AXIOM: Advanced X-ray Imaging Of the Magnetosphere

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Abstract

AXIOM is a concept mission which has been proposed in response to the European Space Agency's 2010 Cosmic Vision M3 Mission Call, in view of a 2022 launch. AXIOM aims to explain how the Earth's magnetosphere responds to the changing impact of the solar wind in a global way never attempted before, by performing wide-field soft X-ray imaging and spectroscopy of the magnetosheath, magnetopause and bow shock, at high spatial and temporal resolution.

1 – Introduction

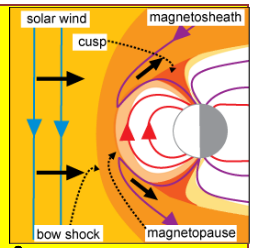
Planetary plasma and magnetic field environments can be studied in two complementary ways – by in situ measurements, or by remote sensing.

In situ measurements provide precise information about plasma behaviour, instabilities and dynamics, but lack the global view which is necessary to understand the overall interaction with the solar wind.

Remote imaging gives excellent information about global configurations and overall evolution, but do not offer the level of local information required to fully understand the microphysics.

We propose a new approach: To use remote X-ray imaging techniques, made possible thanks to the relatively recent discovery of solar wind charge-exchange (SWCX) X-ray emission, found by XMM-Newton to occur in the vicinity of the Earth's magnetosphere; the emission peaks in the sub-solar magnetosheath, where solar wind and neutral exospheric densities are high.

2 – AXIOM Key Science Questions



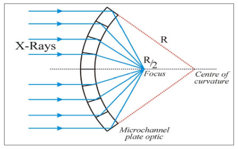
- ***Magnetopause physics***
  - **How do upstream conditions control magnetopause position and shape and magnetosheath thickness?**
  - **How does the location of the magnetopause change in response to prolonged periods of sub-solar reconnection?**
  - **Under what conditions do transient boundary layers, 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?**
- ***Interaction of coronal mass ejections (CMEs) with the magnetosphere***
- ***Secondary science objectives* (at times of Sun or bright Earth avoidance)**
  - **What are the conditions along the flanks of the magnetosheath?**
  - **How wide and how populated is the tail magnetopause?**

3 – AXIOM instrument requirements and capabilities

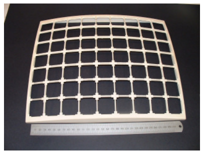
AXIOM's main instrument is a wide field soft X-ray telescope (WFI – Wide Field Imager) developed by Leicester University, for imaging and spectroscopy of the Earth's dayside magnetosphere, magnetosheath and bow shock, with a temporal and spatial resolution sufficient to address many key outstanding questions concerning how the solar wind interacts with planetary magnetospheres on a global level. This translates into the requirements:

- **Energy range 0.1 – 2.5 keV (where most of SWCX X-ray line emission arises)**
- **Energy resolution < 65 eV (FWHM) at 0.6 keV, to resolve the SWCX lines**
- **Angular resolution ~ 7 arcmin (equivalent to 0.1 R_E scale size at 51 R_E)**
- **Wide FOV (baseline 10° x 15°)**
- **Time resolution of ~ 1 minute**

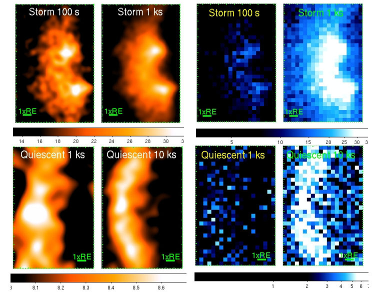
These requirements can be met by a telescope coupling a microchannel plate (MCP) optic with an X-ray sensitive CCD.



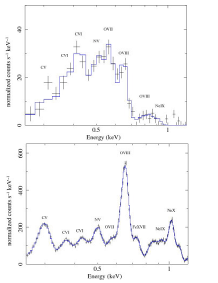
Basic focusing geometry of MCP optic



Example frame constructed at Leicester University for holding individual MCP plates

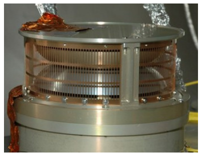


Simulated WFI images (left) and significance maps (right) for storm (upper) and quiescent (lower) solar wind conditions. The solar wind flows in from the left and the magnetosheath and cusps, bounded by the bow shock (left) and magnetopause (right), emit brightly via SWCX

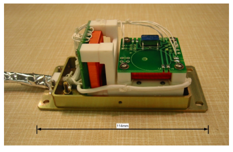


Simulated WFI SWCX spectra (1ks) for quiescent solar wind (top) and a CME (bottom)

Simultaneous in situ measurements of the solar wind will be provided by a Proton and Alpha particle Sensor (PAS) designed to measure the bulk properties of the solar wind, an Ion Composition Analyser (ICA) which aims to characterise the populations of minor ions in the solar wind that cause SWCX emission (both instruments developed by UCL/MSSL), and a Magnetometer (MAG) for accurate measurements of the strength and direction of the solar wind magnetic field (provided by Imperial College London).



Prototype of the top-hat analyser suitable for implementation as the PAS



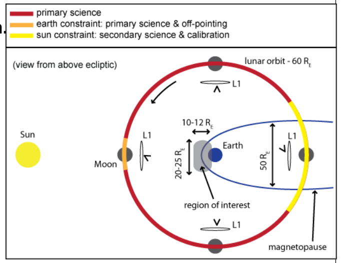
Fluxgate magnetometer sensor

4 – AXIOM mission profile

AXIOM's relatively small, low-resource payload, incorporating a wide-field soft X-ray telescope, a proton and alpha particle sensor, an ion composition analyser, and a magnetometer, can be accommodated in a Vega launcher.

Trade-off of mass in orbit, observing efficiency and radiation environment indicates that a Lissajous orbit at the Earth-Moon L1 point is the best option.

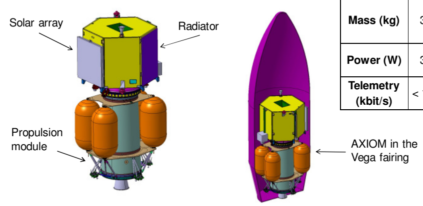
The figure on the right shows ➡ the operational orbit selected (not to scale): the narrow ellipses near the Moon represent the Lissajous orbit; ^ marks indicate the viewing angles for different positions in the orbit; the operational phases for primary and secondary science and the observing constraints are shown in colour.

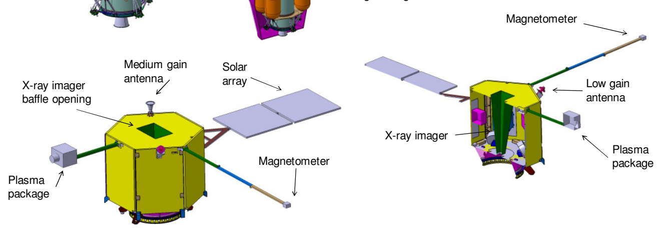


The Vega launcher, in combination with the Propulsion Module adopted for LISA Pathfinder, will take AXIOM into its final orbit over a period of 5 to 7 months.

5 – AXIOM spacecraft & payload

Resources table	WFI	PAS	ICA	MAG	Spacecraft	Total with margins
Mass (kg)	30	4	9	3.2	254 (dry) 19 (fuel)	434 (with 4% launch margin)
Power (W)	30	5.5	8.5	2.5	357	568
Telemetry (kbit/s)	< 100	< 14		< 3.2	8	125





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