Solar wind Magnetosphere Ionosphere Link Explorer: Soft X-ray Imager (SMILE-SXI)

Steve Sembay

SMILE-SXI PI

Department of Physics and Astronomy

University of Leicester, UK

On behalf of the SMILE-SXI collaboration

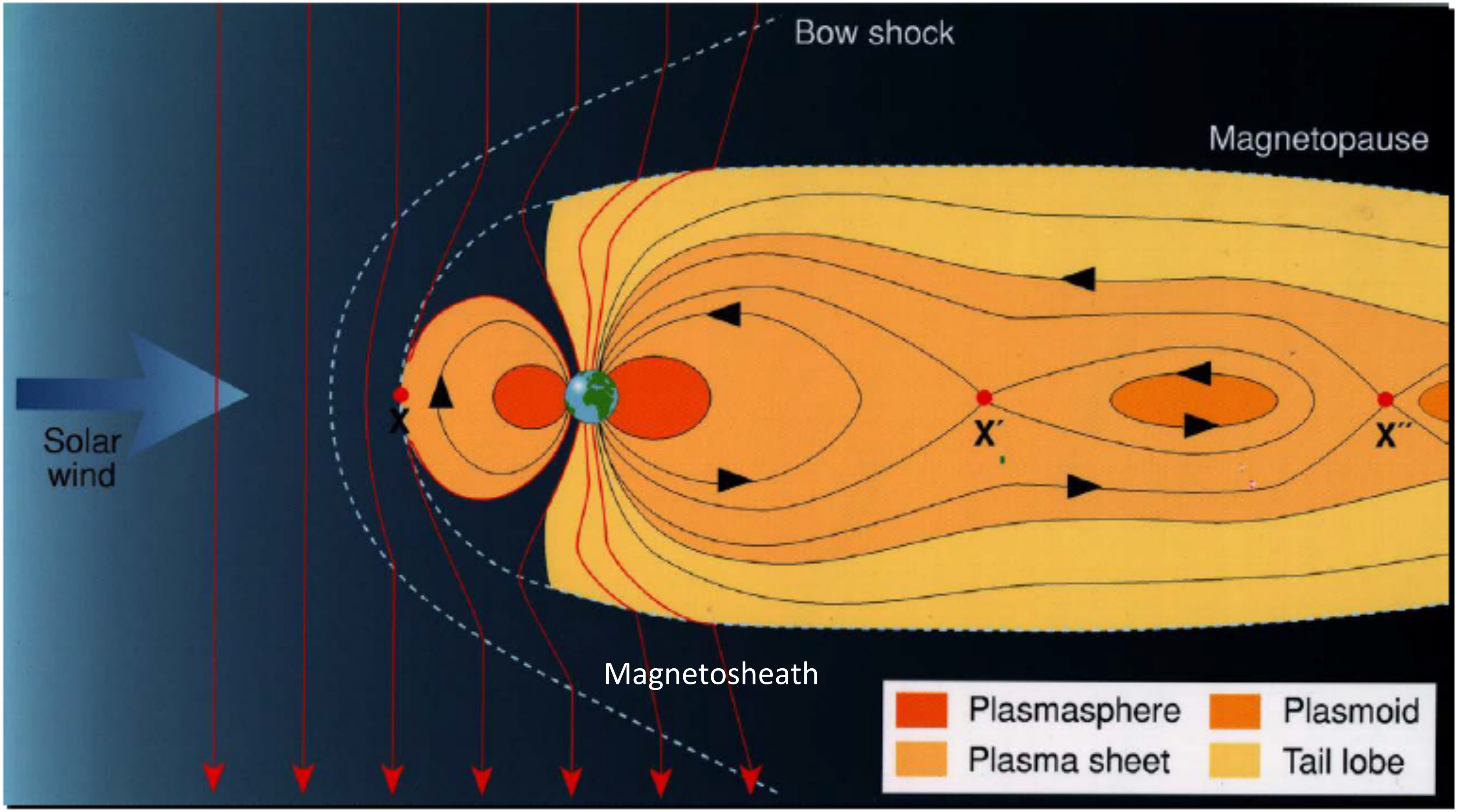
ESA-CAS joint mission

- Call issued in January 2015
- Small class mission
- Small spacecraft (<300 kg) and payload (<60 kg)
- 13 proposals received by deadline of 16 March 2015
- SMILE recommended in June 2015 by a joint European and Chinese scientific committee as candidate for a collaborative science mission with launch now planned Q3 2021
- SMILE formally selected by ESA SPC in November 2015
- SMILE Mission Joint Co-PIs: Graziella Branduardi-Raymont, MSSL, UK
  Chi Wang, NSSC, China

SMILE scientific objectives

- Investigate the dynamic response of the Earth's magnetosphere to the solar wind impact in a unique and global manner
- Combine Solar Wind Charge eXchange (SWCX) X-ray imaging of the dayside magnetosheath and the cusps with simultaneous UV imaging of the northern aurora, while monitoring the solar wind conditions in situ
- → Full chain of events that drive Sun-Earth relationships: dayside reconnection / magnetospheric substorm cycle / CME-driven storms

Reconnection in the Earth's magnetosphere



- Reconnection at magnetopause and in the tail drive plasma dynamics
- Also drives motions in the ionosphere

Magnetospheric Solar Wind Charge eXchange (SWCX)

SWCX: Heavy solar wind ions, A, in collision with neutral target atoms, B

$$A^{q+} + B \rightarrow A^{(q-1)+*} + B^{+}$$

$$A^{(q-1)+*} \rightarrow A^{(q-1)+} + h\nu$$

$$P_X = \eta_H \eta_{SW} v_{av} \alpha$$

where:

P_X = emissivity

η = number density

α = scale factor

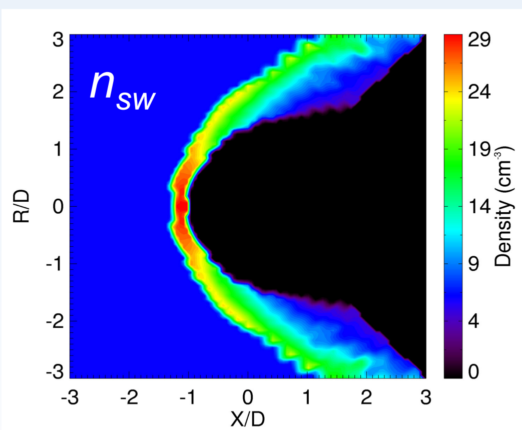
$$v_{av} = \sqrt{v_{sw}^2 + \frac{3k_B T}{m_p}}$$

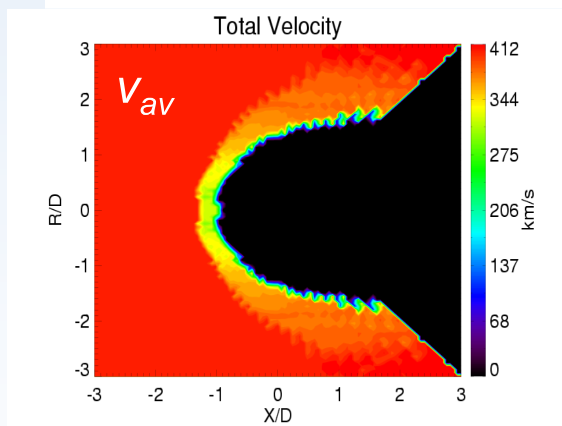
X-ray power depends on SW density and velocity and exosphere density

Efficiency factor α depends on CX X-sections and SW heavy ion and target neutral composition

$\alpha \sim 9.4 \times 10^{-16}$ eV cm^2 (slow wind)
$\alpha \sim 3.3 \times 10^{-16}$ eV cm^2 (fast wind)

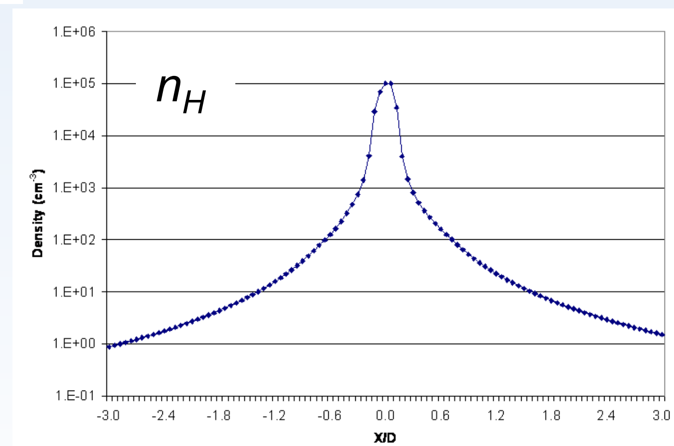
SW heavy ion content is ~1%





MHD model

Robertson & Cravens (2003, 2006)

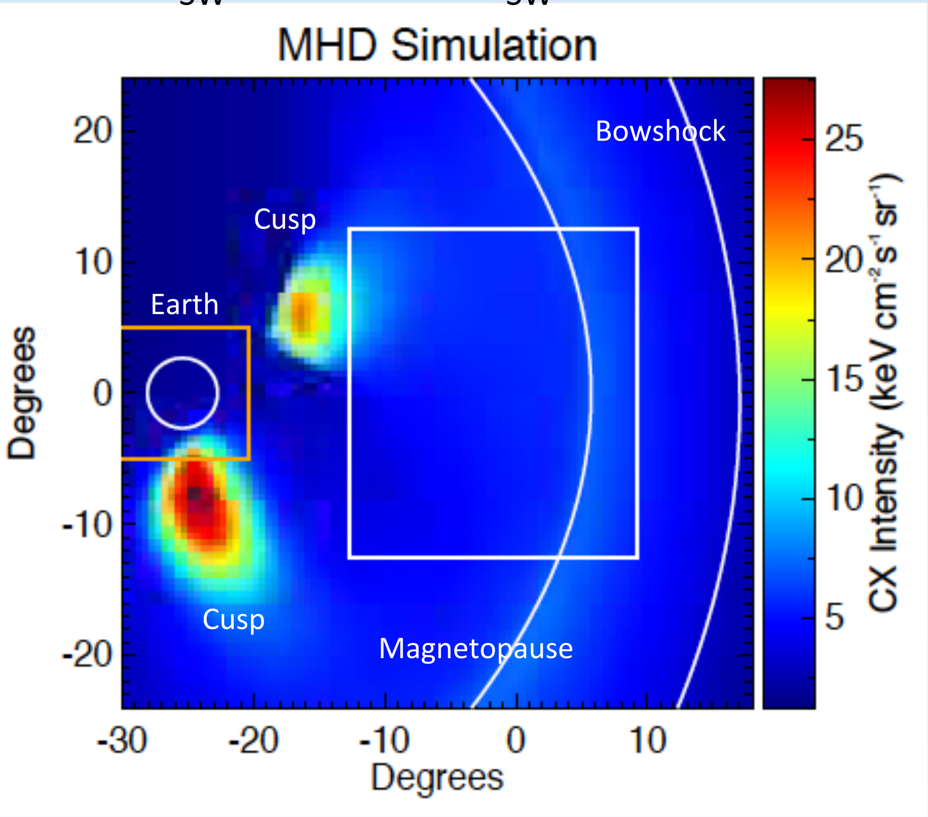


Exosphere model (Hodges 1994)

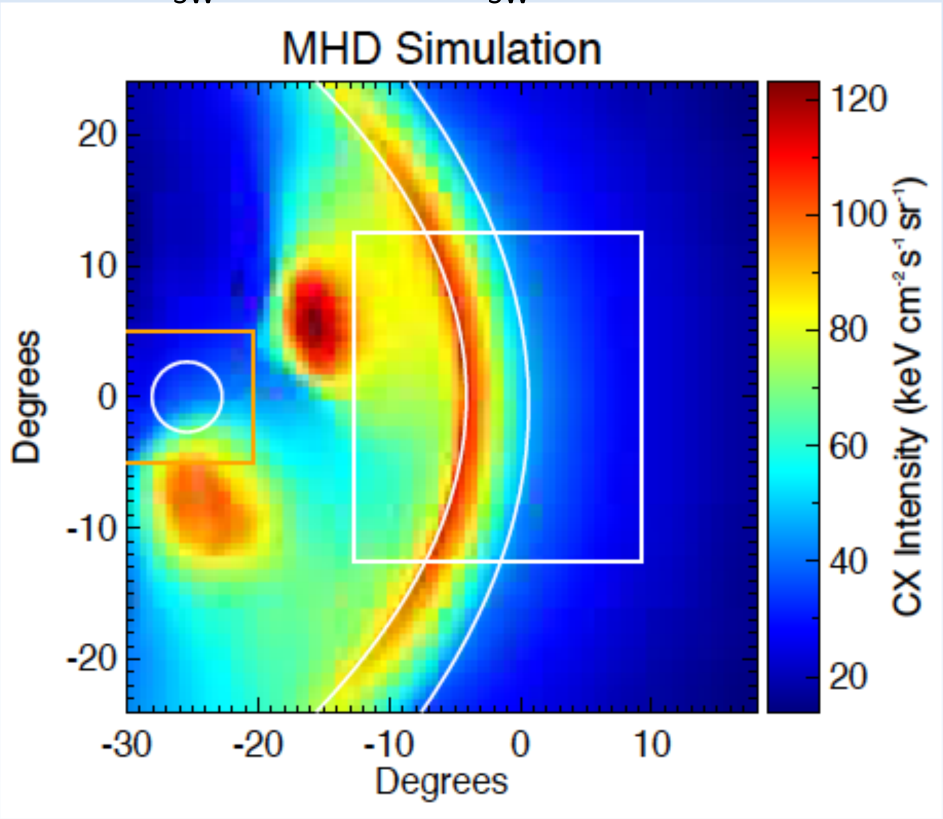
MHD Model CX Emissivity: POV at 20 R_E

T. Sun, NSSC

$N_{SW} = 4.5\ cm^{-3}$ $V_{SW} = 420\ km\ s^{-1}$

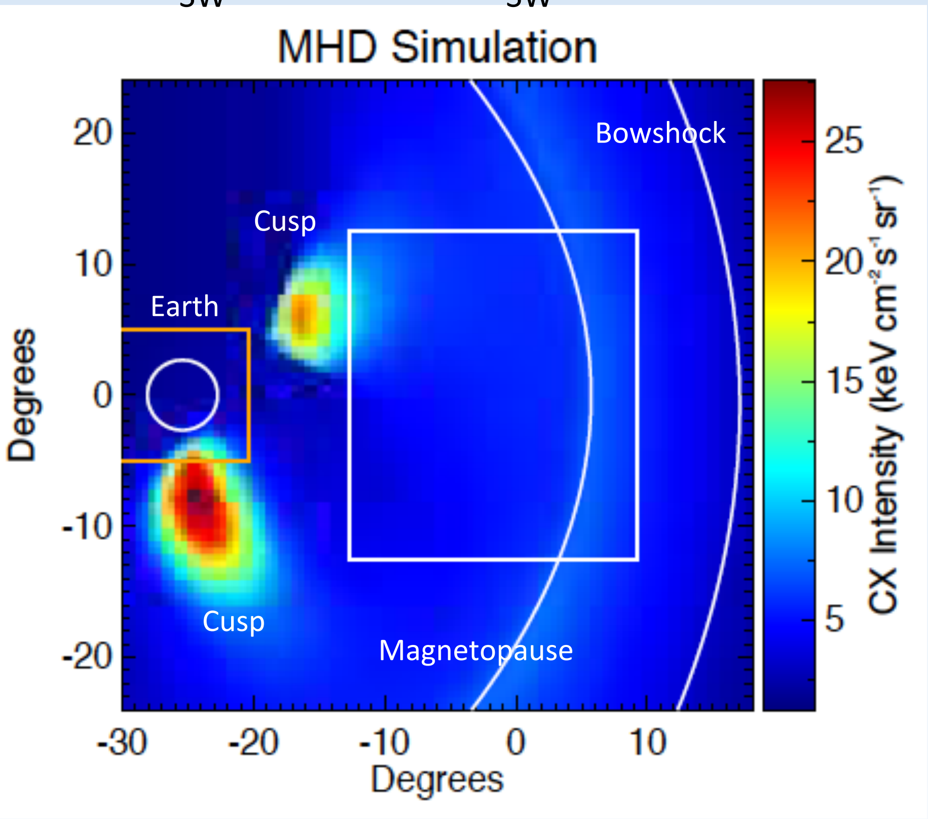


$N_{SW} = 22.7\ cm^{-3}$ $V_{SW} = 623\ km\ s^{-1}$

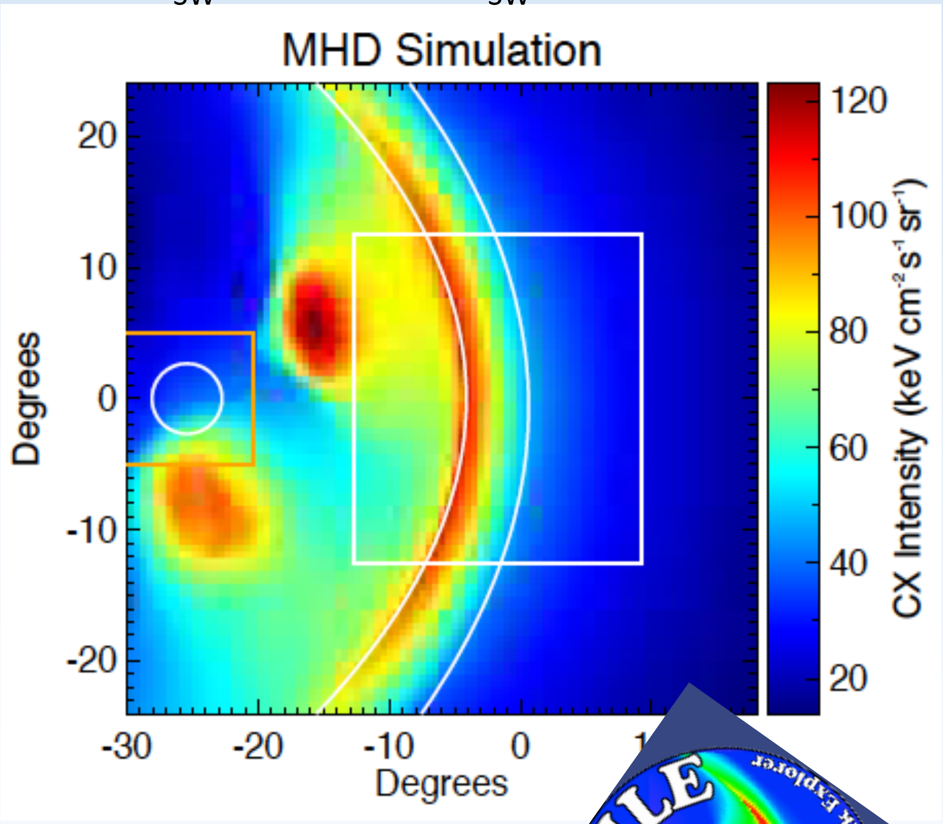


MHD Model CX Emissivity: POV at 20 R_E
T. Sun, NSSC

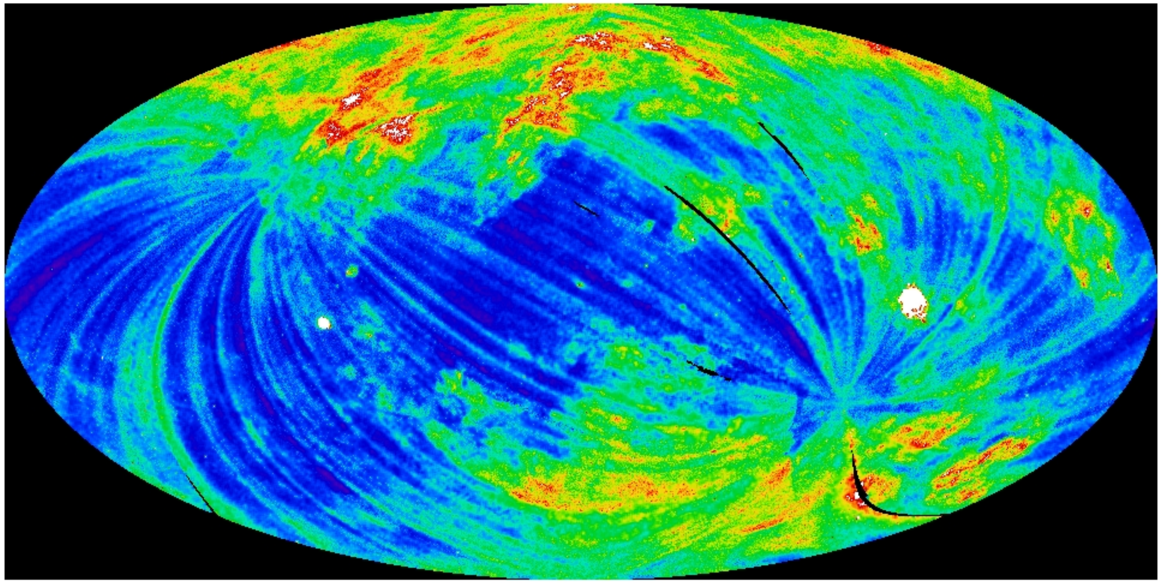
N_{SW} = 4.5 cm^{-3} V_{SW} = 420 km s^{-1}



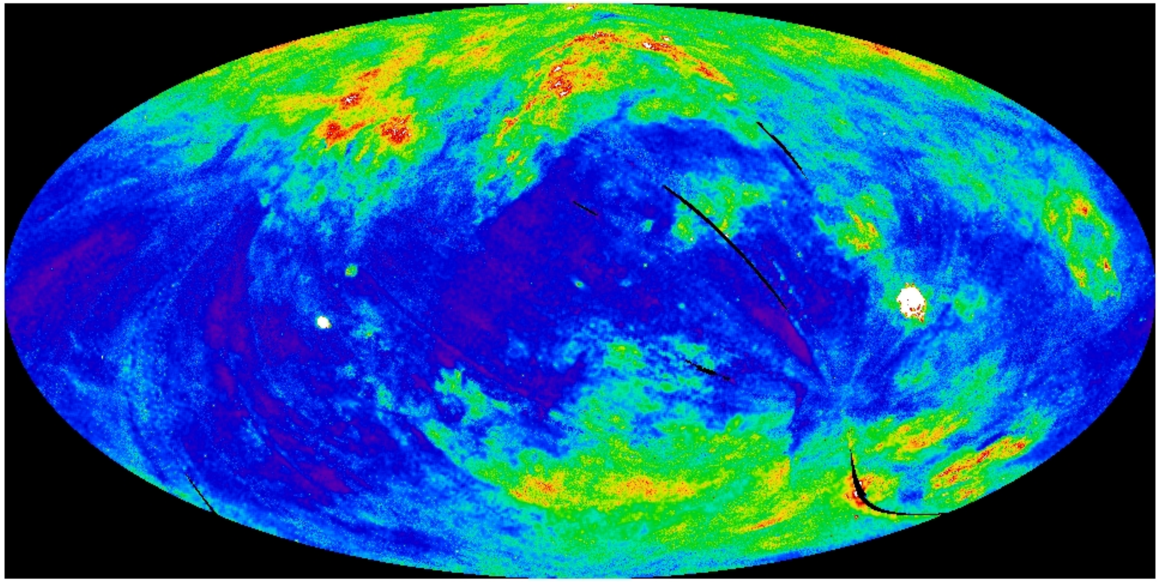
N_{SW} = 22.7 cm^{-3} V_{SW} = 623 km s^{-1}



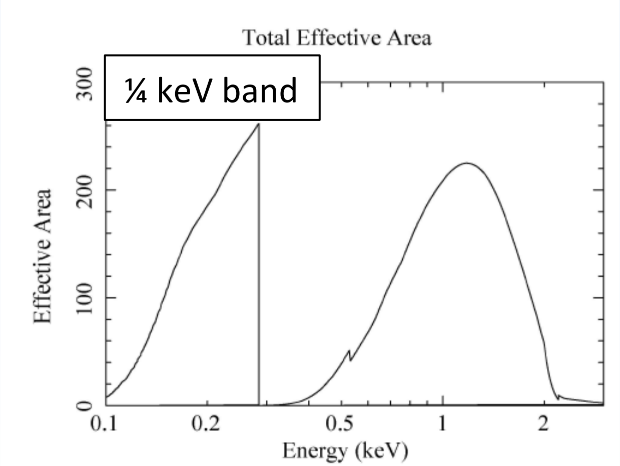
History: ROSAT PSPC LEO All-Sky Survey, 1990



ROSAT ¼ keV Survey
Pre-cleaning

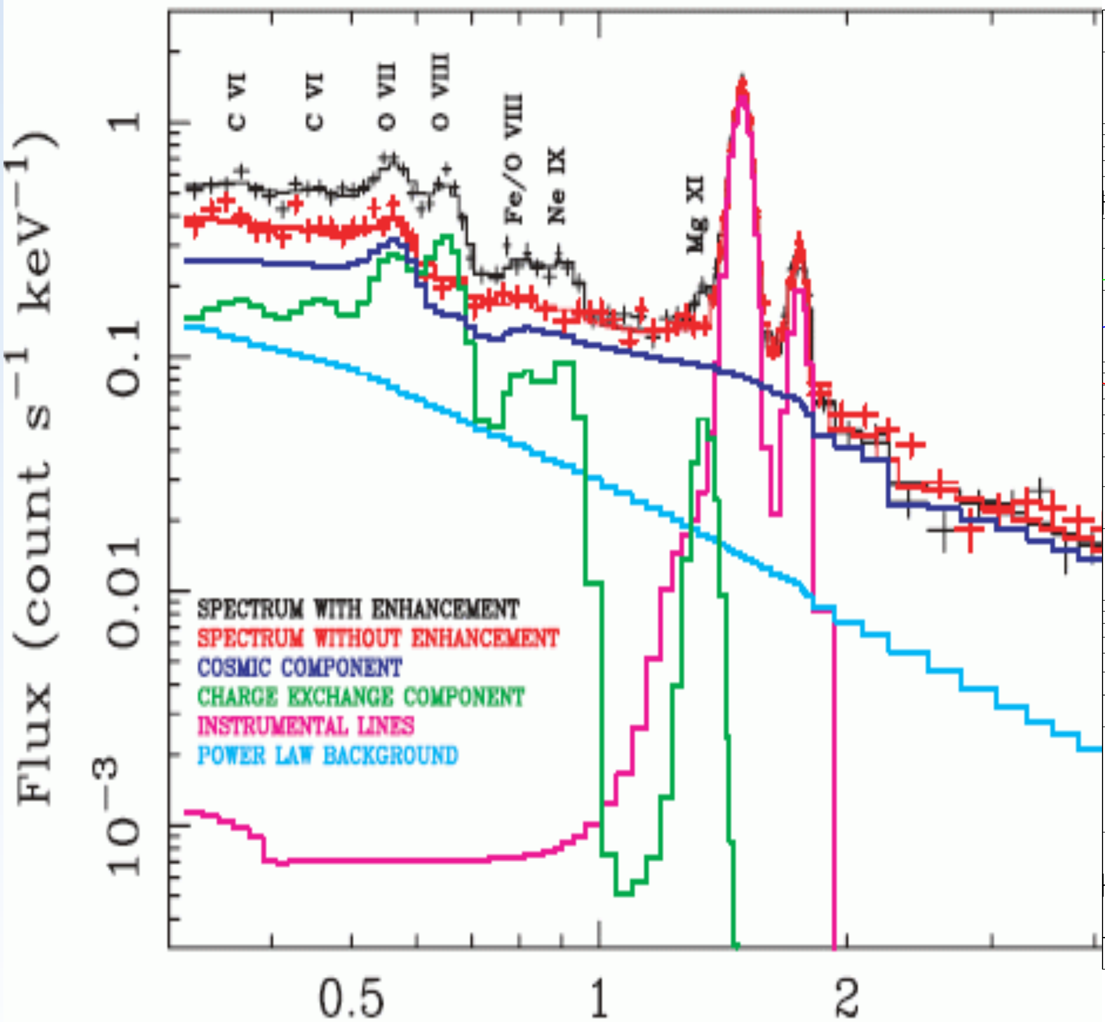


ROSAT ¼ keV Survey
Post-cleaning

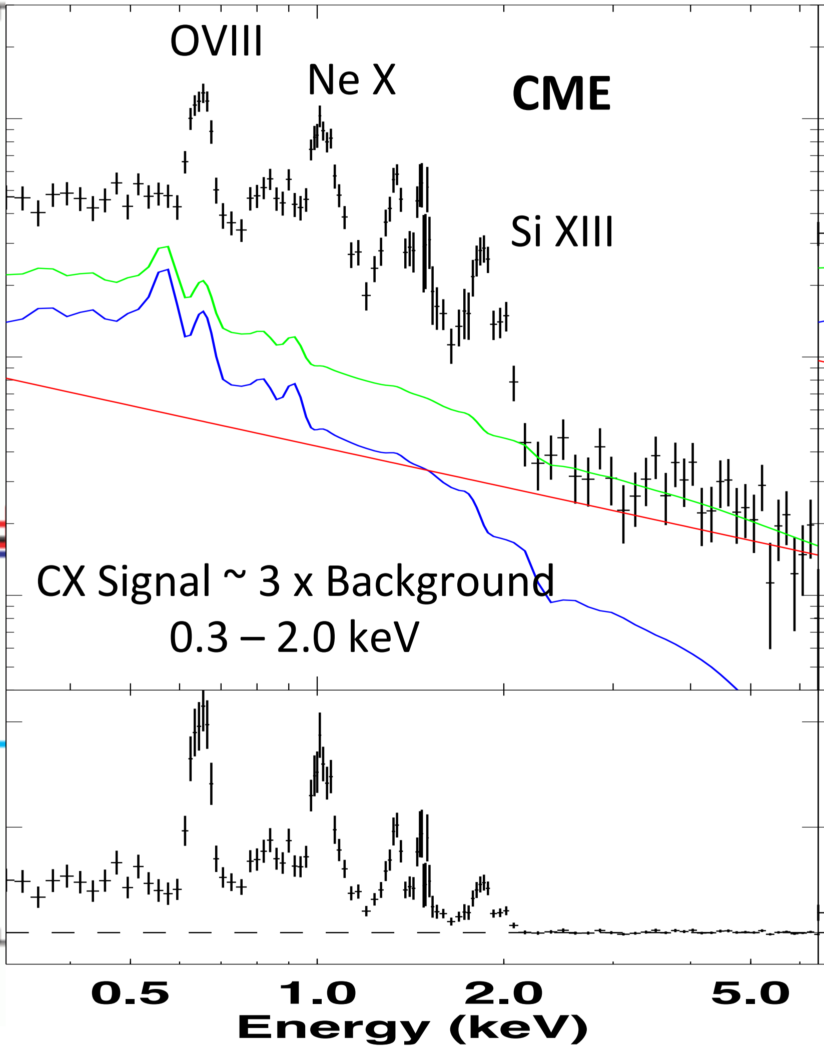


Example XMM Spectra: Narrow FOV LOS through magnetosheath
(similar spectra from Suzaku in LEO)

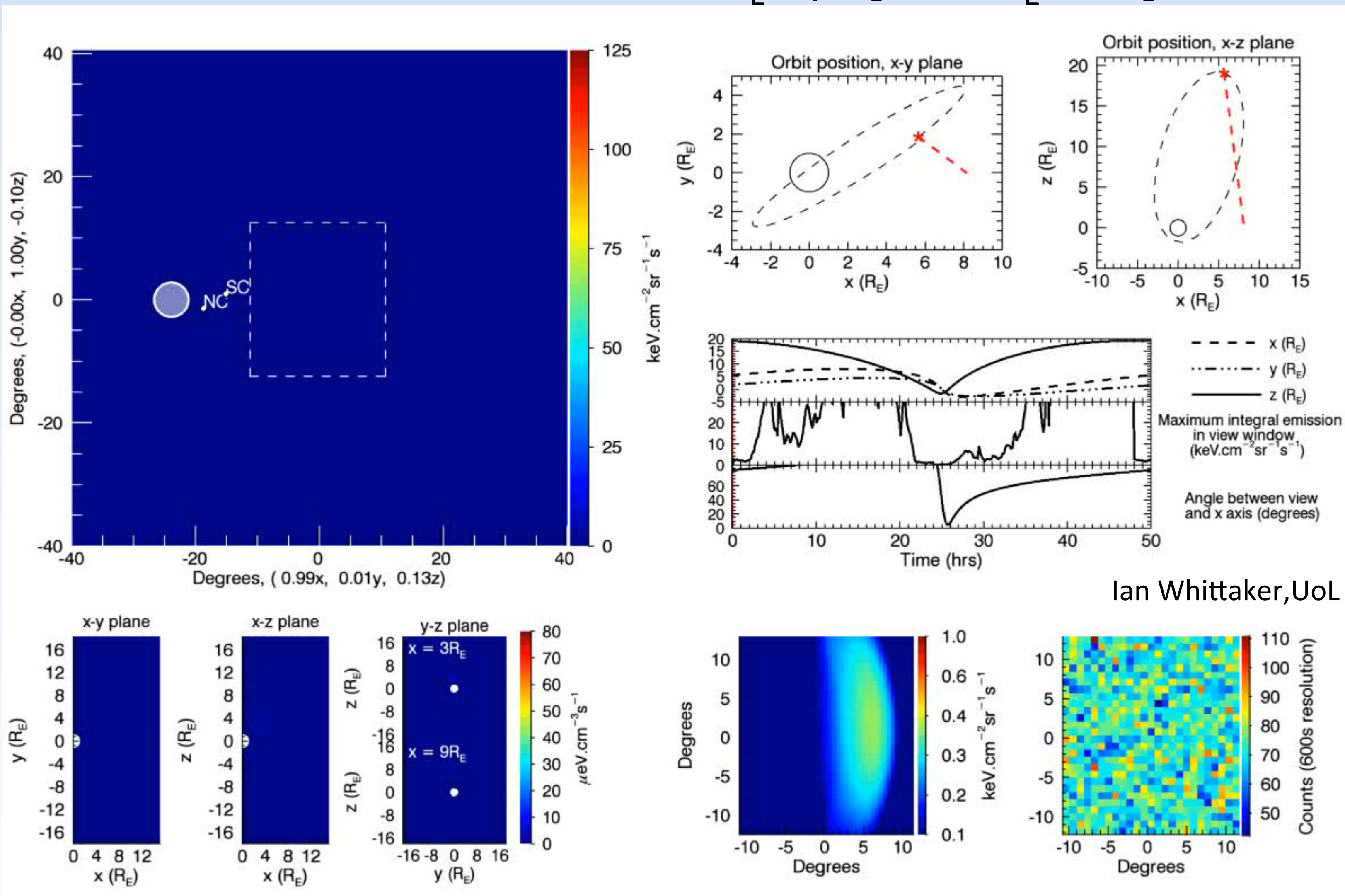
Snowden, Collier & Kuntz 2004



Carter, Sembay & Read 2010

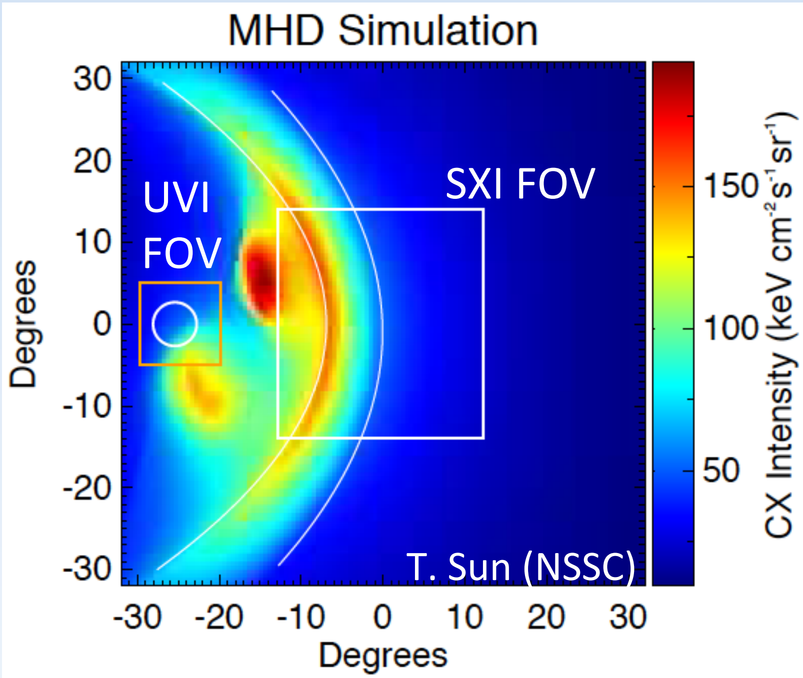


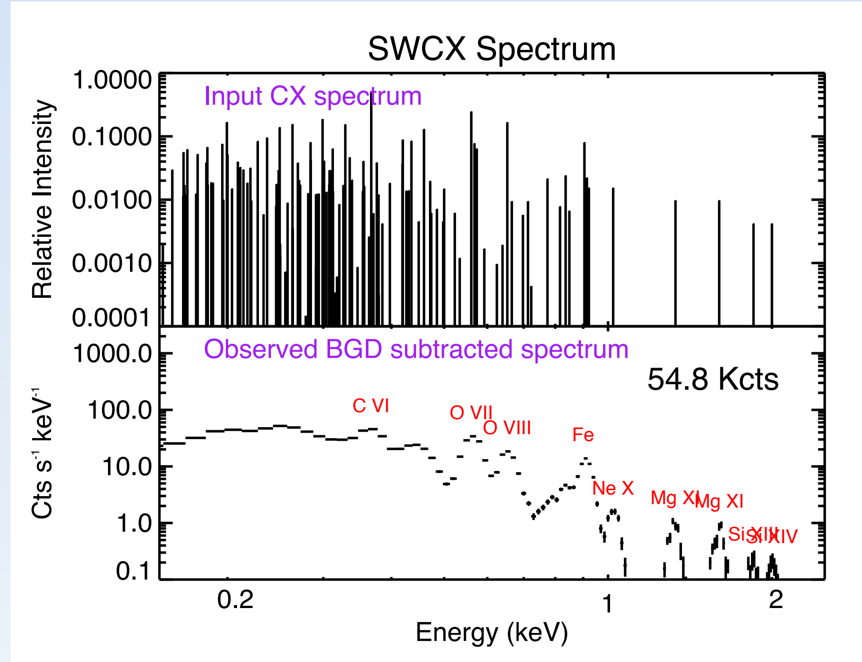
SMILE-SXI simulated observations:
SMILE orbit ~ 50 hours, 19 R_E Apogee, 1R_E Perigee

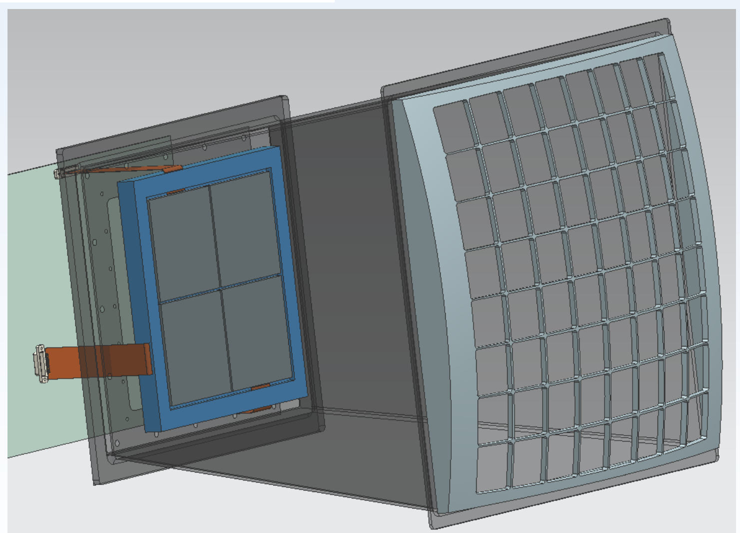


Coronal Mass Ejection interaction: 31 March 2001

Soft X-ray Imager – Basic configuration







CCD Detector Plane

Photon counting

High QE in soft X-rays
~80% at 250 eV

Medium energy resolution
~50 eV FWHM at 500 eV

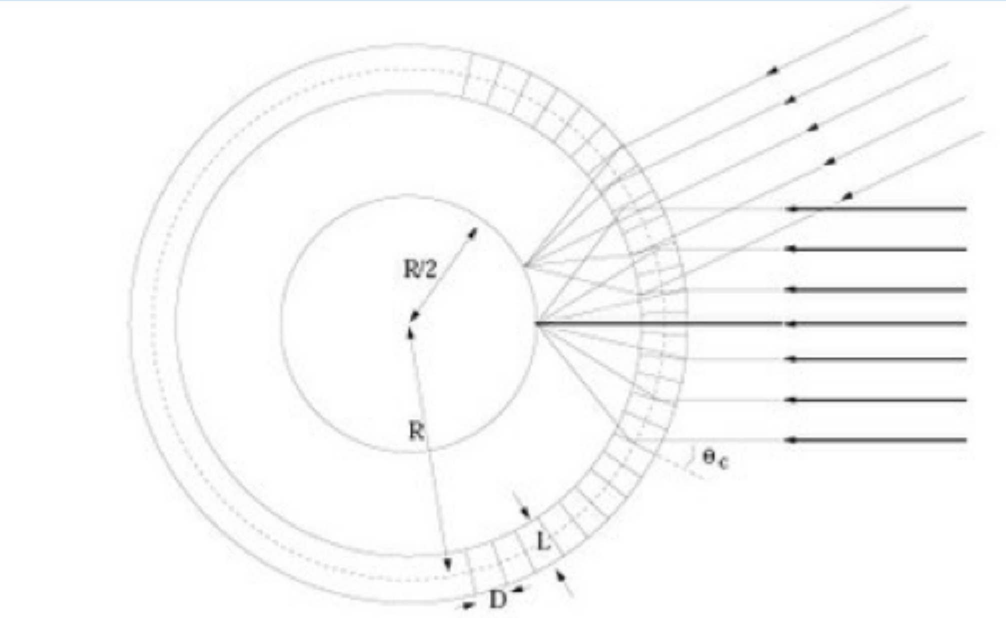
Lobster-eye Micropore Optic

Ultra-wide field of view
~22°x25°

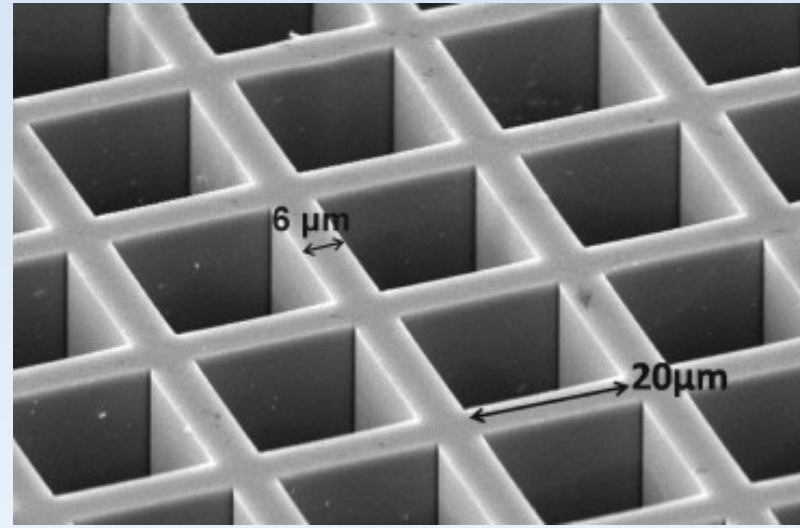
375 mm focal length

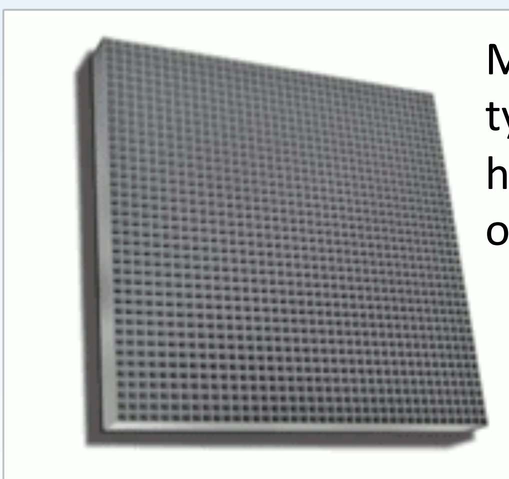
Low Mass
~ 1kg optic array (only)

Optics – Lobster-eye Micropore Optics (MPO)



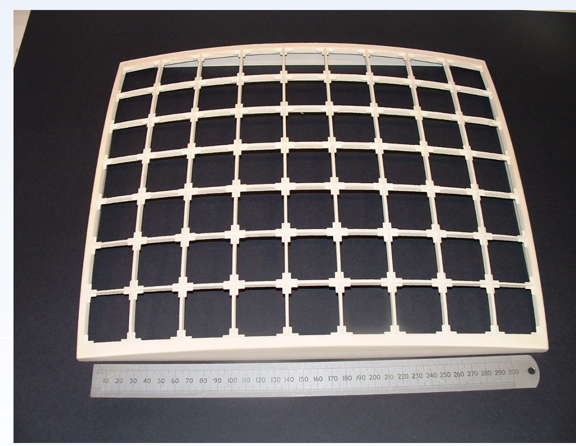
Square-packed 20 µm pores, 6 µm walls



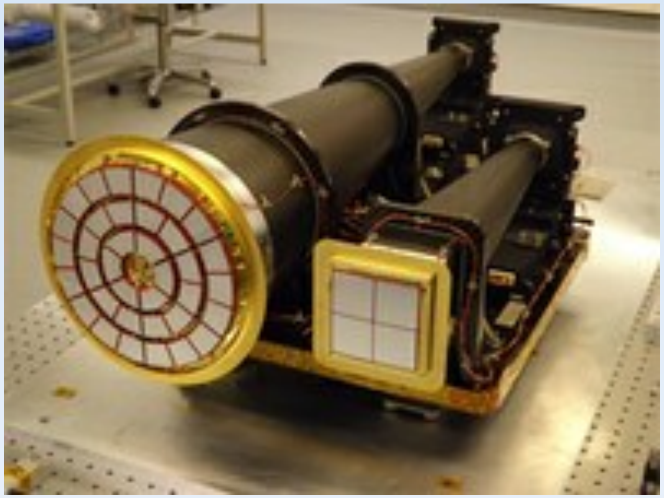


Manufactured (Photonis) as glass plates, typically 4x4 cm, 1mm thick, heat-slumped to required radius of curvature

Plates glued onto frame to build FOV. 1mm overlap.
Low mass: Flight optic ~ 1kg

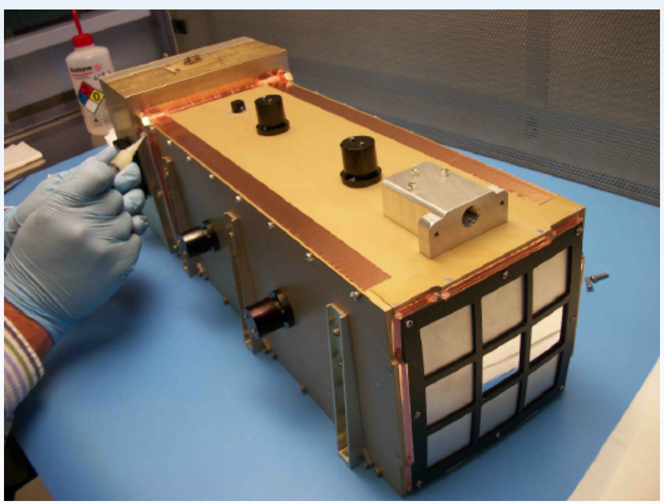


Optics – Space Instrumentation Heritage



MIXS (MIXS-T and MIXS-C) instruments on ESA/JAXA BepiColombo mission to Mercury, Launch 2017, arrival 2024. MIXS PI institute UoL

MIXS-T: Radially-packed MPOs in Wolter Geometry
MIXS-C: Square-packed MPOs employed as collimators. MPOs slumped to 55 cm ROC, detector at distance equal to slump radius



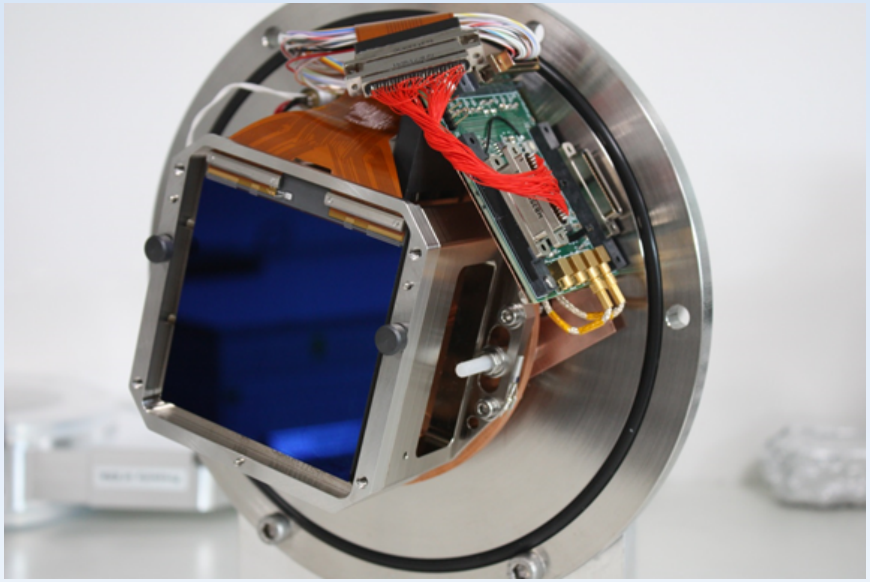
DXL/STORM Module. PI Michael Collier, NASA/GSFC

Flew on DXL sounding rocket flight, December 2012

First Lobster-eye MPO telescope to be launched into space. Detected X-rays from soft X-ray background. Successfully recovered despite abnormal vibration during launch.

Detector plane – CCD

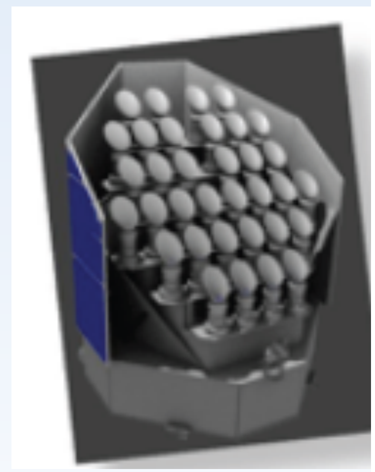
Baseline – 2x2 array e2v CCD270

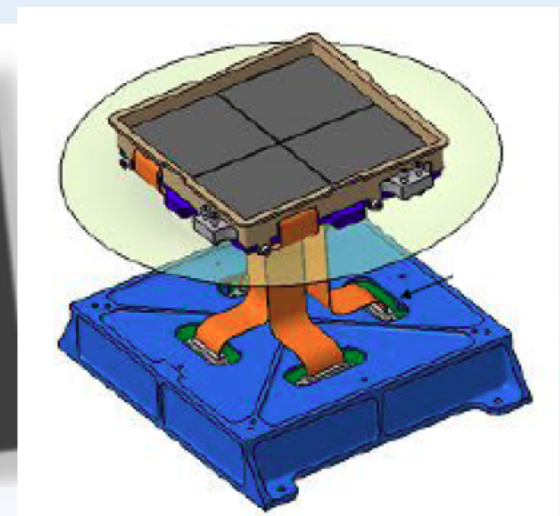


e2v CCD270 – PLATO (ESA M3) derivative
Native 4510 x 4510 18 µm pixels
Native Image area 8.12 x 8.12 cm
Back-illuminated
2-node readout available
Operated with asymmetric frame store
6 x binning giving 108 µm pixels
Baseline ~1s frame time

PLATO:
ESA M3 exoplanet mission
36 cameras, each with
2x2 array of CCDs

SMILE leverages work done for PLATO on CCDs and readout electronics





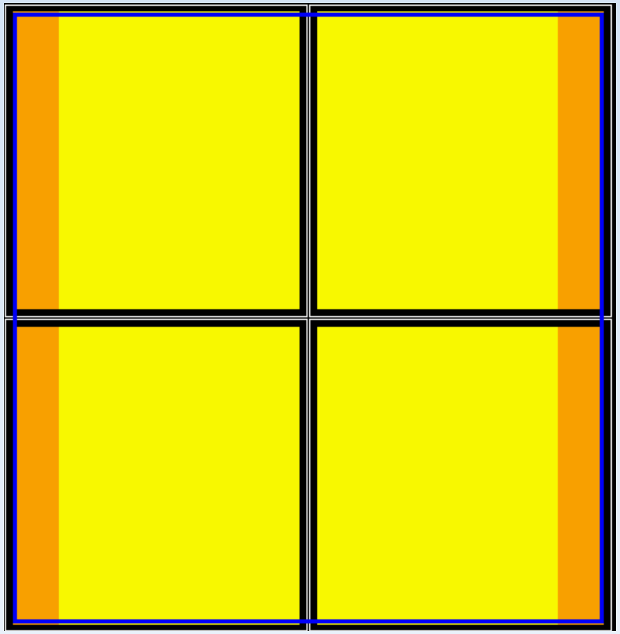
SMILE-SXI CCDs optimised for X-ray detection
e.g. no AR coating

Detector plane – Comparative sizes (to scale)

SMILE-SXI:

4 x PLATO derivative CCDs

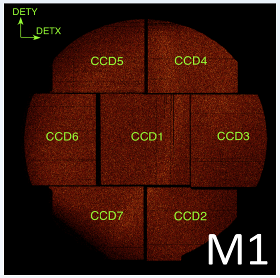
~226 cm^2 Active Area

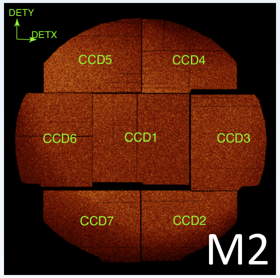


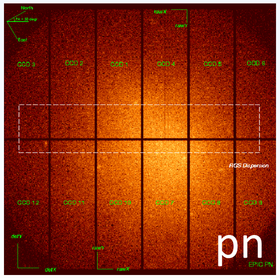
XMM-EPIC:

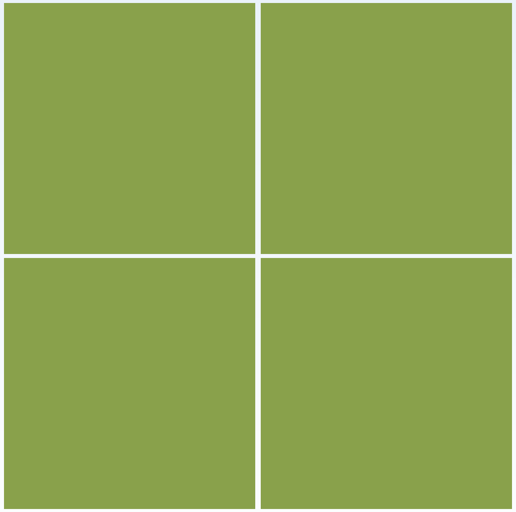
14 x MOS
12 x pn
CCDs

~120 cm^2







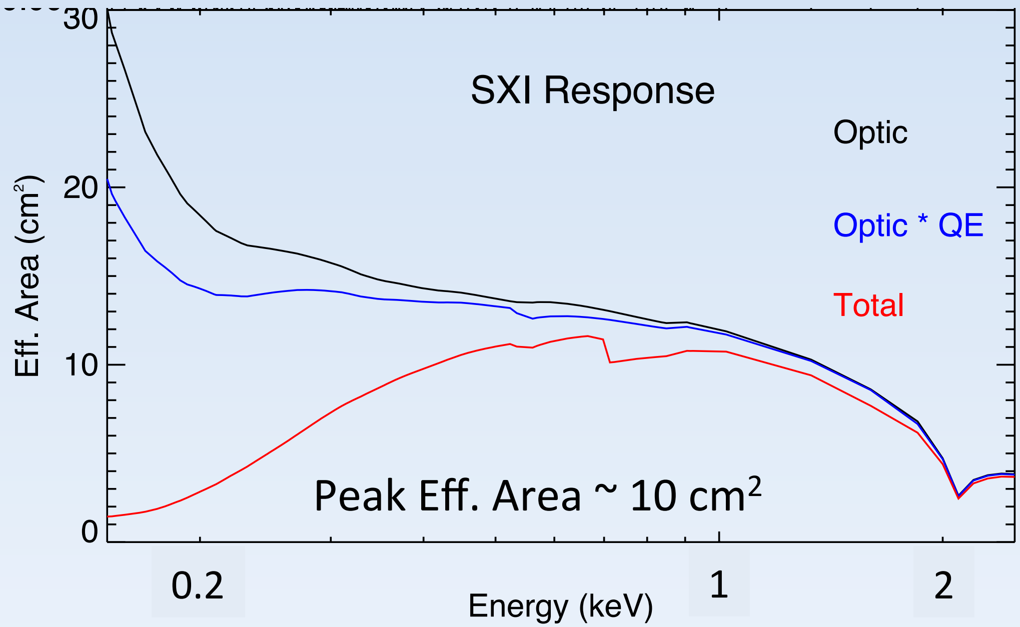


Athena WFI:

4 x DEPFETS

~177 cm^2

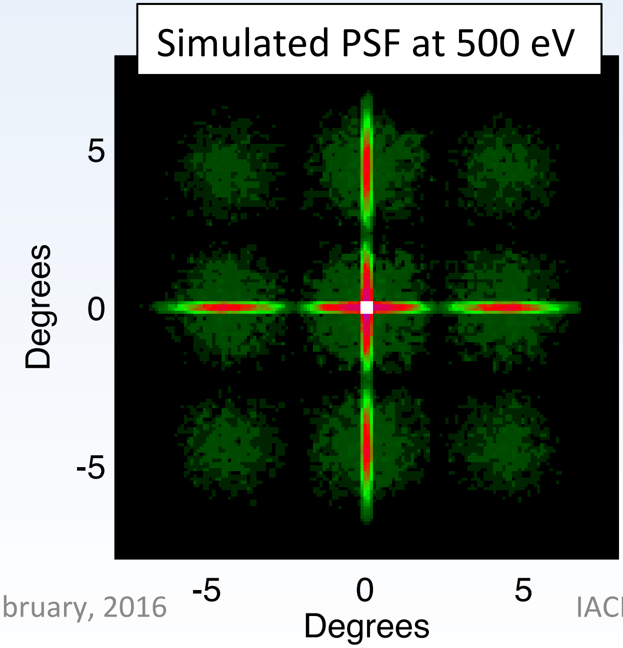
Instrument Response



Optic only, Iridium Coating with 85% baffle vignetting

Optic x CCD-QE

Optic x CCD-QE x Filter 600 Å MgF_2, 600Å Al



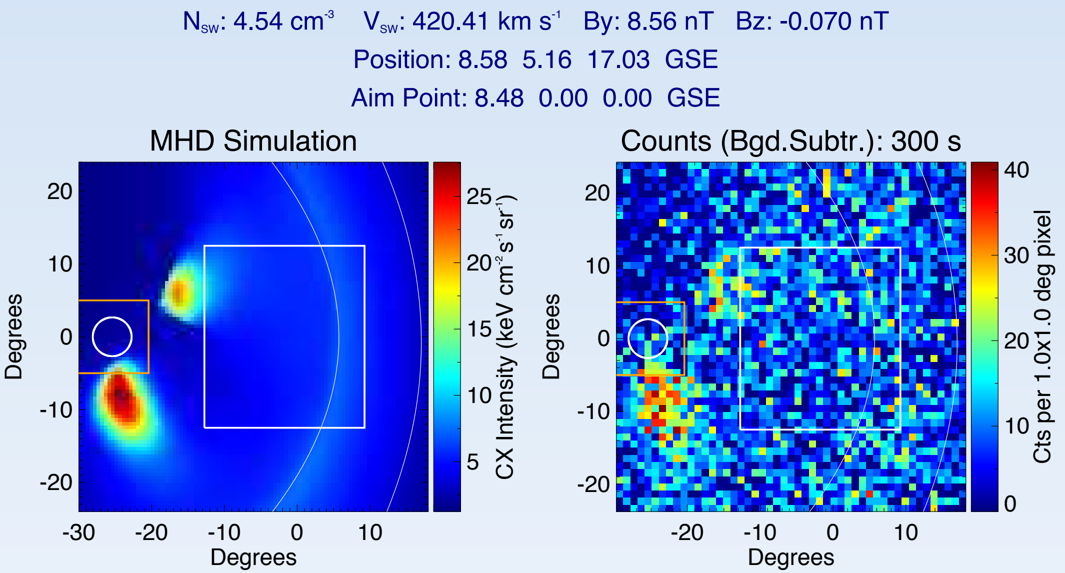
Measured PSF Core ~6 arcminutes FWHM

~32% of flux within 15 arcminutes radius

~48% of flux within 60 arcminutes radius

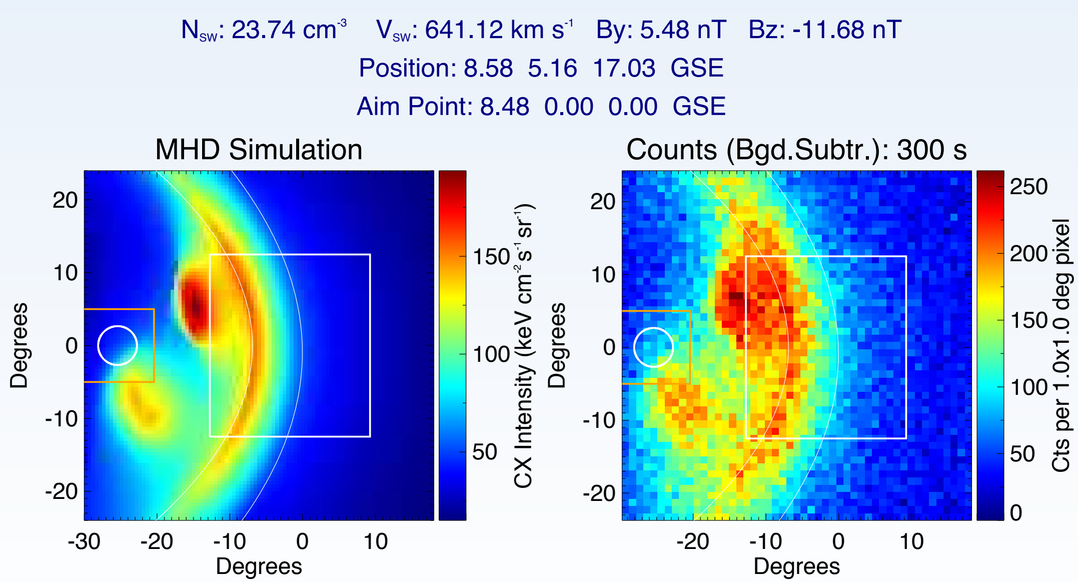
at 500 eV

Predicted SXI performance



SWCX at magnetosheath peak
Energy range 0.1 to 2.0 keV
Pixel = 1.0 degrees

Component	Rate (cts s^{-1} $pixel^{-1}$)
SWCX	0.03
Sky Background	0.12
Particle Background	0.02
Average point sources	0.0015
Time for pixel > 3σ	1700 s



Component	Rate (cts s^{-1} $pixel^{-1}$)
SWCX	0.70
Sky Background	0.12
Particle Background	0.02
Average point sources	0.0015
Time for pixel > 3σ	15 s

Predicted SXI performance

Note on relative particle background:

- Estimated SXI particle background (continuum) is

  ~ 0.024 cts cm^{-2} s^{-1} keV^{-1}

- Observed quiescent XMM EPIC-MOS particle bgd

  ~ 0.0028 cts cm^{-2} s^{-1} keV^{-1}

i.e. SXI factor ~ 10 higher than EPIC-MOS

- 1 cm^2 on SXI detector has grasp (FOV x Eff. Area) of

  ~ 2.3 sq. degrees x 10 cm^2 = 23.3

- 1 cm^2 on MOS detector has grasp (FOV x Eff. Area) of

  ~ 0.0048 sq. degrees x 450 cm^2 = 2.2

i.e. X-ray diffuse flux to particle background ratio per detector pixel is similar in both instruments.

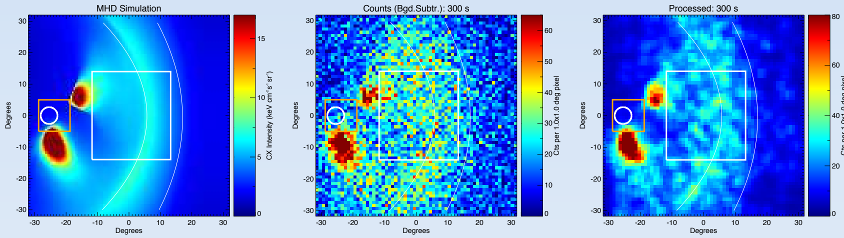
SWCX at magnetosheath peak
Energy range 0.1 to 2.0 keV
Pixel = 1.0 degrees

Component	Rate (cts s^{-1} $pixel^{-1}$)
SWCX	0.03
Sky Background	0.12
Particle Background	0.02
Average point sources	0.0015
Time for pixel > 3σ	1700 s

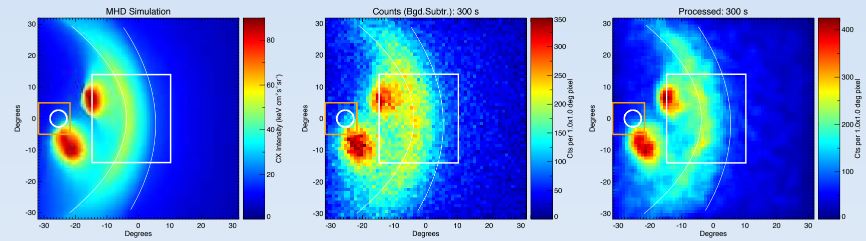
Component	Rate (cts s^{-1} $pixel^{-1}$)
SWCX	0.70
Sky Background	0.12
Particle Background	0.02
Average point sources	0.0015
Time for pixel > 3σ	15 s

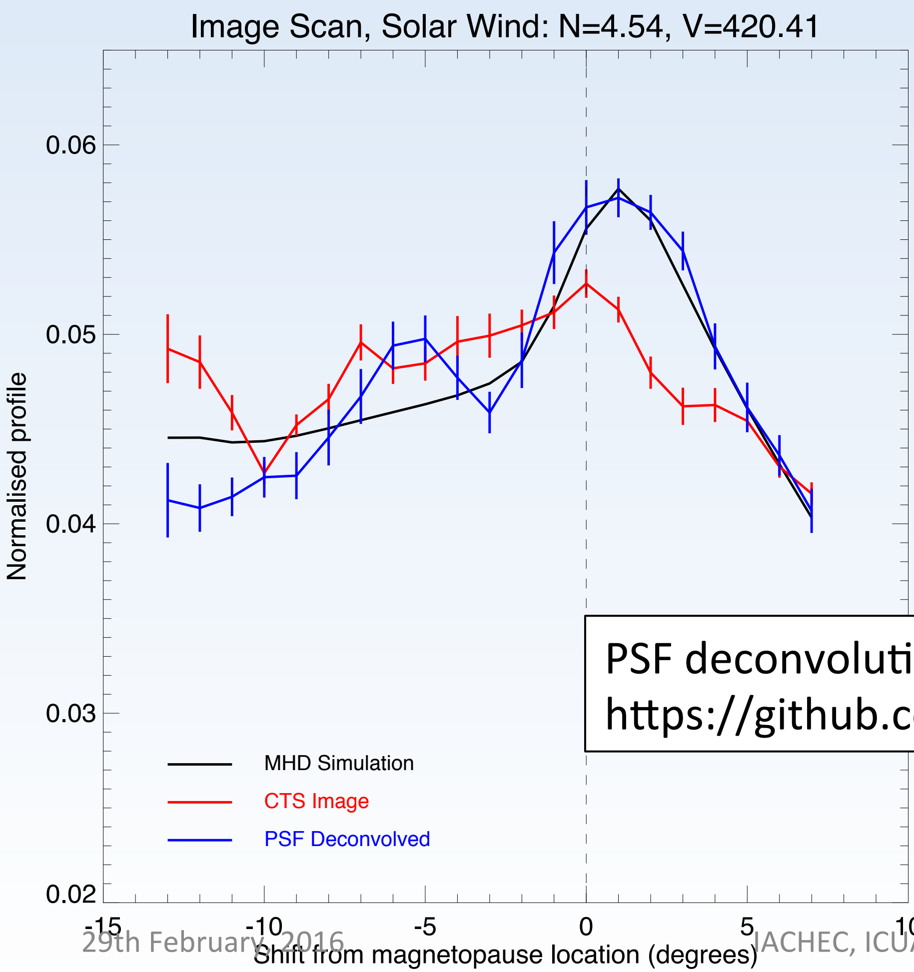
SIMS

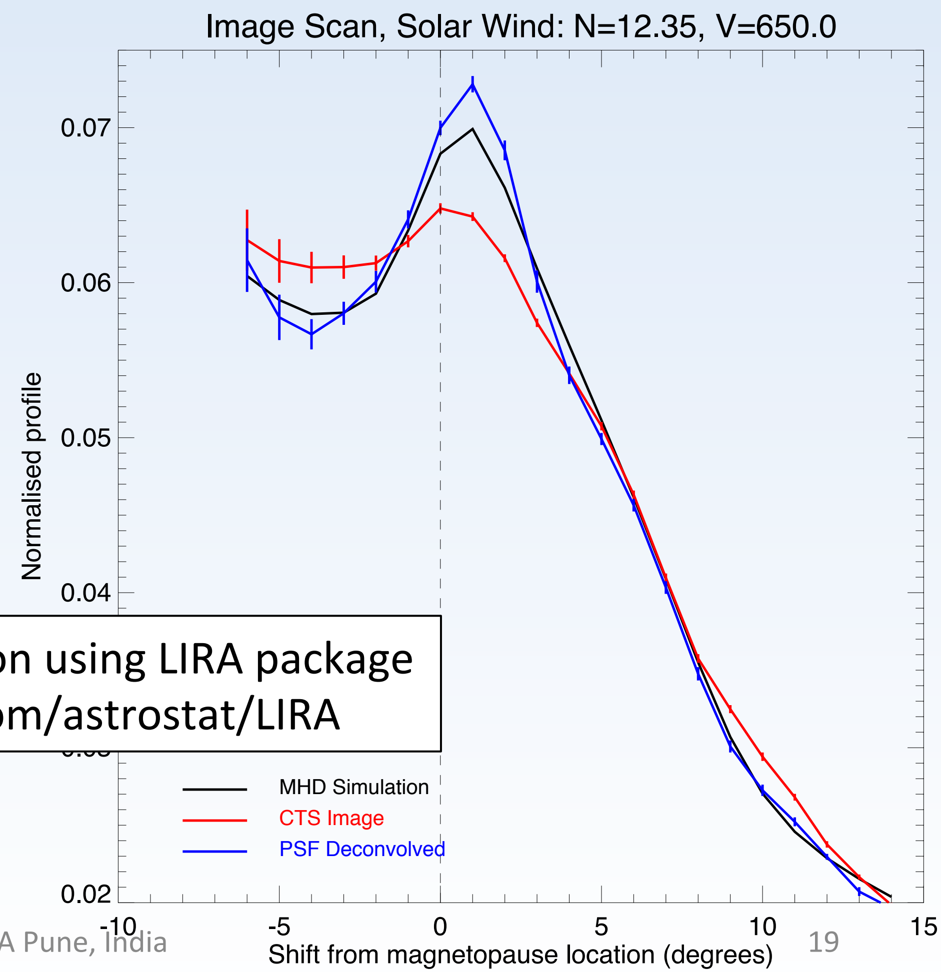
N_{sw}: 4.54 cm^{-3} V_{sw}: 420.41 km s^{-1} By: 8.56 nT Bz: -0.070 nT
Position: 8.58 5.16 17.03 GSE
Aim Point: 8.48 0.00 0.00 GSE



N_{sw}: 12.35 cm^{-3} V_{sw}: 650.00 km s^{-1} By: 23.89 nT Bz: -5.16 nT
Position: 8.58 5.16 17.03 GSE
Aim Point: 8.48 0.00 0.00 GSE

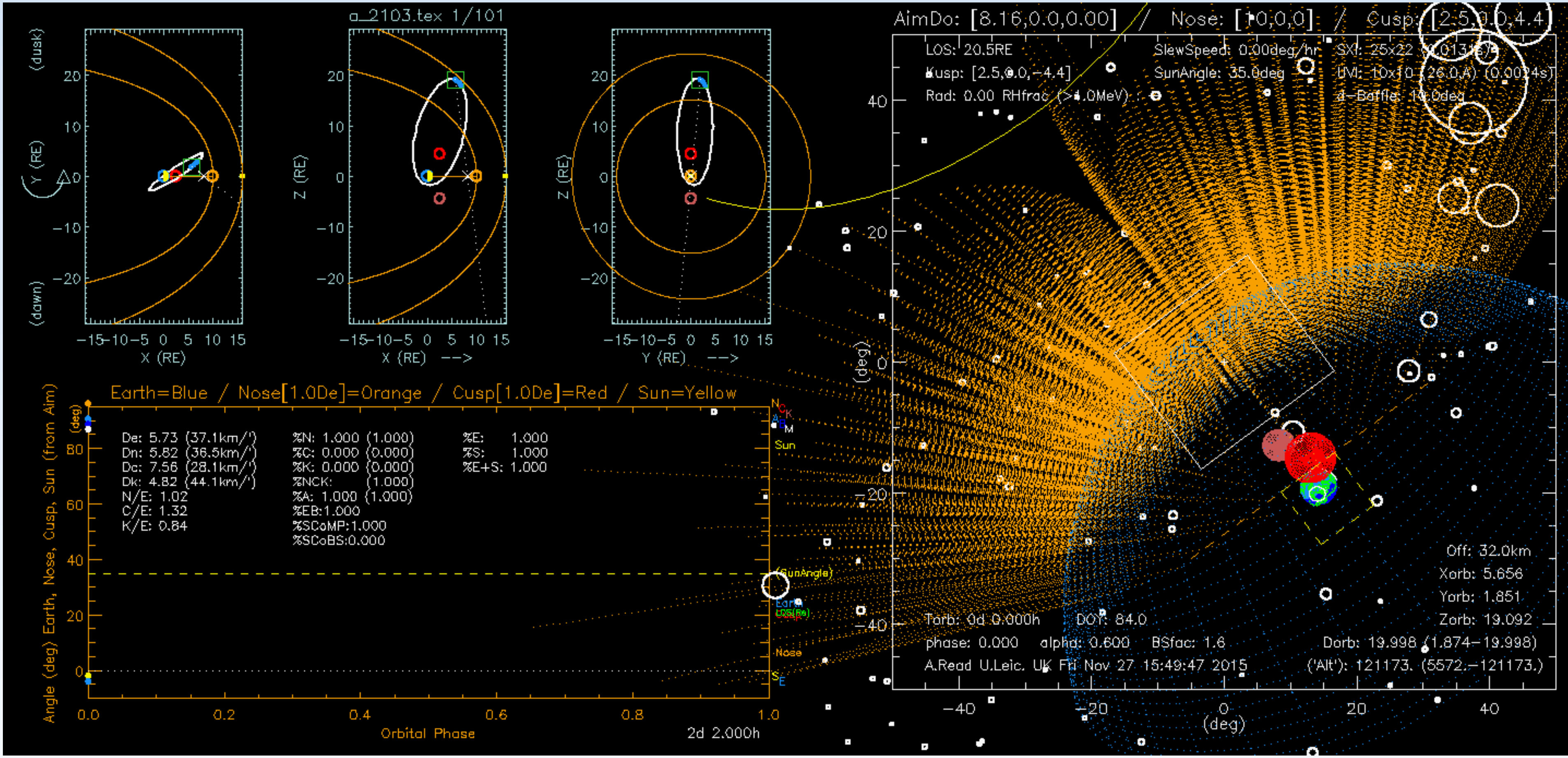






PSF deconvolution using LIRA package
https://github.com/astrostat/LIRA

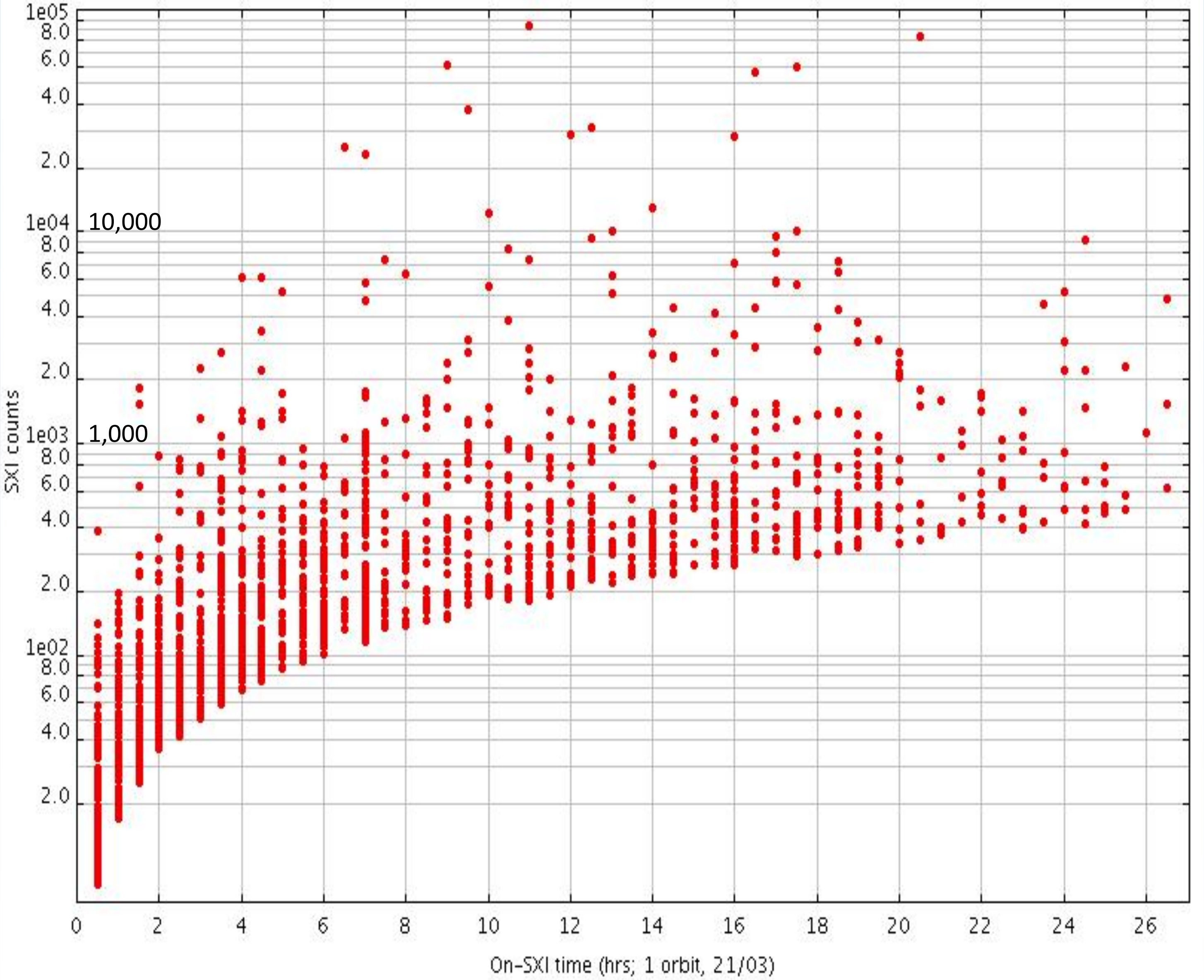
SMILE Orbit Simulator



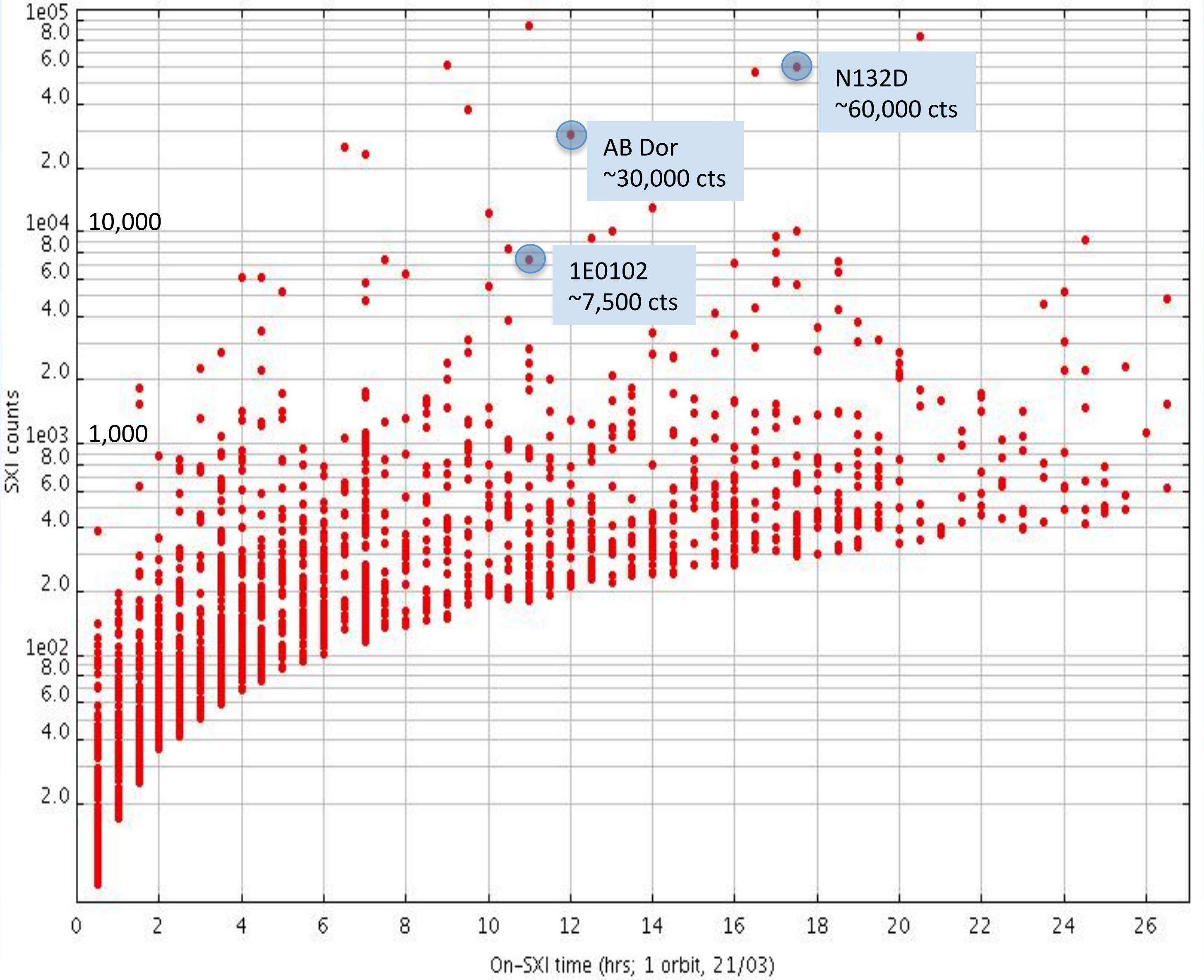
Andy Read, University of Leicester

-> Deep coverage towards South Ecliptic Pole

Bright X-ray sources – SXI counts v on-time, example orbit



Bright X-ray sources – SXI counts v SXI on-time



Thankyou