Global X-ray Imaging of the Earth’s Magnetosphere

G. Branduardi-Raymont
UCL Mullard Space Science Laboratory

S. F. Sembay, J. A. Carter, A. M. Read
Leicester University

J. Eastwood
Imperial College London

D. G. Sibeck
NASA GSFC

and the AXIOM collaboration
The Earth’s magnetosphere

- Magnetosphere carves out a cavity in the solar wind (SW)
- SW compresses it on one side and stretches it on the other into a long tail
- SW is supersonic, a bow shock forms
- SW is slowed, compressed, heated and diverted into the magnetosheath
- This SW plasma interacts with the magnetopause and penetrates into the magnetosphere

This interaction is fundamental to answering ESA’s Cosmic Vision question: ‘How does the Solar System work?’

In situ plasma and field measurements return precise, localised information, but no global view, provided instead by remote imaging
A novel approach to imaging

- Growing interest in X-ray production by the Charge eXchange (CX) process (high cross sections, $\sim 10^{-15} \text{ cm}^2$)

- Solar Wind Charge eXchange (SWCX) expected where high charge state SW ions encounter neutrals, e.g. in the Earth’s exosphere: systematic study with XMM-Newton (Carter et al. 2008, 2011)

- SWCX emission in the Earth’s exosphere modelled (e.g. Robertson et al. 2006)

- Solar wind storms can cause large increase in X-ray flux

- SWCX X-rays can then be used to image boundaries of the Earth’s dayside magnetosphere
Other imaging techniques have been employed, e.g. EUV, radio, Energetic Neutral Atoms (ENA)

Only ENA and SWCX X-rays can provide global images of the magnetosphere’s outer boundaries

Only SWCX offers the temporal resolution commensurate to the timescale of the interactions (min to an hour)

A real step change is required:
A wide FOV soft X-ray telescope, for imaging and spectroscopy, coupled with plasma and magnetic field instrumentation and ENA imaging …
Specific science questions

- **Magnetopause physics**
  - How do upstream conditions control magnetopause location, size and shape, and magnetosheath thickness?
  - Under what conditions do transient boundary layers arise?

- **Cusp physics**
  - What are the size and shape of the cusps? How do they move in response to SW changes? Density, SW/magnetosphere coupling?

- **Shock physics**
  - What controls where the bow shock forms?
  - How does its thickness depend on the upstream conditions?

- **Interaction of a Coronal Mass Ejection with the magnetosphere**

*Carter et al. 2010*
AXIOM as ESA M-size mission (2010)

- Wide FOV X-ray imaging and spectroscopy telescope, compact plasma package and magnetometer: AXIOM = Advanced X-ray Imaging Of the Magnetosphere

- Small size payload, can be accommodated in a Vega launcher

- Vantage point far out from Earth

- Baseline (from mass to orbit, observing efficiency, radiation dose trade-off): Lissajous orbit at Earth – Moon L1 point (~50 R_E)
  - wide FOV imaging (10 R_E scale)
  - spatial resolution 0.1R_E at best
  - 1 – 15 min cadence
  - plasma 3D distribution
  - magnetic field measurements
AXIOM payload – X-ray WFI

X-ray Wide Field Imager (WFI):
- Wide FOV (10° x 15° baseline)
- Energy range 0.1 – 2.5 keV
- Energy resolution < 65 eV (FWHM) at 0.6 keV
- Angular resolution of ~ 7 arcmin (0.1 $R_E$ at 50 $R_E$)
- Time resolution of ~ 1 min

Achievable with MCP optics coupled with X-ray sensitive CCDs at focus

Basic focusing geometry

Frame holding individual MCP plates (Leicester Univ.)
AXIOM WFI simulated images

http://www.star.le.ac.uk/~jac48/axiomsims/
Proton-Alpha Sensor (PAS)  

- **PAS working principle: Top-hat analyser**
- Electrostatic + time-of-flight analysers: optimised to detect high charge state ions, e.g. C$^{6+}$, C$^{5+}$, N$^{7+}$, N$^{6+}$, O$^{8+}$, O$^{7+}$, Fe$^{18+}$, Fe$^{17+}$, Mg$^{12+}$, Mg$^{11+}$, etc.

### AXIOM plasma package – PAS & ICA

<table>
<thead>
<tr>
<th>Energy</th>
<th>PAS</th>
<th>ICA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>0.2 – 20 keV/q</td>
<td>0.5 – 100 keV/q (AZ)</td>
</tr>
<tr>
<td>Resolution ($\Delta E/E$)</td>
<td>7.5%</td>
<td>5.6%</td>
</tr>
<tr>
<td>Angle</td>
<td>360° (AZ)</td>
<td>360°</td>
</tr>
<tr>
<td>Range (EL)</td>
<td>± 15°</td>
<td>± 15°</td>
</tr>
<tr>
<td>Resolution ($AZ \times EL$)</td>
<td>&lt; 2°</td>
<td>&lt; 2°</td>
</tr>
<tr>
<td>Temporal Resolution</td>
<td>3 s</td>
<td>5 min</td>
</tr>
</tbody>
</table>

Mounted on a boom to allow full angle viewing.
To establish the orientation and magnitude of the solar wind magnetic field

Baseline: Dual redundant digital fluxgate magnetometer

Required: 0.25 nT accuracy
          sampling rate up to 32 Hz

Necessary to separate ambient field from magnetic disturbances due to spacecraft:

→ Sensors mounted on a boom
→ Spacecraft as magnetically clean as possible
Looking ahead: AXIOM-C

- AXIOM is a novel, high science and low cost concept mission, looking for opportunities to fly

- Current ESA Call for S-missions ➔ AXIOM-C, re-targeted to focus on the magnetospheric cusps: under discussion, inputs welcome!
  - LEO, where we ‘look out’ to cusps
  - Flying through/below cusps allows (quasi-)simultaneous in situ measurements
  - Include other imaging techniques (ENA)
  - Link high altitude (AXIOM-C) with low altitude (ground observers) measurements
  - Theory and modelling

Cusp science targets: Morphology, response to SW changes, how magnetospheric coupling affects cusp density, ...

- AXIOM-C to pave the way for future dayside magnetosphere imaging missions ➔ understand energy transfer from SW to Earth’s environment ➔ model (and eventually forecast) space weather
Global X-ray Imaging of the Earth’s Magnetosphere

Thank you!

Please e-mail gbr@mssl.ucl.ac.uk to express interest and join the team


EGU 2012, Vienna, 23 April 2012