Measurement Services to Support Compact Hyperspectral Imagers

David W. Allen and Joseph P. Rice
National Institute of Standards and Technology

JACIE May, 2015

Other NIST Talks at JACIE 2015

Wednesday

Simon Kaplan

-Infrared Calibration Transfer Standards for Flood and Collimated Sources

Thursday

Adriaan Carter

-Testing Radiance Calibration Methodology using a High Accuracy Blackbody Source and an Absolute Cryogenic Radiometer

Outline

- *NIST overview*
- *Compact Imaging Spectrometers (CIS)*
- *Basic Calibration and Standards*
- *Scene Characterization (MOI)*
- *Scene Generation*
- *Calibration Service*

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

- U.S. National Metrology Laboratory
- Headquarters in Gaithersburg, MD
- NIST's mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life
- Work closely with the international standards community other government agencies, and industry

Standards

Traceability - NIST Policy and Supplementary Materials

NIST is responsible for developing, maintaining and disseminating national standards- realizations of the SI - for the basic measurement quantities, and for many derived measurement quantities.

The NIST Policy on Traceability is contained in the NIST Administrative Manual, Subchapter 5.16.

http://www.nist.gov/traceability/

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Topic Areas

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Standard Reference Data

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Products and Services

SRM Spotlight

Dimensional Calibrations

Electromagnetic Calibrations

Ionizing Radiation Calibrations

Mechanical Calibrations

Optical Radiation Calibrations

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The calibration services NIST provides help customers achieve the highest measurement quality and productivity. These services include dimensional, electromagnetic, ionizing radiation, mechanical, optical radiation, thermodynamic, and time and frequency calibrations.

ocumented numeric data that
nical problem-solving, research, and
values are based on data extracted
sed for reliability and evaluated to

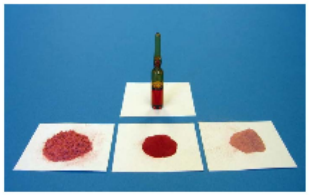
Calibration report: Description of test method, results, uncertainties, SI traceability

d?

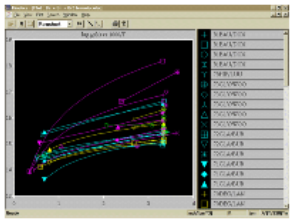
have calibrated.

- I need an artifact to measure in my lab.
- I am looking for scientific data.
- I want to know how to measure something.
- I have a question about meterologic traceability.
- I have a question about laboratory accreditation.
- I am looking for a NIST publication.

Standard Reference Materials®



Standard Reference Data



Calibration Services

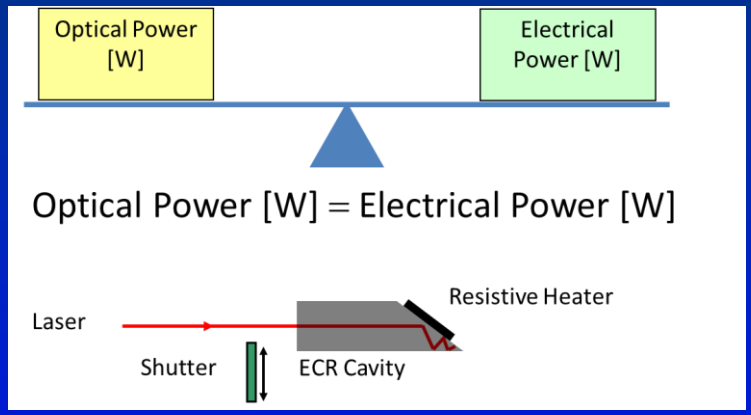
Resources

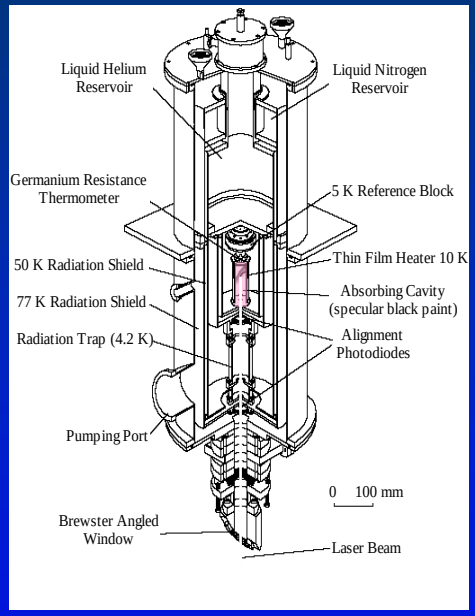
NIST Standard Reference Database

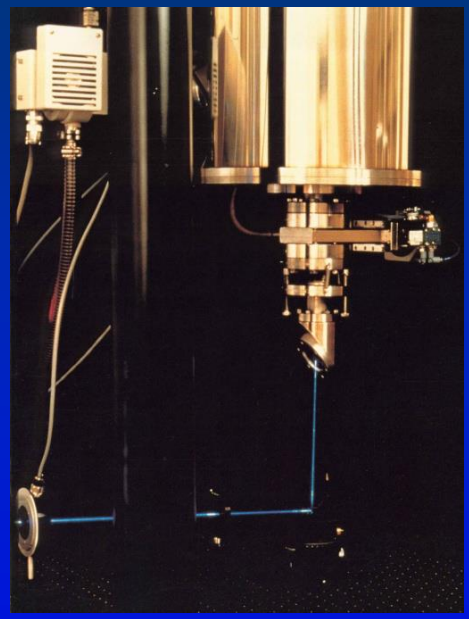
NIST Primary Optical Watt Radiometer

POWR is the U.S. primary standard for optical power

Cryogenic temperatures allow lower degree of non-equivalence:

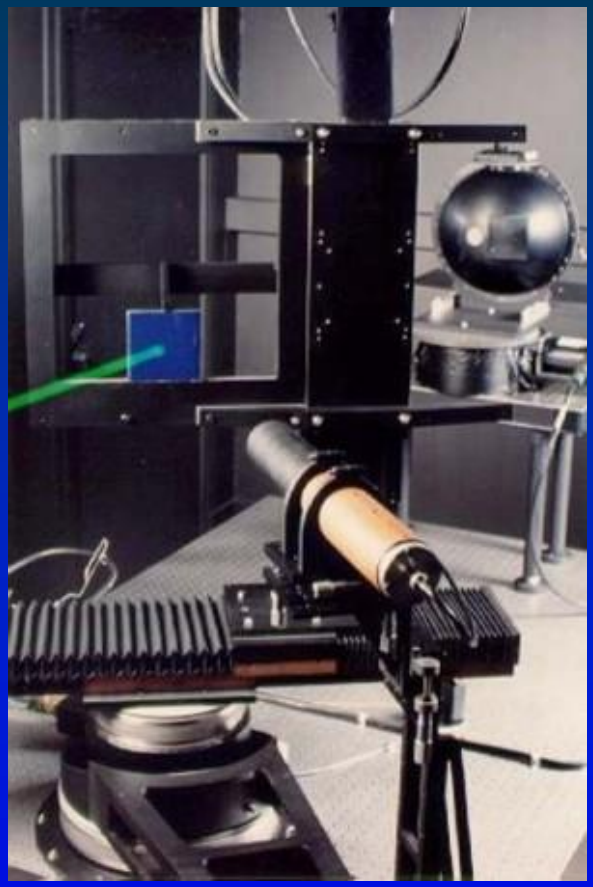






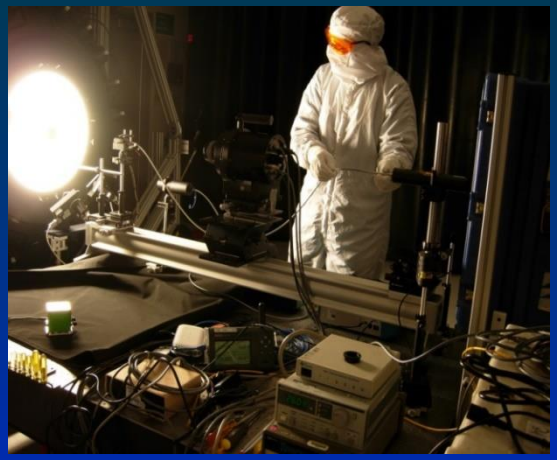
NIST Standards for Remote Sensing

Reflectance

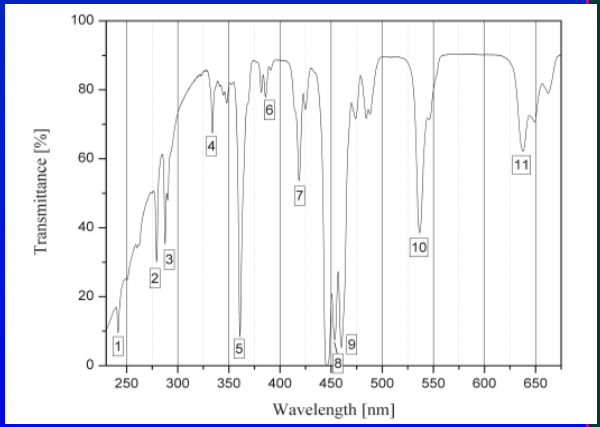


Reference Materials

Radiance



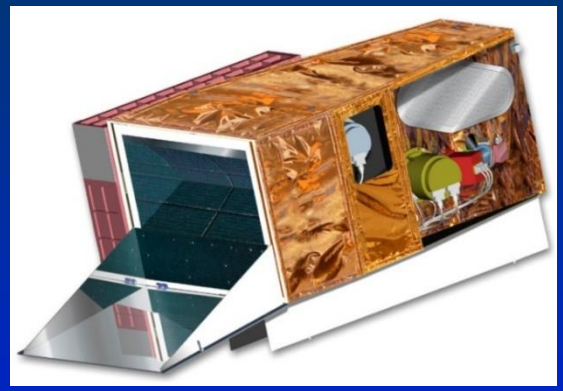
Wavelength

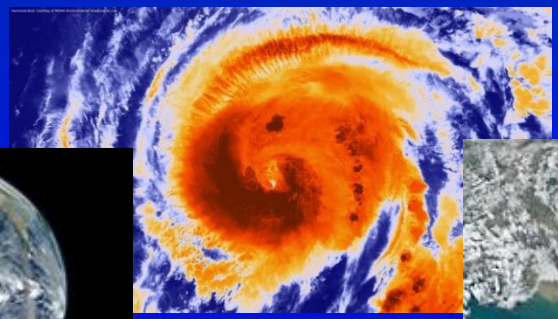


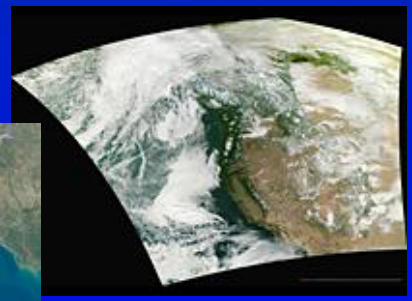
Example: VIIRS Sensor (Visible Infrared Imaging Radiometer Suite)

Also;
Landsat-OLI
GOES-R
OCO-2
CLARREO

- Ocean color (Carbon/Biomass-related)
- Sea surface temperature
- Aerosol characteristics
- Vegetation (Carbon/Biomass-related)
- Land and Ice temperature
- Fire detection and monitoring

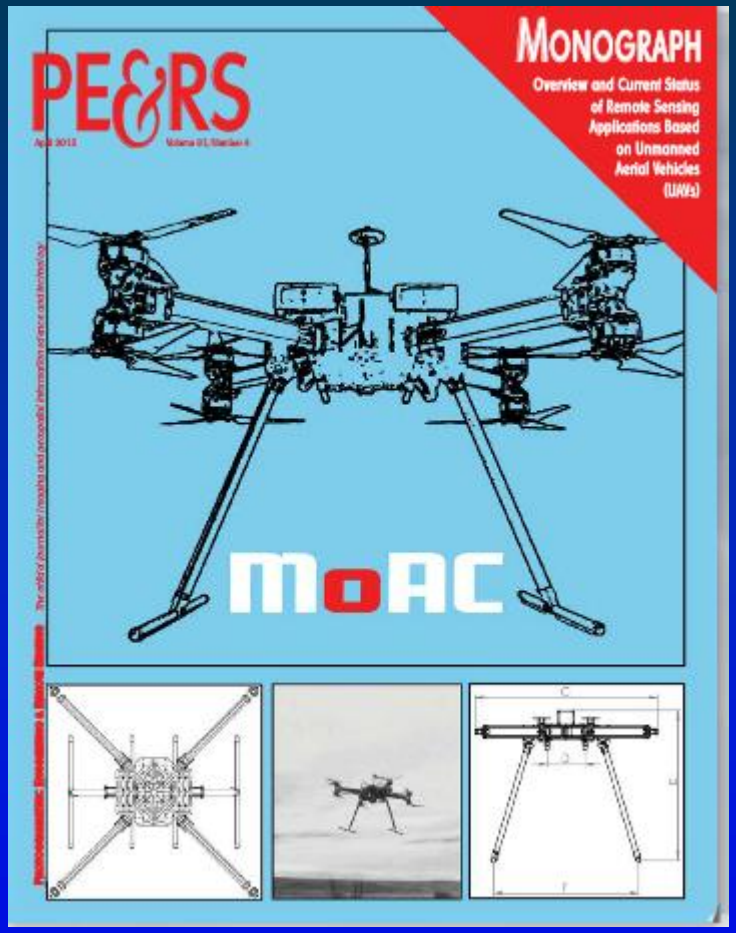






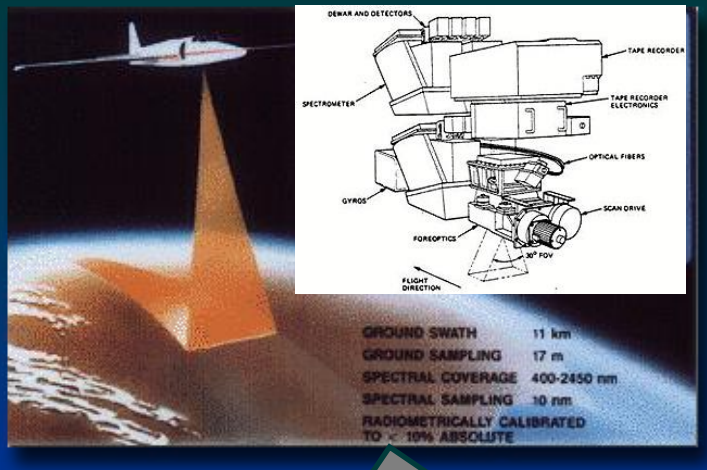
Imagery *Weather* *Ocean Color* *Clouds*

Compact Imaging Spectrometers



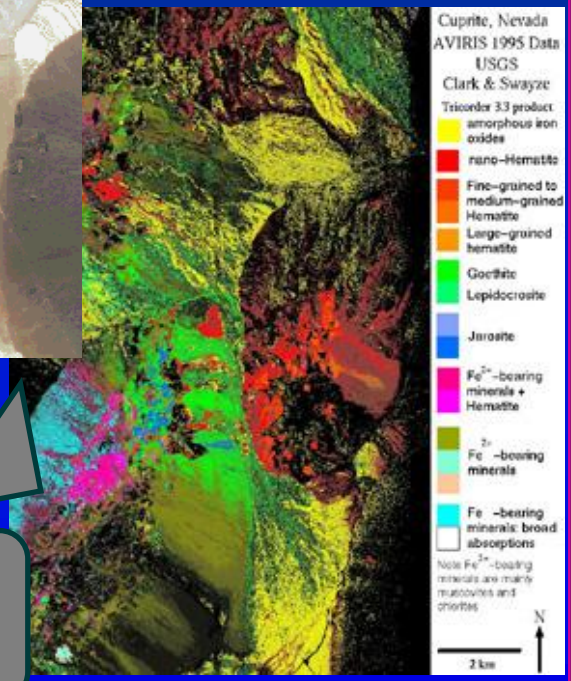
- Market is driving the development of new compact imaging spectrometers (e.g., UAS and CubeSat
- Naturally, may not match the performance of current airborne / spaceborne sensors (e.g. AVIRIS, VIIRS, Landsat 8,)
- Balance SWaP and performance
- But will the performance be a good match for the specific application?

For illustration purposes, not an endorsement by NIST



How is the sensor accuracy (and other components) related to the final Data Product accuracy?

Quantitative non- literal interpretation



Sensor

Scene

Environment

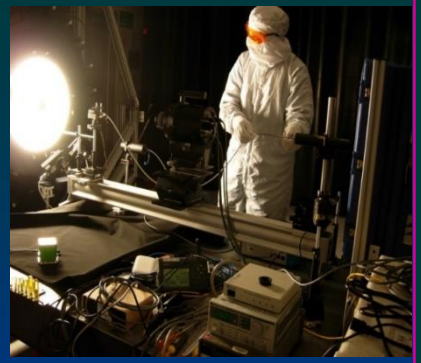
Processing

Data Product

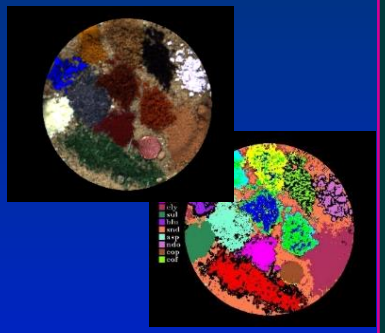
MOI?

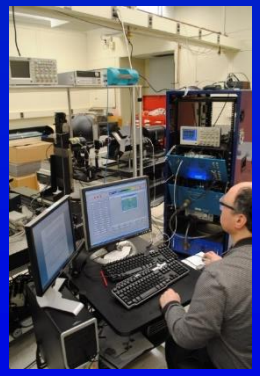
- *Kerekes and Baum, Hyperspectral Imaging System Modeling, 2003*
- *Schott, Image Chain Approach, 2007*
- *DIRSIG, http://dirsig.org/*

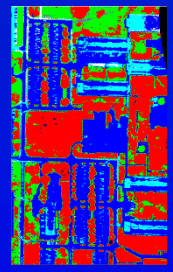
3 Parts of CIS Calibration Service



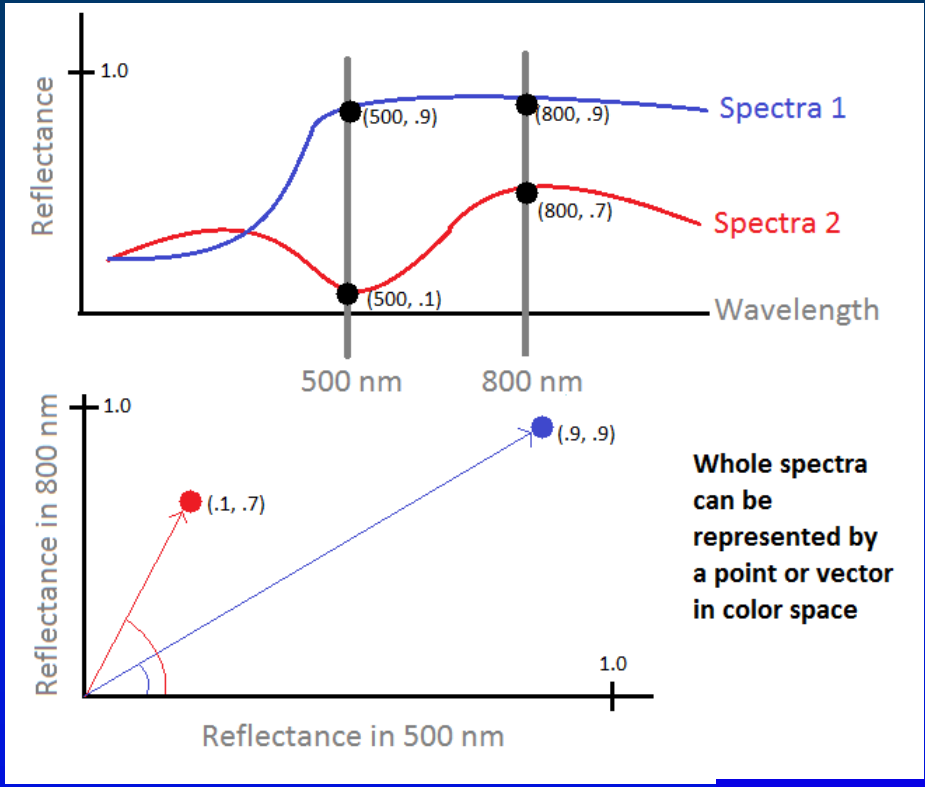
- Basic Radiometric Calibration
- Scene Characterization (MOI)
- Scene Generation

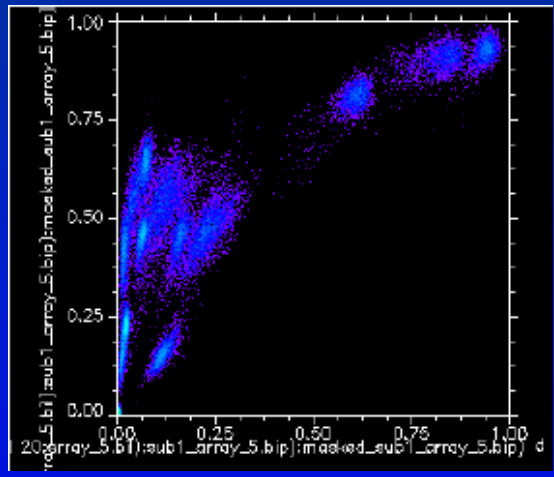






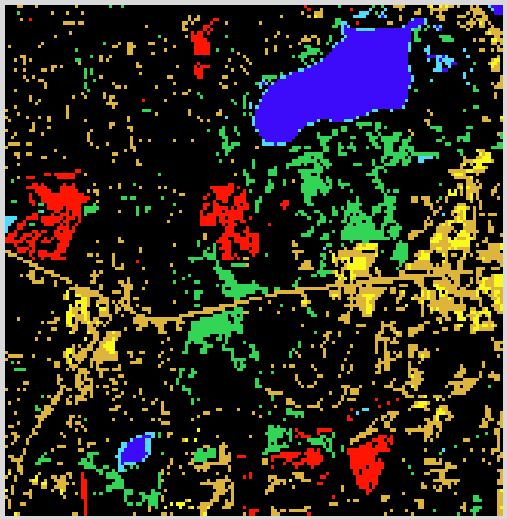
N-dimensional (n-D) Scatter Plot



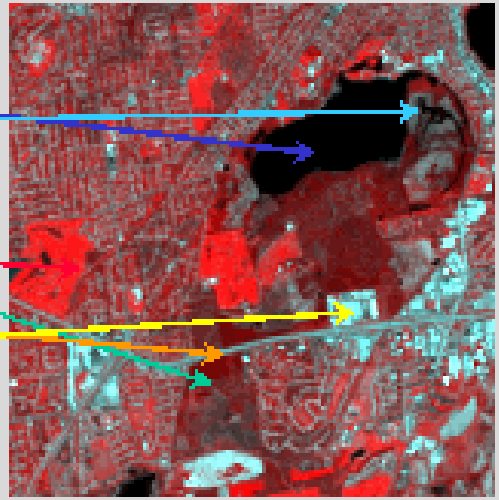


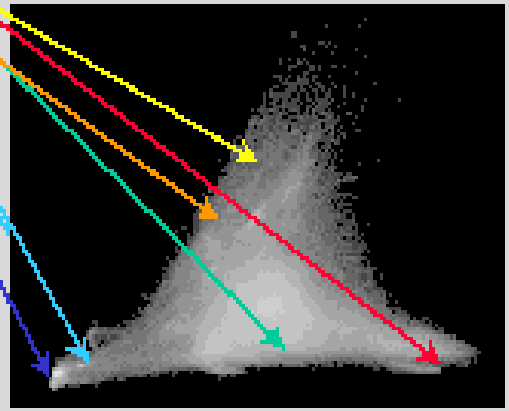
Full image as a 2-D scatter plot

Classification



Water
Wetland
Pines
Grass
Road
Buildings



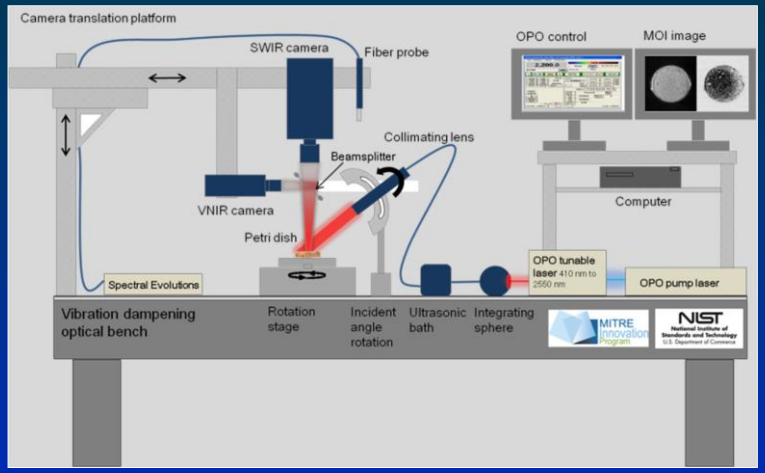


Band b

Band a

Hyperspectral Microscopy

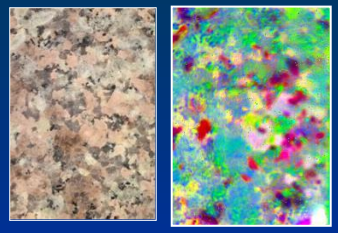
Tunable Laser Baser Hyperspectral Microscopy

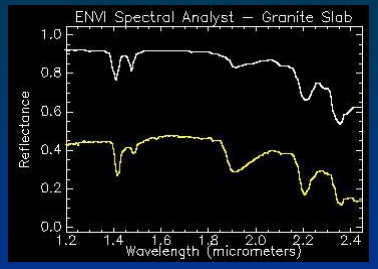


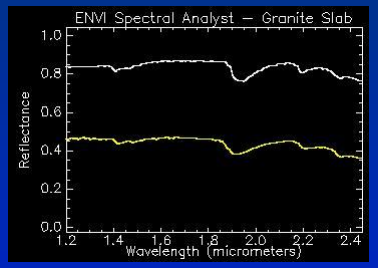
- Laser based hyperspectral microscopy
- 400 nm to 2500 nm by < 1 nm
- Provide 1000's of spectra at the grain level
- Provides compositional information of heterogeneous mixtures
- Outdoor scene can be simulated in the petri dish

Single Substance

Granite slab cm scale

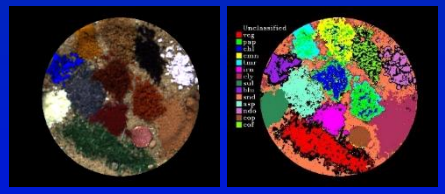


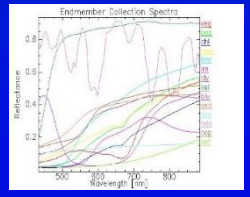


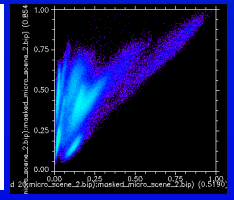


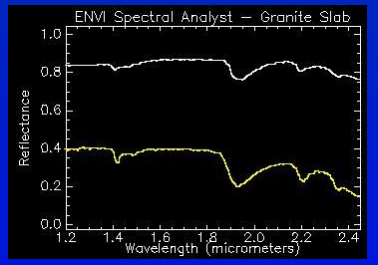
Mixture

Petri dish microscene

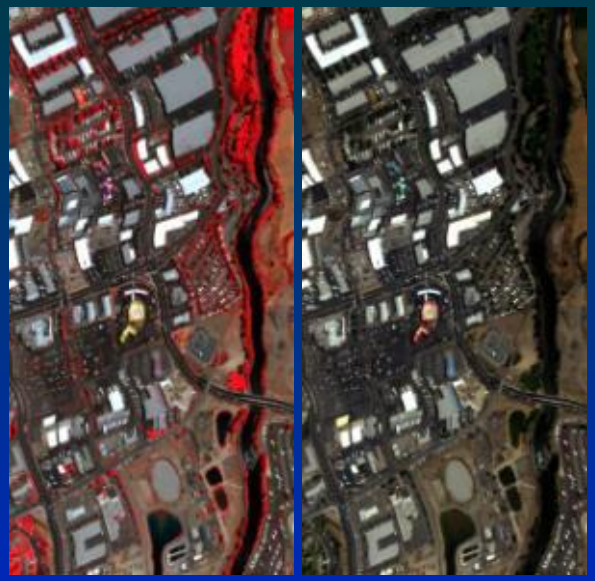


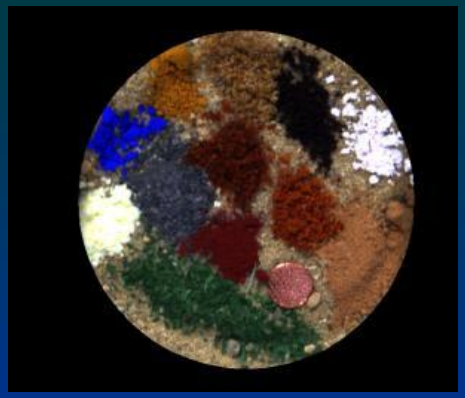


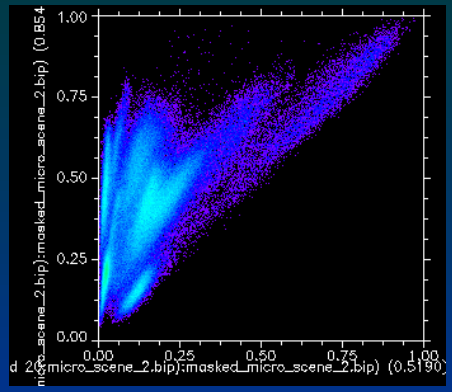




From Allen et al., SPIE DSS 2013

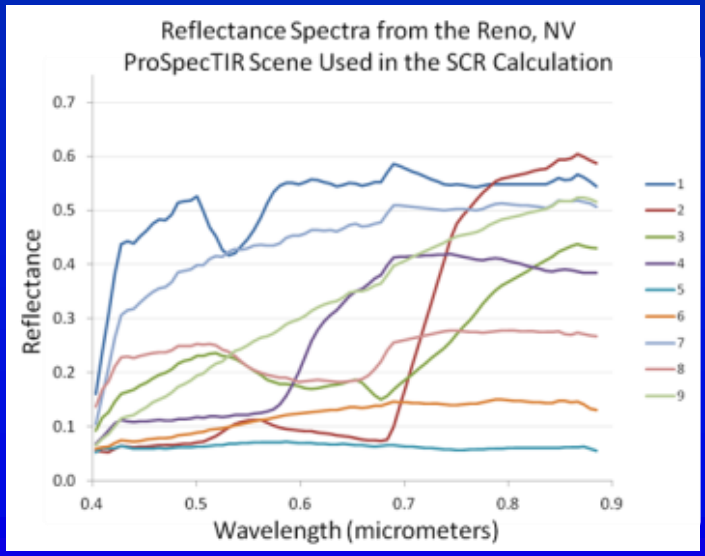






$$SCR = \sqrt{(b-\mu)^T M^{-1}(b-\mu)}$$

Where b is target, μ is mean background, and M is the covariance matrix of the background



Signal-to-Clutter Ratio (SCR)		
Spectrum	SCR in the Microscene	SCR in the Reno Scene
1	16.6	27.2
2	9.2	10.5
3	6.7	29.6
4	11.3	25.9
5	3.1	6.3
6	2.8	7.9
7	7.5	13.0
8	8.4	25.4
9	4.1	10.4

Sensor Characterization

Laboratory radiance sources do not match reality very closely

We calibrate with spectrally and spatially uniform sources…

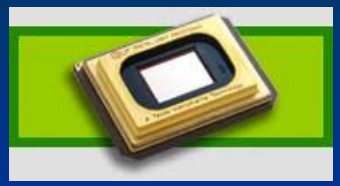
Example: lamp-illuminated integrating sphere for reflective bands,

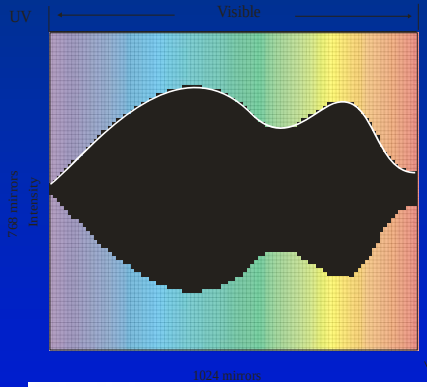
But reality is spectrally/spectrally non-uniform:

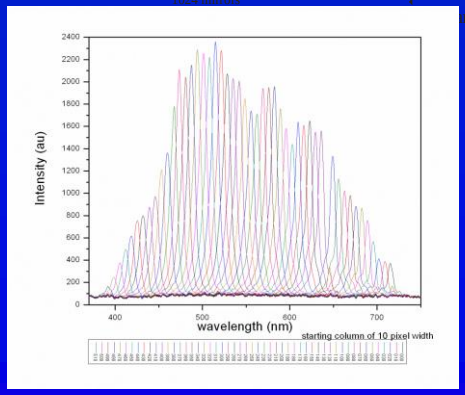
Example: Hyperspectral Image of North Island Naval Air Station,San Diego, CA

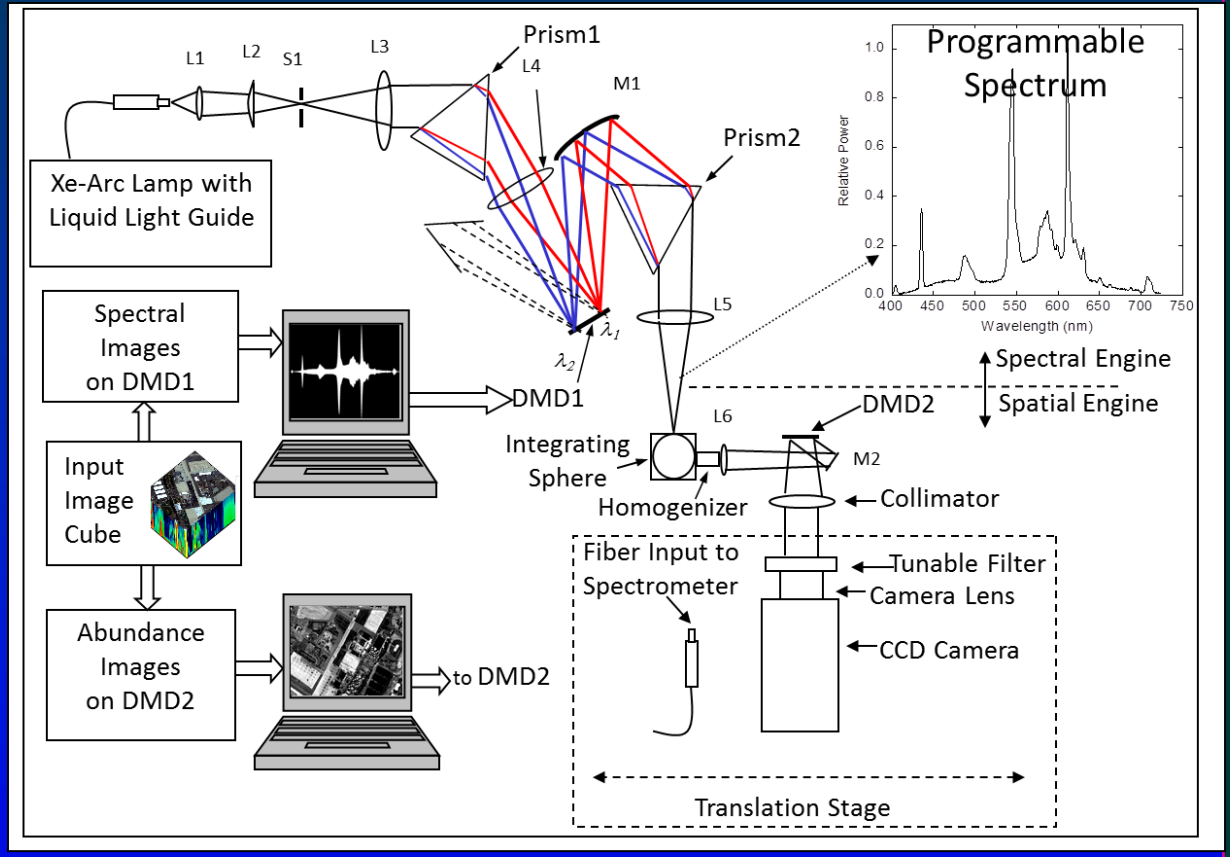
Hyperspectral Image Projector (HIP)

- Provides hardware-in-the-loop testing with full spectral and spatial content
- Application specific
- In essence, brings the vast outdoors into the lab









Dr. Joseph Rice

NIST/Resonon VNIR-SWIR HIP System

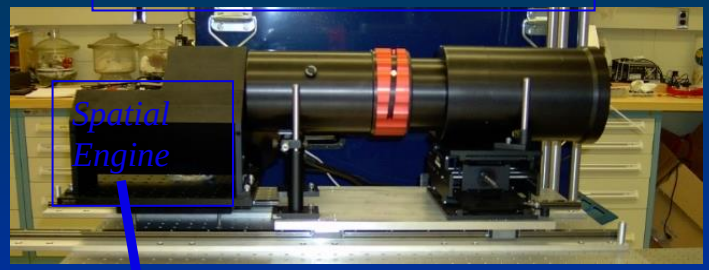
SWIR Spectral Engine

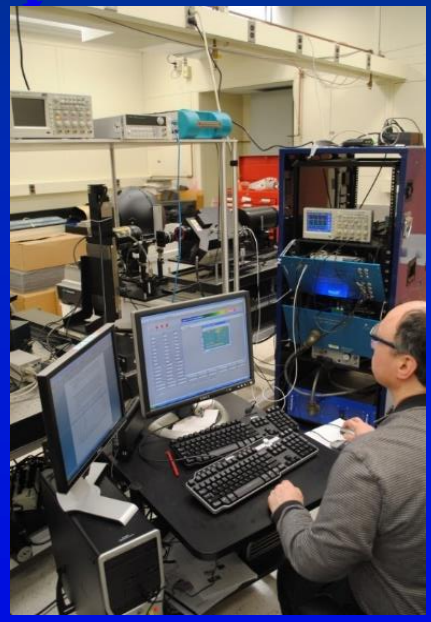
VNIR Spectral Engine

Super-continuum Source

Power Supply

Collimator For Projection to UUT



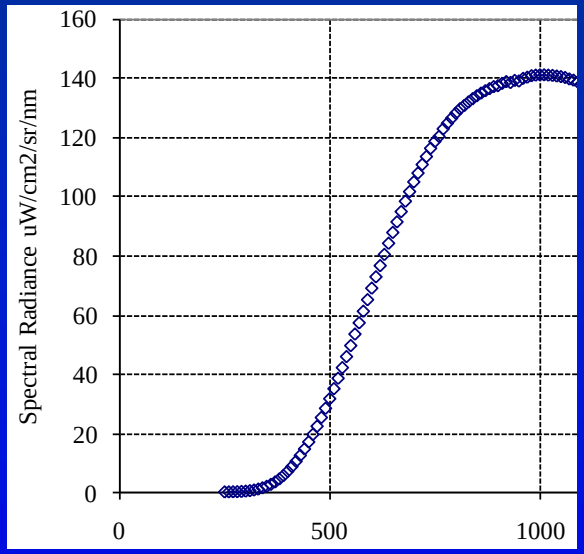


Dr. Joseph Rice

Hyperspectral Image Projector (HIP)

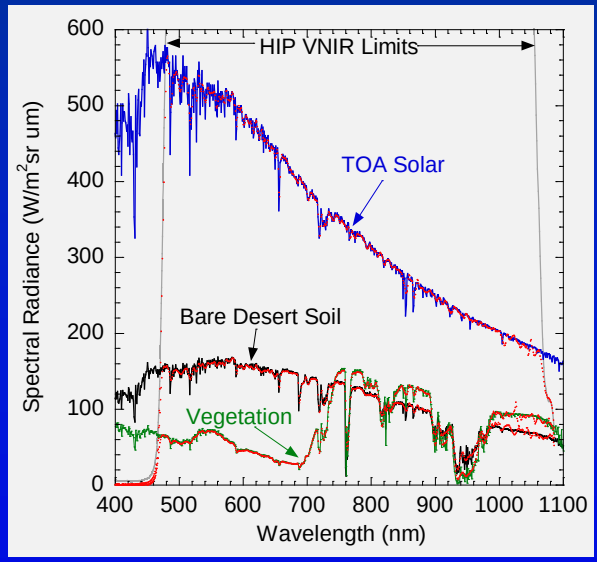
- *The HIP is a NIST scene projector providing high resolution spectra at each spatial pixel.*
- *Using this for sensor testing prior to flight could validate designs and avoid future problems.*
- *Red data below right shows actual HIP output spectra matched to some typical Earth-reflected spectra, shown in other colors, including Top-of-Atmosphere (TOA).*
- *This demonstrates that the HIP can simulate the scene from a bright sunny day outside.*

Lamp-spectrum (for comparison to HIP)



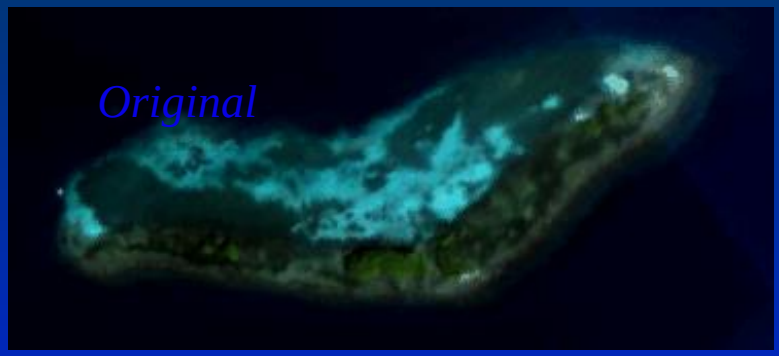
Wavelength (nm)

HIP Spectra

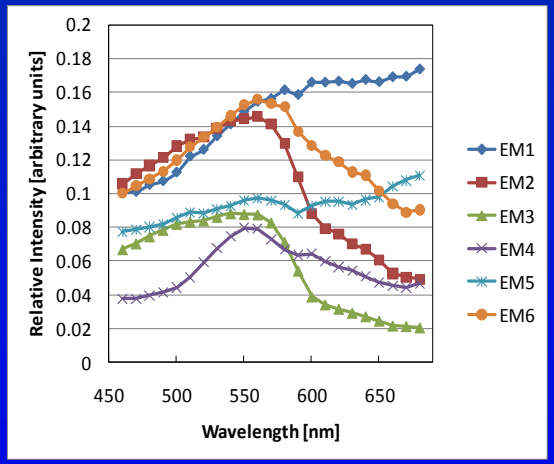


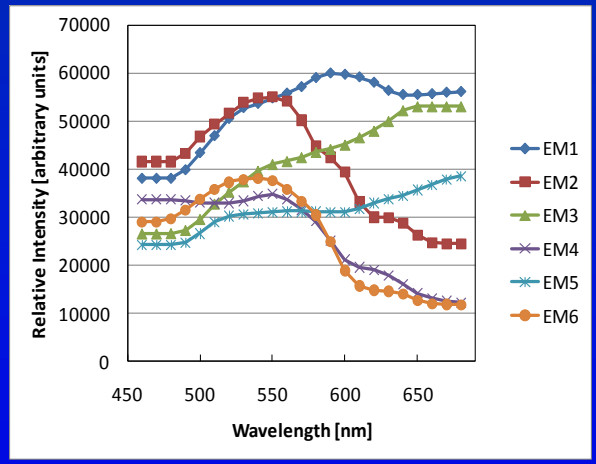
HIP Projection

- *"Original" is an actual hyperspectral image cube of a coral reef measured from an aircraft platform*
- *"HIP-Projected" is the original as projected by the HIP breadboard directly into a laboratory imaging spectrometer*
- *Images below are color composites from only three (460 nm, 550 nm, 650 nm) of the 23 bands measured*
- *Differences result from a combination of imperfect HIP breadboard and imperfect imaging spectrometer calibration*



Eigenspectra of the original image cube

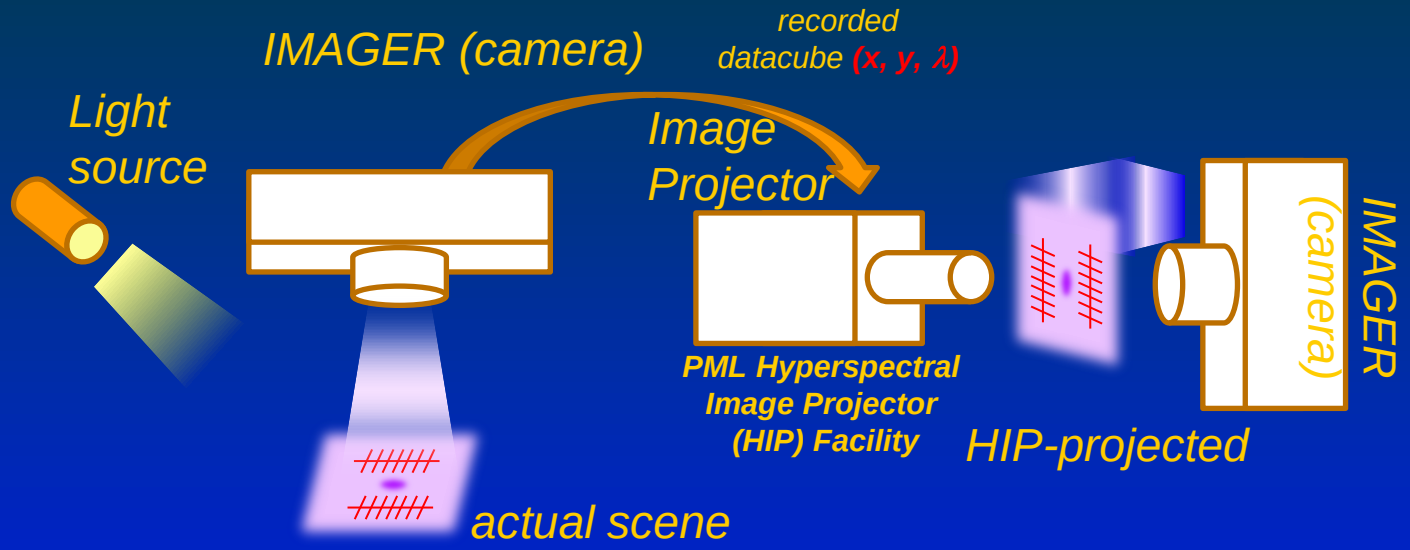




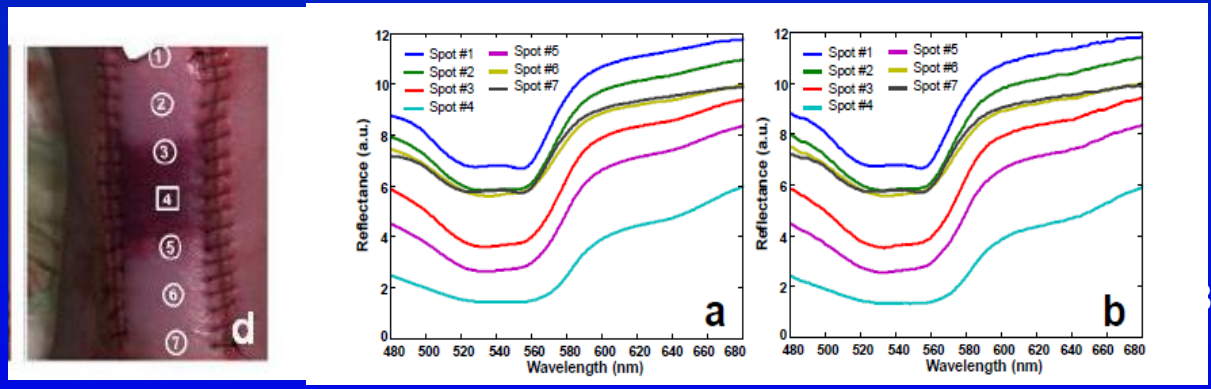
Eigenspectra of the HIP-projected image cube

Digital tissue phantoms

Realistic references standards for optical device calibration



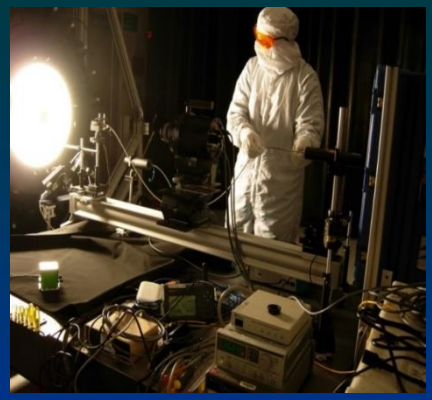
Pig Skin flap



Original spectra *HIP-projected*

Radiometric Calibration

CIS

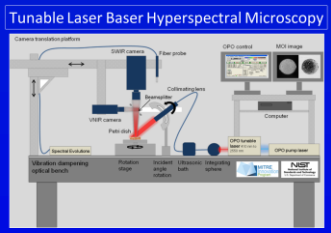


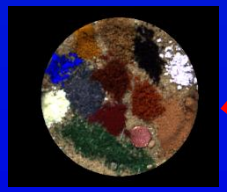
- Radiance responsivity
- SNR
- NUC

CIS

HIP

- Error Matrix
- SNR (signatures)
- Spectral band response
- MTF
- Synthetic test targets





Conclusions

- *New remote sensing platforms will continue to drive the development of Compact Imaging Spectrometers (CIS)*
- *Due to the variety of optical designs, matching the SWaP and performance to the right application will be critical*
- *NIST calibration services provides a means to evaluate the performance of a CIS in relationship to the application*

Hyperspectral Standards

SPIE. DSS SENSING TECHNOLOGY + APPLICATIONS

Hyperspectral Imaging Standards Workshop

Date: **Wednesday 22 April 2015**
Time: **4:30 PM - 6:00 PM**
Location: **Conv. Ctr. 346**

Add To My Schedule

Workshop Chair: **David Allen**, National Institute of Standards and Technology (USA)

Panel Members: **Ronald Resmini**, MITRE Corporation (USA); **Oliver Weatherbee**, SpecTIR LLC (USA); **Terry Slonecker**, USGS (USA); **Karen Reczek**, National Institute of Standards and Technology (USA)

Panel Moderator: **Karen Reczek**, National Institute of Standards and Technology (USA)

Purpose: Hyperspectral imaging as a field is in the process of maturing from a specialized tool to a routine method applied to many facets of society. Standards provide common reference points that foster an understanding between different entities. This meeting is intended to survey the range of standards currently available and to identify gaps where new standards are needed. The range of standards open for discussion encompass all aspects related to hyperspectral imaging and may include performance specifications, calibration standards, data formats, terminology, and best practices. This workshop will provide an open forum for metrology laboratories, instrument vendors, data product analysts, data product vendors, and end-users. The outcome of this meeting will provide guidance for future activities including an expanded workshop to address areas determined to be significant bottlenecks restricting the full potential of this field. This meeting is open to all DSS registered attendees.

Goals:

- Provide a forum for the hyperspectral imaging community to discuss current and needed standards
- Identifying international standards organizations that are the most logical homes for new standards
- Address the need for standards to address regulatory requirements
- Discuss the possibility of a uniform set of performance metrics
- Discuss the need for traceability to national standards
- Consider formalizing best practices

NIST National Institute of Standards and Technology U.S. Department of Commerce

USGS science for a changing world

MITRE

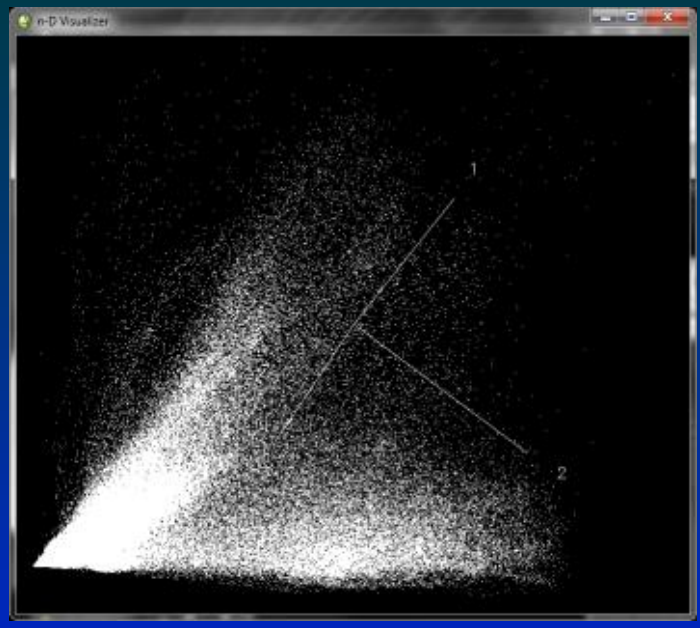
SpecTIR™

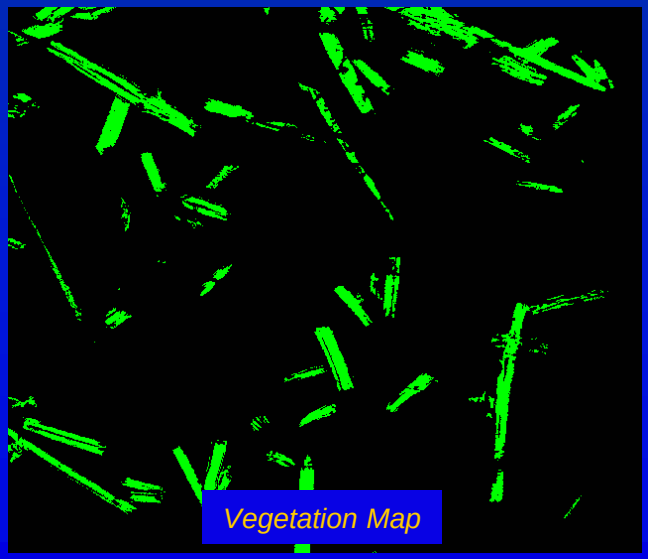
EXTRAS

The Microscene

Pika II Normal Color Composite

35 mm DSLR Photo





Vegetation Map