Imaging Spectrometer Implementation on a Small Satellite Platform for Aquatic Ecosystems Science

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Science/Mission Payloads – Small Satellite Conference

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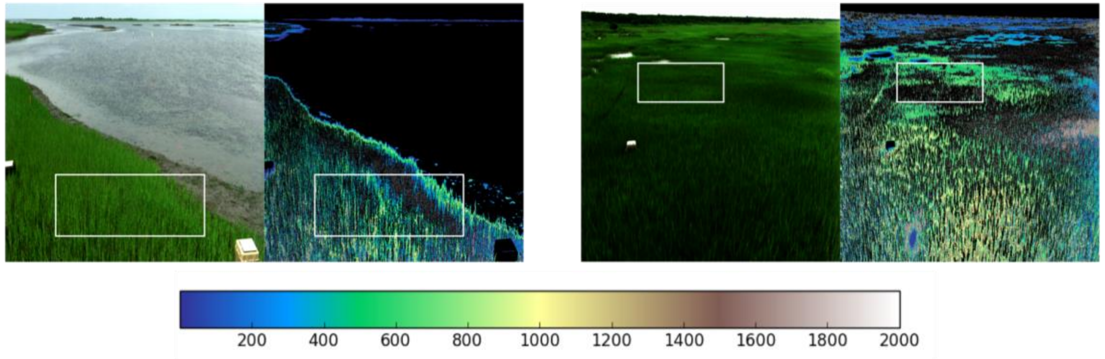
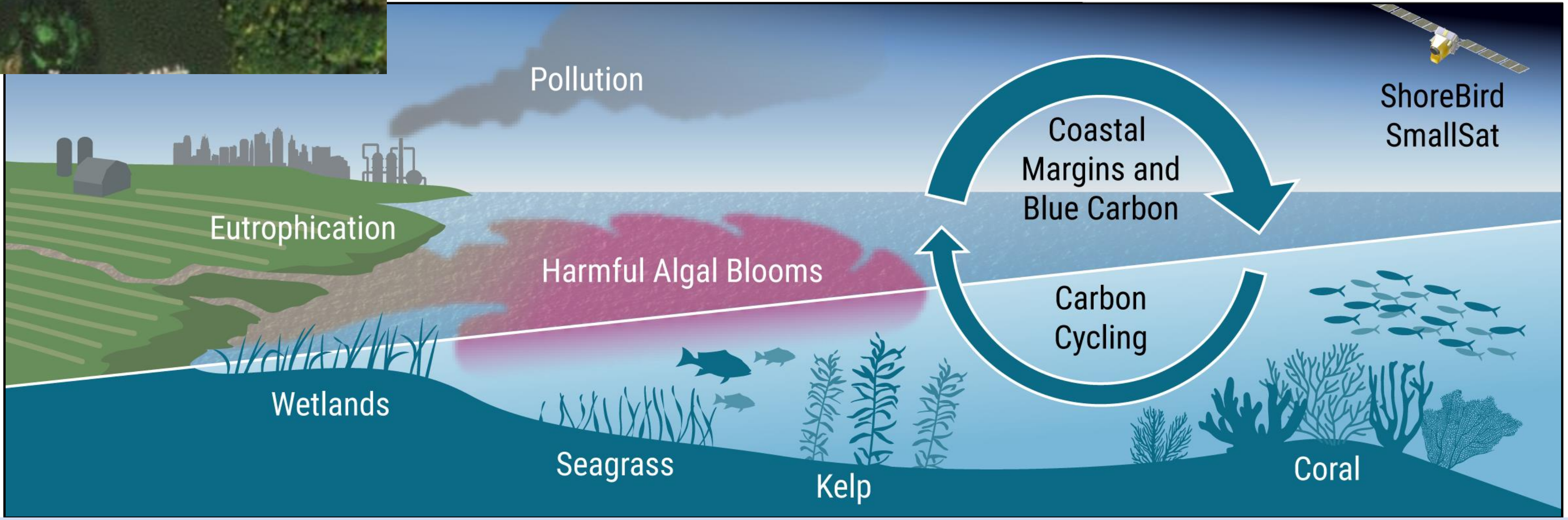
Coastal Zone Remote Sensing

Quantifying Above Ground Biomass & Carbon Storage





Changes to coastal ecosystems impact human health, food, water, safety, and global climate change

Eon et al. https://doi.org/10.3390/rs11111385

Challenges of Space-Based Hyperspectral Imaging

Spectral Sensing Challenges	Optical System Requirements
Varying reflectance of scene content	High dynamic range (9000:1)
Resolution of boundaries between ecosystems	Small ground sample distance (≤ 30 m)
Signal dominated by radiance from the atmosphere	High signal-to-noise ratio (> 250)
Large spectral bandwidth	VNIR – SWIR (380 – 2500 nm)
Species identification and discrimination	Spectral resolution (≤ 10 nm)

CONOPS Challenges	Mission Requirements
Monitoring transient environmental conditions	Short revisit times
Global coverage	Wide swath width and/or constellations

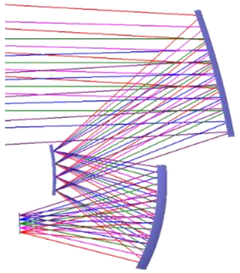
Outline

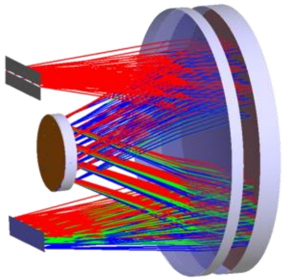
- Aquatic Ecosystem Science from Space
- ➡ Enabling Technologies for SmallSat HSI
- SmallSat Instrument Design
- Predicted System Performance
- Summary & Next Steps

HSI – Hyperspectral Imaging

Enabling Component Technologies for SmallSat HSI

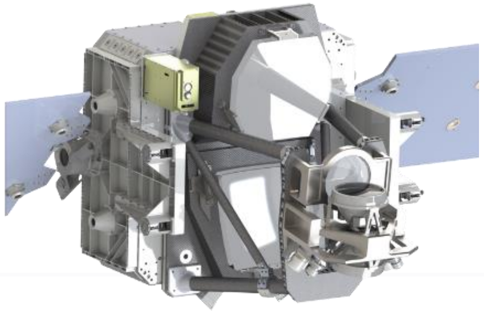
Novel Optical Designs


Freeform Telescope

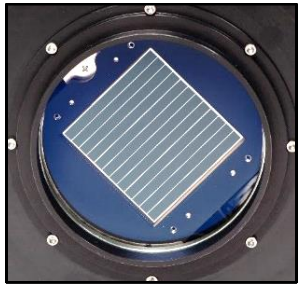

Compact Spectrometer

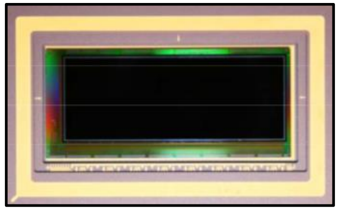
Future HSI Systems

- Wide bandwidth
- High resolution
- Rideshare compatible

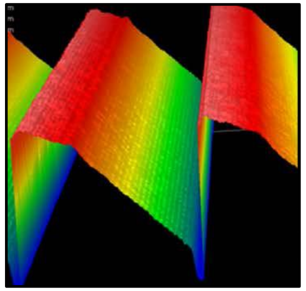


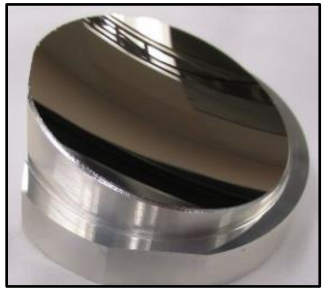
Focal Plane Advances



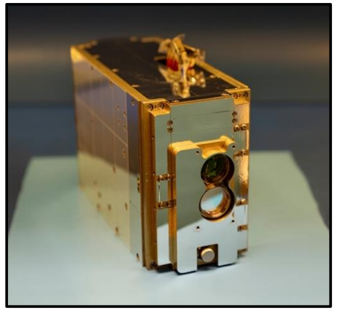


Fabrication & Metrology Techniques





Data Handling & Communications



HSI – Hyperspectral Imaging

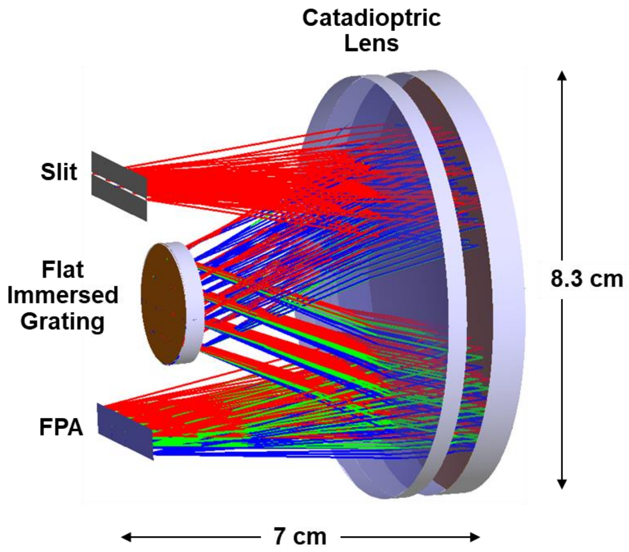
Chrisp Compact VNIR-SWIR Imaging Spectrometer (CCVIS)

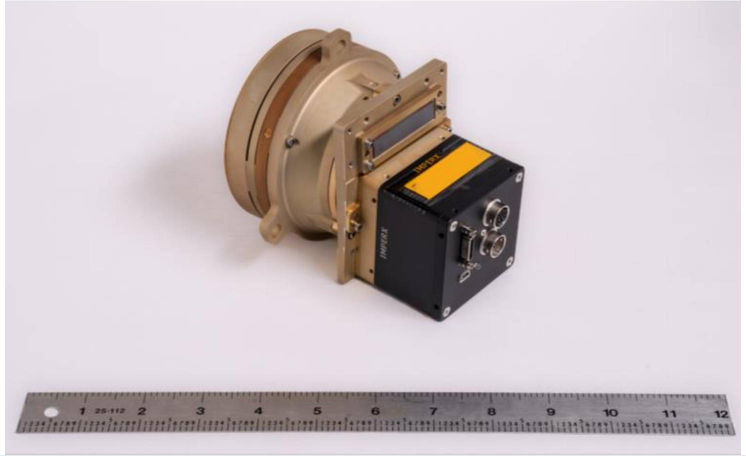
Unique Design Features

- Excellent aberration control
- Spectral accuracy and precision
- Small SWaP (×11 smaller than state-of-the-art)
- Flat grating that is easily manufactured
- Thermally and mechanically stabilized
- Modular implementation

Design Parameter	Predicted Performance
Spectral range	380 - 2500 nm
Spectral resolution	10 nm
SNR	> 400 (380 – 1100 nm); > 250 (1100 – 2500 nm)
Spatial-spectral uniformity	± 0.5 µm
Spatial samples	1600

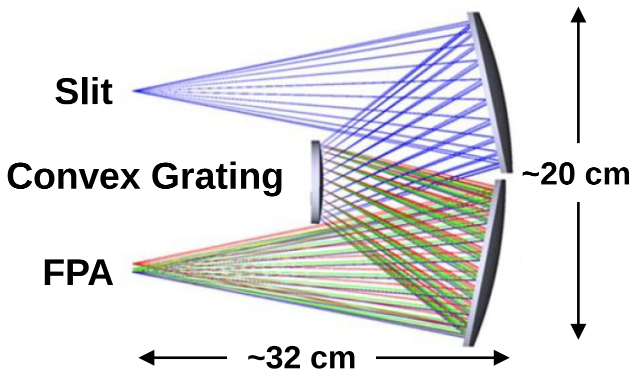
Lincoln Patented Invention





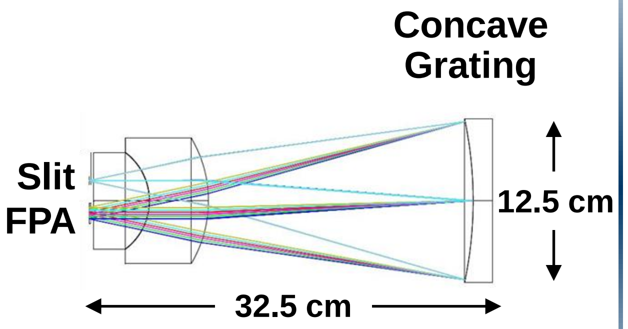
CCVIS Compared to Current State of the Art

JPL HyspIRI



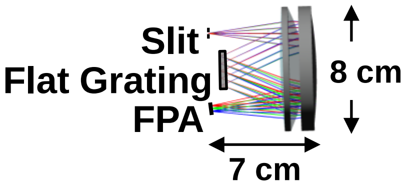
H. Bender et al.
https://doi.org/10.1117/12.2062768

JPL CWIS



B. Gorp et al.
https://doi.org/10.1117/12.2062886

LL CCVIS

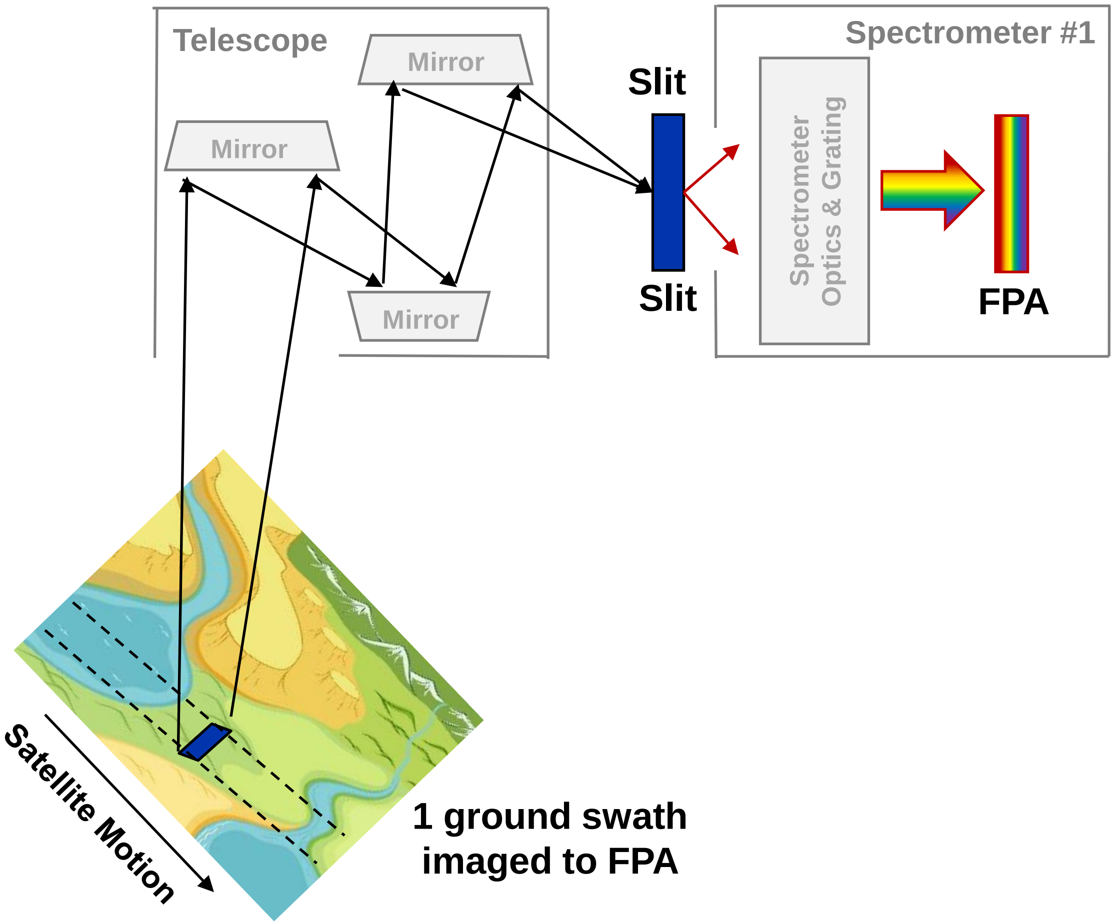


	HyspIRI	CWIS	CCVIS
Spectral Bandwidth (nm)	380 - 2500		
Optics	All reflective	Reflective & refractive	
F-number (limit)	2.8	1.8	2.3
Dual-blaze Grating	Convex	Concave	Flat
Volume (cm3)	~6400	3988	352

JPL - Jet Propulsion Laboratory
HyspIRI - Hyperspectral Infrared Imager

CWIS - Compact Wide-swath Imaging Spectrometer

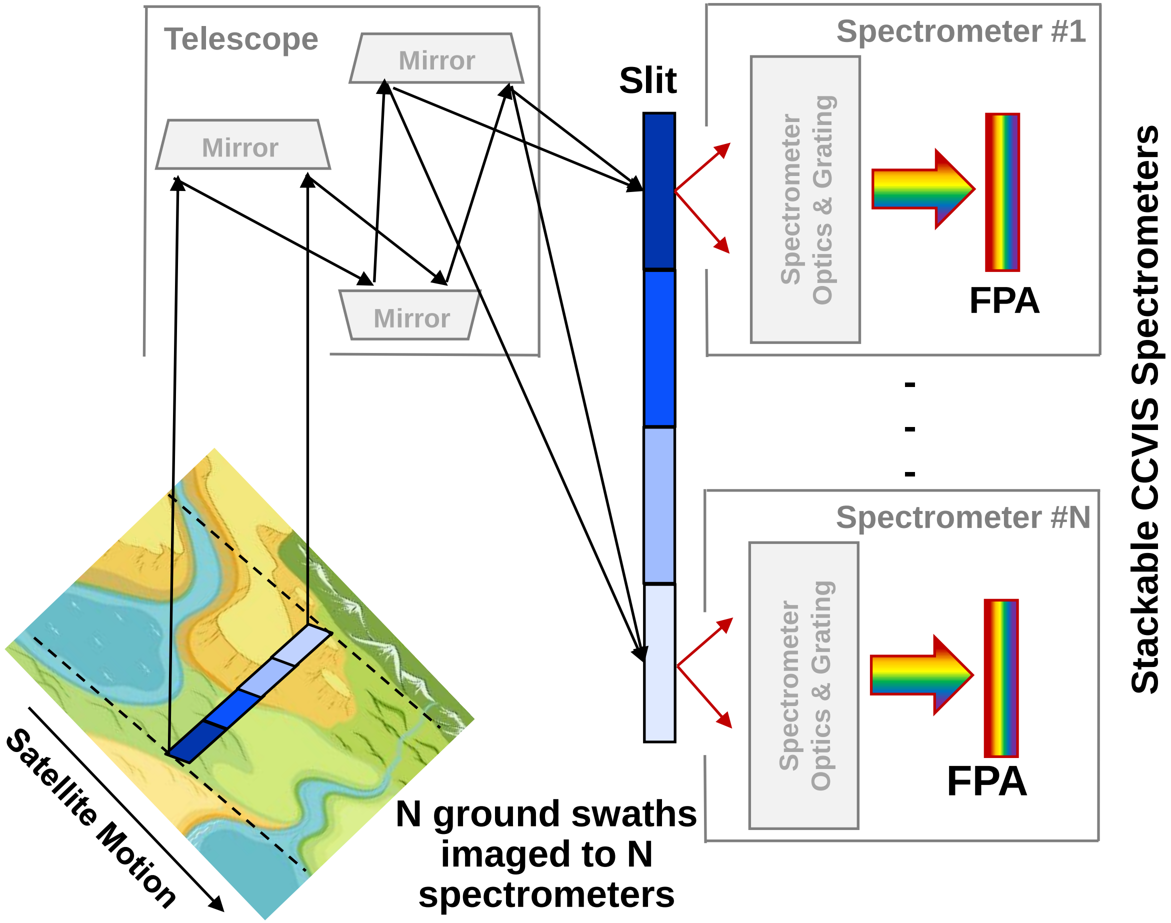
Stacking For Large Swath Hyperspectral Imaging



1 ground swath imaged to FPA

FPA – Focal Plane Array

Stacking For Large Swath Hyperspectral Imaging

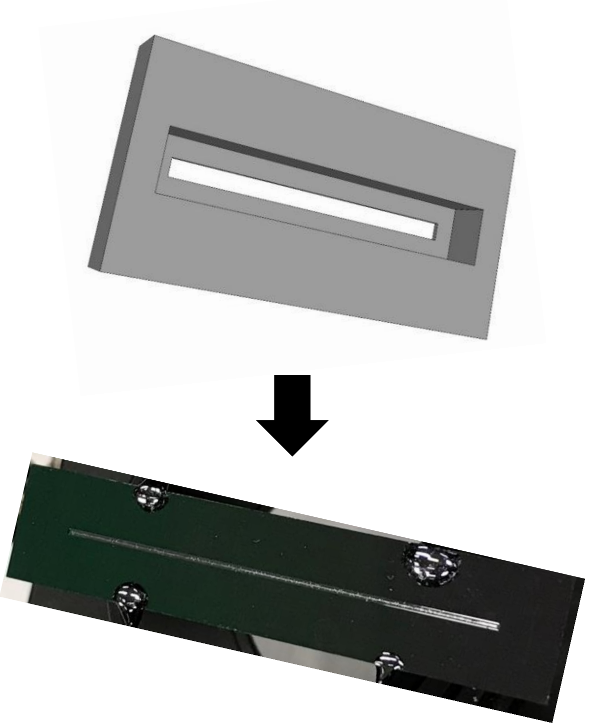


Stacked CCVIS spectrometers get much larger effective swath width and maintain resolution using a single wide field telescope

FPA – Focal Plane Array

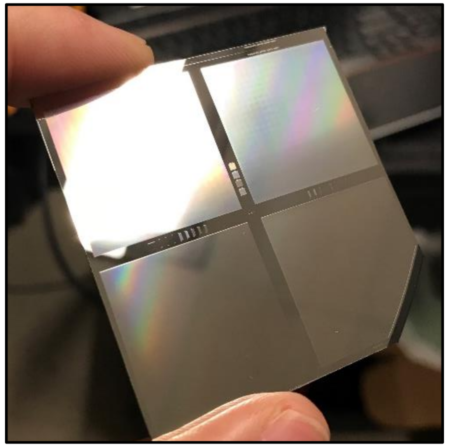
Fabrication of Slit and Dual-Angle Grating

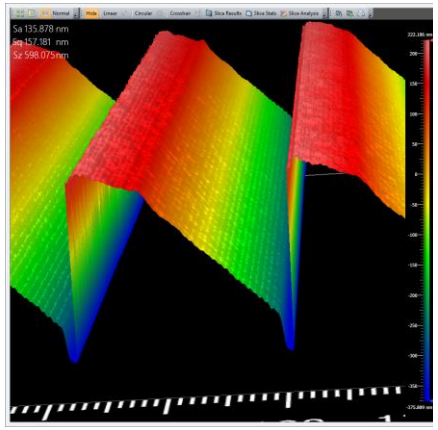
Slit Fabrication
Slit Parallelism ~ 100nm

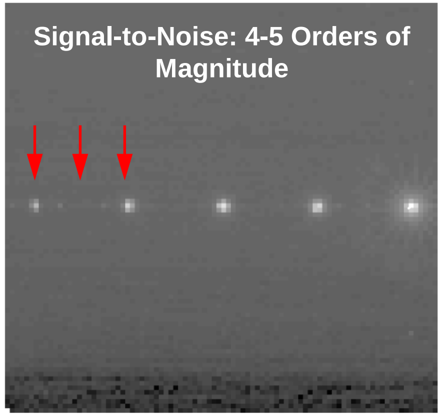


Grayscale Photolithography
Surface RMS ~ 3.5 nm

Dual-Angle Grating





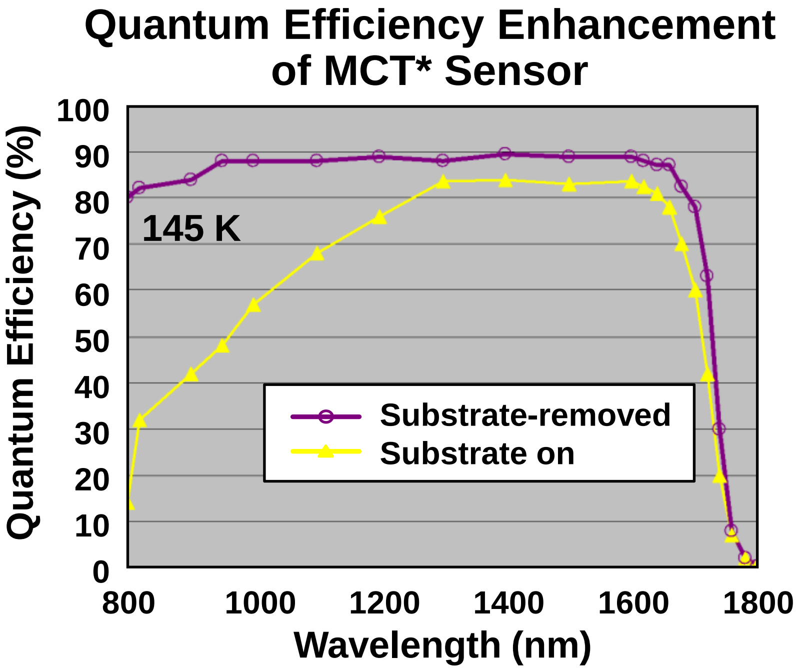


Signal-to-Noise: 4-5 Orders of Magnitude

Grayscale photolithography fabrication process enables high performance, low cost spectrometer gratings and slits

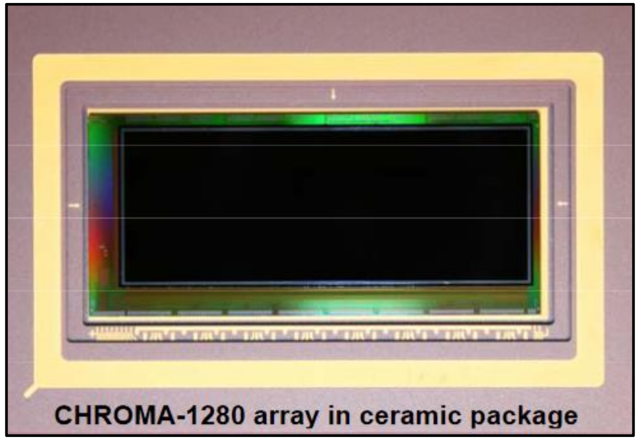
[1] M. A. Smith et al., “Design, simulation, and fabrication of three-dimensional microsystem components using grayscale photolithography,” J. Micro/Nanolith. MEMS MOEMS, vol. 18, no. 04, p. 1, Nov. 2019, doi: 10.1117/1.JMM.18.4.043507.

Broadband Focal Plane Array Technology



Jerram, Beletic; https://doi.org/10.1117/12.2536040

Teledyne CHROMA Sensor



CHROMA-1280 array in ceramic package

https://www.Teledyne-si.com/products/Documents/CHROMA%20Brochure%20-%20rev%201%20v5%20-%20OSR.pdf

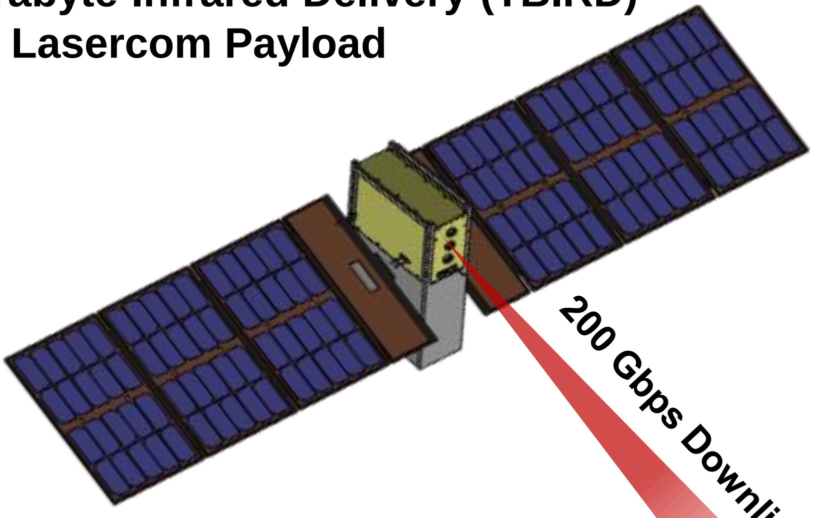
- **Substrate-removed MCT allows for sensitivity over broad bandwidth**

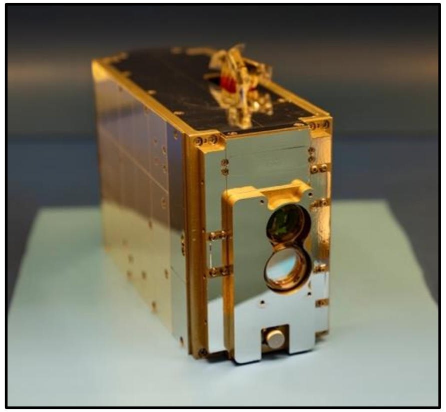
COTS broadband focal planes available for HSI applications in the visible-SWIR bands

MCT – Mercury Cadmium Telluride

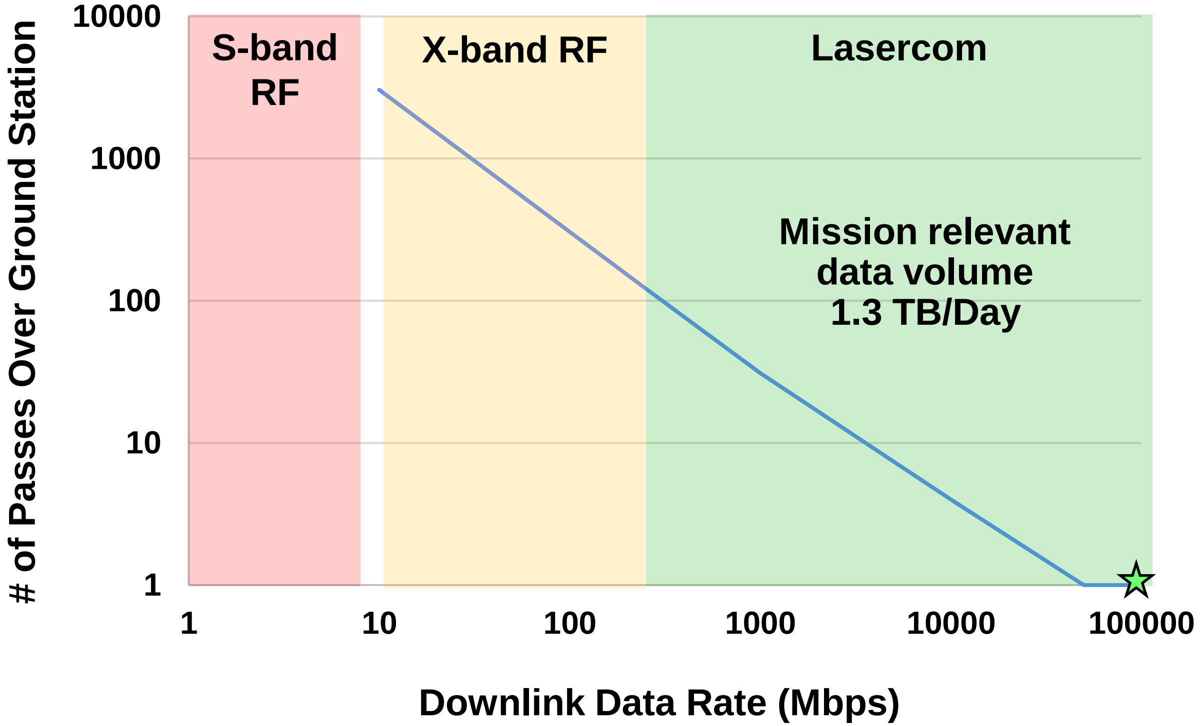
Example Mission Data Downlink Analysis

Terabyte Infrared Delivery (TBIRD)
3U Lasercom Payload





SmallSat LEO to Ground Downlink Analysis



Compact lasercom terminals demonstrate downlink capability for large data volume

TBIRD Point of Contact: Jade Wang

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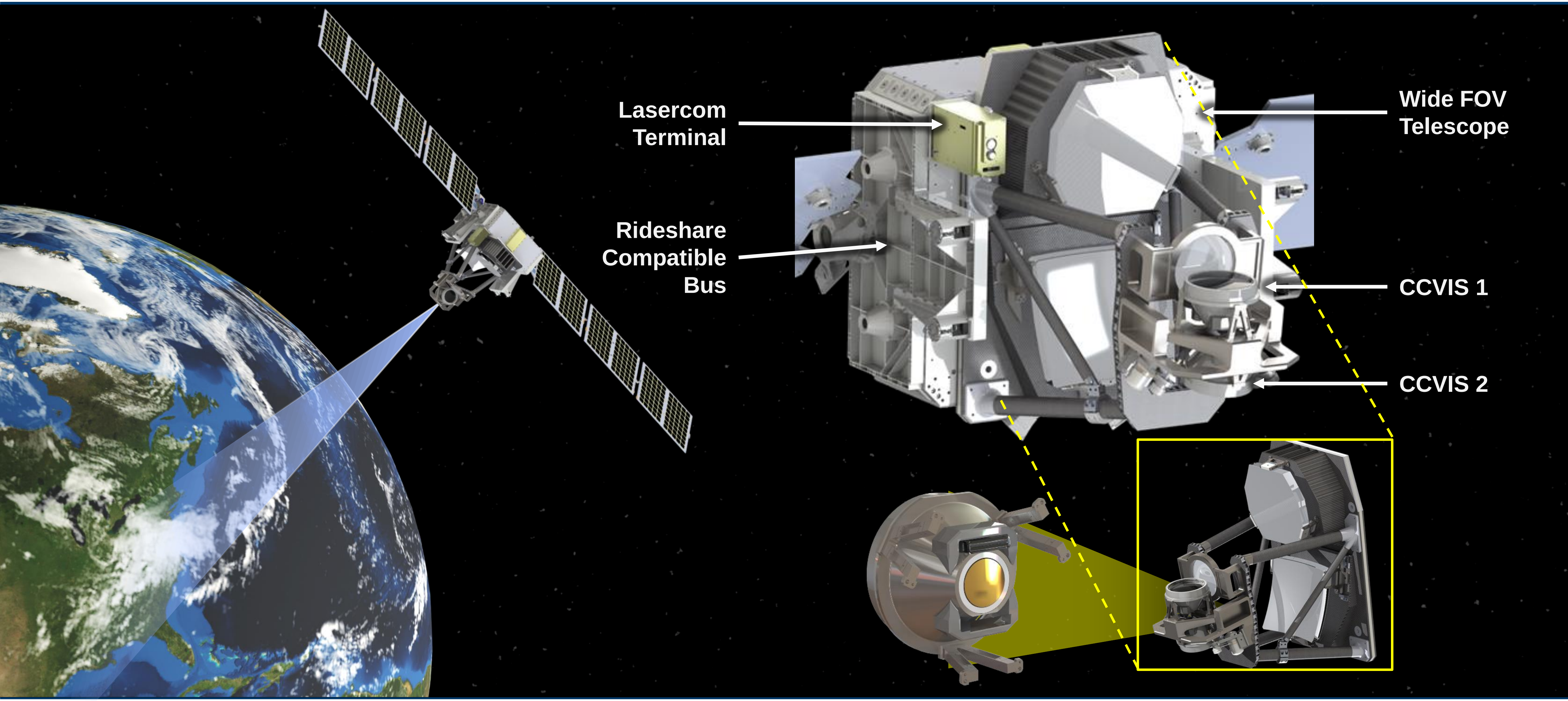
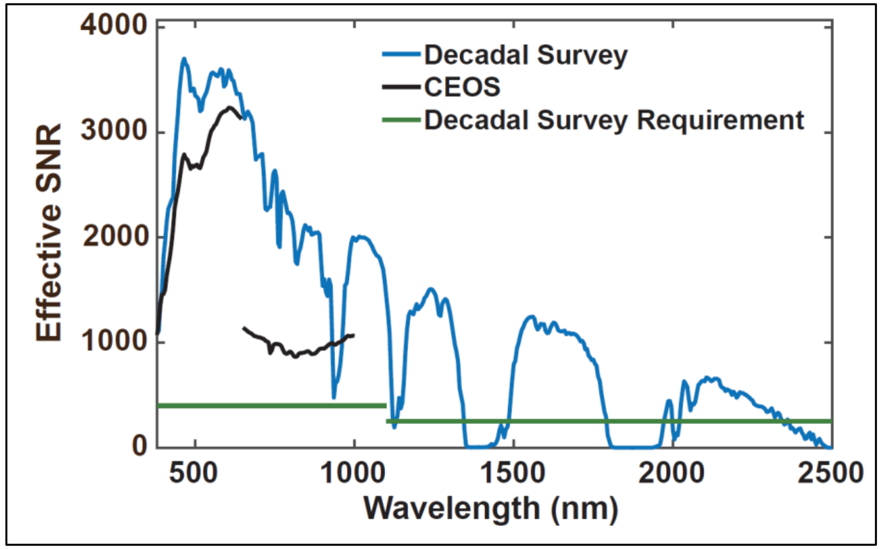
Hyperspectral Imaging Small Satellite Design

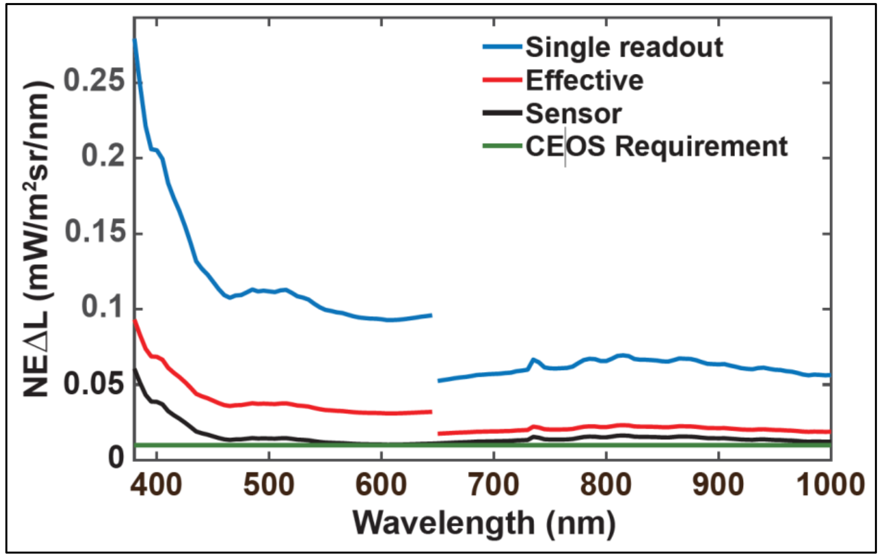


FOV – Field Of View

Payload Predicted Performance

Design Parameter	Predicted Performance
Telescope	26 cm aperture, f/2.5 TMA
Field of view	9.6° cross track
Spectral range	380 – 2500 nm
Spectral resolution	< 10 nm
Ground sample distance	25 m (nadir)
Nadir swath	75 km
Bus	ESPA-grande Class
Orbit	450 km sun-synchronous orbit



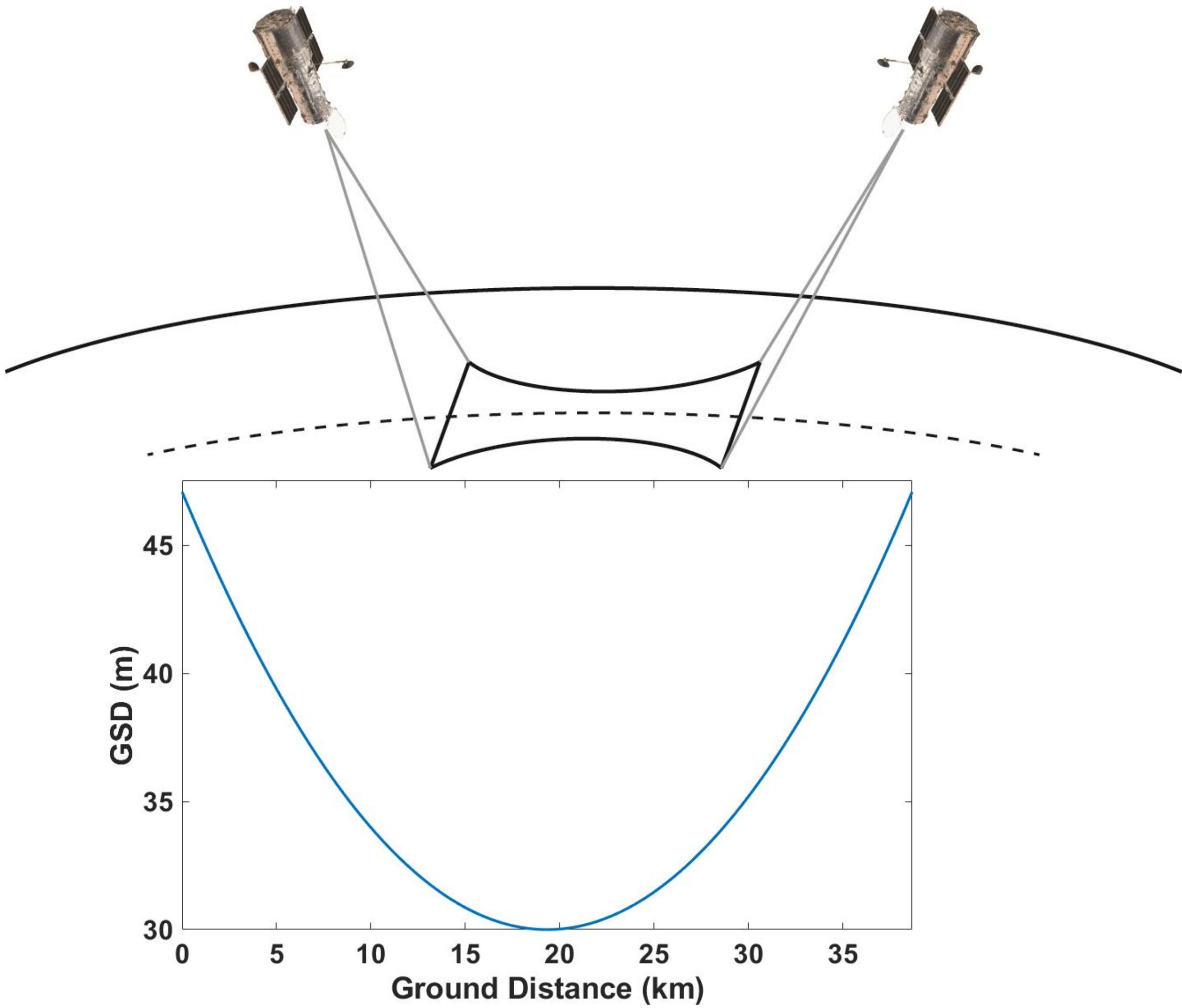


TMA: Three Mirror Anastigmat

Data Acquisition: Pitchback Maneuver

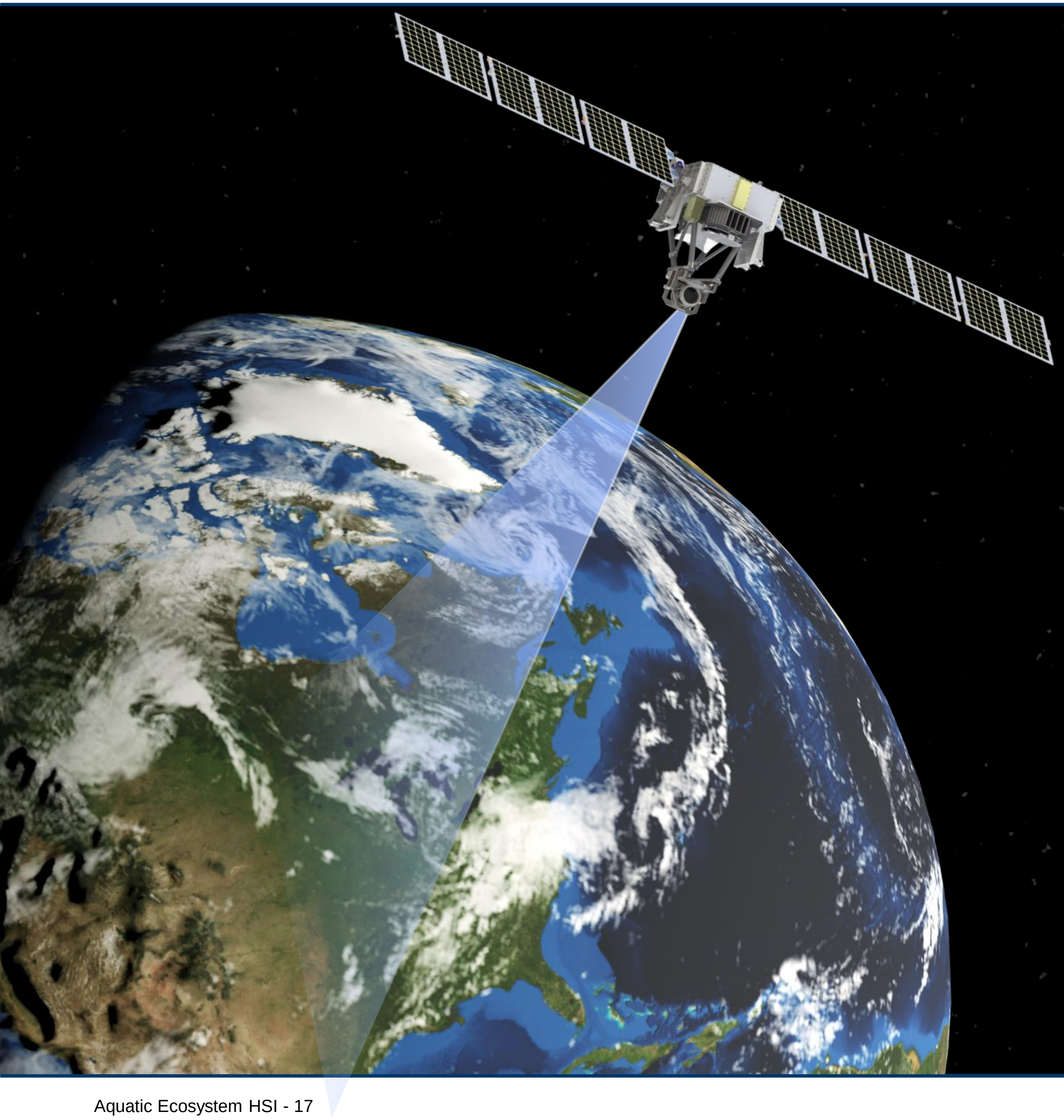
- **Spacecraft will execute a pitchback maneuver**
  - **Image of the slit projected onto the surface is slowly scanned while recording FPA readouts at a higher rate.**
  - **Effective frame rate determined by time to scan the projected slit one GSD**

- **Avoids saturation over land while obtaining higher SNR over water**



FPA: Focal Plane Array
GSD: Ground Sample Distance

Summary & Next Steps



- MIT LL has long history of prototyping cutting edge space-based optical systems
- On-going work focused on technology maturation of subsystems
- CCVIS environmental testing is ongoing

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