Detector Development for Future Space missions

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Future Astrometry Mission Workshop, IAP, Sep 2024

CENTRE FOR ELECTRONIC IMAGING

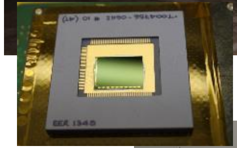
Research group at the Open University, UK, specialising in CCD & CMOS R&D for Space Science

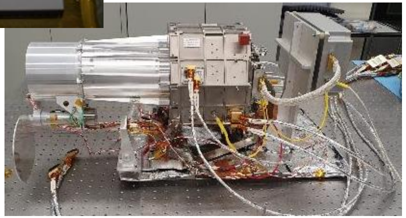
- A collaboration between Teledyne e2v and Open University
- Founded in 2004

Areas of expertise:

- Complementary metal-oxide-semiconductor (CMOS) image sensors and charge coupled devices (CCD)
- Image sensor design and customization
- Sensor characterization and calibration
- Radiation damage effects in space
- Interaction of radiation with matter, shielding
- Semiconductor physics and device simulations
- Cryogenics and vacuum
- Electronics

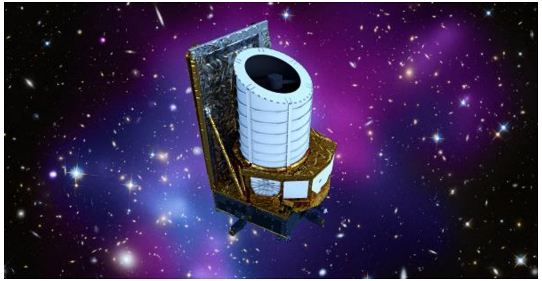
MAIN WORK – IMAGE SENSORS FOR SPACE MISSIONS

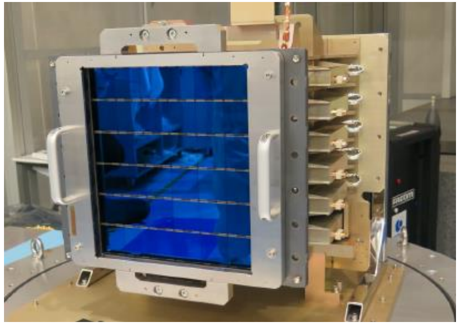




JUICE –JANUS camera

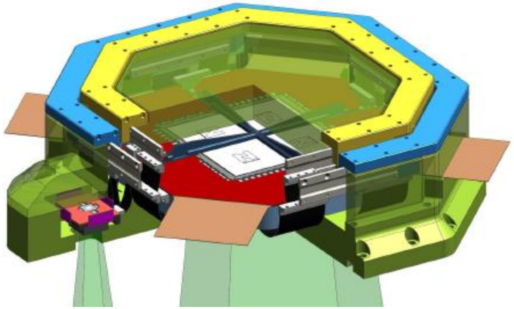
- Radiation and EO characterisation of CIS115 detector
- Proton, electron, gamma, heavy ions





Euclid – VIS Instrument

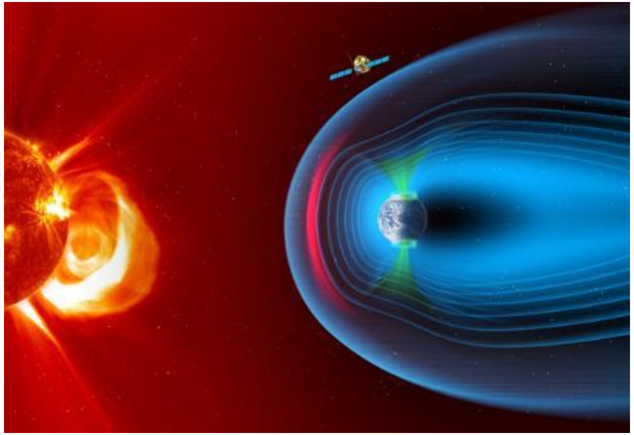
- Cryogenic proton irradiation of its CCD273s
- In-orbit radiation monitoring

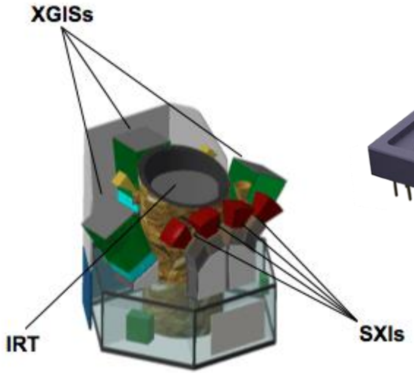


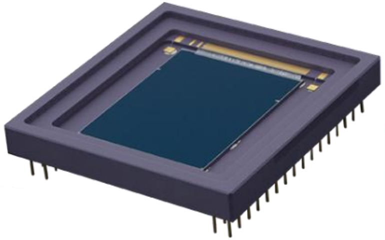
ATHENA – WFI instrument

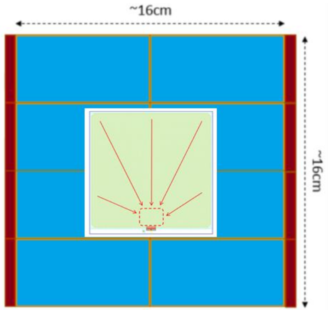
- Modelling radiation backgrounds and design of graded Z-shield for the WFI X-ray camera

MAIN WORK – IMAGE SENSORS FOR SPACE MISSIONS









SMILE – Investigating the interaction of Earth’s magnetosphere with the Solar wind

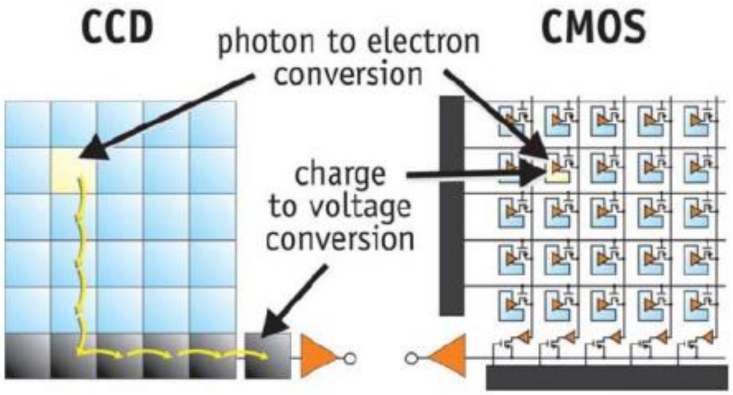
- Radiation damage effects in a soft X-ray imager (CCD)
- Very large CCDs
- Joint Chinese-ESA mission
- Launch in 2025

THESEUS – CMOS sensor for the Soft X-ray Imager (0.3 – 6 keV)

- Project to develop a prototype funded by ESA
- Designed at the CEI: 40 µm and 10 µm pixels, fully depleted, 40 µm thick, 2 e- noise, based on our patent
- BSI CIS221-X sensors manufactured by Te2v
- Gamma and proton irradiation campaigns underway

DETECTORS FOR ASTRONOMICAL INSTRUMENTS

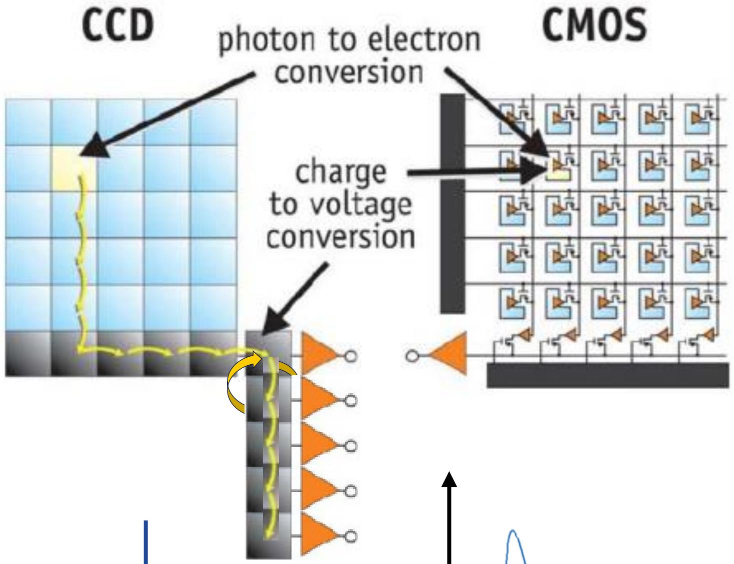
- Detectors are essential for any instrument
- Often a major cost driver
- Important that detector selection/development and testing is started early
- Many detector types to choose from:
    - CCD
    - CMOS
    - MCT
    - APD
    - MKID
    - Microchannel plates
    - Superconducting nanowires
    - *Many more…*
- All technologies have different pros and cons

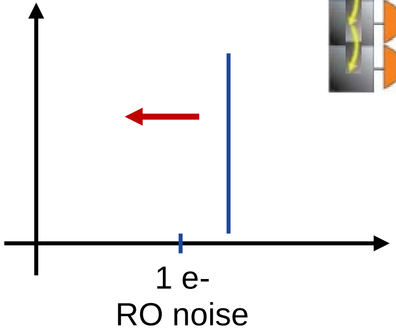


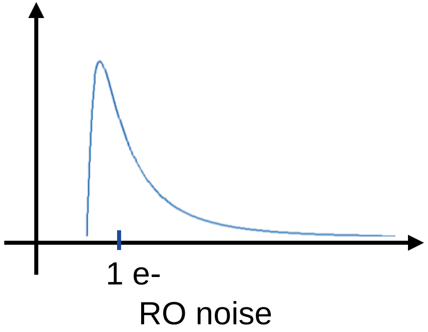
- Gaia made use of the CCD clocking principle by transferring the charge across the device at the same speed as the stars moved across the detector
    - Time-delayed Integration (TDI)
    - Not possible with other technologies
        - Column parallel CMOS
    - TDI therefore limited to wavelengths observable with silicon (<1100)

LOW NOISE DETECTOR DEVELOPMENTS

- A lot of detector developments are currently driven by HWO requirements
    - Noise < 0.2 e-
- CCDs have well-defined noise
    - Difficult to get below 1 e-
- Skipper CCDs
    - Very long readout times
- Multi-Amplifier CCDs
    - Limited by RO circuits and power consumption
- CMOS can have sub-electron noise
    - Very low Full Well capacity
    - Noise distribution

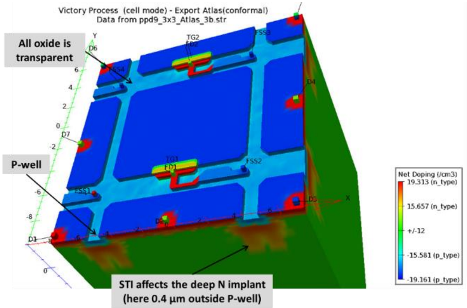


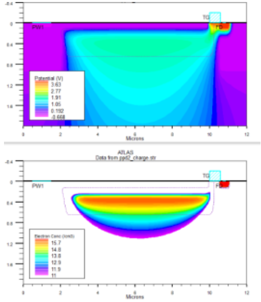


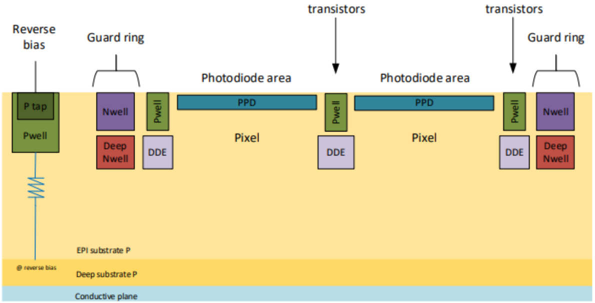


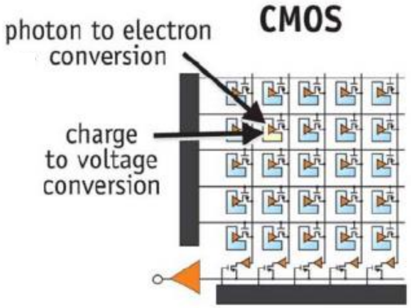
CMOS DETECTOR DEVELOPMENTS AT CEI

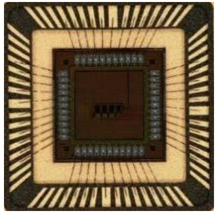
- Strong expertise in semiconductor device simulations
  - Device physics and manufacturing process
  - 2D and 3D
- Pixel and sensor design in-house
  - Layout and tape-out of test chips
  - Custom chip designs for several space missions
- 4 patent applications, one granted patent
  - High-rho CMOS (Deep depletion – better red response)
    - Standard product for Teledyne e2v CIS
  - High Dynamic Range (HDR)
    - Dual sense nodes
    - Now part of CIS300 product line
  - Large Pixel design
  - Skipper CMOS
    - Skipper structure in each pixel
    - Low-noise at by multi-sampling in parallel
    - Test chip is currently being taped out









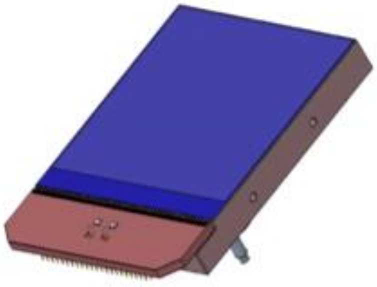


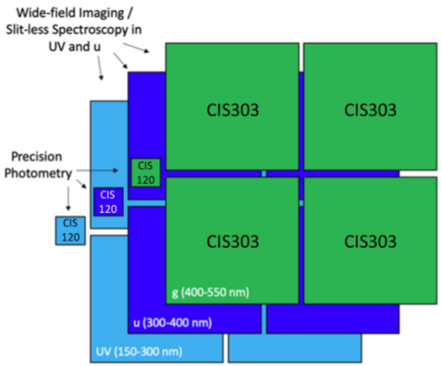
Own design test chip

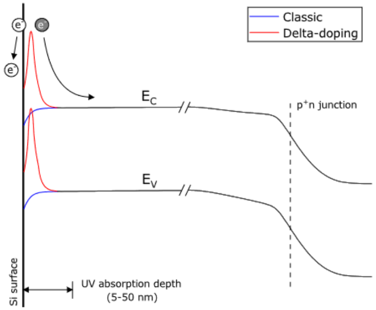
(Work by K Stefanov)

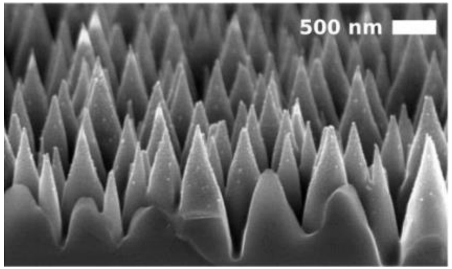
LARGE AREA CMOS DEVICE

- As part of studies for CASTOR we are testing CIS303 devices from Teledyne e2v
  - 9k x 8.6k device, 10um pixels, 2 e- noise
  - HDR, rad-hard design, (high-rho)
- CASTOR will have 3 large focal planes covering
  - 150-300 nm, 300-400nm, 400-550nm
- UV photons often stopped in “dead layer” at first few nm of detector
- Testing UV enhancement techniques
  - 2D-doping technology from JPL
    - Backside passivation using Multilayer Beam Epitaxy
  - Teledyne e2v UV-enhanced coating
    - Low energy boron implantation
  - Black silicon technology from Aalto Uni / Elfys
    - Etching of nm-sized spikes in the surface
    - Surface passivation with Al_2O_3 using atomic layer deposition
- QE testing down to 40 nm (120 nm+ can be done in-house)









RADIATION DAMAGE

- In space there is a high flux of highly energetic particles mainly from the Sun
- These particles can damage the detector creating defects in the silicon lattice
- These defects (or traps) can cause
  - Increased dark current
  - Image lag
  - Latch-up events
- Rigorous radiation testing is therefore necessary
  - Proton
  - Electron
  - Gamma
  - Heavy ions
- For Euclid *Keep Cold* testing was performed
  - Irradiating the devices cold
  - Keeping cold for up to a year while monitoring

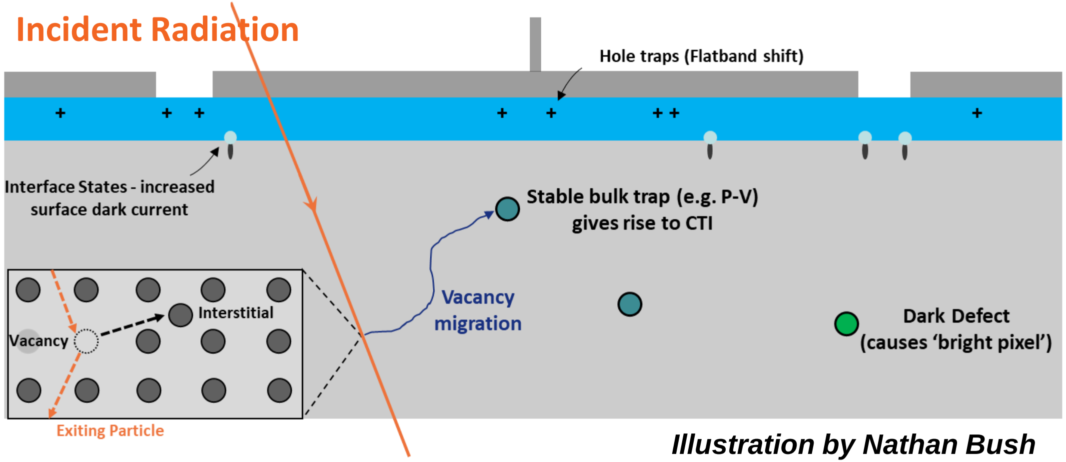
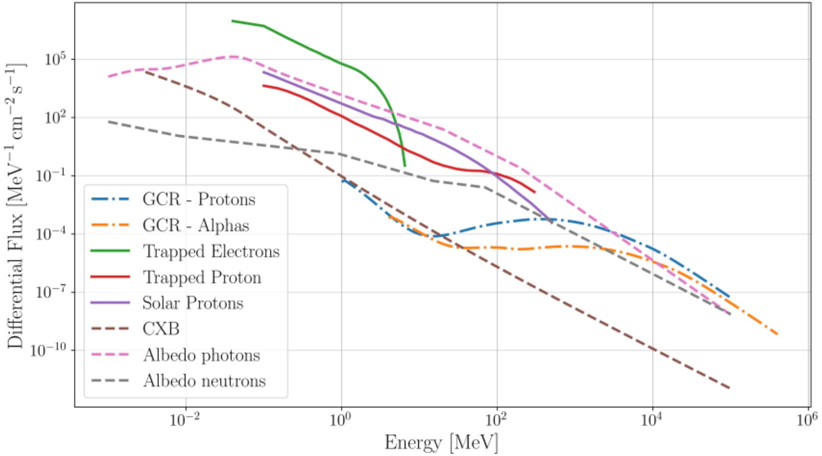
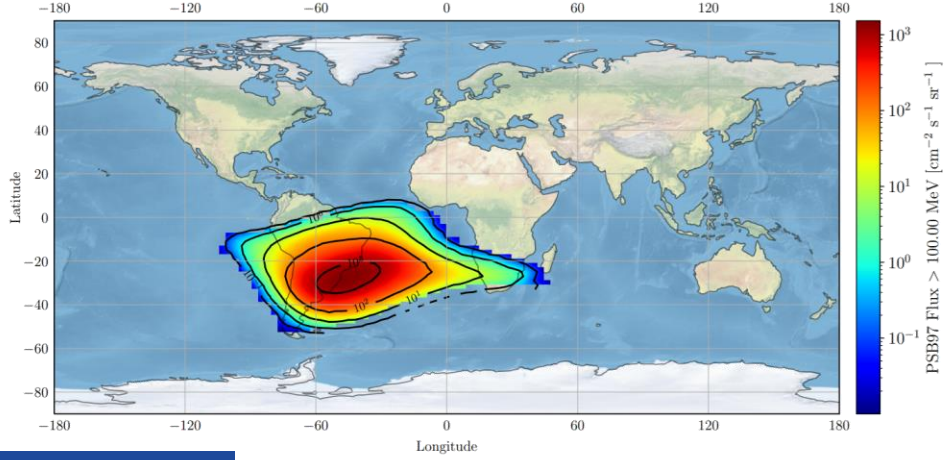


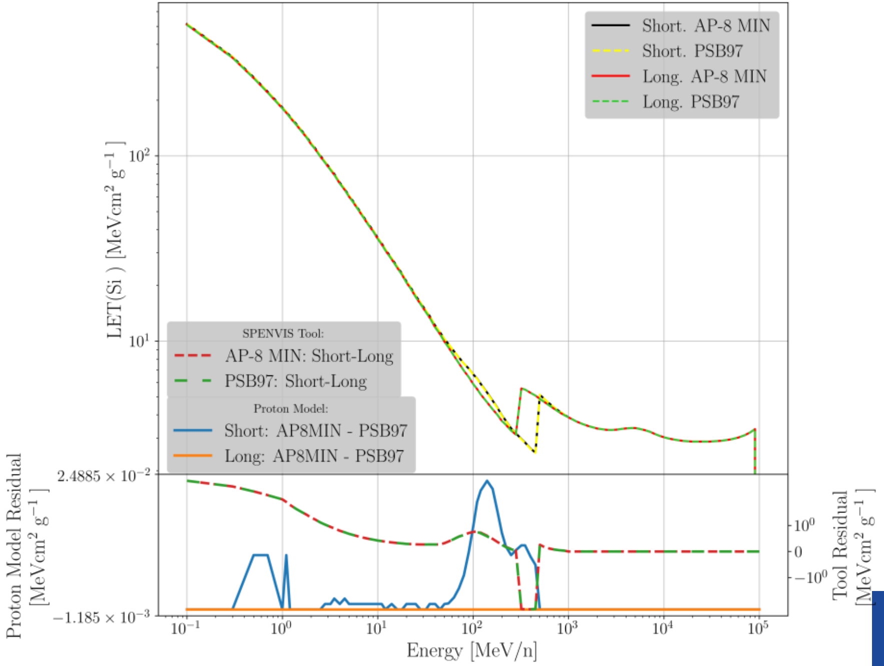
Illustration by Nathan Bush

RADIATION ENVIRONMENT ASSESSMENT

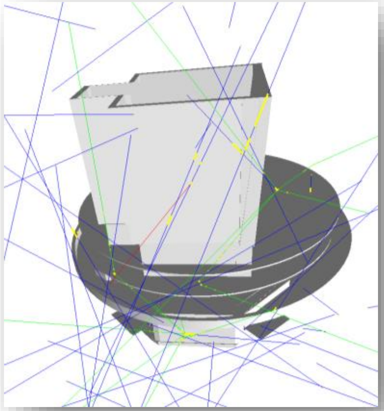
- Evaluation of the space radiation environment
- Evaluation of potential Total ionising dose (TID) and Total Non-ionising dose (TNID)
- Assessments for many different orbits LEO, GEO, HEO, L1/L2



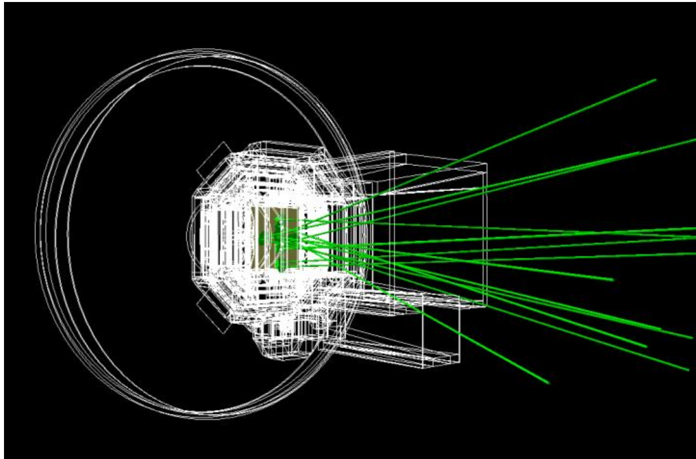


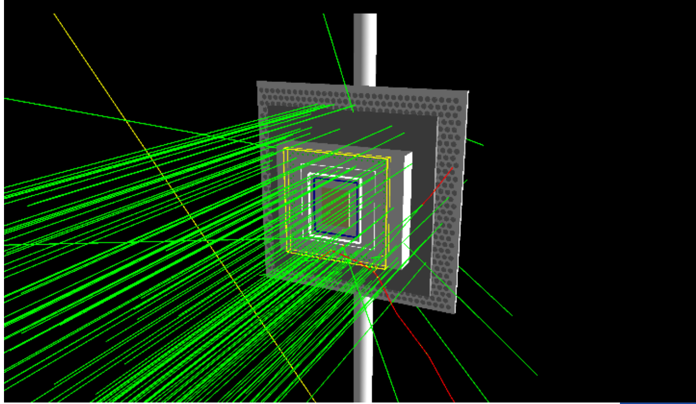


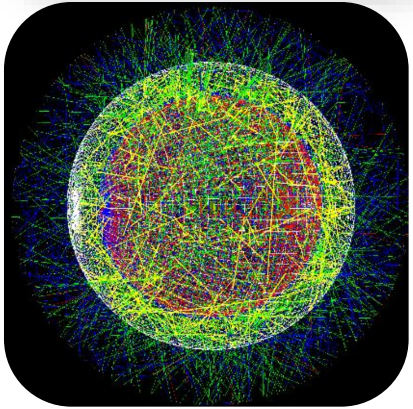
SIMULATION OF THE RADIATION ENVIRONMENT

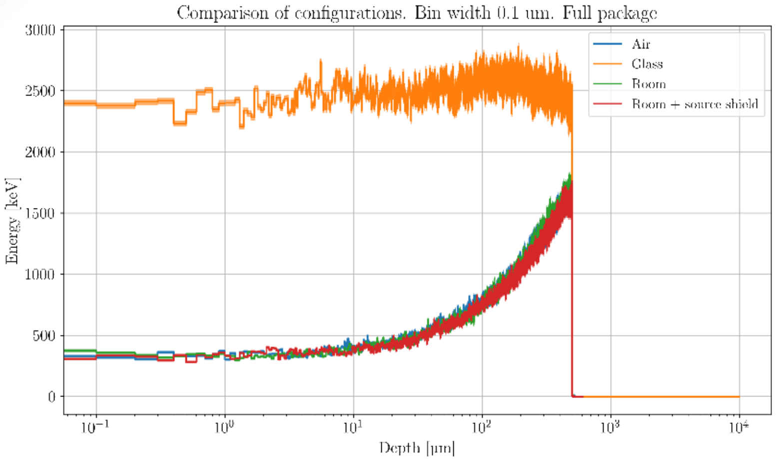


- Experience of modelling radiation interactions with spacecraft
- Extensive experience of laboratory testing and validation at beamlines of physics processes
    - Experience at BESSY II (Germany), PSI (Switzerland), Cyclotron at the University of Birmingham, UK.
    - ESTEC Co-60 facility









SUMMARY

- Detectors are important!
- New developments take time, so important to start this work early
- A lot of detector work at the moment is driven by HWO requirement
    - Sub e- noise (< 0.2 e-)
- Different technologies are being explored
- Radiation damage effects can have large impact, especially on sub e- level
    - Rigorous testing is important

- The CEI is keen to work with you on detector development and testing
    - Jesper.Skottfelt@open.ac.uk

THANK YOU