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About TNO

- ~ 5000 people
- Distributed over 5 core areas
  - Quality of Life
  - Defense, Security and Safety
  - Science and Industry
  - Built Environment and Geosciences
  - Information and Communication Technology
- Science and Industry
  - ~ 1000 people
  - Precision opto-mechanics
    - ~ 100 people
    - 35 in optics
Past
Spectrometers at TNO

• TNO has a (good) reputation if it comes to designing, building and calibrating space based spectrometers

• TNO has significant flight heritage and is working on reducing the size of spectrometers for future space applications which will widen their use
# Instruments timeline

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GOME (pushbroom)

TNO-TPD / Officine Galileo

- **Spectral coverage**
  240 - 793 nm

- **Spectral resolution**
  0.2 - 0.4 nm (channel-dependent)

- **Instantaneous field-of-view**
  2.9° x 0.14° (along x across track)

- **Scan swath**
  approx. 30.976° maximum (corresponding to 960 km on ground).

- **Mass**
  54 kg

- **Power consumption**
  approx. 50 Watt.

- **Launched April 1995 on ERS2**
- **Baseline Ozone Instrument for METOP 1,2,3**
SCIAMACHY (line arrays)

An imaging spectrometer whose primary mission objective is to perform global measurements of trace gases in the troposphere and in the stratosphere.

The solar radiation transmitted, backscattered and reflected from the atmosphere is recorded at relatively high resolution (0.2 nm to 0.5 nm) over the range 240 nm to 1700 nm, and in selected regions between 2.0 µm and 2.4 µm.
OMI on EOS AURA (2D sensors)

Monitors trace gasses in the atmosphere

High spectral resolution (0.2 nm)
Medium spatial resolution (15 km)
**Daily global coverage**

Small enough to fit on a microsatellite if the electronics are modernized

Sunday, 7/11/04

Tuesday, 9/11/04
Present
Microbolometer Spectrometer (MIBS)

- twelve 0.35 μm bands
- 0.25K NETD @300K
- target for 1 μm band (0.15K with American detectors)
- Spectrometer
- 0.03 m³
- <25 kg

Small enough to fit on a microsatellite
RamanLIBS spectrometer EBB
(ESA contract: 19608/06/NL/GM)

- Support the search for past or present life on Mars!
- Raman spectroscopy:
  - low power laser excitation gives rise to (weak) spectral lines dependent on specific molecular content
- LIBS spectroscopy:
  - high power laser for plasma generation (factor \( \sim 10^6 \) higher than Raman), allows determination of atomic composition

- In Flight Model program TNO will be responsible for spectrometer part of instrument wide spectral range (240 – 840 nm)
  - resolution < 0.2 nm
  - low mass / volume
EBB spectrometer status

- everything integrated - working
Raman shift detection in order 3: 650 to 840 nm
Sulphur

- **Sulfur / Azufre (RA004a01)**
  KOSI Holospec f/1.8i - 1.5 s 30 ac – laser
  633 nm 18.0 mW 5.7 kW/cm²

- EBB measurement, preliminary wavelength calibration, ambient pressure, detector -10°C
Immersed grating

Immersed grating spectrometers: volume decrease

Volume scales with $3^{\text{rd}}$ power of refractive index. In NIR region refractive index of 3.4 (Silicon) is available, leading to a volume decrease with a factor of 40

In the visible, volume gain is less (3x - 5x), but still can be worthwhile

Example: SWIR channel (2300nm – 2390nm) of OMI successor
Tropomi SWIR breadboard

- Silicon immersed grating
- Etched: very nice groove shape, determined by crystal
TROPOMI SWIR breadboard
Innovation: spectrometer-on-a-chip

• Research & development in co-operation with Technical University of Delft in STW project
• Typical overall dimensions: 10x5x5 mm³
Spectrometer-on-chip downside

- Low efficiency
- Low etendue
- Spectral resolution now ~3nm, 0.5nm should be possible. Not good enough for most gas measurements
  - How to increase this?
Future

LARS
Low Altitude Remote Sensing

• Funded with internal money, first customers are very interested

• Use UAV helicopter at 50m – 150m height
  • Flown in 2007 with RGB & TIR cameras
  • Image processing (stitching, classification)

• In May 2008 spectrometer will be flown to measure water color
  • ~5nm resolution
  • Off-the-shelf system

• In 2008 spectrometer should be designed to measure gas concentrations (NOx first)
  • Calibration?
  • Variable background?
  • Helicopter exhaust?
  • Collaboration is possible on this project
Beyond LARS

- Use designs of LARS spectrometers to fly on higher altitude platforms
  - Higher spatial resolution than satellite based
  - Weather forecasts
  - Ozone measurements

- Further future: Micro-satellites
Future (space) applications of spectrometers

- Micro and mini-satellites
  - Forest fire detection
  - Pollution monitoring
  - Water management
  - CO2 monitoring
  - Crop monitoring
  - Interplanetary missions

- UAV’s
  - Pollution monitoring
  - Water management
  - Spill monitoring
Conclusions:

- Small spectrometers on board of microsatellites and/or UAV’s will most probably change the remote sensing landscape
- The killer application is still to be defined
- Once developed, spin-off to non space applications and larger space mission is to be expected
- Small spectrometers will allow cost effective monitoring constellations
Discussions...

- Glass properties at non-ambient temperatures
  - Example: CTE invar @ 20°C: 0 ppm
    @ -170°C: 5 ppm

- Programmable gratings
  - Straylight
  - Efficiency

- Modeling (tolerancing) freeform components
  - No norm available

- Gas measurements from low altitude platform
Thank you for your attention

Rob Vink
+31 15 269 2730
rob.vink@tno.nl