ARCSTONE:
Calibration of Lunar Spectral Reflectance

PI: Constantine Lukashin (NASA LaRC)

Lead Engineer: Trevor Jackson (NASA LaRC)

Partners:

**Resonon Inc., Quartus Engineering,
LASP Colorado U,
Blue Canyon Technologies**

Earth Science Technology Forum 2018, Silver Spring, MD

NRC Decadal Survey 2017: Accuracy

1. *Lukashin et al., "Accurate Inter-Calibration of Spaceborne Reflected Solar Sensors," input to NRC Decadal Survey, 2017.*

2. *Stone et al., "Redeveloping the Lunar Reflectance as a High-accuracy Absolute Reference for On-orbit Radiometric Calibration," input to NRC Decadal Survey, 2017.*

ARCSTONE relevance via enabling accurate calibration of instrument on orbit:

1. Aerosols: polarization imaging radiometer
2. Surface Biology & Geology: Hyperspectral imagery in the visible and shortwave infrared
3. Greenhouse gases: Multispectral shortwave infrared
4. Atmospheric winds: Passive imagery
5. Aquatic Biochemistry: PACE
6. Program of Records: MODIS, VIIRS, Landsat and SLI, GOES ABIs, CLARREO Pathfinder, CERES, and past mission SeaWIFS.
7. Incubation: Development of cost-efficient technology for sensor inter-calibration on orbit.

Relevant opportunities: Earth Venture and Earth Venture Continuity: Cubesat options

Lunar Calibration Applications

Team	Satellite	Sensor	G/L	Dates	Number of obs	Phase angle range (°)
CMA	FY-3C	MERSI	LEO	2013-2014	9	[43 57]
CMA	FY-2D	VISSR	GEO	2007-2014		
CMA	FY-2E	VISSR	GEO	2010-2014		
CMA	FY-2F	VISSR	GEO	2012-2014		
JMA	MTSAT-2	IMAGER	GEO	2010-2013	62	[-138,147]
JMA	GMS5	VISSR	GEO	1995-2003	50	[-94,96]
JMA	Himawari-8	AHI	GEO	2014-	-	
EUMETSAT	MSG1	SEVIRI	GEO	2003-2014	380/43	[-150,152]
EUMETSAT	MSG2	SEVIRI	GEO	2006-2014	312/54	[-147,150]
EUMETSAT	MSG3	SEVIRI	GEO	2013-2014	45/7	[-144,143]
EUMETSAT	MET7	MVIRI	GEO	1998-2014	128	[-147,144]
CNES	Pleiades-1A	PHR	LEO	2012	10	[+/-40]
CNES	Pleiades-1B	PHR	LEO	2013-2014	10	[+/-40]
NASA-MODIS	Terra	MODIS	LEO	2000-2014	136	[54,56]
NASA-MODIS	Aqua	MODIS	LEO	2002-2014	117	[-54,-56]
NASA-VIIRS	NPP	VIIRS	LEO	2012-2014	20	[50,52]
NASA-OBPG	SeaStar	SeaWiFS	LEO	1997-2010	204	(<10, [27-66])
NASA/USGS	Landsat-8	OLI	LEO	2013-2014	3	[-7]
NASA	OCO-2	OCO	LEO	2014		
NOAA-STAR	NPP	VIIRS	LEO	2011-2014	19	[-52,-50]
NOAA	GOES-10	IMAGER	GEO	1998-2006	33	[-66, 81]
NOAA	GOES-11	IMAGER	GEO	2006-2007	10	[-62, 57]
NOAA	GOES-12	IMAGER	GEO	2003-2010	49	[-83, 66]
NOAA	GOES-13	IMAGER	GEO	2006	11	
NOAA	GOES-15	IMAGER	GEO	2012-2013	28	[-52, 69]
VITO	Proba-V	VGT-P	LEO	2013-2014	25	[-7]
KMA	COMS	MI	GEO	2010-2014	60	
AIST	Terra	ASTER	LEO	1999-2014	1	-27.7
ISRO	OceanSat2	OCM-2	LEO	2009-2014	2	
ISRO	INSAT-3D	IMAGER	GEO	2013-2014	2	

Instruments with lunar observation capabilities

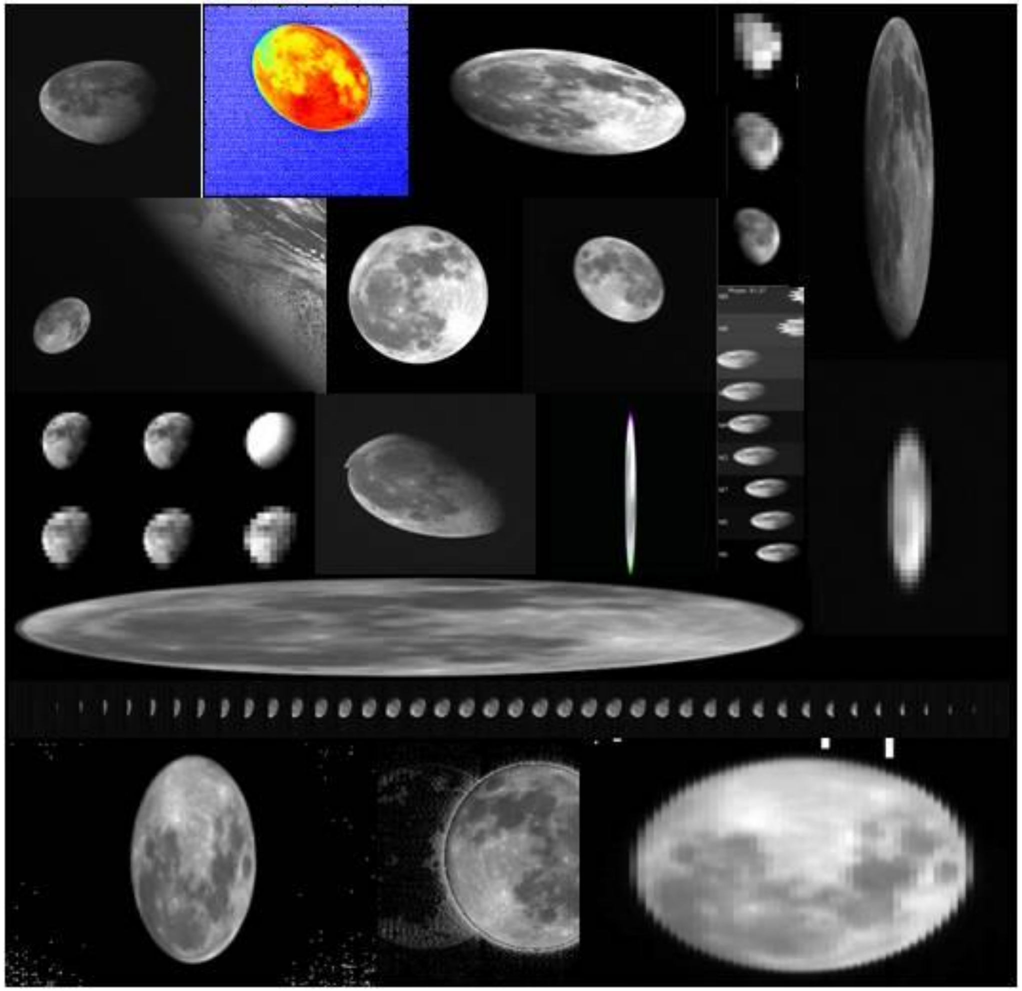
From GSICS Lunar Calibration Workshop, December 2014, EUMETSAT.

Moon: Solar Diffuser For Instrument Calibration In-orbit

Reflectance of Lunar surface stable to < 10^{-8}

Calibration reference:
Lunar irradiance (entire disk)

Lunar Calibration Applications

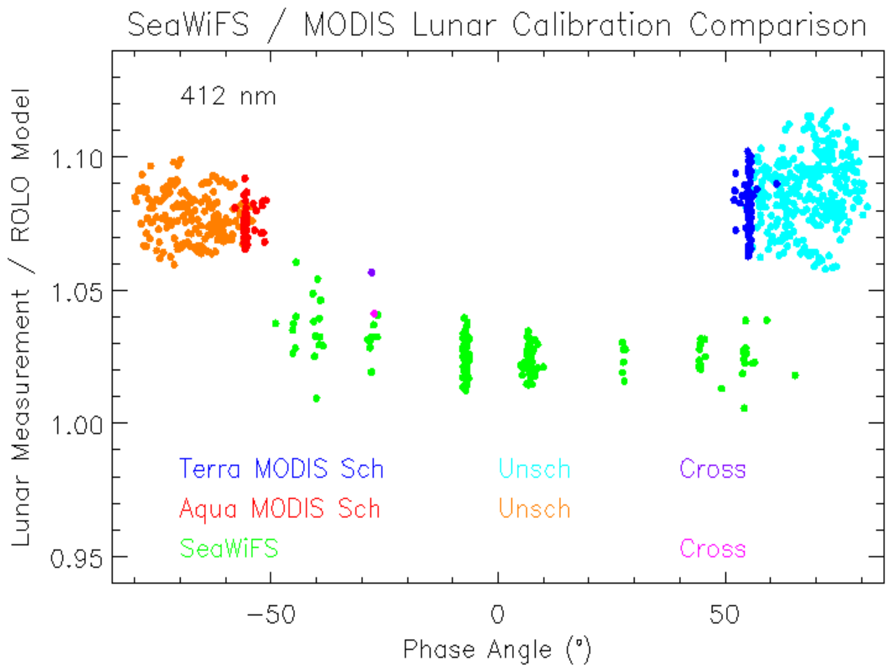


The Figure shows the Lunar views from currently operational sensors on-orbit.
The Lunar calibration is an available reference source for most sensors in LEO and GEO.

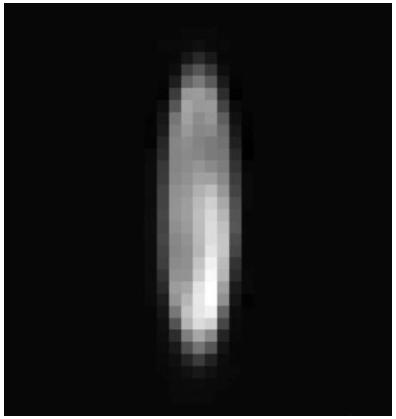
Lunar Calibration On-Orbit:
State of the Art - SeaWIFS Example

SeaWiFS gain stability 0.13% (k=1) achieved with Lunar calibration monthly !
Absolute biases up to 3% (k=1)

SeaWIFS and MODIS lunar calibration comparison, at 412 nm wavelength:



Lunar image by SeaWIFS



- SeaWIFS scatter due to oversampling corrections.
- MODIS scatter due to lower lunar signal at higher lunar phase angle.

Need: Absolutely accurate irradiance for all lunar phase and libration states !

ARCSTONE Mission Concept

Concept of Operations and Data Products:

- Data to collect: Lunar spectral irradiance every 12 hours.
- Data to collect: Solar spectral irradiance TBD (at least weekly).

  Collection within 10 min each day to achieve combined accuracy < 1% (k=2).

  Spectrometer with single field-of-view about 0.5° (no scanning !).
- Preferred orbit – 90° inclination polar (best sampling).
- Spectral range from 350 nm trade to 2300 nm, spectral sampling 3 nm.

After 1 year: Improvement of current Lunar Calibration Model (factor > 2);
After 3 years: New Lunar Irradiance Model, improved accuracy level (factor > 6).
Longer time: More Lunar geometries covered – better model reliability.

Key Technologies to Enable the Concept:

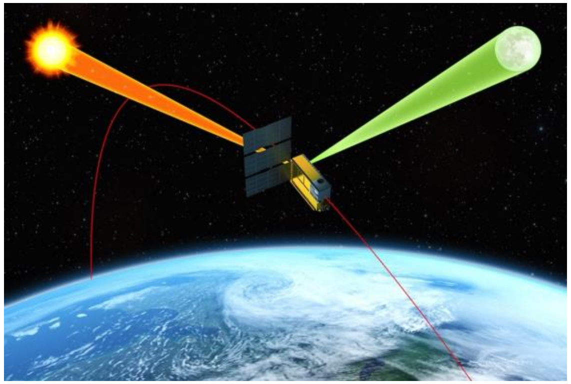
- Approach to orbital calibration via referencing Sun:
  Demonstration of lunar and solar measurements with the same optics/detector using *integration time to reduce solar signal*
- Pointing ability (precision & accuracy) of small spacecraft now permits obtaining required measurements

ARCSTONE: Key Mission Performance Parameters

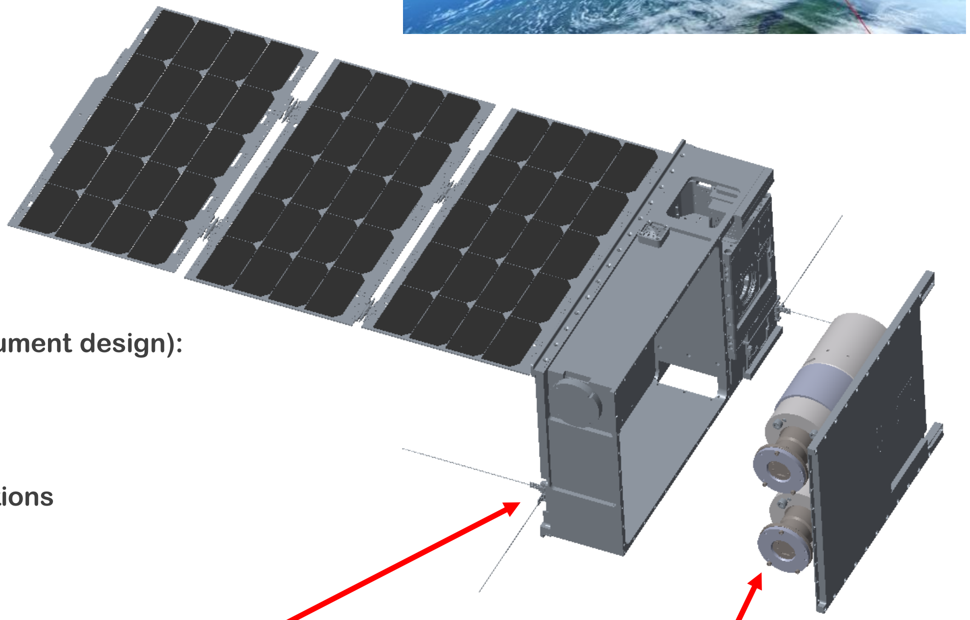
Key Performance Parameters (KPP)	Threshold Value	Goal Value
Accuracy (reflectance)	1.0% (k=1)	0.5% (k=1)
Stability	< 0.15% (k=1) per decade	< 0.1% (k=1) per decade
Orbit	Sun-synch orbit	Sun-synch orbit
Time on-Orbit	1 year	3 years
Frequency of sampling	24 hours	12 hours
Instrument pointing	< 0.2° combined	< 0.1° combined
Spectral Range	380 nm – 900 nm	350 nm – 2300 nm
Spectral Sampling	8 nm	4 nm

Reference for radiometric requirements (ROLO, T. Stone):
Lunar Phase Angle = 75°;
Irradiance = 0.6 (micro W / m^2 nm)
Wavelength = 500 nm

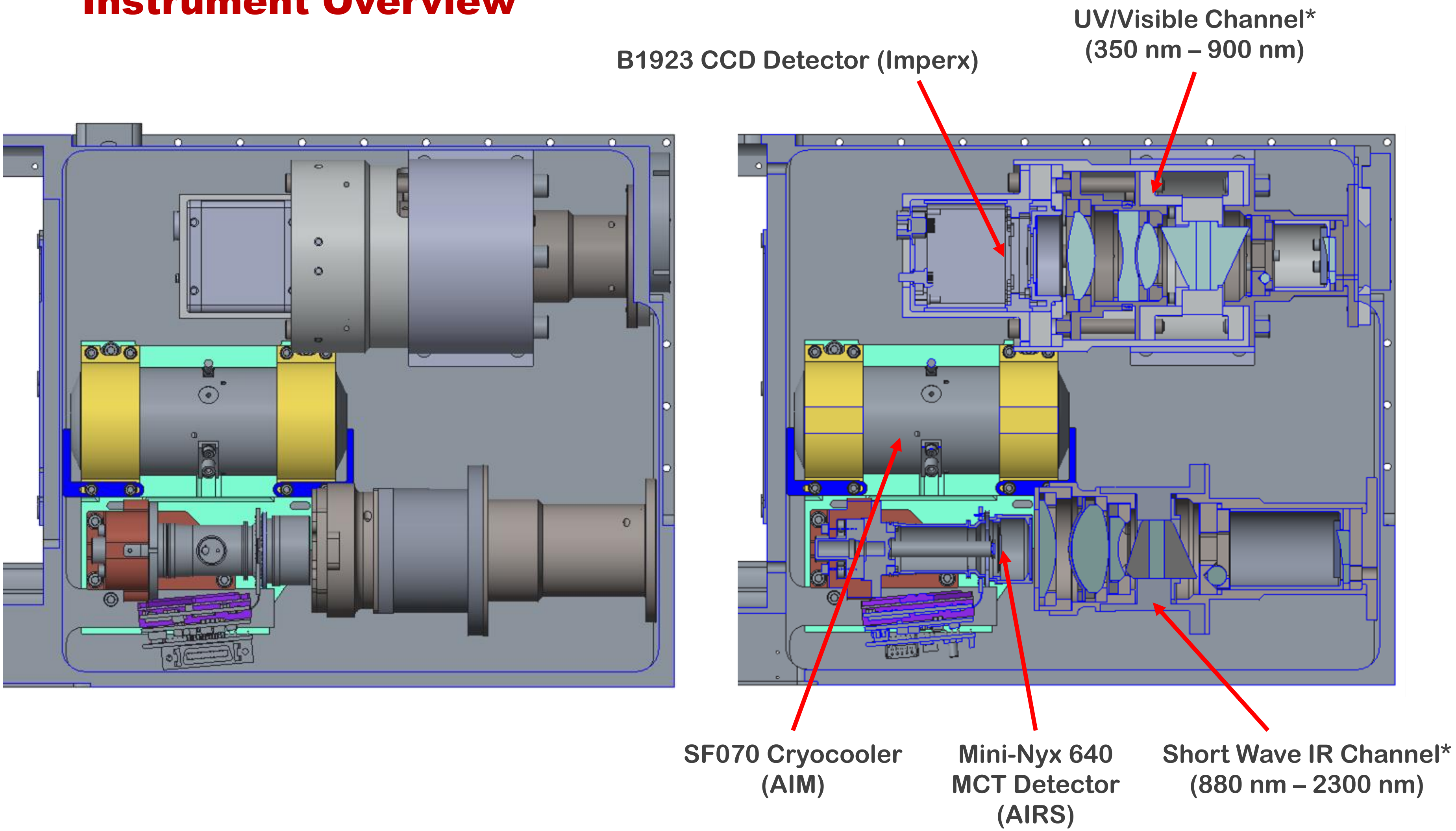
ARCSTONE: Mission Concept and Week in Life



1. Lunar spectral irradiance observations:
- Every 12 hours
- Close to polar locations
- Multiple measurements within 10 minutes to get required SNR
2. Solar spectral irradiance observations:
- Every TBD days (e.g. daily)
- Multiple measurements to get required SNR
- This is radiometric calibration to the TSIS reference
3. Dark images:
- Multiple measurements with closed shutter
- Before every lunar and solar observations
4. Dark field (to calibrate out shutter temp):
- Multiple measurements of dark space
- TBD (e.g. daily)
5. Field-of-view sensitivity characterization:
- Calibration of instruments alignment
- TBD (e.g. weekly)
6. Mercury-Argon Pen-Ray Lamp (not included in the instrument design):
- Spectral calibration with contamination door closed
- TBD (e.g. weekly)
7. Spacecraft pointing calibration (and other checks):
- Defined by the BCT for calibration of spacecraft functions
8. Stand by mode:
- Mode between lunar and solar observations
9. Safe mode (TBD)
10. On-board data processing mode
11. Down-link data mode



ARCSTONE Design 6 Months Ago: Instrument Overview

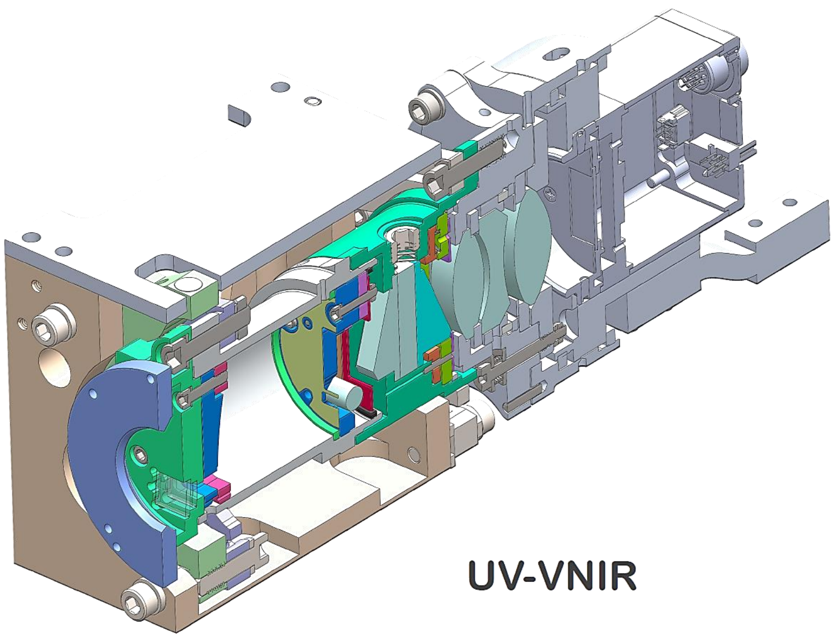


UVVNIR Design

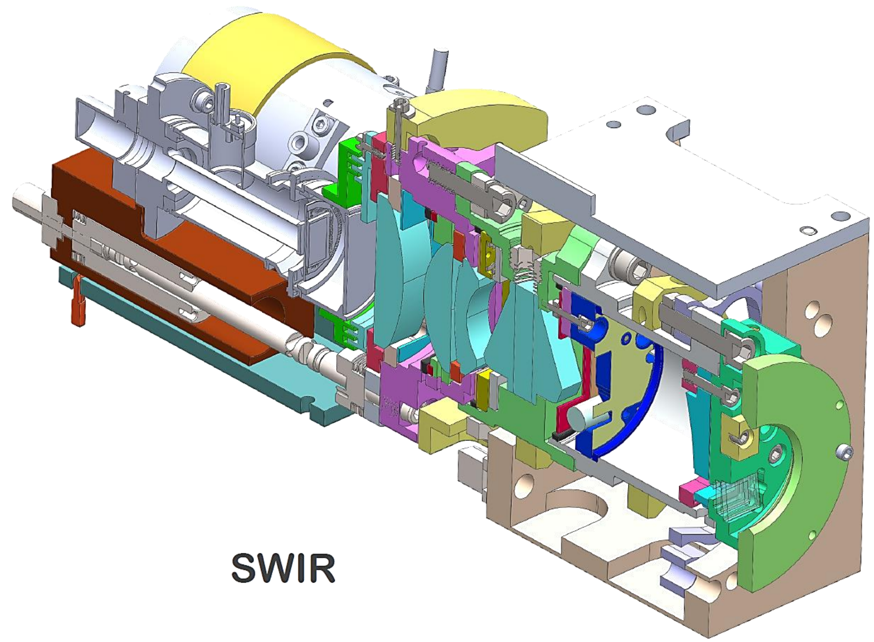
- Optical design complete
- Optomechanical design complete
- Optical and engineering drawings currently being produced
- Long lead item orders placed or RFQ submitted

SWIR Design

- Optical design complete
- Optomechanical design complete
- Drawings begin after UVVNIR
- Long lead item orders placed or RFQ submitted



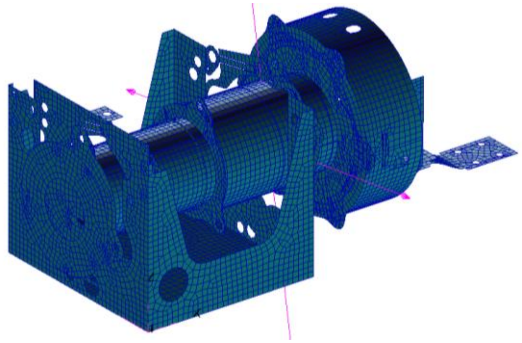
UV-VNIR

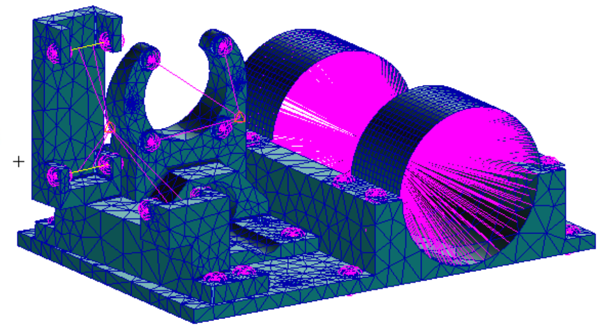


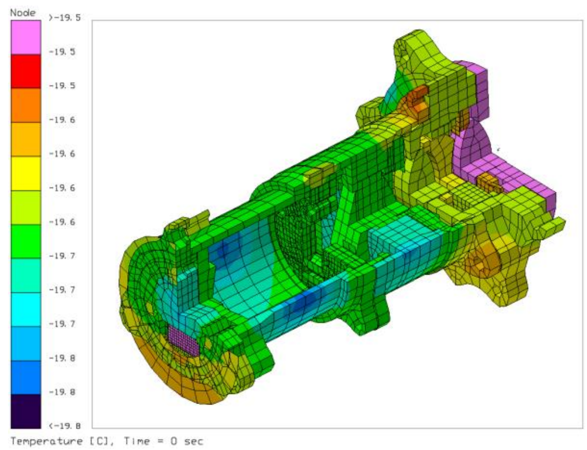
SWIR

Structural Analysis

- Instrument level analysis
- Vibration test planning
- Cryocooler vibration assessment

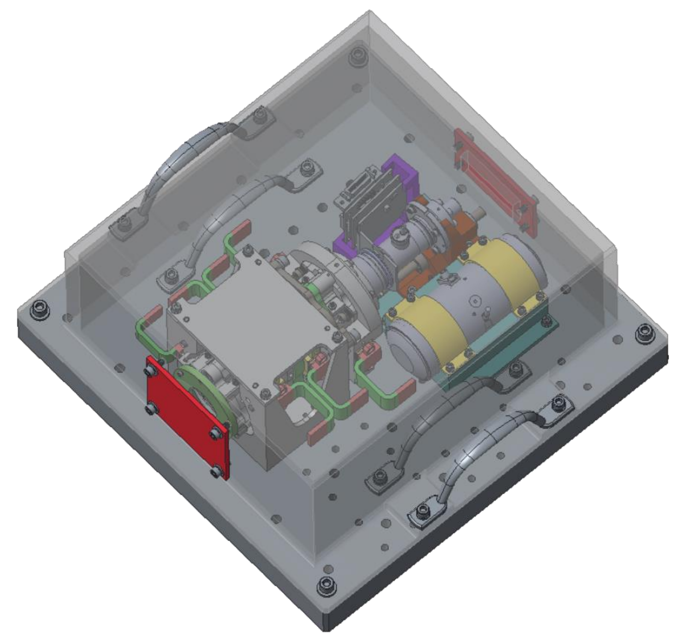






Thermal Analysis

- Thermal background mitigation required addition of SWIR cooling system
- SWIR detector and cryocooler analysis
- UVVNIR and SWIR detector TVAC testing

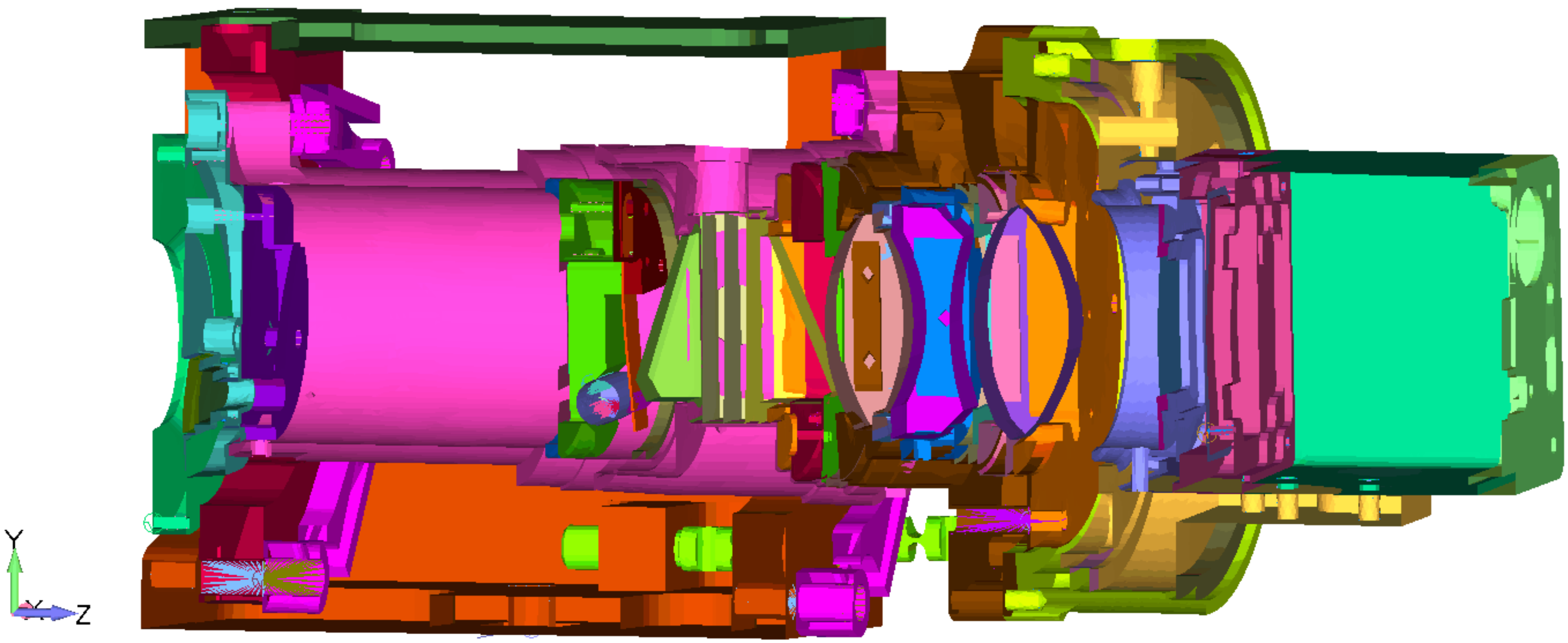


Thermoelectric Coolers (TECs) / Thermal Straps

UVVNIR Thermoelastic Analysis

Output Set: COLD 600 SECONDS
Animate(0.000128): Total Translation

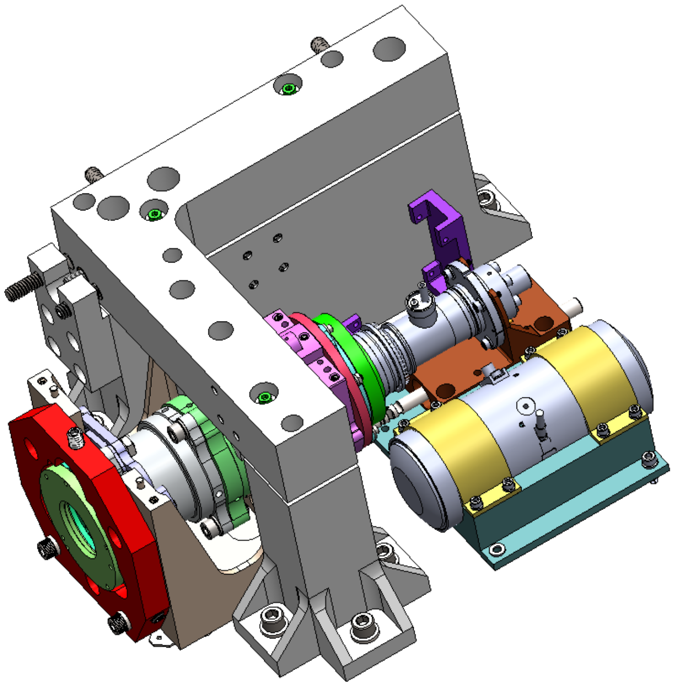
Deformations scaled 100x



Section cut shown to better visualize displacement

Alignment

6-Degree of Freedom Alignment Tool

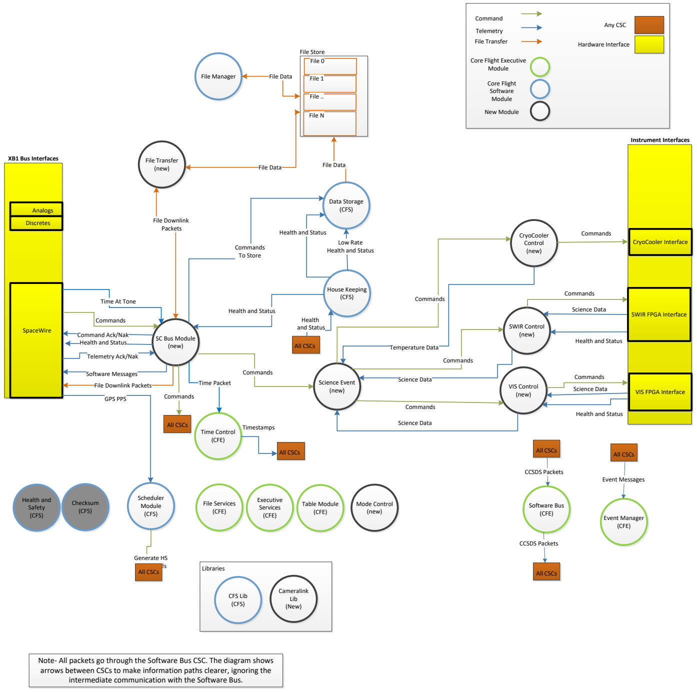


- UVVNIR and SWIR alignment plans
- Identified need for 6 degree of freedom alignment tool for SWIR
- UVVNIR and SWIR staking plans

Fabrication in Progress

Software Development

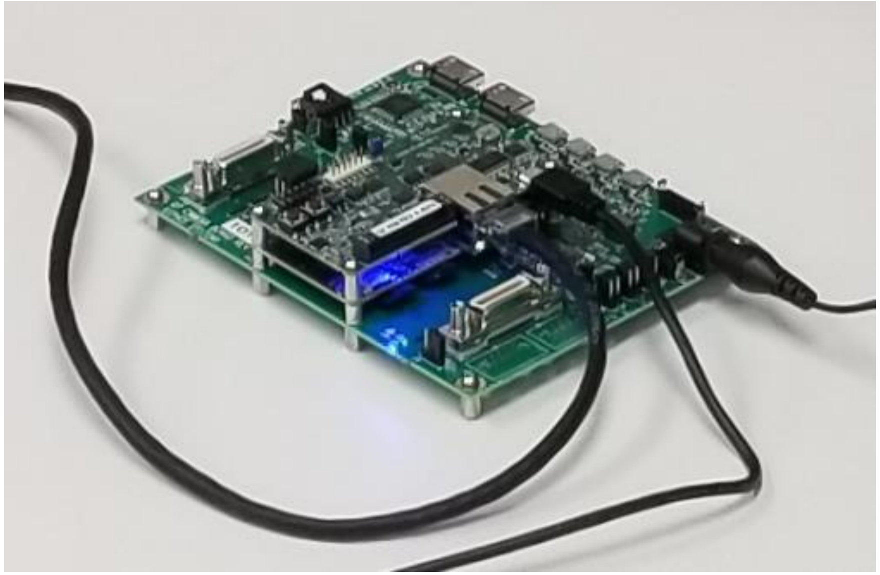
- Flight-like and ground test architecture design
- Blue Canyon Technologies (BCT) spacecraft bus software simulator
- Instrument controller testing and verification



Flight-like Software Architecture

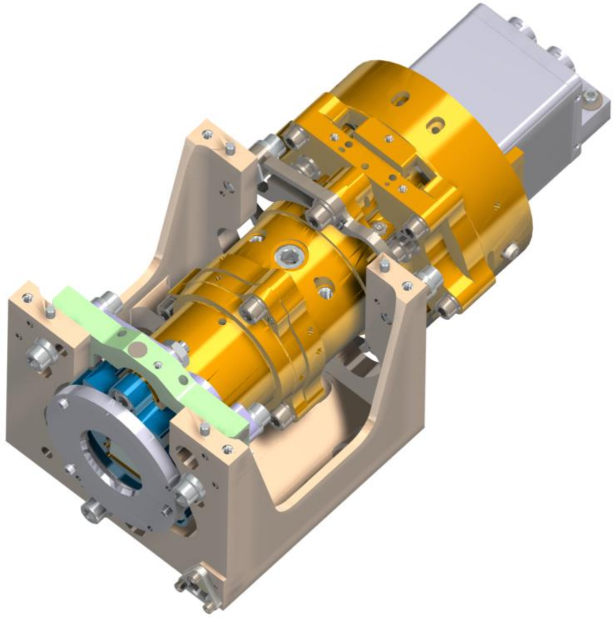
Electronics Development

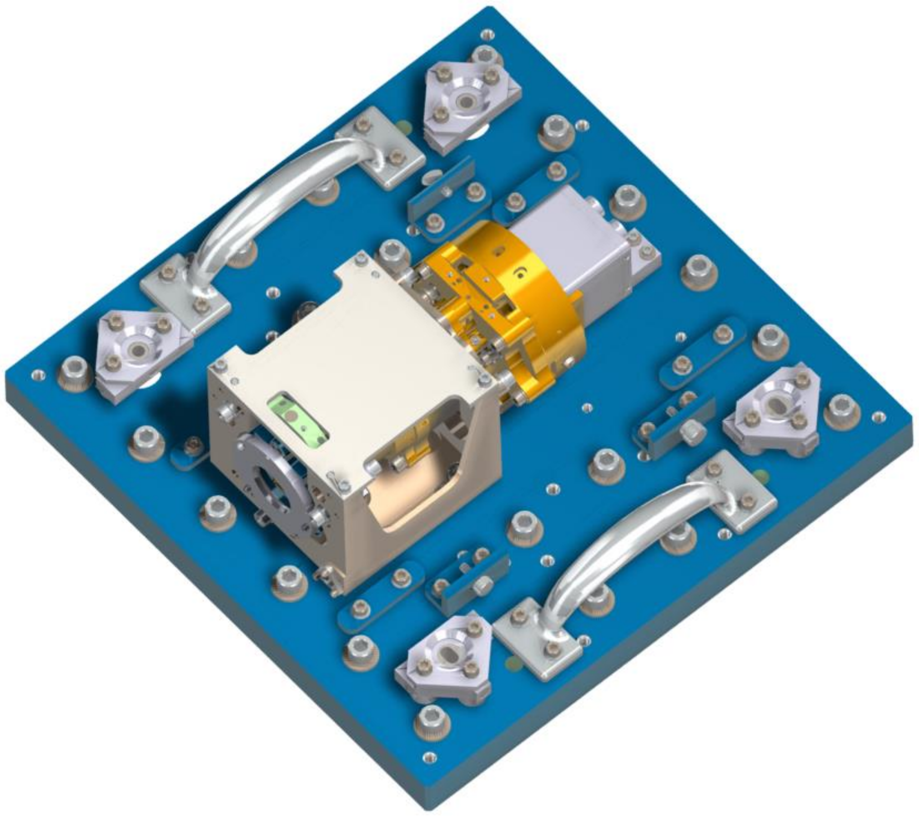
- UVVNIR and SWIR detector TVAC testing
- UVVNIR and SWIR detector calibration preparation
- Instrument controller configuration



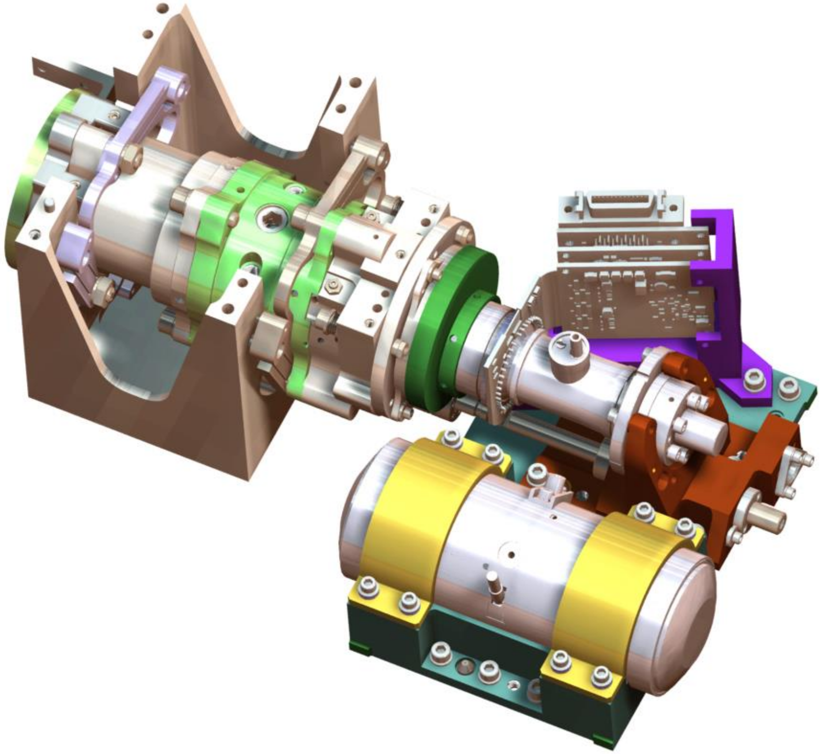
Q7 + Camera Board

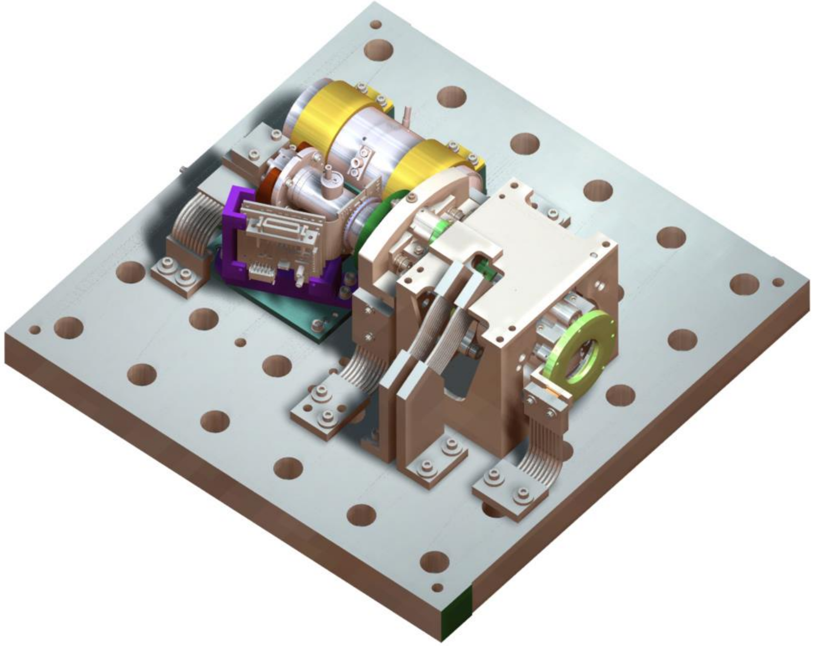
ARCSTONE UVVNIR Rendering (as fabricated)





ARCSTONE SWIR Rendering (as fabricated)



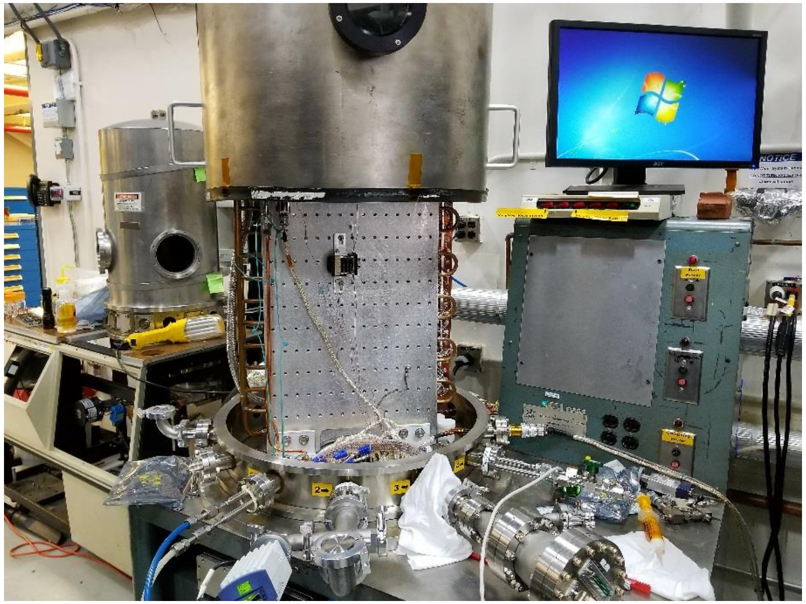


Contamination and Optical Black Coatings

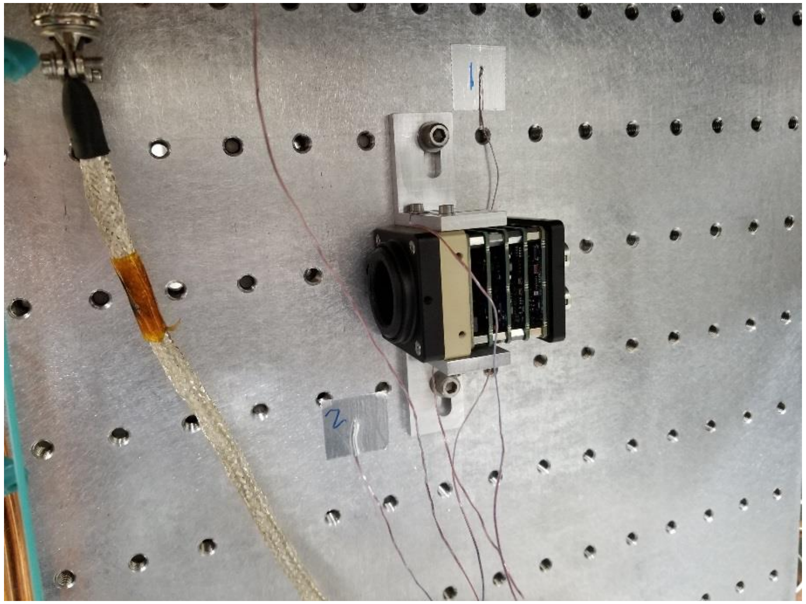
- Contamination control plan
- TVAC testing measurements and support
- Optical black coating collaborative quote from GSFC

Testing

- UVVNIR detector TVAC testing started and on-going
- SWIR detector acceptance testing once received (end of July 2018)



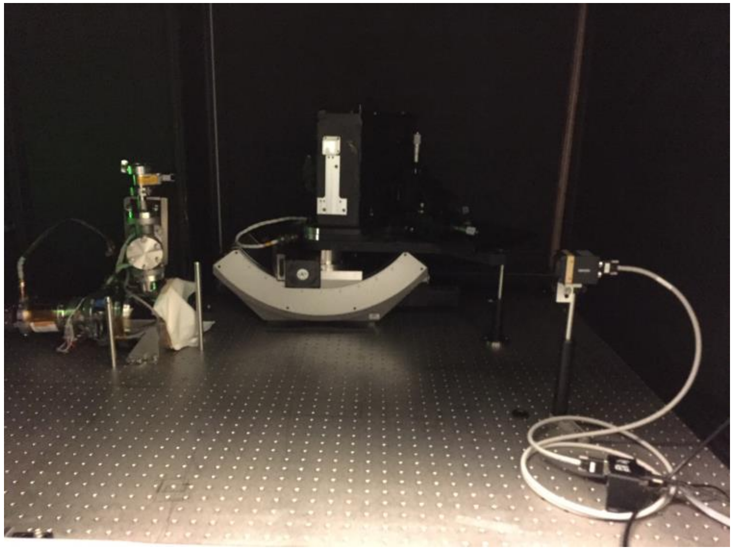
Stainless Steel Bell Jar Building 1250

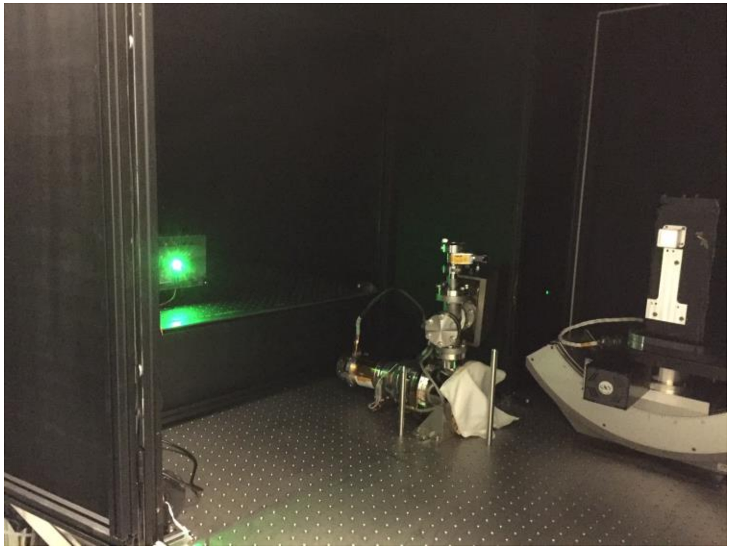


UVVNIR Channel Detector in TVAC Test Configuration

Calibration at LASP

- UVVNIR detector stand-alone calibration in progress
- SWIR detector stand-alone calibration preparation





LASP calibration facility

ARCSTONE: Project Summary for June 2018

1. The formulation phase is completed successfully

2. Long-term procurement is completed

3. Instrument design 1st iteration by LaRC & Resonon completed

4. Instrument design 2nd iteration completed: Team and Quartus

5. STOP analysis completed: Quartus and Team

6. ARCSTONE started fabrication phase

7. ARCSTONE UVVNIR camera testing at LaRC and LASP

6. Schedule: coordinated for IIP and SBIR projects

7. Leveraging SBIR Phase-II (Resonon) and LaRC B&P funding

ARCSTONE IIP: Major Milestones

Major milestones (6 month intervals):

End of fiscal year (EOFY) 2017

MCT Detector/cryocooler assemblies and BCT bus simulator delivered

Initial instrument design (DAC 1 and DAC 2) and STOP analysis completed

Middle of fiscal year (MOFY) 2018

Custom parts fabrication started, optic fabrication started, assembly hardware/components ordered (build phase)

EOFY 2018

Instrument assembled and aligned at Resonon, Inc

MOFY 2019

Calibration and characterization at LASP

EOFY 2019

Environmental testing at LaRC

Documentation and closeout

ARCSTONE Web, *http://arcstone.larc.nasa.gov*

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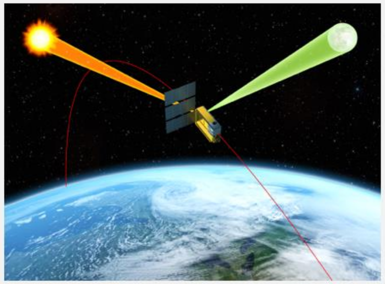
ARCSTONE

Achieving Instrument High Accuracy In-Orbit

One of the most challenging tasks in remote sensing from space is achieving required instrument calibration accuracy on-orbit. The Moon is considered to be an excellent exoatmospheric calibration source. However, the current accuracy of the Moon as an absolute reference is limited to 5 - 10%, and this level of accuracy is inadequate to meet the challenging objective of Earth Science observations. ARCSTONE is a mission concept that provides a solution to this challenge. An orbiting spectrometer flying on a small satellite in low Earth orbit will provide lunar spectral reflectance with accuracy sufficient to establish an SI-traceable absolute lunar calibration standard for past, current, and future Earth weather and climate sensors.

LEARN MORE



The ARCSTONE observatory is shown in low Earth orbit with the spectrometer viewing the Sun and Moon. The spacecraft rotates in order to view the Moon or the Sun.

"The Moon is available to all Earth-orbiting spacecraft at least once per month, and can be used to tie together the sensor radiance scales of all instruments participating in lunar calibration without requiring near-simultaneous observations."

– HUGH KIEFFER & TOM STONE

A new website… It will be developed further as the project goes forward

Thank you !

Questions ?