Nuscis: XCAM's Next Generation Imaging System for CubeSats and Small Satellites

Centre for Earth Observation Instrumentation, Emerging Technologies Meeting
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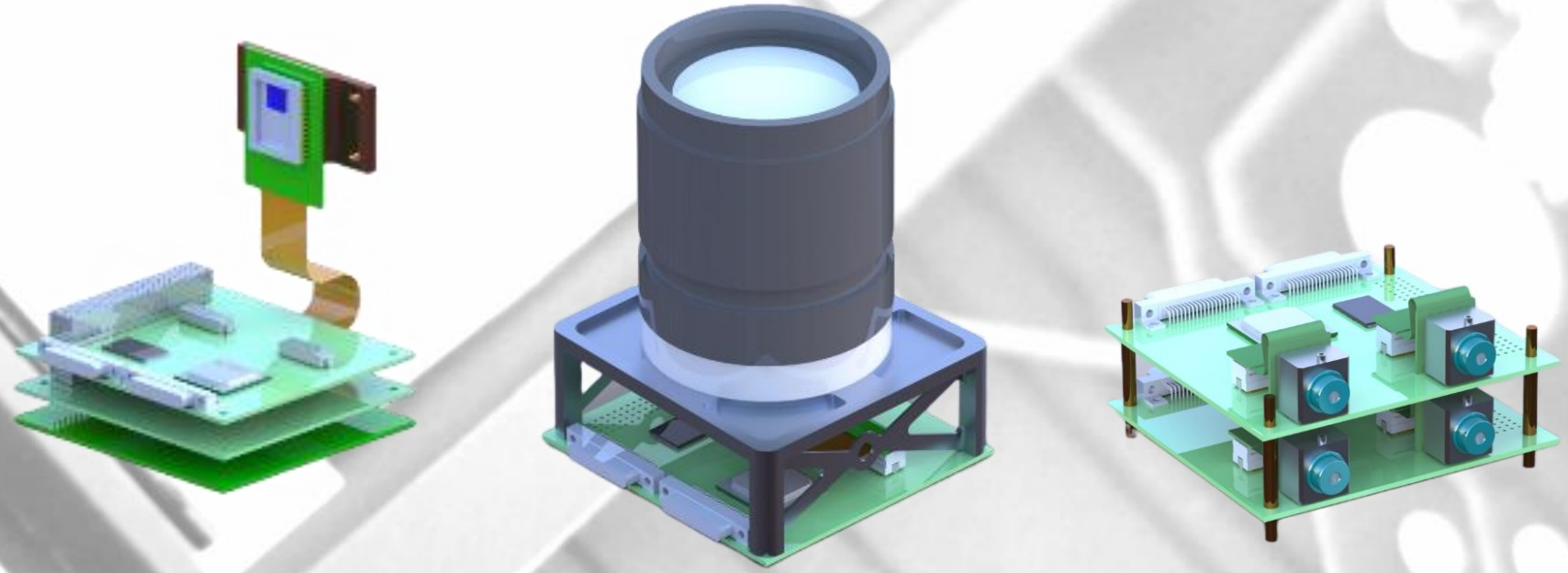

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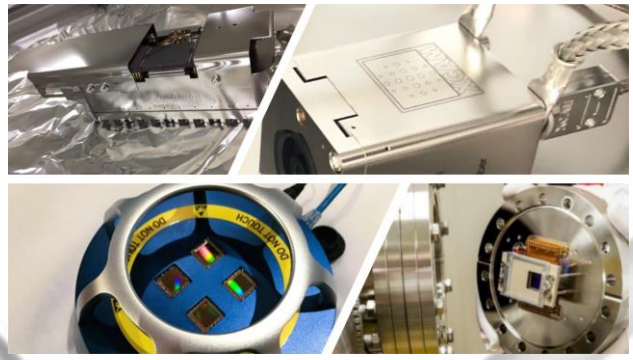
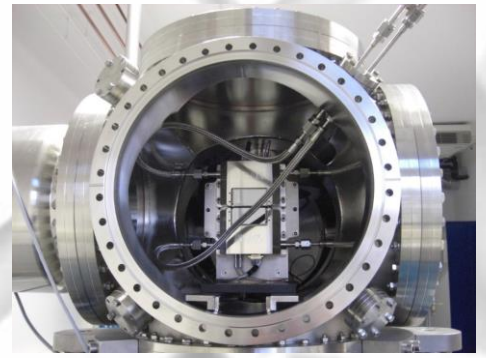
Introduction to XCAM

- Founded in 1995 as a spin-out from the University of Leicester X-ray Astronomy Group.
- XCAM has built a reputation for developing highly customised digital camera solutions for vacuum science, industrial, and space applications





Medilink EM awards 2011 FINALIST Export Achievement Award

MEDILINK UK AWARDS 2012 WINNER INNOVATION

insider MADE IN THE MIDLANDS WINNER 2016

MADE IN THE MIDLANDS WINNER ADVANCED MANUFACTURING/ TECHNOLOGY AWARD 2017

SME NATIONAL Business Awards 2020 FINALIST BUSINESS INNOVATION

SME NATIONAL Business Awards 2020/21 SILVER WINNER

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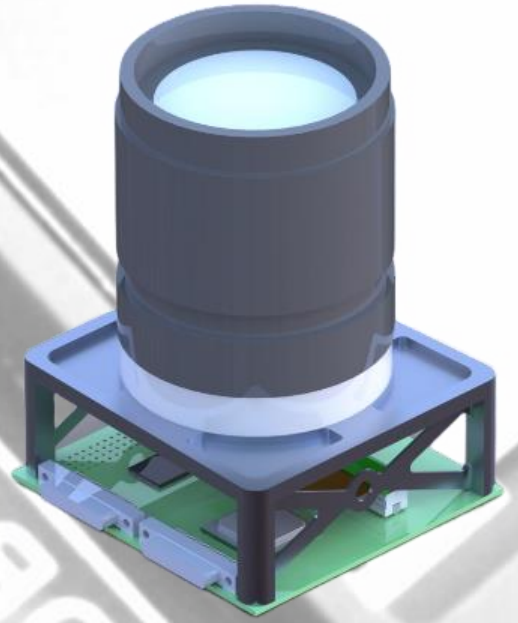
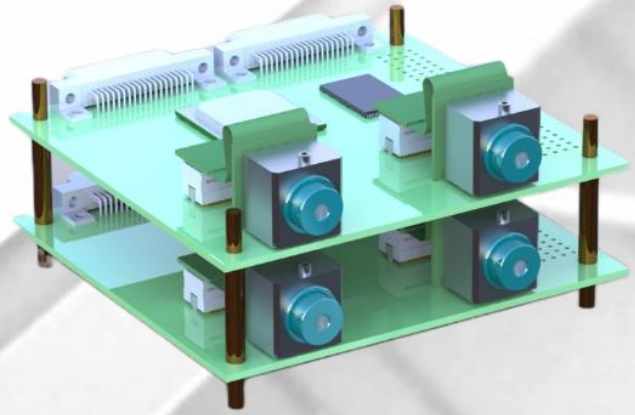
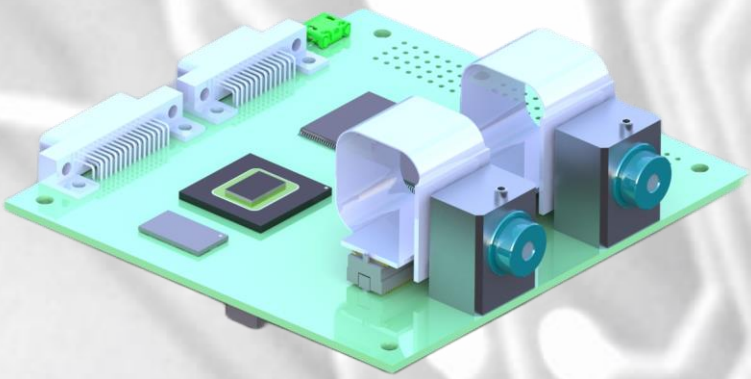
Introduction to Nuscis

Nuscis is a range of compact space imager products offering un-paralleled flexibility in space imaging systems design. The modular architecture of Nuscis, supporting many different sensor-types (CMOS, CCD and EM-CCD) and opto-mechanical solutions, means that it can be easily customised to support a whole range different SmallSat and CubeSat imaging applications for example: Earth observation, remote sensing, space situational awareness, rendezvous and docking and in-orbit servicing.







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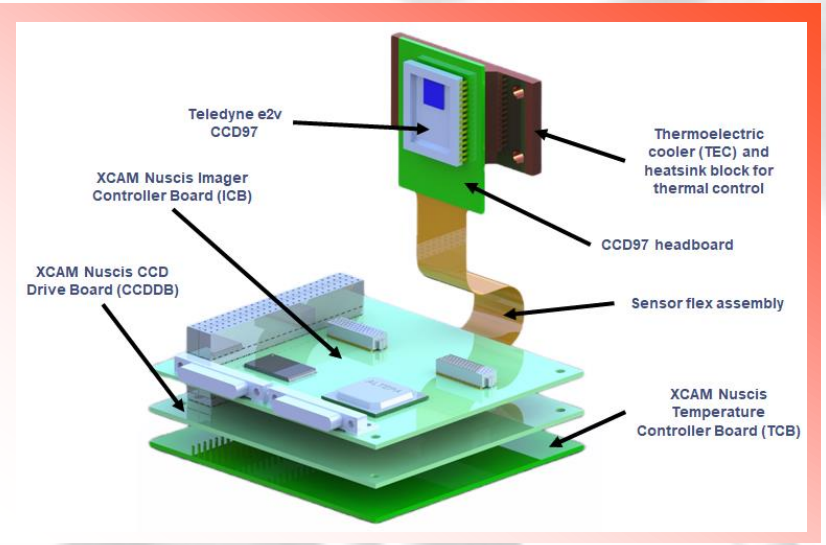
Nuscis - a modular system for science, monitoring and tech-demo

A ‘newspace’ modular, flexible imager system

- Image Controller Board – can be used alone, with potential to drive up to two 1.3M pixel or 4M pixel sensors
- An ‘Auxiliary’ board, which adds to the ICB board to drive CCDs and EMCCDs
- An imager subassembly board
- A temperature controller board



Early concept model of the WINDCUBE EMCCD temperature-controlled variant

The system offers:

- A longer lifetime, higher duty cycle replacement for XCAM’s original CubeSat payload
- Modular system providing a platform to create a product range

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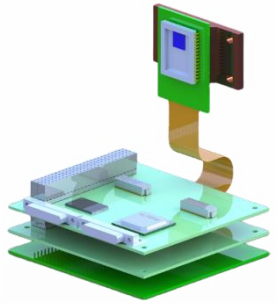
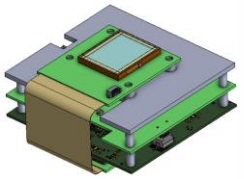
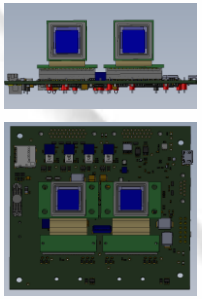
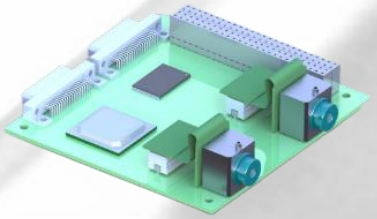
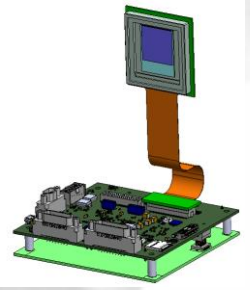
Nuscis Variants and Developments

Stage	In development (funded)			Additional Options with Nuscis Core		In development
						
Sensor	CCD97	sCMOS	CMV4000	Ruby	Sapphire	CIS120/220 CIS221-X
Resolution	0.26MP	> 9MP	4.2MP	1.3MP	2.0MP	4.2MP
Array Size	512 x 512	> 4k x 2k	2048 x 2048	1280 x 1024	1600 x 1200	2048 x 2048
Pixel Size	16µm	< 5µm	5.5µm	5.3µm	4.5µm	10/40µm
PCBs required	ICB, CCDDB, CCD97HB	ICB, CISDB, HB	ICB, sensor flex PCBs, up to 2 sensors per ICB			ICB, CISDB, CIS120HB
Other sensor options potentially available using ICB with CCDDB/CISDB and custom sensor HBs						

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CEOI Funded Development of the Ultra Low-Light Camera

- XCAM won funding from the UK Centre of Earth Observation Instrumentation to develop the Ultra Low-Light Camera
- The project kick-off was held in June 2023 with an 18-month total duration
- Schedule consists of:
  - 10 months of prototype design and build
  - 13 months of firmware and embedded software in parallel
  - Demonstration model testing at the start of the project
  - Test and characterisation of the Nuscis electronics in the final six months
  - Radiation tests with heavy ions, ionising radiation and protons in parallel to final characterisation
- Progress
  - Design, firmware and software definition started, loan evaluation system testing to commence soon
- Output:
  - Test reports, product information sheet, non-deliverable hardware

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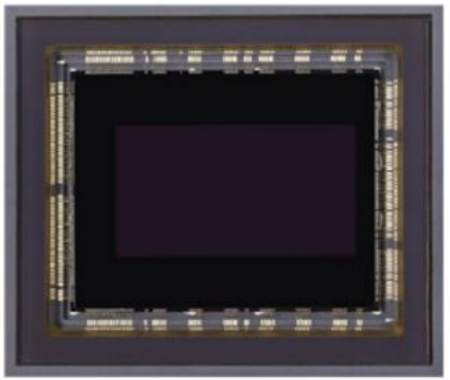
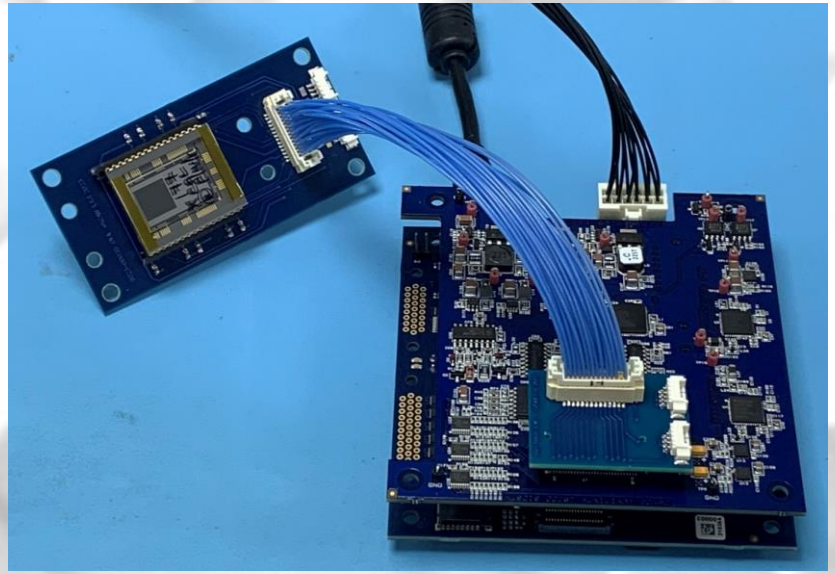
An Ultra Low-Light Camera for Earth Observation Applications

This development uses a high frame rate low-noise sensor developed for the battlefield to address Earth observation applications with high performance components without space qualification.



The high frame rate low-noise sensor



Engineering Model with cable loom to a CCD headboard, driven from an auxiliary board with a Nuscis ICB

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Multispectral Imager for Monitoring of Biodiversity and Land Use Change

- Multi-spectral imaging in low Earth orbit is either achieved with time-delay and integration or a step and stare approach.
- Occasionally instruments increase the target dwell time by rotating to compensate for satellite motion.
- Here the high frame rates of an area sensor are used to target 1-2 m ground sample distance with up to 6 spectral bands in the visible to near infrared.

Conclusion

- The ultra low-light sensor has sufficient area, framerate, noise and peak signal to provide multispectral images for biodiversity and land use change detection

Parameter	Multi-Spectral Imager	Suitability of the ultra-low-light camera
Ground Resolution (m)	1-2	Determined by the instrument optics
Swath (km)	10-20	A single sensor could provide a 4km swath at 1m GSD, 8km at 2m
Wavelengths (nm)	At least 6 bands visible – NIR	Sensor quantum efficiency exceeds 50% from 400-800nm
Peak Signal (ke-)	Depends on resolution, optics, imaging technique, scene radiance	>20
Noise (e-)	< 1 for snapshot < 3 for staring	<1 in rolling shutter mode
Frame Rate (fps)	20	120 in rolling shutter, 60 in global shutter
Sensor Width (pix)	10,000 or more	4k or multiple cameras
Sensor Height (pix)	2,100	2k

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Fluorescence Imaging Spectrometer

- ESA's FLEX mission targets a 300 m GSD collecting very weak fluorescence signals from vegetation.
- Can the next generation in instrumentation and missions improve by a factor of 10?
- A baseline to improve the spatial resolution by a factor of 10 would reduce the signal level by a factor of 100 for a step and stare or snapshot imaging approach utilised by FLEX and will increase the framerate by a factor of 10.
- Does the ultra low noise high framerate sensor open up this parameter space?

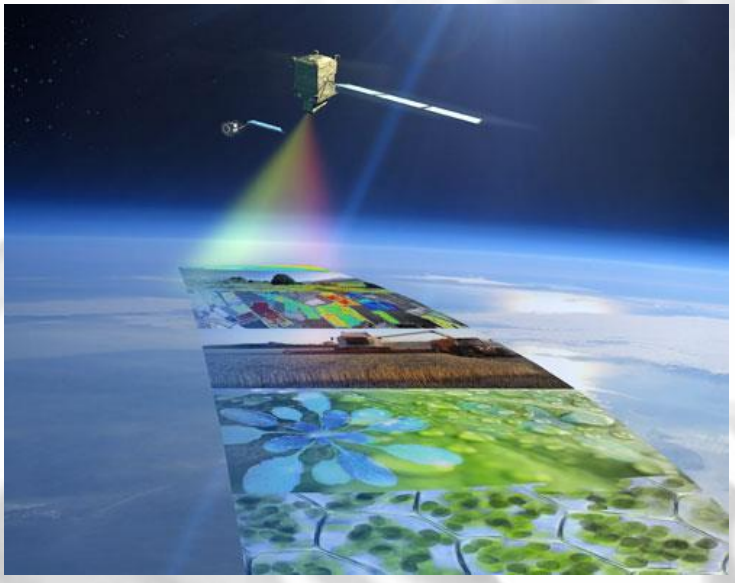

Image from FLEX Objectives - Earth Online (esa.int)

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Fluorescence Imaging Spectrometer

- Challenges at the detector/electronics level:
  - ROI size at the desired frame rate
  - Bit depth of 11 (TBC) limiting peak signal or noise resolution
  - 5.5 Gbits/s at 240 fps at 11bit, 1080p, 240 fps
- Challenges at the instrument level:
  - Alignment and tolerances
  - Optical throughput
  - Manufacturability
- Conclusion
  - Looks very challenging and would involve compromises in performance.

Parameter	**Fluorescence Imaging Spectrometer**	**Suitability of the ultra-low-light camera**
Ground Sample Resolution (m)	30	Determined by the instrument optics
Swath (km)	150	< 60 km with ROI
Wavelengths (nm)	500 – 780 677 – 697 755 - 780	Wavelengths are compatible and sensor quantum efficiency exceeds 50% from 400-800nm
Peak Signal (ke-)	> 25	>20
Noise (e-)	< 2	<1 in rolling shutter mode
Frame Rate (fps)	232.5	240 Region of Interest
Sensor Width (pix)	>5,000	>4k but limited to < 2k 240 fps
Sensor Height (pix)	>450	>2k but limited to 1080 at 240 fps

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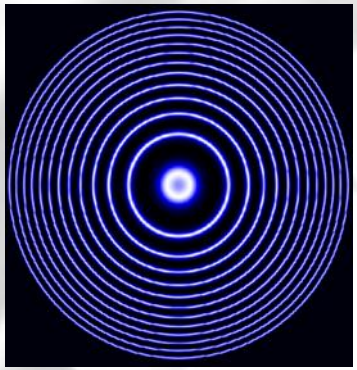
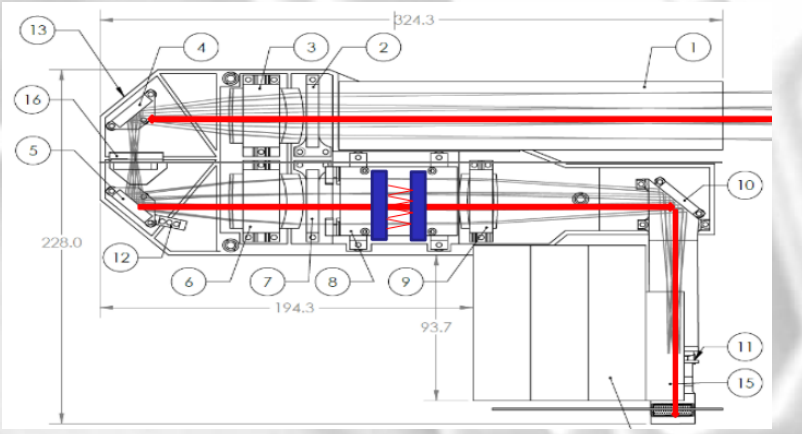
Thermospheric Wind Speed Mapping

- XCAM is already developing an imaging system for thermospheric wind speed mapping in the NASA funded WindCube mission.
- The technique uses spectral line broadening of airglow emissions by pointing a Fabry-Perot interferometer at aurorae.
- Precise emission wavelengths can be characterised giving a measure of wind speeds and direction, while line broadening gives a measurement of the temperature.
- Electron-Multiplying CCDs are used in the current development.
- In the future ultra low light CMOS will reduce the system power and mass requirements.



Left: Astronaut Photograph ISS062-E-98264 showing both auroral and airglow processes at work. Right: an idealised interference pattern. Below: payload optical system layout.
Images from NCAR presentation to Small Satellite Conference 2022



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Thermospheric Wind Speed Mapping

- Ultra low light level sensor provides higher pixel resolution and sampling of the interference rings.
- Signal to noise ratio is comparable or slightly better than the existing requirement
- ADC digitisation is inferior but use of dual gain could be considered
- Framerate is superior
- Dark current at low temperatures for long exposures is unknown, however, the 30°C level is already low
- Wavelength is compatible

Parameter	WindCube	Suitability of the ultra-low-light camera
Pixel Size (um)	16 x 16	< 5 x 5
Resolution (pixels)	512 x 512	> 4k x 2k
Signal to Noise	11,250:1	~14,000:1
Digitisation (bit)	14	12 or 11 ADC or 16 with dual gain
Frame Rate (fps)	2	60 typical
Exposure Range (s)	0.5 - 200	Dark current versus temperature is TBD
Wavelength (nm)	630	Sensor quantum efficiency exceeds 50% from 400-800nm

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Potential Impacts

- Access to missions
  - Seen as an export or bilateral opportunity rather than ESA missions
  - UK industry maybe a route to market, however, Nuscis is a sub-system for instrument or camera builders and the UK market is extremely small
- Mission enablement
  - Smaller, lighter instruments with new capabilities in frame rate, noise performance and resolution
- Science enablement
  - Watch this space…it's for the scientists to drive this
- Commercial traction
  - Offering a new capability at the image sub-system level

Summary

- The development of Nuscis, XCAM's next generation of CubeSat and small satellite imaging electronics has been presented.
- Three examples of potential uses of the ultra-low noise Nuscis variant in Earth observation applications have been described.
- XCAM welcomes enquiries from mission and instrument teams who are interested in building this imaging system into their future plans.

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