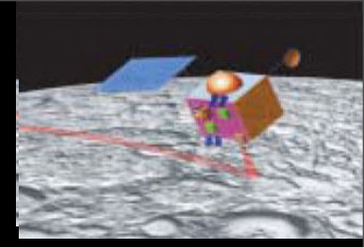
Remote Compositional Analysis of Lunar Olivine with Moon Mineralogy Mapper (M3) Vis/NIR Reflectance Spectra

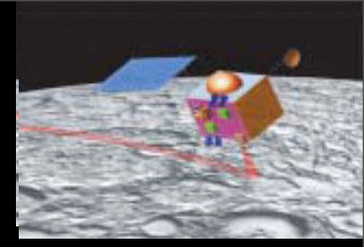
Peter Isaacson, Roger Clark, Jim Head, Rachel Klima, Noah Petro, Carlé Pieters, Matt Staid, Jessica Sunshine, Larry Taylor, Kevin Thaisen, Stefanie Tompkins, and the M³ Team

Outline



- Compositional evaluation of lunar olivine: Overview of methodology
- Results of compositional analysis for olivines observed at:
  - Moscoviense basin,
  - Copernicus central peak
  - Aristarchus
- Compositional study of Copernicus: current results

Importance of Olivine

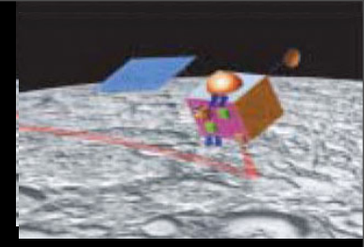


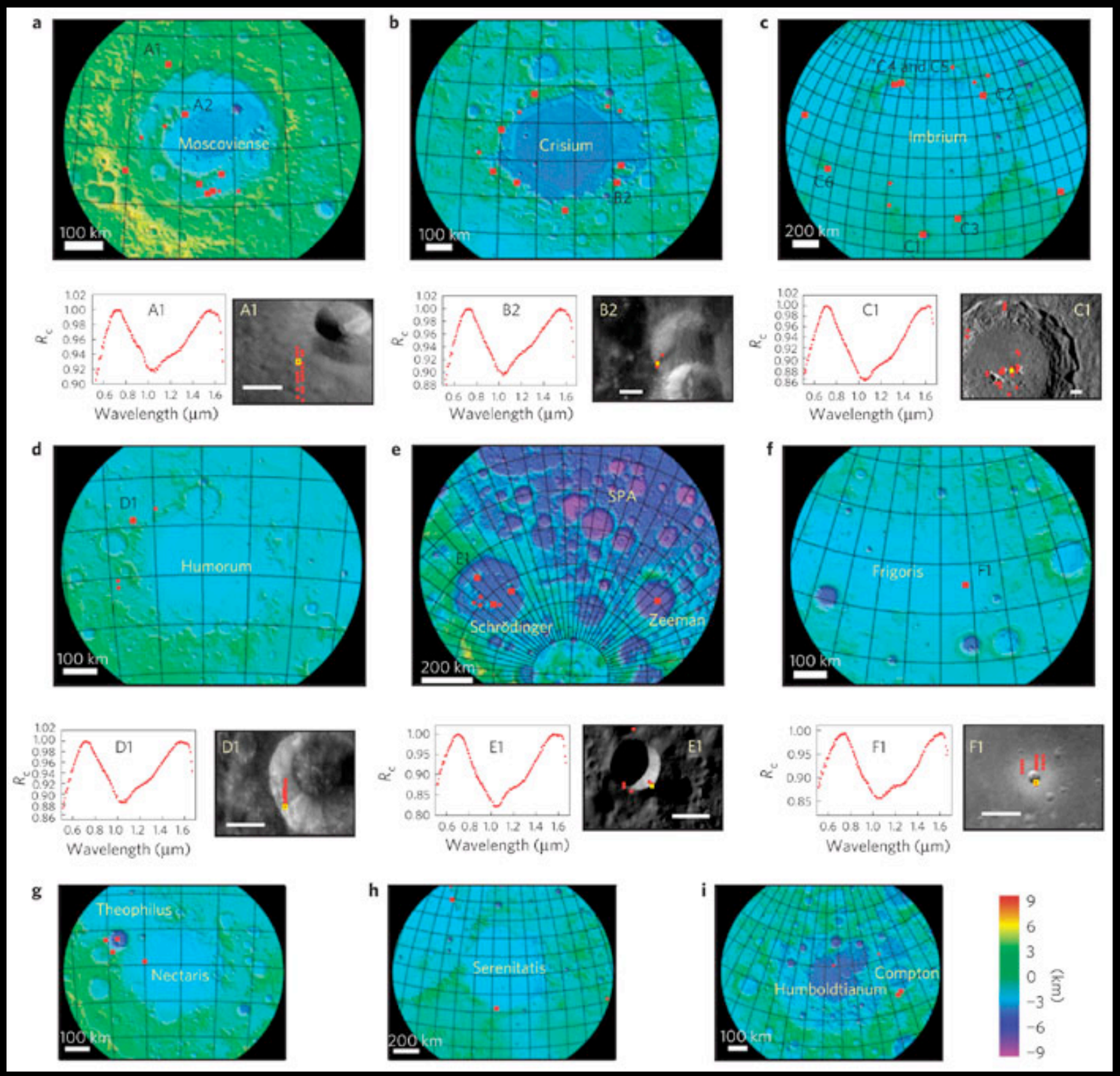
Apollo 17 troctolite 76535

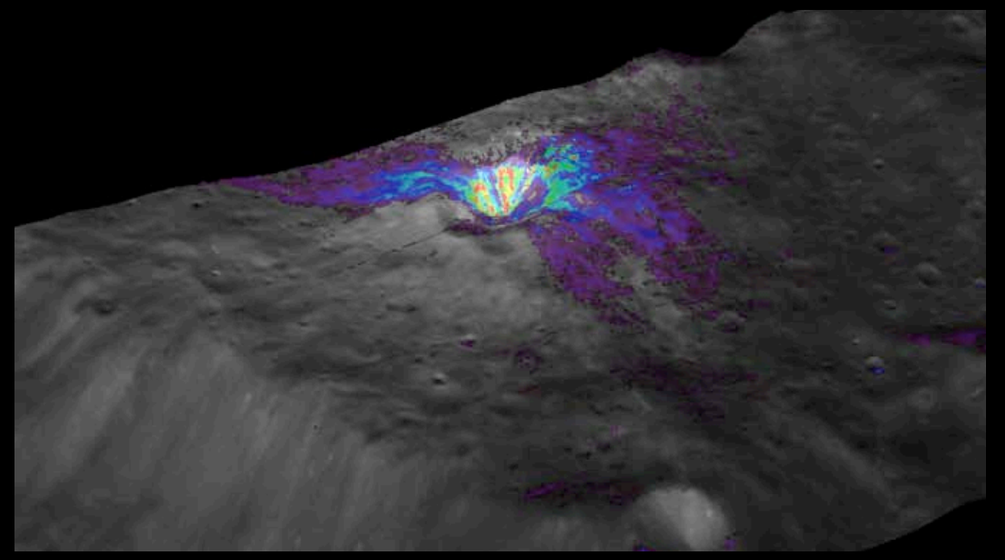
NASA/Johnson Space Center photograph

- First to crystalize from magma ocean
- Likely a dominant mineral in the lunar mantle
- Occurrence and context may indicate exposures of mantle and provide constraints for evolution of lunar crust and mantle
- Olivine composition an important clue to source and relevant geologic processes

Beyond Distribution

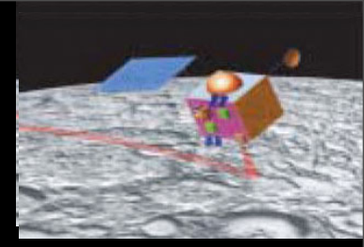


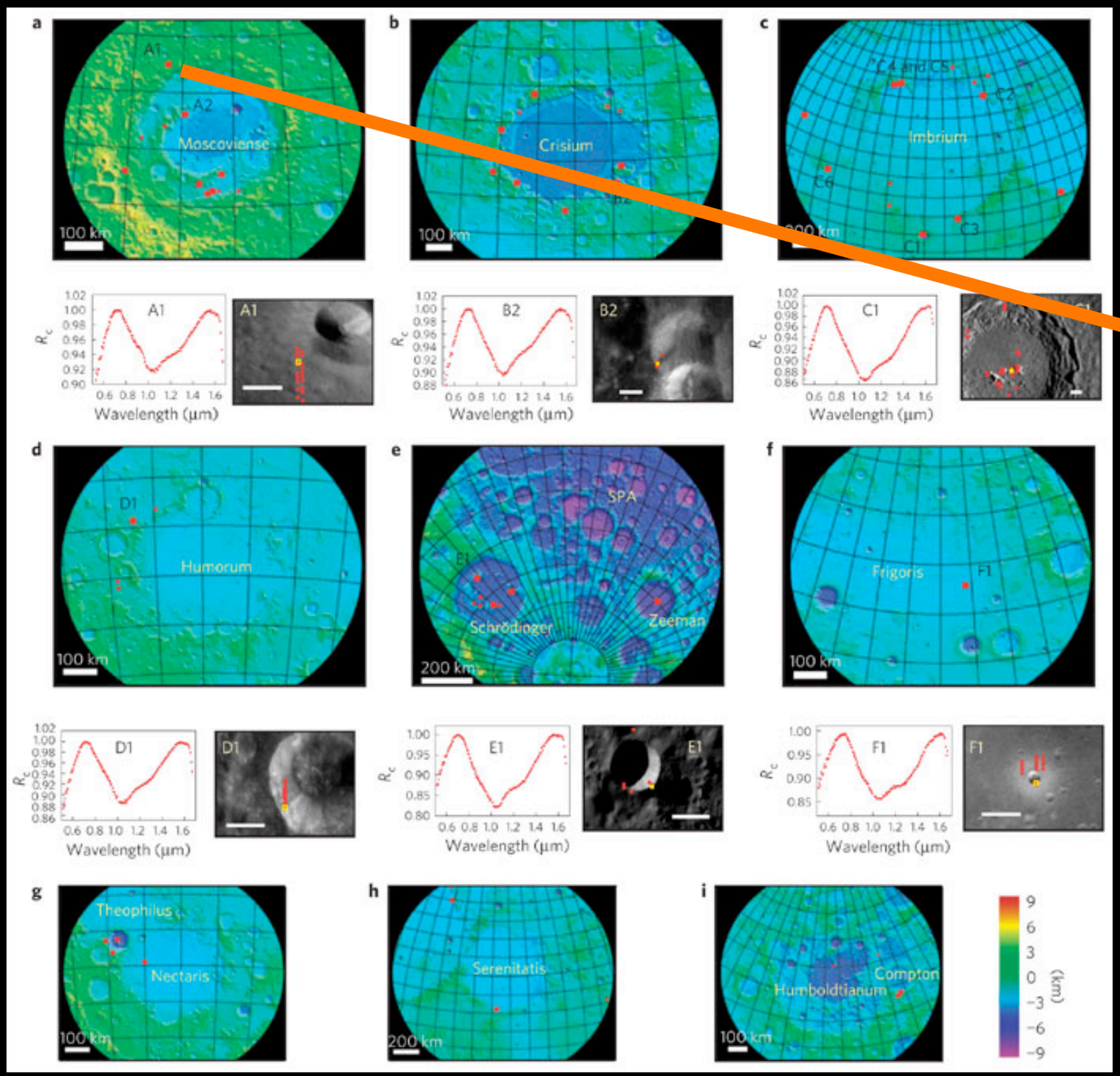


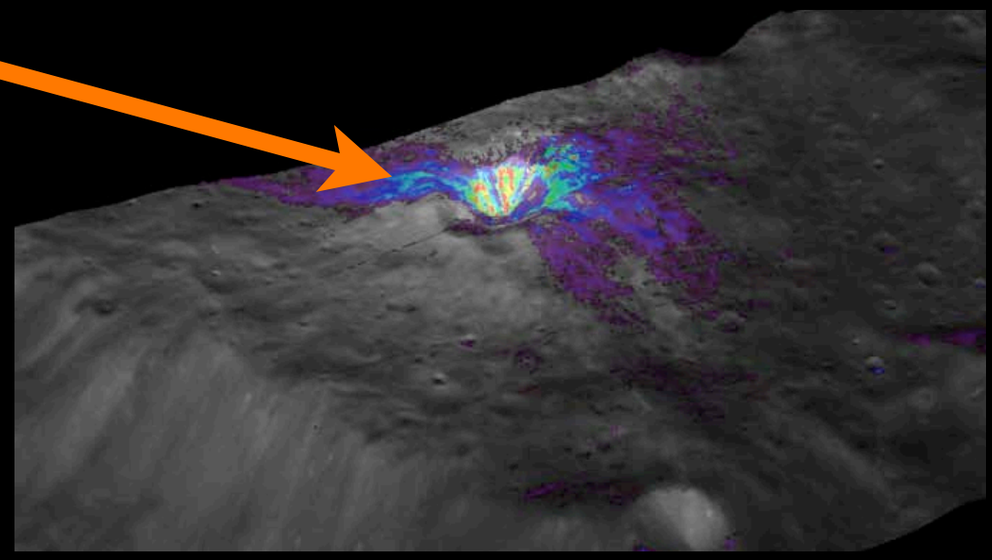


Yamamoto et al., 2010

Beyond Distribution

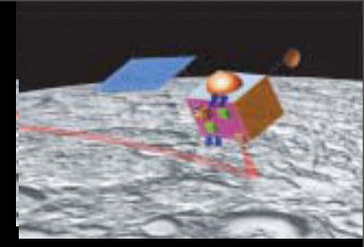




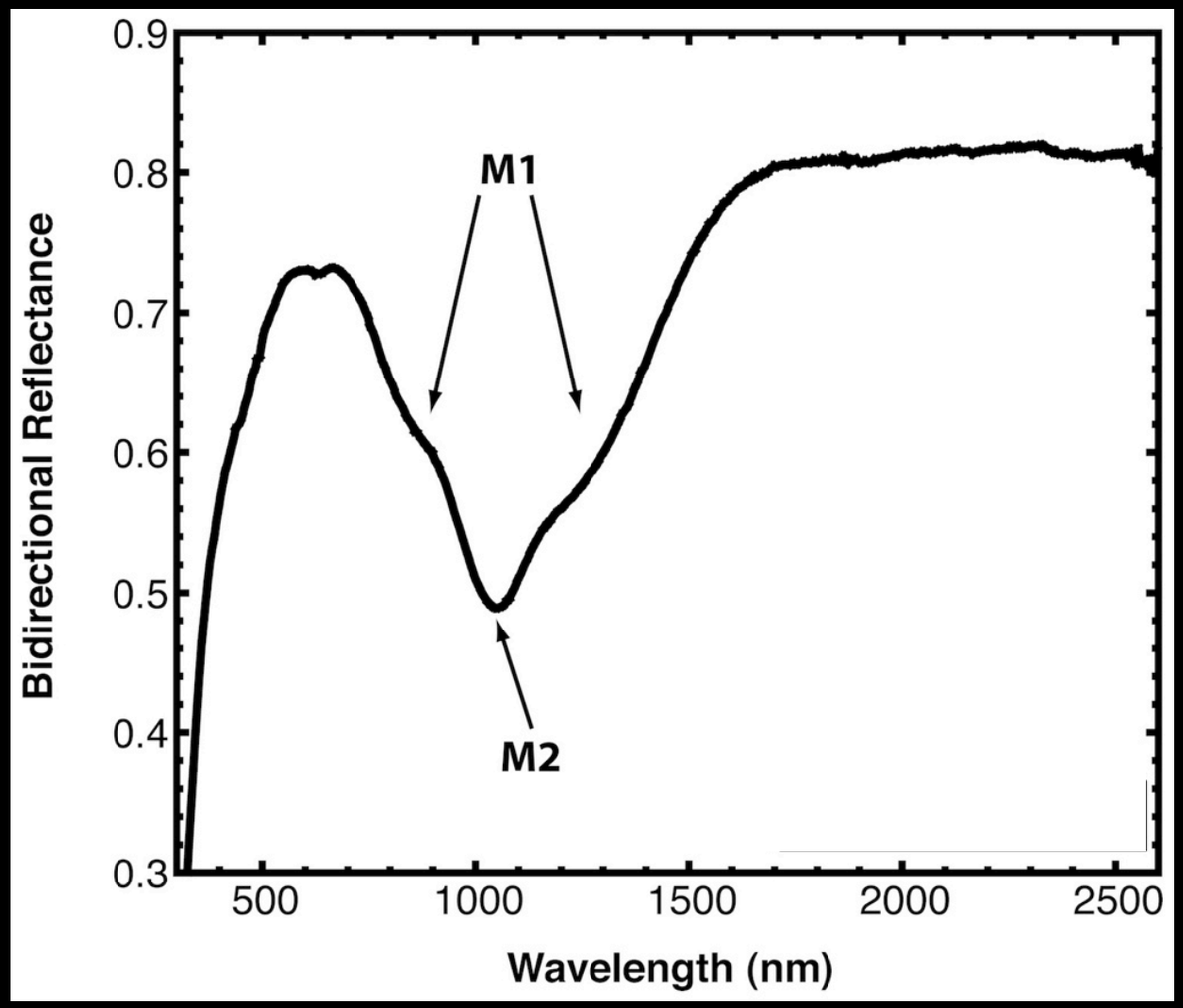


Yamamoto et al., 2010

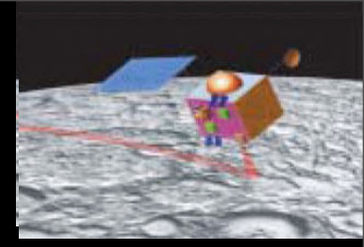
Background: Basics of Olivine Spectroscopy

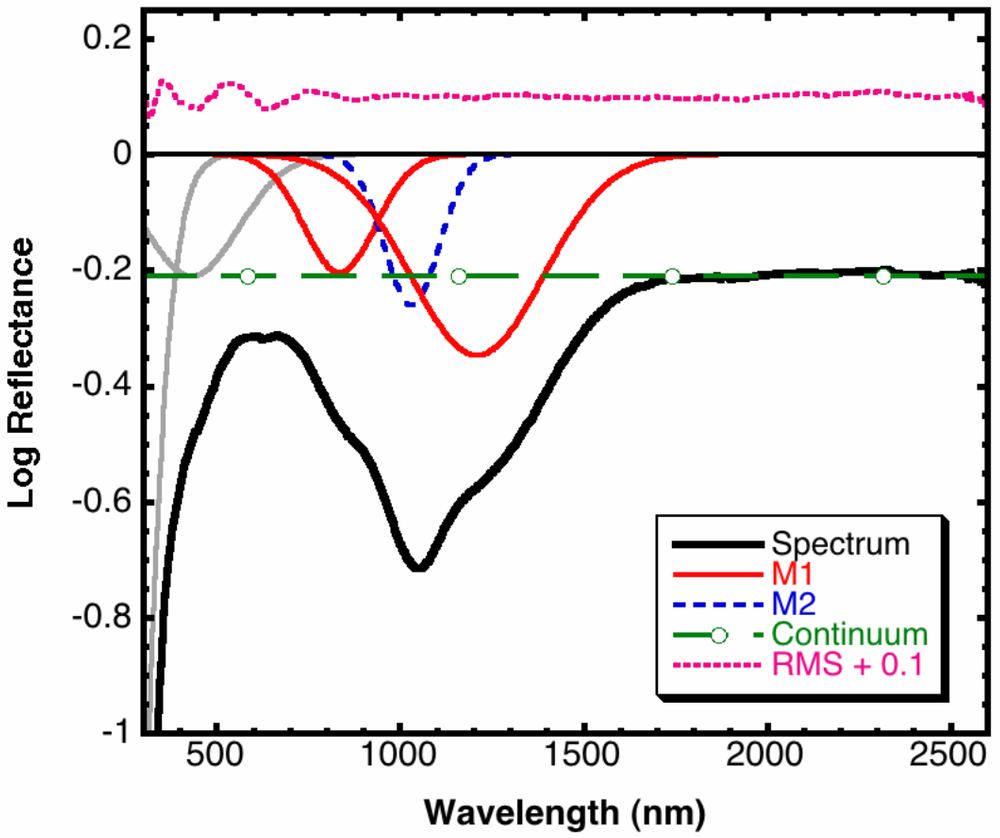


- 3 principle absorptions near 1 μm
- Electronic transitions in Fe^{2+} atoms in distorted octahedral crystallographic sites
- Bright, featureless spectra > 1700 nm (terrestrial olivine)



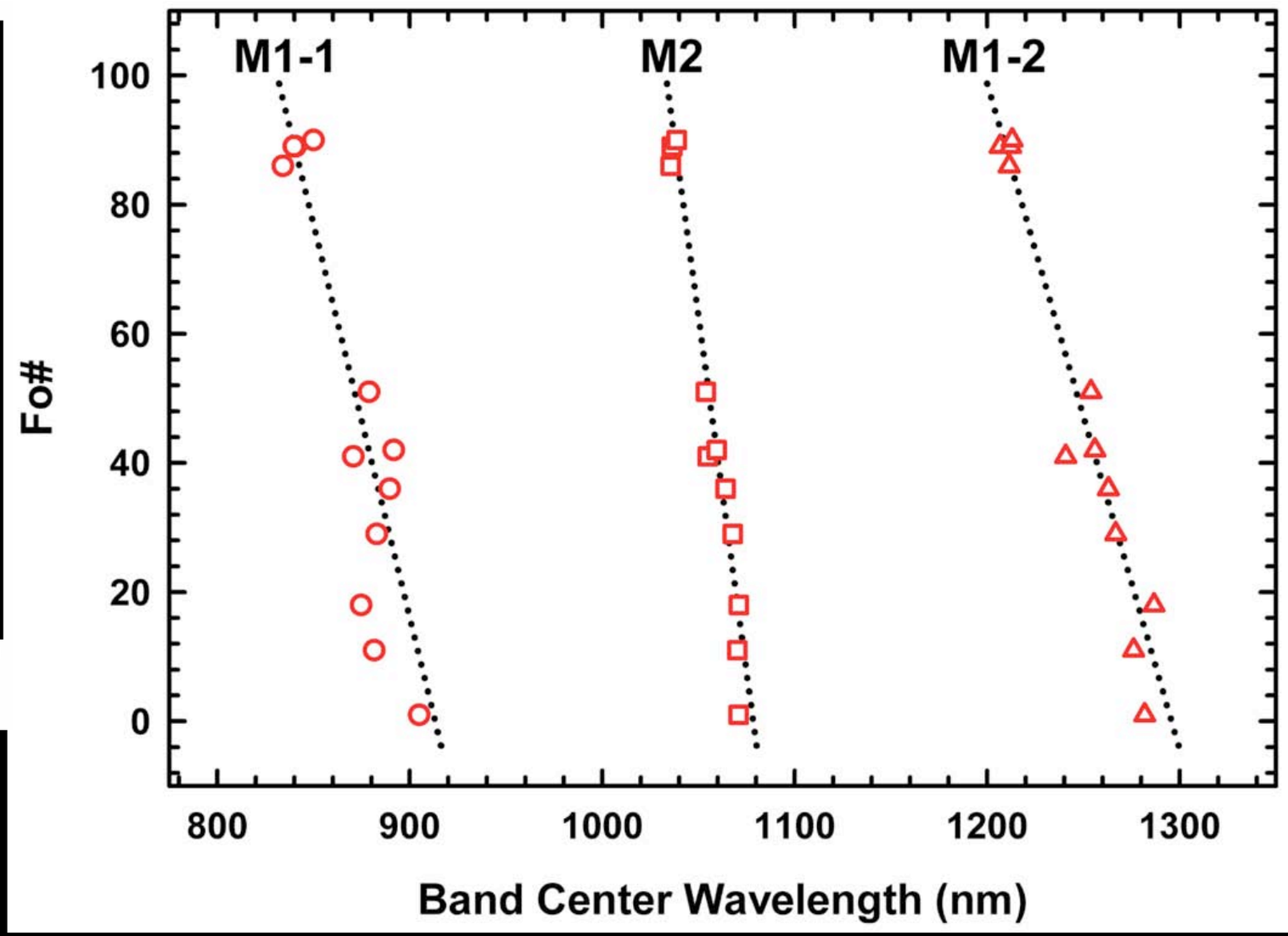
Compositional Trends





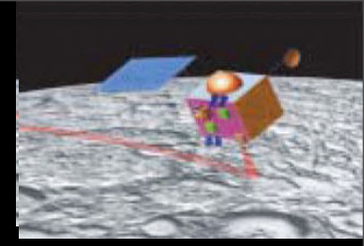
San Carlos Olivine, ~Fo_{90}

Systematic trends in band centers, widths, and strengths as derived by the Modified Gaussian Model (MGM)

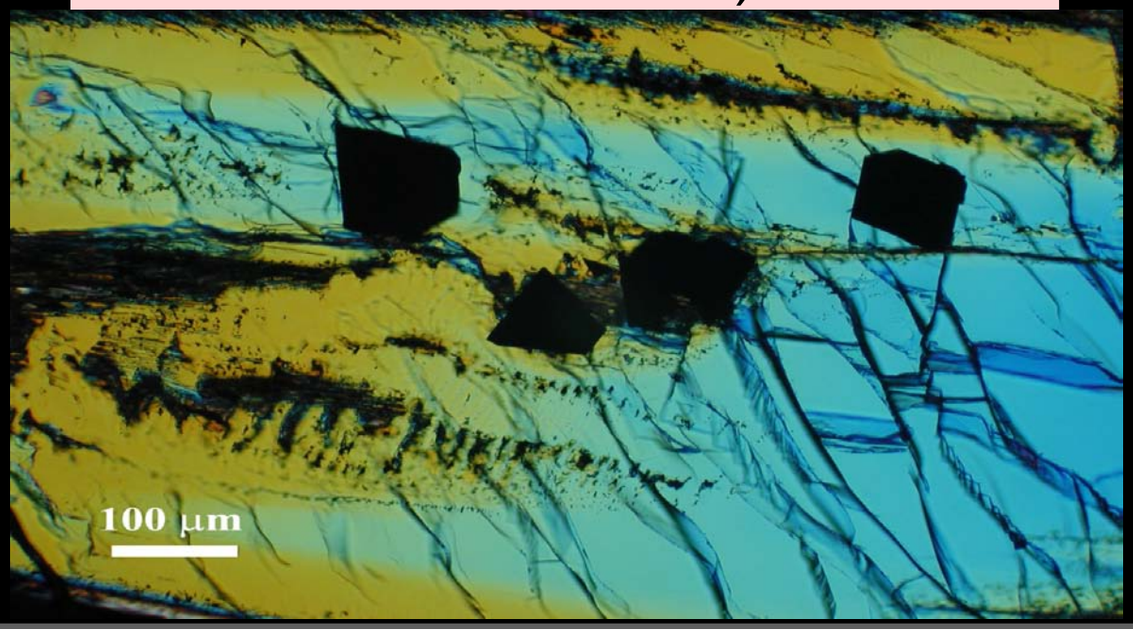


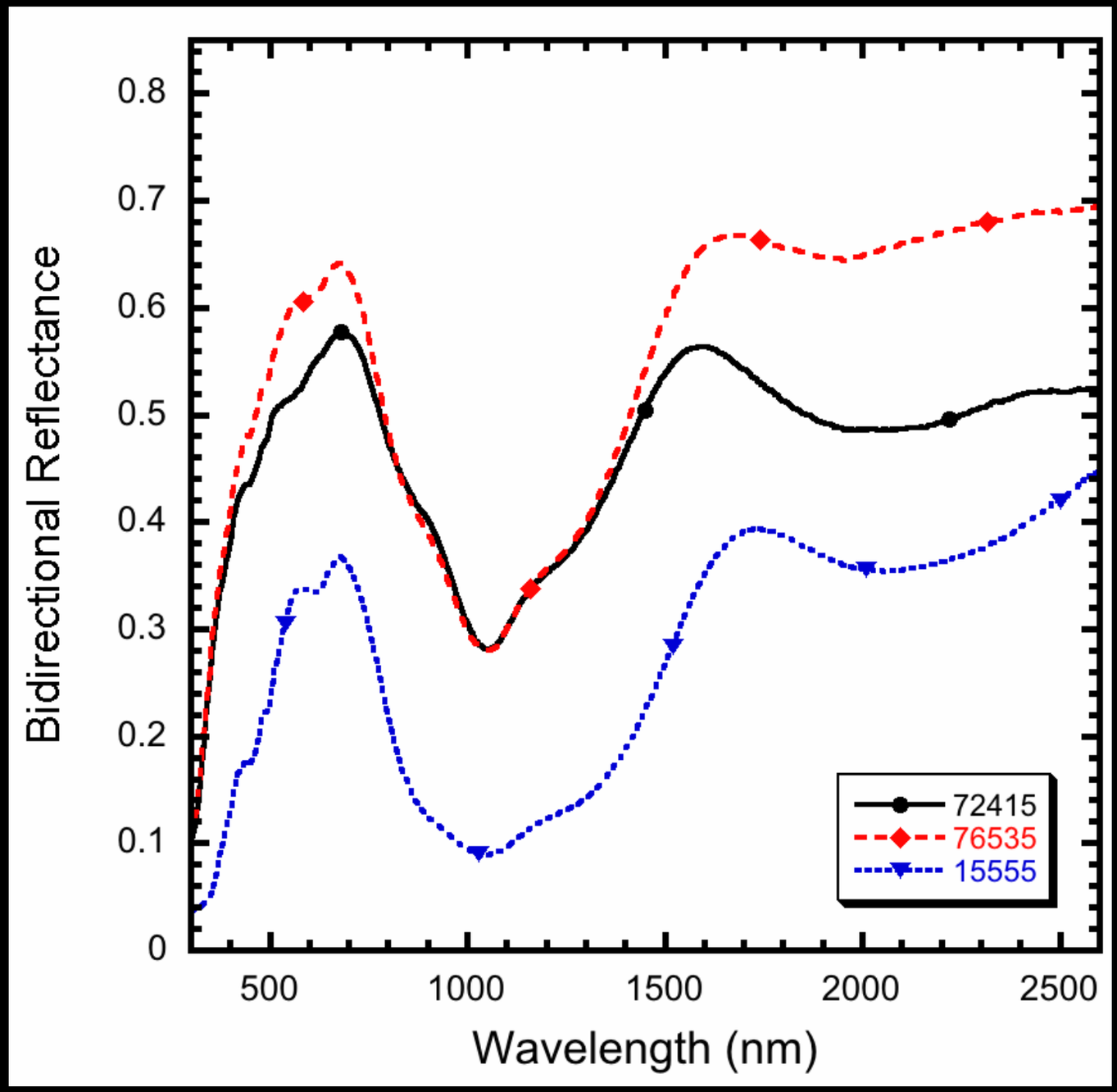
Data from Sunshine & Pieters, 1998

Lunar olivine complications



- Lunar olivine contains small inclusions of Cr-spinel ($FeCr_2O_4$).
- Spinel produces long wavelength absorptions.
- Requires modified approach ("standard" approach does not produce consistent results)





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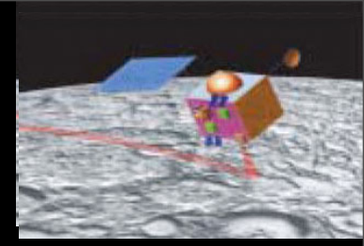

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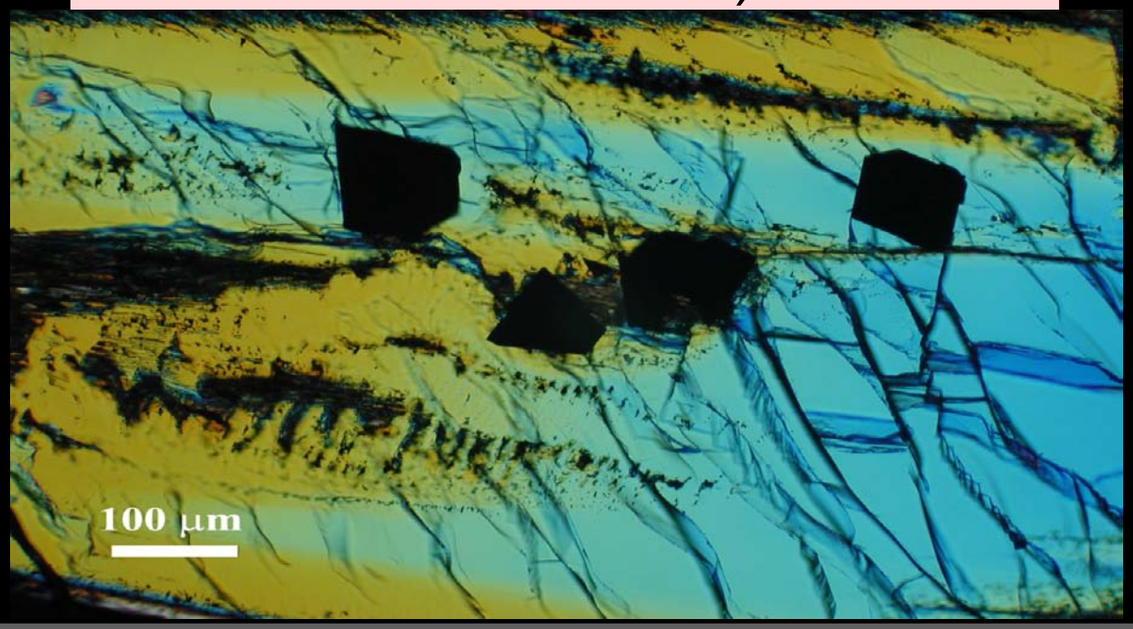
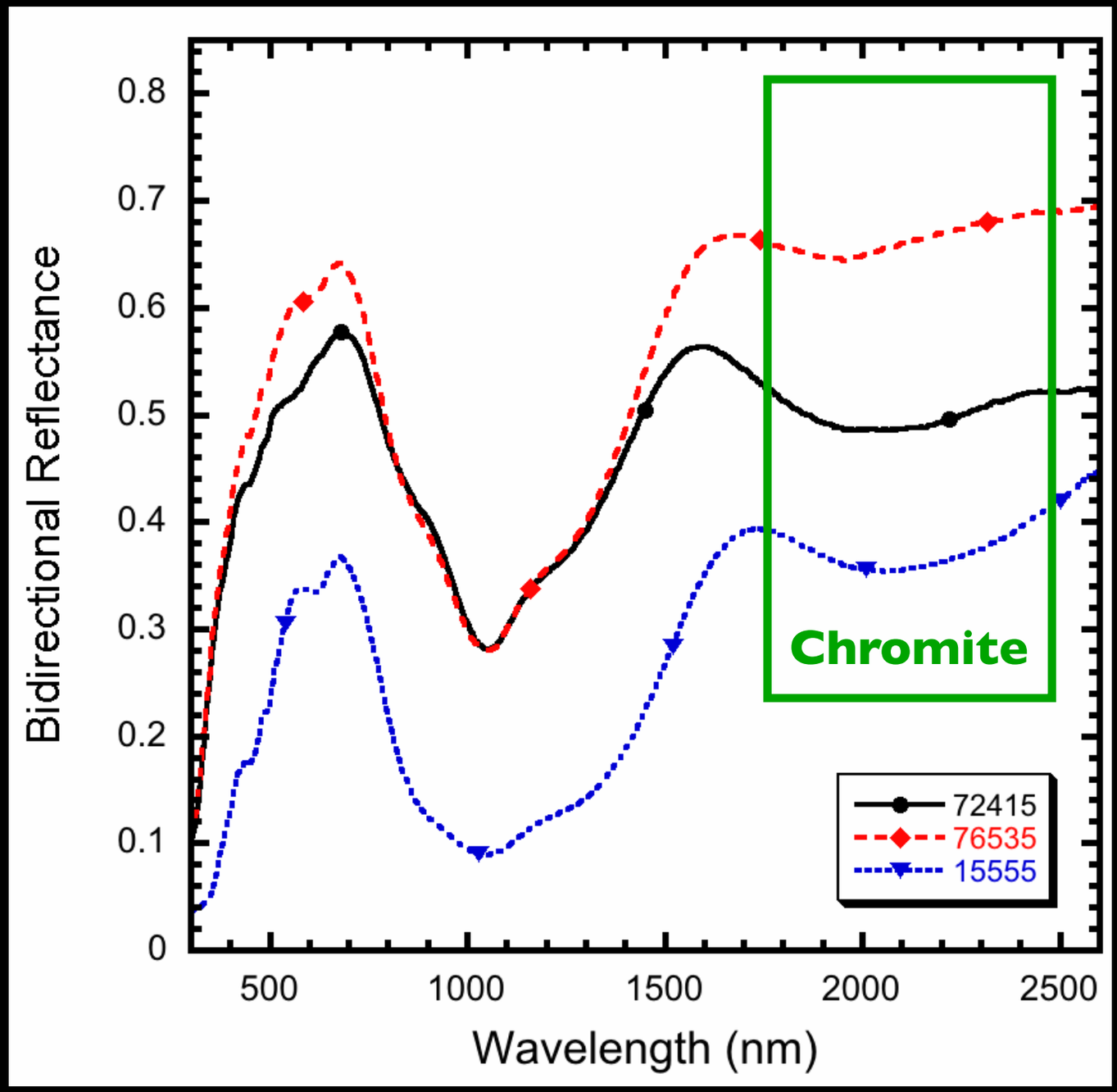
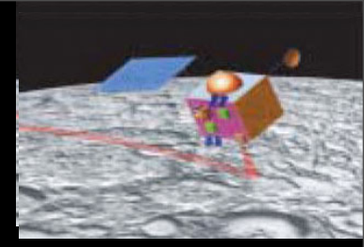
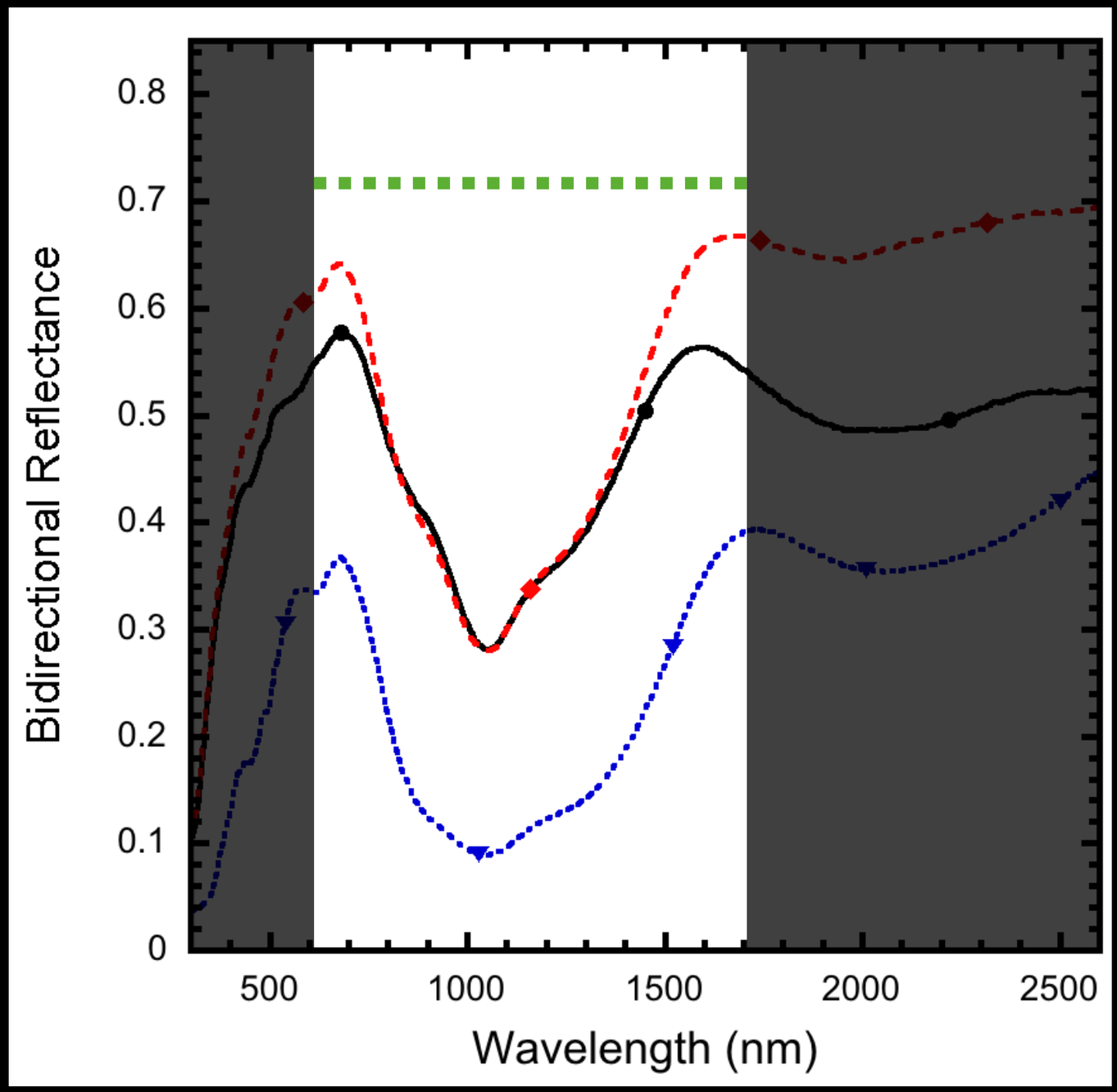




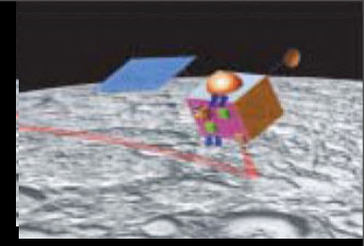
Lunar olivine approach

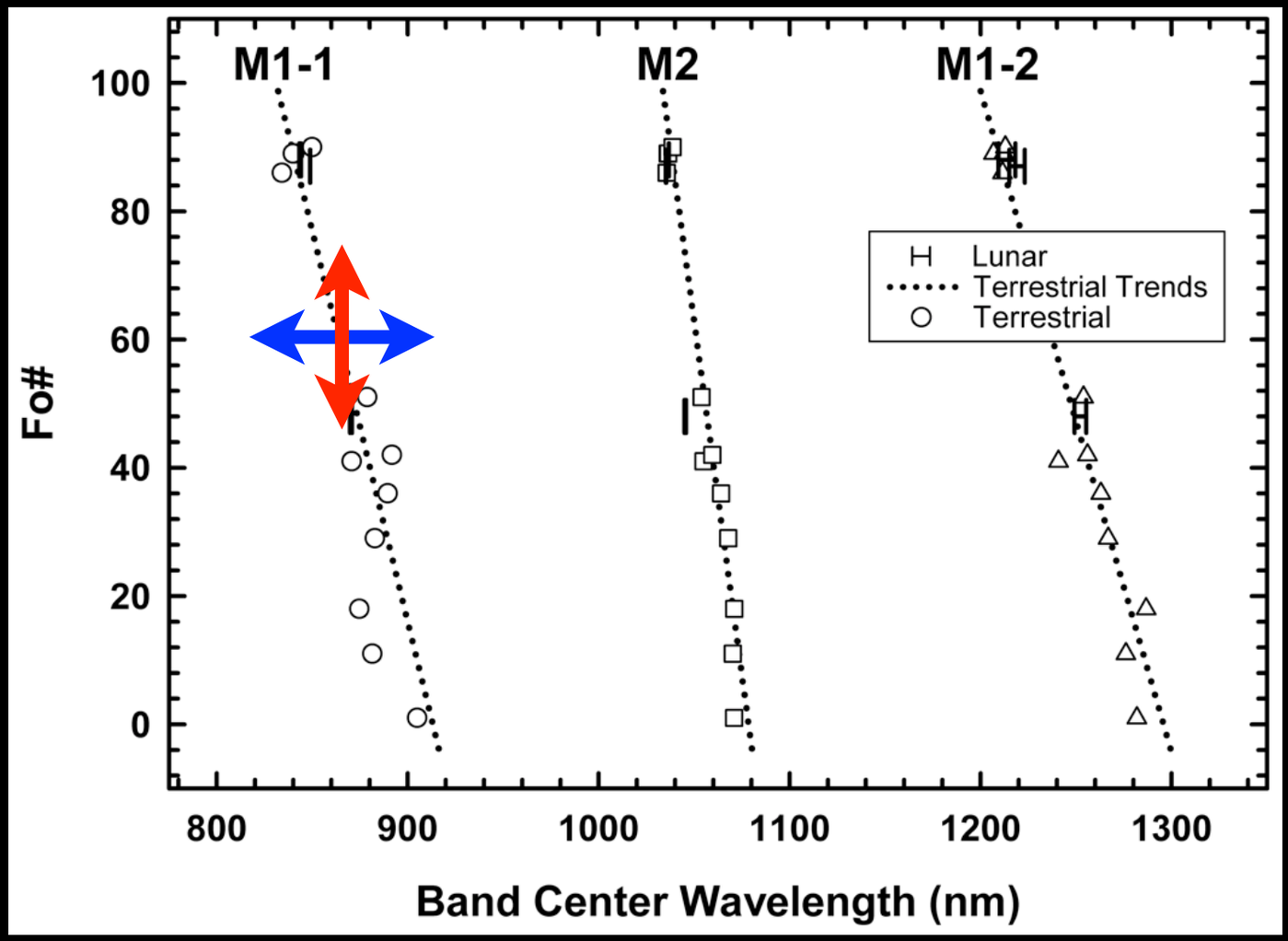


- Lunar olivine contains small inclusions of Cr-spinel ($FeCr_2O_4$).
- Spinel produces long wavelength absorptions.
- Requires modified approach ("standard" approach does not produce consistent results)
- Approach:
  - truncate spectrum
  - enforce flat continuum slopes
- Results consistent with previous trends



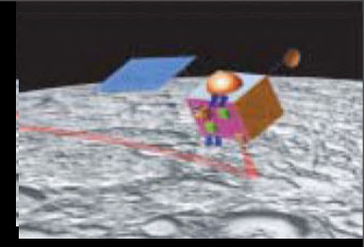
Compositional Evaluation

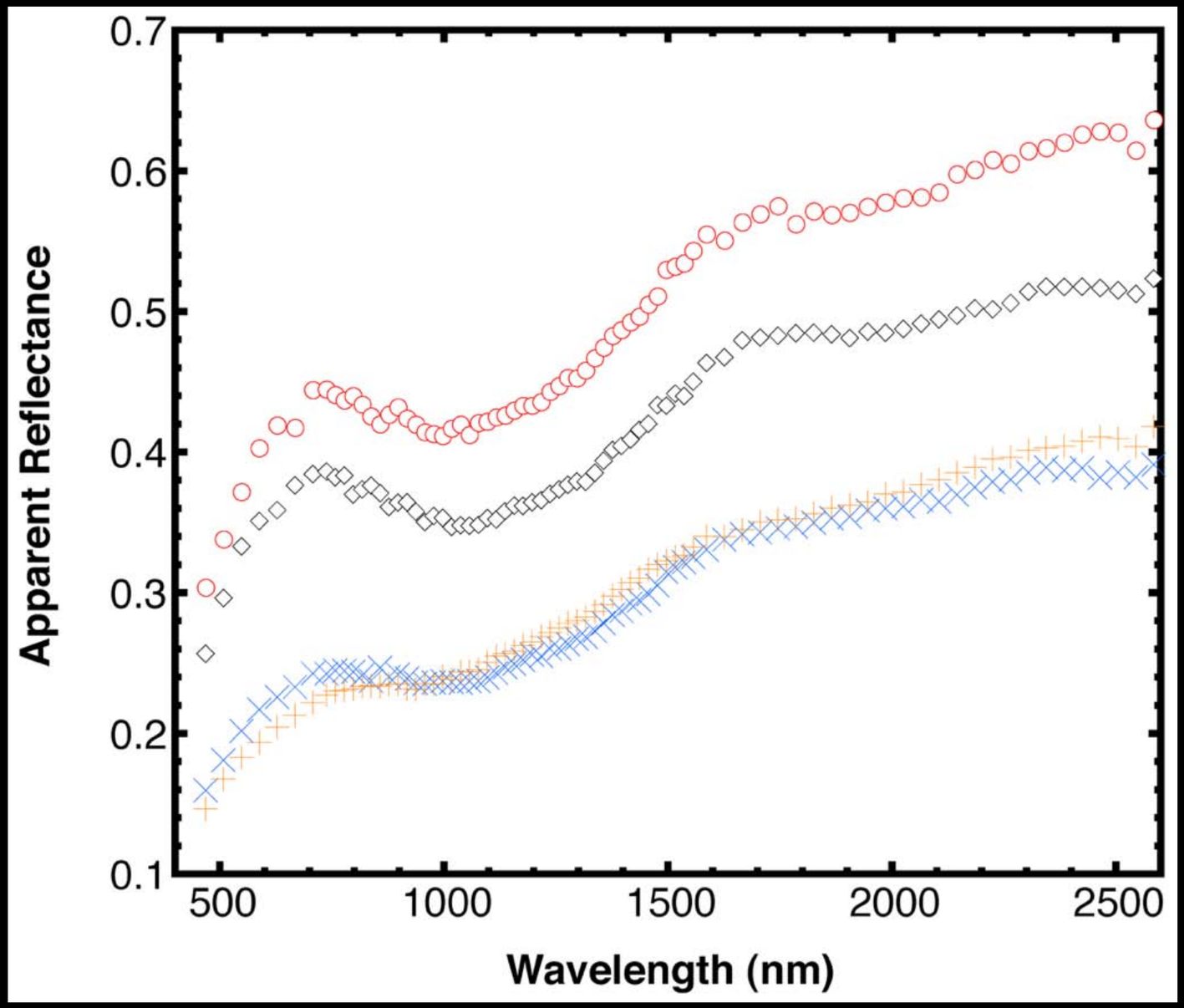




Compositional predictions: **Minimize deviations** from trend lines ***simultaneously*** by **varying Fo#**

Lunar olivine approach: Remote

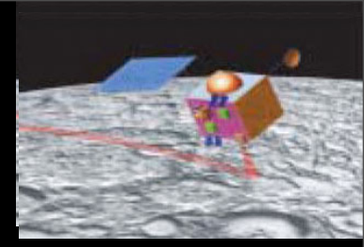


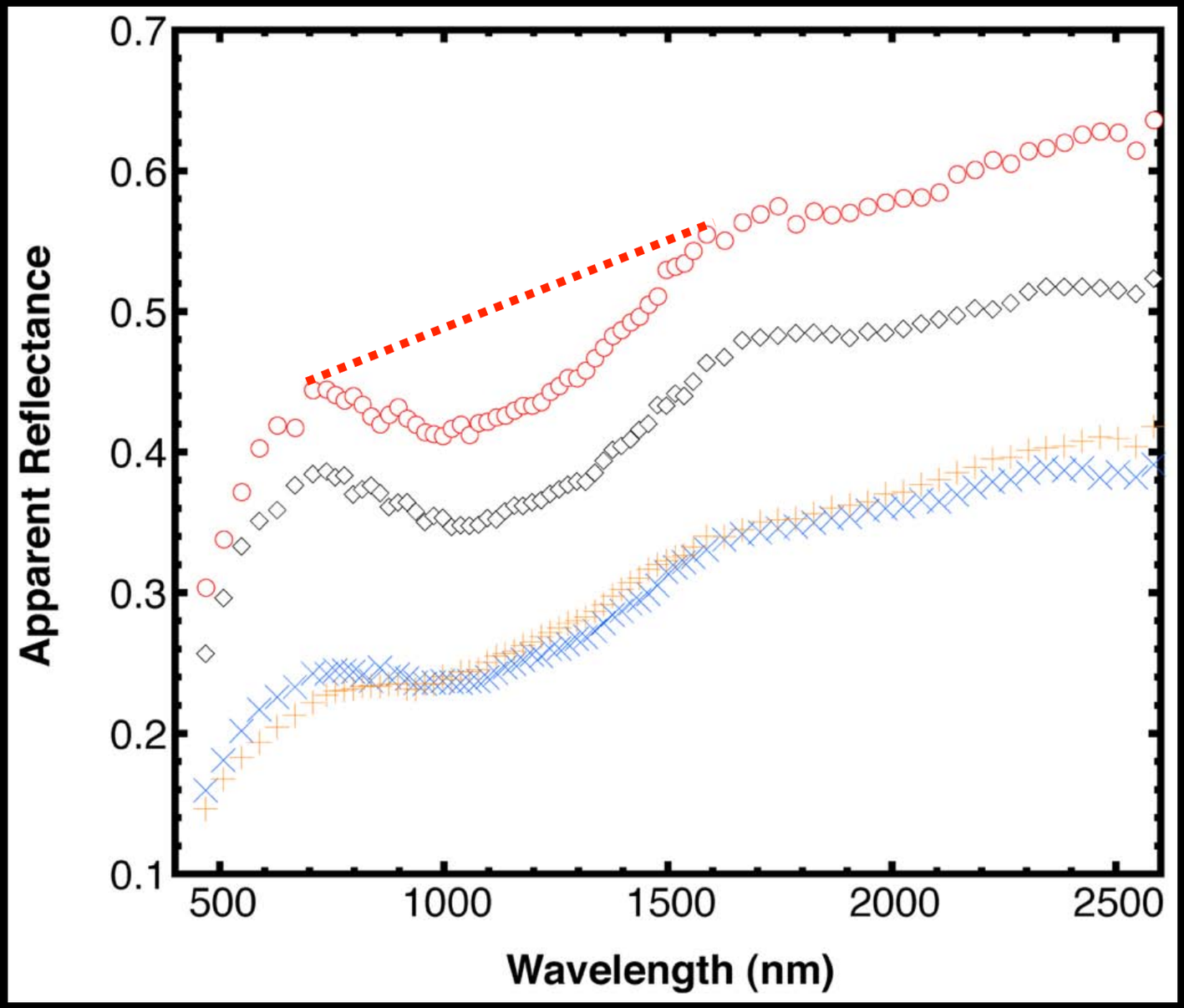


- Consistent fit results require consistent continuum slope
- Flat slope not realistic/ practical
- Tangential continuum slope removed: low λ - 1700 nm
- Requires a CORRECTION for apparent band shift as a function of continuum slope
- "Lunar approach" applied otherwise

Spectra collected by M³, Jan. 25 2009

Lunar olivine approach: Remote





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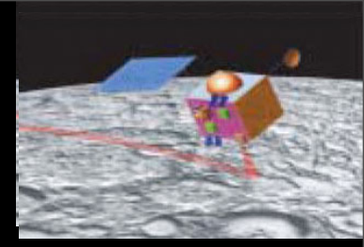
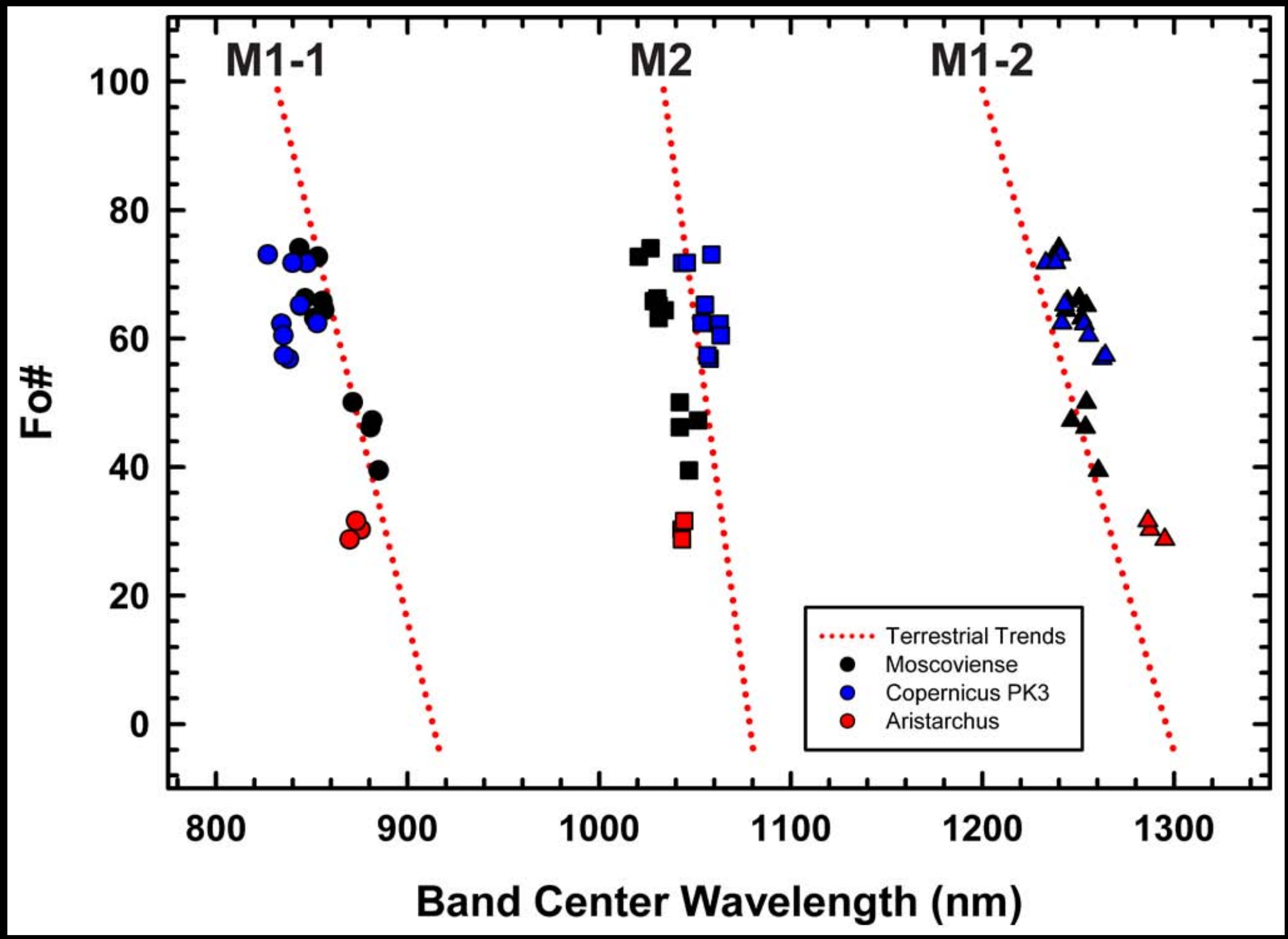
Results of Deconvolutions





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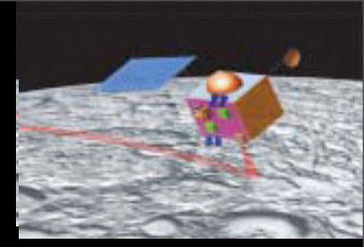
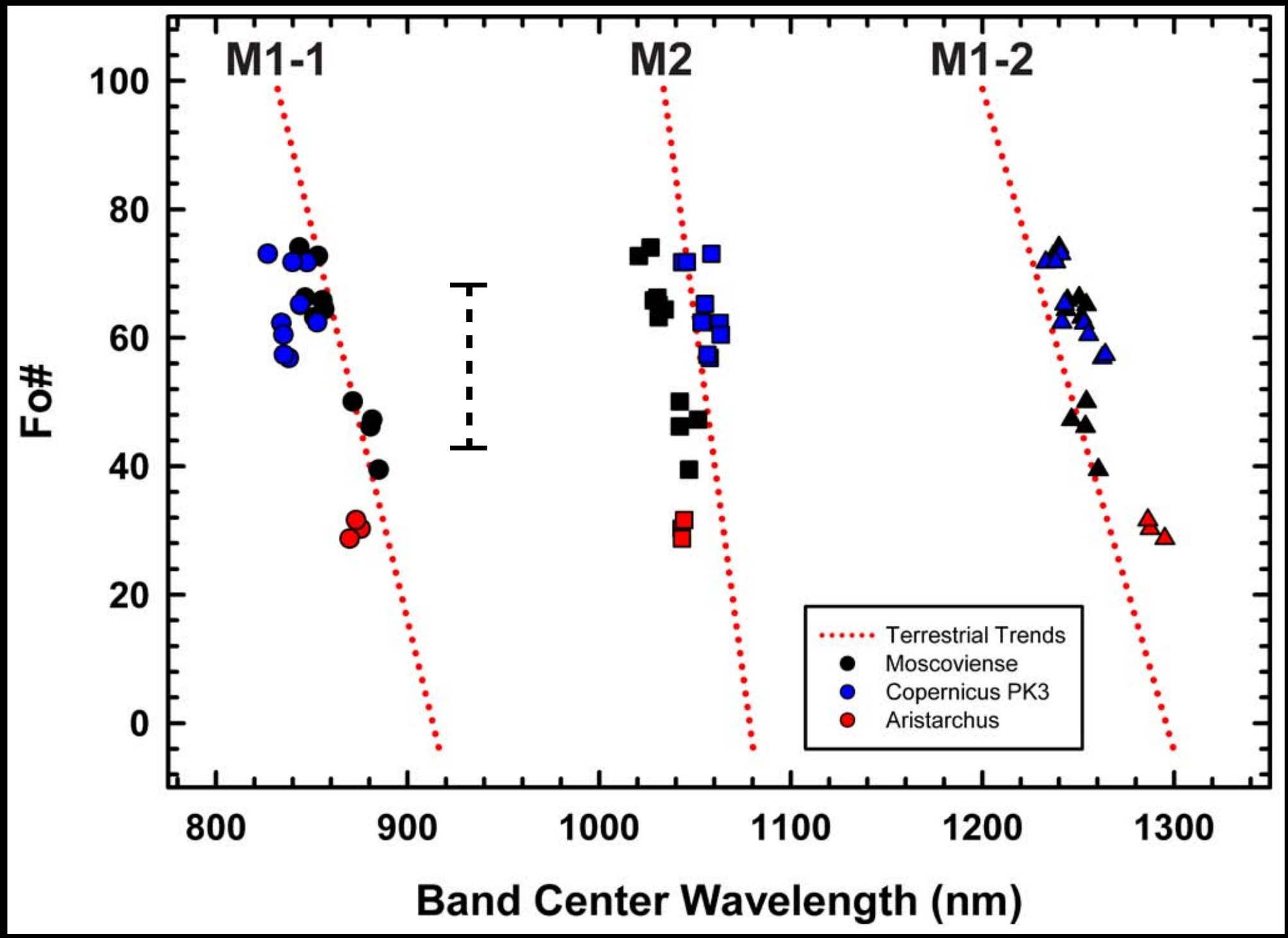
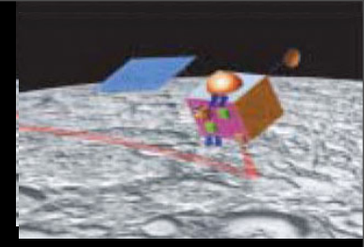


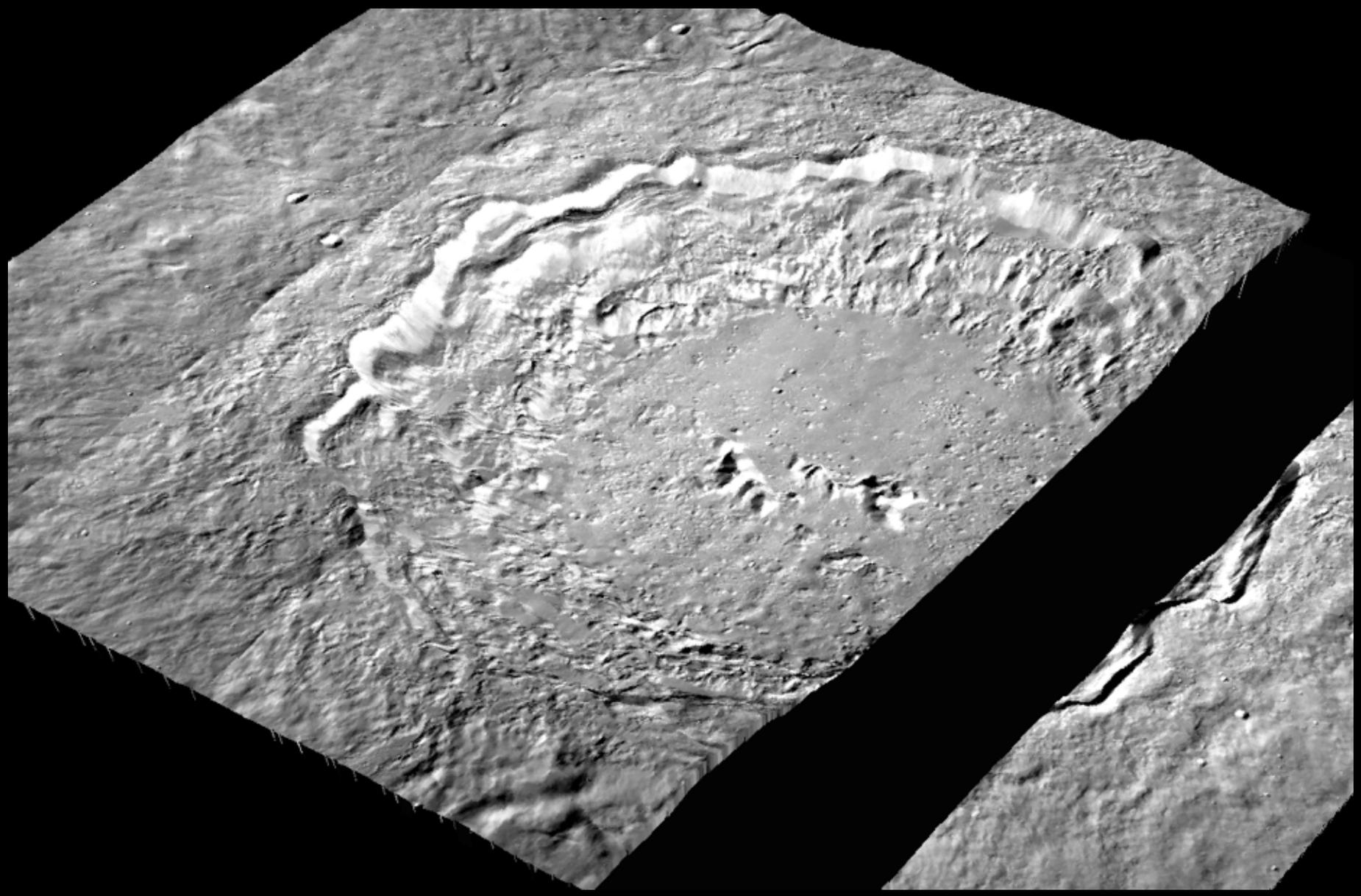


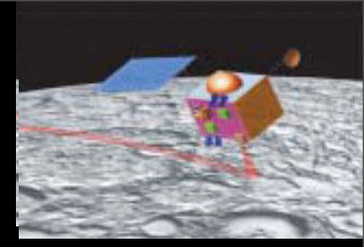
Olivine Composition: Conclusions



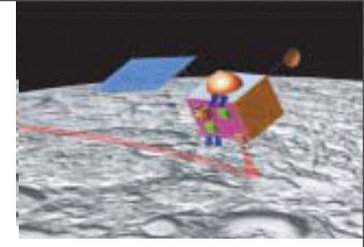
- M^3 data are sufficient (but not always ideal) for estimating olivine (& pyroxene) composition through MGM deconvolutions.
  - Relative to laboratory spectra, reduced spectral sampling, low signal levels, scattered light are substantial challenges.
- Error bars are critical but not quantified.
- Relative compositions: Copernicus peak Mg-rich, Moscoviense Mg-rich but diverse, Aristarchus Fe-rich (but possibly contaminated).

Copernicus





The Moon Mineralogy Mapper (M^3)



Chandrayaan-1 launched October 22, 2008 on an Indian rocket

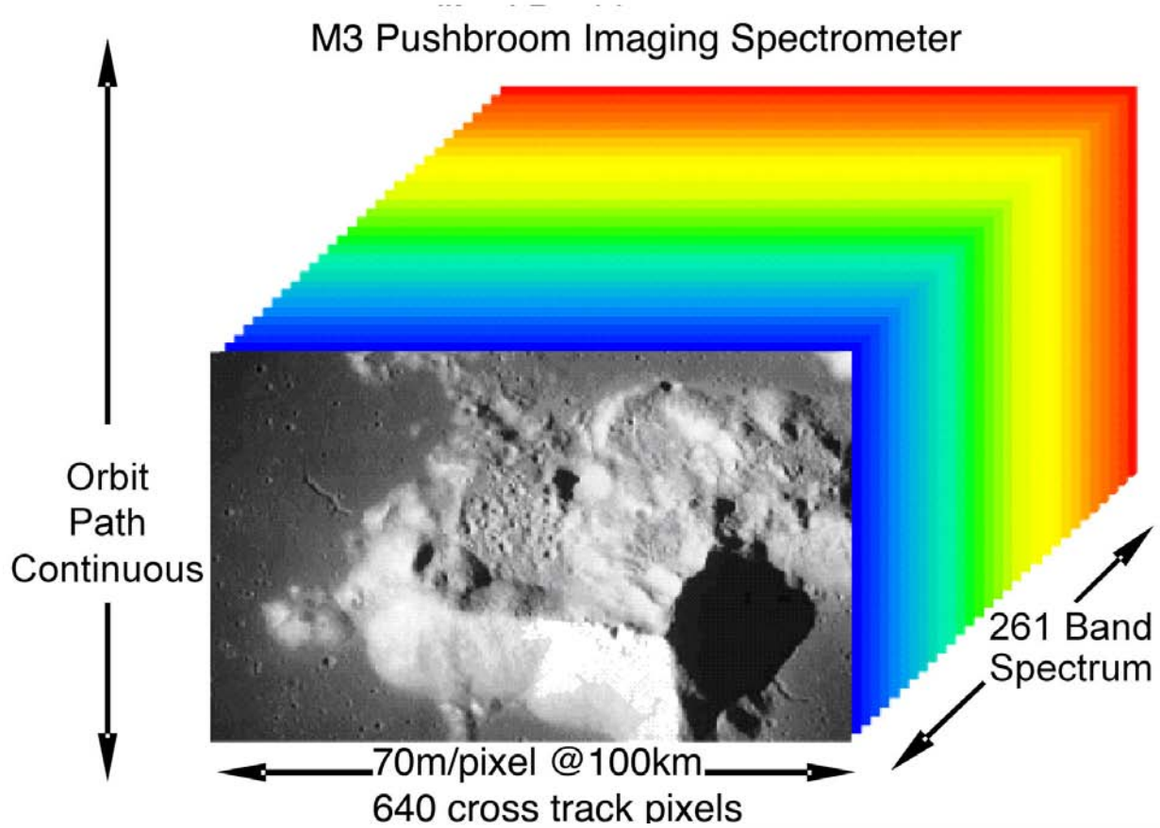
- Two-year mission planned; 10 month actual
- 100 km circular polar Orbit [200 km orbit May - August 2009]

M^3 is a NASA Discovery "Mission of Opportunity"

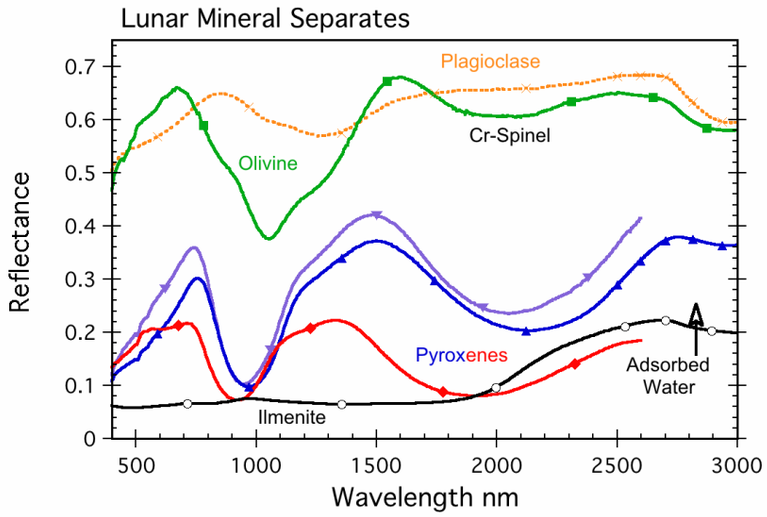
- Peer-reviewed competitive selection
- Team led by PI: C. Pieters
- Designed and built at JPL

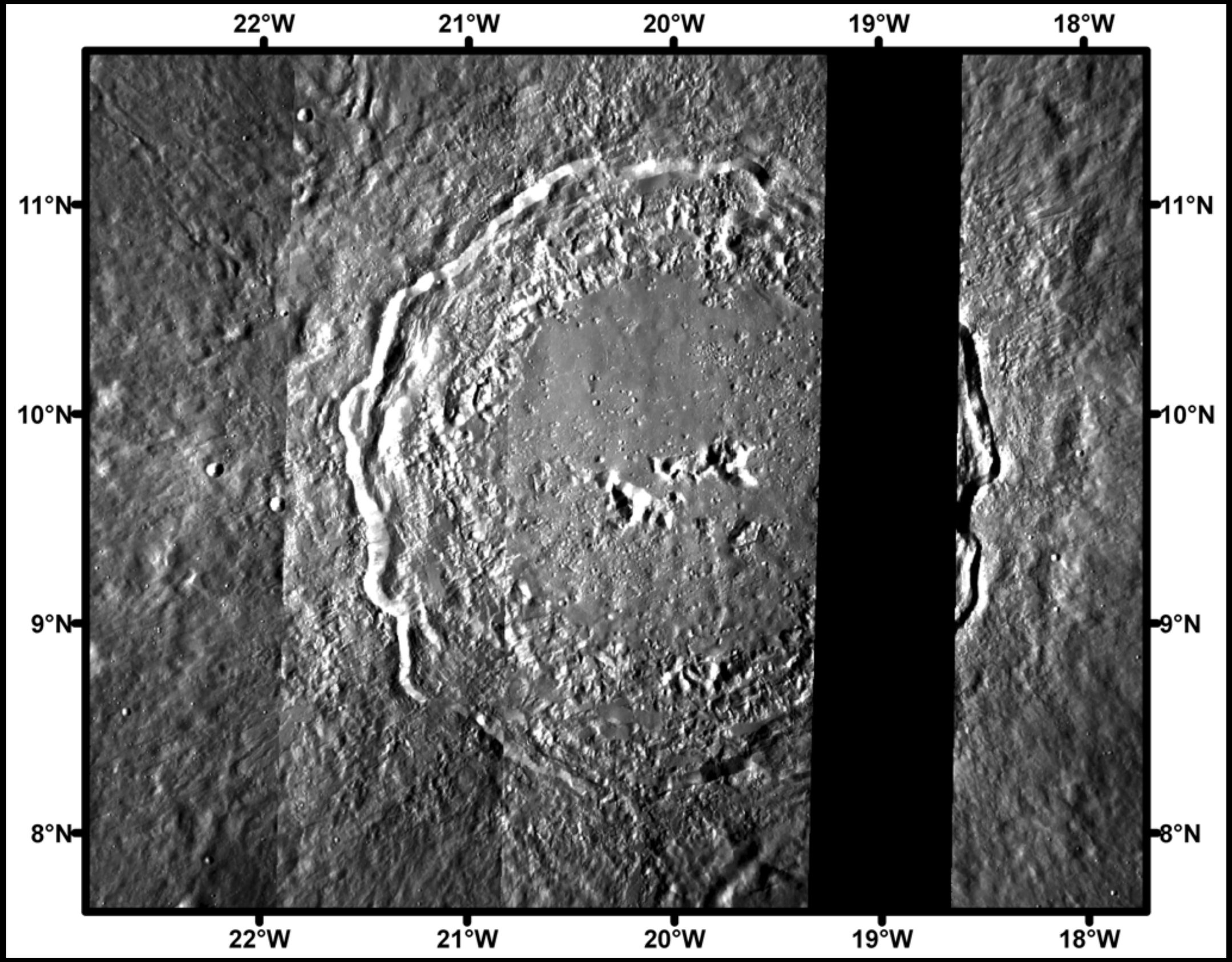
M^3 is a pushbroom imaging spectrometer

- Two spatial dimensions
- One spectral dimension

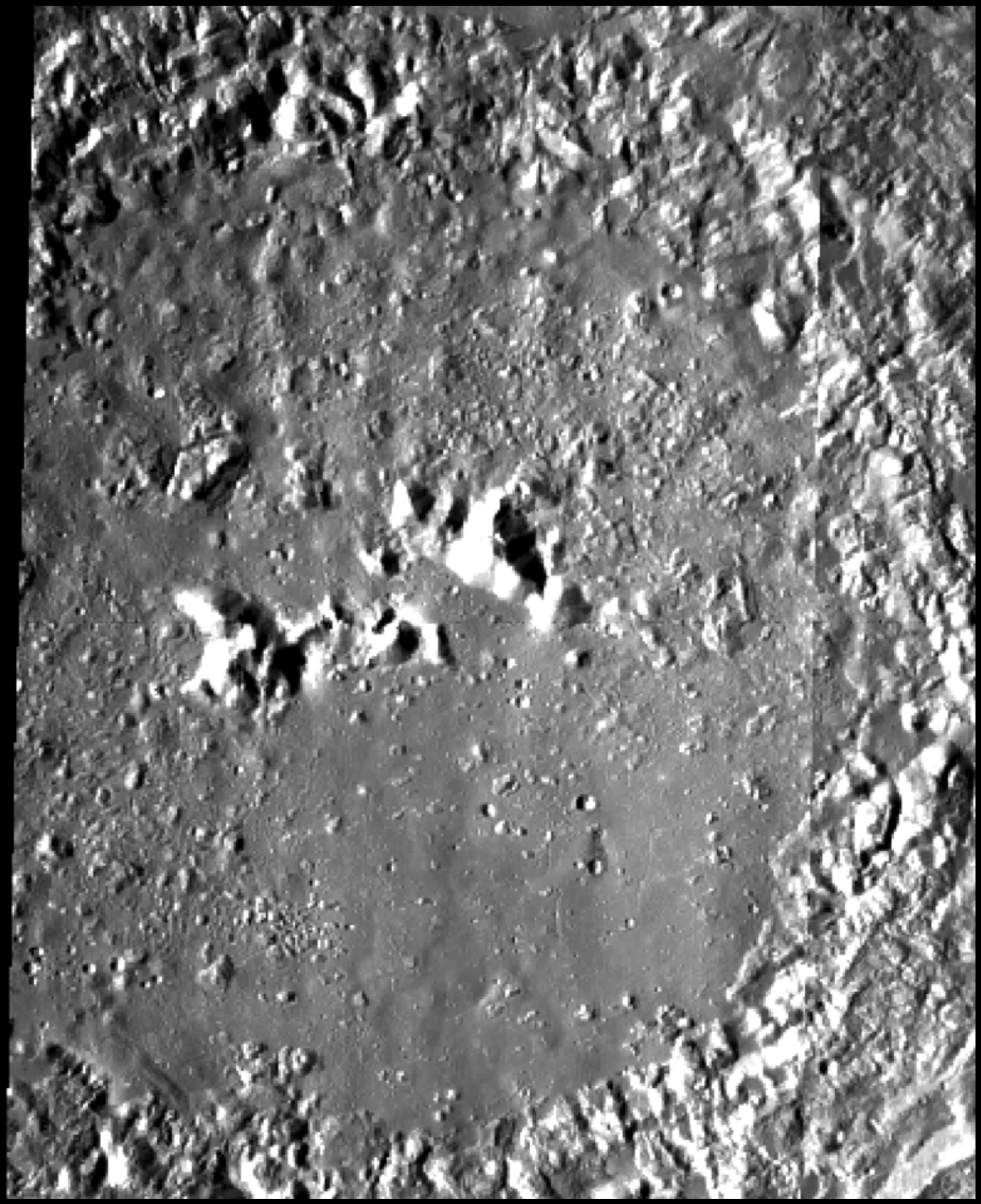


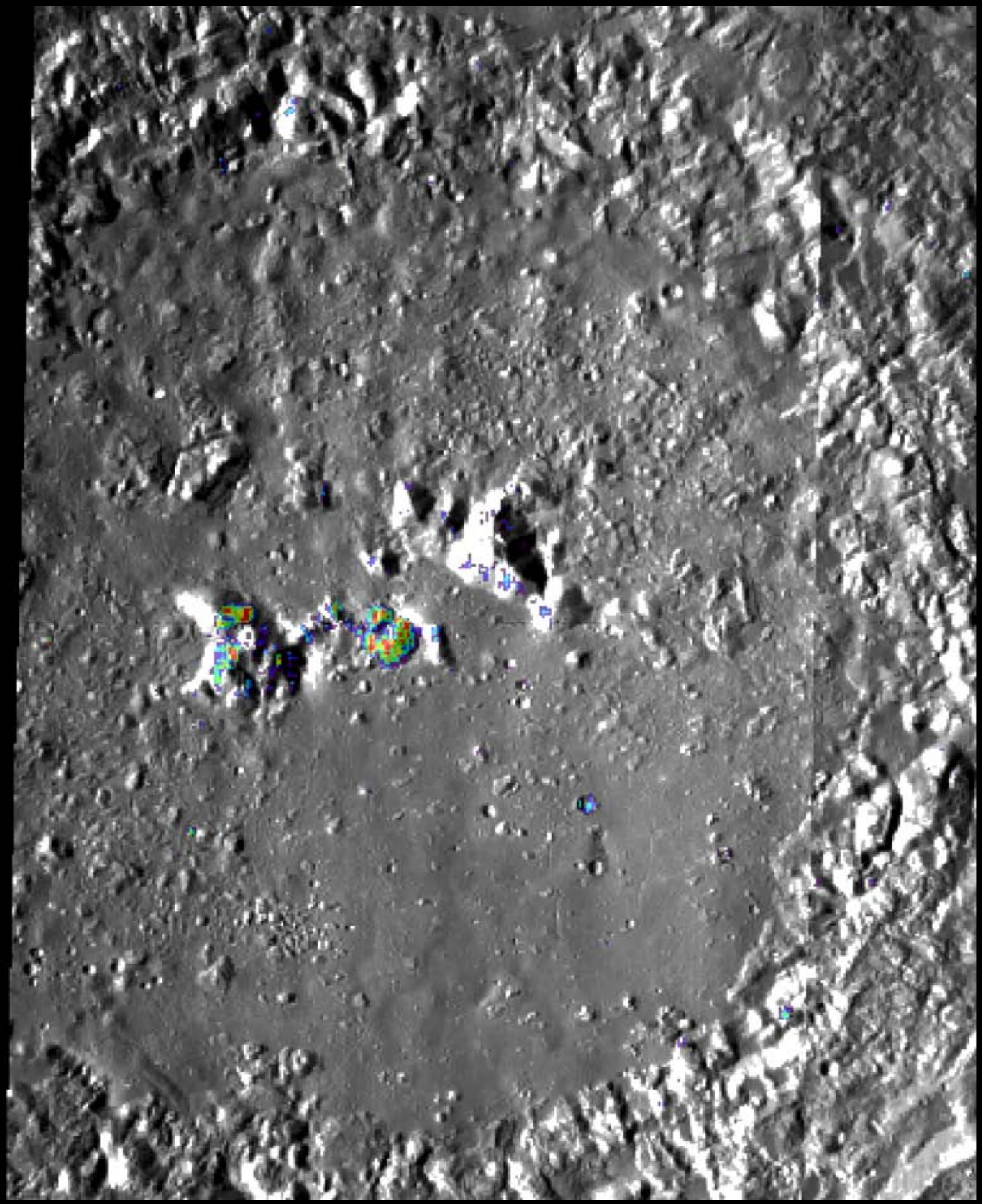
M3 covers the spectral range where diagnostic features occur for all common rock-forming minerals **and** hydrous phases [0.43 to 3.0 μm].

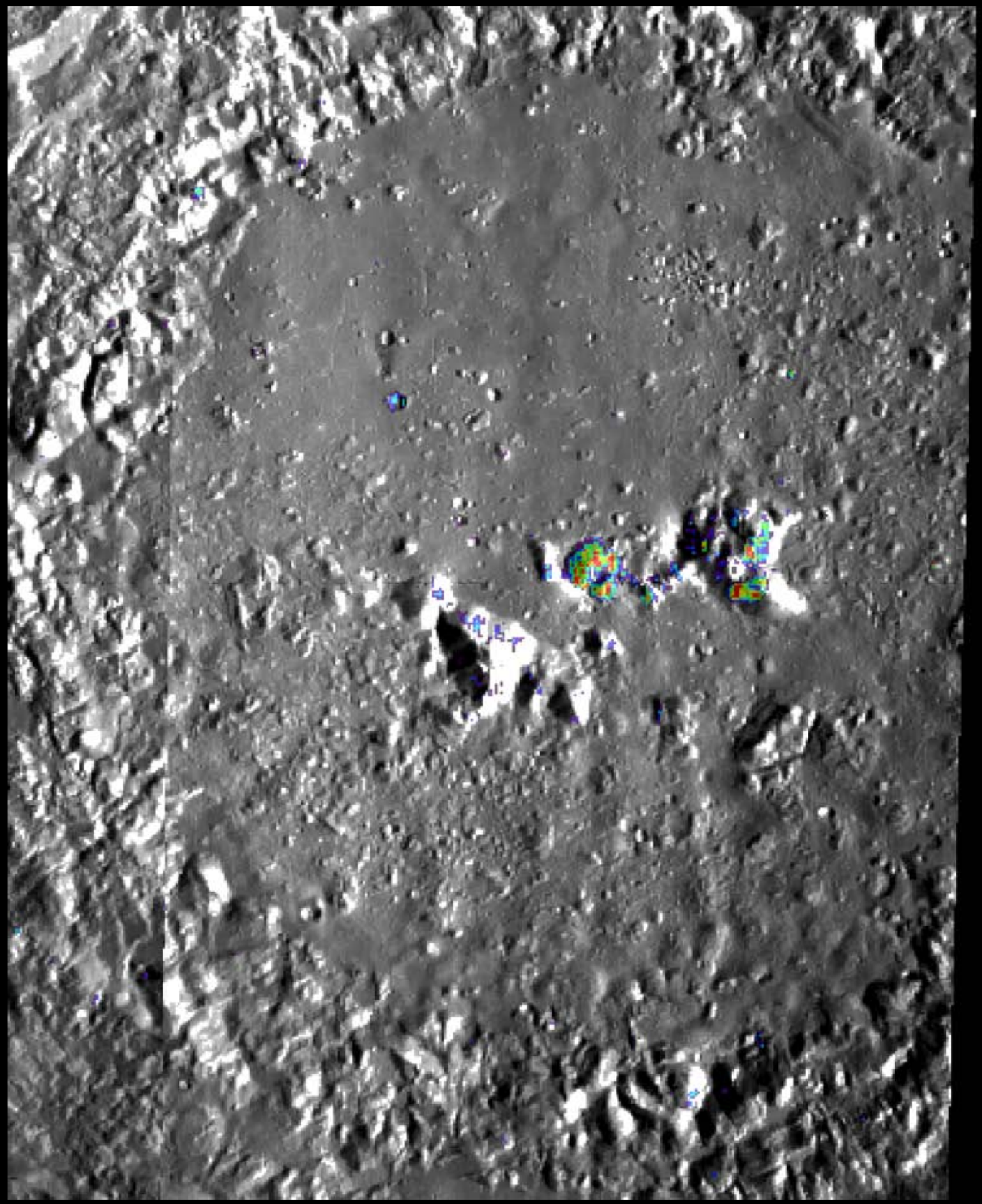


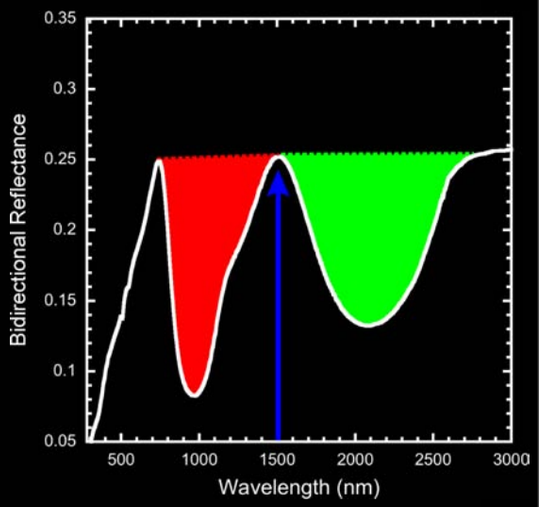

22°W
21°W
20°W
19°W
18°W
11°N
10°N
9°N
8°N

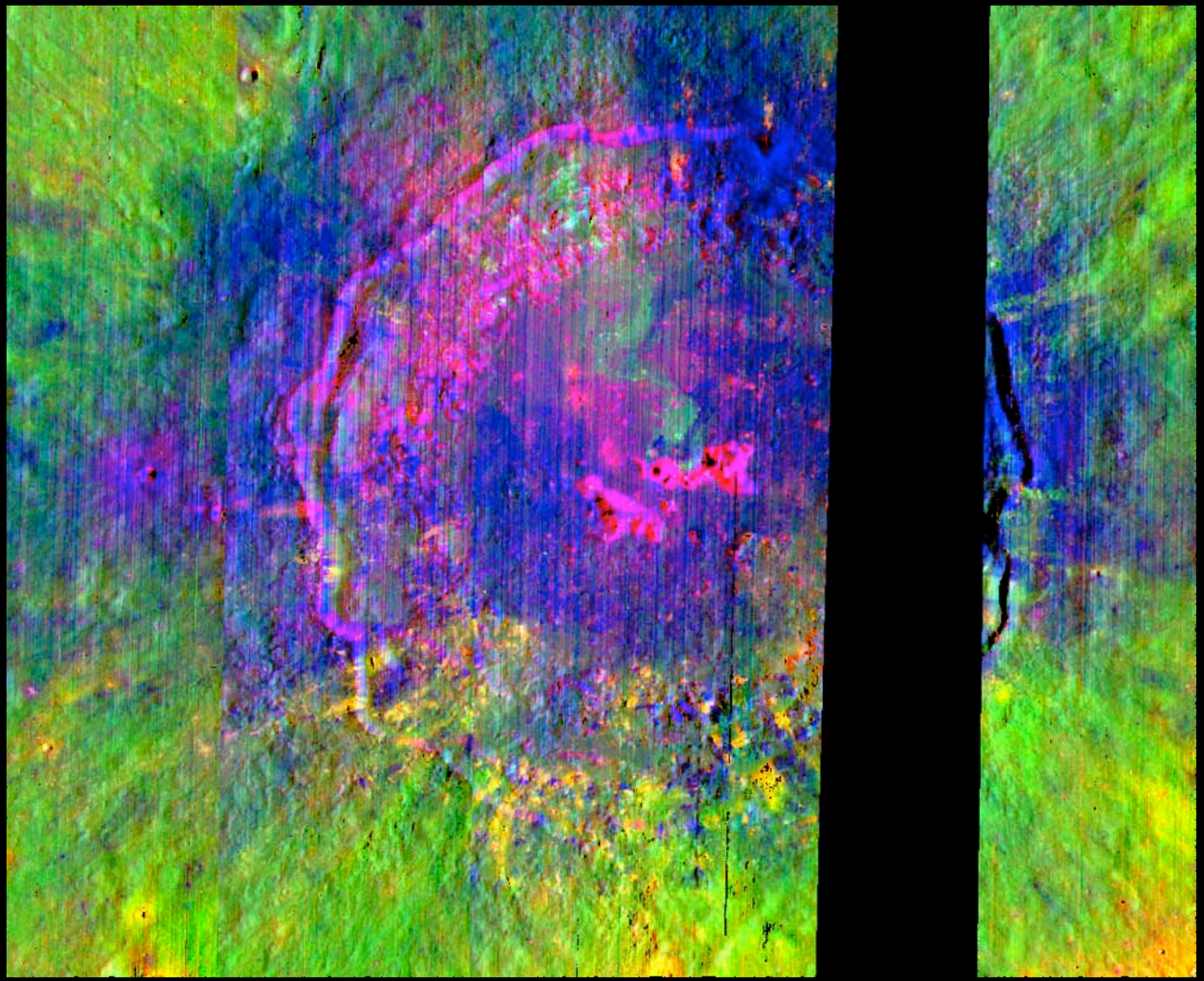
22°W
21°W
20°W
19°W
18°W
11°N
10°N
9°N
8°N





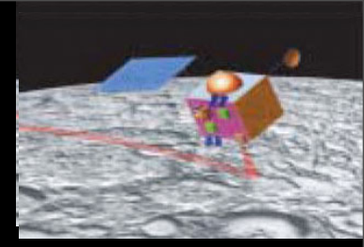



0.35
0.3
0.25
0.2
0.15
0.1
0.05
Bidirectional Reflectance
500
1000
1500
2000
2500
3000
Wavelength (nm)



IBD1000, BD1900, R1489

Copernicus: M³ & LROC NAC



M109365462RE + M³ Color

M109365462RE

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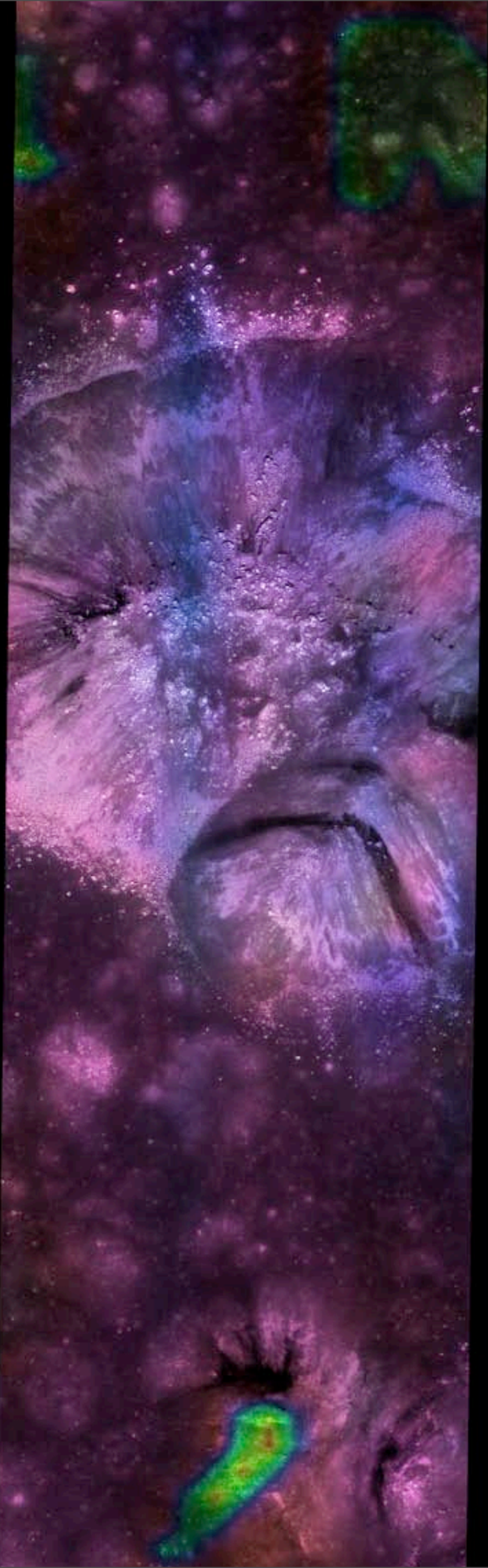

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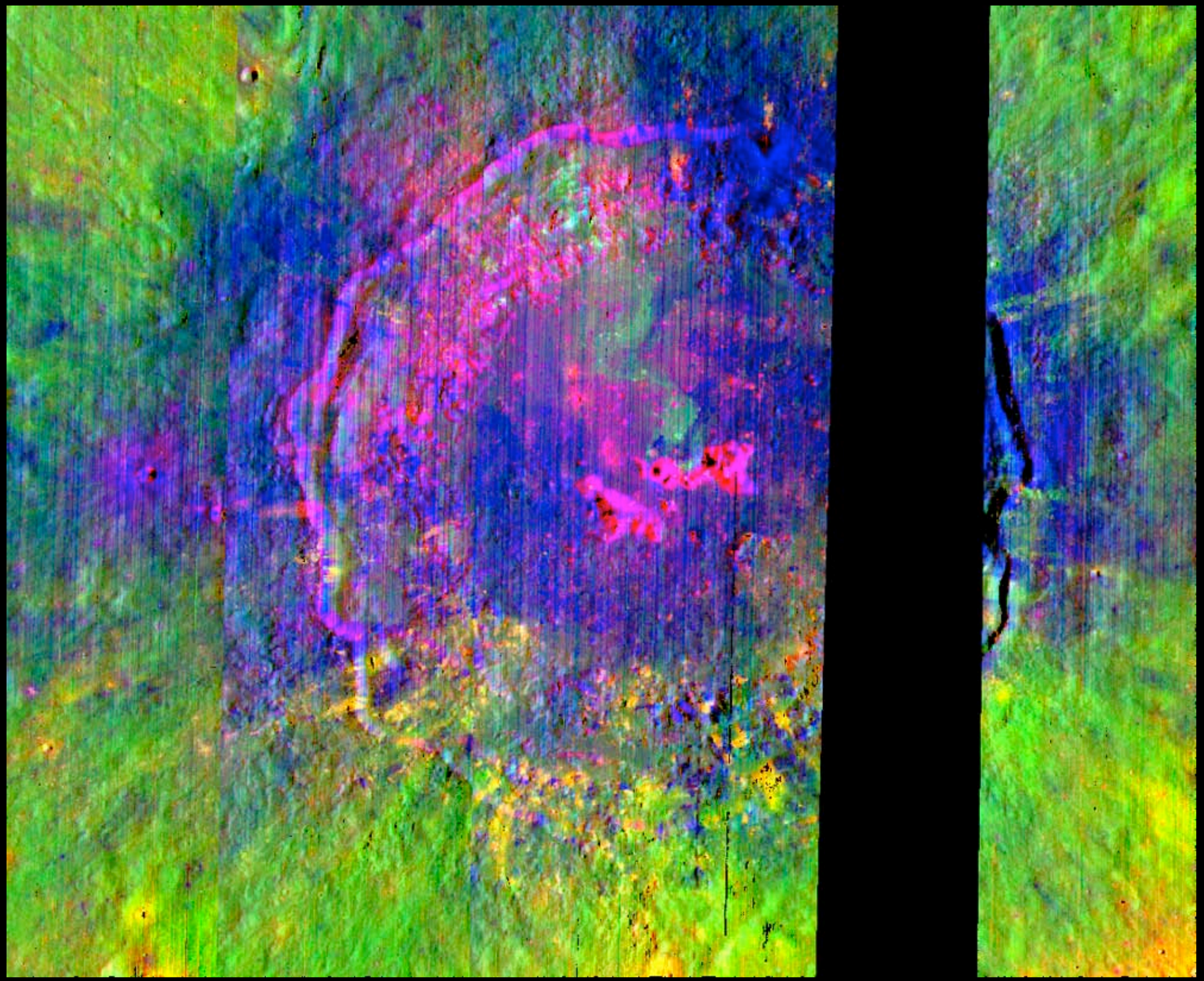

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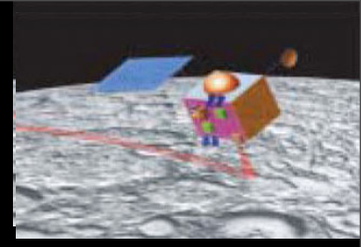


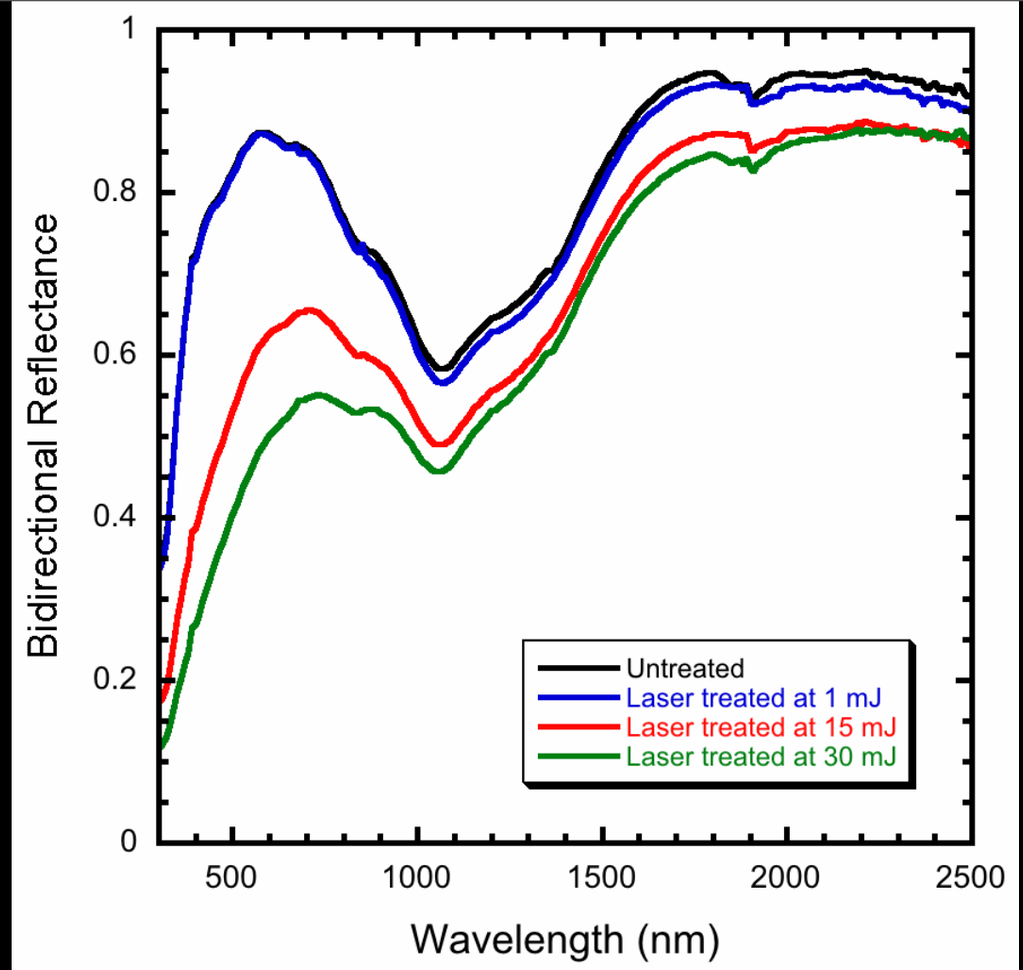
- M^3 co-authors
- M^3 mission operations and processing "teams"
- ISRO mission operations
- NASA Discovery Program, ISRO

Supplemental

Continuum Slope Evaluation: Laboratory Spectra

- Experimentally weathered (irradiated) San Carlos studied by Yamada et al.
- Tangential continuum slopes removed, fits performed from standard starting conditions
- Hiroi & Sasaki (2001) found that absorptions do not shift with increased degree of "weathering".
- Systematic *apparent* shifts between original & C.R. spectra used to "**correct**" for band shift due to continuum removal for M^3 spectra.

Yamada et al., 1999



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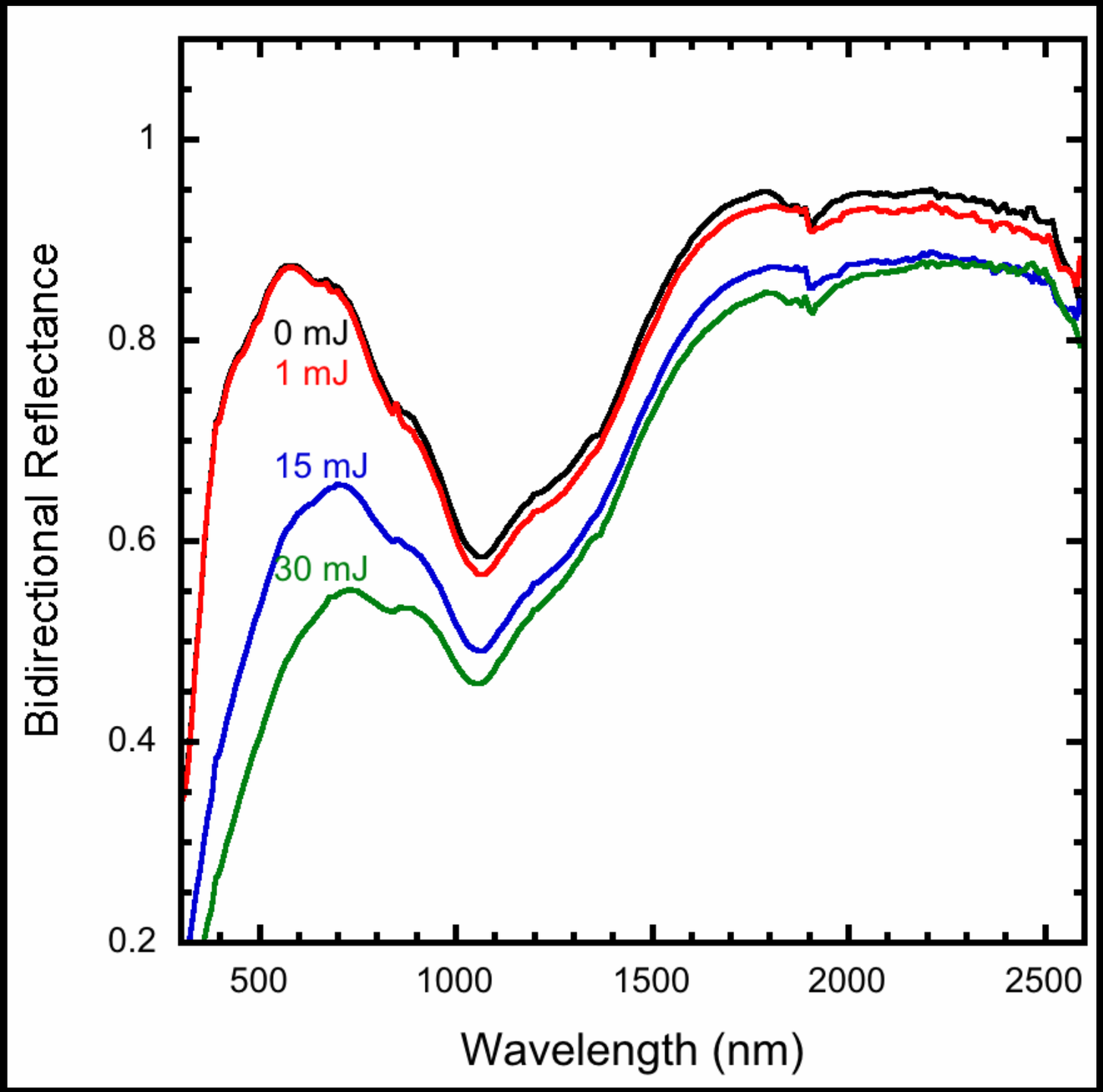

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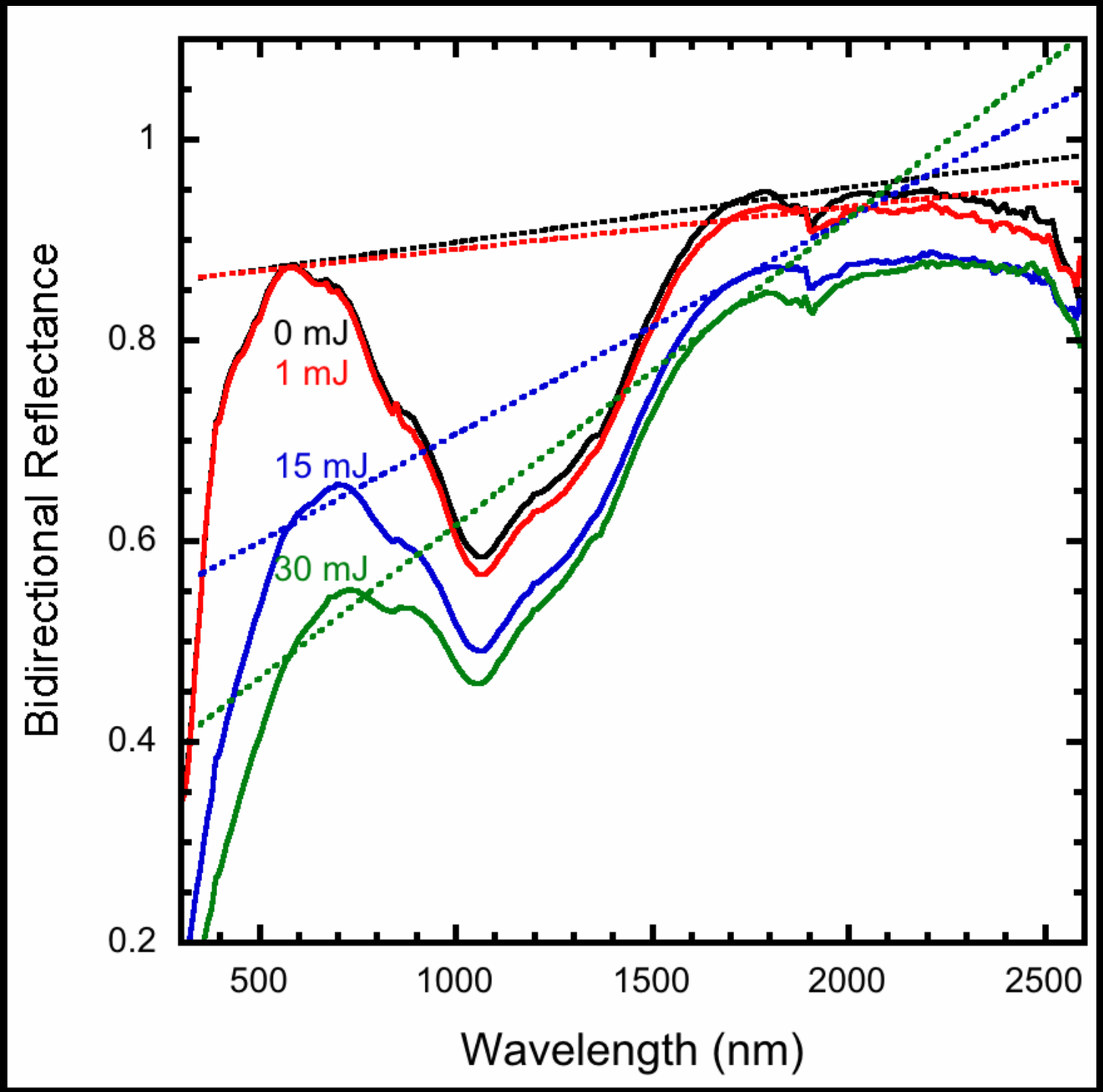
Continuum Slope Evaluation: Laboratory Spectra



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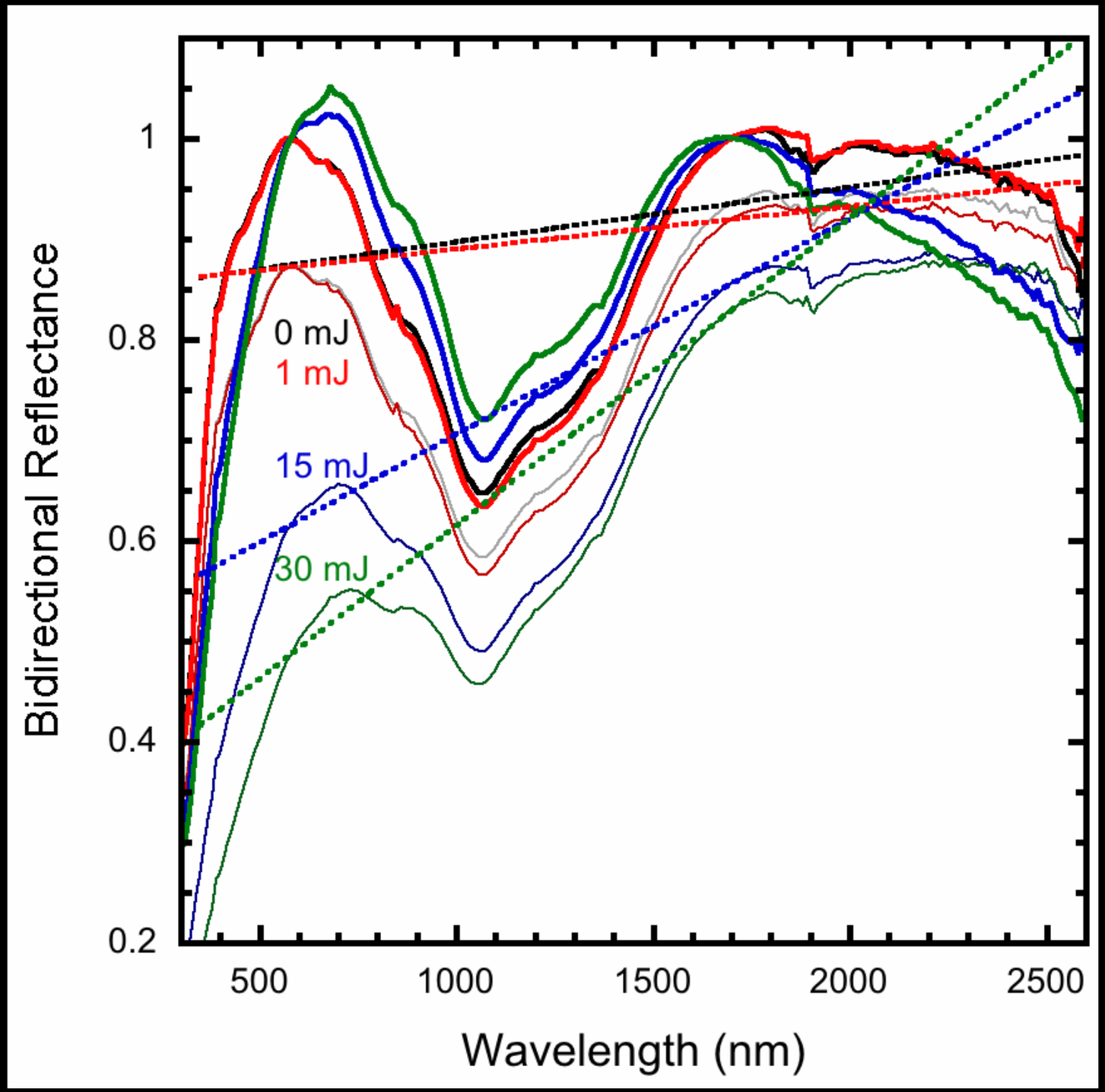

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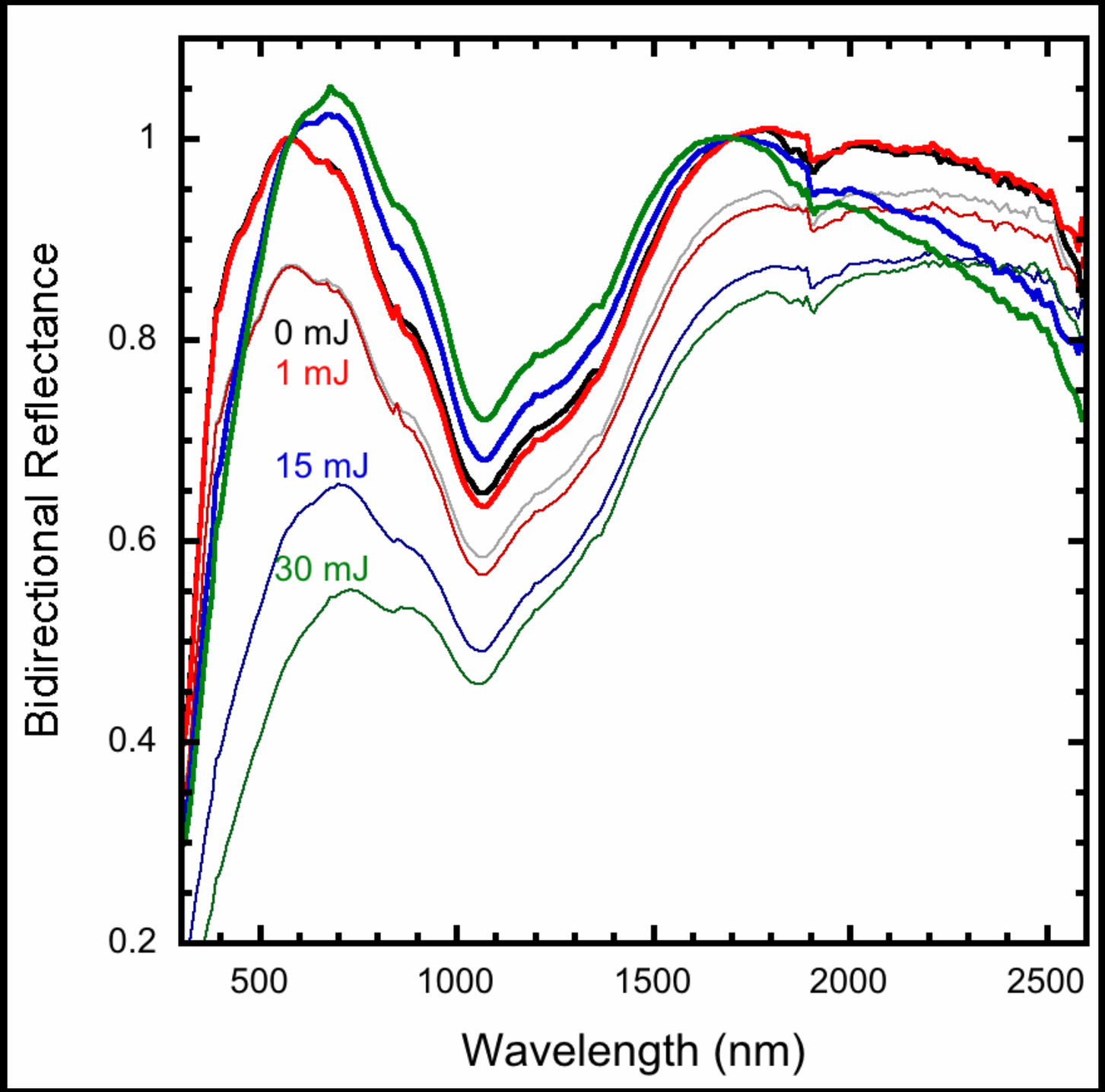
Continuum Slope Evaluation: Laboratory Spectra



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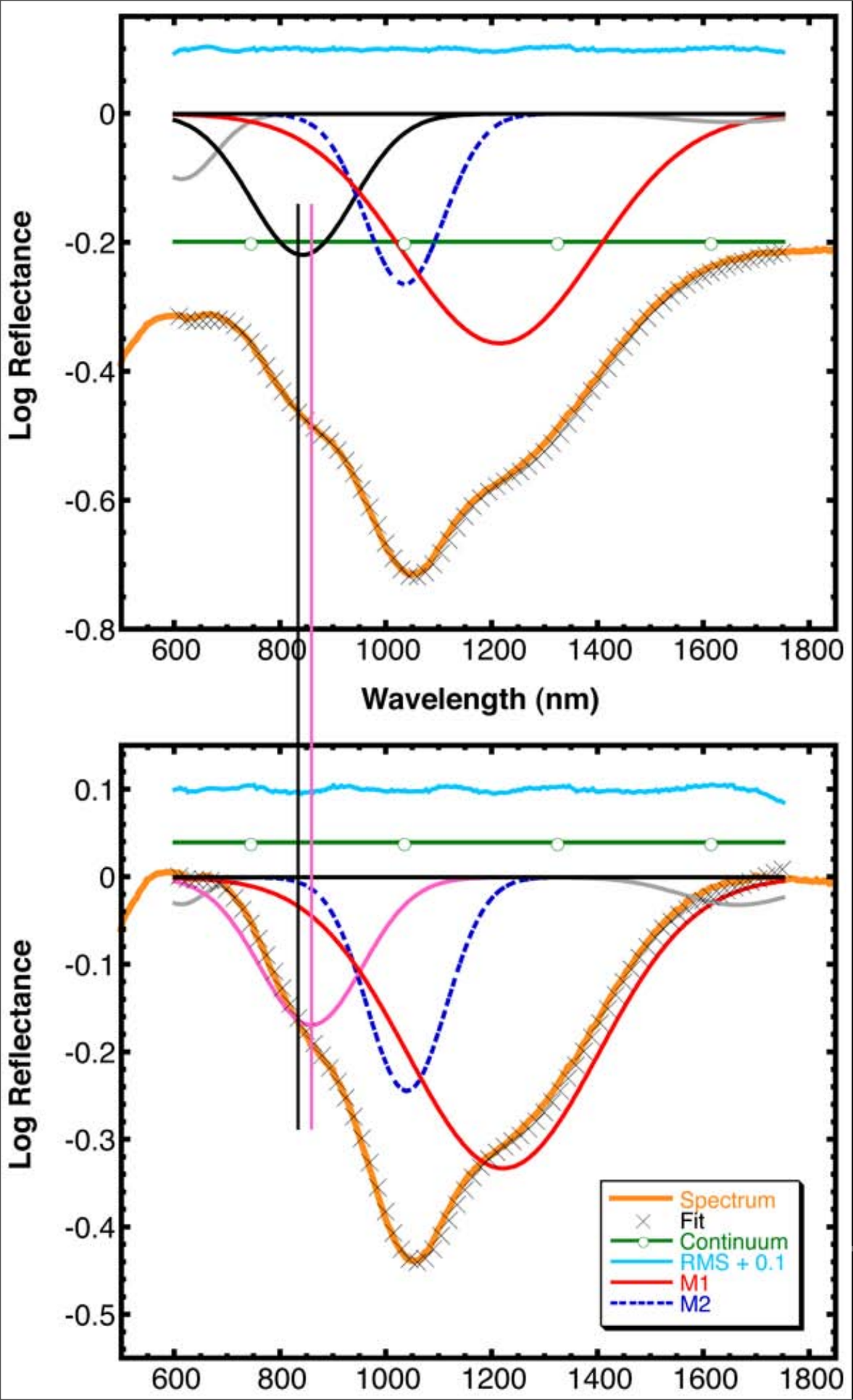
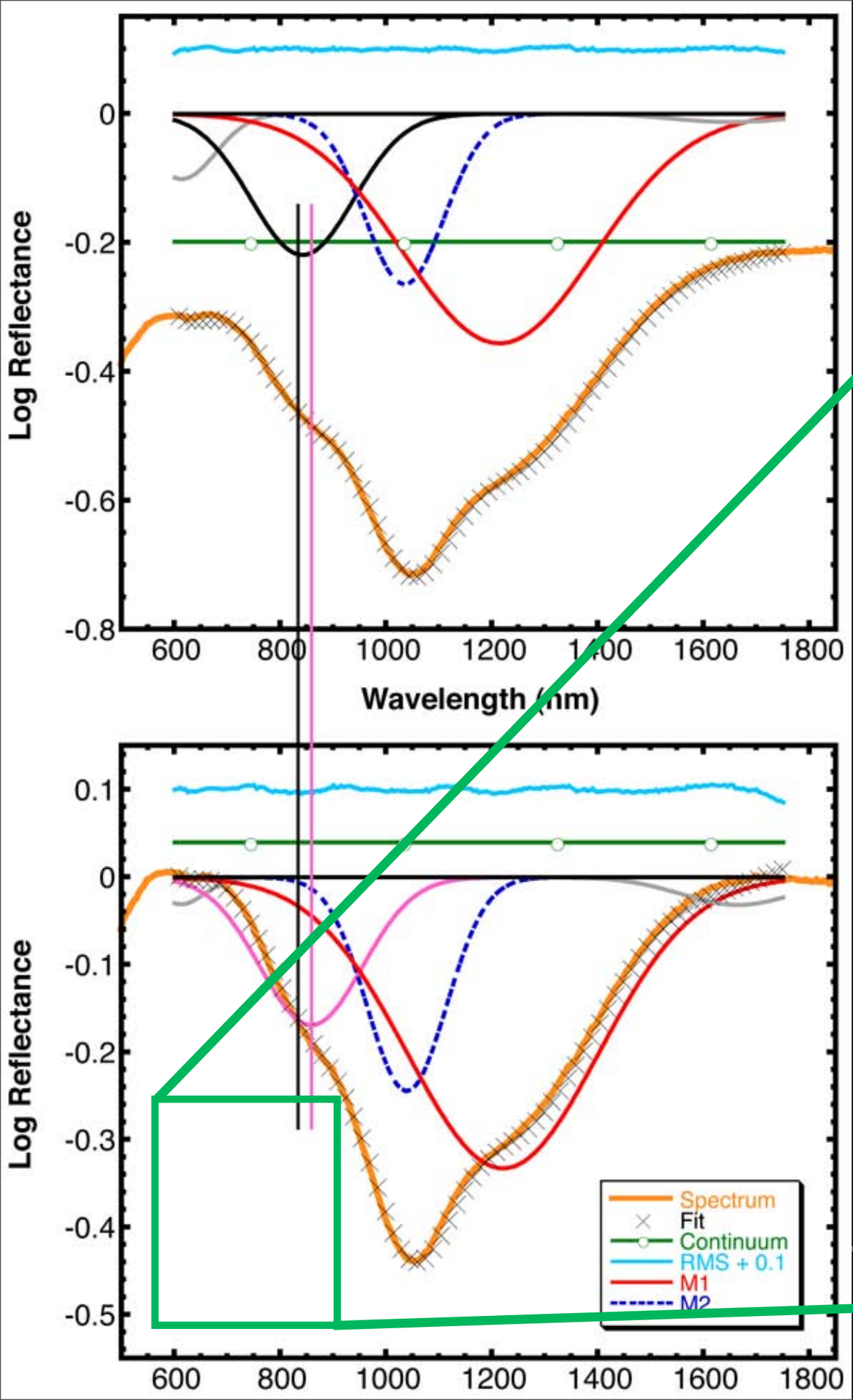
Continuum Removal Evaluation: *Band Shift*

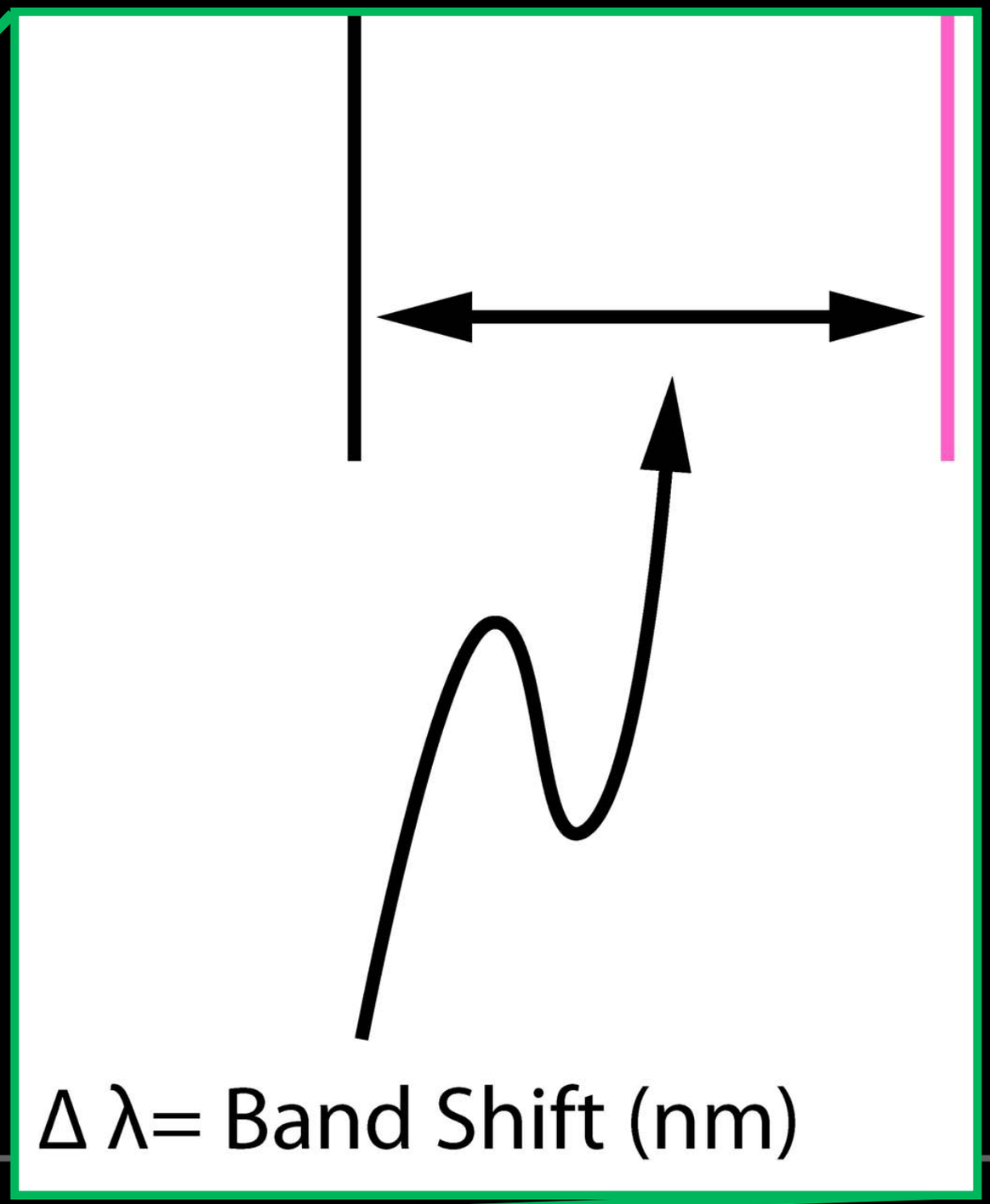
Standard



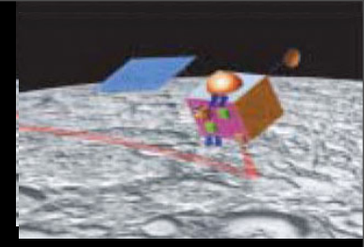
Continuum Removed

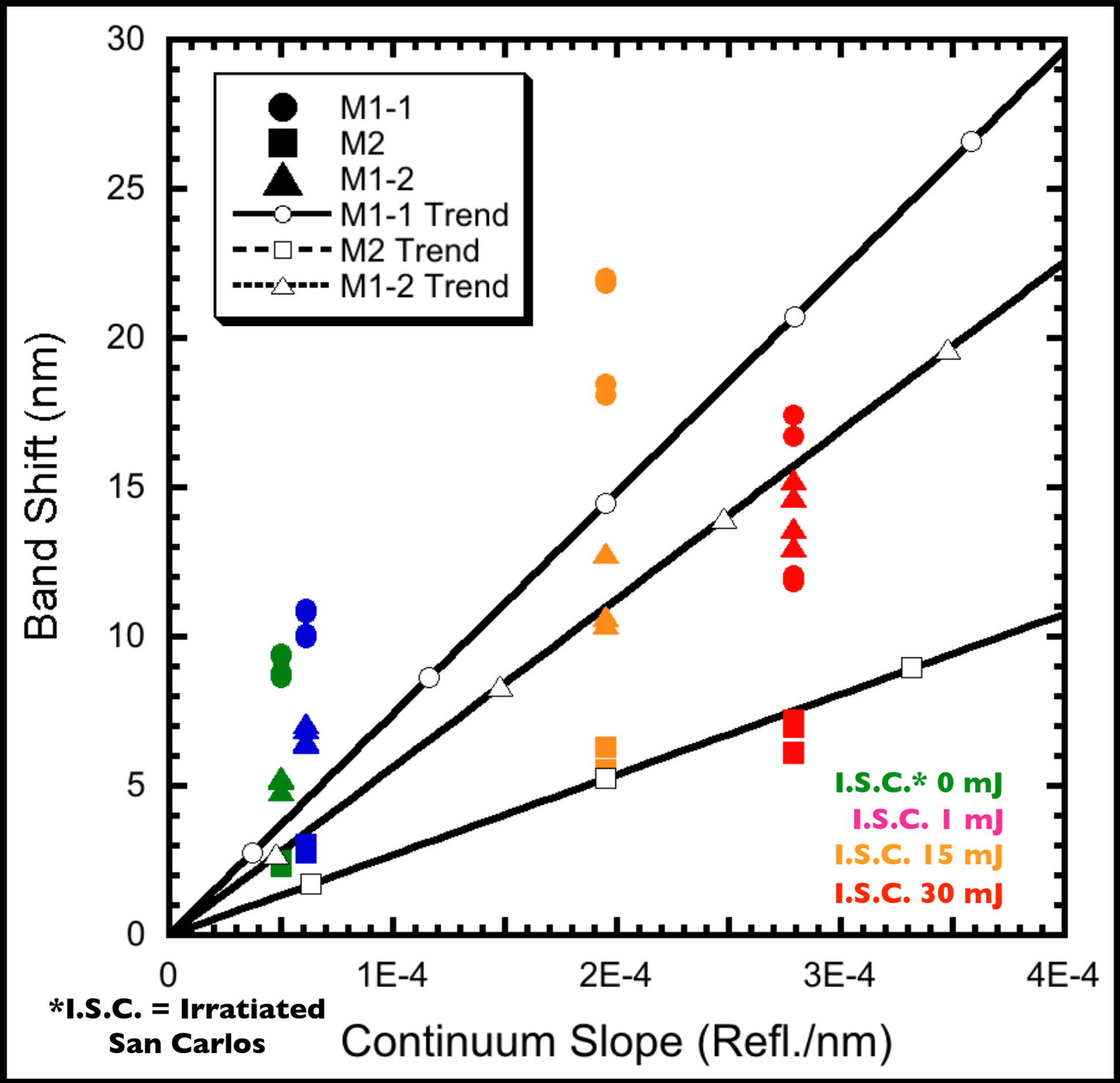
Continuum Removal Evaluation: *Band Shift*





Band shift based on continuum slope





*I.S.C. = Irratiated San Carlos

- Bands shift to longer wavelengths after continuum removal.
- Systematic trend in band shift (continuum removed relative to no continuum removal) vs. continuum slope
- Trends fit for individual bands, constrained to 0,0
- Trends used to "correct" band positions (and est. Fo#)