PROCEEDINGS OF SCIENCE

ESA satellites SMILE and THESEUS

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SMILE is a space mission which aims to measure Earth's global system responses to solar wind and geomagnetic variations with innovative instrumentation, e.g. wide–field X-ray telescope of Lobster–Eye type, on board. It is a collaborative project of the European Space Agency and the Chinese Academy of Sciences. Transient High-Energy Sky and Early Universe Surveyor (THESEUS) is a space mission proposal accepted by the European Space Agency for a phase A study that would study gamma-ray bursts and X–rays for investigating the early universe and for the multi–messenger astrophysics. It involves a Lobster–Eye X–ray telescope as well. The SMILE and THESEUS international consortia involve the Czech Technical University in Prague and the Czech teams are expected to contribute to the projects, mainly to the X–ray telescopes and related science and software.

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1. Introduction

SMILE is a space mission which aims to measure Earth's global system responses to solar wind and geomagnetic variations [1][2][3]. SMILE will investigate the dynamic response of the Earth's magnetosphere to the impact of the solar wind in a unique manner, never attempted before: it will combine soft X-ray imaging of the Earth's magnetopause and magnetospheric cusps with simultaneous UV imaging of the Northern aurora. For the first time we will be able to trace and link the processes of solar wind injection in the magnetosphere with those acting on the charged particles precipitating into the cusps and eventually the aurora. SMILE will also carry in-situ instrumentation to monitor the solar wind conditions, so that the simultaneous X-ray and UV images can be compared and contrasted directly, and self-sufficiently, with the upstream driving conditions. With its unparallelled payload SMILE will provide answers to many of the open questions in solar-terrestrial relationships in a thoroughly novel way.

THESEUS is a mission concept proposed in response to the ESA call for medium-size missions (M5) within the Cosmic Vision Programme and selected by ESA on 2018 May 7 to enter an assessment phase study. The mission is designed to vastly increase the discovery space of the high energy transient phenomena over the entirety of cosmic history [11–12]. Its primary scientific goals will address the Early Universe ESA Cosmic Vision themes "How did the Universe originate and what is made of?" (4.1, 4.2 and 4.3) and will also impact on "The gravitational wave Universe" (3.2) and "The hot and energetic Universe themes". This is achieved via a unique payload providing an unprecedented combination of: 1) wide and deep sky monitoring in a broad energy band (0.3keV – 20 MeV); 2) focusing capabilities in the soft X-ray band providing large grasp and high angular resolution; and 3) on board near-IR capabilities for immediate transient identification and redshift determination. (https://www.isdc.unige.ch/theseus/).

2. ESA SMILE

The key science questions for SMILE [1][2][3] are: What are the fundamental modes of the dayside solar wind/magnetosphere interaction? What defines the substorm cycle? How do Coronal Mass Ejections (CME) driven storms arise and what is their relationship to substorms? SMILE will determine when and where transient and steady magnetopause reconnection dominates.

The following instrumentation forms the payload for SMILE satellite[1][2][3] .

SXI: a telescope with a wide field of view FOV (26.5 x 15.5 degrees) Lobster–eye X–ray optic based on microchannel plate technology and CCD detector at the focal plane. The SXI will observe the location, shape and motion of the dayside magnetospheric boundaries. X-rays in the Earth's exosphere result from the charge exchange interaction between ions in the solar wind and neutrals such as hydrogen in the Earth's exosphere and interplanetary space. PI: Steve Sembay, University of Leicester, UK.

UVI: a wide field of view optic sensitive to the Lyman-Birge-Hopffman band of ultraviolet radiation. Filters and coatings will be used to suppress day glow. The UVI will observe the polar cap, and measure the location and width of the auroral oval. It will also observe transient and localised brightenings that occur on the auroral oval edges. PI: Eric Donovan, University of Calgary, Canada.

LIA: a wide field of view proton and alpha particle analyser. This will determine the basic moments of the solar wind ion distributions, such as velocity, density, temperature and the heat flux vector. These measurements, taken simultaneously with the UV and X-ray images, obviate the concerns of arrival times and spatial extents when external solar wind monitors at the distant Langrangian Point L1 are used. The LIA will include a top-hat-type electrostatic analyser. The centre plane of the field of view will be parallel to the ecliptic, to ensure that the solar wind and average plasma sheet flow directions remain within the field of view. Larger dynamic range will be obtained using a variable geometric factor system. PI: Lei Dai, National Space Science Center, Chinese Academy of Sciences, China.

MAG: a dual-redundant digital fluxgate magnetometer, with two tri-axial fluxgate sensors connected by a boom to a spacecraft-mounted electronics box. The accompanying electronics unit consists of a FPGA digital processing unit with a DC-DC converter. PI: Lei Li, National Space Science Center, Chinese Academy of Sciences, China.

2.1 Solar Wind Charge Exchange (SWCX)

Charge exchange emission can occur when ions interact with neutral atoms or molecules; one or more electrons are transferred to the ion into an excited state. In the subsequent relaxation of the ion (with the charge now reduced by the number of electrons captured), a cascade of photons may be emitted.

X-ray emission from Solar Wind Charge Exchange (SWCX) recombination occurs in planetary atmospheres, comets, interplanetary space, and in the Earth's exosphere, while evidence for extrasolar charge exchange emission has been observed in supernova remnants, galaxies and galaxy clusters. Consequently, the heliophysics, planetary science, and astrophysics communities all have an interest in SWCX.

SWCX emission could be used to image the Earths magnetosheath. The magnetosheath is the area near the Earth's where the magnetic field, embedded in the solar wind plasma, is confronted by the Earth's magnetic field. This results in the magnetosphere; a cavity of Earth–confined plasma which protects the Earth from the harsh conditions within the solar wind. This picture, however, is not static as the Earth system responds quickly to changes in the solar wind density and velocity.

2.2 Czech Participation in SMILE

CTU in Prague and Rene Hudec are the SMILE project consortium members. The Czech participation is based on very long experience with imaging X ray telescopes and monitors in the Czech Republic with emphasis on wide field X ray monitors Lobster Eye type [4–10].

The expected Czech contribution is based on scientific and data evaluation software and data analyses, with emphasis on the SXI telescope. Two SMILE meetings were held in Prague, namely a SMILE session at Prague AXRO conference in December 2015 with presentations of SMILE PIs negotiating details on Czech participation, and SMILE meeting in Prague in July 2016.

3. ESA THESEUS

The main scientific goals of the proposed mission are to explore the Early Universe (cosmic dawn and reionization era) by unveiling a complete census of the Gamma-Ray Burst (GRB) pop-

ulation in the first billion years and to perform an unprecedented deep monitoring of the X-ray transient Universe [11–12]. The foreseen payload of THESEUS includes the following instrumentation (https://www.isdc.unige.ch/theseus/):

Soft X-ray Imager (SXI, 0.3 – 6 keV): a set of 4 lobster-eye telescopes units, covering a total field of view (FOV) of $\sim$ 1sr with source location accuracy < 1-2 arcmin; InfraRed Telescope (IRT, 0.7 – 1.8 microns): a 0.7m class IR telescope with 10 x10 arcmin FOV, for fast response, with both imaging and spectroscopy capabilities; X-Gamma rays Imaging Spectrometer (XGIS, 2 keV – 20 MeV): a set of coded-mask cameras using monolithic X-gamma rays detectors based on bars of Silicon drift detectors coupled with CsI crystal scintillator, granting a $\sim$ 1.5sr FOV, a source location accuracy of $\sim$ 5 arcmin in 2-30 keV and an unprecedently broad energy band. The mission profile includes: an onboard data handling units (DHUs) system capable of detecting, identifying and localizing likely transients in the SXI and XGIS FOV; the capability of promptly (within a few tens of seconds at most) transmitting to ground the trigger time and position of GRBs (and other transients of interest); and a spacecraft slewing capability of $\sim$ 10–20 degrees/min). The baseline launcher / orbit configuration is a launch with Vega–C to a low inclination low Earth's orbit (LEO, $\sim$ 600 km, <5 degrees), which has the unique advantages of granting a low and stable background level in the high–energy instruments, allowing the exploitation of the Earth's magnetic field for spacecraft fast slewing and facilitating the prompt transmission of transient triggers and positions to the ground.

3.1 Czech Participation in THESEUS

CTU in Prague and Rene Hudec are the THESEUS project consortium members. The Czech participation is based on very long experience with imaging X ray telescopes and monitors in the Czech Republic with emphasis on wide field X ray monitors Lobster Eye type [4–10].

The expected Czech contribution is as follows: SXI, optics tube, mechanics, electronics, and software. There is expected participation of Czech space industry. The Czech participation in the project is supportded by the Czech PRODEX Office for phases A and 0.

4. Conclusions

The SMILE satellite with innovative instrumentation on-board including a Lobster Eye X-ray telescope will study X-rays from the magnetosphere. SMILE will trace and link processes of solar wind injection with those acting on charged particles precipitating into the cusps and the aurora. There will be outreach potential as well: The possibility of captivating the public to science (magnetic field) so far invisible. The project is based on cooperation with China: SMILE is a showcase, building on Double Star experience. The THESEUS mission is designed to vastly increase the discovery space of the high energy transient phenomena over the entirety of cosmic history. Both missions represent scientifically valuable satellite projects with wide international participation, including Czech scientists. The satellite designs include Lobster Eye X-ray telescopes in both cases.

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References

[1] http://www.mssl.ucl.ac.uk/SMILE/

[2] Graziella Branduardi-Raymont et al., SMILE: A new approach to exploring solar-terrestrial relationships. Geophysical Research Abstracts Vol. 19, EGU2017-8153, 2017.

[3] Branduardi-Raymont, G.; Wang, C.; Smile Team. SMILE (Solar wind Magnetosphere Ionosphere Link Explorer): X-ray imaging of the Sun-Earth connection, in XMM-Newton: The Next Decade, Proceedings of the Conference held 9-11 May, 2016 at ESAC, Madrid. Online at http://www.cosmos.esa.int/web/xmm-newton/2016-workshop, id.81.

[4] Hudec, R., et al., Proc. SPIE 5488, UV and Gamma-Ray Space Telescope Systems, (11 October 2004); doi: 10.1117/12.551915, 2004

[5] Hudec, R., Pína, L., Inneman, A., Švéda, L., LOBSTER - Astrophysics with Lobster Eye Telescopes, in Exploring the Cosmic Frontier, ESO Astrophysics Symposia European Southern Observatory 2007, pp.73-74, 2007

[6] Inneman, A., et al., 2000, Proc. SPIE, 4138, 94

[7] Hudec, R., et al., 2000, SPIE Proc. 4012, 432

[8] Hudec, R., et al., 2003, SPIE Proc. 4851, 578

[9] Hudec, R., et al., 2004a, SPIE Proc. 5488, 449

[10] Hudec, R., et al., 2004b, Nucl. Phys. B Proc. Suppl. 132, 320

[11] Stratta, G., R. Ciolfi, L. Amati, E. Bozzo, G. Ghirlanda, E. Maiorano, L. Nicastro, A. Rossi, S. Vinciguerra, F. Frontera, D. Gouml;tz, C. Guidorzi, P. O'Brien, J. P. Osborne, N. Tanvir, M. Branchesi, E. Brocato, M. G. Dainotti, M. De Pasquale, A. Grado, J. Greiner, F. Longo, U. Maio, D. Mereghetti, R. Mignani, S. Piranomonte, L. Rezzolla, R. Salvaterra, R. Starling, R. Willingale, M. Bouml;er, A. Bulgarelli, J. Caruana, S. Colafrancesco, M. Colpi, S. Covino, P. D'Avanzo, V. D'Elia, A. Drago, F. Fuschino, B. Gendre, R. Hudec, P. Jonker, C. Labanti, D. Malesani, C. G. Mundell, E. Palazzi, B. Patricelli, M. Razzano, R. Campana, P. Rosati, T. Rodic, D. Szeacute;csi, A. Stamerra, M. van Putten, S. Vergani, B. Zhang, and M. Bernardini: THESEUS: A key space mission concept for Multi-Messenger Astrophysics, Advances in Space Research, Volume 62, id.662 (2018)

[12] Amati, L., P. O'Brien, D. Gouml;tz, E. Bozzo, C. Tenzer, F. Frontera, G. Ghirlanda, C. Labanti, J. P. Osborne, G. Stratta, N. Tanvir, R. Willingale, P. Attina, R. Campana, A. J. Castro-Tirado, C. Contini, F. Fuschino, A. Gomboc, R. Hudec, P. Orleanski, E. Renotte, T. Rodic, Z. Bagoly, A. Blain, P. Callanan, S. Covino, A. Ferrara, E. Le Floch, M. Marisaldi, S. Mereghetti, P. Rosati, A. Vacchi, P. D'Avanzo, P. Giommi, S. Piranomonte, L. Piro, V. Reglero, A. Rossi, A. Santangelo, R. Salvaterra, G. Tagliaferri, S. Vergani, S. Vinciguerra, M. Briggs, E. Campolongo, R. Ciolfi, V. Connaughton, B. Cordier, B. Morelli, M. Orlandini, C. Adami, A. Argan, J.-L. Atteia, N. Auricchio, L. Balazs, G. Baldazzi, S. Basa, R. Basak, P. Bellutti, M. G. Bernardini, G. Bertuccio, J. Braga, M. Branchesi, S. Brandt, E. Brocato, C. Budtz-Jorgensen, A. Bulgarelli, L. Burderi, J. Camp, S. Capozziello, J. Caruana, P. Casella, B. Cenko, P. Chardonnet, B. Ciardi, S. Colafrancesco, M. G. Dainotti, V. D'Elia, D. De Martino, M. De Pasquale, E. Del Monte, M. Della Valle, A. Drago, Y. Evangelista, M. Feroci, F. Finelli, M. Fiorini, J. Fynbo, A. Gal-Yam, B. Gendre, G. Ghisellini, A. Grado, C. Guidorzi, M. Hafizi, L. Hanlon, J. Hjorth, L. Izzo, L. Kiss, P. Kumar, I. Kuvvetli, M. Lavagna, T. Li, F. Longo, M. Lyutikov, U. Maio, E. Maiorano, P. Malcovati, D. Malesani, R. Margutti, A. Martin-Carrillo, N. Masetti, S. McBreen, R. Mignani, G. Morgante, C. Mundell, H. U. Nargaard-Nielsen, L. Nicastro, E. Palazzi, S. Paltani, F. Panessa, G. Pareschi, A. Pe'er, A. V. Penacchioni, E. Pian, E. Piedipalumbo, T.

Piran, G. Rauw, M. Razzano, A. Read, L. Rezzolla, P. Romano, R. Ruffini, S. Savaglio, V. Sguera, P. Schady, W. Skidmore, L. Song, E. Stanway, R. Starling, M. Topinka, E. Troja, M. van Putten, E. Vanzella, S. Vercellone, C. Wilson-Hodge, D. Yonetoku, G. Zampa, N. Zampa, B. Zhang, B. B. Zhang, S. Zhang, S.-N. Zhang, A. Antonelli, F. Bianco, S. Boci, M. Boer, M. T. Botticella, O. Boulade, C. Butler, S. Campana, F. Capitanio, A. Celotti, Y. Chen, M. Colpi, A. Comastri, J.-G. Cuby, M. Dadina, A. De Luca, Y.-W. Dong, S. Ettori, P. Gandhi, E. Geza, J. Greiner, S. Guiriec, J. Harms, M. Hernanz, A. Hornstrup, I. Hutchinson, G. Israel, P. Jonker, Y. Kaneko, N. Kawai, K. Wiersema, S. Korpela, V. Lebrun, F. Lu, A. MacFadyen, G. Malaguti, L. Maraschi, A. Melandri, M. Modjaz, D. Morris, N. Omodei, A. Paizis, P. Paacute;ta, V. Petrosian, A. Rachevski, J. Rhoads, F. Ryde, L. Sabau-Graziati, N. Shigehiro, M. Sims, J. Soomin, D. Szeacute;csi, Y. Urata, M. Uslenghi, L. Valenziano, G. Vianello, S. Vojtech, D. Watson, and J. Zicha: The THESEUS space mission concept: science case, design and expected performances, Advances in Space Research, Volume 62, id.191 (2018)