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

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Overview

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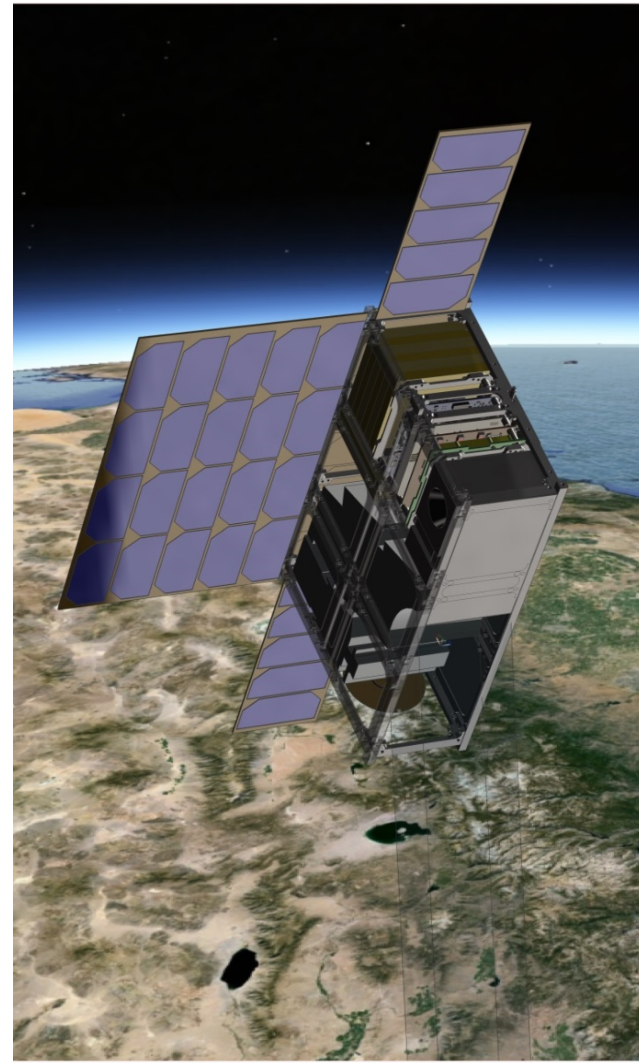
- Summary and Conclusions



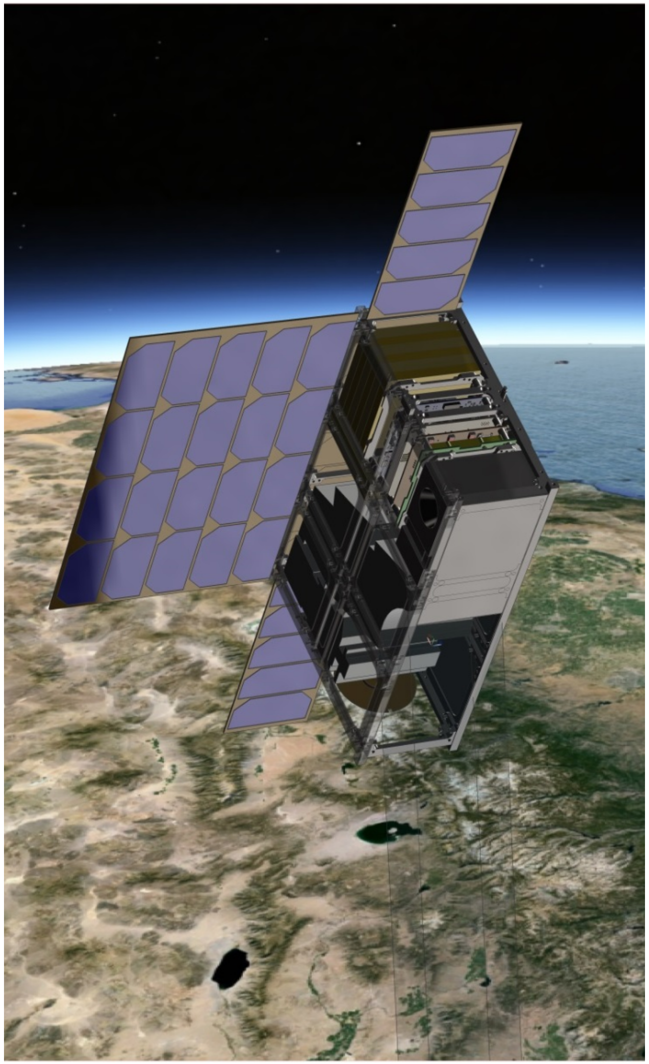
SWIS CubeSat, artist's concept

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

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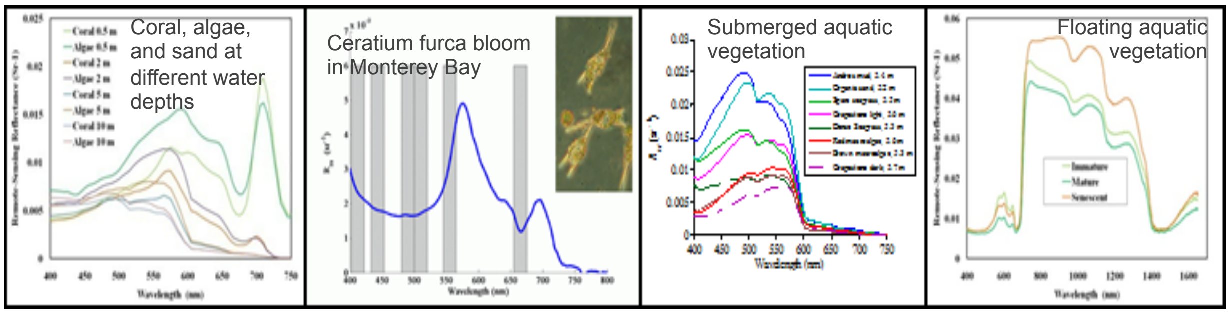
Research and applications

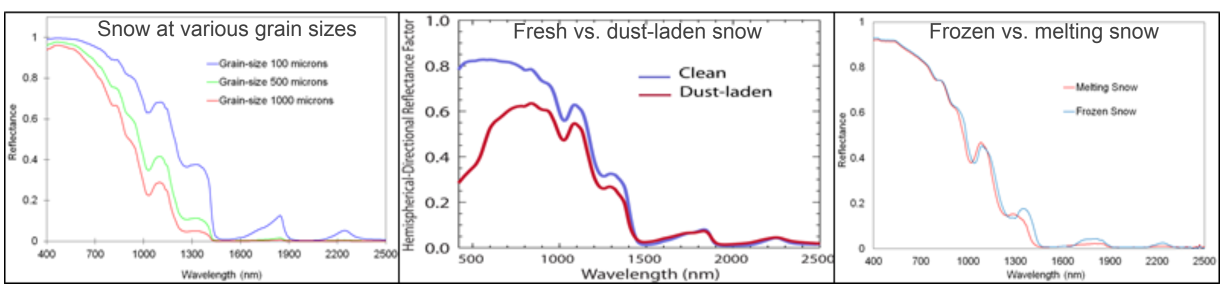
Coastal science: Complex spectral signatures from the coastal environment demonstrate that heritage multi-spectral sensors are inadequate

- 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**

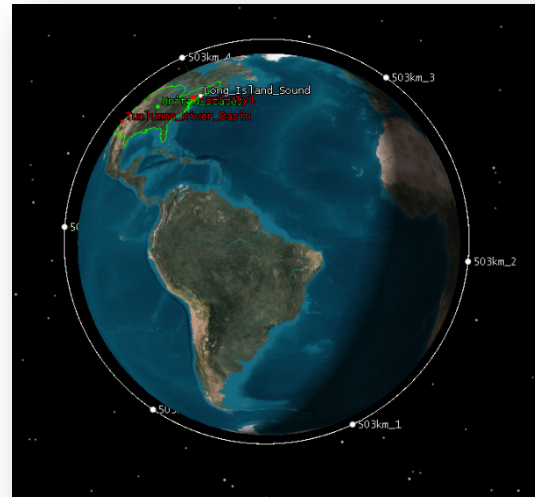
Snow cover: Spectral signatures of snow in various states demonstrate the utility of spectroscopy in understanding energy transfer and hydrology

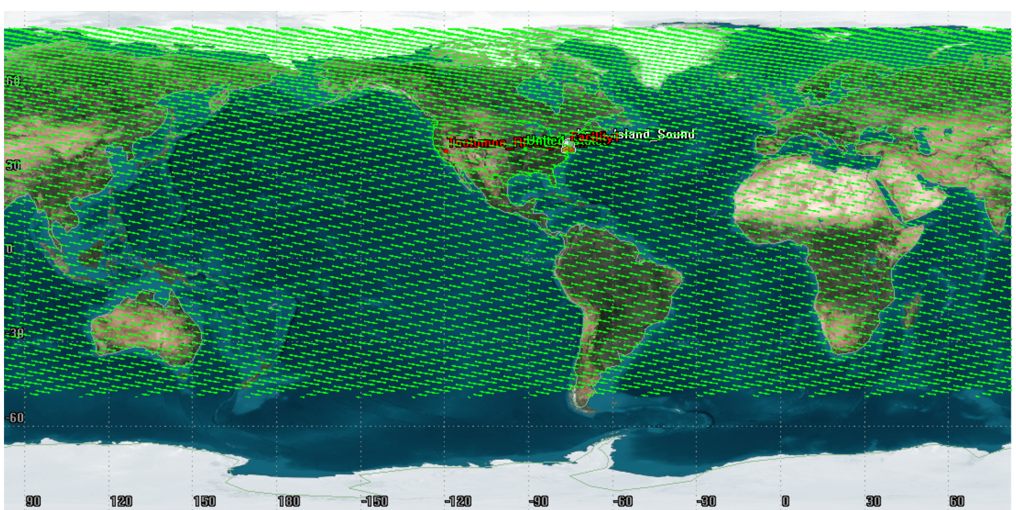


Snow spectral signatures (T. Painter) contain critical features in **1000-1500 nm** range

Research and applications

SWIS	
Resolution	160m from 500km orbit
Swath	640 spatial elements
Mission lifetime	~2 years (no propulsion)
Target frequency	Global daily coverage with 6 CubeSats
Application	Coasts, snow cover
*Global coverage at low (~1 km) resolution subject to future data transmission rate improvements	



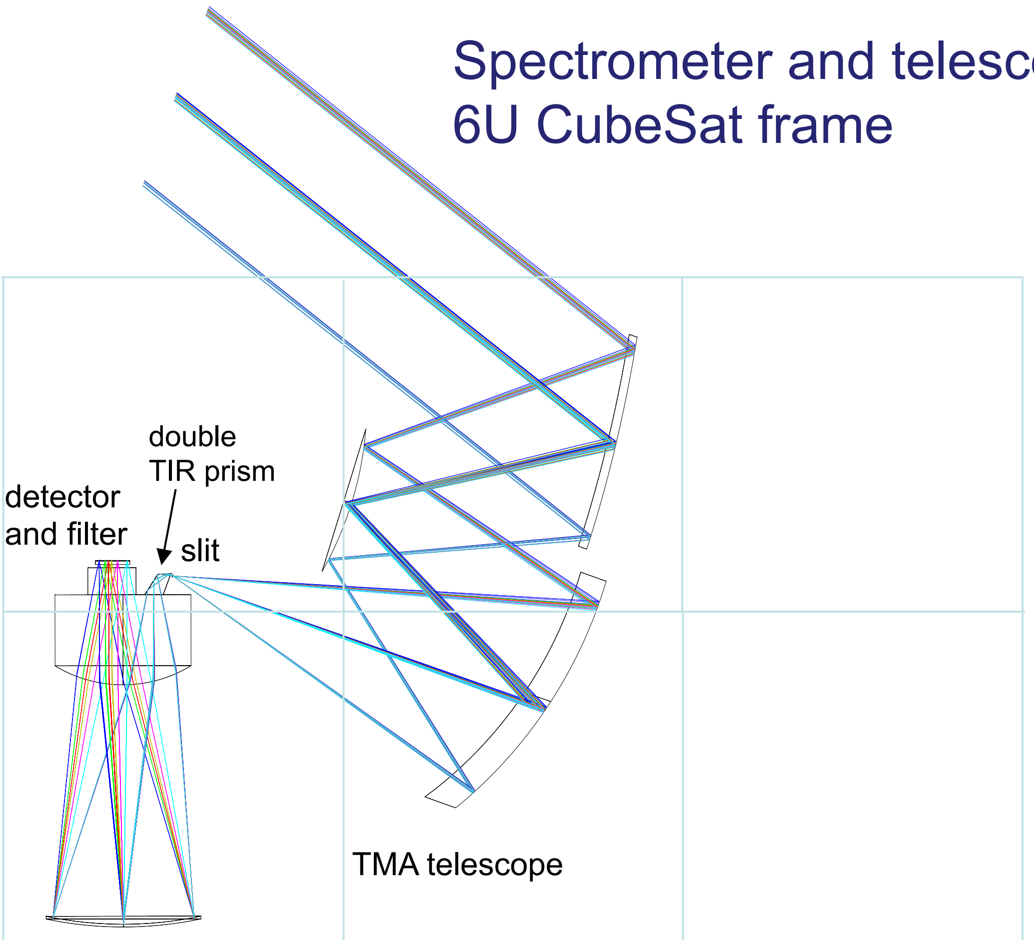


To access any point on the globe on a given day:

- 6 CubeSats, 500 km orbit
- 10^{o} Field of view
- 50^{o} Field of regard with pointing

Optical Design

Spectrometer and telescope inside 6U CubeSat frame

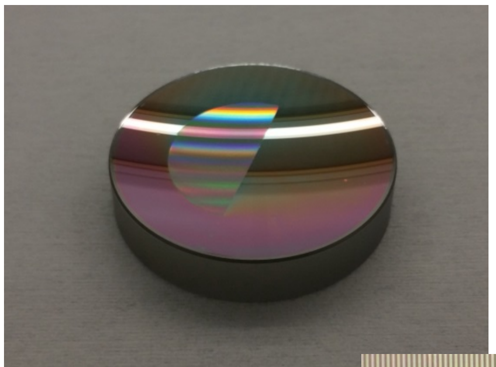


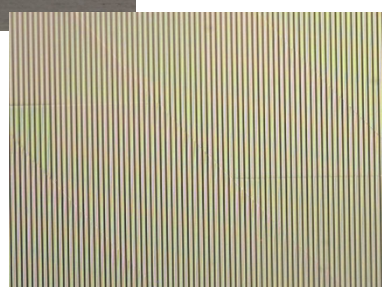
SWIS specifications	
Spectral range	350-1700 nm, single FPA
Spectral sampling	5.7 nm
Cross-track spatial elements	600 (+40 monitor)
Cross-track FOV	10°
Resolution	0.3 mrad
Detector pixel size	30 mm
Focal length	100 mm
F-no	1.8
Uniformity	95%

Mouroulis et al, Proc. SPIE 9222, Imaging Spectrometry XIX (2014)

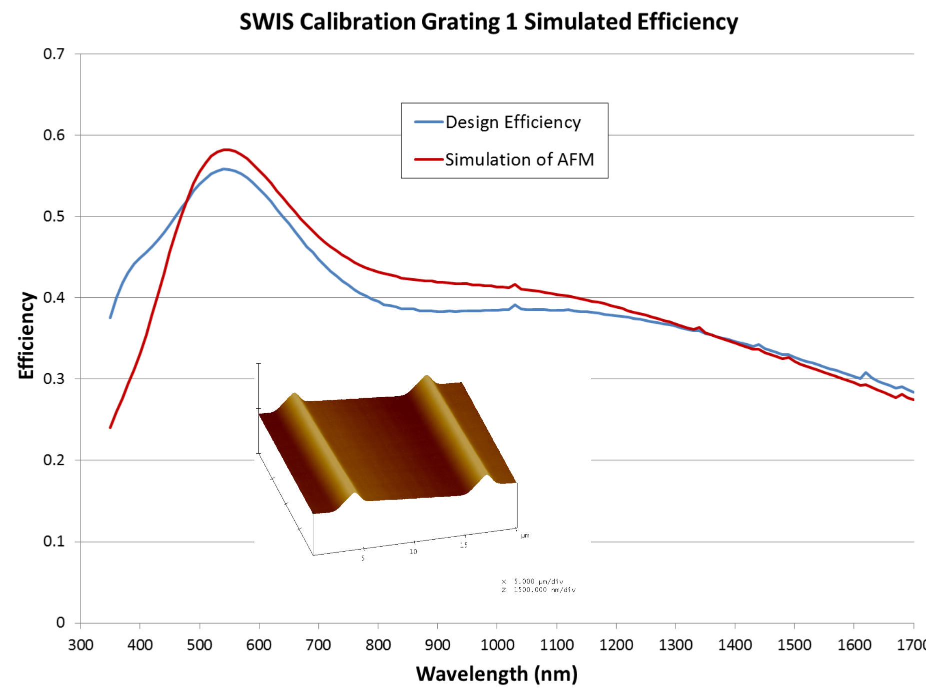
Optical design: Diffraction grating

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





- E-beam writing on concave substrate is well calibrated (minimal field boundaries within each annular writing height zone)



Atomic Force Microscope profile and simulated efficiency of SWIS Test Grating

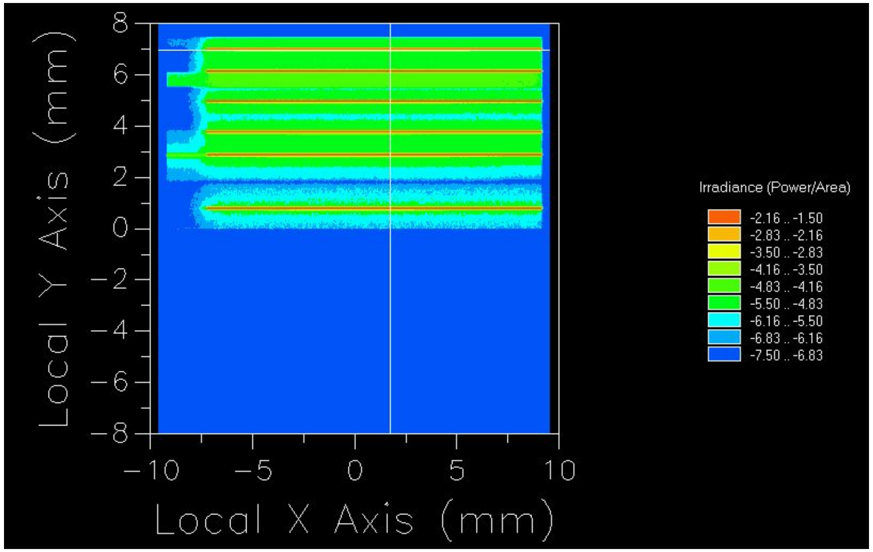
- Further calibration of the resist exposure details at 50kV e-beam voltage (recently switched from 100kV) on this substrate (BK7) should produce better agreement on future runs

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

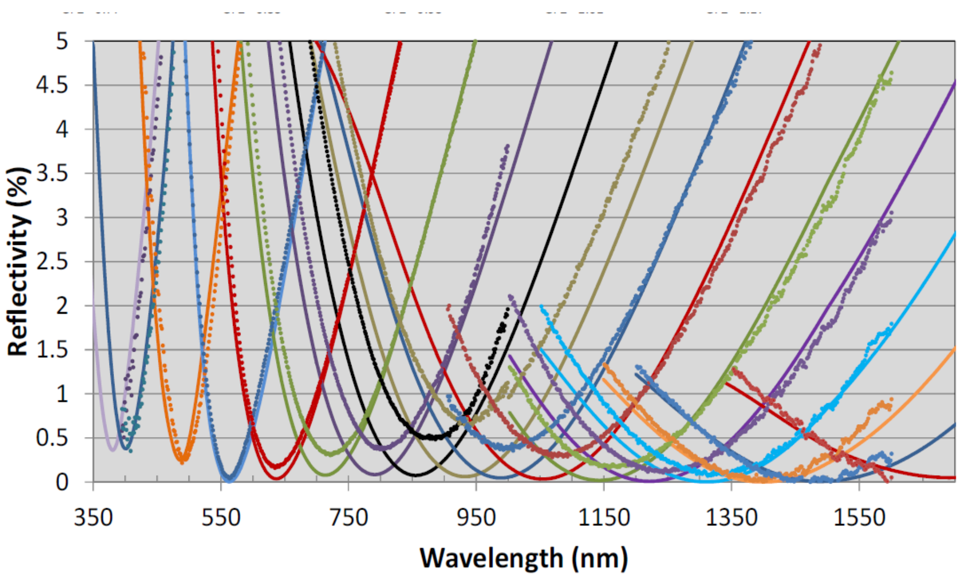


Irradiance distribution on the detector for 6 finely sampled 10nm wavelength bands covering most of the field of view (log scale)

Mouroulis et al, Proc. SPIE 9222, Imaging Spectrometry XIX (2014)

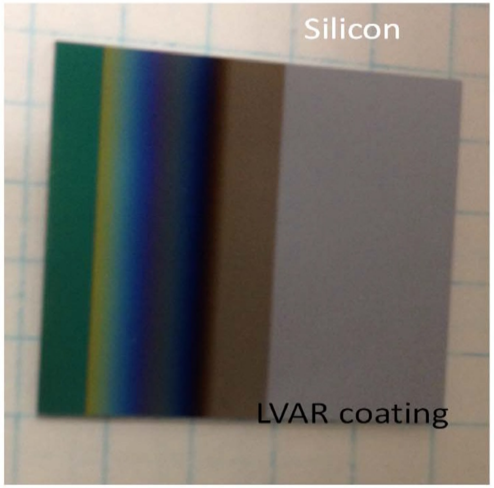
LVAR coating development

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

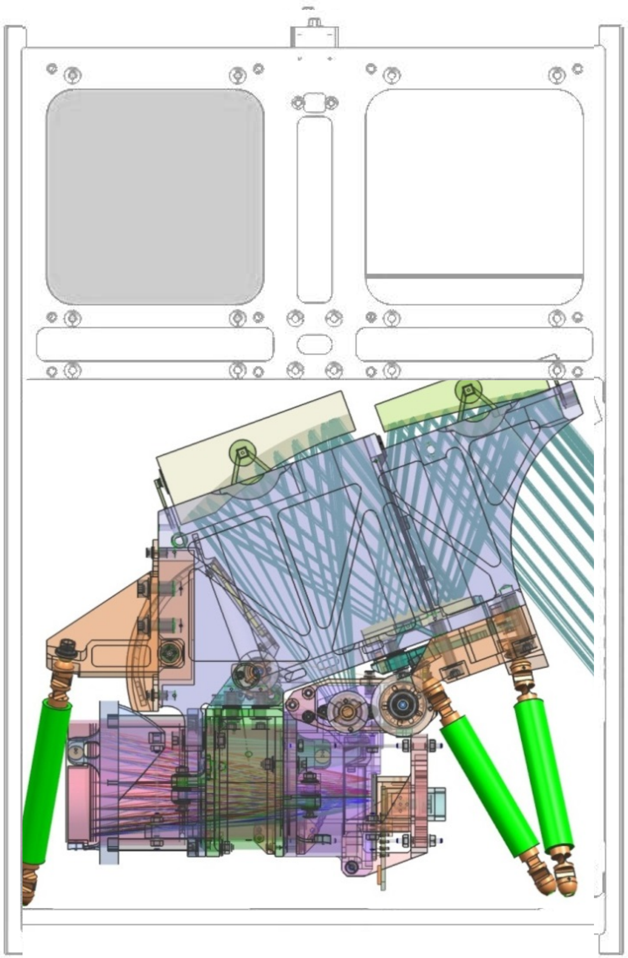
LVAR coating testing *(Teledyne Internal Company Proprietary)*

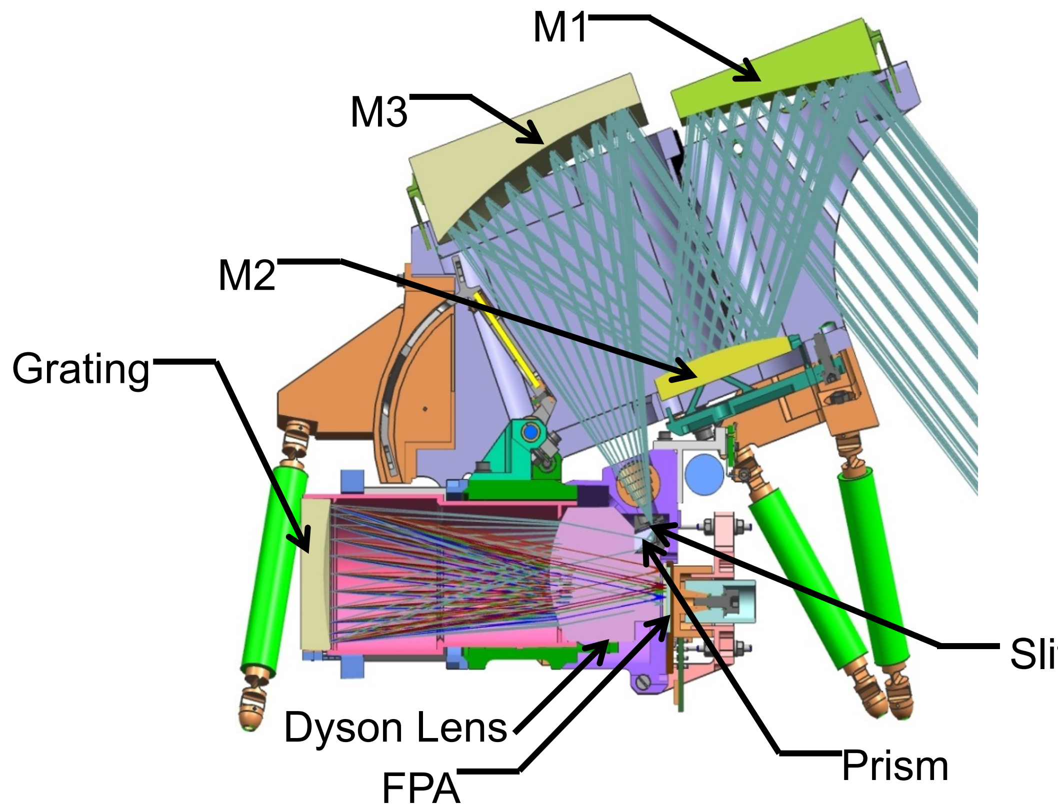


LVAR coating on silicon coupon *(Teledyne Internal Company Proprietary)*

Optomechanical design

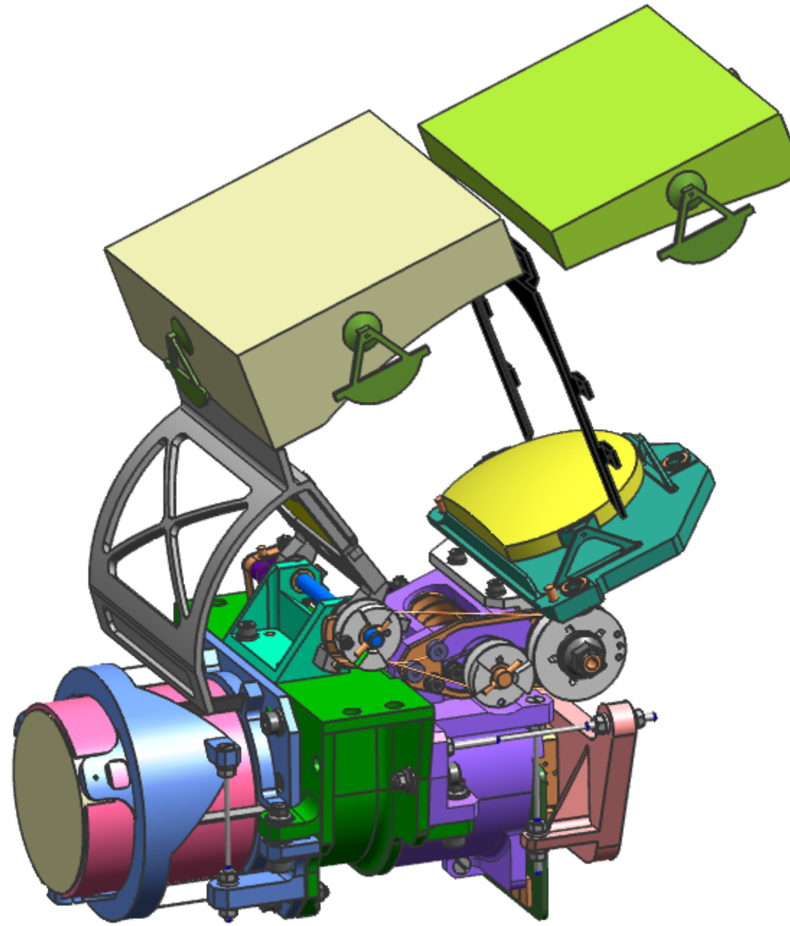
Dyson Spectrometer and TMA telescope
fit in 4U of 6U CubeSat





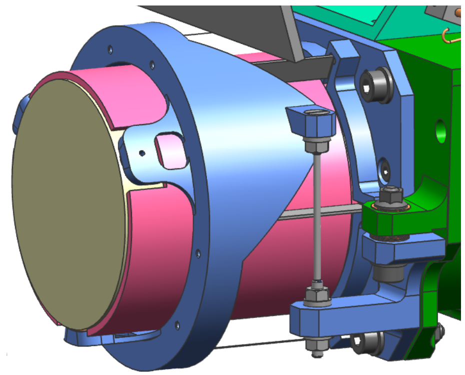
Optomechanical design

- 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

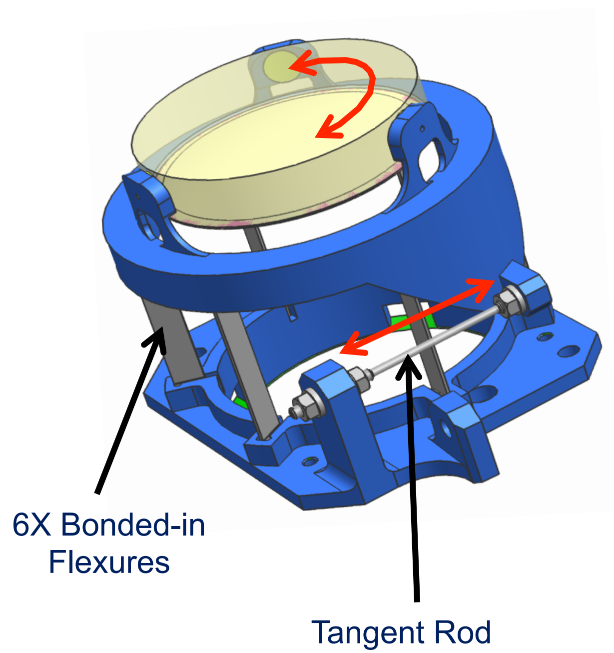


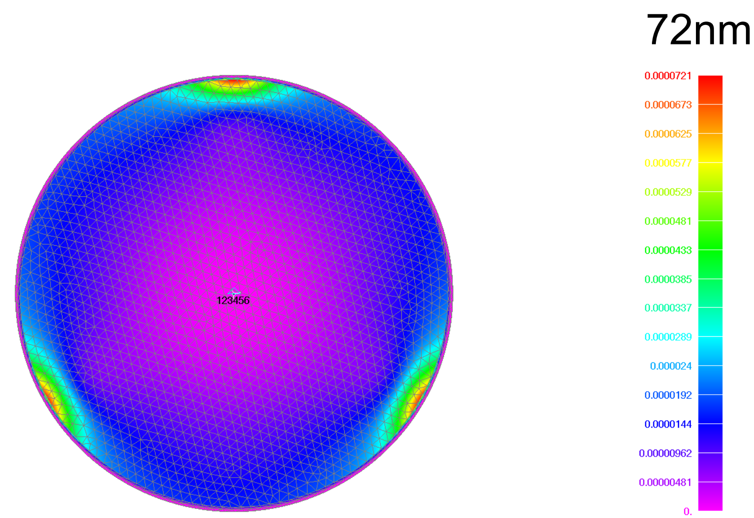
SWIS Optomechanical System
(bipods and telescope housing hidden)

Diffraction grating mount



Grating mount with clocking adjustment tangent rod for high accuracy and stable clocking adjustment



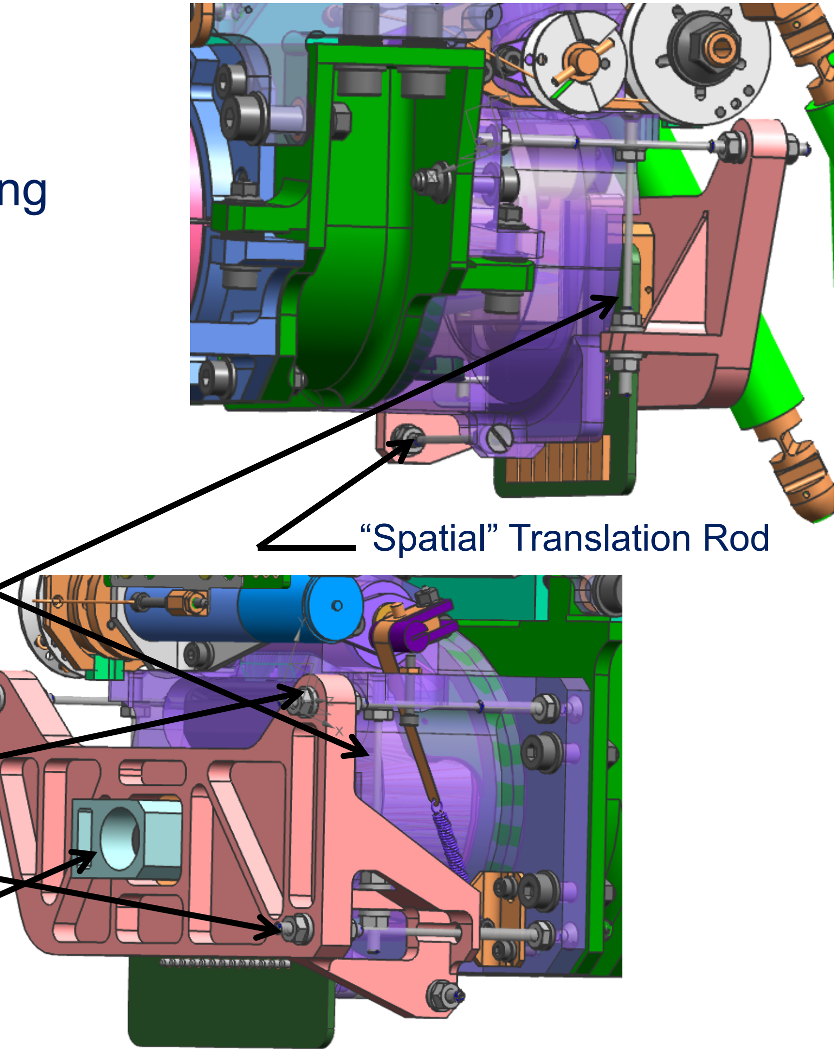


Grating Surface Deformation FEM

Focal Plane Array Mount

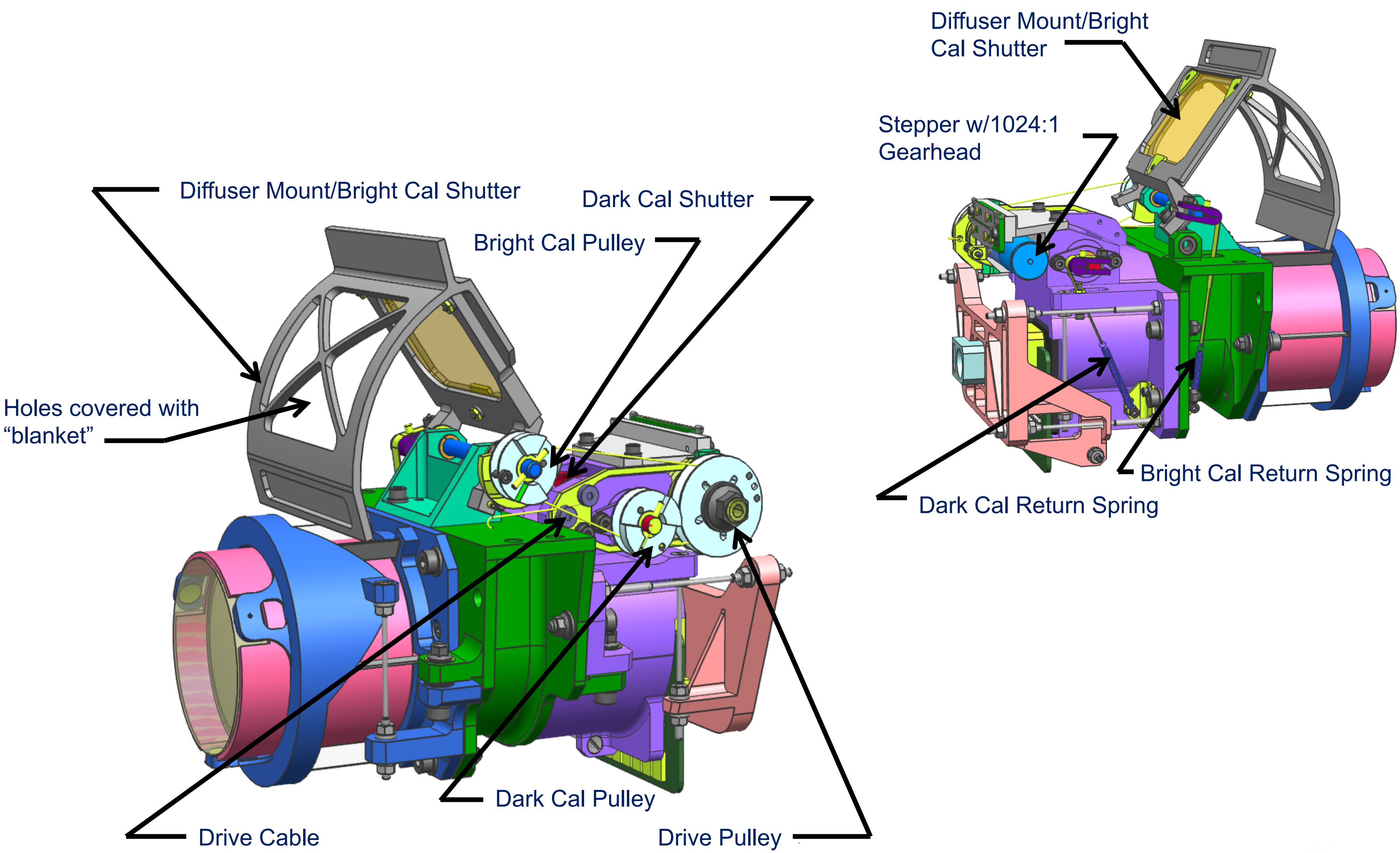
FPA 6 DOF Mount

- Design tested on previous JPL imaging spectrometers including M^3
- Capable of sub-micron resolution



View of FPA mount showing adjusters and heat strap attachment

Calibration Mechanism



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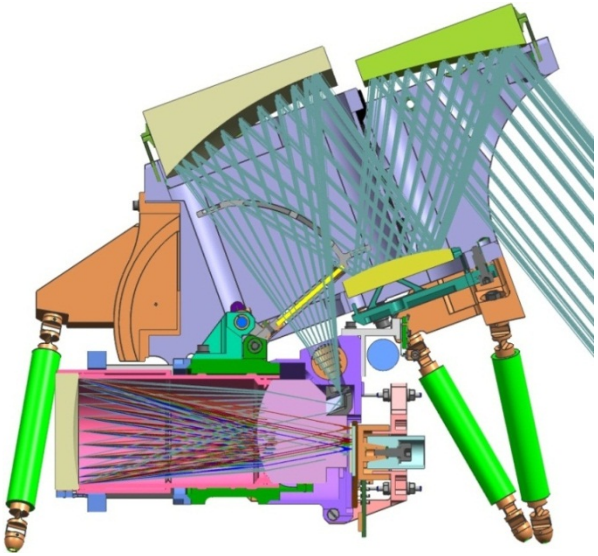
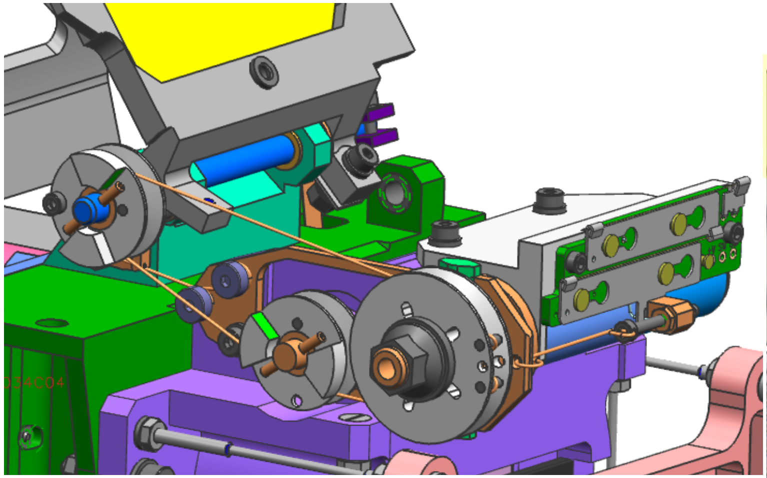
Calibration Mechanism

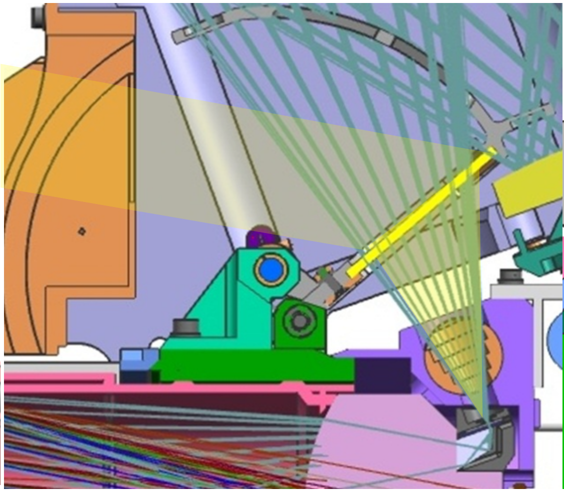
Calibration Mechanism Features

- 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

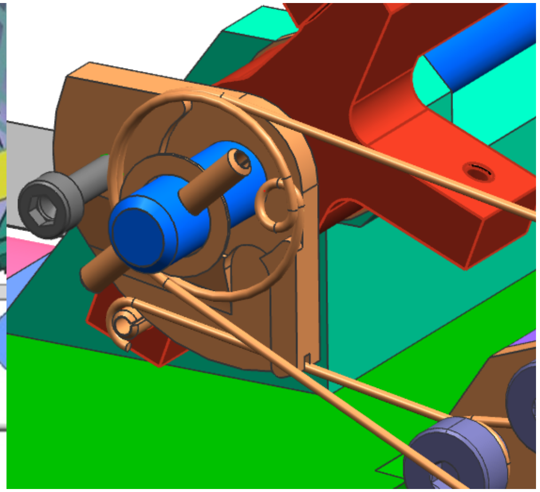




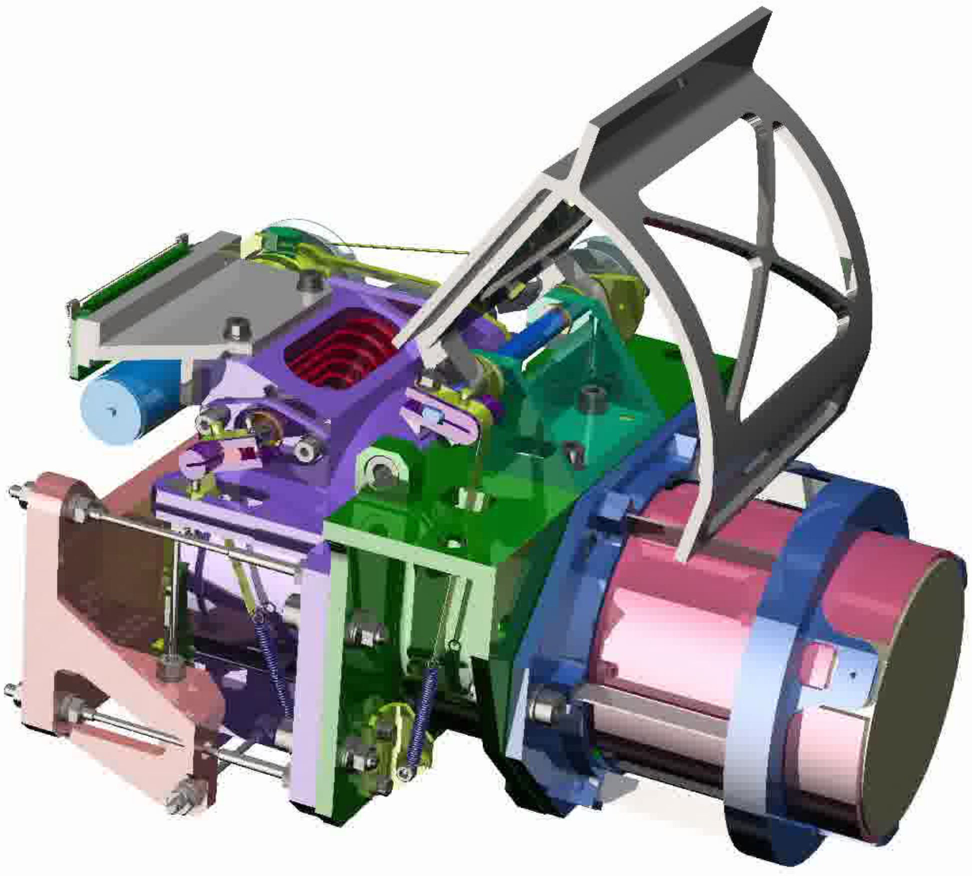
Calibrator Drive Mechanism



Bright Cal Light Path

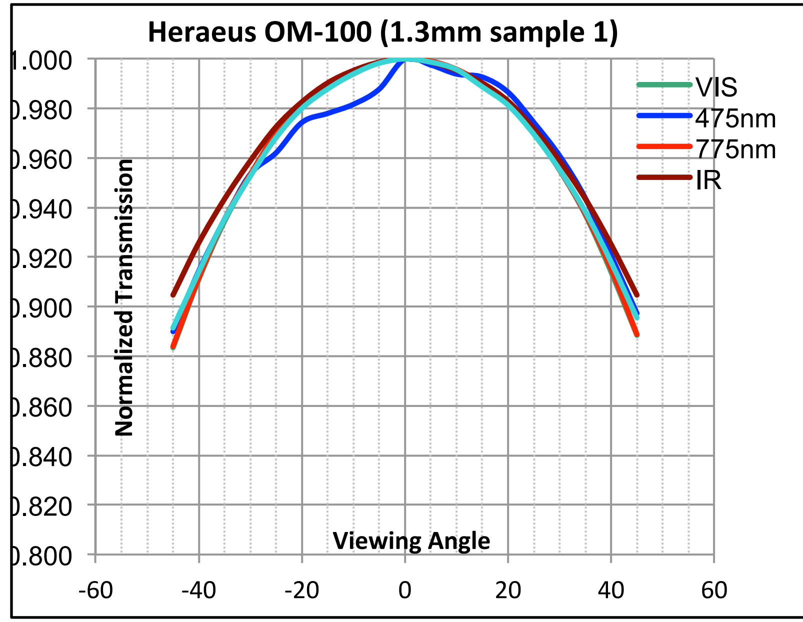


Launch Latch

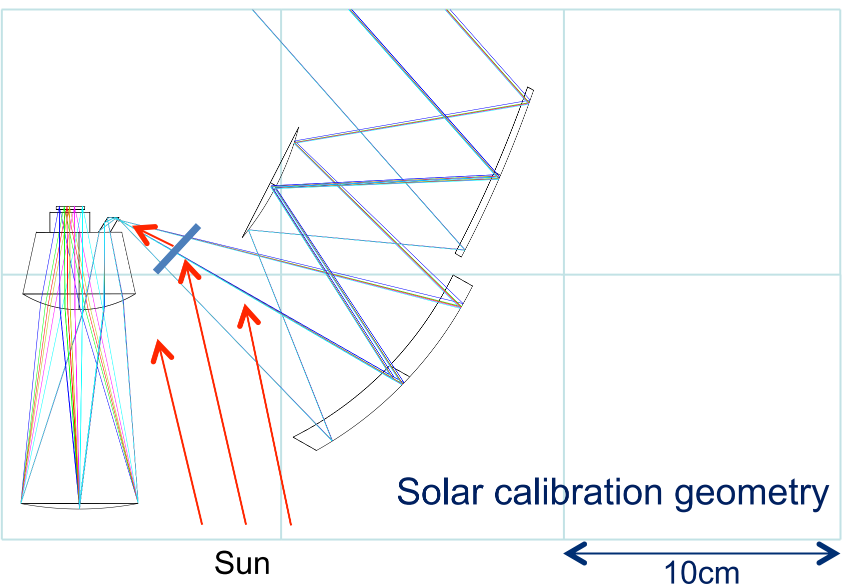


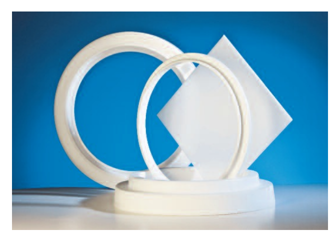
Diffuser material testing

- 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

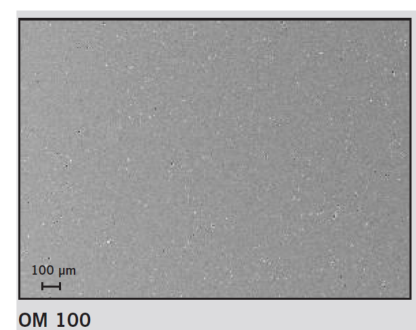


Spectrometer and telescope in 6U CubeSat frame





Heraeus OM100

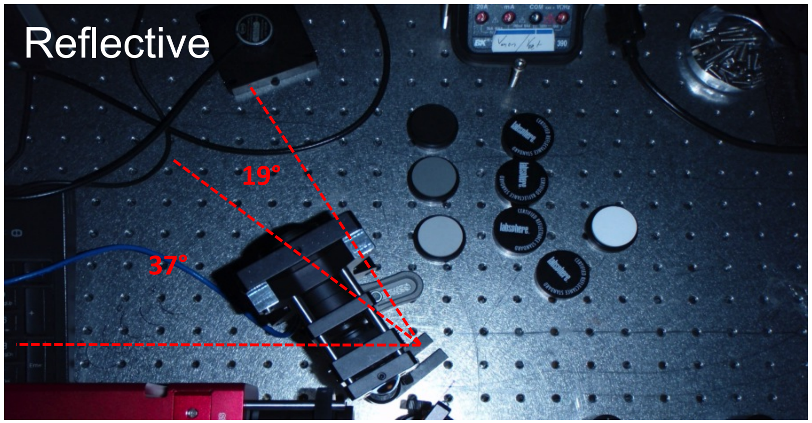


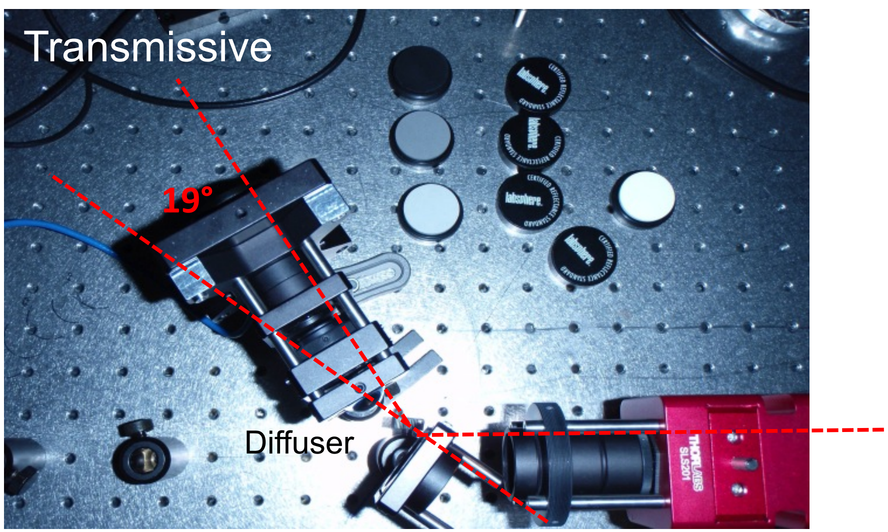
Microphotograph shows uniformity

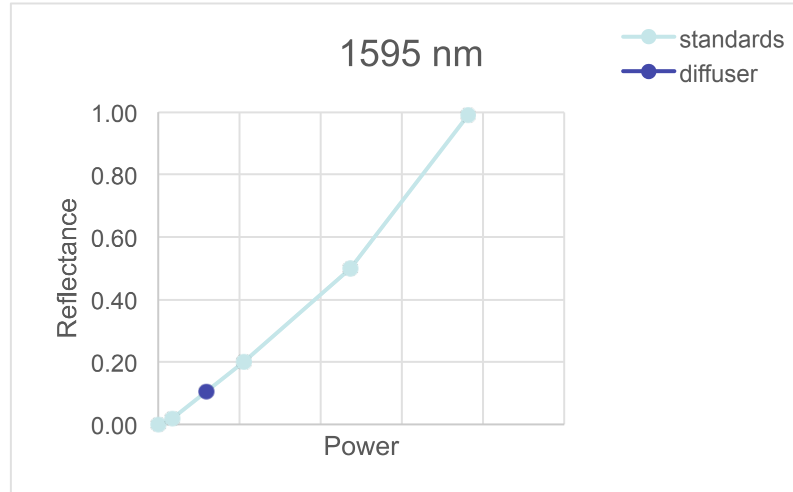
http://www.heraeus.com

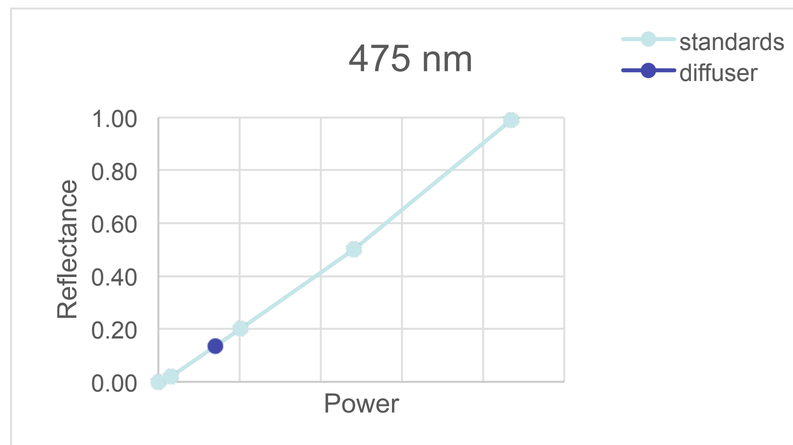
Diffuser material testing

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



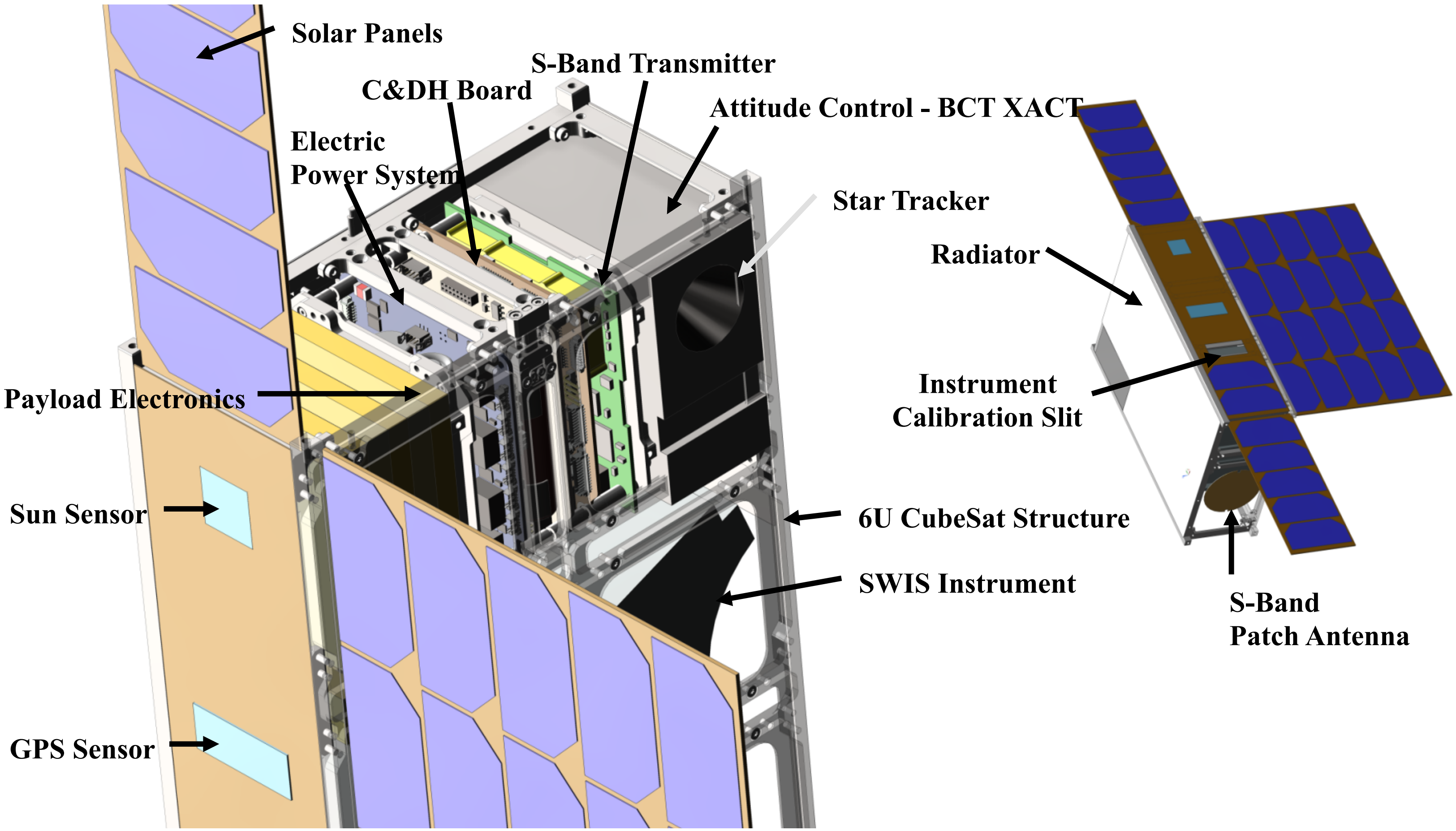






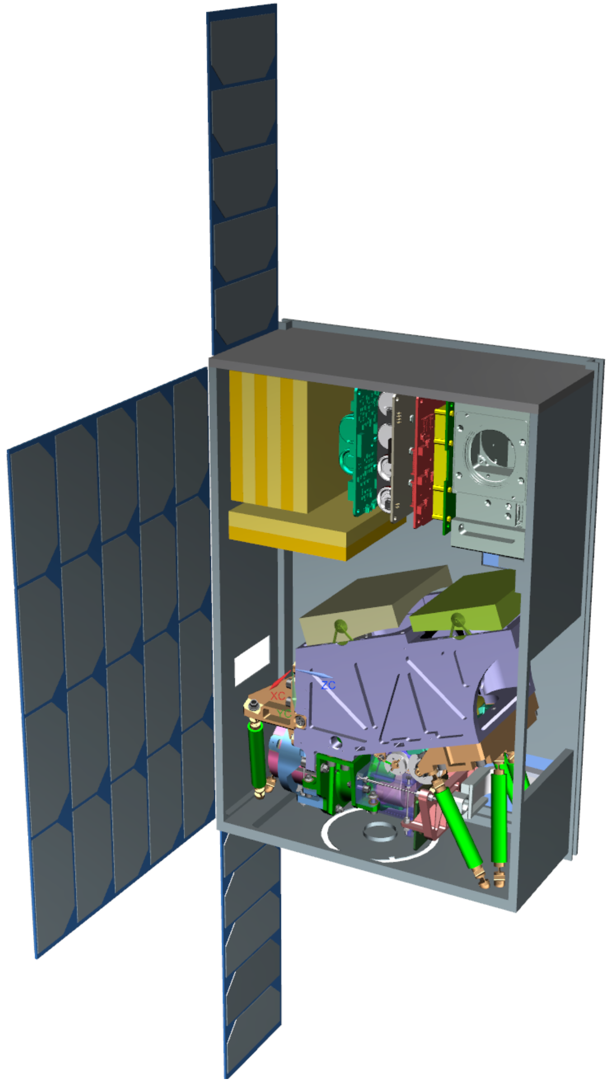
Expected radiance equivalent to a surface with a reflectance of 10-13%

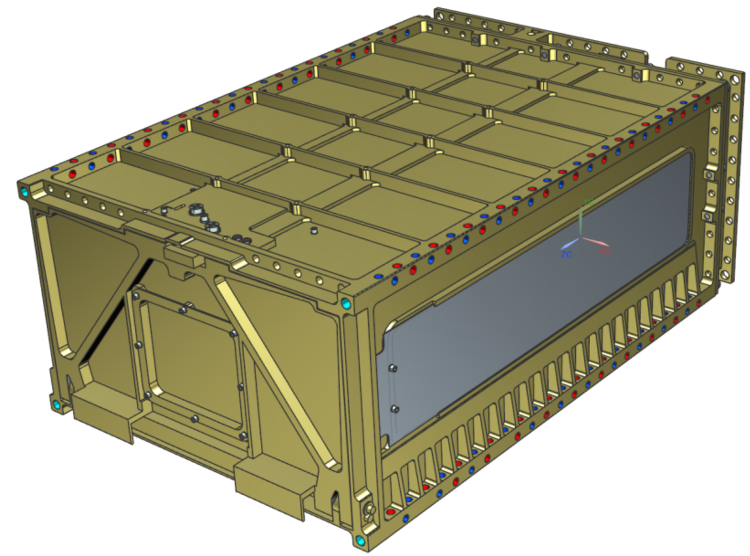
CubeSat configuration



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

CubeSat configuration



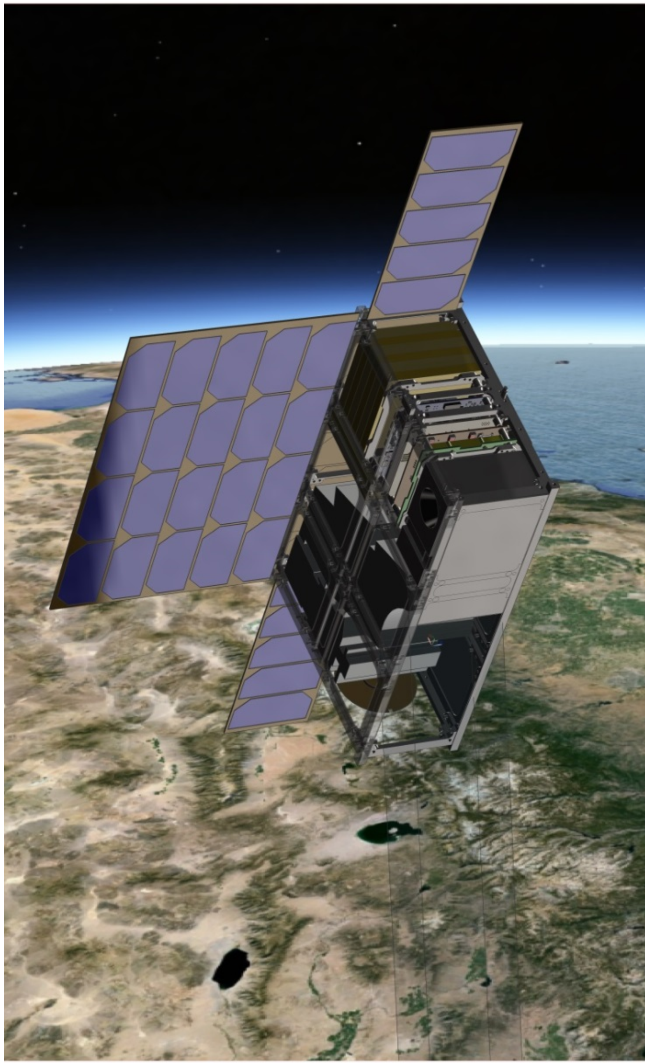


Spacecraft designed to fit within a 6U Canisterized Satellite Dispenser (Planetary Systems Corporation)

Complete CubeSat configuration within 6U structure

Summary & Conclusions

- 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



SWIS CubeSat, artist's concept

Acknowledgments

The SWIS Project Team:

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Co-Is: Rob Green, Tom Painter, Heidi Dierssen (UConn), Byron Van Gorp, Dan Wilson, Michael Eastwood, Jose Rodriguez

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Industrial Partner: Teledyne (Jianmei Pan, task manager)