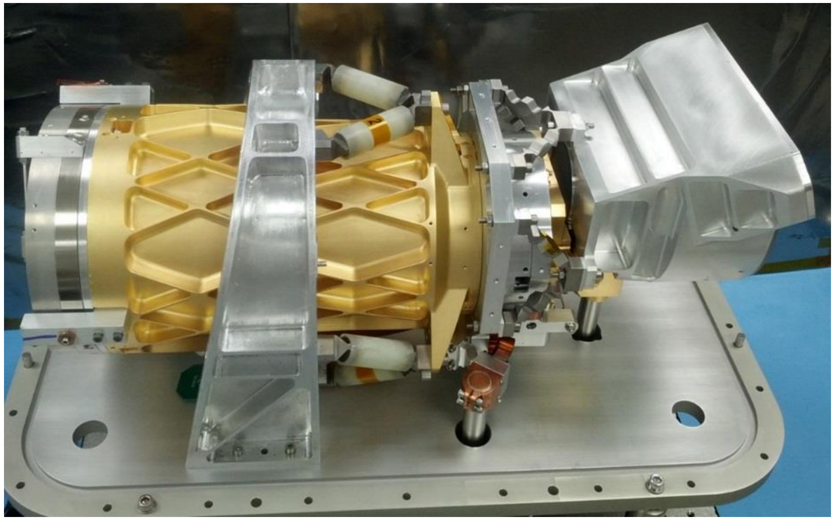
VSWIR-Dyson Imaging Spectrometer: Design, Alignment, Laboratory Calibration, and Testing



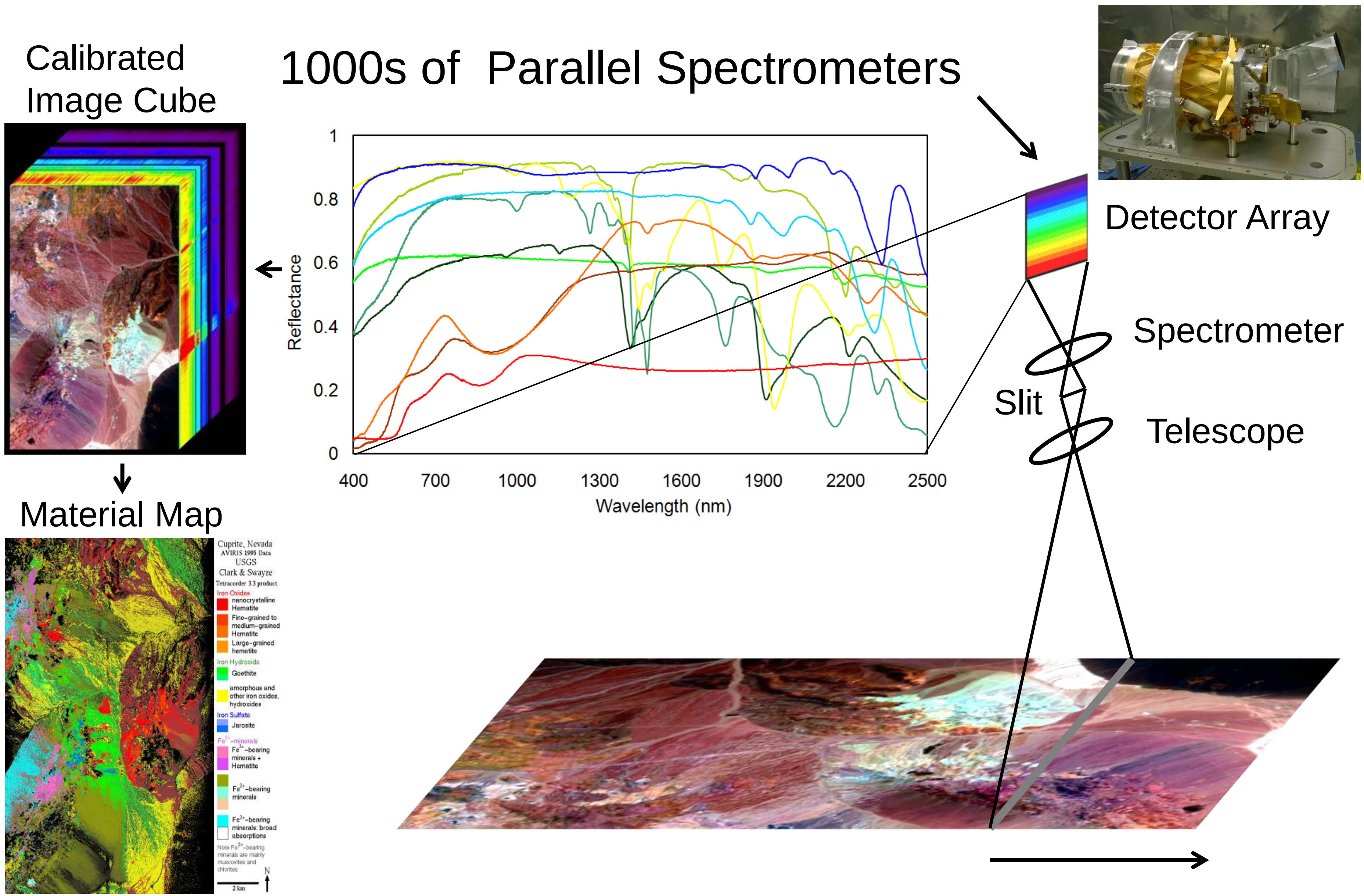
Robert O. Green, Byron van Gorp, Jose Rodriguez, Ian McKinley and the Imaging Spectroscopy Team

Jet Propulsion Laboratory, California Institute of Technology

Overview

- Imaging Spectroscopy
- VSWIR-Dyson Description
- Laboratory Tests and Calibration
- Sample Reflectance Measurements
- Vibration Testing
- Summary and Conclusions

Imaging Spectroscopy: Measurement of a Complete Spectrum for Each Sample in the Image



VSWIR-Dyson Imaging Spectrometer

- The VSWIR-Dyson demonstrates an F/1.8 optical speed, compact, wide-swath imaging spectrometer covering a 2.5 octave wavelength range from 380 to 2510 nm.
- The VSWIR-Dyson implementation is much lower volume and mass than the equivalent Offner imaging spectrometer design.
- The higher SNR and wider swath of the VSWIR-Dyson enables a new class of spectroscopically based measurements for Earth System science.
- The reduced mass and volume support deployment of the VSWIR-Dyson on a range of platforms and missions including hosted payloads
- Optical bench assembly achieves compact size and mass with total mass of ~6.5 kg.

Instrument Description

The VSWIR-Dyson is a compact imaging spectrometer system for the solar reflected spectrum (380-2510 nm) with wide swath (1600 elements), fast optical speed (F/1.8), and high uniformity (≥95%). The basic system specifications are given in below.

SPECTROMETER SPECIFICATIONS

Spectral	**Range**	**380-2510 nm**
	Sampling	**7.4 nm**
Spatial with test telescope	**Field of view**	**52 deg**
	Instantaneous FOV	**0.56 mrad**
	Spatial swath	**1600 pixels (1280 test array)**
Radiometric	**Range**	**0 – 100% R**
	SNR	**>2000 ***
Uniformity	**Spectral cross-track**	**>95% *****
	Spectral IFOV	**>95% *******

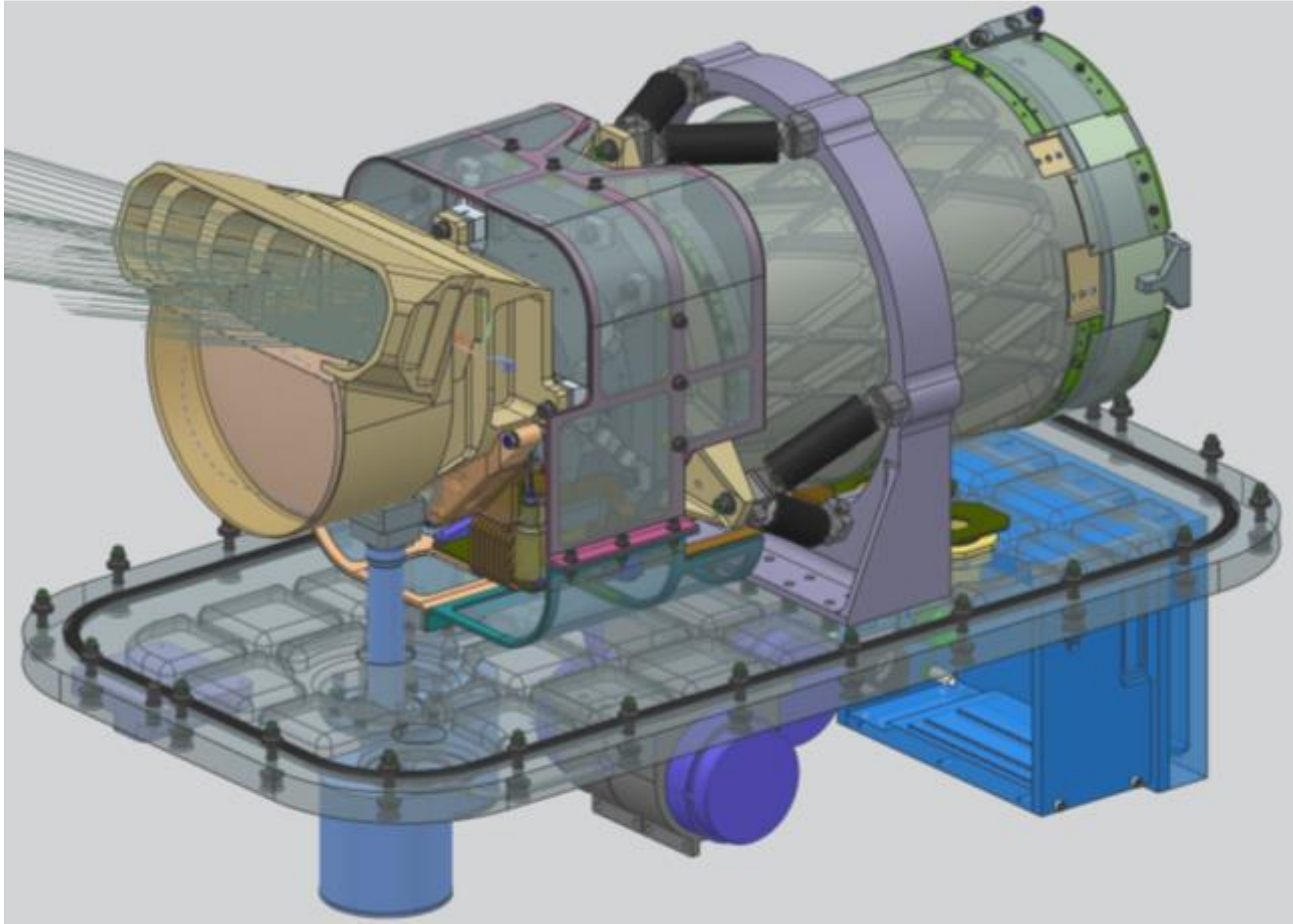
*: at an equivalent 10 nm sampling and 12 fps, reference radiance R = 0.05, 45o zenith angle.

**: straightness of cross-track monochromatic slit image (smile <3% of pixel width).

***: mis registration of spectrum to array row (keystone)

Instrument Description

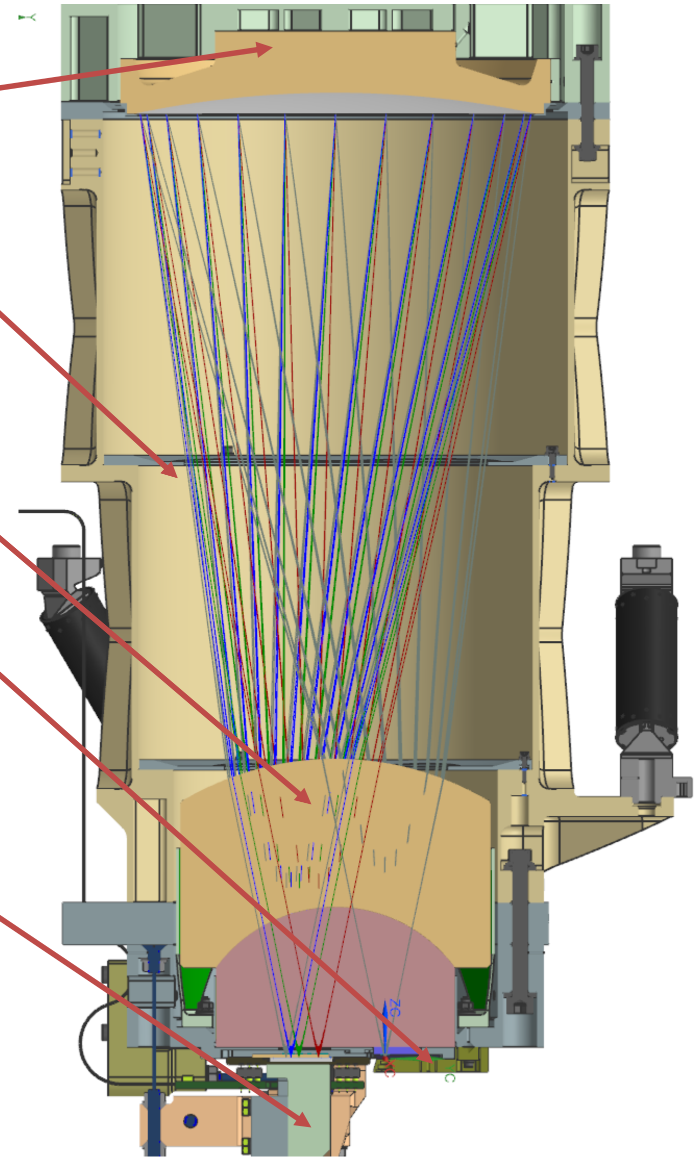
- Spectrometer optical bench and thermal hardware demonstrate low mass.
- Vacuum enclosure assembly built for cryogenic laboratory testing.
- FPA mount provides thermal isolation from the spectrometer housing.



Instrument layout showing the VSWIR-Dyson spectrometer, two-mirror laboratory test telescope, and cryo-cooler.

Instrument Description

- Spectrometer Assembly
  - Diffraction Grating Assembly (Substrate, Mount)
  - Spectrometer Bench (Bench, Baffles, Thermal Spacer)
  - Dyson Block Assembly (AL & Moly Mounts, CaF2/Fused Silica Lens)
  - Slit Assembly (Ti Mount, Blackened Si Slit)
  - Focal Plane Array Assembly (FPA, Mount, OSF)
- Spectrometer Bipods
- Spectrometer Thermal Shields (Floating, FPA 210k shield)
- Two Mirror Laboratory Test Telescope (Not shown)

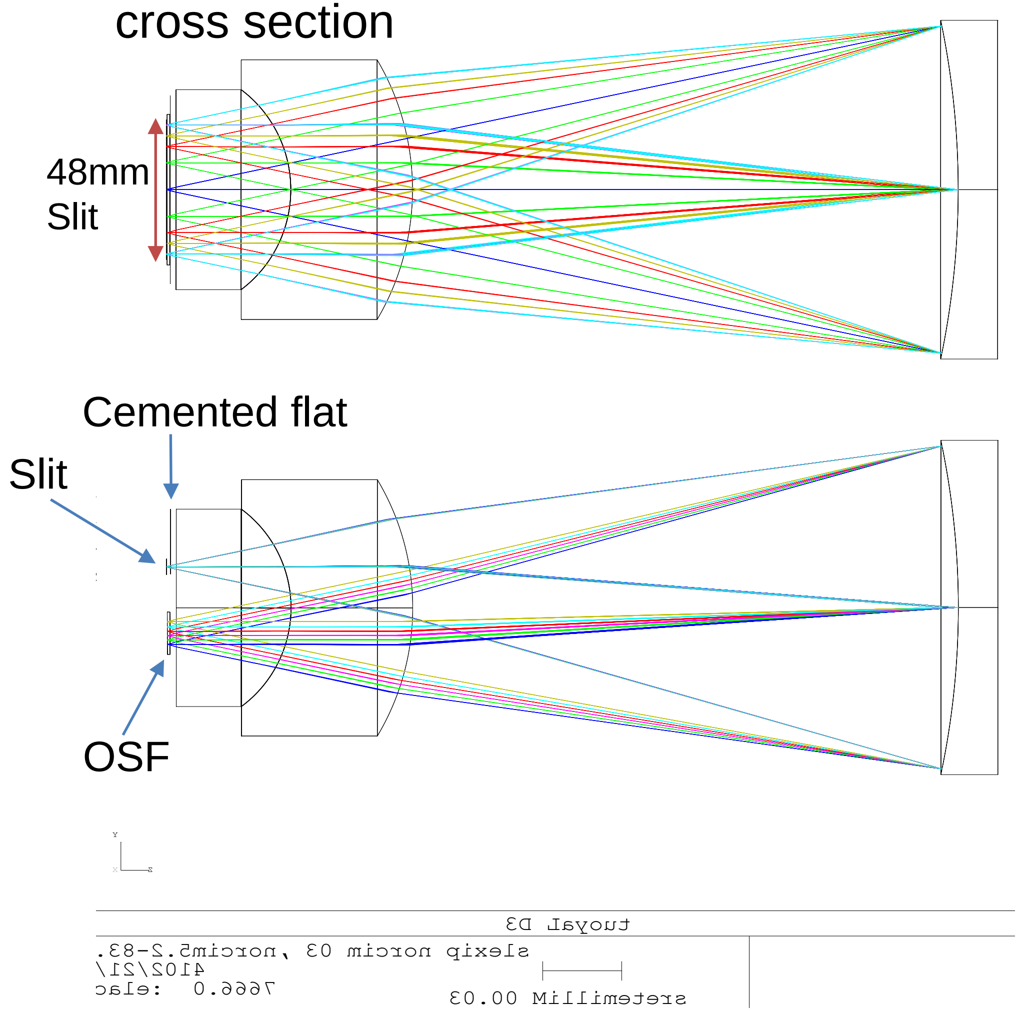


Optical Design

Spectrometer Optical Design:

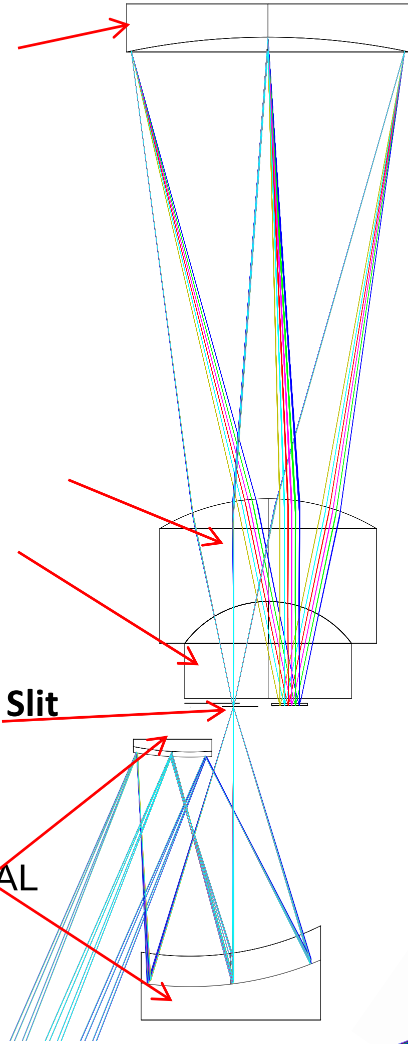
- Challenging design because of large spectral range (380-2510 nm) and wide swath (48mm/1600 pix).
- CaF_2-Fused Silica doublet was required in order to meet spectrometer uniformity requirement.
- Dyson block has one cemented flat near spectrometer input.
- Spectrometer is 325mm end-to-end with a 125mm diameter grating.
- Diffraction grating substrate is post-polished diamond turned Aluminum.

VSWIR-Dyson spectrometer ray trace; top spatial cross section and bottom spectral cross section



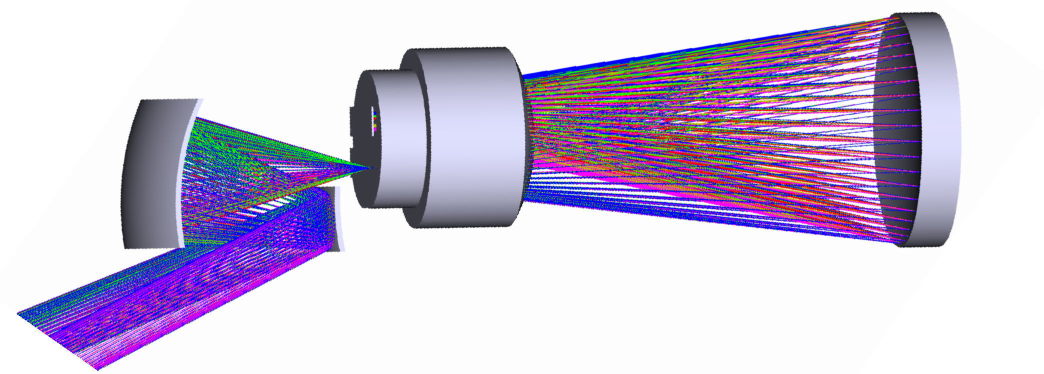
Optical Design

- **E-Beam Fabricated Grating**
- **Dyson Block Doublet**
  - Fused Silica meniscus lens
  - CaF_2 Plano Convex Lens with Cemented Flat
- **E-Beam Lithographic Slit**
- **Test Telescope Mirrors**
  - Glass Substrates w/ AL Coating



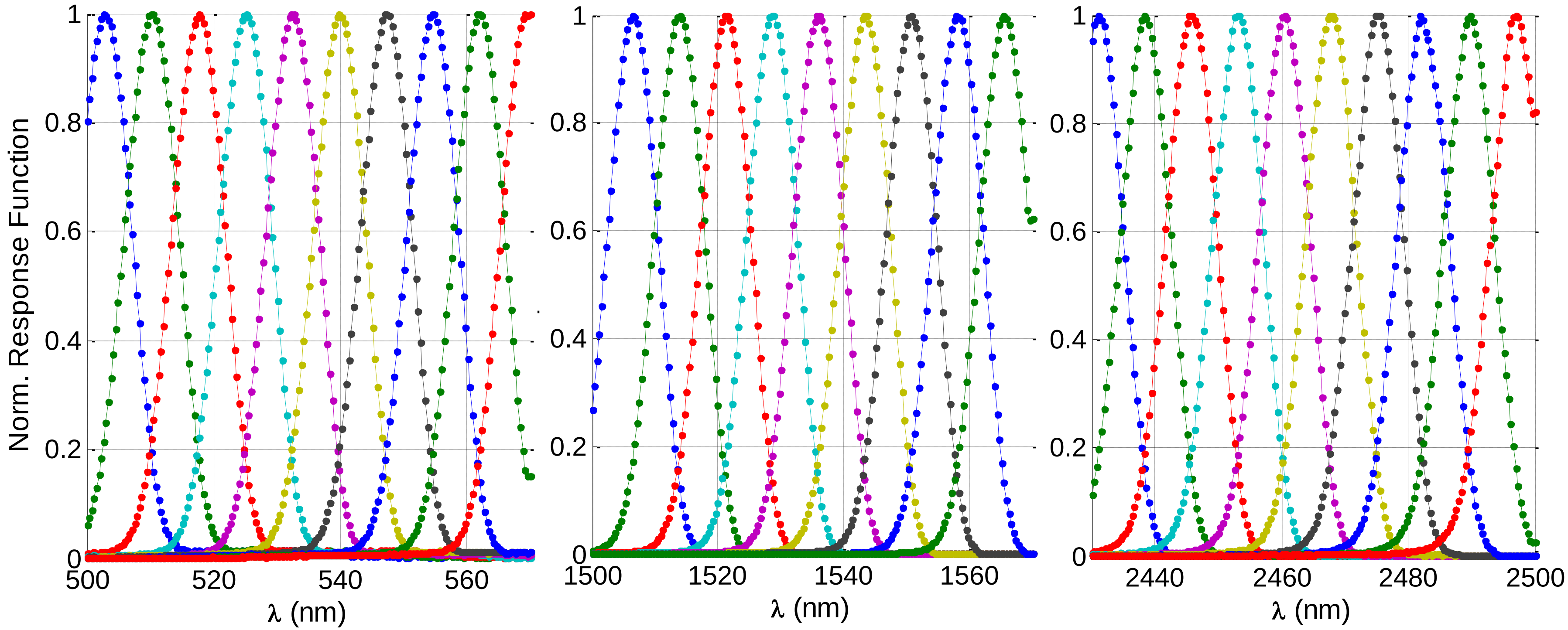
Optical Design Key Characteristics:

- Minimum number of optical components for high throughput
- Compact Wide-Field design
- Specially designed grating groove profile to tune SNR, reduce polarization dependence and minimize energy in negative orders
- Low angles of incidence on optical components



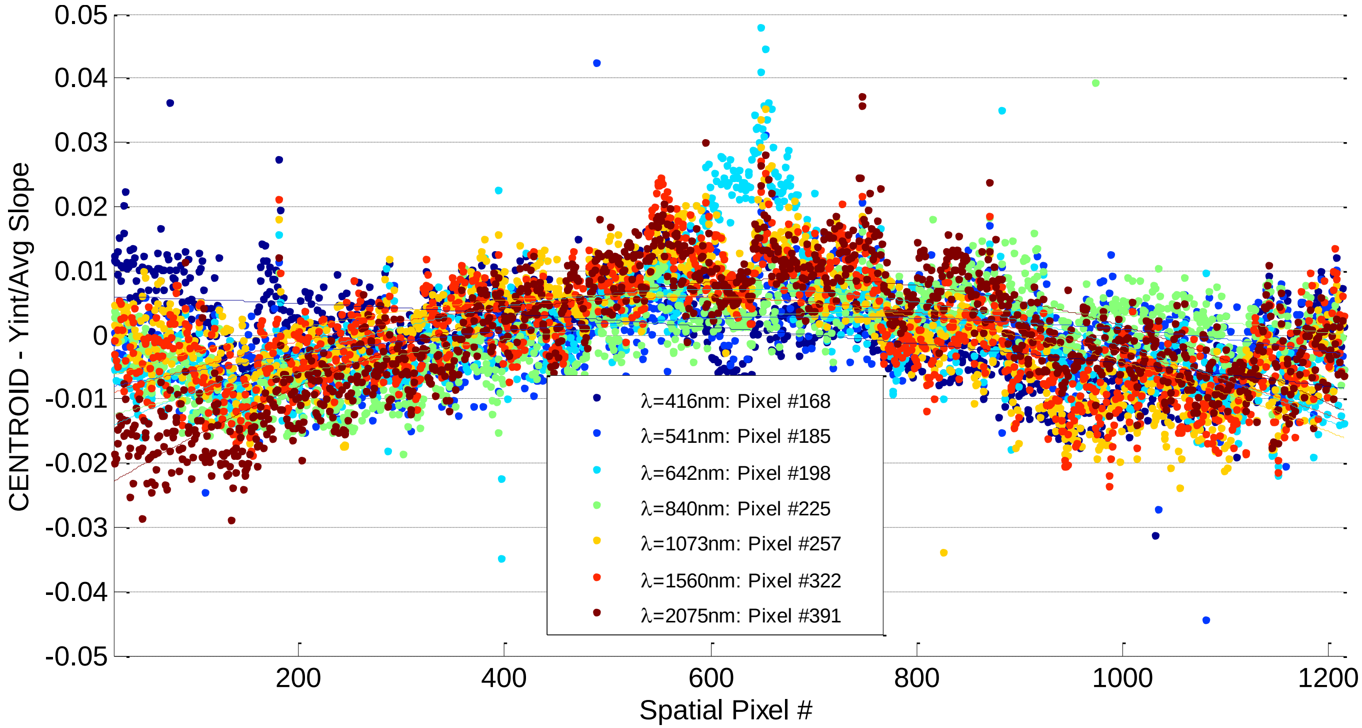
Laboratory Tests and Calibration: SRF

- SRF's are normalized to unity and compiled with measurements throughout the field; excellent through-field FWHM uniformity is demonstrated.
- Representative SRF below; other field positions and wavelength SRF's are similar.



SRF's (Spectral Response Functions) for the middle of the field of view centered at 535, 1535, and 2465nm.

Laboratory Tests and Calibration: Cross-Track Spectral Uniformity

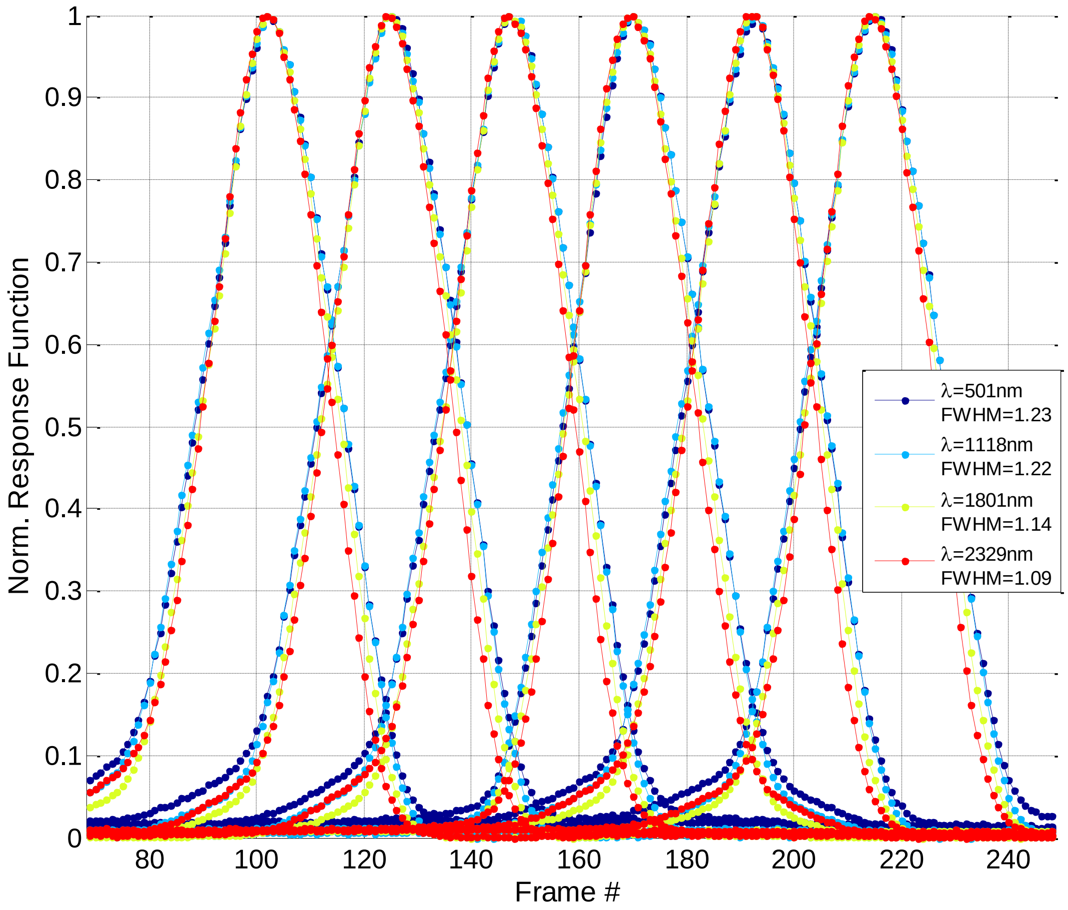


Plot above shows the spectral alignment and of the curvature (smile) of a monochromatic slit image.

The inherent cross-track spectral uniformity is ≥95% or less than 5% smile.

Laboratory Tests and Calibration: CRF

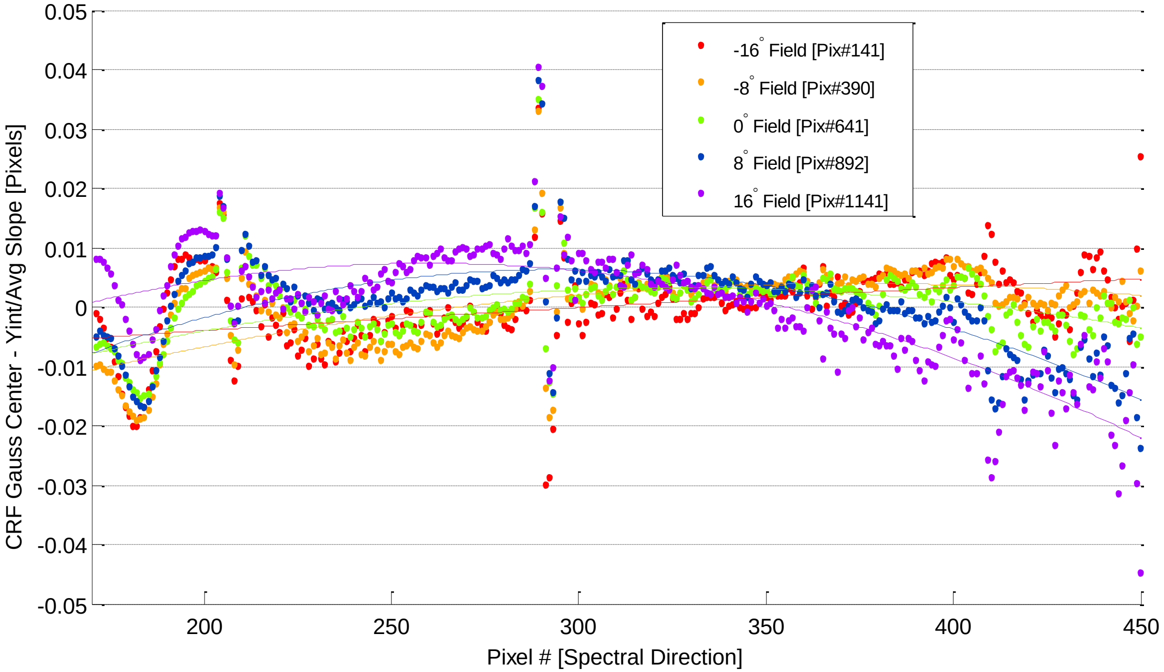
- Spatial characteristics established through cross and along track spatial response functions (CRF and ARF).
- Scan sub-pixel slit, at focus of collimator illuminating the instrument aperture, oriented either parallel (ARF) or perpendicular (CRF) to the spectrometer slit.
- Representative CRF's are shown for adjacent pixels with wavelengths spanning the spectral range.
- The IFOV uniformity and alignment meets requirements



Cross-track spatial response functions for 0 degree field, nominal telescope focus.

Laboratory Tests and Cal.: Keystone

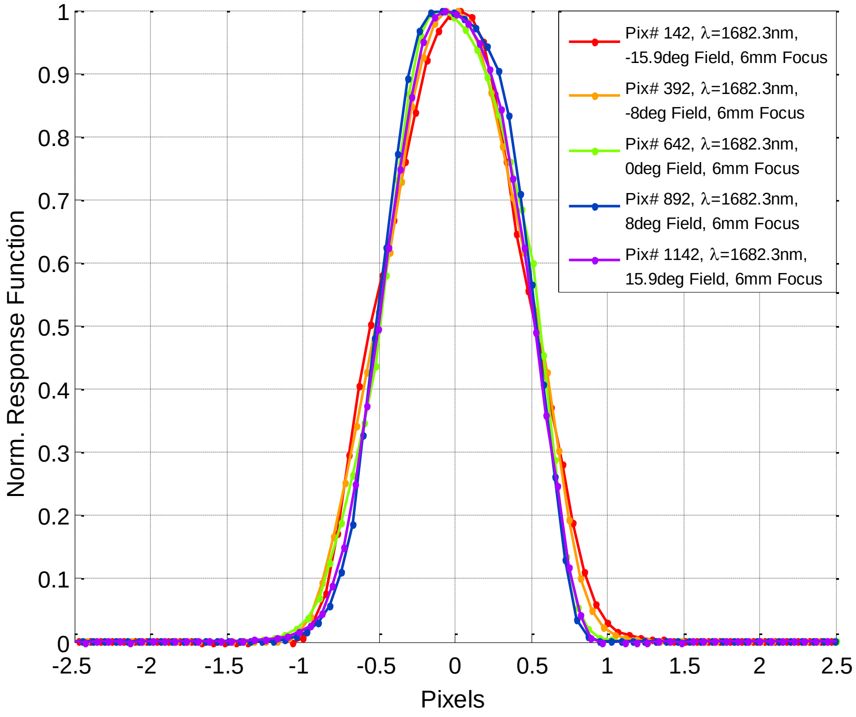
- Keystone measurement made with spectrally broad point source forming a line in the dispersion direction.
- Point source is scanned in cross-track direction (CRF) and centroid location of the resulting distribution is measured.
- Corresponding centroids plotted against spectral channel, the points cluster within the ±2% band.
- The inherent spectral IFOV uniformity is ≥95% (or below 5% keystone).

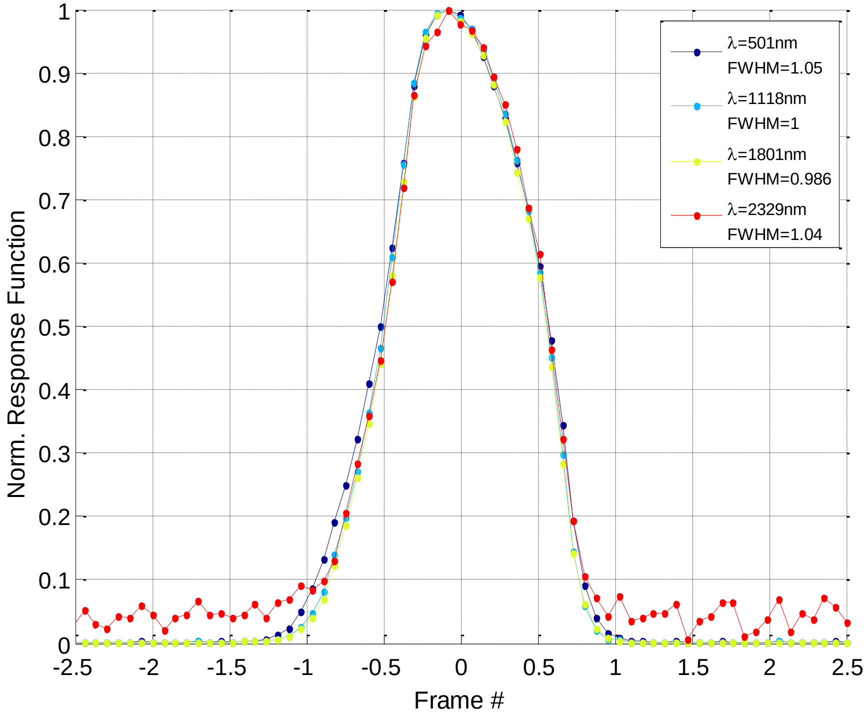


Cross-track response function centroid's versus spectral channel for five fields

Laboratory Tests and Calibration: ARF

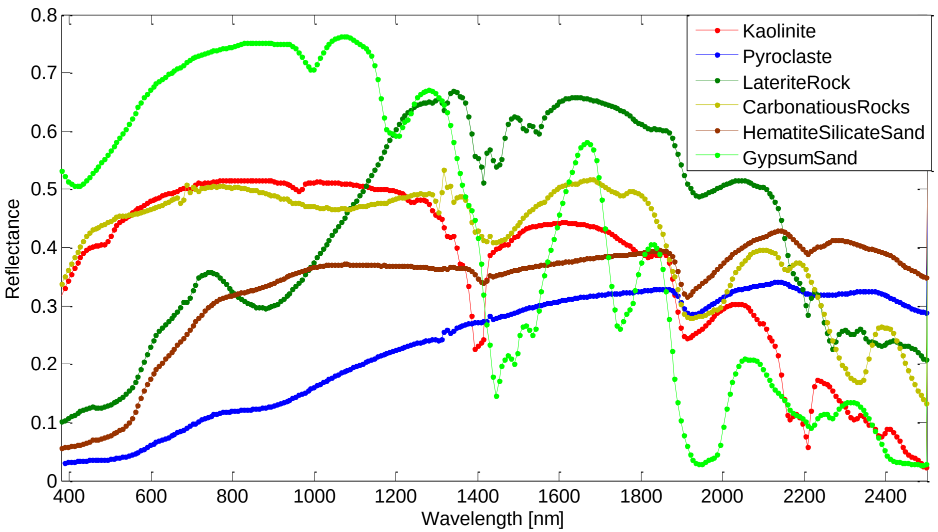
- The telescope response (along scan direction) was measured at several different spatial fields.
- Along-track response functions for several field positions and one wavelength (left), and for a single field/several wavelengths (right).
- Representative ARFs show small variation through wavelength and all field positions.

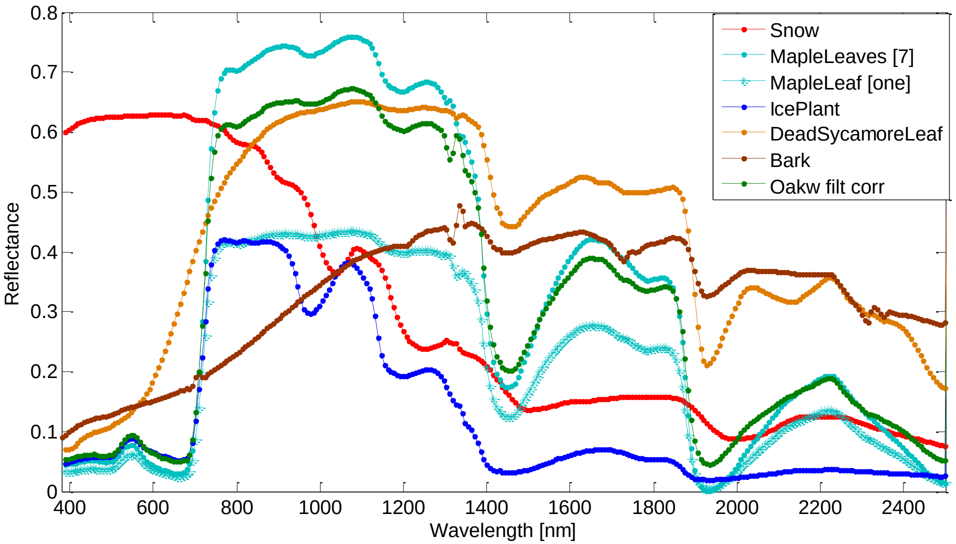




Sample Reflectance Measurements

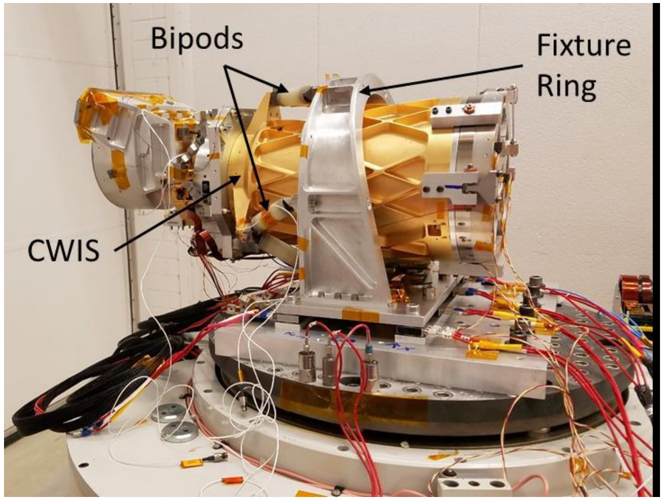
- Figure (top) shows measured spectra of several minerals [Kaolinite, Pyroclast, Laterite, Hematite and Gypsum].
- The reflectance curve has been processed using a Richardson-Lucy algorithm, in order to correct for spectral response.
- Figure (bottom) shows measured spectra of several organic samples [Snow, Maple Leaves, Ice Plant Succulent, Dead Sycamore Leaf, Bark and Oak].
- Concurrent spectra were take with an ASD spectrometer. Both show nearly identical results.



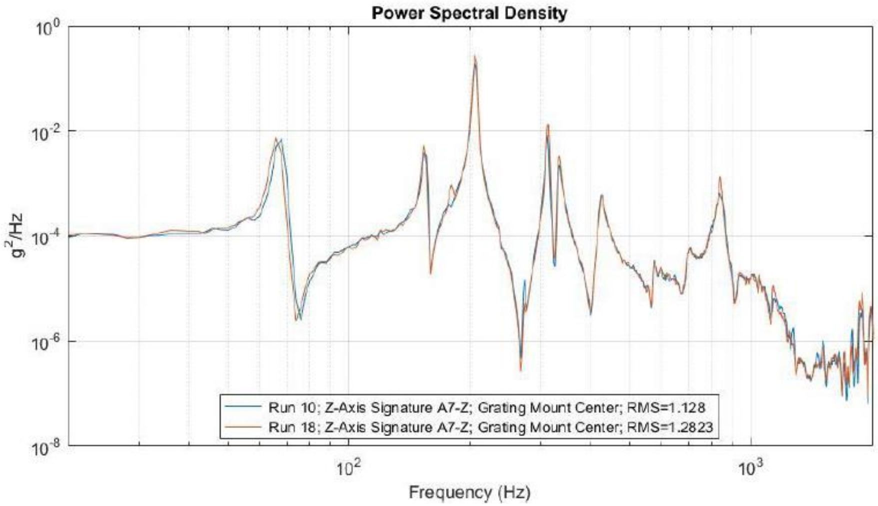


Vibration Testing

- To assure viability for a space mission the VSWIR-Dyson was subjected to vibration testing in the Autumn of 2016.
- The integrated VSWIR-Dyson on the vibration table during vibration testing to GEVS levels. Fifteen accelerometers and six force transducers capturing input and response levels at 13.5 and14grms.



Example vibration testing



- Following vibration testing the VSWIR-Dyson was returned to the laboratory for alignment and calibration testing. The alignment remained within specification.

Summary & Conclusions

- A VSWIR-Dyson imaging spectrometer has been designed to support a range of potential NASA space missions including HyspIRI.
- The instrument measures the spectral range from 380 to 2510 nm with F/1.8 optical throughput and high uniformity (≥95%) and accommodates a wide swath of up to 1600 samples. An array with 1280 samples has been used for testing. A scaled dual VSWIR-Dyson can support > 6000 samples.
- The VSWIR-Dyson is currently equipped with a laboratory test telescope that is expected to be replaced with the appropriate flight telescope as required.
- The VSWIR-Dyson has been aligned, calibrated and characterized at cryogenic temperatures.
- To demonstrate viability for space flight, the VSWIR-Dyson was subjected to random vibration testing in the Autumn of 2016.
- Post vibration testing shows the instrument remained within specifications and this VSWIR-Dyson design and implementation is suitable for use in a space mission.