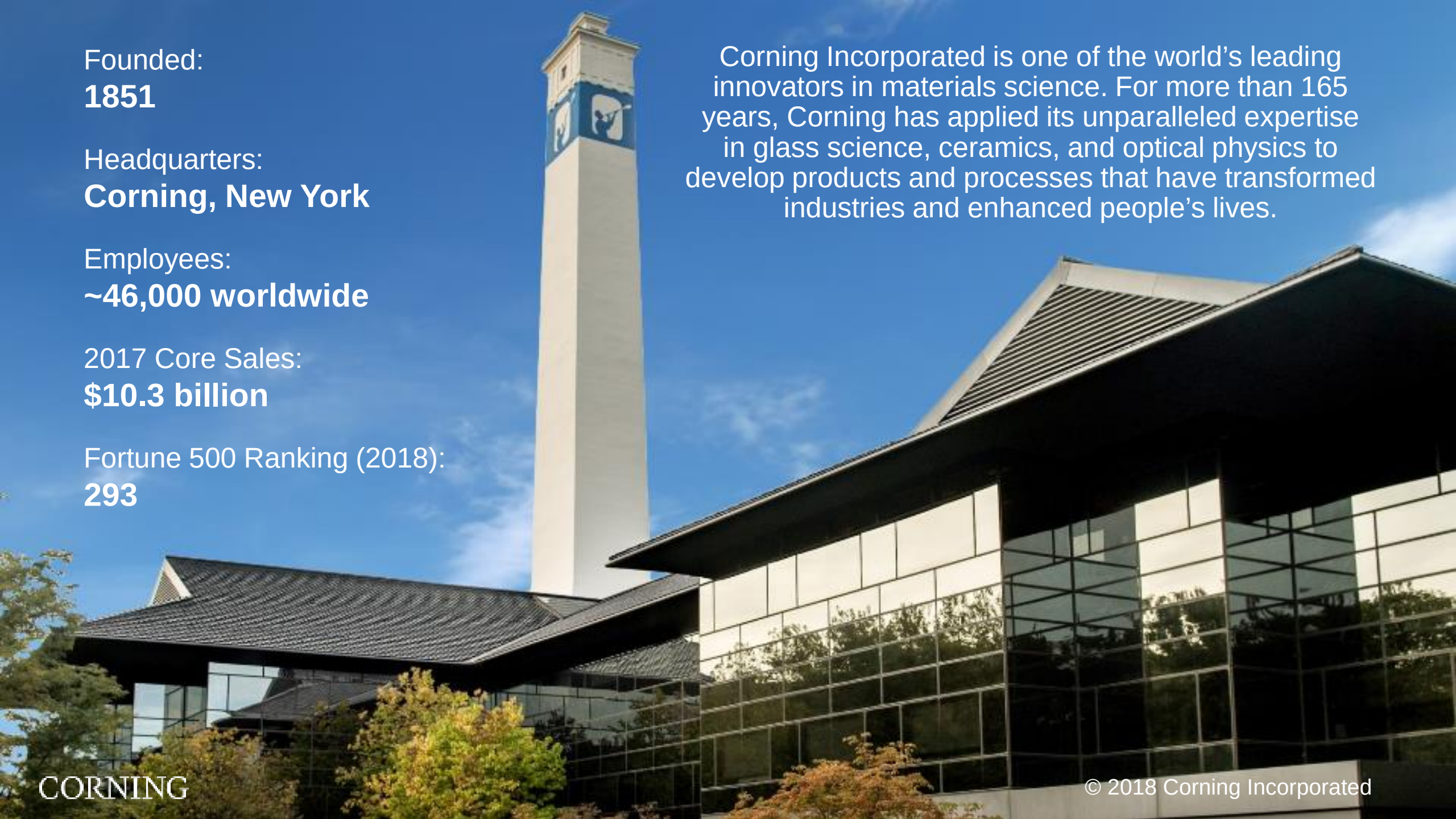
Bringing Hyperspectral Imaging Into the Mainstream

Rich Zacaroli
Product Line Manager, Commercial Hyperspectral Products
Corning Advanced Optics

August 2018



Founded:
1851

Headquarters:
Corning, New York

Employees:
~46,000 worldwide

2017 Core Sales:
$10.3 billion

Fortune 500 Ranking (2018):
293

Corning Incorporated is one of the world's leading innovators in materials science. For more than 165 years, Corning has applied its unparalleled expertise in glass science, ceramics, and optical physics to develop products and processes that have transformed industries and enhanced people's lives.

CORNING

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Corning has a proven track record of innovation

1877
Signal Lenses

1879
Glass Bulb for Edison's Electric Light

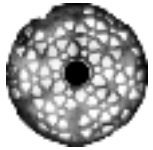
1912
Railroad Lanterns

1915
Heat-Resistant PYREX® Glass

1932
High-Purity Fused Silica

1934
Silicones

1935
Hale Telescope Mirror



1947
Television Picture Tube Processes

1952
Glass-Ceramics

1961
Space Window Glass

1964
Fusion Overflow Process

1970
Low-Loss Optical Fiber

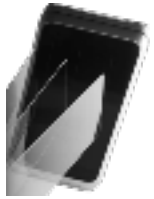
1972
Ceramic Substrates for Catalytic Convertors

1982
Liquid Crystal Display Glass

2000
Low-Density LCD Glass

2006
High Throughput Cell Culture Solutions

2007
Tough, Thin Cover Glass for Mobile Devices



Ultra-Bendable Optical Fiber

2012
Ultra-Slim Flexible Glass

2013
All-Optical Converged Cellular & Wi-Fi Solution

Antimicrobial Glass

2015
Light, Tough Automotive Glass

2016
High-Transmission Light-Guide Plate for LCD Displays

Advanced Glass for Wearables

Gasoline Particulate Filters

2017
Damage-Resistant Pharmaceutical Glass Packaging

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Presentation Agenda

- Practicalizing hyperspectral imaging
- Use cases
- Corning Hyperspectral Products

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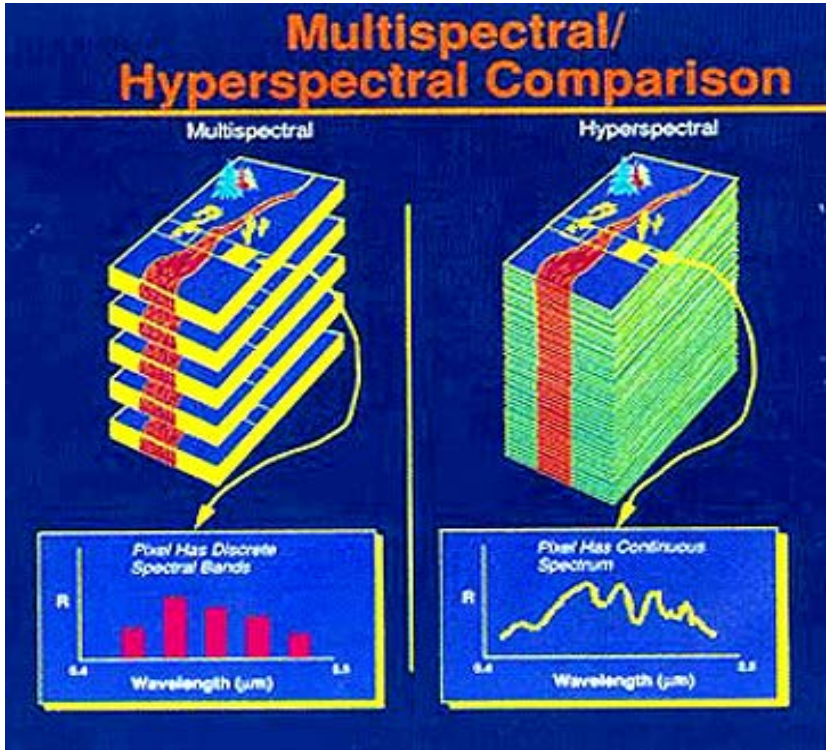
Hyperspectral vs. Multispectral Imaging Technology

- Hyperspectral imagers (HSI) cover many dozens to hundreds of spectral bands contiguously
- Multispectral imagers (MSI) cover a selected set of bands non-contiguously
  - Spectral information critical for research and development of specific applications may be missing
  - Number of spectral bands is insufficient to address multitude of developed and proven applications
  - Ease of deployment and low cost makes MSI attractive for many applications
- A product that can be both HSI and MSI and is reasonably priced provides high flexibility for research and practical applications



Source: NASA (public domain information)

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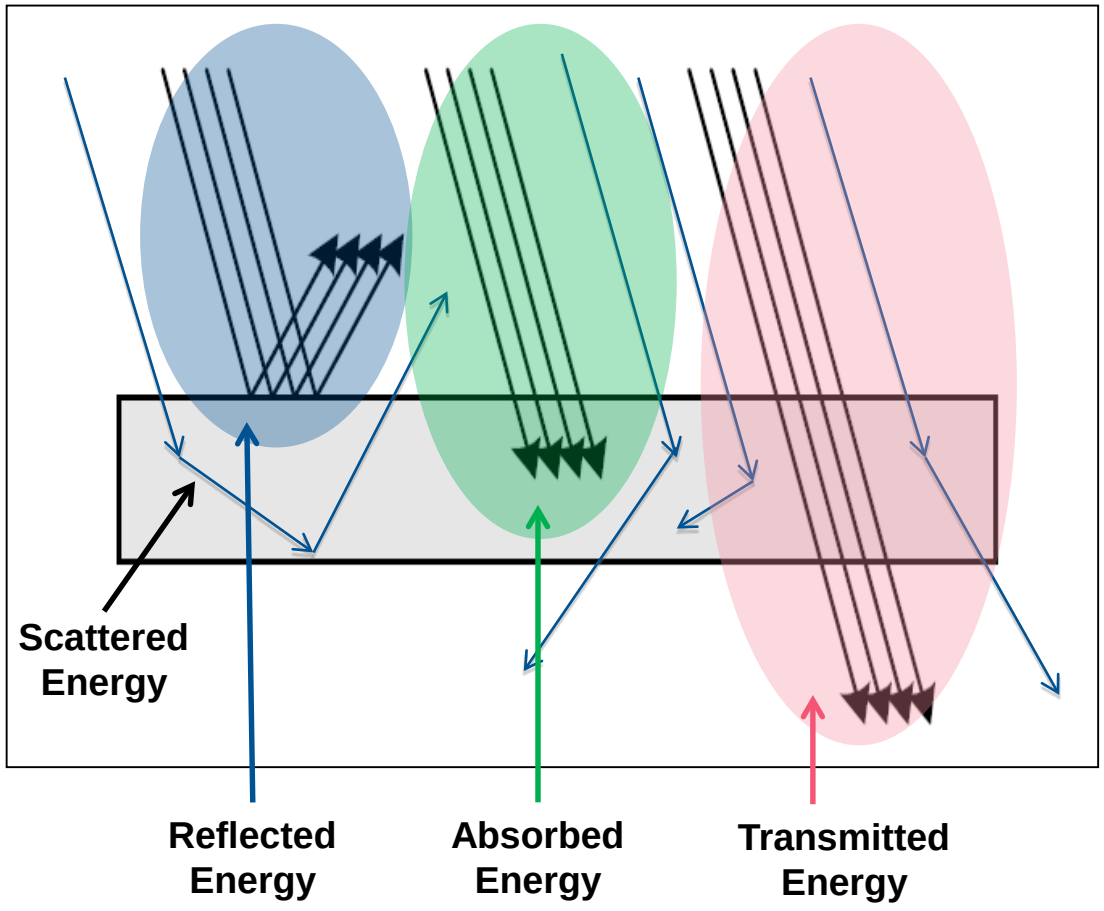
Concept of Spectral Signature

- ***Electromagnetic Radiation (EMR) interactions with matter***: Substances interact with EMR in different ways. They absorb, reflect, transmit, or scatter various wavelengths of EMR differently.

- ***Visible and invisible light are EMR***

- ***Spectroscopy:*** The branch of science concerned with the investigation and measurement of spectra produced when matter interacts with and **reflects** electromagnetic radiation.



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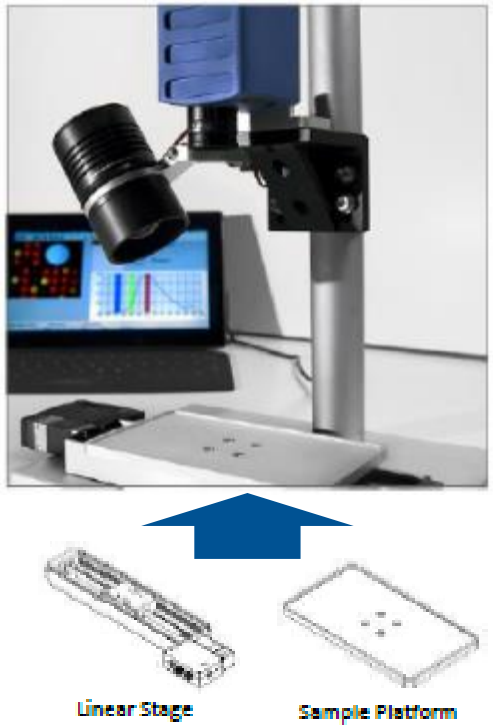
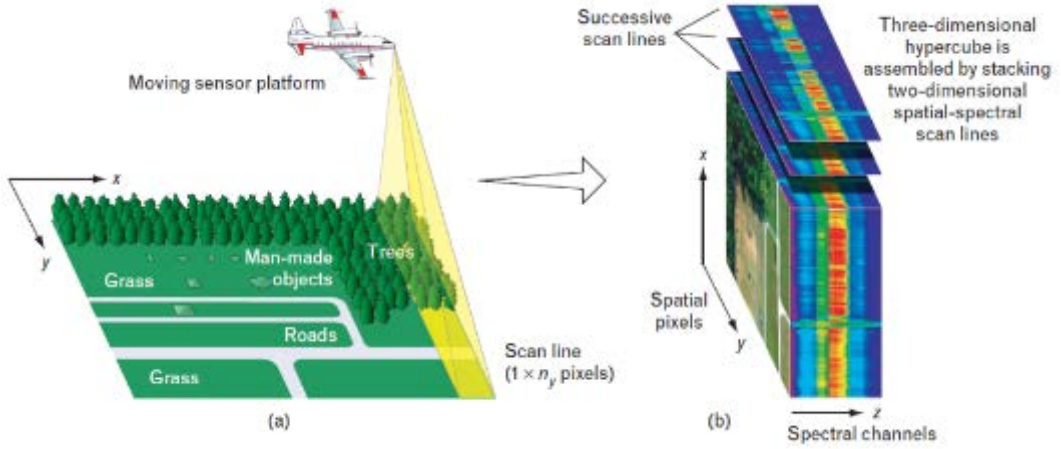
Spectral Data Cube Formation

- High performance hyperspectral sensors are scanning instruments
  - In an airborne application the spectral data cube is formed using aircraft motion
  - In a field application a rotational stage may be used to form a spectral data cube by scanning the HSI camera
  - In a laboratory or field application a linear stage is used to translate the subject matter across the camera field-of-view
  - In an in-line processing environment the product is scanned as it is moving along a conveyor





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What is driving the need for Hyperspectral Sensors?

Four main points…

1. All new applications and indices are developed using hyperspectral imagery data, and are often simplified for MSI

2. The number of proven vegetation indices has far surpassed the capability of multispectral sensors

3. New algorithms/applications are being developed that utilize the entire spectrum instead of a few spectral bands

4. The size, weight, and cost of hyperspectral imaging sensors and systems now approaches higher end multispectral sensors and systems

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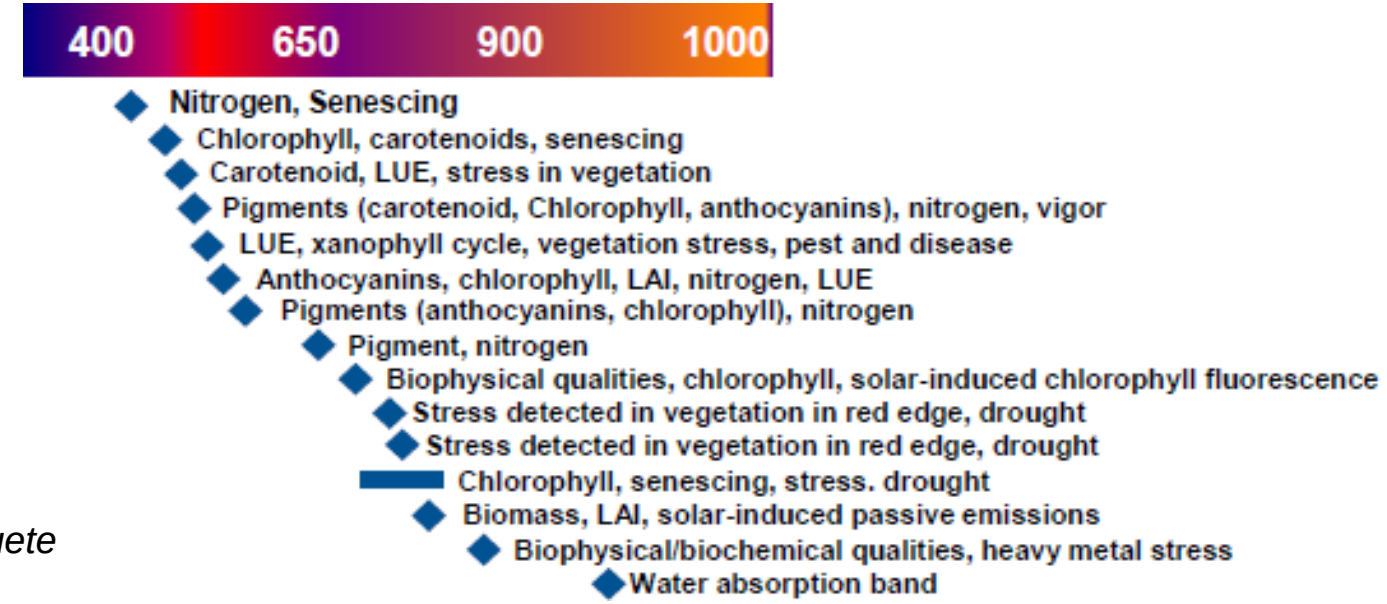
The Need for Contiguous Spectral Coverage *in Practical Applications*

- Dozens of proven vegetation indices use dozens of spectral bands
  - ENVI + Crop Science has 60+ vegetation indices
- Crop and application specific indices have been developed, and development is accelerating
  - Irrigation management of wine grapes and field crops
  - Specific insects and diseases – aphids, red blotch, red-leaf, etc.
  - Fruit ripeness (grapes, tomatoes, berries, etc.)
  - Biofuel growth management



Source: Hyperspectral Remote Sensing of Vegetation
Edited by: Prasad S. Thenkabail, John G. Lyon, & Alfredo Huete

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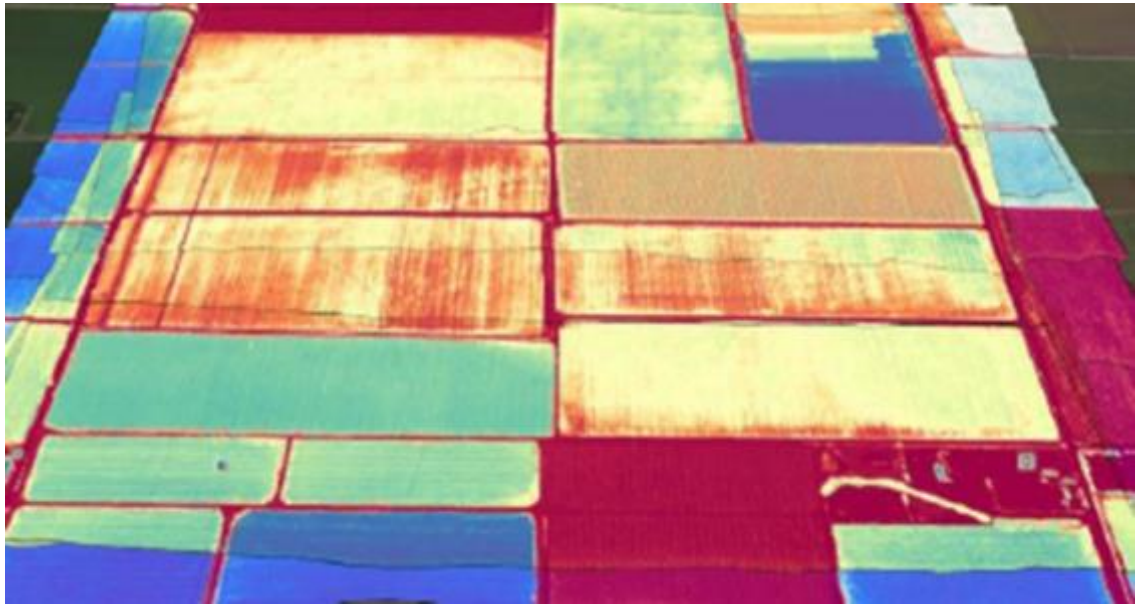
The Need for Hyperspectral Imaging
in Agriculture

ENVI software provides the following categories of vegetation indices:

- Broadband Greenness
- Narrowband Greenness
- Canopy Nitrogen
- Canopy Water Content
- Dry or Senescent Carbon
- Leaf Pigments Light Use Efficiency



44+ spectral narrow bands
30+ < 1000 nm
14 > 1000 nm

…are used to generate…

60 vegetation indices
52 < 1000 nm
8 > 1000 nm

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The Need for Hyperspectral Imaging
in other ENVI Applications

- Burn Indices
- Geology Indices
- Fire Fuel Tool
- Forest Health Tool
- Built-up Index
- Water Index
- Mud Index
- Snow Index
- Non-Homogeneous Feature Index
- Petroleum and Mineralogy Exploration

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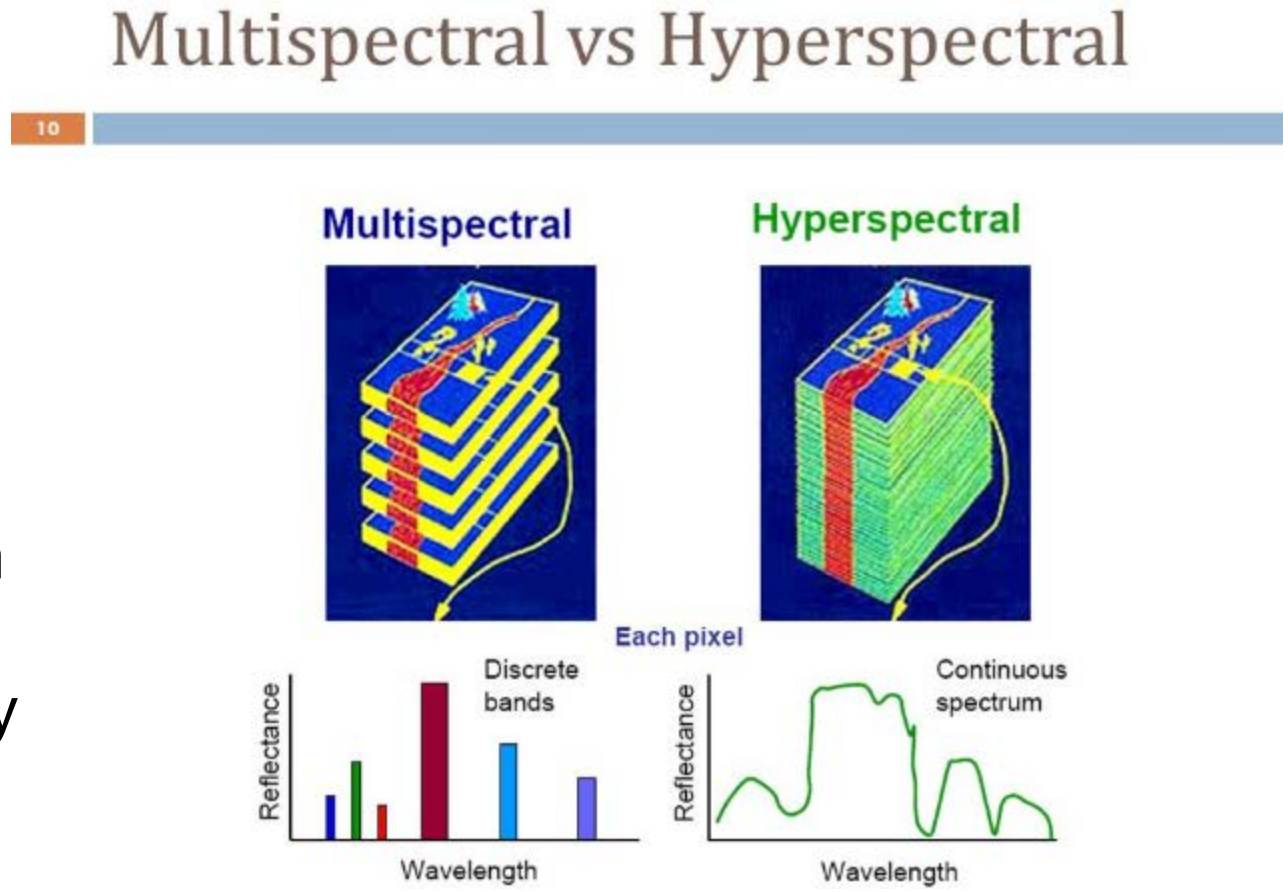
The Need for Contiguous Spectral Coverage
in Practical Applications - Continued

- A new generation of applications are using/will use the entire spectrum and not just selected spectral bands for detection, identification and classification
  - Multispectral sensors will not be able to leverage these indices
- This will enable going beyond detection of stress and becoming diagnostic
- Using the entire spectra will significantly increase the probability of successful detection/ identification/ classification



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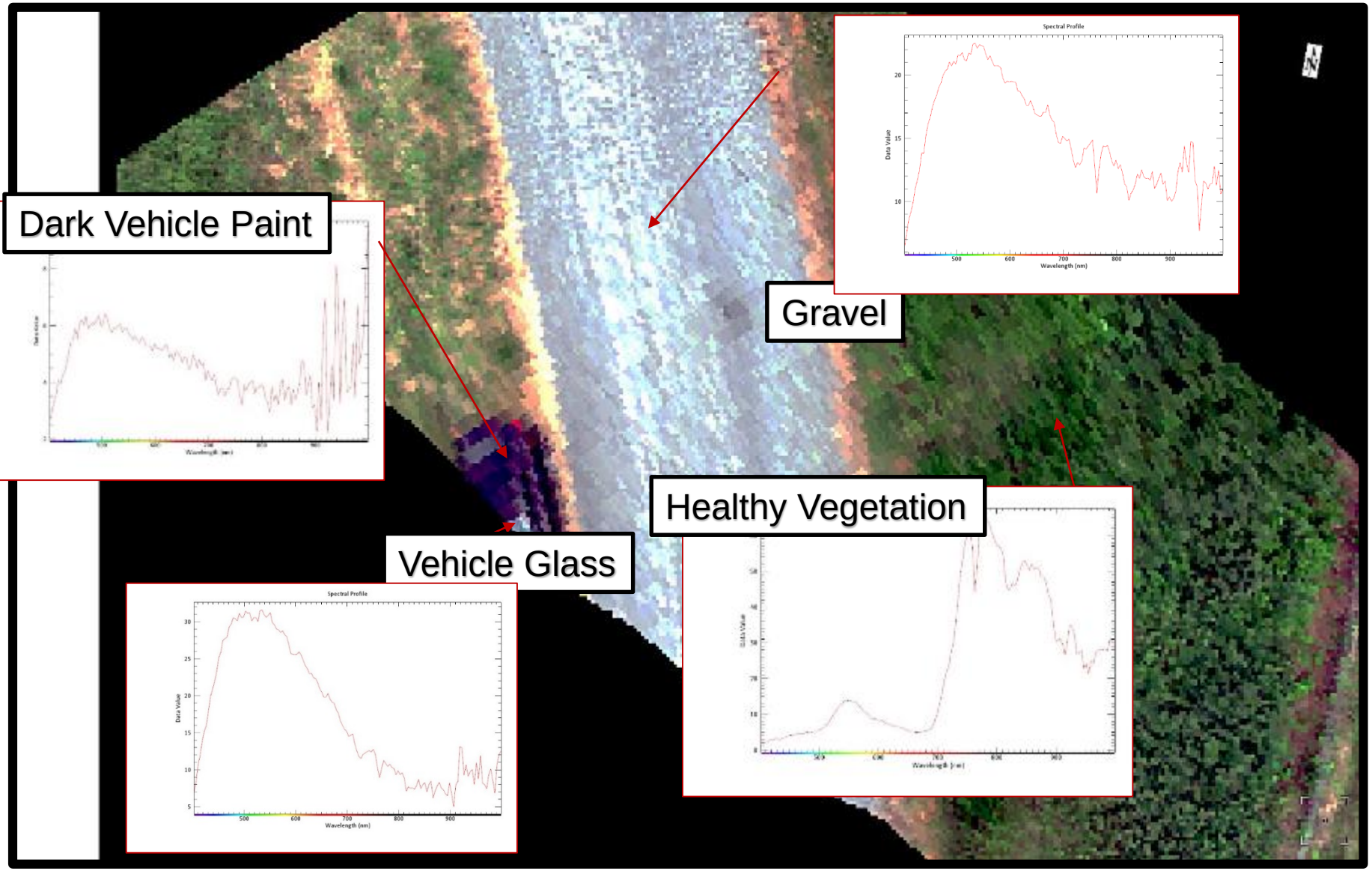
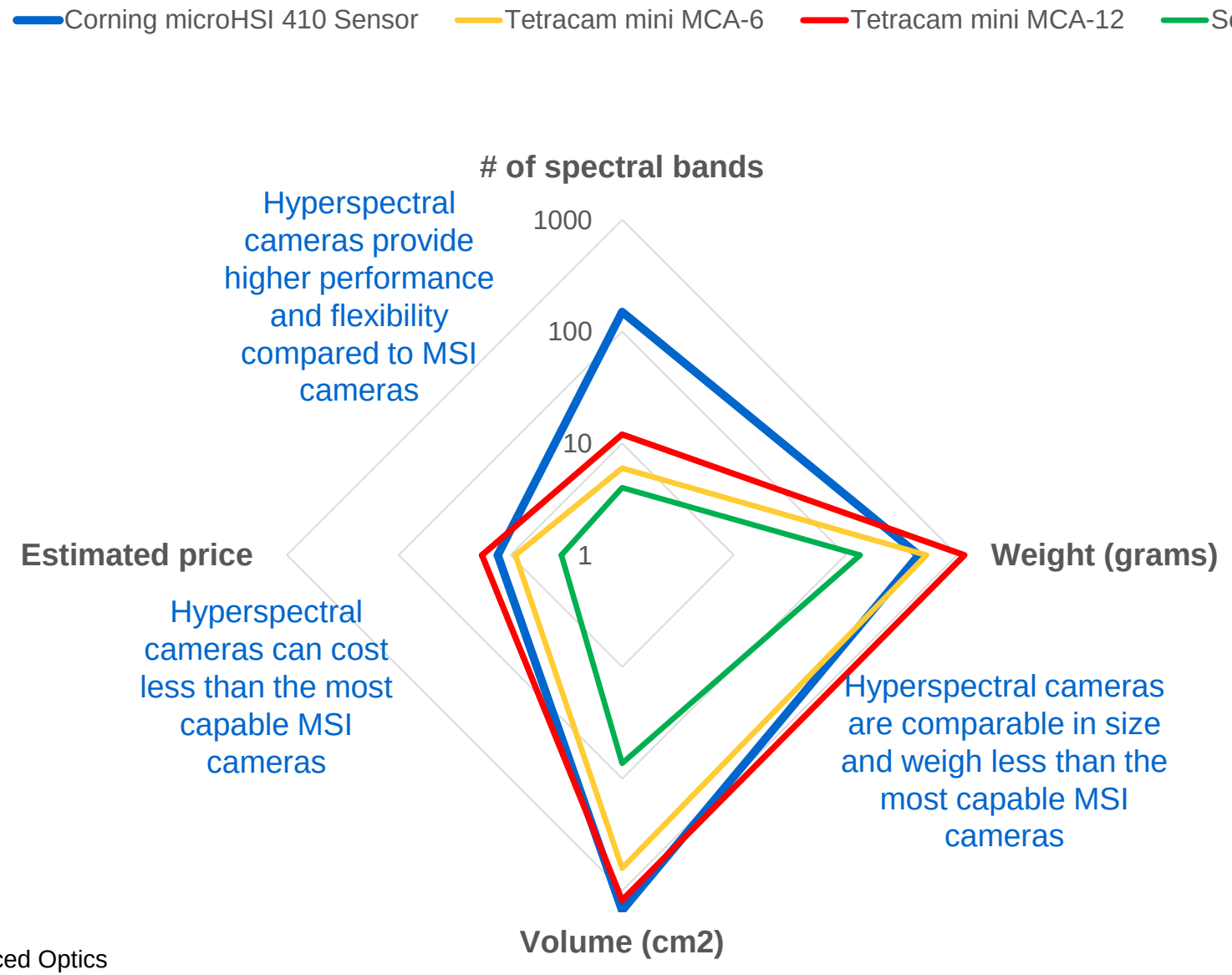
Use of the entire spectrum increases probability of detection, identification, and classification

(*Imagery from Corning® microHSI™ 410 SHARK provided by MTSI, Inc.)*



Comparative Assessment

Hyperspectral vs. Multispectral Sensors



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Integrated Airborne Hyperspectral System Miniaturization

(*Images are approximately to scale)*

2008 → **2013** → **2018**

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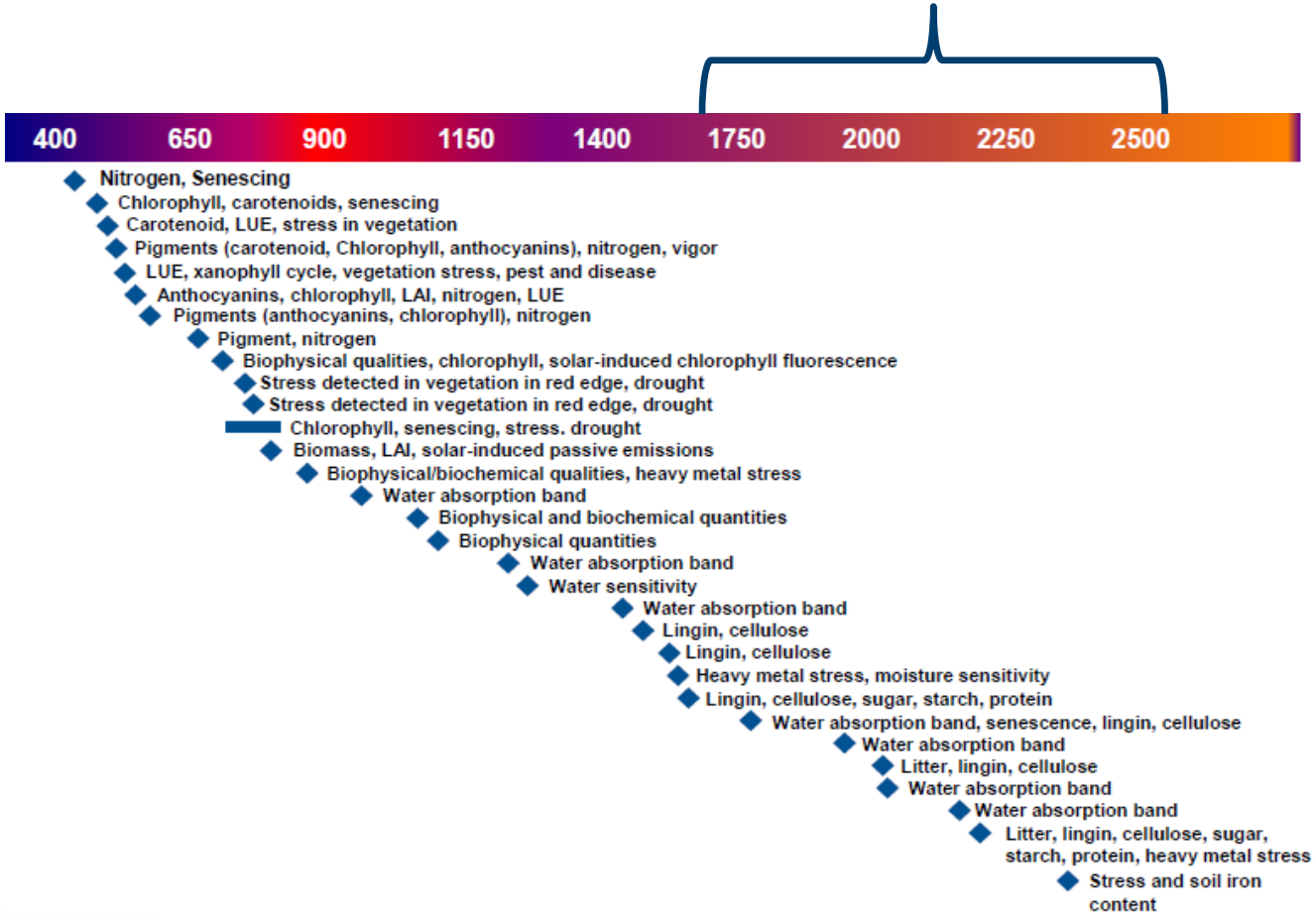
Applications are expanding beyond the visible-NIR spectrum

- Soil analysis
- Mineral and petroleum exploration
- Aerospace and Defense



- There is a cost increase for going beyond 1000 nm
- There is an additional cost increase for going beyond 1700 nm, but is justified for high-value applications

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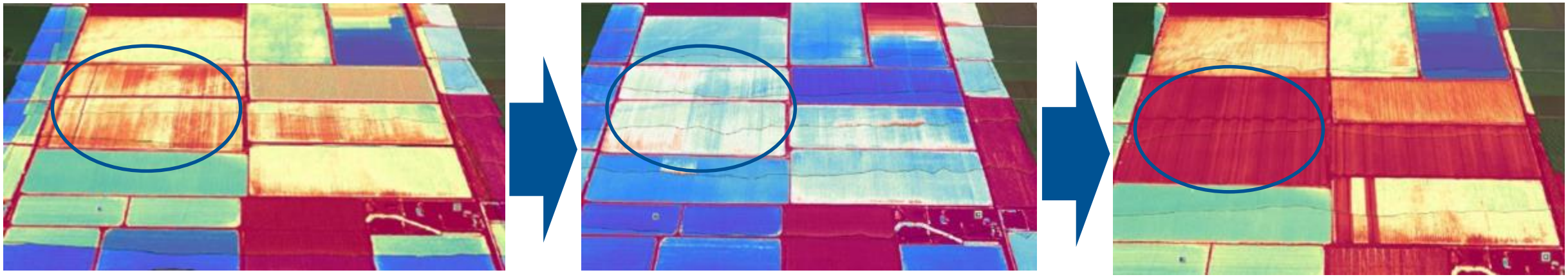
Hyperspectral Imaging Use Cases

Crop Growth and Health Assessment/Management

- Enables the evaluation of vegetation stress, often before it is visible to the human eye or with other sensors
- Enables the visualization of change in crop growth and health, and yield prediction throughout the growing season
- Data products: NDVI reNDVI, Senesis and other indices



Early season

Late season

Post-harvest

Early stage or stressed

Late stage/ robust growth

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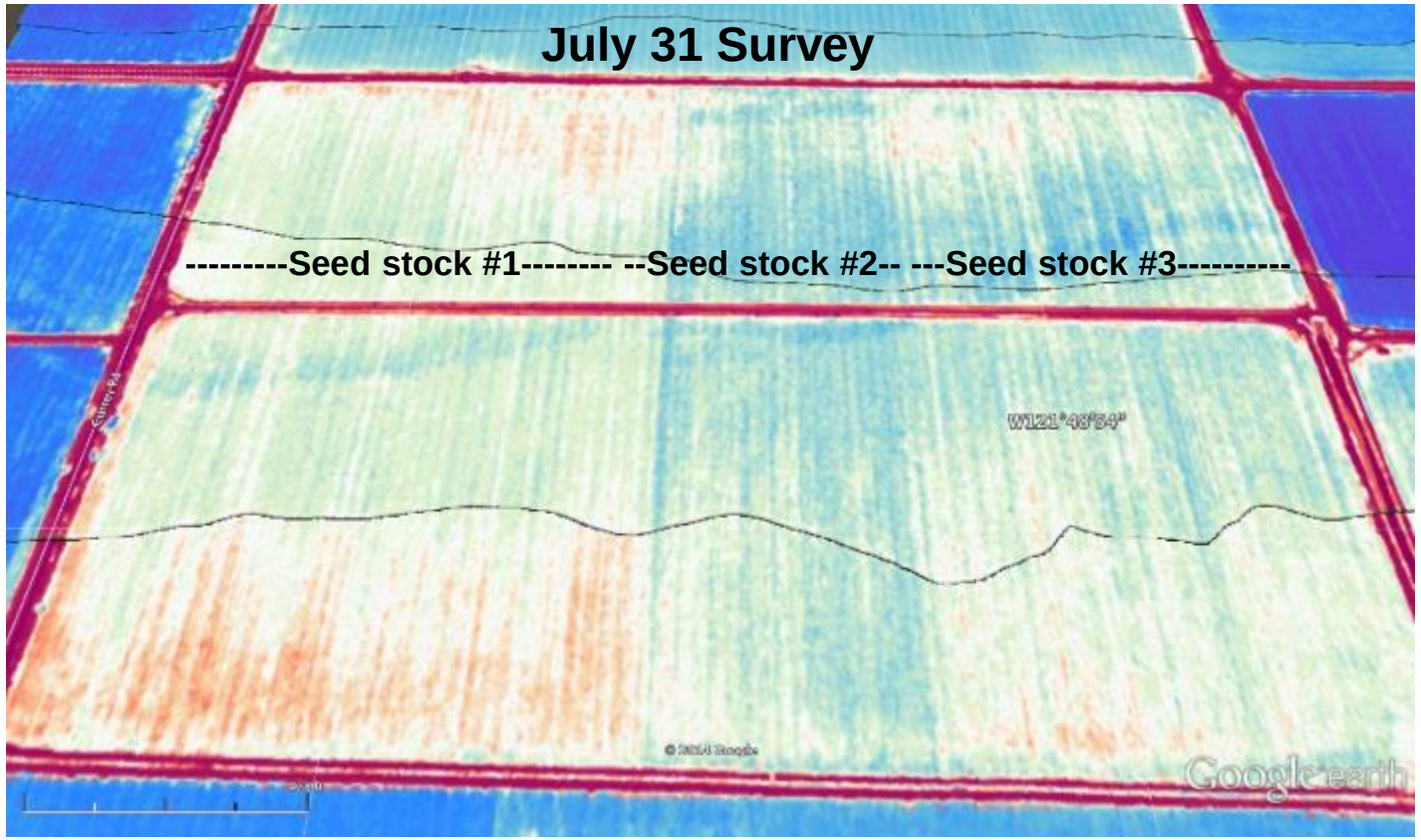
Seed Performance Analysis

- Hyperspectral imagery enables the evaluation of crop performance for different seed stocks
- The below spectral map clearly shows defined boundaries for three different Roma tomato stocks and crop performance.



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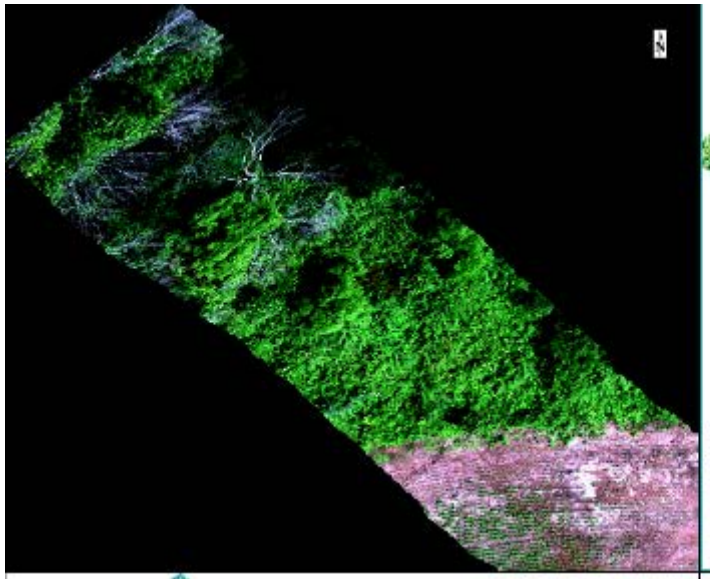
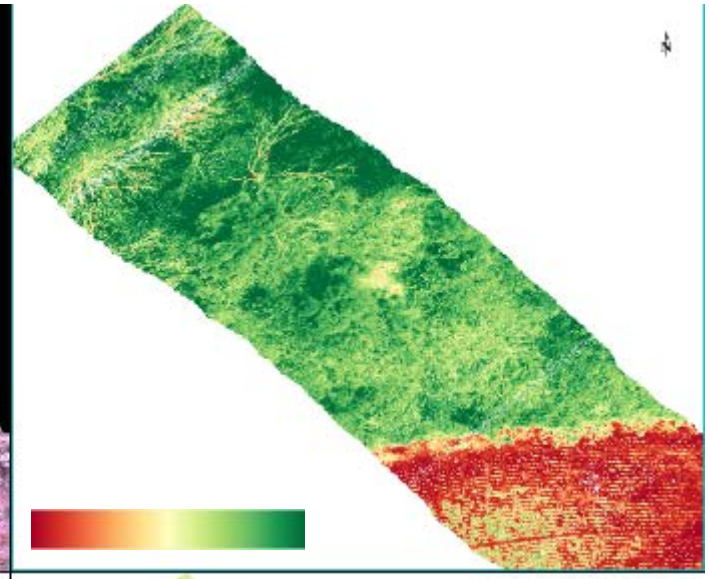
Native Virginia Forest

(Data collected by MTSI with Corning ® microHSI™ 410 SHARK)

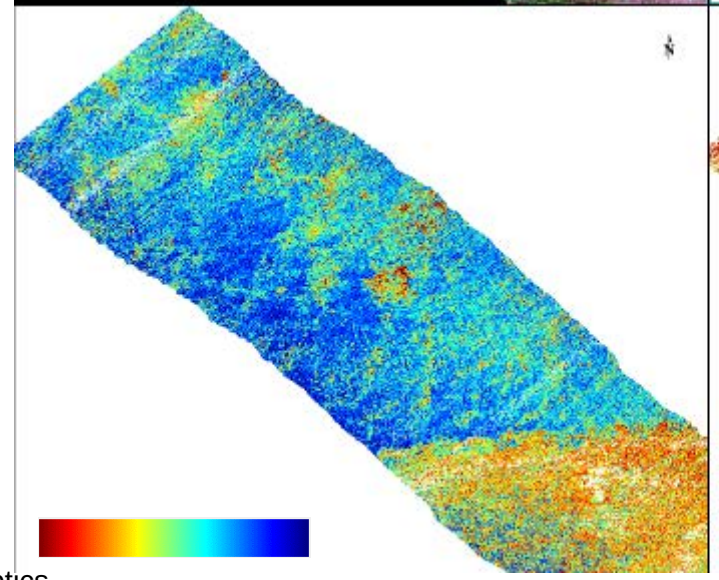
RGBGeo-referenced

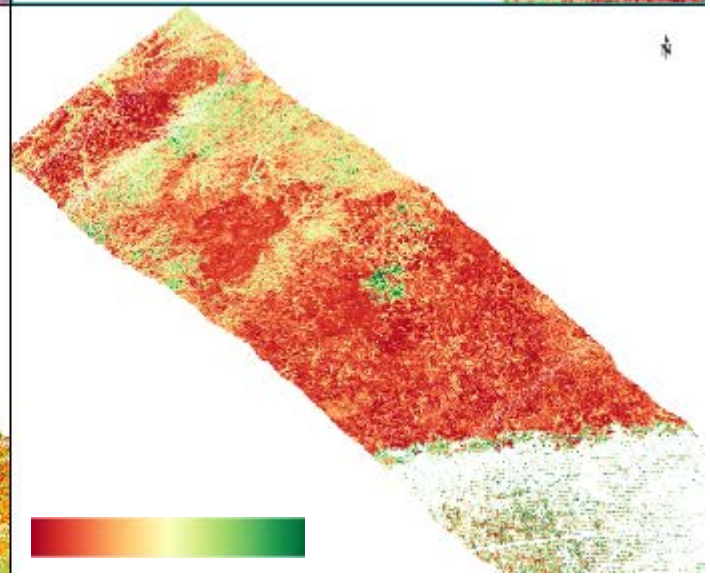




Modified Red Edge NDVI

Water Band Index





Red Green Ratio Index

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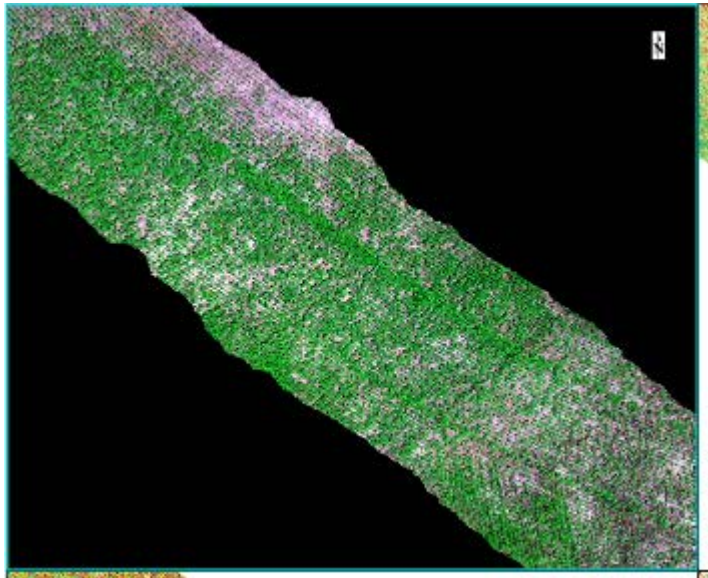
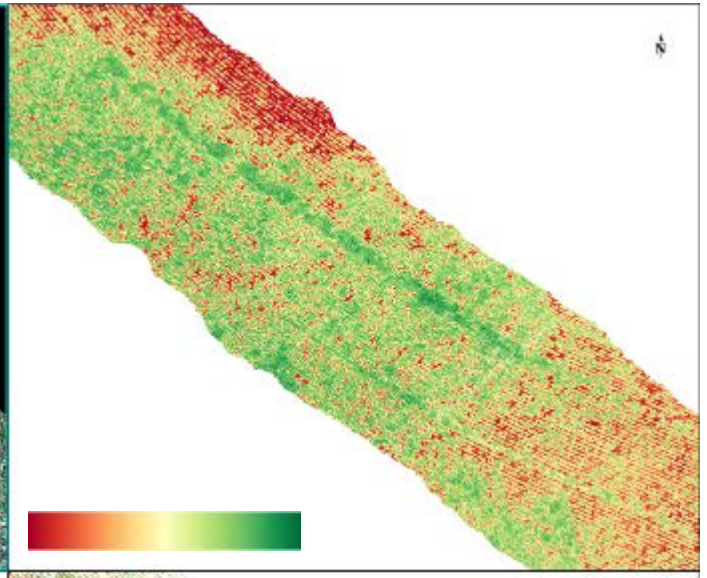
Baby Soy Crop

(Data collected by MTSI with Corning ® microHSI™ 410 SHARK)

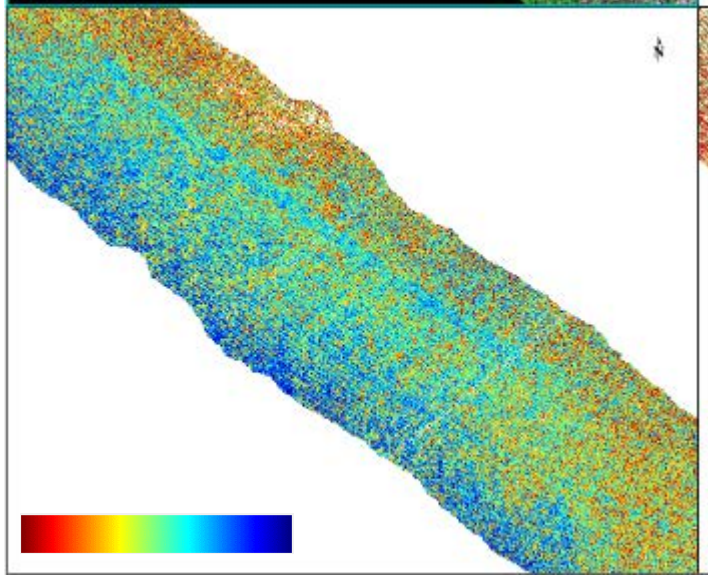
RGB Geo-referenced

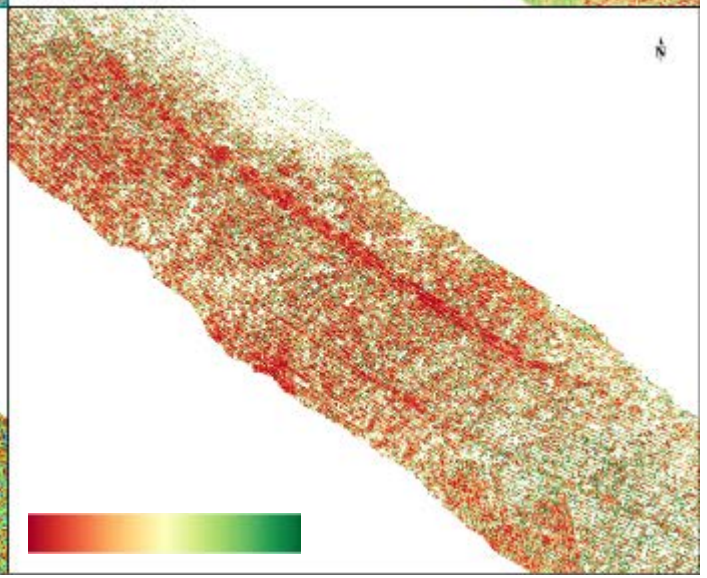




Modified Red Edge NDVI

Water Band Index





Red Green Ratio Index

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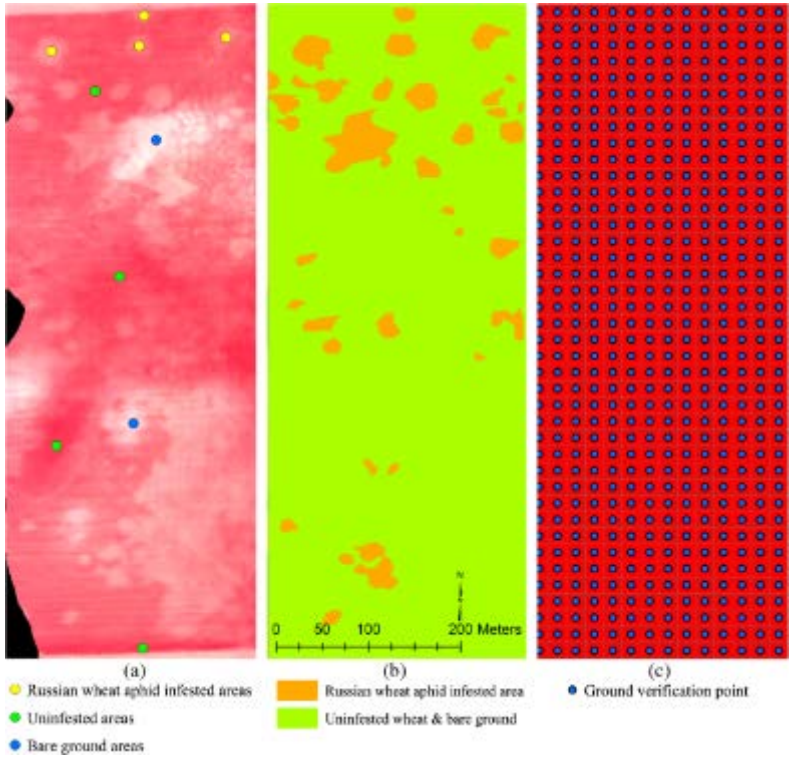
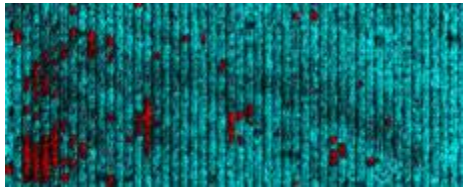
Vegetation Stress Characterization and Detection

- Enables the spectral characterization of the impacts on vegetation of specific stress inducers
- Enables development if custom applications that detect and geo-registers impacts using airborne imagery
  - Actionable information more quickly and economically





Grapevine Leaf Roll Disease

Hyperspectral characterization of known affected foliage → Algorithm development, test and optimization → User application development and validation → User access via existing image data supply chain

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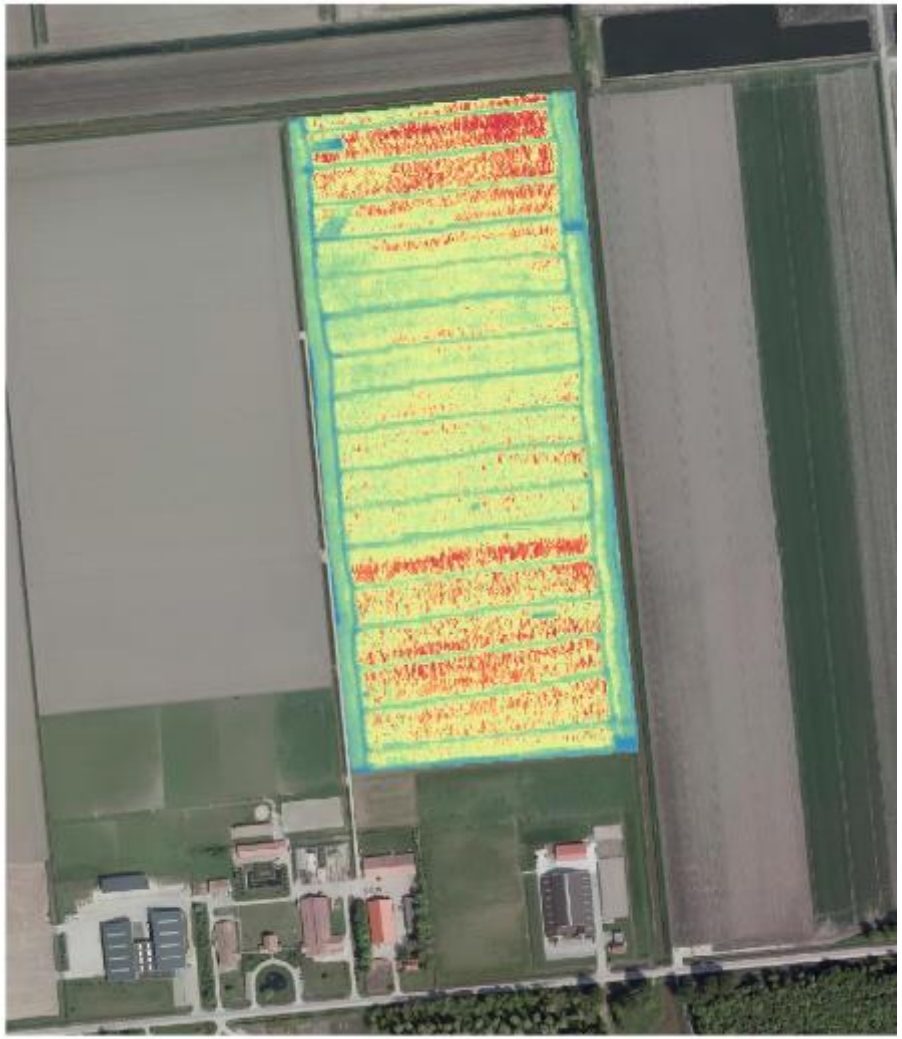
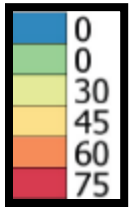
Nitrogen Fertilization Recommendation



Nitrogen Fertilization Recommendation (kg/ha)



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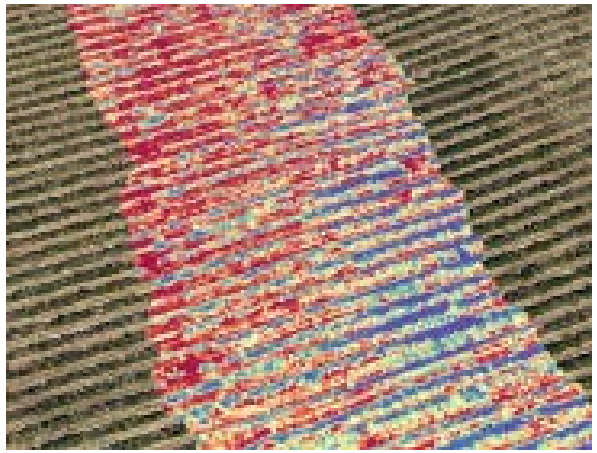
Augmentation/Replacement of Manual Processes

- HSI applications that replicate results obtained using reliable and stable processes that:
  - Are labor intensive
  - Cost of equipment is high
- Successful implementation can significantly reduce operating costs
- Co-develop with University Research Centers
  - Often leveraging grant funding



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Coastal/Lake Environmental Surveys

- 2018-19: Joint Corning Incorporated and State University of New York (SUNY) initiative to detect and analyze harmful algae blooms (HABs) in New York State fresh water lakes
  - Four Corning hyperspectral sensor-equipped small UAS

Golf of Taranto, Italy
7 March 2014

Lake Erie, OH
3 Sep 2011

Long Island, NY
11 Nov 2012

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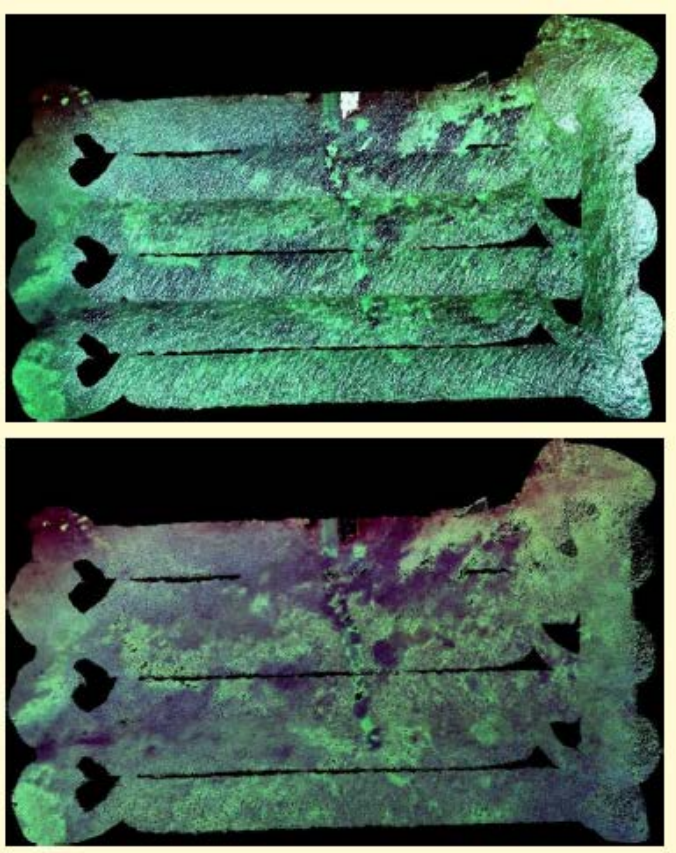
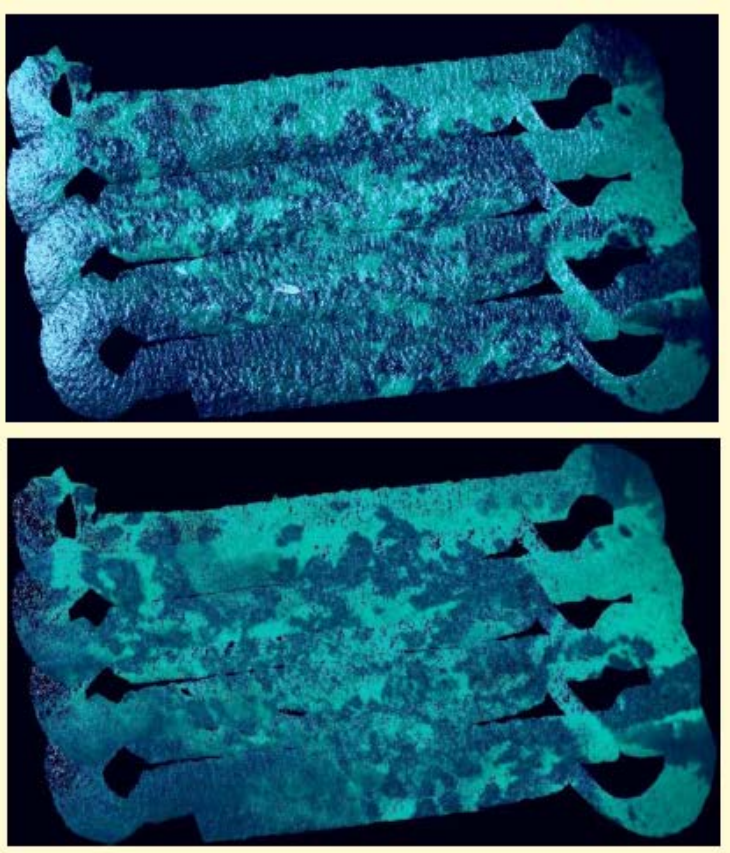
Processed Images With and Without Glint Reduction

- Corning® Hyperspectral System was flown over shallow reef, sea grass in Florida Keys for climate change assessment study
- Platform: rotary wing UAV
- Image processing applied by University of South Florida College of Marine Science



3-band composite image over seagrass study area; lower image used glint reduction algorithm



3-band composite image over Cheeca Rocks coral study area; lower image used glint reduction algorithm

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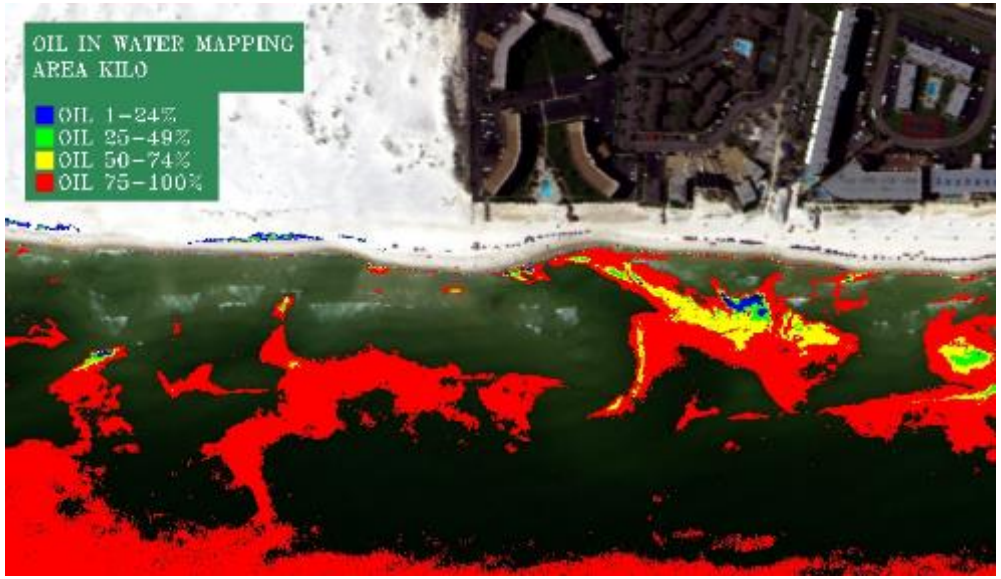
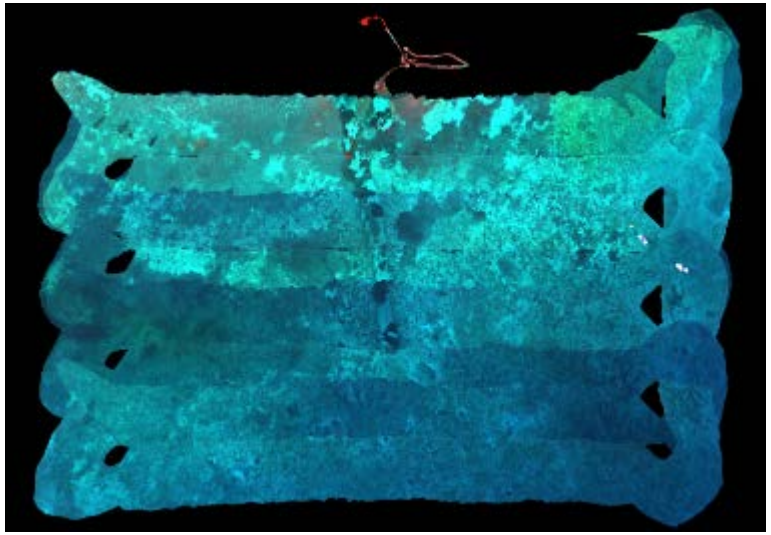
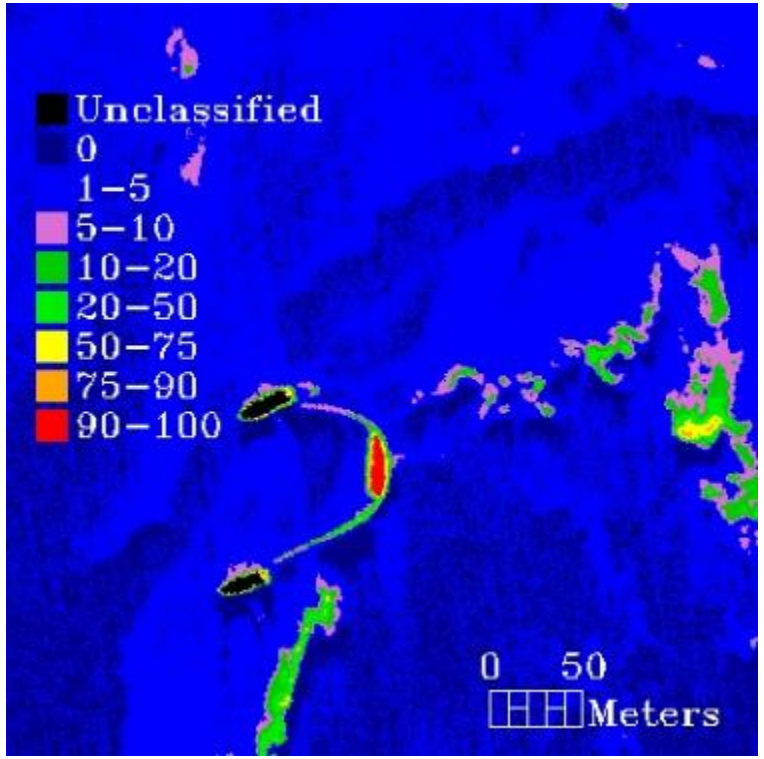
Other Remote Sensing Applications

Coastal Contamination



Monitoring Marine Habitats





Open Water Surface Contamination

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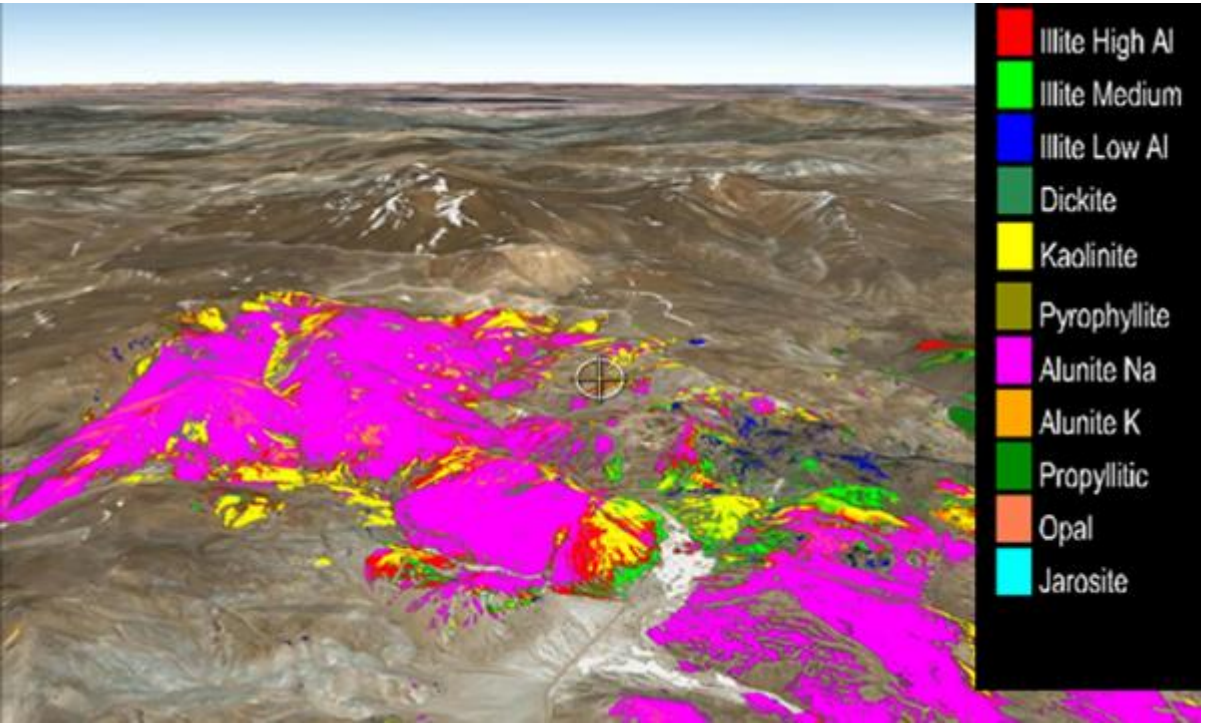
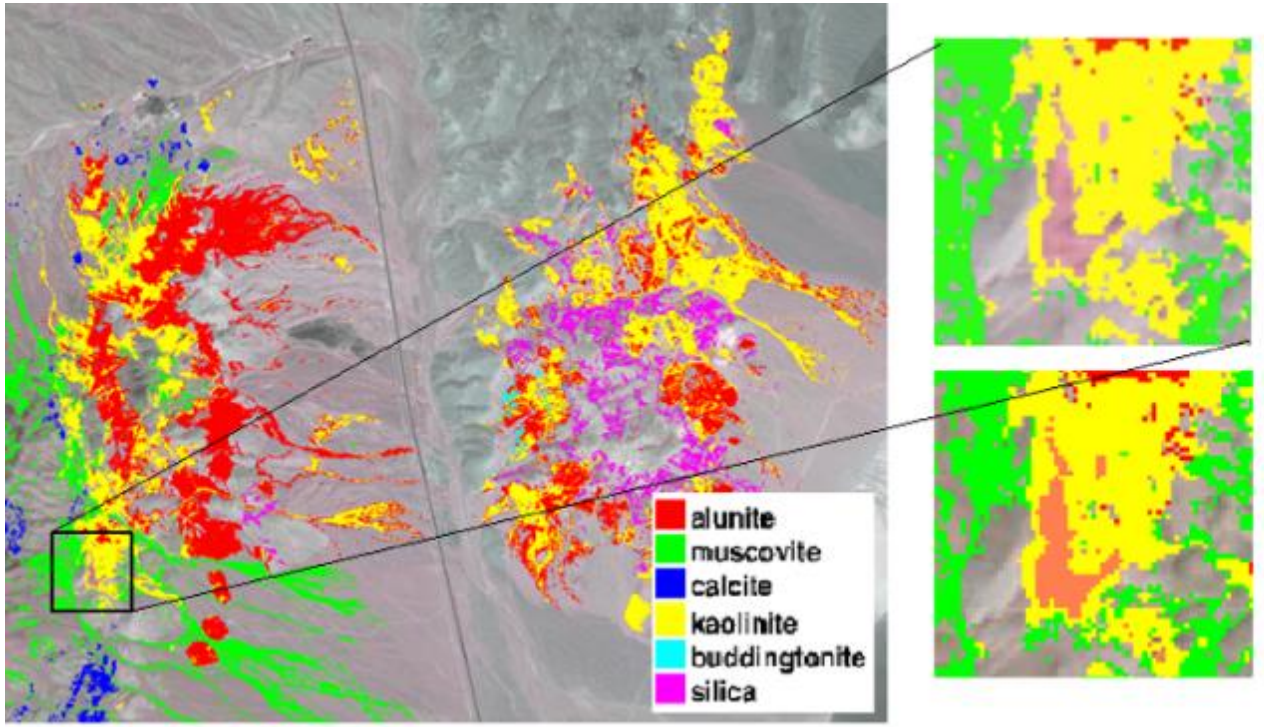
Mineral Exploration and Core Processing





Many minerals have defined spectral response with specific absorption feature(s).

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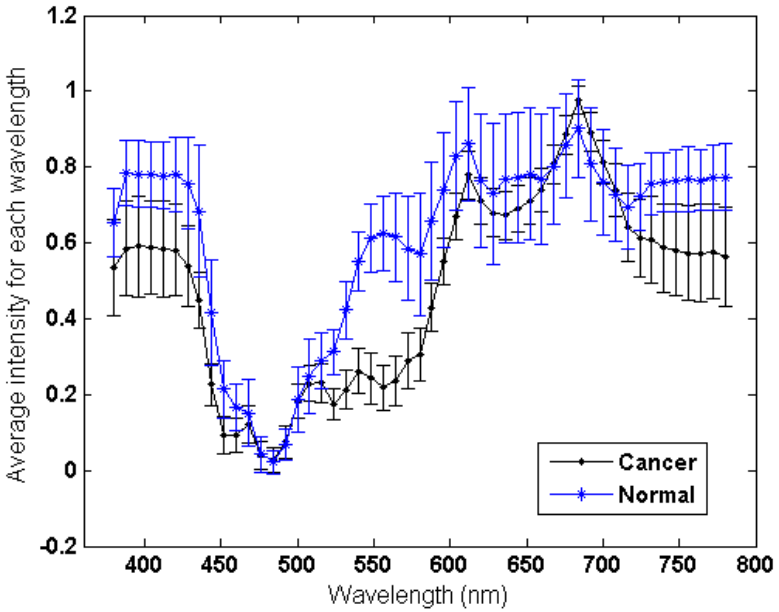
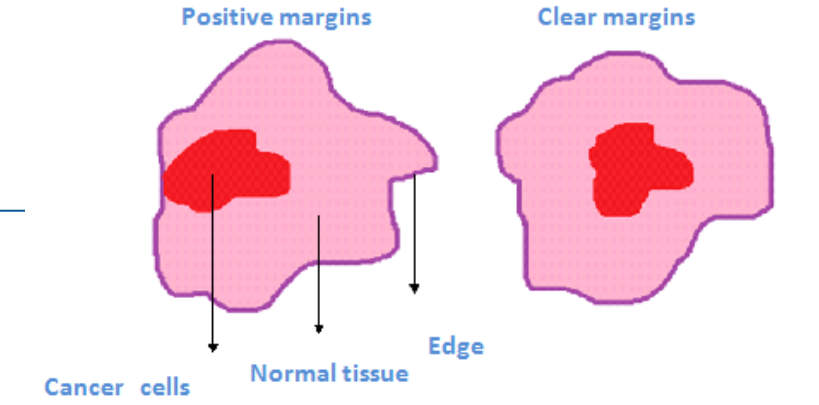
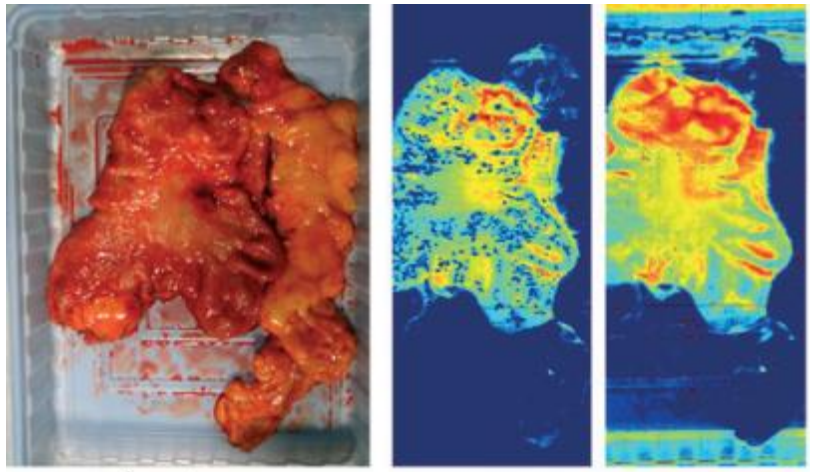
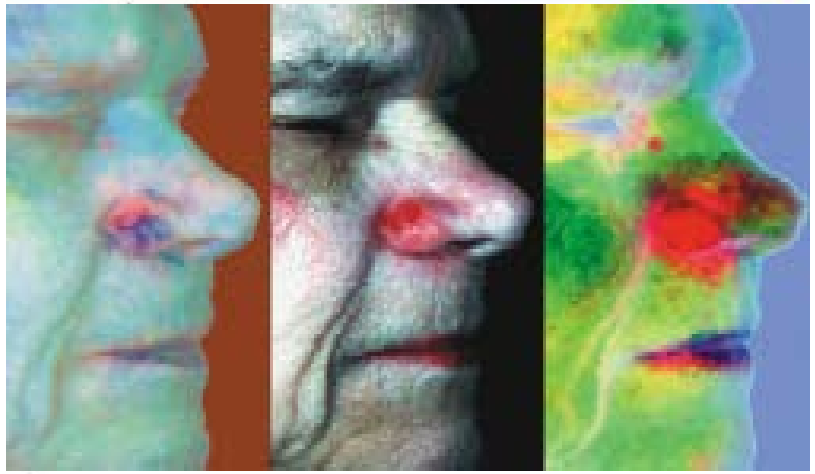
Applications in Health and Medicine

- Cancer detection and comparison with pathological results
- Studies underway for detection of sepsis
  - Positive indications
  - Moving into clinical trials
- Requires exploitation of the entire spectrum, not just selected bands









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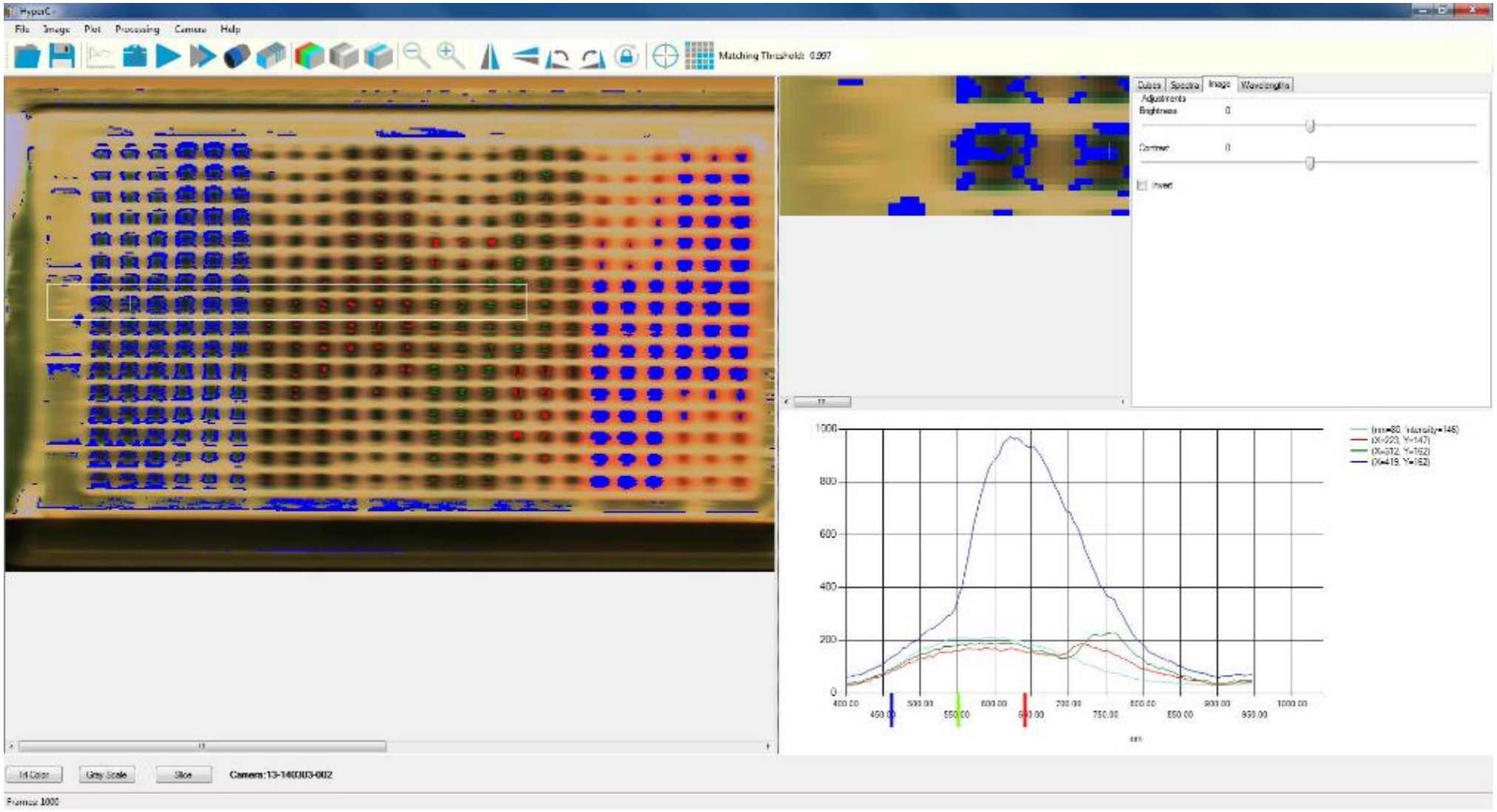
Industrial Processing Applications



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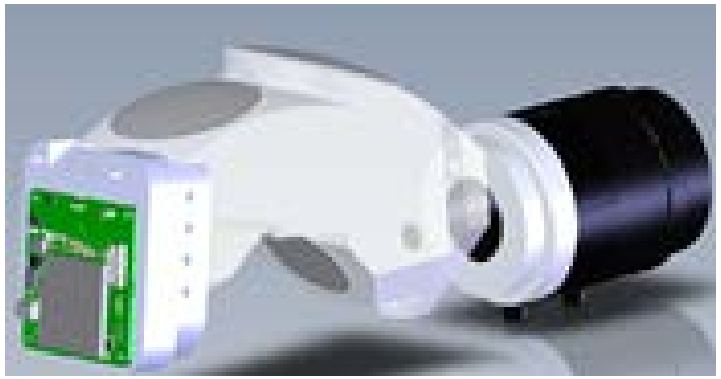
Corning® microHSI™ 410 Family of Products

Spectrometer Core

Spectrometer Sub-Assembly



410 Sensor

Selectable Hyperspectral
Airborne Remote Sensing Kit (SHARK)

410 Application Development Kit
(ADK)

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Corning ® microHSI™ 410 SHARK

Airborne Hyperspectral Imaging (HSI) System

- ✓Smallest, lightest, lowest cost fully integrated airborne hyperspectral imaging system
  - ✓Sensor, lens, INS/GPS, microprocessor control and data acquisition/storage
  - ✓1.5 lbs (680 grams)
- ✓Web interface for system management and control
- ✓1 TB internal recording capacity for min. 60 minute recording time; expandable via eSATA port
- ✓Flexible data management
  - ✓Capture and record full hyperspectral data cube
  - ✓Record only the bands needed to produce deliverable data products
- ✓API enables integration into air vehicle command and control
- ✓Imagery is plug-and-play compatible with ENVI image processing software and web-based image processing services that have ENVI readers

microHSI™ 410 SHARK

microHSI™ 410 SHARK integrated with DJI™ Matrice 100

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Introduction to Corning® MicroHSI™ 425 Sensor

- World's first commercially available hyperspectral sensor covering entire visible range through extended short wave infrared range from 400nm to 2500nm in a single high spatial resolution (640 spatial pixels) sensor
  - One focal plane array
  - One optical path
  - 460 spectral bands
- Lower size, weight and power than two sensor configuration
  - 2.4 kg (5.3 lb), 35 watts
- Eliminates need for precise alignment of focal length and field-of-view of two sensors, and a more complicated mechanical and electrical integration

microHSI™ 425 Sensor

False color image from microHSI™ 425 Sensor

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