REMI - Reduced Envelope Multi-Spectral Imager for Sustained Land Imaging

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LandSat: An Early & Enduring Earth Observation Mission
Landsat Data are Widely Distributed for Use in Science Research and Applications

Top Ten Landsat Data Usages
(10/01/2017 through 03/31/2017)

- Fire science/management: 4.9%
- Land use/land cover change: 24.2%
- Climate science/change: 6.6%
- Education: university/college: 6.2%
- Agriculture forecasting: 7.2%
- Water resources: 7.3%
- Ecological/ecosystem science/monitoring: 8.5%
- Forest science/management: 8.9%
- Software development: 21.2%
- Biodiversity conservation: 5.1%

376 Abstracts for 2016 AGU Fall Meeting
5,270 entries in Google Scholar for 2017

https://landsat.usgs.gov/top-ten-uses
The goals of the SLI-T program are to research, develop, and demonstrate new measurement technologies that improve upon the Nation’s current land imaging capabilities while at the same time reducing the overall program cost for future SLI measurements.

The SLI-T program seeks to:
- Reduce the risk, cost, size, volume, mass, and development time for the next generation SLI instruments, while still meeting or exceeding the current land imaging program capabilities;
- Improve the temporal, spatial, and spectral resolution of SLI measurements; and
- Enable new SLI measurements that can improve the program’s operational efficiency and reduce the overall costs of the Nation’s land imaging capabilities.
Landsat 8/9 Top Level Architecture

## Landsat 8 Space Segment - Sensors

<table>
<thead>
<tr>
<th>Parameter</th>
<th>OLI</th>
<th>TIRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (kg)</td>
<td>470</td>
<td>236</td>
</tr>
<tr>
<td>Envelope Vol. (m³)</td>
<td>6.5</td>
<td>2.0</td>
</tr>
<tr>
<td>GSD (m)</td>
<td>30 (15 PAN)</td>
<td>100</td>
</tr>
<tr>
<td>Sensor Type</td>
<td>Pushbroom</td>
<td>Pushbroom</td>
</tr>
<tr>
<td>X-track Angular FOV (°)</td>
<td>15 (185 km)</td>
<td>15 (185 km)</td>
</tr>
<tr>
<td>Wavelength (mm)</td>
<td>0.4–2.4</td>
<td>10–13</td>
</tr>
<tr>
<td>FPA</td>
<td>SiPIN (VNIR), HgCdTe (SWIR)</td>
<td>QWIP (Thermal), Actively cryo-cooled</td>
</tr>
<tr>
<td>Primary Calibration</td>
<td>On-board solar diffuser</td>
<td>On-board blackbody</td>
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</table>

### LandSat 8 - $975 M

<table>
<thead>
<tr>
<th>Segment</th>
<th>Price</th>
<th>% of Mission</th>
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<tbody>
<tr>
<td>Space</td>
<td>$555.1M</td>
<td>56.9%</td>
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<tr>
<td>Launch</td>
<td>$157.1M</td>
<td>16.1%</td>
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<tr>
<td>Ground / Ops</td>
<td>$184.3M</td>
<td>18.9%</td>
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<tr>
<td>Mgmt</td>
<td>$78.2M</td>
<td>8.1%</td>
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<tr>
<td>Total</td>
<td>$974.7M</td>
<td>100%</td>
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REMI Design Concept Guided by NASA/USGS Architecture Studies

What is an Architecture?
- Payload
- Spacecraft
- Launch
- Technology Infusion Plan
- Mission Risk Class
- Org Partnerships
- Procurement Approach

Architecture Trade Space

- 8 Day Repeat, Average Availability (0 to 100%)
- 16 Day Repeat, Average Availability (50% to 100%)

Options:
- Combined Aperture, Wide-Swath Inst
- TIRS FF with Sentinel-2
- LandSat 8-like Sats w/ New Sensors
- Disaggregated VSWIR & TIR

Future Small Sats
Scan Approach Opens the Design Space

- **Whisk Broom**: LandSat 1-7
- **Push Broom**: LandSat 8 & 9
- **Step-Stare with Image Motion Correction**: SLI-T/REMI

*Comparison of three different scan methodologies: Whisk Broom, Push Broom, and Step-Stare.*
Performance Model Developed to Guide Design Trades

MODEL INPUTS
- System Reqs
- Detector Physics Model
- Spectral Radiance
- Optical Throughput
- Scan Mechanism
  - Step / Settle
- Flight Parameters
  - Alt / Velocity
- Stray Light

MODEL OUTPUTS
- Performance against Key Reqs
- Design Parameters
- Edge Response Extent
- Optical Setup: Focal Length
- Edge Response Slope
- Optical Setup: Aperture Diameter
- SNR
- Detector Integration Time
- Aliasing
- Filter Sizes
- FOR
- Pixel Binning

FOR Pixel Binning
## Derivation of REMI Reqs from SLIT RMA

<table>
<thead>
<tr>
<th>Band #</th>
<th>Band Name</th>
<th>Nominal GSD (m)</th>
<th>Min Edge Slope (m⁻¹)</th>
<th>Min Edge Slope (µrad⁻¹)</th>
<th>Max Half Edge Extent (m)</th>
<th>Max Half Edge Extent (µrad)</th>
<th>Nominal GSD¹ (m)</th>
<th>Predicted GSD (m)</th>
<th>Equivalent GSD¹ (m)</th>
<th>Min Edge Slope² (m⁻¹)</th>
<th>Min Edge Slope² (µrad⁻¹)</th>
<th>Max Half Edge Extent² (m)</th>
<th>Max Half Edge Extent² (µrad)</th>
<th>Max Aliasing⁴</th>
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<td>0.027</td>
<td>0.0190</td>
<td>23.0</td>
<td>32.6</td>
<td>0.168</td>
<td>0.069</td>
<td>12.1</td>
<td>4.7588</td>
<td>0.0190</td>
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<td>32.6</td>
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<td>2</td>
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<td>0.027</td>
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<td>32.6</td>
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<td>0.069</td>
<td>12.1</td>
<td>4.7588</td>
<td>0.0190</td>
<td>0.13</td>
<td>32.6</td>
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<td>0.0190</td>
<td>23.0</td>
<td>32.6</td>
<td>0.168</td>
<td>0.069</td>
<td>12.1</td>
<td>4.7588</td>
<td>0.0190</td>
<td>0.13</td>
<td>32.6</td>
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<td>0.0190</td>
<td>23.5</td>
<td>33.3</td>
<td>0.168</td>
<td>0.069</td>
<td>12.1</td>
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<td>33.3</td>
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<tr>
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<td>0.027</td>
<td>0.0190</td>
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<td>34.0</td>
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<td>12.1</td>
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<td>0.14</td>
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<tr>
<td>6</td>
<td>SWIR 1</td>
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<td>28.0</td>
<td>39.7</td>
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<td>SWIR 2</td>
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<td>0.069</td>
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<td>0.168</td>
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<td>4.7588</td>
<td>0.0190</td>
<td>0.15</td>
<td>38.3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

**Diagram:**
- **Margin**
- **No Margin**

**Legend:**
- **Upper Edge Extent**
- **Lower Edge Extent**
- **Slope**
- **Aliasing**

**Text:**
- Best Margin Against Multiple Reqs

**Chart:**
- Increasing Aperture
- Increasing Focal Length
### All VSWIR Spectral Bands Demonstrated

#### Full VSWIR optical solution for SLI-T demo

- **Proposal:** 4 visible bands and 2 SWIR bands
  - Demonstrate step-stare approach
  - Multiple optical paths with single aperture
- **Baseline:** Enable all 5 visible bands, the Cirrus band and both SWIR bands

#### TABLE A.2 SLI-T REFERENCE MISSION SPECTRAL IMAGE PERFORMANCE REQUIREMENTS

<table>
<thead>
<tr>
<th>Band #</th>
<th>Band Name</th>
<th>Band #</th>
<th>Center Wavelength (nm)</th>
<th>Center Wavelength Tolerance (nm)</th>
<th>Minimum Lower Band Edge (nm)</th>
<th>Maximum Upper Band Edge (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coastal Aerosol</td>
<td>1</td>
<td>448</td>
<td>2</td>
<td>443</td>
<td>453</td>
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<tr>
<td>2</td>
<td>Blue</td>
<td>2</td>
<td>482</td>
<td>5</td>
<td>450</td>
<td>515</td>
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<tr>
<td>3</td>
<td>Green</td>
<td>3</td>
<td>562</td>
<td>5</td>
<td>525</td>
<td>600</td>
</tr>
<tr>
<td>4</td>
<td>Red</td>
<td>4</td>
<td>655</td>
<td>5</td>
<td>630</td>
<td>680</td>
</tr>
<tr>
<td>5</td>
<td>NIR</td>
<td>5</td>
<td>865</td>
<td>5</td>
<td>845</td>
<td>885</td>
</tr>
<tr>
<td>6</td>
<td>SWIR 1</td>
<td>6</td>
<td>1610</td>
<td>10</td>
<td>1560</td>
<td>1660</td>
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<tr>
<td>7</td>
<td>SWIR 2</td>
<td>7</td>
<td>2200</td>
<td>10</td>
<td>2100</td>
<td>2300</td>
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<td>8</td>
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<td>1390</td>
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<td>200</td>
<td>10300</td>
<td>11300</td>
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<td>11</td>
<td>Thermal 2</td>
<td>N/A</td>
<td>12000</td>
<td>200</td>
<td>11500</td>
<td>12000</td>
</tr>
</tbody>
</table>
Initial packaging complete

- The VNIR and SWIR channels can be packaged within the allocated volume.

- Inclusion of the TIR Channel will likely cause the system to exceed the space allocation and may require a larger baseplate to hold all three channels (still a manageable option)
Scan Profile for (Airborne System)

- **Ground Sample Locations (center of FOV):**
  - In-track position vs. cross-track position
  - Ground speed indicated

- **WASM scan profile:**
  - Cross-track and In-track (back scan compensates for ground speed)

- **Ground coverage with triangular scan profile:**
  - 0.45° cross-track step size at 15 Hz step rate;
  - 5.2 s scan period;
  - 4000 m AGL;
  - 50 m/s ground speed;
  - 15 Hz frame rate

- **Sensor integration time at end of settle time:**
  - Sensor integration time

- **LOS Cross-Track Command and LA-WASM Position:**
  - Sensor integration time at end of settle time

**Notes:**
- 0.45° cross-track step of 0.66° filter width provides 32% cross-track scan overlap. In-scan overlap = 24%.
Scan Modeling (Airborne System)

(OLI equivalent VIS IFOV = 42 urad)

- VIS sensor field of view (with individual channels)
- Ground coverage plot (color indicates # of VIS channels that sampled point on ground)
- Ground speed
- RMS motion of corner pixels during integration time
- LA-WASM pointing angles within field of regard
- Ground sample locations of upper-left and lower-right corner pixels during integration time
Scan Modeling (On-Orbit Case)
(OLI equivalent VIS IFOV = 42 urad)
Rate Table for Simulating Spacecraft Motion
Calibration Approach

- Absolute calibration performed during ground testing with NIST traceable sources (blackbody & lamps)
- Relative calibration in airborne configuration that has been scaled against absolute calibration on ground
- Heliostat testing (fall 2018) for direct comparison to OLI2 (LandSat9)
Heliostat Testing Provides Direct Comparison with OLI

- Solar source provides realistic spectral profile for direct comparison between REMI and OLI
- OLI planned Heliostat testing is Fall 2018
- REMI positioned outside the chamber so that the beam is folded the opposite direction for testing without cleanliness and feedthrough requirements
- University of Arizona is contracted for OLI to perform atmospheric transmission measurements during Heliostat testing from roof
Airborne Stability Monitoring

- Broadband light source & fiber optic
- Diffuse Lambertian light from engineered diffusor
- Mirror on back of external shutter in “closed” position
- Relative calibration in-flight (stability)
Mechanical Layout in Twin Otter

Twin Otter Open View
Flight Plans

- **Eng. Flights** ensure proper interfacing and functionality while airborne
- **Data Flights** used to generate data used to validate concepts
- **Science Flights** used to acquire data of specific interest to the science community
Acknowledgements

- Funding from ESTO/SLI-T, Contract No. NNX16AP63G
- Ball Team:
  - Tom Kampe, Optics
  - Bob Warden, Mechanical
  - Kyle Solander, Electronics
  - Jonathan Fox, Software
  - Homero Gutierrez, Scan Mechanism
  - Lyle Ruppert, L1B Data Processing
  - Bill Good, Aircraft Ops
THANK YOU!