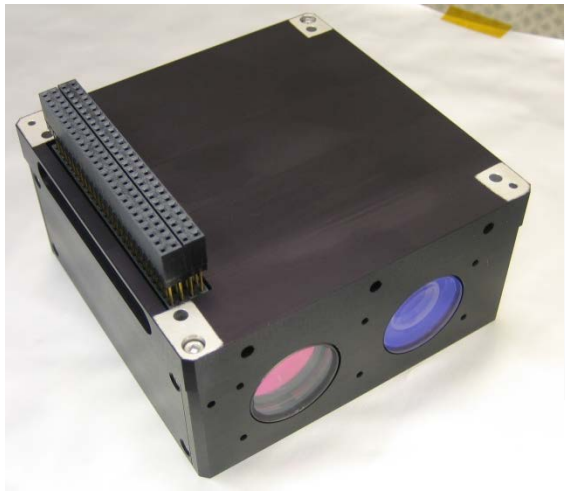


Aalto-1 Spectral Imager

Status update: Towards Flight Model

9th ESA MNT Round Table, Lausanne, Switzerland

10.6.2014

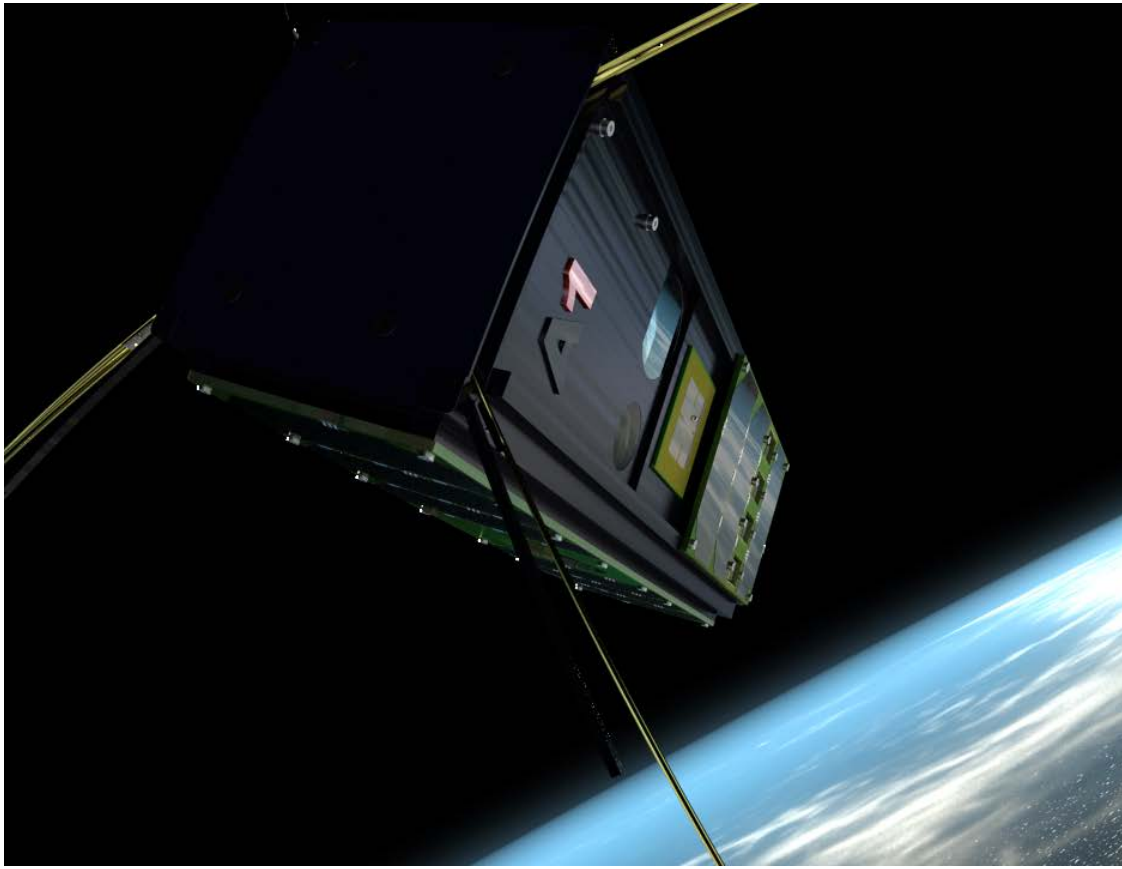
Antti Näsilä, K. Viherkanto, H. Saari, C. Holmlund, I. Näkki, J. Mäkynen, A. Akujärvi, R. Mannila, U. Kantojärvi, T. Antila, H. Toivanen

VTT Technical Research Centre of Finland

Outline

- Project overview
- DM Integration & calibration
- DM test campaign
- Imaging tests
- Summary

Image credit: Pekka Laurila / Aalto-1 Team



Project overview

The Aalto-1 Mission

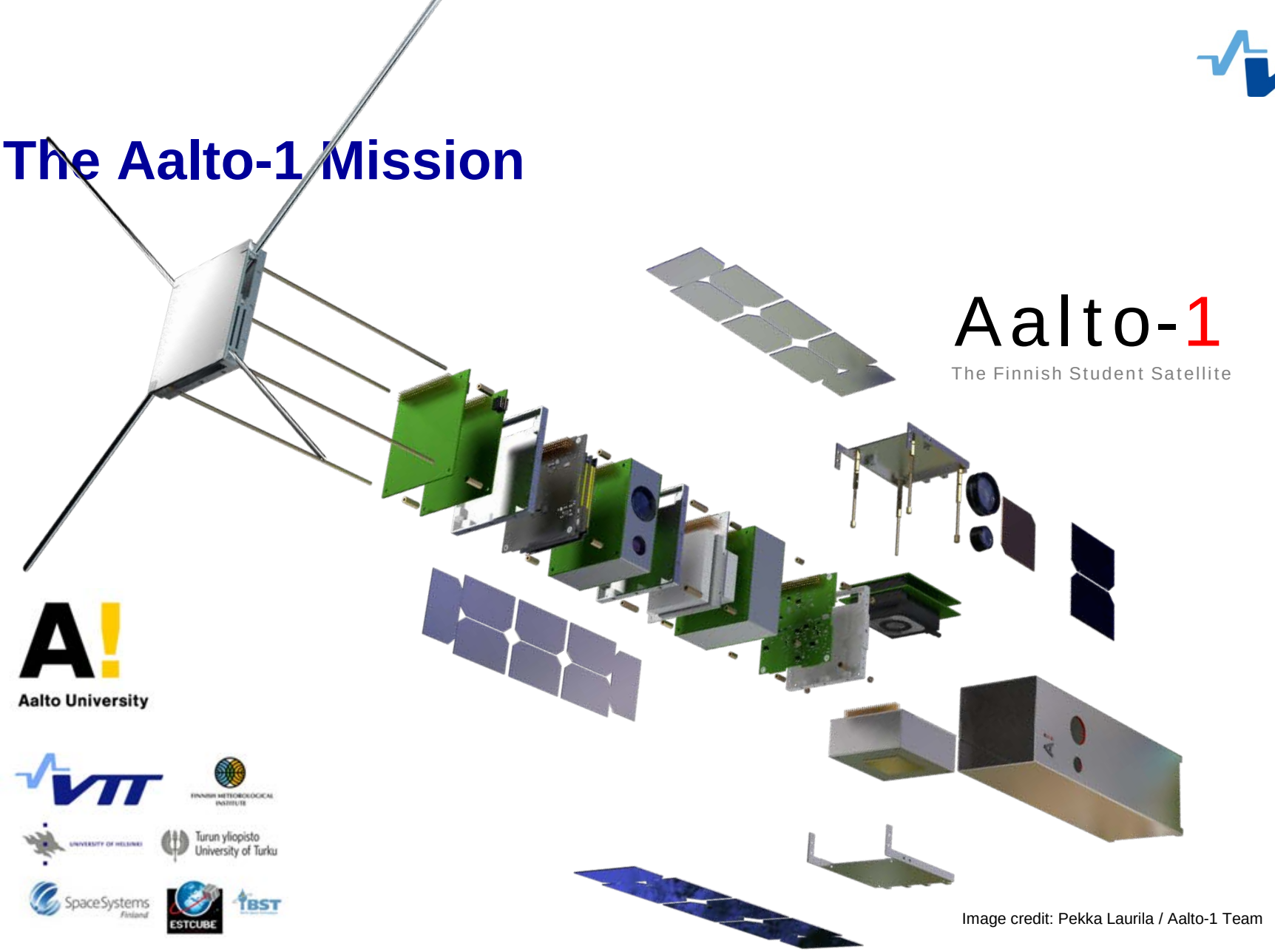
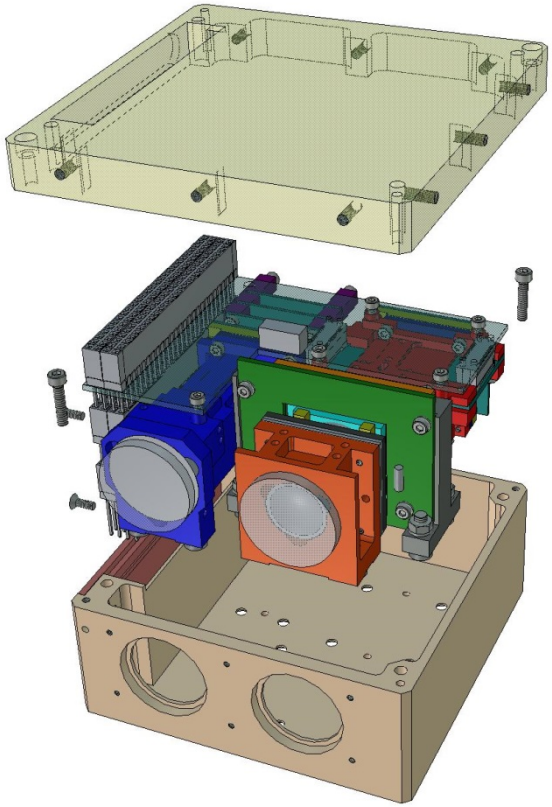
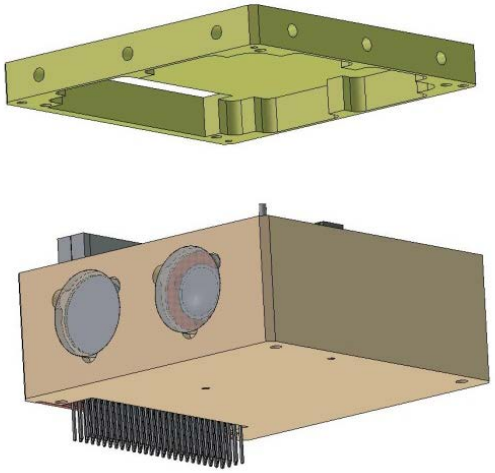


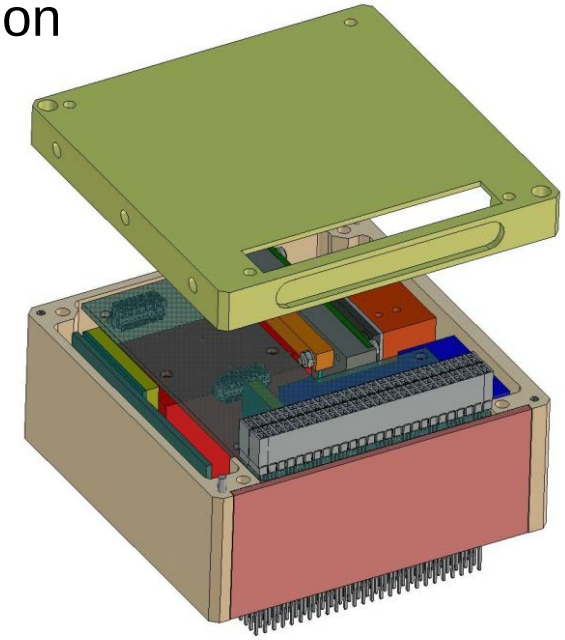
Image credit: Pekka Laurila / Aalto-1 Team

Aalto-1 Spectral Imager (AaSI)



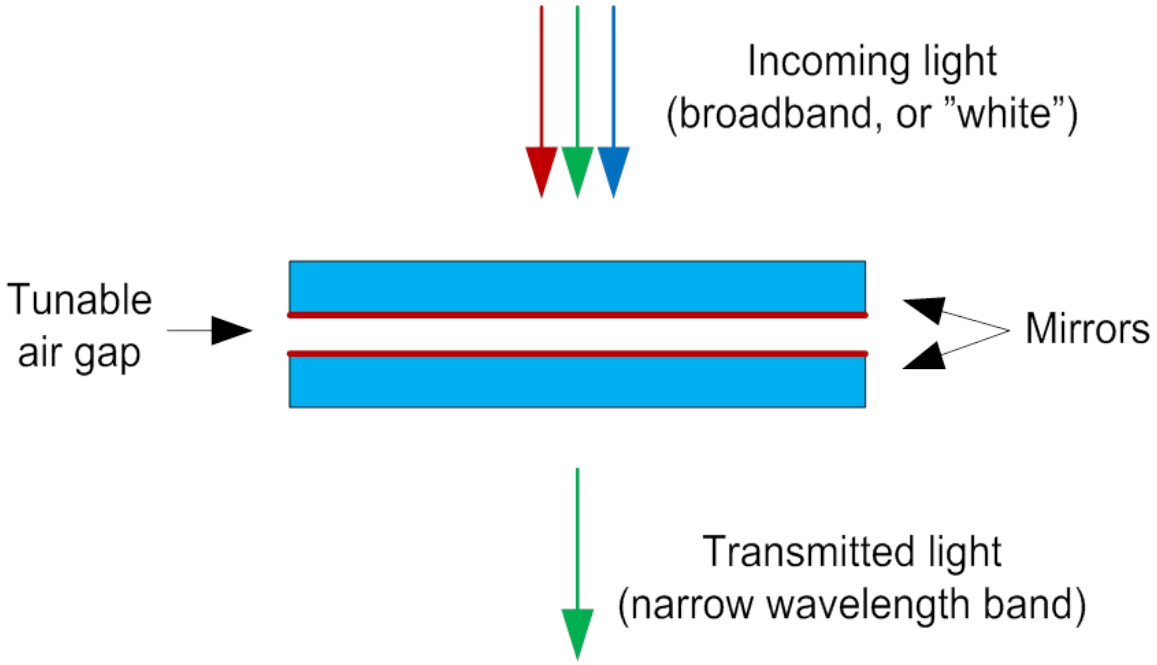
- Includes a spectral imager and a normal RGB camera
- Dimensions 97x97x48 mm
- Mass < 600g, Power < 3W
- CubeSatKit connector interface
- Technology demonstration





Aalto-1 Spectral Imager (AaSI)

Fabry-Perot Interferometer technology

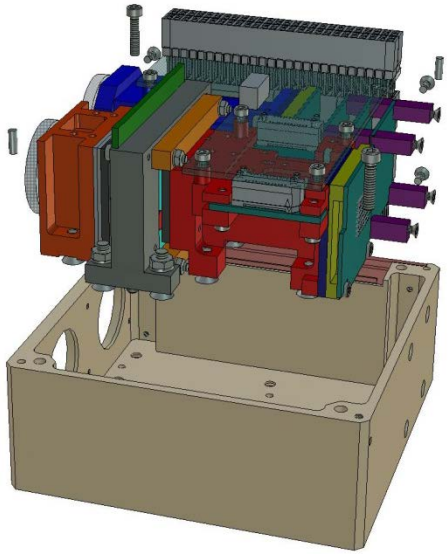


Basic equation:

$$m\lambda = 2d$$

where m is operation order
and d is air gap width

Aalto-1 Spectral Imager (AaSI)

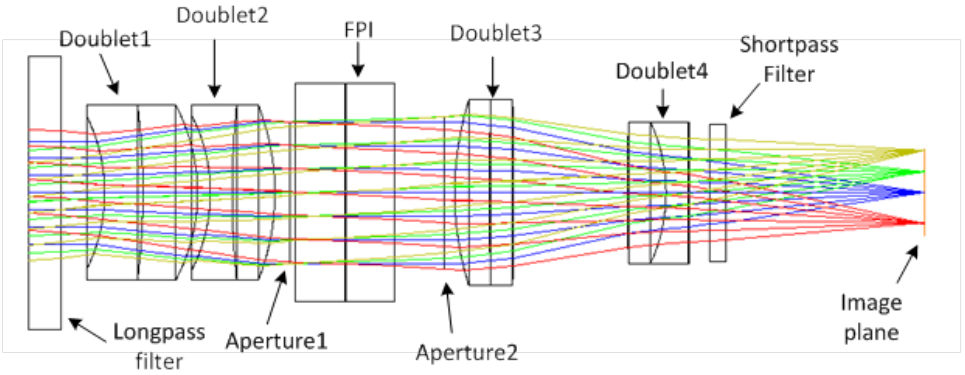


Spectral camera Module (SPE)

- 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



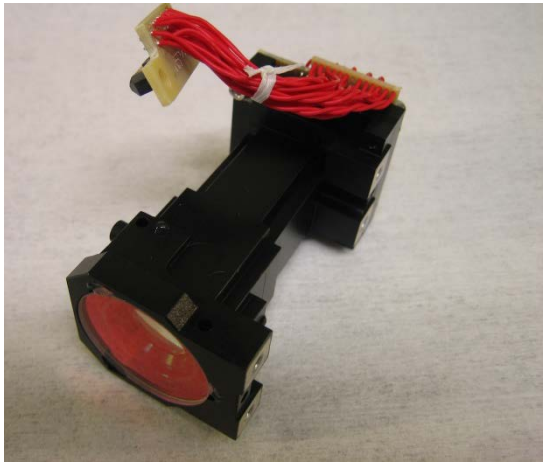
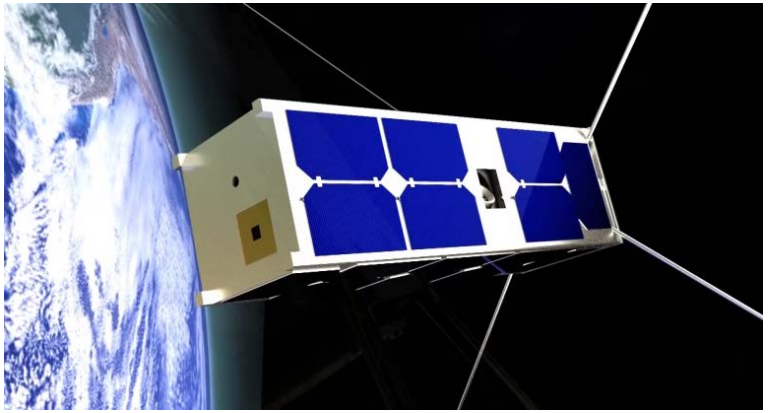


Image credit: Pekka Laurila / Aalto-1 Team



Benefits of AaSI

Pros:

- Wavelength bands relevant for a specific appliction can be selected independently.
- Good optical throughput
- Moderate spectral and ground resolution
- Compact and robust design

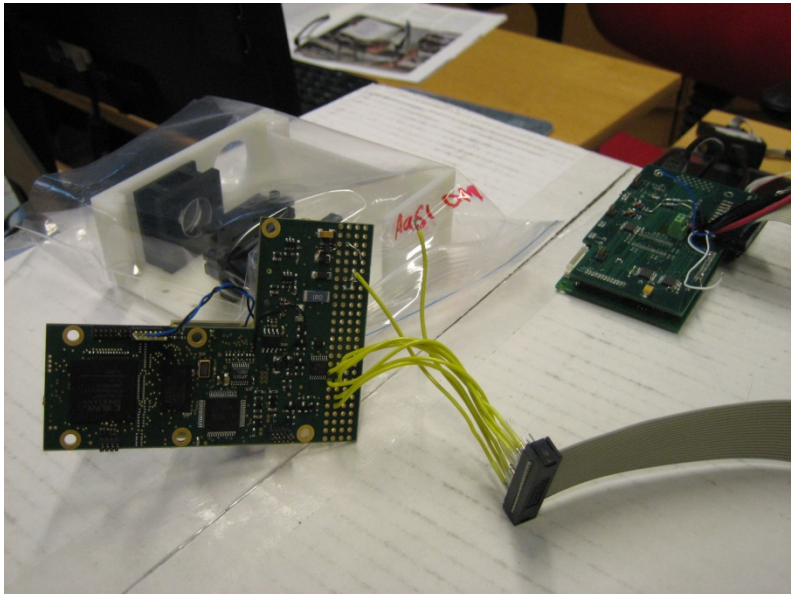
Photo credit: Tuomas Tikka / Aalto-1 Team

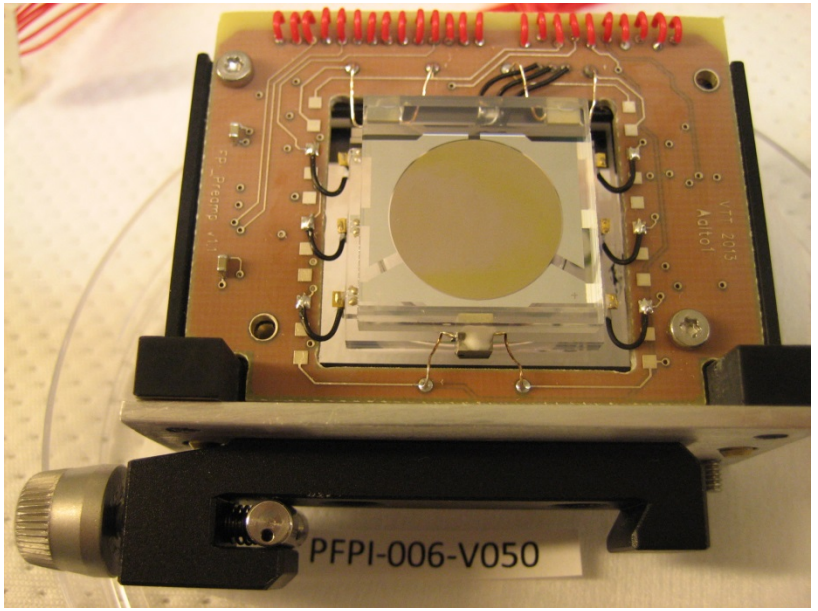
Cons:

- Rather narrow field of view
- Moderate spectral and ground resolution
- There's a delay between spectral bands

DM Integration

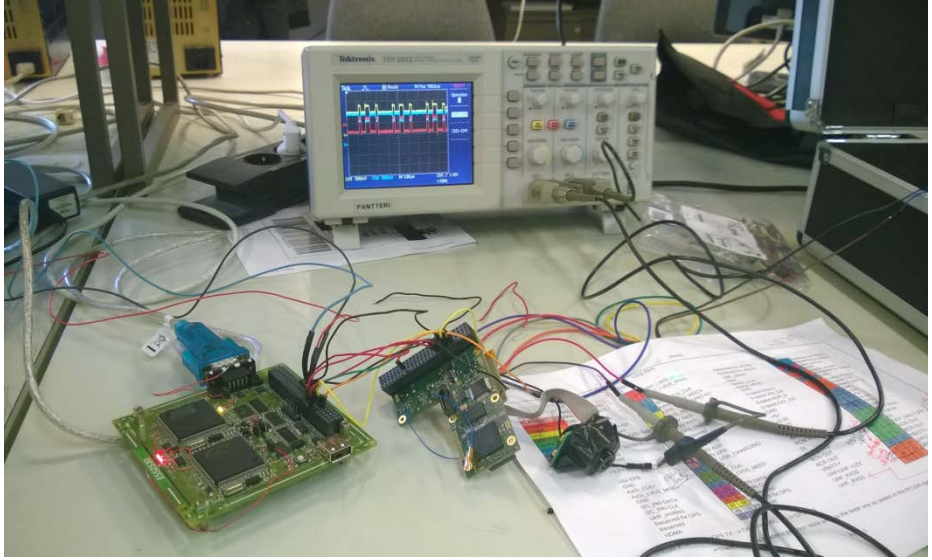
DM integration
Status in November 2013





DM integration

Status January-April 2014



Writing the software…

Visiting RADEF for proton irradiation testing…

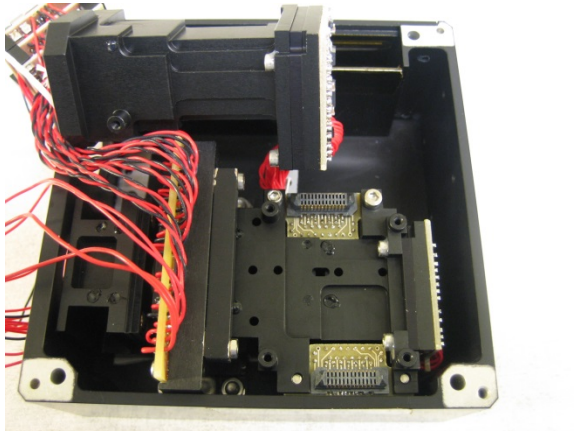
Testing Aalto-1 on-board computer interface…

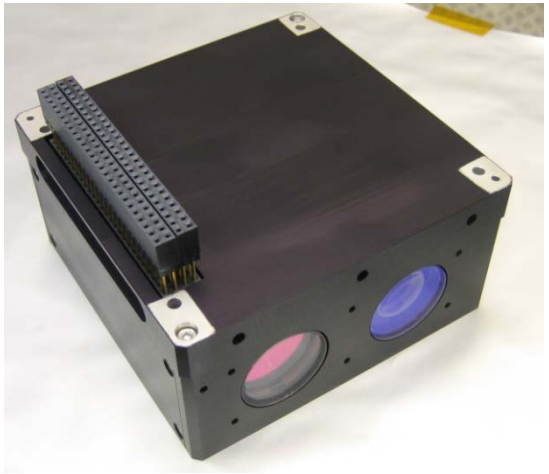
Focusing the cameras…

Waiting for the last mechanical parts…

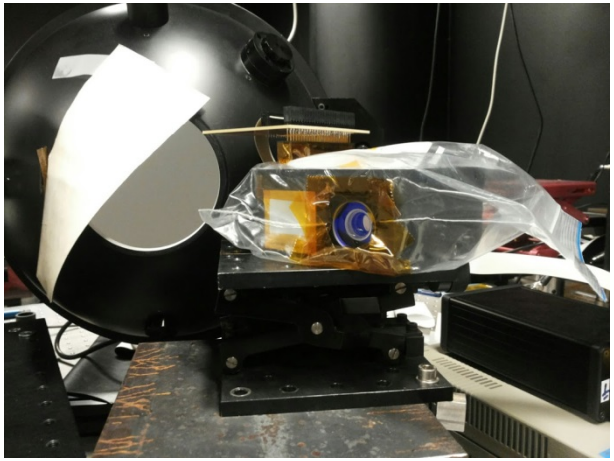
DM integration

Status in May 2014



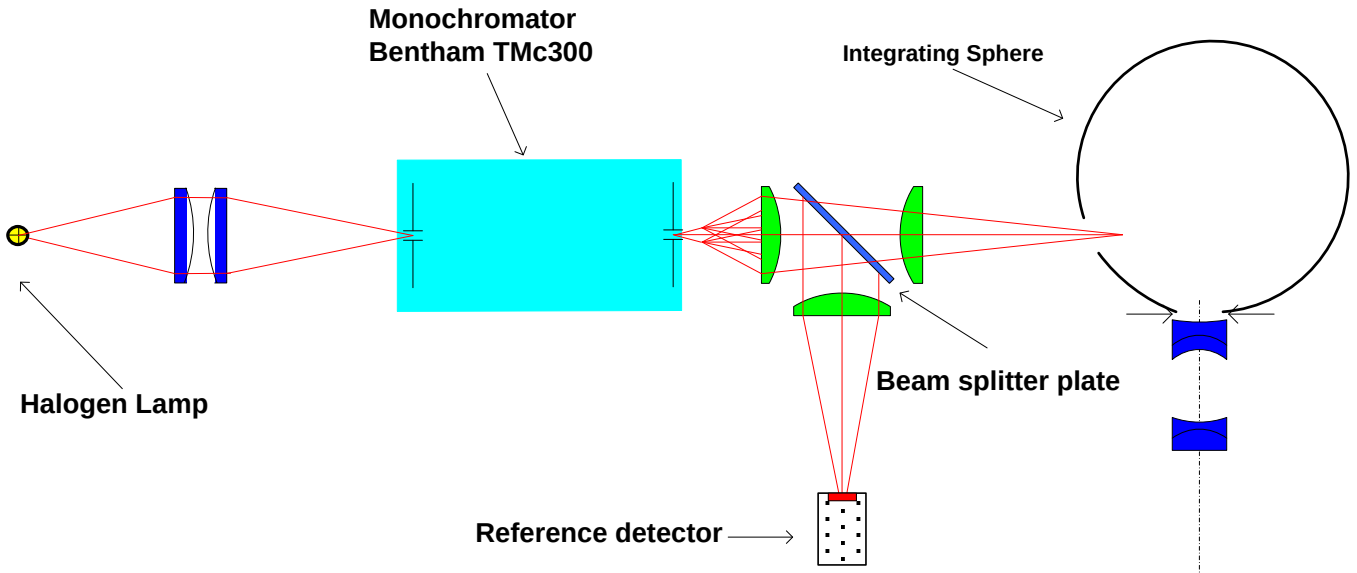


AaSI DM fully integrated and ready for testing



DM Calibration

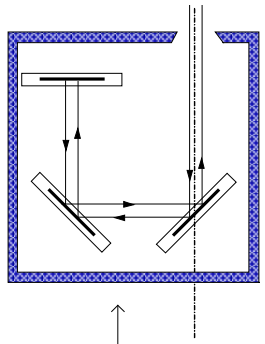
Calibration setup



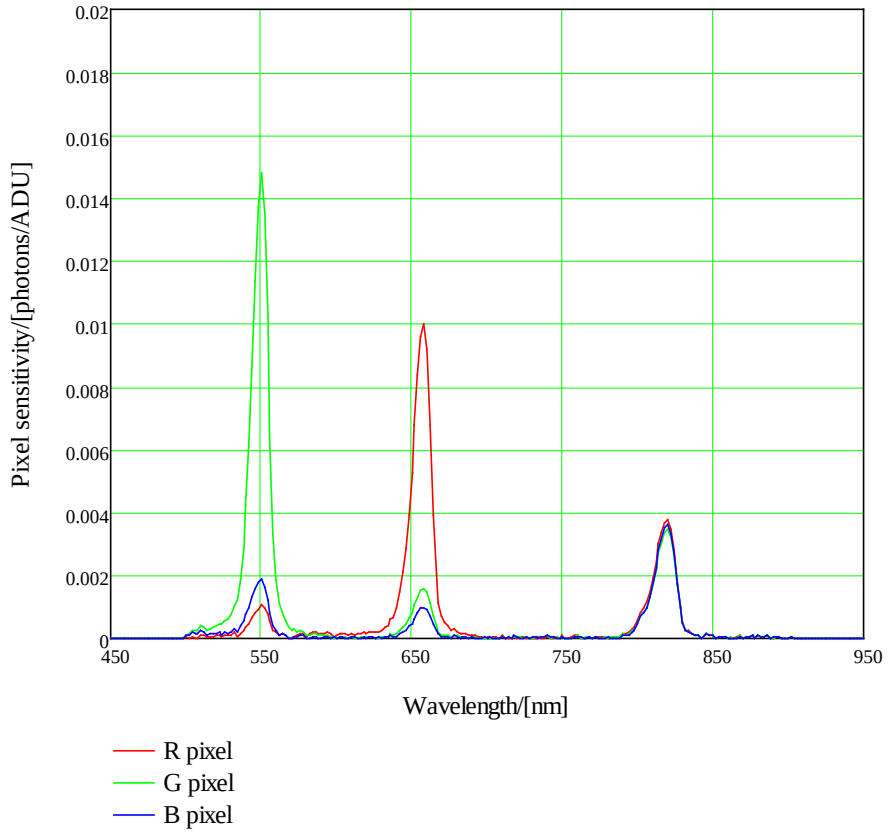
First the spectral photon flux entering the spectral imager is measured

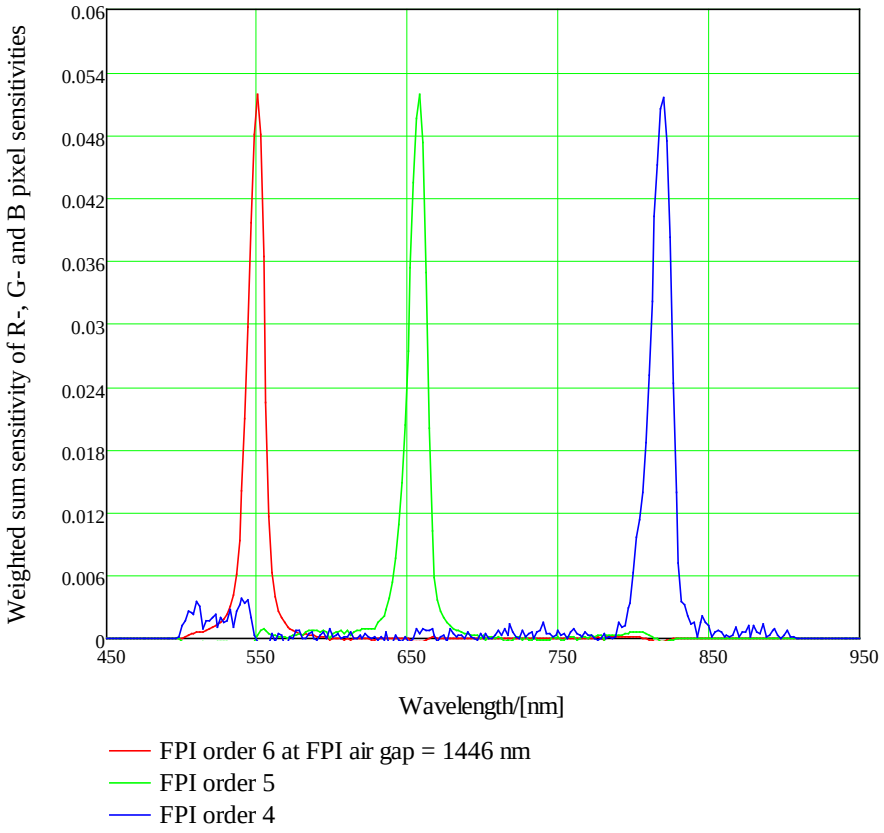
After this the signal of the RGB image sensor at selected air gap values is measured at the same wavelengths

or



Typical result of an FPI Hyperspectral Imager Calibration





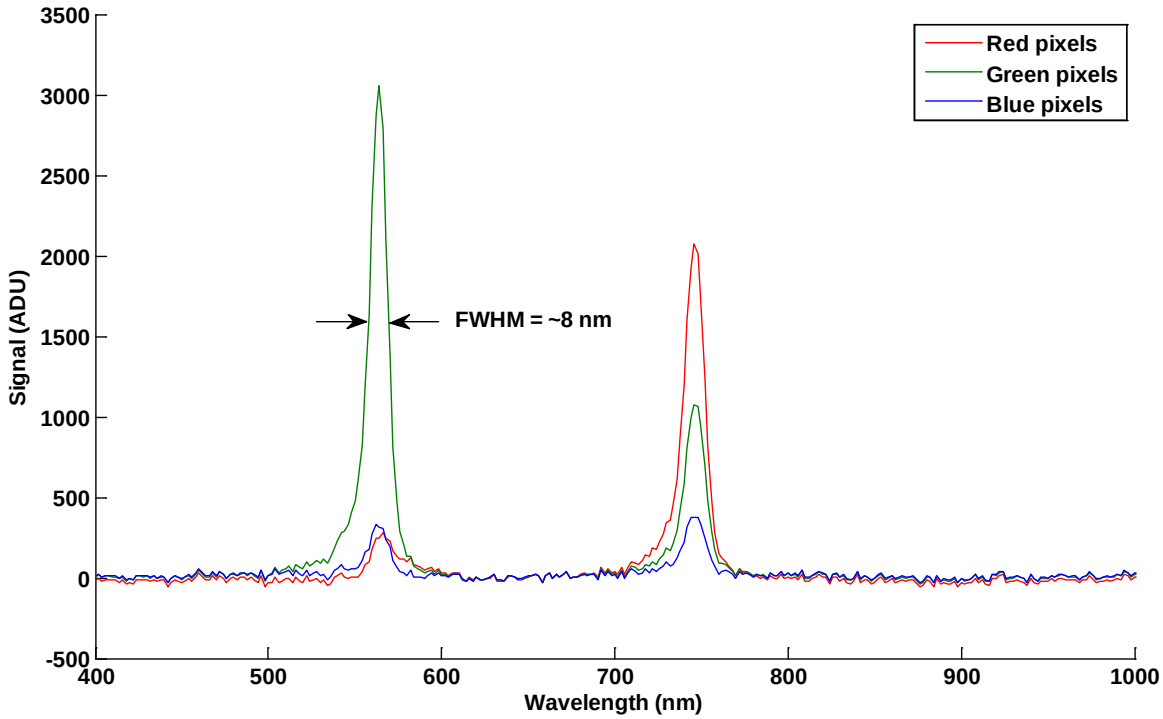
Measured bandwidth

Original PFPI FWHM specification: 10 – 30 nm

Measured FWHM = 5 – 15 nm depending on interference order

Spectral performance well within specifications

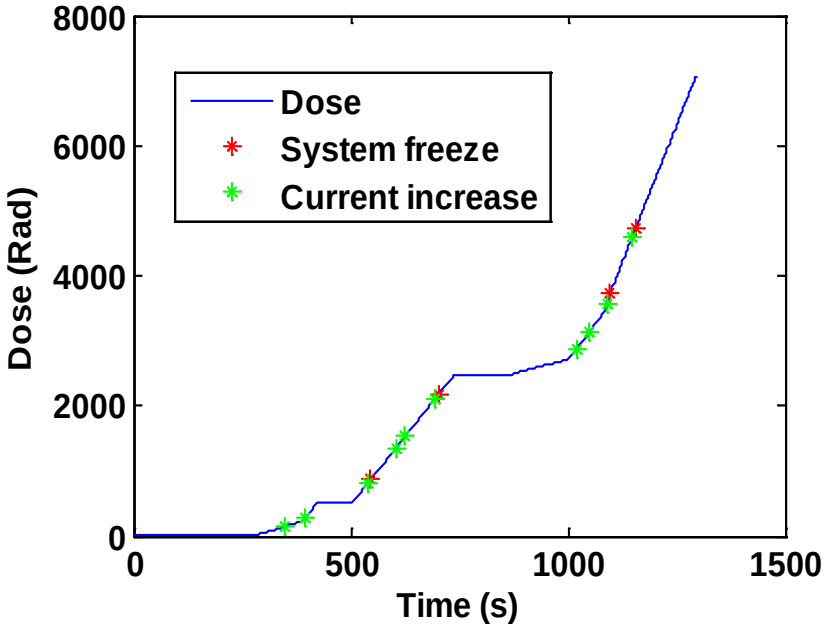
Measured spectra at air gap ca. 950 nm

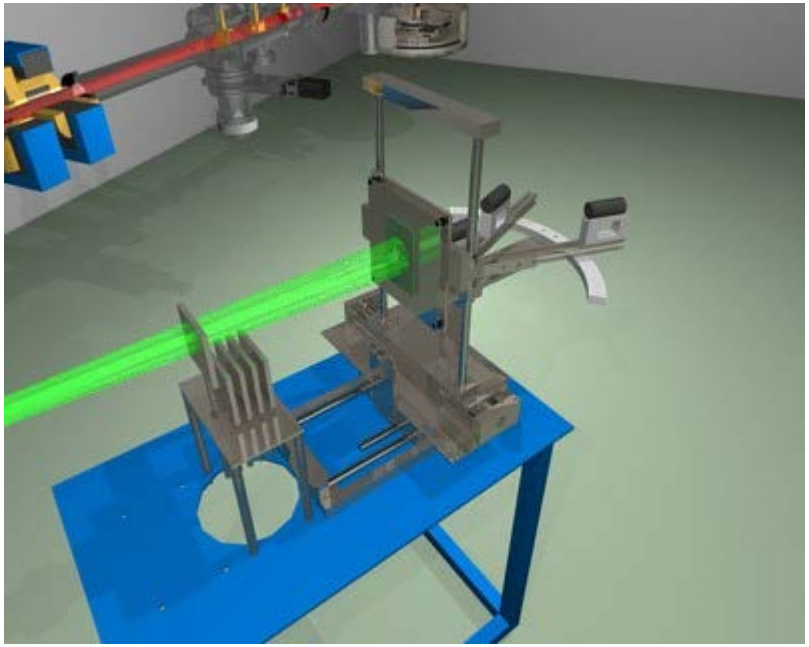


Proton irradiation tests
RADEF, Jyväskylä, Finland

RADEF Proton station

Proton energy: 50 MeV





Radiation test summary

- System failed to boot after a dose of 4.7 krad due to a failed voltage supervisory circuit
  - The voltage threshold of the circuit drifted by 28 mV and thus went out of the design limit
  - This caused the circuit to prevent the bootup of the microcontroller
- System booted and operated normally after bypassing the supervisor circuit
- For the flight model the circuit will be upgraded to a more robust design

Environmental test results

Thermal cycling

Operational range: 30 +/- 15 °C

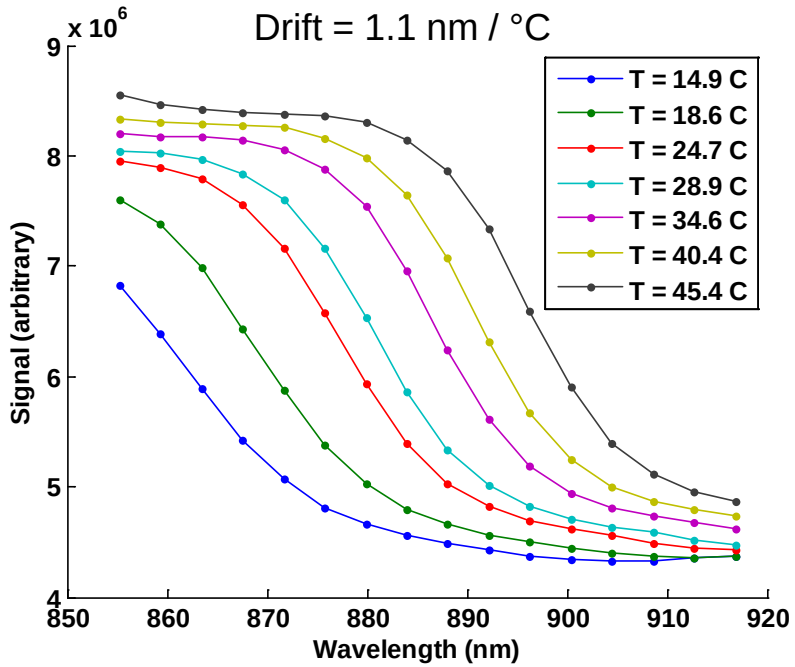
- Quick thermal characterization test was done before vibration and shock testing
- 4 cycles between 15 and 45 °C
- Measuring the 900 nm shortpass filter edge every 2 minutes

Result:

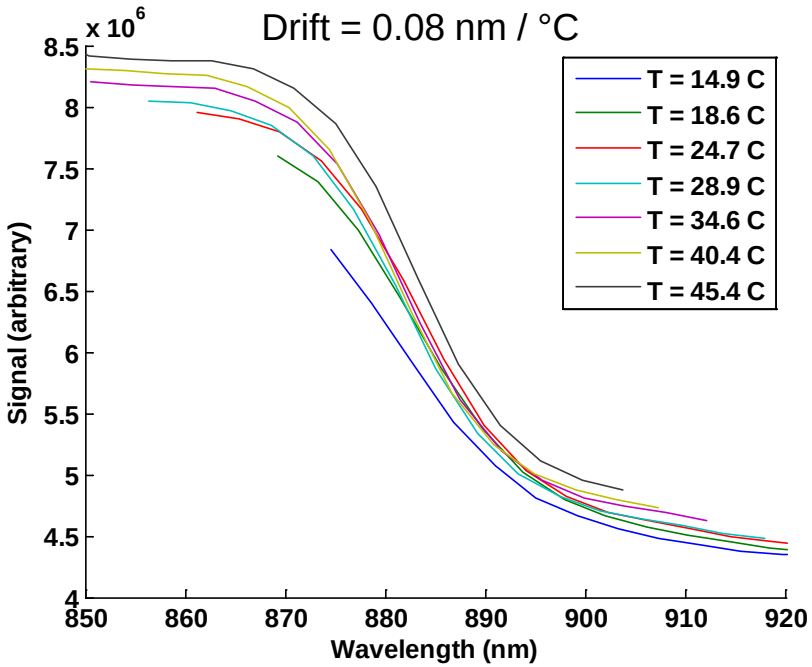
- A temperature drift was found in the wavelength calibration
  - This was expected, as it was already known that the FPI air gap drifts with temperature
- The test was primarily used to verify the new on-board wavelength calibration method

On-board wavelength calibration

Original measured signal

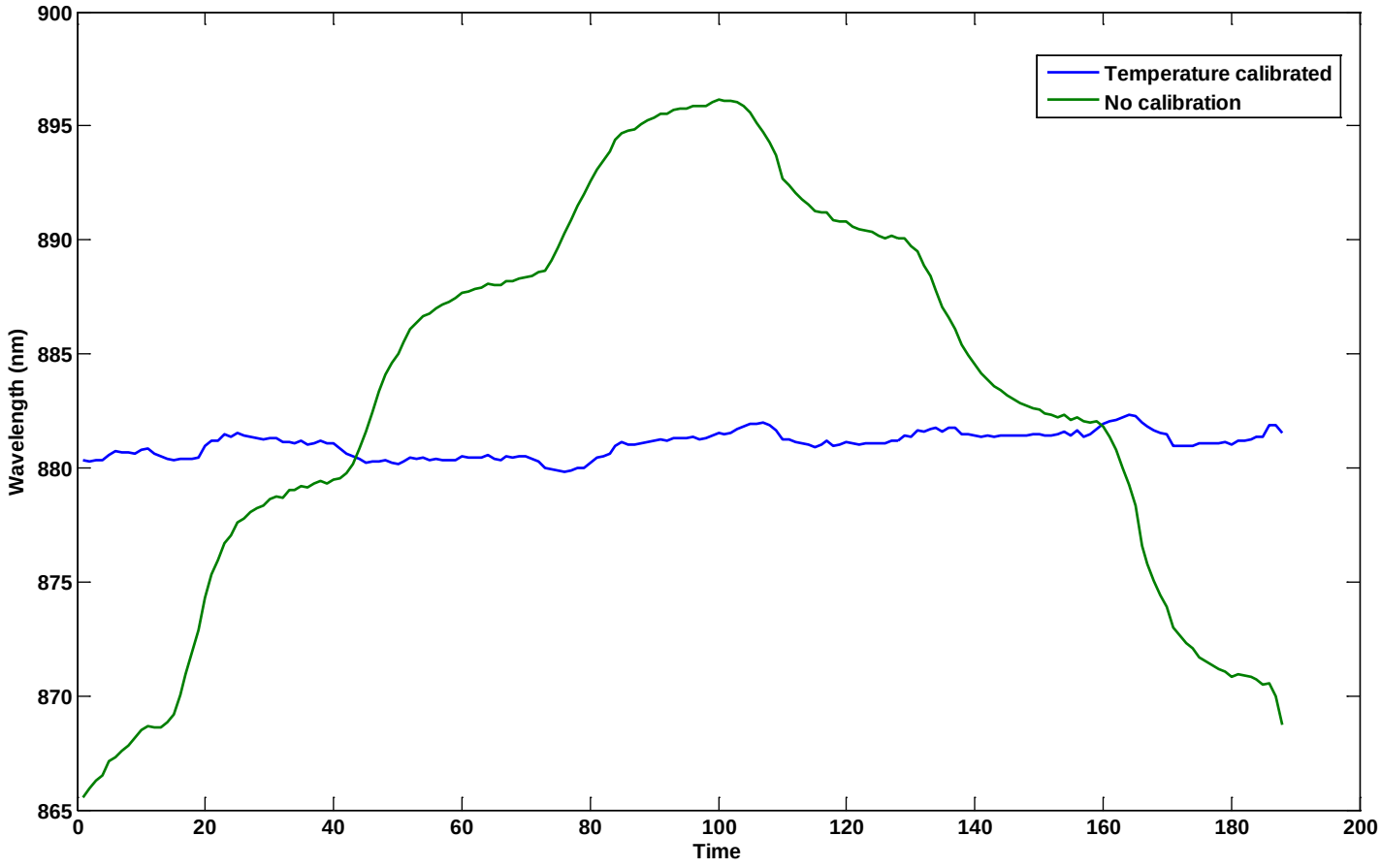


Temperature compensated measurement

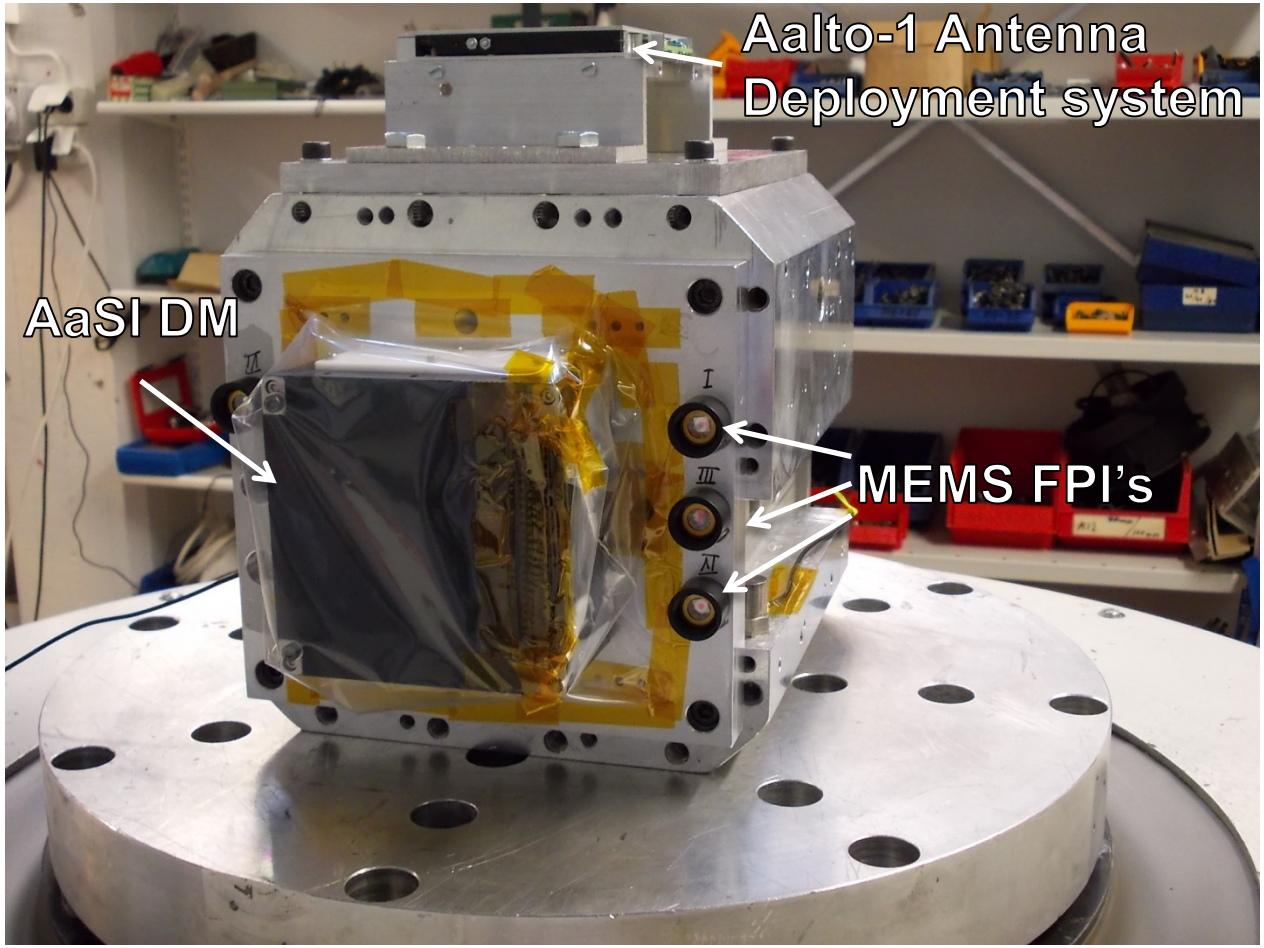


The method seems promising, testing will continue in thermal vacuum during the following weeks

On-board wavelength calibration



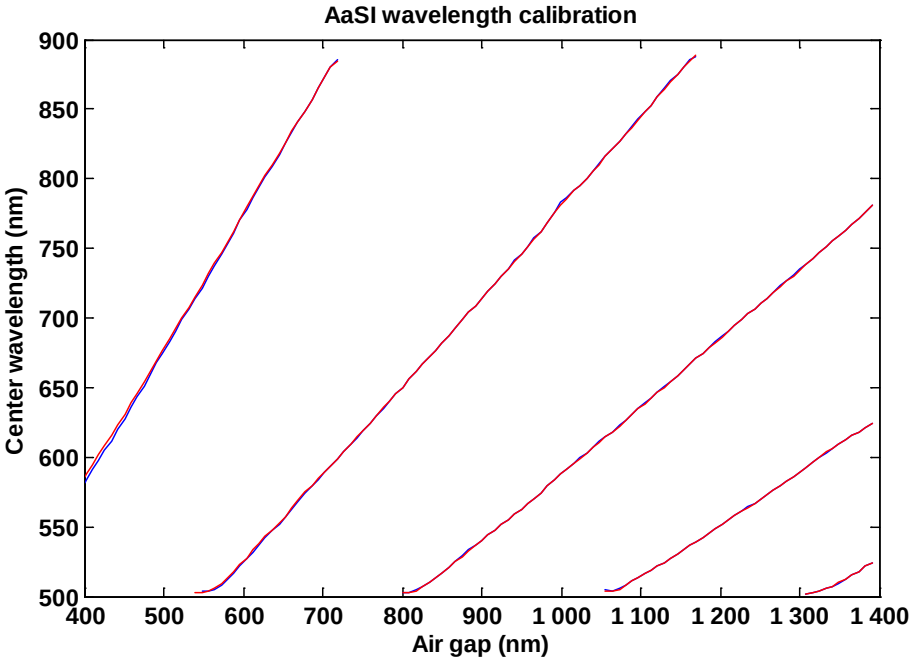
Vibration and shock testing



Vibration and shock testing

- GEVS qualification levels were used
- No changes were seen during the testing
- Post-testing calibration deviated from the pre-test calibration by less than 0.2 nm on average

Frequency [Hz]	Qualification	Acceptance
20	0.026	0.013
20 - 50	+6 dB/oct	+6 dB/oct
50 - 800	0.16	0.08
800 - 2000	-6 dB/oct	-6dB/oct
2000	0.026	0.013
Overall	14.1 G_{rms}	10.0 G_{rms}



Imaging tests

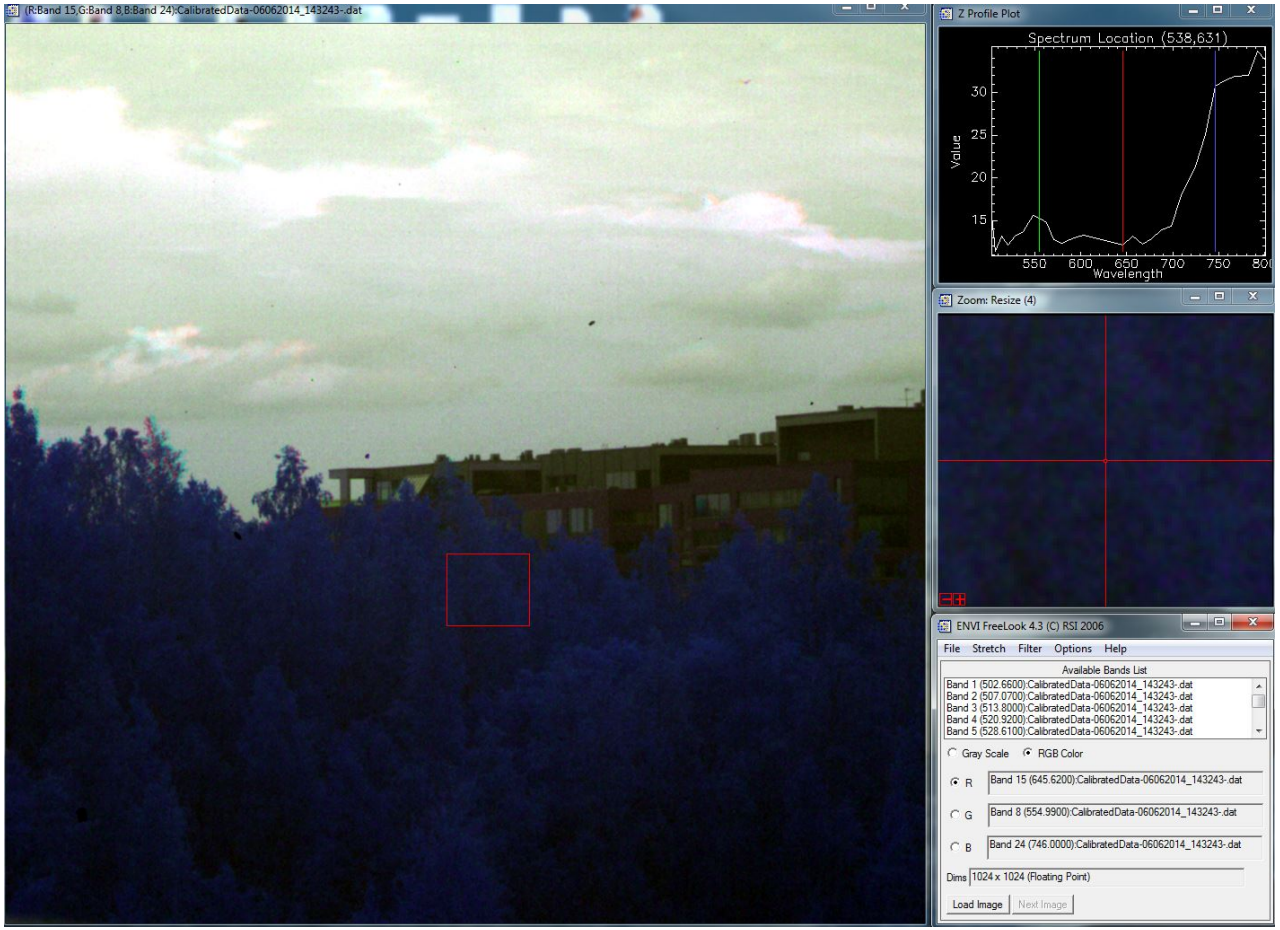
First imaging tests

First images

Raw SPE image

VIS image

First images



First processed spectral image, 29 bands

DM Technical specifications

Parameter	Value	Notes
Field of View	10° x 10° (SPE)	
Power consumption	< 3W	
Wavelength range	500 – 900 nm	
Spectral resolution	5 – 15 nm	Depending on interference order
Spectral bands	10 – 100	Limited by buffer memory and downlink capacity
Ground pixel size	200 x 200 m	600 km orbit
Tuning speed	< 20 ms	

Next steps and conclusions

Next steps

- Complete thermal vacuum cycling (operational + non-operational)
- Upgrade the DM to PFM
  - Change current image sensors to ones with cover glass
  - Upgrade electronics to more radiation tolerant design
  - Assemble the FM electronics
- Thorough integration testing with Aalto-1
- Launch next year, operations 2015-2017

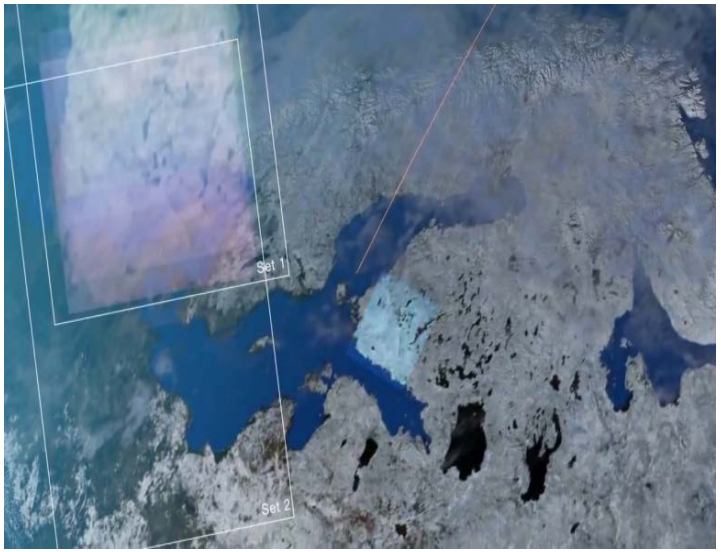
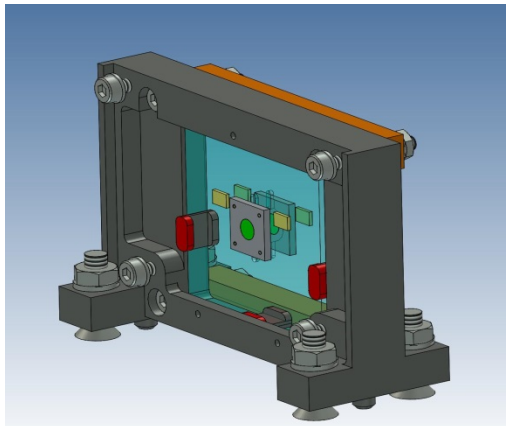


Photo credit: Tuomas Tikka / Aalto-1 Team

Image credit: Pekka Laurila / Aalto-1 Team

MFPI Imager prototype

- MEMS FPI's with 2 mm aperture have passed qualification testing
- 4 mm MFPI processing has been completed



The MFPI module

Brand new 4 mm MFPI chips

Summary

- AaSI DM has been succesfully integrated and it has passed vibration and shock testing
- The flight model will be assembled during autumn and it will be launched with the Aalto-1 nanosatellite in 2015
- The work here has been done as a part of the ESA activity ”MEMS Fabry-Perot interferometer technology for miniaturized hyperspectral imagers and microspectrometers” (RFQ/3-13517)

Thank you for listening!


TECHNOLOGY FOR BUSINESS