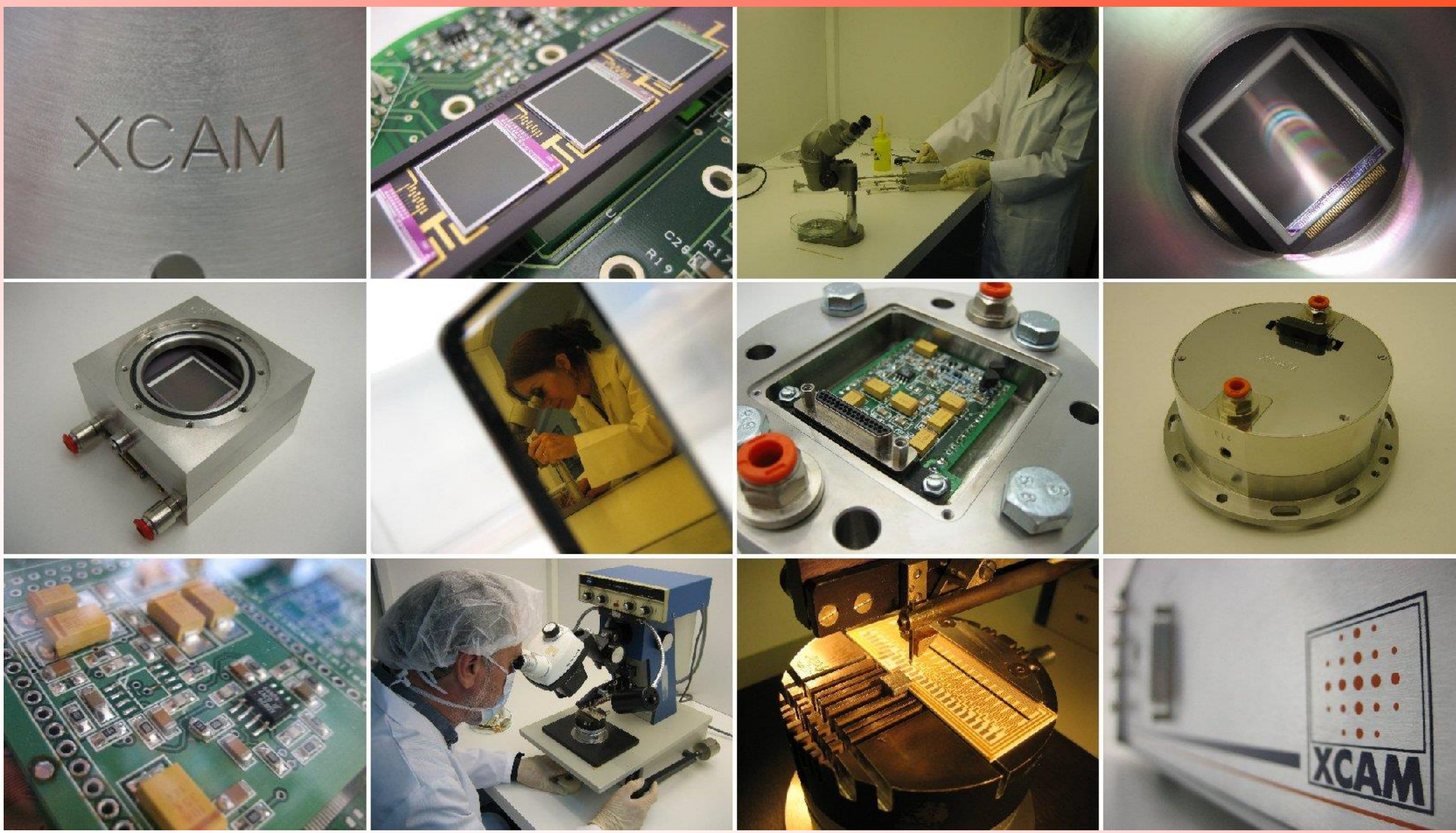
Design and Test of ESA EM Space Particulate Contamination Monitor



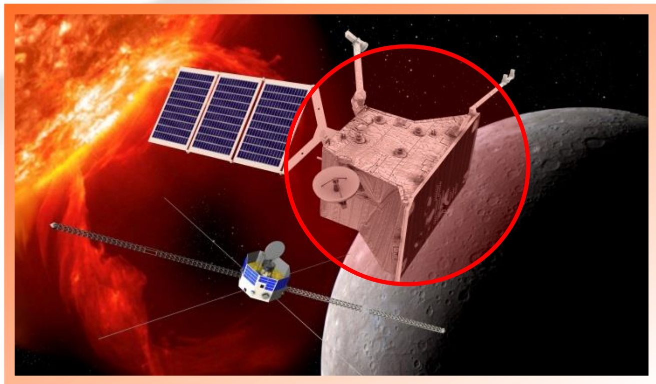
Design and Test of ESA EM Space Particulate Contamination Monitor

- Background to the ESA requirement
    - •Particulate contamination in controlled environments
    - •Monitoring inside rocket fairings is a difficult environment
- Prototype System Development
    - System description and results
    - Application software
- Flight System Development
- Design Challenges and Trade-Offs
- Design and Assembly of the Flight Unit
- Testing of the EM unit
- Next Steps

Importance of Particulate Monitoring and Control

Typical controlled environments

AIT @ System level



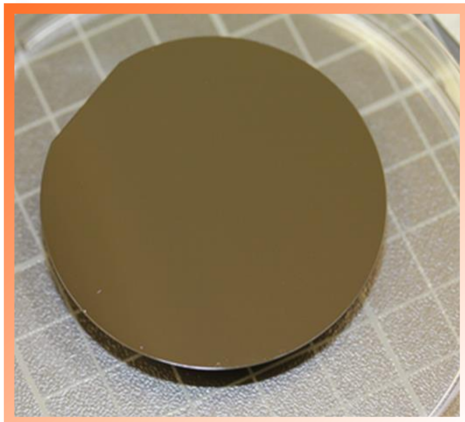
Monitoring Deposited Particles

Methods typically defined in ECSS-Q-ST-70-50C

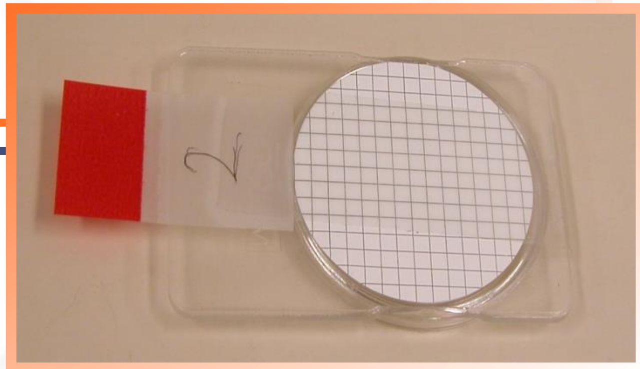
PFO plate

PFO meter

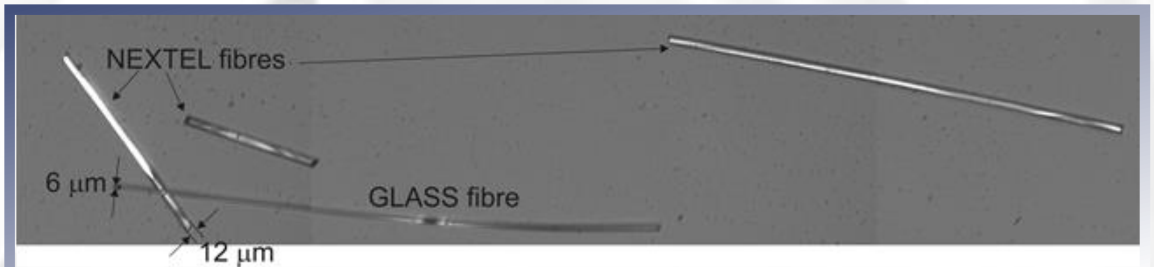
PFO →**Total obscuration**



Silicon wafer



Tape lift sample



Tape lift & Silicon wafers →Particles and fibres **distribution**

A not so easy environment…!

- Manufacturing Assembly Integration and Test methods generally apply but contamination control has severe limitations
- Predicting and monitoring of the launcher contamination environment is a great challenge

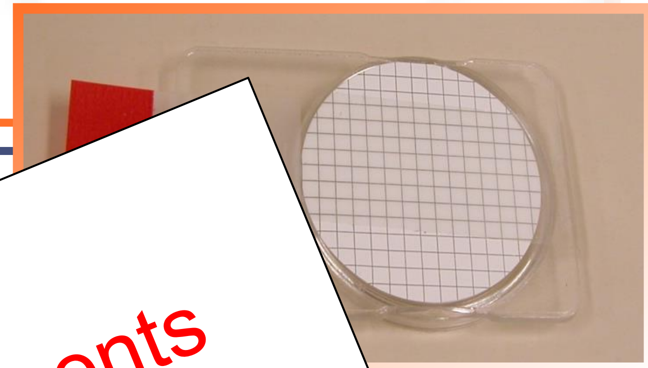
Accessibility restrictions

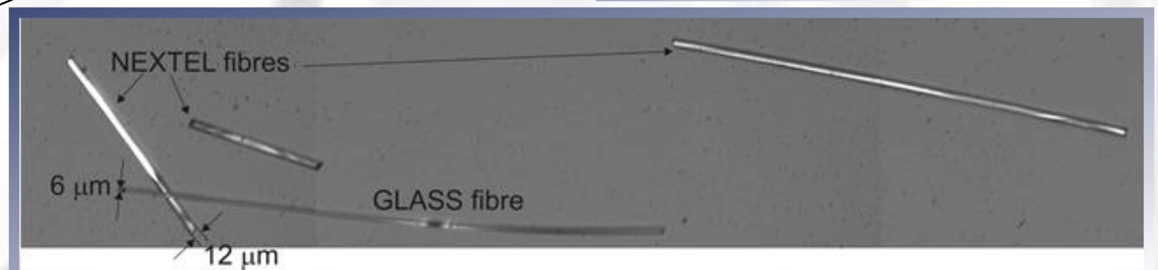
Monitoring Deposited Particles

Methods typically defined in ECSS-Q-ST-70-50C

PFO plate

PFO meter





No real time
No continuous
No remote
} measurements

PFO → **Total obscuration**

Tape lift & Silicon wafers → Particles and fibres **distribution**

Prototype System Development

In September 2014 XCAM began an ESA project to develop a particulates contamination monitor which is designed for ultimate use inside rocket fairings.

The objectives of the activity were:

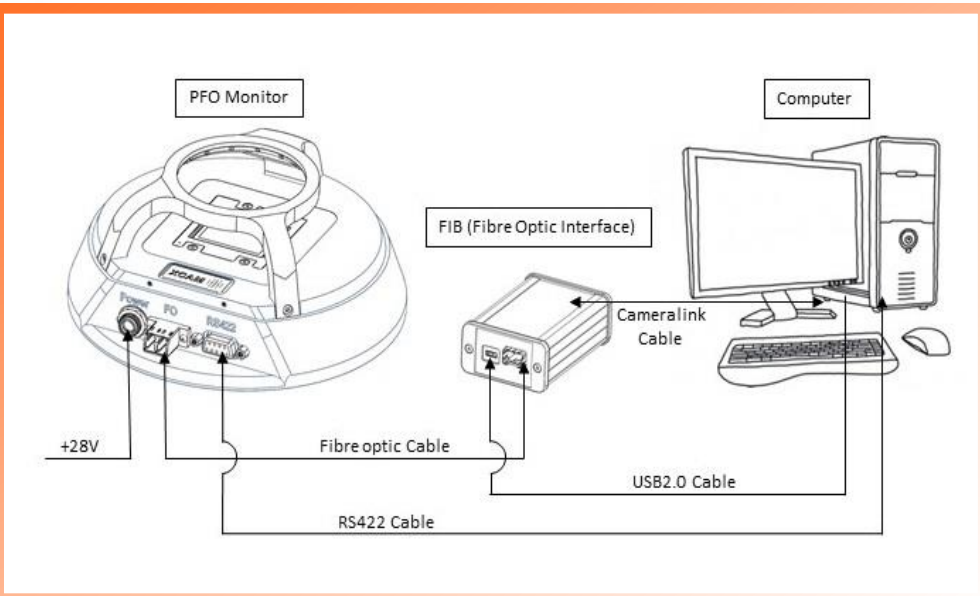
- To design and develop, manufacture and test a breadboard model of a real-time system for the measurement of particle fall-out
- Monitoring of those environments typically encountered by spacecraft systems just before and after launch
- Use of the developed method in cleanliness controlled areas and cleanrooms e.g. during AIT

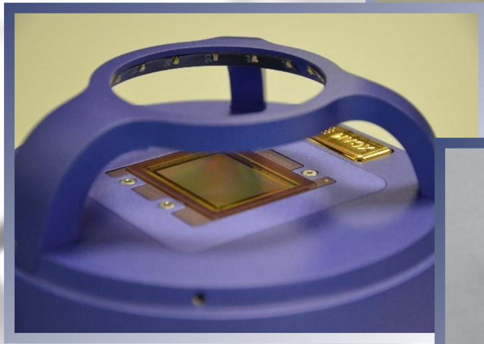
The key requirements of the instrument were:

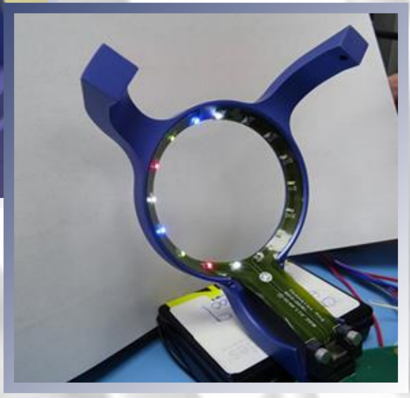
- Minimum particle size detection of 5 micron or better
- Differentiation between particles and fibres
- Capability to detect the shape of the particle and fibres detected (straight vs curly fibres?)
- Ability to count and size all deposited particles and fibres
- Ability to perform continuous measurements with a rate of at least 1 measurement every 10 seconds during key times e.g. launch(?)

Prototype System Development

- Imaging sensor
- Overhead illuminating LED ring without obscuring falling particles
  - Red, green, blue and white LEDs for experimentation
- Communications for interface to rocket – RS422 - with proprietary XCAM fibre-optic interface for high speed lab testing



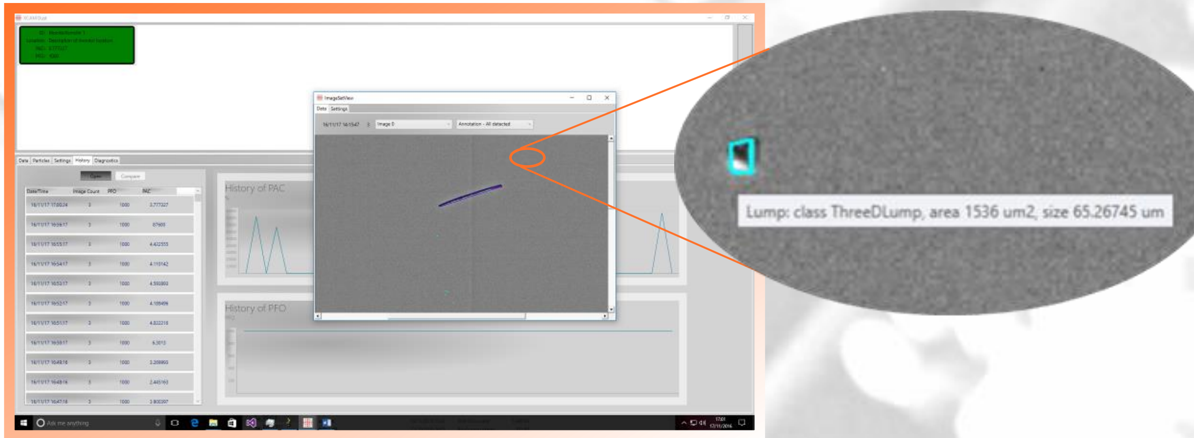


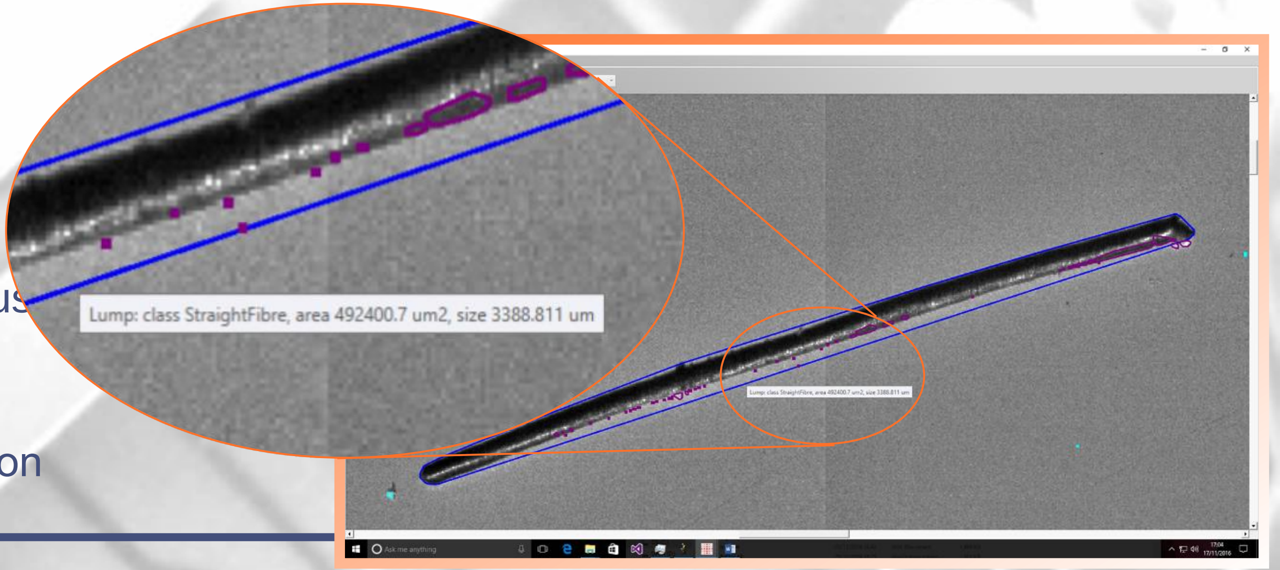


Prototype System Development

Software developed provides:

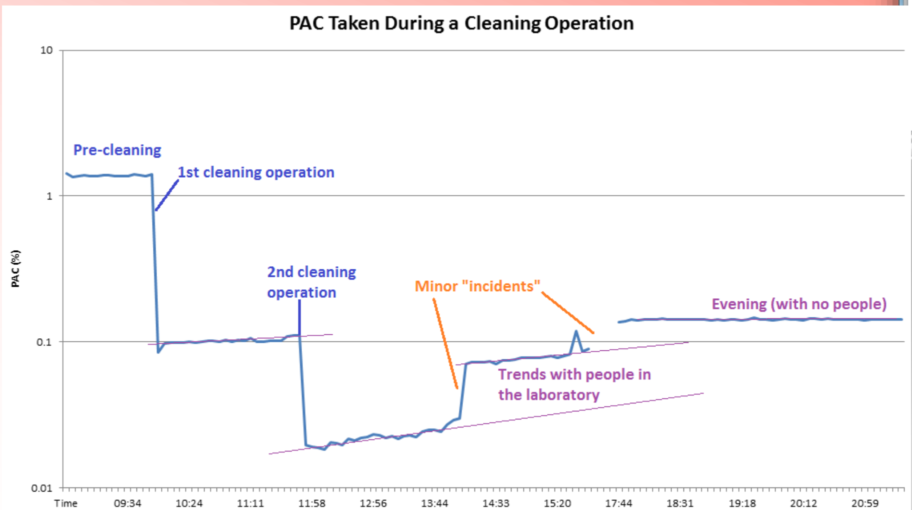
- Classification of particle types
  - Particles
  - Fibres
  - Straight vs. Curly fibres
- Detailed dimensional information for each particle
  - Location
  - Area
  - Size





- Particle distribution by size with us definable bins
- Historical trend enabling contamination “event” identification

Prototype System Development



Ability to look at individual images and compared two images, distinguishing particles vs fibres

Ability to look at particle size distribution, particulate fall-out level PFO, percentage area covered PAC

Ability to set PFO and PAC alarms

Prototype System Development

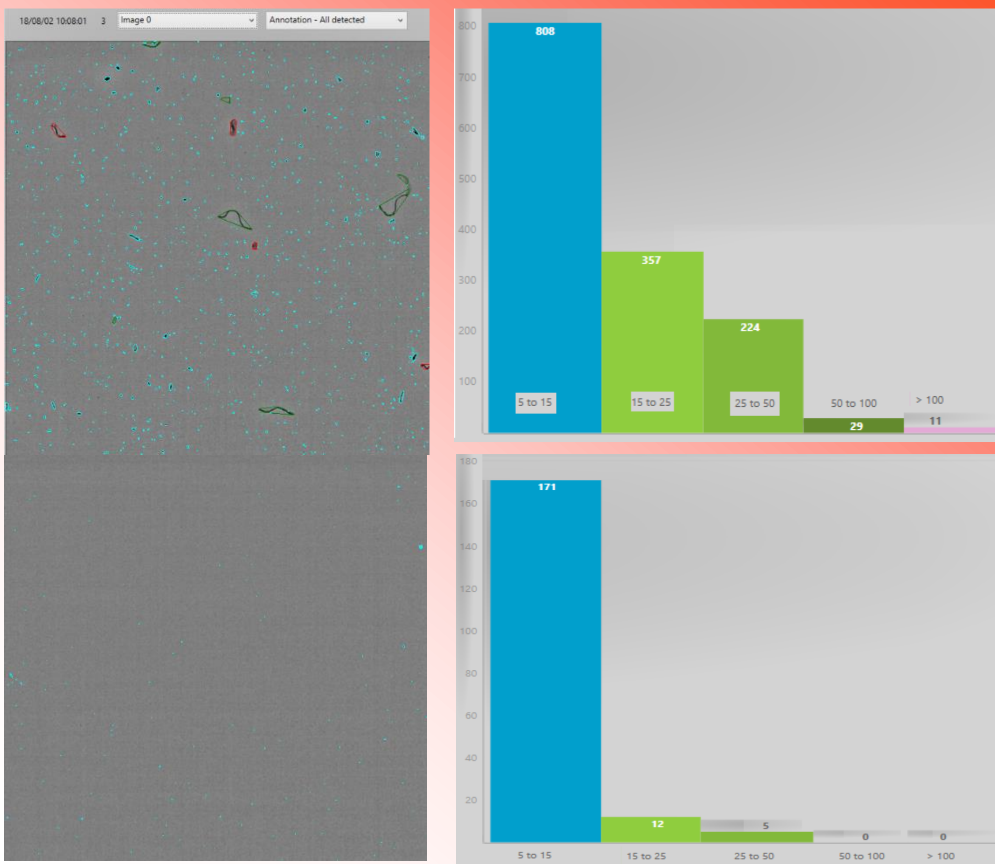
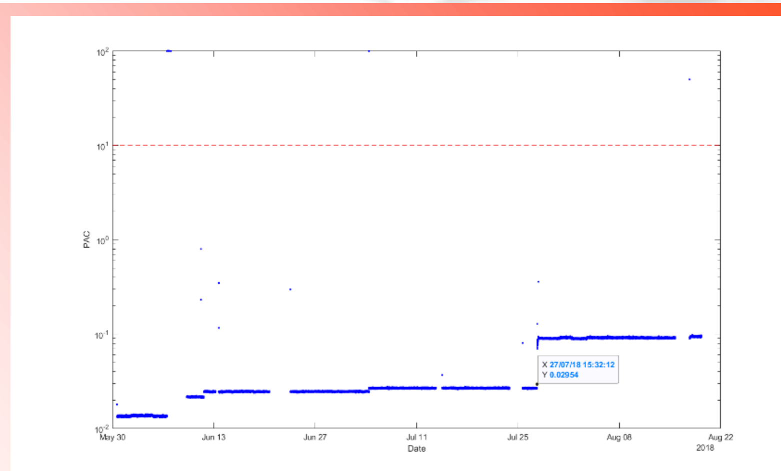
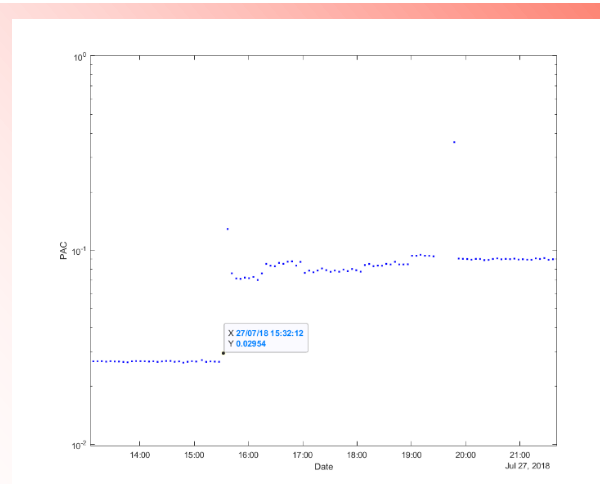


Image and histogram top pre-clean; bottom post clean



3 months real time operation in Spain Euclid flow bench during NIR filter wheel assembly



Prototype System Development
Commercial Particulates Monitor

Smoother cleaner finish than ESA prototype for easy-clean

CE-compliant design

Four 1 cm^2 sensors depending on requirements and budget

Waterproof design enabling wet or dry cleaning (under development)

Illumination ring similar to ESA prototype

Ethernet connection for convenience vs ESA rocket RS422 interface

Flight System Development

Requirements for flight system:

- All of the requirements previously noted for the prototype system ie
  - Detection of a minimum particle size of 5 micron or better
  - Ability to differentiate between particles and fibres
  - Ability to detect the shape of the particle and fibres detected
  - Ability to count and size all deposited particles and fibres
  - Ability to perform continual measurements with a rate of at least 1 measurement every 10 seconds *before launch and after launch until fairing ejection*
- Ability to operate inside a launcher fairing – VegaC baselined, but other launchers should be feasible without redesign being needed. This means ability to
  - Not only survive but operate during the shock and vibration of launch
  - Ability to detect and store the contaminant image regions and send down to earth for later analysis
  - Ability to operate completely autonomously without a connection to the launcher other than for power connection and to send data to data acquisition unit
- Since project began, and due to download data limit restrictions, there is also a need to process the images on-board to find those pixels which represent contaminants, and to compress these pixels into a tight data stream for low data volume download

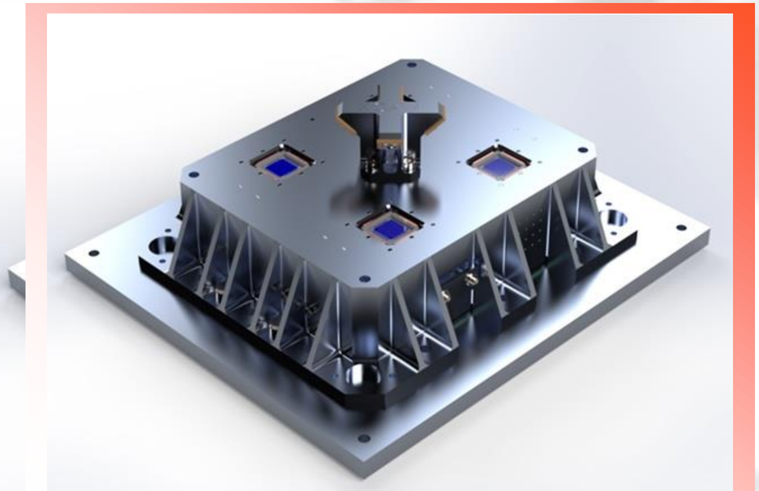
Design Challenges and Trade-Offs

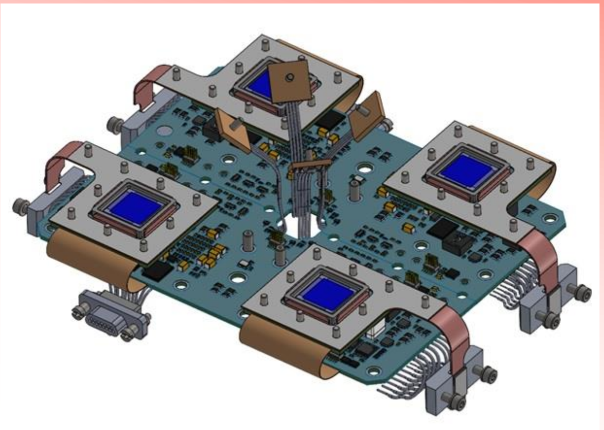
Design Challenges and Trade-Offs

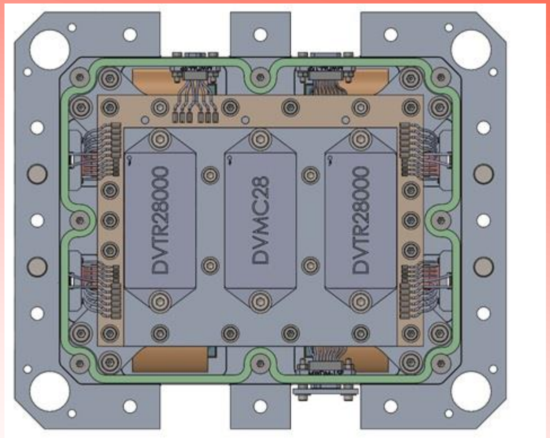
- Lack of defined mission to create requirements specification
- Finding parts/techniques to enable the unit to operate during the shock and vibration at launch within the low budget envelope of the project
- Illumination support structure
- Fully redundant/partially redundant approach
- Autonomous operation and launch detection
- On-board processing of images
- Ensuring we meet very stringent potential EMC standards due to needing to operate during launch

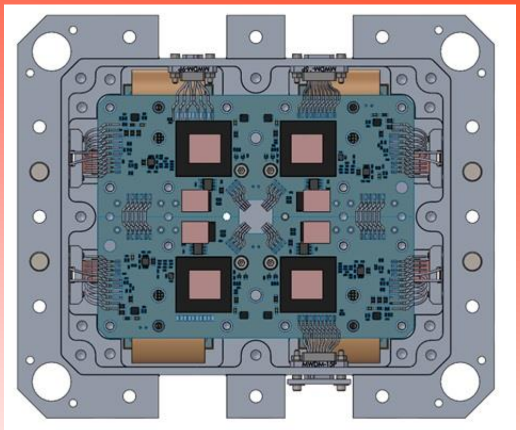
Design of the Flight Unit

- Ruggedised version of commercial unit
- But with a totally different architecture
- Each particulate sensor operates independently of the others providing multi-redundant approach
- Air-pressure monitor and accelerometer network enables independent detection of launch



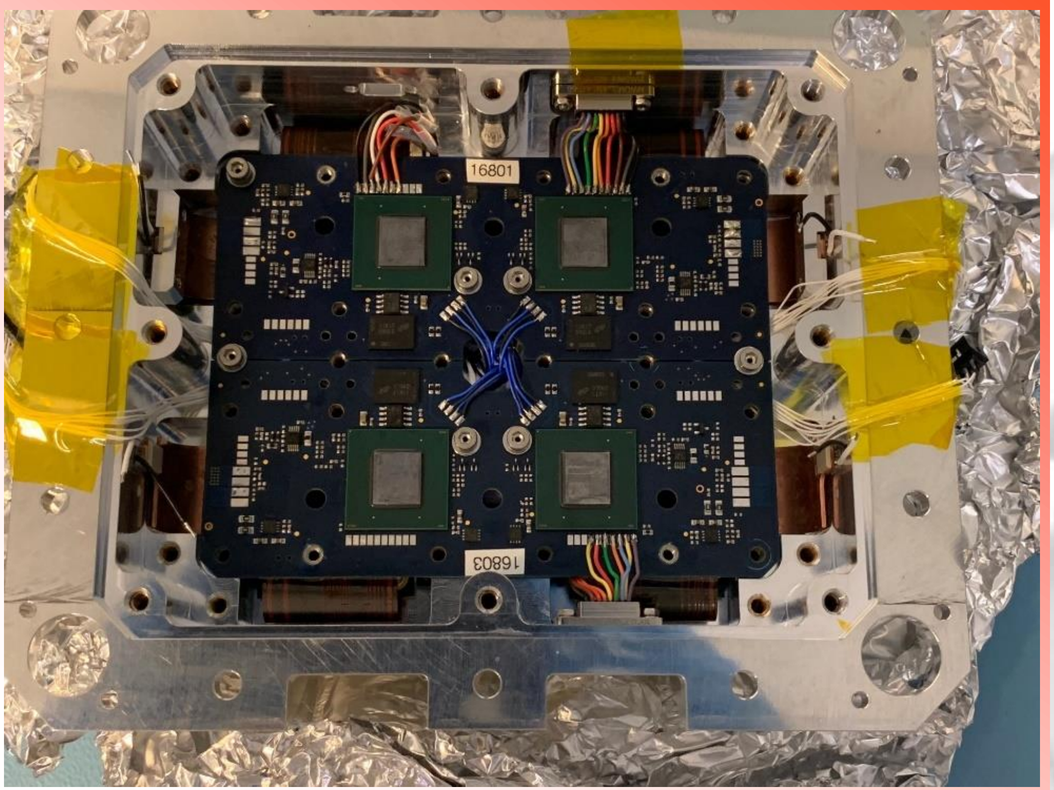






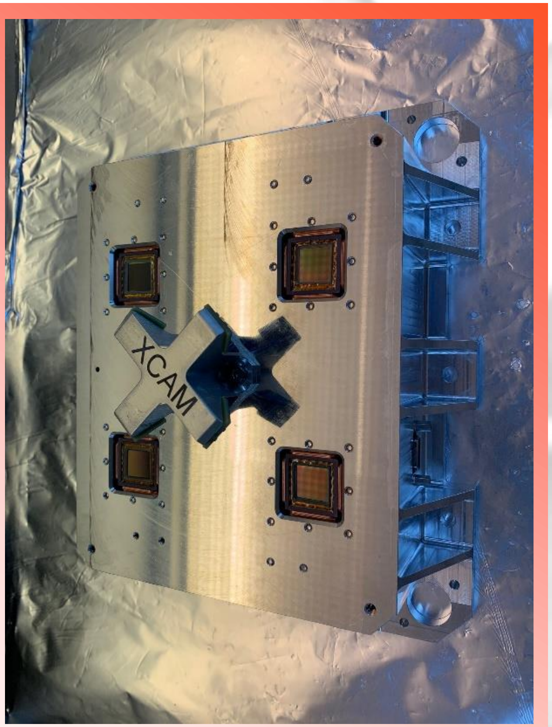
Assembly of the Flight Unit

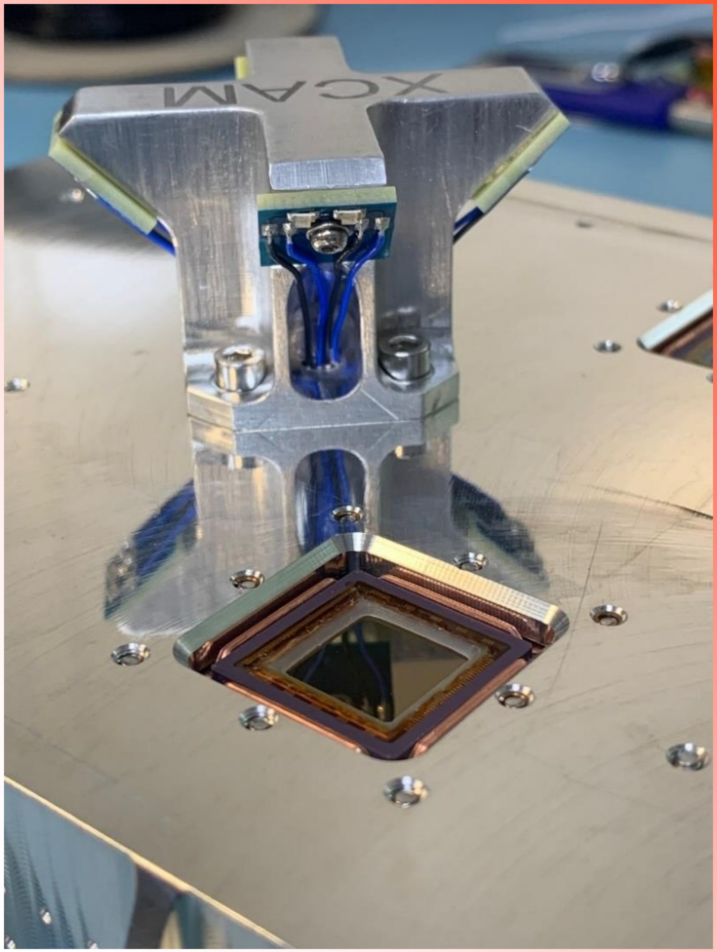
- Power supply (Right)
- FPGA control boards (below)



Assembly of the Flight Unit

- Images of the EM unit being prepared for test



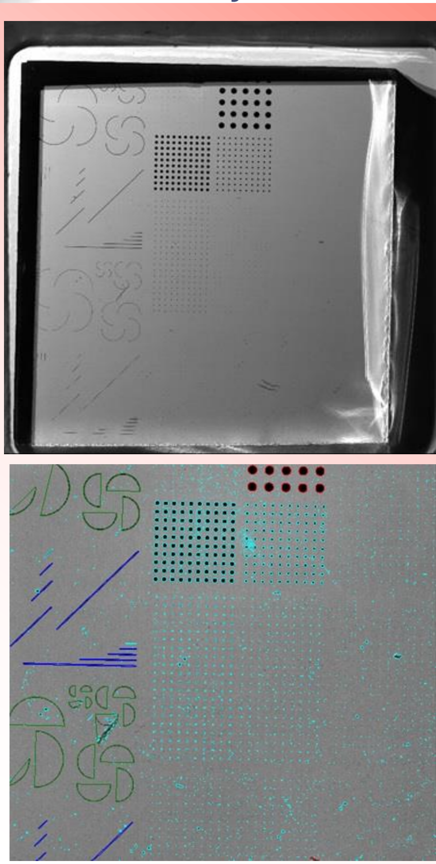


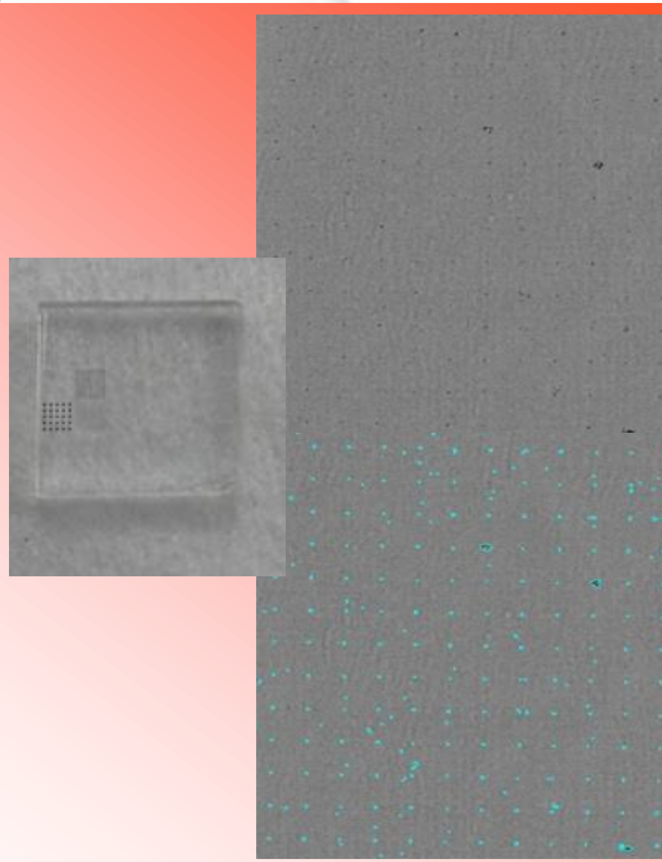
Testing of the EM Unit

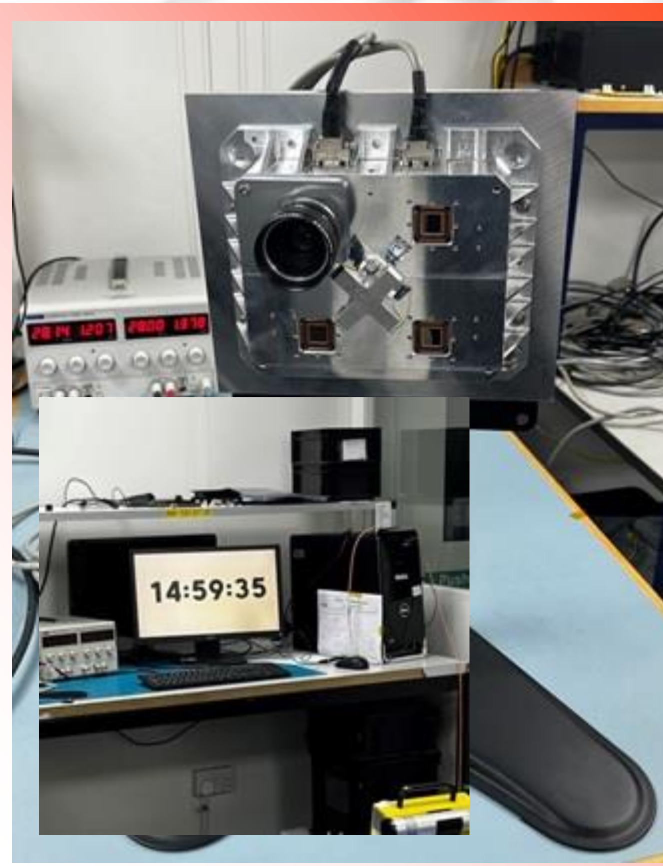
- Functional and performance tests to test that the unit operates in the way that it should in terms of detection of particles and fibres and acquisition rate etc; all power, control and interfaces operate as they should
- Tests to check that the unit can operate autonomously
- Check the unit can control the in-built illumination level so it can operate in a range of environments
- Electromagnetic emissions tests, to test that the unit doesn’t emit electromagnetic radiation in any of the bands where it must be ‘quiet’ due to launchers using those bands for communication or other purposes
- Electromagnetic susceptibility tests to test the units susceptibility to electromagnetic emissions that it may see when in a launcher
- Tests to ensure the unit could operate with micro-cut-off of power
- Checks that built in tests are performed
- Thermal testing
- In vacuum testing

Testing of the EM Unit

Many of the functional and performance tests used features printed on a chrome on glass mask to test ability to detect particulates and fibres of different dimensions

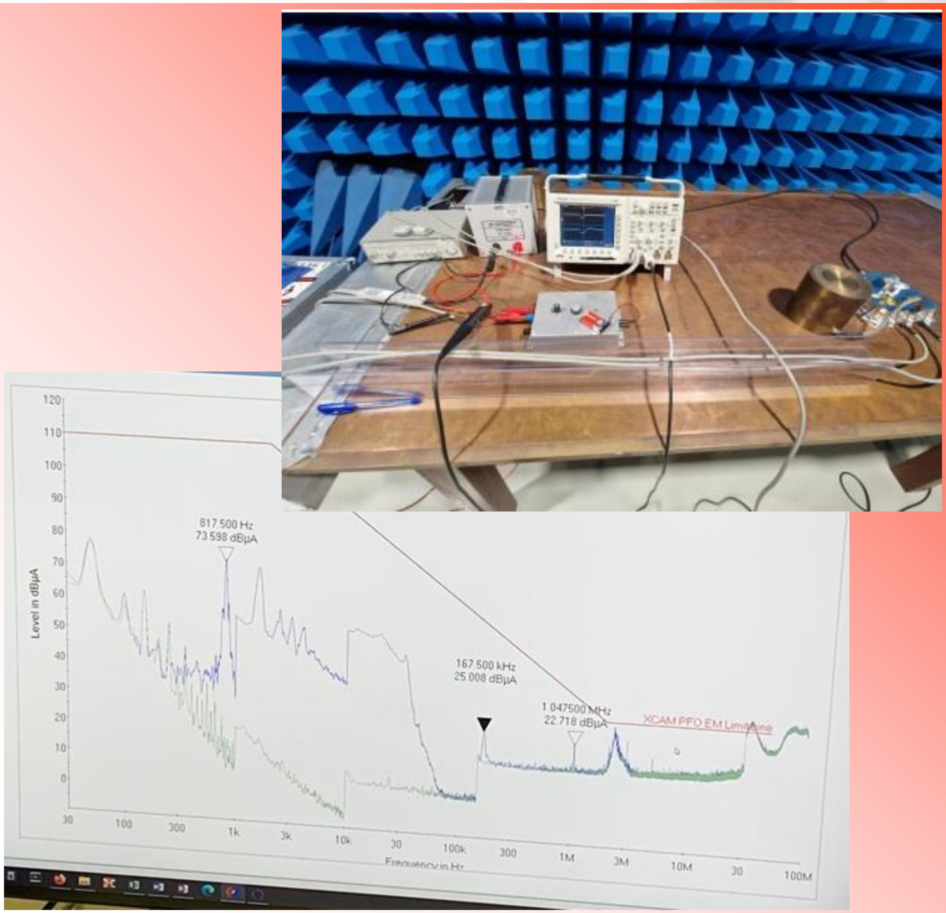






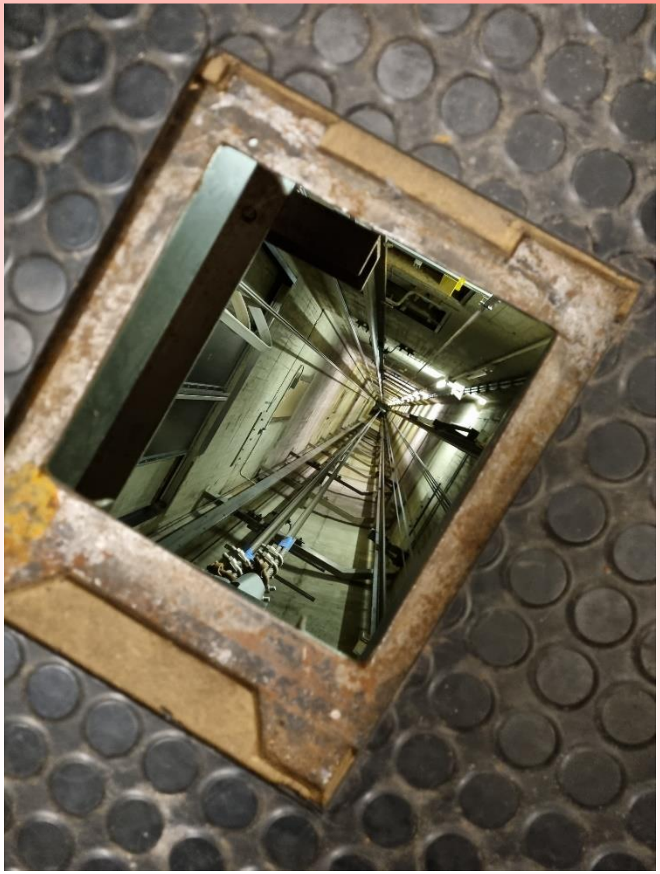
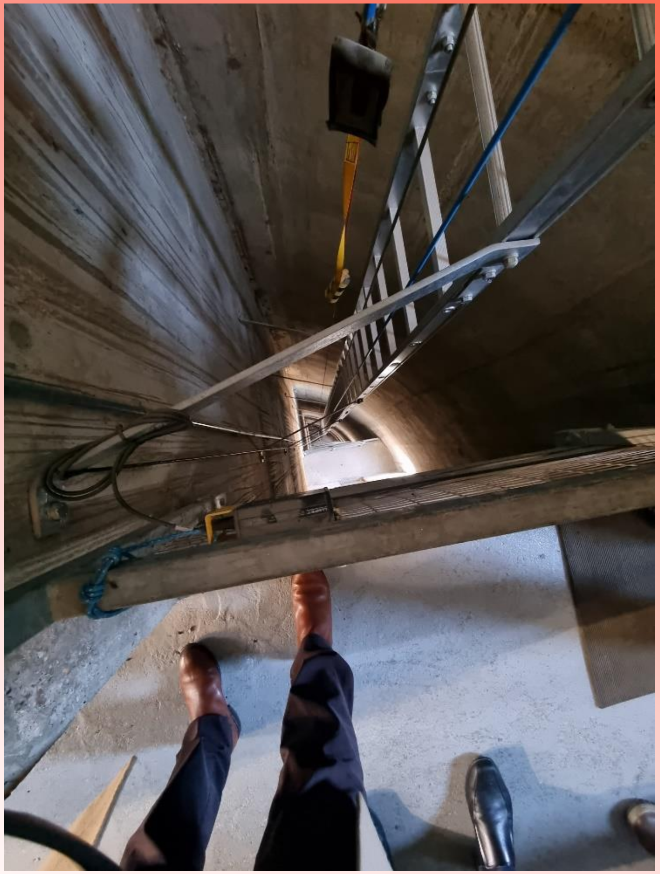
Testing of the EM Unit

Temperature Cycling and vacuum testing



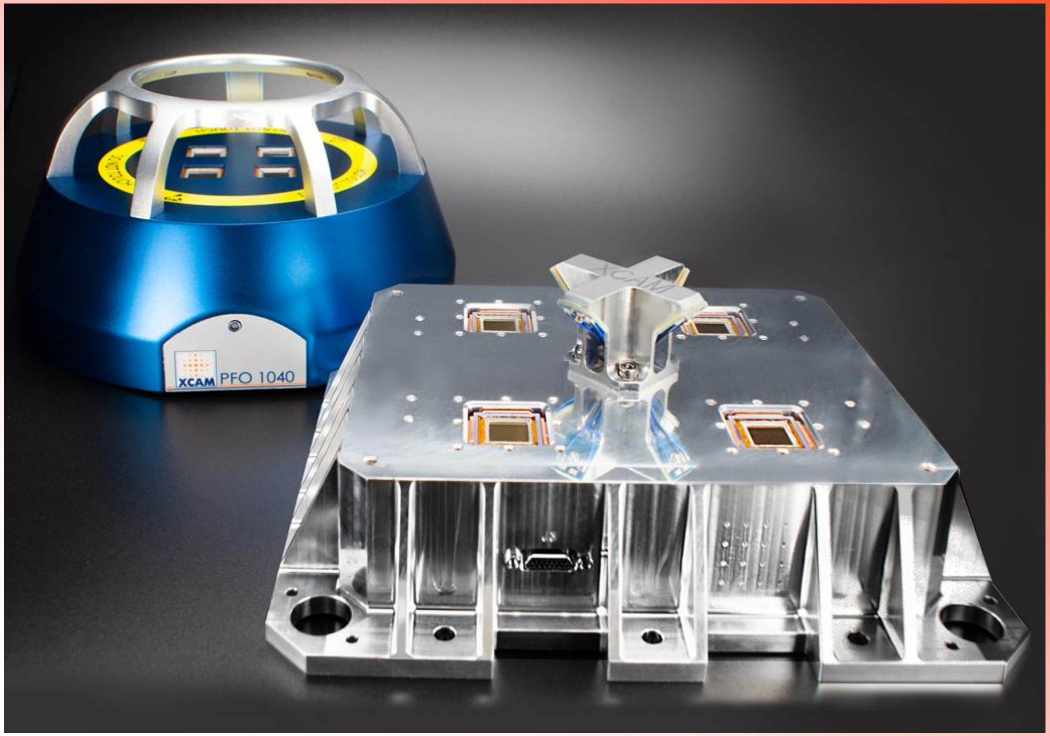
Testing of the EM Unit

Automated start testing based on pressure change and acceleration (coming next)


Next Steps

- Design of QM phase, taking into account learning from EM phase begins in October 2023 and should end with QM testing review in October 2023
- Then we proceed to build an FM with FM TRB in June 2025
- Working closely with ESA to consider when the unit could be tested out on a real flight
- Working closely with Blue Origin who have been using our cleanroom monitor both in ambient environments and also in a vacuum (modified version). They will be running qualification tests on the unit this summer in preparation for 'Hotfire' testing on the New Glenn launcher – to be discussed at this meeting separately



Summary

- We have described the development of a real-time PFO unit for ESA to monitor conditions during launches
- The original prototype has been spun-out into a commercial product for cleanrooms
- Meanwhile, development of the flight unit for rocket fairings is well underway, with the EM unit undergoing tests
- Working closely with ESA, Arianespace, AVIO and Blue Origin
- FM acceptance test anticipated 2025