Space-borne Submillimeter-wave Sounder for Molecular Emissions in the Stratosphere: SMILES

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**SMILES:**
*Superconducting Submillimeter-wave Limb-emission Sounder*

**Mission Objectives**

- Space Demonstration of Submillimeter Sensor Technology based on a Superconductive Mixer and 4-K Mechanical Cooler
- Experiments of Submillimeter Limb-Emission Sounding of the Atmosphere
- Global Observations of Trace Gases in the Stratosphere and Contribution to the Atmospheric Sciences
Scientific Objectives

Understanding global mechanism of ozone depletion

• Overall chemical processes:
  => Multi-species observations

• Global dynamics & Regional interactions:
  => Global 3-D observations

Advantages of SMILES

• High sensitivity:
  => Real-time map without spatial averaging

• Fine spectroscopy:
  => High detectability for minor weak species
Limb Sounding from the ISS

<table>
<thead>
<tr>
<th>Hj [km]</th>
<th>La [km]</th>
<th>dHa [km]</th>
<th>dLa [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
<td>2050</td>
<td>3.40</td>
<td>209</td>
</tr>
<tr>
<td>400</td>
<td>2209</td>
<td>3.66</td>
<td>217</td>
</tr>
<tr>
<td>450</td>
<td>2358</td>
<td>3.91</td>
<td>224</td>
</tr>
</tbody>
</table>

Ha = 30 km, HPBW = 0.095 deg
Expected Spectra: Band-1

- H2O2
- H37Cl
- O3
- O3(v2)
- O3(v3)
- O18OO
- 18000
- HO35Cl
- HNO3
- SO2
- O35ClO
- HO79Br
- 35ClONO2
- 81BrO
- HO81Br
Expected Spectra: Band-2

1: HO2
3: H35Cl
5: O3
6: O3(v2)
7: O3(v3)
8: O17OO
11: 18000
14: HNO3
15: SO2
16: O35ClO
17: HO79Br
20: HO81Br
21: (35ClO)2
Expected Spectra: Band-3

1: HO2
8: O1700
9: 17000
11: 18000
12: 35ClO
14: HNO3
15: SO2
19: 81BrO
20: HO81Br
21: (35ClO)2
Global Mapping

Latitudes Coverage: 65 N to 38 S

Distribution of atmospheric regions sampled in consecutive frames of antenna scanning. Length of each frame is 53 sec.
Submm Signal is down-converted:

$\Rightarrow 11 - 13 \text{ GHz} \Rightarrow 1.55 - 2.75 \text{ GHz}$

Emission-line Spectra are derived by AOS (Acousto-optic Spectrometer).
View of SMILES
Submillimeter Receiver

Key Technology

- Superconductivity Electronics (SIS mixer)
- Cryogenic LNA Technology (HEMT amplifiers)
- Submillimeter Devices & Components
- Submillimeter Quasi-optics
- Cryostat Technology (4K level)
- Mechanical Cryo-cooler Technology (4K level)
Superconductive SIS mixer receivers have some 20 times higher sensitivity than conventional Schottky-diode mixer receivers for frequencies less than 700 GHz.
640 GHz SIS Mixer

Nb/AlOx/Nb Device
1.2 um x 1.2 um, 5.5 kA/cm2
Fabricated at
Nobeyama Radio Observatory
Cooled HEMT Amplifiers

20K-stage Amplifier

Two HEMT Devices: FHX76LP
Gain: 20-22 dB @300K
23-26 dB @20K

100K-stage Amplifier

Three HEMT Devices: FHX76LP
Gain: 28-32 dB @300K
30-33 dB @100K

By Nitsuki Ltd.
Submillimeter LO Source

BBM by RPG/Ominisys

Gunn Phase Noise:
< -90 dBC/Hz @ 1MHz

Submm Freq. Stability:
$1 \times 10^{-8}$ /deg
**Receiver Optics**

- LO SOURCE
- CRYOSTAT
- SIS MIXER 1
- SIS MIXER 2
- U1 + L1
- U2 + L2

**Ambient -Temperature Optics**

- FSP: Frequency Selective Polarizer
- Absorber
- U1 L2
- L1 U2
- TO COLD SKY
- TO ANTENNA

**Cooled Optics**

- Antenna Port
- Cold sky for Cold Load
- Wire-Grid #1
- Wire-Grid #2
- Wire-Grid #3
- Wire-Grid #4
- Wire-Grid #5
- SIS SIS Mixer
- Focussing Mirror
- Flat Mirror
- 100 K shield
- 20 K shield
- 4 K stage
- Optics in Ambient Temperature

**Two Functions**

- RF/LO Coupling
- Sideband Separation
**SSB Filter with FSP’s**

**Single Sideband Filter:** To separate USB and LSB signals

**Frequency-Selective Polarizer:**
- Suitable for a fixed-frequency application
- Extremely low reflection --- Low standing waves

SSB Filter (BBM) by Thomas Keating Ltd.
SRX Subsystem

Cryostat

AOPT

AAMP

CREC

He Compressor (ST)

To Antenna

Ambient Temperature Optics

To Cold-Sky Terminator

Single Sideband Filter

He Compressor (JT)

Sub-mm LO Source
Thermal Design of SMILES

Requirements

• State-of-the-art cryogenic design is needed to keep SIS mixers at 4.5 K, HEMT amplifiers at 20 K /100 K.

• Ambient-temperature Thermal Design is based on the Use of Coolant (FC-72)

• Detail Analysis is Needed on Influences of Radiation Coupling to Space

• High Temperature Stability is Needed for the Stable Operation of the Receiver
Cryogenics

• Requirements
  – SIS Mixers & Cooled Optics @ 4.5 K
  – HEMT Amplifiers @ 20 K & 100 K

• Mechanical Cooler
  – Cooling Method: Two-Stage Stirling & Joule-Thomson
  – Cooling Capacity:
    1000 mW @ 100 K
    210 mW @ 22 K
    20 mW @ 4.5 K
  – Power Consumption: 210 W (Coolers) + 90 W (Loss in PS)
Cryostat

Radiation Shield: MLI (40 layers)
Signal Input Window: IR Filters (‘Zitex’)
Support for 100 K Stage: S2-GFRP Straps (12 pieces)
Support for 20 K Stage: GFRP Pipes (4 pieces)
Support for 4 K Stage: CFRP Pipes (4 pieces)
## Thermal Design of Cryostat

<table>
<thead>
<tr>
<th>Component</th>
<th>@100K-stage</th>
<th>@20K-stage</th>
<th>@4K-stage</th>
<th>Total Heat Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Window</strong></td>
<td>151</td>
<td>0</td>
<td>2.4</td>
<td>184</td>
</tr>
<tr>
<td><strong>Wall</strong></td>
<td>374</td>
<td>22</td>
<td>0.1</td>
<td>396</td>
</tr>
<tr>
<td><strong>Support</strong></td>
<td>231</td>
<td>47</td>
<td>2.4</td>
<td>280</td>
</tr>
<tr>
<td><strong>IF cables</strong></td>
<td>49</td>
<td>13</td>
<td>4.1</td>
<td>66</td>
</tr>
<tr>
<td><strong>BIAS cables</strong></td>
<td>9</td>
<td>2</td>
<td>0.1</td>
<td>11</td>
</tr>
<tr>
<td><strong>BIAS current</strong></td>
<td>8</td>
<td>3</td>
<td>0.0</td>
<td>11</td>
</tr>
<tr>
<td><strong>Monitor cables</strong></td>
<td>11</td>
<td>4</td>
<td>0.6</td>
<td>15</td>
</tr>
<tr>
<td><strong>HEMT/SIS</strong></td>
<td>30</td>
<td>20</td>
<td>1.0</td>
<td>51</td>
</tr>
<tr>
<td><strong>JT HEX</strong></td>
<td>167</td>
<td>87</td>
<td>0.0</td>
<td>254</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1030</td>
<td>198</td>
<td>10.7</td>
<td>1248</td>
</tr>
</tbody>
</table>

**Window:** Heat flow is reduced with two IR filters

**IF cables:** CuNi coaxial cables

**HEMT current:** Circuit is optimized for a Starved Bias Condition

**JT load:** Minimized by reducing the rate of GHe flow
Two-stage Stirling Cooler
Joule-Thomson Cooler

Cryostat (inc. ST Cold Head): 29 kg
Stirling Compressor: 10 kg
JT Compressors (2 units): 15 kg
GHe Piping: 7 kg
Control & Drivers: 23 kg
**Concept of Thermal Control**

Radiation coupling to space occurs through HCAM, FRGF and Antenna. This effect should be connected with the analysis for the coolant.
Quality of the Output Data

Key Parameters

- Tangent-Point Heights Covered: 10 – 60 km
- HPBW: 4.1 – 3.5 km (for the ISS altitude of 400 km)
- Sampling Interval: 2.4 – 2.1 km (for the ISS altitude of 400 km)
- Height Error: Bias 0.76 km (rms) + Random 0.34 km (rms)
- Sensitivity: 0.7 K (rms) for unit data
- Absolute Tb Accuracy: 3 K (rms) for Tb < 50 K
- Relative Tb Accuracy: 1.7 % (rms)
**Antenna Response Pattern**

**Effective Pattern:**
- Integrated over AZ angles
- Averaged for six consecutive EL points involved in a unit data
**SMILES Radio Spectrometer**

- **Bandwidth:**
  - 1200 MHz x 2 units
  - IF: 1.55 - 1.75 GHz / unit
- **Focal Plane:**
  - 1728-ch. CCD array x 2 units
- **Frequency Resolution:**
  - 1.8 MHz (FWHM)
  - cf. Channel Separation: 0.8 MHz / ch.
- **AD Conversion:**
  - 12-bit, 2-CCD readouts in 4.9 msec
- **Adder Output:**
  - 16 bits x 1728 ch. x 2 units in 500 msec

_Acousto-Optic Spectrometer (Astrium & OPM)_
Expected Sensitivity

![Graph showing expected sensitivity vs. atmospheric brightness temperature. The graph includes various lines and symbols representing different factors such as Radio(unit), GainVar(unit), SW(const), DNL(unit), DNL(>day), OA(unit), OA(1-day), and OA(1-month). The x-axis represents atmospheric brightness temperature in [K], and the y-axis represents sensitivity in [K, RMS].]
Accuracy of Absolute Brightness Temperature
ISS Environmental Issues

Compatible Design Needed

– Deterioration of environmental vacuum may occur due to contamination. Measures needed to protect SMILES operation.
  • Space Shuttle: Water Dumps
  • JEM-PM: Cabin Air Vents
– Some EMI may deteriorate the data quality of SMILES, even if it is too low to damage the instruments.
  • Most careful measures for EMI are indispensable.
  • EM-shielding designs are adopted.
Shield against ISS Environmental Fields

- 161 V/m, 2.2 GHz
- 79 V/m, 8.5 GHz
- 110 V/m, 25.5-27.5 GHz
- 12 V/m
- 20 V/m, 13.7-15.2 GHz
- 22 V/m, 25.5-27.5 GHz
- 33 V/m, 2.2 GHz
- 20 V/m, 8.5 GHz
- 50 V/m, 13.7-15.2 GHz
- 5 V/m, 30-200 MHz
- 20 V/m
**Design Concept**

- **Twofold Electromagnetic Shields:**
  - EM-Shield by **System Enclosure**: Isolation > 20 dB (Target)
  - EM-Shield by **Receiver Cryostat**: Isolation > 60 dB (Target)

- **To Suppress Radiation Leakage:**
  - Complete Gap Sealing for Enclosure Panels
  - Indium-coated “O-ring” for All Flanges in the Cryostat
  - “Back-to-back Horn” for Antenna/Receiver Interface
    (Cut-off Waveguide against EMI at 27.5 GHz or less)

- **To Suppress Leakage through Cables:**
  - Use of Shielded Cables
  - Use of EMI-shielded Connectors
  - Use of Low Pass Filters
  - Strict EMI Design in Each Component
Conclusion

• Outline of SMILES is described.
• Design of SMILES system and its components are almost finished.
• Expected performance matches the basic requirements of the atmospheric researches.
• SMILES will realize the highest-ever sensitivity for space-borne submillimeter observations.
• More efforts needed to overcome some difficulties associated with the ISS environments.