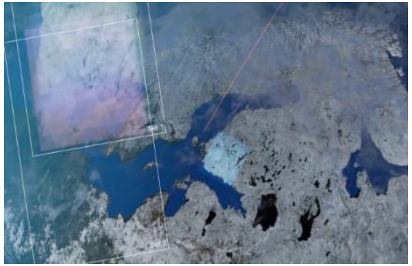


Miniaturized hyperspectral imagers for VNIR and SWIR small satellite missions

Antti Näsilä, Heikki Saari, Christer Holmlund, Rami Mannila, Kai Viherkanto, Altti Akujärvi, Harri J. Ojanen, Ismo Näkki, Tapani Antila, Ingmar Stuns, Hans Toivanen, Tahvo Havia, Osmo Viljamaa

Dr. Anna Rissanen

Research Team Leader, VTT Microspectrometers

Outline

Introduction

FPI technology

Hyperspectral imaging for small satellites

VTT Technical Research Centre of Finland Ltd

VTT IS

- Globally networked multitechnological applied research organisation
- Not-for-profit and impartial research centre

VTT CREATES

- New technology and science-based innovations in co-operation with domestic and foreign partners

VTT HAS

- Extensive cross-disciplinary expertise
- Unique research infrastructure
- Comprehensive global partnership networks

Net turnover and other operating income 272 M€ for VTT Group in 2015
(VTT Group's turnover 185 M€ in 2015)

Personnel 2,470
(VTT Group 31.12.2015)

Unique research and testing infrastructure

Wide national and international cooperation network

VTT Microspectrometers team in brief

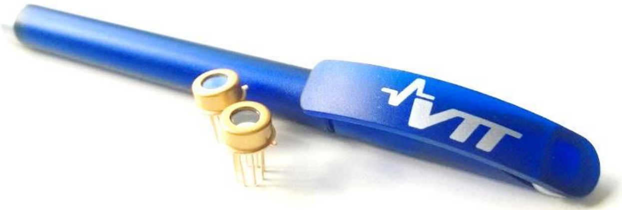
Team expertise:
- MEMS process design
- Optics, electronics and mechanics design
- Assembly, testing & characterization
- Software and UI development

Key research topics
- Space CubeSat instruments
- Environmental sensing
- Stand-off detection
- Medical and diagnostics
- MEMS sensors for automotive, mobile and process industry
- Gas sensors
- Optical readers

Our offering
- Contract R&D
- Product prototyping
- Pilot MEMS production
- IPR out-licensing and sales

Team motivation

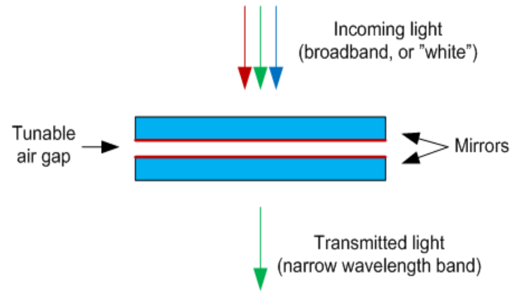
- *Miniaturizing spectrometers - opportunity for novel sensing applications*



From bench-top to handheld

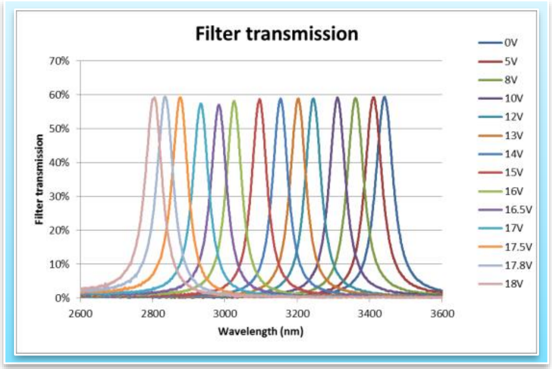
Fabry-Perot (FPI) technology for miniaturizing optical sensors

- ✓ **FPI is a tunable optical filter – electrical actuation changes the passband wavelength**
- ✓ **VTT develops miniaturized spectrometers based on tunable FPIs, for both imaging and non-imaging application**
- ✓ **FPI-based microspectrometers and hyperspectral imagers can be scaled to volume production**



Basic equation: $m\lambda = 2d$

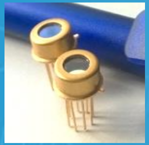
where m is operation order and d is air gap width

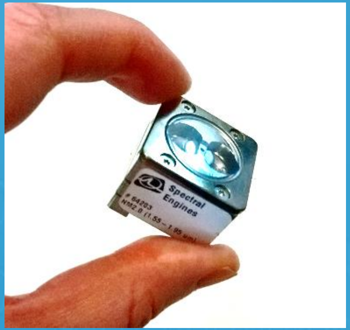


FPI tunable pass-band filter in spectroscopy

Single-point spectroscopy

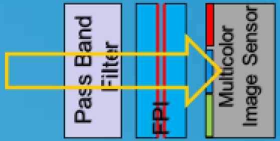
- FPI combined with IR detector
- No array detector needed –> reduced sensor cost
- Examples: NDIR sensors, portable NIR analyzers, selective gas sensors

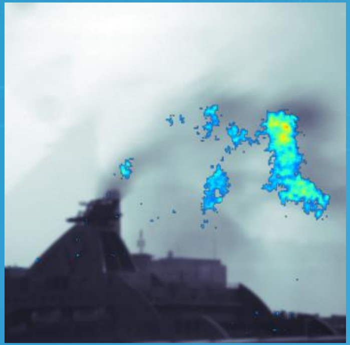




Hyperspectral imaging

- FPI combined with imaging detector
- Both spectral and spatial data
- Example: Visulization of gas distribution in stand-off detection





Comparison to pixel array-HSIs:

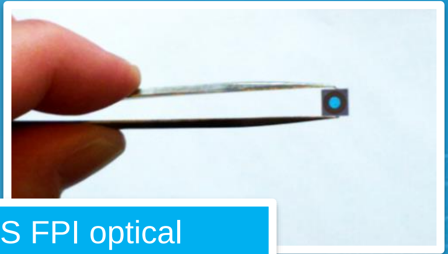
- ✓ **Smaller** size than pixel-based spectral imagers
- ✓ **Hundreds** of spectral bands
- ✓ **Does not require bulky and expensive telemetric lenses**
- ✓ Compatible with **low-cost mobile optics**!

VTT's complementary FPI technologies

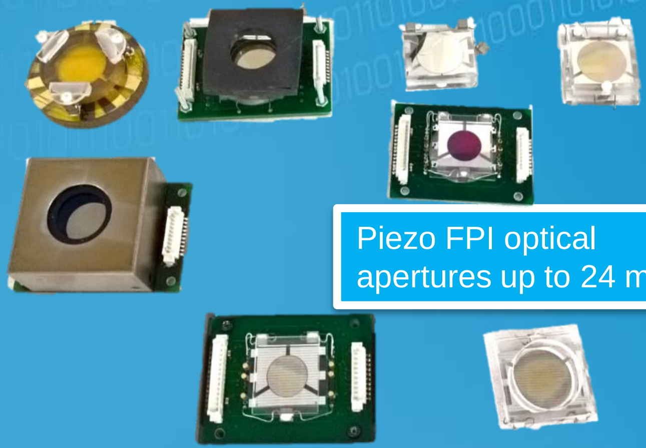
- **MEMS FPIs** for mass-producible microspectrometers in large-volume applications
  - Monolithic cleanroom fabrication processes
  - ➢ ***Hyperspectral imaging, gas sensing, IR sensors***
  - ➢ ***Automotive, mobile, IoT***

- **Piezo-actuated FPI** for small-to-medium volume applications
  - Separately assembled filter structure
  - Large optical apertures enable enhanced light throughput for high-performance applications
  - ➢ ***CubeSats, drones, medical, defense***

- **Wavelengths available from *UV to thermal IR***

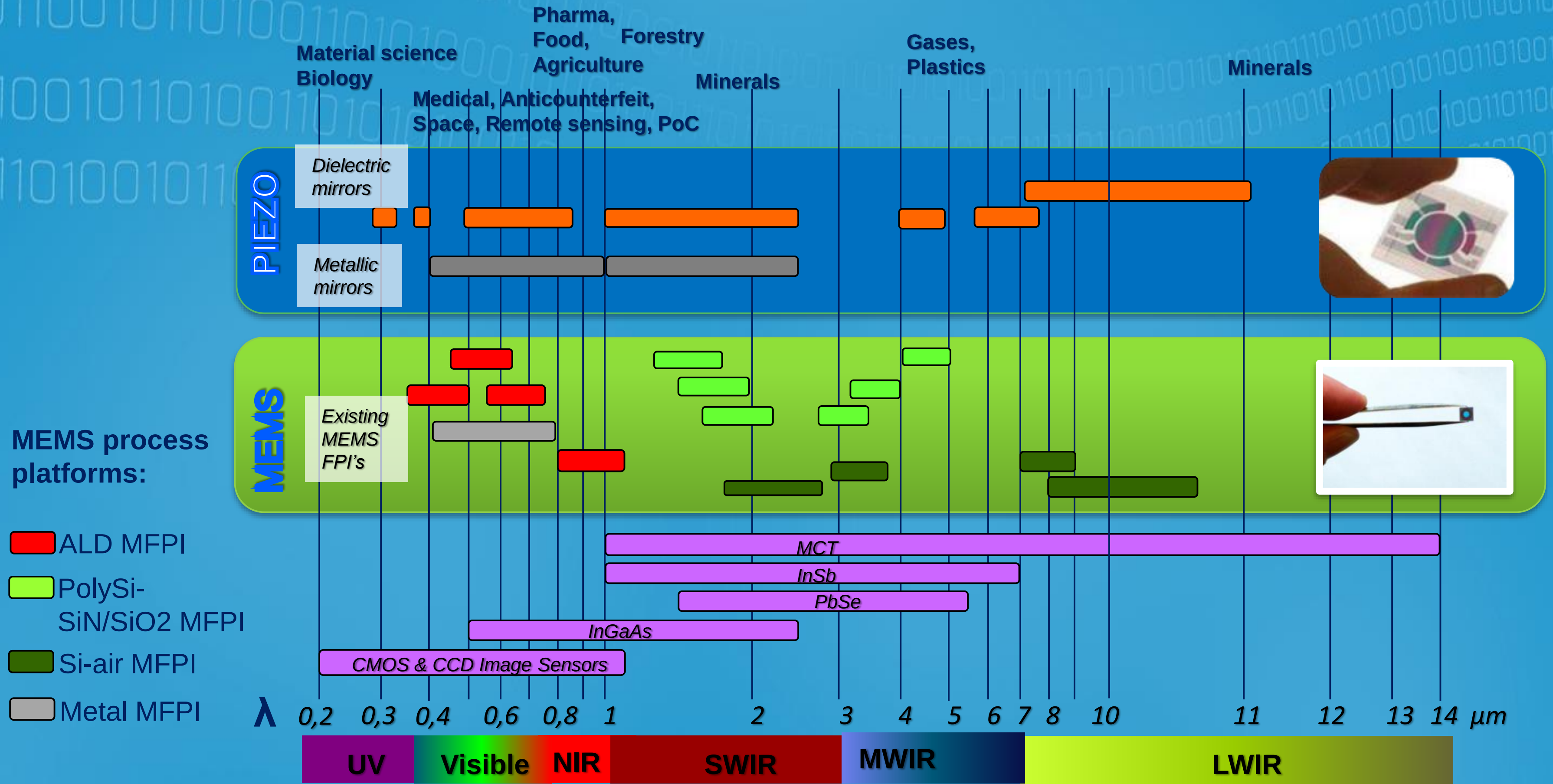


MEMS FPI optical apertures up to 4 mm



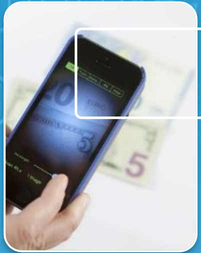
Piezo FPI optical apertures up to 24 mm

FPI platforms and examples of realized filters



FPI technology applications – examples and demonstrators

Mobile and hand-held



Mobile hyperspectral iPhone demo (2016)

Spectral Engines
NIR sensor (2016)

MEMS-based hyperspectral imager demo (2012)

Mobile CO2 sensor demo (2014)

Space and environmental sensing

Hyperspectral imagers for space instruments

- NASA OMI (2006)
- **Aalto-1 (2014-2017)***
- **PICASSO Vision (2015-2018)***
- **Hello World 2017-2018**

Drone hyperspectral imagers for forestry, precision agriculture, gas sensing and UV-Raman

Visible-VNIR (2011), SWIR (2016), UV (2016)

Health and diagnostics

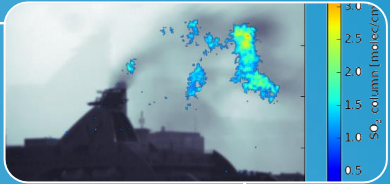
Skin cancer hyperspectral imager (2014-2017)

Hyperspectral microscope
Imaging of cells, micro well arrays & fluorescence imaging (2016)

Fundus camera
Detection of glaucoma and diabetes, oxygen saturation (hypoxia, apnea)

Brain surgery spectral imaging integrated to the Zeiss Pentero brain surgery microscope

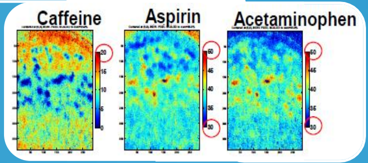
Stand-off - and and chemical detection



SO_2/NO_x ship emissions imaging (2016)

Thermal IR hyperspectral imager (2014)

UV-FPI Raman stand-off trace detection (2014)



Chemical imager for 1-2.5 µm
Distribution of active ingredients

Impact

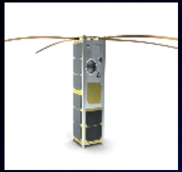
- **Customization of FPI technology** to novel applications in research- and contract projects
- **Several successfully commercialized sensing technologies**
- **Space R&D activities have also generated first commercial CubeSat mission with Reaktor Space Labs**

Space R&D activities:

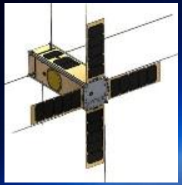
Hyperspectral imaging for small satellites

- Traditional optical remote sensing from nanosatellites can be challenging due to the limited size and capabilities of nanosatellite platforms
- Larger optical apertures are hard or even impossible to realize within a 3U CubeSat platform
- Tunable FPI spectral filter offers high throughput which enables instrument miniaturization
- Currently three nanosatellite missions with VTT’s miniaturized spectral imagers are planned to be flown in 2017-2018

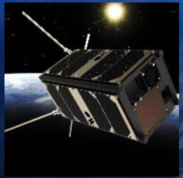
CubeSat missions



1. Aalto -1 imager will image land and ocean targets at wavelengths 500 - 900 nm to demonstrate the technology at low Earth orbit environment



2. VISION-instrument on-board the Belgian PICASSO nanosatellite will look at the Sun through the Earth’s atmosphere and record the atmospheric transmission spectrum between 430 - 800 nm at different altitudes



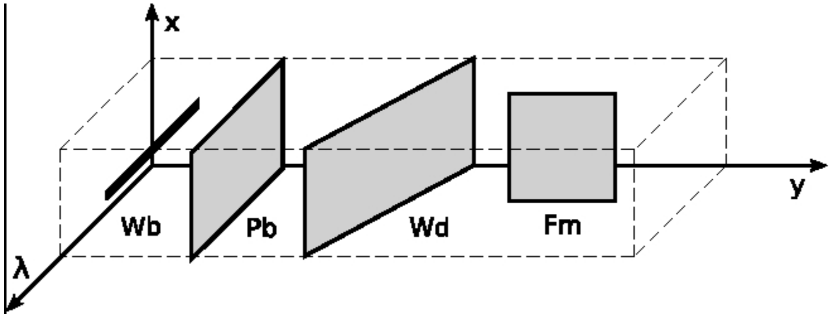
3. Reaktor Hello World –satellite will image in the infrared region (1000 - 1600 nm). These wavelengths will be used for vegetation monitoring, but it is also possible to use this range for mineral detection.

Classification of imaging spectrometers for remote sensing applications

- Spectral imagers have traditionally been realized as push-broom instruments, where the movement of the spacecraft provides the other spatial dimension for the images.
    - Requires a stable and precise attitude control, which can be difficult to achieve with a nanosatellite

Table 1 Classification of imaging spectrometers.

	Along-track scanning			
	Whiskbroom	Pushbroom	Windowing	Framing
Spectral				
Filtering	• Multiband radiometer	• (No known examples)	• Filter array • Wedge filter • Linear variable filter	• Band-sequential • Filter wheel • Tunable filter (AOTF or LCTF)
Dispersive	• Grating or prism	• Grating or prism	• (No known examples)	• Image slicer • Tomographic
Interferometric	• Traditional FTS • Point FTS (Michelson)	• Static FTS (Sagnac)	• Static FTS (Mach-Zender, Sagnac)	• Traditional FTS (Michelson)



Ref. R. Sellar&G. Boreman, “Classification of imaging spectrometers for remote sensing applications“, Opt.Eng. 44(1), Jan 2005.

Ref. X. Prieto-Blanco & al., “Optical configurations for Imaging Spectrometers, Comput. Intel. For Remote Sensing, SCI 133, pp. 1-25, 2008 Springer-Verlag, Heidelberg 2008.

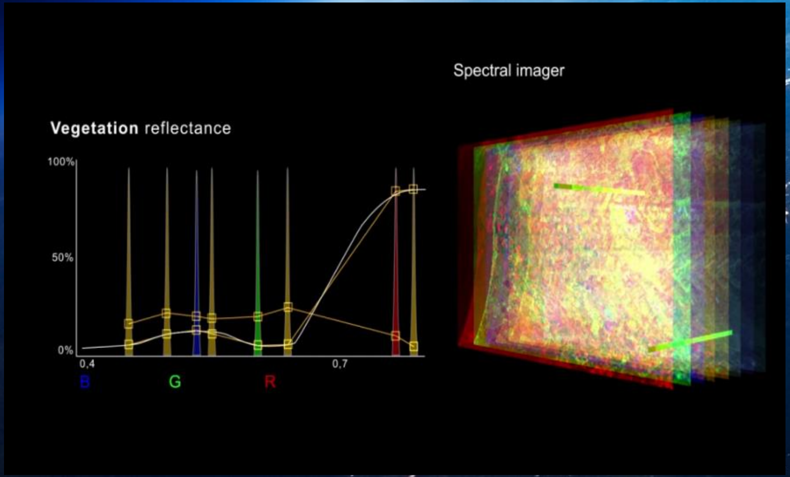
Spectral imaging with tunable filters

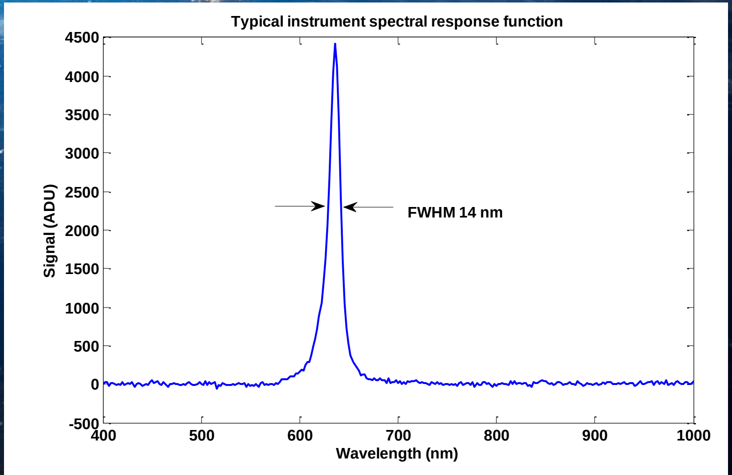
Selectable wavelengths reduce downlink data

Good spatial resolution

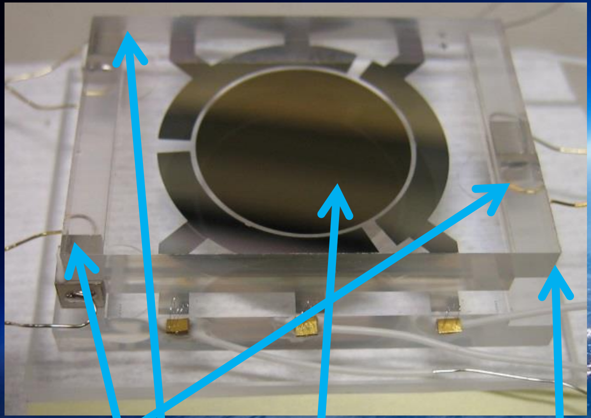
Programmable software configuration - Customization of operation wavelengths enables a large variety of applications with same hardware

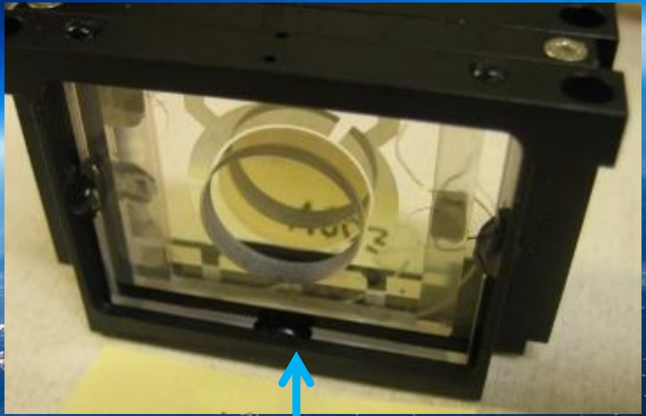
- Tunable filter imagers acquire 2D images at a given wavelength
- Spectral data cube is constructed by taking multiple images of the same target at different wavelengths
- This method is more robust spatially, as the whole 2D scene is imaged at once, which makes the technology suitable for more unstable platforms, such as UAVS or nanosatellites

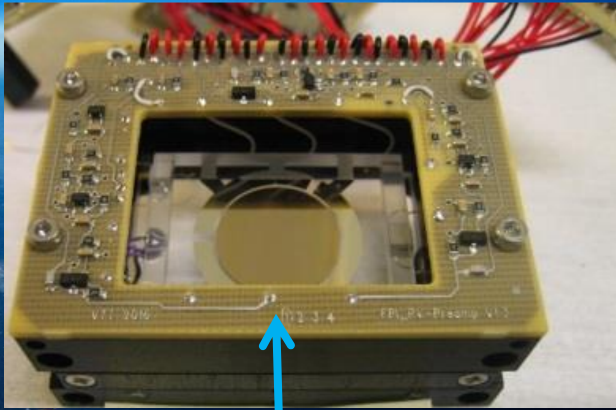




Piezo FPI assembly concept for space environment







Piezo actuators

Metal (Ti-Ag-SiO2) FPI mirrors

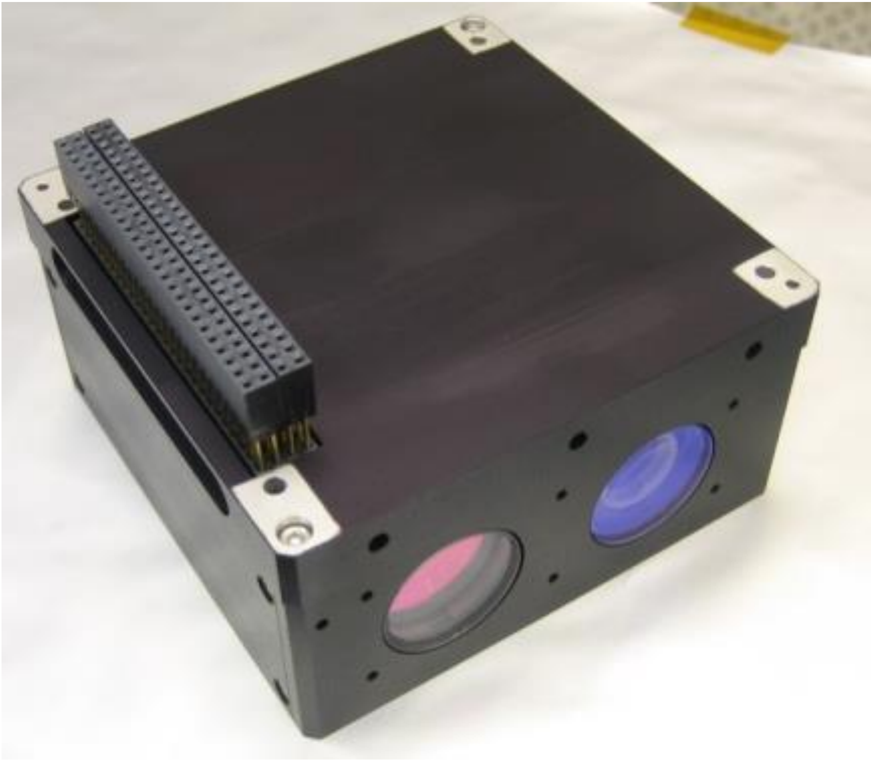
Fused Silica support plate

Supporting frame

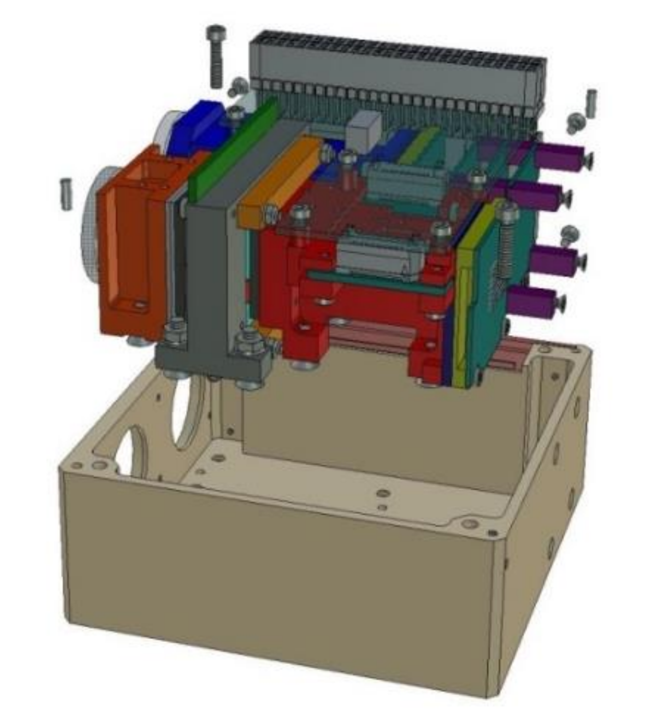
FPI Preamplifier PCB

Mission 1 – Aalto-1 technology demonstrator

- Launched 23.6.2017
- Two cameras: the spectral imager (SPE) and a normal RGB camera (VIS)
- Size: 0,5U, weight < 600g
- 3 operational modes: 6, 25 and 75 wavelengths
- Built-in temperature compensation
- Operation temperature: +10 °C to +55 °C
- On-board calibration possibility



Aalto-1 Spectral Imager – AaSI

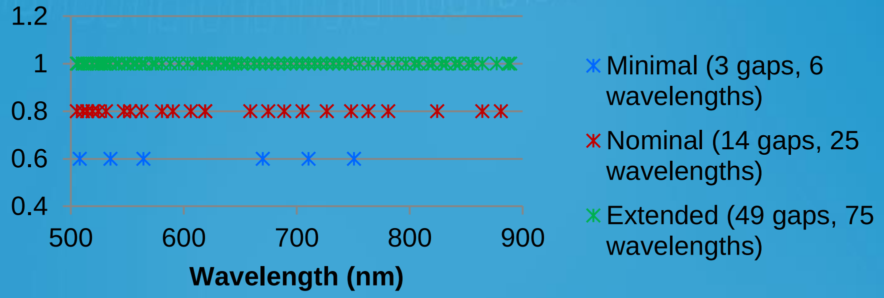


Spectral camera Module (SPE)

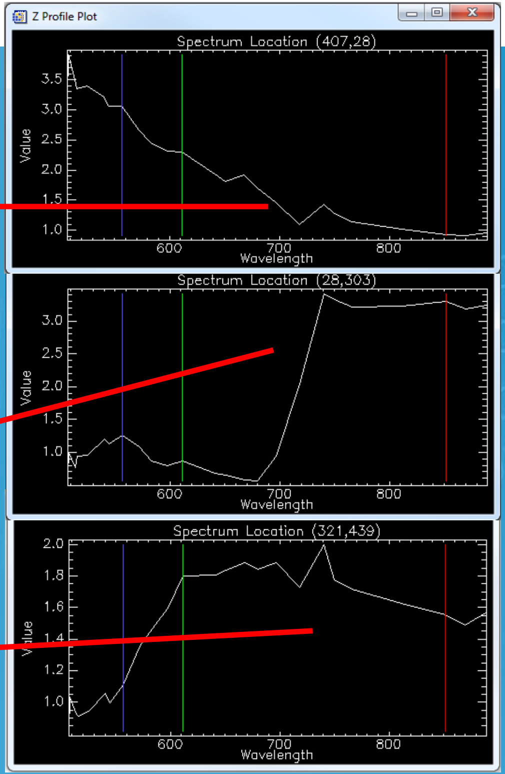
- Field of View: 10 deg x 10 deg
- Focal length 32 mm
- F-number 3.4
- Image size 512x512 pixels
- Ground pixel size ca. 200 m from 600 km orbit
- Selectable wavelength bands between 500 and 900 nm

Visible RGB-camera (VIS)

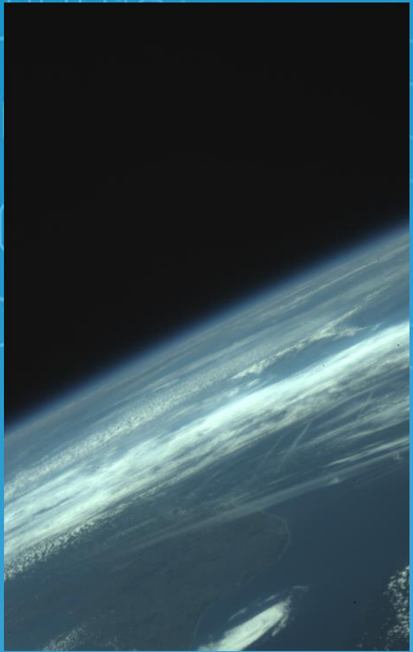
- Commercial micro-objective (Kokagu AVR40)
- Field of view 15 deg x10 deg
- Focal length 40 mm
- F-number 3.2
- Image size: 2048 x 1280 pixels
- Ground pixel size ca. 100 m from 600 km orbit



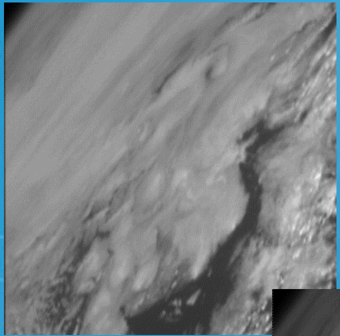
Ground imaging tests



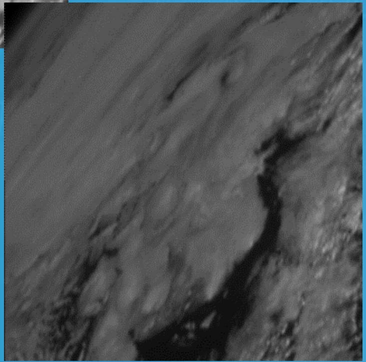
First images from AaSI



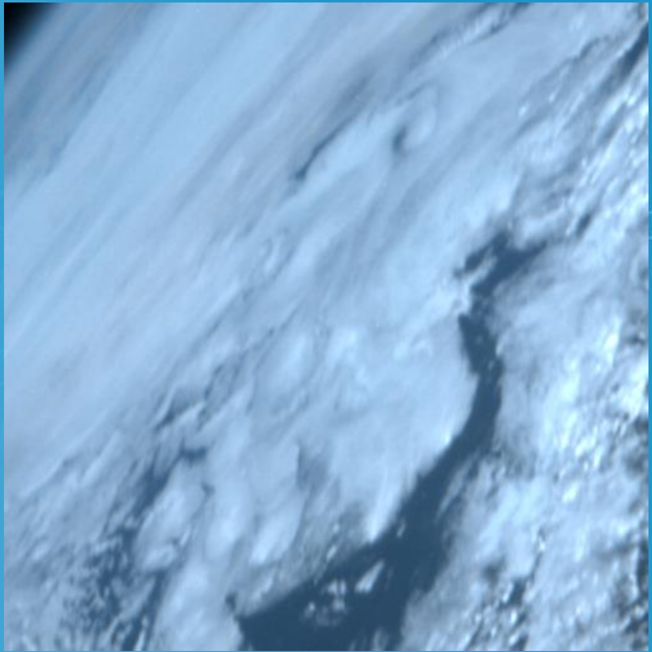
RGB image



509 nm



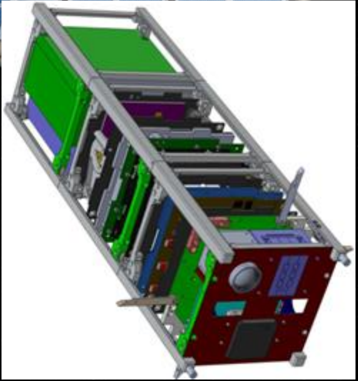
671 nm



False color image: red pixels show 671 nm, blue pixels 509 nm (green pixels are average).

Mission 2 - PICASSO VISION

- **Picasso: Picosatellite for Atmospheric and Space Science Observations**
- **VISION: Visible Spectral Imager for Occultation and Nightglow**
- **2 scientific experiments for Earth observation**
  - **VISION: retrieving vertical profiles of ozone and temperature via Sun occultation**
  - **SLP: studying the ionosphere (Langmuir probe)**



Accepted as ESA In-Orbit Demonstrator with kick-off on 21.10.2014

Belgian Institute for Space Aeronomy (BEL), prime: management, mission definition & scientific aspects (incl. data analysis), whole development of SLP & software of VISION

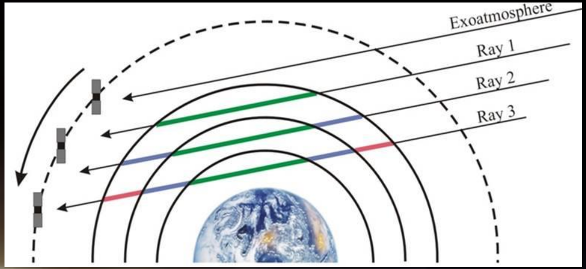
CSL: system engineering and PA/QA

Clyde Space: platform development & payload items integration, tests, ground-station & operations

VTT: VISION hardware

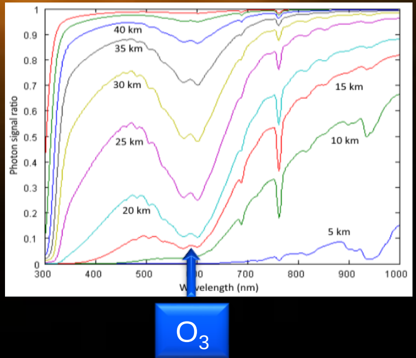
Solar occultation and mission scientific goals

- Observation of sunsets and sunrises through the Earth's atmosphere
- Occultation technique is self-calibrating (dividing by out-of-atmosphere signal)
- Vertical distribution retrieved by onion peeling method



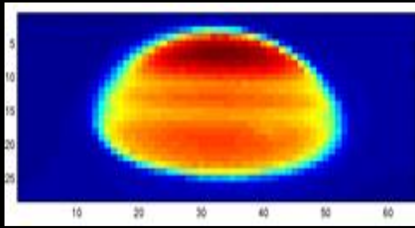
Scientific goal 1: Polar and mid-latitudes stratospheric ozone vertical profiles

Absorption increases when looking deeper in the atmosphere (lower tangent heights). Ozone retrieved from the Chappuis band (~600 nm)



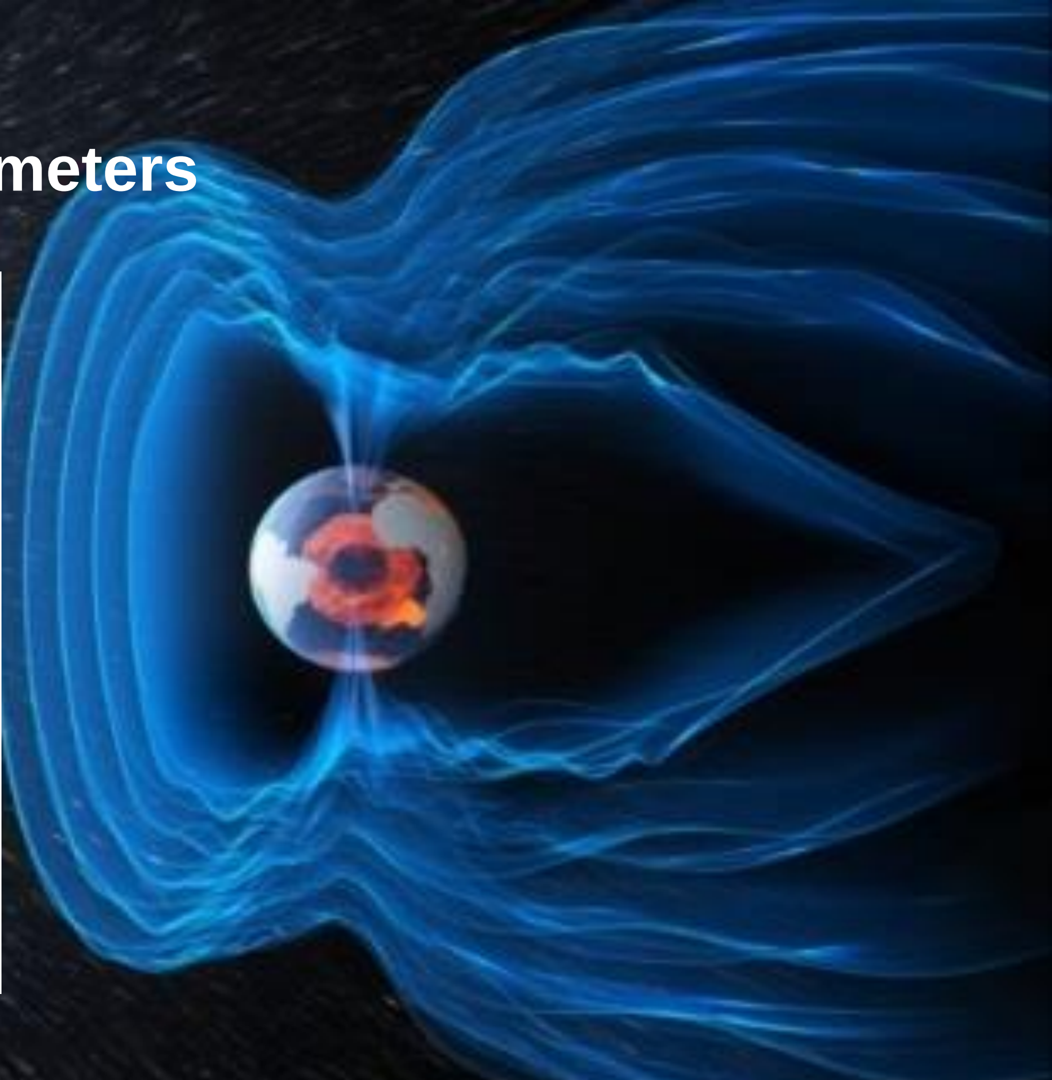
Scientific goal 2: Mesosphere and stratosphere temperature profiles

Methods: 1) shape of the sun, 2) sunlight dilution



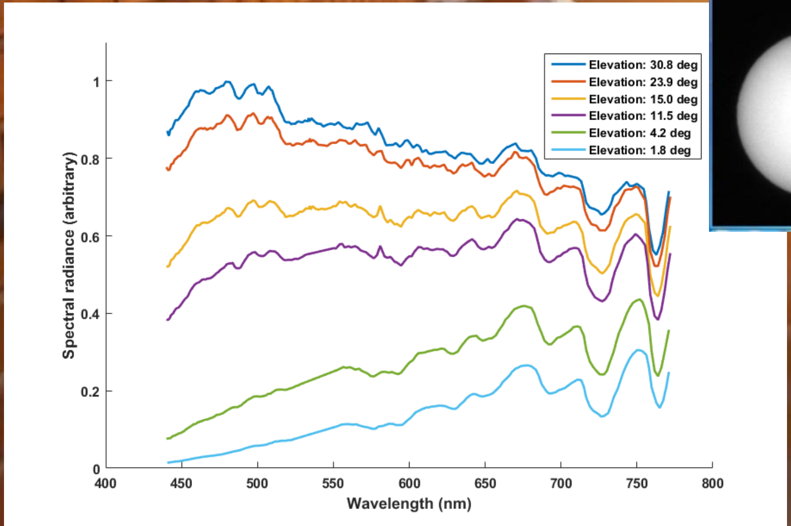
VISION instrument parameters

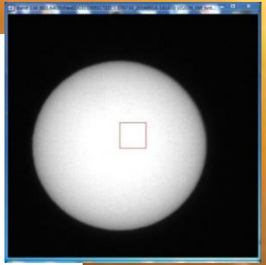
Parameter	Value	Notes
Field of View	2.5° x 2.5°	f = 244 mm
Image size	2048 x 2048 RGB pixels	1024 x 1024 spectral pixels
Spectral range	430 – 800 nm	
Spectral resolution (FWHM)	< 10 nm	
Mass	526 g	
Power	< 3W	
Operation temperature	-35 °C to +55 °C	



Ground based measurements

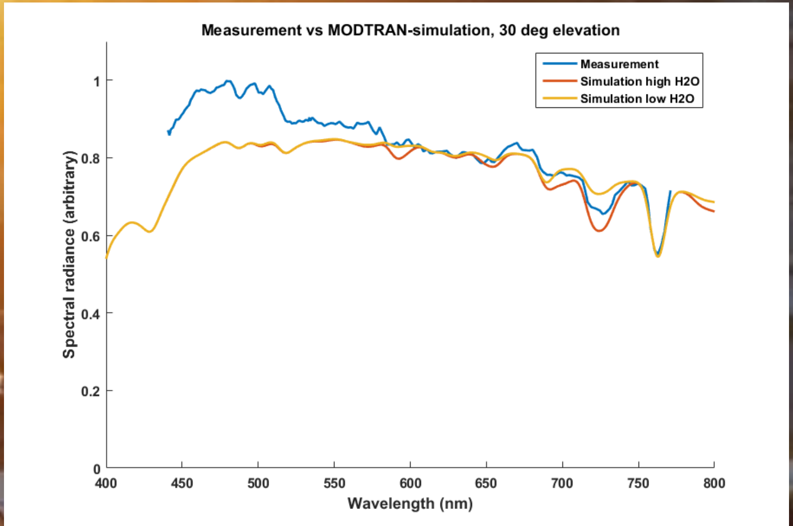
Measurement time: noon to sunset





187 wavelengths between 440 nm – 770 nm at elevations from 30 deg to 2 deg

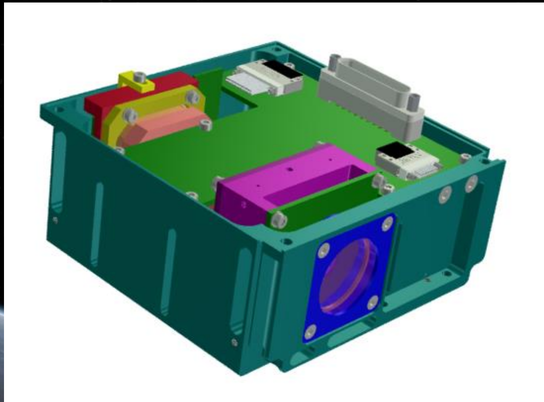
Comparison to simulation



Good correlation at 600 nm – 770 nm.

Mission 3 - Hello World

- In-orbit demonstration mission
- NIR spectral imager payload
  - 1000 – 1600 nm
  - 512 x 512 pixels
- RSL reusable CubeSat platform, 2-6U
- Reconfigurable software
- Linux application processor
- S-band user communications
- Launch: Q2/2018

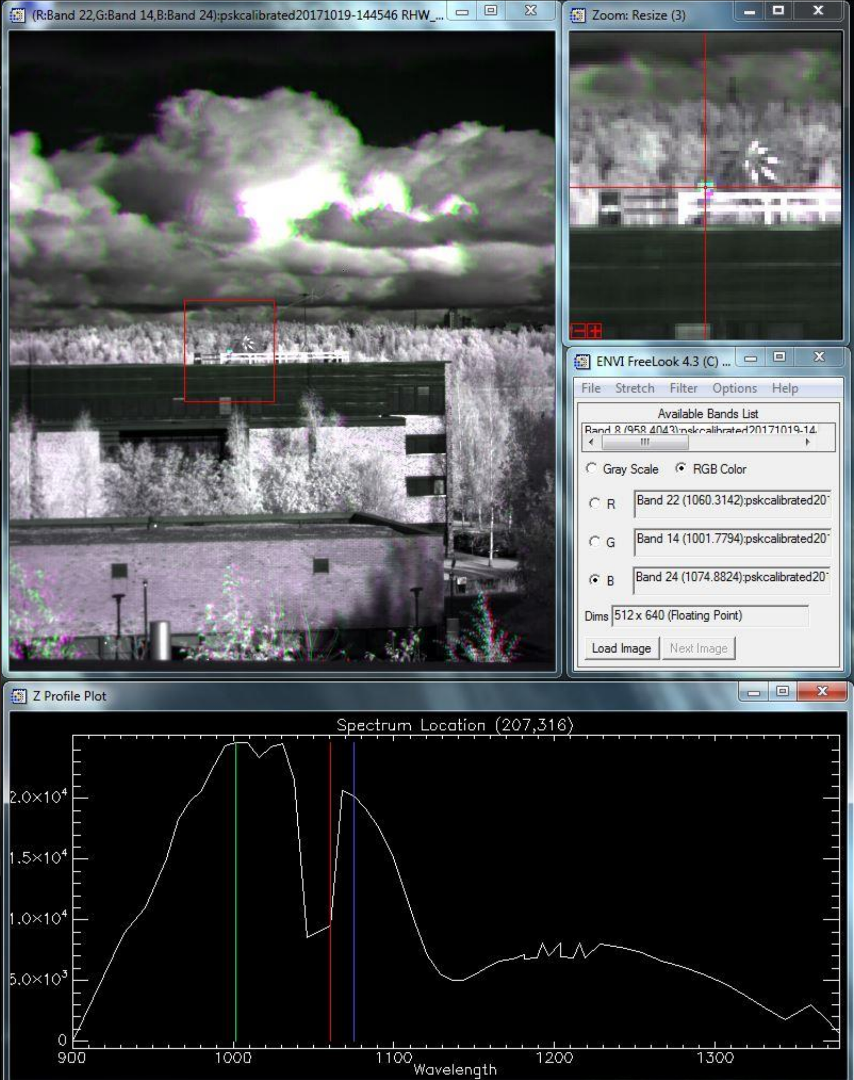


VTT

Reaktor Space Lab RSL

Ground measurements
for Hello World NIR/SWIR payload

SWIR hyperspectral imaging example - detecting person on a roof based on reflectance spectra:



Future plans

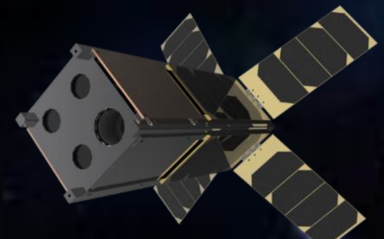
Asteroid Spectral Imager mission (ASPECT)

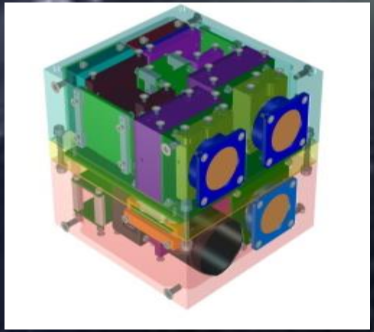
- 3U CubeSat capable of measuring from 500 nm to 2500 nm (can be extended to 3000 nm)
- Aims for measuring asteroid composition
- Instrument envelope: 1U
- 2 spectral imagers, VIS and NIR
- 1 SWIR spectrometer
- Includes the AOCS navigation camera

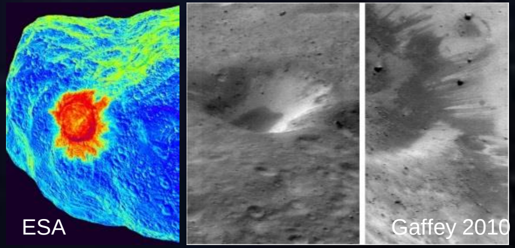
VIS channel
Based on Aalto-1 Spectral Imager
Spectral range: 500 – 900 nm
Image size: 614 x 614
Spectral bands: ca. 14

NIR channel
Spectral range: 900 – 1600 nm
Image size: 256 x 256 / 512 x 512
Spectral bands: ca. 24

SWIR channel
Spectral range: 1600 – 2500 nm
Image size: N/A (1 pixel)
Spectral bands: ca. 30







Summary and conclusions

- VTT has developed spectral imager solutions for UV, visible and infrared regions
- FPI-based technology enables small payload miniature hyperspectral imaging with CubeSats
- The technology is easily tailored for different mission needs
- Three missions to be flown in 2017 - 2018

Contact:
anna.rissanen@vtt.fi
antti.nasila@vtt.fi


TECHNOLOGY FOR BUSINESS