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Exploring geospace via solar wind charge exchange X-rays

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Abstract

We propose to investigate the impact of the variable solar wind on the Earth's magnetosphere by taking the global approach afforded by remote sensing, to be precise by imaging the solar wind charge exchange X-ray emission from the dayside magnetosheath and the magnetospheric cusps. We propose an ultra-light-weight X-ray telescope with a 10º x 10º FOV capable of encompassing a large part of the primary region of scientific interest centred on the nose of the magnetopause and covering both magnetospheric cusps together. This will lead to having long term, semi-continuous monitoring of the response and evolution of geospace conditions under the buffeting of the solar wind and will expand very significantly the coverage available at any one time to the X-ray imager currently being developed for SMILE.

1. Introduction

As our world becomes ever more dependent on complex technology, both in space and on the ground, it becomes more exposed to the vagaries of space weather, i.e. 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. Fundamental research into the Earth's plasma and magnetic field environment, and its response to solar activity, directly leads to the validation of models, and to strategies for predicting and mitigating the effects of space weather. This is the area of research that our idea is focused on.

2. In situ measurements vs remote sensing

Plasma and magnetic field environments can be studied in two ways – by in situ measurement, which provides precise information about plasma behaviour, instabilities and dynamics on a local scale, or by remote sensing, which offers the global view necessary to understand the overall behaviour and evolution of the plasma. The vast majority of our knowledge of the Earth's magnetospheric boundaries response to solar activity comes from very localised in situ measurements which inform us on the microscale. However, piecing the individual parts together to make a coherent overall picture, capable of explaining and predicting the dynamics of the magnetosphere at the system level, proves to be extremely difficult.

3. Solar wind charge exchange and SMILE

A novel and global way to explore solar-terrestrial relationships by soft X-ray imaging is offered by the SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) mission (Figure 1), currently being developed jointly by the European Space Agency and the Chinese Academy of Sciences and due for launch in the 2021-2022 timeframe [1]. Remote sensing of the magnetosheath and the cusps with X-ray imaging is now possible thanks to the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission, first observed at comets, and subsequently found to occur in the vicinity of the Earth's magnetosphere [2]. SWCX occurs when highly charged ions of the solar wind interact with exospheric neutrals, acquire an electron, are left in an excited state and then decay emitting soft X-ray lines of wavelengths characteristic of the de-exciting ion.

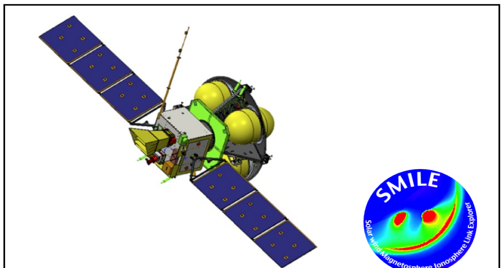

Figure 2: SMILE spacecraft (ESA/CAS) and logo

4. The DSG opportunity

SMILE's soft X-ray imaging of the Earth's magnetopause and magnetospheric cusps will establish this novel technique as a powerful diagnostic tool of the conditions of geospace under the vagaries of the solar wind; SMILE will break new ground, but as a small class mission will have limited spatial, temporal and sensitivity reach over the whole of geospace.

The Deep Space Gateway (DSG) allows observing from a distance of 50 – 70 R_E (Earth-Moon L1 or L2) from Earth depending on orbit, hence offers the opportunity of expanding very substantially the coverage of geospace available at any one time to an X-ray imager compared to SMILE: for example a 10º x 10º FOV provides a good compromise for encompassing continuously a large part of the primary region of scientific interest (7 – 10 R_E centred on the nose of the magnetopause depending on L1 or L2) whilst excluding the bright Earth, and covering both magnetospheric cusps together (which SMILE cannot do most of the time from its Earth polar orbit).

5. Instrumentation

For the DSG X-ray imager we are considering adopting as a baseline the Japanese concept instrument GEO-X which has been proposed for magnetosheath imaging from the Earth-Moon L1 point. It is therefore well-matched to adoption for the DSG. GEO-X employs novel ultra-light-weight X-ray telescope units (see Figure 2) with large aperture (Φ100 mm ~ 5º), short focal length (250 mm) and good spatial resolution (<10 arcmin). The Wolter-type optic is a low cost in-house fabrication constructed from metal coated Si wafers [3]. To realise the combined 10º x 10º FOV required for the DSG X-ray imager four GEO-X telescope units are required. Radiation hard DepFET devices operating at -70º C, ideal for deep space missions, are under consideration for the detector. The X-ray imager would be accommodated externally, operate autonomously and require no intervention by the crew of the DSG. Preliminary estimates of the resources required include a total hardware mass of 60 kg, 60 W power, and a volume of 20 cm x 20 cm x 30 cm for each one of the 4 telescope units.

It is worth noting that for a small increase in required resources (~4 kg, 5W) the addition of an in situ package (comprising a light ion analyser and a magnetometer) would add very significant benefit to the research by self-sufficiently providing measurements of the solar wind conditions, so as to set the X-ray observations into context.

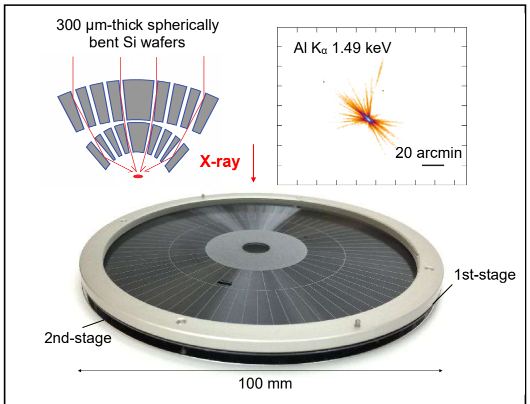

Figure 2: Ultra-light-weight X-ray telescope

6. Summary and Conclusions

Observations with the DSG X-ray imager which we propose will extend those of SMILE to the level of having long term, semi-continuous monitoring of the response and evolution of geospace conditions under the buffeting of the solar wind. This will provide direct scientific input to the studies of space weather and to the validation of global models of solar wind-magnetosphere interactions, leading to the mitigation of the possibly disastrous effects of space weather on Earth's technological infrastructure and human life and health.

References

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