Exospheric solar wind charge exchange emission as viewed by XMM-Newton

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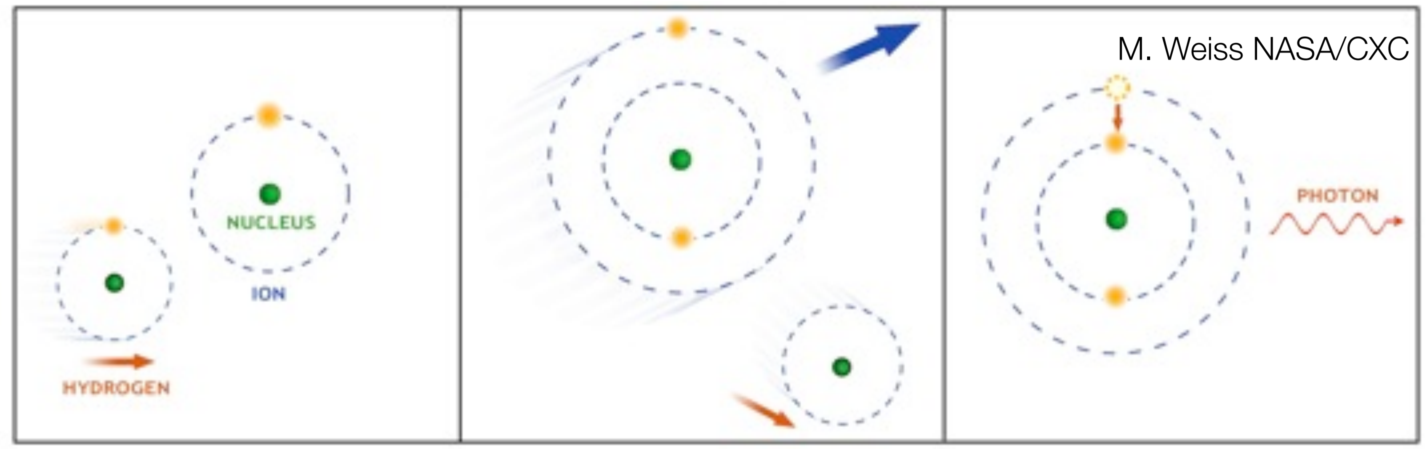
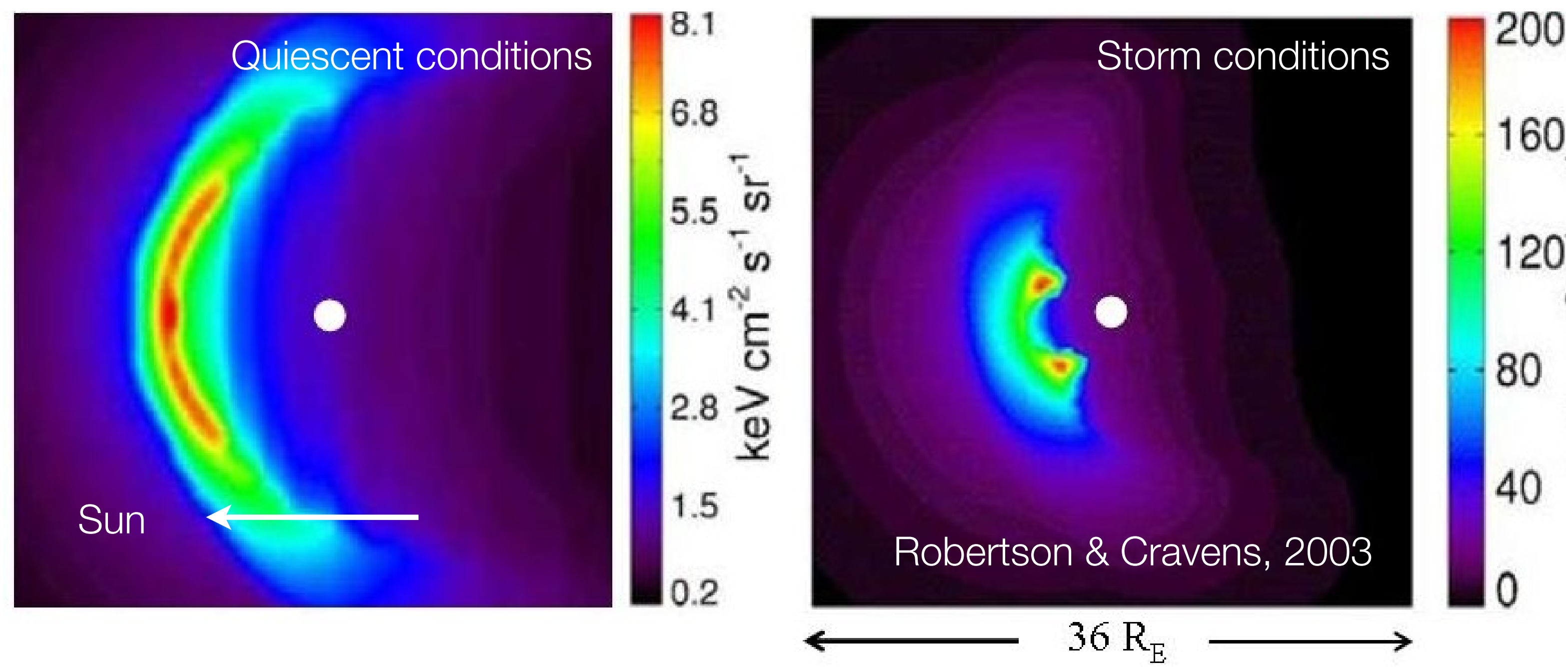
Talk outline

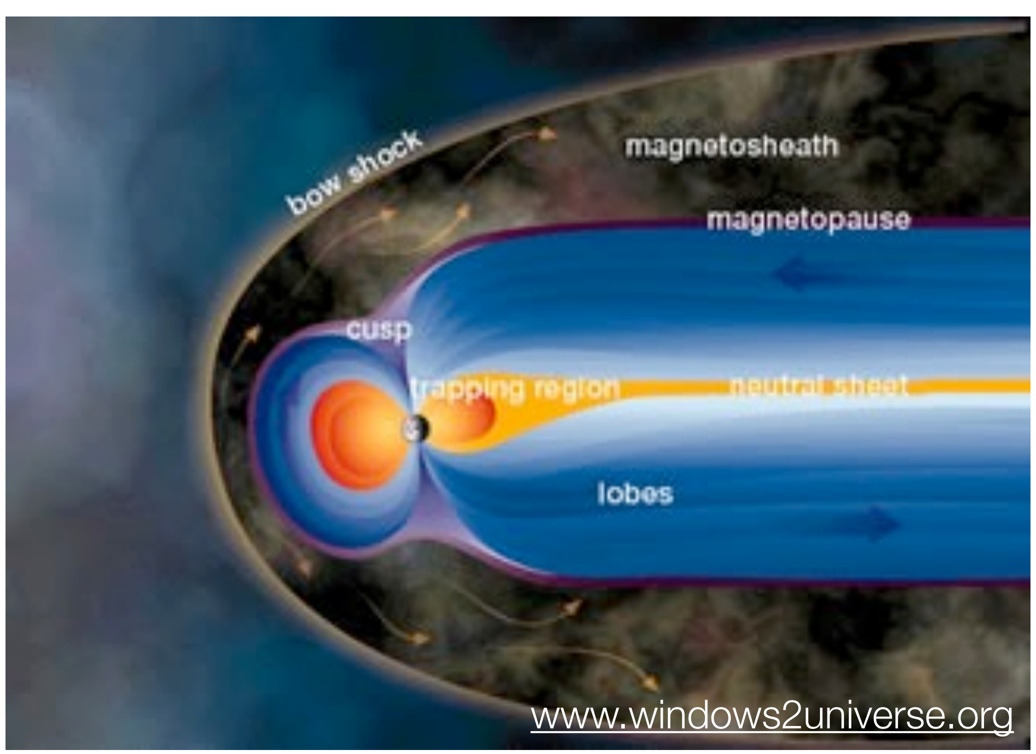
- Charge exchange in the solar wind - locations and signatures
- Observing exospheric solar wind charge exchange (SWCX) with XMM-Newton
- General results of project - characterisation of exospheric SWCX emission as seen by XMM-Newton
  - Level of ‘contamination/enhancement’ (depends on perspective) within archive
  - Relationship with solar cycle and solar wind flux
  - Spectral characteristics
- A particular case of interest; viewing a Coronal Mass Ejection
- Future instrumentation using charge exchange to image the Earth’s magnetosheath

Charge exchange and the solar wind

- Solar wind: velocities ~ 200-1000 km s^{-1}, densities ~ 7-40 cm^{-3}
- 1% heavy ions
- Solar wind charge exchange (SWCX): charge exchange between a solar wind ion and a neutral in the Solar System
- Cross-sections for charge exchange are high ~10^{-16} cm^{-2}

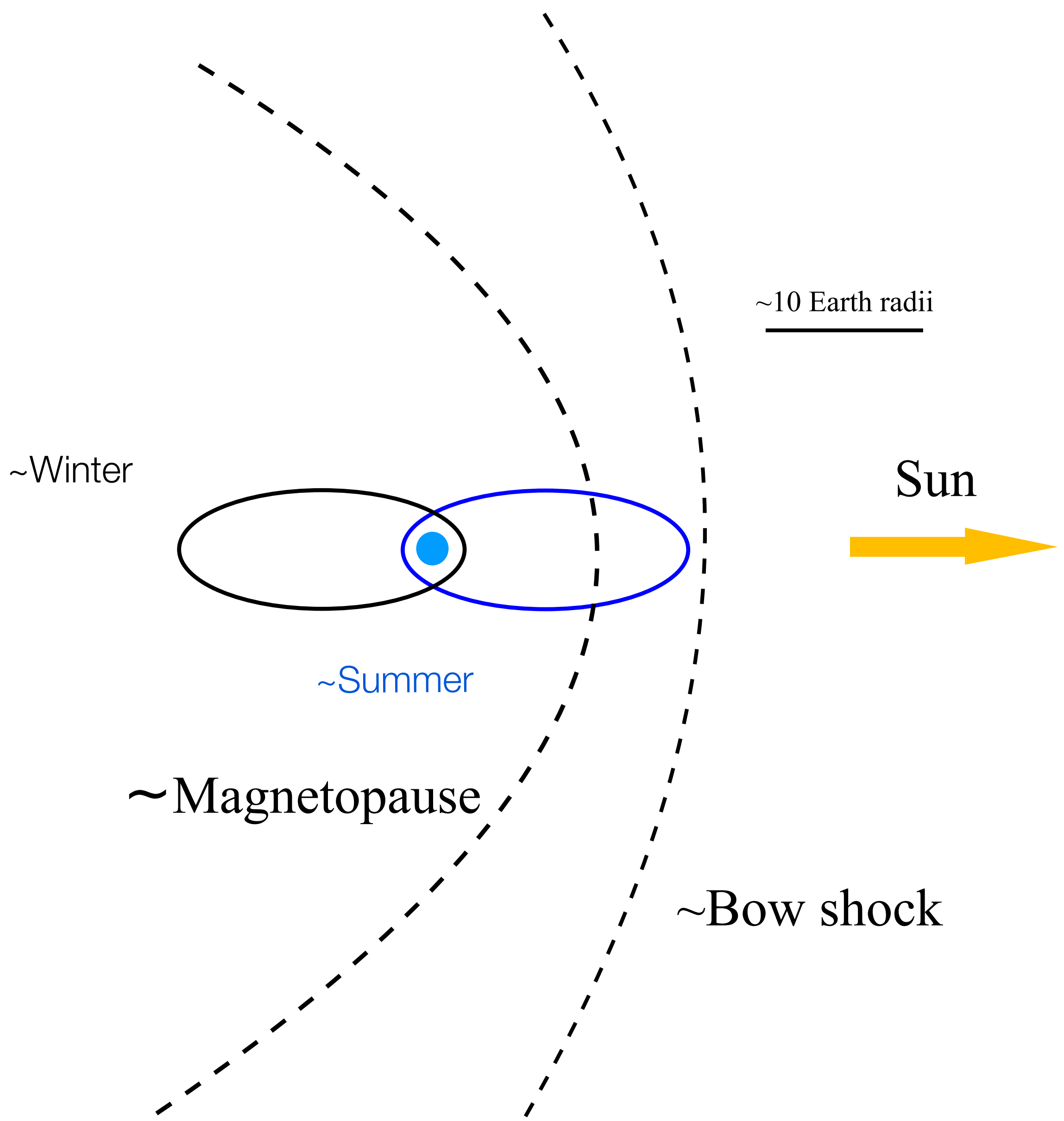






- SWCX emission modelled in Earth's exosphere
- Solar wind storms cause large increases in expected flux
- ...important consequences for XMM-Newton

XMM-Newton's orbit and viewing angles

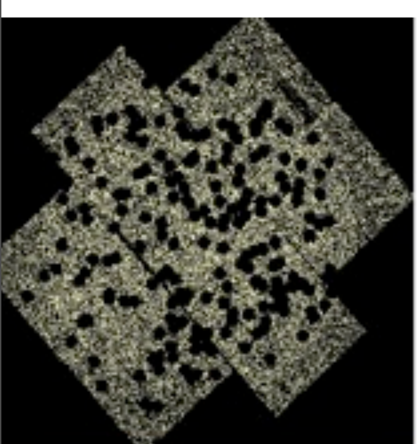


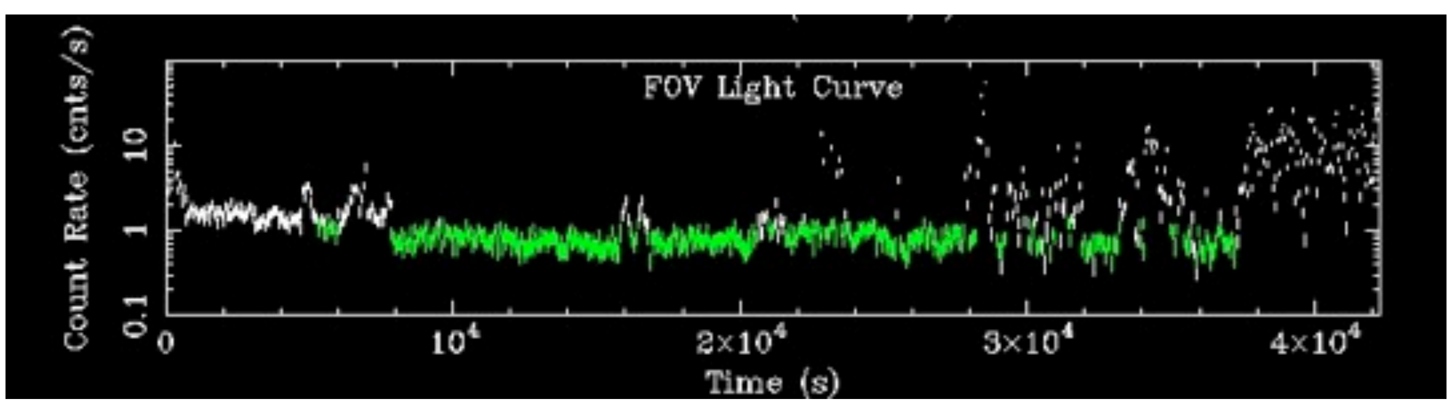
- XMM-Newton: X-ray observatory in highly elliptical orbit
- Seasonal effects expected
- Rough winter/summer split
- Dynamic magnetosheath, responds to solar wind pressure
- In summer, XMM-Newton can observe SWCX when line-of-sight passes through the magnetosheath
- Motivation of project: how many XMM-Newton observations are affected and the characterisation of these cases

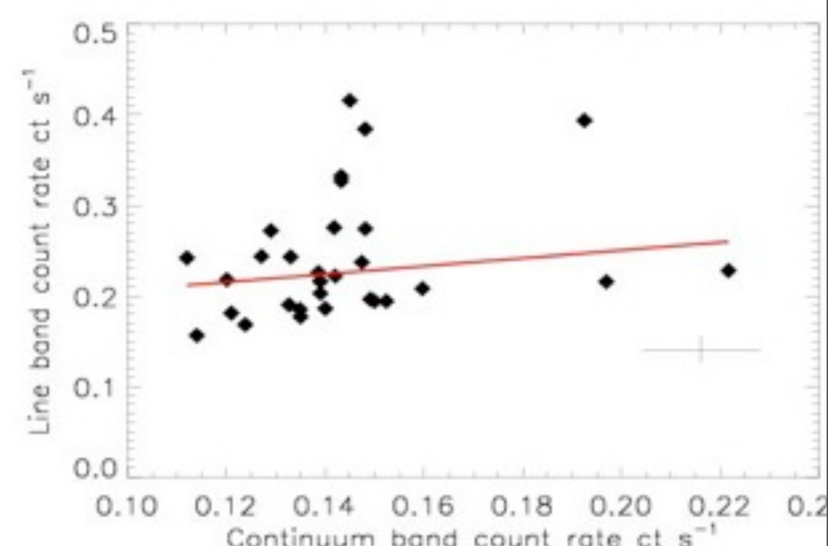
Searching for XMM-Newton observations affected by SWCX

- Using the imaging EPIC-MOS cameras combined, in full-frame mode
- No. obs., 3012, up to revn. 1781 (February 2000 - August 2009).

1. Cleaned observations for flare periods & point sources
2. Looked for short timescale variability - indicative of **variable SWCX** near Earth
3. Create two lightcurves; 0.5 - 0.7 keV & 2.5 - 5.0 keV (SWCX, continuum)
4. Scatter plot between lightcurves, statistics of line fit to judge if variable SWCX seen



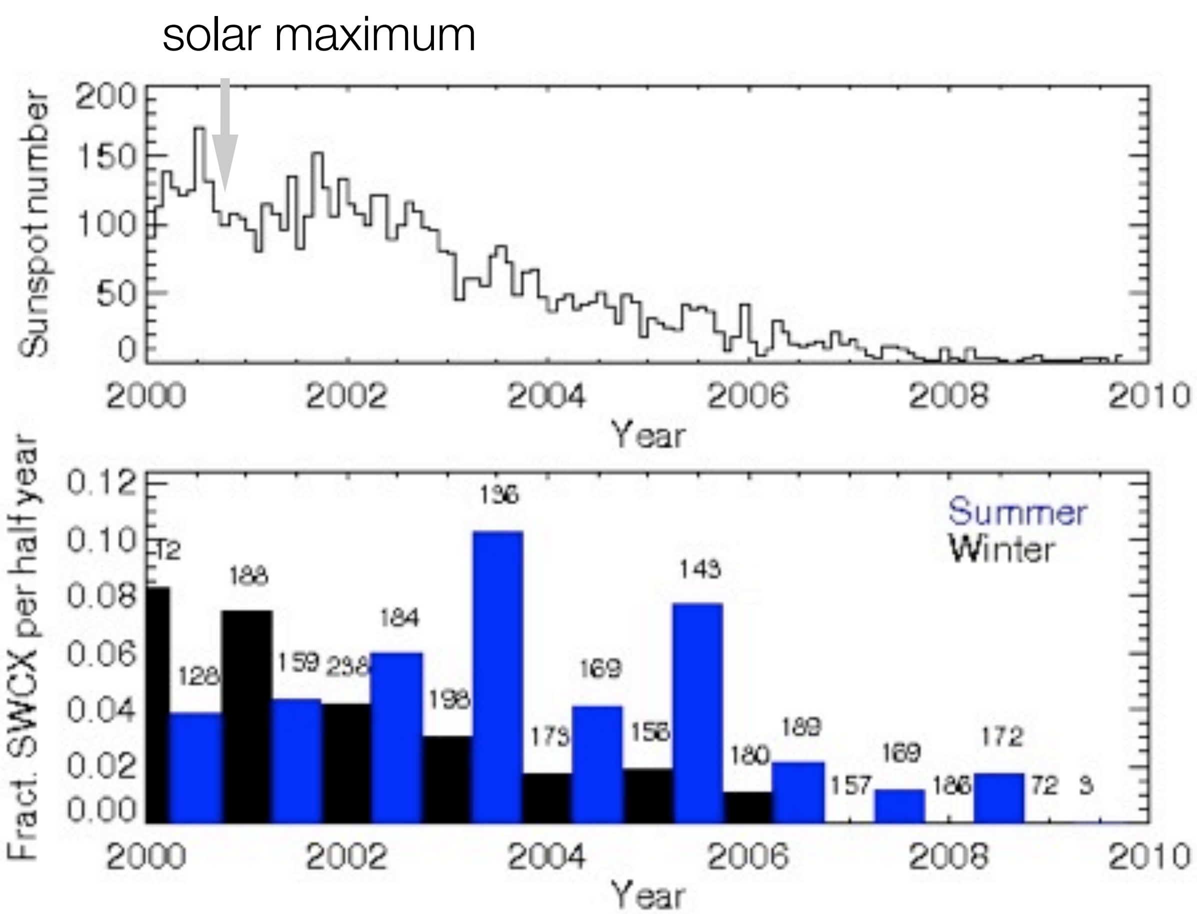




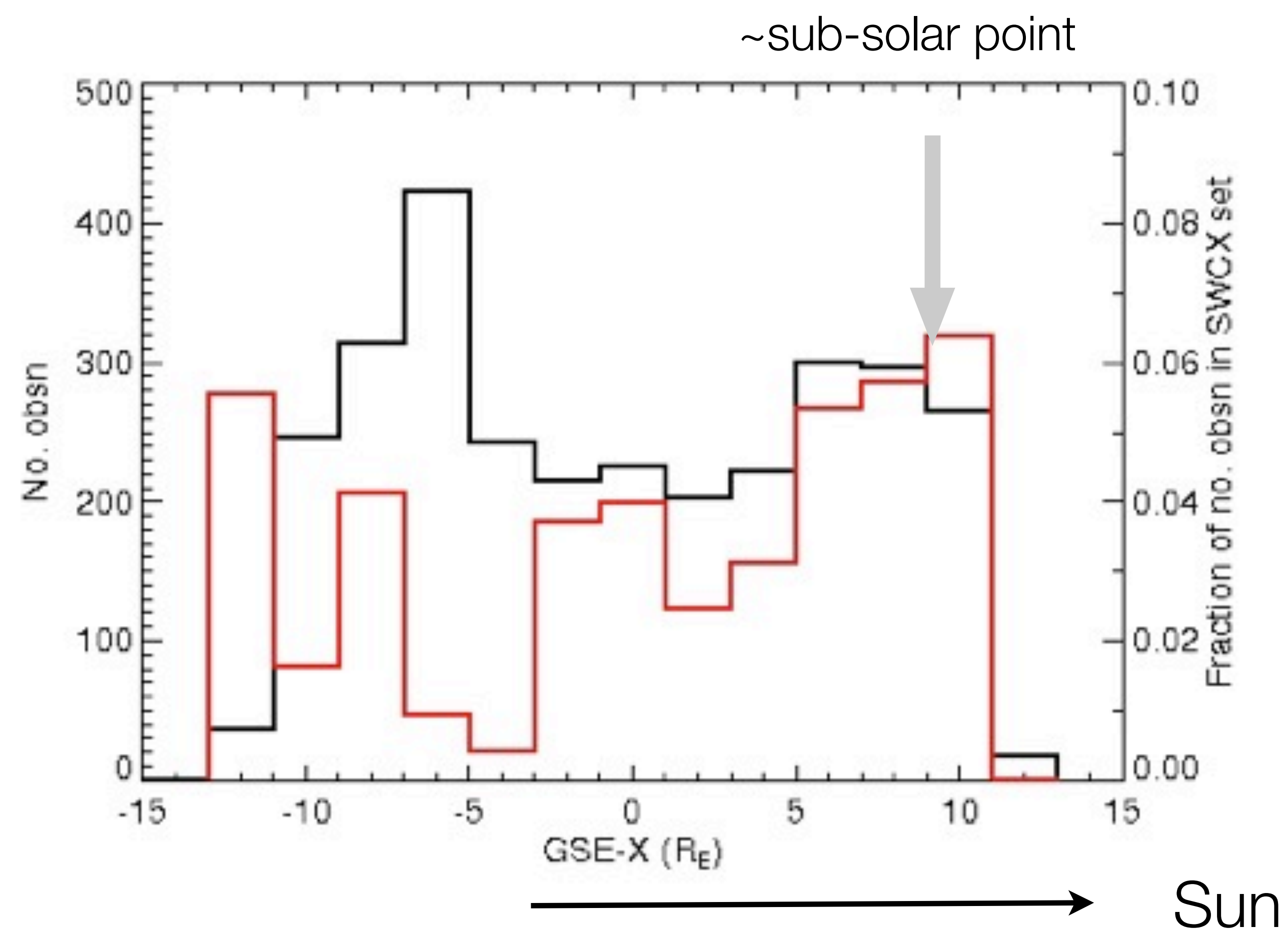
- **103 cases (~3.4% of set) of variable SWCX found** (Carter, Sembay & Read, 2011)

SWCX cases with respect to solar activity and XMM-Newton orbital position

- Cases preferentially detected in **summer**, as expected (summer/winter - 64/39)
- Cases preferentially detected about the **sub-solar point** (sunward magnetosheath)



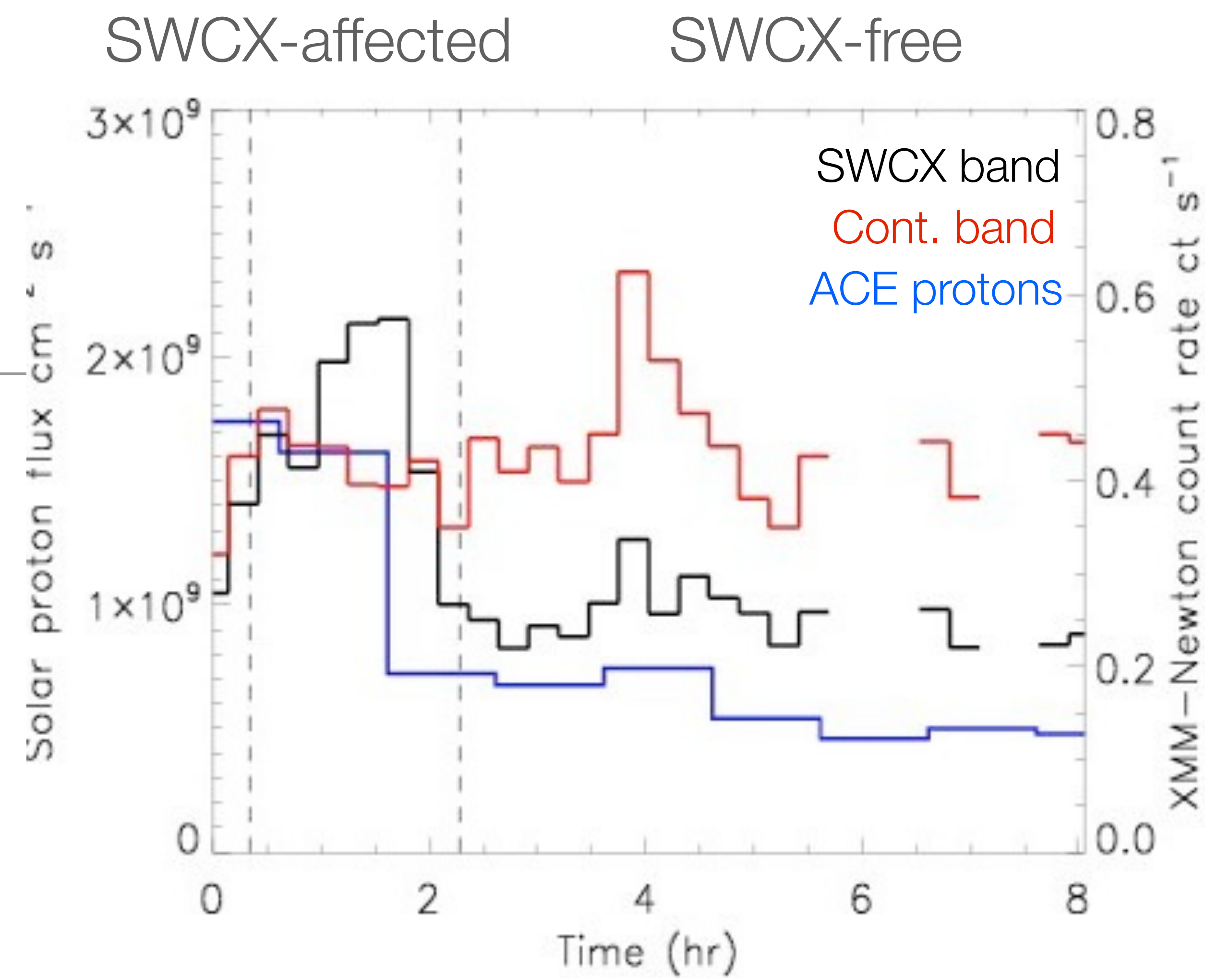
Very few observations with exospheric SWCX signatures towards solar minimum



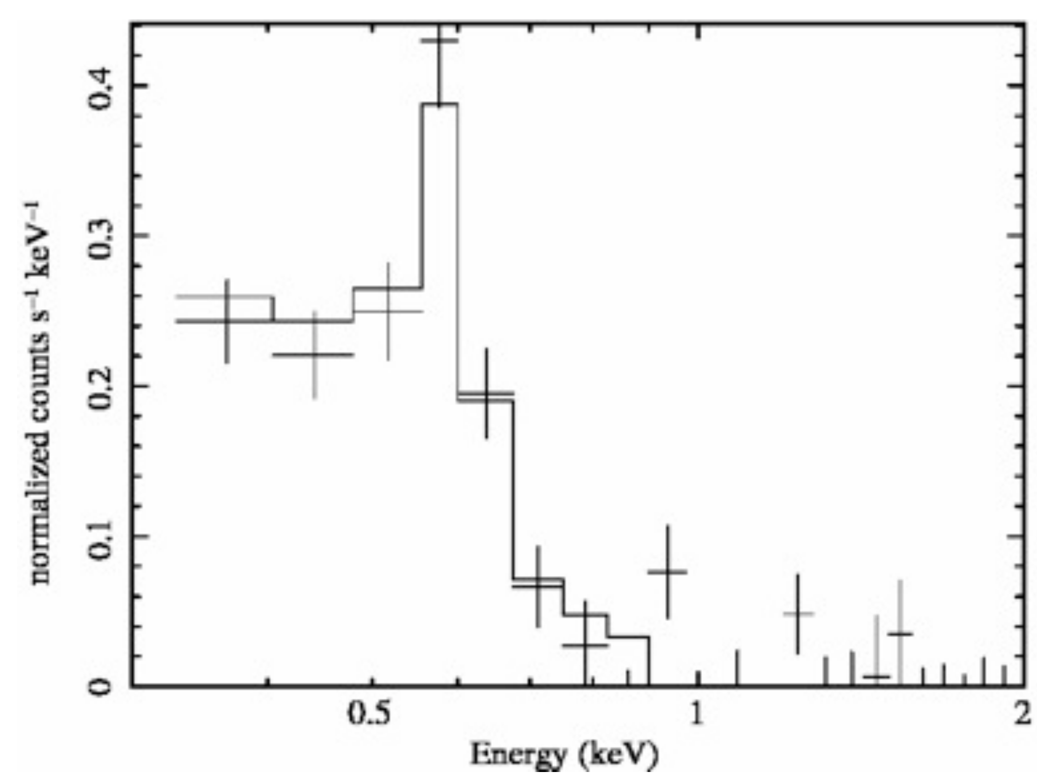
Fraction of all cases affected by SWCX in red

Spectral modelling

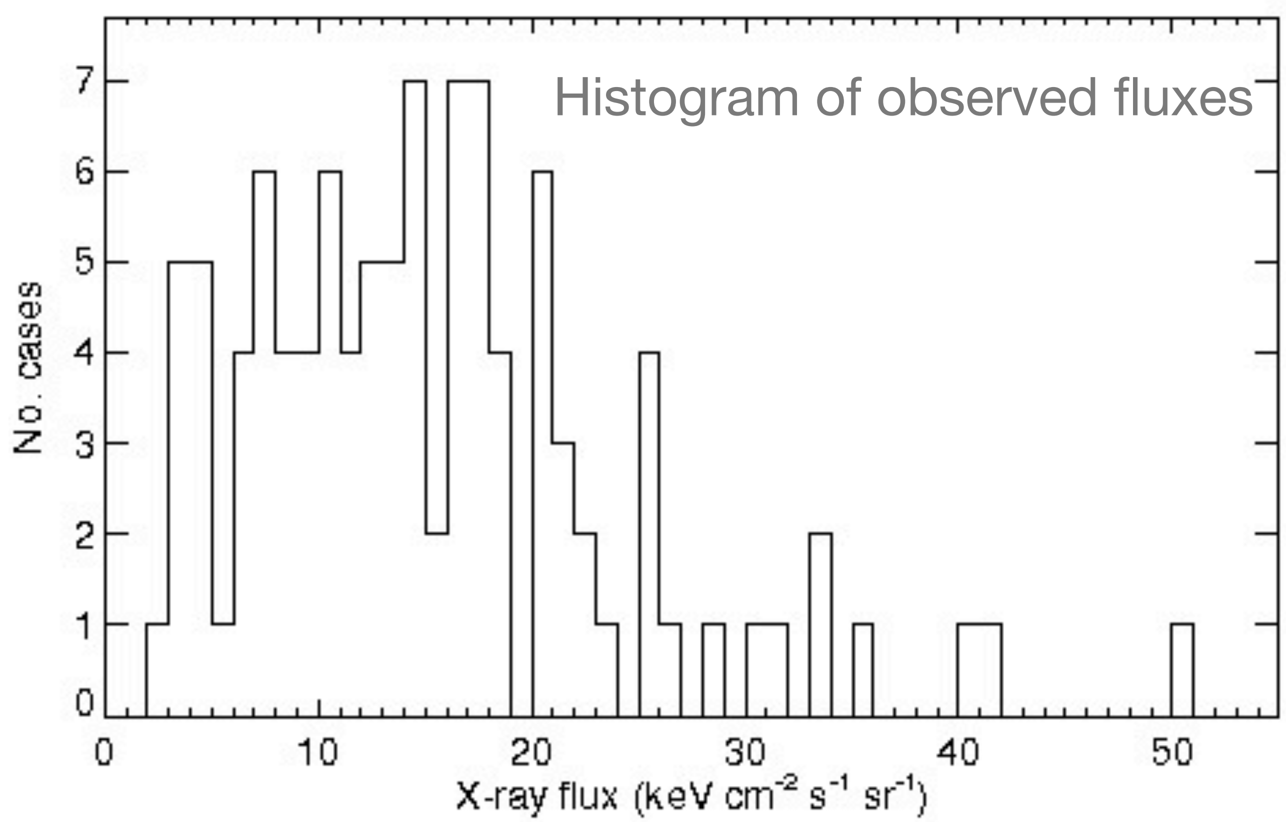
- Defined SWCX-affected and SWCX-free periods for each lightcurve
- Created spectra for each period
- Created resultant spectra
- Modelled each resultant spectrum using 38 Gaussian lines
- Relative normalisations based on the cross-sections of Bodewits 2007 (0.2 - 1 keV)
- Calculate flux 0.25 - 2.5 keV and also fluxes from individual lines



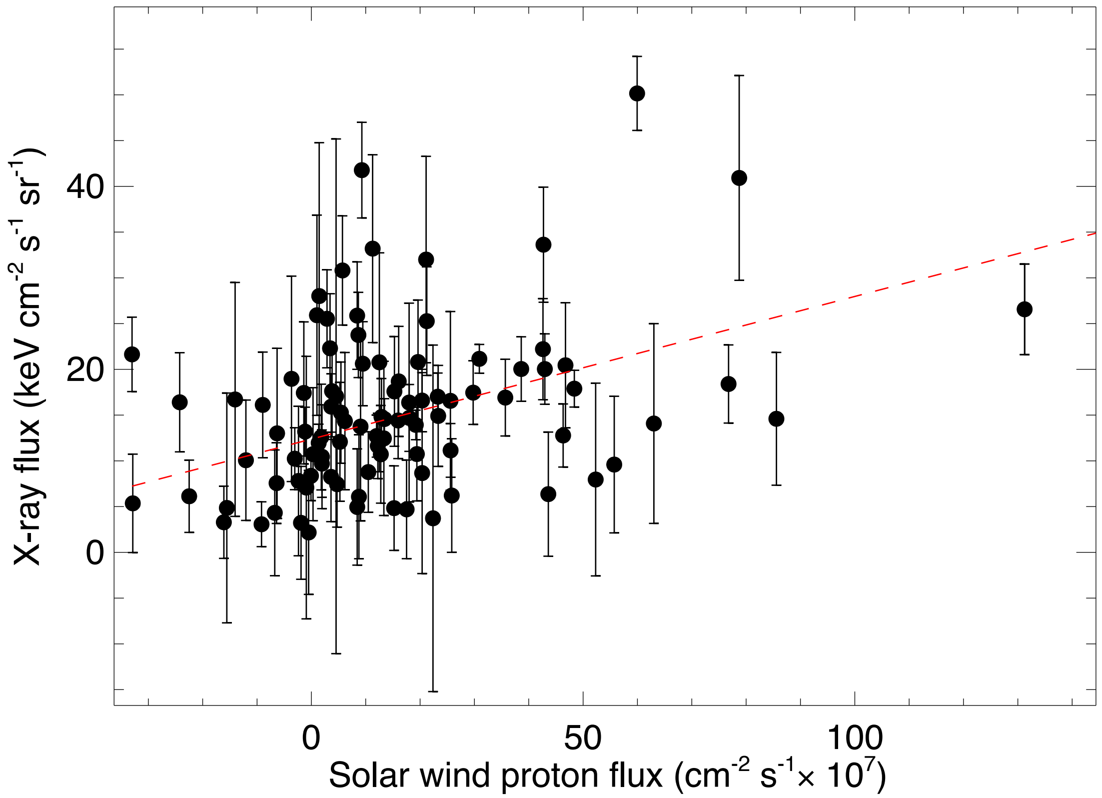
Ion	Energy (keV)
CV	0.299
CVI	0.367
NVI	0.420
NVII	0.500
OVII	0.561
OVIII	0.653
NeX	1.022
MgXI	1.330
SiXIV	2.000



Observed SWCX fluxes, 0.25 - 2.5 keV



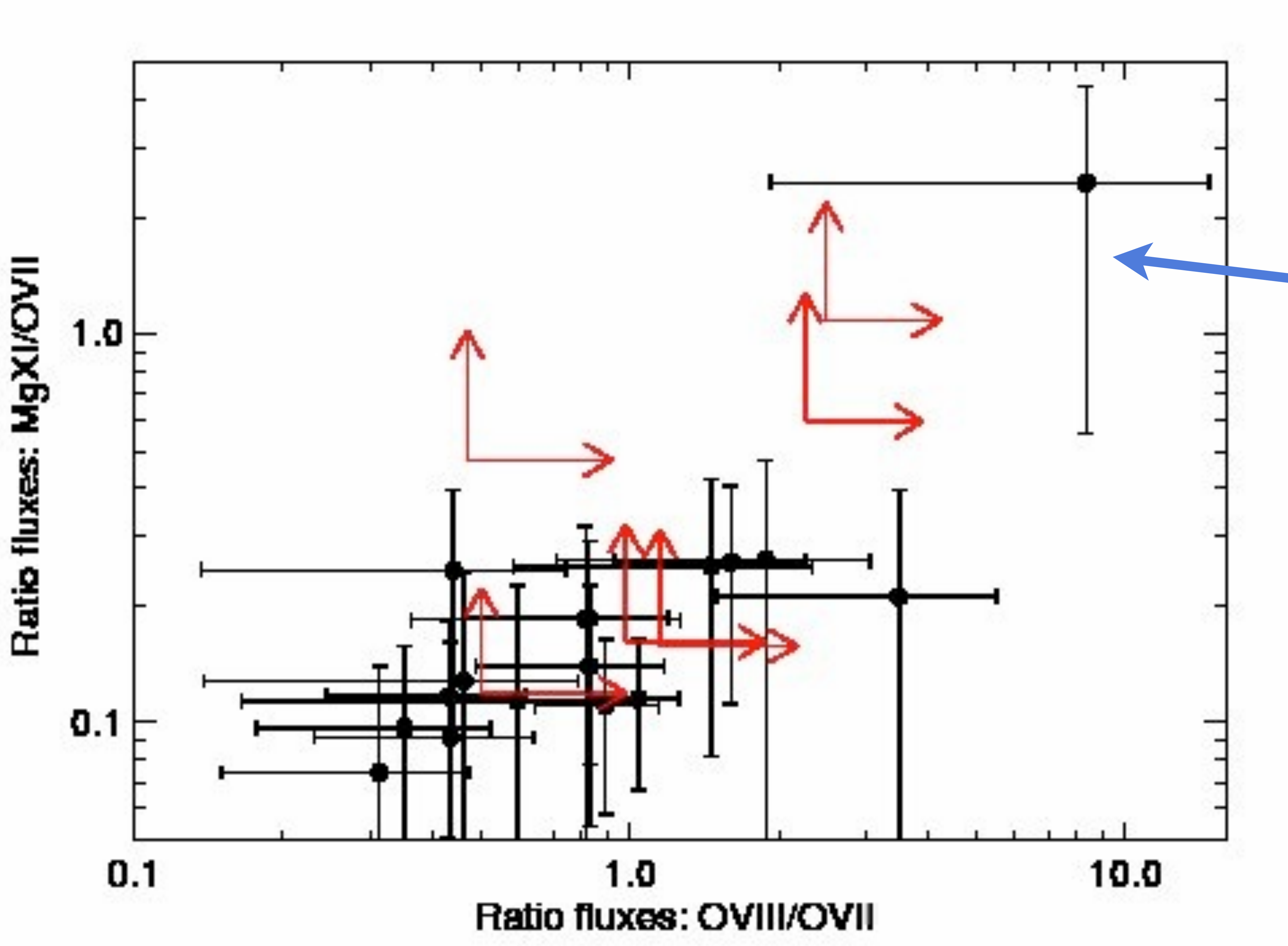
Observed flux versus mean solar wind proton flux difference between SWCX-affected and SWCX-free period as selected from X-ray lightcurve



High solar wind proton flux ⇒ high SWCX X-ray flux

- However, no simple linear relationship
- Considerable scatter, but SW can have large compositional differences: slow, fast, Coronal Mass Ejection

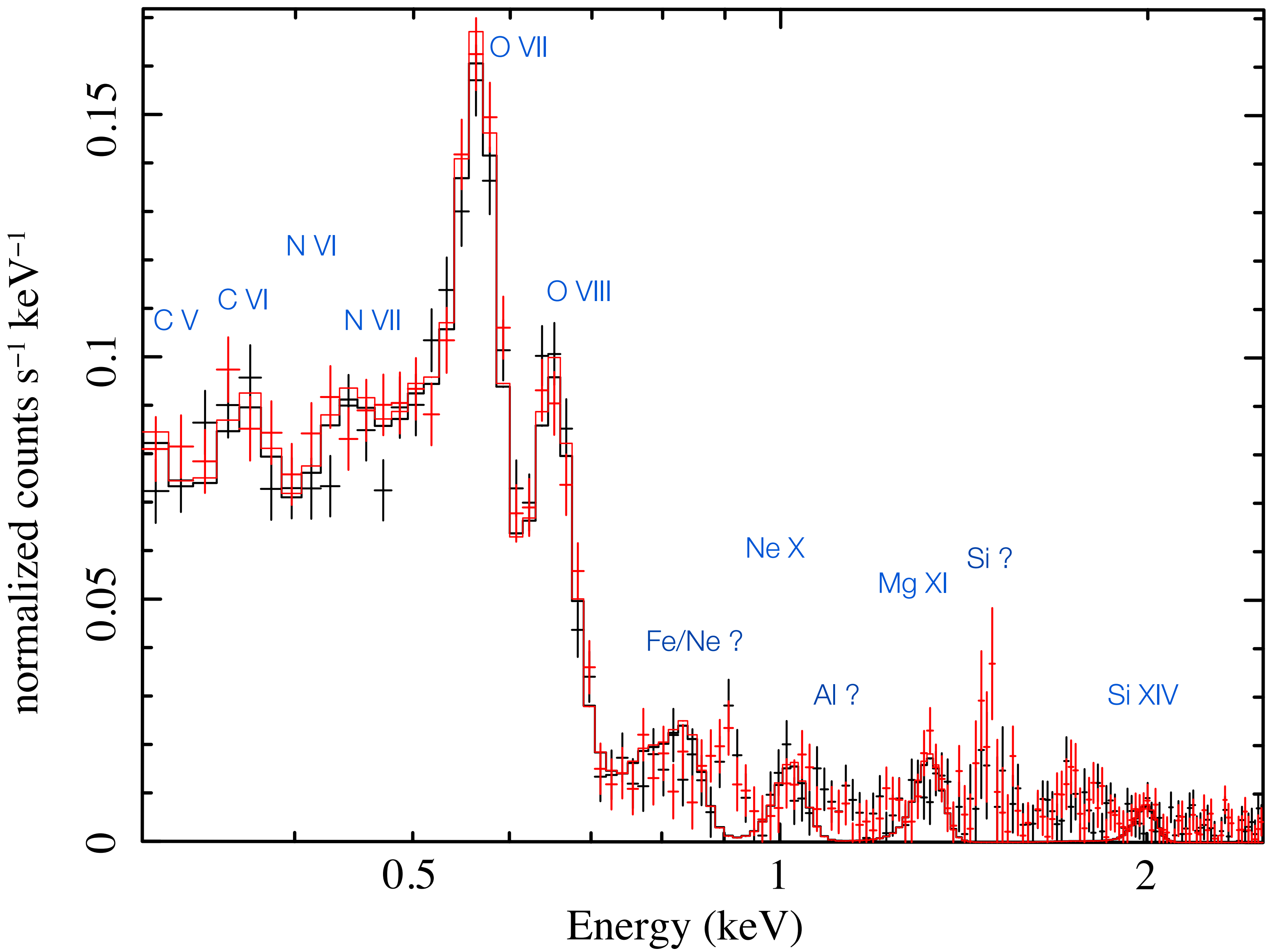
Line strengths - diagnostics of solar wind type?



Coronal Mass Ejection, Carter, Sembay & Read 2010 - later in the talk

Stacked SWCX spectra for all exospheric cases

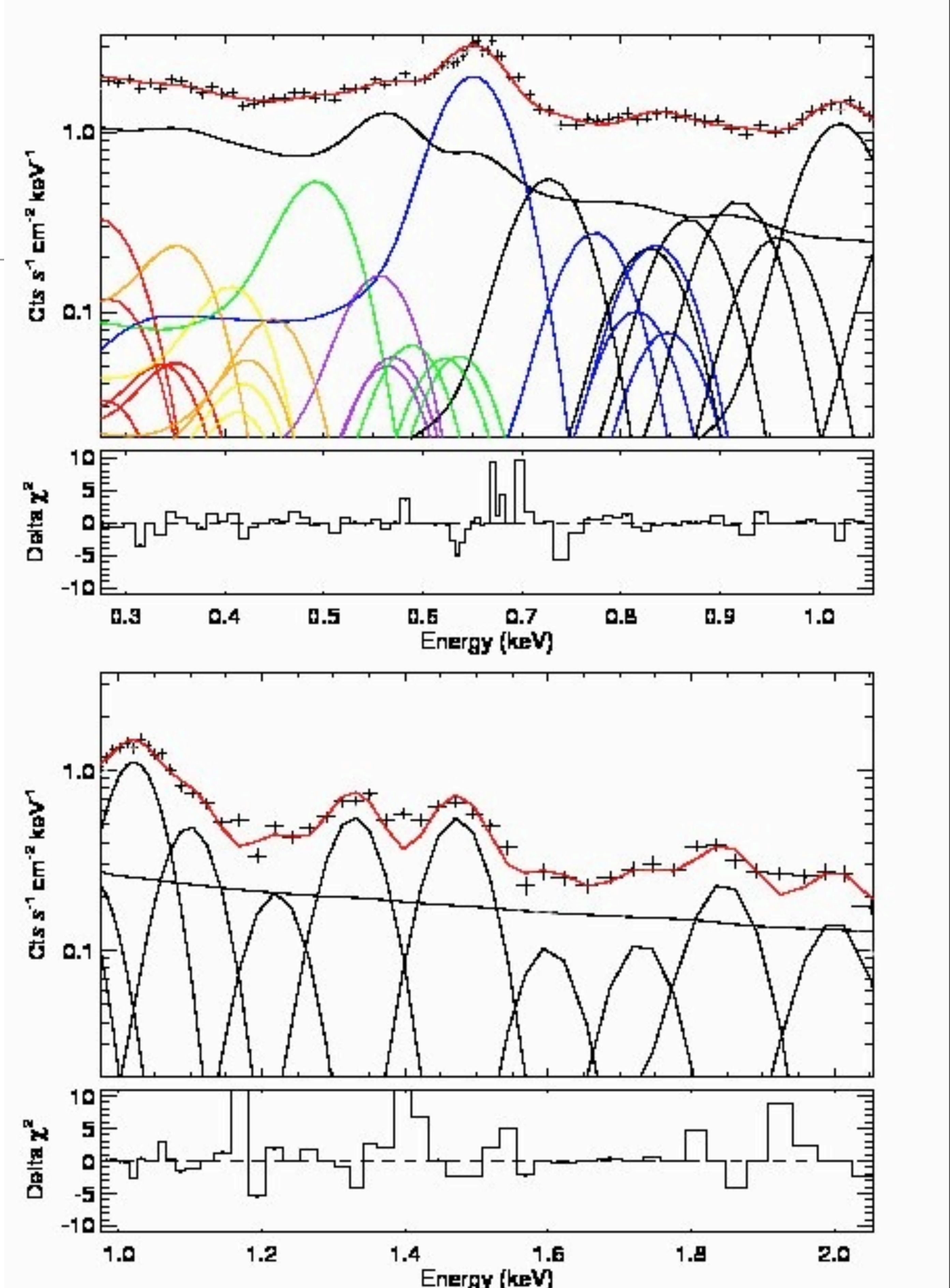
- For MOS1 (black) and MOS2 (red), 103 cases
- Spectral resolution of EPIC-MOS cameras: moderate, E/ΔE ~ 20 at 1 keV



- OVII triplet: 7.6 +/- 0.3 LU
- OVIII: 3.0 +/- 0.1 LU
- But, O^{8+} can charge exchange to O^{7+} along line of sight, so ratio does not accurately represent SW composition
- OVII triplet: forbidden line normalisation stronger than resonance line as expected for charge exchange

A standout case

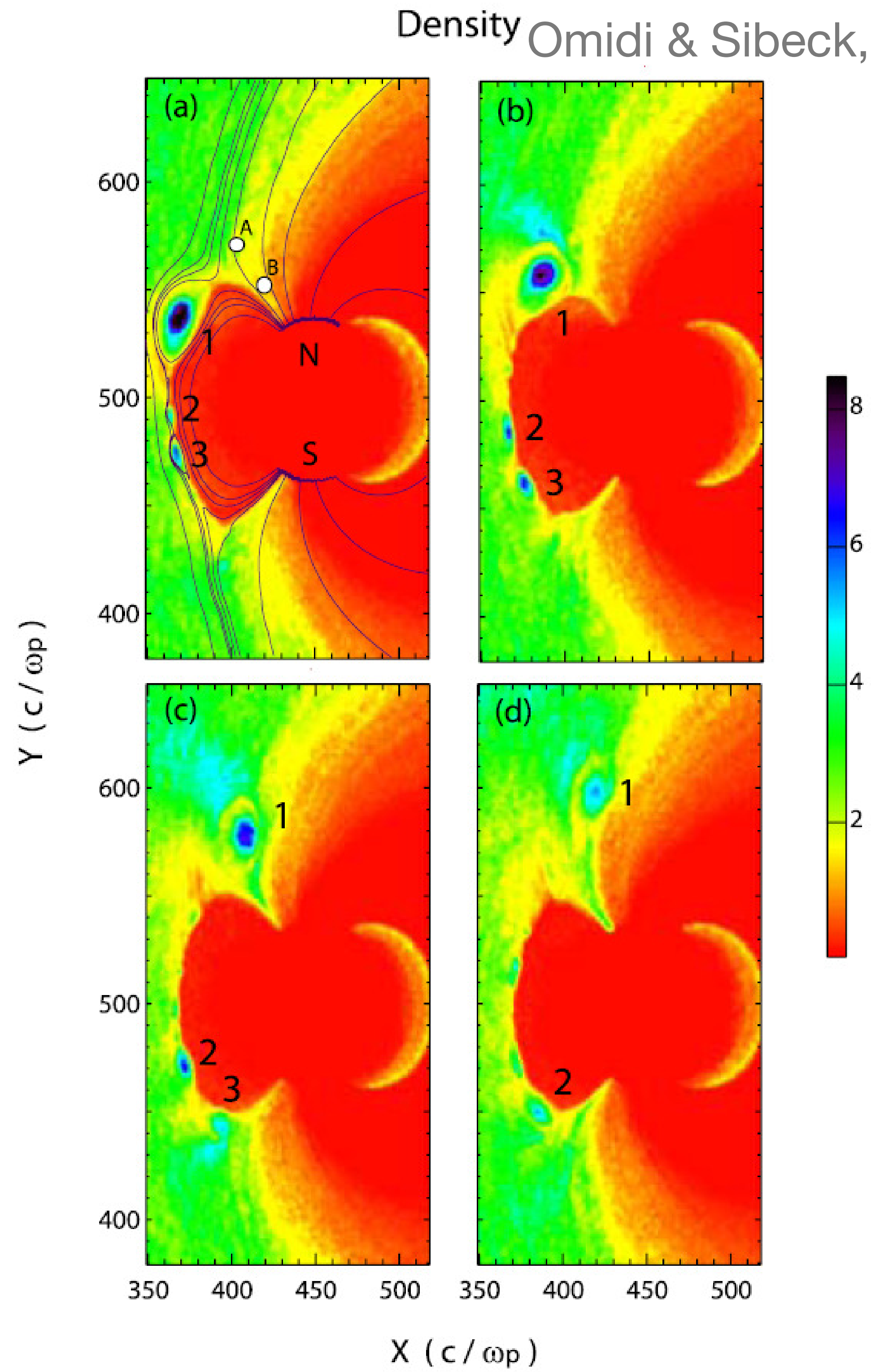
- Case warranted particular extra study - strongest case (Carter, Sembay & Read 2010)
- Two other observations, same sky target - helpful to extract the sky background and concentrate on the SWCX signatures
- Anything left over is (mainly/assumed) SWCX
- Looked at data from all three X-ray imaging detectors on XMM-Newton
- Very strong OVIII and upstream Coronal Mass Ejection detected by solar wind monitors
- Lots of other high-energy lines

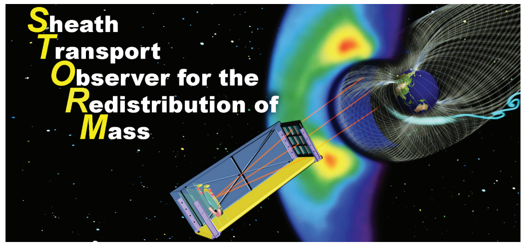


Using CX to image the magnetosheath

- Charge-exchange could be used to **image large areas** of the magnetosheath
- Various transient phenomena could be observed, for example ‘flux-transfer events’ or boundary events at the magnetopause
- Use **very large field of view** optics
- X-ray imaging using microchannel plates, and a CCD or MCP detector at the focal plane
- Several mission proposals have been submitted, in Europe and the US
- **AXIOM, AXIOM-C and STORM**
- Sounding rocket experiment due late 2012

Omidi & Sibeck, 2007



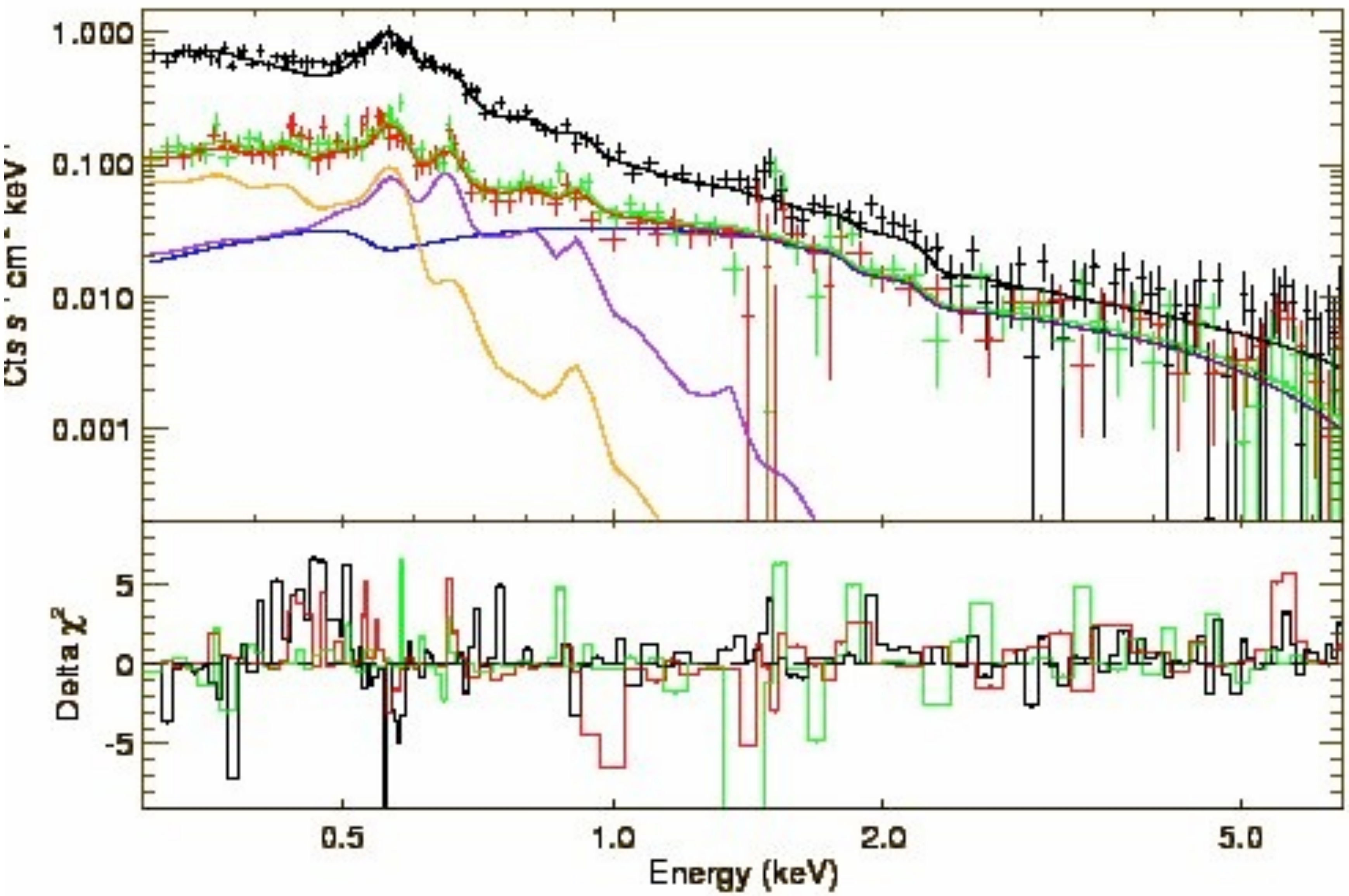


Summary

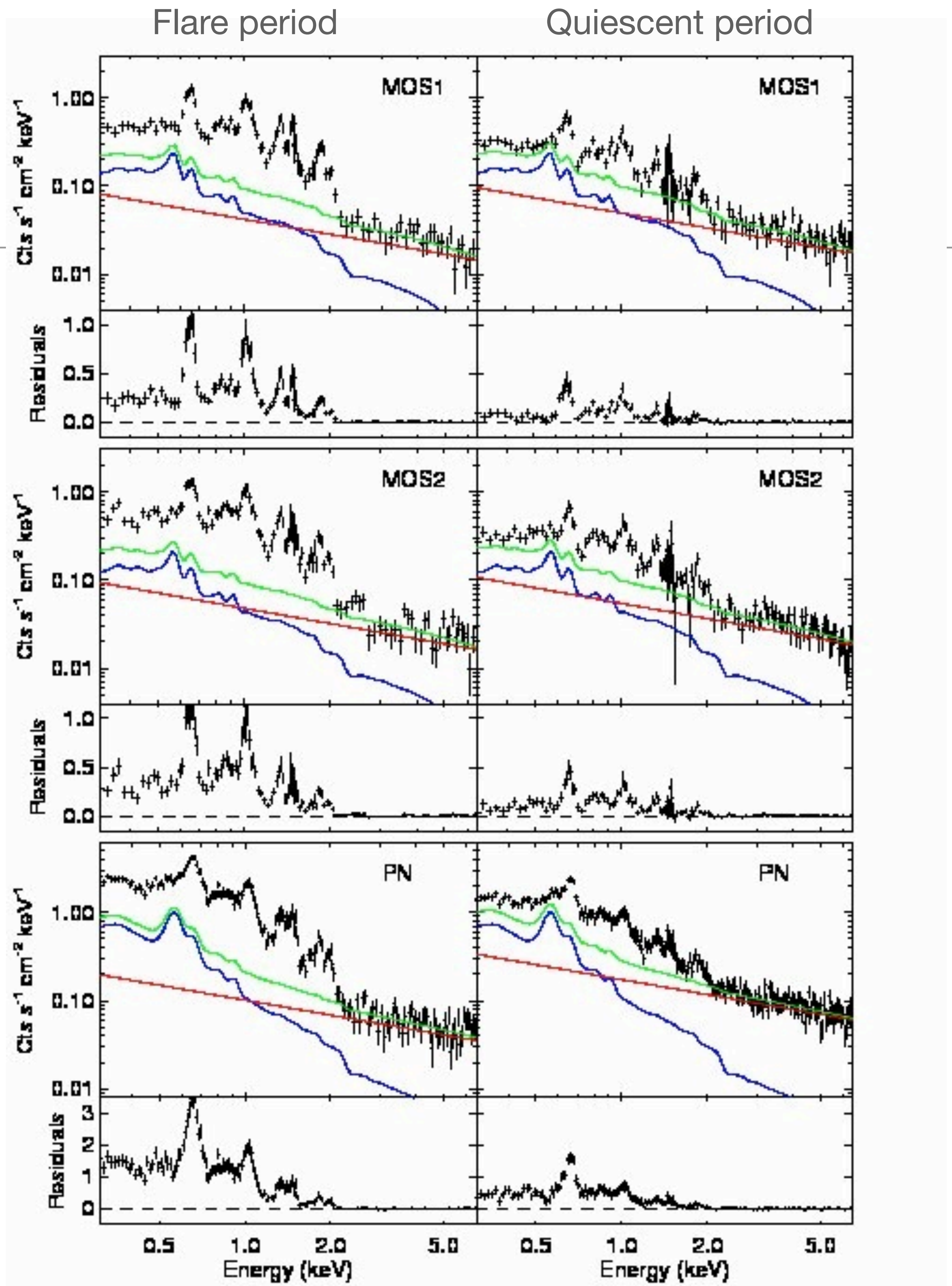
- 3.4% of XMM-Newton observations contain a detectable level of temporally variable SWCX, important for users
- Lower limit to the number of observations affected (SWCX at heliopause, slowly varying cases etc. not detected by this method)
- A coronal mass ejection has been observed by XMM-Newton, with distinct spectral characteristics
- Temporal and spatial information from SWCX occurring in the vicinity of the Earth can be used to understand how the Sun and Earth plasmas interact and provide information about the heavy-ion composition of the solar wind
- **Could use SWCX to image the Earth's magnetosheath with wide field optics: AXIOM/AXIOM-C/STORM**

- THANK YOU

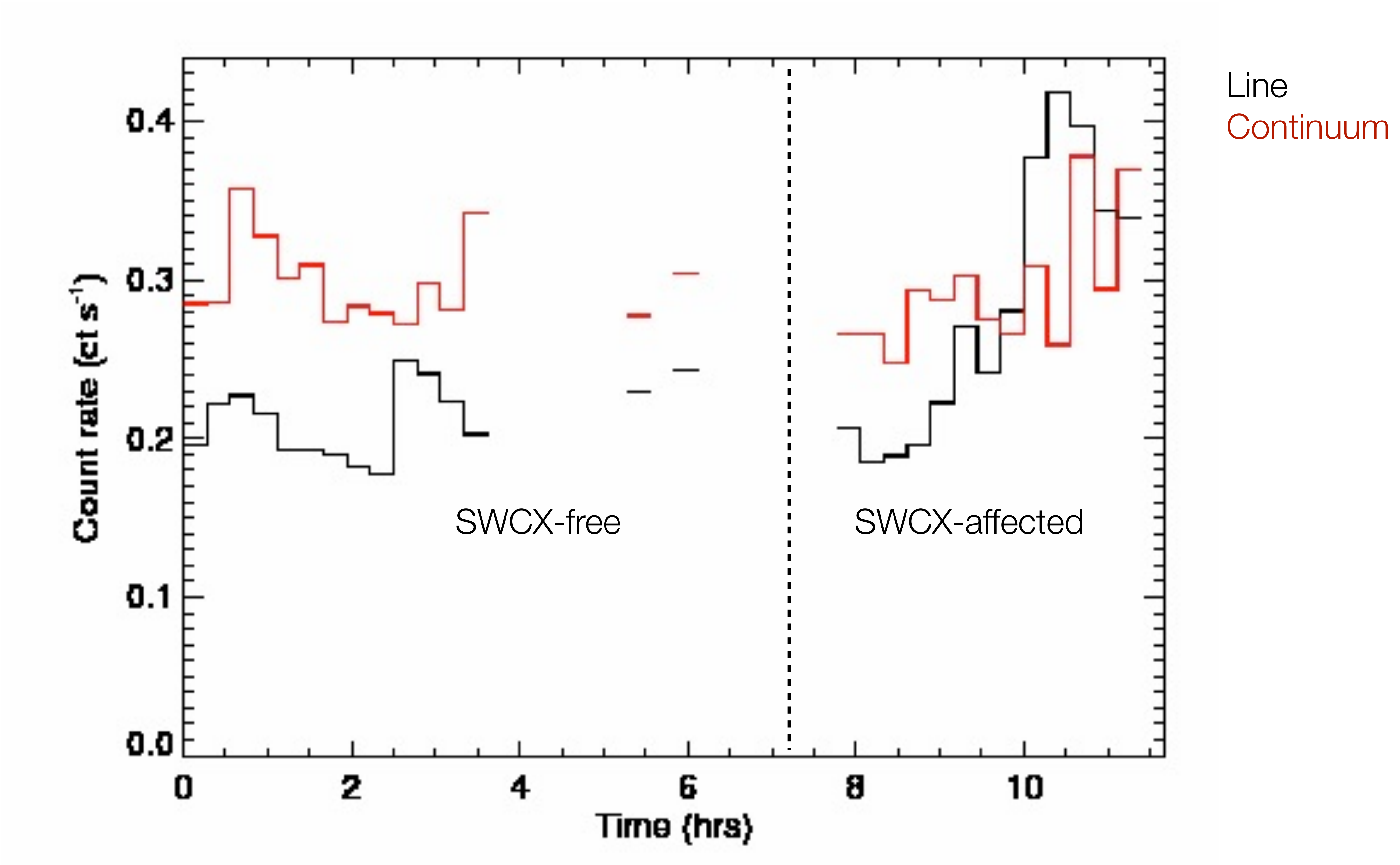
Background subtraction for CME case



- CME split into flare and quiescent periods

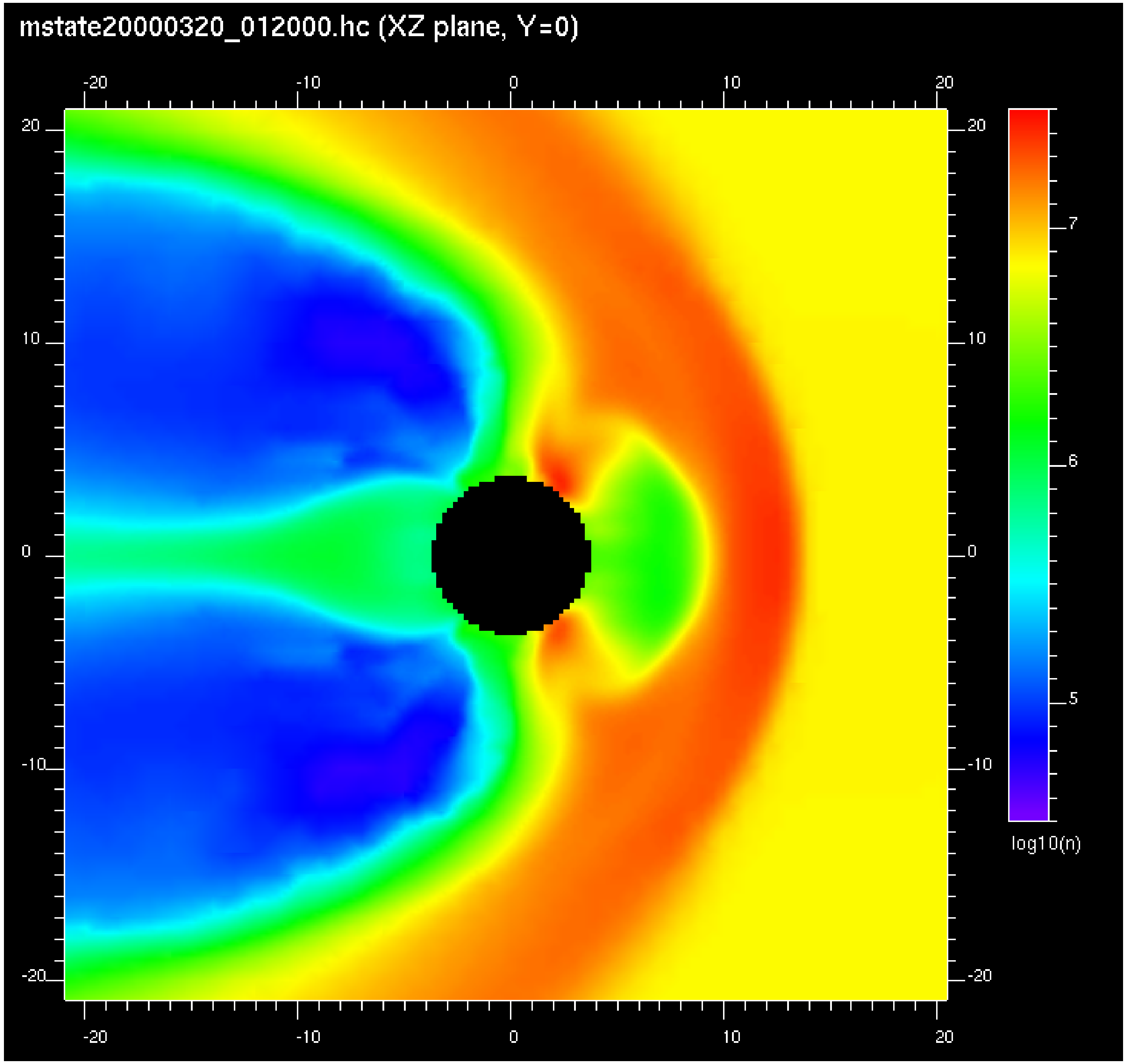


Alternative standard lightcurves

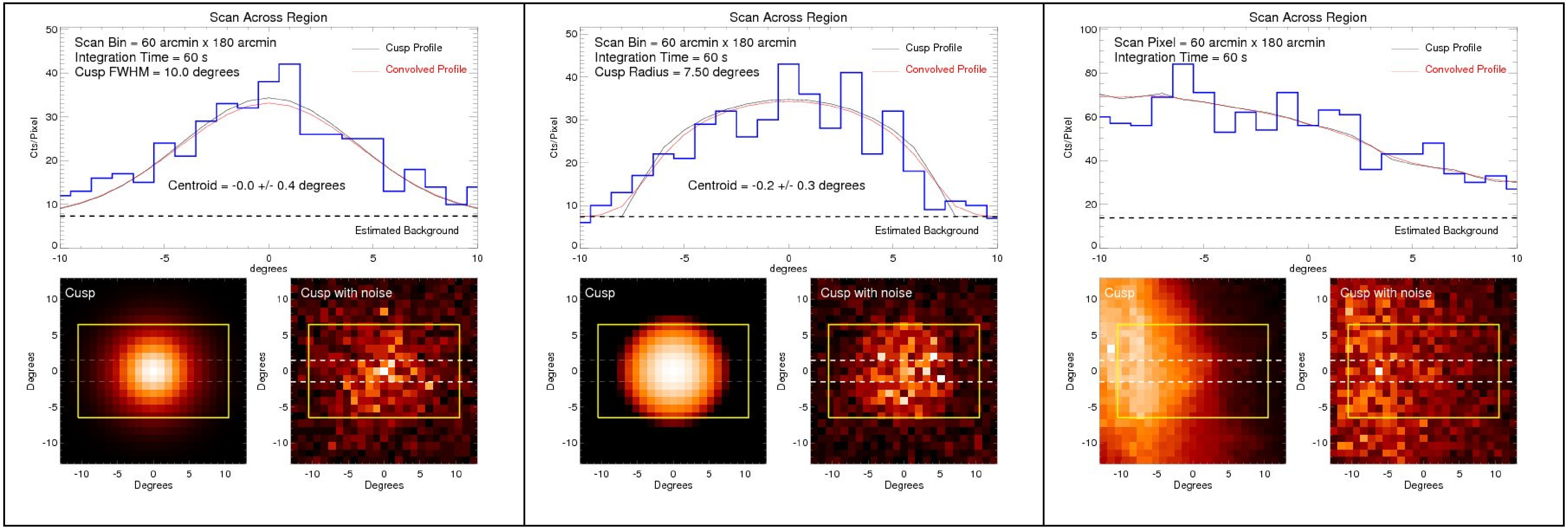


Minna Palmroth GUMICS, MHD simulation

- Plasma density



AXIOM-C WFI feasibility



- Simulated WFI observations of cusp like structures
- 60 s integration
- Left and centre: simulated cusp structures based on an XMM-Newton observation of a CME
- Right: CCMC BATSRUS simulation of the geocoronal storm for conditions observed during the Bastille Day event