

Lunar Reconnaissance Orbiter: Enabling CLPS Mission Success



Barbara Cohen, GSFC

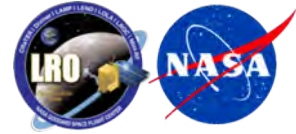


Noah Petro, John Keller,
Maria Banks, NASA GSFC



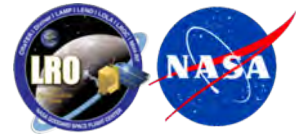
Erick Malaret, Applied
Coherent Technology Corp.

Outline

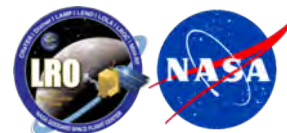


- Goals: What data already exist, what data can you ask for, and what to expect when you ask for new data
- Data: LRO Instruments, data, and examples
- Visualization tools: Quickmap and Jmoon
- Archives: The Planetary Data System
- Menu of help options

Lunar missions & datasets



- Ranger, Surveyor, Lunar Orbiter, Apollo, Luna, Lunokhod (1970's)
- Galileo & Cassini (1990's) - flybys
- Clementine (1994) – orbiter, mapped most of the lunar surface in UV-VIS-NIR (TiO₂, FeO, soil maturity maps)
- Lunar Prospector (1998-99) – orbiter. Gamma Ray Spectrometer (GRS) - global element maps (U, Th, K, Fe, Ti, O, Si, Al, Mg, Ca) at 150 km/px and variable precision, and Neutron Spectrometer (NS) – H abundance at 150 km/ px
- SMART-1, Kaguya, Chang'E, Chandrayaan-1 – international orbiters – see next slide
- Ch-1 Moon Mineralogy Mapper (M3) - Global mineral maps, surface water
- LRO (2009) – mapping orbiter – more to come
- LCROSS (2009) – polar impactor at south pole: 5-10 wt.% water, other volatile substances
- ARTEMIS (2010) - Lunar space environment, solar wind, magnetotail and lunar wake
- GRAIL (2011) - Highest-quality gravity field of the Moon
- LADEE (2012) - Characterize the lunar atmosphere, document the dust environment at 50 km
- EM-1 Cubesats (2020) - Lunar Flashlight, Lunar IceCube, LunaH-Map, LunIR, OMOTENASHI



Mission	Kaguya (Japan) 2007-09	Chang'e 1,2 (China) 2007-09	Chandrayaan (India) 2008-09	LRO/LCROSS (NASA) 2009-
<i>Imaging:</i>				
Camera (VIS monochrome)	x	x	x	x
Typical VIS image resolution (m)	10 (global)	120 (global?)	100 (global)	0.5 (regional)
UV imaging	x			x
IR imaging	x	x	x	x
Thermal (broadband) IR				x
Multi-band UV-VIS-IR imaging	x		x	x
<i>Spectroscopy:</i>				
Gamma Ray Spectrometer	x	x	x	
Neutron Spectrometer				x
Alpha Particle Spectrometer	x			
X-Ray Spectrometer	x	x	x	
Infrared Spectrometer	x		x	
<i>Planetary shape and structure</i>				
Radar	x	x	x	x
Laser Ranging/Altimeter	x	x	x	x
Gravity	x (far side)	x	x	x
<i>Particles and fields:</i>				
High-energy Detector	x	x		
Solar Wind Detector		x	x	
Solar X-Ray Monitor			x	
Lunar Radiation Environment				x
Plasma Analyzer	x			
Plasma Imager (terrestrial)	x			
Radio Science (lunar ionosphere)	x			
Radiometer		x		
Magnetometer	x			
<i>Impactor experiments:</i>		LRO Data Workshop for CLPS	x	x

LRO Overview

• Safe Landing Sites

- High resolution imagery
- Global maps
 - Topography
 - Rock abundances

• Locate potential resources

- Water at the lunar poles?
- Continuous source of solar energy
- Mineralogy

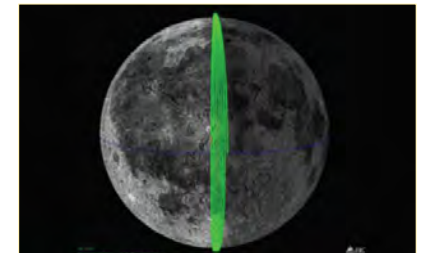
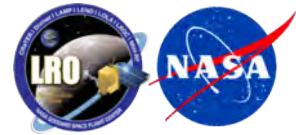
• Space Environment

- Energetic particles
- Neutrons

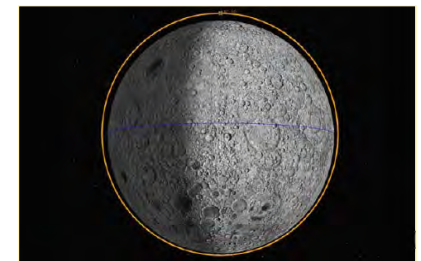
• New Technology

- Advanced Radar

- Launched on an Atlas V into a direct insertion trajectory to the moon. Co-manifested with LCROSS lunar impactor mission.
- On-board propulsion system used to capture at the moon, insert into and maintain 50 km mean altitude circular polar orbit.
- 1 year exploration mission followed by handover to NASA Science Mission Directorate.
- Orbiter is 3-axis stabilized, nadir pointed, operates continuously during the primary mission.
- Data products delivered to Planetary Data Systems (PDS) within 6 months of completion of primary mission.

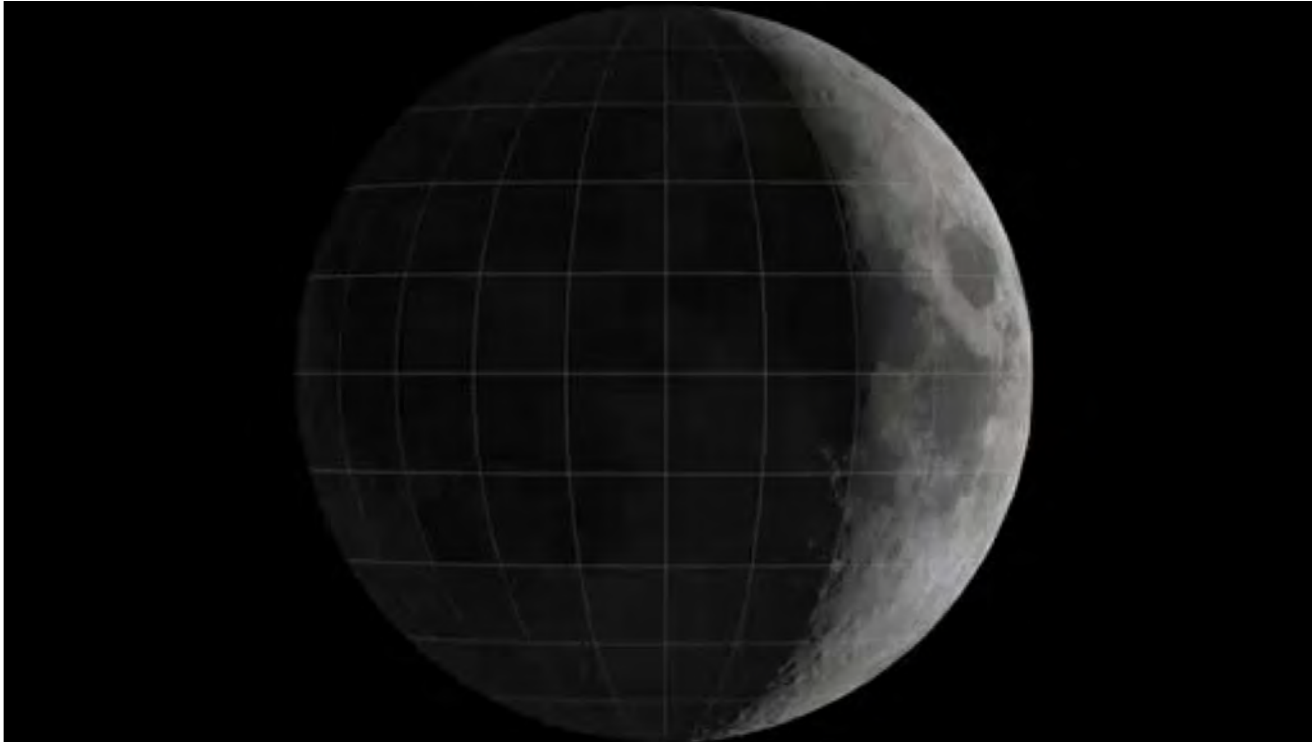
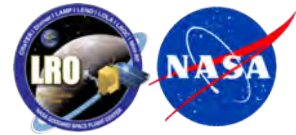


**Polar Mapping Phase, 50 km
Altitude Circular Orbit,
At least 1 Year**



**Commissioning Phase, 30 x 216 km
Altitude Quasi-Frozen Orbit, Up to 60
Days**

LRO maps in a fixed polar orbit



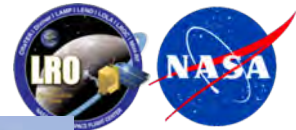
Current orbital altitude: 100 km; period:

<https://www.lroc.asu.edu/about/whereislro>

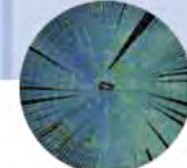
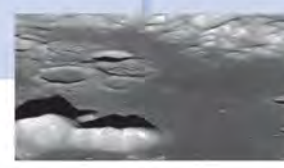
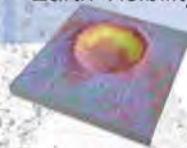
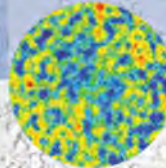
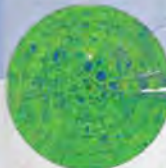
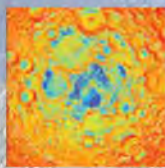
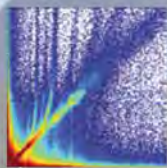
Can see an LRO-eye view in Quickmap (more following)

LRO Data Workshop for CLPS

LRO Data and Data Products

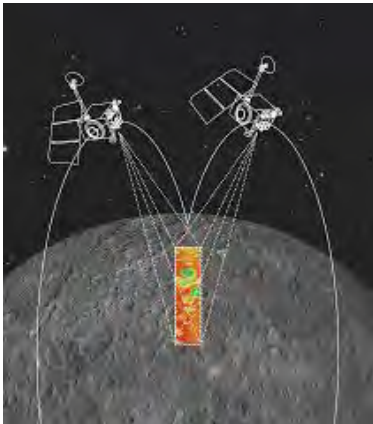


Instrument	CRaTER	Diviner	LAMP	LEND	LOLA	LROC NAC	LROC WAC	Mini-RF
Instrument Classification	Primary and albedo cosmic ray sensor	Radiometer	UV Imaging Spectrograph	Neutron Detector	Laser Altimeter	High Resolution Camera	Multi-Spectral Camera	X-and S-band Synthetic Ap. Radar
Primary Data	Lunar and Deep Space Radiation environment	NIR Spectra of the lunar surface	UV Spectra of the lunar surface	Neutron abundances in the near surface	Surface Topography	~50 cm scale images	UV-VIS at 100m	Radar imaging
Key Data Products	<ul style="list-style-type: none"> • Proton Albedo of the Surface • Radiation exposure from GCR's and the Sun 	<ul style="list-style-type: none"> • Temperature (Max/Min/ local time) • Rock Abundance • Regolith "density" 	<ul style="list-style-type: none"> • Surface volatiles • UV Albedo 	<ul style="list-style-type: none"> • Water equivalent Hydrogen 	<ul style="list-style-type: none"> • Global 100 m Topography • Slope • Roughness • Albedo at 1024 nm • Degree of Permanent Shade • Earth Visibility 	<ul style="list-style-type: none"> • Local 2m topography • Slope • Roughness • Hazard mapping • Roughness 	<ul style="list-style-type: none"> • TiO2 abundance • Topography • Slope • Roughness 	<ul style="list-style-type: none"> • Roughness • Ice at depth • Circular Polarization Ratio Maps

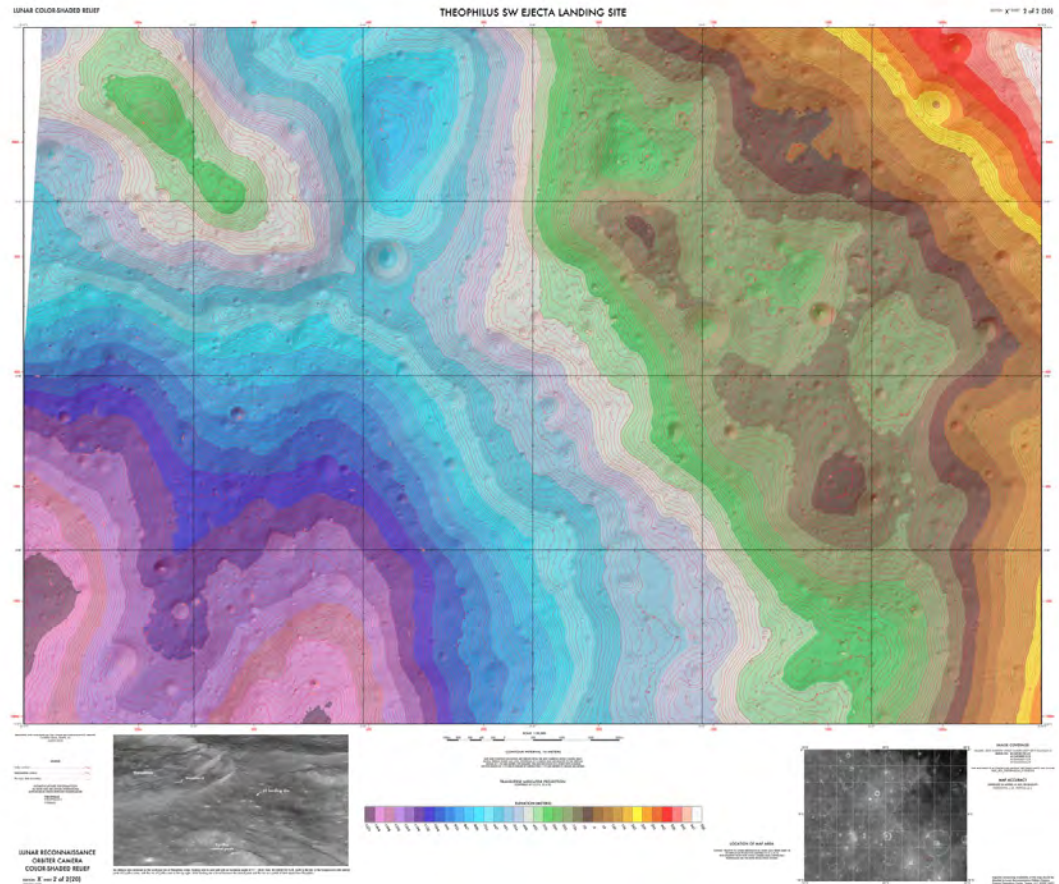
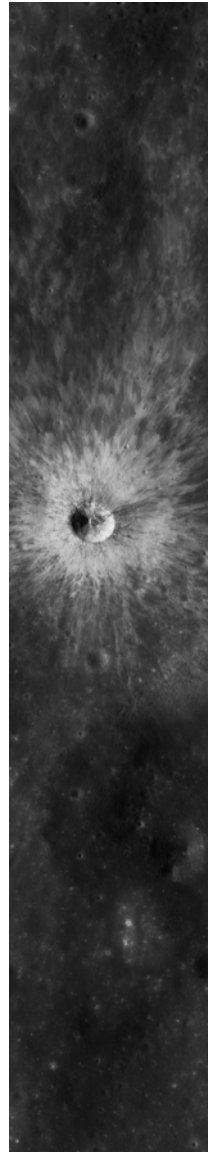


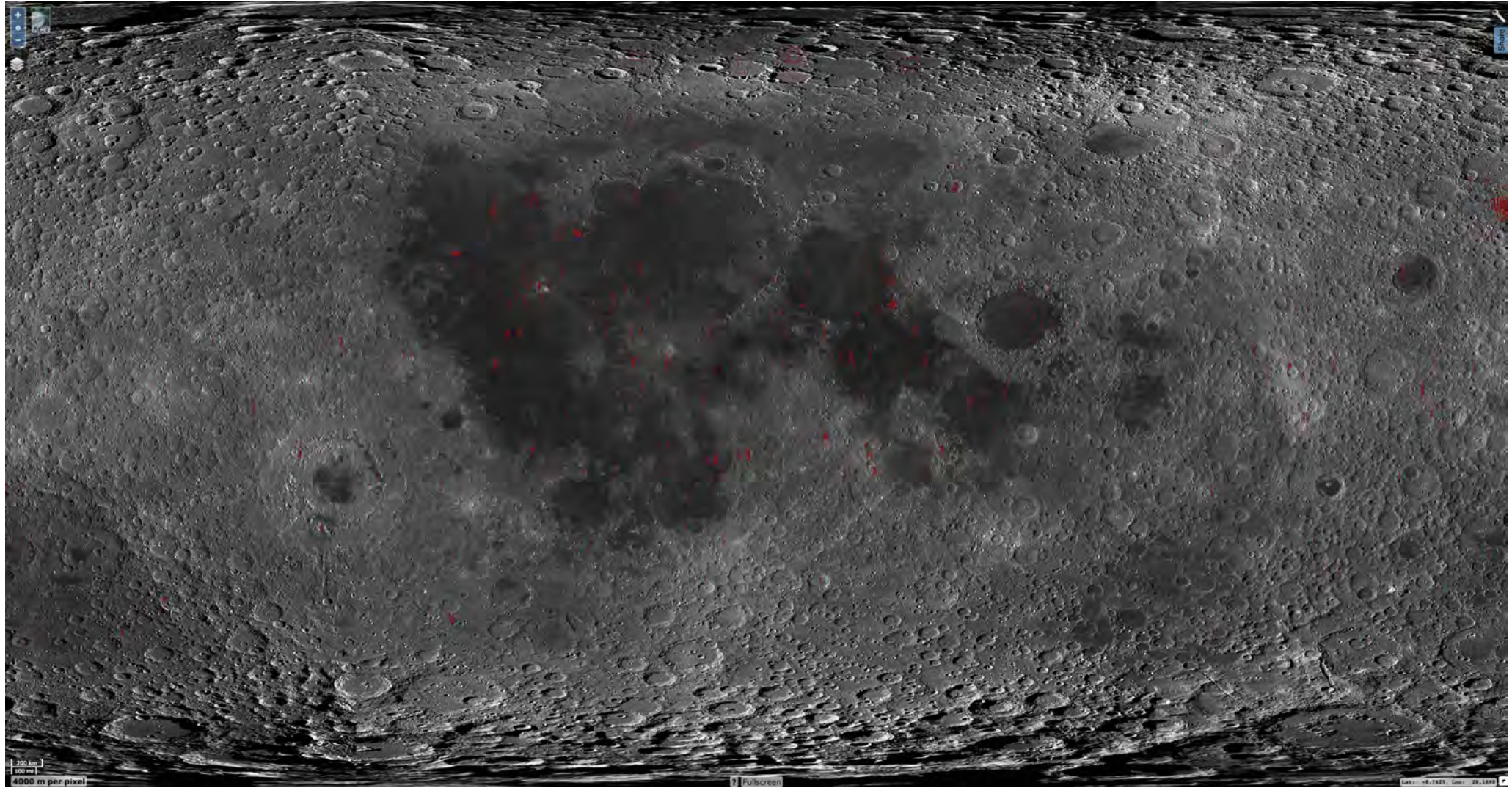
Images

Data: High-resolution images (50 cm per pixel)
Products: NAC mosaics, high resolution Digital Terrain models (DTMs), slope and roughness maps

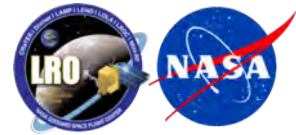


LROC NAC-derived DTMs require multiple observations of the same area at the same lighting conditions

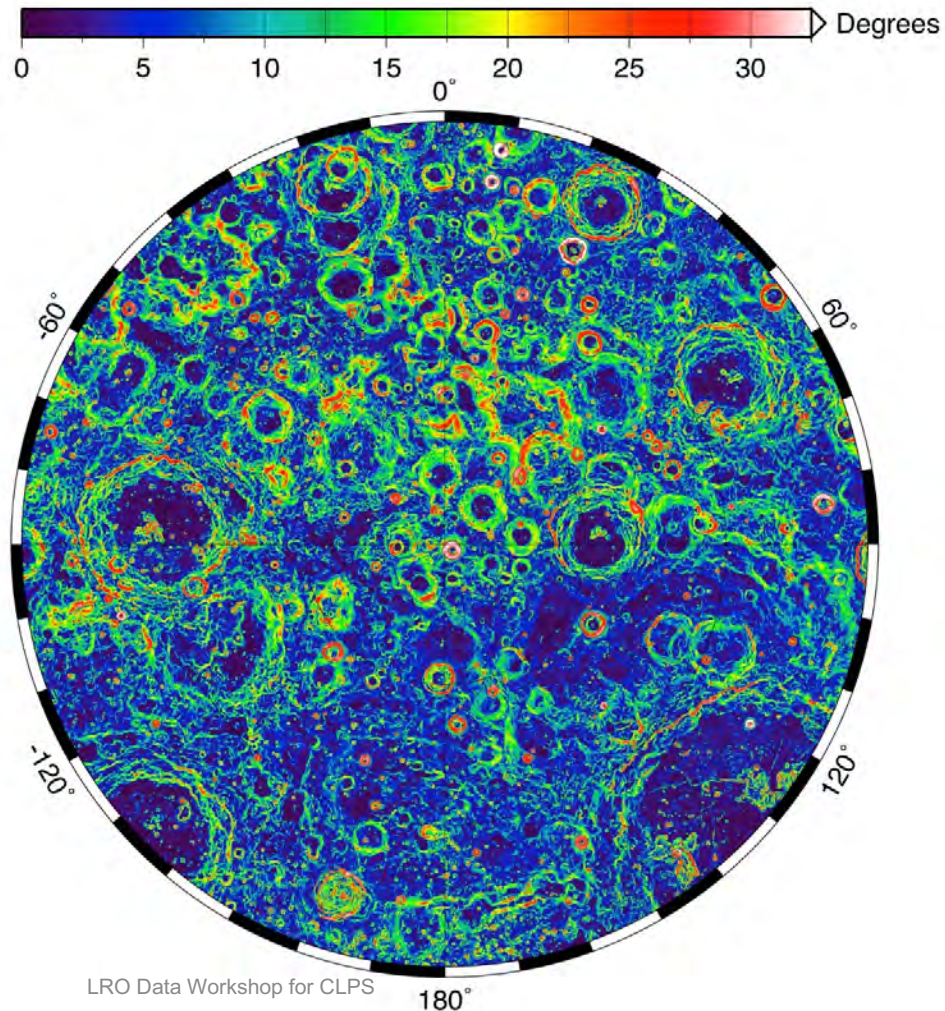




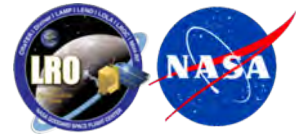
Topography



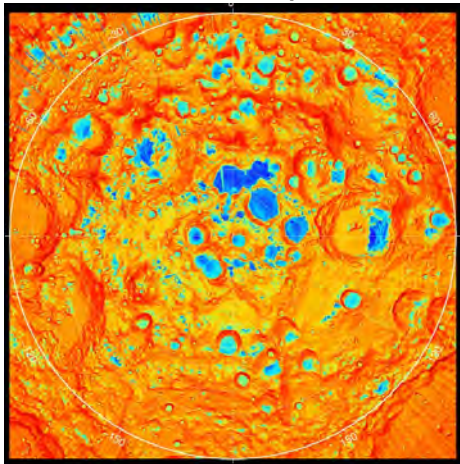
- Data from the LOLA instrument provides global topography
- Products: local and regional slope data
- Slope data can be used for identifying safe landing sites as well as traverse planning.



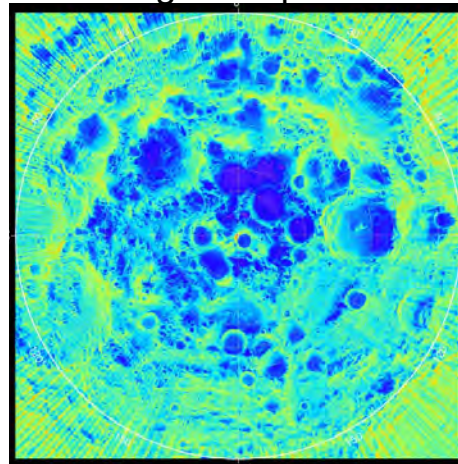
Temperature



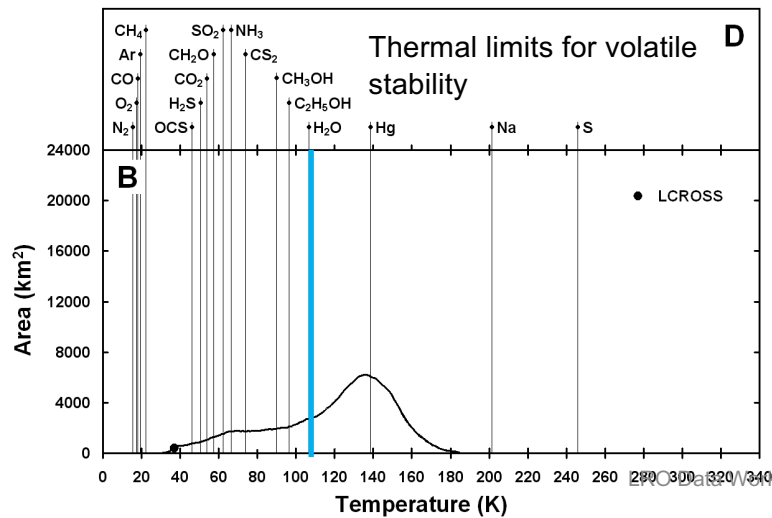
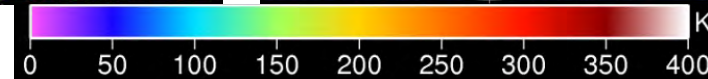
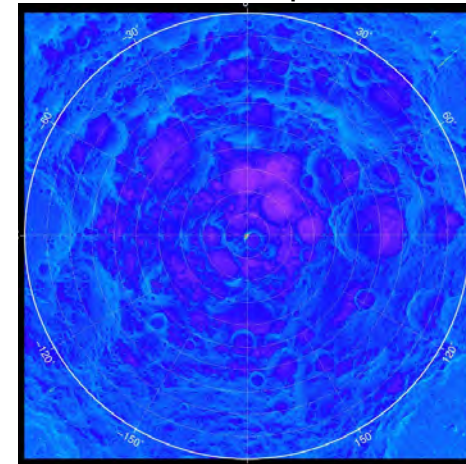
Maximum Temperature



Average Temperature



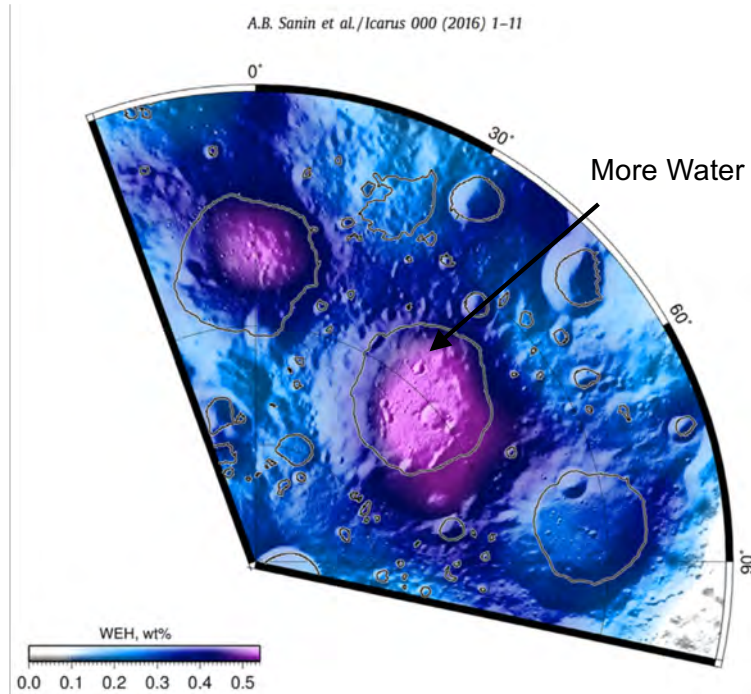
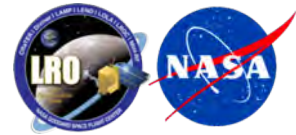
Minimum Temperature



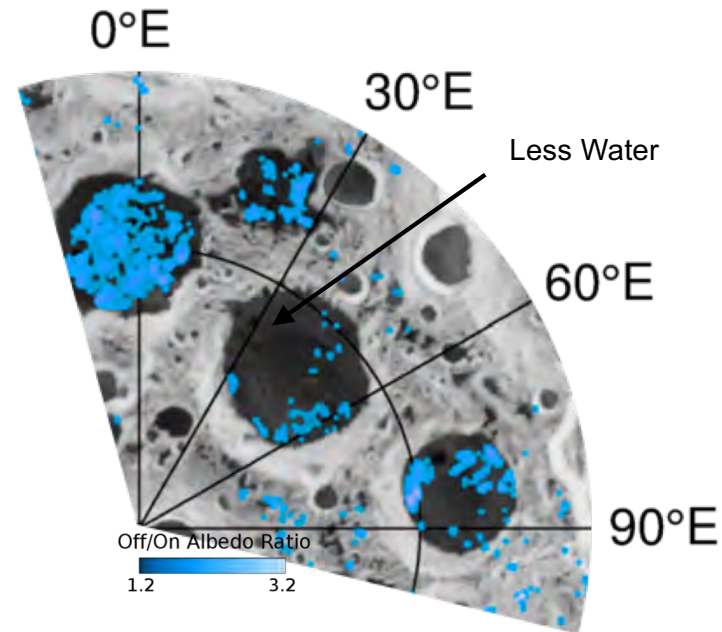
Diviner has observed the lunar poles over a wide range of local times and seasons
Diviner data constrains subsurface temperature

- Map 3-d Volatile Stability
- Guide Volatile Detection

Surface and subsurface ice

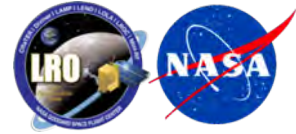


LEND - Water-equivalent hydrogen (WEH) in the **upper ~1 m** (Sanin et al., 2016). Some areas near the South Pole contain more than .34% hydrogen or 3% water equivalent (model dependent)

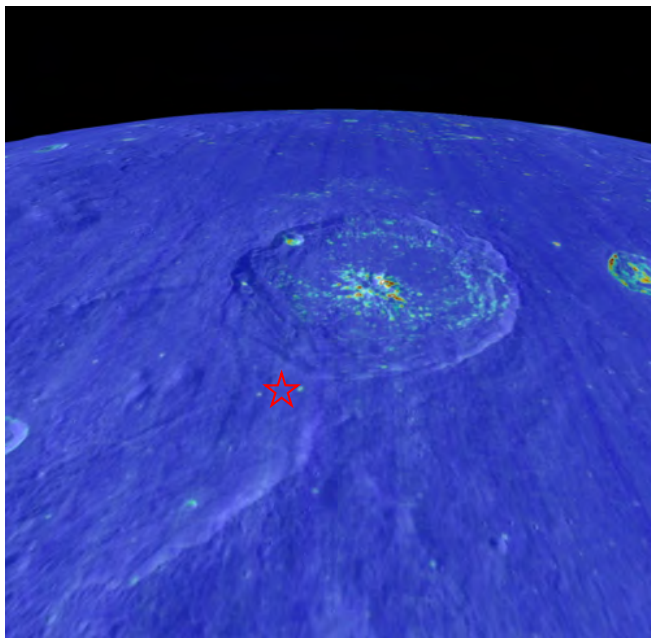


LAMP, LOLA, M3 - H₂O detection **at the surface** (Hayne et al., 2015) – concentrations unknown

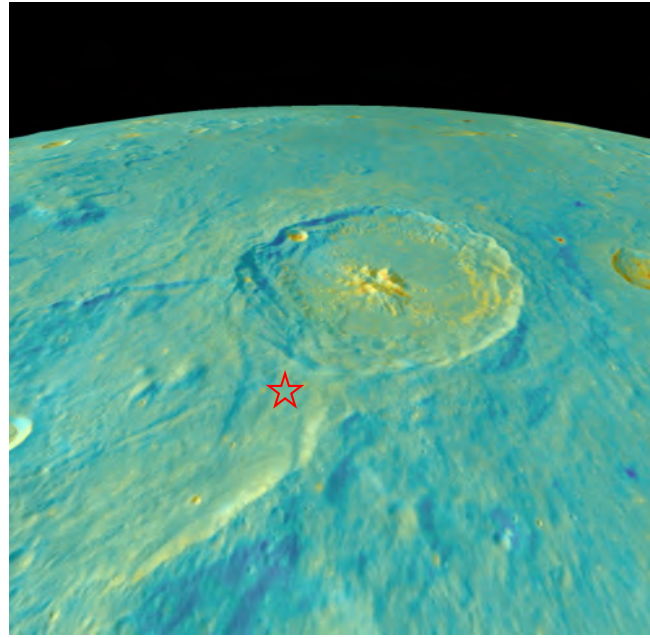
Landing hazards and environment



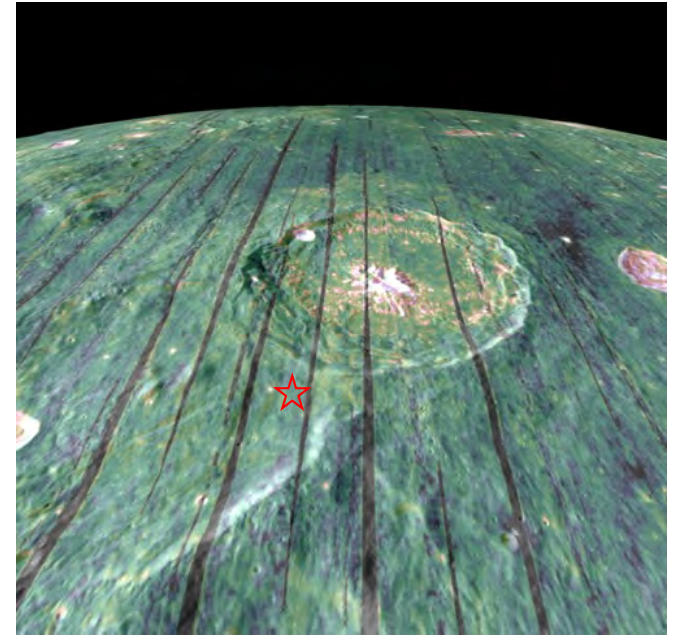
Diviner level 3 summary products on LOLA DEM shaded with WAC global mosaic
Crater Theophilus ~100 km across



Rock abundance



ΔT - night regolith T

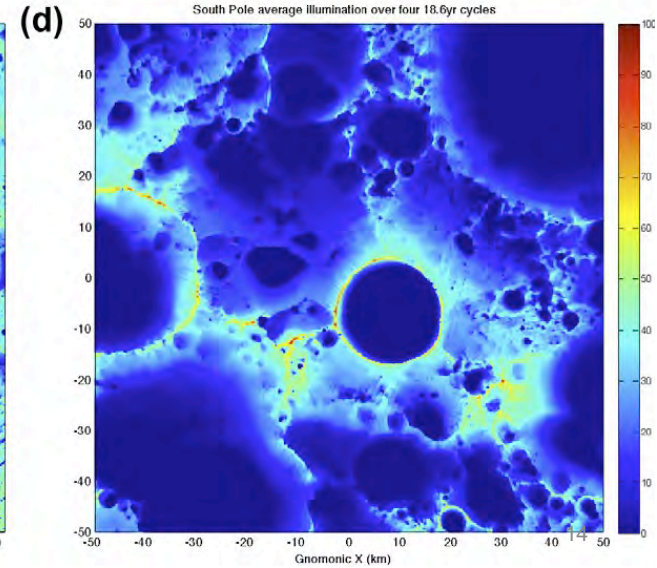
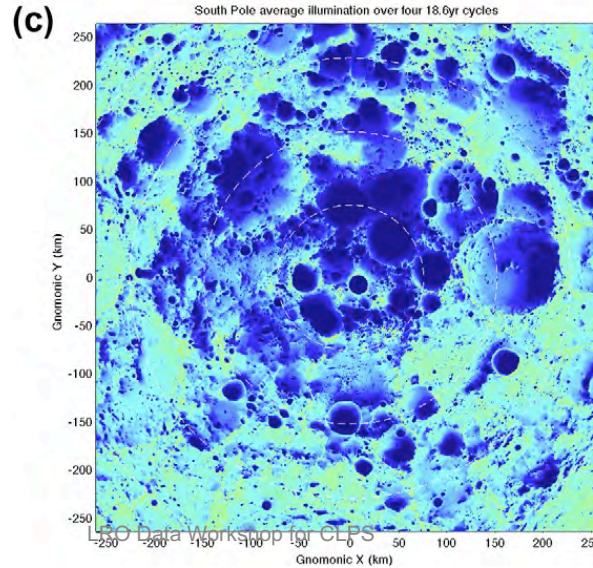
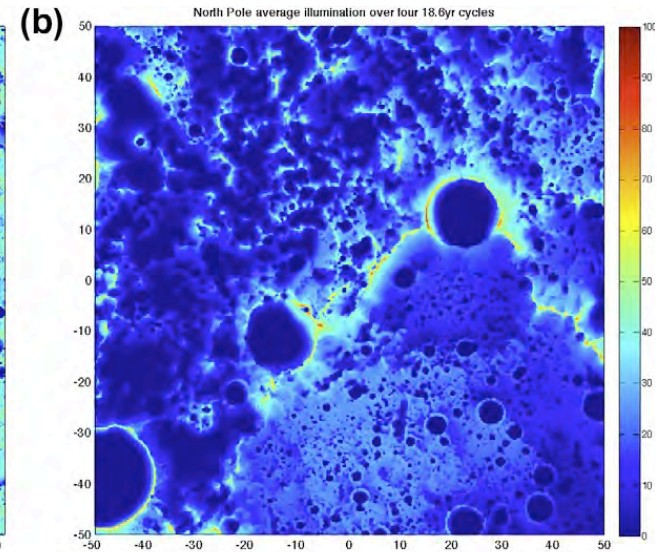
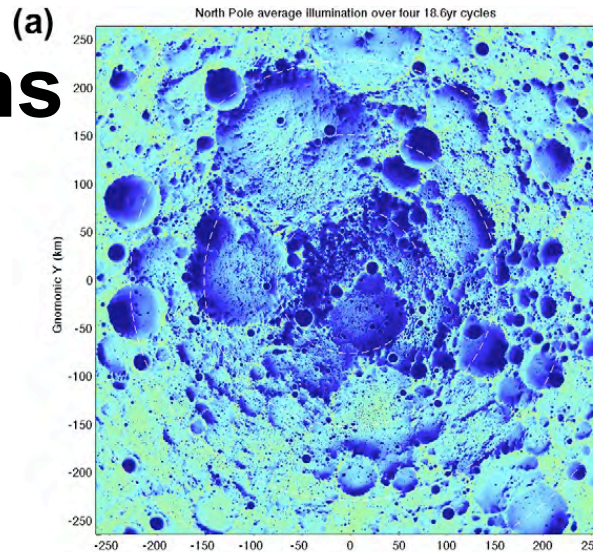


H parameter

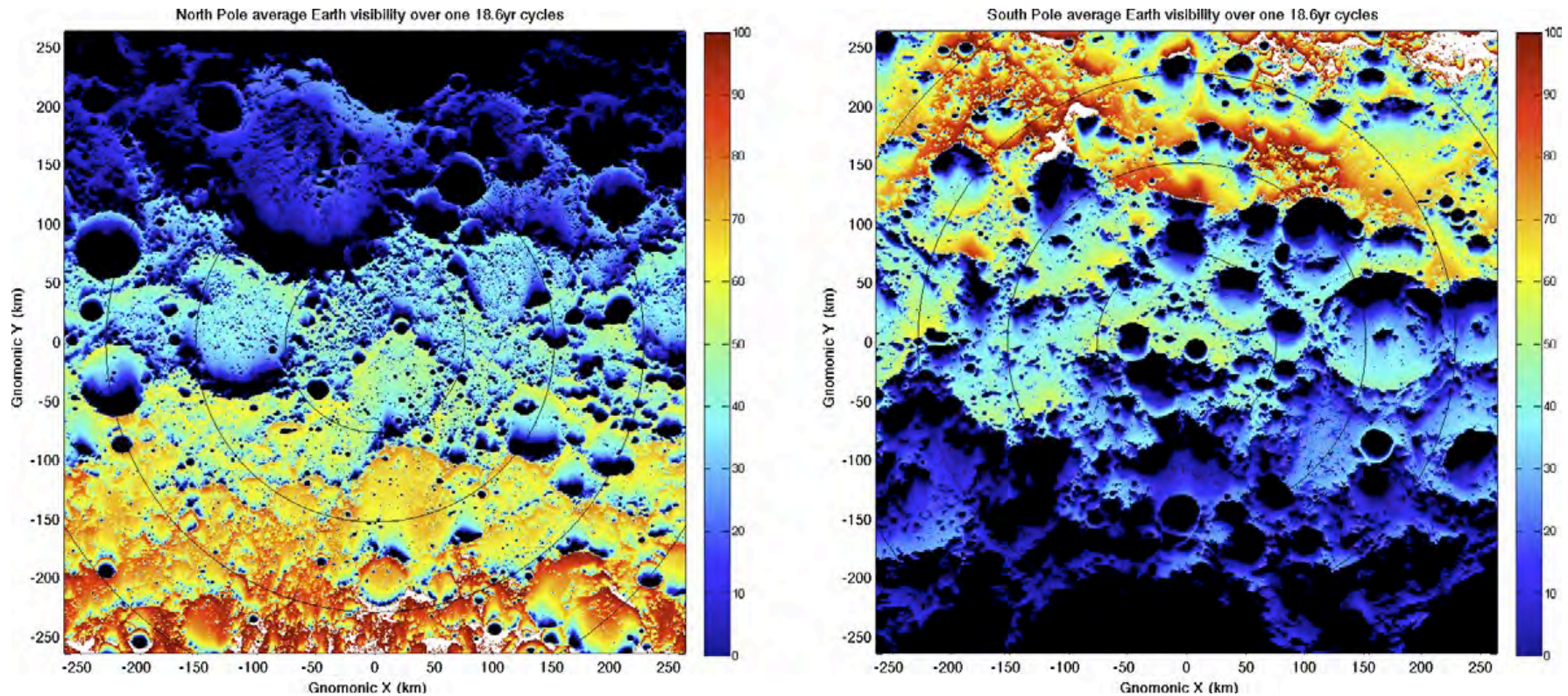
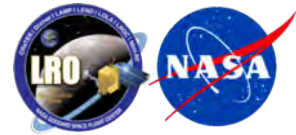
Lighting conditions

Calculated average illumination (in percent) for the north (top) and south (bottom) polar regions. Frames (a,c) extend to 80° ; (b,d) extend to 88° . Model based on LOLA Topography

Areas of nearly continuous illumination can utilize photovoltaic power systems!



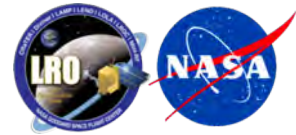
Earth Visibility Maps



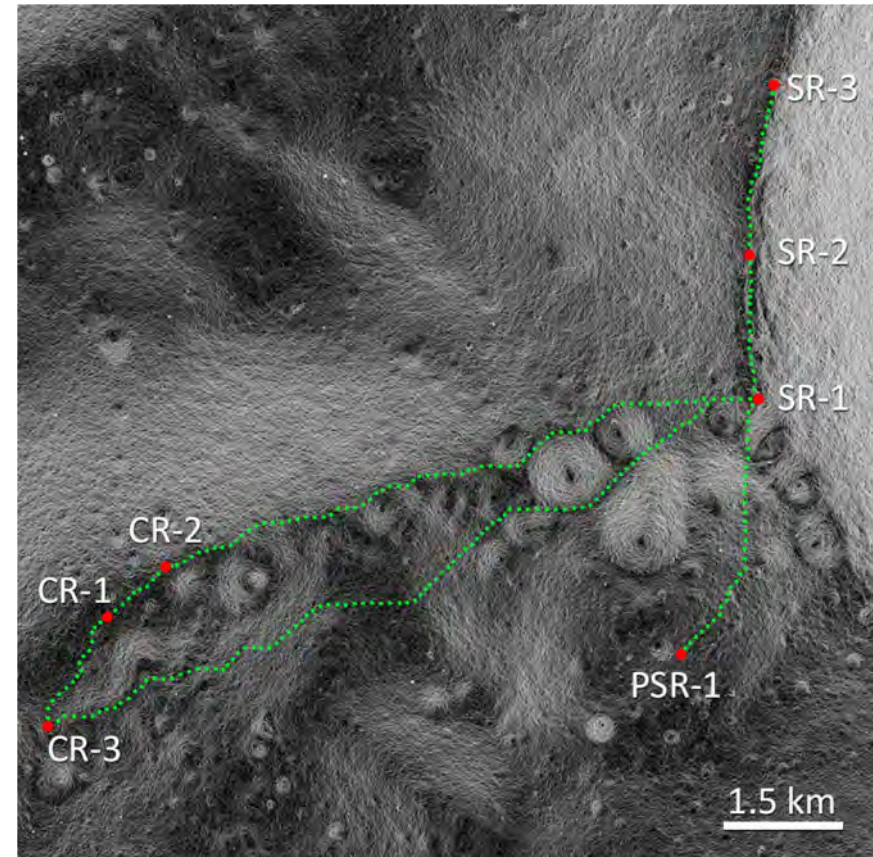
The average visibility of Earth (in percent of a full 18.6 year cycle) for the north (left) and south (right) polar regions.

Full visibility and total lack of visibility are indicated by white and black respectively.

Surface Navigation/Trafficability

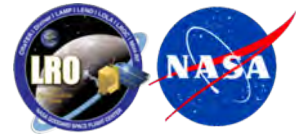


- LRO data, such as topography models from the Narrow Angle Camera and LOLA as well as temperature data derived from the Diviner, has enabled the development of a tool for use in surface traverse planning.
- Based on topography from NAC and LOLA and known surface properties, we can estimate the energy required to traverse between different targets using a terra-mechanics model.
- We also can calculate the illumination conditions along the traverse at any point in time.

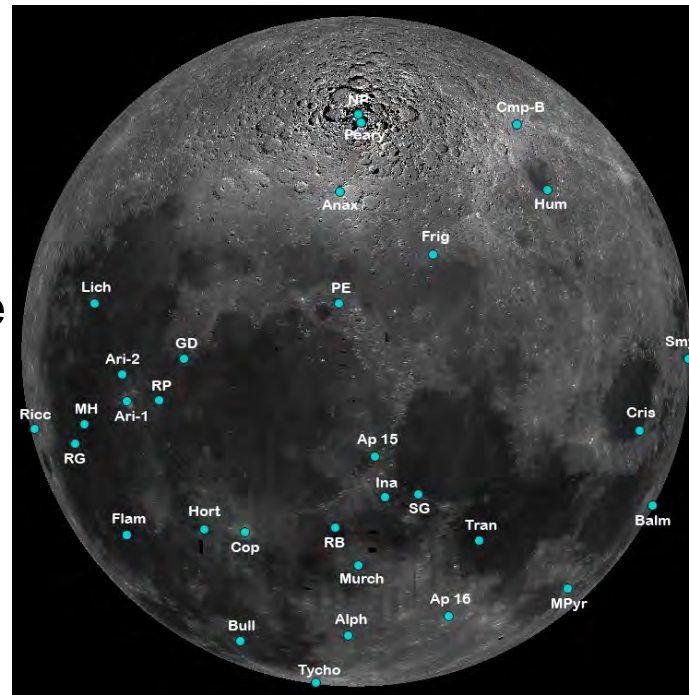


Example of an optimized traverse located along nearly persistently illuminated points on the rim of Shackleton crater (Speyerer et al., 2016).

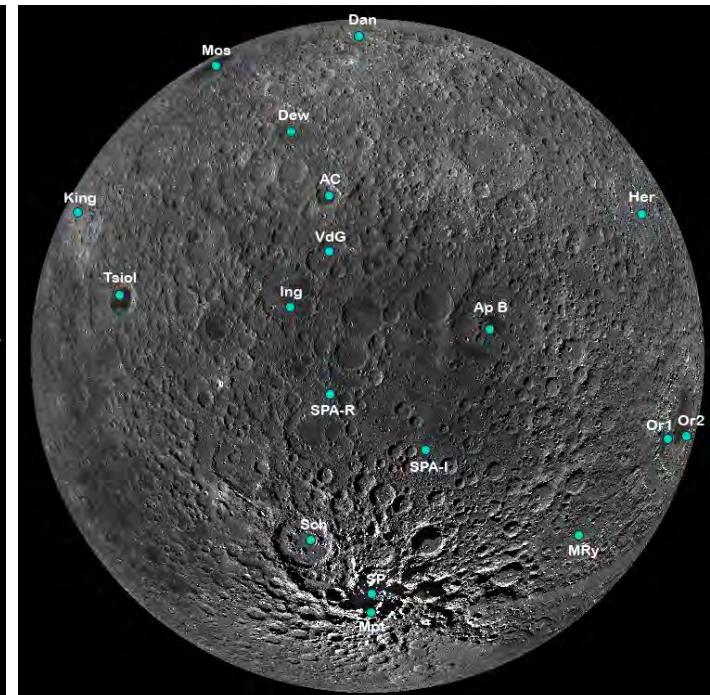
Constellation Regions of Interest



- NASA's Constellation Program selected 50 sites for intense mapping*
- Represent broad range of terrain types and geologic features of interest for human and robotic exploration
- Cx targets included nested 10, 20, and 40 km square regions of interest (ROI).

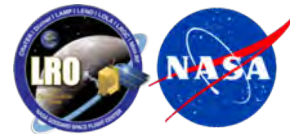


Near Side and North Polar



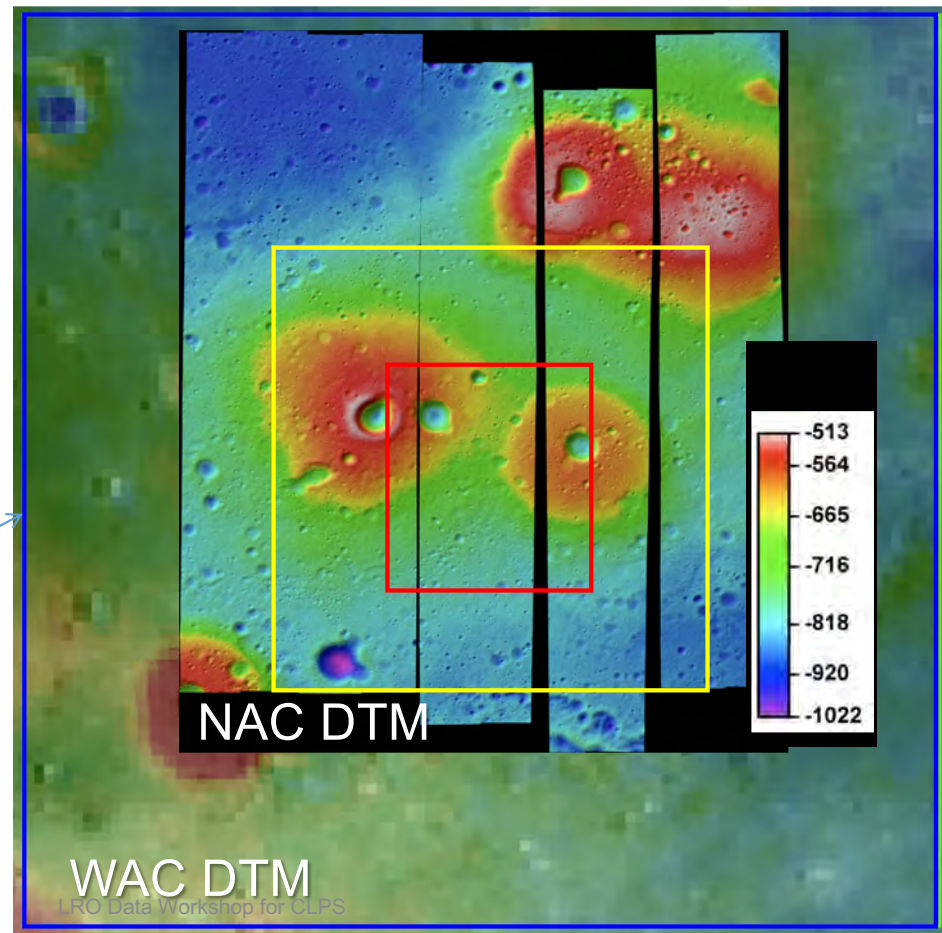
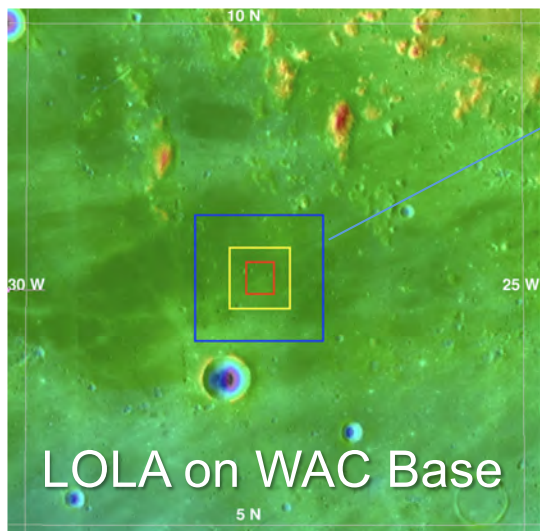
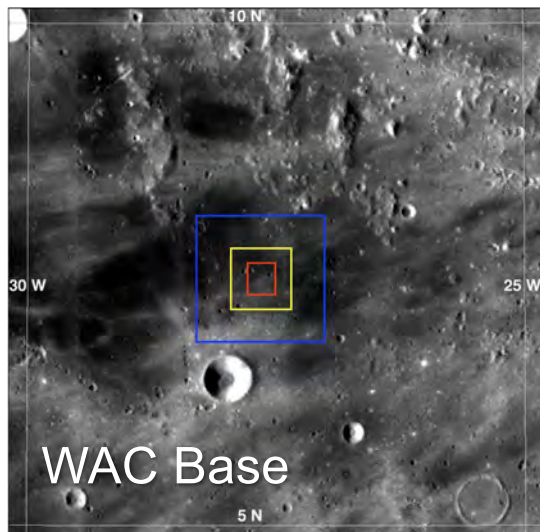
Far Side and South Polar

*Gruener, J. E. And B.K. Joosten, NASA Constellation Program Office Regions of Interest on the Moon: A Representative Basis for Scientific Exploration, Resource Potential, and Mission Operations, Lunar Reconnaissance Orbiter Science Targeting Meeting, Tempe, 2009.



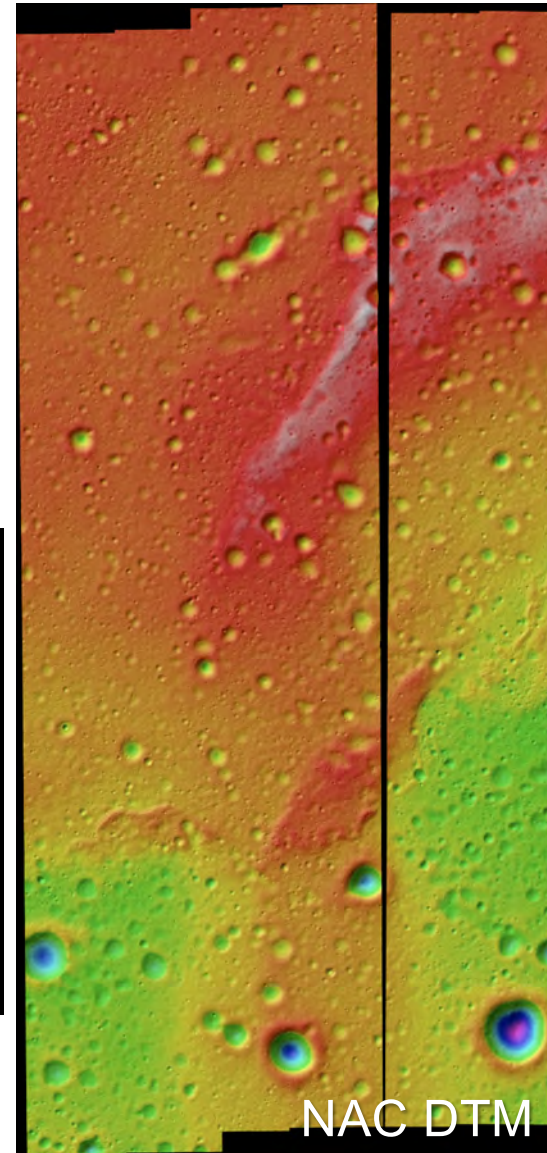
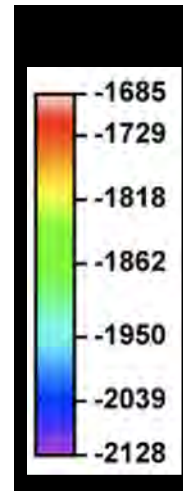
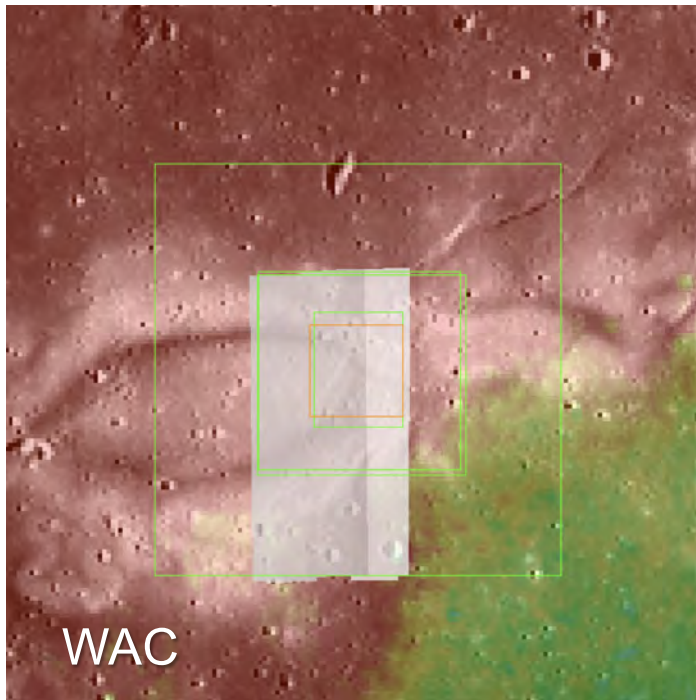
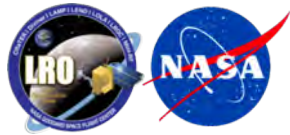
Hortensius Domes

Low Shield Volcanoes in Mare Terrain

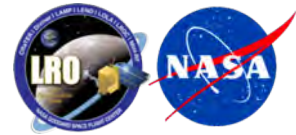


Reiner Gamma

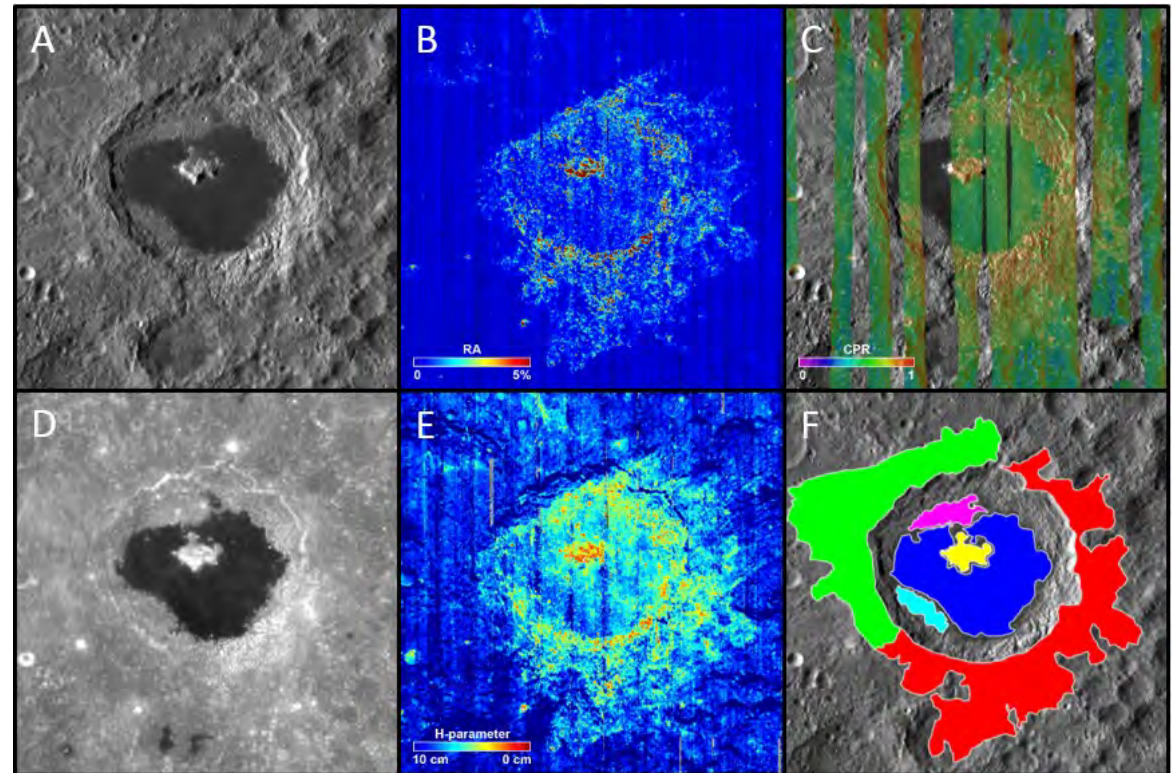
magnetic swirl



LRO Results – easy reference



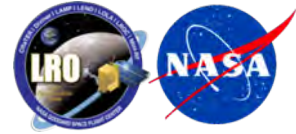
- Icarus, Volume 273, Pages 1-356 (15 July 2016) and Volume 283, Pages 1-358 (February 2017)
- A collection of 50 articles featuring results from each of the seven instrument teams
- Many of the results include cross-instrument data analysis



Tsiolkovskiy crater as seen in various datasets from LRO (A) LROC WAC morphological mosaic, (B) Diviner rock abundance, (C) Mini-RF Circular Polarization Ratio, (D) LROC WAC 689 nm normalized albedo, (E) Diviner H-parameter, and (F) ROIs used in the rock abundance study.

LRO Data Workshop for CLPS

Exploring LRO (and other lunar) data



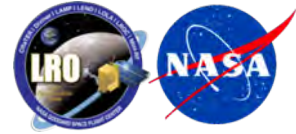
Visualization tools: ACT-REACT Quickmap and JMARS for Earth's Moon

- Free to use
- Online access using web browser – nothing to store locally
- Feature-rich
- Ability to export custom products
- Accessible for the life of the project

Planetary Data System

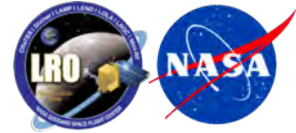
- All data ever collected in raw and processed forms
- Free and permanent
- Includes community-created content (like crater catalogs, mosaics, etc.)
- No limits to data download – but easier to use tools to look at data

How can the LRO team support you?



- POC: Barbara Cohen, Barbara.A.Cohen@nasa.gov, 301-614-6803
- Mission Planning
- Landing and Concurrent Observations
- Post-Landing Assessment

Mission Planning



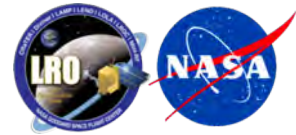
Finding a landing site

- The LRO science team are the world's experts in lunar science and data analysis – we can help you find a great site!
- Sites based on safety and/or mission objectives - water ice, pyroclastic deposits, lava pits, etc.
- Science community priority sites are in the Landing site workshop report from 2017: https://lunar-landing.arc.nasa.gov/downloads/LunarLandedScience_Publication.pdf
- NASA guidelines on historical sites: https://www.nasa.gov/pdf/617743main_NASA-USG_LUNAR_HISTORIC_SITES_RevA-508.pdf

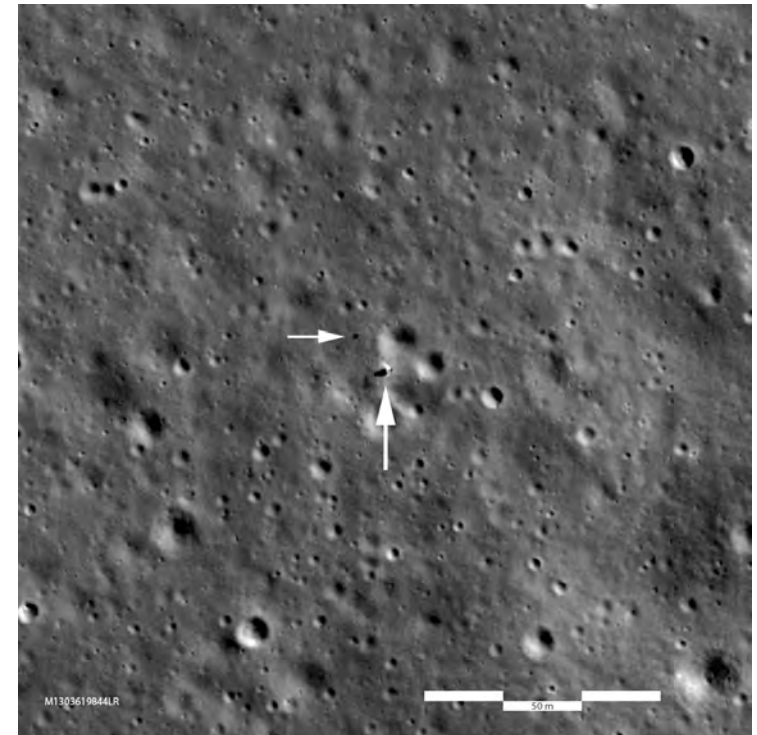
Characterizing a landing site

- You can request new coverage of a previously-unexplored site, with any instrument (tool for LROC request in QuickMap)
- First – use the tools to check the coverage that exists!
- Remember that LRO is in a fixed orbital plane, so we can't improve imaging resolution (currently ~100 cm/px)
- Data are delivered to PDS and are publicly-accessible
- Data products (stereo, rock abundance, predictive maps, etc.) may be worked on a case-by-case basis - these take time (months) and coordination with the project and possibly HQ, depending on volume

Landing and Concurrent Observations



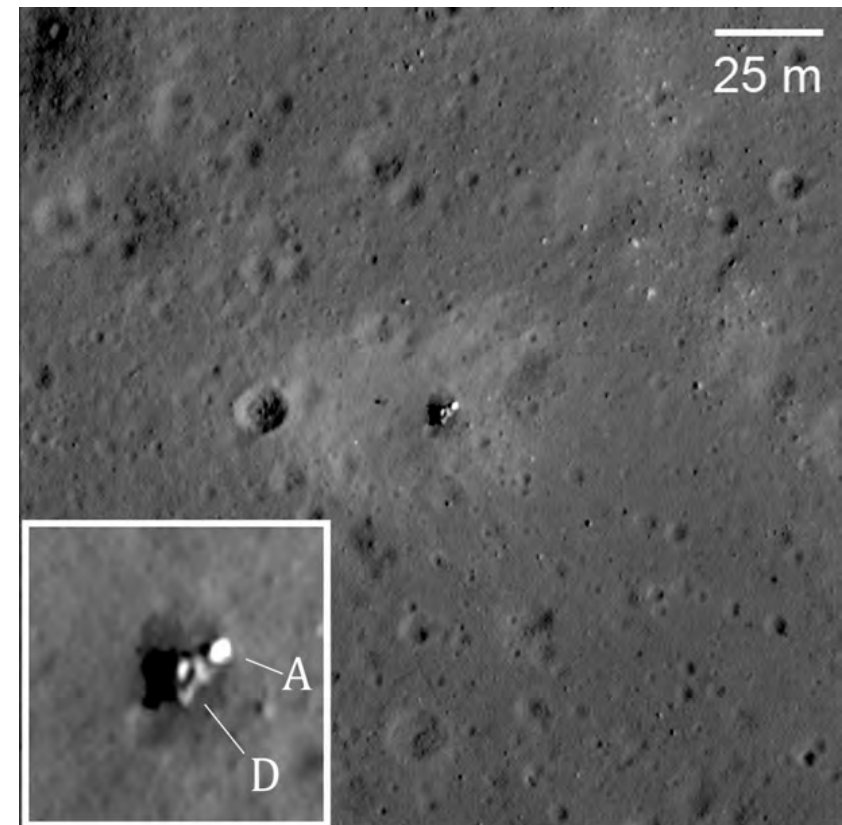
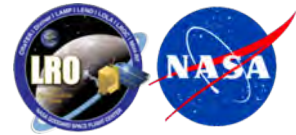
- LROC uses a pushbroom camera to build up images line by line – we can't snap a photo while you're landing like you see at Mars
- LRO's fixed orbit means that coverage of any given site is not continuous but changes day to day – it may be weeks before a site comes into view
- LRO can fairly easily observe a site before-and-after landing, but the timing depends on the site and how far in advance coordinates are provided
- LAMP and Diviner can attempt to observe the evolved gases from the landing plume and temperature changes if you pick an appropriate site and date
- Careful & constant coordination is needed – think *months* in advance, the sooner you can provide a date and landing coordinates the better!



Looking down on the Chang'e 4 landing site; lander is just beyond tip of large arrow, rover at tip of small arrow. Image is 468 meters (1535 feet) across, 2x enlargement, LROC M1303619844LR [NASA/GSFC/Arizona State University].

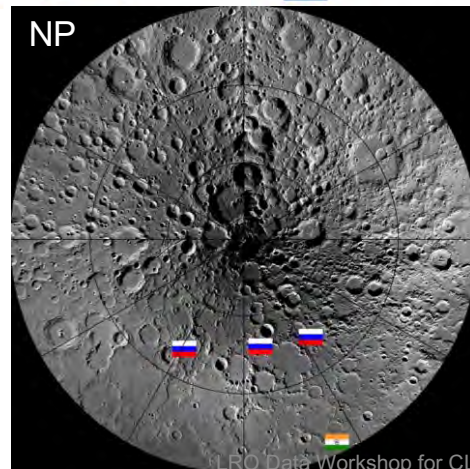
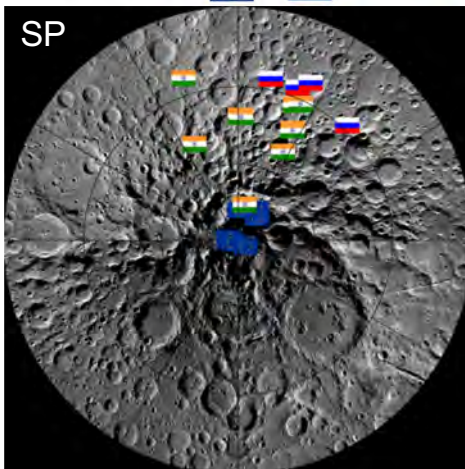
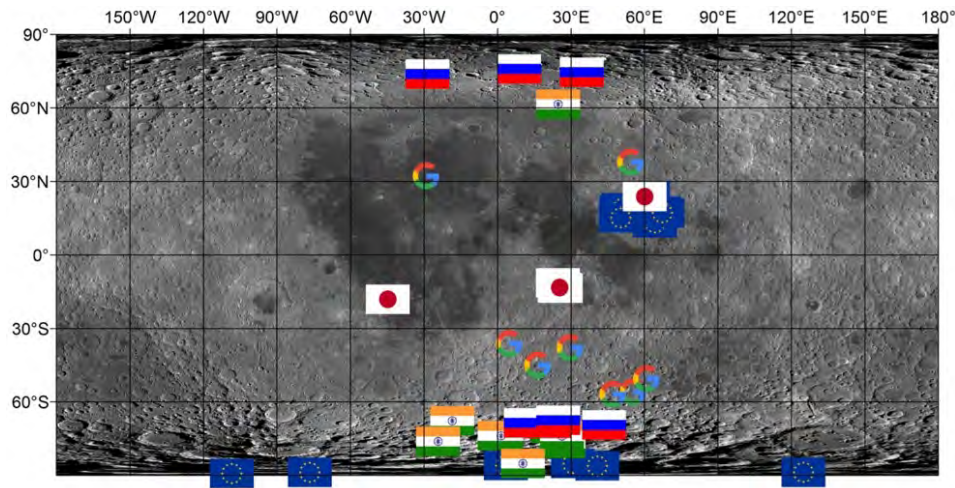
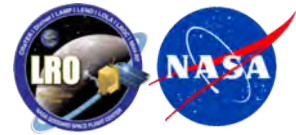
Post-Landing Assessment

- LRO can image the landing site and precisely locate (at NAC resolution) the lander as well as track the motion of a rover
- LRO can attempt to range to the lander using the LRO laser altimeter (LOLA) assuming a NASA-provided corner cube is included on the payload
- Regolith disturbance by landing and any subsequent operations
- LRO can perform “accident investigation” if necessary (we hope not!)



Luna 23 crash site

LRO wants to work with you!



LRO Data Workshop for CLPS

ESA

13 sites, 194 total images

- 70 nadir
- 74 geo stereo
- 34 featured mosaic
- 2 oblique

ISRO

14 sites, 252 total images

- 150 nadir
- 52 geo stereo
- 36 featured mosaic
- 12 oblique

JAXA

5 sites, 110 total images

- 42 nadir
- 36 geo stereo
- 26 featured mosaic
- 4 oblique

ROSCOSMOS

7 sites, 114 total images

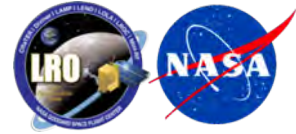
- 64 nadir
- 18 geo stereo
- 20 featured mosaic
- 10 oblique

X-PRIZE

8 sites, 102 total images

- 22 nadir
- 60 geo stereo
- 20 featured mosaic

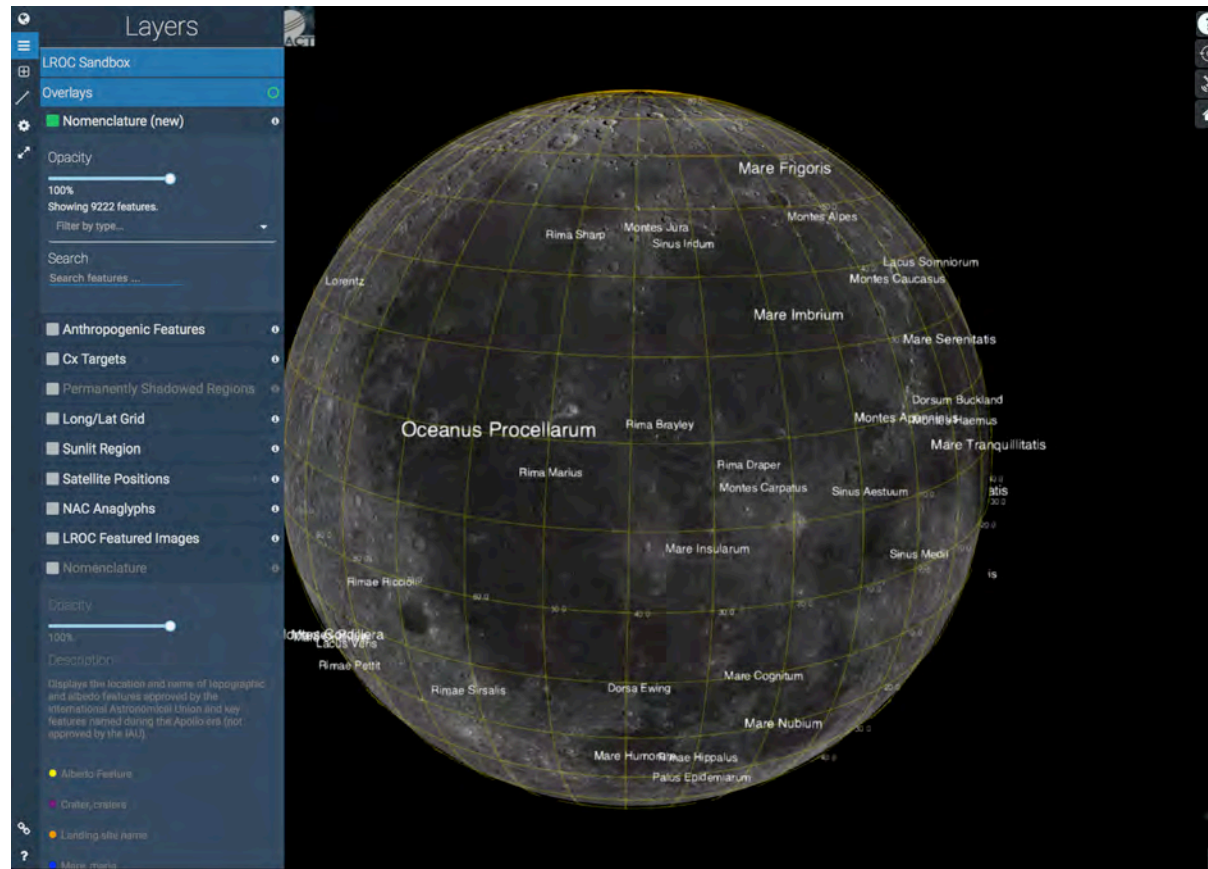
JMARS for the Earth's Moon Interactive tool



To download JMARS, go to this website: <http://jmars.asu.edu/>

The screenshot shows the JMARS website homepage. At the top, there is a navigation menu with links for Home, Getting Started, Documentation, Download JMARS, Open Source, References, and Forums. A search bar is located in the top right corner. Below the navigation menu, a welcome message reads: "Welcome to the JMARS website". A paragraph of text describes JMARS as a geospatial information system (GIS) developed by ASU's Mars Space Flight Facility. The page is divided into several sections: "JMARS Announcements" with a list of recent events, "JMARS Webinar Information" with a link to a video, a "Login" section with input fields for Username/Email Address and Password, and "JMARS Public Downloads" which lists several installers for Windows 64-bit systems. A red arrow points to the "JMARS Public Downloads" section. At the bottom of the page, there is a "Tour of the JMARS user interface" section with a video player and a "Tour of the JMARS Layers" section with a row of small thumbnail images.

Lunar QuickMap Demo



Erick Malaret , ACT Corp.

www.actgate.com malaret@actgate.com

Lunar QuickMap : Overview

- QuickMap provides an easy-to-use yet powerful web interface for many Lunar products.
 - works on desktops and mobile devices
- It was designed with the end-user in mind.
- QuickMap offers rapid access to data without the tedium of handling file format details and data ingestion and archive structures.
- **Access from → ASU LROC webpage**

Lunar QuickMap : Overview

- In general it provides easy access to:
 - **Global** and **regional** mosaics
 - Digital Elevation Models (**DEM**)
 - Instrument coverage views
 - Location overlays, e.g. latitude and longitude grid, recent feature images, sites of interest, ...
 - Special products, e.g. master target lists ...
 - Satellite position (based on JPL/NAIF/SPICE kernels)
 - Ability to validate products and fuse data both within a mission and across servers.
 - Ability to generate products on the fly → **Boolean Layers**
 - Ability to export cartographic views for other applications
 - Export **active views as short URL** → good for collaboration

QuickMap Search Tools

QuickMap Search Tools can be configured to access/analyze many types of lunar data and products

Present list of search tools:

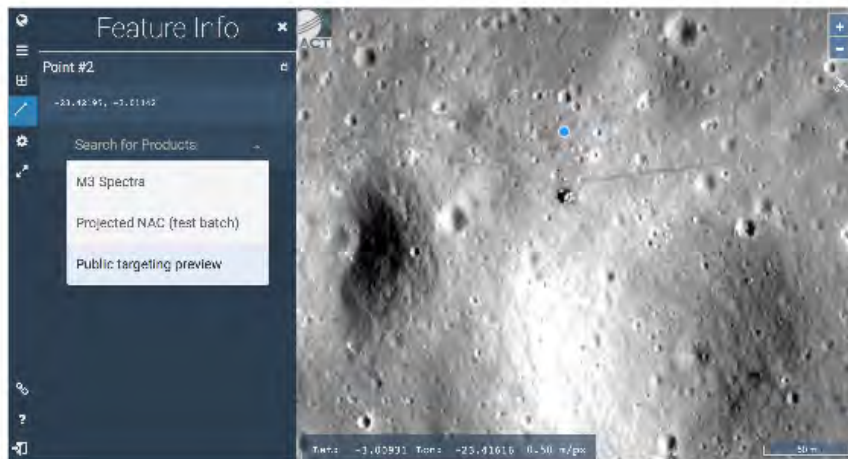
Summary of Actions for different Drawn Objects ⇒ 17 search/action types!		
Point items	Line segment items	Close Polygon items
<ol style="list-style-type: none">1. M3 Spectra (at PDS)2. Projected NAC3. LROC Public Targeting	<ol style="list-style-type: none">1. DEM Profiling2. M3 L2 Cal Steps	<ol style="list-style-type: none">1. 3D printing (of ROI)2. ALL LROC products3. Hiesinger Mare Age Units4. M3 (list over ROI)5. M3 observations (generate links to summary info)6. NAC7. NAC (unfiltered)8. NAC DTMs9. NAC Feature Mosaics10. NAC Regional Mosaics11. NAC Stereo12. WAC

Note: More actions can be added based on community feedback.

Examples of QuickMap Search Tools

Point Based Search Tools

Points allow to search for products, using 3 different actions , as [shown below](#):



Point Query Option	Sample Output Screen
<p>M3 Spectra</p> <p>List of M3 images with regional previews radiance and apparent reflectance plots of chosen location.</p> <p>User can download a hyperspectral subcube</p> <p>(stand alone external resource)</p>	

Projected NAC (test batch)	Sample Output Screen
<p>Zoom-out to Zoom-in context views of available NAC images at the chosen location</p> <p>100m==> 25m==> 5m==> 1m</p> <p>(stand alone external resource)</p>	

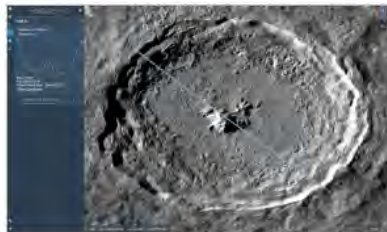
Public targeting preview	Sample Output Screen
<p>LROC target submission interface for the general public</p> <p>(stand alone external resource)</p>	

Examples of QuickMap Search Tools

Line Based Search Tools

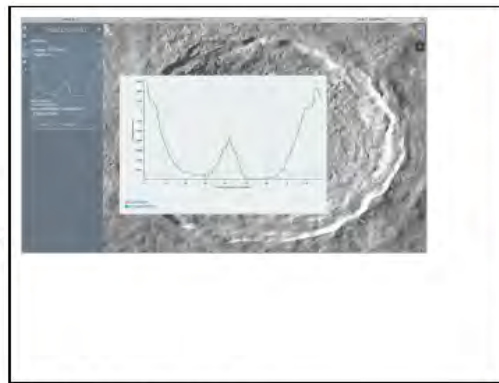
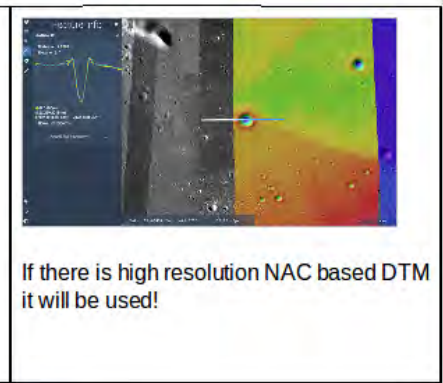
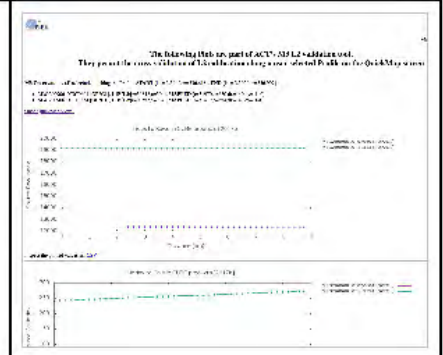
Line based search tools allow to inspect line profiles using 2 different actions, i.e. DEMs and also access M3 calibration plots

DEM Profiling



example: This [link](#) shows profiles of the different DEMs now in QuickMap. To see it, go to the draw/search tool, and select Feature#1. Also note that in the layers tree, the SLDEM2015 is displayed using the same palette as GLD100.

Zoomed-in on NAC DTM

	 <p>If there is high resolution NAC based DTM it will be used!</p>
<h3>M3 L2 Calibration Steps</h3> <p><i>This tool provides detail information on all parameters used in the calibration of hyperspectral data for M3.</i></p>	

Examples of QuickMap Search Tools

Closed Polygon Based Search Tools

Closed Polygons allow to do search/act over an area of interest (AOI). Presently it allows for **12 different actions!**



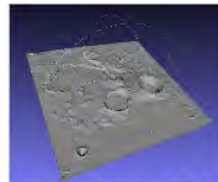
The different actions are :

- 3D printing (of ROI)**
- ALL LROC products**
- Hiesinger Mare Age Units**
- M3 (list over ROI)**
- M3 observations (generate links to summary info)**
- NAC**
- NAC (unfiltered)**
- NAC DTMs**
- NAC Feature Mosaics**
- NAC Regional Mosaics**
- NAC Stereo**
- WAC**

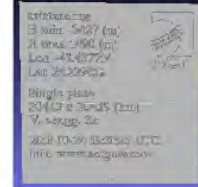
Examples of QuickMap Search Tools

3D printing (of ROI)

Create a custom 3D model export (for 3D printing) and interactive visualization



Note: detail info on back of 3D model



ALL LROC products

List of NAC/WAC/Featured Images within ROI

The listing is limited to 50 records, contains key metadata and link to detailed page from ASU

LROC NAC images within ROI (9 records)

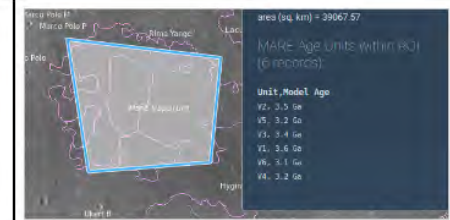
image_id	orbit_no	start_time	i_angle	e_angle
LROC_NAC_569	2899-08-10	19:08:43	62.133	1.787
LROC_NAC_569	2899-08-10	19:08:43	62.215	1.149
LROC_NAC_3506	2918-03-30	23:59:14	44.234	1.692
LROC_NAC_18278	2811-09-14	06:29:13	42.013	1.691
LROC_NAC_18278	2811-09-14	06:29:13	42.032	1.153
LROC_NAC_11820	2812-01-14	23:19:45	72.721	1.148
LROC_NAC_18930	2813-08-23	14:41:27	43.797	1.703
LROC_NAC_26846	2815-04-01	08:14:08	57.710	1.787
LROC_NAC_36253	2817-07-18	09:54:09	42.374	1.782

LROC WAC images within ROI (limited to 50 records)

image_id	orbit_no	start_time	i_angle	e_angle
LROC_WAC_1935	2909-11-28	01:28:30	63.855	1.141
LROC_WAC_2803	2918-02-04	06:03:47	65.125	1.148
LROC_WAC_2804	2918-02-04	07:57:02	64.907	1.142
LROC_WAC_2805	2918-02-04	09:49:52	65.312	1.138
LROC_WAC_2807	2918-02-04	13:36:24	64.952	5.333
LROC_WAC_2808	2918-02-04	15:29:14	65.719	28.357
LROC_WAC_3151	2918-03-03	14:02:08	49.515	1.148
LROC_WAC_3152	2918-03-03	15:55:25	49.088	1.145
LROC_WAC_3153	2918-03-03	17:48:14	49.865	1.146
LROC_WAC_3846	2919-04-27	04:18:41	58.245	1.141

Hiesinger Mare Age Units

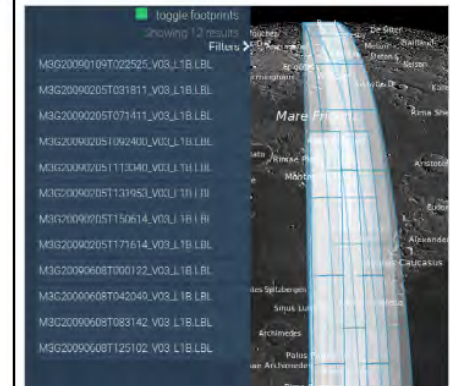
Mare Age (from crater counting)



M3 ⇒ Moon Mineralogy Mapper Observations

Interactive footprints and metadata for M3 observations within ROI

Note: each footprint is made out of multiple polygons.



M3 observations

Generates a list M3 observations within the AOI selected. The resulting list contains:

- image ID
- OP
- links to metadata

M3 Observations within ROI (12 records)

filename	OP sub group
M3G2009019T022525_V03_L1B.LBL	OP1A
M3G2009020T031811_V03_L1B.LBL	OP1B
M3G2009020T073411_V03_L1B.LBL	OP1B
M3G2009020T092400_V03_L1B.LBL	OP1B
M3G2009020T113340_V03_L1B.LBL	OP1B
M3G2009020T113951_V03_L1B.LBL	OP1B
M3G2009020T130614_V03_L1B.LBL	OP1B
M3G2009020T171614_V03_L1B.LBL	OP1B
M3G2009060T000122_V03_L1B.LBL	OP2C1
M3G2009060T017049_V03_L1B.LBL	OP2C1
M3G2009060T083142_V03_L1B.LBL	OP2C1
M3G2009060T125102_V03_L1B.LBL	OP2C1

Examples of QuickMap Search Tools

NAC

Interactive list of NAC images in ROI.
Note: EXCLUDES dark or bad quality images.

Special Features:

- for many images if there is data available it is possible to display the content of the NAC on-the-fly, not just the footprint, just by clicking on the image ID
- Another feature is that it is possible to change the stretching on-the-fly using the intensity slidebar
- Allows interactive filtering

NAC (unfiltered)

Interactive list of NAC images unfiltered
Note: INCLUDES dark or bad quality images.

Same as above but shows ALL available footprints, without any prefiltering for dark or bad quality images

TBD: merge unfiltered and filtered into same source shapefile with a new attribute

NAC DTMs

List of NAC DTMs within ROI

The listing is limited to 50 records, contains key metadata and link to detailed page from ASU

NAC Featured Mosaics

List of NAC images selected as part of a featured mosaic

The listing is limited to 50 records, contains key metadata

NAC Regional Mosaics

Interactive list of NAC Regional Mosaics within ROI.

NOTE: for many items if there is data available it is possible to display the content of the Mosaic on-the-fly, not just the footprint, just by clicking on the mosaic ID

Another feature is that it is possible to change the stretching on-the-fly using the intensity slidebar

NAC Stereo

List of NAC images selected as part of a stereo pair

The listing is limited to 50 records, contains key metadata

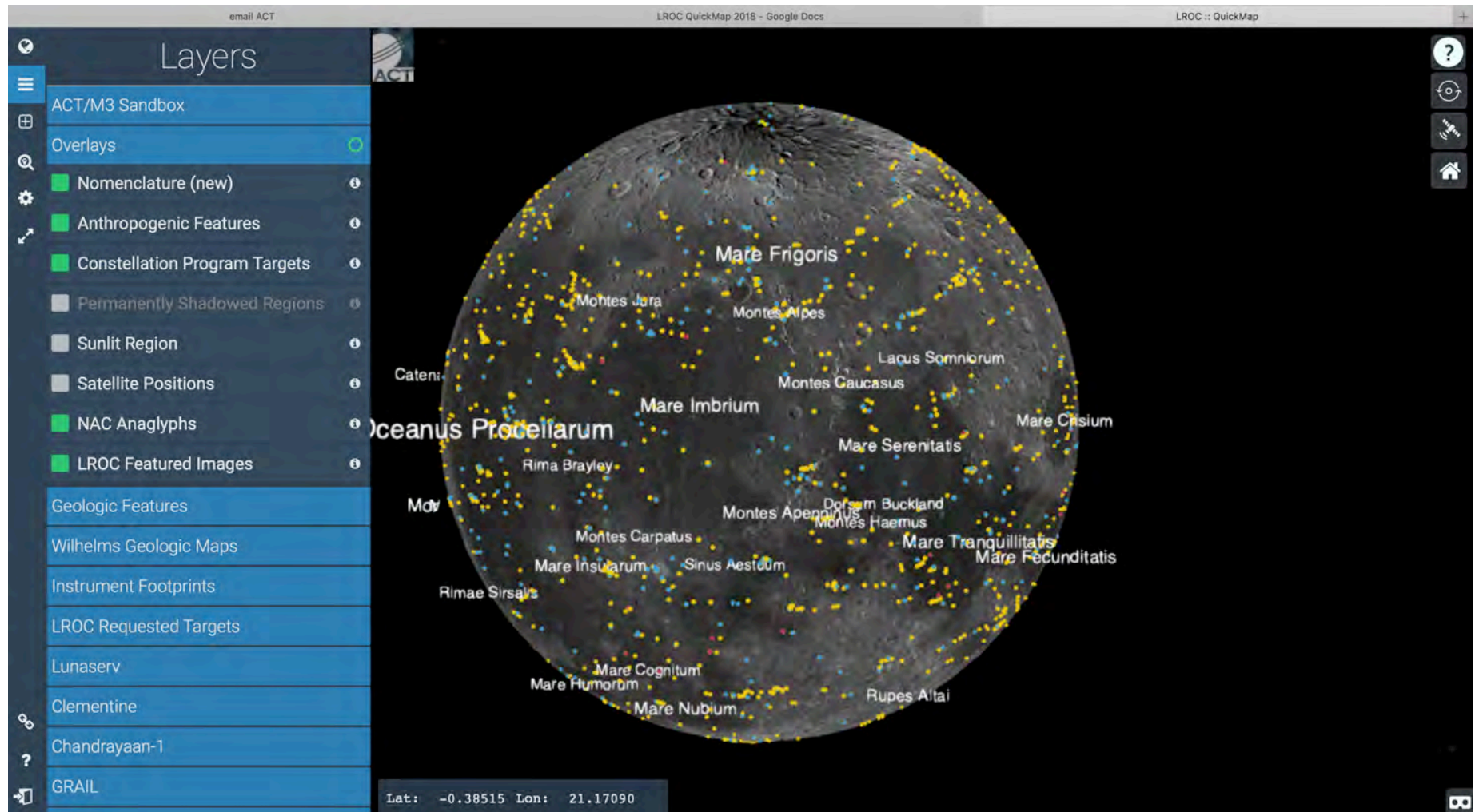
WAC

Interactive list of WAC images within ROI.

Special Features:

- User can sort using different criteria.

EXAMPLE SESSION... or live demo if possible → <http://bit.ly/2H56VGR>



Concluding Remarks..

ACT is committed to continue expanding the capabilities of Lunar QuickMap with

- Additional relevant data sources
- Additional analytical resources
- New virtual layers

Your feedback is highly welcome.

➔ It can be provided directly from QuickMap.



NASA's Planetary Data System



Planetary Data System (PDS):

- Established by NASA in 1989
- A solution to concerns that the data being returned by scientific satellites was in danger of being lost

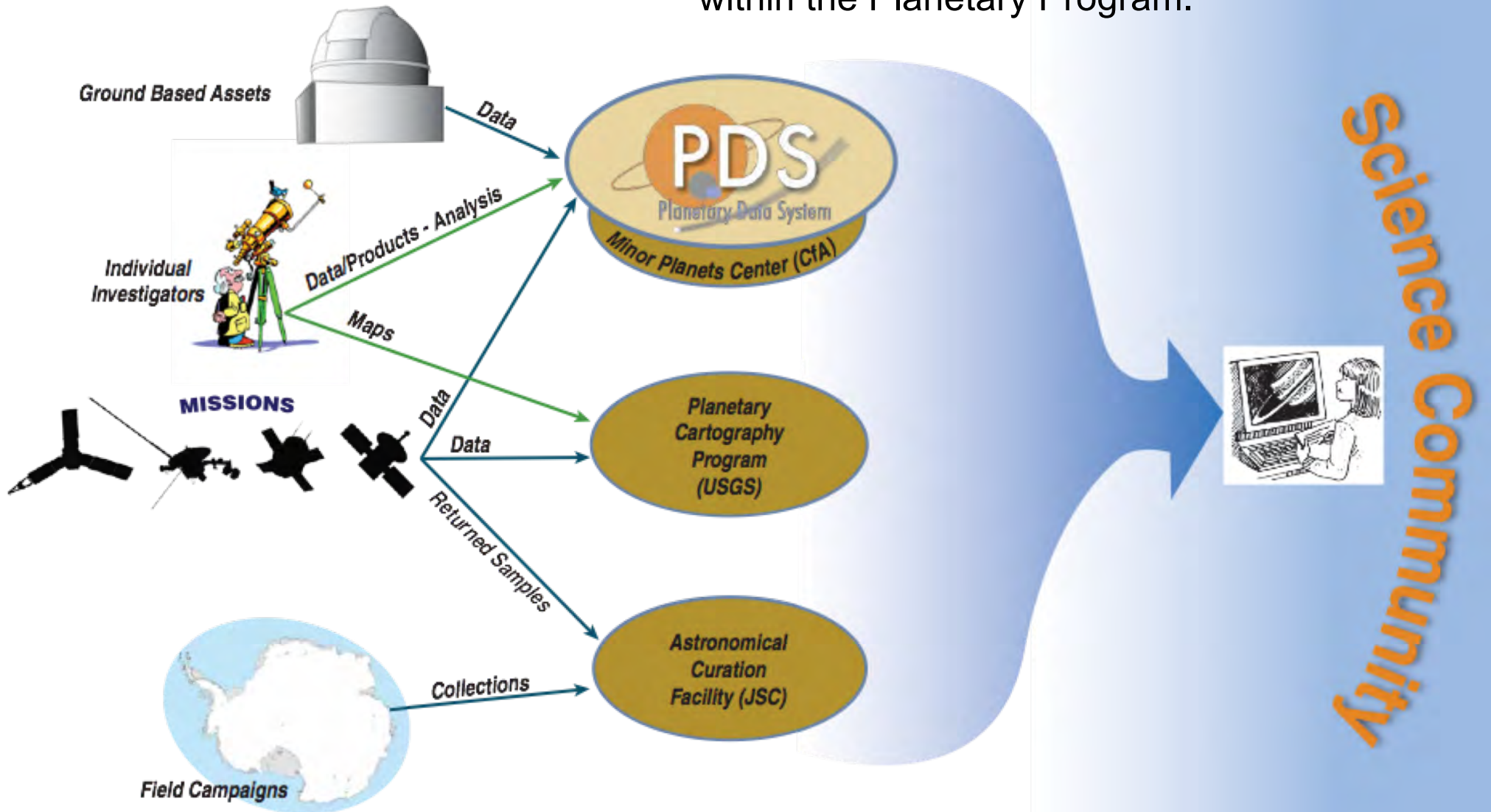
Purpose: Collect, archive and make accessible for *current and future* use the digital data and documentation produced from NASA's exploration of the solar system from the 1960s to the present.

- ◆ PDS works with every NASA planetary mission with the goal of obtaining a complete archive of data from that mission.
- ◆ All PDS-curated products are peer reviewed, well documented, and ***available online to scientists and to the public without charge.***
- ◆ Online search capabilities are provided.
- ◆ The PDS is an actively accumulating data archive.

The PDS is the archive for NASA's planetary missions, but it is only one of 16 formal NASA Archives, plus 22 Guest Observer Facilities and Science Centers, supporting all of the science missions within the Science Mission Directorate within NASA.

Overview - What is the Planetary Data Environment Like?

The PDS is one of three complementary archival elements within the Planetary Program.

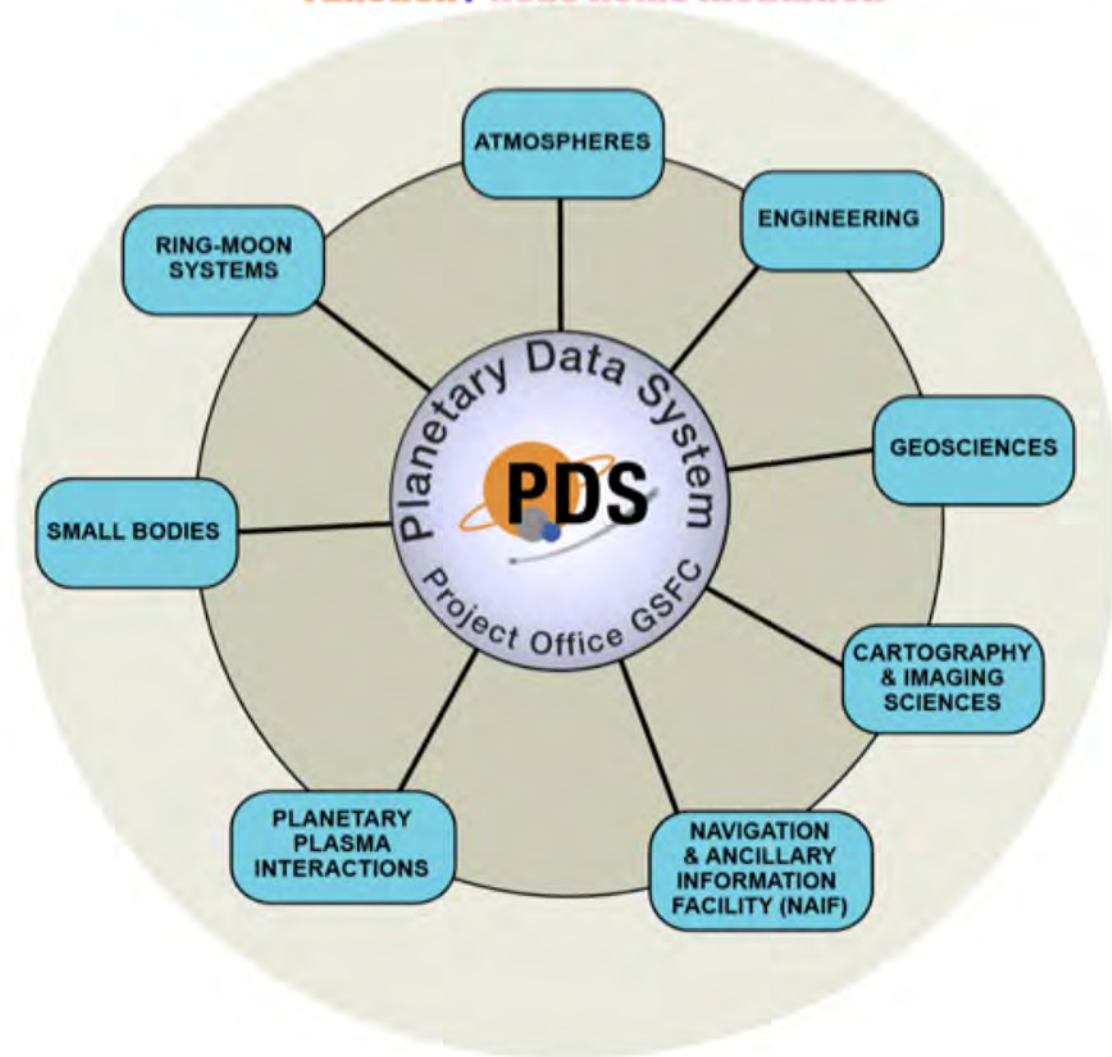


Overview - PDS Structure Detailed

Following the National Academy's recommendations, the PDS uses:

- I. Discipline oriented nodes,
- II. Two support nodes
- III. Small project office at **GSFC** to manage funds, and to coordinate activities

NODES/SUBNODES/DATA NODES
Function / Node Home Institution

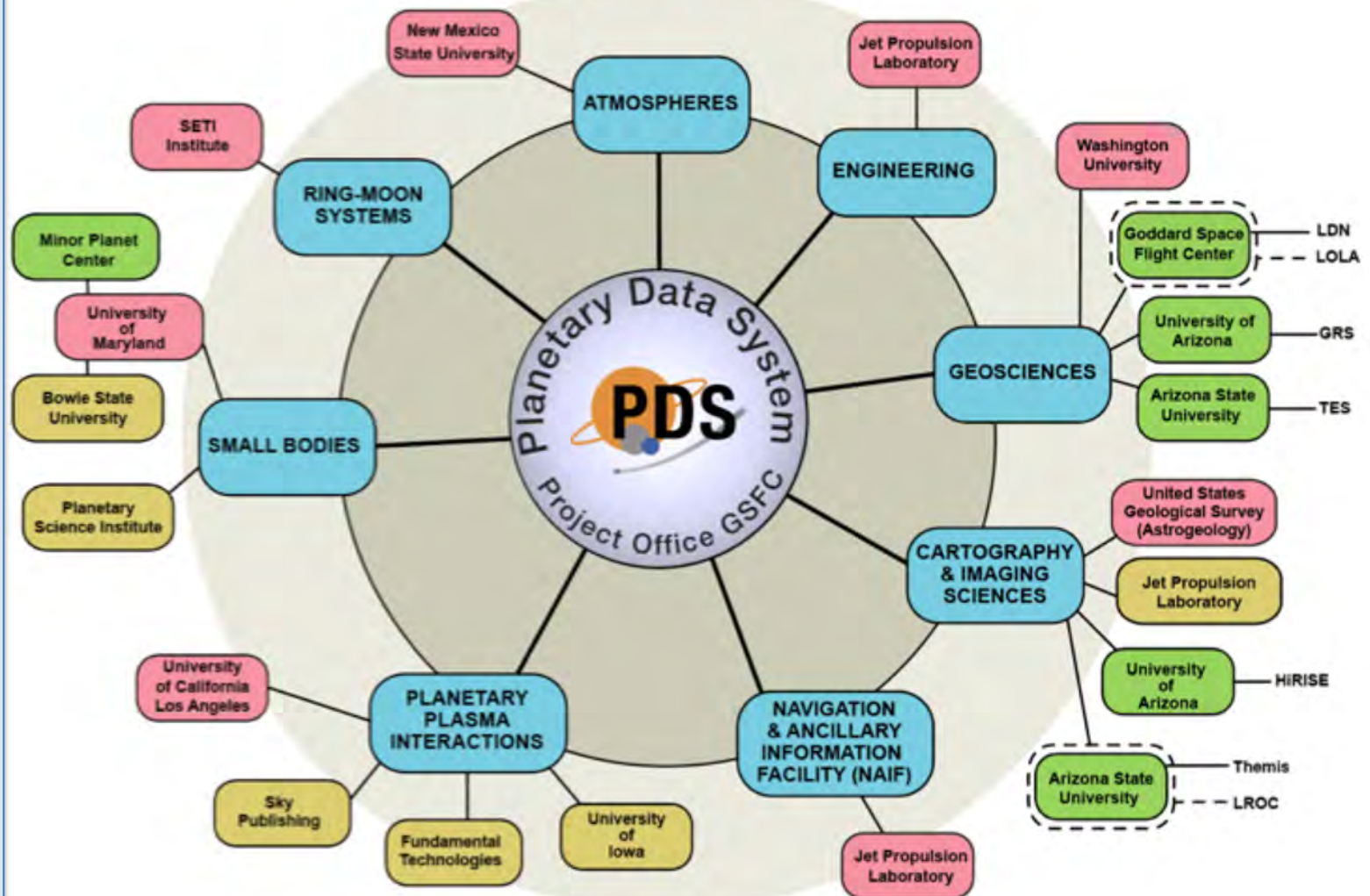


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- I. Discipline oriented nodes,
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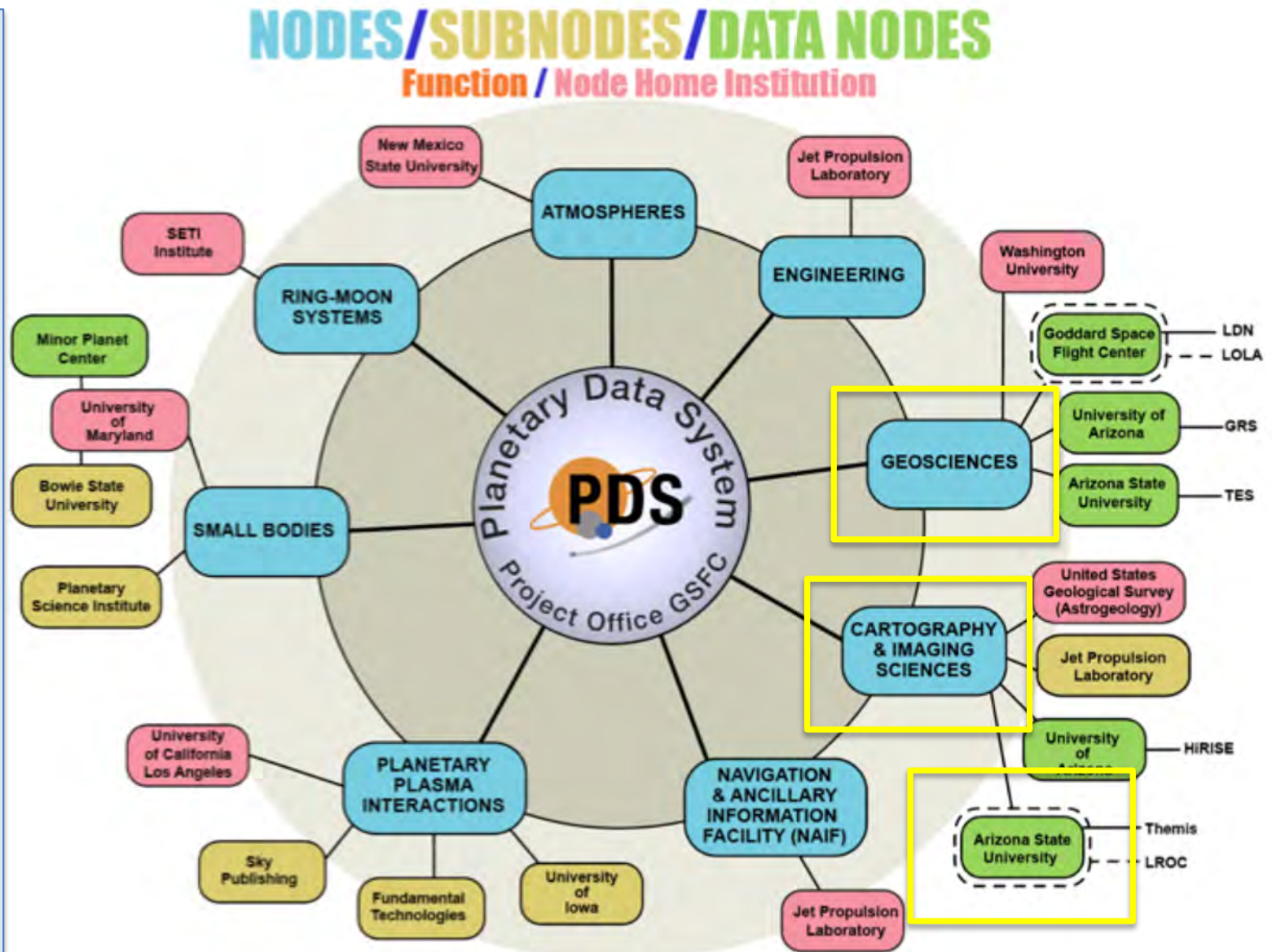
NODES/SUBNODES/DATA NODES Function / Node Home Institution



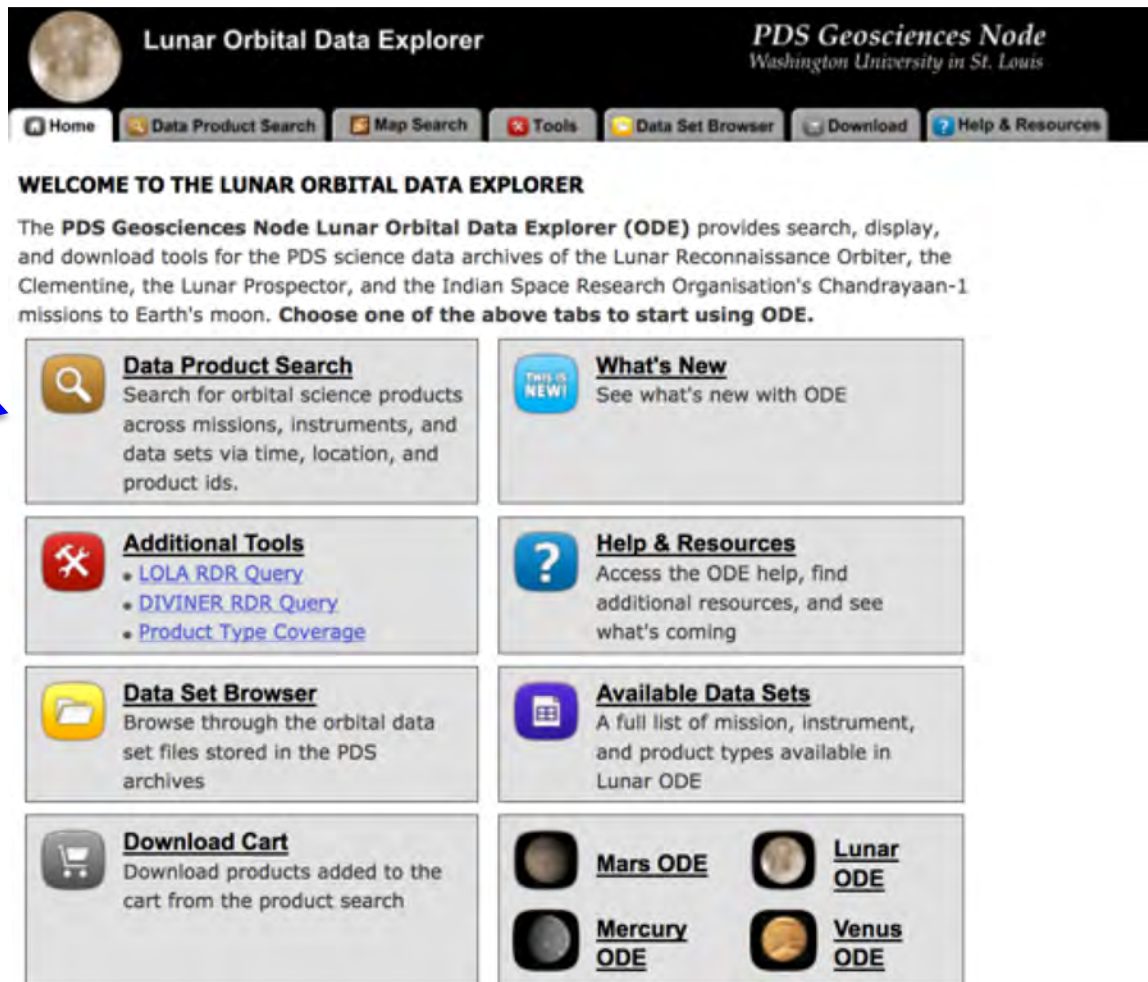
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<https://ode.rsl.wustl.edu/moon/index.aspx>














Lunar Orbital Data Explorer *PDS Geosciences Node*
Washington University in St. Louis

Home Data Product Search Map Search Tools Data Set Browser Download Help & Resources

WELCOME TO THE LUNAR ORBITAL DATA EXPLORER


The **PDS Geosciences Node Lunar Orbital Data Explorer (ODE)** provides search, display, and download tools for the PDS science data archives of the Lunar Reconnaissance Orbiter, the Clementine, the Lunar Prospector, and the Indian Space Research Organisation's Chandrayaan-1 missions to Earth's moon. **Choose one of the above tabs to start using ODE.**

 Data Product Search Search for orbital science products across missions, instruments, and data sets via time, location, and product ids.	 What's New See what's new with ODE
 Additional Tools <ul style="list-style-type: none">• LOLA RDR Query• DIVINER RDR Query• Product Type Coverage	 Help & Resources Access the ODE help, find additional resources, and see what's coming
 Data Set Browser Browse through the orbital data set files stored in the PDS archives	 Available Data Sets A full list of mission, instrument, and product types available in Lunar ODE
 Download Cart Download products added to the cart from the product search	 Mars ODE  Lunar ODE  Mercury ODE  Venus ODE

The Lunar Orbital Data Explorer is produced by the [PDS Geosciences Node](#) at Washington University in St. Louis.

Send comments to ode@wunder.wustl.edu.

<https://ode.rsl.wustl.edu/moon/indexproductsearch.aspx>



Lunar Orbital Data Explorer
PDS Geosciences Node
Washington University in St. Louis

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Data Product Search
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Data Set Browser
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DATA PRODUCT SEARCH

Planetary science data stored in PDS is organized by [data products](#) and [data sets](#). A data set is a collection of related data products, usually products acquired by a particular instrument and processed in a certain way. The data set also includes all documentation and supporting materials needed to understand and use the data products. A data product is a set of measurements resulting from a science observation, usually products acquired by a particular instrument and processed in a certain way.

No filtering parameters are set in the product search form. Filtering parameters can be cleared with the "Reset Form" button. Reset Form

STEP 1. SELECT DATA SETS TO SEARCH (A SELECTION IS REQUIRED)

Select One or More Desired Data Sets (Released PDS Archives) (Show Options - 0 Parameters Set)

STEP 2. SET ADDITIONAL FILTERING PARAMETERS (OPTIONAL)

Filter by Product ID (Show Options - 0 Parameters Set)

Find by Location or Feature (Show Options - 0 Parameters Set)

Filter by Time Range (Show Options - 0 Parameters Set)

Filter by Observation Angle (Show Options - 0 Parameters Set)

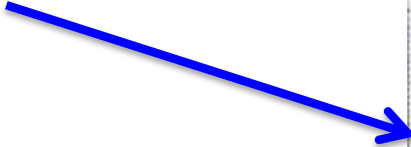
STEP 3. PREVIEW SEARCH RESULTS SUMMARY (OPTIONAL)

Preview Search Results Summary

STEP 4. SUBMIT QUERY

A selection must be made in Step 1 to submit a query.

View Results in Table
Select Results on Map Display



Select One or More Desired Data Sets (Released PDS Archives) (Hide Options - 0 Parameters Set)

- Map location data are available for these products.
- Observation time data are available for these products.
- Product emission, incidence, and phase angle data are available for these products.
- Solar longitude data are available for these products.

Lunar Reconnaissance Orbiter

DLRE - DIVINER Lunar Radiometer Experiment

✓ **Raw Data** (0 Parameters Set)

✓ **Calibrated Data** (0 Parameters Set)

✓ **Derived Data** (0 Parameters Set)

LAMP - Lymap Alpha Mapping Project

✓ **Raw Data** (0 Parameters Set)

✓ **Calibrated Data** (0 Parameters Set)

✓ **Derived Data** (0 Parameters Set)

LEND - Lunar Exploration Neutron Detector

✓ **Raw Data** (0 Parameters Set)

✓ **Calibrated Data** (0 Parameters Set)

LOLA - Lunar Orbiter Laser Altimeter

✓ **Raw Data** (0 Parameters Set)

✓ **Calibrated Data** (0 Parameters Set)

✓ **Derived Data** (0 Parameters Set)

LROC - Lunar Reconnaissance Orbiter Camera

✓ **Raw Data** (0 Parameters Set)

✓ **Calibrated Data** (0 Parameters Set)

✓ **Derived Data** (0 Parameters Set)

MRFLRO - MINI-RF LRO

✓ **Raw Data** (0 Parameters Set)


✓ **Calibrated Data** (0 Parameters Set)

✓ **Derived Data** (0 Parameters Set)

Also:

- ISRO's Chandrayaan-1
- GRAIL
- Clementine
- Lunar Prospector
- Lunar Orbiter
- Arecibo Observatory

<https://ode.rsl.wustl.edu/moon/indexproductsearch.aspx>



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No filtering parameters are set in the product search form. Filtering parameters can be cleared with the "Reset Form" button. Reset Form

STEP 1. SELECT DATA SETS TO SEARCH (A SELECTION IS REQUIRED)

Select One or More Desired Data Sets (Released PDS Archives) (Show Options - 0 Parameters Set)

STEP 2. SET ADDITIONAL FILTERING PARAMETERS (OPTIONAL)

Filter by Product ID (Show Options - 0 Parameters Set)

Find by Location or Feature (Show Options - 0 Parameters Set)

Filter by Time Range (Show Options - 0 Parameters Set)

Filter by Observation Angle (Show Options - 0 Parameters Set)

STEP 3. PREVIEW SEARCH RESULTS SUMMARY (OPTIONAL)

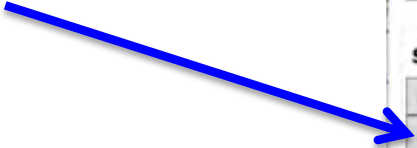
Preview Search Results Summary

STEP 4. SUBMIT QUERY

A selection must be made in Step 1 to submit a query.

View Results in Table

Select Results on Map Display



STEP 2. SET ADDITIONAL FILTERING PARAMETERS (OPTIONAL)

Filter by Product ID (Show Options - 0 Parameters Set)

Find by Location or Feature (Hide Options - 0 Parameters Set)

Select a Specific Feature

A selected feature's Latitude and Longitude bounding box will be used for search criteria.

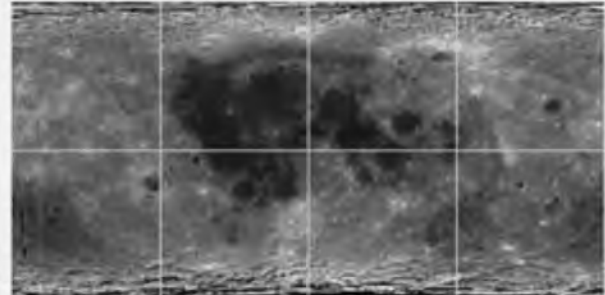
Feature Type: [Feature Type](#)
[Descriptions](#)

Feature Name: [Full Feature Name List](#)

or

Directly specify a Latitude and Longitude coverage area


Lunar ODE uses [planetocentric coordinates](#) that are based on the product's center latitude and longitude. [?](#)

<p>Max Latitude (-90 to 90)</p> <input type="text"/>	<p>Selected Search Area</p> 
<p>Western most Longitude (0 to 360)</p> <input type="text"/>	<p>Eastern most Longitude (0 to 360)</p> <input type="text"/>
<p>Min Latitude (-90 to 90)</p> <input type="text"/>	<input type="button" value="Show Area On Map"/>

Filter by Time Range (Show Options - 0 Parameters Set)

Filter by Observation Angle (Show Options - 0 Parameters Set)

<https://ode.rsl.wustl.edu/moon/indexproductsearch.aspx>



Lunar Orbital Data Explorer
PDS Geosciences Node
Washington University in St. Louis

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DATA PRODUCT SEARCH

Planetary science data stored in PDS is organized by [data products](#) and [data sets](#). A data set is a collection of related data products, usually products acquired by a particular instrument and processed in a certain way. The data set also includes all documentation and supporting materials needed to understand and use the data products. A data product is a set of measurements resulting from a science observation, usually products acquired by a particular instrument and processed in a certain way.

No filtering parameters are set in the product search form. Filtering parameters can be cleared with the "Reset Form" button. Reset Form

STEP 1. SELECT DATA SETS TO SEARCH (A SELECTION IS REQUIRED)

Select One or More Desired Data Sets (Released PDS Archives) (Show Options - 0 Parameters Set)

STEP 2. SET ADDITIONAL FILTERING PARAMETERS (OPTIONAL)

Filter by Product ID (Show Options - 0 Parameters Set)

Find by Location or Feature (Show Options - 0 Parameters Set)

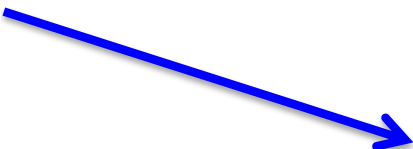
Filter by Time Range (Show Options - 0 Parameters Set)

Filter by Observation Angle (Show Options - 0 Parameters Set)

STEP 3. PREVIEW SEARCH RESULTS SUMMARY (OPTIONAL)

STEP 4. SUBMIT QUERY

A selection must be made in Step 1 to submit a query.



Arizona State University Data node: LROC data

<https://www.lroc.asu.edu/>

LROC

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Images

Archive

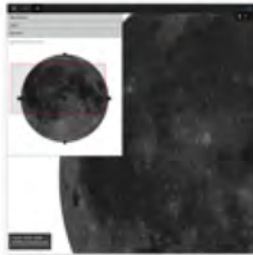
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Educators

Tours



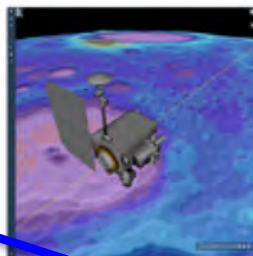
Mapping Tools, Data Products, & Mosaics



Lunaserv Global Explorer

With LROC's Lunar mapping service, Lunaserv, you can rotate the Moon, zoom down to the Moon's surface, deploy existing image overlays, and much more!

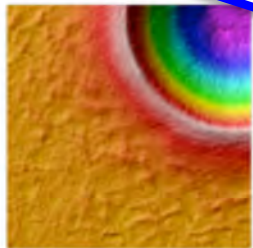
Lunaserv is a Web Map Service (WMS) implementation, much like MapServer and GeoServer. Lunaserv was developed as part of the Lunar Reconnaissance Orbiter Camera (LROC) project at Arizona State University to circumvent some issues with rendering global non-Earth datasets. The LROC team determined that planetary science creates unique requirements in a map server such as the need for fast and accurate rendering of global datasets, support for the JMWAF projection, for 1400000 scale reference systems and accurate rendering of non-linear projections.



Quickmap 3D

The LROC NAC is systematically collecting images, with the ultimate goal of complete coverage of the Moon. How to quickly sort through all these data? Quickmap to the rescue!

Quickmap includes overlays of lunar feature names, locations of our featured images, a WAC base map, NAC topography, NACs with Sun angles to enhance surface features, and more. Check back often as the NAC coverage increases, more datasets are added, and updates are made.

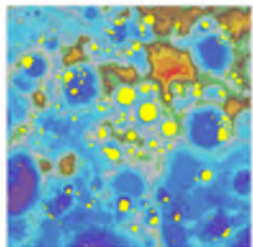


Data Products (EDRs, CDRs, RDRs)

LROC collects more than one million collected images in a variety of data products. An EDR (Engineering Data Record) is an image and its associated metadata. A CDR is an EDR that has been decompressed and calibrated. An RDR (Reduced Data Record) can be made from as few as one image or as many as thousands that are processed and reduced for the purpose of, for example, making a mosaic that combines multiple images of a particular area or feature, or a high resolution global digital elevation model created with stereo observations.

- There are many ways to search through LROC's Data products:
- Map Interface
 - Browse EDRs and CDRs
 - Search by metadata for EDRs and CDRs
 - Search for RDRs

You may also view a list of our Popular Downloads.



Permanently Shadowed Regions Atlas

One area of scientific interest for the LROC experiment includes permanently shadowed regions (PSRs). While not designed to image within shadowed regions, the LROC Narrow Angle Camera (NAC) can obtain useful images with long exposure observations of PSRs at times of maximum secondary illumination.

Acquisition of NAC PSR observations was refined over several campaigns to optimize the trade-off between signal-to-noise ratio (SNR) and pixel scale, resulting in a comprehensive dataset. The atlas presented here compiles NAC observations of PSRs larger than 10 square km to facilitate scientific analysis. For each PSR, a context mosaic, associated metadata, and comments regarding features of interest are included.



PDS Image Data

LROC releases much more than just cool images, we also release technical and scientific data. The PDS archives and distributes scientific data from NASA planetary missions, astronomical observations, and laboratory measurements. The PDS is sponsored by NASA's Science Mission Directorate. To learn more about PDS, visit here.

Arizona State University Data node: LROC data



<https://www.lroc.asu.edu/archive>

Arizona State University Data node: LROC data

http://wms.lroc.asu.edu/lroc/rdr_product_select

Lunar Reconnaissance Orbiter Camera

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Search for RDR products

Text Search:

Coordinate Point: Lat: Lon: Radius:

Coordinate Range: West: East: South: North:

Topographic Product: True: False: Either:

RDR Product Type:

RDR Prefix:

Show Thumbnails: Products Per Page:

◀ Previous 1 2 3 4 5 6 7 8 9 ... 322 323 Next ▶

Displaying rdr groups 1 - 10 of 3225 in total

Name	Title	Type
NAC_DTM_CHAPLYGIN	Chaplygin NE Rim DTM	Regional Product
NAC_DTM_TSINGER01	Tsinger Crater Impact Melt DTM	Regional Product
NAC_ANAGLYPH_M1105723789_M1105709502	NAC Anaglyph: Lunokhod 2	Regional Product
NAC_ANAGLYPH_M1160184438_M1160177319	NAC Anaglyph: Pyroclastic Cone East of Lassell H	Regional Product
NAC_DTM_VAPORDOME01	Mare Vaporum Dome DTM	Regional Product

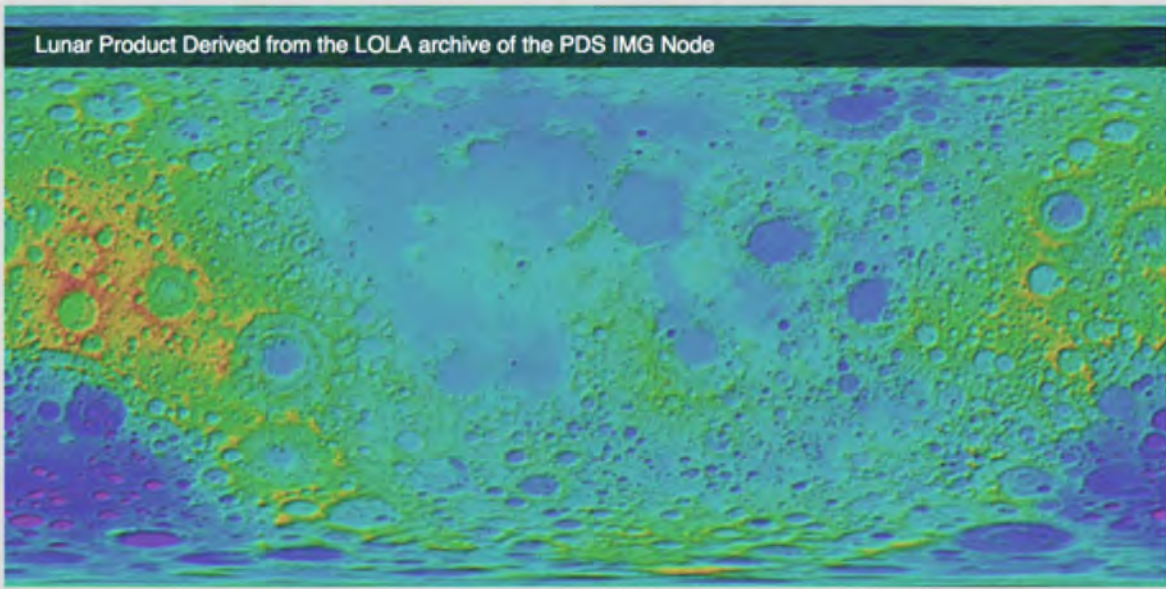
Imaging node: PDS Annex of Geospatial Products

<https://astrogeology.usgs.gov/pds/annex>

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Lunar Product Derived from the LOLA archive of the PDS IMG Node




The PDS Cartography and Imaging Sciences Node (“Imaging” or IMG) Annex is a data portal designed to support the public delivery of NASA-funded geospatial data products derived from PDS image data. Examples of geospatial derived products are cartographic and thematic maps of moons and planets, local and regional geologic feature maps, topographic and perspective views of planetary landing sites, and tabular data containing feature or unit information derived from planetary data. Many of these products have been developed as a result of NASA data analysis programs, often years after active missions (and their accumulating archives) have ended. As of January 2017, the Annex is considered PDS-Equivalent by NASA as a long-term data repository. It is our intention to migrate all PDS data products served via the Annex to PDS4-compliant archives.











Imaging node: PDS Annex of Geospatial Products

<https://astrogeology.usgs.gov/pds/annex>

Annex Products

Filter by

Powered by 

 <p>Robbins Lunar Crater Database 2018-08-15 This is a database of approximately 1.3 million lunar impact craters...</p>	 <p>MARS MRO MARCI Mars Daily Global Maps Archive This PDS4-compliant archive contains version 2.0 MRO MARCI Mars Daily...</p>
 <p>Taurus-Littrow Valley Apollo 17 Orthomosaic 50cm This is an orthomosaic of the Apollo 17 landing site created from...</p>	 <p>Taurus-Littrow Valley Apollo 17 DEM 150cm This is a digital elevation model (DEM/DTM) of the Apollo 17 landing...</p>
 <p>Apollo 17 landing site map scale 15000 This is an (ortho-) mosaic map of the Apollo 17 landing site (L15K...</p>	 <p>CTX Orthoimage of Lethe Vallis This orthorectified image was created by projecting an image from the...</p>
 <p>CTX Orthoimage of Cerebus Palus Wrinkle Ridge This orthorectified image was created by projecting an image from the...</p>	 <p>CTX Orthoimage of Cerebus Palus Wrinkle Ridge This orthorectified image was created by projecting an image from the...</p>
 <p>CTX Orthoimage Northwest Kasei Valles Constriction This orthorectified image was created by projecting an image from the...</p>	 <p>CTX Orthoimage Northwest Kasei Valles Constriction This orthorectified image was created by projecting an image from the...</p>

1 2 3 4 ... 27