SIFTI: A new generation FTIR Spectrometer for the Tropospheric composition and Air Quality Mission (TRAQ)


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Temperature sounding in $\text{N}_2\text{O}$ band (1)

$1200 - 1350 \text{ cm}^{-1}$
Temperature sounding in N$_2$O band (2)

1200 - 1350 cm$^{-1}$
Temperature sounding in N₂O band (3)

<table>
<thead>
<tr>
<th></th>
<th>1230-1290</th>
<th>1280-1340</th>
<th>2160-2220</th>
<th>2220-2280</th>
<th>CO₂ longwave</th>
<th>CO₂ shortwave</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOFS</td>
<td>7.8</td>
<td>8.9</td>
<td>5.0</td>
<td>5.4</td>
<td>6.1</td>
<td>5.8</td>
</tr>
</tbody>
</table>

- Better performances in N₂O band around 1300 cm⁻¹ than in CO₂ at a resolution of 0.1 cm⁻¹.
- However, performances for the CO₂ band are kept roughly constant requires a resolution of 0.1 cm⁻¹.
How fast is air quality changing on a global and regional scale?

What is the strength and distribution of the sources and sinks of trace gases and aerosols influencing air quality?

What is the role of tropospheric composition in global change?

Saturday 15 October 2005

Sunday 16 October 2005

Monday 17 October 2005
Mission Requirements

- Primary pollutants: NO₂, SO₂, H₂CO
- Ozone profile and specially good in the lowest tropo
- CO profile with good accuracy in the lowest tropo
- Aerosols and more specially PM2.5

Others: CH₄, H₂O, Temperature etc.

- At the highest spatial resolution (clouds) typically 10km
- As frequent as possible: every 2 hour

SIFTI associated with other instruments:

<table>
<thead>
<tr>
<th>Species</th>
<th>spectral domain</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosols</td>
<td>UV-VIS-SWIR</td>
<td>OCAPI</td>
</tr>
<tr>
<td>NO₂</td>
<td>UV-VIS</td>
<td></td>
</tr>
<tr>
<td>H₂CO</td>
<td>UV-VIS</td>
<td>TROPOMI</td>
</tr>
<tr>
<td>SO₂</td>
<td>UV-VIS</td>
<td></td>
</tr>
<tr>
<td>O₃</td>
<td>TIR</td>
<td>SIFTI</td>
</tr>
<tr>
<td>CO</td>
<td>SWIR+TIR</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Product</th>
<th>Degrees of freedom</th>
<th>Absolute uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₃</td>
<td>strato profile [12 – 50 km]</td>
<td>4</td>
<td>1 - 4 %</td>
</tr>
<tr>
<td></td>
<td>tropo profile [0 – 12 km]</td>
<td>2.3</td>
<td>10 – 30 %</td>
</tr>
<tr>
<td>CO</td>
<td>tropo profile [0 – 12 km]</td>
<td>2.5</td>
<td>6 – 12 %</td>
</tr>
<tr>
<td>CH₄</td>
<td>tropo profile [0 – 12 km]</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>
TRAQ Payload

**TROPOMI:** Backscatter instrument (trop) columns of $O_3$, $NO_2$, $SO_2$, $HCHO$, aerosols & CO and $CH_4$. Heritage: Aura-OMI, Envisat-Sciamachy

**SIFTI (FTIR):** $O_3$, CO, $CH_4$: trop columns and profiles with intelligent pointing for cloud free pixels. Heritage: IASI

**OCAPI:** POLDER type of instrument: AOD, single scattering albedo ($\Omega_0$), Air quality index (AQI), aerosol sizes and aerosol type. Heritage: POLDER, PARASOL
Non-sun synchronous LEO orbit: 720 km, 57°

- Measures air pollution at mid-latitude up to 5 times a day with 90 minutes interval
- Retains most of global coverage, except for poles

**Range:**
- Swath: 2000 – 2600 km
- Pixel sizes: 5 km × 5 km to 10 km × 10 km

**LEO versus GEO**

GEO does not provide global coverage and such detailed characteristics of aerosol.
SIFTI: Instrument specification rationale

Retrieval performances:
- concentration accuracy
- vertical resolution
- ...

Instrument performances:
- spectral resolution
- noise
- ...

forward model (4AOP)

retrieval algorithm (optimal estimation theory)

→ best compromise for spectral band selection, spectral resolution specification

→ impact of instrumental noise, compared to contribution of uncertainty on model parameters (SST, humidity, ...)
Optimizing spectral window for tropospheric sounding considering a 40 cm\(^{-1}\) wide interval

### Lower troposphere
(0-6 km column)

- Band centre between 1040 and 1055 cm\(^{-1}\) provides optimal results in terms of both vertical sensitivity (DOFS of 5) and errors (8 % on tropospheric column).
  - 20 % for the lower troposphere
  - 60 % for the boundary layer

### Boundary layer
(0-2 km column)

- 60 % for the boundary layer
SIFTI instrument specifications

- Objective performances:

<table>
<thead>
<tr>
<th>Species</th>
<th>spectral band (cm⁻¹)</th>
<th>Non apodized spectral resolution (cm⁻¹)</th>
<th>NEDT / non apodized channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₃ profile</td>
<td>[1030 – 1070] (9.71 µm – 9.35 µm)</td>
<td>0.0625 (R = 8500)</td>
<td>65 mK</td>
</tr>
<tr>
<td>CO profile</td>
<td>[2140 – 2180] (4.67 µm – 4.59 µm)</td>
<td>0.0625 (R = 17000)</td>
<td>73 mK</td>
</tr>
<tr>
<td>CO column</td>
<td>[4270 – 4300] (2.34 µm - 2.32 µm)</td>
<td>0.1 (R = 20000)</td>
<td>SNR = 100</td>
</tr>
</tbody>
</table>

→ very high SNR required in interferograms

- Geometric requirements:
  resolution = 10 km, sampling = 50 x 50 km² at nadir
  > 25 footprints along the ± 50° swath

- System requirements: 2 hour revisit time
  5 fly by over Europe / 24h, by daytime 25 % of the year
  3 year lifetime
Instrument requirements

- Altitude = 720 km

- 2 options:
  - agile earth scanning
  - cloud hole hunting either to view in cloud free areas or target cloudy homogeneous areas ➔ better mission efficiency

- SWIR spectral band : SIFTI / TROPOMI trade-off
Principle of the "Static Infrared Fourier Transform Interferometer"

\[ \delta_{\text{ech}} = \frac{k}{2 \Delta \sigma} \]

- Varying OPD
- Fixed OPD

MOPD = \( \frac{1}{d \sigma_{\text{apod}}} \)

Under sampled interferogram → limited number of channels / narrow spectral band(s)

No translation mechanism

Knowledge of the position of each sample (OPDs)
Reading interferograms

Effects of diffraction and optical quality
Narrow band optical filter
Phase 0 preliminary budget: 1 m × 0.6 m × 0.3 m
≈ 70 kg
100 – 150 W
24 Mbit/s
## Radiometric budget: preliminary results

<table>
<thead>
<tr>
<th>SNR at interferogram level</th>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal requirement</td>
<td>11000</td>
<td>5300</td>
</tr>
<tr>
<td>Threshold requirement</td>
<td>5300</td>
<td>2700</td>
</tr>
<tr>
<td>Budget without phase modulation</td>
<td>8500</td>
<td>2200</td>
</tr>
<tr>
<td>Budget with phase modulation</td>
<td>11000</td>
<td>3000</td>
</tr>
<tr>
<td>Most important noise items</td>
<td>OPD knowledge + diffraction</td>
<td>Photon</td>
</tr>
</tbody>
</table>

### Assumptions:
- Total integration time = 157 ms
- Aperture: 112 mm × 112 mm
- \( T \) instrument = 273 ± 0.1 K; \( T \) cold box = 110 K ± 0.01 K
- \( T \) detector = 65 K (B1) and 90 K (B2) ± 1 mK
- Detector material = MCT
- Quantization: 14 bits (B1) and 11 bits (B2)
- Facet reading: 4 × 4 pixels surrounded by margin of 1+1 in B1, of 1 in B2
- Detection electronics noise: state of the art ++
- Knowledge on OPDs: better than ± 2 nm for the first ones
- Efficiency of deconvolution algorithm against diffraction better than 95 %
Conclusions

■ An innovative technology

■ The fruit of long term R&T activities

■ Unprecedented instrumental performances

■ New class atmospheric products

■ A promising instrument that deserves further feasibility studies

■ A CNES managed phase A, starting end 2006

■ An InfraRed Performance Breadboard to be developed at CNES

■ Possibly a pathfinder for future GMES air quality monitoring systems

■ Paving the way to another concept of atmospheric sounder for new generation sounders based upon high spectral resolution in essential sub bands