ARCSTONE:
Calibration of Lunar Spectral Reflectance

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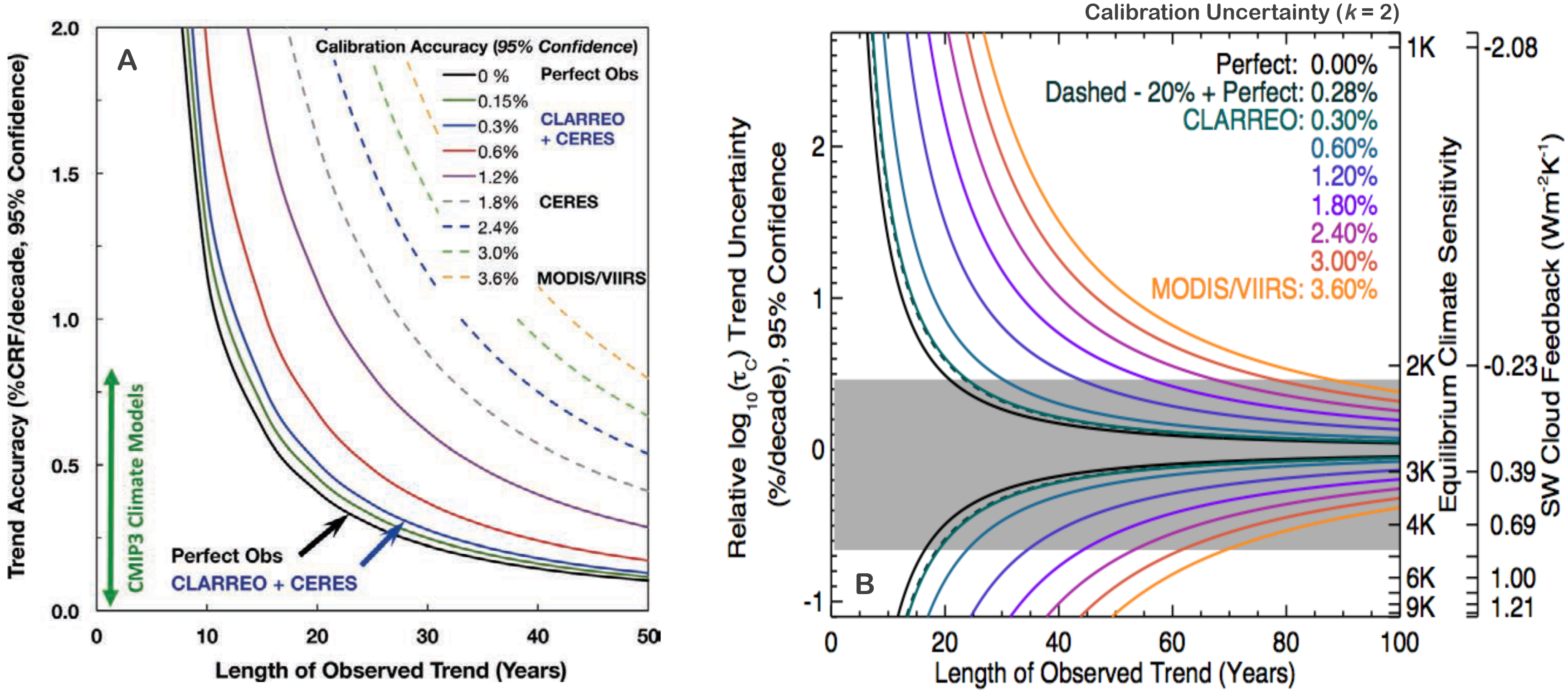
Partners:

Resonon, NIST, LASP Colorado U,
Blue Canyon Technologies

NRC Decadal Survey 2017: Accuracy

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



Effect of measurement accuracy on both climate trend accuracy (Y-axis) as well as the time to detect trends (X-axis): (a) Relationship between reflected solar spectra and changes in broadband CRF and cloud feedback. (b) The estimated time to detect a relative cloud optical thickness trend (left y-axes) from natural variability is shown here linked to the SW Cloud Feedback and the equilibrium climate sensitivity (right y-axes).

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Moon: Solar Diffuser For Instrument Calibration In-orbit

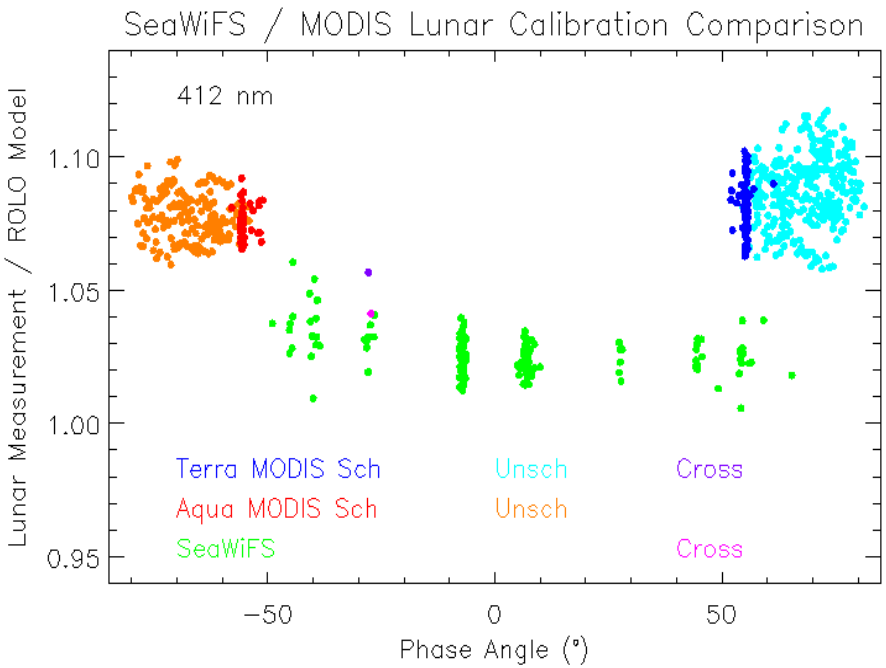
Reflectance of Lunar surface stable to $< 10^{-8}$

Calibration reference:
Lunar irradiance (entire disk)

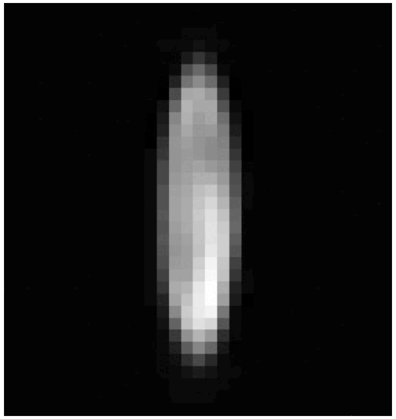
Lunar Calibration On-Orbit: State of the Art - SeaWIFS Example

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:



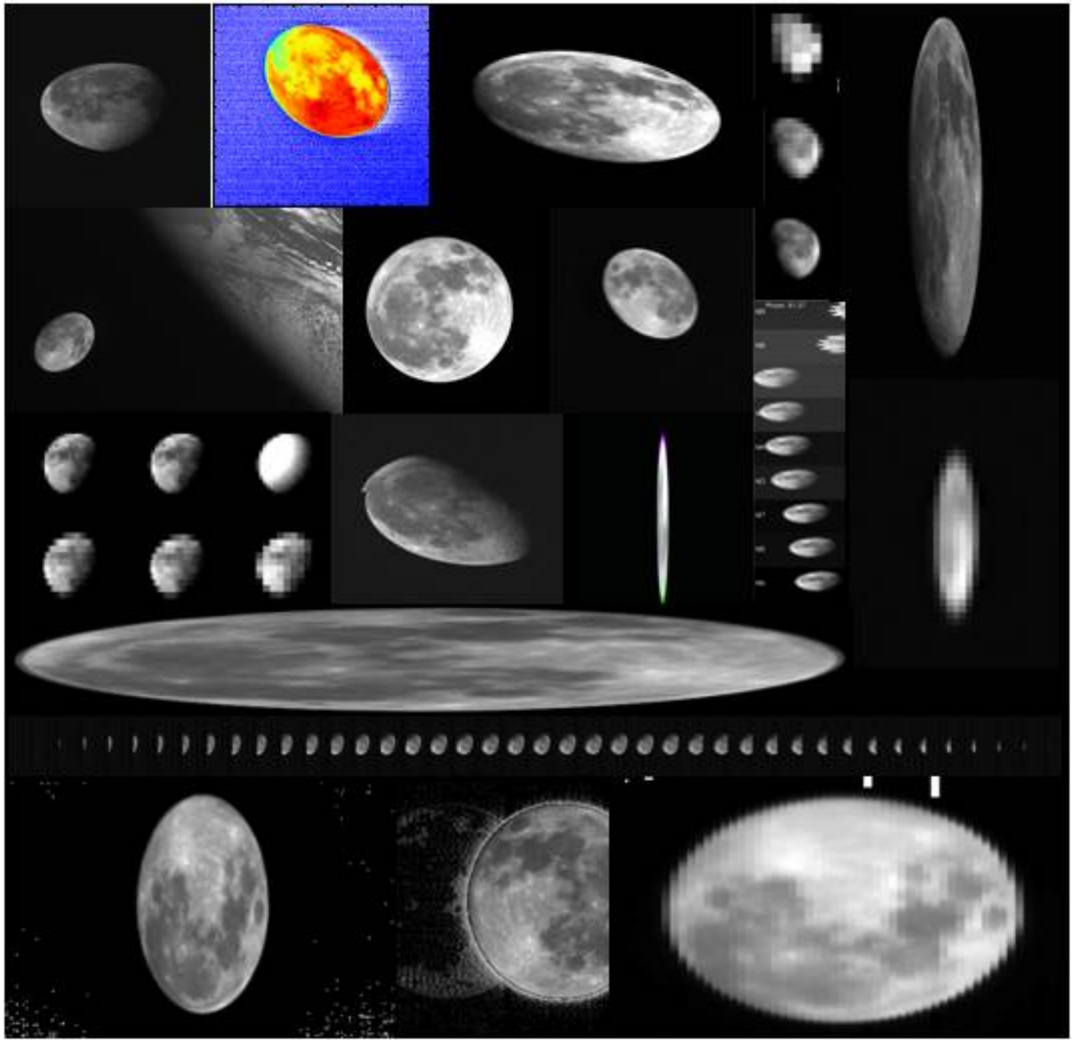
Lunar image by SeaWIFS



- 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 !

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.

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Lunar Calibration Applications

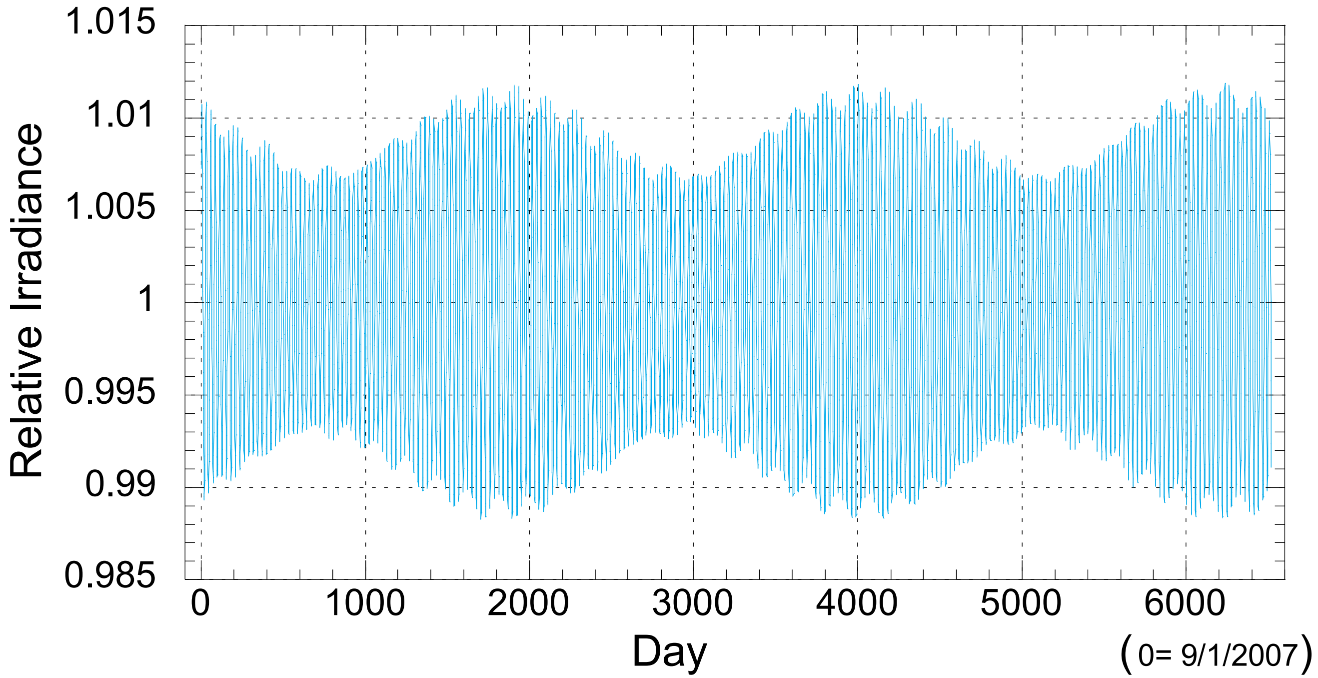
Team	*Satellite*	*Sensor*	*G/L*	*Dates*	*Number of obs*	*Phase angle range (°)*
CMA	FY-3C	MERSI	LEO	2013-2014	9	[43 57]
CMA	FY-2D	VISSR	GEO	2007-2014		
CMA	FY-2E	VISSR	GEO	2010-2014		
CMA	FY-2F	VISSR	GEO	2012-2014		
JMA	MTSAT-2	IMAGER	GEO	2010-2013	62	[-138,147]
JMA	GMS5	VISSR	GEO	1995-2003	50	[-94,96]
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.

Lunar Calibration On-Orbit: Effect of Libration

From Lorentz et al., LUSI Concept, 2009

Effect of Libration on Lunar Irradiance: 2% variation in amplitude



Threshold requirement for covering lunar libration space: measurements over approximately 3 years time period of daily sampling !

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^{o} (no scanning !).

- Preferred orbit – 90^{o} 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:

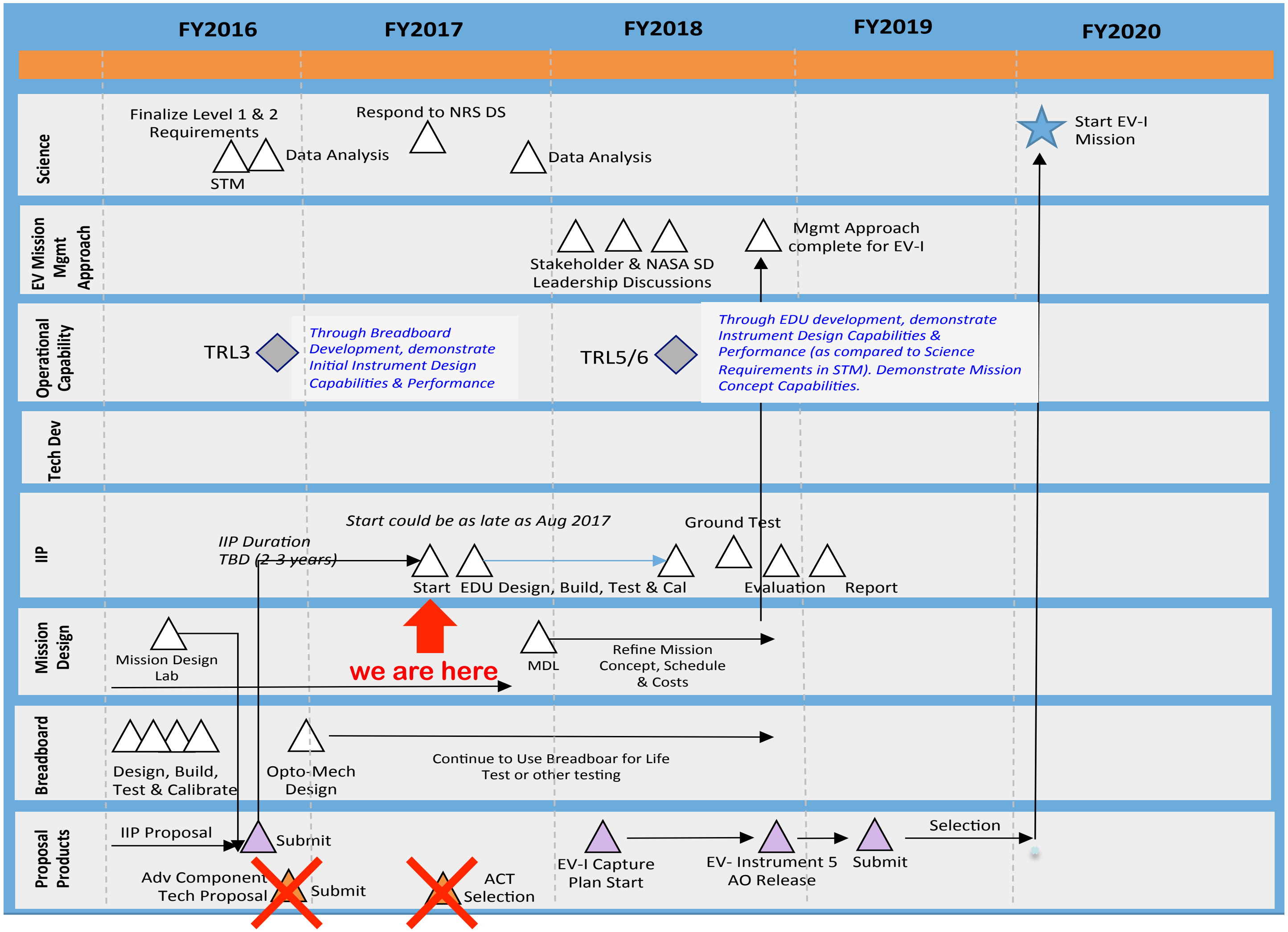
- Approach to orbital calibration via referencing Sun:
  Demonstration of lunar and solar measurements with the same optics/detector using *integration time to reduce solar signal*
- Pointing ability (precision & accuracy) of small spacecraft now permits obtaining required measurements

ARCSTONE: Key Mission Performance Parameters

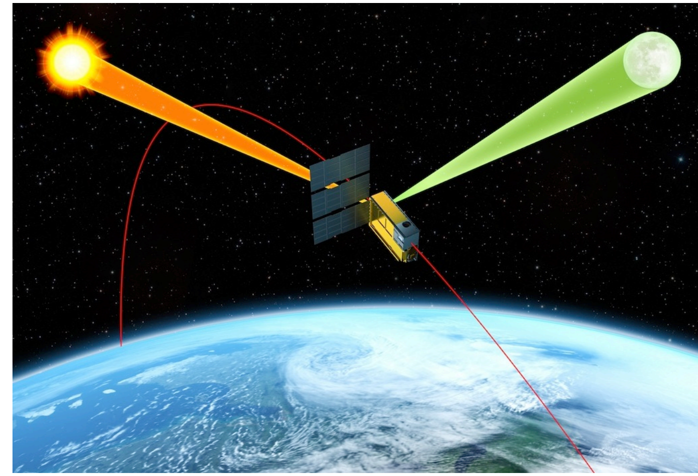
Key Performance Parameters (KPP)	Threshold Value	Goal Value
Accuracy (reflectance)	1.0% (k=1)	0.5% (k=1)
Stability	< 0.15% (k=1) per decade	< 0.1% (k=1) per decade
Orbit	Sun-synch orbit	Sun-synch orbit
Time on-Orbit	1 year	3 years
Frequency of sampling	24 hours	12 hours
Instrument pointing	< 0.2^{o}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

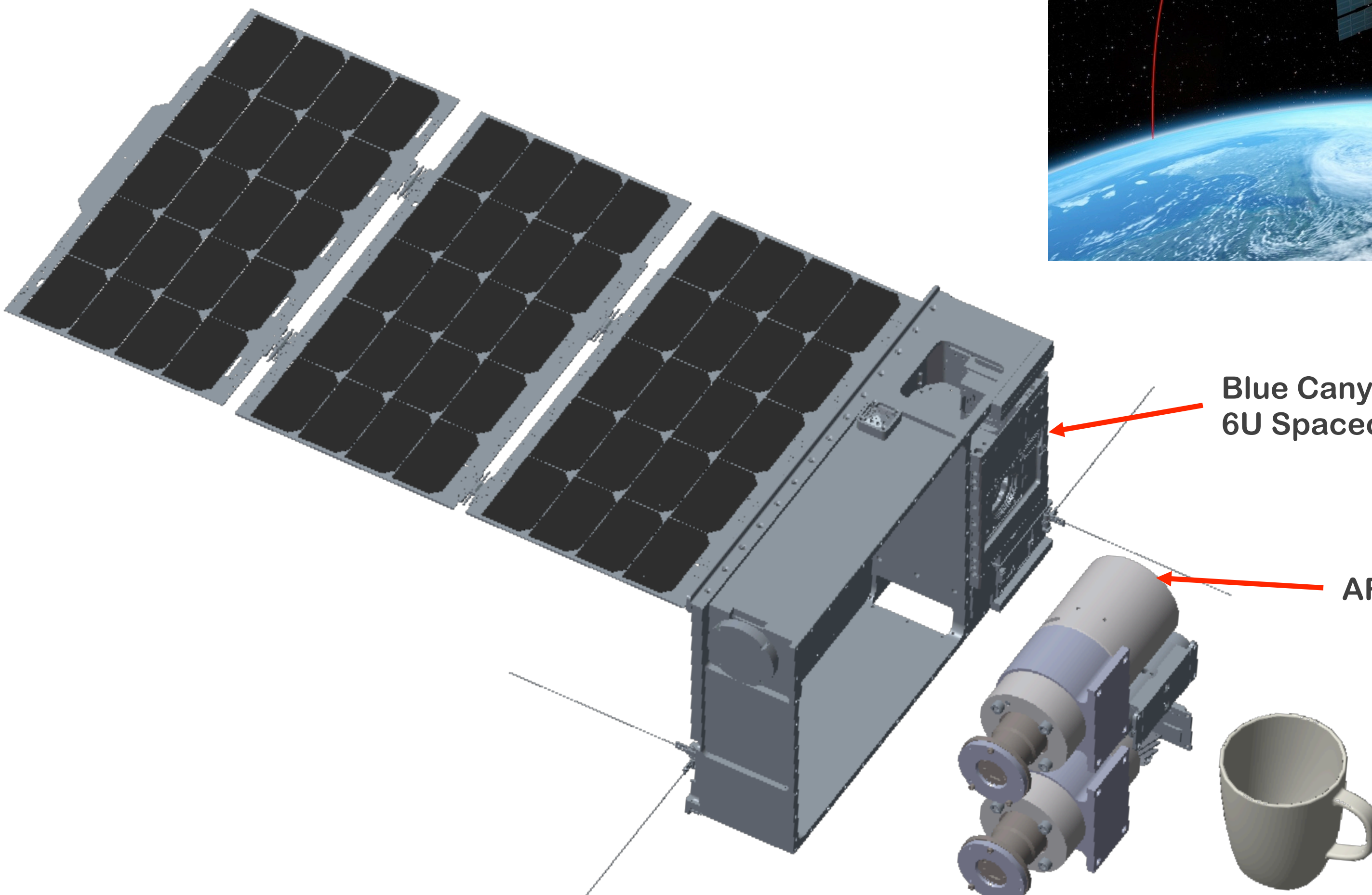
Reference for radiometric requirements (ROLO, T. Stone):
Lunar Phase Angle = 75^{o};
Irradiance = 0.6 (micro W / m^2 nm)
Wavelength = 500 nm

ARCSTONE: Mission Development Roadmap



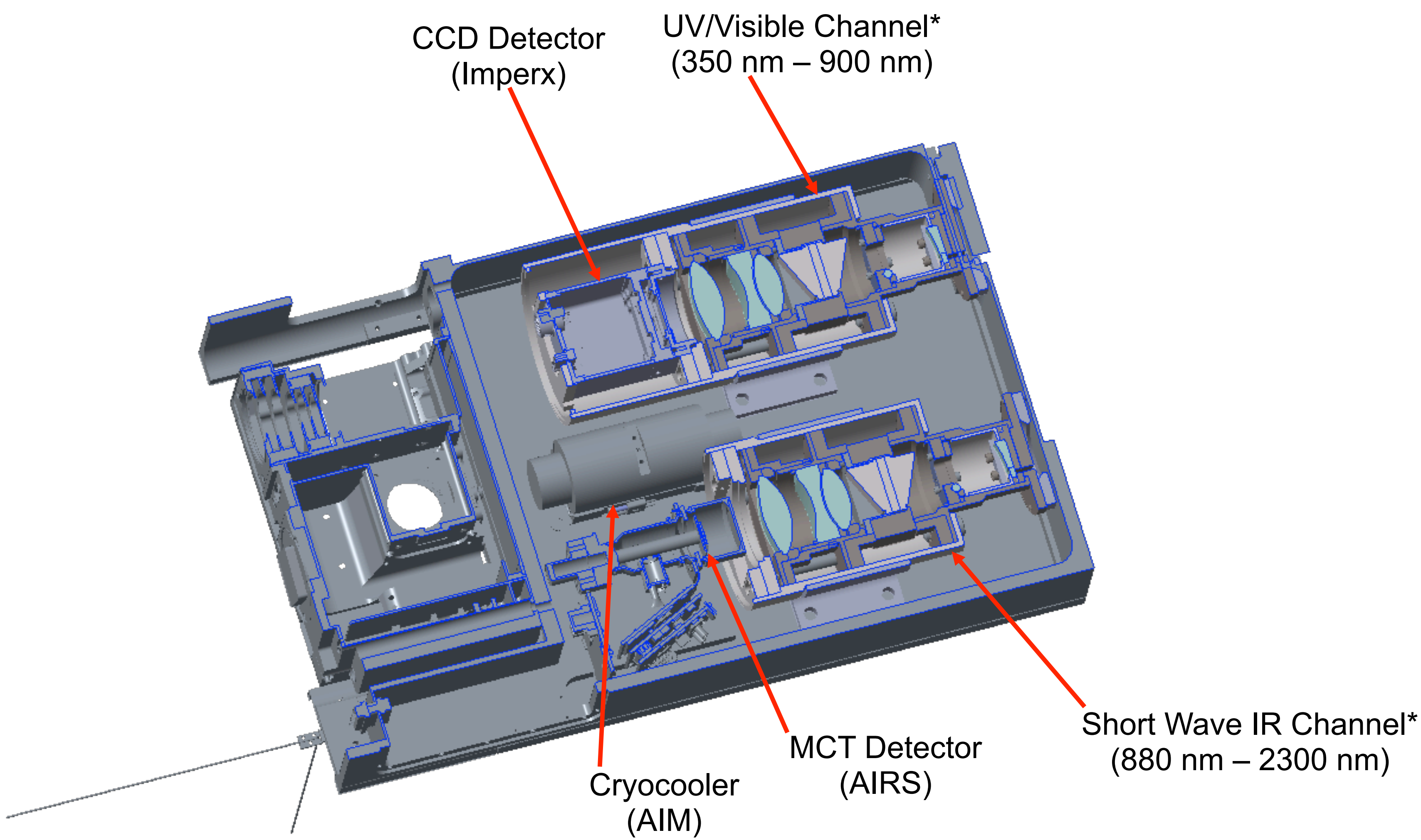
ARCSTONE: Mission Concept



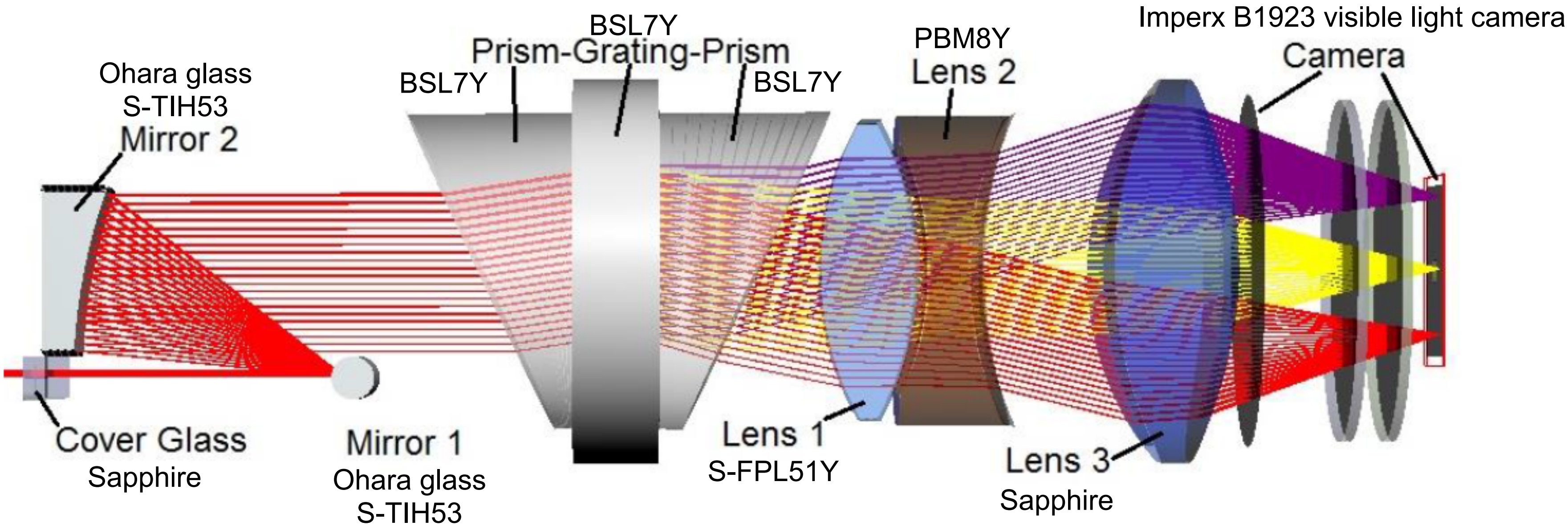


ARCSTONE: Bus and Payload Concept

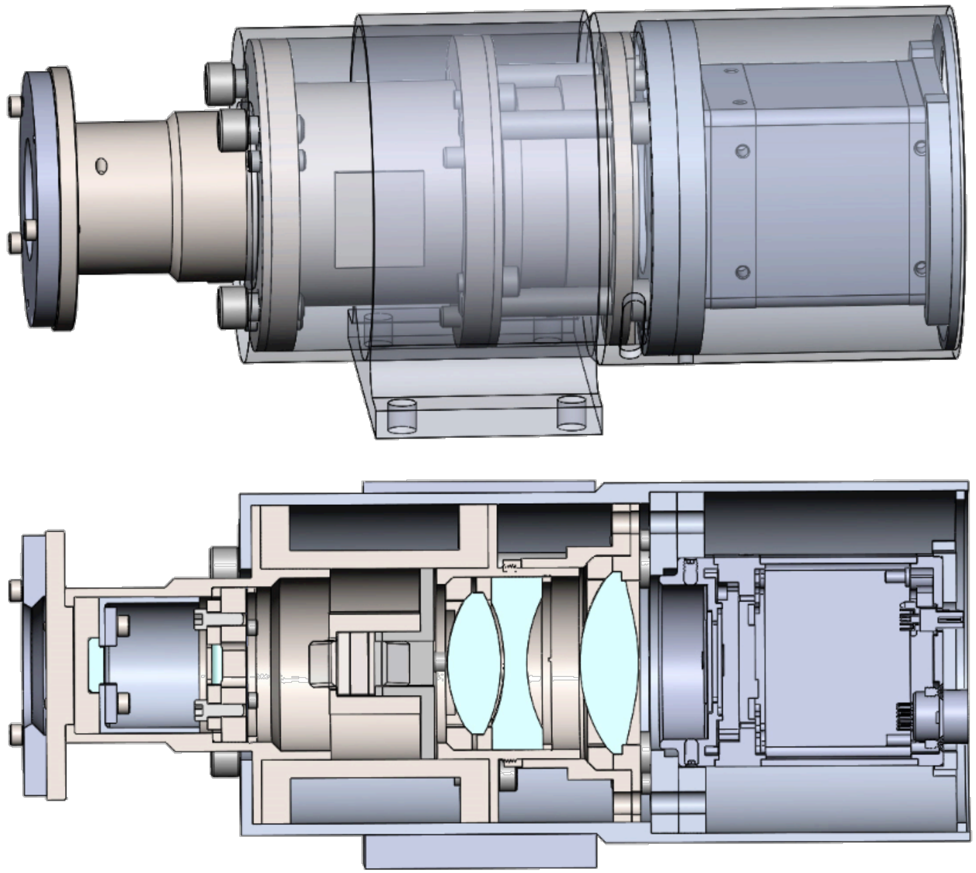
*Optical Design: Resonon, Inc
* Spacecraft: Blue Canyon Technologies XB6



Optics Design: UVVNIR Spectrometer

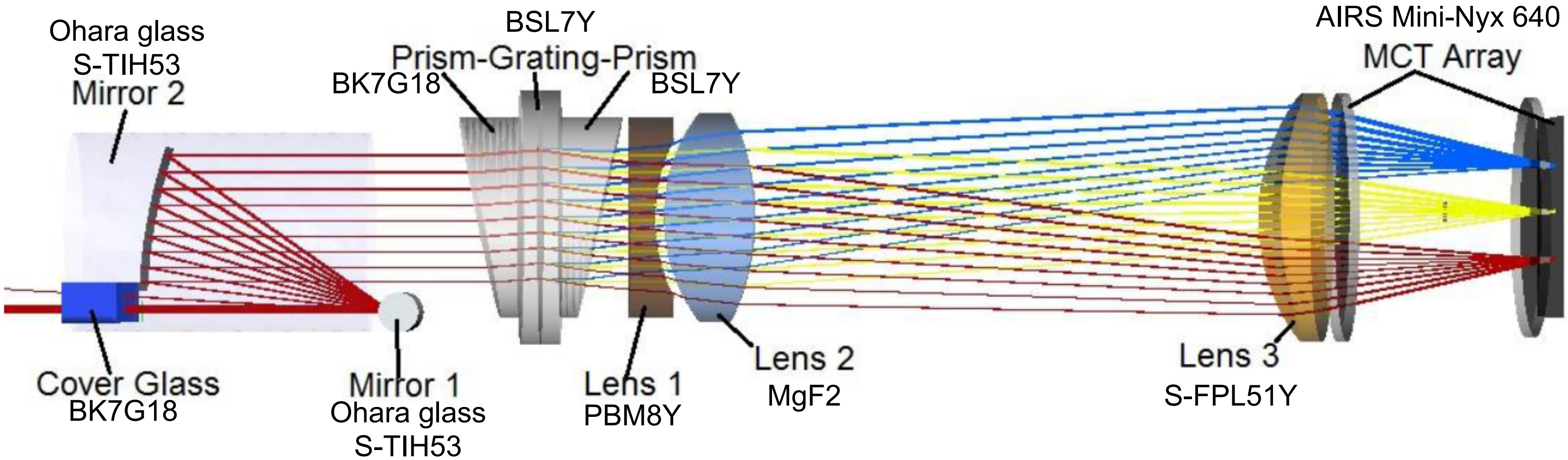


Packaging – UVVNIR Channel



Current mechanical CAD model:
Titanium – grey-brown, aluminum – grey, optical glass – blue-green.
Nuts and bolts, also shaded grey-brown, alloy steel.

Optics Design: SWIR Spectrometer



ARCSTONE IIP: Major Milestones

Major milestones (6 month intervals):

September 2017

- MCT Detector/cryocooler assemblies and BCT bus simulator delivered
- Initial instrument design (DAC 1 and DAC 2) and initial analysis (STOP analysis) completed

March 2018

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

September 2018

- Instrument assembled and aligned

March 2019

- NIST calibration/characterization
- LASP calibration/characterization

September 2019

- Simplified environmental testing
- Documentation and closeout

ARCSTONE: Summary

(1) What is needed from the mission ?

Accurate SI-traceable calibration source on-orbit for past, current and future Earth Science missions in LEO and GEO.

(2) What can we do ?

ARCSTONE mission shall obtain the accurate Lunar spectral irradiance to enable reference calibration of weather and climate operational sensors in the reflected solar wavelength range.

(3) Who will care ?

- NASA Missions: SeaWIFS, MODIS, CERES, RBI, CLARREO, PACE, ACE;
- NOAA Missions: VIIRS, GOES-R ABI;
- International Space Agencies: ESA, EUMETSAT, etc., LEO and GEO imagers;
- GSICS Lunar Calibration community.