The Snow and Water Imaging Spectrometer (SWIS): Progress, optomechanical, and detector updates

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24 June 2015
Overview

- Introduction
  - Research and applications
- Optical design
- LVAR detector coating
- Optomechanical design
  - Overview and adjustments
  - On board calibration mechanism
  - Diffuser material testing
- CubeSat configuration
- Summary and Conclusions

SWIS CubeSat, artist’s concept
Introduction

• Imaging spectrometry places heavy demands on satellite in terms of aperture size, data volume, and power resources

• To stay within CubeSat resources:
  • No cryogenic temperatures (limits wavelength range)
  • Low data volume and rate (limits area coverage to specific target areas)
  • Limited spatial resolution / telescope aperture

• Coastal ocean science and snow cover monitoring are two critical niche applications that can be potentially served by CubeSats

SWIS CubeSat, artist’s concept
**Research and applications**

**Coastal science:** Complex spectral signatures from the coastal environment demonstrate that heritage multi-spectral sensors are inadequate

- High temporal variability makes consistent airborne monitoring costly
- High spatial variability requires higher resolution than heritage sensors

Coastal ocean spectral signatures (H. Dierssen), mainly below 900 nm

**Snow cover:** Spectral signatures of snow in various states demonstrate the utility of spectroscopy in understanding energy transfer and hydrology

Snow spectral signatures (T. Painter) contain critical features in 1000-1500 nm range

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Research and applications

<table>
<thead>
<tr>
<th>SWIS</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>160m from 500km orbit</td>
</tr>
<tr>
<td>Swath</td>
<td>640 spatial elements</td>
</tr>
<tr>
<td>Mission lifetime</td>
<td>~2 years (no propulsion)</td>
</tr>
<tr>
<td>Target frequency</td>
<td>Global daily coverage with 6 CubeSats</td>
</tr>
<tr>
<td>Application</td>
<td>Coasts, snow cover</td>
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<td></td>
<td>*Global coverage at low (~1 km) resolution subject to future data transmission rate improvements</td>
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To access any point on the globe on a given day:
- 6 CubeSats, 500 km orbit
- 10° Field of view
- 50° Field of regard with pointing

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Optical Design

Spectrometer and telescope inside 6U CubeSat frame

SWIS specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>350-1700 nm, single FPA</td>
</tr>
<tr>
<td>Spectral sampling</td>
<td>5.7 nm</td>
</tr>
<tr>
<td>Cross-track spatial elements</td>
<td>600 (+40 monitor)</td>
</tr>
<tr>
<td>Cross-track FOV</td>
<td>10°</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.3 mrad</td>
</tr>
<tr>
<td>Detector pixel size</td>
<td>30 mm</td>
</tr>
<tr>
<td>Focal length</td>
<td>100 mm</td>
</tr>
<tr>
<td>F-no</td>
<td>1.8</td>
</tr>
<tr>
<td>Uniformity</td>
<td>95%</td>
</tr>
</tbody>
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E-beam writing on concave substrate is well calibrated (minimal field boundaries within each annular writing height zone)

SWIS E-Beam calibration test grating (Uncoated resist grating, partial area):

Atomic Force Microscope profile and simulated efficiency of SWIS Test Grating

- Further calibration of the resist exposure details at 50kV e-beam voltage (recently switched from 100kV) on this substrate (BK7) should produce better agreement on future runs
Optical Design: Stray light

- Significant concern; drives design
- Spatial ghosts <1e-3, depend critically on detector and OSF etalon reflections

- Ghosts have been minimized with:
  - Judicious positioning of the slit
  - Optimization of dispersion to exclude zero order reflected ghosts
  - Ensuring that all reflected ghosts are returned in negative (weak) grating orders
  - Undispersed spatial ghost at ~1140 nm handled by appropriate positioning of OSF
  - Development of special LVAR detector coating

Irradiance distribution on the detector for 6 finely sampled 10nm wavelength bands covering most of the field of view (log scale)

LVAR coating development

Measured Data Shows <1% Reflectivity, 380nm - 1700nm

- Measured and theoretical data use SWIR HgCdTe material and n,k values
- NIR HgCdTe n, k values are not know and may impact results for SWIS 1.7
- Nearly all wavelengths show <0.5% reflectivity

LVAR coating on silicon coupon (Teledyne Internal Company Proprietary)
Optomechanical design

Dyson Spectrometer and TMA telescope fit in 4U of 6U CubeSat
Optomechanical design

- Telescope housing designed for ease of machining and assembly

- Spectrometer assembly leverages airborne Dyson spectrometer design heritage with enhancements to grating mount

- Interfaces between mounts, elements, and components are designed to avoid hysteresis; Common materials and relatively simple fabrication

SWIS Optomechanical System (bipods and telescope housing hidden)
Grating mount with clocking adjustment tangent rod for high accuracy and stable clocking adjustment

6X Bonded-in Flexures

Tangent Rod

Grating Surface Deformation FEM

72nm
Focal Plane Array Mount

FPA 6 DOF Mount
- Design tested on previous JPL imaging spectrometers including M³
- Capable of sub-micron resolution

View of FPA mount showing adjusters and heat strap attachment

“Spectral” Translation/Clocking Rods
“Spatial” Translation Rod
Tip-Tilt-Piston Rods
Heat Strap Attachment
Calibration Mechanism Features

- Single COTS Stepper Motor
- Drive cable operating in tension against return spring
- Actuates bright and dark calibrators
- Releases launch latch
- Simple, low-cost COTS shape memory actuator for fail-open
Diffuser material testing

- Diffuser material (Heraeus OM100) found to satisfy requirements
- Diffuser testing performed in an arrangement that simulates the position of the sun and the location of the diffuser in the CubeSat

Spectrometer and telescope in 6U CubeSat frame

[Image: Spectrometer and telescope in 6U CubeSat frame]

[Graph: Normalized Transmission vs. Viewing Angle]

Microphotograph shows uniformity

http://www.heraeus.com

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Diffuser material testing

Diffuser testing setup position of the sun and the location of the diffuser in the CubeSat

Reflective

Transmissive

Expected radiance equivalent to a surface with a reflectance of 10-13%

June 2015
Complete CubeSat configuration with 6U structure, attitude control unit, radio, power electronics, and custom FPA electronics
CubeSat configuration

Spacecraft designed to fit within a 6U Canisterized Satellite Dispenser (Planetary Systems Corporation)

Complete CubeSat configuration within 6U structure

June 2015
We present an imaging spectrometer design suitable for CubeSat applications requiring high throughput (SNR).

Advances the state of the art in compact sensors of this kind in terms of size and spectral coverage.

Design optimized to minimize stray light, including utilization of linear variable antireflection (LVAR) detector coating.

Innovative single drive performs dual mechanism function of positioning the on-board calibrator (OBC) as well as providing a shutter for dark frames.

Diffuser material identified for solar calibration.

Preliminary spacecraft configuration design favorable for accommodation in 6U CubeSat frame.

Useful missions can be designed with high spatial and temporal resolution to address targeted areas of the Earth’s surface.
Acknowledgments

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**Industrial Partner:** Teledyne (Jianmei Pan, task manager)