Design of an Airborne Portable Remote Imaging Spectrometer (PRISM) for the Coastal Ocean

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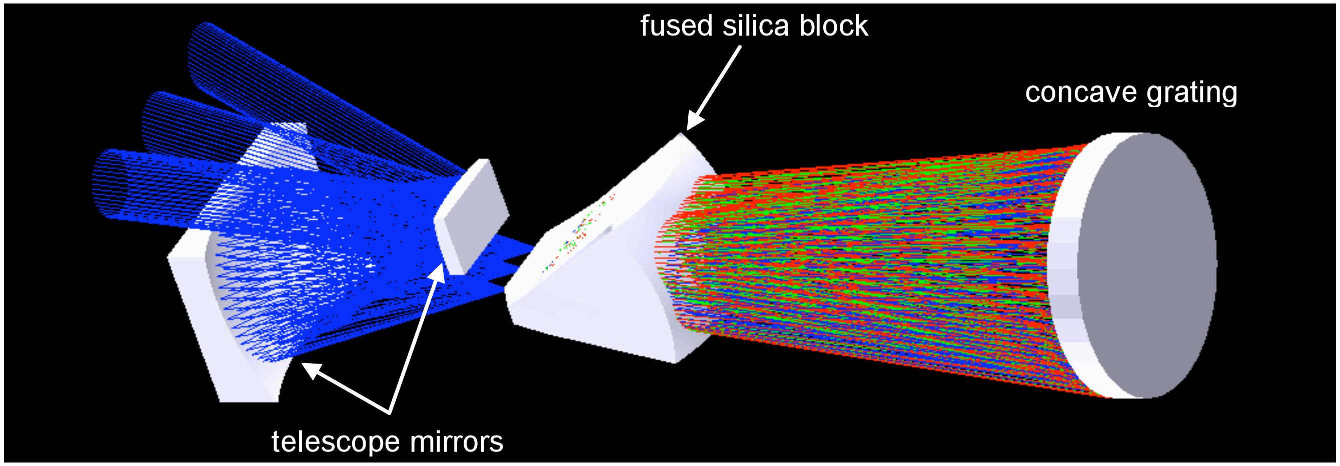
Overview

- Introduction
- Instrument Specifications
- Optical Design
- Opto-Mechanical Design
- Focal Plane and Electronics
- Calibration and Flight
- Summary

Introduction

- PRISM is a pushbroom imaging spectrometer intended to address the needs of airborne coastal ocean science research.
- Eventual NASA facility instrument, currently under development at the Jet Propulsion Laboratory.
- 350-1050 nm range with a 3.1 nm sampling and a 33^{o} field of view.
- High signal to noise ratio, high uniformity of response, and low polarization sensitivity.
- Two additional wavelength bands at 1240 and 1610 nm in a spot radiometer configuration to aid with atmospheric correction.



Introduction

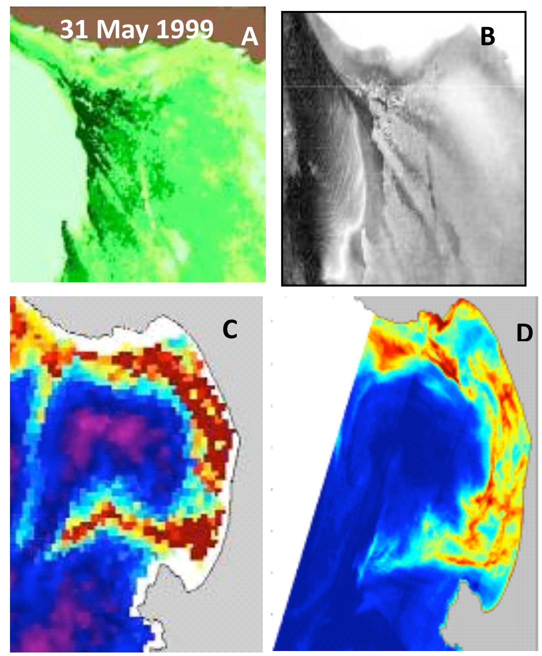
Example: Ocean Science Problems

- Opportunity for imaging coastal margins at high spatial, spectral, and temporal resolution (NASA OBB report)

Mapping river plumes, flooded land regions, and seafloor features/ habitats

Hazardous and episodic events require repeat sampling on the order of hours and not days or weeks

Assessing water quality of inland lakes, rivers, and coastal estuaries



Seagrass Leaf Area Index (LAI) and B) shallow water bathymetry 0-6 m estimated from the PHILLS sensor at Lee Stocking Island, Bahamas.

A dense algal bloom or red tide in Monterey Bay measured from C) SeaWiFS satellite imagery at 1 km resolution and D) AVIRIS Airborne imager at 30 m resolution

Dierssen et al., 2003, L&O
Ryan et al., 2005, Oceanogr.

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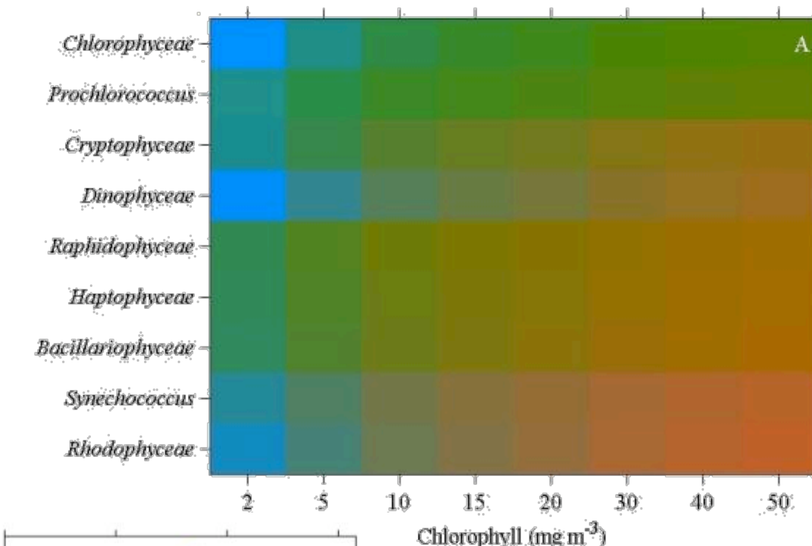
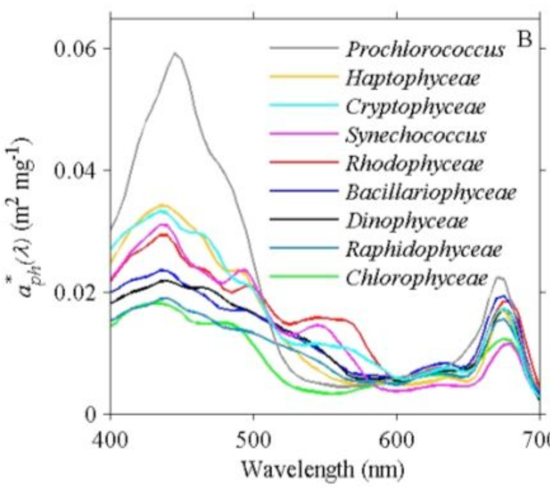
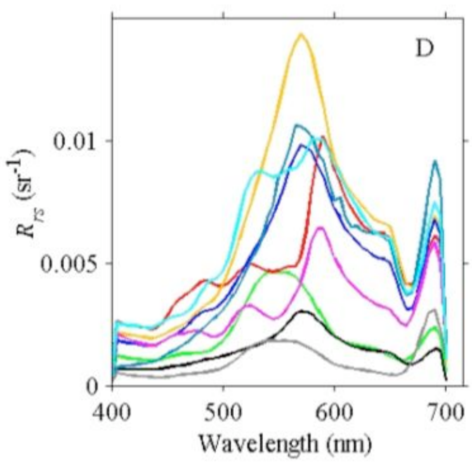
Introduction

Ocean Science Example: Spectral Information

- Phytoplankton groups play different ecological roles
- Differentiating taxa requires detecting subtle shifts in color







Dierssen et al., 2006, L&O

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Introduction

PRISM

Expected Science Benefits of PRISM:

- Understand the role of coastal habitats in human health and well-being
- Assess impacts of inland nutrient, sediment, and pollutant inputs on coastal zones
- Make observations in support of coastal management and ports operations
- Improve monitoring and forecasting of acute and chronic natural and anthropogenic hazards, including large storms, tsunamis, toxic spills, and icebergs.

There is an important need in coastal ocean science for high spatial and temporal resolution spectral measurements.

PRISM can provide on-demand monitoring of coastal areas to assess episodic events and also permit longer term monitoring at spatial scales that would be difficult to achieve from space.

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Instrument Specifications

PRISM is two instruments integrated into one assembly:

- **Imaging spectrometer covering the visible and near-infrared (VNIR) range.**
- **Short-wave infrared (SWIR) spot radiometer.**

SPECTROMETER SPECIFICATIONS

Spectral	**Range**	**350-1050 nm**
	Sampling	**3.1 nm**
Spatial	**Field of view**	**33.1 deg**
	Instantaneous FOV	**0.95 mrad**
	Spatial swath	**610 pixels**
	Spatial resolution	**0.3-20 m**
Radiometric	**Range**	**0 – 75% R**
	SNR	**2000 @ 450 nm ***
	Polarization variation	**< 2%**
Uniformity	**Spectral cross-track**	**>95% ****
	Spectral IFOV mixing	**< 5% *****

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

**: straightness of monochromatic slit image (pixel fraction)

***: registration of spectrum to array row (pixel fraction)

Instrument Specifications

SWIR SPECIFICATIONS

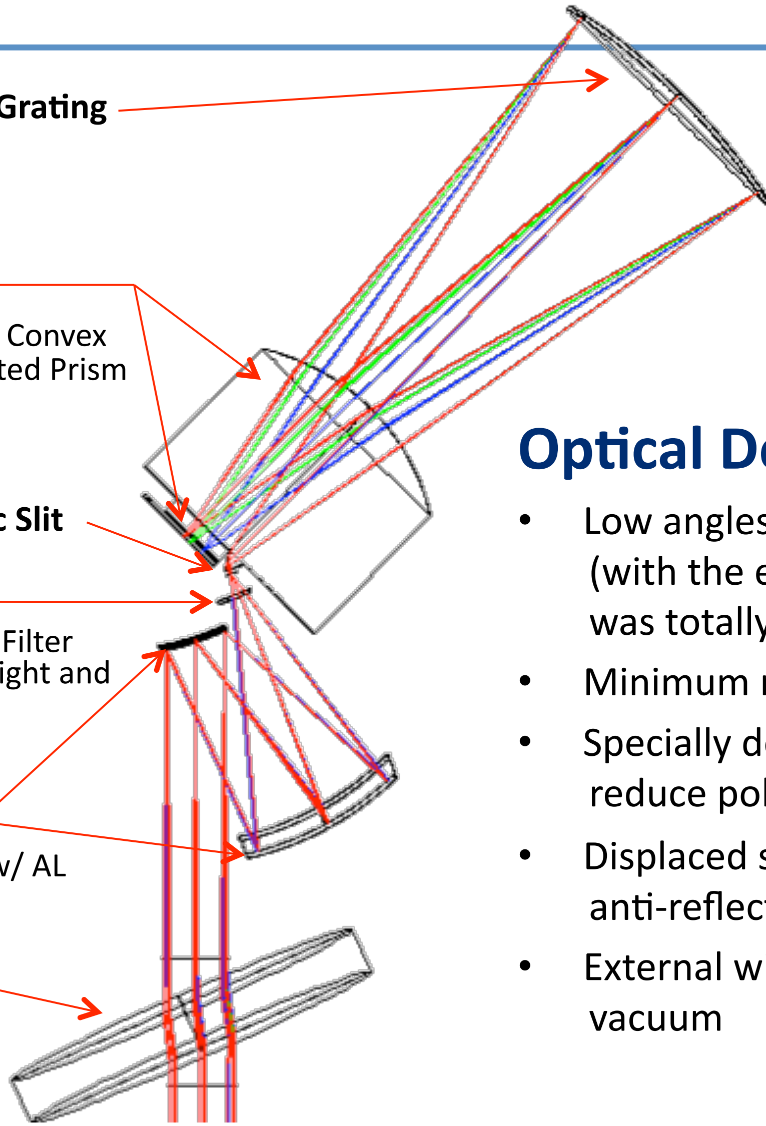
Spatial	**FOF/IFOV**	**1.9x1.9 +/-0.1 mrad**
Spectral	**Channel 1 center**	**1240 nm**
	Ch. 1 bandwidth	**20 nm**
	Channel 2 cener	**1610 nm**
	Ch. 2 bandwidth	**60 nm**
Radiometric	**SNR**	**>350**
	Ch. 1 ref. radiance	**0.054 mW/cm2 sr nm**
	Ch. 2 ref. radiance	**0.017 mW/cm2 sr nm**

SWIR radiometer design comprises:

- 60mm F/2 cemented doublet for a telescope
- Precision square pinhole aperture 0.12 x 0.12 mm
- Collimating doublet and identical focusing doublets
- Dichroic beamsplitter and bandpass filters
- Two InGaAs detectors of 0.3mm diameter.

Spectrometer Optical Design

- **E-Beam Fabricated Grating**
- **Dyson Block**
  - Fused Silica Plano Convex Lens with Cemented Prism and Flat
- **E-Beam Lithographic Slit**
- **Input Filter**
  - 340nm Long pass Filter coating for stray light and UV suppression
- **Telescope Mirrors**
  - Glass Substrates w/ AL Coating
- **Vacuum Window**
  - Fused Silica

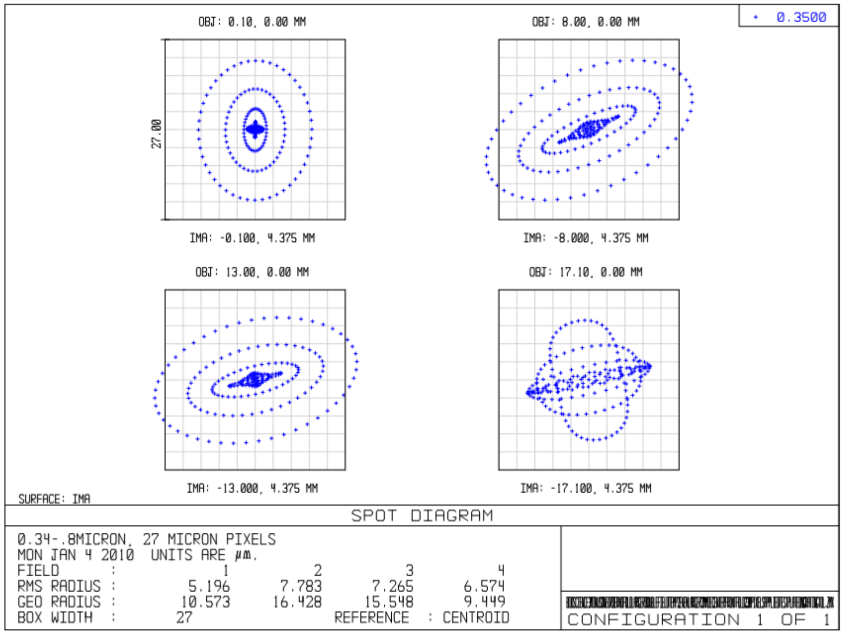


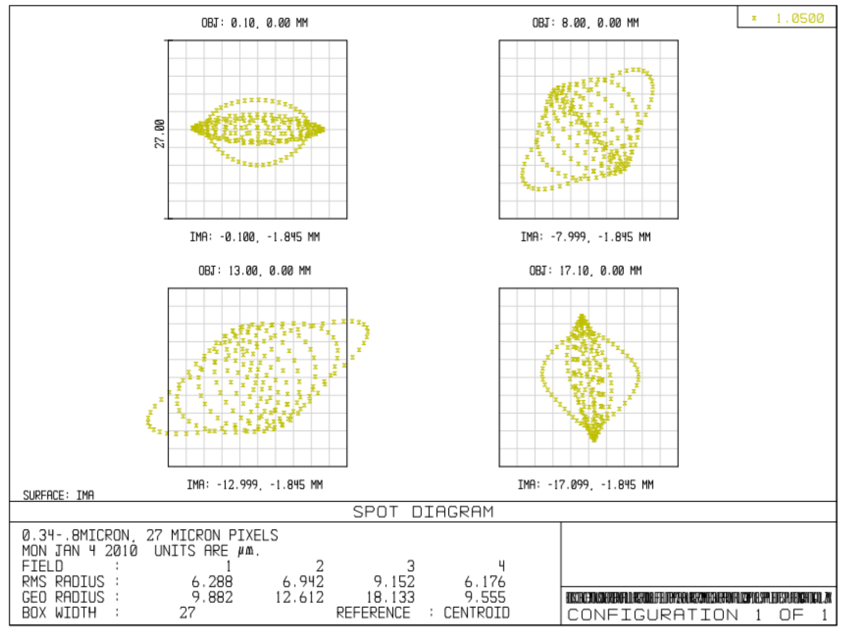
Optical Design Key Characteristics:

- Low angles of incidence on optical components (with the exception of one surface where light was totally internally reflected)
- Minimum number of optical components
- Specially designed grating groove profile to reduce polarization dependence
- Displaced slit to remove the need for high-quality anti-reflection coating on the array detector
- External window to seal the entire system in vacuum

Spectrometer Optical Design

Spectrometer spot diagrams





350 nm
Box is 27 mm square

1050 nm

Uniformity errors: Smile 0.6% (0.17 mm), keystone 3% (0.8 mm) < 5%

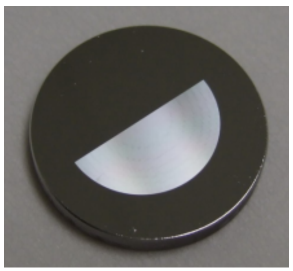
Spectrometer Optical Design

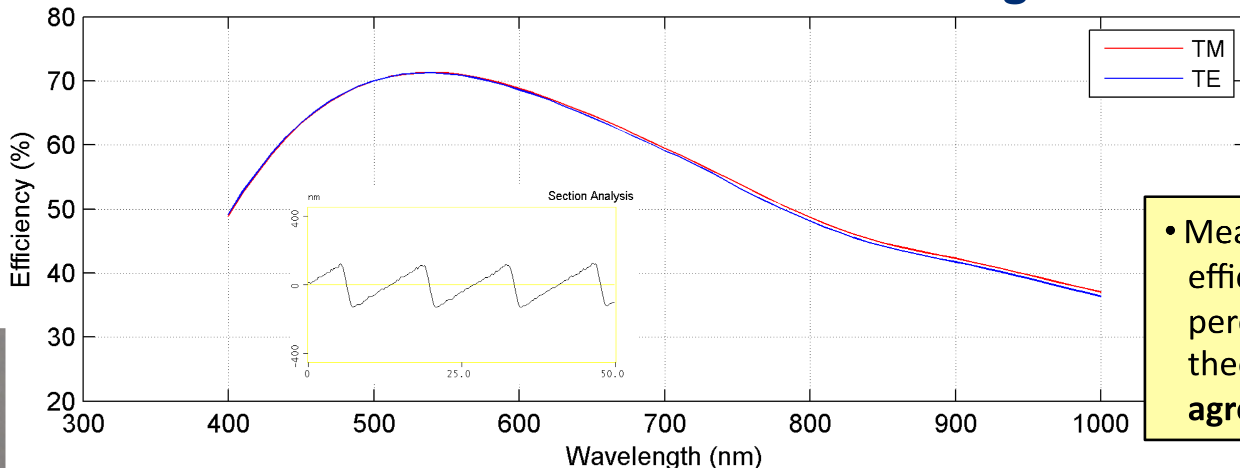
Spectrometer Polarization Sensitivity Characterization:

- Grating groove design is critical in achieving the reduced polarization sensitivity of the overall instrument.
- Gratings are fabricated through electron-beam lithography techniques developed at JPL. Various test groove designs have been implemented on flat substrates in order to confirm agreement with theory.
- Overall polarization sensitivity of the system depends on the quality of the anti-reflection coatings on the refractive surfaces as well as the telescope mirror coatings.
- AL coatings used for telescope mirrors and grating have been characterized experimentally. Samples of AR coated windows have also been procured.
- Complete system-level polarization computation accounting for all effects has been calculated. Predicted polarization sensitivity stays below the specification of 2% throughout the wavelength range.

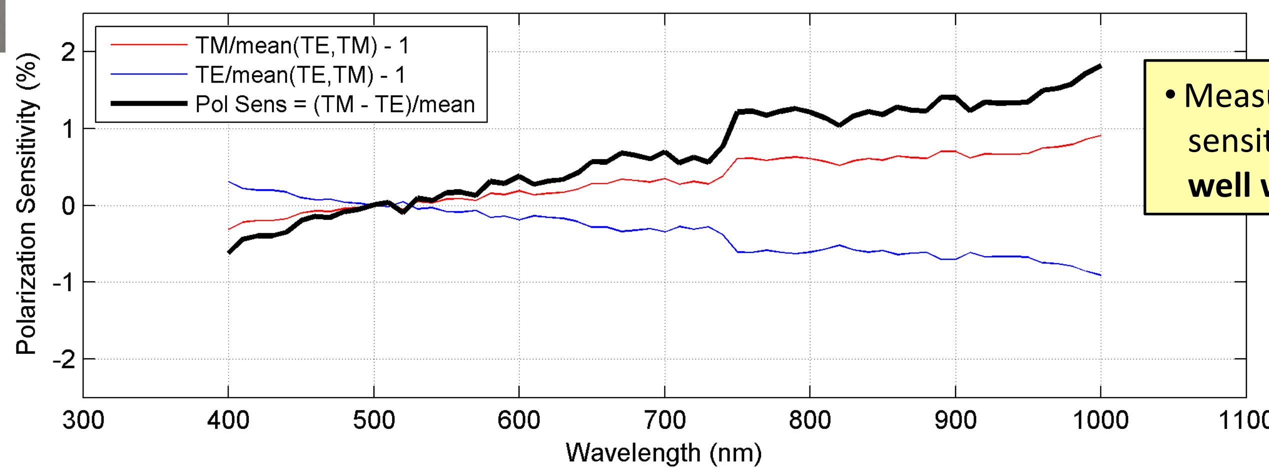
Spectrometer Optical Design

Measurement of Flat Test Grating





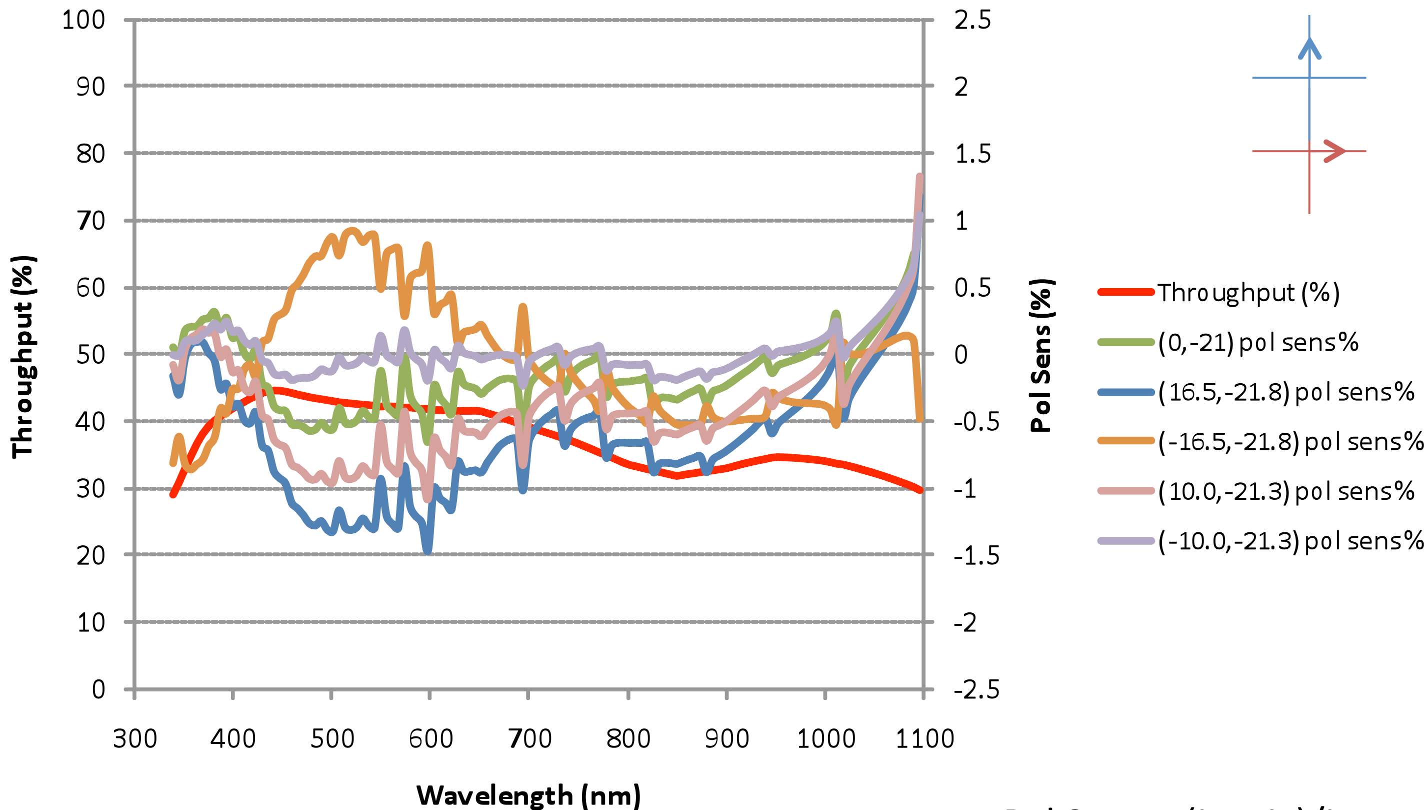
- Measured peak efficiency a few percent lower than theory, but **shape agrees well**



- Measured polarization sensitivity **agrees quite well with theory**

Spectrometer Optical Design

Predicted polarization variation for various field positions.



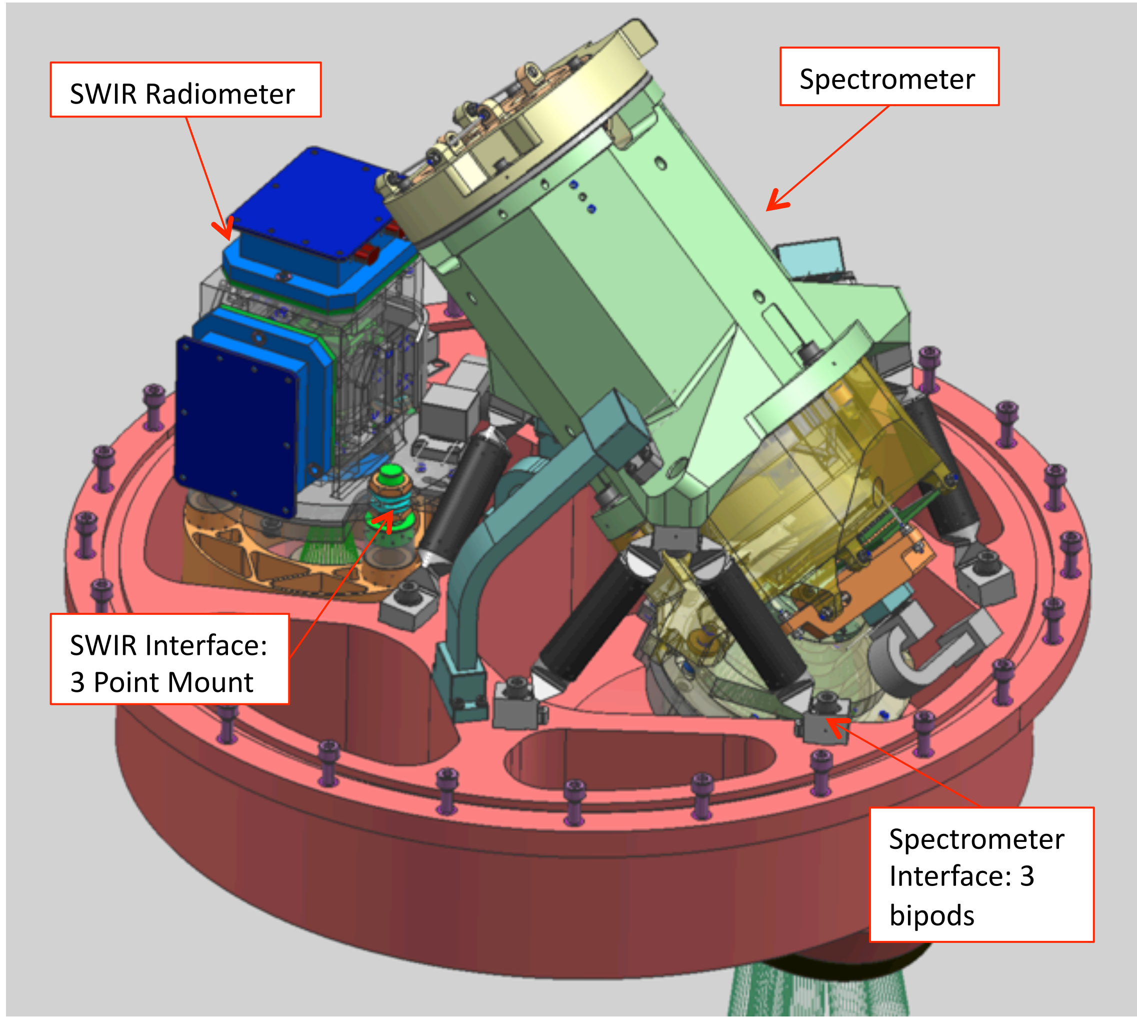
Pol Sens = (Iy – Ix)/Imean

Note: The incident polarization vectors are parallel and perpendicular to the slit. Other orientations give similar results.

Opto-Mechanical Design

OPTICAL HEAD ASSEMBLY

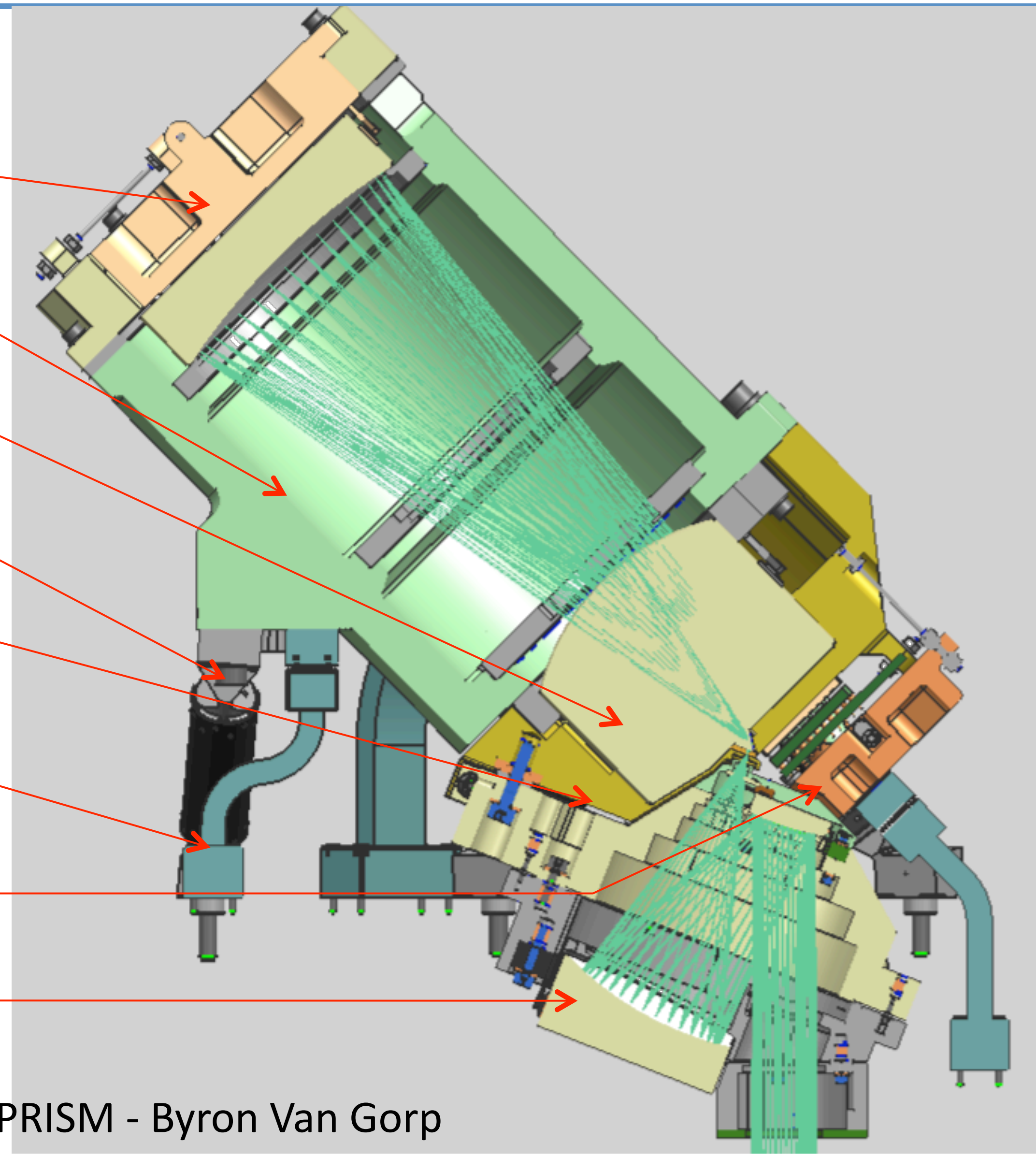
- Spectrometer and SWIR radiometer are housed in a vacuum enclosure, the bottom plate of which is used for mounting both structures.
- Thermal stability (1 deg K) achieved via thermal isolation, vacuum environment and TEC's.
- Nominal temperature of 23° C. System at operational temperature within < 2 hrs from turn-on.
- Spectrometer mounted via kinematic bipod Ti struts.
- SWIR mounted via 3 point cone/ spherical nut interface, facilitating co-boresight alignment with spectrometer.



Opto-Mechanical Design

SPECTROMETER COMPONENTS

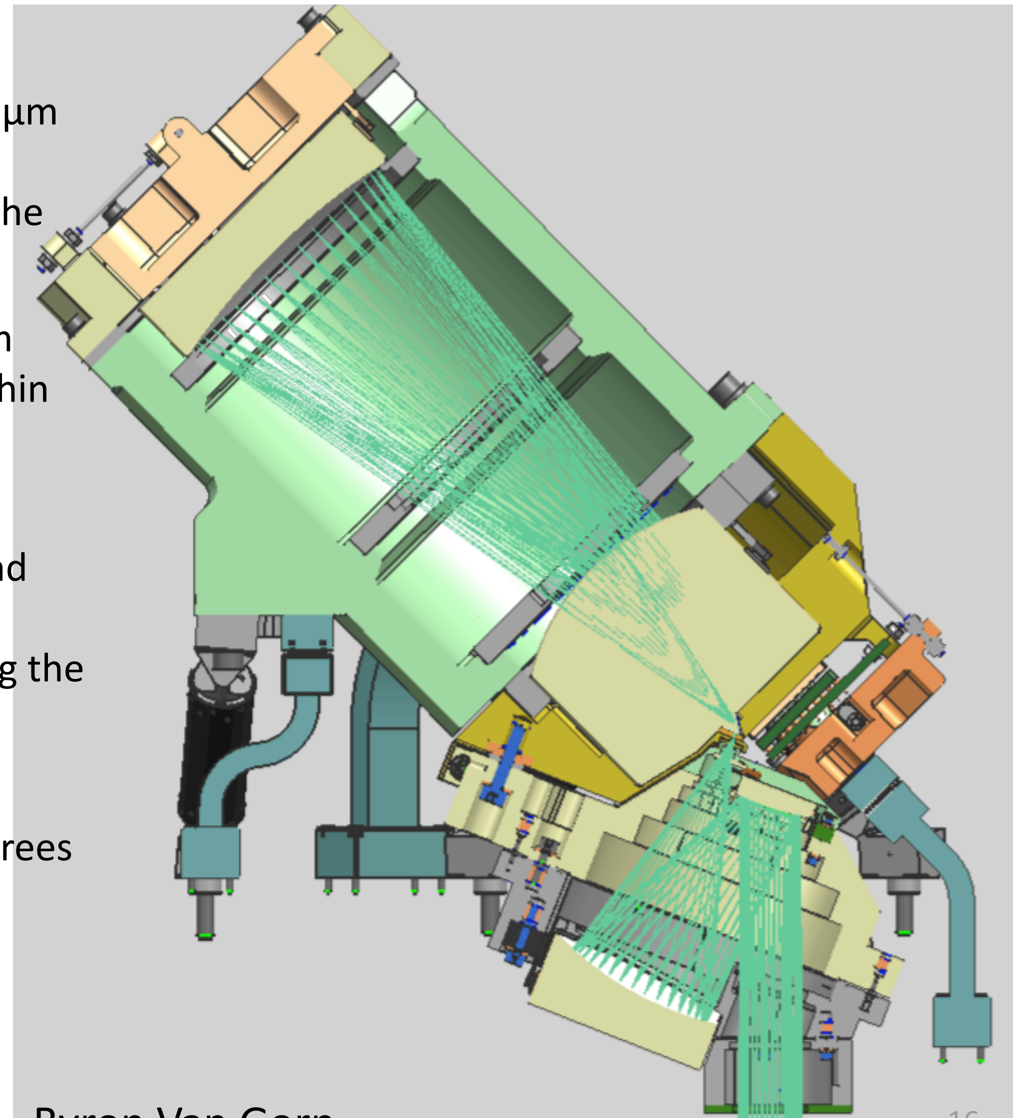
- Grating Mount Assembly
- Spectrometer Housing Assembly
- Dyson Block Assembly
- Spectrometer Struts
- Telescope-FMA Mount
- TEC Assembly
- Focal Plane Mount Assembly (FMA)
- Telescope Assembly



Opto-Mechanical Design

SPECTROMETER

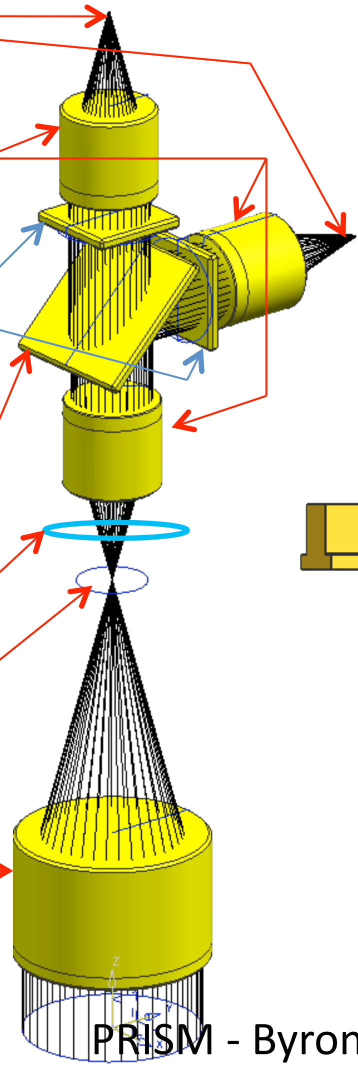
- Fabrication and assembly tolerances, ~ 50 µm decenter, are achieved with a technique utilizing the rotational symmetry of both the telescope and the spectrometer designs.
- Stability goal of 0.05 nm requires spectrum registration stable relative to detector within ~0.4 µm. Requires a very stiff mechanical structure.
- Telescope and spectrometer assembled and pre-aligned independently, then brought together for a final adjustment, fine-tuning the detector position, grating clocking, and telescope focus.
- Detector assembly adjustable in all six degrees of freedom in fine increments required to reach the 95% uniformity specification..

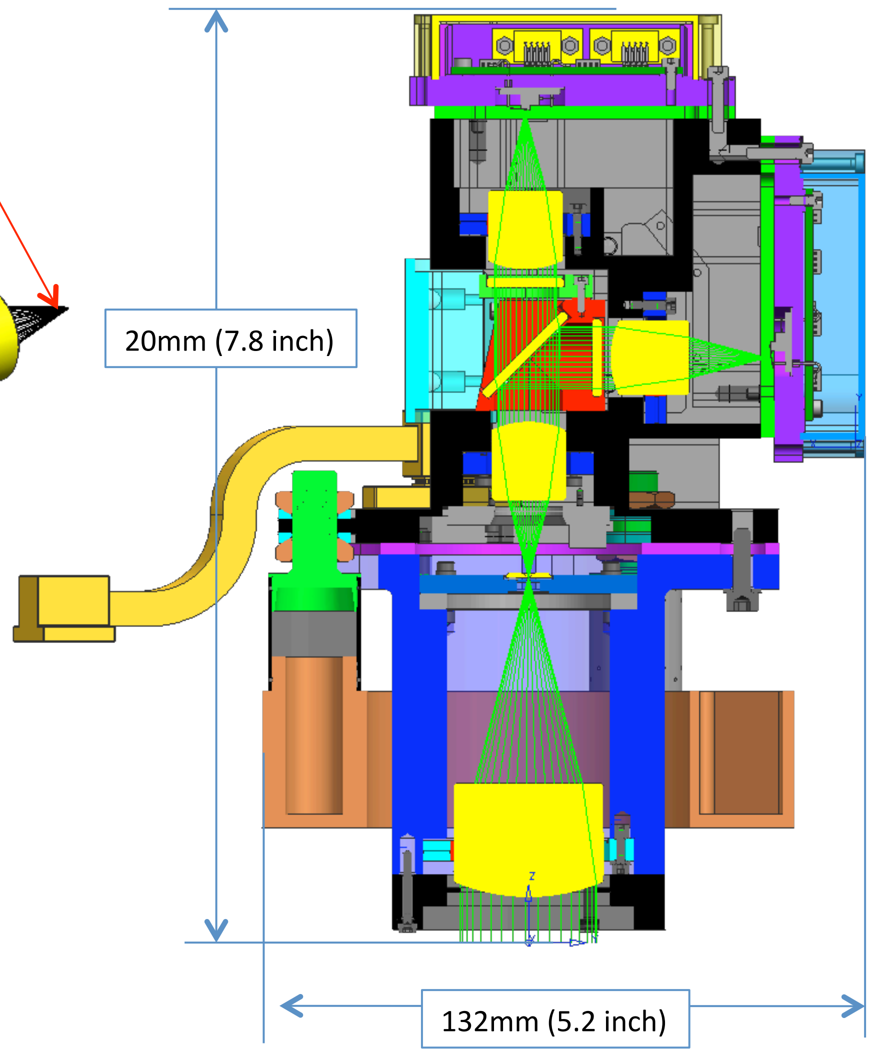


Opto-Mechanical Design

SWIR Channel Optical Design

- **Photo Diode x 2**
  - Aluminum Housing
  - TEC with InGaAs Diode Package
- **Relay Doublets x 3**
  - Ø16.4mm x 17.8mm
- **Filter x 2**
  - $17mm^2$
  - 1240 nm bandpass filter
  - 1610 nm bandpass filter
- **Dichroic Beamsplitter**
  - $25mm^2$
- **Shutter**
  - UNIBLITZ II N-CAS NS15B
- **Pin Hole**
  - 0.12 x 0.12 mm
  - MDL E-Beam Lithographic Precision Aperture
- **60 mm F/2 Telescope**
  - Ø33mm x 27.6mm

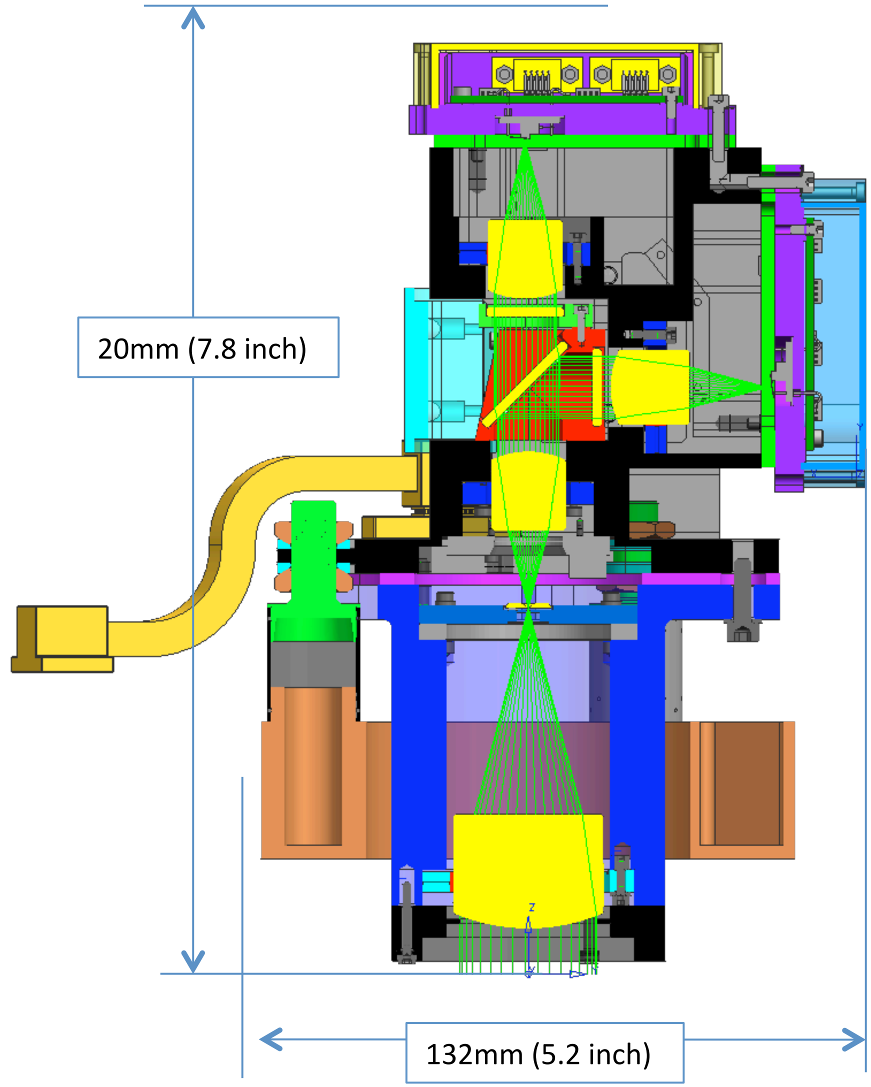




Opto-Mechanical Design

SWIR Channel

- Driving requirements are radiometric and boresight stability, which are achieved with a stiff structure and temperature control to within 1K.
- First mode frequency of the SWIR assembly is > 300Hz.
- Two InGaAs diode assemblies are independently aligned and bonded in place.
- SWIR boresight will be characterized during calibration relative to the spectrometer with an accuracy of 0.1 mrad.



Focal Plane and Electronics

SPECTROMETER

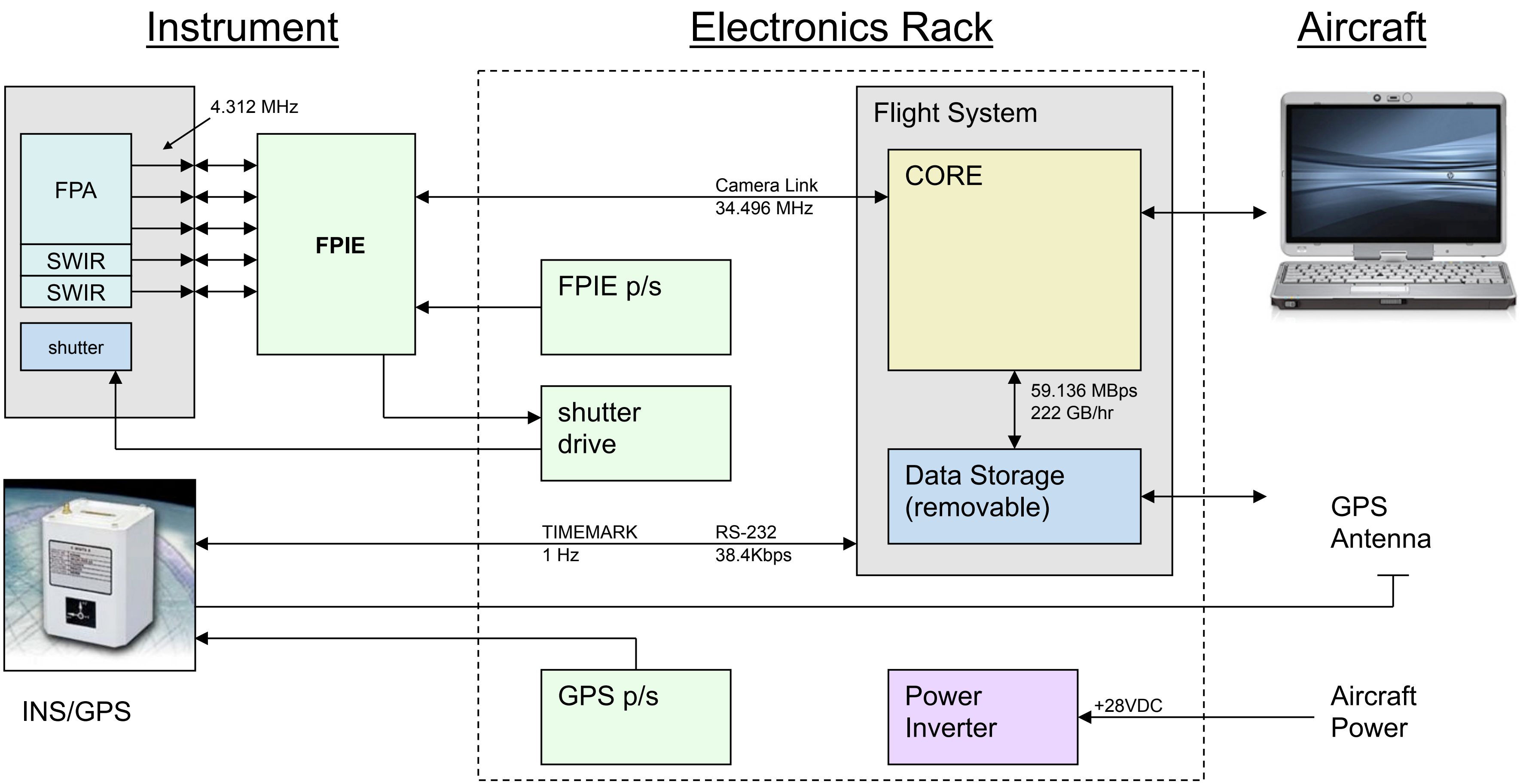
- 640x480 format HyViSI® FPA from Teledyne that operates in snapshot readout mode, which is best suited for pushbroom systems due to the lack of image smear.
- ~Half of the 480 columns are used (230 spectral channels total), which allows rapid readout rate (200 Hz) and consequent expansion of dynamic range.
- Readout electronics are custom-built at JPL and have been tested previously with similar arrays.
- 14 bits data digitization. Geolocation data are acquired and stored to ensure pointing knowledge within one IFOV.

SWIR

- Special attention has been paid to the SWIR electronics due to the very low signals expected (pA). A fully differential circuit has been implemented that reduces dark current to negligible levels, and an integrated thermoelectric cooler assembly is used for temperature stability.
- Breadboard circuit is currently under evaluation.

Focal Plane and Electronics

ELECTRONICS BLOCK DIAGRAM



Calibration and Flight

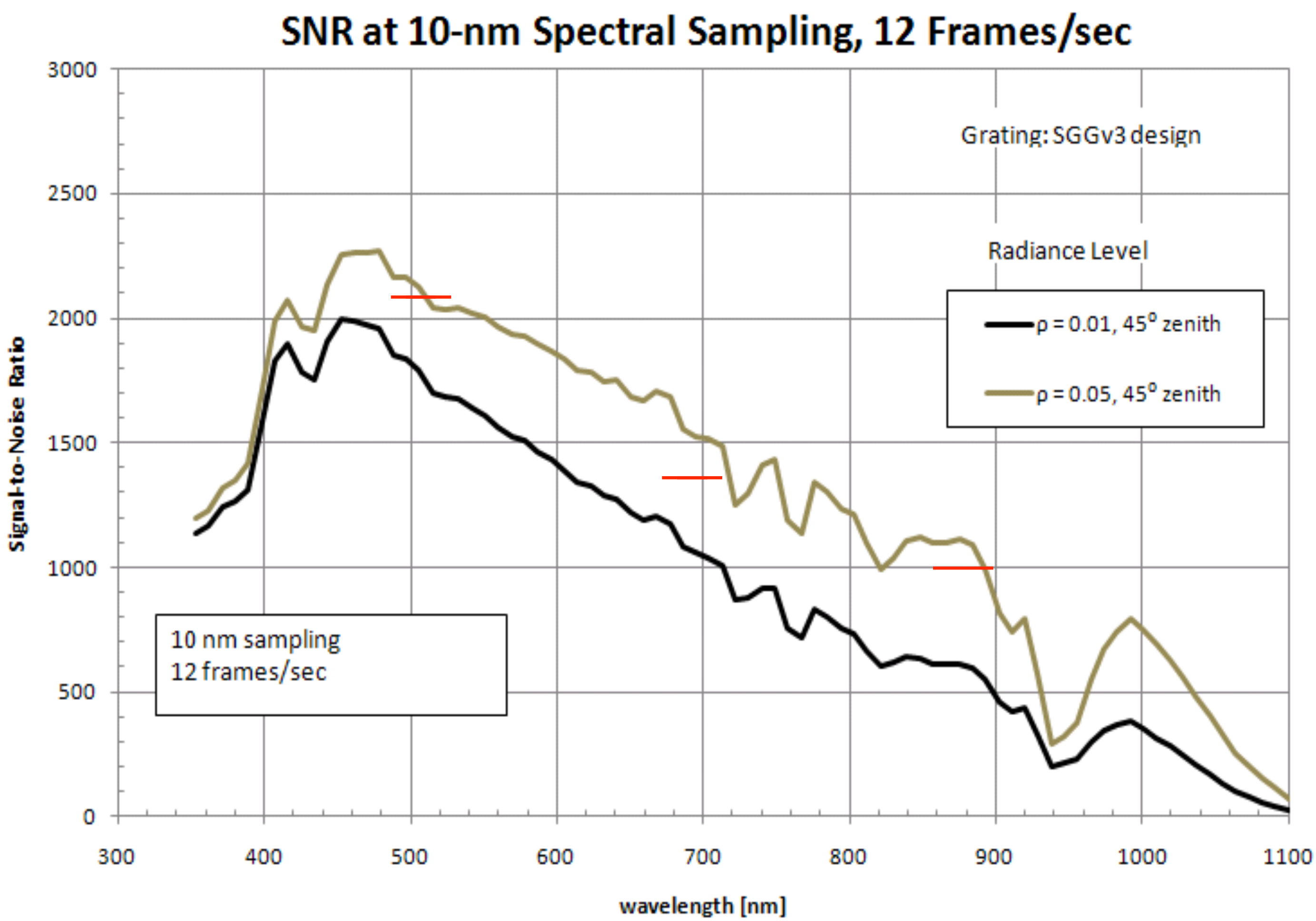
INSTRUMENT LAB CALIBRATION

- PRISM will undergo thorough spectral, radiometric, and spatial calibration/ characterization in the laboratory.
- Radiometric error budget shows that calibration uncertainty within 1% is achievable.
- Spectral and spatial response functions are derived for all channels across the field of view, with center and bandwidth knowledge to better than 0.1nm.

INSTRUMENT PRE/POST FLIGHT CALIBRATION

- A well-characterized integrating sphere fed by tungsten halogen lamps and two lasers will be used before take-off and after landing to confirm the stability of instrumental characteristics.
- Test flights utilize the Twin Otter aircraft which can fly without a port window. PRISM can be adapted for other aircraft, however each new platform may require a custom window with appropriate AR coating.

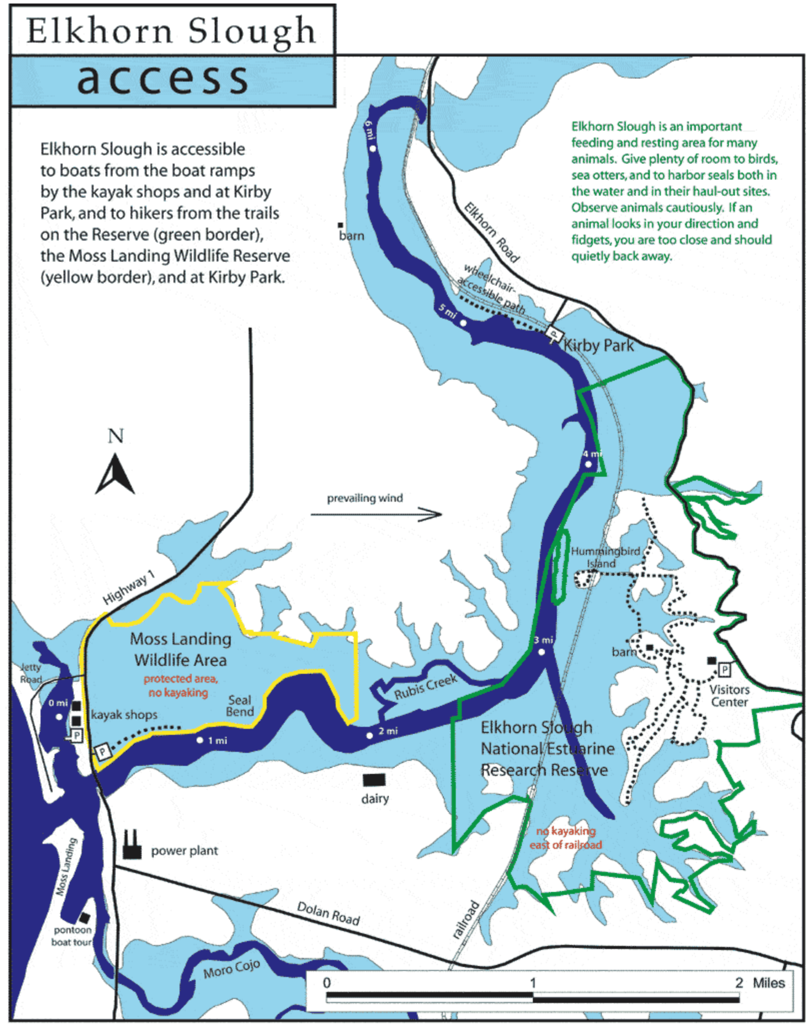
Calibration and Test Flight



Calibration and Test Flight

After a calibration flight, the instrument will prove its utility through a test flight during a planned coastal science investigation

- Monterey Bay – Coastal CA
  - Dark eelgrass targets
  - Turbid water
- During Overflights
  - Transect of stations up the Slough
  - Moored spectrometer and Sun photometer
- Not necessarily coincident
  - Eelgrass beds using divers
  - Emergent aquatic vegetation
  - Land-based targets



Summary

- PRISM is a pushbroom imaging spectrometer that will address important needs of airborne coastal ocean science research.
- PRISM covers the 350-1050 nm range with a 3.1 nm sampling and a 33^{o} field of view. The design provides for high signal to noise ratio, high uniformity of response, and low polarization sensitivity.
- Low polarization test gratings have been successfully fabricated demonstrating capability.
- Robust opto-mechanical design completed, leveraging on lessons from previous imaging spectrometer instruments.
- Development was initiated in September 2009 and delivery is expected in 2012. Hardware fabrication currently in process.
- NASA programmatic support through ESTO, Airborne Science, and Ocean Biology and Biogeochemistry programs is gratefully acknowledged.

Questions ?

Backup