Status of the Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR) for the HyspIRI TIR Instrument Concept

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Washington, DC USA.

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Organization: NASA/Jet Propulsion Laboratory

Outline

- Introduction
- Goals and Objectives
- Design Approach
  - Concept, Optical, Mechanical, Thermal, FPA, Testing
- Summary and Next Steps
**Science Questions:**

- **TQ1. Volcanoes/Earthquakes**
  - How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

- **TQ2. Wildfires**
  - 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**
  - 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**
  - 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**
  - 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

**Andean volcano heats up**

**Urbanization**

**Volcanoes**

**Water Use and Availability**

**Surface Temperature**

**Evapotranspiration**
HyspIRI, HyTES and PHyTIR

Science Risk Reduction

Hyperspectral Infrared Imager (HyspIRI)

Engineering Risk Reduction

Hyperspectral Thermal Emission Spectrometer (HyTES)

Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)

10/18/2012
HyspIRI, HyTES and PHyTIR

Airborne Instruments

<table>
<thead>
<tr>
<th>Airborne Name</th>
<th>TIMS</th>
<th>MASTER</th>
<th>QWEST</th>
<th>HyTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of TIR Bands</td>
<td>6</td>
<td>10</td>
<td>56</td>
<td>256</td>
</tr>
</tbody>
</table>

Spaceborne Instruments (incl. lab prototypes)

<table>
<thead>
<tr>
<th>Spaceborne Name</th>
<th>ASTER</th>
<th>Landsat 8 (LDCM)</th>
<th>PHyTIR</th>
<th>HyspIRI-TIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Year of Operation</td>
<td>1999</td>
<td>2013</td>
<td>2014</td>
<td>2020</td>
</tr>
<tr>
<td>Number of TIR Bands</td>
<td>5</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Swath Width</td>
<td>60 km</td>
<td>185 km</td>
<td>600 km</td>
<td>600 km</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>90m</td>
<td>100 m</td>
<td>60 m</td>
<td>60 m</td>
</tr>
</tbody>
</table>

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# HyspIRI-TIR Science Measurement Requirements

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

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PHyTIR Overall Goal and Objective

• Goal
  – Demonstrate for HyspIRI that:
    • The detectors and readouts meet all signal-to-noise and speed specification.
    • The scan mirror, together with the structural stability, meets the pointing knowledge requirements.
    • The long-wavelength channels do not saturate below 480 K.
    • The cold shielding allows the use of ambient temperature optics on HyspIRI without impacting instrument performance.

• Objective
  – Build the Prototype HyspIRI Thermal Infrared Radiometer. A laboratory demonstration of the performance of the key components HyspIRI.
HyspIRI Scan Concept

- **Spectral Bands**: 8 Spectral Bands x 256 Pixels
- **Distance**: 596 km ±25.5°
- **Resolution**: 256 Pixels ±0.7°
- **Direction of Spacecraft Motion**: Upward
HysPIRI TIR Instrument Block Diagram

MECHANICAL SYSTEM & STRUCTURE

- BRUSHLESS DC MOTOR + ROTARY ENCODER
- SCAN MIRROR
- NADIR
- SPACE VIEW
- BLACKBODY VIEW
- MOTOR SYSTEM CONTROL UNIT
- TEMP MONITORING AND CONTROL UNIT
- HOUSEKEEPING (PRT's)
- COLD HOUSING
- FILTERS
- IR FP + ROIC
- IR FP INTERFACE ELECTRONICS
- PASSIVE COOLER
- FP ASSEMBLY
- THERMAL RADIATOR
- ACTIVE COOLER
- THERMAL SYSTEM CONTROL UNIT
- Xilinx Virtex-5 FPGA
- SCIF / Xilinx VIRTEX-5 FPGA
  - FOCAL PLANE COMMANDS AND CLOCK SIGNALS
  - MOTOR & ENCODER CLOCK SIGNALS
  - CRYOCOOLER VOLTAGES, BIAS AND CLOCKS SIGNALS
  - SPACECRAFT TC/TM & SCIENCE DATA INTERFACES
  - TIME DELAY INTEGRATION (TDI) & DATA COMPRESSION (2:1, LAND VS. OCEAN)
  - TEST INTERFACE

Data Pipeline (LVDS)
- Light Path
- Data, Control, Sensing Path
- Data Pipeline (LVDS)
- Power Lines
- Heat Pipes

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PHyTIR will demonstrate prototypes of key HyspIRI components - optics, scan mirror, and focal-plane, stable structure

Other components will be not be flight like – electronics outside of focal plane, cooling system

Only 3 filter bands will be incorporated into filter assembly (4, 8, and 12 microns)
Double-Sided Paddle Wheel Scan Mirror

(Only 3-mirror positions shown for clarity)

Three-Mirror Anastigmat Telescope

51° NADIR Sweep

PHyTIR will use only 3 of 8 filters.
Optics

Design to best practices. Use non-sequential raytrace program as a verification.

Main Baffles Used on PHyTIR
- E1 (Earth baffle), 295K
- P1 (Primary baffle), 295K
- S1 (Secondary baffle), 295K
- Sp (Space baffle), 295K
- C1 (Cold baffle/stop), 60K
- H1 (Housing baffle), 295K
- FS1 (Field stop baffle), 295K
- Sc (Scan mirror baffle), 295K

Eliminate single bounce ray events to the focal plane (example shown in orange)

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Three custom filters will be deposited on a single ZnSe substrate. The filters should span the passband of HyspIIRI-TIR but do not need to be exact matches to HyspIIRI-TIR bands due to cost limitations.

### HyspIIRI-TIR Bands

<table>
<thead>
<tr>
<th>Filter #</th>
<th>center $\lambda_o$ (µm)</th>
<th>SW10% (µm)</th>
<th>LW10% (µm)</th>
<th>BW (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.982</td>
<td>3.9745</td>
<td>3.9895</td>
<td>0.015</td>
</tr>
<tr>
<td>2</td>
<td>7.35</td>
<td>7.19</td>
<td>7.51</td>
<td>0.320</td>
</tr>
<tr>
<td>3</td>
<td>8.278</td>
<td>8.103</td>
<td>8.453</td>
<td>0.350</td>
</tr>
<tr>
<td>4</td>
<td>8.628</td>
<td>8.453</td>
<td>8.803</td>
<td>0.350</td>
</tr>
<tr>
<td>5</td>
<td>9.074</td>
<td>8.894</td>
<td>9.254</td>
<td>0.360</td>
</tr>
<tr>
<td>6</td>
<td>10.5284</td>
<td>10.2584</td>
<td>10.7984</td>
<td>0.540</td>
</tr>
<tr>
<td>7</td>
<td>11.3284</td>
<td>11.0584</td>
<td>11.5984</td>
<td>0.540</td>
</tr>
<tr>
<td>8</td>
<td>12.046</td>
<td>11.786</td>
<td>12.306</td>
<td>0.520</td>
</tr>
</tbody>
</table>

### PHyTIR Focal Plane Filters

<table>
<thead>
<tr>
<th>$\lambda$ (µm)</th>
<th>$\Delta \lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.015</td>
</tr>
<tr>
<td>8</td>
<td>0.35</td>
</tr>
<tr>
<td>12</td>
<td>0.52</td>
</tr>
</tbody>
</table>
Mechanical

Scan Mirror

M2

M1

Housekeeping connector

Vacuum feed through

Bulkhead

Vacuum side of telescope

FP electr. connector
Mechanical

- Scan Mirror Assembly Cross Section

- Double-sided Al Mirror
- Mirror Shaft
- Interferometric Encoder Scale
- Rotary Encoder
- Flex Coupler
- DC Motor
- Duplex Bearing Pair

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Mechanical

• The Cryocoolers
  Model: Thales Cooler LPT9310

  Cryocooler (for 200degK)
  Cryocooler (for 60degK)
  Cold Housing (top removed to show inside)
  Vacuum Housing (top removed to show inside)
  Bulkhead

Sample Thermal Strap:
Mechanical

- The FP Assembly

FP Electr. Board
FP Mounting Structure
FP Frame
Focal Plane & Filter
6 dof FP Mount (Moore Mount)
Mounting Flexures (Th. isolators)

FP Front Side (FP Baffle not shown)
FP Backside (FP Baffle on)

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Cooling

Wall (left) and top (right) of 200 K baffle in place. Vacuum cover (not shown) encloses cold stage and mirrors.

Bulkhead with cryocooler cold tips: FPA stage shown for orientation

Lower stage of 200 K baffle supports FPA structure, intercepts conducted loads. Baffle is cooled by RH cold tip. FPA is cooled by LH cold tip via strap.
Cooling

- PHyTIR uses two identical Thales 9310 pulse tube coolers
  - 20,000 hour MTTF (2.3 years)
  - Drive electronics will incorporate lab-level active vibration cancellation for the dual opposed pistons, enabling evaluation for future flight potential
- Cooler motor mounted to interface plate, may require vibration isolation (TBD)
- Cooling of motors and cold head flange will be via pumped-fluid loop, simulating heat pipes for HyspIRI

Thales 9310 lift capacity vs temperature
174 W input, 0 C skin temperature

Expected heat lift req’d at 200 K at 60 K

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Focal Plane Concept

- 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

- 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)

- Teledyne under contract to provide focal planes. Contract for external readout electronics in place.
- Digitization in off-chip ADCs
- TDI performed after digitization

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Focal Plane Readout Architecture

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

6 eight-inch wafers have been fabricated and delivered to Teledyne with over 100 dies each. Diced ROICs are ready for hybridization.

Wafer probe station. Wafer has been tested at room temperature and at nearly the required readout speed. Noise and power performance are as expected, as well as register functionality.
Detector Status

- Detectors wafers have been fabricated using ~13.2 micron cutoff MCT material.

- Diced detectors are ready to hybridize.

- Antireflective coating on a test detector shows adequate quantum efficiency.

- Detectors will be hybridized with readout chips in December 2012

![Graph showing quantum efficiency vs. wavelength](image)
FPA Electronics

- Teledyne FPA board contains the ROIC, other passive devices, and SAMTEC connector to get data, control, and supply signals in and out.
- Flex cable is being designed to replicate the performance of an existing SAMTEC cable, but we must use a different conductor to meet thermal performance specifications.
- Teledyne interface board contains SAMTEC connector, test points, voltage regulation circuits, and two 78 pin DSUB connectors to interface with digitization board.
- Teledyne DICE board digitizes ROIC data and generates low-noise biases, clocks, and communication signals for the ROIC.
Performance

Noise-Equivalent Temperature Difference with TDI

NETD (K)

Scene Temperature (K)

- 4 microns
- 8 microns
- 12 microns
Performance – Full Temperature Range

Noise-Equivalent Temperature Difference with TDI

- 4 microns
- 8 microns
- 12 microns
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PHyTIR Test Configuration

- Instrument is in air. Vacuum enclosure around focal-plane is evacuated (to be described in detail in mechanical presentation). Scan mirror rotating.

Room-temperature reference blackbody. Flat plate with corrugated, painted surface. Emissivity <1 acceptable.

Variable-temperature blackbody: room temperature to 500 K. Flat plate with corrugated, blackened surface. Emissivity <1 acceptable.

MCS Target Projector with slit source. Will underfill PHyTIR aperture.

Test Sources Placed Within PhyTIR Scan Range
Summary and Next Steps

• PHyTIR will reduce the risk associated with key aspects of the HyspIRI-TIR performance (signal to noise, pointing, saturation, shielding)

• PHyTIR is on track with all the large procurements in place and delivery of the first detectors expected in December. Key components are already being assembled e.g. scan mirror.

• Next steps will be to assemble the instrument and start testing in mid 2012
Backup
• Instrument w/o Enclosure

Bipods

Yoke

Alignment Cube (Alignment of Telescope Structure by shims and slotted holes)

Scan Mirror Assembly

DICE Electronics

Telescope

Vacuum Enclosure
Mechanical

- Inside the Vacuum Enclosure

Sample Thermal Strap:

Thermal Straps

Cold Housing (top removed to show inside)

Vacuum seal O-Ring groove

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