Mini-RF Overview

S.Nozette

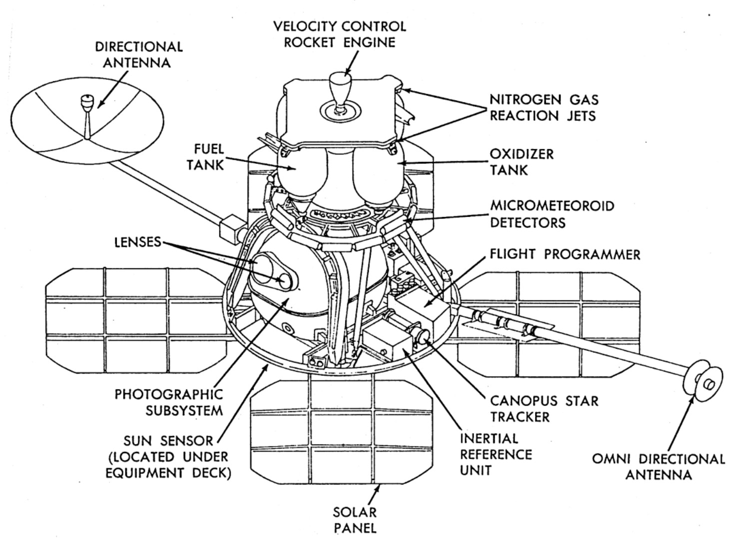
PI LRO Mini RF

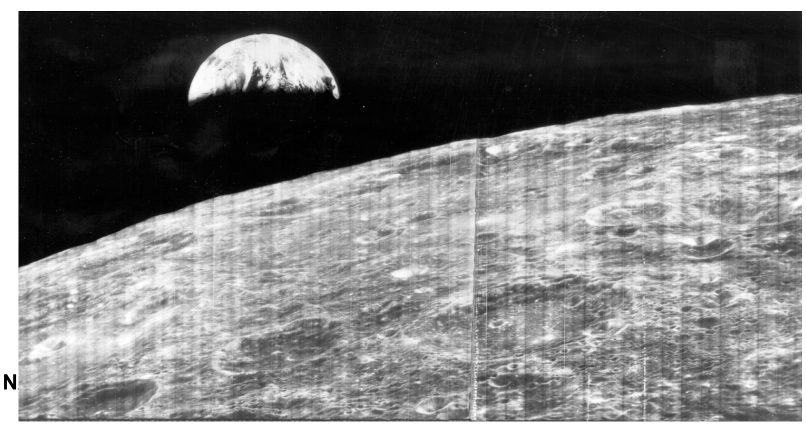
Lunar and Planetary Institute, Houston TX

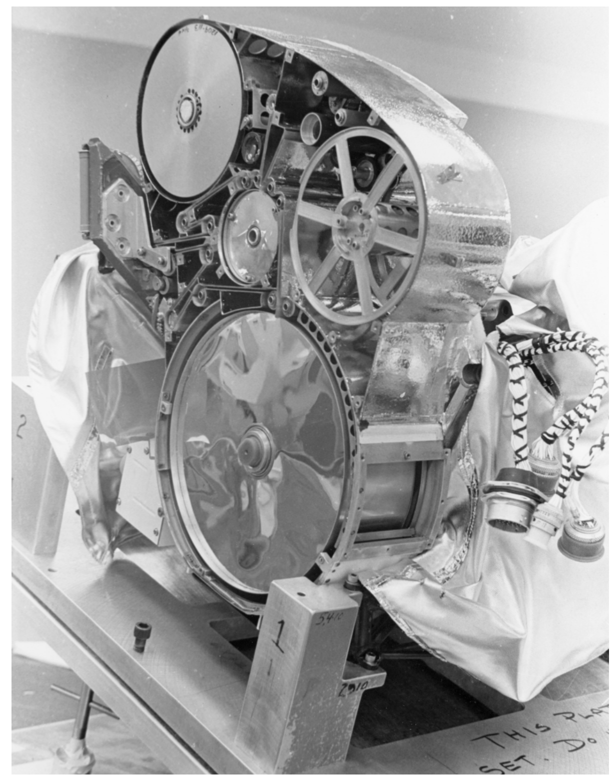
And The Mini RF Team

Previous Lunar Exploration By DoD and NASA

- Lunar Orbiter Camera was developed by DoD in 60's







Mini-RF Technology Demonstration Objectives

- Verification of Mini-RF technology for communications & radar
- Demonstrate value of hybrid-polarity SAR architecture
- Document differences in lunar response vs. resolution (baseline and zoom) and radar band (X-band and S-band)
- Generate radar topography using interferometry and stereo techniques
- Mapping of areas of interest identified by Mini-SAR on Chandrayaan-1, or by any other lunar instruments

Top-level Mini RF Parameters

Parameter	*Chandrayaan-1*	*LRO*
• Frequency	S-band	S-band and X-band
• Polarization	*Tx* RCP	
	Rx Two orthogonal polarizations, coherently	
• Scatterometry	S Band	None
• Imaging	Strip maps	Site-specific selections
• Resolution (m/pixel)	75	75, 7.5 azimuth x 15 range
• Looks	16	16 or 8
• Swath (km)	12	6 or 4
• Altitude (km)	100	50
• Incidence	35°	35°
• Interferometry		15 m x 25 m, 3.5 km

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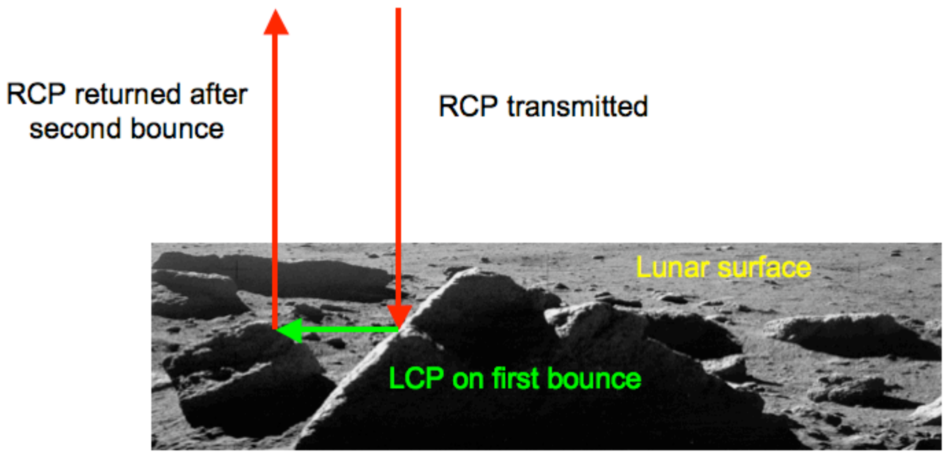
LRO Mini-RF Performance Summary

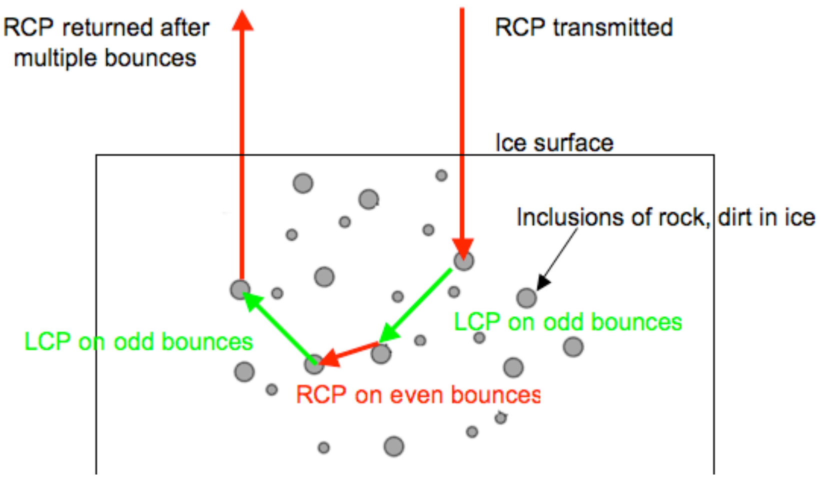
Overall Requirements		Performance	LRO I&T
Radar Bands	S- and X-band	✓Spectrum analyzer ✓All Modes Tested	TVAC
Min. operating time	3 min. on 50 min. off 3 min. on	✓ 10 min. on 20 min. off 10 min. on	EMI
Tx polarization	Circular polarization 1.7 dB axial ratio	✓ RISK – Need in-flight CAL ✗ ~2 dB S and X	Knowledge of channel balance improved
Rx polarization	H and V > 18 dB	✓ >40 dB isolation	Not needed
Radar Requirements			
S & X Band Baseline Ground Resolution	Azimuth – 150 m Range -- 150 m	✓ 150 × 150 m	Delay line tests verified range
S & X Band Zoom Ground Resolution	Azimuth – 15 m Range -- 30 m	✓ 15 × 30 m	Delay line tests verified range
Num Required Looks	16 looks in Baseline mode	✓ Analysis	I&T data supports
Sensitivity, Noise Equivalent Sigma-0 (Reflectivity)	-27 dB S-Baseline Mode -20 dB X-Baseline Mode	✓ -33.6 S-Baseline ✓ -26.9 S-Zoom ✓ -26.3 X-Baseline ✓ -19.3 X-Zoom	Predictions updated from I&T Tx power & system noise values
Comms Demonstration			
Bands	S-Band 2380 MHz	S & X-Band	Tested over temp
Tx Modulation	Variable	BPSK, Manchester, Variable data rate & mod index	Tested over temp
Rx Signal	Digitized	Continuous 500 ksps	Data verified

Ice or Roughness ?

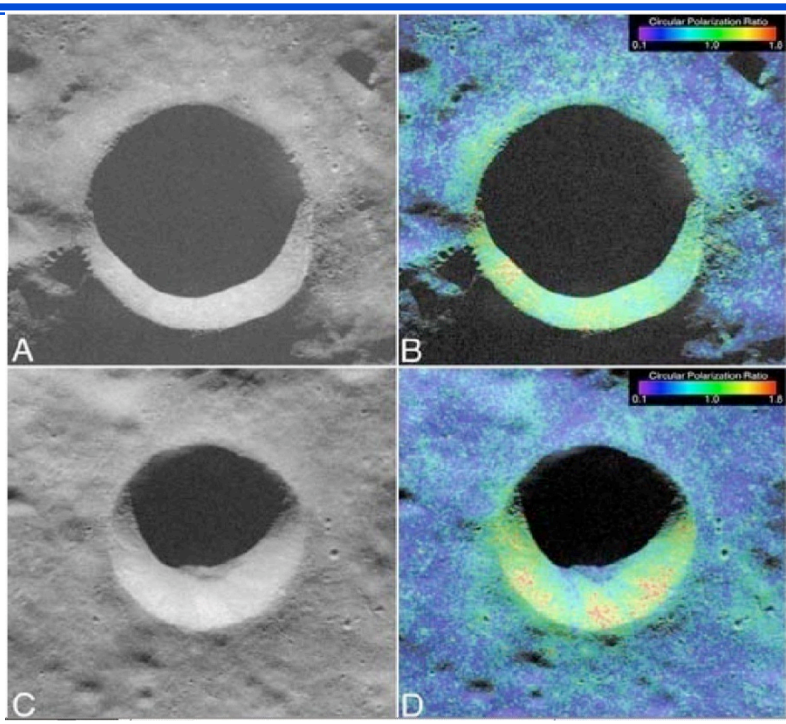
High CPR caused by surface roughness/scattering



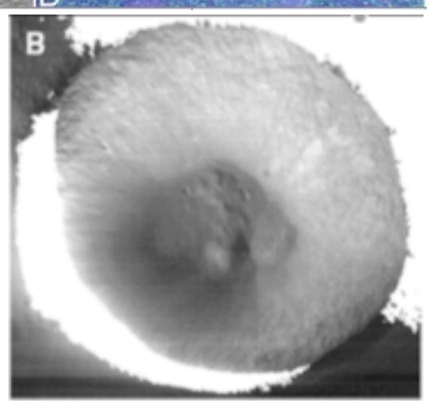
High CPR caused by ice/volume scattering



IS IT ICE OR ROUGHNESS ?



Campbell et al. *Nature*, 2006



Haruyama, et al, Science Express 10.1126 2008

- Surface Roughness and Coherent Backscatter (e.g. ice) both produce high (greater than 1) Circular Polarization Ratio (CPR)
- High CPR is observed in both shadowed (Shackleton) and illuminated (Schomberger B) terrain
- Kaguya suggests Shackleton is "mature" Schomberger G is younger (rougher)
- Mini RF will provide new data to distinguish the effects

Multiple Scattering Mechanisms?

Stoke Parameter m_L
Degree of linear polarization is an Indicator of Volume *vs* Surface Scattering for
$m_L > 0$ (if CP transmission)

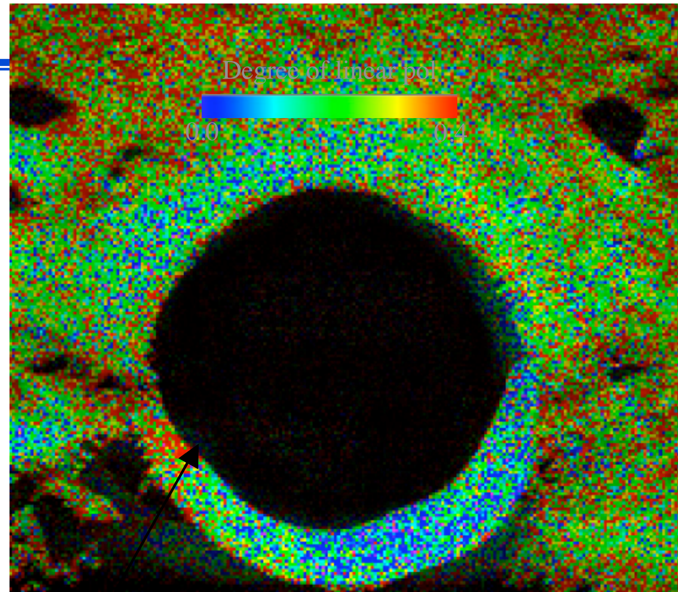
High degree of linear polarization

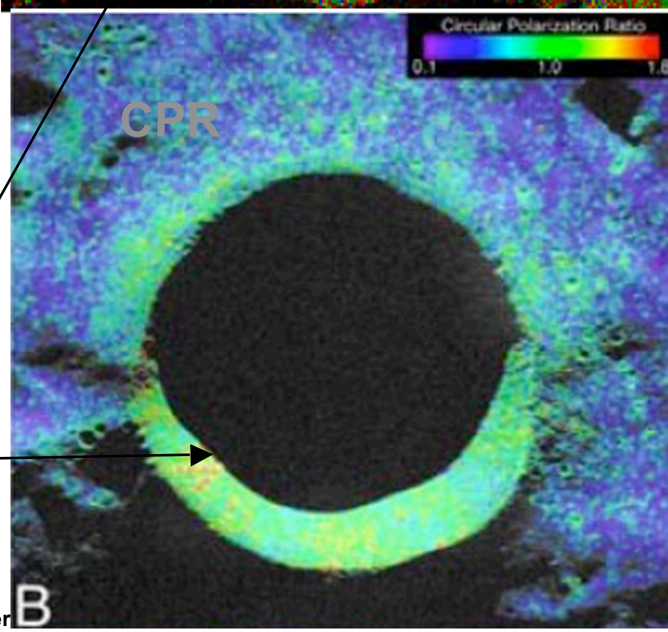
- High Sub-Surface Scatter

Low Degree of Linear Polarization

- λ-scale Surface Roughness

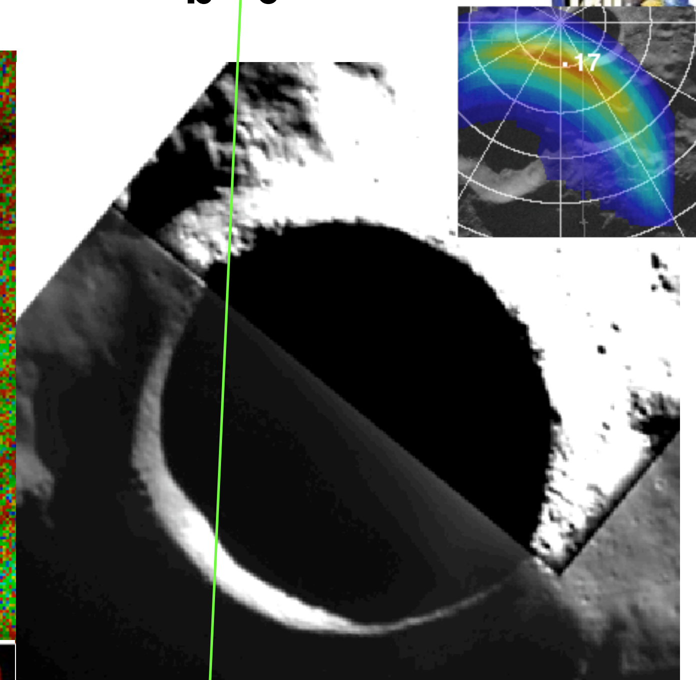
or Low Subsurface Scatter

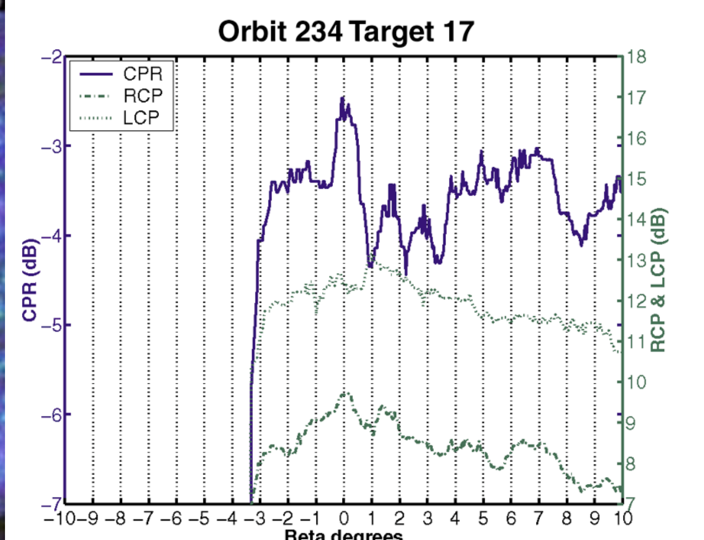


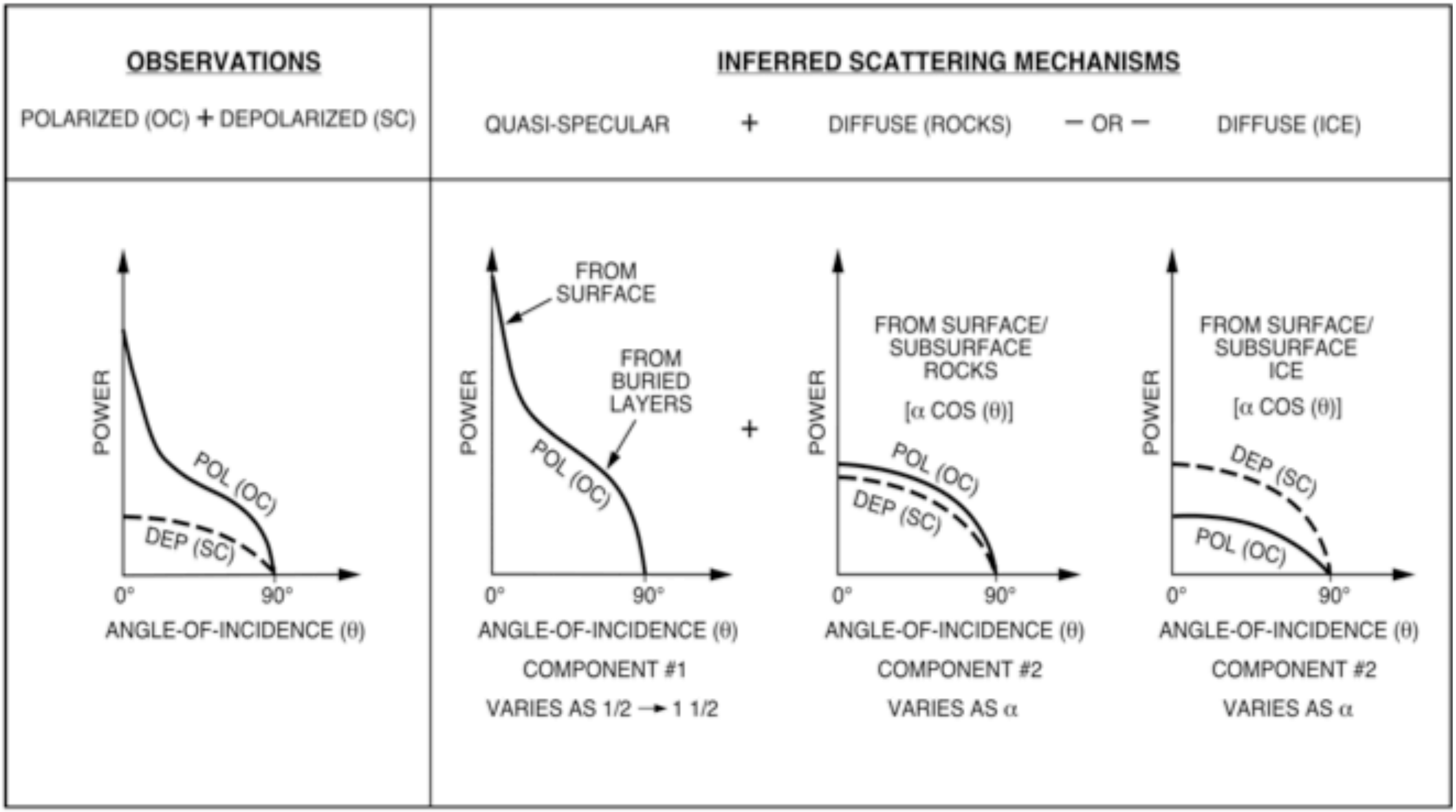


CPR> 1.8

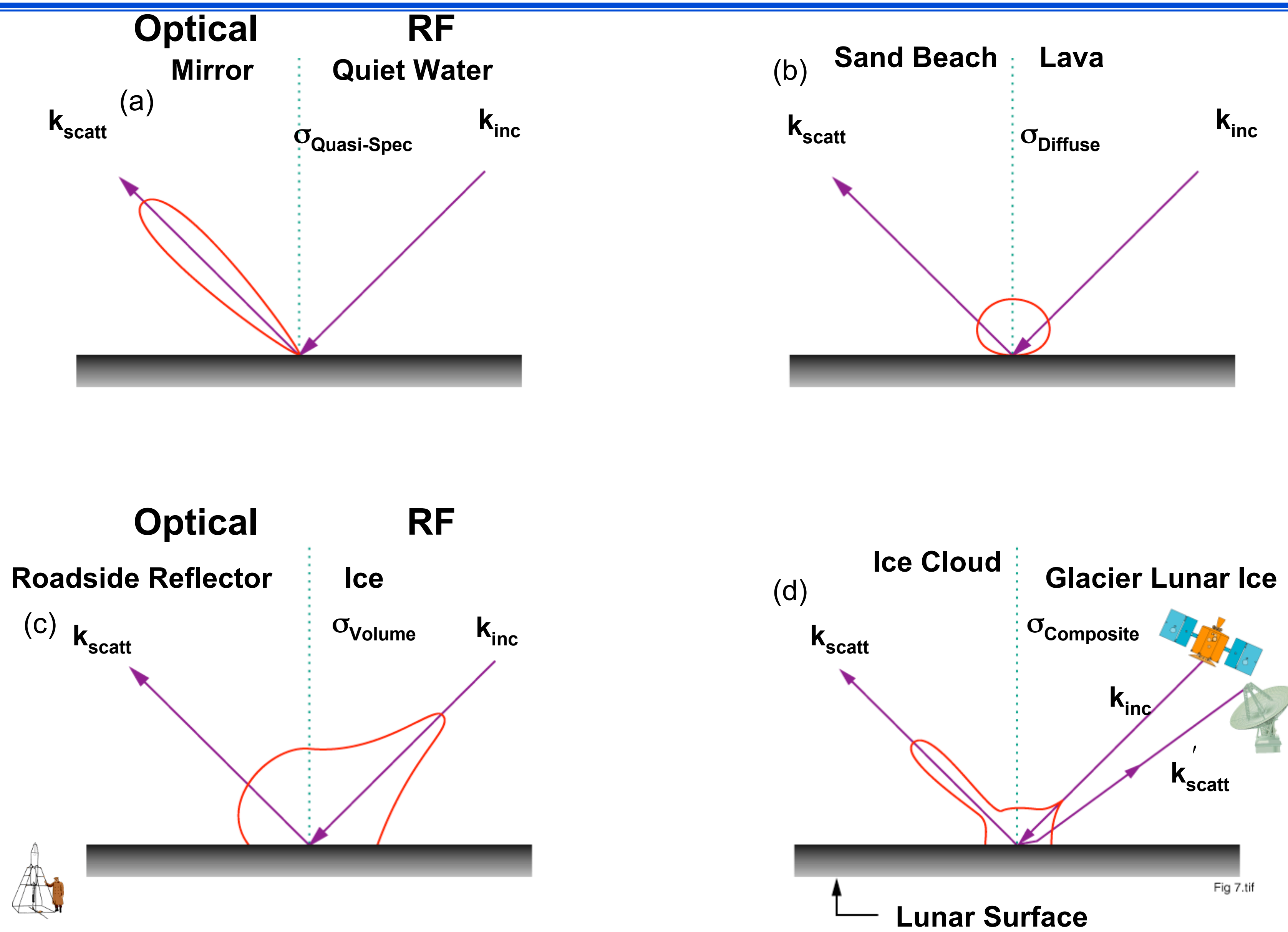
ß= 0º






OBSERVATIONS
POLARIZED (OC) + DEPOLARIZED (SC)
INFERRED SCATTERING MECHANISMS
QUASI-SPECULAR
+
DIFFUSE (ROCKS)
— OR —
DIFFUSE (ICE)
POWER
POL (OC)
DEP (SC)
0°
90°
ANGLE-OF-INCIDENCE (θ)
FROM SURFACE
FROM BURIED LAYERS
COMPONENT #1
VARIES AS 1/2 → 1 1/2
FROM SURFACE/ SUBSURFACE ROCKS
[α COS (θ)]
COMPONENT #2
VARIES AS α
FROM SURFACE/ SUBSURFACE ICE
[α COS (θ)]
COMPONENT #2
VARIES AS α

Bi-Static Radar Target Scattering Models



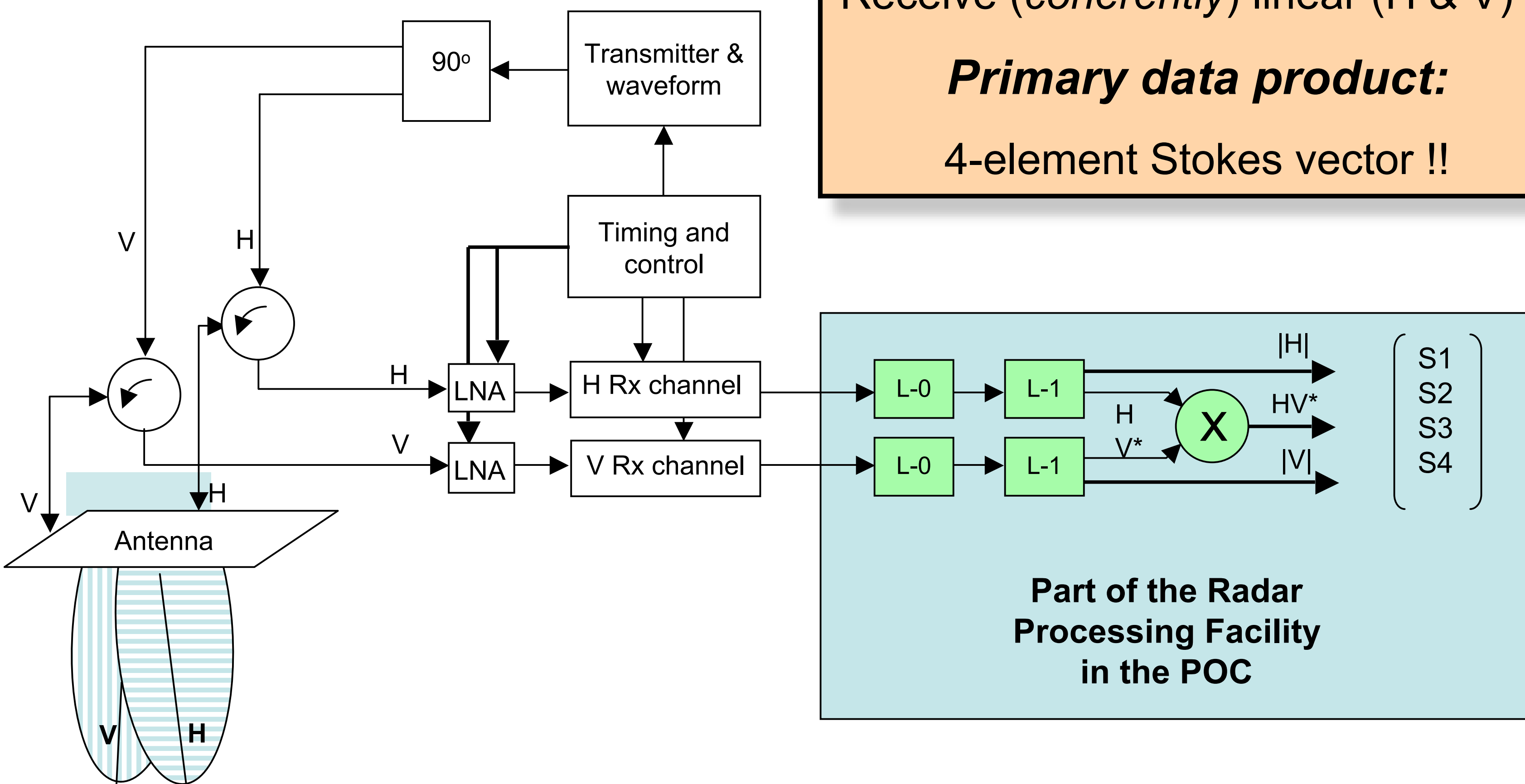
Hybrid-Polarity Instrument Architecture

Transmit RCP (*note the 90º hybrid*)

Receive (*coherently*) linear (H & V)

Primary data product:

4-element Stokes vector !!



Stokes "Daughter" Products

Degree of polarization

$$m = (S_2{}^2 + S_3{}^2 + S_4{}^2)^{½} / S_1$$

Degree of depolarization $m_D = 1 - m$

Degree of linear polarization

$$m_L = (S_2{}^2 + S_3{}^2)^{½} / S_1$$

Degree of circular polarization

$$m_C = S_4 / S_1$$

Circular polarization ratio

$$\boldsymbol{\mu}_C = (S_1 - S_4) / (S_1 + S_4)$$

Linear polarization ratio

$$\boldsymbol{\mu}_L = (S_1 – S_2) / (S_1 + S_2)$$

Relative phase δ = arctan (S_4 / S_3)

Fundamental; 1:1 mapping *wrt* Entropy *E*
$E \sim (1 – m^2)^{\gamma}$, $\gamma \sim 0.74$

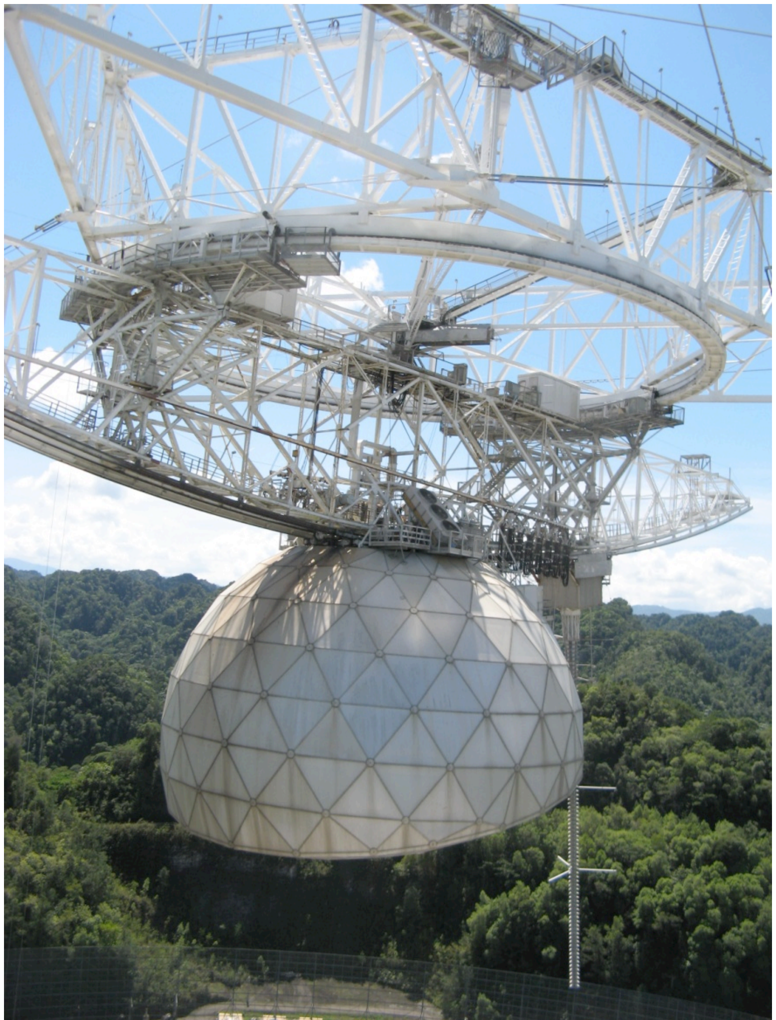
Aiello and Wordman, Phys. Rev. Lett. (2005)

Indicator of volume *vs* subsurface scattering for $m_L > 0$ (if CP transmission)

Indicator of scattering associated with planetary ice deposits and fresh ejecta: $\boldsymbol{\mu}_C > 1$

Sensitive indicator of "double bounce" backscattering

EARTH-BASED CALIBRATION



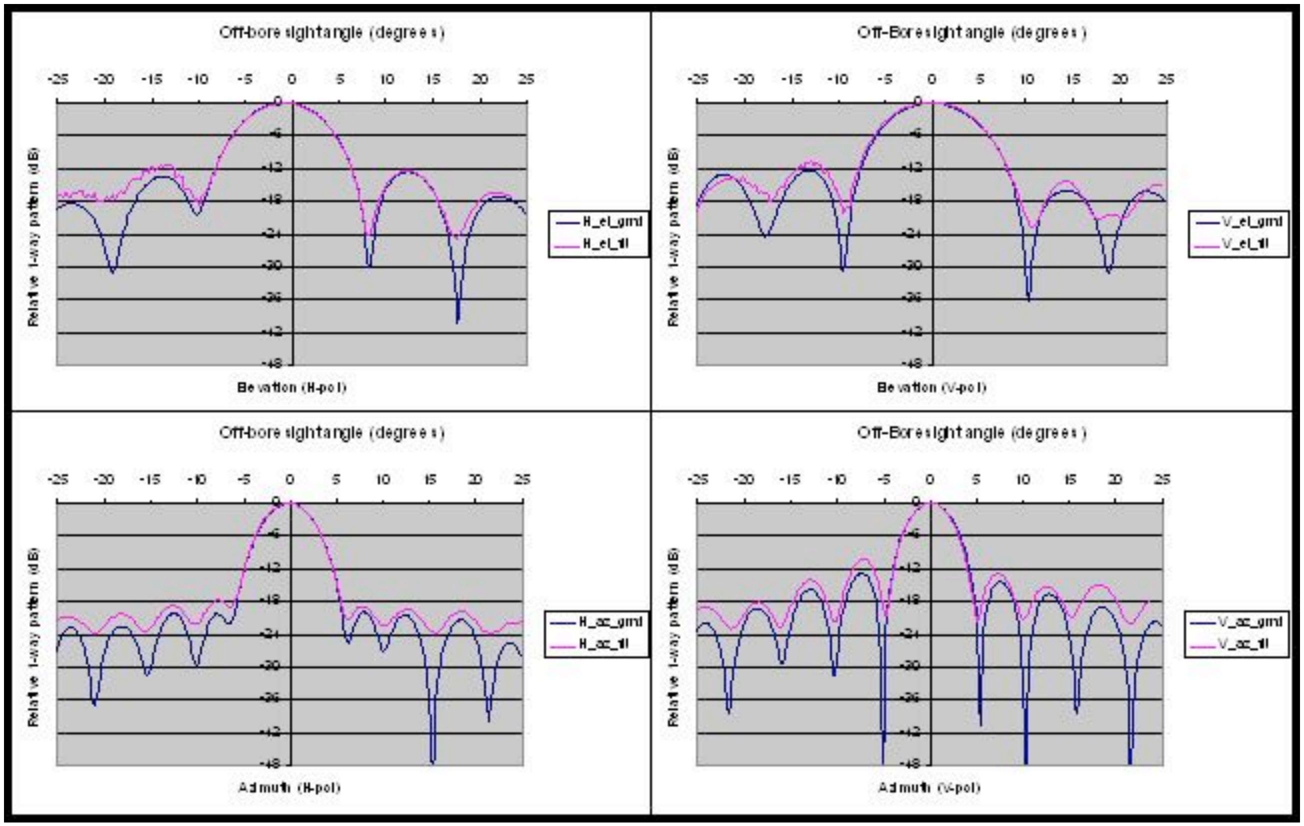
- LRO Mini RF Calibration Procedures validated with Chandrayaan-1 Mini SAR
- Greenbank radiotelescope transmit calibration (27 Feb. pure RCP signal to Chandrayaan-1
  - Map Rx channel gain/separation
  - Chandrayaan-1 Tx to Earth
  - Measure Tx signal
  - Articulate spacecraft to map antenna pattern
- Arecibo radiotelescope receive calibration (31 Jan. 2009)
  - Ground transmit

Comparison With Ground Patterns

H **V**

Elevation

Azimuth



Mare Tranquillitatis

Mini-SAR strip on Clementine 750 nm base map

Mini SAR Equatorial Calibration, 20 Jan. 2009

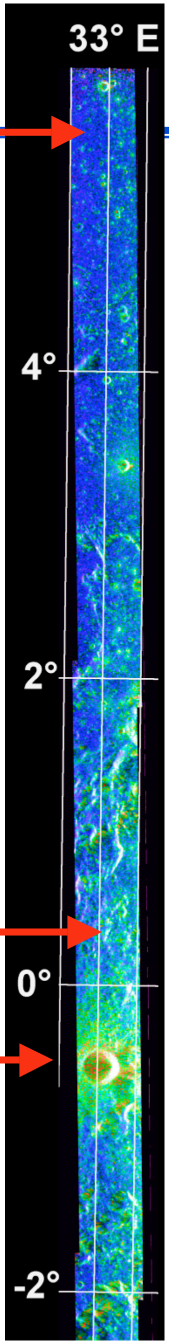
Collect SAR strip such that viewing geometry matched that of Earth-based radar imaging

Data successfully gathered along longitude 33° E, from 6° S to 6° N latitude

Nectaris basin highlands

Censorinus A

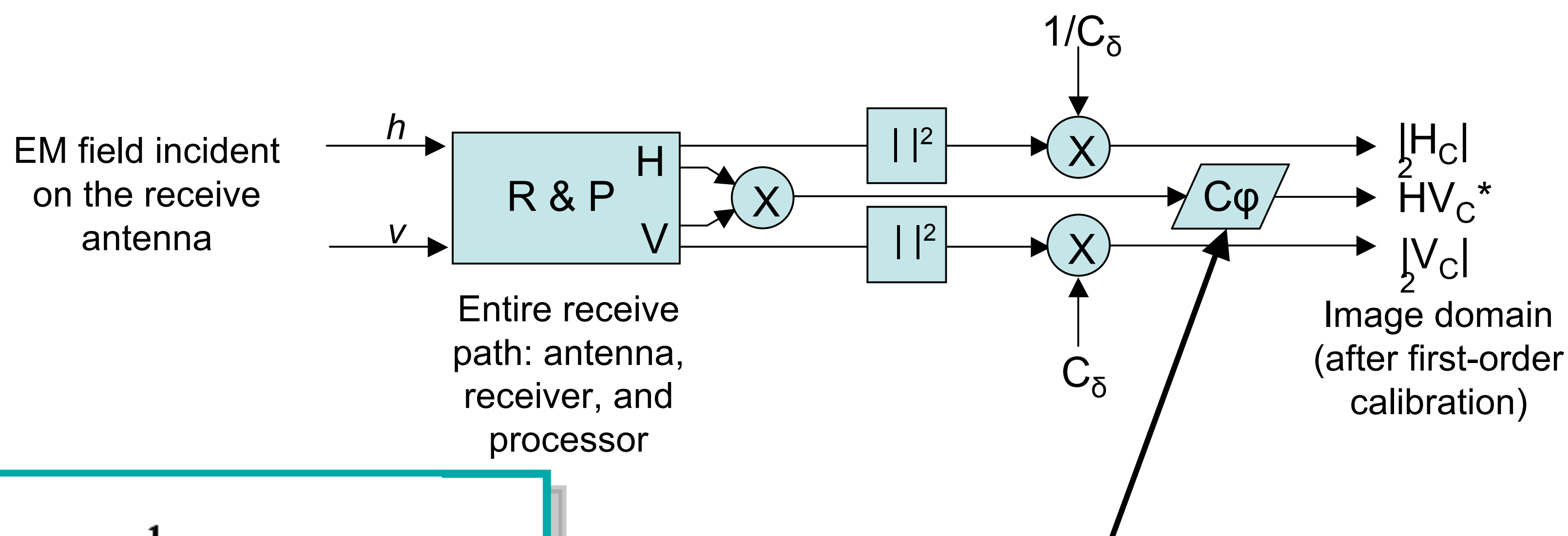
CPR image



NAS

Receive Chain Calibration Coefficients

- **Objective: find C_δ and $C\varphi$ to "perfectly" balance the receiver**



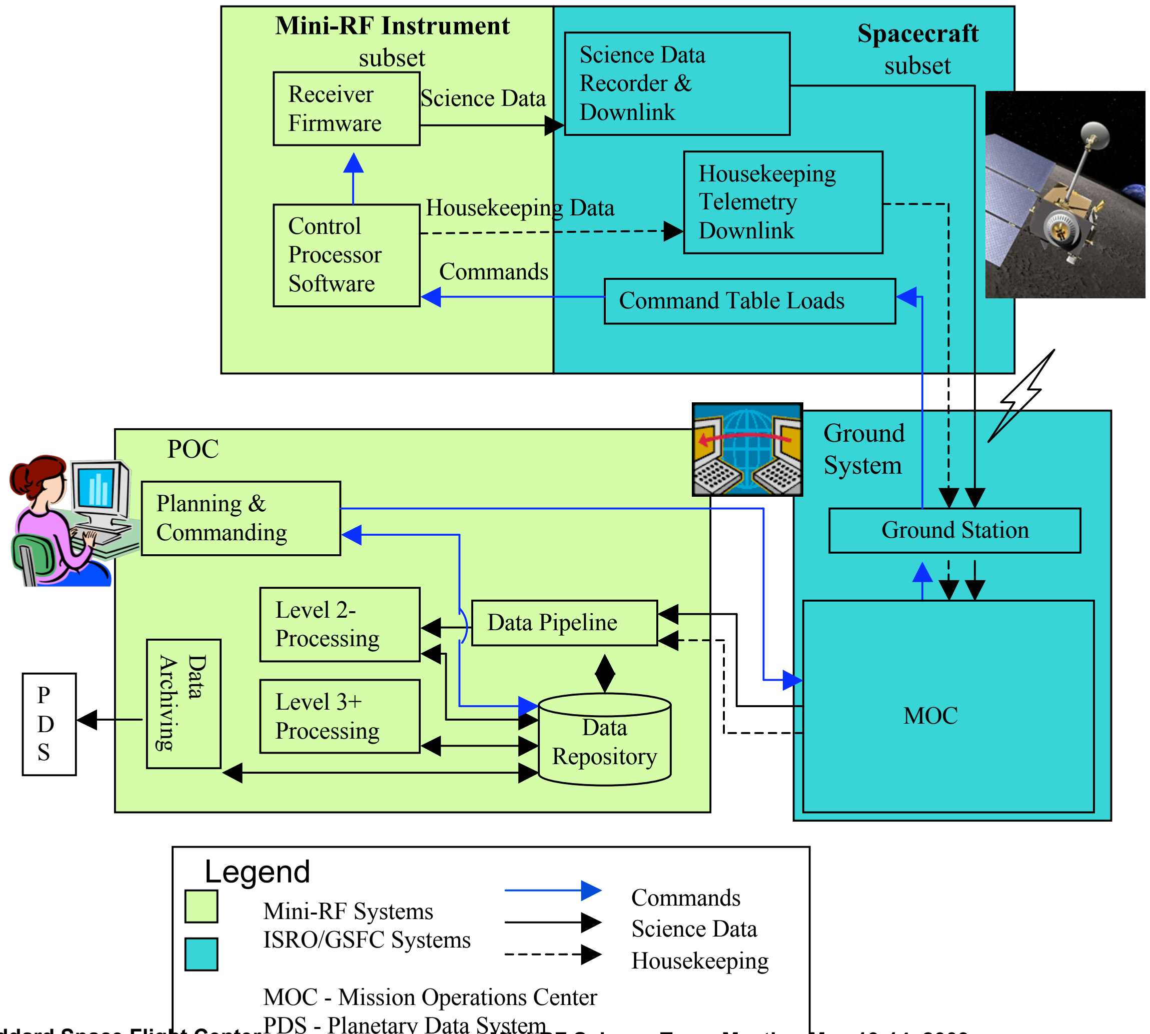
$$Re\,HV_C^* = Re\,HV^*\cos C_\phi - Im\,HV^*\sin C_\phi$$
$$Im\,HV_C^* = Re\,HV^*\sin C_\phi + Im\,HV^*\cos C_\phi$$

$$C_\delta = \frac{1}{\left(V_{Rx}/H_{Rx}\right)} = 0.966$$

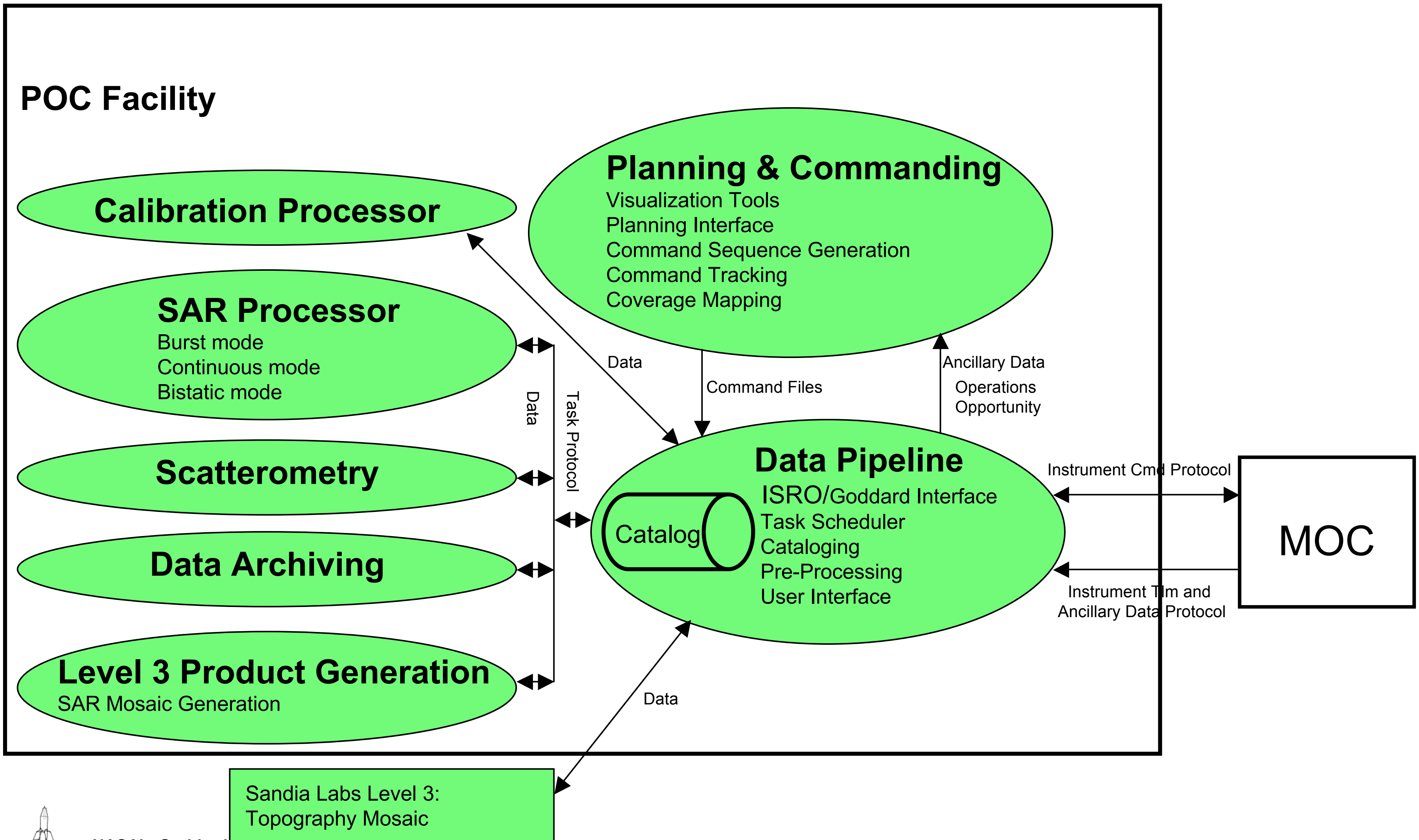
$$C_\phi = \Delta\phi_{Rx,(V-H)} = 46^o$$

Arecibo measurements

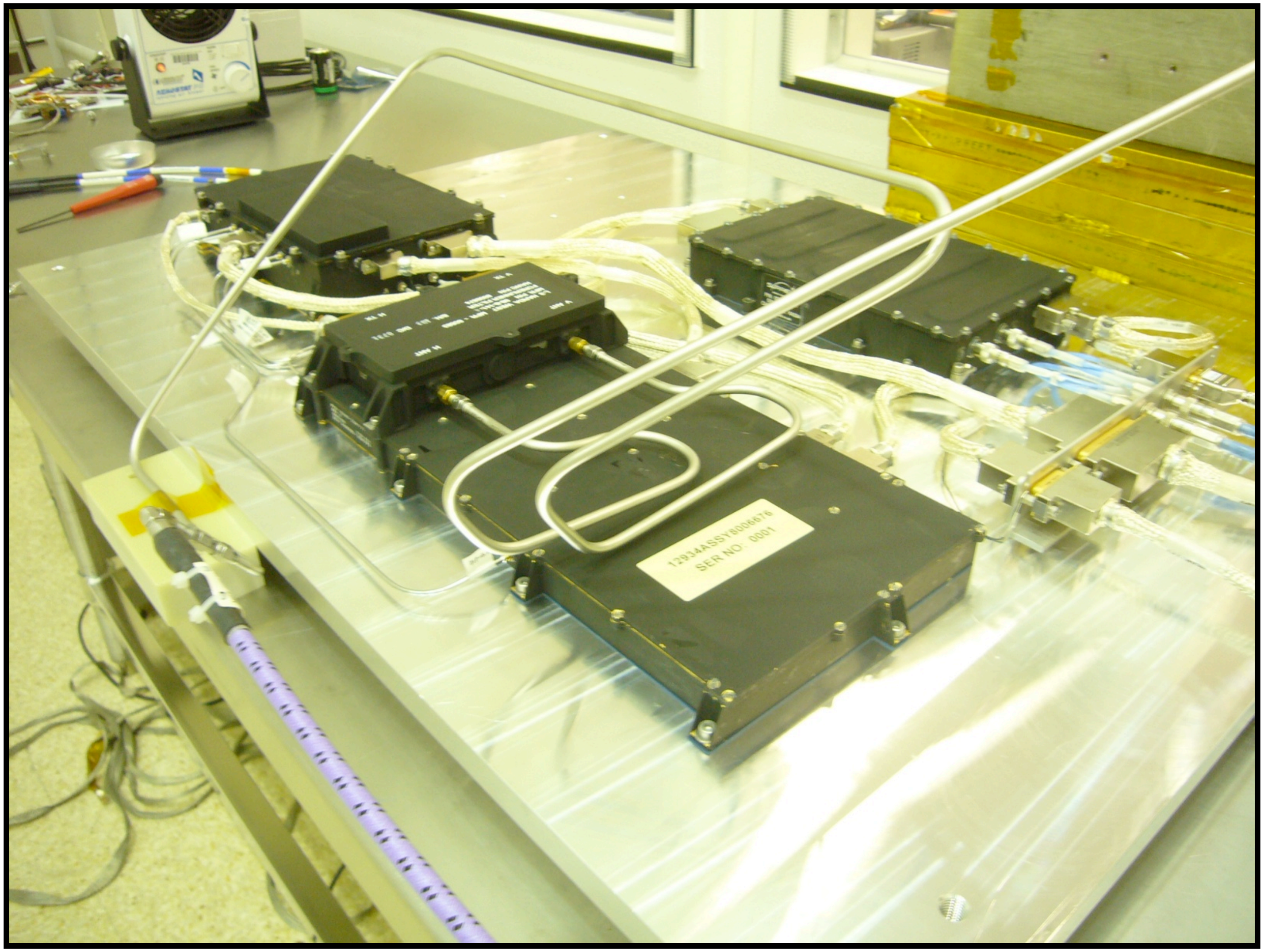
Operations Systems / Data Flows



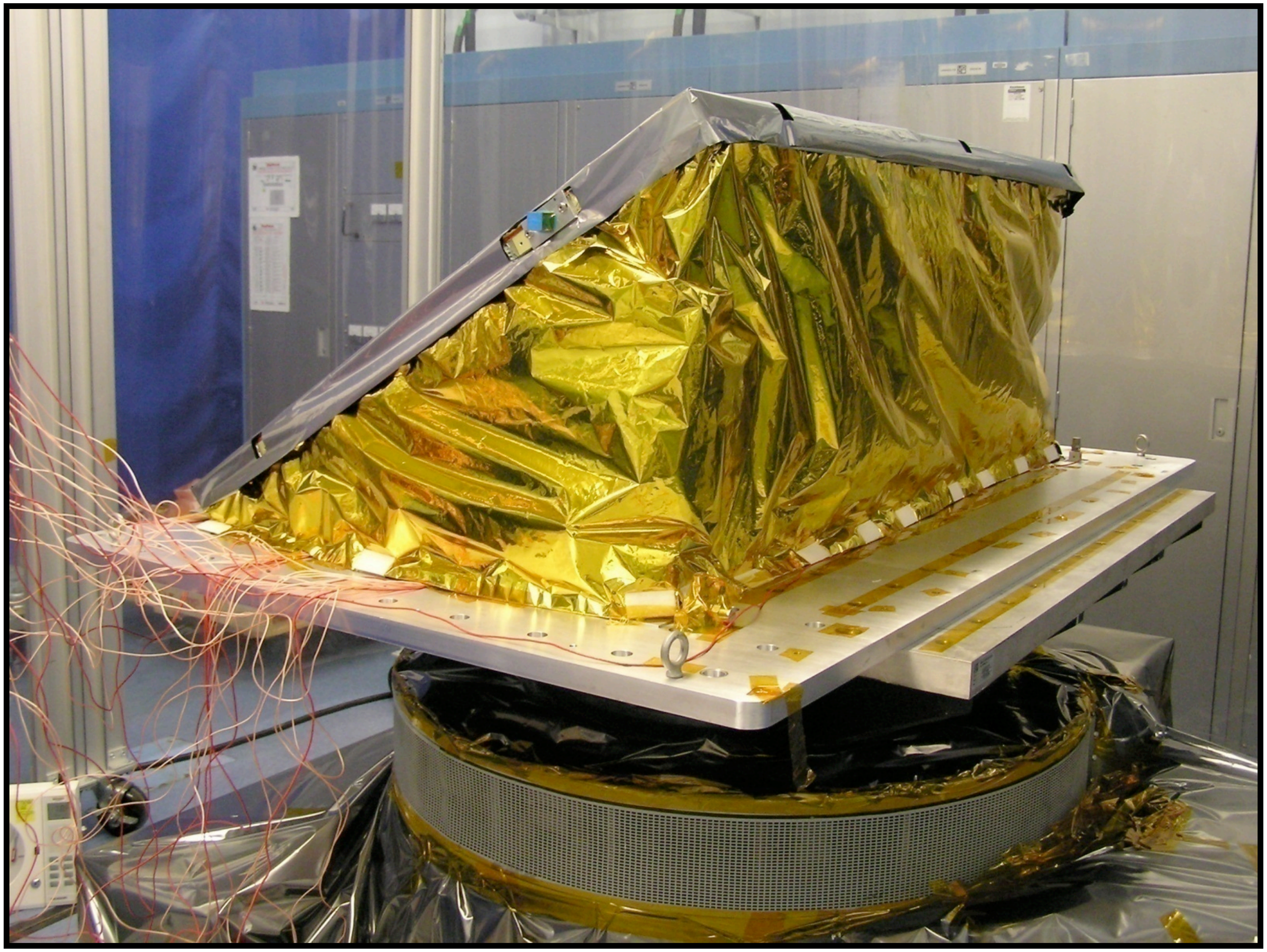
Mini-RF Payload Operations Center



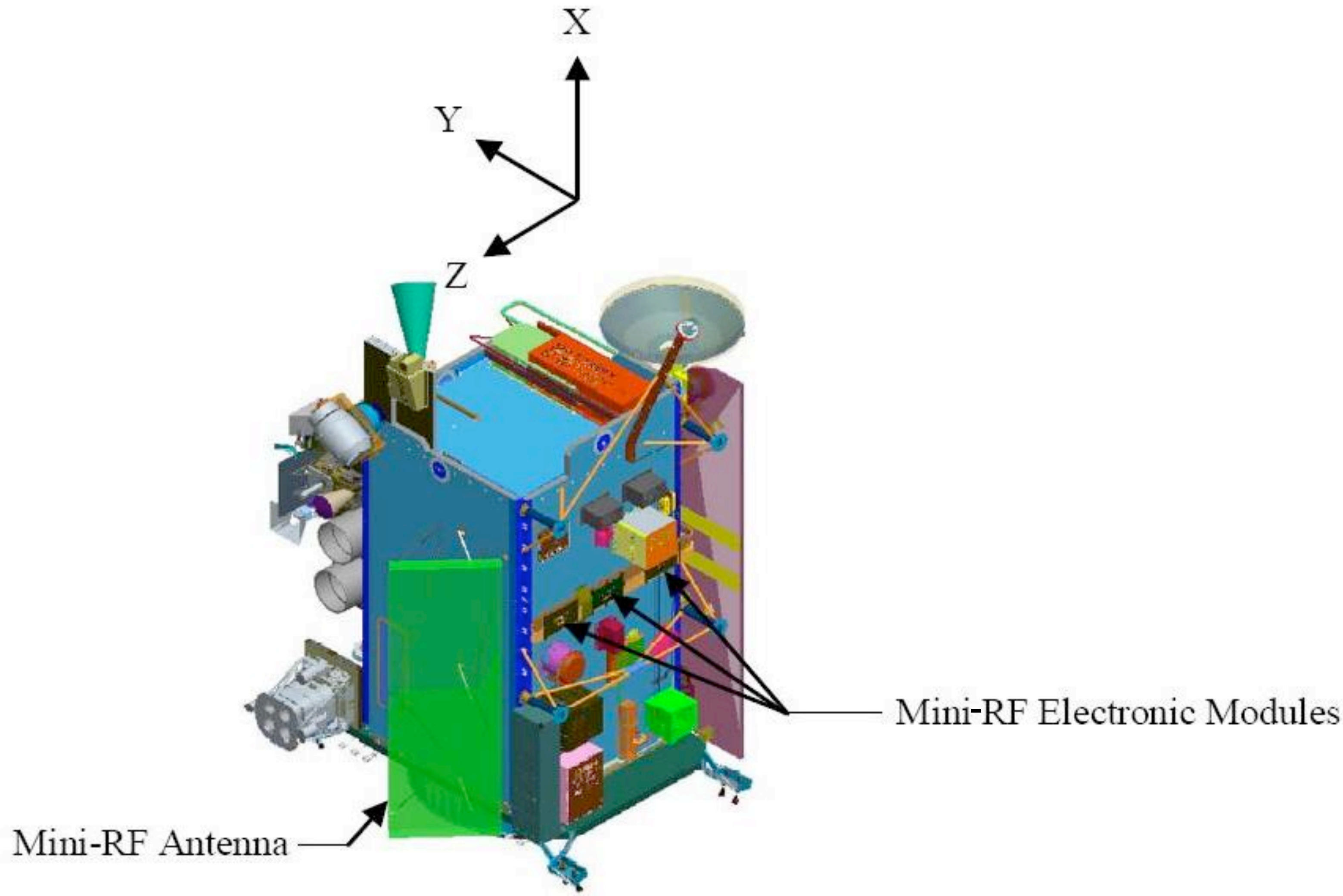
Chandrayaan-1 Flight Electronics



Chandrayaan-1 Flight Antenna

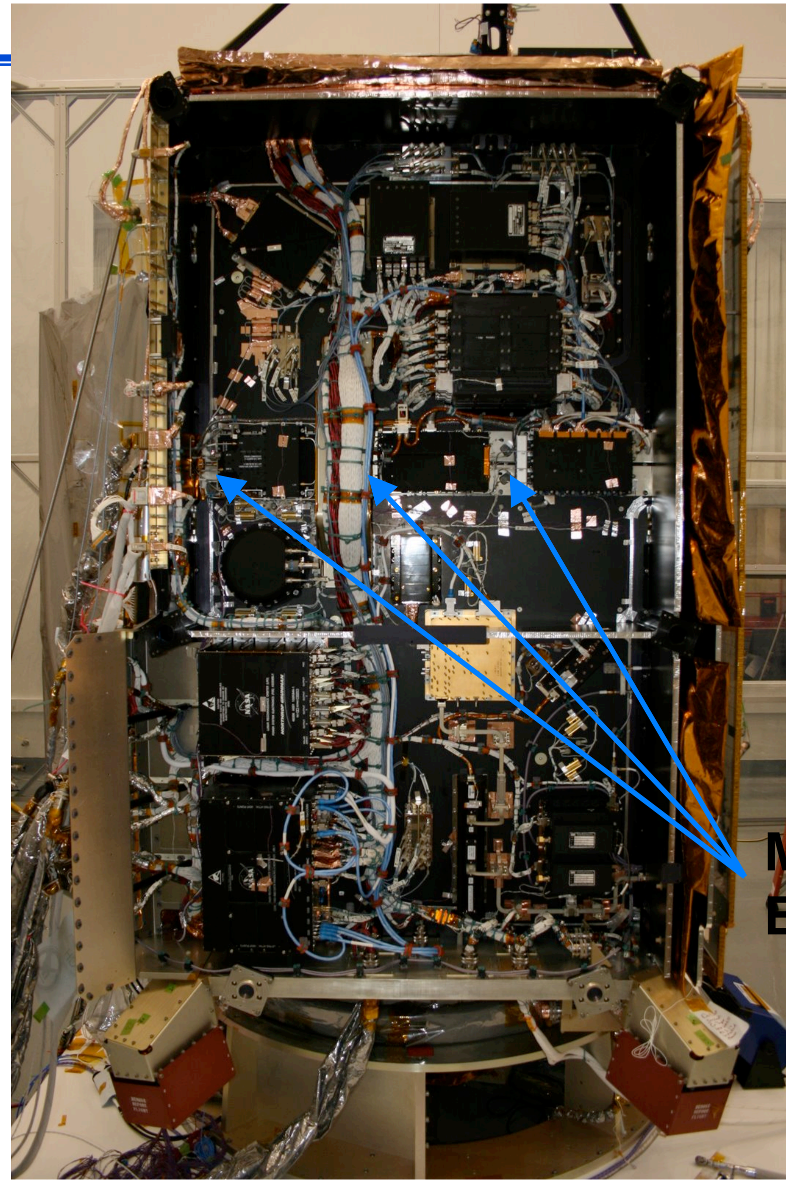


Mini RF Location on LRO



Mini-RF Installation

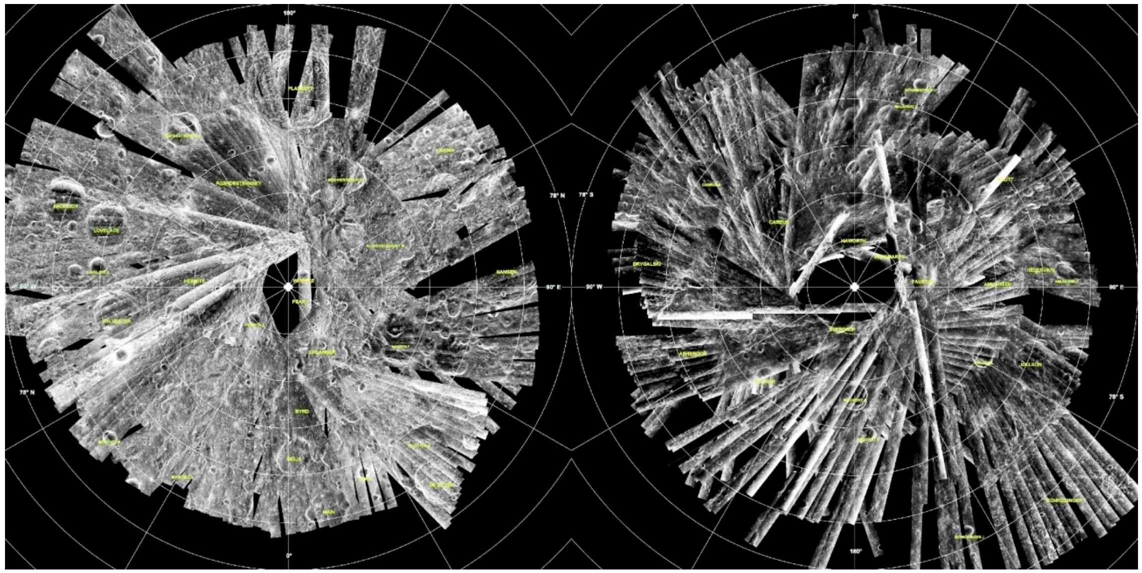
Mini-RF
Antenna



Mini-RF
Electronics

LRO Mini-RF to Chandrayaan-1 Mini- SAR Comparison – What's New!

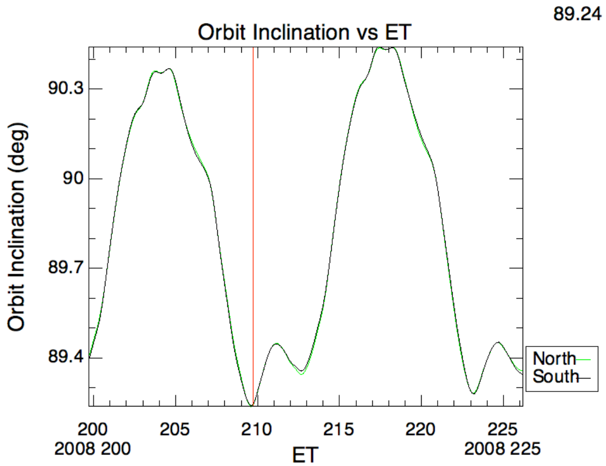
Chandrayaan-1 Mini SAR data has polar coverage gaps
LRO's Mini-RF can fill in polar gaps



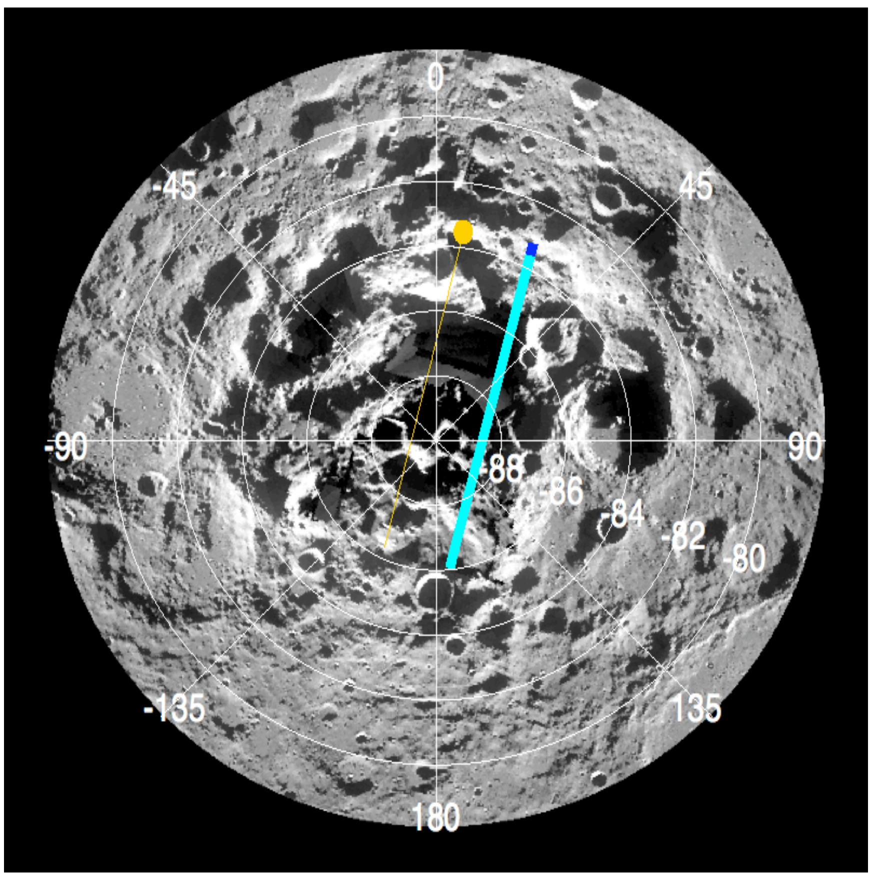
- •Chandrayaan-1 orbit is ~100 km altitude
- •LRO plans 50 km altitude
- •Chandrayaan-1's Mini-RF can image gaps with steeper (10-20 deg) incidence
- •LRO's Mini-RF can extend incidence angles

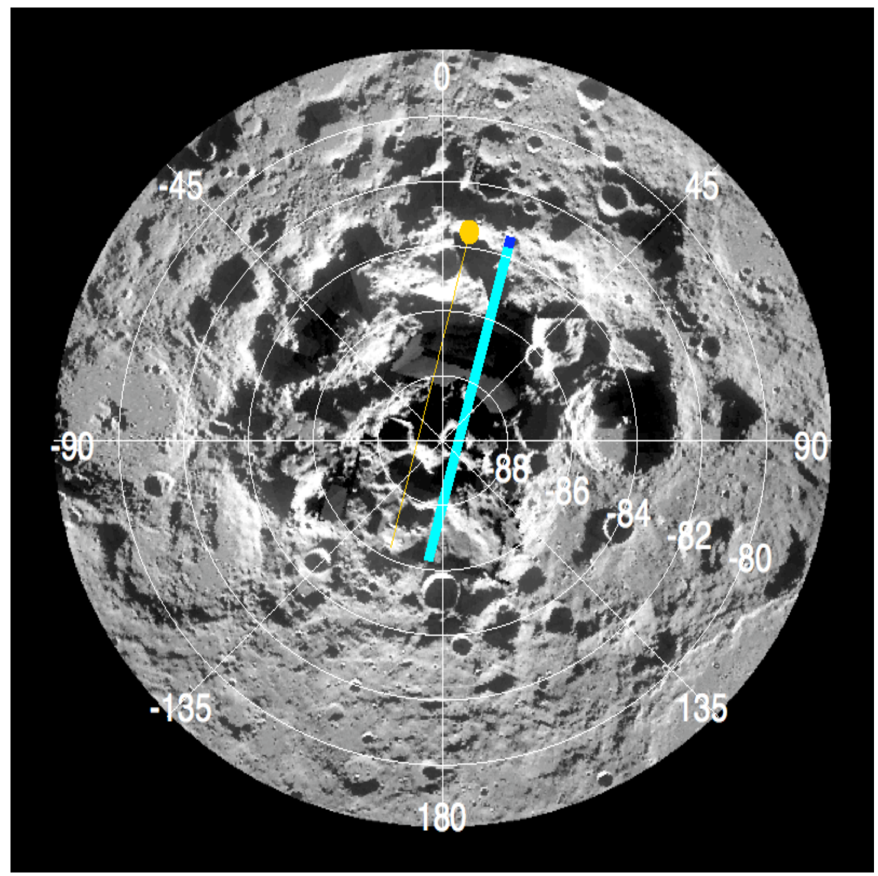
Gain unique scattering measurements

LRO Polar Imaging



We want to take advantage of 50 km high-inclination orbits to acquire medium incidence SAR of key areas close to the poles

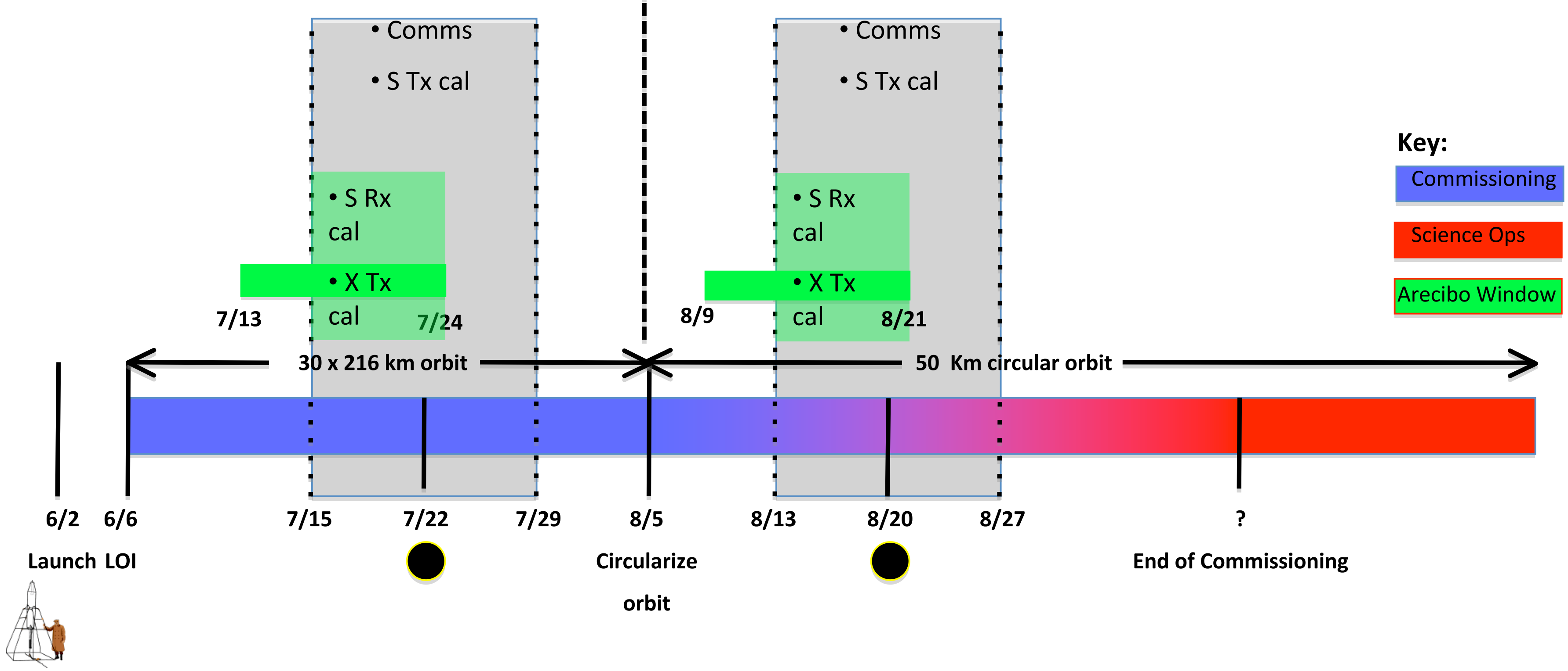




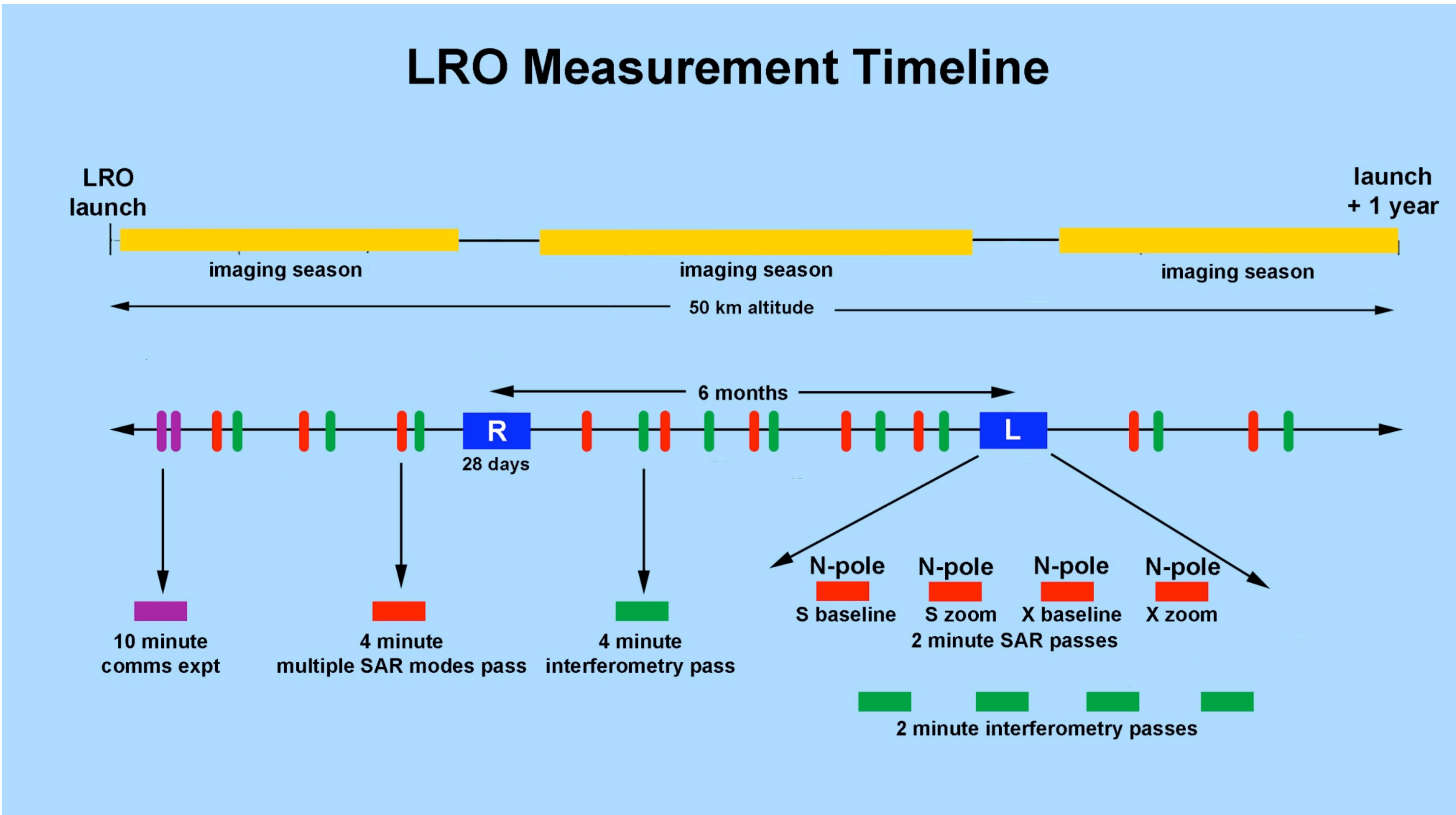
LRO Commissioning Timeline

- Pole-to-pole data acquisition
- Possible nadir cal
- LCROSS support

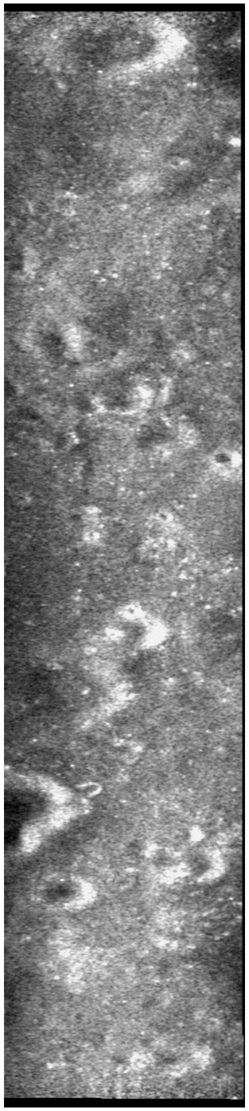
- SAR-mode test (attenuation settings)
- Possible nadir cal
- *Equatorial cal (after SAR-mode test)*

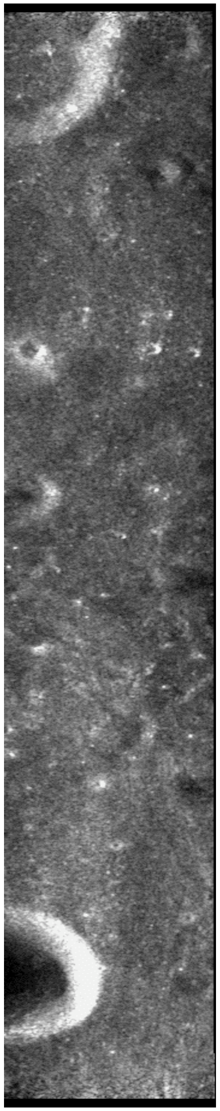


Nominal LRO Conops

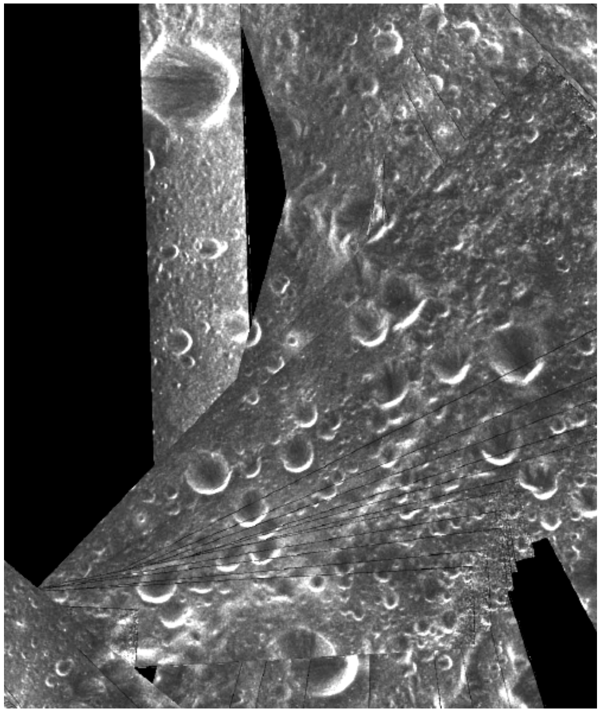


LRO S Band Baseline

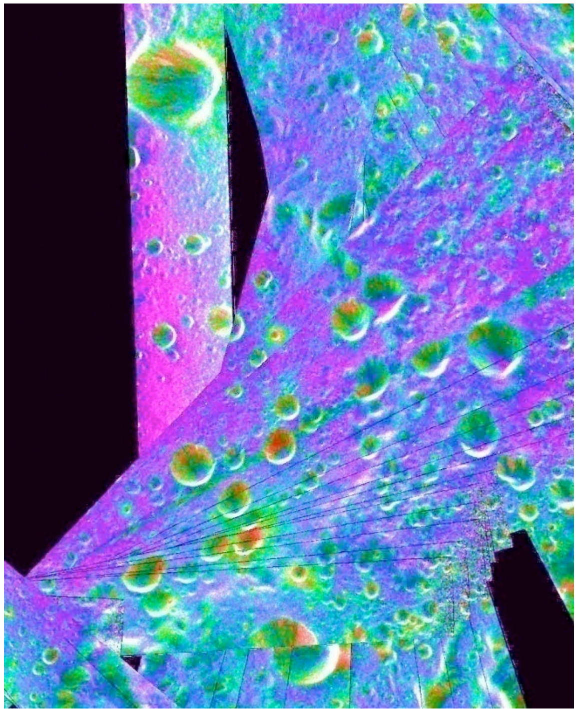




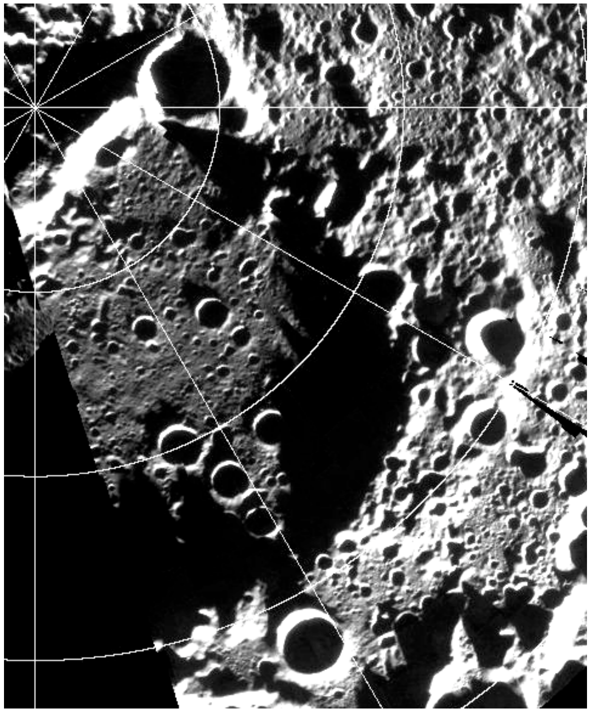
High CPR at North Pole



Peary OS SAR mosaic

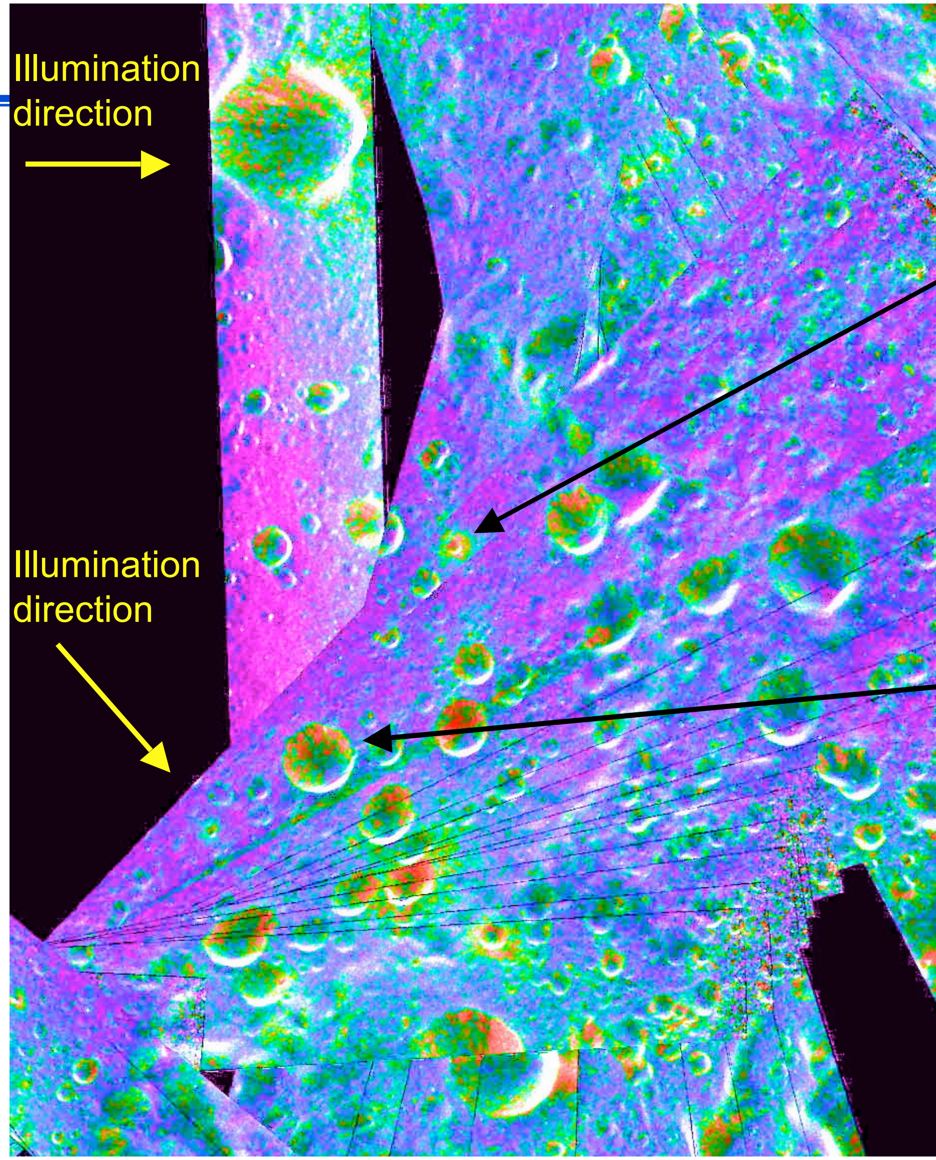


Peary CPR mosaic



Peary Clem hires mosaic

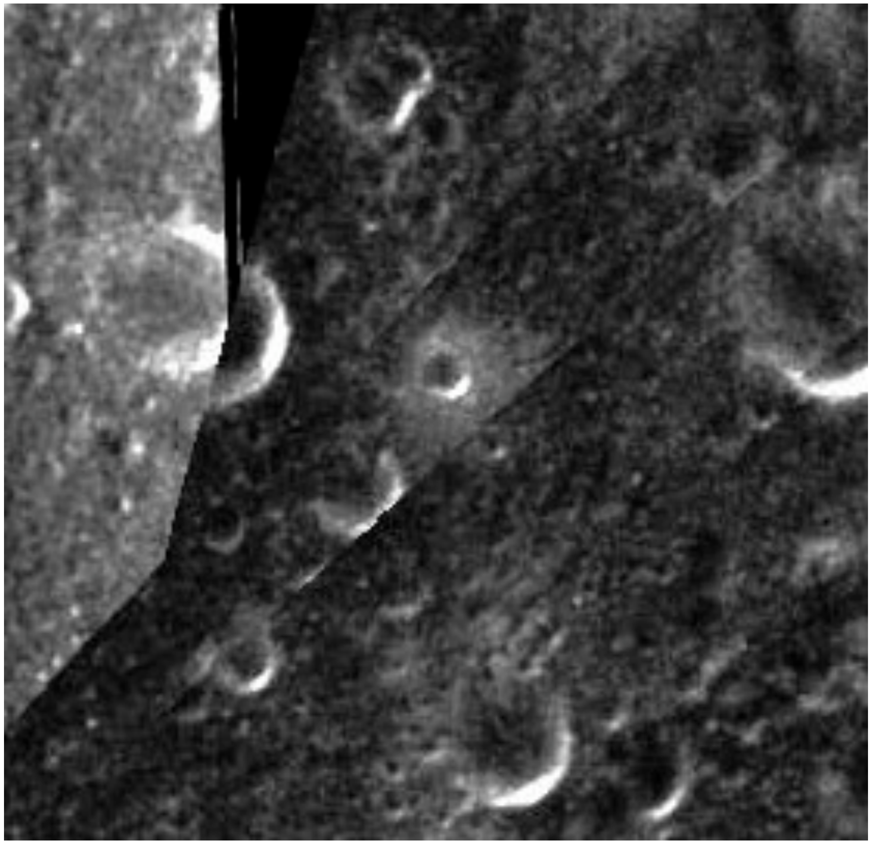
Floor of Peary
73 km diameter
88.6° N, 33° E



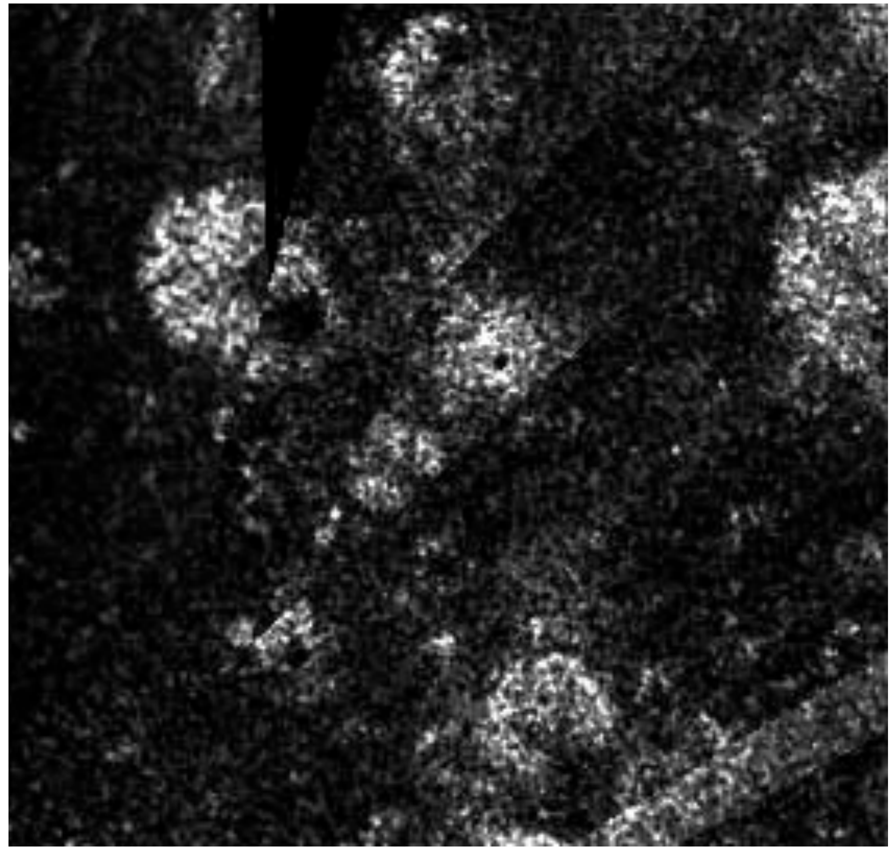
"Normal" fresh crater CPR

Atypical CPR crater

Close-up of Floor of Peary

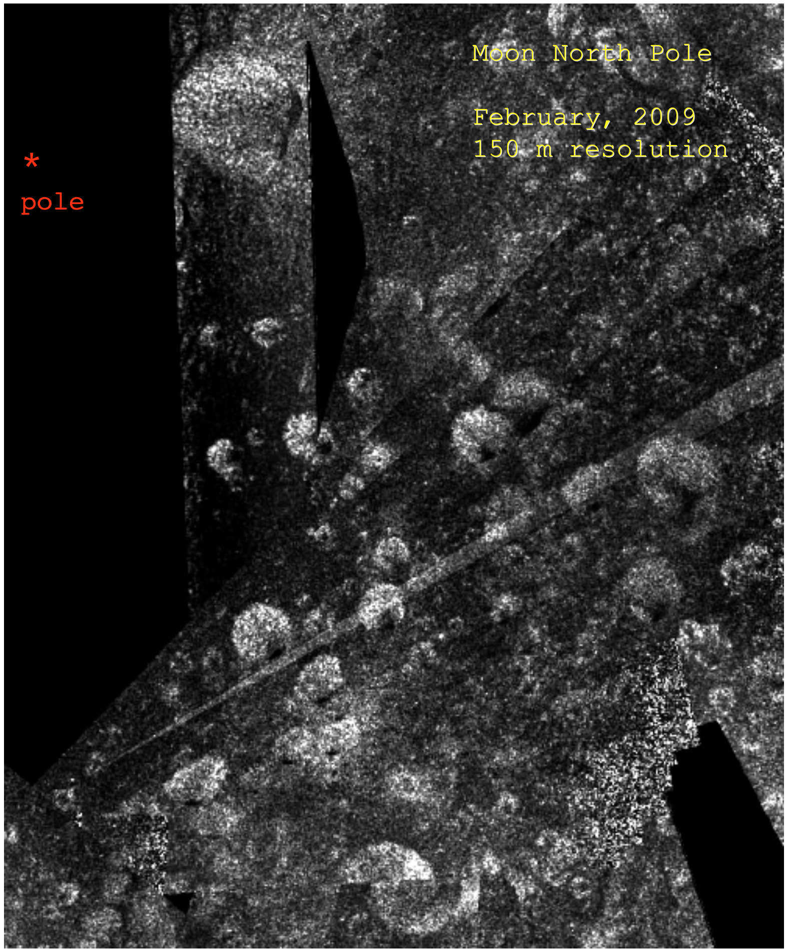


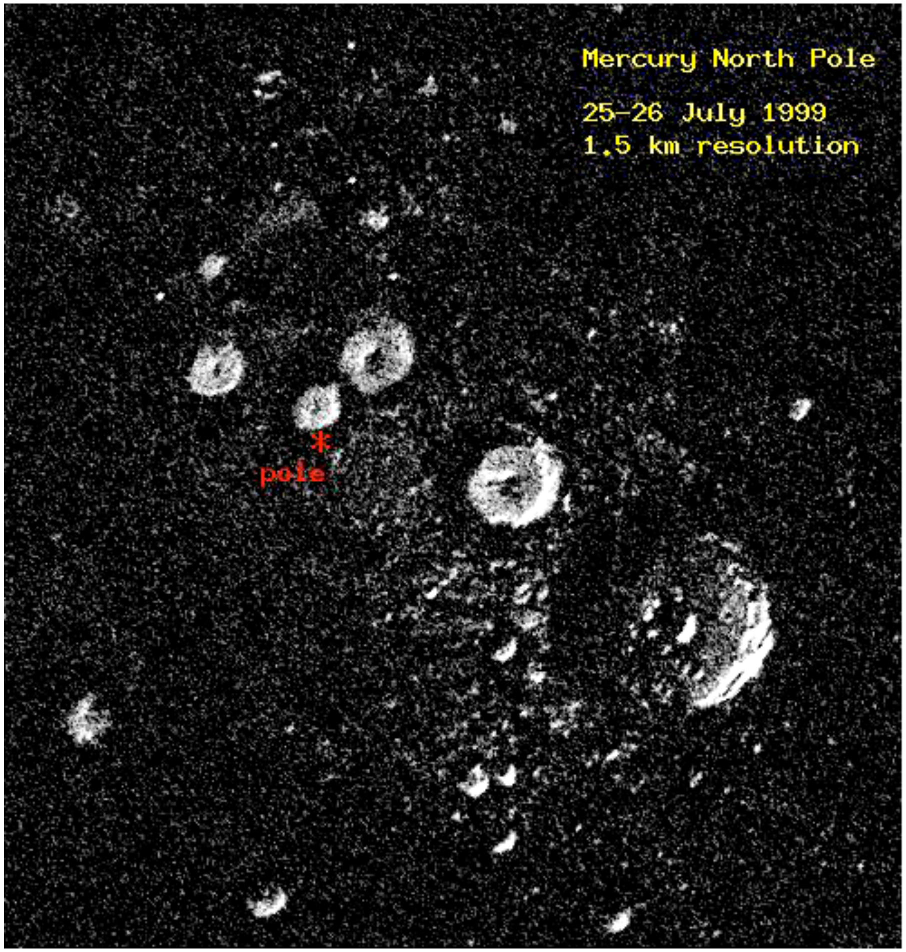
OS SAR image



CPR SAR image

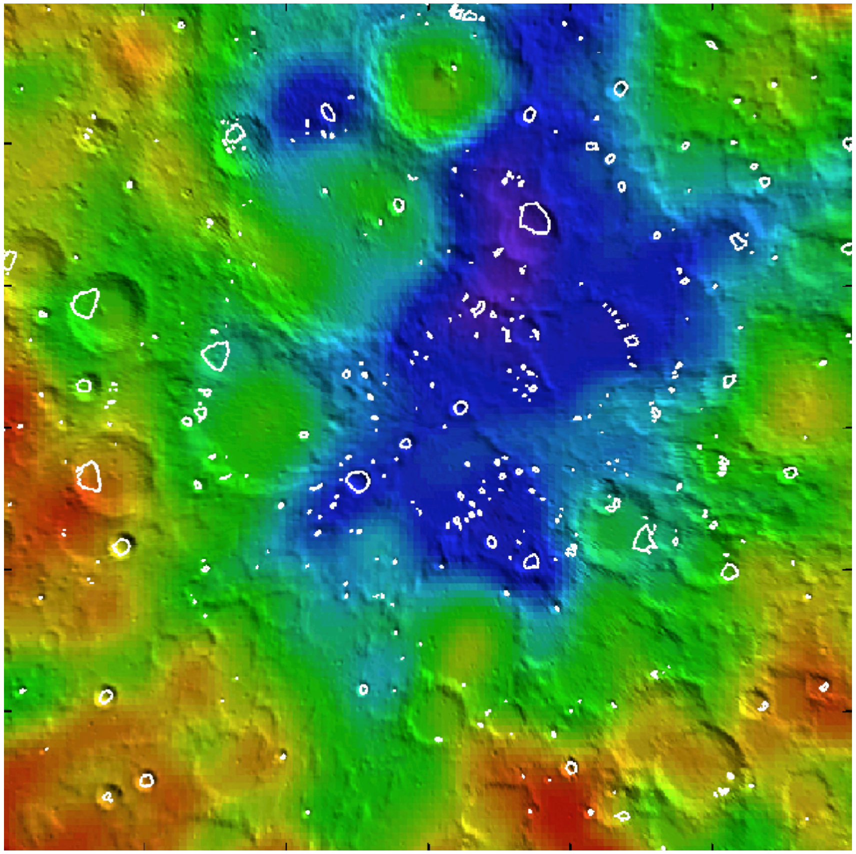
High CPR at North Pole

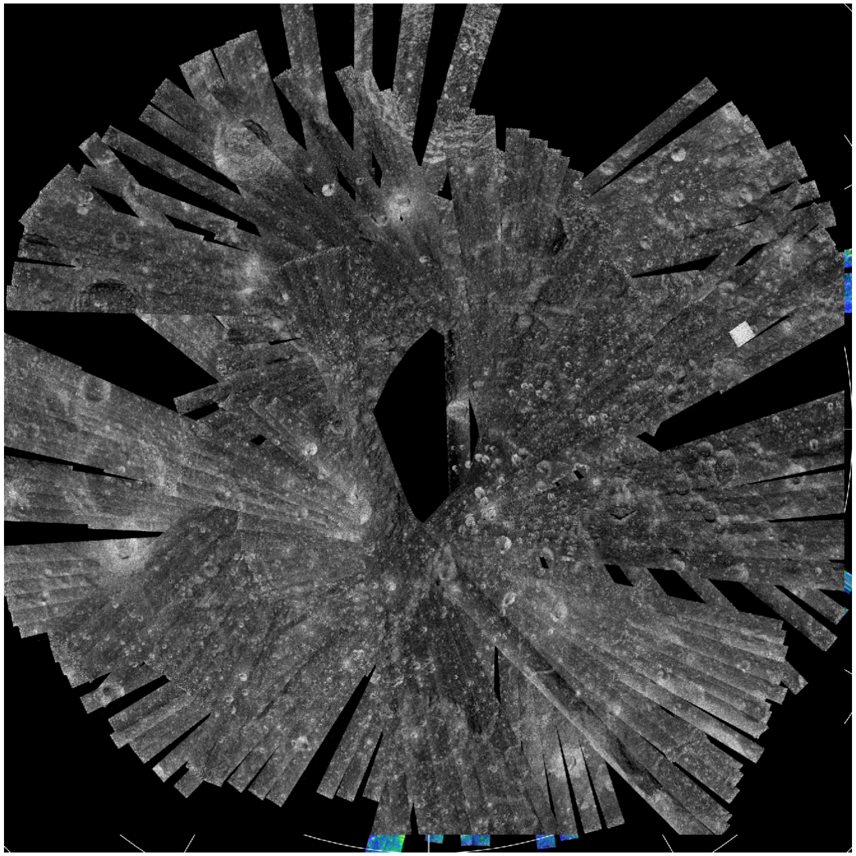




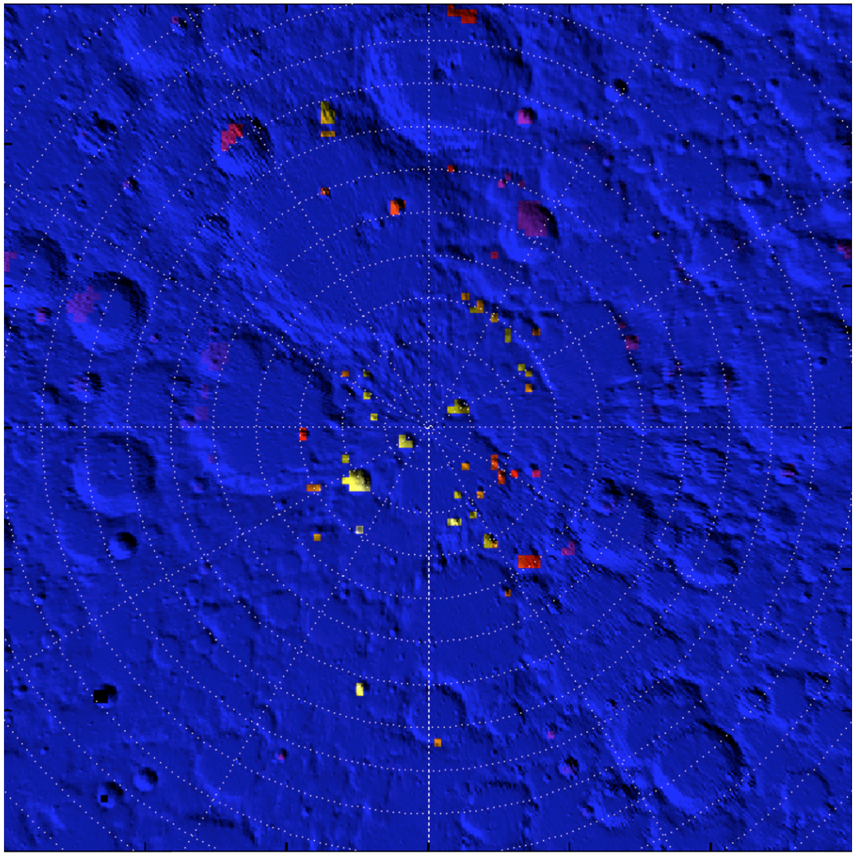
Moon (CPR) Mercury (SS)

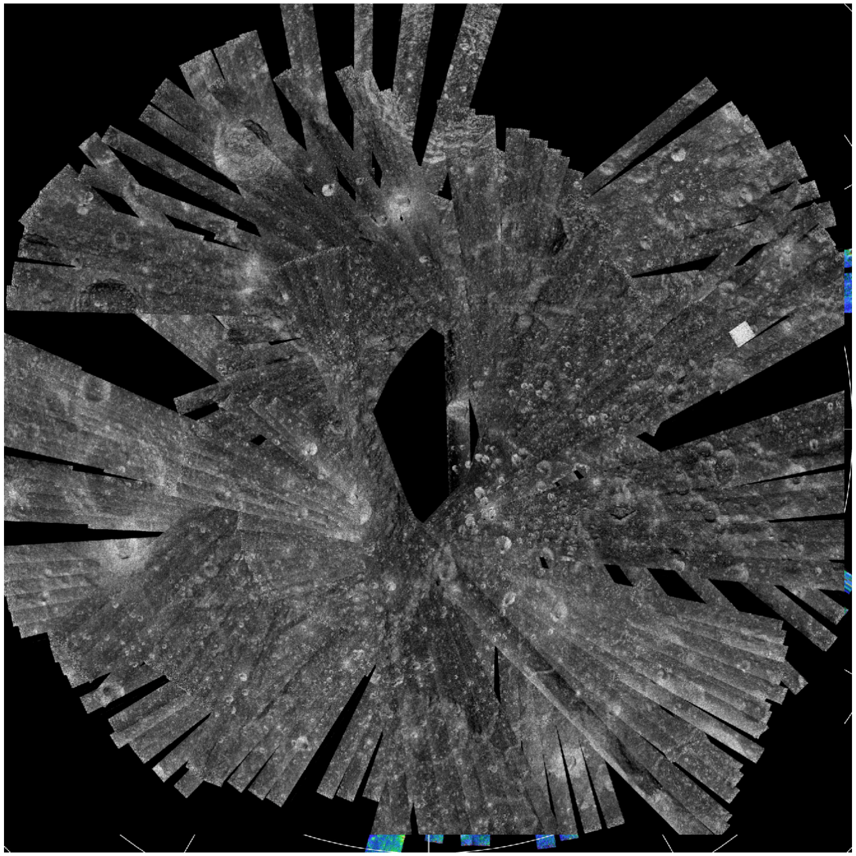
Neutron Shadow CPR Data



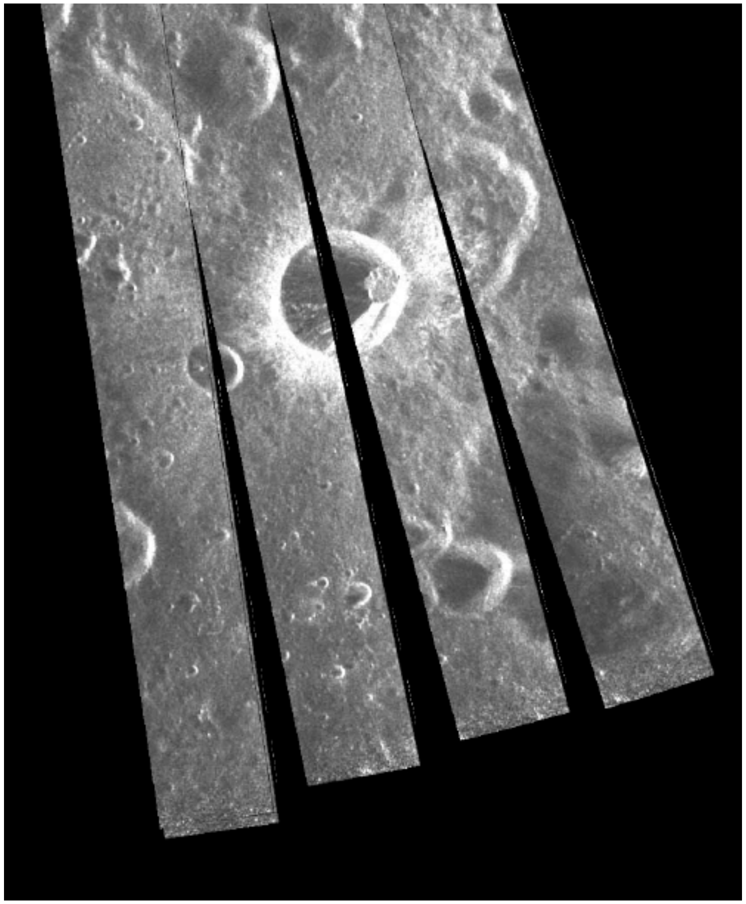


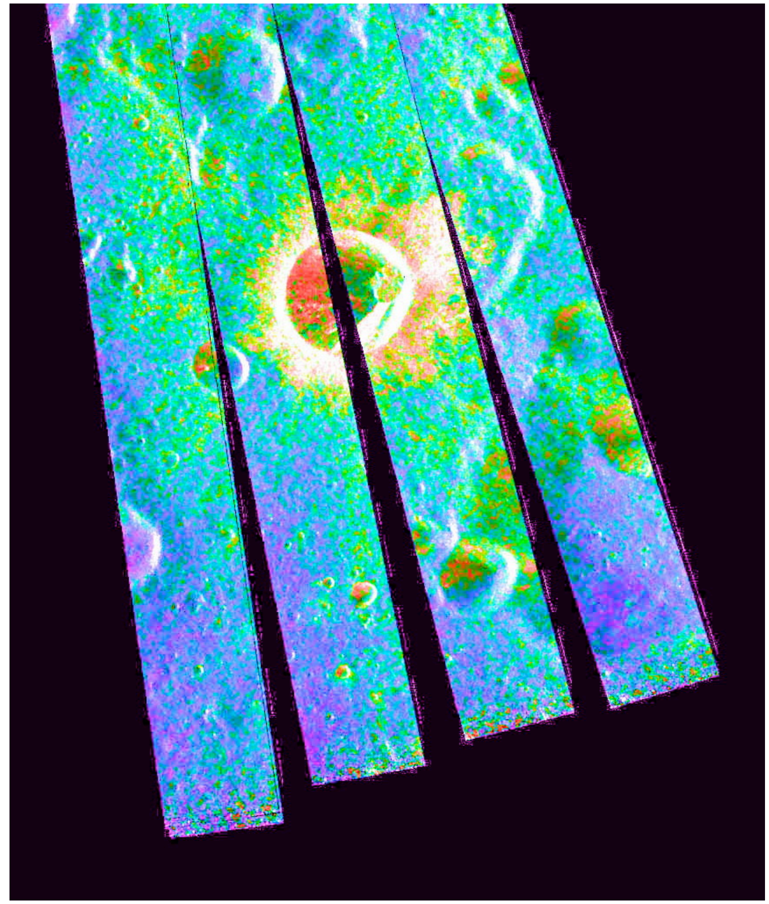
Neutron (PSR) and CPR





High CPR Caused by Surface Scattering



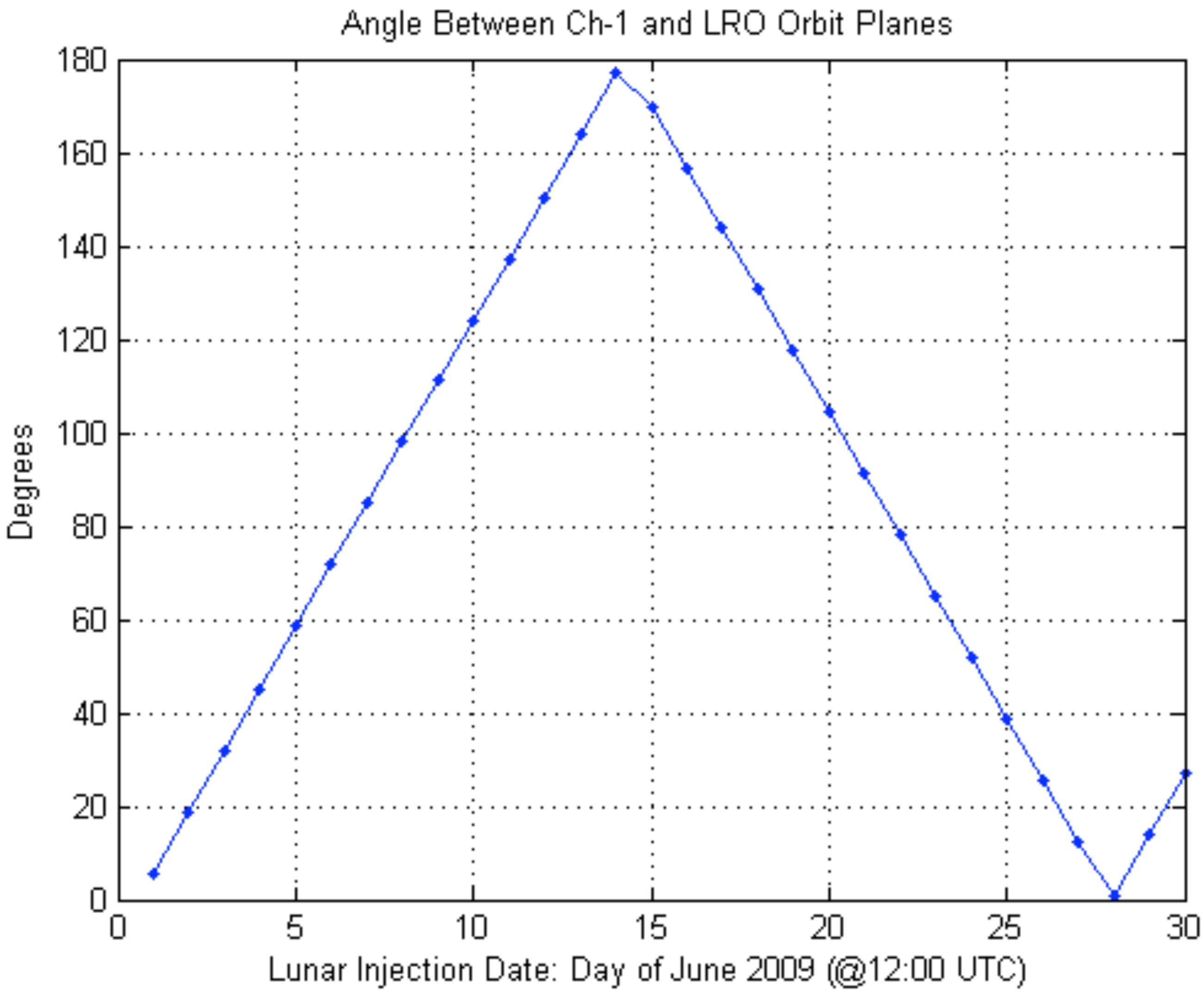


OS SAR image   Main L   CPR image

14 km diameter

81.4° N, 22° E

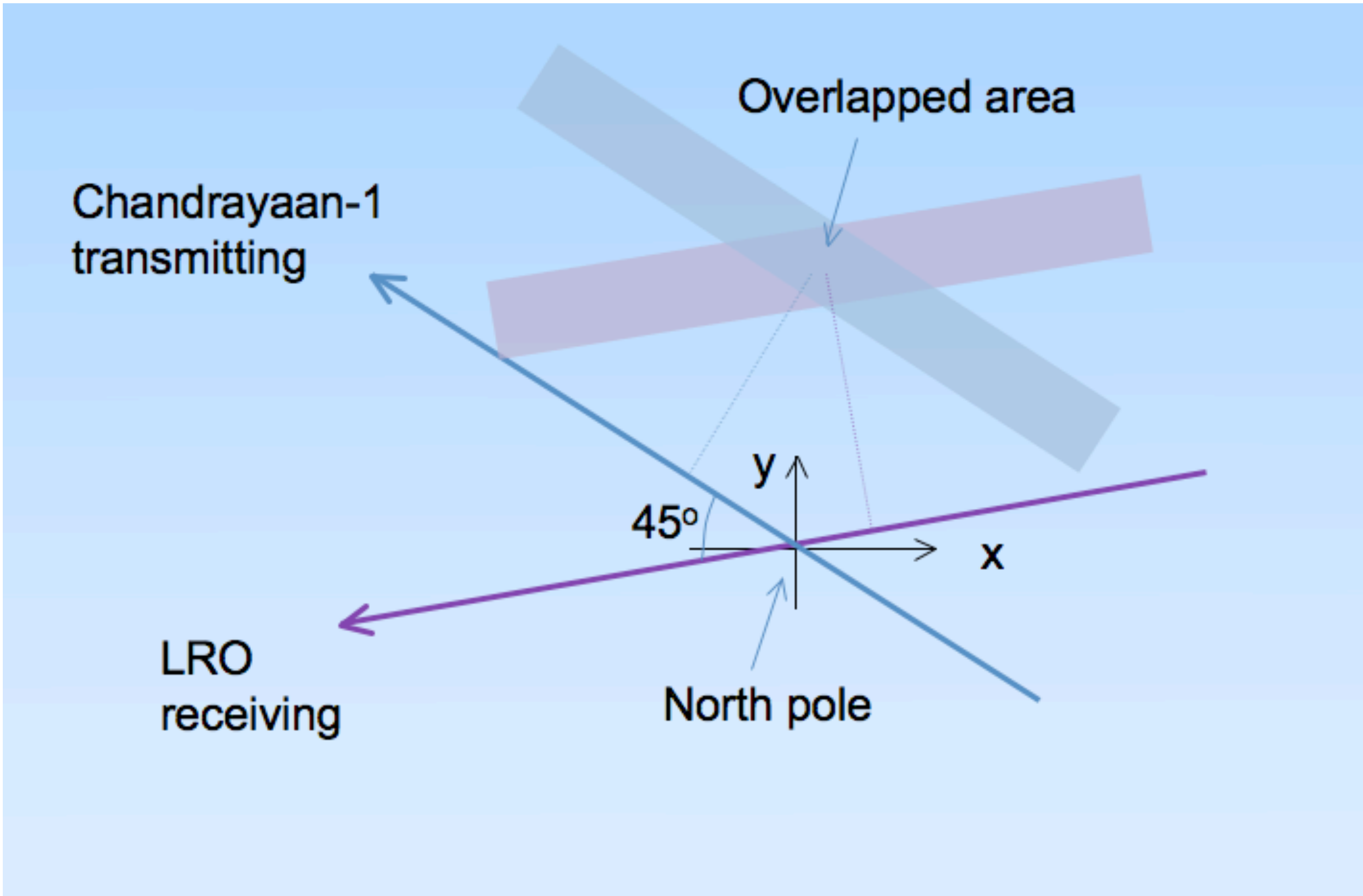
Bistatic Opportunities



- Crossing Angles > 90° mean s/c moving in opposite directions

Launch Date	Crossing Angle
6/2	70°
6/5	110°
6/17	90°
6/20	50°
6/24	0° ☺

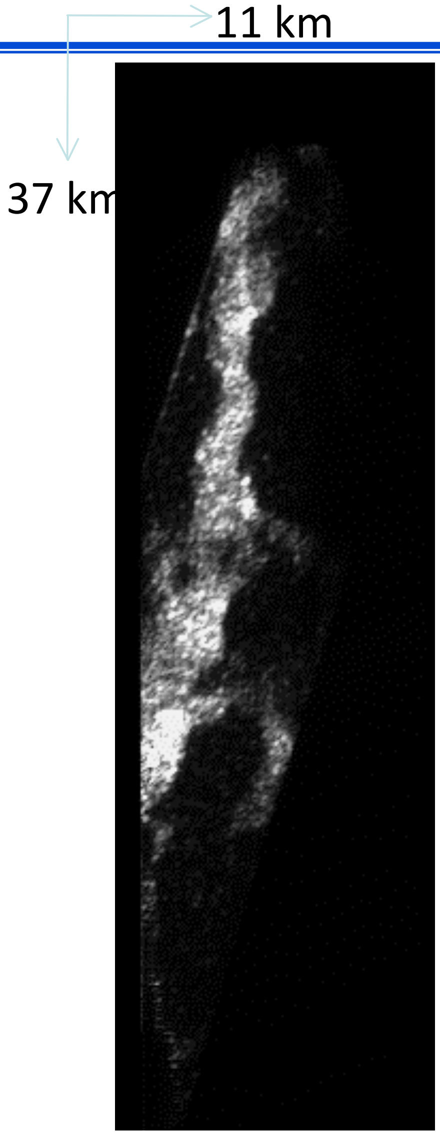
Bi Static data collection geometry



Results

Reflectivity

For simulation

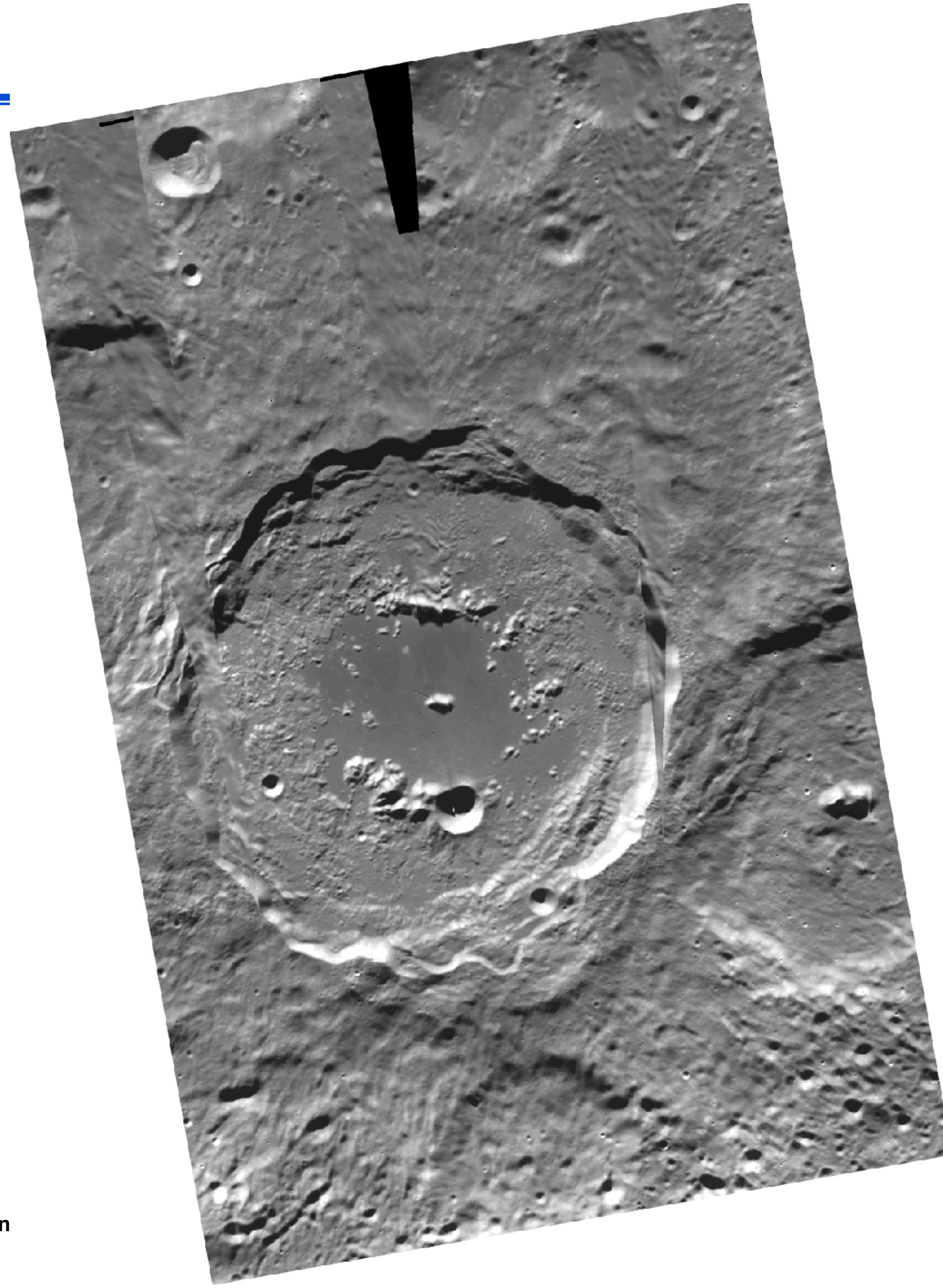


Processed image

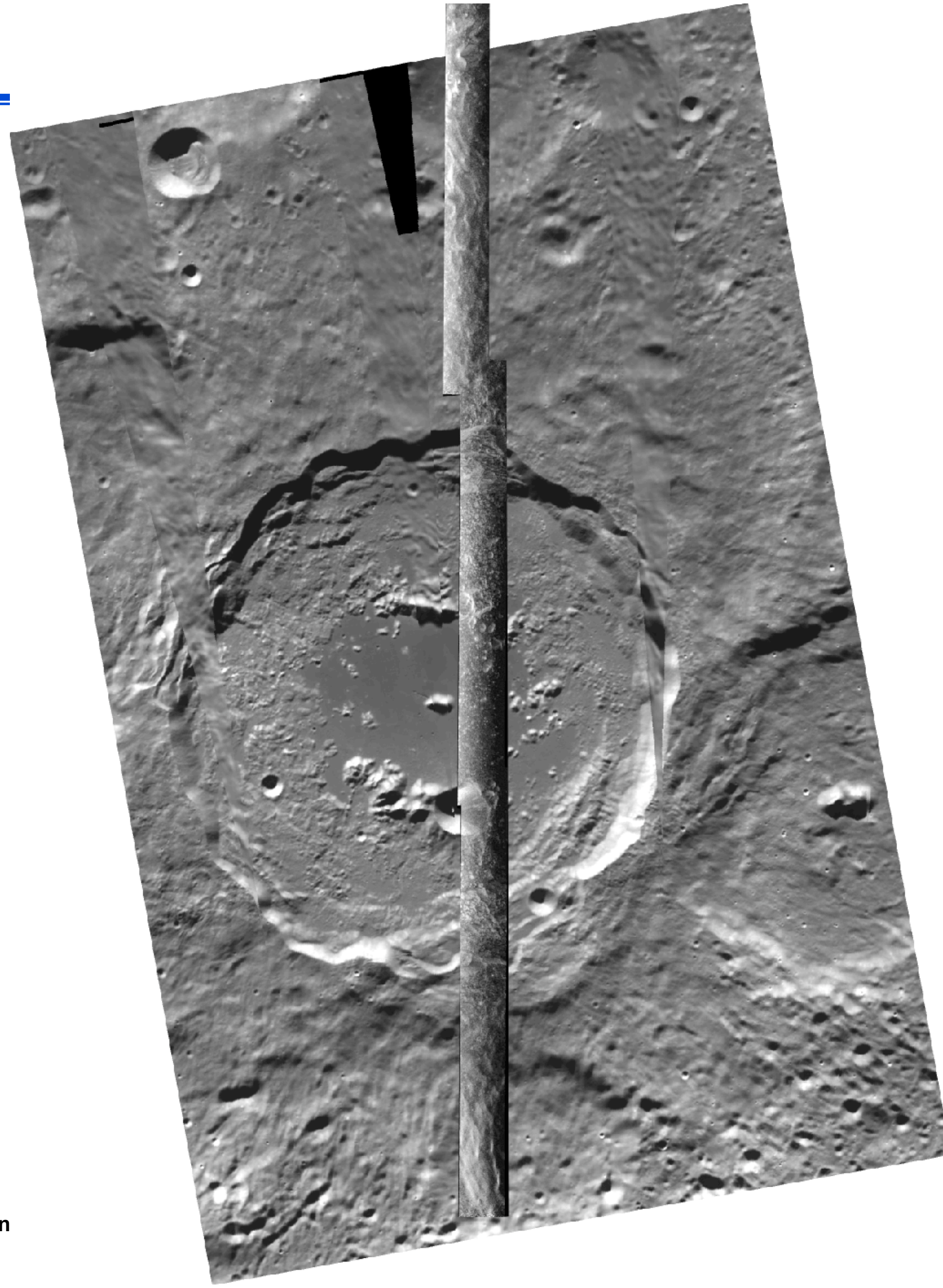
Bistatic Opportunities

- We have investigated the orbital aspect of conducting bistatic operations.
- First and second June launch windows were considered
- Assume south-polar LOI insertion is the only option
- Assumes a 96 hour lunar transit duration
- Chandrayaan-1 now in 200 +/- 15 km circular orbit
- North Pole opportunities in LRO commissioning period for experiments ?

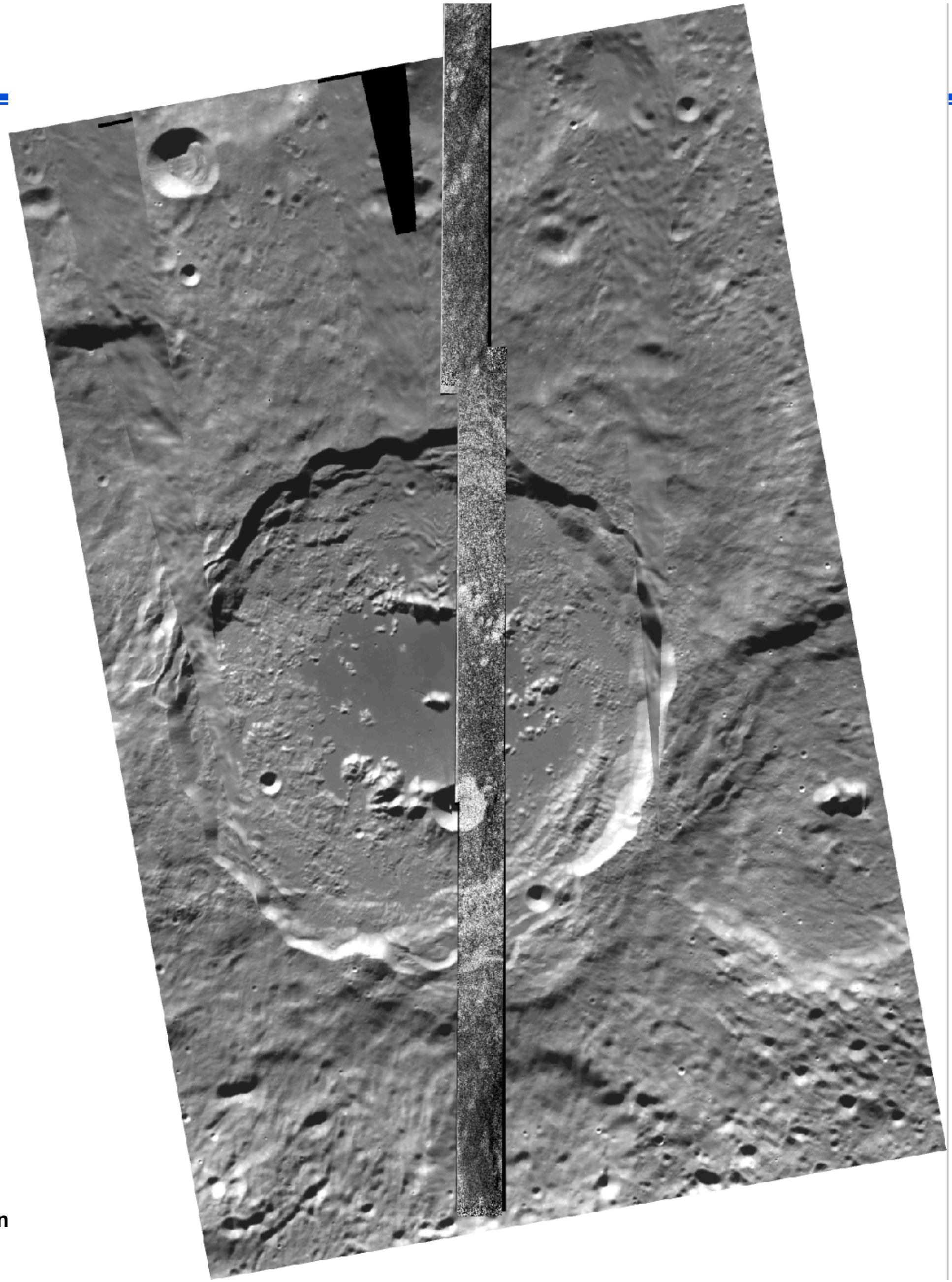
Antoniadi



Antoniadi



Antoniadi



Antoniadi

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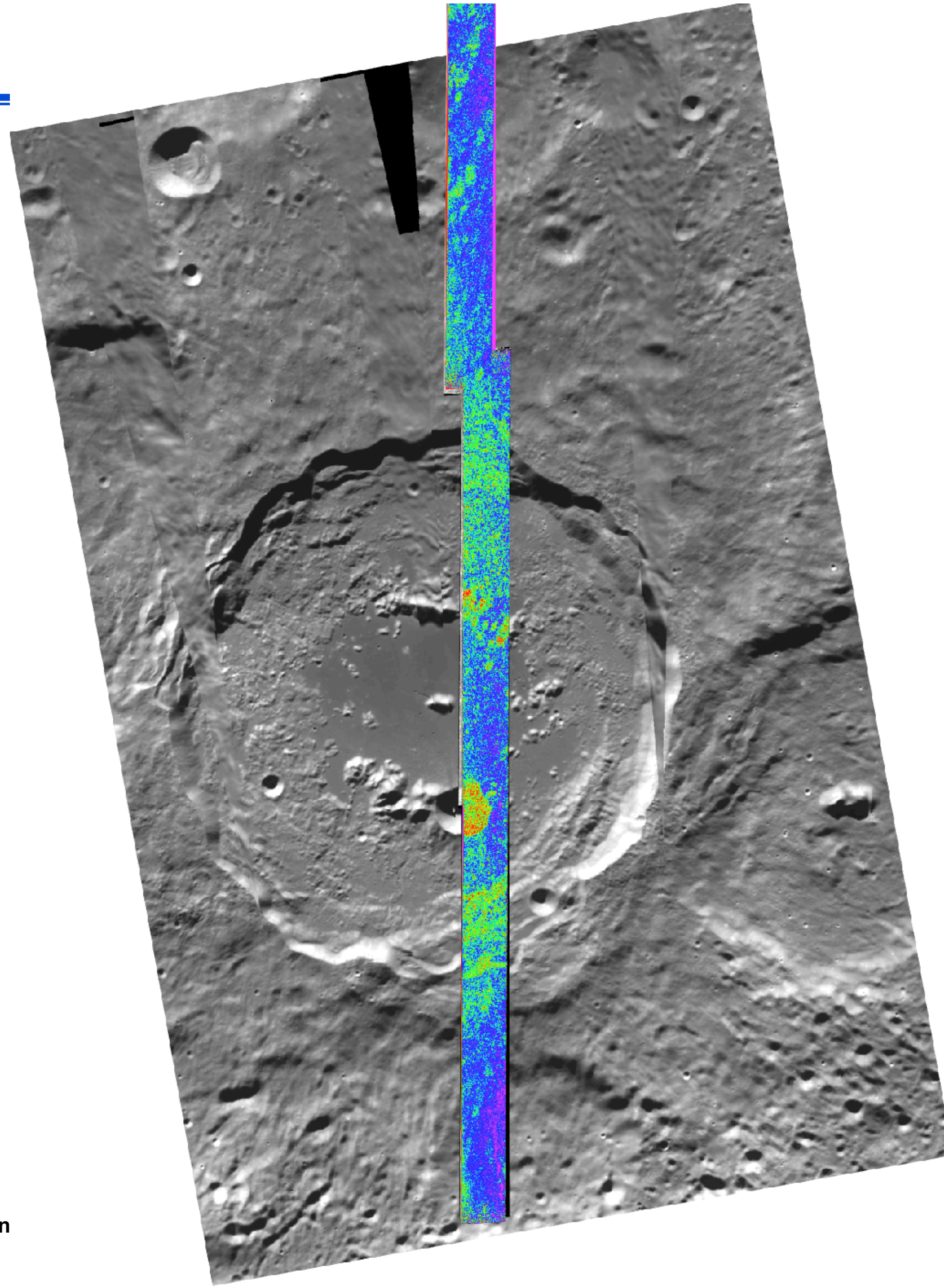

Mini-RF Data Volumes

Mode	S-baseline	S-zoom	X-baseline	X-zoom	In-SAR
Volume / 1 min (Gbits)	**0.45**	**1.91**	**0.42**	**1.91**	**1.61**
Volume / 10° (Gbits)	**1.39**	**5.88**	**1.29**	**5.90**	**4.98**
Volume pole-to-pole (Gbits)	**25.0**	**105.8**	**23.2**	**106.2**	**89.6**

Spacewire

- Only conflict is with LROC NAC
  - LROC normally takes images in the light
    - Mini-RF can operate in the nighttime hemisphere
    - Operate at night!

- Sharing the Spacewire
  - NAC takes 110 secs to transfer single barrel image to the SSDR
  - Worse case, double barrel NAC at a pole would use the spacewire for 220 secs, ∴ Mini-RF could not turn on until 78°
  - Mini-RF dumps straight to the SSDR. So spacewire is free for the NAC immediately after a Mini-RF collect
    - Concentrate on night-day pole

Instrument Conflicts

- Main conflicts to be avoided are with LROC
  - Data volume & SpaceWire
- Data volume
  - LROC & Mini-RF have the highest data production rates
  - Finite downlink capability
- Sharing the SpaceWire
  - Both LROC & Mini-RF share SpaceWire
  - Mini-RF can not operate simultaneously with the NAC

Solutions

- Data Volume
  - Take advantage of any spare capacity not being used by LROC
    - LROC maximum daily volume ≤ 443 Gbits
    - LROC terminator orbits data volume significantly less
  - Take advantage of extra downlink capacity between LRO and Earth.
- Space Wire
  - Image the night-to-day pole
  - Image over the nighttime hemisphere

Data Volume

- Only conflict is with LROC

- Data volume
  - Worst case ~460 Gbits / day can be sent back to Earth
    - Assumes 2 Ka downlinks
    - 2 - 9 downlinks are possible
  - Typical LROC amount is 441 Gbits / day

- Need to be able to take advantage of any spare capacity not used by LROC
  - One-day turnaround?

Mini-RF Data Rates

Mode	S-baseline	S-zoom	X-baseline	X-zoom	In-SAR
Rate (Mbits/s)	7.5	31.8	7.0	31.9	26.9
1 min (Mbits)	450	1908	420	1914	1614
10° (Gbits)	1.39	5.88	1.29	5.90	4.98
pole-2-pole (Gbits)	25.0	105.8	23.2	106.2	89.6

Logistics

- Weekly LRO Planning Meetings
  - LROC will have a better understanding of the likely data volume usage for the week ahead
  - Permits Mini RF to do detailed observation planning and commanding
- Daily 48-hour warning
  - Each day the LRO project will tell Mini-RF of any available downlink capacity that will occur 48 hours later
  - We then have X (24?) hours to provide our commanding sequence to LRO
  - Hopefully this will be a fine tuning of what resulted from the weekly planning meeting