

# Mini-RF Bistatic Data: LRO Data Users Workshop

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**APL**  
JOHNS HOPKINS UNIVERSITY  
Applied Physics Laboratory

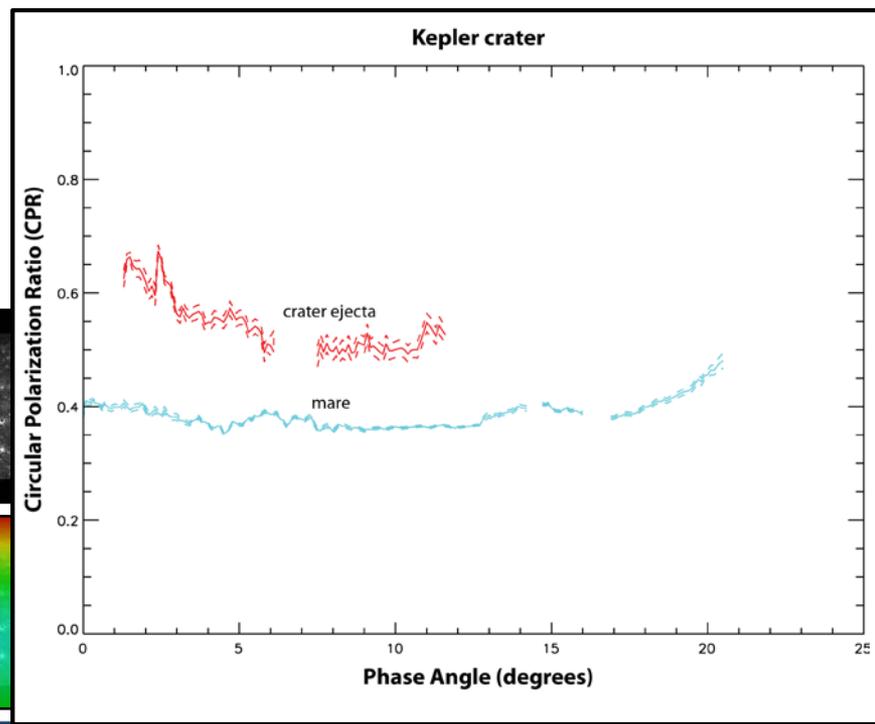
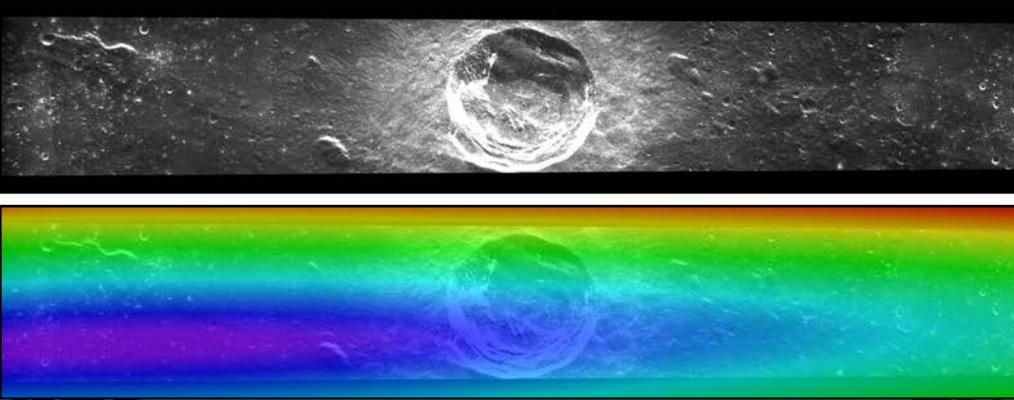
# INTRODUCTION

Exploring the  
Moon with Radar

**Mini-RF**  
Miniature Radio Frequency

The Mini-RF team is acquiring bistatic radar measurements of the lunar surface to understand the radar scattering properties of different materials as a function of phase angle.

- These properties can be affected by the size and distribution of scatterers in a material and the composition of the material.
- Understanding these properties can provide a means of differentiating between scattering indicative of surfaces that are rough versus surfaces that harbor detectable quantities of water ice.



# BISTATIC OPERATIONS

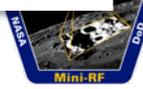
Exploring the  
Moon with Radar

Mini-RF  
Miniature Radio Frequency

## 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



# BISTATIC CAMPAIGN: NON-POLAR

Exploring the  
Moon with Radar

**Mini-RF**  
Miniature Radio Frequency

- Target primary lunar terrains at a variety of phase angles
  - Non-polar

Target	Feature
Ejecta	Kepler
Ejecta	Harpalus
Ejecta	Bouguer
Ejecta	Byrgius A
Ejecta	La Condamine S
Mare	Insularum
Mare	Frigoris
Mare	Imbrium
Mare	Sinus Iridium
Pyroclastic	Aristarchus*
Pyroclastic	Sinus Aestuum

\* Also a calibration target



# DATA ACQUISITION

*Exploring the  
Moon with Radar*

**Mini-RF**  
Miniature Radio Frequency

- Arecibo transmits LHCP signal to the moon, the backscatter is received in orthogonal linear polarizations by MiniRF
- Goal: to explore radar backscatter characteristics as a function of bistatic angle,  $\beta$ 
  - Bistatic Angle: The angle between the transmitted and received signals (beta)
- Data is initially processed by Sandia National Laboratory into the real and imaginary parts of the horizontal and vertical polarizations

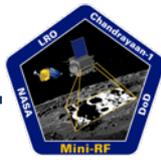


# DATA CALIBRATION

Exploring the  
Moon with Radar

Mini-RF  
Miniature Radio Frequency

- Described in: *Bistatic\_proc\_calib.pdf*
- The raw HI,HR,VI,VR data products are
  - 1. Available in the PDS
  - 2. Calibrated at APL and higher-level data products are calculated and provided to the PDS





# ACCESSING MINI-RF BISTATIC DATA IN THE PDS



# Geosciences Node

Exploring the  
Moon with Radar

**Mini-RF**  
Miniature Radio Frequency



NATIONAL AERONAUTICS  
AND SPACE ADMINISTRATION

+ NASA Homepage  
+ NASA en Español  
+ Contact NASA

## PDS Geosciences Node

Washington University in St. Louis

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### Services

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### Geosciences Node Data

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[Venus](#)  
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[MSX](#)  
[Lunar Prospector](#)  
[Lunar Radar](#)  
[Lunar Spectroscopy](#)  
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### Scheduled Maintenance

This site may be down on  
**Thursdays** between 7:00 and  
9:30 pm Central Time for  
maintenance.

### 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
<a href="#">LROMRF_2XXX</a>	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
<a href="#">LROMRF_0001</a>	2007-07-13 to 2010-01-19	200-2599
<a href="#">LROMRF_0002</a>	2010-01-19 to 2010-06-17	2600-4499
<a href="#">LROMRF_0003</a>	2010-06-17 to 2010-07-23	4500-4999
<a href="#">LROMRF_0004</a>	2010-07-23 to 2010-12-05	5000-6699
<a href="#">LROMRF_0005</a>	2010-12-05 to 2011-01-23	6700-7302

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



# AVAILABLE BISTATIC PRODUCTS

## 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](#)



# TOP LEVEL INDEX

Exploring the  
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Miniature Radio Frequency

[http://pds-geosciences.wustl.edu/lro/lro-l-mrflro-2\\_3\\_5-bistatic-v1/lromrf\\_2xxx/](http://pds-geosciences.wustl.edu/lro/lro-l-mrflro-2_3_5-bistatic-v1/lromrf_2xxx/)

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[\[To Parent Directory\]](#)

10/16/2013	11:15	AM	9986	<a href="#">aareadme.txt</a>
10/16/2013	11:27	AM	<dir>	<a href="#">calib</a>
10/16/2013	11:27	AM	<dir>	<a href="#">catalog</a>
10/16/2013	11:35	AM	<dir>	<a href="#">data</a>
10/16/2013	11:40	AM	<dir>	<a href="#">document</a>
10/16/2013	11:13	AM	2706	<a href="#">errata.txt</a>
10/16/2013	11:52	AM	<dir>	<a href="#">extras</a>
10/16/2013	11:57	AM	<dir>	<a href="#">index</a>
10/16/2013	11:15	AM	3277	<a href="#">volDESC.cat</a>

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# SUBDIRECTORY SUMMARY

Exploring the  
Moon with Radar

Mini-RF  
Miniature Radio Frequency

- [Areadme.txt](#): Introduction to the data set, the PDS record, and the file formats available
- [Calib](#): contains the Mini-RF and Bistatic radar calibration documents
- [Data](#): Contains the science data products organized by orbit number and product type
- [Document](#): Contains the archive volume software interface specs describing the archive, the original MRF data products, and describing the bistatic data acquisition and processing
- [Extras](#): Contains reduced-size jpegs browse images produced from Level 1 data
- [Index](#): Contains index formation on each data file included in the volume



# DATA DIRECTORY

RDR subdirectory

■ Incl  
pro  
the  
ED

7/1/2013	5:48	PM	6417604	<a href="#">lst 08234 lcp xiu 09s307 vl.img</a>
10/16/2013	1:41	PM	3790	<a href="#">lst 08234 lcp xiu 09s307 vl.lbl</a>
7/1/2013	5:48	PM	6417604	<a href="#">lst 08234 ls1 xiu 09s307 vl.img</a>
10/16/2013	1:41	PM	3734	<a href="#">lst 08234 ls1 xiu 09s307 vl.lbl</a>
7/1/2013	5:48	PM	6417604	<a href="#">lst 08234 ls2 xiu 09s307 vl.img</a>
10/16/2013	1:41	PM	3788	<a href="#">lst 08234 ls2 xiu 09s307 vl.lbl</a>
7/1/2013	5:48	PM	6417604	<a href="#">lst 08234 ls3 xiu 09s307 vl.img</a>
10/16/2013	1:41	PM	3797	<a href="#">lst 08234 ls3 xiu 09s307 vl.lbl</a>
7/1/2013	5:48	PM	6417604	<a href="#">lst 08234 ls4 xiu 09s307 vl.img</a>
10/16/2013	1:41	PM	3803	<a href="#">lst 08234 ls4 xiu 09s307 vl.lbl</a>
7/1/2013	5:48	PM	11557068	<a href="#">lst 13302 lcp xiu 07n353 vl.img</a>
10/16/2013	1:41	PM	3784	<a href="#">lst 13302 lcp xiu 07n353 vl.lbl</a>
7/1/2013	5:48	PM	10874764	<a href="#">lst 13302 lcp xiu 82s351 vl.img</a>
10/16/2013	1:41	PM	3787	<a href="#">lst 13302 lcp xiu 82s351 vl.lbl</a>
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7/1/2013	5:48	PM	11557068	<a href="#">lst 13302 ls2 xiu 07n353 vl.img</a>
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7/1/2013	5:49	PM	10874764	<a href="#">lst 13302 ls2 xiu 82s351 vl.img</a>
10/16/2013	1:41	PM	3784	<a href="#">lst 13302 ls2 xiu 82s351 vl.lbl</a>
7/1/2013	5:49	PM	11557068	<a href="#">lst 13302 ls3 xiu 07n353 vl.img</a>
10/16/2013	1:41	PM	3792	<a href="#">lst 13302 ls3 xiu 07n353 vl.lbl</a>
7/1/2013	5:49	PM	10874764	<a href="#">lst 13302 ls3 xiu 82s351 vl.img</a>
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7/1/2013	5:49	PM	11557068	<a href="#">lst 13302 ls4 xiu 07n353 vl.img</a>
10/16/2013	1:41	PM	3797	<a href="#">lst 13302 ls4 xiu 07n353 vl.lbl</a>
7/1/2013	5:49	PM	10874764	<a href="#">lst 13302 ls4 xiu 82s351 vl.img</a>
10/16/2013	1:41	PM	3799	<a href="#">lst 13302 ls4 xiu 82s351 vl.lbl</a>

[dr](#)  
[dr](#)  
[dr](#)

[\[To Parent](#)

<http://pdv1/lromr>



# TYPICAL LABEL FILE EXAMPLE

Exploring the  
Moon with Radar

```
/* File Identification and Structures. */
RECORD_TYPE           = FIXED LENGTH
RECORD_BYTES          = 2306764
FILE_RECORDS          = 1001

/* Pointer to data object. */
^IMAGE                = "LST_13302_0HI_XIU_07N353_V1.IMG"

/* Identification Data Elements. */
DATA_SET_ID           = "LRO-L-MRFLRO-2/3/5-BISTATIC-V1.0"
DATA_SET_NAME         = "LRO MOON MINI-RF 2/3/5 BISTATIC RADAR V1.0"
PRODUCER_ID           = "JHUAPL"
PRODUCER_FULL_NAME    = "MINI-RF POC TEAM"
PRODUCER_INSTITUTION_NAME = "JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY"
LABORATORY            = "LST_13302_0HI_XIU_07N353_V1"
PRODUCT_ID            = "1.0"
PRODUCT_VERSION_ID    = "EDR"
PRODUCT_TYPE          = "ImgHorizImag.576691.1001.r4"
ORIGINAL_PRODUCT_ID   = "SCIENCE MISSION"
MISSION_PHASE_NAME    = "2012-12-12"
PRODUCT_CREATION_TIME = "0001"
RELEASE_ID            = "LUNAR RECONNAISSANCE ORBITER"
MISSION_NAME          = "LUNAR RECONNAISSANCE ORBITER"
INSTRUMENT_HOST_NAME  = "LRO"
INSTRUMENT_HOST_ID    = "MINI-RF LRO"
INSTRUMENT_NAME       = "MRFLRO"
INSTRUMENT_ID         = "MOON"
TARGET_NAME           = "2012-05-16T13:12:29"
START_TIME            = "2012-05-16T13:18:31"
STOP_TIME             = "UNK"
SPACECRAFT_CLOCK_START_COUNT = "UNK"
SPACECRAFT_CLOCK_STOP_COUNT = "UNK"
ORBIT_NUMBER          = 13302
INCIDENCE_ANGLE       = 17.01 <deg>
EMISSION_ANGLE        = 31.22 <deg>
PHASE_ANGLE           = 16.69 <deg>
CENTER_FREQUENCY      = 2380 <GHz>
INSTRUMENT_MODE_ID    = "BISTATIC"
INSTRUMENT_MODE_DESC  = "Bistatic Collect"
LRO:LOOK_AZIMUTH_ANGLE = 294.2 <deg>
LOOK_DIRECTION        = RIGHT
SOURCE_PRODUCT_ID     = {
  "arecibo.bsp",
  "arecibo.tf",
  "moon_pa_de421_1900-2050.bpc",
  "pck00010.tpc",
  "moon_080317.tf",
  "de421.bsp",
  "naif0010.tls",
  "lro_frames_2010214_v01.tf",
  "LRO_DEF_20110516_00.BSP",
  "LRO_DEF_20110516_00.RC".
}

}
DESCRIPTION           = "Mini-RF Level 0 bistatic experiment data record (EDR) of the imaginary portion of the horizontal polarized backscattered signal"

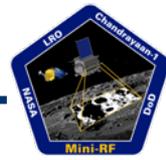
/* Data Object Description. */
OBJECT                = IMAGE
NAME                  = "MINI-RF SAR DATA"
CENTER_LONGITUDE     = -6.993 <deg>
CENTER_LATITUDE      = 6.756 <deg>
MAXIMUM_LATITUDE     = 15.78 <deg>
MINIMUM_LATITUDE     = -2.394 <deg>
WESTERNMOST_LONGITUDE = -8.072 <deg>
EASTERNMOST_LONGITUDE = -5.803 <deg>
LINES                 = 1001
LINE_SAMPLES         = 576691
SAMPLE_TYPE          = PC_REAL
SAMPLE_BITS           = 32
MINIMUM              = -9.55914E6
MAXIMUM              = 9.44040E6
MEAN                 = 2.90264
STANDARD_DEVIATION   = 2.45093E5
HORIZONTAL_PIXEL_SCALE = 1.00 <meter>
VERTICAL_PIXEL_SCALE = 50.00 <meter>

END_OBJECT            = IMAGE
END
```





# USING MINI-RF BISTATIC DATA

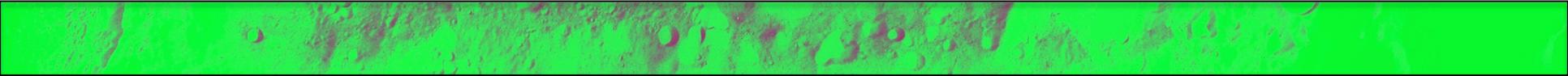


# 2012-137: NEWTON EDR

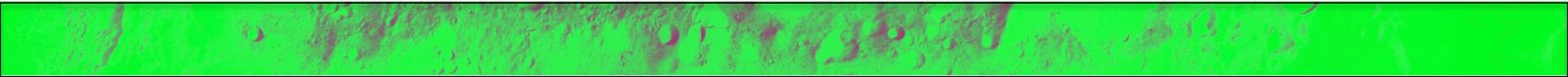
Exploring the  
Moon with Radar  
**Mini-RF**  
Miniature Radio Frequency

HI

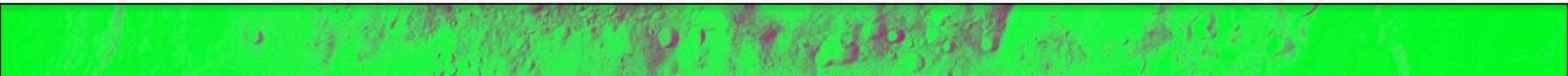
N ←



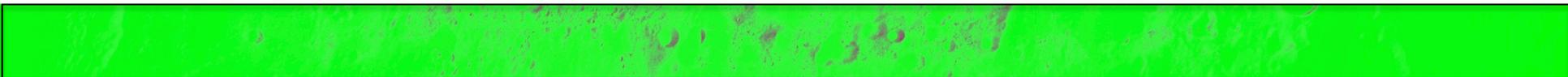
HR



VI



VR



APL



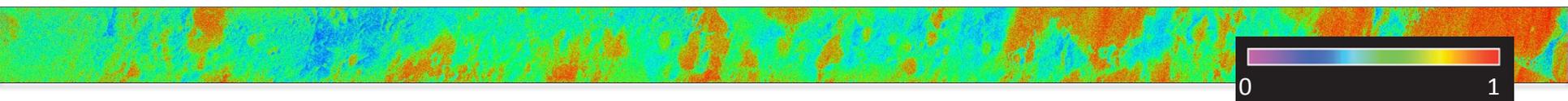
# 2012-137: NEWTON RDR

Exploring the  
Moon with Radar

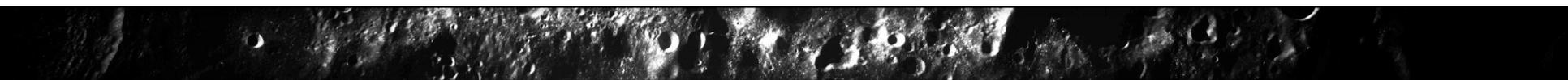
**Mini-RF**  
Miniature Radio Frequency

Circular Polarization Ratio

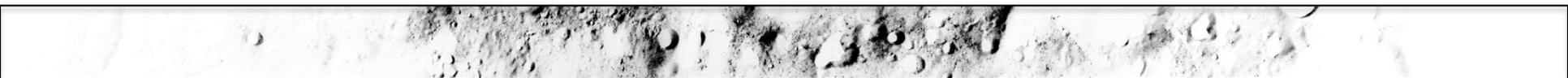
N ←



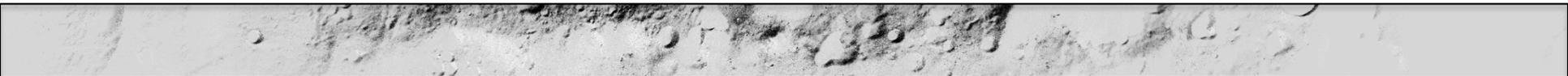
S1 (total backscattered power)



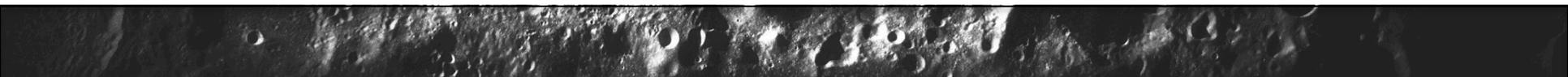
S2



S3



S4

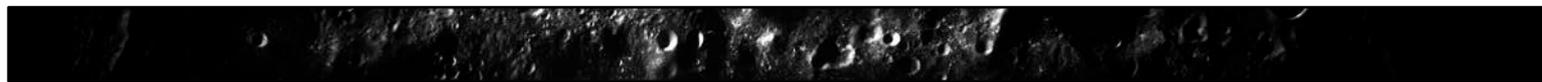


# 2012-137: NEWTON DDR

Exploring the  
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S1 (total backscattered power)



Latitude



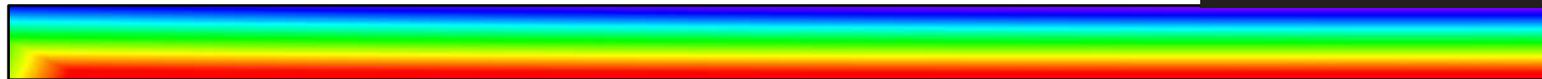
Longitude



Incidence Angle



Emission Angle



Phase Angle (beta)

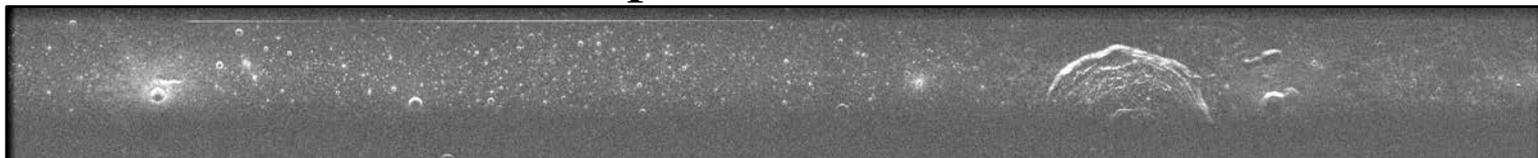


# 2011-096:LOW POWER 1

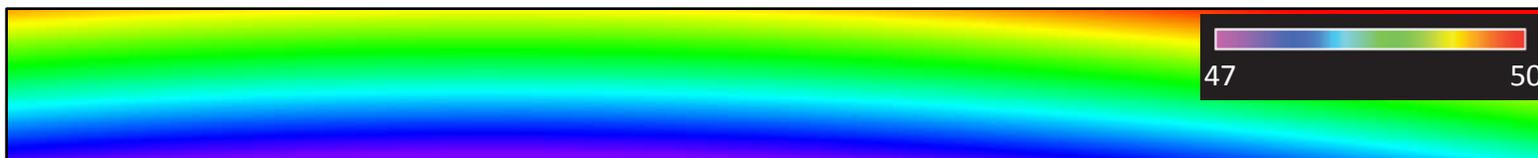
Exploring the  
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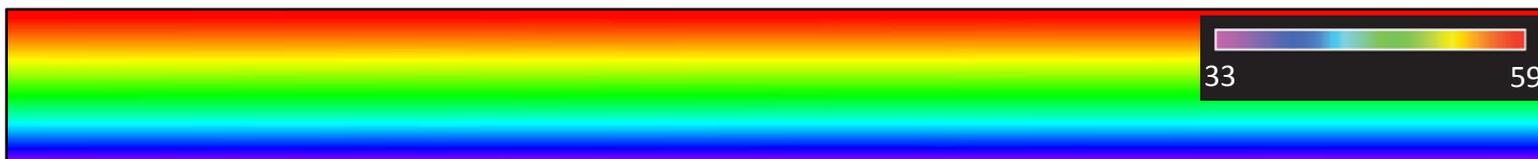
## S1 (total backscattered power)



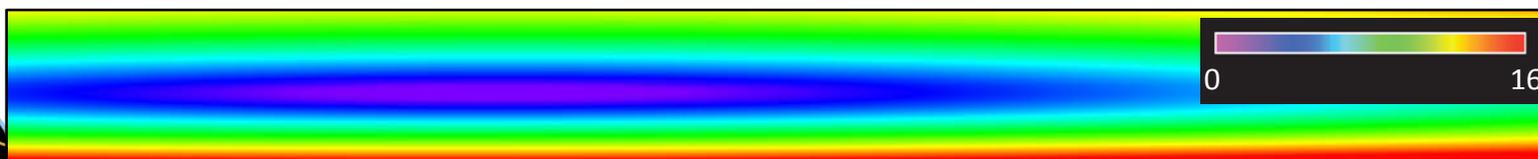
## Incidence Angle



## Emission Angle



## Phase Angle (beta)

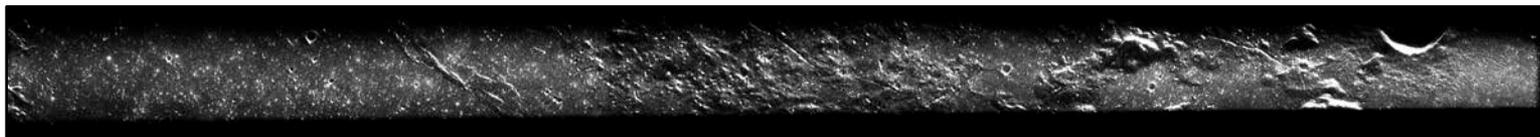


# 2012-137: SINUS AESTUUM

Exploring the  
Moon with Radar

Mini-RF  
Miniature Radio Frequency

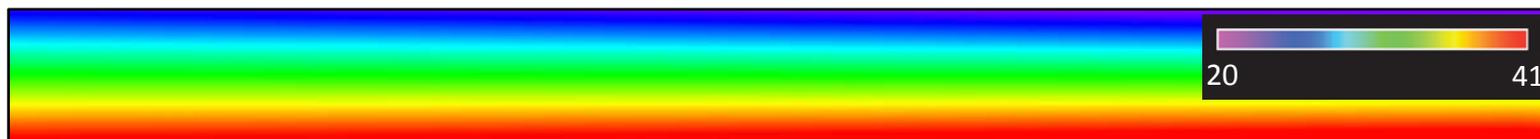
## S1 (total backscattered power)



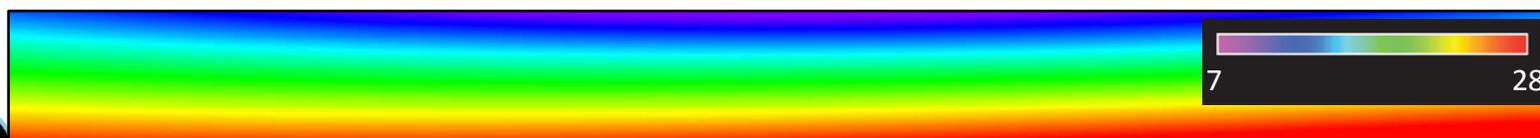
## Incidence Angle



## Emission Angle



## Phase Angle (beta)

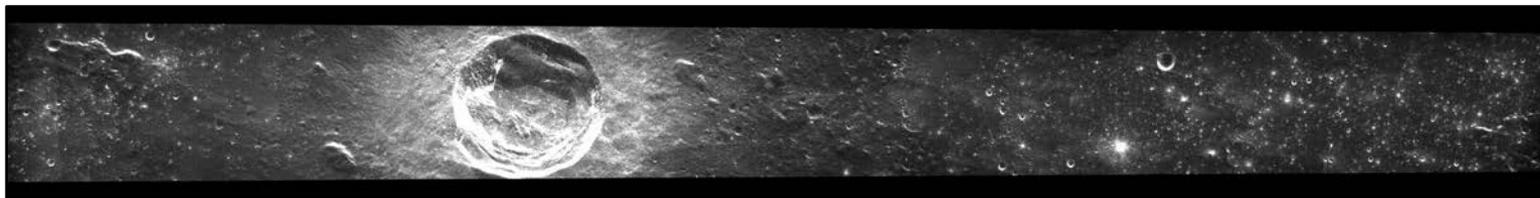


# 2012-276: Kepler

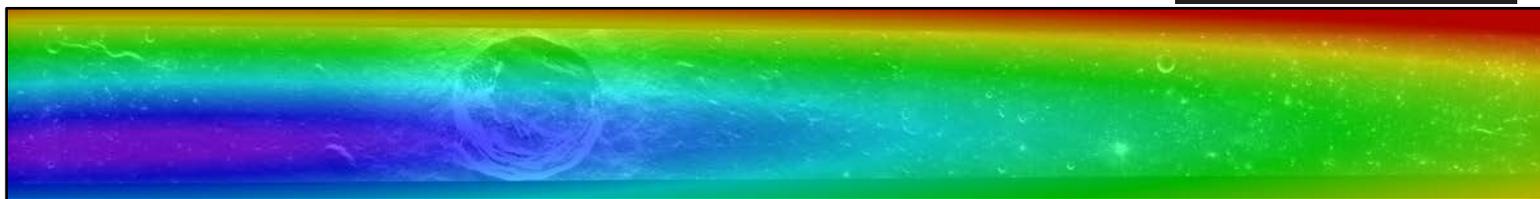
Exploring the  
Moon with Radar  
**Mini-RF**  
Mini-UHF Radio Frequency

S1 (total backscattered power)

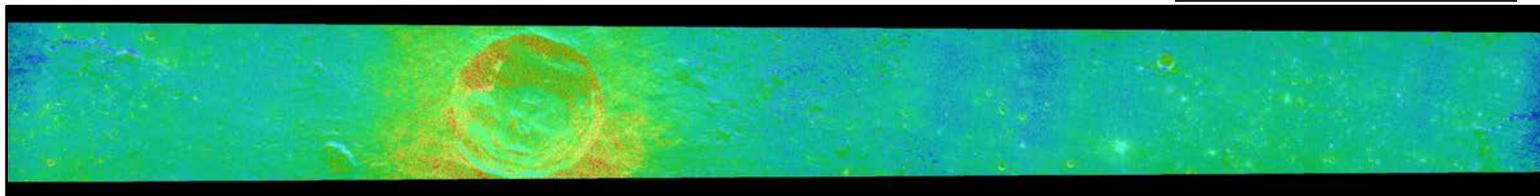
N ←



Phase Angle



Circular Polarization Ratio



(Not yet in PDS)

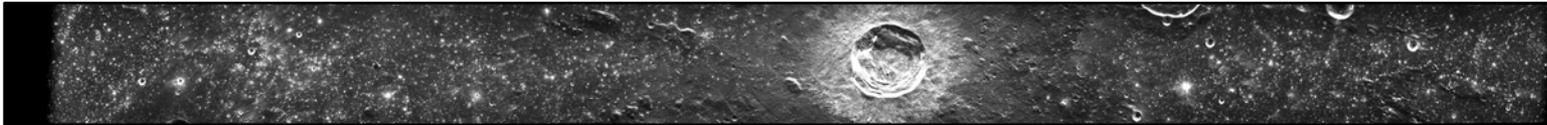


# 2013-073:Kepler

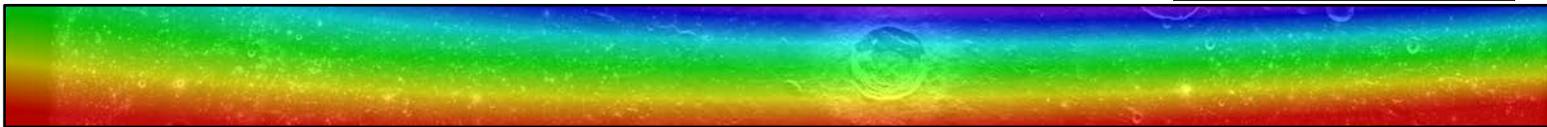
Exploring the  
Moon with Radar

Mini-RF  
Miniature Radio Frequency

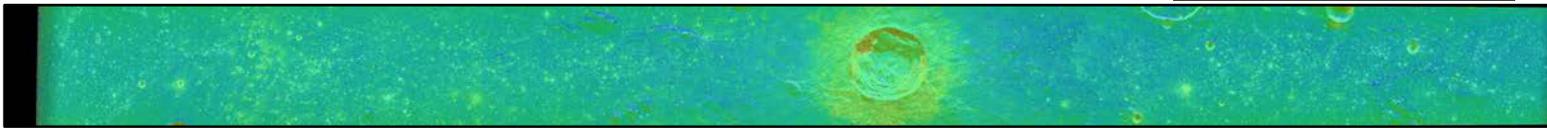
## S1 (total backscattered power)



## Phase Angle

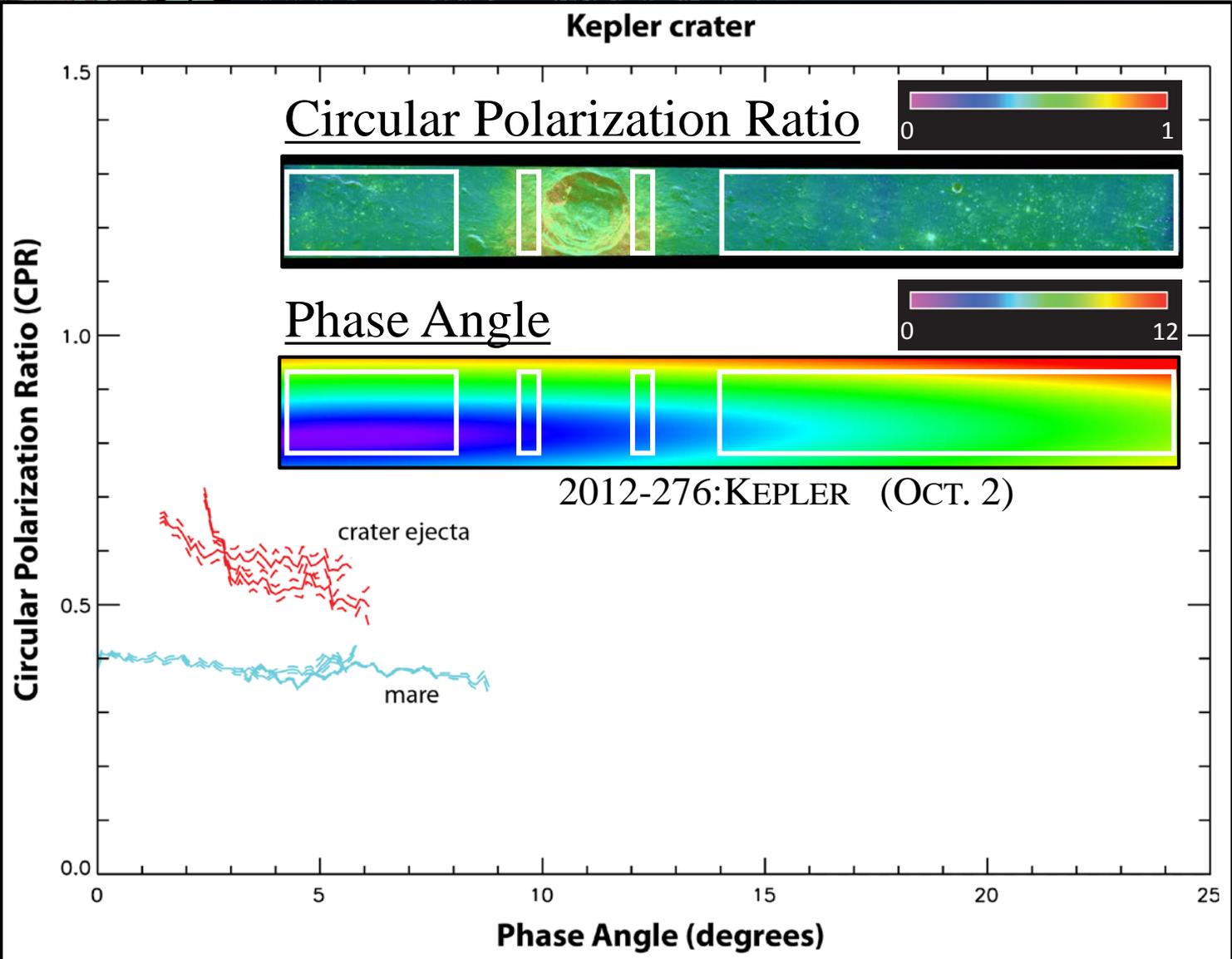


## Circular Polarization Ratio



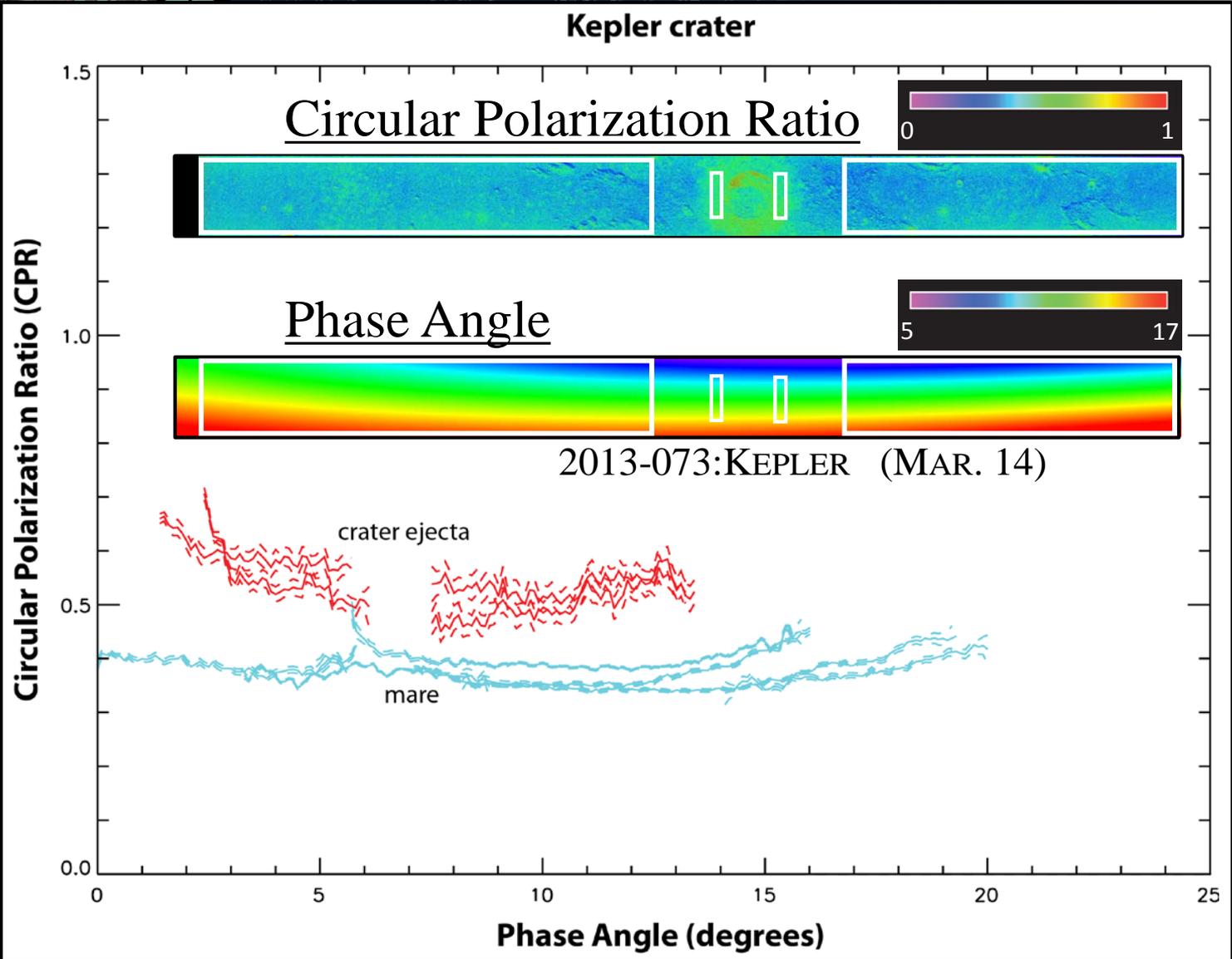
# 2012-276: Kepler

Exploring the Moon with Radar



# 2013-073:Kepler

Exploring the Moon with Radar





Exploring the  
Moon with Radar

**Mini-RF**  
Mini-RF Radio Frequency

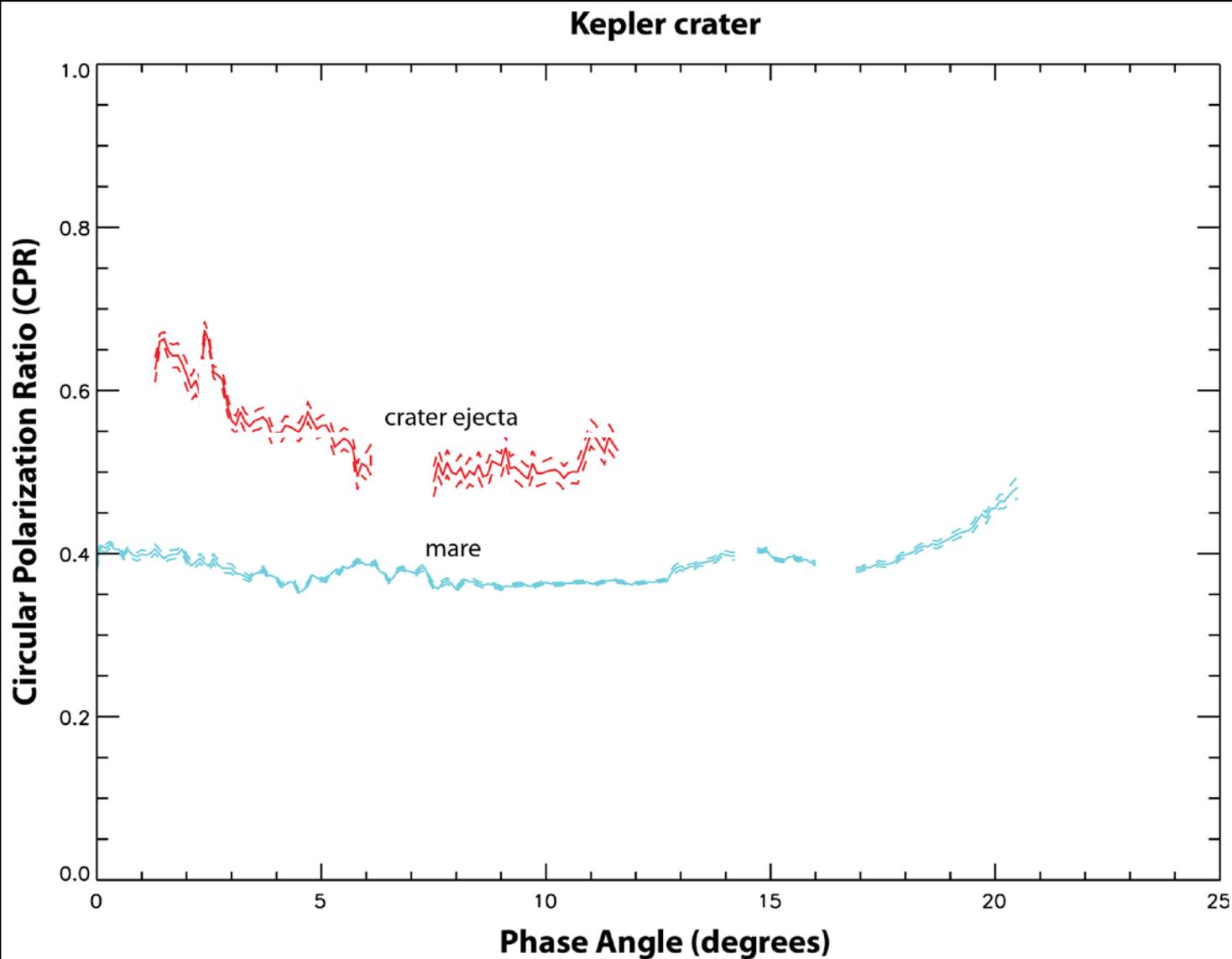


APL

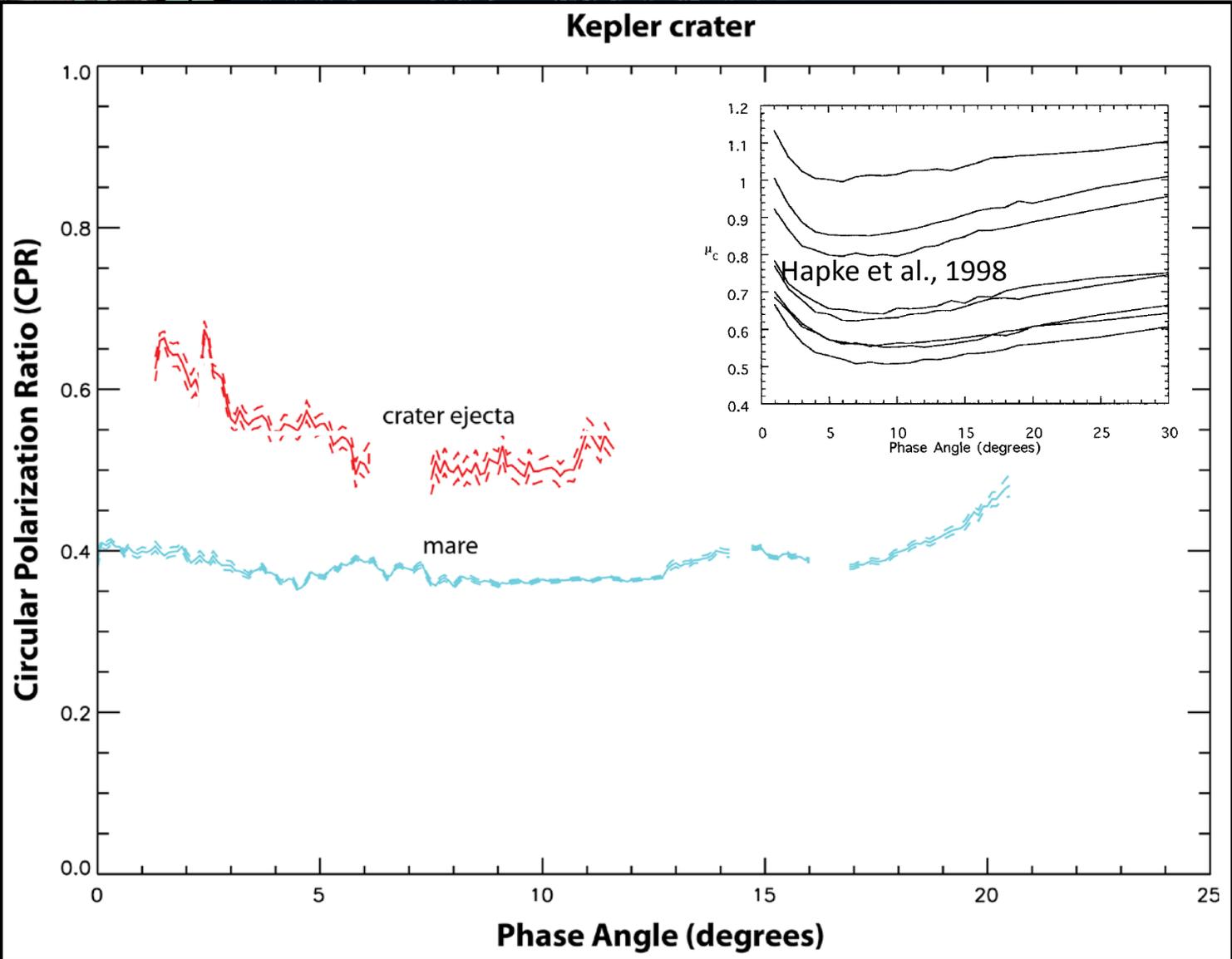


# BISTATIC CAMPAIGN: NON-POLAR

Exploring the  
Moon with Radar



# BISTATIC CAMPAIGN: NON-POLAR



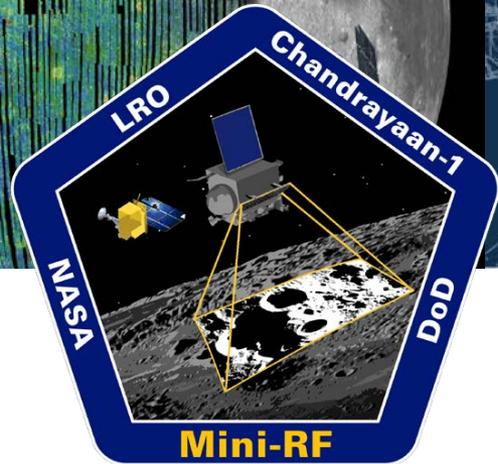
# Provided Data

*Exploring the  
Moon with Radar*

**Mini-RF**  
Miniature Radio Frequency

- Level 0 (EDR) and Level 1 (RDR, DDR) data products
- Projected onto a sphere, but currently we don't have a sensor model





# USING MINI-RF BISTATIC DATA FROM THE PDS

