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X-ray imaging of the Earth's magnetosphere

G. Branduardi-Raymont[1], S. F. Sembay[2], J. P. Eastwood[3], D. G. Sibeck[4], J. A. Carter[2], A. M. Read[2], and the AXIOM Collaboration, with the support of Astrium Ltd and Surrey Satellite Technology Ltd

[1] University College London, Mullard Space Science Laboratory, Holmbury St Mary, Dorking, Surrey RH5 6NT, UK, e-mail: gbr@mssl.ucl.ac.uk
[2] Department of Physics and Astronomy, University of Leicester, Leicester LE1 7RH, UK
[3] The Blackett Laboratory, Imperial College London, London SW7 2AZ, UK
[4] Code 674, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

Abstract. Solar wind charge exchange X-rays are produced in and near the Earth's magnetosphere, peaking in the sub-solar magnetosheath and in the magnetospheric cusps, where solar wind and neutral exospheric densities are high. We propose a new approach to the study of the Sun-Earth relationship and the impact of the solar wind on the Earth's environment: remote X-ray imaging of the Earth's magnetosphere, providing the global view necessary to understand the nature of the solar wind – magnetosphere interaction.
We present a dedicated mission that can image the Earth's dayside magnetosphere, magnetosheath and bow shock in X-rays from a vantage point close to the Moon (AXIOM), or, alternatively, focuses on the cusps from a low-Earth orbit (AXIOM-C). Both missions address key outstanding questions concerning how the solar wind interacts with the terrestrial magnetosphere. Their observations and the resulting models will also help understand this foreground emission which is all-important for Earth-orbiting X-ray observatories.

Key words. Sun: solar wind – Sun: solar-terrestrial relations – Earth: magnetosphere – X-rays: diffuse background

1. Introduction

The supersonic solar wind (SW) compresses the Earth's magnetosphere on the dayside and a bow shock forms; the SW plasma is slowed and diverted into the magnetosheath, interacts with the magnetopause and penetrates into the magnetosphere. Many specific questions relating to this interaction are still unanswered, e.g. how do upstream conditions control magnetopause location, size and shape, and magnetosheath thickness? What are the size, shape and density of the magnetospheric cusps? What determines where the bow shock forms? How does a Coronal Mass Ejection interact with the magnetosphere? There are two ways to try and answer these questions: In situ plasma and field measurements return precise, localised information about plasma composition, instabilities and dynamics, but no global view, necessary to understand the overall behaviour and evolution of the plasma, which is provided instead by remote imaging.

Send offprint requests to: G. Branduardi-Raymont

2. A novel imaging approach: AXIOM

Over the last decade interest has been growing in the process of Charge eXchange (CX) as a mechanism to produce X-rays in an astrophysical context. Solar Wind Charge eXchange (SWCX) is expected where high charge state SW ions encounter neutrals, e.g. in the Earth's exosphere: the ensuing X-ray emission has been studied with XMM-Newton (e.g. Carter et al. 2008, 2011) and has also been 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). However, only SWCX X-rays can provide global images of the magnetosphere's outer boundaries with temporal resolution commensurate to the timescale of the interactions (min to an hour). Thus, a real step change is required: A wide FOV soft X-ray telescope, for imaging and spectroscopy, coupled with a compact plasma package and a magnetometer, to establish the local magnetospheric conditions.

In response to ESA's 2010 call for medium size missions we proposed AXIOM (Advanced X-ray Imaging Of the Magnetosphere, Branduardi-Raymont et al. 2012). This small size payload can be accommodated in a Vega launcher; we chose a vantage point far out from the Earth, so that we could observe a large portion of the magnetosphere, and a Lissajous orbit at the Earth-Moon L1 point ($\sim$50 R_E). The X-ray Wide Field Imager (WFI) has a FOV of 10^o x 15^o (10 R_E scale), an angular resolution of $\sim$7 arcmin (0.1 R_E at 50 R_E), covers an energy range 0.1 – 2.5 keV with energy resolution <65 eV (FWHM) at 0.6 keV, and maximum time resolution of $\sim$1 min; this is all achievable with MCP optics coupled with X-ray sensitive CCDs at the focus. The AXIOM plasma package incorporates electrostatic and time-of-flight analysers for measuring 3D plasma distributions, optimised to detect high charge state ions of e.g. C, N, O, Fe, Mg. The magnetometer is used to establish the orientation and magnitude of the SW magnetic field. Fig. 1 shows WFI simulated X-ray images for SW storm conditions.

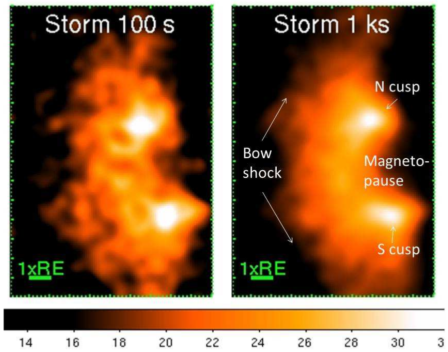

Fig. 1. WFI simulated X-ray images for SW storm conditions (100 s and 1 ks integrations)

3. Conclusions

AXIOM is a novel, high science and low cost concept mission, still looking for opportunities to fly. ESA's 2012 call for small missions stimulated our collaboration to propose AXIOM-C, a smaller version of AXIOM, re-targeted to focus on the magnetospheric cusps, in a Sun-synchronous LEO; flying through/below the cusps allows (quasi-) simultaneous in situ measurements, linking high altitude (AXIOM-C) data with low altitude (ground) observations, to be complemented by theory and modelling. AXIOM-C would pave the way to future global dayside magnetosphere imaging missions, which would lead to a fuller understanding of the energy transfer from the SW to the Earth's environment, with important implications for modelling and ultimately predicting the consequences of space weather.

References

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