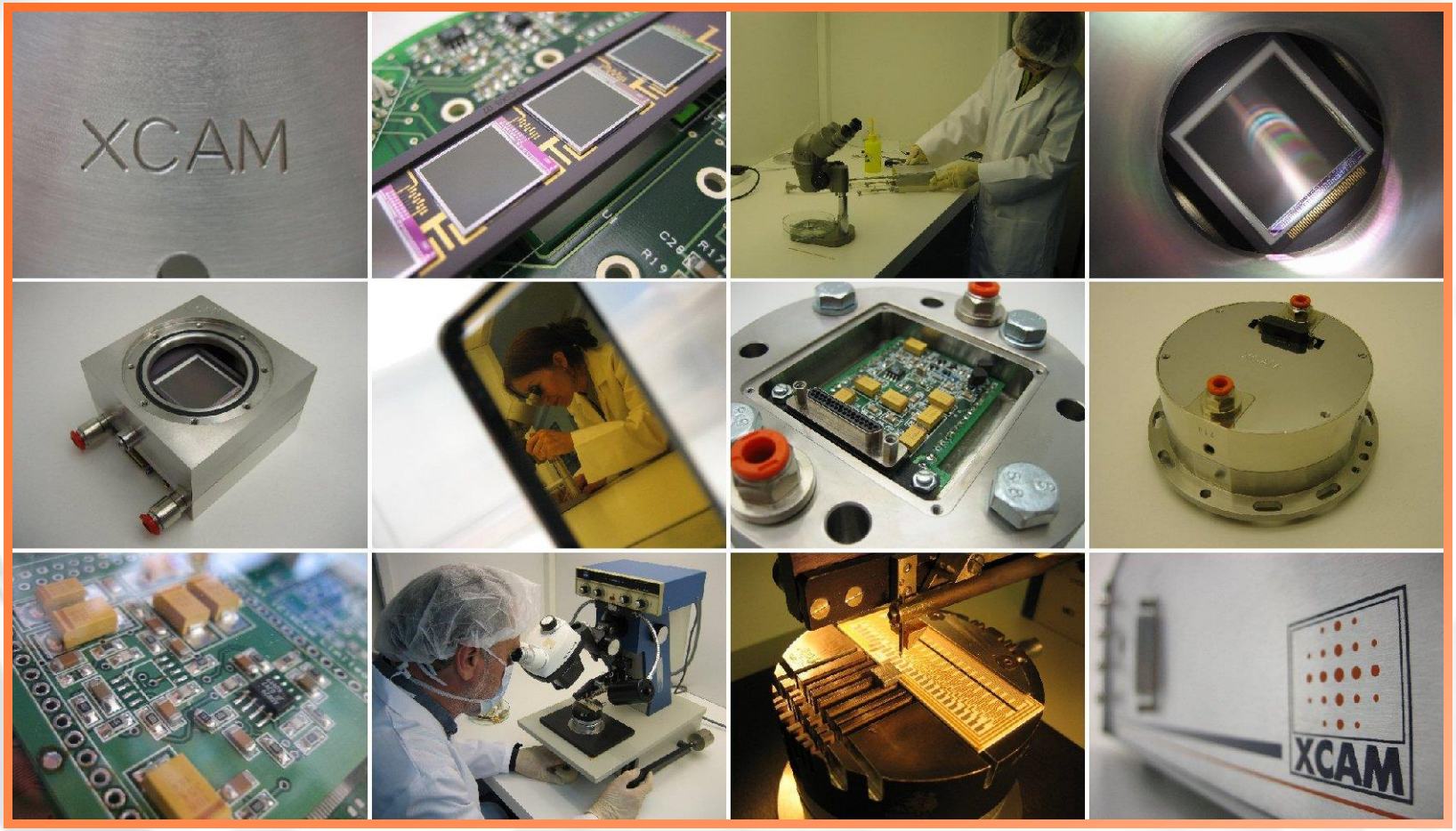
Continuous Particle Fall Out Monitoring With High Resolution Silicon Sensors



Contents

- Background to the Project
  - Particulate contamination
  - Controlled environments
  - Monitoring
  - A not so easy environment…! -> need for the development in subject

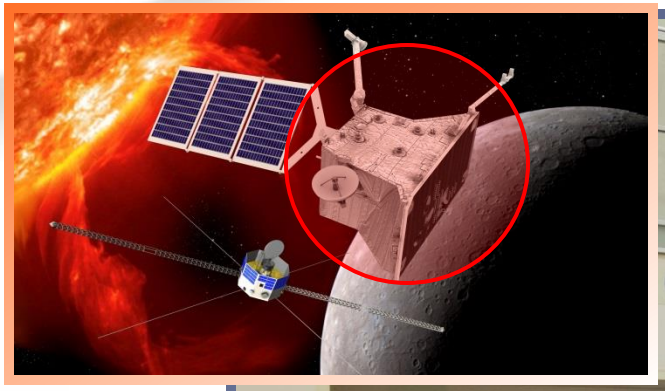
- Instrument concept – prototype monitor for a rocket environment
  - System description
  - Initial results from the prototype instrument
  - Test methodology
  - Test results
  - Application software

- Further work towards a space qualified particle fall out monitor for space
- Development of a commercial Particle Fall Out Monitor for cleanrooms

Particulate contamination

Typical controlled environments

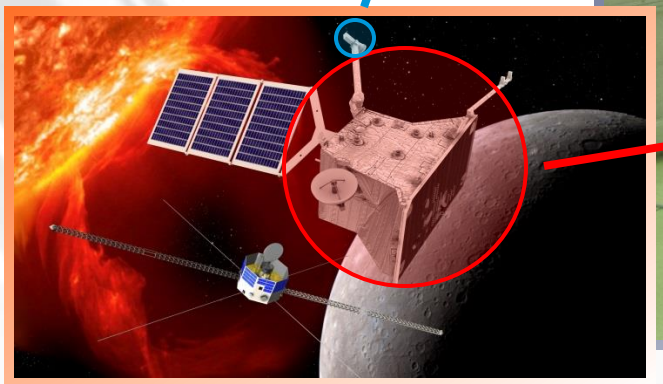
AIT @ System level

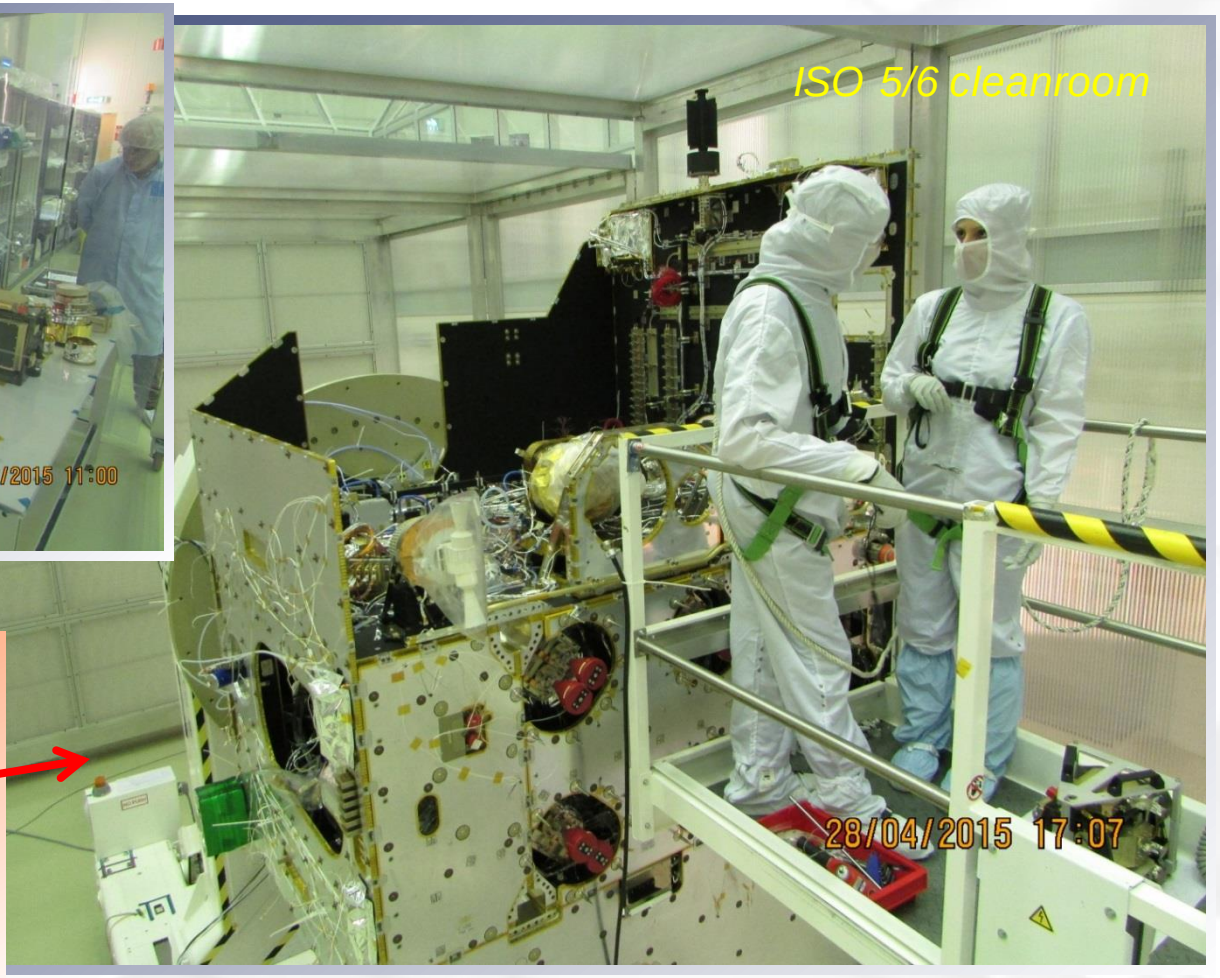


Typical controlled environments

AIT @ Instrument level

Credit: TAS-I

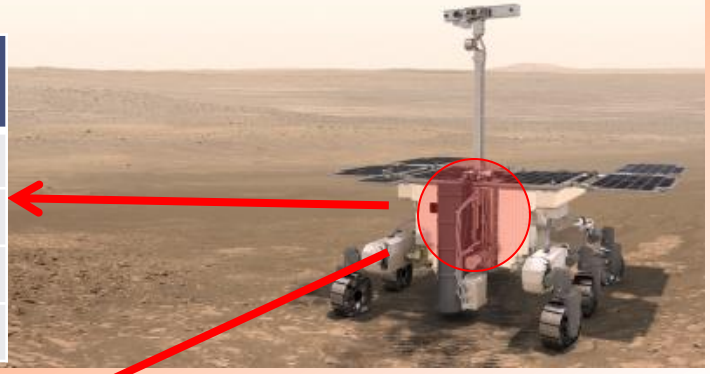




Credit: TAS-I

Controlled environments for specific missions

Analytical Laboratory Drawer - Ultra Clean Zone & Sampling mechanisms	
Airborne Particulate	ISO 3
Airborne Molecular	ACC-8/9 wrt selected organics
Airborne Biological	0 CFU per cubic meter of air
Surface Biological	0 bacterial spores per fall-out plate



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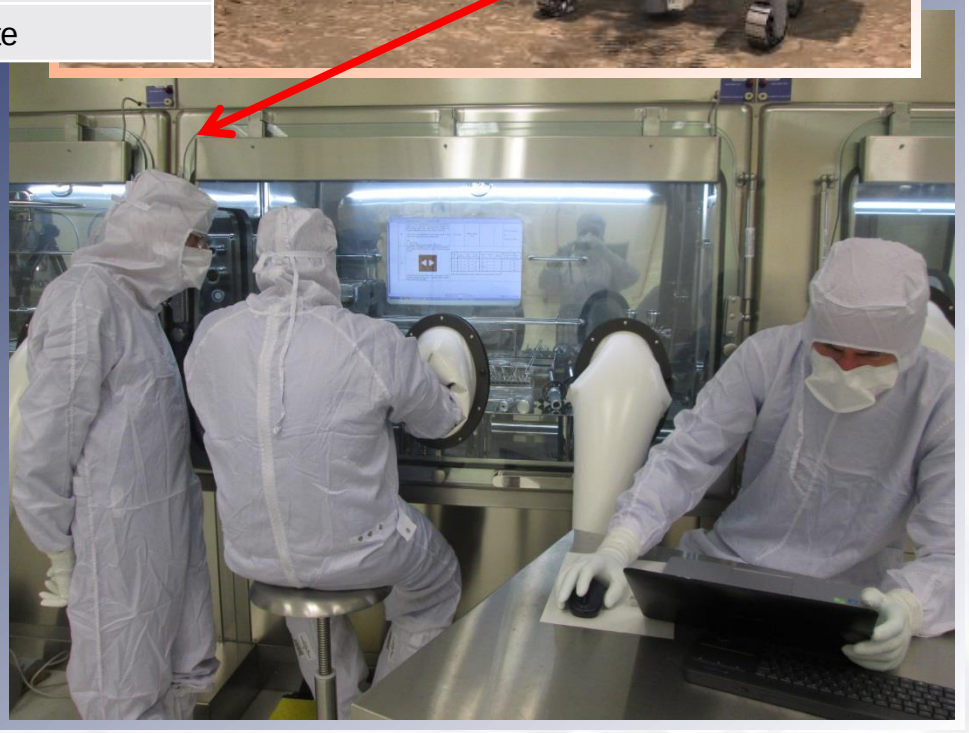

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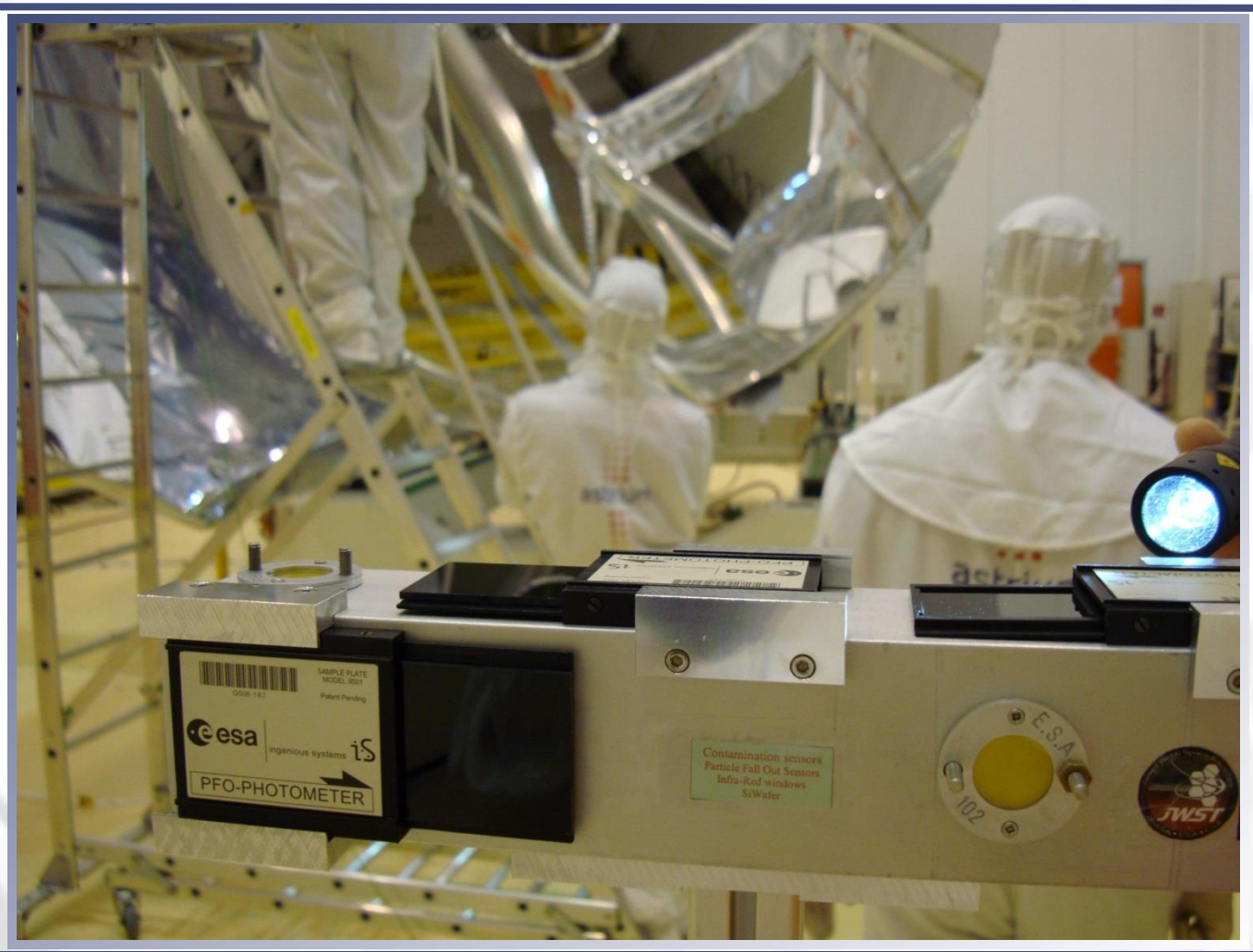
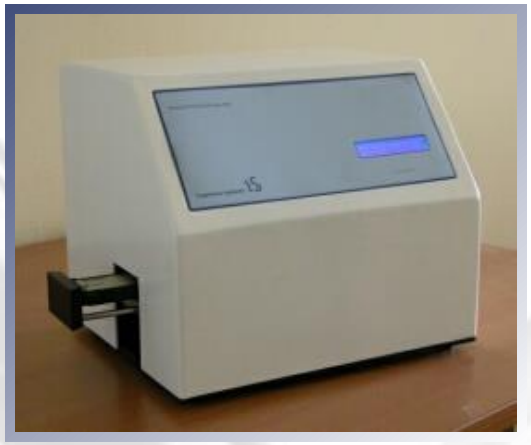
Monitoring deposited particles



Monitoring deposited particles

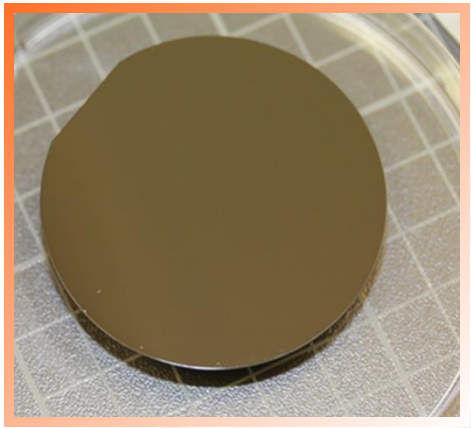
Methods typically defined in ECSS-Q-ST-70-50C

PFO plate

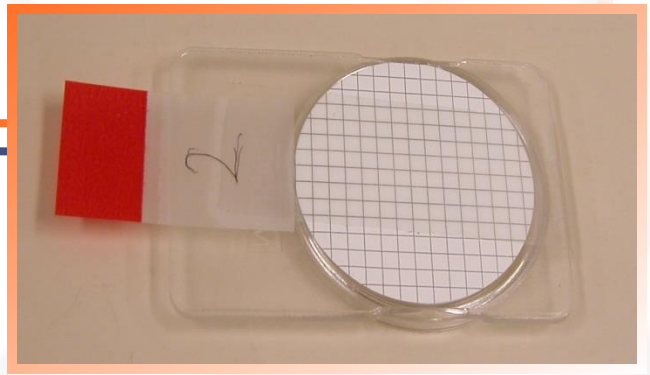


PFO meter

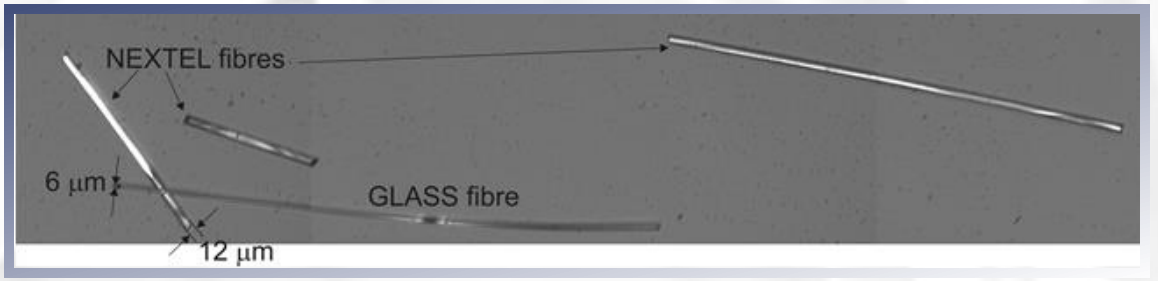
PFO →**Total obscuration**



Silicon wafer



Tape lift sample



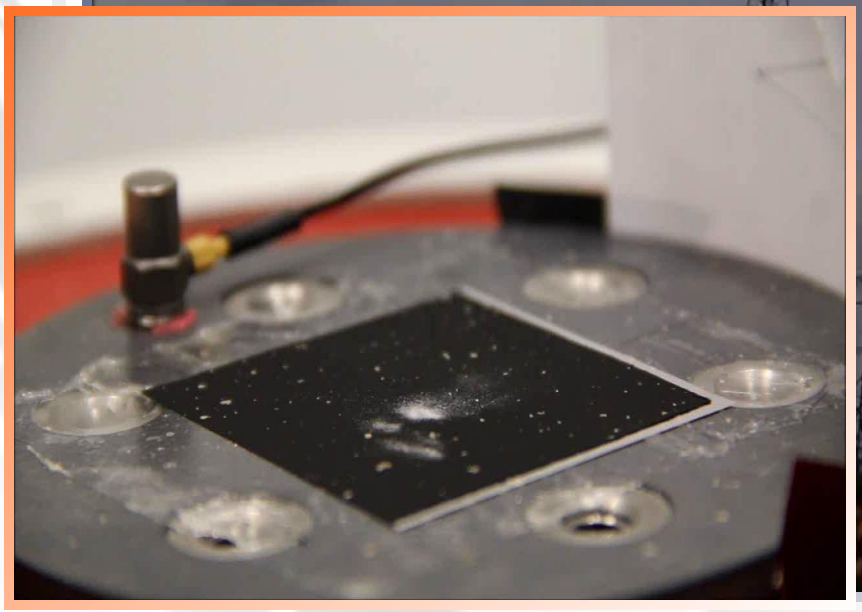
Tape lift & Silicon wafers →Particles and fibres **distribution**

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

A not so easy environment…!



Monitoring deposited particles

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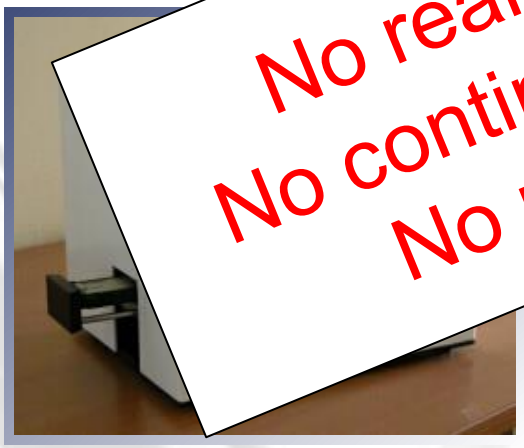
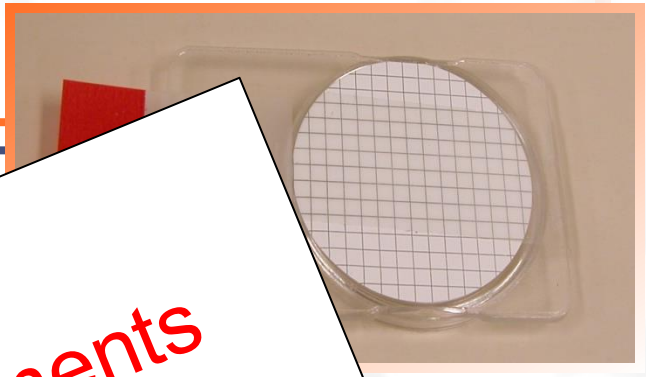
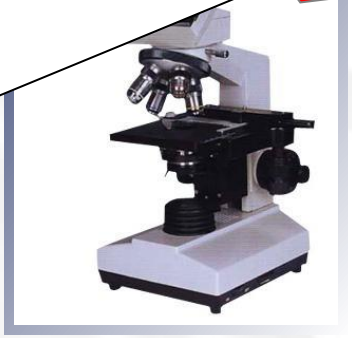


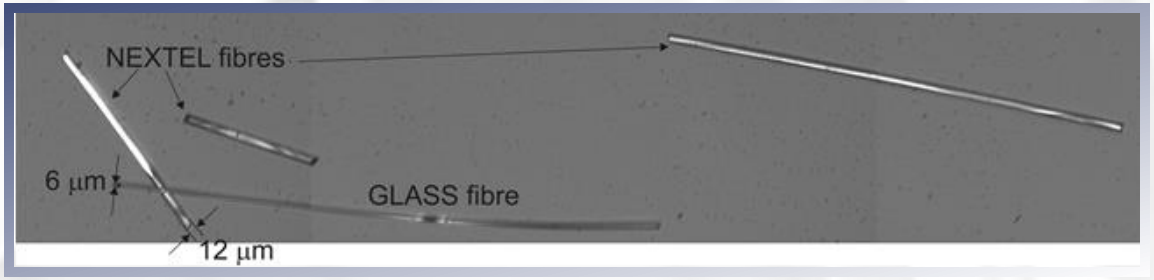
PFO meter

No real time
No continuous
No remote

measurements





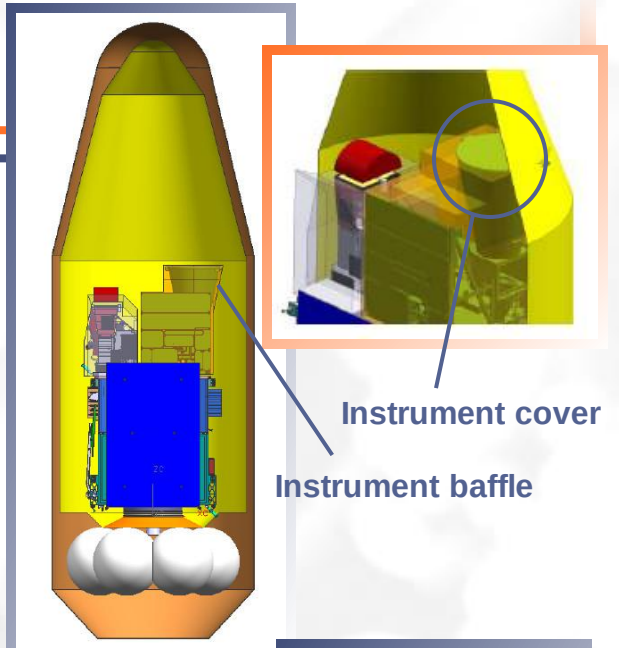


PFO → **Total obscuration**

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

Requirements allocation

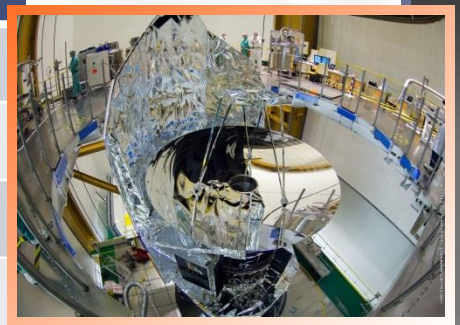
Particulate contamination allocations [ppm]					
Sensitive surfaces/areas	Pre-delivery to Instrument Contractor	Instrument AIT*	Satellite AIT* and long-term storage	Launch including preparation	Total at BOL
Scan Mirror	90	360	570	50	1070
Mirrors M1, M2	90	360	570	50	1070
Mirror M3 up to Beam Splitter	100	250	400	50	800
Interferometer	100	250	300	50	700
Back Telescope mirrors	100	250	300	50	700
Cold Box outside	100	250	300	50	700
Cold Box inside	200	0	0	0	200



Instrument design with baffle and cover

…when baffle and cover are not an option

Particulate contamination allocations [ppm]				
Sensitive surfaces/areas	Pre-delivery to Satellite	Satellite AIT* until encapsulation	Encapsulation and Launch	Total at BOL
Telescope	300	1890	2300	4490
Cryostat Vacuum Vessel - esternal	400	2100	2300	4800
Service Module	3000	400	2300	5700



A new R&D

Objective of the activity:

- designing, developing, manufacturing and testing a breadboard model of a real-time system for the measurement of particle fallout
- with the focus on the monitoring of those environments typically encountered by spacecraft systems just before and after launch
- without precluding the use of the developed method in cleanliness controlled areas and clean rooms.

Key requirements:

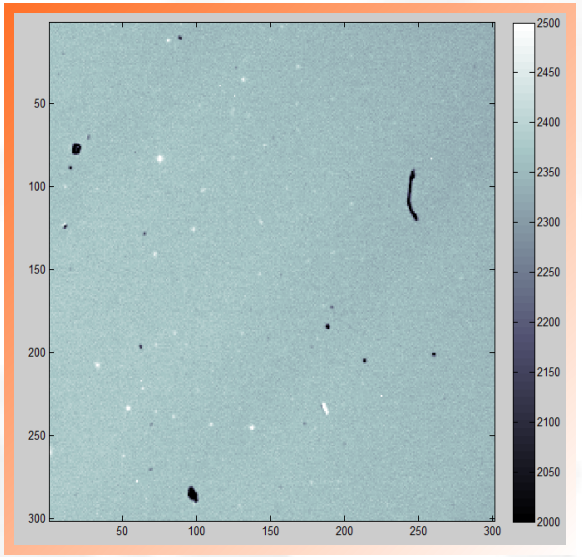
- capability to detect a minimum particle's size of 5 micron or better
- capability to differentiate between particles and fibres
- capability to detect the shape of particle and fibers
- capability to count and size all deposited particles and fibres
- capability to perform continual measurements with a rate of at least 1 measurement every 10 seconds

Development of Prototype PFO Monitor for ESA

Instrument Concept

Sensing Technique

- Large area silicon sensor to provide direct imaging of particles down to <5 µm over >5 cm^2 detection area
- Provides particle size and shape (particle vs. fibre)
- Measures percentage area covered (PAC)
- Is directly exposed to the environment to be monitored so no sampling/process losses
- Tracks real time PFO during pre-launch, launch and in-flight; continuous measurements every 10s

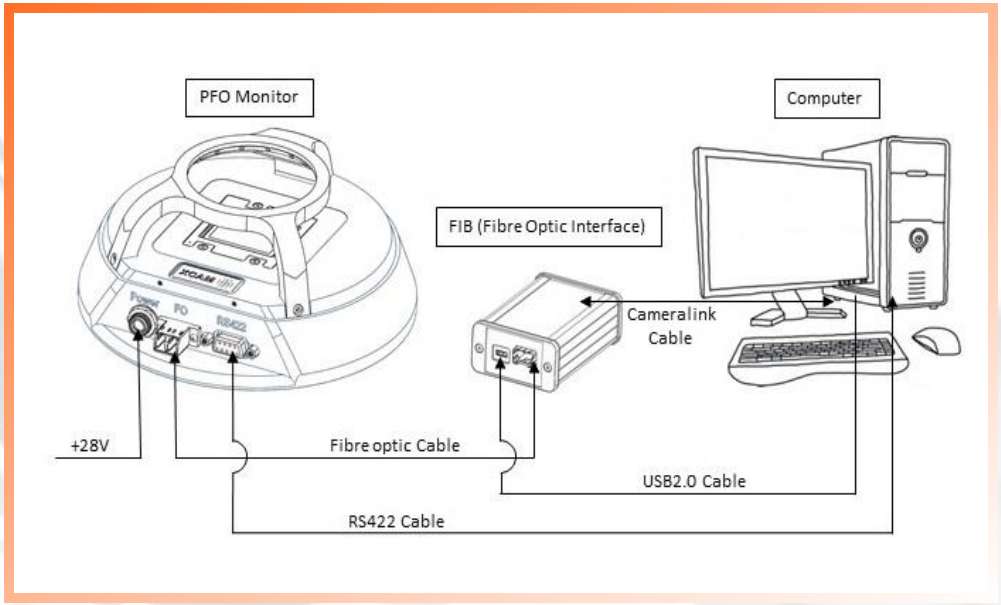


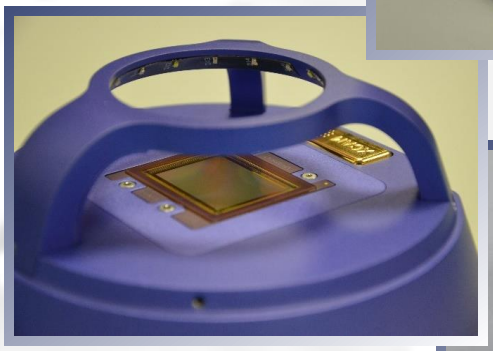
Challenges

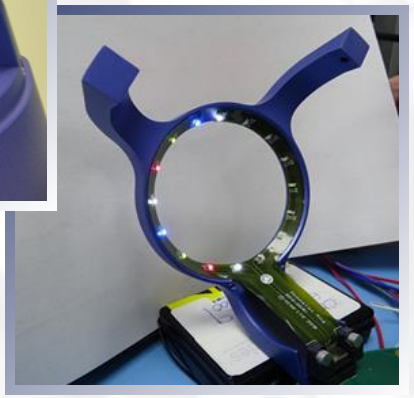
- Sensor selection
- Illumination
- Testing philosophy
- Design suitable for space qualification at future stage

System Description

- Sensor: CMOS sensor with 6.4 micron pixels
- Overhead illumination with LED ring
  - Red, green, blue and white LEDs for experimentation
- Communications for interface to rocket – RS422 - with proprietary XCAM fibre-optic interface for speedy lab testing







Initial Test Results from the Prototype Instrument

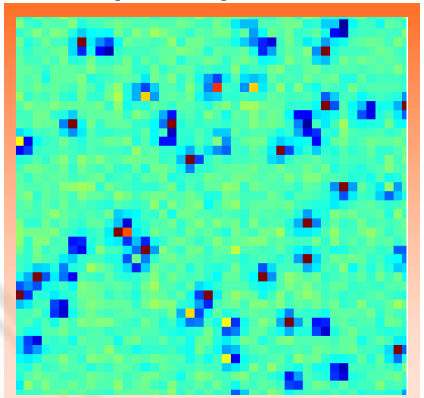
Seven day sequence provides **continuous, in-situ monitoring**.

This differs to current methods which are retrospective and are valid only at the point at which human intervention takes the slides off for test.

Test Methodology

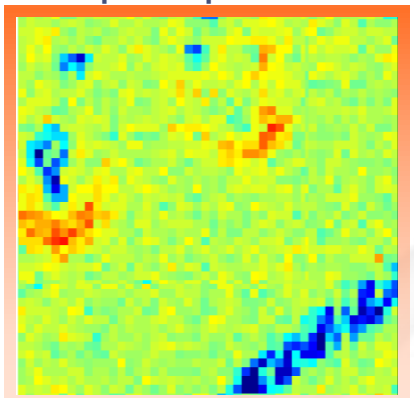
NIST calibrated spheres were initially used in liquid format for very early testing on the sensors

10 µm spheres



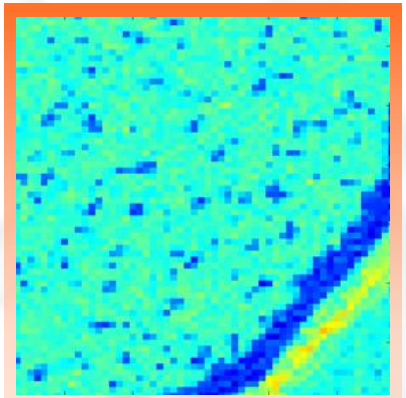
Microspheres clearly visible

5 µm spheres

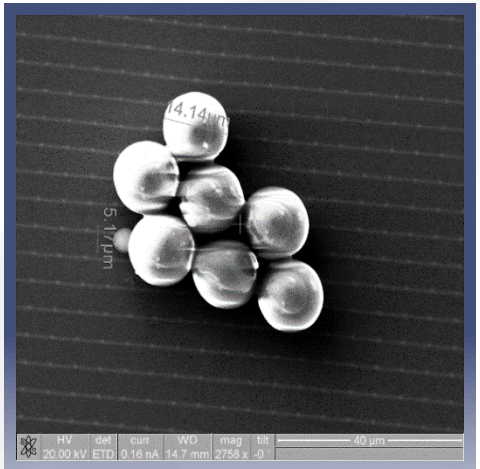


Microspheres clearly visible with a concentration of particles around liquid tide mark

2.5 µm spheres



Microspheres clearly visible with a concentration of particles around liquid tide mark



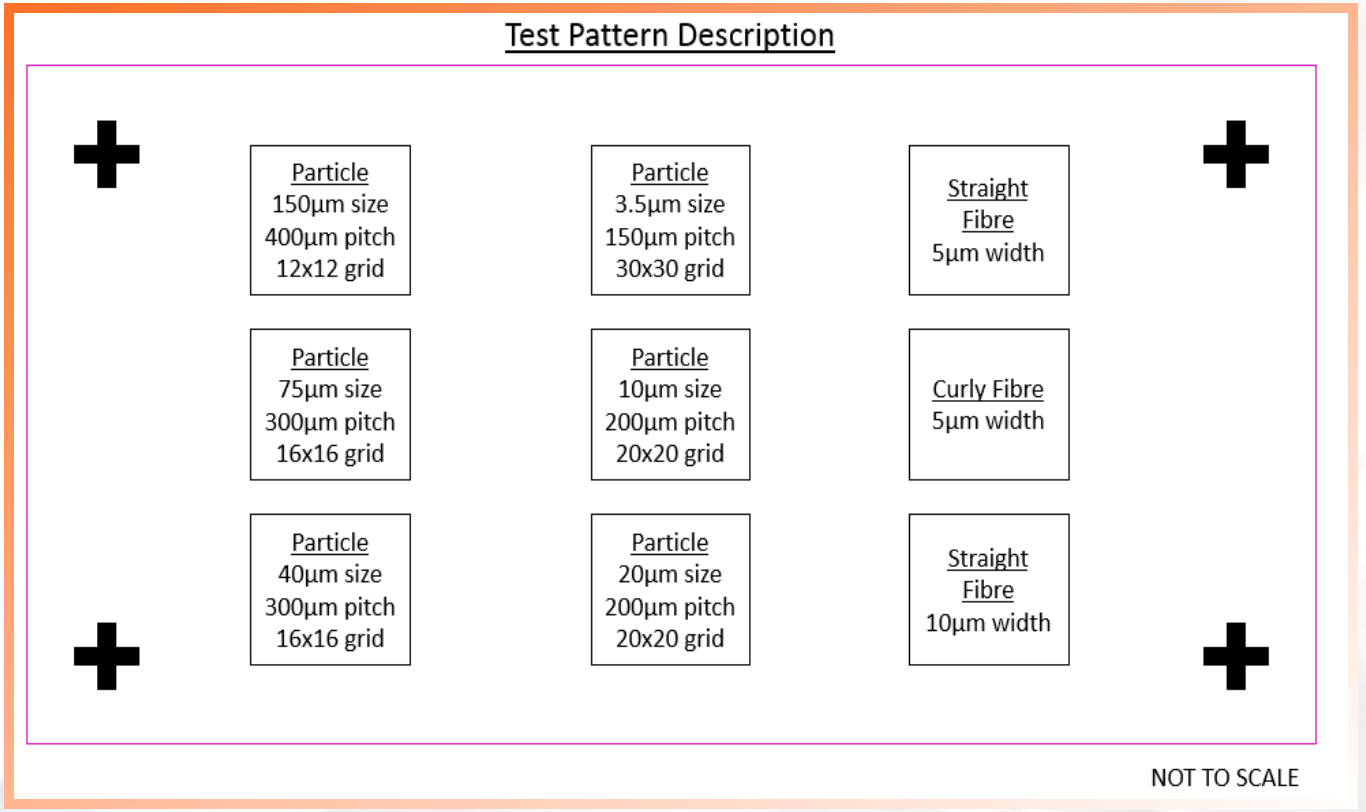
SEM image showing a single 5 micron microsphere nestled amongst 15 micron microspheres on a detector surface

Test Methodology

A chrome on glass mask with well-defined features was produced for the final testing.

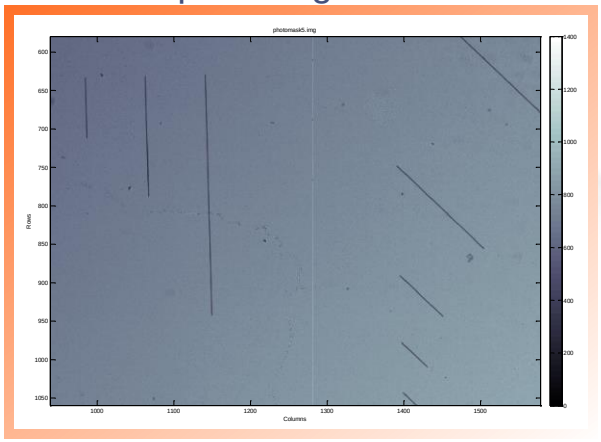
This included different size and particle type combinations:

- 3.5, 10, 20, 40, 75 and 150 µm particles
- 5 and 10 µm thick fibres
- 5 µm thick, curly fibre

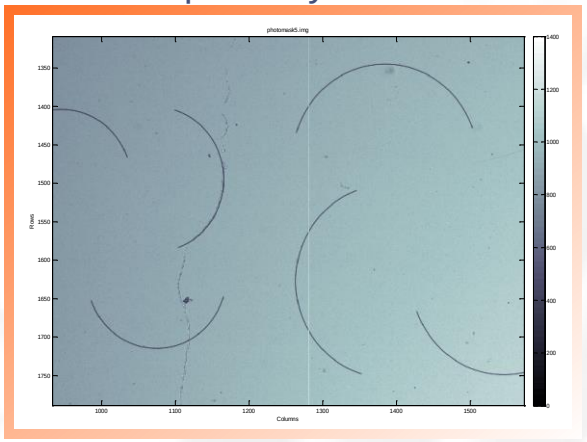


Test Results

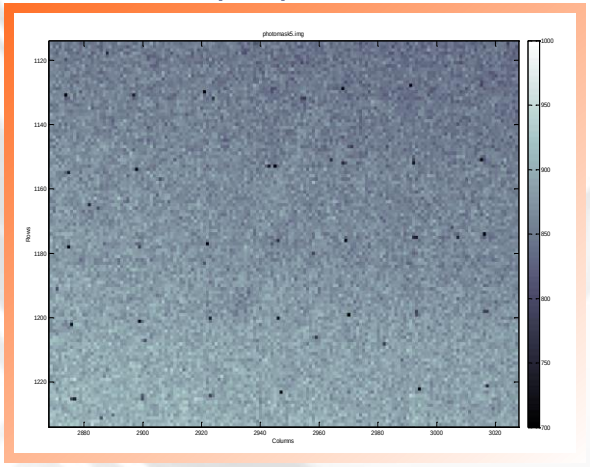
5 µm straight fibres



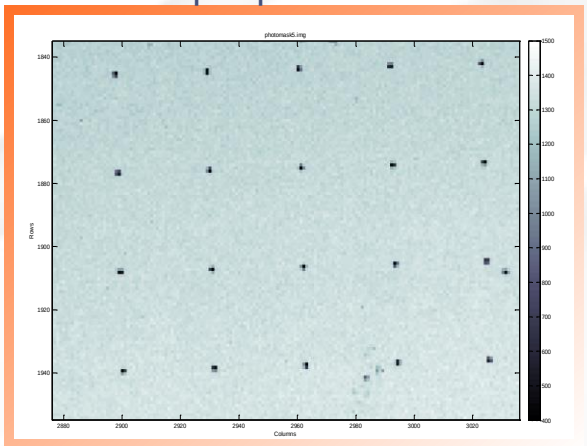
5 µm curly fibres



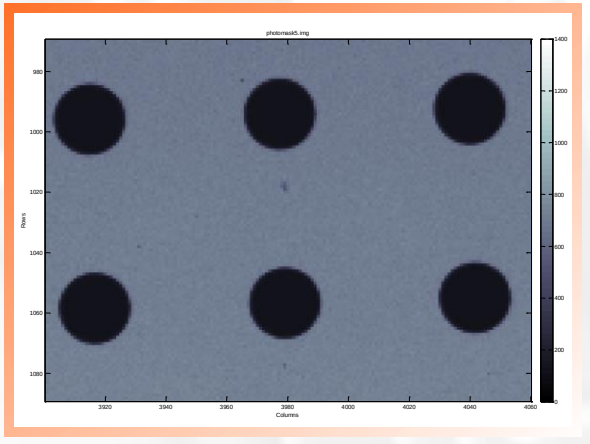
3.5 µm particles



5 µm particles



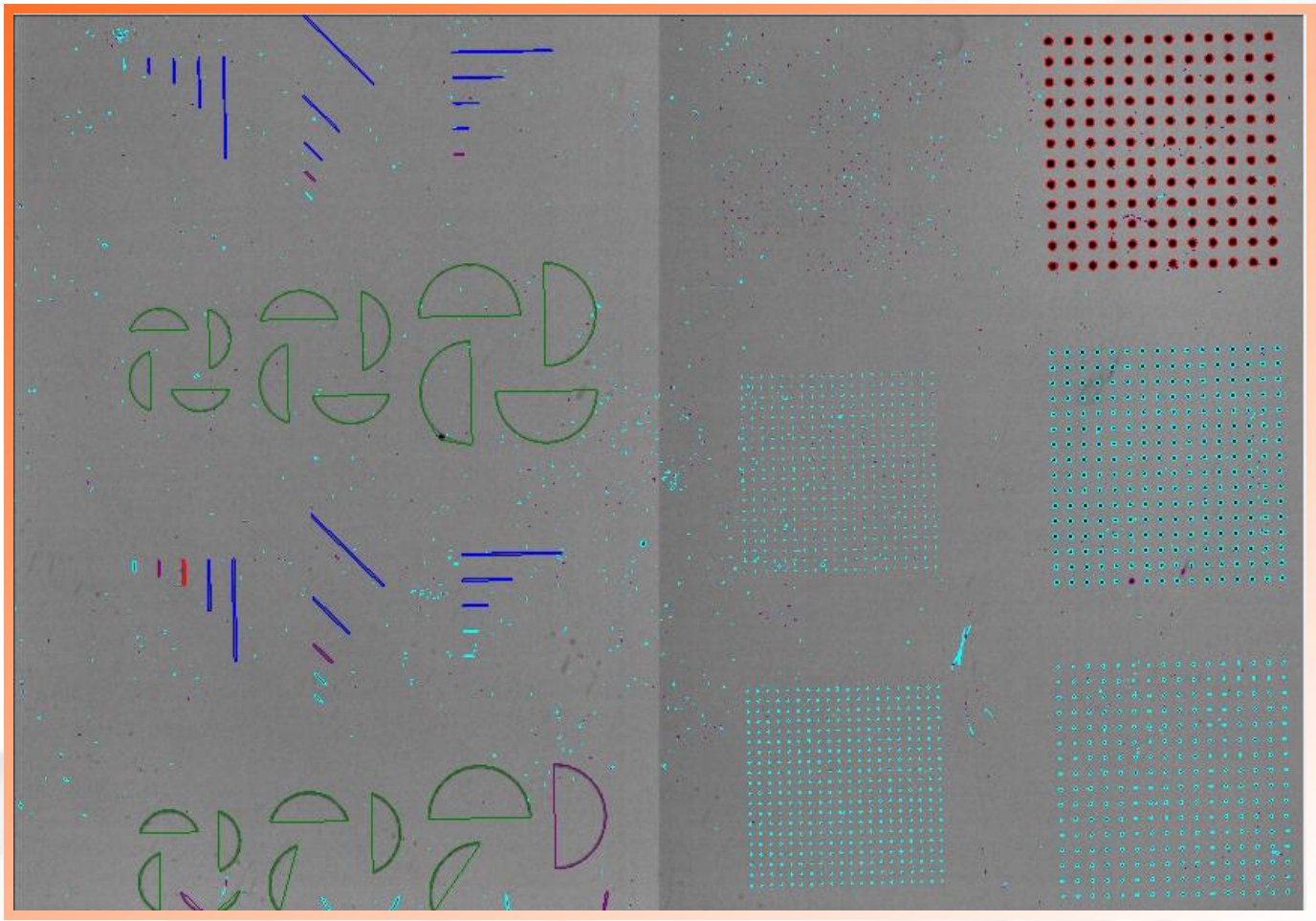
150 µm particles



Test Results

Image taken of test pattern.

The image shown is after software processing and annotation.

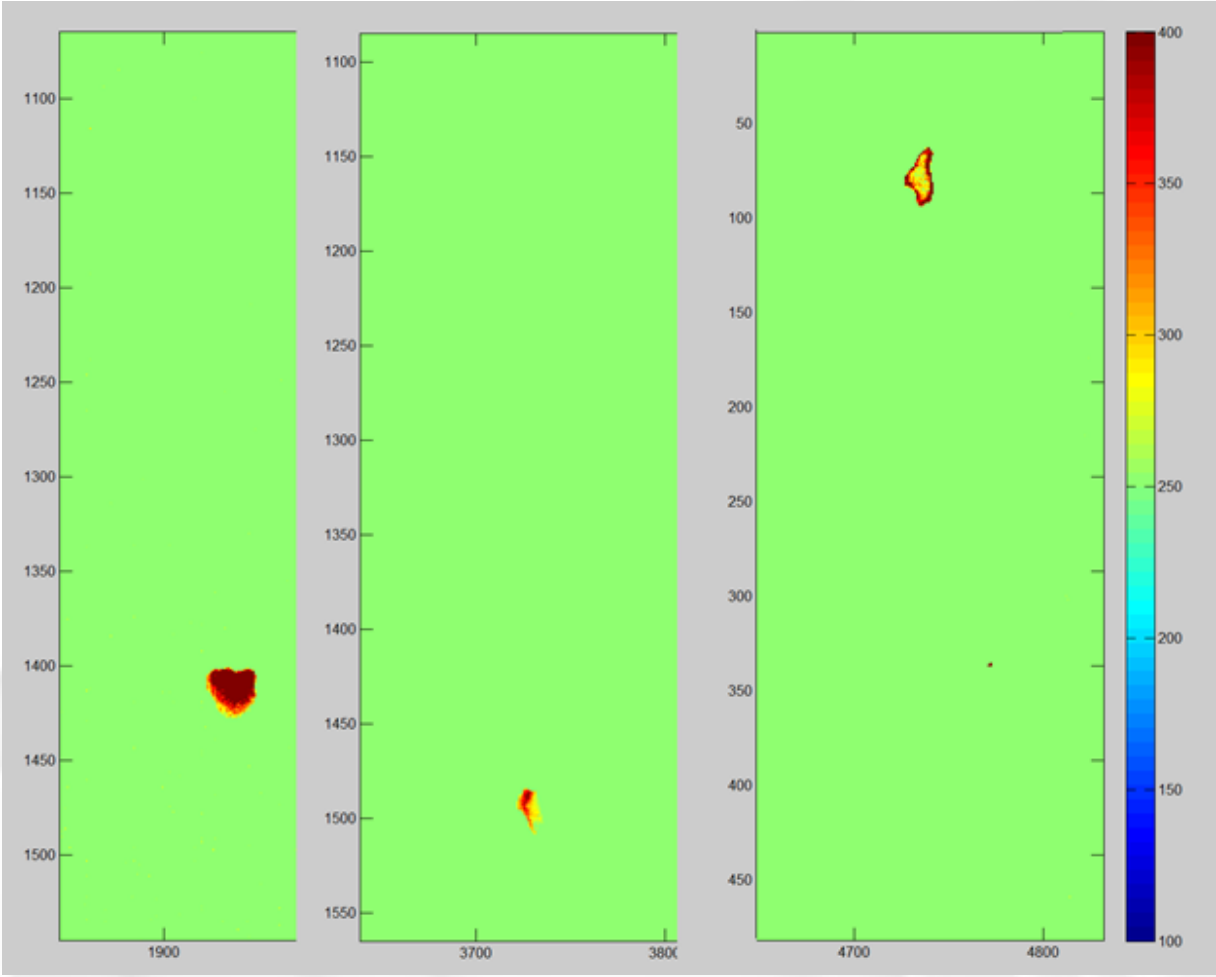


Test Results – Acoustic Load

Very basic acoustic load testing was conducted by obtaining loudspeakers of nnn power, and playing the sound of a rocket launch to excite the debris on the detector.

The image shows where movement of a particle has occurred between frames.

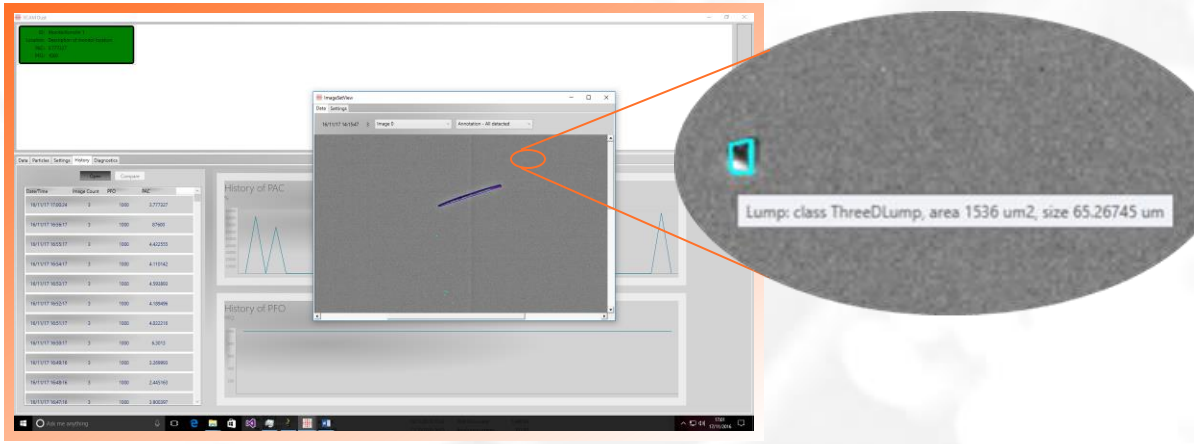
Red is a particle which has disappeared after acoustic testing; blue would

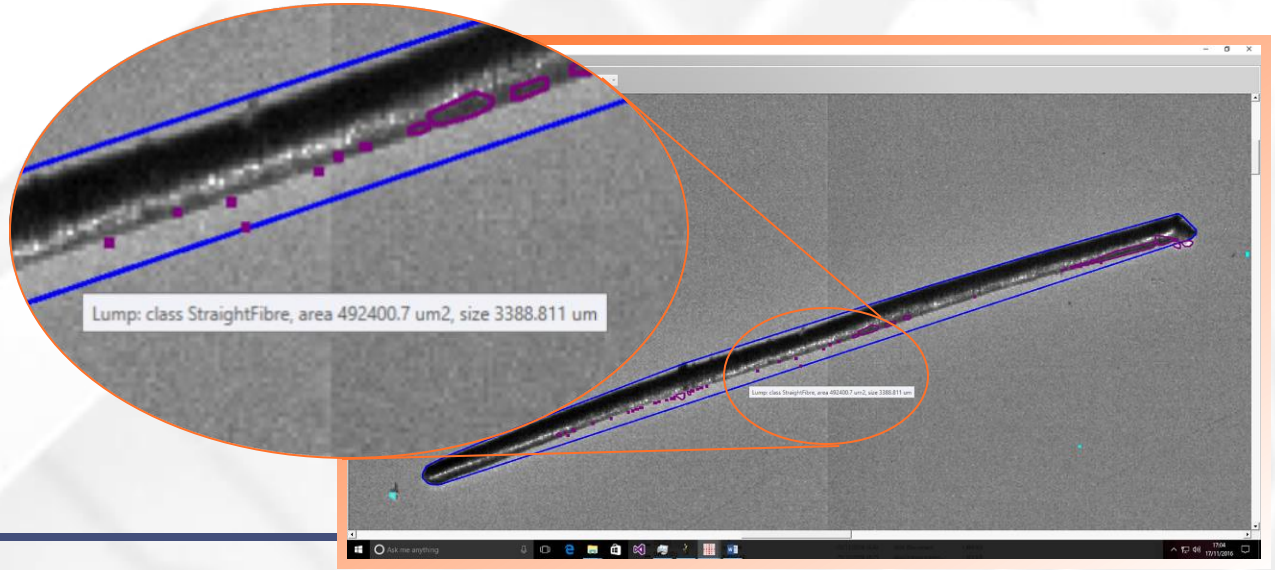


Application Software

Software developed provides:

- Classification of particle types
  - Particles
  - Fibres
  - Curly fibres
- Detailed dimensional information for each particle
  - Location
  - Area
  - Size
- Particle distribution by size with user-definable bins



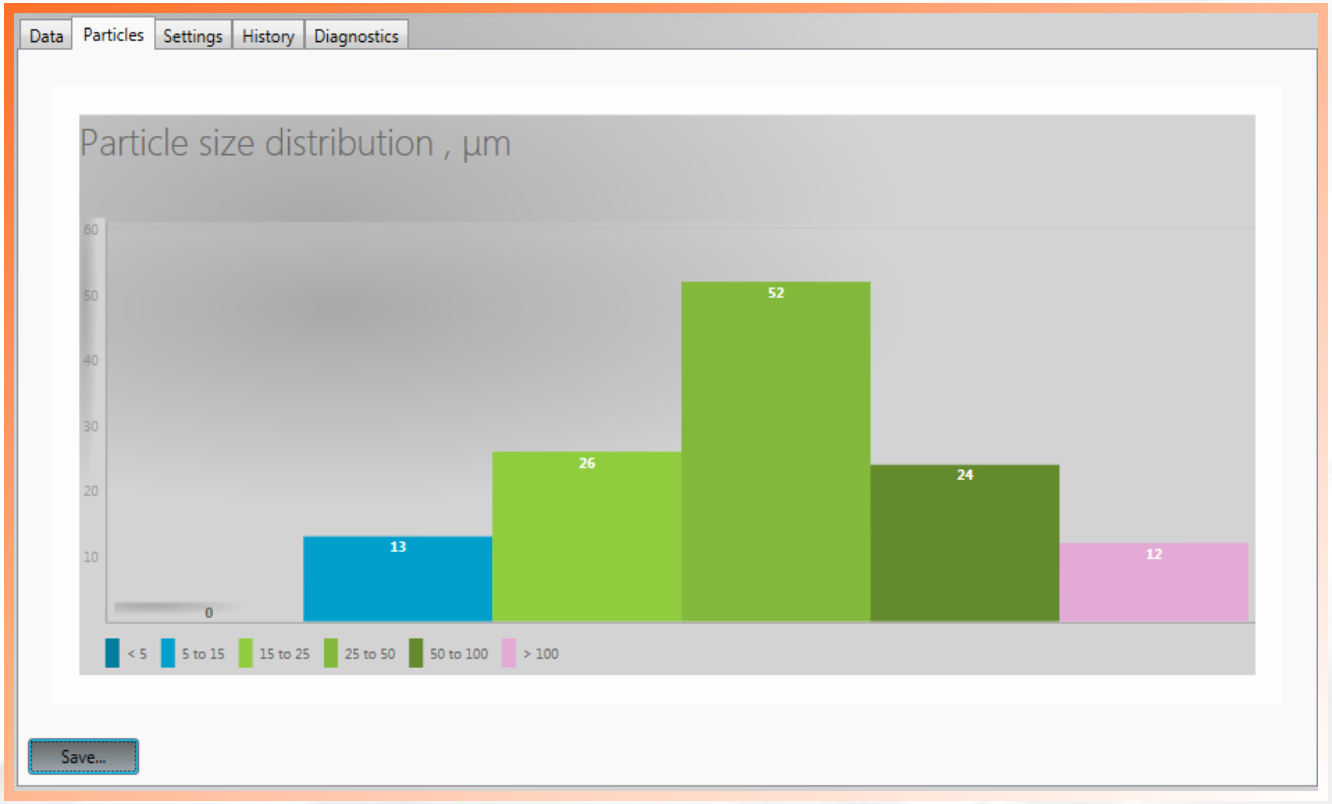


Application Software

Particles and fibres are binned according to their size.

Number of particles within each bin is displayed.

Bin sizes can be set to correspond with standards (e.g. NASA, ESA or user-defined).



Application Software

PAC and PFO level plotted as a function of time (minute/hour/day/week/all).

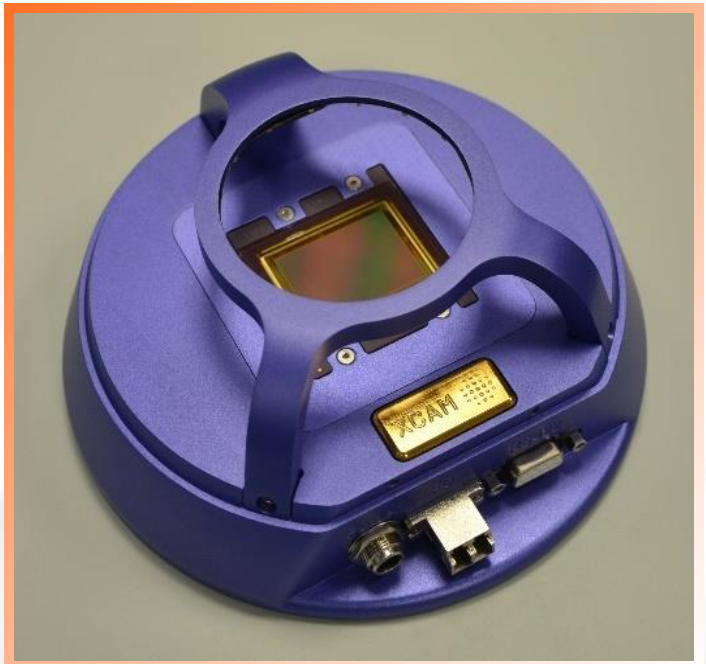
Save all images, every n images, or none; save raw and/or processed for retrospective viewing and analysis.

Open an image, or compare the difference between two images for analysis

Further Work Towards a Space Qualified PFO Monitor for Space

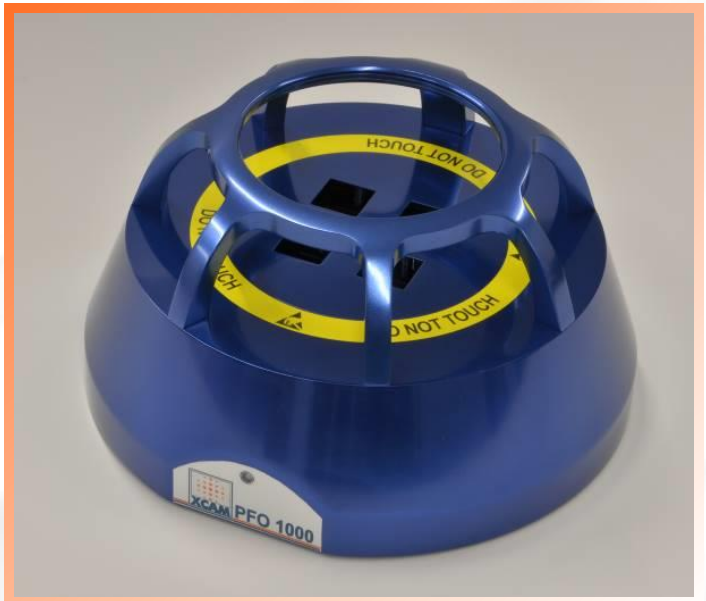
Requires significant development including:

- Review of best sensor for flight model
- Embedding of dust detection and characterisation algorithms into on-board FPGA
- Development of code to recognise standard contaminants e.g. Nextel fibre which has a specific dimension
- Redundancy and fail-safe design
- Selection and use of space qualified parts
- FEA modelling of mechanical design
- Full qualification of resulting system
- Possible radiation qualification depending upon operating lifetime requirement in-orbit



Development of a Commercial Cleanroom PFO Monitor

- Patent applied for development of commercial monitor
- Up to four sensors gives four price-point/area options
- **Real-time monitoring** for trends, exceptions & alarms
- **Automatic detection** – measurement without involvement of personnel
- **Remote reporting** – live dashboard and historical reports
- **Portable** – locate at key processes/operator stations
- Ethernet communications
- Reporting package:
  - Particle count, size, % area covered, particles vs. fibres
  - Supports up to 10 monitors



Summary

- Successfully delivered prototype to ESA
- Currently working on development plan for space qualified version
- Hope to issue commercial monitors for initial end-user trials in very near future
- Further optimization according to end-user feedback
- Hope to establish distribution channels and start selling commercial version soon