A Miniature UV Imaging Spectrometer for Remote Sensing of the Atmosphere

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Overview

- Introduction
  - Atmospheric constituents: Ozone, Sulphur Dioxide
  - Current UV Instrumentation: TOMS, OMI, GOME

- UV Imaging Spectrometer
  - Optics (Transmission Grating)
  - Detectors (Silicon Carbide)
  - Electronics (Switched Integrator)

- Atmospheric Simulations
  - Noise Equivalent Radiance

- Conclusions
Introduction

- Atmospheric Constituents
- Current Instrumentation in UV
Atmospheric Constituents

- **Ozone (O₃)**
  - Absorbs in UV range < 325 nm
  - Prevents harmful UV radiation reaching the surface

- **Sulphur Dioxide (SO₂)**
  - Emitted from anthropogenic activities or volcanic origin
  - Hazard for aviation
  - Important for climate studies

- **Absorbing Aerosols**
  - Play an important role in the Earth’s Radiative Budget
  - Have a strong Influence in Cloud formation

- **Clouds**
  - Increase Earth’s reflectance (Albedo)
Band ratios are commonly used to derive atmospheric products (2 orders of magnitude range).

Different spectral bands and resolutions are required to discriminate different constituents (SO$_2$ from O$_3$).
Spectral Requirements

- All instruments split UV channels to cope with stray light in the SO$_2$ absorbing region
- Use of CCD’s (Thinned, Back-illuminated)
Payloads: UV Instruments

OMI (65 kg / 66 W)

OMAD (2 kg / 0.5 W)

GOME (55 kg / 32 W)

TOMS (34 kg / 25 W)
Requirements and Instrumentation

- Spatial, Temporal and Spectral Requirements
- UV Imaging Spectrometer baseline specifications
## Application Requirements

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Most Significant Influencing Factors</th>
<th>Baseline Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial Resolution</td>
<td>Satellite Altitude</td>
<td>7 x 31 km</td>
</tr>
<tr>
<td></td>
<td>Optics Focal Length</td>
<td>OMI (12 x 24 km) TomS (50 x 50 km) GOME2 (80 x 40 km)</td>
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<tr>
<td></td>
<td>Detector pixel pitch</td>
<td></td>
</tr>
<tr>
<td>Temporal Resolution (Revisit Time)</td>
<td>Detector array size</td>
<td>1 day (Swath ~600 km in DMC-type constellation)</td>
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<tr>
<td></td>
<td>Spatial Resolution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Constellation size</td>
<td></td>
</tr>
<tr>
<td>Spectral Channels and Resolution</td>
<td>O$_3$ and SO$_2$ Absorption Aerosols</td>
<td>10 channels : 305 – 315 nm / spectral resolution &lt;1 nm</td>
</tr>
<tr>
<td></td>
<td>Reflectivity</td>
<td>2 aux channels: 331 nm and 360 nm / Spectral resolution ~ 1nm</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Systems Noise</td>
<td>Equivalent to &lt; 2 DU</td>
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<tr>
<td></td>
<td>Detector Responsivity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spectral Resolution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Optics</td>
<td></td>
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<tr>
<td></td>
<td>Aperture</td>
<td></td>
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<tr>
<td>Dynamic Range</td>
<td>Cloud Cover</td>
<td>Solar angles up to 85 degrees</td>
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<tr>
<td></td>
<td>Integration Time</td>
<td></td>
</tr>
<tr>
<td>Timeliness and delivery of products</td>
<td>Downlink rate</td>
<td>&lt;24 hrs via internet</td>
</tr>
<tr>
<td></td>
<td>Number of ground stations</td>
<td></td>
</tr>
<tr>
<td></td>
<td>User infrastructure</td>
<td></td>
</tr>
</tbody>
</table>
## Instrument Requirements

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Most Significant Influencing Factors</th>
<th>Baseline Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>Optics (materials, aperture) Electronics (amplifiers)</td>
<td>2- 5 kg</td>
</tr>
<tr>
<td>Volume</td>
<td>Optics (focal length, aperture) Electronics (amplifiers)</td>
<td>&lt;0.01 m³</td>
</tr>
<tr>
<td>Overall dimensions</td>
<td>Same as volume</td>
<td>150 mm x 150 mm x 150 mm</td>
</tr>
<tr>
<td>Peak Power</td>
<td>Detector operation Electronics</td>
<td>2-5 Watts (Continuous operation)</td>
</tr>
</tbody>
</table>

- Application Requirements: Based on Committee on Earth Observation Satellites (CEOS) Disaster Management Support Group (DMSG)
- Instrument Requirements: Based on SSTL Disaster Monitoring Constellation (DMC) Platform
UV Imaging Spectrometer

Advantages

- Small, Low Power
- Reduced Wavelength Range
- Simple Optical Layout
- High Efficiency Gratings
- Solar Blind SiC detectors
- Very Low-Noise Electronics
  (~2 fA with Switched Integrator + 16-bit ADC)

Optical Design

- Silicon Carbide (SiC) Detectors
- Fused Silica Transmission Grating

(~5 kg / < 5 W)

Low-noise Electronics
Optical Design

Drivers

- Minimum number of elements:
  - Input, Slit, Collimator, Gratings, Focusing Lens
- Aspherical surfaces to minimise optical aberrations
- Maximum optical throughput
- 3 UV bands
- Coupled to custom-made photodiode arrays
- Pixel size (300 μm x 300 μm)
- Calibration using miniature spectral line-source
Spectral Imaging

Relative Illumination

305 – 315 nm O₃/SO₂

331 nm O₃/Aerosols

360 nm Reflectivity

SiC Detector Responsivity
**Imaging Performance**

**Spatial Performance**
- Spot size increases at the edge of the swath (larger pixels)
- Slant path is longer reducing signal

**Spectral Performance**
- Resolution should remain relatively constant with wavelength
- 1nm is equivalent to TOMS
Atmospheric Simulations

- Noise Equivalent Radiance
- Sensitivity to SO$_2$
Sensitivity to SO₂

Volcanic Emissions
(> 5 DU)

Anthropogenic Emissions
(< 2 DU)

Noise Equivalent Radiance (NEL)
Conclusions

- Utility and capabilities of UV monitoring on small satellites with continuous operation
- Atmospheric applications have a great potential
- Volcanic Monitoring of low gas emissions (~2 DU)
- Proven algorithms can be used with different detector technology
- New miniaturised UV Imaging Spectrometer
- DMC + UV = Potential for monitoring atmospheric and volcanic activity
- Suitability for constellation of small satellites (Latin American, Ring of Fire countries ?)
Thank you for your attention

Questions ?