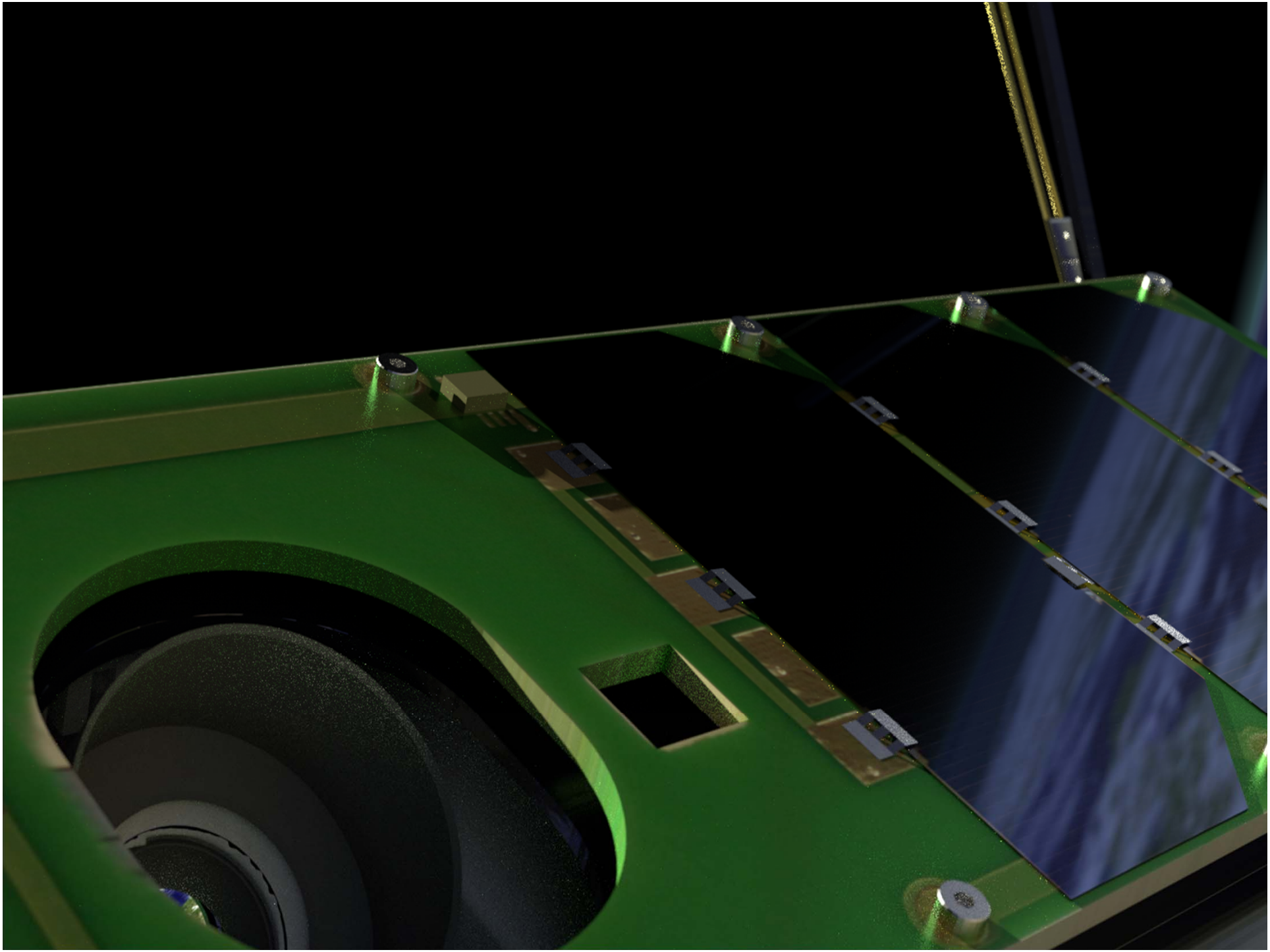


Business from technology

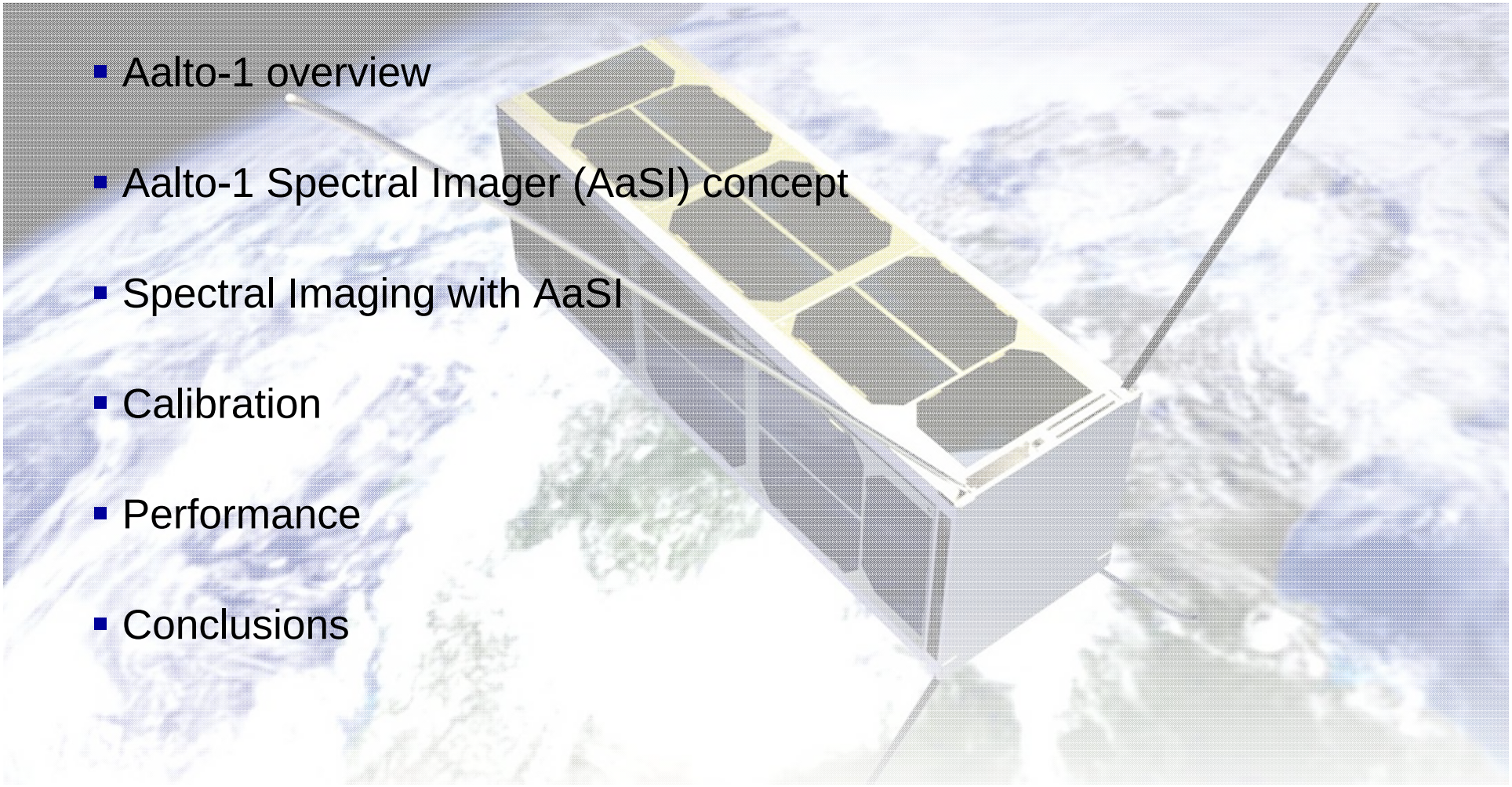
The Aalto-1 Spectral Imager (AaSI) mission

18.10.2012

8th ESA Round Table on MNT, ESTEC, Noordwijk

Christer Holmlund, Heikki Saari, Antti Näsilä, Anna Rissanen, Rami Mannila, Uula Kantojärvi, Kai Viherkanto, Hans Toivanen, Ismo Näkki, Jarkko Antila, Altti Akujärvi, Jussi Mäkynen

Outline

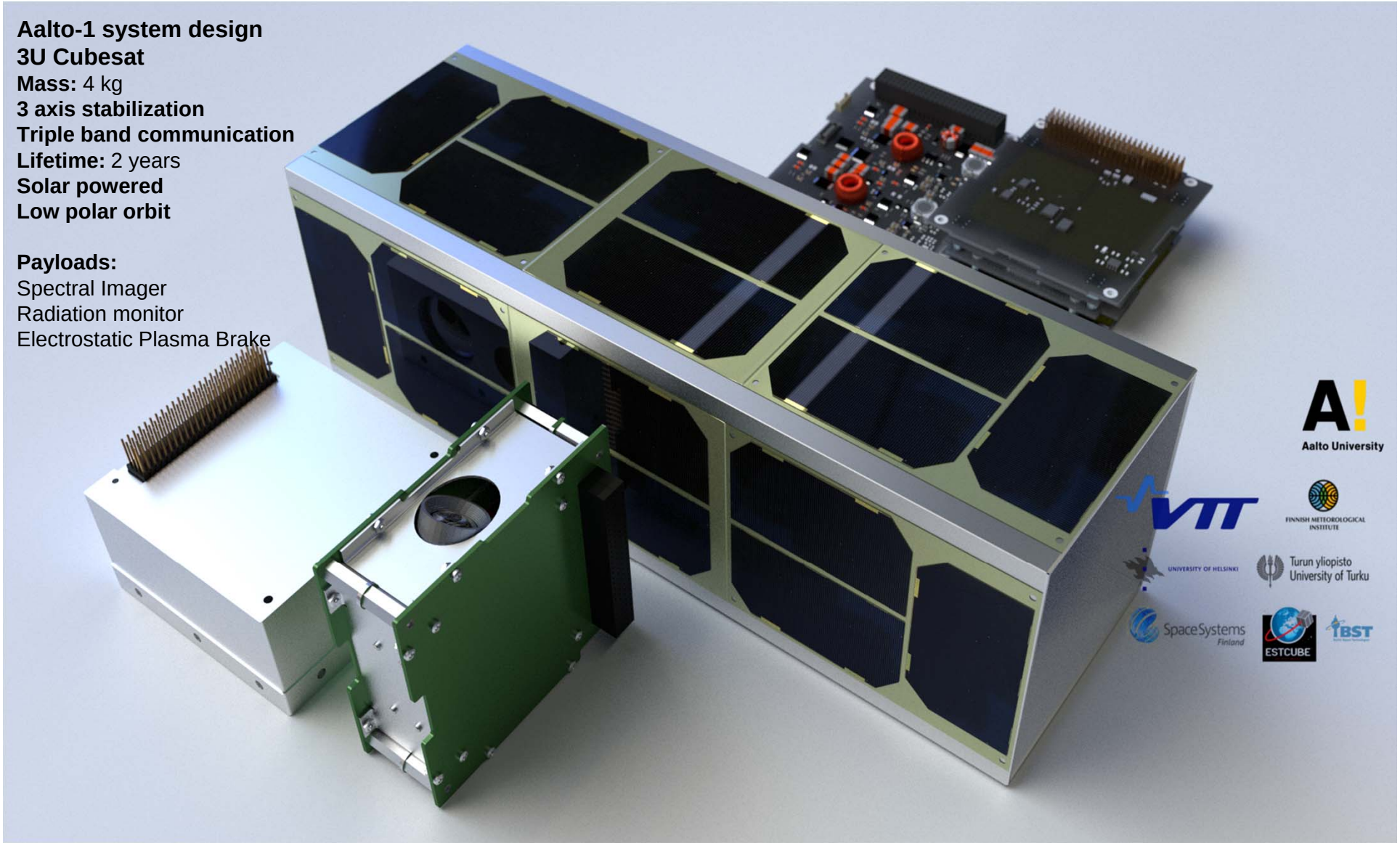


- Aalto-1 overview
- Aalto-1 Spectral Imager (AaSI) concept
- Spectral Imaging with AaSI
- Calibration
- Performance
- Conclusions

Aalto-1 overview

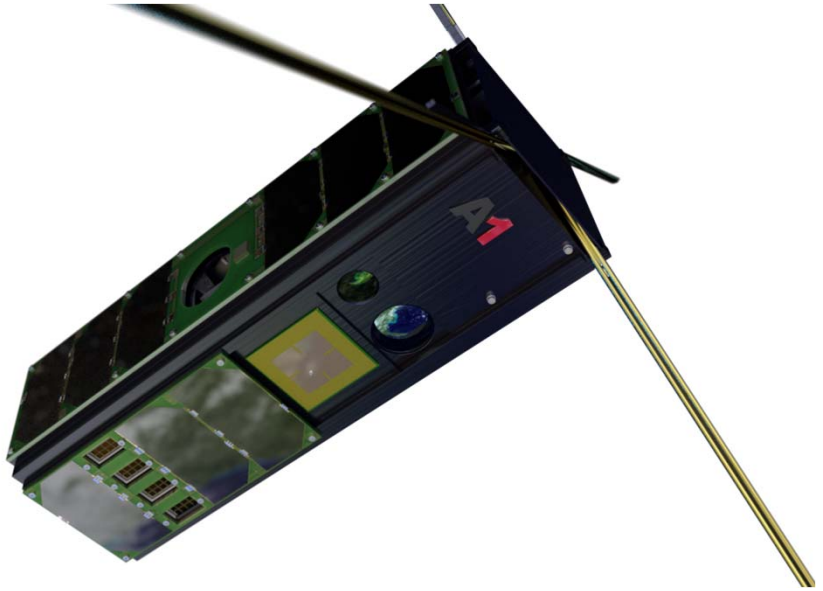
Aalto-1 system design
3U Cubesat
Mass: 4 kg
3 axis stabilization
Triple band communication
Lifetime: 2 years
Solar powered
Low polar orbit

Payloads:
Spectral Imager
Radiation monitor
Electrostatic Plasma Brake



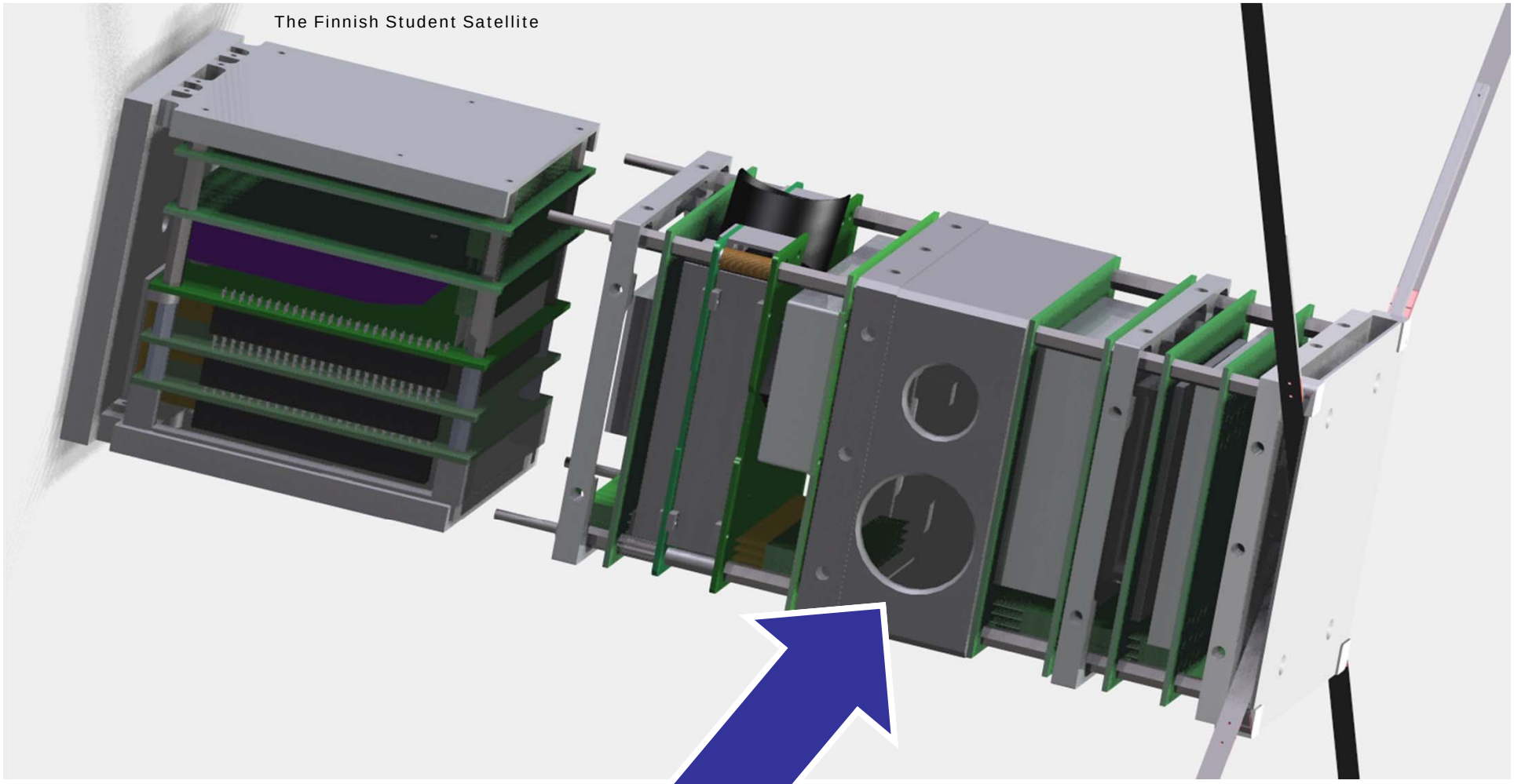
Aalto-1 mission goals

1. To design, build and operate the first Finnish nanosatellite.
2. Technology demonstration of a very small spectral imager for spaceborne Earth observation.
3. Development and demonstration of a deorbiting device for nanosatellites based on the e-sail concept and measurement of its performance.
4. Technology demonstration of a very small radiation detector for future satellites.
5. Promotion of engineering education in Finland with the aid of the satellite project.



Aalto-1

The Finnish Student Satellite



Spectral imager

AaSI = spectral camera + normal camera

Spectral Camera Module

- Custom optics
- Field of view: 10 deg x 10 deg
- Moderate ground resolution (ca. 200 m ground pixel from 600 km orbit)
- Selectable wavelength bands at 500 – 900 nm
- Technology demonstration

VIS Camera Module

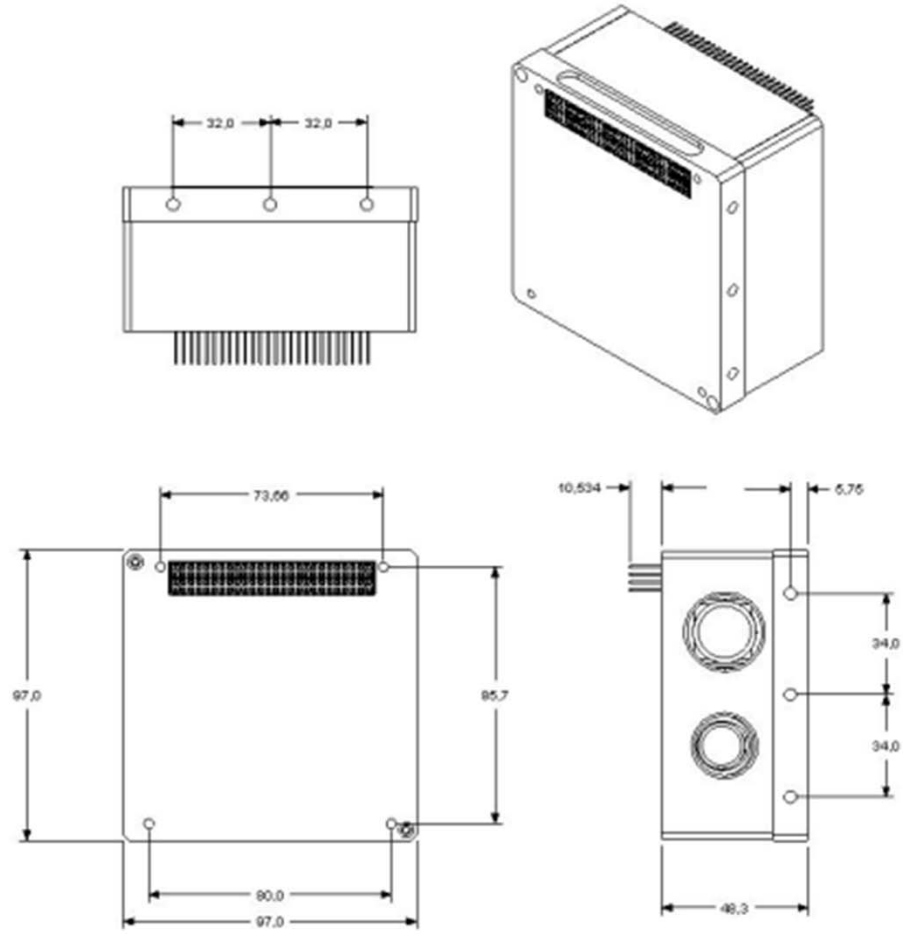
- Commercial micro-objective
- Field of view: 15 deg x 10 deg
- Higher resolution: ca. 100 m ground pixel from 600 km orbit
- Used for verifying spectral image targets

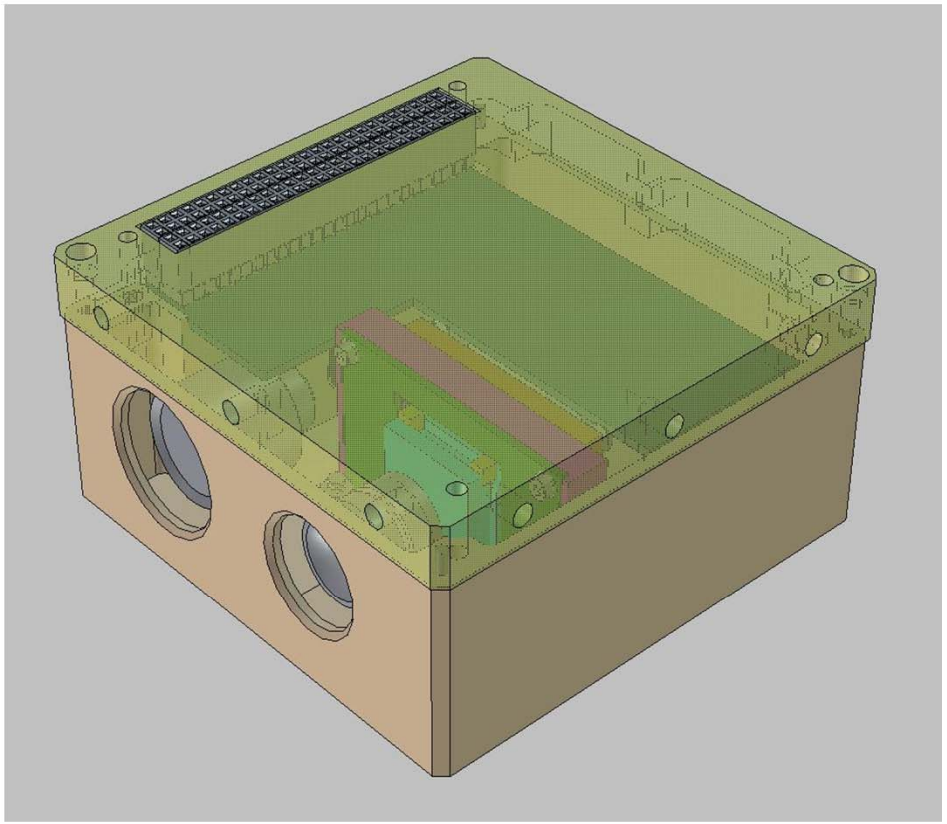
AaSI Mission

The major scientific and technological objective is to demonstrate the operation of the novel staring spectral imager in a nanosatellite.

Parameter	Specified value	Remarks
Across the flight FOV	10° (0.174 rad)	105km swath width @ 600 km altitude.
Along the flight FOV	10°	
Instantaneous FOV	0.02° (0.34 mrad)	FOV/512 pixels, ground pixel 205 m at nadir @ 600 km
Wavelength range	500 – 900 nm	The wavelength range can be selected within the spectral response of a silicon image sensor
Spectral resolution	10..30 nm @ FWHM	The target applications require medium spectral resolution. Center wavelength and resolution is programmable.
Number of spectral bands	10..30	Number limited by buffer memory and downlink capacity.
Spectral step	< 1 nm	Adjustable by controlling the air gap of the Fabry-Perot interferometer (FPI)
SNR @ 20 ms integration time & 20 nm FWHM	> 50	SNR requirement is defined for June and latitude of Helsinki (60) and for albedo 30%.
Volume	48x97x97mm^3	
Mass	500 g	

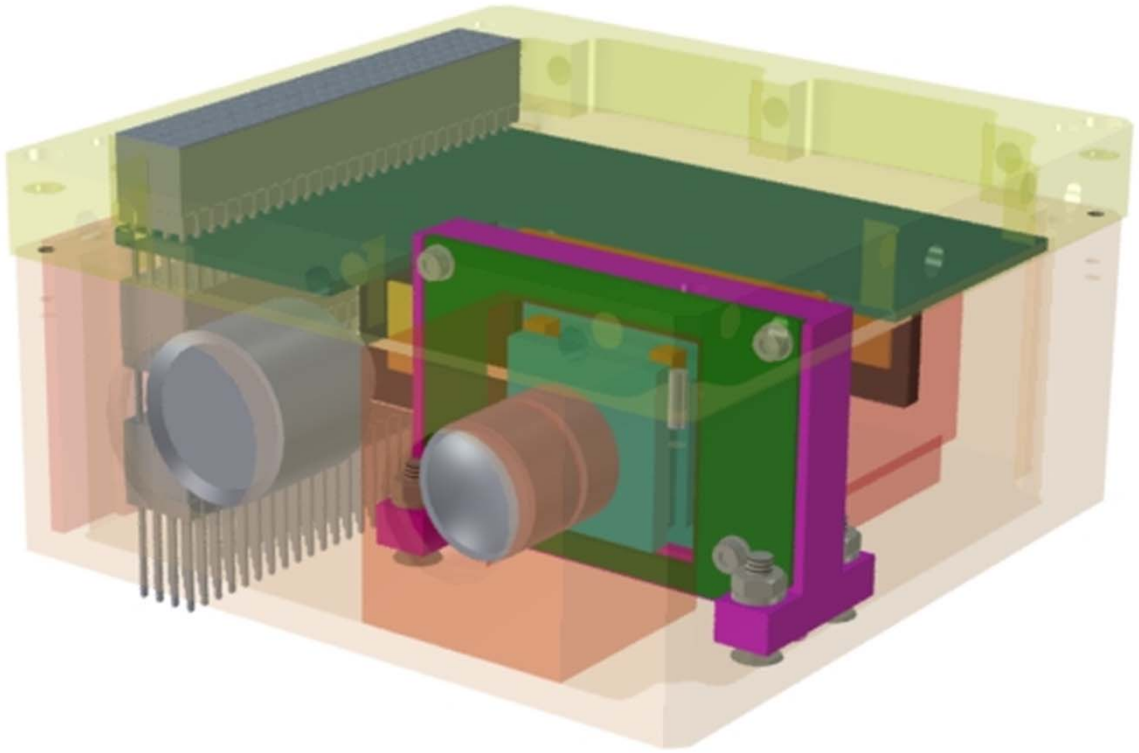
AaSI Preliminary Design



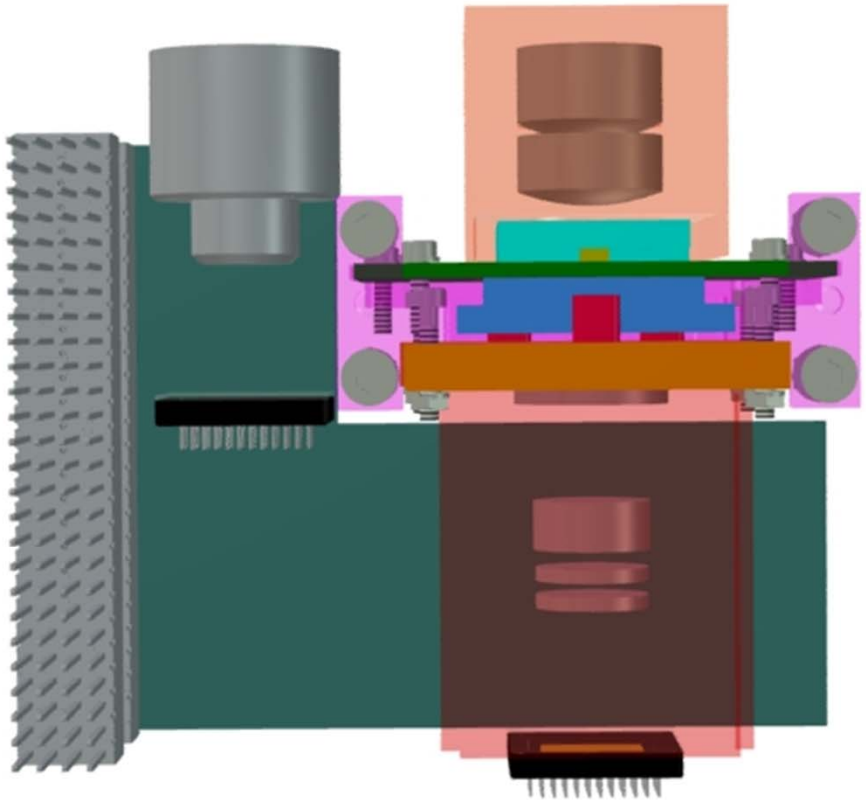


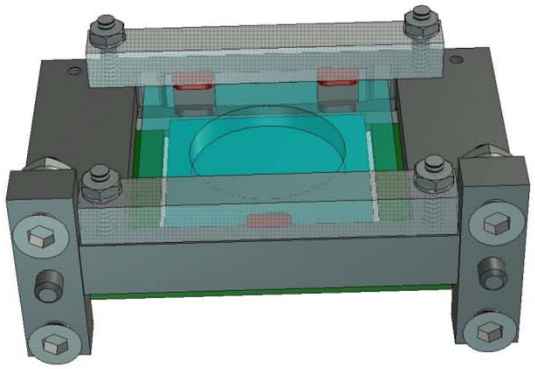
Mass 500 g
Size 97x97x48 mm^3

AaSI Preliminary Design

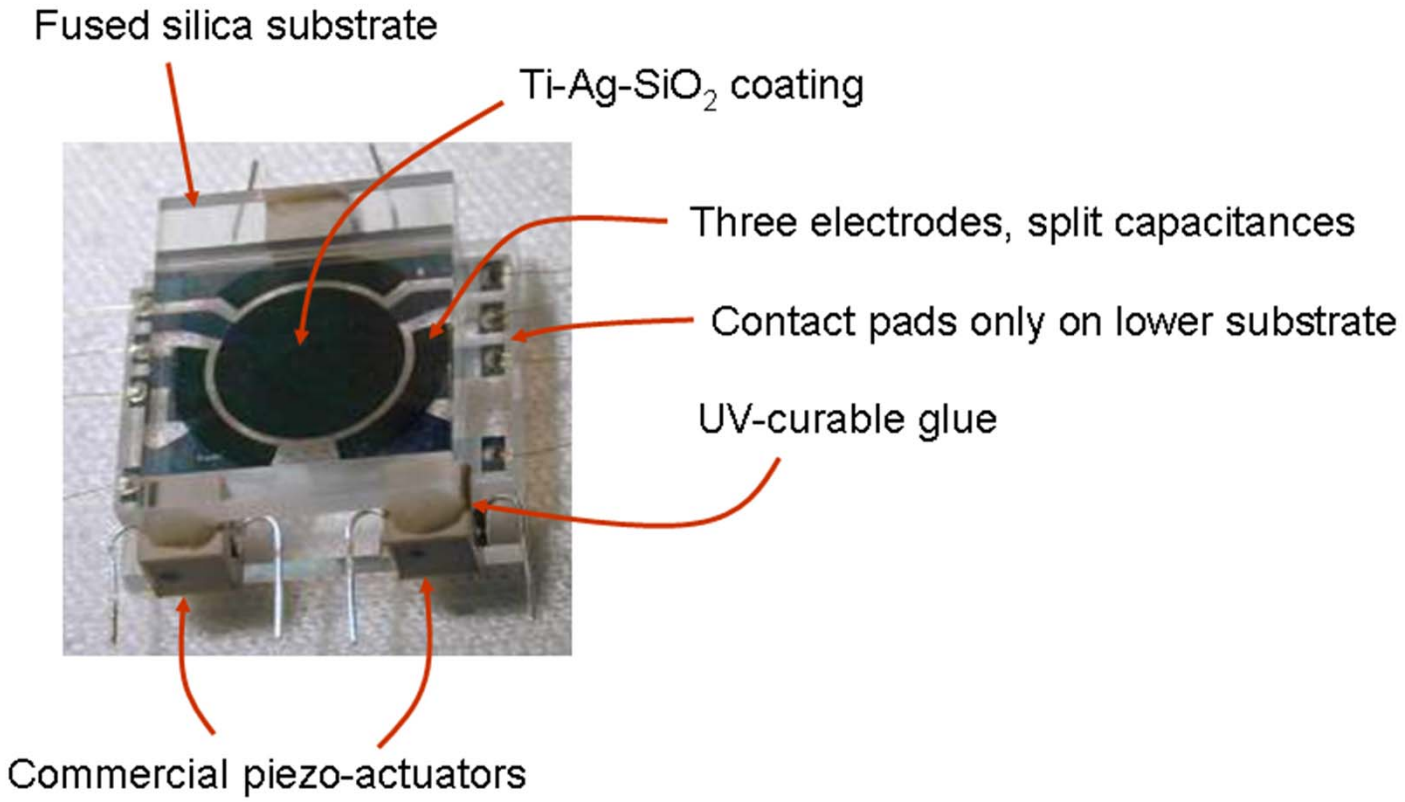


AaSI Spectral Camera Preliminary Design

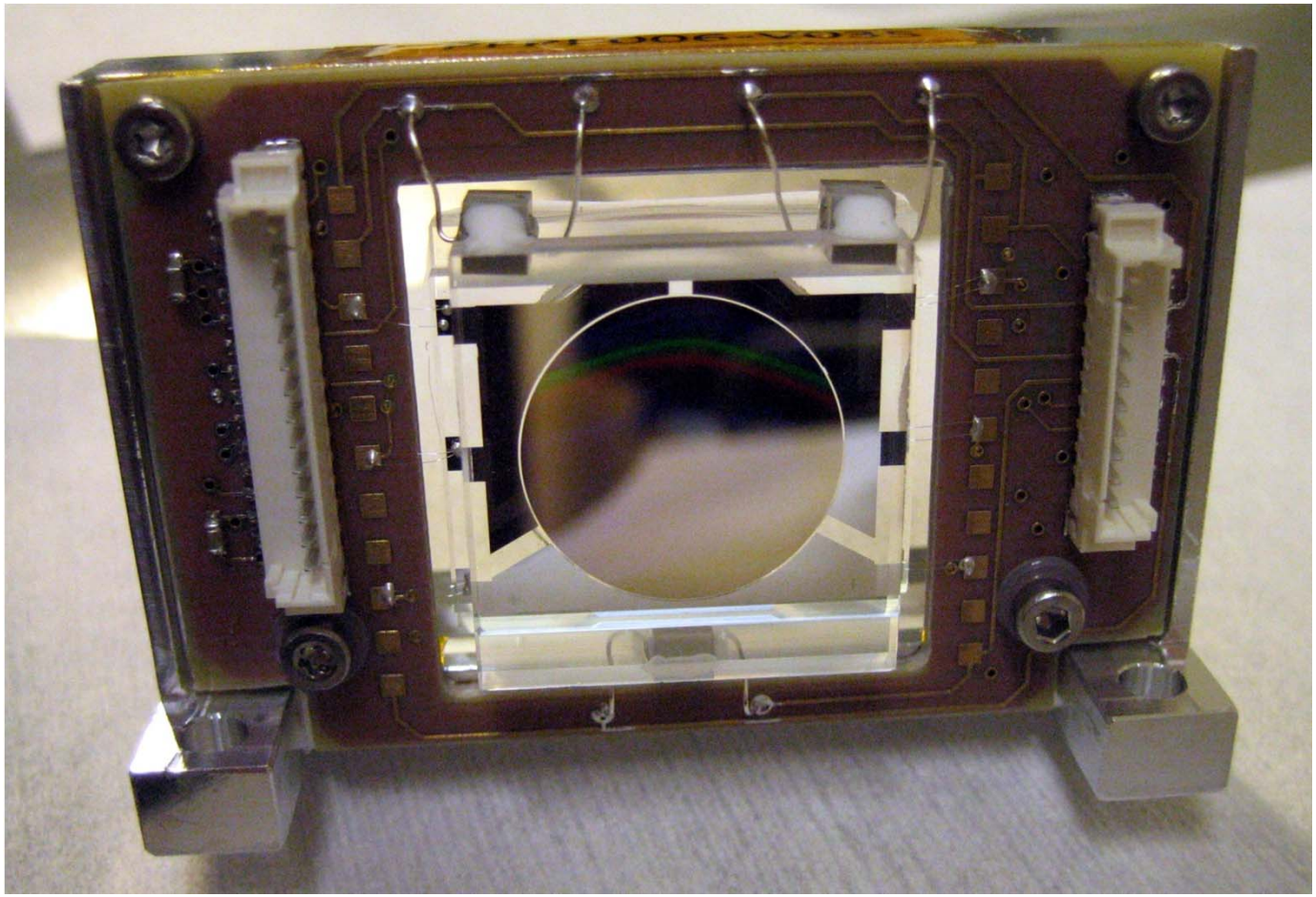




Piezo-Actuated Fabry-Perot Interferometer selected for the Aalto-1 Imaging Spectrometer

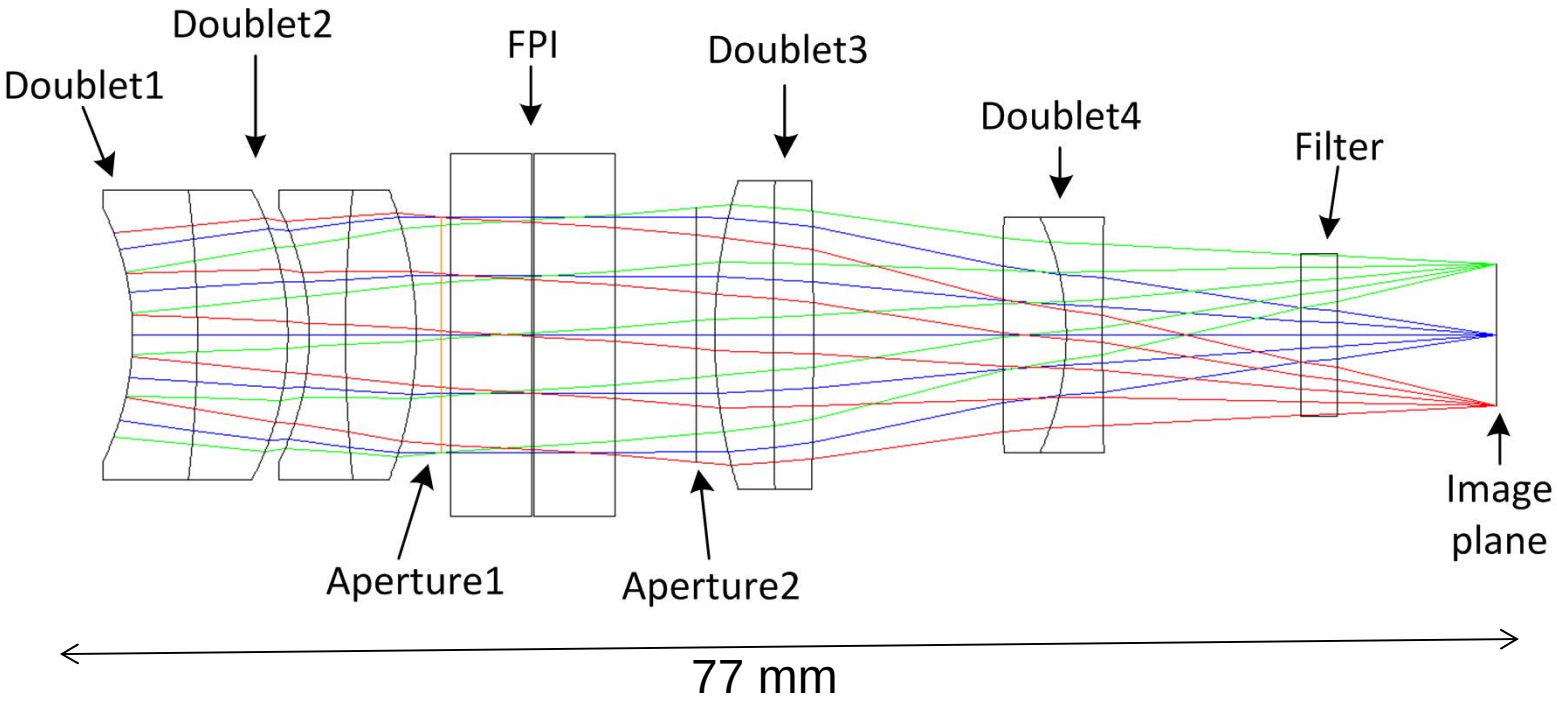


The PFPI module for AaSI



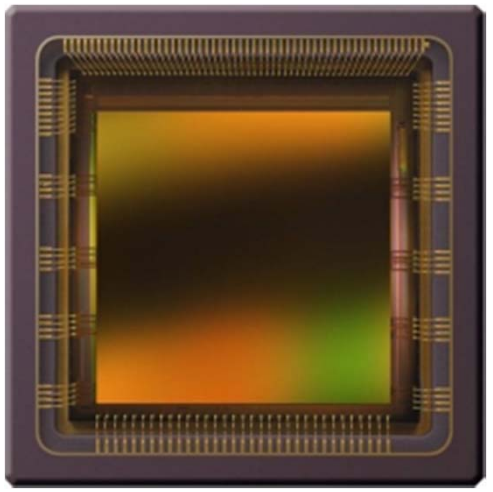
Optics concept for the spectral camera

Focal length 32 mm
F-number 3.6
Manufactured by Millog Oy



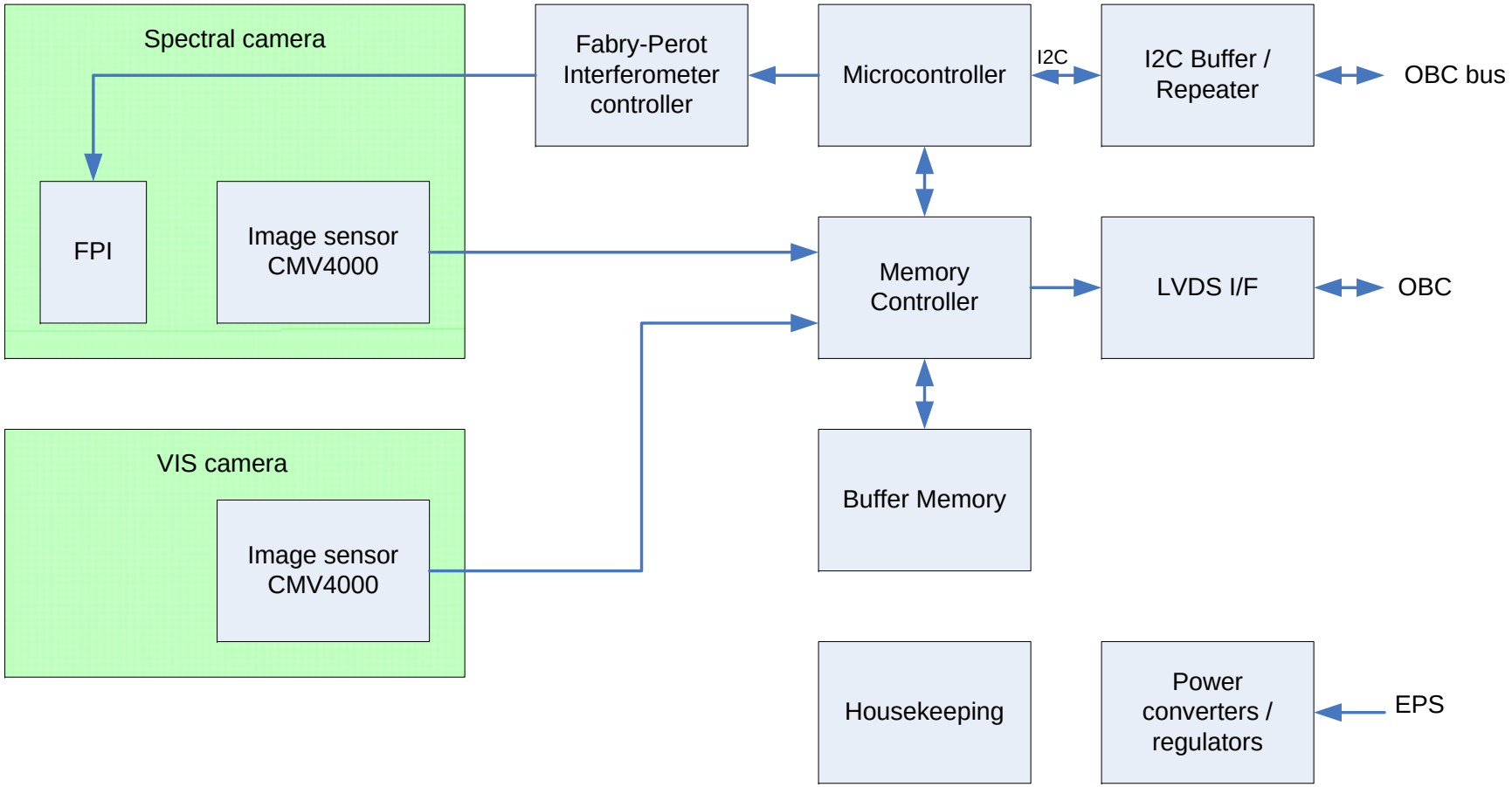
RGB detector: CMOSIS CMV4000

- Identical detector in both modules
- 2048 x 2048 RGB CMOS with global shutter
- 1024 x 1024 pixels for spectral camera (2x2 binning)
- 1680 x 1120 pixels for VIS camera (no binning)
- Read noise: 15 electrons
- Dark current 125 e/s

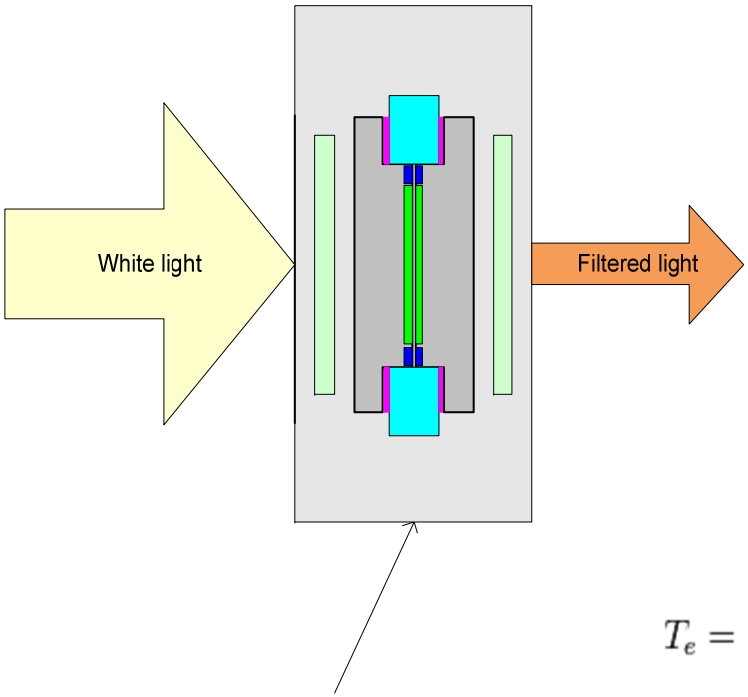


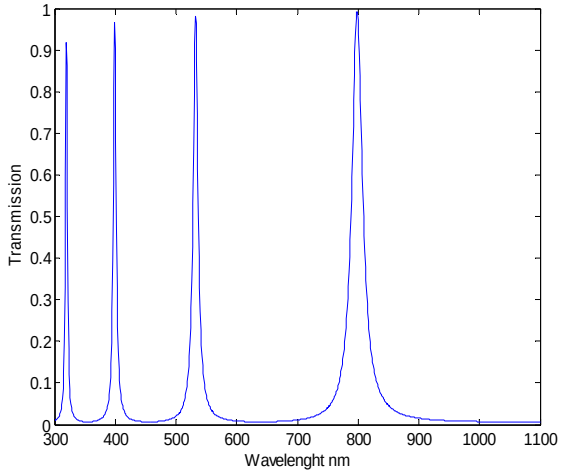
CMOSIS CMV4000

Block diagram of AaSI electronics



The Fabry-Perot Interferometer



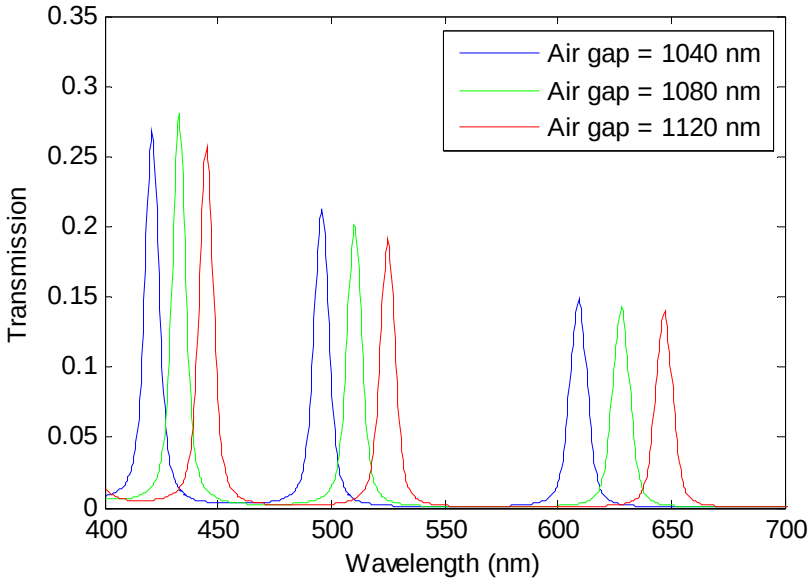


Fabry-Perot Interferometer Module

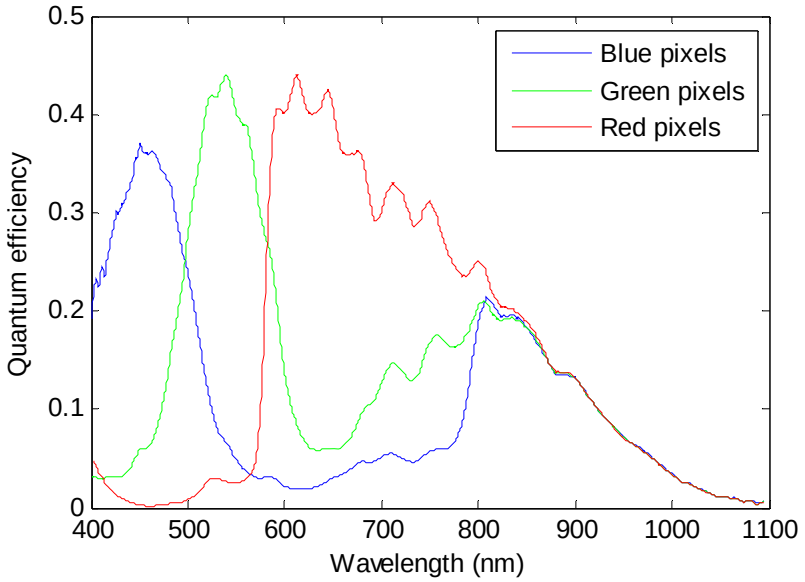
$$T_e = \frac{(1-R)^2}{1+R^2-2R\cos\delta} = \frac{1}{1+F\sin^2(\delta/2)},$$

$$\delta = \left(\frac{2\pi}{\lambda}\right) 2n\ell\cos\theta.$$

Matching three Fabry-Perot Interferometer orders to color image sensor R-, G-, and B-pixels

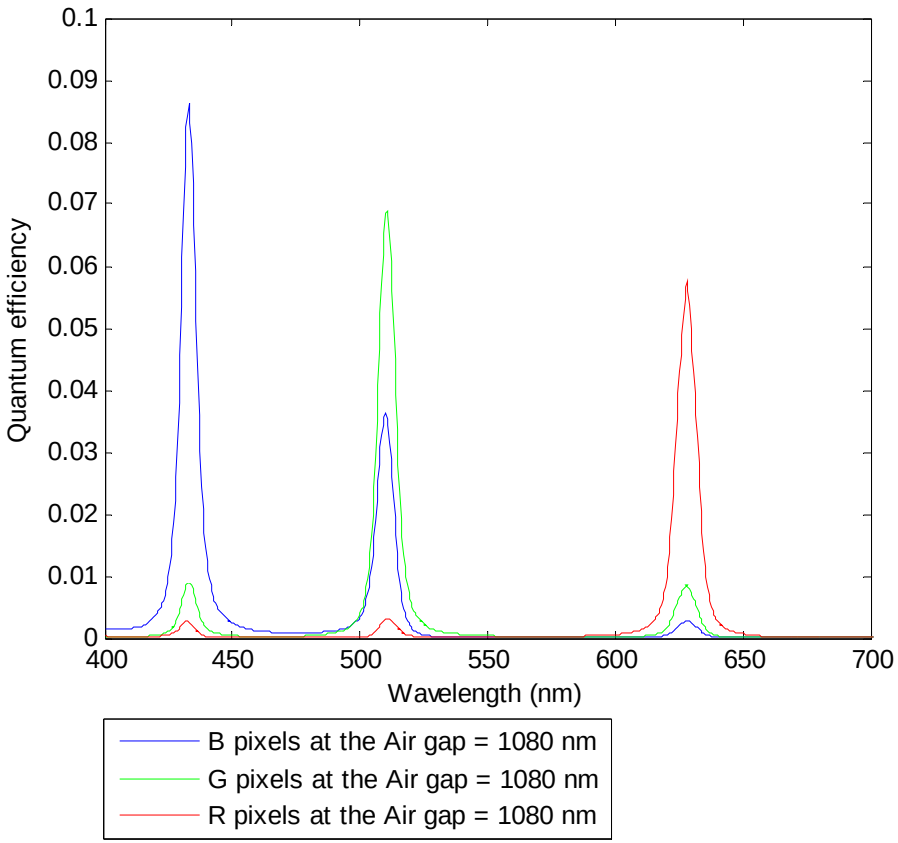


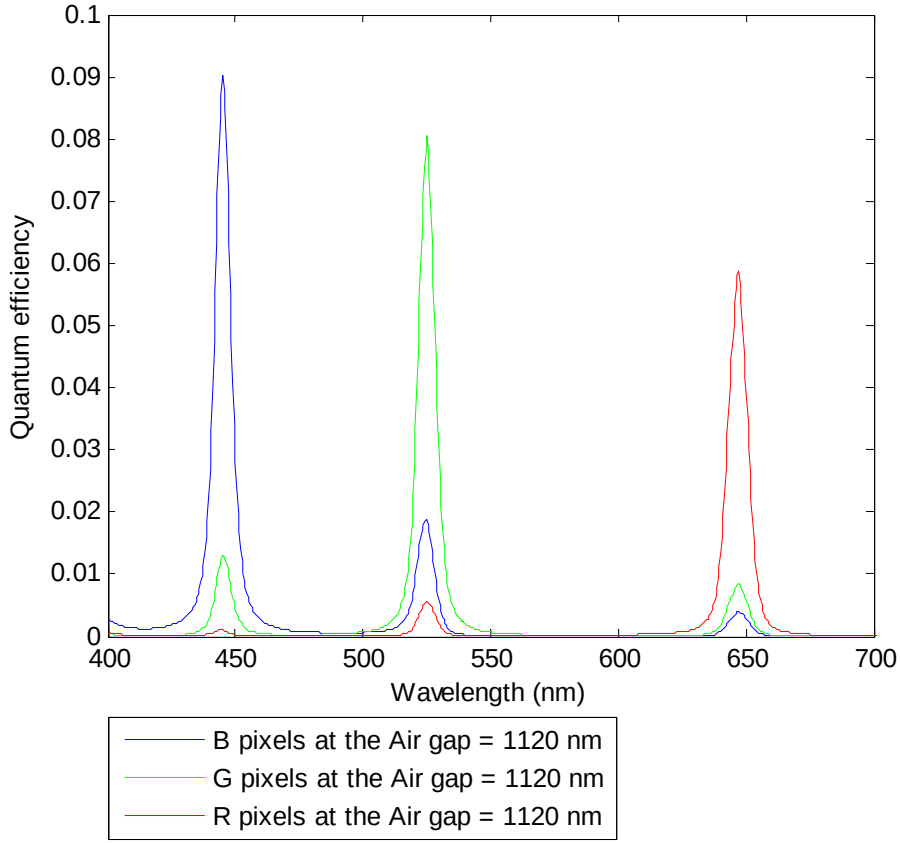
Spectral transmission through the Fabry-Perot Interferometer



Measured quantum efficiency of a CMOS color sensor (CMOSIS CMV4000).

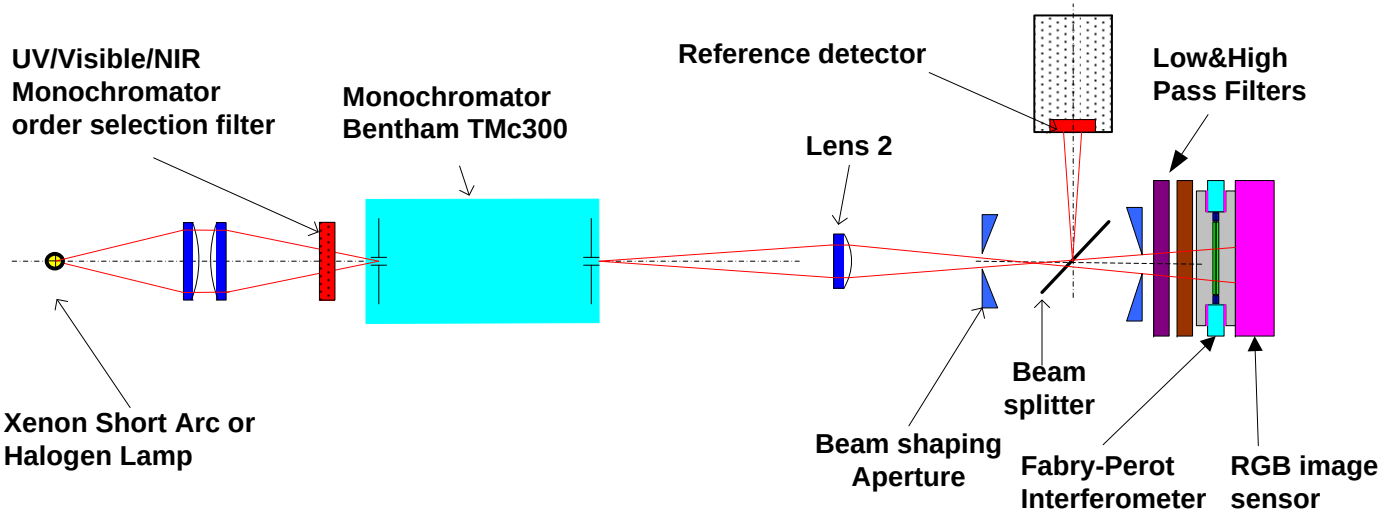
Combined quantum efficiencies of the Fabry-Perot Interferometer and R-, G-, and B-pixels at two air gap values



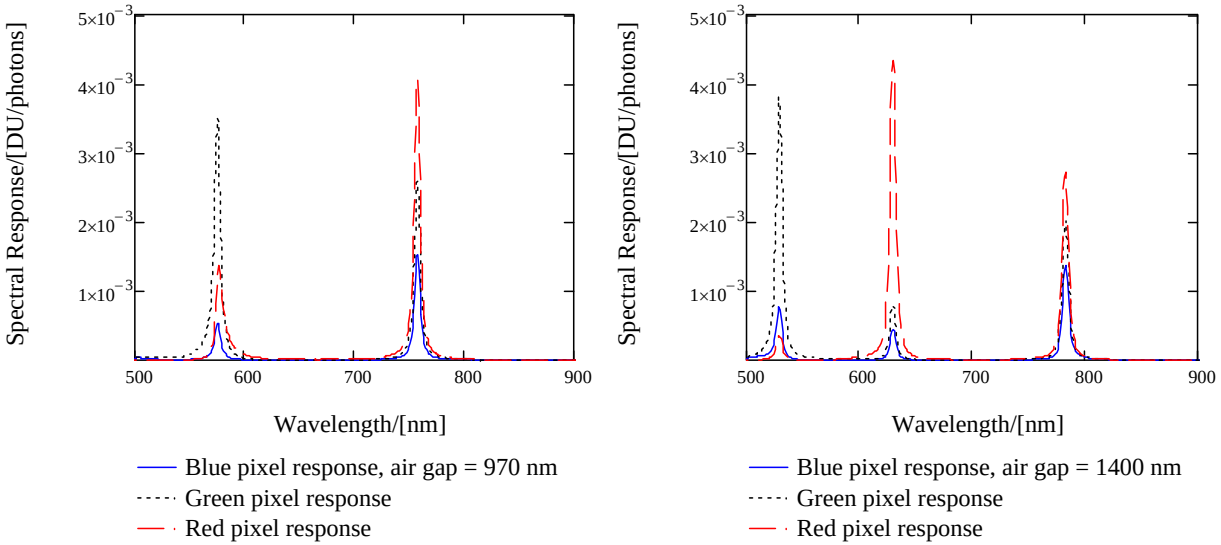


The sensitivities of the R-, G-, and B-pixels have their maxima at the blue, green and red wavelength bands.

Spectral calibration of AaSI

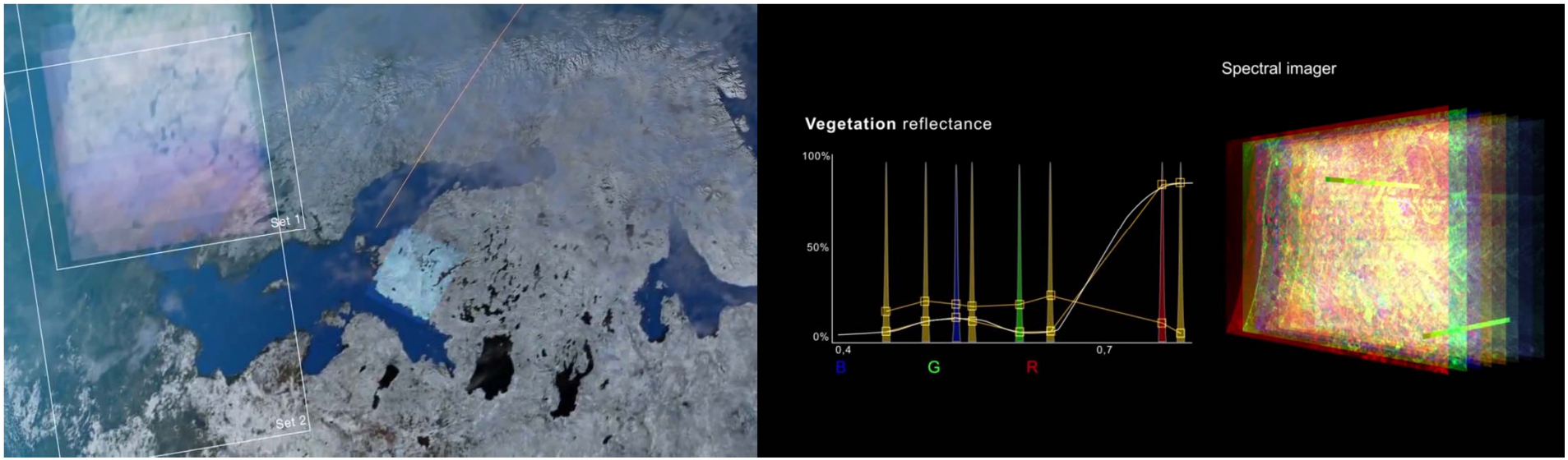


Calibration setup of the FPI multispectral image sensor spectral imager



The measured spectral response curves of the R-, G-, and B-pixels of a FPI spectral imager for air gap values of 970 and 1400 nm.

Imaging example



Imaging of a 2D target with multiple selectable wavelength bands

AaSI calibration strategy

- Gap quality characterisation and optimisation of the gap control loop.
- Spectral and radiometric calibration of the spectral imager.
- Temperature and spatial corrections implemented in the spectral signal retrieval.
- Regular calibration checks
  - Known calibration targets: Antarctica, Sahara etc.

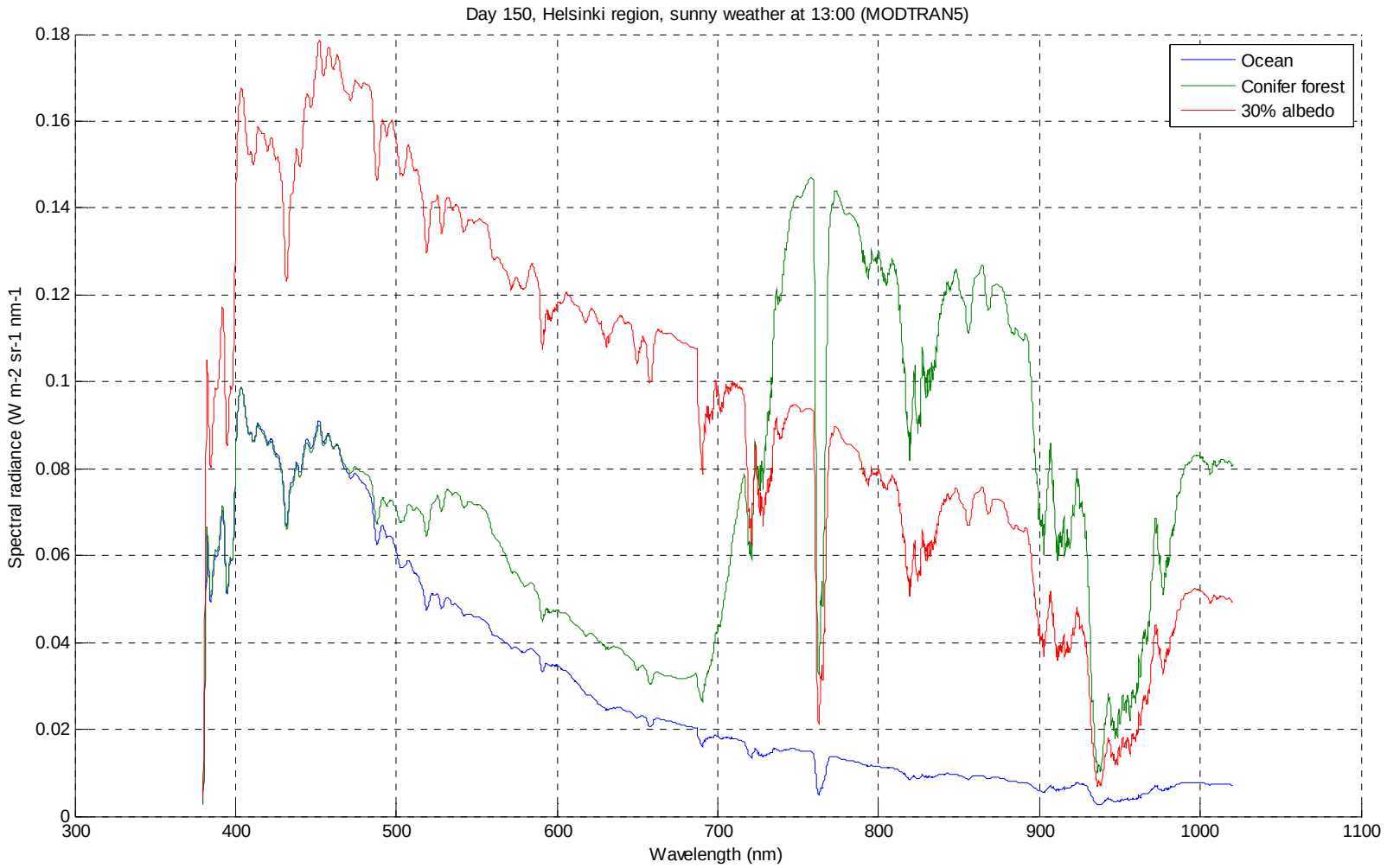
Critical Items and planned risk reduction actions

- PFPI thermal stability tests (wavelength calibration temperature sensitivity) in climate chamber.
  - The purpose is to verify that it is possible compensate for the FPI wavelength calibration dependence on the ambient temperature using the temperature measurements at the PFPI preamplifier and other locations near the PFPI module.
- PFPI vacuum performance characterization in vacuum chamber.
  - The purpose is to verify that the closed loop control loop for the FPI air gap operates also in vacuum.
- PFPI vibration tests
  - The purpose is to verify survival after exposure to vibration environment.
- PFPI thermal vacuum tests.
  - The purpose is to verify that PFPI module operates at the Aalto-1 thermal vacuum environment.

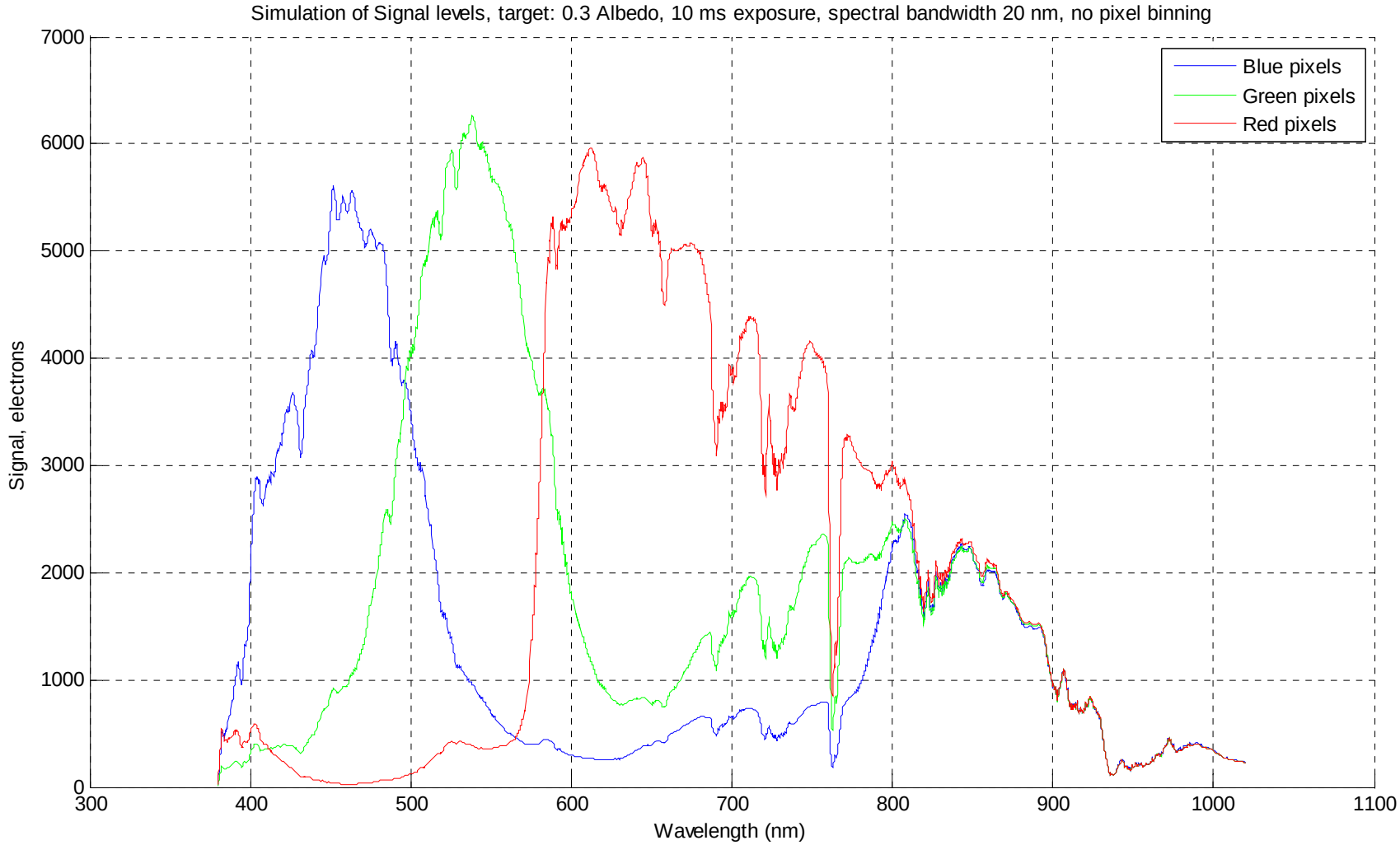
Simulation parameters

- Orbit height: 600 km
- Target location: Helsinki, Finland (Noon, midsummer)
- 10 ms exposure
- Read noise: 15 electrons
- Dark current 125 e/s

Spectral radiance simulation (MODTRAN5)

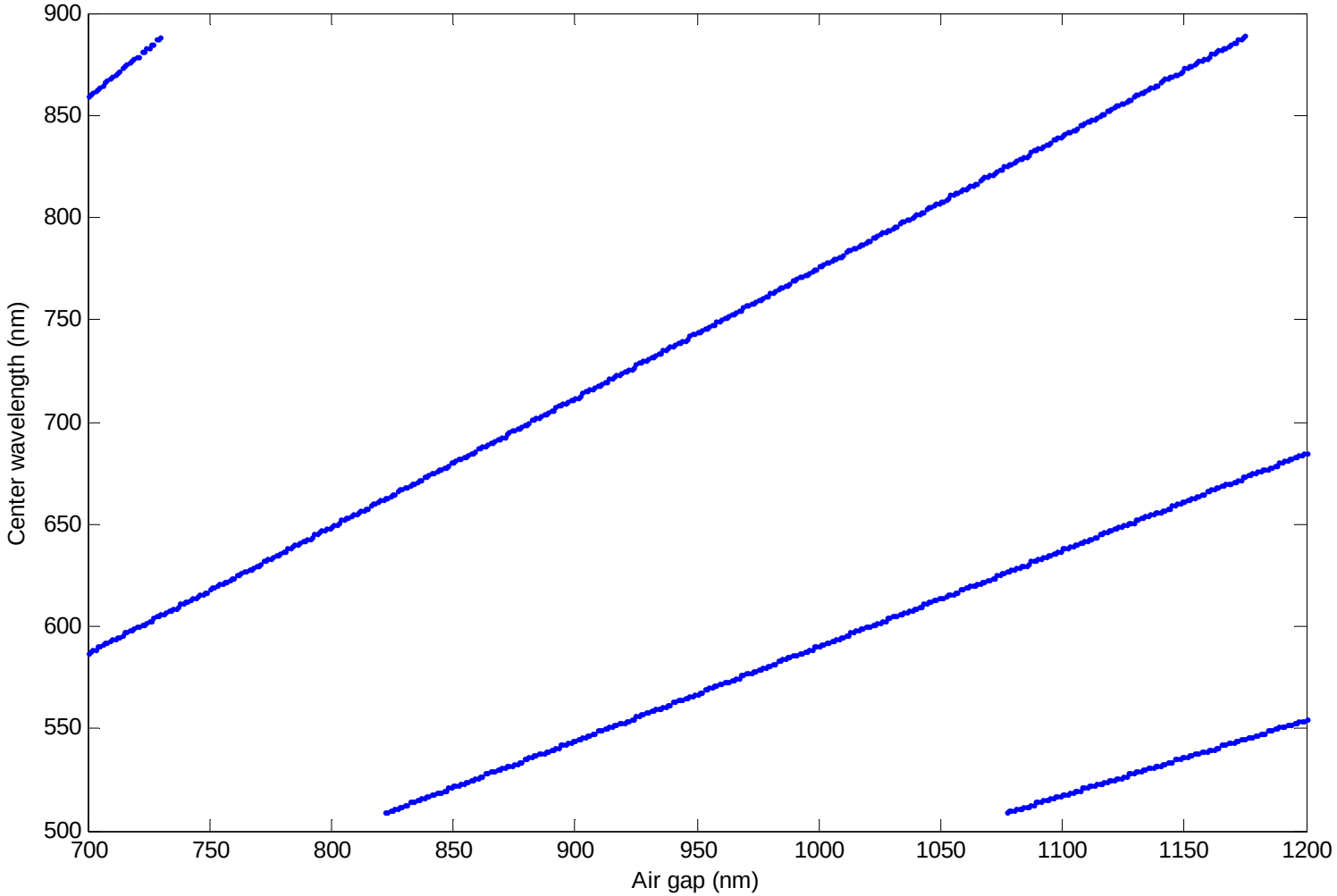


Radiometric performance, signal levels

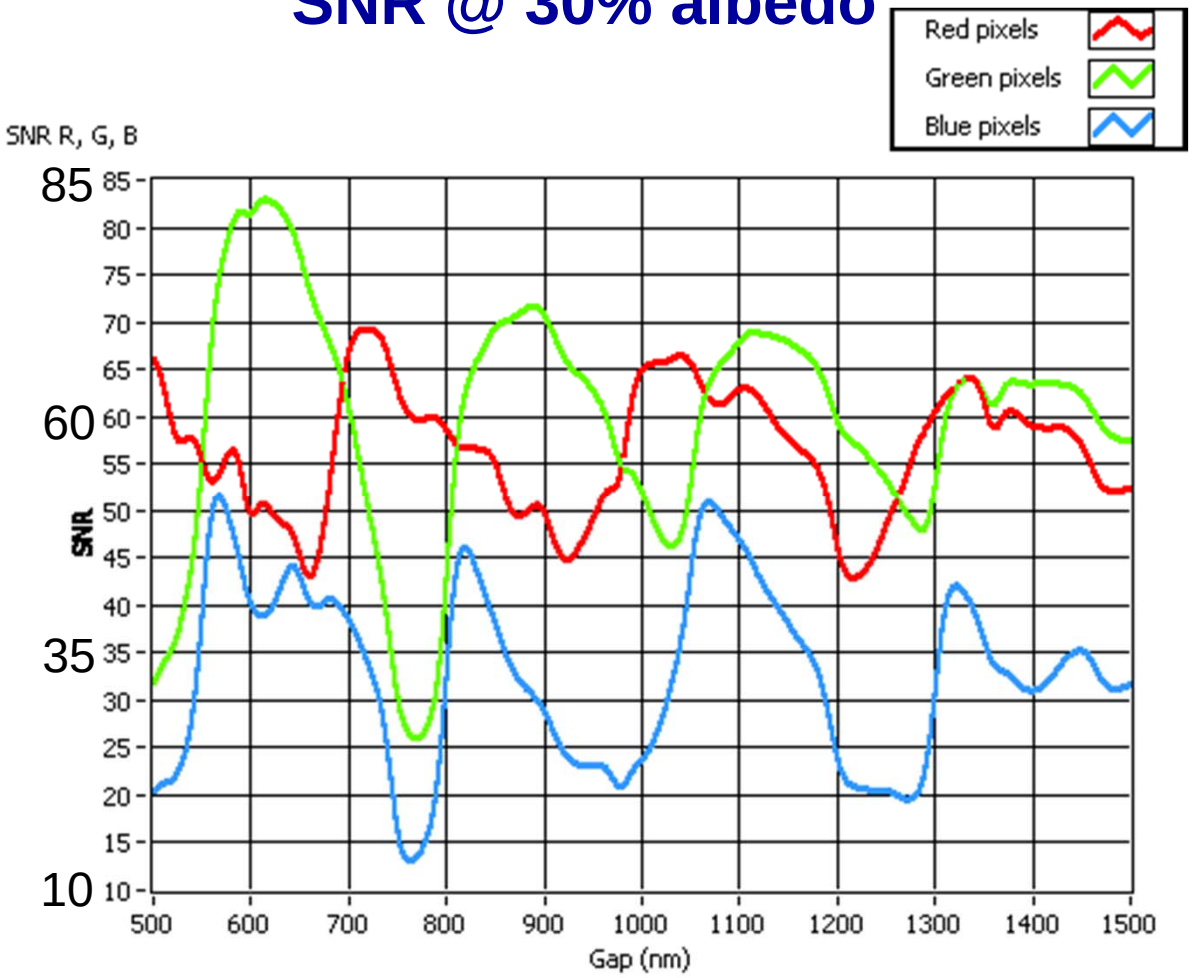


Target: 30% albedo, day 150, time 13:00, Helsinki, Finland

Wavelength to Air gap

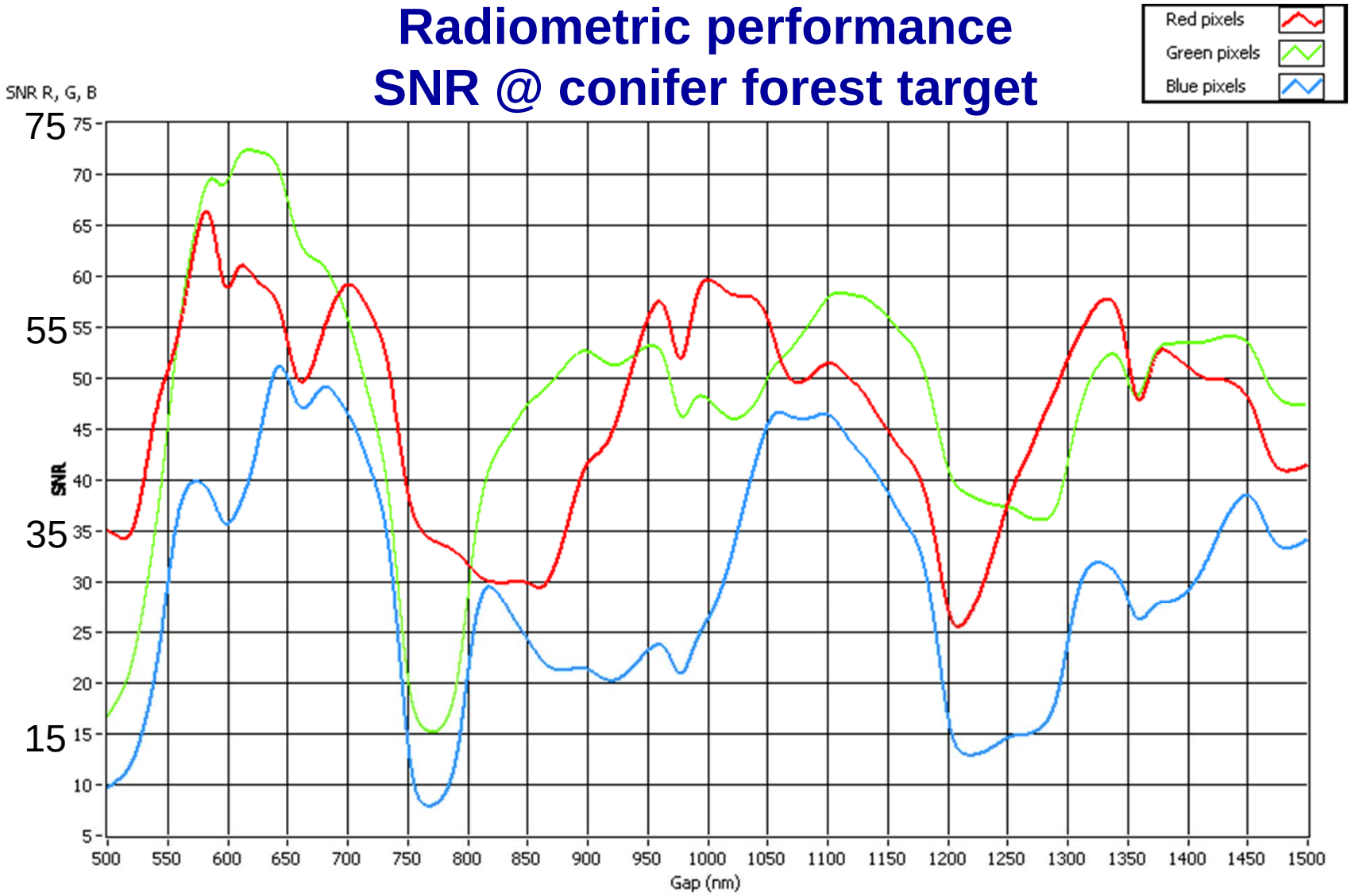


Radiometric performance
SNR @ 30% albedo



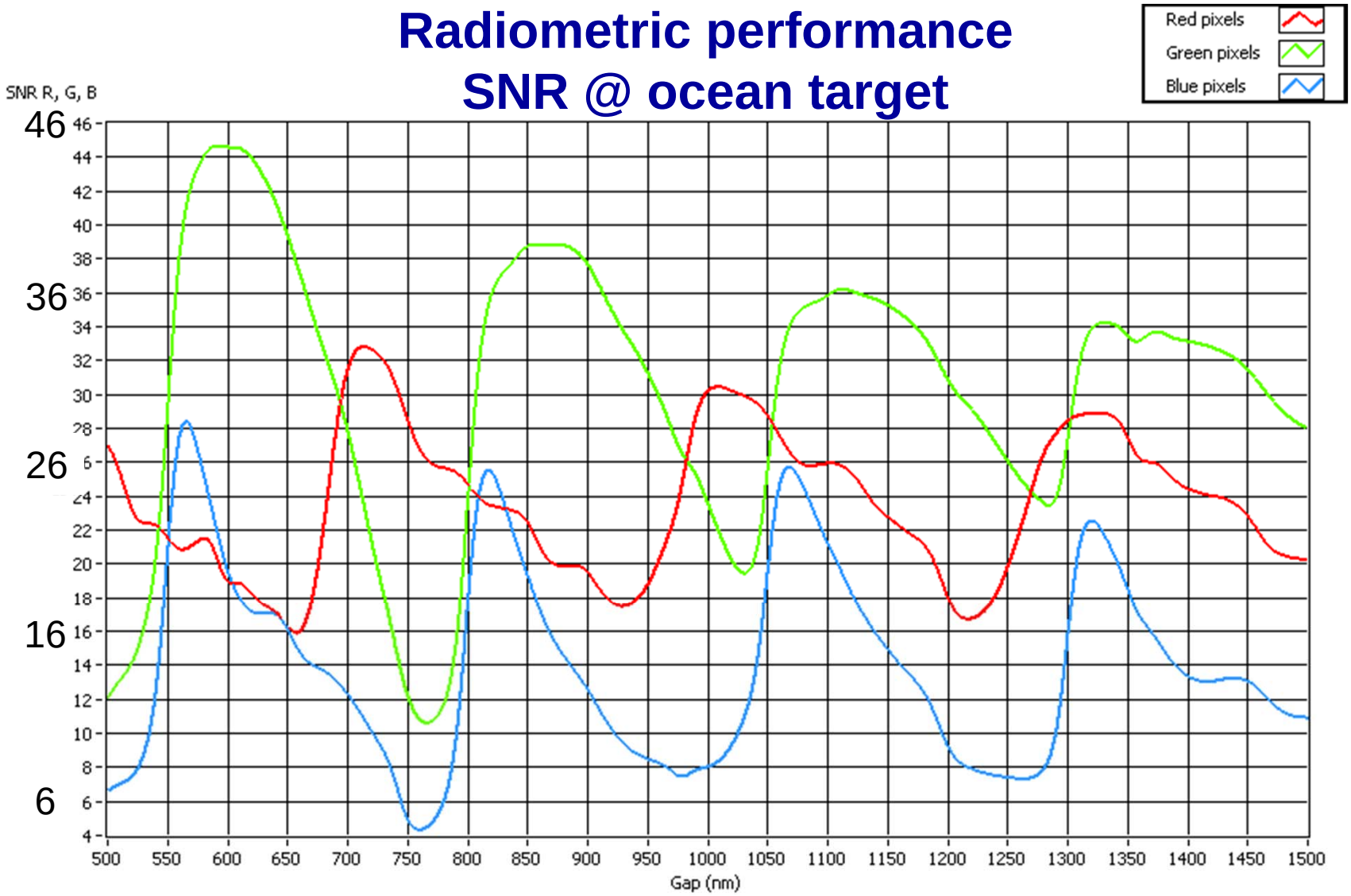
Target: 30% albedo, day 150, time 13:00, Helsinki, Finland

Radiometric performance
SNR @ conifer forest target



Target: conifer forest, day 150, time 13:00, Helsinki, Finland

Radiometric performance
SNR @ ocean target



Target: ocean, day 150, time 13:00, Helsinki, Finland

Conclusions

- The smallest spectral imager in space
  - Mass: 500 g
- Capable of taking 2D images at selectable wavelength bands at 500 – 900 nm
- Technology demonstrator to be launched with the Aalto-1 Student nanosatellite in 2014
- AaSI is developed as a part of the ESA activity “MEMS Fabry-Perot interferometer technology for miniaturized hyperspectral imagers and microspectrometers” (RFQ/3-13517/12/NL/CP**)**

Thank you for your attendance!
Questions?