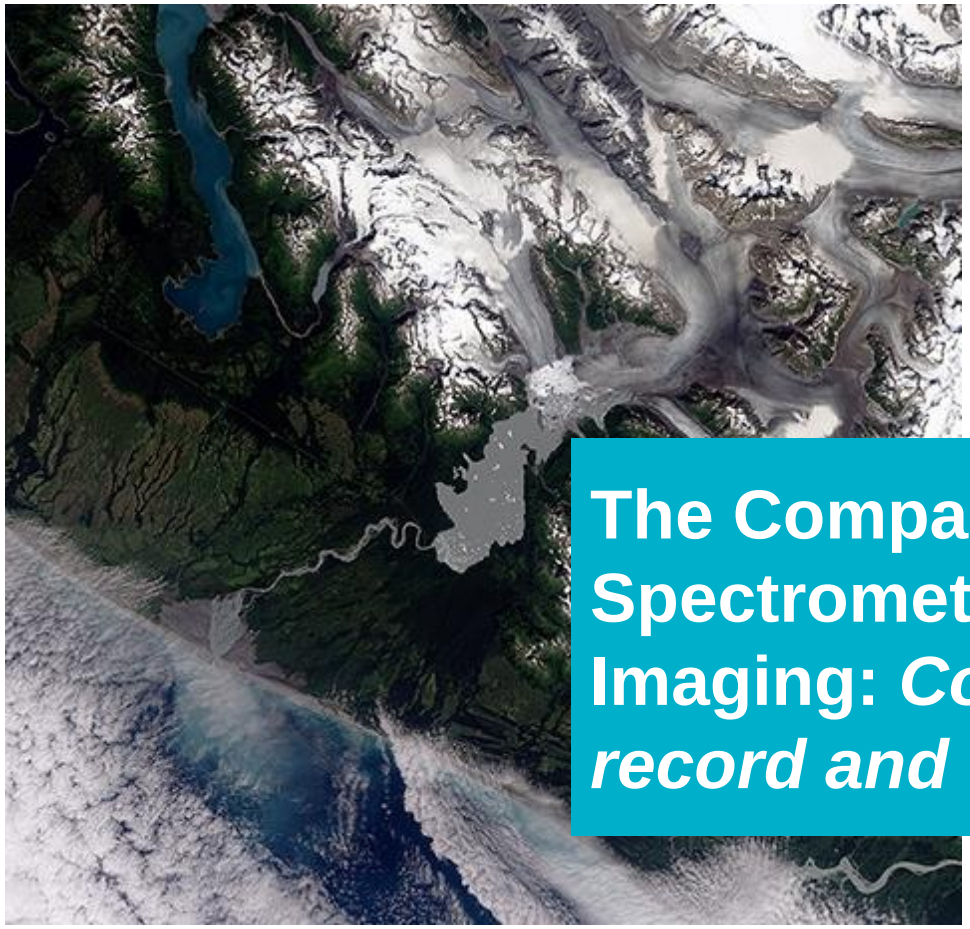
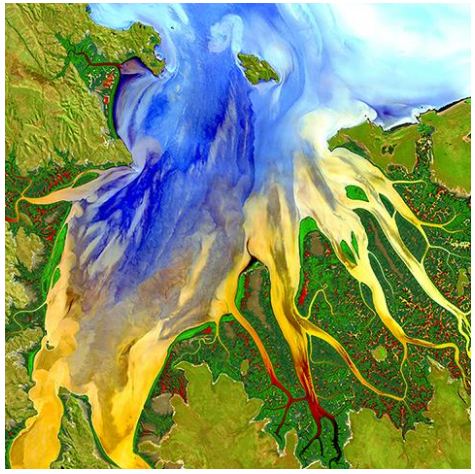


The Compact Hyperspectral Prism Spectrometer for Sustainable Land Imaging: *Continuing the Landsat data record and enabling new discoveries*



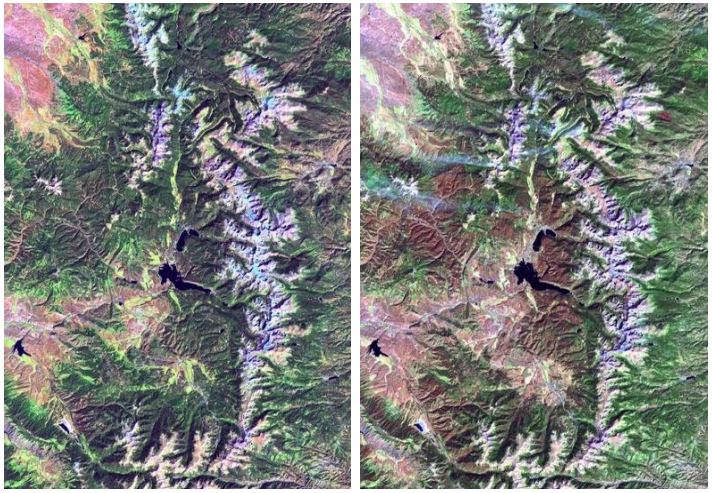
Tom Kampe
Ball Aerospace & Technologies

A7P5
Earth Science Technology Forum 2018
June 14, 2018

Sustainable Land Imaging Program

Sustainable Land Imaging-Technology Program

- *Reduce the risk, cost, size, volume, mass, and development time for the next generation **Sustainable Land Imaging (SLI)** instruments while meeting or exceeding the current **Landsat** land imaging capabilities;*
- *Improve temporal, spatial, and spectral resolution of SLI measurements; and*
- *Enable new SLI measurements that can improve operational efficiency and reduce overall costs*
- ***Maintain continuity with heritage Landsat instrument to continue 40+ year data series***



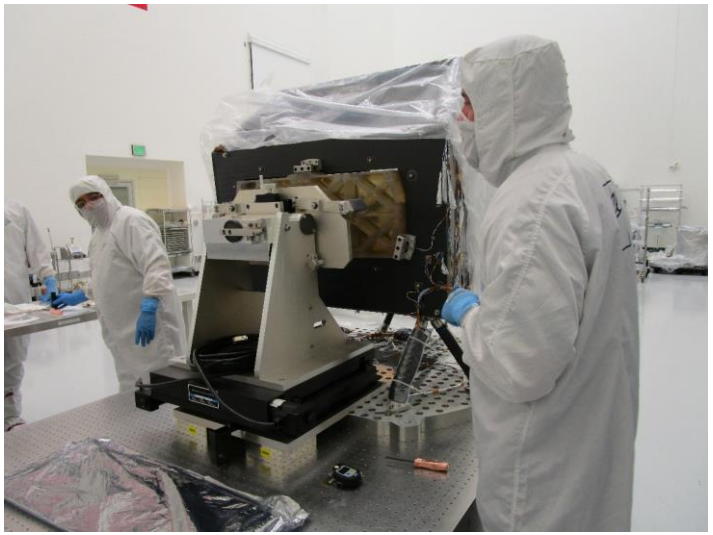
NASA

Ball Aerospace

Ball's Involvement in the Landsat Program

- Ball has extensive involvement in the Landsat program
- Ball built the Operational Land Imager (OLI) instrument for Landsat 8; which just reached its fifth year on-orbit this month!
  - https://landsat.gsfc.nasa.gov/operational-land-imager-oli/

- We are currently building OLI-2 for Landsat 9
  - Telescope completed & Focal Plane Assembly installed
  - Launch in 2021
  - https://landsat.gsfc.nasa.gov/landsat-9/instruments/landsat-9-science-instrument-details/#oli



SLI-T Compact Hyperspectral Prism Spectrometer (CHPS)

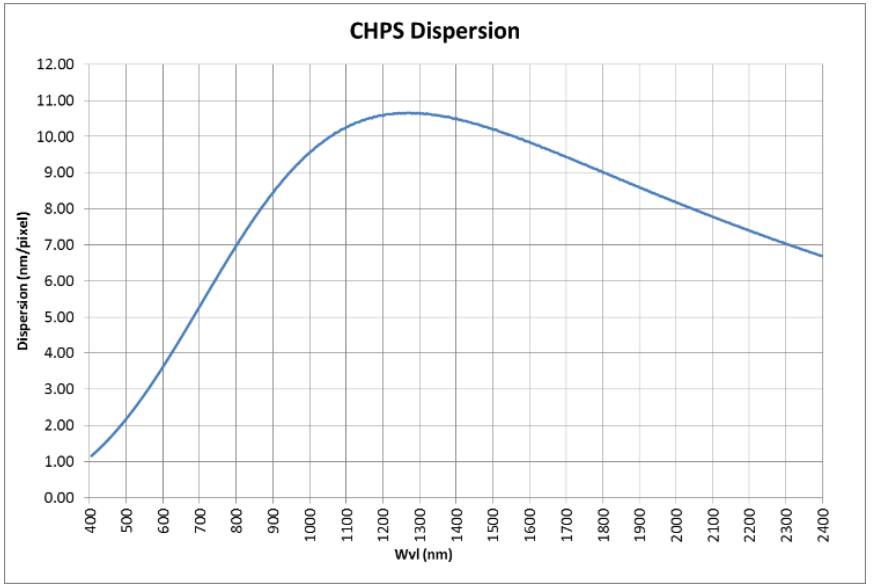
CHPS is a pushbroom prism imaging spectrometer operating over the VSWIR region

- Multiple channels binned to provide the heritage SLI bands
- Will provide data continuity with legacy Landsat instruments

SLI-T Band Name	CWL(nm)	CWL Tolerance (nm)	Min Lower Band Edge (nm)	Max Upper Band Edge (nm)
Coastal Aerosol	443	2	433	453
Blue	482	5	450	515
Green	562	5	525	600
Red	655	5	630	680
NIR	865	5	845	885
SWIR 1	1610	10	1560	1660
SWIR 2	2200	10	2100	2300
PAN	590	10	500	680
Cirrus	1375	5	1360	1390
Thermal 1	10800	200	10300	11300
Thermal 2	12000	200	11500	12000

SLI-T Compact Hyperspectral Prism Spectrometer (CHPS)

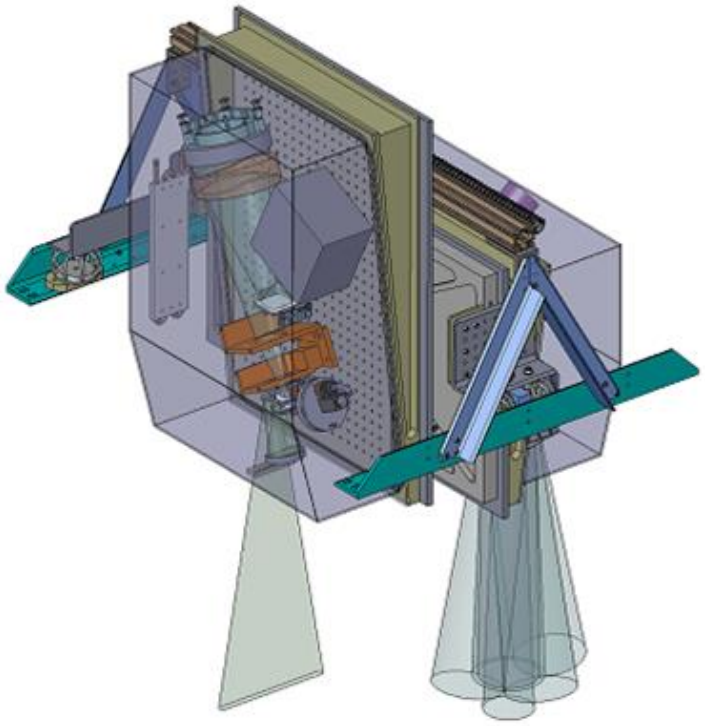
- **Continuous high spectral resolution from 400 to 2500 nm provides spectroscopic information to support wide range of emerging land science products:**
  - *Plant functional types and distribution*
  - *Intelligent agriculture (crop selection, water use practices, drought mitigation, etc.)*
  - *Ecological disturbances (invasive species, wild fires, forest thinning and dieback, insect infestation, etc.)*
  - *Near-shore Coastal Water Science (chlorophyll concentrations, algae blooms, water pollution)*



CHPS offers advantages for SLI

- ***Small Size/Cost:*** Compact form factor utilizing dual purpose optical elements for efficient space-saving design
- ***Low stray-light*** prism-based design eliminating multiple orders and scattering common in grating based instruments
- ***High SNR*** utilizing hyperspectral binning to match Landsat bands while also providing additional bands
- ***Low polarization*** increasing utility for inland and coastal water studies

Current Focus on Airborne Demo Instrument



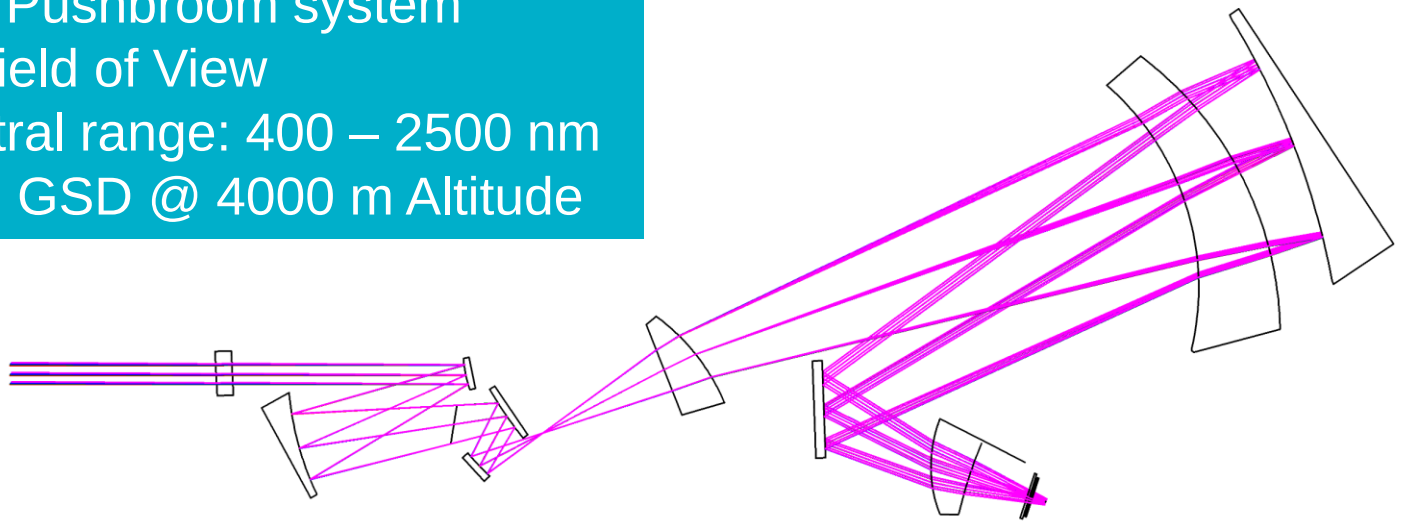
- Airborne demonstrations to be flown on De Havilland DHC-6 Twin Otter Aircraft with a large open nadir-viewing port
- Baseline co-manifest with REMI
- Engineering test flights in Fall 2018
- Vicarious calibration flight over uniform region(i.e., Railroad Valley, NV)
  - Timed to coincide with OLI overflight
  - Coincident ground-based measurements
- Overflights over diverse ecosystems in Year 3
  - Forested regions
  - Agricultural regions
  - Water bodies, coastline
  - Potential overflights of NEON sites

Top-Level Parameters – Airborne Demo Instrument

Parameter	Value
Aircraft	Twin Otter De Havilland DHC-6
Flight altitude	4000 m AGL nominal; 5486 m (18,000 ft) max
Ground sampling distance	2.5 m
Aircraft velocity	50 m/sec
Hyperspectral spectral coverage	400 – 2500 nm; 1.6 to 10 nm/pixel sampling
Required SLI Spectral Bands	Data binned to generate SLI Bands 1-9
Instrument Environment	Pressure-controlled enclosure; thermally controlled
In-flight calibration	Spectral and radiometric calibration before and after every flight line
Typical flight day	4.0 hours; 3.25 hours of data collection
On-board electronics & data system	Controls data acquisition, telemetry and data archiving; real-time display of data; instrument control
Data volume, typical flight day	~ 1 Tb
Ground data system	Management and archiving of data acquired during flights; Quick-look data assessment

Airborne CHPS Optical Subsystem

- F/3.0 Pushbroom system
- 20^0 Field of View
- Spectral range: 400 – 2500 nm
- 2.5 m GSD @ 4000 m Altitude



- 4-Mirror Telescope coupled with prism spectrometer
- Fused Silica refractive elements
- Protected silver coated mirrors
- Each major optical subsystem assembled and tested independently and then brought together to form full system

FOCUS ON COASTAL AND INLAND WATERS

OLI Provides the Capability for Monitoring Near-Shore Waters

Coastal water science enabled by the addition of the Coastal Water Band, improved dynamic range, and high spatial resolution (30-m)

- Chlorophyll, suspended sediments, colored-dissolved organic matter
- phytoplankton and algae blooms
- Improved spatial resolution: 30-m

Landsat 8 “natural color" image using coastal/aerosol band 1 of Lake Erie (https://landsat.usgs.gov/)

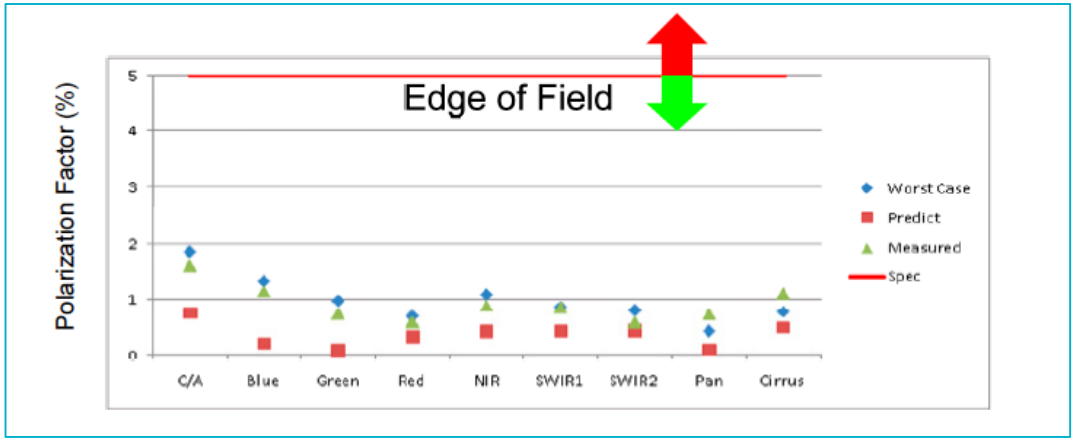
Blue-green algae bloom visible in image of Lake Okeechobee (7/2/16) by OLI) on the Landsat 8 satellite. The natural-color image combines red light, green light, and coastal aerosol (blue) light (bands 4, 3 and 1).

Images care of Landsat web site (https://landsat.usgs.gov/)

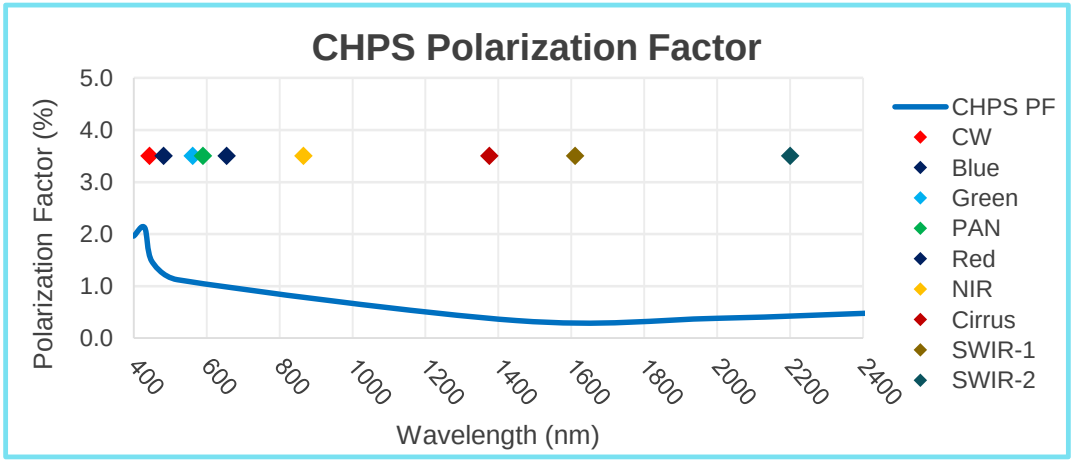
CHPS Provides Low Polarization Sensitivity - Key for Coastal Water Science

Minimizing polarization in the near-UV to visible region required due to polarized scatter from the atmosphere

- The OLI instruments exhibit low polarization sensitivity
- Our goal is for similar performance across the continuous VSWIR spectrum provided by CHPS
- Enabled by optical design
  - low angles of incidence on optics
  - Silver coated mirrors
  - High-efficiency BBAR coating

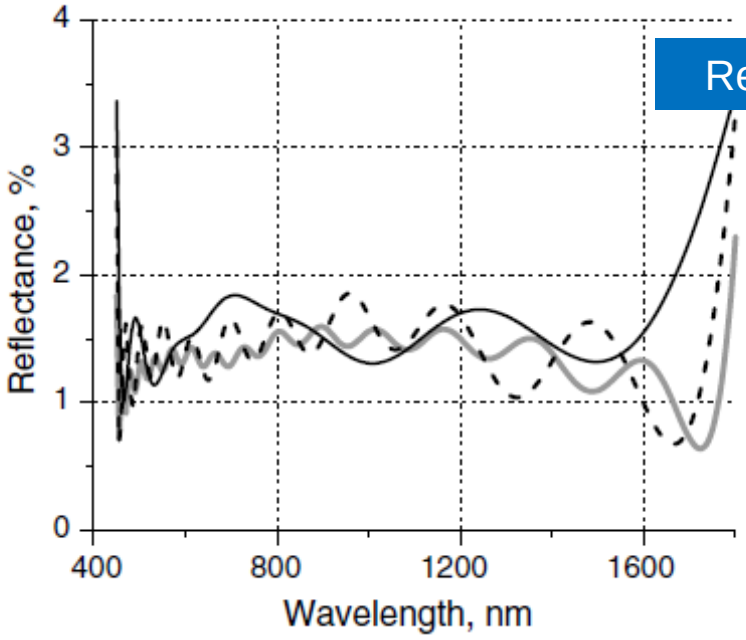


OLI Pre-launch measured PF well below the 5% requirement *(Knight & Kvaran,"Landsat-8 Operational Land Imager Design, Characterization and Performance", Remote Sens. 2014).*



Broadband AR-Coating Development

- With a broadband optical system with multiple refractive elements, spectral throughput can be an issue
- Prior to this program, broadband anti-reflection coatings limited to ~2 octaves (e.g., 450 – 1800 nm).
- *Amotchkina* [2011] demonstrated that manufacturable two-octave BBAR coatings were feasible over the 450-1800 nm spectral band using two materials in the thin-film stack organized as clusters

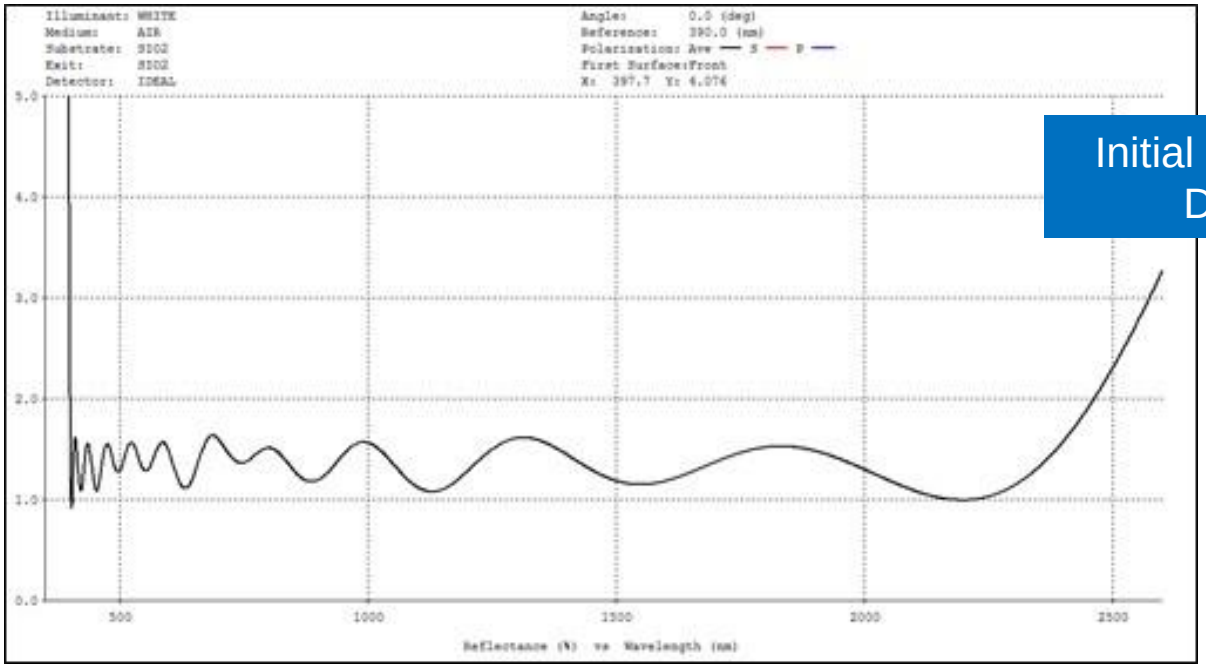


Amotchkina, et al.; "Design, production, and reverse engineering of two-octave antireflection coatings," Appl. Opt. 50, 6468 – 6475 (2011).

Broadband AR-Coating Development

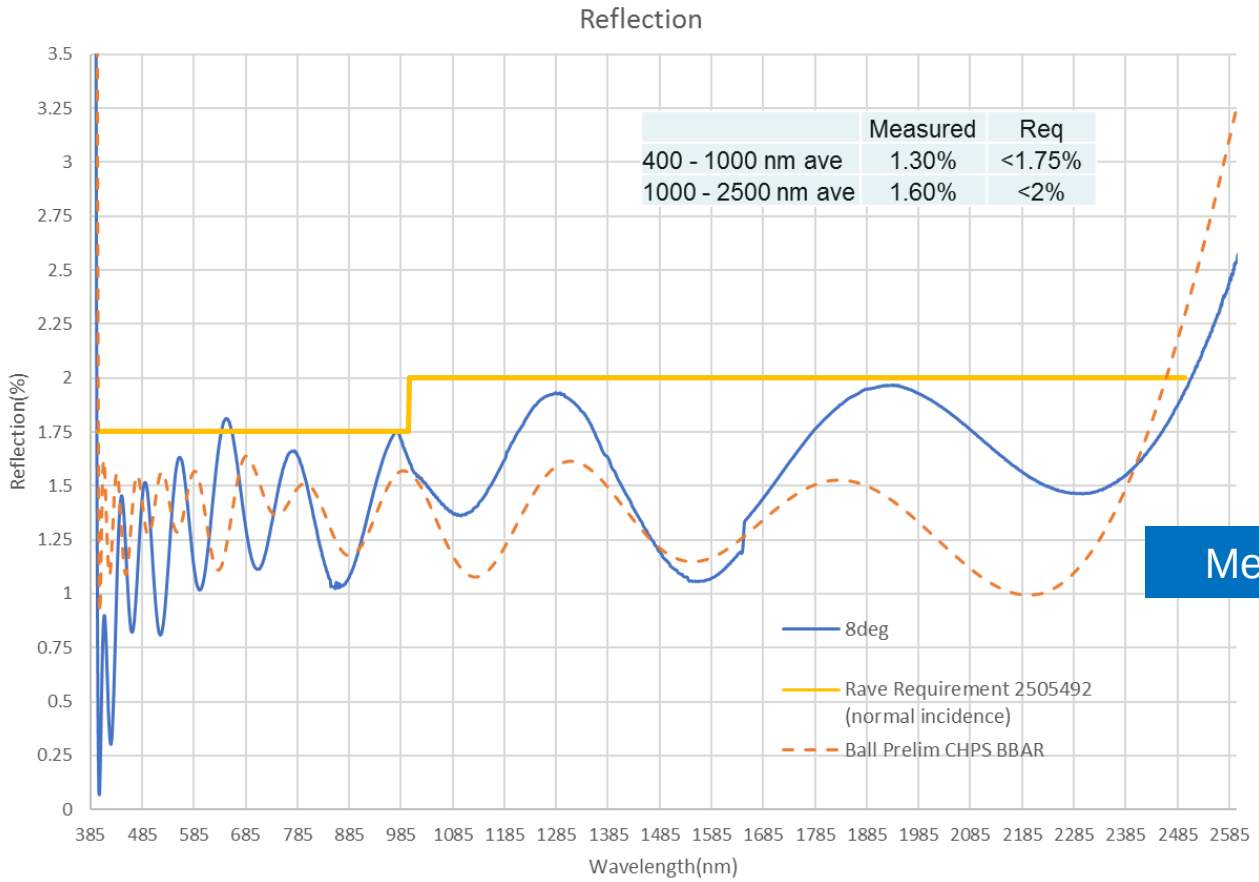
On this program, we developed a high-efficiency BBAR that extends the region of low reflectance over 2.5 octaves (400 – 2500 nm)

- ~ 1.5% R_{AVE} over spectral band



Initial Ball BBAR Design

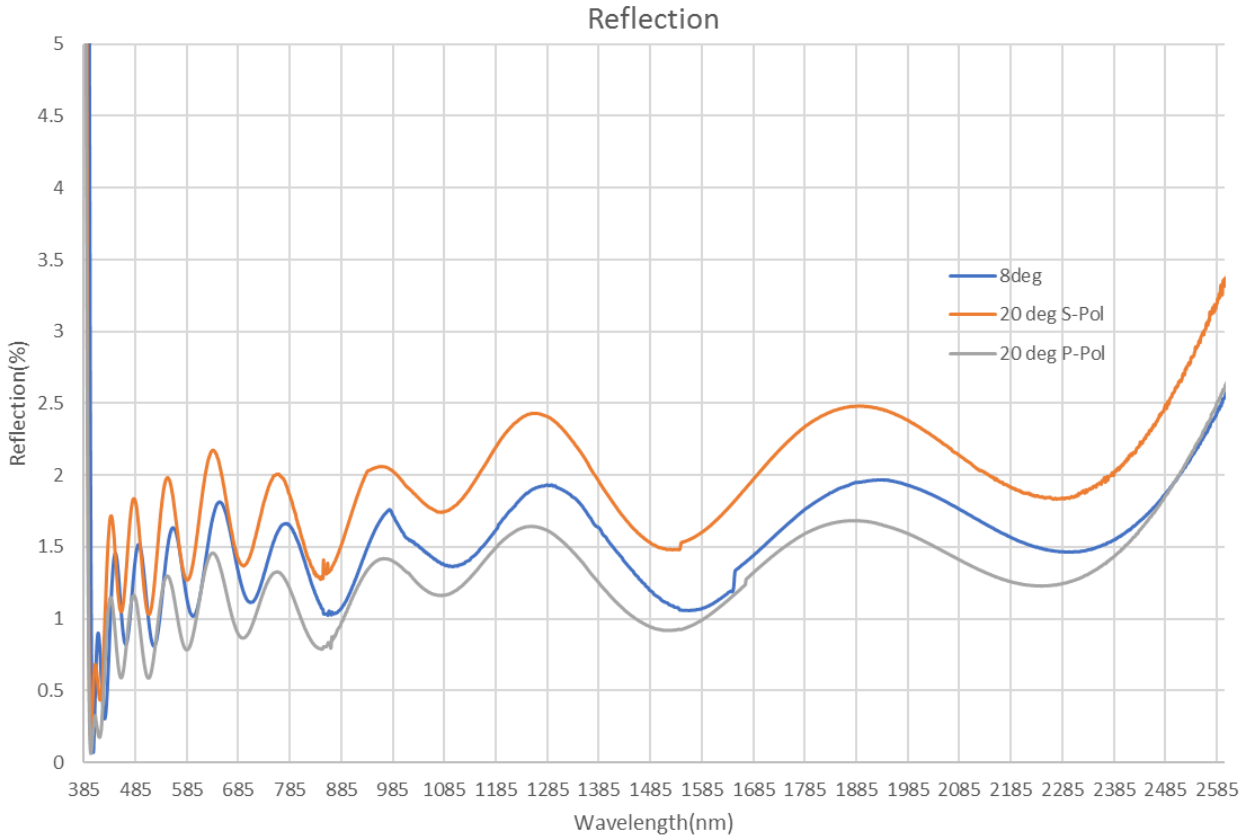
Broadband AR-Coating Feasibility Demonstrated



Measured Data

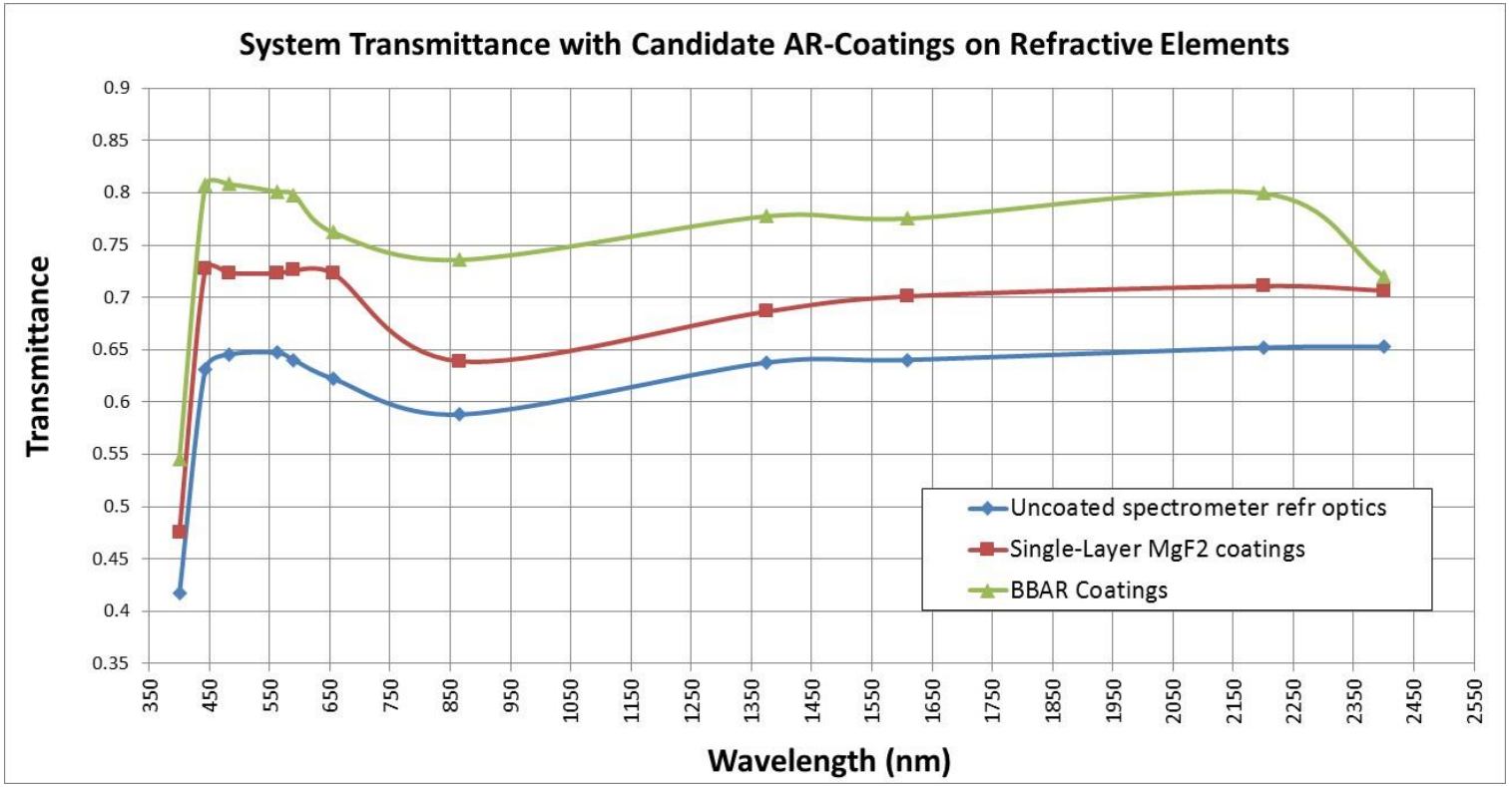
- Low reflectance, well within specification, was achieved
- Manufacturability is reasonable, but layer thicknesses need to be monitored carefully
- Coating has been shown to be highly durable through environmental tests

CHPS Broadband AR-Coating Exhibits Low Polarization Sensitivity



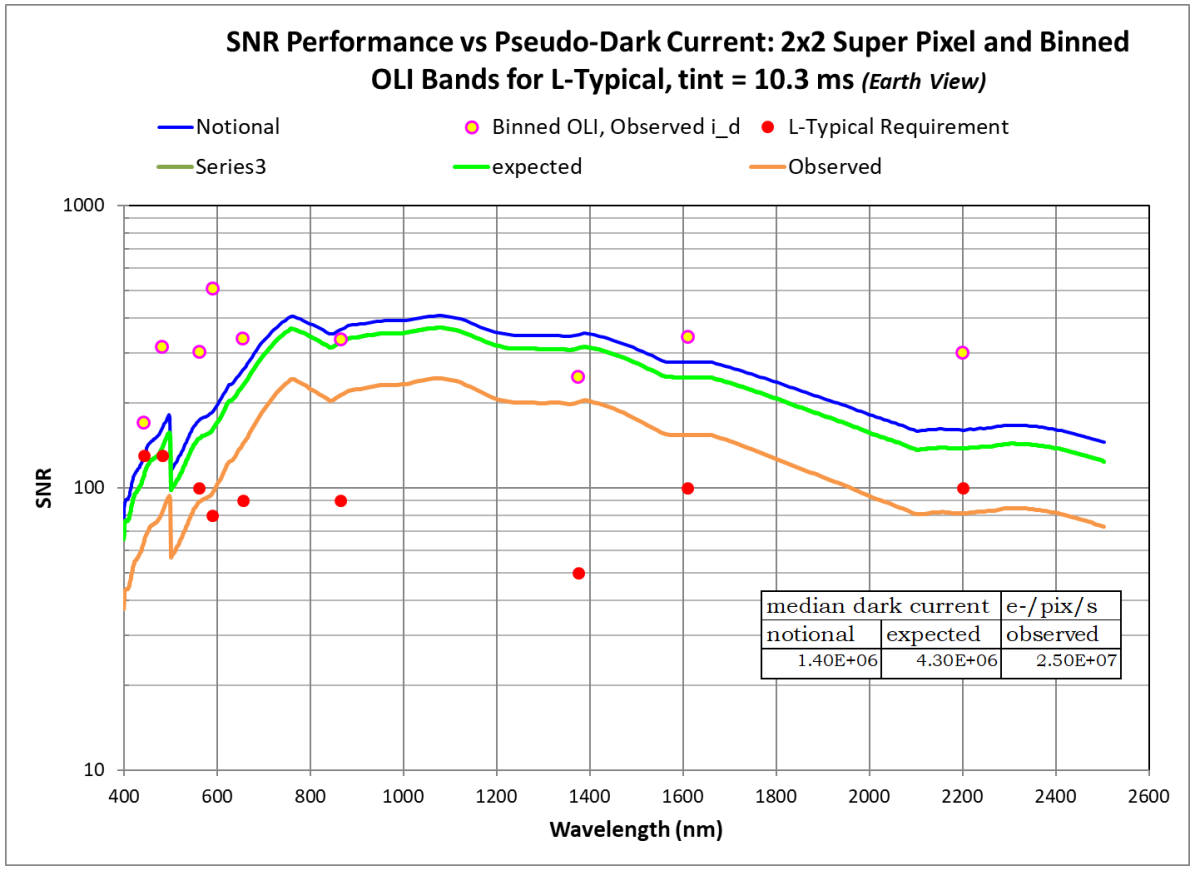
- Low BBAR polarization over broad spectral range and range of incidence angles enables the low polarization sensitivity of the CHPS instrument

Airborne CHPS Instrument Throughput



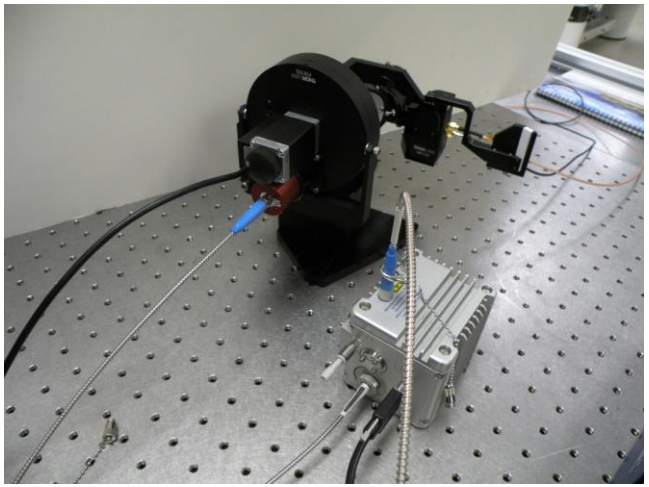
- Throughput modeled using Code V TRA option with modeled coatings applied to all air-glass interfaces
- Instrument spectral throughput significantly improved with BBAR coatings

Airborne CHPS SNR meets SLI requirements



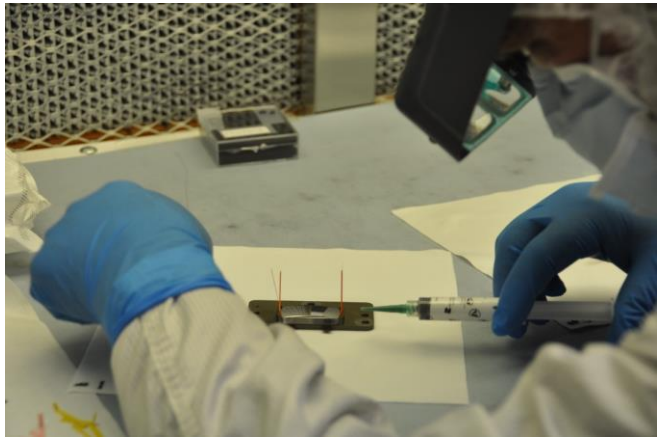
- As-built transmission incorporated into system model
- Focal Plane Array received and characterized
- FPA performance incorporated into radiometric model

Hardware Status

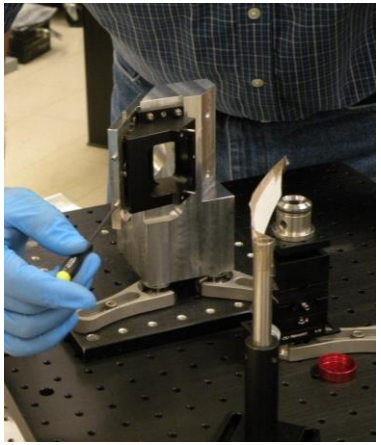


Calibration Subsystem

GN2 Purge and Pressure Control System and CHPS Equipment Rack

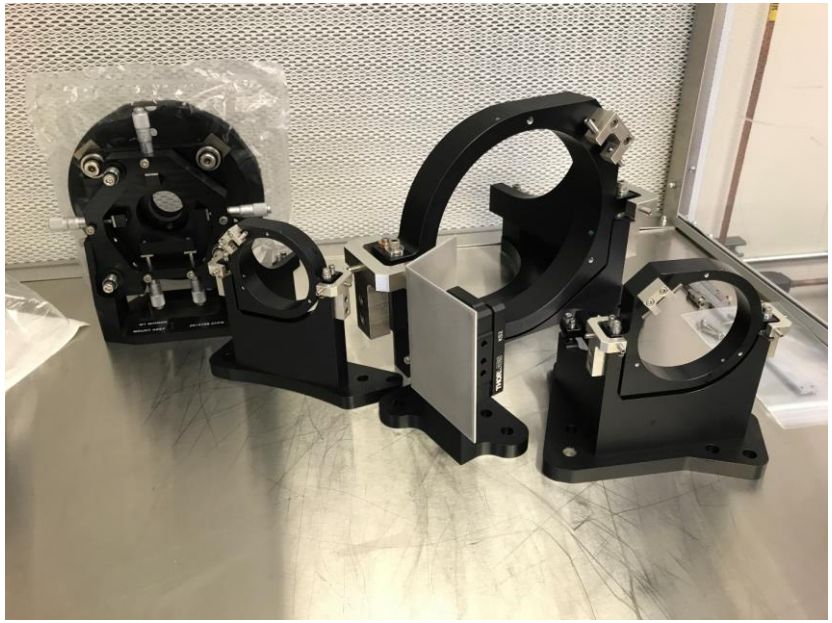


Telescope Optics Bonding

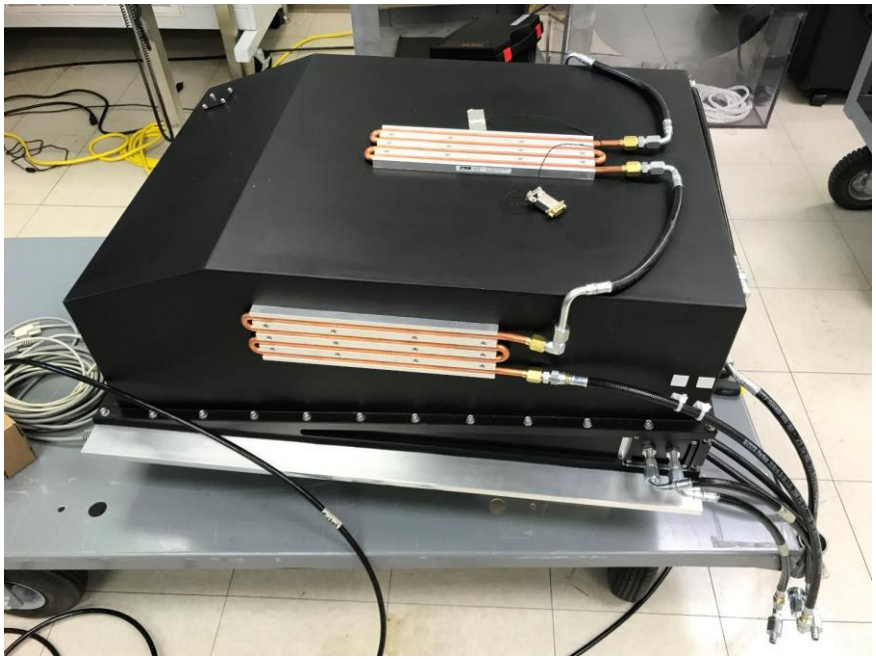


Telescope Optics Alignment

More Hardware



Spectrometer Optics Mounts



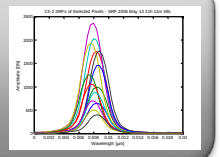
Instrument Enclosure

Upcoming Activities

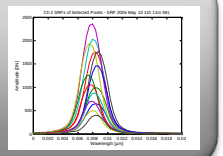
- Mechanical assembly nearing completion
- Telescope and spectrometer optical alignment on-going
- Calibration and validation tests including altitude chamber, performance, and Heliostat testing
- Flight tests – engineering flights in 4th-Quarter 2018
- Science flights in 2019
  - OLI under-flight, vicarious calibration sites, and inland/coastal water collects
- Data distribution to Landsat science collaborators for data product demonstrations
- Further development of spaceborne CHPS

Project Timeline

2017-18 Design & Development



2018Q4 Laboratory Testing



2018 Q4 Eng. Flight Campaign

2019 Q2/3 Science Flights

- Spectrometer characterization Spectral response function, smile; keystone distortion, dispersion
- Heliostat Solar source provides realistic spectral profile & opportunity for direct comparison between CHPS SLIT and OLI-2

- Eng. Flights ensure proper interfacing and functionality while airborne
- Science Flights used to acquire data of specific interest to the science community

Acknowledgements

- This project funded by the NASA Earth Science Technology Office, Grant NNX16AP61G