MERTIS – the design of a highly integrated IR imaging spectrometer


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Background

- Mercury has probably the oldest surface among the terrestrial planets with large daily temperature variations
- Investigation of the mineralogical composition and thermo-physical properties are motivating measurements of the spectral emittance and the radiometric behavior in the IR

Study of Mercury’s surface composition
Identification of rock-forming minerals
Mapping of the surface mineralogy

Spectrometer objectives

Study of surface temperature and thermal inertia

Radiometer objective

Laboratory emittance spectra of fine-grained feldspar (ref. Wagner 2000)
Instrument Simulations

- Scientific performance assessment for initial instrument architecture
- Simulation of spectral signal and noise values depending on Mercury surface data and instrument parameters

**Surface parameters**
- Temperature
- Mineral emissivity
  
**Instrument parameters**
- Intensity sampling distance
- Spectral channel bandwidth
- Dwell time, optics efficiency
- F-number
- Pixel size, macro-pixel

**Simulated surface brightness temperatures**

**Probability for correct spectral feature detection**

- Performance Model (ref. Jahn/Reulke 1995)
- Noise Photon Detector

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as initial, 2x pixel size
**Instrument Concept**

- **MERTIS – MERcury Thermal Infrared Spectrometer**
- IR-imaging spectrometer based on the push-broom principle (80 channels @ 90 nm)
- Application of un-cooled micro-bolometer array providing spectral separation and spatial resolution according to its 2-dimensional shape
- Operation concept principle is characterized by intermediate scanning of the planet surface and 3 different calibration targets – free space and on-board black body sources
- In-field separated micro-radiometer based on thermopile line arrays
Optics

- All - reflective optics design for high efficiency (0.95 mirrors * 0.57 grating)
- Off - axis TMA behind a IR- entrance window (F# 2 / 50, 7- 40 µm transparence)
- Offner spectrometer including convex grating (blaze structure 90 x 5 µm, angle 3.7°)
- Innovative integrated dual focal plane concept
- Pointing mirror to target orientation (FOV 4° x 1° each)
Design Overview

- Space Port Baffle
- Telescope Optics
- Sensor Head Structure
- Detectors Compartment
- S/C Radiator Thermal Link (optional)
- Spectrometer Optics
- Electronics Unit
- Reflective Planet Baffle
- Pointing Device
- Calibration Device
## Main Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Spectrometer</th>
<th>Radiometer (µRAD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal length</td>
<td>F</td>
<td>50 mm</td>
<td></td>
</tr>
<tr>
<td>F – number</td>
<td>F#</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Optical efficiency</td>
<td>η&lt;sub&gt;opt&lt;/sub&gt;</td>
<td>0.54</td>
<td></td>
</tr>
<tr>
<td>Microbolometer array detector</td>
<td>pixels</td>
<td>160 x 120 @ 35 µm</td>
<td>100 spatial</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>80 spectral</td>
</tr>
<tr>
<td>µRAD thermopile line array</td>
<td></td>
<td>2 x 15 @ 250 µm</td>
<td></td>
</tr>
<tr>
<td>Spectral channel width</td>
<td>λδ</td>
<td>90 nm / pixel</td>
<td></td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>λ/λδ</td>
<td>78 – 156</td>
<td></td>
</tr>
<tr>
<td>Spectral range</td>
<td>λ</td>
<td>7 – 14 µm</td>
<td>7 – 40 µm</td>
</tr>
<tr>
<td>Detectivity</td>
<td>D*</td>
<td>0.95 x 10&lt;sup&gt;9&lt;/sup&gt; cm Hz&lt;sup&gt;1/2&lt;/sup&gt; W&lt;sup&gt;-1&lt;/sup&gt;</td>
<td>7 x 10&lt;sup&gt;8&lt;/sup&gt; cm Hz&lt;sup&gt;1/2&lt;/sup&gt; W&lt;sup&gt;-1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Instantaneous field of view</td>
<td>IFOV</td>
<td>0.7 mrad</td>
<td>5 mrad</td>
</tr>
<tr>
<td>Ground sample distance</td>
<td>GSD</td>
<td>280 - 1400 m (M = 1- 5)</td>
<td>2000 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1050 m</td>
<td>7500 m</td>
</tr>
<tr>
<td>Dwell time</td>
<td>τ</td>
<td>109 ms</td>
<td>775 ms</td>
</tr>
<tr>
<td></td>
<td></td>
<td>784 ms</td>
<td>5597 ms</td>
</tr>
<tr>
<td>Field of view</td>
<td>FOV</td>
<td>4° ACT, 0° ALT</td>
<td>4° ACT, 1° ALT</td>
</tr>
<tr>
<td>Swath width</td>
<td></td>
<td>28 km</td>
<td></td>
</tr>
<tr>
<td>Instrument overall dimensions</td>
<td></td>
<td>140 x 160 x 120 mm&lt;sup&gt;3&lt;/sup&gt;</td>
<td>93 x φ54 &amp; 92 x φ68 mm&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>+ ext. Baffle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Instrument total mass incl. 20% margin</td>
<td></td>
<td>2.85 kg</td>
<td></td>
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</table>
Detector Spectrometer

- Resistive semi-conductor micro-bolometer
  (Array 120 x 160 pixels @ 35 µm pitch)

- Thermally controlled MEMS Device
  (TEC at 10 mK stability)

- Established technology to be space-qualified for BepiColombo
Detector Radiometer

- Thin film IR thermopile with thermoelectric high-effective material
  (2 line arrays 2 x 15 pixels @ 250 µm pitch)

- Spaced in-parallel from the optical axis
  (0,5 mm from slit centre)

- Technology study and performance simulations ongoing

Tentative radiometer detector design

FEM simulation and experimental Si-wafer for tests
Electronics Architecture

- Modular concept based on FPGA technology
- Cold redundancy of main electronics parts
- Tasks
  - Independent control of the MERTIS sub-systems
  - Acquisition and processing of science data
  - Providing of internal voltages and interfacing the +28V S/C power bus
  - TMC management and interfacing to the S/C DHU
  - Control of the pointing mirror black bodies and optional shutters
  - Providing of HK and status information
  - Control of the detector
  - Temperature stabilization of the detector
  - Detector signal conditioning
**Development - Actuators**

- In-flight calibration purposes
- Pointing Unit for target selection
  - Planet (65% duty cycle min.)
  - Deep space
  - 300 K black body
  - 700 K black body
- Short Term Shutter for instrument temperature reference
  - Operated every dwell time (~10 Hz)

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**STS prototype**
- Slit width 460 µm
- $F_{\text{res}} \sim 200 \text{ Hz}$
Development – Optics Technology

- Early identification of flight optics technology
  - Single point diamond turning
  - All aluminium + gold coating
  - Element parameters and efficiency measurements (grating)

- Verification of Phase A Sensor Head design
  - TMA Unit performance
  - Spectrometer Unit performance
  - Optics structure design

Offner mirror surface (data ref. IOF Jena)
Development – Laboratory Work

- Radiometric Analysis Breadboard (RAB)
  - Investigations of the environment stability (lab conditions), pattern correction and calibration approach
  - Adaptation and verification of MERTIS components (detector, proximity electronics, EGSE)

- Spectro Radiometric Breadboard (SRB)
  - Investigations of the optical performance of TMA and spectrometer (grating, detector)
  - Verification of the MERTIS baseline design (grating, detector, F#, D*)

λ = calibration of focal plane (12.1 - 8.2 µm)
See you in 2018 !