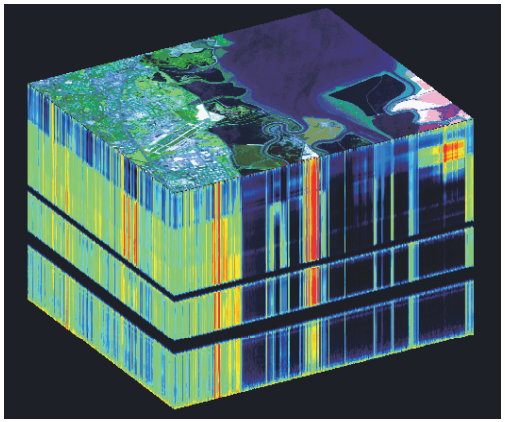
Science Measurement Requirements for Imaging Spectrometers from Airborne to Spaceborne



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[2]Carnegie Institute of Washington
[3]Applied Imaging and Geophysics
[4]Goddard Space Flight Center

Overview

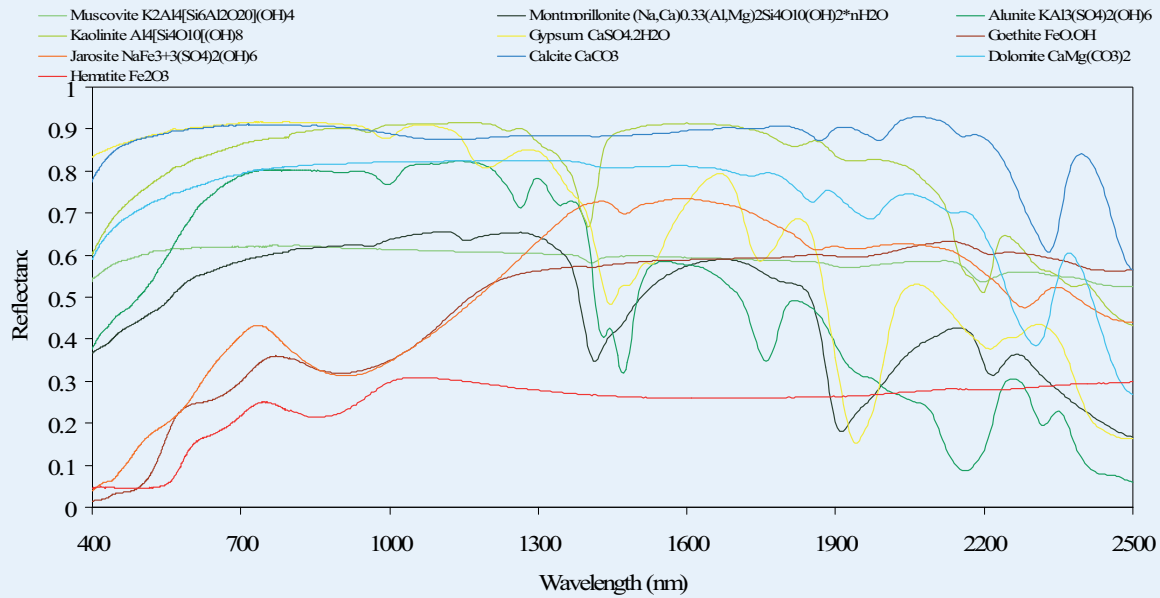
- Imaging Spectroscopy Science Objective
- Uniformity Requirements
- Spectral Requirements
- Radiometric Requirements
- Spatial Requirements
- A Requirements Driven Imaging Spectrometer
- Summary and Conclusion

Imaging Spectroscopy Science Objective

- To remotely determine the properties of the surface and atmosphere (physics, chemistry and biology) revealed by the interaction of electromagnetic energy with matter via spectroscopy.

- AKA Remote Measurement

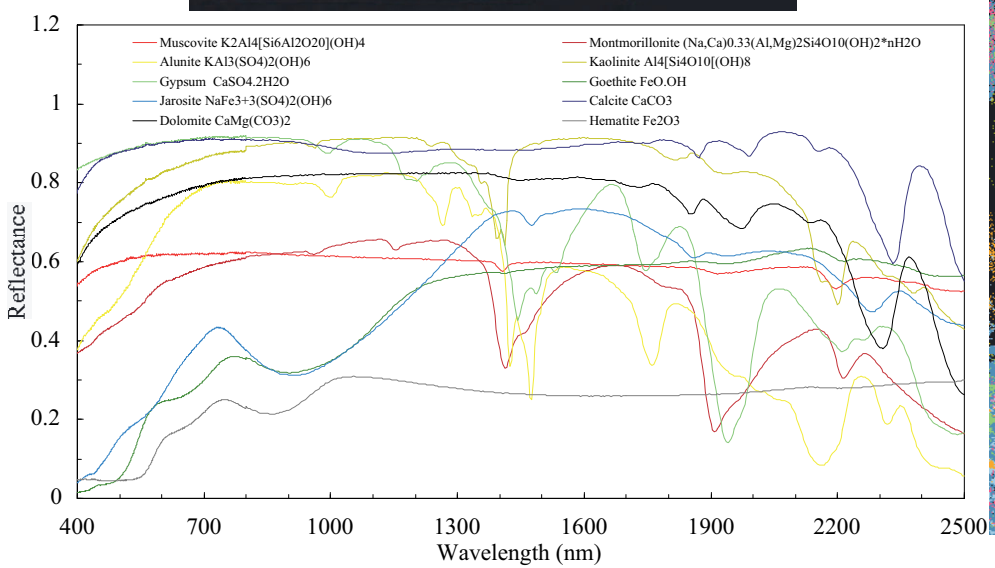
Example: Spectroscopic Approach

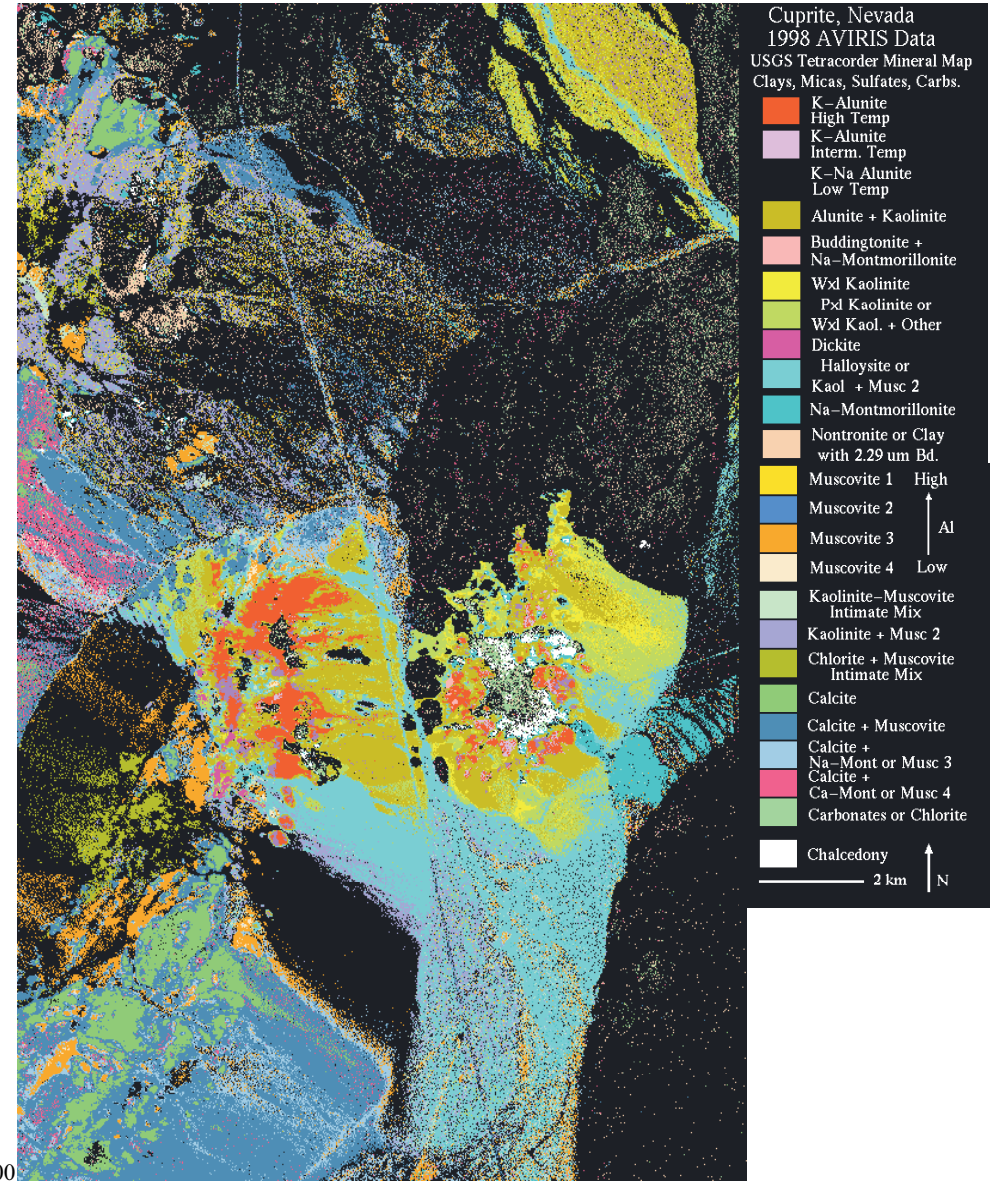


Spectroscopic Approach: Enables Detection, Identification, Quantification and Monitoring

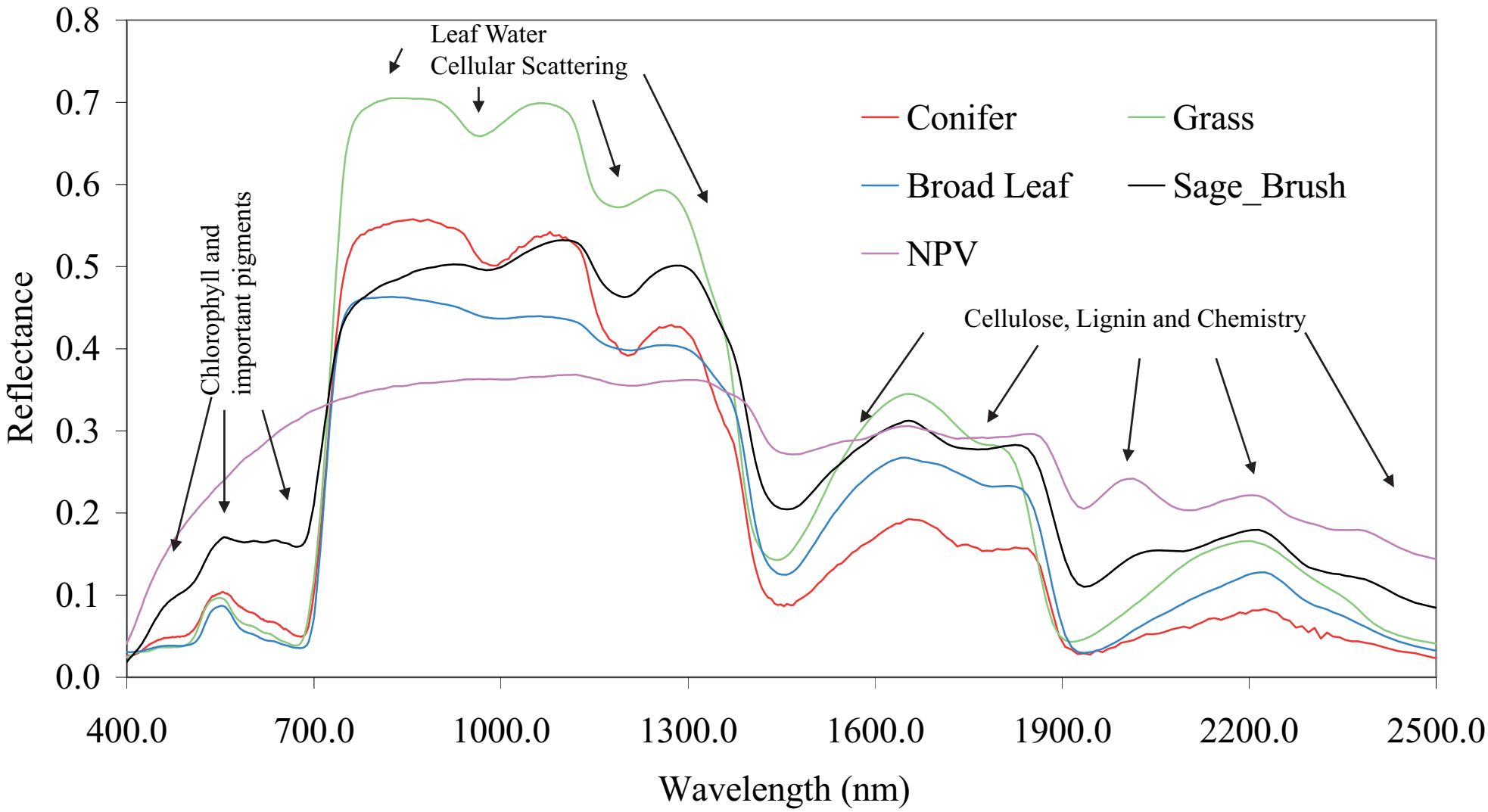
Multi-Spectral Fails: Detection, Identification, Quantification and Monitoring

Cuprite, NV:
Spectroscopic identification of surface composition



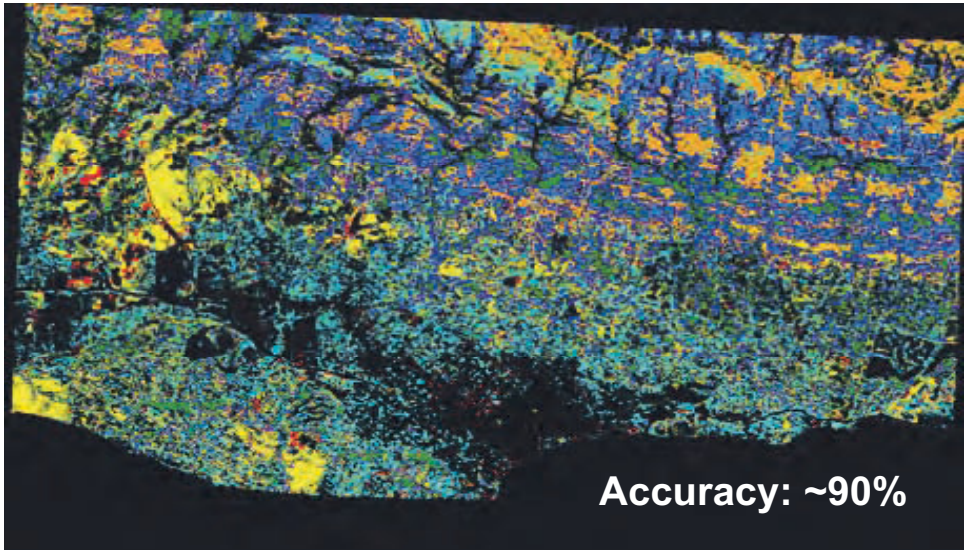


Imaging Spectroscopy is Required for Vegetation Type, Water, Carbon, Cover, Light use, Chemistry, etc



Carbon Cycle and Ecosystems Focus Area
FLORA Measurement Contributions

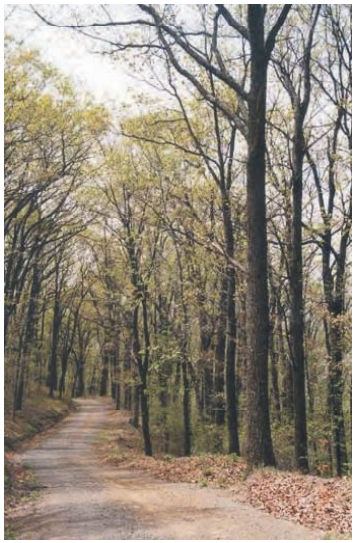
- Fractional Cover
  - *Photosynthetic vegetation (PV)*
  - *Non-photosynthetic vegetation (NPV)*
  - *Soil, Water, Snow/ice*



Adenostoma fasciculatum
Ceanothus megacarpus
Arctostaphylos spp.
Quercus agrifolia
Herbaceous
Soil

- Plant Functional Types
  - *Grass/forb/shrub/tree*
  - *Broad/needle leaves*
  - *Deciduous/evergreen*
  - *New types based on water, LUE, pigments*

- Disturbance Response and Vegetation Cover
  - *Recovery/change in fractional carbon cover*
  - *Changes in plant functional types (**Invasive Species**)*
  - *Change in canopy water, pigments*
  - *Change in light-use efficiency*



Uniformity Requirements

- Spectral Cross-Track Uniformity

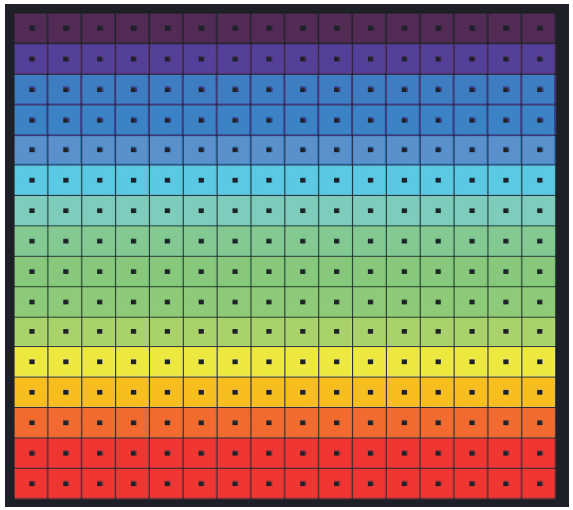
- Spectral IFOV Uniformity

Uniformity is Requirement

Depiction
-Grids are the detectors
-Spots are the IFOV centers
-Colors are the wavelengths

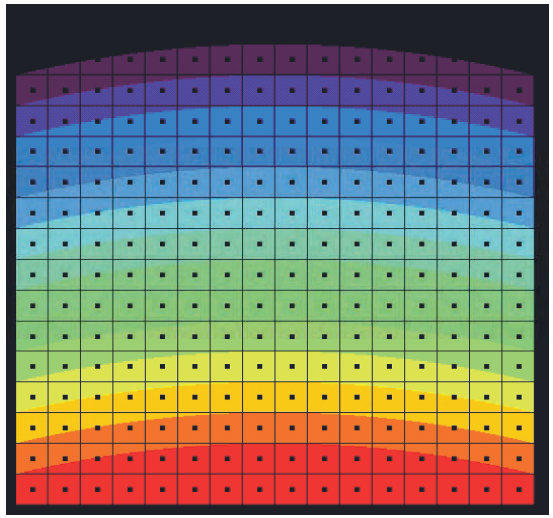
Factors for success
-Design
-Manufacture
-Alignment
-Stability

Cross Track Sample

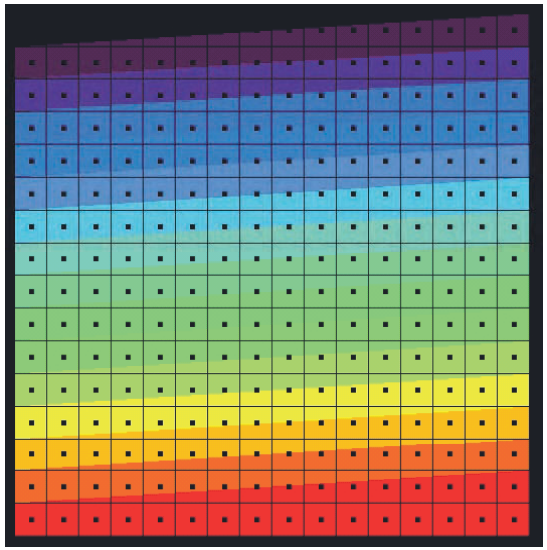


+ Requirement

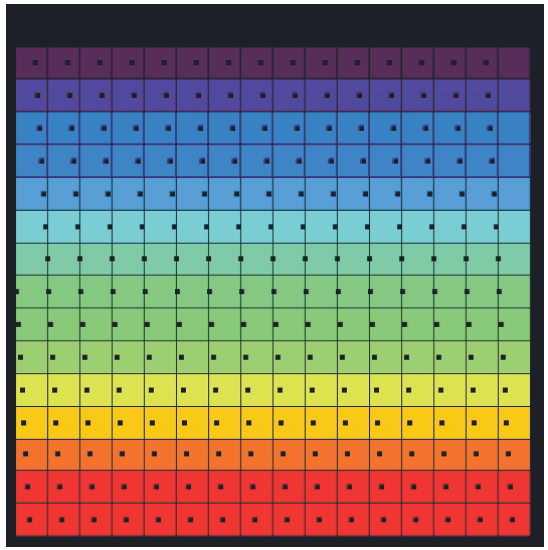
Wavelength



X Failure by Frown

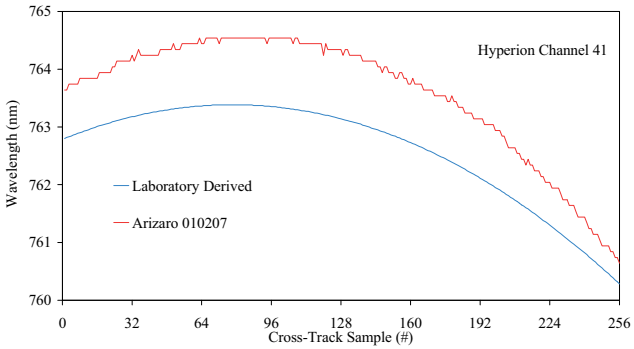


X Failure by Twist

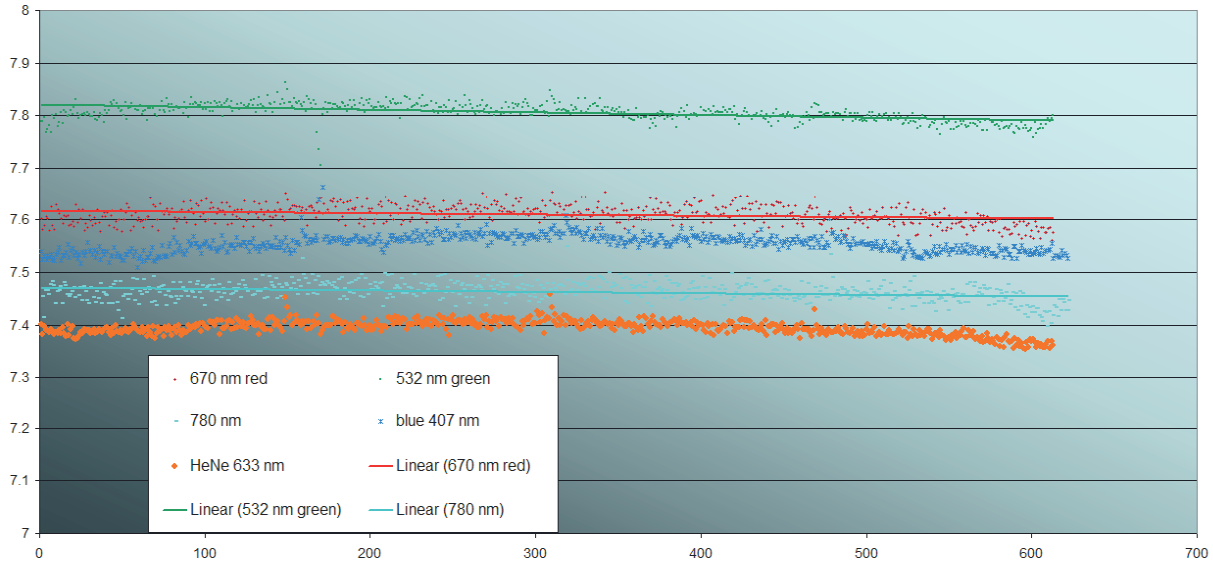


X Failure by Spectral-IFOV-Shift

Hyperion 60% X-Track

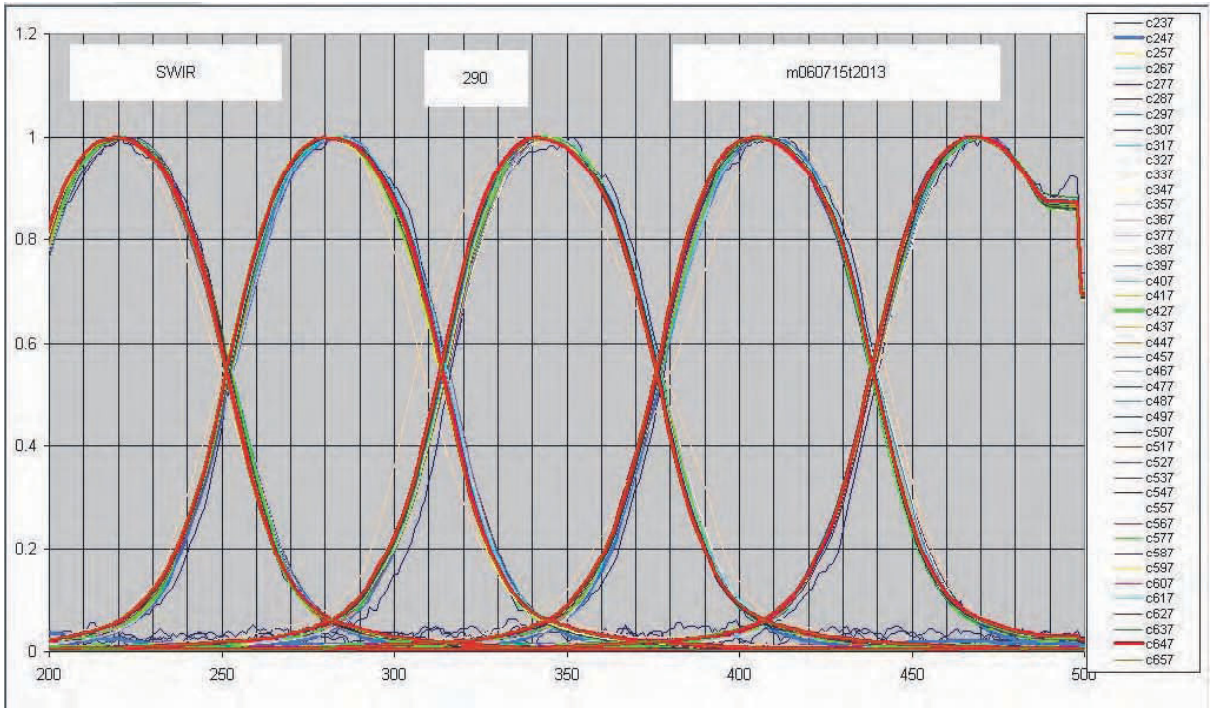


Example Achieved Uniformity



>95% Spectral Cross-track Uniformity
Design through alignment

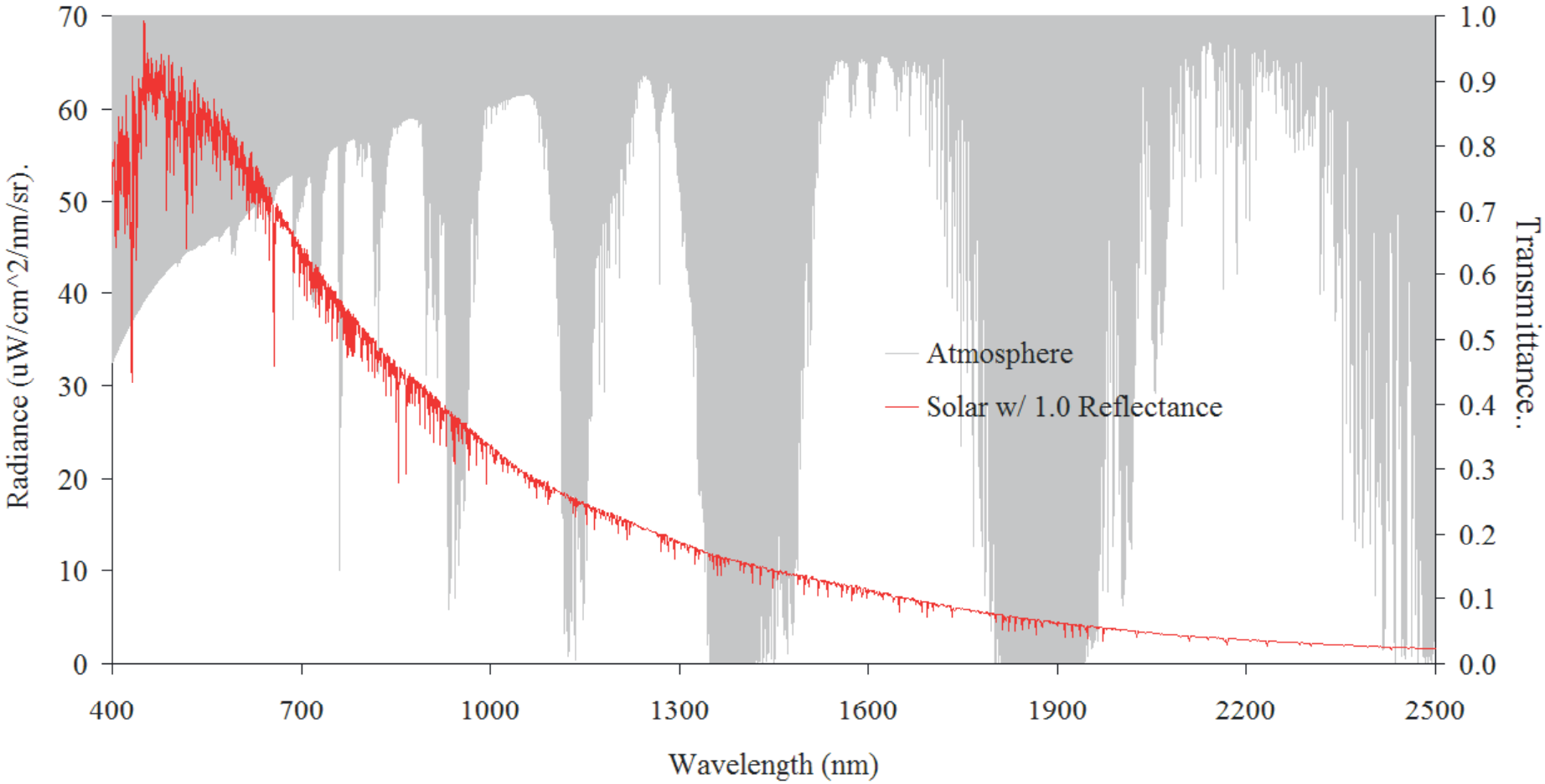
>95% Spectral-IFOV-Uniformity
Design through alignment



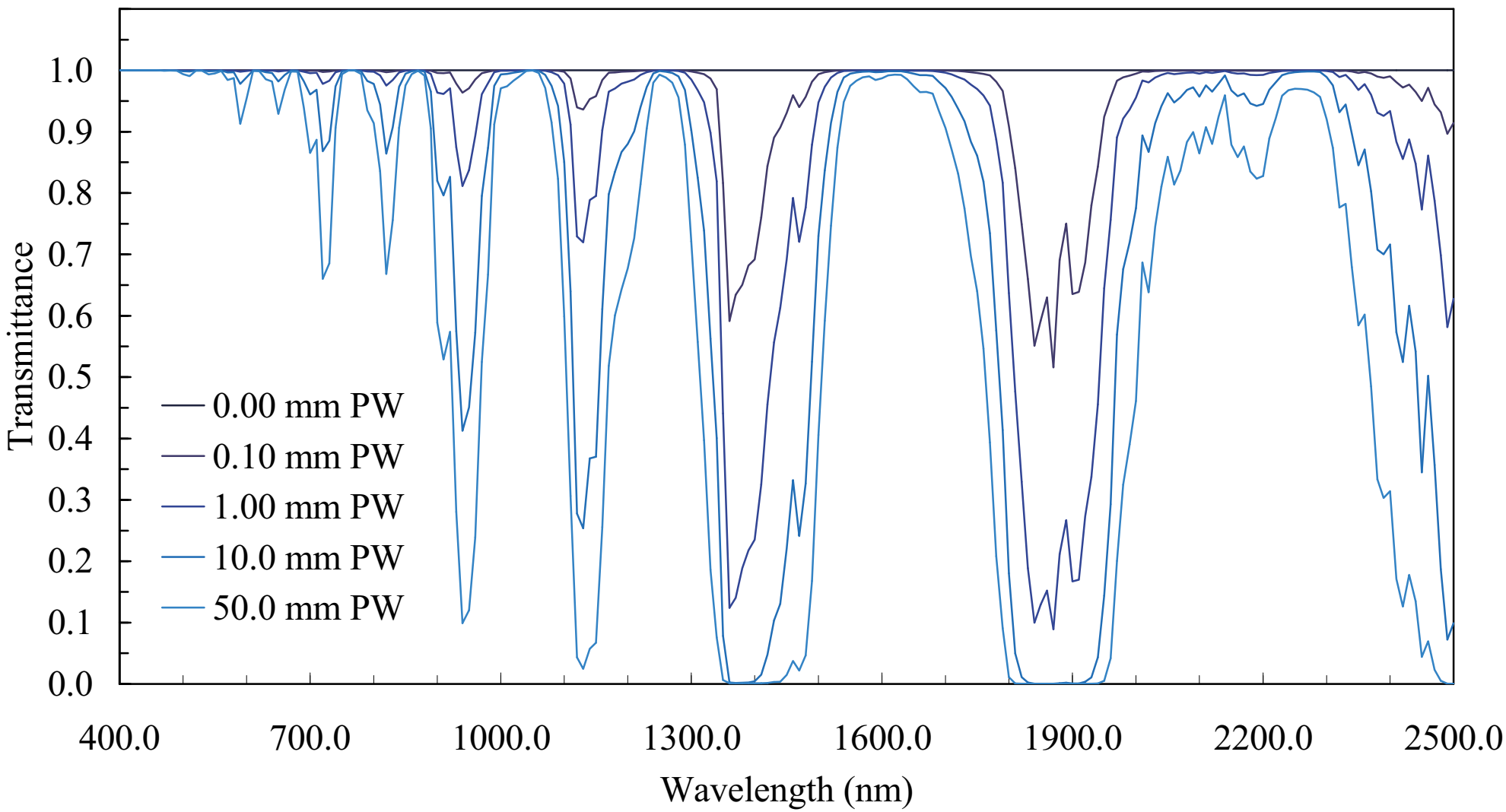
Spectral Requirements

- Range
- Sampling
- Response
- Accuracy
- Precision

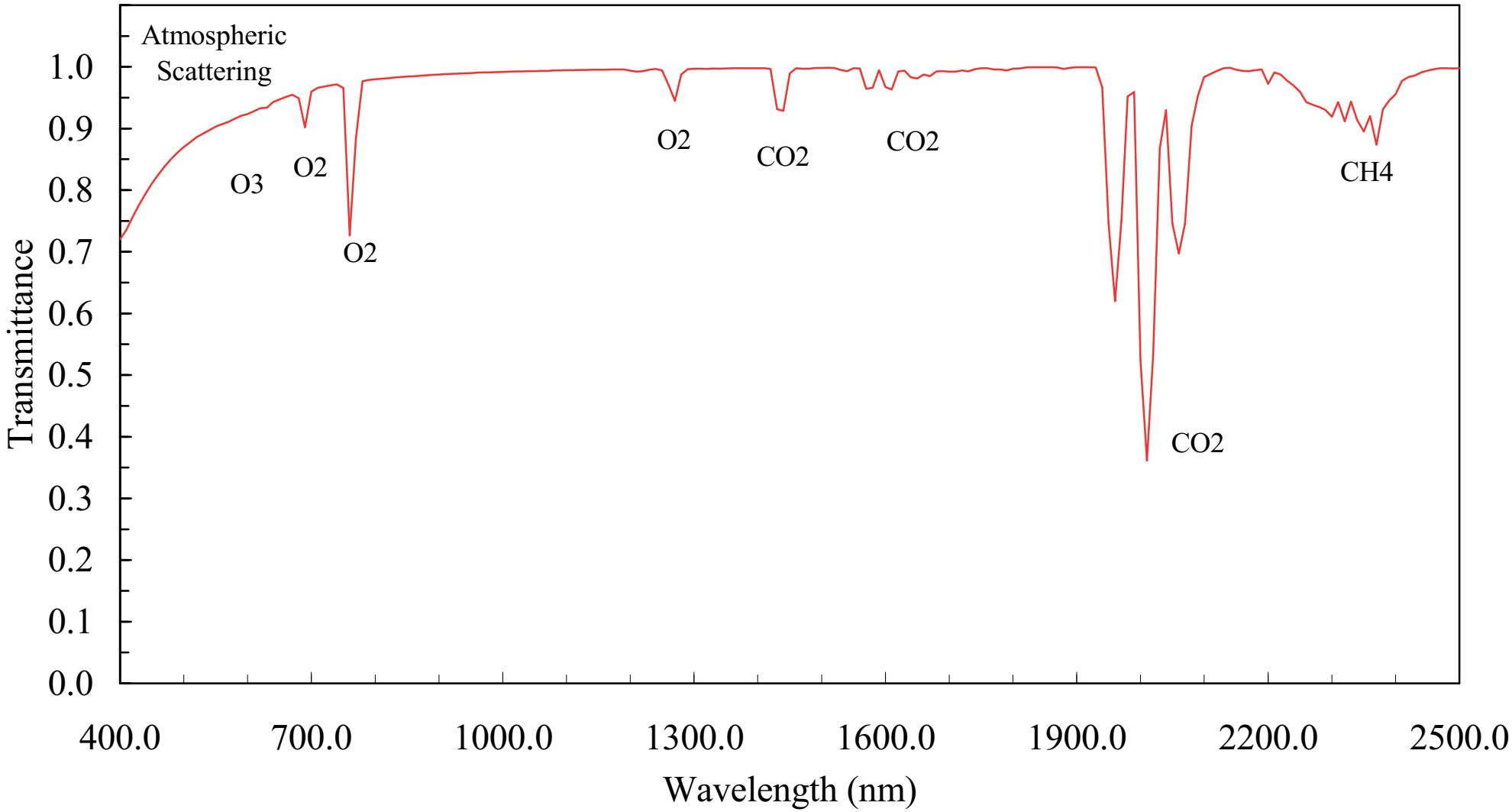
Spectral Range: Solar Reflected



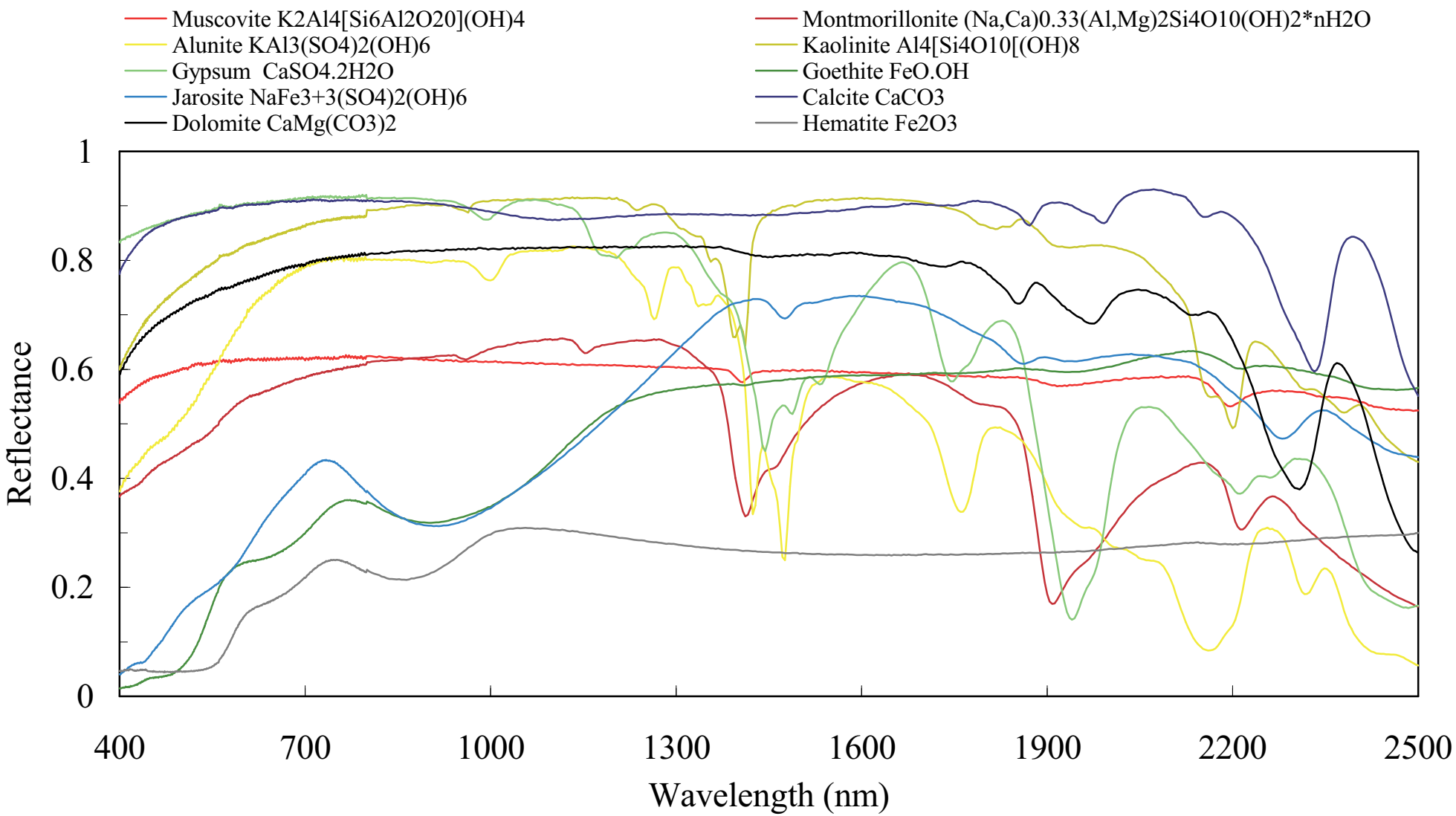
Atmospheric Water Vapor



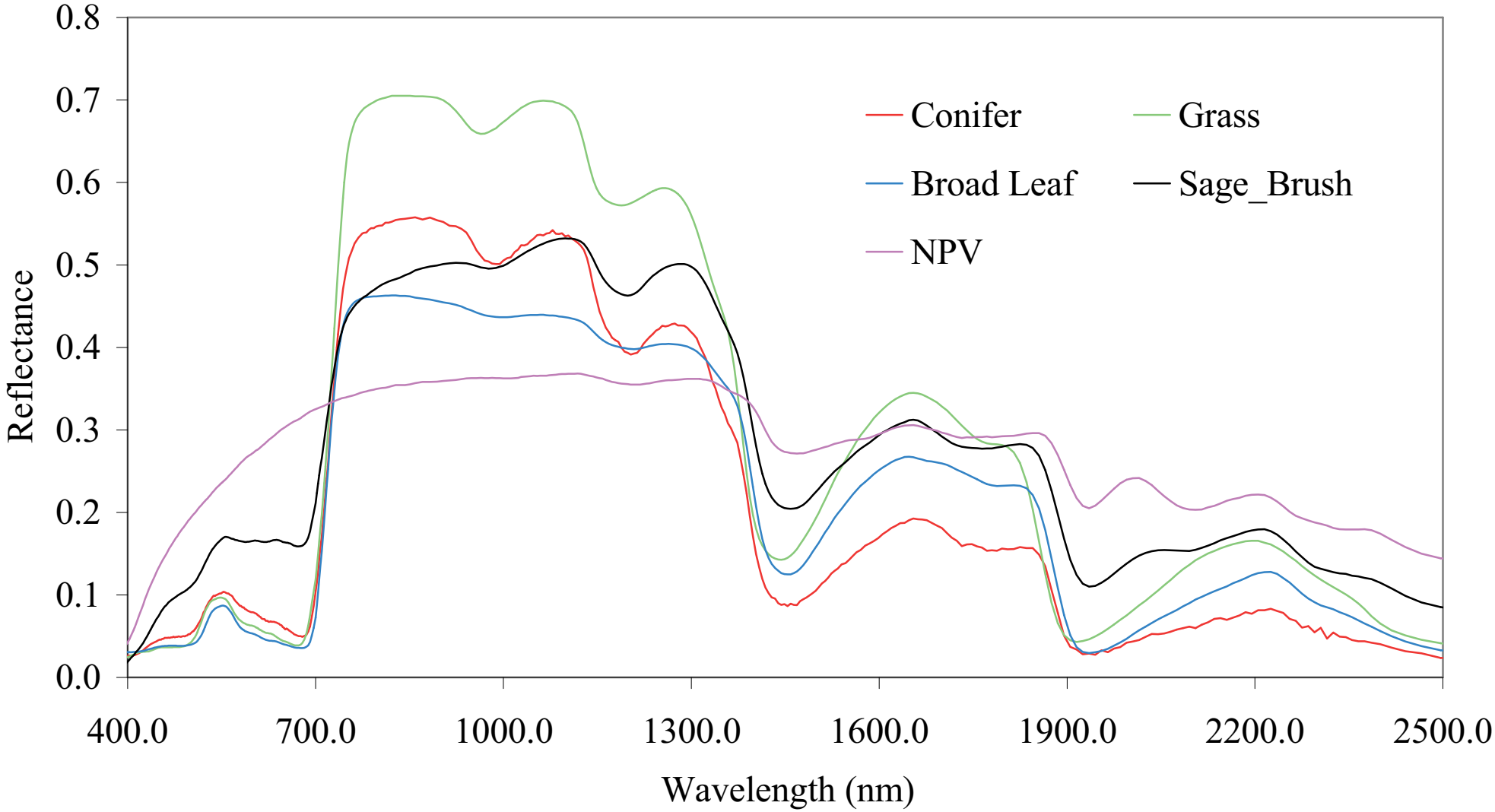
Atmospheric Constituents other than Water



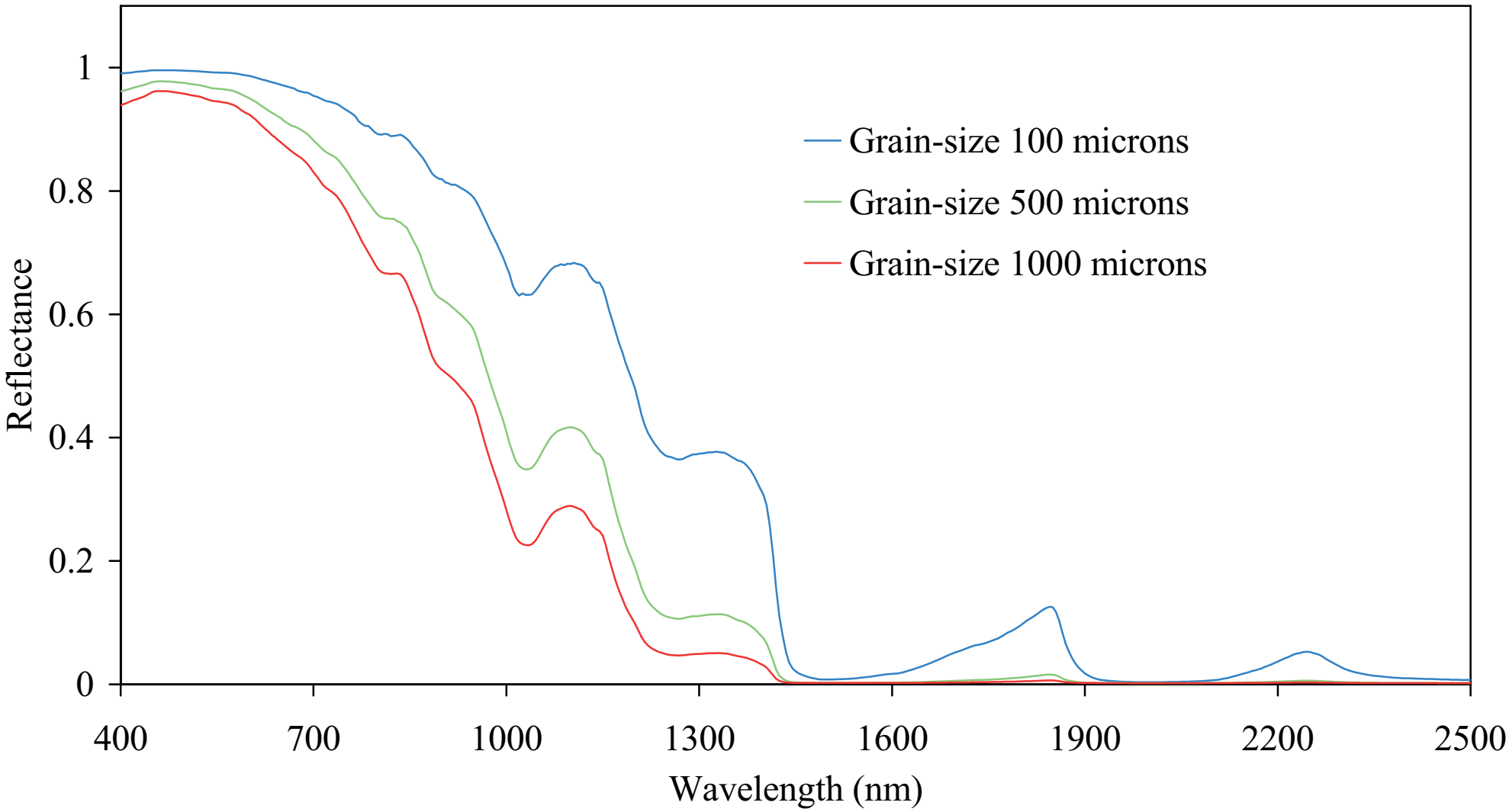
Mineral Spectra



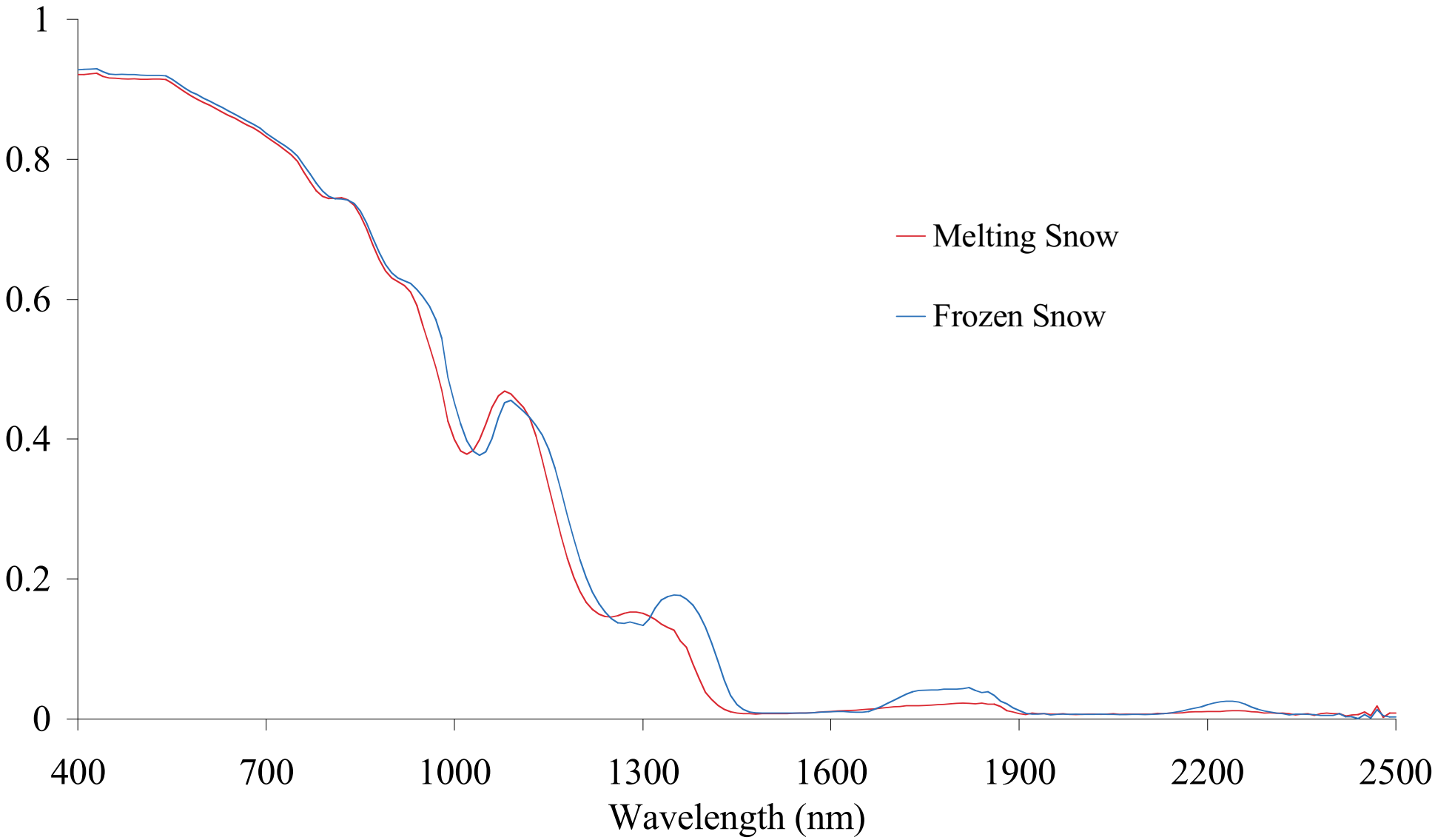
Vegetation Spectra



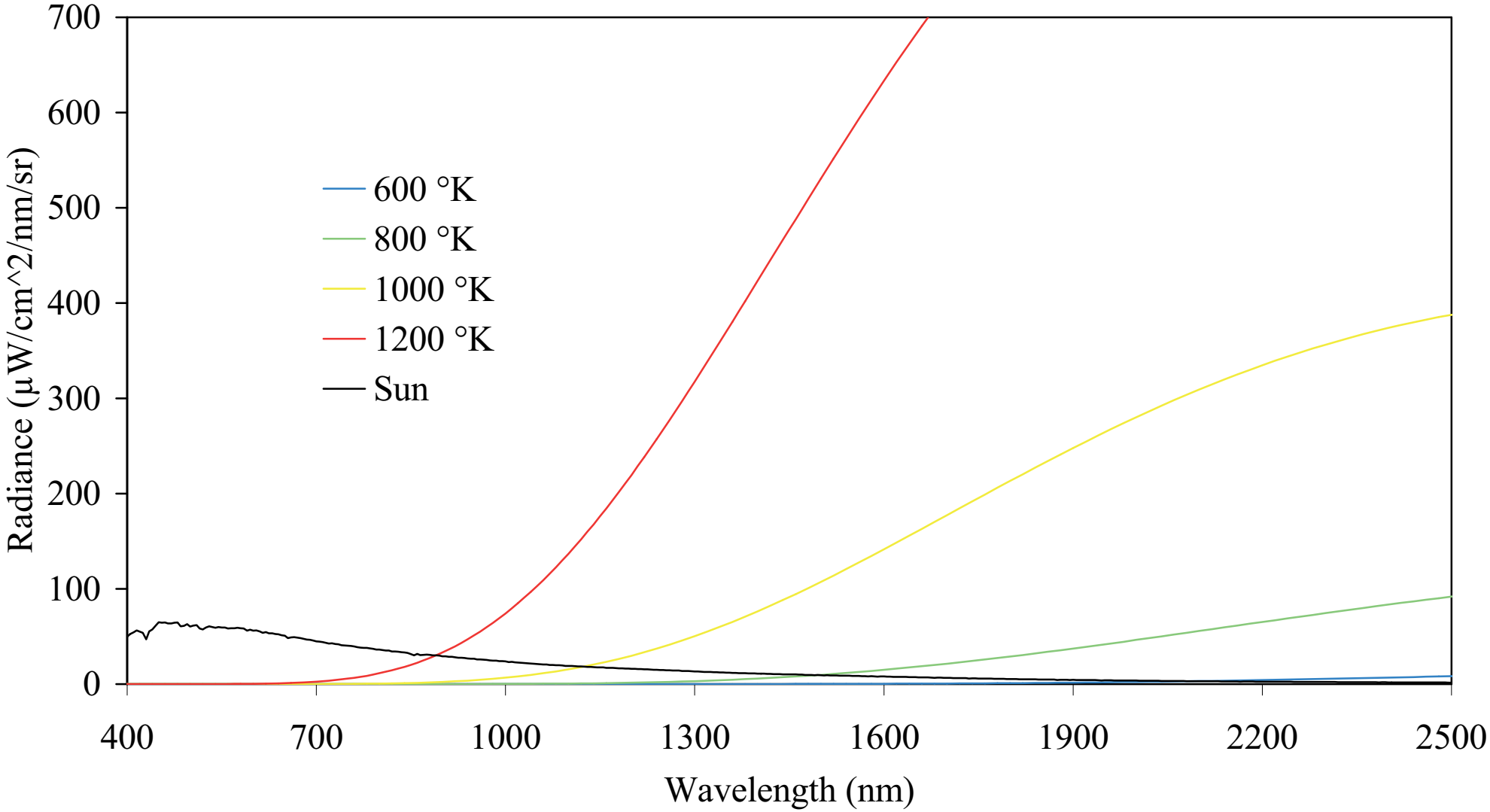
Ice Properties



Ice Melting and Frozen

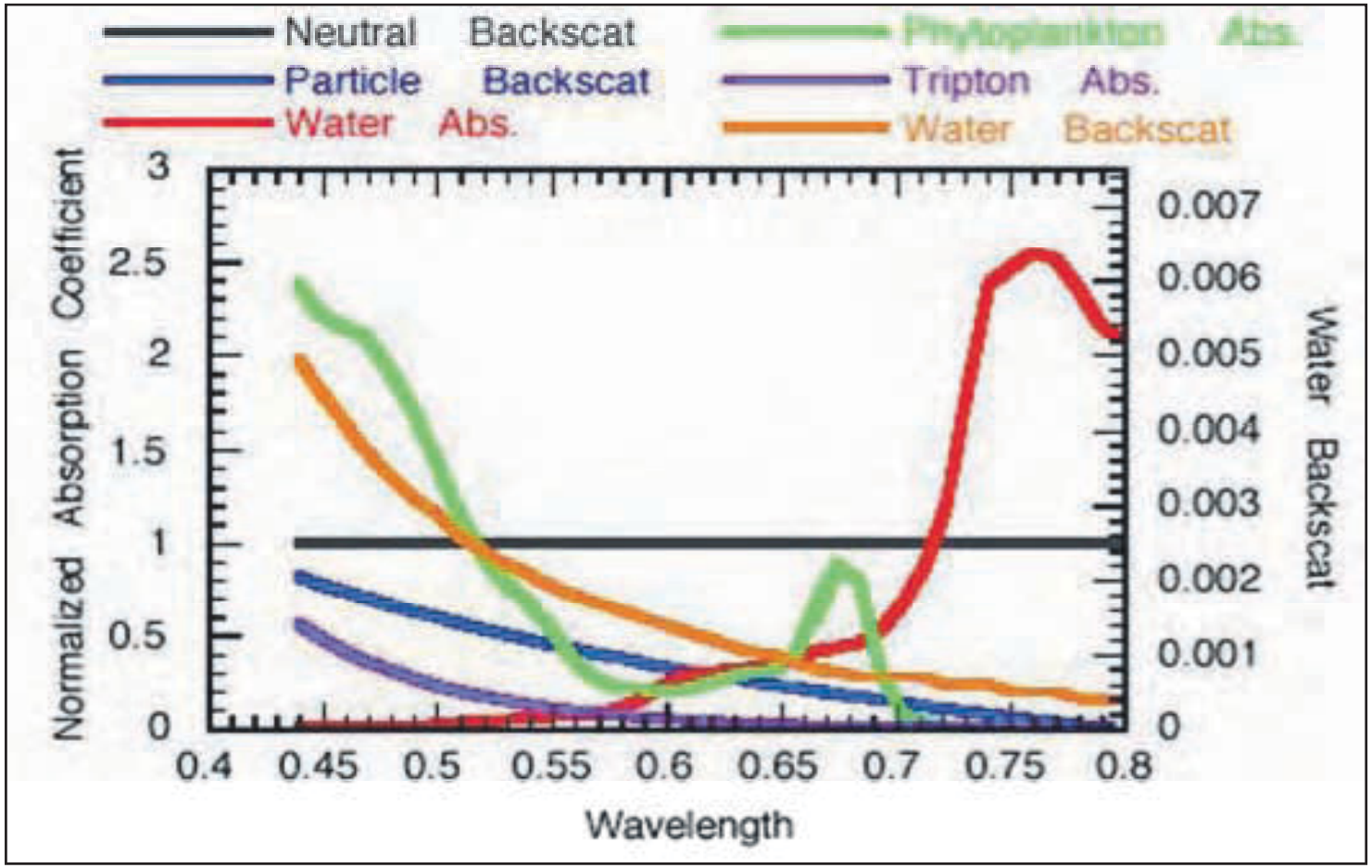


Spectral Signatures of Hot Sources

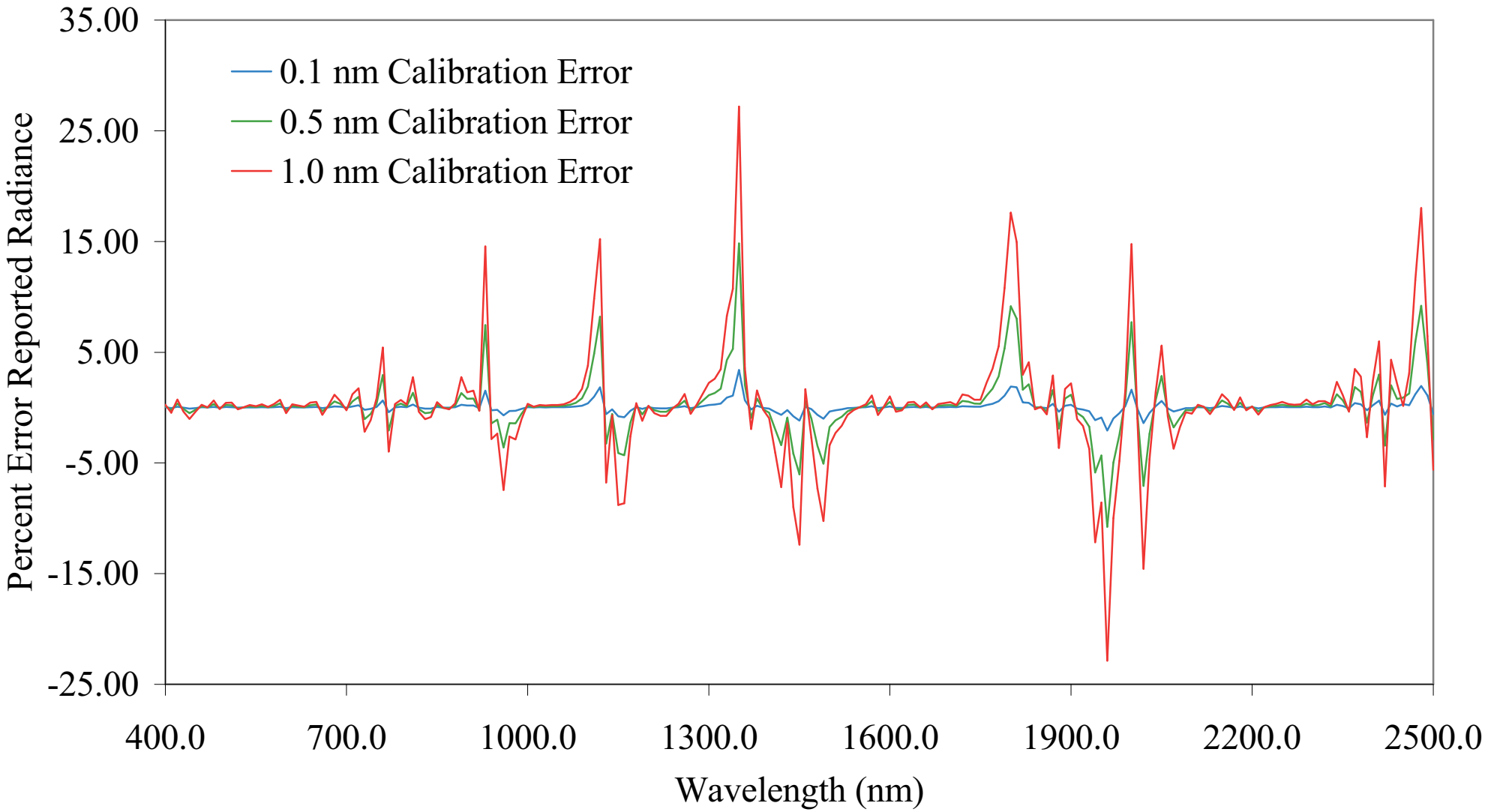


Spectral Signatures of Water Constituents

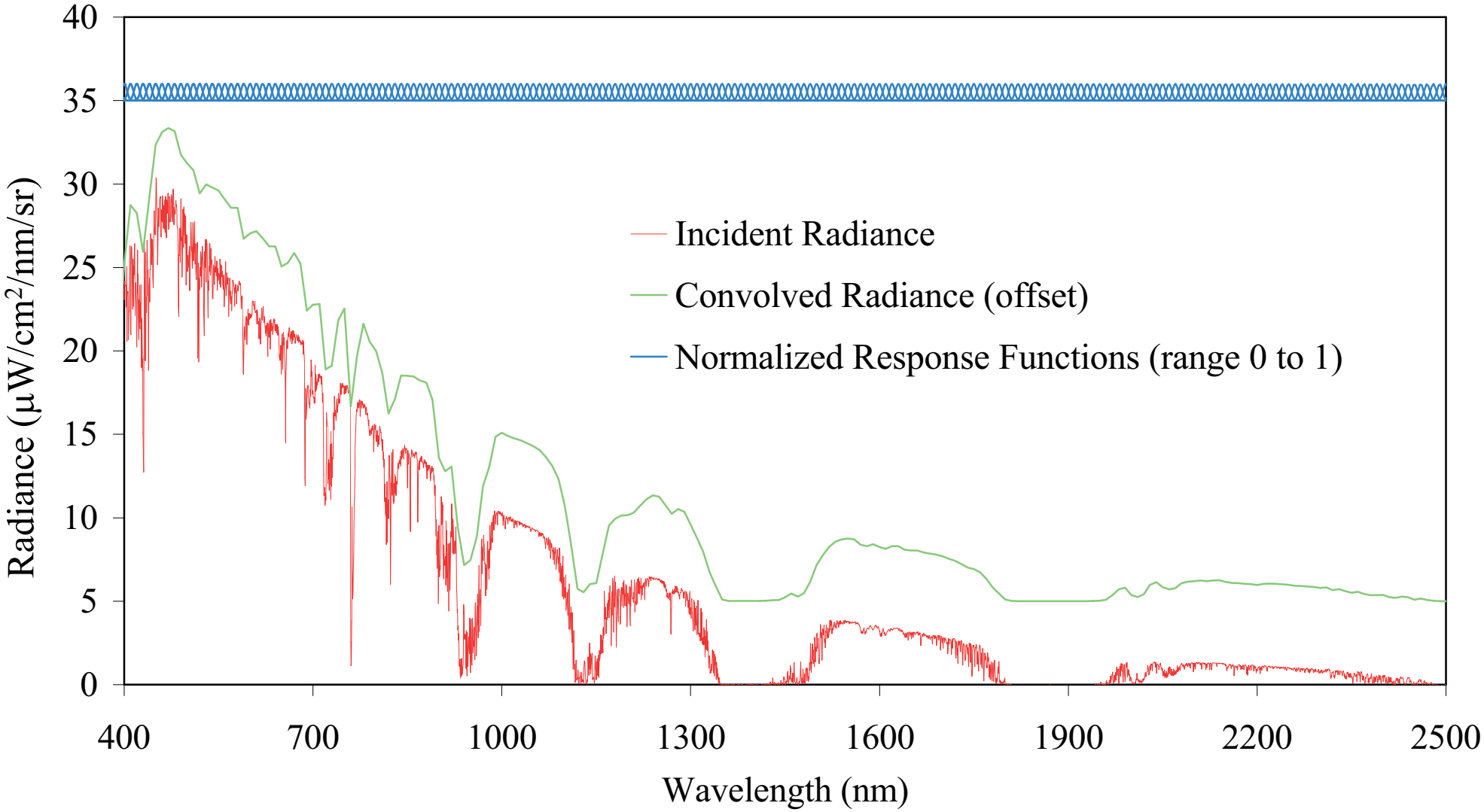
(from John Mustard)



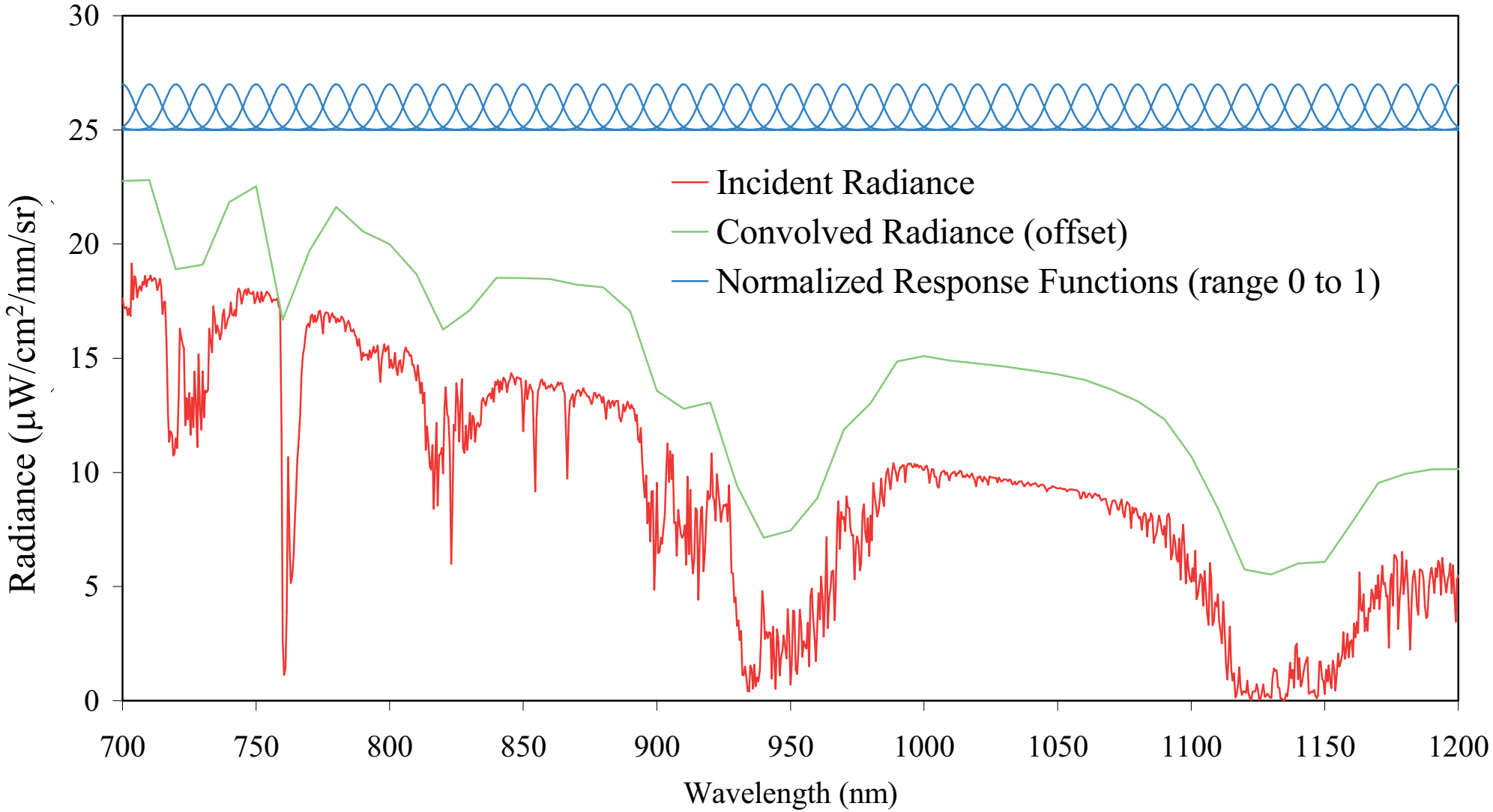
Spectral Accuracy and Precision Requqirements



Spectral Convolution



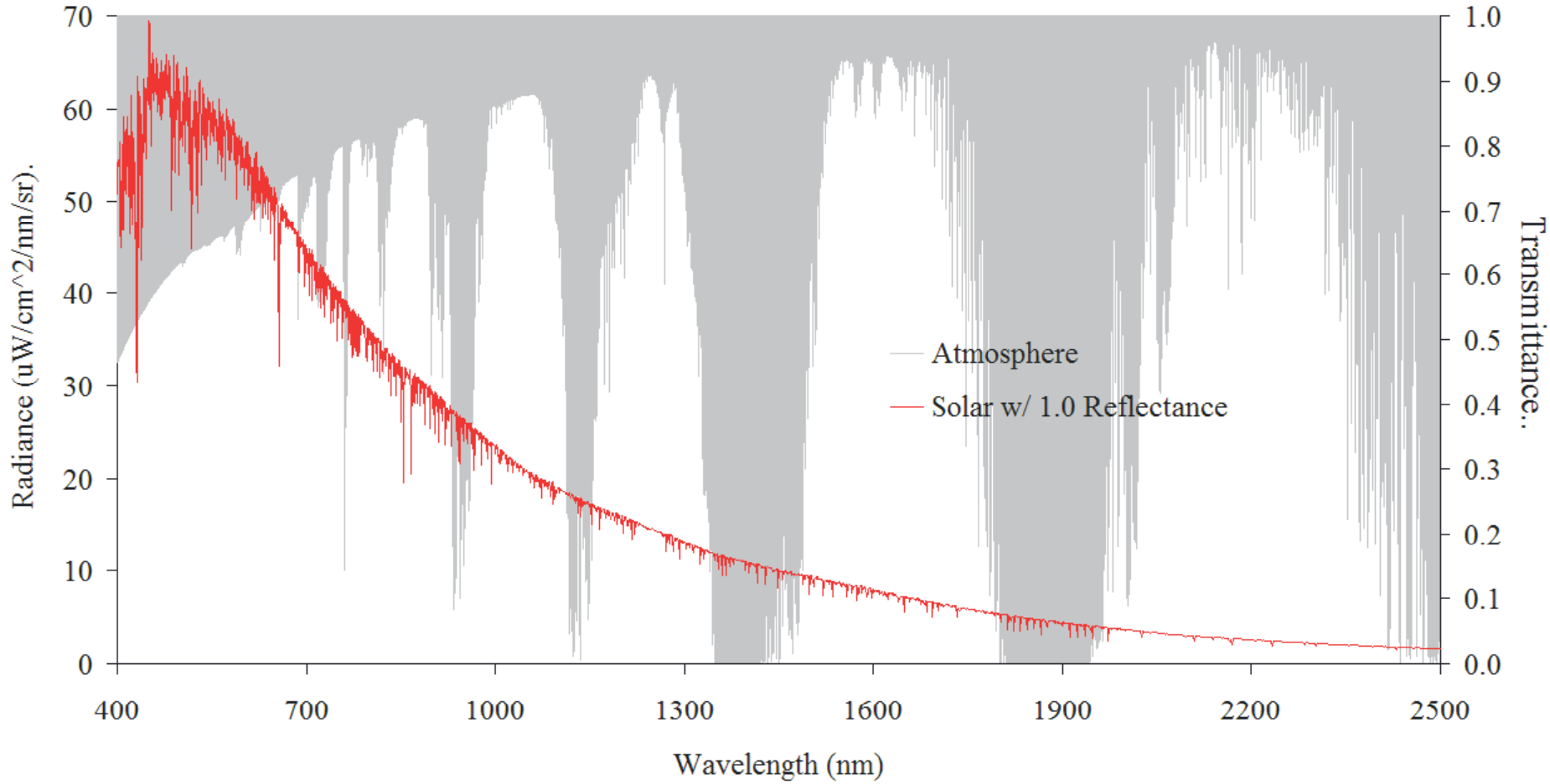
Expanded Spectral Convolution



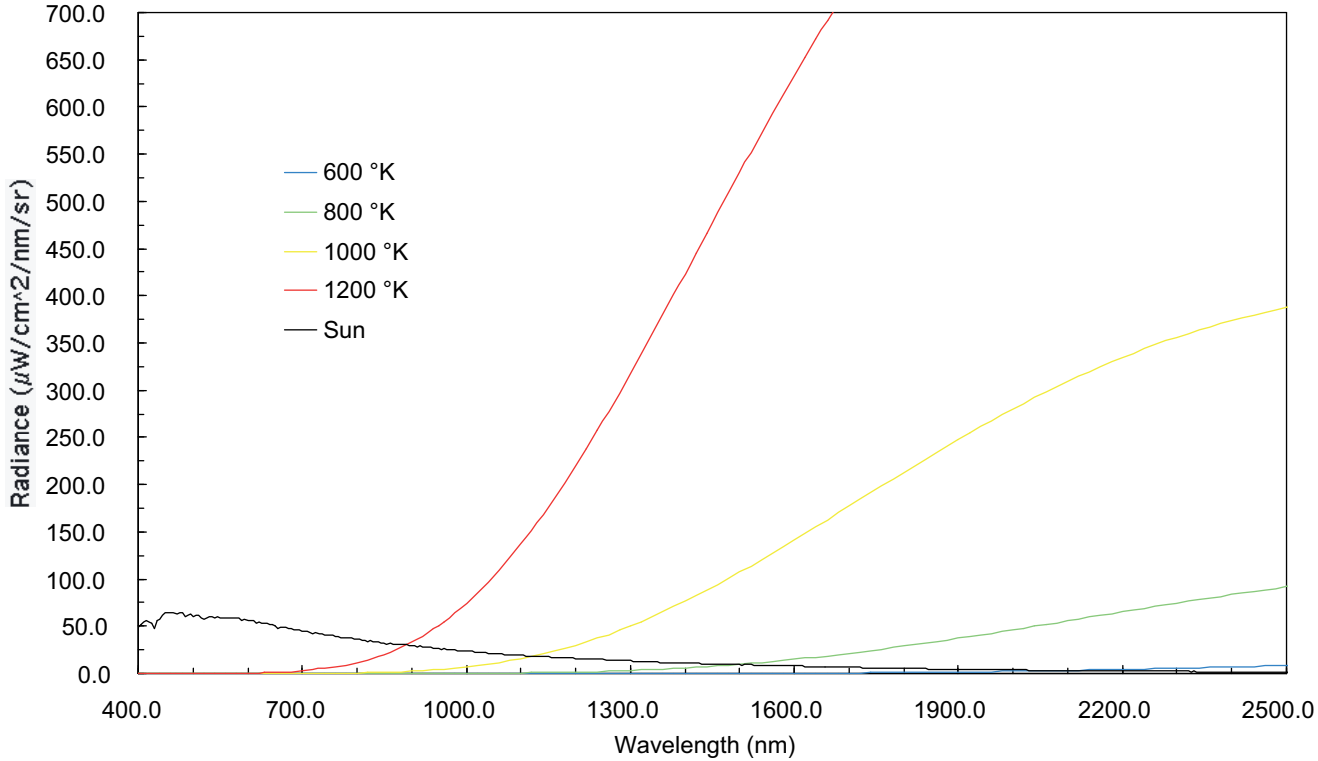
Radiometric Requirements

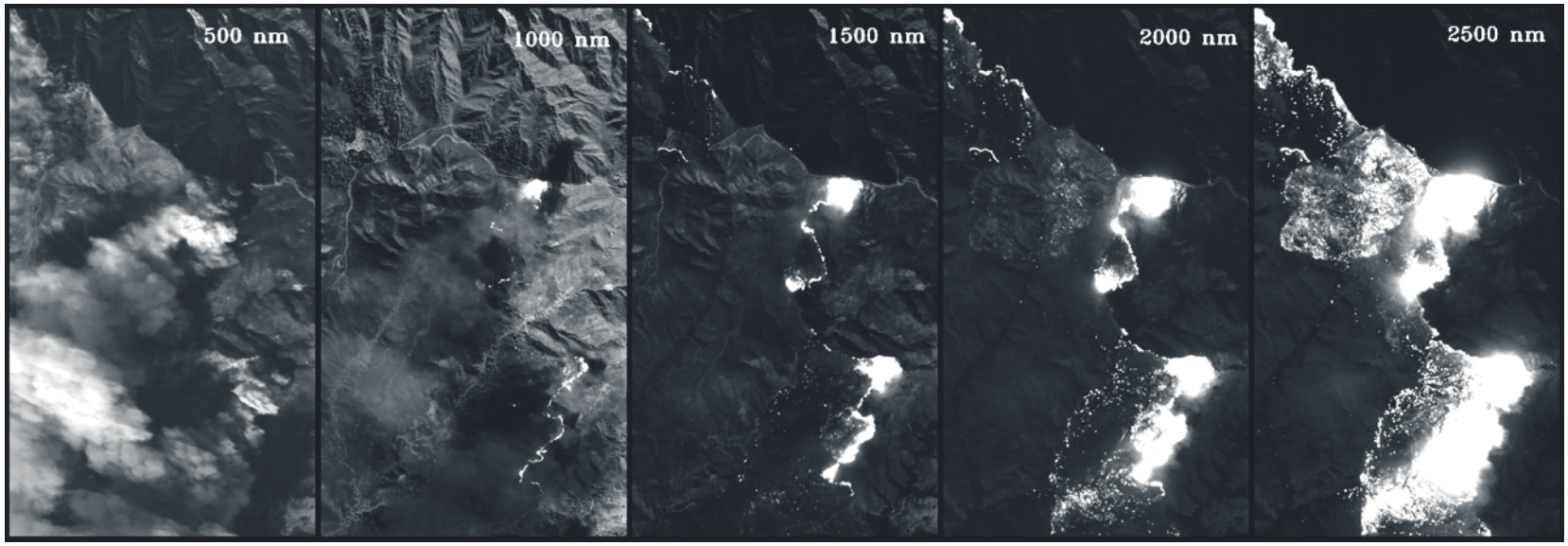
- Range
- Sampling
- Response
- Accuracy
- Precision

Radiometric Range: Solar Reflected

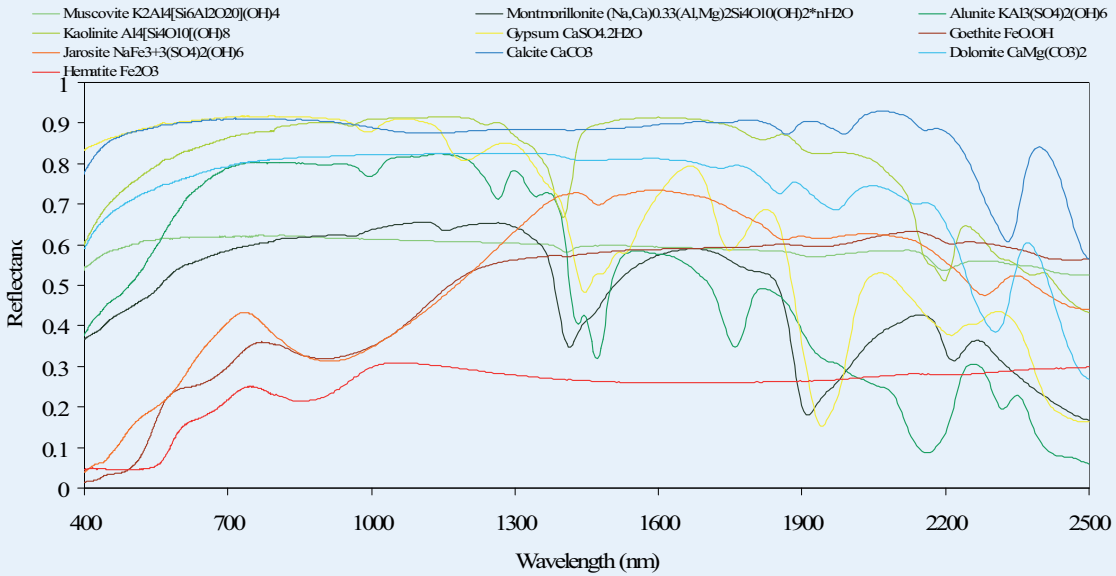


Radiometric Range: Wild Fires





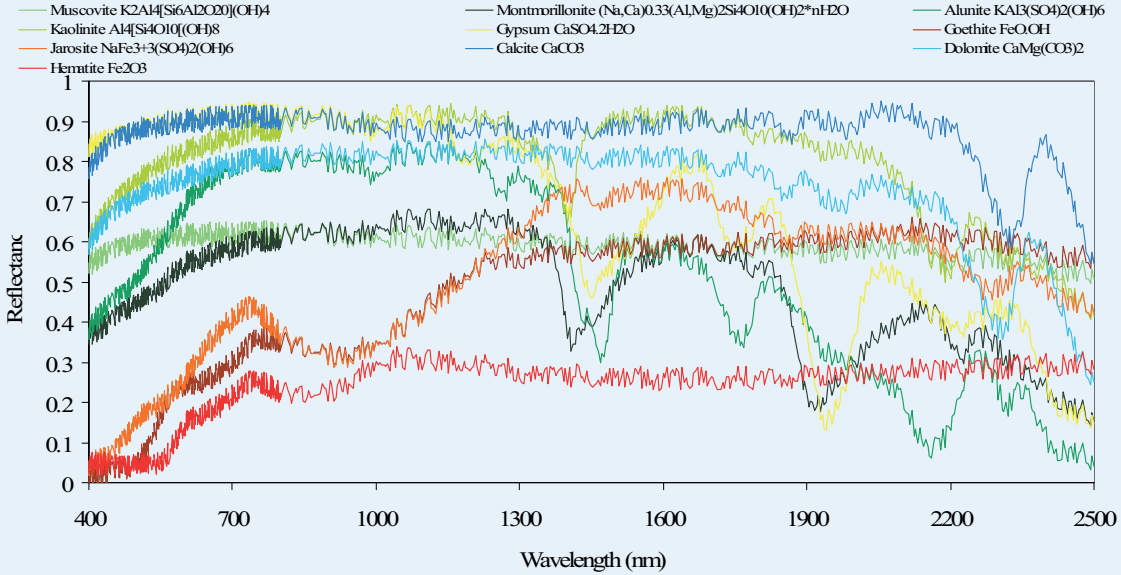
Radiometric Precision



High Precision is required to answer questions of value with imaging spectroscopy

JPL Systems are High Precision (AVIRIS, M3)

Low Precision undermines: Detection, Identification, Quantification and Monitoring

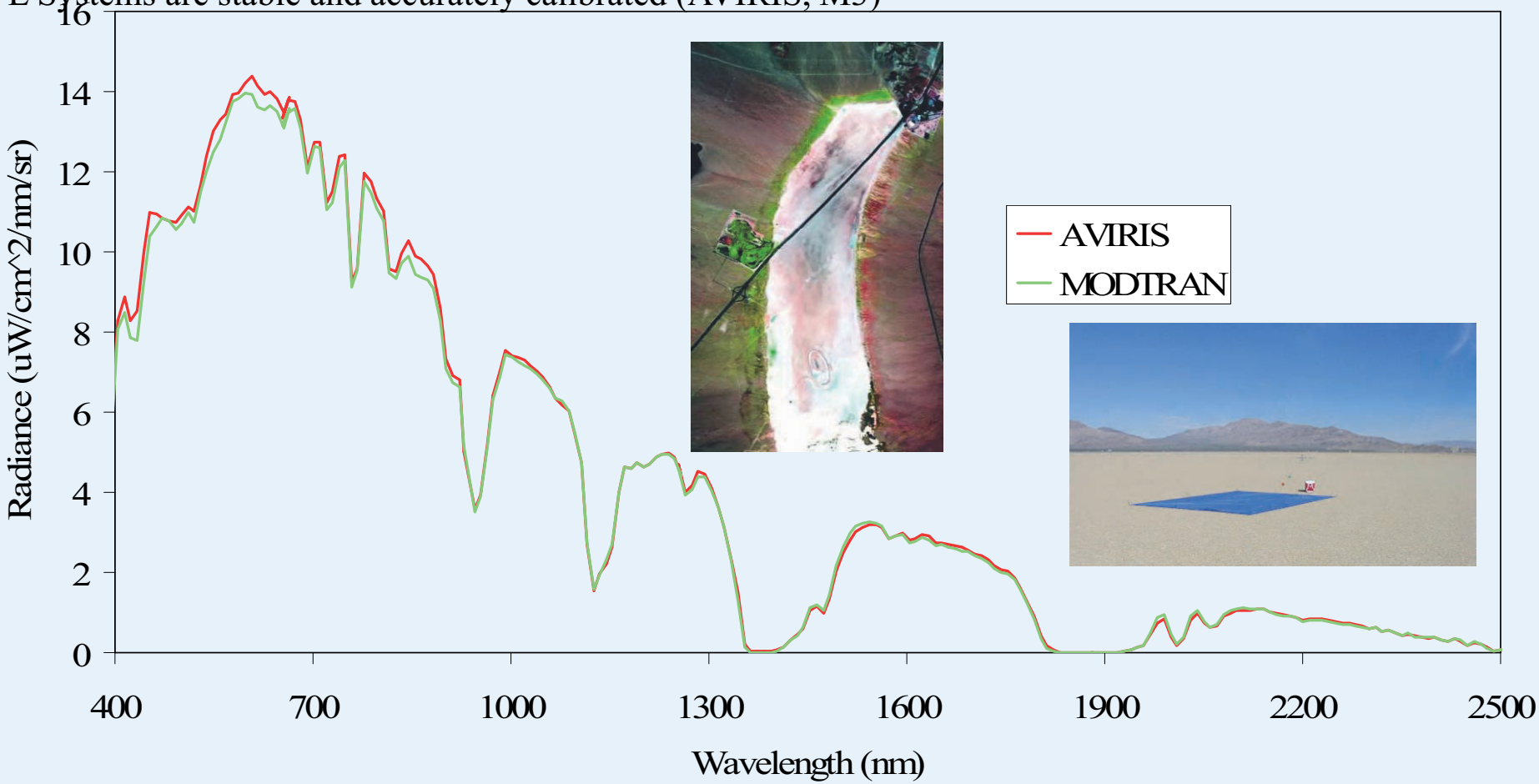


Radiometric Accuracy

Excellent Spectral, Radiometric and Spatial calibration is required to answer questions of value with imaging spectroscopy

- Compare information acquired from different regions and different times
- Compare and analyze imaging spectroscopy measurements with measurements from other instruments
- Extract information from spectral image measurements using physically based computer models

JPL Systems are stable and accurately calibrated (AVIRIS, M3)

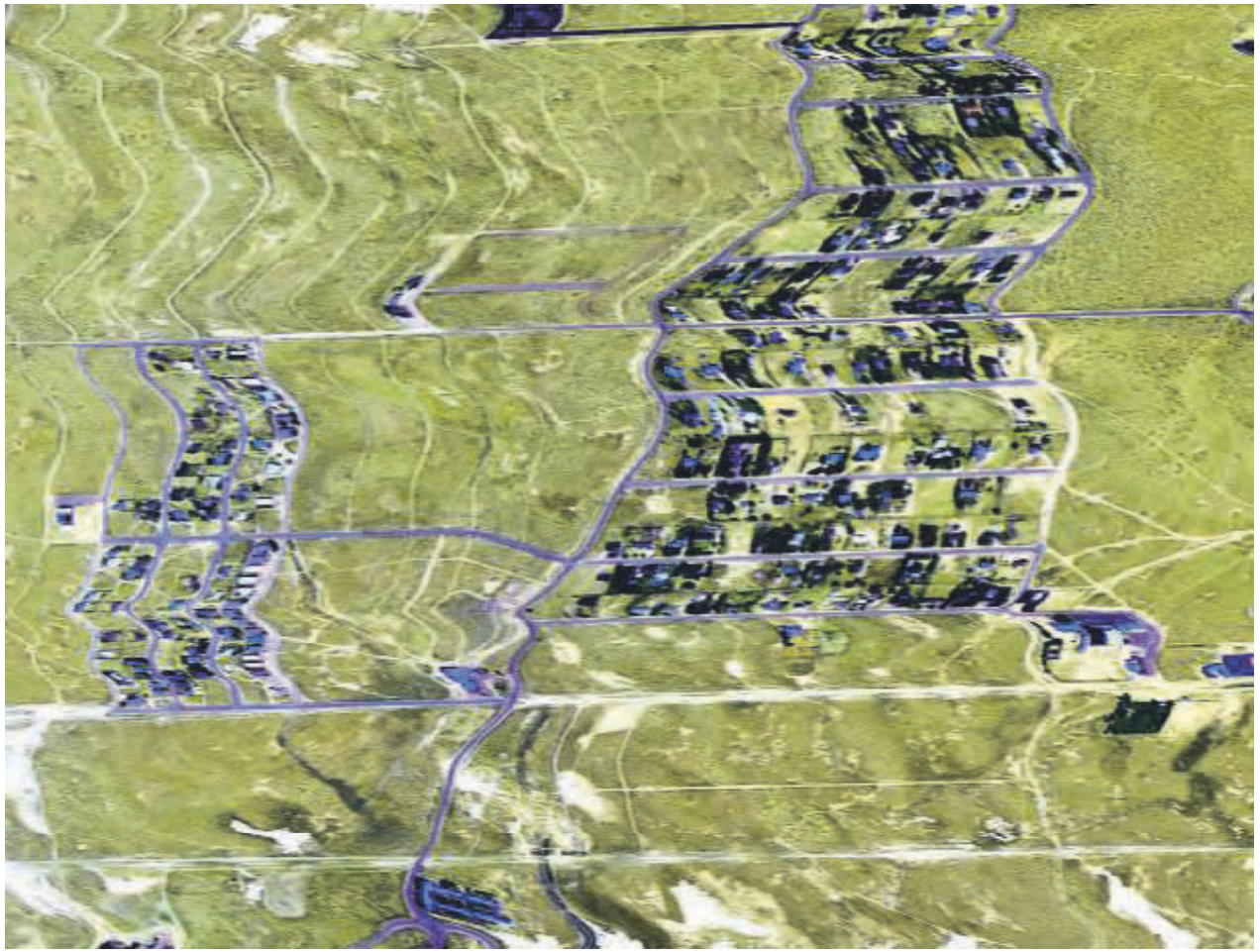


2005 inflight calibration validation shows AVIRIS to be calibrated to better than 96%

Spatial Requirements

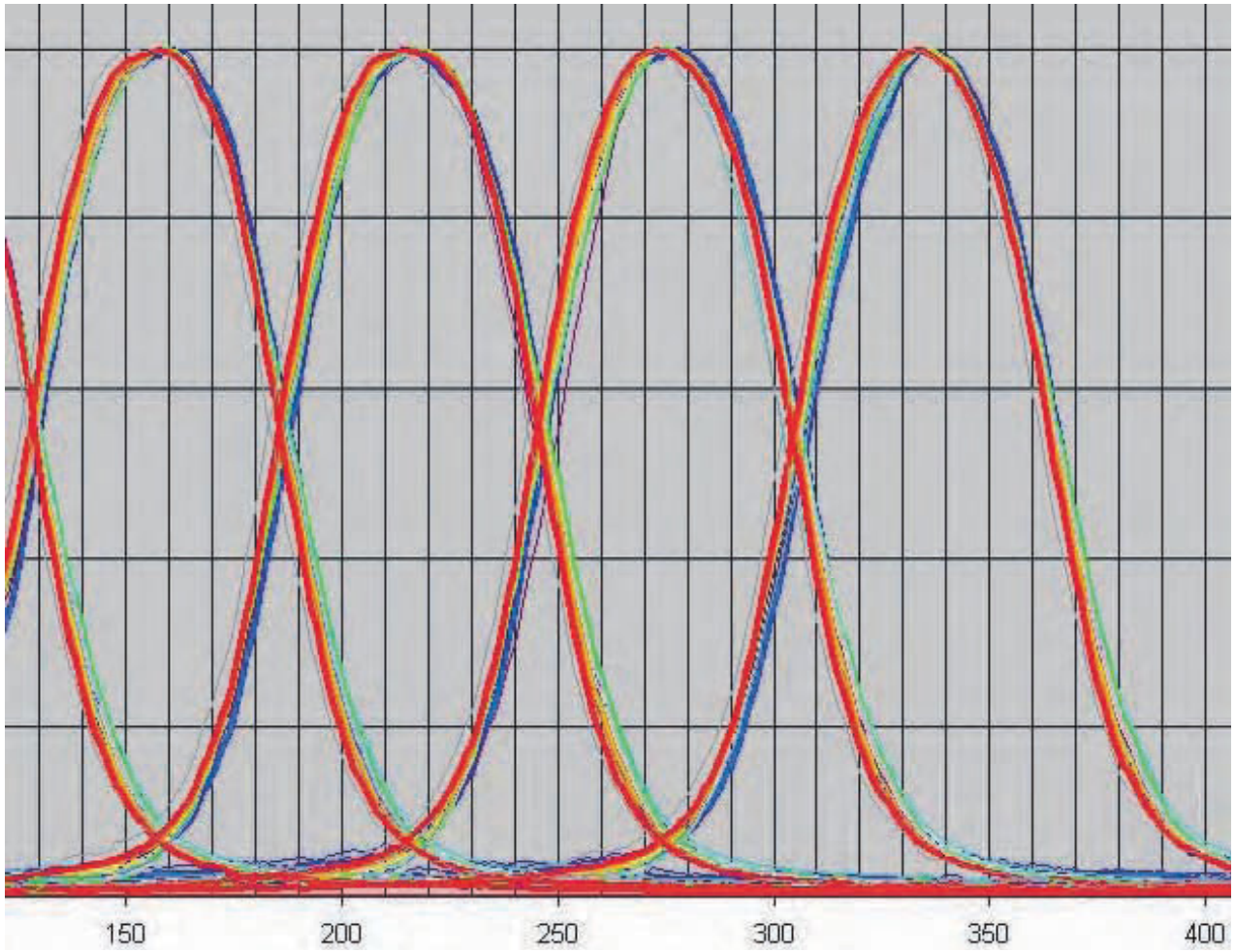
- Range
- Sampling
- Response
- Accuracy
- Precision

Field of View



AVIRIS: 34 degree FOV and 0.87 milliradian sampling

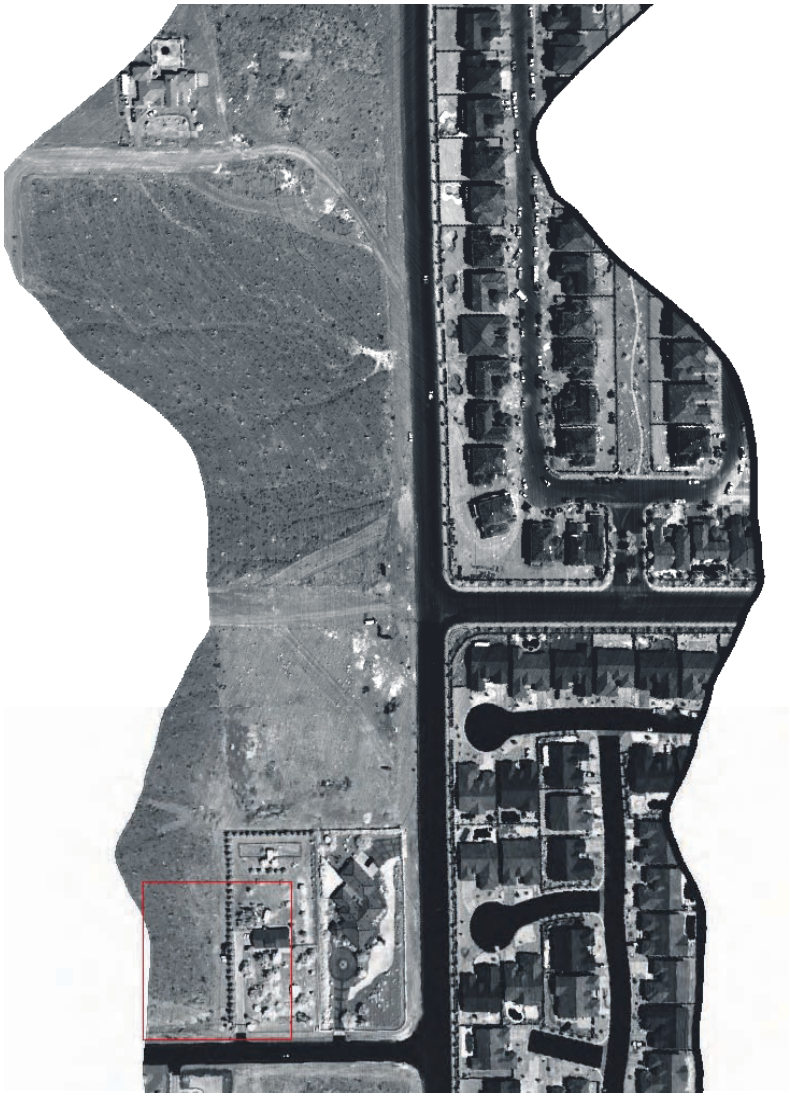
Spatial IFOV



Spatial Acuracy & Georectification

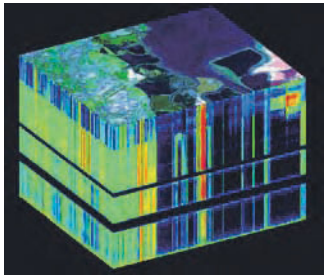
Raw

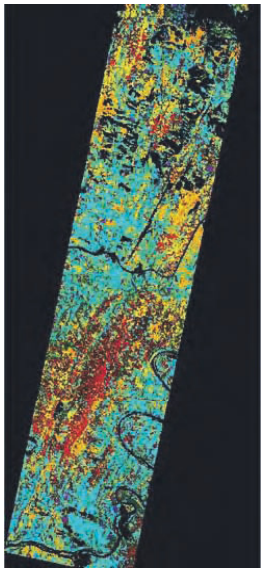
Georectified

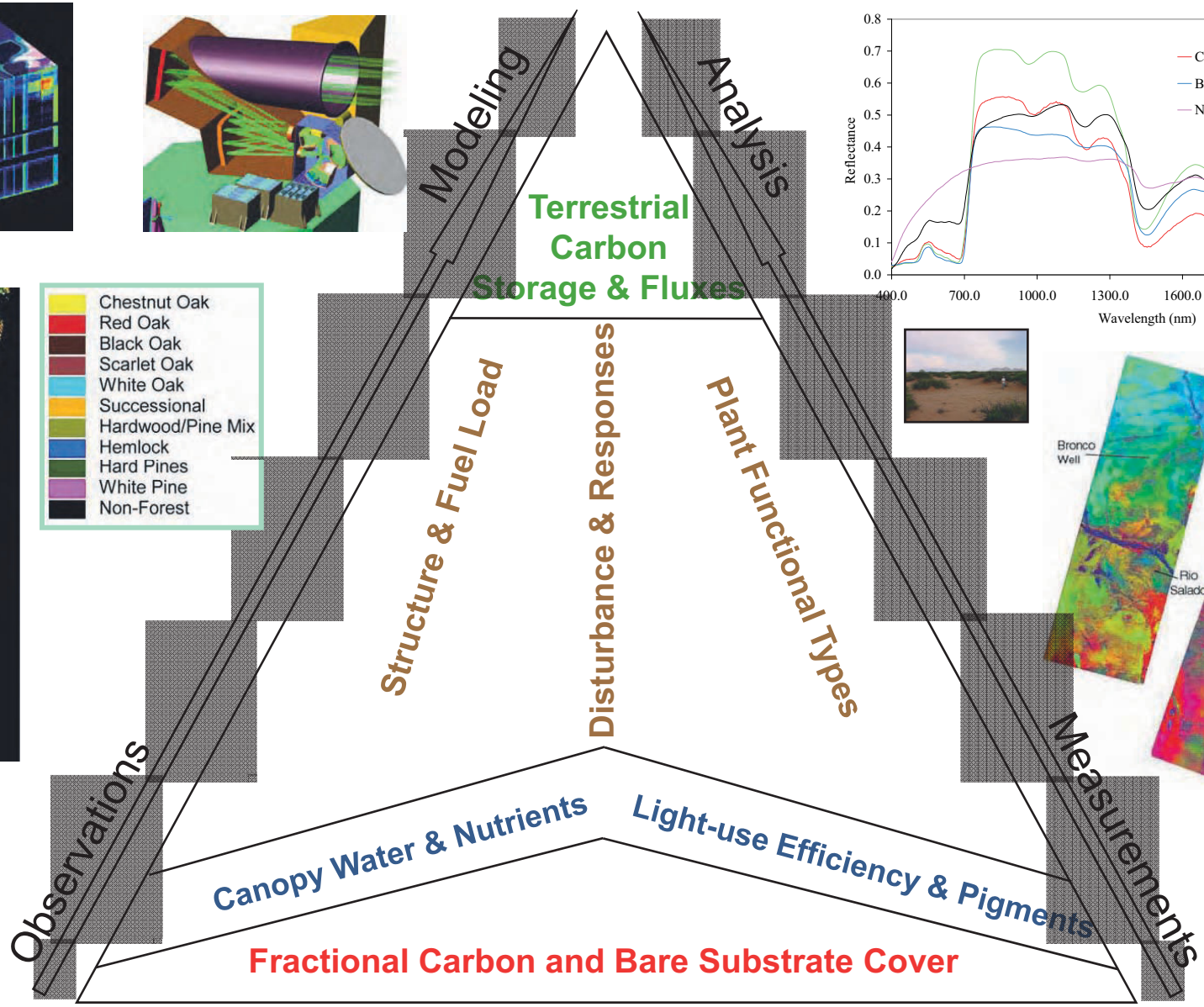


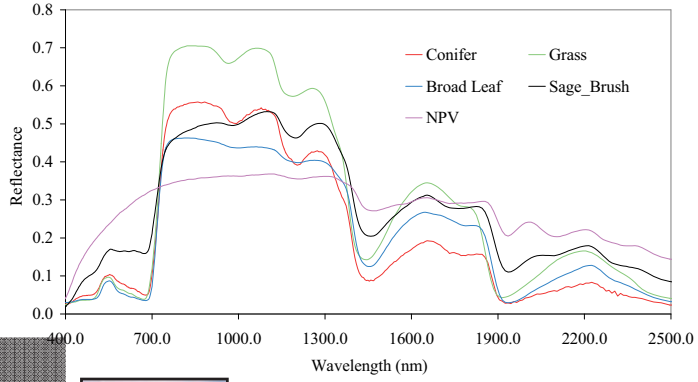
A Requirements Driven Imaging Spectrometer

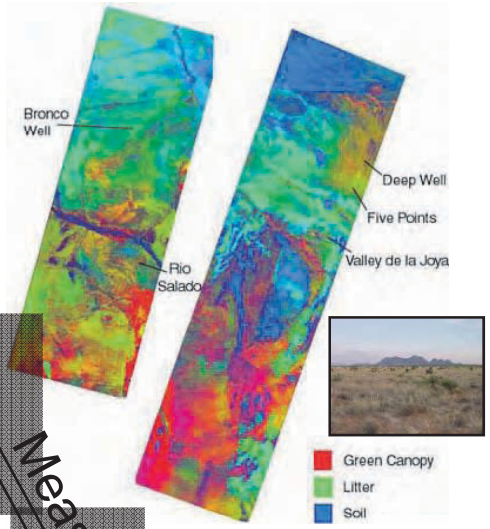
FLORA Mission: Carbon Cycle and Ecosystems Focus Area





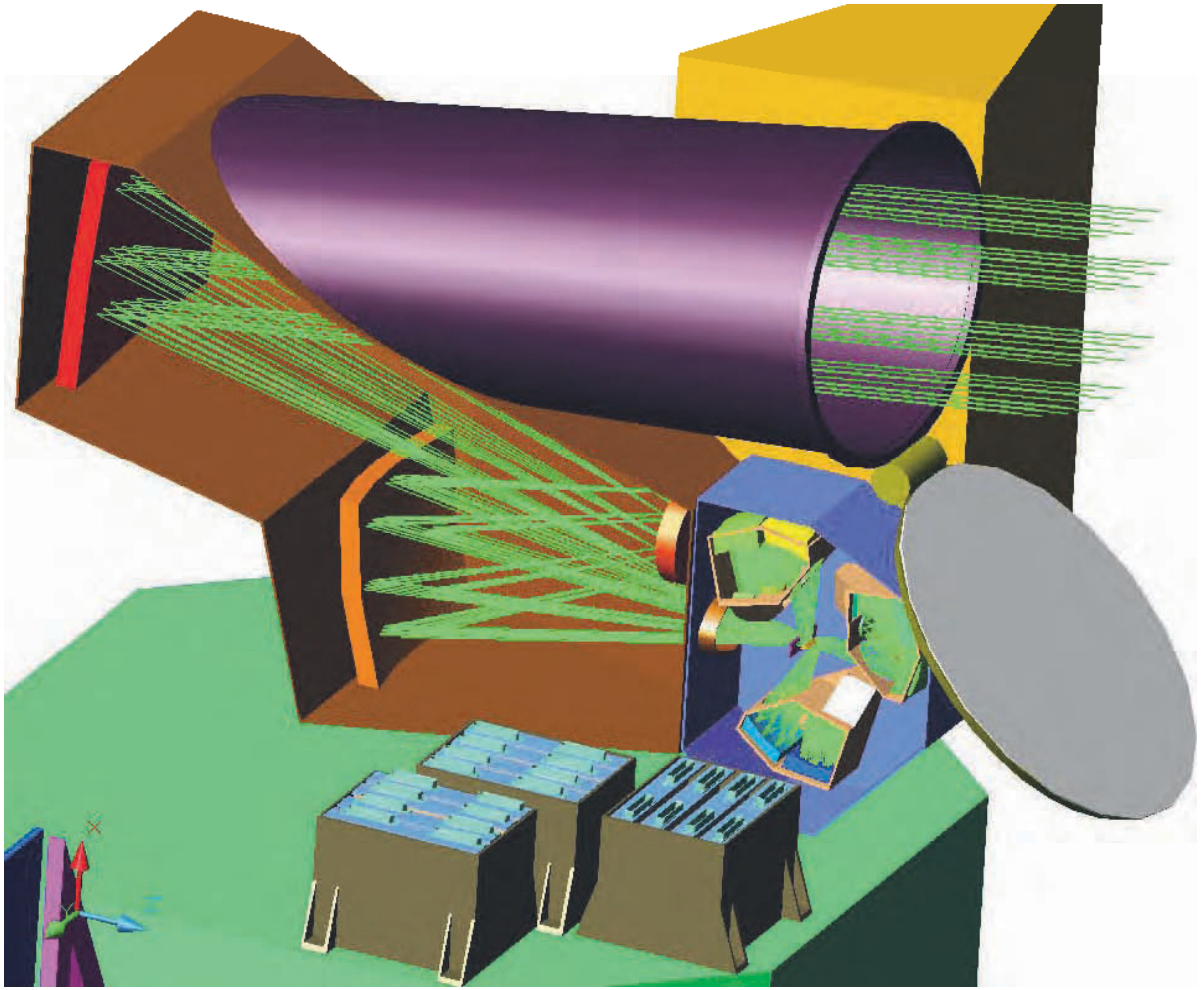


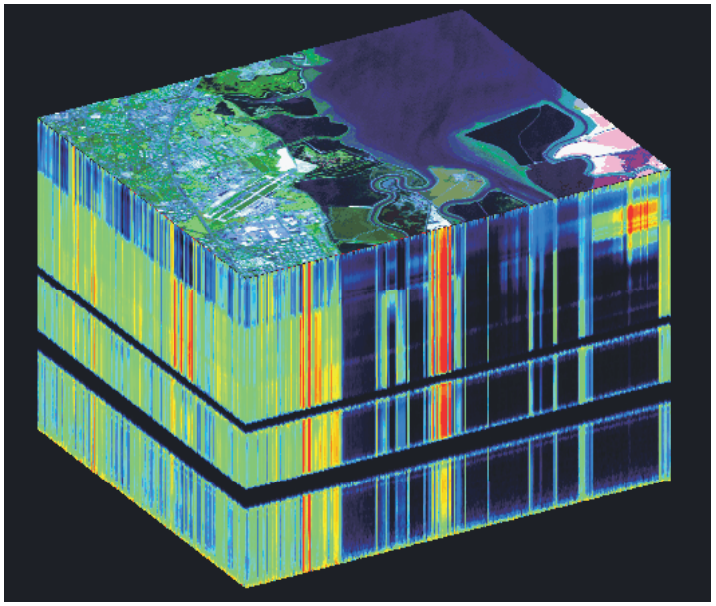


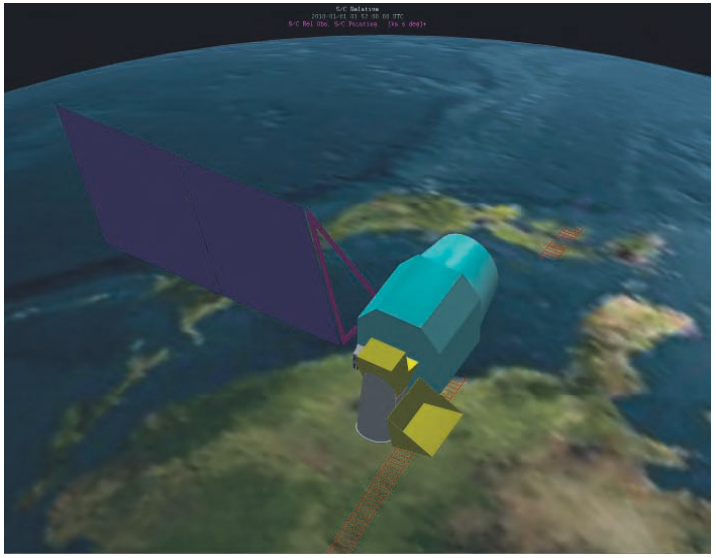


The Technology is Ready for FLORA Implementation

Coverage: Full land surface every 30 days
Spectral: 400 to 2500 at 10 nm
Spatial: 90 km swath at 45 meter
Signal-to-Noise Ratio: AVIRIS Class
Uniformity: >95%



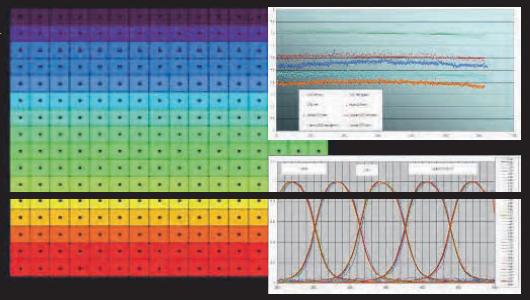




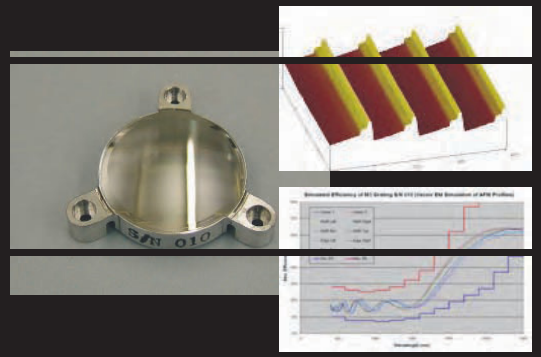
FLORA Imaging Spectrometer

PI: Gregory P. Asner

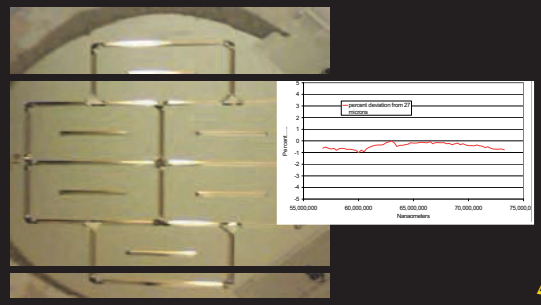
1) Mouroulis uniform & high SNR design



2) Electron beam grating with shaped groove on curved surface

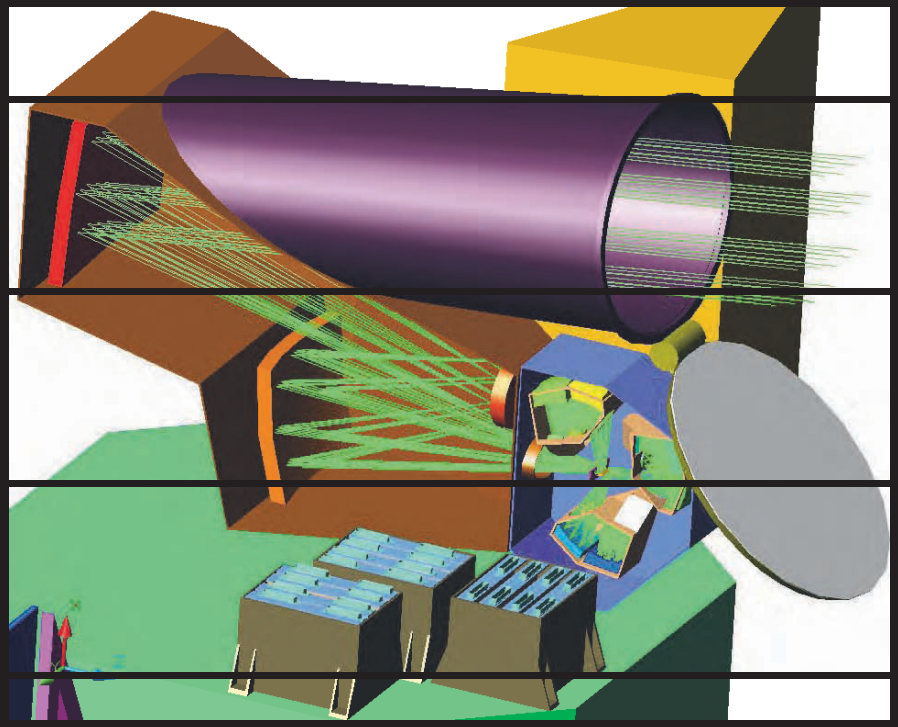


3) Electron beam slit. Parallel to 100 nm over 18,000,000 nm.

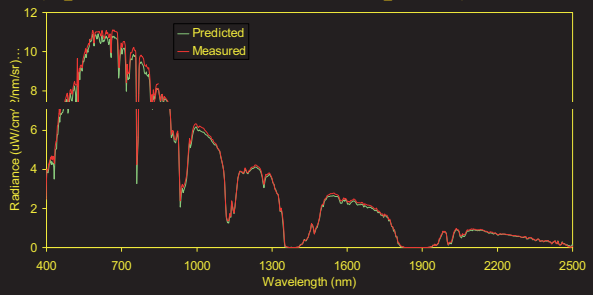


4) Spectrometer bench with submicron adjustment that remains stable

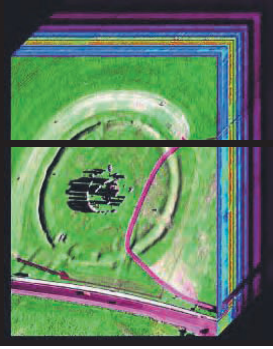
INSTRUMENT: Uniform & High SNR Imaging Spectrometer



5) Alignment and Calibration (Spectral, Radiometric, Spatial)



6) Data system calibration pipeline



Summary and Conclusion

- Beginning in the early 1980s, airborne imaging spectroscopy has been used to pursue scientific research across a wide range of disciplines.
- From this experience as well as from first principles an understanding of the science measurement requirements has grown.
  - Uniformity, Spectral, Radiometric, and Spatial
- With this requirements knowledge underpinning the next generation of High Fidelity Imaging Spectrometer instruments are being built and proposed.
  - Moon Mineralogy Mapper, FLORA, etc.