Compact visible to extended-SWIR hyperspectral sensor for Unmanned Aircraft Systems (UAS)

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International Diffuse Reflectance Conference 2018
August 2, 2018

Spectral Sciences, Inc.

WHAT WE DO

- Electro Optical Sensors and Imagers
- Geospatial Systems and Remote Sensing
- Gas Dynamics and Signatures
- Environment and Space Physics
- Applied Nanoscience

OUR CAPABILITIES

- Physics-based modeling
- Concept analysis
- System & experiment design
- Prototype development & testing
- Trade studies to facilitate customer decision-making & product development
- Collaboration & licensing opportunities are available for software, hardware technologies, or customer specific solutions

SSI Hyperspectral Imaging Systems

0.35-2.5µm

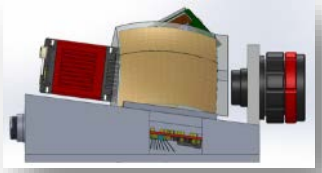
UV/VIS/SWIR UAS–based HSI for carbon cycle monitoring (DOE Phase II)

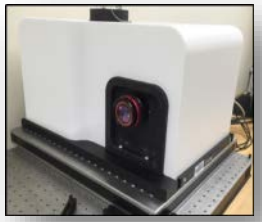
Technology: *miniaturized classic pushbroom imager, automated processing.*

0.85-1.7µm

CONDOR NIR/SWIR Multifunction Multi-mission portable sensor (DOD Phase II)

Technology: *miniaturized* ***staring*** *spectral imager with* ***both spectral and temporal capabilities.***





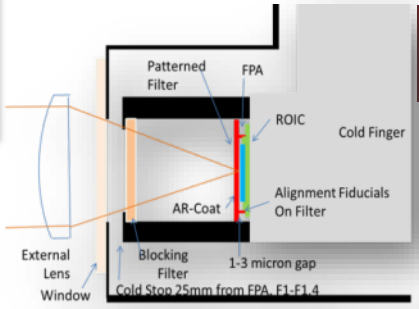
1.2-2.4µm

BLAST SWIR HSI/HTI Battlefield Surveillance sensor (DOD Phase II)

Technology: *spaceborne staring spectral imager with* ***both spectral and temporal capabilities*** *for synergistic spectra/temporal early warning surveillance.*

7.8-13µm

hypertemporal/hyperspectral *sensor designs and algorithms provide an entirely new dimension to information collection*



SAFIRE-based LWIR snapshot imager (DOD Phase II)

Technology: *ultrafast* ***single-shot*** *miniaturized thermal HSI with no moving parts using 2D array of filters at the focal plane.*

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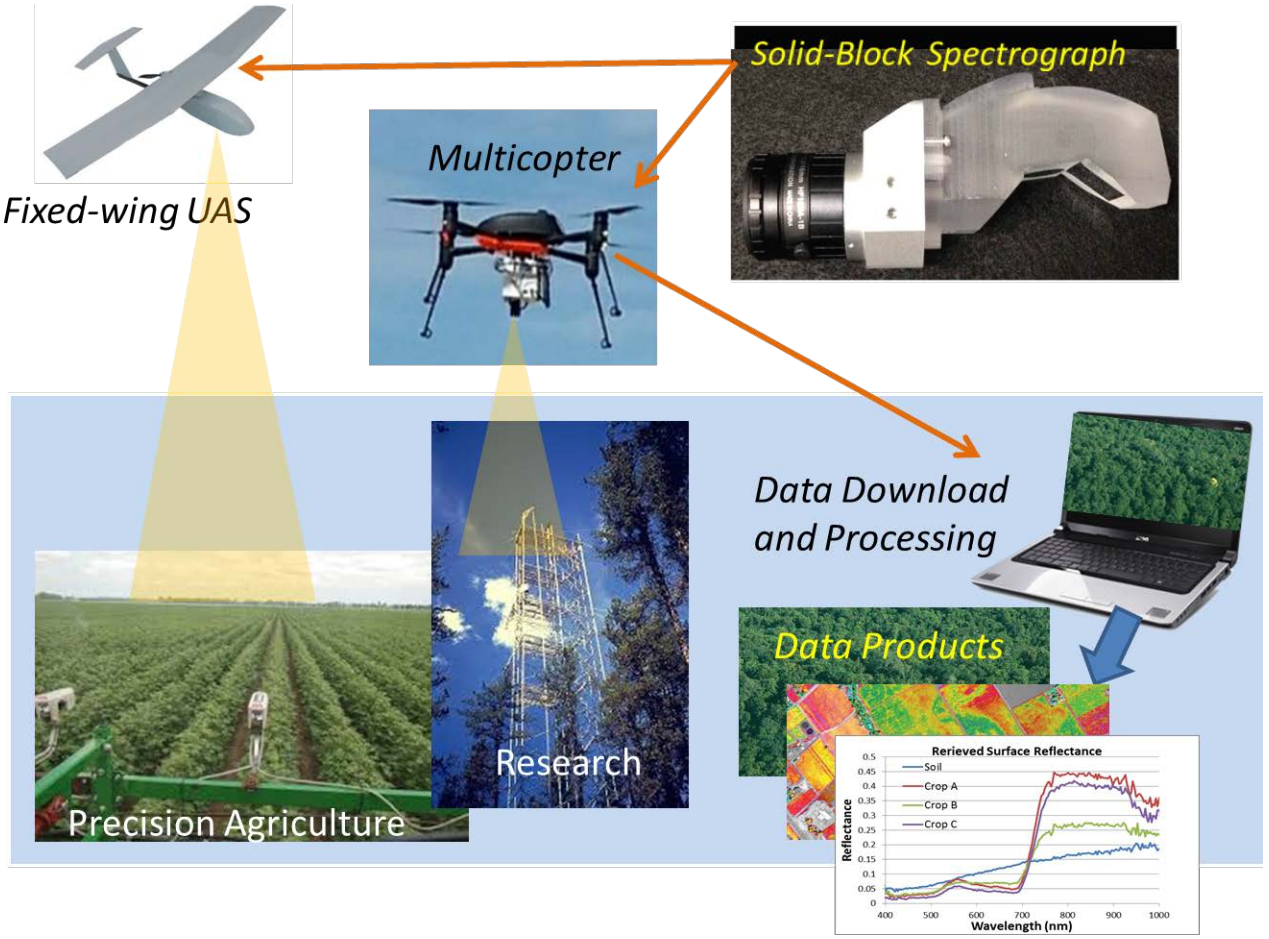
Overview

- Design and build sensor
- Enable mapping of vegetative state and carbon sequestration at the landscape scale
- Correlate HSI signatures from the leaf scale to landscape scale

Collaboration with Shawn Serbin of DOE Brookhaven National Laboratories



Measurements in instrumented test fields in Summer 2019

Financial support from DOE under SBIR Contact No. DE-SC0015126, Daniel Stover Program Manager

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Compact Ready-to-fly Extended Vis/SWIR HSI Sensor for UAS Applications

- Based on Corning microHSI™ 410 SHARK Vis/NIR sensor
  - Complete flight package
  - Will be sold as the Corning microHSI™ 425 Shark
- New 0.4-2.5 µm monolithic spectrograph and telescope
  - F/1.5
  - 640 x 460 (spatial x spectral) channels
  - 4.7 nm spectral bin
- Mount on UAS
  - 2.4 kg
- Application for vegetative state monitoring
  - Extended SWIR adds capability for vegetative mass, foliar nitrogen, water content, etc.

Corning's microHSI™ 410 SHARK

Mock-up of 425 SHARK mounted on DJI Matrice-600 hexa-copter

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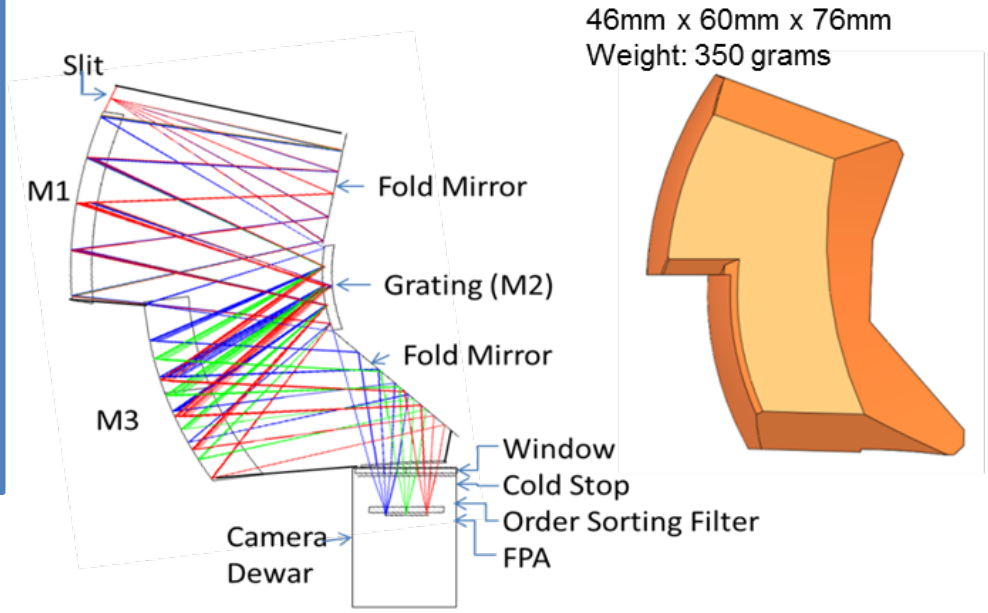
Enabling Technology: Monolithic Spectrograph

- Diamond-machined from a solid block
- Higher NA and SNR due to high index medium (f/1.5)
- Mechanically and thermally stable
- Non-spherical optics
- High mechanical tolerances
- Minimal alignment
- Corning's advanced manufacturing techniques allow volume production at low cost



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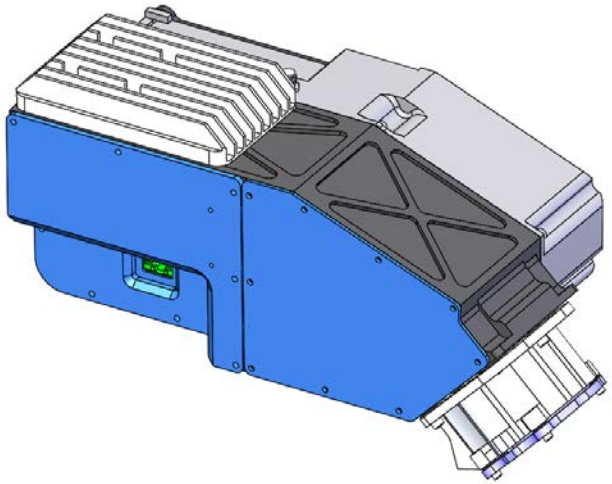
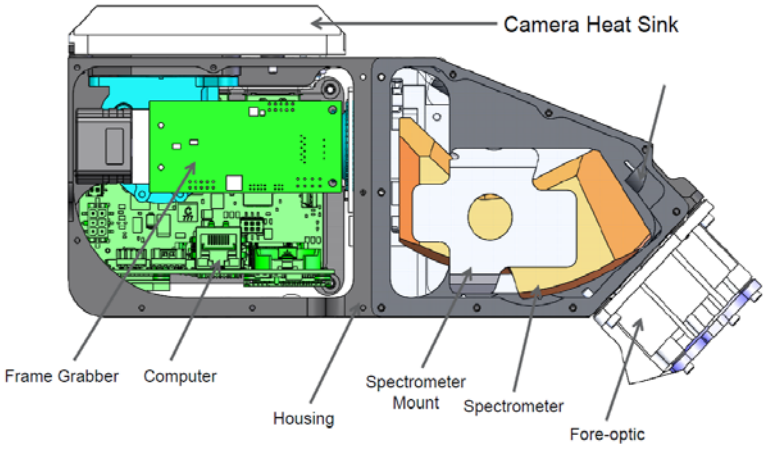
Shark Flight Package

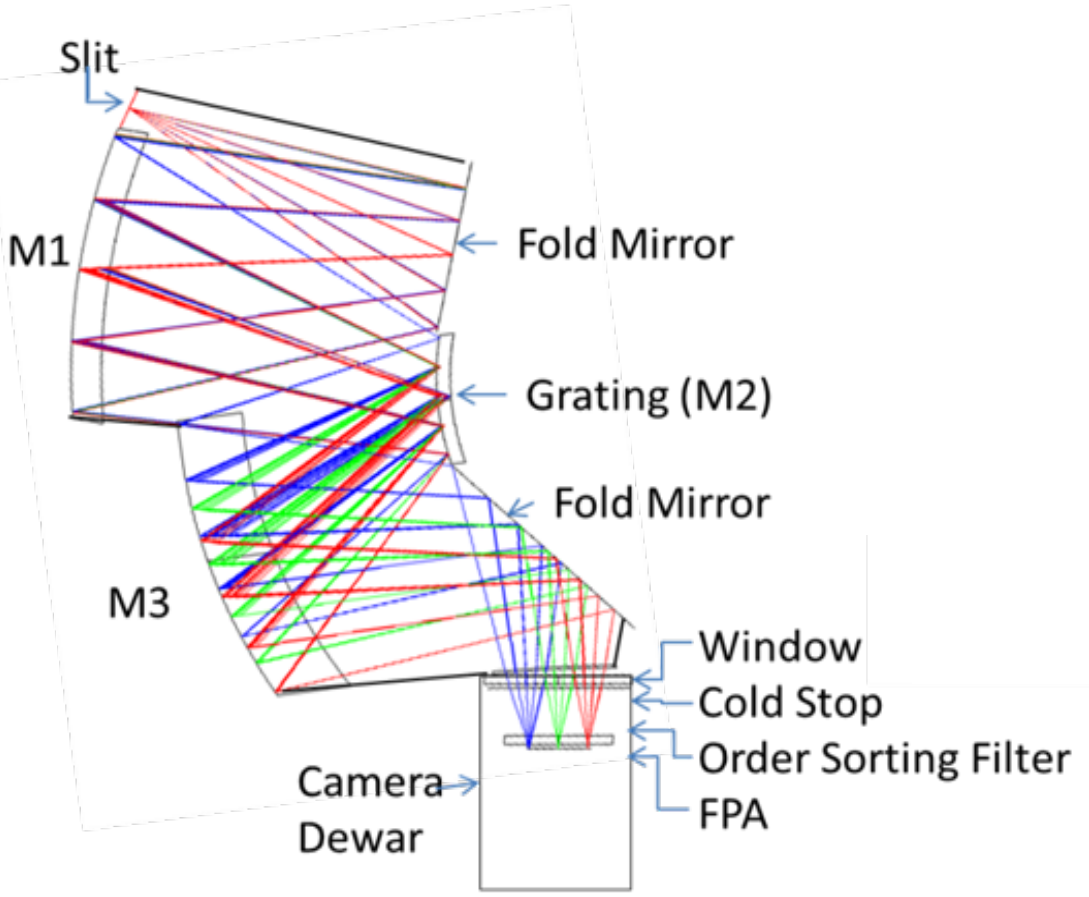




- Integrated Package
  - Spectrograph
  - Telescope
  - Camera
  - Inertial Navigation System
  - Data logger
- Self-contained, simple operator interface
- Mounts on UAS for push-broom mode operation

Extended SWIR Spectrograph 0.4-2.45 um

- Offner Spectrograph
  - CaF_2 block
  - F/1.5
  - Folded path
  - 3 powered mirrors
    - Non-spherical
  - Double-blazed grating
- Visible –to extended SWIR camera
  - 640 spatial x 460 spectral bands
  - Cryo-cooled
  - Large well depth (1.6 Me-) and low noise allows high SNR
- Order sorting filter in Dewar



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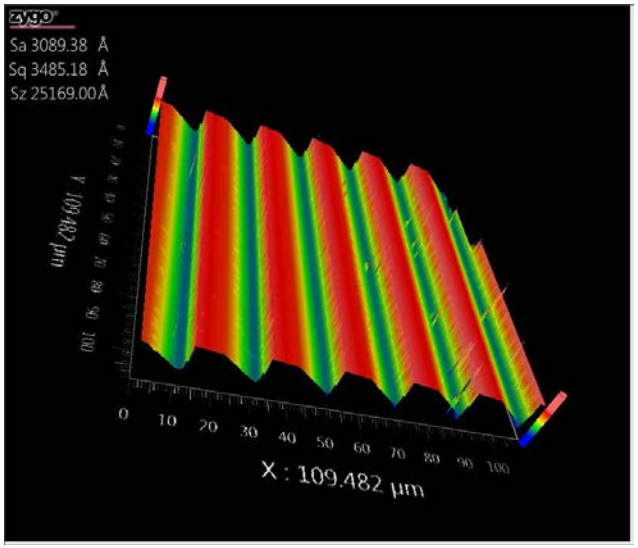
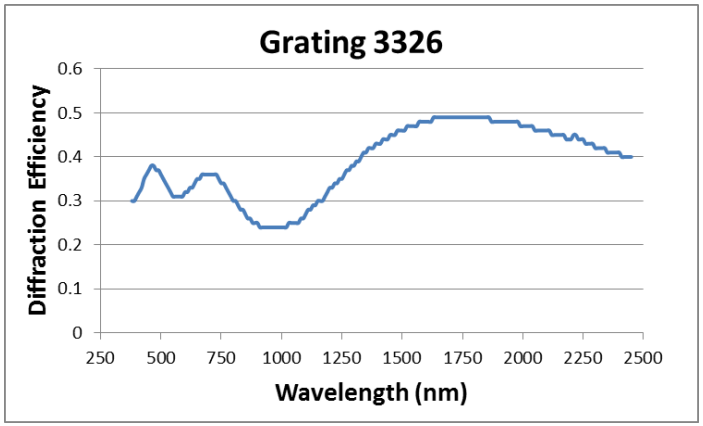
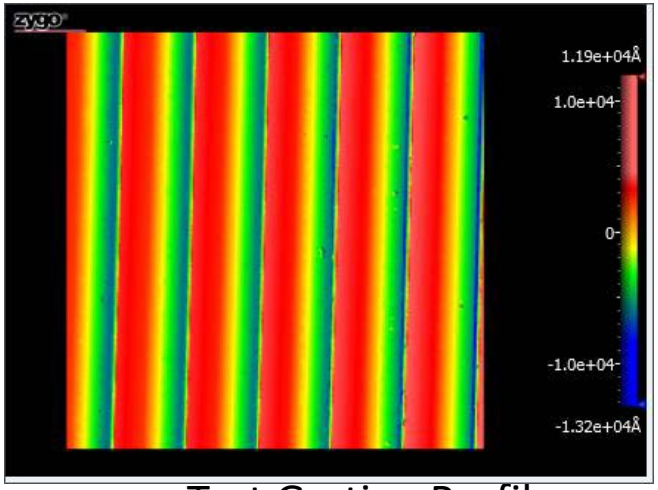
Dual Blazed Grating

- Very large spectral range 0.4-2.45 µm
  - Double blaze necessary to cover full range
- High throughput
  - Optimized for SWIR and UV to match solar radiance
  - Evens out dynamic range for daylight conditions
- Diamond machined
  - Excellent surface quality





Grating Transmission



Test Grating Profile

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Ziph-Schatzberg, L., B. Swartz, C. Warren, J. Santman, M. Saleh, R. Wiggins, J. Crifasi, L. Comstock, and K. Taylor, "Hyperspectral Grating Optimization and Manufacturing Considerations," SPIE Vol. 9482 (2015).

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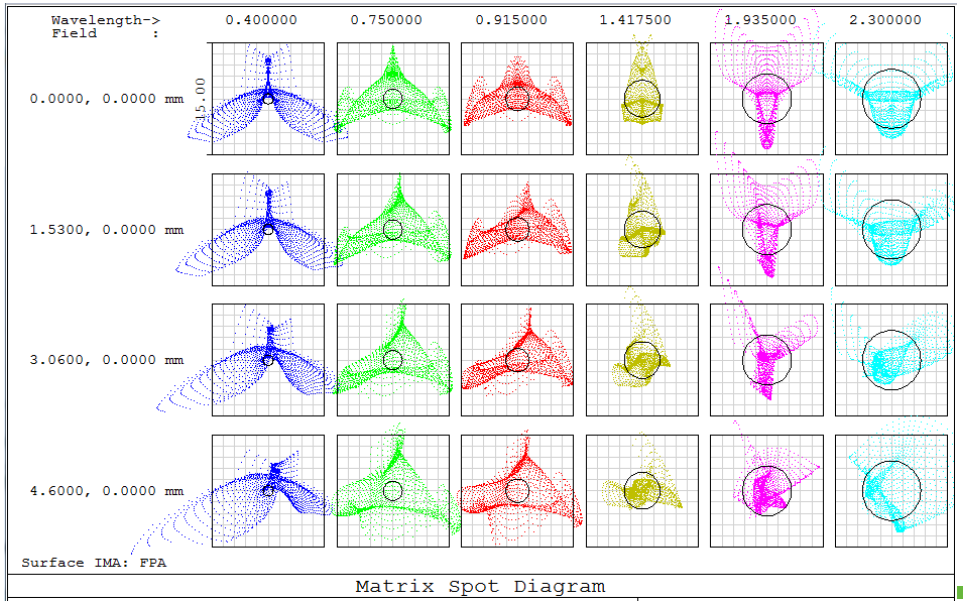
Sensor Performance

- Good image quality
  - Sub-pixel image spots
  - Minimal distortion
- High resolution
  - 640x460
- High speed
  - 100 Hz



MicroHSI™ 425	Values	UNIT
MCT FPA		
pixel width (spatial)	15	[um]
pixel width (spectral)	15	[um]
Spatial pixels	640	[px]
Spectral pixels	460	[px]
Optical		
NA	0.36	[]
f/#	1.5	[]
focal length	15.5	[mm]
aperture	10.5	mm
Spectral		
λ max	2450	[nm]
λ min	385	[nm]
Δλ	2065	[nm]
Slit length	9.6	[mm]
dispersion	4.6	[nm/px]
dispersion	300	[nm/mm]
spectrum width	6.8	[mm]
Distortion		
Smile	<0.2	[px]
Keystone	<0.2	[px]

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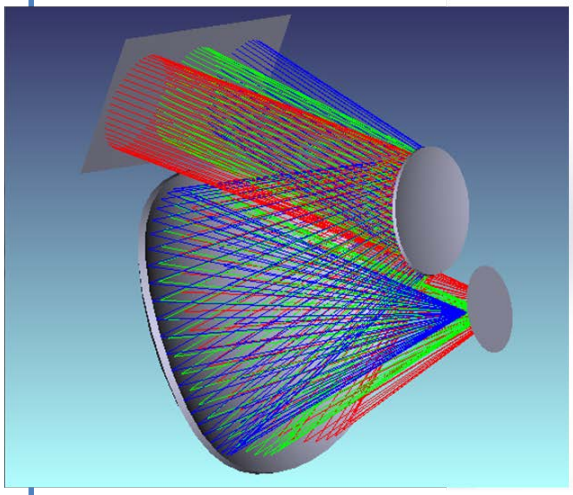
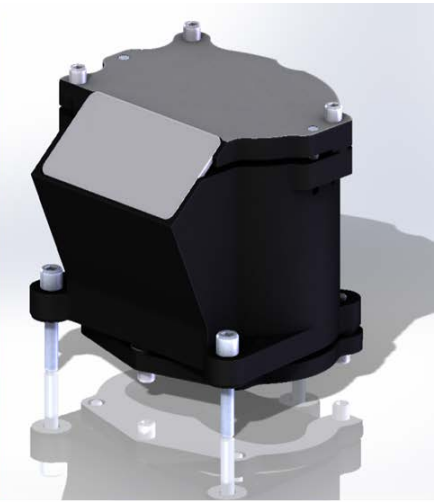
Telescope and GSD

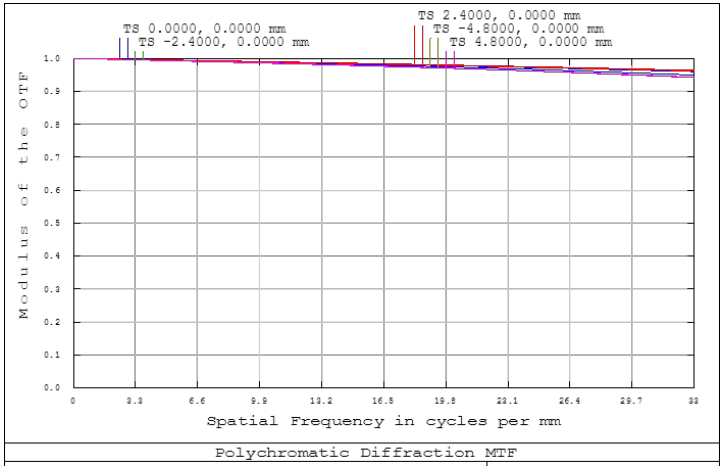
- Reflective optics required to avoid chromatic aberration
- 15 mm telescope for low-altitude use
  - Longer focal length for fixed wing aircraft
- High throughput (f/1.3)
- Large field (9 mm)
- High spatial resolution
  - MTF>0.9
  - Rms spot size <3 μm
- GSD and FOV
  - +/-17° FOV
  - 640 spatial channels
  - 15 cm GSD at 150 M elevation
  - 100 m Swath at 150 M elevation



Ray trace



Housing



MTF

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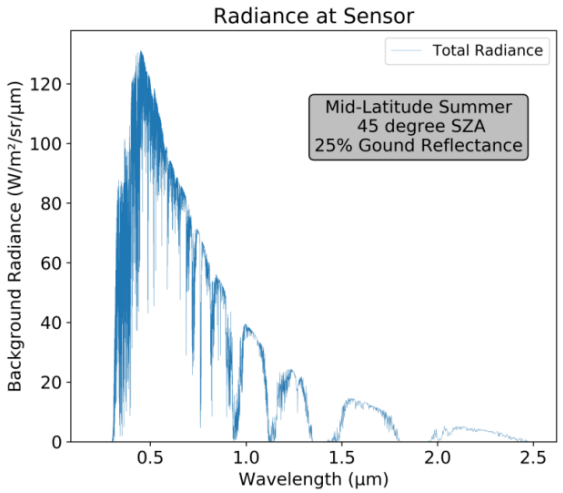
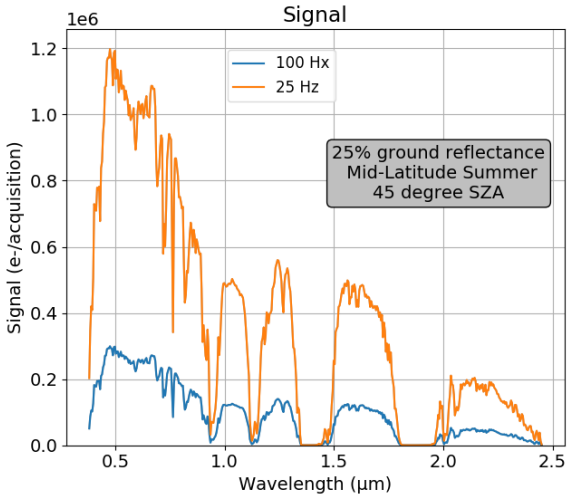
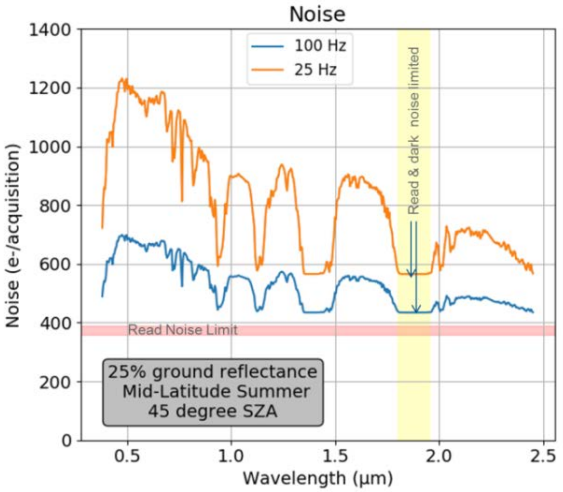
Projected Signal and Noise Performance

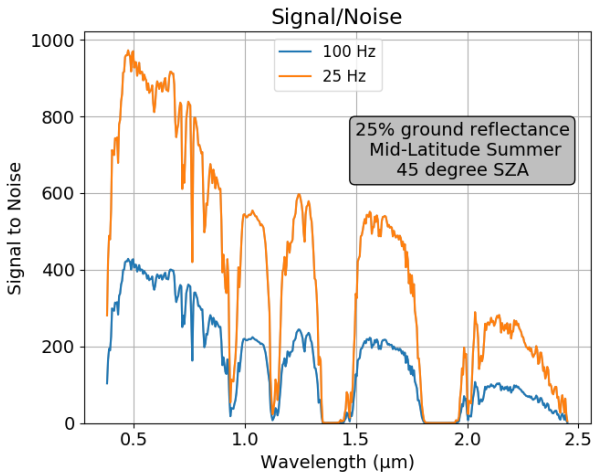
- Standard scene used for SNR specification
  - Radiance at sensor calculated with MODTRAN[R]
- Detailed physical model of sensor
  - Signal and Noise in each spectral band
- High signal levels in all bands
  - Saturates below 25 Hz
- Shot-noise limited through most of visible and SWIR
  - Typical SNR>250:1
  - 500:1 at 25 Hz
- Dark-noise limited above 2 microns
  - Typical SNR>100
  - 200:1 at 25 Hz

High sensor throughput enables high SNR









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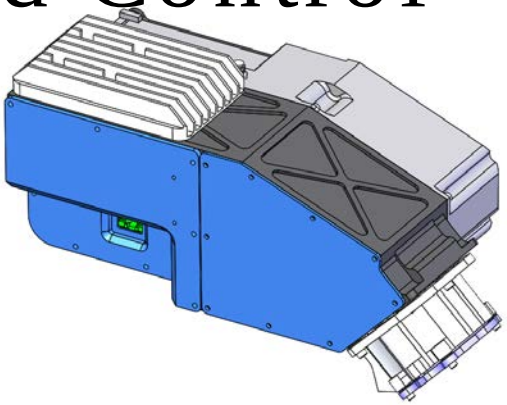
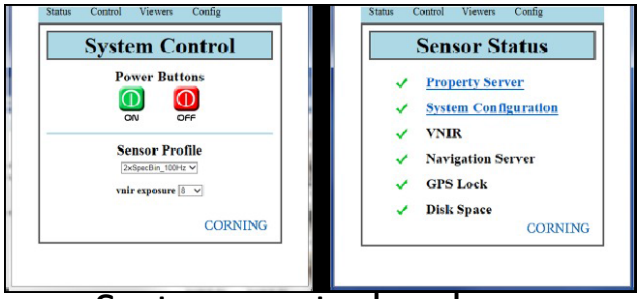
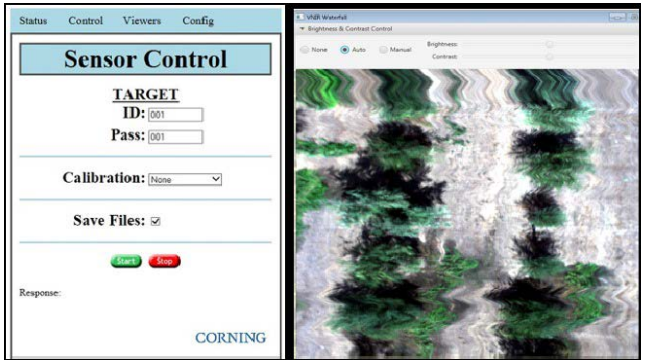
Shark Setup and Control

- Common interface for 410 SHARK and 425 SHARK
- Ethernet interface to web browser
- Setup menus
- Waterfall display
- Data Storage and download





System control web page



Sensor Control web page and waterfall plot

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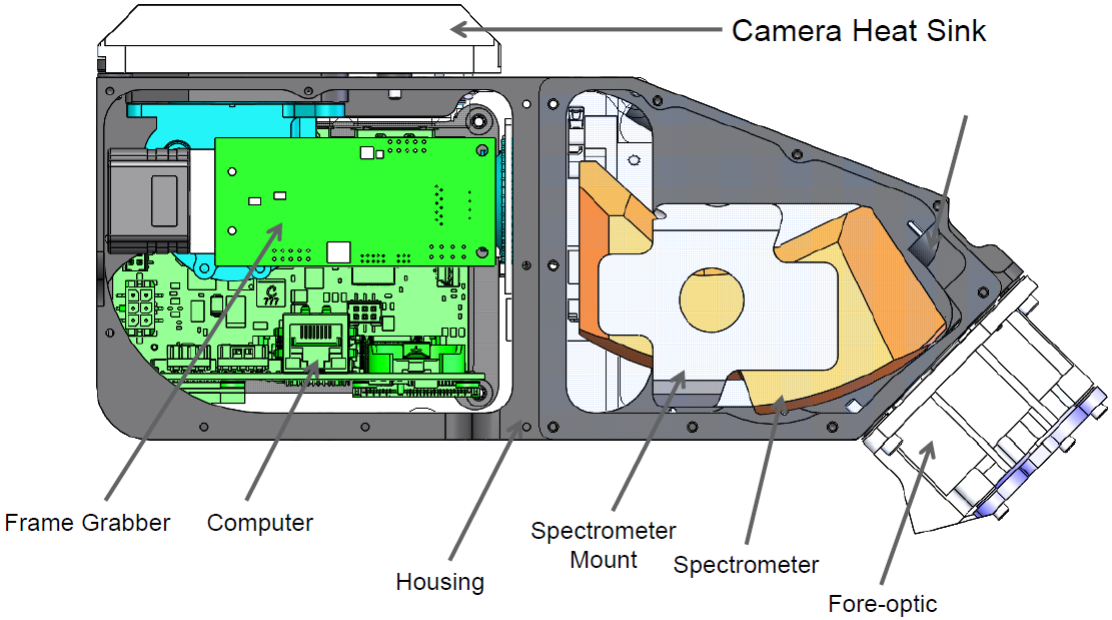
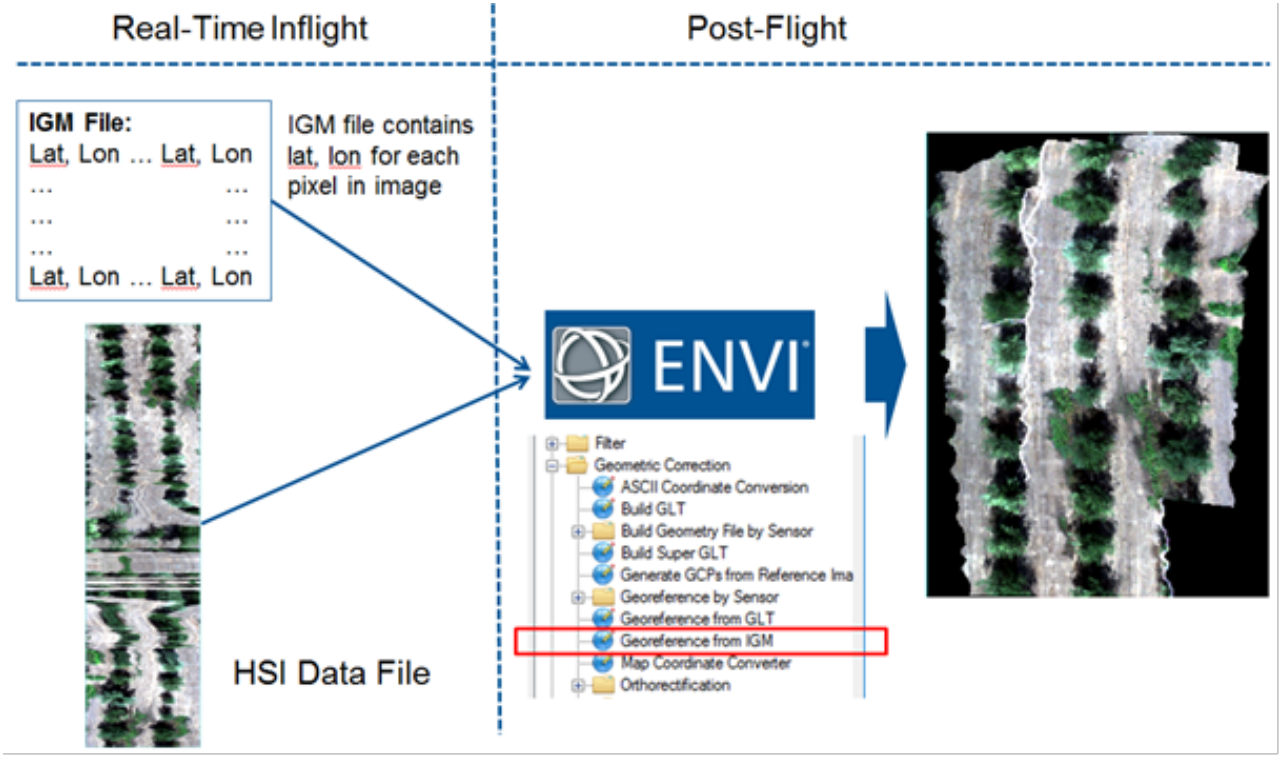
Shark Setup and Control



- Integrated Package
  - Spectrograph
  - Telescope
  - Camera
  - Inertial Navigation System
  - Data logger
- Self-contained, simple operator interface
- Mounts on UAS for push-broom mode operation

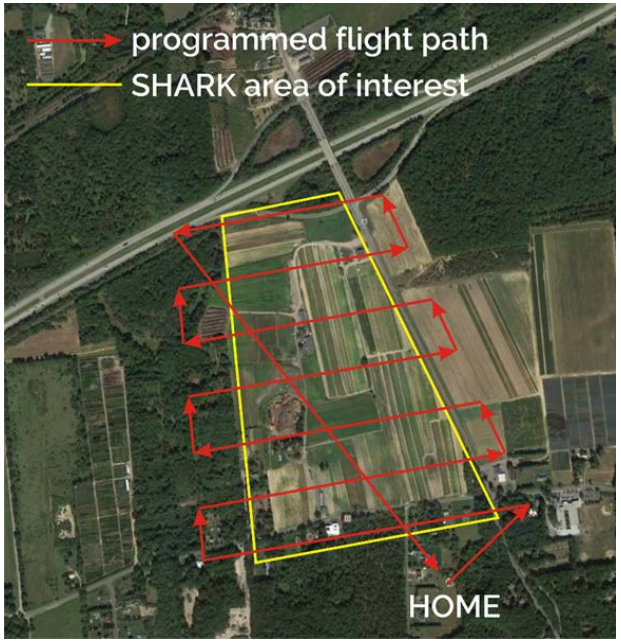
Data Processing

- On board radiometric and spectral calibration
- On board calculation of IGM file
  - Lat. and long. for each pixel
- Download data to PC
- Post-flight processing with ENVI or other tools



Typical Flight Operations

- Program UAS flight path using UAS controller
- Load defined area of interest to SHARK
- SHARK will automatically collect and record data whenever it is within the area of interest



Planned Test Flights over BNNL Research Plots.

Earth Dynamics Research

- Enabling tool for rapid mapping of plant traits & health at landscape scale
  - Potential global coverage
- Collaborate with researchers to develop HSI indicators of carbon content, etc.
- First test flights at BNNL in cooperation with Source/Sink Experiment
  - Instrument test plots
  - Ground Truth
  - HSI data at multiple scales
    - 0.5-15 cm resolution

Key Features

Feature	Advantage
Small size/weight	Light enough to fly on a small UAS (<2.5 kg) .
Broad spectral range	Extended Vis/SWIR spectral range from 380-2450 nm in a single instrument
Mechanically stable design	Sufficiently accurate and reproducible to enable comparison of measurements at different times and locations.
Product family	Many aspects already developed and field tested.

Conclusions

- Compact ready-to-fly VIS x SWIR HSI Package
  - 2.4 kG
  - Class 1 UAS
- Currently in fabrication
- Ready for test flights in 2019
- Monolithic spectrograph machined from solid CaF_2.
  - 0.385-2.45 um
  - 640 spatial channels
  - 460 spectral channels with 4.7nm spacing
- SNR > 250:1 from 0.4-1.8 µm and >100:1 from 2-2.4 µm
- Extension of Corning microHSI™ Shark Product line

Contact Information

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  - **Multiphase Physics and Radiation** – Dr. Jason Cline, jcline@spectral.com
  - **Environmental and Space Physics** – Dr. Raphael Panfili, rpanfili@spectral.com

- **Legal, contracts, IP, NDAs** – Dr. Marsha Fox, VP of Operations mfox@spectral.com