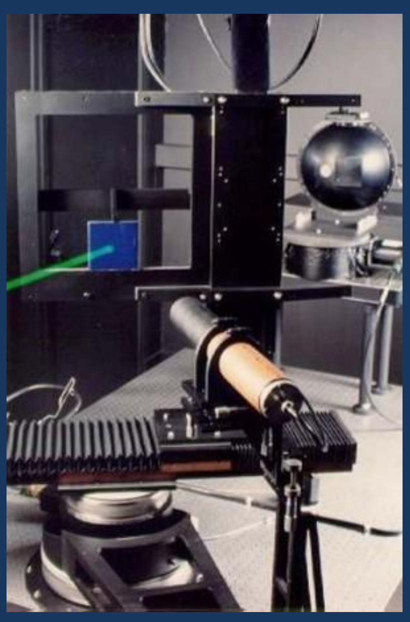
Hyperspectral microscopy for enhanced characterization of ground-truth spectral signatures

Abstract: Hyperspectral imagery (HSI) microscopy allows for vegetation and geologic material to be examined at the sub-centimeter spatial scale. NIST has developed a laboratory dedicated to measuring the optical properties of materials through the use of commercial and custom hyperspectral imagers. The custom built hyperspectral imaging microscope covers the 400 nm to 2500 nm spectral range. This system provides a means to collect >10,000s of spectra from both pure substances and mixtures. The large abundance of spectra allows for a more detailed understanding of the distribution and variability of spectra. This additional information may aid in understanding the variability observed in ground truth spectra collected from portable spectrometers. Additionally, the datacubes collected can serve as proxies for airborne and spaceborne collected datasets for test and evaluation purposes.

STARR Facility

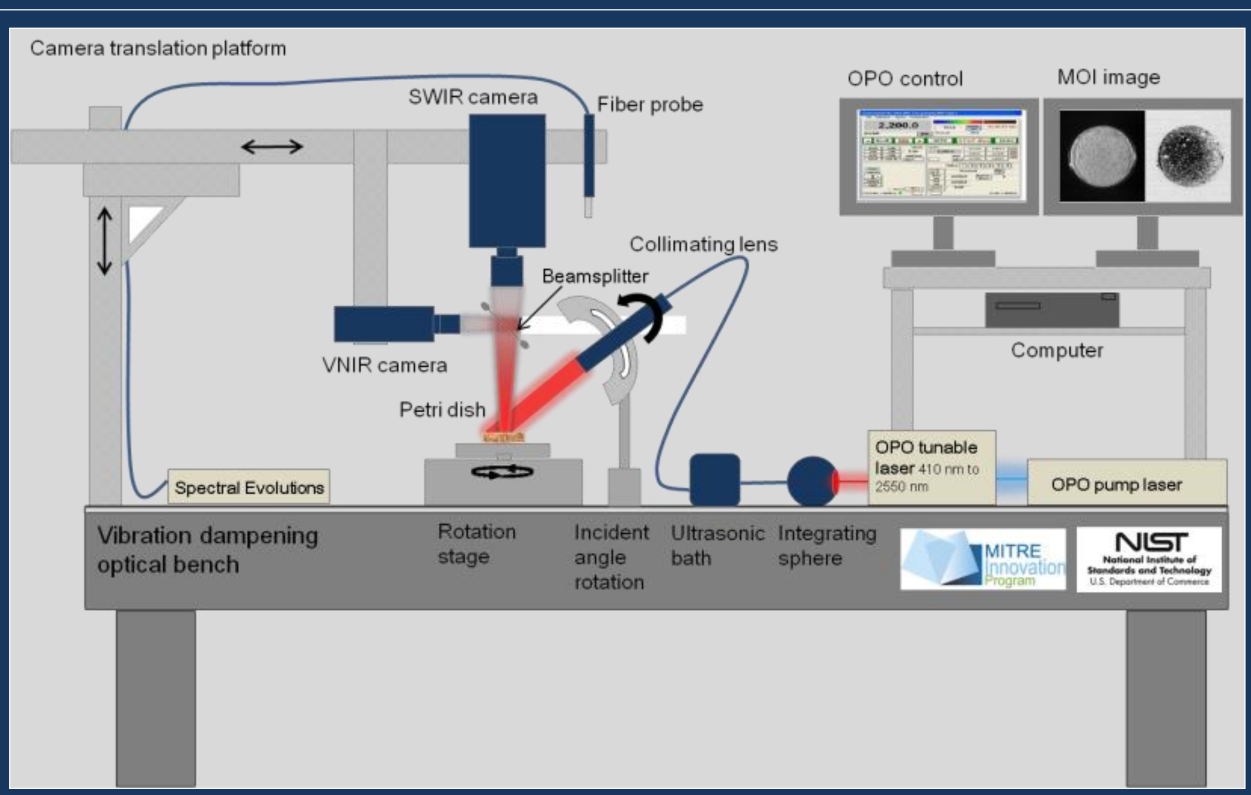


STARR is the national reference facility for scales of reflectance

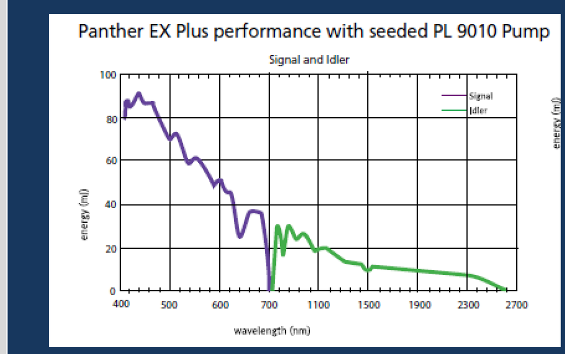
The scales of reflectance can be transferred through PTFE reflectance plaques with uncertainties of 0.2 % *k*=2

Direct traceability to national scales minimizes measurement uncertainty

Tunable Laser Baser Hyperspectral Microscopy



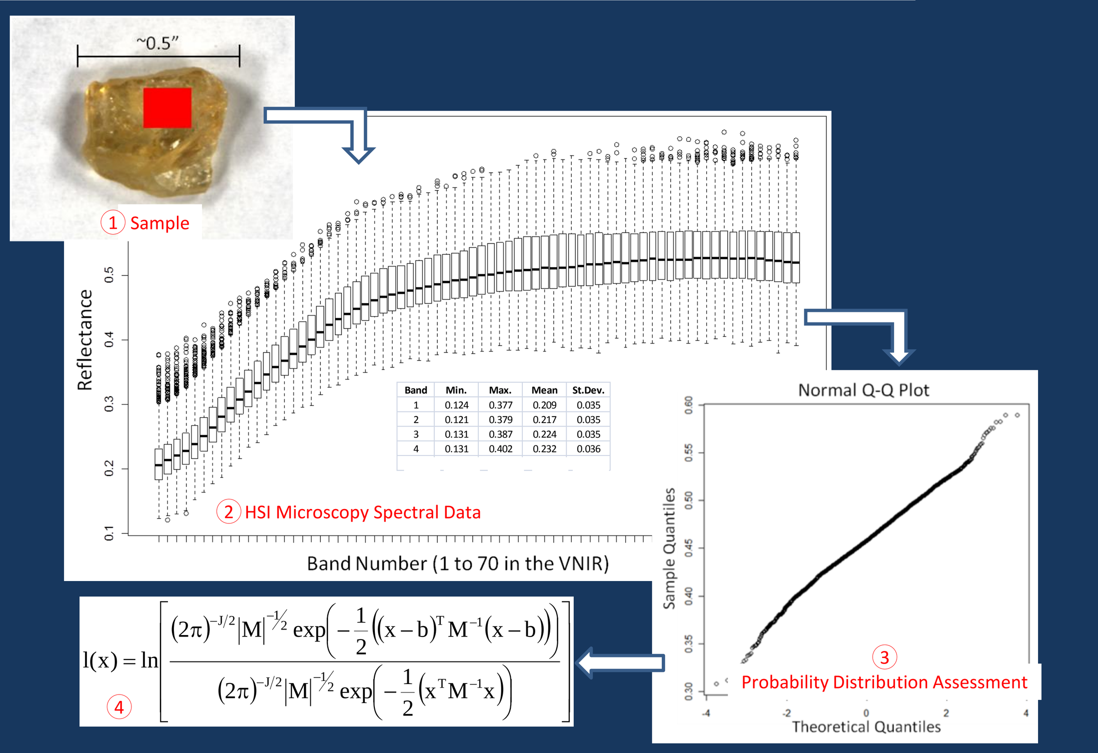
Broad spectral coverage: 405 nm to 2500 nm
High spectral resolution: typ. < 2 nm
1 cm sample area ~ 7 µm resolution
Aprox. 80,000 spectra in SWIR



COTS Hyperspectral Microscopy

Several hyperspectral imagers provide spatial coverage from 1µm up to cm spatial scales in order to bridge the gap between the microscopic realm and common remote sensing GSD s

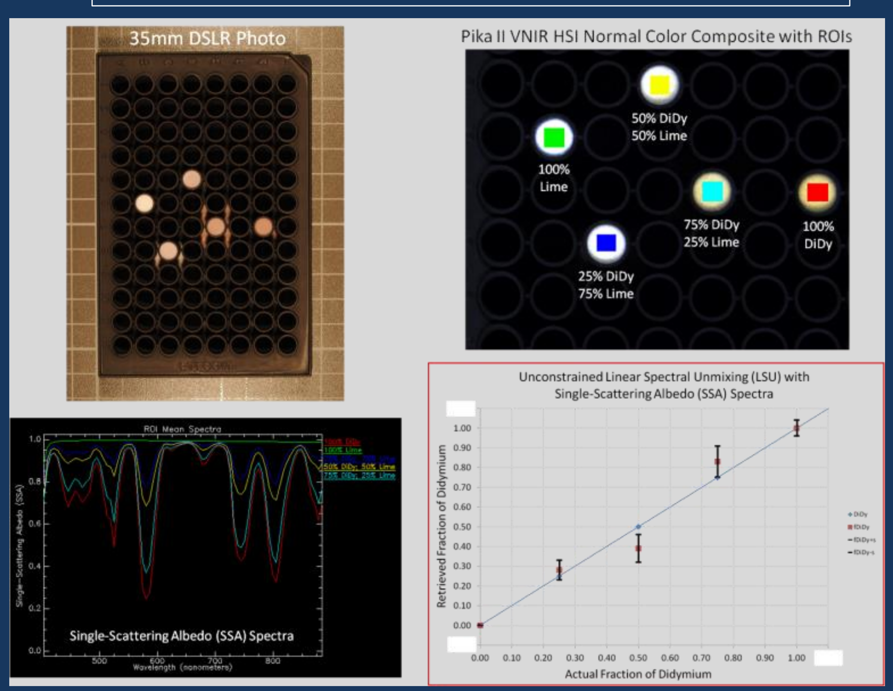
Statistical Distribution of Spectra



$$I(x) = \ln\left[\frac{(2\pi)^{-J/2}|M|^{-1/2}\exp\left(-\frac{1}{2}\left((x-b)^T M^{-1}(x-b)\right)\right)}{(2\pi)^{-J/2}|M|^{-1/2}\exp\left(-\frac{1}{2}\left(x^T M^{-1} x\right)\right)}\right]$$

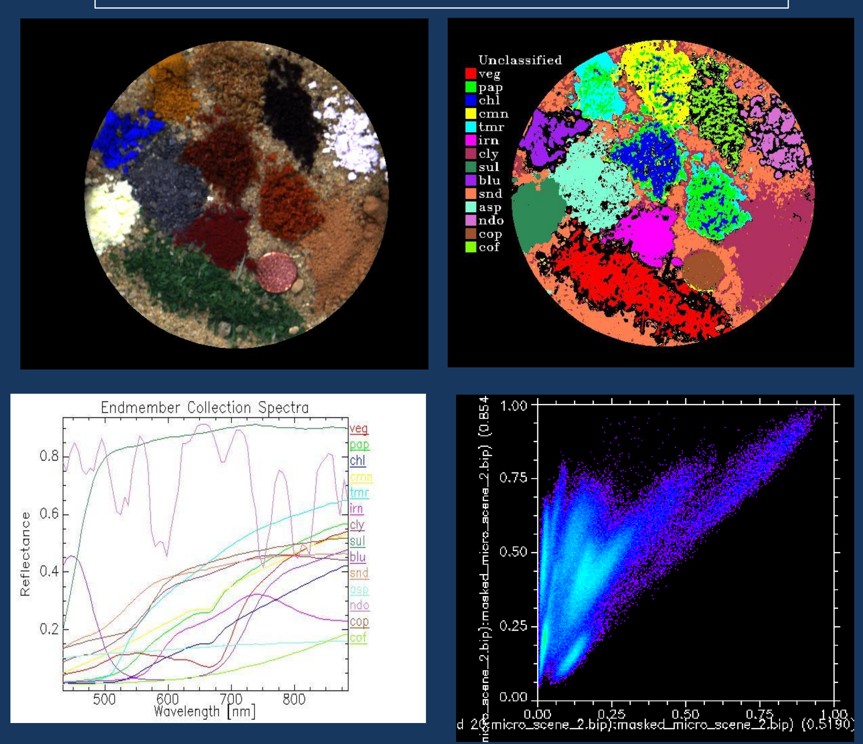
A large number of spectra of a material allows for the evaluation of the parameters of the probability distribution (PD) that describes the data (i.e., density estimation); estimates of the multivariate PD are then compared to a multivariate normal PD. The PDs are used to build algorithms. Ref 1

Non-Linear Spectral Mixing



Mixtures of pure materials can be examined and used to study non-linear mixing. The resulting data set can then be used to develop predictive models. Ref 2

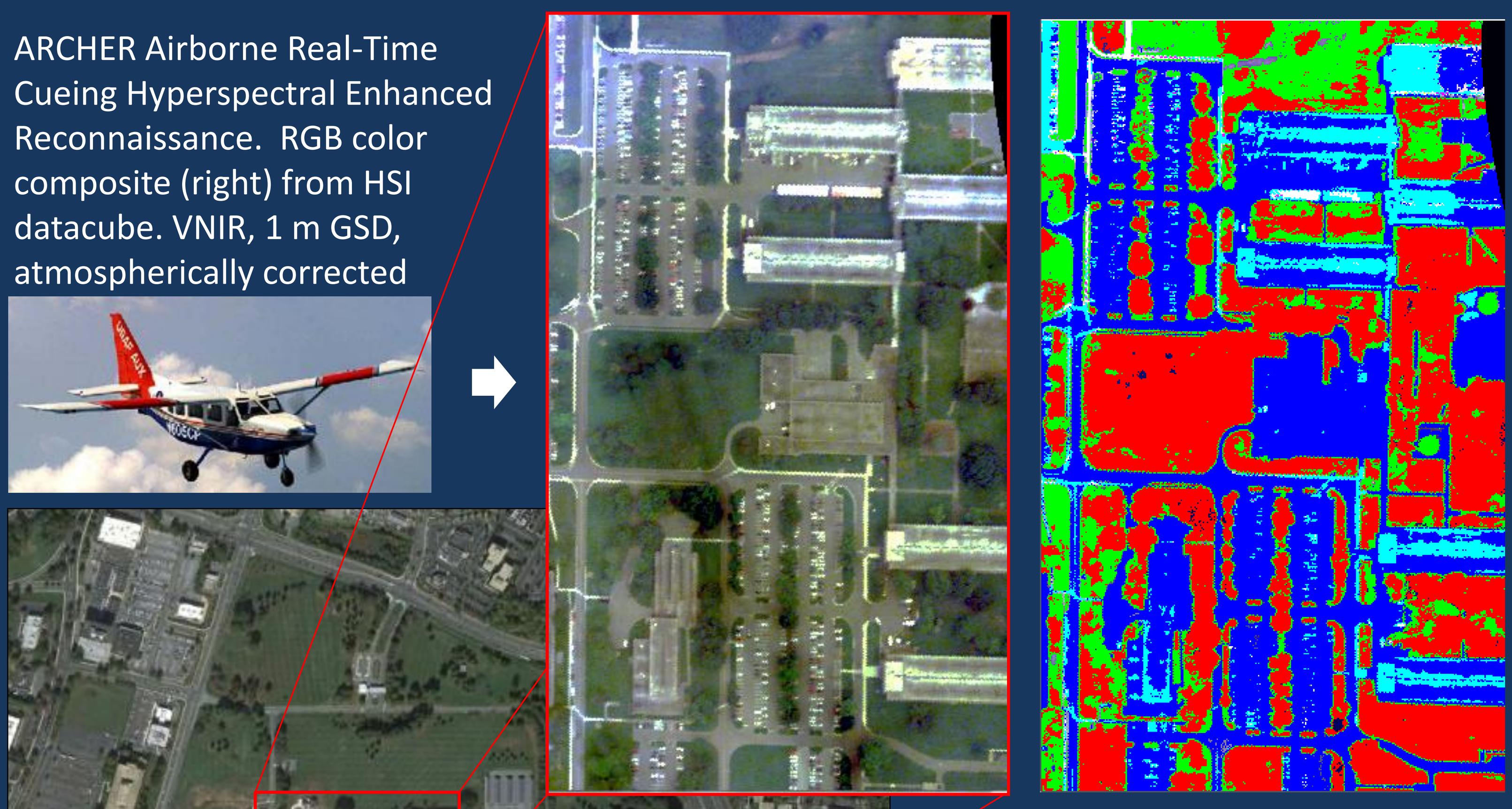
Microscene Composition

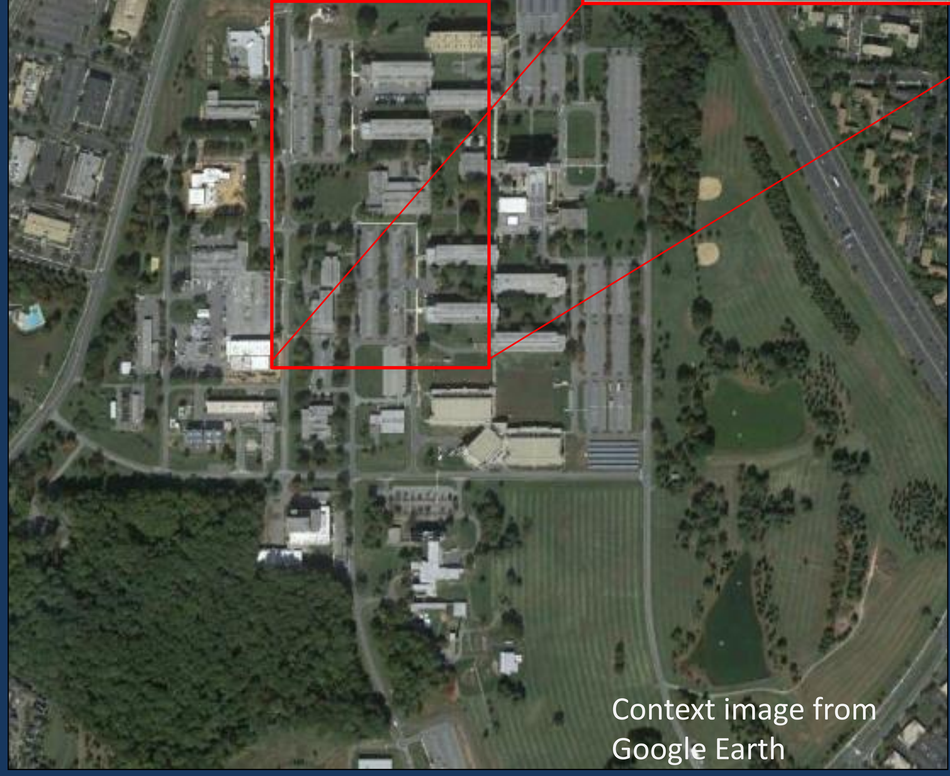


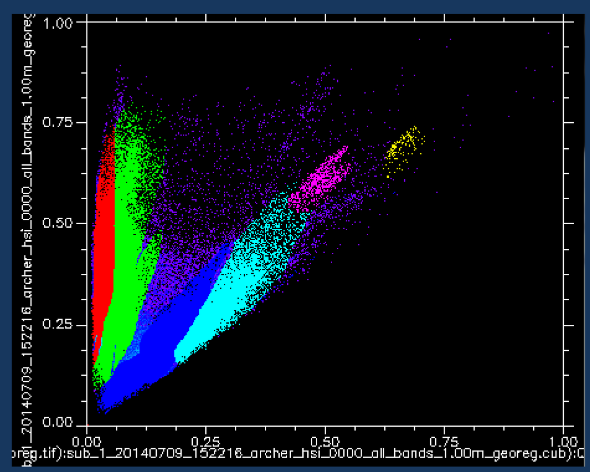
The microscene allows for the rapid production of hyperspectral data sets that may be used in test and evaluation of hyperspectral imaging systems and applications . Ref 3

Case Study: Spectral signatures of NIST Gaithersburg Campus

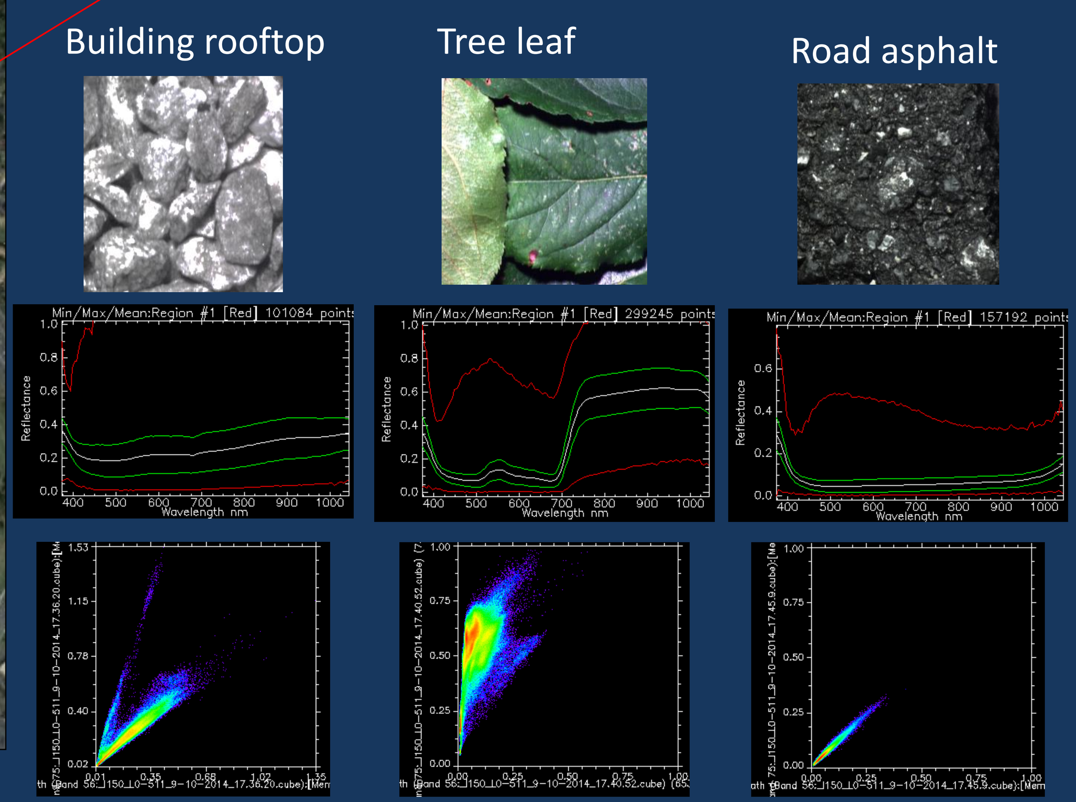
ARCHER Airborne Real-Time Cueing Hyperspectral Enhanced Reconnaissance. RGB color composite (right) from HSI datacube. VNIR, 1 m GSD, atmospherically corrected





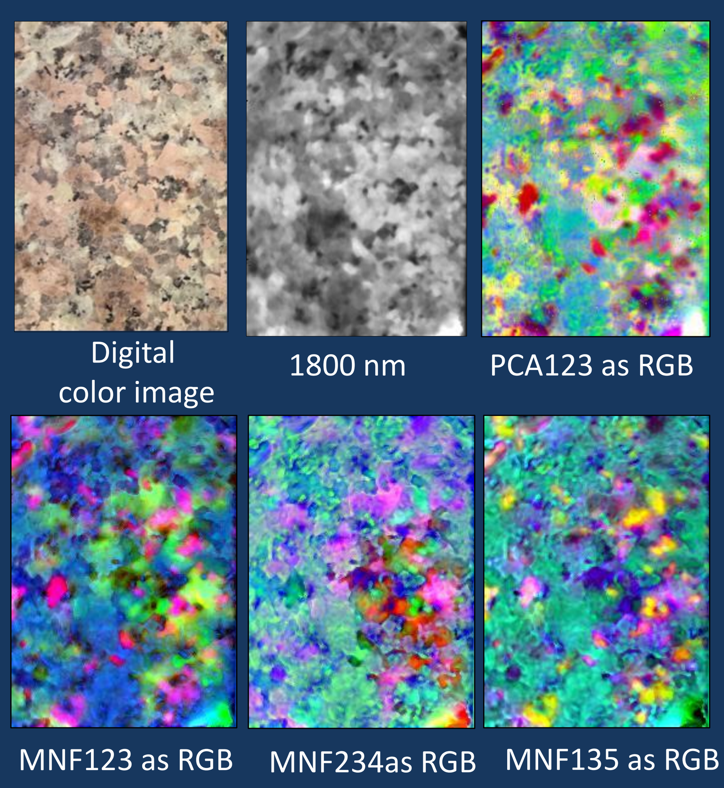


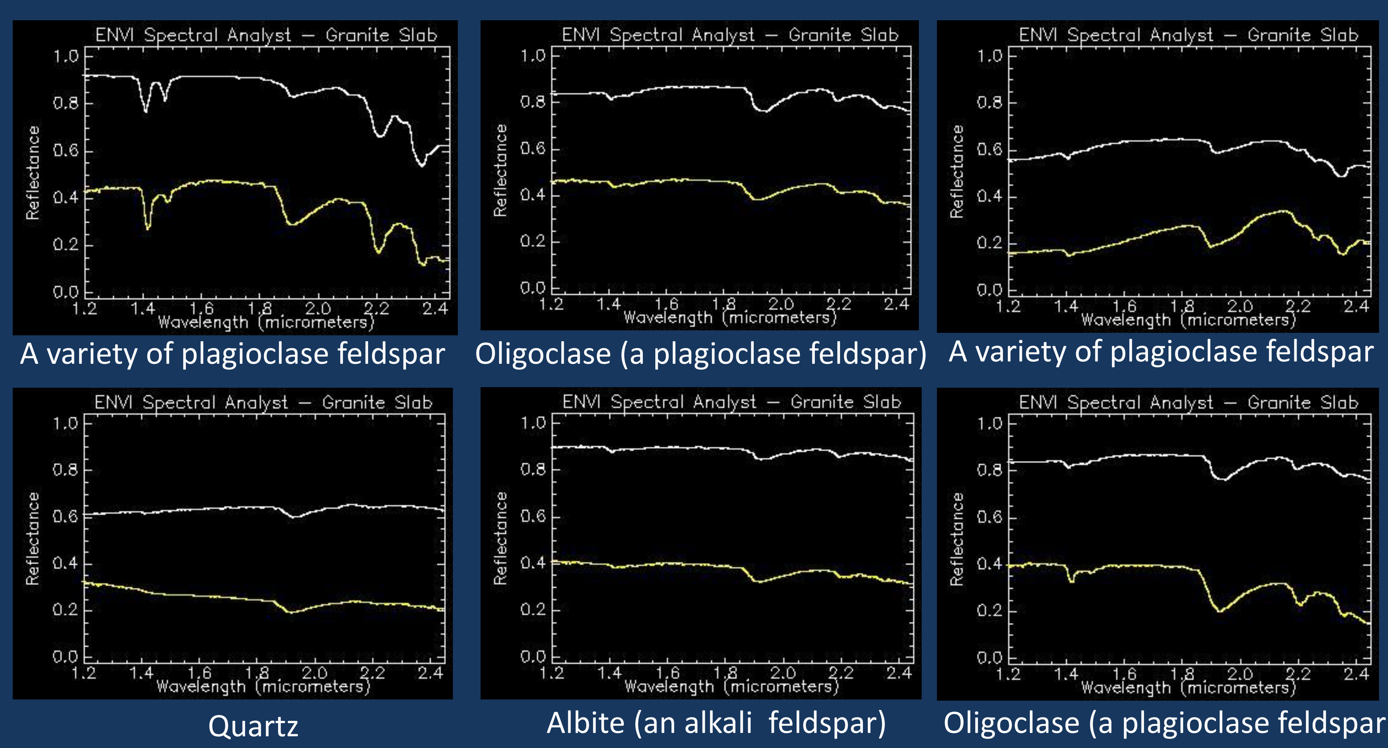
Class map of major scene components from the ARCHER datacube (left) grass, trees, roads, and rooftops. 2D scatter plot x-axis 650 nm , y-axis 750 nm (above) shows inherent variability of general material classes.



Rooftop, tree leaves, and asphalt were measured using a VNIR benchtop hyperspectral imager. Spectral plots show the mean spectrum (white) of each datacube with the standard deviation (green) and min/max (red). Each are >100,000 spectra. 2D scatter plots show variability of each material (x-axis 650 nm , y-axis 750 nm)

Examination of granite slab in SWIR (900 nm to 2500 nm)





Granite slab, 4 cm by 5 cm, images (above left) show spatial heterogeneity based on composition. The slab was measured using the OPO based hyperspectral microscope over the 900 nm to 2500 nm spectral range at every 5 nm. The illumination/observation geometry was 45/0. The spatial resolution was approximately 200 µm per pixel. RGB color composites from principal component analysis (PCA) and minimum noise fraction (MNF) are shown. Spectra from discrete regions were matched to the USGS spectral library (above right).

References:

1) Ronald G. Resmini ; Christopher J. Deloye ; David W. Allen; An analysis of the probability distribution of spectral angle and Euclidean distance in hyperspectral remote sensing using microspectroscopy. Proc. SPIE 8743, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIX, 87431I (May 18, 2013)

2) Ronald G. Resmini; Robert S. Rand; David W. Allen; Christopher J. Deloye; An analysis of the nonlinear spectral mixing of didymium and soda-lime glass beads using hyperspectral imagery (HSI) microscopy. Proc. SPIE, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XX, (May 2014)

3) David W. Allen ; Ronald G. Resmini ; Christopher J. Deloye ; Jeffrey R. Stevens; A microscene approach to the evaluation of hyperspectral system level performance . Proc. SPIE 8743, Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIX, 87431M (May 18, 2013)

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