Lunar Hydration as Observed by LRO LAMP

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and the LAMP team

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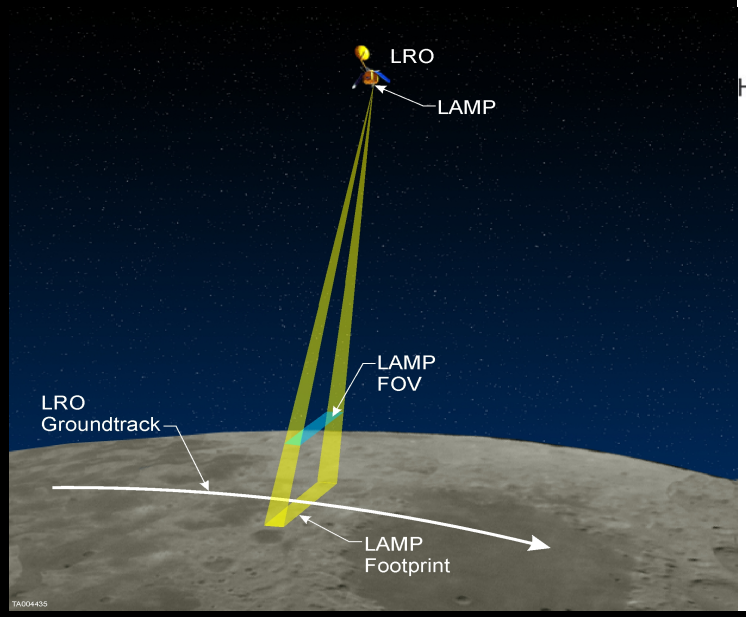
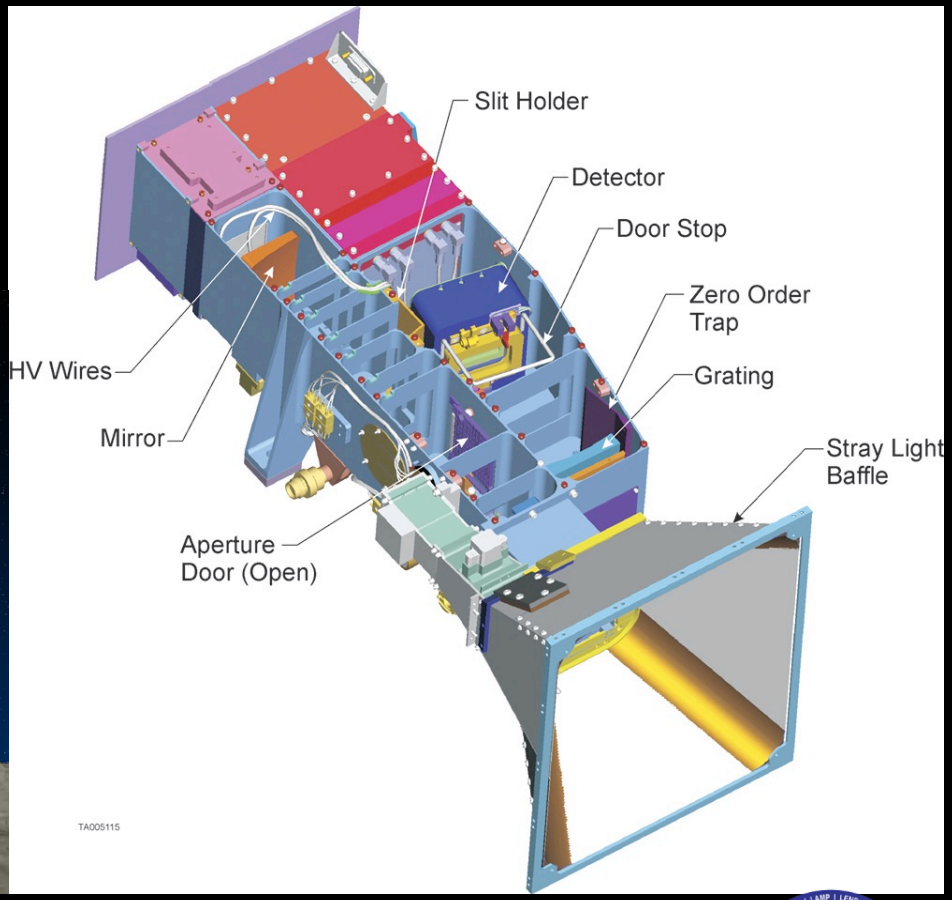
LRO LAMP
Lyman Alpha Mapping Project

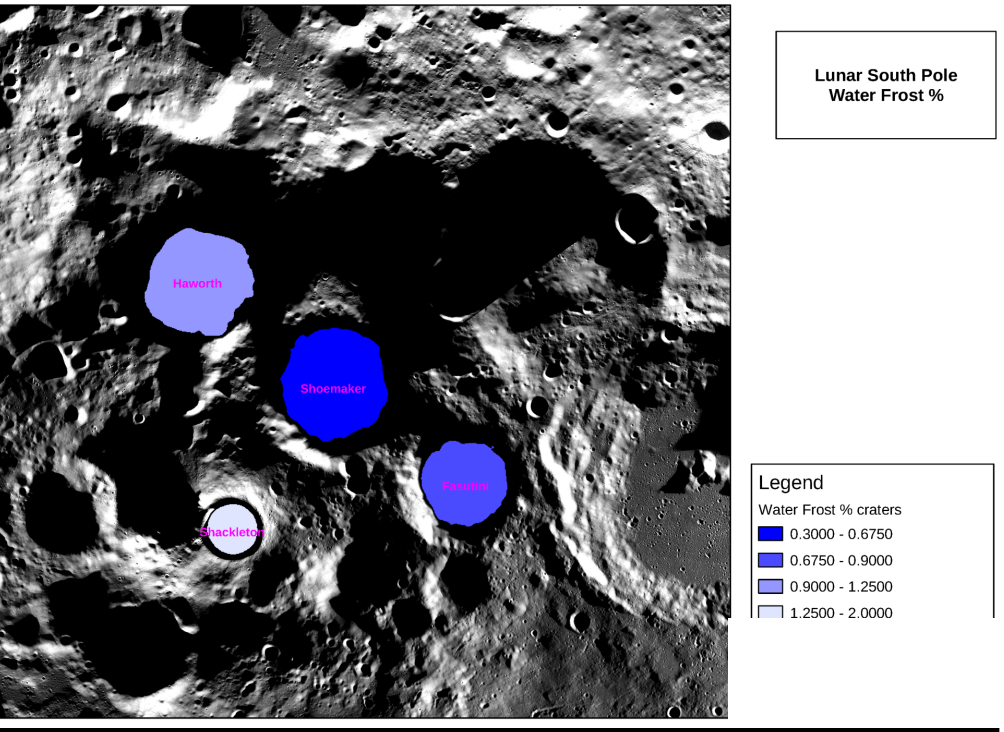
LAMP:
FUV Spectrograph
Mass: 6.08 kg
Power: 4.8 W
λ Range: 57-196 nm
FOV: 0.3º × 6.0º
Filled-Slit λ Range:
<4 nm

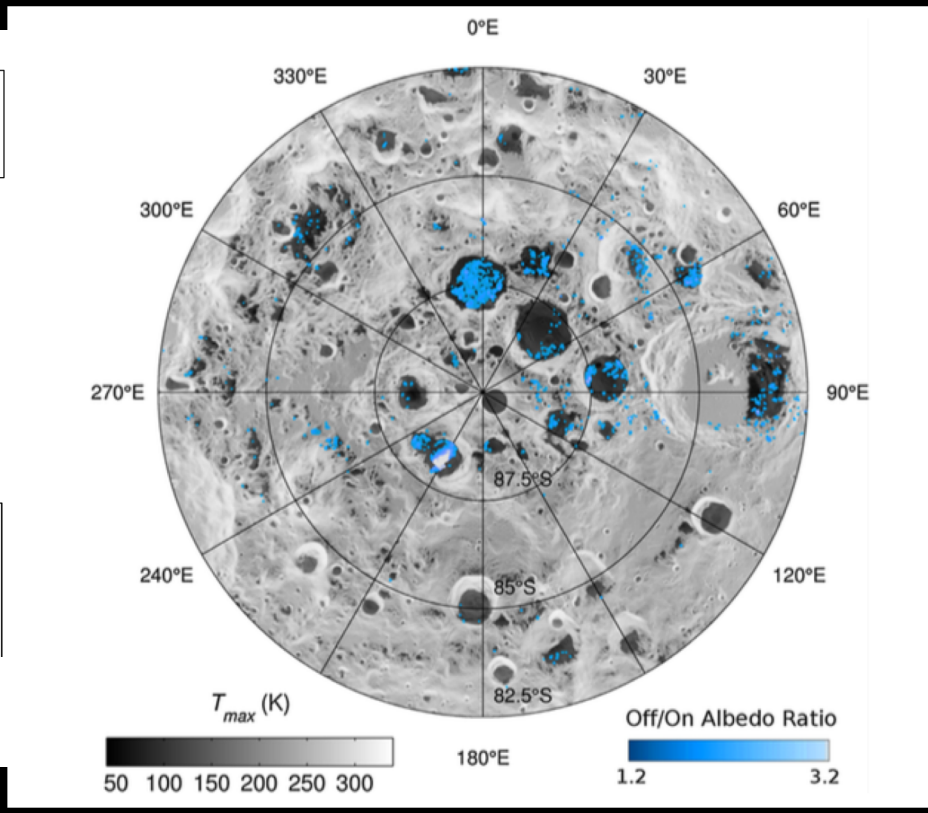
Observes in PSRs, on nightside and on dayside!





LRO LAMP-measured H_2O frost in polar regions



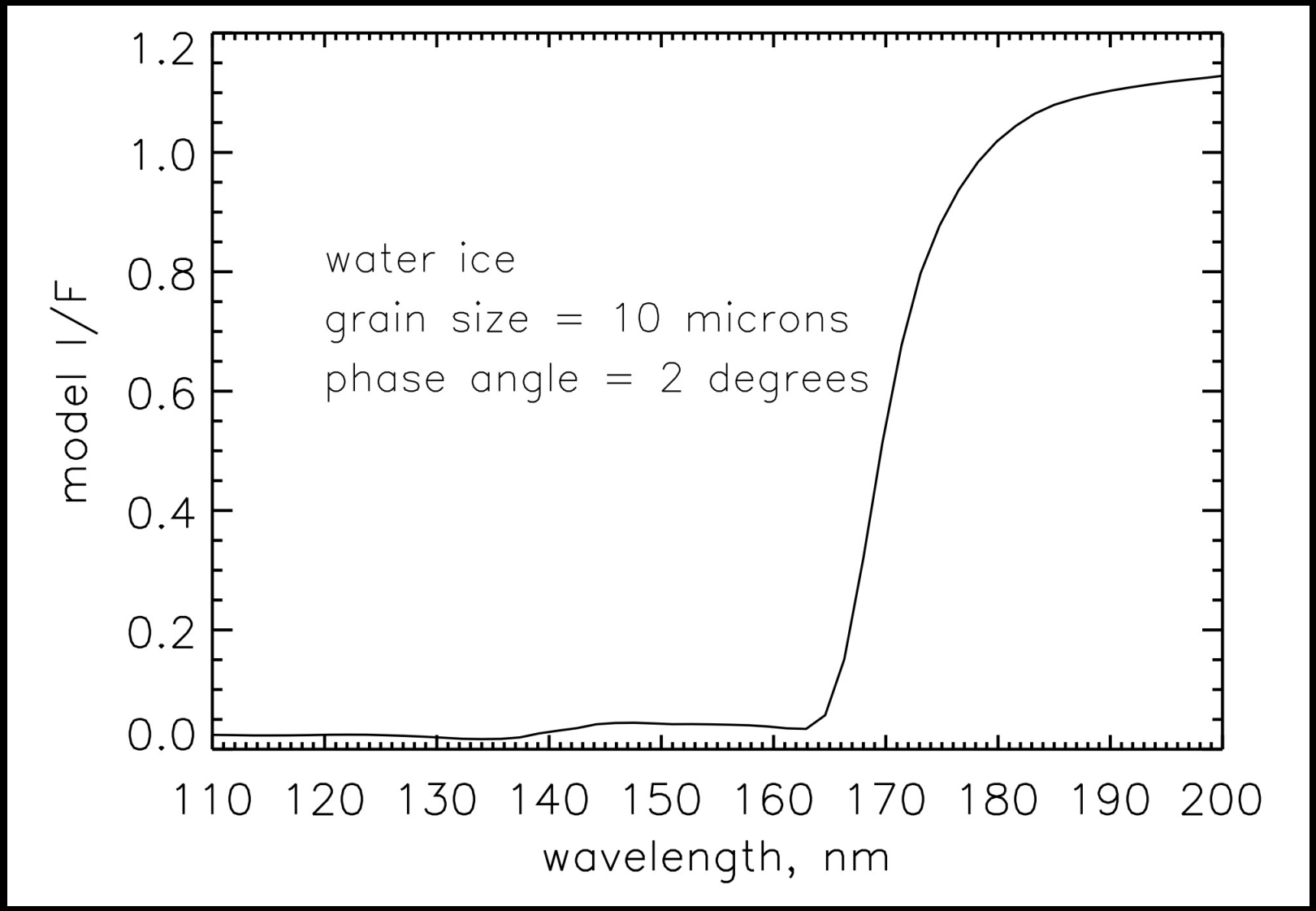


Consistent with H_2O ice concentrations of 0.1-2% by mass; more if patches are areally-mixed with dry regolith (up to 10%)

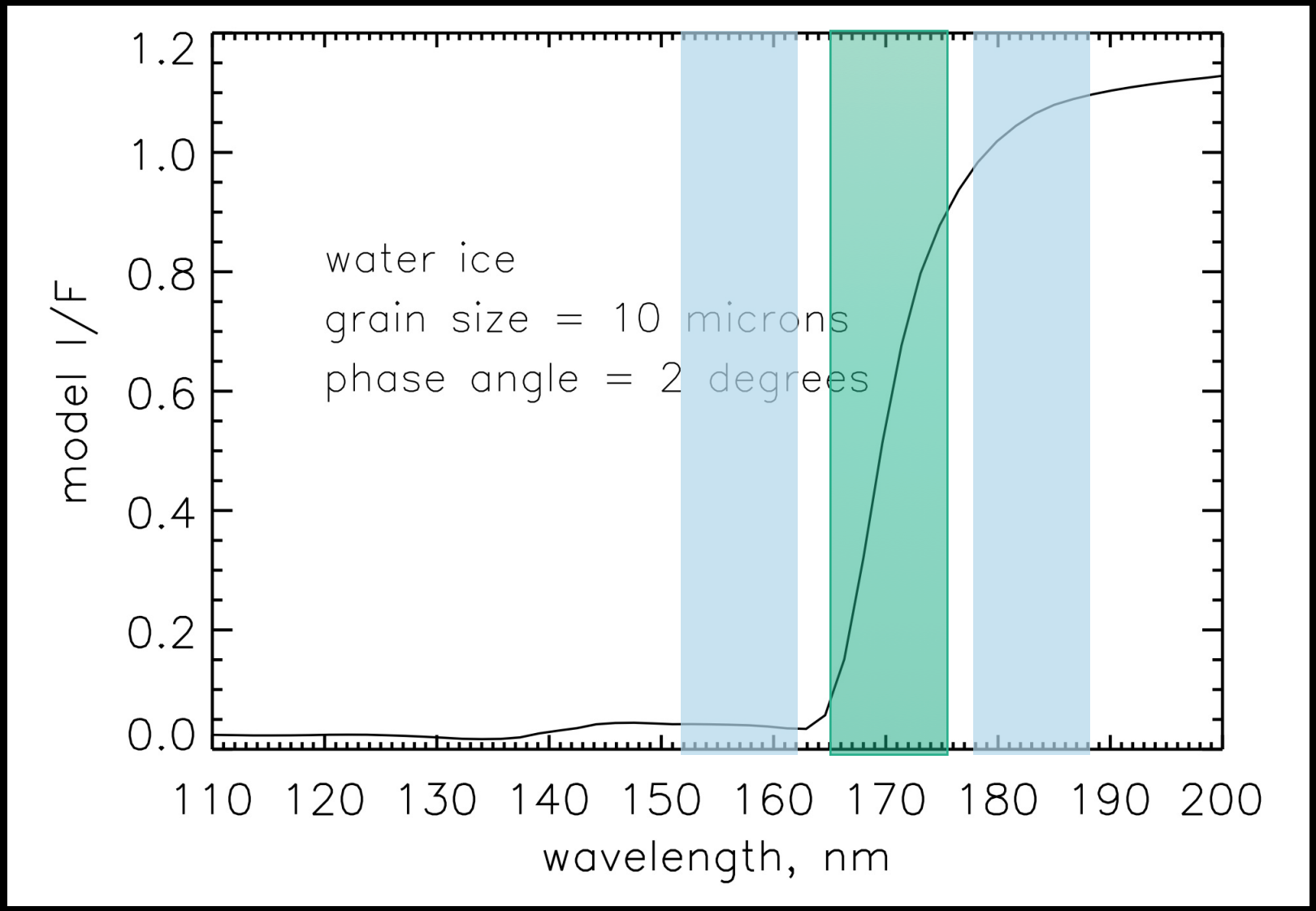
Gladstone et al. 2012

Hayne et al., 2015

Water spectral signature in FUV

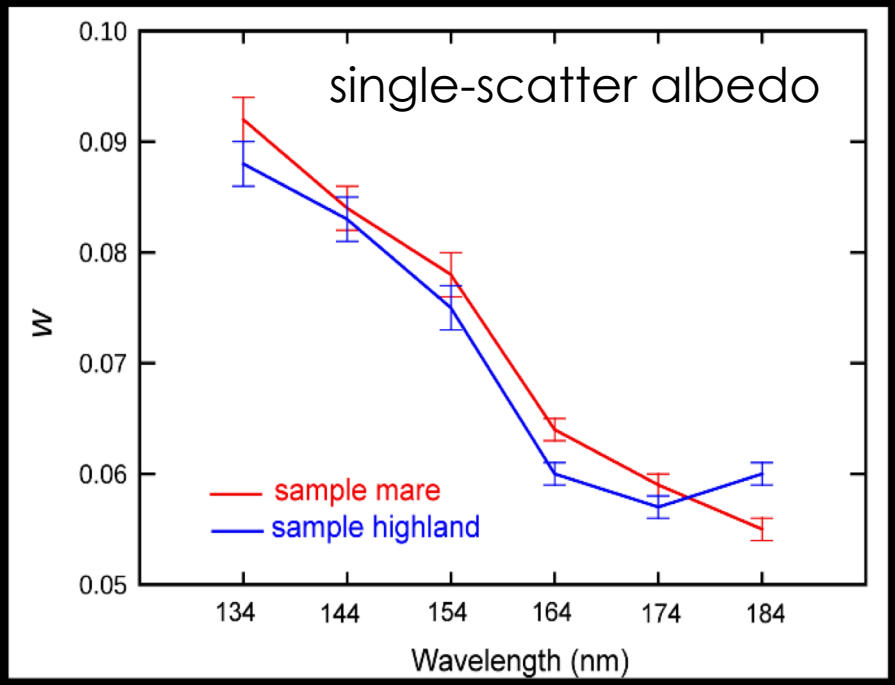


Water spectral signature in FUV

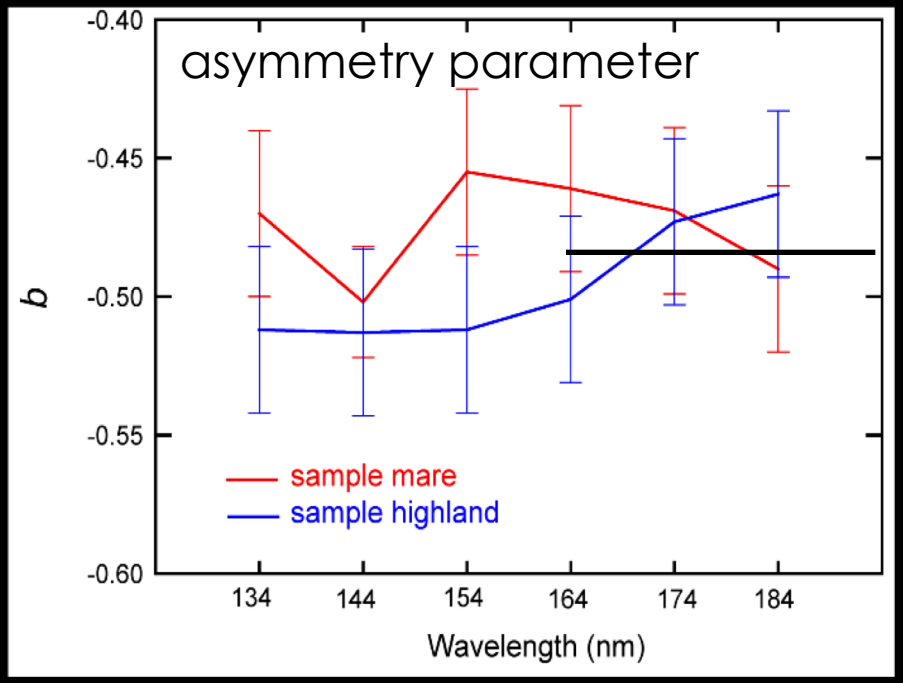


FUV photometric models (Liu et al. 2018)

A



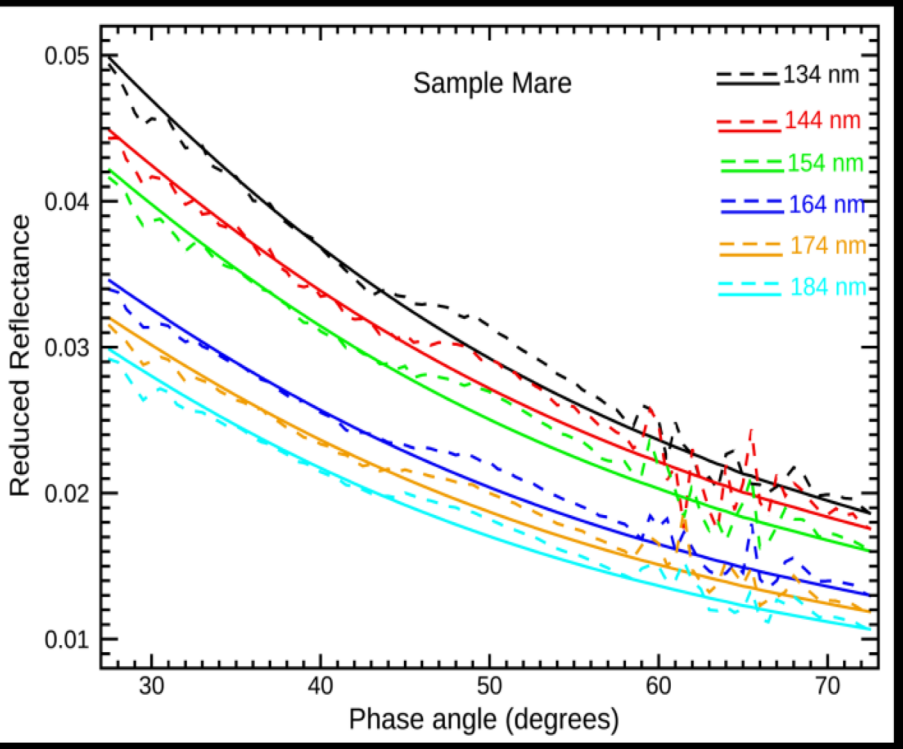
B



We choose to use b=-0.48 to re-calculate slopes in the 164-173 nm and 175-190 nm ranges

New FUV photometric models (Liu et al. 2018)

A



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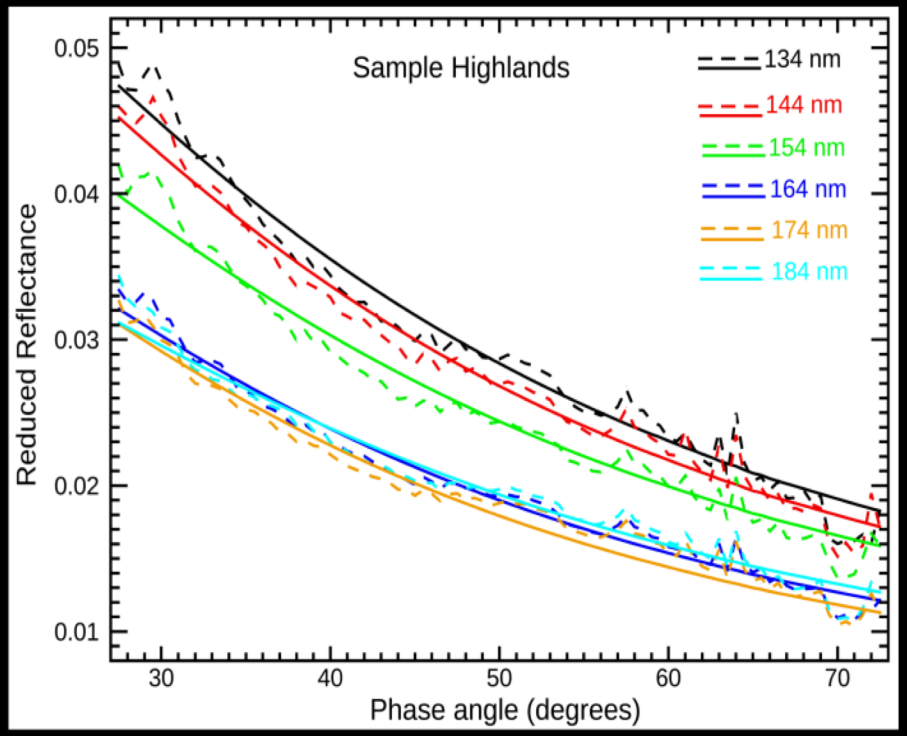
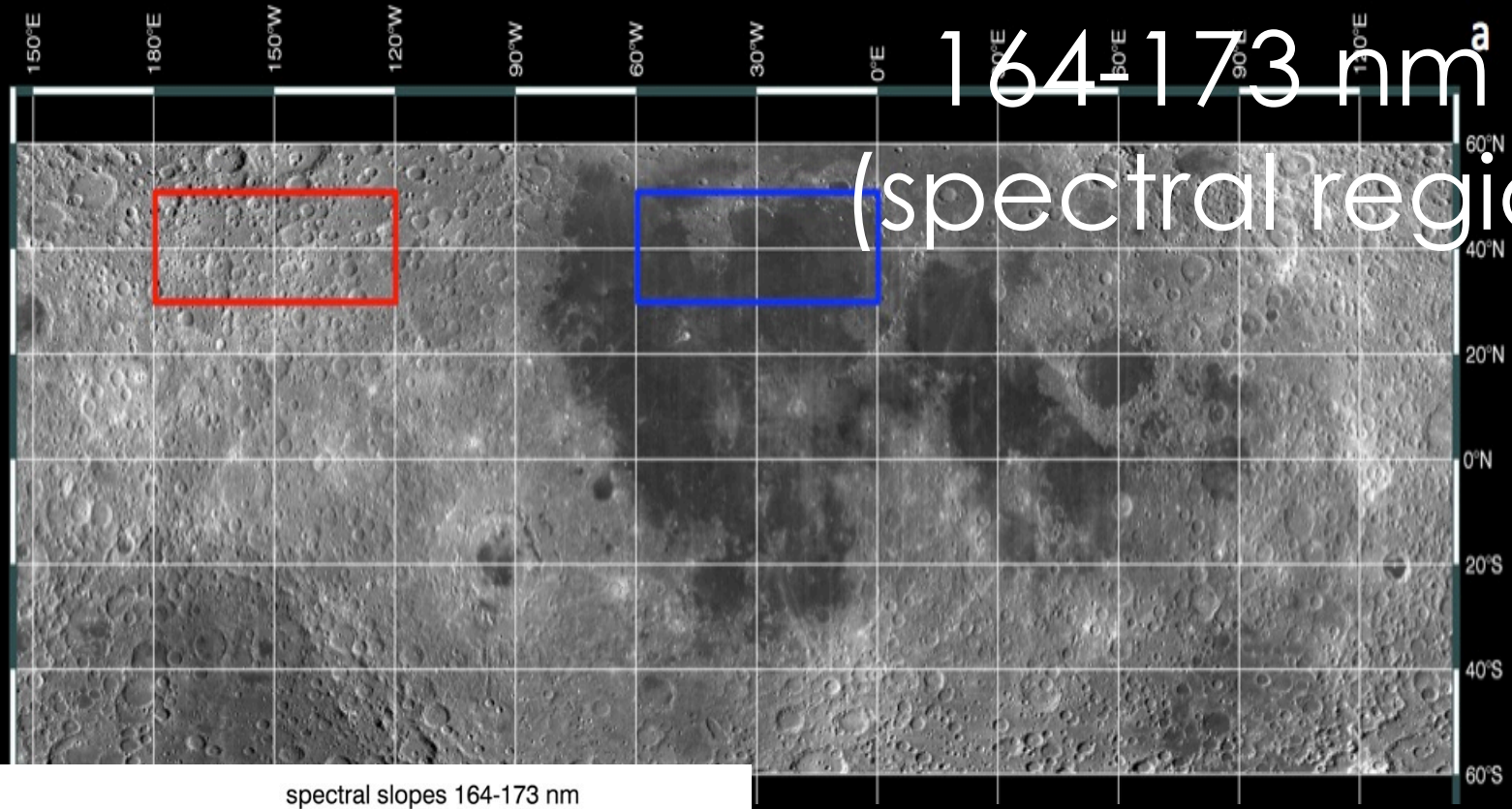
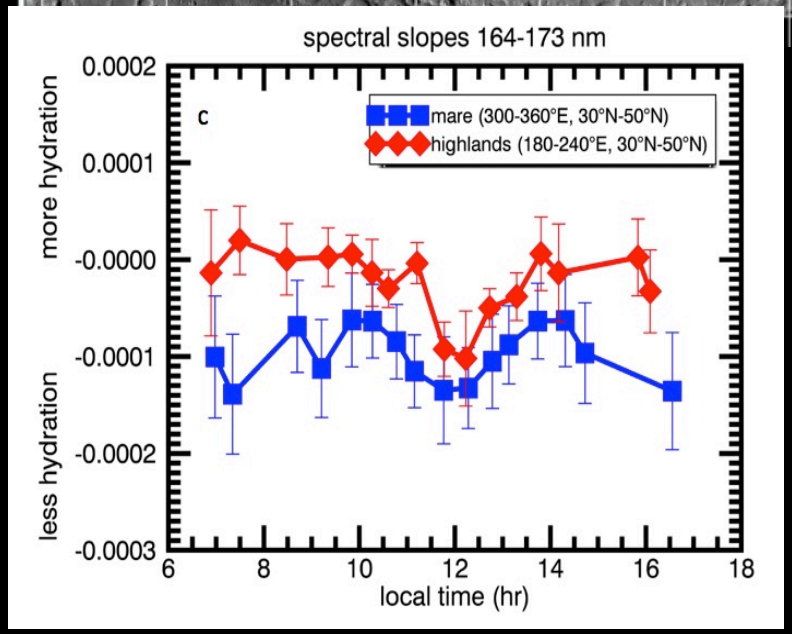


Note that these fits are derived over ~27-73° phase angle; not clear how well the fits work outside that region

164-173 nm slopes (spectral region #2)

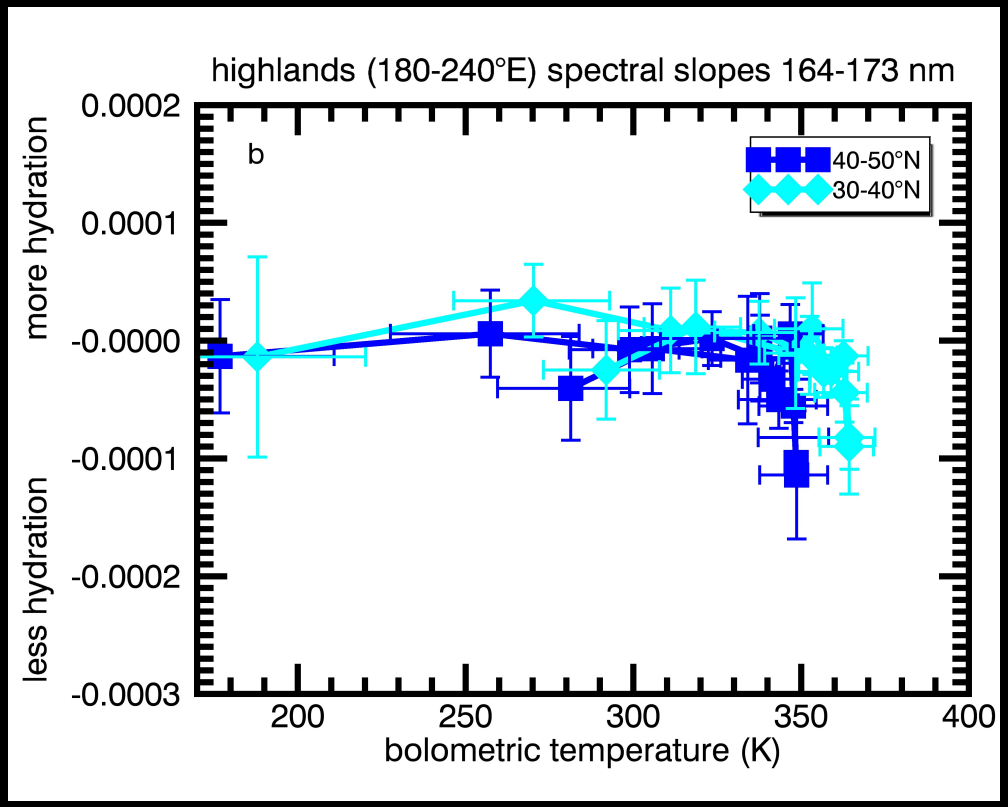




Greater retention of hydration in highlands than mare terrains

Consistent with lab results (e.g. Poston et al. 2015)

Error bars represent standard deviation



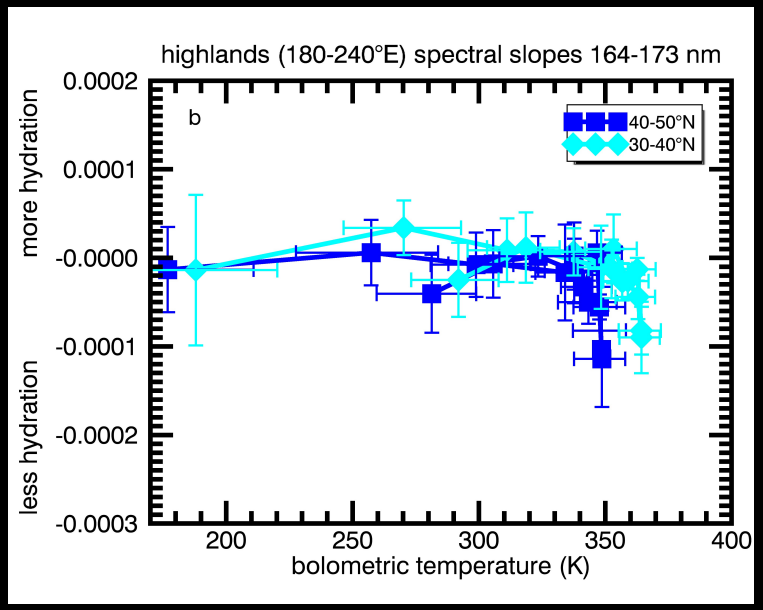
Using Diviner data

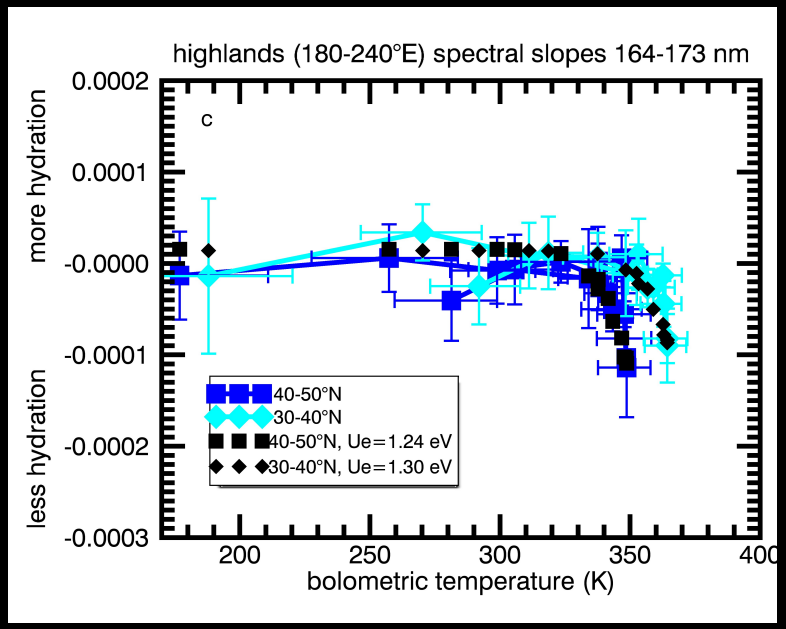
In these two latitude bins,

- Lower lats retain hydration to the highest temps
- Suggests some other factor is important, besides just temperature

LAMP trends are consistent with adsorption (cryosorption) and desorption of H2O, where H2O molecules adsorb onto grains and then desorb when the temperature is high enough.

Other possible loss processes include non-thermal ones such as electron- photon-dissociation. These could be going on but are not as apparent in the LAMP data





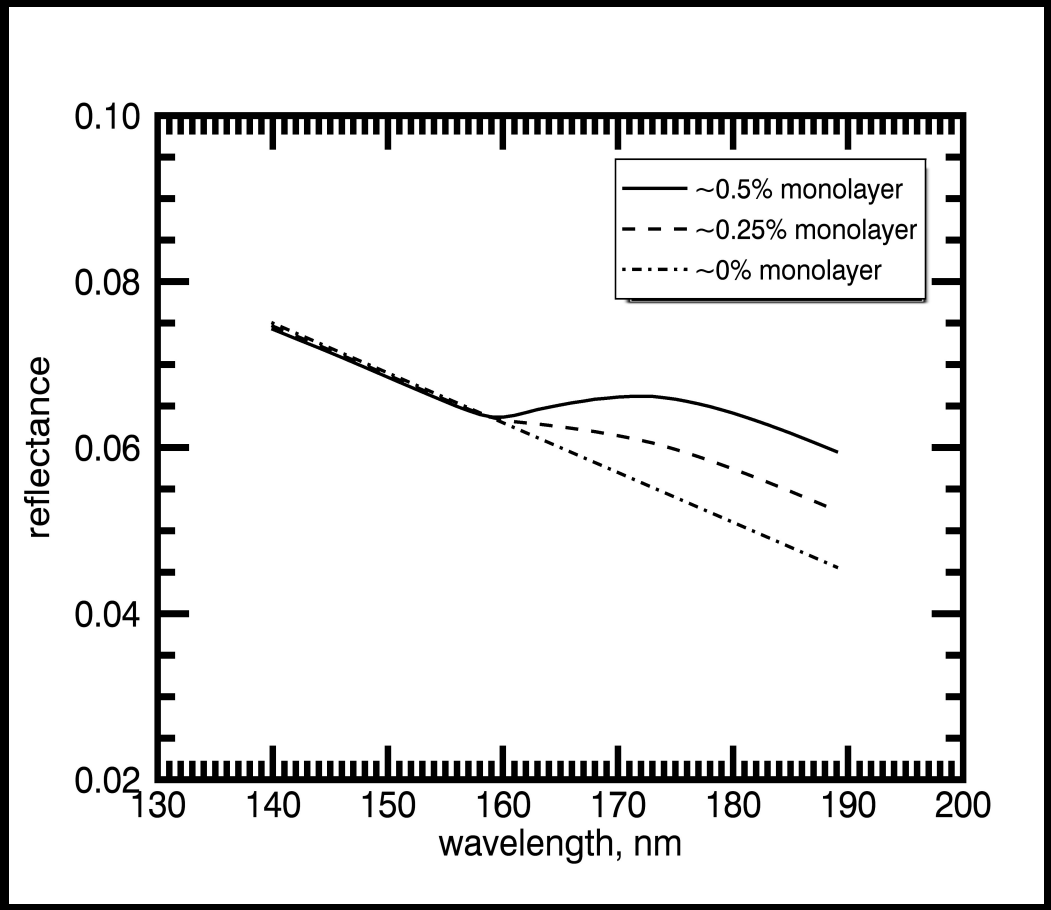
the change in concentration of water (N) with time can be related to activation energy:

$N=N_0\exp(-kDt)$ where

$k=1\times10^{13}(s^{-1})\exp(-Ue/k_BT)$;

k_B is the Boltzmann constant.

There may be a latitudinal dependnce in Ue?
(Hard to say whether the latitudinal temperature differences are significant)



we model the signature in terms of a layer of H2O overlying lunar regolith (Hapke, 1993) and determine the range of optical depths of the water layer required to produce the observed spectral slopes.

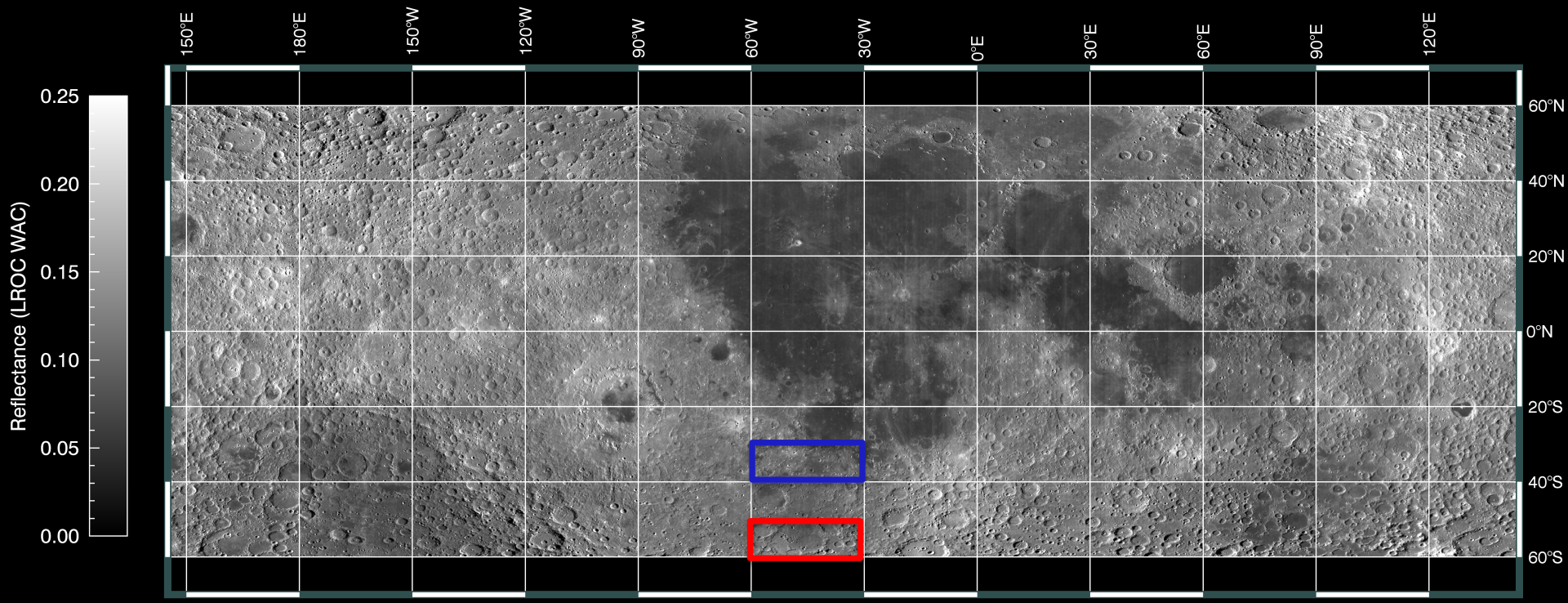
The optical depth can be represented as

$\tau = Nz\sigma Qe$

For the maximum optical depth ($\tau \sim 0.0035$), the areal coverage $Nz \sim 6 \times 10^{12}$ cm−2, or roughly 0.5% of a monolayer.

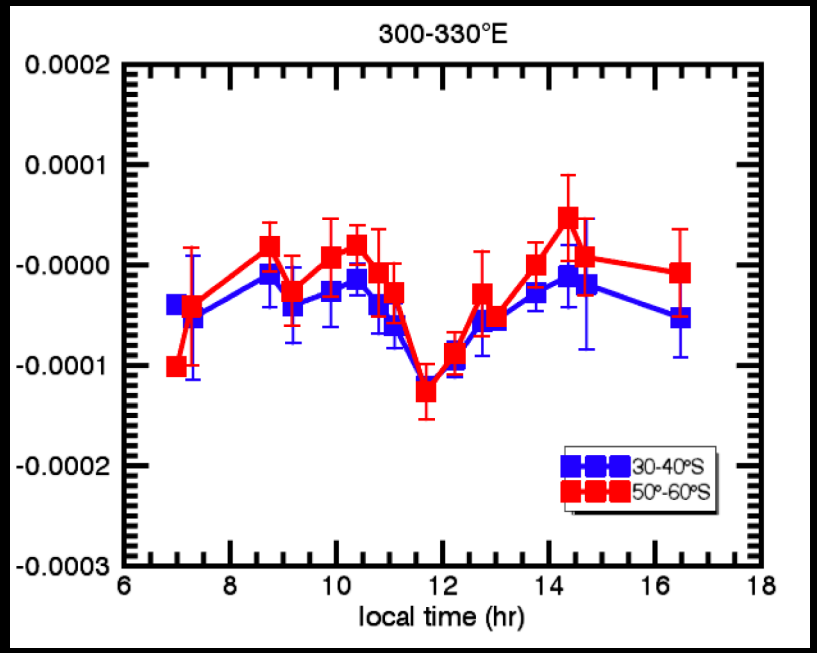
New (Preliminary) Results

- Now that we have established that this technique seems to work, we can expand to additional regions and make maps
  - Here we look at diurnal variations from place to place on the surface
  - Parallel efforts to do proper mapping are underway
- We still want to stay within our "zone of photometric correction comfort"
- We are playing with the best size of region to analyze for the optimal SNR

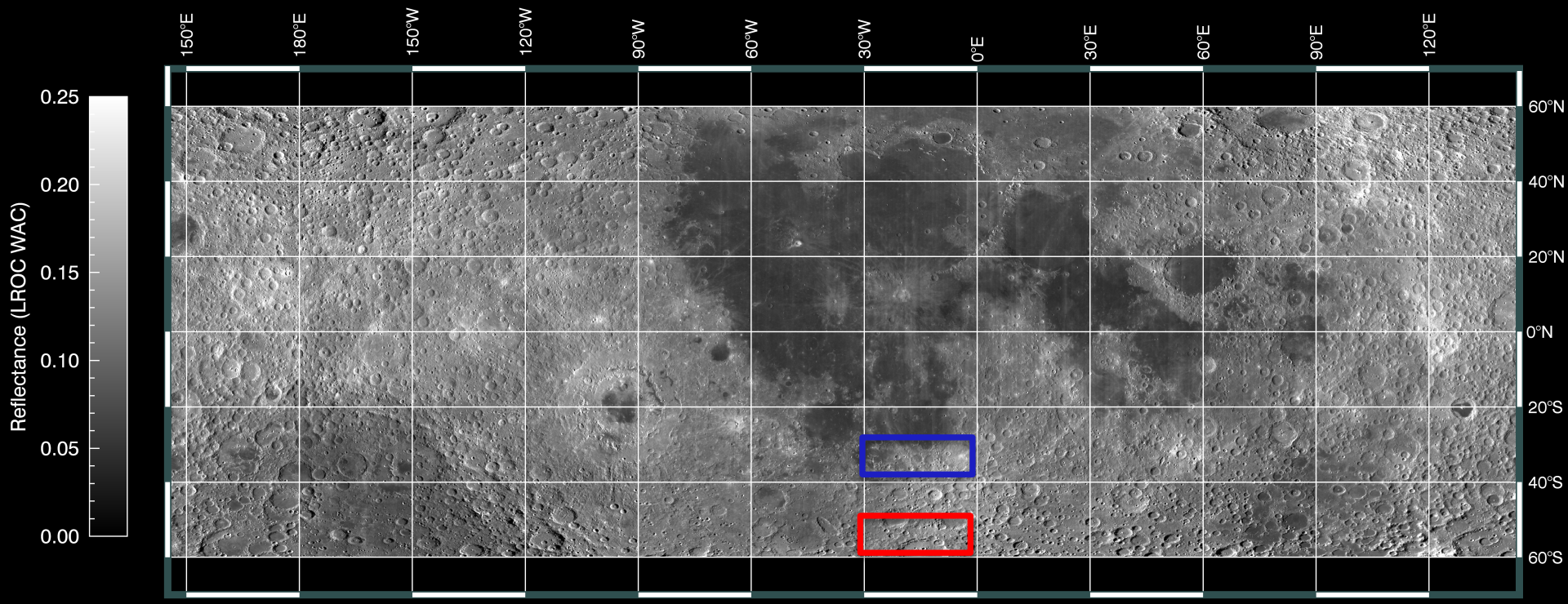


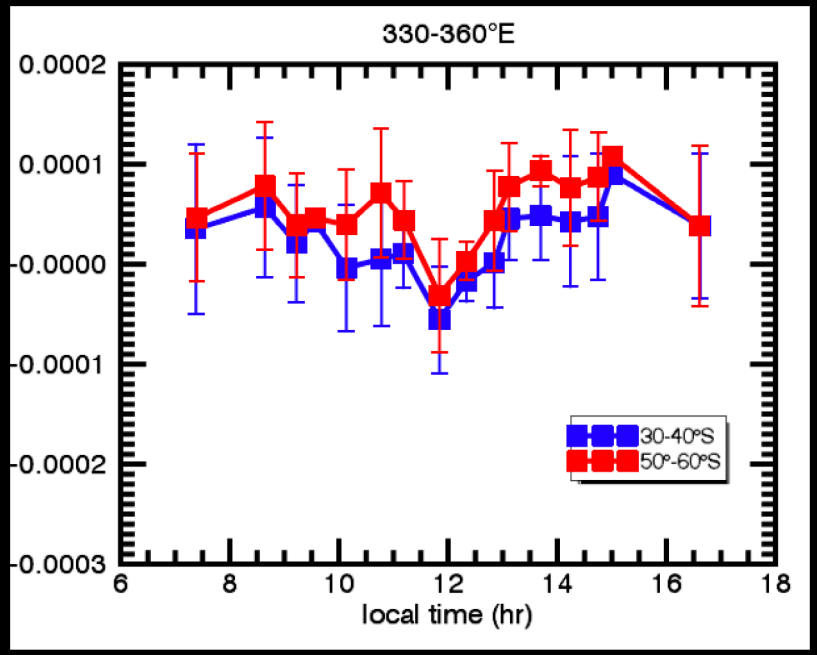
The amount of H_2O (% monolayer) can be approximated from baseline slope (early/late in day).

Subtle variations are seen from place to place



preliminary results





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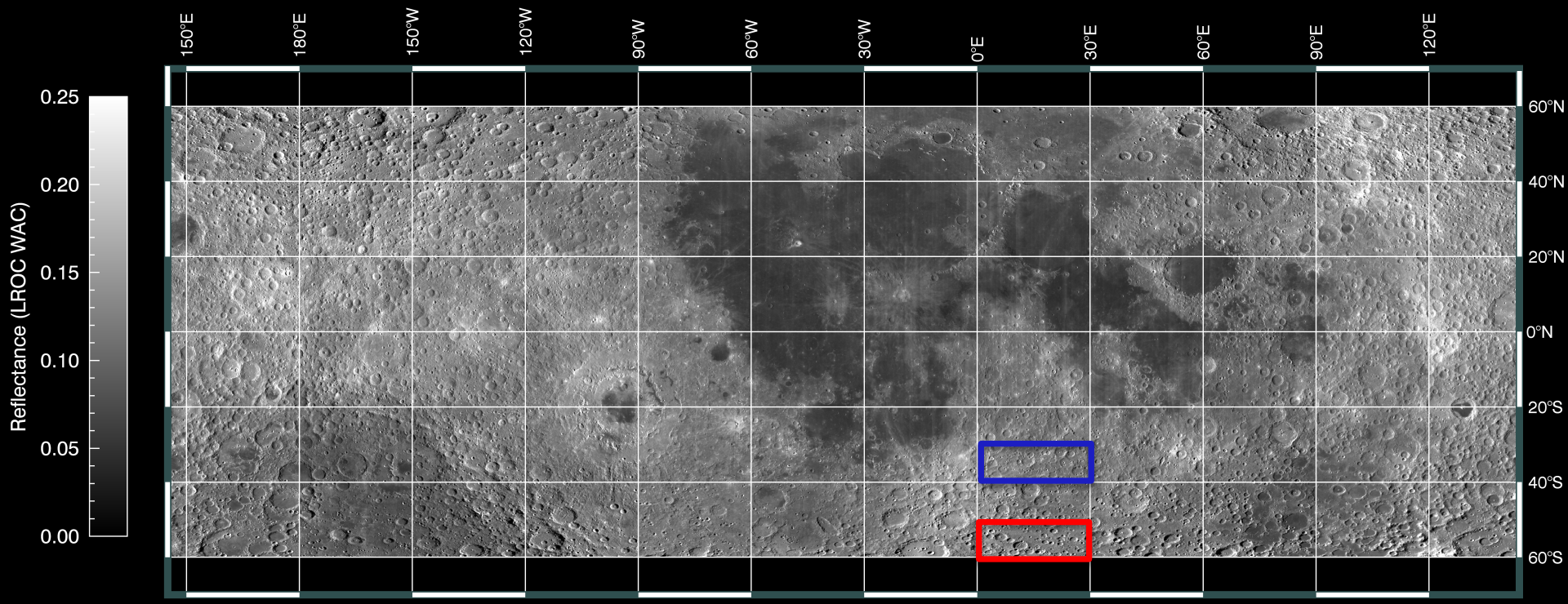

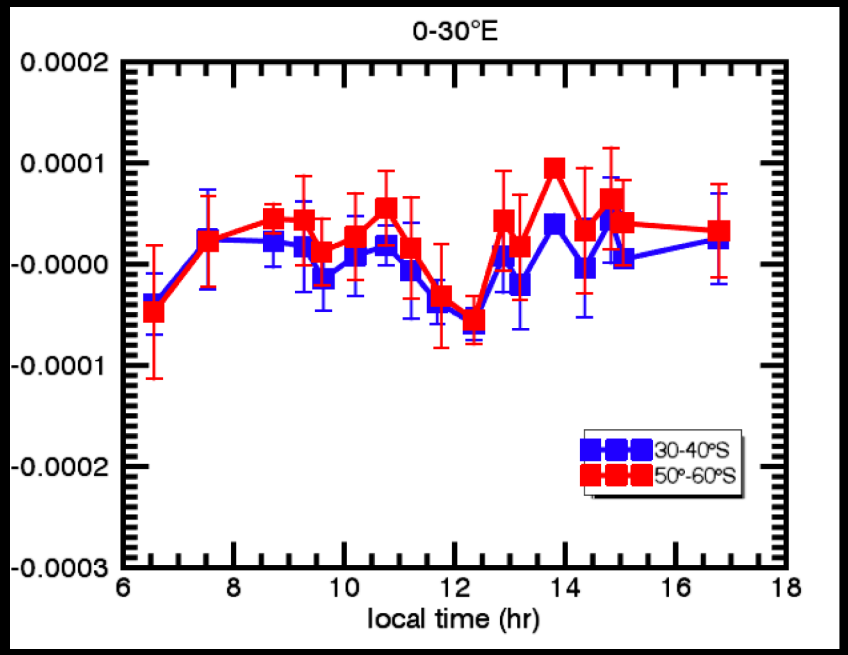

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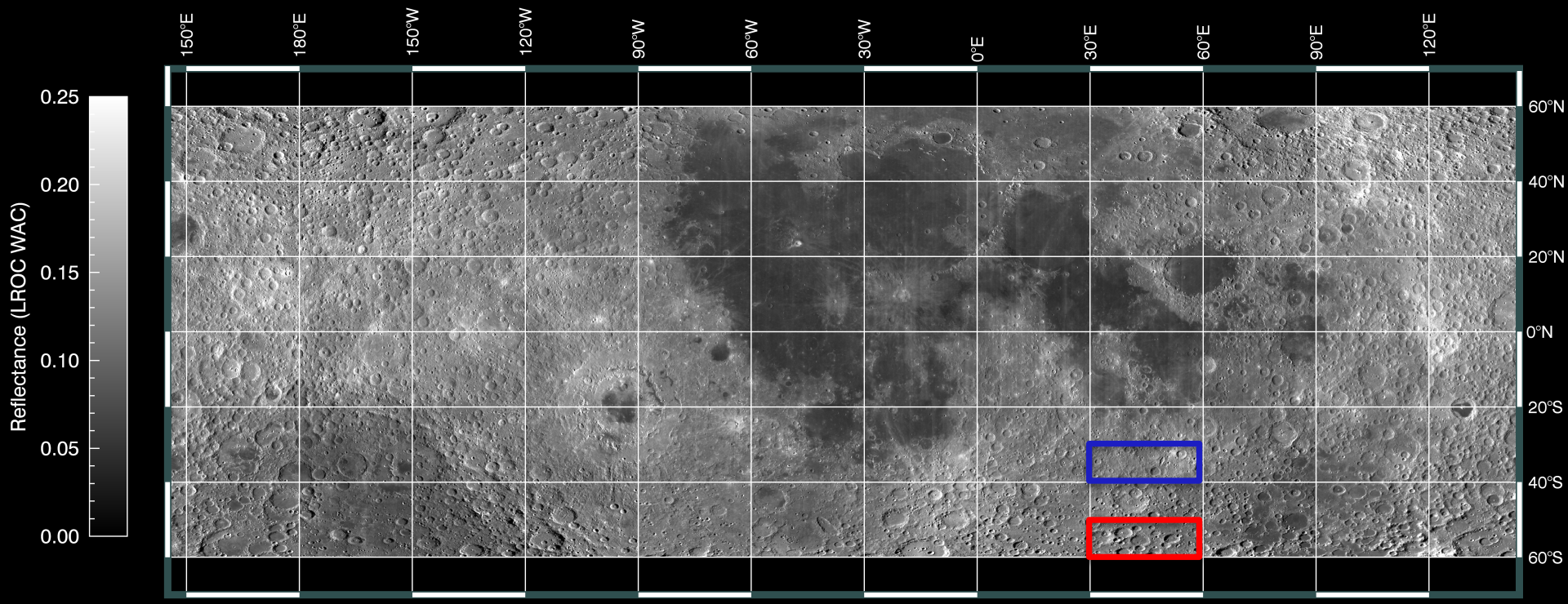

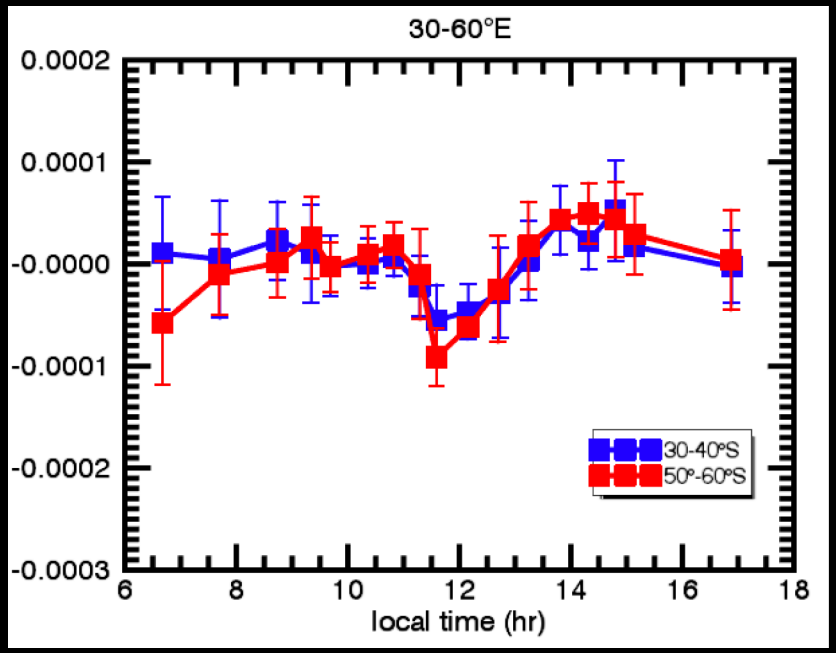

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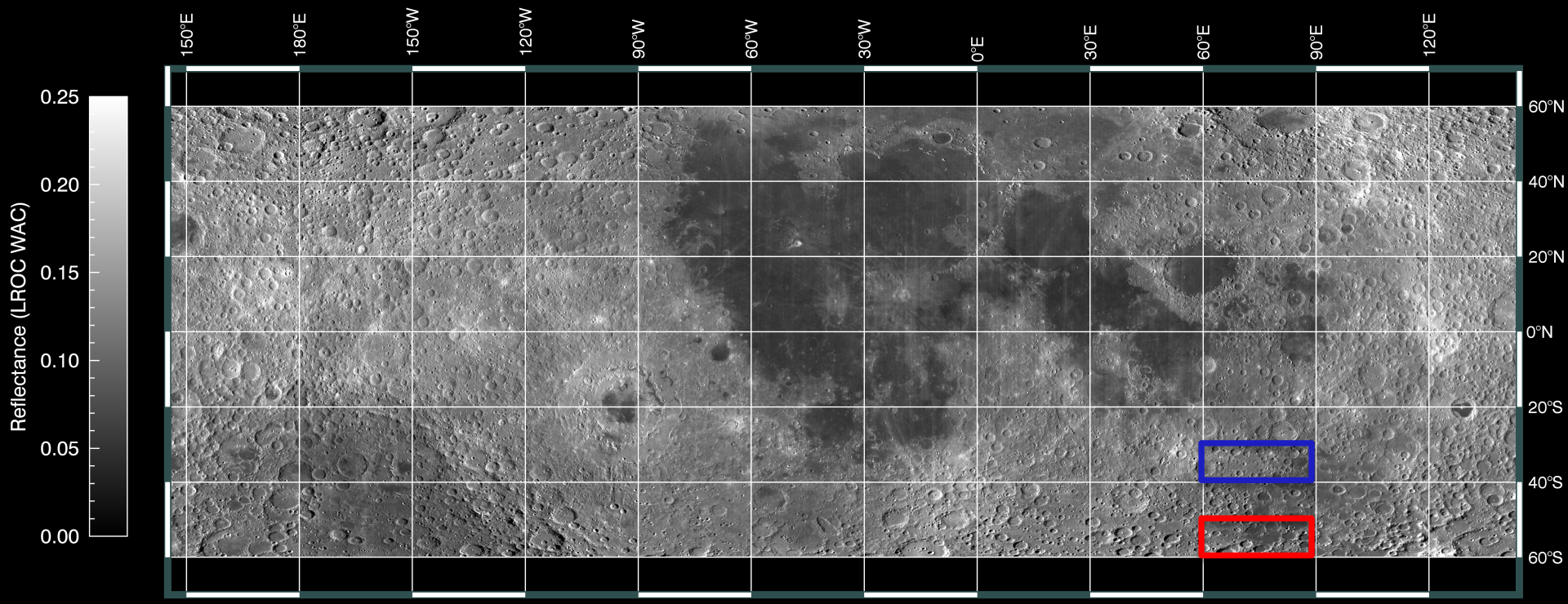

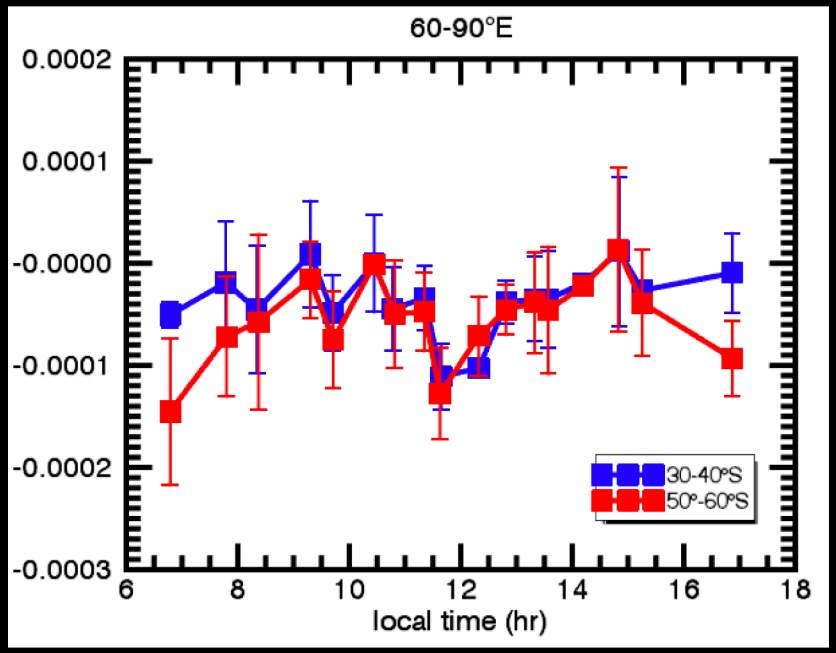

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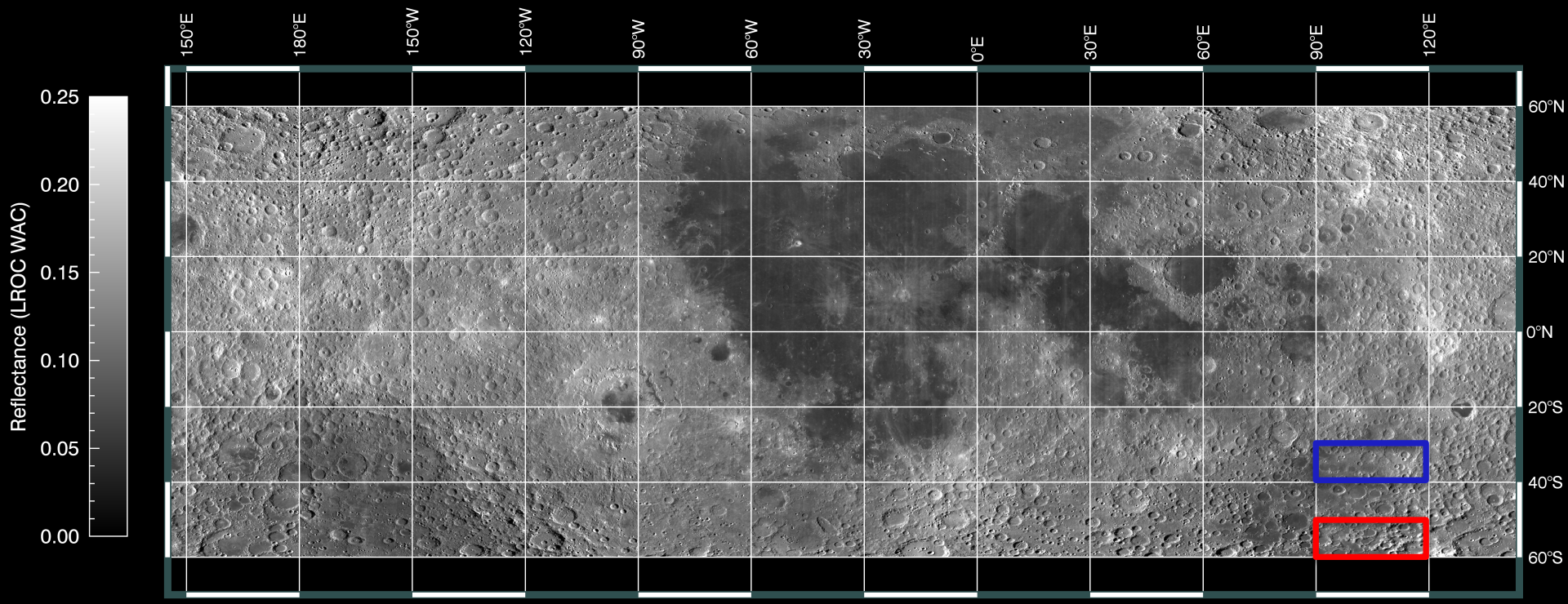

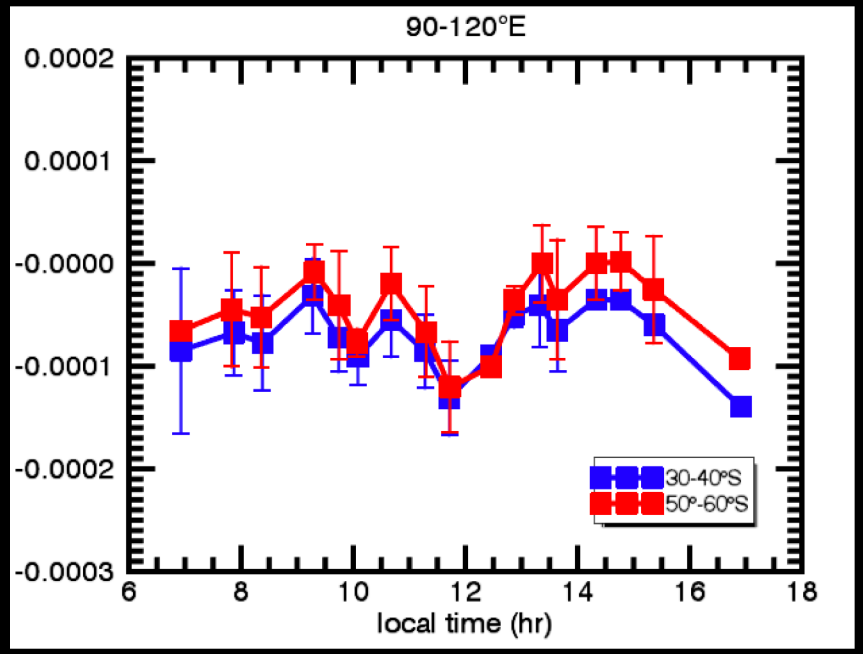

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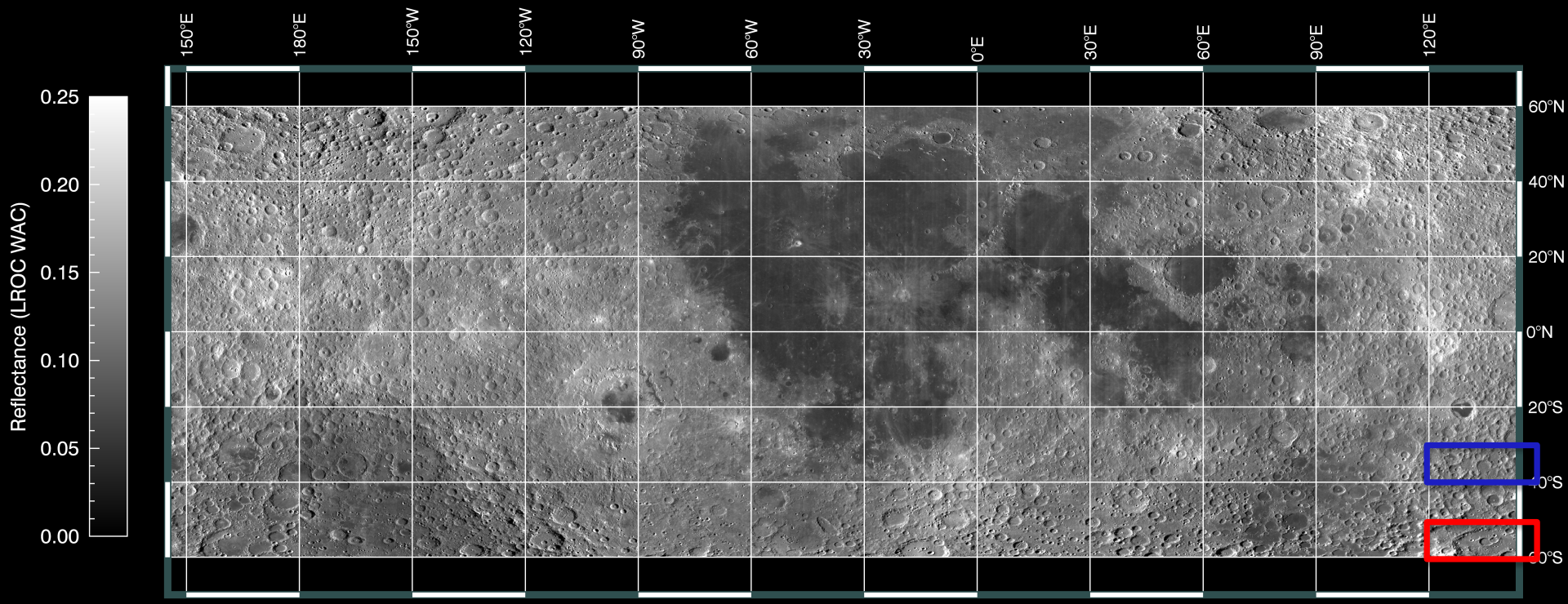

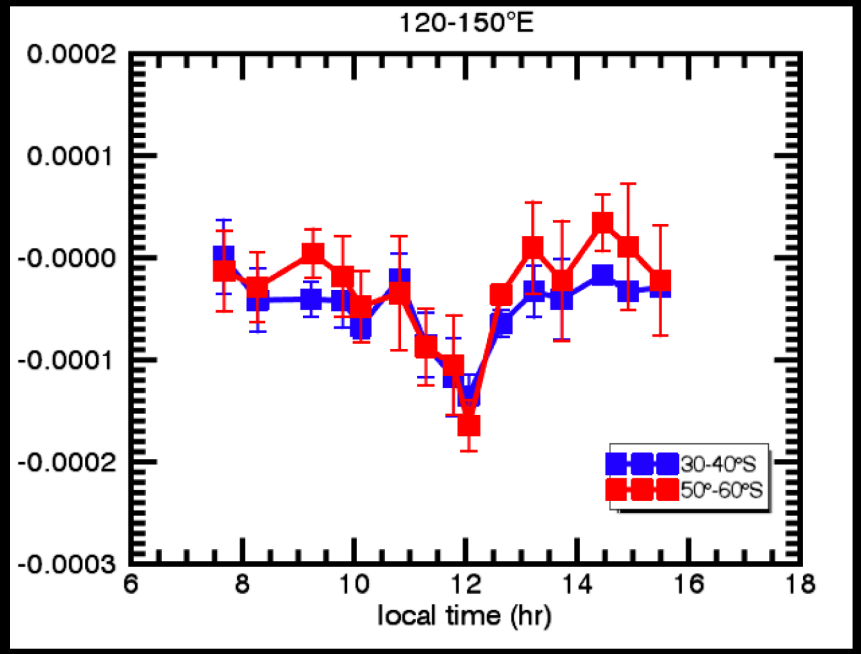

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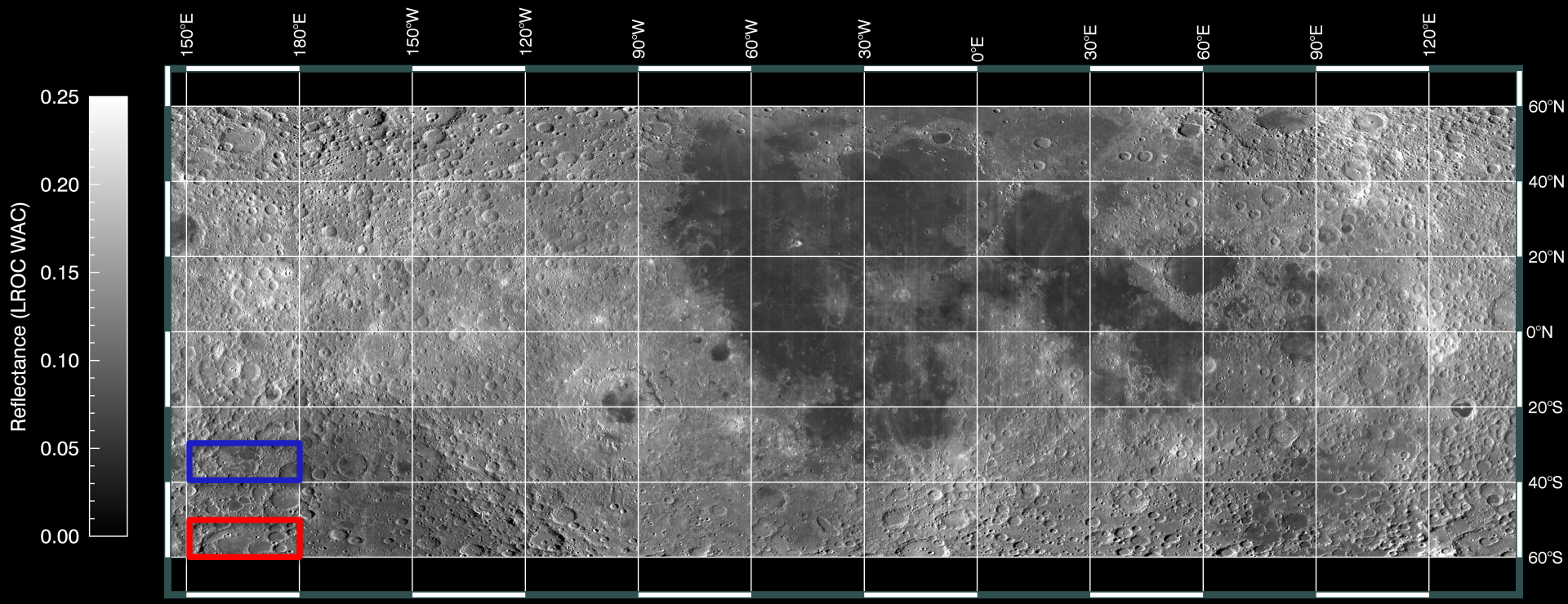

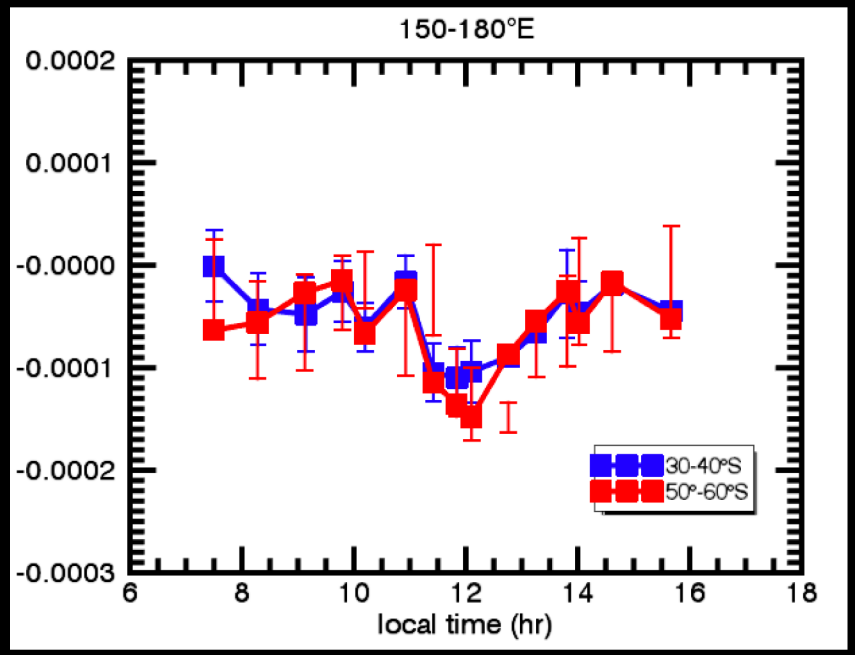

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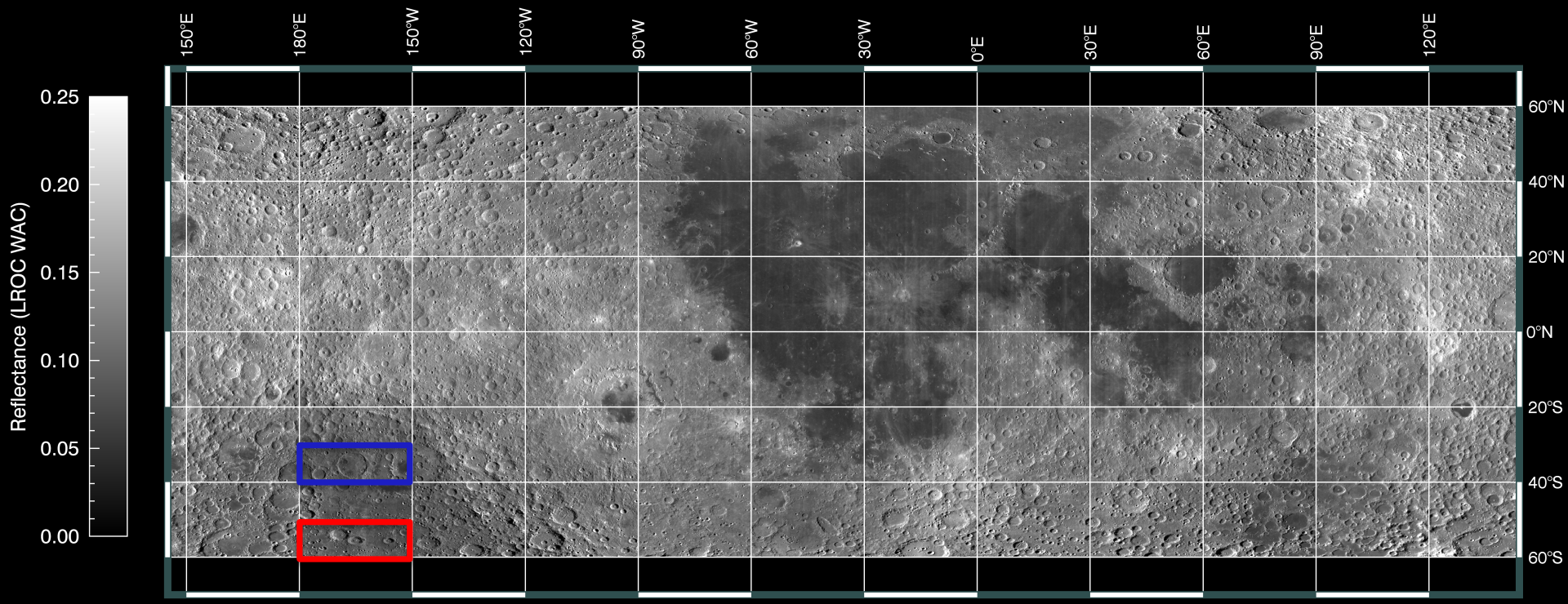

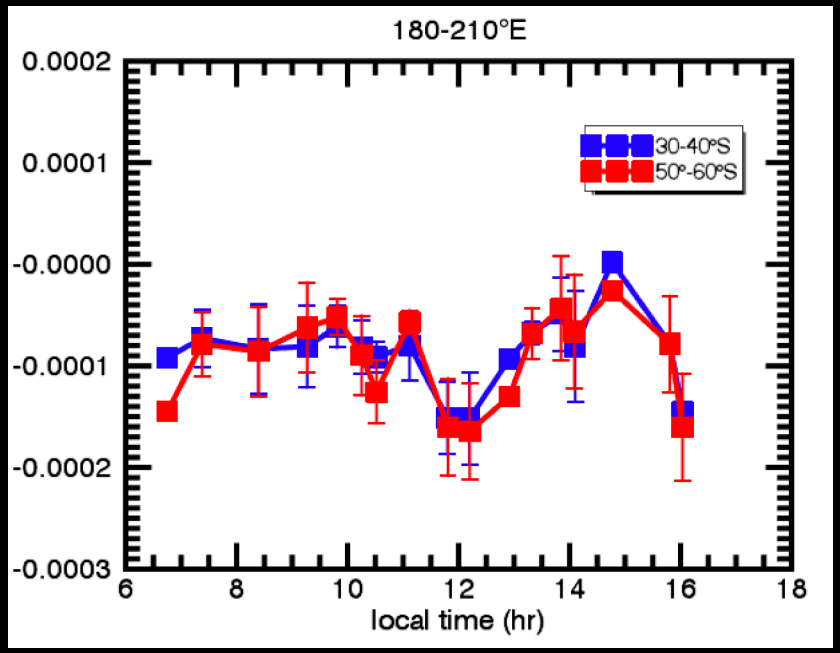

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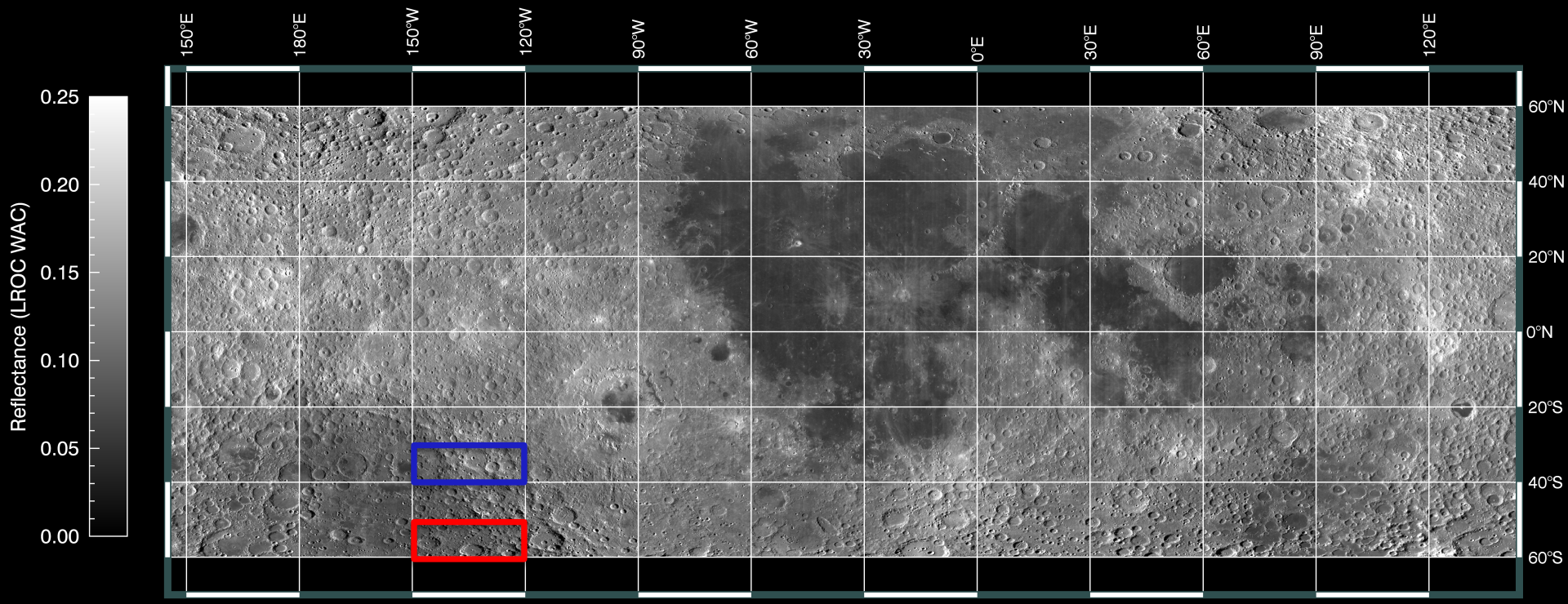

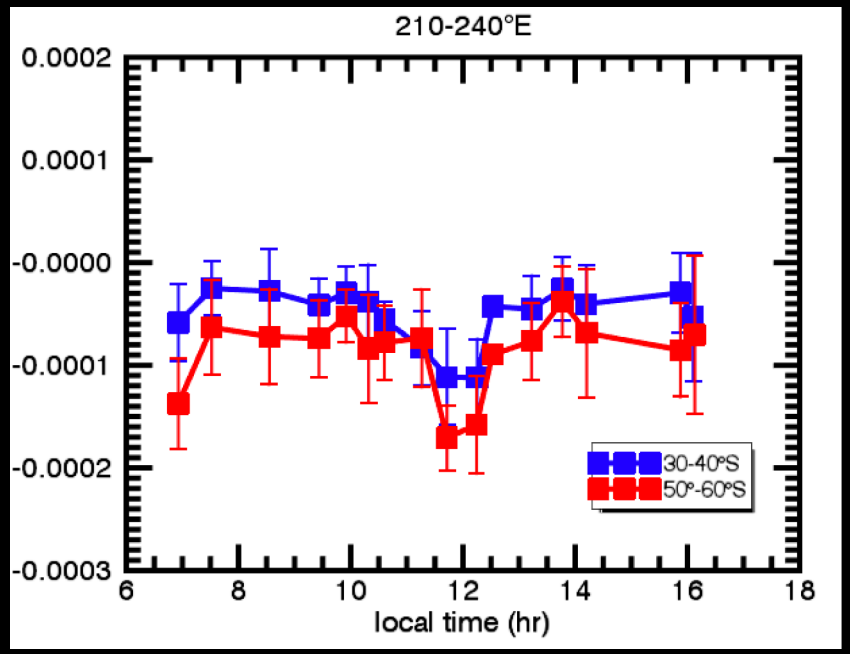

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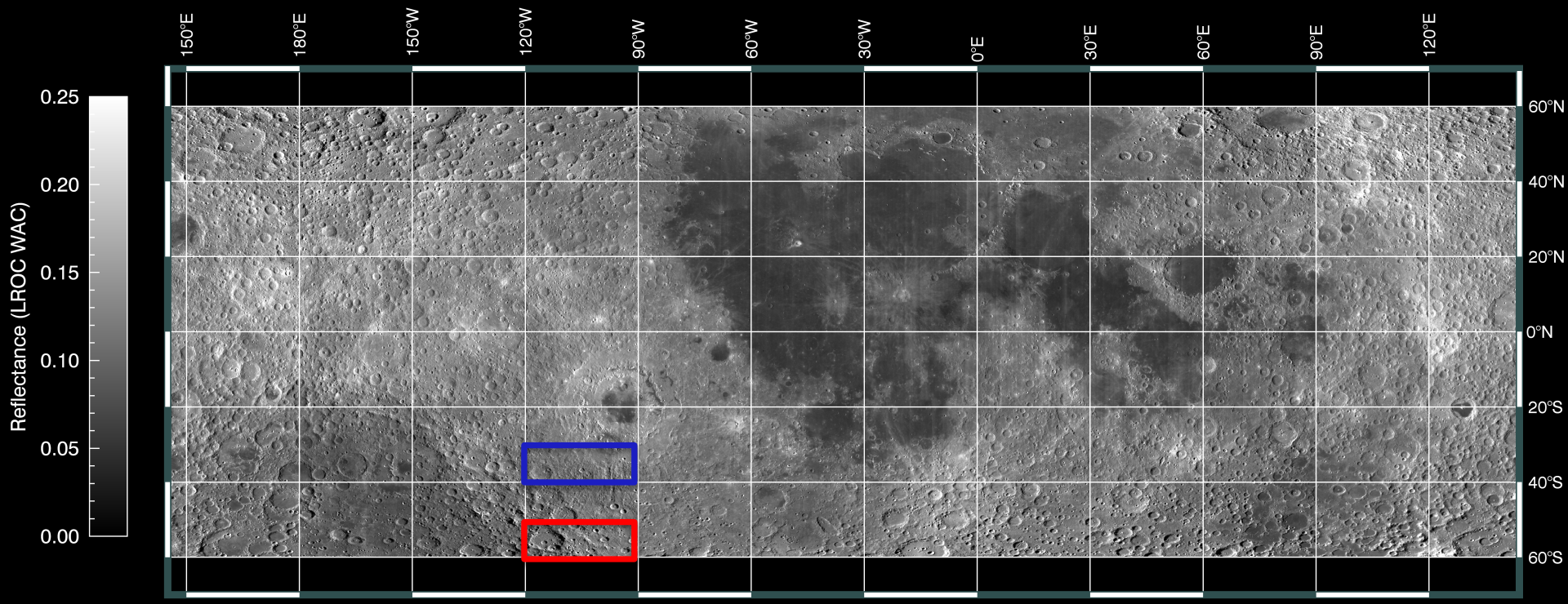

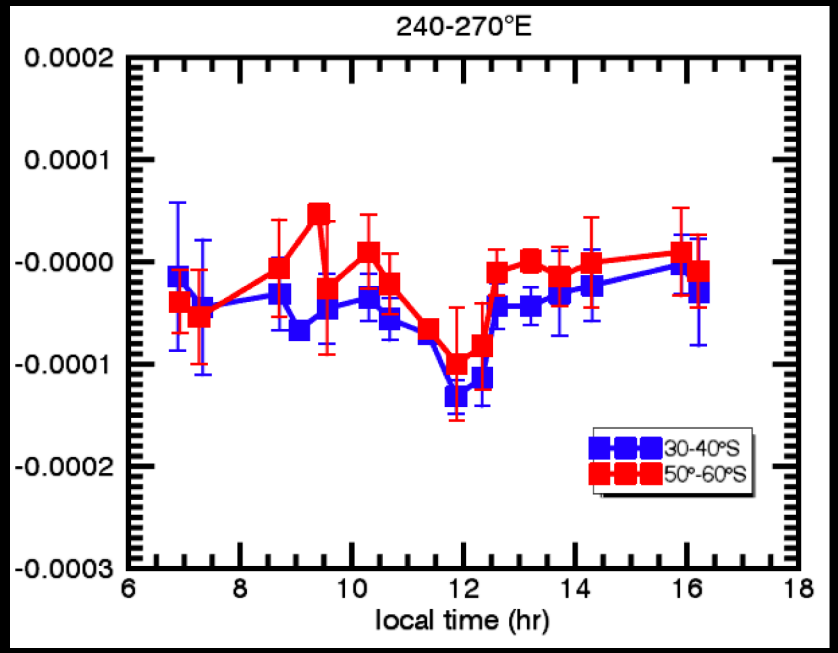

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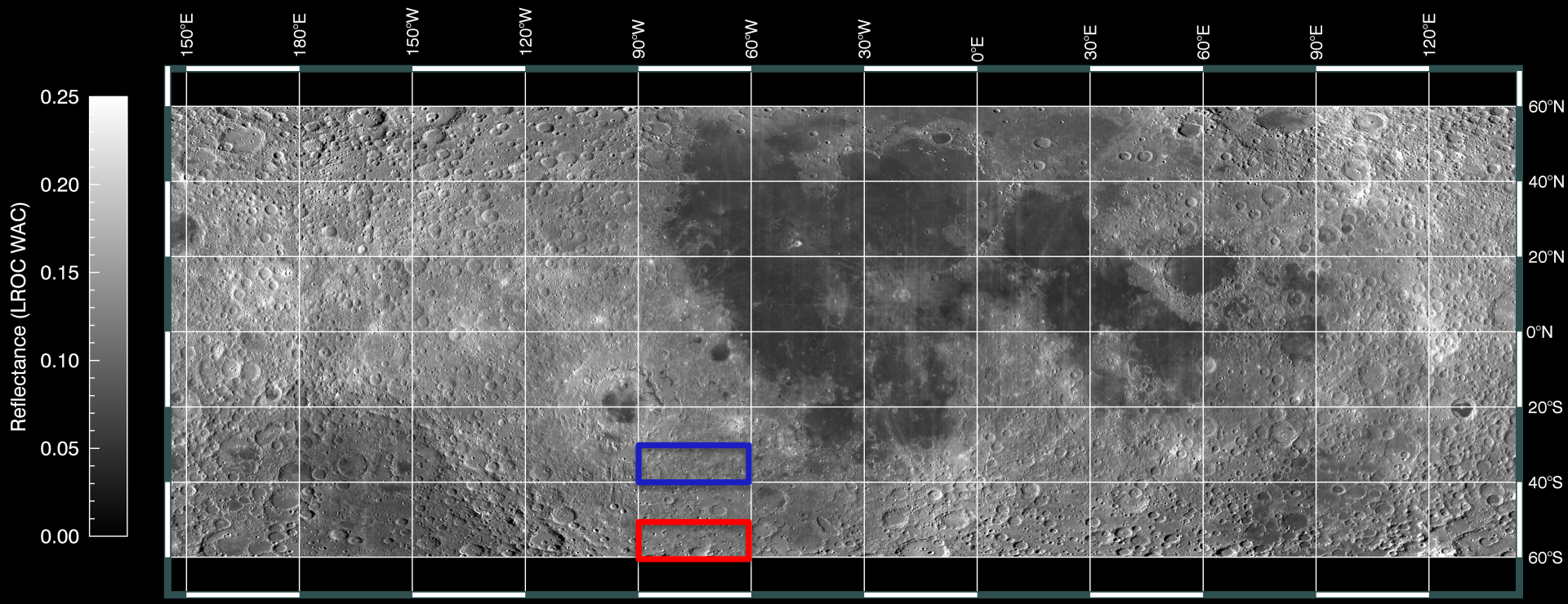

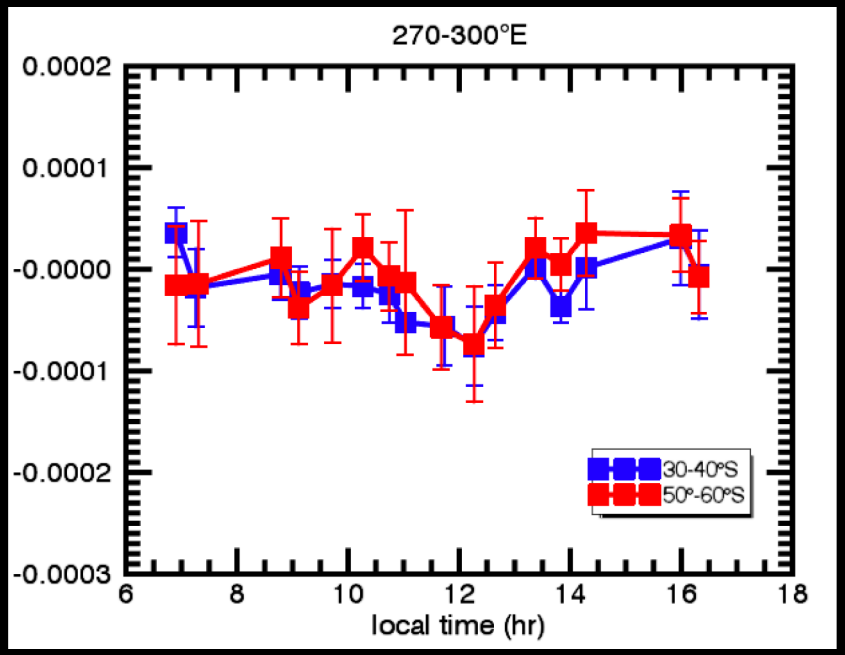

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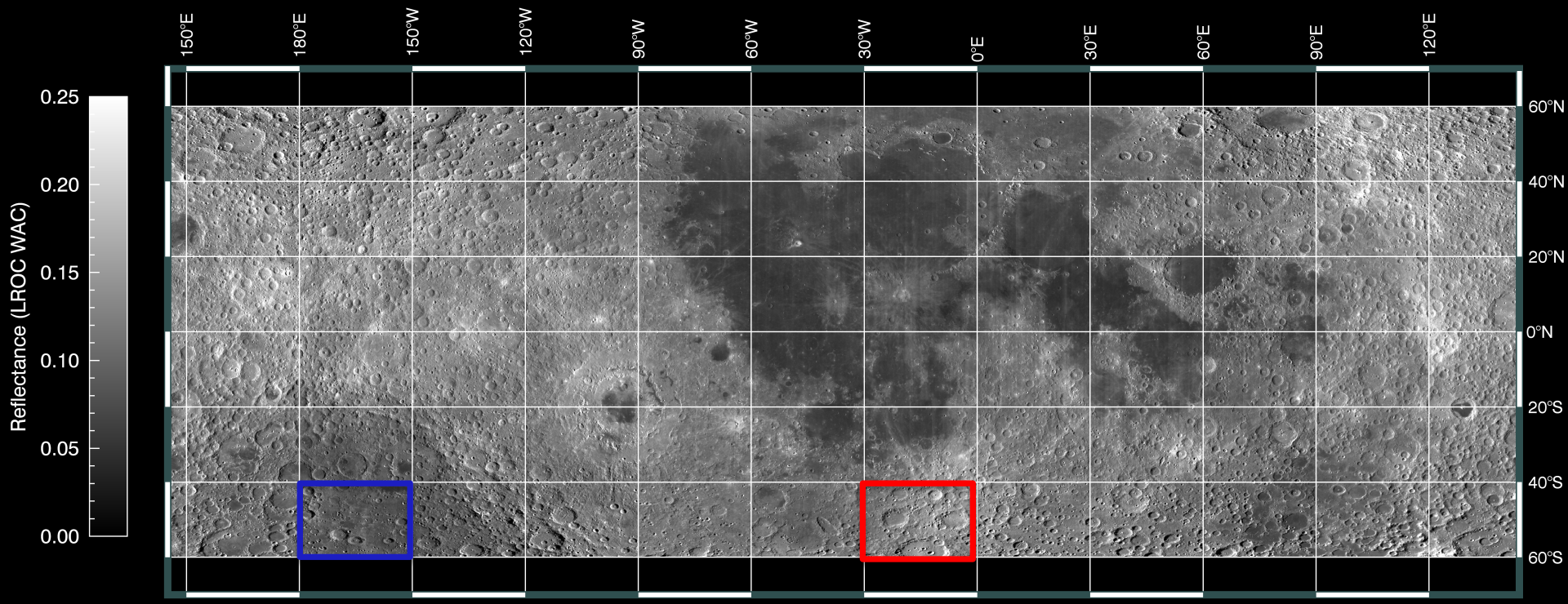
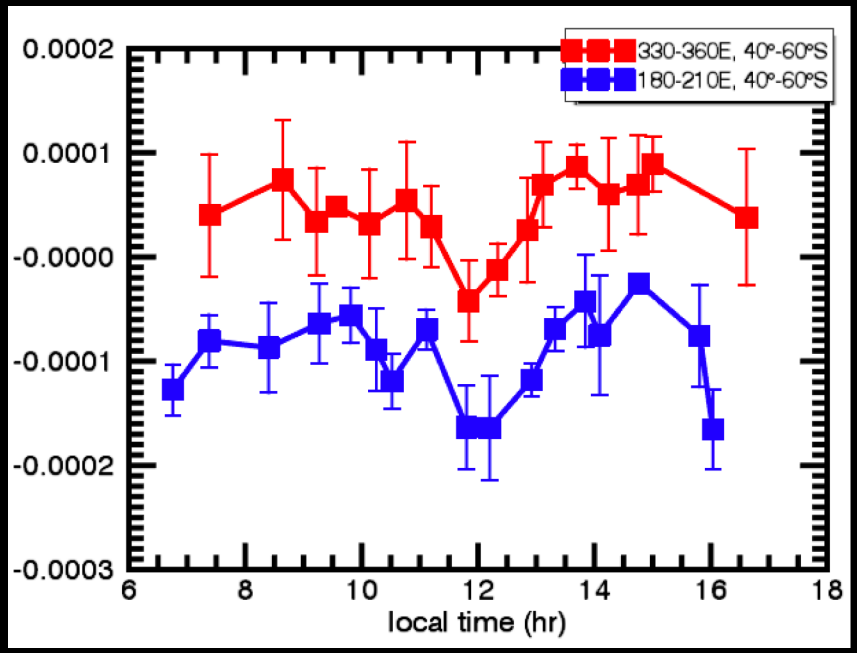


Lower overall hydration amounts in SPA (fewer sites) … due to higher Fe content?

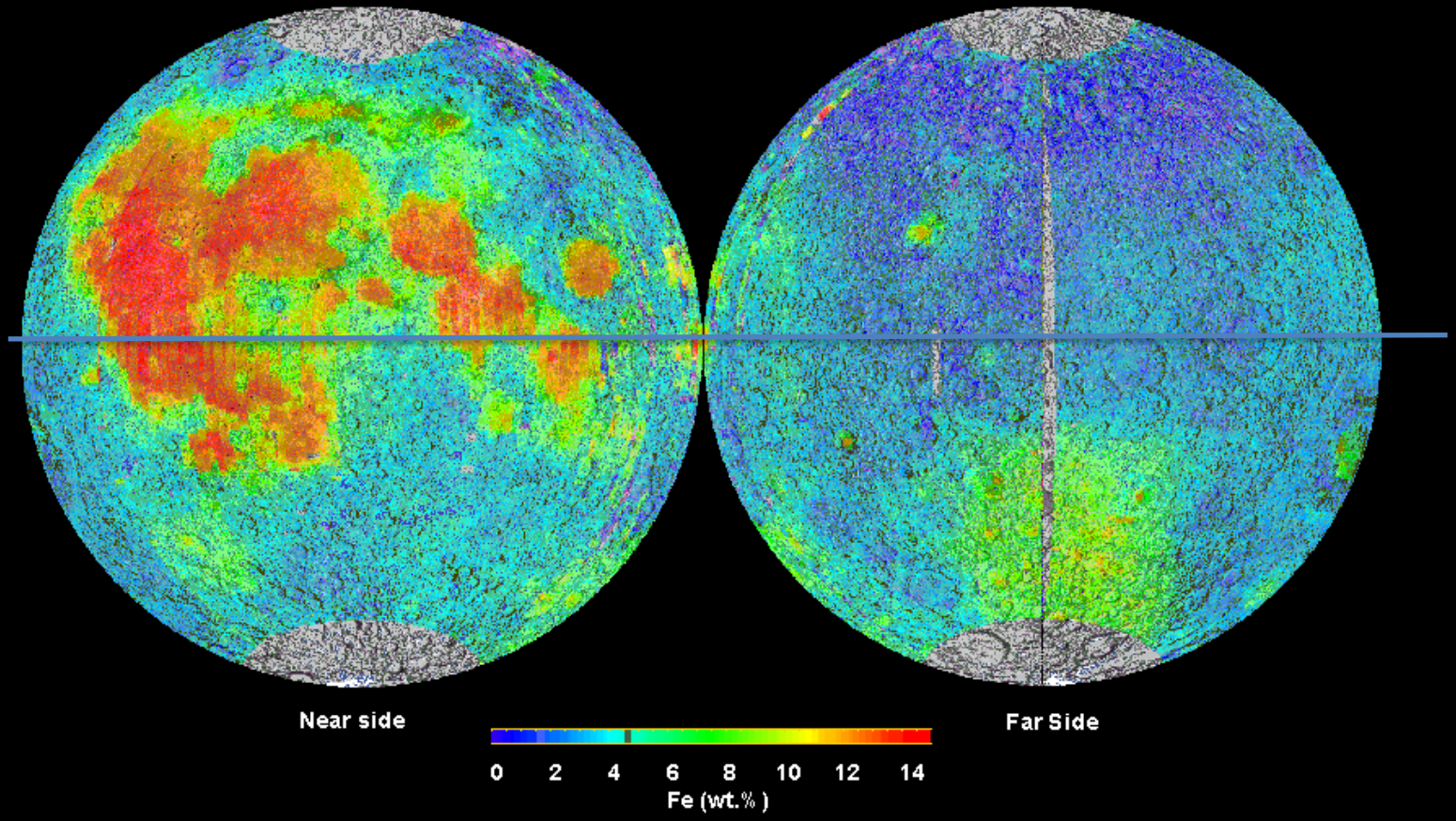


Some of the responsibility for the higher slopes could be the crater rays

preliminary results

Clementine Iron Map of the Moon

Equal Area Projection



Summary of LAMP results & Next Steps

- New phase correction has been applied
- Diurnal variation observed in highlands terrains
  - Consistent with <1% monolayer of hydration
  - Consistent with cryosorption and desorption of H_2O, apparent activation energies of up to Ue~1.3eV
- Variations be due to composition
  - More iron … less water?
  - Next step: compare H_2O abundances vs. Fe abundance

(not to scale)

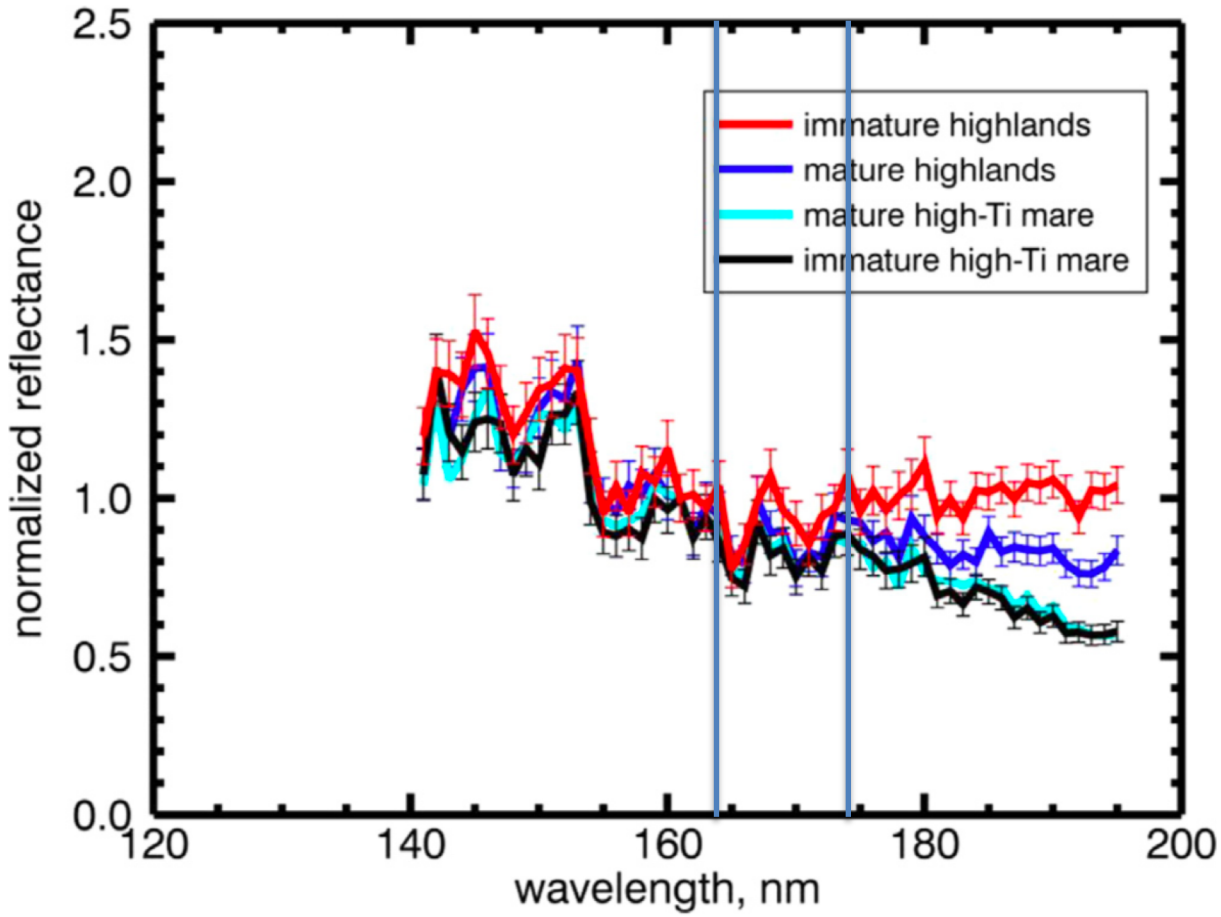
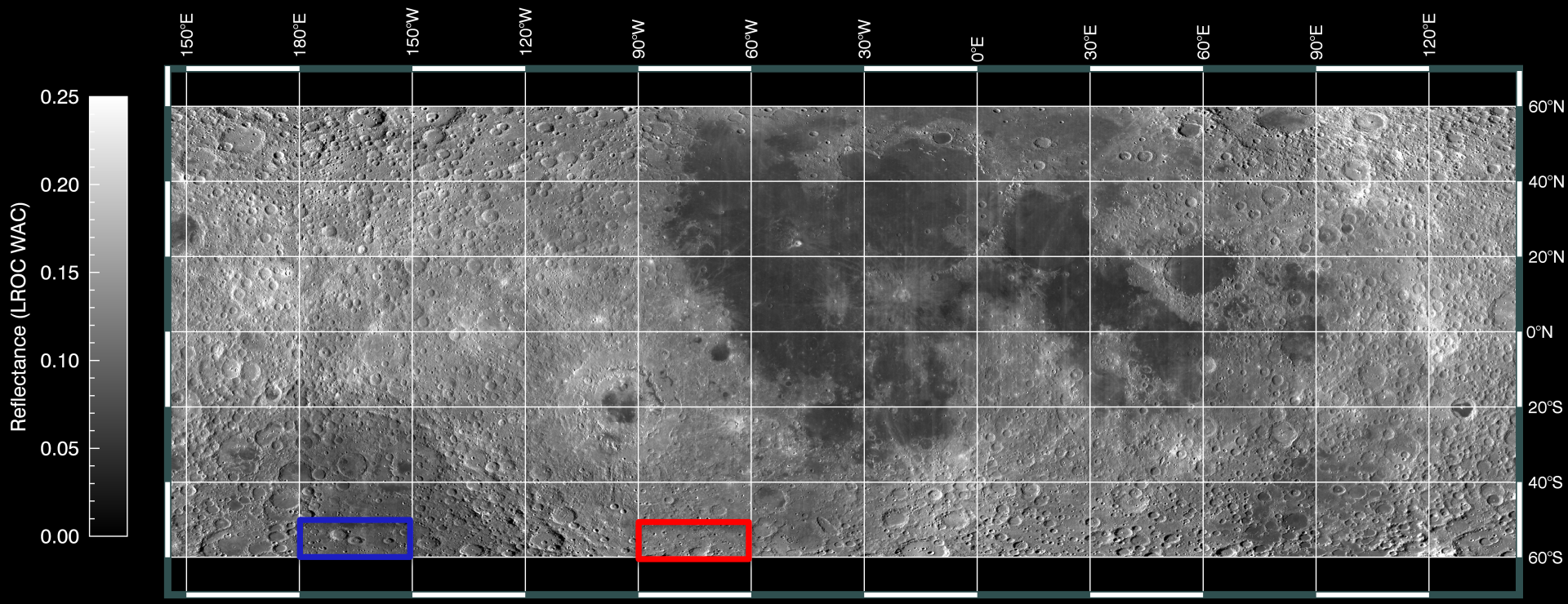
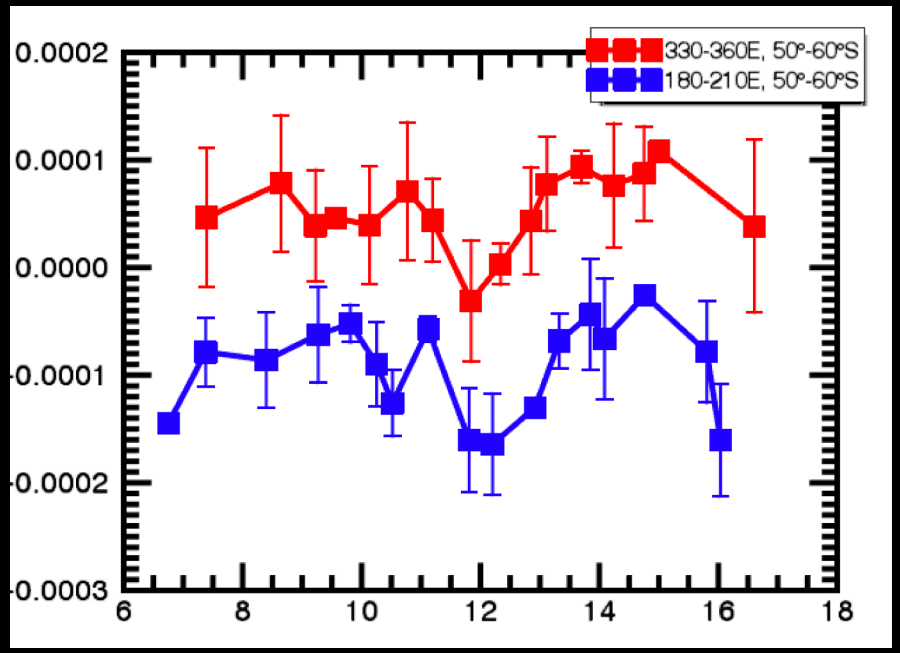


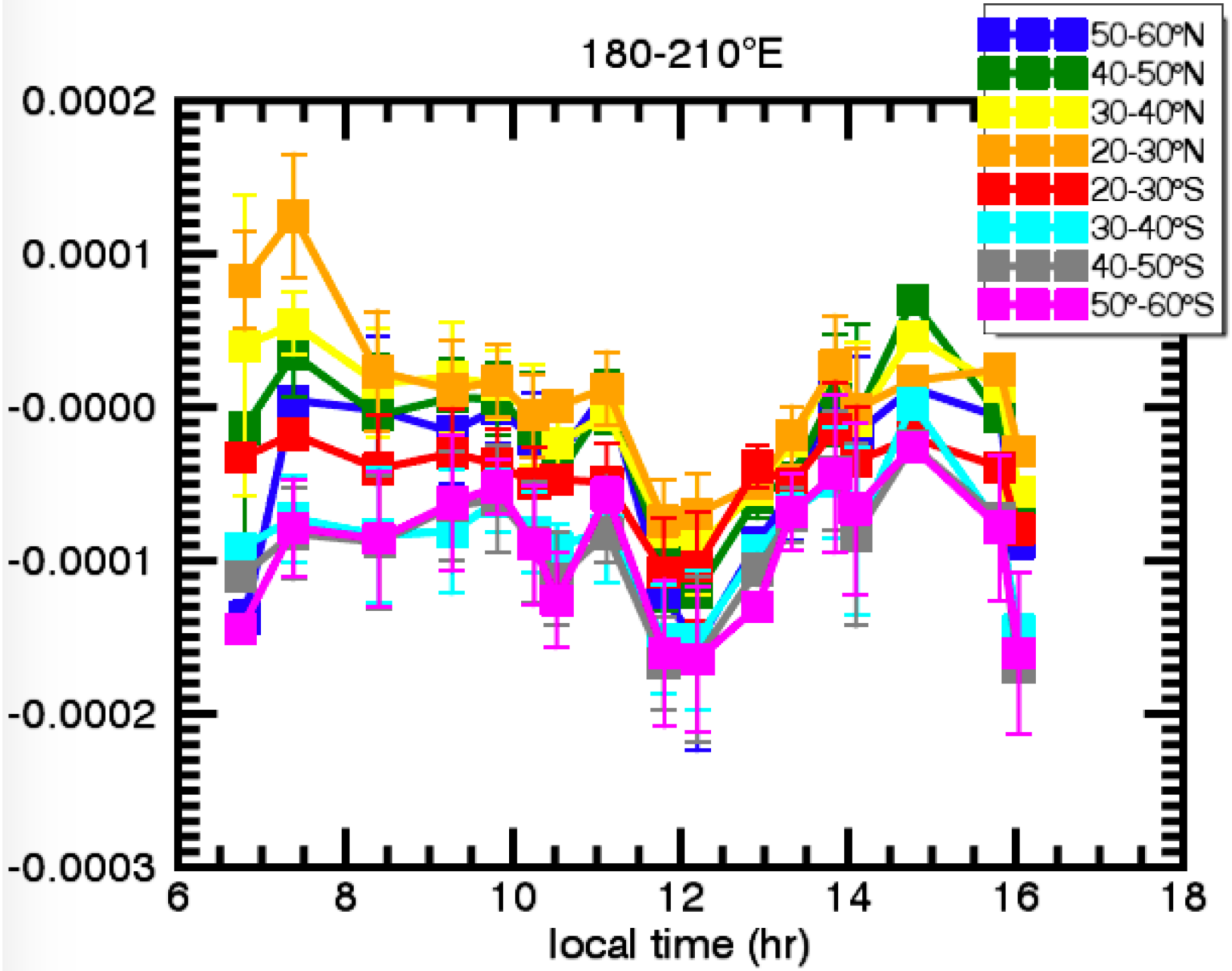
Fig. 1. LAMP spectra of representative lunar terrains: a mature highlands region (13°N, 145°E), an immature highlands region (Jackson crater, 19°N, 193°E), a mature high-Ti (11.17°N, 314.44°E) and an immature high-Ti (9.88°N, 311.66°E) region. Mare regions are bluer than highlands regions; in the highlands, more weathered regions are bluer than less-weathered regions at wavelengths longer than ~160 nm, however no difference is found between the mature and immature high-Ti mare regions.

Hendrix et al., 2016

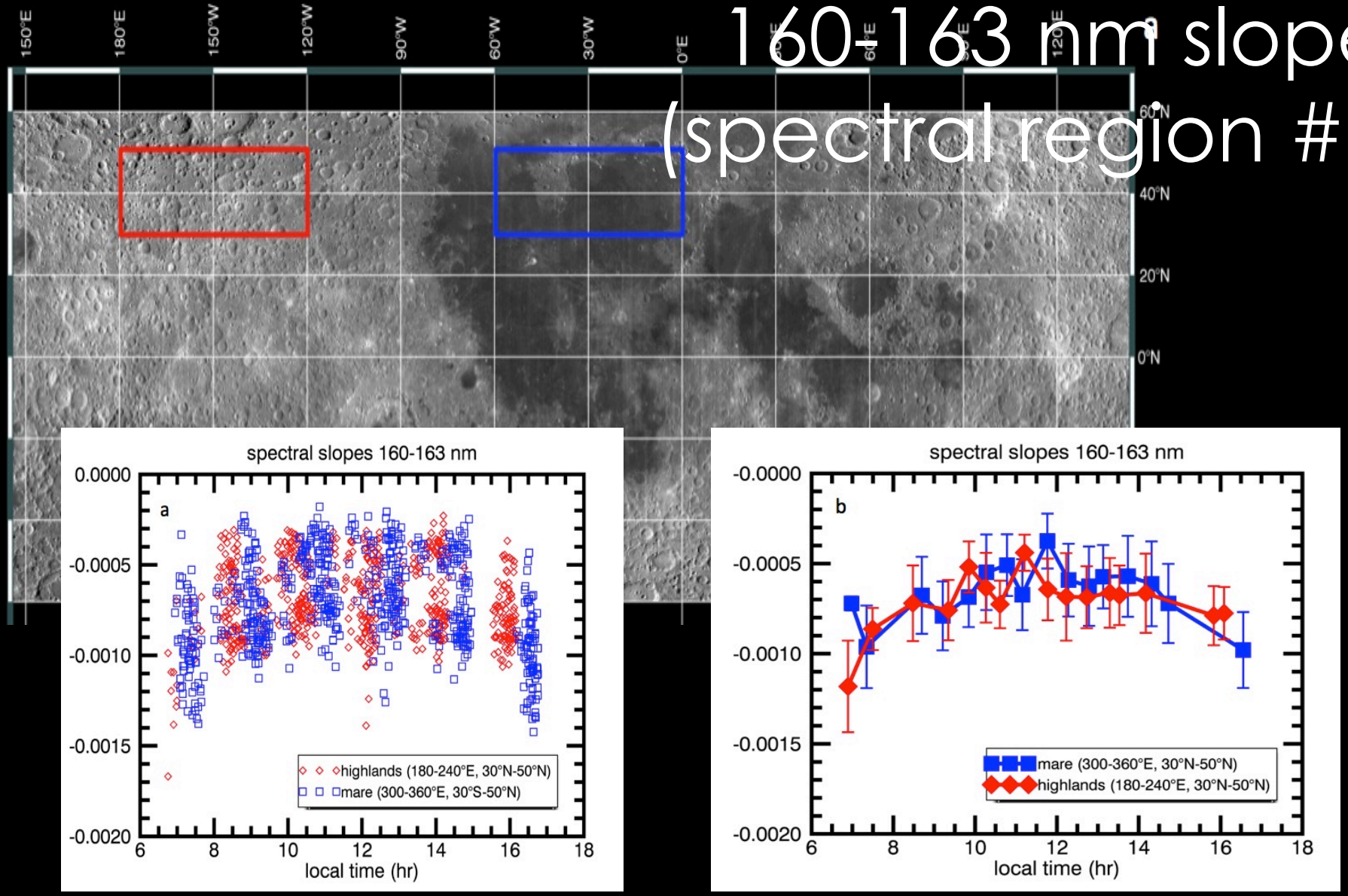




preliminary results

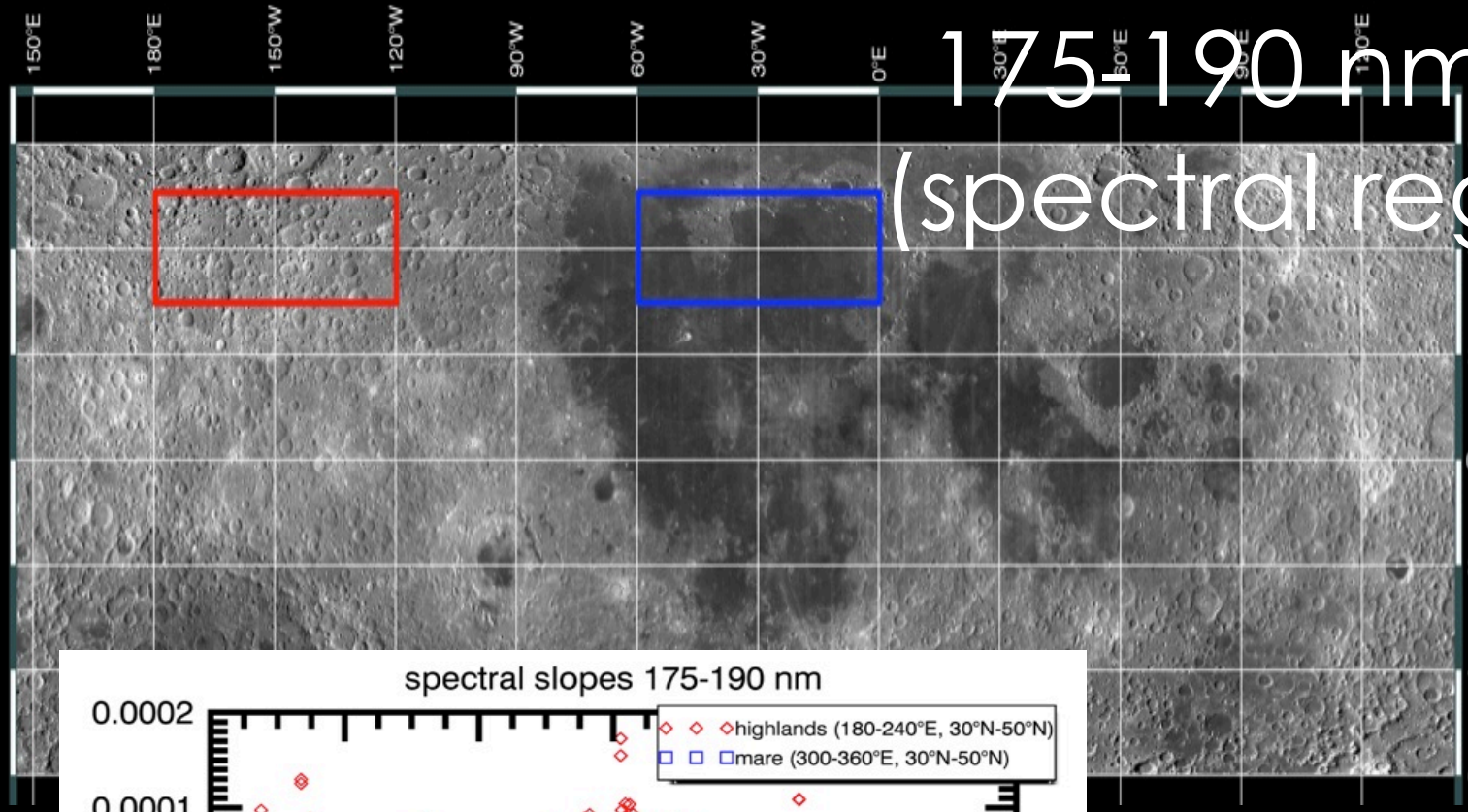

180-210°E
50-60°N
40-50°N
30-40°N
20-30°N
20-30°S
30-40°S
40-50°S
50°-60°S
0.0002
0.0001
-0.0000
-0.0001
-0.0002
-0.0003
6
8
10
12
14
16
18
local time (hr)

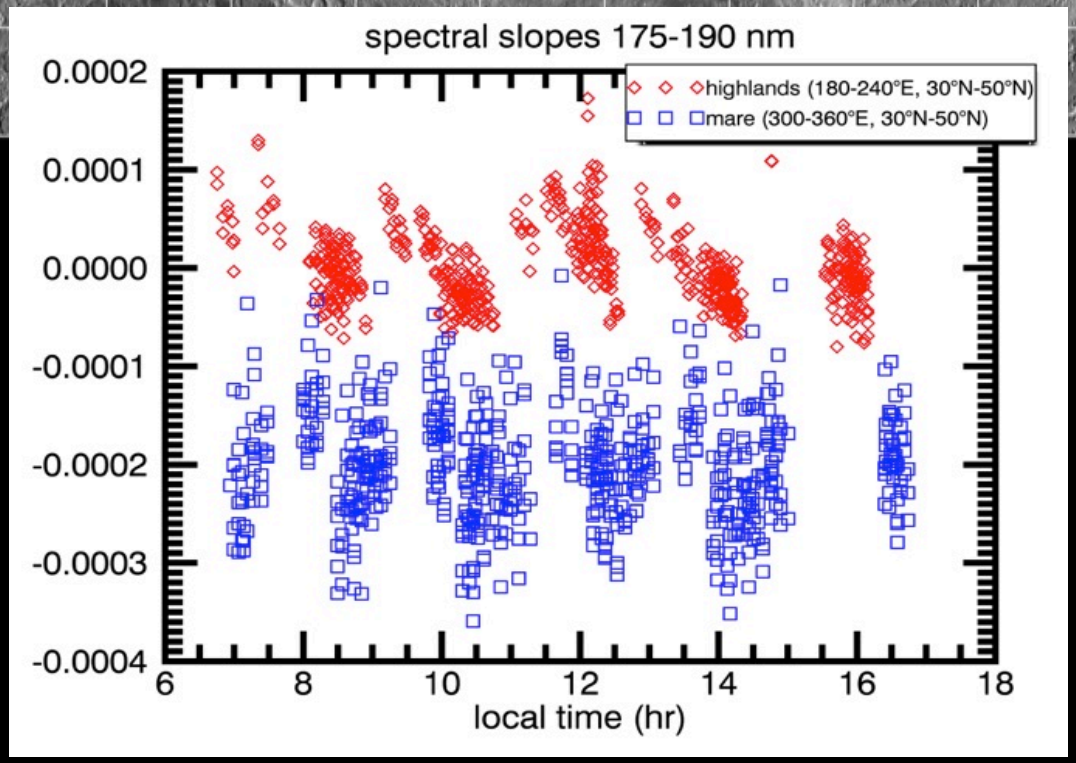
160-163 nm slopes (spectral region #1)



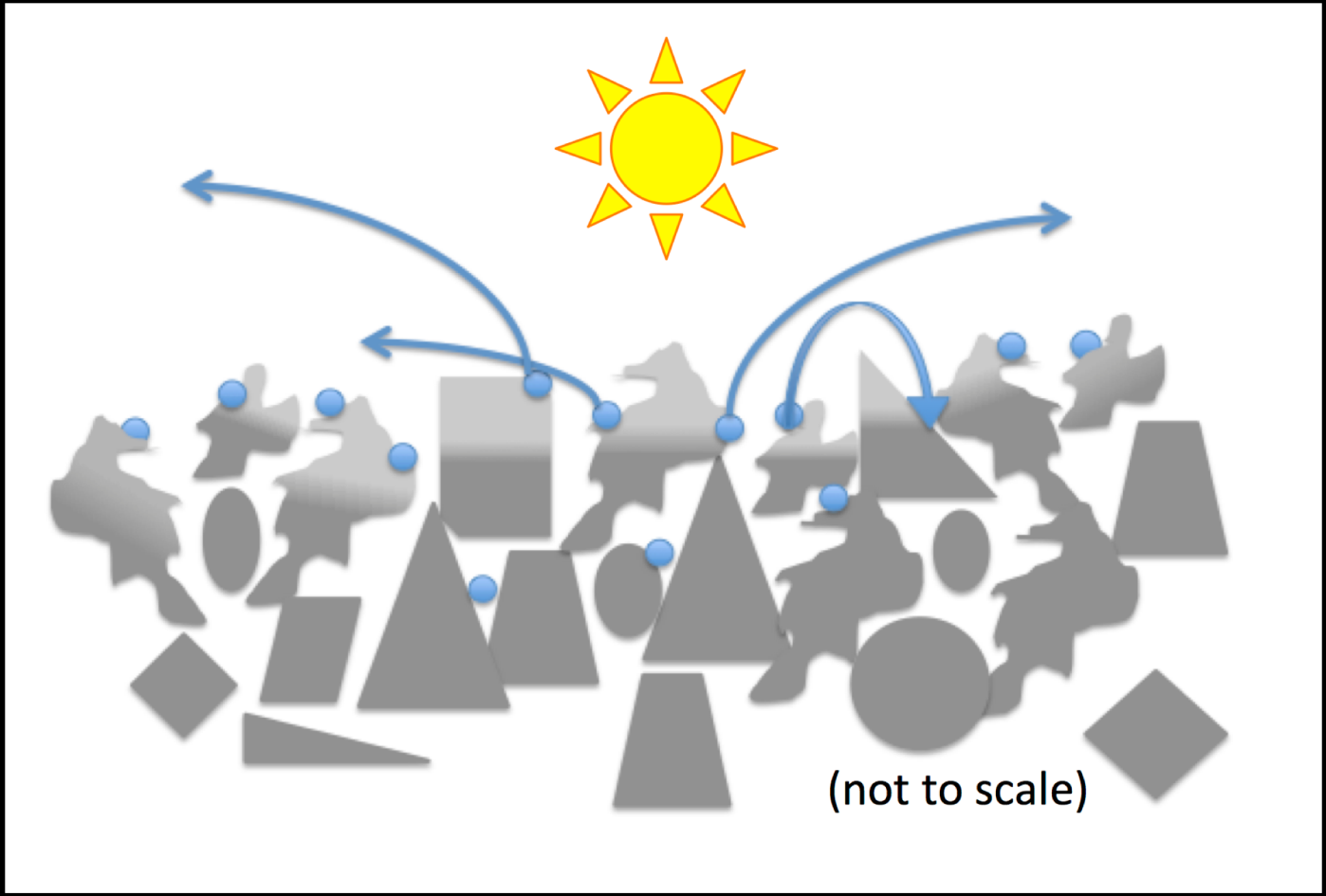
No significant diurnal variation in this spectral region

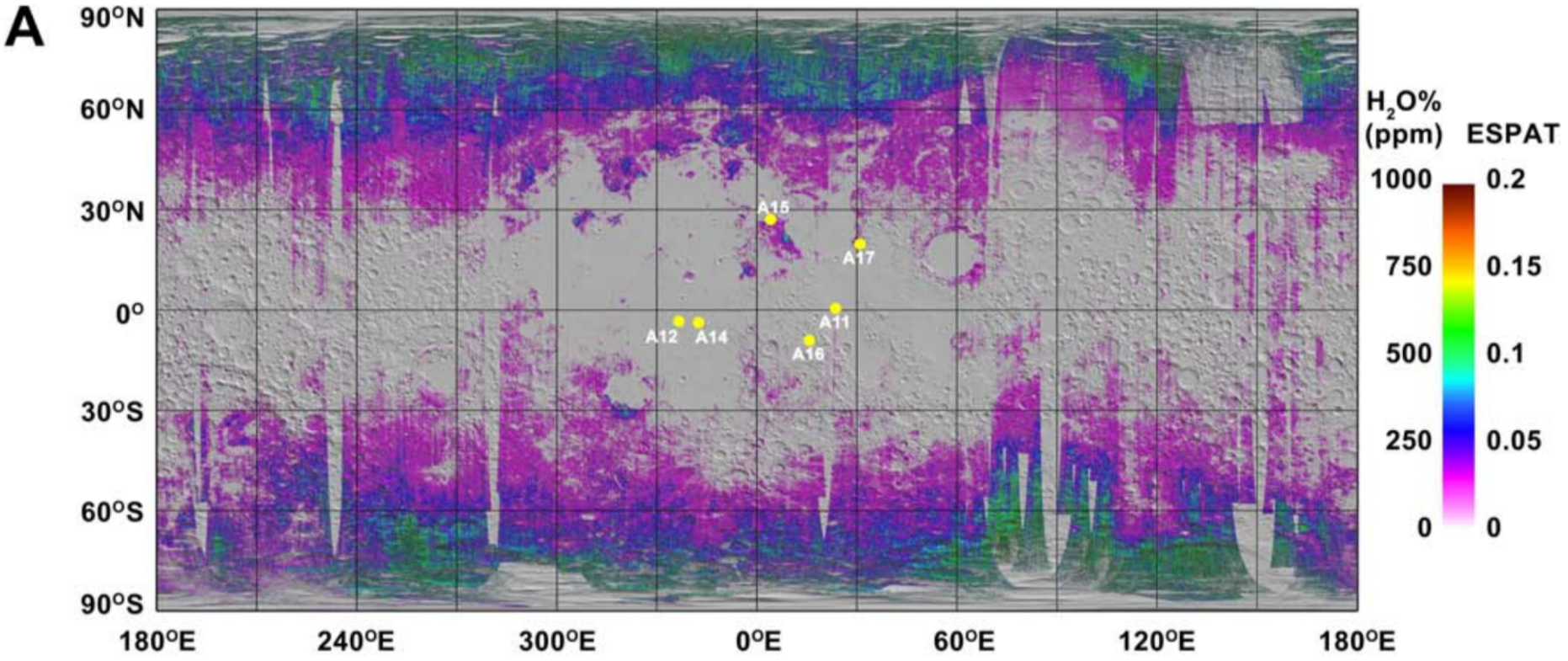
175-190 nm slopes (spectral region #3



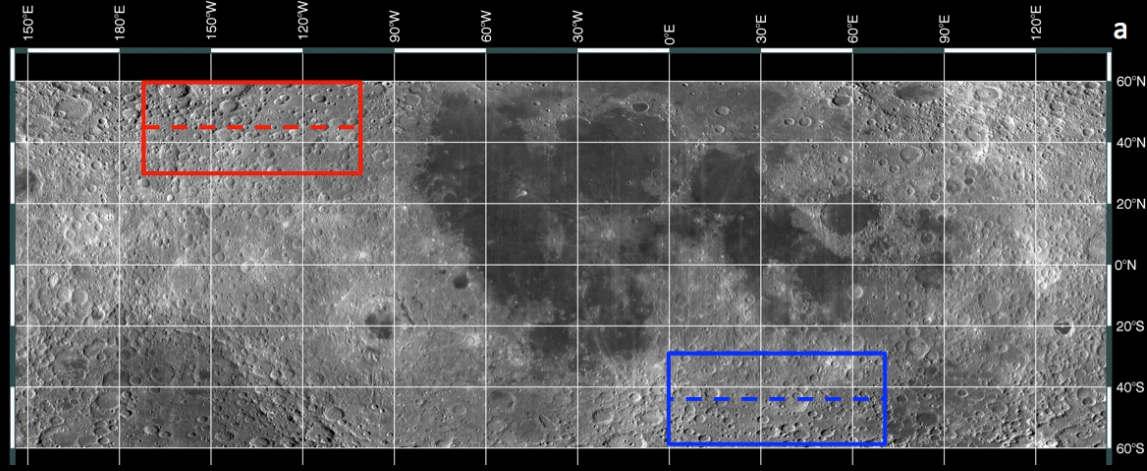


No diurnal variation in slope in either terrain region


(not to scale)

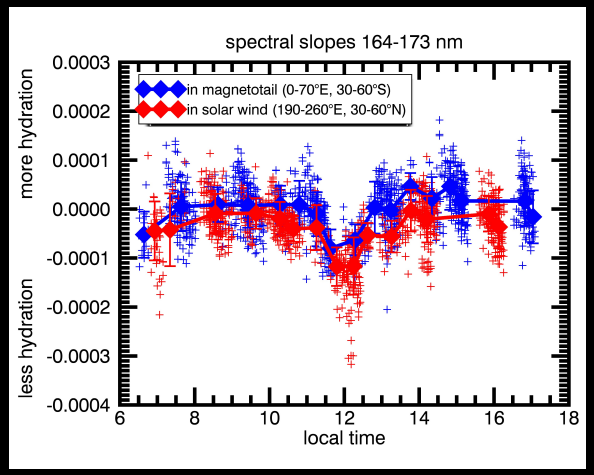

A
90°N
60°N
30°N
0°
30°S
60°S
90°S
180°E
240°E
300°E
0°E
60°E
120°E
180°E
A15
A17
A11
A12
A14
A16
H2O%
(ppm)
ESPAT
1000
750
500
250
0
0.2
0.15
0.1
0.05
0

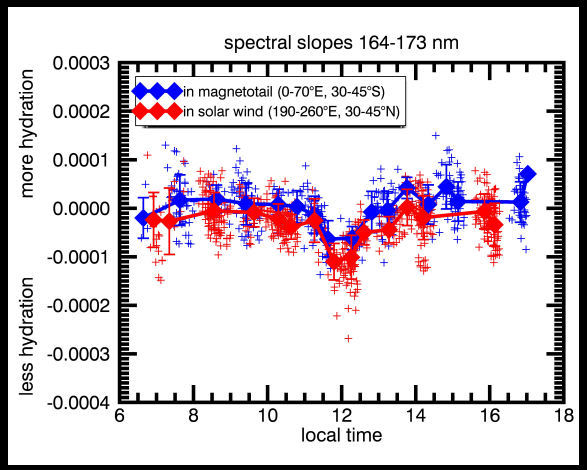
Changes when in magnetotail?

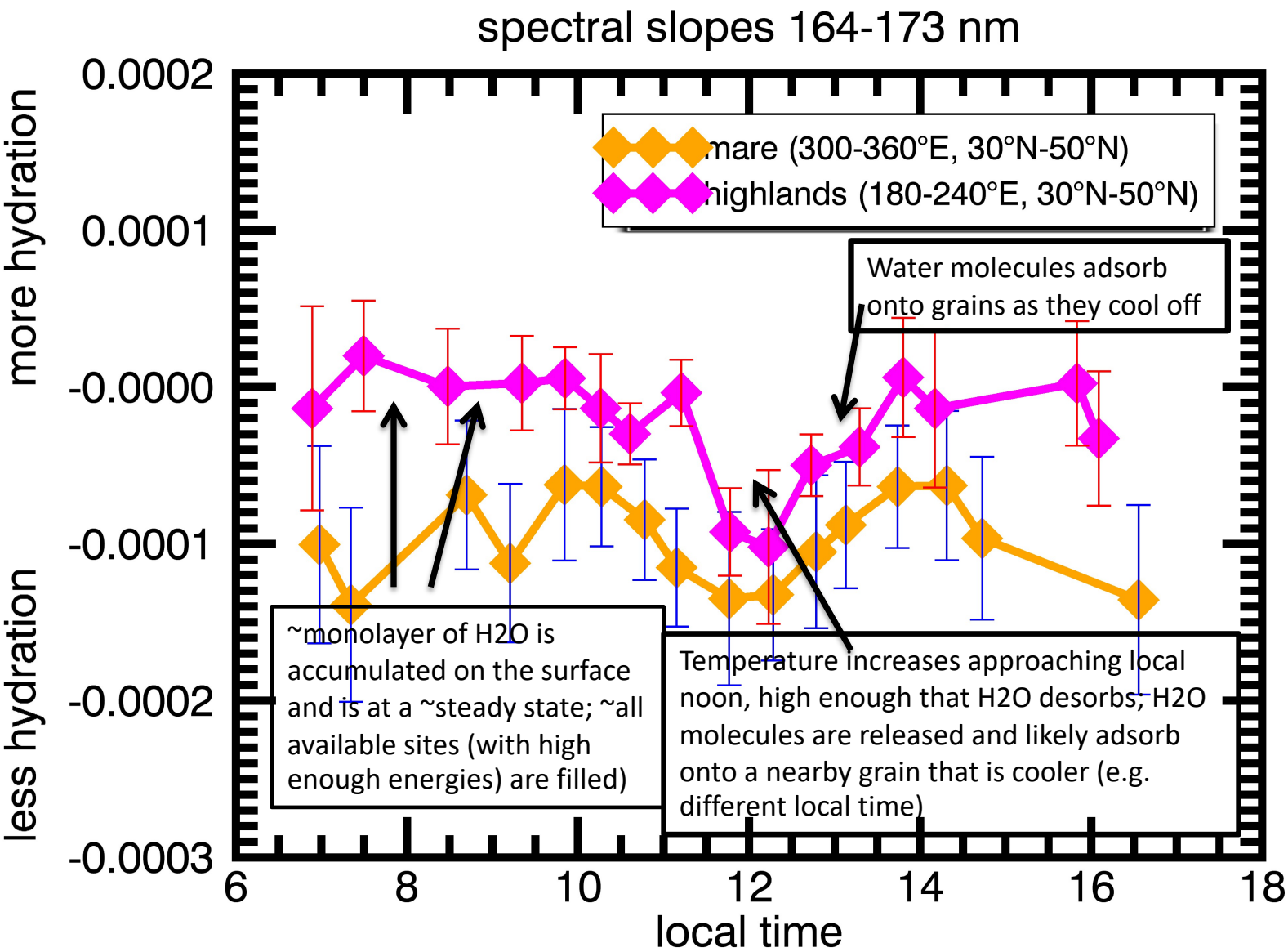


Here we compare a region that is sometimes in the magnetotail to a similar one that is always in the solar wind.

Differences are minimal.

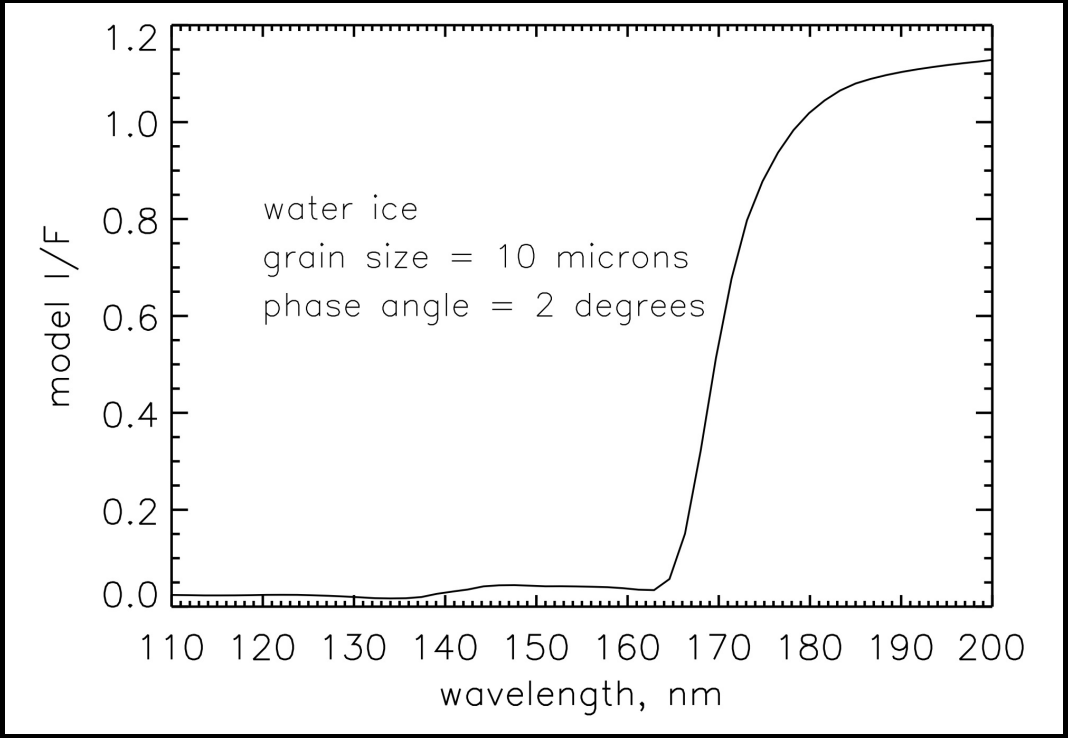


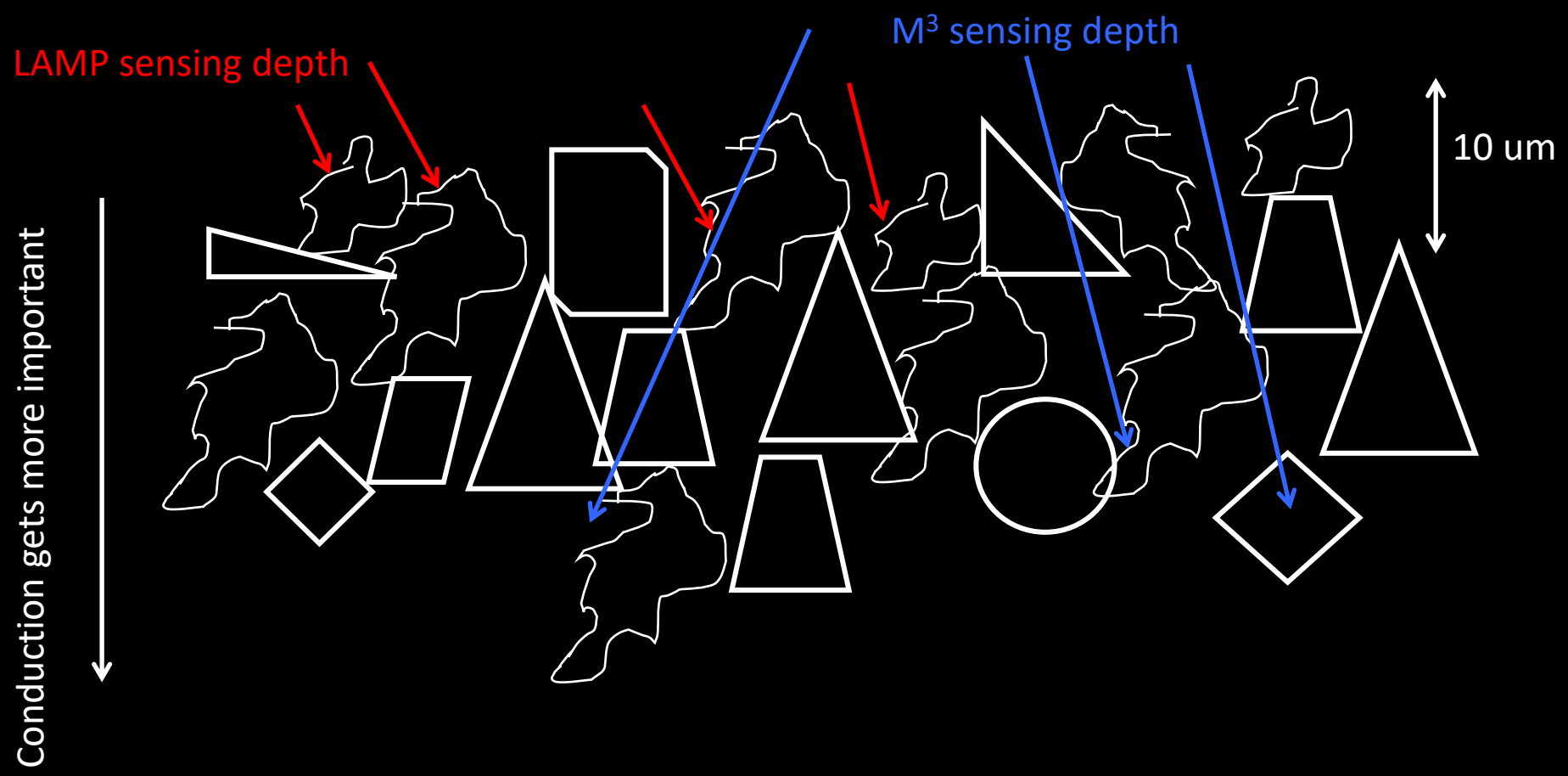



spectral slopes 164-173 nm
more hydration
less hydration
0.0002
0.0001
-0.0000
-0.0001
-0.0002
-0.0003
6
8
10
12
14
16
18
local time
mare (300-360°E, 30°N-50°N)
highlands (180-240°E, 30°N-50°N)
Water molecules adsorb onto grains as they cool off
~monolayer of H2O is accumulated on the surface and is at a ~steady state; ~all available sites (with high enough energies) are filled)
Temperature increases approaching local noon, high enough that H2O desorbs; H2O molecules are released and likely adsorb onto a nearby grain that is cooler (e.g. different local time)

LAMP

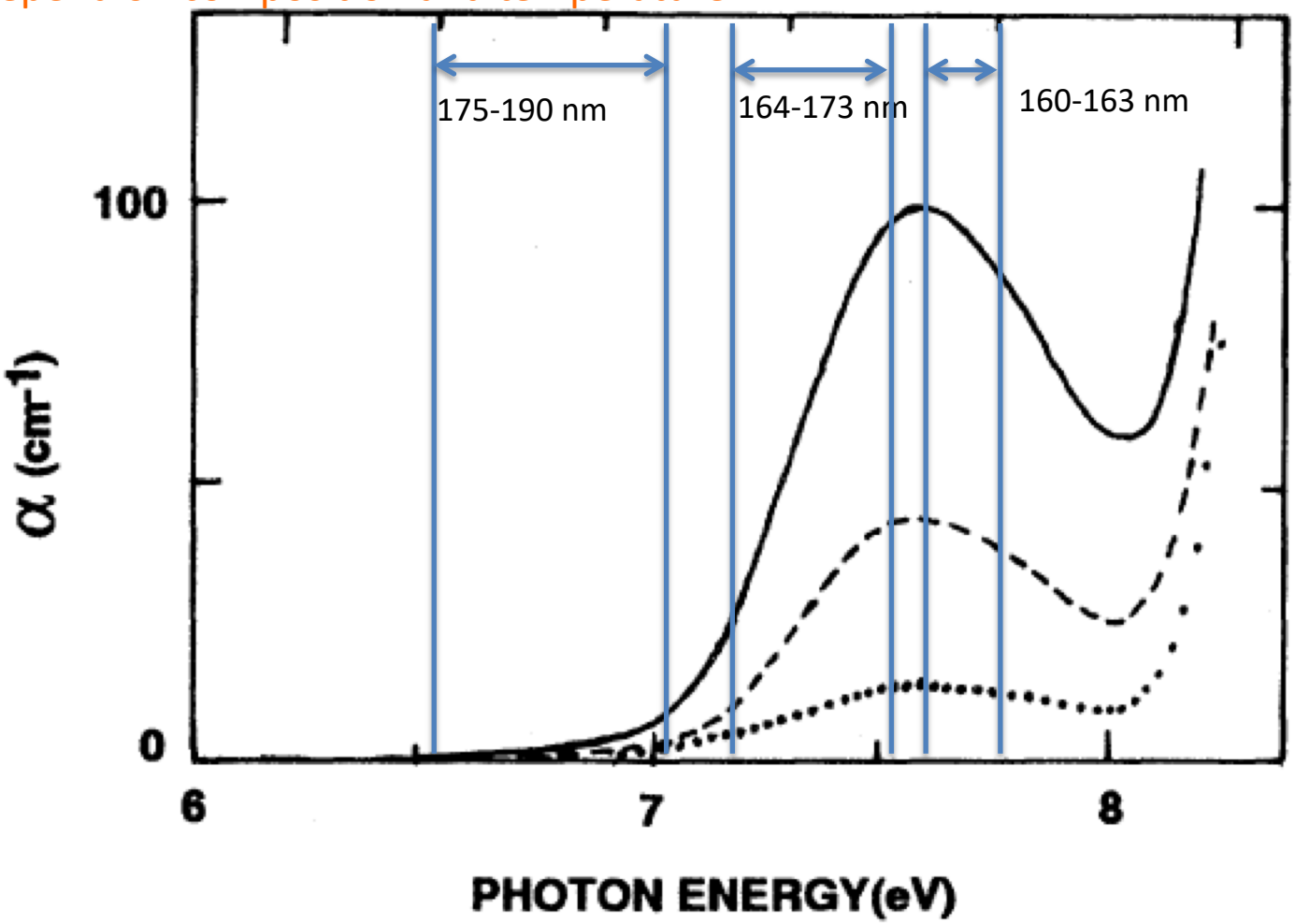
- thermal emission is not an issue
- In looking at LAMP data, we are sensing the top-most grains of the epiregolith
- H_2O has strong absorption edge (is this also expected from OH?)





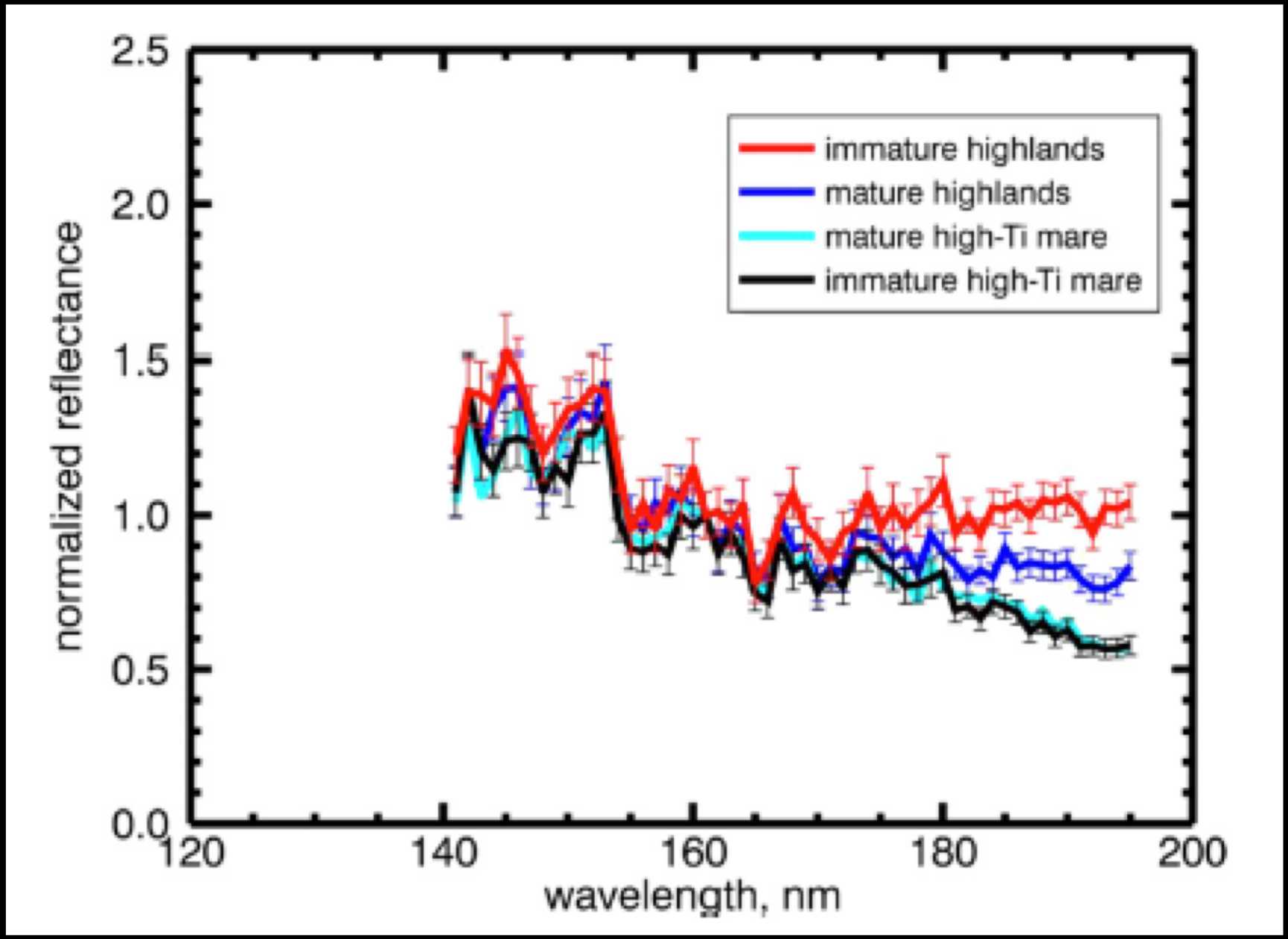
Rough, fluffy grains – not much contact between them, ~10's μm in size

Glassy silicates have strong absorptions around 160 nm (7.6 eV) due to radiation coupling to electrons in the Si-O bonds and with point defects that include –OH sites, Si-Si and “strained” Si-O-Si bonds. The location of the band can depend on composition and temperature.



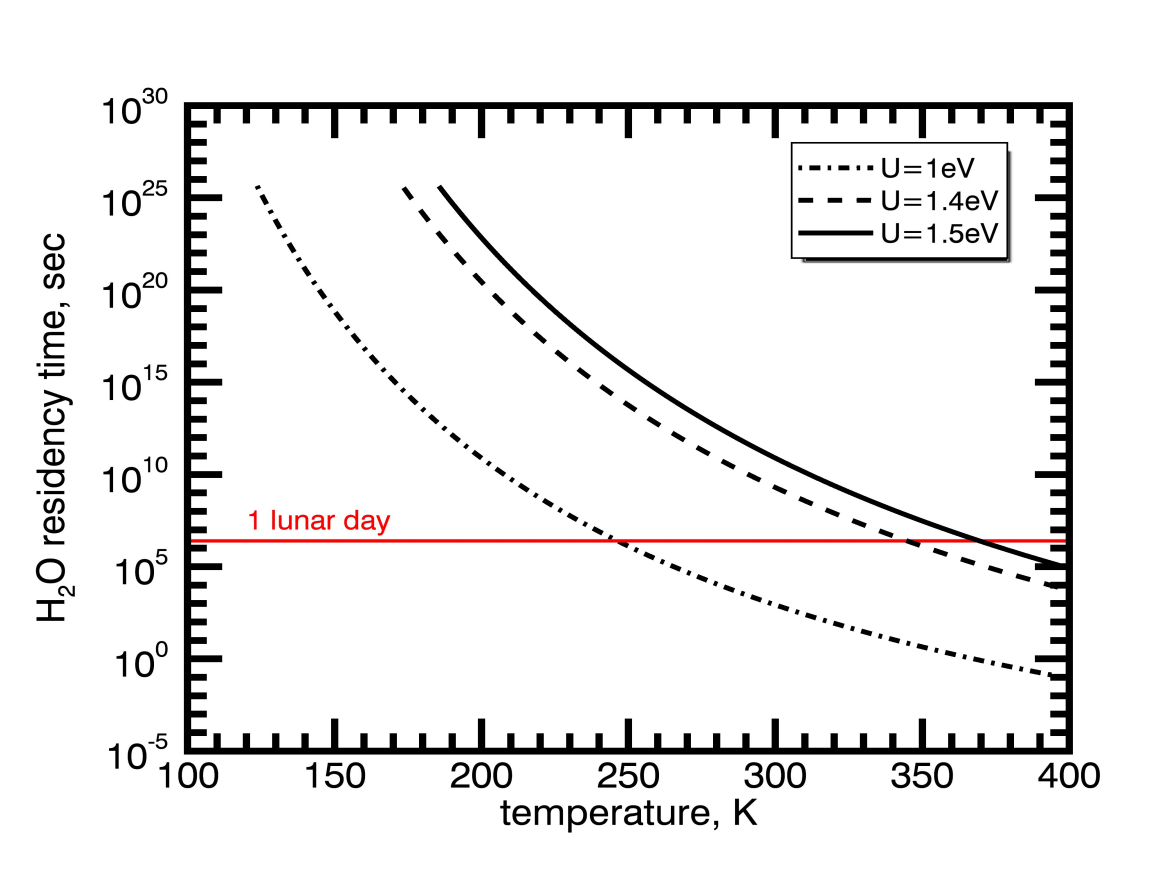
160-163 nm: 7.75-7.6 eV
164-173 nm: 7.56-7.17eV
175-190 mm: 7.08-6.5

Hosono et al. (1991)


immature highlands
mature highlands
mature high-Ti mare
immature high-Ti mare
normalized reflectance
wavelength, nm
0.0
0.5
1.0
1.5
2.0
2.5
120
140
160
180
200

Residency time of adsorbed water

- The residency time (t) of adsorbed water molecules can be related to temperature and activation energy via the Arrenhius equation, $t=t_0\exp(-Ue/T)$.
- The activation energy Ue is related to the molecular trapping energy that is a result of defects and impurities in the grains.



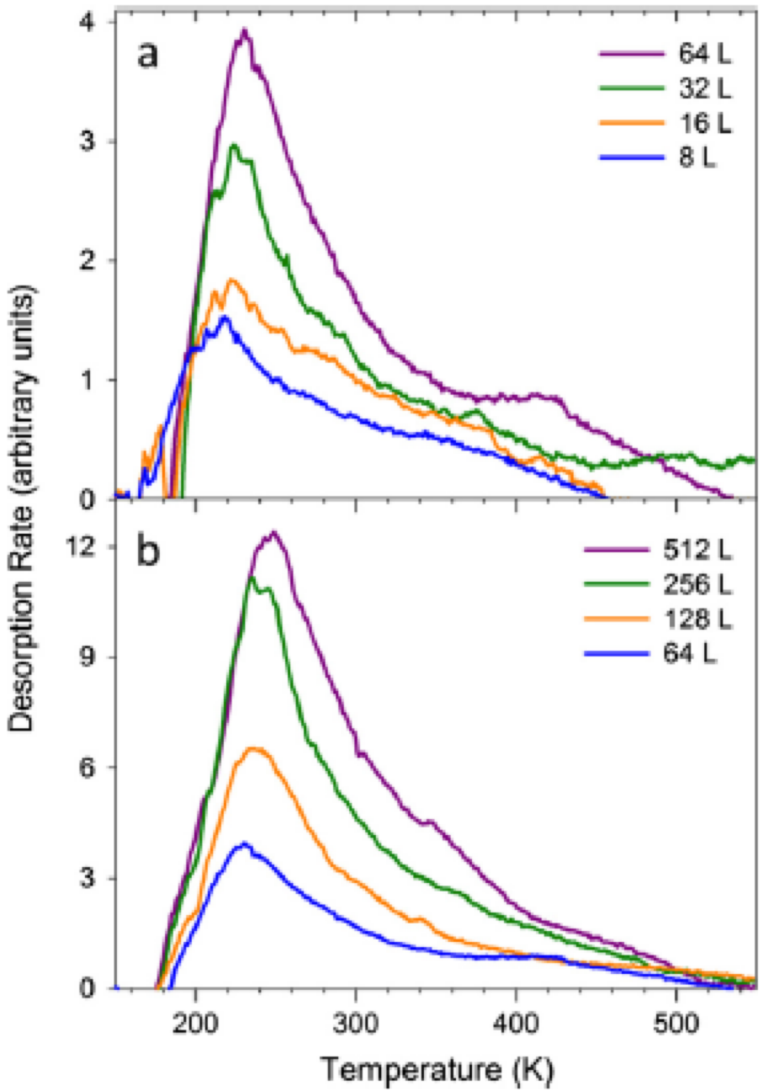


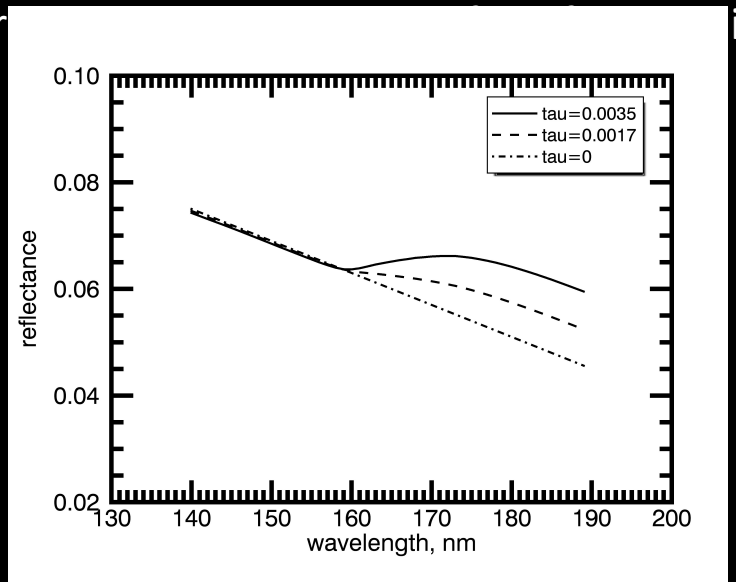
Fig. 2. TPD spectra for water dosed on the sub-90 μm fraction of Apollo lunar soil sample 72501 at 165 K. Data have been corrected for both heater and blank contributions. Panel (a) contains water exposures from 8 to 64 L, while panel (b) extends the exposures from 64 L to 512 L. The tallest peak in each panel corresponds to the top label in the legend, next-tallest peak to next label, etc.

Chemisorbed/adsorbed H2O, thermally desorbed at temps >400K

Related to Ue values as high as 1.3-1.5 eV (may be lower, 0.9eV, per recent unpublished Orlando work)

Poston et al. (2014)

To estimate the abundance of water sensed by LAMP, and given that LAMP senses the top tens of nm to ~100 nm of the surface (i.e. the top grains of the regolith), we model the signature in terms of a layer of H_2O overlying lunar regolith (Hapke, 1993) and determine the range of optical depths of the water layer required to produce the observed spectral slopes. The optical depth can be represented as $t = NzsQ_e$, where N is the volume density of molecules (molecules/cm^3), s is the cross-sectional area of each molecule, Q_e is the extinction efficiency (estimated ~1) and z is the thickness of the water layer. Resultant spectral models are shown in Fig. 6, for three optical depths (tau, t) corresponding to the maximum, intermediate and minimum measured slopes. For the maximum optical depth (□□~ 0.0035), the ar is significantly less than a monolayer.



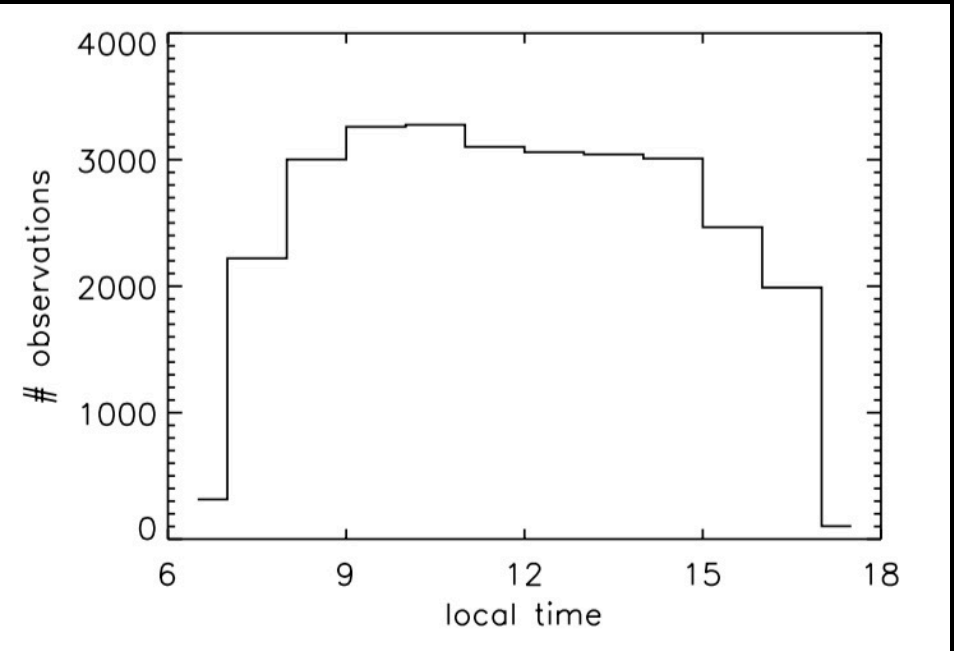
LAMP does not sense very deeply into the regolith

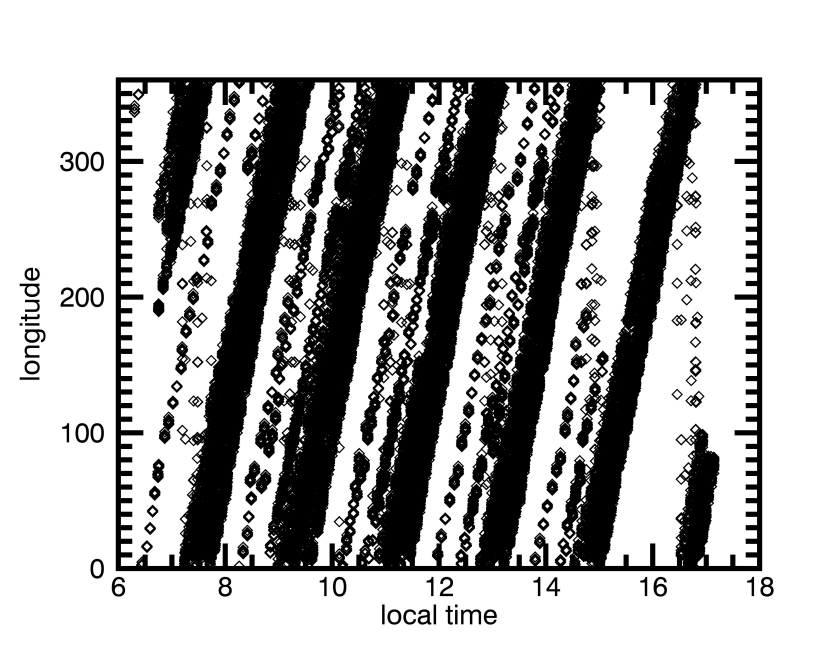
- Consider pathlengths/sensing depth $L=\lambda/4\pi k$

	wavelength	k	L
LAMP	160 nm	~2.7	5 nm
	190 nm	~0.52	30 nm
M^3	3 μm	~1.e-3	200 μm

This has important implications for the temperatures sensed by LAMP as compared with M^3, with further implications for hydration

All dayside data through Oct 4 2016 (end of fail-safe-door-closed mode)





- LAMP is sensitive to the top several tens of nm to 100 nm; the observed spectral shape does not approach pure H2O, suggesting that we are sensing up to a monolayer of H2O (so we sense through the H2O to the underlying grains) and not H2O bonded to H2O on top of each other.