ABSTRACT

Future generations of Earth and planetary remote sensing instruments will require extensive developments of new long-wave and very long-wave infrared detectors. The upcoming NASA Earth Observing System (EOS) will carry a suite of instruments to monitor a wide range of atmospheric and surface parameters with an unprecedented degree of accuracy for a period of 10 to 15 years. These instruments will observe Earth over a wide spectral range extending from the visible to nearly 17 micrometers with a moderate to high spectral and spacial resolution. In addition to expected improvements in communication bandwidth and both ground and on-board computing power, these new sensor systems will need large two-dimensional detector arrays. Such arrays exist for visible wavelengths and, to a lesser extent, for short wavelength infrared systems. The most dramatic need is for new LWIR and V LWIR detector technologies that are compatible with area array readout devices and can operate in the temperature range supported by long life, low power refrigerators. A scientific need for radiometric and calibration accuracies approaching 1% translates into a requirement for detectors with excellent linearity, stability and insensitivity to operating conditions and space radiation. Current examples of the kind of scientific missions these new thermal IR detectors would enhance in the future include instruments for Earth science such as AIRS, MODIS, SAFIRE and OVO. Planetary exploration missions such as Cassini also provide examples of instrument concepts that could be enhanced by new IR detector technologies.
SENSOR REQUIREMENTS FOR EARTH AND PLANETARY EXPLORATION

Moustafa T. Chahine

DETECTOR REQUIREMENTS — GENERAL REMARKS

- PERFORMANCE OF PROPOSED INSTRUMENTS DEPENDS ALMOST ENTIRELY ON DETECTOR PERFORMANCE

- INSTRUMENT PERFORMANCE REQUIREMENTS OFTEN DictATED BY EXISTING DETECTOR PERFORMANCE DATA
  - NASA FUNDING PROCESS ENSURES THAT PROPOSED DETECTOR PERFORMANCE MUST:
    a, EXIST
    b, BE READILY AVAILABLE, WITH FLIGHT HERITAGE
    c, BE BELIEVED TO SATISFY a, AND b, BY THE COMMUNITY

- PROPOSED INSTRUMENTS REQUIRING DETECTOR DEVELOPMENT PROGRAMS FARE POORLY AGAINST THOSE THAT DO NOT

- FOR THESE REASONS, REAL DETECTOR REQUIREMENTS ARE OFTEN NOT COMMUNICATED TO THOSE ABLE TO ADDRESS THEM

- THE PRIMARY PURPOSE OF THIS MEETING IS TO ACHIEVE THIS COMMUNICATION.

EARTH OBSERVING SYSTEM (EOS) PAYLOAD

<table>
<thead>
<tr>
<th>Eos-A</th>
<th>Eos-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRS (JPL) 3-15.4 μm</td>
<td>ALT/RA</td>
</tr>
<tr>
<td>AMSU</td>
<td>GGI</td>
</tr>
<tr>
<td>CERES (LaRC) 0.2-100 μm</td>
<td>GLRS</td>
</tr>
<tr>
<td>HIRDLS (NCAR/6-18 μm)</td>
<td>IPEI</td>
</tr>
<tr>
<td>EOSP</td>
<td>LIS</td>
</tr>
<tr>
<td>GGI</td>
<td>MLS</td>
</tr>
<tr>
<td>HIMSS/MIMR/AMSR</td>
<td>SAFIRE (LaRC) 6.4-125 μm</td>
</tr>
<tr>
<td>HIRIS</td>
<td>SAGE III</td>
</tr>
<tr>
<td>IPEI</td>
<td>SCANSCAT/STIKSCAT</td>
</tr>
<tr>
<td>ITIR (JAP) 0.52-11.65 μm</td>
<td>SOLSTICE</td>
</tr>
<tr>
<td>MISR</td>
<td>SWIRLS (JPL) 7.6-17.2 μm</td>
</tr>
<tr>
<td>MODIS-N (GSFC) 0.4-14.24 μm</td>
<td>TES (JPL) 2.9-17 μm</td>
</tr>
<tr>
<td>MODIS-T/MERIS</td>
<td>XIE</td>
</tr>
<tr>
<td>MOPITT/TRACER</td>
<td></td>
</tr>
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</table>

Original page is of poor quality
## CRAF PAYLOAD

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Investigation</th>
<th>PI/Team Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS</td>
<td>Imaging (Facility)</td>
<td>J. Veverka/Cornell</td>
</tr>
<tr>
<td>VIMS</td>
<td>Visual/Infrared Mapping Spectrometer (Facility)</td>
<td>T. McCord/U of Hawaii</td>
</tr>
<tr>
<td>TIREX</td>
<td>Thermal Infrared Radiometer Experiment</td>
<td>F. P.J. Valero/NASA Ames</td>
</tr>
<tr>
<td>PEN</td>
<td>Penetrator</td>
<td>W. Boynton/U of Arizona</td>
</tr>
<tr>
<td>COMA</td>
<td>Cometary Matter Analyzer</td>
<td>J. Kissel/Max Planck Institut</td>
</tr>
<tr>
<td>CIDEX</td>
<td>Comet Ice/Dust Experiment</td>
<td>G. Carle/NASA Ames</td>
</tr>
<tr>
<td>SEMPA</td>
<td>Scanning Electron Microscope and Particle Analyzer</td>
<td>A. Albee/CIT</td>
</tr>
<tr>
<td>CODEM</td>
<td>Comet Dust Environment Monitor</td>
<td>W.M. Alexander/Baylor Univ</td>
</tr>
<tr>
<td>NGIMS</td>
<td>Neutral Gas and Ion Mass Spectrometer</td>
<td>H. Niemann/NASA GSFC</td>
</tr>
<tr>
<td>MAG</td>
<td>Magnetometer</td>
<td>B. Tsurutani/JPL</td>
</tr>
<tr>
<td>CREWE</td>
<td>Coordinated Radio, Electrons, and Waves Experiment</td>
<td>J. D. Scudder/NASA GSFC</td>
</tr>
<tr>
<td>RSS</td>
<td>Radio Science (Facility)</td>
<td>D. K. Yeomans/JPL</td>
</tr>
</tbody>
</table>

## CASSINI PAYLOAD

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Investigation</th>
<th>Wavelength/Freq Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIRS (GSFC)</td>
<td>Mid &amp; Far IR Spectrometer</td>
<td>7.5-1000(\mu m)</td>
</tr>
<tr>
<td>HSP</td>
<td>High Speed Photometer</td>
<td>117-180 nm</td>
</tr>
<tr>
<td>ISS</td>
<td>Solid State Imaging</td>
<td>0.2-1.1(\mu m)</td>
</tr>
<tr>
<td>MSAR</td>
<td>Microwave Spectrometer/Radiometer</td>
<td>15-230 GHz</td>
</tr>
<tr>
<td>PRWS</td>
<td>Plasma/Radio Wave Spectrometer</td>
<td>5 Hz - 20 MHz</td>
</tr>
<tr>
<td>RADR</td>
<td>Radar</td>
<td>14, 30 GHz</td>
</tr>
<tr>
<td>RS</td>
<td>Radio Science</td>
<td>3.6-13 cm</td>
</tr>
<tr>
<td>UVSI</td>
<td>UV Spectrometer</td>
<td>500-3200 Å</td>
</tr>
<tr>
<td>VIMS (JPL)</td>
<td>Visual/Infrared Mapping Spectrometer</td>
<td>0.4-5.2 (\mu m)</td>
</tr>
</tbody>
</table>
AIRS is a high spectral-resolution sounder covering the range between 3 and 17 μm with more than 4000 spectral measurements, having a resolving power Δλ/λ = 1/1200. AIRS permits simultaneous determination of a large number of atmospheric and surface parameters including temperature and humidity profiles, ocean and land surface temperature, clouds, O₃, CH₄, and other minor gases. This is accomplished in part through multispectral, narrow bandpass channels which can be selected away from unwanted absorption lines, while taking advantage of the unique spectral properties of several regions such as the high J-lines in the R-branch of the 4.3 μm CO₂ band and the clear super-windows near 3.6 μm.
AIRS (used with AMSU) provides simultaneous determination of a large number of atmospheric and surface parameters under both day and night conditions:

1. Atmospheric temperature profiles with an average accuracy of 1°C and in 1 km thick layers.
2. Relative humidity profiles and total precipitable water vapor
3. Sea surface temperature.
4. Land surface temperature and infrared spectral emissivity.
5. Fractional cloud cover, cloud infrared emissivity, and cloud-top pressure and temperature.
6. Total ozone burden of the atmosphere.
7. Mapping of the distribution of minor atmospheric gases such as methane, carbon monoxide and nitrous oxide.
8. Surface albedo.
9. Snow and ice cover.
10. Outgoing long wave radiation.
11. Precipitation index.

**AIRS**

**Atmospheric Temperature Profile**

Atmospheric temperature profiles $T(p)$ will be derived with an average accuracy of 1°C in 1 km thick layers. Clear-column temperature profiles will be derived in the presence of multiple cloud layers without requiring any field-of-view (FOV) to be necessarily completely clear. Observations over adjacent FOVs will be used to filter out the effects of clouds on all channels. Improvements in the $T(p)$ are a result of:

- AIRS narrow contribution functions
- Number of available sounding channels
- Minimizing contamination by $O_3$, $H_2O$, ...
- Simultaneous determination of the surface temperature, emissivity and reflectivity
- Use of AMSU lower atmosphere sounding channels to filter out the effects of clouds
Humidity profiles will be derived from channels selected in the 6.3 μm water vapor band and the 11 μm windows which are sensitive to water vapor continuum. The radiance measured in these channels depends on atmosphere and surface temperature and the distribution of humidity in the atmosphere. The 6.3 μm channels are more sensitive to humidity in the middle and upper troposphere, while the narrow bandpass channels in the 11 μm continuum are more sensitive to humidity in the lower troposphere. Determination of surface temperature and spectral emissivity is essential for obtaining accurate low level water vapor distribution.

**TABLE 1**

| Design Altitude | 705 km |
| Cross-track Scan Motion | ± 48.95° |
| Spectral Coverage | 3.4 - 17.0 μm |
| Spectral Resolution | 1200 |
| NEAT Channels | 115 (minimum) |
| Visible Light Spectral coverage | 0.4 - 1.1 μm |
| Channel wavelengths (tentative) | 0.40 - 0.50 μm |
| | 0.67 - 0.71 μm |
| | 0.70 - 0.80 μm |
| | 0.9 - 1.0 μm |
| | 0.4 - 1.0 μm |
| Sensitivity | SNR = 100 at albedo = 0.4 |
| Data Encoding | 12 bits/sample |
| Number of Samples/Cross-track Scan | 89 |
| Mean Data Rate | 1.8 Mb/s |
| Maximum Data Rate | 1.8 Mb/s |
TABLE 2
OPTICAL SYSTEM PARAMETERS

<table>
<thead>
<tr>
<th>IFOV</th>
<th>± 0.52°</th>
</tr>
</thead>
</table>

**Visible/near IR system:**

<table>
<thead>
<tr>
<th>Fore optics:</th>
<th>full aperture</th>
<th>subapertures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture (mm)</td>
<td>10.0</td>
<td>2.0 (5)</td>
</tr>
<tr>
<td>EFL (mm)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Focal Ratio</td>
<td>F/5</td>
<td>F/25</td>
</tr>
</tbody>
</table>

**Relay:**

<table>
<thead>
<tr>
<th>Magnification</th>
<th>4:1</th>
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<tbody>
<tr>
<td>Final Focal Ratio</td>
<td>F/13.7</td>
</tr>
<tr>
<td>Detector Diam. (mm)</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**IR systems:**

<table>
<thead>
<tr>
<th>Fore optics:</th>
<th>full aperture</th>
<th>subapertures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture (mm)</td>
<td>121.0 x 5.5</td>
<td>5.5 x 5.5 (8)</td>
</tr>
<tr>
<td>EFL (mm)</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Focal Ratio</td>
<td>F/4.1 x F/90.9</td>
<td>F/90.9</td>
</tr>
</tbody>
</table>

**Spectrometers:**

<table>
<thead>
<tr>
<th>Short-Wave</th>
<th>Long-Wave</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture (mm)</td>
<td>69.3 x 138.6</td>
</tr>
<tr>
<td>Grating Incidence Angle</td>
<td>60°</td>
</tr>
<tr>
<td>Grating Diffraction Angle</td>
<td>0°</td>
</tr>
<tr>
<td>Grating Spacing (mm)</td>
<td>0.057</td>
</tr>
<tr>
<td>EFL (mm)</td>
<td>138.6</td>
</tr>
<tr>
<td>Focal Ratio</td>
<td>F/2.0 x F/1.0</td>
</tr>
<tr>
<td>Pixel size (mm)</td>
<td>0.2 x 0.1</td>
</tr>
</tbody>
</table>

**Figure 2**

SCHEMATIC MULTI-APERTURE SPECTROMETER DIAGRAM

In the multi-aperture spectrometer, several sub-apertures (1) in a line across the telescope aperture are relayed to the spectrometer slit (5), then dispersed (7) and re-imaged onto a series of linear arrays (9).
## AIRS INSTRUMENT DIAGRAM WITH X-RAY VIEW OF THE TWO SPECTROMETERS

## AIRS DETECTOR TECHNOLOGY REQUIREMENTS / CHALLENGES

<table>
<thead>
<tr>
<th>ISSUE</th>
<th>REQUIREMENT</th>
<th>CHALLENGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon Flux Range</td>
<td>$10^7 - 10^{12}$ photons/sec/pix</td>
<td>Large dynamic range, low readout noise, storage and speed</td>
</tr>
<tr>
<td>Radiometric Performance</td>
<td>BLIP at all flux levels, 1% linearity and calibration accuracy</td>
<td>Low noise detectors, high QE, feedback in cell, radiation tolerance</td>
</tr>
<tr>
<td>Wavelength Range</td>
<td>To 15.4 μm extendable to 17 μm</td>
<td>Only single pixels demonstrated in MCT, linear arrays required</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>Compatible with long life coolers, $T \geq 60$ K</td>
<td>Not demonstrated, new options needed</td>
</tr>
<tr>
<td>Power Dissipation</td>
<td>10 - 50 μW per pixel with readout 0.1 - 0.2 W for full focal plane</td>
<td>Cooler power limitation</td>
</tr>
</tbody>
</table>
MODERATE RESOLUTION IMAGING SPECTROMETER
(MODIS-N)

[Team Leader: Vince Salomonson, GSFC]

MODERATE RESOLUTION IMAGING SPECTROMETER
SCIENCE OBJECTIVES

- STUDIES OF SPATIAL AND TEMPORAL VARIABILITY OF OCEANIC SURFACE PROPERTIES WITH SPECIAL EMPHASIS ON OCEAN PRIMARY PRODUCTIVITY

- STUDIES OF THE SPATIAL AND TEMPORAL VARIABILITY IN LAND SURFACE PROPERTIES WITH EMPHASIS ON PROBLEMS SUCH AS DESERTIFICATION, REGIONAL VEGETATION STRESS DUE TO ACID RAIN OR DROUGHT, AND SUCCESSION OR CHANGE IN VEGETATION SPECIES DUE TO DEFORESTATION AND ANTHROPOGENIC EFFECTS

- STUDIES OF TROPOSPHERIC DYNAMICS, CLIMATOLOGY AND CHEMISTRY AS OBTAINED THROUGH OBSERVATIONS OF CLOUD CHARACTERISTICS, AEROSOLS, WATER VAPOR, AND TEMPERATURE (INCLUDING SURFACE TEMPERATURE)
MODERATE RESOLUTION IMAGING SPECTROMETER
INSTRUMENT DESCRIPTION

• SCANNING IMAGING SPECTROMETER
• PIXEL SIZES OF 214 M, 428 M, AND 856 M
• SWATH WIDTH OF 2300 KM
• SPECTRAL RANGE 0.6-15 MICRONS, 36 BANDS
• 200 KG, 8.3 MBPS, 250 W

MODIS-N
SPECTRAL CHANNEL CHARACTERISTICS

<table>
<thead>
<tr>
<th>No. CHANNELS</th>
<th>λ (µm)</th>
<th>Δλ (nm)</th>
<th>IFOV (meters)</th>
<th>S/N (AT 70° SZA)</th>
<th>NEDT (TYPICAL)</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.6 - 0.9</td>
<td>40 - 50</td>
<td>214</td>
<td>100 - 200</td>
<td>EDGE DETECTION</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.4 - 2.1</td>
<td>20 - 50</td>
<td>428</td>
<td>100 - 300</td>
<td>LAND PROCESSES AND CLOUD CHARACTERISTICS</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.4 - 0.9</td>
<td>10 - 15</td>
<td>856</td>
<td>500 - 900</td>
<td>OCEAN COLOR</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.6 - 0.7</td>
<td>10 - 15</td>
<td>856</td>
<td>1100</td>
<td>FLUORESCENCE</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.9 - 1.0</td>
<td>10 - 50</td>
<td>856</td>
<td>60-250</td>
<td>WATER VAPOR</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>3.7 - 8.6</td>
<td>50 - 300</td>
<td>856</td>
<td>0.05K AT 300K</td>
<td>ATMOS. PARAMETERS AND SURFACE TEMPERATURE</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>9.7 - 14.2</td>
<td>300 - 500</td>
<td>856</td>
<td>0.25K AT 250K</td>
<td>CLOUD AND SURFACE TEMPERATURE</td>
<td></td>
</tr>
</tbody>
</table>

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### MODIS-N

#### INSTRUMENT SUMMARY

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>DESIGN SPECIFICATIONS OR EXPECTED PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLATFORM ALTITUDE</td>
<td>705 km</td>
</tr>
<tr>
<td>IFOV (NO. OF BANDS AT IFOV)</td>
<td>29 AT 1.21 mrad (656 m)</td>
</tr>
<tr>
<td></td>
<td>5 AT 0.607 mrad (428 m)</td>
</tr>
<tr>
<td></td>
<td>2 AT 0.303 mrad (214 m)</td>
</tr>
<tr>
<td>SWATH</td>
<td>110 deg/2330 km</td>
</tr>
<tr>
<td>SPECTRAL BANDS</td>
<td>36 BANDS TOTAL</td>
</tr>
<tr>
<td></td>
<td>(19/0.4-3.0 μm; 17/3-15 μm)</td>
</tr>
<tr>
<td>RADIOMETRIC ACCURACY</td>
<td>5% ABSOLUTE, &lt; 3 μm</td>
</tr>
<tr>
<td></td>
<td>1% ABSOLUTE, &gt; 3 μm</td>
</tr>
<tr>
<td></td>
<td>2% REFLECTANCE</td>
</tr>
<tr>
<td>QUANTIZATION</td>
<td>12 bit</td>
</tr>
<tr>
<td>POLARIZATION SENSITIVITY</td>
<td>2% MAX, &lt; 2.2 μm</td>
</tr>
<tr>
<td>MODULATION TRANSFER FUNCTION</td>
<td>0.3 AT NYQUIST</td>
</tr>
<tr>
<td>S/N PERFORMANCE (70 degree SOLAR ZENITH/OCEANS)</td>
<td>830:1 (443 nm)</td>
</tr>
<tr>
<td></td>
<td>745:1 (520 nm)</td>
</tr>
<tr>
<td></td>
<td>503:1 (865 nm)</td>
</tr>
<tr>
<td>NEDT PERFORMANCE (THERMAL BANDS) AT 300 deg K/WINDOW BANDS</td>
<td>LESS THAN 0.05</td>
</tr>
<tr>
<td>SCAN EFFICIENCY</td>
<td>(TO BE DETERMINED)</td>
</tr>
<tr>
<td>INTEGRATION TIME</td>
<td>(TO BE DETERMINED)</td>
</tr>
<tr>
<td>SIZE (APPROX)</td>
<td>1 x 1.5 x 1 m</td>
</tr>
<tr>
<td>WEIGHT</td>
<td>APPROX 200 kg</td>
</tr>
<tr>
<td>POWER</td>
<td>250 W</td>
</tr>
<tr>
<td>PEAK DATA RATE</td>
<td>15 MBS (DAYTIME)</td>
</tr>
<tr>
<td>DUTY CYCLE</td>
<td>100%</td>
</tr>
</tbody>
</table>

### MODIS-N

#### LWIR PARAMETERS

<table>
<thead>
<tr>
<th>BAND NUMBER</th>
<th>CENTER WVLNGTH (μm)</th>
<th>DELTA WVLNGTH (nm)</th>
<th>TYP. SCENE TEMP (K)</th>
<th>TYP. SPECTRAL RADIANCE (+)</th>
<th>NEDT (K)</th>
<th>NOISE EQUIV. SPECTRAL RADIANCE (+)</th>
<th>REQ. SIGNAL/NOISE RATIO</th>
<th>NOMINAL NEP (W)</th>
<th>CALCULATED D*</th>
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</thead>
<tbody>
<tr>
<td>30</td>
<td>9.73</td>
<td>300</td>
<td>250</td>
<td>3.69</td>
<td>0.25</td>
<td>2.19E-02</td>
<td>168</td>
<td>6.04E-11</td>
<td>4.39E+10</td>
</tr>
<tr>
<td>31</td>
<td>11.03</td>
<td>500</td>
<td>300</td>
<td>9.55</td>
<td>0.05</td>
<td>7.01E-03</td>
<td>1362</td>
<td>3.22E-11</td>
<td>6.22E+10</td>
</tr>
<tr>
<td>32</td>
<td>12.02</td>
<td>300</td>
<td>300</td>
<td>8.94</td>
<td>0.05</td>
<td>6.06E-03</td>
<td>1475</td>
<td>2.79E-11</td>
<td>9.51E+10</td>
</tr>
<tr>
<td>33</td>
<td>13.34</td>
<td>300</td>
<td>260</td>
<td>4.52</td>
<td>0.25</td>
<td>1.83E-02</td>
<td>247</td>
<td>5.05E-11</td>
<td>5.25E+10</td>
</tr>
<tr>
<td>34</td>
<td>13.64</td>
<td>300</td>
<td>250</td>
<td>3.76</td>
<td>0.25</td>
<td>1.61E-02</td>
<td>234</td>
<td>4.44E-11</td>
<td>5.97E+10</td>
</tr>
<tr>
<td>35</td>
<td>13.94</td>
<td>300</td>
<td>240</td>
<td>3.11</td>
<td>0.25</td>
<td>1.41E-02</td>
<td>221</td>
<td>3.89E-11</td>
<td>6.81E+10</td>
</tr>
<tr>
<td>36</td>
<td>14.24</td>
<td>300</td>
<td>220</td>
<td>2.08</td>
<td>0.35</td>
<td>1.54E-02</td>
<td>135</td>
<td>4.25E-11</td>
<td>6.24E+10</td>
</tr>
</tbody>
</table>

**NOTE:**

The columns up to required signal-to-noise ratio are specification values from the Sept. 19, 1989 specification circulated to industry for review. The calculated values depend on system assumptions and must be achieved at focal plane temperatures warmer than 85K.

System assumptions anticipate the use of short linear whiskbroom arrays of less than 20 detectors.

**ASSUME:**

- APERTURE (cm) = 20
- F-NUMBER = 2.00
- TRANSMISSION = 0.20
- IF0V = 1.21E-03
- DET. SIZE (μm) = 4.84E-02
- NOISE BW (Hz) = 3000

**WATTS/(cm²·sr·μm)**

**ORIGINAL PAGE IS OF POOR QUALITY**
TROPOSPHERIC EMISSION SPECTROMETER (TES)

[P.I.: Reinhard Beer, JPL]

TROPOSPHERIC EMISSION SPECTROMETER
SCIENCE OBJECTIVES

- Generate vertical concentration profiles on a global basis of the following species with sub-scale-height resolution and 5° latitude spacing:

<table>
<thead>
<tr>
<th>Misc.</th>
<th>HO*</th>
<th>NO*</th>
<th>Hydrocarbons</th>
<th>SO2*</th>
<th>CFCs*</th>
</tr>
</thead>
<tbody>
<tr>
<td>O3</td>
<td>H2O</td>
<td>NO</td>
<td>CH4</td>
<td>SO2</td>
<td>CF2Cl2</td>
</tr>
<tr>
<td>CO</td>
<td>H2O2</td>
<td>NO2</td>
<td>C2H6</td>
<td>COS</td>
<td>CF2Cl2</td>
</tr>
<tr>
<td>(CO2)</td>
<td>HNO3</td>
<td>C2H2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N2O</td>
<td>NH3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**TES: SPECIES DETECTABILITY MATRIX**

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>LOWER STRATOSPHERE (15 - 30 km)</th>
<th>FREE TROPOSPHERE (2 - 15 km)</th>
<th>BOUNDARY LAYER (0 - 2 km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C H</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>N N F</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>H N</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>S C</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>2 2 2</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
<tr>
<td>2 0 3 4 0 0 0 0 2 3 1 2 1 3 2 5 6 2 2</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
</tr>
</tbody>
</table>

**MEASURABILITY KEY:**

- ACCURACY 1 - 10 %
- FACTOR OF 2 OR BETTER
- TBD
- UNLIKELY TO BE MEASURABLE

VALUE ASSUMED FOR TEMPERATURE SOUNDING
TROPOSPHERIC EMISSION SPECTROMETER
INSTRUMENT DESCRIPTION

- HIGH SPECTRAL RESOLUTION INFRARED IMAGING FOURIER TRANSFORM SPECTROMETER
- 491 KG, 660 W PEAK POWER
- SPECTRAL COVERAGE 600 TO 3200 CM⁻¹ (2.9 TO 16.6 MICRONS)
- FOUR LINEAR ARRAYS OF 32 DETECTORS, EACH WITH ITS OWN SIGNAL CHAIN, IN CONJUGATE FOCAL PLANES
- ALL DETECTOR ELEMENTS ARE 0.1 MM BY 1.0 MM
- DETECTOR FOV 0.75 X 7.5 MRAD. NADIR PIXEL SUBTENDS 0.5 X 5 KM
- ON-BOARD SOURCES ARE PROVIDED FOR RADIOMETRIC CALIBRATION AND DETECTOR ALIGNMENT

TROPOSPHERIC EMISSION SPECTROMETER
CONCEPTUAL DESIGN
## TROPOSPHERIC EMISSION SPECTROMETER

### FOCAL PLANE ARRAY - TECHNICAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>InSb (PV)</th>
<th>HgCdTe (PV)</th>
<th>HgCdTe (PV)</th>
<th>HgCdTe (PC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAVEBAND (µm)</td>
<td>2.9-5.6</td>
<td>8.3-12.5</td>
<td>5.3-9.1</td>
<td>11.1-16.7</td>
</tr>
<tr>
<td>CUT-OFF FREQ (cm⁻¹)</td>
<td>1800-3400</td>
<td>800-1200</td>
<td>1100-1900</td>
<td>600-900</td>
</tr>
<tr>
<td>QUANTUM EFFICIENCY</td>
<td>0.6</td>
<td>0.6</td>
<td>0.6</td>
<td>0.8</td>
</tr>
<tr>
<td>IMPEDANCE (OHMS)</td>
<td>100 M</td>
<td>10 K</td>
<td>100 K</td>
<td>100</td>
</tr>
<tr>
<td>BKGRD FLUX DENSITY (Ps⁻¹cm⁻¹)</td>
<td>2.9E11-2.6E14</td>
<td>1.3E14-3.0E15</td>
<td>8.9E12-1.1E15</td>
<td>1.2E15-3.9E15</td>
</tr>
<tr>
<td>D* (cm Hz¹/² W⁻¹)</td>
<td>&gt;7.0E11</td>
<td>&gt;5.0E11</td>
<td>&gt;6.0E11</td>
<td>&gt;2.0E11</td>
</tr>
</tbody>
</table>

#### ELECTRICAL

- BANDWIDTH (kHz): 27, 12, 14, 8.5
- OPERATING TEMP (K): 6.5, 6.5, 6.5, 6.5

---

**THESE DETECTOR REQUIREMENTS ARE COMPATIBLE WITH DETECTOR MATERIAL CURRENTLY BEING PRODUCED**

---

## TROPOSPHERIC EMISSION SPECTROMETER

### PERFORMANCE ESTIMATES

<table>
<thead>
<tr>
<th>FREQ. RANGE (cm⁻¹)</th>
<th>WAVELENGTH (microns)</th>
<th>NADIR SNR (2 sec scan)</th>
<th>LIMB SNR (8 sec scan)</th>
</tr>
</thead>
<tbody>
<tr>
<td>600 - 900</td>
<td>11.1 - 16.7</td>
<td>500 - 600</td>
<td>200 - 300</td>
</tr>
<tr>
<td>800 - 1200</td>
<td>8.3 - 12.5</td>
<td>400 - 500</td>
<td>100 - 200</td>
</tr>
<tr>
<td>1100 - 1900</td>
<td>5.3 - 9.1</td>
<td>100 - 600</td>
<td>40 - 300</td>
</tr>
<tr>
<td>1800 - 3450(N)</td>
<td>2.9 - 5.6</td>
<td>30 - 150</td>
<td>na</td>
</tr>
<tr>
<td>1800 - 2450(L)</td>
<td>4.1 - 5.6</td>
<td>na</td>
<td>20 - 40</td>
</tr>
</tbody>
</table>

---

16
SPECTROSCOPY OF THE ATMOSPHERE USING FAR INFRARED EMISSION (SAFIRE)

[P.I.: Jim Russell, LaRC]

• SCIENTIFIC GOAL
  - To improve understanding of the middle atmosphere ozone distribution by conducting and analyzing global-scale measurements of important chemical, radiative, and dynamical processes, including coupling among processes and atmospheric regions.

• SCIENTIFIC OBJECTIVES
  - Study key processes in the Oy, HOy, NOy, ClOy, and BrOy chemical families
  - Study polar night chemistry
  - Conduct non-LTE investigations
  - Investigate diurnal change processes (OH, HO2, NO2, N2O5, O3)
  - Conduct dynamics studies and study coupling between chemistry and dynamics
  - Investigate lower stratosphere phenomena (e.g. polar night O3 depletion)
TROPOSPHERIC EMISSION SPECTROMETER
CONCEPTUAL DESIGN

PAYLOAD ASSEMBLY
PLATE INTERFACE 1.35x1.0 m

STANDARD INTEGRATED CONNECTOR

ELECTRONICS BAY (WARM)

CUBE CORNER ACTUATOR
CALIBRATION SOURCES
LASERS
CUBE CORNER REFLECTOR
STAR TRACKER
2 AXIS POINTING MIRROR
SERVICE ACCESS

OPTICS HOUSING (150 K)
BEAM RECOMBINER
BEAM SPLITTER
8 POINT SUSPENSION MOUNT (PARTIAL)
IMAGING PARABOLA

COOLER REGENERATOR

COOLER COMPRESSORS

REFLECTIVE SLIT
DICHROIC BEAMSPLITTER
COLLIMATING PARABOLA
FILTER WHEEL
ARRAY DETECTOR
FLEXIBLE COLD STRAP

COOLER REPETITION FREQUENCY

DOVE MIRROR ASSEMBLY

18° NADIR

26° NADIR


## TROPOSPHERIC EMISSION SPECTROMETER

### FOCAL PLANE ARRAY - TECHNICAL SPECIFICATIONS

<table>
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<th>MATERIAL:</th>
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<td>&gt;6.0E11</td>
<td>&gt;2.0E11</td>
</tr>
</tbody>
</table>

### ELECTRICAL

- BANDWIDTH (kHz): 27, 12, 14, 8.5
- OPERATING TEMP (K): 65, 65, 65, 65

THESE DETECTOR REQUIREMENTS ARE COMPATIBLE WITH DETECTOR MATERIAL CURRENTLY BEING PRODUCED

## TROPOSPHERIC EMISSION SPECTROMETER

### PERFORMANCE ESTIMATES

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<th>LIMB SNR (8 sec scan)</th>
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<td>1800 - 2450(L)</td>
<td>4.1 - 5.6</td>
<td>na</td>
<td>20 - 40</td>
</tr>
</tbody>
</table>
ORBITAL VOLCANOLOGICAL OBSERVATIONS (OVO)

[P.I.: Dave Pieri, JPL]

ORBITAL VOLCANOLOGICAL OBSERVATIONS

SCIENCE GOALS

• IMPROVED UNDERSTANDING OF ERUPTION MECHANISMS

• IMPROVED DETERMINATION OF THE NATURE AND AMOUNT OF VOLCANIC CONTRIBUTIONS TO THE GLOBAL ENVIRONMENT

• IMPROVED UNDERSTANDING OF HOW THE PRODUCTS OF VOLCANIC ERUPTIONS INTERACT WITH THE ENVIRONMENT TO PRODUCE SIGNIFICANT GLOBAL CHANGES

ORBITAL VOLCANOLOGICAL OBSERVATIONS

MEASUREMENT OBJECTIVES

• MULTISPECTRAL THERMAL IR MAPPING OF VOLCANIC LITHOLOGIES

• BRIGHTNESS TEMPERATURE AND HEAT SOURCE DISTRIBUTION MAPS OF ACTIVE VOLCANIC FEATURES (E.G. LAVA FLOWS, SUMMIT CRATERS, LAVA TUBE SYSTEMS, FUMAROLES, HOT WATER LAKES, HOT WATER OCEANIC PLUMES)

• BRIGHTNESS TEMPERATURE MAPS OF ERUPTION COLUMNS AND DISPERSED VOLCANIC PLUMES

• MULTISPECTRAL DETECTION AND MAPPING OF AIRBORNE ASH PLUMES IN THE PRESENCE OF METEOROLOGICAL CLOUDS

• DETERMINATION OF COMPOSITION AND VOLUME OF SUBAERIAL GLOBAL VOLCANIC GAS BUDGET OVER TIME
ORBITAL VOLCANOLOGICAL OBSERVATIONS
DATA PRODUCTS

• THERMAL MAPS OF SOLID PRODUCTS OF VOLCANIC ERUPTIONS ON THE GROUND

• MULTISPECTRAL MAPPING IMAGES OF THE SURFACE OF VOLCANOES

• 2-D THERMAL MAPS OF AIRBORNE PLUMES

• 3-D THERMAL PROFILES OF ERUPTION PLUMES

ORBITAL VOLCANOLOGICAL OBSERVATIONS
INFRARED DETECTOR REQUIREMENTS

• 1.0-2.5 μm, 5-10 CHANNELS FOR HIGH TEMPERATURE THERMAL RADIOMETRY, GAS AND AEROSOL MEASUREMENTS

• 2.5-5.0 μm, 5 CHANNELS FOR LOWER TEMPERATURE RADIOMETRY, GEOLOGICAL MAPPING, GAS AND AEROSOL MEASUREMENTS

• 8-12 μm, 10+ CHANNELS FOR MULTISPECTRAL MAPPING, LOWEST TEMPERATURE THERMAL RADIOMETRY, ATMOSPHERIC MEASUREMENTS AND CORRECTIONS

• IMAGING CAPABILITY REQUIRED, ≥ 25 km SWATH, ≤100 m SPATIAL SAMPLING

• LOW TEMP RADIOMETRY REQUIRES -0.3K NedT MEASUREMENT CAPABILITY

• MASS CONSIDERATIONS ARGUE FOR DEVELOPMENT OF DETECTORS WITH REDUCED COOLING REQUIREMENTS
MULTISPECTRAL THERMAL IMAGER (MSTI)

[P.I.: Tim Schofield, JPL]

MULTISPECTRAL THERMAL IMAGER
SCIENCE OBJECTIVES AND KEY MEASUREMENTS

- UNDERSTAND THE INTERPLAY BETWEEN RADIATIVE, DYNAMICAL AND PHOTOCHEMICAL PROCESSES IN THE ATMOSPHERES OF SATURN, TITAN AND JUPITER

- OBTAIN MEASUREMENTS OF THE 3-D DISTRIBUTION OF TEMPERATURE, DYNAMICAL FIELDS, KEY SPECIES CONCENTRATIONS AND AEROSOL EXTINCTION IN THESE ATMOSPHERES WITH COMPREHENSIVE COVERAGE AND RESOLUTION, BOTH SPATIALLY AND TEMPORALLY

- DEVELOP A DESCRIPTION OF THE PHYSICAL AND COMPOSITIONAL UNITS OF THE SATELLITES AND RINGS

OBTAIN COMPREHENSIVE MULTISPECTRAL MEASUREMENTS OF BRIGHTNESS TEMPERATURE AND ALBEDO

MULTI-SPECTRAL THERMAL IMAGER (MSTI)
CONCEPTUAL INSTRUMENT SPECIFICATIONS

<table>
<thead>
<tr>
<th>INSTRUMENT PARAMETER</th>
<th>VALUE/COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>INSTRUMENT TYPE</td>
<td>MULTI-SPECTRAL THERMAL IMAGER</td>
</tr>
<tr>
<td>MEASUREMENT TECHNIQUES</td>
<td>GAS CORRELATION AND FILTER RADIOMETRY</td>
</tr>
<tr>
<td>SPECTRAL CHANNELS AND RANGE</td>
<td>8 CHANNELS, 8-14 μm</td>
</tr>
<tr>
<td></td>
<td>7 CHANNELS, 15-100 μm</td>
</tr>
<tr>
<td></td>
<td>1 CHANNEL, 0.3-3.0 μm</td>
</tr>
<tr>
<td>TELESCOPE APERTURE</td>
<td>NARROW ANGLE, 15 cm</td>
</tr>
<tr>
<td></td>
<td>WIDE ANGLE, 4 cm</td>
</tr>
<tr>
<td>NARROW ANGLE FOV</td>
<td>ARRAY, 1.15° x 1.15°</td>
</tr>
<tr>
<td>WIDE ANGLE FOV</td>
<td>ARRAY, 4.58° x 4.58°</td>
</tr>
<tr>
<td>MID-IR DETECTOR</td>
<td>64 x 64 PV HgCdTe ARRAY, 70K</td>
</tr>
<tr>
<td>FAR-IR AND SOLAR DETECTOR</td>
<td>64 x 64 BOLOMETER ARRAY, 180K</td>
</tr>
<tr>
<td>DATA RATE</td>
<td>1.5 kbps, APOCHRONE</td>
</tr>
<tr>
<td></td>
<td>3.0 kbps, FAR ENCOUNTHER</td>
</tr>
<tr>
<td></td>
<td>6.0 kbps, NEAR ENCOUNTHER</td>
</tr>
<tr>
<td>INSTRUMENT DATA BUFFER</td>
<td>2 MBytes</td>
</tr>
<tr>
<td>SPACECRAFT POINTING</td>
<td>CONTROL, 2 mrad</td>
</tr>
<tr>
<td>PITCH, ROLL, AND YAW</td>
<td>KNOWLEDGE, 1 mrad</td>
</tr>
<tr>
<td></td>
<td>STABILITY, 100 μrad - 2 seconds</td>
</tr>
<tr>
<td></td>
<td>STABILITY, 500 μrad - 30 seconds</td>
</tr>
<tr>
<td>MASS GOAL</td>
<td>23 kg</td>
</tr>
<tr>
<td>POWER GOAL</td>
<td>19 WATTS (AVERAGE)</td>
</tr>
</tbody>
</table>

ORIGINAL PAGE IS OF POOR QUALITY
MULTI-SPECTRAL THERMAL IMAGER (MSTI)
CHANNEL SPECTRAL CHARACTERISTICS
AND MEASUREMENT FUNCTIONS

<table>
<thead>
<tr>
<th>CHANNEL (1)</th>
<th>BANDPASS CENTER, cm⁻¹</th>
<th>CHANNEL TYPE (2)</th>
<th>MEASUREMENT FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FILTER WHEEL A - MID INFRARED, 70 K HgCdTe DETECTOR ARRAY, 64 x 64 PΙXELS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>1240 - 1290</td>
<td>7.9</td>
<td>0.5 cm CELL, 300 mbar CH₄</td>
</tr>
<tr>
<td>A2</td>
<td>1240 - 1290</td>
<td>7.9</td>
<td>1.5 cm CELL, 300 mbar CH₄</td>
</tr>
<tr>
<td>A3</td>
<td>805 - 845</td>
<td>12.1</td>
<td>0.5 cm CELL, 300 mbar C₂H₆</td>
</tr>
<tr>
<td>A4</td>
<td>805 - 845</td>
<td>12.1</td>
<td>1.5 cm CELL, 300 mbar C₂H₆</td>
</tr>
<tr>
<td>A5</td>
<td>730 - 760</td>
<td>13.4</td>
<td>0.5 cm CELL, 150 mbar C₂H₂</td>
</tr>
<tr>
<td>A6</td>
<td>730 - 760</td>
<td>13.4</td>
<td>1.5 cm CELL, 150 mbar C₂H₂</td>
</tr>
<tr>
<td>A7</td>
<td>920 - 1050</td>
<td>10.2</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>A8</td>
<td>1120 - 1180</td>
<td>8.7</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>FILTER WHEEL B - FAR INFRARED, 180 K BOLOMETRIC DETECTOR ARRAY, 64 x 64 PΙXELS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>570 - 630</td>
<td>16.7</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>B2</td>
<td>470 - 510</td>
<td>20.4</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>B3</td>
<td>350 - 390</td>
<td>27.0</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>B4</td>
<td>210 - 250</td>
<td>43.5</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>B5</td>
<td>170 - 210</td>
<td>52.6</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>B6</td>
<td>80 - 140</td>
<td>90.1</td>
<td>BANDPASS FILTER</td>
</tr>
<tr>
<td>B7</td>
<td>OPEN</td>
<td>-</td>
<td>OPEN</td>
</tr>
<tr>
<td>B8</td>
<td>3333 - 3333</td>
<td>0.54</td>
<td>LONGWAVE BLOCKER</td>
</tr>
</tbody>
</table>

1. Imaging is performed in all spectral channels.
2. Channels A1 - A6 perform gas correlation radiometry using bandpass filters and cells containing the gas indicated to obtain high energy grasp, spectral discrimination, and species selectivity. Channels A7, A8, and B1 - B8 bandpass filters only.

MULTISPECTRAL THERMAL IMAGER (MSTI)
LWIR FOCAL PLANE ARRAY REQUIREMENTS

- \( D^* \) (cm hz\(^{1/2}\) w\(^{-1}\))
  
  **GOAL:** \( \geq 2.0 \times 10^{11} \) (8μm), \( \geq 2.0 \times 10^{10} \) (13.5μm), \( \geq 1.0 \times 10^{09} \) (100μm)
  
  **REQ:** \( \geq 1.0 \times 10^{11} \) (8μm), \( \geq 1.0 \times 10^{10} \) (13.5μm), \( \geq 1.0 \times 10^{09} \) (100μm).

- Current PV-HgCdTe technology can meet the \( D^* \) requirements, but cannot meet the goals at both 8 and 13.5 μm simultaneously.
COMPOSITE INFRARED SPECTROMETER (CIRS)

[P.I.: Virgil Kunde, GSFC]

COMPOSITE INFRARED SPECTROMETER
SCIENCE OBJECTIVES

• DETERMINE THE TROPOSPHERIC AND STRATOSPHERIC TEMPERATURE AND AEROSOL STRUCTURE OF SATURN AND TITAN

• DETERMINE THE MIXING RATIOS AND SPATIAL DISTRIBUTIONS OF TRACE GASES IN BOTH ATMOSPHERES
  - MANY ORGANIC MOLECULES FOR TITAN
  - PH$_3$ AND NH$_3$ FOR SATURN

• CONSTRAIN THE PROPERTIES OF NH$_3$ ICE CLOUDS IN SATURN'S ATMOSPHERE

• DETERMINE THE BULK COMPOSITION OF SATURN'S ATMOSPHERE

• DETERMINE SURFACE TEMPERATURE PROPERTIES OF THE SMALLER Icy SATELLITES AND THE EMISSIVITY OF THE RINGS
Figure B6  CIRS sensitivity for Saturn.

Figure B7  CIRS sensitivity for Titan.
COMPOSITE INFRARED SPECTROMETER
INSTRUMENT CHARACTERISTICS

- DUAL INTERFEROMETER CONFIGURATION SHARING A 50 CM CASSEGRAIN TELESCOPE
- SPECTRAL RANGE 7.5-1000 μm
- SPECTRAL RESOLUTION 0.25 cm⁻¹ UNAPODIZED
- INDIVIDUAL DETECTOR FIELD-OF-VIEW .25° (FAR-IR), .0057° (MID-IR)
- FAR-IR INTERFEROMETER EMPLOYS A 1x5 ARRAY USING EITHER THERMOPILES OR PYROELECTRICS
- MID-IR INTERFEROMETER EMPLOYS TWO 1x43 HgCdTe ARRAYS, COOLED TO 70-90K

POLARIZING FTS (CIRS)

Figure B8 Optical schematic for CIRS.
## COMPOSITE INFRARED SPECTROMETER
### FOCAL PLANE PARAMETERS

<table>
<thead>
<tr>
<th>Spectral Range (cm⁻¹)</th>
<th>#1: 10-700°C</th>
<th>#2: 700-1200°C</th>
<th>#3: 1200-1400°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detectors</td>
<td>THERMOPILE (1x5)</td>
<td>HgCdTe (1x43)</td>
<td>HgCdTe (1x43)</td>
</tr>
<tr>
<td>Pixel FOV (mrad)</td>
<td>4.3x12.9</td>
<td>0.1x0.3</td>
<td>0.1x0.3</td>
</tr>
<tr>
<td>Pixel AΩ (cm²-sr)</td>
<td>1.1x10⁻¹</td>
<td>6.1x10⁻⁵</td>
<td>6.1x10⁻⁵</td>
</tr>
<tr>
<td>NEP (W Hz⁻¹/²)</td>
<td>2x10⁻¹¹</td>
<td>8x10⁻¹⁴</td>
<td>2x10⁻¹⁴</td>
</tr>
<tr>
<td>NESR (W cm⁻²sr⁻¹cm⁻¹)</td>
<td>7x10⁻¹⁰</td>
<td>5x10⁻⁹</td>
<td>1x10⁻⁹</td>
</tr>
<tr>
<td>Temperature (K)</td>
<td>170</td>
<td>90</td>
<td>90</td>
</tr>
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</table>

## GENERAL AREAS FOR EXPERIMENT ENHANCEMENT

- All the proposed experiments would be enhanced by one or more of the following improvements.
  - Improved detector performance, giving:
    - Same instrument performance at higher detector temperatures.
    - Improved performance at the same detector temperature
  - Lower instrument and detector operating temperatures, giving:
    - Improved performance with existing detectors
  - Improved detector performance plus lower operating temperatures
  - Improved cooling is expensive in mass and power
  - Improved detector performance is expensive in up front development costs
SAFIRE MEASUREMENT OBJECTIVES

- Conduct global-scale, simultaneous, vertical profile measurements of temperature and key $O_y$, $HO_y$, $NO_y$, $ClO_y$, and $BrO_y$ constituents, including the following:

\[
\begin{align*}
O_3, O^{50}, O^{(3P)}; \quad OH, HO_2, H_2O_2, H_2O, HDO, CH_4; \quad NO_2, HNO_3, N_2O_5; \quad HCl, HOCl; \quad HBr \text{ and HF}
\end{align*}
\]

- Conduct measurements (e.g. $T$, $O_3$, CH$_4$, and H$_2$O) that can be used to derive and study dynamical quantities such as geopotential height, potential vorticity, winds, and Eliassen Palm flux

- Employ a 3 km IFOV in the far IR and 1.5 km in the mid IR

- Provide scan mode flexibility to enhance science return
  - Chemistry mode, 10-110 km vertical scan, 1.5 km sampling interval, 5° of latitude
  - Polar chemistry mode, 10-106 km, 3 km, 2.5°
  - Dynamics mode, 10-100 km, 0.75 km, 1.25°
  - Thermospheric mode, 84-180 km, 3 km, 5°

### SAFIRE Experiment Measurement Objectives

<table>
<thead>
<tr>
<th>Parameters Measured</th>
<th>Spectral Range (cm$^{-1}$)</th>
<th>Alt. Range (km)</th>
<th>IFOV$^2$ (km)</th>
<th>Horizontal Resolution$^2$</th>
<th>Temporal Resolution (sec)$^4$</th>
<th>Lat. Cov. (deg)</th>
<th>Estimated Precision$^5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_3$</td>
<td>82 - 84.4; 926 - 1141</td>
<td>10 - 100</td>
<td>1.5 - 3</td>
<td>1 - 5</td>
<td>25</td>
<td>18 - 72</td>
<td>86°S - 86°N</td>
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<tr>
<td>$O^{(3P)}$</td>
<td>157 - 159</td>
<td>90 - 180</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<td></td>
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<tr>
<td>$OH$</td>
<td>82 - 84.4; 117.8 - 119.6</td>
<td>20 - 50</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
<td></td>
<td></td>
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<tr>
<td>$HO_2$</td>
<td>93.8 - 96; 110.0 - 112.6</td>
<td>20 - 75</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<tr>
<td>$H_2O_2$</td>
<td>93.8 - 96</td>
<td>20 - 50</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<tr>
<td>$H_2O$</td>
<td>157 - 159</td>
<td>10 - 100</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<tr>
<td>HDO</td>
<td>93.8 - 96</td>
<td>10 - 60</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<tr>
<td>CH$_4$</td>
<td>1335 - 1365</td>
<td>10 - 65</td>
<td>1.5</td>
<td>1 - 5</td>
<td>18 - 72</td>
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</tr>
<tr>
<td>NO$_2$</td>
<td>1560 - 1630</td>
<td>15 - 60</td>
<td>1.5</td>
<td>1 - 5</td>
<td>18 - 72</td>
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<tr>
<td>HNO$_3$</td>
<td>850 - 920</td>
<td>10 - 45</td>
<td>1.5</td>
<td>1 - 5</td>
<td>18 - 72</td>
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<tr>
<td>N$_2$O$_5$</td>
<td>310 - 390; 1230 - 1250</td>
<td>10 - 45</td>
<td>1.5 - 3</td>
<td>1 - 5</td>
<td>18 - 72</td>
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<tr>
<td>HCl</td>
<td>82 - 84.4</td>
<td>10 - 65</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<tr>
<td>HOCl</td>
<td>98.5 - 100; 117.8 - 119.6</td>
<td>20 - 45</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<tr>
<td>HBr</td>
<td>98.5 - 100</td>
<td>15 - 40</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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<td></td>
</tr>
<tr>
<td>HF</td>
<td>82 - 84.4</td>
<td>40 - 60</td>
<td>3</td>
<td>2.5 - 5</td>
<td>36 - 72</td>
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</tr>
<tr>
<td>Temp.</td>
<td>630 - 670; 580 - 760</td>
<td>10 - 110</td>
<td>1.5</td>
<td>1 - 5</td>
<td>18 - 72</td>
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<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>630 - 670; 580 - 760</td>
<td>10 - 110</td>
<td>1.5</td>
<td>1 - 5</td>
<td>18 - 72</td>
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<tr>
<td>$O_2$</td>
<td>82 - 120</td>
<td>10 - 80</td>
<td>3</td>
<td>1 - 5</td>
<td>36 - 72</td>
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<tr>
<td>$O_2$($v_2$)</td>
<td>82-84.4</td>
<td>20 - 50</td>
<td></td>
<td>2.5 - 5</td>
<td></td>
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<tr>
<td>$O_2$($v_1,3$)</td>
<td>82-84.4</td>
<td>20 - 35</td>
<td></td>
<td>2.5 - 5</td>
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<tr>
<td>$H_2$O$_2$</td>
<td>82-84.4</td>
<td>20 - 40</td>
<td></td>
<td>2.5 - 5</td>
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</table>
### SAFIRE Experiment Measurement Objectives (Con't)

<table>
<thead>
<tr>
<th>Parameters Measured</th>
<th>Spectral Range (cm⁻¹)</th>
<th>Alt. Range (km)</th>
<th>IFOV² (km)</th>
<th>Horizontal Resolution³</th>
<th>Temporal Resolution (sec.)⁴</th>
<th>Lat. Cov. (deg.)</th>
<th>Estimated Precision⁵</th>
<th>% (1σ)</th>
<th>Vertical Range (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₁₈O₀</td>
<td>82-84.4</td>
<td>20-35</td>
<td>3</td>
<td>2.5-5</td>
<td>36-72</td>
<td>86°S-86°N</td>
<td>15*</td>
<td>20-30</td>
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</tr>
<tr>
<td>O₁₇O₀</td>
<td>117.8-119.8</td>
<td>20-40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15*</td>
<td>20-35</td>
<td></td>
</tr>
<tr>
<td>O¹₂⁰O</td>
<td>82-84.4</td>
<td>20-35</td>
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<td></td>
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<td></td>
<td>10*</td>
<td>20-50</td>
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<tr>
<td>H₂₁₈O</td>
<td>93.8-96, 117.8-119.8</td>
<td>20-60</td>
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<td></td>
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<td>10*</td>
<td>20-40</td>
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<tr>
<td>H₂¹₇O</td>
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<td>35*</td>
<td>25-30</td>
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<td>HCN</td>
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<td>15*</td>
<td>20-35</td>
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<td>N₂O</td>
<td>1230-1260</td>
<td>20-40</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*These are estimated precisions based on spectral features and absorption strengths. Retrieval simulations have not been performed.

¹Does not include derived quantities such as winds, potential vorticity, and others.

²Vertical resolution is estimated to be 4 km.

³Latitudinal resolution is determined by vertical profile skew or ground-track motion during the measurement time. Longitudinal resolution is determined by the orbital spacing. The horizontal FOV width is ~ 0.1°.

⁴Observations are made continuously with a vertical profile scan time of 72 sec in the chemistry and thermospheric modes, 36 sec in the polar chemistry mode, and 18 sec in the dynamics mode.

⁵Precision is the 1σ uncertainty determined from simulation set of 5 retrievals, except for HDO which is for a single retrieval only.

### SAFIRE INSTRUMENT PARAMETERS

- **Mass** 304 kg
- **Power (watts)** Average--304, Peak--350, Standby--175
- **Data Rate** 9 mbs (FTS), 9 kbs (Radiometer)
- **Envelope** 1.5m(L) x 1.5m(W) x 1.5m(H)
- **Limb View Direction**
  - Elevation 14° to 27° depression angle
  - Azimuth + 10° Forward
  - - 170° Aft
### SAFIRE MID-IR DETECTOR REQUIREMENTS

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>FREQUENCY (cm⁻¹)</th>
<th>DYNAMIC RANGE (E+03)</th>
<th>D* REQUIRED (E+10 cm (Hz/W)¹/₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>630-670</td>
<td>7</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>580-760</td>
<td>28</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>850-920</td>
<td>7</td>
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</tr>
<tr>
<td>4</td>
<td>1335-1365</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>5</td>
<td>1560-1630</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>6</td>
<td>926-1141</td>
<td>15</td>
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</tr>
<tr>
<td>7</td>
<td>1230-1260</td>
<td>1</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Configuration: 15 x 7 Array
Element Size: 0.2 x 0.3 mm

### SAFIRE FAR-IR REQUIREMENTS

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>FREQUENCY (cm⁻¹)</th>
<th>NO. OF DETECTORS</th>
<th>TYPE</th>
<th>NEP (W Hz⁻¹/₂) x E⁻¹⁵</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>82-85</td>
<td>8</td>
<td>Ge:Ga</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>94-96</td>
<td>8</td>
<td>Ge:Ga</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>98-100</td>
<td>8</td>
<td>Ge:Ga</td>
<td>1</td>
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<tr>
<td>4</td>
<td>111-113</td>
<td>8</td>
<td>Ge:Ga</td>
<td>1</td>
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<tr>
<td>5</td>
<td>118-120</td>
<td>8</td>
<td>Ge:Ga</td>
<td>1</td>
</tr>
<tr>
<td>6A</td>
<td>157-160</td>
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</tr>
<tr>
<td>6B</td>
<td>310-390</td>
<td>4</td>
<td>Ge:Be</td>
<td>10</td>
</tr>
</tbody>
</table>

Configuration: (3) 2 x 8 Arrays
Electronics: TIA-JFET 10 kHz Bandwidth
Blip-Limited Performance (10⁹ ph/sec-typical)
Detectors to be provided by France