UNIVERSITY OF LEICESTER

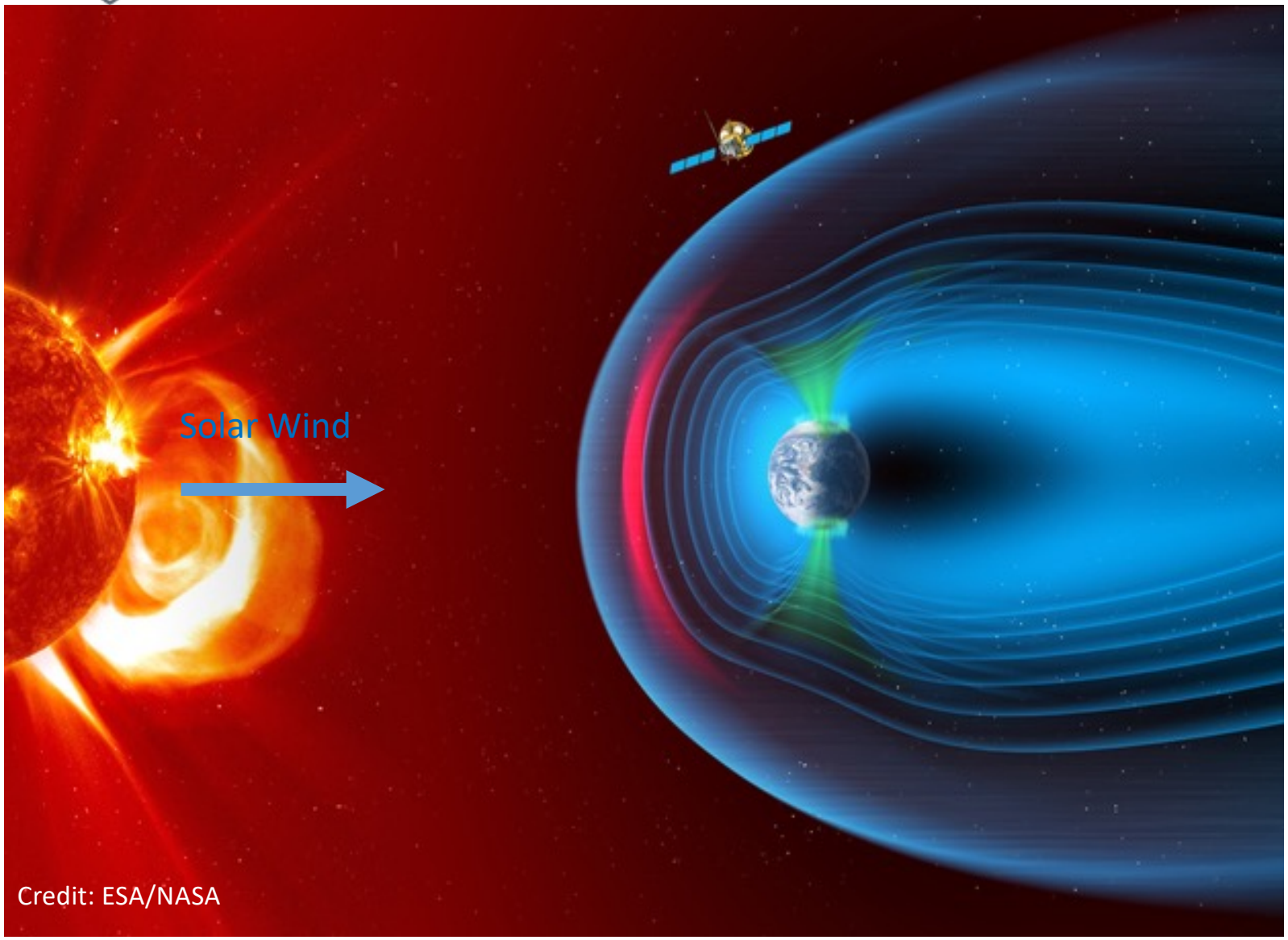
Imaging Earth's magnetosphere with the Soft X-ray Imager (SXI) on the SMILE mission

Authors:
Steve Leach, Steve Sembay (PI) and the SMILE SXI Instrument Team

Solar wind Magnetosphere Ionosphere Link Explorer: SMILE

SMILE is a collaborative science mission between the
European Space Agency (ESA) and the Chinese Academy of Sciences (CAS)

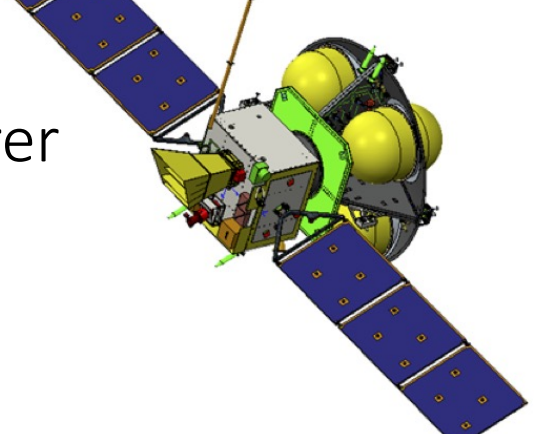
The Sun-Earth interaction - Space Weather



Credit: ESA/NASA

- The solar wind and embedded interplanetary magnetic field (IMF) interacts with the Earth's magnetic field (magnetosphere)
- Dipolar terrestrial field –> direct entry of solar wind plasma into Earth ionosphere (ionised upper atmosphere)
- Several ground/space instruments have studied independently
- Simultaneous data required on multiple temporal and spatial scales (explore the link)

Solar wind Magnetosphere Ionosphere Link Explorer



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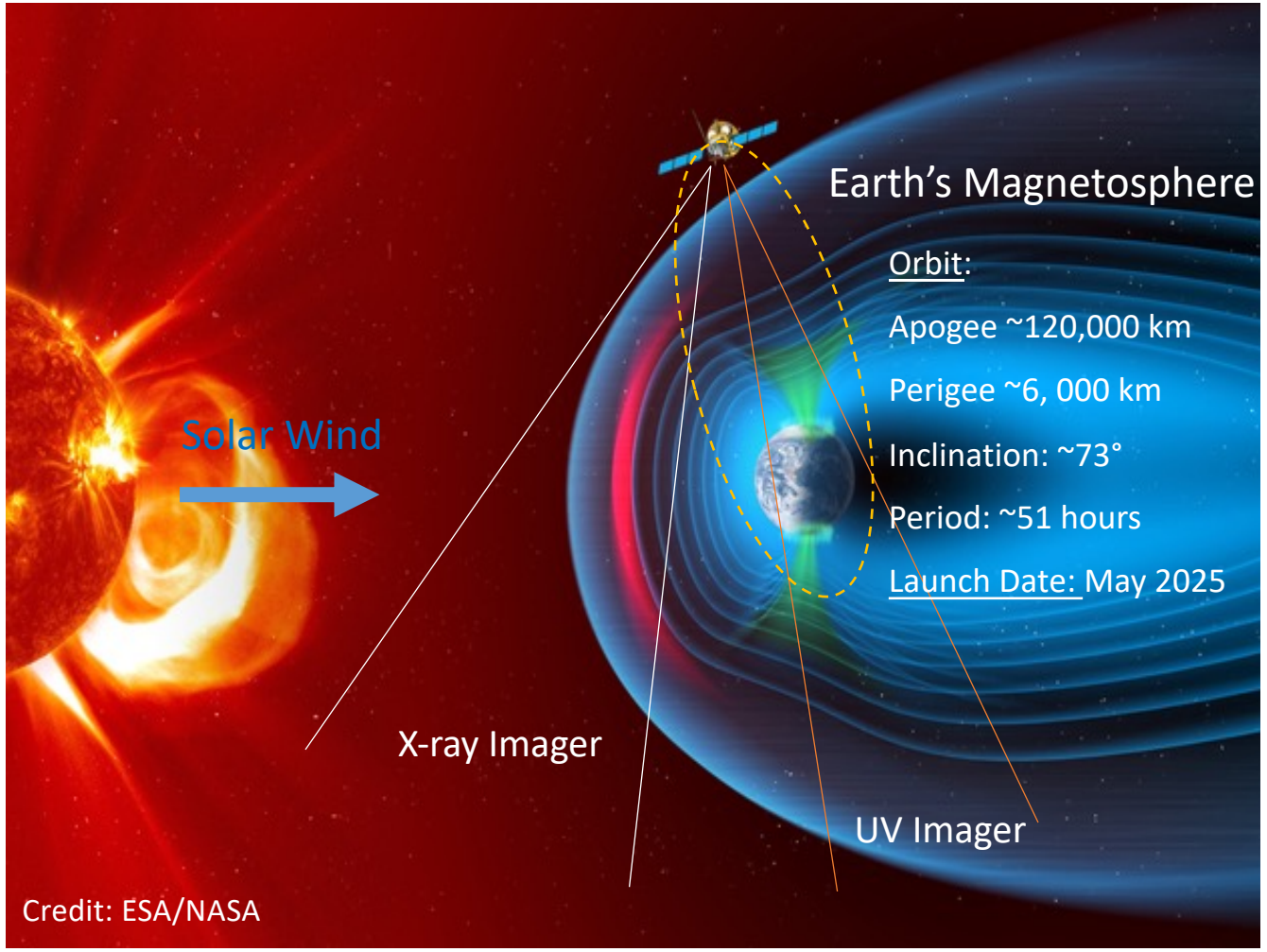
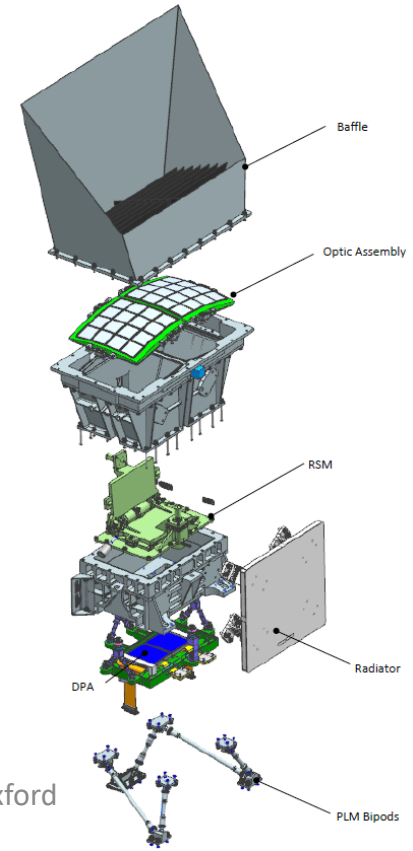
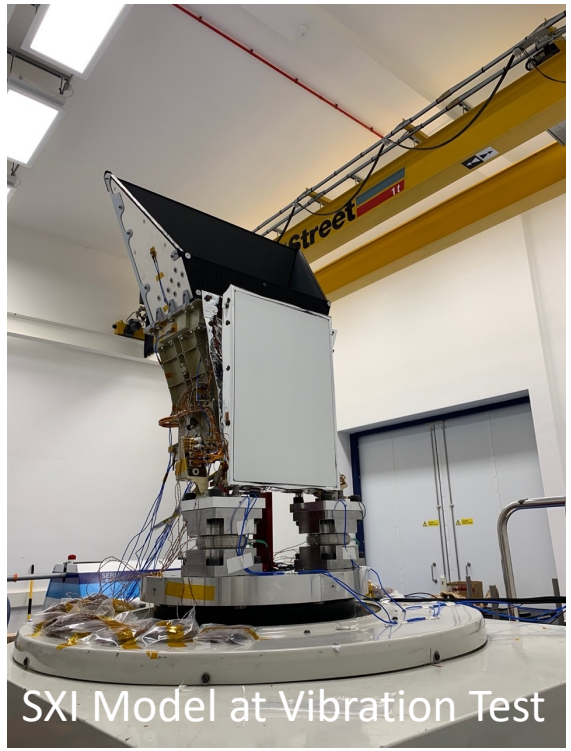


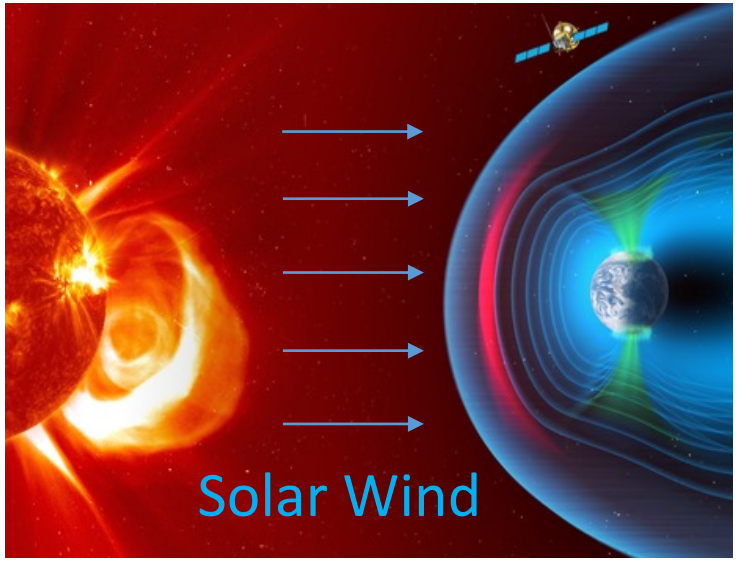
Soft X-ray Imager (SXI) is led by the University of Leicester in collaboration with other UK and European Institutions



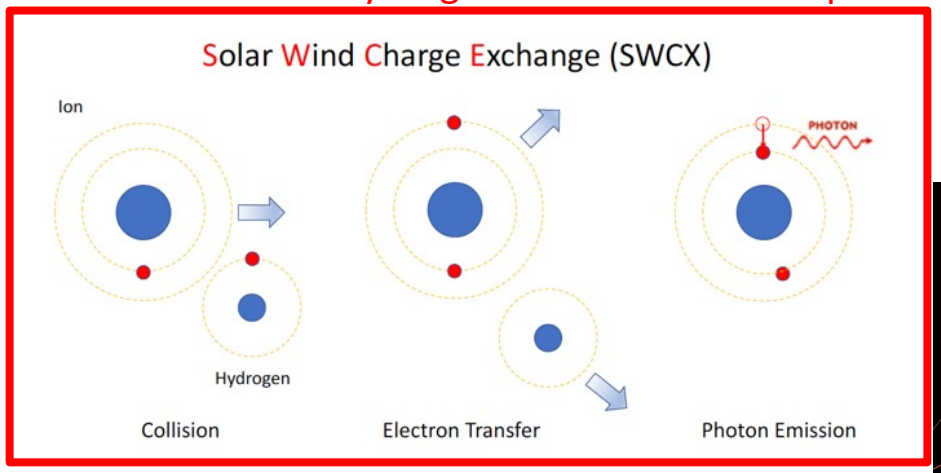

SXI Model at Vibration Test

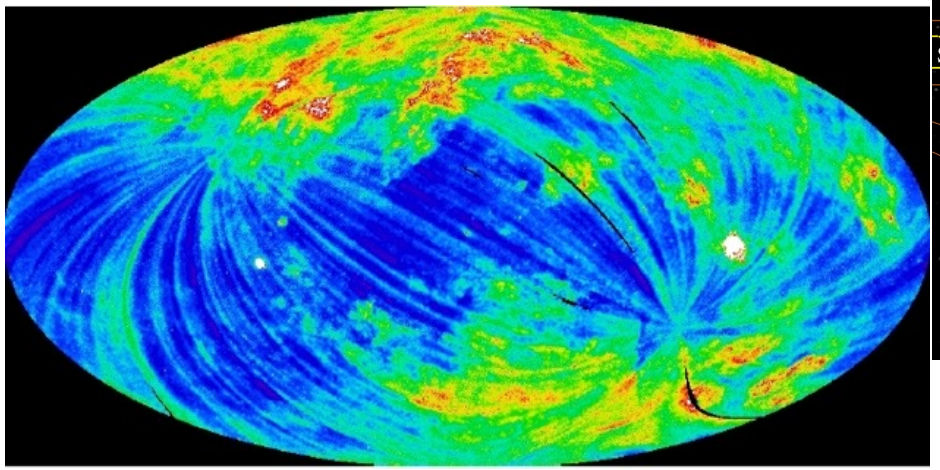
Global imaging using Solar Wind Charge Exchange (SWCX)

SWCX: High charge state solar wind ions in collision with hydrogen in the Earth's exosphere to produce photons at X-ray energies



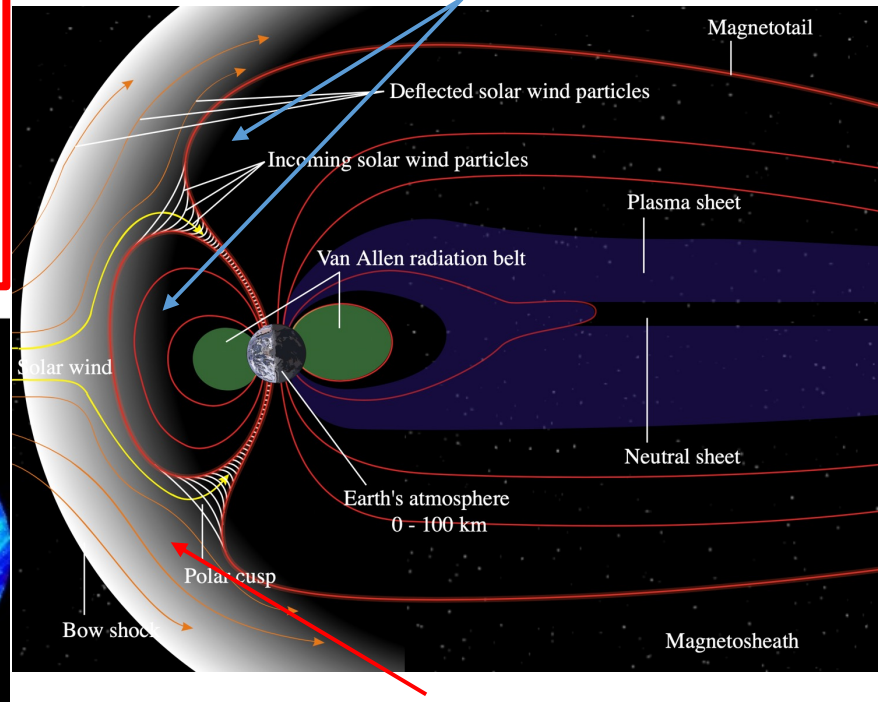
Solar Wind: electrons & protons with some (~2%) heavy ions such as carbon, nitrogen and oxygen embedded in the Sun's magnetic field





ROSAT All-Sky Survey in 1990 (Scanning observations)
SWCX Can be brighter than X-ray background

No Solar Wind in these regions
therefore no SWCX X-rays



Solar Wind in these regions
therefore SWVC X-rays

<u>Hence: magnetopause boundary can be detected using X-ray imaging</u>

Soft X-ray Imager (SXI) CONSORTIUM

Steve Sembay (SXI PI)
University of Leicester, UK

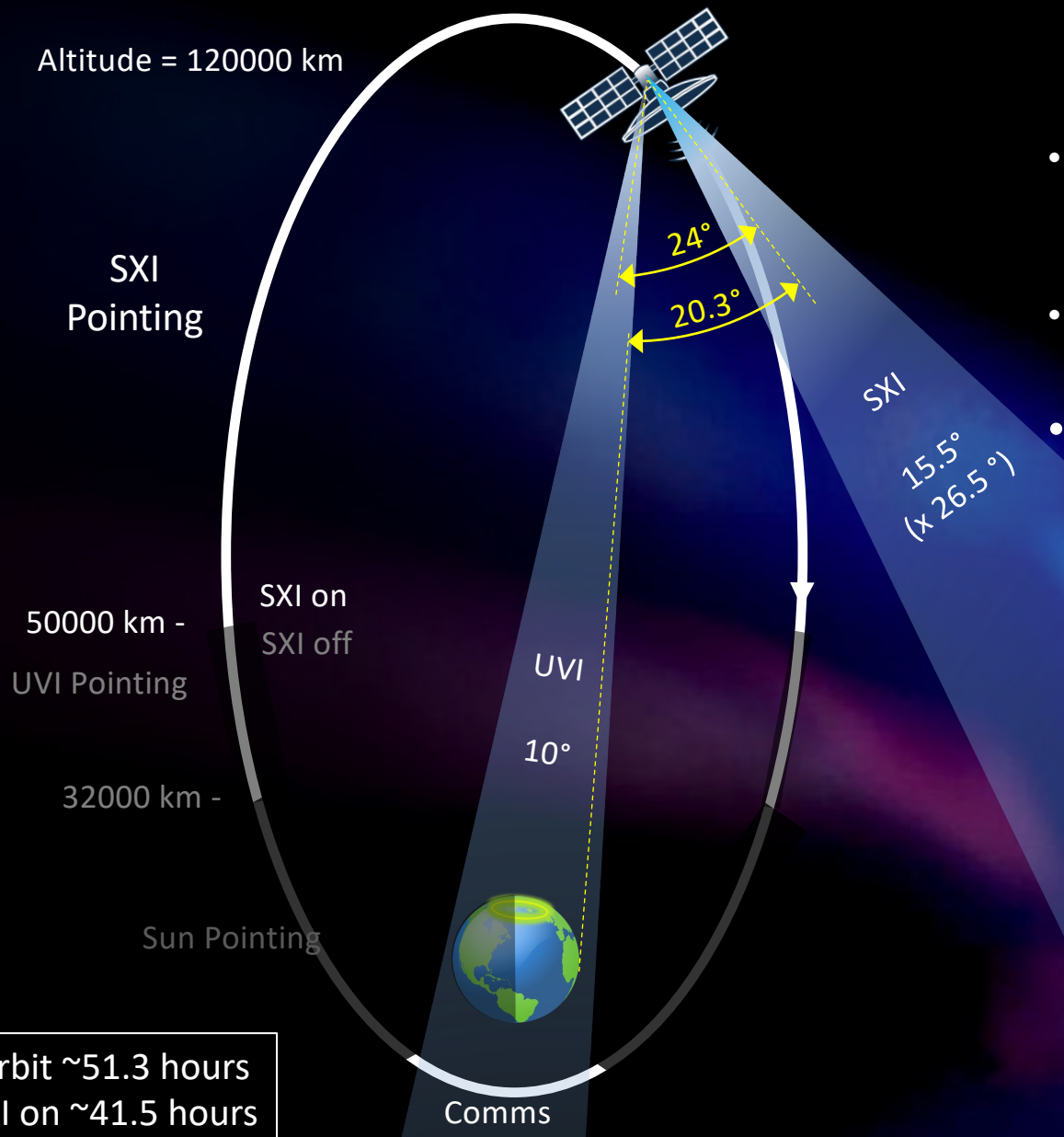
- All hardware and flight SW is supplied by UK and European Institutions including ESA
- US and China contribute some ground software and science support

University of Applied Sciences and Arts Northwestern Switzerland

SMILE

Solar wind Magnetosphere Ionosphere Link Explorer

- Soft X-ray Imager (SXI) is pointed at a constant angular distance (20.3°) from the Earth limb, and along the Earth-Sun line
- SXI footprint on cosmic X-ray sky is pre-determined - known in advance, & SXI FOV is large
- All SXI background images/spectra have potential for secondary science

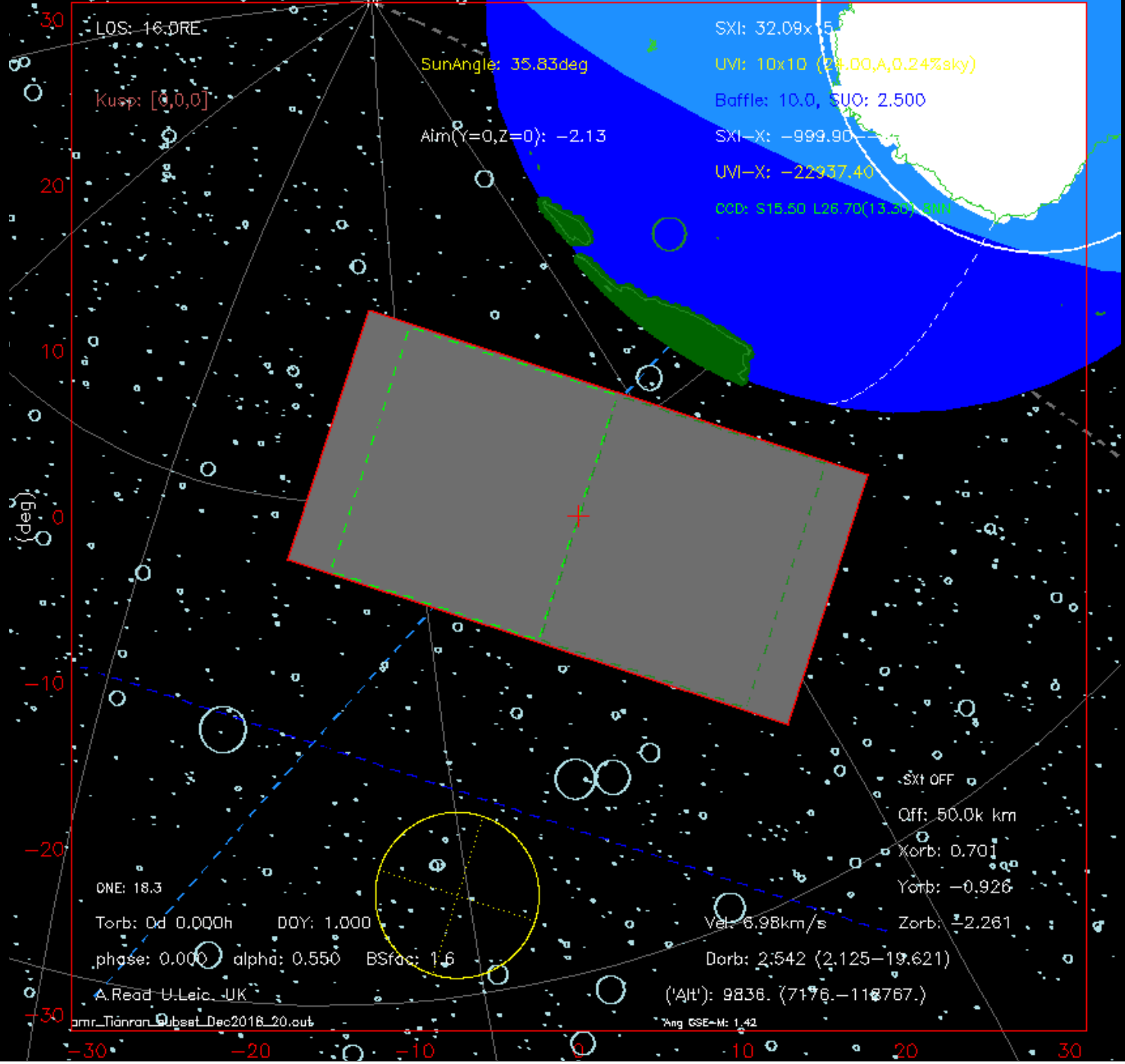


Credit: Andy Read, Leicester

SMILE Orbit simulations
Secondary/serendipity science observations and potential links with other operational space telescopes

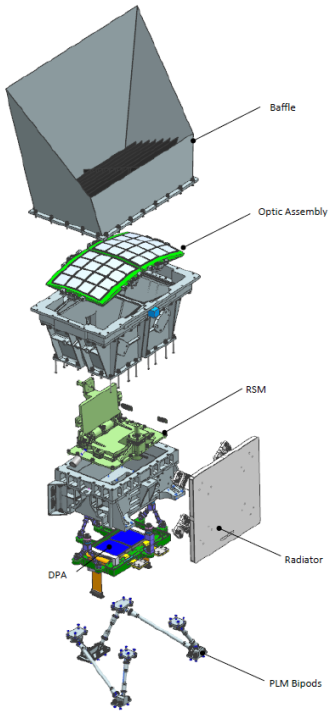
- One typical SMILE orbit (~51.3hr, May 2025)
  - Apogee semi-towards Sun
- Large central rectangle: SXI FOV
  - Active FOVs of 2 CCDs
- Red/orange/yellow emission: Science Targets – SWCX X-ray emission from Magnetosheath & bright Cusps (static MHD model shown)
- UVI (yellow circle) observes Earth
- Many bright cosmic X-ray sources pass through SXI FOV
- White circles: ROSAT Bright Source Catalogue [BSC] (size~brightness)
- Contributing to BG (need to model)

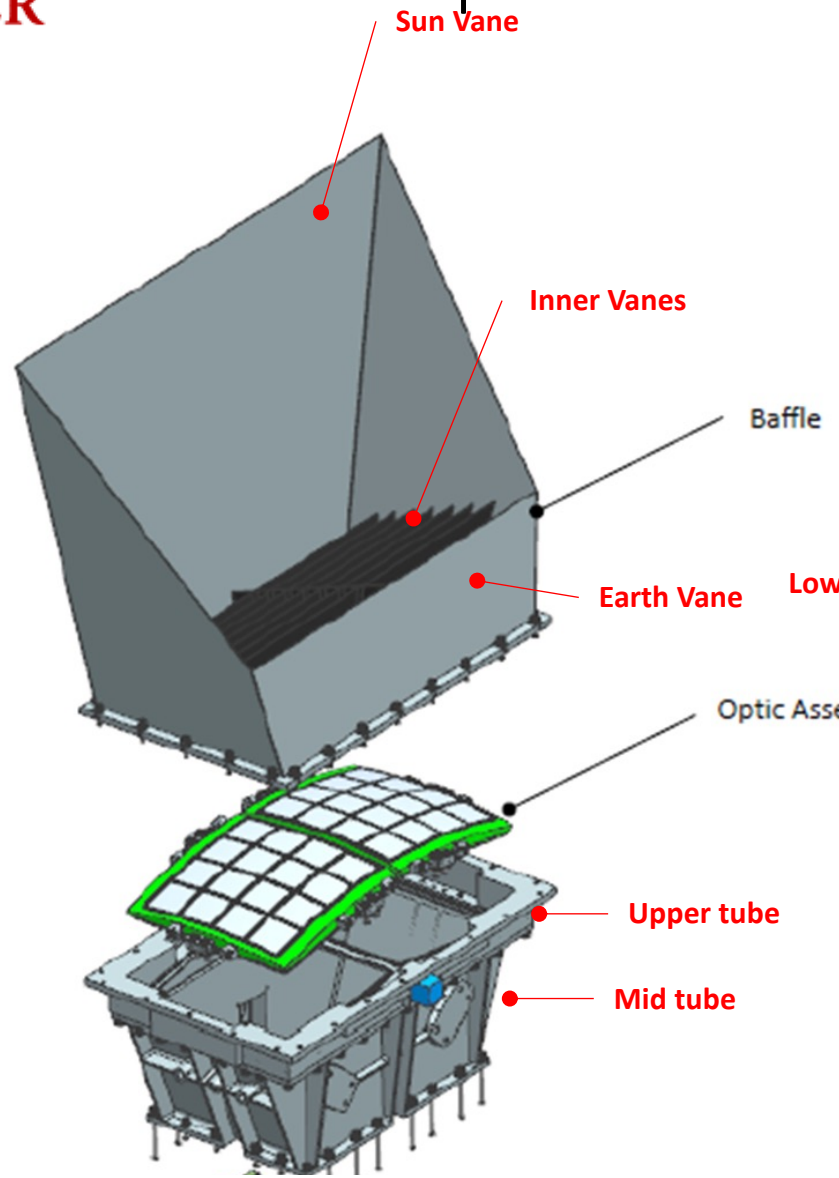
Sources used for dynamic calibration

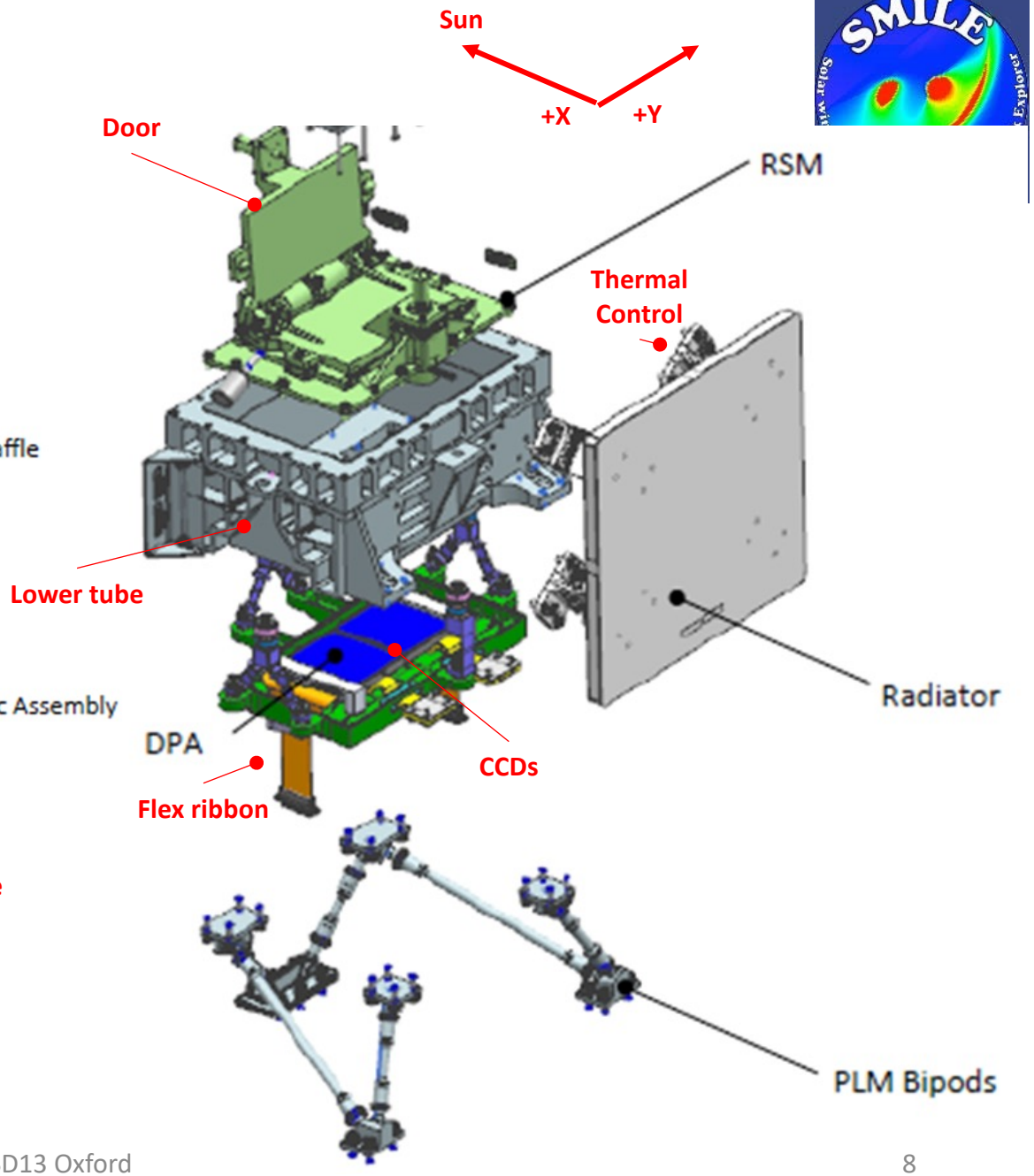


Credit: Andy Read, Leicester

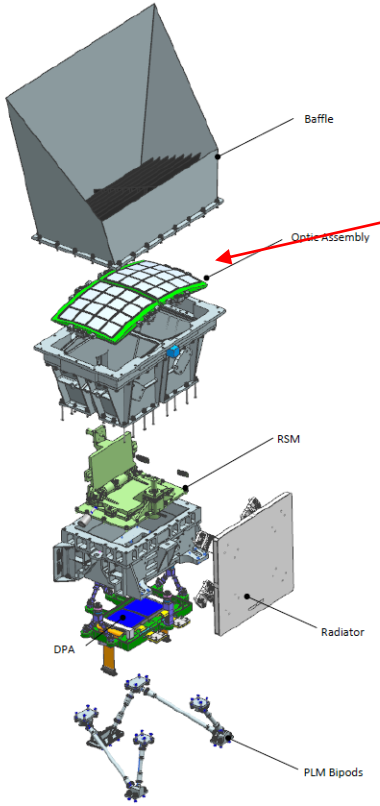
SXI Telescope

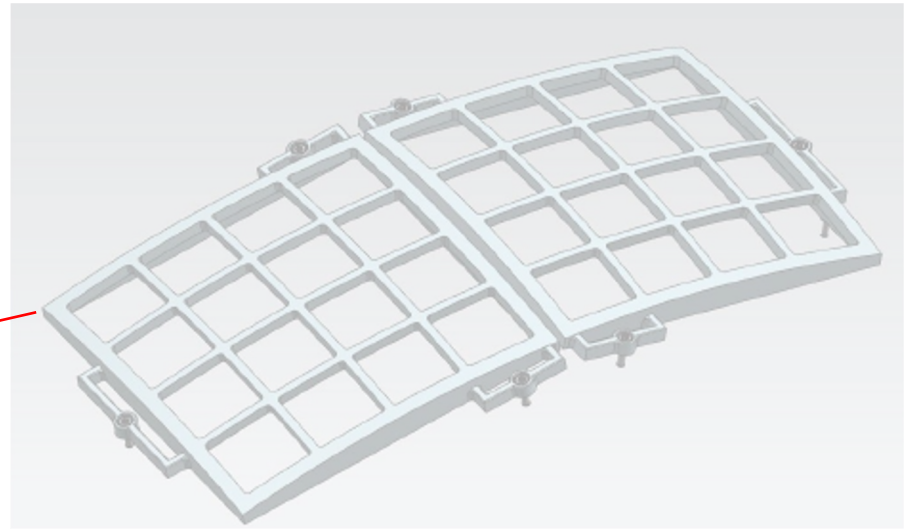


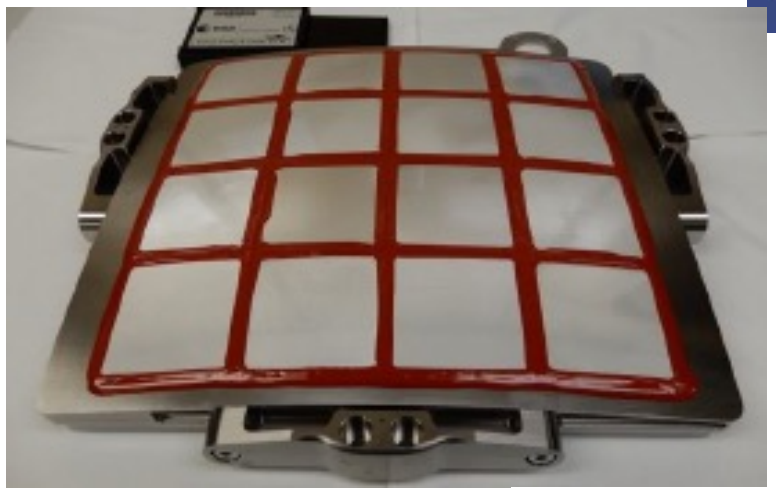




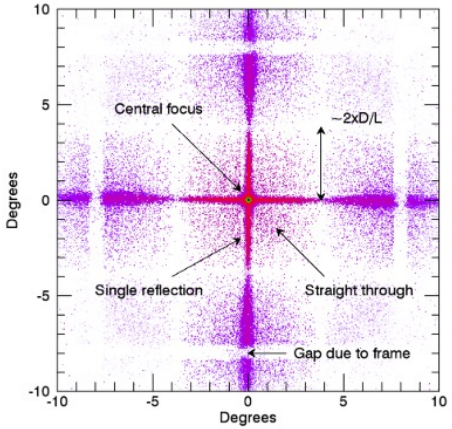
SXI Optics



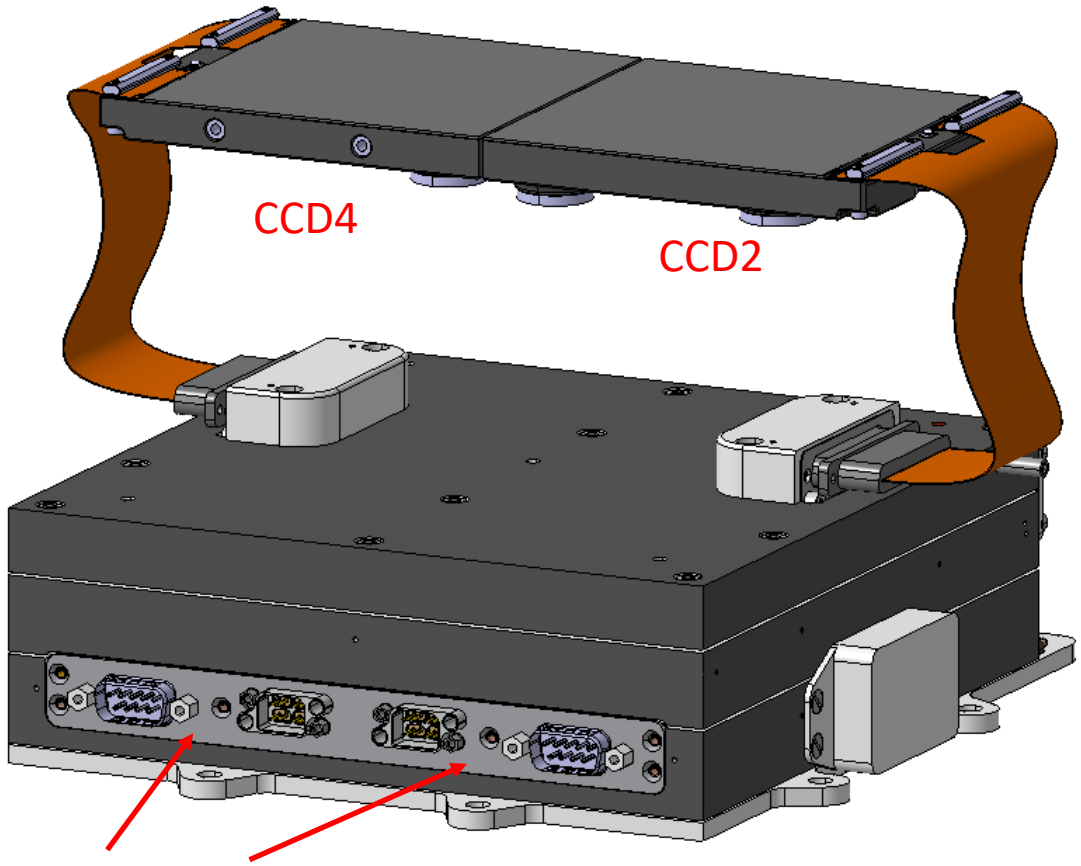




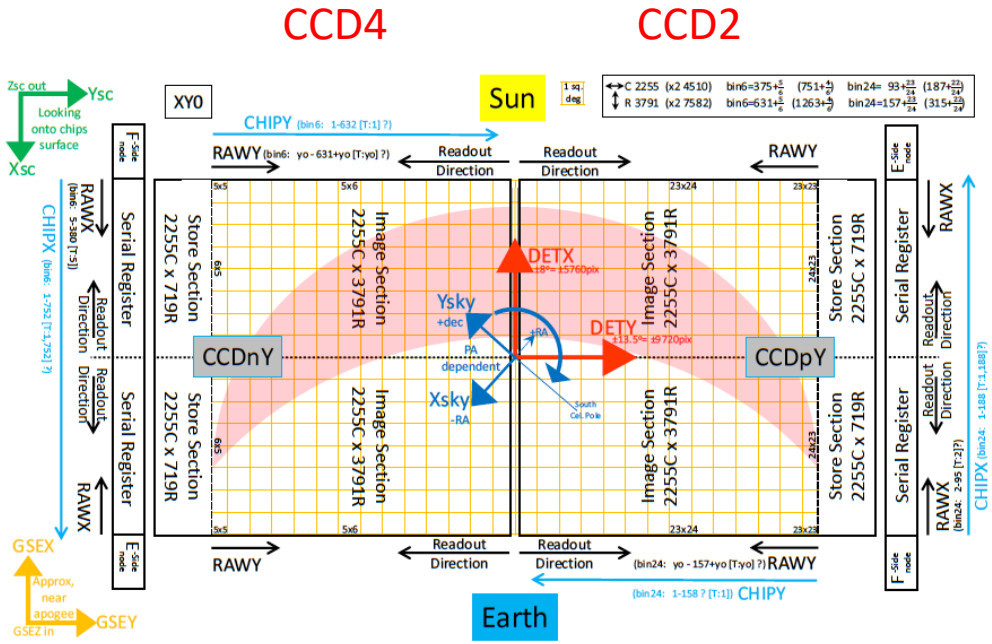
- Soft X-ray focusing using micropore optics (MPOs)
  - Manufactured by Photonis
  - Each MPO 40 x 40 mm^2
  - 100 nm Aluminum film (to block optical straylight)
- Optical Assembly holding 16 MPOs (x2)
- SXI wide-field imaging in the soft X-ray (~0.15 to 1.1 keV) band
- Qualification completed, FM calibration in progress at Leicester's facility



SXI Detector Front-End Electronics (FEE)



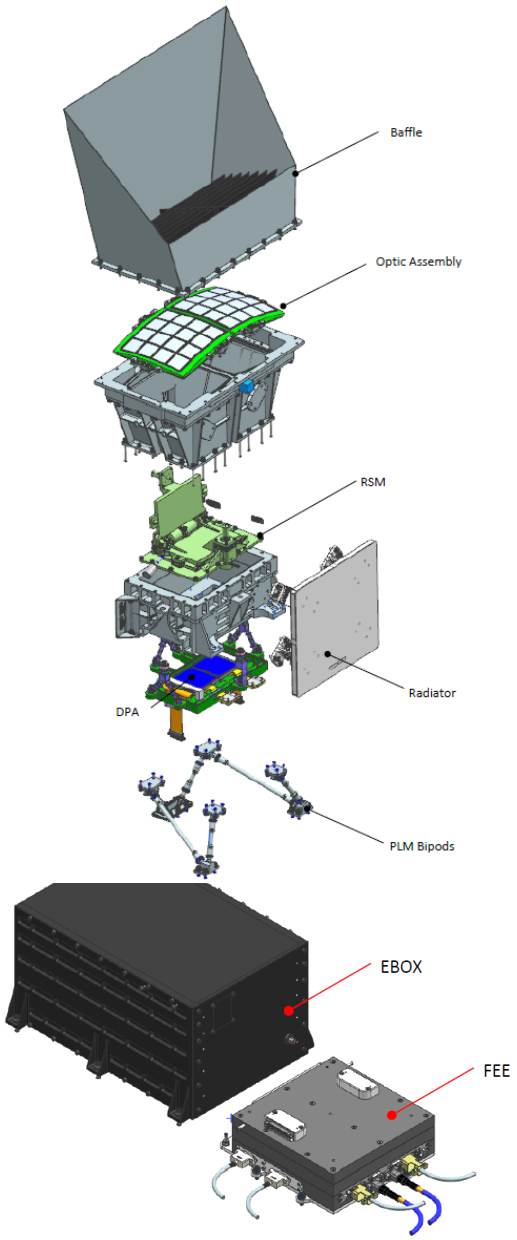
- Two large format Te2v CCDs
- Passively cooled by radiator and heaters
- -95 C to -120 C (-117 C nominal)
- Back-side illuminated
- 4510 x 4510 native 18 μm pixels (FF)
- FT 6x6 binning, 719 frame store + shield



FEE and CCDs have PLATO heritage (4x CCDs)
FEE is being developed at MSSL

Credit: MSSL

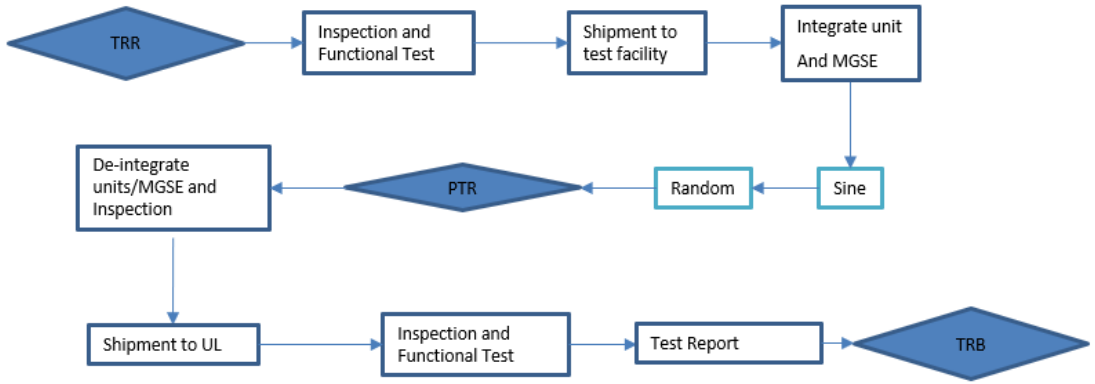
SXI Hardware Model Versions



Model	Description	Objective (Instrument level)	Objective (PLM level) (EID-1903/R-MIS-PROG-9250 AD1)	Delivery
BB Electronics System • BBV1 FEE • BBV2 FEE • BB EBOX • BB Harness • BBV1 RSM • BBV2 RSM • BBV1 RSE	Development models of electronic elements	• Development, function, performance, HW/SW interaction	-	Internal only
STM Instrument • STM Telescope • STM FEE • STM EBOX • STM Harness	Represents structural and thermal system	• Structural qualification of the Telescope • Thermal qualification	STM S/C integration	PLM
EQM Instrument • EQM Telescope (partial) • EQM FEE • EQM EBOX • EQM Harness	Represents electronic system	• Functional verification • EMC/EMI verification • Grounding • ESD	Support the verification of key electrical I/Fs with the PLM	PLM (Loan of FEE, EBOX and Harness)
PFM SXI Instrument • PFM Telescope • FM FEE • FM EBOX • FM Harness	SXI Instrument for flight	• Acceptance	Integration in FM S/C	PLM

SXI Space Environment Qualification

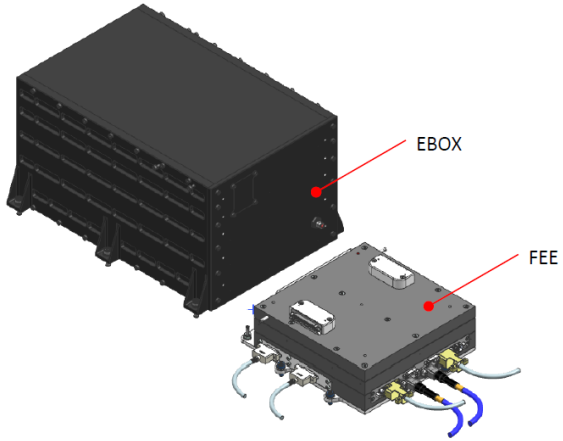
- Vibration, Thermal and EMC

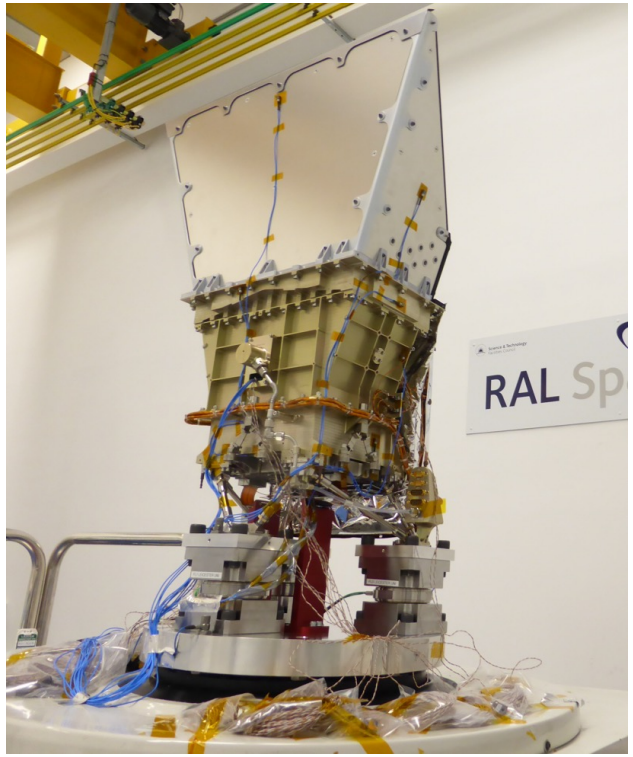


Subsystem level (DPU, FEE), then instrument level

Vibration

- Sine & random vibration in x-y-z axes





STM Telescope vibration test Setup, PFM scheduled at RAL for Sep-Oct 23

SXI Space Environment Qualification

- Vibration, Thermal and EMC

Thermal balance

- Hardware in vacuum to simulate thermal conditions of space
- Instrument surrounded by thermally controlled plates
- Verify the thermal control subsystem
- Correlate with SXI thermal model

RAL Space TVAC Facility

Now at instrument level

Thermal Balance

- Thermal test cycle
- Verify CCDs before/after

29-day campaign, scheduled at RAL for Nov-Dec 23

SXI Space Environment Qualification

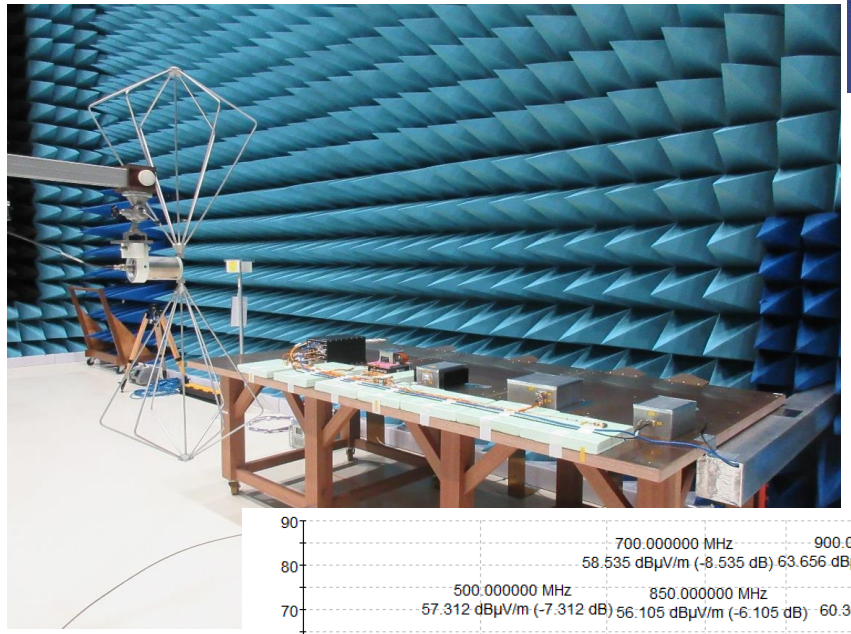
- Vibration, Thermal and EMC

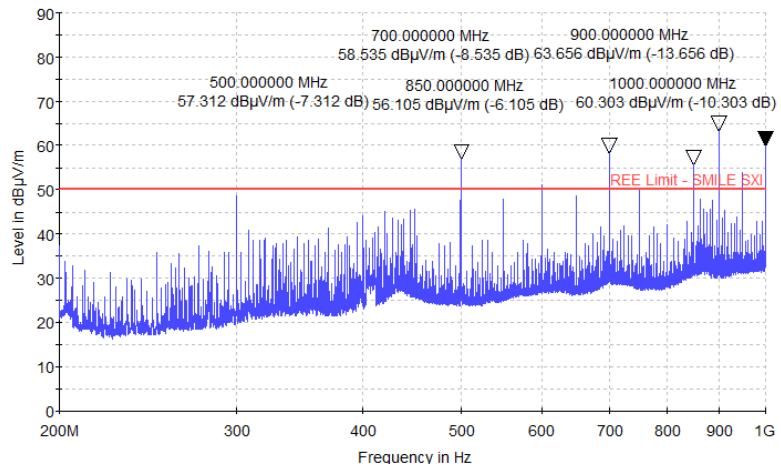
  EQM Instrument ‘FlatSat’ EMC testing completed Dec ‘22

  Multiple failures. Most significant – Radiated Emissions (RE) in S-Band comms frequency

  Unit level EMC tests show both EBox and FEE contribute to RE test failure

  Investigation (at ESTEC July ’23) making enclosures ‘RF tight’ via gaskets shows promise.





Instrument level verification
EMC planned at ESTEC ~Jan 24

EMC

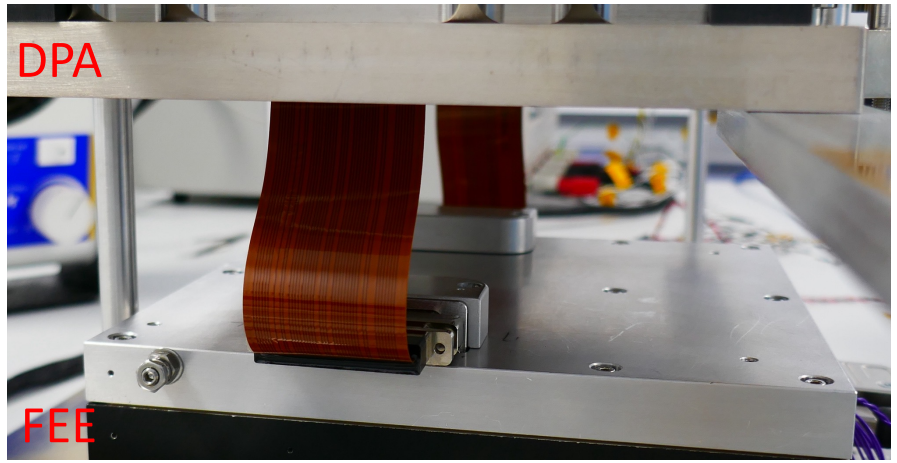
Unit level system retest of EQM FEE to assess impact of the design changes (in progress)

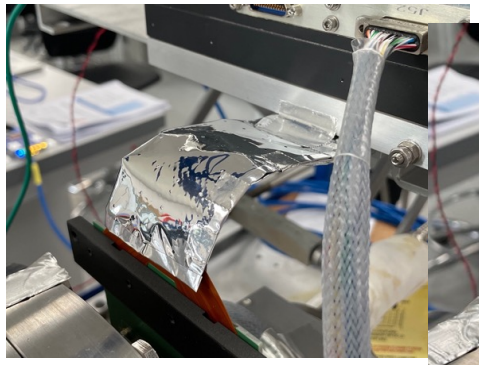
Unit level test of FM FEE with EMC modifications (in progress)

Unit level test of FM EBox with EMC modifications (TBD)

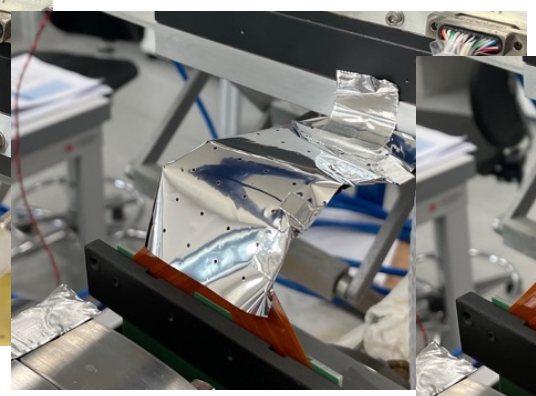
SXI Instrument FM test (~Jan ’24)

SXI CCD Flex Cable Investigations

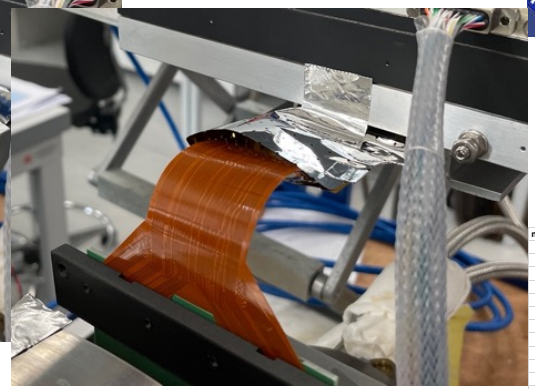




Full blanket:
Multiple folded layers,
outside GND to FEE

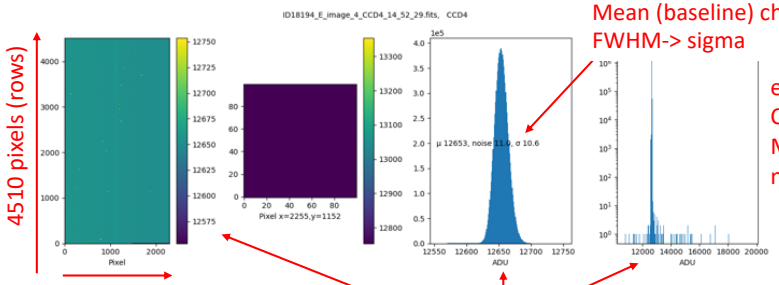


Shield only:
Single layer,
GND to FEE



Half shield only:
Single layer,
GND to FEE

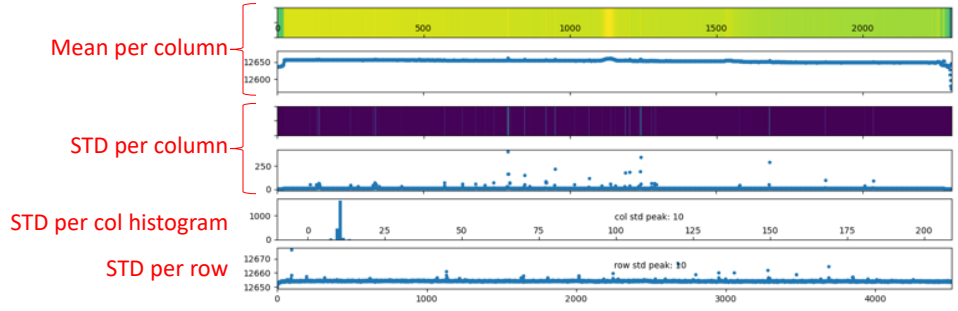
Analysis method, Full-Frame (FF) mode, 2 sides (E & F) per CCD

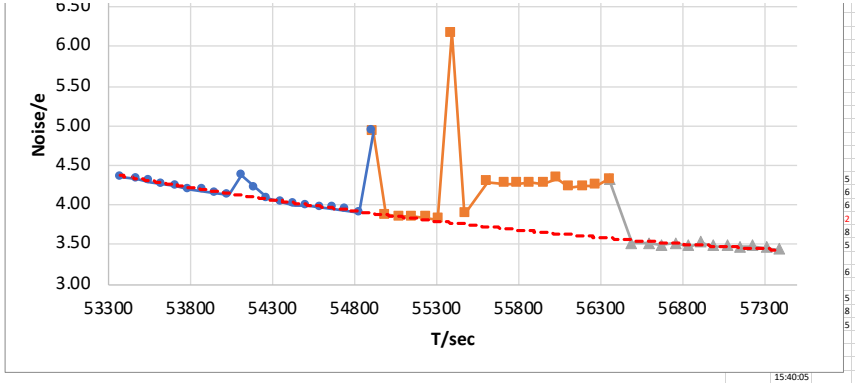


Mean (baseline) charge (ADU),
FWHM-> sigma

e.g.
CCD Side E
Mean 12653 ADU,
noise 10.6 (4.3 e⁻)

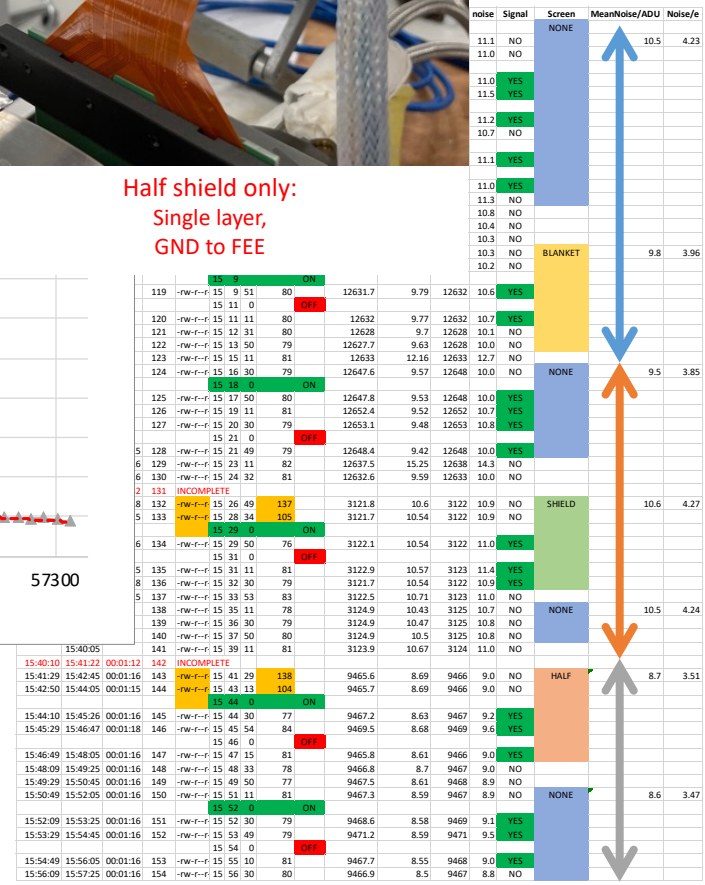
16bit ADC, 2^{16}, 0-65535 ADU, 2.47 e⁻/ADU





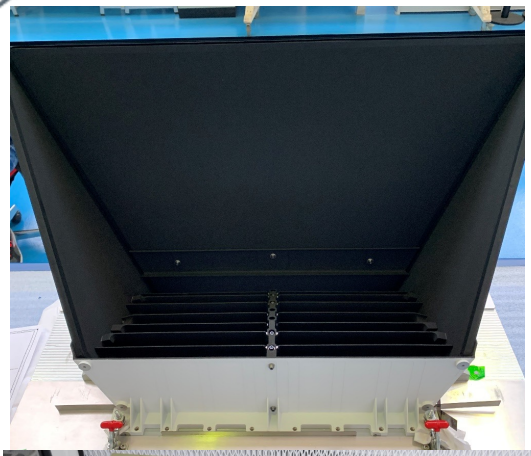
- Noise follows Residual Charge Decay
- Anomaly caused by handling flex/comms loss

- No measured increase in noise with screening

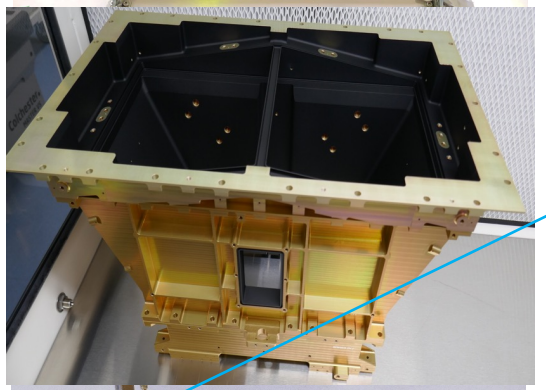


SXI Hardware Status (as July)

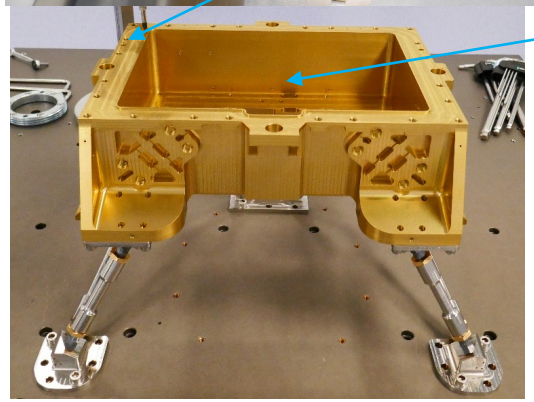
Baffle

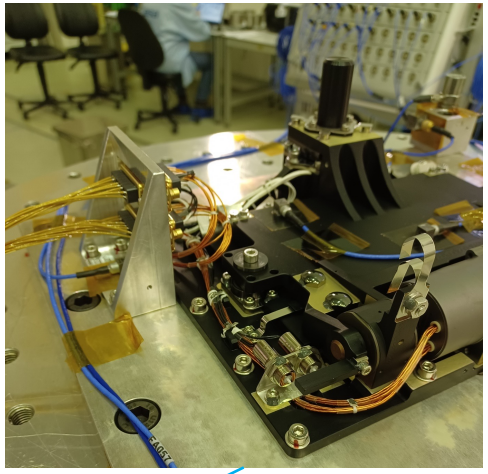


Primary Structure

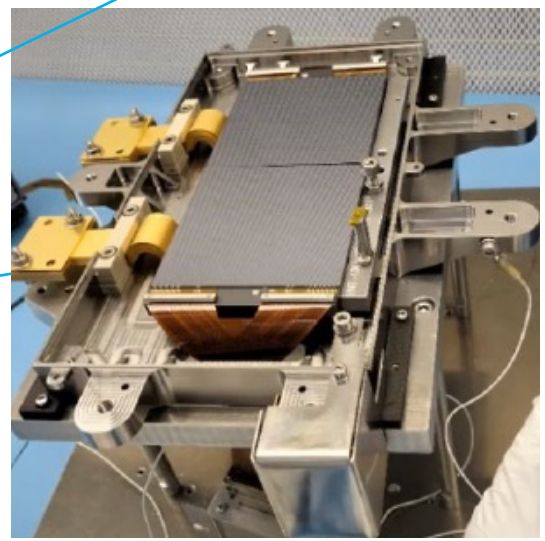


Bipods

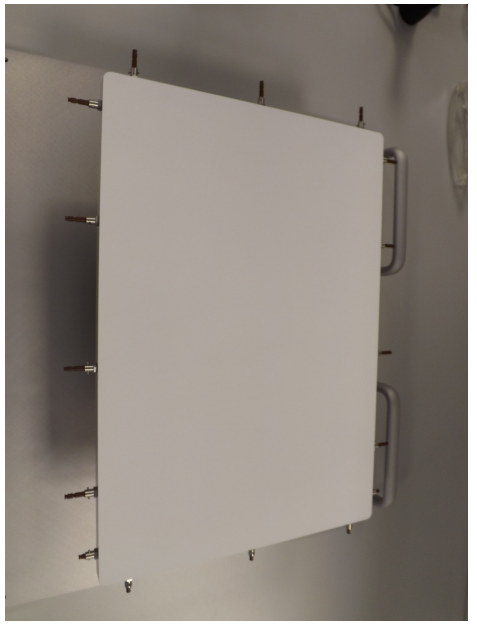




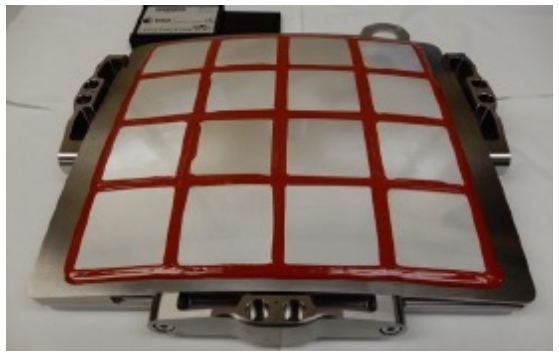
Radiation Shutter Mechanism



Detector Plane Assembly

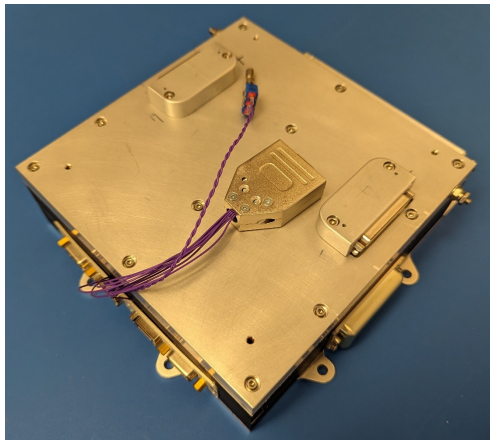


Radiator



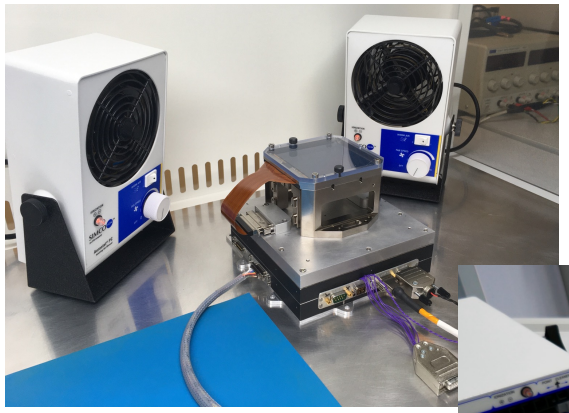
Optic Assembly x2

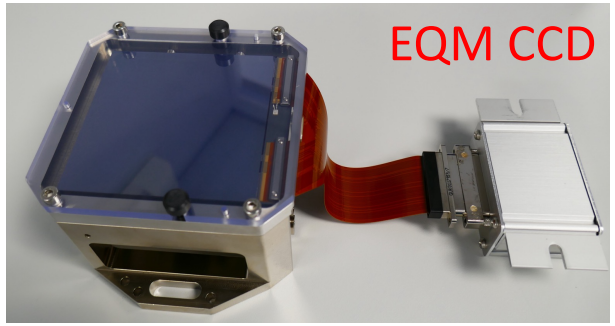
Electronics Box (DPU) (EQM)

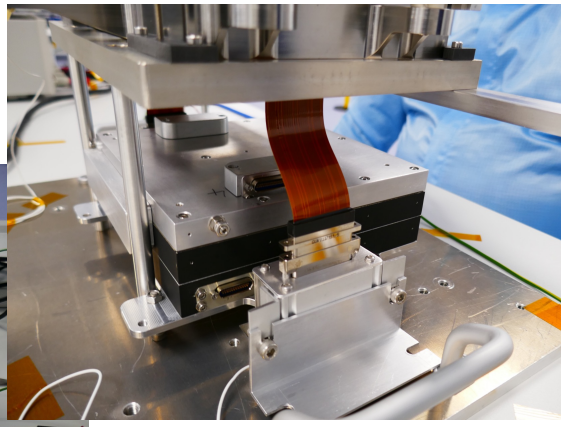


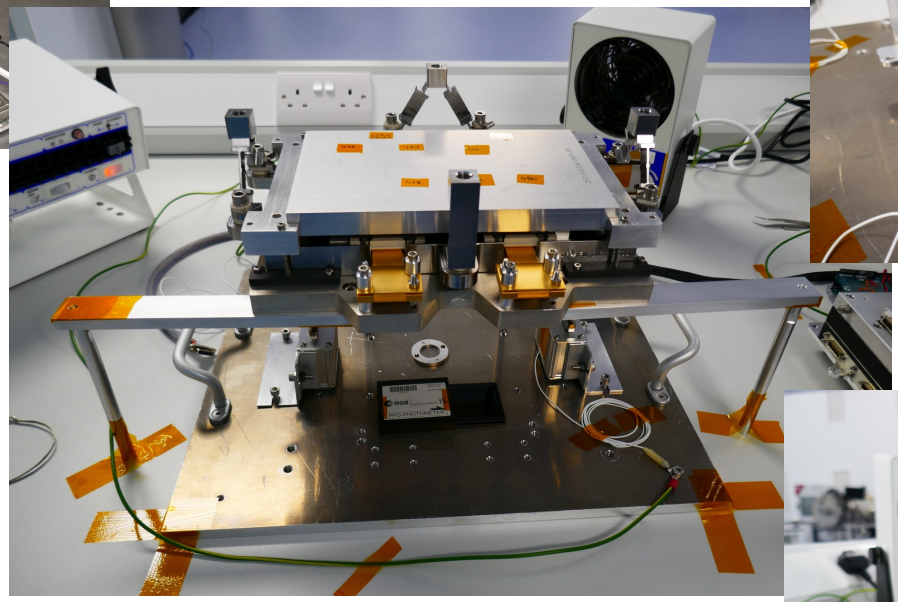
Front-End Electronics (BBv2)

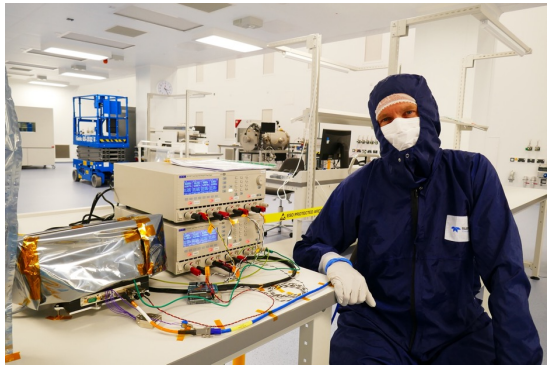
SXI Assembly Integration Verification (DPA)







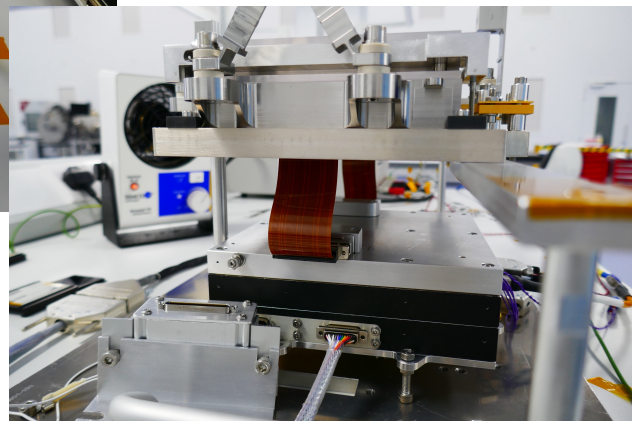




CCD aliveness verification

- Ambient temperature
- Reverse clocked CCDs –> noise analysis
- Preparation -> EQM -> Flight Units
- Strict ESD precautions

FM DPA (Detector Plane Assembly)



SXI Timeline

Activity/Milestone	Date
Vibration Test Slot @ RAL	Sept – Oct ‘23
Thermal Test Slot @ RAL	Nov – Dec ‘23
EMC Test Slot @ ESTEC	Q1 2024
QAR	Oct through Dec ‘23
Instrument Delivery to ESA	End Feb ‘24
PLM and Platform Integration	June – July 2024
Spacecraft AIT	July ‘24 – March ’25
Launch Campaign and Launch	April – May ’25
In-orbit Commissioning	Launch + 3 months
Nominal Science	3 years
Extended	2 years
Decommission	

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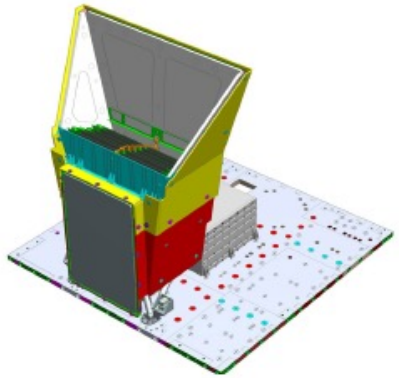
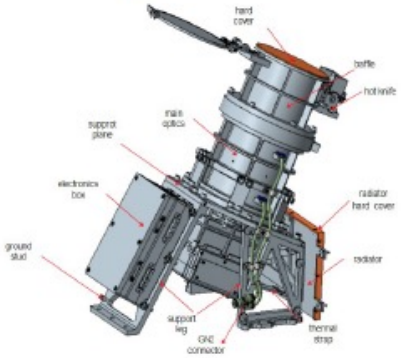
SMILE Instruments

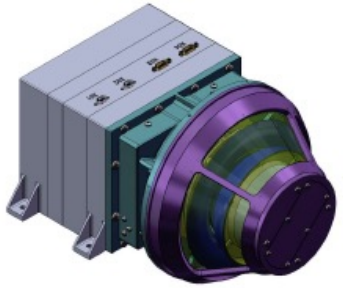
- SXI: Soft X-ray imager
  - Wide field lobster-eye 0.2-2.5 keV X-ray
  - Two large CCD detectors (8.12x8.12 cm).
  - 15.5° x 26.5° FOV, Res.: 1-5 min., 0.25-1°, △E=50 eV.
  - PI: Steve Sembay, Leicester, UK



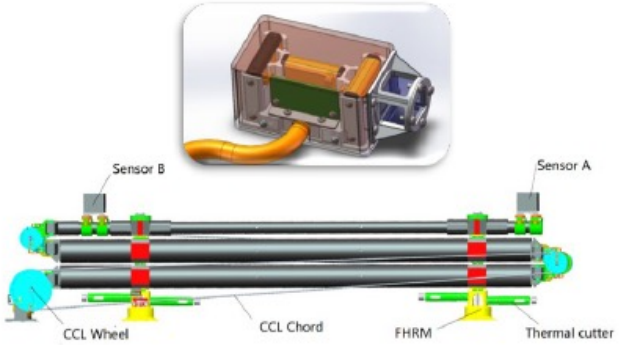
- UVI: UV imager
  - Four mirror imager, 10° FOV
  - Wavelength:160-180 nm.
  - Resolution: 60 s, 150 km at 19 R_E altitude
  - CCD detector. Coated mirrors (dayglow rejection)
  - PI: ZHANG Xiaoxin, NCSW, CMA, China



- LIA: light ion analyser (2 sensors)
  - Top-hat analyser for ions, 3D, density, velocity and temperature
  - Energy range: 50 eV - 20 keV
  - FOV : 4 π (at up to 0.25s time resolution)
  - PI: DAI Lei, NSSC, CAS, China



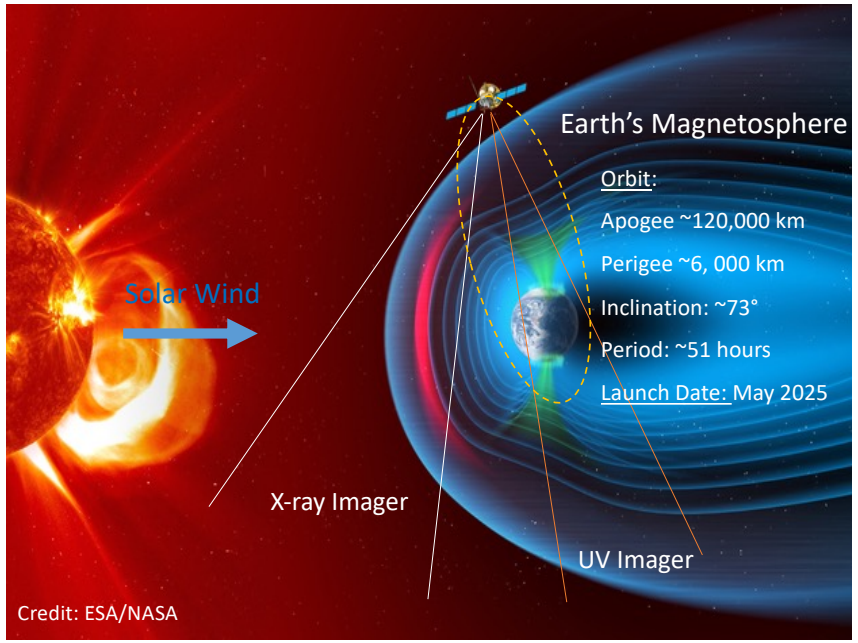
- MAG: Magnetometer
  - Fluxgate magnetometer for magnetic field strength and direction up to 40 Hz
  - 3 m boom, 2 sensors separated by 0.8 m
  - PI: LI Lei, NSSC, CAS, China

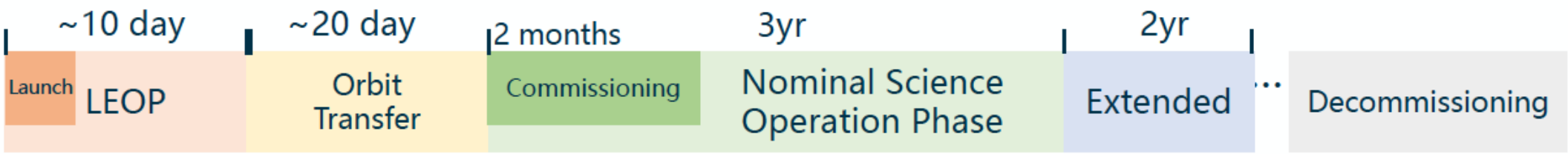


Credit: ESA

SMILE Mission Timeline

0 Pre-launch Phase (Launch Campaign)
1 Launch and Early Operations Phase (LEOP)
2 Transfer Phase to HEO
3 Commissioning Phase
4 Nominal Science Operations Phase
5 Extended Science Operations Phase (if any)
6 Decommissioning Phase





Credit: ESA

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Imaging Earth's magnetosphere with the Soft X-ray Imager (SXI) on the SMILE mission

Authors:
Steve Leach, Steve Sembay (PI) and the SMILE SXI Instrument Team

THANK YOU

Solar wind Magnetosphere Ionosphere Link Explorer: SMILE

SMILE is a collaborative science mission between the
European Space Agency (ESA) and the Chinese Academy of Sciences (CAS)

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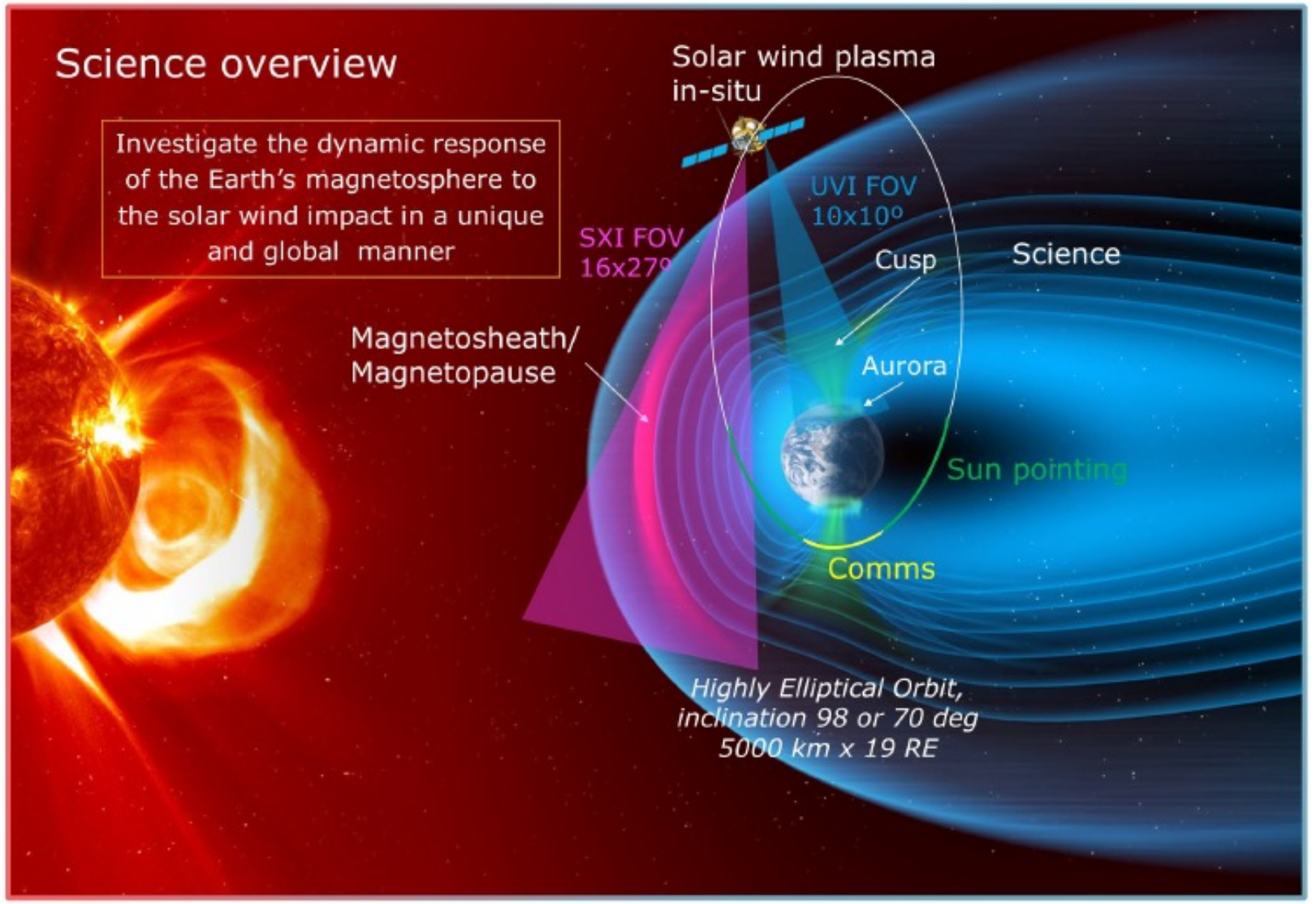
EXTRA slides

SMILE Science

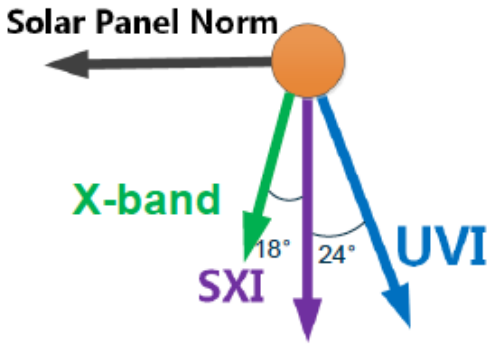


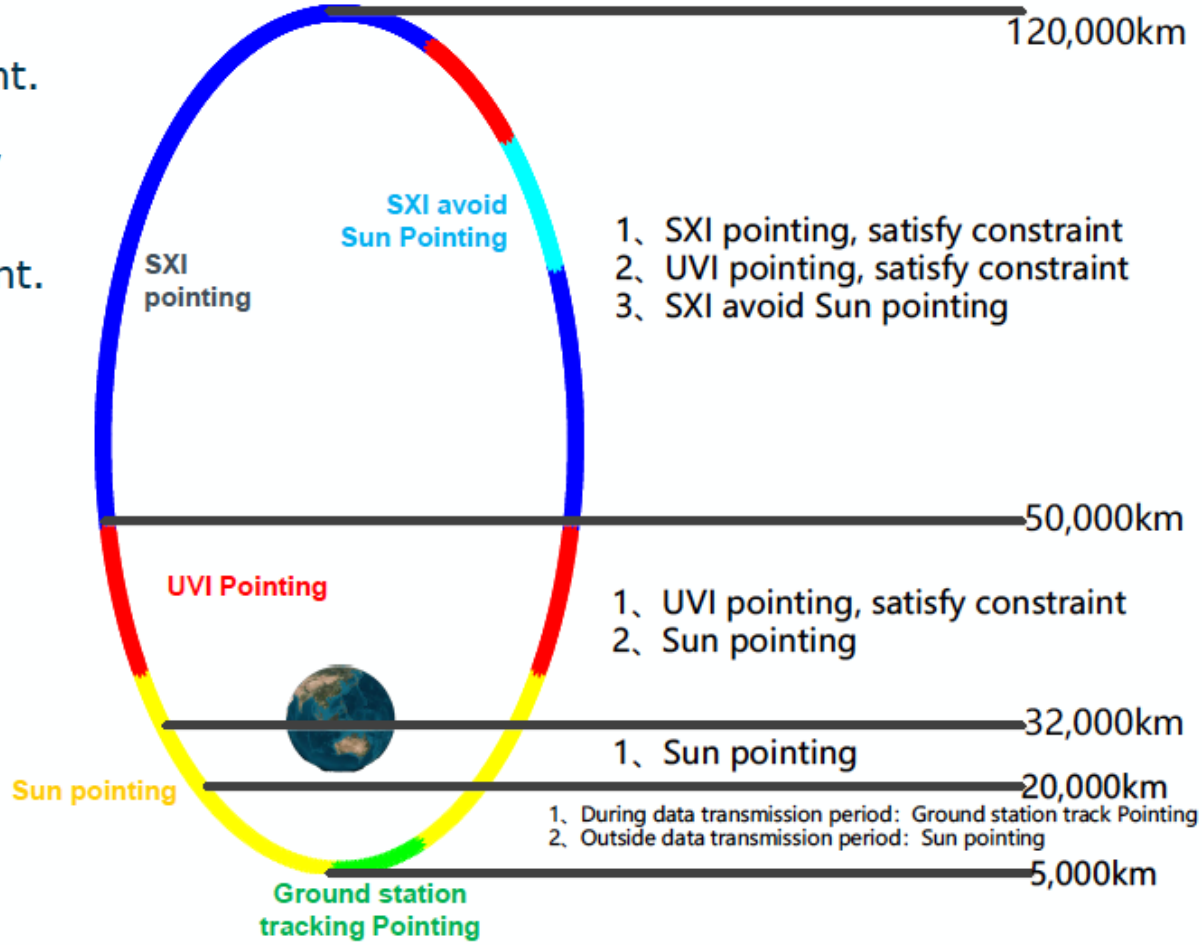
Credit: ESA

SMILE Complex Pointing Arrangement

Pointing design

- **SXI pointing**: Driven by SXI pointing requirement.
- **SXI avoid Sun Pointing**: Based on SXI Pointing, S/C rotate to the earth around the body Y axis.
- **UVI pointing**: Driven by UVI pointing requirement.
- **Sun pointing**: Solar array points to Sun.
- **Ground station tracking Pointing**: the X-band antenna points to the relevant Ground Station.





Credit: ESA

SXI Image and spectra simulations