

An SLI Cross-Calibration Radiometer (SCR) Concept for Improved Calibration of Disaggregated Earth Observing Satellite Systems

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Dennis Helder

Senior Calibration Advisor, USGS EROS

dhelder@usgs.gov, +1 605 594 2629

Outline

- **Background—Landsat Architecture Study Team**
- **Notional Instrument Design**
- **Orbital Insertion**
- **Relationship to TRUTHS and CLARREO**
- **Summary/Conclusions**

- *Special thanks to Jon Christopherson, Cody Anderson, Doug Daniels for their contributions.*

AST 2019 Charter Purpose & Guidelines

Purpose:

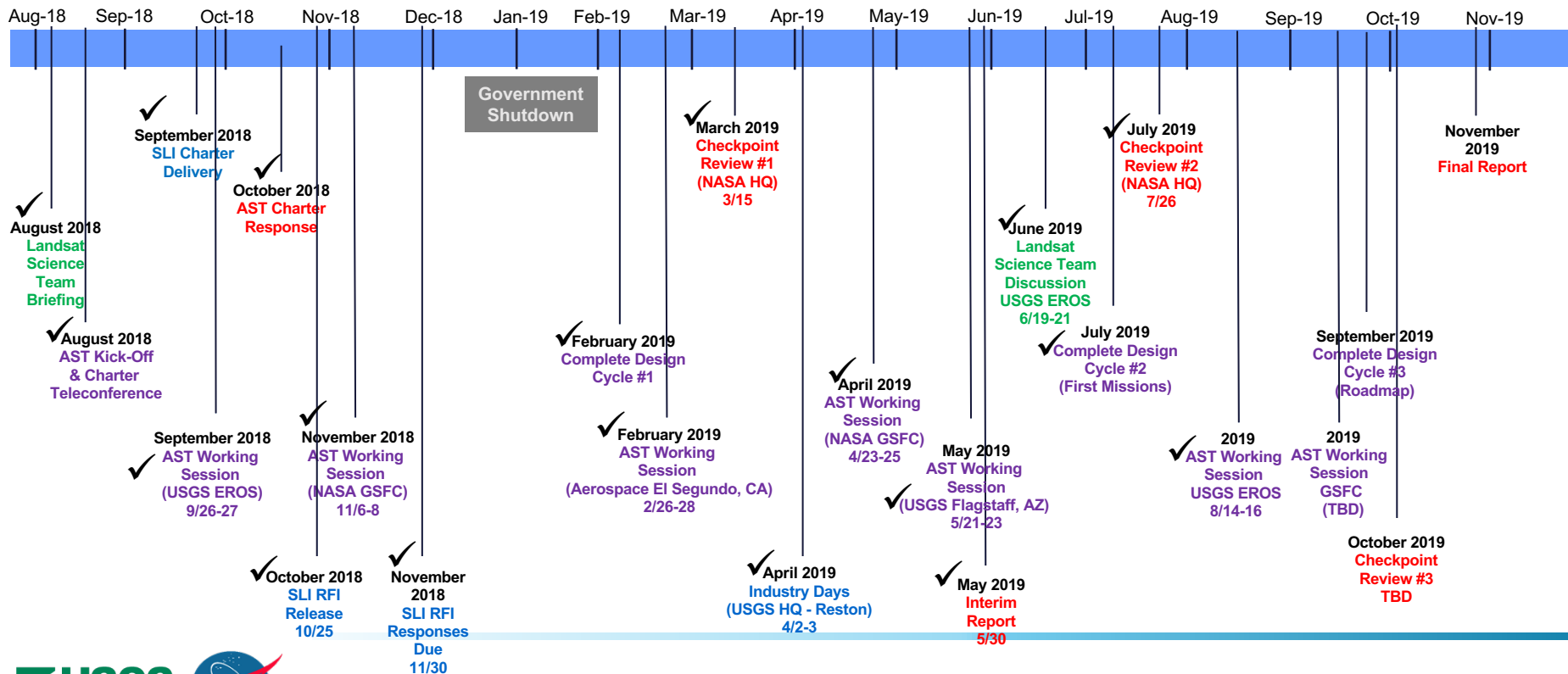
- ♦ **Execute a feasibility study for the design and implementation approach of a [spaceborne system to provide global, continuous Landsat-quality multispectral and thermal infrared measurements](#) for approximately a fifteen-year period starting in 2026**
 - ♦ Apply advancements in space systems technologies
 - ♦ Address a broad set of civil land imaging needs and science applications collected by USGS
- ♦ **AST 2019 is sponsored and implemented by:**
 - ♦ Director, USGS, James Reilly; SLI Representatives: Tim Newman/Steve Covington; AST Co-Lead: Doug Daniels
 - ♦ Director (Acting), NASA Earth Science Division, Sandra Cauffman; SLI Representatives: Eric Ianson/Marissa Herron; AST Co-Lead: Jeff Masek

Guidelines:

- ♦ **Address commercial, international, and other Government providers of Earth observation data**
 - ♦ Understand these environments, assess their merits and potential contributions, and present business models which might best be used to exploit these capabilities
- ♦ **Ground System is a substantial driver**
 - ♦ Due to the decrease in costs for spacecraft technology and launch systems, the potential for data volume increase, by orders of magnitude, may shift the balance of investment from the historically-higher space segment to the ground segment and long-term operations
- ♦ **Address feasibility of multi-mission science data harmonization in terms of data interoperability for science quality**
- ♦ **Abide by cost constraints and the important goal of lowering long-term costs to the Nation**
- ♦ ***Deliverable:* Set of viable architecture concepts (~3) that will provide NASA and USGS a basis for formulating future acquisition strategies and approaches**



AST Timeline

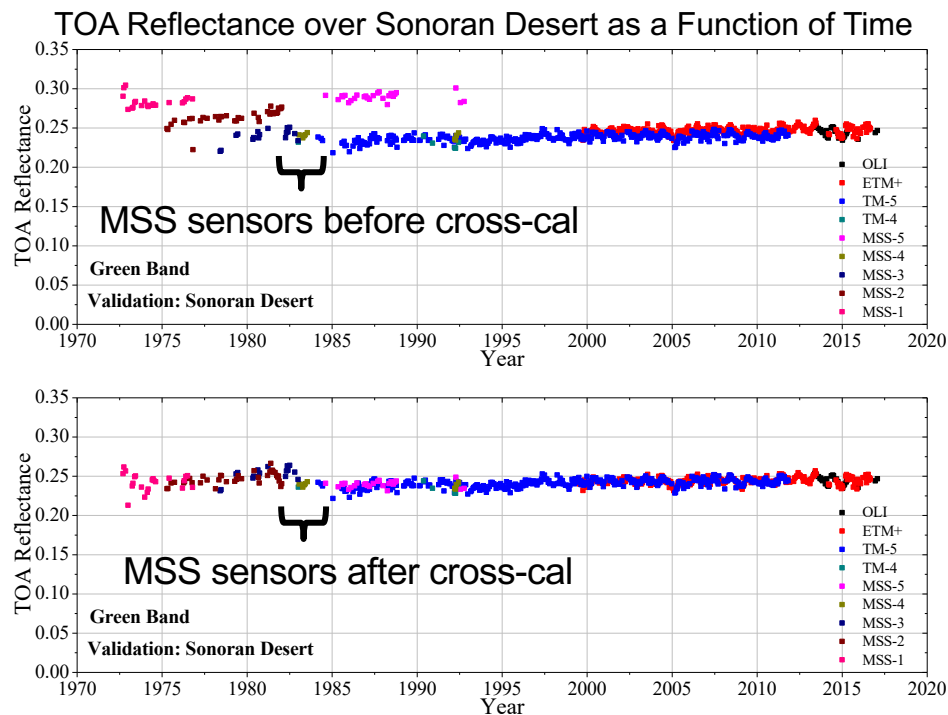


Why is this important– A little history...

Sustainable Land Imaging
AST 2019

The Landsat MSS Era – 1970s

- ◆ $\rho = 0.23$ to $0.30 \rightarrow 23\%$ error!
- ◆ Recalibration over the past couple years has brought that down to about 5%.

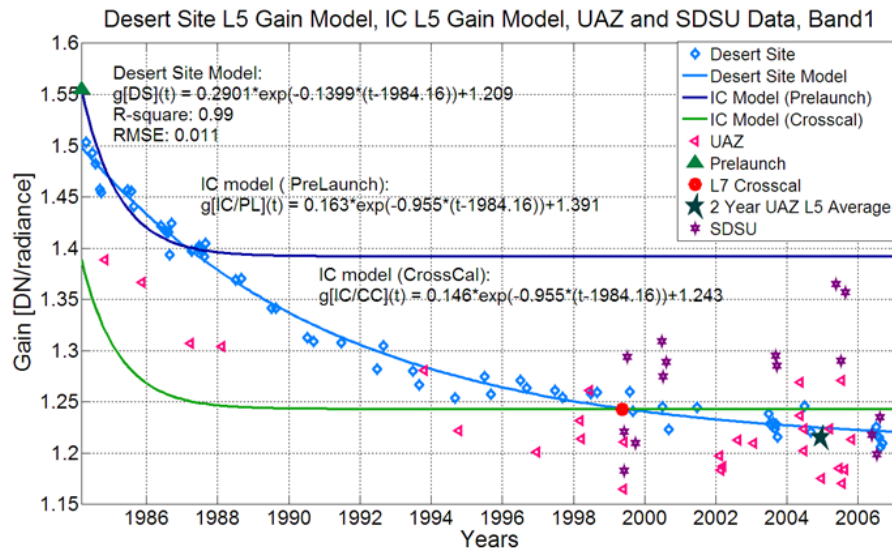


Why is this important– A little history...

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The Landsat TM Era

- ◆ Gain = 1.55 instead of 1.25 → 16% error
- ◆ Recalibration in early 2000s has reduced this to ~5%.

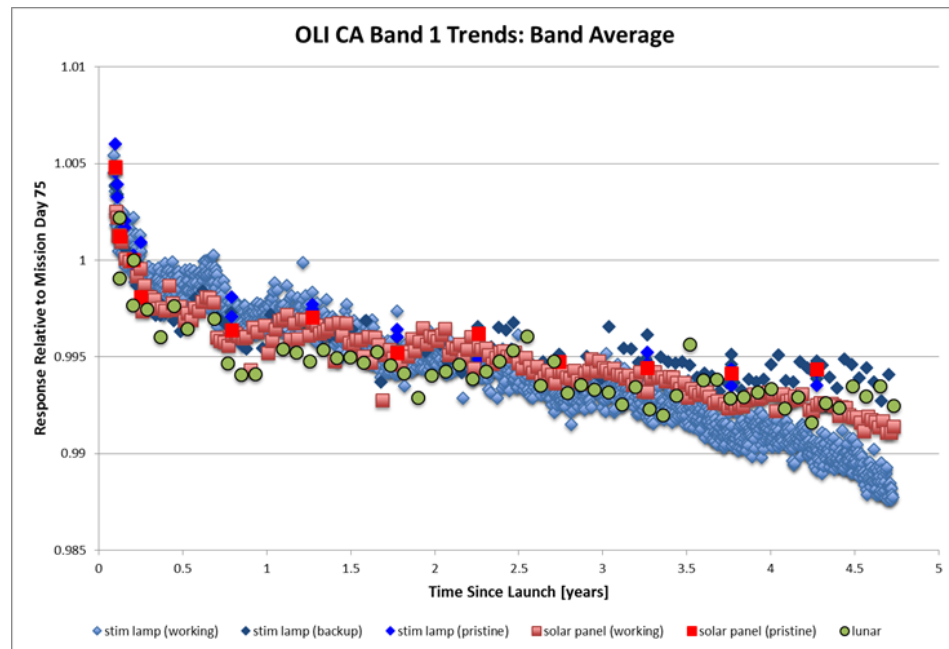


Why is this important– A little history...

*Sustainable Land Imaging
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The Landsat OLI Era

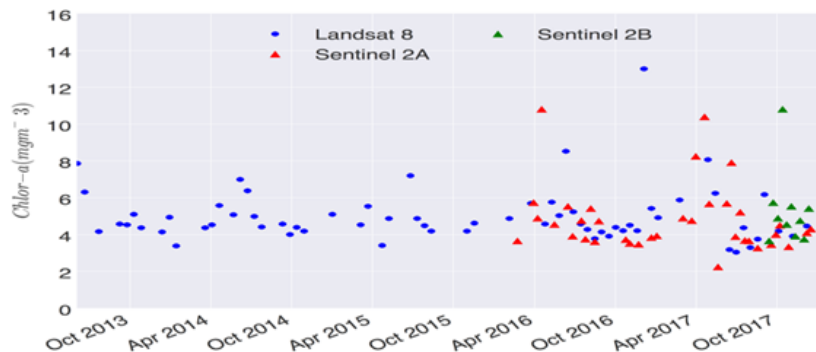
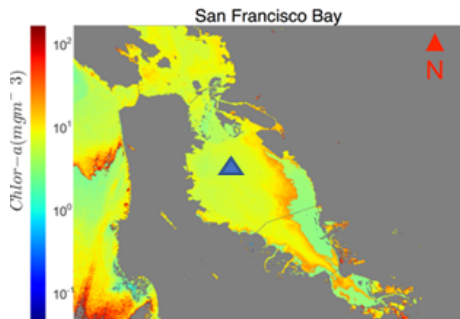
- ◆ Radiometric accuracy requirements for reflectance: 3%
- ◆ Actual performance: possibly closer to 2.5%
- ◆ Largest change during lifetime (see figure): 1%
 - ◆ Corrected in April 2017
- ◆ Key Points:
 - ◆ There has been a continual improvement in Landsat calibration as well as other EO systems
 - ◆ EO data users are accustomed to and expect improved calibration [and now validation] of their data



Why is this important? – Value to Science

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- ◆ “From the ocean color literature, it is well-known that a 1% calibration offset in the blue bands yields a 10% error in R_{rs} over blue ocean waters...” —Nima Pahlevan
 - ◆ Helder, D., et al., Observations and Recommendations for the Calibration of Landsat 8 OLI and Sentinel 2 MSI for improved data interoperability, Remote Sens. 2018, 10(9), 1340;
<https://doi.org/10.3390/rs1009134>.
- ◆ A major driver for 1% radiometric accuracy
- ◆ Water science was limited with Landsat until the SNR and radiometric accuracy of Landsat 8 OLI



Time-series of chlorophyll-a products derived from Landsat-8 and Sentinel-2A/B.

Why is this important– Value to Science

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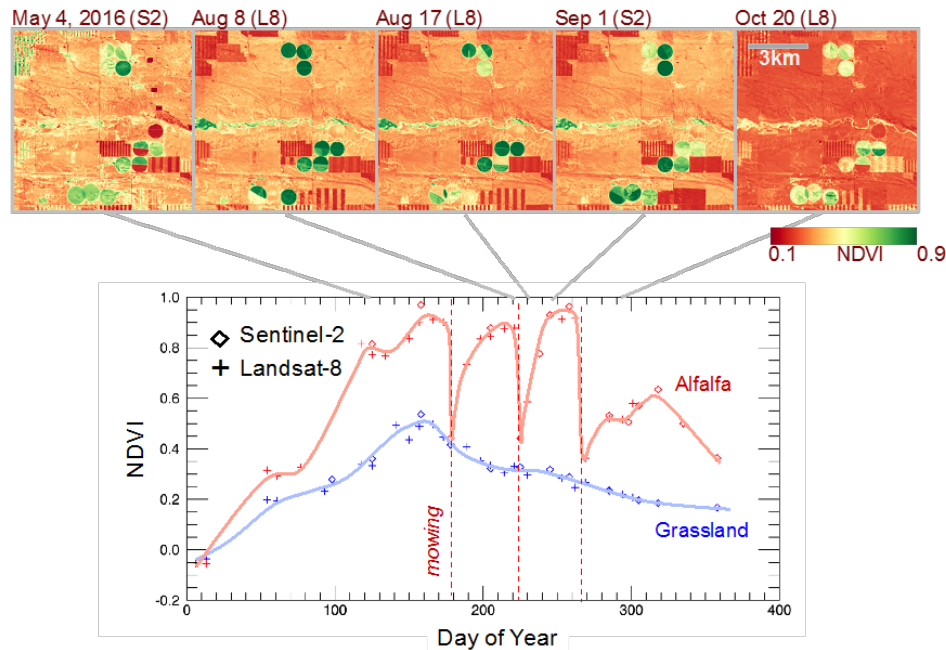
◆ Interoperability – NASA HLS Project

◆ Uncertainties:

- ◆ Absolute calibration: 3%, 5%
- ◆ Cross-calibration: 1-3%
- ◆ Atmospheric correction: 5-10%
- ◆ BRDF: ???

◆ What impact can improved calibration produce in the future?

- ◆ For demanding science applications
- ◆ For data harmonization
- ◆ **Approach:** Develop an on-orbit SLI Cross-Calibration Radiometer (SCR)



SLI Cross-Calibration Radiometer (SCR)

Notional Instrument Design



➤ VSWIR

- ❑ 100m IFOV
- ❑ 60 km FOV
- ❑ 400nm – 2400nm
- ❑ 5nm center wavelength spacing
- ❑ 8nm BW
- ❑ $\leq 1\%$ radiometric accuracy
- ❑ SNR > 300
- ❑ ~0.5 TB/day

➤ TIR

- ❑ 300m IFOV
- ❑ 8um – 12um
- ❑ 5 spectral bands
- ❑ $\leq 0.3K$ radiometric accuracy
- ❑ NEDT < 0.15K



Notional Hyperspectral VSWIR Approach

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Note: Integrated version of Headwall VNIR E and SWIR 640. Both have flown on 6/12U Cubesat

PRODUCT DATA SHEET

TRL 6-7

Hyperspec®
Co-Aligned
VNIR-SWIR
Sensor



Notional

- Wavelength range: 400-2500nm
- Dual VNIR/SWIR Sensors with Co-Aligned Pixels
- 270 & 267 Spectral Pixels (VNIR/SWIR)
- 640 Spatial Pixels
- Small size, low weight
- Suitable for airborne & ground use
- Internal data storage
- All-reflective, concentric optical design

PRODUCT DATA SHEET



Dual-Sensor VNIR-SWIR Package

Spectral Range	VNIR (400-1000nm)	SWIR (900-2500nm)
Spectrograph Design	High throughput aberration-corrected concentric imager	
Spectral pixels	270	267
Detector Pixel Pitch (microns)	7.4	15
Dispersion per pixel (nm/pixel)	2.2	6
FWHM Slit Image (nm)	6	8
Spatial pixels	640	
f/#	2.5	
Slit width (microns)	20	
Camera Technology	CMOS	Stirling-cooled MCT
Max Frame Rate (Hz)	350	200
Bit Depth	12	16
Size	approx. 10.7" x 8.2" x 6.5" (272mm x 208mm x 165mm)	
Weight (lb / kg)	6.25 / 2.83	



Ball Compact Infrared Radiometer In Space (CIRiS)

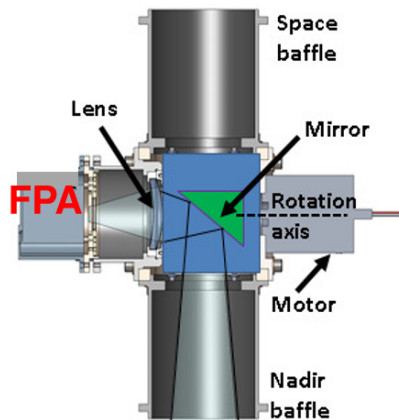
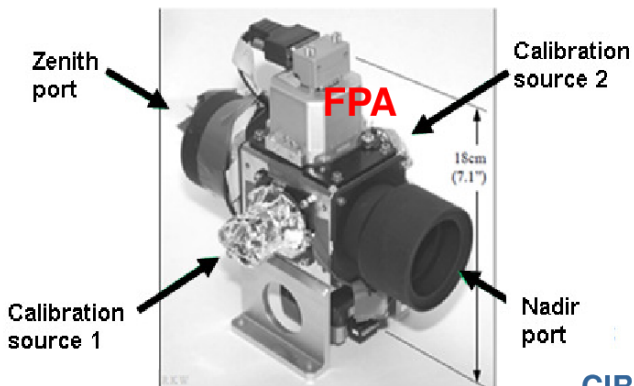
Uncooled Microbolometer FPA

Carbon Nanotube Blackbody Cal Source

6U Cubesat Design

Launch Scheduled 2019

Notional



CIRiS (cal sources out of dwg plane)

	CIRiS
Weight (kg)	1.05
Avg power (W)	10
Envelope (cm ³)	18x19x9

	CIRiS
FOV	12.2 deg x 9.2 deg
FPA Pixel Size	12 um
FPA Format	640 x 480
FPA NEDT	< 50 mK
Frame rate	30 Hz/60 Hz
Band 1	9.9 – 11.4 um
Band 2	7.5 -13.0 um
Band 3	11.8 to 12.7 um



➤ VSWIR SWaP

- ❑ 272mm x 208mm x 165mm (Headwall Hyperspec® Co-Aligned VNIR-SWIR Sensor)
- ❑ 4.6 kg (Headwall VNIR E + SWIR 640 sensors)
- ❑ 30W (est.)

➤ Thermal SWaP

- ❑ 180mm x 190mm x 90mm (Ball CIRIS)
- ❑ 1.05 kg (Ball CIRIS)
- ❑ 10W (Ball CIRIS)

➤ Additional Costs

- ❑ Calibration source design/assembly/test
- ❑ Telescope for combined instrument
- ❑ Spacecraft bus

SLI Cross-Calibration Radiometer (SCR)

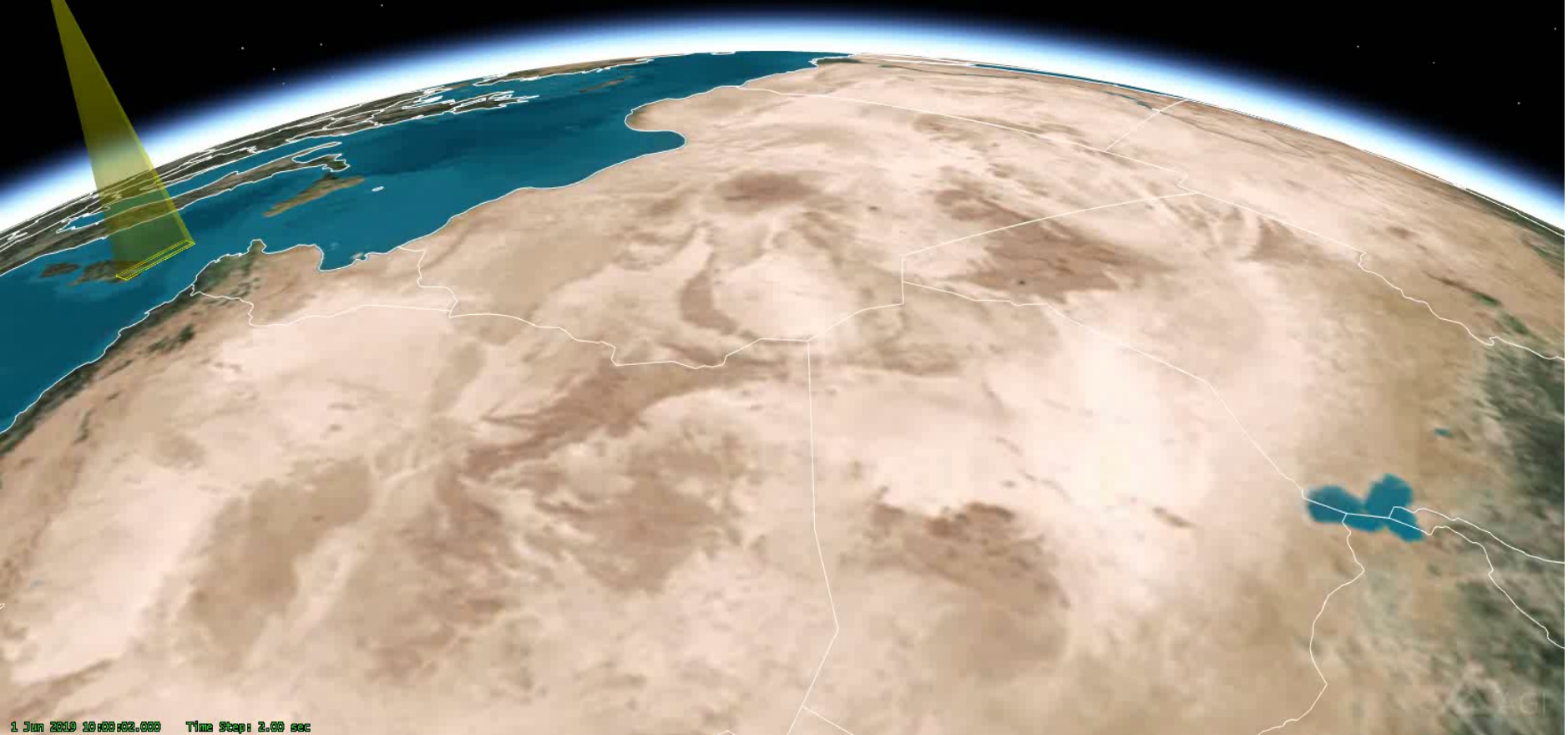
ORBITAL INSERTION

Orbital Insertion

- **Bolt-on**
 - Attach to large imaging observatories such as Landsat, Sentinel 2, others.
 - Provides continuous high performance characterization of large observatories.
 - Builds a well calibrated hyperspectral library of the Earth's surface.
 - Provides limited SNO cross-calibration opportunities with other sensors.

Orbital Insertion

- **Free-Flyers**
 - Concept: provide a constellation of SCRs to optimally calibrate disaggregated optical imaging sensors, both government and commercial.
 - Small SWaP suggests use of possibly 16U spacecraft or multiple instruments on ESPA class launch vehicle.
 - Deploy multiple SCRs in a single launch.
 - Requires spacecraft development.
 - What might an optimal constellation look like?

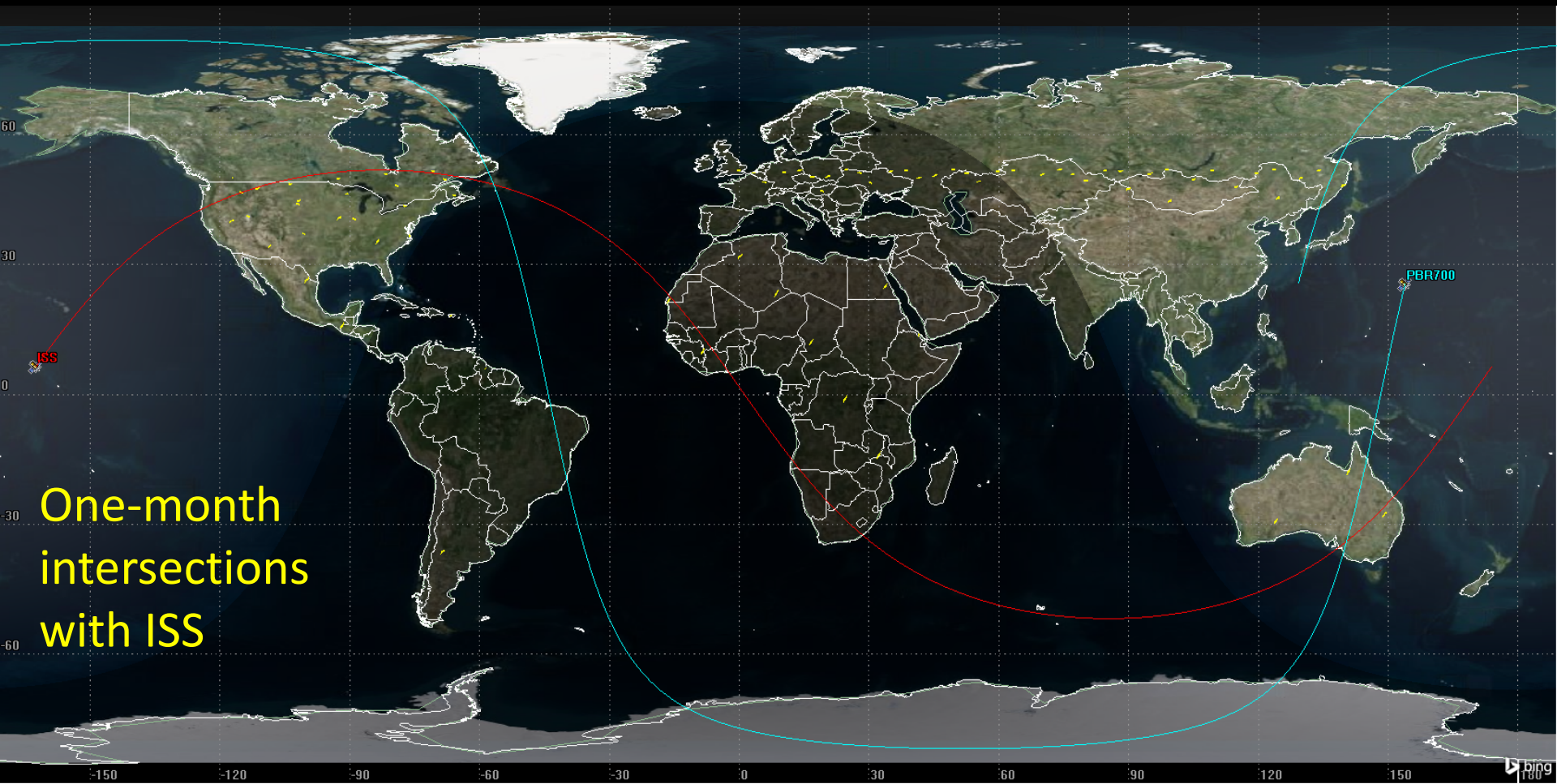








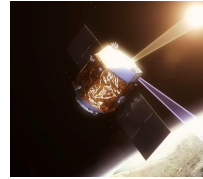
One-month
intersections w/
AQUA MODIS



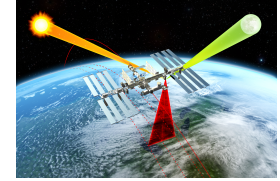
SLI Cross-Calibration Radiometer (SCR)

RELATIONSHIP TO TRUTHS/CLARREO

TRUTHS



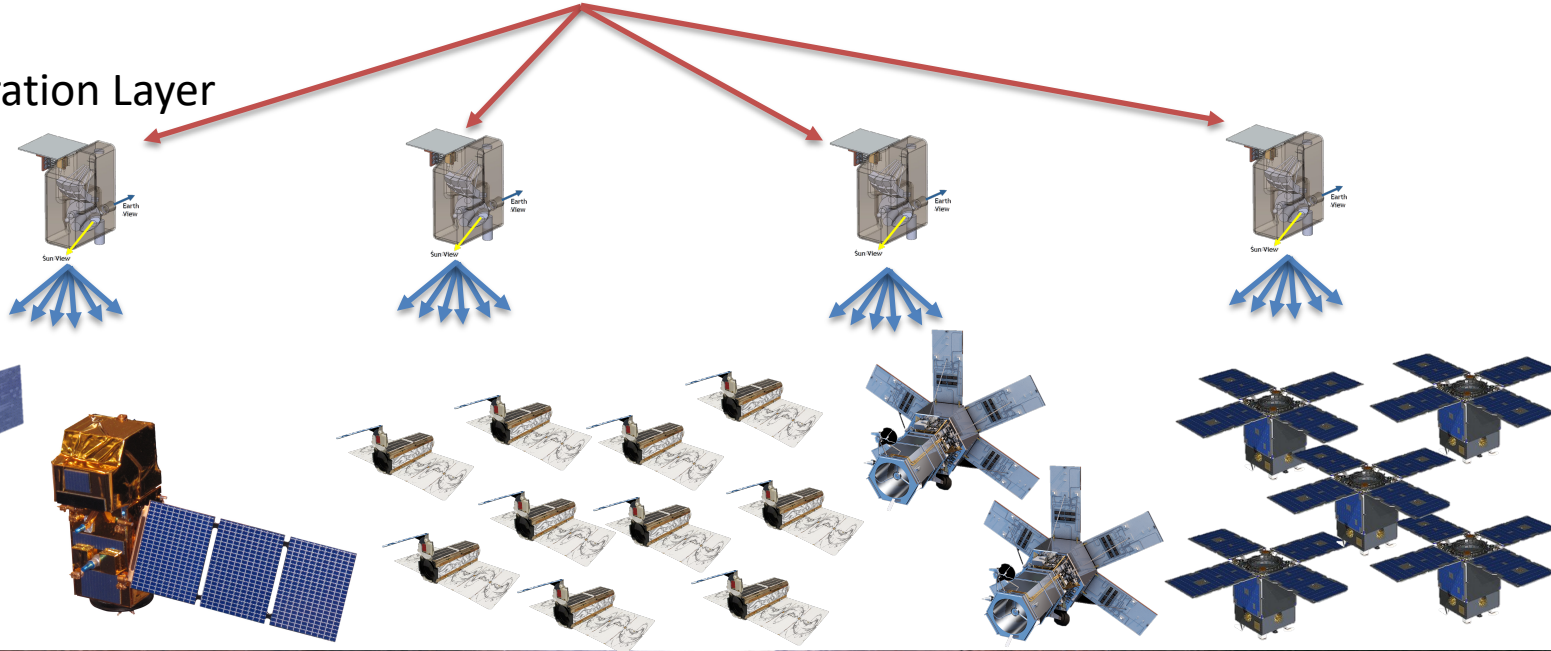
CLARREO Pathfinder



- Primary Calibration Layer

- Transfer Calibration Layer (SCRs)

- Imaging Layer



Summary/Conclusions

- **SCR concept designed to bring optical imaging systems radiometric accuracy from 3% to 1%**
 - Driven by demanding applications and need for harmonization of disaggregated systems
- **Preliminary design concepts suggest small hyperspectral package, 'low-cost' instrument possible**
- **Free-flyer constellation is feasible, as well as bolt-on option**
- **High accuracy hyperspectral record of the Earth**
- **High accuracy hyperspectral lunar model possible**
- **SCR provides needed transfer radiometry layer between TRUTHS/CLARREO and optical imaging systems**
 - Moves large observatories to 1% radiometric accuracy
 - Particularly useful for systems with short lifetimes and poor stability