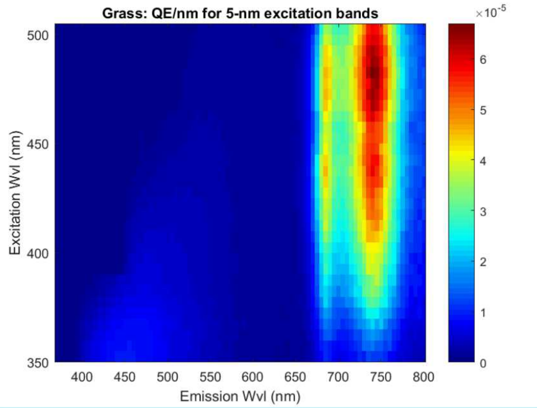
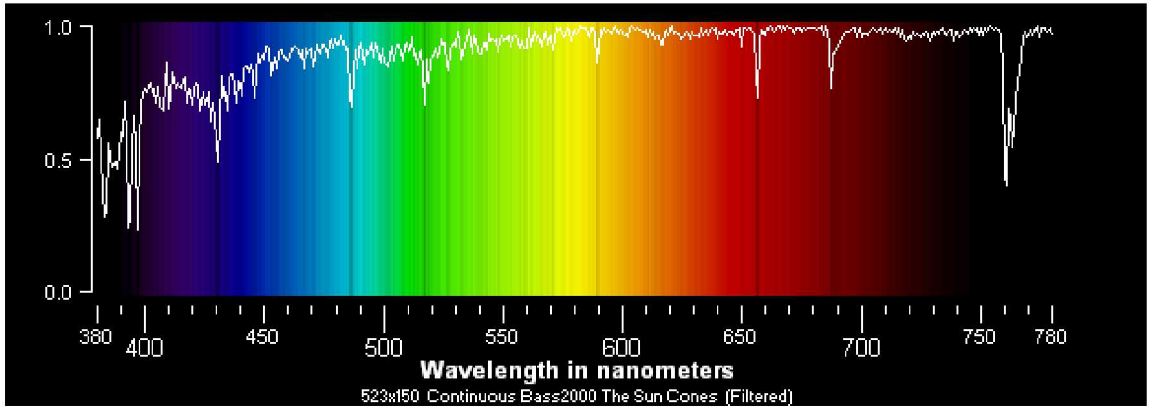
SAND2019-3564C

Fraunhofer Line Discrimination (FLD)





PRESENTED BY

Mark W. Smith, Sandia National Laboratories

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Remote Sensing via Fraunhofer Line Discrimination (FLD)

Name	Lab	Role
Mark W. Smith	SNL	Principal Investigator
David Baldwin	STL	Co-Principal Investigator
	LANL	Providing support for final field test
	LLNL	Reviewed spectrometer design

SNL contributing staff: Patrick Barnett, Sam Eaton, Todd Embree, Tom Kulp, Randy Schmitt, Karl Schrader, Shane Sickafoose, Jon Slater, Braden Smith

STL contributing staff: Jonathan Madajian, Field test personnel?

Project Overview and Goals

Primary project goals

1) Develop novel sensor technology to resolve Fraunhofer lines
2) Create new data analysis techniques to exploit detailed spectra
3) Demonstrate passive detection of solar pumped fluorescence

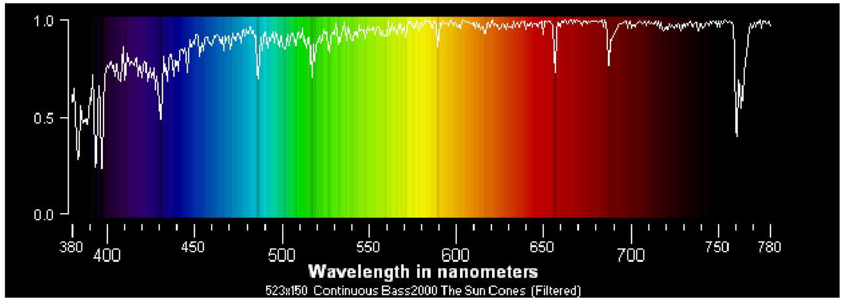
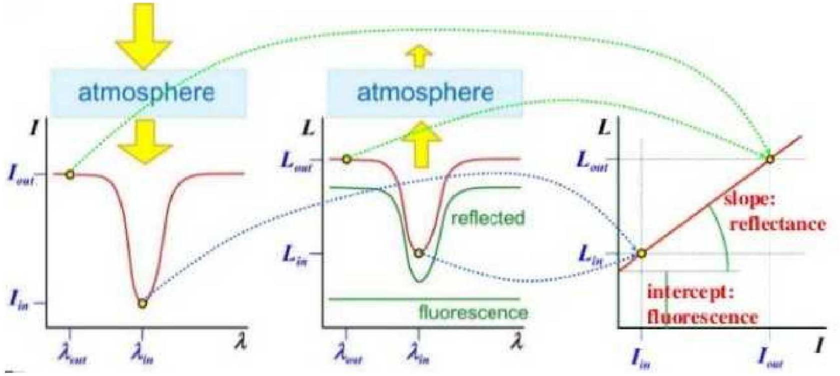


Image at left shows a solar spectrum.
The narrow dips are the Fraunhofer lines,
due to absorption in the sun's atmosphere.



Reflectance spectra mimic the solar spectrum.
Fluorescence introduces an offset in the spectra
that varies slowly as a function of wavelength.

Approach and Deliverables

Overall Approach

- Measure the fluorescence properties of various materials
- Complete a trade study of various types of spectrometers
- Build an ultra-high spectral resolution (0.01-0.02 nm) sensor
- Develop new data analysis techniques to exploit full spectra
- Conduct a field demonstration

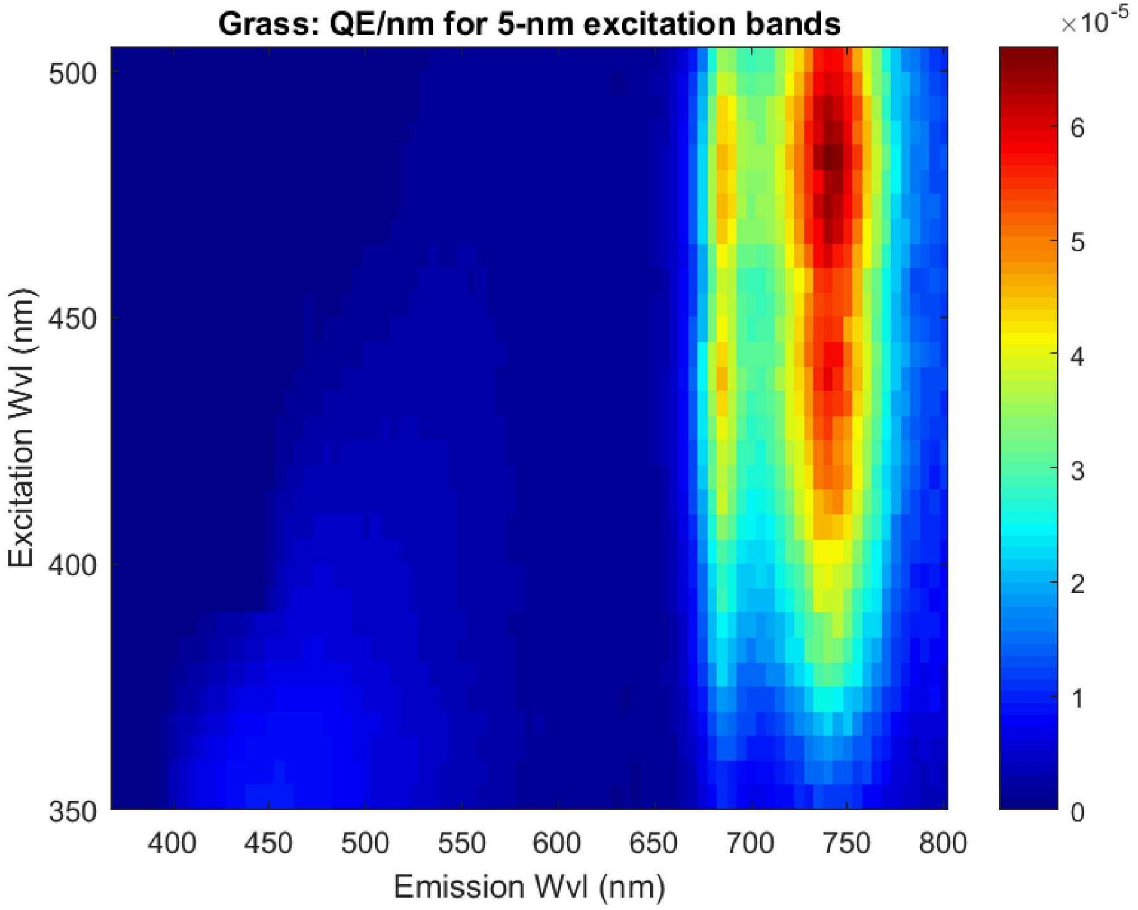
Technical Deliverables

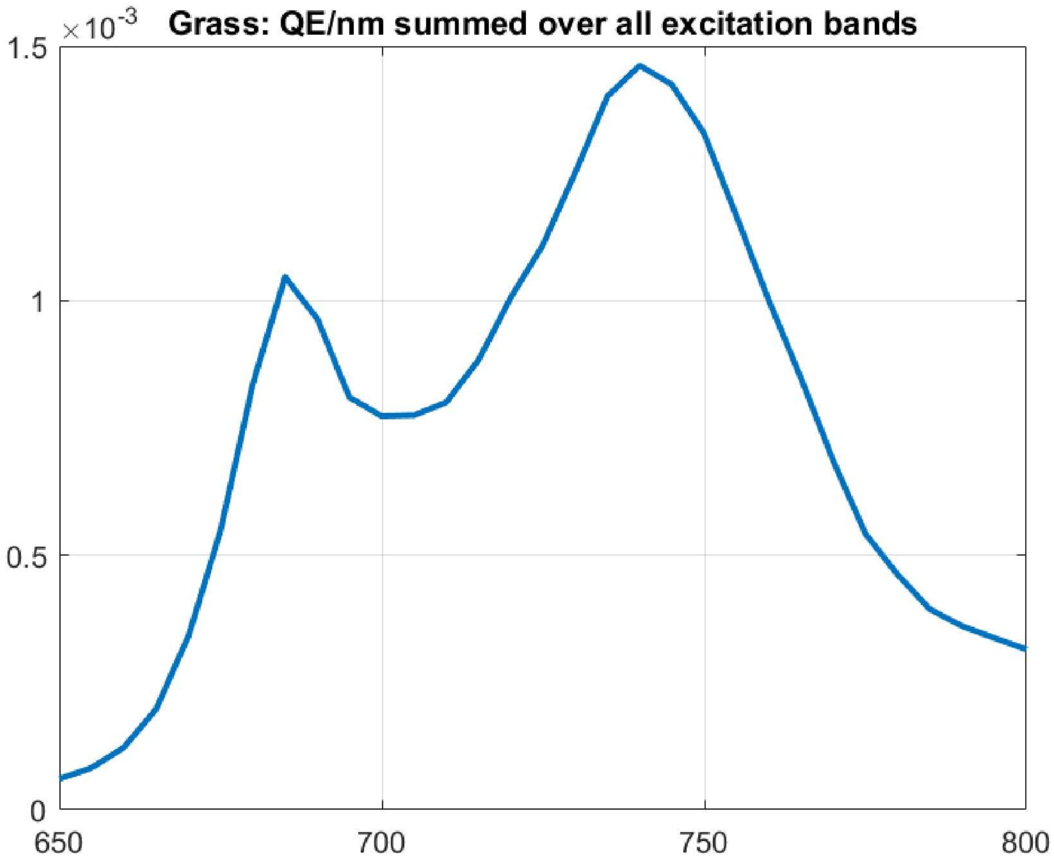
- Results of feasibility study
- Excitation-emission matrix data
- Software models of scene/sensor
- New data analysis algorithms
- Performance predictions
- Brass board sensor for lab use
- Ruggedized sensor for field use
- Conduct final field test
- Final report on results

Capability Improvement

- Science Question: What new things could you do in remote sensing with data collected at a spectral resolution of ~0.01 nm instead of 1 nm?
- Answer: Fluorescence detection using Fraunhofer Line Discrimination (FLD) is a promising application for spectra with ~0.01 nm resolution
- We have developed new data analysis techniques to exploit full spectra
  - Our algorithms make use of all points in a spectrum (not just a few)
  - More data points = better SNR through signal averaging effect
  - Greater flexibility in matching detection band to peak fluorescence, since we don't rely on just a single strong Fraunhofer line
  - Latest algorithm handles variations in background reflectance as a function of wavelength, which is important for wide spectral bands
  - Latest algorithm produces a fluorescence spectrum, which should improve the ability to identify and discriminate different materials

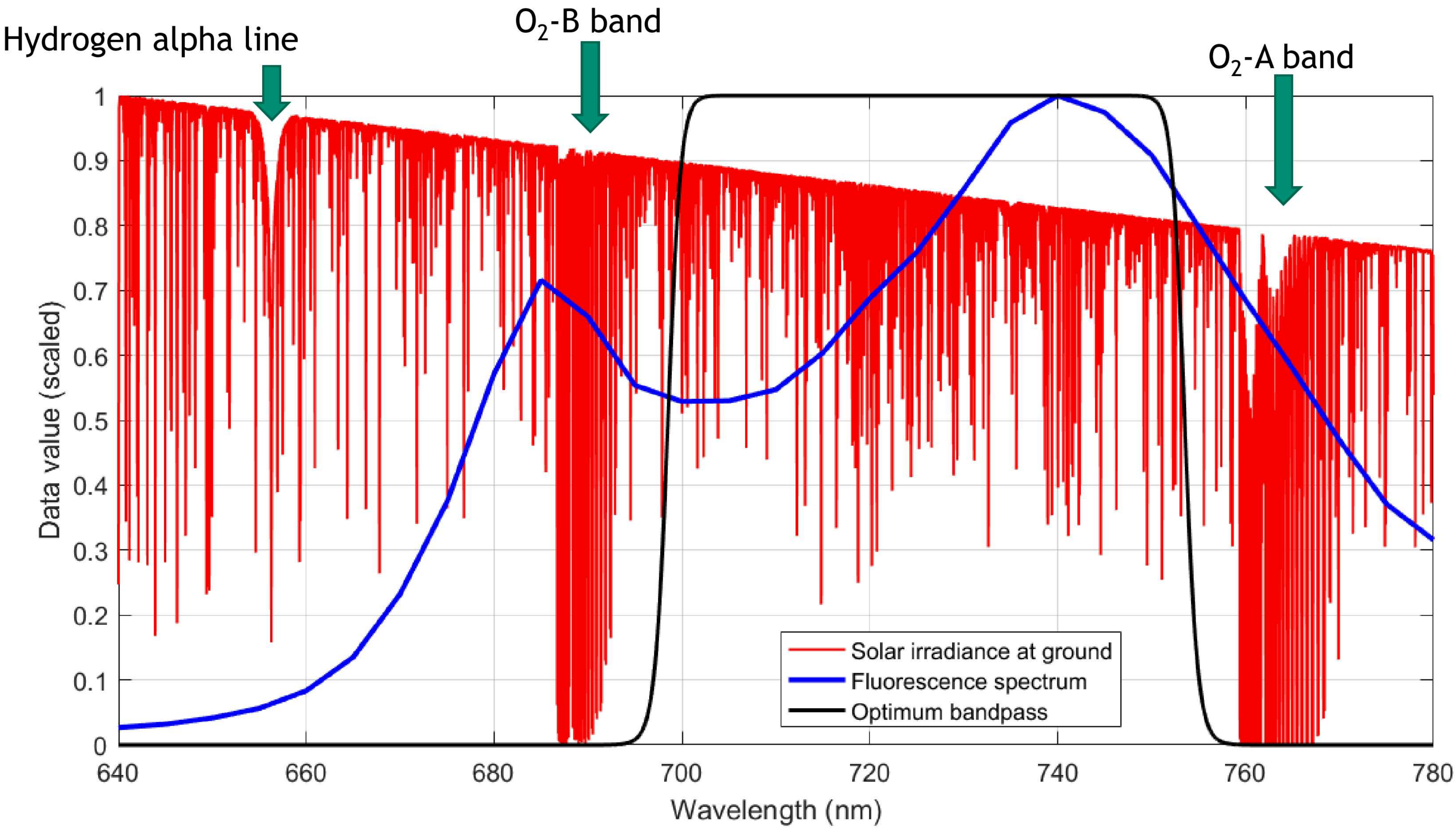
Excitation-Emission Matrix Data



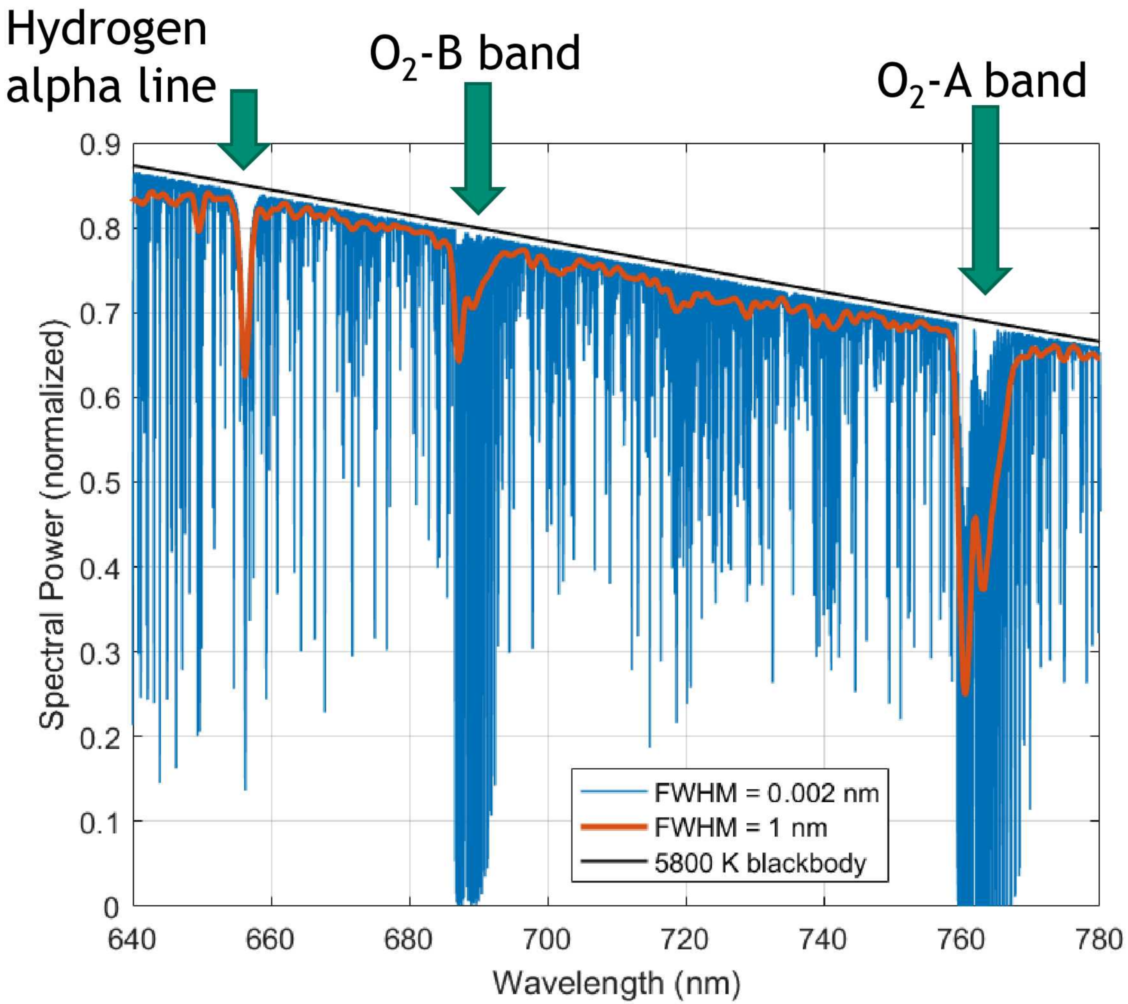


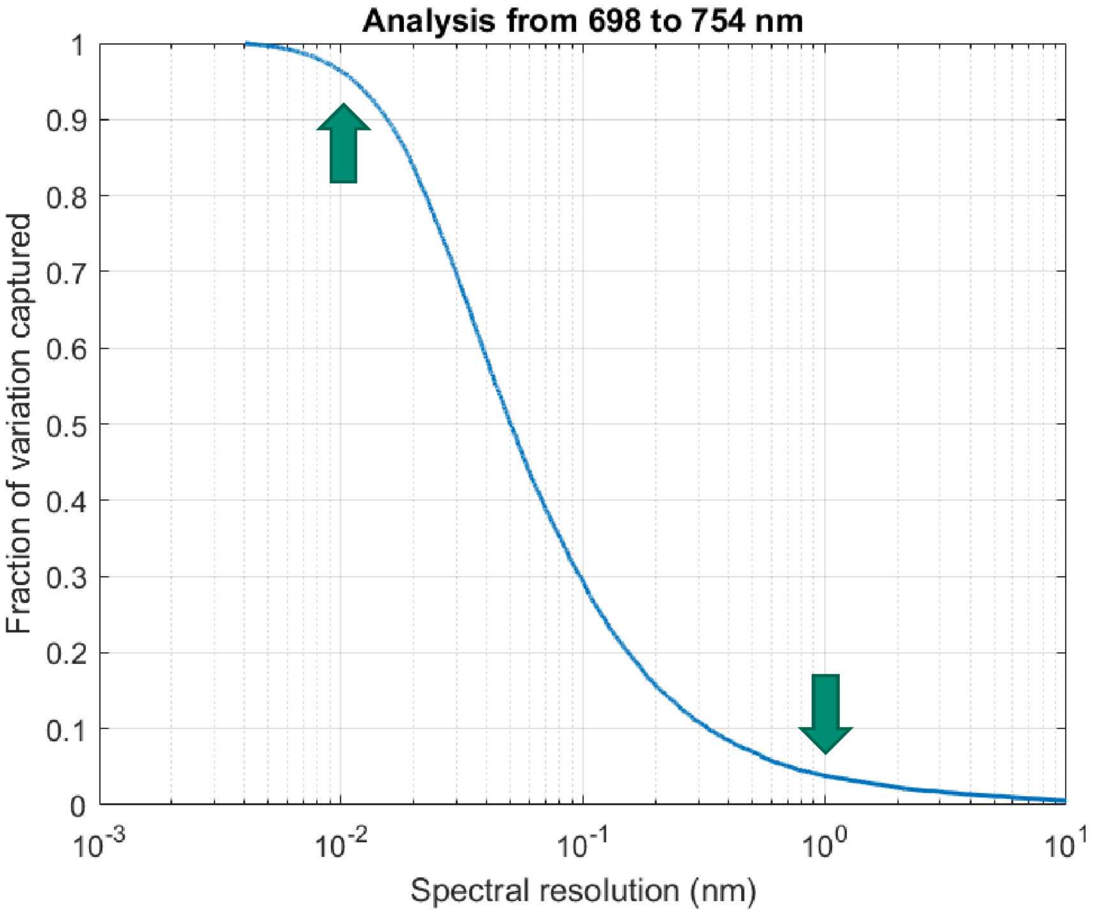
We measured excitation-emission matrix (EEM) data for 25 different types of materials

Spectroscopic Features



Spectral Resolution Requirements





Spectral resolution of 0.01 nm captures over 95% of FFT amplitude variations between 698-754 nm
Spectral resolution of 1.0 nm captures less than 5% of FFT amplitude variations between 698-754 nm

Signal Processing Theory

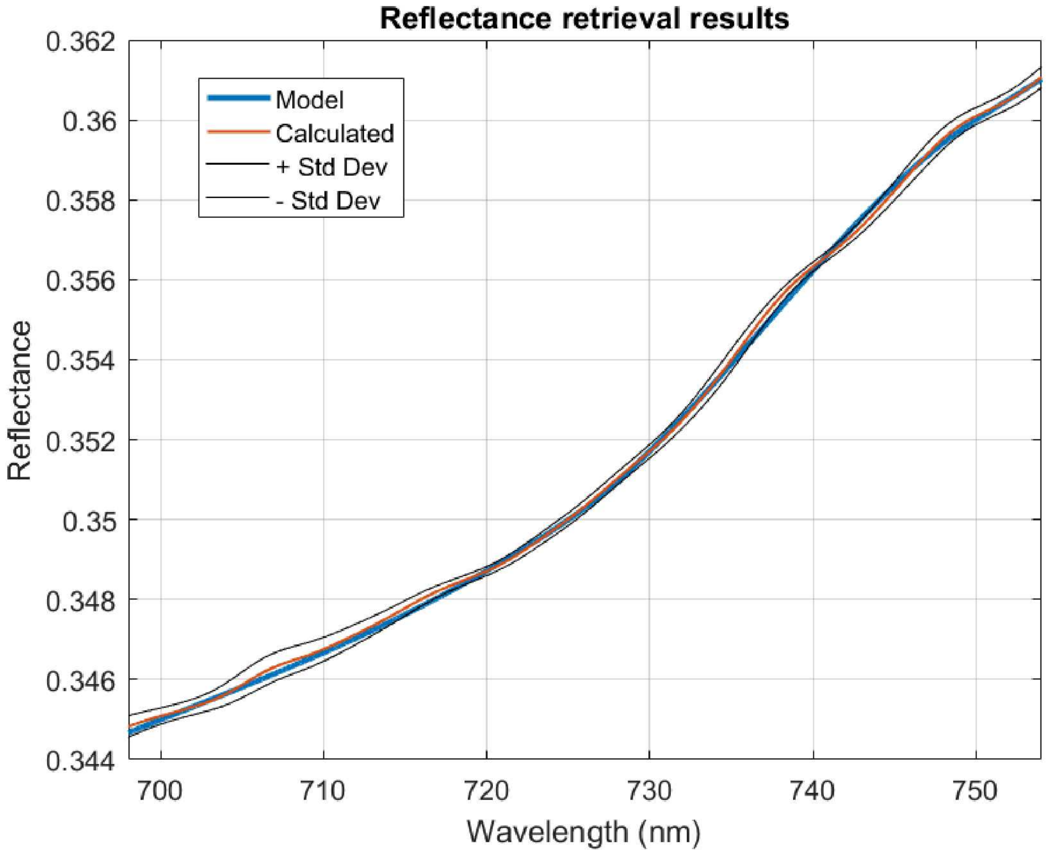
$$M(\lambda, moi, background) = \{S(\lambda) \times R(\lambda, m, b)\} + F(\lambda, m, b) + \xi$$

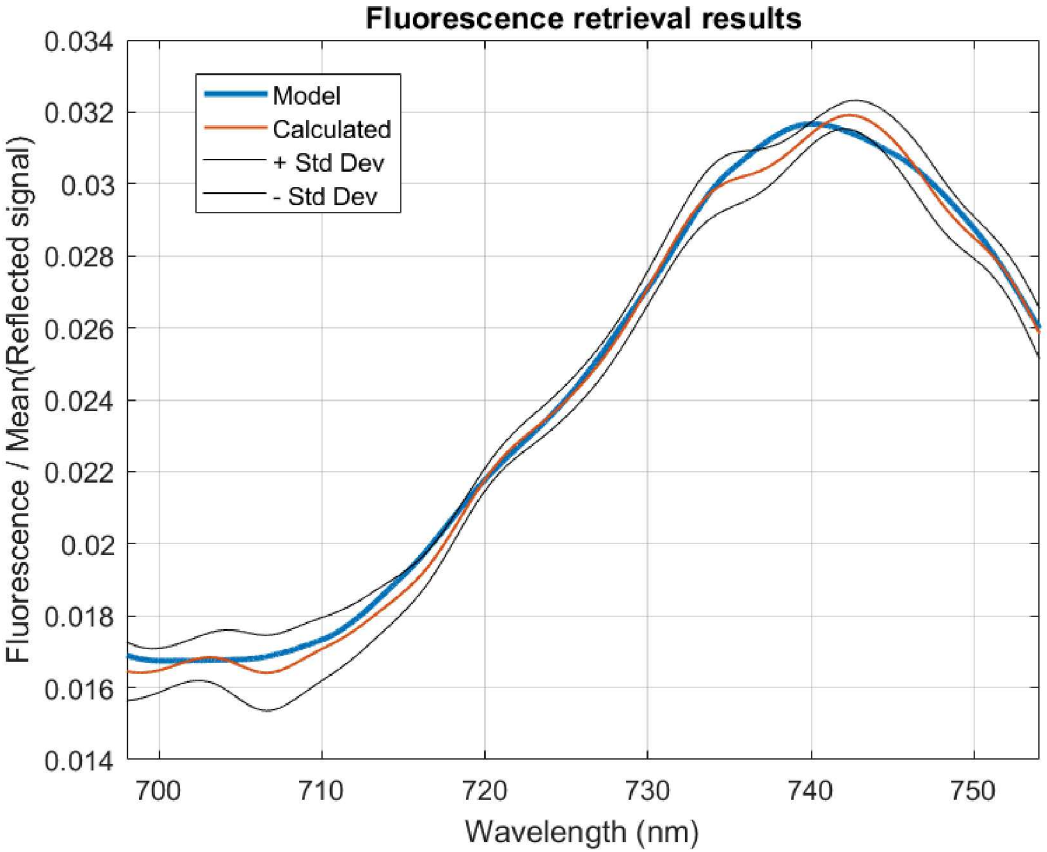
- M is the measured sample spectrum
- S is the solar reference spectrum (measured or modeled)
- R is the net reflectance of a target pixel
- F is the net fluorescence of a target pixel
- ξ is the noise in the measured spectrum

➢ General approach to separating Fluorescence (F) from reflectance (R)

- For high resolution measurements the Fraunhofer lines in the solar spectrum (S) modulate the reflectance (R) at high frequency
- Fluorescence (F) has only slowly varying, low frequency, features
- The difference in frequency content (dimensions of $1/\lambda$) makes the two terms separable using digital signal processing techniques

Simulated retrieval results





$$M(\lambda, moi, background) = \{S(\lambda) \times R(\lambda, m, b)\} + F(\lambda, m, b) + \xi$$

1. High pass filter to suppress $F(\lambda, m, b)$ and isolate $\{S(\lambda) \times R(\lambda, m, b)\}$
2. Retrieve estimated $R^* = \{S(\lambda) \times R(\lambda, m, b)\} \ / \ S(\lambda)$
3. Retrieve estimated $F^* = M(\lambda, moi, background) - \{S(\lambda) \times R^*(\lambda, m, b)\}$

Technical Challenges

- The spectral resolution required for full spectrum FLD measurements is approximately 2 orders of magnitude finer than current “hyperspectral”
  - ~0.01 nm resolution is optimal for FLD, versus 1 nm for reflectance
- Difficult to combine such high spectral resolution with high throughput
- We had a baseline sensor design, but we discovered some problems when we built and tested a brass board system in a laboratory
- We have chosen a different design for a fieldable sensor, but the schedule for assembling and testing this new system is very aggressive
- While we understand the signal processing theory well, we will need to fine tune this once we start acquiring real data with the new sensor
- Systematic errors are hard to predict, but we will need to figure out methods to characterize them and account for them in the analysis

Future Work

- We are assembling a custom sensor with ~0.015 nm resolution.
- We will collect lab data in April and May using a heliostat.
- We will conduct outdoor risk reduction measurements in June.
- We will conduct an outdoor field test in July.
- As we acquire real data we will continue to refine our signal processing and data analysis algorithms.
- We have developed a suite of models for scene + sensor + analysis. We will use these models to predict performance for various hypothetical scenes and sensors.