Multi-Slit Offner Spectrometer

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Outline

- NASA Geostationary Coastal and Air Pollution Events (GEO-CAPE) Oceans Mission
- Multi-Slit Offner Spectrometer (MOS)
  - What it is
  - Origin of the benefits
  - Technical challenge
- Program Goals and Plan
- Conclusion

GEO-CAPE Oceans Science

- The Earth Science Decadal Survey objectives for the GEO Event Imaging mission are to understand and monitor the dynamics of coastal marine ecosystems including their response to land-ocean exchanges, human activity, climate change and episodic events and hazards.
  - GEO-CAPE Ocean objectives have been defined:
    - Quantify the response of marine ecosystems to short-term physical events (e.g., storms and tidal mixing).
    - Assess the importance of high temporal variability in coupled biological-physical coastal-ecosystem models.
    - Monitor biotic and abiotic material in transient surface features (e.g., river plumes and fronts).
    - Detect, track and predict the location of hazardous materials (e.g., oil spills, waste disposal storm events, and harmful algal blooms)

HICO image: Columbia River Plume, processed to show plume details
(N. Tufillaro, C. Davis, OSU)

MOS: GEO-CAPE Oceans Science with reduced mass and risk

- Motivation
  - Instrument for the GEO-CAPE Oceans mission meeting the Science Traceability Matrix (STM) requirements tend to be large
    - Ball strawman, scale 550 kg
    - Coastal Ecosystems Dynamics Imager (CEDI), Instrument Design Lab Study scale 620 kg (Scott Janz, et al., NASA OCRT Meeting May 11-13 2010)
  - Look for approaches to reduce volume, mass, and mission cost, with < 1 hr coverage time

GEO-CAPE Oceans STM

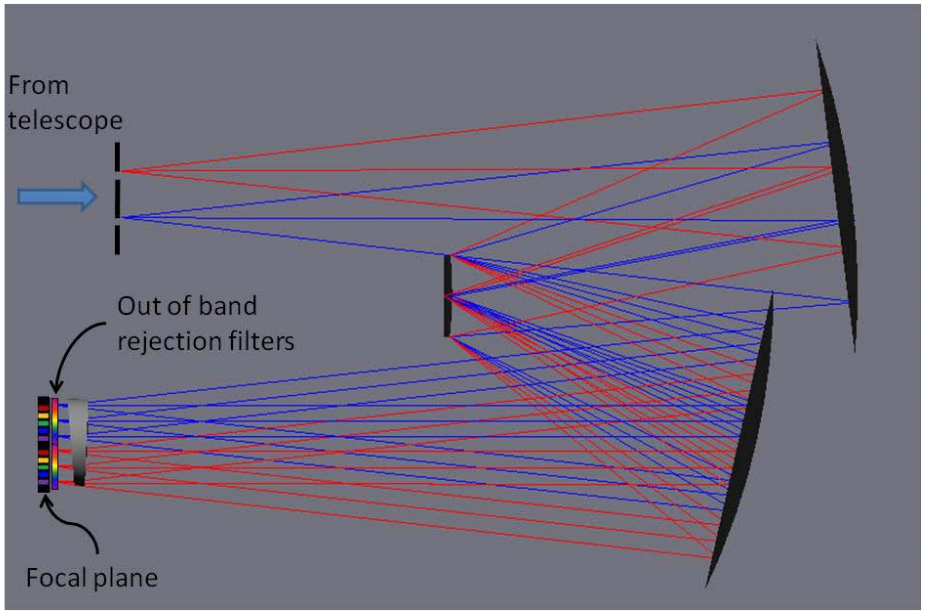
Draft v.2.7 - March 24, 2010

Science Focus	Science Questions	Approach	Measurement Requirements	Instrument Requirements	Platform Requirem.	Ancillary Data Requirem.
Short-Term Processes Land-Ocean Exchange	1 How do short-term coastal and open ocean processes interact with and influence larger scale physical, biogeochemical and ecosystem dynamics? (OBB1) 2 How are variations in exchanges across the land-ocean interface related to changes within the watershed, and how do such exchanges influence	PRODUCTS Standing Stocks: Aquatic chlorophyll a, POC, DOC, PIC, DIC*, inherent & apparent optical properties, total suspended matter, phytoplankton biomass*, pigments* and key functional groups, terrigenous DOC*, & black carbon*. Rate Measurements: Aquatic primary productivity, respiration*, air-sea CO_2 fluxes*, photooxidation, phytoplankton fluorescence responses*, phytoplankton vertical migration*, net community production of DOC* and POC*, and other associated trophic responses* Hazards: Aquatic HABs, petroleum-derived hydrocarbons, and other pollutants*. *Products not currently derived from ocean color observations. Targeted, high-frequency, episodic event-	Water-leaving radiances in the near-UV, visible & NIR for separating absorbing & scattering constituents & chlorophyll fluorescence Product uncertainty TBD Temporal Resolution: *Targeted Events:* - Threshold: 1 hour - Goal: 0.5 hour *Routine Coastal U.S.:* - Threshold: ≤3 hours - Goal: 0.5 hour *Regions of Special Interest*	Spectral Range: Hyperspectral UV-VIS-NIR - Threshold: 345-900 nm; 3 SWIR bands 1245, 1640, 2135 nm - Goal: 340-1100 nm; 3 SWIR bands 1245, 1640, 2135 nm -Spectral Resolution: - Threshold: UV-VIS: 0.5 nm FWHM; NIR: 1 nm; SWIR: 20-50 nm - Goal: UV-VIS: 0.25 nm FWHM; NIR: 0.5 nm; SWIR: 20-50 nm - Retrieval of NO_2 and O_2 A-band for atm. corrections? (TBD)	Geostationary orbit to permit sub-hourly observations of coastal waters adjacent to the continental U.S., Central and South America Storage and download of full spatial data and spectral data.	Western hemisphere data sets from models, missions, or field observations: Measurement Requirements (1) Ozone (2) Total water vapor (3) Surface wind velocity (4) Surface barometric pressure (5) NO_2 concentration (6) Vicarious

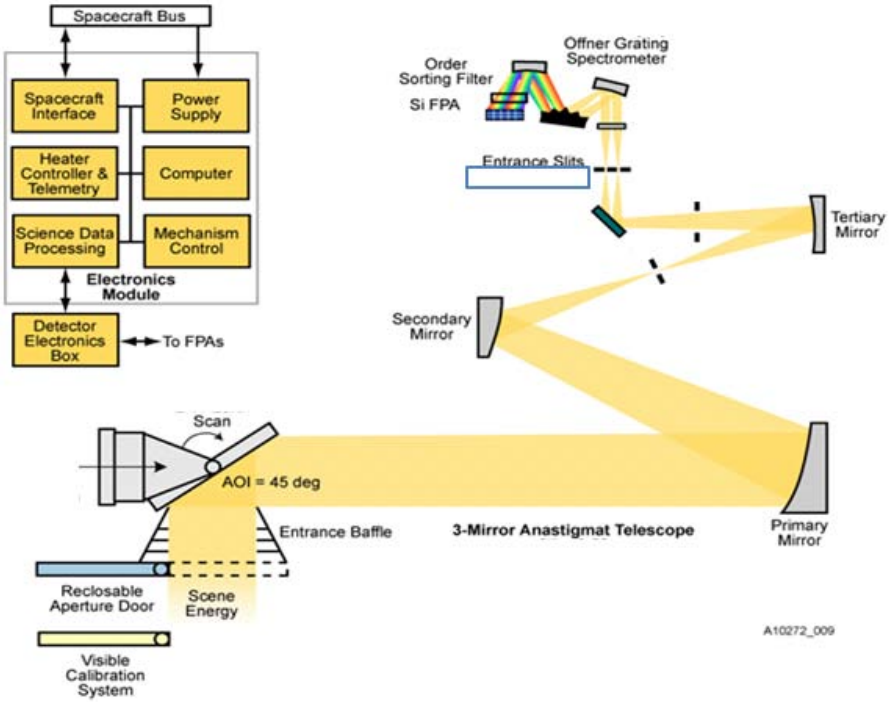
MOS goal is to meet relevant STM Instrument Requirements in a comparatively small package

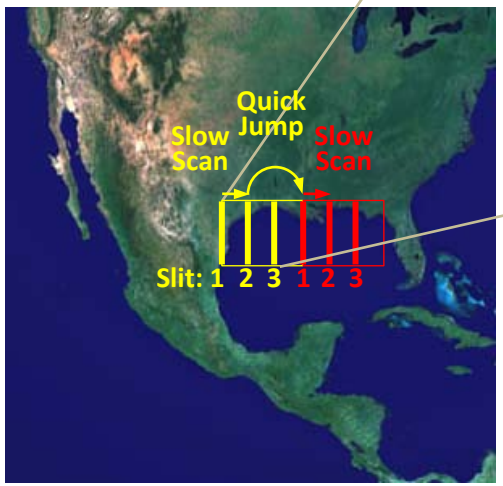
Multi-Slit Offner Spectrometer performs like multiple spectrometers operating simultaneously

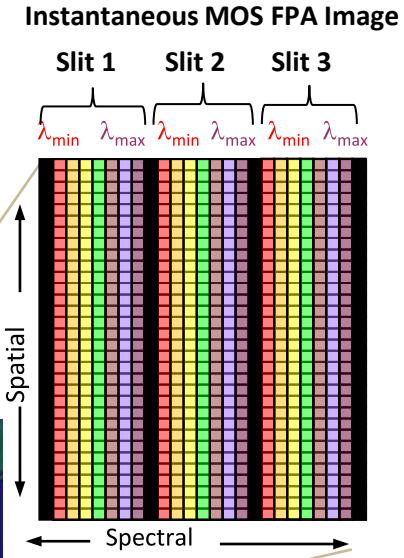
- The Multi-Slit Offner Spectrometer is a dispersive spectrometer providing spectral imagery from multiple, spatially separated slits simultaneously
- Technology Challenge: out-of-band rejection achieved by optical filters & slit displacement
- One goal of the IIP is determine the optimal number slits, realize the greatest mass savings



Imaging from several slits simultaneously can reduce payload aperture by ~2x and mass by ~3x for the same performance.

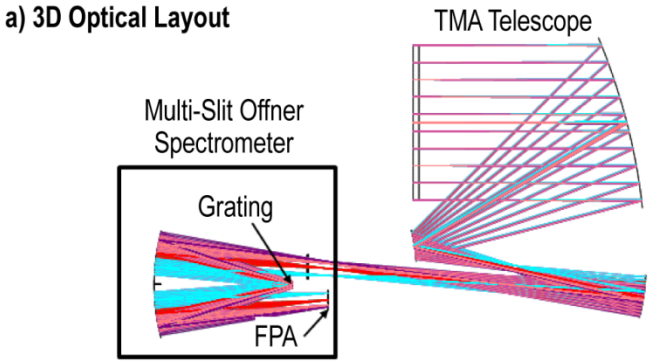


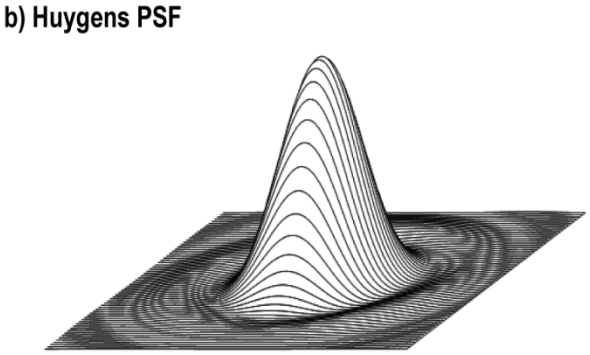


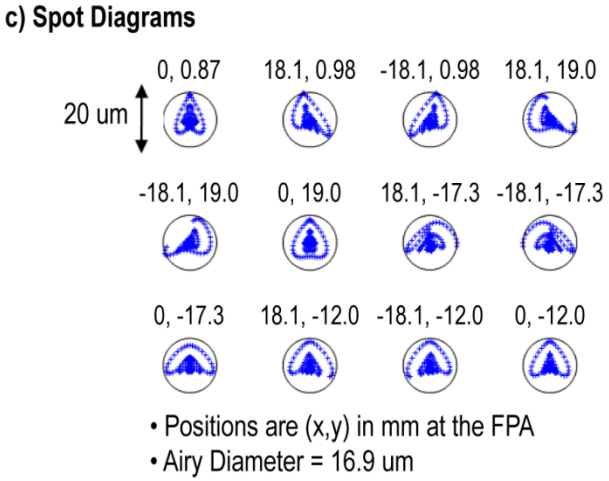


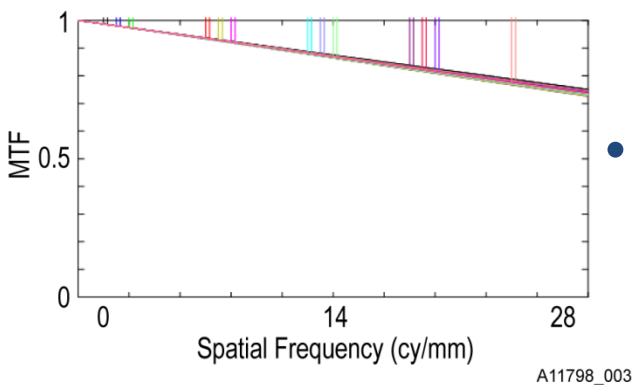
- Simultaneous measurement is a multiplexing approach that can either
  - Decrease the revisit time by N, the number of slits by allowing a faster field of regard scan, or
  - Decrease the aperture by sqrt(N) by allowing a longer stare at each ground sample

Multi-Slit Offner is an extension of a conventional Offner – detailed analysis shows exceptional performance









- Multi-Slit Offner spectrometer payload has been analyzed for GEO remote sensing
- Optical performance from each slit is exceptional over the 2-D field of view
  - Little distortion
  - Diffraction limited performance
- We have analyzed multi-slit interference, and can minimize crosstalk
  - Order sorting filters
  - Slit separation

ZEMAX performance at 609 nm. a) The complete ray-trace of the spectrometer and a TMA telescope. b) The quality Huygens PSF. b) Spot diagrams from the top, middle and bottom of four slits show the rays are contained within the airy circle. d) Diffraction limited performance over the FOV.

Comparison of Multi-Slit Offner Strawman and Single Slit Spectrometer

Strawman design parameters

Conventional Design Parameters		
System	Aperture (cm)	72
	Frame Rate (Hz)	3.6
	Spatial FOV (deg)	1.2
	Coadds	10
	f/#	3.6
	GSD (m)	375
	# Slits	1
	Spectral Samp. (nm)	3.5
FPA	Pitch (um)	27x27
	Spat/Spect Samp.	2048
	Size (cm)	5.5
	Rate (Mp/s)	1.3
Conventional Spectrometer Performance		
Mass (kg)		550
Coverage Time (min)		54
Coverage Area ($10^6 km^2$)		3.3
Minimum SNR*		1000
Data Rate (Mbits/sec)		18.2

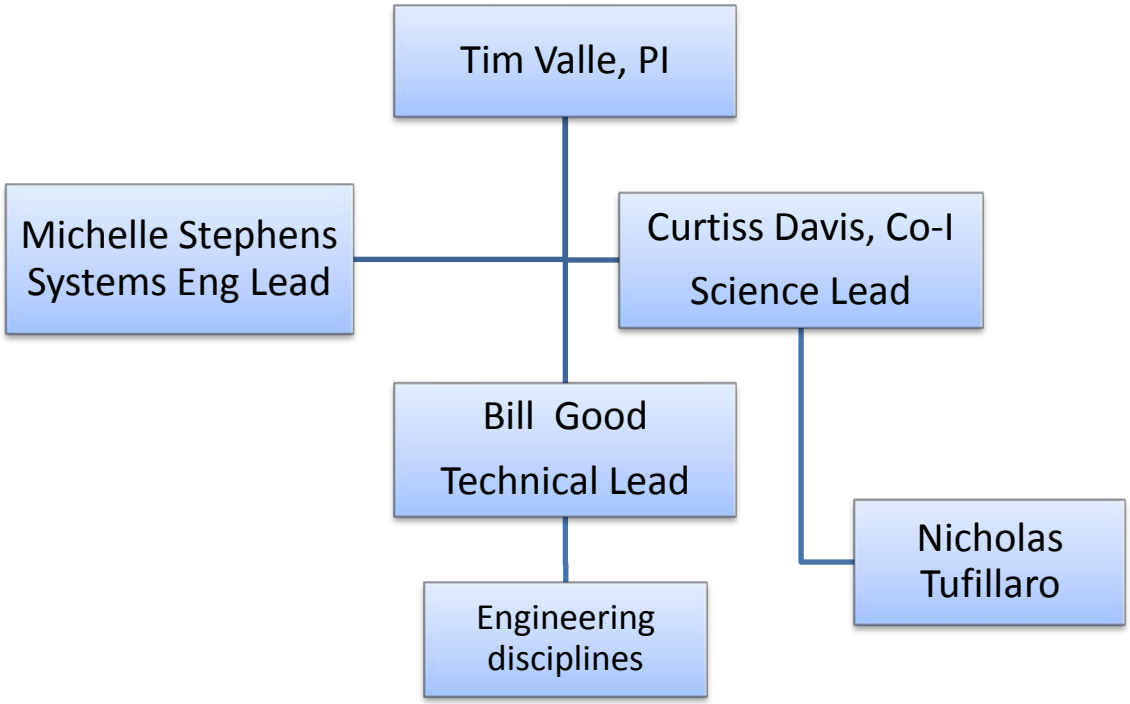
Multi-Slit Offner Design Parameters		
System	Aperture (cm)	33
	Frame Rate (Hz)	0.87
	Spatial FOV (deg)	1.2
	Coadds	8
	f/#	7.8
	GSD (m)	375
	# Slits	5
	Spectral Samp. (nm)	3.2
FPA	Pitch (um)	27x27
	Spat/Spect Samp.	2048
	Size (cm)	5.4
	Rate (Mp/s)	1.7
Multi-Slit Offner Spectrometer Performance		
Mass (kg)		147
Coverage Time (min)		54
Coverage Area ($10^6 km^2$)		3.3
Minimum SNR*		1000
Data Rate (Mbits/sec)		24

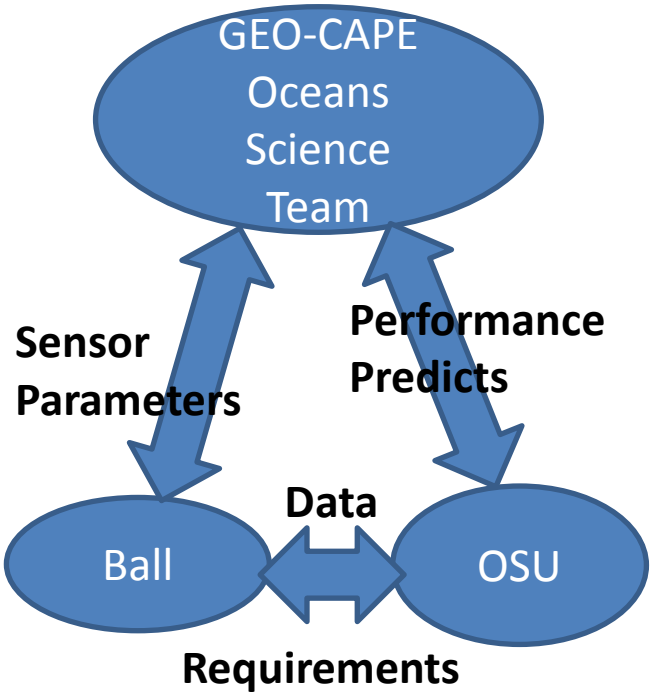
- Both designs meet the requirements traced to the GEO-CAPE mission
  - 1 hour Coverage
  - Visible bands
  - SNR 1000
  - GSD 375 m
- The Conventional Spectrometer has parameters which add risk (red)
  - Aperture ~2x larger
  - Mass ~3.5x larger
  - System f/# 2x faster

Multi-Slit Offner Spectrometer IIP Overview

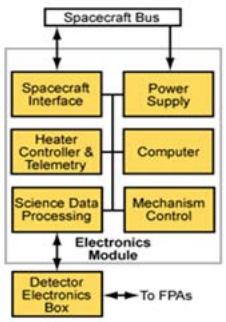
- Goals
  - Design, build and test a high impact technology
  - Determine optimal number of slits for mission, highest achievable impact
  - Understand the suitability of the MOS concept to the GEO-CAPE Event Imager mission
  - Spectrometer hardware TRL 6 at end of program

Core team stays relevant to GEO-CAPE Ocean Science

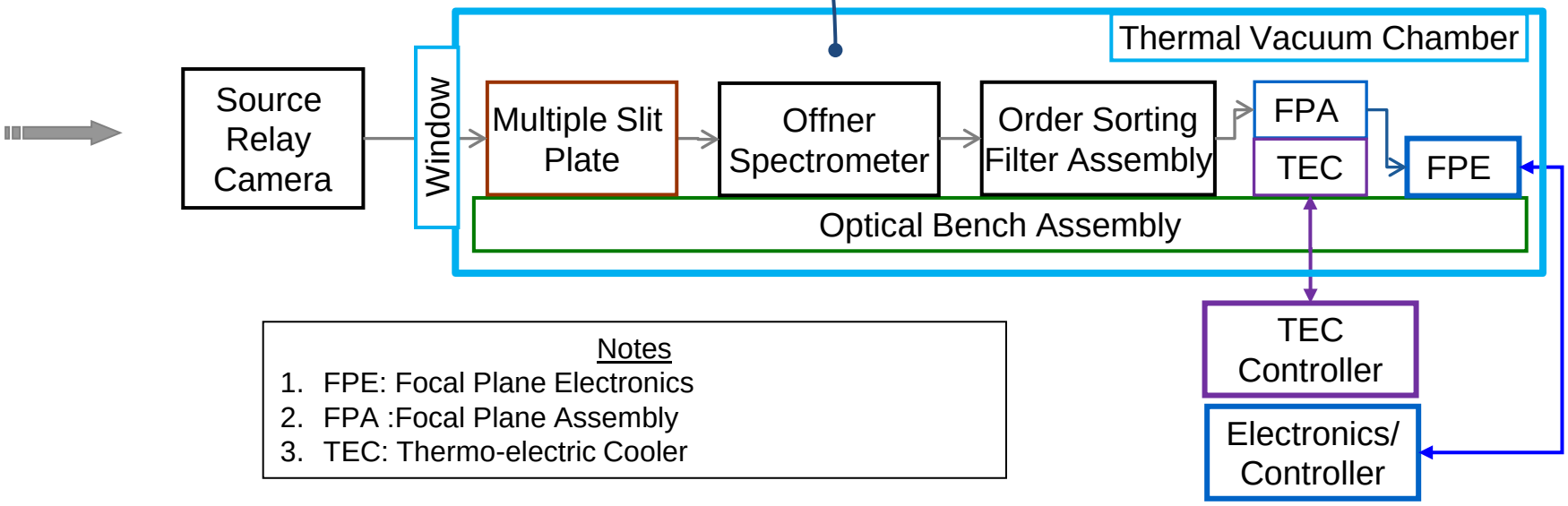




MOS IIP develops the opto-mechanical spectrometer subsystem

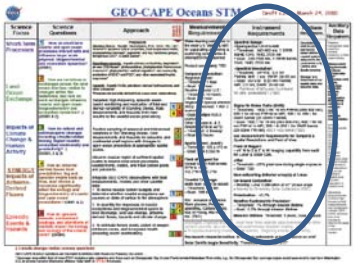


- GEO-CAPE Oceans STM guides spectrometer requirements
- Event Imager schematic
- MOS IIP block diagram

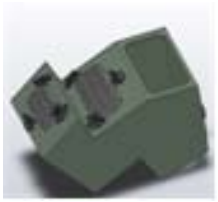


Notes
1. FPE: Focal Plane Electronics
2. FPA :Focal Plane Assembly
3. TEC: Thermo-electric Cooler

Exit program with ready to fly technology and confidence in ability to deliver science data products

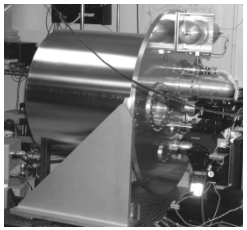


Requirements & Trades



Design, assemble, align

FPA packaging



Test
T-Vac, vibe, T-Vac

NASA Technology Readiness Level 6

OSU team

Use HICO data and MOS performance measurements to simulate on-orbit imagery and assess coastal water data products.

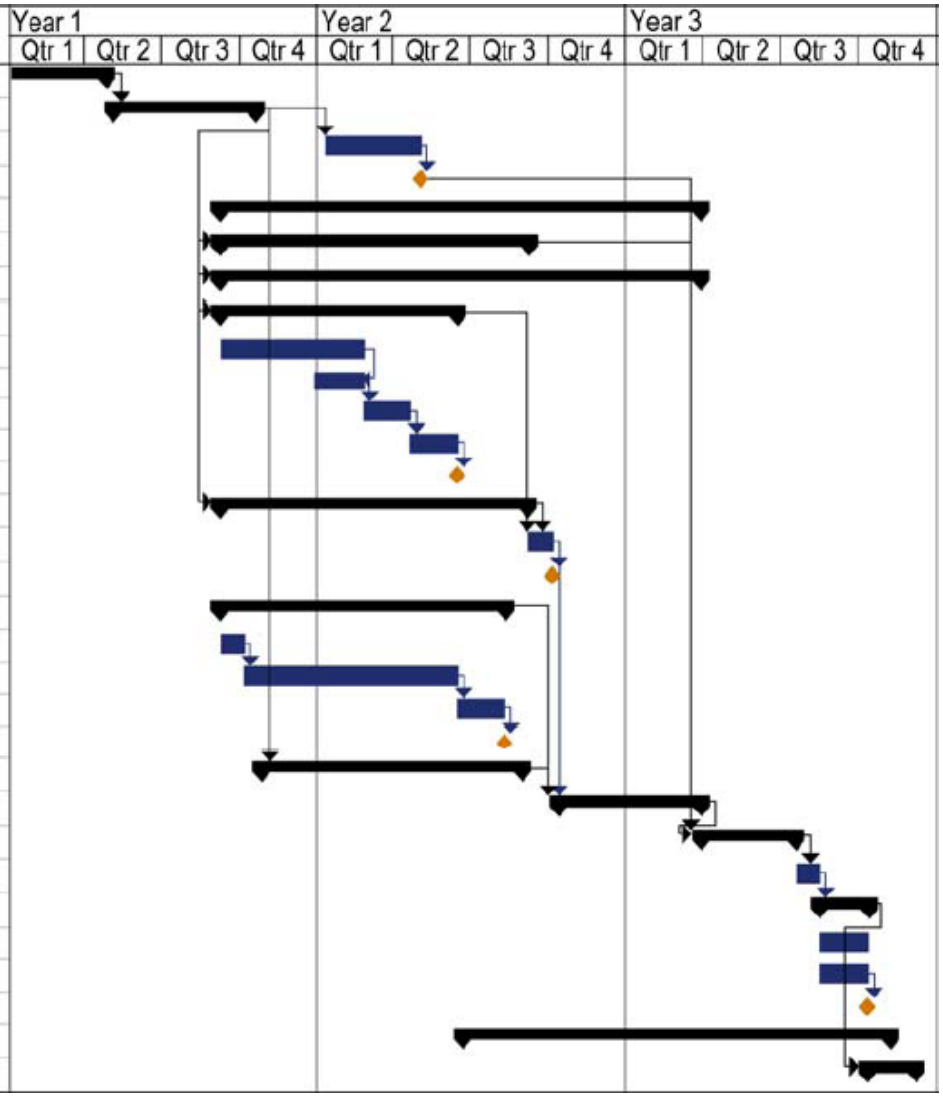
Coastal Water Impact Studies:
spectral sampling
out-of-band
SNR

Mission Suitability Validation

3 year program

Top Level Schedule

ID	Task Name
1	Trade Space Study, and Point Design Closure
5	Detailed Design
12	Vacuum Chamber
13	Vacuum Chamber Complete
14	System Fabrication
15	Optical Relay Development
21	Spectrometer Development
22	FPA
23	FPA Packaging
24	FPA Electronics Fabrication
25	FPA/Electronics Integration
26	FPA Test
27	Complete FPA Test
28	Order Sorting Filter
33	FPA/Filter Integration
34	FPA/Filter Complete
35	Grating
36	Design
37	Manufacture
38	Test
39	Grating Complete
40	Offner Optics
44	Spectrometer System Integration
47	System Integration and Test
51	System Vibe
52	Post Vibe Testing and Characterization
53	Radiometric Testing
54	Spectral Testing and Characterization
55	Complete Post Vibe System Test
56	Mission Suitability
60	Final Closeout



Project Summary

- A Multi-Slit Offner Spectrometer can reduce risk for a hyperspectral GEO ocean color payload by imaging multiple ground points at the same time
  - Smaller aperture, lower mass and/or slower f/# than a conventional spectrometer designed to achieve the same performance
  - Reduced mission risk
- Technical challenge is out-of-band performance, largely controlled by out of band rejection filter assembly

Exit program with

- Ready to fly technology (TRL 6) and
- Validated ability to deliver ocean science data products

Thank you for your attention.