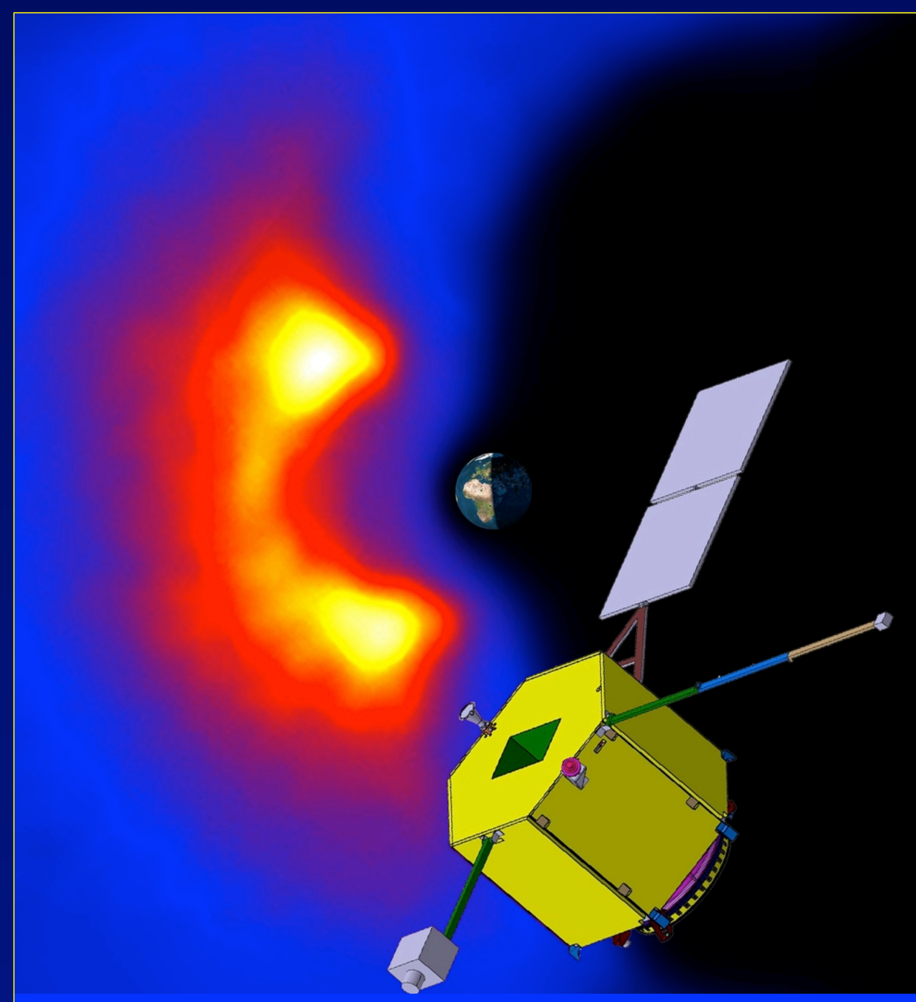
AXIOM: Advanced X-ray Imaging of the Magnetosphere

S. Sembay[1], G. Branduardi-Raymont[2], J. Eastwood[3], C. Wang[4], J. A. Carter[1], M. Collier[5], H. Hietala[3], Z. X. Ling[4], S. Milan[1], M. Palmroth[6], J. Rae[2], A. M. Read[1], D. G. Sibeck[5], T. Sun[4], B.Walsh[5], W. M Yuan[4]

[1]Department of Physics and Astronomy, University of Leicester, UK
[2]Mullard Space Science Laboratory, University College London, UK
[3]The Blackett Laboratory, Imperial College London, UK
[4]National Space Science Center, CAS, China
[5]NASA/Goddard Space Flight Center, USA
[6]Finnish Meteorological Institute, Helsinki, Finland

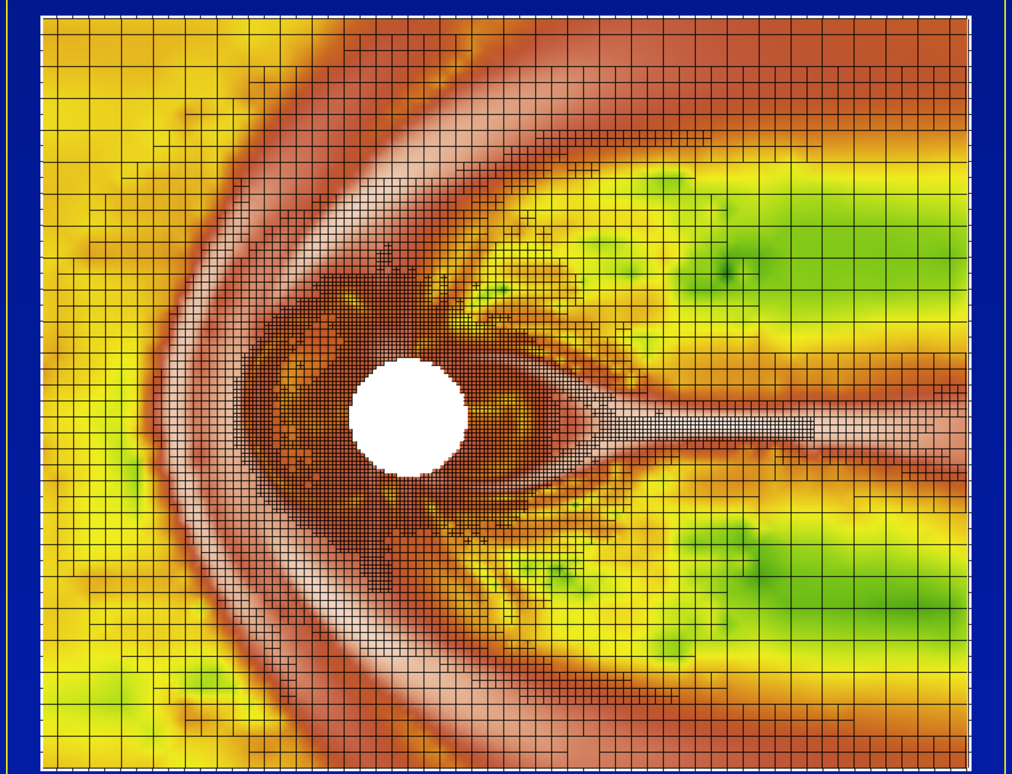
Abstract: AXIOM is a concept mission which aims to explain how the Earth's magnetosphere responds to the changing impact of the solar wind. As the world becomes more dependent on complex technology, both in space and on the ground, we become more exposed to the vagaries of space weather, the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of technological systems and in extreme cases endanger human life and health. Basic research into the plasma and magnetic field environment of the Earth, and of the Solar System overall, directly leads to strategies for predicting and mitigating the effects of space weather. Plasma and magnetic field environments can be studied in two ways; by in situ measurement, or by remote sensing. These two techniques are complementary. In situ measurements provide precise information about plasma behaviour, instabilities and dynamics, however, they cannot give the global view which is necessary to understand the large-scale configurations and overall evolution of the plasma. AXIOM can provide that global view via ultra-wide field-of-view imaging of the X-ray emission which maps the magnetosheath structure.



Magnetosheath imager near the Earth-Moon L1 point. See Branduardi-Raymont et al. 2012 for an in-depth description of this particular mission profile, instrumentation and science goals

Scientific Target

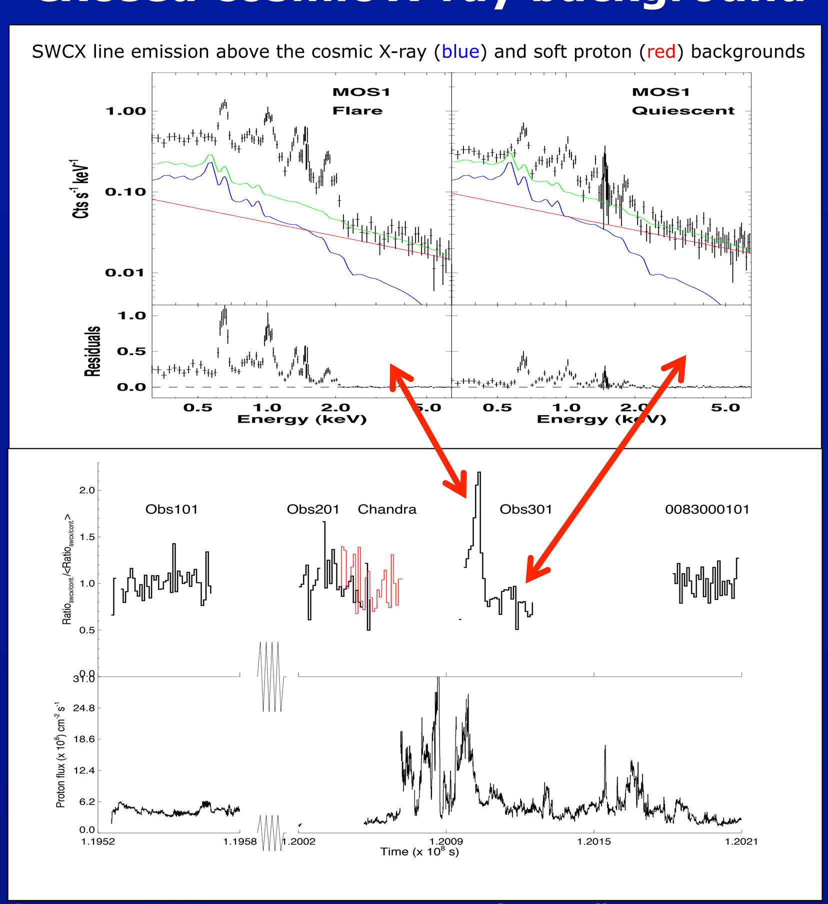
The collisionless shock formed by the interaction of the solar wind with the Earth's magnetic system



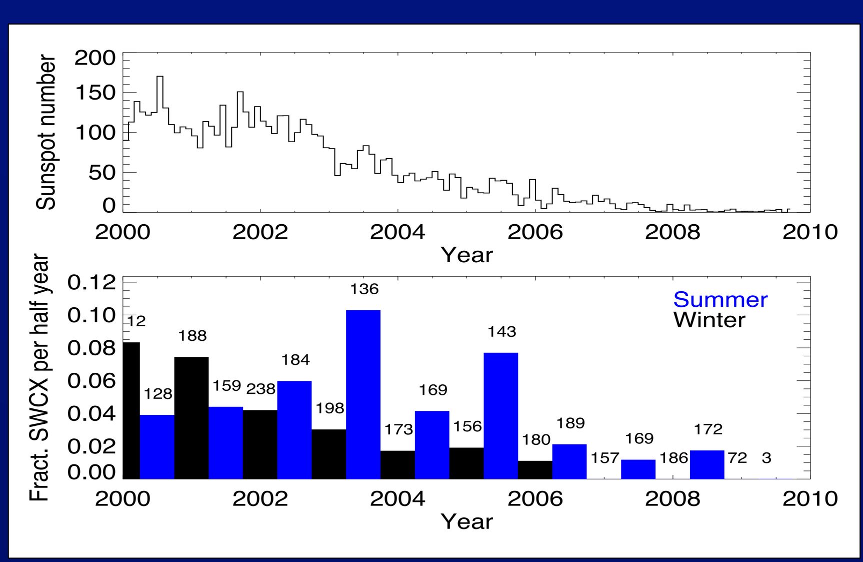
2-D cut of an MHD simulation of the plasma density around the Earth generated by the GUMICS-4 code (see Janhunen et al. 2012)

Validation of detectable SWCX X-ray Emissivity

Detection of local SWCX by narrow field X-ray observatories(e.g. XMM-Newton and Suzaku). Signature is a variable diffuse signal with spectrum characteristic of the CX process. **Strength can significantly exceed cosmic X-ray background**



(Top) XMM EPIC X-ray spectra from flaring portion of light curve of diffuse emission (middle) from XMM (black) and Chandra (red). (Bottom) ACE solar wind proton flux (Carter, Sembay & Read 2010)



Frequency of XMM observations with detectable geospace SWCX emission (bottom) compared with sunspot frequency (top). SWCX events are correlated with solar activity as expected (Carter, Sembay & Read 2011)

Key Science Questions that can be addressed by Global Imaging

Magnetopause physics

- How do upstream conditions control magnetopause position and shape and magnetosheath thickness?
- How does the location of the magnetopause change in response to prolonged periods of sub-solar reconnection?
- Under what conditions do transient boundary layers, such as the plasma depletion layer, arise?

Cusp physics

- Cusp morphology – what are the size and shape of the cusps?
- How do the cusps move in response to changes in the solar wind?
- How does cusp density depend on magnetospheric coupling?

Shock physics

- What controls where the bow shock forms upstream of a planetary magnetosphere?
- How does the steady-state thickness of a collisionless shock depend on the upstream conditions?

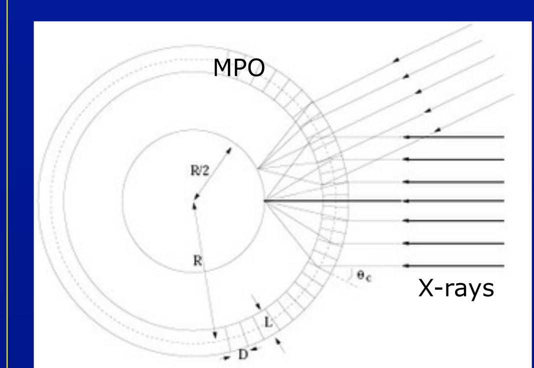
How do coronal mass ejections (CMEs) interact with the magnetosphere?

What are the conditions along the flanks of the magnetosheath?

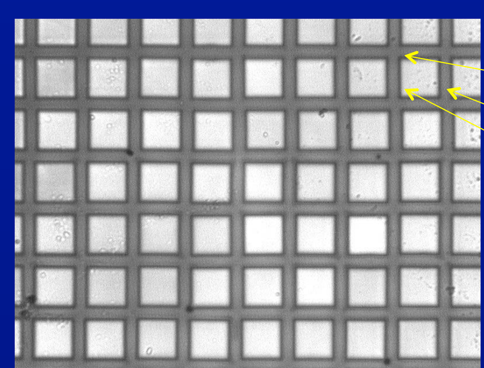
How does the shape of the magnetosphere change in response to strong internal currents and geomagnetic storms?

Imaging Technology

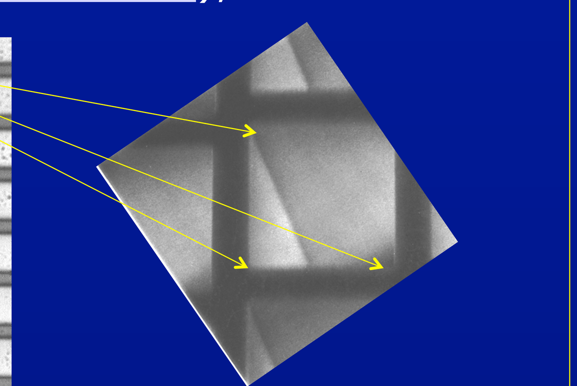
Ultra-wide field-of-view X-ray imaging can be achieved with low mass using micropore optic (MPO) plates configured as a Lobster-eye optic. MPOs have been developed in a collaborative programme by Leicester University, UK and Photonis (www.photonis.com), France



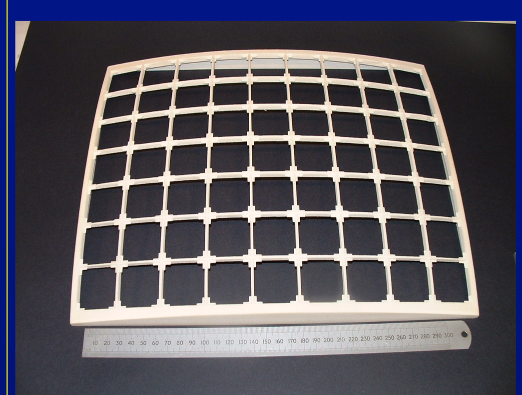
Principle of Lobster-eye optics. Parallel rays are brought to a focus at half the radius of curvature of the optic plane.



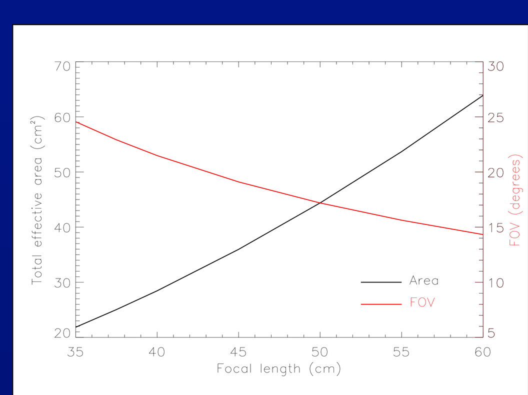
Optic plane is made from an array of slumped glass plates, each typically 4 cm x 4 cm, of 1 mm thickness.



Plates have square channels typically 20 µm in width with a wall thickness of 6 µm (open area is ~ 60%)



FOV is built up by placing required number of plates in a holder. e.g. 30 cm optic with a focal length of 37.5 cm has a 23° FOV. Typical optic mass is ~ 1 kg



Optic design involves a trade-off between focal length, effective area and FOV for a given optic size. Here these parameters are shown for a 30 cm x 30 cm optic.

A prototype imager using one MPO (central facet) has been built by NASA/GSFC and flown on a sounding rocket experiment (Thomas, N. E. et al. 2013)

References:
[1] Branduardi-Raymont, G., Sembay, S., Eastwood, J. P. et al. 2012, Expr. Astr., 33, 403
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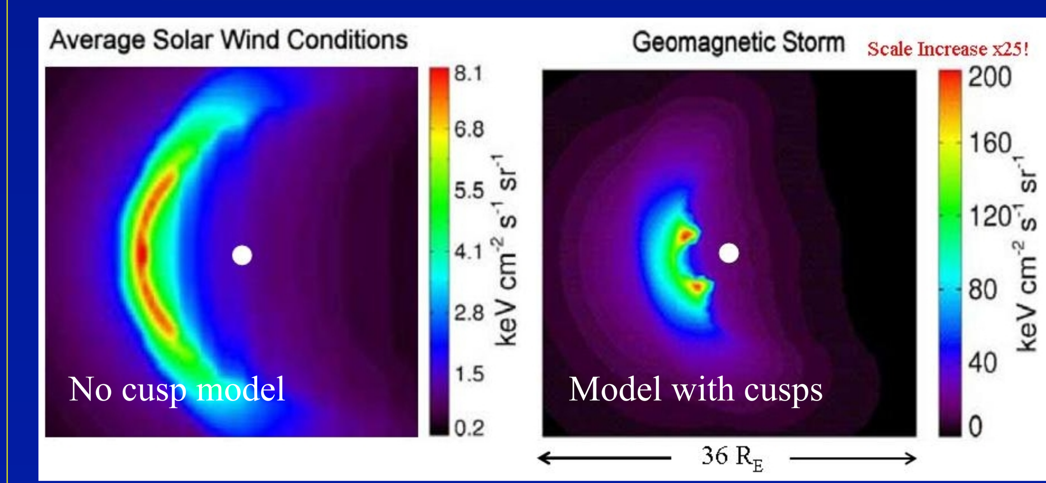
[7] Robertson, I. P. and Cravens, T. E. 2006, ApJ, 544, 558

Mechanism for Global Imaging of the System

Solar Wind Charge Exchange (SWCX): Heavy solar wind ions in collision with neutral target atoms (hydrogen) in the Earth's exosphere produce EUV and X-ray photons

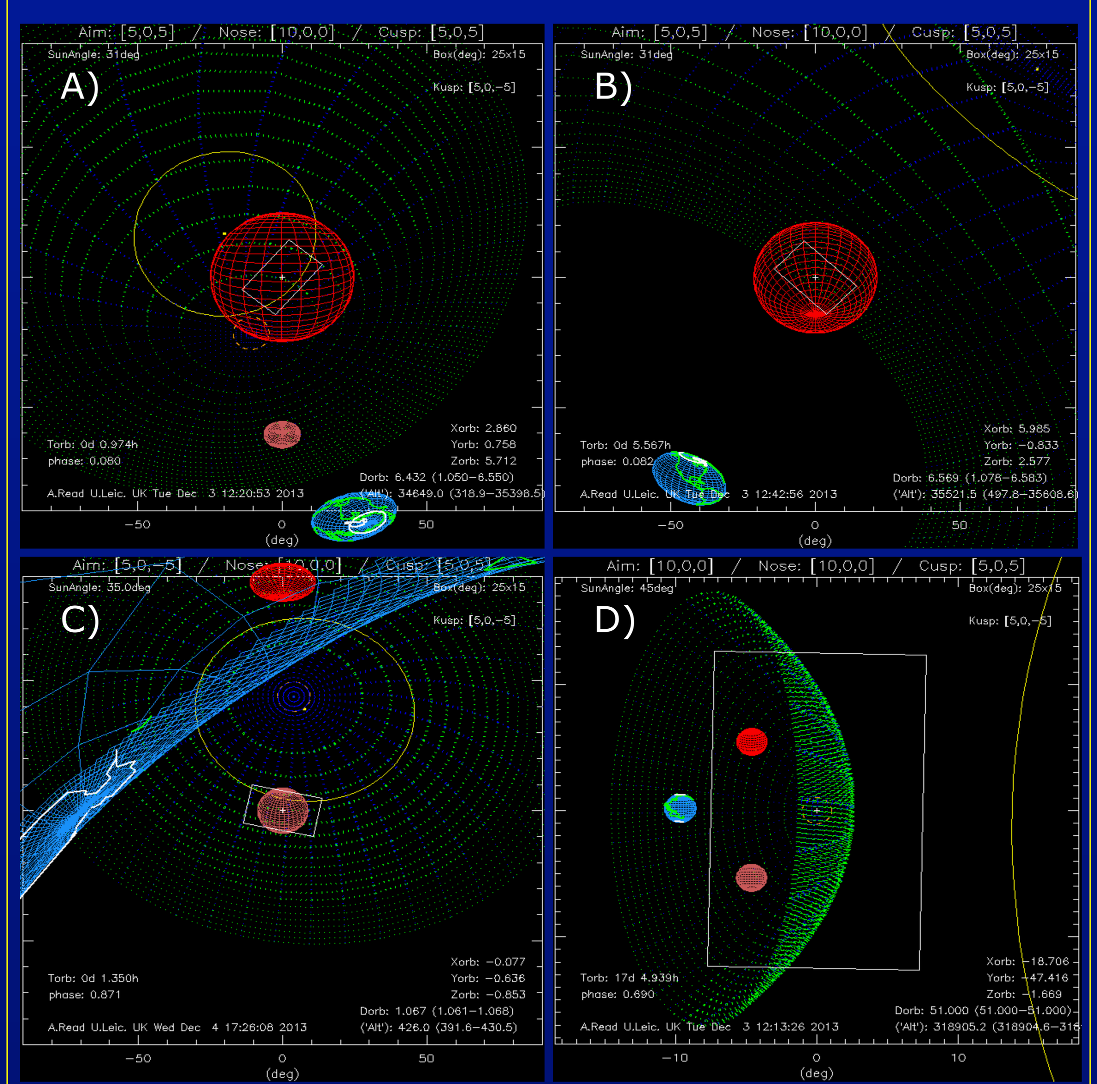
$$A^{q+} + B \rightarrow A^{(q-1)+*} + B^{+}$$
$$A^{(q-1)+*} \rightarrow A^{(q-1)+} + h\nu$$



Predicted SWCX X-ray emissivity maps for two solar wind states (Robertson & Cravens 2003, 2006). Heavy SW ions map the magnetosheath and cusp regions via SWCX X-ray emission.

Possible Orbits and Targets

Possible orbits for a magnetosheath imager include Low-Earth Orbit (LEO), Geostationary Transfer (GTO), Molniya or Earth-Moon L1 Lissajous. Each has pros and cons depending on the focus of the target (e.g. bow shock versus cusps) and spacecraft mass constraints. At Leicester University we have developed a simulator that can calculate observing efficiencies (including Sun, Earth and radiation constraints) for any orbital configuration.



Example snapshots of the simulator FOV. Red and pink spheres represent North and South Cusps. Green represents the magnetosheath. Earth is the blue sphere. Sun avoidance region is in yellow.

A) Sunwards 12 hr Molniya orbit close to apogee.
Aim: North Cusp
B) Sunwards GTO orbit close to apogee.
Aim: North Cusp
C) LEO orbit.
Aim: South Cusp
D) Earth-Moon L1 orbit:
Aim: Magnetosheath nose