Characterization and Performance of the Prototype HyspIRI-TIR (PHyTIR) Sensor

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Outline

• HyspIRI Background
  • ECOSTRESS
  • Instrument Design
• Instrument Performance
  • Initial Testing Results
  • Concluding Remarks
HyspIRI Background

Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer + Multispectral Thermal InfraRed (TIR) Scanner

VSWIR: Plant Physiology and Function Types (PPFT)

Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH

Red tide algal bloom in Monterey Bay, CA
Science Questions:

TQ1. Volcanoes/Earthquakes (MA,FF)
– How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

TQ2. Wildfires (LG,DR)
– What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

TQ3. Water Use and Availability, (MA,RA)
– How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?

TQ4. Urbanization/Human Health, (DQ,GG)
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

TQ5. Earth surface composition and change, (AP,JC)
– What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

Measurement:

• 7 bands between 7.5-12 µm and 1 band at 4 µm
• 60 m resolution, 5 days revisit
• Global land and shallow water

Multispectral Scanner

Schedule: 4 year phase A-D, 3 years operations

High Heritage

http://hyspiri.jpl.nasa.gov

Andean volcano heats up

Urbanization

Volcanoes

Water Use and Availability

Surface Temperature

Evapotranspiration
ECOSTRESS

ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station

**Instrument**
- Leverages functionally-tested PHyTIR space-ready hardware developed under the NASA Instrument Incubator Program:
  - Spectral resolution: 5 bands in the thermal infrared window (8-12.5 μm) part of the electromagnetic spectrum
  - Noise equivalent delta temperature: ≤ 0.1 K
  - Spatial resolution: 38 m x 57 m
  - Swath width: 384 km (51°)
- Well understood measurement and algorithms based on prior missions, such as ASTER, MODIS, and Landsat

**Science Data Products**
- L0: Raw data
- L1: Radiometrically corrected Brightness Temperature
- L2: Surface Temperature and Emissivity
- L3: Evapotranspiration
- L4: Water Use Efficiency, Evaporative Stress Index
# HyspIRI-TIR Science Measurement Requirements

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>BASELINE</th>
<th>SCIENCE REQUIREMENT</th>
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<tbody>
<tr>
<td>Ground Resolution (m)</td>
<td>60</td>
<td>&lt;100</td>
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<tr>
<td>Revisit (days)</td>
<td>5</td>
<td>&lt;6</td>
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<tr>
<td>Noise equivalent delta temperature (K)</td>
<td>0.2</td>
<td>&lt;0.3</td>
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<tr>
<td>Absolute accuracy (K)</td>
<td>0.5</td>
<td>&lt;1</td>
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<td>Saturation – low temperature bands (K)</td>
<td>500</td>
<td>&gt;400</td>
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<tr>
<td>Saturation – high temperature band (K)</td>
<td>1200</td>
<td>&gt;1100</td>
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<td>Overpass time (hh:mm)</td>
<td>10:30am</td>
<td>10-3pm</td>
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<td>Nighttime imaging</td>
<td>Yes</td>
<td>Required</td>
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<tr>
<td>Number of Bands (spectral range: 3 – 12 µm)</td>
<td>8</td>
<td>&gt;=8</td>
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<tr>
<td>Coverage</td>
<td>Land and coastal regions</td>
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<td>Data latency</td>
<td>2 days</td>
<td>&lt; 1 week</td>
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HyspIRI Scan Concept

- 60 m Pixel Footprint at Nadir
- Time-Averaged Science Data Rate 0.020 Gbps
- Assuming 14 bits, 2:1 Compression, 34% Land
- Scan Mirror Rotation Rate 14.2 RPM
- Pixel Dwell Time 32 microseconds
TIR Focal Plane Concept

- MCT Detector Array – 256 elements cross-sweep
- 1 Bandgap to Cover Full Spectral Range
- ≥ 4 Detector Columns per Spectral Channel to Allow Time Delay and Integration (TDI)

- Butcher-Block Filter Assembly
- Baffles to Prevent Crosstalk Between Spectral Channels
- HyspIRI will have 8 filters, PhyTIR demonstration will have 3 filters

- CMOS Read-Out Integrated Circuit (ROIC)
- 32 Analog Output Lines to Enable Necessary Pixel Read Rate

- 60 K Cold Tip of Cryocooler

- JPL now has focal plane detectors and readout electronics.
- Digitization is performed using off-chip ADCs
- TDI performed after digitization
# Focal Plane Readout Architecture

16 x 256 pixels in each spectral band. Only 4 x 256 pixels are read out.

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<tr>
<th>4 µm</th>
<th>7.3 µm</th>
<th>8.3 µm</th>
<th>8.6 µm</th>
<th>9.1 µm</th>
<th>10.5 µm</th>
<th>11.3 µm</th>
<th>12 µm</th>
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<td>Analog MUX</td>
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Optics Design

- Optical Prescription: Three-Mirror Anastigmat Telescope with Scan Mirror

Double-Sided Paddle Wheel Scan Mirror (3 different positions shown):
FPA assembly is analogous to an infrared light trap, since it’s positioned at an intermediate pupil plane.

Full angle reflectance measurement using integrating sphere of paint surface used on cold baffle. Measurement shows good performance for stray light suppression.

Actual unit in PHyTIR.
Halo around each spot due to diamond turned optical polishing

Stray reflections off painted cold box

Butcher block filter glass

Non-sequential ray trace model developed using ABg scattering for optical surfaces and lambertan for painted surfaces. Implemented in FRED (Photon Engineering).

\[
BSDF(\beta - \beta_0) = \frac{A}{B + (\beta - \beta_0)^2} \quad [sr^{-1}]
\]

\[
BSDF = \frac{\sigma}{\pi} \quad [sr^{-1}]
\]
Cold baffling near the focal plane minimizes stray light from adjacent filters.

**Final filter parameters (as delivered, tested at cryogenic temperatures)**

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<th>Wavelength (µm)</th>
<th>Bandwidth (nm)</th>
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<tr>
<td>4.03</td>
<td>60</td>
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<tr>
<td>8.345</td>
<td>310</td>
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<tr>
<td>12.05</td>
<td>444</td>
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</table>
Cold (60K) interference filter assembly + fpa filter baffle (3 filters currently used in PHyTIR).
Entrance telescope baffling

Telescope - Front
NETD of PHyTIR Bands

Noise-Equivalent Temperature Difference with TDI

- 4 microns
- 8 microns
- 12 microns

Scene Temperature (K)

NETD (K)
NETD of PHyTIR Bands – Full Temperature Range

Noise-Equivalent Temperature Difference with TDI

- **NETD (K)**
- **Scene Temperature (K)**

- Red: 4 microns
- Black: 8 microns
- Blue: 12 microns
Enough spatial columns are present to support 4 pixel TDI

8μm channel combinatorial optimization
Solve for the maximum number of pixel per column such that the single pixel NEDT < 0.2°C. It’s expected that 4 pixel TDI will allow ~0.1°C NEDT.
12\(\mu\)m band combinatorial optimization

Solve for the maximum number of pixel per column such that the single pixel NEDT < 0.2\(^\circ\) C. It’s expected that 4 pixel TDI will allow ~0.1\(^\circ\) C NEDT.
System measurement: Saturation Temperature

PHyTIR Saturation Test

Demonstrates that long-wavelength bands (8 and 12 µm in PHyTIR) do not saturate below 480 K, as required.
System measurement: Saturation Temperature

Expected saturation level based on the 6.2 Me- well size was adjusted to 880K for the 4µm channel due to the increased size of the delivered filter bandwidth.
The scan mirror, together with the structural stability, meet the pointing knowledge requirements.
PHyTIR Summary

• PHyTIR currently demonstrates the state-of-the-art in sensor technology.
  A. The detectors and readouts meet all signal-to-noise and speed specifications.
  B. The cold shielding allows the use of ambient temperature optics on the HyspIRI-TIR instrument without impacting instrument performance.
  C. The pointing knowledge does meet the predefined requirements.
  D. The long-wavelength channels do not saturate below 480 K.

• The current design shows no indication of artifacts from stray light in a laboratory environment. An extensive series of tests are planned for further verification/validation.

• Installation on the ISS is expected in 2019.

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