AXIOM

Advanced X-ray Imaging Of the Magnetosphere

Executive Summary

ESA's Cosmic Vision 2015-2025 plan addresses four questions, established as being highest on the agenda of European scientific space research. '*How does the solar system work?*' describes our need to understand how the Sun creates the heliosphere, and how the planets interact with the solar wind and its magnetic field. This is not just a matter of scientific curiosity – it also represents a clear and pressing practical problem. As Europe, and the world, become more dependent on complex technology – both in space and on the ground – they become more exposed to the vagaries of *space weather*, the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of technological systems and endanger human life and health. Basic research into the plasma and magnetic field environment of the Earth, and of the solar system overall, directly leads to strategies for predicting and mitigating the effects of space weather.

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 and more elegant 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. Cravens 2002), and subsequently found to be occurring in the vicinity of the Earth's magnetosphere. In this proposal we describe how an appropriately designed and located X-ray telescope, supported by simultaneous in situ measurements of the solar wind, can be used to image the dayside magnetosphere, magnetosheath and bow shock, with a temporal and spatial resolution sufficient to address several key outstanding questions concerning how the solar wind interacts with planetary magnetospheres on a global level.

The Advanced X-ray Imaging Of the Magnetosphere (AXIOM) mission is a novel proposal that will revolutionise magnetospheric physics by providing images and movies of the dynamic solar wind – magnetosphere interaction based on SWCX X-ray emission using state-of-the-art detection techniques.

Mission Profile: To image the dayside magnetospheric boundaries it is necessary to use a vantage point outside the magnetosphere. Initial studies have identified that the most appropriate mission profile uses a Vega launcher with a LISA Pathfinder-type Propulsion Module to place the spacecraft in a Lissajous orbit around the Earth – Moon L1 point.

Model Payload: The model payload consists of an X-ray Wide Field Imager (WFI), capable of both imaging and spectroscopy, and an in situ measurement package. This in situ package comprises a Proton-Alpha Sensor (PAS), designed to measure the bulk properties of the solar wind, an Ion Composition Analyser (ICA), which has the aim of characterising the populations of minor ions in the solar wind that cause SWCX emission, and a Magnetometer (MAG), designed to measure the strength and direction of the solar wind magnetic field. Simulations show that the proposed WFI design is capable of imaging the predicted emission from the dayside magnetosphere. The in situ package is derived from previous experience with many space plasma missions, including Cluster and Solar Orbiter.

Spacecraft: It is proposed that the spacecraft is three-axis stabilized, so that the WFI instrument can continuously point towards the Earth's magnetosphere or other science targets. Based on studies by Astrium, it is proposed that a standard Astrium platform be used.

Programmatics and Costs: AXIOM is a low risk mission with no significant technology development required. The overall mission cost at completion is estimated to be 250 Million euro, well below the M-mission cost ceiling. This proposal is the result of the collaboration of three UK institutes with a long heritage in developing hardware for space research, and NASA scientists from the USA, who provide scientific and modeling support, and may also provide hardware in future.

Communication and Outreach: The key obstacle to effective communication of research in solar-terrestrial physics and space weather is that it involves the study of many processes that are complicated and essentially invisible to the naked eye. AXIOM has the potential to revolutionise the general understanding of this area of science by providing an 'X-ray' of the magnetosphere surrounding our Earth. A comprehensive communication and outreach programme is proposed to take full advantage of these novel data.