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space research centre

ESTCUBE
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ESTCube-1 attitude determination and camera flight results

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UNIVERSITY OF TARTU

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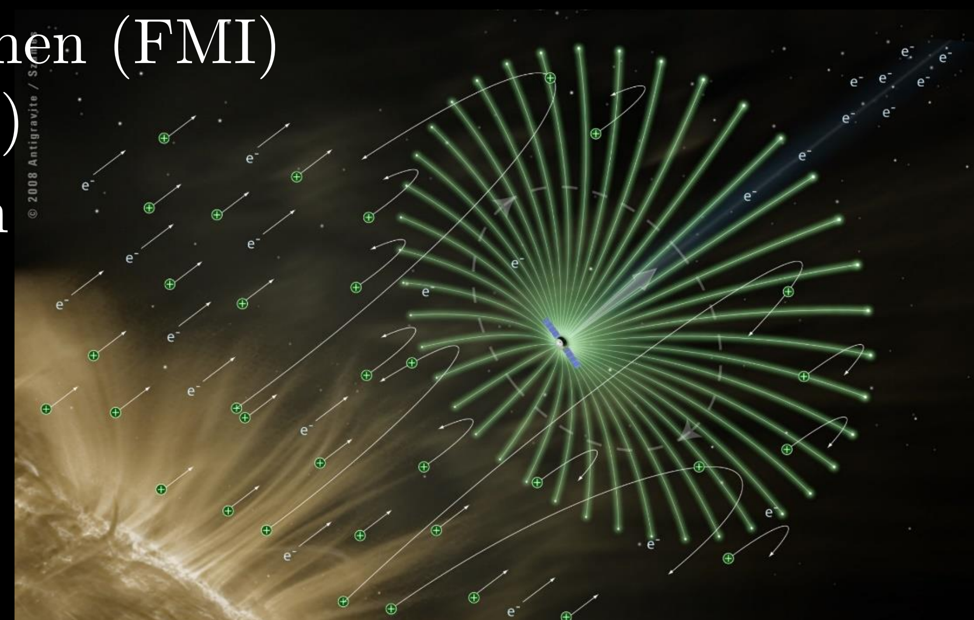
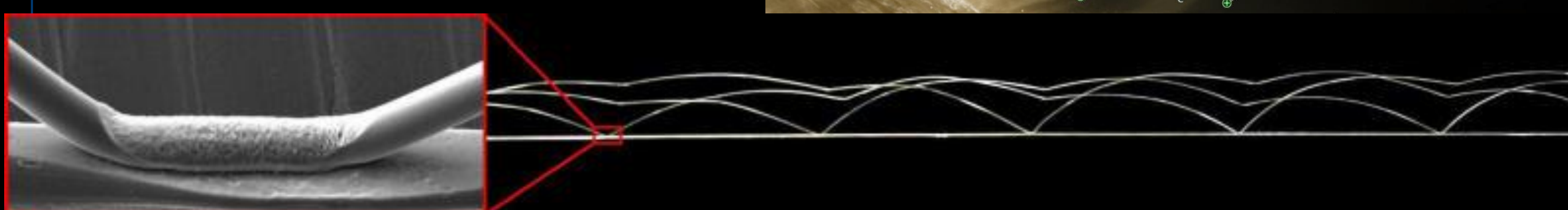
Electric solar wind sail (E-sail)

- Propellantless propulsion system
- Charged long thin tethers
- Charged particles in the solar wind
- Invented by Pekka Janhunen (FMI) (will give a talk tomorrow)
- Record fast transportation in Solar System
- Enables new missions
- Has to be tested!

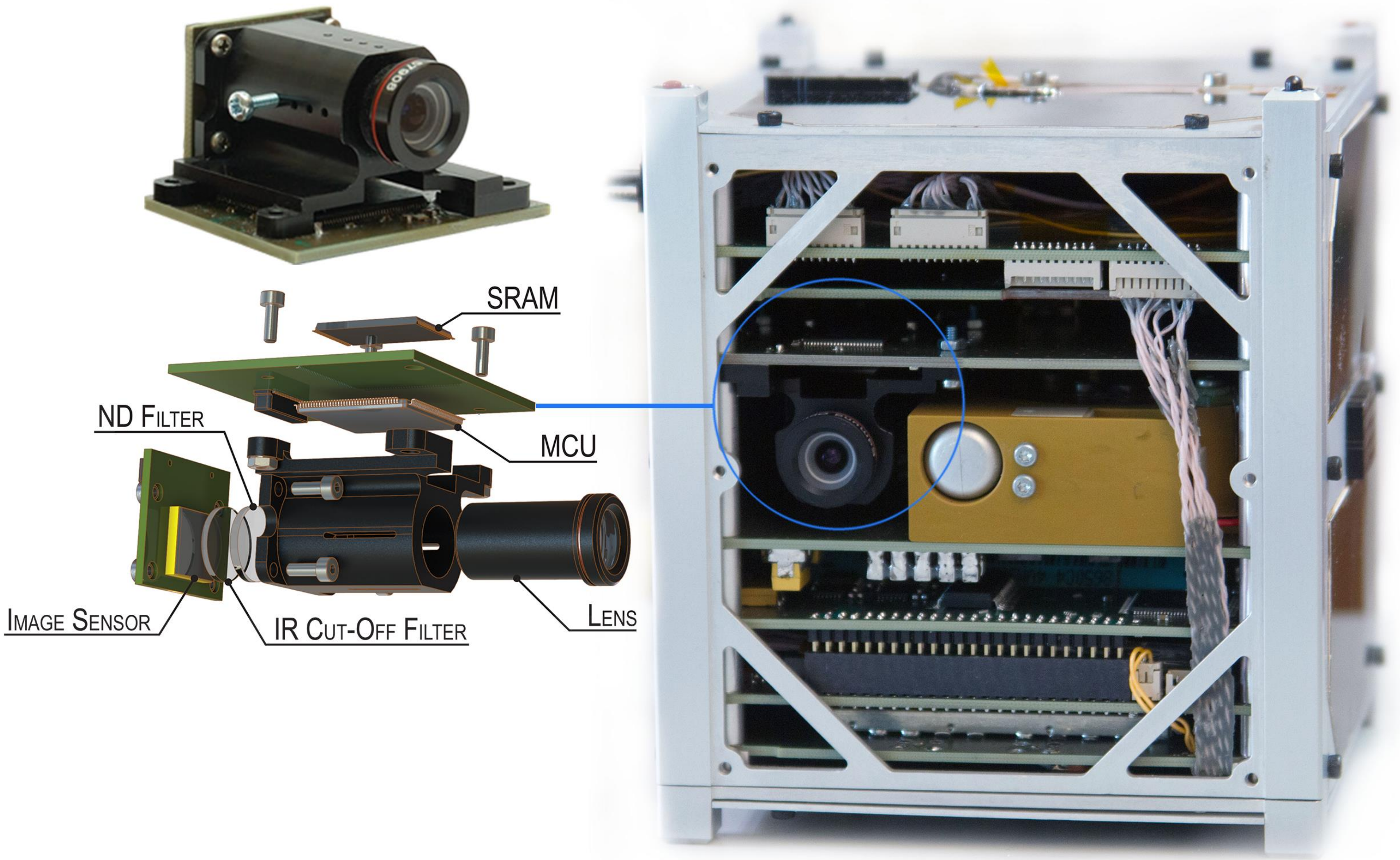




ESTCube-1 overview

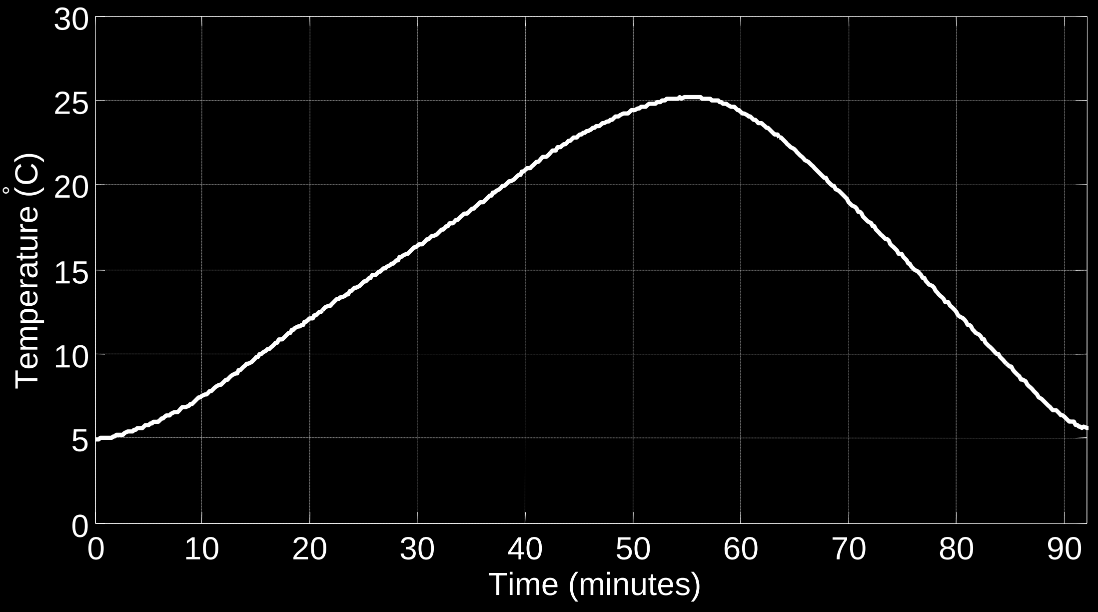
- First E-sail in-orbit experiment
- 10-metre tether interacts with ionospheric plasma
- Tether experiment update tomorrow by Mart Noorma
- Subsystems
  - Camera to image the end-mass
  - Attitude determination to measure the E-sail force and to provide attitude for control
  - Attitude control to spin up the satellite (next talk by Hendrik Ehrpais)
  - Electrical power system
  - Command and data handling system
  - Communication system
  - Structure

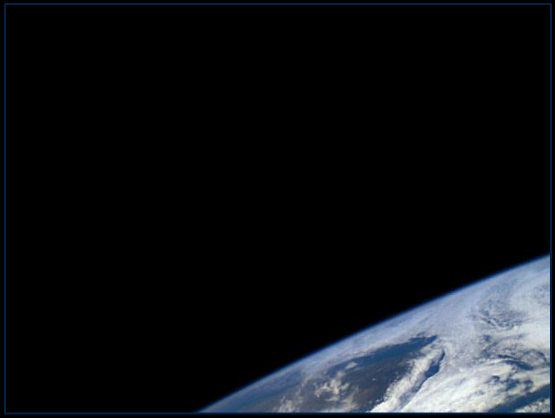
The camera system



A year in space

- Launched with basic firmware
- Two in-orbit firmware upgrades
  - Histogram based image evaluation
  - Power consumption from 120 mW to 75 mW
- Sensor temperatures over an orbit





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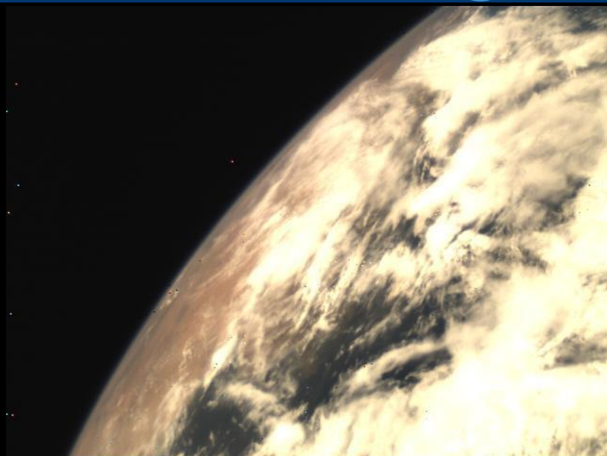
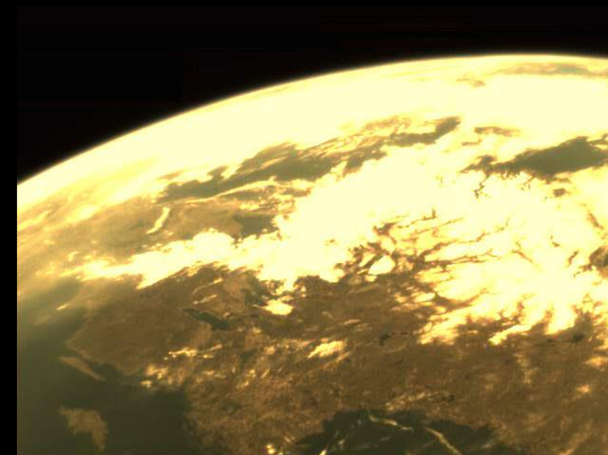
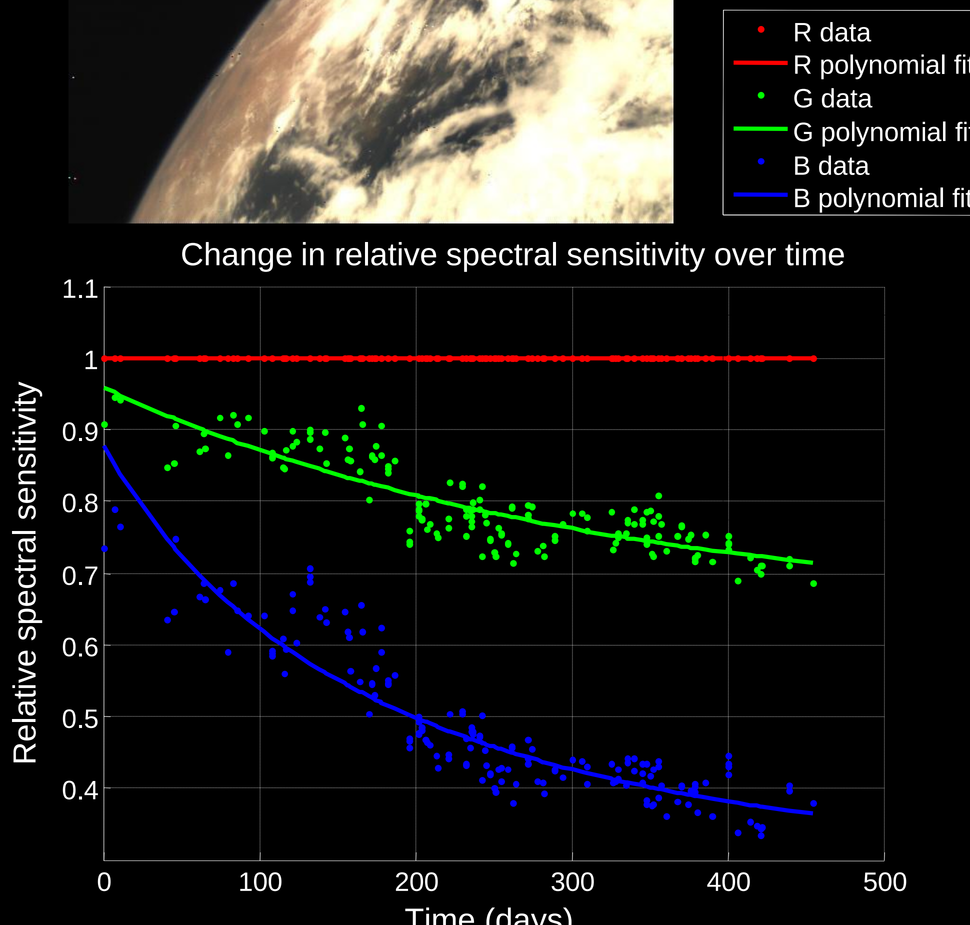
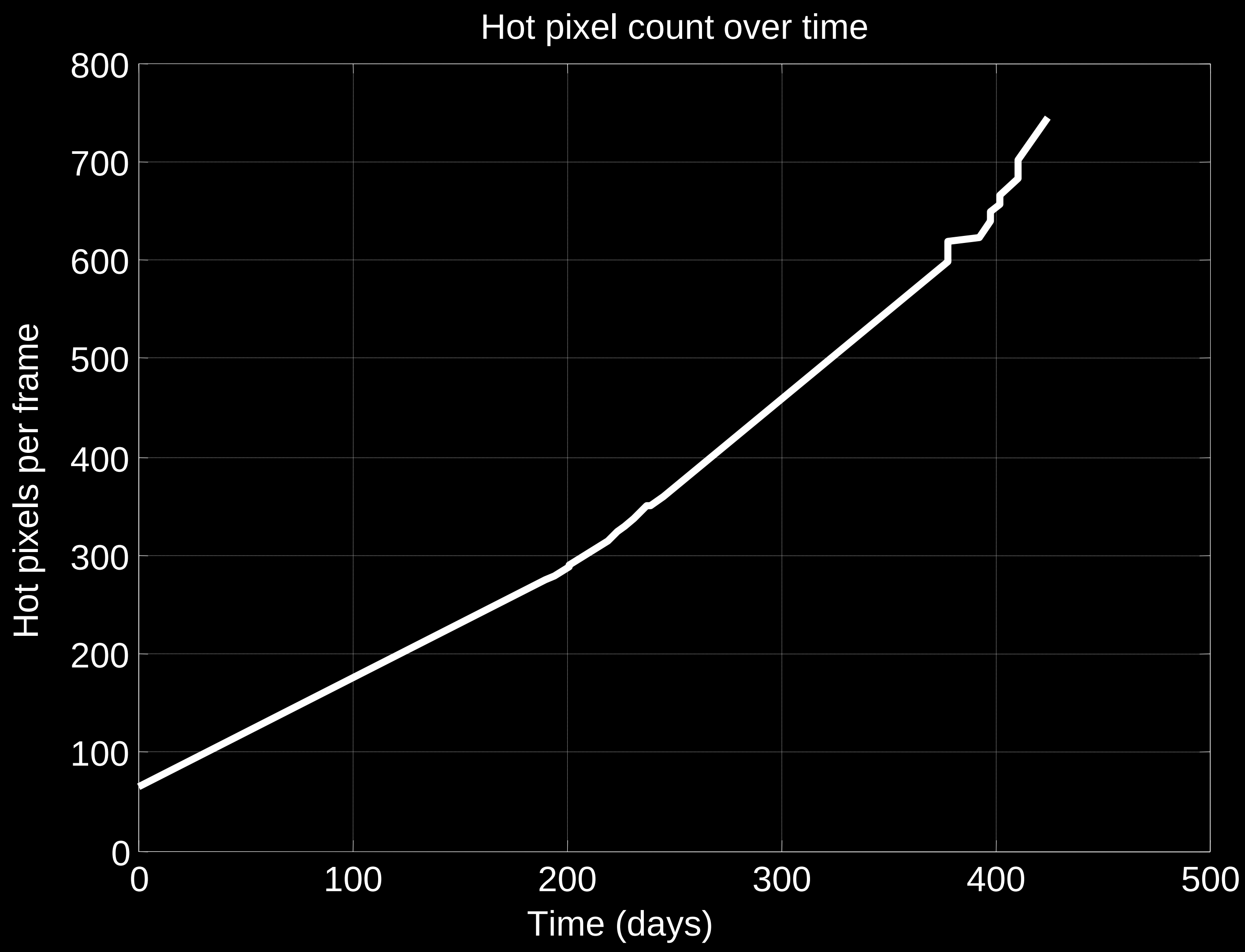
Degradation of optics



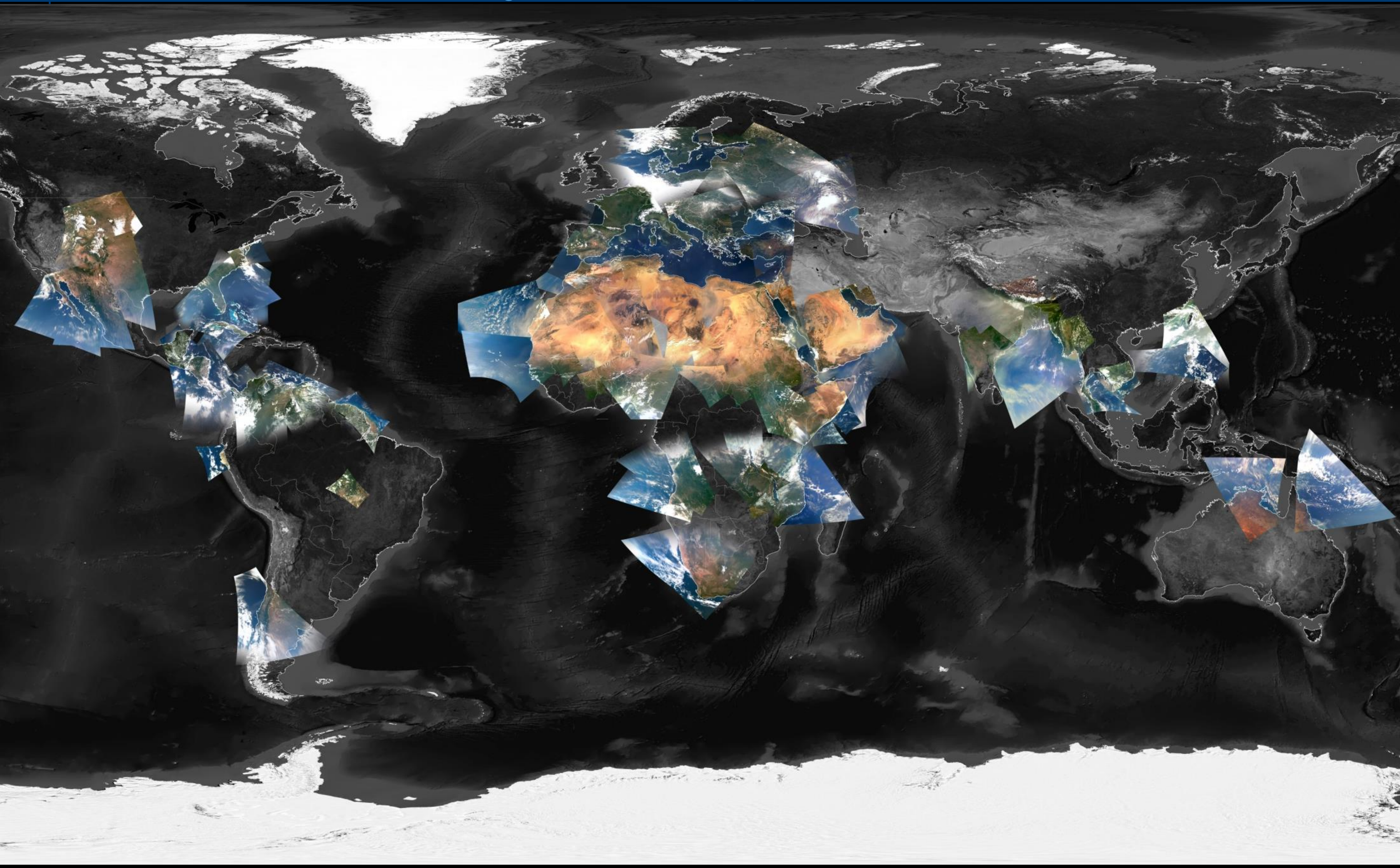




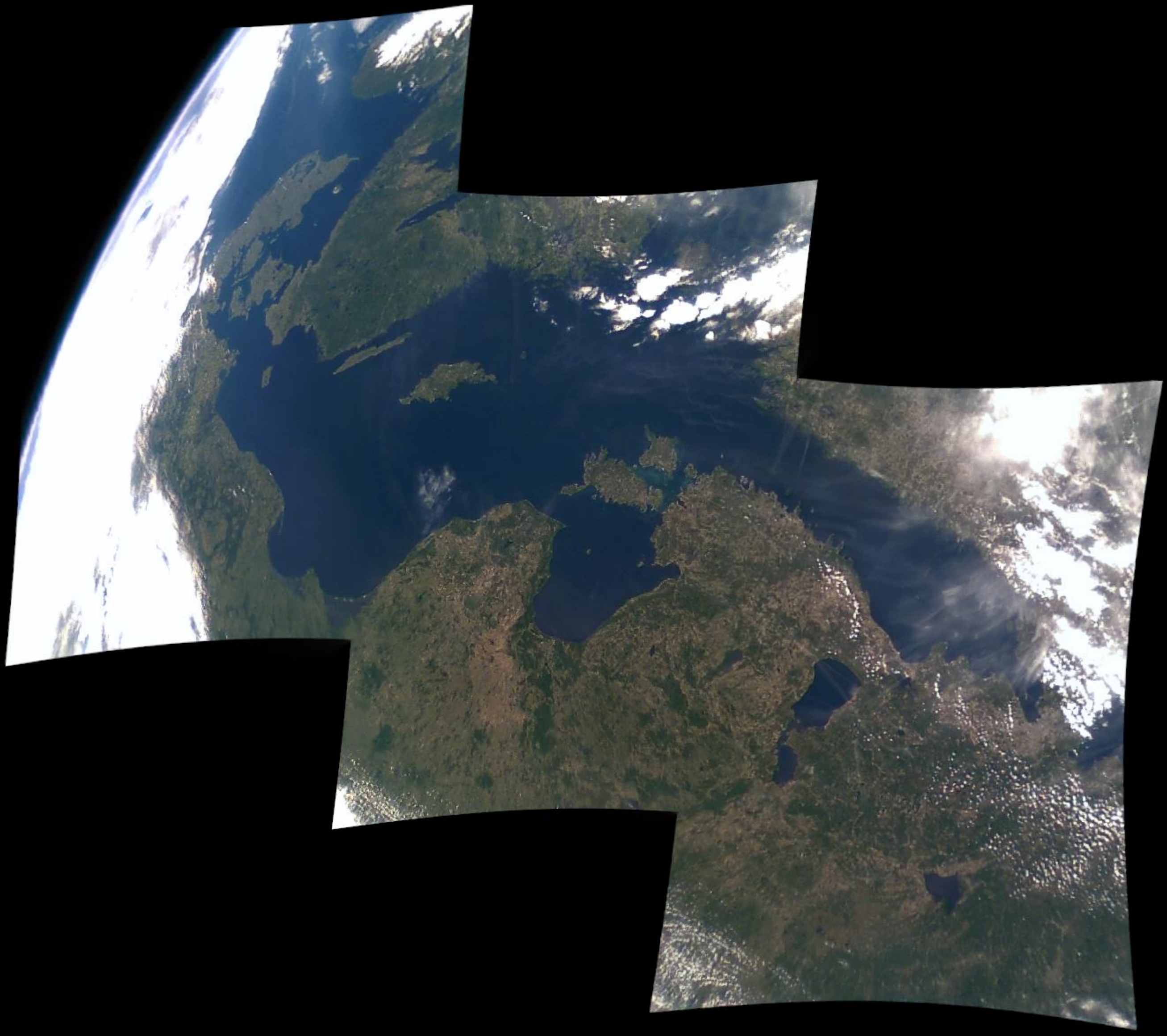
Analysis of dark frames



A year in pictures



Mission objectives



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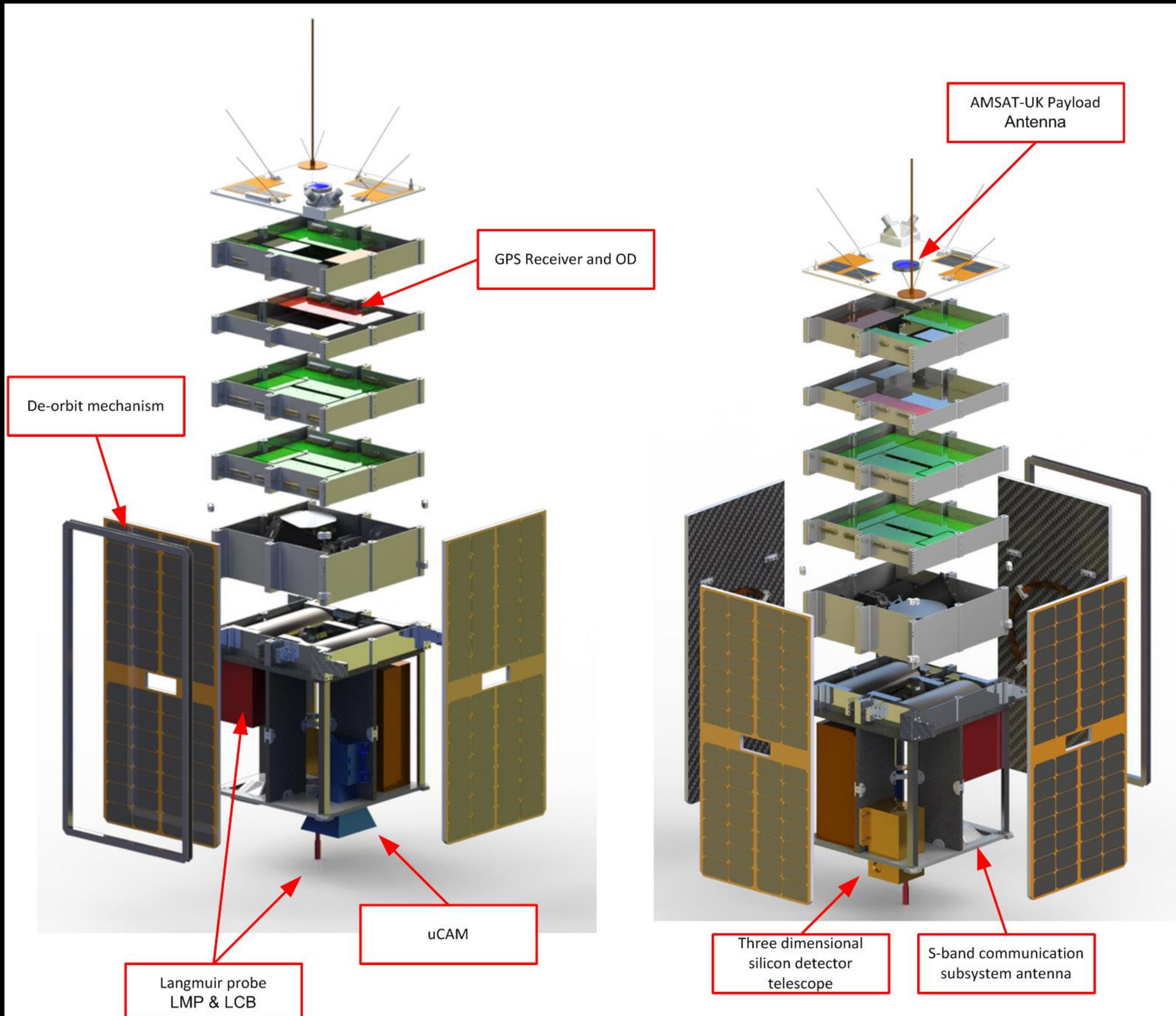
European Student Earth Orbiter



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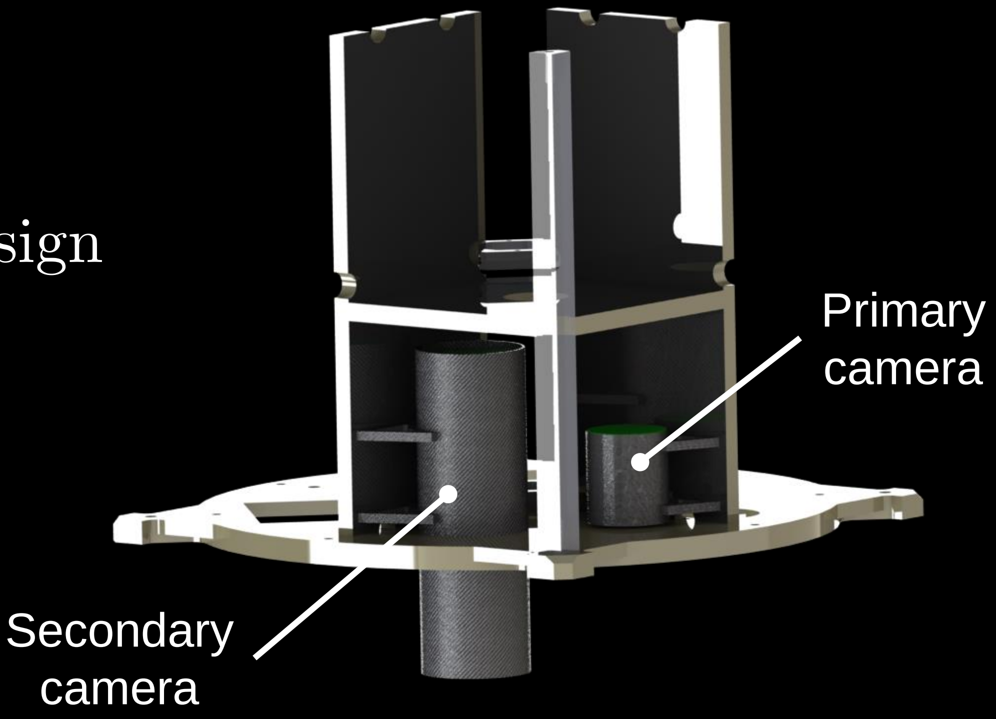
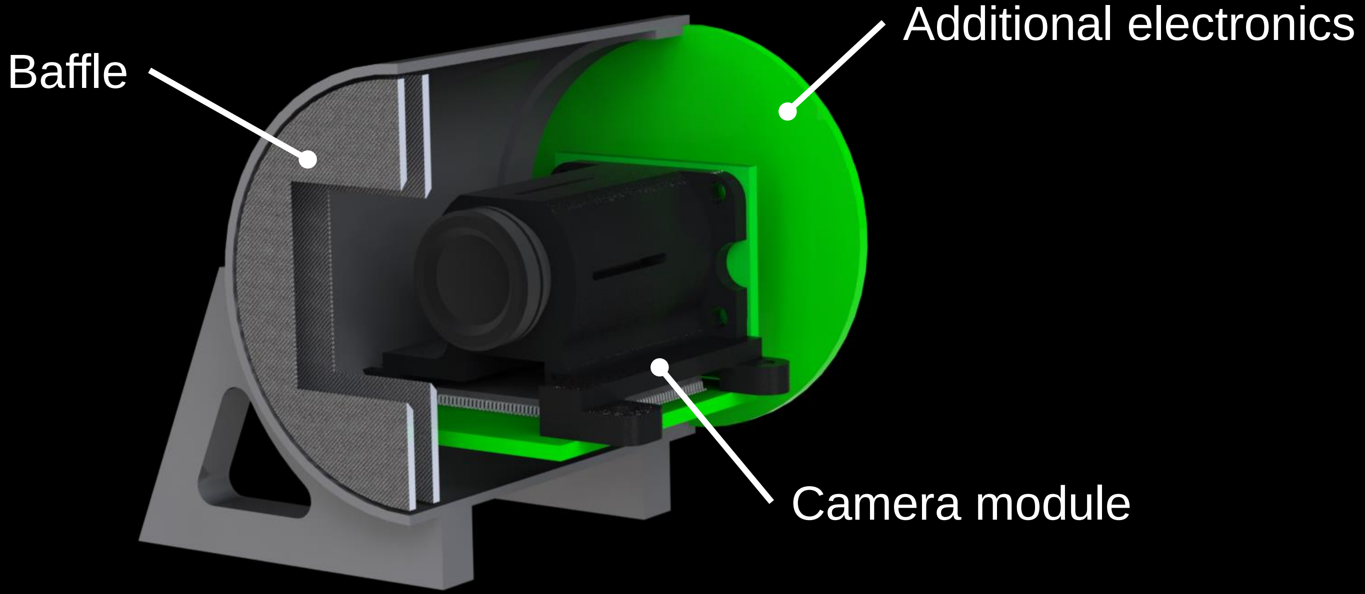
ESEO optical payload

- Earth imaging
- Two cameras for redundancy
- Carbon fiber and aluminium structure
- Baffles
- CAN interface
- Low power consumption
- Reliable and reusable design



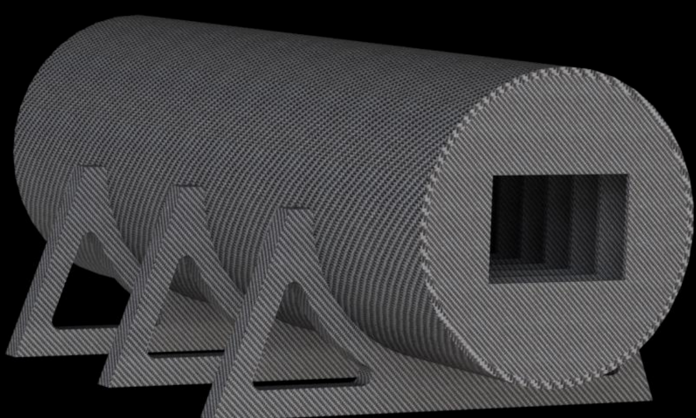
Primary payload

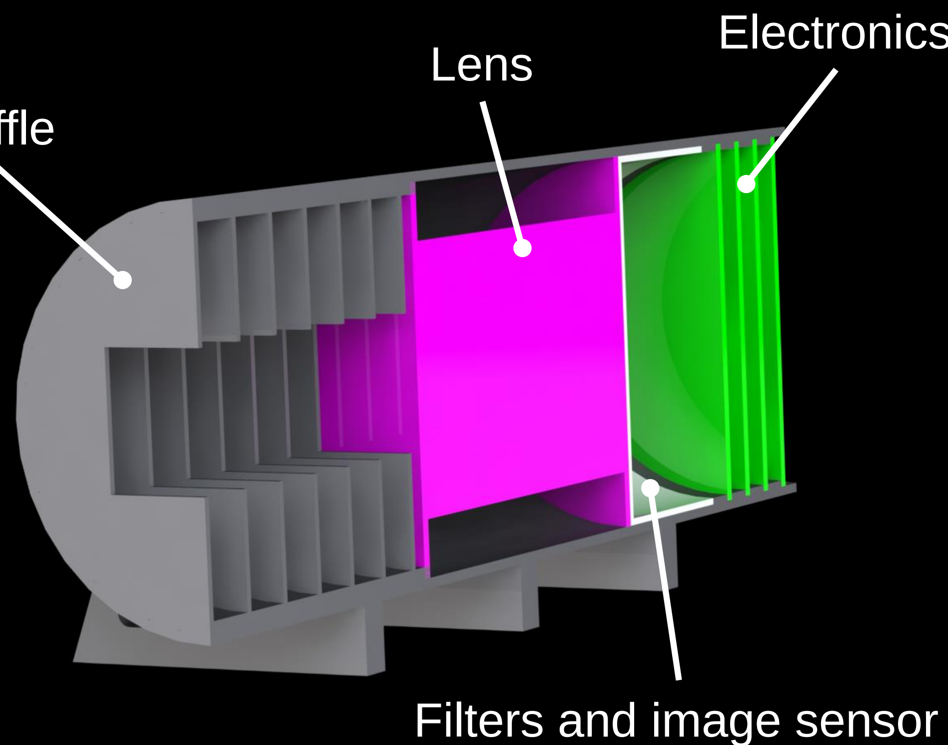
- Slightly modified ESTCube-1 camera
  - Additional interfaces (CAN and SPI) to communicate with the satellite and the mass storage
  - Same optics
    - Ground resolution – 630 meters per pixel



Secondary payload

- A larger, upgraded version of the ESTCube-1 camera
  - 50 mm lens and 5 megapixel sensor
    - Ground resolution – 23 meters per pixel
  - Additional SDRAM and mass storage

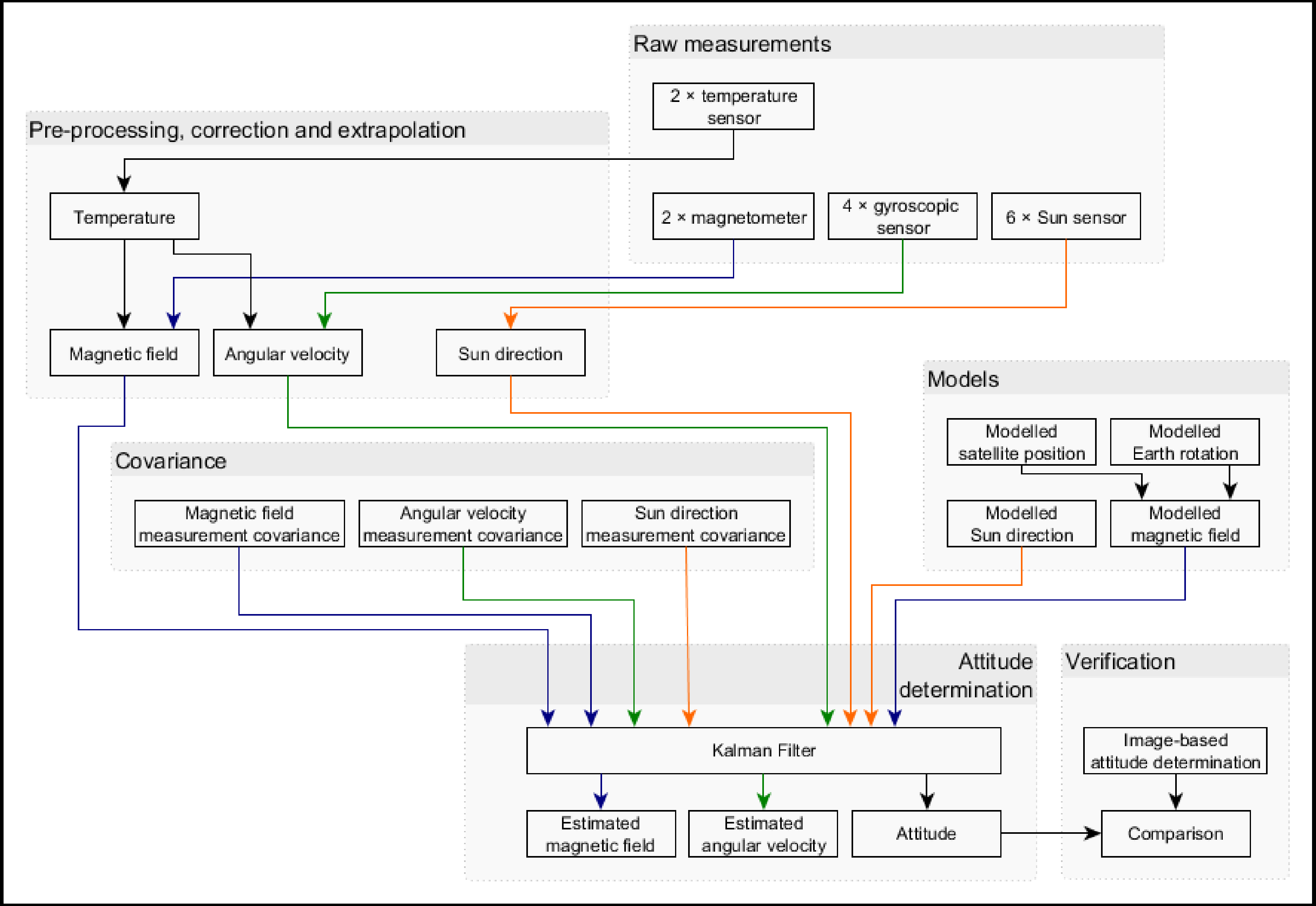




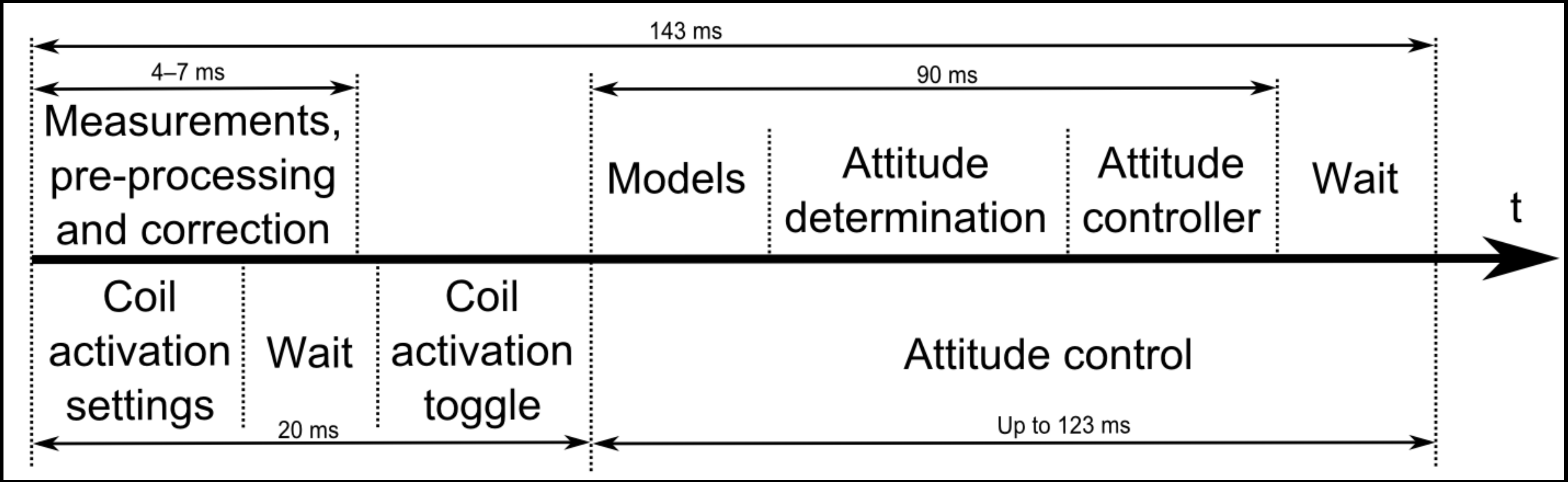
Attitude determination system (ADC)

- Requirement: attitude determination accuracy better than 2°
- Sensors: magnetometers, Sun sensors, gyroscopic sensors
- Unscented Kalman Filter
- Sensors calibrated in laboratory
- Recalibrated and tuned in orbit
  - Intercompared
  - Compared with geomagnetic and Sun models
  - Compared with Kalman filter's output
- Validated by comparing with attitude from images

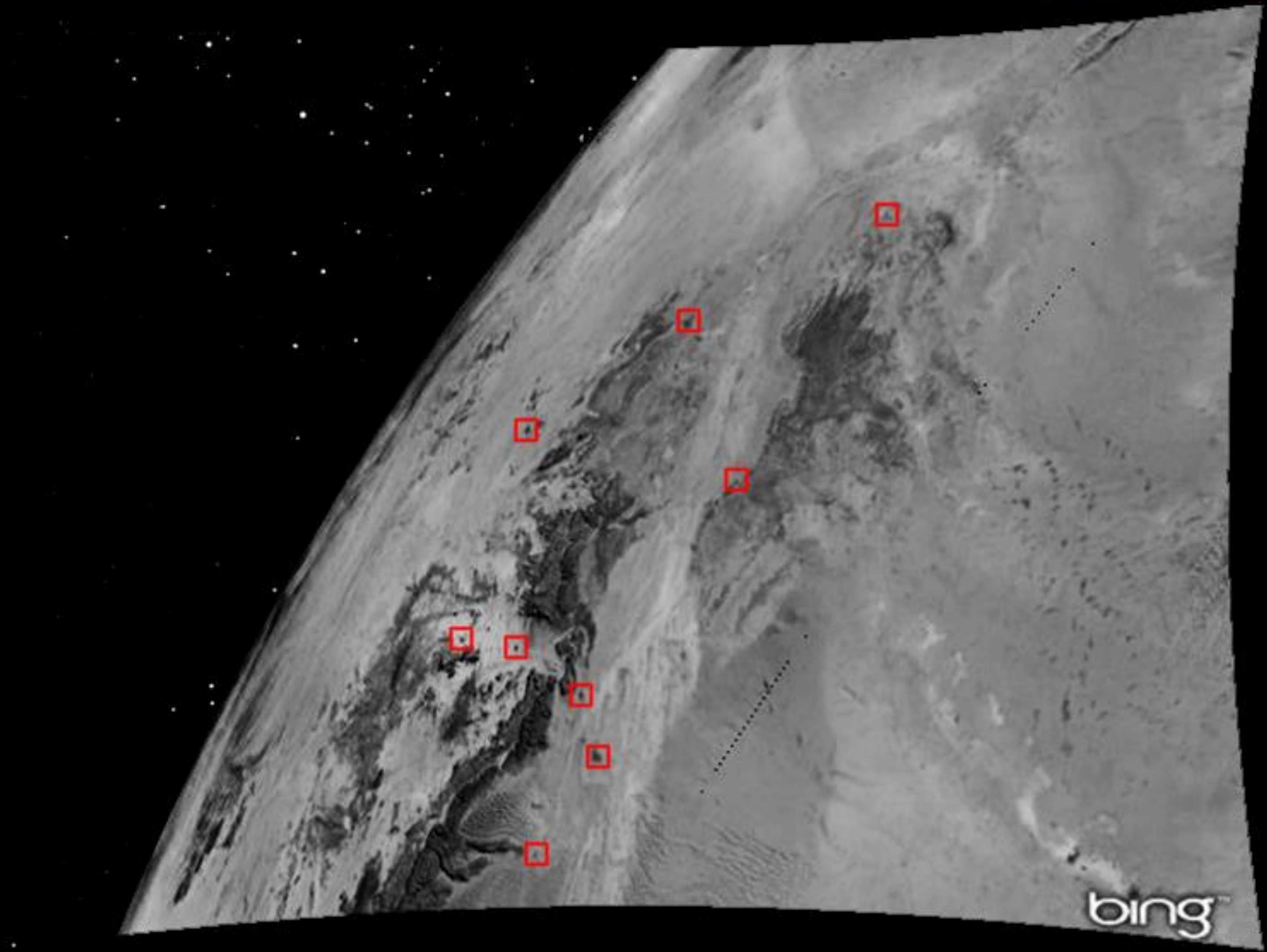
ADS flow chart



ADS timeline



Validation of ADS



ADS uncertainty budget

Quantity	Uncertainty contribution
Simulation-based uncertainty estimated by standard deviation	0.6°
Earth precession uncertainty	0.15°
Earth nutation uncertainty	0.1°
Orbit propagator uncertainty	0.01°
Sun direction model uncertainty	0.0015°
Geomagnetic field model uncertainty	0.001°
Combined standard uncertainty	**0.63°**
Expanded uncertainty (95% confidence level, *k*=2)	**1.26°**

Uncertainty budget of image-based attitude determination

Quantity	Uncertainty contribution
Point selection uncertainty	0.37°
Time uncertainty	0.21°
Camera resolution uncertainty	0.04°
Lens distortion uncertainty	0.02°
Combined standard uncertainty	**0.43°**
Expanded uncertainty (95% confidence level, k=2)	**0.86°**

Comparison results

- The expanded uncertainty of comparison (95% confidence level, $k=2$) is 1.52°

Sample	1	2	3	4	5	6	7	8
Difference, degree	0.31	0.63	1.26	0.7	1.16	1.32	1.43	0.17
Sample	9	10	11	12	13	14	15	
Difference, degree	1.14	0.45	0.78	0.32	0.18	0.31	0.42	

Conclusions

- One of the best CubeSat cameras
- Fulfils mission requirements
- Its heritage used to develop a camera for ESEO mission (scheduled to be ready on Q1 2015)

- ADS is calibrated, characterised and validated
- Uncertainty budget fulfils mission requirements
- Comparison results within uncertainty budget
- Its heritage used to develop an attitude and orbit control system for next E-sail test missions