Outline

1. Background
2. Science Objectives
3. Mission Profile
4. Summary
Collaboration between ESA and Chinese Academy of Science (CAS)

Follows a successful collaboration of Cluster – Double Star (DS)

Recommended by a joint European and Chinese scientific committee as candidate for a collaborative science mission and selected by ESA Science Programme Committee (SPC) in Nov. 2015

First time that ESA and China jointly select, design, implement, launch and operate a space mission

Adopted by CAS in November 2016 (13th 5-year plan) and by ESA in March 2019

Mission PDR successfully conducted January, 2020

Mission CDR successfully conducted June, 2023

Launch expected Sep/Oct 2025
The solar wind – magnetosphere interaction is one of the key links in the Sun-Earth connection.
Magnetic Reconnections

Dayside reconnection
particle and energy entry into the geospace.

Tail reconnection
release of energy, injecting particles deep into the magnetosphere, causing auroral substorms.

(Credit: Oslo University)
The open magnetic flux is closely related to magnetic reconnections in the dayside magnetopause and magnetotail.

The open magnetic flux governs the substorm intensity.

The open-close field line boundary (OCB) defines the aural oval.
What do we know already?

(1) **Basic features of the magnetosphere**

For instance: position of the magnetopause

Empirical model of the magnetopause:

MP crossing observed by an in-situ satellite

Tsyganenko, 2002
What do we know already?

(2) Configurations of the magnetosphere
(Cusps, magnetotail, plasmasphere, boundary layers...)

For instance: cusp

Statistical study of cusp plasma during plenty of crossings:
What do we know already?

(3) Dynamics of the magnetosphere
(magnetic reconnection, instabilities, response to solar wind disturbances, and etc.)

For instance: Magnetic reconnection

Reconstruction:
In Situ Missions

Cluster + DS

MMS

THEMIS

Cusp

Magnetosphere

Solar wind

Bow shock

Magnetosheath

Magnetopause
In situ measurements provide localized information about plasma, field and their dynamics.

However, they fail to provide the global view, large-scale configurations and overall evolutions of the magnetosphere.
Solar Wind Charge eXchange (SWCX)

\[ P_X = \alpha n_N \ n_{SW} \ \nu_{SW} \ \text{eV} \ cm^{-3} \ s^{-1} \]

X-ray emission proportional to density of solar wind ions and neutrals, hence brightest in dayside magnetosheath and the cusps
What is SMILE?

- Vantage point outside the magnetosphere
- Polar Orbit, 19 $R_E$ apogee
- Nominal mission lifetime 3 years
Investigate the dynamic response of the Earth’s magnetosphere to the solar wind impact in a unique and global manner.
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To provide global view of the magnetosphere for the first time

Since the innovative prediction of the magnetosphere in 1940, scientists have been studying this field for more than 70 years.

With SMILE, we would actually see the magnetosphere for the first time, and further understand its global features.
To determine the fundamental modes of the dayside interaction of the solar wind/magnetosphere.

- Determine when and where transient and steady magnetopause reconnection dominates.
- Explore the triggering mechanisms and the effects of solar wind conditions on the reconnection.
- Estimate the total solar wind energy, momentum, and plasma transported into the geospace.
(2) To define the substorm cycle

- Define the substorm cycle, including timing and flux transfer amplitudes

- Explore the substorm triggers (external trigger, BBF, local instabilities etc.)
(3) To explore the arising of CME-driven storms and their relationship to substorms

- To investigate the effect of the ring current on the magnetopause location and substorm activation

- To determine what the degree of magnetopause erosion (flux removal) needed to initiate substorms during storms

Milan et al. [2009]
In Summary,
SMILE is a novel mission that addresses basic macroscale interaction questions

- Rate, extent, and triggers of magnetopause reconnection
- Consequences of nightside reconnection and substorms
- Nature of geomagnetic storms
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SMILE Observables

Remote sensing

Soft X-ray images of the magnetosheath and cusps
Bow shock, magnetopause, cusp locations

UV images of the auroral oval
Location, structure, transients

In Situ Measurements

Interplanetary/magnetosheath magnetic field (B)

Solar wind/magnetosheath plasma (n, V, T)
Soft X-ray Imager – SXI

**PI Steve Sembay, University of Leicester, UK**

- SXI will provide global soft X-ray imaging of the cusps and the day-side magnetosheath
- Wide-field Lobster-eye optics (micro-channel plates), CCD-based detector, 0.2 – 2.5 keV (5keV Goal)
- Wide FOV (15.6° x 26.5°)
- Lobster-type optic, focal length 30 cm
- Angular resolution of 6 arcmin FWHM
Auroral Imager (UVI)

**PI X.X. Zhang, China Meteorological Administration**

- UVI will obtain auroral imaging of both dayside and night-side
- Waveband: 140-180 nm
- FOV: 10° x 10°
- Spatial resolution: 0.04°
Light Ion Analyser (LIA)

**PI Lei Dai, NSSC CAS, China**

- LIA will determine the basic moments and the distribution function of the ions
- FOV: 360° x +/-45°
- Energy band: 50eV – 20 keV/q
- Energy resolution: 10%
- Time resolution: 2s
Magnetometer (MAG)

PI Lei Li, NSSC CAS, China; Co-PI Rumi Nakamura, SRI, Austria

- MAG will measure the magnetic field simultaneously with LIA.
- Range: 12,800 nT
- Resolution: < 0.01 nT, Noise: < 0.1 nT (RMS)
- Sample frequency: 40Hz
- outer sensor ~3 m, inner sensor 1.7~2.0 m
SXI expected data based on MHD simulation of Sun-Earth connection

UVI expected images of aurora

S. Sembay & T. Sun

(NASA Polar UVI image)
MAG expected data

LIA expected data

(Cluster data over 1 orbit of 54h)
SMILE SXI: 17th March 2015 solar storm
Satellite:
Payload PLM + Service SVM

Ground Sector:
TM & TC + Ground Support + Science Application
Responsibilities

- **Spacecraft:**
  - **Platform:** CAS/NSSC (via IAMC)
  - **Payload Module:** ESA (via Airbus)
  - **Instruments:**
    - SXI & UVI: ESA Member States provision (UK & CAN)
    - MAG & LIA: CAS/NSSC (+ UVI-E)
  - **Spacecraft-level verifications:** CAS/NSSC (IAMC) + S/C FM test facilities by ESA (ESTEC)

- **Launch vehicle/services:**
  - ESA

- **Mission operations:**
  - CAS/NSSC + ESA ground stations

- **Science operations:**
  - CAS (planning/commanding + MAG/LIA data processing) + ESA (SXI/UVI data processing)
Summary of operations over one orbit

Full Science Mode:

- All 4 instruments active,
- Pointing law: SXI LoS points 20.4° from the Earth edge (UVI offset 24° from SXI)
- Above 50000 km all instruments ON, unless Sun avoidance angles are met (then change to one of the reduced science modes and change pointing law)
- Below 50000 km, SXI cannot observe due to CCD sensitivity to radiation (door closes, re-opens at next 50000 km pass)
- Phase D study
- FM AIT in ESTEC: Oct. 2024-July 2025
- Launch in Kourou: Sep. 2025

SMILE configuration

<table>
<thead>
<tr>
<th>UVI</th>
<th>LIA</th>
<th>MAG</th>
</tr>
</thead>
<tbody>
<tr>
<td>SXI</td>
<td>Payload Module (PLM)</td>
<td>Platform (PF)</td>
</tr>
</tbody>
</table>
SMILE Mission Milestone

- MCR in Beijing: 2017.06
- SRR in ESTEC: 2018.10
- PDR in ESTEC: 2020.01
- M-CDR in Shanghai: 2023.06
- S/C IRR: 2024.11
- QFAR: 2025.07
- Launch in Kourou: 2025.09
- We are here now: 2025.01

National Space Science Center, CAS
## Schedule

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>SXI CDR</td>
<td>June, 2022 - Jan. 2023</td>
<td>Closed</td>
</tr>
<tr>
<td>UVI interface CDR</td>
<td>Feb. - Apr. 2023</td>
<td>Closed</td>
</tr>
<tr>
<td>PLM CDR</td>
<td>Feb. - May, 2023</td>
<td>Closed</td>
</tr>
<tr>
<td>S/C and Mission CDR</td>
<td>June, 2023</td>
<td>Closed</td>
</tr>
<tr>
<td>MAG delivery to PLM</td>
<td>Mar. 2024</td>
<td>Completed</td>
</tr>
<tr>
<td>SXI PFM delivery to PLM</td>
<td>June, 2024</td>
<td></td>
</tr>
<tr>
<td>UVI QM delivery to PLM</td>
<td>May, 2024</td>
<td>Completed</td>
</tr>
<tr>
<td>UVI FM delivery to PLM</td>
<td>Aug. 2024</td>
<td></td>
</tr>
<tr>
<td>PLM and Platform (P)FM delivery (and LIA)</td>
<td>Oct. - Nov. 2024</td>
<td>PF readiness ~ Aug.2024</td>
</tr>
<tr>
<td>S/C AIT</td>
<td>Oct. 2024 - Aug. 2025</td>
<td>@ ESTEC</td>
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<tr>
<td>S/C and mission QFAR</td>
<td>June - Aug. 2025</td>
<td></td>
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<tr>
<td>Launch Campaign</td>
<td>Aug. - Sep. 2025</td>
<td></td>
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<tr>
<td>Launch</td>
<td>Sep. /Oct. 2025</td>
<td></td>
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<tr>
<td>In-orbit commissioning review</td>
<td>Dec. 2025</td>
<td></td>
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</tbody>
</table>
First magnetospheric imaging

In-situ measurement

How to image?

How to reconstruct?

How to understand?
Modeling working group (MWG)

Method

Global MHD simulation

+ radiation model

\[ \frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0 \]

\[ \frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot (\rho \mathbf{v} \mathbf{v} + p \mathbf{I} - \frac{1}{\mu} \mathbf{B} \mathbf{B}^\prime) = \frac{1}{\mu} (\nabla \times \mathbf{B}) \times \mathbf{B} - \mathbf{B} \nabla \cdot \mathbf{B} \]

\[ \frac{\partial \mathbf{B}}{\partial t} + \nabla \times (\mathbf{v} \times \mathbf{B}) = \nabla \times (\mathbf{v} \times \mathbf{B}) - \nabla \cdot \mathbf{B} \]

\[ \frac{\partial E}{\partial t} + \nabla \cdot \{ (E + p)(\mathbf{v} - \frac{1}{\mu} (\mathbf{v} \cdot \mathbf{B}) \mathbf{B}^\prime) \} = -\nabla \cdot \{ (\nabla \times \mathbf{B}) \times \mathbf{B} \} + \frac{1}{\mu} \mathbf{B} \cdot [\nabla \times (\mathbf{v} \times \mathbf{B})] - (\mathbf{v} \cdot \mathbf{B}) \nabla \cdot \mathbf{B} \]

+ \[ I_x = \frac{1}{4\pi} \int \alpha n_i n_{sw} \sqrt{v_{sw}^2 + v_{th}^2} \, dr \]

Expected X-ray images for storm on 17 Mar. 2015

A dynamic model for prediction of global X-ray images

(Sun et al., 2015; SMILE proposal)
Modeling working group (MWG)

**Method** balance between information and assumptions

**Current arsenal** of reconstruction techniques

- e.g. CT method

<table>
<thead>
<tr>
<th>information we need</th>
<th>approaches to derive MP</th>
<th>assumptions we make</th>
</tr>
</thead>
<tbody>
<tr>
<td>one image</td>
<td>boundary fitting approach, BFA (3D MP position)</td>
<td>functional forms of MP, its and X-ray emissivity</td>
</tr>
<tr>
<td>one image</td>
<td>tangent fitting approach, TFA (3D MP position)</td>
<td>functional form of MP, maximum intensity is tangential direction</td>
</tr>
<tr>
<td>two images</td>
<td>tangential direction approach, TDA (MP position at tangent points) (3D MP position)</td>
<td>maximum intensity is tangential direction, different images are taken for the same MP profile</td>
</tr>
<tr>
<td>a set of images</td>
<td>computed tomography approach, CTA (3D MP position)</td>
<td>different images are taken for the same MP profile</td>
</tr>
</tbody>
</table>

2D images with different vantage points  3D magnetosphere and cusps
Modeling working group (MWG)

How to understand?

\[
I_x = I_{SWC} + I_b = \frac{1}{4\pi} \int \alpha N_{iH} N_{sw} V_{sw}^2 + V_{th}^2 dr + I_b
\]

- Neutral density and storm
- Background signals
- Efficiency factor
- Proton flux
- Viewing direction

Solar activity
- Magnetopause
- Particle escape
- \(\text{O}^{6+}\)
- \(\text{X-ray}\)
- \(\text{H}^{+}\)
GSS Progress and Status

Mission Operation Center: will be ready by the end of 2024
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Currently, the SMILE mission is going through Phase-D, the final Flight Model (FM) assembly and testing phase. FMs of MAG, LIA, SXI and QM of UVI have been completed and will be integrated on the PLM.

The FM of PF is under assembly, Integration and Tests (AIT) and will be shipped to ESA for integration with the PLM in September 2024. The schedule remains challenging, but all work progresses smoothly.

It is expected that the SMILE mission will be launched in the last quarter of 2025.
SMILE on the map