SMILE

Solar wind Magnetosphere Ionosphere Link Explorer

Chi Wang/NSSC

On behalf of SMILE Team

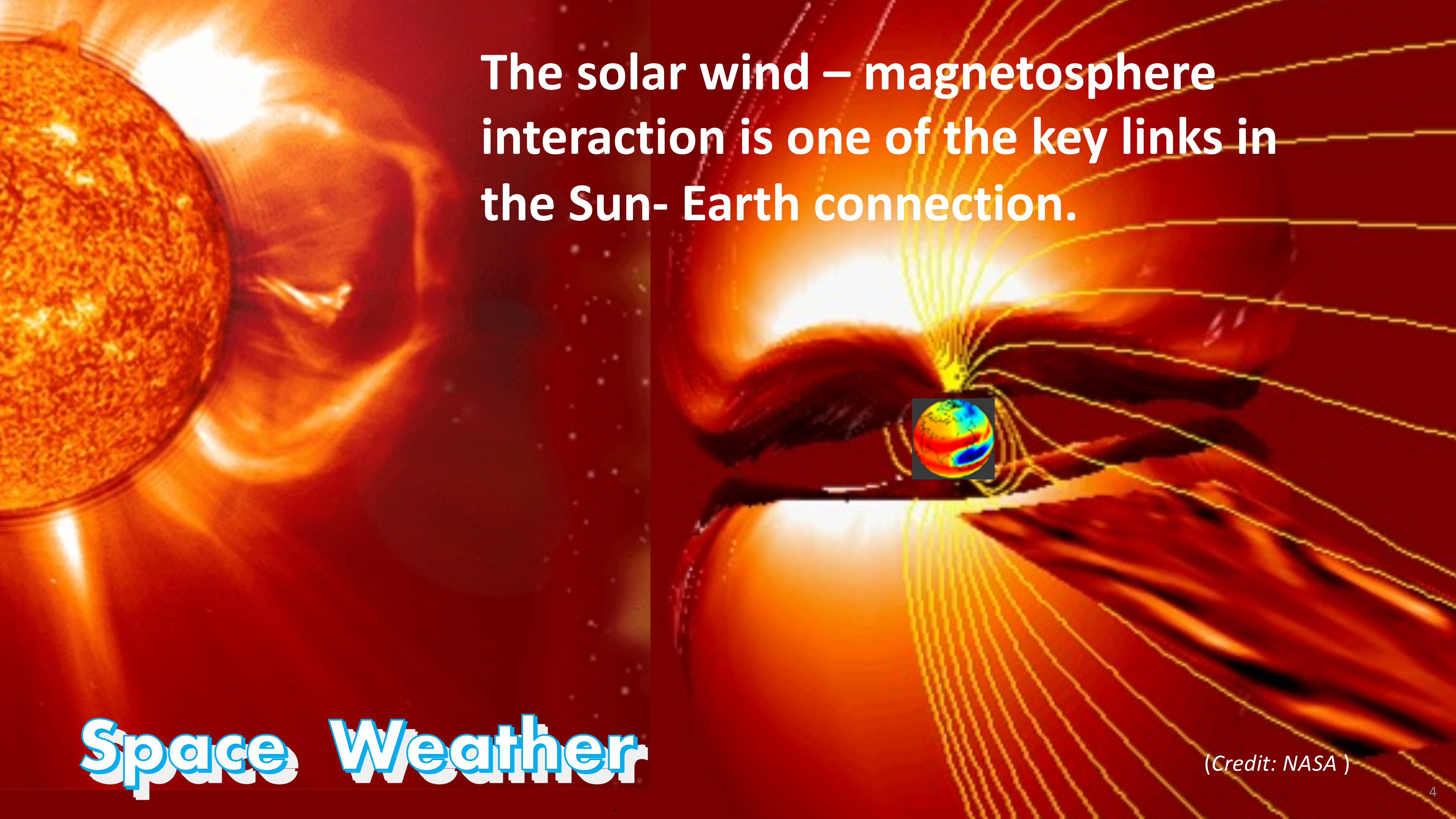
Outline

1. **Background**
2. Science Objectives
3. Mission Profile
4. Summary

Background

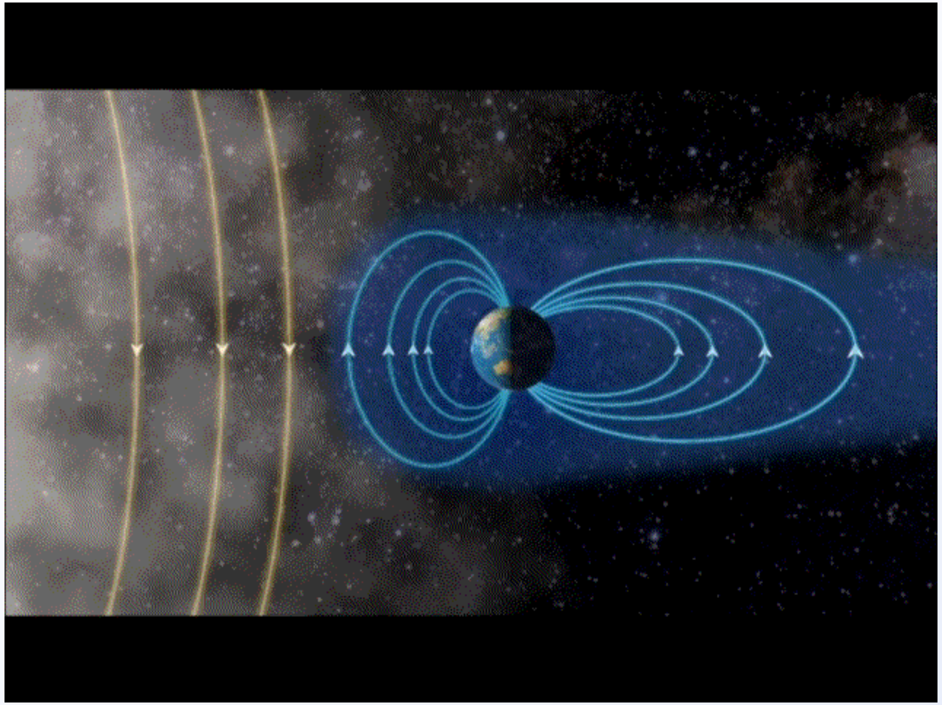
- ❑ Collaboration between ESA and Chinese Academy of Science (CAS)
- ❑ Follows a successful collaboration of Cluster – Double Star (DS)
- ❑ Recommended by a joint European and Chinese scientific committee as candidate for a collaborative science mission and selected by ESA Science Programme Committee (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.



(Credit: NASA)

Magnetic Reconnections



(Credit: Oslo University)

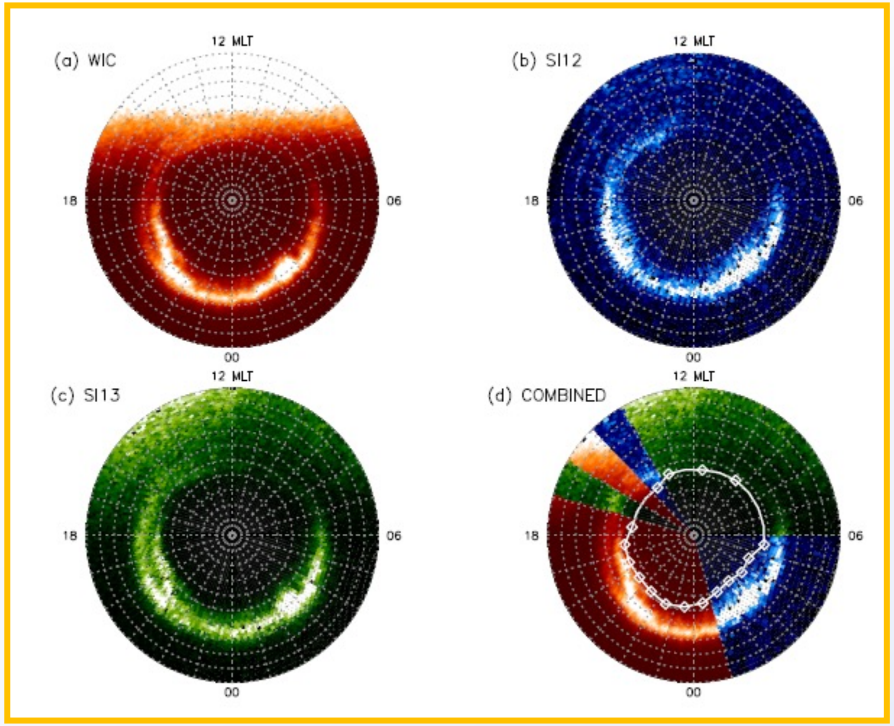
Dayside reconnection

particle and energy entry into the geospace.

Tail reconnection

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

Open Flux



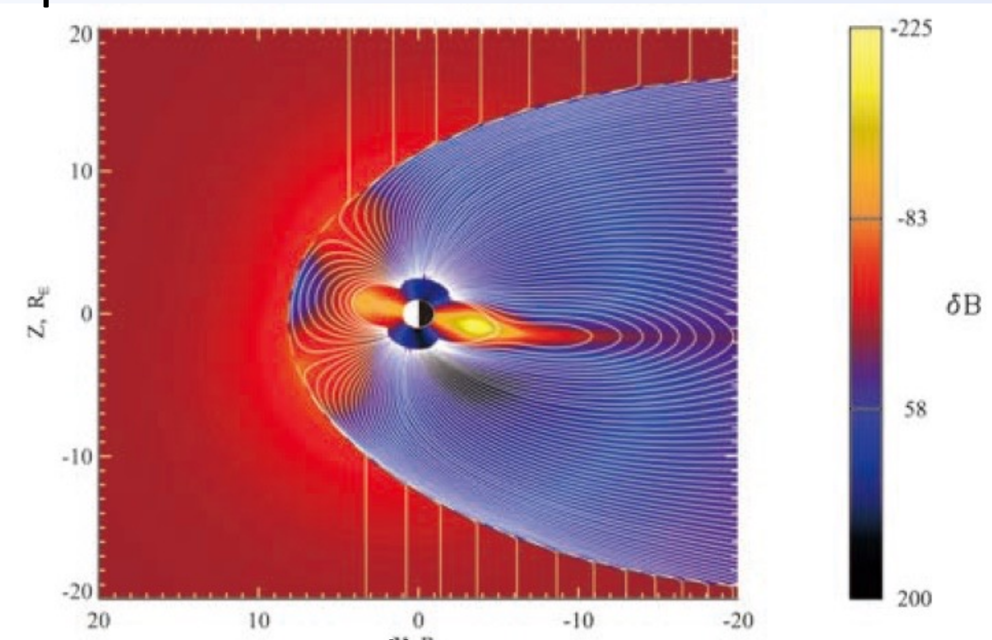
- The open magnetic flux is closely related to magnetic reconnections in the dayside magnetopause and magnetotail
- The open magnetic flux governs the substorm intensity.
- The open-close field line boundary (OCB) defines the aural oval.

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

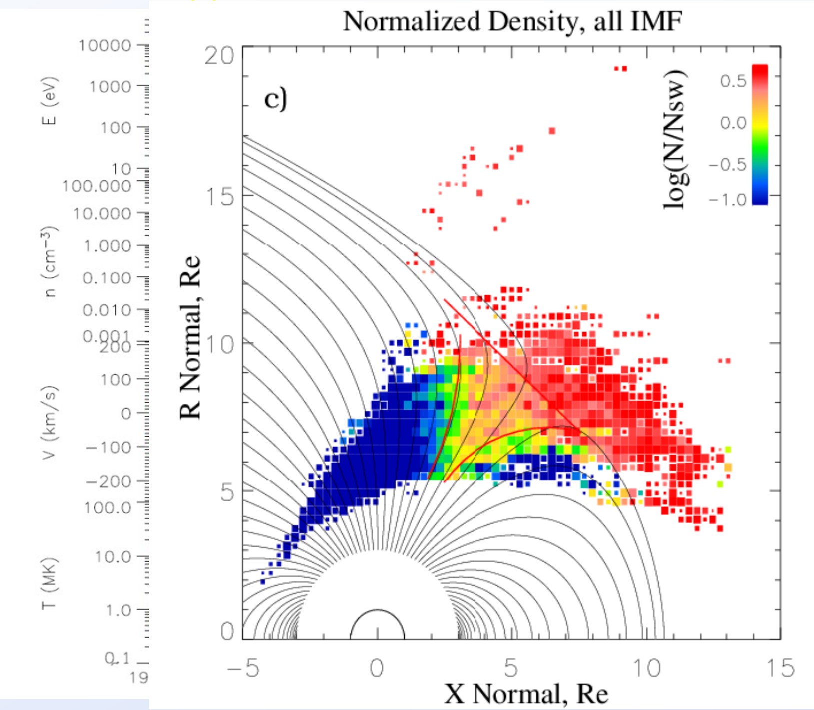
What do we know already?

(2) Configurations of the magnetosphere

(Cusps, magneotail, plasmasphere, boundary layers...)

For instance: cusp

Statistical study of cusp plasma during plenty of crossings:



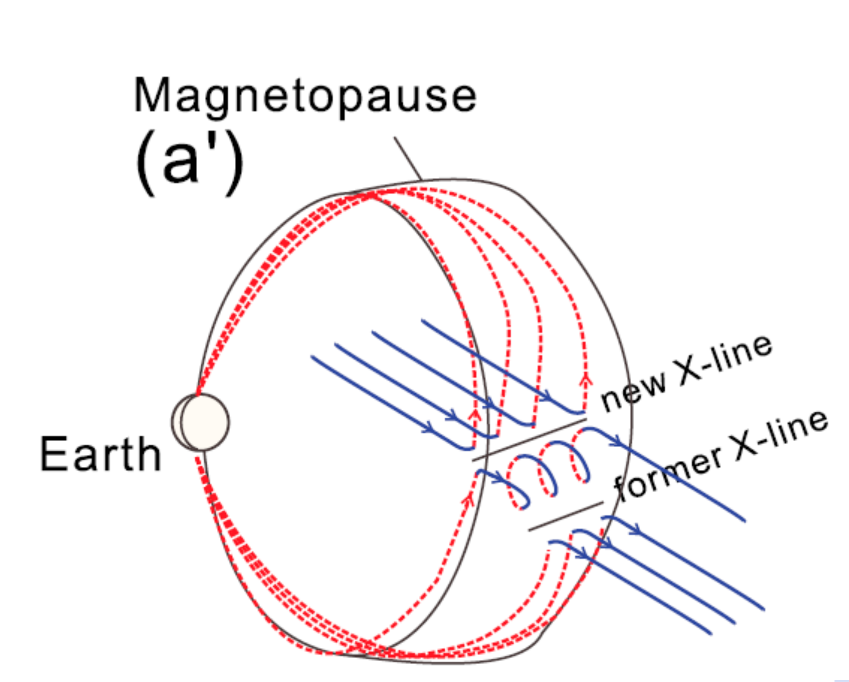
What do we know already?

(3) Dynamics of the magnetosphere

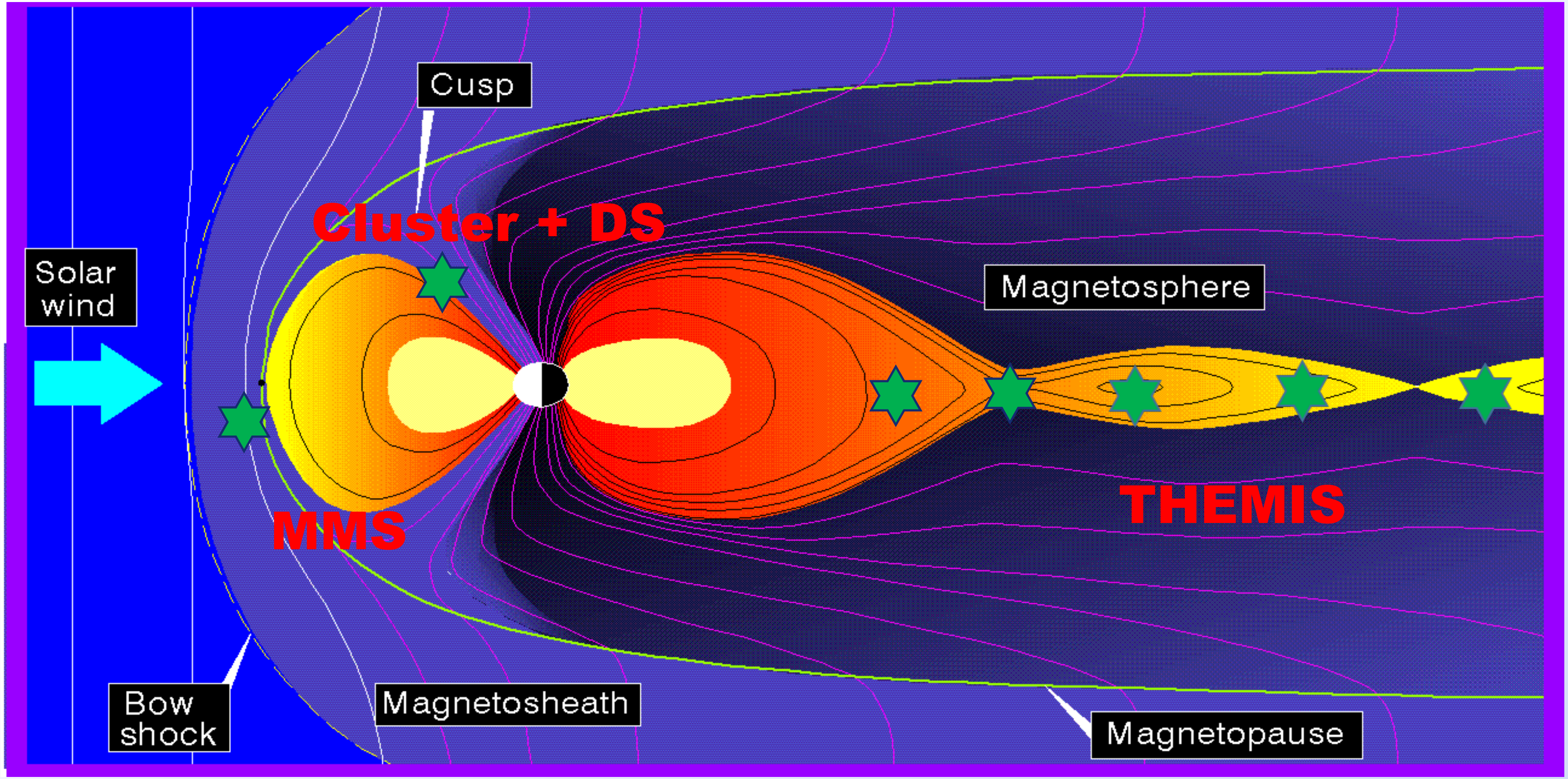
(magnetic reconnection, instabilities, response to solar wind disturbances, and etc.)

For instance: Magnetic reconnection

Reconstruction:



In Situ Missions

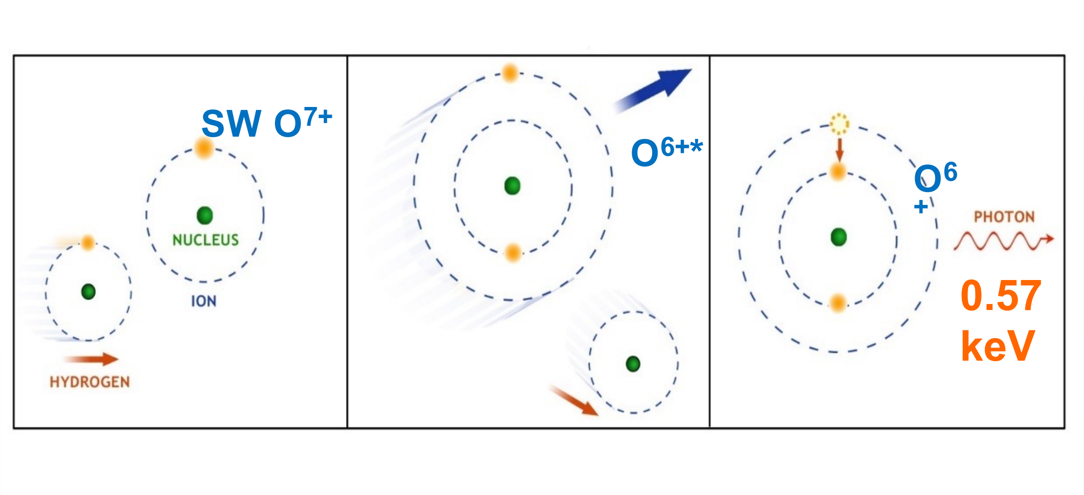


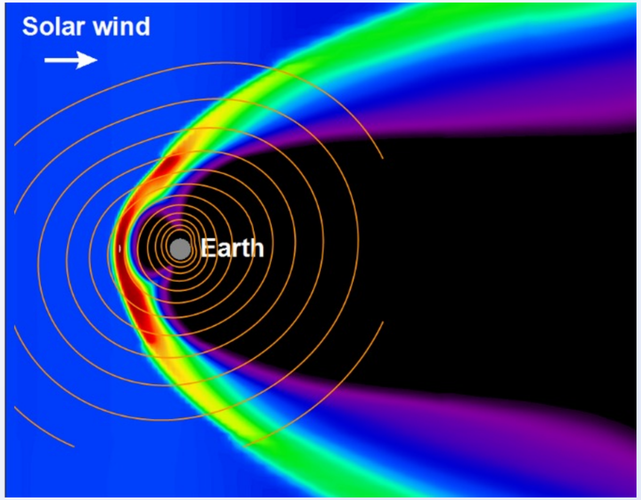
What are the limitations?

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)

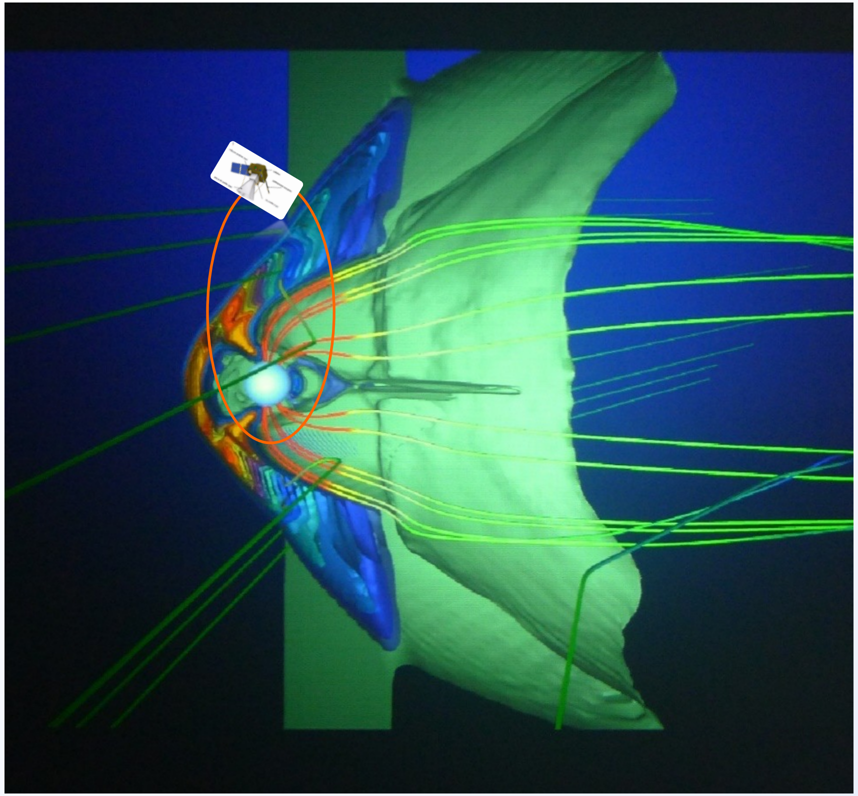




$$P_X = \alpha\, n_N\ n_{SW}\ v_{SW} \quad \mathrm{eV}\ cm^{-3}\ s^{-1}$$

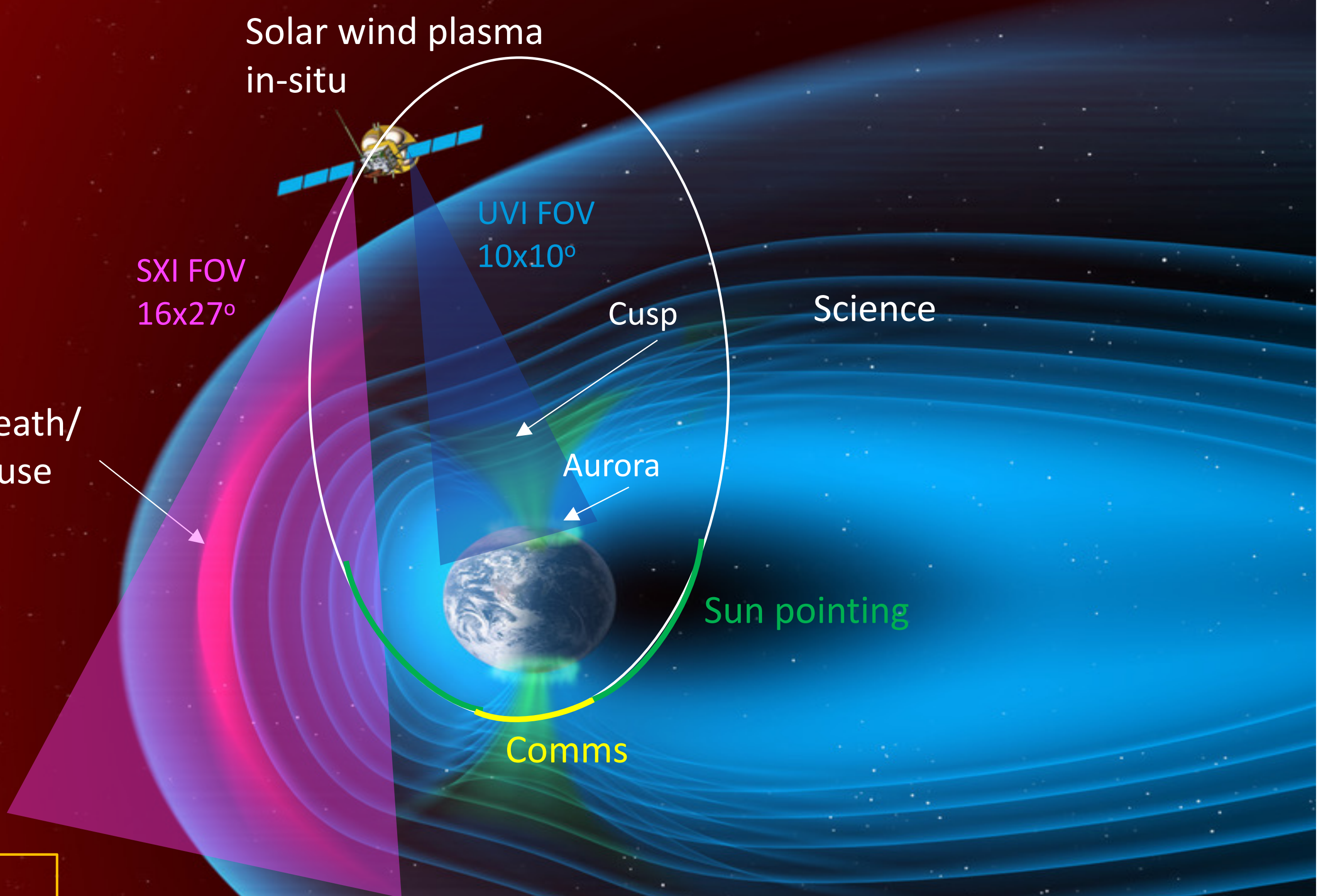
X-ray emission proportional to density of solar wind ions and neutrals, hence brightest in dayside magnetosheath and the cusps

What is SMILE ?



- **Vantage point outside the magnetosphere**
- **Polar Orbit, 19 R_E apogee**
- **Nominal mission lifetime 3 years**

Science overview



Highly Elliptical Orbit, inclination 98° or 70°, 5000 km x 19 R_E

Investigate the dynamic response of the Earth's magnetosphere to the solar wind impact in a unique and global manner

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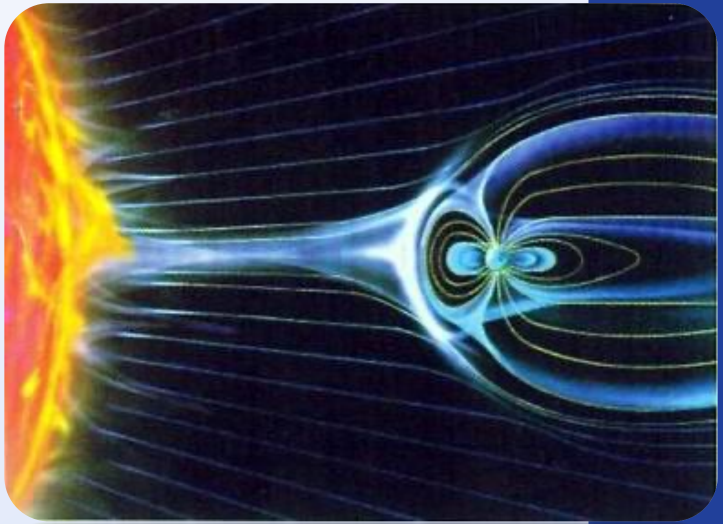
Science Objectives

(1) 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.



Science Objectives

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.

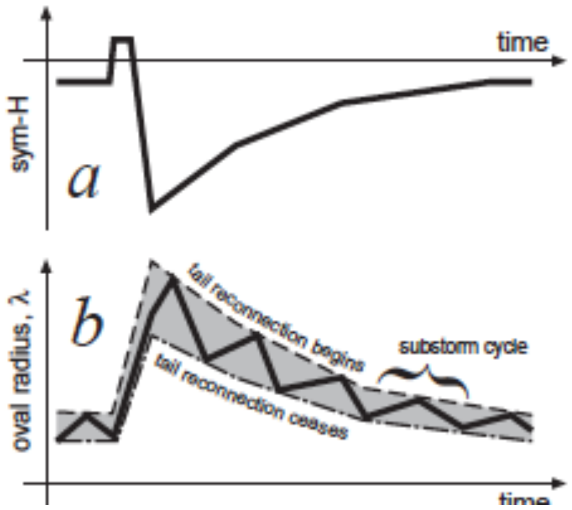
(2) To define the substorm cycle

- Define the substorm cycle, including timing and flux transfer amplitudes
- Explore the substorm triggers (external trigger, BBF, local instabilities etc.)

Science Objectives

(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]

Science Objectives

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

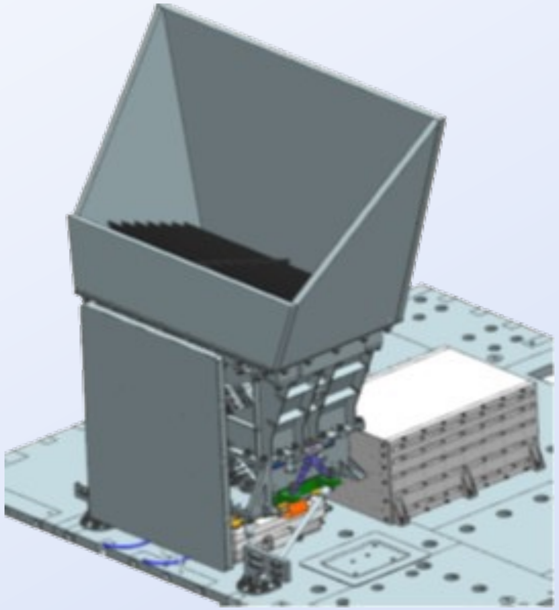
Interplanetary/magnetosheath magnetic field (B)

Solar wind/magnetosheath plasma (n, V, T)

Soft X-ray Imager – SXI

PI Steve Sembay, University of Leicester, UK

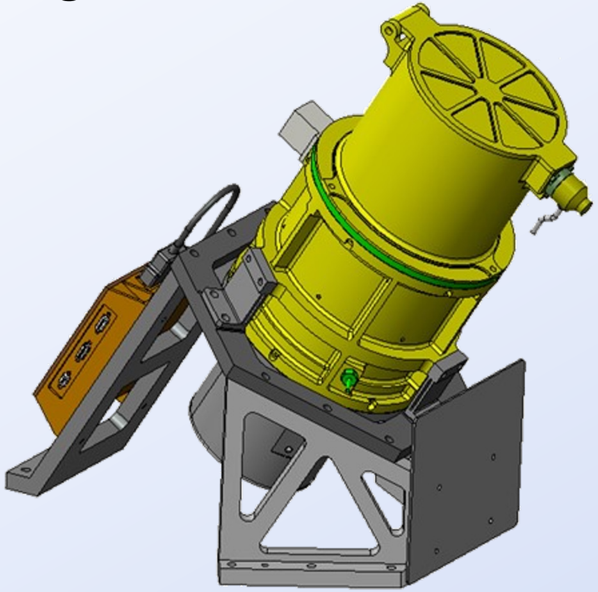
- SXI will provide global soft X-ray imaging of the cusps and the day-side magnetosheath
- Wide-field Lobster-eye optics (micro-channel plates), CCD-based detector, 0.2 – 2.5 keV （5keV Goal）
- Wide FOV (15.6° x 26.5°)
- Lobster-type optic, focal length 30 cm
- Angular resolution of 6 arcmin FWHM



Auroral Imager (UVI)

PI X.X. Zhang, China Meteorological Administration

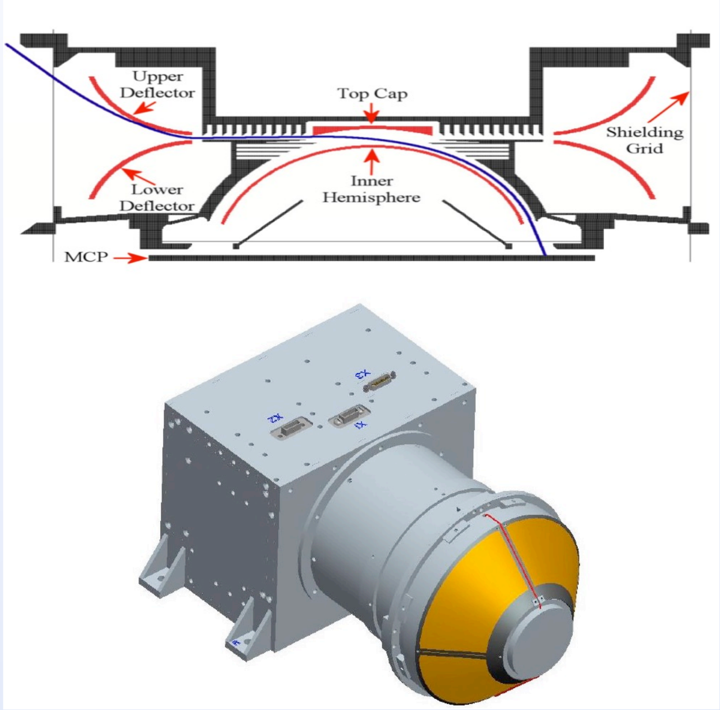
- **UVI will obtain auroral imaging of both dayside and night-side**
- **Waveband: 140-180 nm**
- **FOV: 10º x 10º**
- **Spatial resolution: 0.04º**



Light Ion Analyser (LIA)

PI Lei Dai, NSSC CAS, China

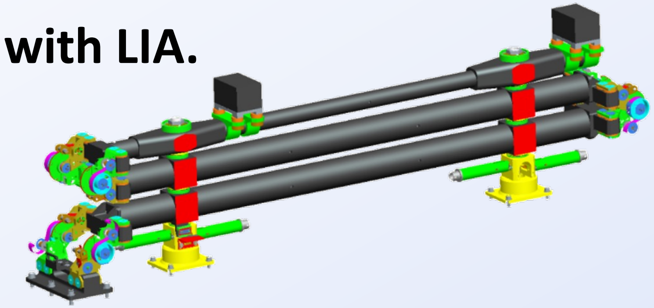
- **LIA will determine the basic moments and the distribution function of the ions**
- **FOV: 360^{o} x +/-45^{o}**
- **Energy band: 50eV – 20 keV/q**
- **Energy resolution: 10%**
- **Time resolution: 2s**

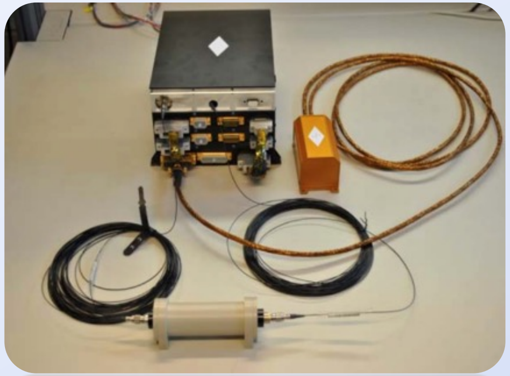


Magnetometer (MAG)

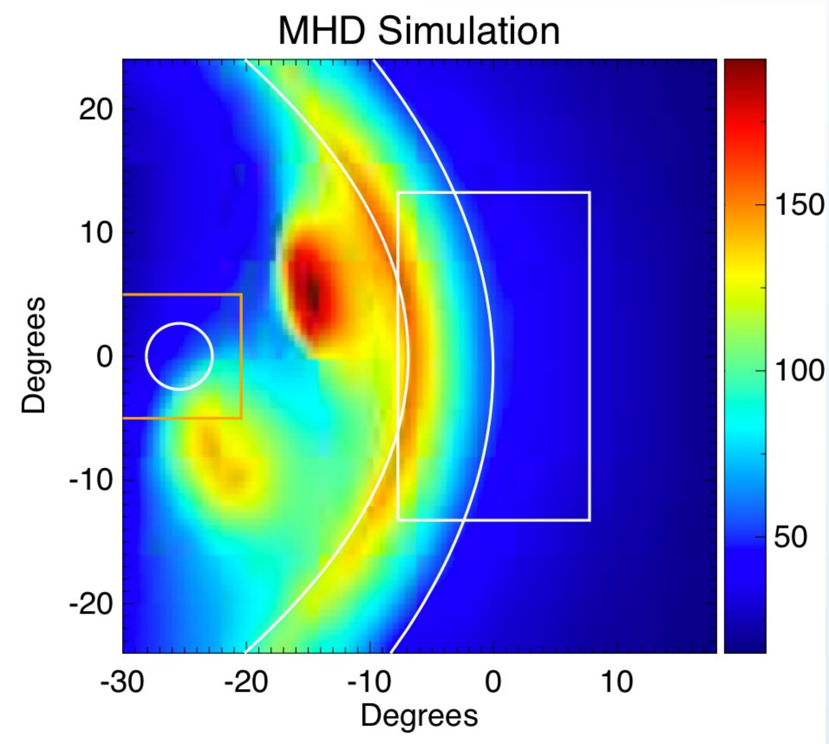
PI Lei Li, NSSC CAS, China; Co-PI Rumi Nakamura, SRI, Austria

- **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**



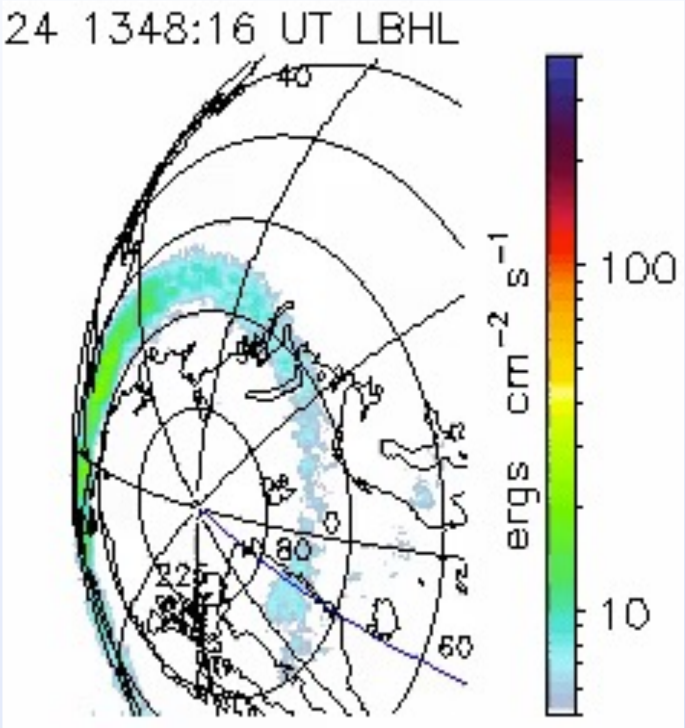


SXI expected data based on MHD simulation of Sun-Earth connection



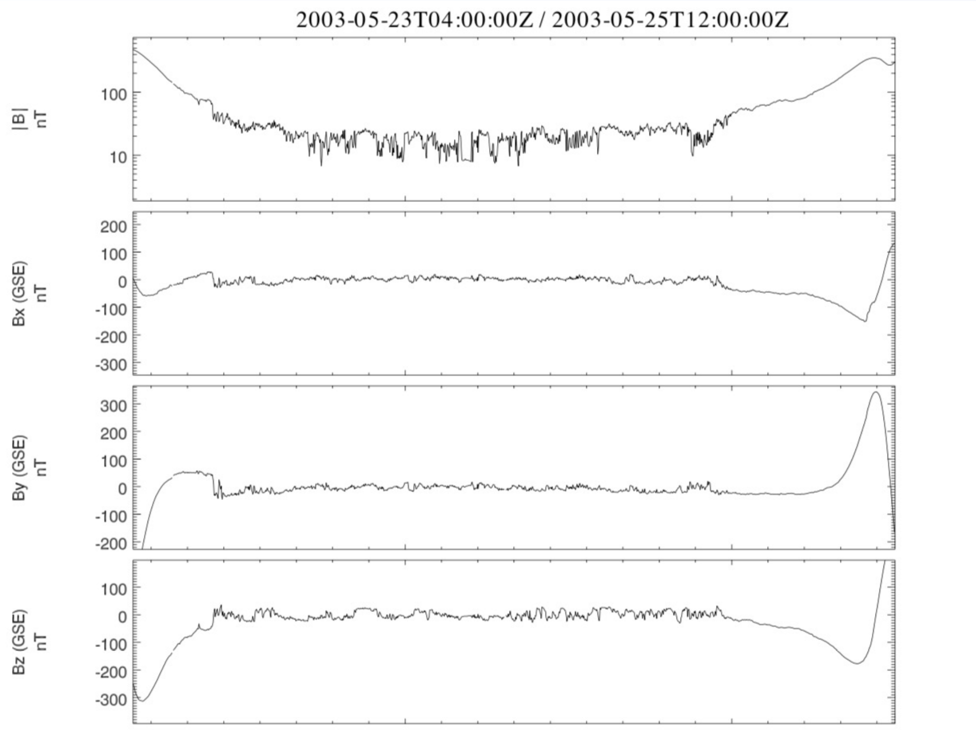
(S. Sembay & T. Sun)

UVI expected images of aurora

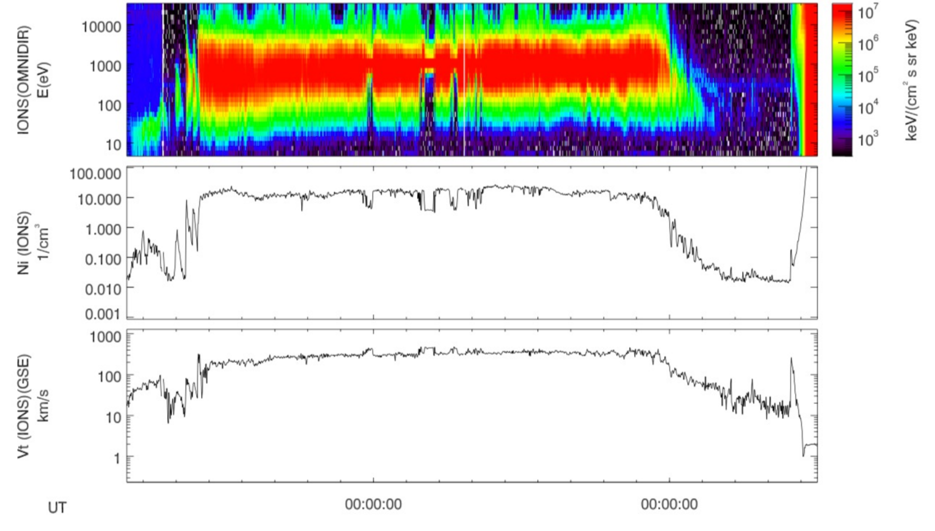


(NASA Polar UVI image)

MAG expected data

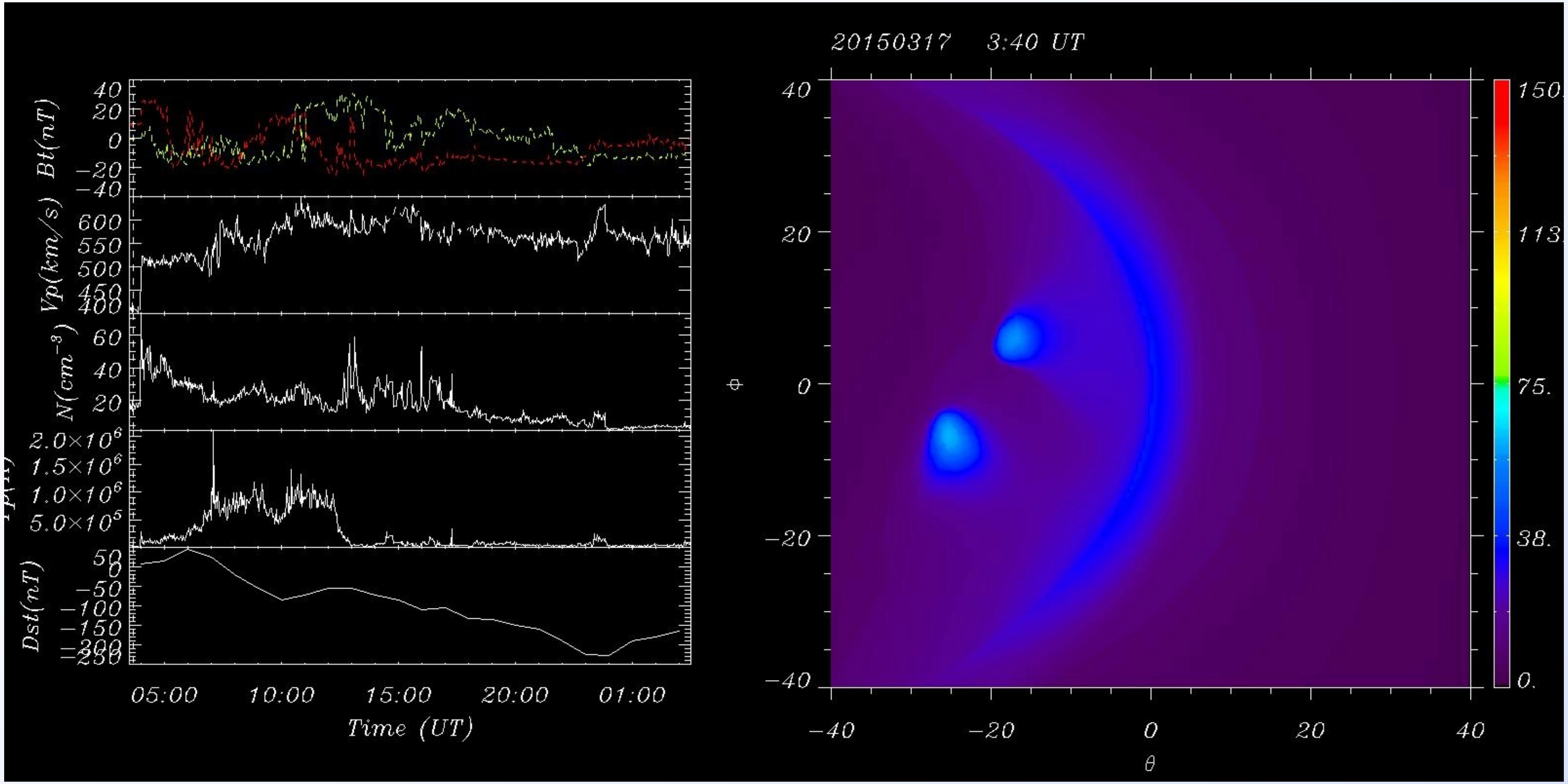


LIA expected data



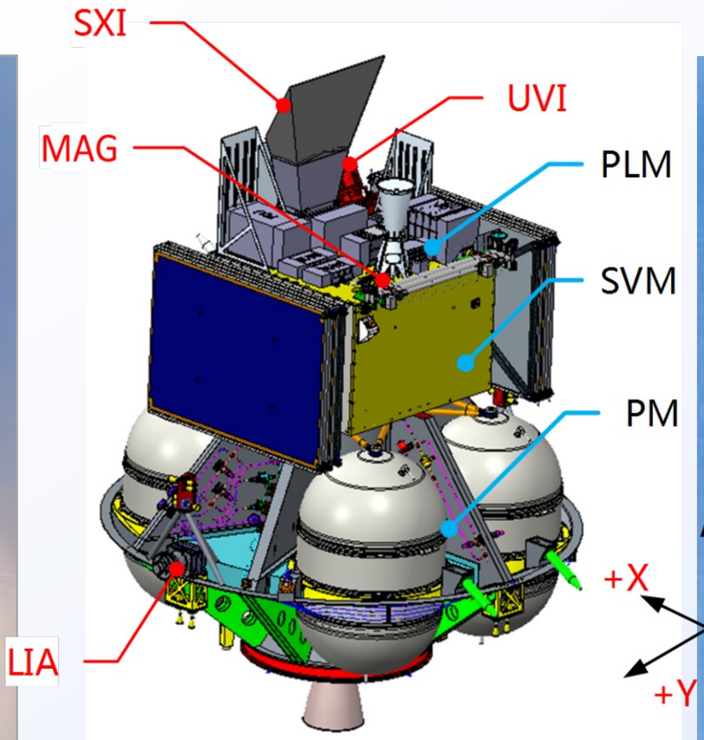
(Cluster data over 1 orbit of 54h)

SMILE SXI: 17th March 2015 solar storm



Sun, Wang, NSSC, CAS

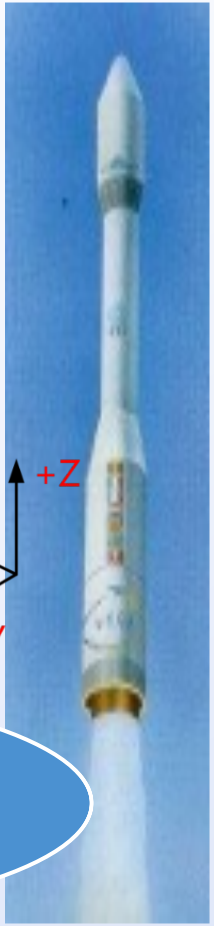
Ariane 6



Ground Sector

(ESA: SOC, CAS: MOC/SOC)

VEGA-C



Satellite：

⬇

Payload PLM + Service SVM

Ground Sector：

⬇

TM & TC + Ground Support + Science Application

Kourou

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:**

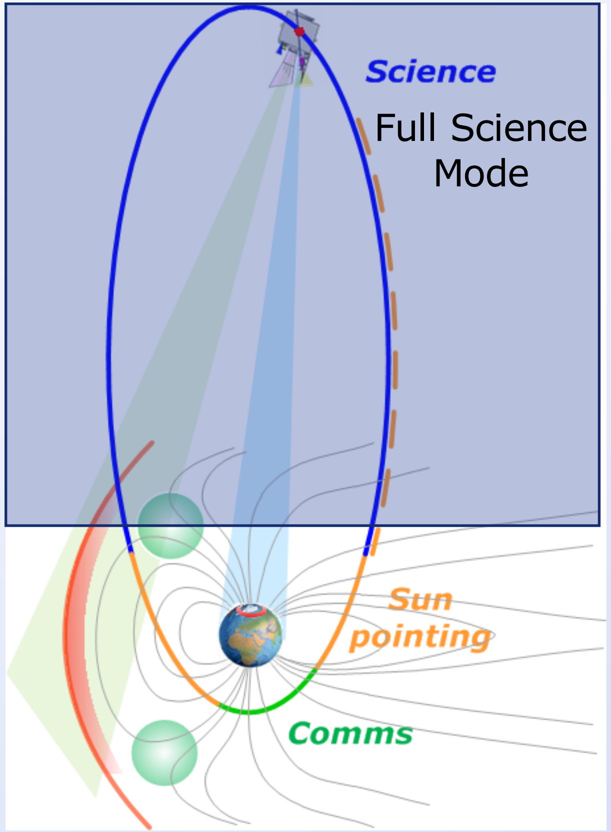
  CAS (planning/commanding + MAG/LIA data processing) + ESA (SXI/UVI data processing)

Mission architecture/requirements

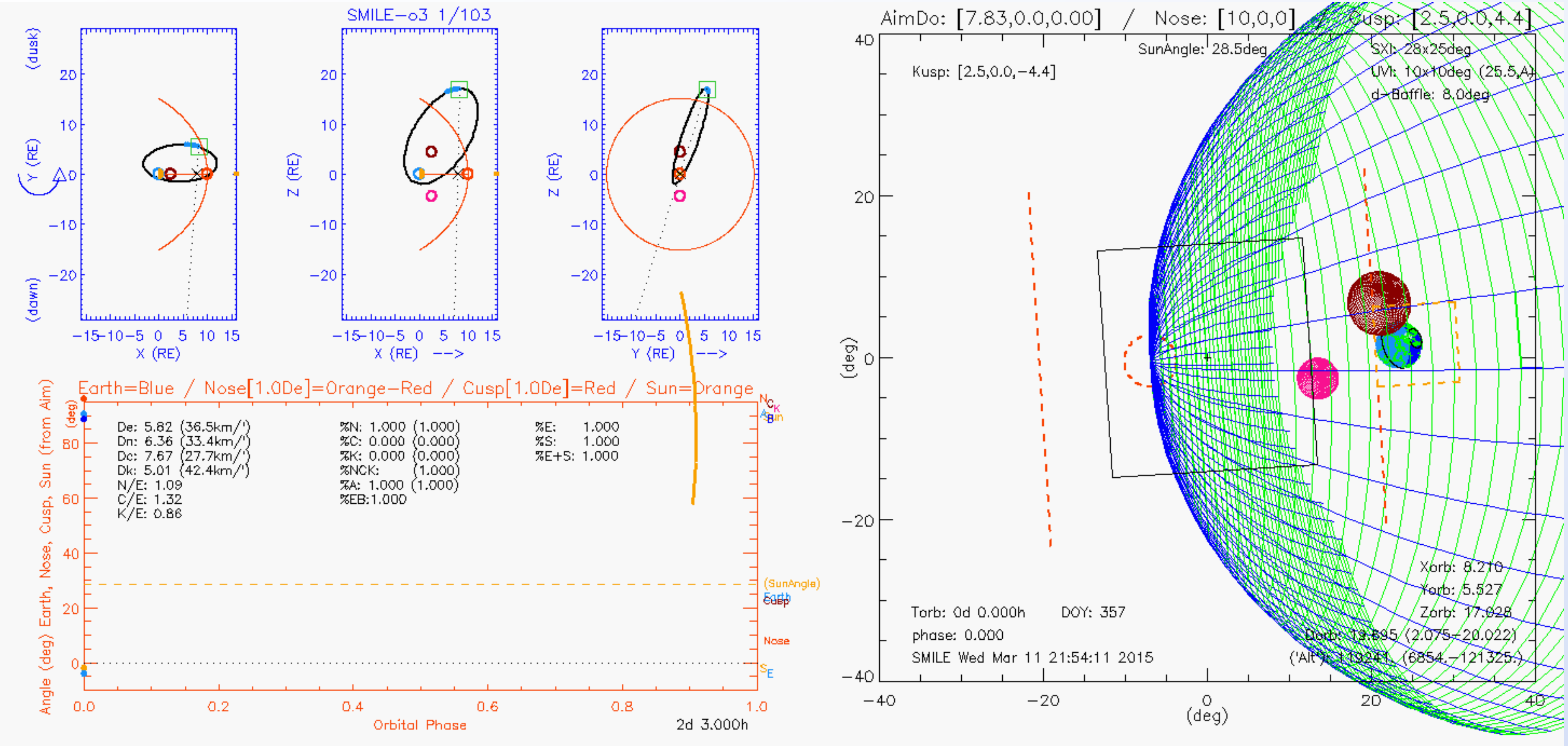
❑ Summary of operations over one orbit

➢ **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)



SMILE orbit simulation



A. Read, Leicester Univ., UK

Schedule

2016.06 – 2017.12
Feasibility study

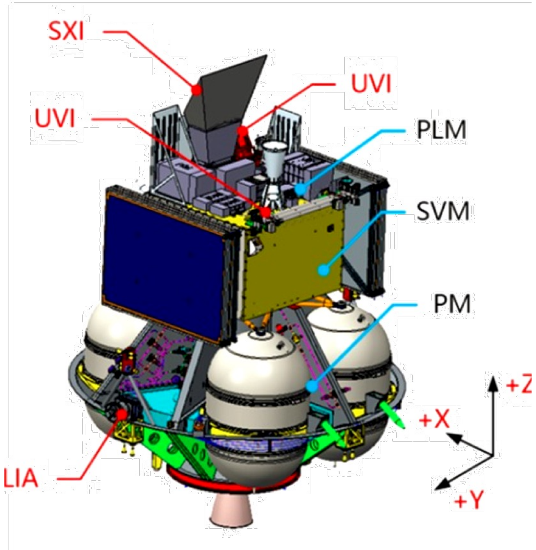
2018.01 – 2019.12
Preliminary Design

2020.01 – 2022.10
Engineering Model

2022.08 – 2024.12
Flight Model

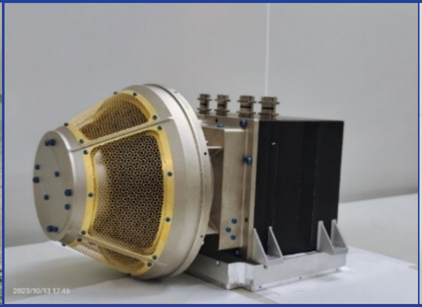
2025.09
Launch

- Phase D study
- FM AIT in ESTEC： Oct. 2024-July 2025
- Launch in Kourou： Sep. 2025

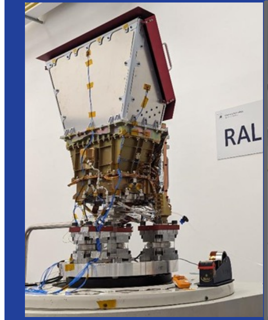


SMILE configuration


UVI

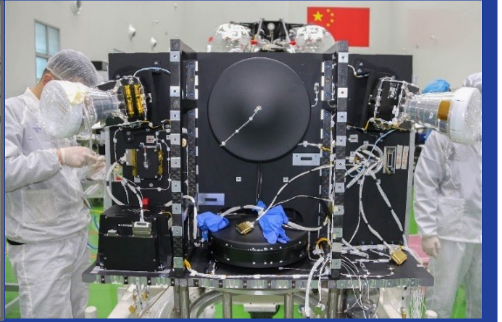

LIA


MAG



SXI


Payload Module(PLM)


Platform (PF)

SMILE Mission Milestone

Schedule

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

Modeling working group (MWG) Tianran Sun, Andrey Samsonov, Hyunju Connor

First magnetospheric imaging

In-situ measurement

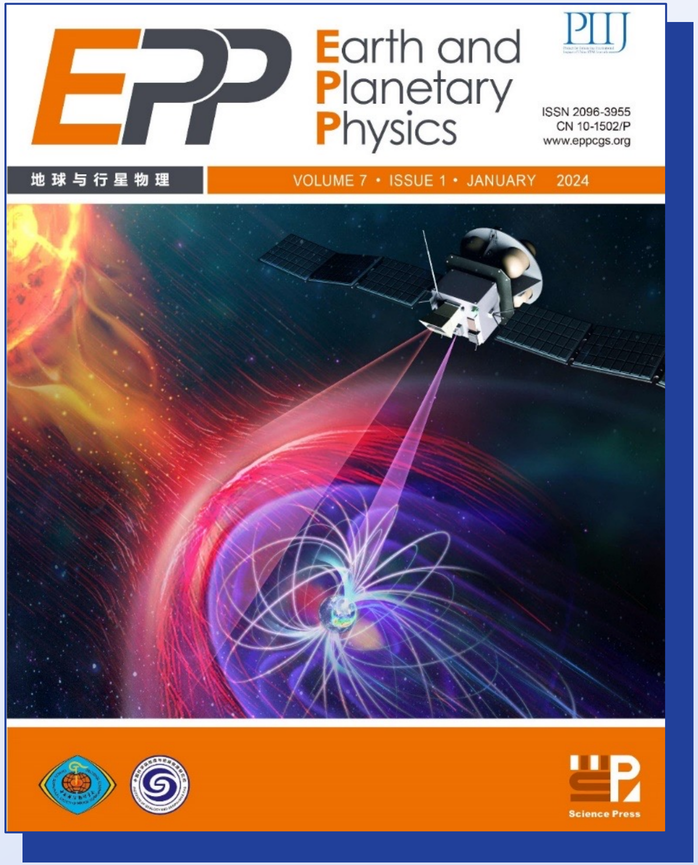
↓

Global imaging

How to image?

How to reconstruct?

How to understand?



Modeling working group (MWG)

How to image?

Method | Global MHD simulation + radiation model

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

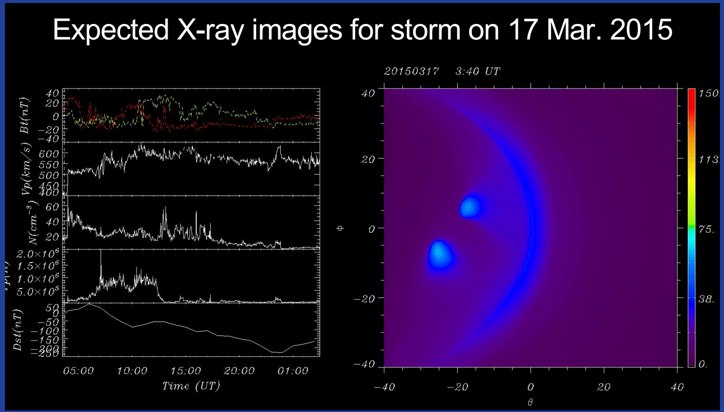
$$\frac{\partial (\rho \mathbf{v})}{\partial t} + \nabla \cdot \left(\rho \mathbf{v}\mathbf{v} + p^{*}\mathbf{I} - \frac{1}{\mu}\mathbf{B}'\mathbf{B}'\right) = \frac{1}{\mu}(\nabla \times \mathbf{B}') \times \mathbf{B}_{d} - \mathbf{B}'\nabla \cdot \mathbf{B}'$$

$$\frac{\partial \mathbf{B}'}{\partial t} + \nabla \cdot (\mathbf{v}\mathbf{B}' - \mathbf{B}'\mathbf{v}) = \nabla \times (\mathbf{v} \times \mathbf{B}_{d}) - \mathbf{v}\nabla \cdot \mathbf{B}'$$

$$\frac{\partial E}{\partial t} + \nabla \cdot \left[(E + p^{*})\mathbf{v} - \frac{1}{\mu}(\mathbf{v} \cdot \mathbf{B}')\mathbf{B}'\right] = \frac{1}{\mu}\mathbf{v} \cdot [(\nabla \times \mathbf{B}') \times \mathbf{B}_{d}] + \frac{1}{\mu}\mathbf{B}' \cdot [\nabla \times (\mathbf{v} \times \mathbf{B}_{d})] - (\mathbf{v} \cdot \mathbf{B}')\nabla \cdot \mathbf{B}'$$

+

$$I_x = \frac{1}{4\pi} \int \alpha \, N_H \, N_{sw} \sqrt{V_{sw}^{2} + V_{th}^{2}} \, dr$$



A dynamic model for prediction of global X-ray images

(Sun et al., 2015; SMILE proposal)

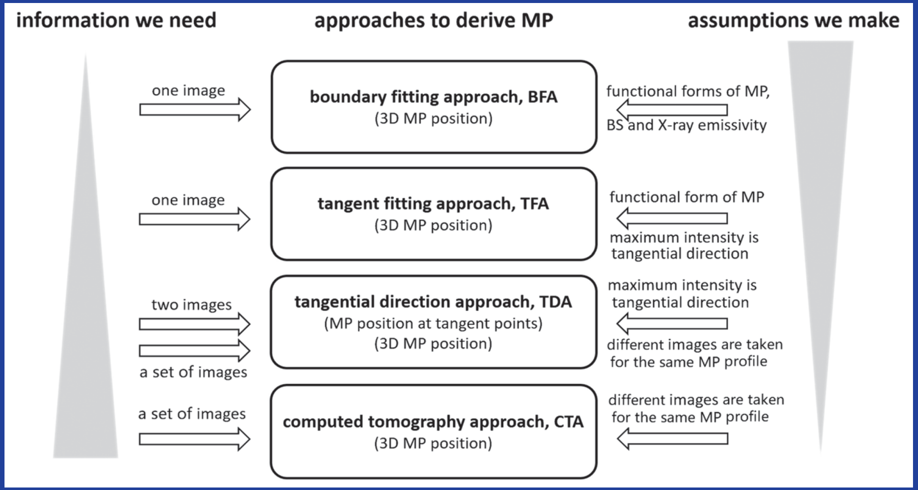
Modeling working group (MWG)

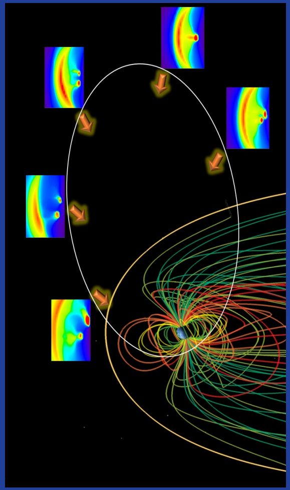
How to reconstruct?

Method balance between information and assumptions

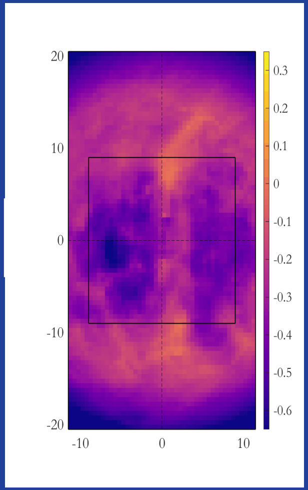
Current **arsenal** of reconstruction techniques

- e.g. CT method





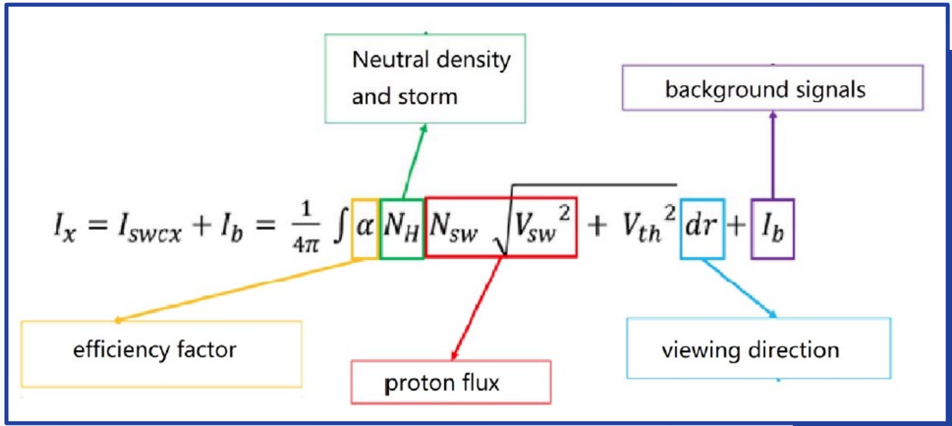
2D images with different vantage points

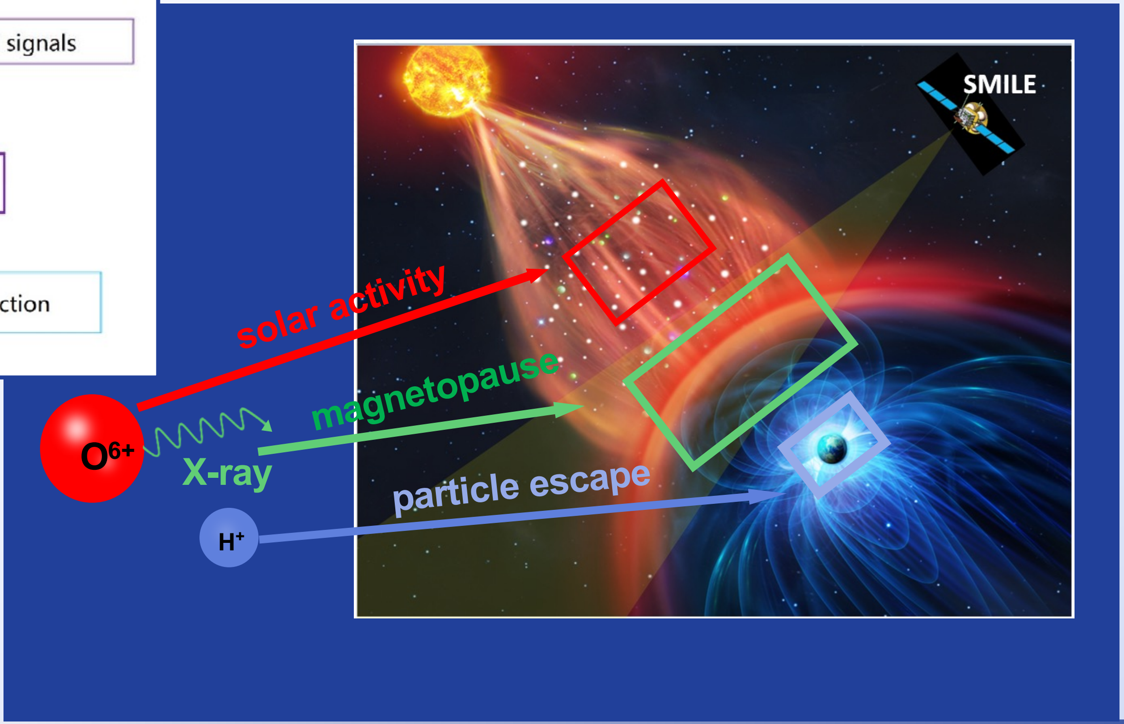


3D magnetosphere and cusps

Modeling working group (MWG)

How to understand?





GSS Progress and Status

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Mission Operation Center: will be ready by the end of 2024

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Summary

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

Thank you!