LRO Diviner Lunar Radiometer Observations of the Moon

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NLSI Lunar Forum
NASA Ames
July 17, 2012

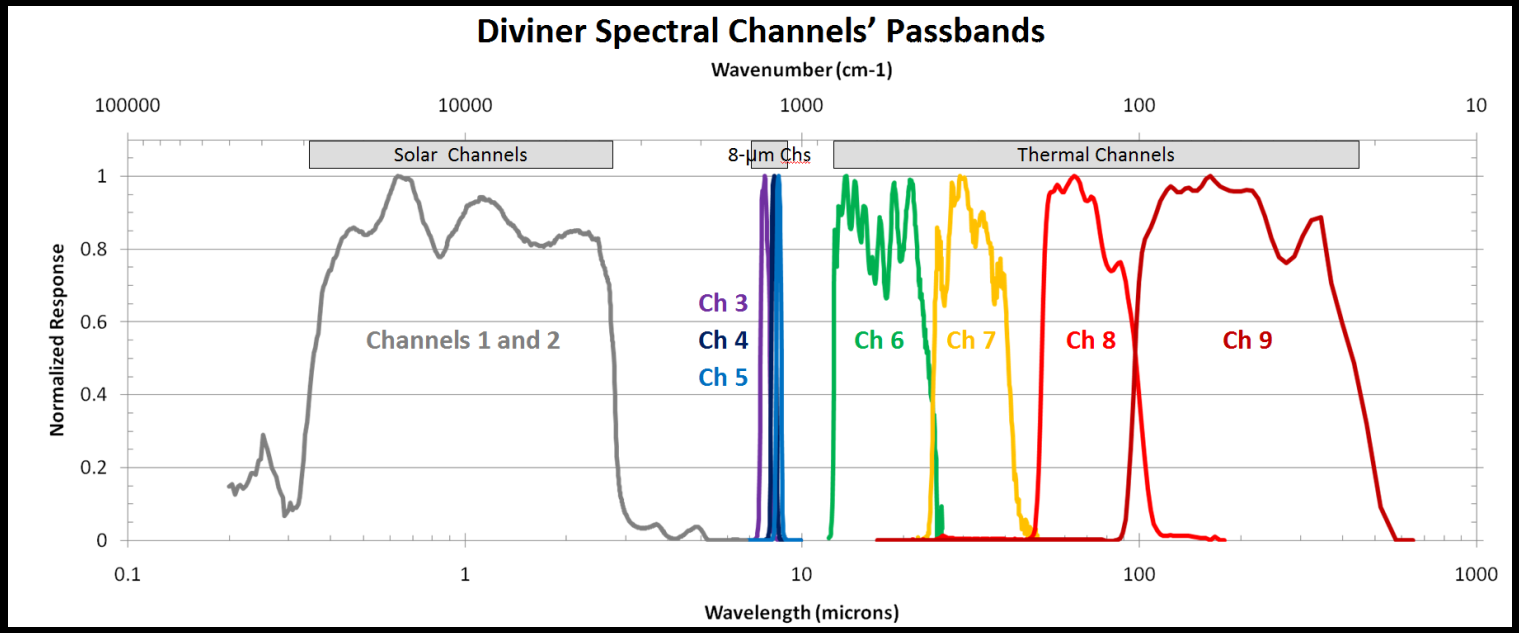
http://diviner.ucla.edu

LRO Diviner Lunar Radiometer

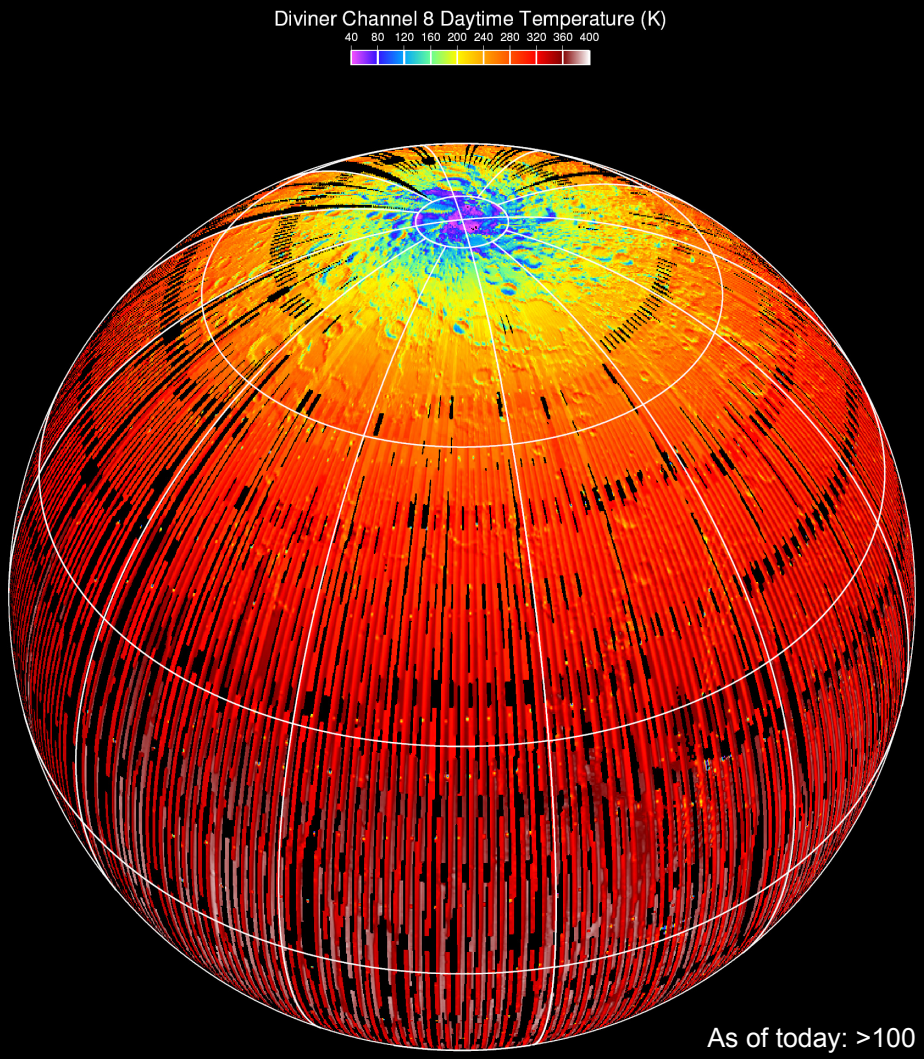
Science Goals

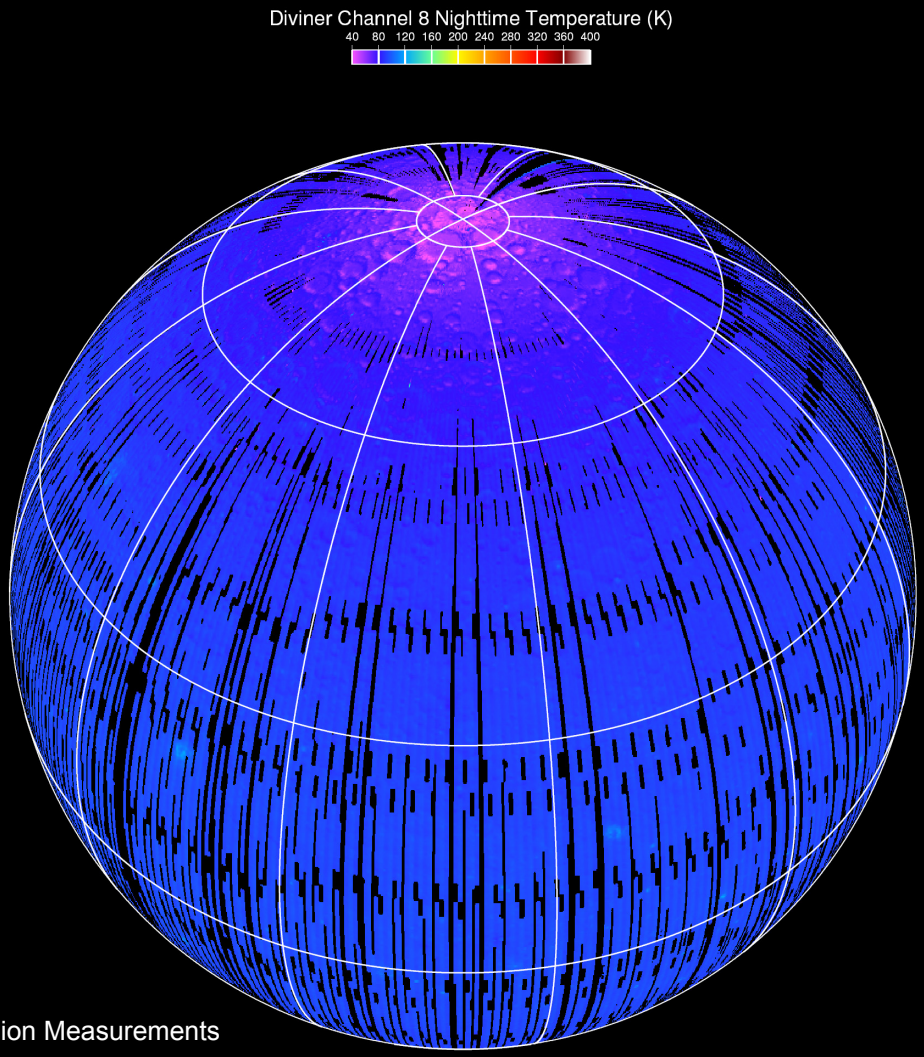
1. Characterize the Moon's surface thermal environments:
   - Daytime
   - Nighttime
   - Polar
2. Map properties of the lunar surface:
   - Bulk thermal properties
   - Rock abundance
   - Composition
3. Characterize polar cold traps:
   - Map cold trap locations
   - Determine their temperatures and thermophysical properties
   - Assess potential lunar volatile resources

IFOV: 160 x 320m
Swath Width: 3.4 km
Operating Since July, 2009



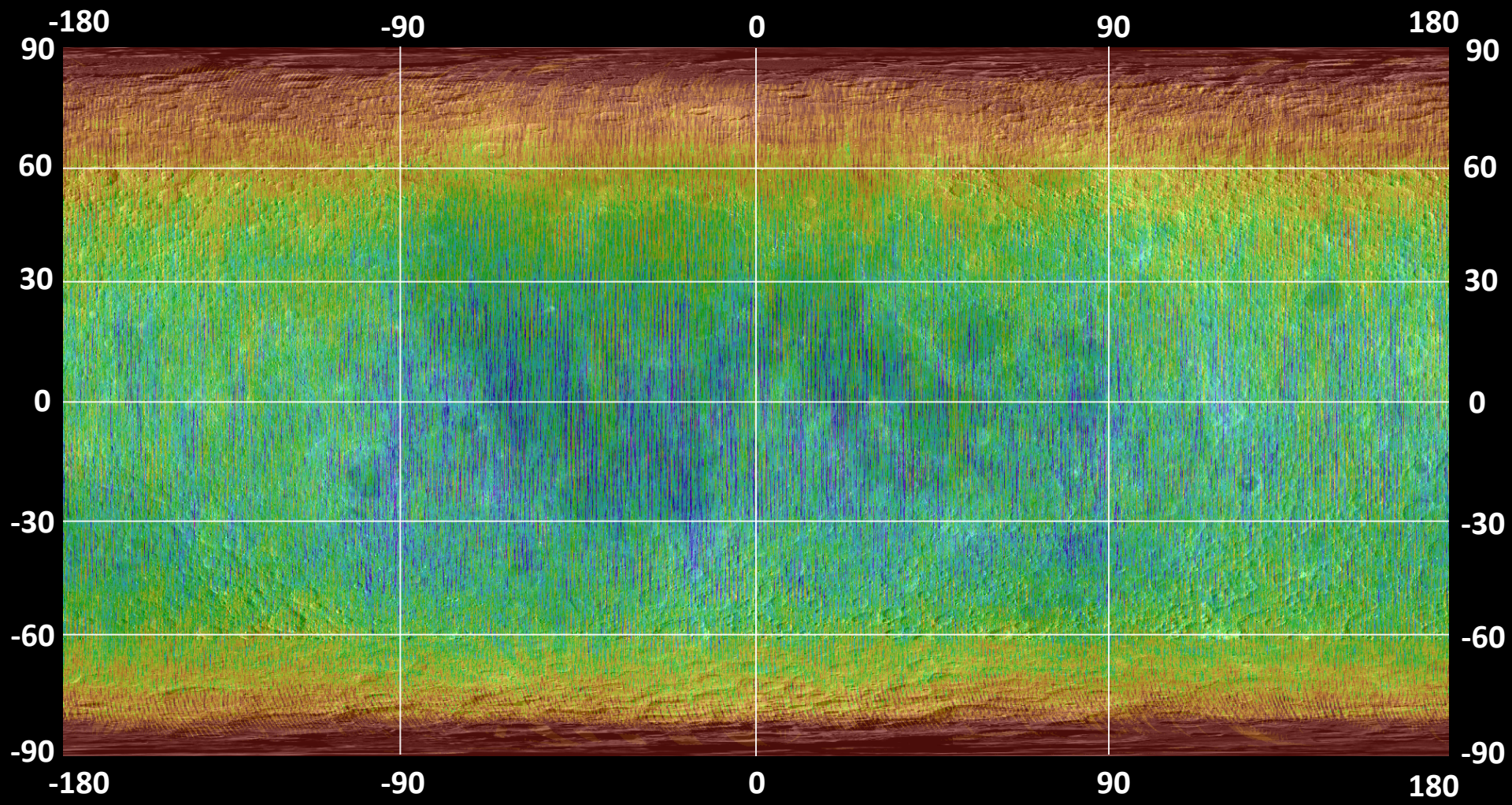
First Diviner Day and Night Global Thermal Maps

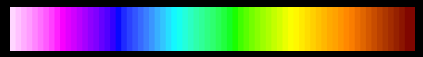




As of today: >100 Billion Measurements

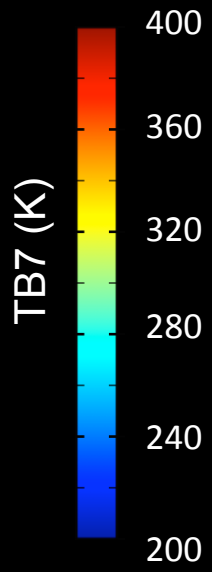
Diviner Cumulative Local Time Coverage

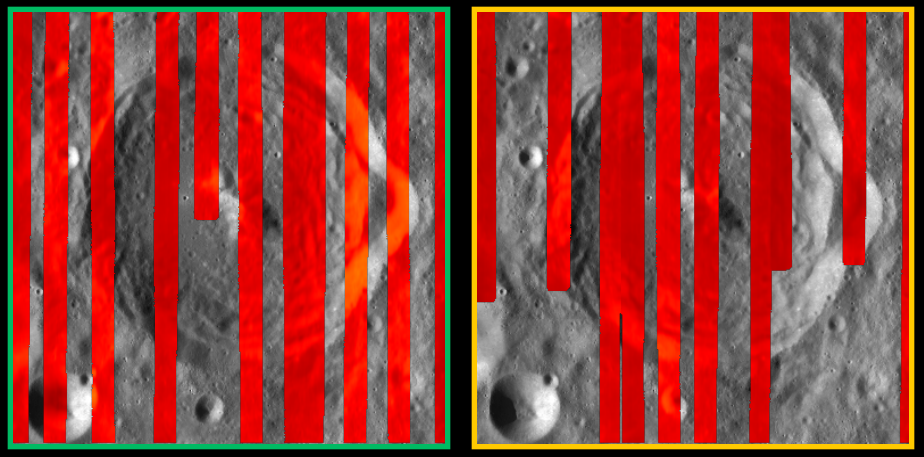


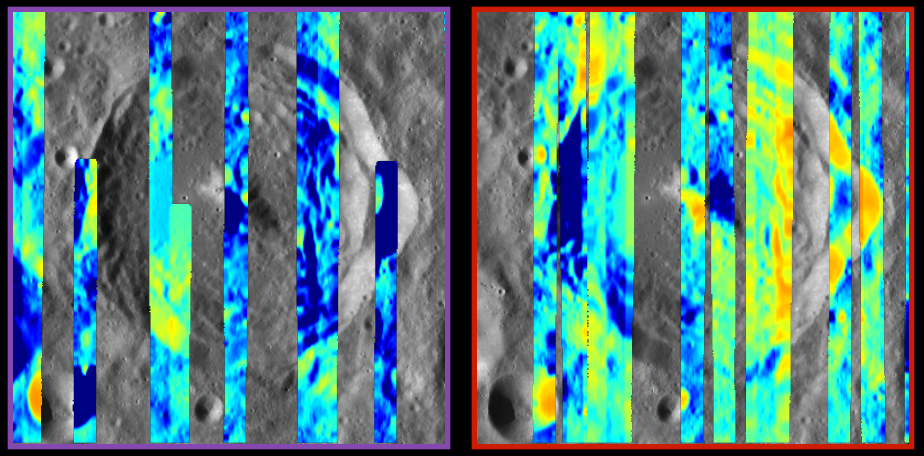


Distinct Hours of Coverage

Equatorial Daytime Coverage





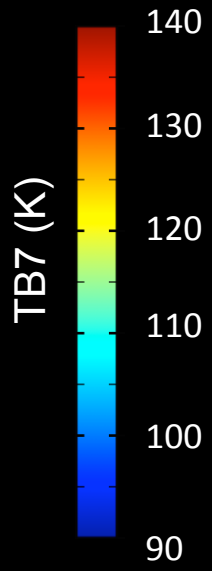


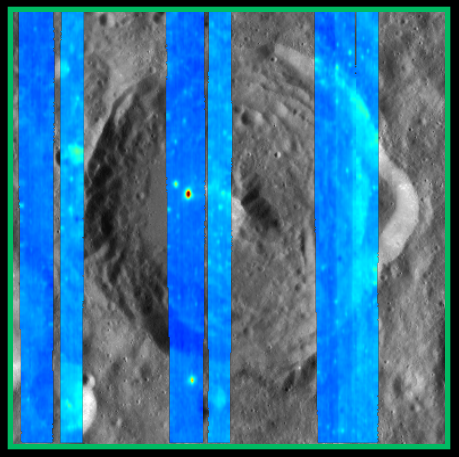
Green Crater

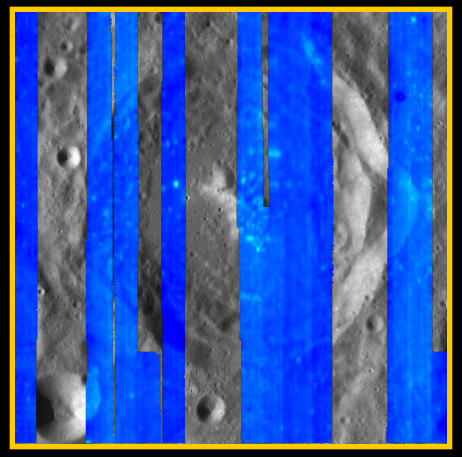
133 E / 3.5 N

3° x 3° box

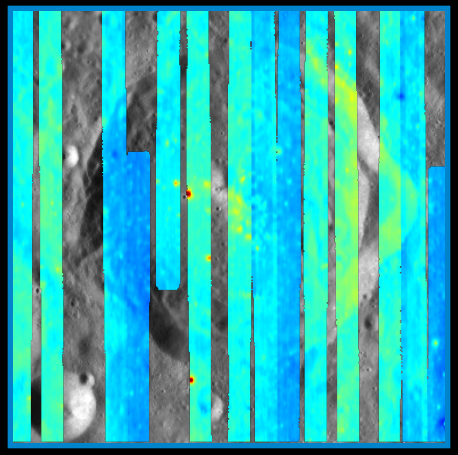
Equatorial Nighttime Coverage

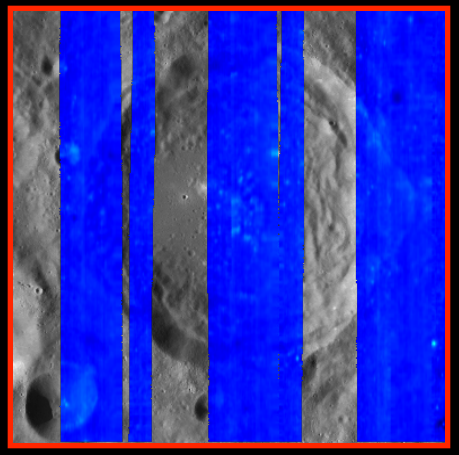






0000 - 0200





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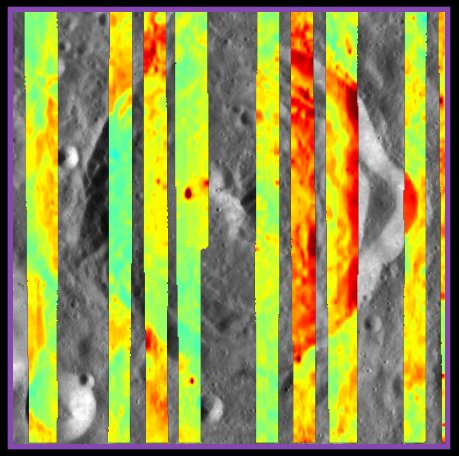
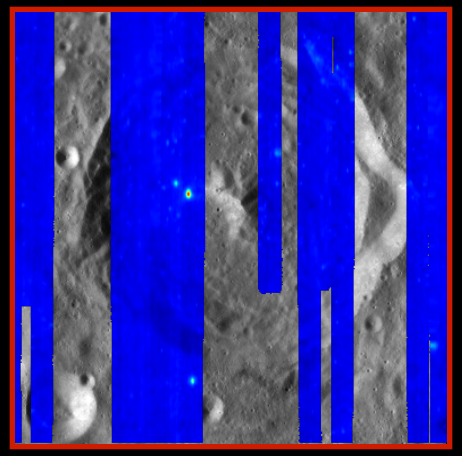




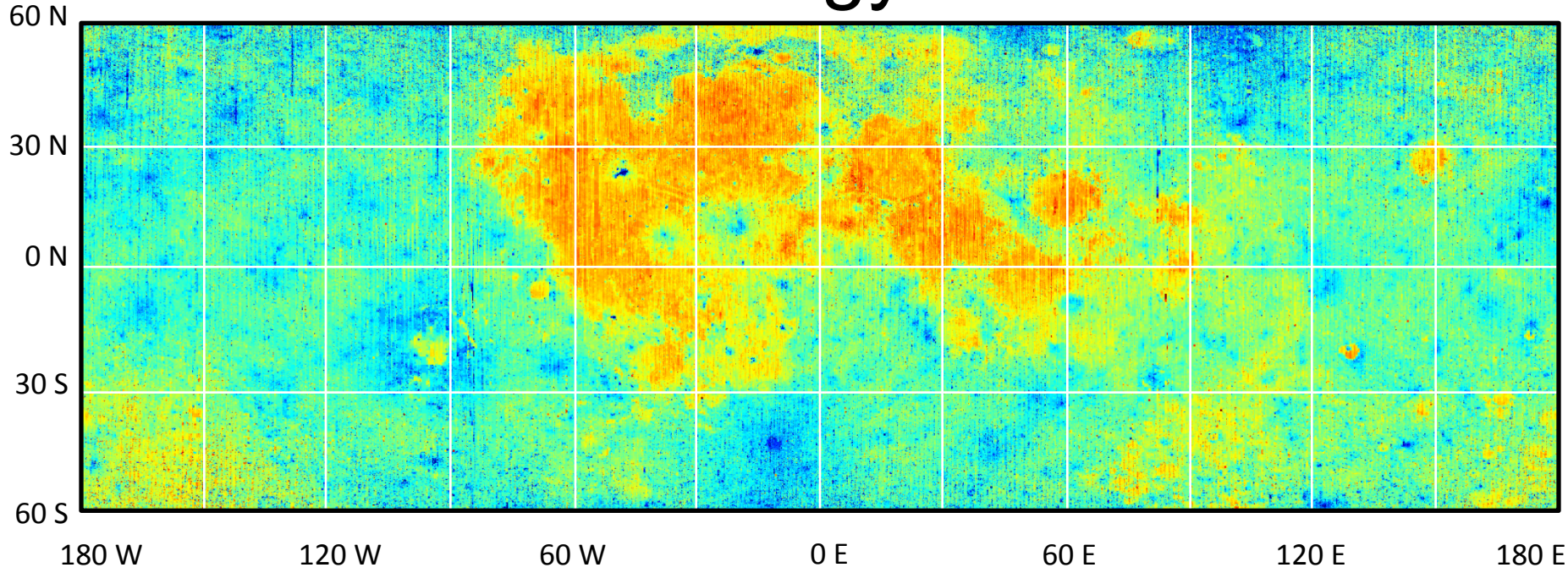
0400 - 0600

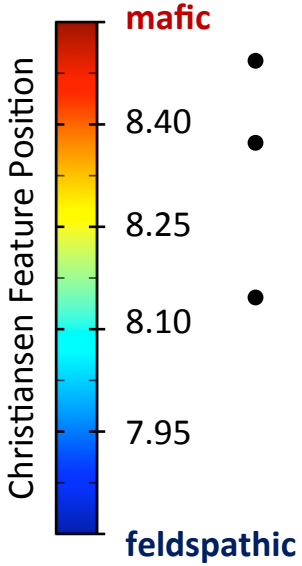
Green Crater

133 E / 3.5 N

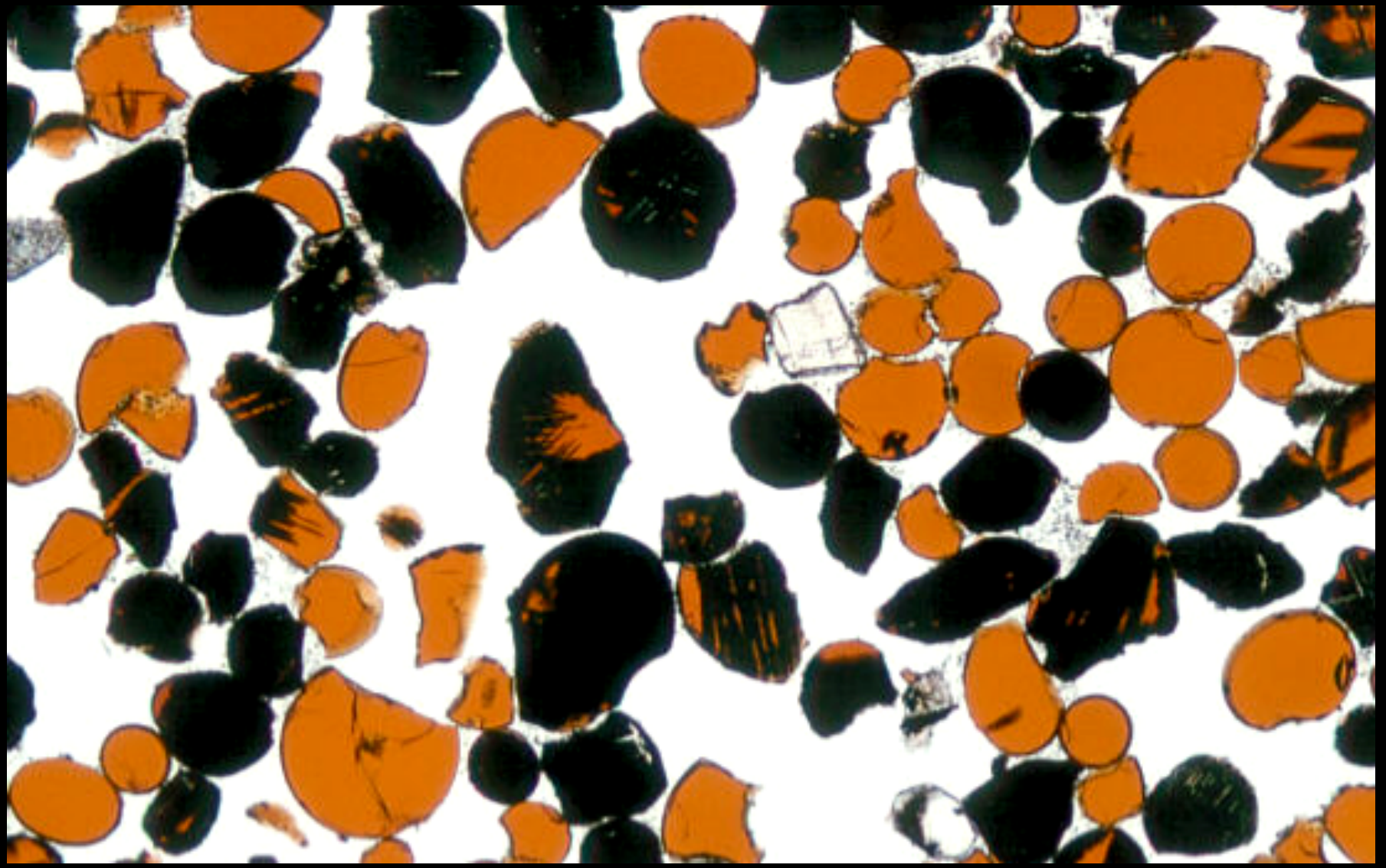
3° x 3° box

Silicate Mineralogy from Diviner

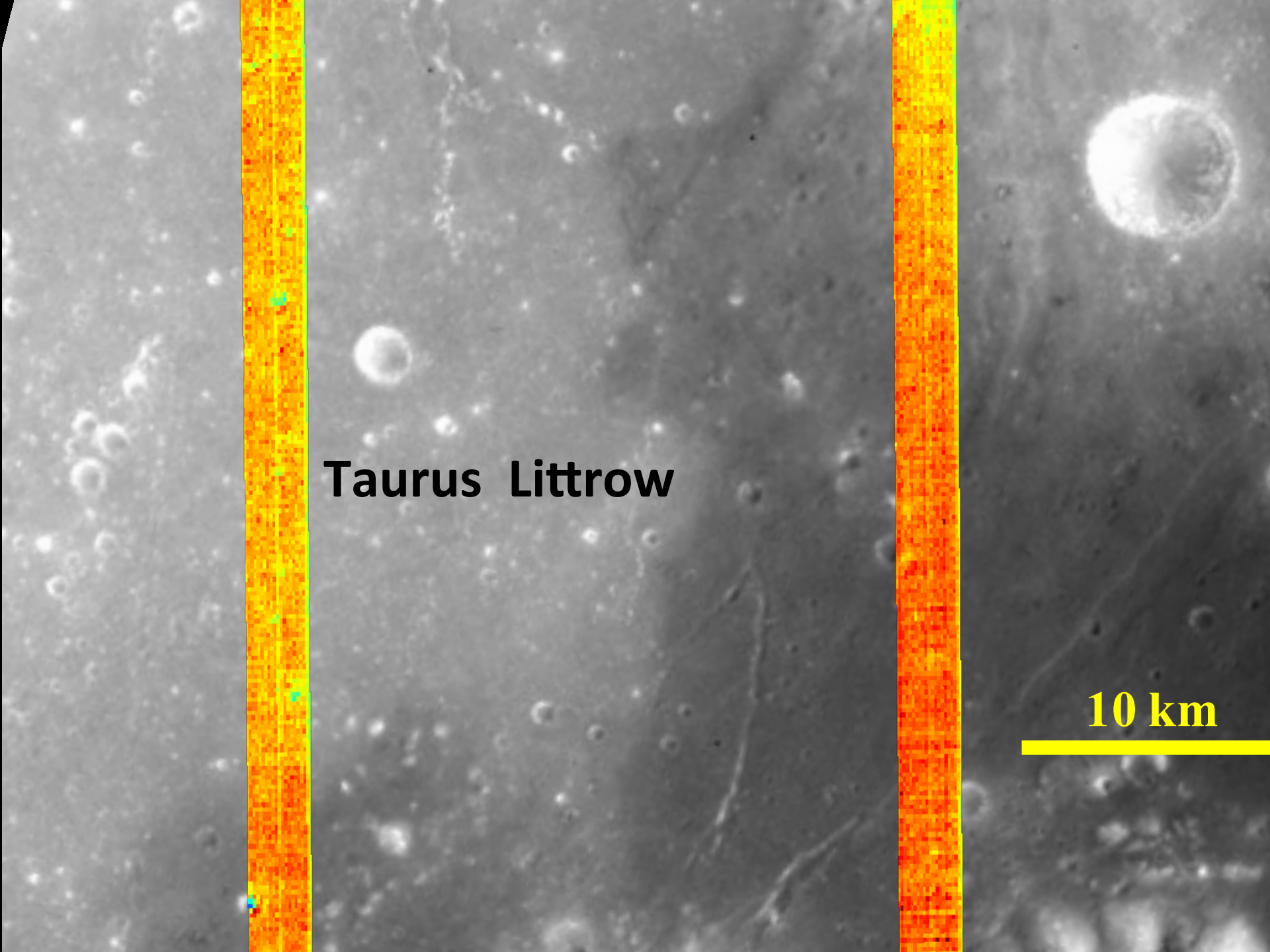


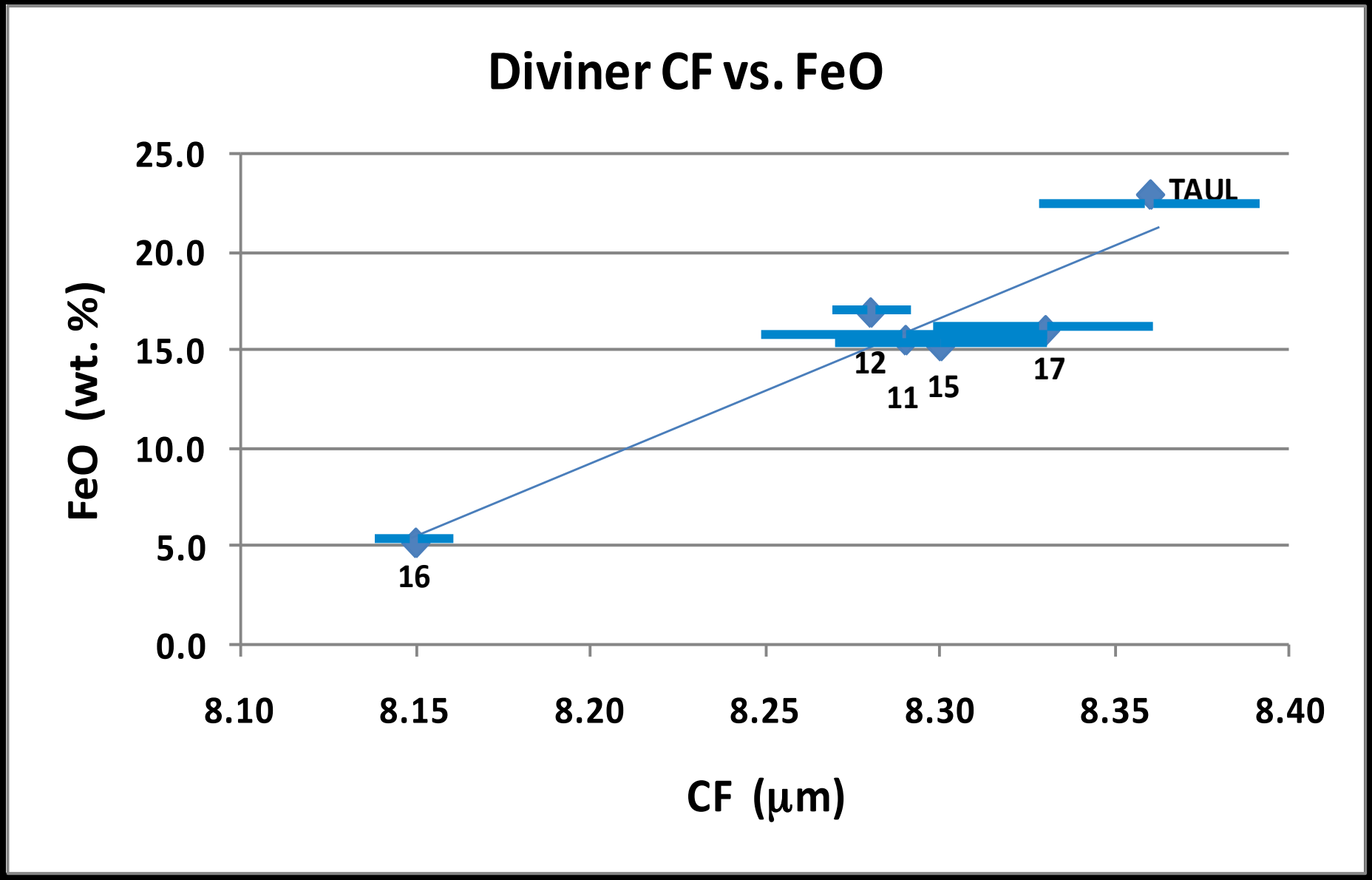


- Highland and mare regions are clearly distinguishable
- South-Pole Aitken basin is intermediate to highlands and maria
- Significant composition diversity has been observed
  - Areas with high silica contents (quartz or alkali feldspar)
  - Widely distributed intermediate plagioclase (bytownite?)
  - Small exposures of plagioclase-poor, olivine-rich materials

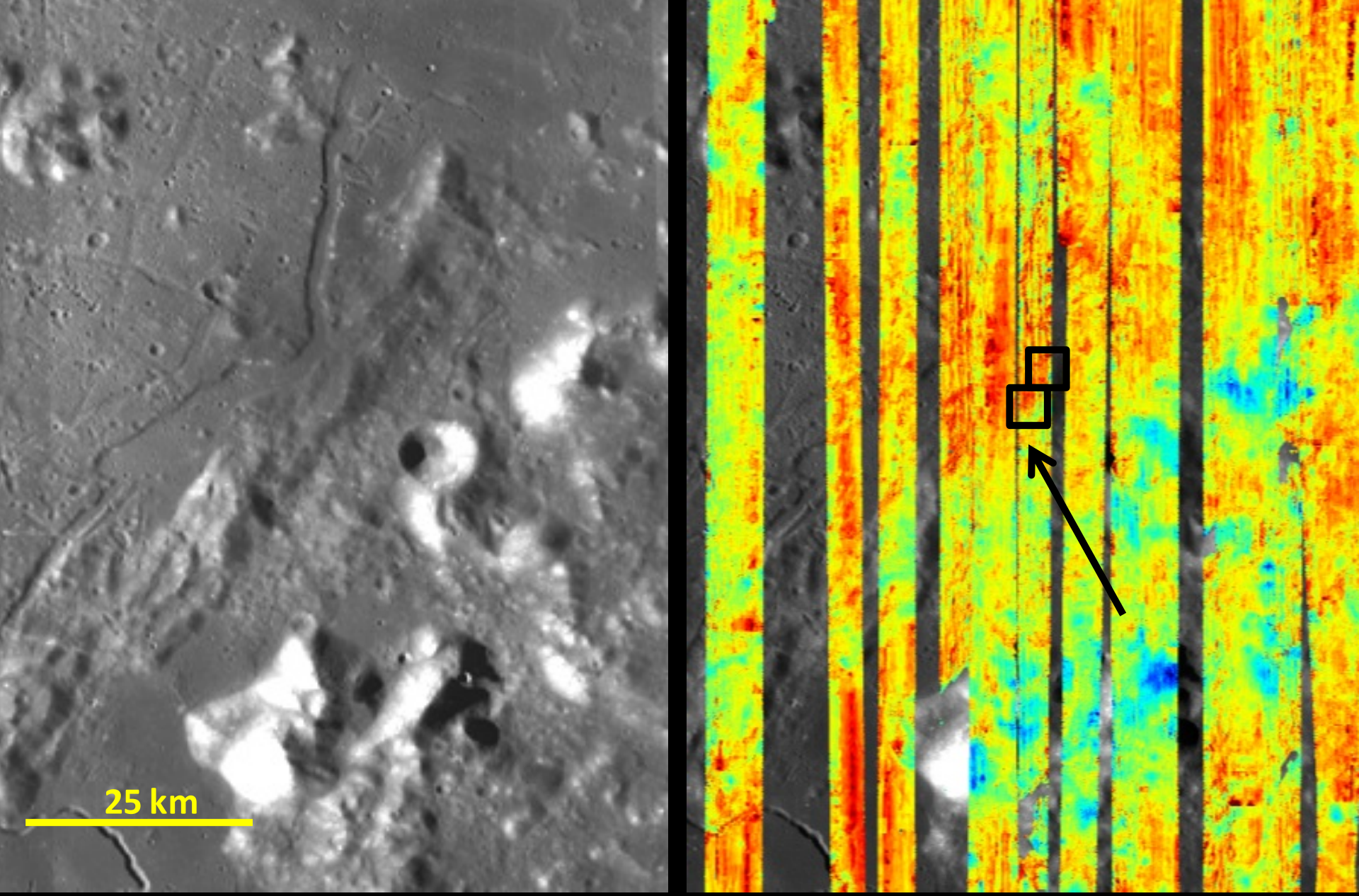


Apollo 17 orange and black glass (22.9 wt.% FeO)
Samples of the Taurus Littrow deposit


Taurus Littrow
10 km



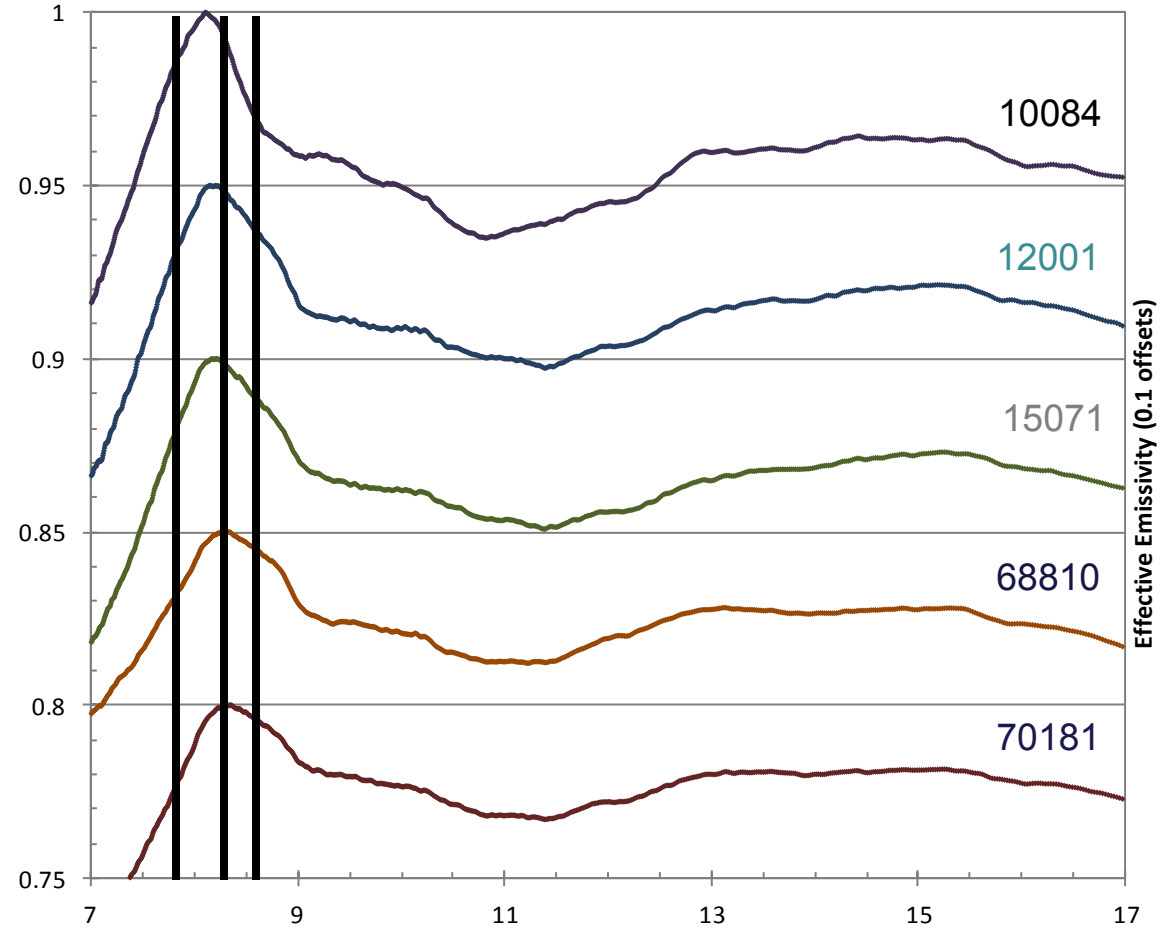
$FeO = 74.24 \times CF - 599.9$ $r^2 = 0.90$



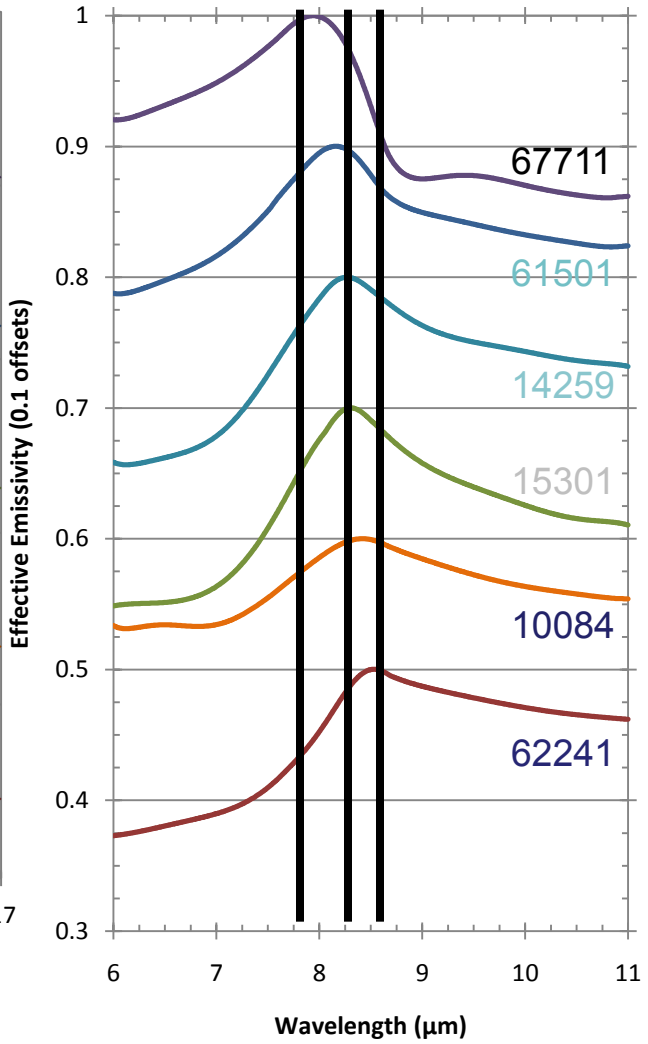
Rima Fresnel FeO = 17.8 +/- 3.0 wt. % and 15.6 +/- 2.2 wt. %

Characterizing the CF

New SLE Measurements



Previous SLE Measurements

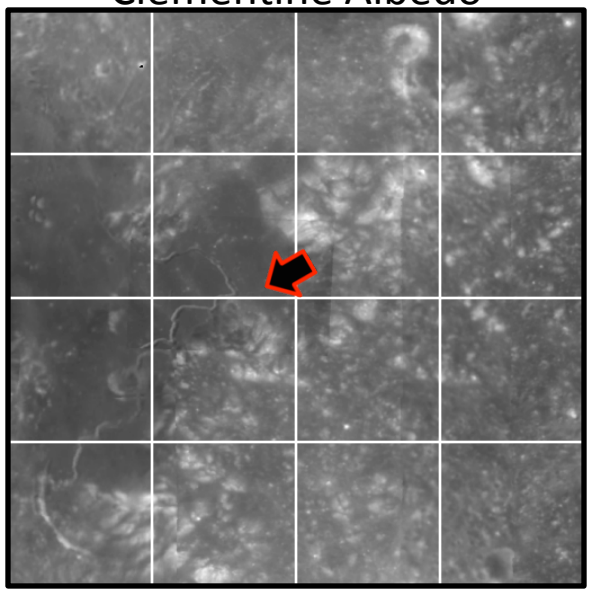


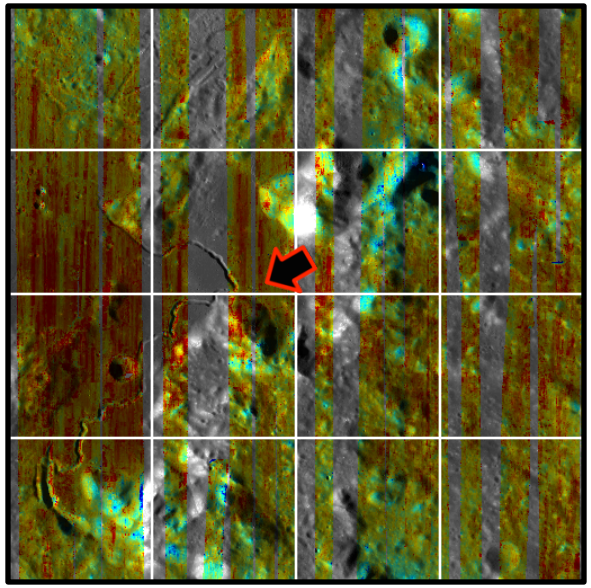
Diviner was designed to characterize the CF using three channels near 8 microns

Right after Salisbury et al., 1973 and Logan et al., 1975

Apollo 15

Clementine Albedo

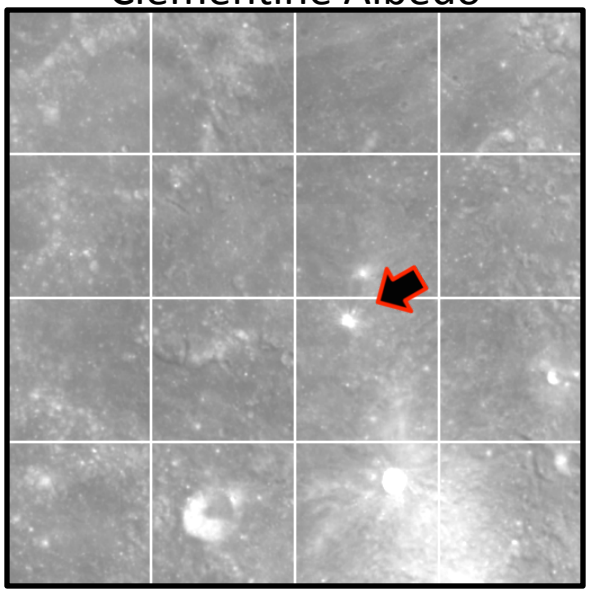


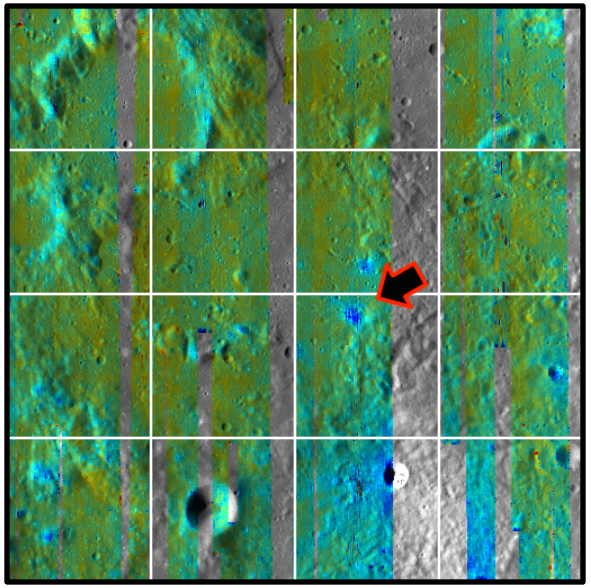


Diviner CF over LROC WAC

Apollo 16

Clementine Albedo

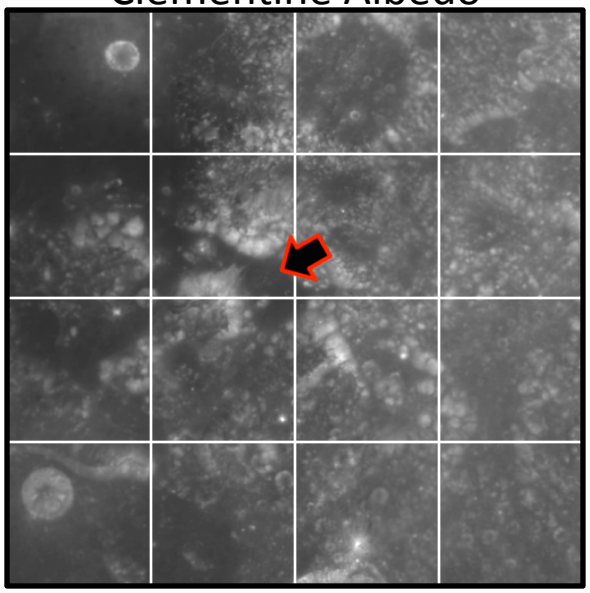


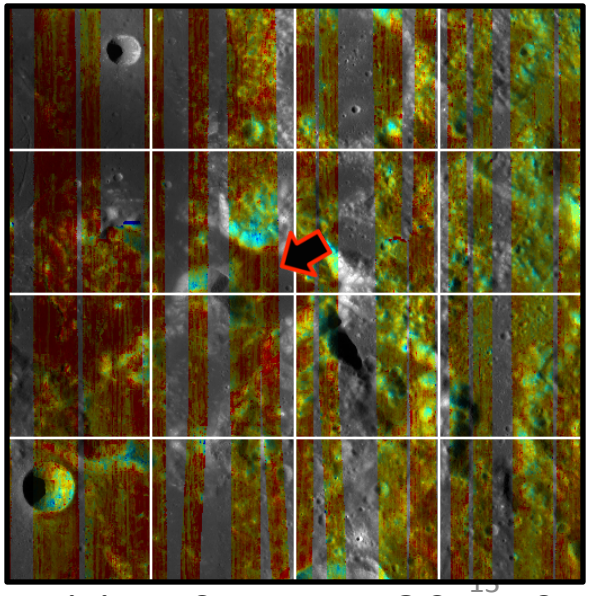


Diviner CF over LROC WAC

Apollo 17

Clementine Albedo



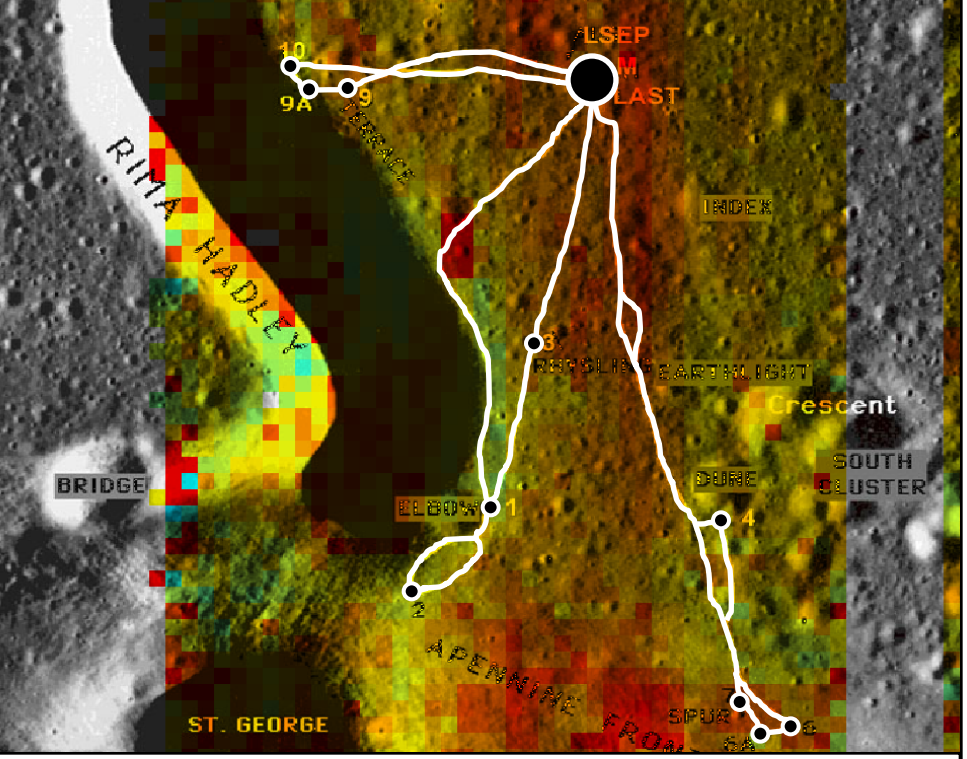


Diviner CF over LROC WAC

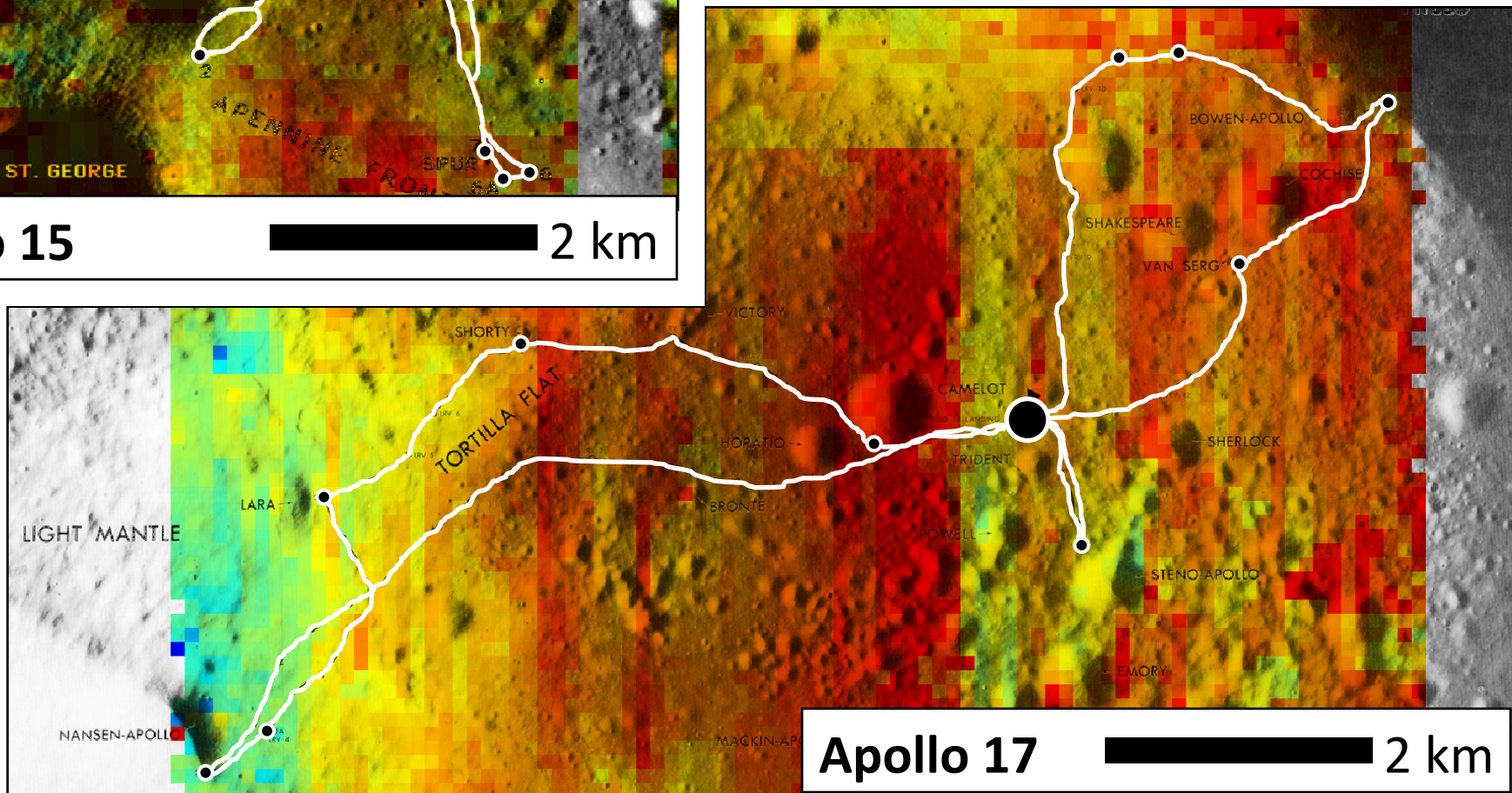
Detailed Diviner analysis for Apollo 15, 16, and 17 sampling stations

Used single point average for Apollo 11-14

Correlated each sampling site observation to laboratory-measured geochemical properties of Apollo soils

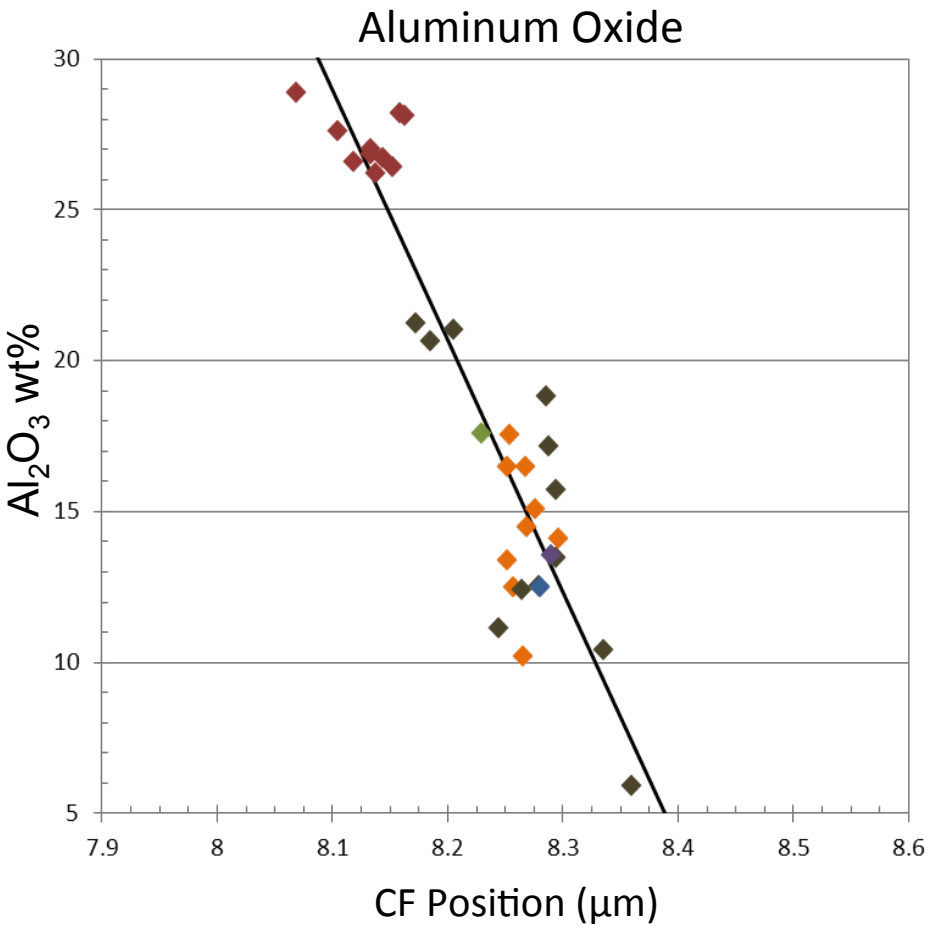


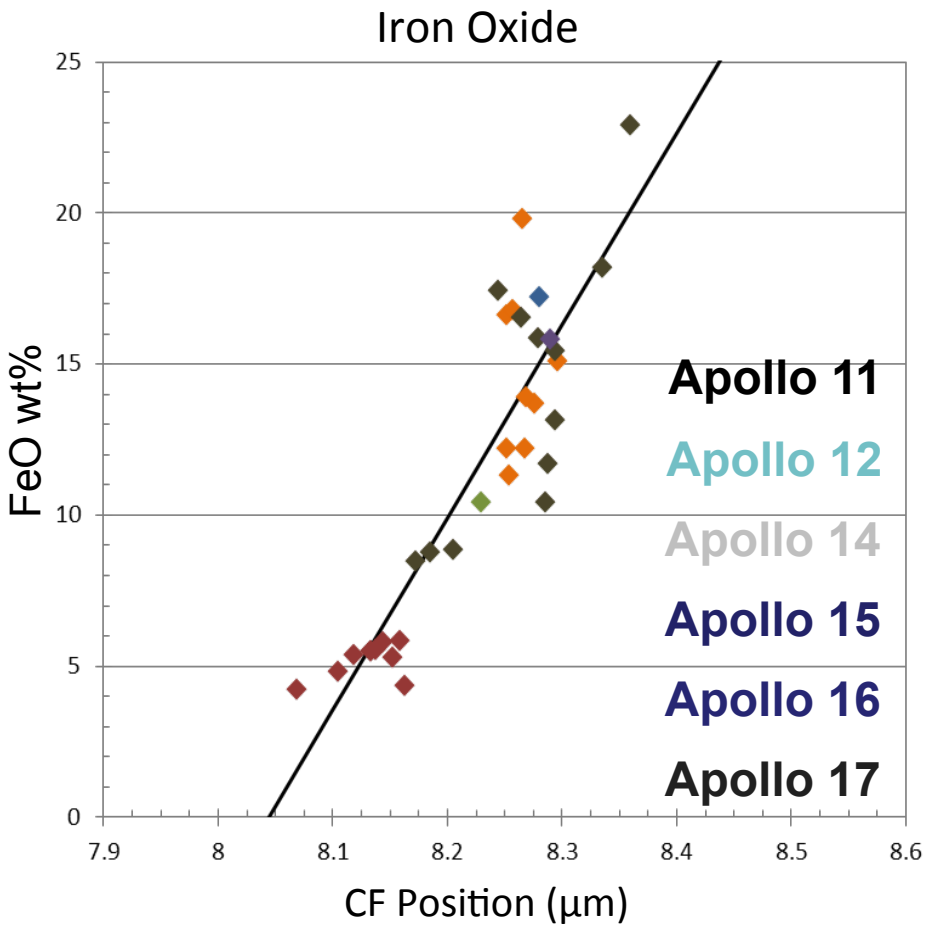
Apollo 15 2 km



Apollo 17 2 km

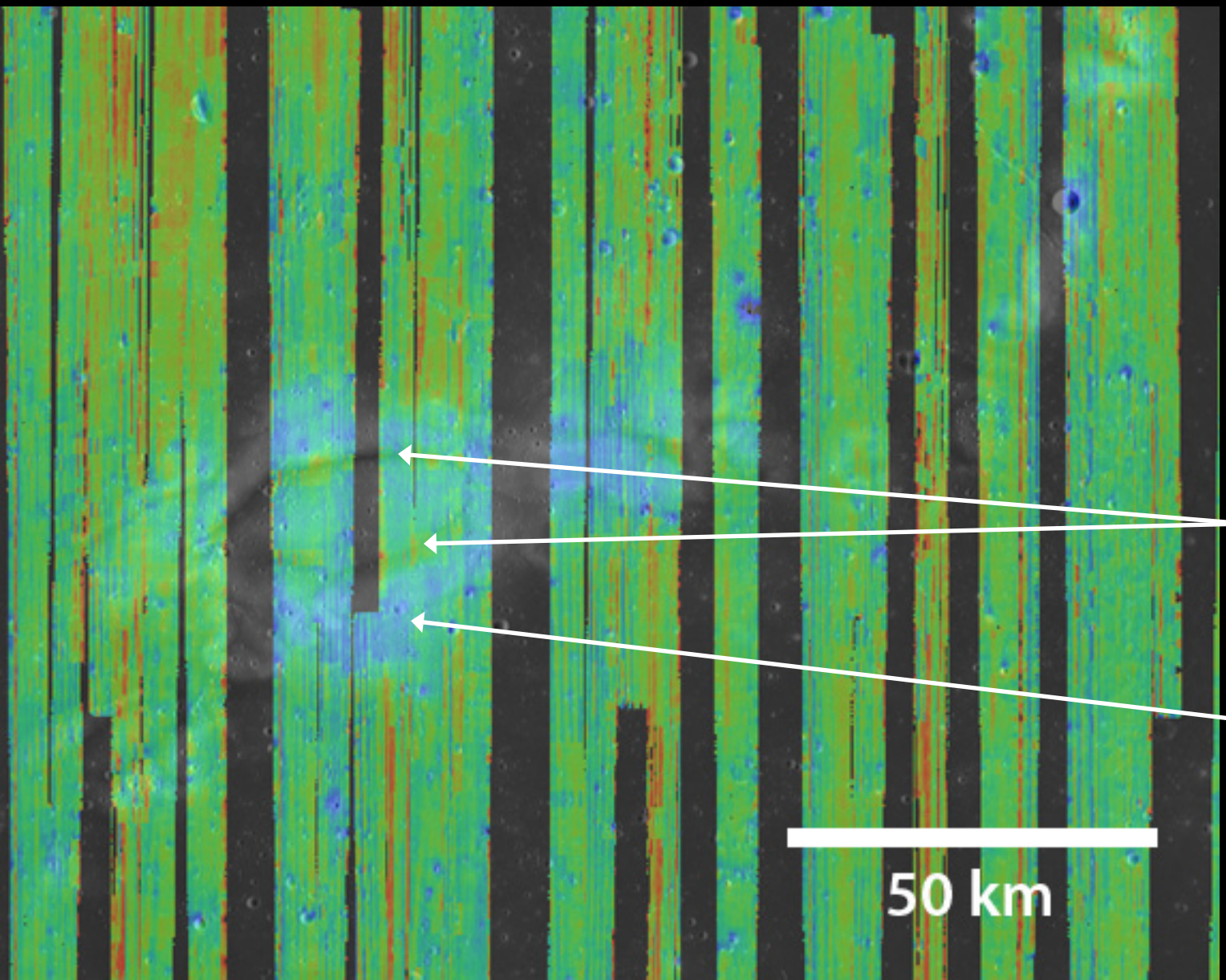
Compositional Correlations



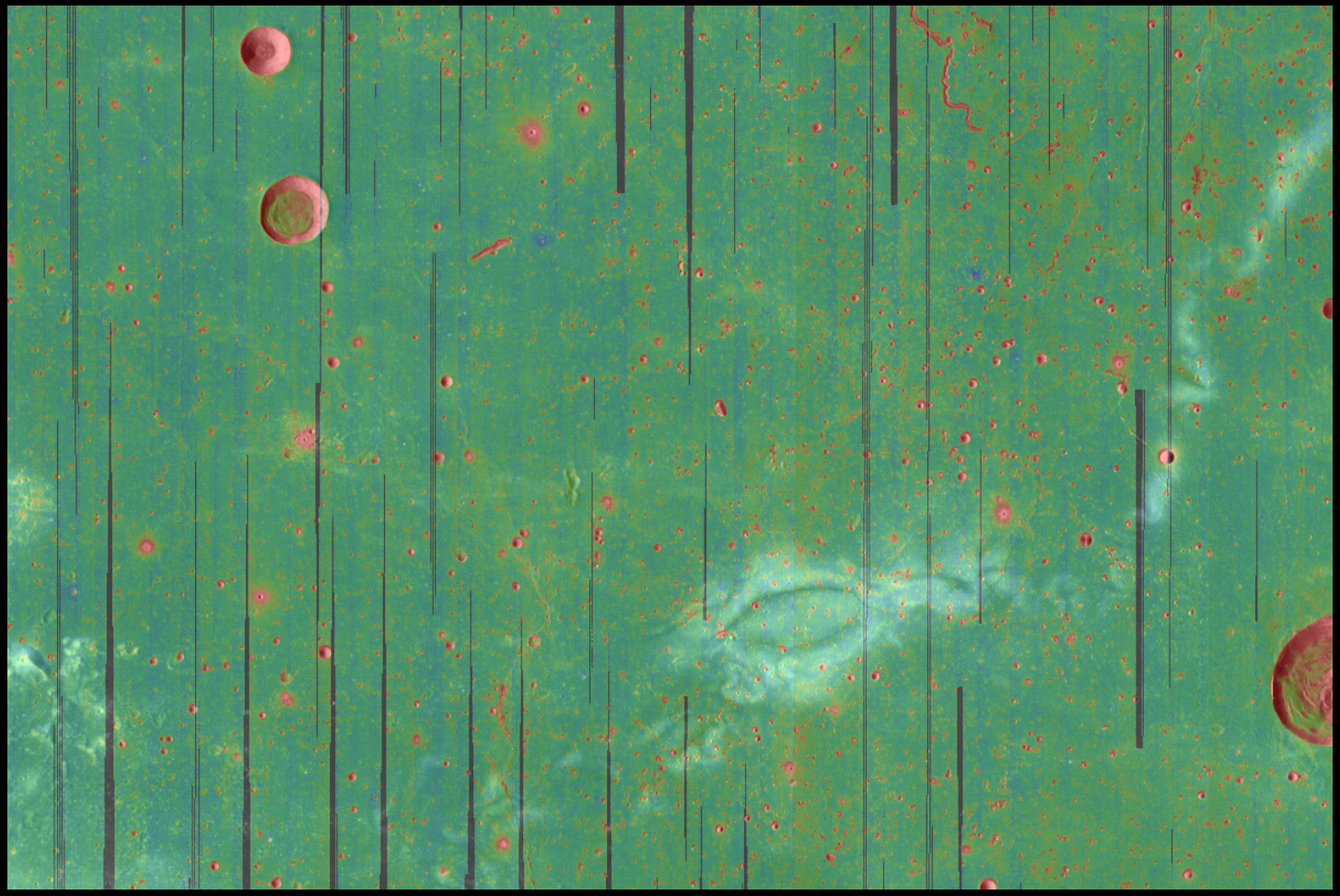


Good correlation between CF and Al_2O_3 and FeO content for Diviner observations

Reiner Gamma, Oceanus Procellarum



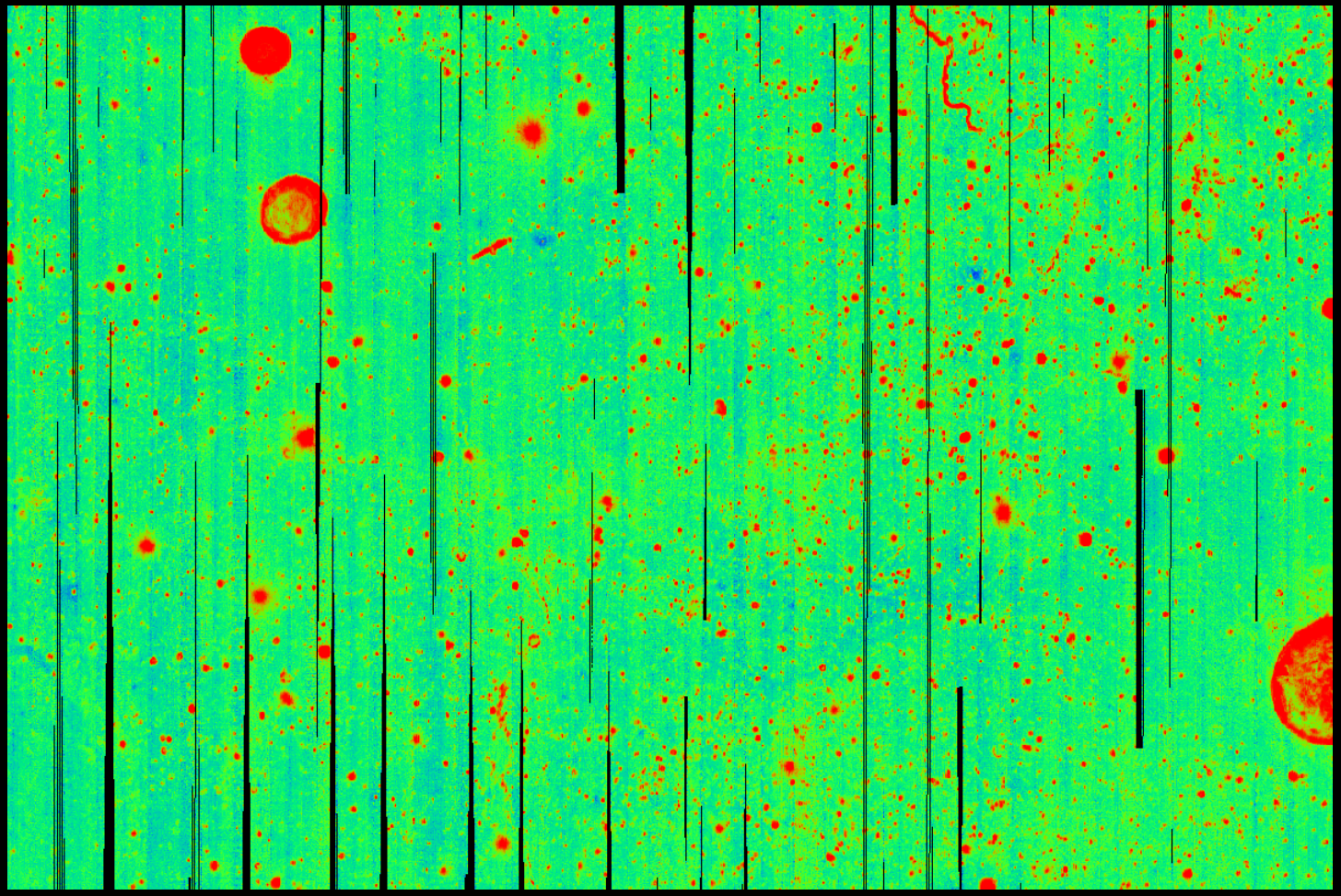
Reiner Gamma, Oceanus Procellarum



Reiner Gamma, Oceanus Procellarum

Diviner Night-time regolith temperature

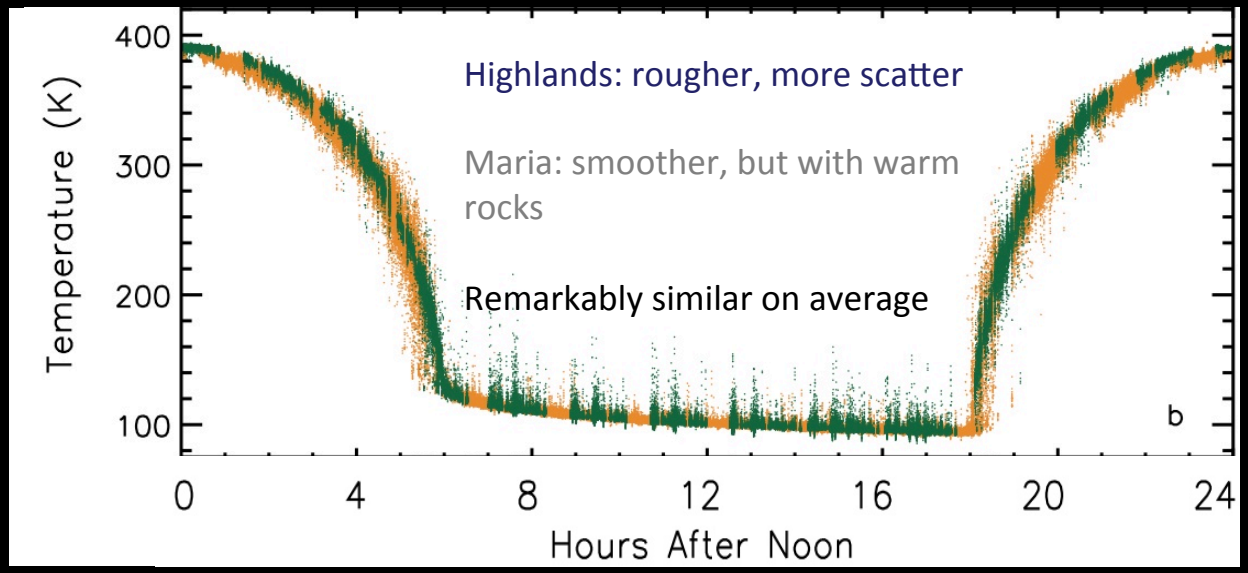
Small temperature difference between regolith and swirl

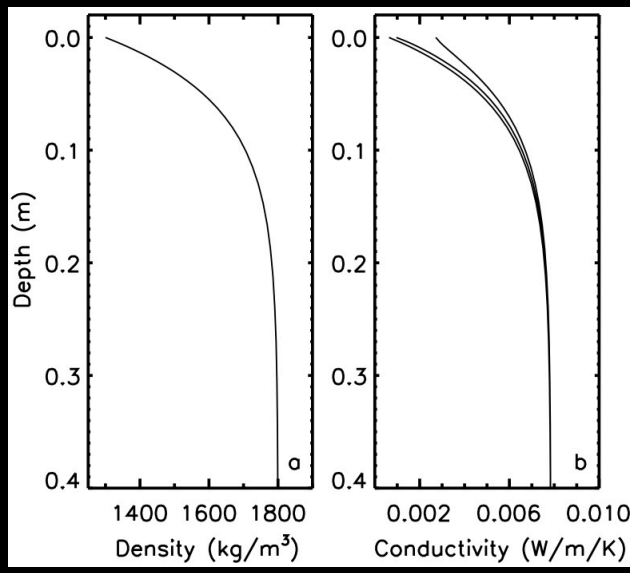


Summary of Swirl Results

- Diviner detects a “CF anomaly” associated with lunar swirls.
- Swirls have CF positions that are ~0.05 μm shorter than the surrounding terrain.
- Night-time Diviner data and thermal modeling indicate swirl “layer” must be < 1 cm thick.
- Differential space weathering the strongest hypothesis for formation of swirl albedo patterns

Diviner Thermophysical Properties

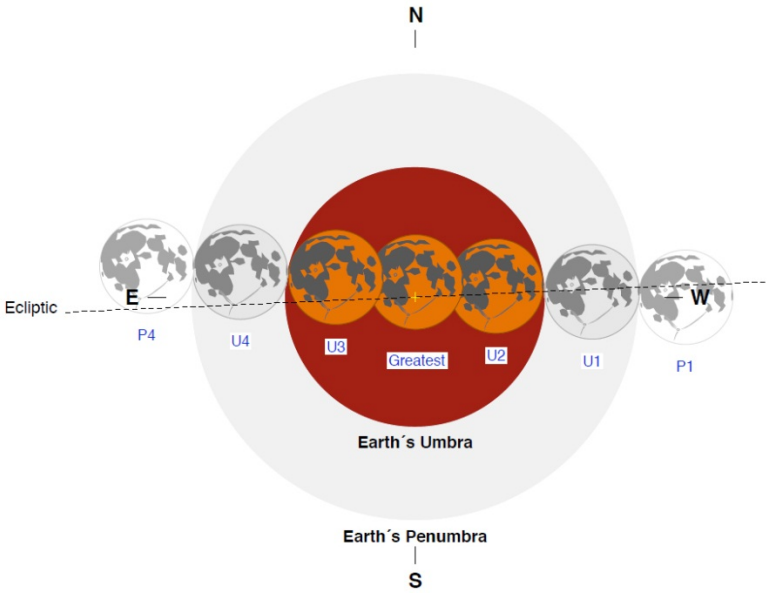




Equatorial Thermophysical Properties – Observations and Models

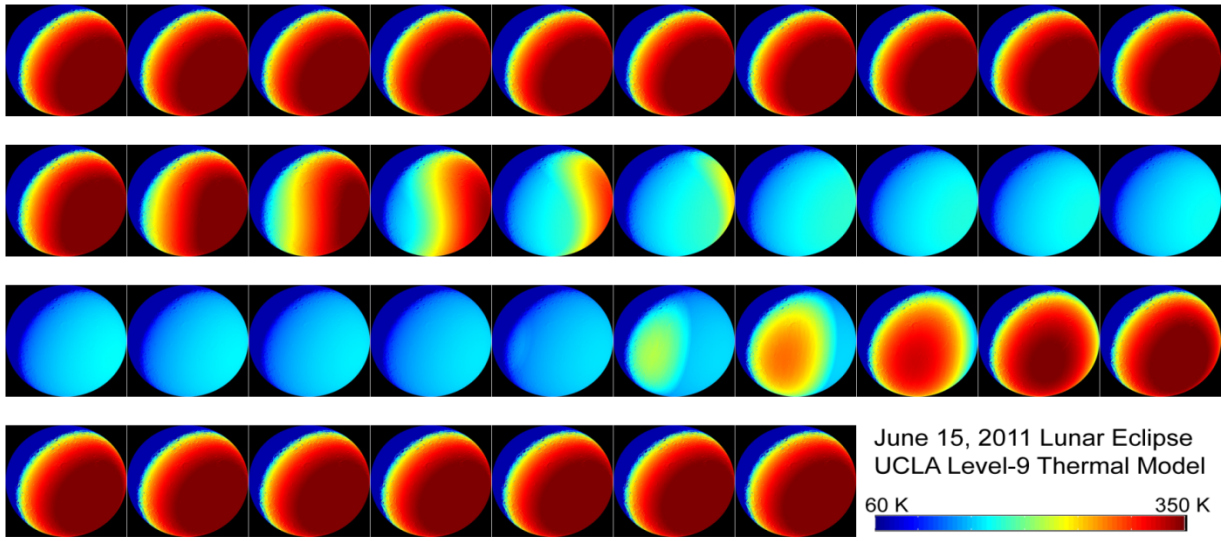
Eclipse Observations Summary

- Eight eclipses since start of primary mission, three total eclipses
- Diviner acquired targeted observations during four eclipses to measure cooling at specific sites

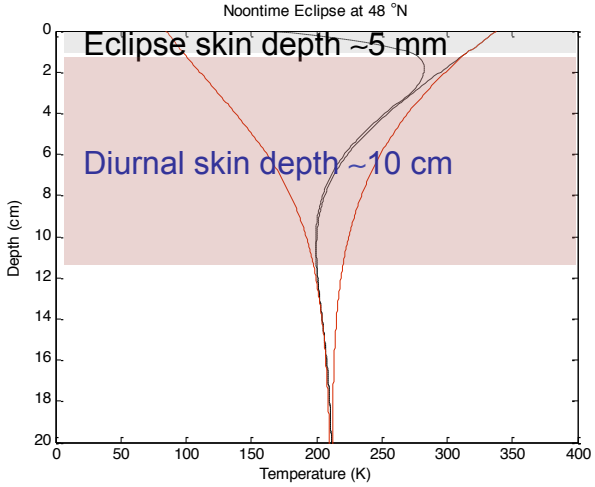


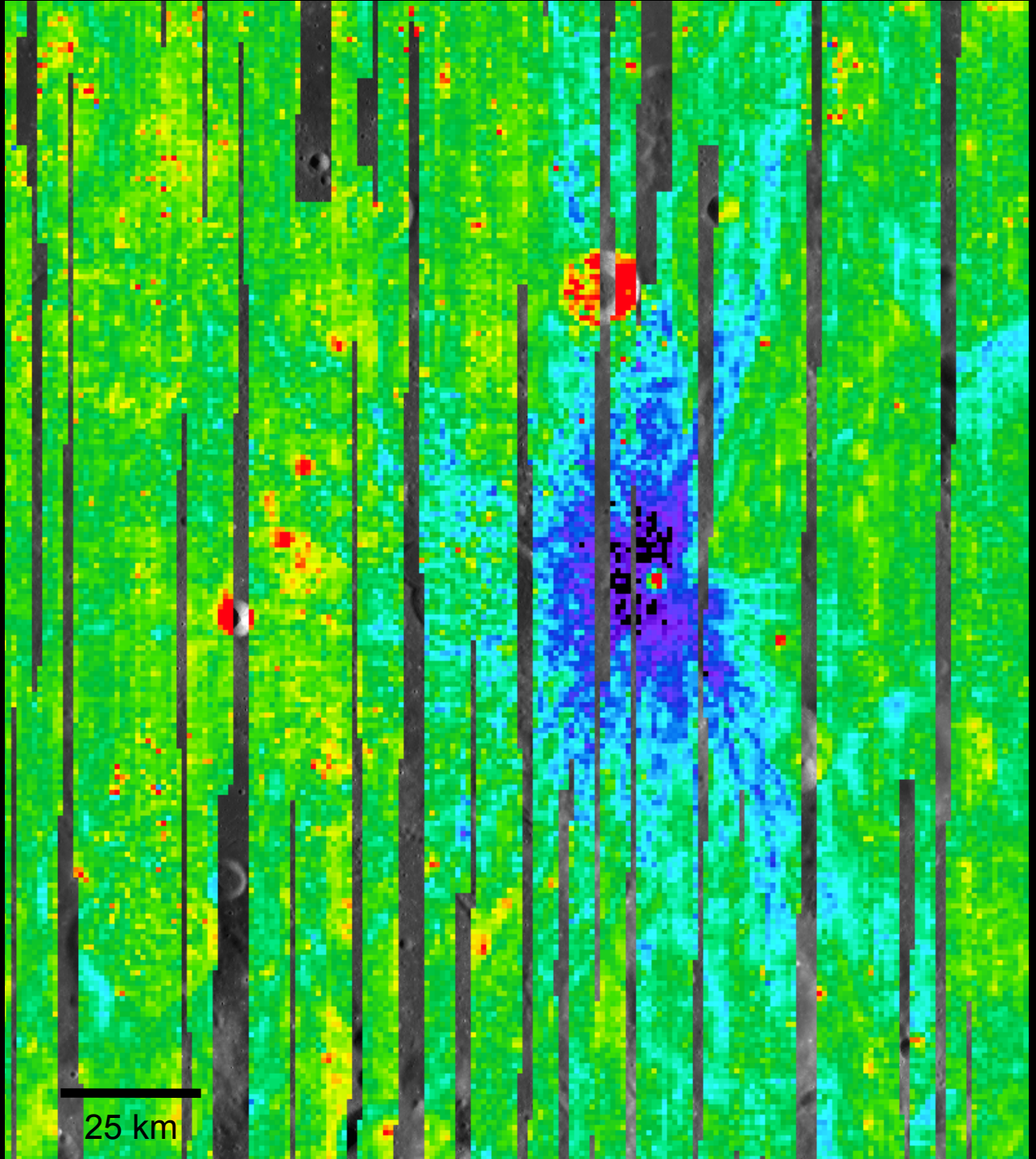
Date	Type	P1	U1	U2	Max	U3	U4	P4
7/7/2009	Penumbral	8:37:51	-	-	9:38:36	-	-	10:39:20
8/6/2009	Penumbral	23:04:21			0:39:11			2:14:08
12/31/2009	Partial	17:17:08	18:52:43	-	19:23:46	-	19:52:41	21:28:11
6/26/2010	Partial	8:57:21	10:16:57	-	11:38:27	-	12:59:50	14:19:34
12/21/2010	Total	5:29:17	6:32:37	7:40:47	8:16:57	8:53:08	10:01:20	11:04:31
6/15/2011	Total	17:24:33	18:22:55	19:22:29	20:12:36	21:02:41	22:02:14	23:00:44
12/10/2011	Total	11:33:32	12:45:42	14:06:16	14:31:49	14:57:24	16:17:58	17:30:00
6/4/2012	Partial	8:48:09	9:59:53	-	11:04:20	-	12:06:30	13:18:17

Eclipse Science Summary



- Amount of cooling during eclipse depends on physical structure of upper few millimeters of regolith; more cooling for “fluffy” material
- Allows constraints on upper regolith not possible with diurnal wave alone
- Detailed 3-d modeling required to accurately match change in insolation and IR fluxes

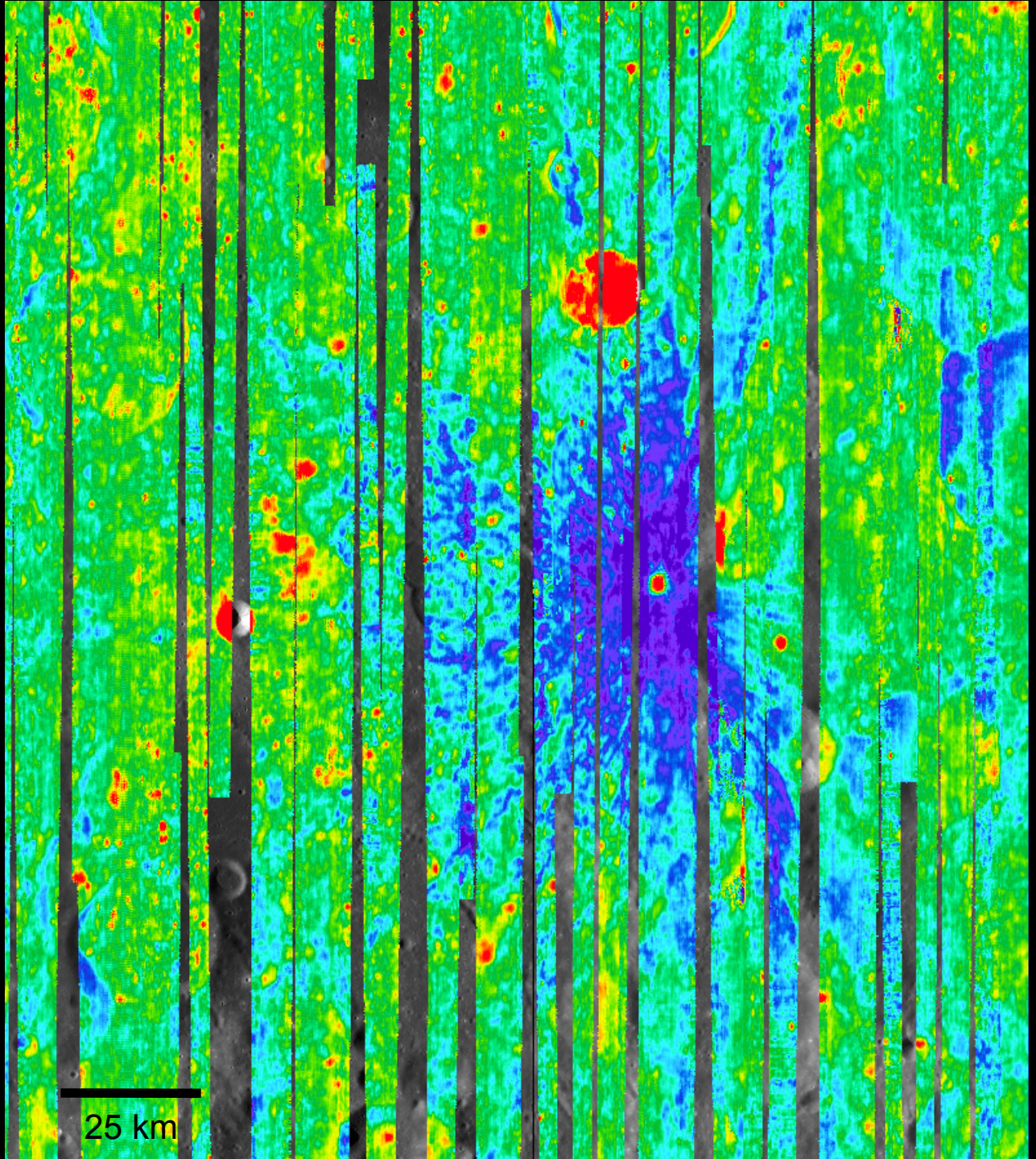




New Rock Abundance and Regolith Temperature Maps

- Same algorithm, but new maps are constructed from Diviner Level 2 GDR products
- Maps will be available at 16, 64, and 128 pixels per degree (previously only available at 32 ppd)

32 PPD
Regolith
Temperature

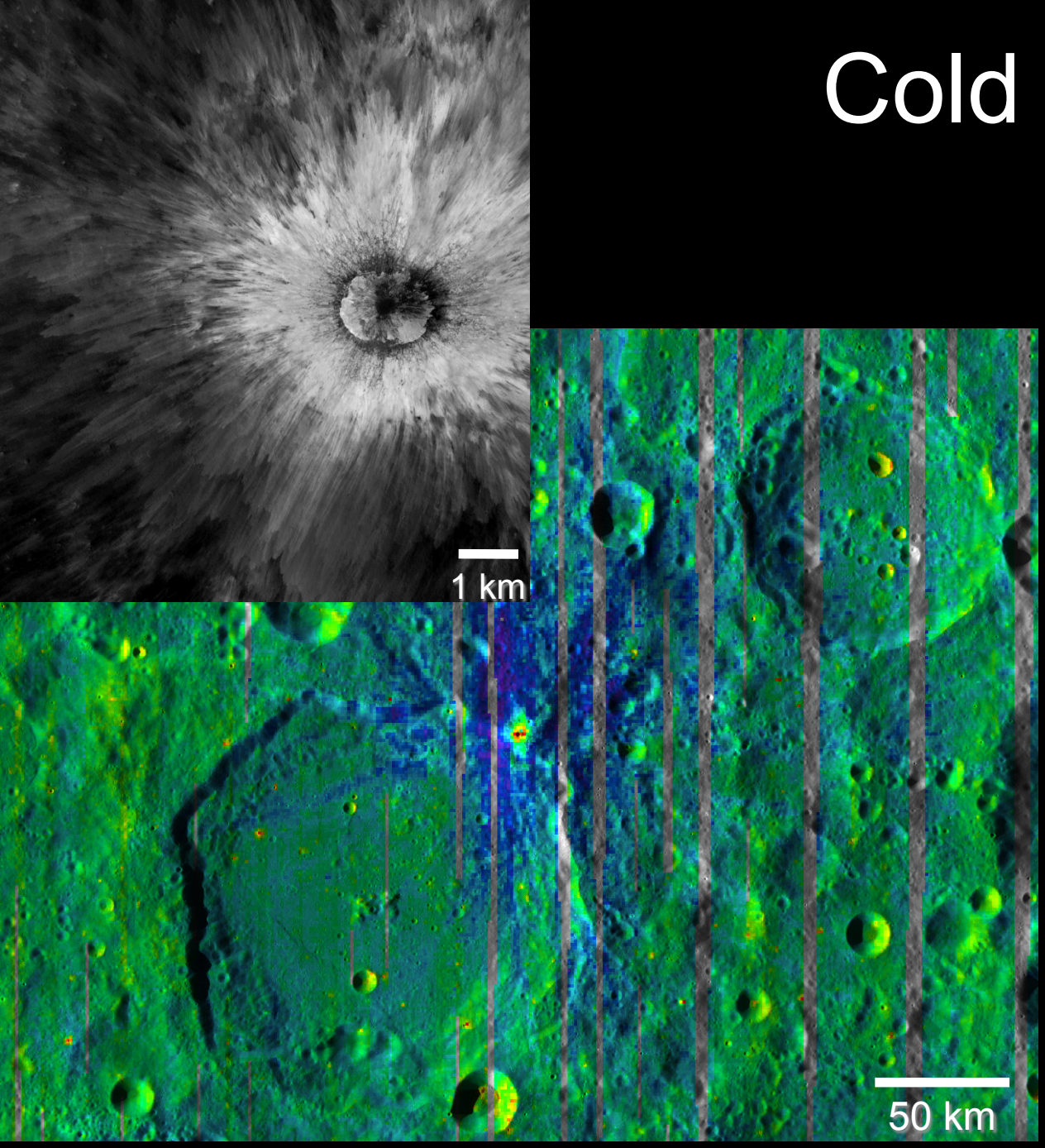


New Rock Abundance and Regolith Temperature Maps

- Same algorithm, but new maps are constructed from Diviner Level 2 GDR products
- Maps will be available at 16, 64, and 128 pixels per degree (previously only available at 32 ppd)

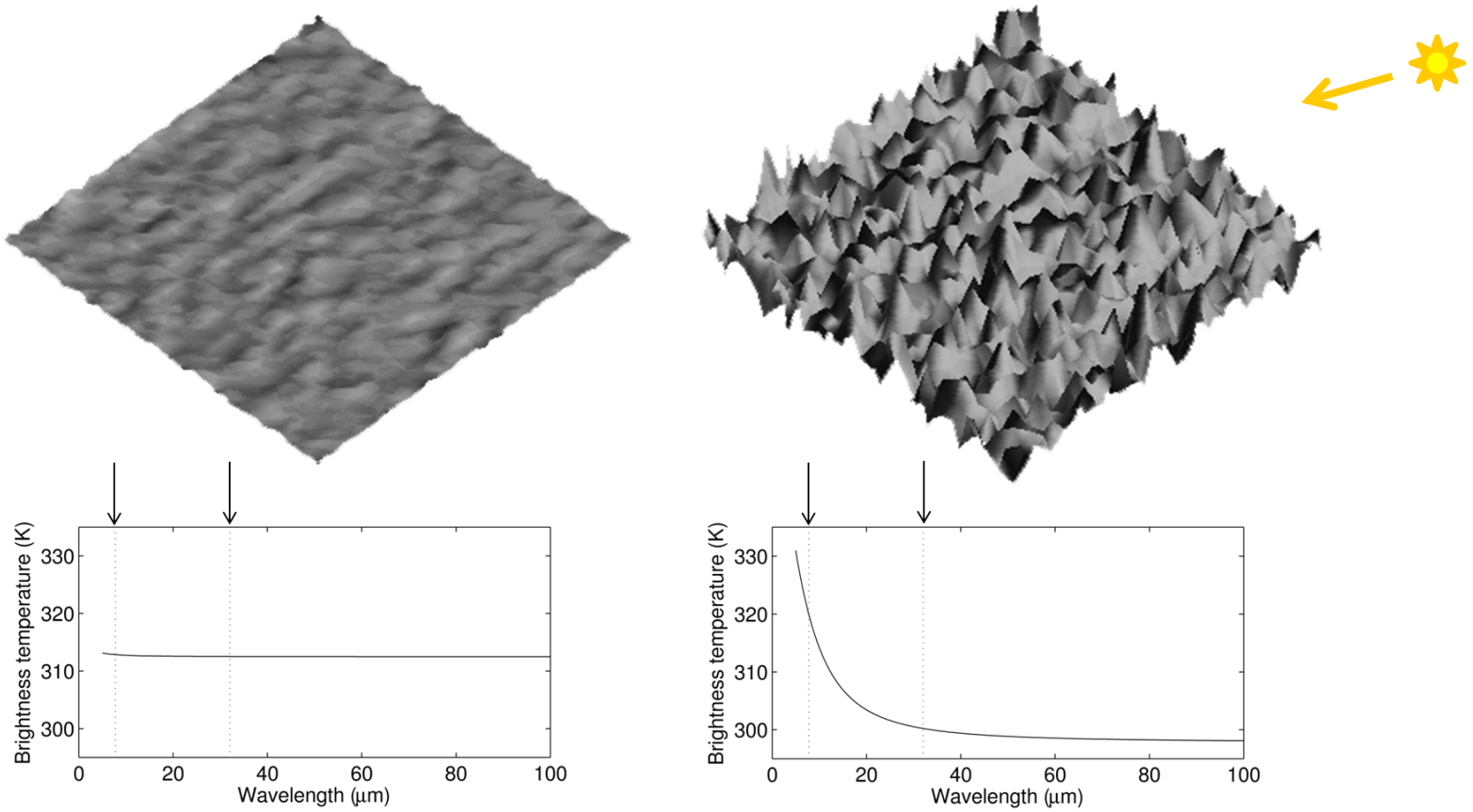
128 PPD
Regolith
Temperature

Cold Spots



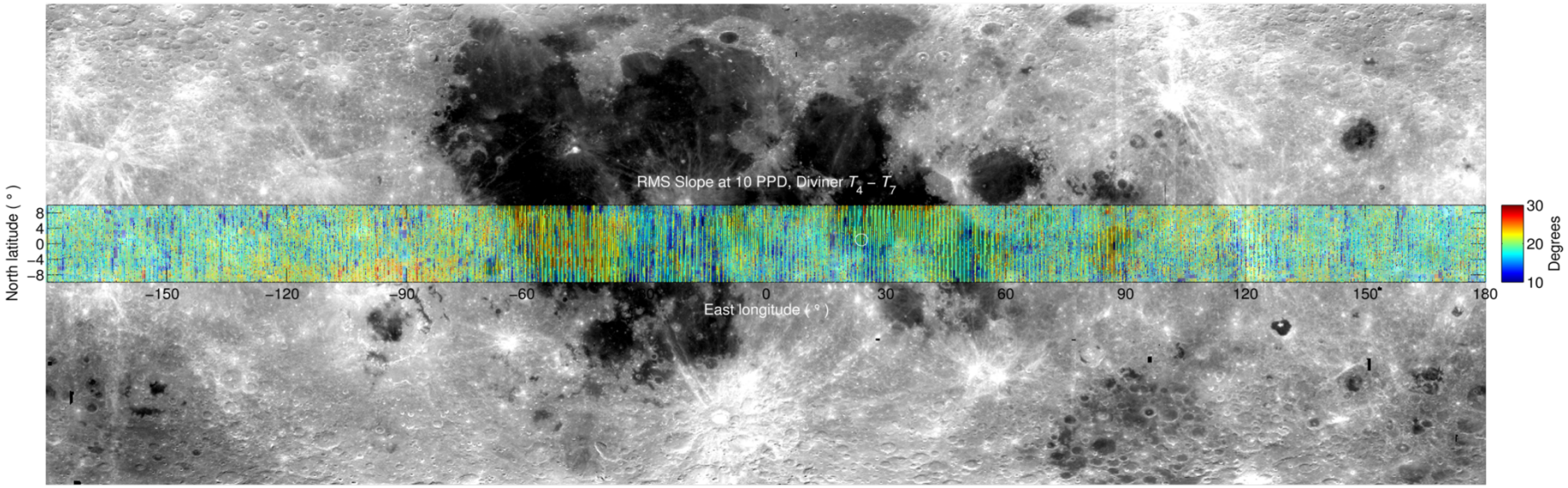
- Small young craters with large areas of “fluffed-up” regolith
- Not visible in other datasets
- Near-crater deposits have continuous layered ejecta indicative of granular flow
- Hundreds have been identified in all terrains

Infrared Emission from a Rough Surface



Thermal emission at shorter wavelengths dominated by warmer facets (two example Diviner channels indicated by arrows)

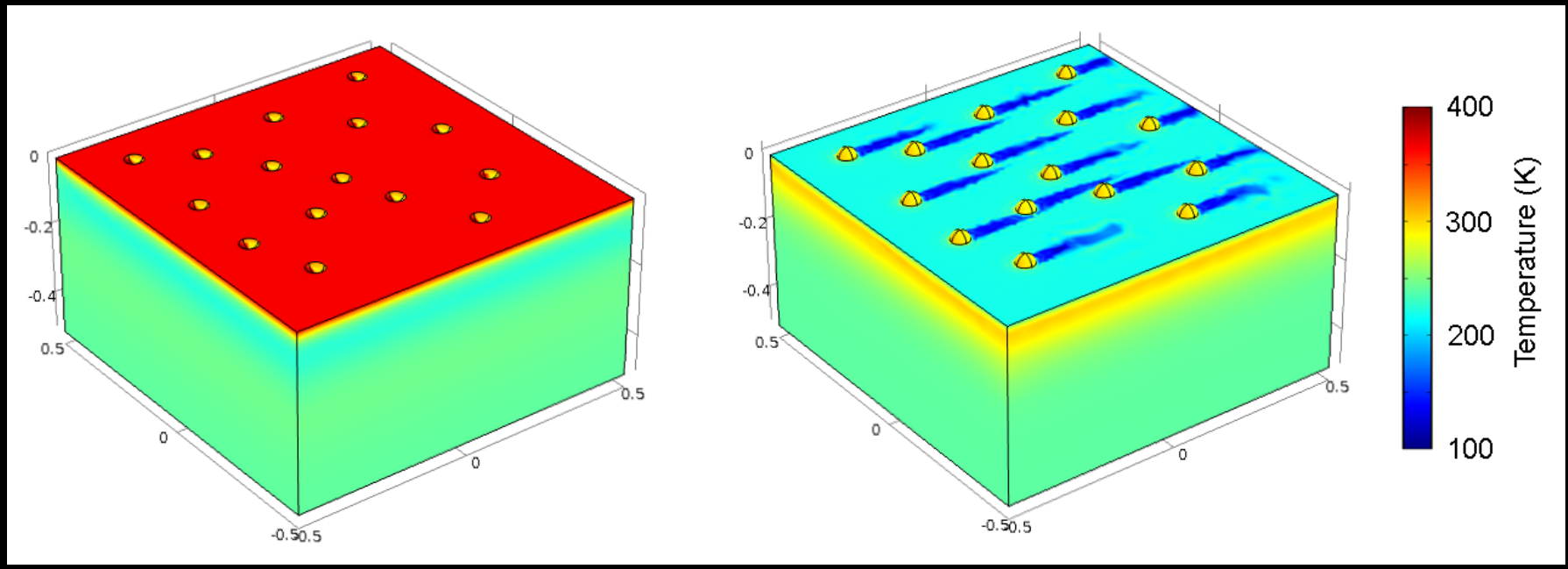
Preliminary Diviner Roughness Map



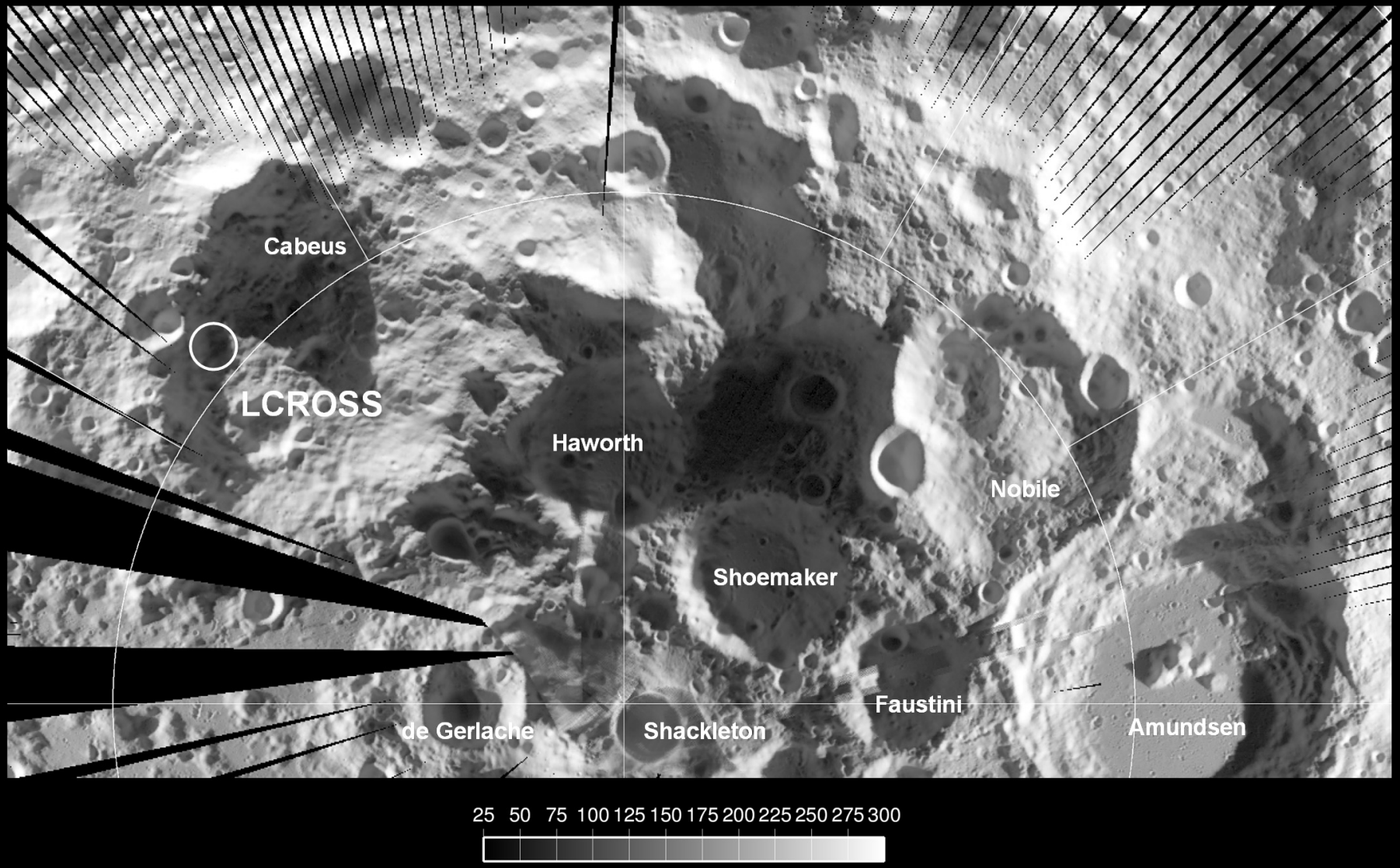
- RMS surface slopes, derived from channels 4 and 7, corrected for emissivity
- Maria slightly rougher than highlands at thermal length scales (< 1 m?)
- "Thermal roughness" maps also important for understanding 3-micron H_2O absorption (McCord et al. 2011)

(We are working on a global map, but emissivity correction is challenging at higher latitudes.)

3D Thermal Modeling – Effects of Rocks and Roughness

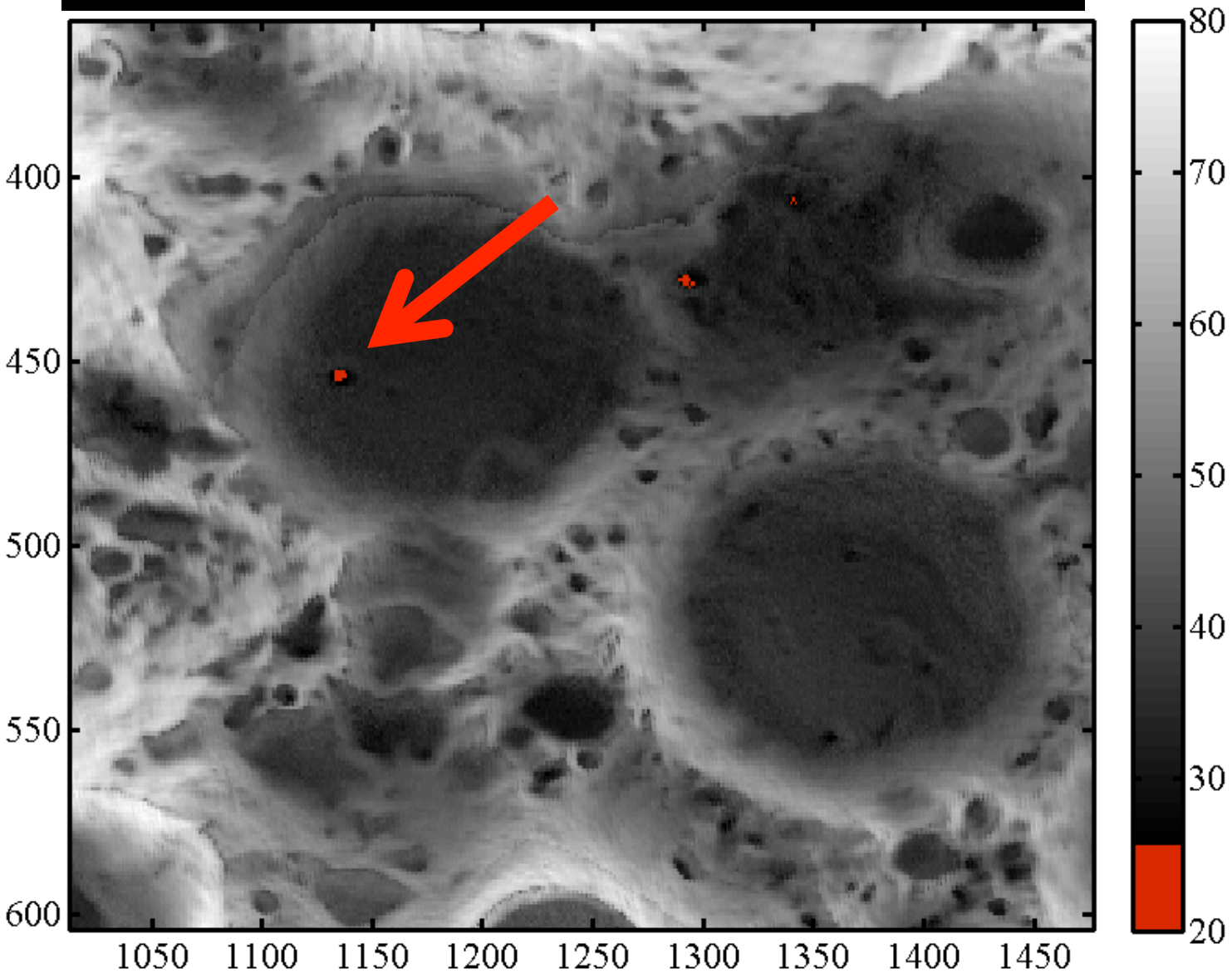


Diviner Polar Results

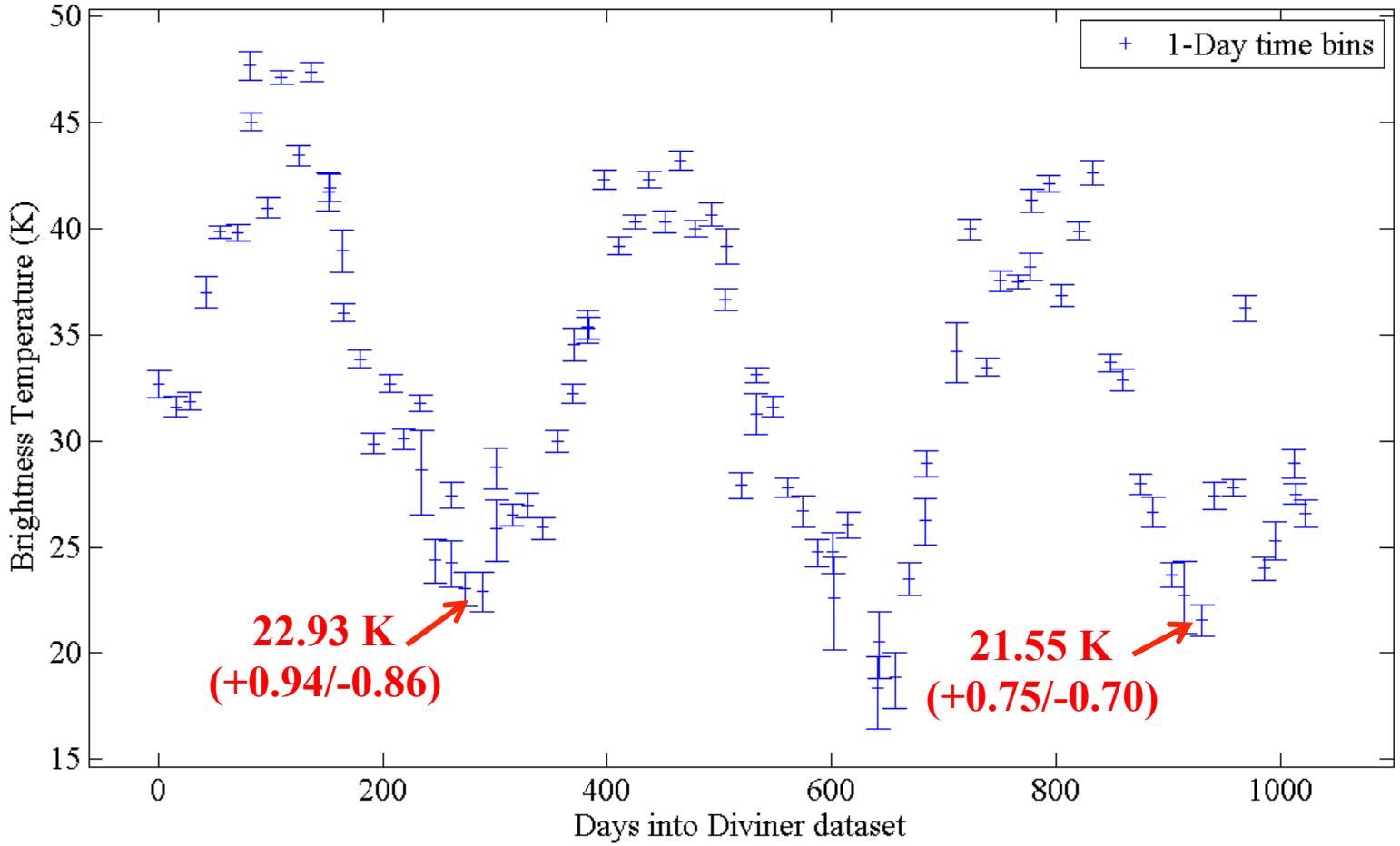


Diviner Channel 8 Brightness Temperature Map (K)

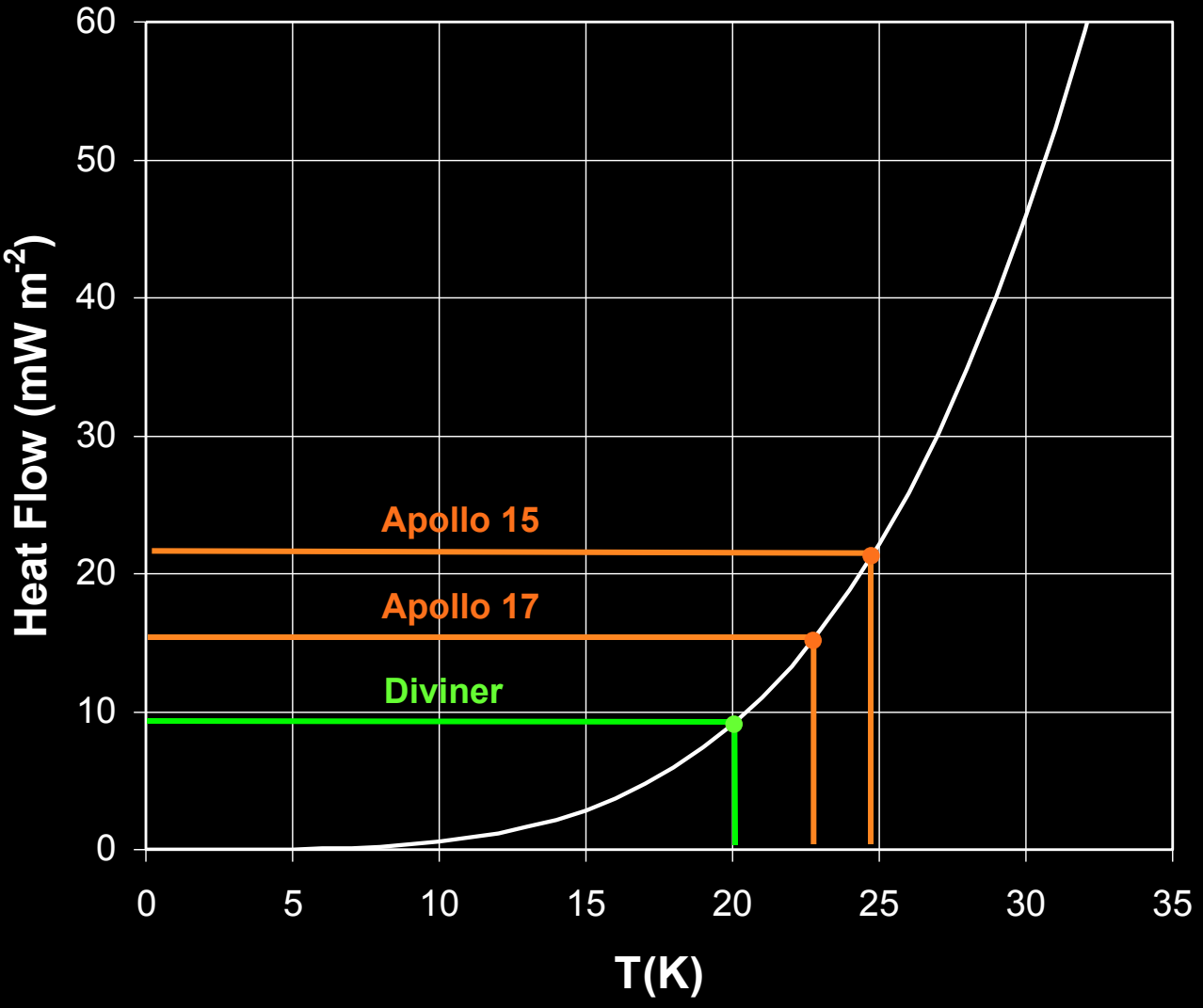
Model Minimum below 25K in Haworth Crater

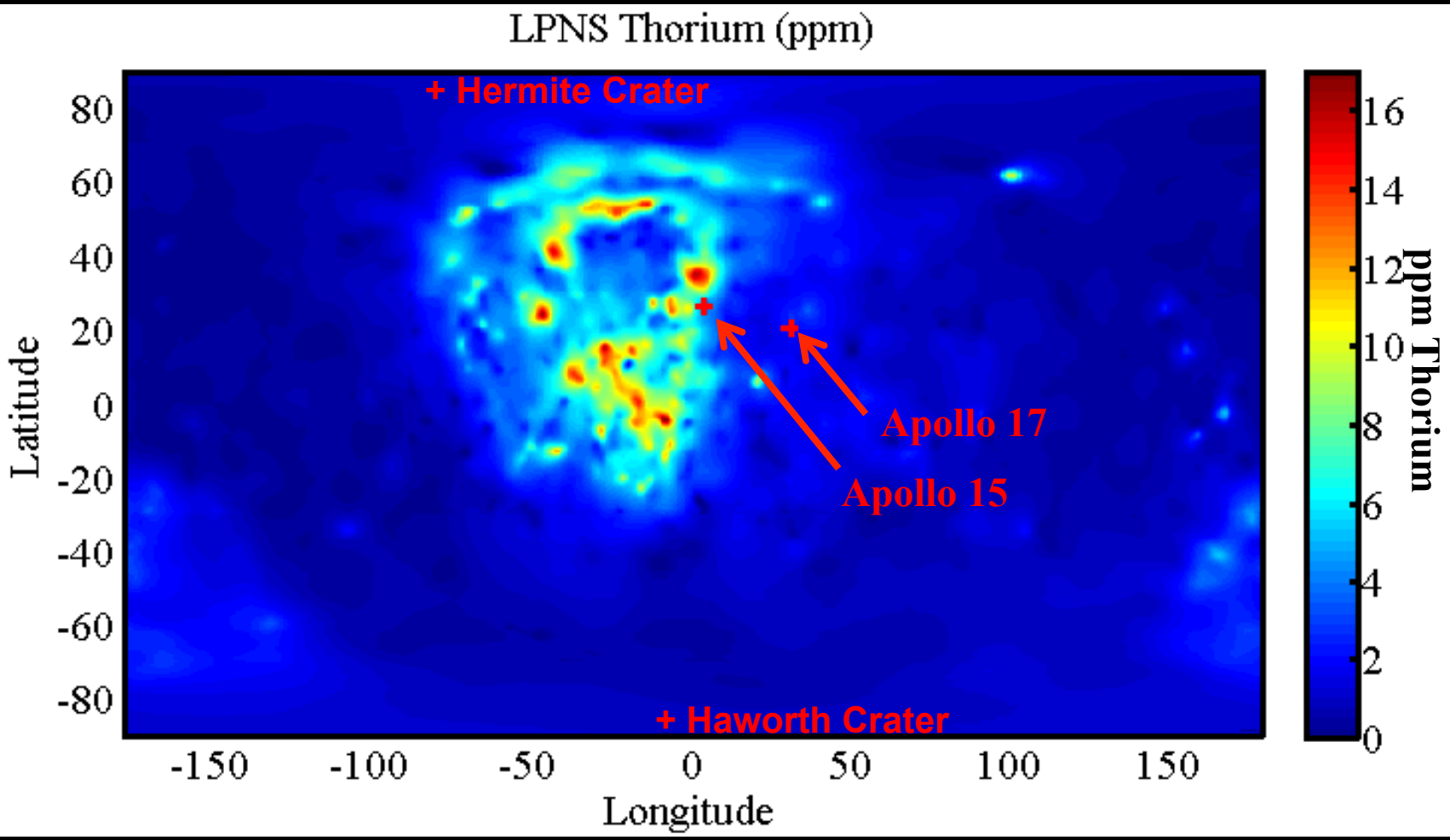


Multi-Year Diurnal and Seasonal Temperature Variations



Lunar Heat Flow Measurements




LPNS Thorium (ppm)
+ Hermite Crater
Apollo 17
Apollo 15
+ Haworth Crater
Latitude
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
Longitude
16
14
12
10
8
6
4
2
0
ppm Thorium

Data Product Level	Archived Data Product Name	Description	Format	Accessibility	Value to Science and Exploration	PDS Delivery Schedule	Data Volume
Current Data Products							
CAL	Pre-Flight Calibration Data	Pre-flight calibration data (Spectral Response, Blackbody Response, Solar Target Reflectance, Fields of View)	Ascii	PDS Download	Primary reference for calibration/recalibration	9-Dec-09	10 Mbytes
NOTEBOOK	Experimenter's Notebook	Chronological text description of instrument operation and performance	Ascii	PDS Download	Primary reference for dataset validation and interpretation	6 months after receipt	54 MBytes/3 months
0	Experimenter Data Records	Depacketized time-sequenced raw science and housekeeping data	Binary	PDS Download	Primary reference	6 months after receipt	1 MByte/3 months
1	Reduced Data Records	Calibrated radiances and housekeeping data merged with project-supplied geometry and timing information	Ascii	PDS Download, PDS Lunar Orbital Data Explorer	Lowest level of processing that is useful for science, No information loss	6 months after receipt	2 TBytes/3 months
2	Gridded Data Products	3-D Projected and Gridded (Lat, Lon, Month, Day/Night) global and polar brightness temperature and visual brightness. Multi-Resolution, LOLA compatible.	IMG and JPEG2000	PDS Download, PDS Lunar Orbital Data Explorer, LMMP	More highly processed dataset that can be overlain on other mapped datasets, GIS	6 months after mission phase completion	2 Tbytes/ delivery
3	Gridded Derived Data Products	Gridded (Lat, Lon, Month) global CF, Rock Abundance, Nighttime Soil Temperature, Bolometric Temperature	IMG and JPEG2001	PDS Download, PDS Lunar Orbital Data Explorer, LMMP	Derived lunar properties through comparison with physical models, Can be easily overlain with other mapped datasets, GIS	6 months after mission phase completion	1 TByte/ delivery
4	Polar Products	Model-Calculated Annual Min/ Max/Average polar surface temperature, water ice stability depth	Ascii	PDS Download	Loations of permanent shadow, cold traps, comparisons with other lunar polar datasets	6 months after mission phase completion	4 Mbytes
4	Global Thermal Model Product	Model-calculated surface temperatures every 3 hours from 2000-2025	Binary	PDS Download	Lunar thermal environment model for future mission planning	6 months after mission phase completion (Not yet delivered)	45 Tbytes

New Foundation Data Products	Archived Data Product Name	Description	Format	Accessibility	Value to Science and Exploration	PDS Delivery Schedule	Data Volume
1	Recalibrated Reduced Data Records	Recalibrated and reflagged radiances and housekeeping data merged with project-supplied geometry and timing information	Ascii	PDS Download, PDS Lunar Orbital Data Exporer	More accurate results at low temperatures for heat flow and polar illumination studies. Reduces systematic calibration issues at high temperatures and flaggs data contaminated by spectral leaks and noise.	6 months after mission phase completion	48 TBytes/ delivery
2	Diviner Map Tiles	Geographically Tiled 3-D Projected and Gridded (Lat, Lon, Month, Day/Night) global brightness temperature and visual brightness	IMG and JPG2000	PDS Download, PDS Lunar Orbital Data Explorer, LMMP	Improved access to Diviner mapped data for comparion with physical models and other lunar datasets and GIS. Includes higher accuracy 3-d gridding, and preservation of original geometric and temporal metadata for photometric corrections.	6 months after mission phase completion	2 TBytes/ delivery
3	Diviner Summary Maps	Gridded annual and/or cumulative maps of minimum/ maximum/average maps of brightness temperatures, visual brightness, rock abundance, nighttime soil temperature, CF and bolametric brightness temperature.	IMG and JPG2000	PDS Download, PDS Lunar Orbital Data Explorer, LMMP	Defines the measured extrema of the lunar thermal and illumination environments, and subsurface temperatures.	6 months after mission phase completion	1 Tbyte/delivery
3	Diviner Earth Scans	Projected and mapped Earth brightness temperatures and visual brightness	IMG and JPG2000	PDS Download	Unique analog dataset valuable for detection and characterization of extrasolar Earthlike planets	6 months after mission phase completion	100 Mbytes/ delivery
4	Diviner Special Data Collection	Off-nadir datasets acquired during eclipses, emission phase function observations, landing sites, and the LCROSS impact	Ascii, IMG and JPG2000	PDS Download	Compendium of Diviner's most valuable non-routine datasets with additional documentation for detailed analysis	6 months after mission phase completion	10 Gbytes