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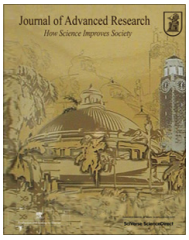
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REVIEW

The Space Weather and Ultraviolet Solar Variability (SWUSV) Microsatellite Mission

Luc Damé *, and The SWUSV Team (Mustapha Meftah, Alain Hauchecorne, Philippe Keckhut, Alain Sarkissian, Marion Marchand, Abdenour Irbah, Éric Quémerais, Slimane Bekki, Thomas Foujols, Matthieu Kretzschmar, Gaël Cessateur, Alexander Shapiro, Werner Schmutz, Sergey Kuzin, Vladimir Slemzin, Alexander Urnov, Sergey Bogachev, José Merayo, Peter Brauer, Kanaris Tsinganos, Antonis Paschalis, Ayman Mahrous, Safinaz Khaled, Ahmed Ghitas, Besheir Marzouk, Amal Zaki, Ahmed A. Hady, Rangaiah Kariyappa)

Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), Institut Pierre-Simon Laplace (IPSL), CNRS, Université Versailles Saint-Quentin (UVSQ), 11 Boulevard d'Alembert, 78280 Guyancourt, France

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Abstract We present the ambitions of the SWUSV (*Space Weather and Ultraviolet Solar Variability*) Microsatellite Mission that encompasses three major scientific objectives: (1) Space Weather including the prediction and detection of major eruptions and coronal mass ejections (Lyman-Alpha and Herzberg continuum imaging); (2) solar forcing on the climate through radiation and their interactions with the local stratosphere (UV spectral irradiance from 180 to 400 nm by bands of 20 nm, plus Lyman-Alpha and the CN bandhead); (3) simultaneous radiative budget of the Earth, UV to IR, with an accuracy better than 1% in differential. The paper briefly outlines the mission and describes the five proposed instruments of the model payload: SUAVE (*Solar Ultraviolet Advanced Variability Experiment*), an optimized telescope for FUV (Lyman-Alpha) and MUV (200–220 nm Herzberg continuum) imaging (sources of variability); UPR (*Ultraviolet Passband Radiometers*), with 64 UV filter radiometers; a vector magnetometer; thermal plasma measurements and Langmuir probes; and a total and spectral solar irradiance and Earth radiative budget ensemble

* Corresponding author. Tel.: +33 1 80285119; fax: +33 1 80285200.
E-mail address: luc.dame@latmos.ipsl.fr.
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(SERB, *Solar irradiance & Earth Radiative Budget*). SWUSV is proposed as a small mission to CNES and to ESA for a possible flight as early as 2017–2018.

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Introduction

The proposed microsatellite mission SWUSV (*Space Weather and Ultraviolet Solar Variability*) is two-fold since addressing solar-terrestrial relations and in particular Space Weather with the very early detection of major flares and CMEs through Lyman-Alpha imaging, and the solar UV variability influence on the climate, through a complete coverage of the UV from 180 to 400 nm, Lyman-Alpha and the CN bandhead, but also the modeling of stratospheric circulation and atmospheric chemistry of the middle atmosphere. It also includes a simultaneous local radiative budget, so that simultaneous measurements allow to properly capture the correct amplitudes of local variations and sudden stratospheric warnings (SSWs).

Modern technological infrastructures on the ground and in Space are vulnerable to the effects of natural hazards. Of increasing concern are extreme Space Weather events, such as geomagnetic storms and coronal mass ejections (CMEs), that can have serious impacts on ground- or Space-based infrastructures such as electrical power grids, telecommunications, navigation, transport or even banking. In terms of power-grid assets, damage to high voltage transformers is a likely outcome leading, through cascading effects, to power outages that could ripple to impact other services reliant on electrical power like disruption of communication, transport, distribution of potable water, lack of refrigeration, loss of food and medication, etc. [1]. A superstorm like the one that happened in 1859 (and known as the "Carrington event")—largest with measurements—would seriously impact activities on Earth. However, forecasting a solar storm is a challenge and present techniques are unlikely to deliver actionable advice. To mitigate the risk, early precursor indicators of major solar events with geoeffectiveness are required.

SWUSV aims at observing space environment, and more specifically the onset of Interplanetary Coronal Mass Ejections, ICMEs, that is, the most important since with a potential impact on Earth. They manifest themselves in extreme ultraviolet and in X-rays, but their early detection (often linked to a filament or prominence disappearance, or to a newly emerging bipolar region) is best carried in the far ultraviolet (FUV), that is, in Lyman-Alpha (121 nm). With these resolved solar disk observations and the appropriate modeling (noticeably differences between Lyman-Alpha and H-Alpha), we expect to be able to better forecast and predict large flares and CMEs and their incoming potential (geoeffectiveness) destructive force.

Solar ultraviolet irradiance below 350 nm is the primary source of energy for the Earth's atmosphere. The basic thermal structure of the atmosphere results from the absorption of solar radiation via photodissociation and photoionization of neutral species. An understanding of solar UV radiation input is also essential for studying atmospheric chemistry. For example, solar far UV (FUV) radiation (100–200 nm) photodissociates molecular oxygen in the stratosphere and mesosphere, leading to the creation of ozone. On the other hand, the solar middle UV (MUV) radiation (200–310 nm) is the primary loss mechanism for ozone through photodissociation in the stratosphere. The balance of these two processes, along with a series of complex ozone chemical reactions, creates the ozone layer with its peak density in the stratosphere.

The FUV is the only wavelength band with energy absorbed in the high atmosphere (stratosphere), in the ozone (Herzberg continuum, 200–220 nm) and oxygen bands, and its high variability is most probably at the origin of a climate influence (UV affects stratospheric dynamics and temperatures, altering interplanetary waves and weather patterns both poleward and downward to the lower stratosphere and tropopause regions). Recent measurements at the time of the recent solar minimum [2] suggest that variations in the UV may be larger than previously assumed what implies a very different response in both stratospheric ozone and temperature.

With SWUSV, we expect to have observations in the FUV to UV range to understand how solar UV radiation directly influences stratospheric temperatures, and how the dynamical response to this heating extends and de-multiply the solar influence. A simultaneous Earth radiative budget allows to feed properly, without phase delay, the atmospheric models. With the lost of SORCE expected in the next years, the UV observations proposed are essential. SWUSV gives us the unique opportunity to develop measurements and analysis tools to apprehend the influence of UV variability on climate.

Space Weather awareness and solar UV forcing on climate are strong themes, relevant to the Solar-Terrestrial extended community, and measurements/observations to support them are lacking. SWUSV is intending to get them quickly.

The SWUSV Microsatellite Mission investigation was first proposed as a French–Egyptian mission for a study in 2010 in response to the Joint Research Call of the SDTF/IRD [3], and the proposal was renewed in 2011 [4]. It was then deeply enhanced and proposed in 2012 in response to the ESA Call for a Small Mission opportunity for a launch in 2017 [5]. It is also proposed to CNES [6] and considered for its future—prospective—programs [7]. SWUSV builds on the success of two previous space missions, PICARD and PROBA-2, and proposes to use the same platform as the microsatellite PICARD, MYRIADE, on a similar orbit and with comparable pointing system. The launch is compatible with a Vega launcher in piggy-back with 2 satellites given the small size of the microsatellite (<900 mm width and <1 m height) what should help maintain reasonable the launching costs. Likewise, the instruments will be developed from repeating units of qualified flight instruments (TRL 8–9) from the PICARD and PROBA-2 missions, while significant evolutions (in particular of imaging telescope to the far ultraviolet) are supported by a CNES Research & Technology (R&T) program.

In this paper, we present in "*Scientific objectives*" the two major science objectives of SWUSV: Space Weather early warnings of major events and solar ultraviolet variability influence on climate. In "*Mission profile and spacecraft*", we present the SWUSV mission profile and in "*SWUSV model payload*"

the model payload accounting five instruments: SUAVE (*Solar Ultraviolet Advanced Variability Experiment*), SODISM/PICARD telescope optimized for FUV (Lyman-Alpha) and MUV (200–220 nm Herzberg continuum) imaging (sources of variability); UPR (*Ultraviolet Passband Radiometers*), evolution of PREMOS-LYRA with 64 UV filter radiometers by 20 nm bandpass or specific (Lyman-Alpha, CN bandhead); a scientific grade vector magnetometer (SGVM); a thermal plasma measurements unit (TPMU) and Langmuir probes (DSLP); and a *Solar irradiance and Earth Radiative Budget* ensemble (SERB). In the following sections, we briefly present science operations and data processing, development schedule and technology readiness, and the management and cost of the mission.

Scientific objectives

Space weather

The events preceding the onset of an eruption are called "precursors", and one of the most important precursors is the emergence of a new bipolar region emerging at the solar surface that can/will interact with pre-existing magnetic field in the corona and thus trigger the onset of an eruption. Another well-known precursor is the activation, or eruption, of a filament that is composed of relatively cold plasma (around 10,000 K), floating in the hot coronal plasma. Both emerging regions and filaments are very well observed in Lyman-Alpha (in Space) and H-alpha (on ground), both on the disk and at the limb, and we expect that their combination can lead to better identification of changes at the origin of major eruptions and most important coronal mass ejections (CMEs).

Lyman-Alpha is indeed very sensitive to flares, 1000 times more than H-alpha since, with the LYRA/PROBA-2 instrument in integrated light, one can observe the eruptions as well as in XUV with a signature on light curves almost reaching 1% of the integrated flux (cf. Fig. 1). By comparing the differences

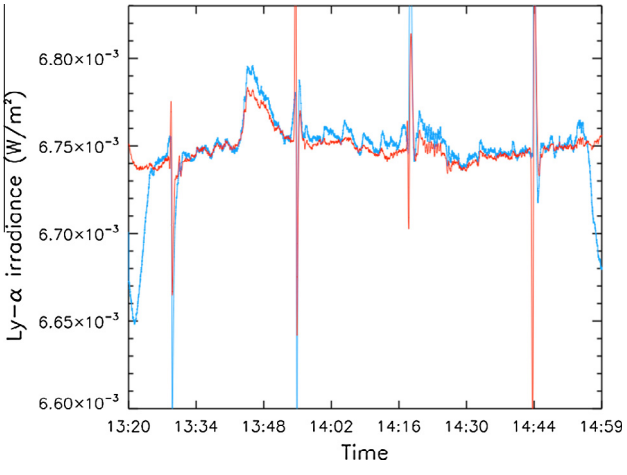


Fig. 1 Eruption 7650 (M2.0) of 8 February 2010 13:45 observed by LYRA/PROBA-2 on the integrated solar disk. Note that the excess, following two calibration methods (red and blue curves), and although probably still underestimated due to the bandpass of filter, is nearly 0.5–0.7%: 1000 times more than in H-alpha [courtesy, M. Kretzschmar].

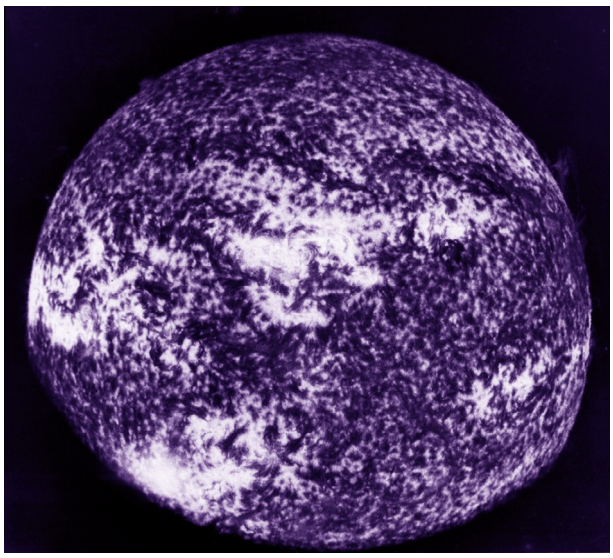


Fig. 2 Filtergram in the Lyman-Alpha line (121.6 Nm) obtained with the first rocket flight of the Transition Region Camera (TRC) in 1979. Note the loops on the edge and the prominences, visible despite a good exposure of the disk itself (and a limited dynamic due to the use of film rather than a CCD). The high resolution (1″) explains the good contrast of the images. Lyman-Alpha is an excellent tracer (probably the best) of solar activity in the chromosphere and lower corona.

in sensitivity with H-Alpha (formed in the lower chromosphere) of the filaments and prominences before and during the eruption, it should be possible to develop leading precursor indicators of major eruptions and CMEs. Sustained H-alpha observations are made daily throughout the world to complement Lyman-Alpha data only possible from Space. It is worth recalling that Lyman α emission line is the most intense solar line. This line is obviously very sensitive to temperature variations in the chromosphere, but also velocities and magnetic fields (Zeeman effect). It is optically much thicker than the H-alpha line (cf. earlier models of P. Gouttebroze, J.C. Vial and, more recently, of Labrosse et al. [8]). Thus, "cold" structures of the corona are highlighted, as evidenced by the first photographic images of the entire disk by French experiences (sounding rockets), with the Transition Region Camera (TRC), by Bonnet et al. [9], Damé et al. [10]. These images (cf. Fig. 2), already old (the first flight was in 1979), are still the best so far for the entire disk (resolution: 1 arcsec) and allow assessing areas where activity gets structured with manifestations of precursors' signs of potential eruptions (filaments, emerging regions). As illustrated in Fig. 3, prominences and filaments are well seen in Lyα and much better on the disk than in He II 304 Å line (where filaments detection and tracking is very difficult due to the low contrast [11], limiting precursor observations), although not so sharply than in Ha since of the higher optical thickness of the line. At the limb, indeed, the He II line, well observed by SOHO/EIT and SDO/AIA, is well suited to observe prominence eruptions [12] but not their early (precursor) detection on the disk, hours before the event as Lyman-Alpha can to provide. Lyman-Alpha imaging, in that respect, is a high value Space Weather complementary product to EUV imaging available on other satellite.

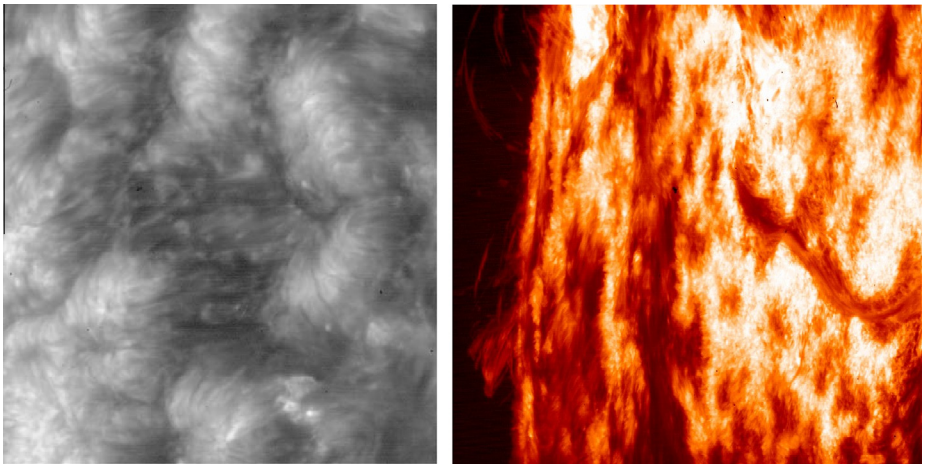


Fig. 3 Lyman-Alpha Filtregrammes at high resolution (~0.75″) obtained on a limited field of view (120 × 120 arcsec) during the second rocket flight (June 14, 2002) of the VAULT experiment of the NRL and showing the detail of the inside a superganulation cell (left) and filaments and prominences at the edge of the disk (right). Notice the "aerial" appearance of the filament on the disk [adapted from [34]].

Another objective of Lyα imaging is a measure of the solar variability of magnetic origin, so important in the context of the study of the Sun's influence on the climate of the Earth and its environment, particularly complementary tools for predicting the onset of CMEs. HI Lyα is indeed measured since 1997, especially by UARS and EOS/SOLSTICE and, since 2010, by the LYRA experience on the ESA/PROBA-2 microsatellite. However, since these experiments measure the irradiance of the Sun as a star, they do not have information on the physical causes of the irradiance changes observed. To identify the causes of these changes and measure their parameters according to solar magnetism, an imaging instrument of the whole disk, with an adequate spatial resolution and a good cadence, is necessary. The nature of changes in the Lyman α irradiance is also important to interpret the changes in ozone and the formation of the D-layer of the ionosphere. In addition, photometric images in Lyα can, by subtraction, see fast phenomena such as Moreton waves that propagate on the surface and produce a signature on the structures of the chromosphere. It is also possible, probably, besides the study the eruptions and sudden disappearances of prominences and filaments with high sensitivity, to detect wave phenomena associated with large-scale coronal instabilities associated with CMEs. The high sensitivity to temperature variations of Lyman α and its insensitivity to Doppler effects (in comparison with H-alpha) is another great advantage that, by combining the two, should allow (by modeling based on observations) to have an idea of the direction of CMEs (and indeed their "geoeffectiveness"). Finally, on disk, the images should help to better understand the slight darkening ("dimming") observed during CMEs. In total, with the images now available in EUV-XUV provided by the Dynamics Solar Observatory (SDO), the Lyman-Alpha images provide the missing link, but essential, with the chromosphere to predict geoeffectiveness of coronal mass ejections. Lyα and the Herzberg continuum (200–220 nm, cf. Fig. 4) are major contributions to observing strategies in Space Weather (cf. Fig. 5).

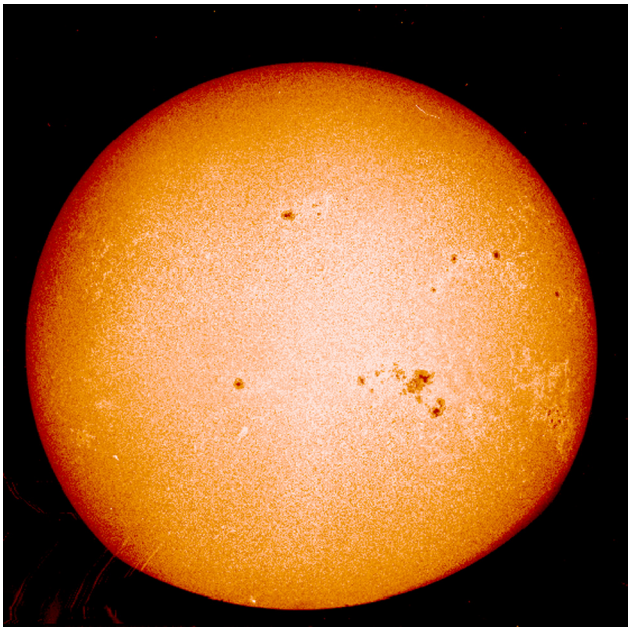


Fig. 4 Example of Herzberg 200–220 nm solar continuum filtergram obtained during the third rocket flight of the *Transition Region Camera* (TRC), July 13, 1982. Note the high contrast of the plages, network, and sunspots on the filtergram. Resolution of SWUSV/SUAVE will be comparable (1 arcsec) to TRC.

Measurements of solar variability, mainly in the UV, are one of the tracks of the possible influence of the Sun on the Earth's climate. The measurement of Lyα flux coupled to imaging will allow to better understand the nature of variability (important: factor 2 in the cycle of 11 years compared to 0.1% for the "solar constant" including the visible). These variations are produced by the surface manifestations of magnetic activity in the Lyα emission line, formed in the upper chromosphere, the best and most effective tracer to follow them. It is important to relate the observed variability of the UV flux with direct manifestations (magnetic activity) on the solar surface to understand the physical origin of these UV variations, only capable by their energy, to influence the Earth's climate.

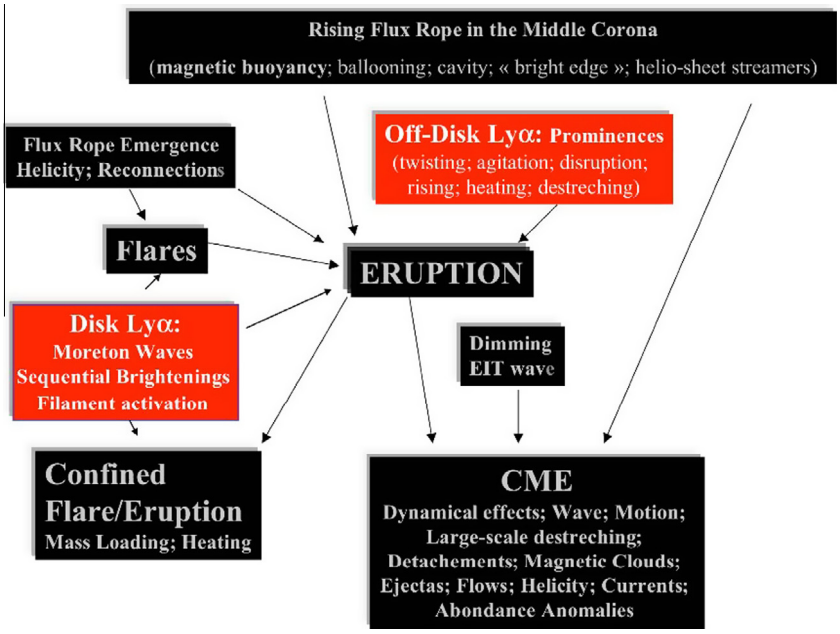


Fig. 5 Illustration of the interest of Lyman-Alpha observations (high chromosphere) for understanding and monitoring solar flares and CMEs. In the process leading to an eruption, either due to a filament or a newly emerging bipolar region, manifestations are distinctly visible in the Lyman-Alpha emission: an indisputable advantage for Space Weather since these signs are available hours before the event [courtesy, S. Koutchmy].

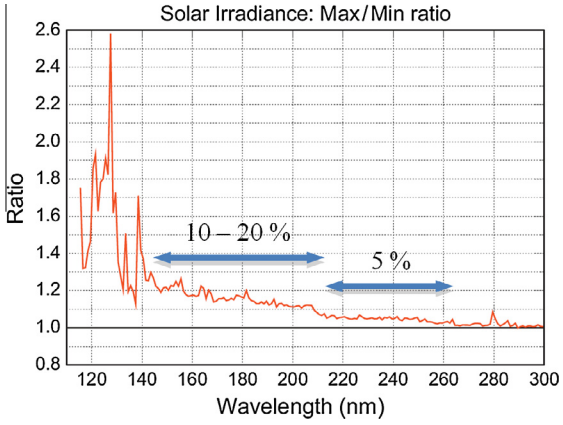


Fig. 6 UV solar variability measured by SUSIM/UARS between February 1992 and October 1996 (ratio between solar maximum and solar minimum) [adapted from [20]].

Solar UV variability and climate

The Sun is the primary source of energy responsible for the Earth's climate. Any change in the amount as in the type of energy/radiation that Earth receives will result in an altered climate. Variability of the solar flux during the solar cycle, between the maximum and minimum, occurs mainly in the far ultraviolet and below 350 nm. It may exceed 5% up to 210 nm and even reach 10–20% between 150 and 210 nm (see Fig. 6). In the far UV (FUV), it can reach, particularly in Lyman-Alpha, more than 100% over the cycle. The UV spectrum < 350 nm does not reach the ground; it is completely absorbed by stratospheric ozone and oxygen and plays an important role in the stratosphere (Lyman-Alpha in the Mesosphere) where it alters the local temperatures, pressures and the winds and, in fact, the conditions of propagation of atmospheric waves (planetary) that create a coupling between high and low levels (and poleward) of the atmosphere.

The UV is only 1% of the total solar flux, but given its high variability, it represents in ABSOLUTE 64% of the variability in the cycle (see Fig. 7). It is much more than the EUV or XUV, negligible even though more variable, and this is because of their very low energy.

Solar UV will locally heat the ozone in the stratosphere and thus create zonal anomalies on the propagation of planetary waves that will, in turn, affect the tropospheric circulation (see Fig. 8). The mechanism, described by Haigh [13–15], Gray et al. [16] and Fuller-Rowell et al. [17], and named "top-down mechanism", works well enough in appearance although, for the last solar minimum that was particularly low, the effect was underestimated mainly because of a non-effective incorporation of UV. Haigh et al. [2], in particular, show the differences of spectral irradiance from April 2004 to November 2007 compared to the overall global model of Judith Lean. The UV variability model is underestimated (factor 4–6) and the visible overestimated! Although these results lend themselves to heated discussions about the factor to consider (2–3 rather than 4–6?), it is clear that these changes induce a significant decrease in stratospheric ozone below 45 km (and the reverse above), affecting dynamics and temperatures in the stratosphere.

These differences show the limits of the current global model at the time of a significantly low solar minimum and the need to take into account the complexity of the UV absorption and the chemistry of their interactions in the Earth atmosphere, in particular by a proper restitution of the amplitudes

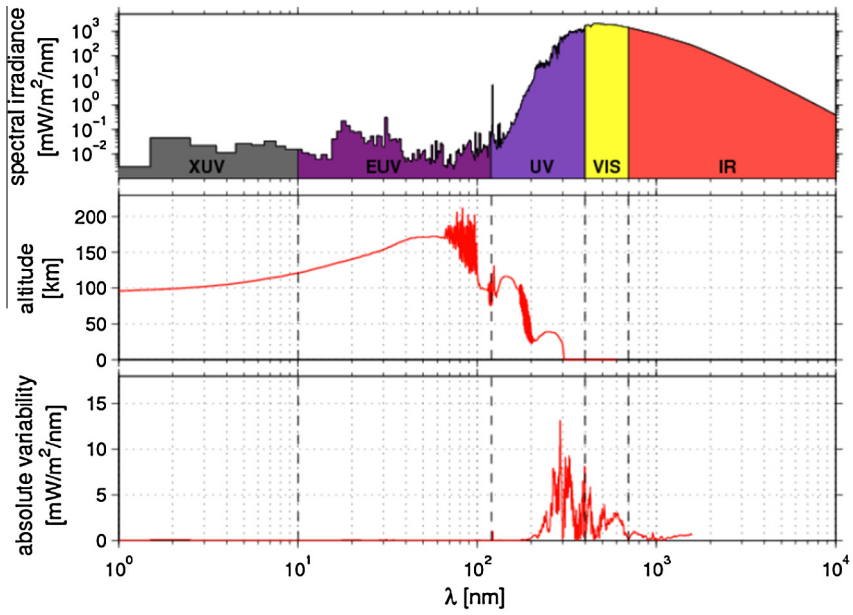


Fig. 7 Solar spectral irradiance, altitude of absorption, and absolute variability during the 11 years solar cycle. (Top) The absorption of Lyman-Alpha and 180–240 nm controls the production and destruction of ozone. (Middle) The UV (< 350 nm) is important because it represents 1% of total irradiance. (Bottom) 64% of the absolute variability comes from UV between 200 and 350 nm: this badpass is the main source of heating of the stratosphere and mesosphere [from SORCE and TIMED].

(avoiding excessive average) and an adequate reference to local conditions, what means simultaneous measurements of Solar inputs and Earth Radiative Budget [18,19], that is, simultaneous measurements of Lyman-alpha, Herzberg continuum (ozone), UV from 180 to 400 nm, and of the Earth radiative budget, what proposes SWUSV model payload indeed.

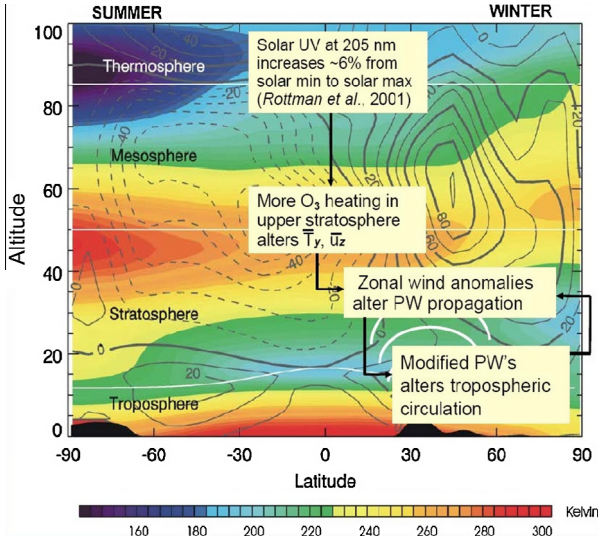


Fig. 8 Illustration of the possible Sun-climate connection through the variability of solar UV that heats the ozone locally and create defects/anomalies on the propagation of the zonal planetary wave that will, in turn, affect the tropospheric circulation [courtesy, J.P. McCormack].

A recent paper by Martin-Puertas et al. [20] directly shows that large changes in solar ultraviolet radiation can indirectly affect climate by inducing atmospheric changes. Martin-Puertas and colleagues, by analyzing sediments from Lake Meerfelder Maar to determine annual variations in climate proxies and solar activity, showed that around 2800 ago, the Grand Solar Minimum known as the Homeric Minimum, caused a distinct climatic change in less than a decade in Western Europe. They infer that atmospheric circulation reacted abruptly and in phase with the solar minimum and suggest solar-induced "top-down" mechanisms, as in another recent study [21] that shows also the importance of solar ultraviolet forcing on northern hemisphere winter climate.

Simultaneous observation of solar UV and terrestrial UV, IR, and total solar irradiance (TSI) is a key issue to understand the Sun-Climate relationship. Solar UV penetrates into the atmosphere but a non-negligible part is scattered by molecules and high altitude aerosols (background aerosol, volcanic aerosol, polar stratospheric clouds, and mesospheric clouds) toward space. Solar UVC and most of UVB radiations are absorbed by stratospheric O_2 creating ozone and regulating stratospheric temperature. This process is well understood and can be modeled with moderate difficulties at low latitudes, but in polar region, many parameters affect the transfer of sunlight through the atmospheric layers because of obvious geometrical difficulties for rising. Moreover, stratospheric ozone and tropospheric water vapor variabilities in these regions are also the key factors that cannot be neglected. Then, climate studies without the most dominant parameters in the polar region are difficult to take into account when working on radiative budget issues. Having simultaneous measurements of solar UV, terrestrial UV, IR and global irradiance, stratospheric ozone and tropospheric H_2O gives access to a complete and

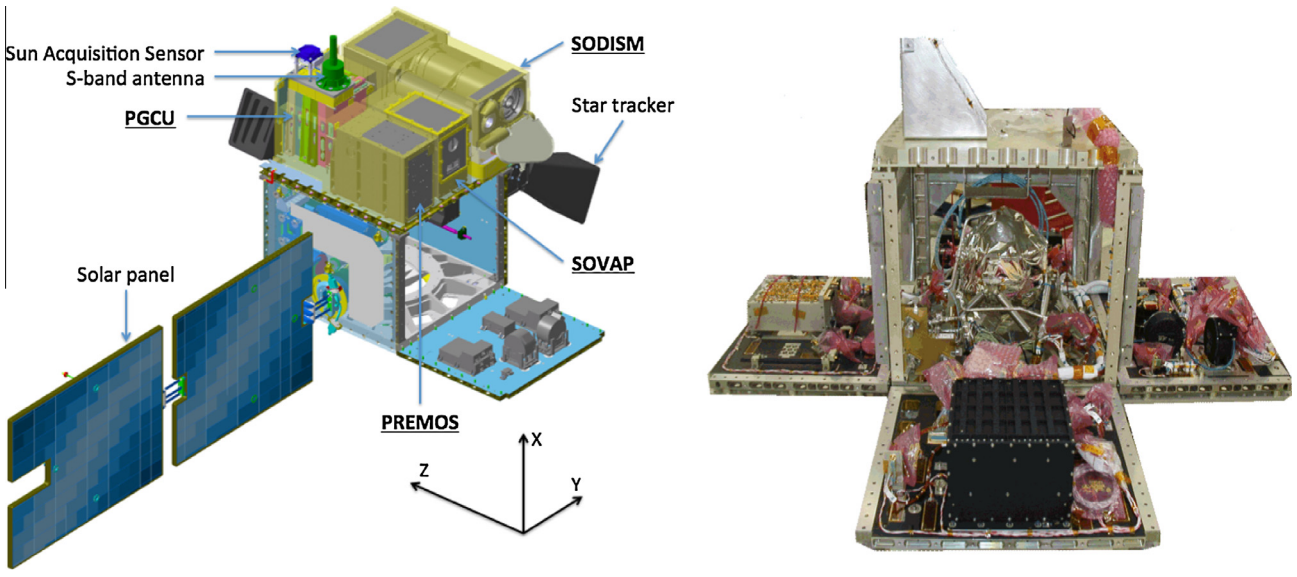


Fig. 9 MYRIADE platform example with the PICARD microsatellite.

original set of data that can help understand the effect of solar UV variability on Earth's atmosphere and therefore on climate.

Understanding the mechanism needs indeed to be able to follow the SSW ("Sudden Stratospheric Warmings") to their full extent [17,22,23], what means with a good measure and representation of the UV variability. Yet, precisely, in the UV, measures and indices to represent this variability are not yet reliable as this was clearly shown by Thierry Dudok de Wit and Waterman [24] or Gael Cessateur (in his thesis [25], and in Cessateur et al. [26]).

The models, climate models, must evolve toward greater consideration and adequate measures of the variability (in all its magnitude) on one hand, and secondly, the right context (radiative budget). On one side, the non-simultaneity of solar and Earth measures may introduce large, unrecoverable bias, and models do not always take into account the good wavelengths despite their potential importance, for example the molecular bands of CN from 385 to 390 nm (assumed to be very variable and very sensitive to even very low temperature).

Furthermore, large differences in the reconstructed flux may result from a modeling in LTE (local thermodynamic equilibrium) rather than in Non-LTE conditions, in particular in bands affected by of important/strong lines like the Magnesium doublet [27].

Models, like the LMDz Reprobus model [22,28], are essential to understand the mechanisms at work in the Earth atmosphere, the specific photoionization processes in the stratosphere and mesosphere that will affect the atmospheric circulation, amplifying the solar signal changes. Models have to evolve since large uncertainties are still at work and underestimation of the solar passed variability probable (cf. Shapiro et al. [19,29]). Proper observations and adequate modeling should help progress in this complex and highly non-linear solar influence on climate.

The following sections present the mission and payload to meet the essential measures expressed by these scientific objectives.

Table 1 Performances offered by the MYRIADE platform to payloads.

Mass	Up to 80 kg
Power	60 W Permanent
Pointing	Accuracy $< 5 \times 10^{-3}$°, stability $< 2 \times 10^{-2}$°
Propulsion	80 m/s
Mass memory	16–32 Gbits
Telemetry rate	400 kbits/s
Hight rate telemetry	16.8 Mbits/s

Mission profile and spacecraft

SWUSV is built on the success of 2 previous Space Weather related missions: PICARD and PROBA-2. SWUSV uses the same microsatellite platform than PICARD, MYRIADE (cf. Fig. 9), and a comparable orbit (altitude, 725 km; inclination: 98.29°; local time of ascending node: 6h00 ±10 min; eccentricity: 0.00104; argument of periapsis: 90°). The MYRIADE platform structure is almost cubic with dimension of 60 cm by 60 cm and a height of 50 cm.

Satellite is on a Sun-synchronous orbit which can maintain constant pointing to the Sun (Earth instruments, SERB in fact, -OS and -ER, will be doubled, one on each side to see Earth on up and down of orbits) and get a near-constant illumination for more stable measurements (short eclipses in December mainly). A recent overview of the MYRIADE product line developed by CNES was given in Landiech and Rodrigues [30]. MYRIADE is 3-axis stabilized and benefits of an excellent pointing stability (cf. Table 1) thanks to the Solar Ecartometry Sensor (SES, see Joannes et al. [31]), demonstrated in orbit and providing arcsec resolution.

SWUSV is probably compatible with a Vega launcher in piggy-back with 2 satellites given the small size of the microsatellite (< 900 mm width and < 1 m height). This should help maintain reasonable (within a few millions Euros maximum) launching costs (VEGA overall cost is approximately € 35 millions). The VEGA launcher is the one suggested by ESA for its

Small Missions, but it could also be used for a CNES mission. It can deliver in Sun-synchronous orbits (SSOs) more than 1400 kg at 725 km (cf. Arianespace VEGA User's Manual [32]), what is fine for the SWUSV 150–160 kg microsatellite. Downlink will be done every 90 min to one of the 6 ESA 2 GHz S band stations (Aussaguel, Kourou, Kerguelen, Hartebeesthoek, Kiruna, or Svalbardevery) with quick recovery of data, to be consistent with predictions of Flares/CMEs with a maximum of 4 h.

The data flow will be reasonable (~3 Gbit/day) even if SWUSV has an imaging experiment since with filtregrammes every 10 min at only two wavelengths, telemetry is limited. Higher cadence (doubled or so) when anticipating major flares or CMEs could be envisaged up to the 6 Gbit limit of the MYRIADE platform downlink. The Sun-synchronous orbit passes through the poles every 90 min and allows to downlink the data on S-band stations (same strategy than PICARD).

Since the SWUSV payload is observed in the UV, it is sensitive to contamination. It is then necessary to quantify the critical level of contamination and to enforce contamination control to ensure compliance with requirements. This implies to control and to select materials and components at satellite (solar panels outgasing, etc.) and payload level (near optical elements in particular). At minimum, we will have to respect the following conditions: TML < 0.1% (Total Mass Loss) and CVCM < 0.01% (Collected Volatile Condensable Material), according to ESA-PSS-51 (guidelines for spacecraft cleanliness control from European Space Agency). For very sensitive surfaces (mirror surface), a slight thermal positive difference will also to minimize deposits that prefer "cold" surfaces.

SWUSV model payload

The model payload of the SWUSV Microsatellite Mission (cf. Fig. 10) includes five instruments or instrumental ensembles:

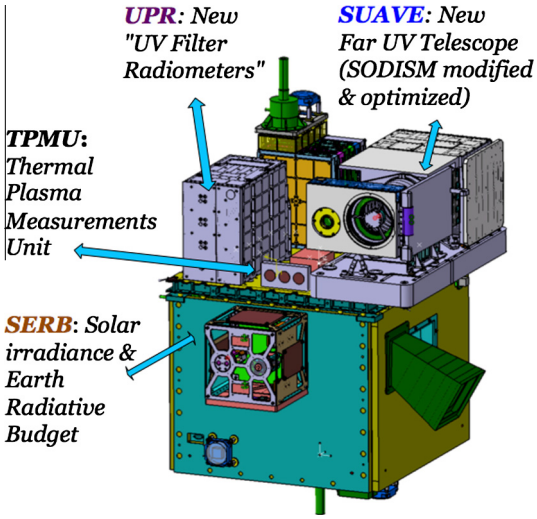


Fig. 10 SWUSV microsatellite model payload that combines far UV imaging (Lyman-Alpha and Herzberg continuum at 200–220 nm), measurements of spectral irradiance (Lyman-Alpha and 180–400 nm by 20 nm bandpass), and radiative budget UV to IR including total irradiance (SERB "nanocube", shown in front in the current preliminary accommodation study of the satellite).

- a new telescope based on SODISM/PICARD and optimized for far-UV (Lyman-Alpha) and the Herzberg continuum (200–220 nm), each with redundant filter sets (4 for Lyman-Alpha and 3 for 200–220);
- an evolution of the instrument LYRA/PROBA-2 (or PREMOS/PICARD) with UV filters for the measurement of the spectral irradiance by 20 nm bands from 180 to 400 nm and at specific wavelengths (Lyman-Alpha, CN bandhead 385–390 nm);
- a vector magnetometer (inheritance of DEMETER and PROBA-2);
- measurements of thermal plasma and Langmuir probes (TPMU + DSLP, ESA/PROBA-2 legacy);
- finally, SERB (*Solar irradiance & Earth Radiative Budget*): a set of four instruments in a cube of 20 cm side and 3 kg for measuring the Earth's radiative budget and the total solar irradiance (TSI).

SUAVE: A far UV imaging telescope

SUAVE (*Solar Ultraviolet Advanced Variability Experiment*) is an 11-cm diameter Ritchey–Chrétien telescope, free of coma and spherical aberration, and with a flat focal plane to which is associated a 2048×2048 pixels CCD detector. The instrument field of view and its angular resolution are, respectively, about 35 arcmin and 1.06 arcsec. It is based on the SODISM telescope [33] of the PICARD mission proposed to CNES in 1998 [34,35]. Evolutions compared to SODISM are several (no window, modified door, mirrors, etc.) but general characteristics stay the same (cf. Figs. 11 and 12, Table 2).

Current spatial measurements favor EUV wide band images, too wide in practice to obtain a good correlation with the measured flux variations (structures of the chromosphere to the outer corona are amalgamated together). This is the case

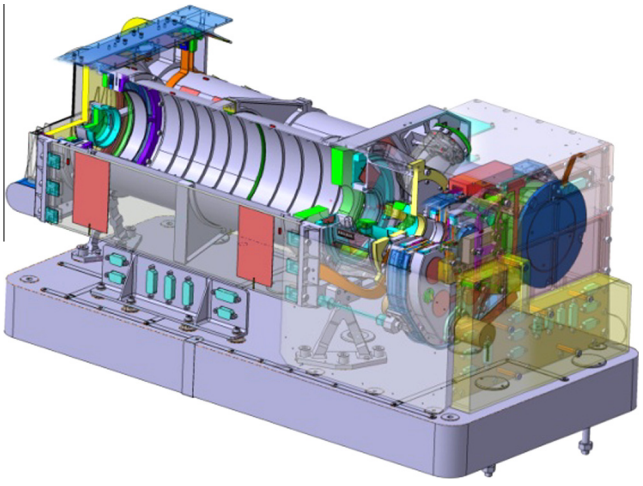


Fig. 11 SUAVE telescope, a FUV optimized version of SODISM/PICARD with SiC mirrors for prolongated observations and ultimate thermal control (heat evacuation, focus control). SUAVE has no entrance window and hosts a main entrance baffle and a new implementation of the door in a rest position on the +Y side. The radiator M2 has been increased to improve the cooling of M2. Two radiators were added: in +Z the CCD radiator, and in +X the M1. All the harness were deported in −Y to the inside of the P/L.

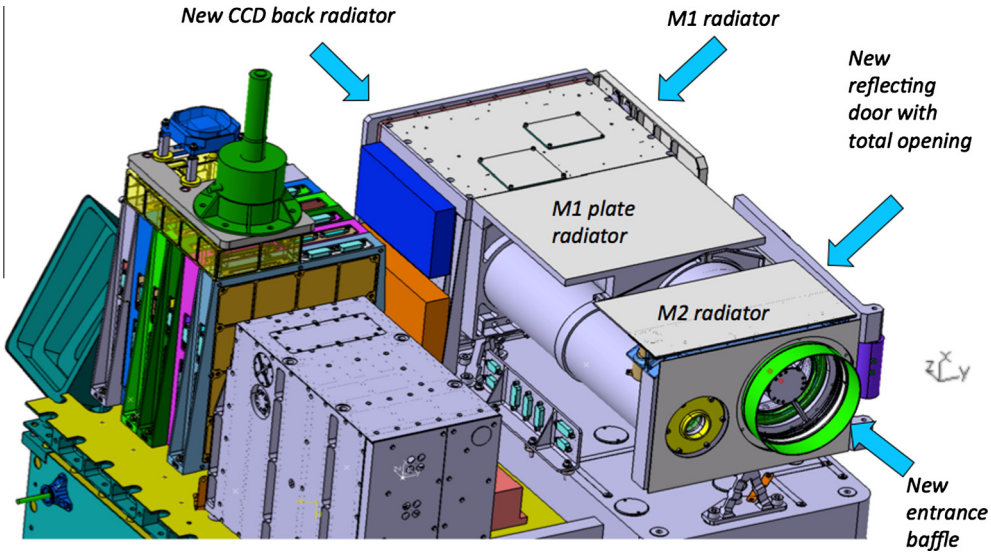


Fig. 12 SODISM instrument (general view of the telescope, filter wheels, and detector) as realized for the PICARD mission and functional for more than 2 years (launch: June 15 2010). Apart from thermal problems associated with the input window and door (albedo of the Earth), the telescope is excellent and its mechanisms working flawlessly.

Table 2 SUAVE main characteristics.

Telescope type	Ritchey–Chrétien
Focal length	2626 mm
Main entrance pupil	90 mm
Volume	670 (d) × 308 (w) × 300 (h) mm^3
Weight	28 kg
Field of view	35 arcmin
Angular resolution	1.06 arcsec/pixel
Power consumption	43.5 W nominal
Data rate	< 2 Gbits per day

for example with AIA/SDO (He II 304 Å) or on PROBA-2 with the imaging instrument SWAP (174 Å). The EUV certainly produces great images, spectacular, but indiscriminating. Lyman-Alpha is an essential "ingredient" to the Space Weather and the "climate forcing", but it is also a difficult image to produce and sensitive to contamination. The TRACE satellite (in the continuation of the rocket program TRC/SPDE, cf. [9,10]) had Lyman-Alpha imaging but of very average quality, as the technologies that were developed by TRC/SPDE had only partially been applied. More recently, the firing rocket VAULT of the NRL [36] achieved excellent images as we have seen (cf. Fig. 3) but only for a few minutes and on a limited FOV. To achieve our goals, we need a telescope designed for high resolution and large field of view. We have almost the ideal telescope on hand at LATMOS: the SODISM/PICARD one, but with some – important – modifications to carry.

The SODISM telescope is excellent up to one or two tenths of an arcsecond resolution, especially if it returns to its original definition, without an entrance window, source of complex problems of thermal stability (gradients in the window), and using SiC mirrors to avoid degradation of coatings (SiC "naked" reflects 40% in the UV and 20% in the visible), limit the thermal load (SiC is very homogeneous and conducting) and the flow on the filters (less than a solar constant: no or limited polymerization possibilities) in order to preserve their lifetime. SiC also has the advantage of being sensitive to

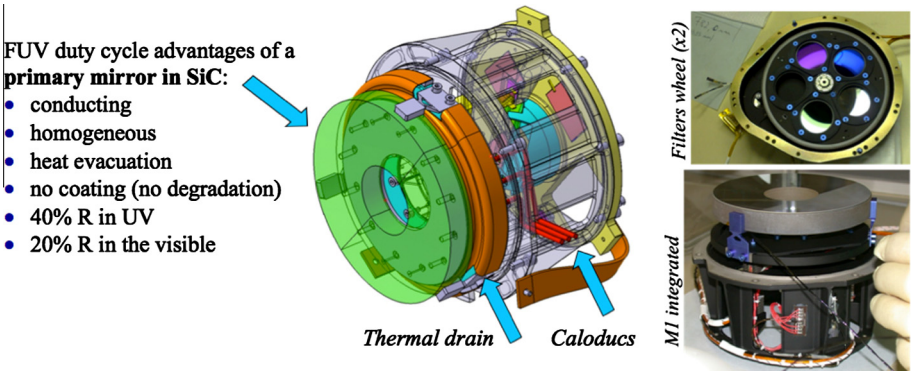


Fig. 13 SUAVE primary mirror is in SiC for FUV duty cycle. This change in the material of the mirror imposes a thermal drain; we added a copper interface on the back of the mirror which is connected to heat pipes which, themselves, are attached to the radiator mirror M1. These changes will be validated on a breadboard model in 2013 (R & T CNES support).

Table 3 Ultraviolet Passband Radiometers (UPR) — UV Solar Radiometers characteristics.

Field of view	3 degrees (full Sun as a star)
Wavelength range	Spectral Irradiance at Lyman a, 121 nm, CN bandhead Δ5 nm, 385–390 nm, and in Δ20 nm passbands from 180 to 400 nm
System	Set of 64 filter radiometers TRL 8–9 (16 or less in use; 48 spare)
Pointing	Center of the Sun
Instrument size	$270 \times 270 \times 330$ mm^3
Mass	20 kg (sensors, electronics & cable; including margin)
Telemetry	<30 kb/s (sampling 15 min; integration time between 0.1 and 10 s)
Power	15 W

temperature that can allow to control the radius of curvature (and hence the focal length of the telescope) through its thermal control (see new design of primary mirror support, Fig. 13). As the orbit is Sun-synchronous and without eclipses (and since the new door now fully opens with a baffle preventing the Earth albedo to enter the instrument), the solar flux on the primary is almost constant, what facilitates the heat regulation.

The SODISM/PICARD telescope is known and we will, accordingly, not present it again in details [33,37,38], but wish to emphasize that its performances in flight are excellent for the SWUSV investigation, even in the far UV, since we only need a resolution of 1 arcsec. SODISM control is rather at a stability of 0.1–0.2 arcsec [37].

New "UV filter radiometers" for climate purposes

A complete measure of the UV spectrum would certainly be attractive although we want to benefit from the full amplitude of events and early precursor identification and require, accordingly, to have measurements every 10 min or so. Also, we want to avoid complex mechanisms and calibrations and achieve a prompt realization. The proper alternative to a complex spectrograph is to use spectral filters in the UV, from 180 nm to 400 nm, with bandwidths sufficiently narrow to adequately address the various chemical species and their variability, in practice 20 nm or so. In addition to these UV bands, specific filters of importance are also planned in Lyman-Alpha and in the molecular bandhead of CN.

The instrument itself, *Ultraviolet Passband Radiometers* (UPR), is simple and already widely used and spatialized, since units were used on both PREMOS/PICARD and LYRA/PROBA-2. The design of the filter radiometers remains the same as on LYRA/PROBA2 [39]. The filter radiometer units have each four independent channels consisting of a silicon-diode interference-filter combination, mounted in a common body that is heated with constant power and always remains a few degrees above the temperature of the heat sink. In our case, we believe that using a volume less than double the one of PREMOS with some 16 filters' units (11 filters from 180 to 400 nm by 20 nm passband, a CN filter of Δ5 nm at 385–390 nm, and four filters for Lyman-Alpha), each filter with four heads for redundancy and monitoring of possible degradation. Lyman-Alpha, due to further potential degradation (although this is a concern addressed in a CNES R&D approved development this year, see "*Development schedule and technology readiness*" "Readiness"), is having four filters' units for extra life (and so 16 heads). Typically, for Lyman-Alpha, a filter works regularly every 10 min, a second every 2 h, a third every day, a fourth weekly, a fifth every 2 months, and a sixth one once a year. This makes 6 heads and 10 in reserve (7 for the 10 mn, 2 for the 2 h, and 1 for the everyday measurement) to help maintain maximal accuracy along the mission. Table 3 summarizes UPR characteristics. Fig. 14 presents its preliminary instrumental concept.

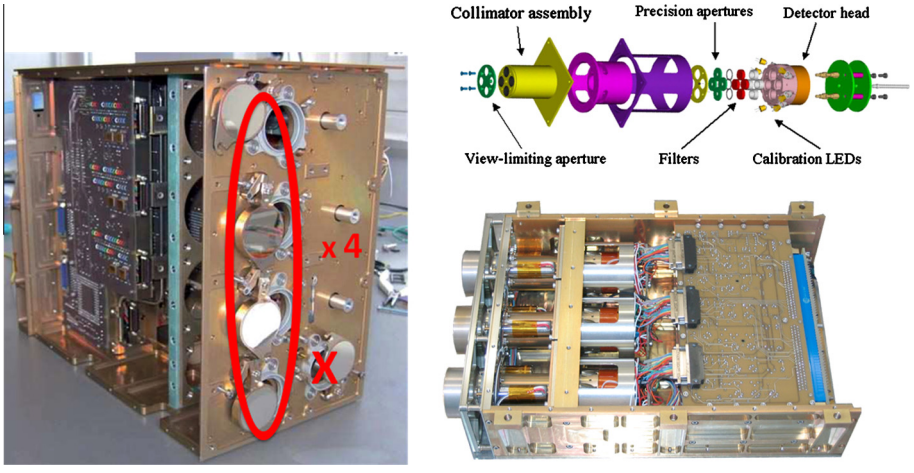


Fig. 14 PREMOS (left) or LYRA (right) will serve as models for the development of the new UV filter radiometers experiment of SWUSV: UPR (*Ultraviolet Passband Radiometers*). 16 filter radiometers, each with four redundant heads are planned in an extended size PREMOS or LYRA. Accommodation on the platform MYRIADE (same as PICARD) poses no problems since UPR uses part of the place left by the PICARD's middle instrument SOVAP (not on SWUSV) and since SERB (which includes the TSI instrument) should be placed in front or, if accommodation allows, inside the platform, bottom corners (to point toward Sun in front and Earth on both sides) or, also, on top of UPR since acceptable height of microsatellite in VEGA's piggyback is 1 m. Like for PICARD, the new PREMOS type instrument, UPR, is under the responsibility of PMOD-WRC.

Table 4 Main characteristics of the TPMU instrument.

Measured parameters	Measurement range
– Total ion density	2×10^7–8×10^{12} m^{-3}
– Ion temperature	800–10,000 K
– Electron temperature	800–20,000 K
– Floating potential of the satellite	±12 V
Instrument size	130 mm × 20 mm × 63 mm
Power	950 mW
Mass	2.43 kg

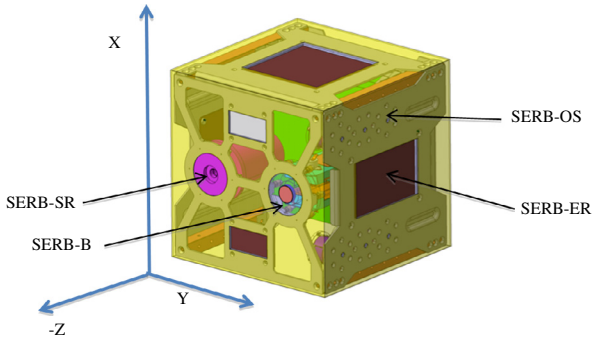


Fig. 15 SERB model payload.

The UV channels are calibrated with synchrotron radiation (PTB, Bessy, Berlin; ESRF, Grenoble; or SLS, Villingen). The absolute calibration of spectral irradiance is of the order of 10% in the UV. From the in-flight performance of the Sun photometers of VIRGO on the SoHO satellite [40], which have the same instrumental design as UPR radiometers, we expect that the transfer to space will not increase the uncertainty and that the instrument will have an absolute accuracy as given by the calibration procedure. The expected variations of the spectral solar irradiance are of the order of 0.1% in the visible, increasing to 10% in the UV at 200 nm for the 11-year solar cycle, and larger than 100 % at Lyman-Alpha and in the EUV [41,42]. By using several identical units with an in-flight calibration strategy, we anticipate to achieve an ambitious goal of a relative long-term stability of 5 ppm per year.

To minimize contamination on the filter surfaces, the optical cavities are separated from the rest of the instrument and shall be purged with nitrogen all the times during ground activities. Once in orbit, unused channels stay closed by means of a shutter.

The final choice of the exact filters' bandwidth will be made later in 2013. A modeling is planned between LATMOS, PMOD-WRC, and Orleans LPC2E to define the best choice of spectral bands to be introduced into the models to reproduce the stratospheric variations, and these choices being arrested to validate them (performance tests of the set of filters).

Space weather instrumentation

Instrumentation proposed is a vector magnetometer, a thermal plasma unit for ionosphere characterization and Langmuir probes for plasma density and temperature, all three inherited from the ESA/PROBA-2 mission. Details of these instruments and their measurements are well-known, so that only their major characteristics are recalled here. These instruments are now relatively classical supports of Space Weather since covering essential information on the ionosphere. Their realization is expected to be very similar than for PROBA-2 (with Czech participation expected). Our main target is to get a better understanding of the spatial and temporal scales over which the ionospheric layer varies.

Science Grade Vector Magnetometer (SGVM)

The vector magnetometer for PROBA-2 was made at the Technical University of Denmark [43]. The SGVM weights less than 1 kg, and it consists of one triaxial fluxgate sensor unit and a cold redundant controlling electronics unit with dimensions of 54 × 46 × 33 mm and 100 × 100 × 50 mm, respectively. The power consumption of the instrument can be less than 0.5 W for continuous operation. Fluxgates are more common in Space due to their significantly lower mass and power. Stability is a fundamental requirement for magnetometer measurements to ensure a profitable scientific return. Considerable effort, including a Magnetic Cleanliness Programme, is thus expected during design stages to ensure that instrument sensors and electronics are stable and robust with respect to radiation damage, launch loads, and thermal cycling due to eclipses in particular. To resolve fairly low fields, magnetometer sensors should be mounted away from the spacecraft in order to minimize the effect of magnetic contamination from spacecraft materials and currents. During the design study, we will investigate the requirement on a possible boom for this instrument.

Thermal Plasma Measurement Unit (TPMU) and Dual Spherical Langmuir Probe (DSLP)

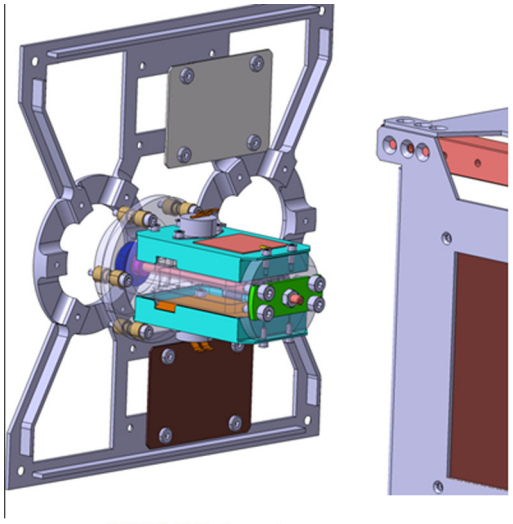
The TPMU and DSPL have been developed previously for PROBA-2 by the Institute of Atmospheric Physics (IAP) of the Academy of Sciences of the Czech Republic (ASCR). The PI was Frantisek Hruska et al. [44].

TPMU's main objective is the study of the ionosphere, its dynamics, and response to solar and geomagnetic activity, to provide a measure of the electron temperature, floating potential, the ion temperature, concentration, and composition. TPMU is a reliable and accurate low-cost instrument suitable for microsatellites (see Table 4). The ion measurement is based on the RPA (Retarding Potential Analyzer) technique. The electron temperature measurement uses another principle and sensor. It is based on the radio frequency probe technique using the RF signal (~50 kHz) modulated by the square wave.

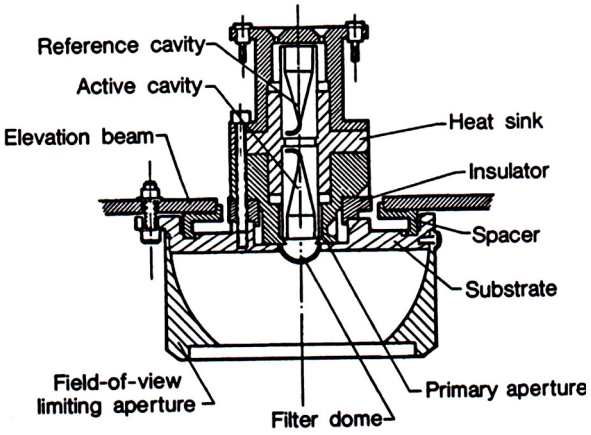
DSLP, the instrument flown with success on PROBA-2, is a heritage of ISL (Instrument Sonde de Langmuir) flown earlier on the DEMETER mission of CNES. DSLP is measuring the density of space plasma and its variations in the range 100–5×10^6 particles/cm^3, the electron temperature in the 500–3000 K range, and the satellite potential in the range of ±5 V. The instrument consists of two Langmuir probes, one is cylindrical and the other is spherical with a 6 cm diameter segmented probe. The plasma density and temperature are determined from the Langmuir probe current–voltage curve.

Radiative budget and irradiance: SERB

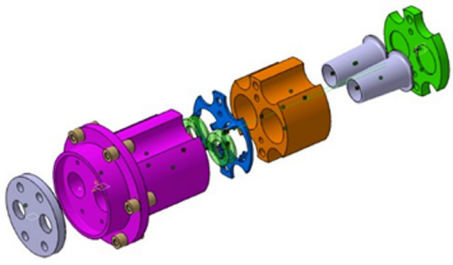
The instrument SERB (*Solar irradiance and Earth Radiative Budget*) is itself made up of four small instruments, arranged



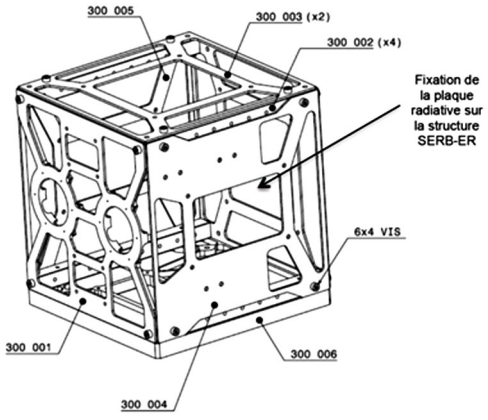
SERB-B Bolometer



Schematic diagram of SERB-SR radiometer



SERB-OS Optical sensor



SERB-ER Radiometer (radiative plate)

Fig. 16 Bolometers and radiometers (solar, top, or terrestrial, bottom) of the SERB instrument.

Table 5 List of SERB space radiometers for long-term measurements.

Instrument	Instrument type	Channel
SERB-OS	Optical sensor	310 nm and Δ20 nm (measuring O^3) 350–450 nm (polar albedo, particle size) 535 nm and Δ20 nm (reference for differential measurements) 760 nm and Δ20 nm (measuring altitude of cloud top) 880 nm and Δ50 nm (particle size) 940 nm and Δ20 nm (water vapor H_20)
SERB-ER	Radiometer	2.5 μm–40 μm
SERB-B	Bolometer	0.2 μm–40 μm
SERB-SR	Radiometer	0.2 μm–3 μm (TSI: PMO6 type)

Table 6 General characteristics of the SERB model payload.

Volume	200 * 200 * 200 mm^3
Mass	3.0 kg
Field of view	180° (along −Z) and 180° (along Y)
Power consumption	3 W nominal
Telemetry	200 kbits per day

in a small cube, "nanocube", $20 \times 20 \times 20$ cm^3 (see Figs. 15 and 16). Characteristics are given in Tables 5 and 6.

Two sensors point to the Sun (SERB-B and SERB-SR) and the other two to Earth (SERB-OS and SERB-ER), and this (almost) continuously since of the heliosynchronous orbit chosen. Note that the SERB-B bolometer and the radiometer SERB-SR (PMO6 type made of PMOD/WRC as used on SOVAP/PICARD, cf. Conscience et al. [45]) are instruments that have already been flown and that SERB-OS optical sensors are inherited sensors of the ODS (Optical Depth Sensor) of the Mars 2016 Mission, currently under spatialization, to which we added a channel to 880 nm (for the particle size) and one at 940 nm (for water vapor) to be as complete as possible.

The sensor SERB-ER for its part is a structural element (a radiative plate), to which we associate an electronic card for heat control management around a microcontroller like the PIC-16F, successfully used on PICARD.

Table 7 SWUSV Data Products.

Level	Source	Description wheel
Level 0	Mission Operations Center (MOC)	Data packets from satellite
Level 0.5	Science Operations Center (SOC)	FITS files containing uncompressed images in all bandpasses. Values are raw counts (uncalibrated)
Level 1a	SOC workstation using SolarSoft	FITS files with calibrations applied 'on the fly' to quicklook images available. Nominal life time of data is a month. Values are physical units of brightness
Level 1b	SOC workstation using SolarSoft	FITS files of all images with calibrations applied with latest software updates. Replace Level 1a when already created. Values are physical units of brightness
Level 2	Users/Laboratories and SOC workstations using SolarSoft	Data products including synoptic maps of variability and other higher-level products combining two or more images (movies, Lyman-Herzberg images, electron densities, etc.). Calibrated in physical units
Level 3	Users/laboratories workstations using SolarSoft	Higher-level derived quantities (CME masses, etc.)

SERB-OS level of validation/demonstration is already high (TRL 5–6) since based on current sensors developed for the Mars 2016 mission and on the thermal/electronics control experienced and successfully demonstrated in Space on PICARD. During the pseudo Phase 0 studies in 2013–2014, we may realize a demonstration bench to further validate electronic and thermal issues (a thermal vacuum chamber for tests of thermal environment was developed by LATMOS; it is equipped with a window in sapphire and allows also to test performance in UV).

The structure is partially made of carbon-carbon, a technology mastered at LATMOS since SODISM/PICARD [46], and used to optimize the mass balance but also to ensure a good thermal decoupling (< 0.03 W/K) with the platform (or underlying instrument) to maintain its record of performance.

Science operations and data processing

The SWUSV Mission Operation Center (MOC), operation facility and full data archive, is foreseen at the level of a large European Institute (LATMOS most probably). The volume of data (2–6 Gbit/day) is reasonable for current technology and trends. It will not pose serious problems for ground stations or archives in view of the present availability of large band equipment driven down by the rapid development of communications and Earth sciences satellites. Note that the operations by themselves are eased by the permanent pointing of the satellite and unique target. Some changes in scheduling (change of filters, calibration sequence, etc.) could be envisaged that would find place in the weekly organized science observing plan. Data are expected to be downloaded every orbit (90 min) in order to have flares/events warnings at a 4 h rate for Space Weather issues.

SWUSV camera and data handling system are conceived so as to offer a tremendous capability and flexibility for in-flight operations and adaptability to the mission (e.g., increased downlink capacity, extended mission, etc.). The operational modes of SWUSV will make full use of its large internal storage capacity (> 32 Gbit), of its processing power for image compression and image selection, and of the MYRIADE platform telemetry allowance (a daily rate of 6 Gbit), to maximize the science output. For instance, lossless compression (factor ≈ 3) will allow downloading 700 equivalent full frame CCD images each day while the nominal 2 per 10 min lead to only 400 a day. Extra images (300 or so) at higher cadence can then be taken when necessary and in particular at possible flaring/CME events following the precursor indicators provided by the mission. After evaluation of the data, a new science operation planning could be elaborated for the following hours. Command uplink requirement on the MOC is limited normally to a single daily upload that will likely take place on working days and during working hours. The SWUSV observations would however benefit from extended uplink possibilities if precursor indicators are effective and useful to warn of catastrophic events.

Science data from SWUSV will be stored and distributed as uncompressed, uncalibrated Flexible Image Transport System (FITS) files, in which a binary data array in units of digital counts is preceded by an ASCII header. This product is referred to as Level 0.5 data. One FITS file will be generated for each image in the spacecraft telemetry stream. The FITS file headers will include keywords to indicate instrument orbit and attitude information, all instrument settings associated with the image, information on all onboard and ground processing steps, image statistics, and any other ancillary information necessary to interpret the image data. Housekeeping data will be extracted from the raw spacecraft telemetry and will be stored in separate files. There will be two versions of SWUSV processed science data: quick-look data produced immediately upon receipt of all necessary telemetry from the spacecraft (Level 1a), and final data incorporating any telemetry packets that may be missing or corrupted in the initial telemetry and that are later recovered (Level 1b). Quick-look data will be available for mission operations verification and planning purposes and will be available immediately for scientific analysis. Final data will replace the quick-look data when they are available and will be suitable for archiving and distribution. Both quick-look and final data will be processed in the same way and will have the same file formats. The quick-look FITS file will be differentiated from the final data product by the completeness of the header. Interactive Data Language (IDL) procedures will be provided in the SolarSoft library to convert the Level 0.5 FITS image files into the higher-level calibrated data products described in Table 7. These procedures will permit

the user to perform standard corrections such as removal of geometric distortion, vignetting and stray light, and photometric calibration on the fly for the data of interest. All calibration data necessary for these corrections will be included as part of the SolarSoft distribution. This approach has been used successfully for previous missions and ensures that the user has access to the most up-to-date calibrations while avoiding repeated processing and redistribution of large amounts of data. Software tools for generation of higher-level data products and common analysis tasks such as image visualization, generation of movies and synoptic maps, feature tracking, and structure measurement, will also be provided in SolarSoft.

Besides the data products of the SWUSV scientific data archive presented in Table 7, all other SWUSV-related information will also be served to the community from the mission-specific web site that will contain:

- a Mission Log of all the observing programs carried out by the science team;
- access to Calibration Data (i.e., flat-field, photometric calibration, positioning);
- access to data analysis routines to allow end users to combine Calibration Data and Level 0.5 Data to create their own Level 1 calibrated FITS files;
- access to Quick-look Summary Images and Movies (in png and mpg formats) including synoptic maps in all wavelengths;
- access to the most recent data analysis software and documentation for further analysis of SWUSV observations (software will be written in IDL and will be incorporated in the SolarSoft environment);
- access to the SWUSV database (a database to allow users to select observations based on instrument set-up or specific parameters or events).

Development schedule and technology readiness

Schedule

In our present mission scenario, SWUSV can be launched by 2017 for a nominal mission of 2 years, extendable to 6 years (half a solar cycle) or more if possible. Whether it is a mission of national initiative (possible contribution of CNES to ESA Space Situational Awareness program?) or directly an ESA "Small Mission", the schedule is the same and, intentionally, as short as possible to truly supplement the current programs that do not benefit from UV measurements related to solar forcing on climate.

Years of 2013–2014 are a pseudo Phase 0 to build, test, and validate the instrumental model of the new telescope SUAVE optimized for UV using the support of a CNES R&T (Research & Technology). We also expect during the same period to validate the spectral bands of the UPR instrumentation through a radiative model using the experience of LATMOS (model-LMDz Reprobus, Marchand et al. [22], Keckhut et al. [28]) and PMOD-WRC (model COSI, Shapiro et al. [47,29,27]).

The SWUSV program, based on these instrumental verifications and results of modeling, could then start with confidence a 3-year realization program for the instruments, from 2015 to 2017, for launch date in late 2017 or 2018.

Key technologies and readiness

There are no major concerns on technologies readiness since the mission is mostly based on an evolution of the PICARD and PROBA-2 missions. However, it is an observational in the far ultraviolet with imaging and this has three impacts on the mission:

(1) it is necessary to have an excellent cleanliness plan to avoid contamination and loss of sensitivity; this requires to validate all components and in particular solar panels;
(2) UV filters at 120 nm (Lyman-Alpha) and 200–220 nm are particularly sensitive to degradation if exposed to a strong UV and visible flux (polymerization); flux has to be limited to below a solar constant in order to avoid major effects, a sound baffling is required and a cleanliness plan for storage and manipulation (dry nitrogen atmosphere) has to be realized; filters have to be doubled and their integrity (no inclusion, pin hole, density variation, etc.) verified;
(3) to preserve the filters and to avoid degradation of the coatings, SiC mirrors are intended for the primary and secondary mirrors: this avoids having any coating on mirrors therefore avoiding totally their degradation! SiC has the further advantage to reflect only 20% of the visible and 40% of the FUV, limiting flux on filters. As such, however, mirror supports have to be modified (thermal drain and caloduc added compared to SODISM) to eliminate the solar flux transmitted (SiC is highly conducting).

We will address theses points in detail since the SWUSV program has an ongoing R&T program with CNES for 2013 and 2014 to realize and test new FUV filters and to develop a breadboard of the new SUAVE telescope and in particular the new mirrors' supports and a proof of concept of the SiC mirrors thermal control (focus adjustment possibilities).

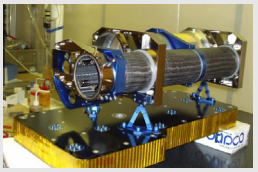
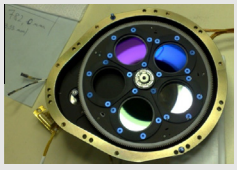
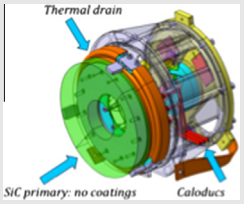
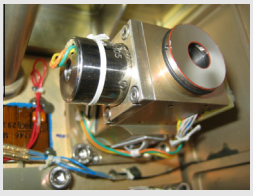
Table 8 summarizes the key technologies and readiness (TRL: Technology Readiness Level).

Management and cost

The SWUSV investigation is proposed by an international consortium under the responsibility of the Principal Investigator (PI) and Mission Coordinator, Luc Damé, assisted by the Instrument Manager (IM), Mustapha Meftah, both at LATMOS, France. The consortium, that is limited to be efficient in view of the short realization delays expected for a small mission (ESA or CNES), gathers the strengths of:

- the LATMOS team that originally proposed the concept of the SWUSV mission based on an evolution toward the far ultraviolet of the PICARD mission, to extend with SUAVE and UPR the possibilities of SODISM and PREMOS;
- the CNES R&T approved program on the development of a breadboard for the new UV telescope SUAVE, including a filters test program;

Table 8 Key technologies and readiness of the SWUSV mission.

Technology	TRL	Description	Illustration
Carbon–Carbon structure	9	Tubes in Carbon–Carbon at low expansion (crossed fibers) *Used with success for 2 years on SODISM/PICARD*	
Filter wheels	9	2 Filter wheels mechanisms with 5 positions, precise positioning, and operating in Space *Used with success for 2 years on SODISM/PICARD*	
UV filters	6	New hard filter for Lyman-Alpha and 200–220 nm to be tested thanks to CNES R&T *Breadboard test and demonstration of units performance and aging*	
SiC mirror and support	6	SiC mirror assembly and its new thermal control: evolution of SODISM mirror support with caloduc and thermal drain *Breadboard (CNES R&T) of the mirror assembly with its thermal control tested in telescope environment*	
PMO6 radiometerSERB package	9	Device is perfectly mastered since based on Sunphotometers back to VIRGO/SOHO *Flown in Space (PREMOS/PICARD,* etc.)	
S-band antennas	9	6 Possible stations for data collection *Used with success for 2 years on SODISM/PICARD*	

- the instrumental expertise of scientists from Europe and Russia who have built or participate to many of the recent space missions: PROBA-2, PICARD, CORONAS/TESIS, etc.
- the modeling potential of French and Swiss teams both on Space Weather and atmospheric chemistry.

The SWUSV program, in view of the short development time foreseen for Small Missions, is not proposed by large consortia with multiple partners and interface as are most of the Space instruments nowadays. LATMOS, in the continuation of PICARD, will be able to devote a significant team to the program, to achieve it in time and cost. The only interface foreseen in SUAVE/SWUSV is with the Lebedev Physical Institute (Moscow, Russia) that will deliver the CCD to SUAVE (2 k × 2 k). The PMOD/WRC UPR instrument is as independent as PREMOS was in PICARD.

All the instruments will be funded, supplied, and run by PIs and Co-Is from institutes in ESA member states or associated (Russia). The payload provision and funding would rest only with the PI and Co-I institutes, supported by their national

Table 9 SWUSV Mission Cost Breakdown (not including instruments).

SWUSV	%	Cost
Pre-implementation phase	2	0.4 M€
Total spacecraft industrial activities	45	9 M€
Launch services VEGA piggy-back	17	3.4 M€
Ground segment (MOC, SOC)	16	3.2 M€
Agency (ESA or CNES) internal cost	10	2 M€
Contingency	10	2 M€
Total	100	20 M€

funding agencies. A short development time is achieved by limiting partners on the different instruments, simplifying the interfaces and building upon previous collaborative arrangements when necessary. There is no doubt that sufficient scientific interest, special capabilities, and hardware experience has built up, both in Europe and in Russia, in order to address SWUSV model payload. Since recurring flight qualified units from SODISM and PREMOS/PICARD (including satellite interfaces), and from LYRA, TPMU-DSLP and Vector Magnetometer (SGVM) from PROBA-2, and since the support in 2013–2014 of a CNES R&T for the SODISM telescope modifications (full breadboard) toward the SUAVE optimized far ultraviolet telescope, we are further confident on the development time of instruments. A very preliminary cost of the instruments, based on PICARD history, is estimated at 25 M€.

At satellite level, including all development phases and integration, we can also evaluate a preliminary cost for the mission, taking advantage of the past CNES missions (DEMETER, PARASOL, PICARD) and ESA (PROBA-2), and on the on-going developments on TARANIS. SWUSV mission inherits from the re-use of most of the functional chains of PICARD since SUAVE and UPR are evolutions of SODISM and PREMOS with comparable requirements. As a result of these considerations, the SWUSV industrial share of the cost envelope, including engineering, management, platform hardware and satellite activities, can be evaluated to 9 M€. Table 9 gives a possible cost breakdown of the mission based on the internal cost models already acknowledged by ESA in several studies.

LATMOS has experience in the far UV (TRC and SPDE rocket programs of the 80 and 90; PHEBUS and SODISM/PICARD investigations more recently), but the realization of a telescope for Lyman-Alpha is even more delicate than in near-UV (SODISM case) and requires a preliminary breadboard to clearly study the problems of scattered light, optical quality, and maintenance of filters. In particular, the new proposed Far-UV telescope (SUAVE) returns to the original concept of the instrument SODISM/PICARD with SiC mirrors and without the highly detrimental input window [34,35]. A breadboard with optical mirrors in SiC has already demonstrated the qualities of this approach in 2000 and the new R&T CNES will now validate SUAVE/SWUSV instrumental concept.

Our Laboratories in France (LATMOS, LPC2E) and in Switzerland (PMOD/WRC) are very well positioned in this issue since we have both instrumentation and knowledge of the solar UV but also all the stratospheric chemistry skills to model the effects of UV on the climate.

Conclusion

Space Weather forecasting capabilities are very limited. Further scientific efforts are required to improve predicting modeling and in particular early warnings possibilities. Due to the absence of the appropriate observational infrastructure, dedicated Space Weather assets (satellites/missions) are certainly needed. Furthermore, the last deep solar minimum revealed how poor our understanding of the ultraviolet variability on climate is and the need of timely, reliable, and continuous observations of the Sun and Earth this is implying.

The microsatellite investigation SWUSV is unique, responding precisely to these needs to understand the influence of stratospheric dynamics on the climate by providing the tools to measure and quantify the influence of UV variability and determine its origin. It also carries, through Lyman-Alpha imaging, probably the best indicator for precursor signs of major Space Weather events. The program has the advantage of relying on technological developments made in very recent microsatellite missions, CNES/PICARD and ESA/PROBA-2, and from a long expertise in far UV imaging (Lyman-Alpha in particular but also Herzberg continuum at 220 nm also). As such risks are limited - since of the bread boarding of the FUV telescope and filters' testing program - development time is expected to be moderate and cost reasonable, below 50 M€, (instruments and operations included).

SWUSV represents a unique opportunity for new measurements to place Europe at the forefront of the studies of the influence of UV variability on climate and early Space Weather warnings of major solar hazards.

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