Active Spectroscopy

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Active Team
Three Concepts Covered

• Laser Reflectometer
  – Tunable IR lasers coupled with proven LIDAR/LA technology

• IR Projector
  – High temperature blackbody IR projector provides active illumination of dark surfaces

• Solar Mirror
  – Satellite-based mirror directs sunlight onto polar surfaces
Laser Reflectometer

• Laser Reflectometer
  – Best general science
    • High SNR at km or smaller resolution
    • Global access
  – Conventional SMD-type instrument
  – 20kg, 25 W, $30M (Class B)
  – Likely competitive in existing technology development and mission opportunities
    – Goddard supporting on IRAD
• UV possible, worth KISS study
# Basic Parameters

<table>
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<th>Table 2. Signal and Noise Input parameters</th>
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<tr>
<td><strong>Transmit power</strong></td>
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<td><strong>Receiver diameter; f-no.</strong></td>
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<td><strong>SNR/Pulse</strong></td>
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<td><strong>System transmission</strong></td>
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<td><strong>Lunar background radiance</strong></td>
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<td><strong>Detector size</strong></td>
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<td><strong>Bandpass filter</strong></td>
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<td><strong>System read noise</strong></td>
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<td><strong>APD gain</strong></td>
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<td><strong>Net integration; sample time</strong></td>
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<td><strong>Dark current</strong></td>
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<td><strong>Nominal range</strong></td>
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<td><strong>Quantum Efficiency</strong></td>
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Polar Relevant Irradiance Sources
W/m2*

- Sunlight
- Scattered moonlight, 70K**
- 8 m reflector with imperfections
- 2.5 m reflector at 30 km
- 1 m reflector at 30 km
- Full Moon (from earth)
- IR Projector
- Integrated starlight
- Bright planets
- Zodiacal light
- Airglow
- Diffuse galactic light
- Cosmic light

<table>
<thead>
<tr>
<th>Source</th>
<th>Irradiance</th>
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</thead>
<tbody>
<tr>
<td>Sunlight</td>
<td>$1.3 \cdot 10^3$</td>
</tr>
<tr>
<td>Scattered moonlight, 70K**</td>
<td>$2.0 \cdot 10^0$</td>
</tr>
<tr>
<td>8 m reflector with imperfections</td>
<td>$0.3 \cdot 10^0$</td>
</tr>
<tr>
<td>2.5 m reflector at 30 km</td>
<td>$1.3 \cdot 10^{-1}$</td>
</tr>
<tr>
<td>1 m reflector at 30 km</td>
<td>$1.9 \cdot 10^{-2}$</td>
</tr>
<tr>
<td>Full Moon (from earth)</td>
<td>$2.1 \cdot 10^{-3}$</td>
</tr>
<tr>
<td>IR Projector</td>
<td>$5.0 \cdot 10^{-5}$</td>
</tr>
<tr>
<td>Integrated starlight</td>
<td>$3.0 \cdot 10^{-5}$</td>
</tr>
<tr>
<td>Bright planets</td>
<td>$2.0 \cdot 10^{-6}$</td>
</tr>
<tr>
<td>Zodiacal light</td>
<td>$1.2 \cdot 10^{-7}$</td>
</tr>
<tr>
<td>Airglow</td>
<td>$5.1 \cdot 10^{-8}$</td>
</tr>
<tr>
<td>Diffuse galactic light</td>
<td>$9.1 \cdot 10^{-9}$</td>
</tr>
<tr>
<td>Cosmic light</td>
<td>$9.1 \cdot 10^{-10}$</td>
</tr>
</tbody>
</table>

*Integrated spectral radiance, different situation at 3um depending on source T
**Flux causes 70K equilibrium temperature
Polar Relevant Irradiance Sources: Issues

- Sunlight
- Earthlight
- Moonlight
- Bright planets
- Zodiacal light
- Integrated starlight
- Airglow
- Diffuse galactic light
- Cosmic light
- Water colored!
- 3 um band!
IR Projector, The Good News

Projector
- 10 cm diameter unobscured optic
- f/2, 0.2 sr
- 5mm² 3000K blackbody
  - @ 3um, 1.5e5 watts/m2-um-sr
  - Area: 2.5e-5 m²
- At 3um, # watts/um exit projector,
  - radiance*solid angle*area
  - 0.6 watts/um (no losses)
- Focal length projector 200mm
- Spot at 25 km is 280 m
  - 62,000 m²
- Irradiance on spot per unit bandpass:
  - 9.6 microwatts/um-m2
- Radiance of spot
  - Irradiance times albedo/π
  - 1.5 x 10^-6/um-m2-sr
- Thermal emission
  - negligible in the cold places
  - Equivalent to the emission by a 180 K bb at 3 um)

Receiver
- 10 cm diameter unobscured optic
- f/2, 200 mm focal length
- Detector 5mm²
- A-omega: 2.5e-5 m²* .2sr
  - .5 e -5 m²-sr
- Power/micron collected:
  - Radiance times A-omega
  - 1.5x10-6 watts/m²-um-sr *.5 e -5 m²-sr
    - 7.5 x 10-12 watts/um
    - 1.1 x 10 8 ph/s-um
- Assume 0.1 total transmission
- Assume 300 nm bandpass
- 3e6 ph/second
- 1 km ground sample, 400 ms integration
- 0.95x10 6 electrons produced
- Neglecting other noise sources
  - SNR=970
IR Projector, Potential Problems

- Irradiance on detector is very small
- 0.007 nA/cm² photocurrent
- 3um cutoff HgCdTe has dark current 0.02 nA/cm² at 77K
- 2.5 micron cutoff very low dark current HgCdTe has 0.1nA/cm² at 120K, 0.01nA/cm² at 90K
- DARK CURRENT IS A MAJOR POTENTIAL PROBLEM at 3um
- 2 micron region is a bit brighter and detectors have lower dark current
  - SNR requirement stiffer
- At 1.4 micron ice band detectors have negligible dark current
- Need to study thermal detectors
- Need to study all kinds of detectors
- Scattered moonlight is common (unavoidable?) and very large
Solar Mirror

1-m mirror
• At 3 μm, solar radiance is 0.4x10^-6 watts/m^2-μm-sr
• Radiance of surface: reflectance radiance * solid angle of sun/π
  – 3 watts/m^2-μm-sr
• 1-m mirror at 30 km gives 4 x 10^-5 watts/m^2-μm-sr, @3μm
  – Projector is 1.5 x 10^-6
• 8-m mirror with ½ degree imperfections
  – 16x the flux of perfect 1-m
  – Allows increase of resolution to ~20nm

Receiver
• 10 cm diameter unobscured
• f/2, 200 mm focal length
• Detector 5mm^2
• A-ω:2.5e-5 m^2*.2sr
  – .5 e^-5 m^2-sr
• Assume 0.1 total transmission
• Assume 300 nm bandpass
• Reasonable losses, 90%
• 7.5e7 ph/second
• .1 km ground sample, 40 ms integration
• 2.5x10^6 electrons produced
• Neglecting other noise sources
  – SNR=1580
• Photocurrent is 10x dark current
• Tempting to go to higher spectral resolution but dark current becomes important again
• There appears to be ample margin however
Mirror issues

- Can get higher radiances with actual focus
  - Relay Mirror Experiment (RME) demonstrated extremely long focal length focus
    - 1 meter mirror, 400km focal length!
- Pointing is a bigger challenge

- Meter class high quality mirror is some kind of a challenge
- Inflatable?
- Are solar sail technologies flat enough?
- Scattered moonlight is common (unavoidable?) and large
Starlight!

- Aggressive passive experiment
- Distribution may be variable owing to distribution of stars
  - See LAMP publications
- Roughly solar color, 3um calculations based on solar scaled to two microns
- Irradiance calculated assuming a hemisphere (pi steradians projected area)
- 6x10^-7 watts/m^2-um-sr
  - Projector: 1.5 x 10^-6/um-m^2-sr
  - Mirror: 4 x 10^-5 watts/m^2-um-sr

Figure 4. The total stellar spectral radiance including interstellar absorption.
Starlight

Receiver
- 10 cm diameter unobscured
- f/2, 200 mm focal length
- Detector 5mm^2
- $A\omega:2.5 \times 10^{-5} \text{ m}^2 \times 0.2 \text{ sr}$
  - $0.5 \times 10^{-5} \text{ m}^2 \times 0.2 \text{ sr}$
- Power/micron collected:
  - Radiance times $A\omega$
  - $6 \times 10^{-7} \text{ watts/m}^2 \times \text{um} \times \text{sr} \times 0.5 \times 10^{-5} \text{ m}^2 \times \text{sr}$
    - $3 \times 10^{-12} \text{ watts/um}$
    - $0.4 \times 10^{8} \text{ ph/s-um}$
- Assume 0.1 total transmission
- Assume 300 nm bandpass
- $1.2 \times 10^{6} \text{ ph/second}$
- $2.5 \text{ km ground sample, 1000 ms integration}$
- $1.2 \times 10^{6} \text{ electrons produced}$
- Neglecting other noise sources
  - SNR=1100
Starlight, The Potential Problem

- 0.003 nA/cm²—this is very small
- 3μm cutoff HgCdTe has 0.02nA/cm²
- DARK CURRENT IS A POTENTIAL PROBLEM at 3μm
- Less of a problem at shorter wavelengths
- Scattered moonlight is common (unavoidable?) and large
Conclusions I

- Laser spectrometer high science, relatively mature, Goddard IRAD in progress, proposals submitted
- UV measurements feasible, possible study topic, instrument would be similar to LOLA
Conclusions II

• IR Searchlight
  – Flexible concept of operation
  – Power consumptive
  – Very challenging detector engineering problem
    • Low intensity on focal plane
    • Dark current competes
  – Potential game changer
  – Worth detailed engineering study
  – Better at 3um
  – Global science possible
  – Stray moonlight!

• Starlight
  – Similar to projector in detection challenge but a bit worse
  – Least complex
  – Data available globally
  – Better at shorter wavelengths
  – Global science possible
  – Stray moonlight!

• Solar reflector
  – Better detection problem than projector
    • Probably within uncertainty due to engineering cleverness
  – Signal depends critically upon mirror quality
    • Large errors permissible wrt a typical optical system, but requires a much flatter surface than a solar sail
    • Stretched membrane, inflatable may be options
  – Pointing requirements small fraction of a degree
  – Better at shorter wavelengths
  – Science at poles, possible non-polar science near terminator
  – Stray moonlight!
Conclusions III

• Receiver problem roughly similar for all three approaches
• Signal levels may diverge on further study but at the outset all approaches can leverage the same receiver
• Stray moonlight needs to be mapped and modeled to see where small enough to ignore

• Mirror may provide most signal, largest spacecraft operations challenge
  – Mirror quality vs size
  – Pointing
• Projector may be competitive, especially at 3um
  – Study needs to optimize performance/power with receiver design
• Starlight intensity needs validation
  – Perhaps LAMP team
## Summary

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<tr>
<th></th>
<th>Pros</th>
<th>Cons</th>
<th>Recommendation</th>
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<tbody>
<tr>
<td>Laser Reflectometer</td>
<td>Diverse high value measurements</td>
<td>Expensive, heavy, evolutionary not revolutionary, reasonable prospect of NASA conventional funding; Goddard IRAD underway</td>
<td>Investigate UV bands</td>
</tr>
<tr>
<td>IR Projector</td>
<td>Flexible concept of operation, potentially revolutionary, global science</td>
<td>Engineering challenge for detection, competes with starlight complicating data analysis; power consumptive</td>
<td>Study detection problem; projector design including power</td>
</tr>
<tr>
<td>Solar mirror</td>
<td>Simple detection problem, leverages solar sail technology, potentially revolutionary</td>
<td>Tricky spacecraft control requirements; mirror quality; , local science</td>
<td>Study control, mirror technology problem, detector design</td>
</tr>
<tr>
<td>Starlight</td>
<td>Least complex, global science</td>
<td>Very challenging receiver</td>
<td>Study receiver, especially dark current</td>
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