SUAVE: a Disruptive Far UV Telescope for Space Weather and Solar Variability Studies

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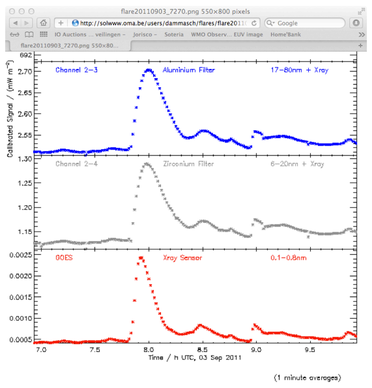
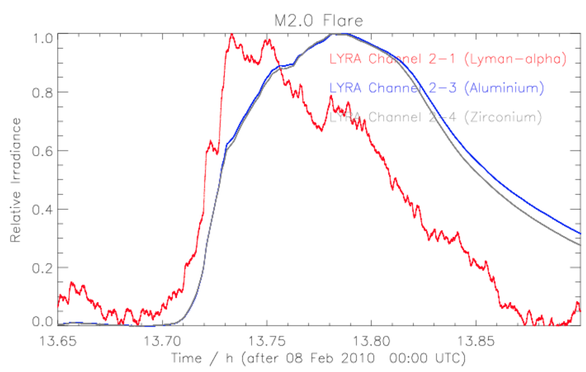
Introduction

SUAVE (*Solar Ultraviolet Advanced Variability Experiment*) is a far UV imaging solar telescope (Lyman Alpha, 121.6 nm, Herzberg continuum, 200-220 nm, etc.) of novel design for ultimate thermal stability and long lasting performances. SUAVE is a 80 mm Ritchey-Chrétien off-axis telescope with SiC mirrors and no entrance window for long and uncompromised observations in the UV (no coatings of mirrors, flux limited to less than 2 solar constants on filters to avoid their degradation), associated with an ultimate thermal control (no central obscuration resulting in limited thermal gradients and easier heat evacuation, focus control, stabilization). Design and anticipated performances are detailed as well as progresses towards realization of a representative breadboard for tests of optical and thermal properties (CNES R&T). SUAVE is the main instrument of the polar microsatellite of the SoSWEET-SOUP (*SOlar, Space Weather Extreme EvenTs and Stratospheric Ozone Ultimate Profiles*) mission presently under study (ex-SUITS/SWUSV mission, *Solar Ultraviolet Influence on Troposphere/Stratosphere / Space Weather and Ultraviolet Solar Variability*); it is also candidate for a military constellation of Space Weather extreme events surveillance.

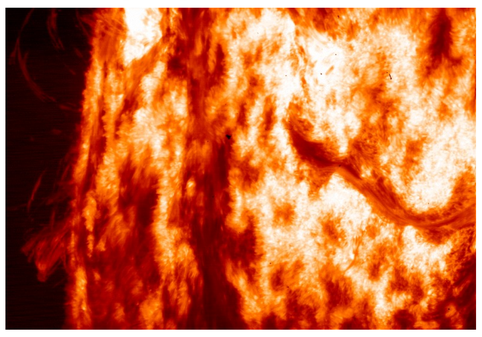
Predicting and monitoring large flares & CMEs: from X-ray to Lyman-Alpha

- Objective is to monitor flares in Lyman-Alpha rather than X-ray or XUV. Lyman-Alpha, much like H-Alpha, is an excellent flares/CMEs precursor indicator since of filaments and emerging bipolar region high visibility (space weather direct application). Furthermore, comparing sensitivity difference with H-Alpha, formed lower in the chromosphere, might lead to directivity (geoeffectiveness) and better and more robust flare/CME predictions.
- Lyman-alpha is EXCELLENT at detecting flares (cf. LYRA/PROBA-2) with an important raise in global integrated light curve (1000 times H-Alpha), and this even before GOES X-ray (1–8 Å) or the LYRA channel 2-3, Aluminium 17–80 nm, or 2-4, Zirconium 6–20 nm.

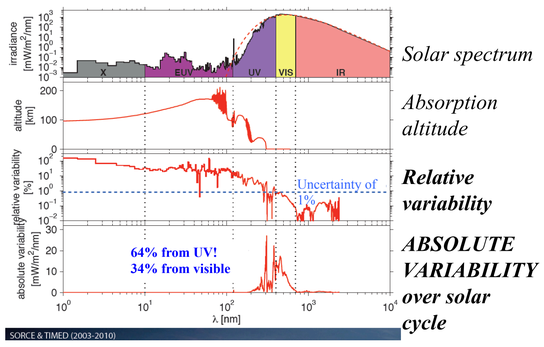




- Filaments and emerging bipolar region (the two major flare's precursors) are EXTREMELLY well seen in Lyman-Alpha allowing their detection and tracking, and their configuration changes to anticipate/predict large flare happenings. Coupled with H-Alpha, some directivity could be predicted hours in advance (geoeffective CME). Modelling the disruption of the flux rope is possible in Lyman-Alpha (Amari, 2015) while not in He II 304 Å.



High resolution image of the Sun in Lyman-Alpha taken by the VAULT rocket of NRL (Vourlidas et al., 2010) and nicely showing details of prominences and filaments (prominences seen in absorption on the disk).



Solar spectrum, its absorption altitude, relative (%) and absolute variability over solar cycle (data from SORCE & TIMED, 2003–2010).

UV affects stratospheric dynamics and temperatures, altering weather patterns

SUAVE Rationale

- SUAVE is a **Space Weather** watch-dog for potentially harmful extreme events with a **unique Lyα imaging telescope (1 arcsec resolution)**, also monitoring UV variability influence on climate through Herzberg continuum (200-220nm) observation.
- Need long duty cycle (> 6 years, ½ solar cycle) => **SiC mirrors** of "**mushroom**" type since: no coating (no degradation) and thermal conductivity and homogeneity -> heat evacuation preserving the filters (SiC reflect 40% in UV and 20% in visible); and no insert on mirrors – no distortion.
- High resolution imaging implies stability and a **thermally optimized configuration: off-axis telescope** => no central obscuration of primary mirror, flux homogeneity minimizes thermal gradients, M2 not back illuminated)
- SUAVE is the main instrument of the **SoSWEET-SOUP small satellite mission**, that combines a solar observing satellite (polar Sun-synchronous orbit) and a constellation of 12 (large) nanosatellites for ozone measurements.
- **Low cost small platforms** (< 150 kg; 60-70 kg P/L) are a new reality (OneWeb, Blue Canyon, etc.), not compromising on performances and telemetry, allowing more ambitious missions in same project envelope.

OneWeb small satellite (<150 kg) production line was inaugurated in June 2017 at the Toulouse premises of Airbus Defence and Space (ADS): the 12 first satellites out of 900 are expected by 2019. Courtesy ADS.

SUAVE Off-axis SiC Telescope Design

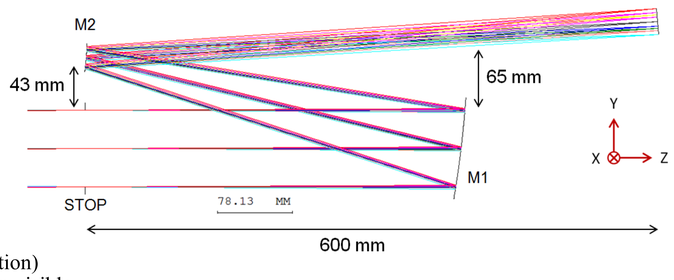
Evolution & optimization of SODISM: off-axis, no window, SiC mirrors & new "thermal" door and radiators

SUAVE is a **disruptive** evolution of the SODISM telescope flown on the CNES PICARD small satellite mission (2010-2014) with a new **optical design limiting thermal gradients**:

- no window, SiC mirrors ("Mushroom"), new "thermal" door and radiators
- thermally optimized off-axis configuration (homogeneity, no central hole, no back flux on M2

SUAVE optical design

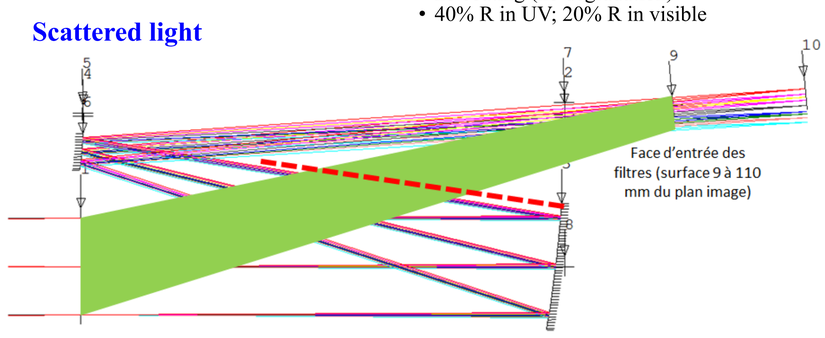
- *Pupil 80 mm; Focal 2630 mm*
- *M1 100 mm vertex inclined 0.15° (useful 84 mm)*
- *M2 28 mm vertex inclined 1.26° (useful 23.5 mm)*
- *Dimensions: 100x200x600 mm³ (200x300x750 mm³ with mechanics)*



SiC Mirrors for FUV long duty cycle since:

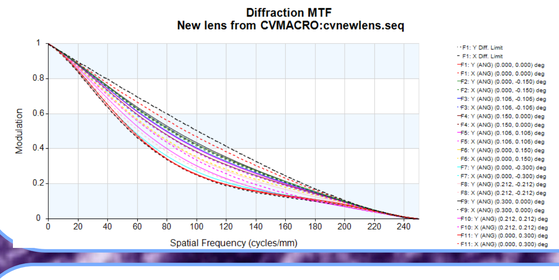
- conducting
- homogeneous
- heat evacuation
- no coating (no degradation)
- 40% R in UV; 20% R in visible

Scattered light



The large distance between the M1 and M2 mirrors and between the M1 mirror border and the beam out of the M2 gives an easy scattered light control by a simple baffle.

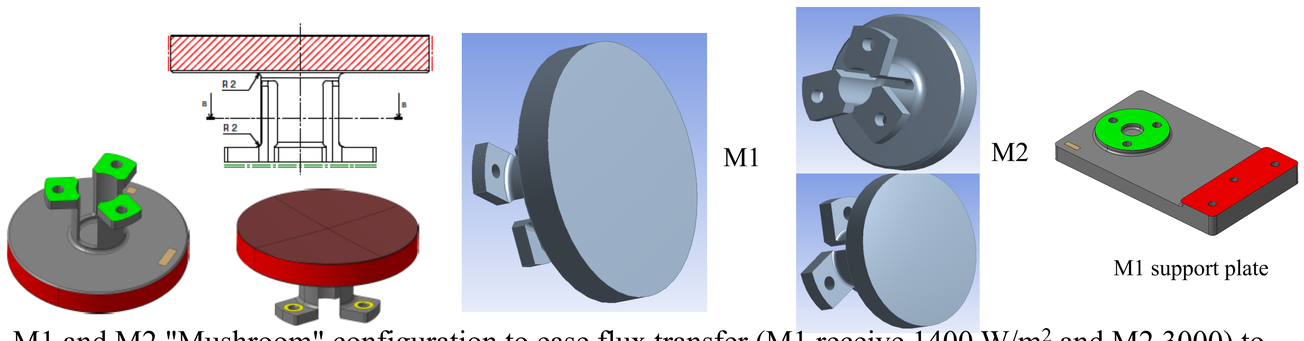
Filters (in plan 9) are protected by flux elimination of the M1 & M2 mirrors: they receive less than 2 solar constants => **no degradation since flux concentration is not sufficient to polarize contaminants**.



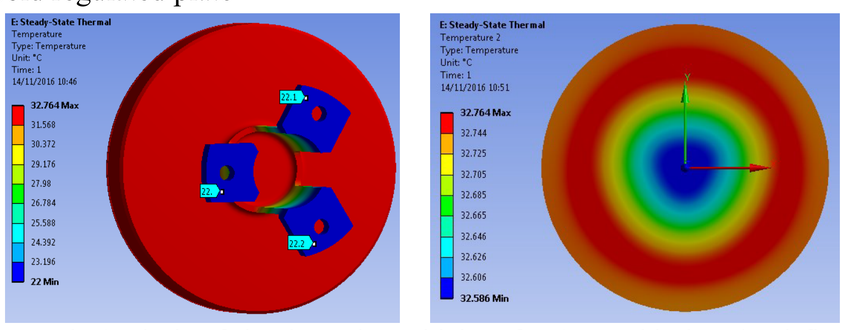
Diffraction limited (10 µm pixels) in FUV. Defocus and astigmatism compensated by refocalization (MTF min: 0.3).

Decentering/Tilts M1/M2: ±10µm - ±10 arcsec. Polishing: 3 nm RMS.

SiC Mirrors in SiC Design and Thermal Modelling



M1 and M2 "Mushroom" configuration to ease flux transfer (M1 receive 1400 W/m² and M2 3000) to cold regulated plate



Example:Analysis of the thermal sensitivity of M1 to cold plate (to define regulation) to varying temperatures, or planarity at the interface (here +/- 0.1° compared to 22° nominal). Deformation up to 9 nm but only **0.57 nm after refocus**. Mirror at 32° and homogeneous.

Conclusion: Opto-thermo-mechanical analysis of the SiC primary and secondary mirrors of SUAVE (M1 & M2) in its nominal orbit and solar flux lightning configuration was carried and showed that even in extreme conditions peak-to-peak surface error of the mirror stays in within prescriptions.

Conclusion

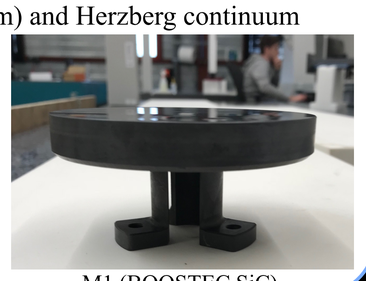
SUAVE is a novel disruptive far UV imaging solar telescope for Lyman Alpha (121 nm) and Herzberg continuum (200-220 nm) using SiC mirrors for long duty cycle (> 6 years) since:

- no coating (no degradation of coatings)
- thermal conductivity and homogeneous -> heat evacuation
- reflect 40% in UV and 20% in visible -> filters are preserved

Thermally optimized configuration with:

- off-axis mirrors (no central obscuration, flux homogeneity minimizing thermal gradients, secondary preserved from direct light: easier heat extraction)
- no insert on mirrors no (distortion) since of "mushroom" type

Breadboard under realization (thermal/optical tests early next year on the M1 SiC/CVD mirror and its support/interface plate).



M1 (BOOSTEC SiC)

Background illustration: Lyman Alpha filtregram obtained in 1979 during the first rocket flight of the Transition Region Camera (TRC) and yet having the best spatial resolution (1 arcsec) for a full disk Lyman Alpha image of the Sun.