Measuring Lunar Spectral Irradiance from a High-Altitude Aircraft
air-LUSI Team

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air-LUSI Objectives

• **Fly SI-traceable instrument** above 90% of the Earth's atmosphere on a high altitude aircraft to measure lunar spectral irradiance [ultimately to an unprecedented level of accuracy (<0.3% k=1 uncertainty)].

• **Build capacity** for acquisition of highly accurate, SI-traceable, exo-atmospheric lunar spectral irradiance.

• **Understand and improve uncertainty** of current knowledge of lunar spectral irradiance to benefit calibration sensitive Earth observations, e.g., ocean colour.
air-LUSI Subsystems

**ARTEMIS – Autonomous, Robotic Telescope Mount Instrument Subsystem** keeps telescope fixed on the Moon to within 0.1°.

**IRIS – IRradiance Instrument Subsystem**
- A non-imaging telescope (integrating sphere at focal point).
- Light fed via a fiber optic cable to a spectrograph.
- On-board LED validation source.
- Instrument enclosure keeps the spectrograph and validation source at surface-level P & T during flight.
• The telescope and robotic mount are in Superpod Aft-body.
• The sensor enclosure and control computer are in Mid-body.
• IRIS telescope views to port through Aft-body Zenith Viewport.
SUBSYSTEM DIAGRAM

- ZENITH APERTURE
  - Robotic Telescope Mount
  - Telescope (Single Lens with Fiber Carbon Tube)
  - Integrating Sphere
  - Optical Fiber Cables With Flexible Heat Jacket
  - LED Input Port

- UNPRESSURIZED AFT BODY
  - Tracking Camera
  - Interface Panel

- PRESSURIZED MID BODY
  - NIST Calibrated Spectrograph
  - LED Validation Source
  - Instrument Computer
  - Thermal Control
  - Tracking System Control Computer and Power
  - Aircraft Power Interface

- BULKHEAD

- N₂ Purge System
Hangar calibration configuration (pre & post flight)
# Uncertainty budget for IRIS Responsivity

Calibration source used to determine IRIS Responsivity

<table>
<thead>
<tr>
<th>Source of Uncertainty</th>
<th>450 nm</th>
<th>655 nm</th>
<th>900 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transfer Spectrograph (TS) Calibration to FEL</td>
<td>0.51</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>Distance, D1, TS to Source</td>
<td>0.16</td>
<td>0.16</td>
<td>0.16</td>
</tr>
<tr>
<td>Distance, D2, IRIS to Source</td>
<td>0.12</td>
<td>0.12</td>
<td>0.12</td>
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<tr>
<td>Alignment, TS to Source</td>
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<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Alignment, IRIS to Source</td>
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<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>TS linearity</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>IRIS linearity</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
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<tr>
<td>Wavelength</td>
<td>0.10</td>
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<td>0.10</td>
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<tr>
<td>TS measurement</td>
<td>0.06</td>
<td>0.05</td>
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<tr>
<td>IRIS measurement</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
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<tr>
<td><strong>Total k=1 % uncertainty IRIS Responsivity (Lab)</strong></td>
<td><strong>0.58</strong></td>
<td><strong>0.45</strong></td>
<td><strong>0.41</strong></td>
</tr>
</tbody>
</table>
# Lunar Irradiance Uncertainty Budget

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<th>655 nm</th>
<th>900 nm</th>
</tr>
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<tbody>
<tr>
<td>IRIS Responsivity</td>
<td>0.58</td>
<td>0.45</td>
<td>0.41</td>
</tr>
<tr>
<td>Lunar Measurement</td>
<td>0.25</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
<td>Radiometric Stability</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Pointing Stability</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
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<tr>
<td>Atmospheric Correction (predicted)</td>
<td>0.2</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Combined Uncertainty [% k=1]</td>
<td>0.72</td>
<td>0.58</td>
<td>0.55</td>
</tr>
</tbody>
</table>
LESSONS LEARNED FROM ENGINEERING FLIGHTS

Engineering flights conducted 01-02 August 2018

• Must address issues regarding hangar calibration (alignment, temperature, stray light) that affected pre- and post-flight calibration stability.

• May refine insulation for fiber optics to minimize possible small temperature effects.

• Must add correction for atmospheric effects during calibration, in addition to observing the Moon.

• Issues with the on-board validation source were addressed and will be tested.

• On-board thermal couples were reconfigured.

• In-flight recovery procedures were developed during engineering flight campaign.

• Creating a cover for telescope while stowed to reduce the risk of dust on lens.

• We plan reconfigure the mounting plates and cabling to reduce risk during upload and download of the instrument.
• air-LUSI functioned beyond expectations during engineering flights (given several months of development, small budget).

• Systems functioned autonomously to a few pilot switches (inc. N₂ purge system).

• Robotic telescope mount moved telescope to viewport, locked onto the Moon keeping it steady to within 0.05°, and return to stow position for descent.

• Instrument enclosure maintained stable environment for spectrometer and validation source (ΔT<2° and stable pressure).

• Measurements appear to have good SNR and precision.

• Demonstration flight campaign scheduled for conducted 12-17 November 2019.

• We would like to have a mini-shop for Satellite Lunar Calibration (TBD) to discuss results.
THANK YOU