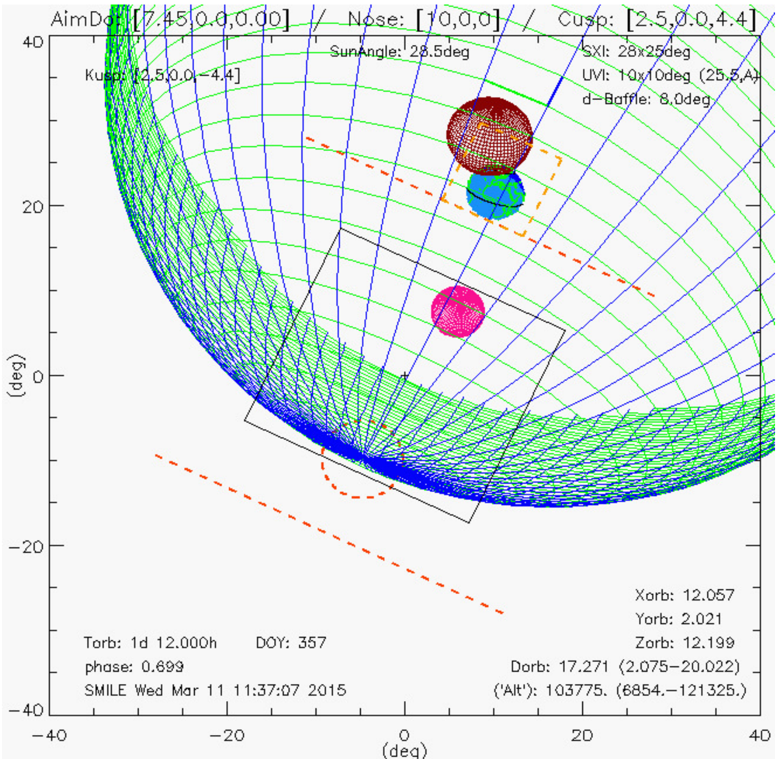
Joint Scientific Space Mission

European Space Agency (ESA) – Chinese Academy of Science (CAS)

PROPOSAL

SMILE: Solar wind Magnetosphere Ionosphere Link Explorer



SMILE orbit viewing simulation (see text in Section 6)

SMILE Website: http://www.star.le.ac.uk/jac48/SMILE/

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Cover pictures – From left to right, top to bottom: SDO solar image from /helioviewer.org; Earth's magnetosphere, courtesy NOAA; SXI simulation, this proposal; FUV aurora from IMAGE; SMILE viewing simulation, this proposal.

Executive Summary

ESA's Cosmic Vision 2015-2025 programme addresses four questions, established as being highest on the agenda of European scientific space research. One of these, '*How does the solar system work?*', expresses our need to understand how the Sun creates the heliosphere, and how the planets interact with the solar wind and its magnetic field. This is not just a matter of scientific curiosity – it also addresses a clear and pressing practical problem. As our world becomes ever-more dependent on complex technology – both in space and on the ground – society becomes more exposed to the vagaries of *space weather*, the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of technological systems and endanger human life and health.

The interaction between the solar wind and Earth's magnetosphere, and the geospace dynamics that result, comprise a fundamental driver of space weather. Understanding how this vast system works requires knowledge of energy and mass transport, and coupling between regions and plasma and neutral populations. Missions such as Cluster, Swarm, and now Magnetospheric Multi-Scale provide *in situ* observations with which we drill into the fundamental microscale processes that enable transport and coupling. *In situ* instruments on a fleet of solar and solar wind observatories now provide unprecedented observations of the external space weather drivers. However, we are still unable to quantify the global effects of those drivers, including the conditions that prevail throughout geospace. *This information is the key missing link for developing a complete understanding of how the Sun gives rise to and controls Earth's plasma environment and space weather.*

Here we propose a novel self-standing mission to observe solar wind-magnetosphere coupling via simultaneous *in situ* solar wind/magnetosheath plasma and magnetic field measurements, X-Ray images of the magnetosheath and magnetic cusps, and UV auroral images of global auroral distributions defining system-level consequences. The **Solar wind Magnetosphere Ionosphere Link Explorer (SMILE)** will complement all solar, solar wind and *in situ* magnetospheric observations, including both space- and ground-based observatories, to enable the first-ever observations of the full chain of events that drive space weather.

Remote sensing of the cusps with X-ray imaging is now possible thanks to the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission, first observed at comet Hyakutake (e.g. *Cravens* 2002), and subsequently found to occur in the vicinity of the Earth's magnetosphere. Charge exchange is now recognised as a ubiquitous mechanism that produces X-rays throughout the Universe, and the approach proposed here allows established astronomical techniques to be applied to our own planet. In this proposal we describe how an appropriately designed X-ray telescope, SMILE's Soft X-ray Imager (SXI), located in a highly-inclined, high-apogee elliptical Molniya-type orbit, can be used to determine the nature of the dayside solar wind-magnetosphere interaction from conditions prevailing at the Earth's bow shock, magnetopause, and cusps.

Both ground-based networks and space-borne instruments have long been used to sense the system-level magnetospheric dynamics via time sequences of auroral images. SMILE's high-heritage Ultra-Violet Imager (UVI) will elucidate the consequences of the dayside interactions observed by SXI. It will provide global auroral images from one hemisphere with the temporal and spatial resolution needed to identify specific responses to dayside processes, and the sensitivity necessary to identify the polar cap boundary at all magnetic local times. The focus on dayside interactions, and need to identify the polar cap boundary at all local times, mean that these images must capture the aurora even in sunlight. For this, the UVI will employ new filter

technologies and an innovative four-mirror telescope design to obtain state-of-the-art UV images.

This scientific research will have a direct impact on our efforts to develop strategies to predict and mitigate space weather. Just like meteorologists studying terrestrial weather, space physicists require in situ ground observations, numerical models, data assimilation, and remote sensing (including imaging). SMILE will provide the in situ solar wind drivers and remote sensing measurements needed to run and validate global models for solar wind-magnetosphere interactions. Consequently, this mission will play a key role in developing our ability to model and ultimately predict space weather effects.

SMILE is a novel proposal that will revolutionise magnetospheric physics by providing simultaneous images and movies of the magnetopause, cusps, and auroral oval using state-of-the-art detection techniques.

Mission Profile: Initial studies have identified that the most appropriate mission profile uses a Long March 2C launcher to place the spacecraft into a highly-inclined (63.4°), high apogee (20 R_E), elliptical Molniya-type orbit from whose apogee continual observations of the solar wind/magnetosheath input, magnetopause and cusp location, and auroral oval can be obtained.

Model Payload: The model payload consists of a wide field Soft X-ray Imager (SXI), an auroral Ultra-Violet Imager (UVI), and an in situ measurement package. The in situ package comprises a Light Ion Analyser (LIA) to measure solar wind ion distributions and a magnetometer (MAG) to measure interplanetary, magnetosheath, and outer magnetospheric magnetic fields. The in situ package has heritage from many space plasma missions, including Cluster and Solar Orbiter.

Spacecraft: SMILE will be three-axis stabilised, so that the SXI and UVI instruments can continuously point towards their magnetospheric and auroral targets. For example purposes we show how SMILE could employ a standard, low-cost AstroBus Small platform solution.

Programmatics and Costs: SMILE is a low risk mission with no significant technology development required. The resources required by the payload are within the boundaries set by the ESA-CAS Joint Call. The overall mission cost at completion is estimated to be 92 M€, well within the boundaries set by the ESA-CAS Joint Call, i.e. the ESA cost at completion ceiling of 53 M€ plus a comparable sized contribution from CAS. This proposal is the result of the collaboration of scientists and engineers from institutes in Europe, China, Canada and the USA.

Communication and Outreach: The key obstacle to effective communication of research in solar-terrestrial physics and space weather is that it involves the study of many processes that are complicated and essentially invisible to the naked eye. SMILE has the potential to revolutionise the general understanding of this area of science by providing 'X-ray' images of the magnetospheric bubble shielding our Earth from inclement solar wind conditions. A comprehensive communication and outreach programme is proposed to take full advantage of these novel data.