Limb sounding of the lunar limb with a Fourier transform spectrometer

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• NASA Goddard has launched a series of Fourier transform spectrometers (FTS) to the solar system – including the IRIS on two Voyagers, and Cassini CIRS at Saturn

• Passive IR remote sensing in emission (limb & nadir) is a power tool for characterization of
  - Surface and atmosphere temperatures
  - Composition
  - Dynamics via the thermal wind equation

• Increased in size, culminating in 43 kg for CIRS, so develop CIRS-lite at 15-20 kg for future planetary missions
• Technology advances include:
  - high Tc superconductor bolometers (YBCO @ 87K, MgB$_2$ @ 37K)
  - Carbon nano-tube (CNT) layer for IR absorption
  - a COTS-based moving mirror mechanism compatible with near 77K operation
  - Synthetic (CVD) diamond beam-splitter
  - Single crystal silicon (SCS) telescope primary

• Very broad spectral coverage, ~ 7 to 300 microns, monitors a rich set of molecular lines
### CIRS-lite and other FTS instruments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>CIRS</th>
<th>CIRS-lite</th>
<th>IRIS Mars</th>
<th>TES</th>
<th>PFS</th>
</tr>
</thead>
<tbody>
<tr>
<td>band-pass ((\mu m))</td>
<td>7 to 1000</td>
<td>7 to 333</td>
<td>5 to 50</td>
<td>6 to 50</td>
<td>0.9 to 45</td>
</tr>
<tr>
<td>resolution (cm(^{-1})) apodized</td>
<td>0.5</td>
<td>0.125</td>
<td>2.4</td>
<td>5</td>
<td>1.5</td>
</tr>
<tr>
<td>telescope diameter (cm)</td>
<td>50</td>
<td>15</td>
<td>4</td>
<td>15</td>
<td>5 /4</td>
</tr>
<tr>
<td>detectors</td>
<td>HgCdTe thermopile</td>
<td>HgCdTe high Tc</td>
<td>thermistor bolometer</td>
<td>DTGS pyroelec.</td>
<td>PbSe, PbS LiTaO(_3)</td>
</tr>
<tr>
<td>detector temperature (K)</td>
<td>75 and 170 170</td>
<td>75 and 89 ~150</td>
<td>250</td>
<td>Uncooled 210 and 290</td>
<td>Uncooled 290</td>
</tr>
<tr>
<td>optics temperature (K)</td>
<td>75 and 170 170</td>
<td>75 and 89 ~150</td>
<td>250</td>
<td>Uncooled 210 and 290</td>
<td>Uncooled 290</td>
</tr>
<tr>
<td>point-able mirror</td>
<td>no</td>
<td>TBD 1 kg</td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>footprint (km @ 250 km)</td>
<td>1 &amp; 0.05</td>
<td>1 &amp; 0.4</td>
<td>16</td>
<td>2</td>
<td>7 &amp; 14</td>
</tr>
<tr>
<td>mass (kg)</td>
<td>43</td>
<td>15 to 20</td>
<td>14</td>
<td>14</td>
<td>31</td>
</tr>
</tbody>
</table>
CIRS to CIRS-lite

- CVD diamond has very broad transmission --> drop one FTS

- more sensitive FIR detectors (HTS bolometers vs. thermopiles) for smaller optics

- double-passed moving cube-corner enables higher spectral resolution
Moving mirror mechanism

Red: speed
Blue: drive force
CIRS-\textit{lite} optical layout
Nominal design

This image shows the optics of a single crystal, weighted honeycomb embedded substrate.

- **Focal Plane**:
  - **TYPE WAVELENGTH**
    - PC: 16 + to 333
    - PV: 7 to 9
  - **Fresnel**: 0.125 cm^-1 apodized (Fraunhofer double-passed; physical travel is 1 inch)
  - **Coverage**: 7 to 333/11, one Fresnel with 60 mm diamond beam splitter, no compensator
  - **Arrays**
    - **Temperature**: 140 K (same as Voyager MIRIS)
    - **All Detectors**: Near 70 to 90 K, with passive cooler
    - **Beam Splitter**: 3.5 mm, need 5 mm clear aperture for beam splitter at 45 degrees

- **Telescope Primary**
Lunar dust, volatiles

<table>
<thead>
<tr>
<th>Mission</th>
<th>Science Goal</th>
<th>Optics temperature</th>
<th>Beam-splitter</th>
<th>detectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planetary deep space</td>
<td>atmospheres: composition, dynamics (remote sensing in emission)</td>
<td>~150K</td>
<td>diamond</td>
<td>HgCdTe high Tc bolometers</td>
</tr>
<tr>
<td>Lunar dust</td>
<td>Dust, gas (remote sensing via solar absorption)</td>
<td>~150K</td>
<td>KBr or diamond</td>
<td>HgCdTe thermal</td>
</tr>
<tr>
<td>Lunar surface ices</td>
<td>Near surface ice (in-situ) Reflection (NIR) Emission (FIR)</td>
<td>100K/ambient</td>
<td>ZnSe (NIR)</td>
<td>HgCdTe (NIR) high Tc bolometer (FIR) MgB$_2$ (near 40K)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>100K/ambient</td>
<td>diamond (FIR)</td>
<td></td>
</tr>
</tbody>
</table>

Solar occultation measurements: from surface, from orbit (limb view)
- lunar surface covered with dust grains levitated by charging mechanisms
- charging via solar wind and UV photons
- particular dust activity near the terminator (vacuum, little/no water)
- dust has implications for lunar exploration (adhesive, mechanisms, …)
- need to measure dust density, size distribution,
- measure vertical distribution from orbit via onion-peeling technique
- also measure H$_2$O and CH$_4$ from orbit
• Clementine radar, Lunar Prospector neutron spectrometer, and LRO/LEND indicate water ice or hydrogen deposits in permanently shadowed regions (PSR)
• LRO/LCROSS plume demonstrates hydroxyl group
• LRO/DIVINER temperatures consistent with ice
• Can distinguish hydrates from water ice via spectroscopy

- combine CIRS-lite with an NIR source (laser, LED or thermal) to measure NIR reflectance of surface deposits

- map concentration of water ice

- use laser source or ultrasonic generator to drive off volatiles and get indication of distribution with depth
- FIR measurements (40 to 100 microns) can measure PSR temperatures (< 100K) and characterize two water ice features in the FIR

- in amorphous ice, longer peak is suppressed

- detection of these FIR emission features in an optically thick source such as the lunar surface requires a vertical temperature gradient

- thermal conductivity of slowly deposited amorphous ice is $10^4$ times less than crystalline

- recent NASA GSFC results show MgB2 bolometers (37K transition) are much faster than YBCO bolometers (consistent with PSR operation)

Water ice FIR emission features observed in interstellar dust, with 40 and 60 micron peaks
THAT’s All, FOLKS!