PROBA-V: AN OPERATIONAL AND TECHNOLOGY DEMONSTRATION MISSION – RESULTS AFTER COMMISSIONING AND ONE YEAR OF IN-ORBIT EXPLOITATION

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ABSTRACT

Proba-V, the third mission of ESA's Programme for In-orbit Technology Demonstration (IOD), conceived and developed following the footsteps of its predecessors, Proba-1 and Proba-2, is an operational mission based on a small, high performance satellite platform and a compact payload, whose main aim is the continuation of the SPOT/Vegetation programme, now planned for decommissioning.

Successfully launched by the ESA VEGA launcher in May 2013, it has completed its commissioning and the full calibration of platform, main instrument and additional payloads and is, since last October, fully operational.

The development of the Vegetation Instrument, the main satellite's instrument, required the use of a number of innovative technologies, in order for it to be compatible with a small platform's resources, while at the same time being able to enhance Vegetation images' resolution performances from 1km to 100m at Nadir.

Besides its main instrument, Proba-V embarks a number of advanced technologies, some of which represent first-ever in-space applications, integrated into its baseline platform's design, for the enhancement of the its capabilities, flexibility and robustness, in order to meet the mission's stringent objectives.

Additionally, Proba-V embarks five technological payloads providing early flight opportunities for novel instruments and space technologies:

- ADS-B: first-ever in-space demonstration of this air traffic surveillance system,
- An X-Band transmitter based on Gallium Nitride RF power amplifier,
- EPT: a new technology application for advanced radiation monitoring,
- HERMOD: a high density fibre optics connector's demonstration device,
- SATRAM: a miniaturised radiation monitoring sensor.

This paper will present the ESA approach to the In-Orbit Demonstration programme, and will highlight the Proba-V mission, focusing on the new technologies flying on-board, their in-orbit initial results and achieved performances.

1 INTRODUCTION

1.1 Mission Background and Objectives

The Proba-V mission has been developed in the frame of the In-Orbit Demonstration activities of the European Space Agency, funded through the General Support Technology Program (GSTP). The main objective of Proba-V is to be an operational mission to continue the data acquisitions of the Vegetation Instruments on-board the CNES SPOT 4 and SPOT 5 satellites in activity since 1998.

In the second half of the last decade, in fact, the large community of over 10.000 institutional, scientific and commercial Vegetation data users distributed over the entire World expressed the need to continue, without interruption, the acquisition of Vegetation data after the de-commissioning of SPOT 4 and SPOT 5 foreseen for mid-2014. The main domains of applications interesting the Vegetation community are:

- Land use and coverage and its associated changes,
- Vegetation behaviour in response to strong meteorological events (e.g. severe drought) and climatic changes (long term behaviour of vegetation),
- Disaster management (detection of fires and surface water bodies),
- Biophysical parameters for the development of models devoted to water budget and primary productivity analysis (agriculture, ecosystem vulnerability, etc.).

Proba-V had then been identified as a “gap filler mission” between the decommissioning of the Vegetation instrument on SPOT 5 and the start of operations of Sentinel-3, providing the necessary risk reduction of data availability in case of gap between these two missions.

With decisive support from the Belgian Scientific Policy Office, Proba-V Phases B, C and D activities were initiated in early 2009, with an industrial consortium composed by Belgian, Canadian and Luxembourg companies, under ESA contract for the development of the full end to end mission (Flight, Ground and Users’ Segments).

Beside the principal mission’s objective, Vegetation data acquisition, and following the footsteps of its predecessors, Proba-1 and Proba-2 [1], [2] and [3], Proba-V has also been, since its initial design phases, required to fly a number of innovative technologies on-board the platform, and to host promising pioneer payloads demonstrators. In total five technological payloads positions were reserved on-board Proba-V for these technology demonstration payloads.

As a consequence, Proba-V has the unique objective to simultaneously be an operationally and technologically demonstrative mission.

1.2 Mission Requirements

The continuation of the SPOT Vegetation (SPOT/VGT) data acquisition has driven the requirements for Proba-V mission. Compared to SPOT/VGT, the requirement to use a small satellite recurring from Proba-2 has forced the technological choices for the design of the Vegetation Instrument (VI) to be flown on-board Proba-V.

The following main requirements have thus been derived for the mission:

- The Proba-V mission shall be operational before the decommissioning of the SPOT 5 Vegetation Instrument,
- The Proba-V mission shall be operational for 2.5 years after its launch, with the possibility to extend its mission to, at least, 5 years,
- The Proba-V mission shall be based on a small satellite based on the ESA Proba platform,
- The Proba-V mission shall embark a multispectral imager covering the blue, red, near infra-red (NIR) and short wave-infrared (SWIR) bands with the same definition as the SPOT/VGT instrument,
- The Proba-V Vegetation Instrument (VI) shall provide the same 2-daily global Earth coverage

of the land surfaces from +75° latitude North to -56° latitude South at an equivalent spatial resolution (1km) of the SPOT 5 VGT instrument. Moreover, as expressed by users' community, the spatial resolution should (as a goal) be improved up to 300m over the full swath,

- The Proba-V orbit shall be chosen to provide similar illumination conditions as SPOT/VGT orbit, i.e. with a range from 10:30 to 11:00 AM local time of the descending node (LTDN),
- The Proba-V mission shall be designed to be as autonomous as possible, to reduce overall mission costs, adopting similar and improved mission operation concepts already adopted for Proba-1 and Proba-2,
- The Proba-V mission shall provide five positions on-board to host technology demonstration payloads to be decided at later stage of the mission's development process.

The above mission requirements have required the adoption of innovative and challenging design choices that will be explained in the following sections.

1.3 Mission Design

The Proba-V mission, using an approach common to all previous Proba missions, has been conceived from the beginning as an end-to-end mission, involving all mission elements in the evaluation of design options, starting from the early project's development phases. Figure 1 below shows the various elements of the Proba-V mission and their interactions.

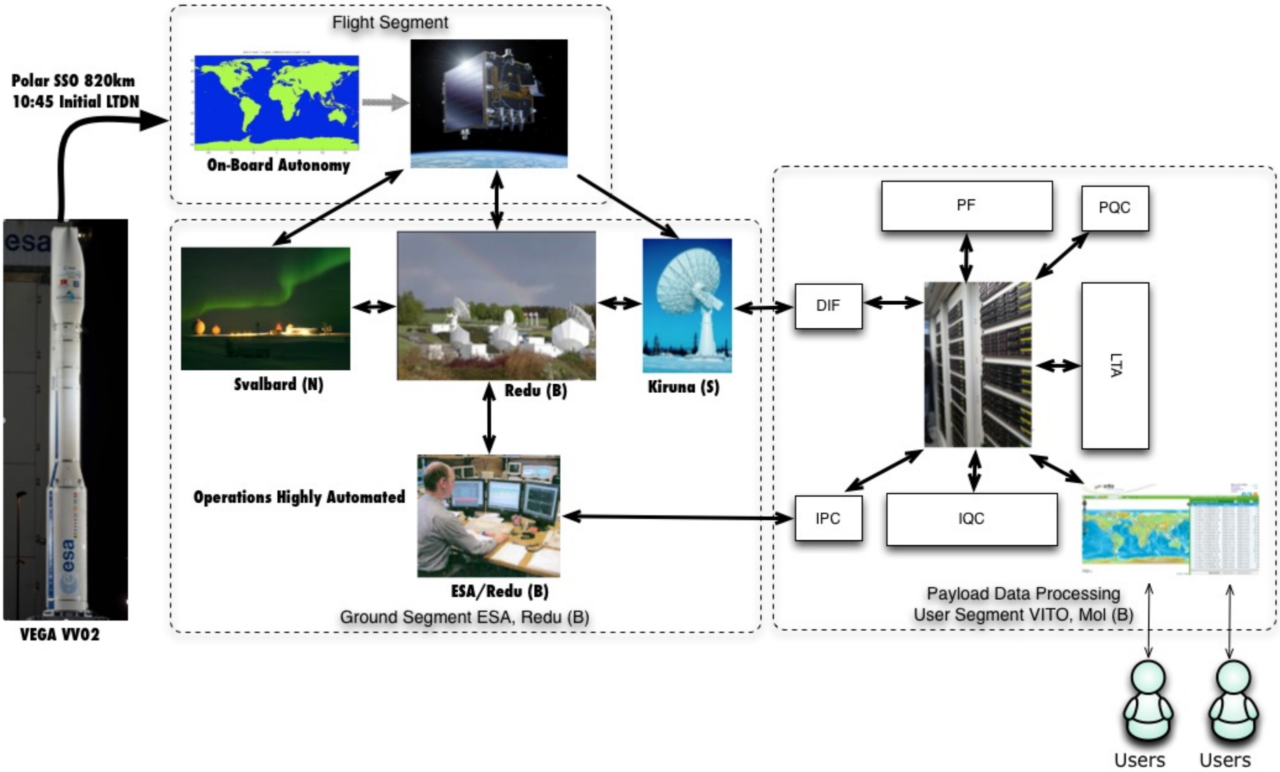

Figure 1: Proba-V Mission Elements

Flight Segment

The Proba-V flight segment, developed under Prime contractorship of QinetiQ Space nv (QS) (B), is composed of the Proba platform, the Vegetation Instrument (VI) and the technological payloads.

Proba-V operational orbit is comparable to the SPOT 4/5 ones, i.e. 820 km circular polar Sun-synchronous orbit, with a LTDN of 10:45 AM at launch time. The orbital parameters at injection have been optimized to remain within the LTDN required interval between 10:30 AM and 11:00 AM during the 5 years (extended) mission's lifetime, with no need for orbit maintenance.

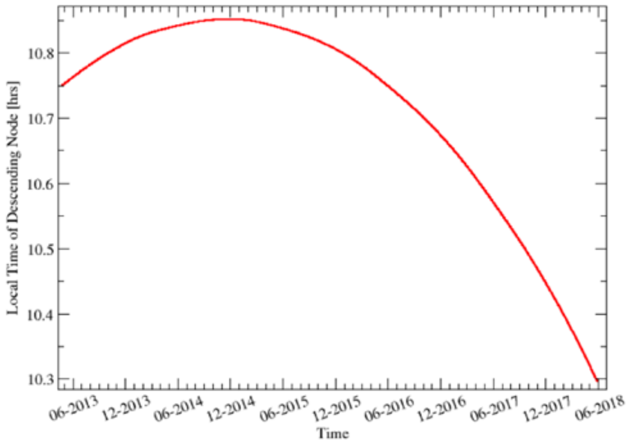

Figure 2: Proba-V LTDN Drift Predicted after Launch

Ground Segment

Located at the ESA Redu Ground Station, in Belgium, the Mission Control Centre (MCC), developed by Spacebel (B) under the responsibility of QS, is in charge of the satellite commanding and control through up to 3 S-Band communication links per day.

Thanks to the extremely high level of automation implemented in the Ground Segment's functionalities, most of the passes can be realised unmanned, allowing to require station manning for the monitoring of the satellite only during normal office hours, while at the same time maintaining a level of availability required by the operational nature of the Vegetation mission.

Beside the MCC, the Ground Segment is composed of the Redu Proba antennas' system, complemented, during the Launch and Early Operations Phase (LEOP) and the early part of the system commissioning, by antennas in Kourou and Svalbard, for contact opportunities' increase.

The Vegetation data are downlinked, in X-Band, through a network of Data Retrieval Stations' (DRS) antennas located at high Northern latitudes, at a pace of 10 passes per day. For this purpose, Kiruna (Sweden) and North Pole (Alaska - USA) stations are used to provide the necessary contacts each day. The downloaded data, in the order of 25 GBytes each day, are then automatically transmitted over a normal Internet link to the Payload Data Processing System, located at Vito, in Mol (Belgium) where the mission's User Segment (US) is located, for further processing.

The data related to the technological payloads are instead downlinked, together with the satellite housekeeping telemetry, on the S-Band channel to Redu. The data are de-commuted at the MCC and placed automatically and securely on a dedicated web server, where the various payloads' providers, in charge of the next level of processing, can access their payload's data together with the necessary platform ancillary information.

User Segment

Upon reception of the downlinked Vegetation data, the User Segment (US) [4], developed by Vito (B), is in charge of de-commuting and processing them, up to the final product (from level 0 up to level 3).

The data distribution and archiving facilities, as well as the Image Quality Centre (IQC), permanently checking the distributed product, are also located at Vito in Mol.

To support the data products' quality, regular calibration campaigns are programmed in the User Segment, for autonomous on-board execution. This process is initiated by the US' operator through a specific tool, called Instrument Programming tool, allowing to schedule calibration campaigns and to program Vegetation instrument's settings. The Instrument Programming tool allows to automatically transmit to the MCC any new request. In turn, the MCC generates autonomously a new schedule of activities to be uplinked on-board the satellite at the next ground pass.

Launch and LEOP

Proba-V was launched from Kourou, as main passenger of the second ESA Vega launcher's flight, on May 7th, 2013 at 02:05 UTC, and precisely injected into its operational orbit 55 minutes later, over Perth, Australia.

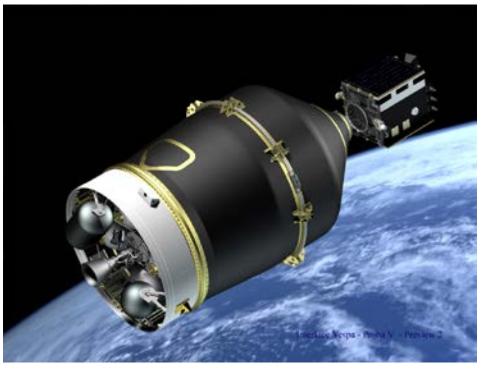

Figure 3: Proba-V Released from Upper Stage of Vega/VESPA

Following first contact about 25 minutes later over the Kourou ground station, the LEOP was performed flawlessly and declared completed within 5 orbits, after confirmation that the flight segment was in stable and nominal conditions.

The first Vegetation Instrument image, visible in Figure 4, was acquired on May 17th, 2013 over Brittany France.

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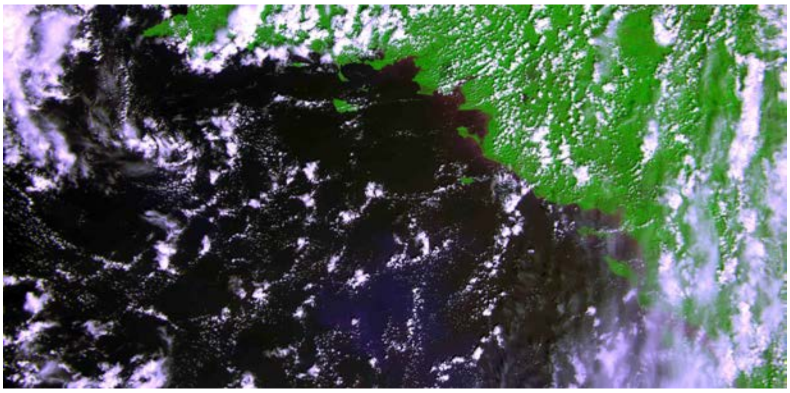

Figure 4: Proba-V First Uncalibrated Vegetation Image

2 THE PROBA-V PLATFORM

Based on the heritage of Proba-1 and Proba-2, the Proba-V platform has inherited many technological choices of its predecessors, however improving a number of elements, as required to achieve the Proba-V mission's demanding objectives.

Compared to the Proba-2 platform Proba-V has been enhanced in the following areas:

- Total satellite launch mass has been incremented from 120 kg to 138 kg, providing allowances for additional payload mass,
- The total power generation has been increased from 120W to 150W, with additional solar array surface and with the adoption of improved triple junctions GaAs cells with an efficiency up to 28%,
- The attitude guidance and control modes have been augmented with the introduction of a Geodetic pointing mode with Yaw steering, and of a magnetic-based 3 axes stabilised Bdot attitude control mode [5], for use in the system safe mode,
- The on-board autonomous navigation features of the satellite have been tuned for Proba-V with the introduction of, between other modules, full autonomous on-board activation and overall management of the Vegetation Instrument, and of forbidden attitudes' prediction and avoidance modules [6].
- An innovative mass memory module, based on flash technology and allowing storage of 100Gbit of payload data, has been added to the on-board computer (ADPMS).
- The downlink capacity has been improved from 2Mbit/s up to 80Mbit/s, with the increment of

the S-band link, used for platform HK TM downlink and TC uplink, with an X-Band transmitter, now standard for the Proba platforms.

2.1 Structure

The Proba-V structure (Figure 5), conceptually very similar to Proba-1 and Proba-2's ones, is based on a load-carrying H-shaped inner core in aluminium honeycomb panels and on an outer shell made of Carbon Fibre Re-enforced Polymer (CFRP) honeycomb panels. The bottom board, interfacing with the launcher and carrying the load to the main body of the satellite, is in milled aluminium. The solar panels are body mounted on three of the outer panels.

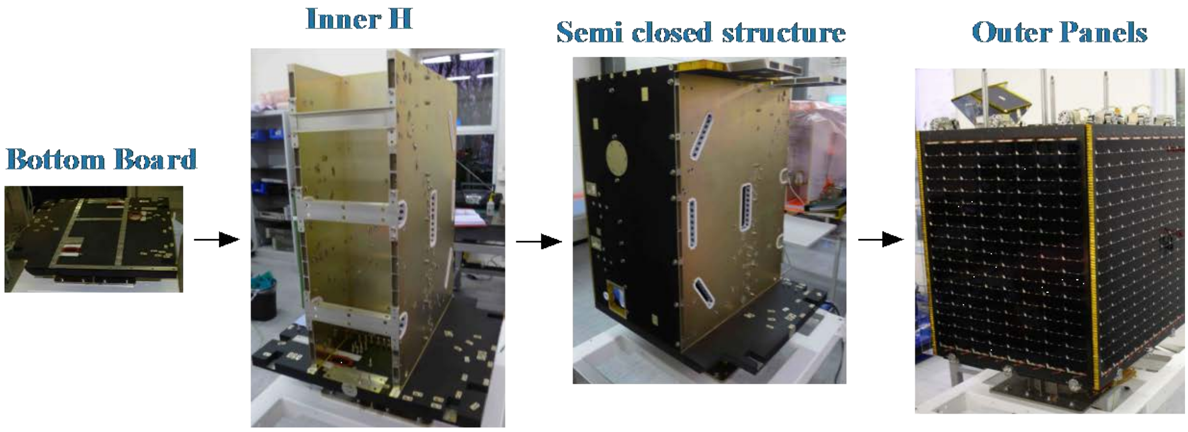

Figure 5:Proba-V Structure at Different S/C Integration Stages

All satellite's units and equipments are mounted on the inner H-core and the top panel. The main advantage of the above concept being the excellently stable thermal environment provided to the various equipments and the high accessibility to all units during the satellite's integration phases.

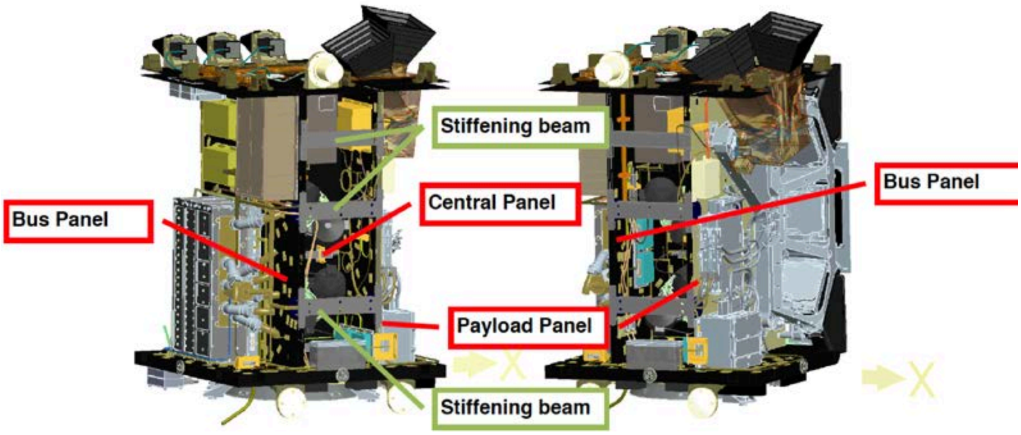

Figure 6: Proba-V Equipment's

2.2 Avionics

The Proba-V avionics system and bus are built around the Advanced Data and Power Management System (ADPMS) developed in parallel to Proba-2 by QinetiQ Space nv (QS). ADPMS is combining in a single box the power conditioning, the power distribution, the data management, the interface to all satellite equipments and the mass memory of the platform.

This fully internally redundant unit, whose data processing module is based on the LEON II processor, ensuring the complete computing power of the satellite with ample margin with respect to platform and payload needs, is capable of conditioning and distributing up to 300W to the satellite, and is interfacing with the rest of the satellite's equipments through serial communication lines and discrete input/outputs analogue and digital channels. The ADPMS is also de-commuting the telecommands from the S-Band receivers and formatting the telemetry and data for the S-Band and X-Band transmitters. Its mass memory is based on NAND Flash cubes providing up to 100Gbit of storage place for the Vegetation Instrument data. The specific organisation of ADPMS allows to concentrate state of the art avionics within a single box and allows an extreme performing and robust avionics on a small platform.

Currently, ADPMS has cumulated more than 5 years of in orbit operation on-board Proba-2 and Proba-V.

The rest of the satellite avionics, fully redundant at unit level, is composed of:

- A set of redundant Phoenix GPS receivers, delivered by DLR (Germany),
- An internally (cold) redundant star tracker fitted with two (hot redundant) optical heads, from DTU (Denmark),
- Three internally redundant magnetotorquers, organised in an orthogonal configuration, manufactured by Zarm (Germany),
- Two 3-axes magnetometers (in cold redundancy) from Billingsley (USA),
- Four (including one redundant) reaction wheels, in a tetrahedral arrangement, supplied by Rockwell Collins (Germany),
- An internally redundant S-Band transceiver, with hot redundant receivers and cold redundant transmitters, from STT (Germany),
- Two (cold redundant) X-Band transmitters with variable output power set point, developed with Syrlinks (France), and based on large use of COTS (fully commercial parts - upscreened) components, having their maiden flight on Proba-V.

2.3 On-Board Software

The ADPMS LEON II processor is running the on-board software (OBSW), developed by Spacebel (B) around the RTEMS real time operating system and re-using the services already available from the Proba-2 OBSW, as well as large number of units' managers. While it is estimated that 90% of the OBSW code is re-used from Proba-2, critical modules, like for example the software mission manager and the payload manager, have been however tuned for the mission.

The Proba-V OBSW is fully in line with the ESA Packet Utilisation Standard (PUS), and has been designed and implemented to provide the system with a very high level of on-board autonomy. It is capable of handling the routine mission (nominal observations and calibrations, including all related manoeuvres) completely on-board, only interacting with the ground segment for the downlink of science data and for the acquisition of new on-board activities' schedules. Besides this, a large quantity of possible on-board anomalies can be handled without ground intervention, due to integrated Failure Detection, Isolation and Recovery (FDIR) capabilities, allowing system automatic reconfigurations, to ensure continuity of scientific data acquisitions, as long as a minimum set of required units is available.

The System Modes have been simplified to the maximum extent (Figure 7). The satellite being in most of the time in Nominal Observation Mode except when calibrations of the Vegetation Instrument are required, for which the satellite autonomously enters Calibration Mode. While in system Nominal Observation Mode, however, the platform is autonomously handled by the OBSW, on the basis of inputs generated by the AOCS SW (integrated in the OBSW and developed by NGC - Canada) [7], to optimise on-board resources and performances handling, with autonomous toggling between Geodetic and Sun pointing attitudes to maximise power generation when no VI imaging is requested and with autonomous powering on and off of AOCS units (e.g. GPS) when not needed, for power demand reduction.

Transitions between Nominal Operation and the Calibration modes are performed autonomously by the satellite. As fully autonomous on-board is the handling of the Vegetation Instrument, based on the use of a “Land-Sea Mask”, stored on-board and defining the areas to be regularly imaged on the ground, and the handling of calibration requests and of the related Regions of Interest, on the basis of high level commands issued from the US with the identification of the regions’ limit longitudes and latitudes, and the required calibration type. The OBSW mission manager is then in charge to autonomously schedule them at the best opportunity.

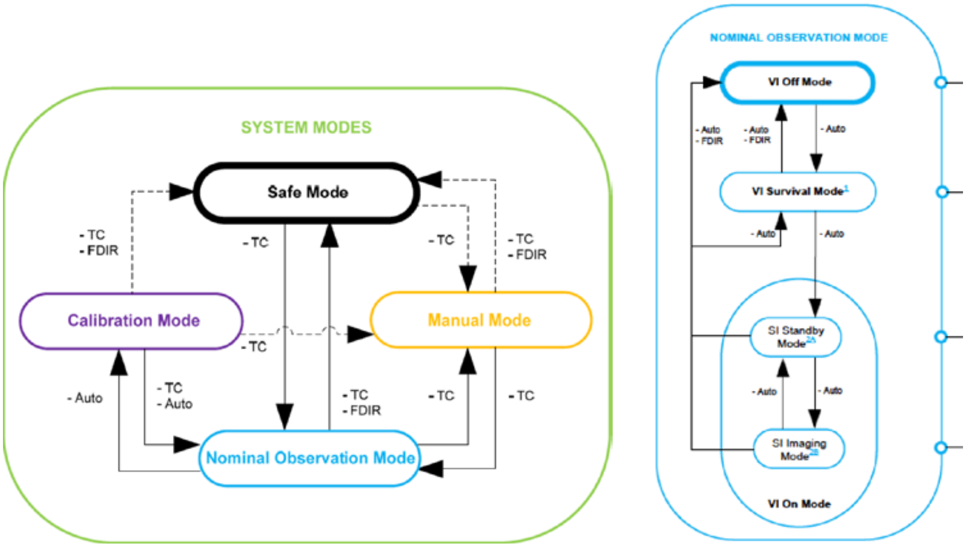

Figure 7: Proba-V System Mode Transition Diagram

2.4 Attitude Determination and Control Accuracies

The stringent Proba-V Vegetation data products geolocation requirements directly transformed into the critical pointing performance requirements specifications to be applicable during VI imaging (i.e. with the satellite in Geodetic mode) listed below:

- Attitude Knowledge Error (AKE): 5 arcsec (95%)
- Absolute Performance Error (APE): 0.1 deg (95%)
- Relative Performance Error (RPE): 80.0 arcsec over 1.5 s (95%)

The actual attitude determination and pointing accuracies achieved in flight by the Proba-V platform’s AOCS system (units and AOCS SW) are listed below:

- Attitude Knowledge Error (AKE): 5 arcsec (95%)
- Absolute Performance Error (APE): < 20 arcsec (95%)
- Relative Performance Error (RPE): < 1.5 arcsec over 1.5 s (95%)

and are, as can be noted, overwhelmingly fulfilling the requirements set in the early project development’s phases.

3 THE PROBA-V VEGETATION INSTRUMENT

The main instrument on-board Proba-V, designed, assembled and verified by OIP (B), is the Vegetation Instrument (Figure 9) [8], a high spatial resolution push broom 4-spectral bands imager with a Field of View (FOV) of 102º, realised with coupling of three identical Spectral Imagers (SI’s) and allowing the daily imaging of the entire Earth land coverage. At the satellite’s 820 km altitude, the field of view allows a swath of 2282 km, with a Ground Sampling Distance (GSD) of 96m at NADIR, to be compared to that of the SPOT Vegetation Instrument, providing a 1km GSD at NADIR.

One of the challenges of the Proba-V VI was to design an instrument capable to fit on a Proba platform and to reduce its consumption to the minimum possible while keeping the image quality requirements equivalent to SPOT Vegetation.

In order to achieve these objectives, two majors technological breakthroughs were needed:

- Design of a very compact optic meeting the performances of SPOT/VGT,
- Design of the instrument based on passive thermal control only, mainly for the SWIR channel.

3.1 Optical Design

The VI optics' basic design concept relies on highly compact Tri Mirror Anastigmats (TMA) telescopes mounted on an optical bench., where all the parts, including the mirrors, are only made from aluminium (Figure 8). In order to keep the optics relatively compact, the large FOV of 102º is realised with the association of three identical TMA's, each having a FOV of 34º.

In the Proba-V VI design, the telescopes' mirrors are mounted directly onto the interconnecting structure, providing a quasi a-thermal system with an increased insensitivity of the optics to thermal deformations, permitting the machining of the various optical elements with exceptionally high accuracy, and allowing easy access during the TMA's integration and alignment process (realised, as well as manufacturing, by AMOS (B)). A challenge in itself has been the manufacturability of the various TMAs' parts, including the mirrors' polishing process (nowadays possible thanks to the single point diamond turning fabrication of aspherical mirrors).

The Focal Plan Assembly (FPA) of each TMA is equipped with a quadri-linear CCD detectors from E2V (F) and a short wave infra-red detector from XenICs (B).

A spectral window is covering the CCD detector, providing the necessary filtering for the two Visual (blue and red) and Near InfraRed bands (VNIR). While the E2V detector is an off-the-shelf detector used in previous space missions, the SWIR detector had to be specifically designed for Proba-V in view of the large number of pixels required to fulfil the swath and GSD requirements. Based on existing detector's design, a mechanical butting of three detectors of 1024 25um pixels (Figure 8) each in a single package solution was selected. The SWIR detectors technology provides with excellent performance around 0ºC.

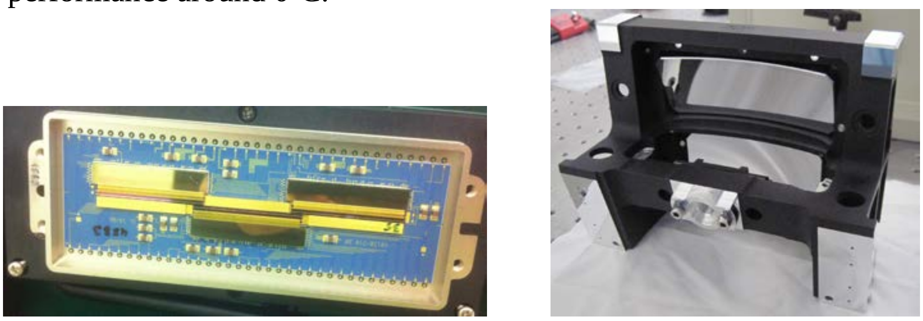

Figure 8: Proba-V XenICs SWIR Detector (left) and TMA (right)

Both the TMA and the SWIR detectors have been pre-developed under ESA contracts within the GSTP program, allowing an early validation of the technological choices.

3.2 Thermal Design

The second challenge for the VI realisation has been the overall payload and system thermal design, requested to rely solely on passive cooling and temperature control to avoid excess power consumption. Here again, a number of design and technical choices had to be made very early in the project, to limit to the maximum possible the effects of thermo-elastic deformations.

Starting at TMA's design level, as mentioned, the a-thermal design allows to reduce the effects of the thermal gradients on the image quality. Additionally, the FPAs mounting on the optics has been realised using iso-static feet, thermally decoupling the FPAs from the optics to the maximum extent. Thermal straps have then been used for heat evacuation from the FPA towards the optical bench.

The optical bench (OBP), presenting a large thermal capacity, is kept at a "constant" temperature (with oscillations in the order of 0.5ºC across imaging sessions, and of less than 1.5ºC across each entire orbit), through a thermal connection to a radiator, accommodated in the platform to face the Earth, beneficiating from a very stable thermal environment. and keeping the overall instrument's temperature steadily around -5ºC without any need for active cooling or thermal regulation.

The entire optical bench, on whom also the star tracker heads have been integrated, is isostatically mounted on one of the satellite internal panels via titanium blades, and the whole VI is wrapped with multi-layer insulation (MLI), to optimise the decoupling of the instrument from the rest of the satellite's thermal and mechanical environment and deformations.

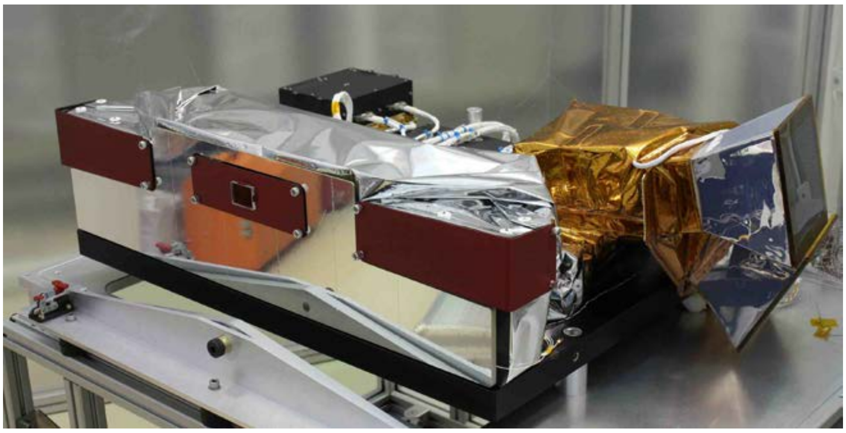

Figure 9: Complete Proba-V VI Assembly

4 THE PROBA-V TECHNOLOGICAL PAYLOADS

Beside operational Vegetation data acquisition, Proba-V main mission objective, the in-orbit technology demonstration objective of the mission had been identified at the start of its development. A survey has then been performed by ESA, to identify candidate units and innovative technologies to be flown for their first time on-board Proba-V, using the additional platform resources remaining available. Accommodation and resources for two technology demonstrators were envisaged at the start of the project. During the project development, however, additional resources became available and were thus reallocated to the accommodation of additional technological payloads. At launch, five technology demonstration payloads were finally embarked.

All the technological payloads have been successfully commissioned and are regularly operated in parallel to the main payload, and have now all reached Technology Readiness Level (TRL) 9.

4.1 GaN X-Band Transmitter

In parallel to the development of an X-Band transmitter based on Gallium Arsenide (GaAs) technology for its RF power amplifier, the development of a similar transmitter based on Gallium Nitride (GaN) technology was started [9]. Indeed, within the Quality Department of ESA, GaN based RF power amplifier technology was identified as a key component technology for space, considering its intrinsic possibilities to be operated reliably at much higher voltages and temperatures than Silicon or Gallium Arsenide, its allowing an increase in communications signal strength without requiring cooling systems, and, in addition, its harder resistance to radiation's effects.

In the frame of a collaboration between the Quality Department and the Proba-V project, Syrlinks (France) was hence contracted to develop a modified version of their X-Band transmitter for small satellites, under development with ESA/CNES funding, with the replacement of its RF output stage with a GaN MMIC produced from an ESA-led European consortium to manufacture high-quality GaN devices for space uses, the "GaN Reliability Enhancement and Technology Transfer Initiative" (GREAT2).

The resulting GaN based X-Band transmitter was introduced in the Proba-V avionics in addition to the two redundant GaAs transmitters already included in the platform's baseline design, providing a triple redundancy for this key unit of the Proba bus, and representing the first flight ever of European GaN space technology.

Today, both the GaN and GaAs X-Band transmitters are regularly used in operations, for the Vegetation data downlink to the DRS ten times a day, with alternation between the two units every second week.

The opportunity provided by Proba-V has allowed to demonstrate in-orbit the performance and the robustness of the GaN component. It has also allowed to tune some manufacturing parameters of the GaN power amplifiers. Finally, the technological payload is providing Proba-V with an additional redundancy.

4.2 Energetic Particle Telescope (EPT)

The Energetic Particle Telescope (EPT), developed by a consortium led by QinetiQ Space nv (B), is a charged particle spectrometer composed of 12 radiation Si sensors (< 5 mm total thickness), mainly operated in digital mode, to achieve direct particle identification and energy measurement. EPT is a high fidelity instrument for environment models' improvement and for cross calibration of coarser space radiation monitors, as the ESA SREM monitoring system, and is flying for its first time on-board Proba-V.

Accessing outer space through an opening in the spacecraft's top panel, the EPT payload is permanently monitoring the radiation environment. In routine operation, the EPT acquires over 40000 spectra of electrons, protons and α-particles per day, which are used in various scientific/engineering studies (PROBA-V/EPT - Data Exploitation project).

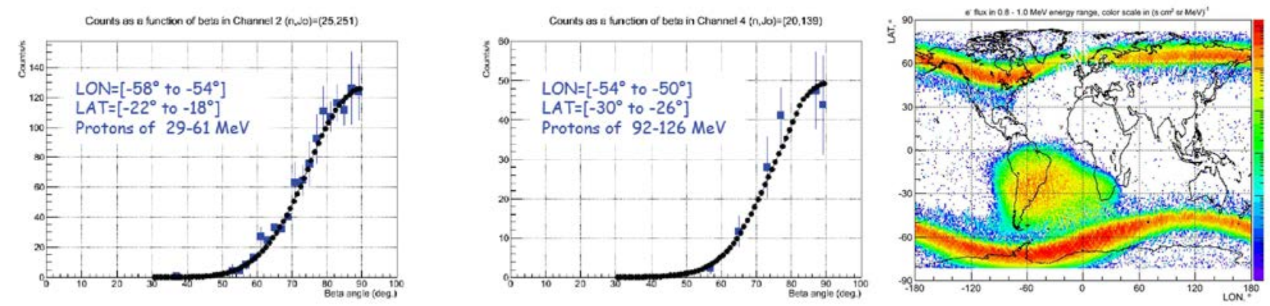

Figure 10: EPT PAD Measurement (Left/Centre); Example of electron flux in the 0.8-1.0 MeV range (Right)

EPT data are available at each S-Band pass on the Redu web server, and further processed by the B-USOC (B), and analysed by the Centre for Space Radiations at the Catholic University of Louvain-La-Neuve.

The EPT commissioning has been fully successful, with positive verification of all its functionalities. Moreover a campaign has been performed over the South Atlantic Anomaly (SAA) where the satellite was commanded in different attitudes to measure the so called Pitch Angle Distribution (PAD) of proton particles in this region of the Earth (Figure 10).

4.3 Air Traffic Surveillance Receiver (ADS-B)

The Automatic Dependency Surveillance Broadcasting System (or ADS-B) [10] is a well-known system embarked on modern civil aircrafts. Its principle relies on messages (or squitter) broadcasting of the principal aircraft information over L-Band (1090 MHz) transmitters. The broadcasted information includes the aircraft position, altitude, call sign, etc., also called Mode-S Extended Squitter telegrams.

The system had been initially designed for ground-based reception systems, as a complement to radar surveillances of air traffic. Studies have however demonstrated that a space based ADS-B system could be beneficial for surveillance of traffic over Non Radar Airspaces (NRA) as, for example, over the oceans or desert areas. Additionally, air traffic optimisation could also benefit from ADS-B World global network, with, for example, a reduction of the inter-aircrafts distances over NRA and routes' optimization to reduce fuel consumption.

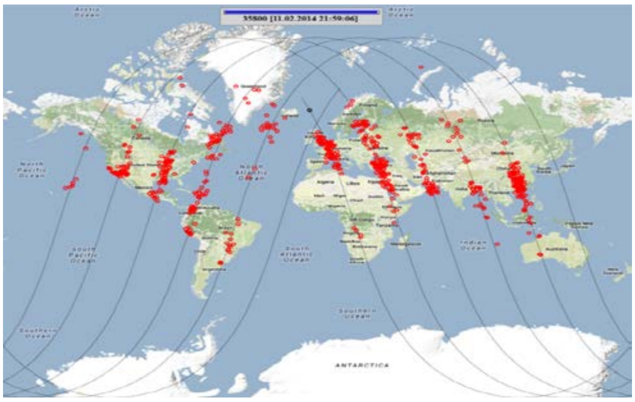

Figure 11: Aircraft tracks observed by PROBA-V

An inter-Agency agreement had been signed between DLR and ESA, aiming to the embarking of the first space-based ADS-B receiver, developed by DLR (D), on-board Proba-V, with the goal of demonstrating the capacity to receive ADS-B signals in space and of characterising possible interferences.

Originally planned to be operated with a duty-cycling of 30% of the time, in compliance with the available resources estimated at the start of the project, thanks to the actual on-board system resources' margin the satellite has shown in orbit, the Proba-V ADS-B receiver is presently activated along the complete orbit, with 100% duty cycle.

The demonstration achieved with the DLR receiver flying on Proba-V, with the first preliminary signal characterisation from space represents the first step in the deployment of a space-based ADS-B system.

The receiver's algorithms will be further tuned to improve reception capabilities and study the optimal constellation to be deployed. DLR, SES Astra and TAS-D are working together to define such a constellation.

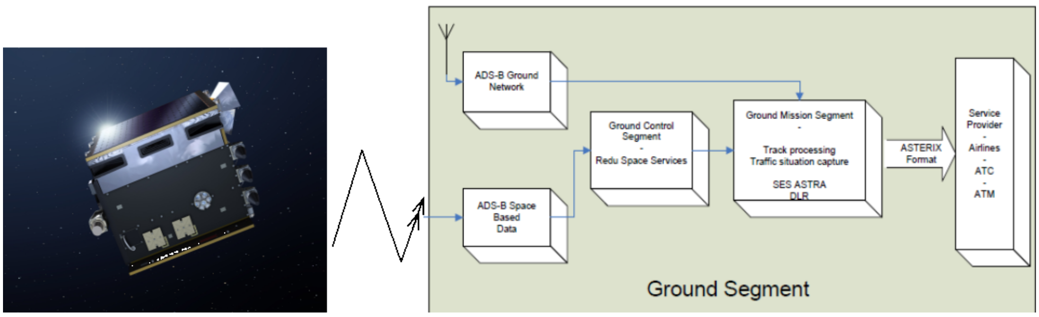

Figure 12:Proba-V ADS-B End to End System

4.4 Timepix Based Radiation Monitor (SATRAM)

Based on the TIMEPIX hybrid semi-conductor pixel detector, the compact, lightweight, SATRAM payload [11] (developed under an ESA contract in collaboration between CSRC (CZ) and IEAP (CZ)) provides single quantum X-ray photons' and charged particles' counting for high sensitivity detection, high-resolution tracking and directional visualization of energetic charged particles over a wide dynamic range of particle fluxes, energies and over a broad field of view. With the SATRAM payload mounted on the external side of the Proba-V satellite's bottom board, the Timepix detector determines, over a wide range of particle fluxes, energies, and for a broad field of view, the composition and spectral characterization of the mixed field radiation environment. The per-pixel energy sensitivity provides linear energy transfer (LET) spectra and enhanced particle-type resolving power and directional sensitivity for energetic charged particles. Results can include spatial- and time-dependent distributions of the radiation environment along the satellite orbit.

The SATRAM payload contains an FPGA controlling the Timepix detector and providing communication with the spacecraft, along with housekeeping, data compression and configuration.

Figure 13:Timepix Detector and SATRAM Payload

SATRAM has been active on a permanent basis since June 2013, collecting data analysed by the Institute of Experimental and Applied Physics (IEAP) in Prague.

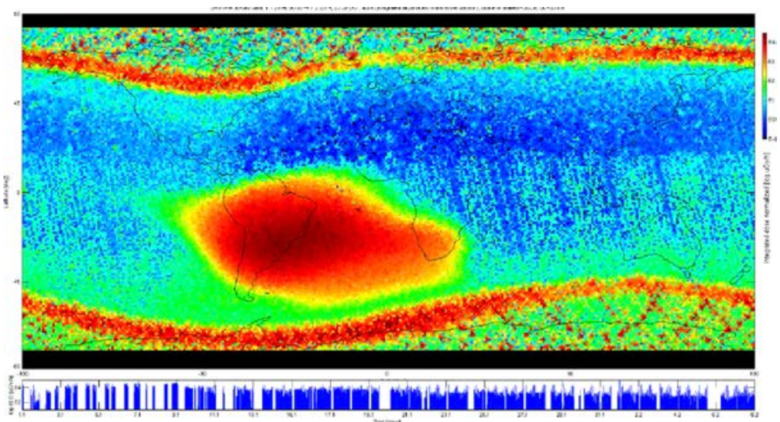
Figure 14:Spatial and time distributions of total absorbed dose by SATRAM

The SATRAM unit flying on Proba-V is the first deployment of the Timepix detector in outer space. Based on its successful commissioning and the optimisation of its detector configuration and settings on Proba-V, a second version of the SATRAM detector is under development, to be possibly flown on the future ESA missions.

4.5 Optical Fibre Connector Demonstrator (HERMOD)

The last payload selected to fly on Proba-V is the High dEnsity space foRM cOnnector Demonstration, or HERMOD. This payload's objective is to validate, through an actual launch and in orbit operation, a new type of high-density optical fibre cable assembly, cumulate space heritage for fibre optics transmission, evaluate possible degradation induced by the space environment compared with on-ground tests' results, and finally to derive the future standard for application of optical communication links for space utilisation. The future applications of this technology are for intra-satellite optical communication in view of mass reduction, electrical grounding simplification, and to increase the transmission rate.

Figure 15 provides a simplified view of one experiment's channel. In total, four identical channels are under test, each one with different optical harness configuration. A continuous data stream is injected into the optical cable and a Bit Error Rate (BER) is computed at the other extremity. Each channel has been differently biased to evaluate in-orbit degradation.

All the channels have survived the launch and no BER has been measured with the exception of the 3rd channel, currently recording a BER of $5.7*10^{-16}$, that exhibits from time to time a burst of errors due to synchronizing issues of the initial data frame. It is expected to observe during the operating life of the payload the first errors within the channel 2, that was designed on purpose with reduced power margin.

Originally planned to be activated in the frame of the Proba-V mission for couple of days per month; the HERMOD payload has been continuously powered on-board since its initial activation.

HERMOD was selected for flight on Proba-V less than year before flight, and the equipment has been developed in less than six months from kick-off to integration on the satellite.

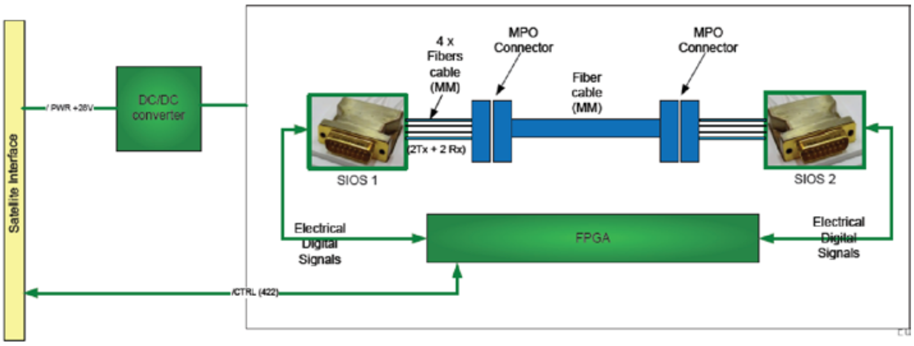

Figure 15: HERMOD Simplified Block Diagram

5 CONCLUSIONS

Developed within the ESA Technical Support Directorate (D/TEC), Proba-V was launched on May 7th, 2013 from Kourou on-board the ESA Vega small launcher. The accuracy achieved at orbit injection guarantees an optimal ground illumination for the five years extended mission's lifetime. Following their successful commissioning and calibration campaigns, all elements (Flight, Ground and User's Segments) of the Proba-V mission have been declared operational and the mission has been transferred to the Earth Observation Directorate (D/EOP) of ESA for the operational mission's management.

The Vegetation Instrument is performing well within the specifications set for the mission for both the mandatory 1km data product and the goal 300m data product [4]. Proba-V is now ready to take over the Vegetation data acquisition after the decommissioning of the SPOT/Vegetation instrument, currently planned for July 2014. The implementation of a number of new technologies into the design of the Proba-V Vegetation instrument has permitted the dramatic reduction of the mass, volume and power consumption of the original Vegetation instrument, in order to fit with the Proba small satellite platform's characteristics.

While encompassing a large re-use of the Proba platform, several innovative technologies and design solutions have been introduced in the Proba-V platform and mission design, and validated in flight, enhancing the performance of the system, with respect to its predecessors, to fully match the very demanding mission objectives.

All embarked technological payloads are working properly and continuously on-board thanks to the allocation of the system resources that became available along with the project implementation. The flexibility of the Proba platform and the integration process of the satellite has allowed to manifest even late flight opportunities for new technological payloads.

Due to the autonomous character of the flight and the ground segments, virtually all operational activities don't require human intervention, while keeping the availability of the system very high.

Proba-V has demonstrated the benefit of the utilisation of small satellites for an operational mission, as well as for the in-orbit demonstration of new technologies and technological payloads that can beneficiate from an early flight opportunity and quick implementation from decision to flight.

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