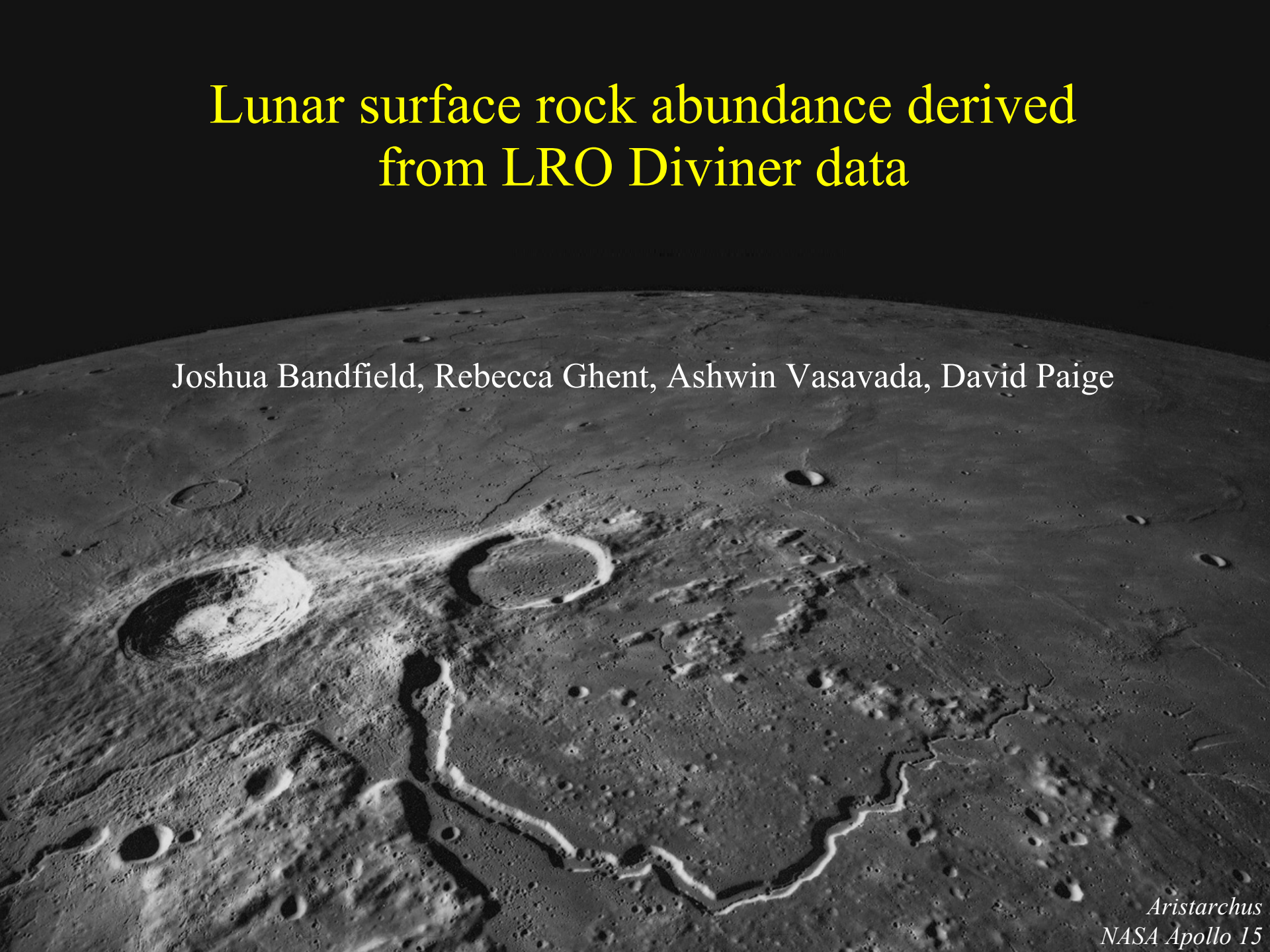
Lunar surface rock abundance derived from LRO Diviner data

Joshua Bandfield, Rebecca Ghent, Ashwin Vasavada, David Paige



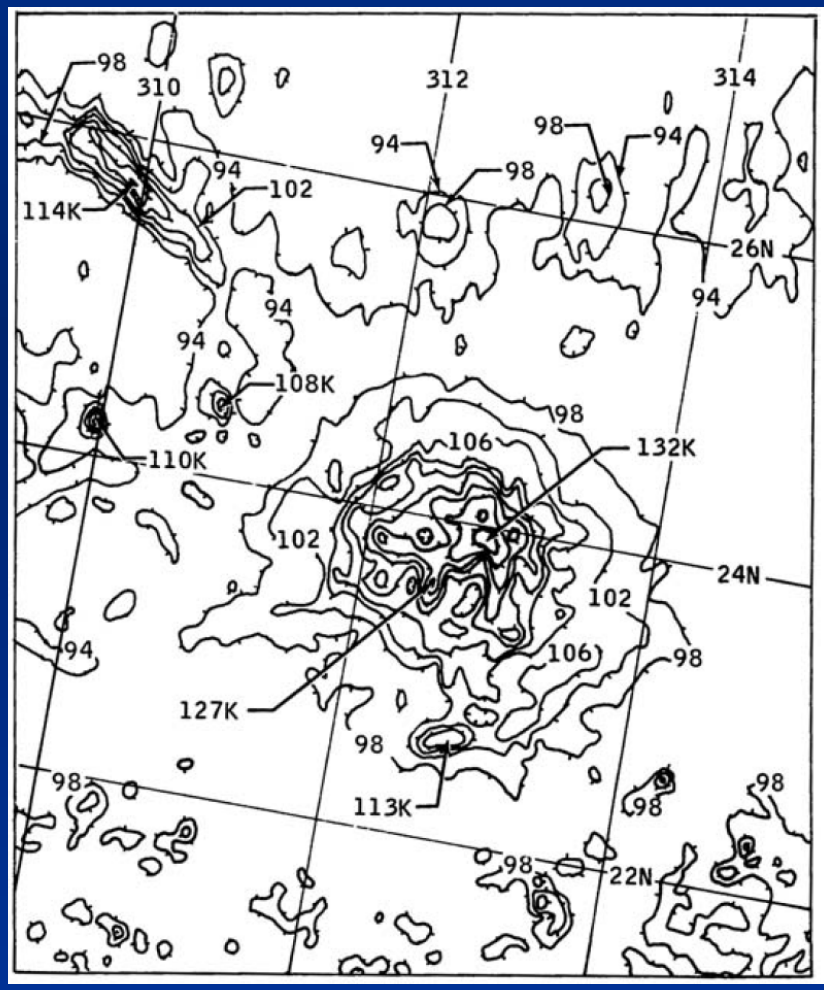
Aristarchus
NASA Apollo 15

Remote Measurements

Arecibo 70 cm CPR, Campbell et al., 2007

- TIR and radar measurements are sensitive to the presence of rocks on and within the regolith
  - We're not the first or only technique to do this!
- Global regolith properties and thicknesses can be mapped

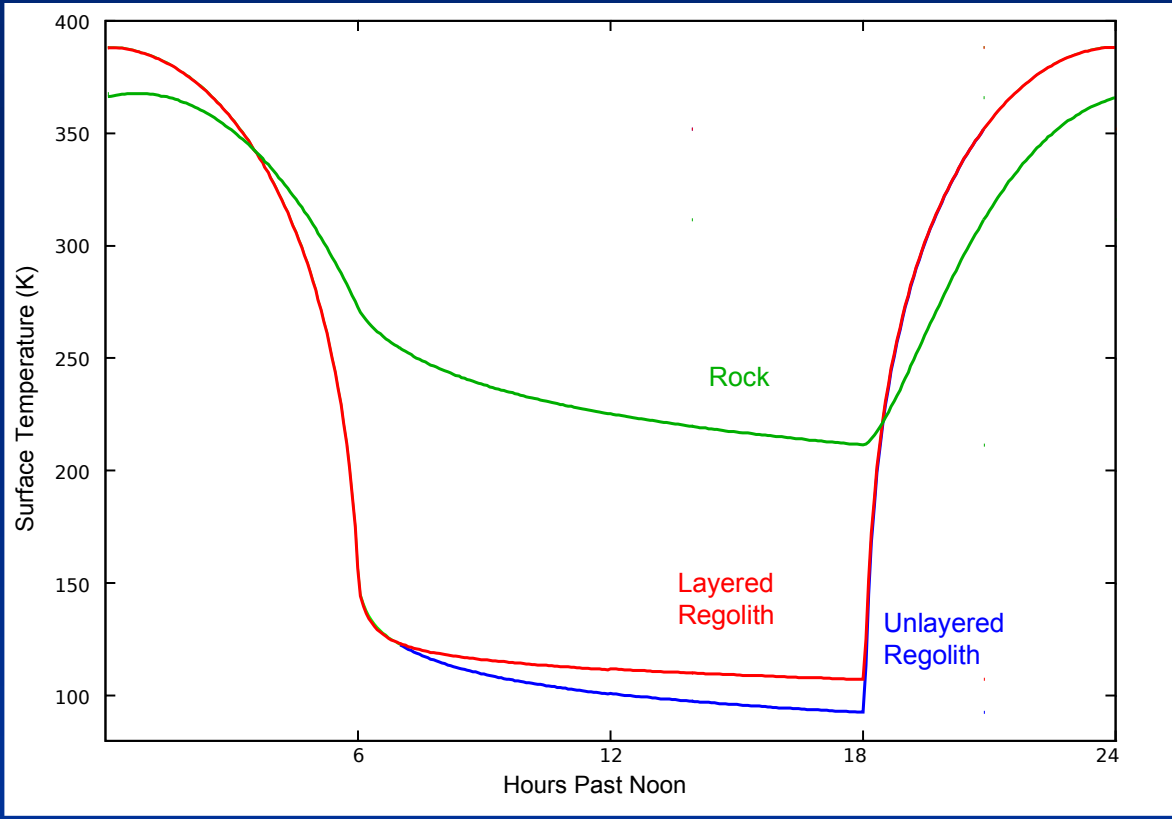
(e.g. *Thompson et al.*, 1974, 2006; *Mendell*, 1976; *Ghent et al.*, 2005; *Campbell et al.*, 2009)



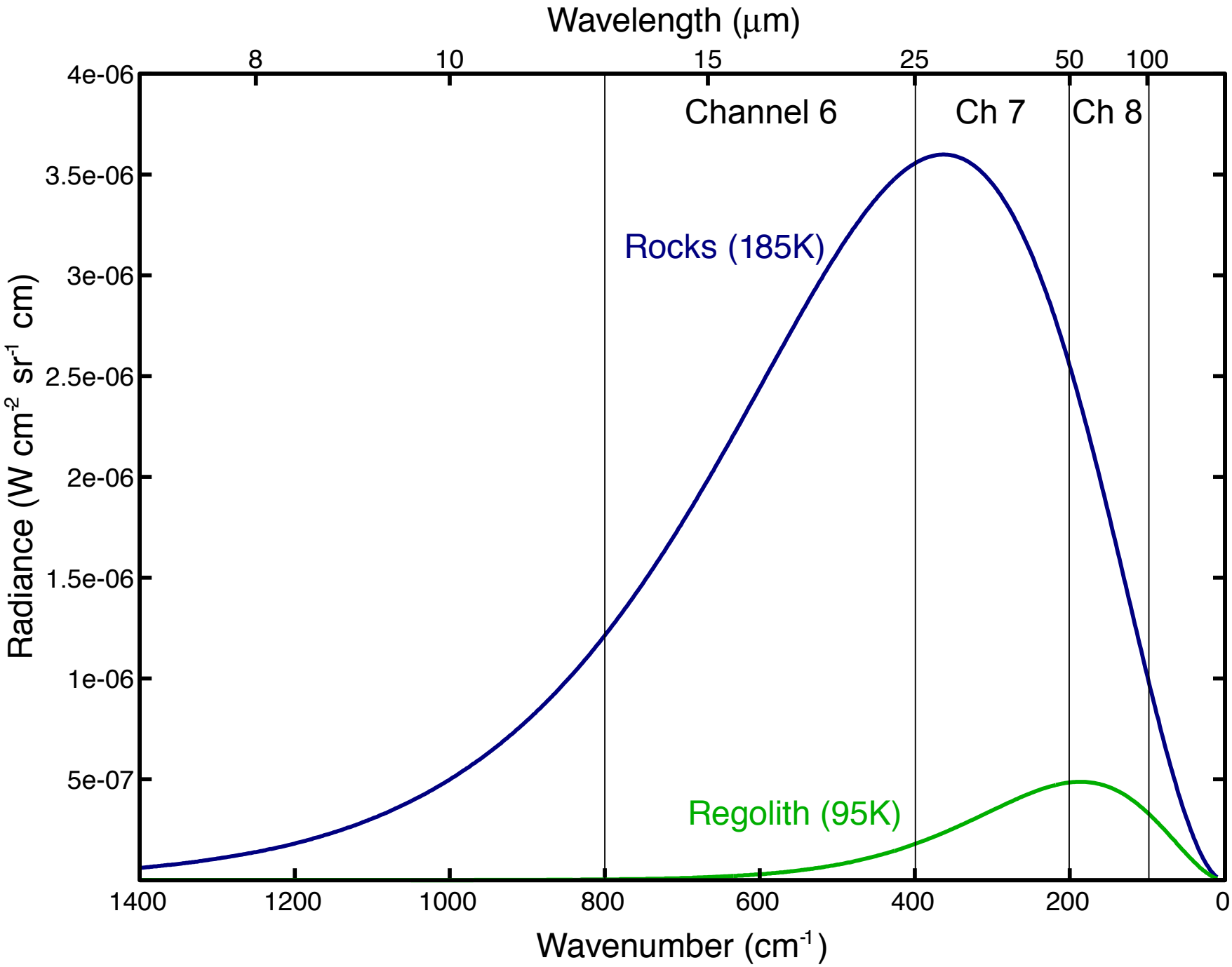
Apollo 17 Infrared Scanning Radiometer, Mendell, 1976

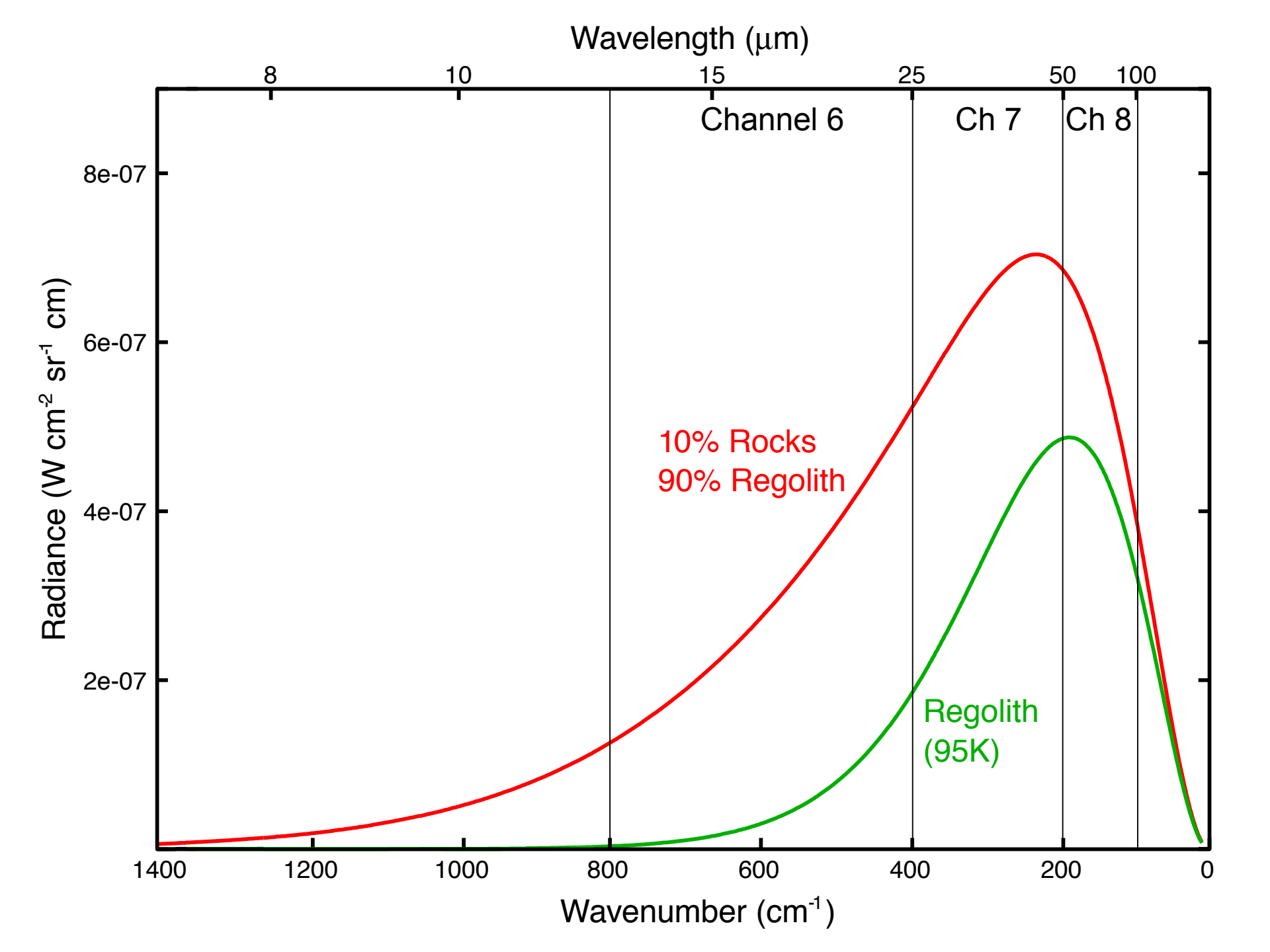
Lunar Thermophysics

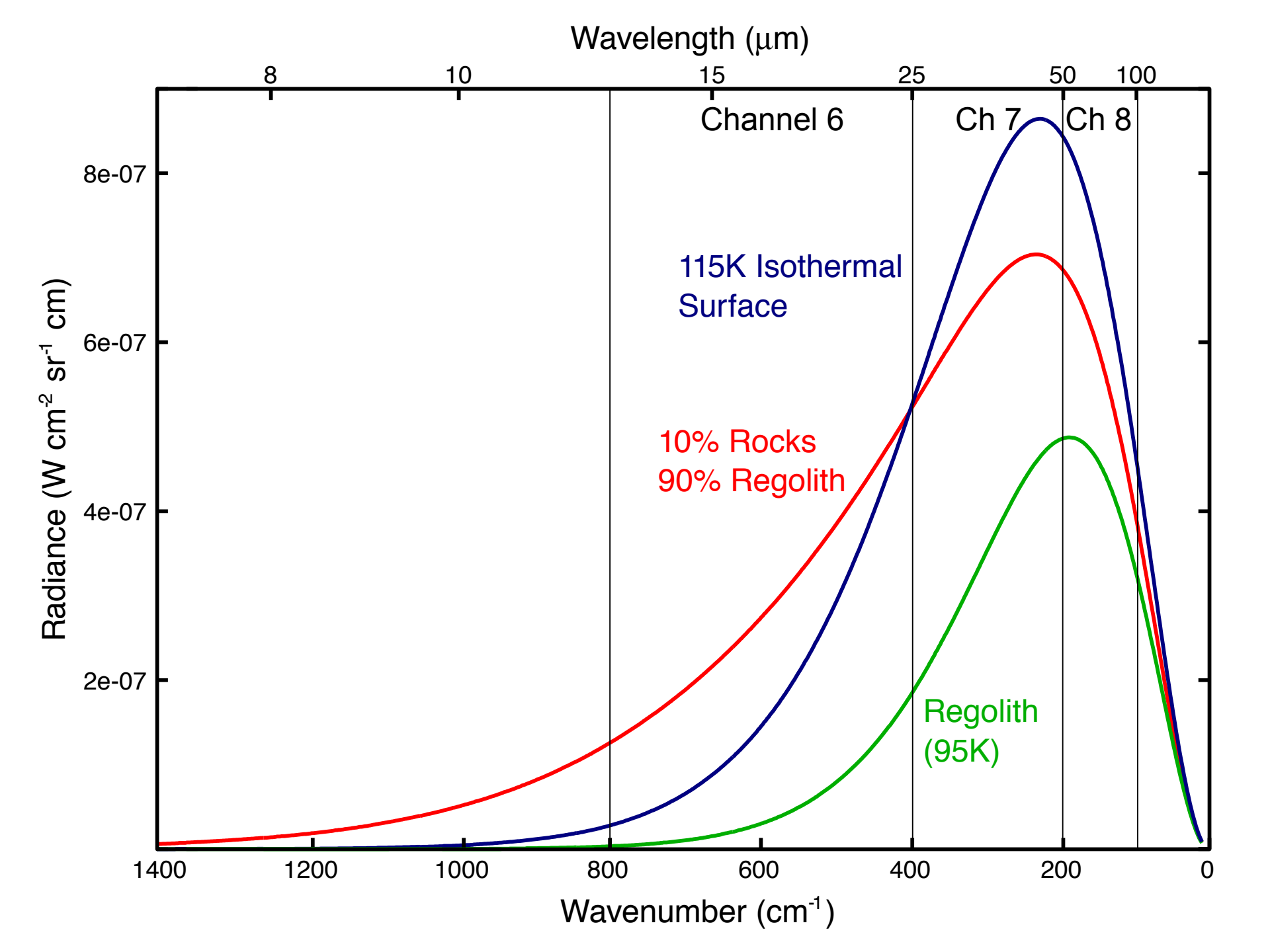
- Nighttime temperatures are very sensitive to the physical nature of the surface
  - Rocks will stay ~100K warmer than the regolith throughout the night
  - Layering, slopes, etc. also affect surface temperatures

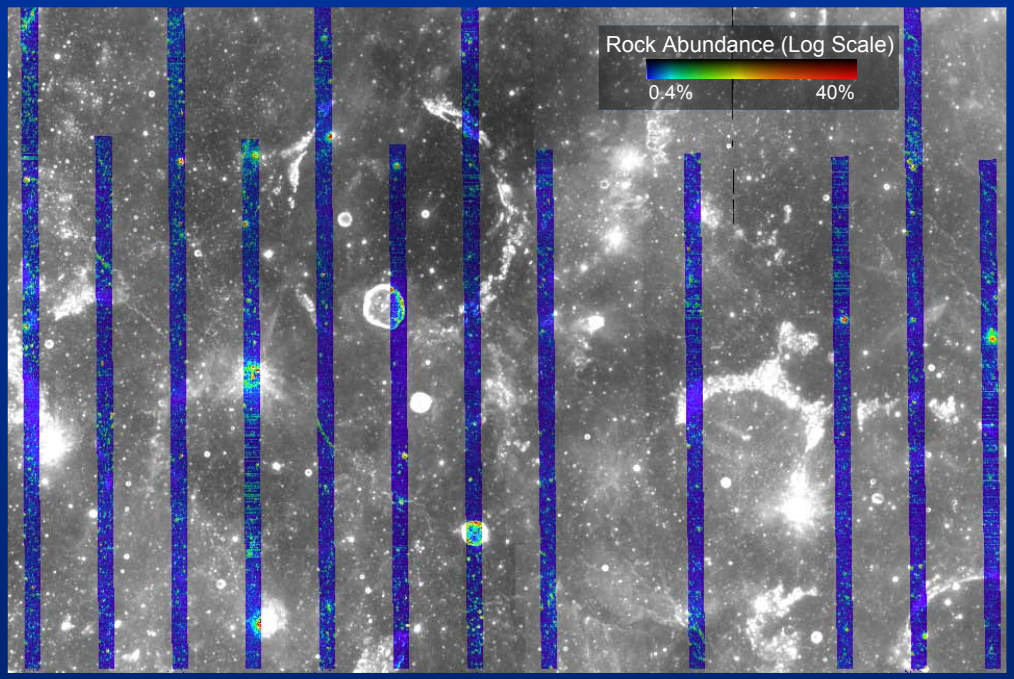


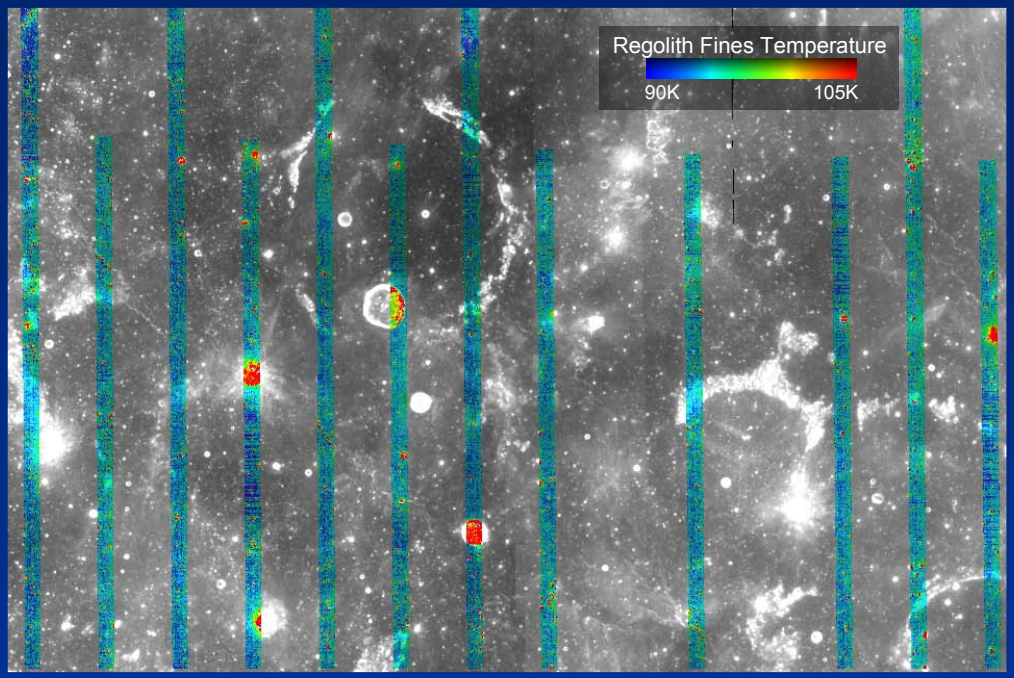
Apollo 15
AS15-82-11146


Wavelength (μm)
8
10
15
25
50
100
Channel 6
Ch 7
Ch 8
Rocks (185K)
Regolith (95K)
Radiance (W cm-2 sr-1 cm)
4e-06
3.5e-06
3e-06
2.5e-06
2e-06
1.5e-06
1e-06
5e-07
1400
1200
1000
800
600
400
200
0
Wavenumber (cm-1)


Wavelength (μm)
8
10
15
25
50
100
Channel 6
Ch 7
Ch 8
8e-07
6e-07
4e-07
2e-07
Radiance (W cm-2 sr-1 cm)
10% Rocks
90% Regolith
Regolith
(95K)
1400
1200
1000
800
600
400
200
0
Wavenumber (cm-1)


Wavelength (μm)
8
10
15
25
50
100
Channel 6
Ch 7
Ch 8
8e-07
6e-07
4e-07
2e-07
Radiance (W cm-2 sr-1 cm)
115K Isothermal
Surface
10% Rocks
90% Regolith
Regolith
(95K)
1400
1200
1000
800
600
400
200
0
Wavenumber (cm-1)





0

-10

310E

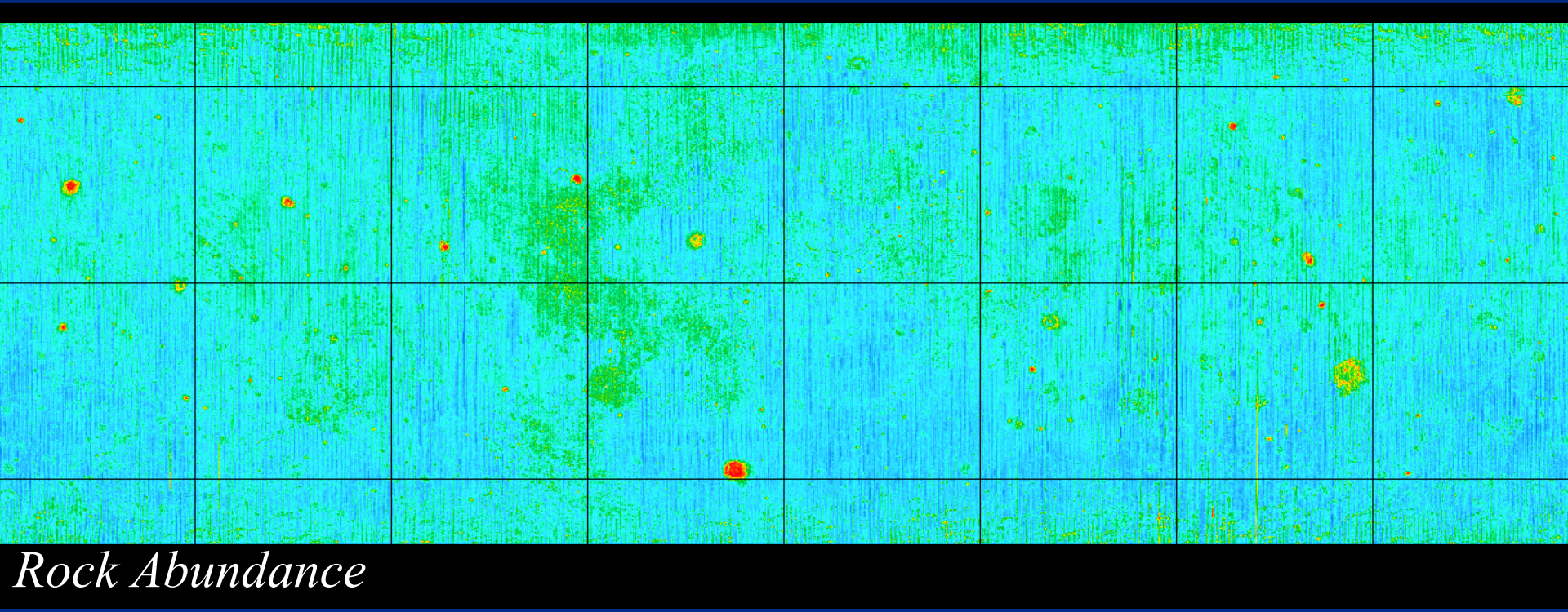
325E

Rock Abundance Model

- Uses Diviner channels 6-8 centered near 18, 35, and 75 μm
- Use modeled T of rocks with latitude/local time and optimize modeled radiance by varying T of regolith and rock areal abundance
- Initial results provide realistic numbers and data are well-behaved

Global Maps

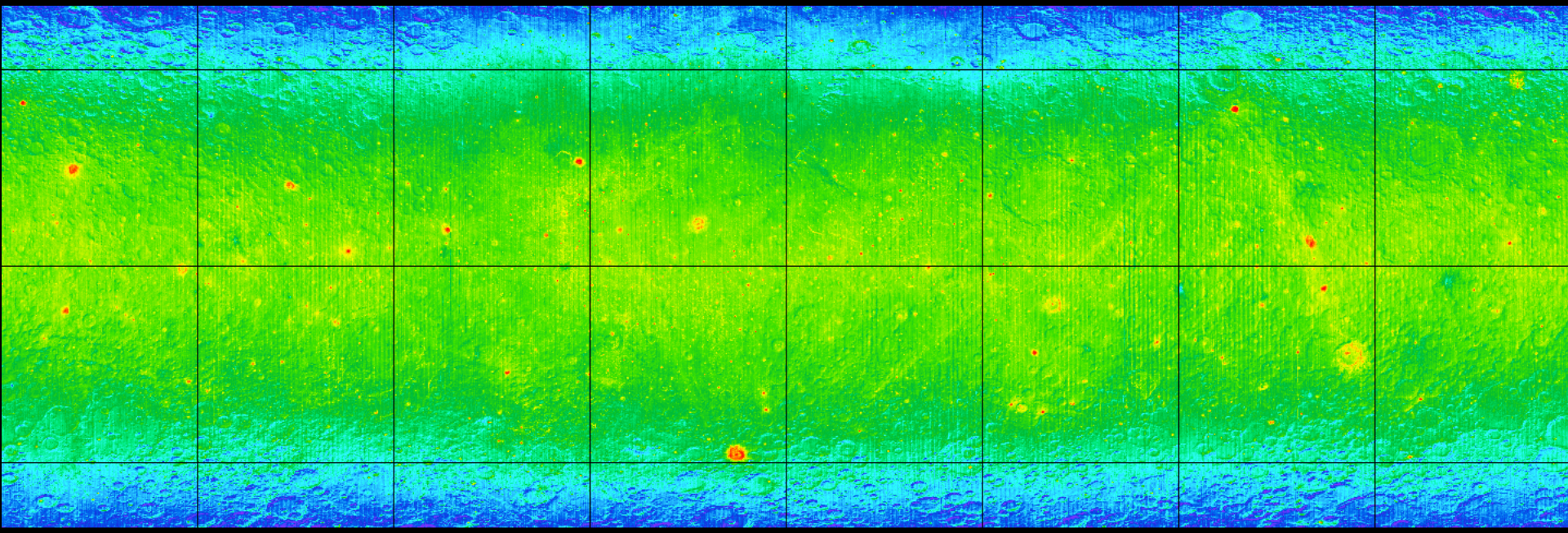
- Younger craters show higher RA values (e.g. Tycho)



Rock Abundance

Global Maps

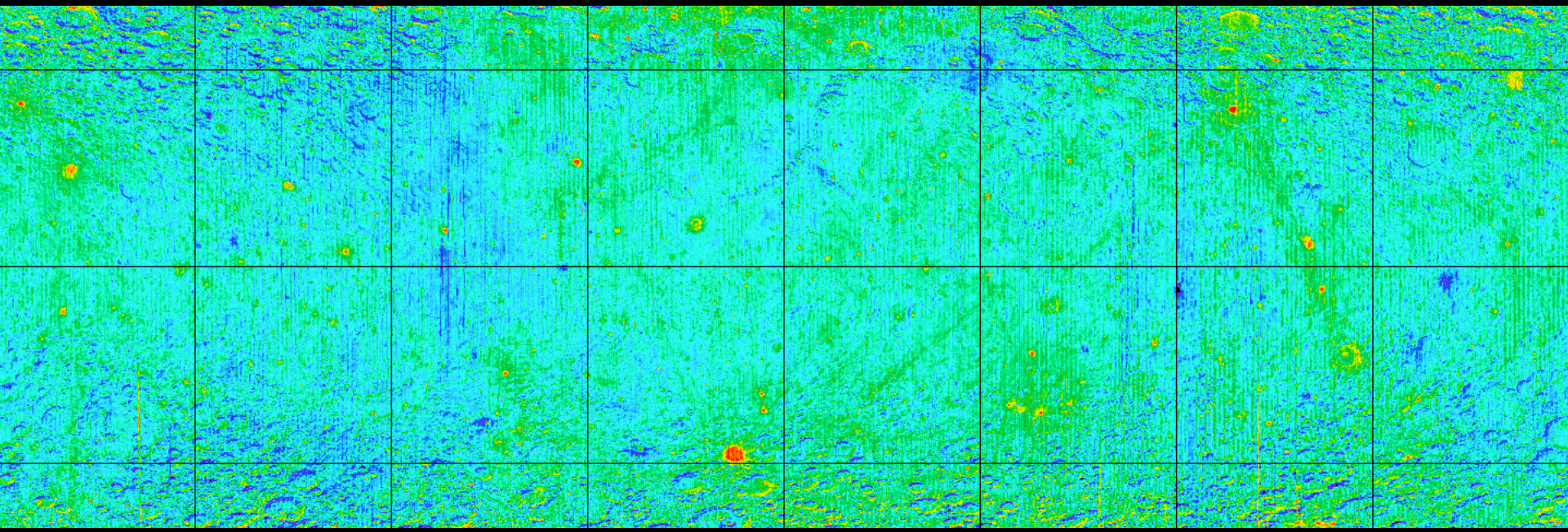
- Slope/latitude variations in regolith temperature are cleanly separated from rock fractions



Regolith Temperature

Global Maps

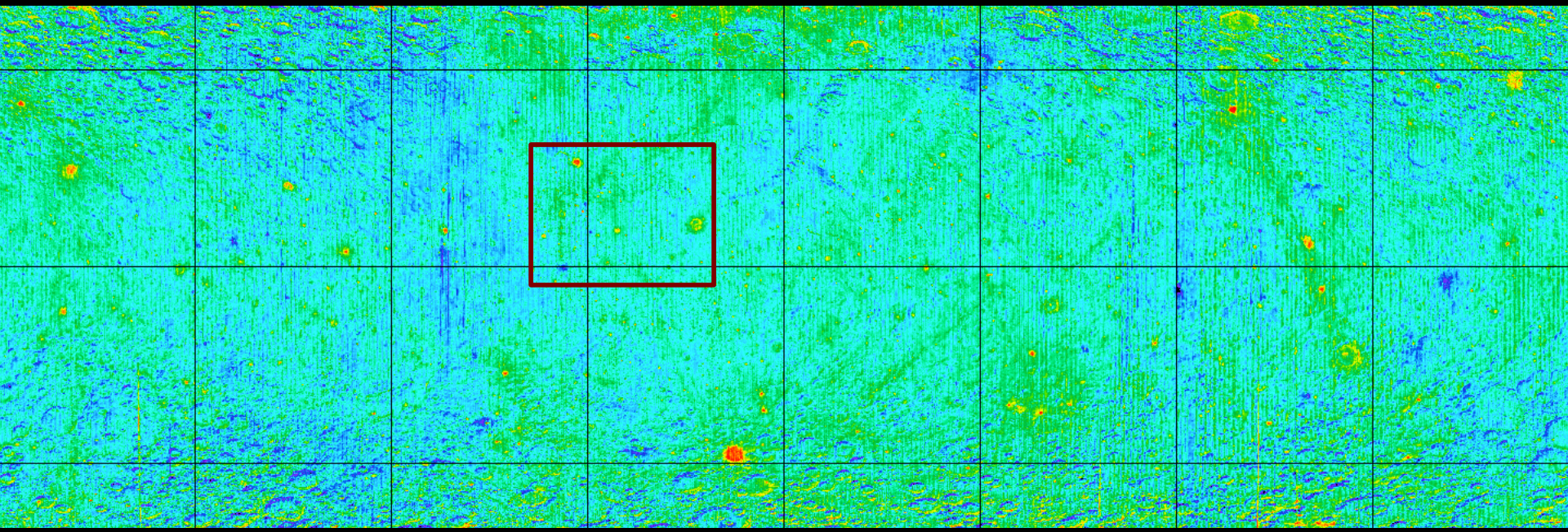
- Regolith temperature is correlated with latitude and slopes
- Note Tycho rays and “cold spots”



Regolith Temperature *(normalized for latitude)*

Global Maps

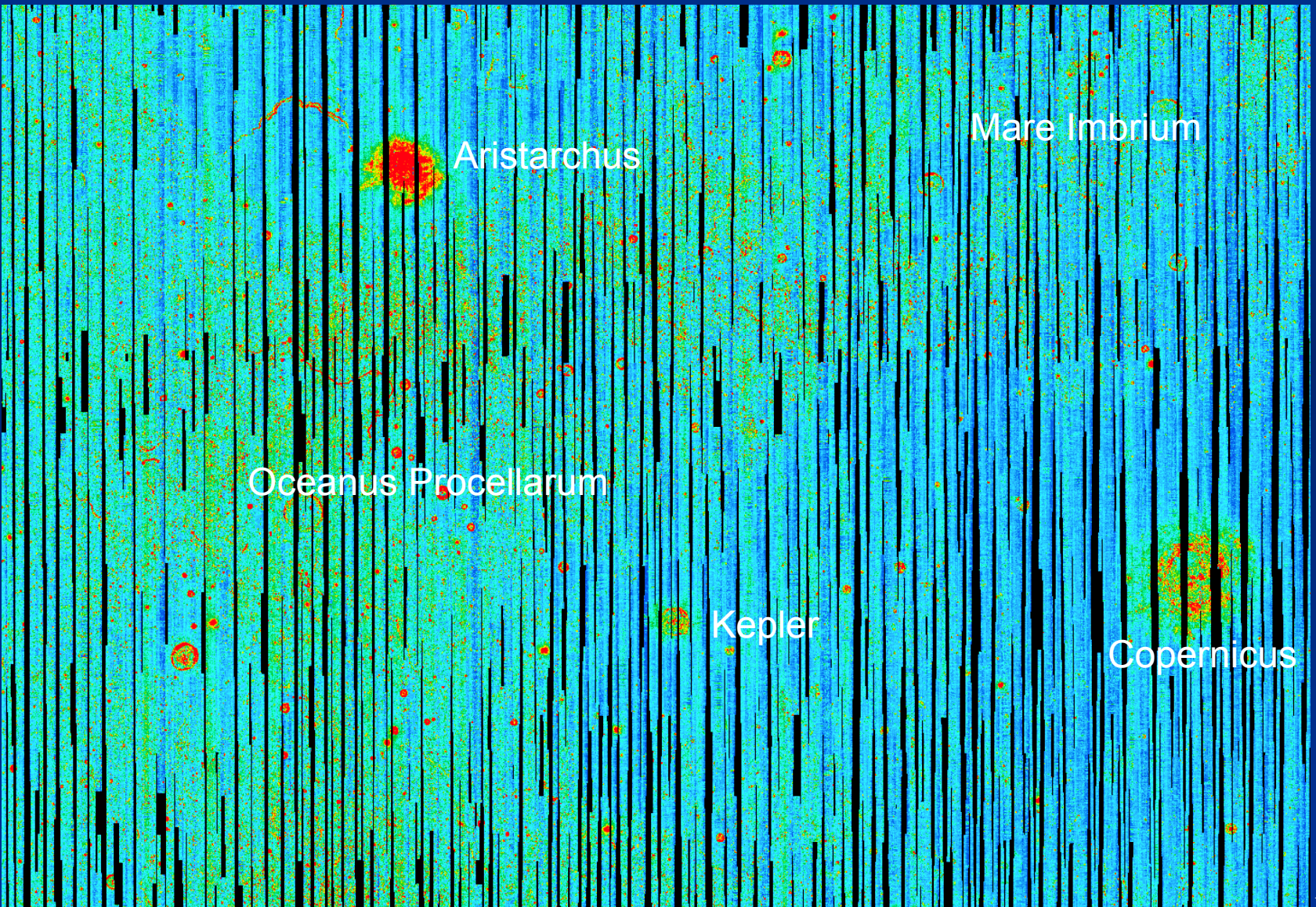
- Regolith temperature is correlated with latitude and slopes
- Note Tycho rays and “cold spots”



Regolith Temperature *(normalized for latitude)*

Small craters in the Mare show elevated rock abundances

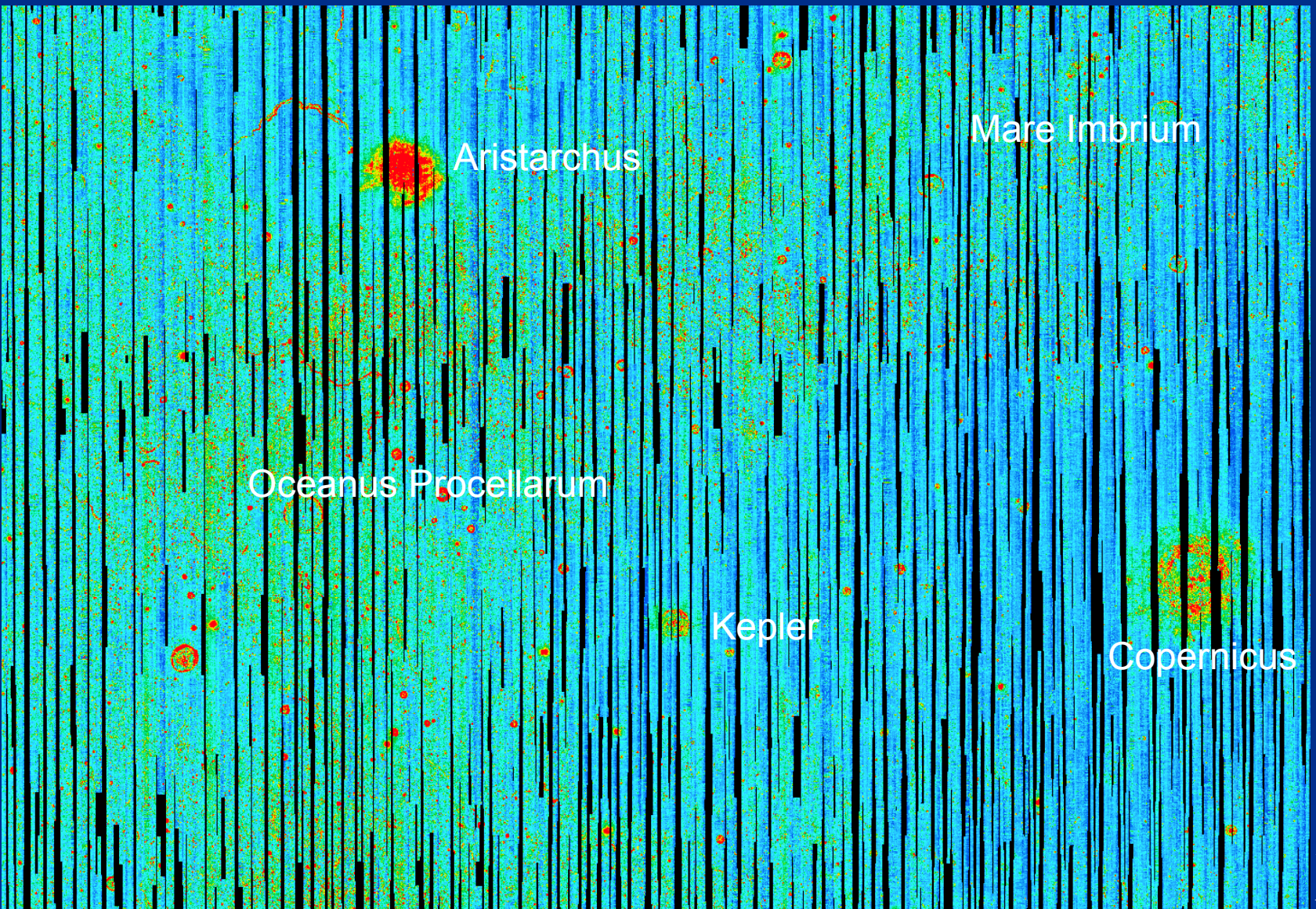
- Radar dark haloes (e.g. Kepler Crater) and highlands do not show rocky small craters



Shorty Crater
AS17-137-20994

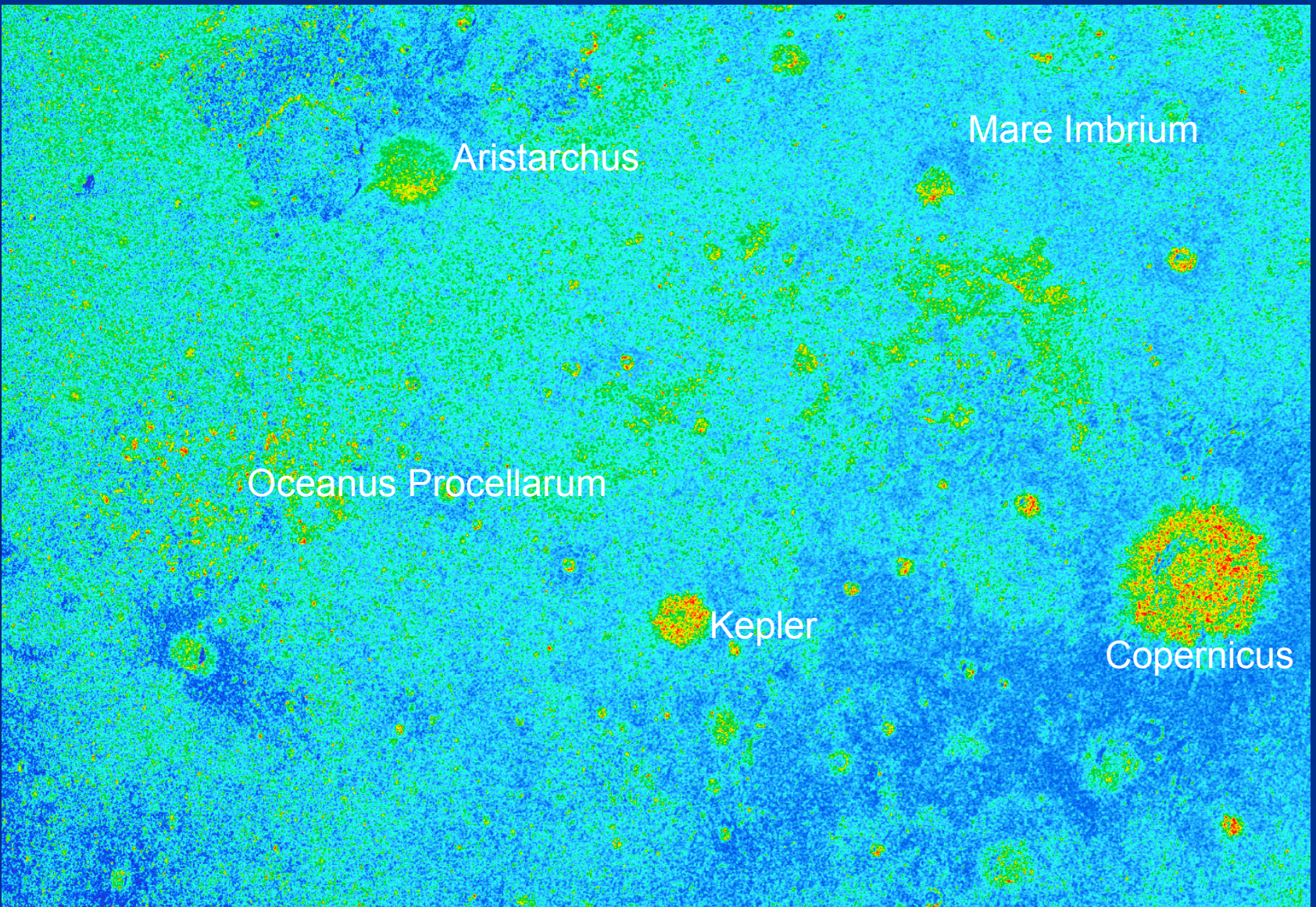
Small craters in the Mare show elevated rock abundances

- Radar dark haloes (e.g. Kepler Crater) and highlands do not show rocky small craters



Rock abundances and radar circular polarization ratios (CPR) show general similarities

- Differences are present – radar sensing of buried blocks?



70 cm Radar CPR
Campbell et al., (2007)

Landing Site Rock Abundances

- Mostly not rocky with obvious exceptions
  - Rocky site = danger + interesting geology!

Lon	Lat		Name	Avg 0.1 deg. %	Max 0.1 deg. %	Max 0.3 deg. %	Center %
173.48	-16.76	ATK	Aitken Crater	0	0	12	0
-2.16	-12.56	ALP	Alphonsus Crater	0	0	1	0
-9.3	73.48	ANX	Anaxagoras Crater				
3.66	26.08	A15	Apollo 15	1	1	9	1
15.47	-9	A16	Apollo 16			1	
-153.72	-37.05	APB	Apollo Basin	0	0	1	0
-48.95	24.56	AR1	Aristarchus 1	0	0	1	
-52.4	27.7	AR2	Aristarchus 2	0	0	1	0
-22.5	-20.7	BUL	Bullialdus Crater	0	1	2	0
-20.01	9.85	COP	Copernicus Crater	1	2	24	1
-40.14	36.03	GRT	Gruithuisen Domes	0	1	3	0
-125.56	0.09	HTZ	Hertzsprung			3	
119.91	6.39	KNG	King Crater	1	3	6	2
-2.93	-85.99	MAL	Malapert Massif				
58.84	10.68	CRS	Mare Crisium	0	1	4	0
-0.42	4.74	MUR	Murchison Crater			1	
76.19	89.6	NPO	North Pole				
-95.38	-26.2	OR1	Orientale 1	0	1	2	0
30	88.5	PRY	Peary Crater				
-3.8	12.9	RMB	Rima Bode	4	13	29	4
-130	-89.3	SPO	South Pole				
-159.94	-60	SPA	South Pole-Aitken Basin Interior				
166.88	-2.08	STR	Stratton			1	
10.37	19.87	SPG	Sulpicious Gallus	1	1	7	
-11.2	-42.99	TYC	Tycho Crater	5	11	33	3
69.82	-18.69	BAL	Balmer Basin	0	0	1	0
99.45	61.11	CMP	Compton/Belkovich Th Anomaly				
177.7	26.14	DAN	Dante Crater	0	0	1	0
-43.22	-2.45	FLM	Flamseed Crater	0	0	1	
-27.67	7.48	HRT	Hortensius Domes			5	
77.14	54.54	HUM	Humboltianum Basin	1	1	4	1
5.29	18.65	INA	Ina (D-caldera)	1	1	1	1
164.42	-35.48	ING	Ingenii	0	3	3	0
-67.23	31.65	LCT	Lichtenberg Crater	0	0	7	0
26.1	59.8	FRG	Mare Frigoris	0	1	2	1
150.47	26.19	MOS	Mare Moscoviense	0	0	7	0
85.33	2.15	SMT	Mare Smythii	0	1	8	0
22.06	6.93	TRN	Mare Tranquillitatis			0	
-55.8	13.58	MAR	Marius Hills	2	8	8	0
-93.07	-51.14	MEN	Mendel-Rydberg Cryptomare	0	1	3	0
40.81	-15.91	PYR	Montes Pyrenaeus	0	1	1	0
-87.91	-18.04	OR2	Orientale 2	0	0	1	0
-5.21	53.37	PLT	Plato Ejecta	1	1	1	1
-58.56	7.53	RNG	Reiner Gamma	1	2	4	1
-74.28	-3.04	RIC	Riccioli Crater	0	1	1	0
-41.72	27.41	RMP	Rimae Prinz	1	2	2	1
138.77	-75.4	SCH	Schrodinger				
170.92	-51	SPR	South Pole-Aitken Rim	0	0	1	0
128.51	-19.35	TSK	Tsiolkovsky Crater	1	2	14	1
172.08	-26.92	VDG	Van De Graaf Crater			0	

Gray indicates high latitude sites where results are less accurate

Landing Site Rock Abundances

- Initial quantitative comparison near Copernicus:
  - LROC: 0.84%
  - Diviner: 0.75%

Manual LROC rock counts are very labor intensive!

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-125.56	0.09	HTZ	Hertzsprung			3	
119.91	6.39	KNG	King Crater	1	3	6	2
-2.93	-85.99	MAL	Malapert Massif				
58.84	10.68	CRS	Mare Crisium	0	1	4	0
-0.42	4.74	MUR	Murchison Crater			1	
76.19	89.6	NPO	North Pole				
-95.38	-26.2	OR1	Orientale 1	0	1	2	0

LROC – M114077509LC

Landing Site Rock Abundances

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58.84	10.68	CRS	Mare Crisium	0	1	4	0
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5.29	18.65	INA	Ina (D-caldera)	1	1	1	1
164.42	-35.48	ING	Ingenii	0	3	3	0
-67.23	31.65	LCT	Lichtenberg Crater	0	0	7	0
26.1	59.8	FRG	Mare Frigoris	0	1	2	1
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85.33	2.15	SMT	Mare Smythii	0	1	8	0
22.06	6.93	TRN	Mare Tranquillitatis			0	
-55.8	13.58	MAR	Marius Hills	2	8	8	0
-93.07	-51.14	MEN	Mendel-Rydberg Cryptomare	0	1	3	0
40.81	-15.91	PYR	Montes Pyrenaeus	0	1	1	0
-87.91	-18.04	OR2	Orientale 2	0	0	1	0
-5.21	53.37	PLT	Plato Ejecta	1	1	1	1
-58.56	7.53	RNG	Reiner Gamma	1	2	4	1
-74.28	-3.04	RIC	Riccioli Crater	0	1	1	0
-41.72	27.41	RMP	Rimae Prinz	1	2	2	1
138.77	-75.4	SCH	Schrodinger				
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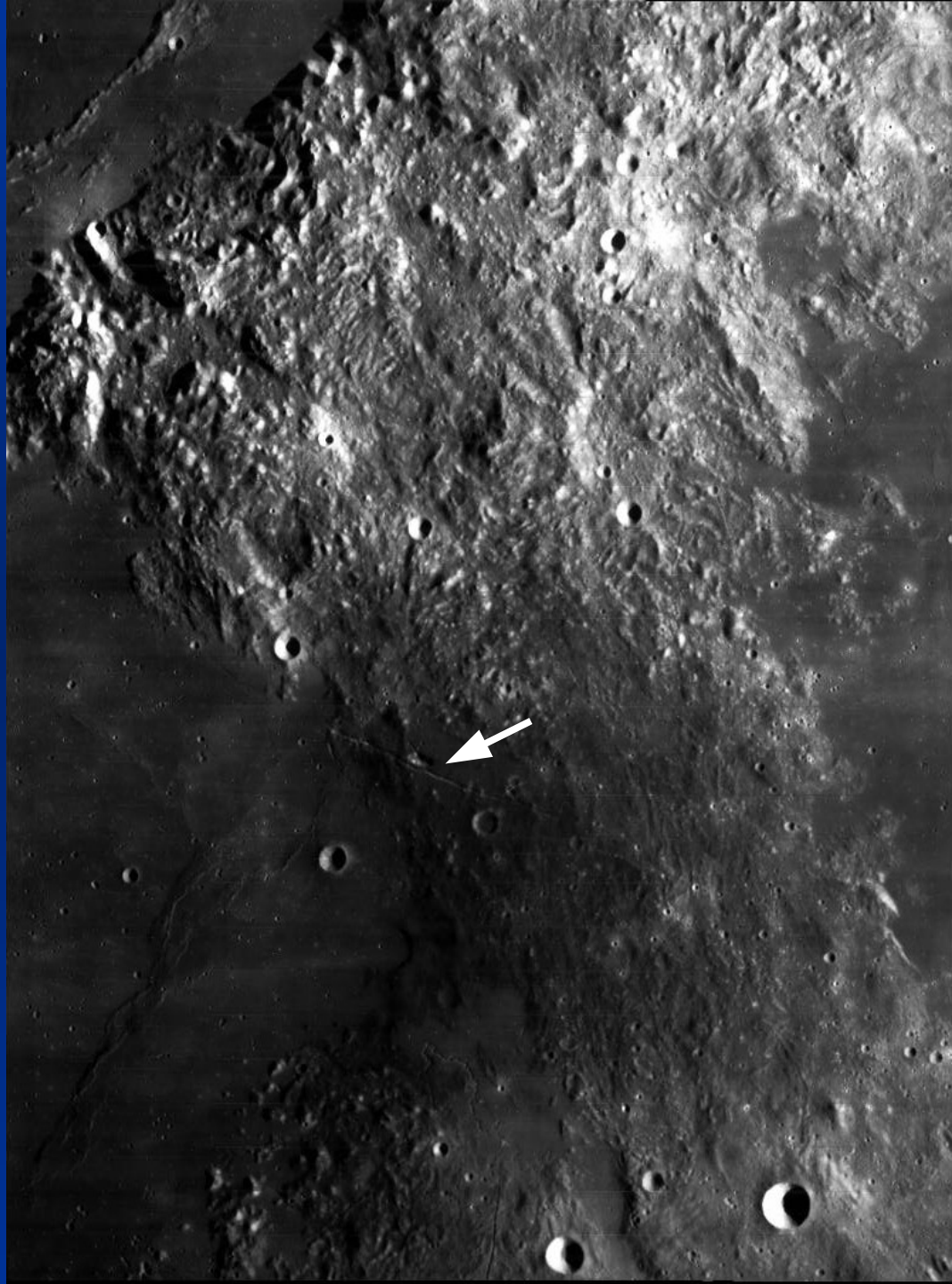
172.08	-26.92	VDG	Van De Graaf Crater			0	

Gray indicates high latitude sites where results are less accurate

Rima Bode

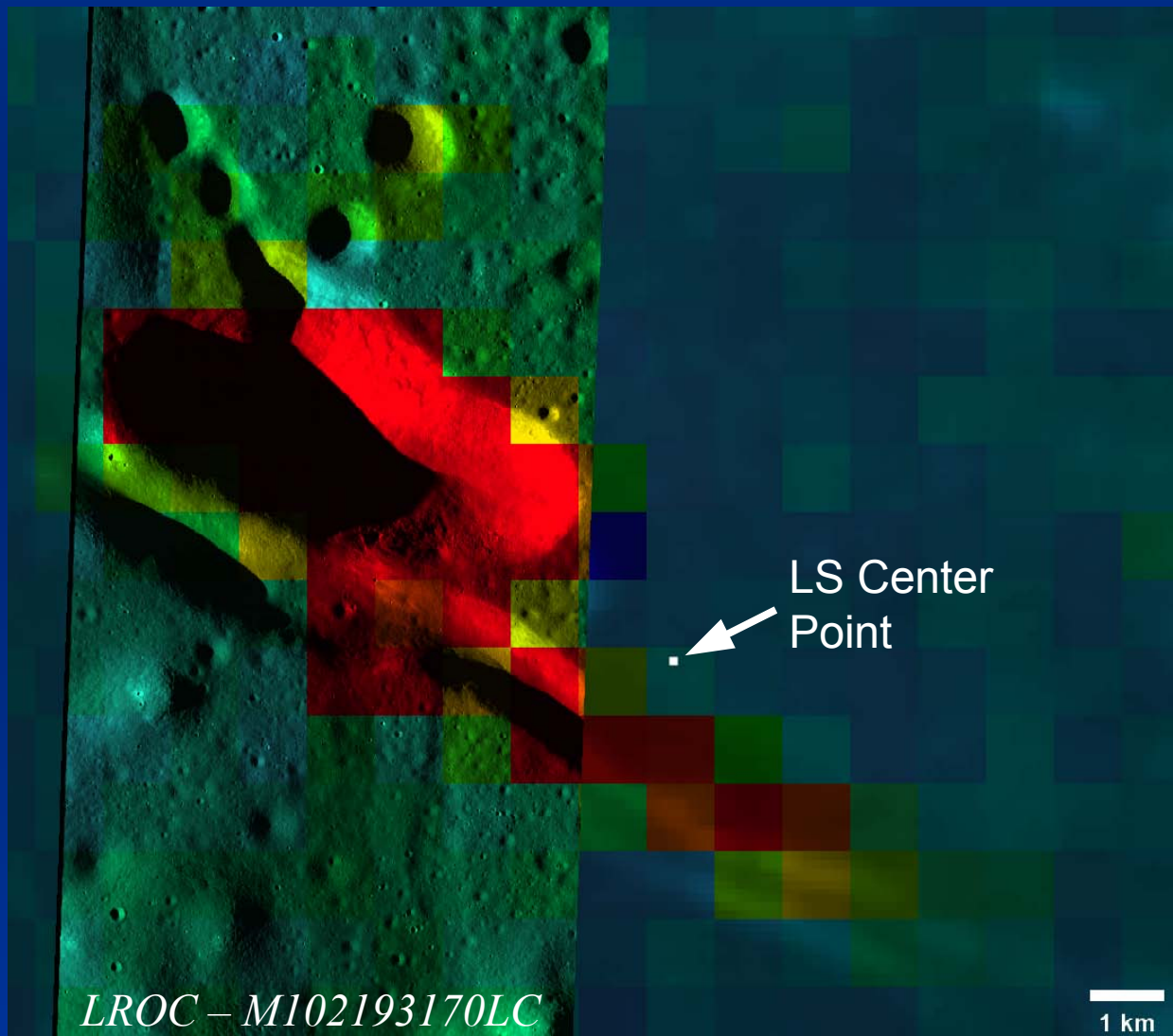
- Dark mantle deposit of pyroclastic origin
  - Low radar returns (CPR) indicating smooth, rock-free materials

    (e.g. *Carter et al.*, 2009)



Rima Bode Landing Site

- Large spatial variability in rock abundance
- Comparisons with LROC NAC images show excellent qualitative agreement



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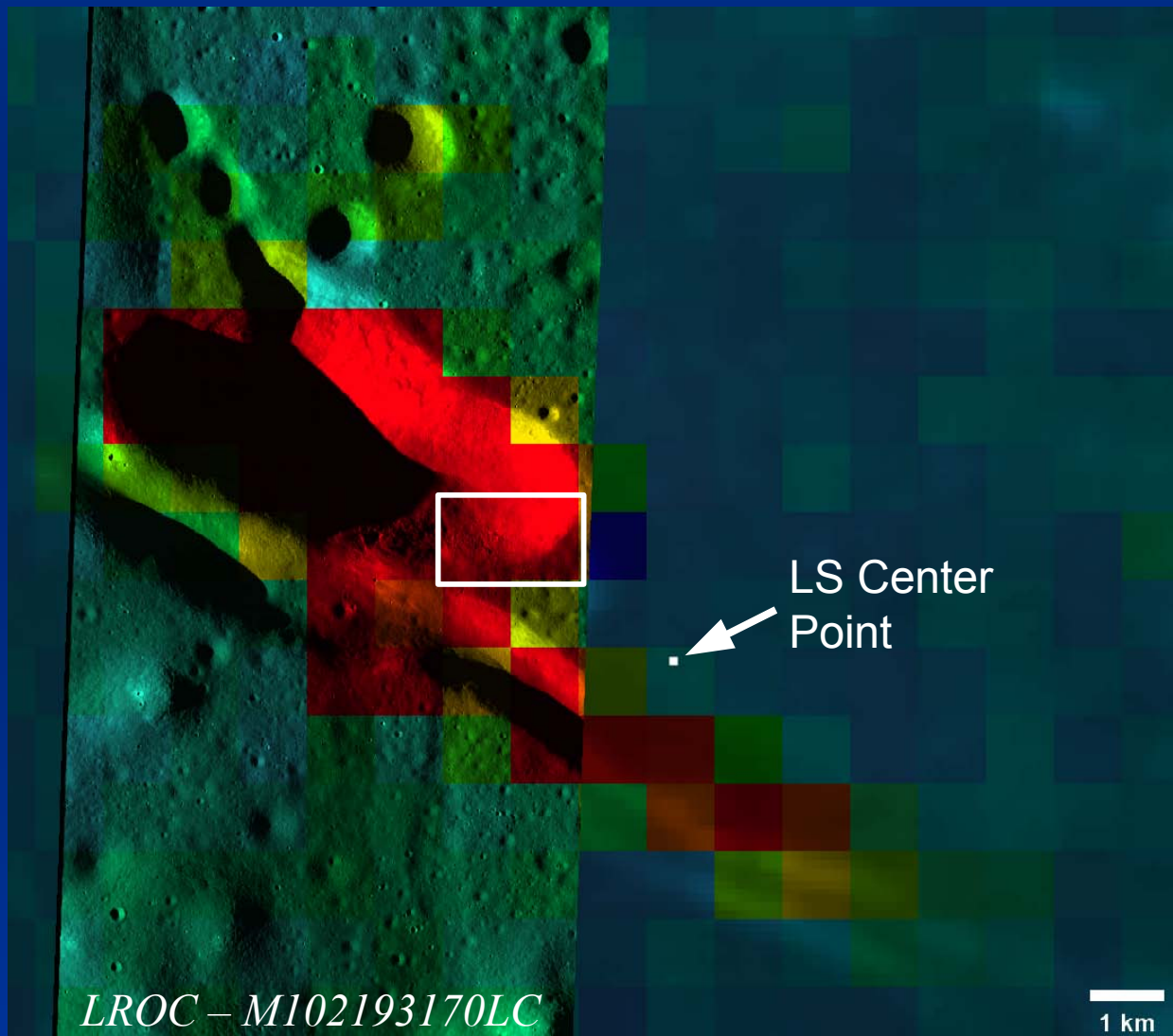
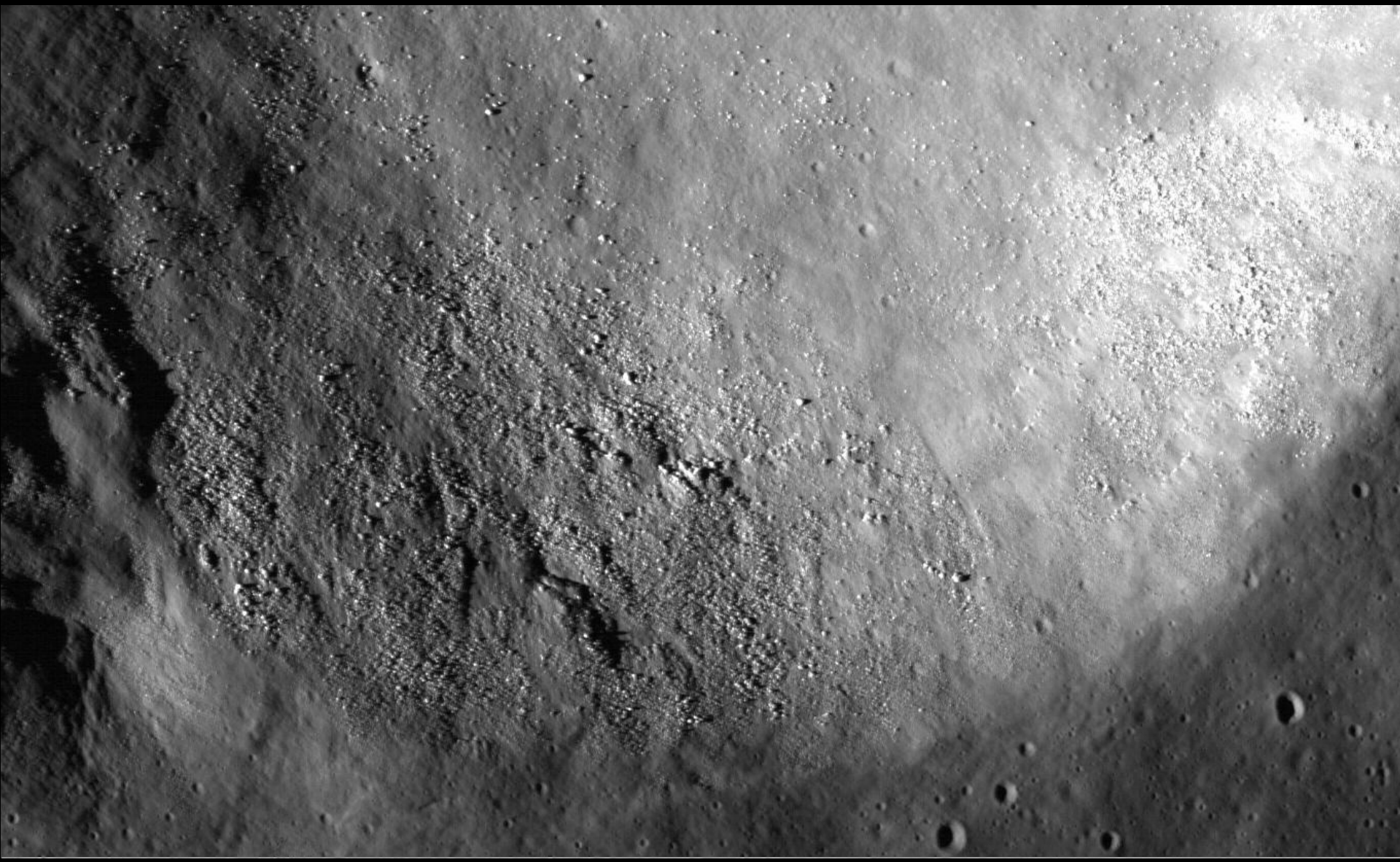
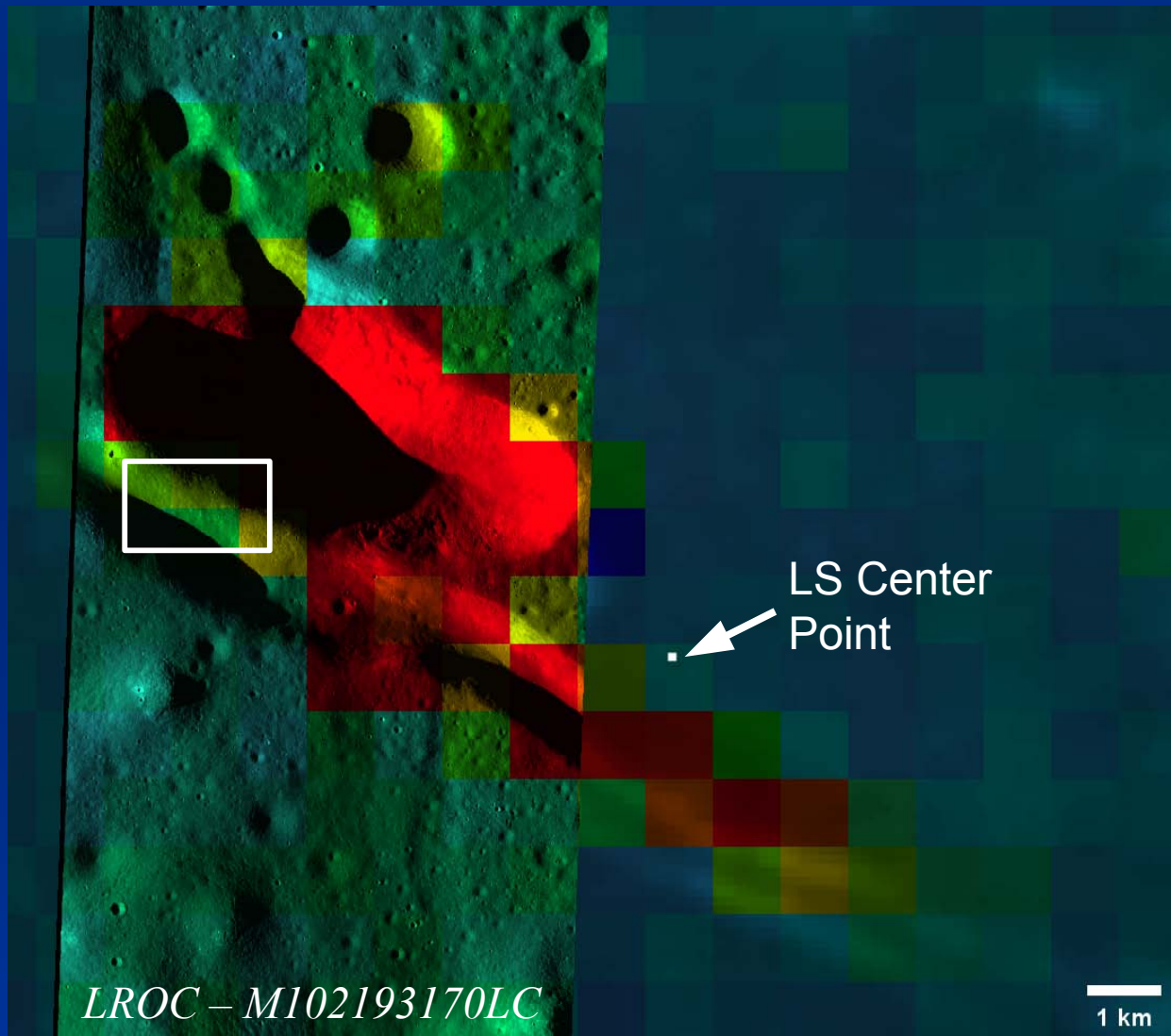




Average Rock Abundance – 10%

Rima Bode Landing Site

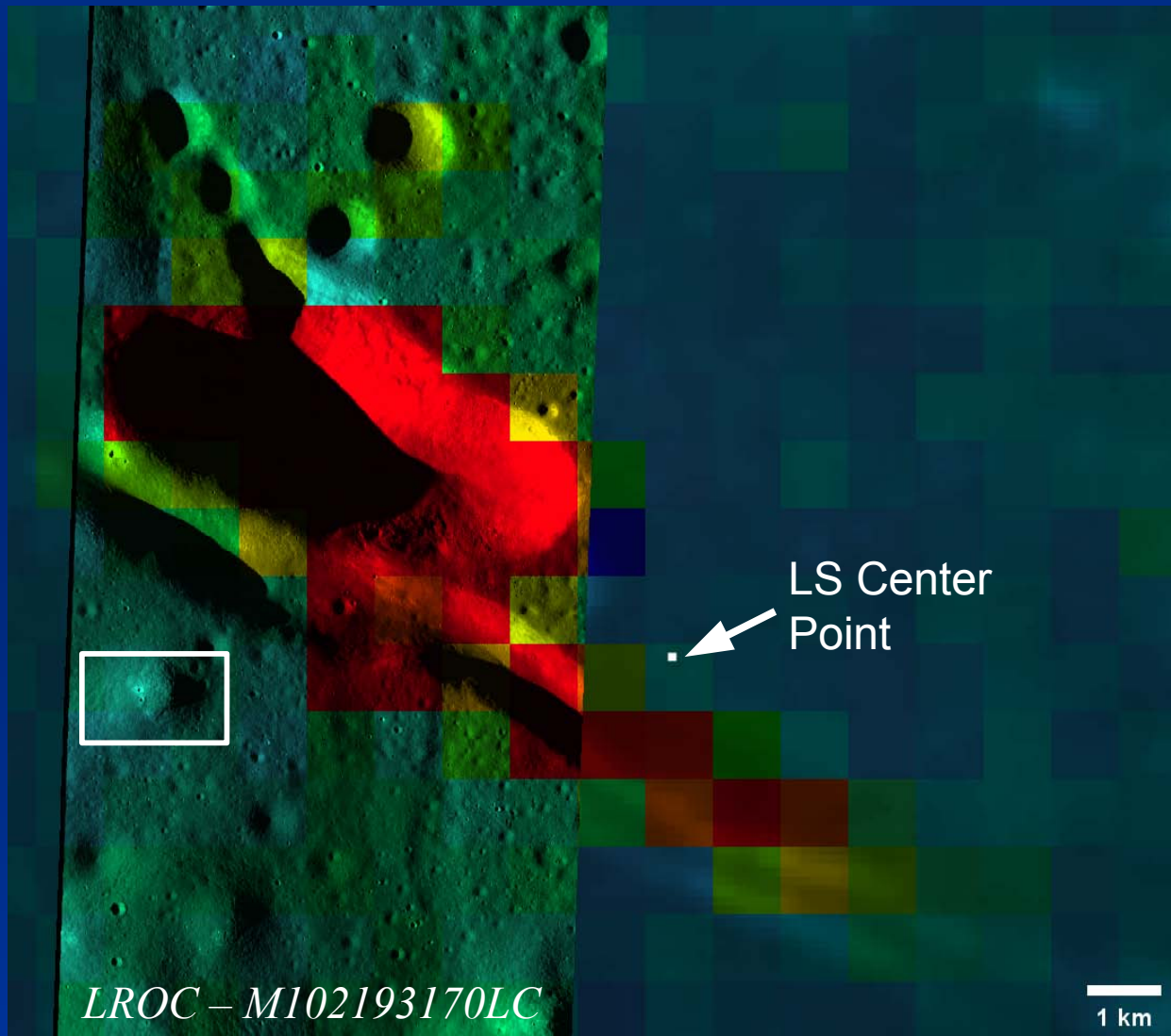
- Large spatial variability in rock abundance
- Comparisons with LROC NAC images show excellent qualitative agreement

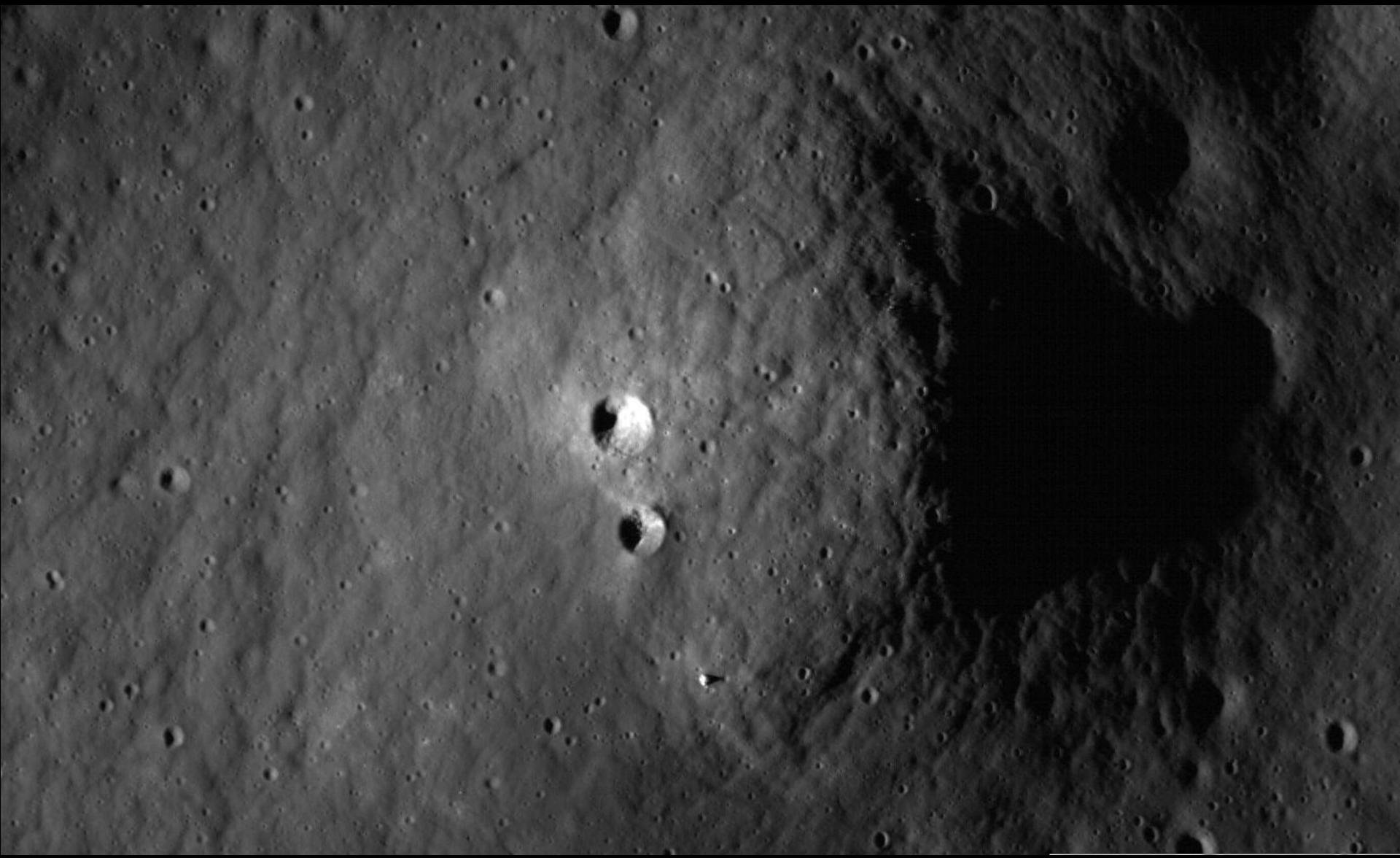


Average Rock Abundance – 1.3%

Rima Bode Landing Site

- Large spatial variability in rock abundance
- Comparisons with LROC NAC images show excellent qualitative agreement



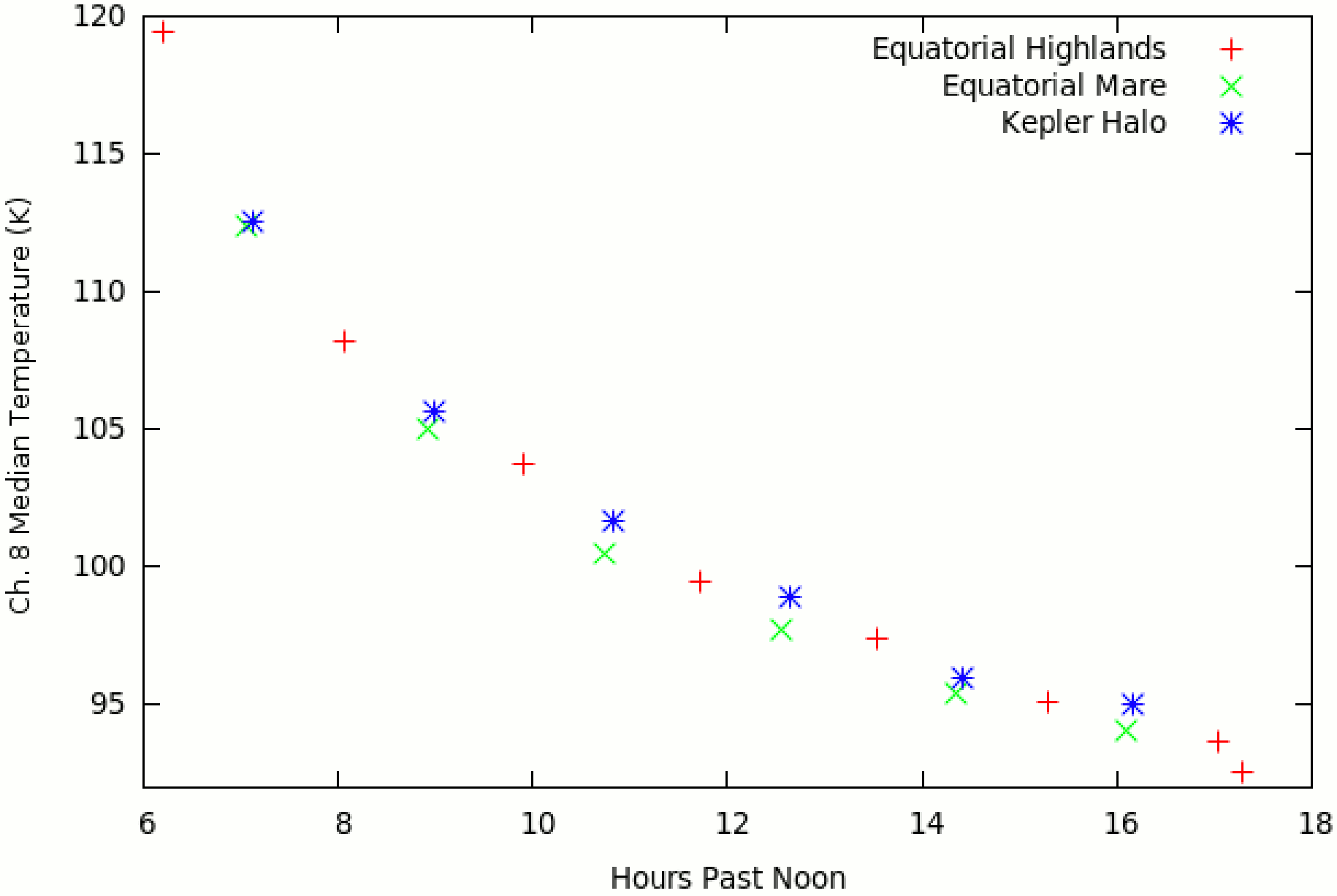


Average Rock Abundance – 0.3%

Summary

- Multispectral modeling of measured Lunar radiance produces realistic values for rock abundance and regolith temperatures
- Diviner rock abundance and radar and imaging datasets show general similarities
  - Distinct differences between measurements indicates layering, thickness, etc. of regolith
- Quantitative validation using LROC rock counts is starting
  - Much needs to be done comparing datasets!

Plum Crater
AS16-114-18422


Equatorial Highlands
Equatorial Mare
Kepler Halo
Ch. 8 Median Temperature (K)
Hours Past Noon
120
115
110
105
100
95
6
8
10
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Apollo 15
AS15-82-11155