Compositionally Ground Truth for the Diviner Lunar Radiometer:

Comparing Apollo Sites and Soils

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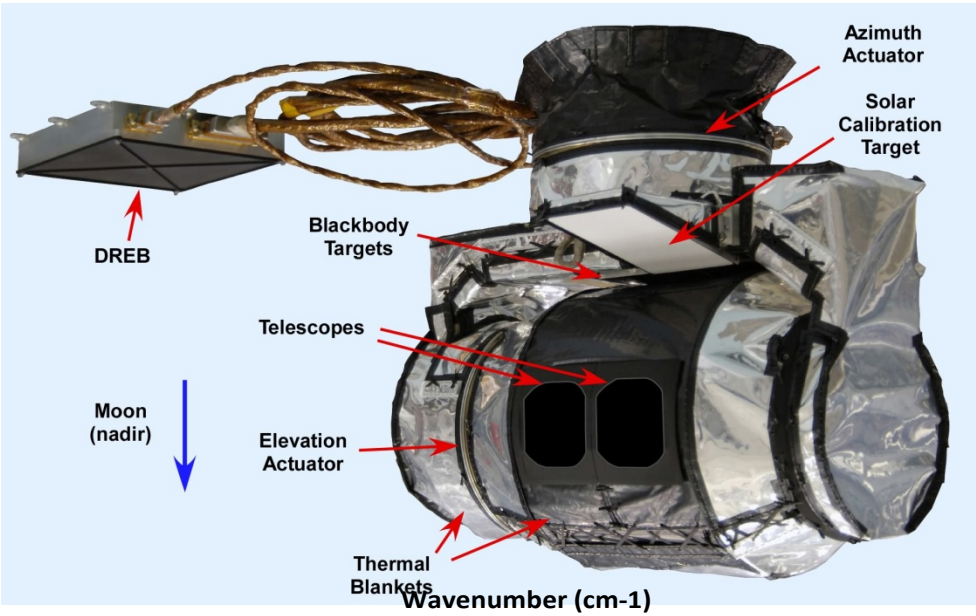
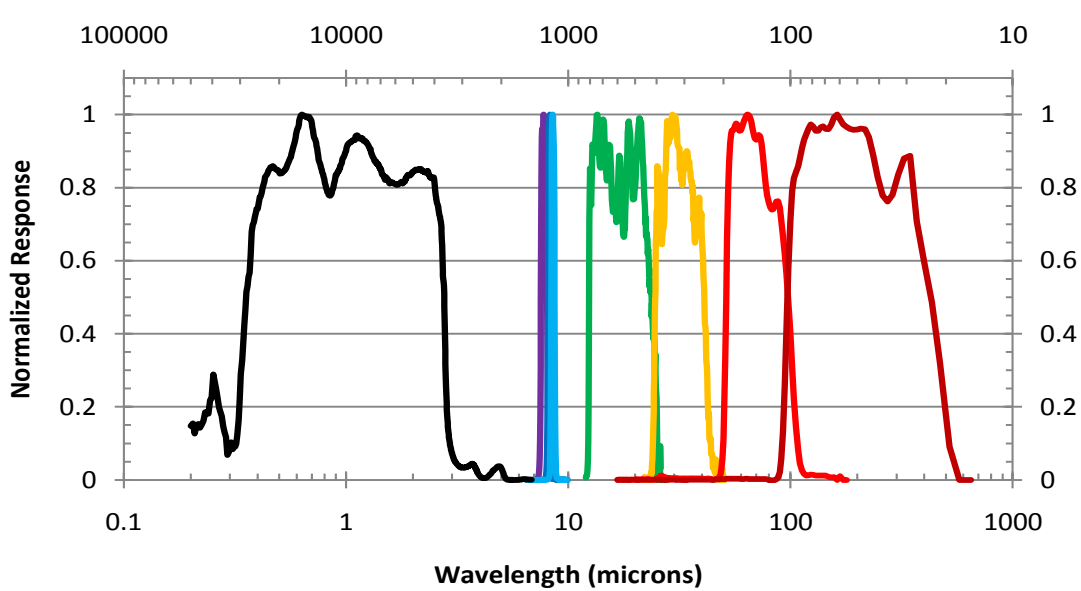
Exploration Science Forum 07/22/14 NASA Ames Research Center

LRO Diviner Overview



Observation Strategy	Primarily nadir pushbroom mapping
Detectors	Nine 21-element linear arrays of uncooled thermopile detectors
Fields of view	Detector Geometric IFOV: 6.7 mrad in-track 3.4 mrad cross track 320 m on ground in track for 50 km altitude 160 m on ground cross track for 50 km altitude Swath Width (Center to center of extreme pixels): 67 mrad; 3.4 km on ground for 50 km altitude

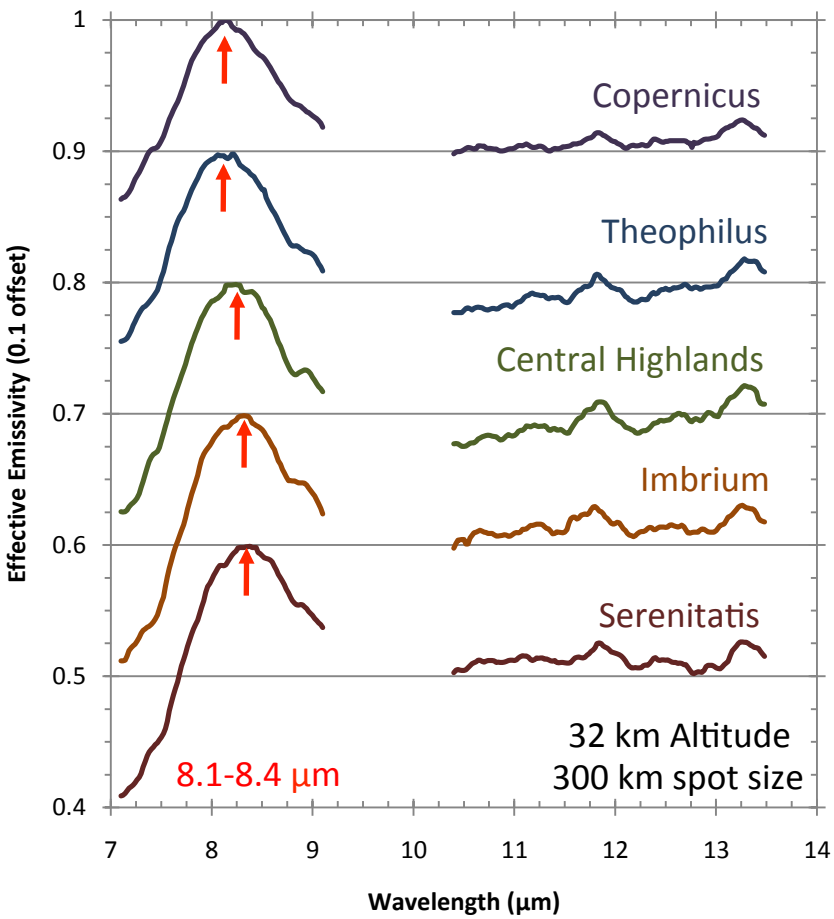


Science Goals

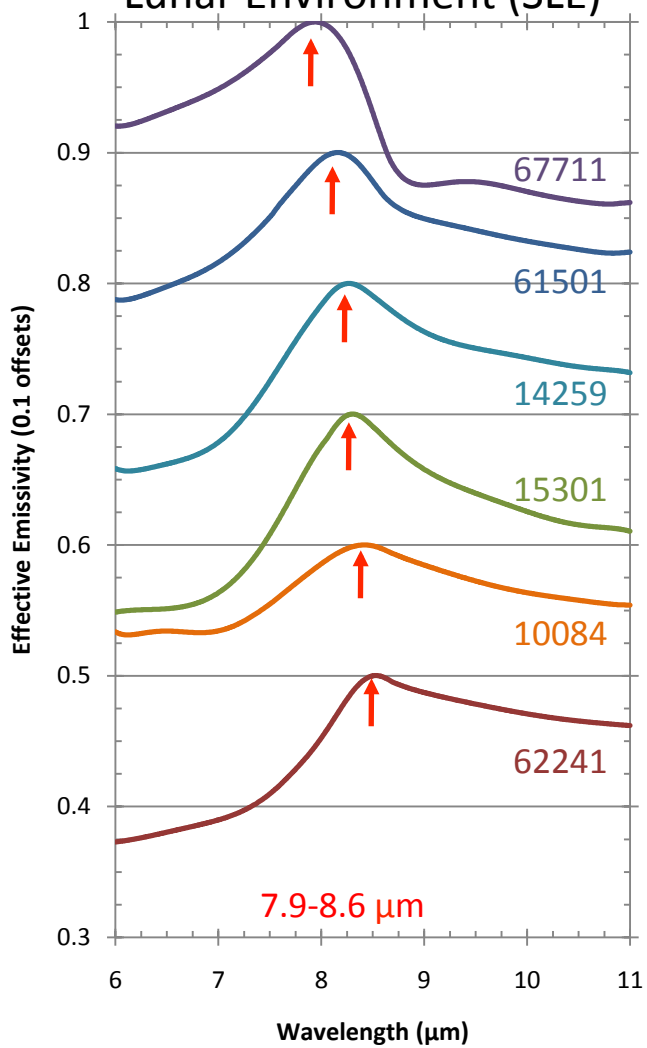
1. Characterize the Moon's surface thermal environments:
   - Daytime
   - Nighttime
   - Polar
2. Map properties of the lunar surface:
   - Bulk thermal properties
   - Rock abundance
   - **Composition**
3. Characterize polar cold traps

How Do We Measure Composition with Diviner?

Balloon-borne Observations



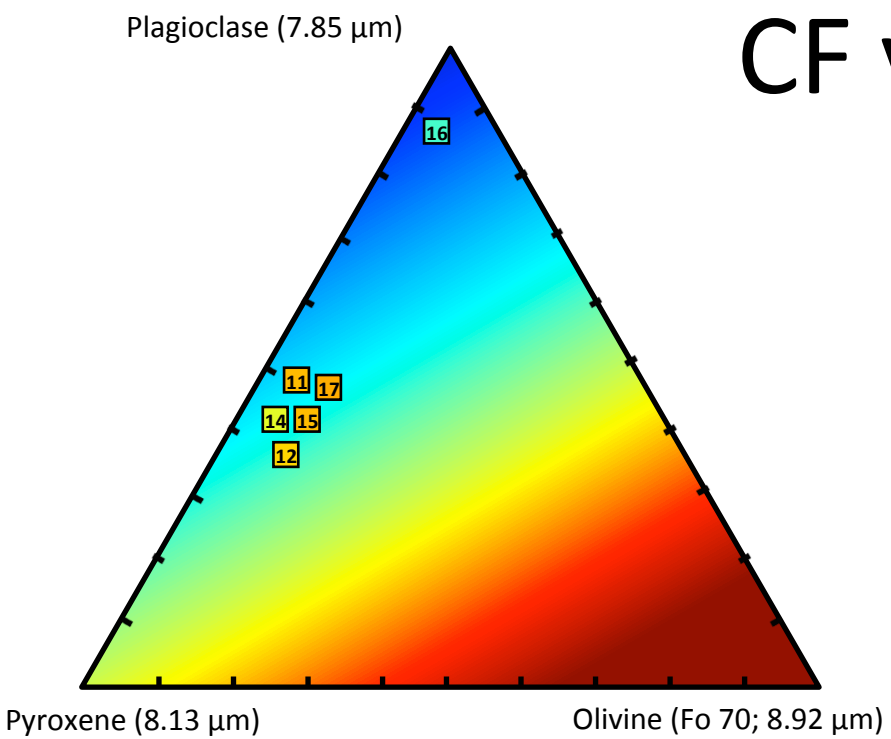
Laboratory Measurements of Apollo Soils in Simulated Lunar Environment (SLE)

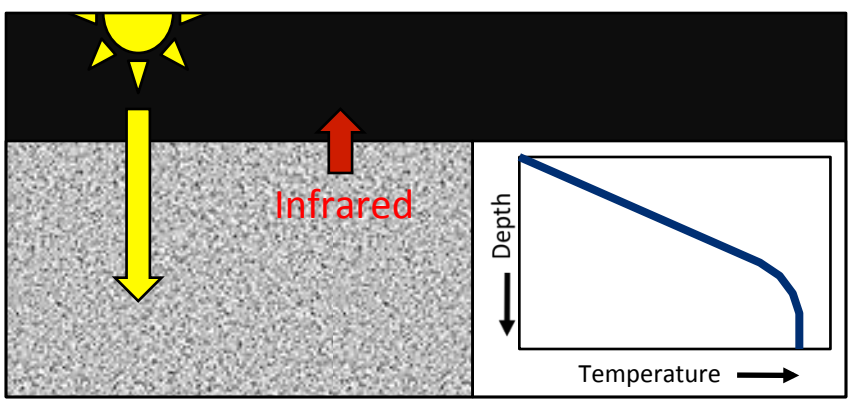


- Christiansen Feature (CF) marked with red arrows
- CF occurs short of strong absorptions where n ≈ 1
- Reflectance minimum / emissivity maximum
- Scattering minimum / transmission maximum

Left after Murcray et al., 1970; right after Salisbury et al., 1973 and Logan et al., 1975

CF vs. Composition

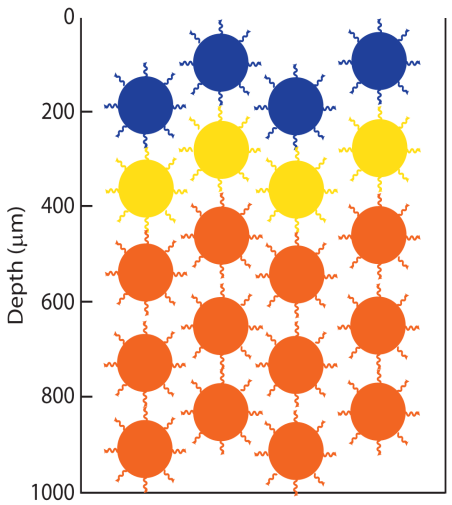


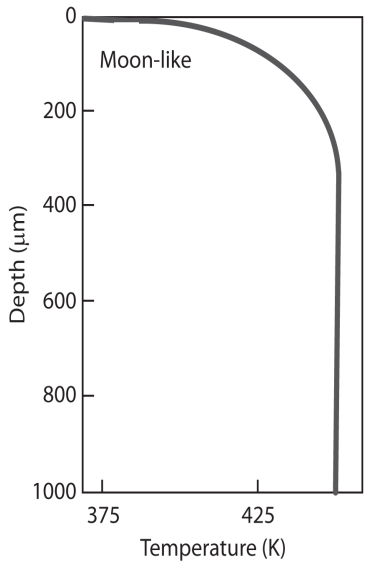


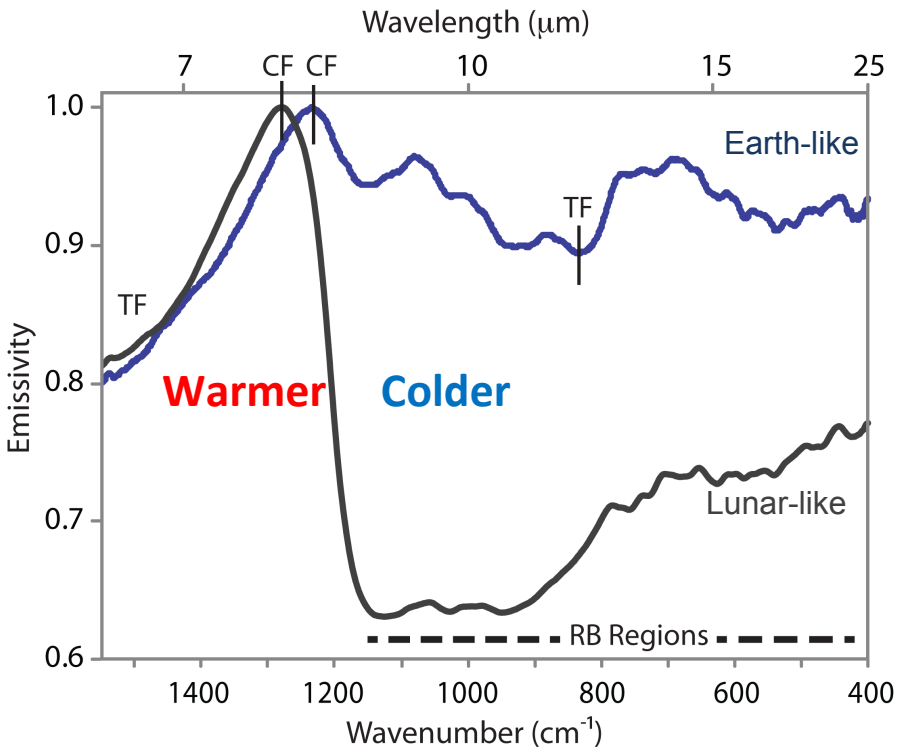
Greenhagen et al., 2010

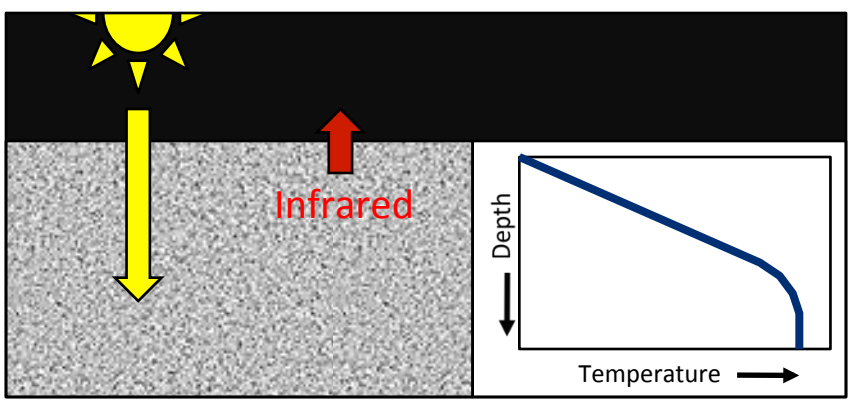
- Christiansen Feature shifts to shorter wavelengths with increasing silicate polymerization
- CF position is most sensitive to plagioclase/olivine abundance
  - Large variation of CF for olivine composition (~8.6 to 9.5 µm)
- CF can shift illumination/viewing geometry (*Greenhagen et al., 2011*)
- CF can shift with space weathering (*Lucey et al., 2013*)
- Optical thermal gradients (e.g. *Logan & Hunt, 1970*)
  - Strong surface boundary gradients are caused by inefficient heat transfer in the absence of convecting gases

Surface Boundary Thermal Gradients





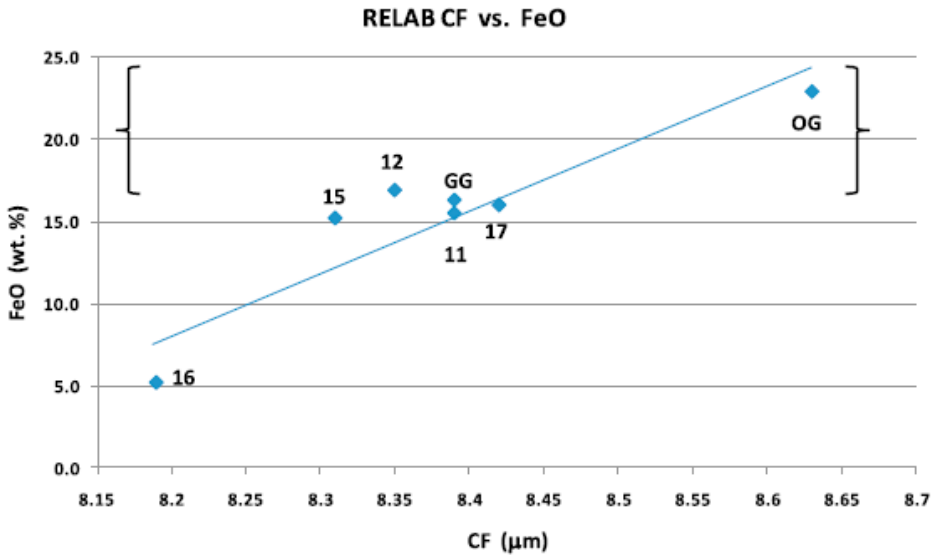


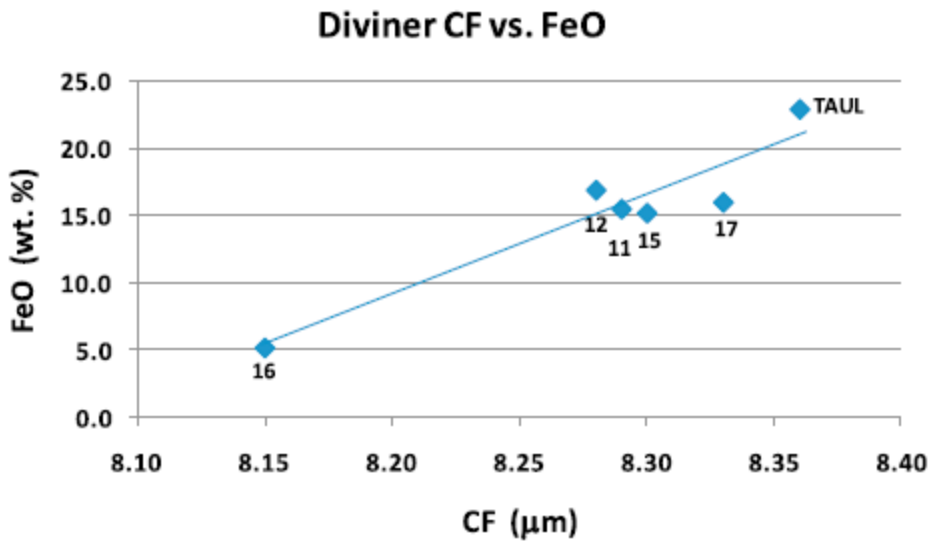


- Thermal Gradient Effects
  - Enhances CF
  - Reduces Reststrahlen Bands
  - Shifts CF to shorter wavelengths
- When thermal gradients are present thermal emission is not the same as emissivity!
  - Not significant for terrestrial environments

Top right after Donaldson Hanna et al., 2012

Initial Work: CF vs. FeO





Work by Allen *et al*., 2012 showed the correlation between CF and FeO

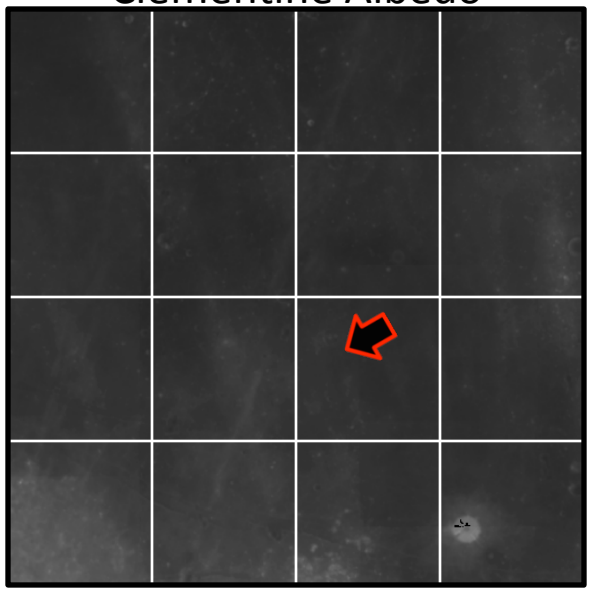
- Reasonable correlation for CF measured in laboratory reflectance
- Better correlation for CF measured by Diviner

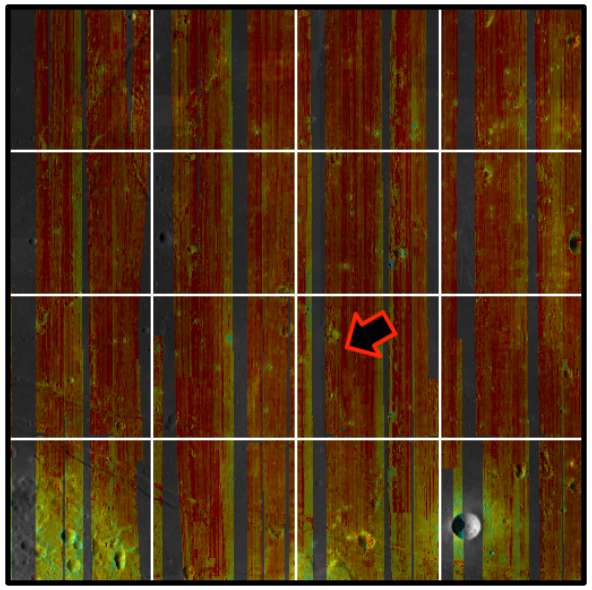
Allen *et al*., 2012 study used a single data point, representative of each Apollo site and one for the Taurous Littrow orange glass

We wanted to utilize the high spatial resolution to resolve individual sampling stations for the Apollo sites and extend these analyses

Apollo 11

Clementine Albedo

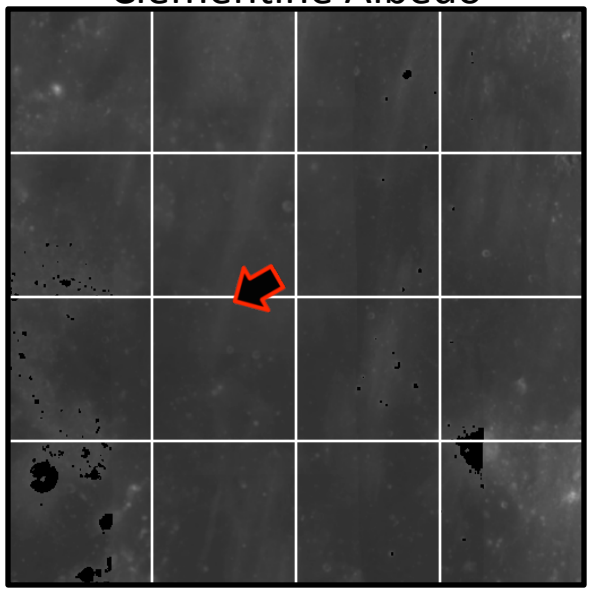


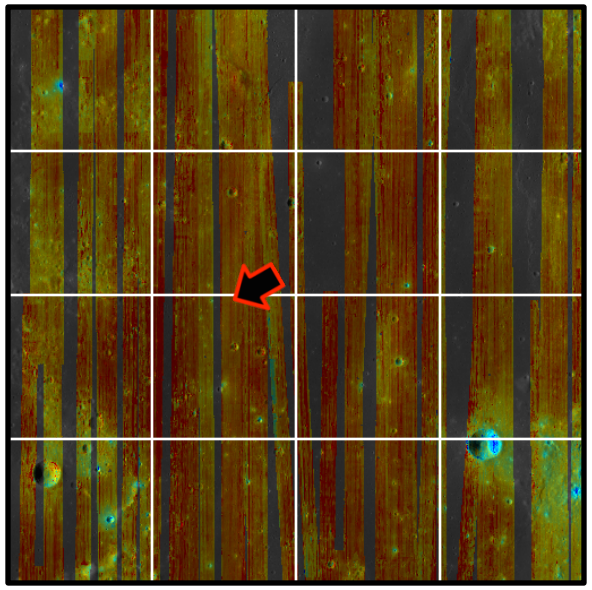


Diviner CF over LROC WAC

Apollo 12

Clementine Albedo

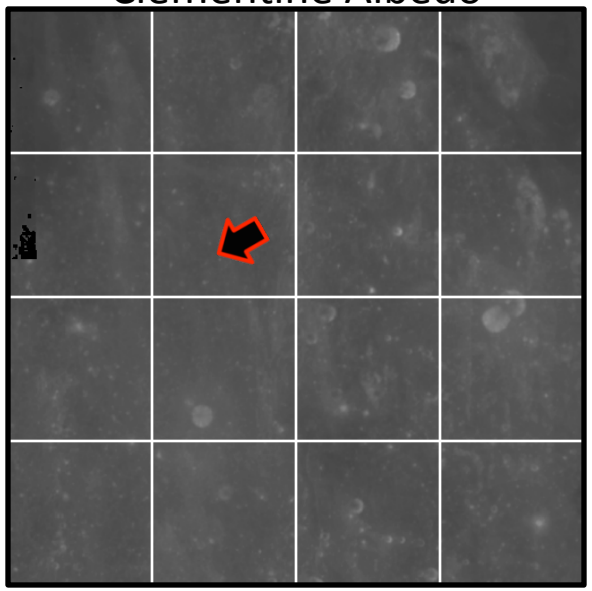


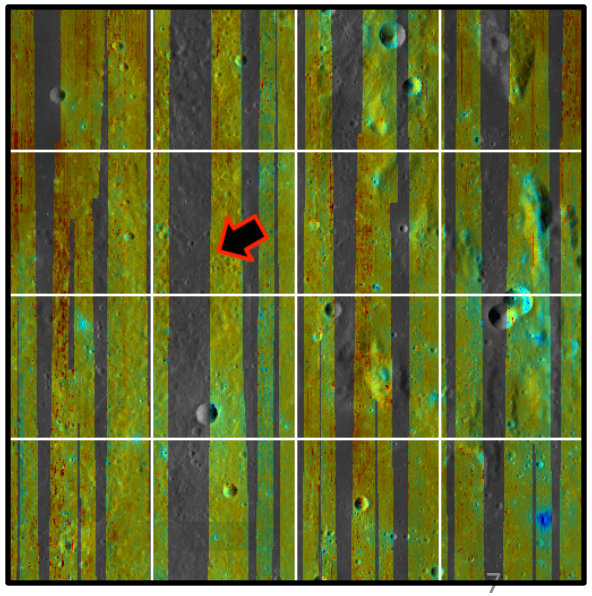


Diviner CF over LROC WAC

Apollo 14

Clementine Albedo

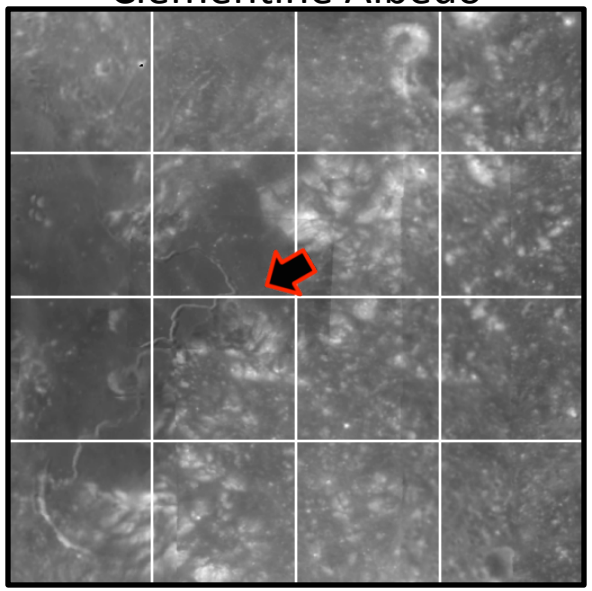


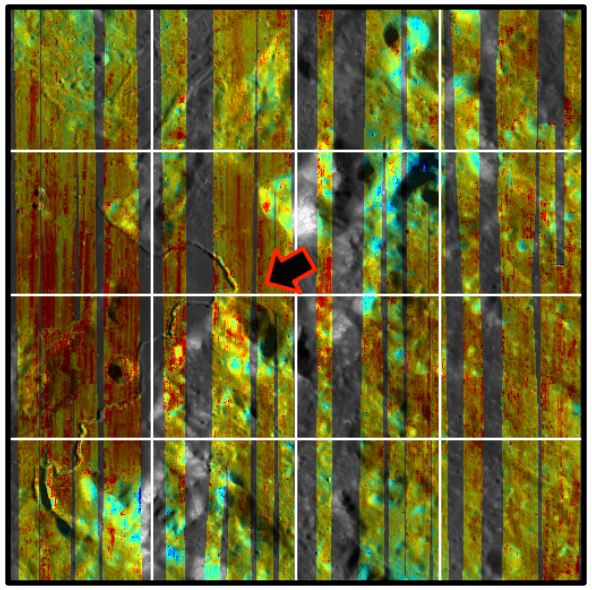


Diviner CF over LROC WAC

Apollo 15

Clementine Albedo

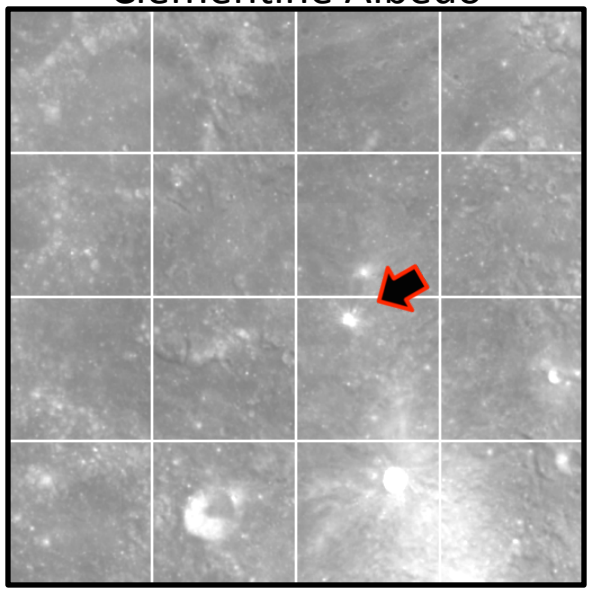


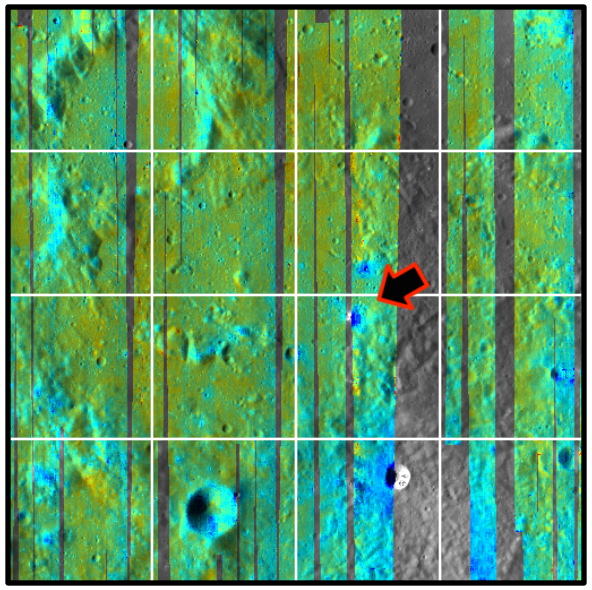


Diviner CF over LROC WAC

Apollo 16

Clementine Albedo

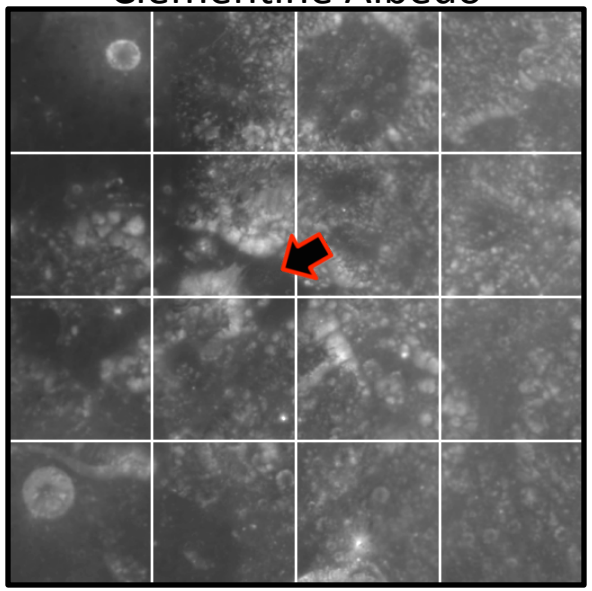


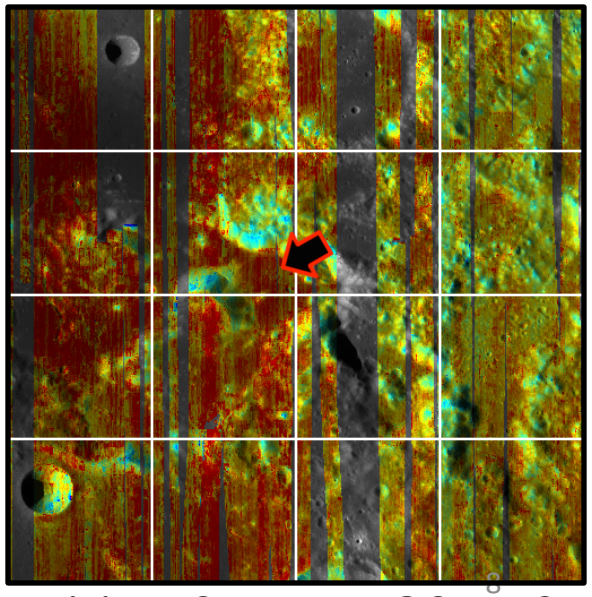


Diviner CF over LROC WAC

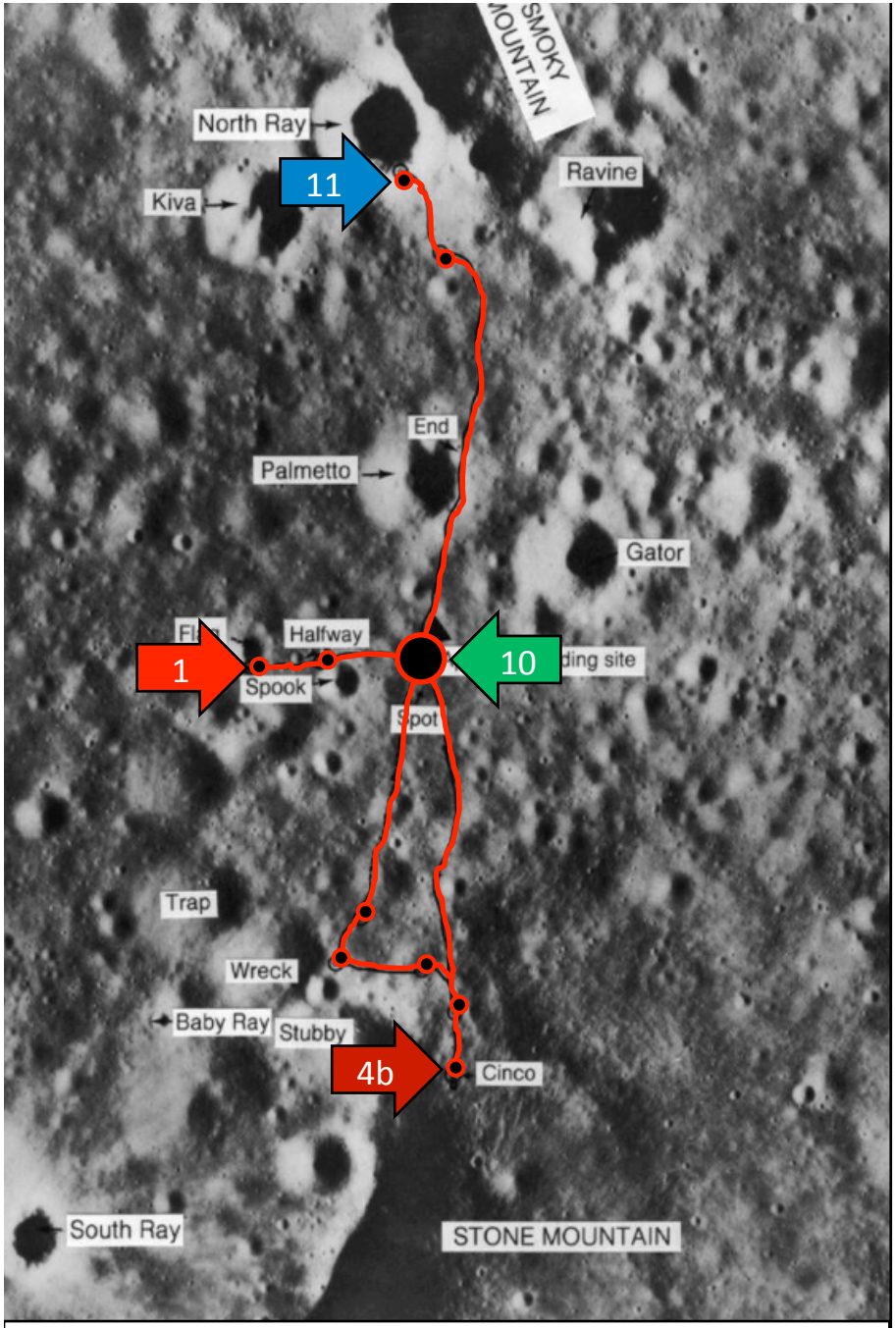
Apollo 17

Clementine Albedo

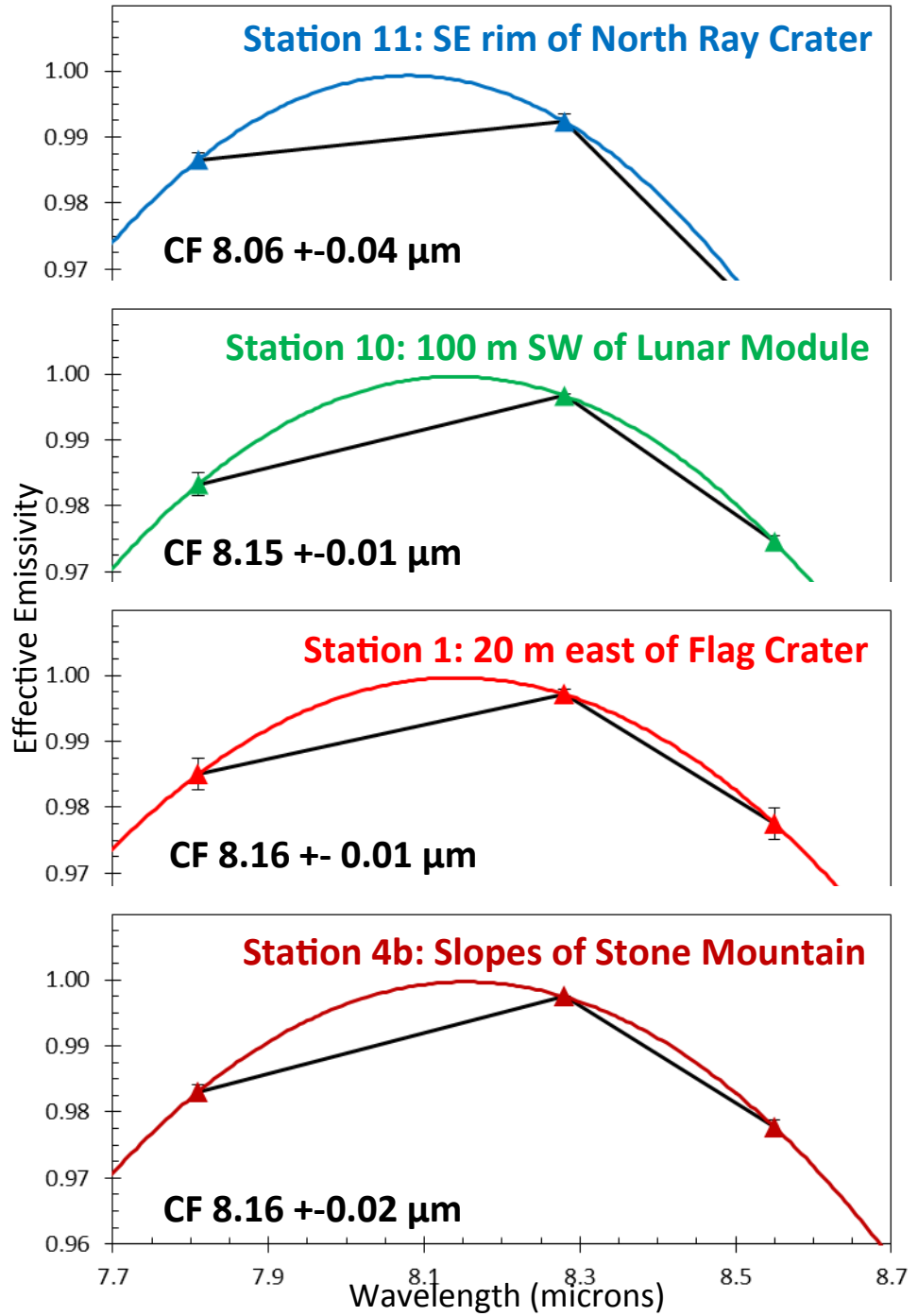




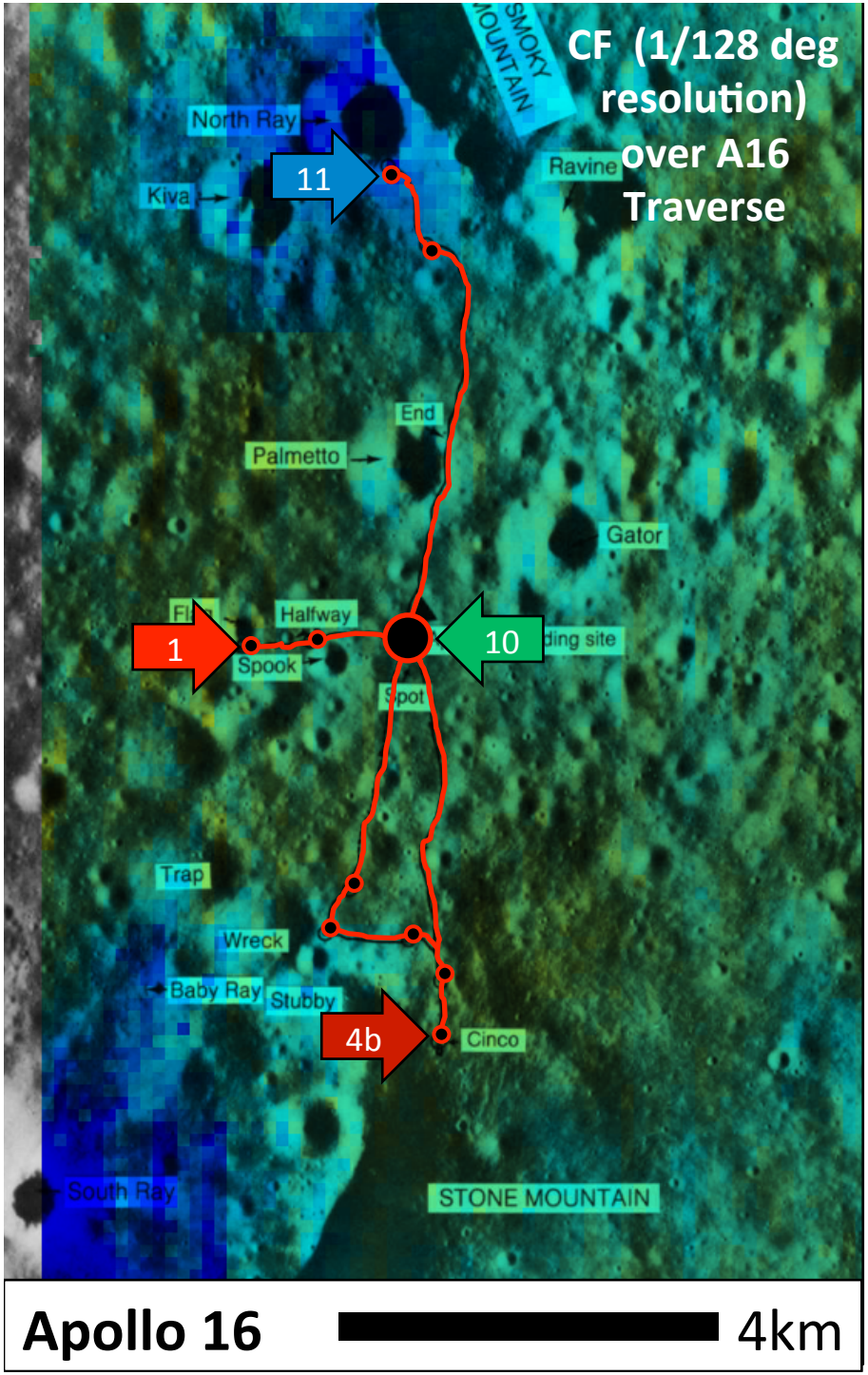
Diviner CF over LROC WAC

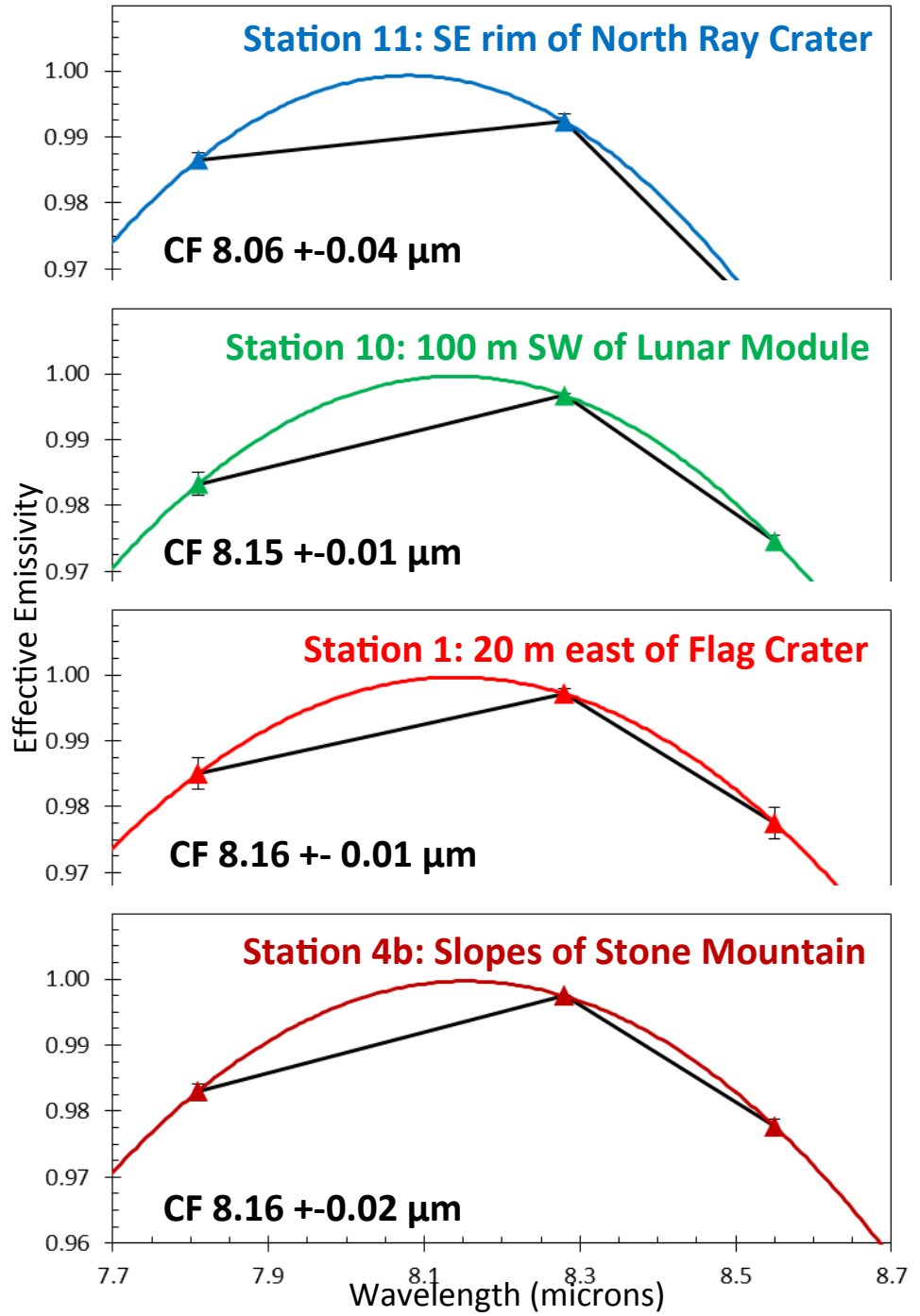


Apollo 16 4km



Colored spectra after Salisbury et al., 1973 and Logan et al., 1975



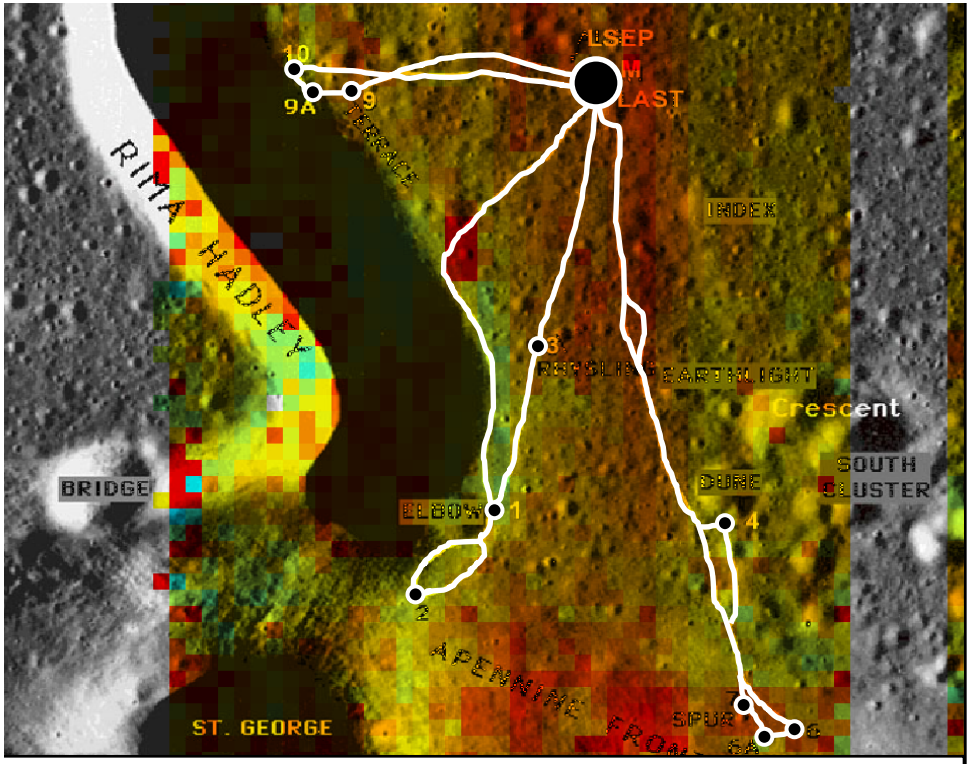


Colored spectra after Salisbury et al., 1973 and Logan et al., 1975

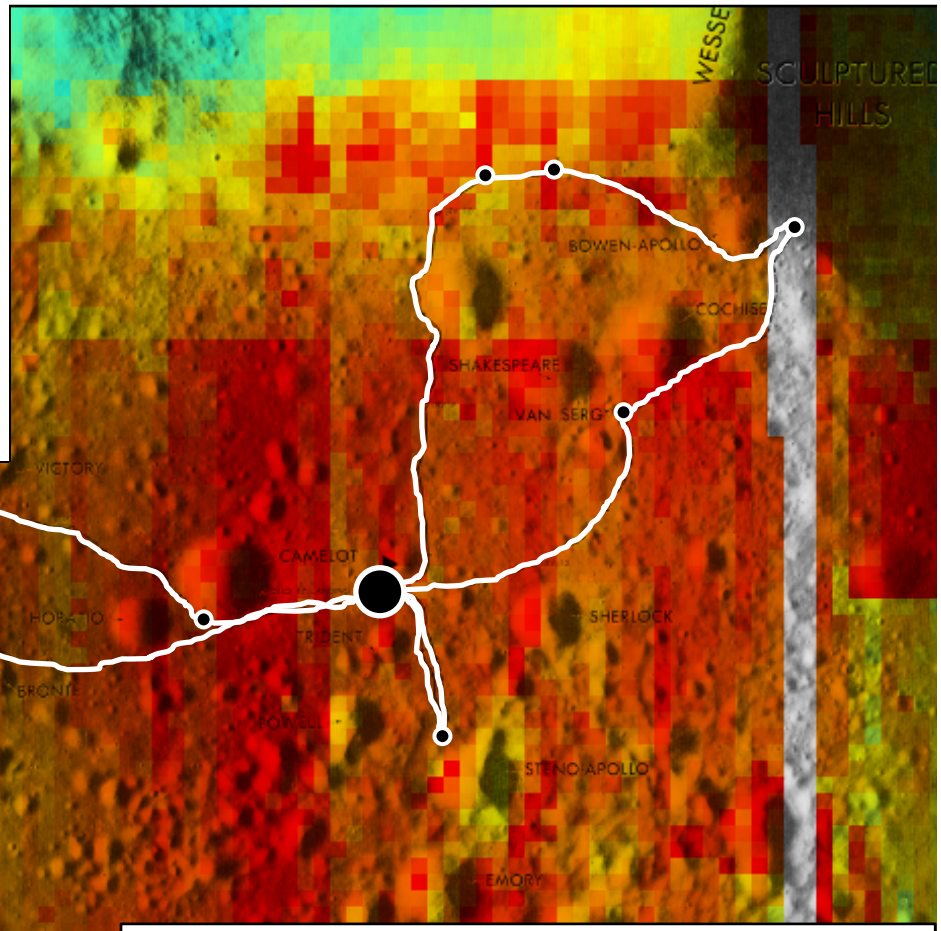
Extended Diviner analysis to 4 Apollo 14, all Apollo 15 and all Apollo 17 sampling stations

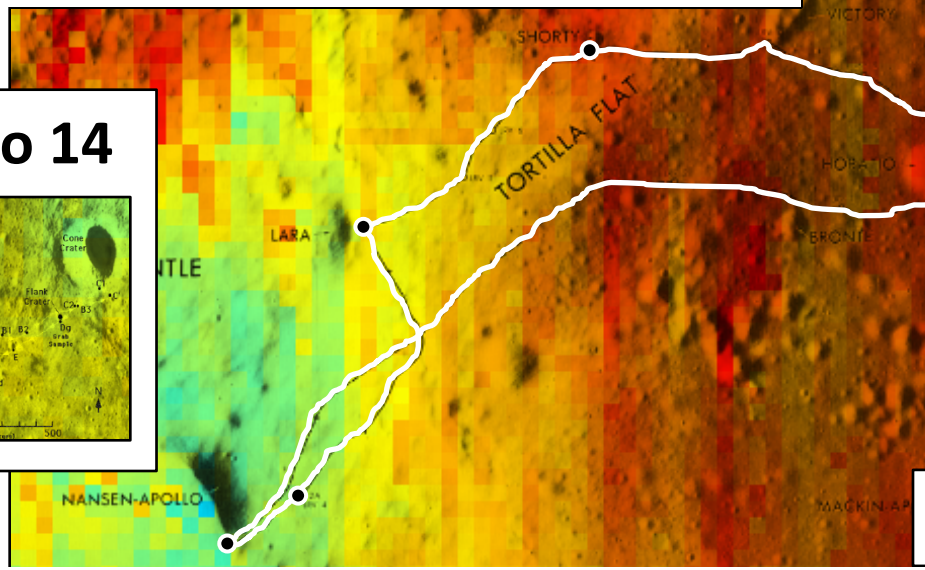
Used single point average for Apollo 11 and 12

Correlated each sampling station observation to measured soil geochemical properties



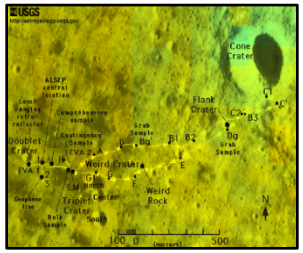
Apollo 15 2 km



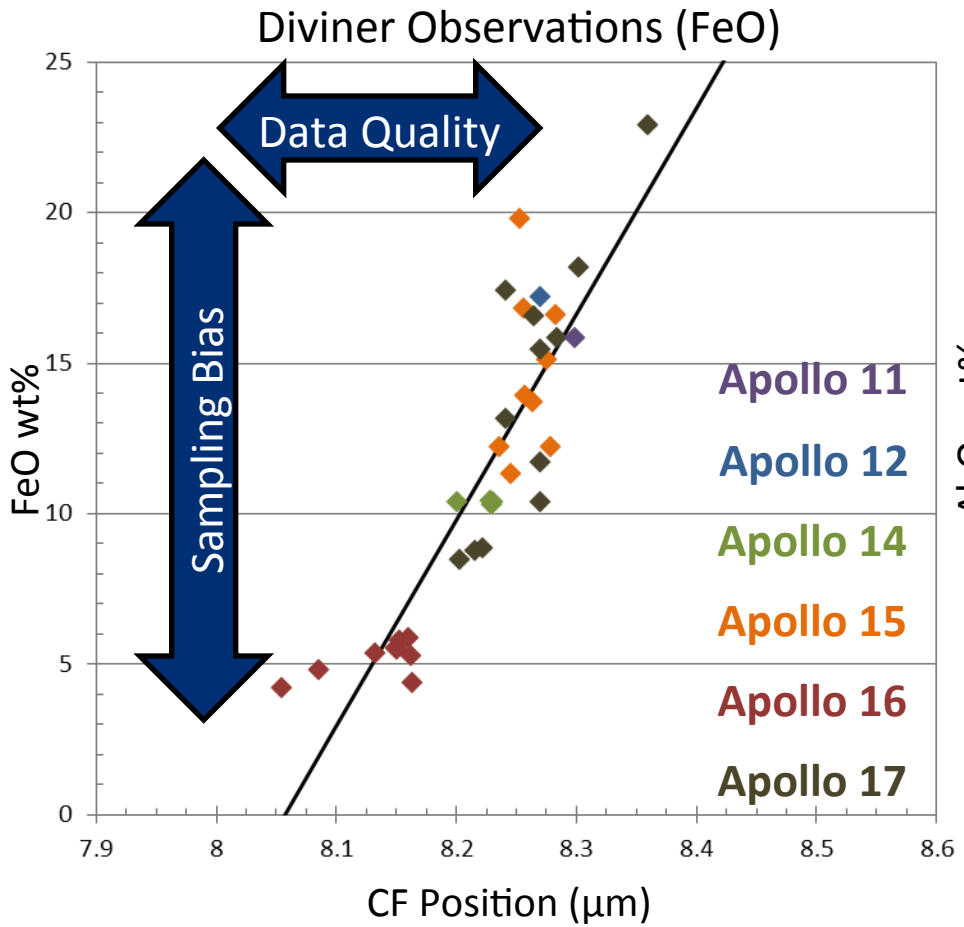


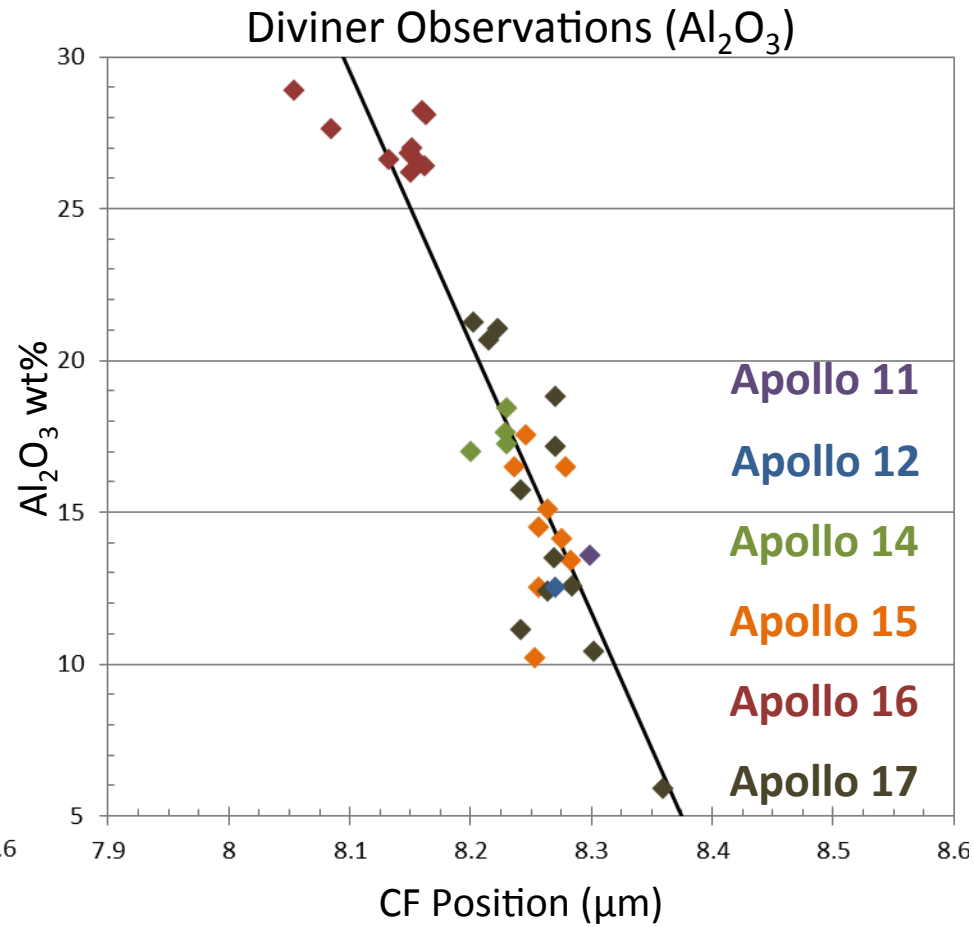
Apollo 17 2 km

Apollo 14



Diviner Observations – Soil Geochemistry

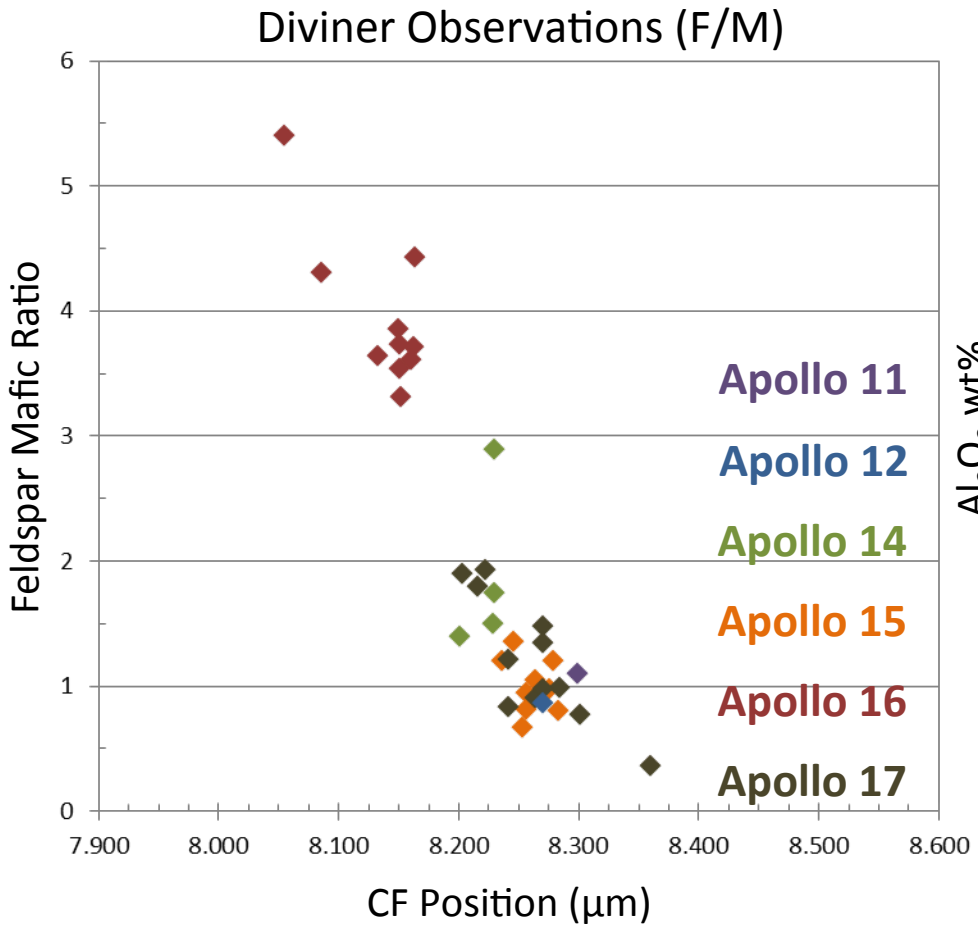


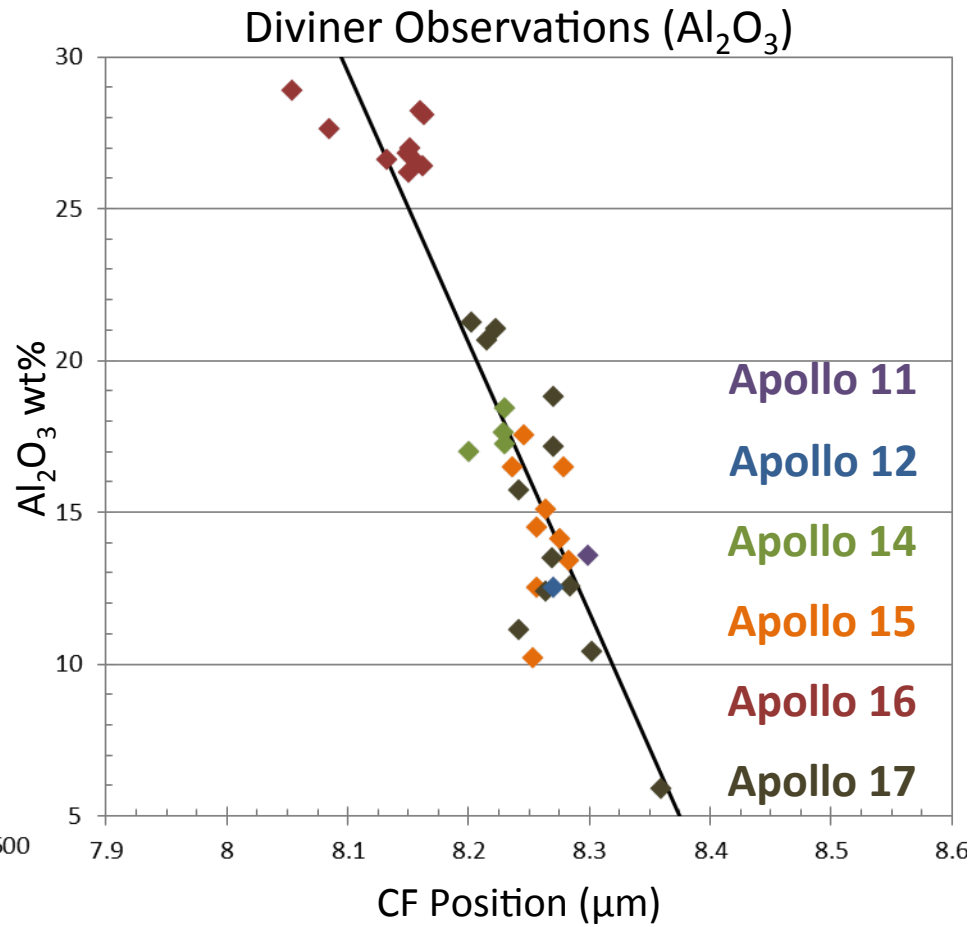


Strong correlation between CF and FeO / Al_2O_3 content for Diviner observations

Similar trends have been used to determine FeO content of pyroclastic deposits (e.g. Allen et al., 2012; Bennett et al., 2014)

Diviner Observations – Soil Geochemistry

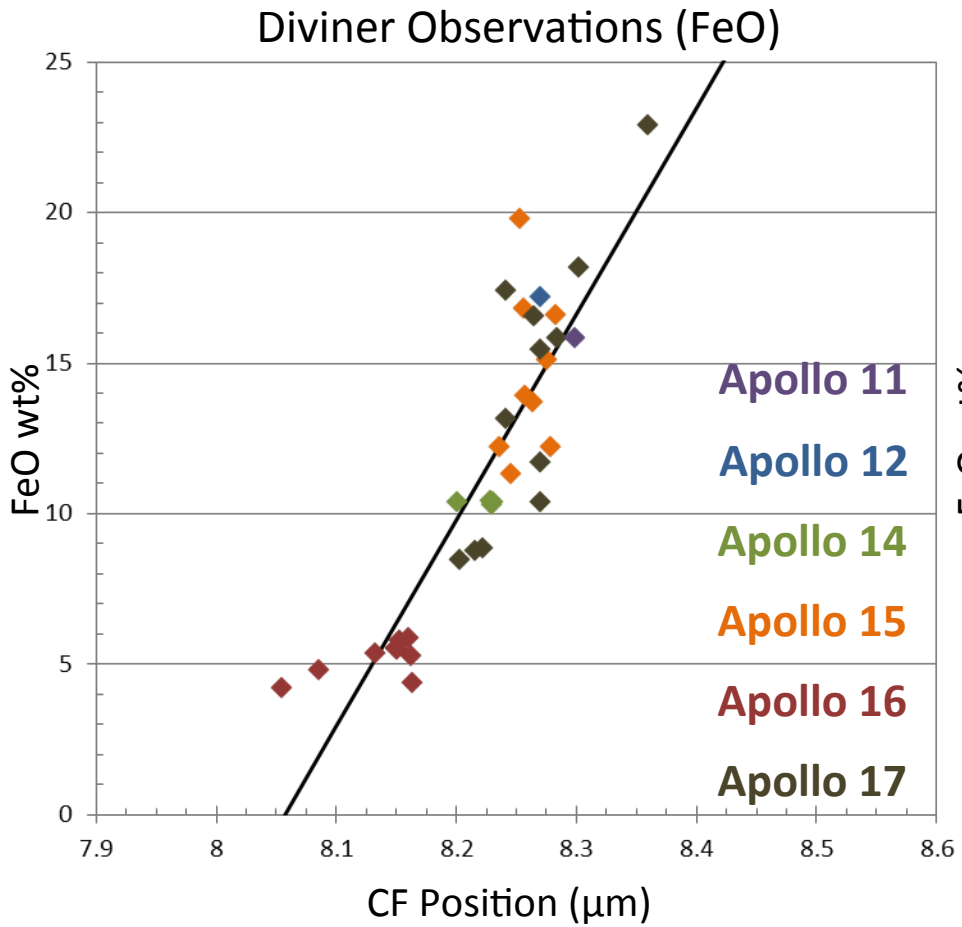


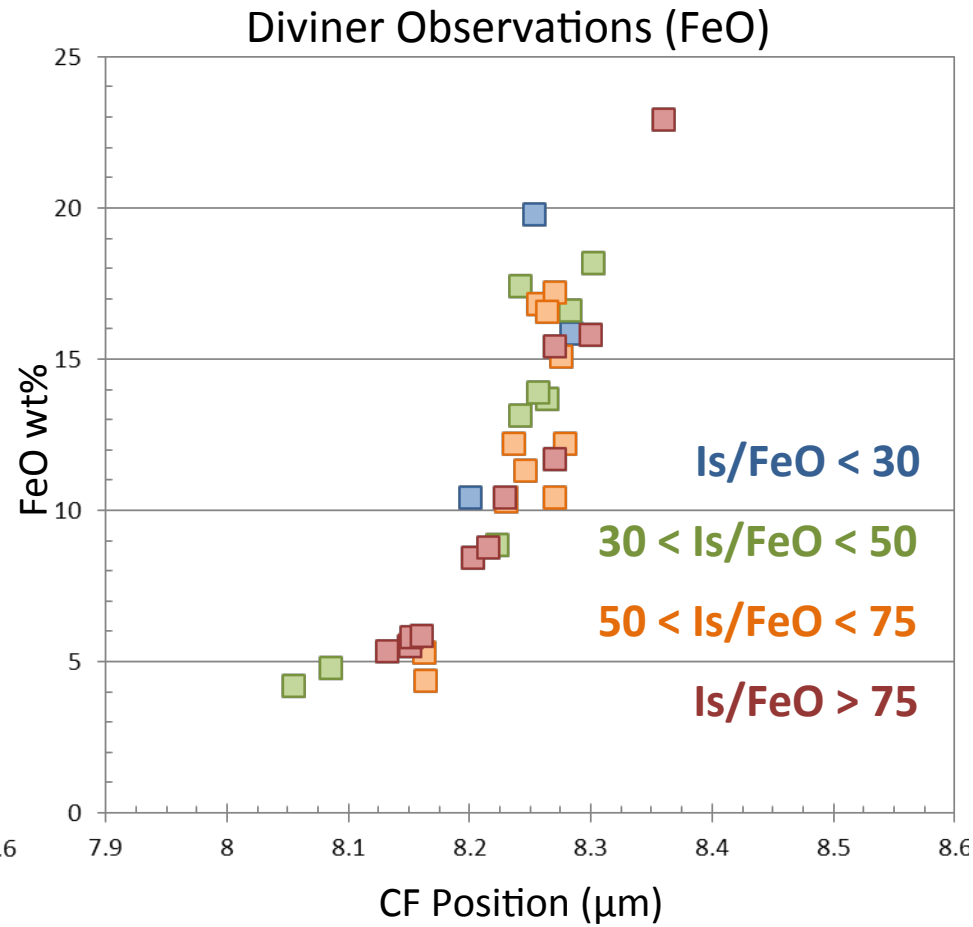


Also a strong (expected) correlation between CF and feldspar-mafic ratio

Diviner constraints on feldspar-mafic ratio combined with near-infrared identifications of iron-bearing minerals enable good estimates of bulk mineralogy

Diviner Observations – Soil Geochemistry

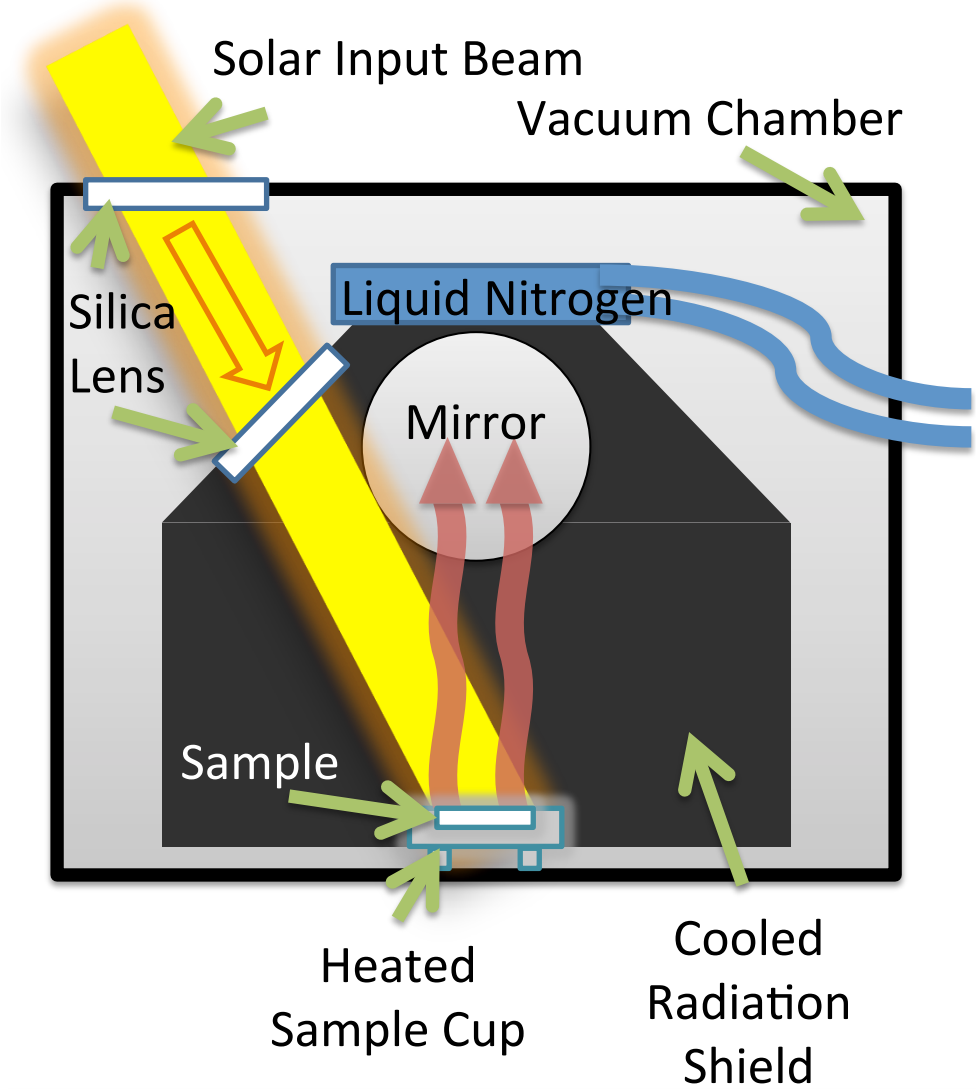




No clear correlation with soil maturity for a given FeO composition

Indicates assumption that returned soils have similar maturity to 100s m scale in situ surfaces is not good - drives need for new laboratory measurements

Diviner Simulated Lunar Environment Experiments



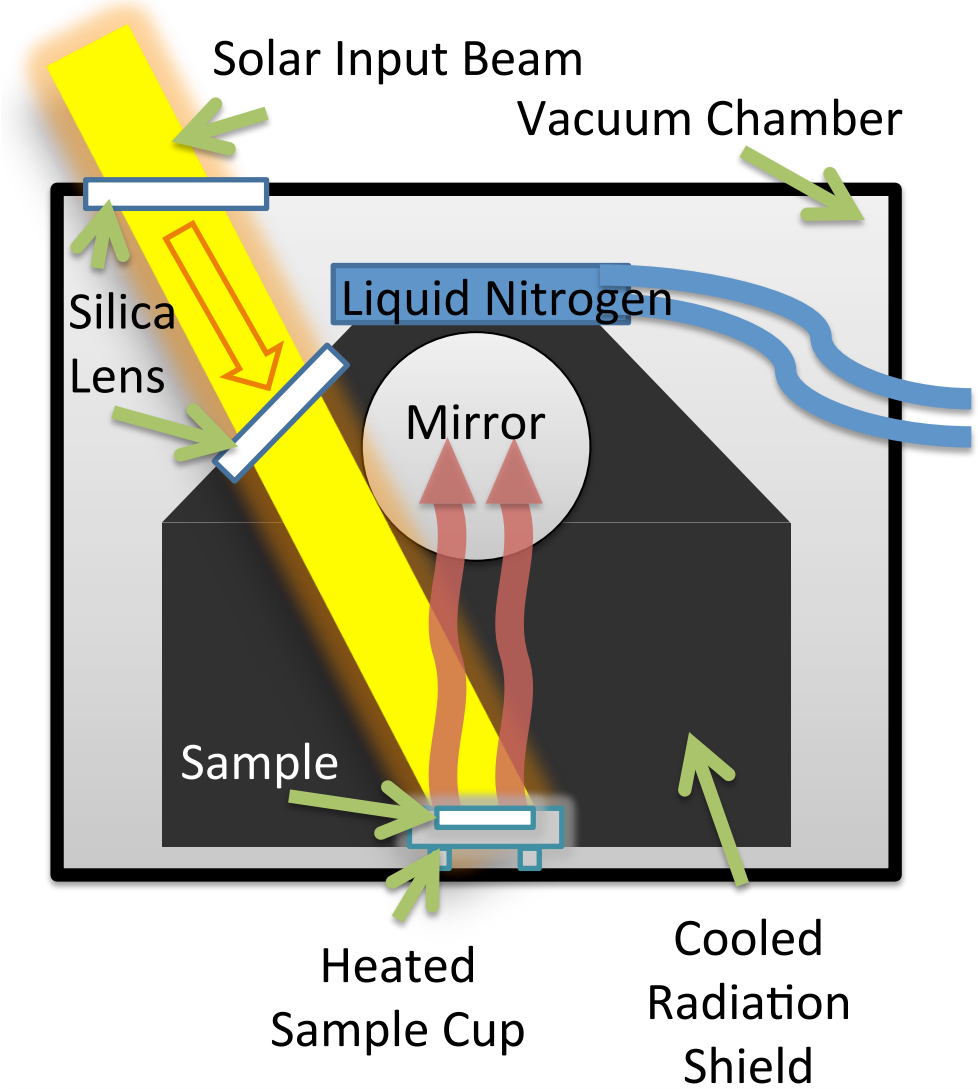
Apollo Site	Station	Soil	Mass	Is/FeO	Consortium
Apollo 11	LM	10084	5 g	78	UCLA-BRDF (Paige)
Apollo 12	LM	12001	5 g	56	UCLA-BRDF (Paige)
Apollo 14	LM	14259	3.5 g	85	TIRES-LSCC (Pieters)
Apollo 15	LM	15021	3.5 g	70	TIRES-LSCC (Pieters)
Apollo 15	Sta. 1	15071	5 g	52	UCLA-BRDF (Paige)
Apollo 15	Sta. 7	15411	3.5 g	43	TIRES-LSCC (Pieters)
Apollo 15	Sta. 9a	15601	3.5 g	29	TIRES-LSCC (Pieters)
Apollo 16	Sta. 1	61141	5 g	56	UCLA-BRDF (Paige)
Apollo 16	Sta. 6	66031	3.5 g	102	TIRES-LSCC (Pieters)
Apollo 16	Sta. 11	67701	3.5 g	39	TIRES-LSCC (Pieters)
Apollo 17	LM	70181	5 g	47	UCLA-BRDF (Paige)
Apollo 17	Sta. 2	72501	3.5 g	81	TIRES-LSCC (Pieters)
Apollo 17	Sta. 9a	79221	3.5 g	81	TIRES-LSCC (Pieters)

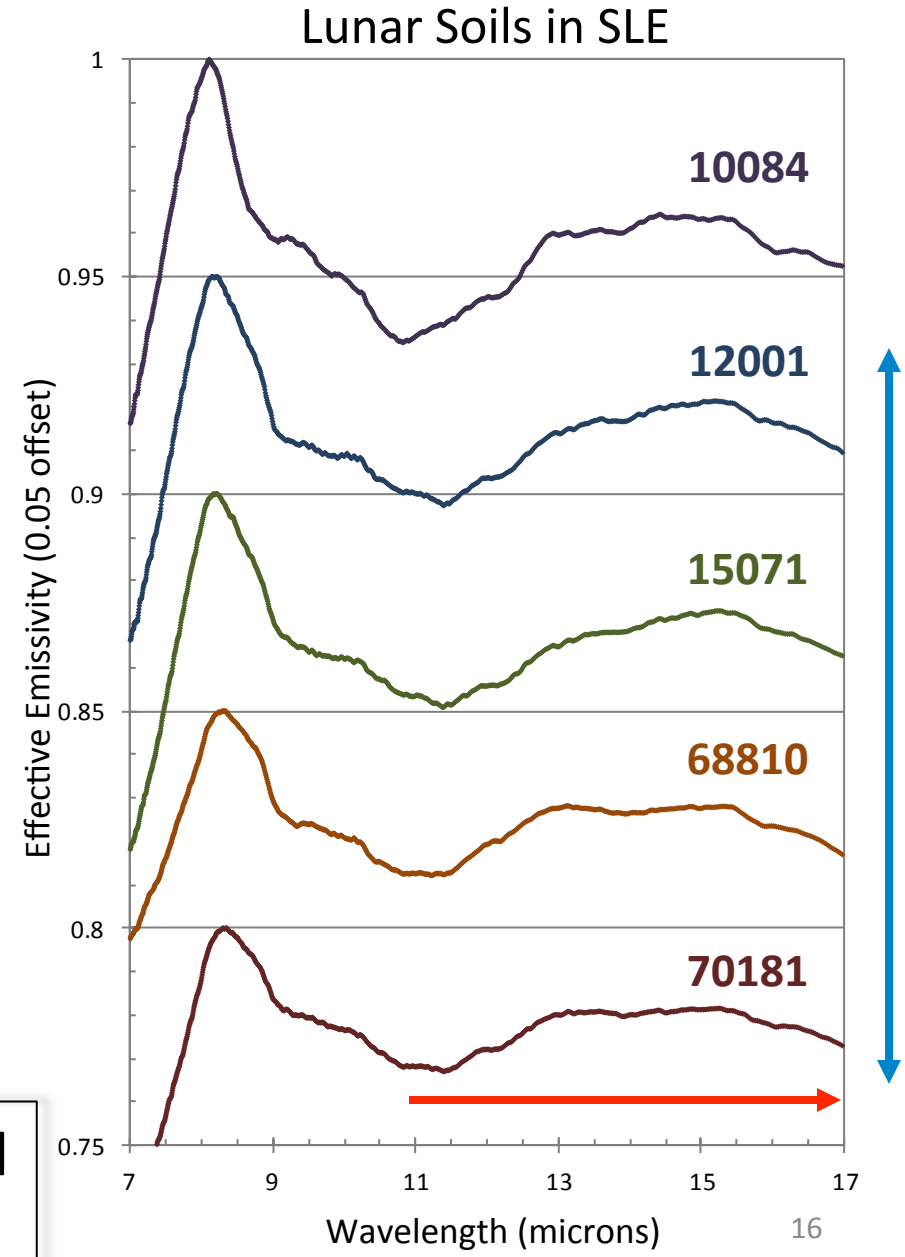
Initial characterization suite chosen to be representative of remote sensing datasets

Future suites will focus on soil maturity and vitrification

Our study includes **new samples** and **extended spectral range** (5-25 µm)

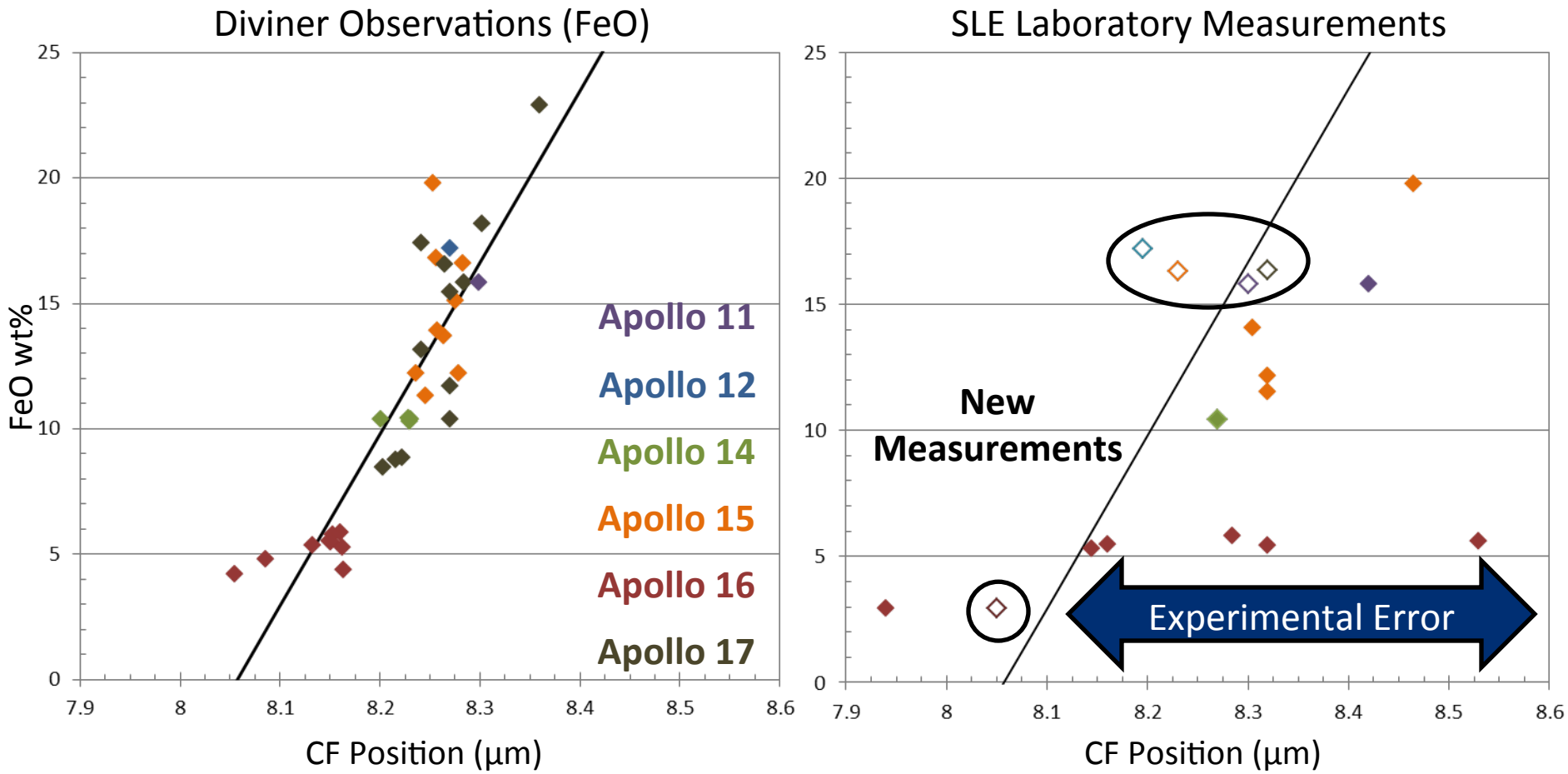
Diviner Simulated Lunar Environment Experiments





Our study includes **new samples** and **extended spectral range** (5-25 µm)

FeO Correlation: Observations vs. Lab



Strong Correlation between CF and FeO / Al_2O_3 content for Diviner observations
Reasonable Trend between CF and FeO content for SLE lab experiments

Significant efforts to ensure properly prepared samples and environment

- See poster by Kerri Donaldson Hanna et al.

Conclusions

- Correlations between Diviner observations of Apollo sites and SLE laboratory measurements enable quantitative analyses of global Diviner data

- Preliminary analyses are encouraging; future work in this direction includes
  - Measurement of additional lunar soils in simulated lunar environment (more stations, different levels of space weathering exposure)
  - Refinement of Diviner MIR "photometric" and space weathering corrections
  - Investigation of different optical periods (e.g. times of day and spacecraft altitudes
  - Applications to science investigations