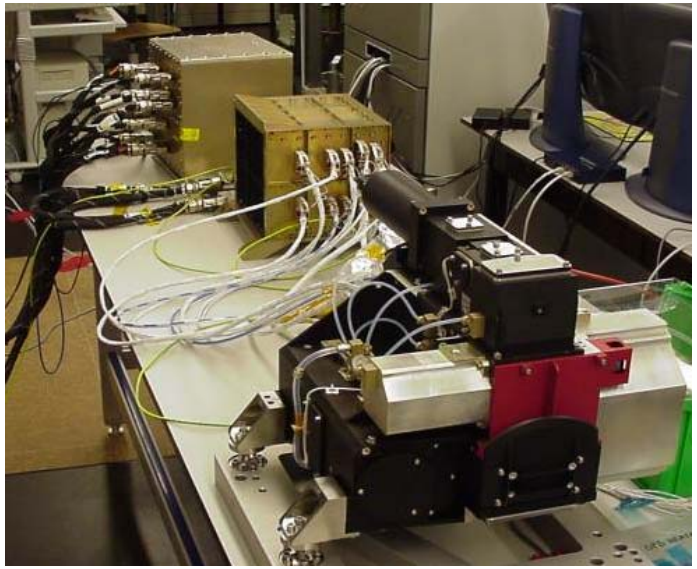
Role of OMI for Finnish Technology



Heikki Saari
VTT Technical Research Centre of Finland

September 2nd 2014

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- Patria Systems and Space Systems Finland OMI Heritage
- OMI influence on VTT spectral imaging technology development
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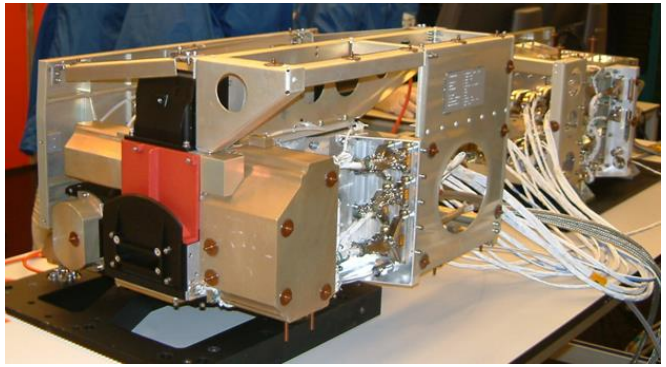
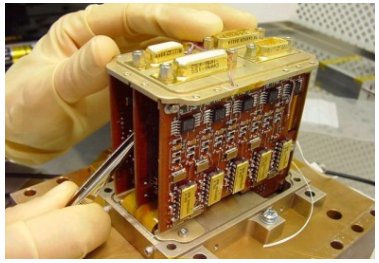
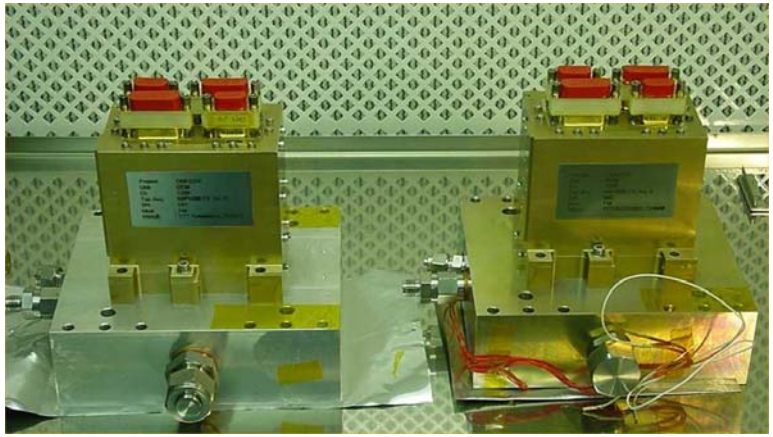
- Tunable Fabry-Perot Interferometer for ALTIUS UV-Channel
- Technology for the GHG satellite measurement validation
- Conclusions on the role of OMI for Finnish Technology



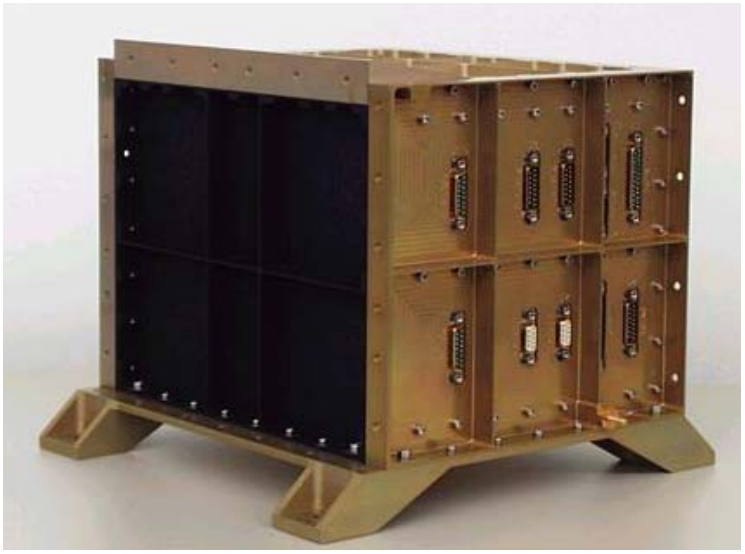
Finnish contributions to the OMI instrument

- Finnish contributions to the OMI instrument





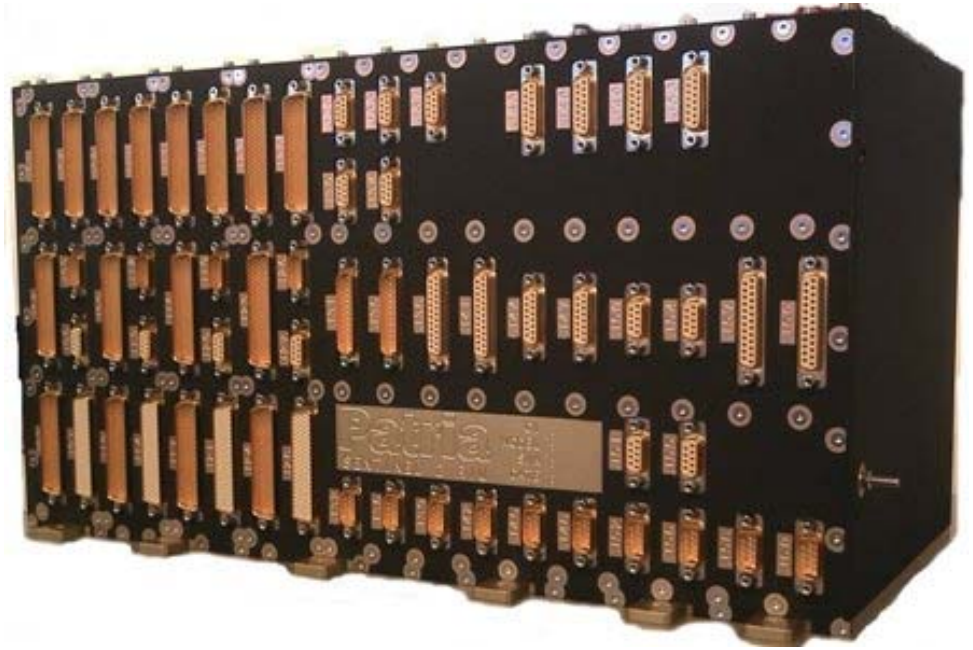
VTT Microelectronic Systems
0.78 kg, 2.8 W each
Proximity electronics for CCD detector
2 Units delivered on 2 March 2001



Electronics Unit by Patria Systems
8 kg, 45 W for the control of CCD readout, TM/TC, sampling, A/D conversion….
Delivery June 2001

Patria Systems OMI Heritage for developing similar Detector Electronic Units for ESA missions.

Patria has delivered signal processing electronics to many recent ESA programs such as Galileo, Gaia, Herschel ,ADM Aeolus, Sentinel-2 and EarthCARE.
Ref.
http://www.patria.fi/EN/Products+and+services/Space/Signal+Processing+Electronics/index.html



Patria provides the Remote Interface Unit to ESA mission Sentinel-2. Image credit ESA - P. Carril

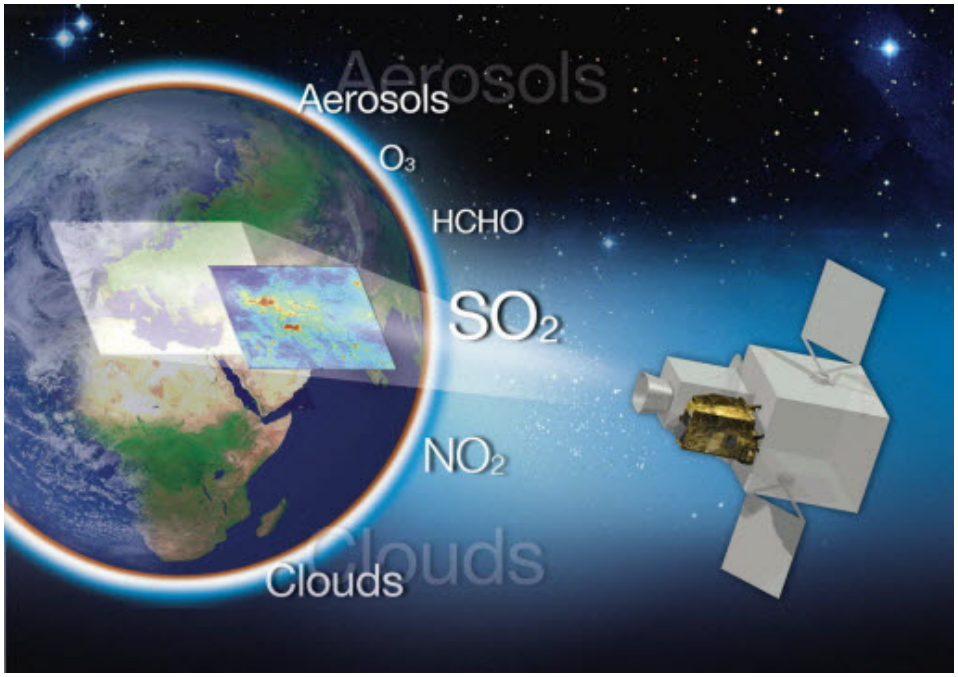
Space Systems Finland OMI Heritage

For Space Systems Finland OMI built experience on developing reliable ground processing systems applicable also in other fields.
Ref. http://www.ssf.fi/pages/index.php?fid=15&pid=50

SSF will develop the Sentinel-4 L1bPP software

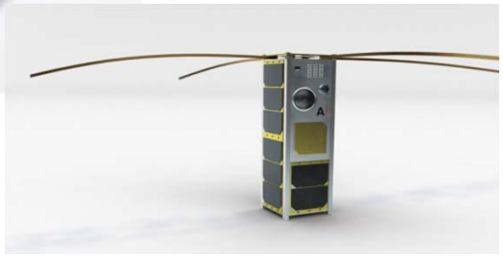
Space Systems Finland was awarded a contract to develop the Level 1b Prototype Processor of the Sentinel-4 UVN Mission.

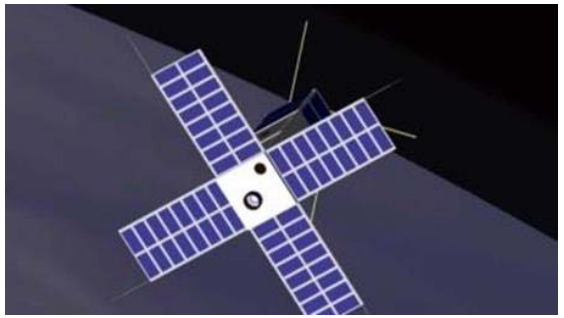
Sentinel-4 is and instrument dedicated to atmospheric monitoring. From geostationary orbit 36 000 km above the equator, on-board the MTG Sounder satellite series, the Sentinel-4 UVN spectrometer, will provide data every hour on the chemical composition of the atmosphere including trace gases and ultraviolet radiation.



OMI influence on VTT remote sensing spectral imaging technology development

- After OMI VTT continued to apply its deep knowledge in CCD detector technology when developing the GeoPIE stereoscopic aerial camera system.
- Later VTT developed hyperspectral imagers for UAVs.
- The Aalto-1 Imaging Spectrometer development will also benefit from the lessons learned in OMI development.
- VTT will develop the VISION sun occultation instrument for the Belgian PICASSO-CubeSat.
- The ALTIUS UV-Channel is planned to be realized with VTT Fabry-Perot tunable filter technology.





Spectral Imaging – from space to other application areas

*Atmospheric Sciences
*Environmental Monitoring

Onboard Satellites
Remote sensing

Onboard Airplanes/Helicopters
Remote Sensing

*Environmental Monitoring
*Pollution Detection
*Forestry Management
*Precision Agriculture
*Crop management
*Mineral Exploration

Onboard UAVs / Drones
Remote Sensing

* Border Protection
*Reconnaissance & Surveillance
*Spectral Tagging
*Targeting

In-line Process/Pharmaceutical
Manufacturing Control

*In-line Quality Control of Drug,
*Safety/Contamination control

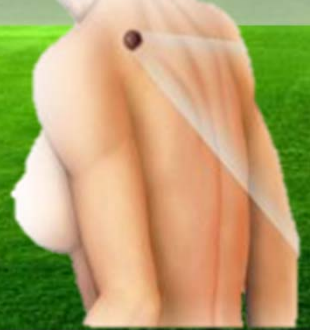
Forensic, Medical, Lifesciences

*Crime Scene Investigation / Latent Print Analysis
Counterfeit Detection / Document Verification
*Non-Invasive Diagnostic Imaging / Optical
Biopsy / Tissue Demarcation / Microscopy

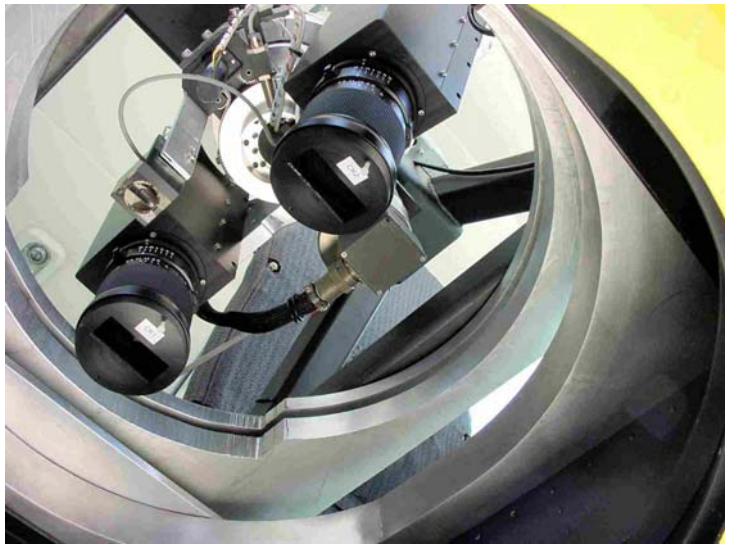
*In-Line Inspection of:
Fruits Vegetables, Poultry, Fish

*Plastic sorting

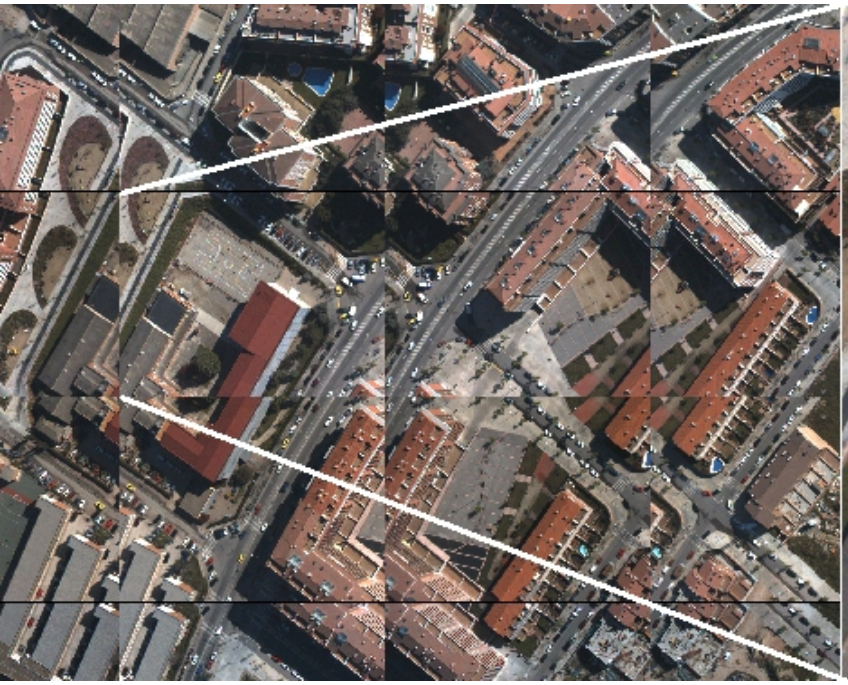
*Quarry & Excavation Analysis



GeoPIE Digital Stereo Aerial Camera Test Flight in April 2004

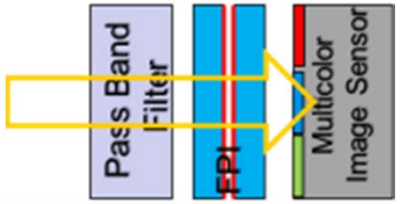


Bottom view of the NMC4 stereo camera heads

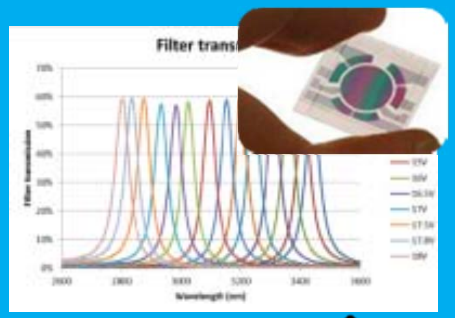


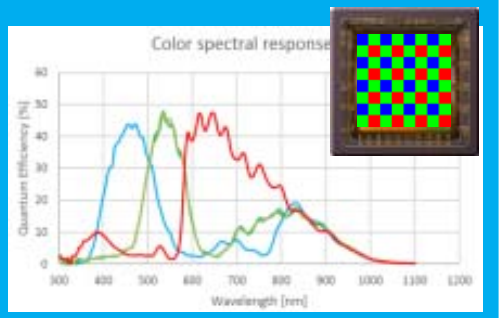
NMC4 Image from Barcelona area: zoomed image to a sports yard

Multicolor image sensor combined with multiple Fabry-Perot orders



FPI AND CAMERA CALIBRATION

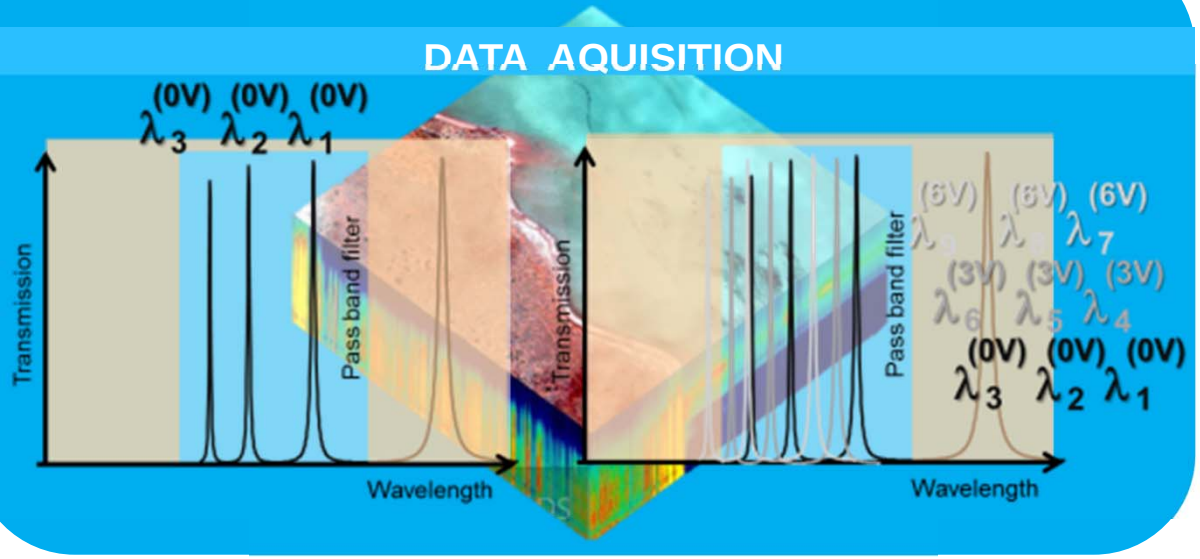




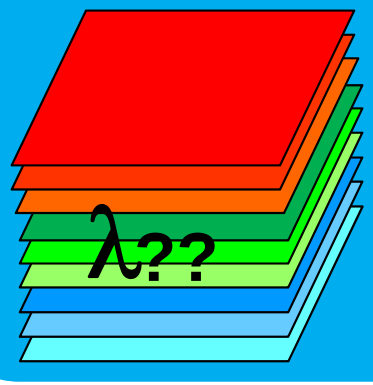
n V (air gap) ⇔ **λ_n** (transmitted)

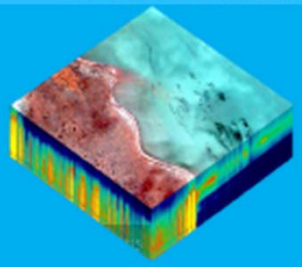
Multicolor Image Sensor (with i.e. Bayer filter)

DATA AQUISITION

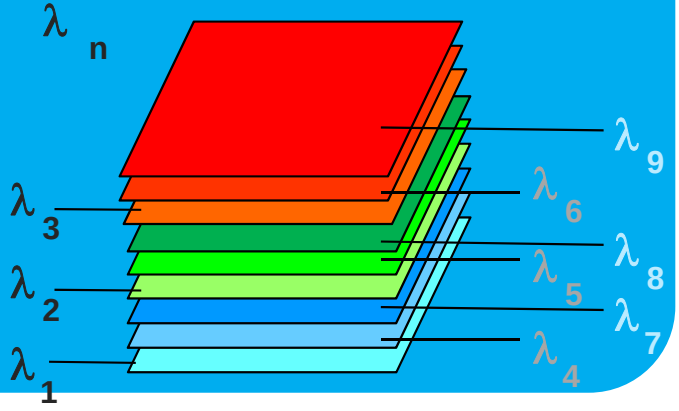


DATA PROCESSING



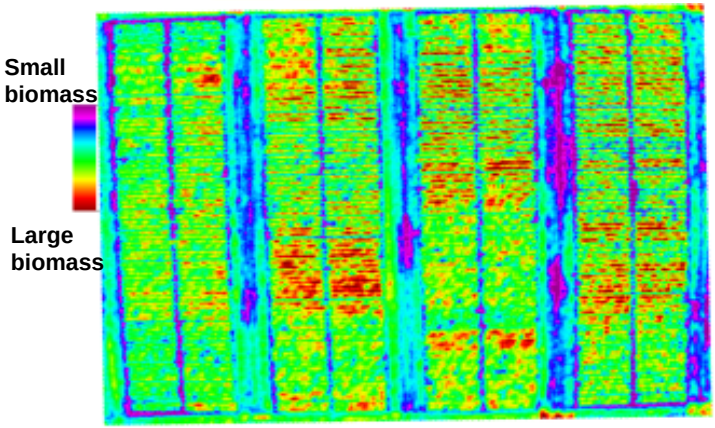


Algorithm that associates colorscale image to determined wavelength

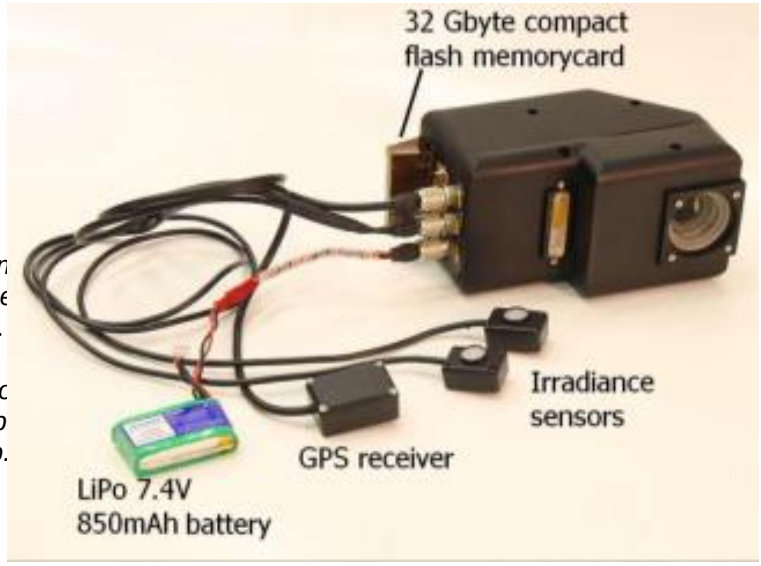


UAV Visible-VNIR hyperspectral imager

- Opening new possibilities for monitoring of biomass, nitrogen content and plant pathogens in crop and fruit fields and in forest applications -



- Light-weight (~0.6 kg): can be operated with low-cost UAVs
- Software-configurable to the wanted application
- 4 data dimensions with a single flight: 2D map, spectral dimension, height dimension
- 48 spectral layers in 1.5 s



Wavelength range: 400-1000 nm (500-900)

Wavelength resolution: Ca. 7 - 20 nm

Spatial resolution: 2 Mpix

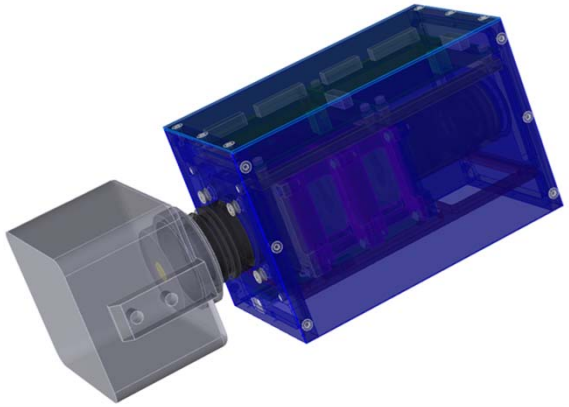
Development status:
- **3rd generation flight model**
- **Commercialized by Rikola Ltd.**

Publications or presentations:

- *Saari, H.; Pellikka, I.; Pesonen, L.; Tuominen, S.; Heikkilä, J.; Holmlun Mäkynen, J.; Ojala, K.; Antila, T., "Unmanned Aerial Vehicle (UAV) ope spectral camera system for forest and agriculture applications", Proc. 8174 (2011).*
- *Honkavaara, E., Hakala, T., Saari, H., Markelin, L., Mäkynen, J., Ro T., 2012b. A process for radiometric correction of UAV image b Photogrammetrie, Fernerkundung, Geoinformation (PFG) 2/2012, pp. 127.*

UAV SWIR 900 – 1700 nm hyperspectral imager

- Light-weight (~1.2 kg): can be operated with low-cost UAVs
- Software-configurable to the wanted application
- 4 data dimensions with a single flight: 2D map, spectral dimension, height dimension
- 48 spectral layers in seconds



Wavelength range:
900-1700 nm (1100-1600)

Wavelength resolution:
Ca. 10 - 25 nm

Spatial resolution:
320 x 256

- **First prototype built and UAV tests performed August 2014.**

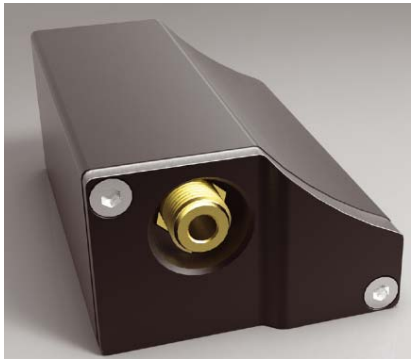
Publications or presentations:

- *Mannila, R., Holmlund, C., Ojanen, H., Näsilä, A., Saari, H., Short-wave infrared (SWIR) spectral imager based on Fabry-Perot interferometer for remote sensing, Proc. SPIE 9241 (2014) to be published.*

From research to commercial products

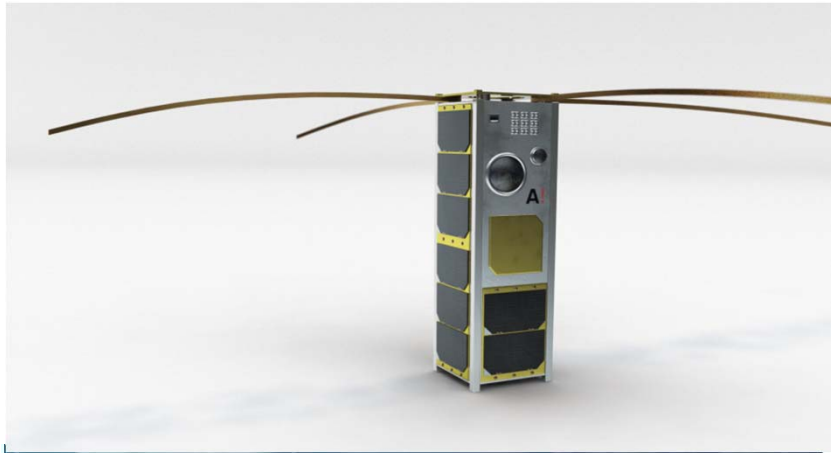
- The spectral imaging technology research has enabled commercial product development by Rikola Ltd.
- VTT spin-off company Spectral Engines has developed a memsNIR & memsMIR spectral sensor product family utilizing the VTT innovative MEMS-based Fabry-Perot tunable filter technology.

Rikola Hyperspectral imager for light weight UAVs. Ref. www.rikola.fi



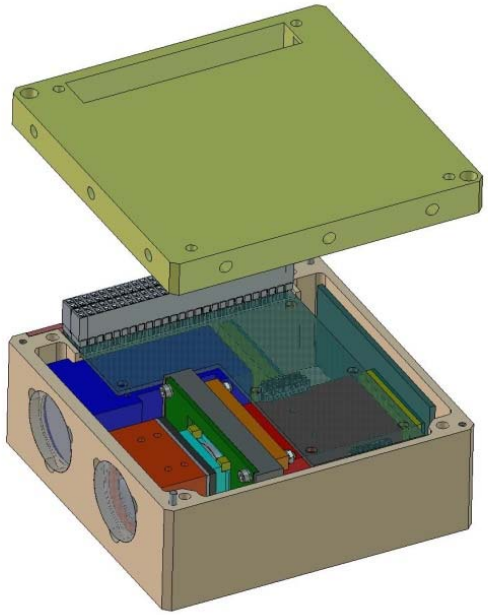
Spectral Engines miniaturized spectrometer. Size 50 x 35 x 20 mm^3, Weight < 50 g. Ref. www.spectralengines.com

Back from UAVs to Nanosatellites - Aalto-1 Spectral Imager



- Nanosatellites (< 10 kg) provide a cheap and fast access to space for any organization
- Spectral imaging provides data for Earth observation for managing and conserving the resources of the Earth
- Spectral sampling programmability and onboard processing minimizes amount of data for fast downlink

Spectral imager for Aalto-1 satellite, mass 600 g



Wavelength range: 500-900 nm

Wavelength resolution: 10-30 nm

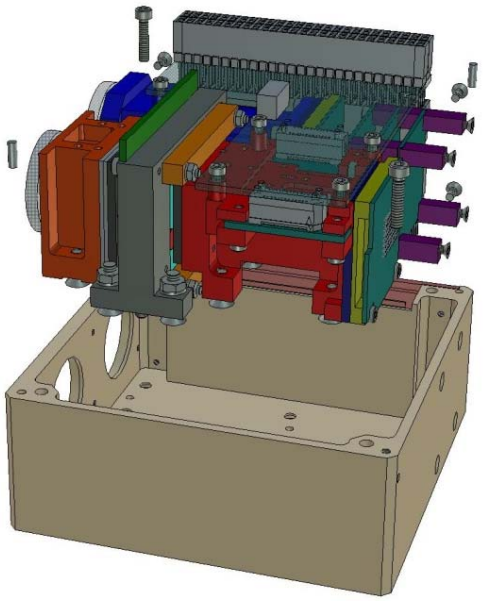
Spatial resolution: 512x512 pixels

Development status:
- **flight model under development**
- **Launch: 2015**

Publications or presentations:

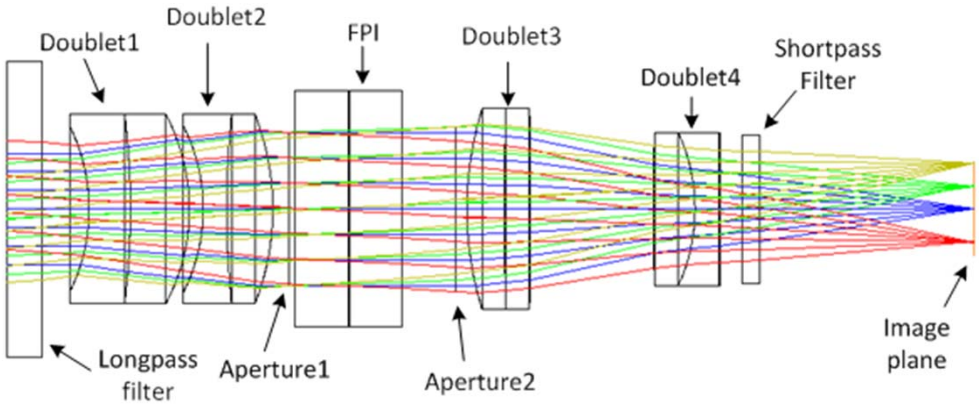
- *A. Näsilä, H. Saari, J. Antila, R. Mannila, A. Kestilä, J. Praks, H. Salo, M. Hallikainen, "Miniature Spectral Imager for the Aalto-1 Nanosatellite", in proceedings of 4th European CubeSat Symposium, pp. 24, Ecole Royale Militaire, Brussels, 30 January – 1 February, 2012.*

Aalto-1 Spectral Imager (AaSI)



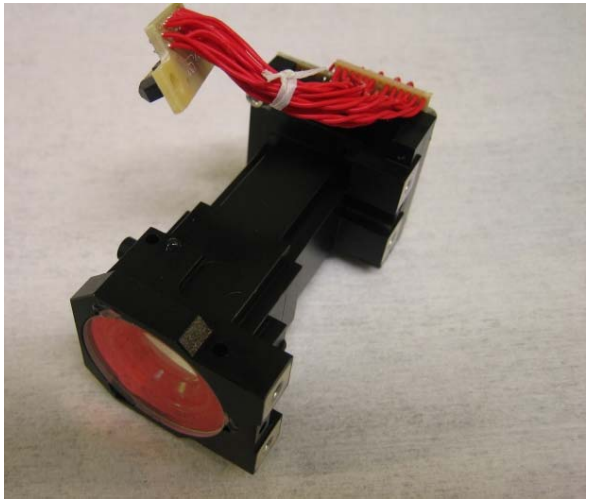
Spectral camera Module (SPE)

- Field of View: 10 deg x 10 deg
- Focal length 32 mm
- F-number 3.4
- Image size 512x512 pixels
- Ground pixel size ca. 200 m from a 600 km orbit
- Selectable wavelength bands between 500 and 900 nm



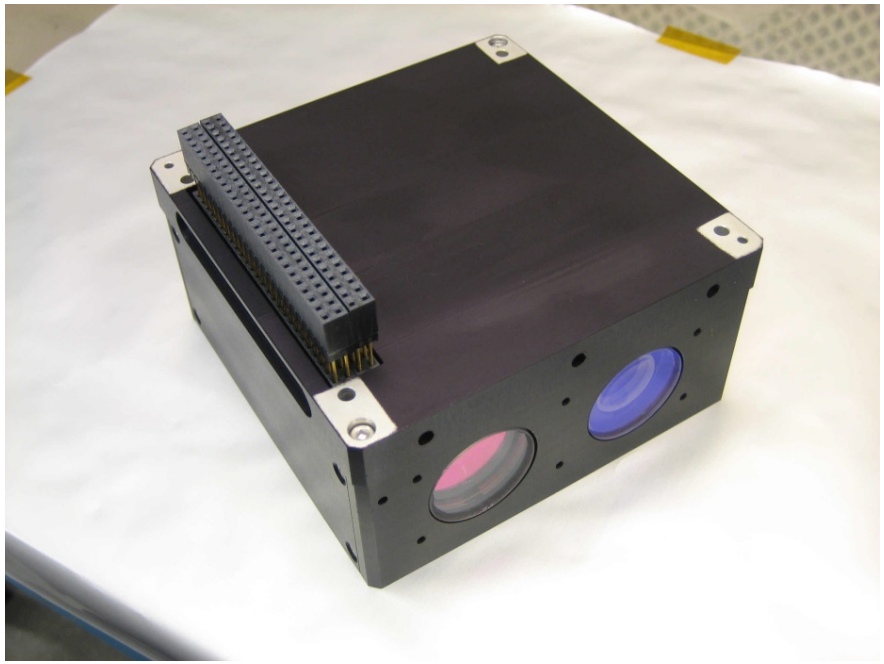
Visible RGB-camera (VIS)

- Commercial micro-objective (Kokagu AVR40)
- Field of view 15 deg x10 deg
- Focal length 40 mm
- F-number 3.2
- Image size: 1910 x 1270 pixels
- Ground pixel size ca 100 m from 600 km orbit



Aalto-1 Spectral Imager Integration

Main housing profile 96 mm x 96 mm
Support Plate profile 97 mm x 97 mm



Atmospheric remote sensing with a CubeSat – PICASSO Vision solar occultation instrument

Pico-Satellite for **A**tmospheric and **S**pace **S**cience **O**bservations

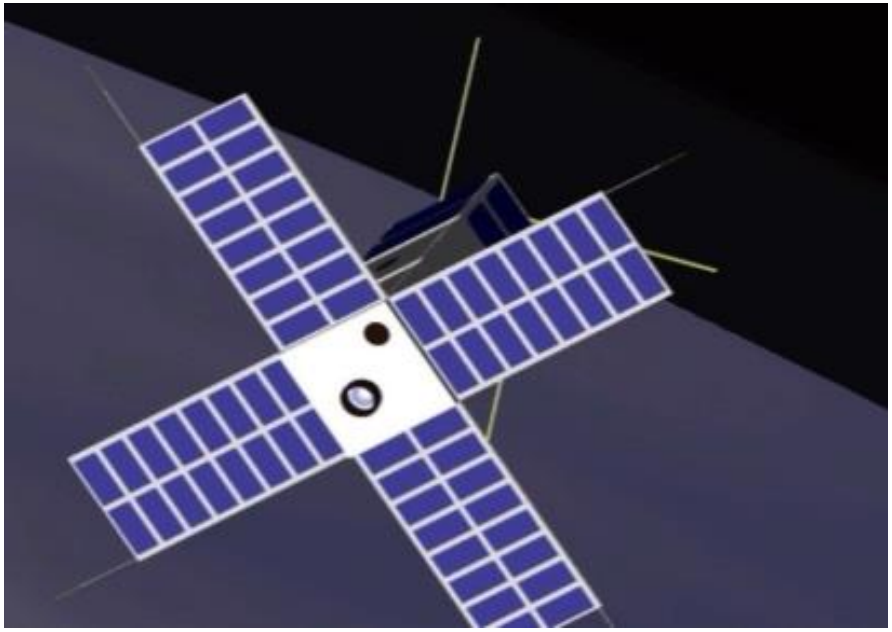
A strategic project

BIRA-IASB, KSB-ORB, VTT, ClydeSpace

- The main objective is to evaluate the potential of pico-satellites for remote sensing and in situ measurements of the Earth and other celestial bodies and demonstrate that it is possible to carry out true scientific experiments with COTS-based components.

PICASSO is a triple CubeSat embarking 3 scientific instruments:

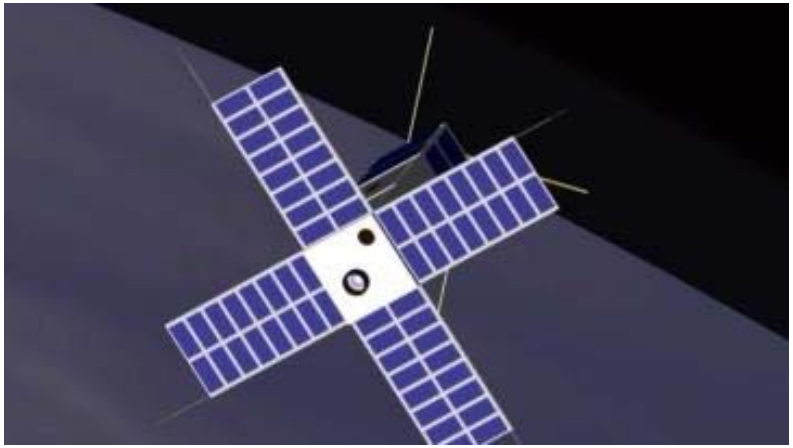
- VISION, a visible and near-infrared hyper-spectral imager;
- SLP, a multi-needle Langmuir probe;
- µBOS, a micro-bolometer oscillation system.

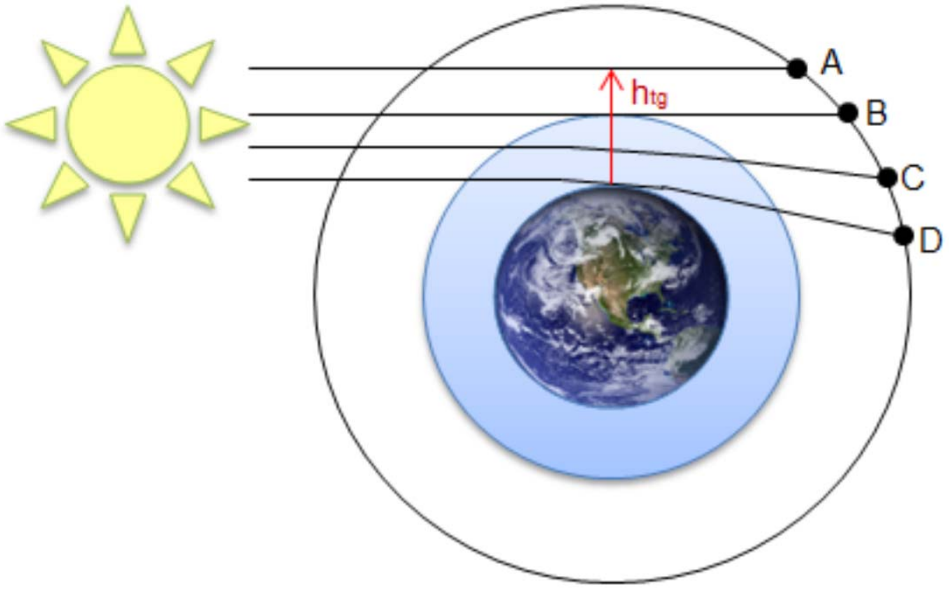


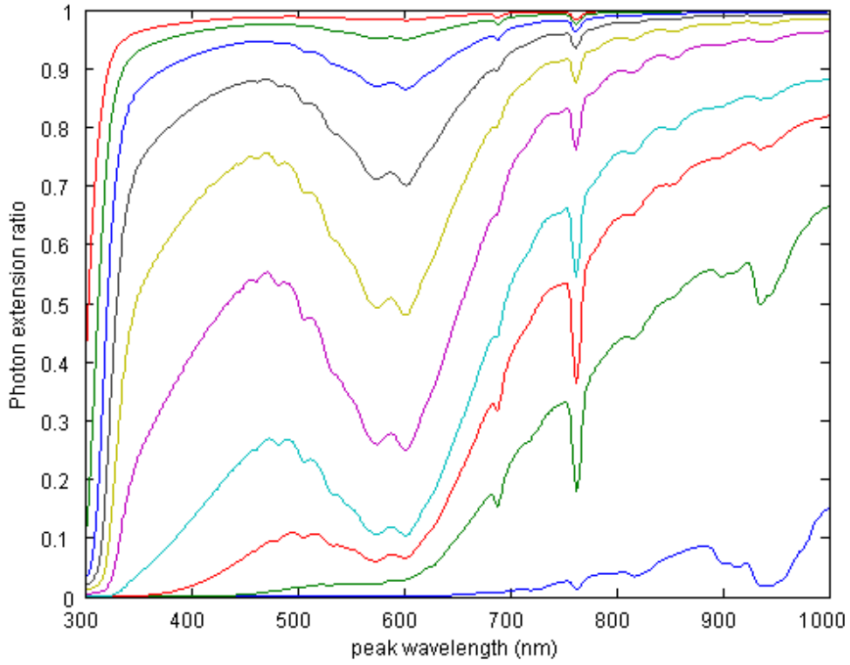
Part of QB50 project

PICASSO-VISION Instrument Overview

- For a baseline circular orbit at 500 km with an inclination of 80°, the mission lifetime should be approximately 2 years.
- VTT is responsible for the development of the VISION instrument in the ESA-GSTP project RFQ/3-14170/14/NL/MH with the Kickoff planned for 7th October 2014.
- It is based on a FPI spectral imager similar to the Aalto-1 Spectral Imager (AaSI).



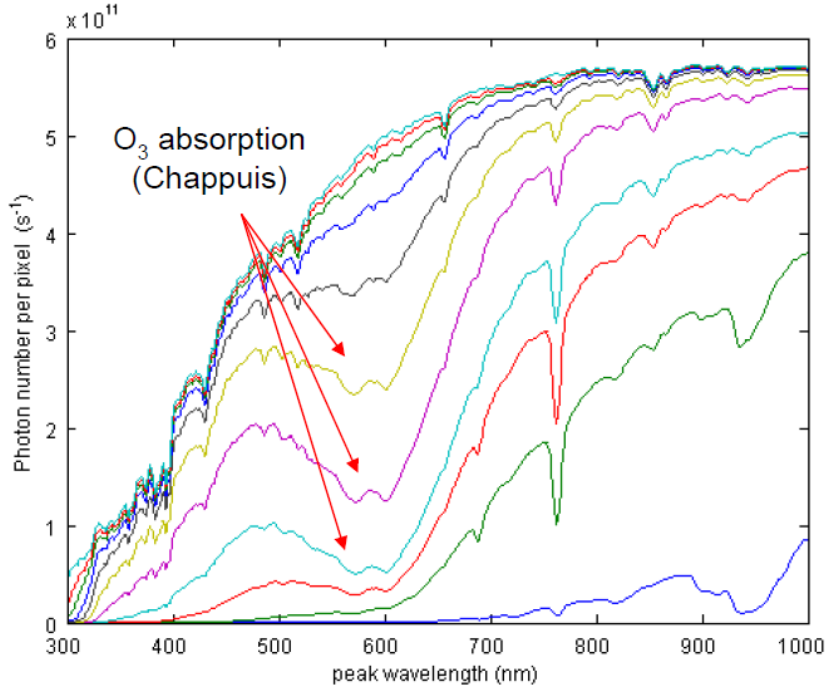


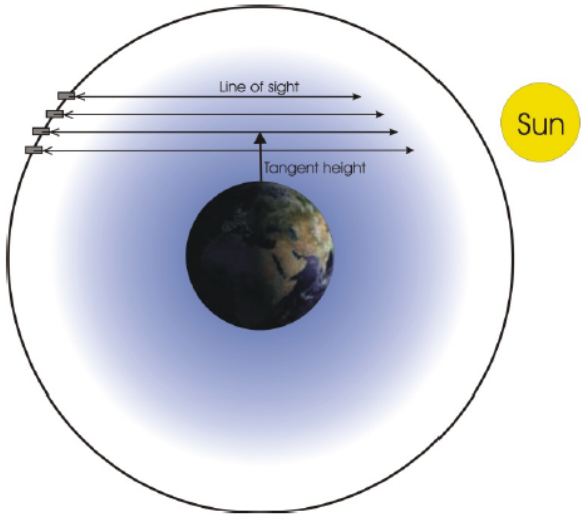


PICASSO – VISION Concept

II.1 Spectral analysis principles

Solar occultation: by traversing the atmosphere, the sunlight is absorbed, scattered and refracted.

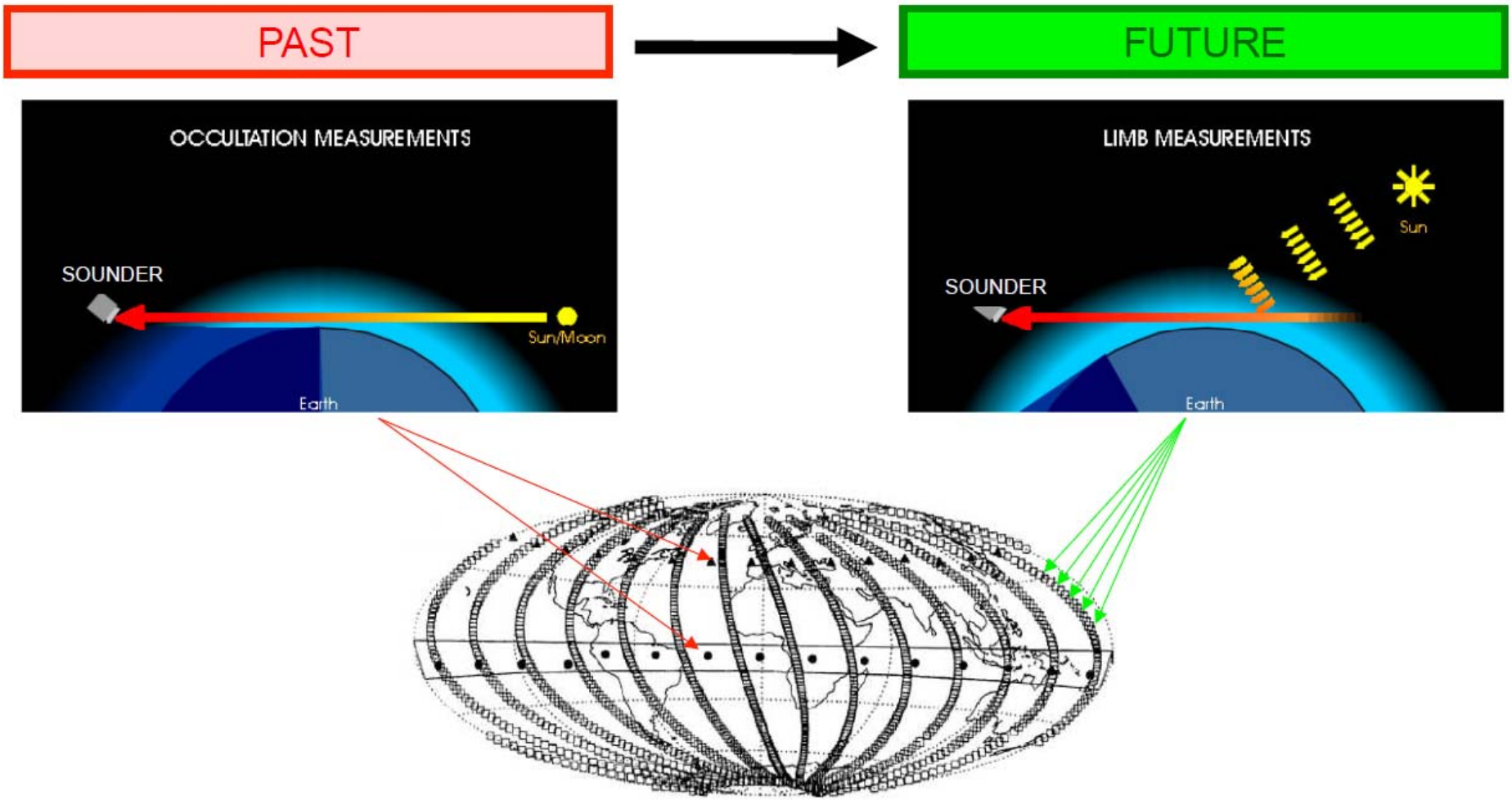




Analysing the absorption and the scattering gives access to the atmosphere composition along the line of sight.

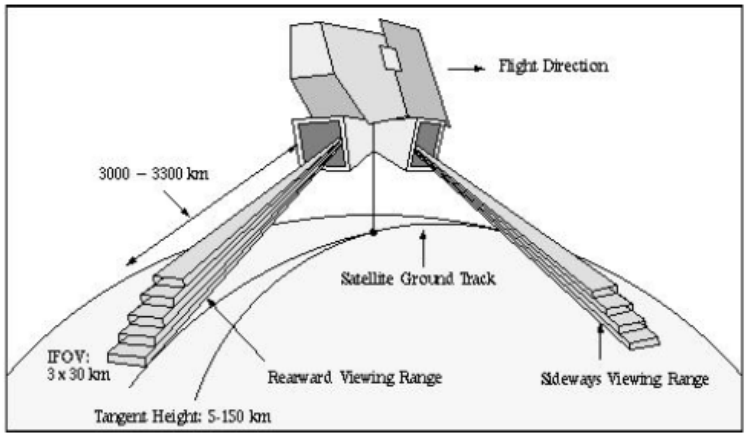
ALTIUS background, Didier Fuessen et.al.

Important technological progresses are presently emerging in the field of vertical atmospheric remote sounding.

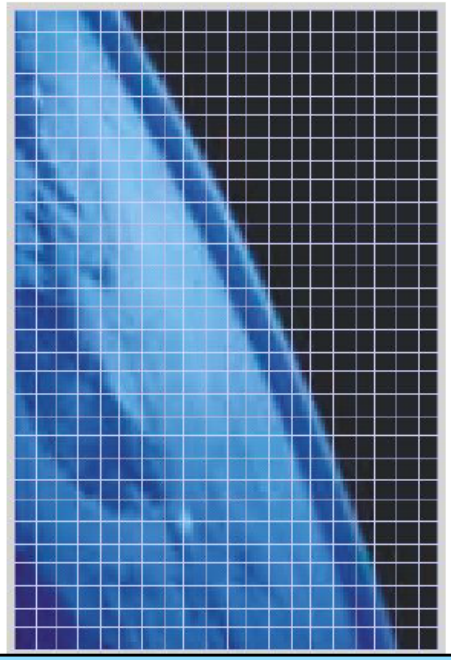


Limb sounding allows for a global coverage in 1-3 days !!!

PAST → FUTURE



Limb scan
Filter or grating spectrometers
No gradients



Full 2-D limb imaging
Acousto-optical filters for visible and NIR
Fabry-Perot tunable filters for UV
Horizontal gradients

ALTIUS uses the simple concept of a spectral camera, i.e., a combination of an AOTF and Fabry-Perot tunable filters with a 2-D imagers

HYPERSPECTRAL CUBE

(wavelength x space) x space = wavelength x (space x space)

Stratosphere : ALTIUS PI: D. Fussen

Atmospheric **L**imb **T**racker for the **I**nvestigation of the **U**pcoming **S**tratosphere

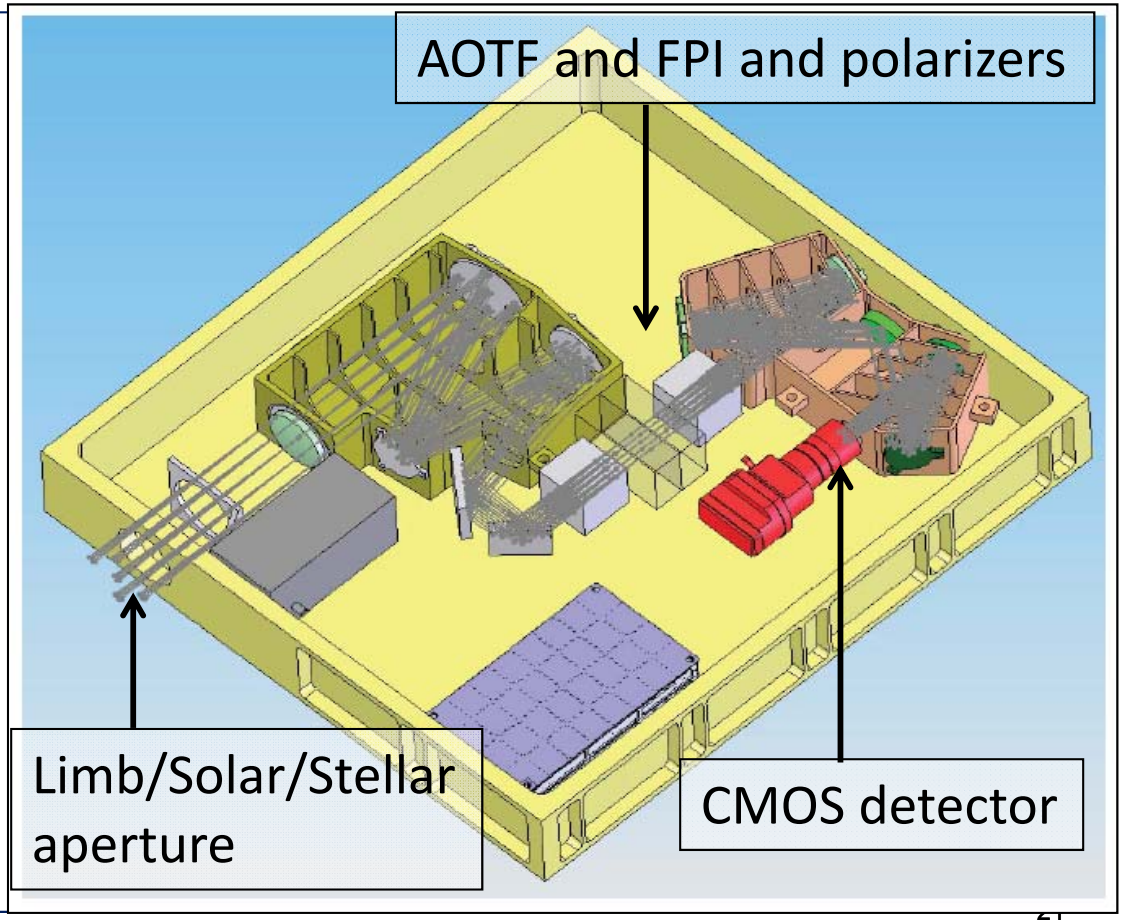
Satellite mission proposed by BIRA-IASB, supported by BelSPo and funded by PRODEX.

Industrial partners : OIP (P/L) and QinetiQ Space (P/F)

Mission goals:

- Measurements of atmospheric trace gases concentration profiles with global coverage in 3 days and ~500 m spatial sampling from UT/LS to US.
- Target species : **O_3**, NO_2, CH_4, H_2O, BrO, PSC, aerosols, ..

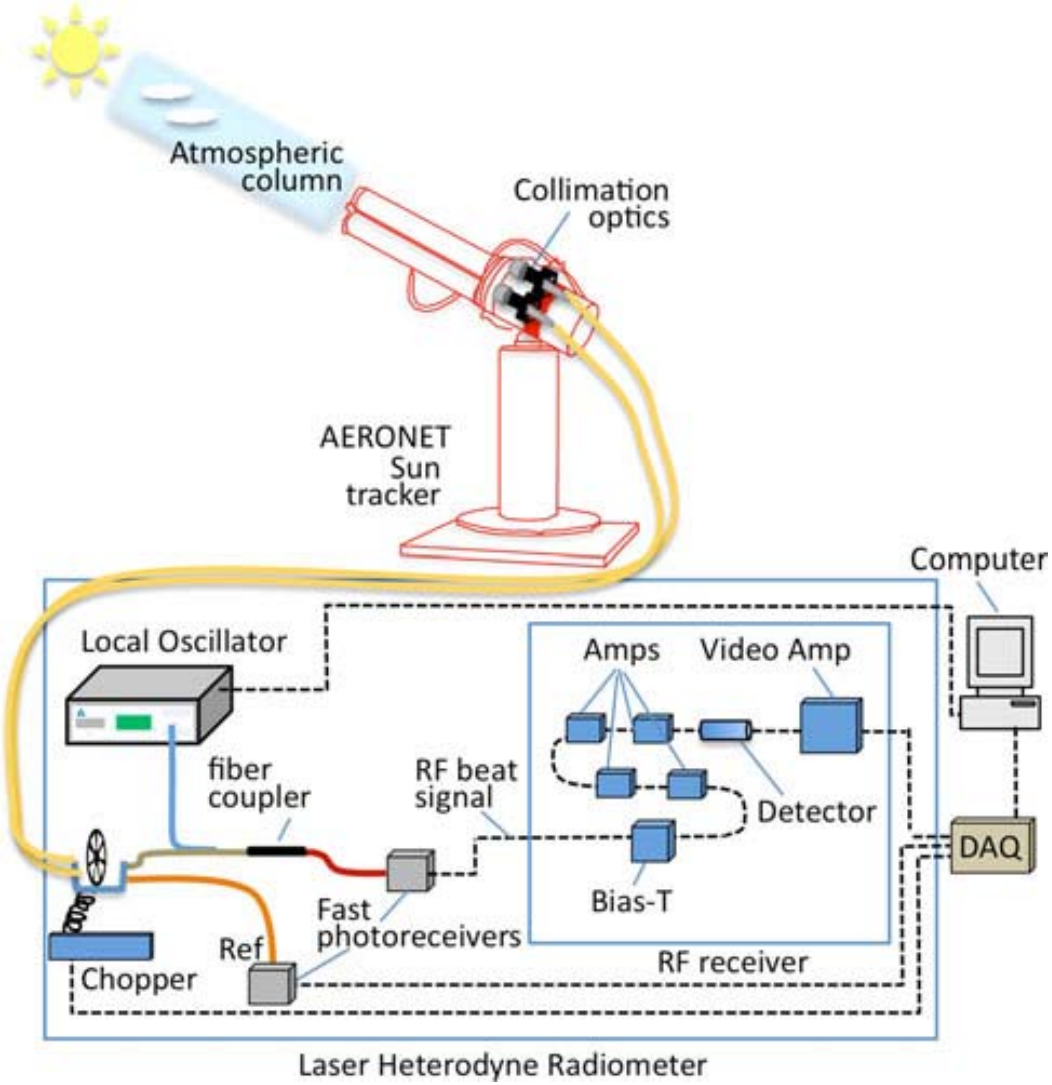
Current status : Phase B1

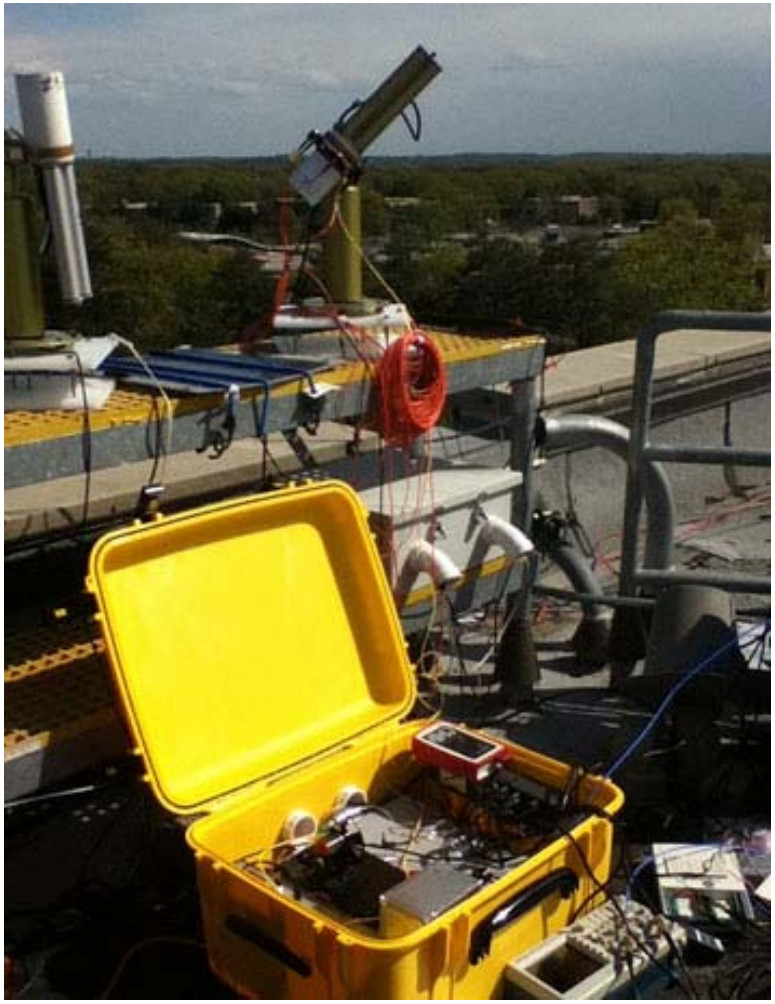


Opportunities for atmospheric remote sensing opened by the new compact spectral imaging technology

- The Fabry-Perot Interferometer technology has been used and is planned to be used in several atmospheric remote sensing missions (GIFS, MEOS, AMIGO, PICASSO-VISION, ALTIUS).
- All of these instruments would benefit from having the opportunity to use the stable, compact Fabry-Perot Interferometer.
- The possibility to build hyperspectral imager compatible with a CubeSat platform opens possibility to scientific measurements with solar occulation method. The Belgian PICASSO mission will use this concept.
- FMI and VTT have proposed the use of high resolution FPI spectrometer technology for ground based and airborne CO2, CH4, O2 and H2O measurements.
- One concept the CO2 measurement is to use the invidual CO2 line (width ~0.05 nm) and very high FPI order but naturally the final selection is made only after detailed simulations of the achievable SNR values.

AERONET sun tracker and Laser Heterodyne Radiometer

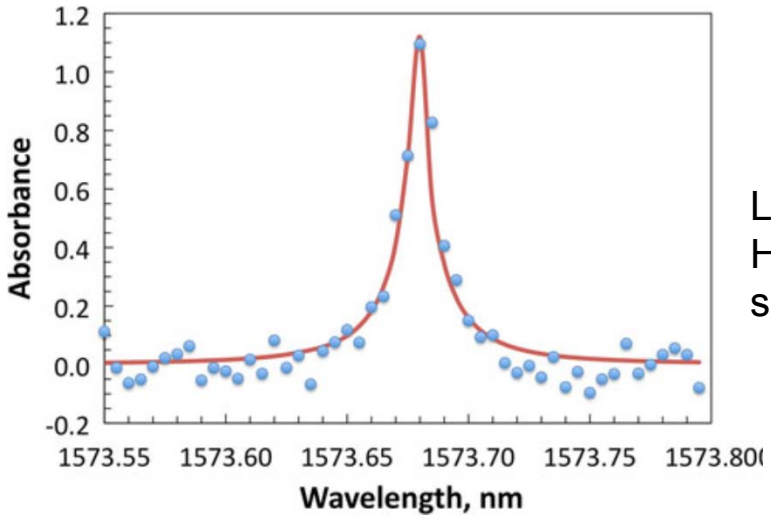




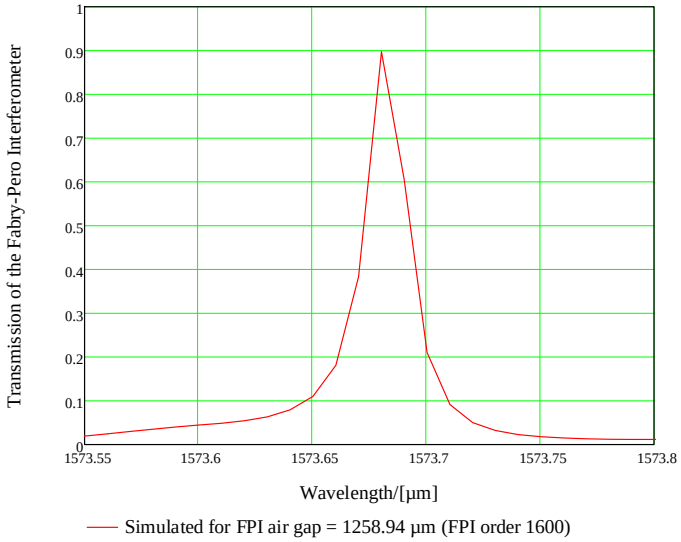
Ref. E. L. Wilson et. Al., ”Miniaturized laser heterodyne radiometer for measurements of CO2 in the atmospheric column”, Applied Physics B, Lasers and Optics, May 2013

Ground based direct sun measurement concept implemented with FPI

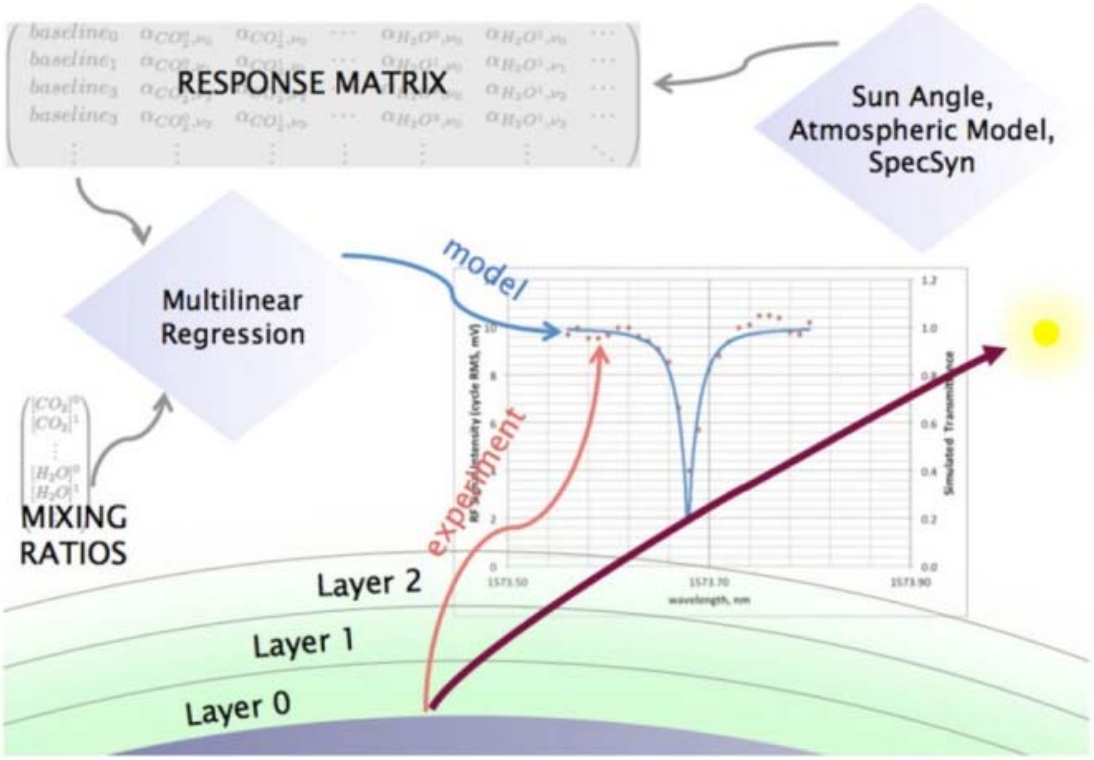
- The CO2 in the atmospheric column has been measured with ground based instrument of Wilson et.al.
- Single absorption line of CO2 at 1573.67 nm was used.



Laser Heterodyne simulation



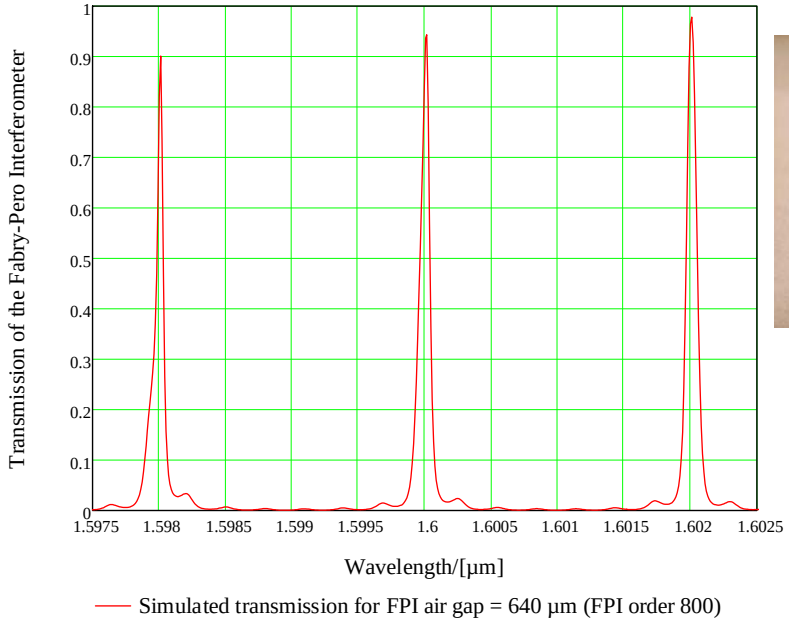
High resolution FPI simulation

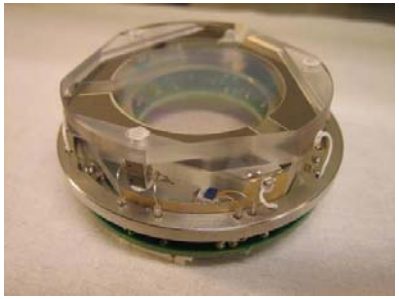


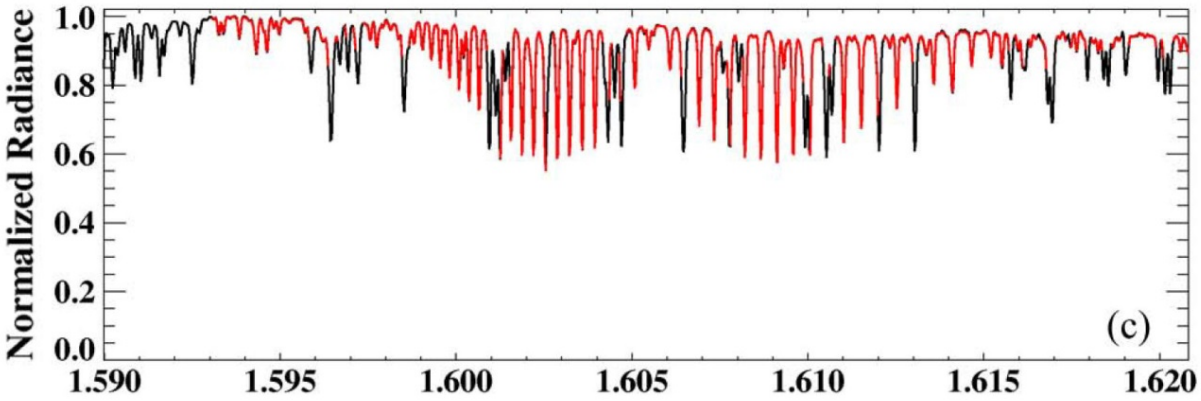
Ref. E. L. Wilson et. Al., ”Miniaturized laser heterodyne radiometer for measurements of CO2 in the atmospheric column”, Applied Physics B, Lasers and Optics, May 2013.

Ground based direct sun measurement OCO-2 concept implemented with FPI

- OCO-2 spectral resolution at the ”weak” CO2 absorption band 1590 - 1621 nm is ~0.076 nm @ 1605 nm.
- This resolution can be achieved with 3 layer Bragg Mirror (Poly-Si and SiO2) FPI at the FPI order ~800.
- The instrument is pointed directly to the Sun and the FPI transmission band is scanned over few CO2 absorption lines.
- Note! This a preliminary concept and the actual implementation might look totally different



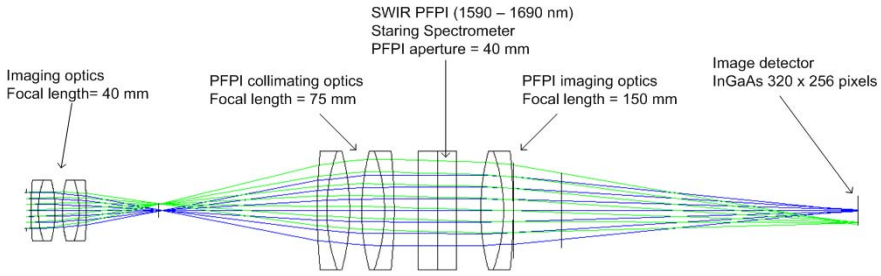




Ref. J.O. Day et. Al., ”Preflight Spectral Calibration of the Orbiting Carbon Observatory”, IEEE Transactions on Geoscience and Remote Sensing, VOL. 49, NO. 7, July 2011.

CH4&CO2 industrial site emission monitoring using UAV FPI instrument and MAMAP NIR and SWIR Spectrometer type of measurement method

Infotron IT-180 UAV helicopter with max payload capacity of 5 kg



Preliminary concept of CH4&CO2 spectral imager

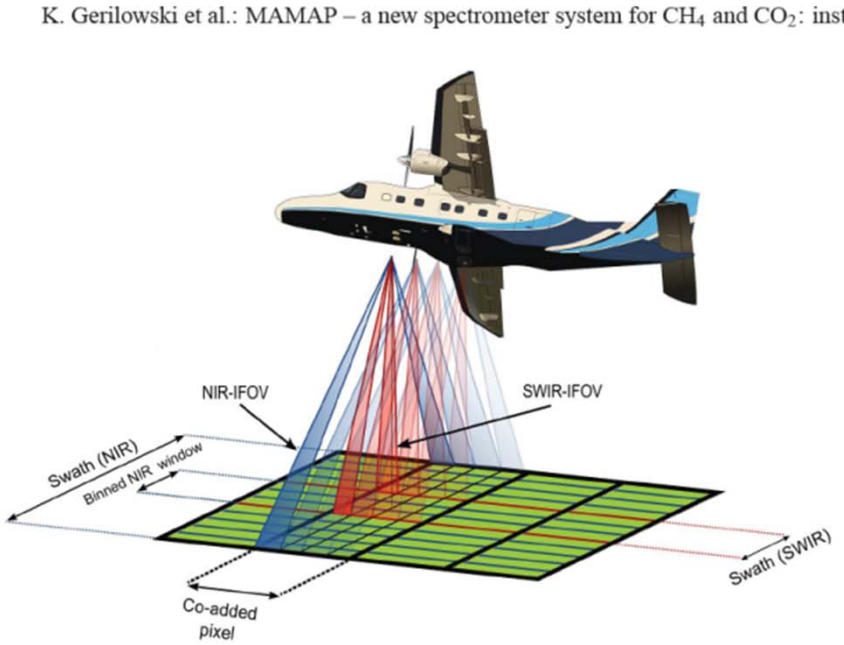
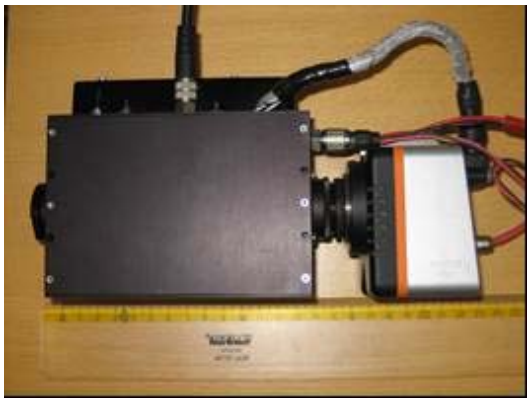


Fig. 3. MAMAP observation geometry for the 1-D-SWIR (red) and the 2-D imaging NIR (blue) spectrometer.



Conclusions on the role of OMI for Finnish Technology

- OMI was the first remote sensing instrument where Finland provided major instrument subsystems.
- Patria and Space Systems Finland have been able to ulitized the OMI heritage in many ESA project contracts.
- VTT team acquired competence on building demanding optical instruments in OMI and has used this knowhow in the development of new remote sensing and industrial spectrometers.
- The focus in VTT technology development for atmospheric remote sensing will be on the PICASSO-VISION CubeSat solar occultation instrument, on ALTIUS UV Channel FPI tunable filter and on the spectral instruments for the validation satellite GHG measurements.

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