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


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

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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)
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:

- 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 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

<table>
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<tr>
<th>Key Performance Parameters (KPP)</th>
<th>Threshold Value</th>
<th>Goal Value</th>
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<tr>
<td>Accuracy (reflectance)</td>
<td>1.0% (k=1)</td>
<td>0.5% (k=1)</td>
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<tr>
<td>Stability</td>
<td>&lt; 0.15% (k=1) per decade</td>
<td>&lt; 0.1% (k=1) per decade</td>
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<td>Orbit</td>
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<td>Time on-Orbit</td>
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<td>Frequency of sampling</td>
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<td>Instrument pointing</td>
<td>&lt; 0.2° combined</td>
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<td>Spectral Range</td>
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<td>Spectral Sampling</td>
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<td>4 nm</td>
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Reference for radiometric requirements (ROLO, T. Stone):
Lunar Phase Angle = 75°;
Irradiance = 0.6 (micro W / m² nm)
Wavelength = 500 nm
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

- B1923 CCD Detector (Imperx)
- SF070 Cryocooler (AIM)
- Mini-Nyx 640 MCT Detector (AIRS)
- UV/Visible Channel* (350 nm – 900 nm)
- Short Wave IR Channel* (880 nm – 2300 nm)
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
NASA Langley Research Center

**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
UVVNIIR Thermoelastic Analysis

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

Deformations scaled 100x

Section cut shown to better visualize displacement
UVVNIR and SWIR alignment plans
Identified need for 6 degree of freedom alignment tool for SWIR
UVVNIR and SWIR staking plans
Software Development

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

Electronics Development

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

Flight-like Software Architecture

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 ongoing
- SWIR detector acceptance testing once received (end of July 2018)
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

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.

"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?