ALTIUS: HIGH PERFORMANCE LIMB TRACKER, BASED ON A PROBA PLATFORM

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ABSTRACT

There is more and more interest in the understanding and the monitoring of the physics and chemistry of the Earth's atmosphere and its impact on the climate change. There is currently a lack of sounders which provide a high vertical resolution in trace gas detection.

ALTIUS (Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere) is a remote sounding experiment proposed by the Belgian Institute for Space Aeronomy (BIRA/IASB). The mission scenario includes bright limb observations in basically all directions, solar occultations around the terminator passages and star occultations during eclipse. These observation modes allow imaging the atmosphere with a high vertical resolution. The spacecraft will be operated in a 10:00 sun-synchronous orbit at an altitude of 695 km, allowing a 3-day revisit time.

The envisaged payload for the ALTIUS mission is an imaging spectrometer, observing in the UV, the VIS and the NIR spectral ranges. For each spectral range, an AOTF (Acousto-Optical Tunable Filter) will permit to perform observations of selectable small wavelength domains. A typical set of 10 wavelengths will be recorded within 1 second.

The different operational modes impose a high agility capability on the platform. Furthermore, the quasi-continuous monitoring by the payload will drive the design of the platform in terms of power and downlink capabilities. ALTIUS is one of the mission which are currently envisaged to use the PROBA-NEXT platform, which is currently under development at QinetiQ Space.

This paper will present the ALTIUS mission, the envisaged instrument and the spacecraft concept.

1. INTRODUCTION

A study has been performed, compiling past, present and future atmospheric missions. This study [10] shows a potential issue in the monitoring of the Earth's atmosphere with a global coverage (Fig 1).

Clearly, the number of available sounders will drop dramatically and this is particularly true for space instruments having a high vertical resolution. Furthermore, during the period 2005-2006, four very important and successful missions were lost or switched off: SAGE II, SAGE III, POAM and HALOE. Not only this loss of instruments is detrimental for pure atmospheric research (all together these four instruments capitalize 47 cumulated years of measurements and about 4800 scientific papers) but it has dramatic consequences on the monitoring of long-term trends for essential atmospheric species like ozone or water vapor.

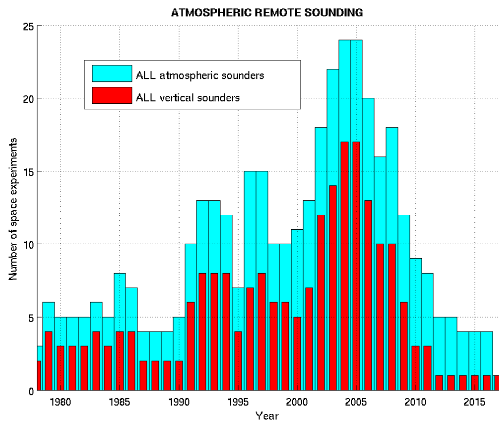

Figure 1: Dramatic decrease of atmospheric sounders between 2006 and 2010

In April 2012, the sudden loss of connection with Envisat caused another drop in the total number of limb sounders (SCIAMACHY, MIPAS and GOMOS), and to date, only a handful of instruments are still active: MLS, OSIRIS, ACE-FTS and OMPS-LP, the first three being already on duty for more than a decade.

Some nadir-looking instruments of the GOME type possess a high horizontal resolution well suited for pollution detection and monitoring but at the price of a poor vertical resolution, not compatible with the refinement of modern CTM modeling codes. A correct understanding of the stratospheric chemistry requires ideally a 1 km vertical resolution, whereas a horizontal resolution of about 300 km, typical for occultation instruments, is acceptable. The ALTIUS mission will be designed to meet these requirements.

The proposed payload for the ALTIUS mission is an imaging spectrometer, operating in the UV, VIS and NIR. Each spectral channel is equipped with an AOTF (Acousto-optical Tunable Filter) to select a narrow spectral band from the incoming light.

Due to the tight budget constraints, a PROBA-like platform has been selected for the mission. The PROBA satellite is a small satellite that was developed by QinetiQ Space for ESA. The proposed platform is based on the PROBA-NEXT bus, which is an upgraded version of the PROBA-V platform. The small satellite approach has its inherent limitations. The main constraint, imposed by the platform onto the mission is the amount of incoming power, which limits the amount of data that can be gathered and downlinked per orbit. However, the improved platform performance of the PROBA-NEXT bus provide a consistent data set for the scientists.

2. ALTIUS SCIENTIFIC CONTEXT

There is an increasing interest in the understanding and the monitoring of the physics and the chemistry of the troposphere due to their potential importance for the human beings. Yet, the evolution of the climate is fundamentally driven by the entire atmosphere through its global transport properties, its chemical composition and its interaction with the solar radiation.

It is now accepted that the global and polar depletions of the ozone layer can be attributed to the presence of halogen compounds released by anthropogenic emissions. The Montreal protocol implementation yielded the decrease of stratospheric long-lived chlorine and bromine species. A turning point was clearly indentified around the year 1997, such that the atmospheric community is now seeking for statistically-significant positive trends in ozone concentration. It seems however that the recovery process is taking more time than expected as the trends detected are very small (probably balanced by greenhouse gases effects). Moreover, studies based on profile data show complex patterns in the ozone field dynamics: hemispheric asymmetry, high altitude positive trends, low altitude negative trends, etc…

Clearly, the monitoring of ozone stratospheric abundances is of crucial importance in assessing the milestones of a clear recovery process.

Among important trace gases, methane is very important for its impact on climate through a large radiative forcing effect and the production of stratospheric water vapor. A global increase of about 0.7 ppm in 1800 AD to 1.8 ppm nowadays is difficult to interpret because of the diversity of the sources: wetlands, enteric fermentation, fires and rice agriculture.

The odd hydrogen family, HOx, contains all active species, i.e. radicals that are involved in catalytic cycles that destroy Ox. The HOx radicals are derived primarily from the oxidation of water vapor in the stratosphere and therefore it is essential to understand and to monitor the intrusion of water vapor into the stratosphere, specially in the region of the tropical tropopause.

Similarly, the NOx family is known to play an essential catalytic role in ozone destruction with a strong diurnal cycle that requires day- and nighttime measurements for a full characterization. On the other hand, these species may be converted into inactive forms or reservoirs. In particular, the NO2 reacts with ClO to form ClONO2 and the measurement of OClO (depending itself from the presence of ClO and BrO) and BrO (daytime) in the UV is very important if it can be anti-correlated with NO2 simultaneous observations.

The role of polar stratospheric clouds (PSCs) in polar ozone depletion has been described extensively in scientific literature ([13]). Briefly, in cold conditions, when PSCs are present, the stable reservoir species HCl, ClONO2 and N2O5 disappear in heterogeneous reactions on the surface of the particles to form HNO3 inside the PSC particles, which are eventually removed from the stratosphere by sedimentation in a process called de-nitrification. The other reaction products are photo-dissociated in the presence of sunlight (at the end of polar winter, when the Sun returns) to chlorine species, which act as catalytic ozone scavengers.

Much remains to be learned about PSCs. The current classification is probably too coarse. We do not know enough about particle sizes, crystal morphology and even composition. On a larger scale, more information is needed about cloud properties such as shape, thickness and density. Satellite measurements can provide this information: PSCs are easily recognized when elevated optical extinctions are observed inside the polar vortex.

Polar mesospheric clouds (PMCs), originally called noctilucent clouds, are (as the name suggests) only visible in the dark sky, long after sunset. PMCs were reported for the first time in 1885. They are similar in appearance to thin cirrus clouds, but are located at the much higher altitudes from 80 to 87 km, near the mesopause. PMCs only occur at high latitudes during summer (a few weeks before and after the solstice), when the mesosphere becomes extremely cold (with temperatures even as low as 100 Kelvin). Various pieces of evidence, including direct rocket sampling, suggest that they are composed of very small water-ice particles (0.05 – 0.1 µm).

According to the IGACO report ([11]), which was taken as a scientific reference for the phase A study, it is necessary to obtain a comprehensive set of global observations of the species quoted in Table 1 for the stratosphere by using LEO satellites. In addition to the needs expressed in the IGACO report, there are also atmospheric modeling capabilities which embark on the creation of a global picture in the combination of these atmospheric date.

It is highly desirable to combine the advantages of nadir-viewing and limb-viewing techniques. What is ideally needed is an instrument with a vertical resolution similar to that of an occultation instrument but with coverage similar to that of a backscatter instrument.

Table 1: Observation needs following IGACO

Atmospheric Region	Requirement	Unit	O3	NO2	CH4	H2O	CO2	BrO	Aerosols
3.	Dx	km	100	250	250	200	500	100	100
Lower stratosphere	Dz	km	3	4	4	3	4	1	1
	Dt		1d	12hr	12hr	1d	1d	6h	1w
	Total error	%	20	40	30	20	2	15	-
	delay		weeks	hours	weeks	weeks	months	weeks	weeks
4.	Dx	km	200	250	250	200	500	100	-
Upper stratosphere, mesosphere	Dz	km	3	4	4	5	4	1	-
	Dt		1d	1d	1d	1d	1d	1d	-
	Total error	%	20	40	30	20	2	20	-
	delay		weeks	weeks	weeks	weeks	months	weeks	-

Since the pioneering work of the SOLSE/LORE experiment ([1]), it has been established that the limb scattering technique is a viable technique for the measurement of atmospheric trace gas profiles in the stratosphere. A confirmation of this approach has been recently published for OSIRIS on board ODIN ([2]), for SCIAMACHY on board ENVISAT ([3]) and for the SAGE III mission before its premature end ([4]).

All the above-mentioned experiments have measured and validated ozone and NO_2 profile retrievals and their results concerning BrO, OClO and aerosols will be published in forthcoming scientific papers. Also, the limb scattered light recorded by the upper and lower bands of the GOMOS detector (on board ENVISAT) is presently investigated in order to develop an inversion algorithm.

However, it is now recognized that the limb scattering technique suffers from a major difficulty associated with the difficulty of an accurate determination of the tangent altitude associated with a particular line-of-sight because of the diffuse nature of the light source ([5]).

ALTIUS will also make use of the limb scattering technique but its imaging capacity will allow solving the issues of altitude registration, cloud identification and horizontal gradients of measured species.

It should be taken into account that any measurement toward the limb (scattering or occultation) leads to an effective path length along the line-of-sight of about 500 km. Perpendicular to the line-of-sight and parallel to the horizon, the spatial resolution shall be mainly limited by the number of pixels needed to obtain the necessary S/N ratio imposed by the inversion algorithm. Finally, the vertical resolution shall be equal or better than 1 km.

3. ALTIUS MISSION REQUIREMENTS

The ALTIUS mission requirements for the target atmospheric species are summarized in Table 2 with a particular focus on vertical resolution. The table considers the priority of data collection. The dark-shaded rows concern global ozone [priority 1] whereas the light-shaded rows [priority 2] refer to species explicitly mentioned in the IGACO requirement table (Table 1). The other species [priority 3] are mentioned in experimental "demonstration" mode.

Table 2: ALTIUS target atmospheric species

	z [km]	Δ [%]	λ [nm]	bright limb	occultation	Dx,Dy,Dz [km]	Full coverage
O_3	10-30	5	550-650	x	x	500,10,1	3d
O_3	30-50	5	300-350/550-650	x	x	500,10,1	3d
O_3	50-100	20	250-300		x	500,NA,1	3d
NO_2	20-50	30	450-550	x	x	500,20,2	3d
CH_4	5-25	20	1600-1800	x	x	500,50,2	3d
H_2O	10-30	20	900-1800	x	x	500,50,2	3d
CO_2	10-30	20	1550-1600	x	x	500,50,2	3d
BrO	10-30	20	320-360	x		500,50,1	3d
OClO	15-50	25	320-400		x	500,50,1	3d
NO_3	20-50	25	662		x	500,50,1	3d
aerosols-PSC	10-30	25	200-2000	x	x	500,20,1	3d/1 y
O_2	60-100	30	1260-1270/1530		x emission	500,100,5	3d
PMC	70-100	50	200-2000	x	x	500,20,1	1 y

The prioritary scientific target of the ALTIUS mission will be the measurement of the ozone concentration vertical profiles. This concentration should be retrieved with accuracy of 5 % between 10 and 50 km, and of 20 % between 50 km and 100 km. The optimal ozone measurements will be performed around 550-650 nm (Chappuis band) in the lower stratosphere, around 320-350 nm (Huggins band) in the upper stratosphere and 230-270 nm (Hartley band) in the mesosphere in occultation mode only. The instrument has to be able to measure ozone in the polar night as well as at different local times in the mesosphere (in particular around the second ozone maximum).

Global coverage has to be performed in a delay equal or less than 3 days to offer continuity with respect to ENVISAT atmospheric instruments, with a resolution of 5 degrees in latitude and 10 degrees in longitude, a threshold requirement for the accuracy of present chemical assimilation models.

The ALTIUS instrument will use the hypercube measuring technique in a limb viewing geometry. Instead of a traditional "spatial x (spatial x wavelength)" construction an innovative "(spatial x spatial) x wavelength" approach will be adopted. Therefore ALTIUS will be a spectral camera with wavelength scanning. This approach will allow solving, in a definitive way, the altitude registration problem that is spoiling the traditional limb scatter technique.

The ALTIUS instrument shall be basically an imager with the limb itself as scope (Figure 2). The field-of-view of the instrument (an extended scene of the sounded atmospheric region has to be aimed for) will cover the entire atmospheric limb, hence different solutions will exist to improve the classical (and unsatisfactory) method of total radiance fitting in the UV ("Knee"-methods – (1)), such as using: the horizon or geographical details in cloudless scenes (2), background stars in the scene (3) and satellite star tracker information (4).

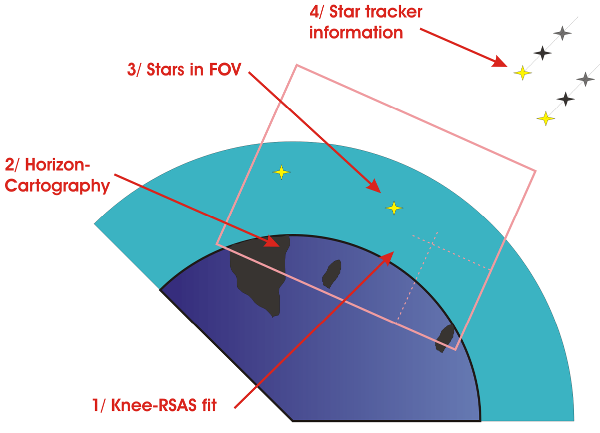

Figure 2: Illustration of the ALTIUS concept. The attitude registration is performed by the combination of the star tracker information, the position of stars in FOV and geographic features

4. MISSION ARCHITECTURE

A sun-synchronous orbit with an altitude of 695 km and a local time of 10:00 has been chosen for the ALTIUS mission. This orbit allows for a revisit time of exactly 3 days.

In the baseline mission concept, no orbit corrections are envisaged during the course of the mission. The lack of orbit maintenance will result in a drift of the local time over the envisaged 5 years mission time. The drift has not been identified as a killer from science point of view, but will result in problems on the spacecraft towards the end of the mission. The problems are related to the reduced incoming power or star tracker blinding, depending on the direction the spacecraft is drifting (depending on the chosen inclination and the orbit injection errors from the launcher).

The implemented propulsion system will cover both the orbit maintenance manoeuvres and the end-of-life disposal.

The ALTIUS mission has been designed towards an operational phase, which will use only the Redu ground station (5.15°E, 50.00°N). The Redu ground station will have to be equipped with a 3m receiving X-band antenna. The average contact time per day for this ground station is 34.5 minutes, which is sufficient to downlink all the collected science and housekeeping data.

5. PLATFORM

The ALTIUS spacecraft will be based on the PROBA-NEXT bus. This bus concept is derived from the PROBA-V mission, with a number of performance and accommodation updates. Most of the bus elements are reused from PROBA-V, which will minimize the development time and risk and will result in a cost effective solution.
The major modifications that have been introduced are the implementation of a propulsion system and a top-mounted payload design.

The spacecraft concept for ALTIUS is shown in Figure 3. Different solar panel configuration can be chosen for the PROBA-NEXT bus. To meet the power needs of the satellite, 4 deployable solar panels are accommodated.
In nominal operational mode, the camera will be backward looking, i.e. in the anti-velocity direction and tilted 64.38° around the pitch axis with respect to nadir.

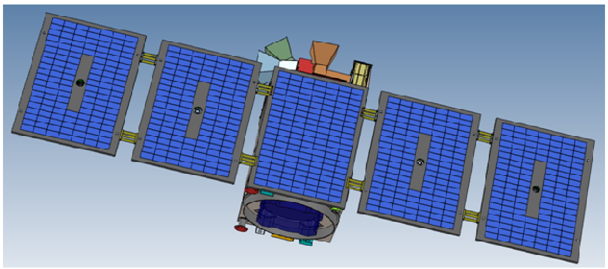

Figure 3: ALTIUS spacecraft concept

5.1. Structure

The satellite structure is made from honeycomb panels with aluminium face sheets, which are mounted to a structural frame. These panel form the primary structure of the satellite and will hold all bus units.
The structural frame is mounted onto an aluminium machined bottom board, which holds the propulsion system. On top of the frame a dedicated payload panel is mounted which is tailored towards the specific payload interfaces.

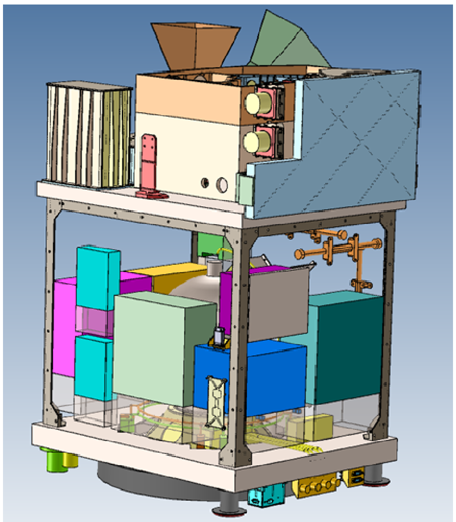

Figure 4: Internal accommodation of the ALTIUS spacecraft

The size of the spacecraft allows to launch the satellite in the dual launch configuration under the VESPA adaptor of VEGA. Figure 4 gives a view of the interior of the ALTIUS spacecraft. The 3 star trackers are mounted on the optical bench of the payload. The payload itself is mounted isostatically to the dedicated payload panel. A view on the outer structure is given in Figure 5.

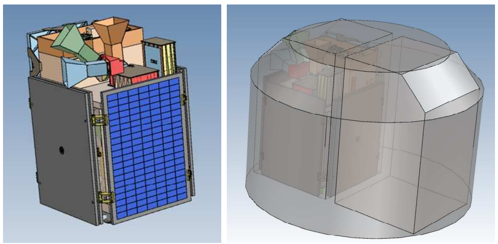

Figure 5: External accommodation with solar panel in stowed configuration – launch configuration

5.2. Avionics

The onboard computer and data handling system for the ALTIUS mission is based on the ADPMS (Advanced Data and Power Management System), which is fault-tolerant computer and power system of PROBA-2 and PROBA-V (developed by QinetiQ Space).

ADPMS consists of two main parts: a Data Management Unit (DMS) and a Power Management System (PMS). The DMS is a powerful computer built on Compact PCI (cPCI) modules around the LEON2 processor. Primary and Redundant PCI lanes form a fault-tolerant architecture. The LEON2 (Atmel AT697F) provides a capacity of 86 MIPs or 23 MFLOPS. The PMS is based on an unregulated battery bus architecture capable of delivering a total of up to 630W in total on 24 outputs that are each limited to 94W.

The DMS provides data handling for all subsystems and control for the space segment. This also involves the execution of attitude control maneuvers either in response to ground command or using on-board algorithms, and the execution of all on-board autonomy related functions.

ADPMS provides up to 25 RS-422 and two PacketWire interfaces, although the design can be easily adapted for other standards (CAN, SpaceWire, MIL-STD-1553). ADPMS also provides 8 programmable channels for clock distribution and 3 channels for datation input, mainly to synchronize the ADPMS clock with the GPS PPS. The 12Gbit of on-board data storage required by the payload are provided by the MCPM (Mass Memory Payload Module) of ADPMS. The Front End Electronics (FEE) of the payload will interface ADPMS through PacketWire. Telemetry and Telecommand are implemented according to CCSDS standards.

The electrical architecture, as shown in Figure 6, is built-up around the ADPMS. Each subsystem in the block diagram is described in the next sections.

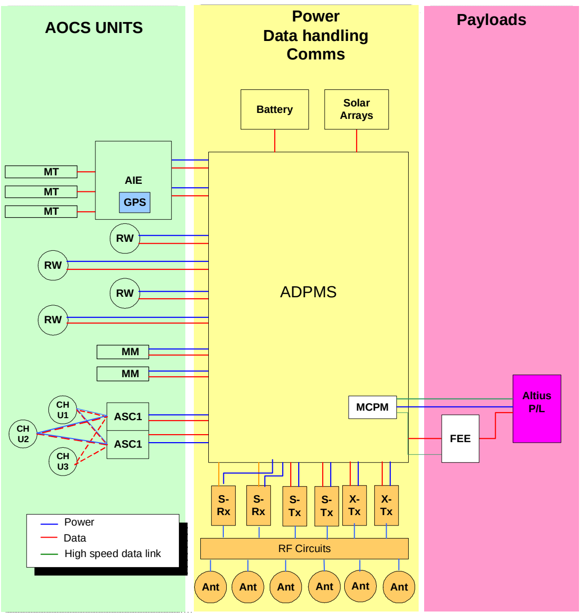

Figure 6: ALTIUS S/C electrical architecture

5.3. AOCS

The ALTIUS satellite is three-axis stabilized.
The attitude measurements are done by:

- Three autonomous **star trackers** (hot-redundant optical heads and one cold redundant star tracker electronics)
- Four **Reaction Wheels**, which are mounted in a tetrahedral configuration.
- A cold-redundant **GPS receiver** and two **antennas** provide the essential orbital position, velocity and correlation to a universal time reference.
- Three **magneto-torquers** are mounted in three orthogonal directions. The torquers will be used to offload wheel momentum. The magneto-torquers are dual winded and are therefore internally redundant.
- Two cold-redundant **magnetometers** to measure the magnetic field of the Earth

The ALTIUS AOCS Software (SW) will be an update of the PROBA AOCS SW and has the following modes:

- ***Safe mode***
  The safe mode is based on the Bdot algorithm. It uses the magnetometers as sensors and the magnetic torquers as actuators. The algorithm will reduce the spacecraft rotational speed to twice the spacecraft orbital rate. This mode is used as safe mode, but also to detumble the spacecraft after separation.

- ***Observation mode***.

  Different observation modes are defined:

  - In the nadir pointing mode, the payload is pointed towards the Earth's centre and the satellites bottom board is oriented towards the negative Pitch axis of the orbit;
  - The backward pointing mode is performed starting from Nadir followed by a rotation around the Pitch axis of -64.38° (angle between Earths centre and bright limb). This is the orientation during the baseline operational scenario. In this attitude, the primary X-band antenna is pointed towards nadir.
  - The forward pointing mode is performed starting from Nadir followed by a rotation around the Pitch axis of 64.38° (angle between Earths centre and bright limb); in comparison with the previous two attitudes, the detector of the payload is rotated 180° around the line of sight;
  - The left pointing mode is performed starting from backward looking followed by a rotation around the Yaw-axis of the orbit of +90°. There remains a single star tracker coverage until a rotation of +130°, which is useful for a tomography scenario. If the left pointing mode is performed starting from forward looking, there is a single star tracker coverage until Yaw-rotations of -40°.
  - A partially right pointing mode can be performed starting from backward looking followed by a rotation around the Yaw-axis of -45°.
  - The dark sky pointing mode can be performed starting from backward pointing followed by a rotation around the Pitch axis of –4° till –6°.
  - A star occultation mode starts from an attitude similar to the dark sky pointing (= payload pointing 4° to 6° above the atmosphere. Once a star is acquired by the payload, the spacecraft will go into inertial pointing mode, until the star has set behind the Earth.
  - The Sun occultation mode uses the same orientation as for backward pointing (for sun set (SS)) or forward pointing (sun rise (SR)).

- ***Sun-bathing mode***

  This is a 3-axis stabilised mode, keeping the solar arrays optimally pointed to the sun in order to maximize the incoming power.

The nominal missions scenario is shown in Figure 7.

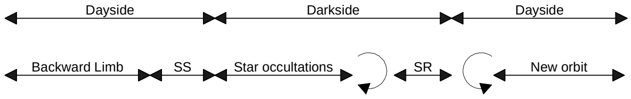

Figure 7: Nominal mission scenario

In the bright limb, the spacecraft is oriented in backward looking mode. When going into eclipse a sun occultation observation is performed. In eclipse, a number of star occultations are performed. Just before reaching the terminator, the spacecraft is oriented in forward looking mode to perform a sun occultation during sunrise. Before resuming the bright limb observations that spacecraft is again oriented in backward looking mode.

A tomography scenario is composed of at least 2 orbits (see Figure 8). A standard backward looking orbit in the bright limb, is followed by a left looking orbit. Due to fact that the angular distance to the side horizon is close to the angle by which the Earth will have rotated at the next LEO revolution, it is possible to combine a backward limb observation followed by a dedicated sideward limb observation of the same location at the consecutive orbit.

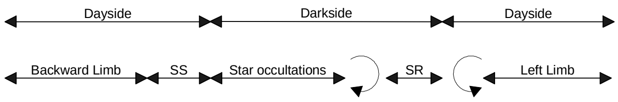

Figure 8: Tomography scenario

The main part of the ALTIUS AOCS SW can be re-used from PROBA-2 and PROBA-V.

5.4. Communication

The S-band receiver and transmitter from PROBA-V are reused on the ALTIUS spacecraft. The S-band system incorporates a hot redundant receiver and a cold redundant transmitter. The S-band system will be used for commanding the spacecraft and for receiving the housekeeping data (in case the X-band system is not used). Four S-band antennas are incorporated to ensure an omni-directional coverage for the receivers.

The S-band system will be complemented by an X-band system for science data downlink. The X-band electronics are implemented in a cold redundancy scheme. Two isoflux X-band antennas are incorporated onto the S/C.

The total amount of science data, gathered during 1 orbit is equal to 1.86 Gbits. A downlink rate of 15 Mbps is chosen. A positive link budget is obtained, assuming a 3 m antenna at Redu.

5.5. Propulsion

The current bus design supports a conventional hydrazine, as well as a HPGP (green propulsion) system.
The chemical propulsion systems typically provide a delta-V of about 100 m/s, which covers the needs for orbit injection error corrections, orbit maintenance during the lifetime of the mission and end-of-life disposal.

In case a significantly higher delta-V would be required, an electrical propulsion system (QinetiQ’s T5 ion engine) can be incorporated. With this systems a delta-V of well above 300 m/s can be achieved.

5.6. Power

The solar panel configuration for ALTIUS consists of four deployable solar panels. It is a simple and compact design using the latest high efficiency triple-junction GaAs solar cells.

An 18 Ah Li-Ion battery is used to supports the eclipse periods and high power phases. A maximum Depth-Of-Discharge of 20 % has been assumed for the sizing of the battery.

The obtained power subsystem provides a 28 V unregulated power bus.

A positive power budget is obtained with the power subsystem in the nominal operational mode. The battery can fully recharge during the bright limb phase (see Figure 9).

In the off-nominal (scientific) modes, the incoming power profile is less favourable and the battery will not recharge completely. Therefore it is required to maintain the spacecraft in a sunbathing mode in the following orbit.

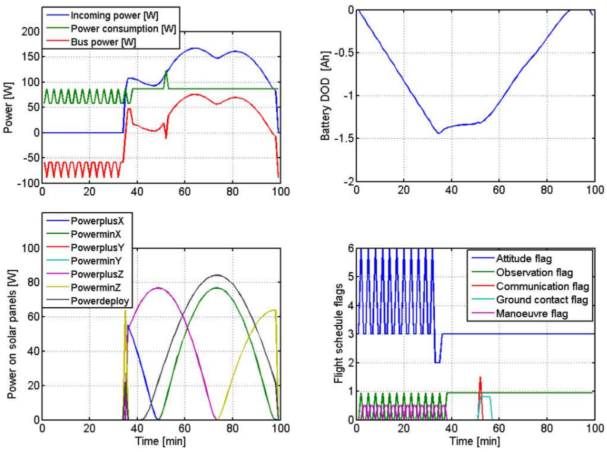

Figure 9: Power budget for baseline operational scenario

6. PAYLOAD

6.1. General description

The ALTIUS payload overview diagram is shown in Figure 10. The payload contains, on its optical bench, three optical channels including the optics, the detector modules and their proximity electronics. The optical bench is thermally insulated from the environment radiation by MLI and from the S/C through conduction by Titanium flexures. It is connected to a dedicated radiator, earth facing, to dissipate its heat.

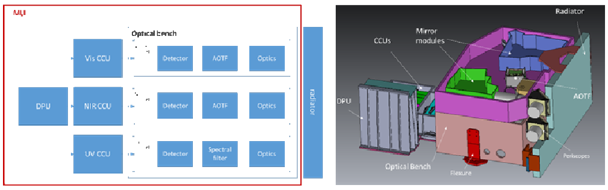

Figure 10: ALTIUS Payload block diagram (left) and ALTIUS payload concept (right)

Two electronic boxes contain, respectively, the Power and data electronics (PDU) and the channels control electronics (CCUs). The PDU interfaces with the S/C ADPMS (Advanced Data and Power Management System) controlling the space segment and communicates with the channels control electronics. The CCUs are driving the optical channels internal functionalities, including detector readout, mechanisms, cooler control and spectral filters handling.

6.2. Optical concept description

The ALTIUS payload optical bench has a modular concept. The three optical channels, operating in the UV, VIS and NIR part of the spectrum, can be seen as individual units containing 4 major optical units and one detector module:

- The Front End Optics (FEO) that collects the light and passes it to the spectral filter.
- The spectral filter that selects the required wavelength band (AOTF in the VIS and NIR, TBC in the UV).
- The Back End Optics (BEO) that forms an image of the selected spectral band in the observed scene on the detector
- The Detector module that consists of the detector and its ADC

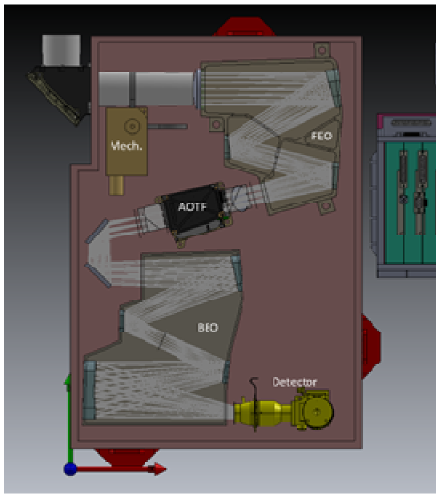

Figure 11: ALTIUS NIR channel opto-mechancial design

The three optical channels of the ALTIUS payload will comply with the specifications as summarized in table 3.

Table 3: Payload specifications

Parameter	Value
Observation modes	Stellar occultation mode Bright limb mode Solar occultation mode
Spectral range channels UV VIS NIR	 250 - 450 nm 440 - 800 nm 900 - 1800 nm
Spectral resolution UV VIS NIR	 Better than 2.5 nm Better than 10 nm Better than 10 nm
FOV1 for each channel (low light levels)	3.4mrad at least
FOV2 for each channel (high light levels)	34mrad (1.95°)
Operational temperature range	-30°C to + 30°C
Volume of the optical bench (approximately)	<410 x 580 x 320 mm³

Based on the ALTIUS mission requirements, challenging requirements on the instrument optical design and the detectors are derived:

- Channels are independent and optically co-aligned
- A high dynamic range in bright limb to be combined with high SNR requirements

- A spatial coverage at tangent point which requires a viewing angle in the vertical direction of about 2 degrees. A 100 km by 100 km section of the bright atmosphere can be observed in one frame.
- Solar occultation observations have to be performed through the same optical path as bright limb observations. As a consequence, a mechanism to place a Neutral Density (ND) filter is implemented in the optical path of each channel.

VIS and NIR channel optical design

The parameters used in the design of the visible and NIR channels of the payload are given in Table 4. The FOV for bright limb observations (FOV1) corresponds to a square of 100x100km^2 projected at earth tangent in each channel. The spatial resolution has been tailored such that MTF at Nyquist and most of the required SNR performances are achievable. The entrance pupil of both channels is limited.

Table 4: Optical Parameters

Parameter	Visible	NIR
Spectral band [nm]	440 – 800	800 – 1800
AOTF material	TeO_2	TeO_2
AOTF aperture [mm]	20 x 20	20 x 20
AOTF acceptance angle [°]	4	4
AOTF bandwidth [nm]	1.5 –9.5	1.5–9.5
FOV1 [°]	1.95x1.95	1.95 x1.95
IFOV [mrad]	0.066	0.133
Entrance pupil diameter 1 [mm]	42	35
number of pixels	512 x 512	256x256

The optical system consists of aspheric mirrors grouped by FEO and BEO mirror groups and one fused silica lenses in a telecentric confocal configuration to correct for aberrations and minimize spectral error on one frame.
As an example, the conceptual design of the NIR channel is shown in Figure 12. The intermediate image from the FEO is located outside the AOTF crystal in order to reduce images non uniformity.

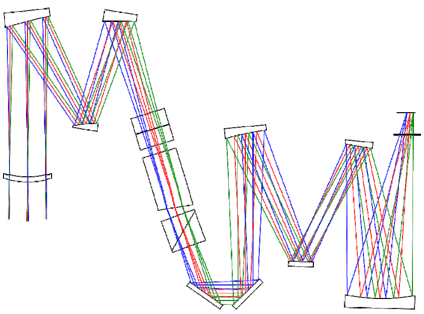

Figure 12: Preliminary optical design of the NIR channel

In both optical channels, blocking of the zero AOTF diffraction order will be done by placing the AOTF in-between two crossed polarizers. The polarizer in front of the AOTF will be oriented such that the polarized input beam will be diffracted into a 90° rotated output beam, which will be transmitted by the second polarizer behind the AOTF, and the undiffracted beam will be stopped by the second polarizer. Considered polarizers in both designs are Glan-Taylor or wire grid polarizers. Both can have an extinction ratio of 1x10^{-5} or better. To stop the residual unwanted light further, an aperture stop is placed at the position of the entrance pupil in the back end optics.

This concept as well as possibility to do straylight correct by background subtraction has been demonstrated in the previous phase of the project by optical breadboarding [6].

UV spectral filter trade-off

For the UV channel, three candidate spectral principles have been considered: grating, Fabry-Perot and AOTF based systems.

Their technical and scientific performances have been checked considering:

- number of optical elements & number of mechanism
- Impact on budgets: Size - Power consumption - Data rate
- TRL level
- Resilience to space environment
- Channel design complexity due to filter selection

The trade-off has been submitted to the instrument PI and the Agency and the Fabry Perot filter has been selected as the most promising system for the instrument design.

6.3. Mechanical concept description

The ALTIUS payload is based on an “all-aluminium” opto-mechanical design. In each channel the FEO and BEO mirror groups are integrated onto mechanical modules (see Figure 13), if possible, within mechanical tolerances. The AOTF and polarizers are also grouped together onto a rigid assembly. Such approach allows implementing baffles and vanes across the optical path to minimize straylight. In each channel a mechanism contains a reflective ND filter that can be inserted in the optical path.

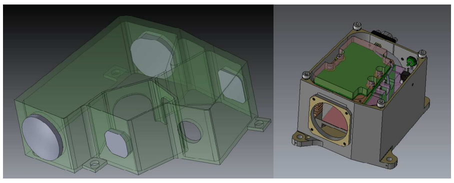

Figure 13: Opto-mechanical module (left); AOTF housing (right)

All these modules are mounted onto the optical bench structure of the instrument. The optical bench of the instrument is presented in Fig.14 and is composed of a rigid H structure optical bench. Two channels are mounted upside down on the central 40mm thick bench while the third channel, integrated on an additional thick box, is finally integrated on top of the assembly.

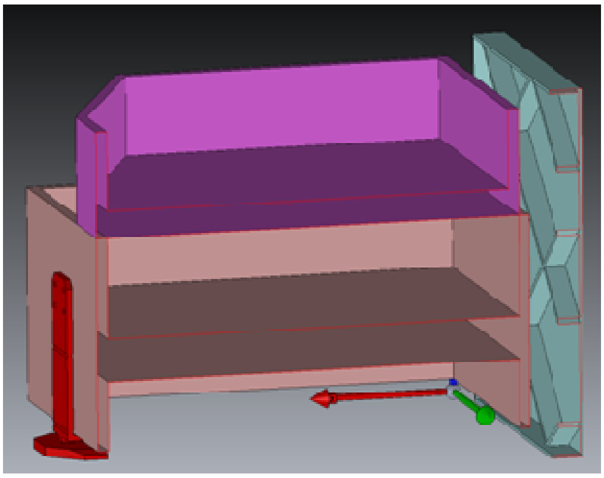

Figure 14: Optical bench structure

The dedicated radiator is interfaced onto this structure in order to dissipate the 15W heat load generated by the AOTF, mechanisms and detector coolers in all channels. The current approach is to have direct thermal link from the heat sources distributed inside the instrument to this radiator.
The optical bench will be mounted onto the S/C using isostatic flexures. These flexures are providing flexibility to cope with interface deformation while insulating from external heat sources.

6.4. Detectors

The detectors have to acquire, from the earth bright limb, an image with a sufficiently large dynamic range of at least 10^3 as shown in Fig. 15. In addition, a high SNR is required in each channel to allow retrieval of the concentration of species of interest in the earth's atmosphere.

To achieve this goal, a CMOS detector development is currently ongoing for both the UV and VIS channels. In the frame of the ALTIUS phase B1 project, this activity will lead to the definition of the pixel schematics of the detector.

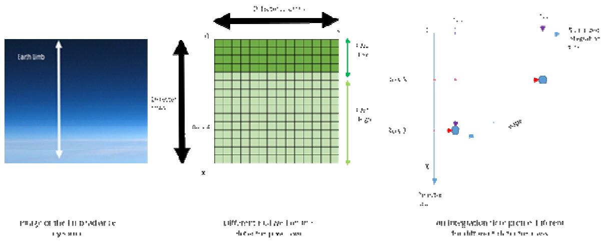

Figure 15: Typical bright limb radiance dynamic and UV-VIS Detector properties, FW=Full Well

The pixel design proposed for the UV/VIS detector of ALTIUS is based on an existing low dark current noise pixel designed for a UV/VIS HDR device . In this pixel the required dynamic range and SNR is achieved by using a 25µm pixel pitch front side thinned photodiode including two different features:

1. The detector has two different full well capacitances which are row selectable to accommodate with Dynamic range and SNR
2. The integration time for the frame acquisition is also row-per-row adjustable, based on commands

Such approach, very specific for a limb looking instrument, allows to optimize the achieved SNR for each layer of the atmosphere.

7. ALTIUS GROUND SEGMENT

The ALTIUS G/S will be decomposed as follows:

- ALTIUS Mission Operations (AMO), headed by a Mission Operations Manager (MOM), containing the ALTIUS Mission Operations Centre (AMOC) and the ground stations;
- ALTIUS Science and Payload Operations (ASPO), headed by a Project Scientist (Principal Investigator) (PS/PI) and a Science Operations Manager (SOM), containing the ALTIUS Science Operations Centre (ASOC), the ALTIUS Instrument Team, the ALTIUS Mission Scenario Team and the ALTIUS Data Processing Team.

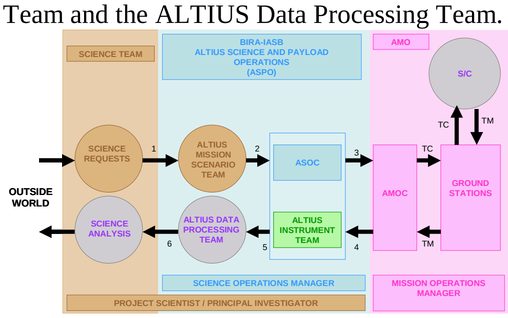

Figure 16: General structure of the ALTIUS ground segment

Figure 17 illustrates the overall AMO. The ALTIUS Mission Operations Centre (AMOC) together with the main ground station (both for telecommanding and telemetry) will be situated in Redu (Belgium). Use of Redu as single G/S is possible thanks to the presence of an isoflux antenna on board the S/C which does not need re-pointing of the S/C for downlinking and hence allows continuous science observations.

As back-up ground station St-Hubert (Canada) is proposed. St-Hubert can also be used as an (occasional) second ground station in case data would be transmitted systematically through the S/C's high gain antenna. In that occurrence the use of only one ground station (in casu Redu) would lead to systematic absence of measurements above a certain region (due to re-pointing of antenna and hence no science observations possible).

The AMOC's Mission Management will plan all routine real-time operations. It will be the interface point with the ASOC.

The EMCS (EGSE and Mission Control System) will execute the pass related activities prepared by the Mission Management. The EMCS has a nominal and a redundant branch.

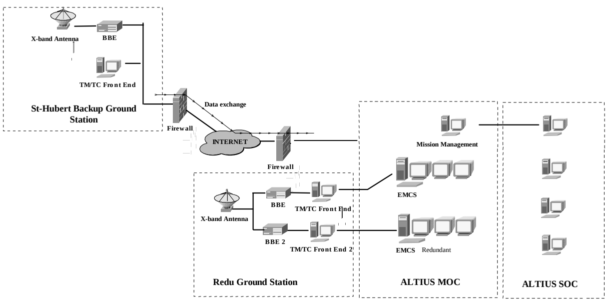

Figure 17: General structure of AMO

The interfaces between the AMOC and the external systems are depicted in more detail in Figure 18.

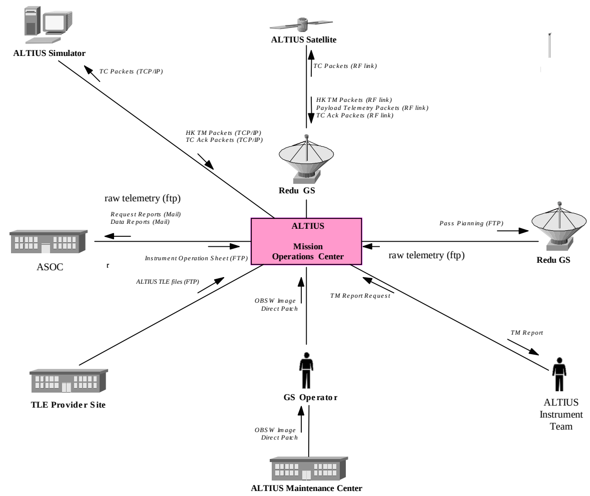

Figure 18: Interfaces to external systems seen from the AMOC

The ASPO building blocks are:

- the Long Term Planning (LTP)
- the Medium Term Planning (MTP)
- the Short Term Planning (STP)
- the Data Ingestion
- the Quick-Look
- the Data Analysis
- the Archive System

The different elements and their interactions are shown in Figure 19.

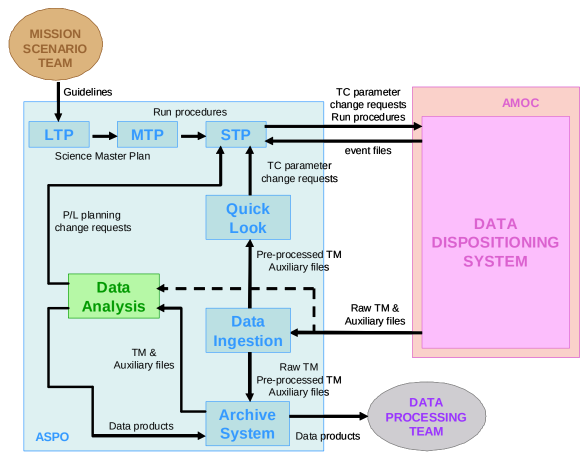

Figure 19: Building blocks of the ASPO

CONCLUSIONS

The paper presents a design of an innovative satellite concept that ensures 3-day global coverage of the Earth's atmosphere.

The proposed imaging spectrometer, equipped with an AOTF, fulfils the scientific requirements, and provides a high flexibility for the scientists towards the selection of the spectral bands.

It has been shown that the baseline operational mission can be performed without any limitations using a small platform, based on the PROBA-NEXT bus. All nominal and off-nominal operations can be supported by the proposed bus, providing the mission all the necessary scientific return.

The performant AOCS system combines a high pointing accuracy with a high agility, which is of major importance to support all the identified observation modes.

The mission can be executed using only the Redu ground station, using a 3m X-band antenna. All the obtained science data can be downlinked to the Redu ground station without the need for repointing and interrupting the observations.

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