HyspIRI VSWIR Science Measurement and Instrument Concept Baseline

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NRD Decadal Survey

HyspIRI Mission Concept

Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer

Multispectral Thermal InfraRed (TIR) Scanner

IPM Low Latency Data

Map of dominant tree species, Bartlett Forest, NH

Soil C:N Ratio

White Mountain National Forest, NH

Surface Temperature

Evapotranspiration
HyspIRI Measures the Optical Spectrum

HyspIRI VSWIR

HyspIRI TIR

Atmosphere

- Solar 1.0 Reflectance
- Earth 300 K, 1.0 Emisivity

Solar Radiance ($\mu$W/cm$^2$/nm/sr)

Earth Radiance ($\mu$W/cm$^2$/nm/sr)

Wavelength (nm)
HyspIRI VSWIR Decadal Survey Science and Decadal Survey Climate Science

- **Key HyspIRI climate objectives from the Decadal Survey and IPCC**
  - Ecosystem Measurement for Climate Feedback
  - Black Carbon/Dust Effects on Snow and Ice
  - Carbon Release from Biomass Burning
  - Evapotranspiration and Water Use and Availability
  - Critical Volcanic Eruption Parameters

- **Imaging Spectrometer (VSWIR)**
  - Pattern and Spatial Distribution of Ecosystems and their Components
  - Ecosystem Function, Physiology and Seasonal Activity
  - Biogeochemical Cycles
  - Changes in Disturbance Activity
  - Ecosystem and Human Health
  - Earth Surface and Shallow Water Substrate Composition

- **Combined Imaging Spectrometer and Multi-Spectral Thermal Science**
  - Coastal habitats, and inland aquatic environments
  - Wildfires
  - Volcanoes
  - Ecosystem Function and Diversity
  - Land surface composition and change
  - Human Health and Urbanization
Example: Imaging Spectroscopy
Mapping Wetland Dominants 2010 LA

Vegetation mapped cleanly across scene boundaries
- Phragmites (*phau*)
- Spartina alterniflora (*spal*)
- Spartina patens (*sppa*)
- Vigna luteola (*vilu*)

D. Roberts, UCSB
Spectroscopy for Species/Functional-type, Biogeochemistry and Physiological Condition

PLSR weighting for foliar Nitrogen

Measuring spectral shift from Lignin : Cellulose ratio

PLSR wavelength selection for one species

Chi a & b
Surface Compositional Derived with Imaging Spectrometer Measurements

Cuprite, Nevada
AVIRIS 1995 Data
USGS
Clark & Swayze
Tetraedron 3.3 product

Surface:
- K-Alunite 150c
- K-Alunite 250c
- K-Alunite 450c
- NaAl-Alunite 100c
- NaAl-Alunite 400c
- Jarosite
- Alunite + Kaolinite and/or Muscovite
- Kaolinite group clays
- Kaolinite, and/or
- Kaolinite, pfi
- Kaolinite + smectite or muscovite
- Halloysite
- Dickite
- Calcite
- Calcite + Kaolinite
- Calcite + montmorillonite
- Clay:
  - Na-Montmorillonite
  - Montmorillonite (Fe clay)
  - Iron-Al. muscovite
  - med-Al muscovite
  - high-Al muscovite
- Chlorite + Mus. Mont
- Chlorite
- Buddingtonite
- Chalcedony
- OH-Gts
- Pyrophyllite + kaolinite

Copper Oxide:
- Nanocrystalline
- Hematite
- Fine-grained to medium-grained
- Hematite
- Large-grained hematite
- Iron Hydroxide
  - Goethite
  - amorphous and other iron oxides, hydroxides
- Iron Sulfate
  - Jarosite
- Fe²⁺ minerals
- Fe³⁺ bearing minerals
  - Hematite
  - Fe³⁺ bearing minerals
  - Fe²⁺ bearing minerals: broad absorptions
  - Note Fe²⁺ bearing minerals are mostly muscovite and fahloites

Montmorillonite Swy-1
Muscovite GDS116
Halloysite NMNH 106237
Kaolinite KGa-2
Alunite GDS83

Weighted Fits
0.963
0.996 (Best Fit)
0.892
0.872 (1.5 μm feature = 0.378)
1.000
1.000
0.628
0.320
0.000

Scaled Reflectance

Wavelength (μm)

1.000
0.899
0.872

reflectance

400 700 1000 1300 1600 1900 2200 2500
Wavelength (nm)
What is causing the downwasting and retreat of Himalayan glaciers and elsewhere?

For snow and ice in the Himalaya, increasing temperatures and increasing dust and soot combine in unknown proportions to accelerate melt through their changes in albedo. Imaging Spectroscopy is the only approach that allows us to attribute changes in albedo into effects from temperature and dust/black carbon and at a fine enough spatial resolution that heterogeneous terrain can be resolved. Multi-band sensors such as NPOESS VIIRS have neither capacity.

Required Measurement: Global glacial covered area, full solar spectrum, < 100 m spatial, < 20 days revisit
HyspIRI: Coral, Benthic Composition, and Aquatic Vegetation

Variation in shallow water HyspIRI-type spectral signatures in coral environments.

Variation in HyspIRI-type spectral signatures of floating aquatic vegetation (e.g. Kelp)

Variation in shallow water HyspIRI-type spectral signatures in seagrass beds and benthic habitat materials

Emergent vegetation signatures are well suited to the HyspIRI measurement. For example mapping in the Gulf of Mexico coastal region with AVIRIS measurements.
HyspIRI VSWIR Science Measurements

HyspIRI is a global mission, measuring land and shallow aquatic habitats at 60 meters and deep oceans and ice sheets at 1km every 19 days (VSWIR).

HyspIRI’ s VSWIR imaging spectrometer directly measures the full solar reflected spectrum of the Earth from 380 – 2500nm at 10 nm.
HyspIRI VSWIR SNR and Uniformity Characteristics

Benchmark Radiances

- 0.01 reflectance (z45)
- 0.05 reflectance (z45)
- 0.25 reflectance (z23.5)
- 0.50 reflectance (z23.5)

Wavelength (nm)

Signal-to-Noise Ratio

- SNR 0.01 Reflectance (z45) 60m
- SNR 0.05 Reflectance (z45) 60m
- SNR 0.25 Reflectance (z23.5) 60m
- SNR 0.50 Reflectance (z23.5) 60m

Wavelength (nm)

Uniformity Requirement

- Spectral Cross-Track
  - >95% cross-track uniformity {<0.5 nm min-max over swath}
- Spectral-IFOV-Variation
  - >95% spectral IFOV uniformity {<5% variation over spectral range}

Depiction
- Grids are the detectors
- Dots are the IFOV centers
- Colors are the wavelengths
Seasonal and Annual Cloud Probability Maps Validate the HyspIRI Coverage Requirements
HyspIRI VSWIR Coverage

- EO-1 Hyperion acquisitions in 10 years. Technology demonstration sampling mission with deep ESTO contribution.

- HyspIRI VSWIR provides complete terrestrial coverage every 19 days.

- It would take Hyperion 100 years to acquire what HyspIRI measures in 1 year.
VSWIR - Instrument Concept

OUTLINE

1. Introduction
2. Key Requirements & Performance
3. VSWIR Concept
4. Technology Readiness & Heritage

HyspIRI – VSWIR

Mass (CBE)  55Kg
Power (Ave.)  41Watts
# Key VSWIR Requirements

<table>
<thead>
<tr>
<th>Spectral</th>
<th>Requirement</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>380 to 2500 nm (solar reflected spectrum)</td>
<td>Demonstrated – AVRIS, MaRS, M3</td>
</tr>
<tr>
<td>Sampling</td>
<td>&lt;= 10 nm {uniform over range}</td>
<td>Demonstrated – MaRS, M3</td>
</tr>
<tr>
<td>Response</td>
<td>&lt;= 13 nm (FWHM) {uniform over range}</td>
<td>Demonstrated – MaRS, M3</td>
</tr>
<tr>
<td>Accuracy</td>
<td>&lt;0.5 nm</td>
<td>Demonstrated – MaRS, M3, CAO-VSWIR</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Radiometric</th>
<th>Requirement</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range &amp; Sampling</td>
<td>0 to 1.5 x benchmark radiance, 14 bits</td>
<td>Demonstrated via analysis and 14 bit ADC bread board electronics</td>
</tr>
<tr>
<td>Accuracy</td>
<td>&gt;95% absolute radiometric, 98% on-orbit reflectance, 99.5% stability</td>
<td>Demonstrated – AVIRIS, MaRS</td>
</tr>
<tr>
<td>Precision (SNR)</td>
<td>See spectral plots at benchmark radiances</td>
<td>Demonstrated via analysis</td>
</tr>
<tr>
<td>Linearity</td>
<td>&gt;99% characterized to 0.1 %</td>
<td>Demonstrated via test, MaRS and CAO-VSWIR</td>
</tr>
<tr>
<td>Polarization</td>
<td>&lt;2% sensitivity, characterized to 0.5 %</td>
<td>Demonstrated via analysis of design and test data on the grating</td>
</tr>
<tr>
<td>Scattered Light</td>
<td>&lt;1:200 characterized to 0.1%</td>
<td>Demonstrated in MaRS and CAO-VSWIR</td>
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</tbody>
</table>
# Key VSWIR Requirements

<table>
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<tr>
<th>Spatial</th>
<th>Requirement</th>
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</tr>
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<tbody>
<tr>
<td>Range</td>
<td>&gt;145 km</td>
<td>Demonstrated by design and analysis (150 km)</td>
</tr>
<tr>
<td>X-track Sampling</td>
<td>&gt;2400</td>
<td>Demonstrated by design and analysis (2500)</td>
</tr>
<tr>
<td>Sampling</td>
<td>&lt;= 60m (Nadir)</td>
<td>Demonstrated by design and analysis</td>
</tr>
<tr>
<td>Response</td>
<td>&lt;= 1.2X sampling (FWHM)</td>
<td>Demonstrated by MaRS and M3</td>
</tr>
<tr>
<td><strong>Uniformity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectral Cross-Track</td>
<td>&gt;95% cross-track uniformity {&lt;0.5 nm min-max over swath}</td>
<td>Demonstrated by MaRS and M3</td>
</tr>
<tr>
<td>Spectral-IFOV-Variation</td>
<td>&gt;95% spectral IFOV uniformity {&lt;5% variation over spectral range}</td>
<td>Demonstrated by MaRS and M3</td>
</tr>
<tr>
<td><strong>Other Key</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data rate</td>
<td>~ 300 Mbits per second</td>
<td>Met by preliminary architecture and parts selection – all required parts are at or above TRL 6</td>
</tr>
<tr>
<td>Compression</td>
<td>3:1 lossless</td>
<td>Met by algorithm test on MaRS data. Algorithms implemented in breadboard electronics and flight FPGA</td>
</tr>
<tr>
<td>Pointing Knowledge</td>
<td>60m radius (3σ)</td>
<td>Met by analysis and the use of ground tie points</td>
</tr>
<tr>
<td>Mass</td>
<td>&lt;55 kg</td>
<td>Met by current design with 30% margin – working to increase margin</td>
</tr>
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Instrument Approach

- **Selected: Offner spectrometer (Hyperion, CRISM, M3, ARTEMIS, COMPASS\textsuperscript{air}, NG\textsuperscript{air})**
  - Full range from 380 to 2500 nm demonstrated. Efficiency for high SNR optimized with multiple blaze grating demonstrated. Uniformity from design through alignment demonstrated. Snapshot acquisition detector. Dispersion efficiency tunable to optimize use of detector.

- **Prism dispersion spectrometer**
  - Dispersion is non-uniform. Cross-track and spectral-IFOV uniformity not inherent in optical design. Dispersion efficiency not tunable in detail to optimize use of detector full well.

- **Wedge/Linear-variable filter spectrometer**
  - Full spectral range coverage from 380 to 2500 nm has not been demonstrated maintaining 10 nm spectral sampling and response function. Filter uniformity is a concern over wide spectral and spatial domain. Fast, high throughput, beams interplay with filter spectral bandpass undermines uniformity.

- **Fourier Transform Spectrometer**
  - Dispersion is non constant with wavelength. Not typically built to operate below 1 micron. Detector dynamic range and photon shot noise concern. Architecture for > 2000 cross track elements and >200 spectral channels not identified. Not well suited for wide or moderate field of view. Requires IMC.

- **Liquid Crystal Tunable & Acousto-Optical Tunable**
  - Time sequential acquisition undermines uniformity. Low TRL, polarization sensitive. Limited spectral range. Requires IMC.
**HyspIRI VSWIR Concept**

**Optics**
- **Front End Telescope**
  - Consists of a primary spherical mirror and a secondary aspherical mirror
- **Back End Spectrometers**
  - Consist of 2 optimized Offner spectrometers

**Spectrometers (2x)**
- 2 identical Offner spectrometers
- Each contains:
  - E-Beam grating
  - Si air slits
  - FPA assembly

**Radiator**
- Area 0.6m²
- M3 technology heritage

**Baffle/Cover/Cal Panel**
- Launch cover
- Used as a solar reflectance calibration target
- Hyperion Heritage

**Electronics**
- M3 Derivative 4x
- Electronic concept is based upon available flight approved parts
- Ins. control, Data Compression, mode control

**FP A (2x)**
- Mount is adjustable in 6 DOF
- Thermal strap connects mount to radiator
- Includes integral OSF

**Detectors**
- Teledyne 6604b detectors, scaled from 6604a detectors flown on M3
- Analog output
- Each spectrum readout as snapshot, so that there is no time delay, yaw, or jitter impact to the spectral-IFOV-uniformity.
Concept Technologies are Proven
Work Continues to Lower Risk

1) Uniform Offner spectrometer (Mouroulis Design)

2) Finely adjustable optics and detector mounts that can be locked within fraction of a micron (0.1 microns)

3) Electron beam fabricated gratings (large ruling period)

4) Electron beam fabricated air slits (non-uniformity < .05 microns)

5) Alignment and calibration sources and methodologies to achieve and verify requirements.
The HyspIRI VSWIR Concept Enables the Full Set of Decadal Survey Science and Science Applications and Climate Science

- Key HyspIRI climate objectives from the Decadal Survey and IPCC
  - Ecosystem Measurement for Climate Feedback
  - Black Carbon/Dust Effects on Snow and Ice
  - Carbon Release from Biomass Burning
  - Evapotranspiration and Water Use and Availability
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*Imaging Spectrometer (VSWIR)*
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*Combined Imaging Spectrometer and Multi-Spectral Thermal Science*
- Coastal habitats, and inland aquatic environments
- Wildfires
- Volcanoes
- Ecosystem Function and Diversity
- Land surface composition and change
- Human Health and Urbanization
Questions?
Backup
1) Uniform Offner spectrometer (Mouroulis Design)

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