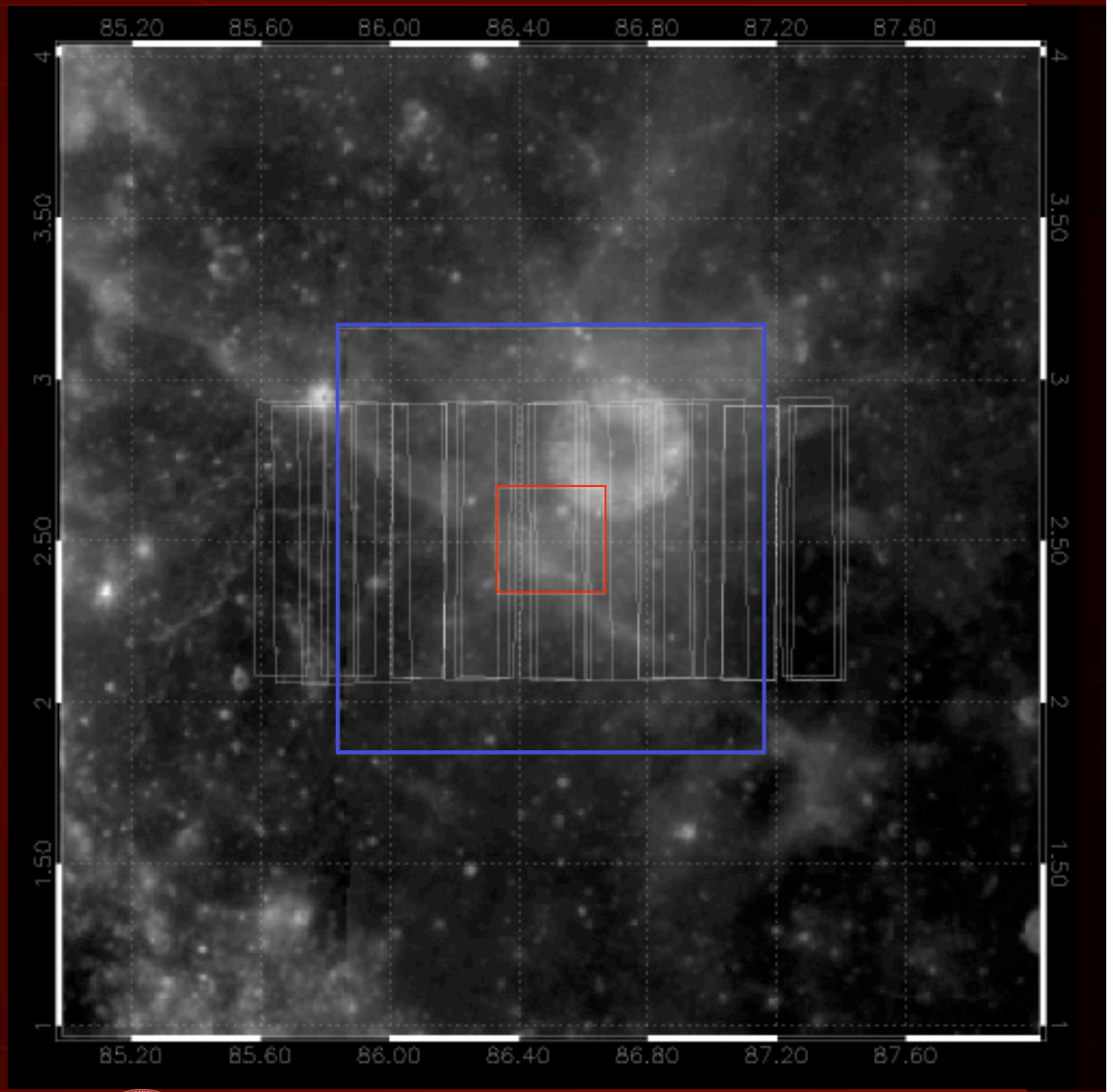
Aristarchus NAC Observation model

- 24 targeted NAC observations available to maximize areal coverage
- Multiple spacecraft rolls required



Mare Smythii NAC Observation Model

- Smythii ESAS site near Peek crater (2.5°N, 86.5°E)
- 23 targeted NAC observations available to maximize areal coverage
- Multiple s/c rolls required
- Note “bunches” of NAC frames due to near-equatorial location

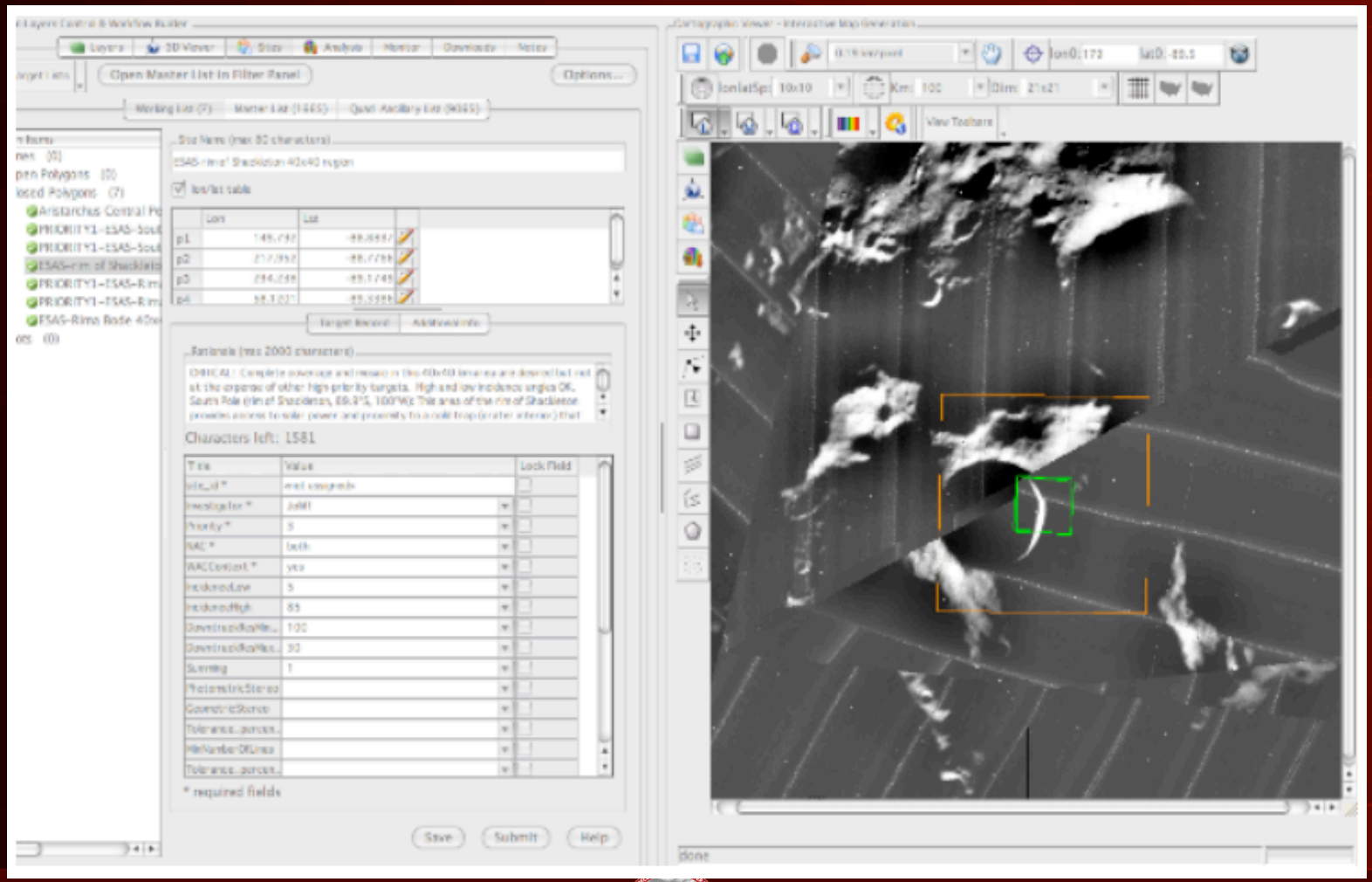


Exploration Targeting Entries into LROC Database

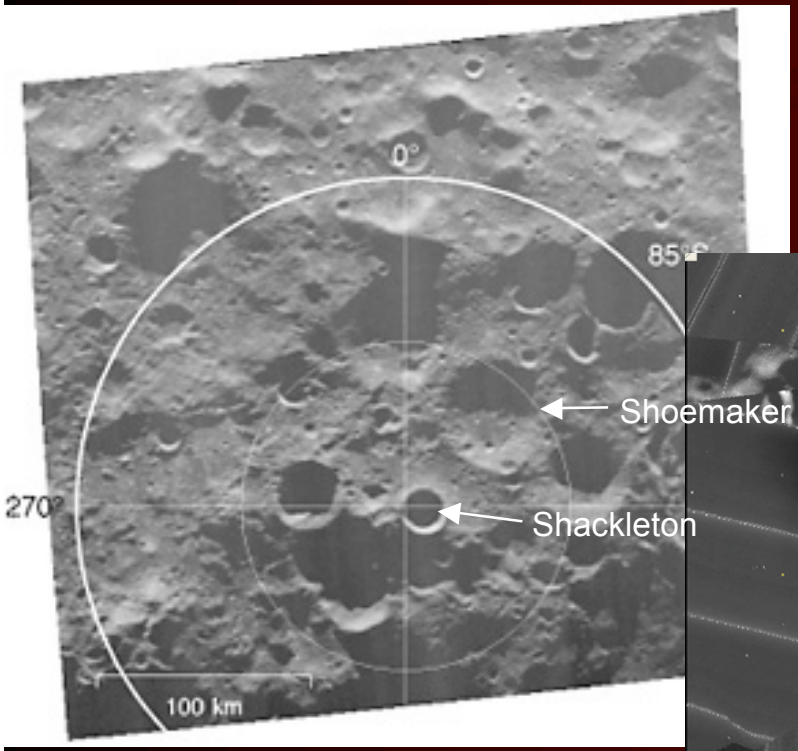
- Ten ESAS targets complete
- Typically multiple ROIs per target
  - Currently defining additional ROIs for each target to fully characterize region
  - Will refine polar targets based on Kaguya dataset provided to LRO project for planning purposes
- "Geoscience and a Lunar Base" targets in progress
  - 32 completed, 27 still in progress

LROC ESAS Target Example: South Pole Shackleton Rim

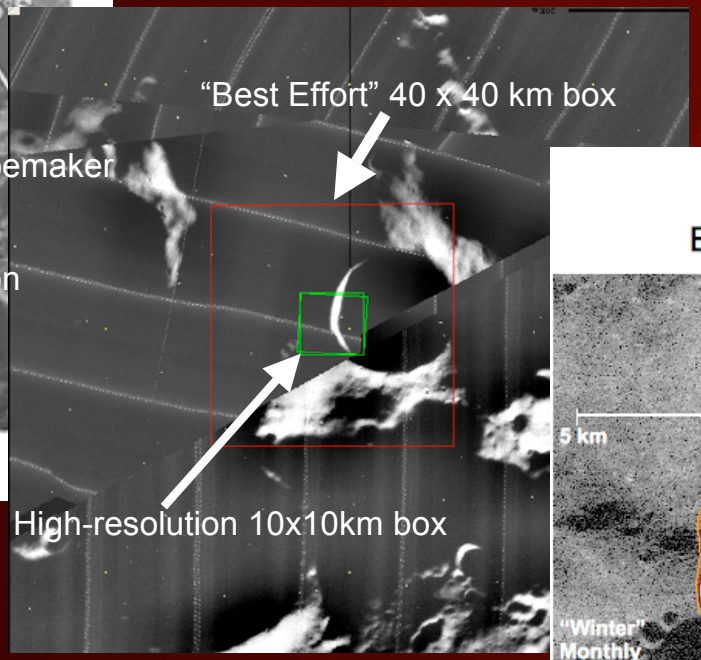
An ESAS Target in REACT Interface



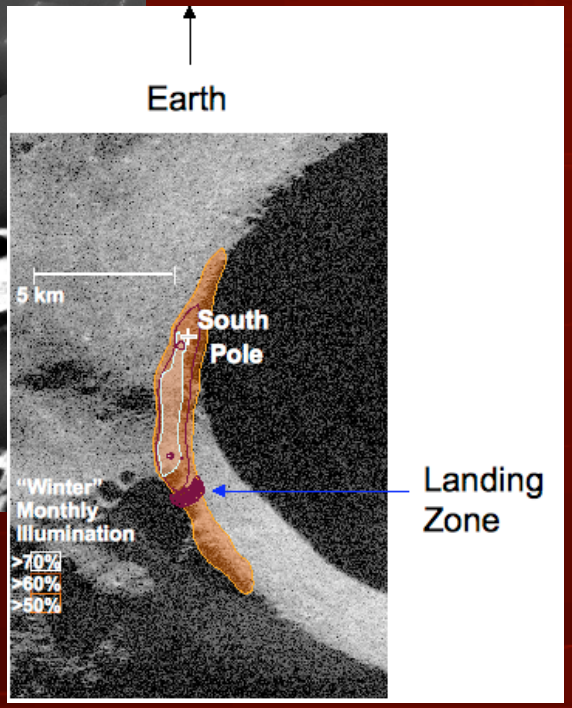
LROC ESAS Target Example: Shackleton Notional Outpost site



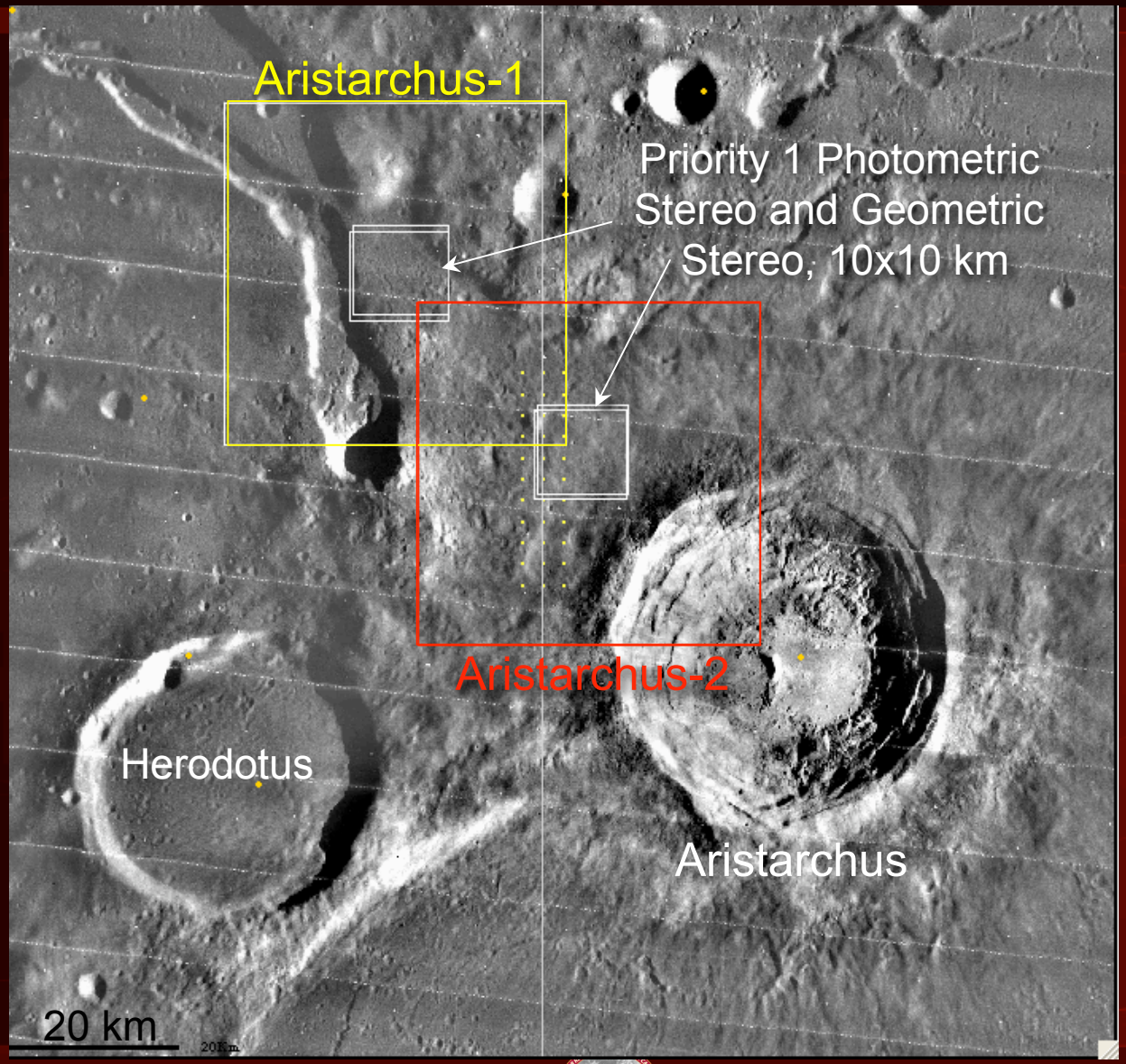
Goldstone Radar image of So. Pole



Lunar Orbiter basemap

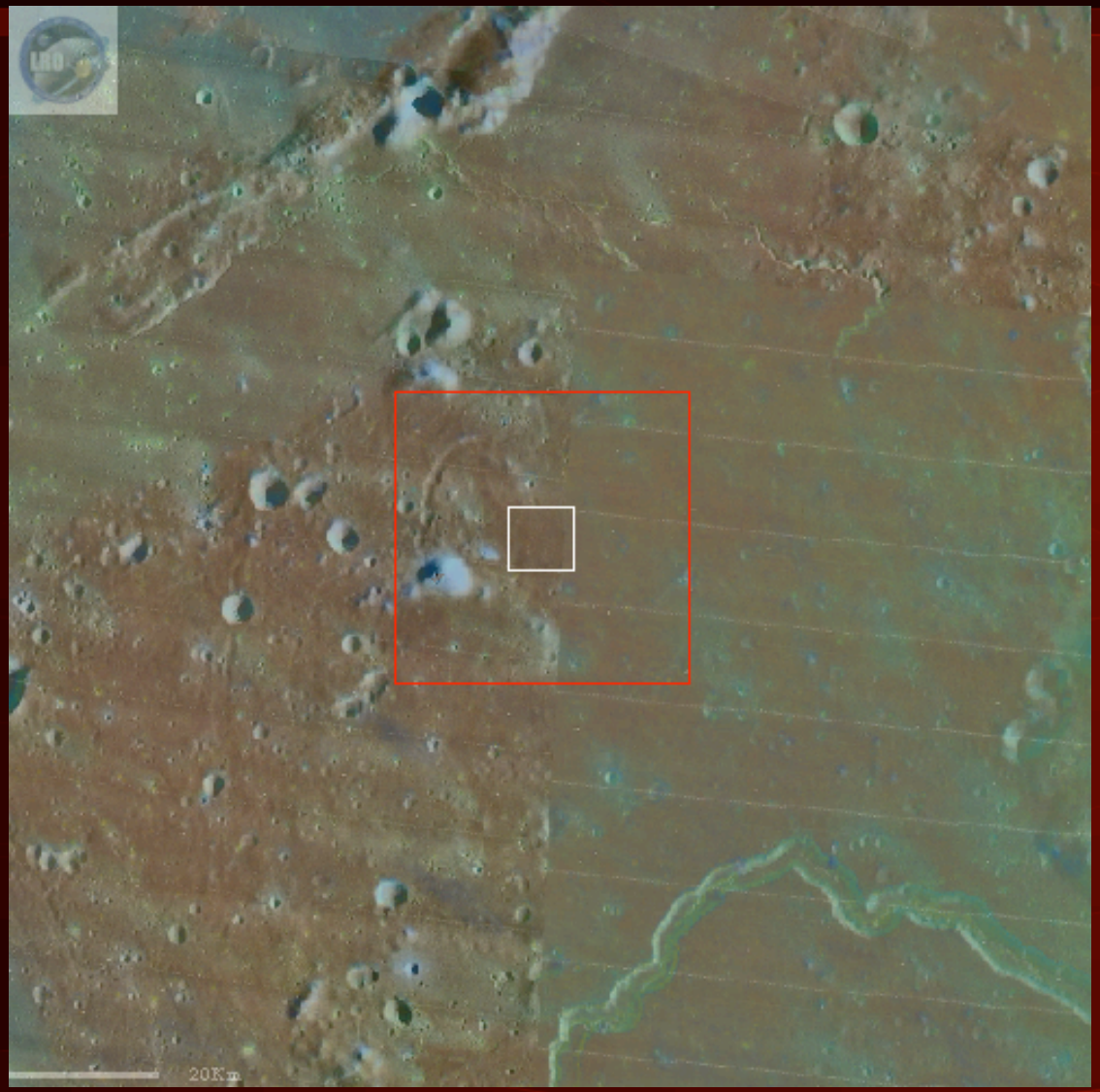


Aristarchus ESAS Targets 1 and 2



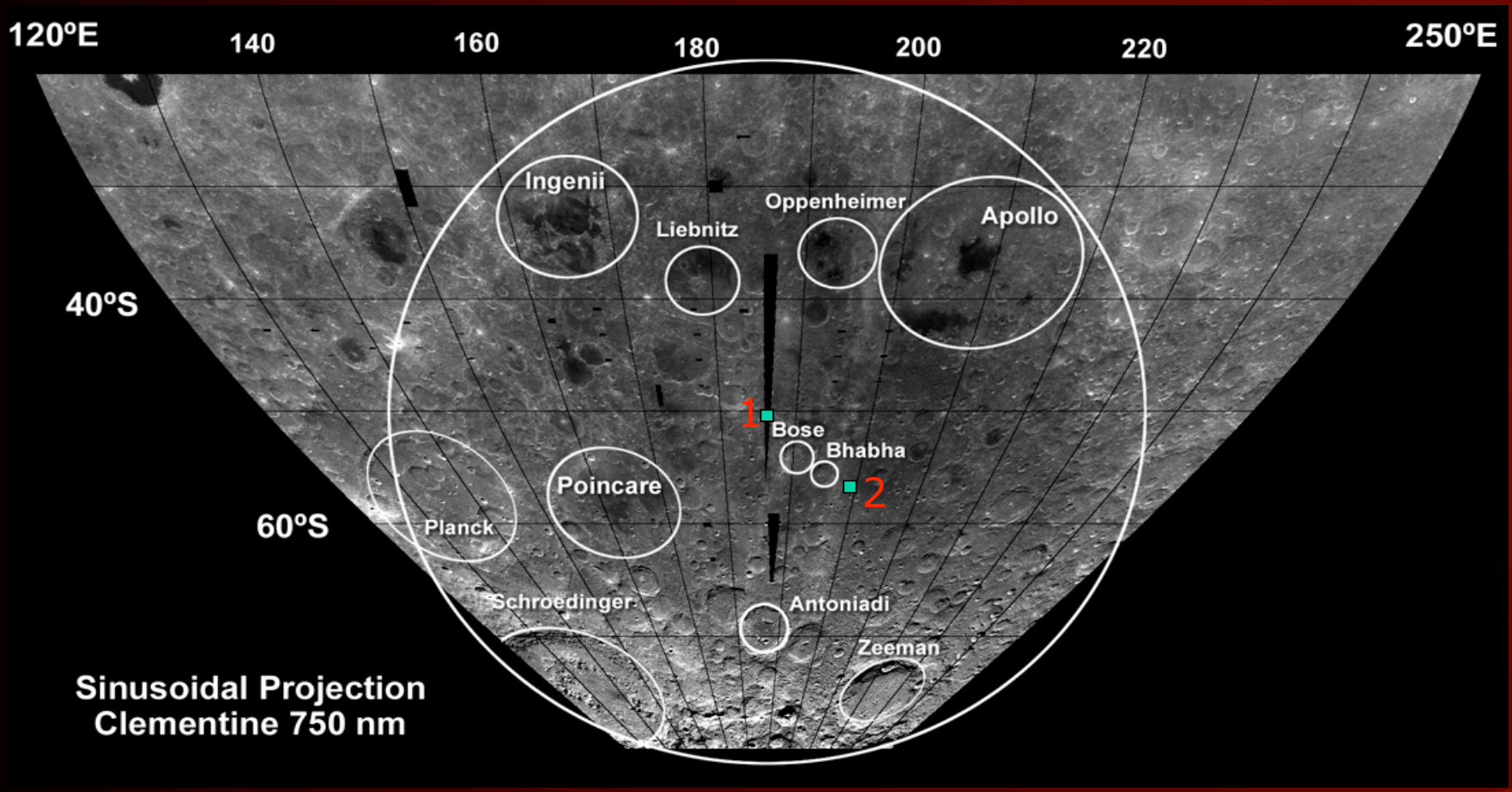
Clementine 750 nm
overlain on LO

LROC ESAS Target Example: Aristarchus ESAS Target 3

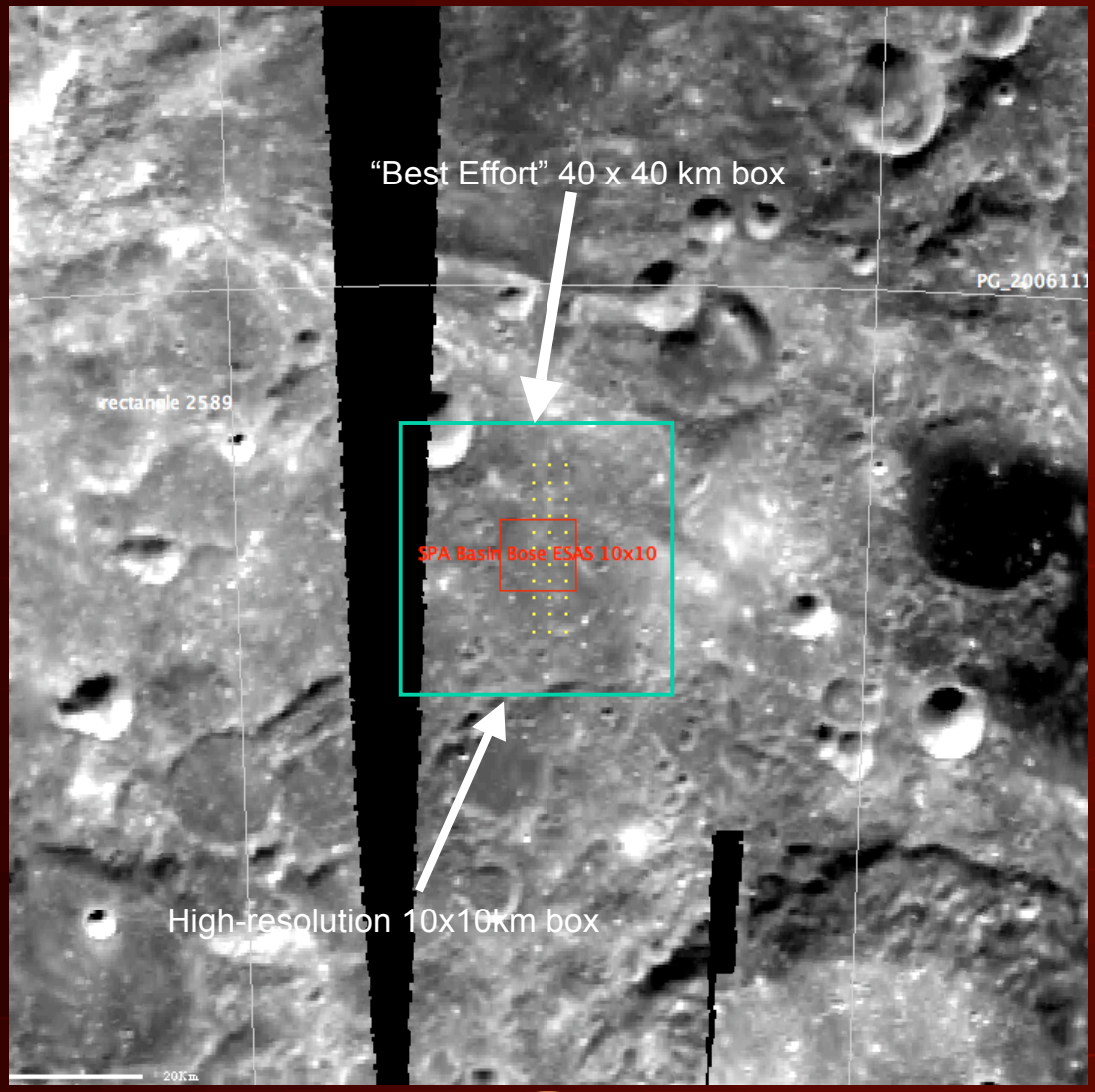


LROC ESAS Target Example: South Pole-Aitken Basin

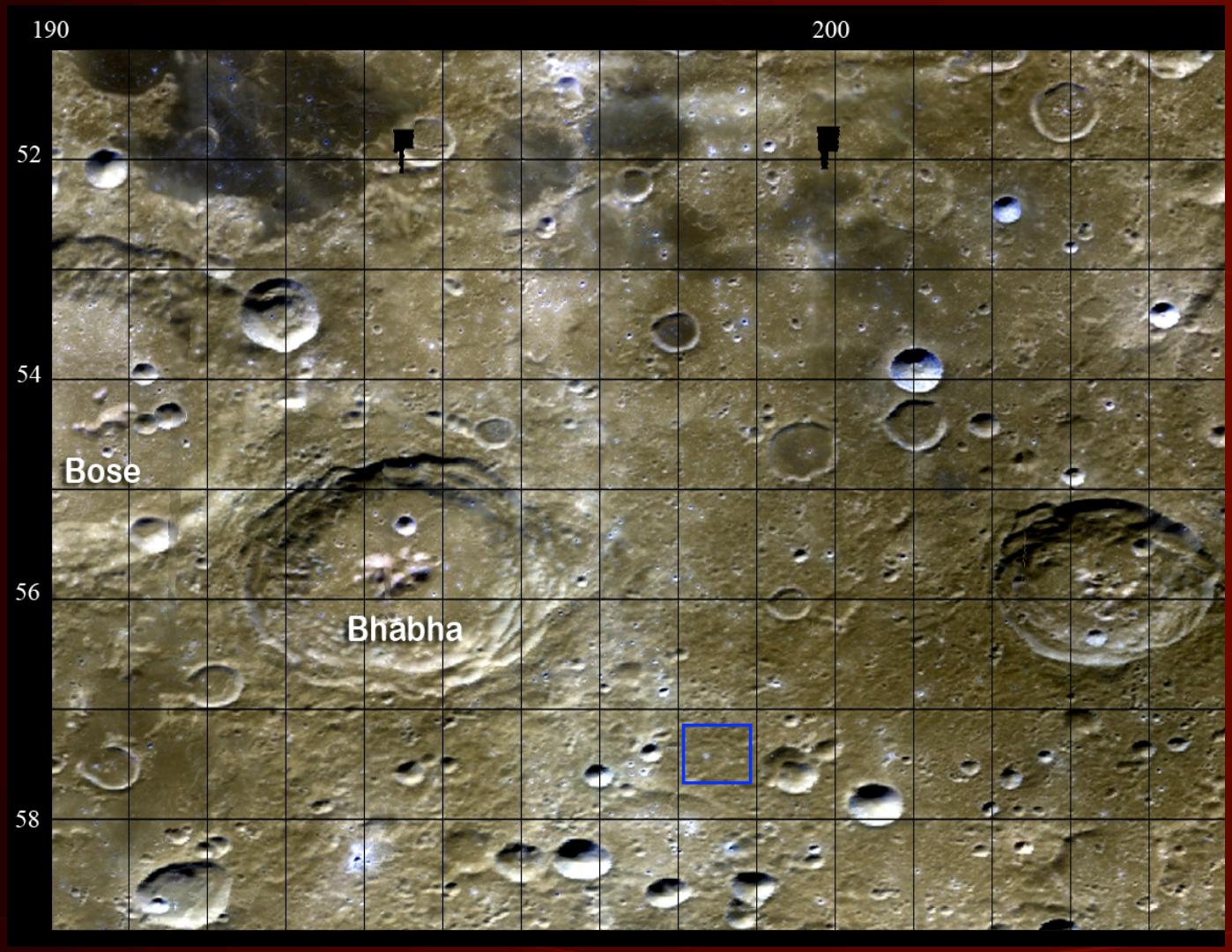
ESAS Reference Site near Bose Crater: 2 NAC Targets Defined



LROC ESAS Target Example: SPA Interior/Bose Crater Site #1



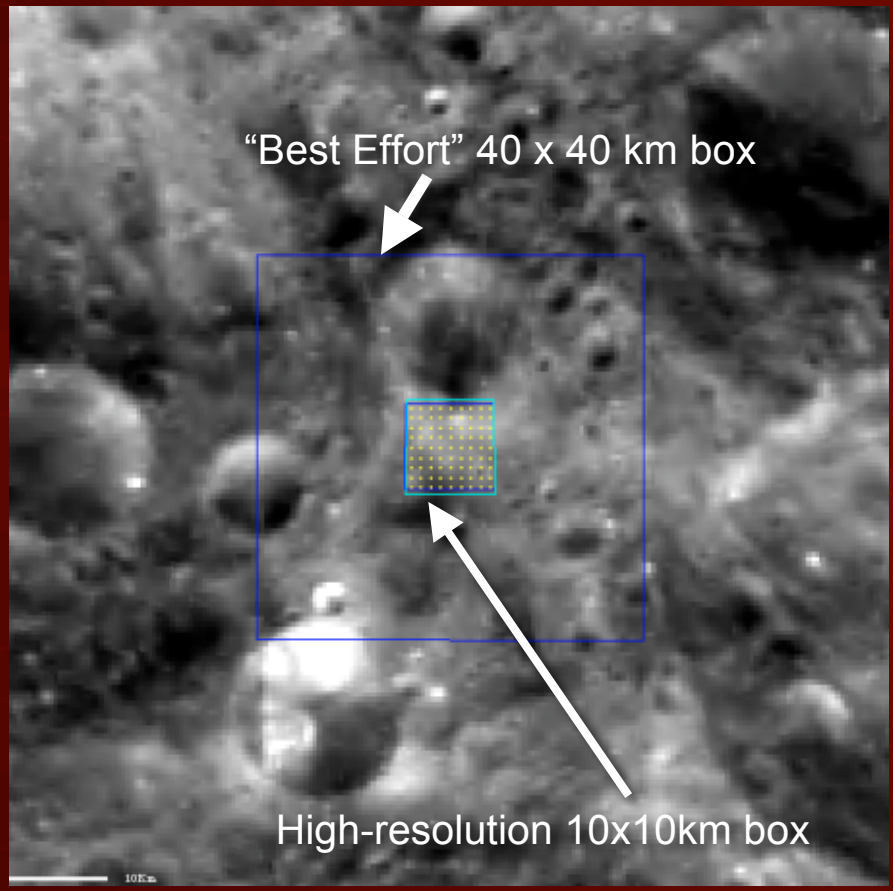
LROC ESAS Target Example: SPA Basin Interior Site #2



ESAS Example: Dante Crater (Central Farside Highlands)

Central Far Side Highlands

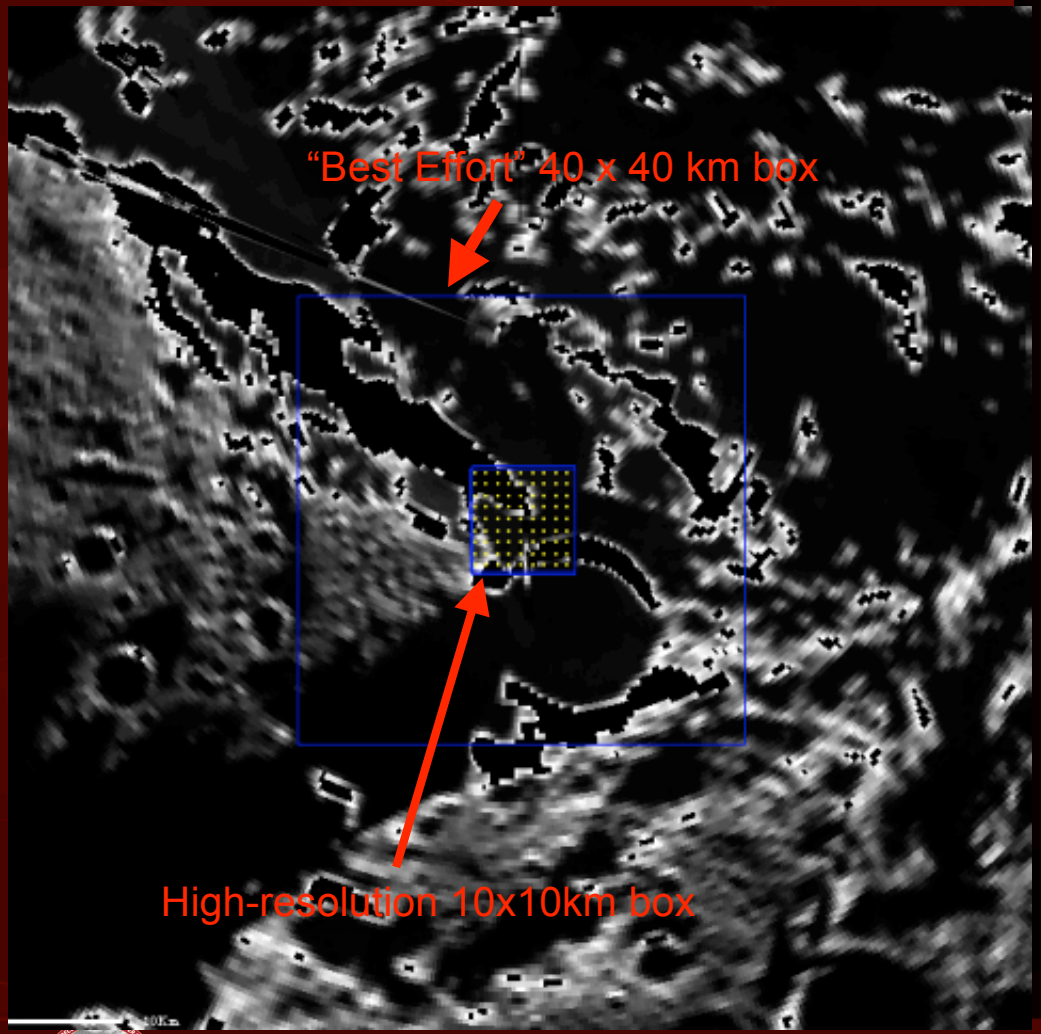
This highland site is on the central far side of the Moon. The site appears to be on the most ancient, primordial crust of the Moon—the original magma ocean anorthosite. There is Al- and Ca-rich regolith available for ISRU processing. Observation of the low-frequency radio sky would be possible here. This site would require relay satellites for Earth communications.



ESAS Example: Peary B (North Pole)

Lunar North Pole, near rim of Peary B

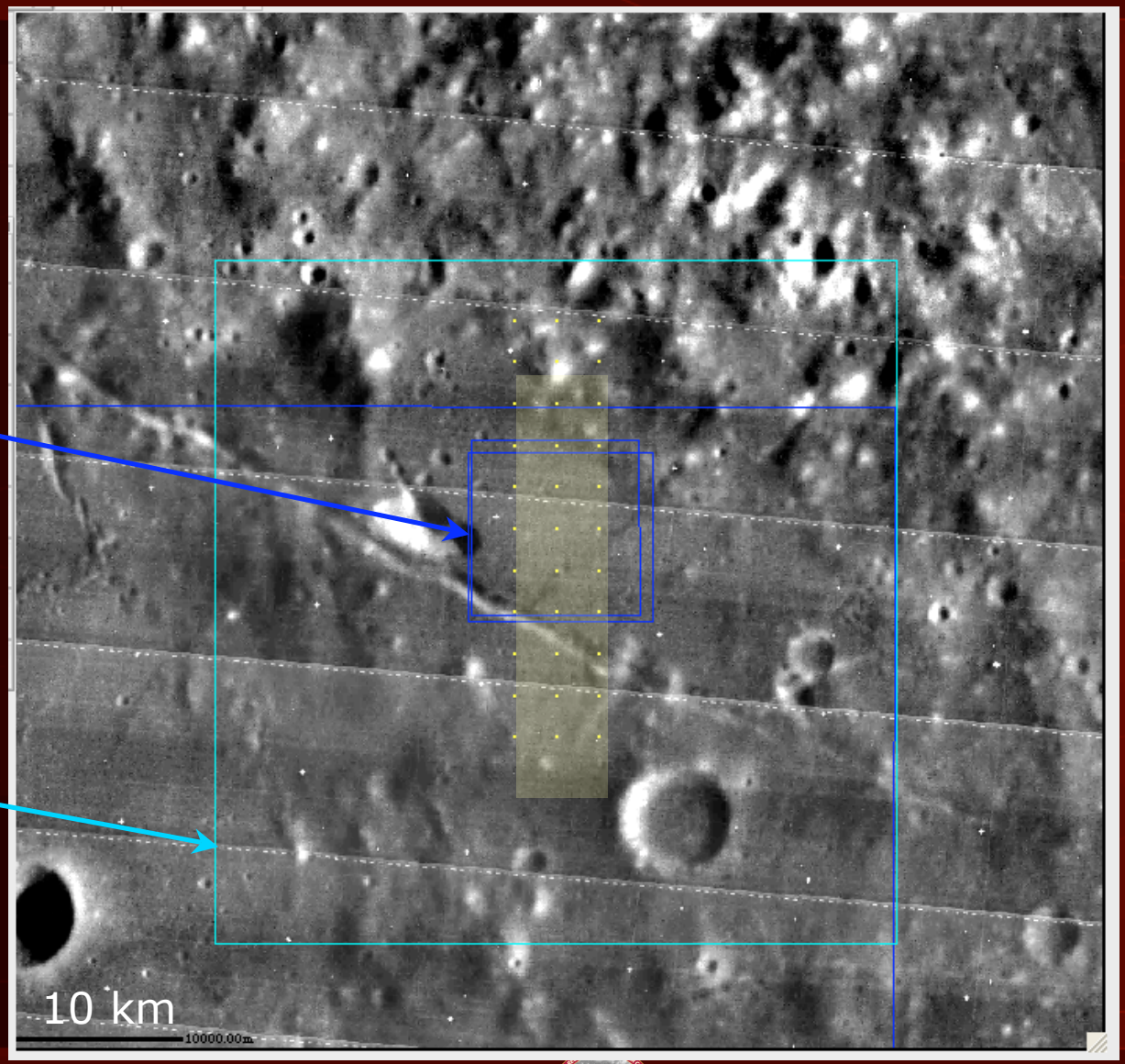
–Area of near-permanent sunlight on the rim provides access to power and proximity to a cold trap (crater interior) that may contain water ice. The site is on the distal edges of the Imbrium basin ejecta blanket. The northern celestial hemisphere is continuously visible.



ESAS Target:
Rima Bode (pyroclastic deposit)

10 x 10 km photometric and geometric stereo priority-1 targets

40 x 40 km best-effort regional mosaic, priority-2

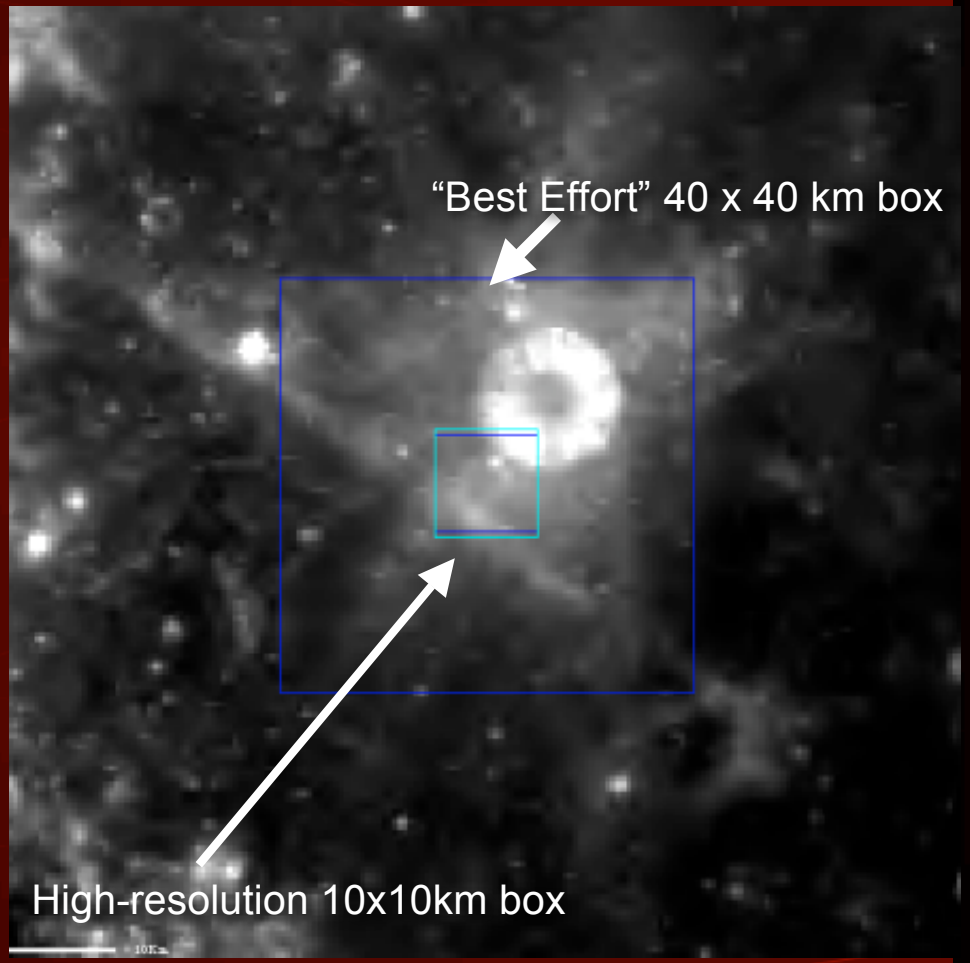


Size of NAC pair shown in yellow

LROC ESAS Example: Mare Smythii, SW of Peek Crater

Smythii Basin Floor

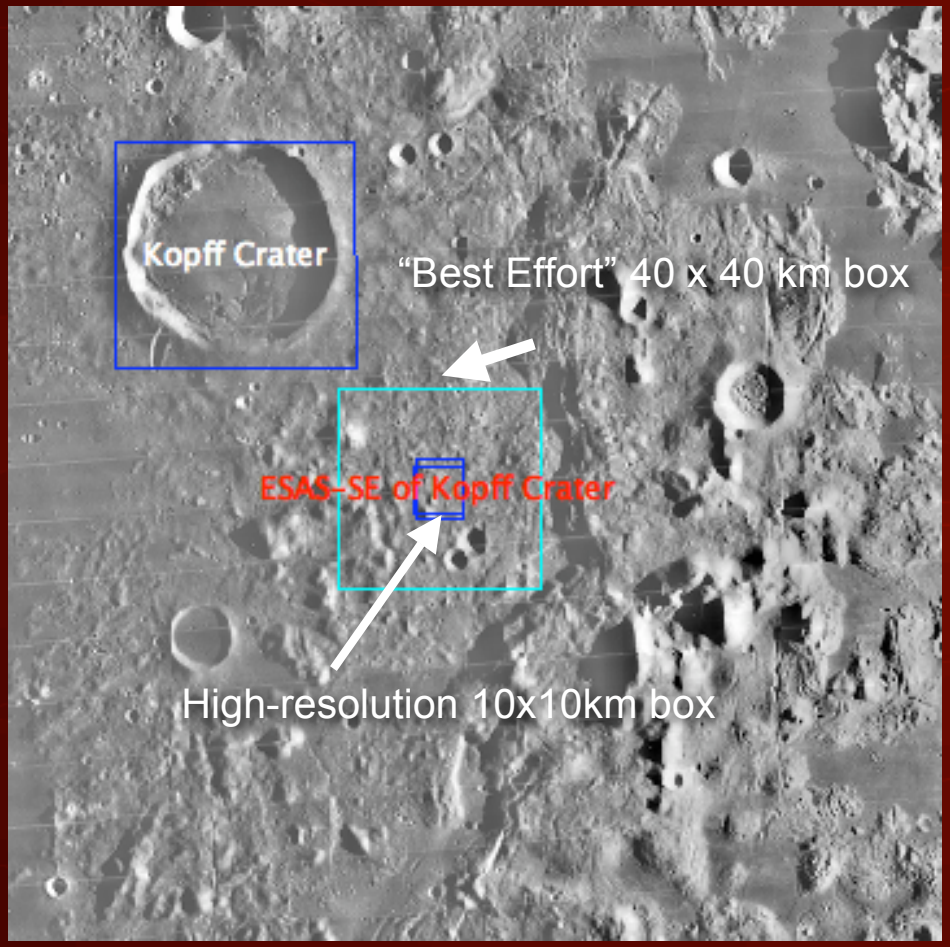
This mare site near Peek crater is on the floor of the ancient Smythii basin on the eastern limb of the Moon. Mare basalts here are very young (approximately 1–2 billion years) and could be used to study lunar thermal history.



ESAS Example: Kopff Crater (Orientale Basin Floor)

Orientale Basin Floor

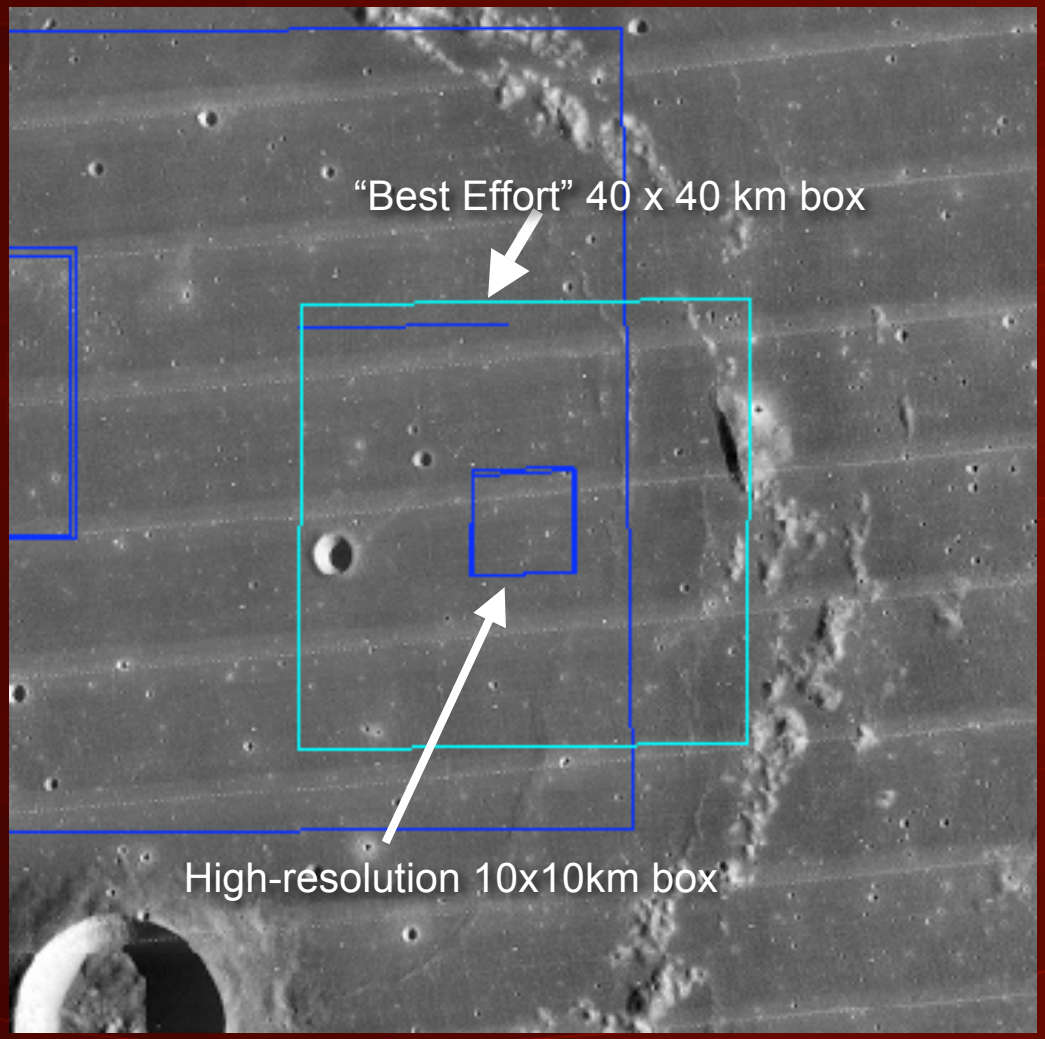
This is a combination highland/mare site on the floor of the youngest major basin on the Moon. Crater Kopff has unusual morphology and may be an endogenically modified impact crater. This site contains both mare and highland regolith feedstock for ISRU processing. The limb site is sometimes out of view of Earth and would require a relay for continuous communications.



ESAS Target: Flamsteed P (Oceanus Procellarum)

Oceanus Procellarum

This mare site is on the western near side. Basalts here appear to be some of the youngest lavas on the Moon, possibly as young as 1 billion years old. High-Ti lavas provide excellent feedstock for ISRU processing.



LROC NAC Target Internal Review

LROC Science Team will review entire LROC target database 2 months prior to launch and assess:

- -Completeness of targeting database
  - -Will targets meet LROC measurement goals?
  - -Technical issues like target priority, naming, and rationale

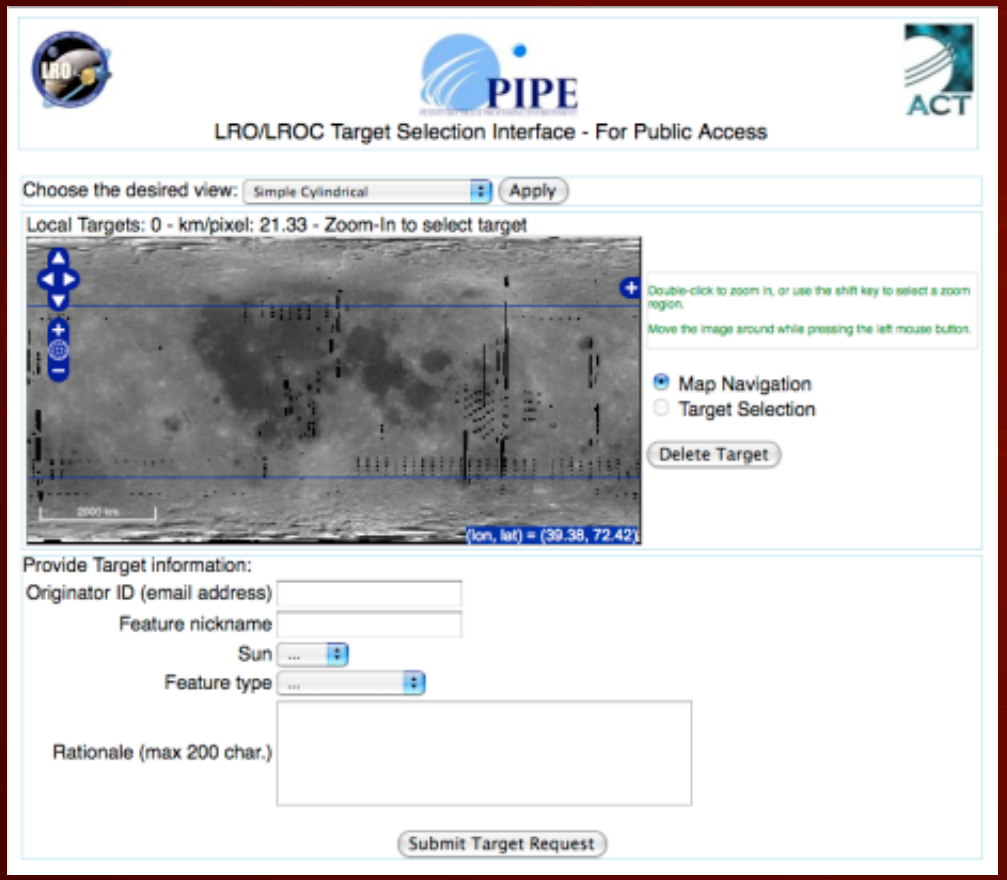
LROC Targeting Action team will go through the database and assess what is lacking in terms of area or feature coverage

We may generate new lists and assignments to help generate additional targets prior to launch

- -Hawke, Giguere, Gaddis, Lawrence, Robinson, Jolliff

Public Targeting Interface

- Will go live two months before launch.
- Allows public to suggest LROC NAC Priority 5 Targets
- Individuals will have to register and provide email address, limited to 5 targets per day



END

SCIENTIA FACULTAS EXPLORATIONIS

EXPLORATIO FACULTAS SCIENTIAE