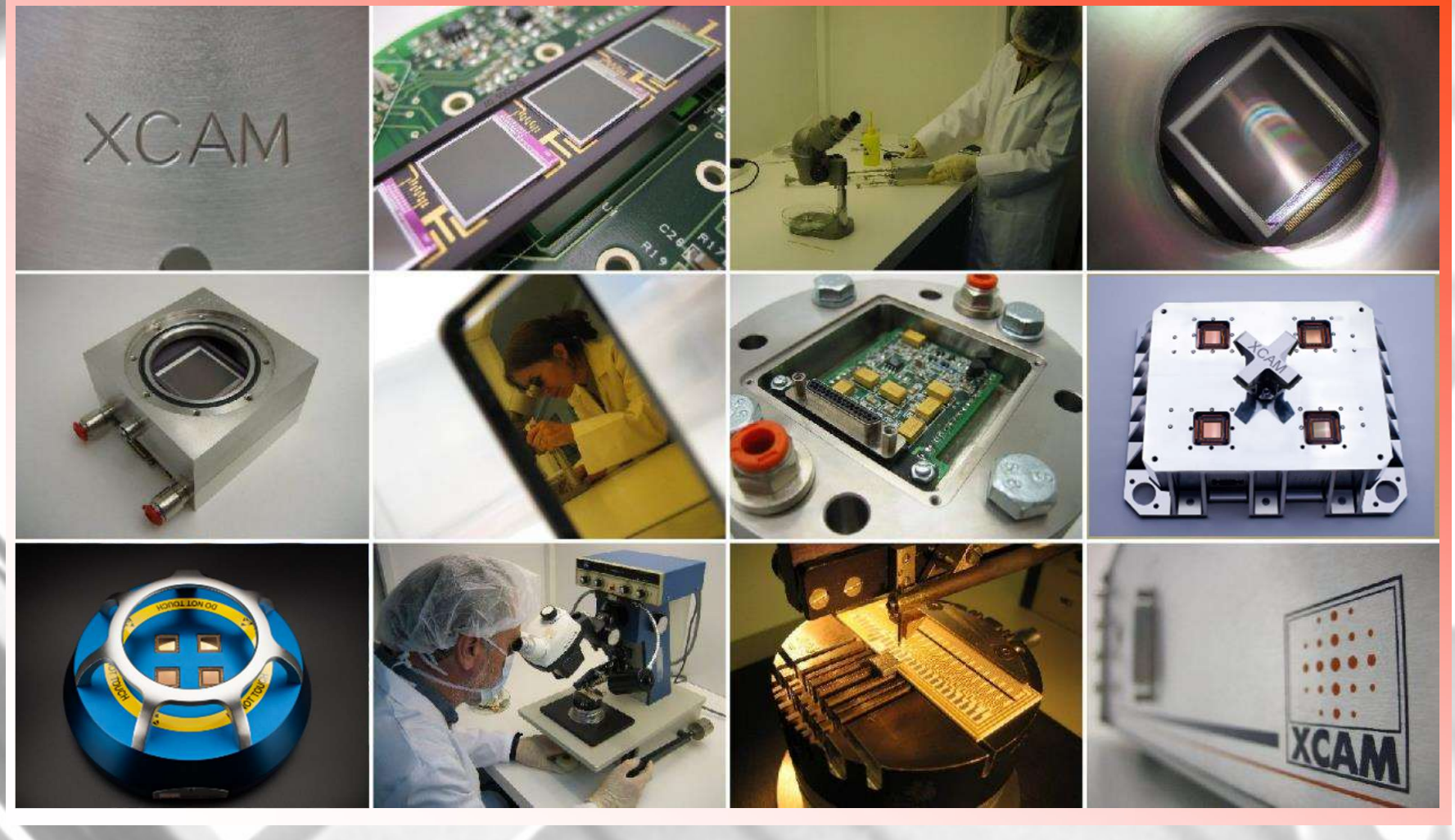
RADOPT 2023 Nuscis



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Nuscis: A NewSpace Scientific Imaging System for SmallSats

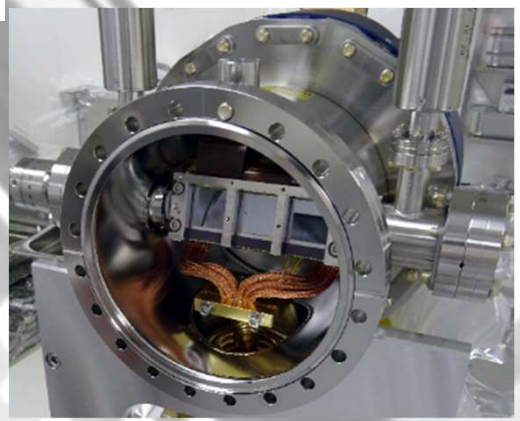
Andrew Holland[1,2], Karen Holland[1], David Colebrook[1],
Ben Dryer[2], David Hall[2]

1. XCAM Ltd, 2 Stone Circle Road, Round Spinney Industrial Estate, Northampton, NN3 8RF, UK
2. Centre for Electronic Imaging, The Open University, Milton Keynes, MK7 6AA, UK

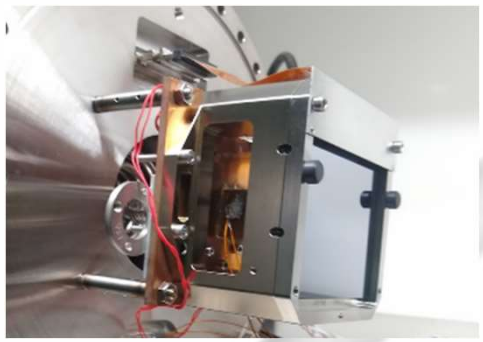
XCAM Heritage

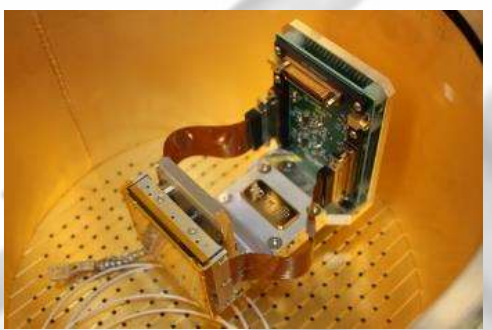
- Formed in 1995, over 28 years history in CCD & CMOS imaging systems

Vacuum Cameras for Science Experiments & EUV Lithogaphy



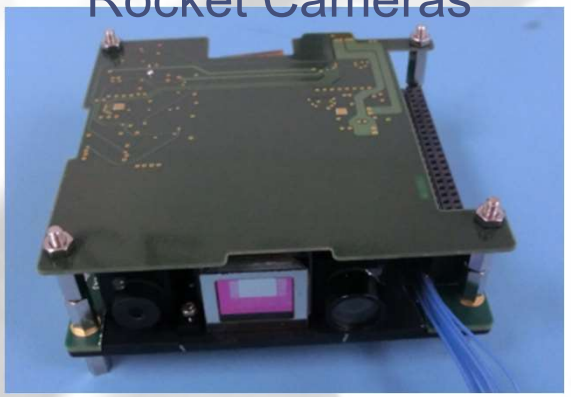
Test Equipment for Major Space Projects





PFO Systems for Cleanroom & Rocket Launch

CubeSat & Sounding Rocket Cameras



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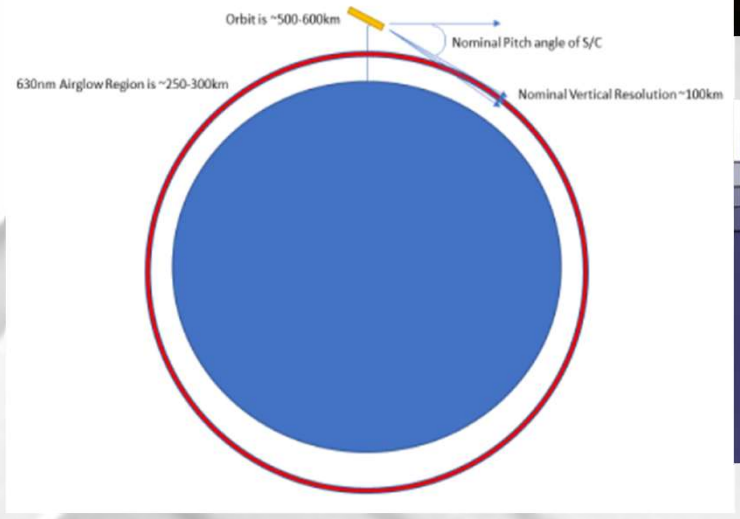
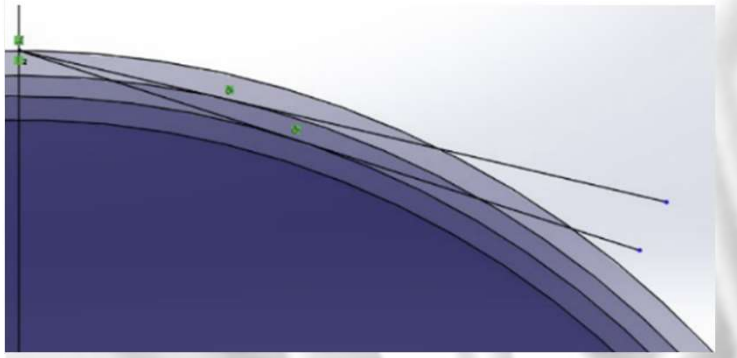
WindCube

- WindCube proposal by UCAR (Boulder), GSFC and XCAM
- Awarded funding in 2022 from NASA's HFORT program
- WindCube is a CubeSat mission selected for implementation
- ~36 month development, integration & testing
- Launch ~2025, at ~500 km orbital altitude
- Mission duration ~12 months operation





Sewell et al, "WindCube: A CubeSat Thermospheric Wind Instrument Utilizing Fabry-Pérot Interferometry", 36th Annual Small Satellite Conference 2022, SSC22-WKIII-08

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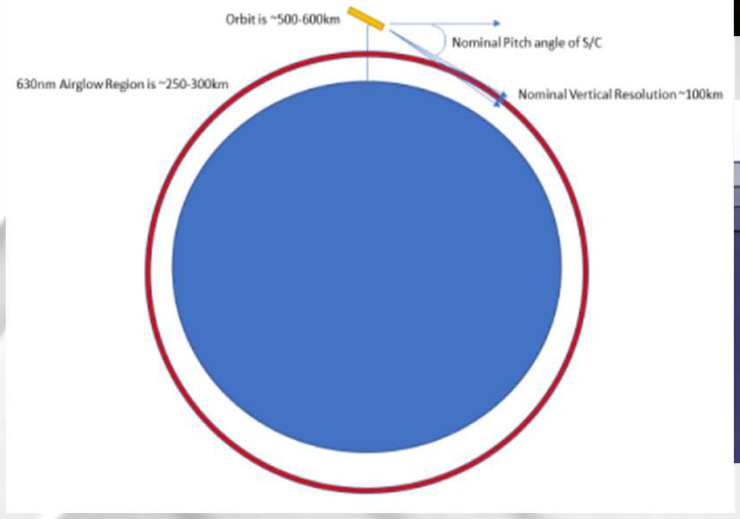
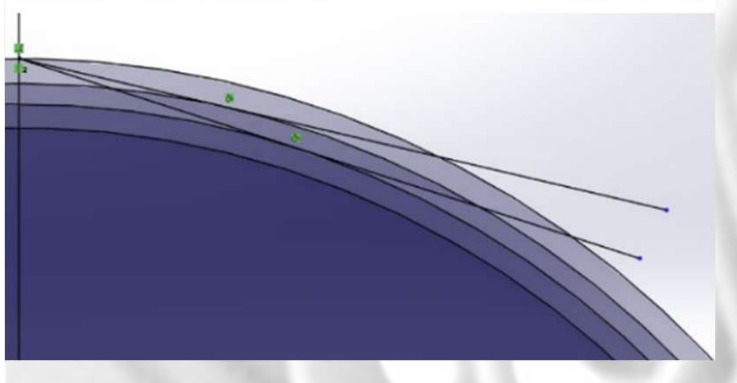
WindCube Mission

- WindCube will make global maps of wind speed derived from the doppler shifted emission of the 630.0nm line from oxygen at altitudes near 250km
- Projected performance includes wind speed retrievals every 10 seconds with an accuracy of 5m/s, a vertical resolution of 63km, and a horizontal resolution of 100km
- Based on a 12U CubeSat spacecraft format
- Mission duration 6-12 months





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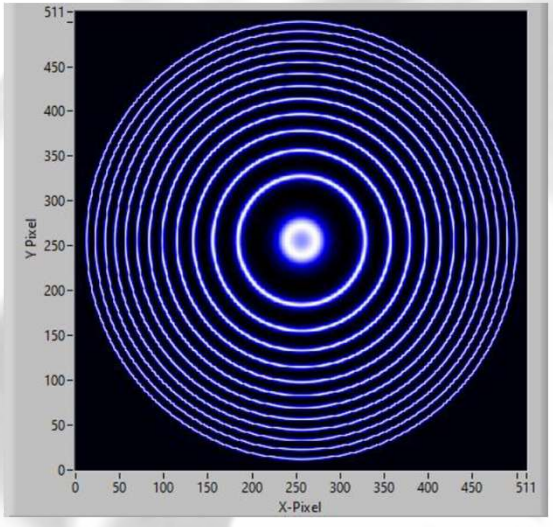
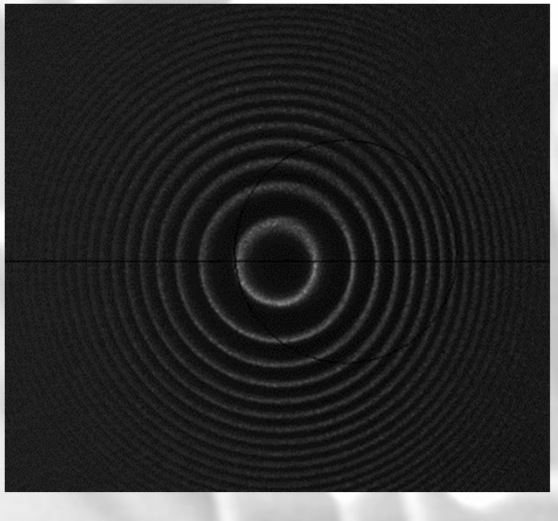
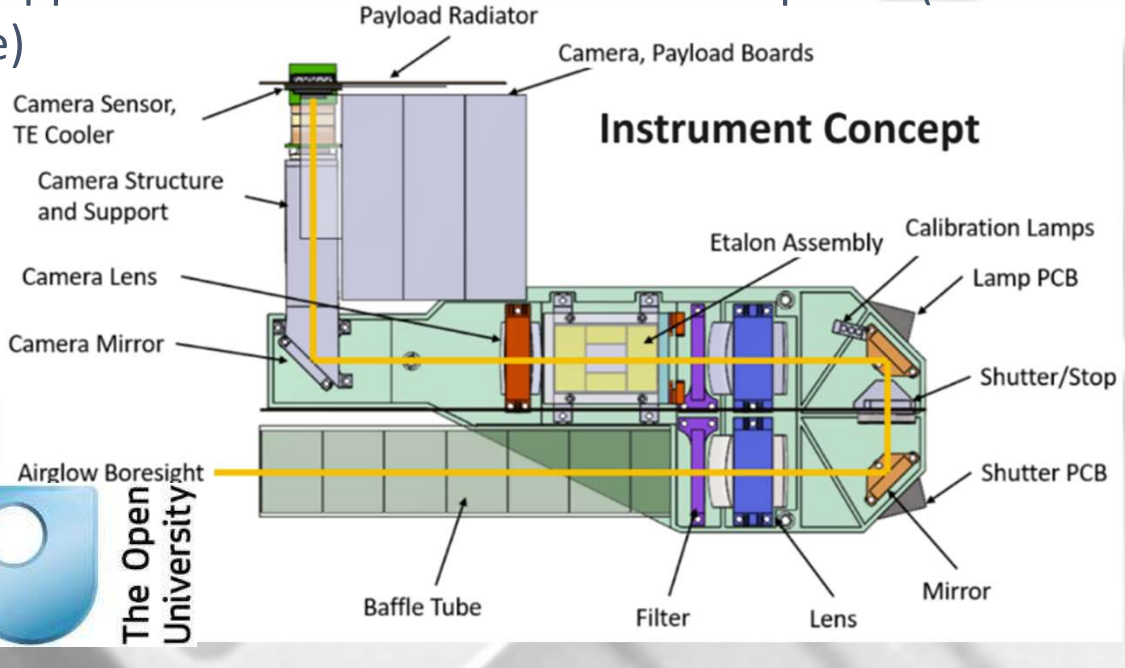
WindCube Instrument Concept

- Fabry Perot Interferometer imaging the oxygen emission at 630 nm
- A modeled FPI transmission spectrum and an actual FPI transmission spectrum using a HeNe laser
- Shifts in the position of these “bullseye” patterns correspond to small doppler shifts - used to retrieve wind speeds (~200-300km altitude)







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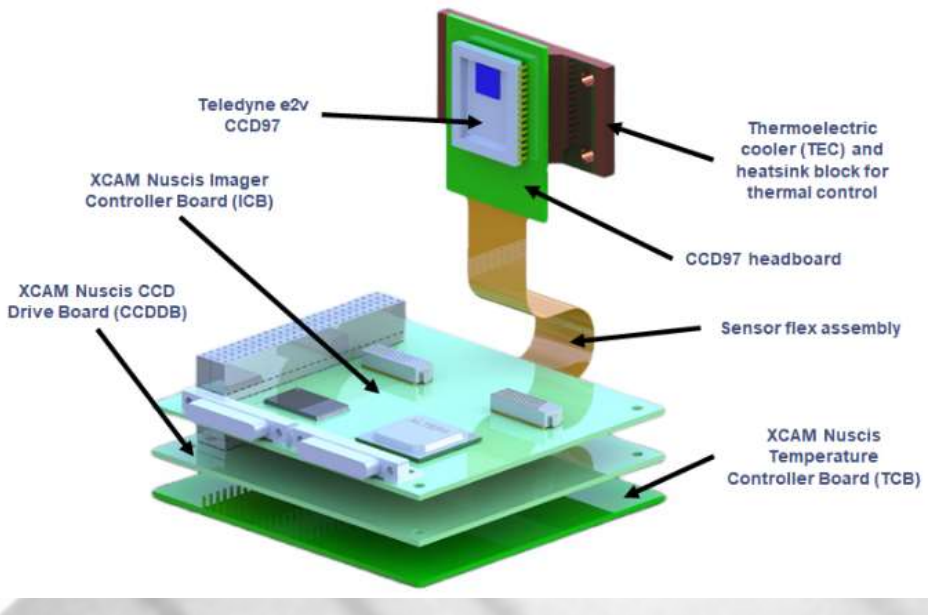
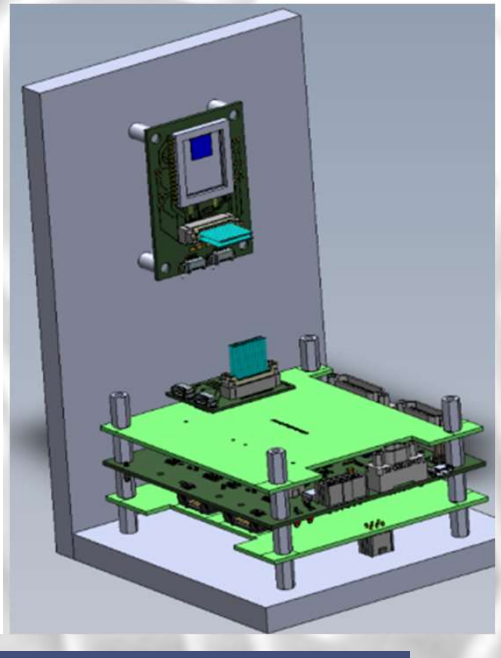
XCAM Nuscis Camera for WindCube

- Developed from a combination of 3 decades experience with CCD & CMOS camera systems for terrestrial and space use
- NewSpace Scientific Camera Imaging System – ***Nuscis***
- Goal is to develop a flexible, multi-purpose camera system utilising a variety of leading image sensors
- WindCube is co-funding the system development with the EM CCD97
- 3 PC104 boards
  - ICB – Imager controller
  - CCDDB - CCD drive board
  - TEC controller board
- GSE for vacuum testing





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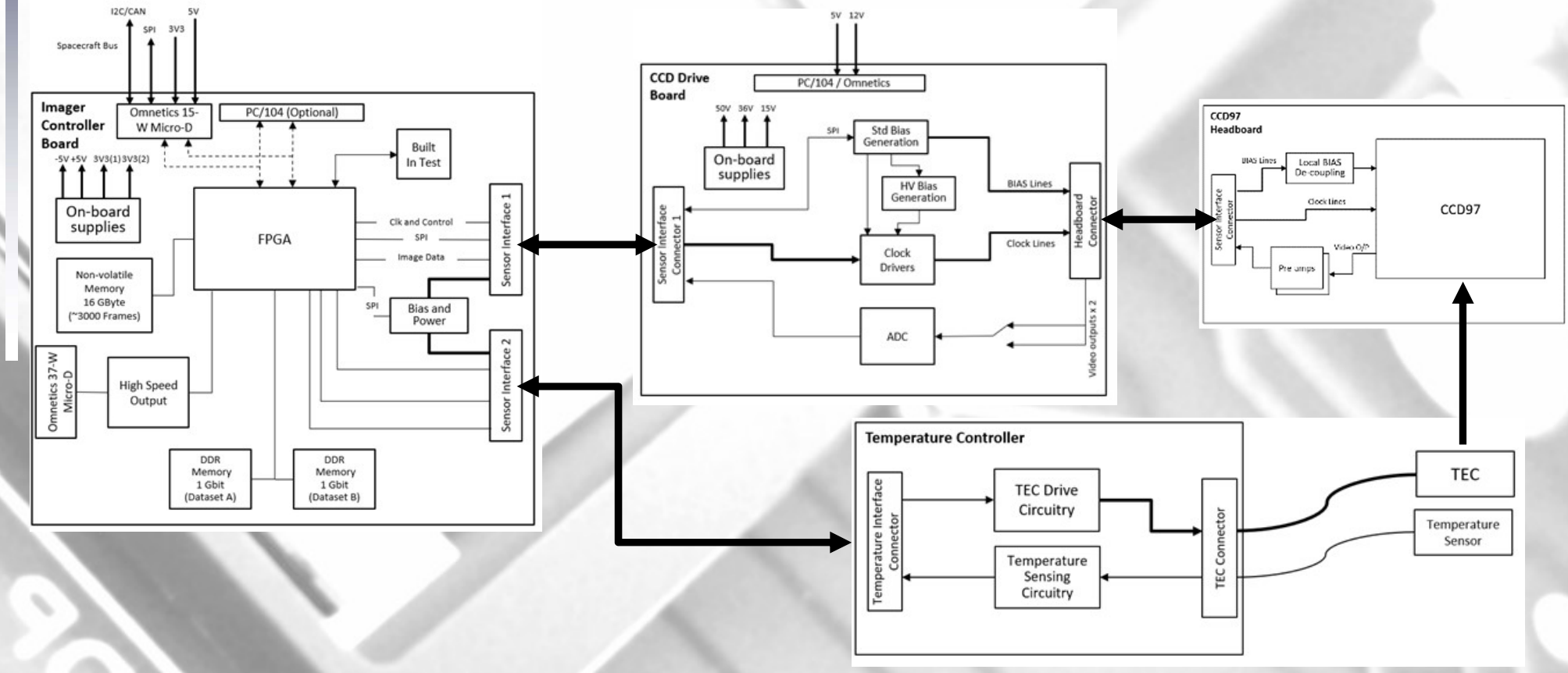
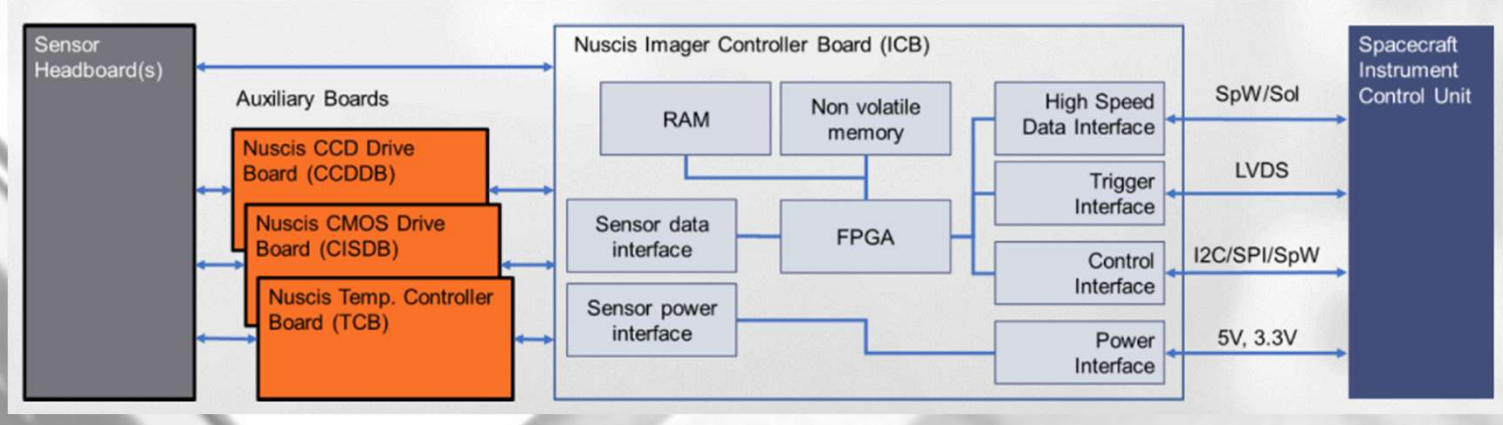
System Block Diagram



Nuscis Interface Controller Board - ICB

- The Nuscis ICB delivered and is currently under test
- TEC controller prototype in manufacture
- CCD drive board (inc. ADC) in manufacture, due imminently
- ICB can couple directly to a number of CMOS image sensors
- Auxiliary board to drive/digitise CCDs or analog CMOS (CIS115)



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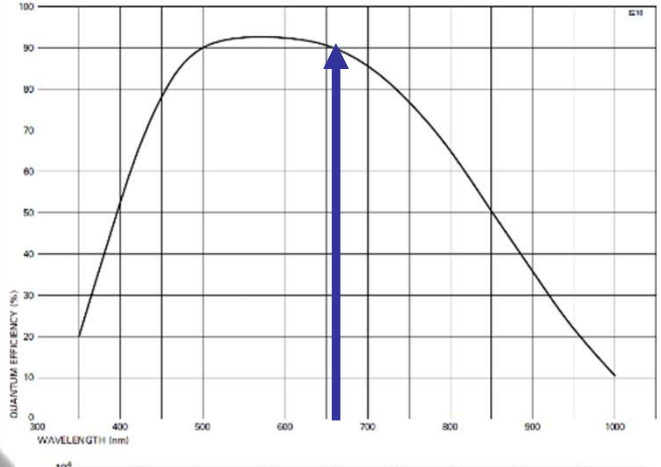
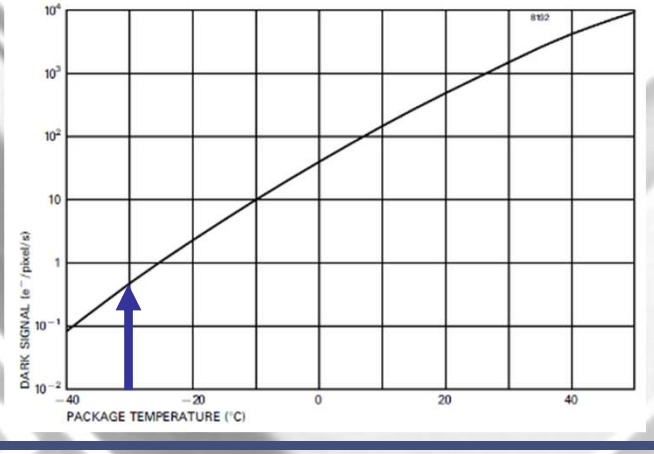
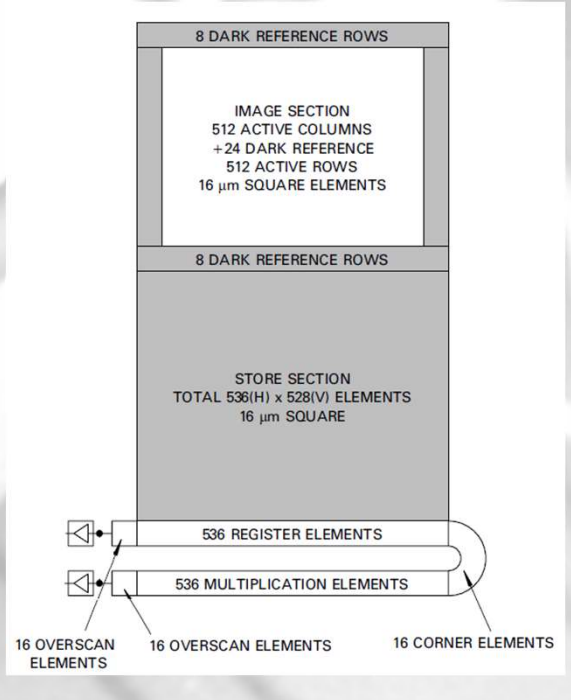
CCD97

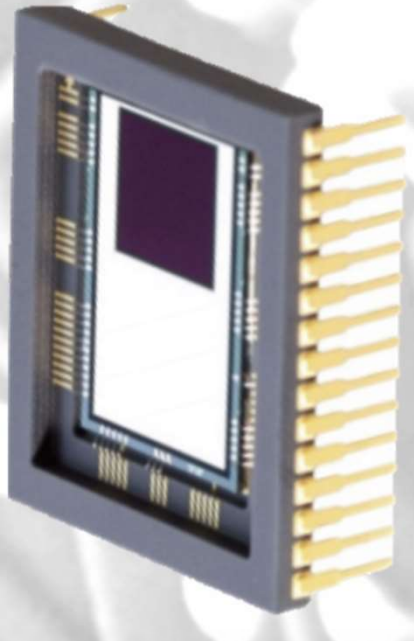
- High QE, low noise, low dark current
- Operation at -30 to -40°C





	CCD97	CCD201-20
Resolution	512 x 512	1024 x 1024
Pixel Size	16um	13um
Readout noise (1MHz, x1000 gain)	<1e-	<1e-
Full Well	130 ke-/pix	80 ke-/pix
Image Mode	Frame Transfer	Frame Transfer
Max. Gain	x1000	x1000





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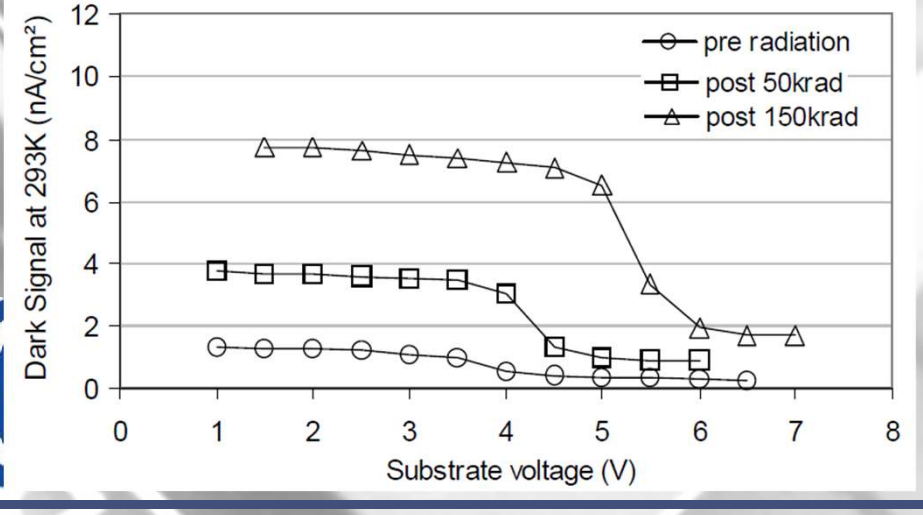
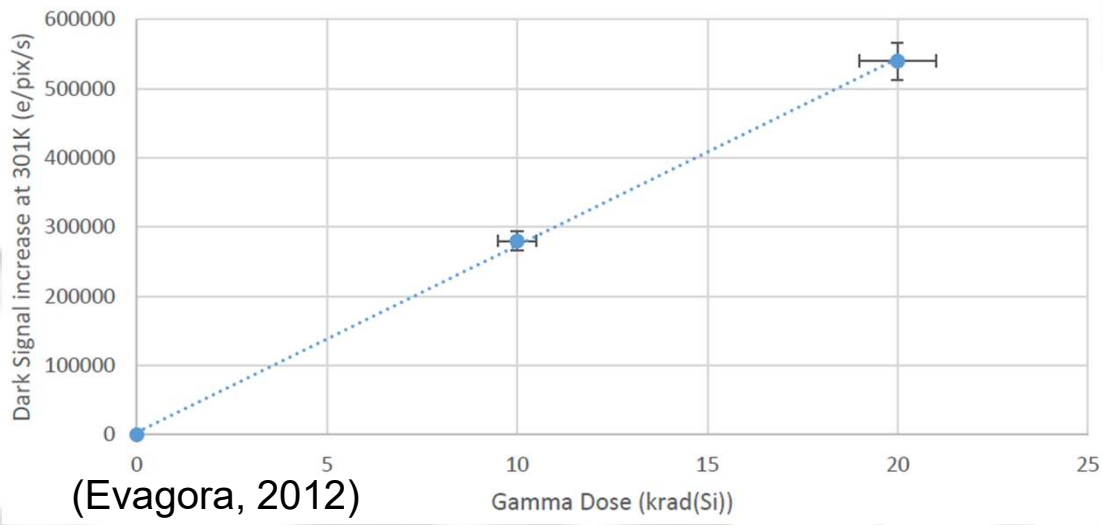
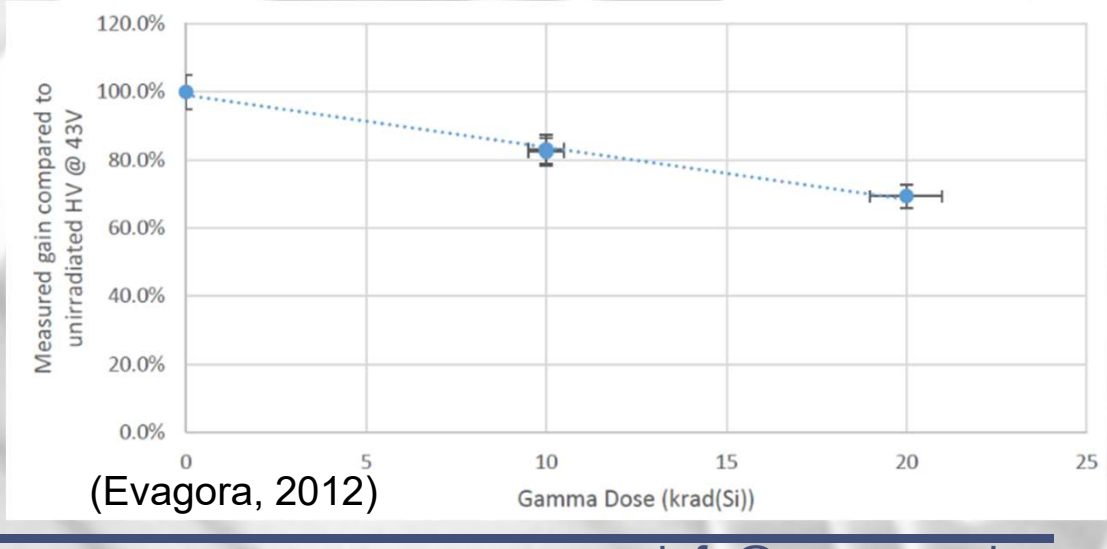
Radiation Damage Effects

- **Ionising**
  - Dark Current
  - EM gain ageing
- **Non-Ionising (protons)**
  - Bright + Flickering Pixels
  - Charge Transfer Inefficiency (CTI)
- **EMCCD Radiation Effects**
  - EM gain ageing
  - Single Event Gate Rupture (no evidence)





(Evagora, 2012)

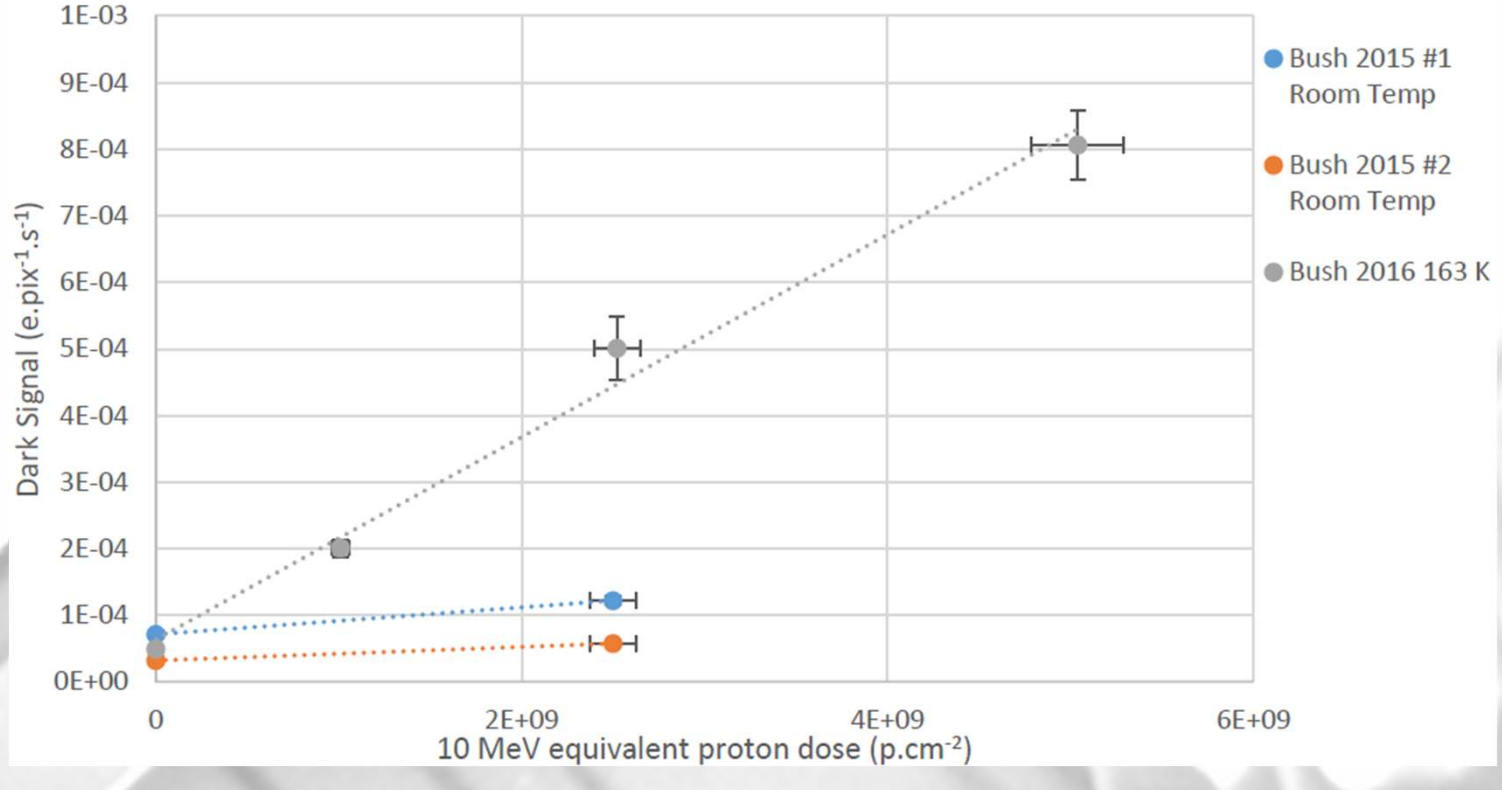


(Evagora, 2012)

Effect of Proton Irradiation Temperature

- 163K irradiation – increase of 2×10^{-13} $(e.pix^{-1}.s^{-1}).cm^2.p^{-1}$ at -100°C
- 293K irradiation – increase of 4×10^{-14} $(e.pix^{-1}.s^{-1}).cm^2.p^{-1}$ at -100°C

- Irradiations at 230-340K are not well explored



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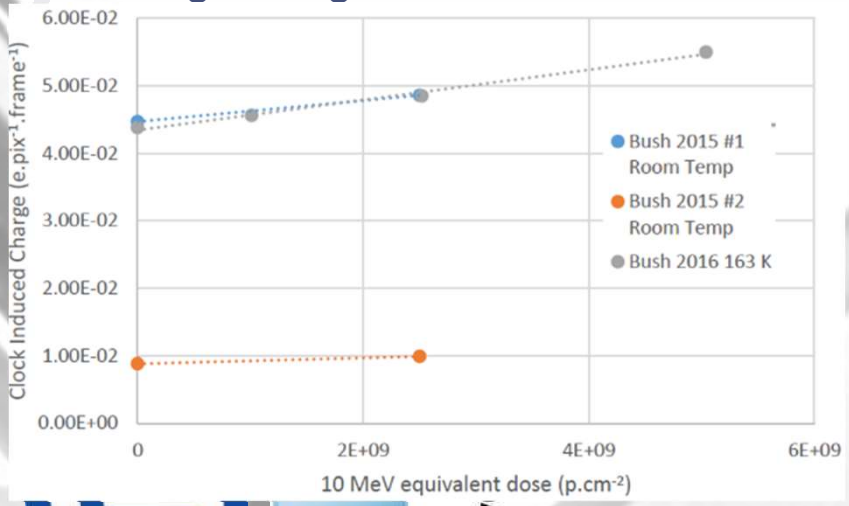
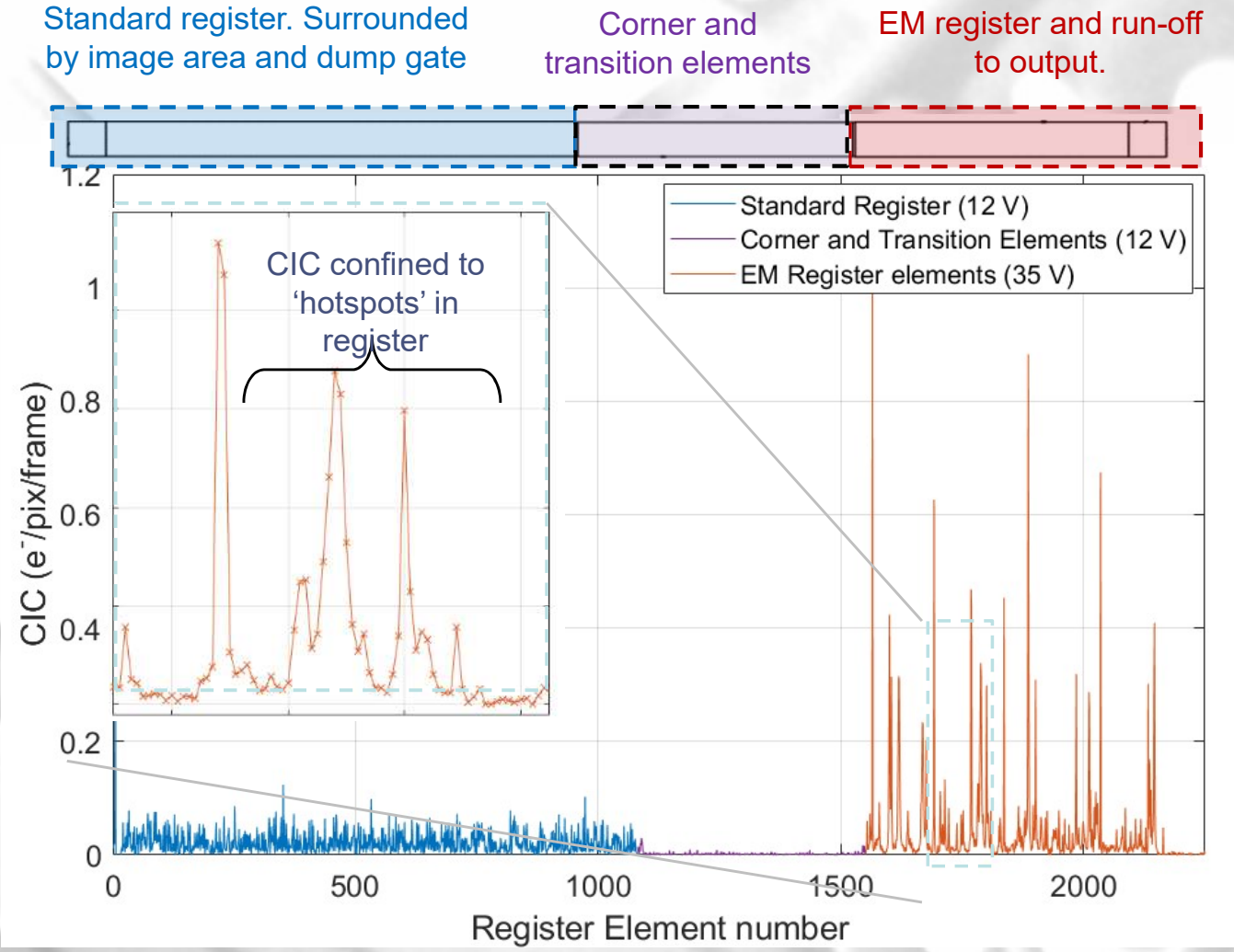
CIC Generation

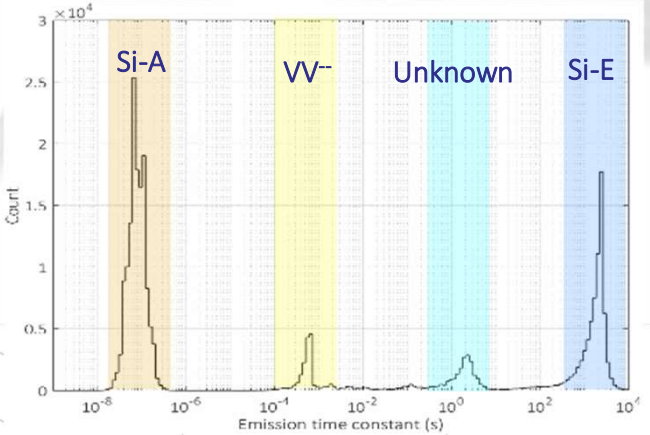
- Clock-Induced-Charge is also a concern for low-light level applications
- Proton damage can increase CIC generation
- Both image and readout registers plus structure in the gain register

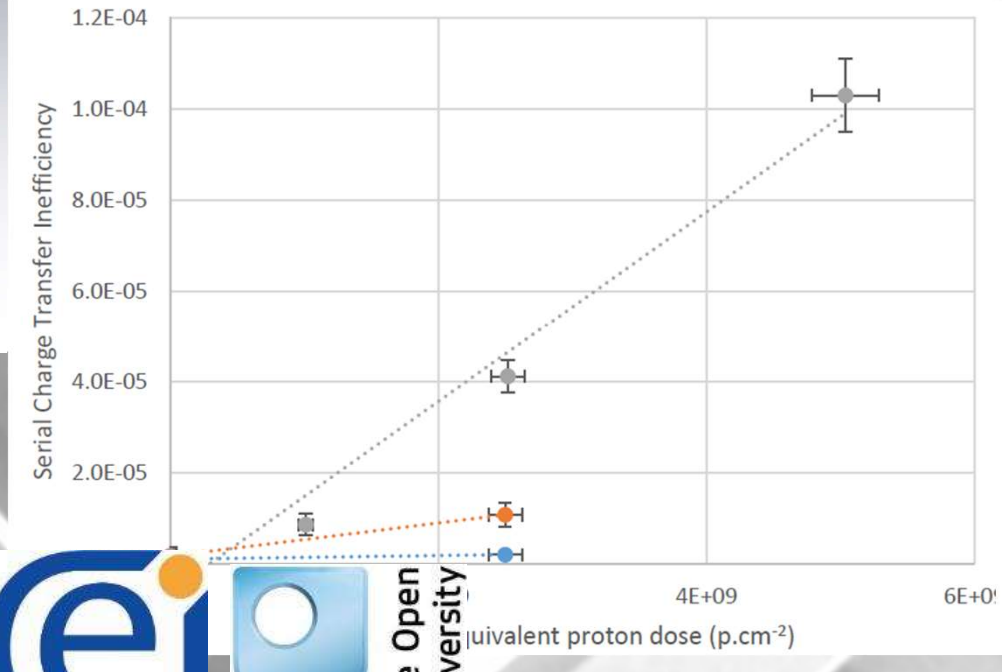


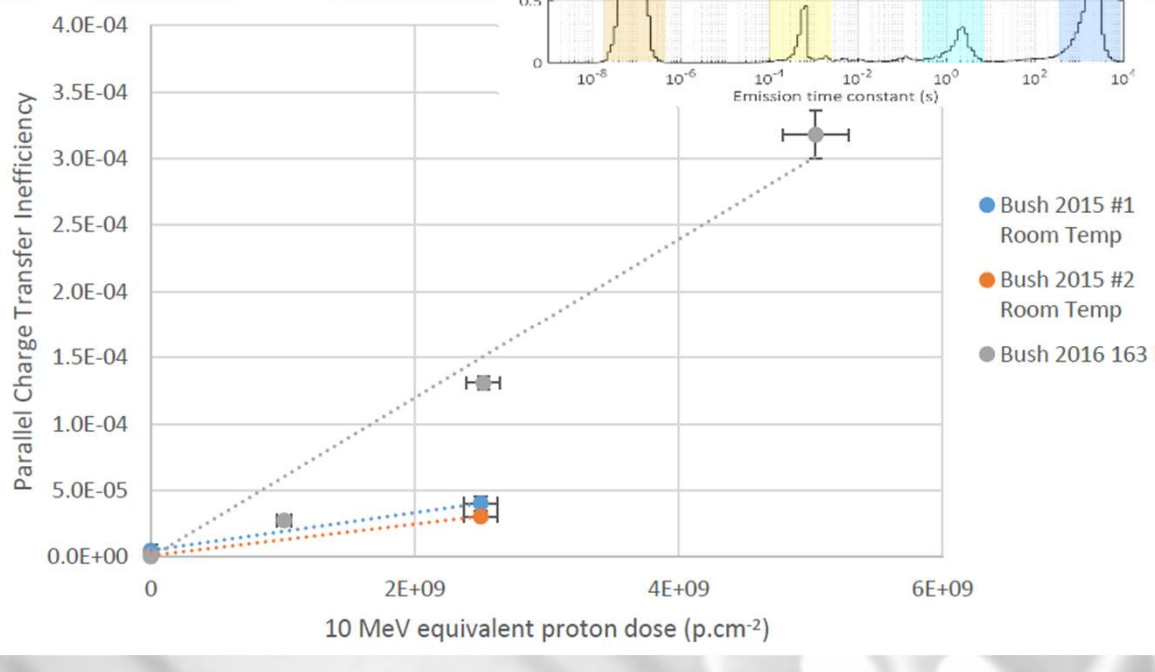


Proton-induced CTI

- CTI readings taken at 165K
- Significant effect of irradiation temperature due to different trap generation







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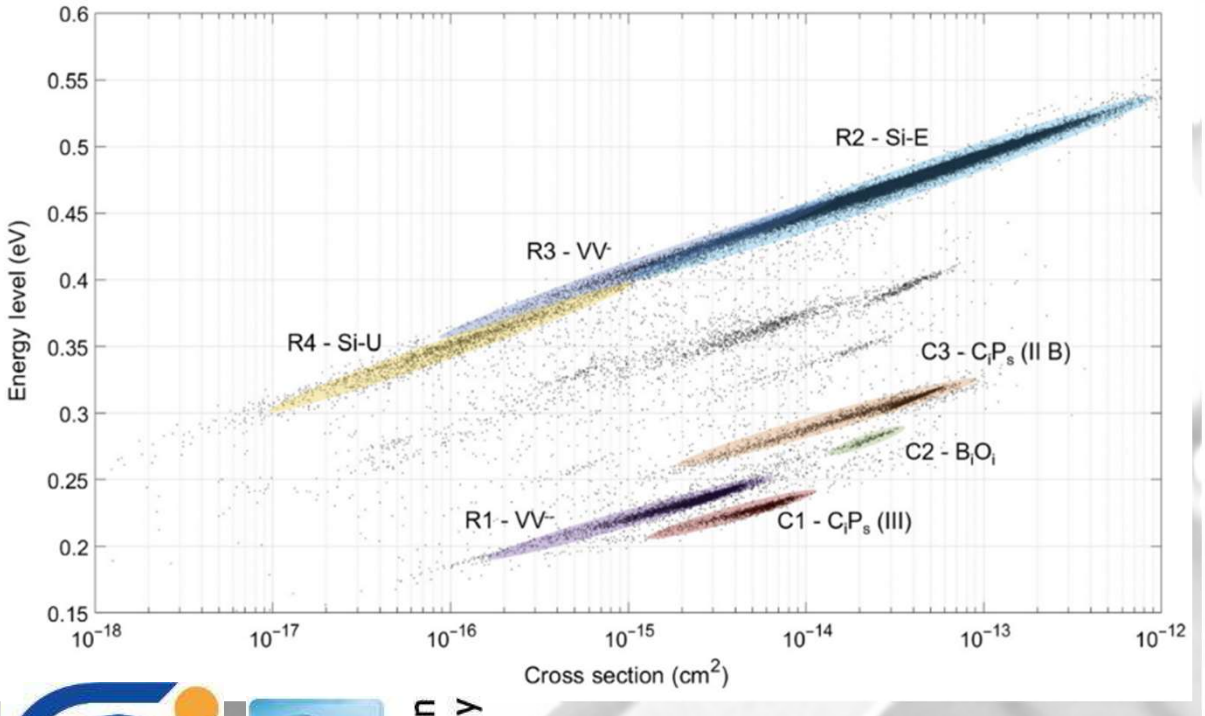
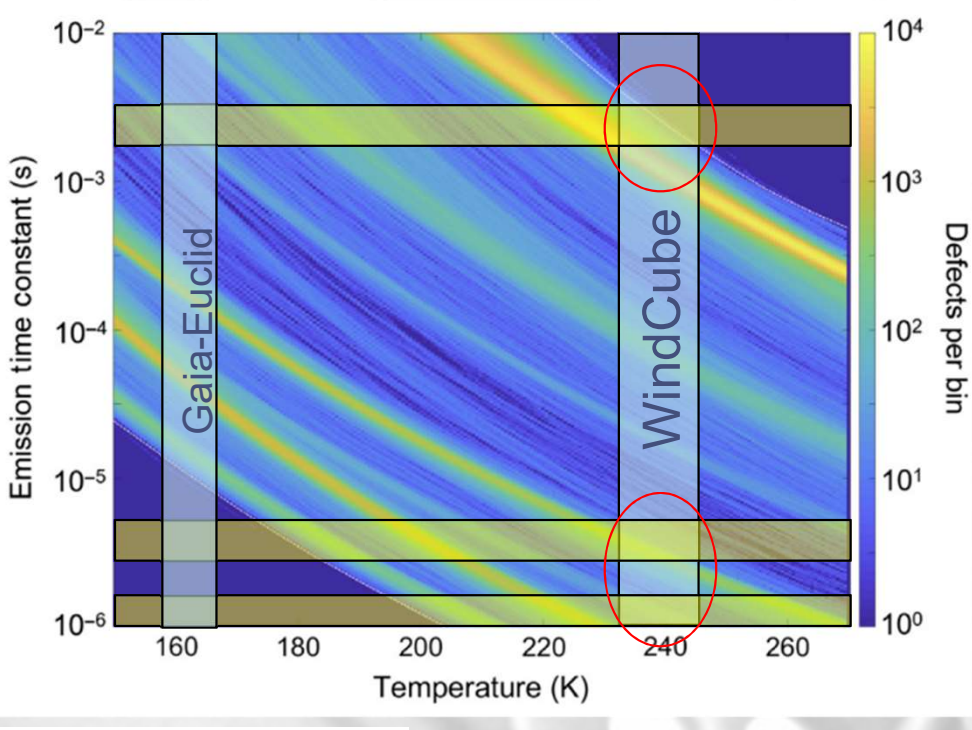
Pre- and Post Proton Trap Landscape

- Trap pumping has been developed to characterise individual traps in the CCD array
- Traps in pre-irradiated CCDs (“C”) have been linked to Carbon and Boron
- Post proton irradiation results show growth of PV and VV species





Bush, Hall and Holland,
“Proton-induced traps in electron multiplying charge-coupled devices”,
Astron. Telesc. Instrum. Syst. 016003-20 (2021)

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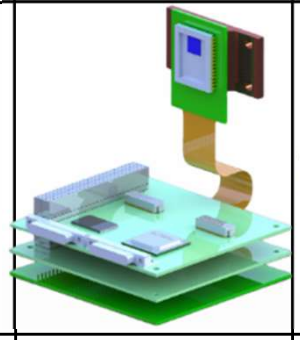
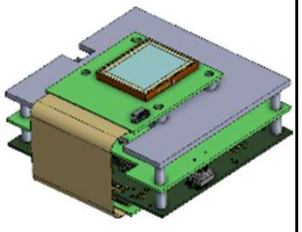
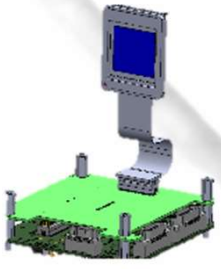
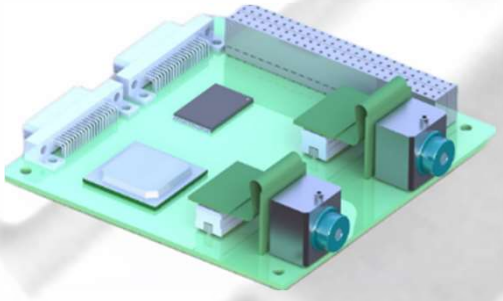
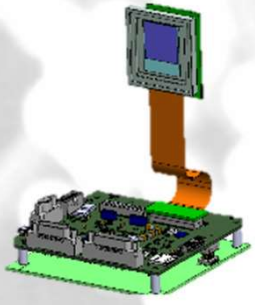
Radiation Test Programme

- System has been designed using parts with space heritage,
- Radiation mitigation design techniques being used
- Radiation testing being performed by the CEI
  - TID using the ESTEC gamma cell
    - unpowered to 1krad (TBC)
    - then powered/operating to 1 krad (TBC)
    - then unpowered to 5 krads (TBC)
  - Proton testing using 200 MeV (TBC)
    - Operation of the system whilst the system is running to simulate operation e.g. in the SAA
    - Irradiation of CCDs to enable measurement of EOL performance
    - CCD97s have already been irradiated to 5E9 cm^{-2} and are awaiting test

Nuscis Variants and Developments

Stage	In development (funded)		Additional Options with Nuscis Core			Stage 2 Proposal
						
Sensor	CCD97	BAE HWK/LTN	Ruby	Sapphire	CMV4000	CIS120/220 CIS221-X
Resolution	0.26MP	10.5MP	1.3MP	2.0MP	4.2MP	4.2MP
Array Size	512 x 512	4432 x 2368	1280 x 1024	1600 x 1200	2048 x 2048	2048 x 2048
Pixel Size	16µm	4.6µm	5.3µm	4.5µm	5.5µm	10/40µm
PCBs required	ICB, CCDDB, CCD97HB	ICB, CISDB, LTNHB	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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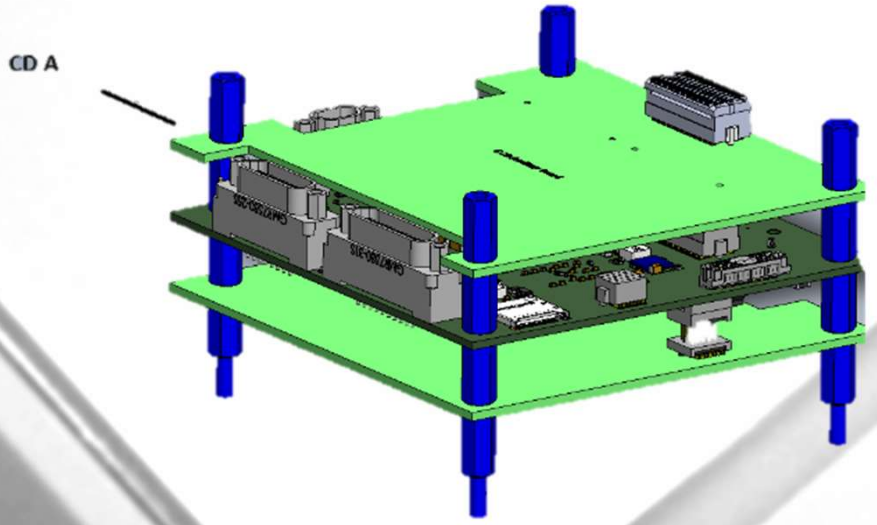
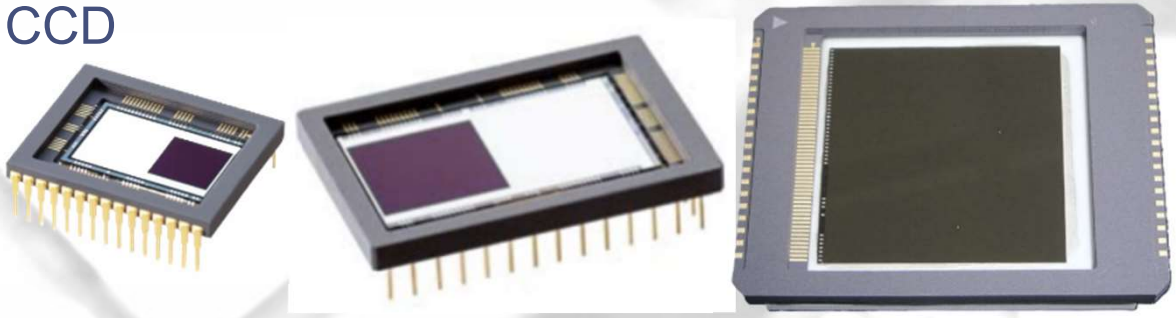
Nuscis Detector Variants

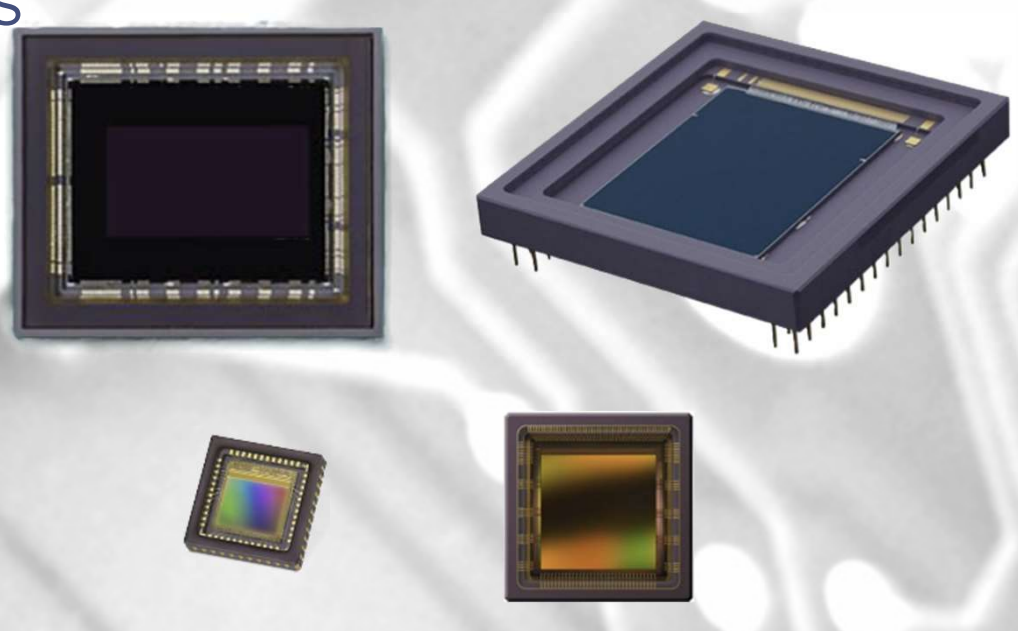
- Several projects are already underway using CCDs & CMOS



CCD



CMOS



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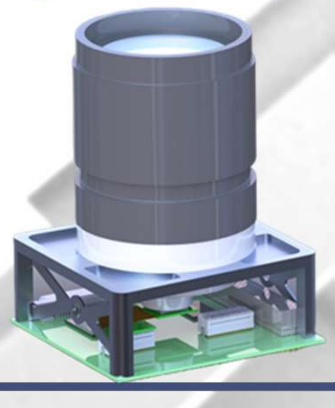
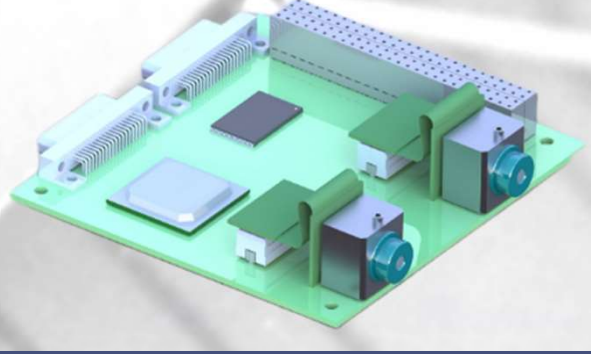
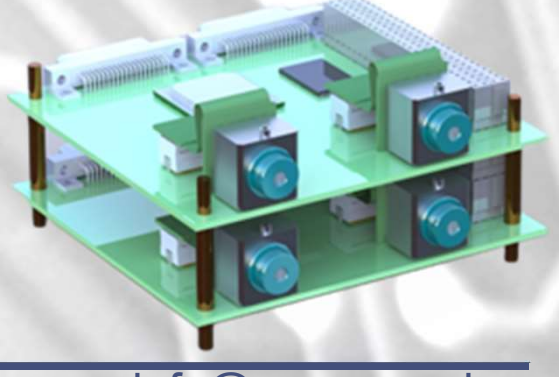
Summary

- Developing a flexible image sensor controller using *New Space* principles
- Initially developed for scientific instrumentation
- WindCube (high performance, low noise etc,)
- Also designed to operate COTS sensors with a growing range being implemented
- Developed mindful of space radiation damage effects to imagers and resulting performance
- Radiation damage test and characterisation being performed by the CEI (shortly)

- Nuscis Variant Offerings
  - CCD/EM-CCD/CMOS/sCMOS
  - High frame rate w. low noise
  - Stereo imaging
  - Deployment + docking
  - X-ray imaging & spectroscopy
  - On-board image processor
  - Thermal control/stabilisation







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Questions?

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