Active Spectroscopy

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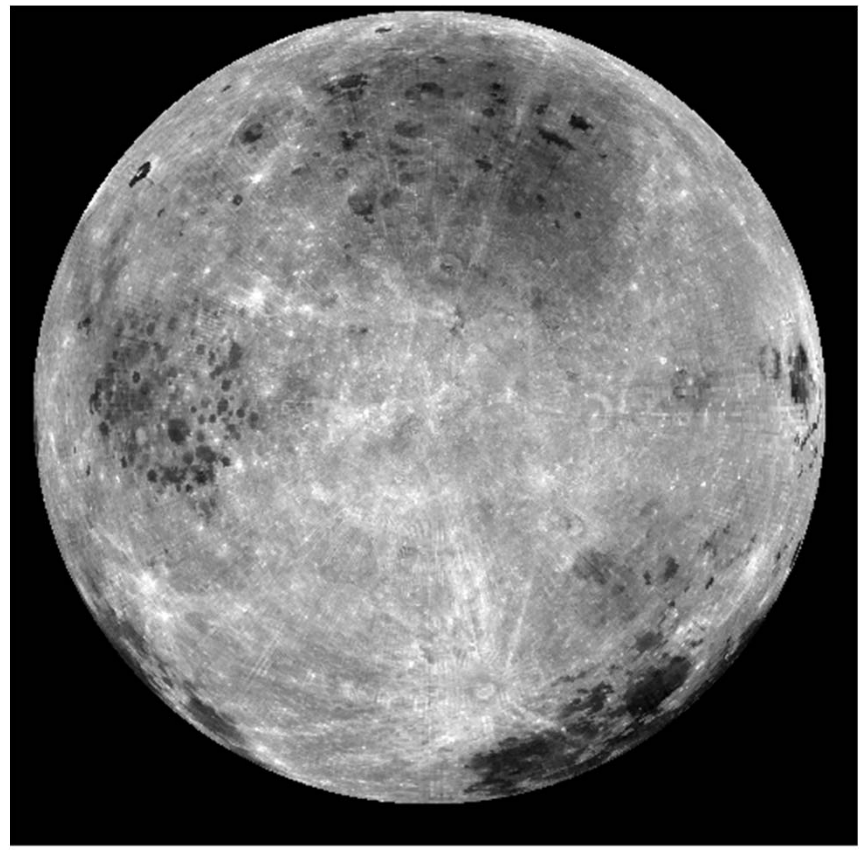
Active Team

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

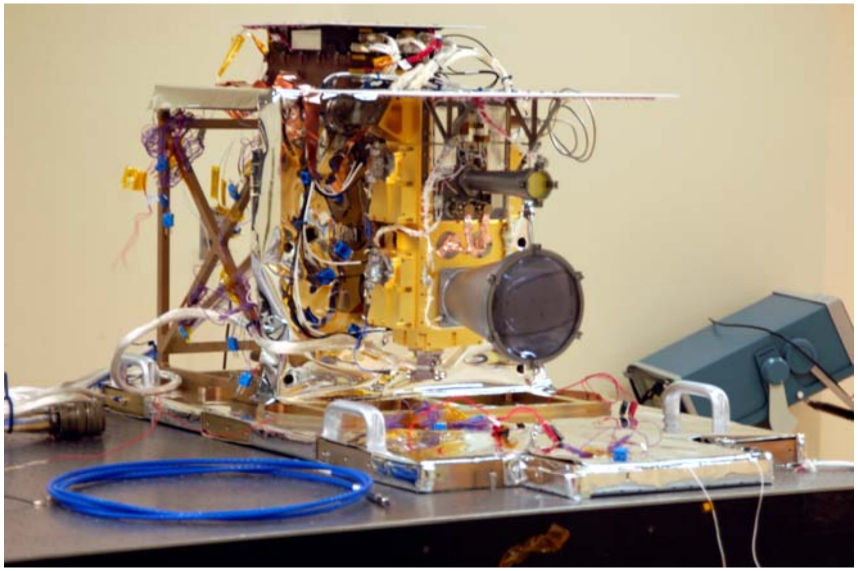
Laser Reflectometer

- 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 2. Signal and Noise Input parameters	
Transmit power	2.5 mJ/pulse
Receiver diameter; f-no.	160 mm; 4
SNR/Pulse	90 @ 100 m samples
System transmission	10%
Lunar background radiance	4 watts/m2-um-sr; 10 watts/m2-um-sr assumed
Detector size	64 microns
Bandpass filter	0.9 microns (2.65-3.55)
System read noise	560 e-
APD gain	1-900 (~5 will be used)
Net integration; sample time	45 ns; 2 ns
Dark current	$3x10^{-10}$ A/cm2
Nominal range	30 km
Quantum Efficiency	0.7



Polar Relevant Irradiance Sources W/m2*

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

*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
- 5mm^2 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/pi
  - 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
- f/2, 200 mm focal length
- Detector 5mm^2
- 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
- <u>Neglecting other noise sources</u>
  - SNR=970

IR Projector, Potential Problems

- Irradiance on detector is very small
- **.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, .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 v large

Solar Mirror

1-m mirror

- At 3 um, solar radiance is 0.4x10 6 watts/m2-um-sr
- Radiance of surface: reflectance radiance * solid angle of sun/pi
  - 3 watts/m2-um-sr
- 1-m mirror at 30 km gives 4 x 10 -5 watts/m2-um-sr,@3um
  - 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-omega:2.5e-5 m2*.2sr
  - .5 e -5 m2-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
- Turner, R.E., Night Sky Spectral Radiance Models, Contract DAABO7-98-D-H752, CECOM Night Vision and Electronic Sensors Directorate, Ft. Belvoir, VA, April 2001
- 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/m2-um-sr
  - Projector: 1.5 x 10 -6/um-m2-sr
  - Mirror: 4 x 10 -5 watts/m2-um-sr

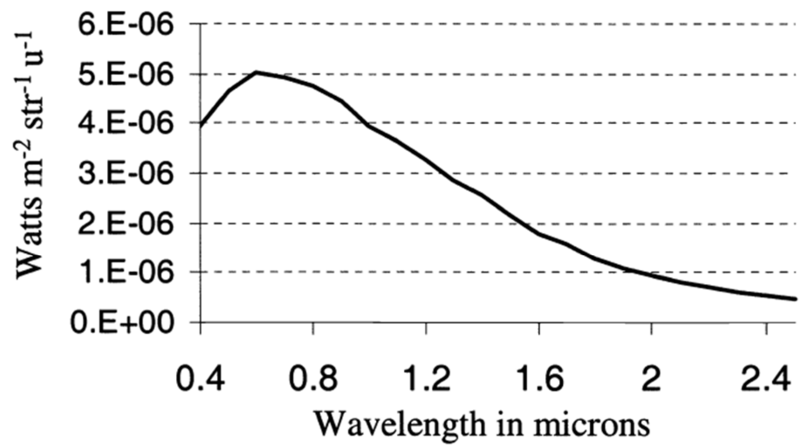


Figure 4. The total stellar spectral radiance including interstellar absorption.

Starlight

Receiver

- 10 cm diameter unobscured
- f/2, 200 mm focal length
- Detector 5mm^2
- A-omega:2.5e-5 m2*.2sr
  - .5 x10 -5 m2-sr
- Power/micron collected:
  - Radiance times A-omega
  - 6x10-7 watts/m2-um-sr *.5 e -5 m2-sr
    - 3 x 10-12 watts/um
    - .4 x 10 8 ph/s-um

- Assume 0.1 total transmission
- Assume 300 nm bandpass
- 1.2e6 ph/second
- 2.5 km ground sample, 1000 ms integration
- 1.2x10 6 electrons produced
- <u>Neglecting other noise sources</u>
  - SNR=1100

Starlight, The Potential Problem

- .003 nA/cm2—this is very small
- 3um cutoff HgCdTe has 0.02nA/cm2
- DARK CURRENT IS A POTENTIAL PROBLEM at 3um
- 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 writ a typical optical system, but requires a much flatter surface than a solar sail
    - Stretched membrane, inflatable may be options
  - Pointing requirements amall 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 v 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

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