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AXIOM: Advanced X-Ray Imaging of the Earth's Magnetosphere

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Abstract

Over the past 50 years, in situ observations of the Earth's magnetosphere have provided very important data which have been used to characterize the basic physics that controls the plasma interaction between the Earth and the Sun. However, in situ observations are fundamentally limited by the number of available spacecraft and whilst they provide precise information about plasma behaviour, instabilities and dynamics, they cannot provide the global view which is necessary to understand the overall behaviour of the plasma. Here we describe a new and elegant approach to study the magnetosphere via remote X-ray imaging, now possible thanks to the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission. This is presented in the context of the AXIOM (Advanced X-ray Imaging of the Earth's Magnetosphere) and AXIOM-C mission proposals.

1. Introduction

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 provide the global view which is necessary to understand the overall behaviour of the plasma. Remote imaging provides excellent information about global configurations and overall evolution, but cannot provide the same level of local information that is required to fully understand the local plasma physics.

In the context of magnetospheric physics, the combination of remote and in situ observations has proved to be a powerful one. The development of global auroral imaging from space (for example with Polar) and Energetic Neutral Atom (ENA) imaging of the inner magnetosphere (for example with IMAGE) transformed these fields of research when combined with excellent in situ measurements from satellites. The combination of in situ measurements and global imaging led to a step change in our understanding of these regions.

However, whilst some parts of the magnetosphere have been remotely sensed, the majority remains unexplored using remote measurements. This lack of global information is a critical issue that significantly impedes our ability to further advance magnetospheric physics, and thus answer the question 'How does the solar system work?'. This was recognised in Cosmic Vision 2015-2025, where it was proposed that a global view could be created by using a so-called 'Earth Magnetospheric Swarm'. In this concept, many in situ measurement points are used to build up a global view.

Here, we propose an alternative approach: to use remote X-ray imaging techniques, which are now possible thanks to the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission, first observed at comet Hyakutake [e.g. 4], and subsequently found to be occurring in the vicinity of the Earth's magnetosphere.

2. Solar Wind Charge Exchange

X-ray and Extreme Ultra-Violet photons are emitted when charge exchange occurs between a highly-ionized heavy minor ion in the solar wind and neutral atom in the Earth's exosphere. Simulations show that theoretically, so-called Solar Wind Charge eXchange (SWCX) emission is strongest in the cusps and magnetosheath, and can be used to image the location of the bow shock and the dayside magnetosphere [e.g. 5]. This emission from the vicinity of the Earth's magnetosphere has been measured, for example by XMM-Newton [e. g. 2-3].

Remote sensing of the magnetosphere has also been demonstrated using other wavelengths and energetic neutral atoms. However, SWCX can accumulate counts sufficiently quickly so as to generate images of the Earth's outer magnetospheric boundaries on a fast enough timescale (minutes to an hour) sufficient to capture the dynamic behavior and processes.

As such, a wide field X-ray telescope, supported by appropriate in situ measurements, can in principle be used to image a significant fraction of the Earth's dayside magnetosphere. Based on this idea, in 2010 the AXIOM mission concept was proposed to the ESA M3 mission call, and in 2012, a mission specifically targeting the cusps, AXIOM-C, was proposed to the ESA S mission call.

3. AXIOM

The proposed AXIOM mission profile uses a Vega launcher to place the satellite in a Lissajous orbit around the first Earth-Moon Lagrange point. From this vantage point, twice a month it is possible to observe the magnetosphere from the outside along a look direction perpendicular to the Sun-Earth line, allowing the dayside magnetospheric boundaries and their response to varying solar wind conditions to be monitored on a global level. Full details of the AXIOM mission concept are given in [1].

The strawman AXIOM satellite payload carries three instruments: An X-ray Wide Field Imager (WFI), which uses a microchannel plate (MCP) optic array with a detector plane employing X-ray sensitive CCDs; a plasma detector to monitor the solar wind input and simultaneously measure the heavy ion populations; and a magnetometer to measure the orientation and strength of the solar wind magnetic field, which controls the modes of solar wind magnetosphere coupling.

4. AXIOM-C

The AXIOM-C mission profile places the spacecraft in a Sun-Synchronous low Earth orbit. In contrast to AXIOM, rather than imaging the magnetosphere from the outside, AXIOM-C targets the cusps and images them from below.

In addition to an X-ray WFI, AXIOM-C again carries an in situ package. However, in this case the plasma instrument is required to measure ions and electrons precipitating along the magnetic field down from the cusps and the magnetometer is required to map between the remote and in situ measurements, as well as measuring the strength of region 1 currents separating open and closed field regions.

5. Conclusions

From theoretical studies, analysis of existing data, and mission studies, it is becoming clear that SWCX imaging offers a novel approach to studying the interaction of the solar wind with planetary magnetospheres. Whilst the AXIOM and AXIOM-C proposals were not successful, a considerable amount has been learned and future possible opportunities will be discussed.

Acknowledgements

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