

Recent Advance in the Solar Wind Magnetosphere Ionosphere Link Explorer (SMILE) Mission*

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Abstract

The SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) mission is a joint space science mission between the European Space Agency (ESA) and the Chinese Academy of Sciences (CAS), aiming to understand the interaction of the solar wind with the Earth's magnetosphere in a global manner. The mission was adopted by CAS in November 2016 and by ESA in March 2019 with a target launch date in the year 2024-2025. We report the recent progress of SMILE mission by April, 2022.

Key words

SMILE, Soft X-ray Imager (SXI), Ultra-Violet Imager (UVI), Light Ion Analyzer (LIA), MAGnetometer (MAG)

1 Introduction

The SMILE^[1] mission is a joint ESA and CAS space science mission, which aims at deepening our understanding of the interaction of the solar wind with the Earth's magnetosphere by making global images of the dayside magnetosheath and cusps of the magnetosphere, and the aurorae at the North Pole simultaneously, while monitoring the in-situ plasma environment. The mission was adopted by CAS in November, 2016 and by ESA in March 2019.

CAS is responsible for the development of satellite Platform (PF), TC/TM (CLTC), Science Application

System (SAS) as well as Ground Support System (GSS), and provides in-situ measurement instruments magnetometer (MAG), Light Ion Analyzer(LIA) and Ultraviolet Imager (UVI). ESA is responsible for the development of Payload Module (PLM), Launch Vehicle, Launch Site, and science operation and ground receiving station supports when necessary, and also the development of the Soft X-ray Imager (SXI), development of intensifiers, mirrors with coating and calibration of UVI.

The SMILE Mission will use novel soft X-ray imaging technology to obtain, for the first time, the global image of the large-scale structures of the geospace. This

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is critical to quantitatively analyzing and understanding of the global feature of the magnetosphere.

The interaction of the solar wind with the Earth’s atmosphere leads to the formation of the large structures of the magnetosphere, including the bow shock, magnetopause, and the cusp regions. The position and shape of the magnetopause and cusps change constantly as the Earth’s magnetosphere responds to the varying solar wind dynamic pressures and interplanetary magnetic field orientations. Both the fast and slow solar wind can be interrupted by large, fast-moving bursts of plasma called interplanetary Coronal Mass Ejections (CMEs). When a CME impacts the Earth’s magnetosphere, it temporarily deforms the Earth’s magnetic field, changing its direction and strength, and induces large electrical currents; this is called a geomagnetic storm and it is a global phenomenon. The southward interplanetary magnetic fields, as presented in a CME event, could induce magnetic reconnection in the Earth’s magnetotail; this launches protons and electrons downward toward the Earth’s atmosphere, where they form the aurora, resulting in substorms.

The Scientific objectives of the SMILE mission are summarized as: (i) explore the fundamental modes of the dayside solar wind/magnetosphere interaction; (ii) understand the substorm cycle; (iii) determine how CME-driven storms arise and their relationship to substorms.

2 Modeling Update

The SMILE Modelling Working Group (MWG) performs studies on the predictions of X-ray signals and the reconstruction techniques from X-ray images to 3D magnetopause. Four approaches have been developed previously to derive the magnetopause position from X-ray images, including the Boundary Fitting Approach (BFA), Tangent Fitting Approach (TFA), Tangential Direction Approach (TDA), and Computed Tomography Approach (CTA). It is found that the 3D X-ray emissivity in the magnetosheath can be reconstructed based on the CTA, if tens of images are provided from different viewing geometries under the same or similar solar wind conditions (see Fig. 1)^[2]. To obtain the images required to better perform the CTA, 87 different orbit locations are considered during one year to allow wide-angle coverage resulting from orbital precession. The magnetopause can be dynamic during the one year,

preventing the application of CTA. This problem can be solved by dividing the solar wind conditions into several bins, and assuming that the magnetopause position corresponding to each solar wind bin is the same. An alternative way is through machine learning techniques^[3]. A 3D GAN network is applied to supplement 2D X-ray images collected at finite angles within limited orbital time during which the magnetopause is almost static. By deriving the information about cusps from the X-ray image, it is revealed that the tangent direction of the cusp boundary is the direction with the appreciable increase of local standard deviation in X-ray intensity^[4]. Instrument simulations are also performed to provide the photon counts images expected to be observed by the SMILE SXI. The effectiveness of TFA is validated based on the simulated photon counts images (see Fig. 2)^[5].

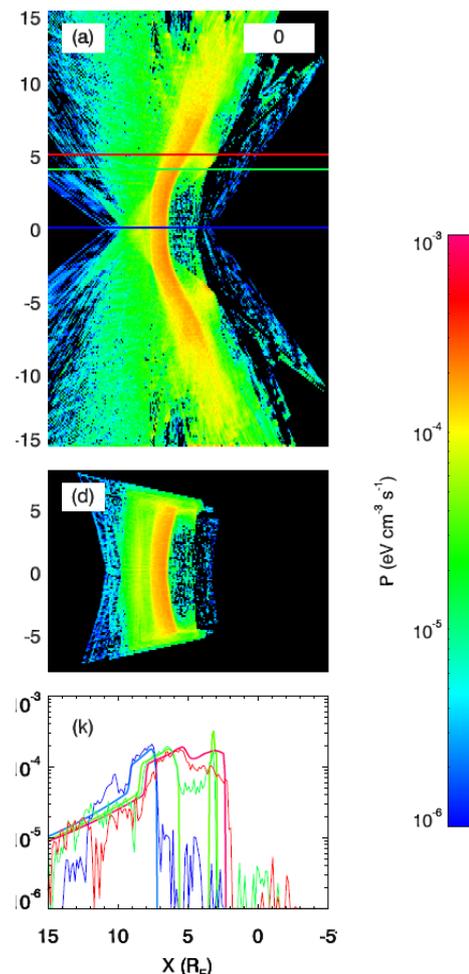


Fig. 1 Reconstructed X-ray emissivity on the noon-midnight meridian plane (a), equatorial plane (b), and along the three lines marked in the top panel (c) based on the CT Approach

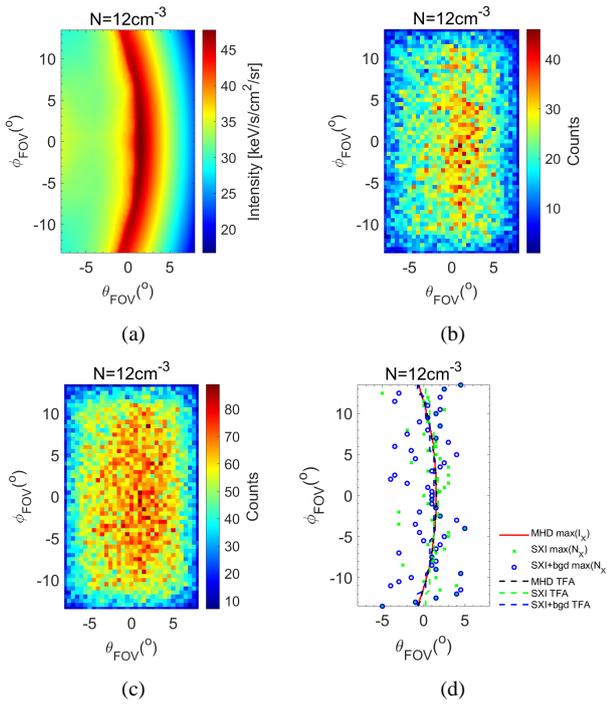


Fig. 2 Instrument simulations of the X-ray photon counts. (a) X-ray image inside field of view of SXI. (b) SXI photon counts image corresponding to (a) without sky background. (c) SXI image after adding the constant sky background. (d) The X-ray maximum intensity of MHD and SXI photon counts images, and their best match curves by using TFA

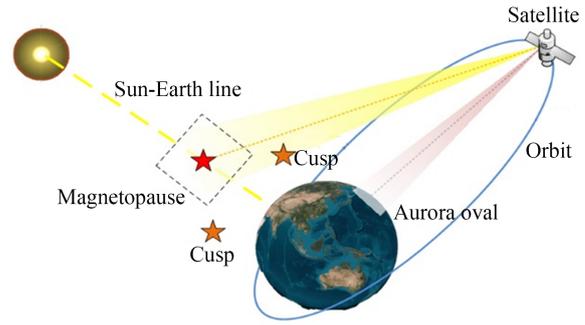


Fig. 3 SMILE satellite HEO orbit

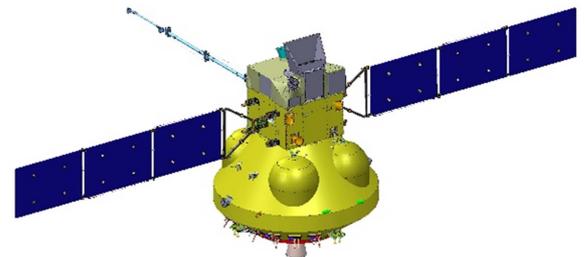


Fig. 4 Diagram of the satellite structure



Fig. 5 SXI STM on a shaker table at RALSpace, UK

Currently, the UVI for imaging the Earth aurora is jointly developed by CAS and ESA. It is planned to begin UVI CDR in December of 2022 (see Fig. 6).

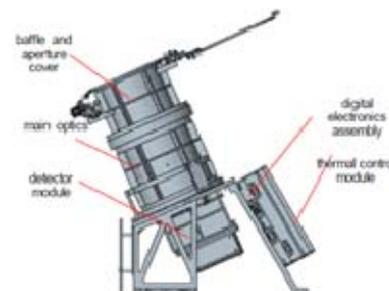


Fig. 6 UVI assembly

3 Mission Update

3.1 Satellite System

The science orbit is a highly elliptical orbit with the apogee altitude of about $19 R_e$ and a perigee of about 5000 km. The inclination is 73° if launched with Vega-C as the baseline, or 98.2° with Ariane 62.

SMILE has a three-axis stabilized satellite which consists of Platform (PF) and Payload Module (PLM). The total mass of the satellite is less than 2250 kg.

The science data will be downlinked by an X-band transmitter with a data volume of 47 Gbit per orbit. The telemetry and telecommand will through Unified S-band TT&C system. The nominal life time is 3 years after delivery to the users. Fig. 3 and Fig. 4 showed SMILE satellite HEO orbit and structure.

SXI for imaging the magnetopause and cusps has passed PDR and STM environment test. The SXI CDR is planned to begin in November 2022 (see Fig. 5).

MAG for measuring the magnetic field has finished PDR. MAG EM and MAG STM were delivered to Airbus for AIT in 2021. MAG BOOM QM has been successfully deployed under the control of PLM in ESTEC (see Fig. 7). It is planned to begin MAG CDR in June of 2022.



Fig. 7 MAG BOOM deployment test in ESTEC

LIA for monitoring the in-situ plasma environment has passed PDR. LIA EM and REM have been delivered to PLM for the test (see Fig. 8). It is planned to begin LIA CDR in June of 2022.



Fig. 8 LIA electrical interface test in Airbus

Payload Module (PLM) which hosts SXI, UVI, MAG and X-band science downlink transmitter has finished PDR. PLM STM integrated with instruments STM has passed mechanical and thermal tests(see Fig. 9). PLM test bench also has finished functional and electric tests with MAG and LIA. PLM STM will be delivered to China in March of 2022. It is planned to begin PLM CDR at the beginning of 2023.

The Platform (PF) provides service for the whole satellite. PF also provides propellants and thruster for orbit maneuver from the insertion orbit to the HEO

science orbit. PF also hosts LIA for 4π space measurement. All the PF QM units have been delivered to PF and have passed through electrical interface and functional tests (see Fig. 9). PF QM has been assembled and will pass the qualification level tests with PLM STM later(see Fig. 10). PF CDR is planned to begin in Oct. of 2022.

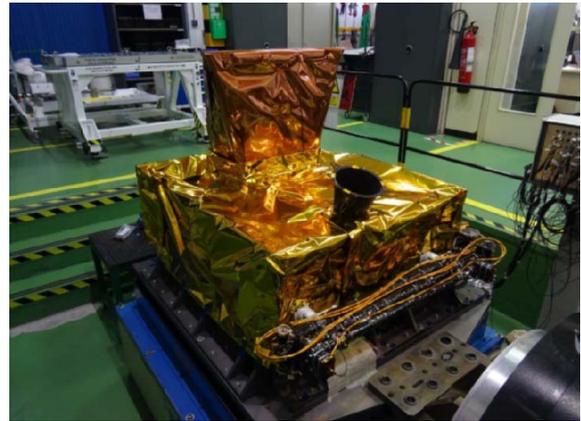


Fig. 9 PLM STM on shaker in ESTEC



Fig. 10 PF electrical interface test

Satellite STM has passed environment test in China in 2020. From April of 2022, Satellite QM AIT campaign will start with PF QM and PLM STM in China. Satellite qualification level test will begin from April to August of 2022. After satellite qualification level test, we will begin fitness and separation tests with launch adapter in ESTEC in September 2022. It is also planned to do an electrical interface test in Madrid in Oct 2022. The mission CDR is scheduled to take place in March 2023. Fig. 11 showed satellite STM on the shaker.

3.2 Launch Vehicle

Launch Vehicle is ESA's responsibility. The baseline is single launching in Kourou with Vega-C. Vega-C is a

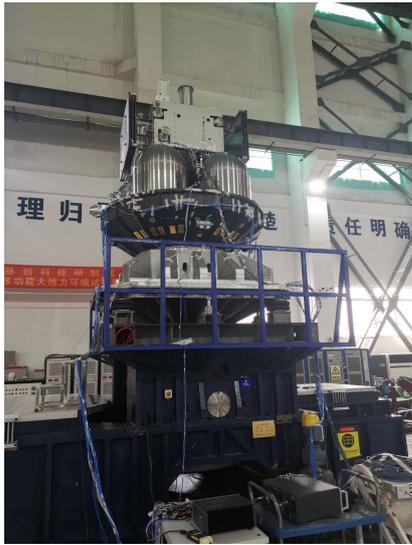


Fig. 11 Satellite STM on the shaker

solid launch vehicle. The launch capability is no less than 2250 kg for 700 km circular injection orbit or 2300 kg for 450 km×700 km injection orbit.

3.3 Launch Site

SMILE will be launched in Kourou. ESA is responsible for the Launch Site and Launch service, and will provide the ground segment support and logistics.

3.4 TC/TM

China Satellite Launch and Tracking Control General (CLTC) will be responsible for the TC/TM of SMILE satellite. European Space Operation Center (ESOC) will be responsible for the TC/TM before the satellite's separation with the Launch Vehicle. In addition, ESA will also provide ground station support for orbit transfer from injection orbit to HEO science orbit and in case of emergency.

Satellite QM to ground S-band interface compatibility test was successful in 2020 (see Fig. 12).



Fig. 12 Satellite to ground S-band interface compatibility test

3.5 Ground Support System (GSS)

GSS has been constructed in China during the 12th Five-Year Plan Period and it will undergo some modifications according to the new requirements of the space science missions during the 13th Five-Year Plan Period. It is mainly responsible for the operation and management of the payloads, scientific data receiving, processing and distribution to the science community.

GSS has finished PDR. Some core software has finished requirement analysis and design. GSS also has finished to establish and test the Docker operation environment. It is planned to start joint GS CDR in June of 2022.

3.6 Science Application System (SAS)

CAS will set up SAS located at NSSC, and ESA will set up Science Operation Center (SOC) located in European Space Astronomy Center (ESAC). Both parties will cooperate closely to make a scientific strategic plan and observation plan, monitor the execution of the plan, analyze the performance of the payloads in orbit, calibrate the payloads in orbit, produce quick look scientific data, and scientific data products.

SAS has finished PDR. Software is in the status of requirement analysis and design. A joint data products definition is finished for SMILE.

4 Future Schedule

Based on Payload Instruments, PLM and PF PDRs, the joint Mission PDR was completed successfully in January 2020 in Netherlands, which is the third joint review of the SMILE mission, marking the kick-off of Phase C study. PLM STM finished all the mechanical and the thermal tests and was shipped to IAMC for integration with QM Platform. The next step is S/C level QM test before the end of July. All the scientific instruments, PLM and SC will finish critical design review and a joint mission level critical design review will be conducted in March 2023. SMILE satellite is planned to be launched around 2024–2025.

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