AXIOM: Advanced X-ray Imaging Of the Magnetosphere

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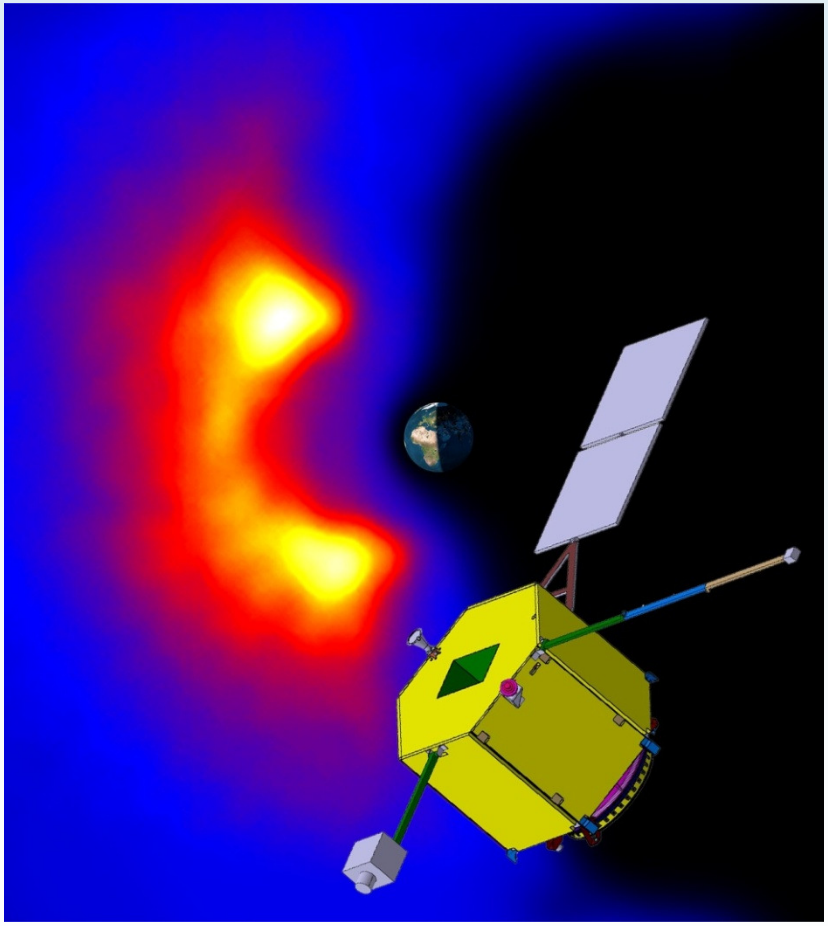
and the AXIOM collaboration

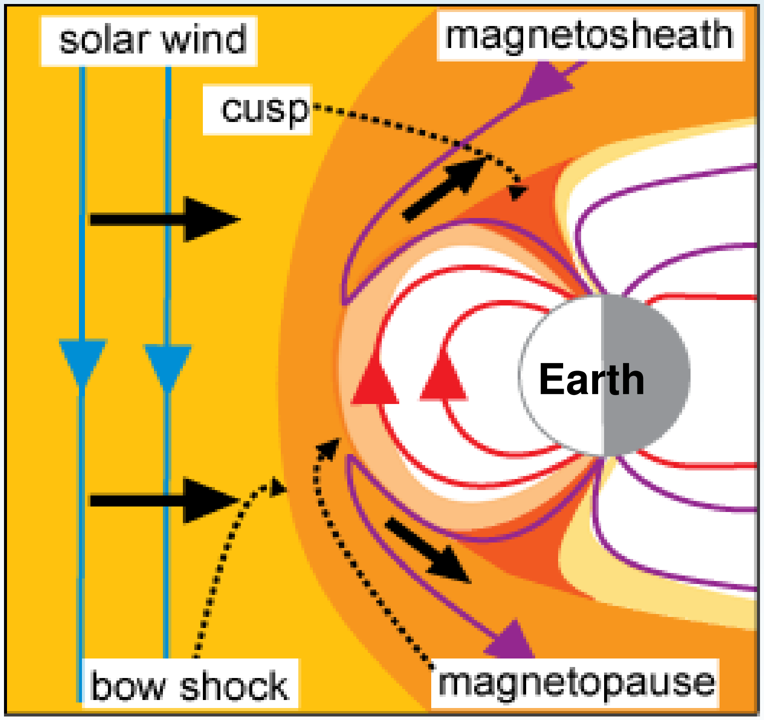
http://www.mssl.ucl.ac.uk/~gbr/AXIOM/



Branduardi-Raymont et al., in press (2011)

The X-ray Universe, Berlin, 27 – 30 June 2011

The Earth's magnetosphere



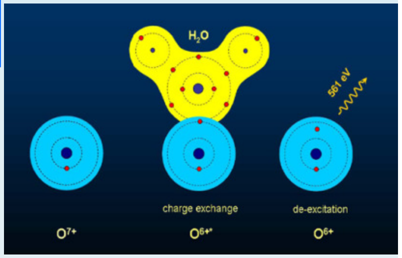
- Magnetosphere carved out into the solar wind (SW)
- SW compresses it on one side and stretches it on the other into a long tail
- SW is supersonic, a bow shock forms
- SW is slowed, compressed, heated and diverted into the magnetosheath
- This SW plasma interacts with the magnetopause and penetrates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

The details of this interaction are not well understood, yet are fundamental to answering ESA's Cosmic Vision question:

'How does the Solar System work?'

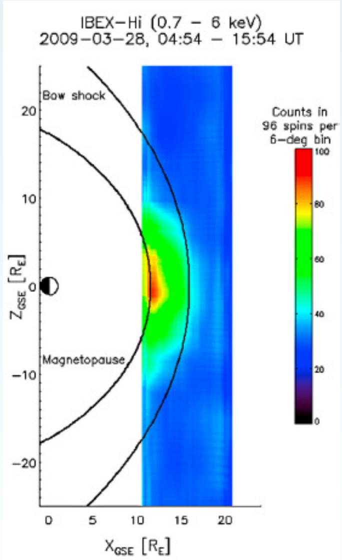
A novel approach to imaging

- Solar Wind Charge eXchange (SWCX) role in soft X-ray production in the Earth's exosphere



Dennerl 2009

- SWCX X-rays could then be used to image boundaries of the Earth's dayside magnetosphere
- Other imaging techniques have been employed: Energetic Neutral Atoms (ENA), radio, EUV, but …



Fuselier et al. 2010

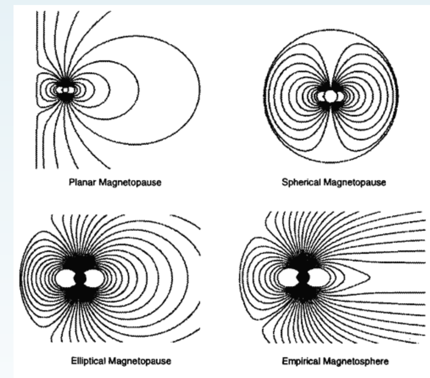
- Only ENA and SWCX X-rays can image boundaries globally
- Only SWCX offers the temporal resolution commensurate to the timescale of the interactions (min to an hour)

***A real step change is required*:**

A wide FOV soft X-ray telescope, for imaging and spectroscopy
Located outside the Earth's magnetosphere
Coupled with plasma and magnetic field instrumentation

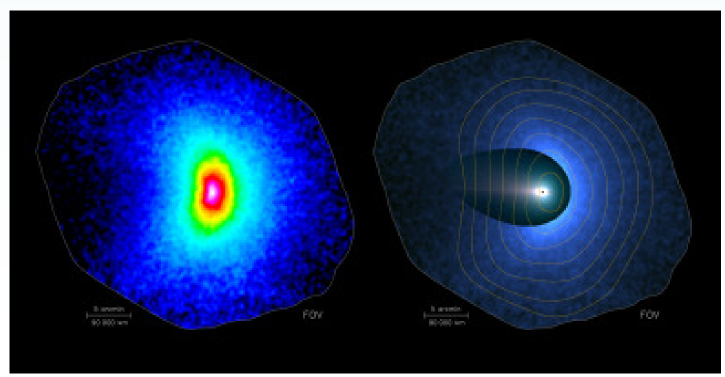
AXIOM science questions

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

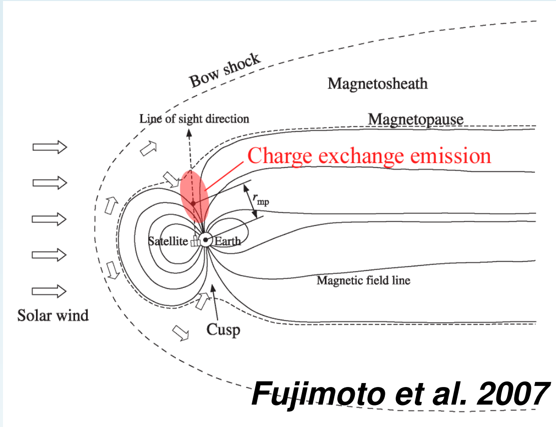


Russell 2000

- **Interaction of a Coronal Mass Ejection with the magnetosphere**
- **Secondary science objectives (comets, SNR)**



AXIOM science requirements



Fujimoto et al. 2007

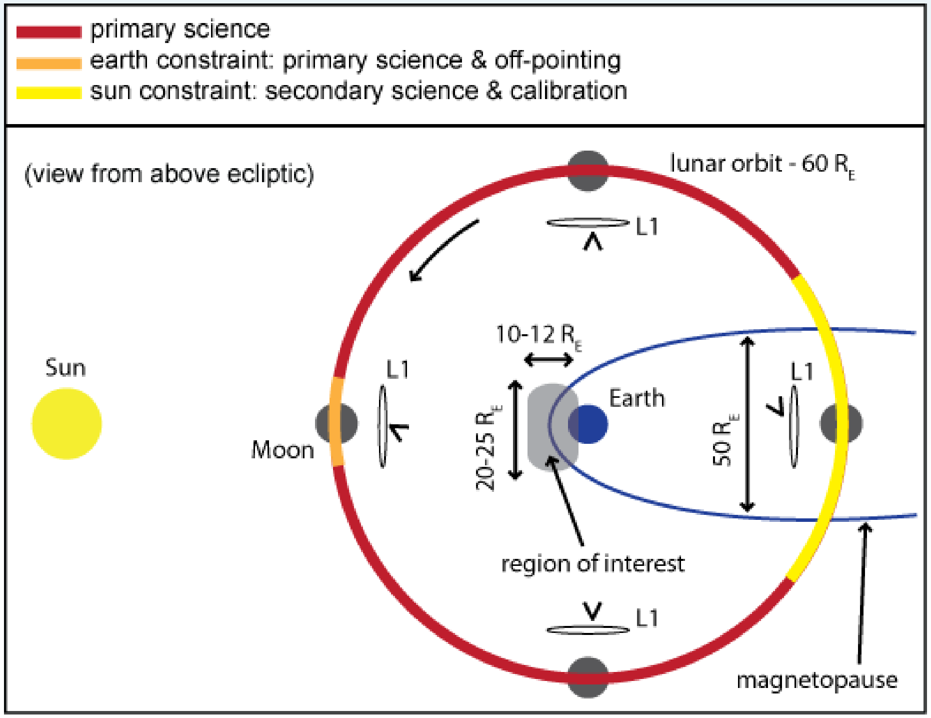
- **Magnetopause physics**
- **Cusp physics**
- **Shock physics**
  - **Wide FOV imaging (10 R_E scale) from outside the Earth's magnetosphere**
  - **Spatial resolution $0.1R_E$ at best, at 1 – 15 min cadence**
- **Interaction of a Coronal Mass Ejection with the magnetosphere**
  - **Spectroscopic X-ray imaging, able to establish SW ion composition**
  - **Spatial resolution $0.5R_E$, at 15 min cadence**
- **In situ particle and field measurements:**
  - **3D distribution (density, velocity, temperature) of H^+ and He^{++} to resolve SW structure (< 20 keV/q in energy)**
  - **SW ion distribution on timescale comparable with X-ray imaging**
  - **Orientation and strength of SW magnetic field**

AXIOM mission profile

Wide FOV X-ray imaging and spectroscopy telescope, compact plasma package and magnetometer

- **Small size payload, can be accommodated in a Vega launcher**
- **Vantage point far out from Earth**
- **Trade-off to establish best option among equatorial and polar orbits**

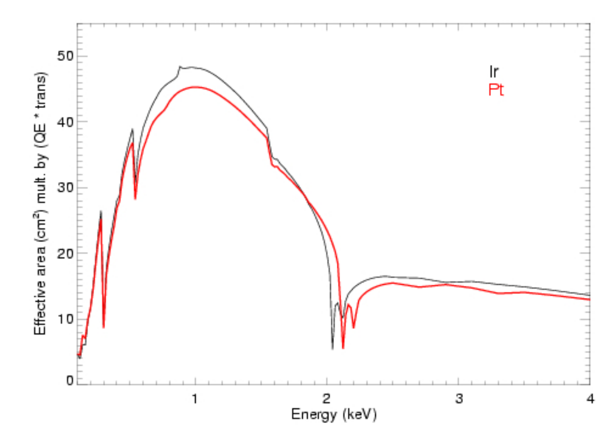
➔ **Baseline: Lissajous orbit around Earth – Moon L1 point (at ~ 50 R_E)**



AXIOM payload – WFI

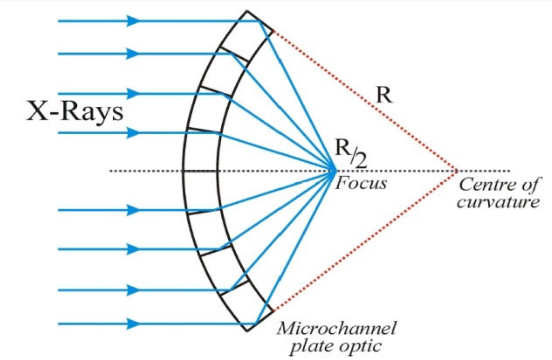
Wide Field Imager (WFI):

- Wide FOV (10^o x 15^o 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

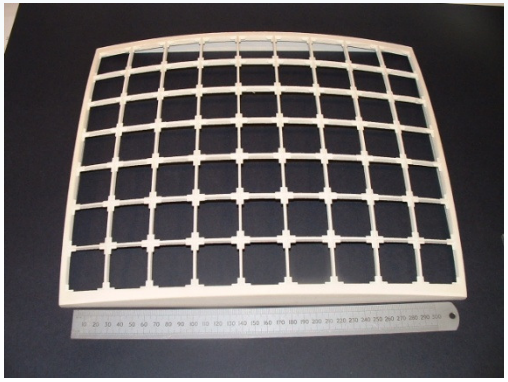


WFI predicted effective area

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



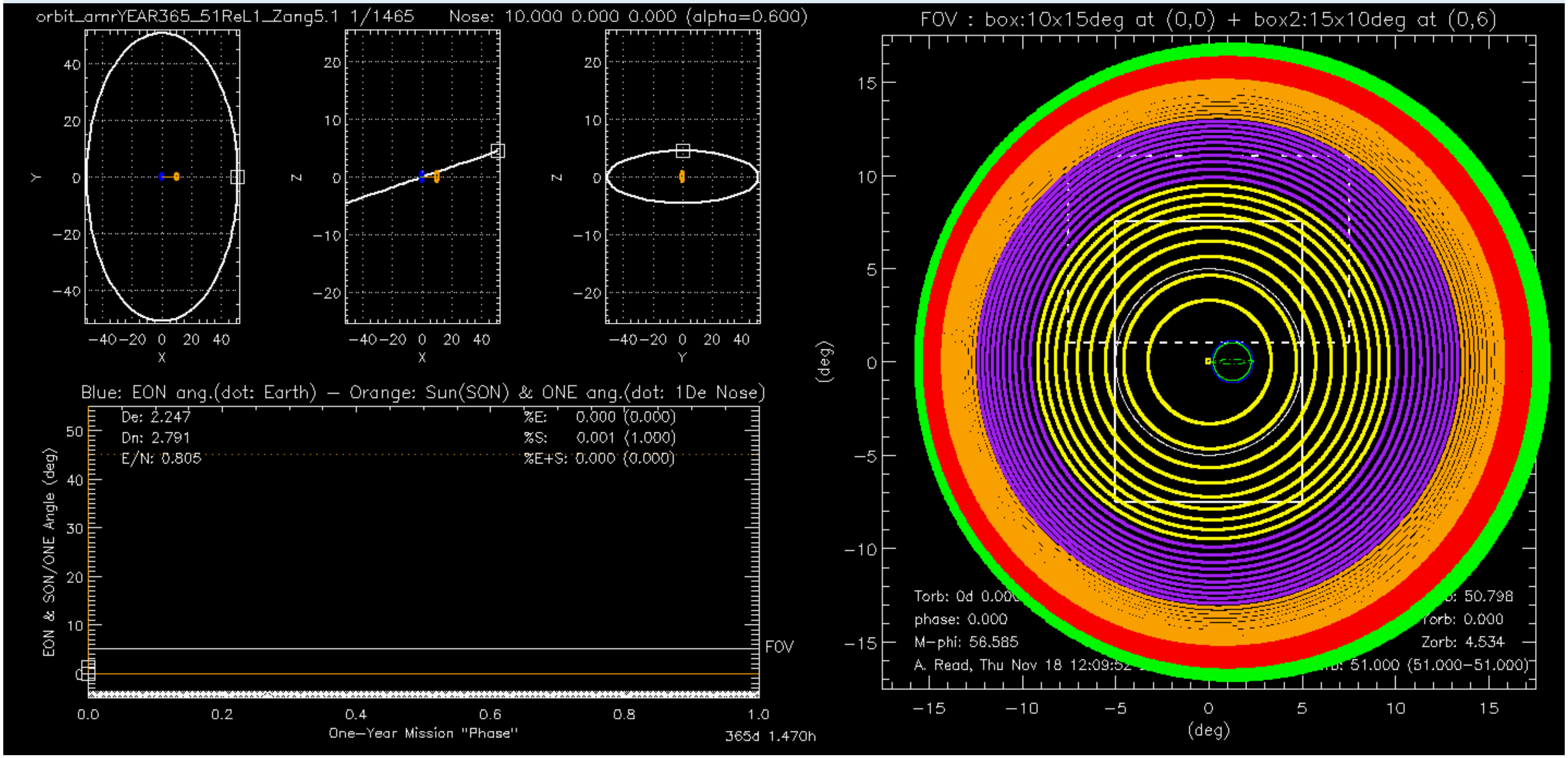
Basic focusing geometry



Frame holding individual MCP plates (Leicester Univ.)

UCL

AXIOM WFI viewing geometry

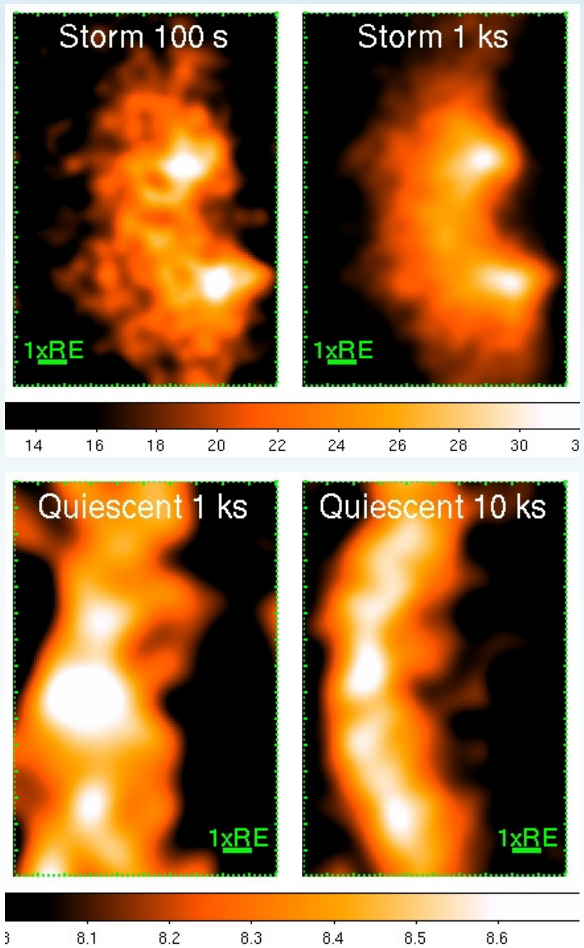


http://www.star.le.ac.uk/~amr30/AXIOM/

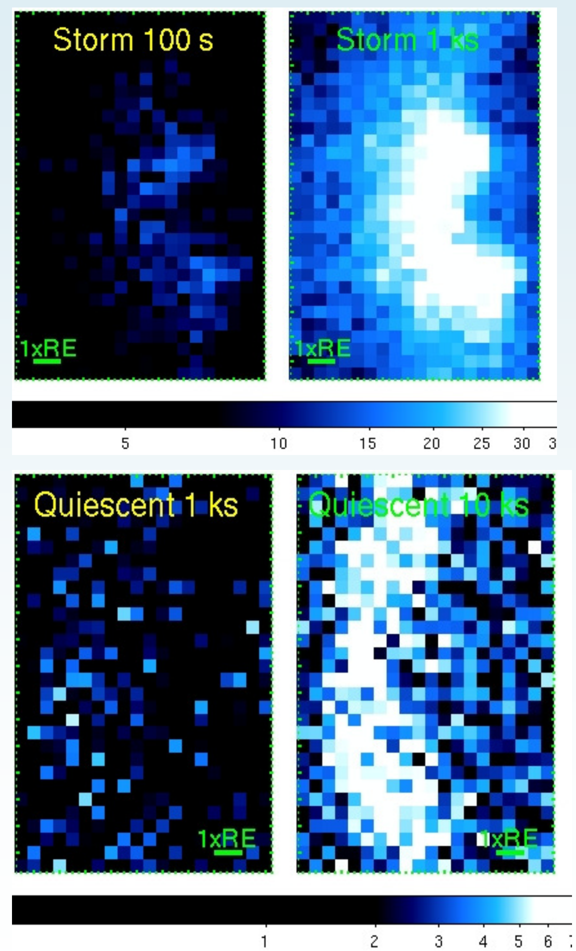
AXIOM

One year mission simulation of AXIOM orbit / WFI FOV at 51 R_E

AXIOM WFI simulated images



Simulated WFI images

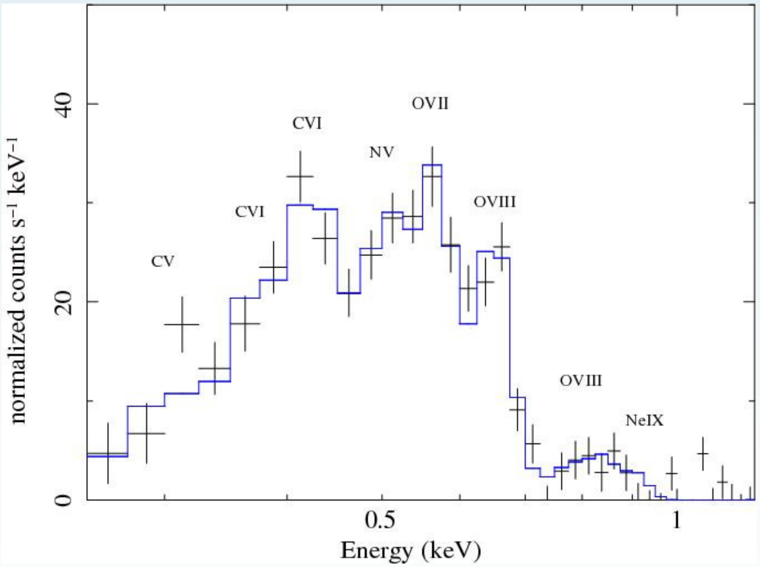


Simulated WFI significance maps

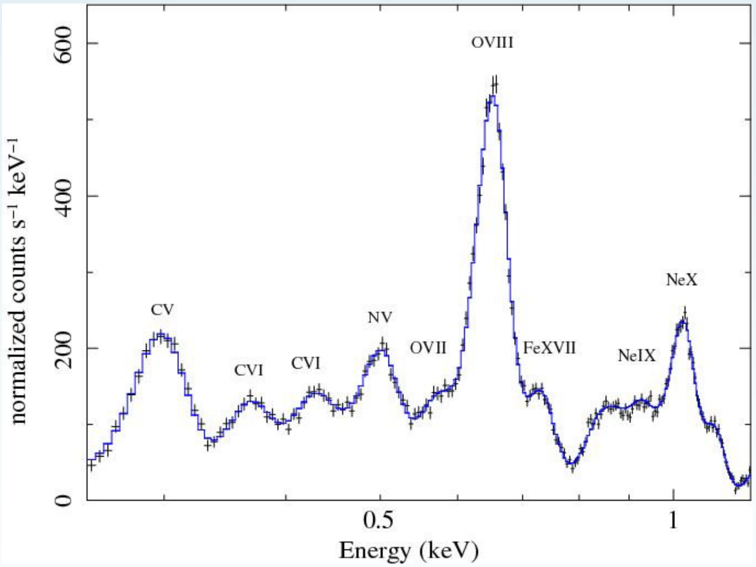
http://www.star.le.ac.uk/~jac48/axiomsims/

AXIOM WFI simulated spectra

Quiescent solar wind



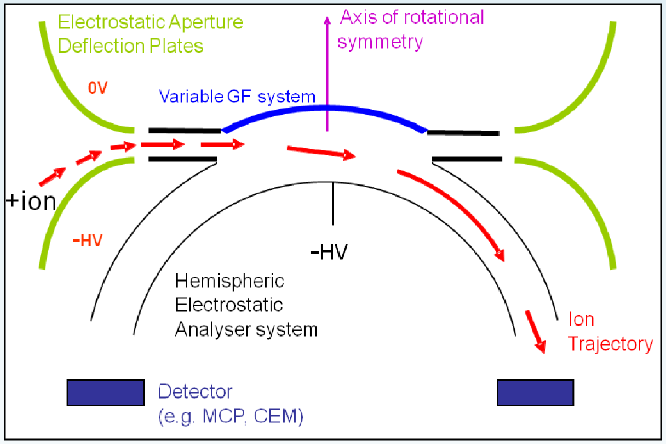
Coronal Mass Ejection



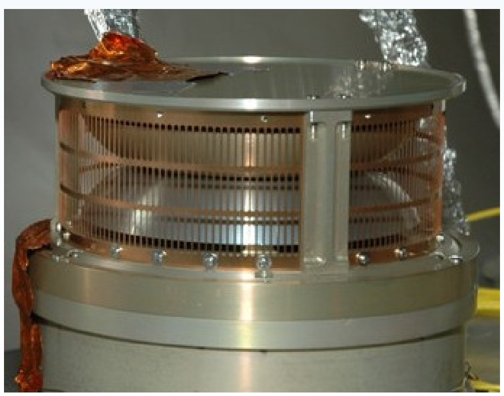
Simulated WFI SWCX spectra (1ks exposure, full FOV)

AXIOM plasma package – PAS & ICA

Proton-Alpha Sensor (PAS)



PAS working principle: Top-hat analyser



UCL/MSSL prototype of top-hat analyser

Ion Composition Analyser (ICA)

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.

		PAS	ICA
Energy	Range	0.2 – 20 keV/q	0.5 – 100 keV/q (AZ) 0.5 – 16 keV/q (EL)
	Resolution ($\Delta E/E$)	7.5%	5.6%
Angle	Range (AZ)	360°	360°
	Range (EL)	± 15º	± 15°
	Resolution (AZ× EL)	< 2°	< 2°
Temporal	Resolution	3 s	5 min

Mounted on a boom to allow full angle viewing

AXIOM magnetometer – MAG

To establish the orientation and magnitude of the solar wind magnetic field

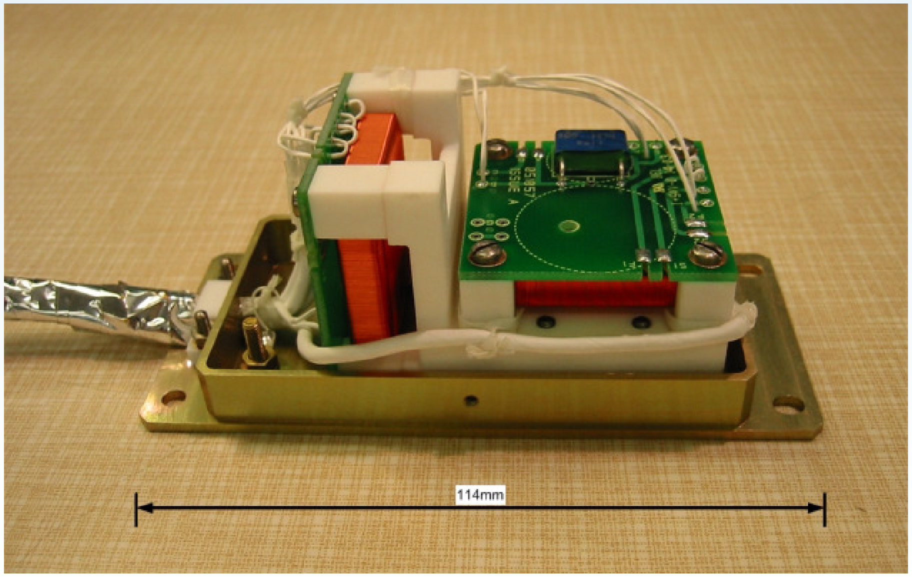
Baseline: Dual redundant digital fluxgate magnetometer

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

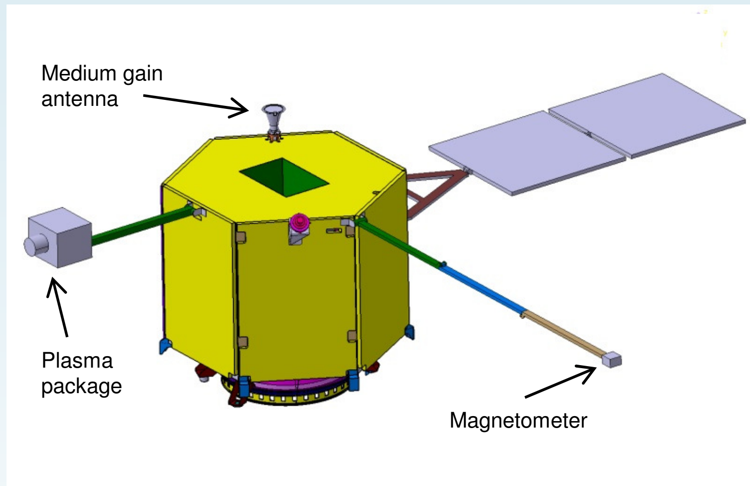
→ Spacecraft as magnetically clean as possible



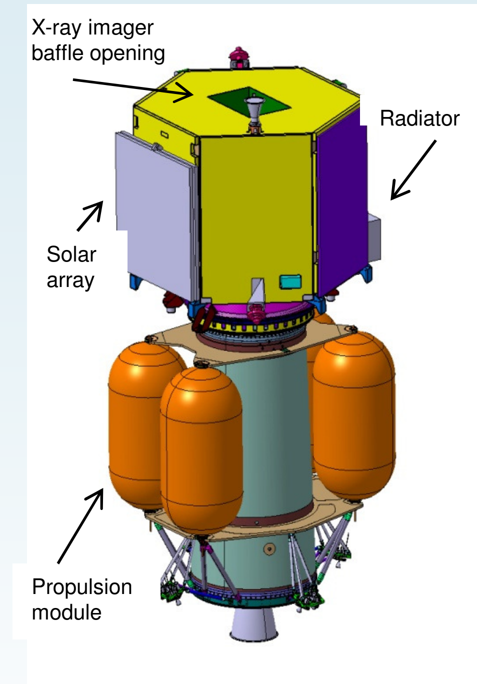
Photograph of a fluxgate sensor (Imperial College London)

AXIOM configuration

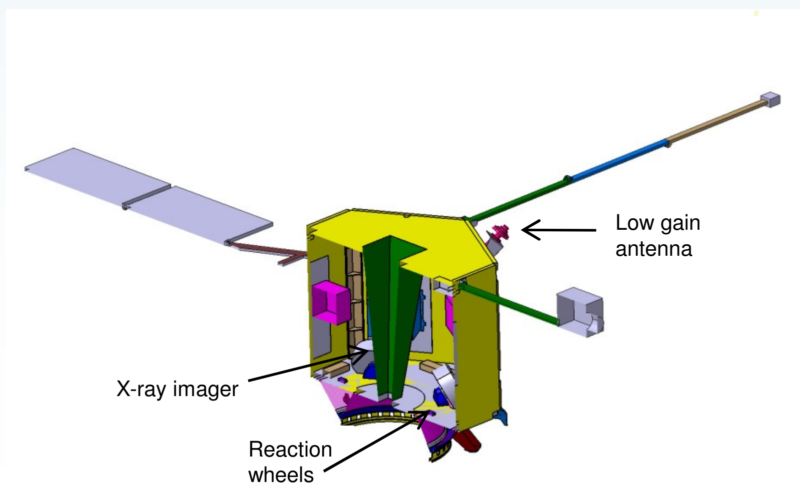
Stowed in Vega fairing



Deployed AXIOM spacecraft



After jettison from Vega launcher



Internal view

Conclusions: AXIOM potential

- **AXIOM is a novel, high science and low cost concept mission**
- **Will provide images and movies of the dynamic SW-magnetosphere interaction exploiting SWCX soft X-ray emission:**

  The Earth's magnetosphere is NOT invisible!
- **Potential to revolutionarise magnetospheric physics while tackling ESA's Cosmic Vision question: '*How does the Solar System work?*'**
- **Unlike local measurements, AXIOM views Earth's entire magnetospheric environment, embedded in the SW**
- **Ultimately will provide a better understanding of energy transfer from SW to this environment ➔ modelling (and eventually forecasting) of space weather**