HYPERCUBE:
Hyperspectral Imaging Using a CUBESAT

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WHO WE ARE

- A technology and innovation leader specializing in defense, homeland security and other government markets throughout the world
- 2010 net sales: $25 billion
- 72,000 employees worldwide
- Headquarters: Waltham, Massachusetts
Raytheon Business Headquarters

- Space and Airborne Systems
  El Segundo, CA
- Integrated Defense Systems
  Tewksbury, MA
- Network Centric Systems
  McKinney, TX
- Missile Systems
  Tucson, AZ
- BD and Raytheon International Operations
  Rosslyn, VA
- Technical Services
  Dulles, VA
- Global Headquarters
  Waltham, MA
- Intelligence and Information Systems
  Garland, TX

72,000 employees; 2010 net sales: $25 billion
Integrated sensing solutions for advanced applications in aviation and space technology

- Tactical Airborne Radars and Processors
- Electronic Warfare Systems
- Intelligence, Surveillance and Reconnaissance
- Integrated Aircraft Solutions
- Civil, National and Military Space Solutions

›› World leader in integrated sensor systems for space and airborne missions
Hyperspectral Imaging

Every Pixel Contains a Complete Spectrum in a Hypercube
Why Hyperspectral Imaging (HSI)?

- Collect Imagery In 100s of spectral bands
- Detects / Quantifies Gases
- Counter CC&D; material ID
- Wide area Automatic Target Cueing reduces Intel analyst load
- Tagging & Tracking
- Single Pixel Detection
- Earth and Atmospheric Science

Materials have unique spectra

Identifying Targets, Materials, & Gases by Chemistry (Not Shape)
Applications of HSI

- Military/Intel
- Geology
- Forestry
- Agriculture
- Mapping/land use, land cover analysis
- Atmospheric analysis
- Environmental monitoring
- Coastal/Ocean
- Many, many others

CubeSat-Scale Hyperspectral Imager for Middle Atmosphere Investigations, Rick Doe et al, 2009 CUBESAT DEVELOPER’S CONFERENCE, SAN LUIS OBISPO, CA
Spatial Heterodyne Spectrometer (SHS)
Very Fine Spectral Resolution
No Moving Parts
Very large pixels
Raytheon Builds “Small” HSI Sensors

ARTEMIS/TACSAT-3

Dual –Band Spectrometer

Payload ~170Kg
Bus ~140Kg

TACSAT-3 Is A “Small Sat” But We Go Much Smaller
Top Level Trades and Drivers

- Can we identify useful missions within CUBESAT and other technological constraints?
- Yes: Many HSI sensors have flown providing Big Science with Small Apertures
## HSI Sensor Parameters

<table>
<thead>
<tr>
<th></th>
<th>Hyperion</th>
<th>Landsat OLI</th>
<th>HYSPIRI*</th>
<th>M3**</th>
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<tbody>
<tr>
<td>SNR (per band)</td>
<td>40-200</td>
<td>~100</td>
<td>300-600</td>
<td>100-400</td>
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<td>Spectral Coverage (microns)</td>
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<td>5%</td>
<td>10%</td>
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<tr>
<td>Radiometric Accuracy (%)</td>
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<tr>
<td>Swath (Km)</td>
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<td>145</td>
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<tr>
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<td>~21</td>
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<td>Aperture (cm)</td>
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<tr>
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<tr>
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<td>12</td>
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<td>Calibration</td>
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<td>OB</td>
<td>OB</td>
<td>Cover</td>
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</table>

* LWIR not included, includes two separate spectrometers
** from 100Km

- **LANDSAT** is multi-spectral, wide swath, continuous recording of changes
- **HYPERION** proved additional utility of HSI
- **M3** found water on the Moon
- **HYSPIRI** is two double sized M3s; heading towards a HyperLANDSAT
## HYPER Sats

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<th>HyperLANDSAT</th>
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<td>&gt;1000</td>
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<td>Avg Power (W)</td>
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<td>200</td>
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<td>15</td>
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<td>Mass (Kg)</td>
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<td>Vicarious</td>
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* LWIR not included, includes two separate spectrometers  
** from 100Km

- HyperLANDSAT is a possible concept requiring only one spectrometer; twice the resolution of HYSPIRI but less SWAP
- HYPERCube can blaze the path
HYPERLandsat Can Be Built Today

Imaging Spectrometer Trade Studies: A Detailed Comparison of the Offner-Chrisp and Reflective Triplet Optical Design Forms, Cook et al, August 2010, San Diego, Vol. 7813


Double Pass Reflective Triplet Spectrometer Is The Enabler
HYPERCUBE Needs

- Small spectrometer
- Low power focal plane assembly and electronics
- Low power/low mass cooling system
- Ability to manage 300+ Mbits/sec
## Compact HSI Cameras By Novosol

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Relative Aperture</td>
<td>f/2.8</td>
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<tr>
<td>Spectral Range</td>
<td>900 – 1700 nm</td>
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<tr>
<td>Spatial Channels</td>
<td>1280</td>
</tr>
<tr>
<td>Channel IFOV</td>
<td>0.205 mrad</td>
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<tr>
<td>Full Field of View (FOV)</td>
<td>15 degrees</td>
</tr>
<tr>
<td>Dispersion/Spectral Channel</td>
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</tr>
<tr>
<td>Integration Time</td>
<td>12 ms max.</td>
</tr>
<tr>
<td>A/D Digitization</td>
<td>13 bits</td>
</tr>
<tr>
<td>Read Noise</td>
<td>110 electrons</td>
</tr>
<tr>
<td>FPA Detector</td>
<td>InGaAs</td>
</tr>
<tr>
<td>Size</td>
<td>11” x 5.9” x 3.2”</td>
</tr>
<tr>
<td>Weight</td>
<td>6 lbs.</td>
</tr>
<tr>
<td>Power</td>
<td>15W</td>
</tr>
</tbody>
</table>

Sensor Dimensions 4.8” x 3.6” x 2.5” w/Lens
Weight 1.2 lb. (0.54 kg) w/Lens Power < 3.3 W @ 12 VDC

*Miniaturization of a VNIR hyperspectral imager*
Key Parameters for HYPERCUBE

- Get closer to target to reduce aperture
  - 8.75 cm ap, F/4
  - 35 cm focal length,

- Match LANDSAT
  - 241 revs in 16 days; 15.0625 revs/day, 95.6 min orbit (525), i=97.5
  - 525 Km altitude

- 30 m Ground Sample Distance (GSD)
  - Pitch =20 um, nadir GSD
  - 250 Hz

- Extend HSI capability beyond HYPERION
  - 200 colors, 640 pixels
  - Data rate at 12 bits is 384 Mbits/sec
  - 20 minute collect is 461 Gbits (58 GB)

- Limit on-board hardware, but can use Vicarious Calibration
Enabling Technologies

USB 3.0 3-5 Gbits/sec transfer on Amazon

Super Talent RAID Drive 128 GB USB 3.0 Flash Drive
STU28GSRK (Black)
Buy new: $503.74

Transcend 500 GB 2.5-Inch USB 3.0 Military-Grade Shock Resistance Portable External Hard Drive for Mac and PC $90.66

Raytheon SB339 SWIR HSI: High-performance Solutions for Hyperspectral Imaging Applications

Raytheon Small-Scale Cryocooler
Space and Long Life Tactical Cryogenic Cooling Solutions
Summary

- HSI can provide unique science capabilities

- HSI provides BIG SCIENCE with small apertures

- CUBESATs may be able to host HSI payloads with few or no modifications; HYPERCUBE can blaze path to Hyperspectral LANDSAT mission

- Enabling (non-space qualified) technologies available to support HYPERCUBE mission