Groundtruthing Laboratory Experiments with Diviner Lunar Radiometer Observations

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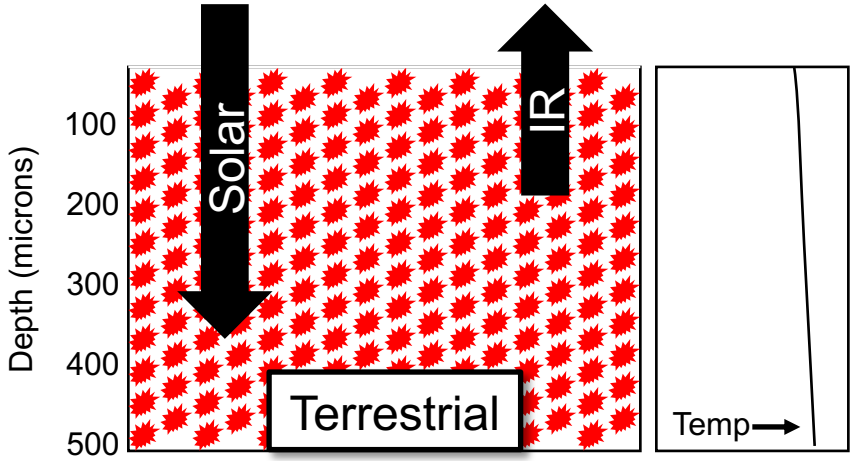
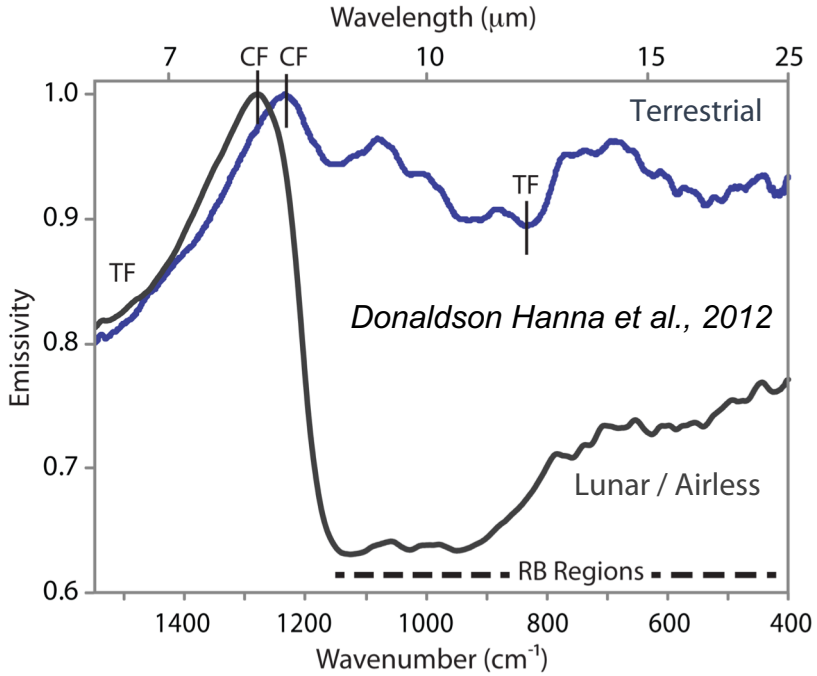
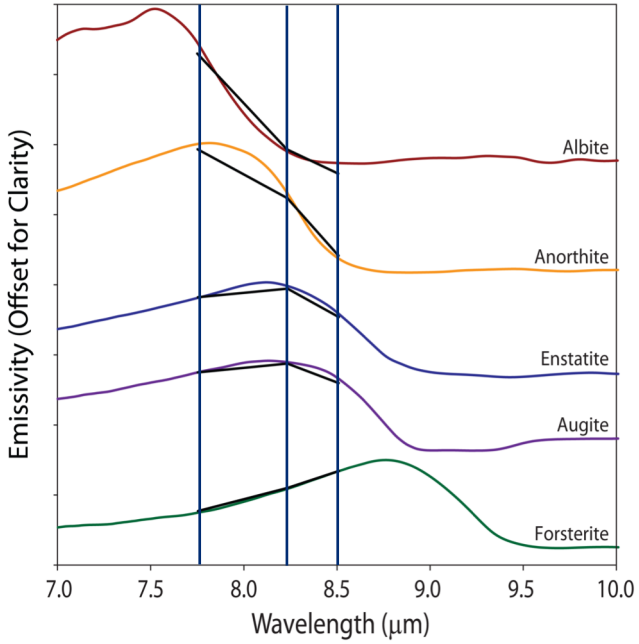
Measuring the CF with Epiregolith Thermal Gradients





- Lack of atmosphere restricts heat transfer to radiation and conduction
  - Inefficient = highly insulating
- Temperature contrast between CF and reststrahlen bands drives differences between terrestrial and lunar observations



- Christiansen Feature shifts to shorter wavelengths with increasing silicate polymerization
- CF position is most sensitive to plagioclase-mafic abundance
  - Pyroxene compositions are not unique
  - Olivine-plag mixtures could have CFs similar to pure pyroxene
  - Olivine and Plagioclase have large compositionally-driven CF variations
- Quartz is effectively off-scale to shorter wavelengths
  - Positive ID of highly silicic deposits

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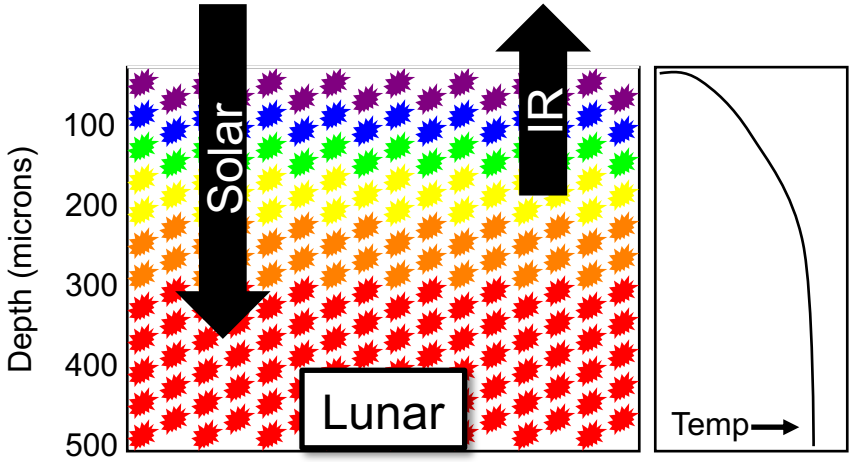

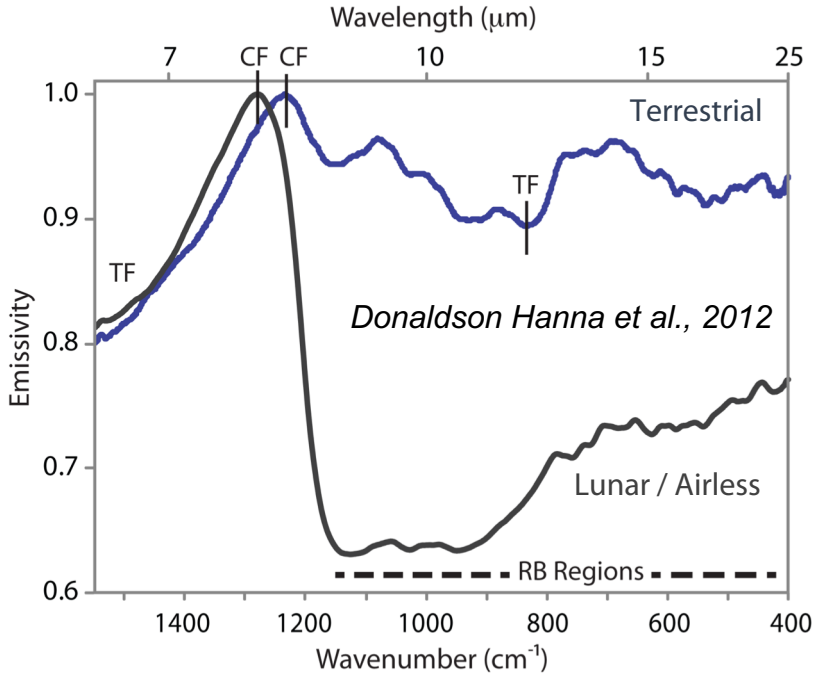

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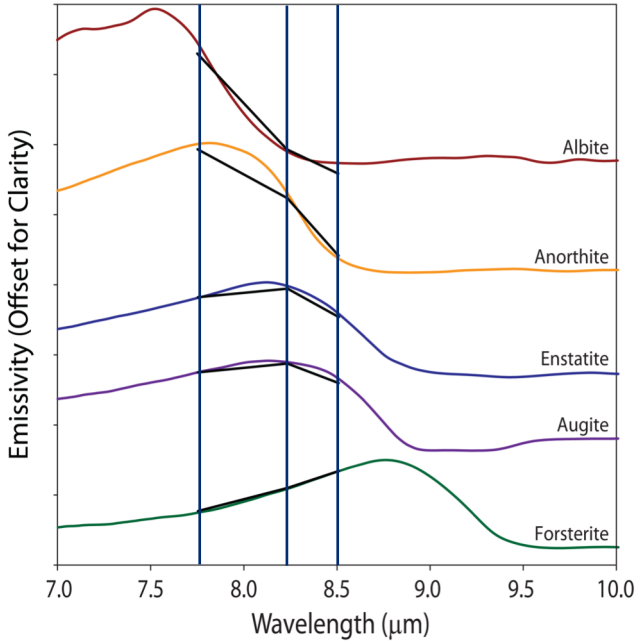

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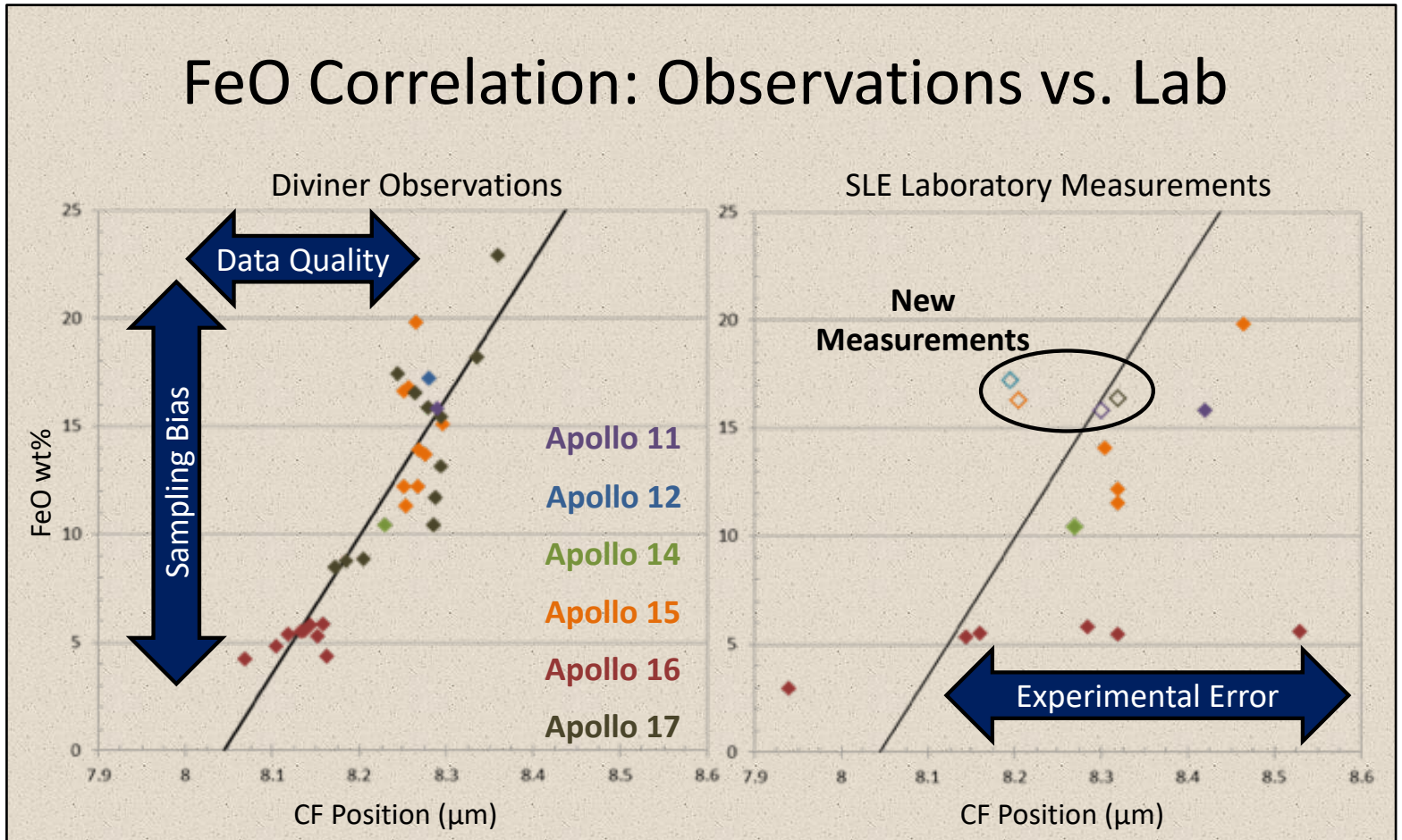
Motivation – Reducing Experimental Errors

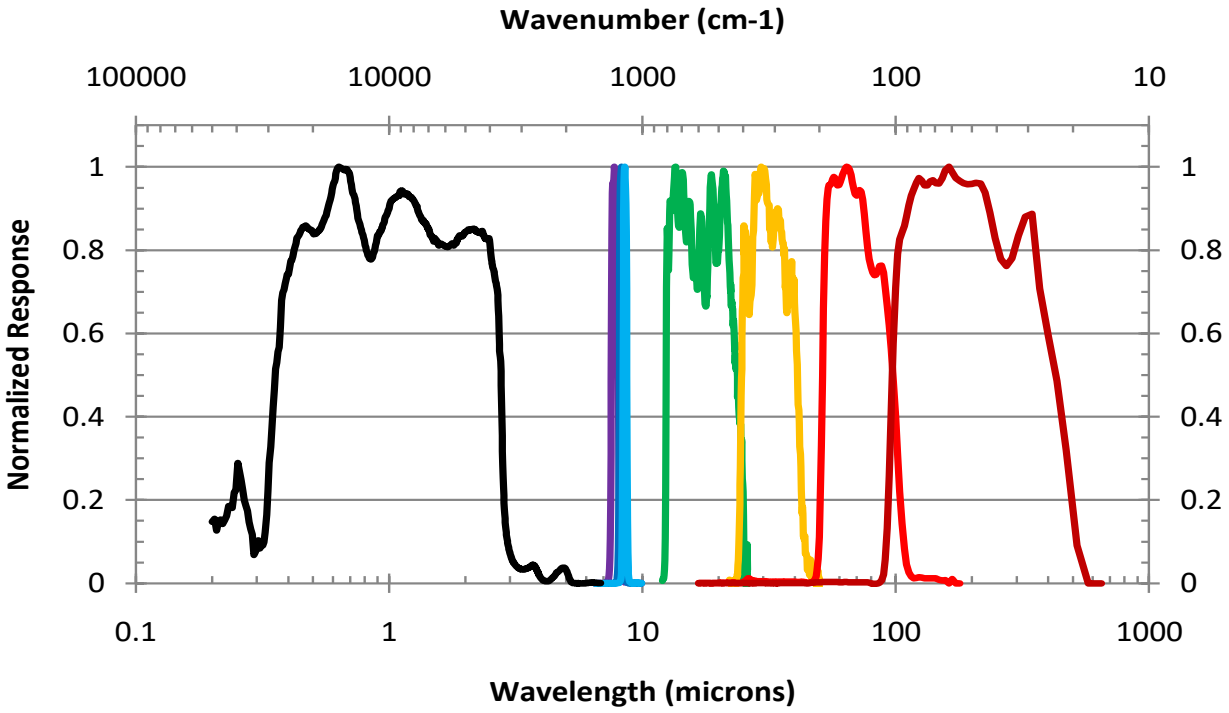


Correlation between CF and FeO content for both Diviner observations and SLE laboratory experiments (especially after removing likely experimental errors)

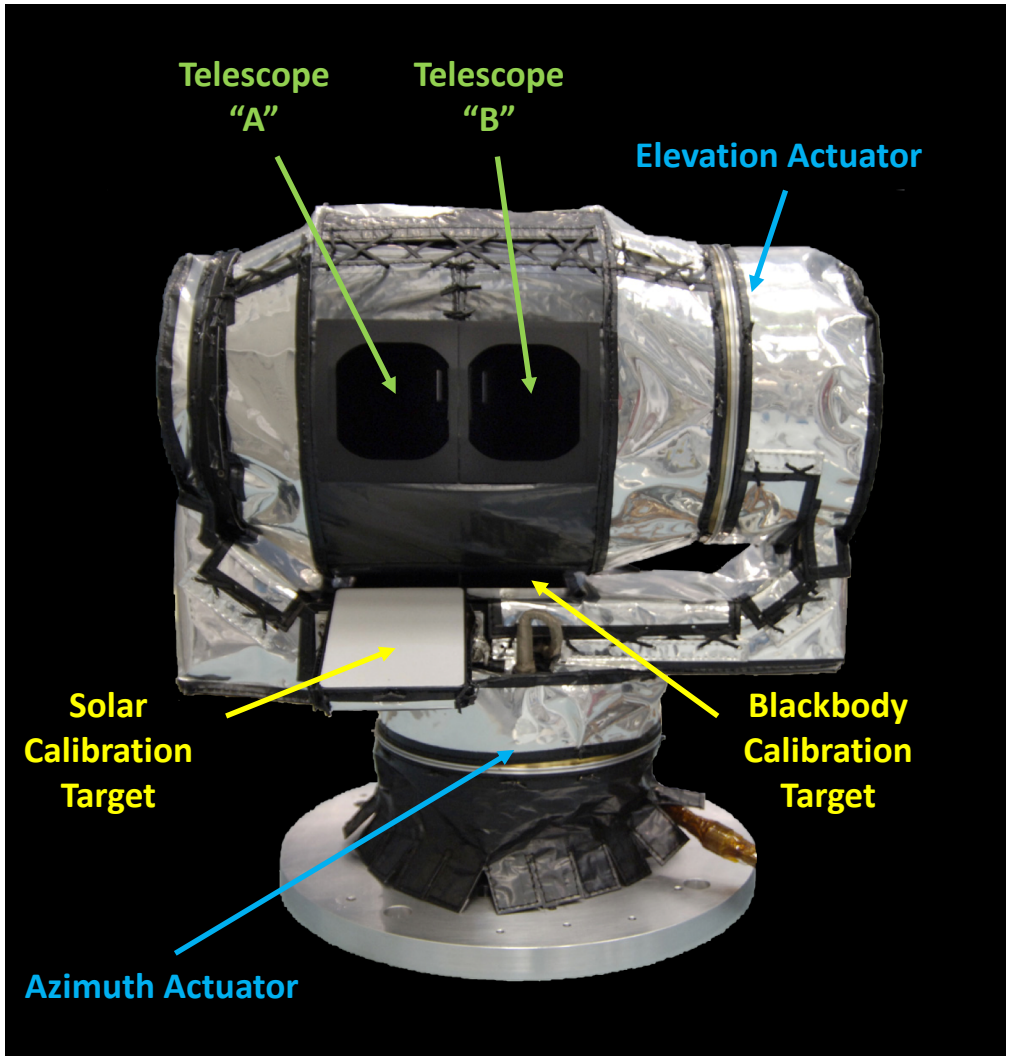
- Why does Diviner data correlate better with regolith composition than laboratory data?
  - LPSC 43 (2012)

- Standardized our instrumentation
- Expanded our Apollo sample collection
- Revised our methodology

Diviner Lunar Radiometer

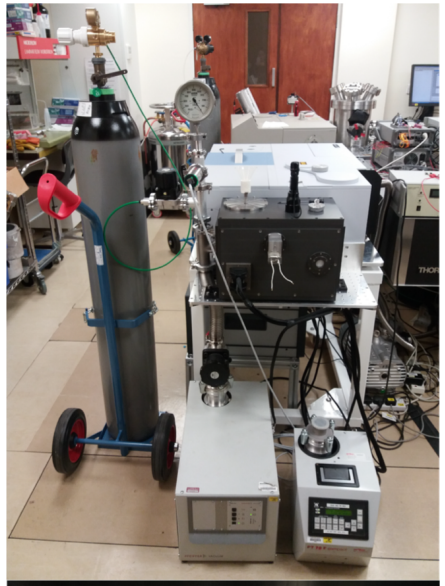


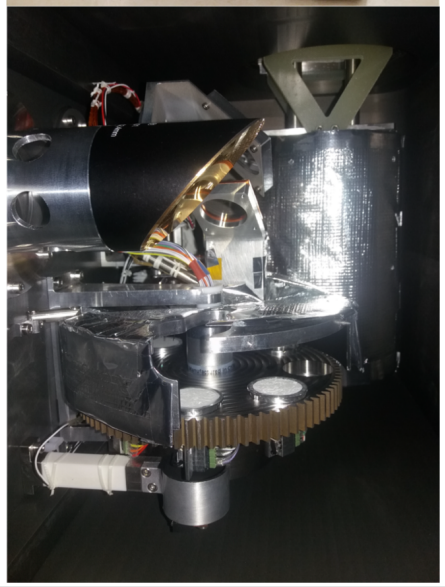
- **Spatial Resolution / Swath Width**
  - 320 m in track and 160 m cross track at 50 km altitude (6.7 x 3.4 mrad)
  - 3.4 km swath at 50 km altitude (71 mrad)
  - Current orbit is ~50 x ~135 km ellipse



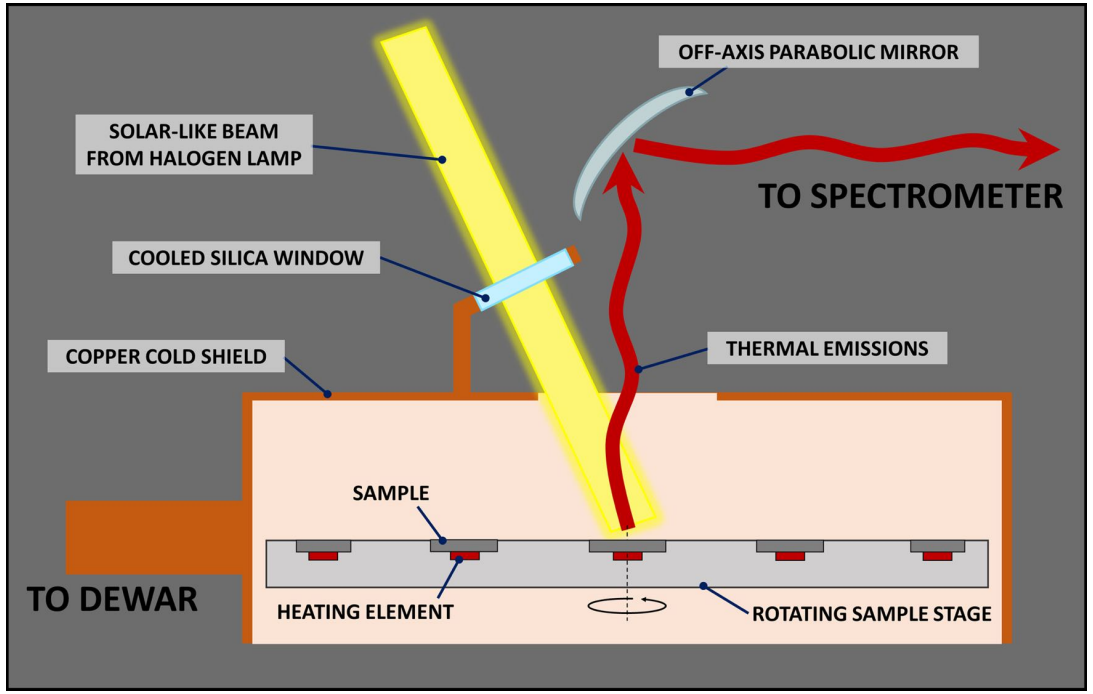
- **Azimuth and Elevation Actuators**
  - 270° range of motion for each actuator
- **Blackbody and Solar Calibration Targets**

Simulated Lunar Environment with PASCALE





Planetary Analogue Surface Chamber for Asteroid and Lunar Environments (PASCALE)



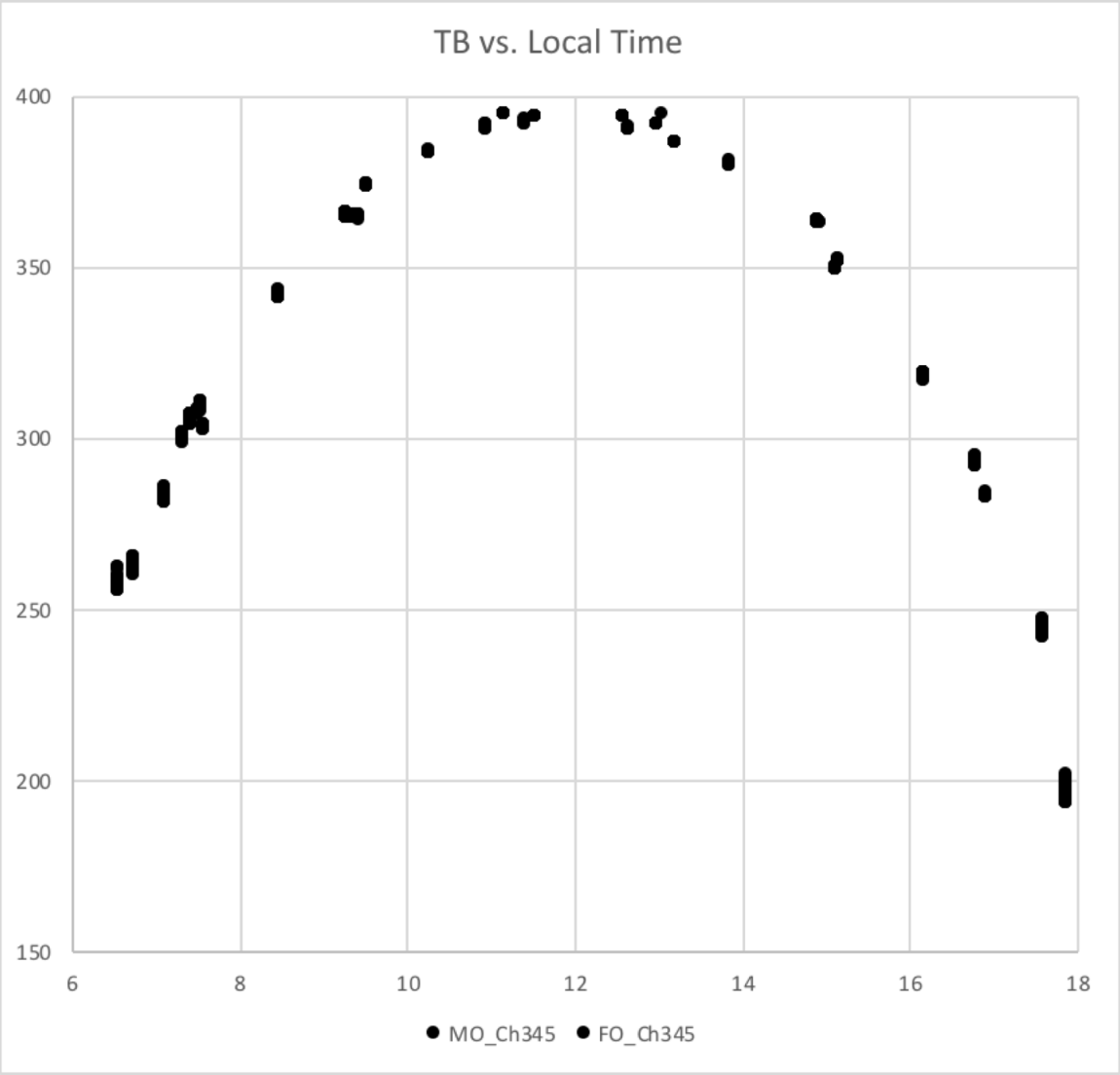
Illumination angle is approximately 52º

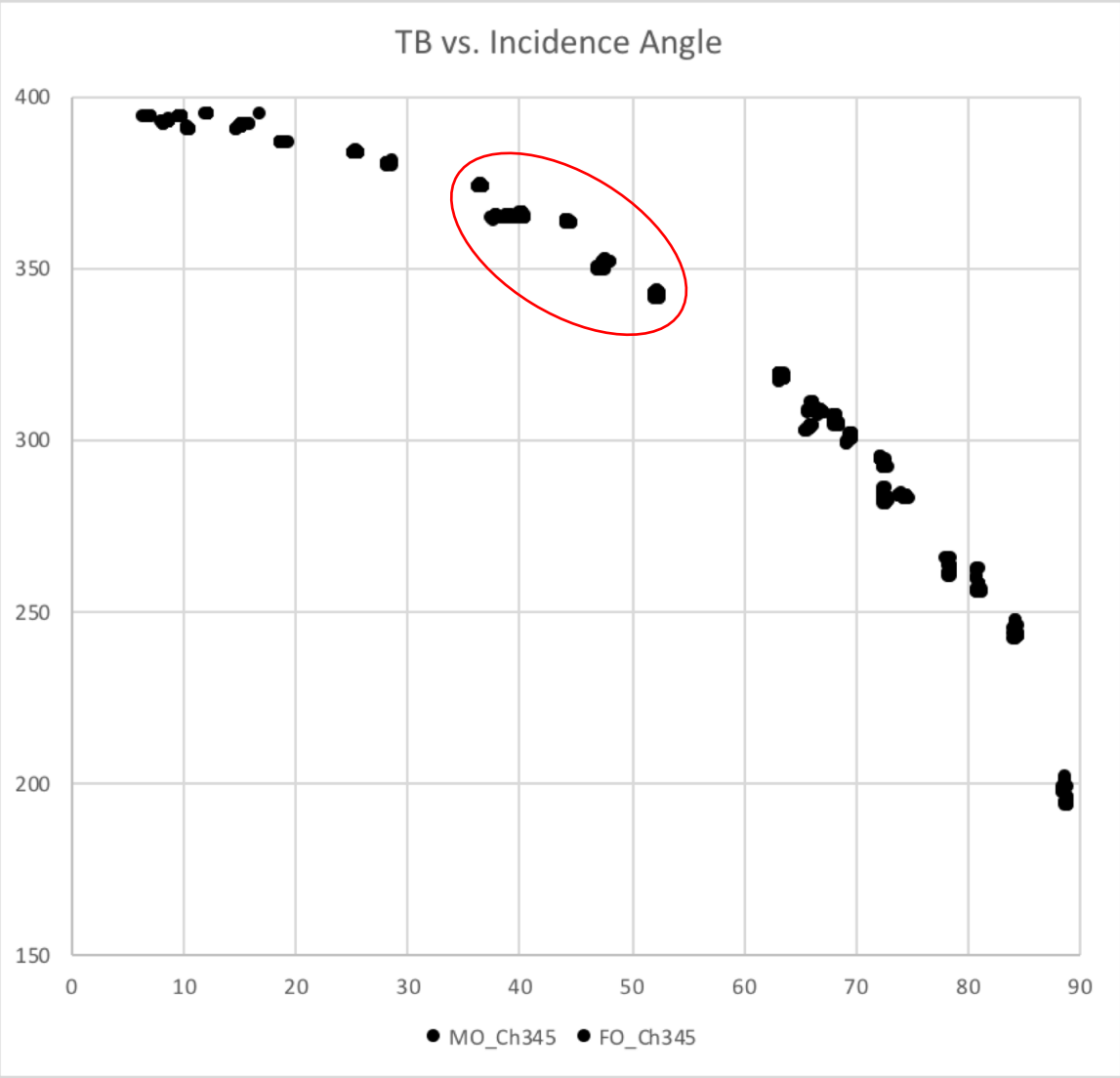
- Heating to midday temperatures is unphysical

- Specifically designed thermal-vacuum chamber to simulate conditions on the lunar surface (Thomas et al., 2012)
  - Pressure: <10-4 mbar
  - Cold Shroud: <135K
  - Sample heating up to ~410K
  - Solar-like illumination
  - FTIR Spectrometer

- Additional SLE-capable Chambers
  - SLEC (Univ. Oxford)
  - SABEL (JHU APL)
  - PARSEC (Stony Brook)
  - ALEC (Brown Univ.)

Example for Apollo 11 LM / Soil 10084





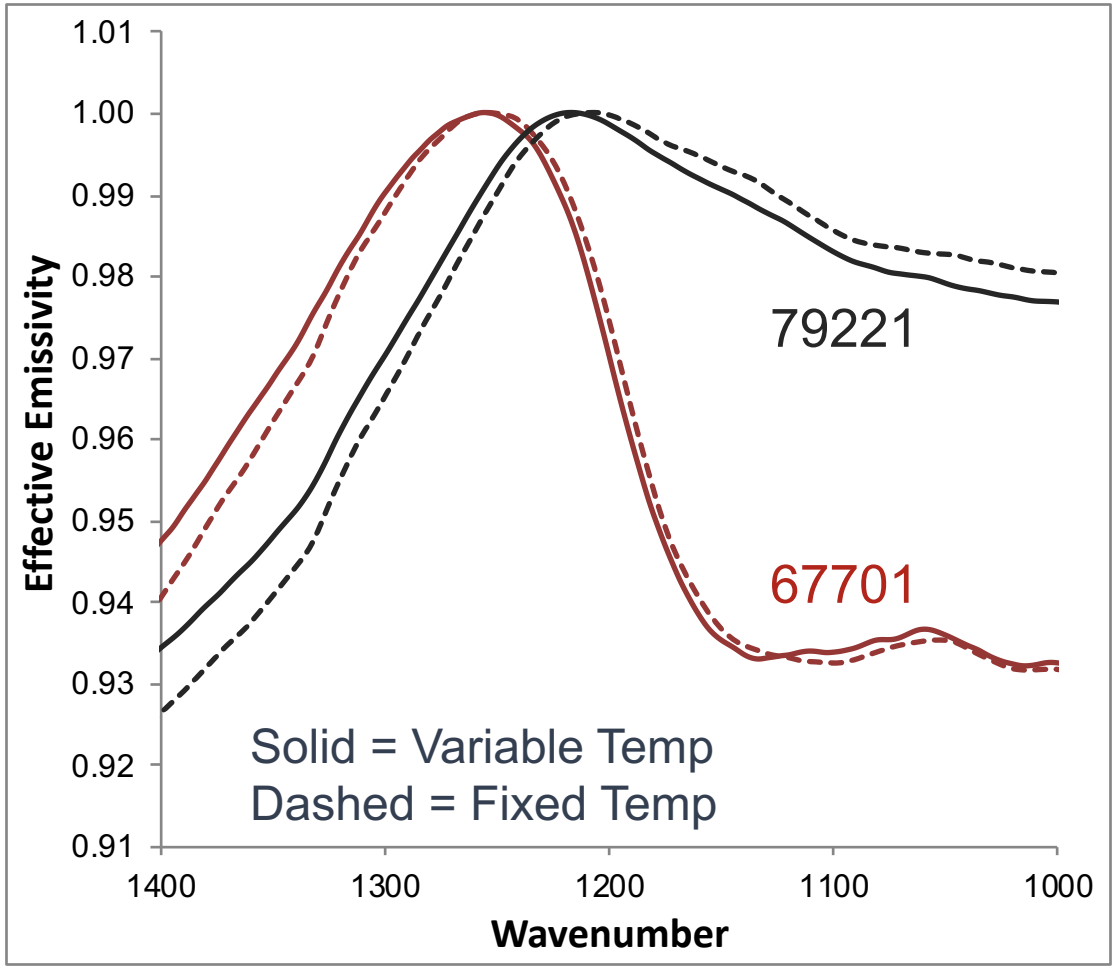
Apollo Samples Used In This Study

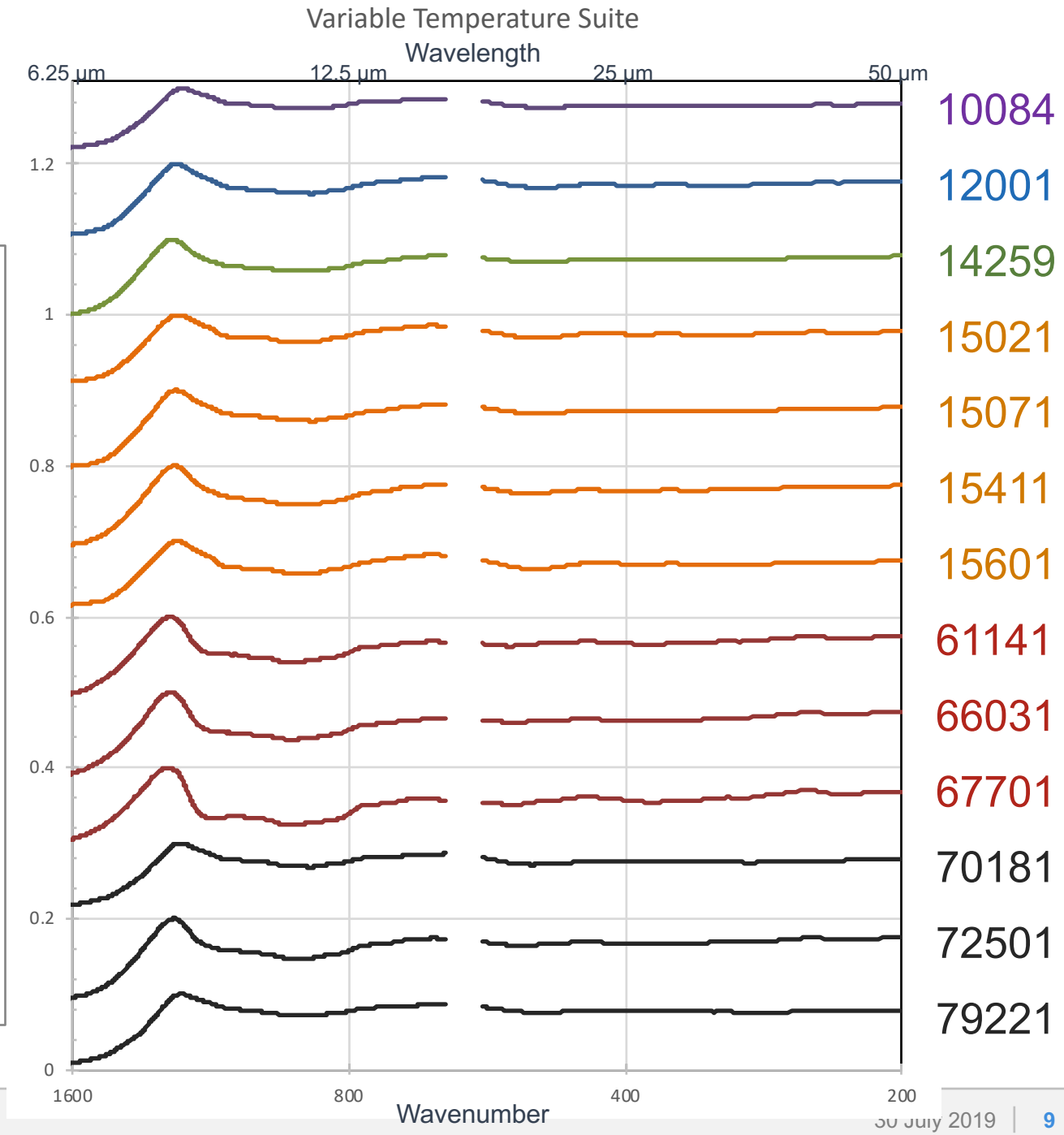
							Local Noon			PASCALE (i~52.5)		
Apollo Site	Station	Lat	Lon	Soil	Mass	Is/FeO	8 µm	13-23 µm	26-41 µm	8 µm	13-23 µm	26-41 µm
Apollo 11	LM	0.67	23.47	10084	5g	78	394.7	394.2	389.7	342.5	338.1	333.5
Apollo 12	LM	-3.01	-23.42	12001	5g	56	395.6	394.5	390.1	343.3	338.5	333.7
Apollo 14	LM	-3.65	-17.47	14259	3.5 g	85	393.1	392.0	387.8	346.9	342.8	339.0
Apollo 15	LM	26.13	3.63	15021	3.5 g	70	382.7	381.4	377.5	343.5	339.4	336.0
Apollo 15	Sta. 1	26.03	3.61	15071	5g	52	378.2	376.5	372.5	348.7	343.5	338.2
Apollo 15	Sta. 7	25.98	3.67	15411	3.5 g	43	373.3	371.5	368.2	342.8	338.1	334.9
Apollo 15	Sta. 9a	26.13	3.56	15601	3.5 g	29	385.3	383.2	378.8	343.2	334.8	327.5
Apollo 16	Sta. 1	-8.98	15.45	61141	5g	56	388.3	386.5	382.3	338.8	333.2	329.0
Apollo 16	Sta. 6	-9.07	15.5	66031	3.5 g	102	389.3	387.4	383.4	336.6	330.8	326.6
Apollo 16	Sta. 11	-8.83	15.49	67701	3.5 g	39	381.0	377.9	373.5	323.1	311.0	305.3
Apollo 17	LM	20.19	30.76	70181	5g	47	389.1	388.2	383.2	343.5	338.6	334.0
Apollo 17	Sta. 2	20.09	30.54	72501	3.5 g	81	381.5	380.2	376.3	338.9	331.3	329.5
Apollo 17	Sta. 9	20.23	30.82	79221	3.5 g	81	388.7	387.7	383.5	345.7	341.0	336.3

Blue from UCLA
Gray from TIRES-LSCC

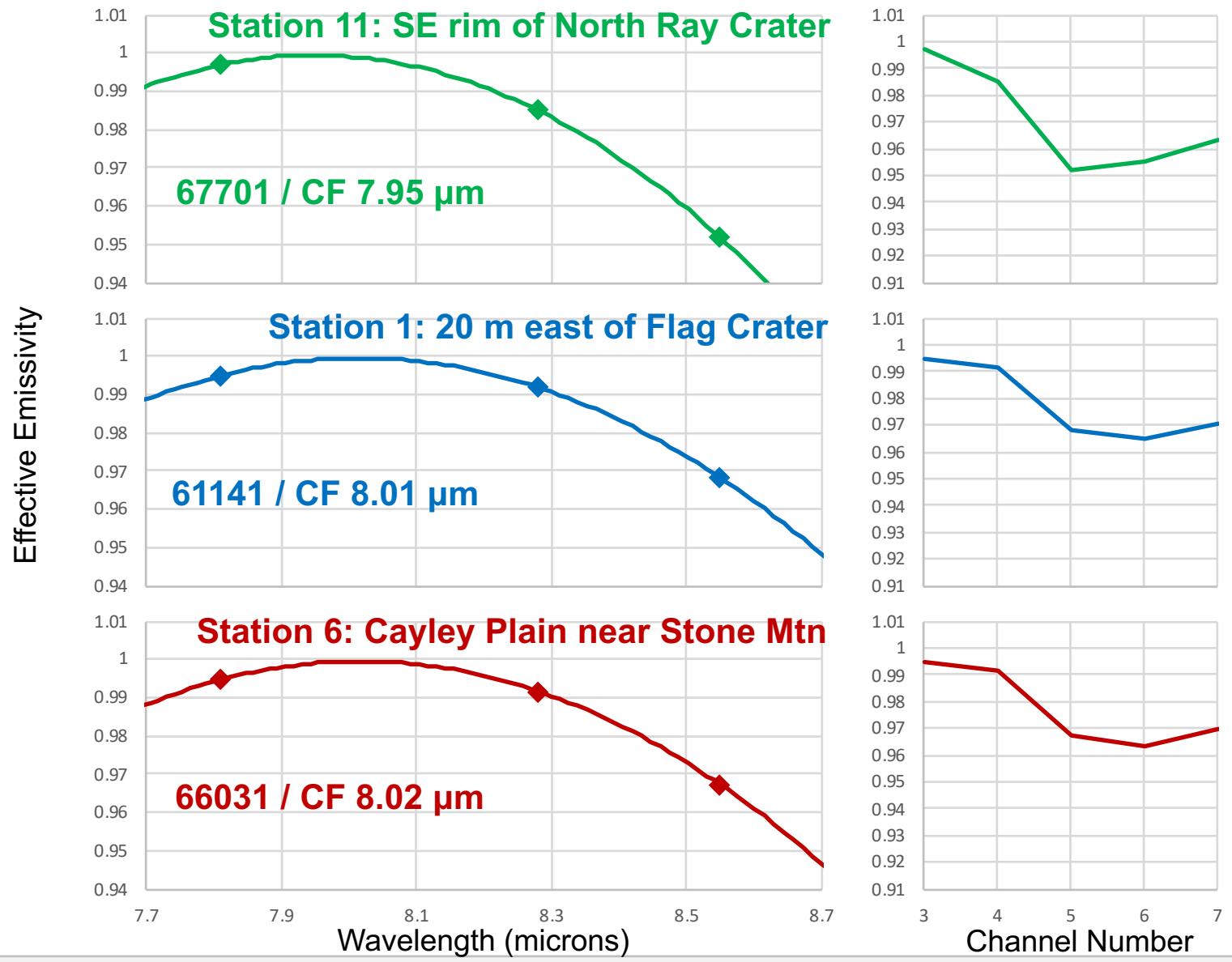
Sample Cup = 323K

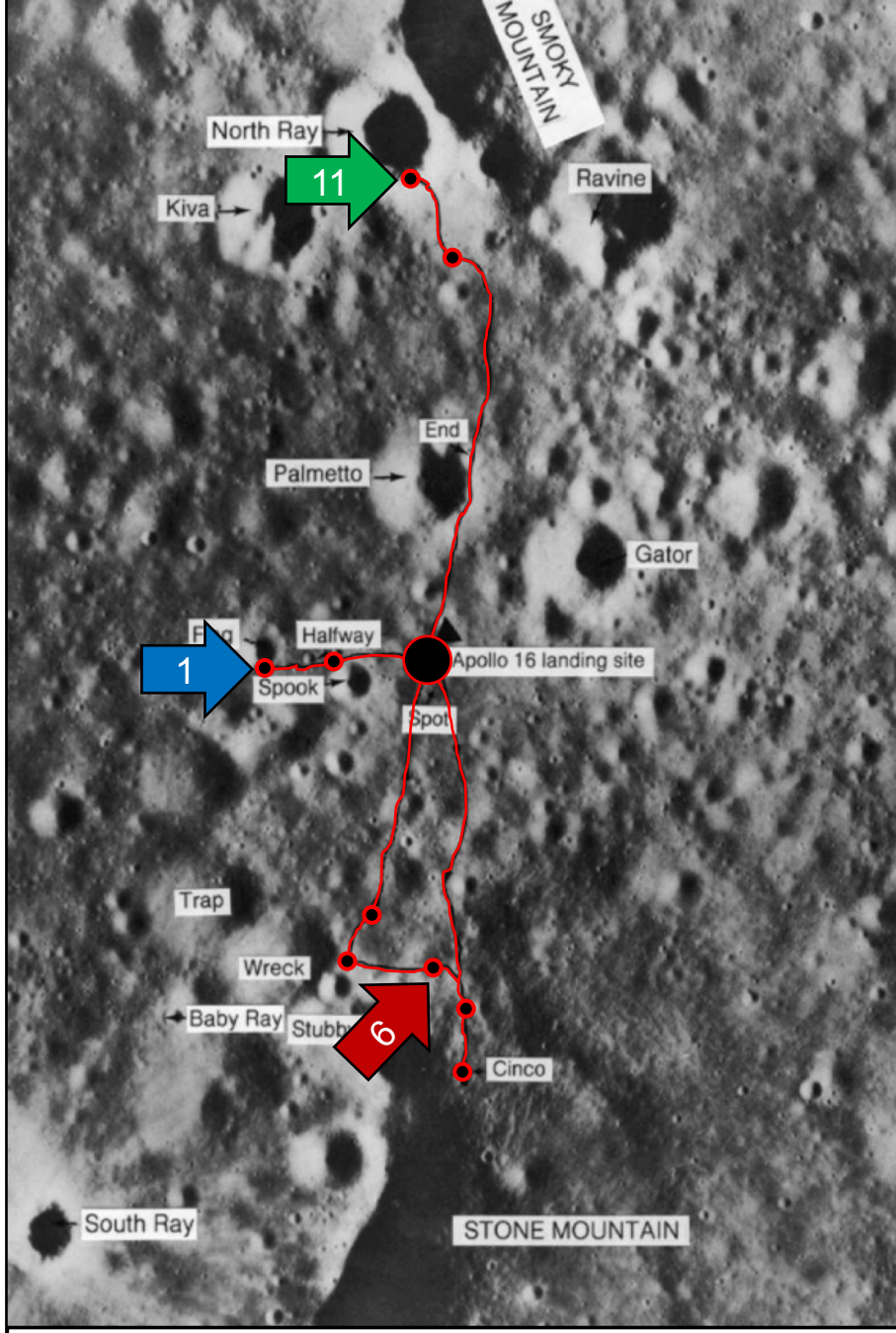
Spectra!


1.01
1.00
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
Effective Emissivity
1400
1300
1200
1100
1000
Wavenumber
79221
67701
Solid = Variable Temp
Dashed = Fixed Temp


Variable Temperature Suite
Wavelength
6.25 µm
12.5 µm
25 µm
50 µm
1.2
1
0.8
0.6
0.4
0.2
0
1600
800
400
200
Wavenumber
10084
12001
14259
15021
15071
15411
15601
61141
66031
67701
70181
72501
79221

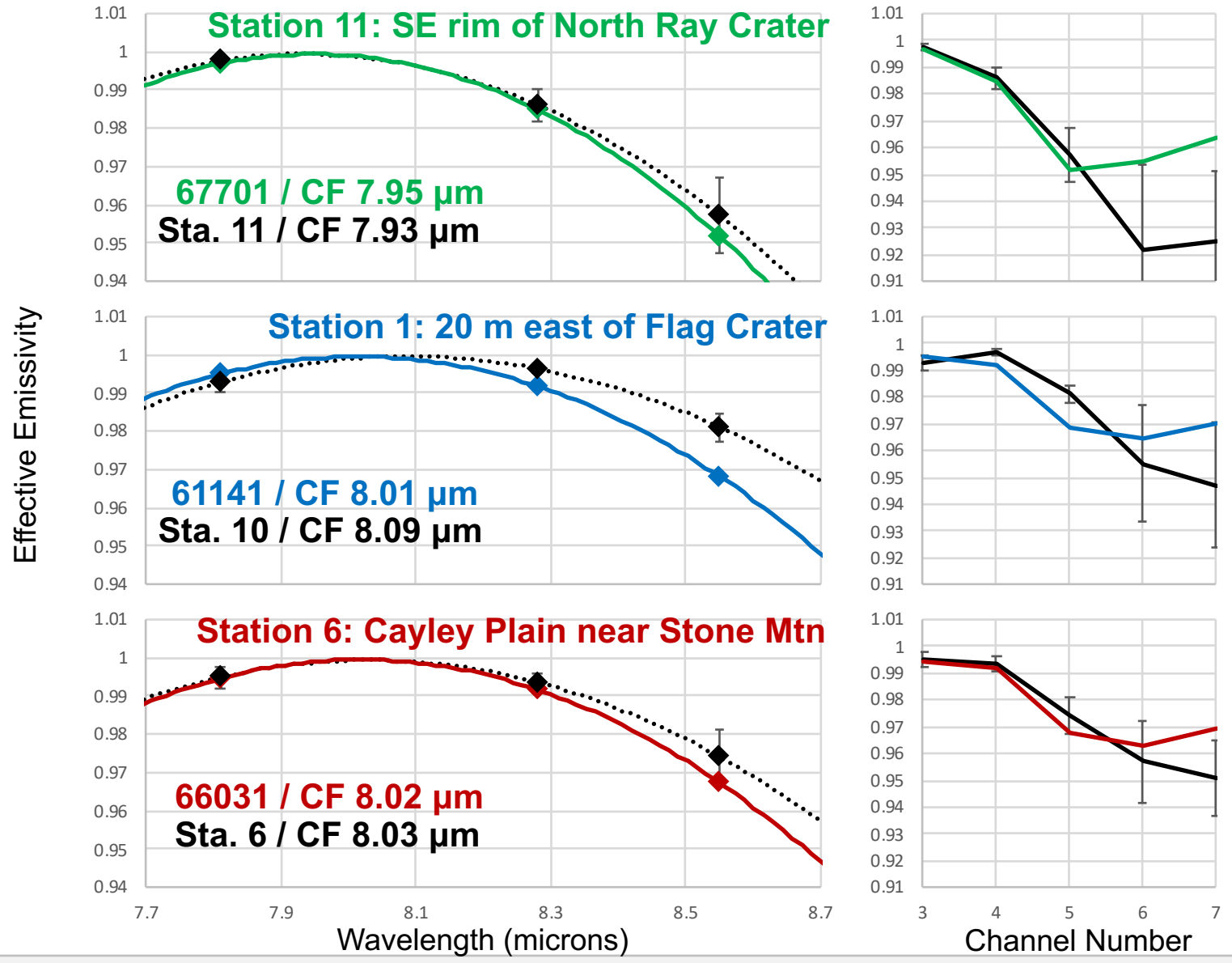
Example: Apollo 16

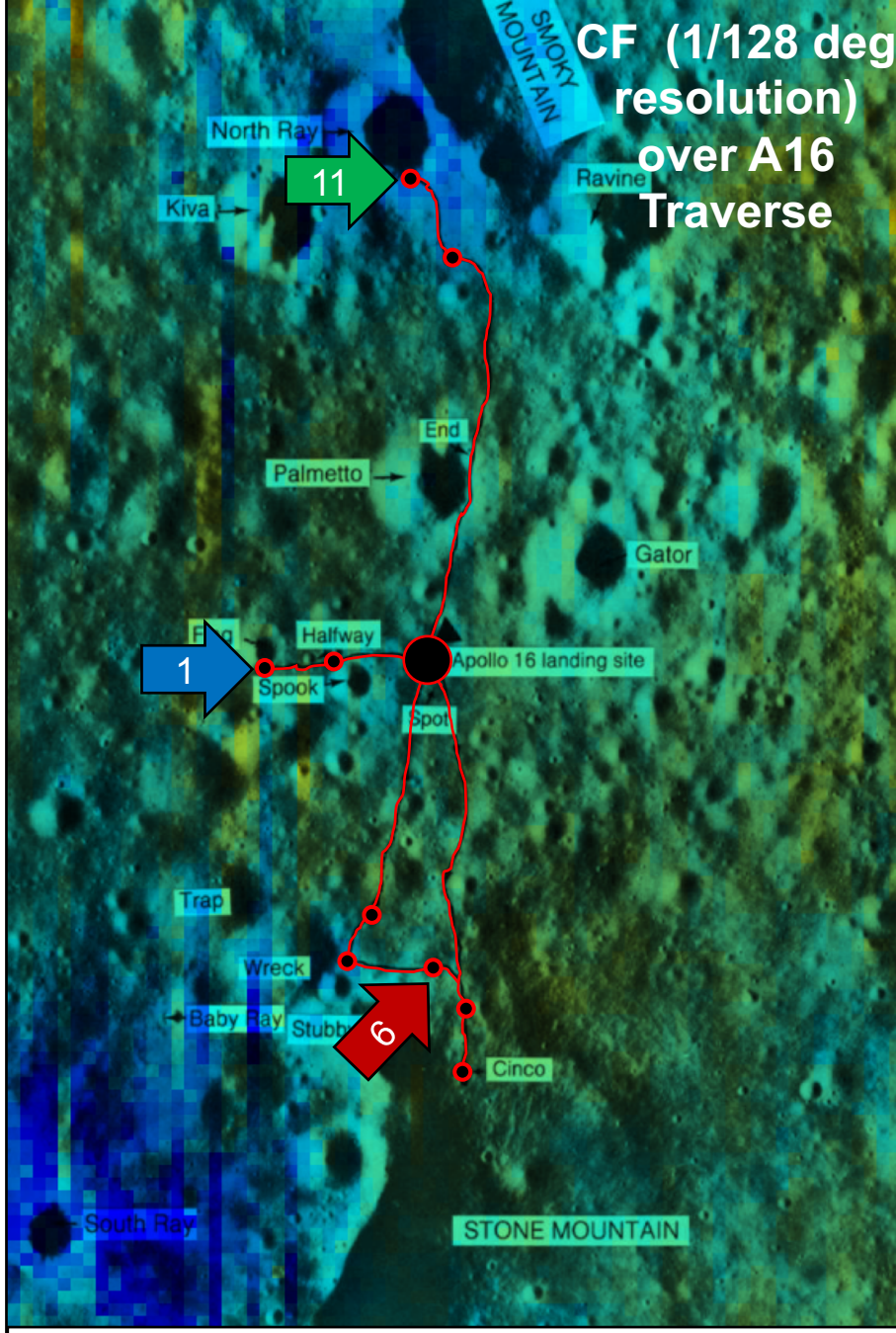




Apollo 16 4km

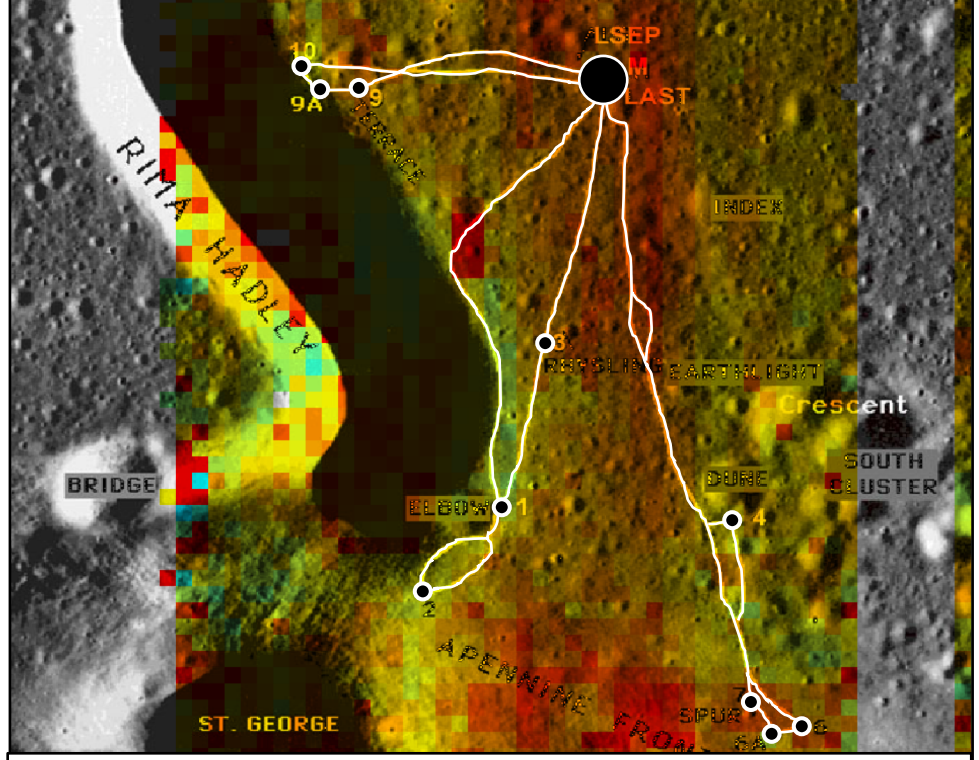
Example: Apollo 16





Apollo 16 4km

Additional Sites

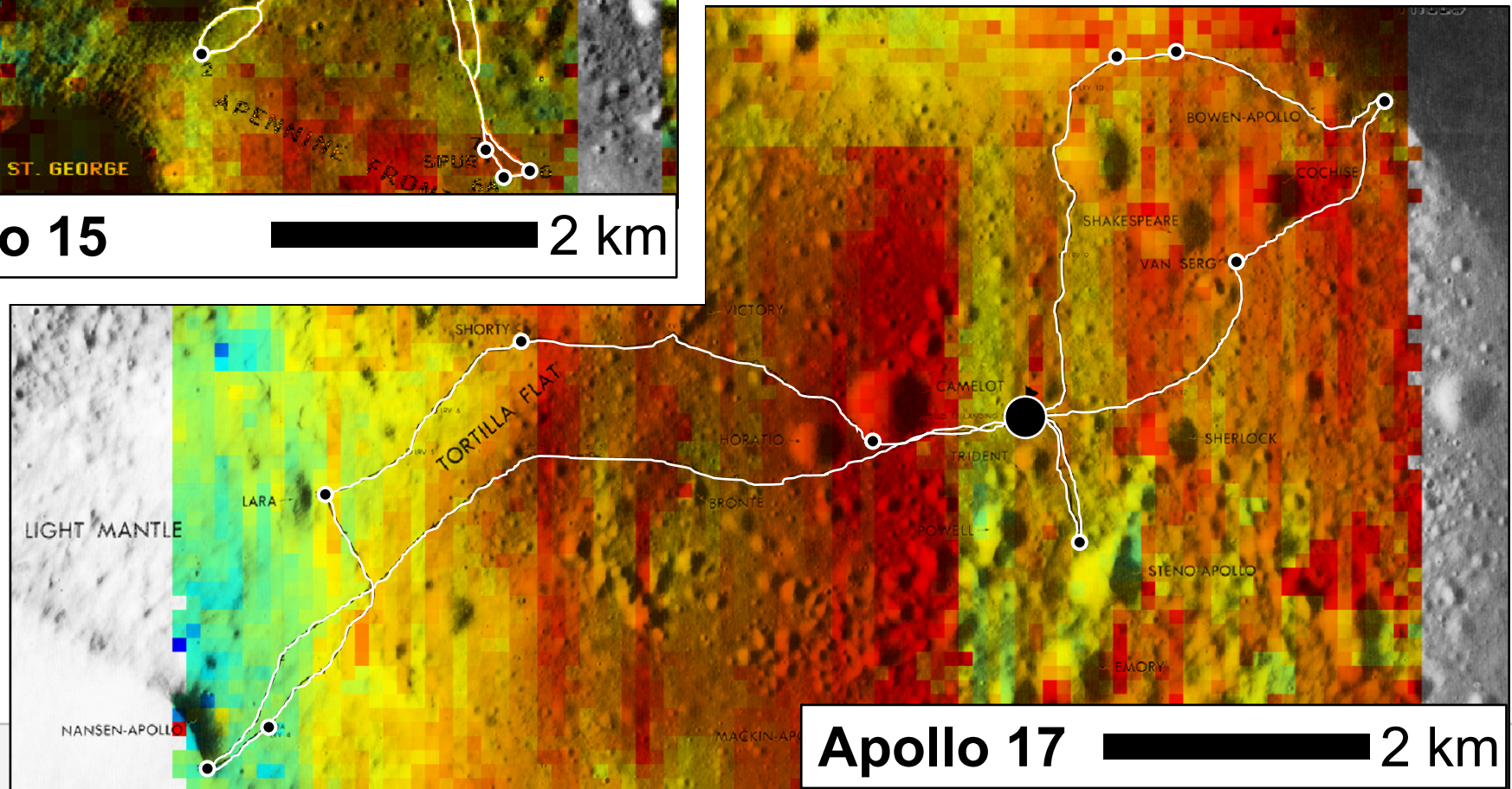


Apollo 15 2 km

Extended Diviner analysis to all Apollo 15 and 17 sampling stations

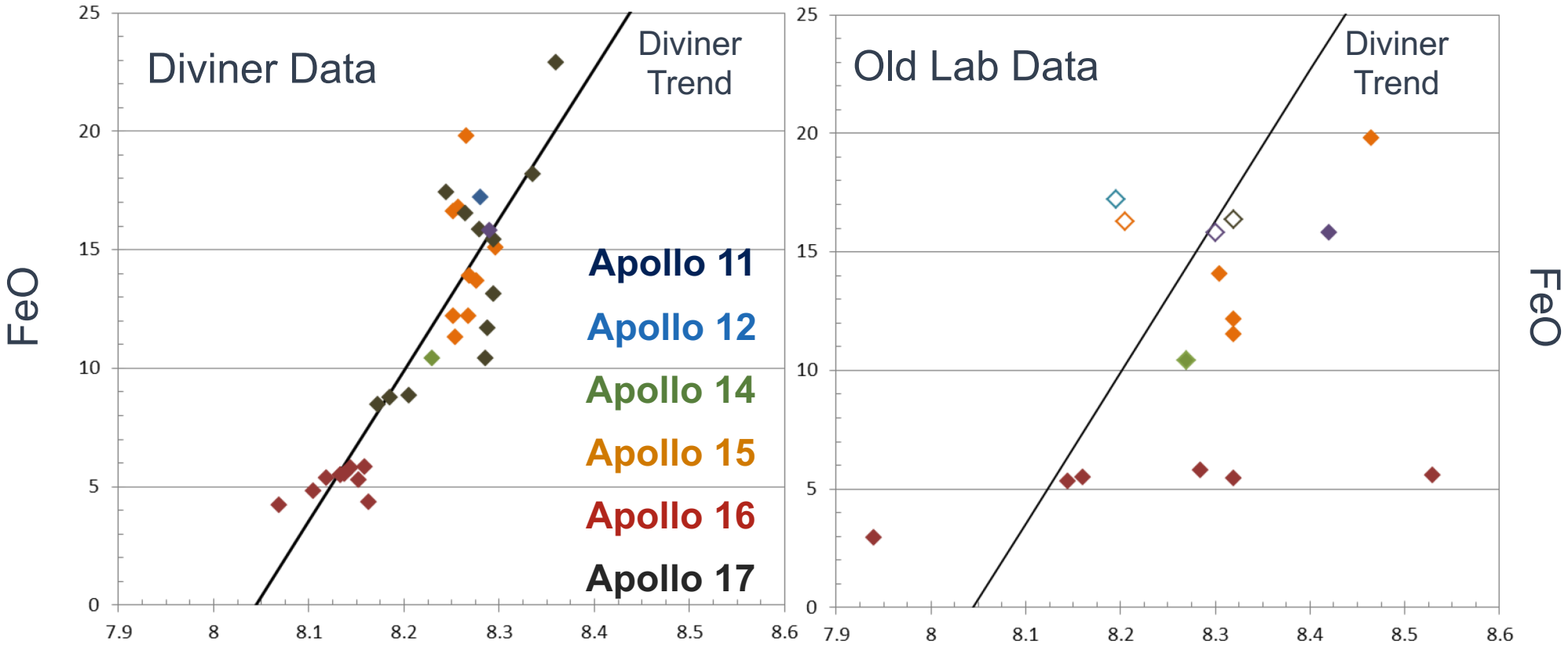
Used single point average for Apollo 11-14

Also, correlated all lunar soils measured In simulated lunar environment to geochemical properties



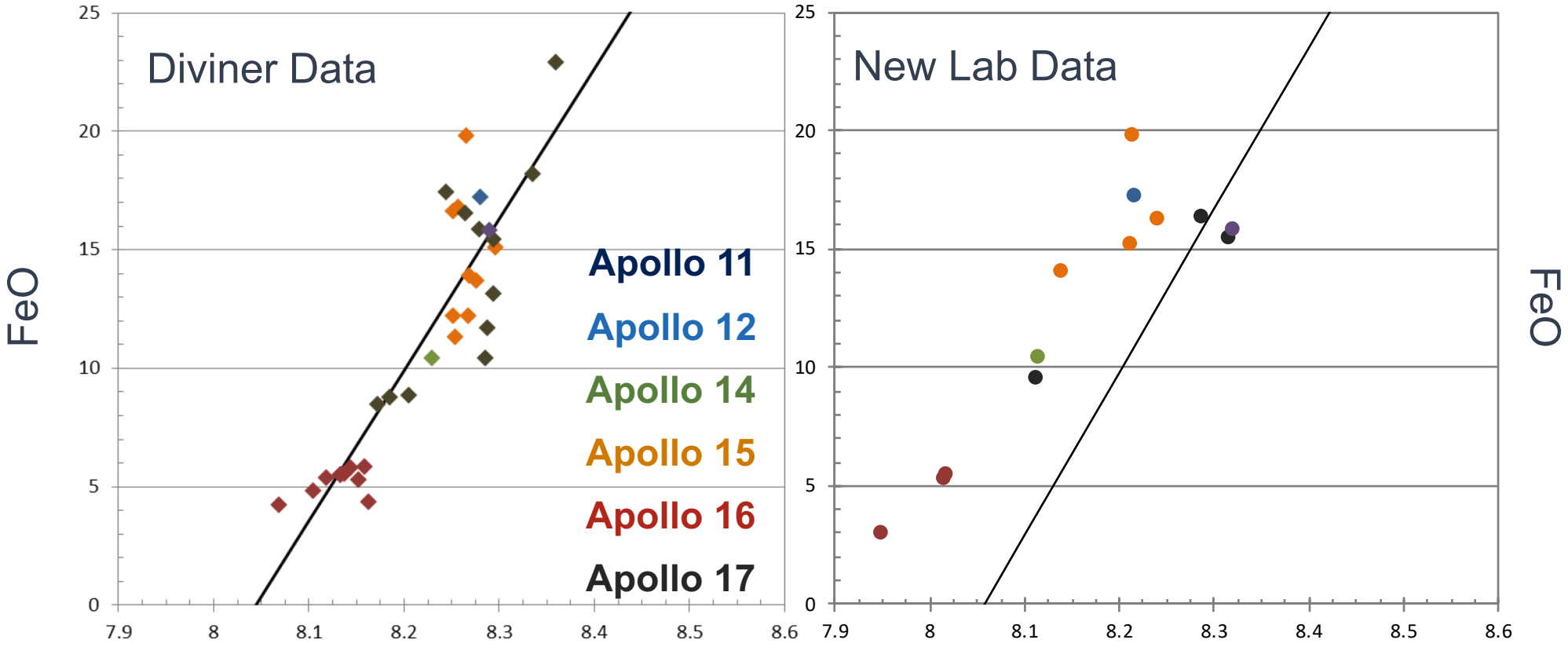
Apollo 17 2 km

So have the correlations improved?



- Diviner data are better correlated to geochemical trends than existing laboratory data

So have the correlations improved? Yes!



- New measurement have significantly less scatter away from the Diviner trend

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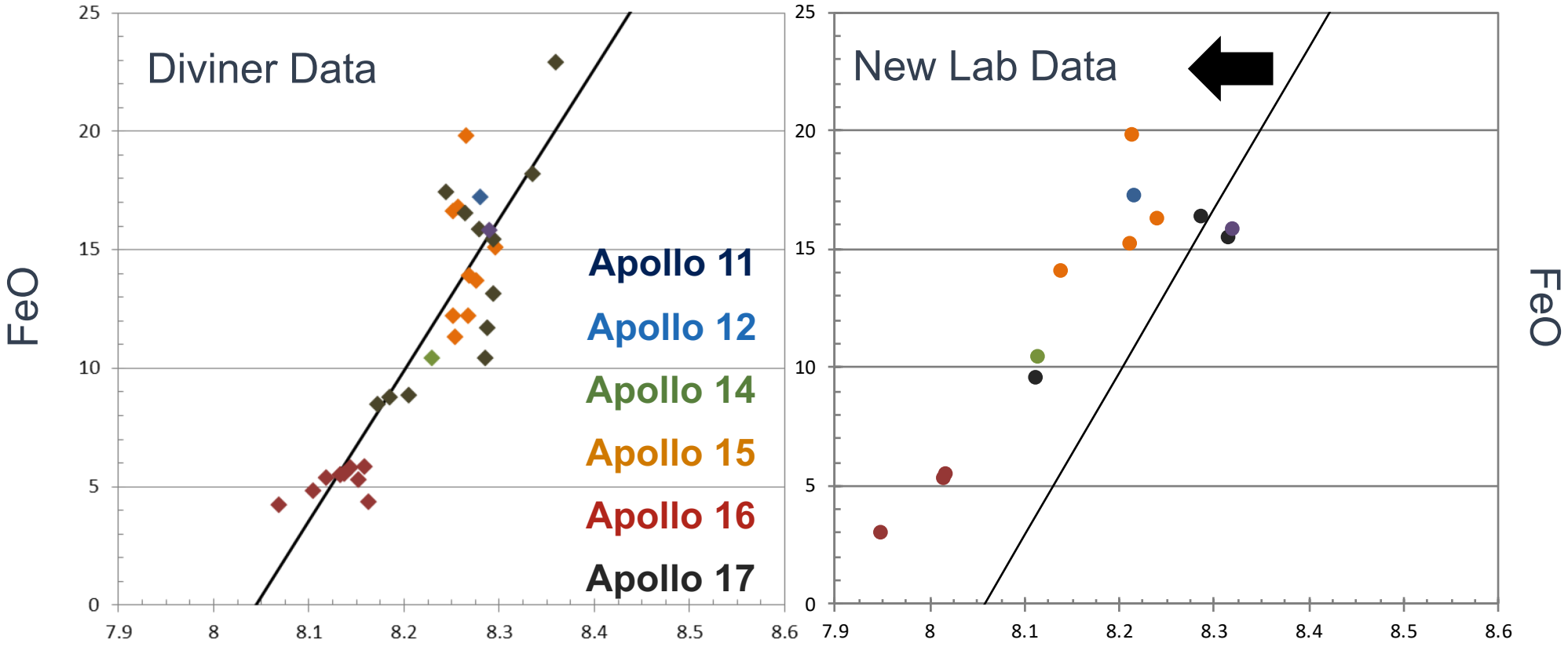
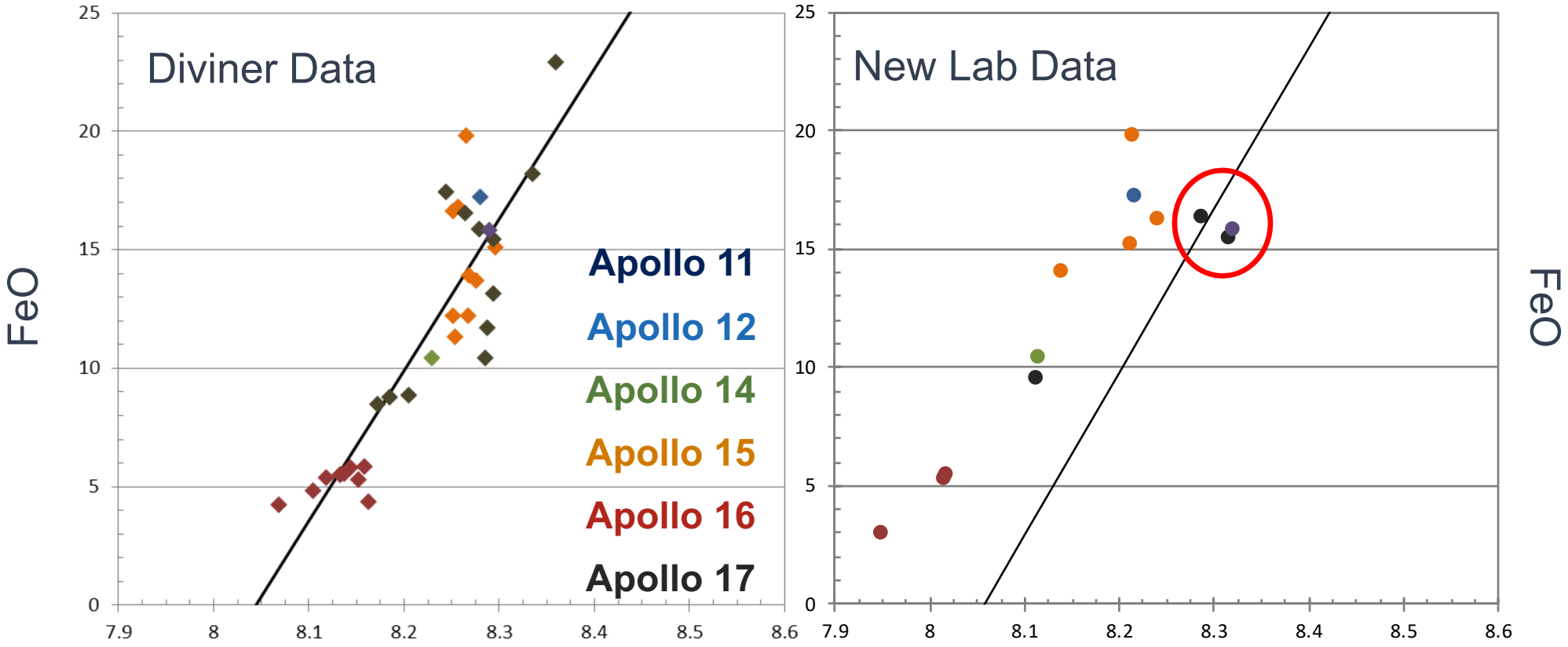


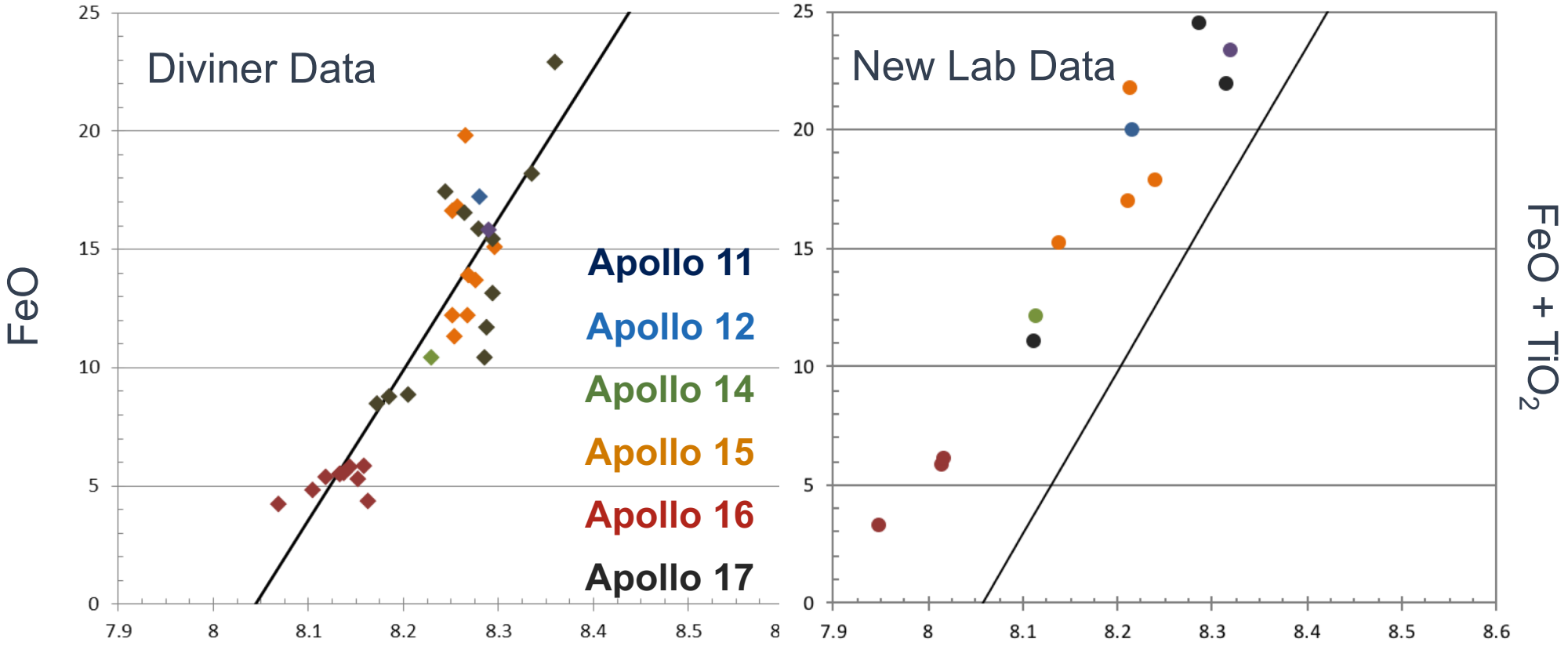
- New measurement have significantly less scatter away from the Diviner trend
- However, new measurements are at different temperatures, which will induce offsets from nominal behavior

What about those clustered points?



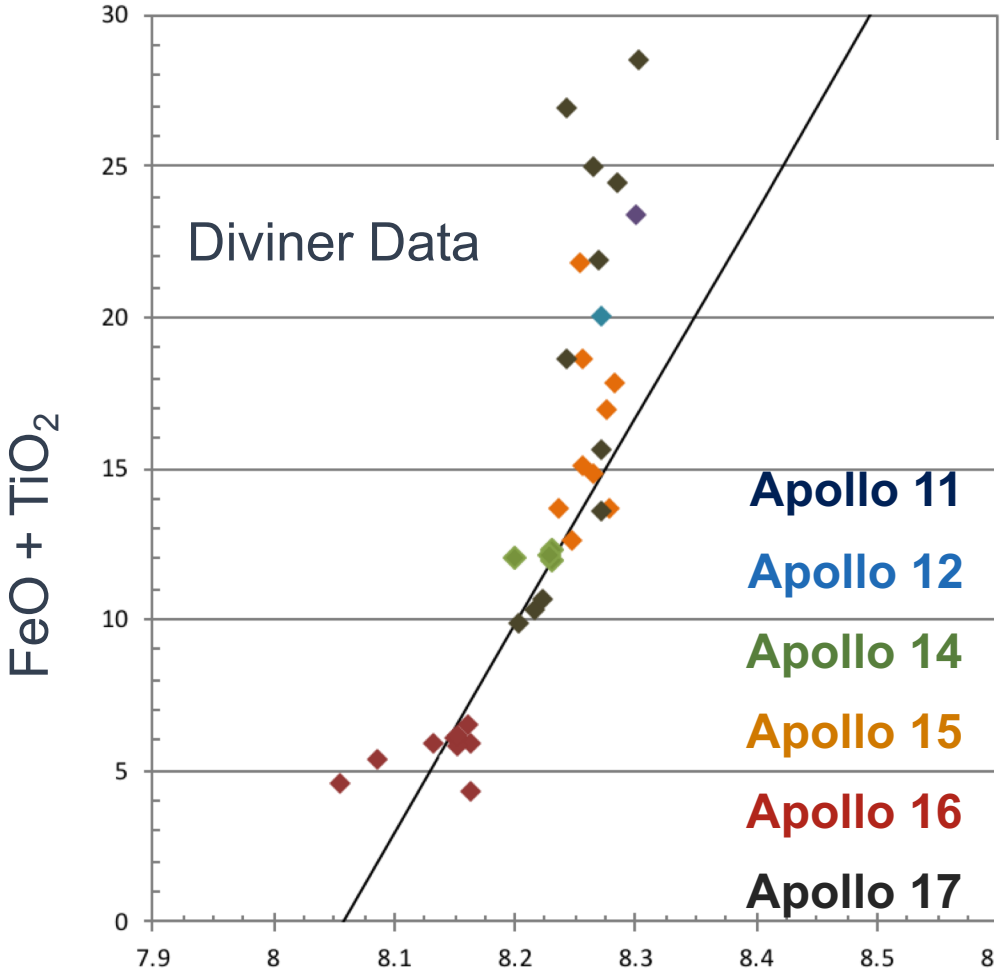
- Cluster of points off new lab data trend around 15 wt% FeO
- These are Apollo 11 and 17 high titanium basalts!
  - Ilmenite reduces albedo and is spectrally flat near 8 microns = shift to longer CF values

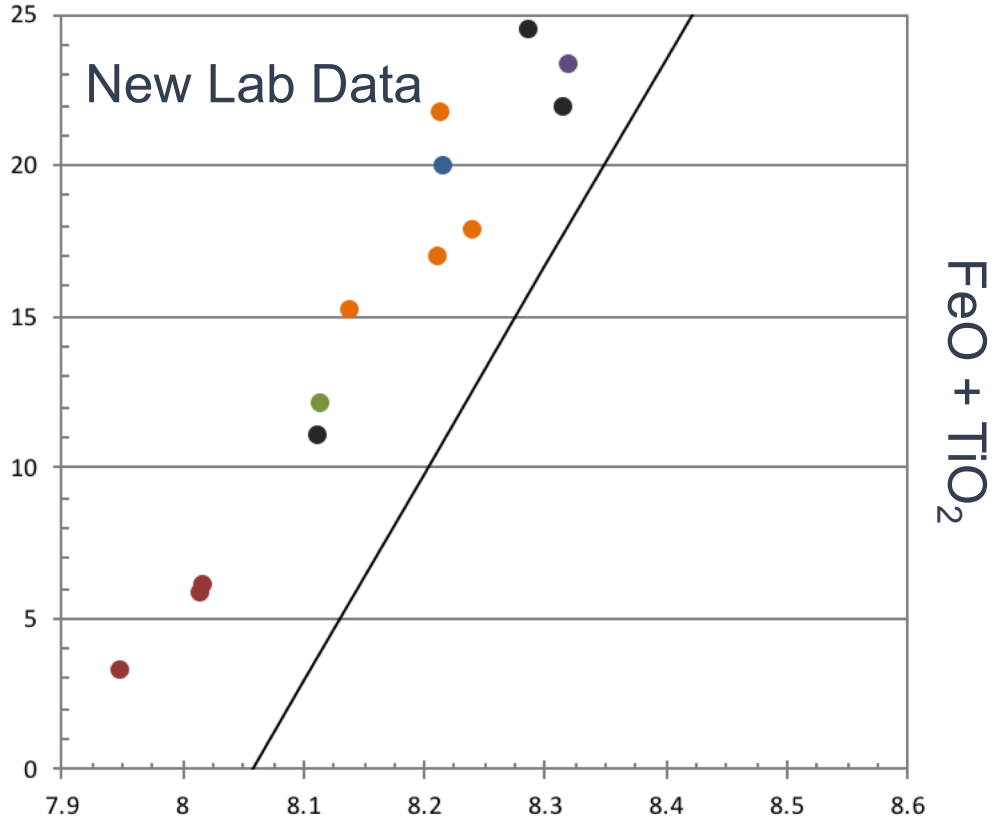
Considering FeO + TiO_2



- Summing FeO and TiO_2 improves trend of new lab data
  - Data still offset to shorter CF values due to 52º solar incidence

Considering FeO + TiO_2





- Summing FeO and TiO_2 improves trend of new lab data
  - Data still offset due to 52º solar incidence
- Summing FeO and TiO_2 significantly changes trend in Diviner data

Conclusions

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

- More representative thermal environments enable the measurement of unusual regolith compositions and aid interpretation of Diviner data

- Future work
  - Evaluation of Diviner emissivity data for laboratory-like incidence angles
  - Method for normalizing laboratory data to equatorial noon equivalent
    - How bad is the noontime temperature assumption with no surface roughness?
  - Continue to study the effects of surface roughness & space weathering
  - Systematic evaluation of the temperature-driven spectral shifts
    - Leverage other SLE chambers with different illumination geometry
    - Space Environment Goniometer (Univ. Oxford)