UCL

Imaging solar-terrestrial interactions on the global scale:
The SMILE mission
(Solar wind Magnetosphere Ionosphere Link Explorer)

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and the SMILE collaboration
(ESA, CAS and European, Canadian, USA, China institutions)

http://sci.esa.int/smile/
http://english.cssar.cas.cn/smile/
http://www.mssl.ucl.ac.uk/SMILE/

vEGU21

SMILE offers a new and global way to explore Sun-Earth connections. It is a joint space mission from start to finish by the European Space Agency and the Chinese Academy of Sciences, it is currently under development and is due for launch at the end of 2024.

Below is the full list of co-authors of this presentation. SMILE is the product of a large collaboration including scientists and engineers from many institutions and countries over the world.

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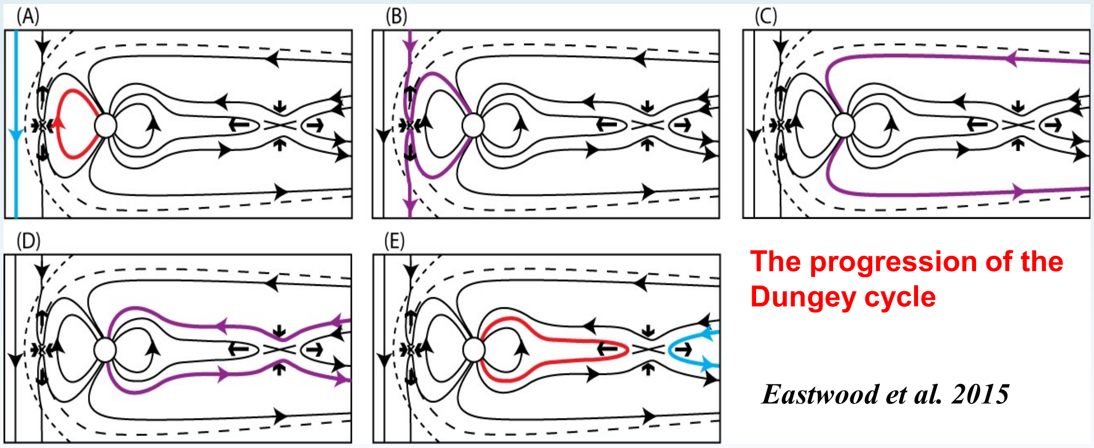
SMILE scientific motivations

Study the full chain of events that drive Sun-Earth relations



The progression of the Dungey cycle

Eastwood et al. 2015

- Structure and dynamics of the magnetosphere mainly controlled by magnetic reconnection: Basic theory of magnetospheric circulation well known, microscale explored by many in situ measurements
- Reality of how complex interaction takes place on a global scale, and how it evolves, still not understood

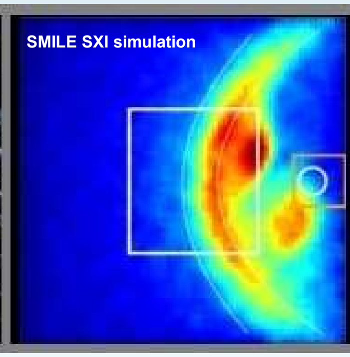
The structure and dynamics of the magnetosphere are thought to be mainly controlled by magnetic reconnection, which takes place between the magnetic field carried in the solar wind with the terrestrial one, and allows the solar wind to penetrate in the magnetosphere.

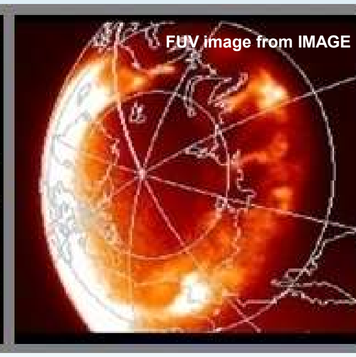
The basic theory of magnetospheric circulation is well known, having being explored in situ by many spacecraft, and is illustrated by the cartoon showing the progression of the Dungey cycle.

Under southward IMF conditions, dayside reconnection (panel A) opens magnetic flux (panel B) which convects over the poles and is stored as magnetic energy in the magnetotail lobes (panel C). This stored energy accumulates until an explosively release (panel D) returns closed flux to Earth in conjunction with dramatic auroral displays at high latitudes (panel E). Substorms may result from changes in the external driving of the magnetosphere and/or internal magnetotail instabilities (Eastwood et al. 2015).

In reality this complex interaction takes place and evolves on the global scale, which has not been investigated to a large extent, and is still poorly understood.

SMILE scientific motivations





- SMILE can answer questions which help distinguishing modes of interaction, the characters of reconnection, what leads to geomagnetic substorms and CME-driven storms → **What drives space weather?**

- When/where is reconnection steady/transient/bursty? Dependence on solar wind parameters?

- What defines the substorm cycle? Changes in solar wind properties? Seasonal effects?

- How do CME-driven storms arise? Are they a sequence of substorms?

Essentially SMILE will contribute to answering the question 'What drives space weather?' which is so relevant to the effects of space weather on our technological infrastructures, in space and on the ground.

The questions SMILE will address are like:

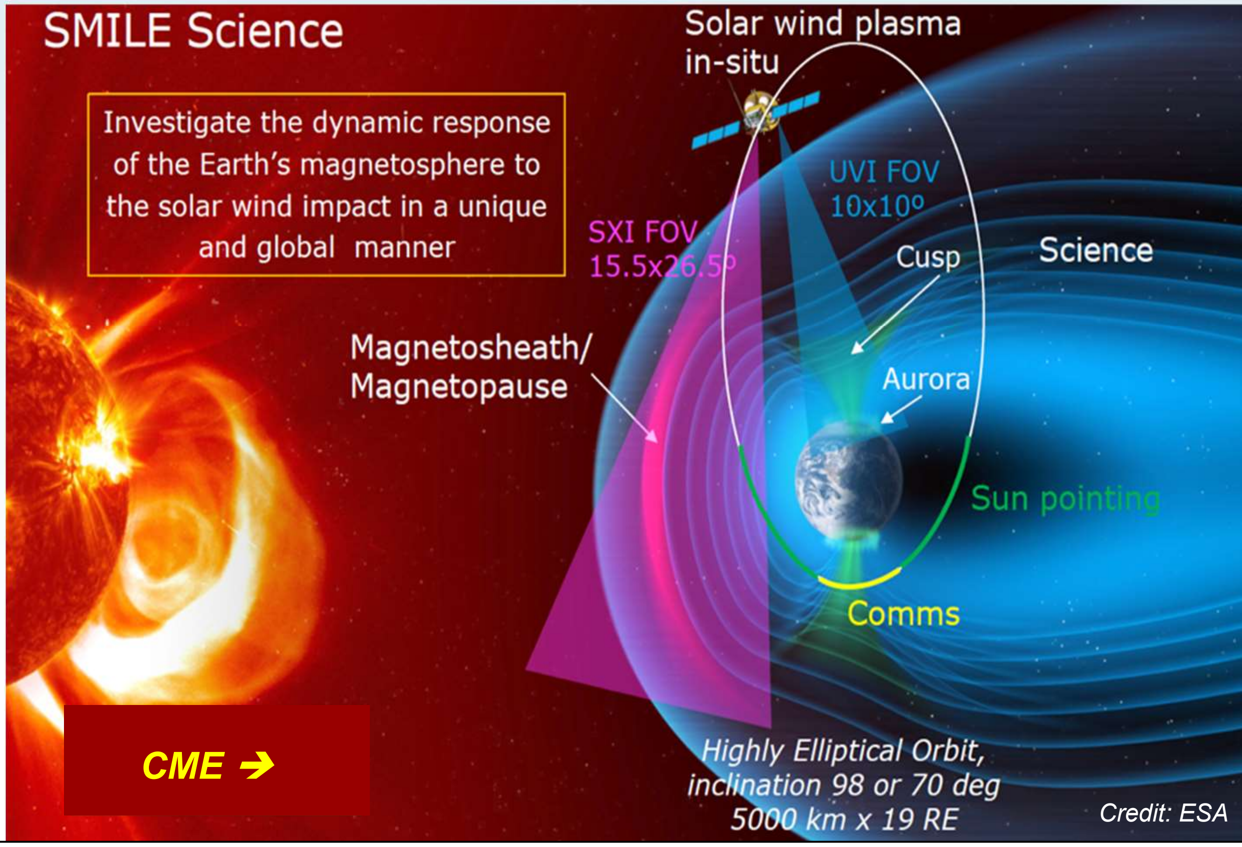
- Under what conditions is reconnection steady/transient/bursty? Does it depend only on solar wind parameters?

- What defines and drives the substorm cycle? Only changes in solar wind properties? Could there be some seasonal effects?

- How do CME-driven storms arise and progress? Are they related to, e.g. are they a sequence of, substorms?

SMILE

Solar wind Magnetosphere Ionosphere Link Explorer

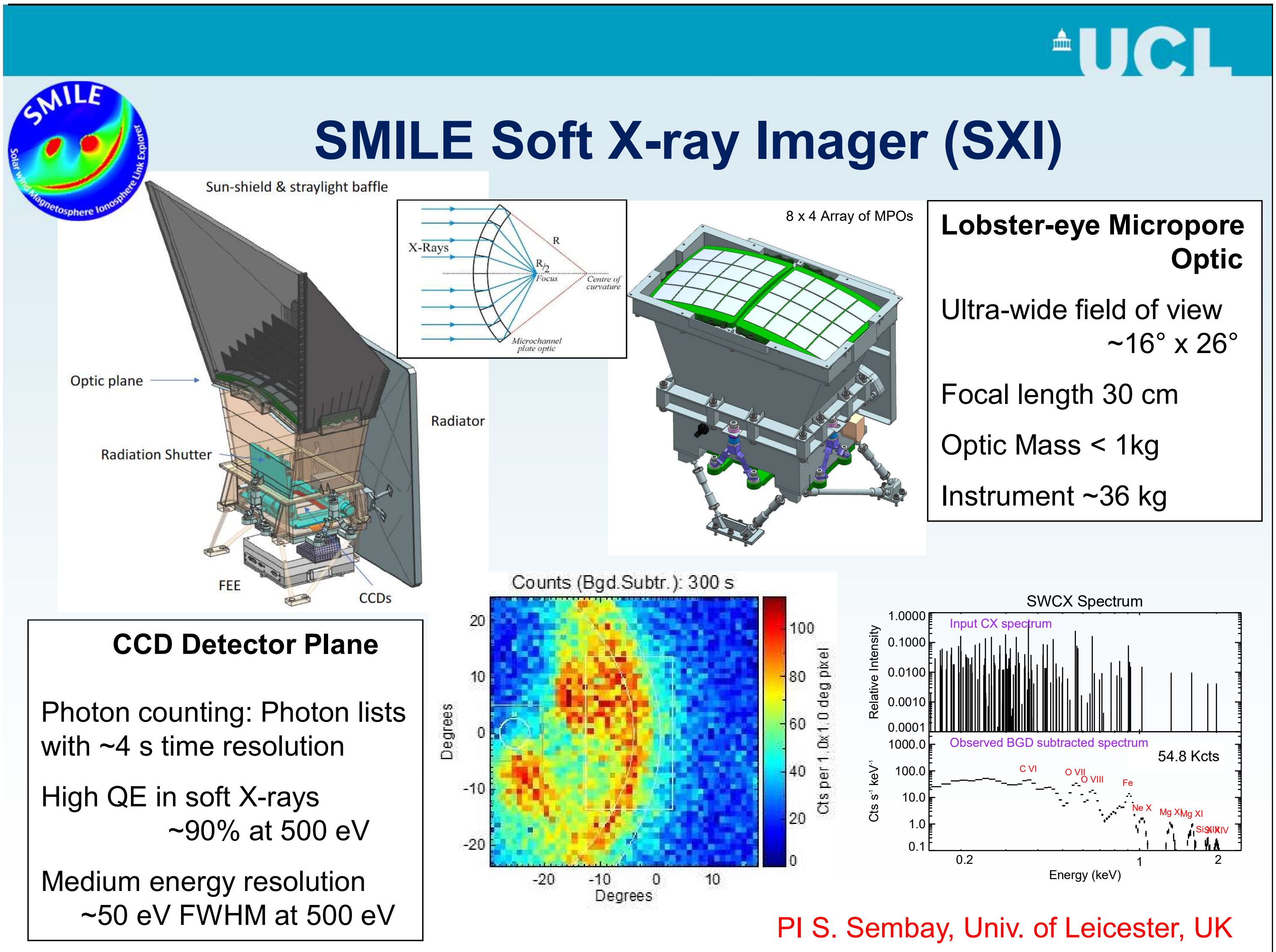


SMILE is a scientific mission that will investigate the dynamic response of the Earth's magnetosphere to the impact of the solar wind in a global manner never attempted before.

Consider the impact of a CME arriving at the Earth. It will compress the magnetosphere and for favourable conditions of magnetic field orientations solar wind plasma will penetrate in the magnetosheath. We know that **soft X-rays are produced** in the dayside magnetosheath and the magnetospheric cusps by the process of Solar Wind Charge eXchange (SWCX).

The **ultimate consequences of the solar wind impact** are geomagnetic storms and particle precipitation into the polar regions, where the aurorae are the footprints of this whole interaction.

So SMILE combines global soft X-ray imaging of the dayside magnetosheath and the cusps, simultaneous **UV imaging** of the northern aurora **and in situ monitoring** of the solar wind and magnetosheath plasma conditions from a **highly elliptical northern polar orbit** that takes it out to 19 Earth's radii.



First thing to notice is that to focus X-rays to make images we need to use grazing incidence (top diagram). **This is realised with arrays of micropores (MPO, or micropore optic)**, which make up light-weight lobster-eye-type optic, with a **very wide field of view.**

The imager operational energy range is 0.2 – 2.5 keV.

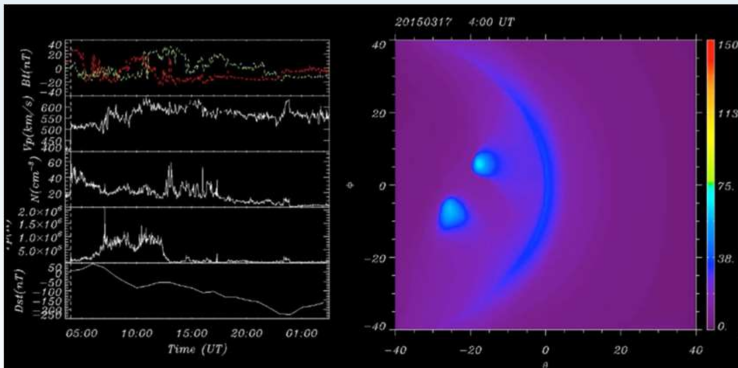
The detecting element at the focus is a couple of large format CCDs, which provide X-ray images (see example in the centre, at bottom) **as well as spectra** (bottom right diagram)**, whose energy resolution is sufficient to separate many of the SWCX emission lines.**

The SXI PI is Steve Sembay (Leicester) and the SXI hardware is provided by UK, Austria, Spain, Switzerland, Norway, Denmark institutes and ESA.

17th March 2015 storm event

Before storm: 04 UT, N=15 cm^{-3}, V= 410 km/s

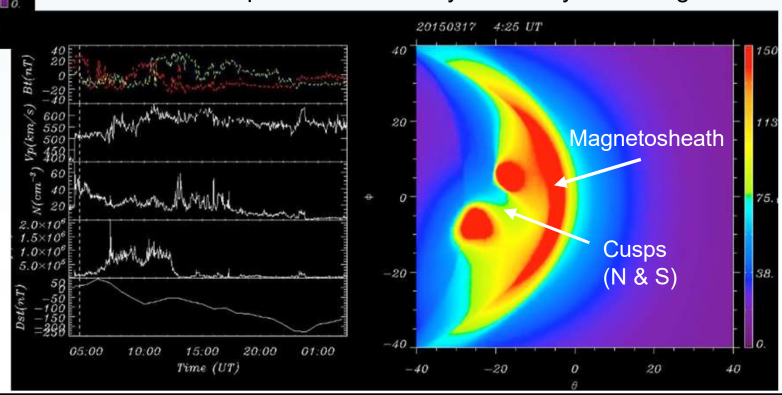
Solar wind input   X-ray emissivity line-of-sight integrated



Predicted SWCX X-ray emissivity from MHD simulation

During storm: 04:25 UT, N=50 cm^{-3}, V= 510 km/s

Solar wind input   X-ray emissivity l-o-s integrated

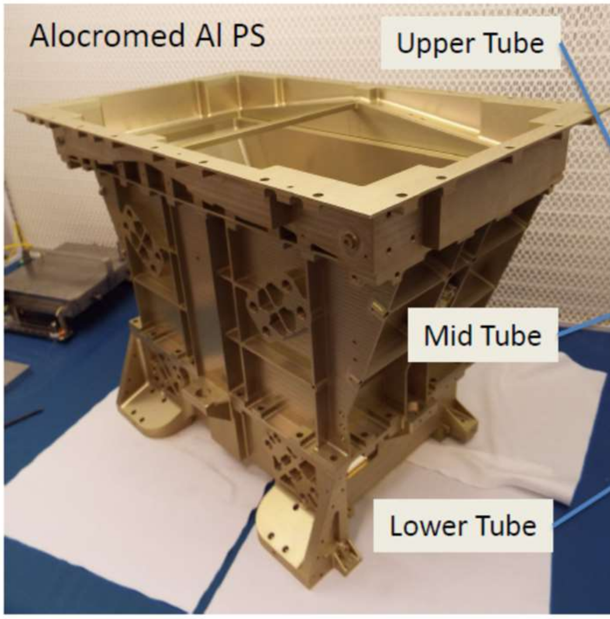


T. Sun, NSSC, CAS, China

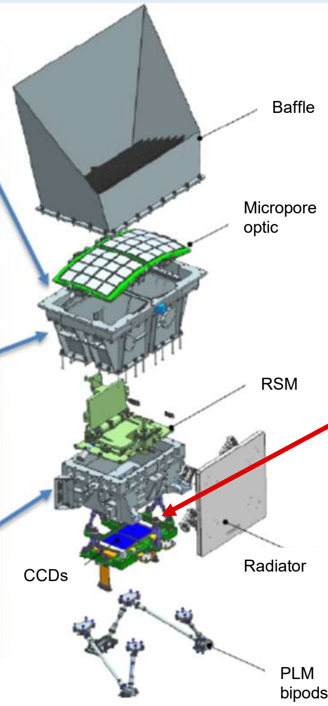
Here are the MHD simulations (by Tianran Sun of CAS-NSSC) of the X-ray emissivity expected for the St Patrick's Day storm conditions as they were actually measured on 17 March 2015 (left diagrams: N – solar wind density, V – solar wind velocity)**. The images correspond to times, and conditions, before the storm (left) and at the peak of the storm (right).**

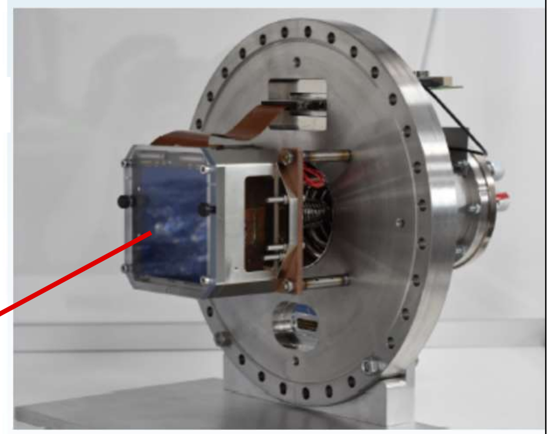
This shows that, had it been observing on that day, SMILE would have had a good view of the magnetopause/magnetosheath from high up in its orbit during 15 hours close to apogee.

SMILE Soft X-ray Imager (SXI)



SXI primary structure:
Structural Thermal Model





SXI CCD (by Teledyne-e2v) mounted in a test camera at The Open University, UK

These are views of the Soft X-ray Imager. In the middle is a CAD drawing of the telescope: you see the MPO arrays that focus at grazing incidence the X-rays (coming from top); below is the Radiation Shutter (RSM) and under it the CCDs that give us images and spectra of the X-rays produced in the magnetosheath and the cusps.

On the left is the STM (Structural Thermal Model) of the SXI structure and on the right you can see one of the large format CCDs in a test camera.

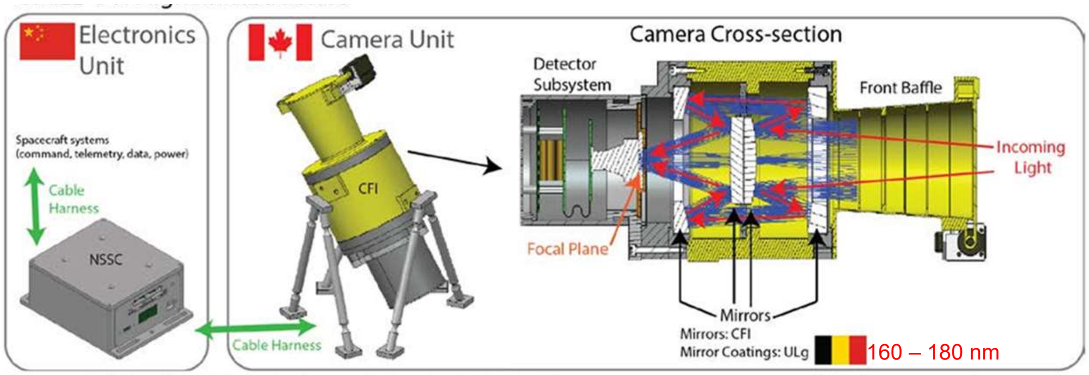
SMILE UltraViolet Imager (UVI)


UVI-C optics module BB


UVI-E EM and simulator

(Courtesy CSA and CAS)

- Four mirror reflective UV imager of whole northern aurora at high spatial and temporal resolution
- UV bandpass (155-175 nm) achieved by coating optical & detector surfaces
- Image intensifier detector (photocathode → MCP → phosphor → CMOS sensor)



Right: Close-up view of the UVI camera and inner infrastructure (Canada, Belgium).
Left: Electronics unit (China).

PI E. Donovan, Univ. of Calgary, Canada

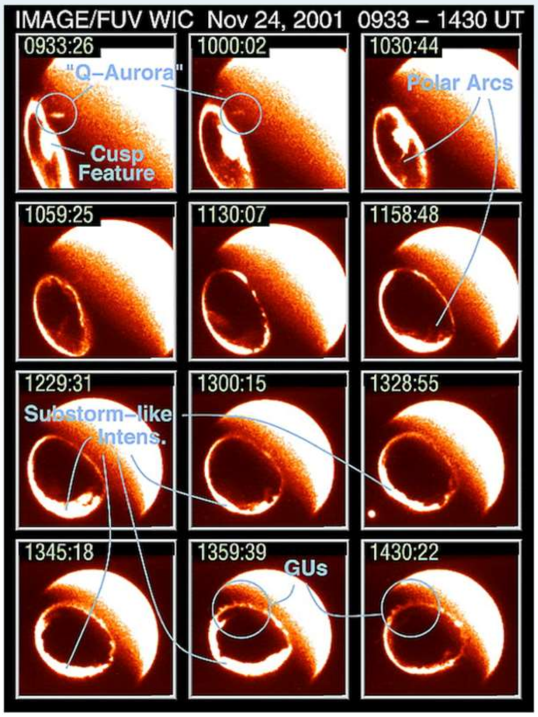
The drawing illustrates the inner workings of the UVI. Mirrors and detector are coated to enable maximum suppression of visible light.

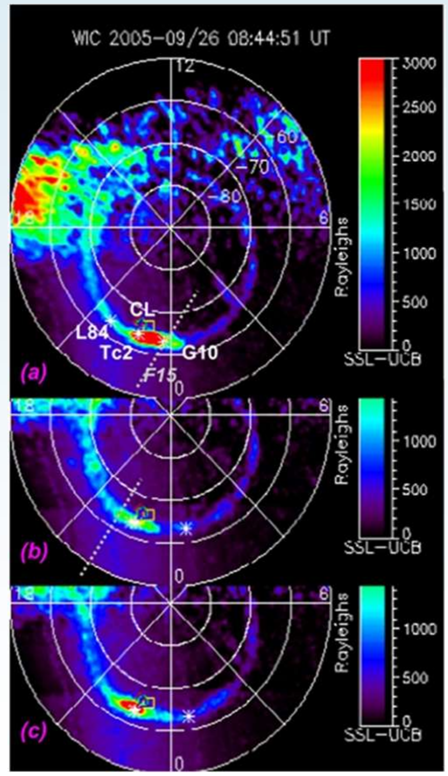
The images show the optics module breadboard (BB, top) and the electronics Engineering Module (EM, bottom).

The UVI hardware is the fruit of a collaboration between Canada, Belgium and China.

SMILE UVI targets the Earth's North aurora

SMILE UVI will observe the Earth's northern auroral oval like the IMAGE satellite did



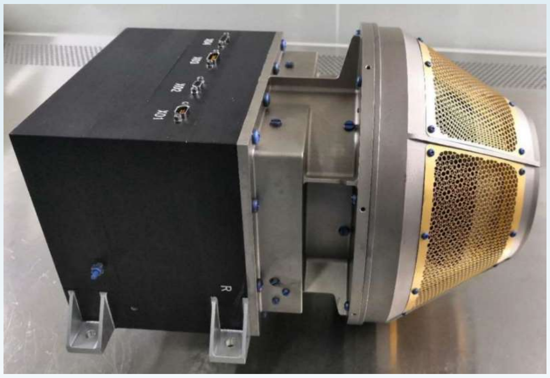


Credit: IMAGE/NASA/GSFC

These are examples of the kind of UV images that we expect will be returned by the SMILE UVI.

SMILE Light Ion Analyser (LIA) & MAGnetometer (MAG)

EM LIA



- Top-hat analyser for p and α density, velocity and temperature
- Energy range: 50 eV - 20 keV
- 2 sensors on platform
- FOV: 360^{o} (azimuth) and up to 90^{o} (elevation)

PI L. Dai, NSSC, CAS, China

- Fluxgate magnetometer for magnetic field strength & direction
- 3 m boom, two sensors

EM MAG

(Courtesy CAS)

PI L. Li, NSSC, CAS, China

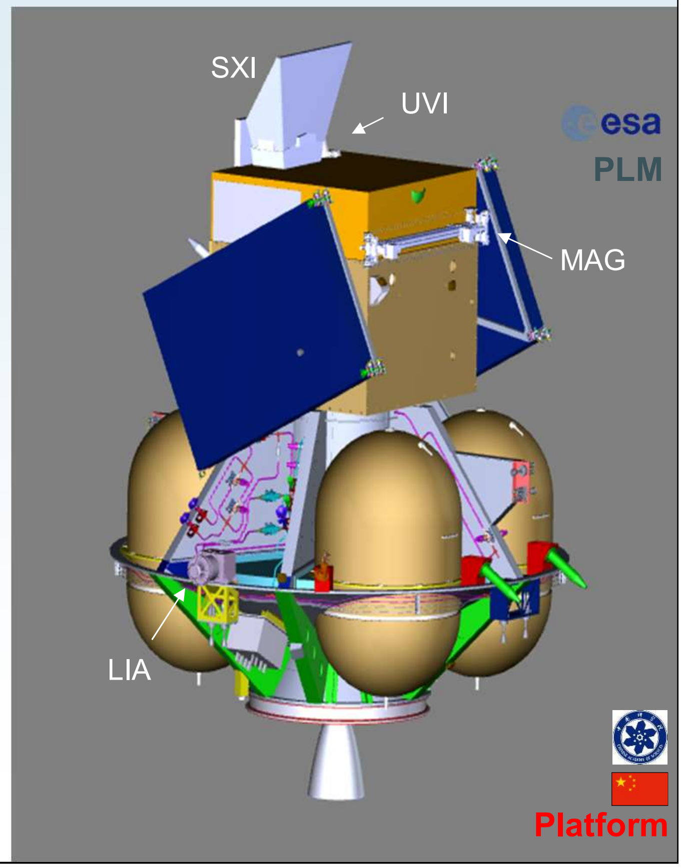
The SMILE in-situ measurement package is China responsibility: it comprises the Light Ion Analyser (LIA, incorporating two sensors) and the magnetometer (MAG).

Engineering Model (EM) of LIA and MAG are shown here, with the MAG boom undergoing its deployment test.

SMILE shares of responsibilities

- **ESA** provides the Payload Module, launcher, AIT facilities for spacecraft integration and testing; ESA member states/Canada provide instruments

- **CAS** provides the Propulsion Module, Service Module, Spacecraft Prime, Mission Operations (with contribution by ESA), Chinese instruments

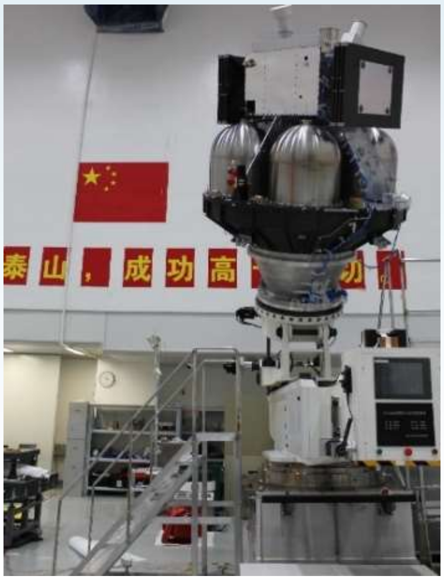


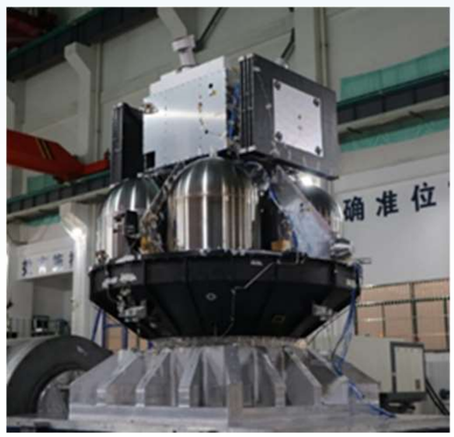
Here SMILE is shown in its launch configuration.

Spacecraft Structural Model tests

Acoustic test

Mass property test



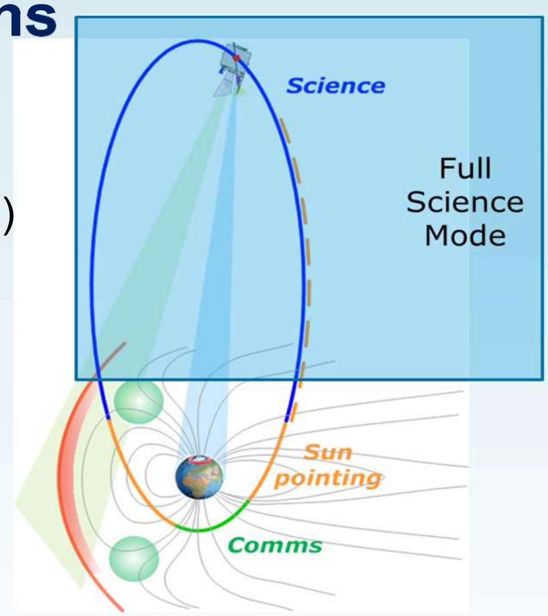


(Courtesy CAS)

Sine test

The Structural Model of the SMILE spacecraft is seen undergoing mechanical tests in China.

SMILE orbit and operations

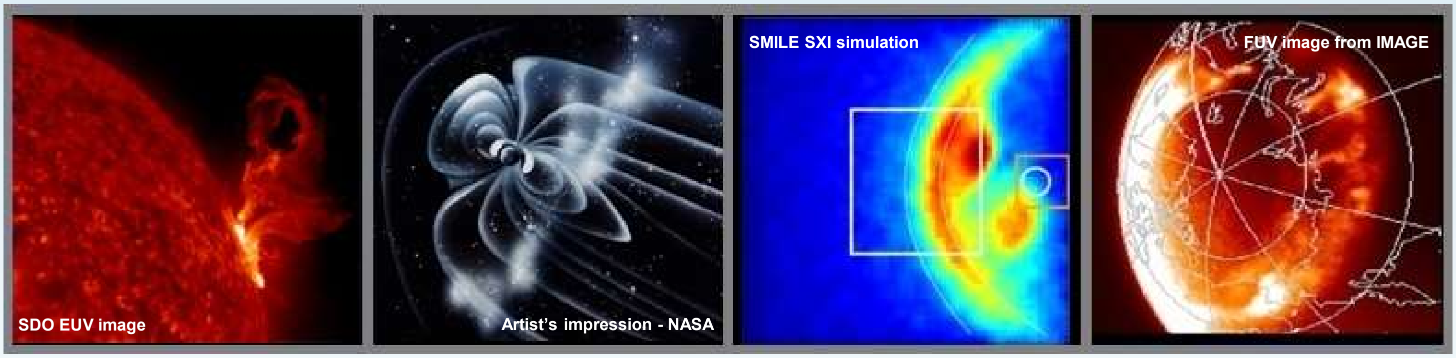


Baseline: ~ 5000 km x 120,000 km HEO,
51 hr orbit (40 hr SXI and UVI science operations)

- Launch (2024): Vega-C (single passenger, ~70° incl.) or Ariane 6 (dual launch into SSO 700 km, 98° incl.), both from Kourou → selection at mission CDR in 2022
- Ground stations: Troll (Antarctica, baseline, ESA) and Sanya (China, support, CAS)

There are two options for the SMILE launcher, Vega-C and Ariane 6: SMILE will reach its final orbit a few weeks, or up to 6 months, after launch in the two cases, respectively.

SMILE impact



- X-rays from the magnetosphere: from 'unwanted background' for X-ray astrophysical observatories to diagnostic tool of Sun-Earth relationships
- SMILE will provide direct scientific input to the studies of space weather by providing the remote sensing measurements needed to validate global models of solar wind-magnetosphere interactions
- Outreach: Images and movies will captivate public to science (Earth's magnetic field) so far invisible
- Cooperation with China: SMILE is a showcase, building on Double Star

In conclusion, SMILE joins up diverse science communities (e.g. magnetospheric physics and astrophysics), will provide much needed inputs to the studies and models of solar-terrestrial interactions, will engage the public with its visual outputs, and is an exemplar of cooperation among diverse countries and science and engineering organisations.