Computational Reconfigurable Imaging Spectrometer (CRISP)
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Earth Observation Technology: Traditional Approach

- Expensive (~$2B/satellite), and heavy (~2000 kg)
- Long development cycle (~10 yrs plus >10 yrs of operation)
- High consequences of failure
Our Approach: Computational Reconfigurable Imaging Spectrometer (CRISP)

- Uses static mask and scan/platform motion to encode spectral data cube
- Sensitivity advantages over traditional designs, enabling smaller infrared instruments that use uncooled thermal detectors

Proposed Operating Modes: Varying Area Coverage Rate

- **Example scenario: Cued Cubesat constellation**
  - First sat identifies interesting phenomenon during wide area search
  - Second sat cued to look more closely with long-dwell mode

- **CRISP concept allows flexible operation, based on mission-specific requirements for area coverage, spatial/spectral resolution, and sensitivity**
## Breadboard Measurements

| $\lambda$  | 7.7 $\mu$m – 14 $\mu$m  
(67 pixel dispersion extent) |
<table>
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<tr>
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<tbody>
<tr>
<td>$\Delta \lambda$</td>
<td>0.14 $\mu$m resolvable</td>
</tr>
<tr>
<td>D</td>
<td>5 cm</td>
</tr>
<tr>
<td>FOV</td>
<td>$\sim$15$^\circ$</td>
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- COTS f/1 camera lenses from FLIR
- Custom ZnSe prisms
- Custom designed mounts and baffles
- Uncooled microbolometer

- Use breadboard to validate model predictions
- Ruggedized breadboard used in flight test
Lab Measurements: Spectra for Extended and Narrowband Sources, and Trace Gas

Breadboard measurements agree with predictions for broadband, narrowband, and trace gas absorption
Lab Measurements: Fast Scan with Motion Blur Removal

Point Source Motion Blur: Cross Section

Point Source Motion Blur: Raw Measurements

CRISP Inversion of Motion Blur

- Modulation from CRISP can be used to invert motion blur
- Maintains image quality even with low frame rates

- exponential decay, $\tau = 11\text{ms}$ (measured)
Flight Measurements: Initial Tests

CRISP demonstrated on real moving platform, with irregular motion
Flight Measurements: Coastal Crossing and TES

CRISP spectra agree with prediction for sand and water, and can support Temperature Emissivity Separation (TES)
Flight Measurements: Trace Gas Detection

CRISP successfully detected a trace gas release

CRISP: Summary and Future Plans

- We have validated key model predictions for CRISP in the lab and demonstrated spectral imaging in flight
- Current emphasis is on developing scan and spectral resolution modes and identifying performance limits
- We are currently proposing a brassboard instrument demo that would aim to meet future LandSat thermal IR band requirements
- Surface Biology and Geology and Planetary Boundary Layer mission concepts also being investigated

Landsat 8 Thermal Imagery
Paluweh volcano, Indonesia, April 2013

Proposed Brassboard Lens Barrel Design
### SNR of CRISP vs. Conventional Slit-Based Spectrometers

<table>
<thead>
<tr>
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<th>Slit-based system SNR scaling</th>
<th>CRISP SNR scaling</th>
<th>Rationale</th>
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| **Background-noise limited**  
(e.g., visible CCD, cooled MCT) | 1                             | $\sim\sqrt{M/2N_\lambda}$ | CRISP is overdetermined: $M \gg N_\lambda$ |
| **Detector-noise limited**  
(e.g., uncooled microbolometer) | 1                             | $\sim\sqrt{M/2}$ | Additional “multiplex” advantage when all $\lambda$ measured at once |

Example:

$M = 1920$ imager rows  
$N_\lambda = 30$ wavelengths

CRISP enables significant SNR improvement over conventional designs due to measurement count and wavelength multiplexing.
Lab Measurements: Fast Scan with Motion Blur Removal

**Point Source Motion Blur:**

- **Cross Section**
- **Raw Measurements**

![Point Source Motion Blur Diagram](image)

- **Blur mode [8 px / frame]**
- **Normal operation**

- **Exponential decay, \( \tau = 11\) ms (measured)**

- **CRISP Inversion of Motion Blur**

![CRISP Inversion Graph](image)

- **Raw Data**
- **Deblurred CRISP processed data**

- **Modulation from CRISP can be used to invert motion blur**
- **Maintains image quality even with very fast scans relative to frame rate**
Flight Measurements: Initial Tests

CRISP demonstrated on real moving platform, with irregular motion