The ALTIUS System Performance Simulator

End-to-end Performance Simulation of the ALTIUS Limb Sounder Spectrally Tuneable Optical Imaging System

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ABSTRACT

ALTIUS will be ESA's next limb-sounding mission for operational ozone monitoring. The space segment is foreseen to be based on the flight-proven PROBA platform, and an innovative instrument that will image the atmospheric limb at tuneable wavelengths simultaneously in its ultraviolet, visible and near-infrared channels, between 250 and 1800 nm. The spectral tuning is achieved thanks to Fabry-Perot interferometer and acousto-optical tuneable filters technologies.

The System Performance Simulator (SPS) described in this paper has been developed in a standardised and fully modular framework, inspired by the ESA OpenSF framework but implemented within the MATLAB environment. Its overall architecture and features are described for each module: (1) scene stimuli (simulating the spectral radiances at the aperture of the instrument), (2) geometry (simulating the spacecraft state), (3) instrument (simulating the electro-optical behaviour of the instrument), (4) platform (simulating the ancillary data generation), (5) L0 processor (raw data formatting), (6) L1 processor simulation (radiometric data correction and geo-referencing), and (7) performance assessment modules (performance assessment and verification based on the generated data up to level 1). Their modularity allows both the update of any parameter of the models and the re-use of modules by external parties. Moreover, the framework can be easily adapted to different missions and applications.

The simulation of data generation - up to level 1- and the associated temporal, spectral, radiometric and geometric performance assessment can be conducted in a variety of different observation modes such as: limb scattering (limb sounding, tomography), occultation (solar, stellar, lunar or planetary) or even Earth observation (geographic pointing, scanning) geometries.

The Simulator represents a powerful tool supporting the overall system (payload, platform & ground processing) specification and design by sensitivity analyses, which are enabled thanks to the extensive amount of parameters and scenarios that can be simulated and to the high efficiency implementation.

The System Performance Simulator will be integrated, thanks to its modularity, with a future level 2 processor prototype into an End-to-End Simulator for the ALTIUS System.

Keywords—*System performance assessment, end-to-end simulation, Acousto-Optical Tuneable Filters, Fabry-Perot interferometer, limb sounder, ozone monitoring.*

INTRODUCTION

Every orbit, the ALTIUS satellite (Fig. 1) will repeat series of observations of the Earth's atmospheric limb (Fig. 2) in scattered, solar-, and stellar occultation geometries thanks to its instrument (Fig. 1), which is capable of acquiring them at tuneable wavelengths simultaneously in multiple spectral bands [1, 2, 3, 4, 5, 6, 7, 8, 9, 10].

The data, once retrieved, will be processed by the ground segment to determine the profile of ozone and other species with a high vertical resolution and medium horizontal resolutions, which is the primary scientific mission objective of the ALTIUS mission (Fig. 3) [11, 12, 13, 14, 15, 16, 17, 18].

The ALTIUS System Performance Simulator (SPS) is the software tool that was developed to support the top-down system design by allowing a bottom-up verification of its complex performance requirements (Fig. 4).

Particular attentional was paid to the modelling of the rather unconventional ALTIUS instrument. The instrument consists in three independent channels being a UV (250–370 nm), a VIS (440–800 nm) and a NIR-channel (900–1800 nm). All three channels include reflective optics built on the same layout: a long front baffle to reduce out-of-field straylight, a mechanism to allow switching between 2 or 3 different observation modes, front-end optics, spectral tuneable filter, back-end optics and focal plane assembly containing a detector. The VIS and NIR tuneable filters are Acousto-Optical Tuneable Filters (AOTF), whilst the UV is a Fabry-Perot Interferometer. The mechanisms allow the insertion of neutral density filters to allow solar occultation measurements, and in the UV channel, an extra mirror that will deviate the light path to perform stellar occultation measurements.

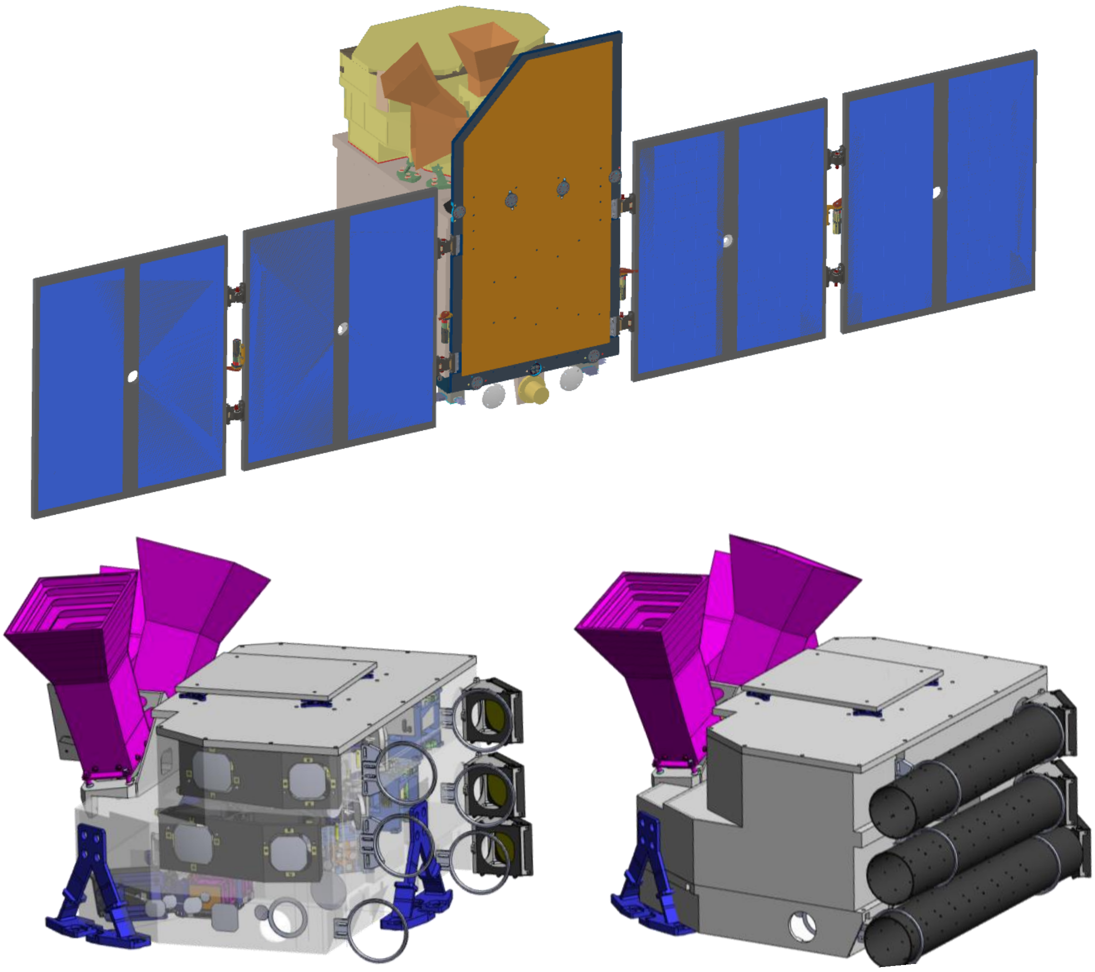

Fig. 1: Representations of the ALTIUS satellite (top image) and its instrument, alone (bottom image). The instrument is mounted on top of the P200 platform, and looking to the right (top image). The 3 channels' baffled apertures are overlapping each other, with the 4th aperture at the bottom being used in stellar occultation only.

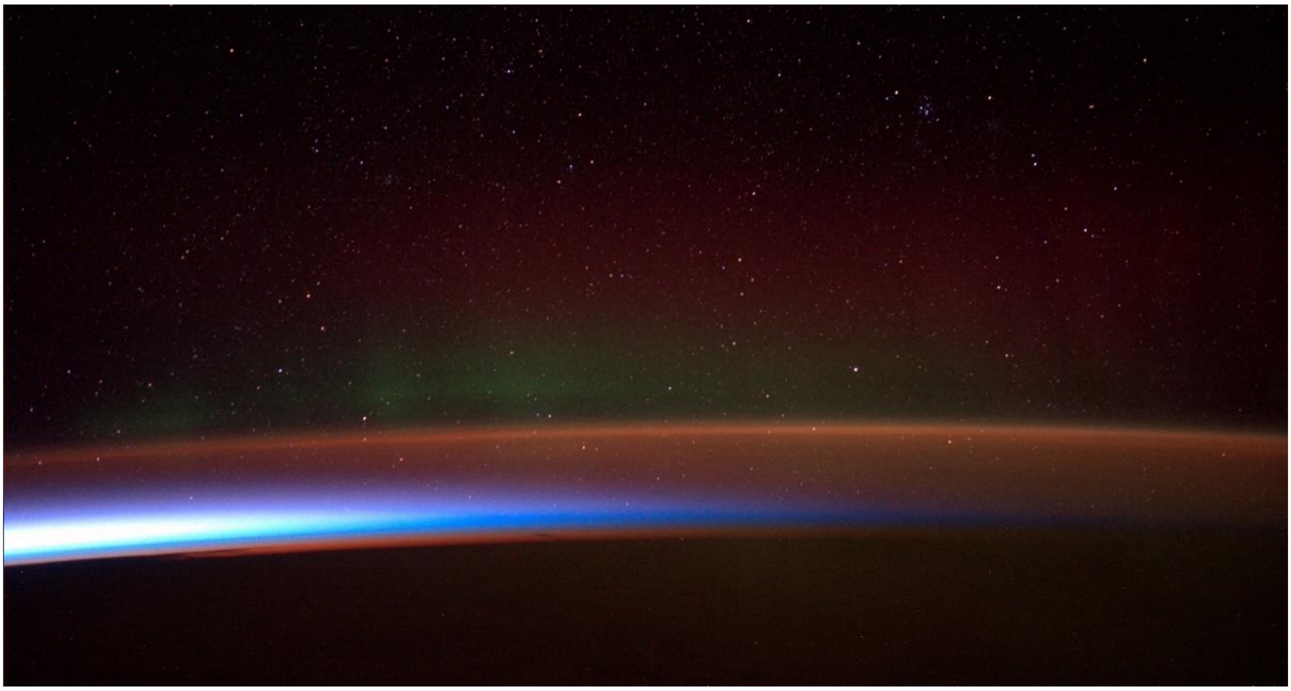

Fig. 2: Antarctic aurora, photographed by ESA astronaut Alexander Gerst *(©2014 ESA, CC BY-SA 3.0 IGO)*

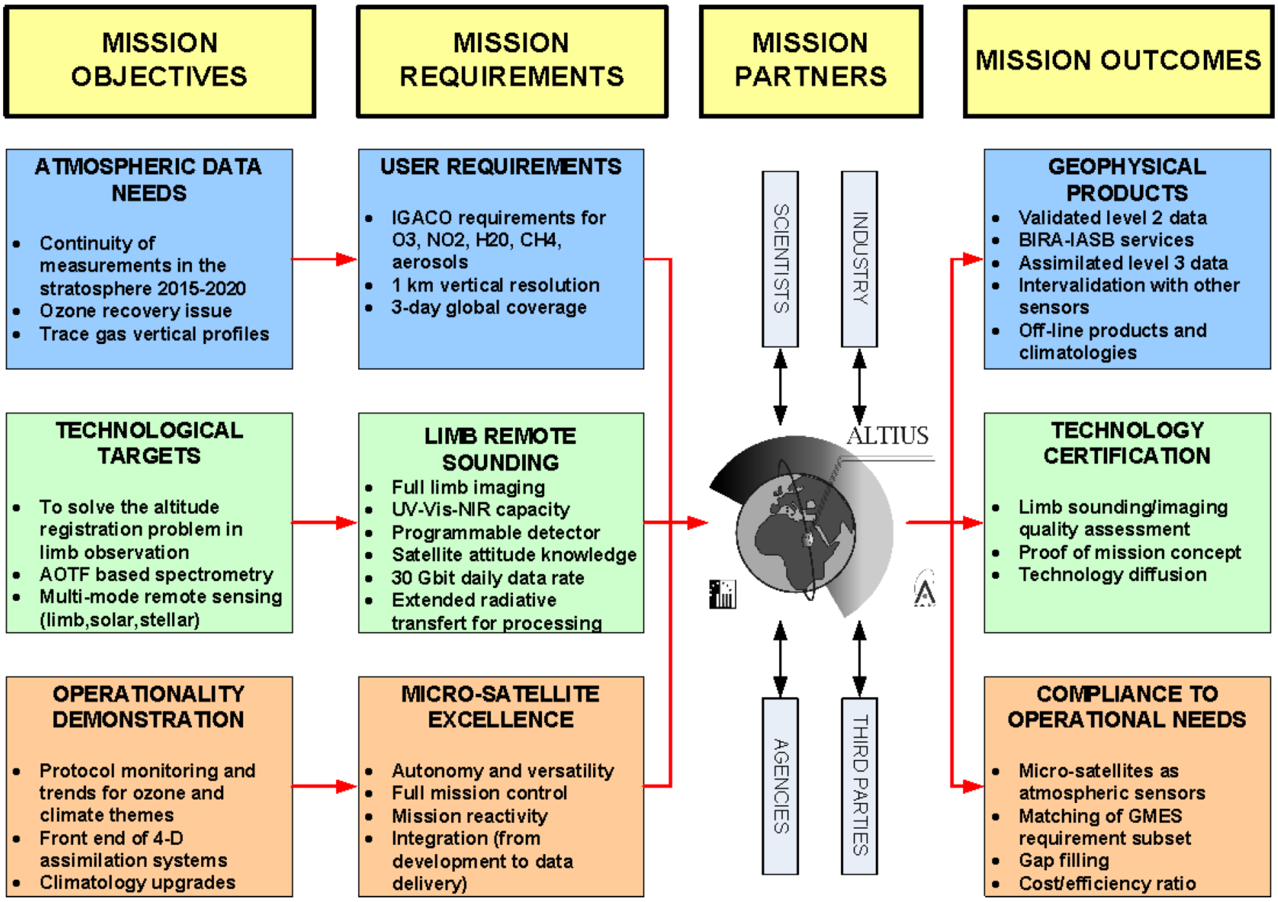

Fig. 3: The ALTIUS mission in a nutshell (*Courtesy of BIRA-IASB*).

SOFTWARE PROCESSOR MODEL

The SPS software has been developed with an approach similar to the one promoted by the ESA OpenSF initiative [19], namely where an orchestration framework invokes a number of modules sequentially (Fig. 6, Fig. 7), which proved to be well adapted to this project where different modules are being developed independently by different parties. The input interfaces are under the responsibility of the module's developer, while the outputs are either generic (e.g. log files) or themselves inputs to other modules. The netCDF file format was used extensively and also proved to be a good choice, as these files are self-explanatory and do not require elaborate documentation for their formatting.

The different modules, as presented in Fig. 7, are the following:
1. **PSM**: Platform Simulation Module
2. **SGM**: Stimuli Generation Module
3. **ISM**: Instrument Simulation Module
4. **SSM**: Satellite and on-board data generation Simulation Module
5. **L0PP**: L0 Processor Prototype
6. **L1PP**: L1 Processor Prototype
7. **PAM**: Performance Assessment Modules

ALGORITHMIC THEORETICAL BASELINE

The SPS mimics the actual architecture and data flows of the ALTIUS system, as represented in Fig. 5. Observation requests are defined by the user to be acquired at particular times, in the specified attitude and acquisition modes, at the required wavelengths. The orbit and attitude of the satellite are determined, and the scene stimuli (spectral radiance) corresponding to the requested acquisitions is generated. An instrument model then generates simulated raw images (based on an extensive set of parameters and variables) that are complemented with ancillary data (such as orbit, attitude, on-board temperatures, etc.). The data is transmitted to the ground segment, and processed into level-0 (L0) and level-1 (L1A, L1B, L1C) data. Ultimately, the data is post-processed to assess the system performance at various levels. The following subsections provide additional details regarding each module identified in the previous section.

Platform Simulation Module

The PSM simulates the state of the satellite over time: orbit (position, velocity), attitude (orientation, angular velocity), temperatures (based on available thermal analyses), *etc*. This information can be available in 3 different forms: true value, estimated value and, when applicable, desired value. As an example, the estimated state as determined by the system is generated, and can be compared with the true state to determine the estimation error (AKE), while the desired state can also be compared to determine the control error (APE).

Stimuli Generation Module

The stimuli generation module determines the spectral radiance at the entrance of the instrument for any type of scene: atmospheric limb, Sun, stars, planets or Moon. Composite scenes (such as the limb with the Sun and other stars in the background) can also be generated. Both point (irradiances) and 2D (radiances) sources are supported.

Instrument Generation Module

The instrument model is a spatial, spectral, radiometric and temporal representation based on a comprehensive set of parameters that can be easily updated based on the best knowledge of the instrument available at that time. It efficiently simulates the acquisition of raw data thanks to extensive spatial and spectral convolutions and comprehensive electro-optical noise modelling.

Satellite and on-board data generation Simulation Module

The science data is associated with the relevant ancillary data available on-board the satellite before being transmitted to the ground. The tool allows the simulation of physical link errors before being processed on ground.

Level-0 Processor Prototype

In the L0PP, the data as received by the ground segment is decoded and a first set of ground-generated ancillary data is appended to it to allow its processing by the level-1 processor.

Level-1 Processor Prototype

The data is radiometrically corrected (L1A) and georeferenced (L1B). The data can also be reduced (L1C).

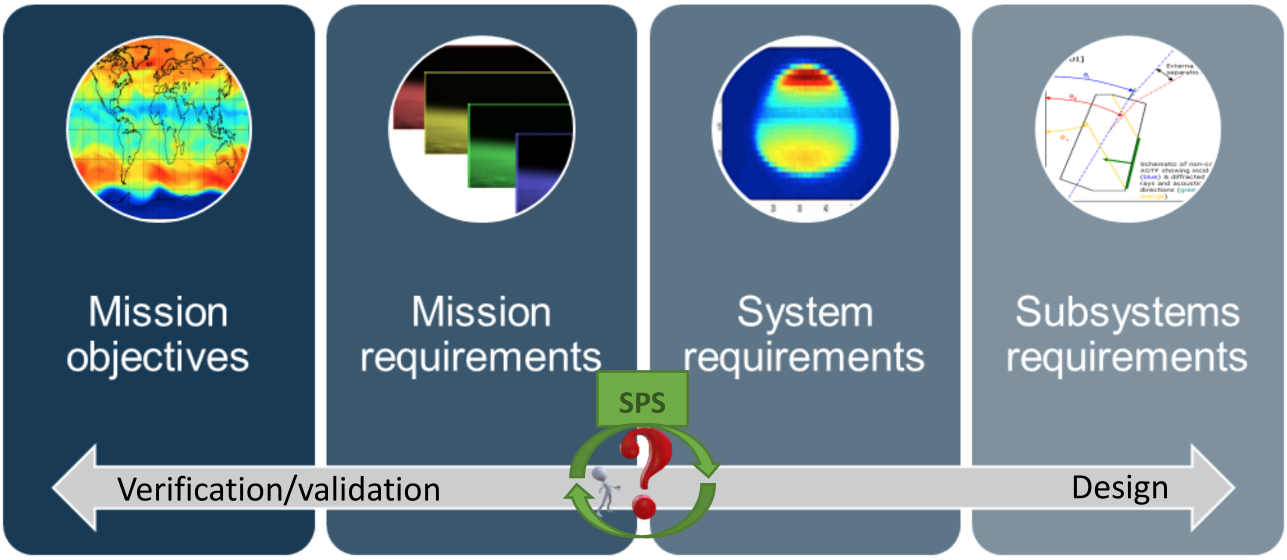

Fig. 4: Top-down design versus bottom-up validation.

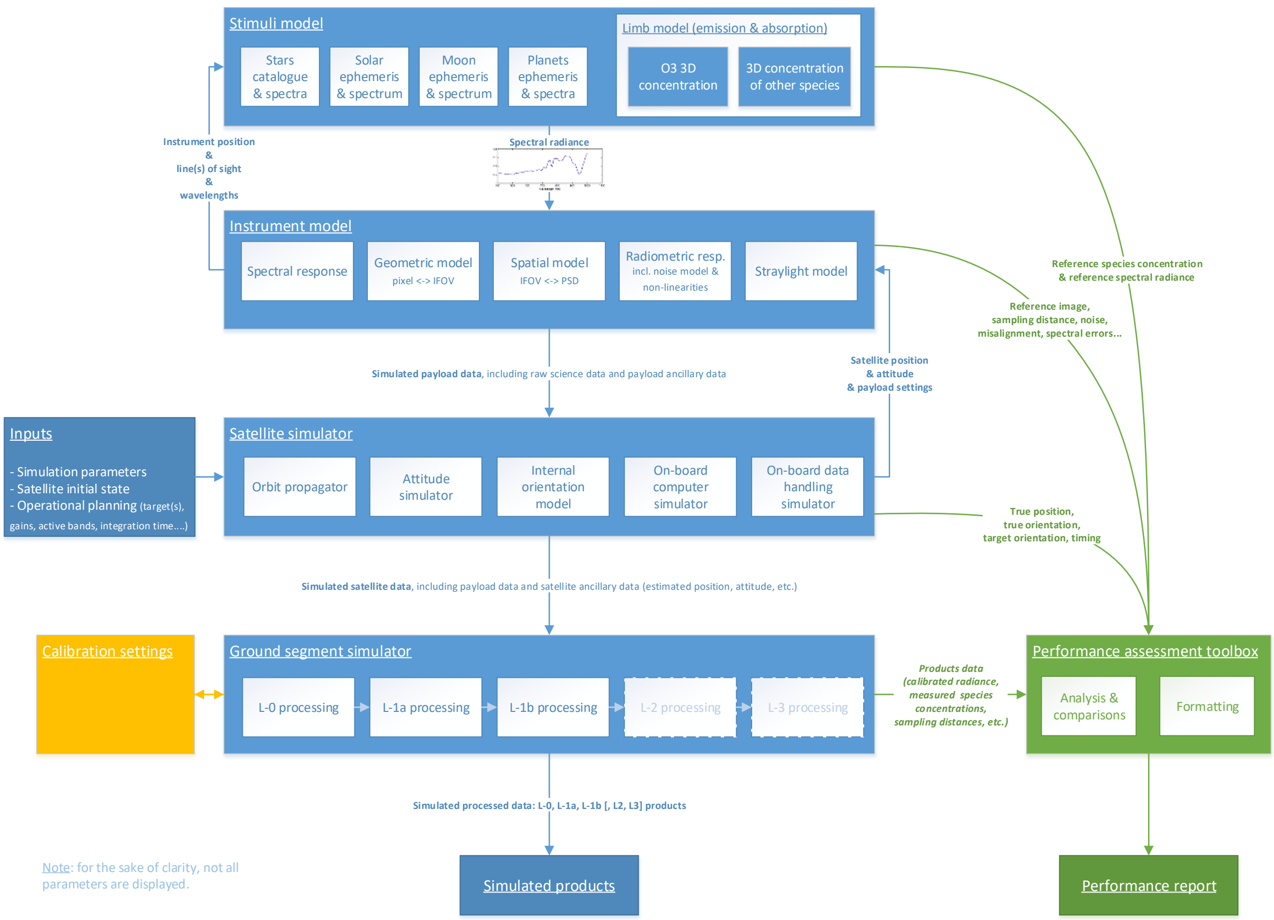

Fig. 5: SPS algorithmic behaviour, mimicking the actual space system architecture. The performance assessment modules (in green) can make use of all the available data to determine any system performance indicator.

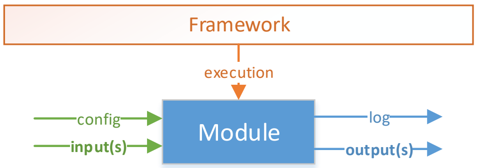

Fig. 6: Generic module interface.

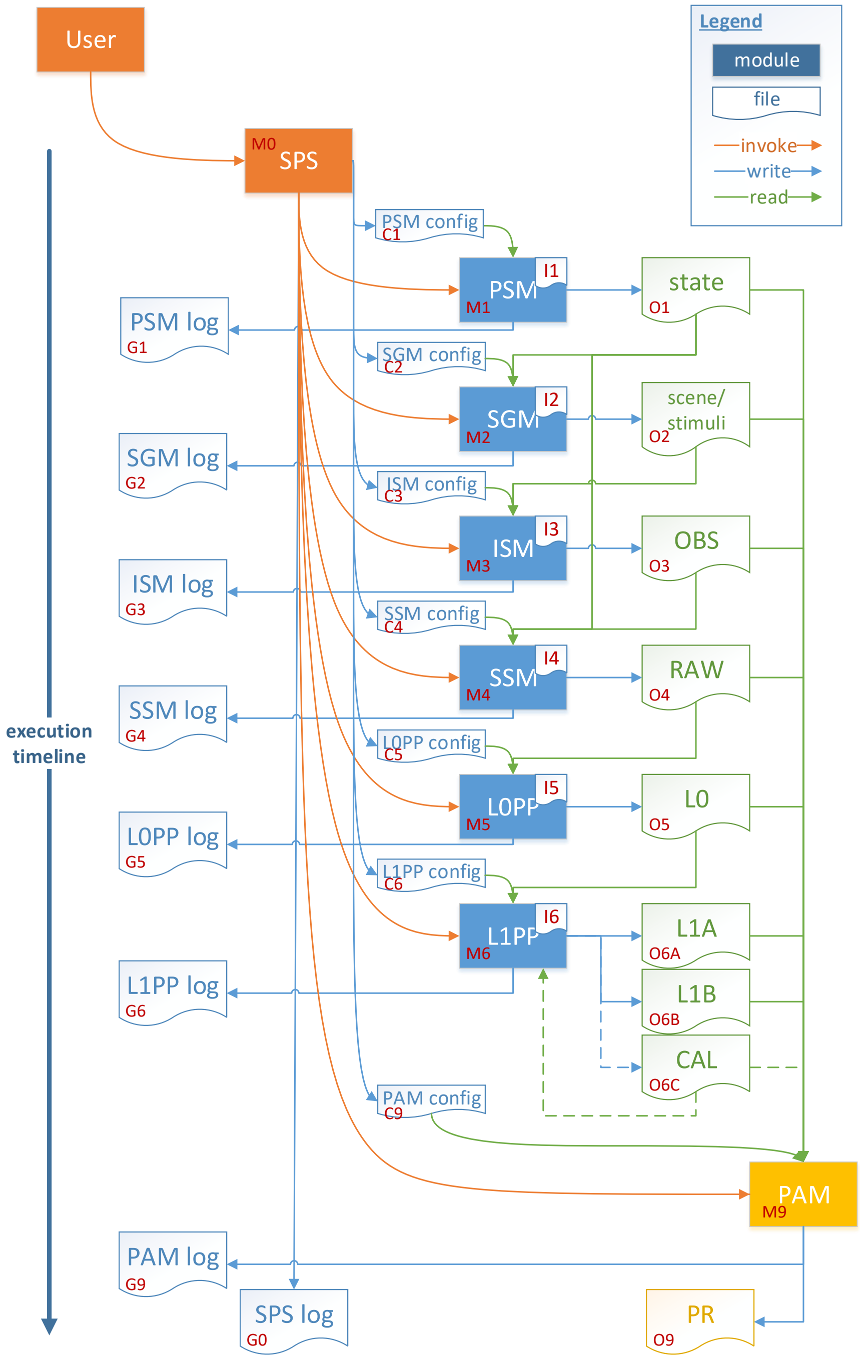

Fig. 7: SPS orchestration framework.

PERFORMANCE ASSESSMENT

Typical raw images are represented in Fig. 8. Ultimately, the ALTIUS system performance, defined by various performance indicators, can be checked automatically against the system performance requirements (SRD). A unique script can be executed to check all defined performance requirements one by one and summarised in a report specifying the result (compliance or non-compliance) and the obtained performance.

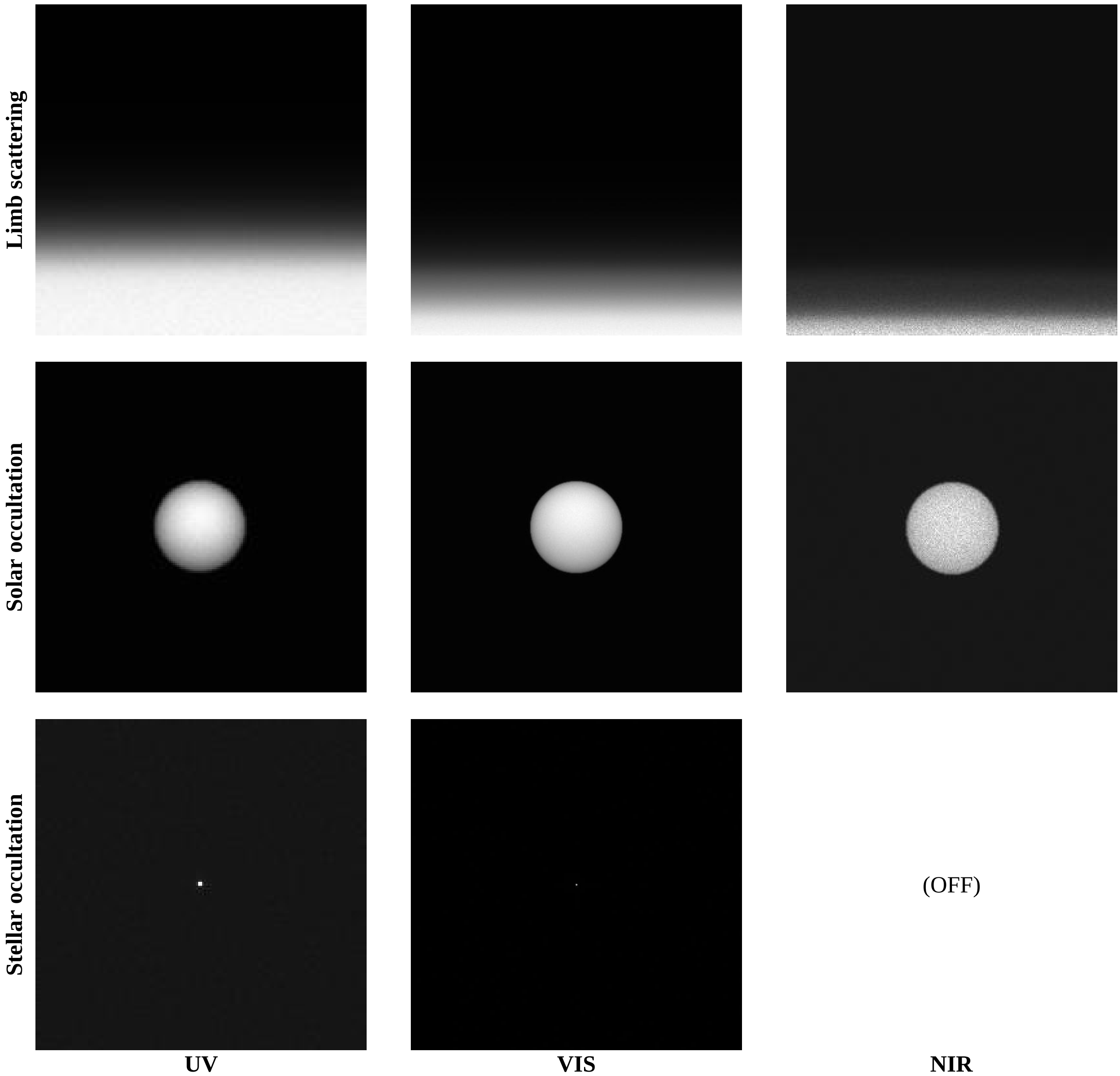

Fig. 8.:Typical RAW images acquired in different observation modes at arbitrary wavelengths.

CONCLUSIONS

The ALTIUS System Performance Simulator proved to be a critical tool for mission success, upon entering phases B2/C/D. It was developed following a standardised approach that will allow its use and continuous update throughout the mission, during the design phase as a system performance verification, sensitivity analysis and optimisation tool, during the development as an enabler for ground processors prototyping. Its generic architecture allows its deployment starting in the early stages of new science, Earth observation, and space exploration missions, at the benefit of more efficient space systems design, development, and verification.

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