Mini-RF:
LRO Data Users Workshop

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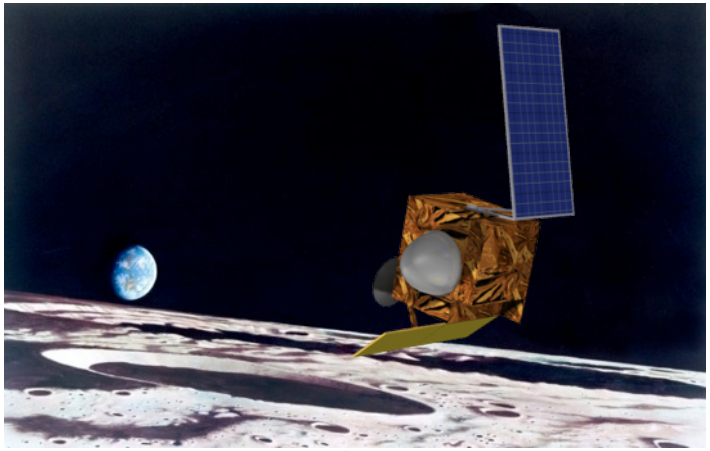
Applied Physics Laboratory

Mini-RF: Lunar SAR Instruments

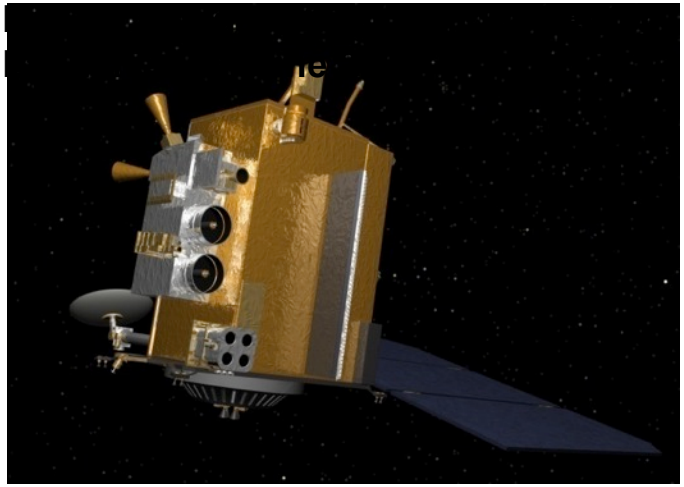
Mission Ended

Build 1: Forerunner Chandrayaan-1

Indian Space Research Organization (ISRO)
Launched 21 October 2008



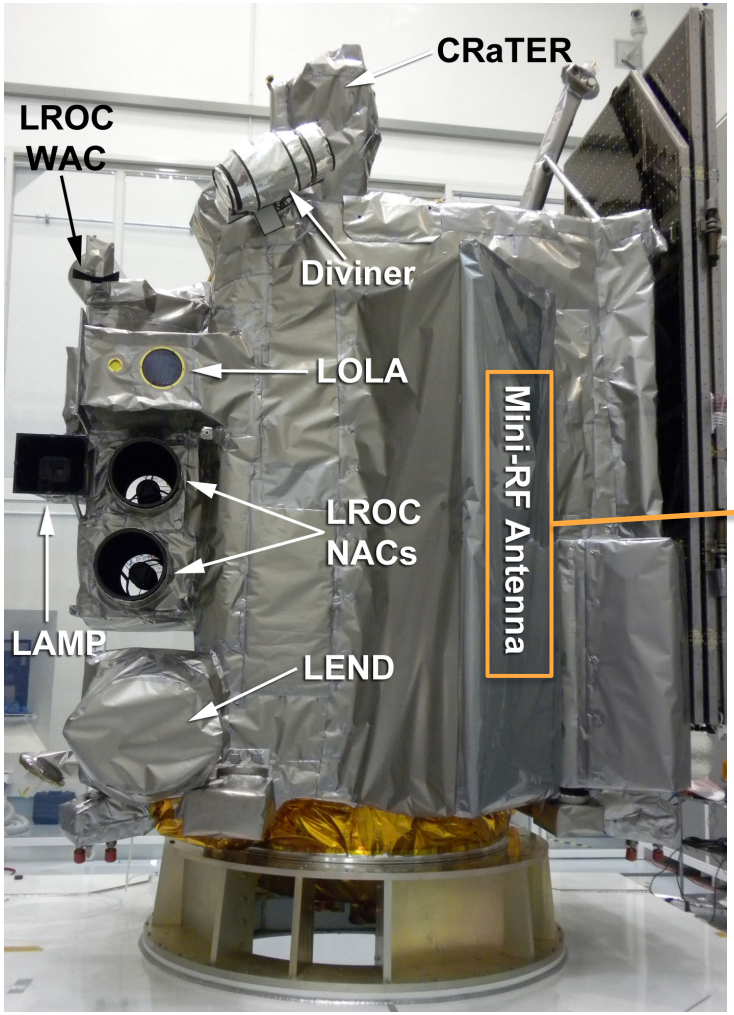
Build 2: LRO Lunar Reconnaissance Orbiter

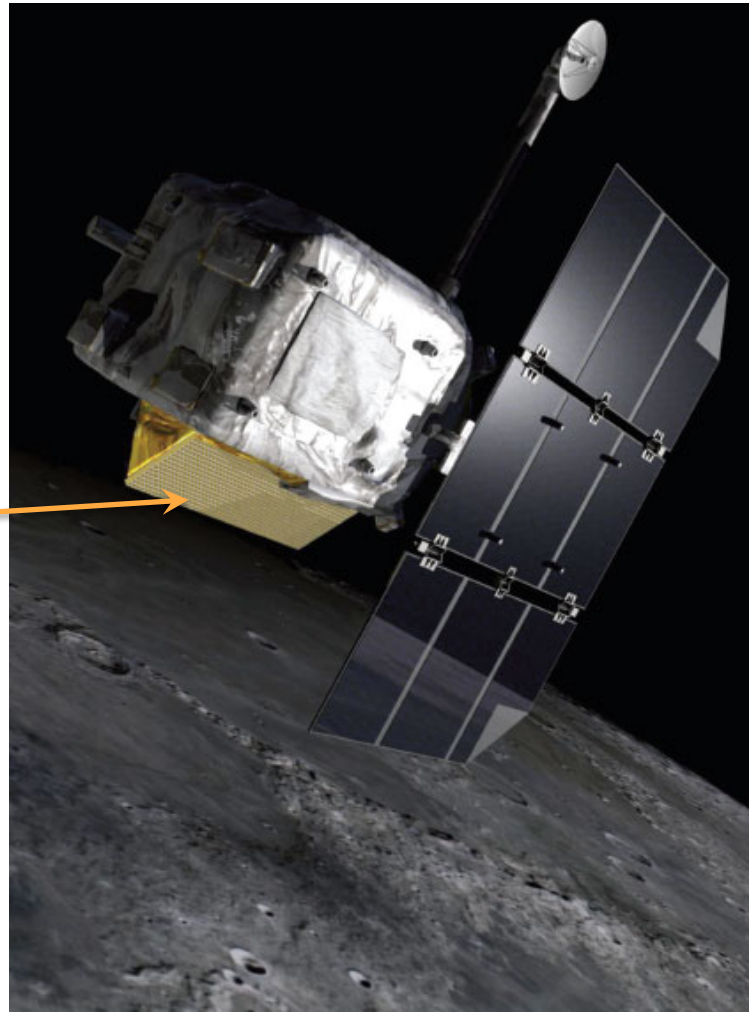


In Operations

Lunar Reconnaissance Orbiter

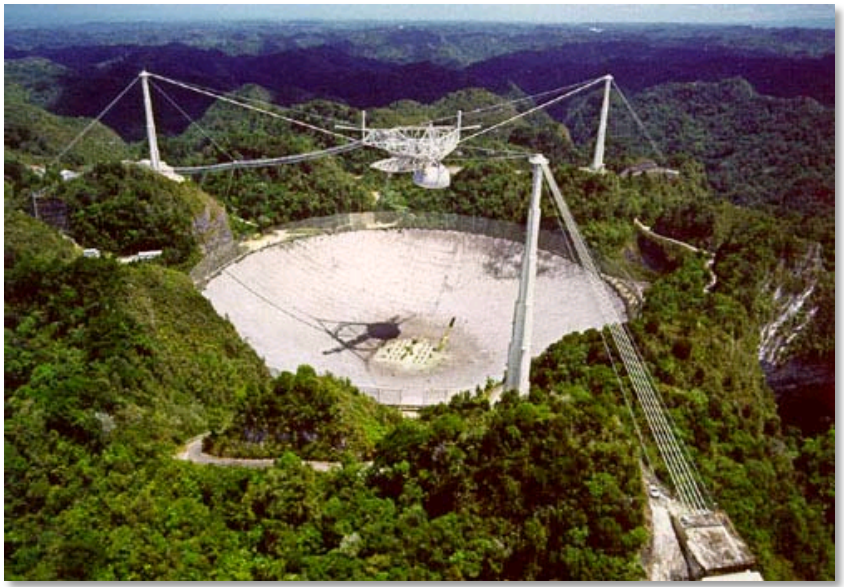
What is Mini-RF?

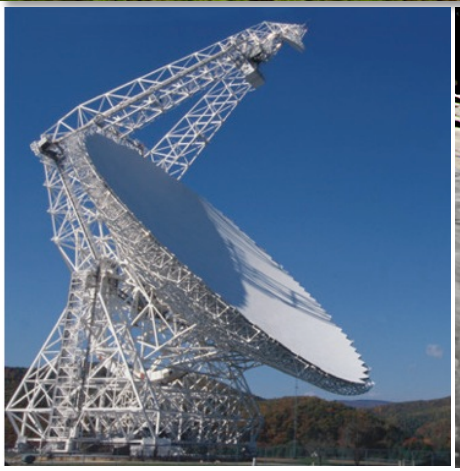


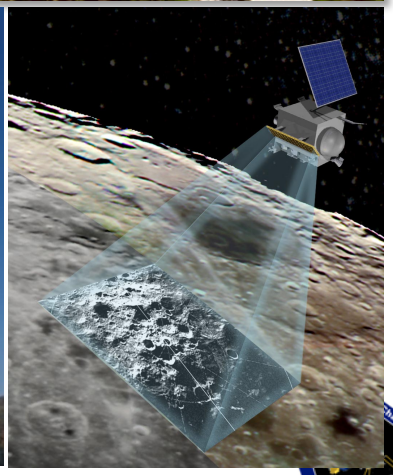


Instrument Description

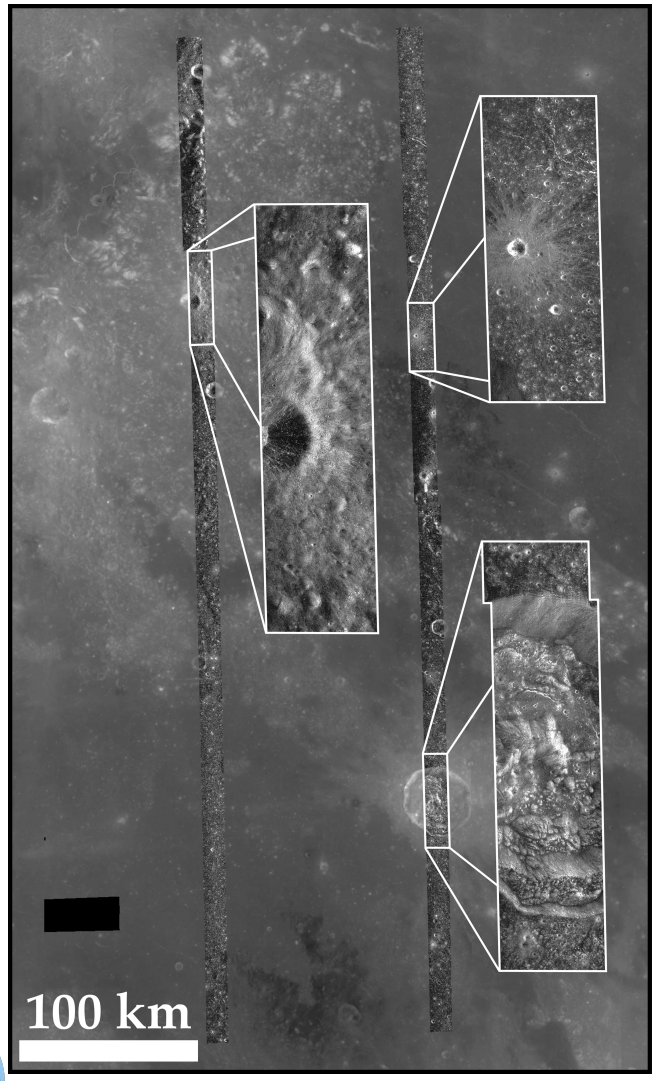
- Two-band, two-resolution imaging radar
  - S-band (λ=12.6 cm)
  - X-band (λ=4.2 cm)
  - SAR Baseline 150 m
  - Zoom 15x30 m
- Hybrid-architecture polarimetric SAR
  - Transmit LCP; Receive *H*- and *V*- linear coherently
  - Four Stokes parameters derived
- Mini-RF can measure topography
  - Interferometry: 15 m/pix spatial, sub-meter vertical resolution
  - SAR-stereo: 30 m/pix spatial, ~10 m vertical
- Low mass and power requirements
  - 13 kg, 150 W





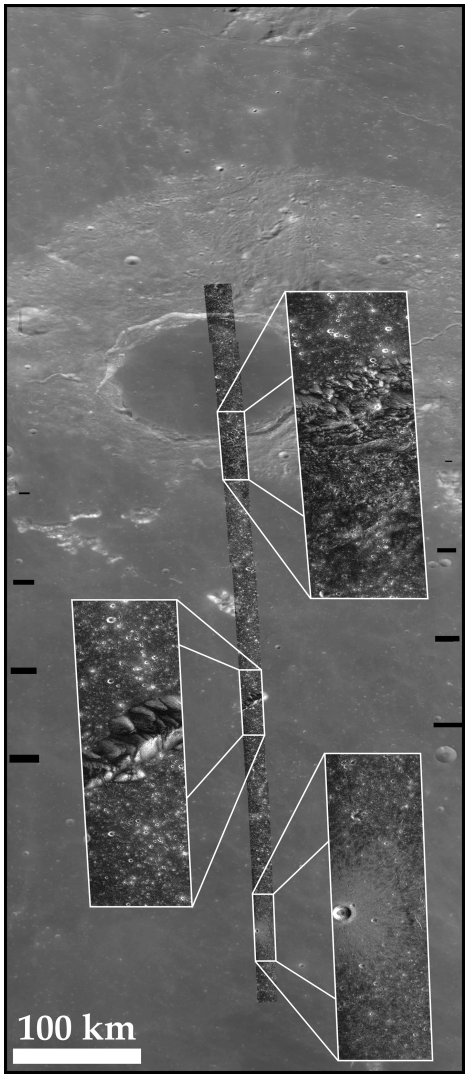


Examples of Mini-RF Data



Typical strip is 1920 x 10 km

Mini-RF SAR data co- registered with Clementine UVVIS context mosaics.



MINI-RF: DATA PRODUCTS

Basic Data Products Often Used and We Provide

Polarization Info: H, V, Re, Im

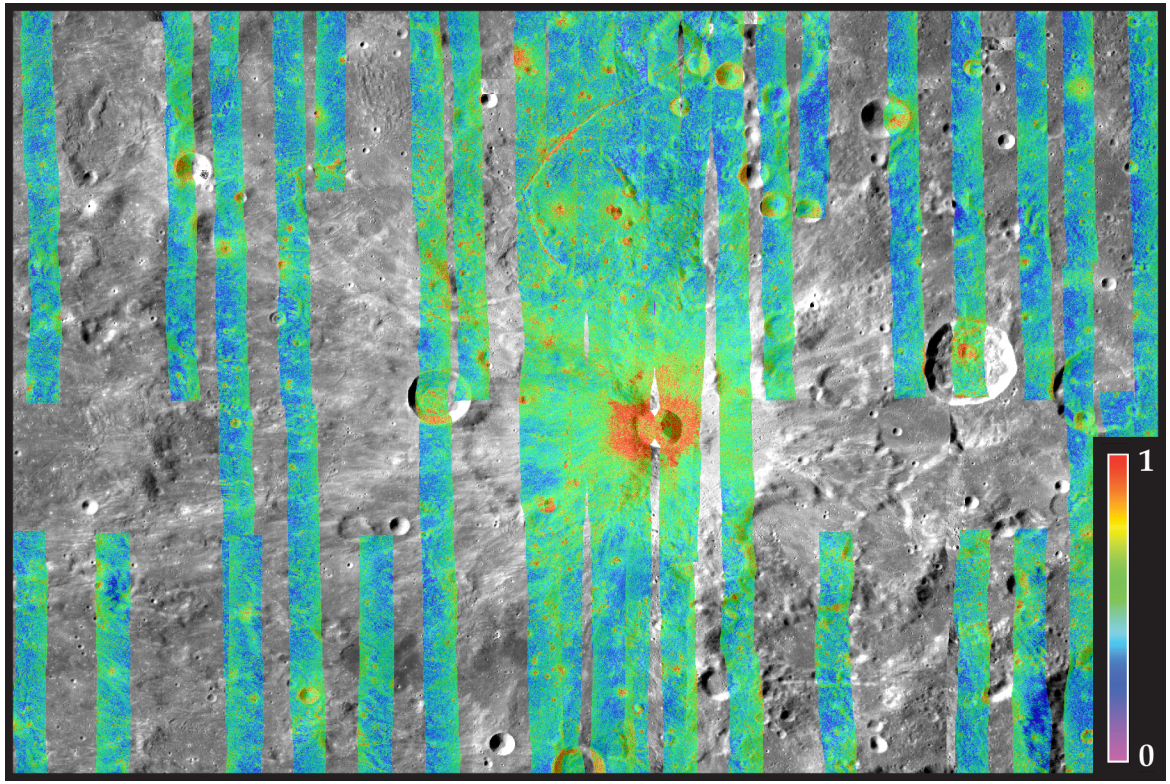
Stokes Products (S_1, S_2, S_3, S_4)

SC = (S_1-S_4)

OC = (S_1+S_4)

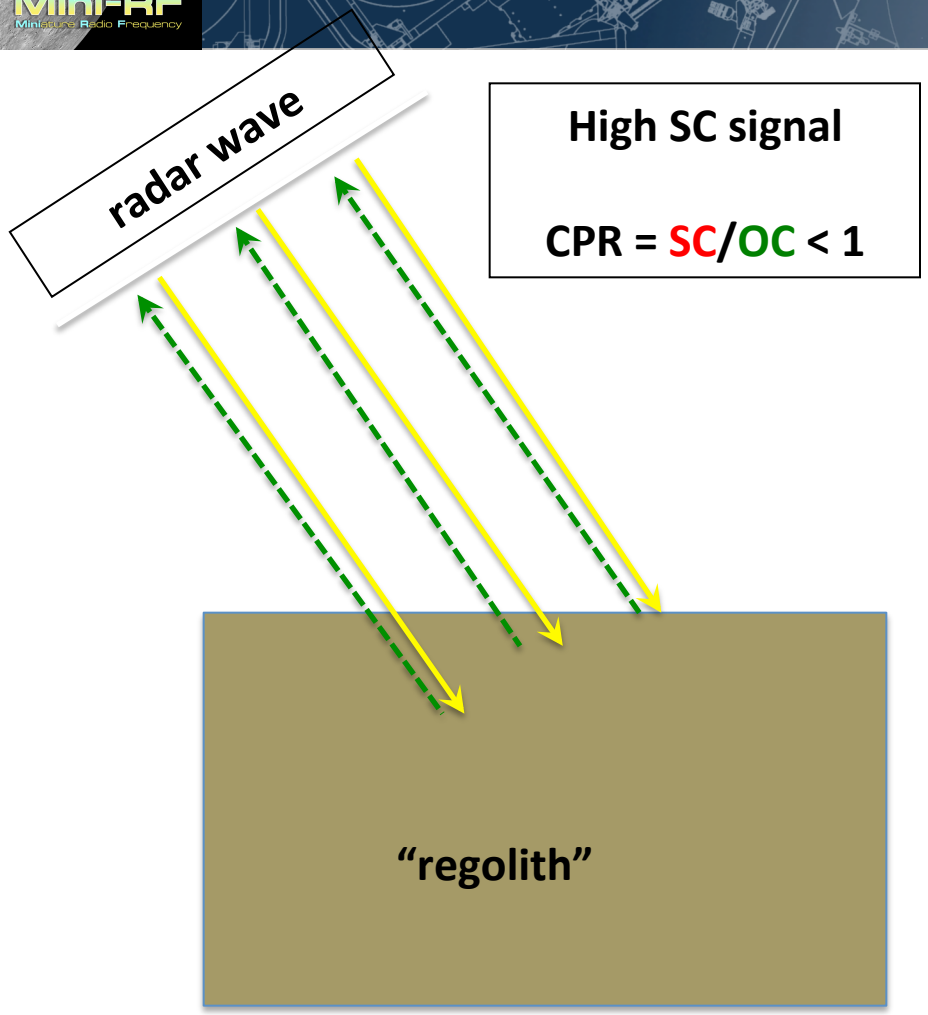
CPR = (S_1-S_4)/(S_1+S_4) = SC/OC

- Indicator of the roughness of a surface, as determined by the distribution of wavelength-scale and larger radar scatterers (*e.g.*, boulders).
- Young, fresh craters are distinctive in radar images obtained with the Mini-RF instrument because of the surface roughness associated with their ejecta deposits.



How do we interpret radar?

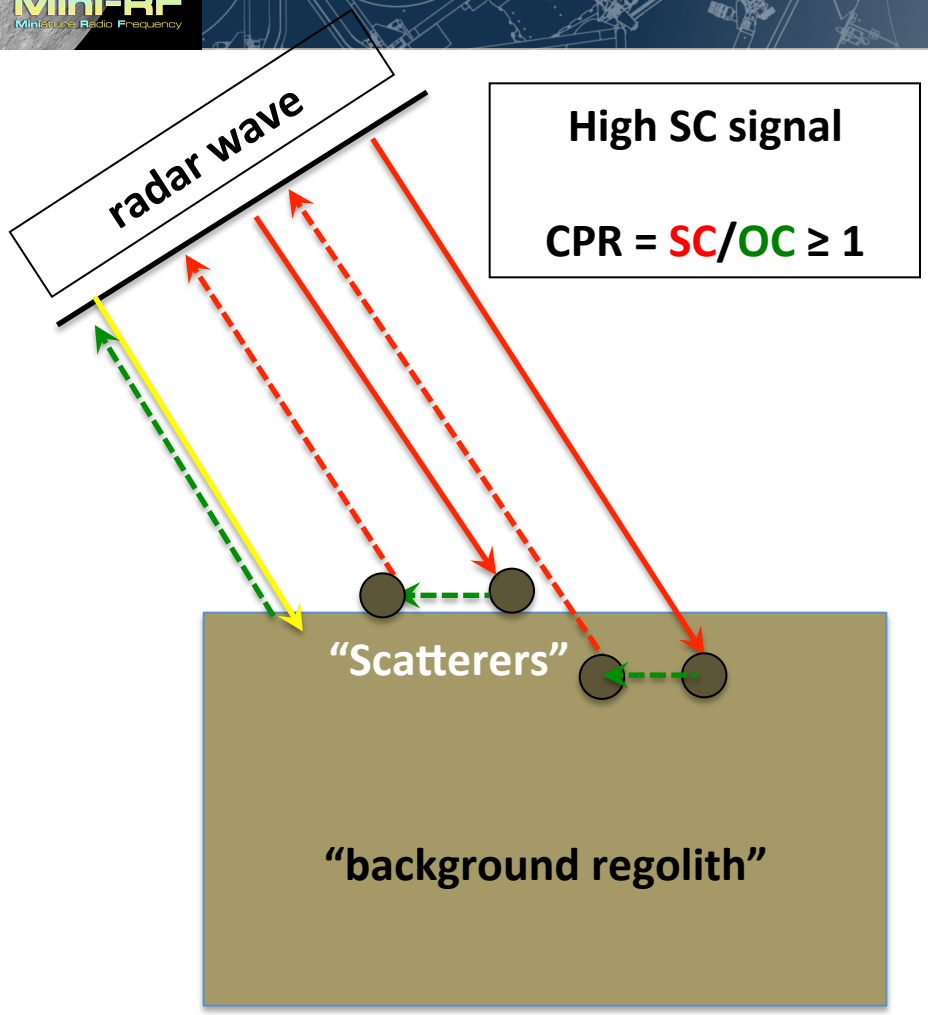
Interpretation of Roughness



Surfaces 'smooth' at the scale of the wavelength will have a low Circular Polarization Ratio

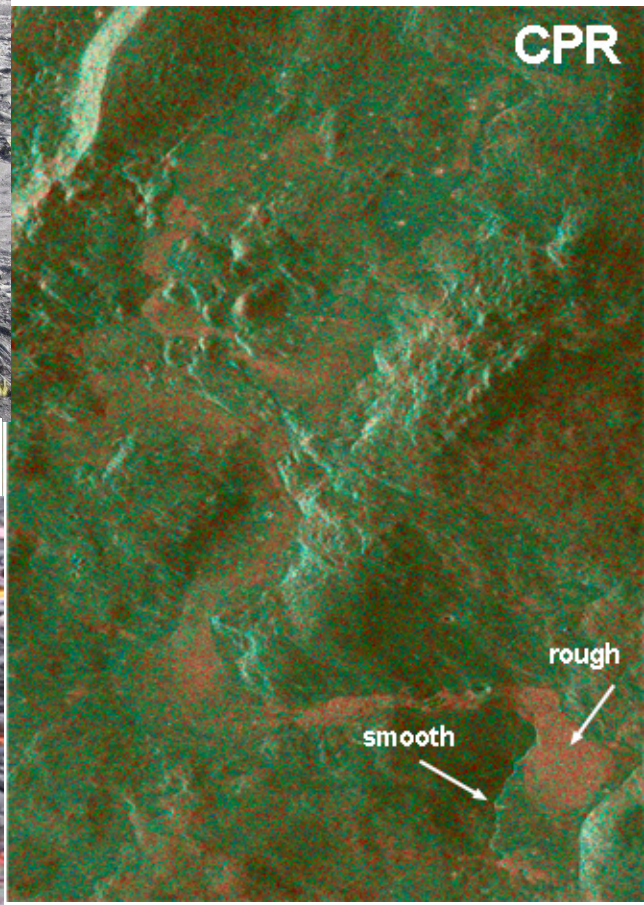
How do we interpret radar?

Interpretation of Roughness



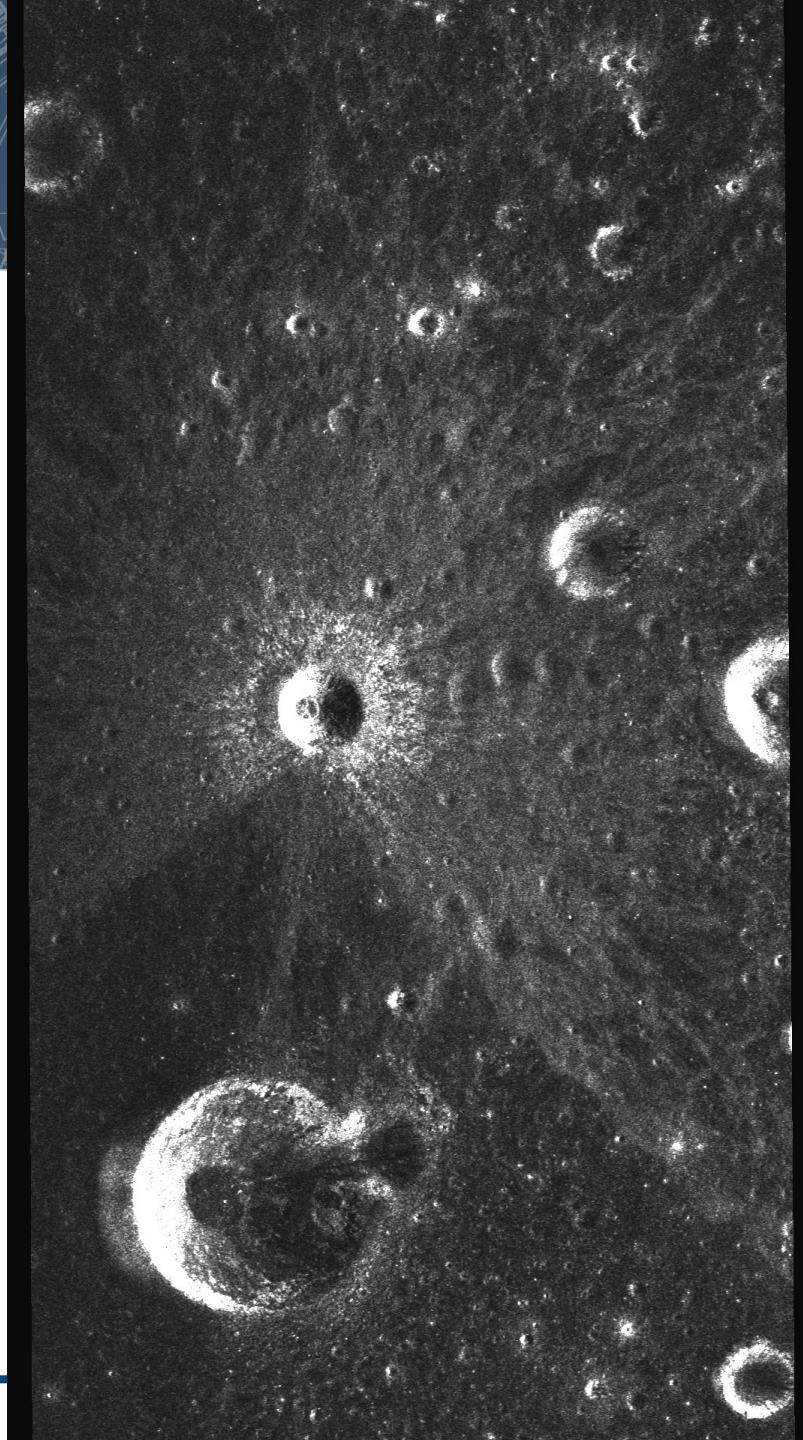
If there is a corner reflector the polarization will change twice returning as it was transmitted in the particular case.

Melt Flow Roughness



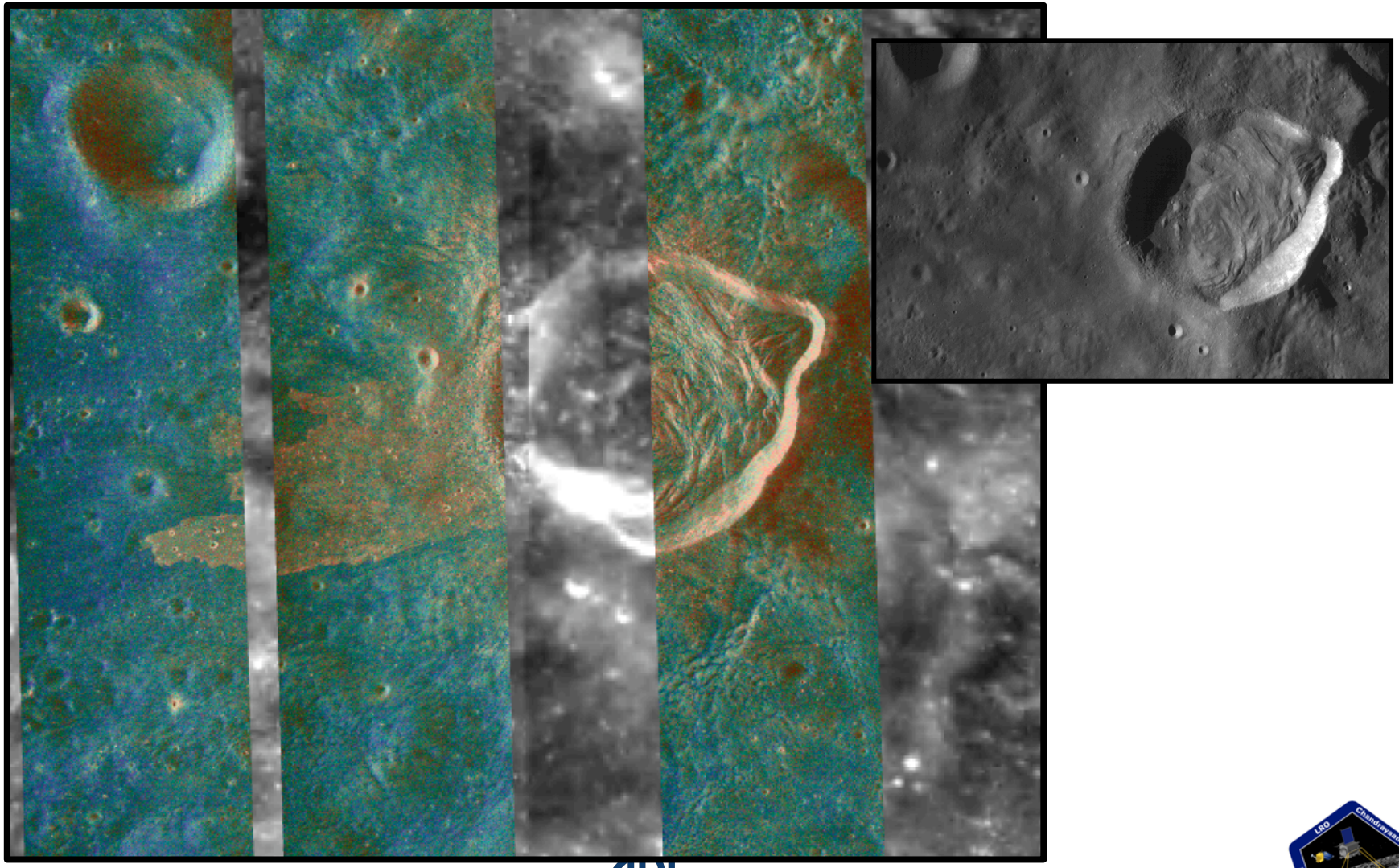
Mini-RF Maps Crater Ejecta Blankets

- Mini-RF maps the roughness of the lunar surface. In doing so it can map the ejecta blankets that surround impact craters
- Mini-RF can see ejecta that are not visible in optical images.
- This could be because the extended ejecta cause subtle variations in surface roughness or that Mini-RF is detecting subsurface effects.
- Mapping the continuous and discontinuous ejecta blankets that surround impact craters will help us to better understand the physics of impact cratering.

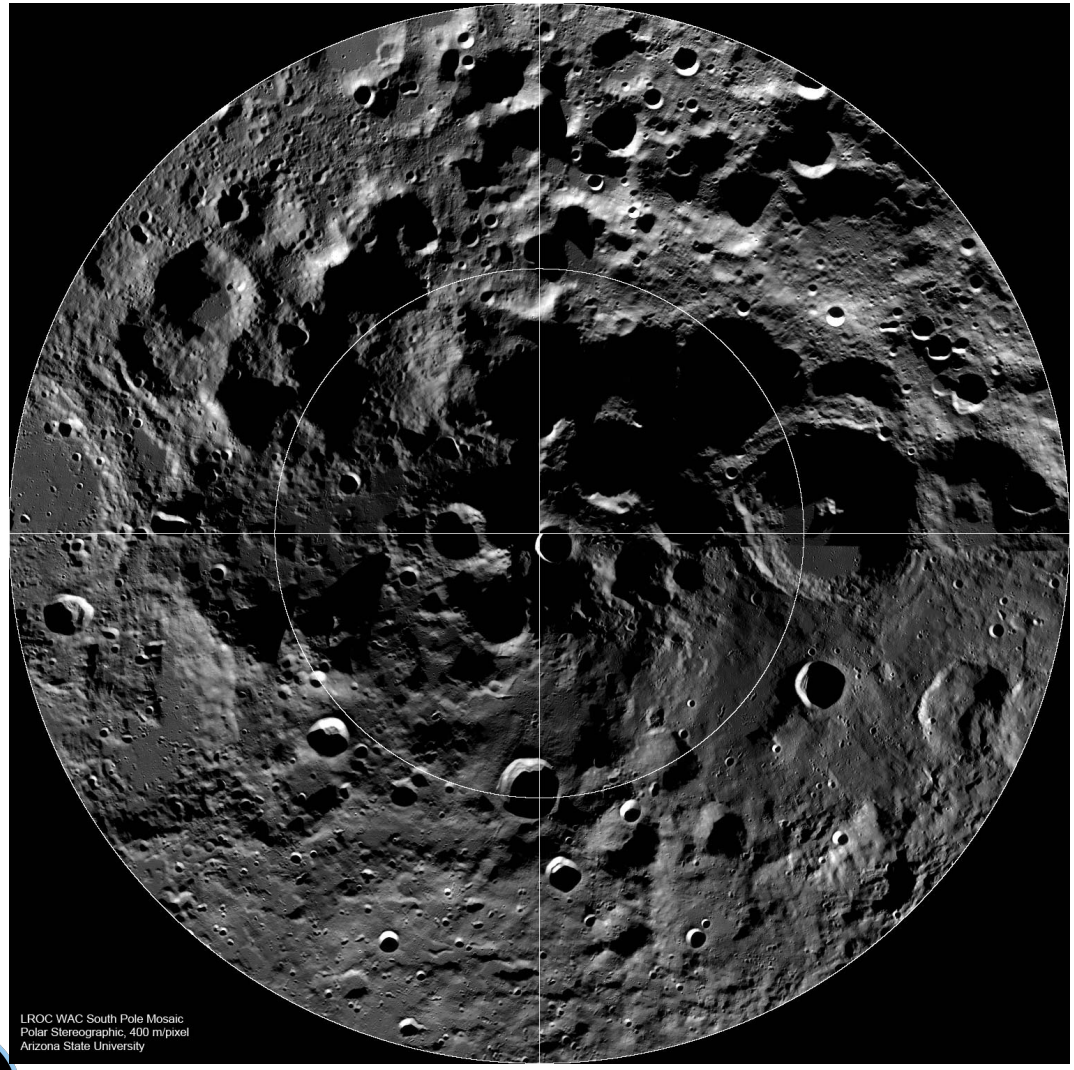


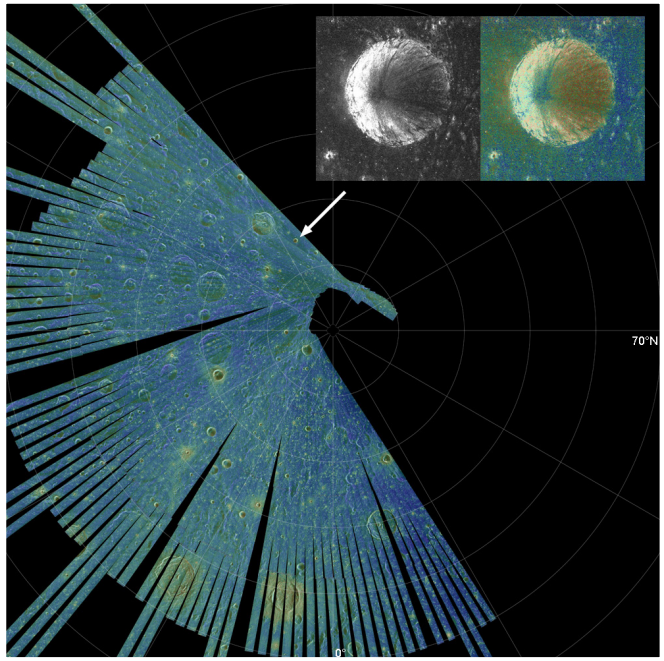
Oblique impact crater in mare Nubium. Both the continuous and extended ejecta blankets are detected

Imaging Shadowed and Subsurface Deposits



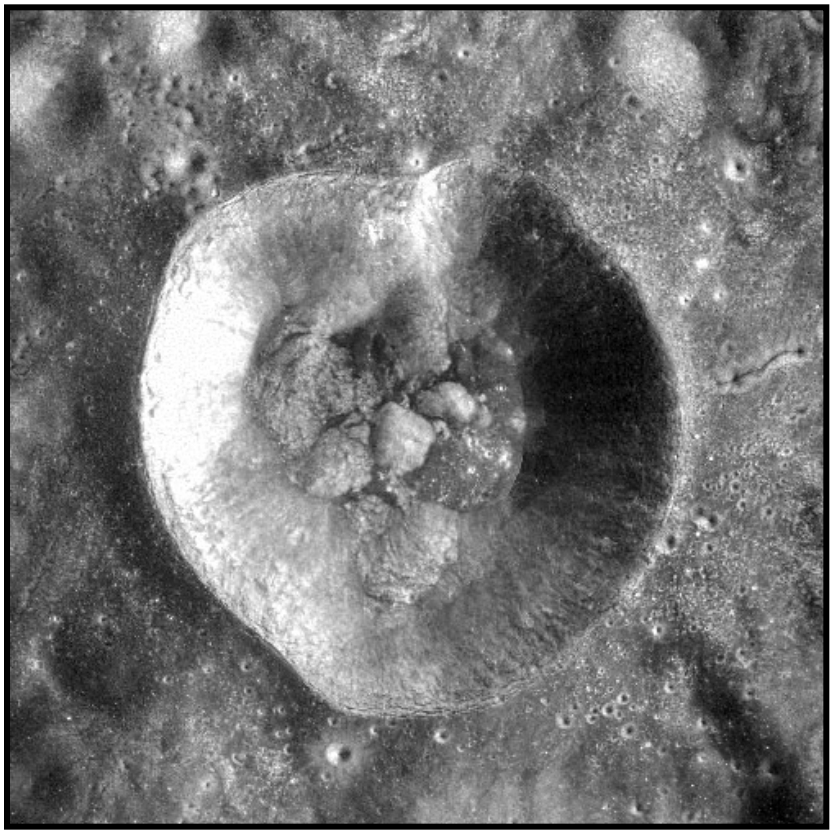
Imaging in Permanent Shadow

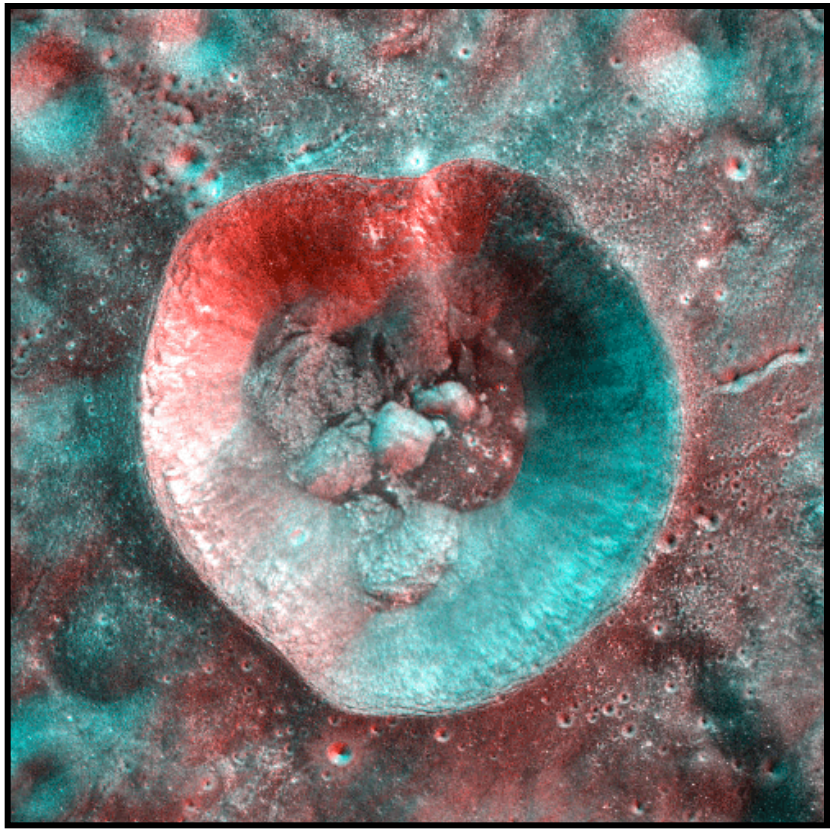




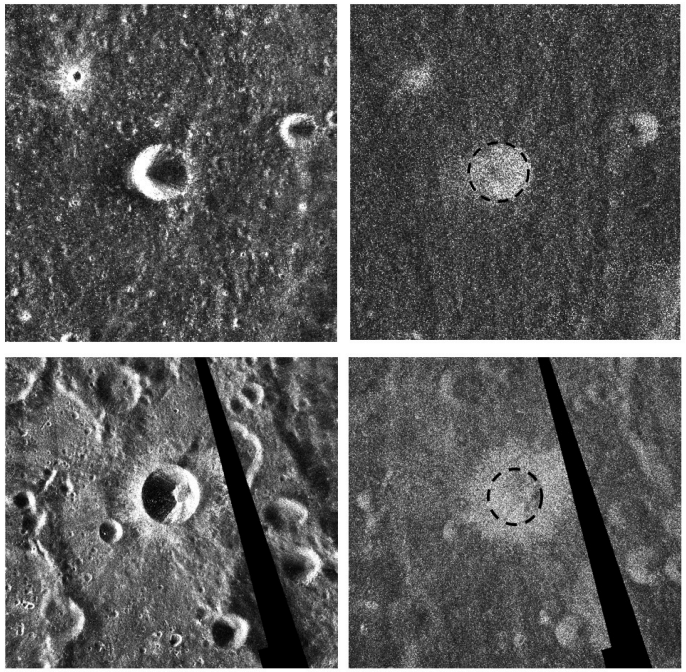
Imaging in Permanent Shadow

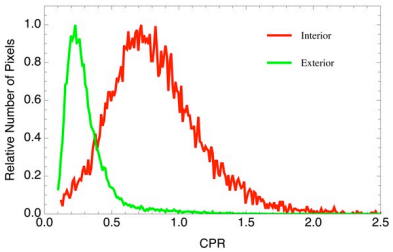
Hermite A: 20 km diameter crater, 88°N 310° E

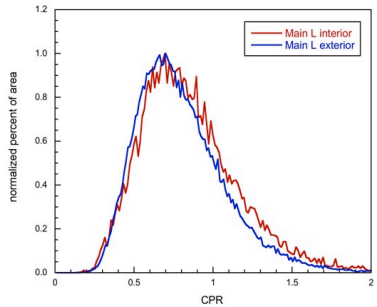




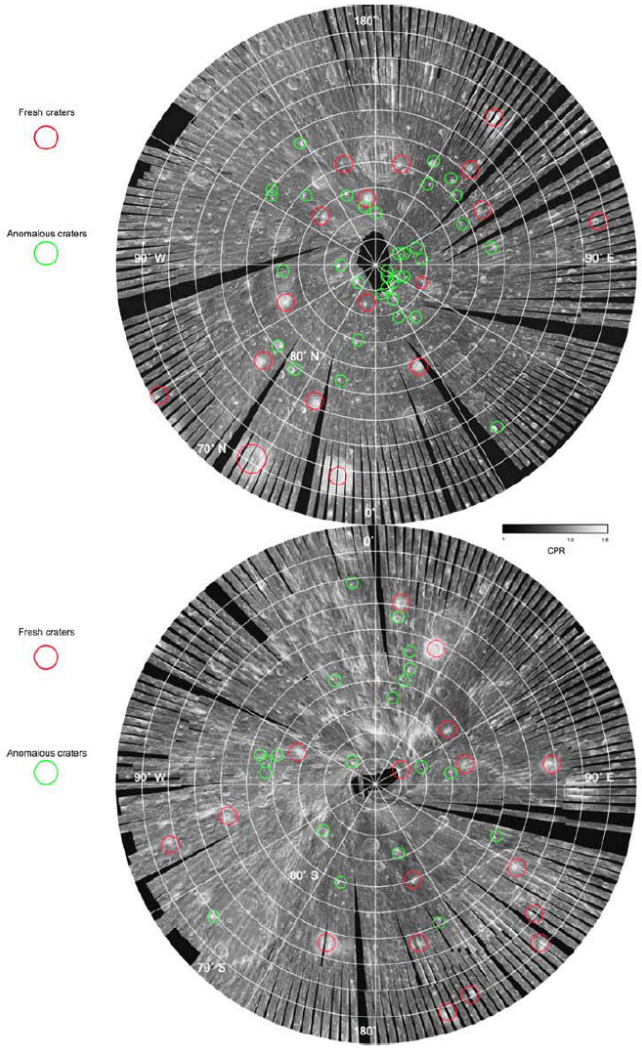
Searching for Ice





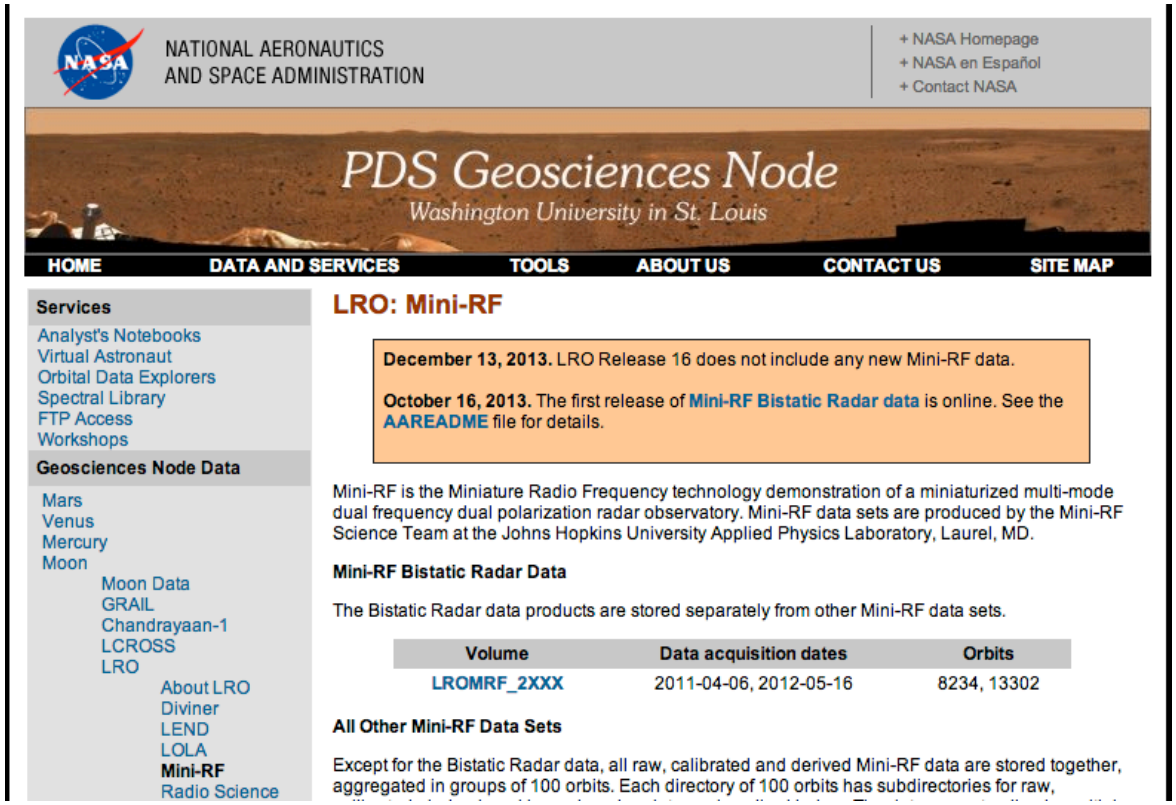


S1 CPR



Where To Find Data

- Planetary Data System – Wash. U. Node (pds-geosciences.wustl.edu)
- http://pds-geosciences.wustl.edu/missions/lro/mrf.htm



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

+ NASA Homepage
+ NASA en Español
+ Contact NASA

PDS Geosciences Node
Washington University in St. Louis

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Mini-RF
Radio Science

LRO: Mini-RF

December 13, 2013. LRO Release 16 does not include any new Mini-RF data.

October 16, 2013. The first release of **Mini-RF Bistatic Radar data** is online. See the **AAREADME** file for details.

Mini-RF is the Miniature Radio Frequency technology demonstration of a miniaturized multi-mode dual frequency dual polarization radar observatory. Mini-RF data sets are produced by the Mini-RF Science Team at the Johns Hopkins University Applied Physics Laboratory, Laurel, MD.

Mini-RF Bistatic Radar Data

The Bistatic Radar data products are stored separately from other Mini-RF data sets.

Volume	Data acquisition dates	Orbits
LROMRF_2XXX	2011-04-06, 2012-05-16	8234, 13302

All Other Mini-RF Data Sets

Except for the Bistatic Radar data, all raw, calibrated and derived Mini-RF data are stored together, aggregated in groups of 100 orbits. Each directory of 100 orbits has subdirectories for raw,

Data Available by Orbit

- Monostatic data was collected until Dec. 25th, 2010 (Merry Christmas!)

Volume	Data acquisition dates	Orbit range
LROMRF_0001	2007-07-13 to 2010-01-19	200-2599
LROMRF_0002	2010-01-19 to 2010-06-17	2600-4499
LROMRF_0003	2010-06-17 to 2010-07-23	4500-4999
LROMRF_0004	2010-07-23 to 2010-12-05	5000-6699
LROMRF_0005	2010-12-05 to 2011-01-23	6700-7302

Data Available

- PDRs: While available need a specialized processor (VEXCEL)
- CDRs: ('LEVEL 1' unprojected .img and .lbl files
- CDR-MAPs: ('LEVEL 2' projected .img and .lbl files – again can be brought into ISIS)
- CDR-MOSAICs

The Mini-RF archive includes these data sets:

Raw Data Products

PDR - Packetized Data Records
(Directories DATA/SAR/.../RAW and DATA/SAR/.../HOUSEKEEPING)

Calibrated Data Products

CDR - Calibrated Data Records
(Directory DATA/SAR/.../LEVEL1)

CDR-INSAR - Interferometric Calibrated Data Records -- to be released later

Derived Data Products

CDR-MAP - Map-Projected Calibrated Data Records
(Directory DATA/SAR/.../LEVEL2)

CDR-MOSAIC - Polar Mosaic Calibrated Data Records
(Directory DATA/SAR/MOSAICS

Level 1 Data

- CDRs: ‘LEVEL 1’
- Non-Orthorectified
- Equirectangular projections
- .img, .lbl, .txt files
- Products Include
  - ‘’cd’ -> H, V, Re, Im (4 Bands)
- ISIS Compatible
  - mrf2isis

[To Parent Directory]

5/18/2012	9:28 AM	7884	aareadme.txt
4/4/2011	12:56 PM	<dir>	calib
6/16/2011	1:16 PM	<dir>	catalog
3/15/2011	9:56 AM	<dir>	data
4/4/2011	12:57 PM	<dir>	document
9/17/2013	9:50 AM	28574	errata.txt
4/11/2011	4:28 PM	<dir>	extras
6/6/2012	11:05 AM	<dir>	index
4/4/2011	12:54 PM	3182	voldesc.cat

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5/27/2011	10:19 AM	<dir>	06800_06899
5/27/2011	10:19 AM	<dir>	06900_06999
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5/27/2011	10:19 AM	<dir>	07100_07199
5/27/2011	10:19 AM	<dir>	07200_07299
5/27/2011	10:19 AM	<dir>	07300_07399
6/4/2012	4:34 PM	<dir>	mosaics

[To Parent Directory]

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4/4/2011	1:13 PM	5116	lsz_06800_2cd_eku_10n173_v1.lbl
5/2/2011	4:57 PM	270515	lsz_06800_2cd_eku_10n173_v1.txt

Level 2 Data

- CDRs: ‘LEVEL 2’
- Non-Orthorectified
- Equirectangular projections
- .img, .lbl, .txt files
- Products Include
  - ‘cd’ -> H, V, Re, Im (4 Bands)
  - ‘cp’ -> CPR
  - ‘oc’ -> opposite sense
  - ‘sc’ -> same sense
  - Stokes denoted ‘s1, s2, s3, s4’
- ISIS Compatible
  - mrf2isis

[To Parent Directory]

5/27/2011 10:18 AM	<dir>	housekeeping
5/27/2011 10:18 AM	<dir>	level1
6/9/2011 10:37 AM	<dir>	level2
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5/27/2011 10:19 AM	<dir>	07300_07399
6/4/2012 4:34 PM	<dir>	mosaics

[To Parent Directory]

4/4/2011 1:16 PM	4745674784	lsz_06800_2cd_eku_10n173_v1.img
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5/2/2011 4:57 PM	270515	lsz_06800_2cd_eku_10n173_v1.txt
4/4/2011 2:33 PM	9023205888	lsz_06800_2cd_eku_34n172_v1.img
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4/4/2011 1:32 PM	25107356064	lsz_06800_2cd_eku_58n171_v1.img
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4/4/2011 1:12 PM	4327	lsz_06800_2cp_eku_10n173_v1.lbl
4/4/2011 3:34 PM	563950368	lsz_06800_2cp_eku_34n172_v1.img
4/4/2011 3:33 PM	4328	lsz_06800_2cp_eku_34n172_v1.lbl
4/4/2011 10:44 AM	1569111488	lsz_06800_2cp_eku_58n171_v1.img
4/4/2011 10:43 AM	4328	lsz_06800_2cp_eku_58n171_v1.lbl

Quikview JPEG Data

- CDRs: jpegs are not in the same place
- Look in ‘Extras’ > ‘Quikview’
- JPEG Products Include
  - ‘cd’ -> H, V, Re, Im (4 Bands)
  - ‘cp’ -> CPR
  - ‘oc’ -> opposite sense
  - ‘sc’ -> same sense
  - Stokes denoted ‘s1, s2, s3, s4’

[To Parent Directory]

5/18/2012	9:28 AM	7884	aareadme.txt
4/4/2011	12:56 PM	<dir>	calib
6/16/2011	1:16 PM	<dir>	catalog
3/15/2011	9:56 AM	<dir>	data
4/4/2011	12:57 PM	<dir>	document
9/17/2013	9:50 AM	28574	errata.txt
4/11/2011	4:28 PM	<dir>	extras
6/6/2012	11:05 AM	<dir>	index
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[To Parent Directory]

5/18/2012	12:39 PM	3523	extrinfo.txt
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[To Parent Directory]

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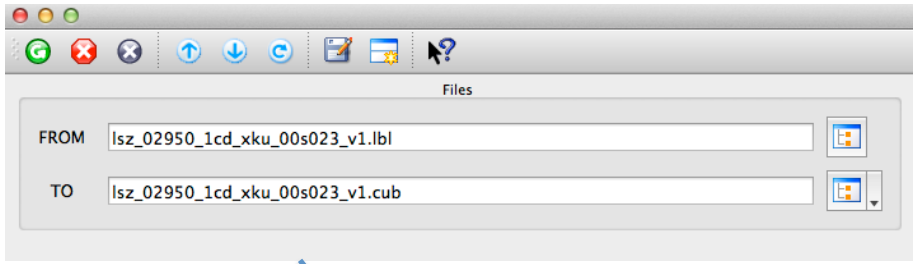
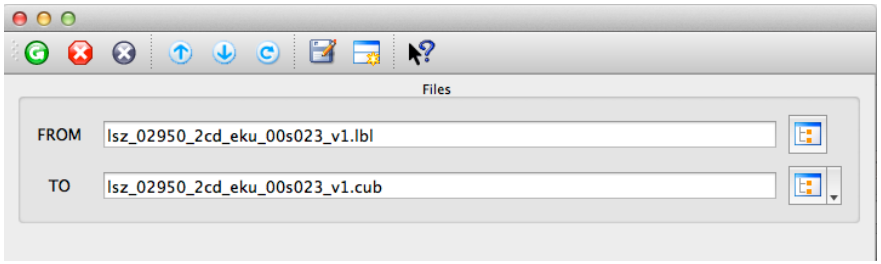
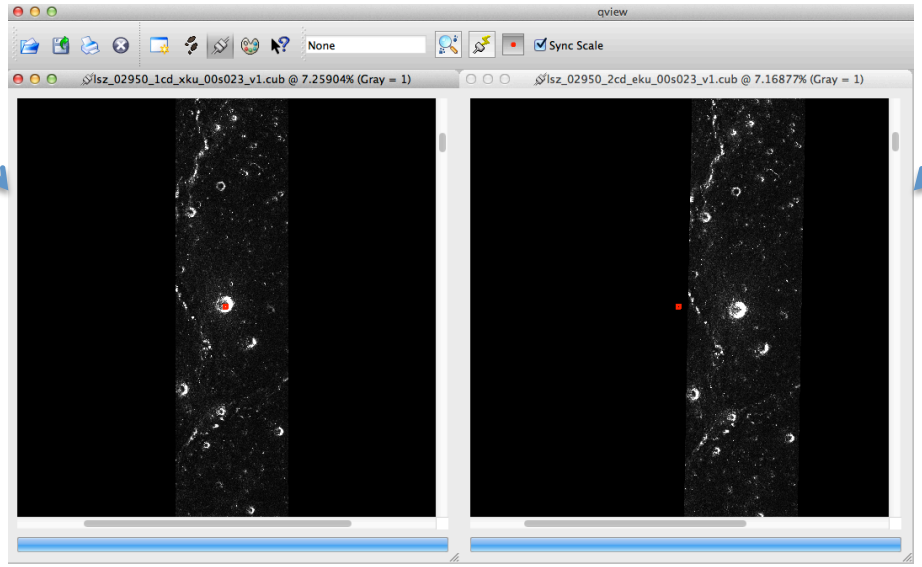
4/1/2011	8:57 AM	2894629	lsz_06800_2s1_eku_10n173_v1.jpg
4/1/2011	8:58 AM	3498037	lsz_06800_2s1_eku_34n172_v1.jpg
4/1/2011	9:00 AM	5610988	lsz_06800_2s1_eku_58n171_v1.jpg

Data Processing Level 1 and 2: ISIS

- ‘mrf2isis’ will process both Level 1 and 2 files in for all data product arrays (S_1, CPR, OC, SC, etc.)







Level 3: Near Complete Polar Coverage

Volume	Data acquisition dates	Orbit range
LROMRF_0001	2007-07-13 to 2010-01-19	200-2599
LROMRF_0002	2010-01-19 to 2010-06-17	2600-4499
LROMRF_0003	2010-06-17 to 2010-07-23	4500-4999
LROMRF_0004	2010-07-23 to 2010-12-05	5000-6699
LROMRF_0005	2010-12-05 to 2011-01-23	6700-7302

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5/27/2011  10:19 AM        <dir> 06900_06999
5/27/2011  10:19 AM        <dir> 07000_07099
5/27/2011  10:19 AM        <dir> 07100_07199
5/27/2011  10:19 AM        <dir> 07200_07299
5/27/2011  10:19 AM        <dir> 07300_07399
 6/4/2012   4:34 PM        <dir> mosaics
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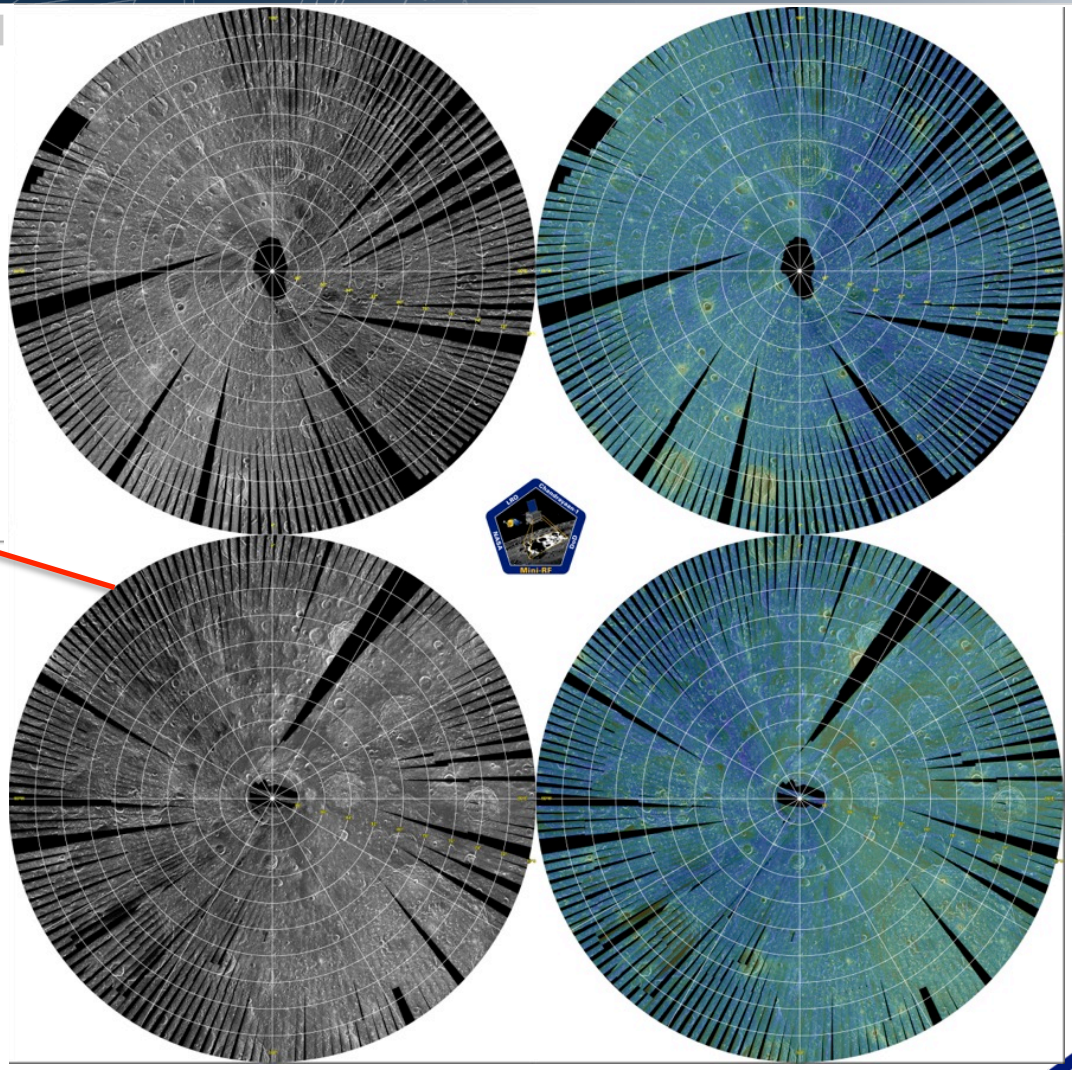
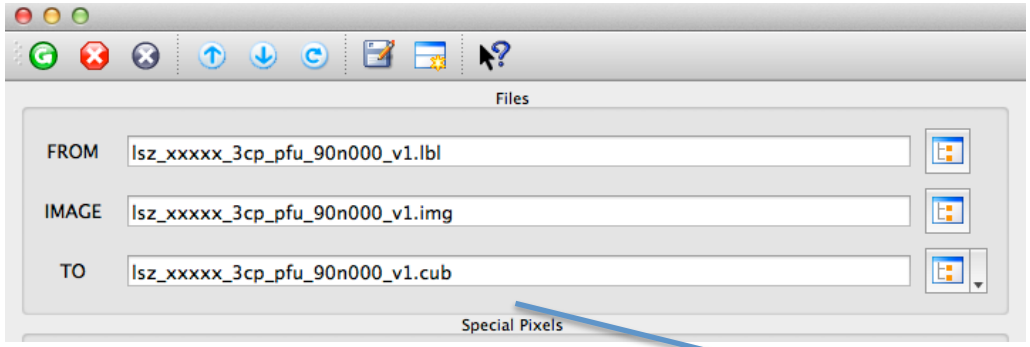
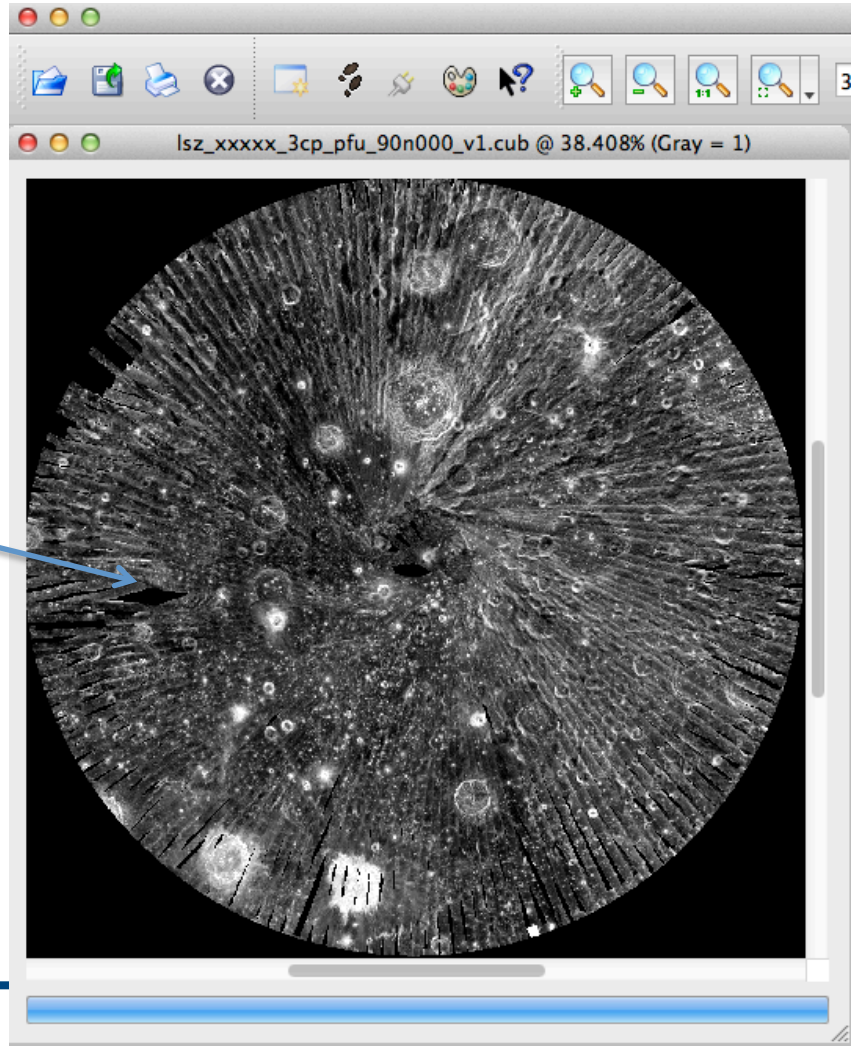


- Polar Mosaics Are available in S- Band if you dig into LROMRF_0005 directory
- Resolutions: 32 & 256 ppd
- S_1 and CPR products
- Both look directions combined

Data Processing Level 3 Mosaics: ISIS

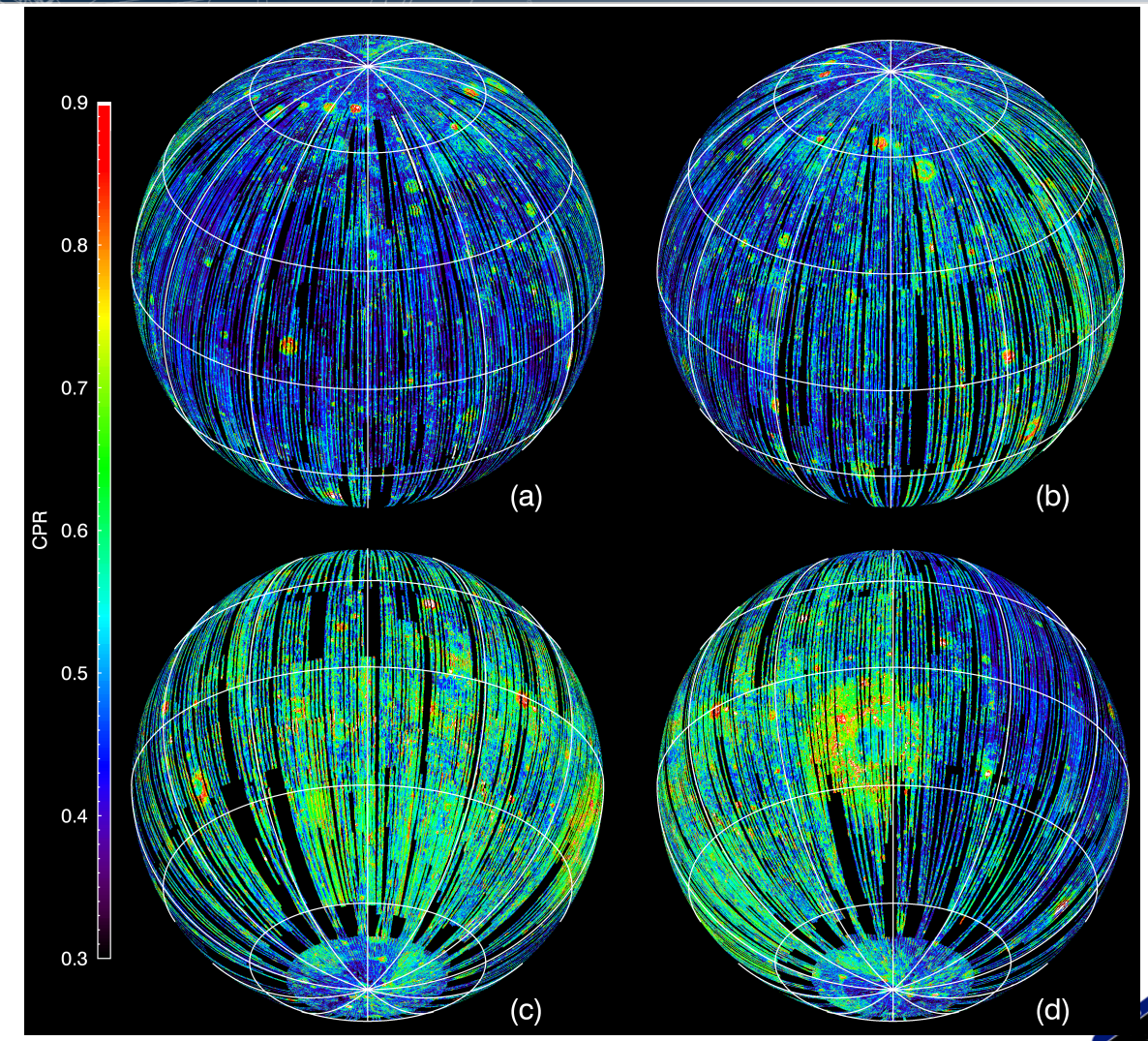
- ‘mrf2isis’ WILL NOT process the mosaics
- Need to use ‘pds2isis’





Near Complete Global Coverage

- Global S-band is coming to the PDS
- Data set was not in the SIS for submittal to PDS
- Is being reviewed as a separate delivery to the PDS
- 128 ppd
- Stokes products, CPR, OC, SC, m-chi, etc.



Monostatic Mini-RF Data Set

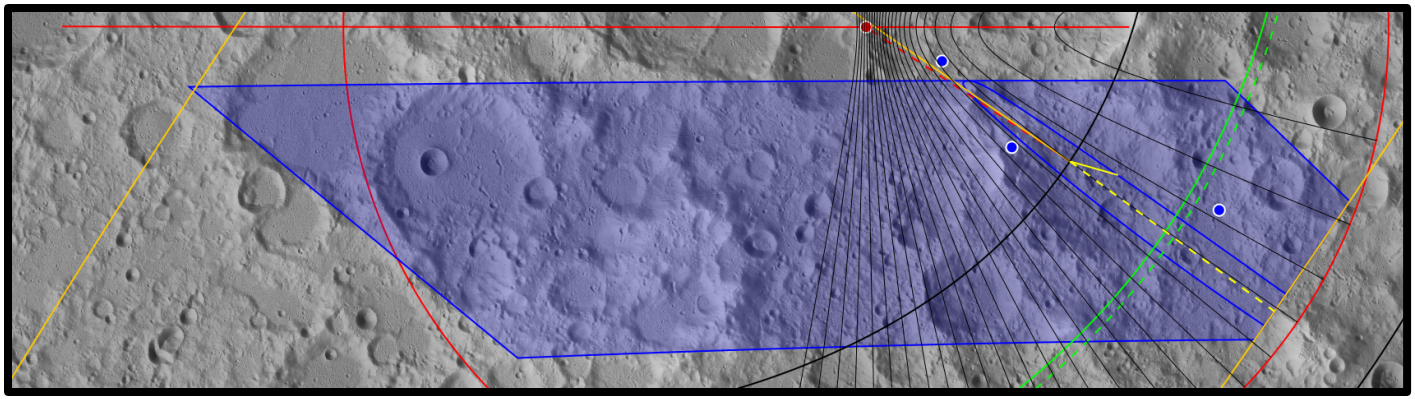
- Mini-RF is a highly capable instrument, obtaining data about lunar surface properties,
- Tech-demo Mini-RF was only supposed to make a very small number of mono-static collects.
- Thankfully, several of the LRO PI's and Project saw the utility of collecting as much data as realistic given data space constraints.
- As a result, Mini-RF is a unanticipated and first Global S-band data set of the Moon which the LRO Project and Mini-RF team is giving the Planetary community.
  - 46% of lunar surface mapped
  - >95% polar regions covered
- >17 TB of Mini-RF delivered to NASA public data archive (PDS)
- The best has not yet been pulled from this data set!

Mini-RF bistatic operations

JOHNS HOPKINS UNIVERSITY
Applied Physics Laboratory

Mini-RF: Bistatic Ops

- Mini-RF is currently operating in a bistatic mode, using the Arecibo Observatory as a transmitter
  - S-band (12.6 cm) with a resolution of ~100 m
  - Provides information on scattering properties of lunar materials as a function of bistatic (phase) angle
    - **Leads to a new and unique way to look for water ice**
  - Data of nearside and polar targets have been successfully collected on 24 occasions



Mini-RF: Bistatic Ops

Target categories:

1. Polar craters
2. Polar anomalous craters
3. Non-polar craters/ejecta blankets
4. Non-polar anomalous craters
5. Pyroclastic deposits

DOY	Date	Description	Target Location	
			Latitude	Longitude
2011-096	6-Apr-11	Low Power 1		
2011-096	6-Apr-11	Low Power 2		
2011-322	18-Nov-11	Censorinus?	-0.789	32
2012-055	24-Feb-12	Hell Q		
2012-055	24-Feb-12	Shackleton	-89.5	125
2012-137	16-May-12	Sinus Aestuum	7	-7
2012-137	16-May-12	Newton	-80.6	-8
2012-193	11-Jul-12	Bouguer	52.3	-35.87
2012-193	11-Jul-12	Haworth (unamed 1)	-87.5	-45
2012-220	7-Aug-12	La Condamine S	57.32	-25.22
2012-220	7-Aug-12	Haworth (unamed 1)	-87.5	-45
2012-248	4-Sep-12	Bouguer	52.3	-35.87
2012-248	4-Sep-12	Shackleton	-89.5	125
2012-276	2-Oct-12	Kepler	7.23	-37.91
2012-304	30-Oct-12	Aristarchus	24.47	-50.15
2013-045	14-Feb-13	Bouguer 2	53.3	-35.87
2013-045	14-Feb-13	Haworth	-87.5	-45
2013-071	12-Mar-13	Newton	-80.6	-8
2013-073	14-Mar-13	Harpalus	51.55	-43.59
2013-073	14-Mar-13	Kepler	7.23	-37.91
2013-127	7-May-13	Bouguer	52.3	-35.87
2013-127	7-May-13	Haworth (unamed 1)	-87.5	-45
2013-157	6-Jun-13	Byrgius A	-25.2	-63.78
2013-157	6-Jun-13	Byrgius A	-25.2	-63.78
2013-181	30-Jun-13	La Condamine S	57.32	-25.22
2013-181	30-Jun-13	Haworth (unamed 1)	-87.5	-45
2013-193	12-Jul-13	Cassini M	41.3	3.7
2013-235	23-Aug-13	Haworth	-87.8	-5.1
2013-236	24-Aug-13	de Gerlache	-88.2	-99.2
2013-263	20-Sep-13	Haworth (unamed 1)	-87.5	-45
2013-273	30-Sep-13	Littrow D	23.7	32.8
2013-273	30-Sep-13	Littrow D	23.7	32.8
2013-303	30-Oct-13	Anaxagoras	74.62	-10.33
2013-345	11-Dec-13	Cabeus	-85	-37.13
2013-346	12-Dec-13	Cabeus	-85	-37.13
2014-007	7-Jan-14	Bouguer	52.3	-35.87
2014-007	7-Jan-14	Cabeus	-85	-37.13

Mini-RF: Bistatic Data Access

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

+ NASA Homepage
+ NASA en Español
+ Contact NASA

PDS Geosciences Node
Washington University in St. Louis

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Help

LRO: Mini-RF

December 13, 2013. LRO Release 16 does not include any new Mini-RF data.

October 16, 2013. The first release of **Mini-RF Bistatic Radar data** is online. See the **AAREADME** file for details.

Mini-RF is the Miniature Radio Frequency technology demonstration of a miniaturized multi-mode dual frequency dual polarization radar observatory. Mini-RF data sets are produced by the Mini-RF Science Team at the Johns Hopkins University Applied Physics Laboratory, Laurel, MD.

Mini-RF Bistatic Radar Data

The Bistatic Radar data products are stored separately from other Mini-RF data sets.

Volume	Data acquisition dates	Orbits
LROMRF_2XXX	2011-04-06, 2012-05-16	8234, 13302

All Other Mini-RF Data Sets

Except for the Bistatic Radar data, all raw, calibrated and derived Mini-RF data are stored together, aggregated in groups of 100 orbits. Each directory of 100 orbits has subdirectories for raw, calibrated, derived, and housekeeping data as described below. The data are put online in multiple archive volumes in time order, as follows. Click the Volume ID below to go to that volume. The INDEX directory of each volume has both a volume-specific index and a cumulative index.

Volume	Data acquisition dates	Orbit range
LROMRF_0001	2007-07-13 to 2010-01-19	200-2599
LROMRF_0002	2010-01-19 to 2010-06-17	2600-4499
LROMRF_0003	2010-06-17 to 2010-07-23	4500-4999

http://geo.pds.nasa.gov/missions/lro/mrf.htm

Mini-RF: Bistatic Data Access

Related Information

PDS Catalog Files

- PDR Data Set Description
- CDR Level 1 Data Set Description
- CDR Level 1 INSAR Data Set Description
- CDR Level 2 Map-Projected Data Set Description
- CDR Level 3 Mosaics Data Set Description
- EDR/DDR/RDR Bistatic Radar Data Set Description
- Mini-RF Instrument Description
- Personnel
- References

Software Interface Specifications (SISs)

- Mini-RF Data Product SIS (PDF, 1.2 MB)
- Mini-RF Archive Volume SIS (PDF, 986 KB)

Mini-RF Team Web Site

Mini-RF: Bistatic Data Access

http://pds-geosciences.wustl.edu/lro/lro-l-mrflro-2_3_5-bistatic-v1/lromrf_2xxx/

[To Parent Directory]

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10/16/2013	11:15 AM	3277	voldesc.cat

Mini-RF: Bistatic Data Access

- Includes all data products provided by the Mini-RF team (DDR, EDR, RDR) with labels

[To Parent Directory]

7/1/2013	4:34 PM		385
10/16/2013	2:13 PM		
7/1/2013	4:34 PM		693
10/16/2013	2:13 PM		
7/1/2013	4:35 PM		652
10/16/2013	1:41 PM		

http://pds-geosciences.w
lromrf_2xxx/data/ddr/

7/1/2013	5:48 PM	6417604	lst_08234_lcp_xiu_09s307_v1.img
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10/16/2013	1:41 PM	3788	lst_08234_ls2_xiu_09s307_v1.lbl
7/1/2013	5:48 PM	6417604	lst_08234_ls3_xiu_09s307_v1.img
10/16/2013	1:41 PM	3797	lst_08234_ls3_xiu_09s307_v1.lbl
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10/16/2013	1:41 PM	3803	lst_08234_ls4_xiu_09s307_v1.lbl
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7/1/2013	5:48 PM	10874764	lst_13302_lcp_xiu_82s351_v1.img
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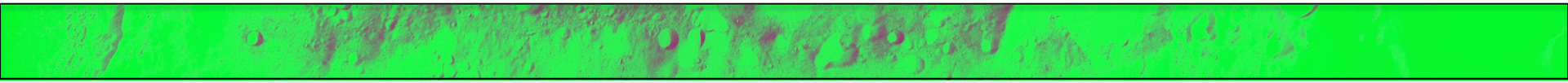
7/1/2013	5:49 PM	10874764	lst_13302_ls4_xiu_82s351_v1.img
10/16/2013	1:41 PM	3799	lst_13302_ls4_xiu_82s351_v1.lbl

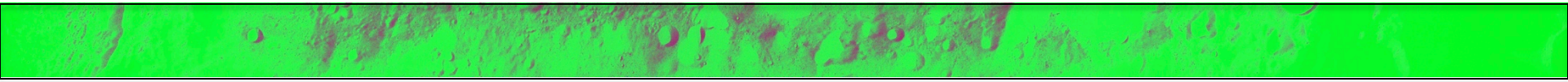
Mini-RF: Bistatic Data EDR (2012-137 Newton)

N ←

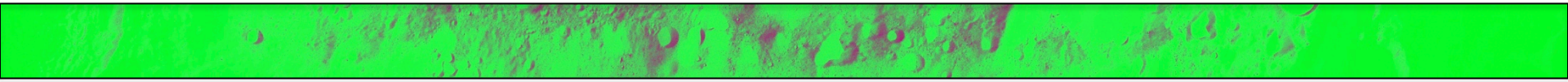
HI



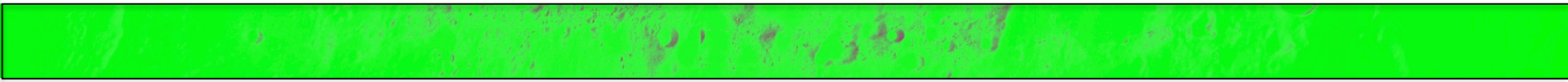
HR



VI



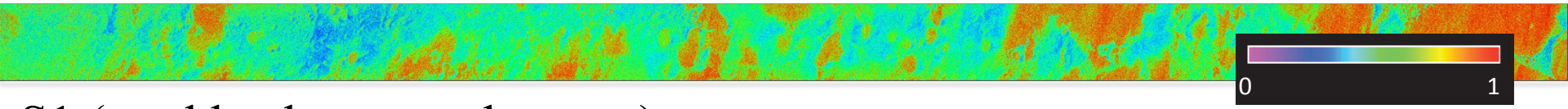
VR



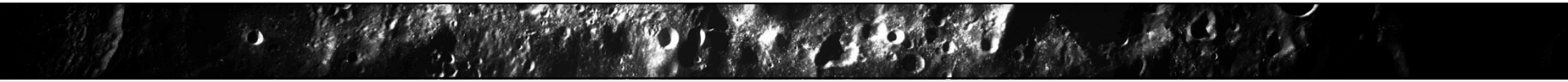
Mini-RF: Bistatic Data RDR (2012-137 Newton)

Circular Polarization Ratio

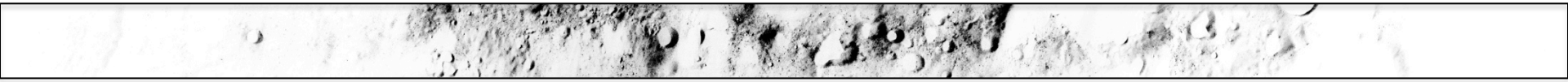
N ←



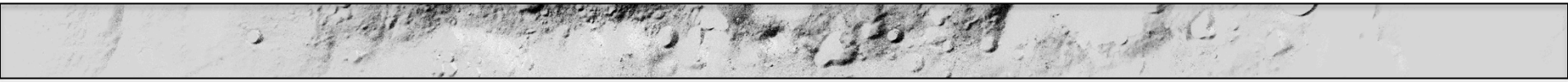
S1 (total backscattered power)



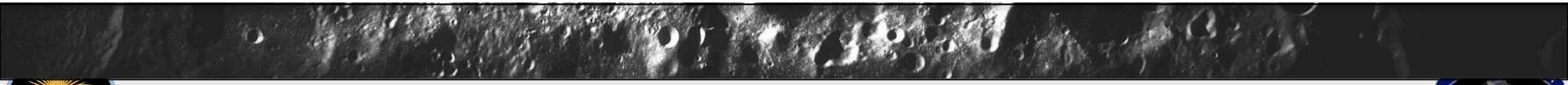
S2



S3

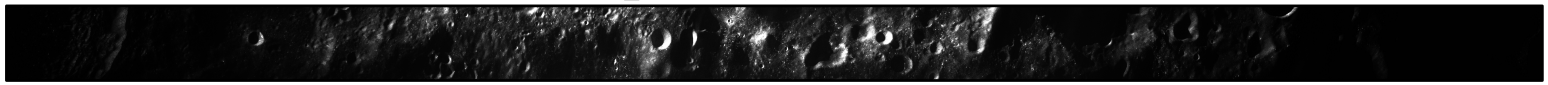


S4



Mini-RF: Bistatic Data DDR (2012-137 Newton)

S1 (total backscattered power)

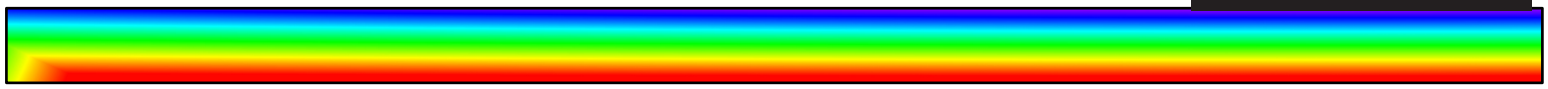


Latitude

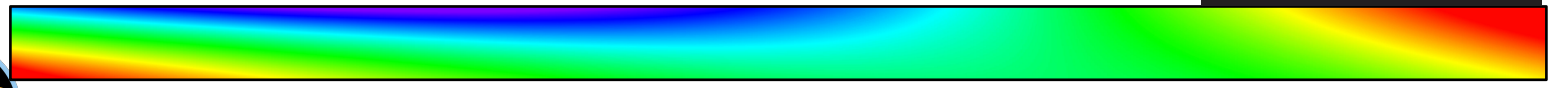
Longitude

Incidence Angle

Emission Angle



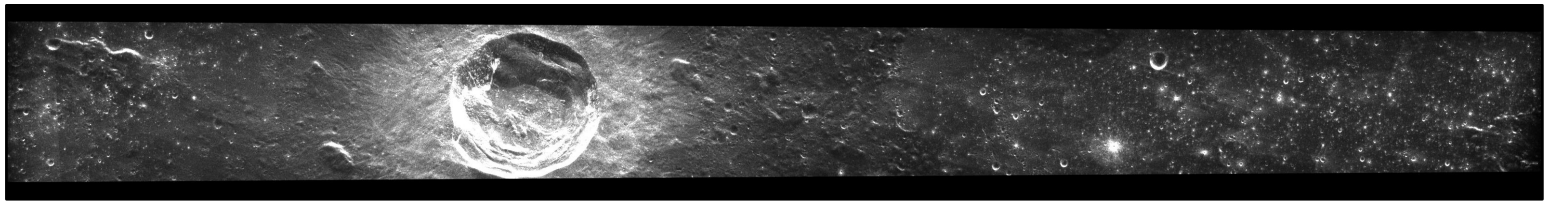
Phase Angle (beta)



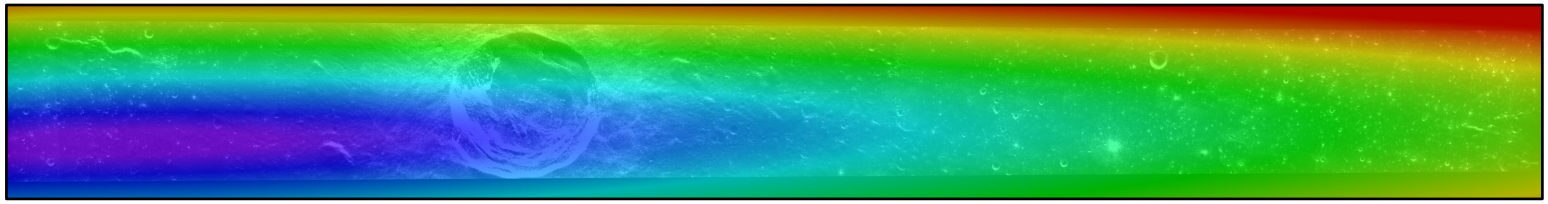
Mini-RF: Bistatic Data (2012-276 Kepler)

S1 (total backscattered power)

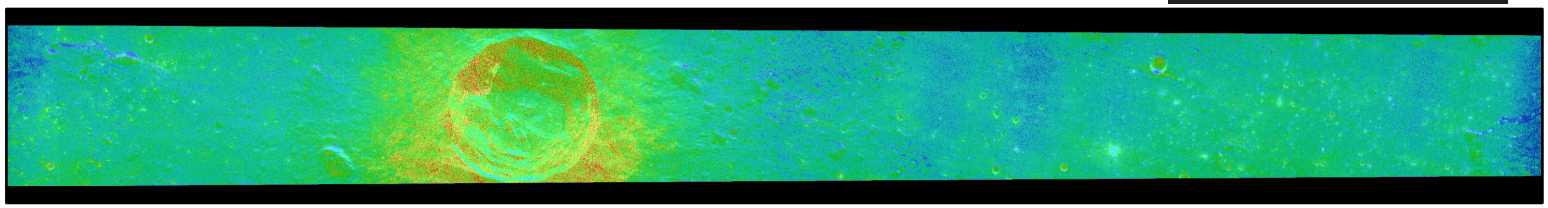
N ←



Phase Angle



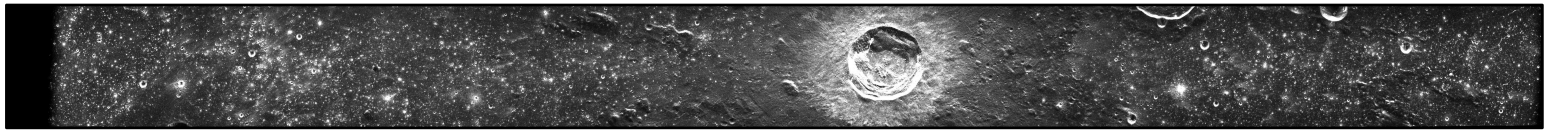
Circular Polarization Ratio



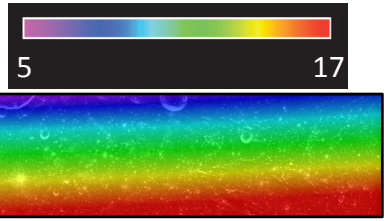
(Not yet in PDS)

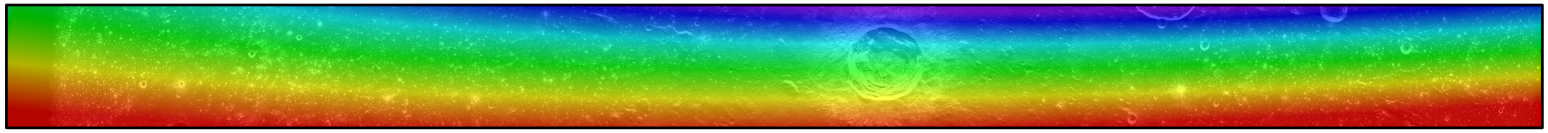
Mini-RF: Bistatic Data (2012-276 Kepler)

S1 (total backscattered power)

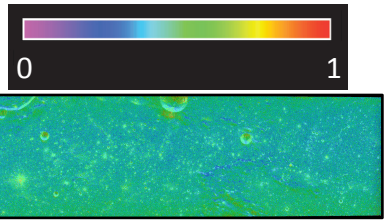


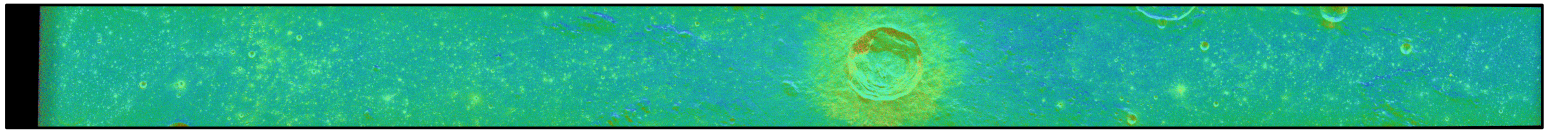
Phase Angle





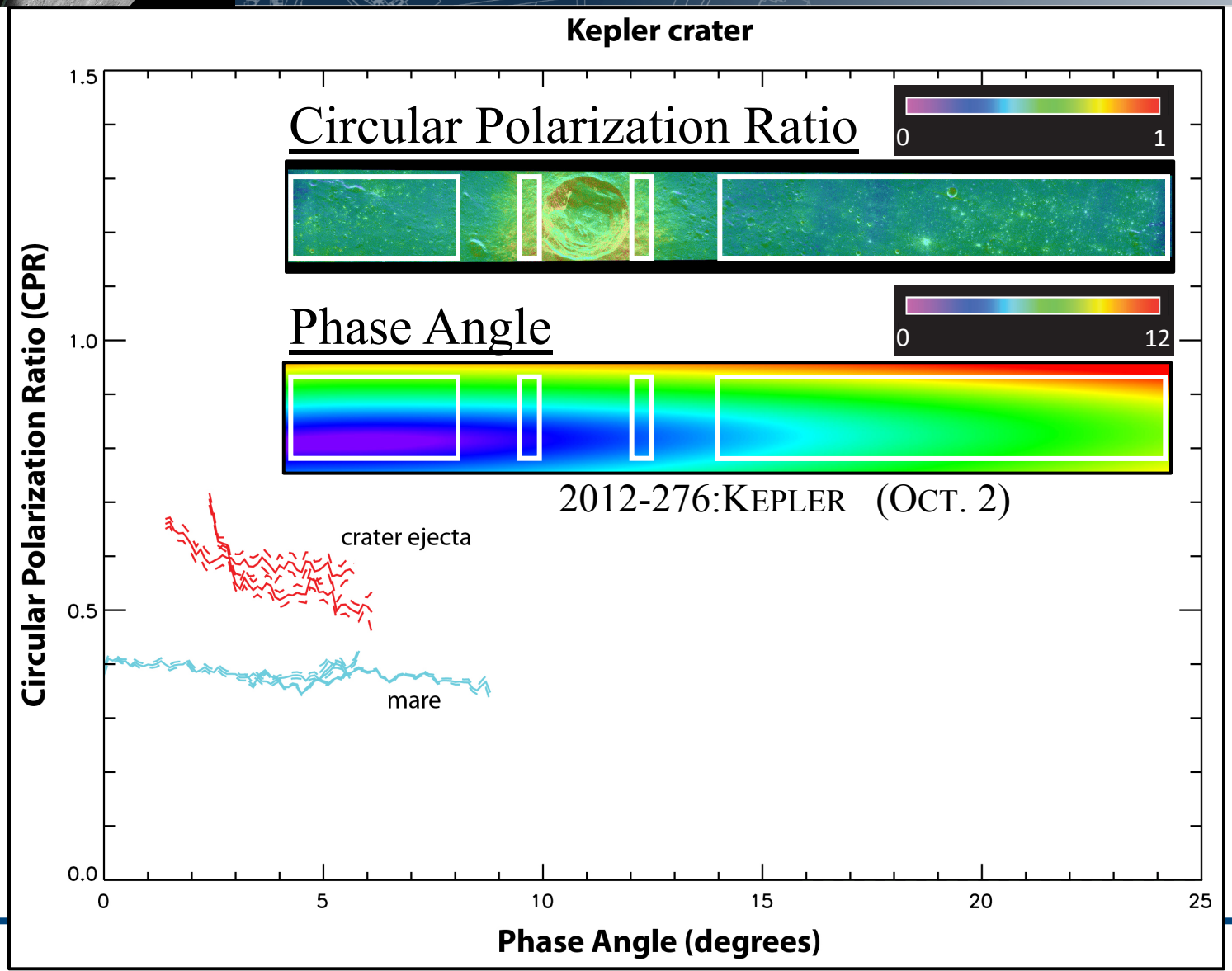
Circular Polarization Ratio



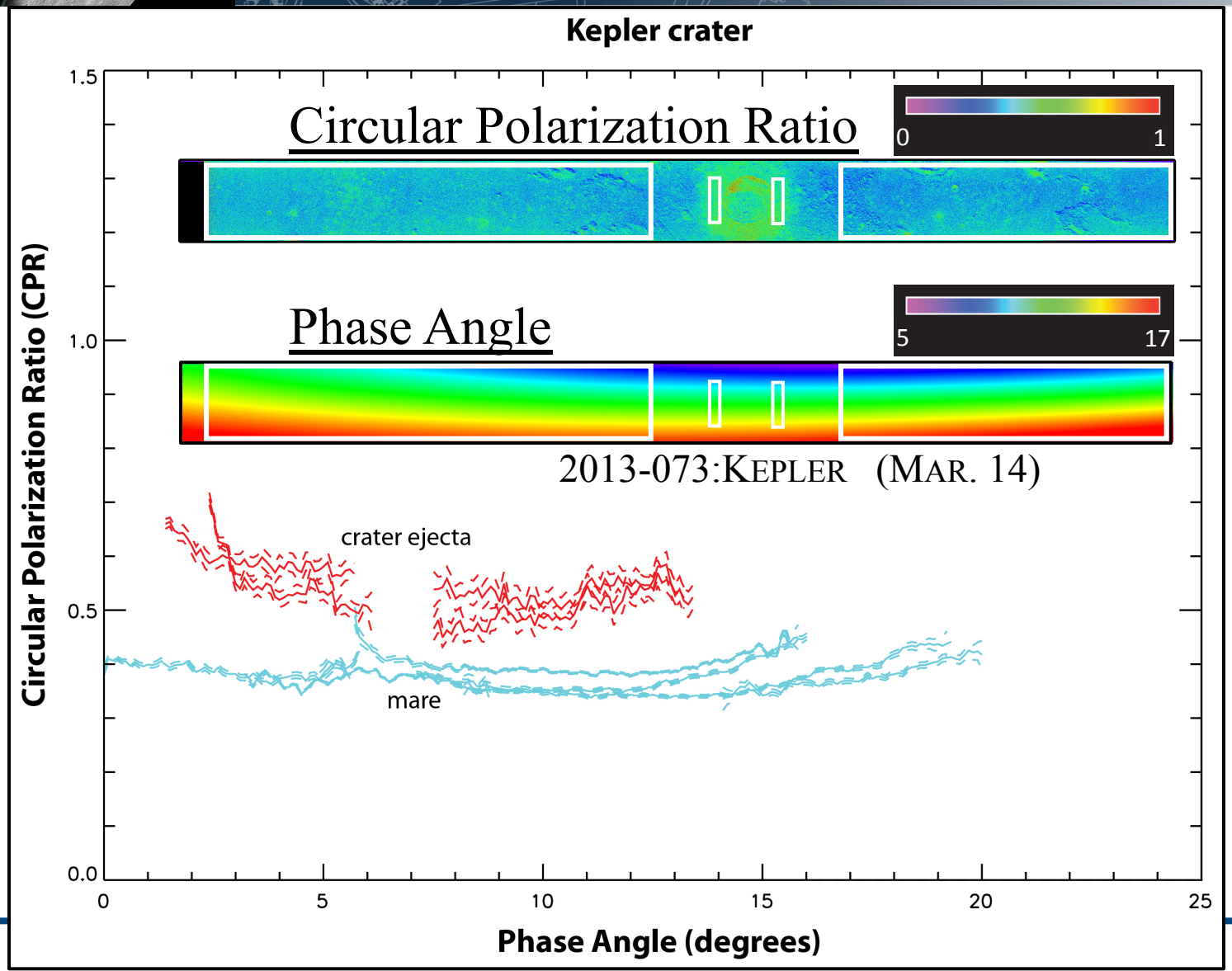


(Not yet in PDS)

Mini-RF: Bistatic Data (2012-276 Kepler)

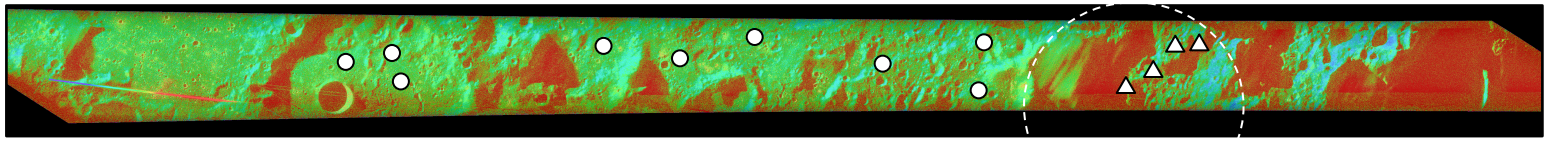


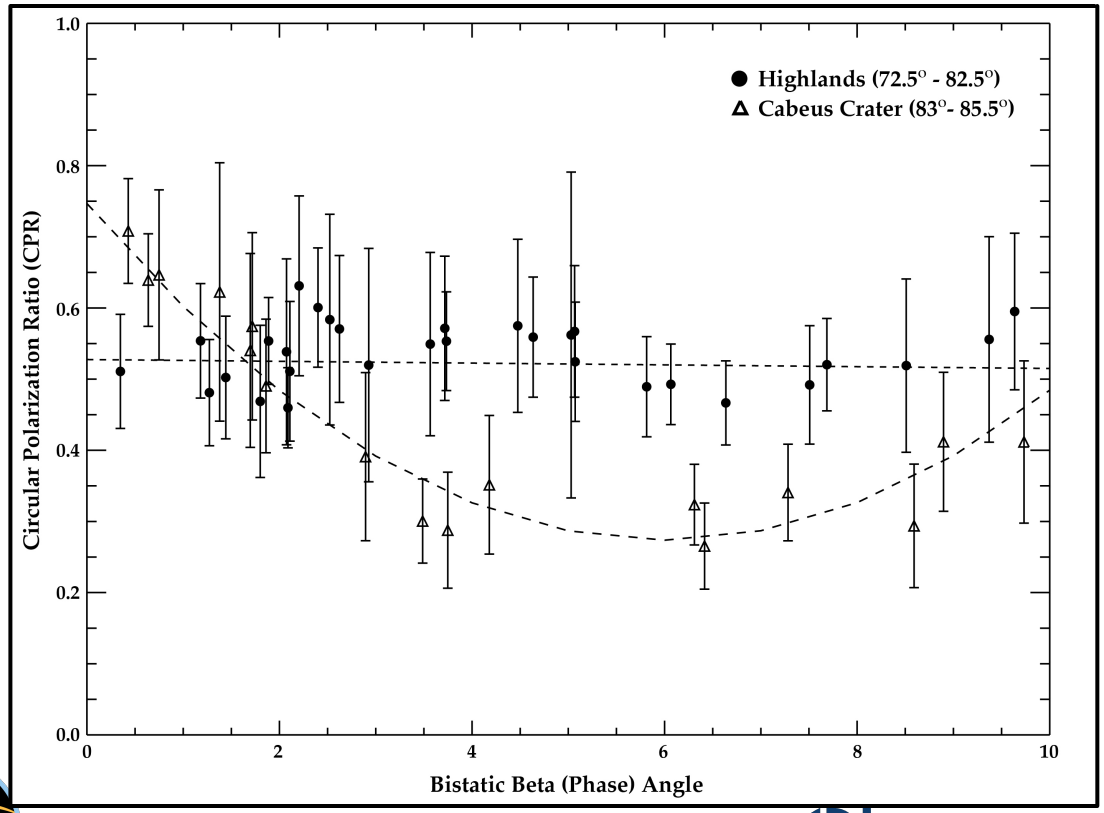
Mini-RF: Bistatic Data (2012-276 Kepler)



Mini-RF: Bistatic Data (2013-127 Cabeus)

Circular Polarization Ratio (CPR)





- The CPR of Lunar terrains equatorward of Cabeus crater are relatively uniform over phase angles <10°
  - This includes the floor of Casatus crater
- The CPR of the floor of Cabeus crater is variable as a function of beta (phase) angle
  - This response is characteristic of an opposition effect (i.e., CBOE)

Mini-RF at LPSC 2015

Team members (present and past)

1. Patterson, G. W. *et al.* Mini-RF on LRO and Arecibo Observatory Bistatic Radar Observations of the Moon.
2. Cahill, J. T. S. *et al.* The Maturely, Immature Orientale Impact Basin.
3. Stickle, A. M. *et al.* Subsurface Layering in Mare Regions Revealed in Mini-RF Profiles of Crater Ejecta.
4. Kirk, R. L. *et al.* A Semi-Rigorous Sensor Model for Precision Geometric Processing of Mini-RF Bistatic Radar Images of the Moon. *46th Lunar and Planetary Science Conference* Abstract #2507 (2015)
5. Matiella Novak, M. A. & Cahill, J. T. S. Physical and Chemical Characterizations of a Selection of Lunar Impact Melt Flows.

Mini-RF at LPSC 2015

Non-Team members

1. Calla, O. P. N. *et al.* Quantification of Water Ice Using MINI-SAR and MINI-RF Datasets Over Lunar Poles.
2. Calla, O. P. N. *et al.* Variation of Dielectric Constant and Brightness Temperature with Respect to Percentage of Water Ice Content.
3. Bhattacharya, A. *et al.* A New Target Decomposition Technique for Compact Polarimetric SAR Data.
4. Bandfield, J. L. *et al.* Lunar Impact Ejecta Strewn Fields ? Distal Regions of Oriented Rocky Deposits. *46th Lunar and Planetary Science Conference* Abstract #1563 (2015).
5. Basantaray, A. K. *et al.* Mineralogical and Morphological Study of Lunar Crater Mosting Using Datasets from Recent Lunar Missions.
6. Ghent, R. R. *et al.* Lunar Crater Ejecta: Physical Properties Revealed by Radar and Thermal Infrared Observations.
7. Trang, D. *et al.* The Compositional and Physical Properties of Localized Pyroclastic Deposits.
8. Saran, S. *et al.* Investigation of the Capability of H-? Decomposition of Compact Polarimetric SAR Data with Application to Lunar Surface.
9. Edmundson, K. L. *et al.* An Integrated Photogrammetric Control Environment for Planetary Cartography.
10. Williams, J. P. *et al.* Impact Melt Deposits at the Antipodes of Tycho and Copernicus Craters.

Any Questions?