National Aeronautics and Space Administration

Next Generation Infrared Spectrometers for Solar System Exploration

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Next Generation Imaging Spectrometer**

Objectives: to design, develop and demonstrate a micro VSWIR+MWIR Dyson Imaging Spectrometer (VMDIS) (~0.6-3.6 μm) based on the new digital readout CHROMA 18 μm pitch detector array with 512 spectral channels and 1024 spatial elements for orbital, flyby and landed/roving missions requiring full imaging spectroscopy (this delivers the performance of 1024 point spectrometers in image format) with mass <8 kg, power <40 W, and volume ≤3U, SNR ≥100. This instrument would be able to perform key science, specifically composition with imaging in a small-spacecraft package for volatile and mafic mineral mapping on the Moon, asteroids, Mars.

Over three years, this initiative focused on 4 Infrared Imaging Spectrometers that maintain JPL's competitive advantage for anticipated mission opportunities over the next 1-2 decades. The overall objective is achieved via 4 focused tasks that develop state-of-the-art, low resource requirement instruments that also take advantage of JPL unique technologies (HOTBIRD detector, thermopile detector, e-beam gratings, etc.).

- **Midwave-infrared and Longwave-infrared Point Spectrometer (MLPS) [FY19]**
- **Visible Midwave Dyson Imaging Spectrometer (VMDIS) [FY 19-20-21]**
- **Compact Imaging Fourier Transform Spectrometer (CIFTS) [FY19]**
- **Planetary Hyperspectral Thermal Emission Spectrometer (pHyTES) [FY19-20]**

This year's sole focus was on VMDIS.

Background: Infrared spectrometers are required to address key Decadal science, especially in the areas of (1) history of small bodies and their use as tracers of solar system reorganization, (2) reservoirs of volatiles on Mars, the Moon, Icy Satellites, and asteroids, and (3) composition, including salt and organic content of ices in the outer solar system. A decade of first generation space imaging spectrometers generated key discoveries (NIMS, VIMS, OMEGA, CRISM; M3). However, limited spectral ranges have limited their ability to decipher a target's full compositional and thermal history. Additionally, current spectrometers are too large to take advantage of SmallSat, CubeSat, and landed missions that would open up many more mission opportunities. A next generation of more capable spectrometers is therefore needed.

This Initiative responds to these needs by addressing two key challenges in Spectroscopy:

(1) Mapping of minerals, volatiles, organic distributions, and thermal properties on comets, asteroids, rocky moons, icy moons, and other solar system targets, via full spectral access from ~0.35 to 13 microns.

(2)Miniaturization for low cost mission platforms (e.g. can be proposed through SIMPLEx and on mass-constrained landers/rovers)

Significance/Benefits to JPL and NASA: Future opportunities for these spectrometers include: SIMPLEx smallsat mission proposals, Discovery Announcements of Opportunity (AOs) that are released every ~2-4 years, and New Frontiers AO that are released every ~3-4 years. These next generation imaging spectrometers may also support future science instrument investigations as part of directed and Flagship missions. At the conclusion of this project, both the MLPS and the VMDIS instrument are at TRL 6 and are ready for inclusion in a range of future solar system exploration science instrument opportunities.

Publications: P. Mouroulis et al, "Compact imaging spectrometer for planetary missions", SPIE Proc. 11504, 1150406 (2020) https://doi.org/10.1117/12.2568062

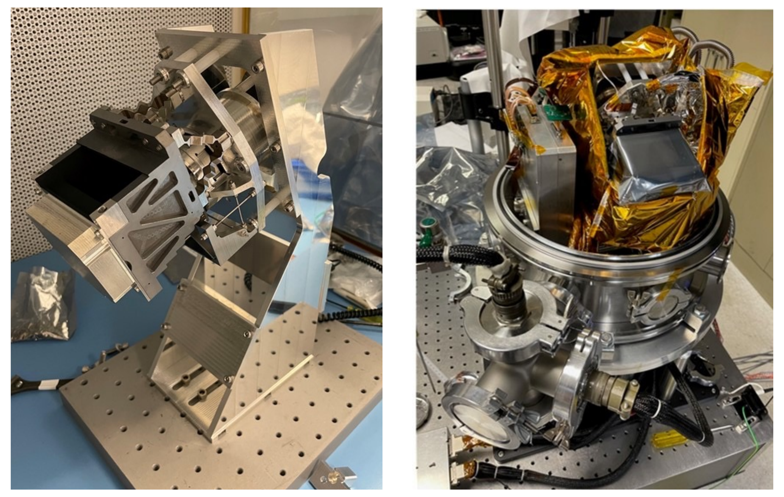
Approach and Results

The VMDIS instrument comprises a miniature athermalized metal/glass telescope with a field of view of 32°, a miniature Dyson imaging spectrometer with an aspheric CaF_2 element and an e-beam structured groove grating that optimizes performance throughout the extended 0.6-3.6 wavelength band. An additional critical element is a lithographically formed slit of 18mm width by 18mm length uniform and straight over the entire length to ~1% of its width. Grating and slit are fabricated at JPL's Microdevices Laboratory, while the aspheric CaF_2 element and telescope mirrors were provided by external vendors.

This year's goals and milestones, all of which have been achieved, were to fabricate the slit and grating, complete telescope and spectrometer optical and optomechanical assemblies, test the instrument in a custom vacuum chamber under cryogenic conditions, and demonstrate the performance through measurements.

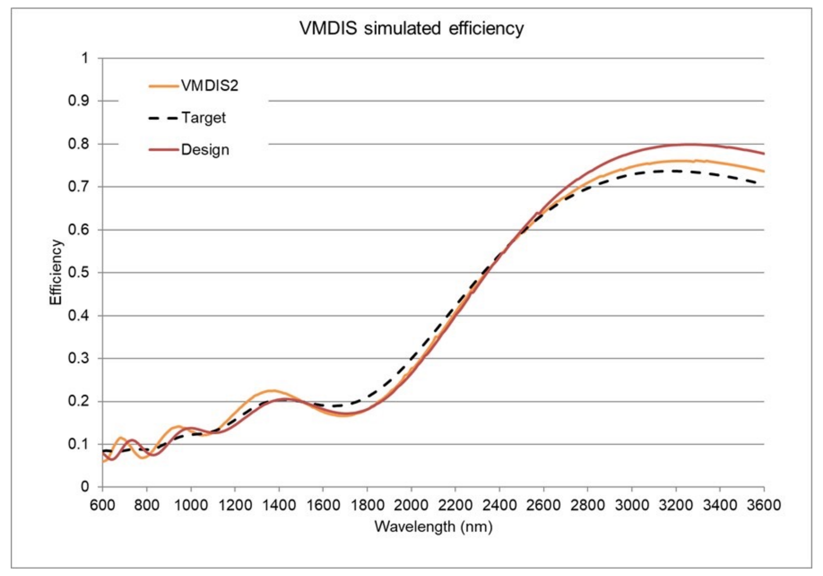
- Two gratings were delivered with similar performance, fabricated by Drs. Daniel Wilson and Sander Zandbergen, and two slits were delivered (Victor White, Karl Yee).

VMDIS aligned and room temperature and preparing for thermal-vac testing



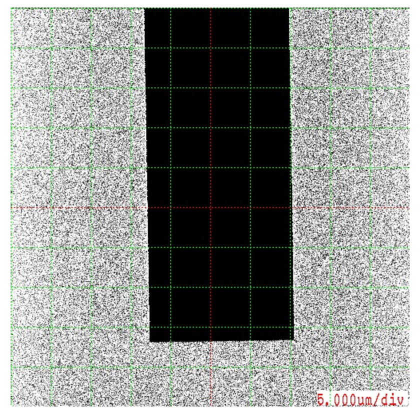
(left) VMDIS optomechanical assembly, showing telescope, spectrometer and detector. (right) VMDIS in vacuum chamber in preparation for cryogenic testing.

VMDIS Grating Efficiency



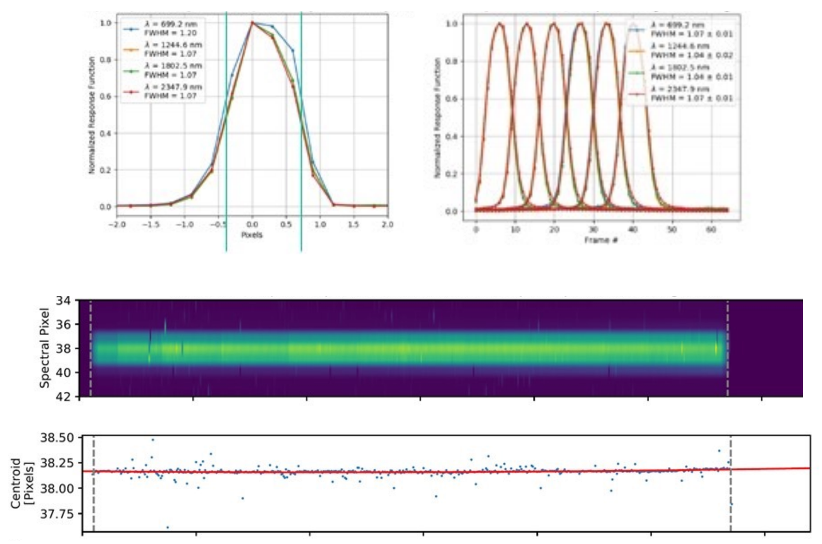
the measured efficiency of the E-beam grating, ("VMDIS2") shows excellent approximation of the desired shape through wavelength, which is optimized towards the long wavelength end to compensate for the dearth of solar photons in that region.

VMDIS Slit



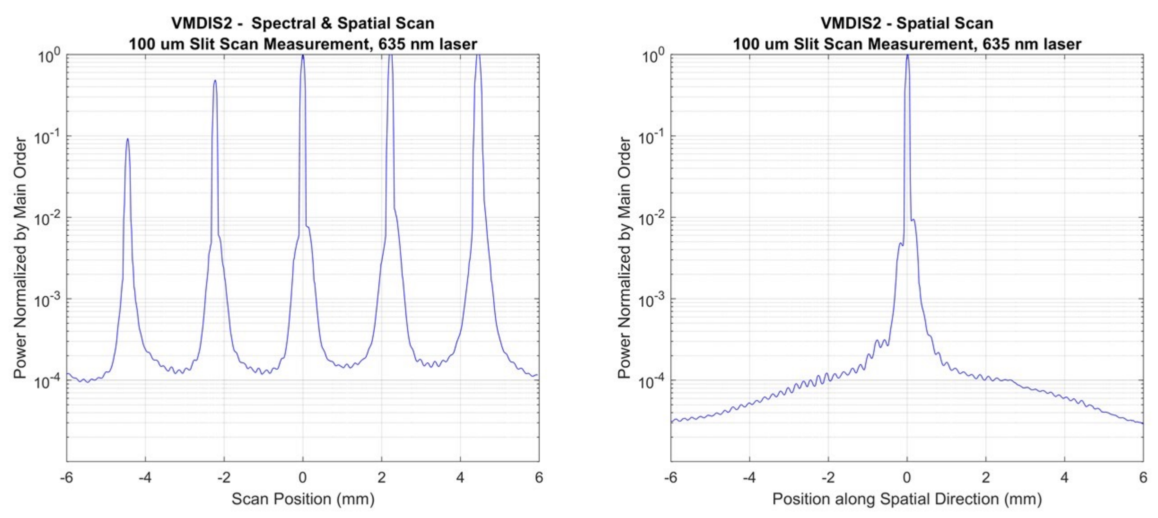
Microphotograph of the VMDIS slit (width ~18mm) shows outstanding definition and uniformity. The slite is formed on a silicon wafer coated with silicon nitride. The silicon is etched to form a rough absorbing surface and reduce stray light.

Spectral and Spatial Response at Operating Temperature



VMDIS spatial and spectral response at operating temperature (~180K detector, 220K spectrometer). Top left" Along-track spatial response, Top right: cross-track spatial response for several adjacent pixels. Colors represent different wavelengths. Bottom: image of laser line spanning entire field, and graph of line centroid as a function of field, demonstrating uniformity better than 10% of a pixel.

VMDIS Spectral & Spatial Grating Performancez



The measured scatter performance of VMDIS structured groove grating shows excellent stray light suppression between orders (left) and in the spatial direction (right). And is among the best achieved.

- The instrument was assembled and aligned at room temperature .
- A simplified spectrometer assembly method was tried utilizing only a measuring microscope and appropriately fabricated alignment spacers; the method proved successful and can be utilized in future instruments (spectrometer assembly and alignment: D. Preston).
- The telescope was aligned interferometrically and achieved its expected performance throughout the field (P. Mouroulis and Z. Small). Subsequent cryogenic testing demonstrated that the performance was maintained, thus proving expected athermalization.
- A CHROMA detector was integrated and pre-aligned with mechanical means (D. Preston).
- Thermal connections, thermal straps, cryocoolers, and control system were added and a custom vacuum chamber was tested (Mason Mok).
- Flex cable and detector electronics were added and tested (C. Sarture and P. Sullivan). Appropriate test optics were implemented to provide the instrument test stimulus (Y. Beregovski). The tests were orchestrated and conducted by Dr. Quentin Vinckier.
- Cryogenic testing demonstrated the spatial response function of the system in cross-track and along track direction as well as the spectral response to a laser line covering the entire field of view. The spatial response functions are only a little wider than the minimum of 1 pixel (~1.2) at the appropriate focus location, when a typical system can tolerate up to 1.5. Chromatic variation of the spatial response functions is small, within tolerance for a high performance system. The laser line is narrowly focused on primarily a single pixel and the its image remains straight within better than 1/10th of a pixel, indicating excellent spectral uniformity.

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