PROCEEDINGS OF SCIENCE

SMILE ESA CAS Satellite Mission

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SMILE is a space mission which aims to measure Earth's global system responses to solar wind and geomagnetic variations with innovative instrumentation, e.g. wide-field X-ray telescope of Lobster–Eye type, on board. It is a collaborative project of the European Space Agency and Chinese Academy of Sciences. The SMILE international consortium involves the Czech Technical University in Prague and the Czech teams are expected to contribute to the project, mainly to the X–ray telescope.

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1. Introduction

SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) is a space mission which aims to measure Earth's global system responses to solar wind and geomagnetic variations [1][2][3]. SMILE will investigate the dynamic response of the Earth's magnetosphere to the impact of the solar wind in a unique manner, never attempted before: it will combine soft X-ray imaging of the Earth's magnetopause and magnetospheric cusps with simultaneous UV imaging of the Northern aurora. For the first time we will be able to trace and link the processes of solar wind injection in the magnetosphere with those acting on the charged particles precipitating into the cusps and eventually the aurora. SMILE will also carry in-situ instrumentation to monitor the solar wind and magnetosheath conditions, so that the simultaneous X-ray and UV images can be compared and contrasted directly, and self-sufficiently, with the upstream driving conditions. With its unparallelled payload SMILE will provide answers to many of the open questions in solar-terrestrial relationships in a thoroughly novel way. SMILE was put forward in March 2015 in response to the European Space Agency and Chinese Academy of Sciences (CAS) joint call for a small-size space mission. Out of 13 missions originally proposed, SMILE was the one chosen for an initial study phase during the summer of 2015. An initial study of the whole mission was carried out by ESA and CAS at their Concurrent Design Facilities during October 2015, and the conclusion is that the mission is feasible, with no show stoppers. In early November 2015 SMILE was formally selected by the ESA Science Programme Committee. We are now in Phase A study, with the objective of reaching mission adoption in early 2018. Launch is expected to take place at the end of 2021.

2. Science with SMILE

The key science questions for SMILE [1][2][3][11] are: What are the fundamental modes of the dayside solar wind/magnetosphere interaction? What defines the substorm cycle? How do Coronal Mass Ejections (CME) driven storms arise and what is their relationship to substorms? SMILE will determine when and where transient and steady magnetopause reconnection dominates. Dayside reconnection causes plasma to flow antisunward through the magnetopause boundaries, the cusps, and over the polar caps. Reconnection can persist for long periods, or be bursty and patchy. It is unclear whether steady reconnection occurs when the plasma beta–factor (ratio of gas to magnetic pressure) is low (when the incoming Interplanetary Magnetic Field (IMF) pressure dominates), and whether unsteady reconnection happens when the converse is true, during high plasma beta conditions. SMILE will test this hypothesis by determining the location and evolution over time of the magnetopause boundary. SMILE will also measure the proton cusp spot latitude, extent in longitude and the proton cusp spot intensity. Measurements of the proton cusp will be used to determine whether the magnetopause has experienced compression, spatially constrain the X-line (the region over which magnetic reconnection occurs) and determine whether steady or bursty reconnection has happened. The trigger that leads to substorm onset remains controversial. Southward turnings of the Interplanetary Magnetic Field (IMF) are required to add energy to the magnetotail lobes. However, the precise nature of how the energy is loaded into the tails and how this precedes a period of enhanced geomagnetic activity is an area of much controversy. A substorm may start after the magnetotail is squeezed by an increase in solar wind dynamic pressure.

Alternatively, a northward turning of the IMF may trigger a substorm. Some substorms have been observed with no obvious external drivers. SMILE will track the evolution of a substorm. SMILE will monitor the loading of energy at the dayside magnetopause through the response of the cusps and the subsequent changes in the size of the open field line region of the polar cap. SMILE will also test whether other modes of magnetospheric behaviours, such as Steady Magnetospheric Convection (when the size of the open-flux region of the polar cap does not change) and Saw-tooth events (a fast expansion and contraction of the open cap), are manifestations of the same process as substorms, but under different external driving conditions. SMILE will follow the development and evolution of the CME-driven storms. The largest geomagnetic disturbances are often associated with CME-driven storms, and they present the largest space-weather threat to world-wide infrastructure. SMILE will determine whether these CME-driven storms are a sequence of substorms. SMILE will also consider the questions: how long does a substorm last, and how and why does a substorm stop? Does this happen when the reserves of stored magnetic energy in the mangetotail have been exhausted? Or does a substorm stop when changes occur in the upstream solar wind? A combination of conditions may be required for the complete cessation of a substorm, and therefore the relative importance of each factor must be considered. SMILE will answer these questions using its novel approach of simultaneously: Measuring the input solar wind driving conditions. Determining the location and shape of the magnetospheric boundaries. Determining the global nature and properties of the auroral oval.

3. Payload

The following instrumentation makes up the payload of the SMILE satellite[1][2][3][11] .

SXI: a telescope with a wide field of view Lobster–eye X–ray optic based on microchannel plate and CCD detector at the focal plane. The SXI will observe the location, shape and motion of the dayside magnetospheric boundaries. X-rays in the Earth's exopshere result from the charge exchange interaction between ions in the solar wind and neutrals such as hydrogen in the exosphere. PI: Steve Sembay, University of Leicester, UK.

UVI: a wide field of view optic sensitive to the Lyman-Birge-Hopffman band of ultraviolet radiation. Filters and coatings will be used to suppress day glow. The UVI will observe the polar cap, and measure the location and width of the auroral oval. It will also observe transient and localised brightenings that occur on the auroral oval edges. PI: Eric Donovan, University of Calgary, Canada.

LIA: a wide field of view proton and alpha particle analyser. This will determine the basic moments of the solar wind ion distributions, such as velocity, density, temperature and the heat flux vector. These measurements, taken simultaneously with the UV and X-ray images, obviate the concerns of arrival times and spatial extents when external solar wind monitors at the distant Langrangian Point L1 are used. The LIA will include a top-hat-type electrostatic analyser. The central plane of the field of view will be parallel to the ecliptic, to ensure that the solar wind and average plasma sheet flow directions remain within the field of view. Larger dynamic range will be obtained using a variable geometric factor system. PI: Lei Dai, National Space Science Center, Chinese Academy of Sciences, China.

MAG: a dual-redundant digital fluxgate magnetometer, with two tri-axial fluxgate sensors connected by a boom to a spacecraft-mounted electronics box. The accompanying electronics unit consists of a FPGA digital processing unit with a DC-DC converter. PI: Lei Li, National Space Science Center, Chinese Academy of Sciences, China.

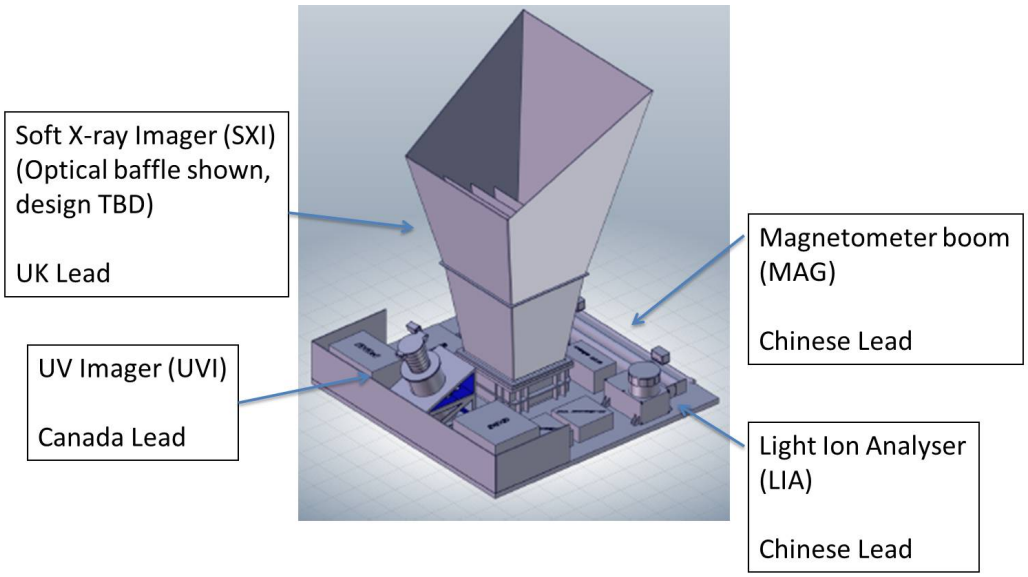

Figure 1: SMILE palyload module.

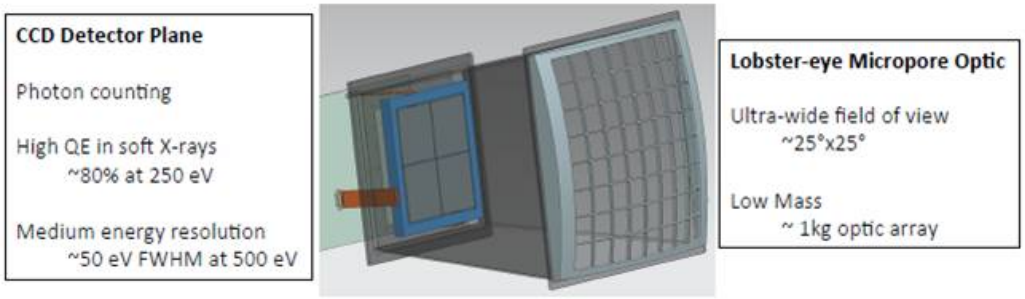

Figure 2: SMILE Soft X-ray Imager (SXI).

4. Solar Wind Charge Exchange (SWCX)

Charge exchange emission can occur when ions interact with neutral atoms or molecules; one or more electrons are transferred to the ion into an excited state. In the subsequent relaxation of the ion (with the charge now reduced by the number of electrons captured), a cascade of photons may be emitted.

X-ray emission from Solar Wind Charge Exchange (SWCX) recombination occurs in planetary atmospheres, comets, interplanetary space, and in the Earth's exosphere, while evidence for extrasolar charge exchange emission has been observed in supernova remnants, galaxies and galaxy

clusters. Consequently, the heliophysics, planetary science, and astrophysics communities all have an interest in SWCX.

SWCX emission could be used to image the Earth's magnetosheath. The magnetosheath is the area near the Earth where the magnetic field, embedded in the solar wind plasma, is confronted by the Earth's magnetic field. This results in the magnetosphere; a cavity of Earth-confined plasma which protects the Earth from the harsh conditions within the solar wind. This picture, however, is not static as the Earth system responds quickly to changes in the solar wind density and velocity.

5. Czech Participation

CTU in Prague and Rene Hudec are the SMILE project consortium members. The Czech participation is based on very long experience with imaging X ray telescopes and monitors in the Czech Republic with emphasis on wide field X ray monitors Lobster Eye type [4–10].

Expected Czech contribution is as follows: SXI with emphasis on focal plane detector system (temperature control, active/passive cooling etc.), thermal control system, optics thermal baffle, mechanics and electronics. There is expected participation of Czech space industry. Two SMILE meetings were held in Prague, namely SMILE session at Prague AXRO conference in December 2015 with presentations of SMILE PIs negotiating details on Czech participation, and SMILE meeting in Prague in July 2016.

6. Conclusions

The SMILE satellite with innovative instrumentation onboard including a Lobster Eye X-ray telescope will study X-rays from the magnetosphere: SMILE will turn "unwanted background" for X-ray astrophysical observatories in to a diagnostic tool of Sun-Earth relationships. SMILE will trace and link processes of solar wind injection in the Earth's magnetosphere with those acting on charged particles precipitating into the cusps and the aurora. There will be outreach aspects as well: SMILE images and videos will captivate public to science (that of the magnetic field) so far invisible. The project is based on cooperation with China: SMILE is a showcase, building on Double Star experience.

Acknowledgments

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