The ALTIUS mission

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ALTIUS

ABSTRACT

The ALTIUS instrument (Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere) is a limb spectral imager that will be proposed by Belgium to ESA in order to demonstrate the potential of small scientific missions to measure the vertical concentration profiles of ozone and other trace gases in the earth's upper atmosphere.
The instrument will allow for observing 2D-images of the scattered solar light from the earth's atmospheric bright limb in the ultraviolet (UV), visible (400-800 nm) and near-infrared (800-1600 nm) spectral domains. Furthermore, the ALTIUS instrument will allow to perform limb observations in solar and stellar occultation modes.
The ALTIUS instrument will be based on the use of dedicated Acousto-Optic Tunable Filter (AOTF) devices to achieve limb imaging observations through spectral snapshots with a resolution better than 10 nm.
The instrument will be designed to be hosted by a small PROBA-like platform. Thanks to the attitude maneuverability of such platforms it will be possible to perform forward, backward and sideward limb observations.
This paper summarizes the objectives and the status of the ALTIUS mission.

1 MISSION OBJECTIVES

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 has allowed observing a decrease in the stratospheric halogen load and a slowing of ozone decline is expected to be the natural precursor of a complete ozone recovery around the mid-century. There is presently experimental evidence that the global mean ozone total column is no longer decreasing with respect to the 1998-2001 period. Also, the ozone stratospheric distribution has been relatively constant during the last decade although both dynamical and chemical processes may contribute to decadal changes in the lower stratosphere. On the other hand, column ozone loss in the 2010/2011 Arctic winter was among the largest ever observed whereas Antarctic ozone depletion has probably stabilized during the last decade.
Clearly, the monitoring of ozone stratospheric abundances is of crucial importance in assessing the milestones of a clear recovery process.

The number of available LEO atmospheric sounders has dropped 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.

There remain a few instruments working: SCISAT, ODIN, TERRA, AURA, and AQUA. Also some new sounders are now active (e.g. on METOP) but this is insufficient to ensure a full spatial and temporal coverage as well as a minimal redundancy in the measurement data set.

Some nadir-looking instruments of the GOME type possess a high horizontal resolution well suited for air quality, troposphere 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 step size, whereas a horizontal grid size of about 300 km, typical for occultation instruments, is acceptable
Recently (Apr 2012), a probable loss of ENVISAT has been announced whereas the launch period of the GMES Sentinel satellites dedicated to atmospheric monitoring, is still uncertain.

It is therefore urgent to address the following general recommendations in the frame of the monitoring of our environment from space:

- Continuity: the data products from satellite, which have to be integrated into a global picture, must have assured a long-term continuity.
- Gaps in observational coverage: for each target species and variable, the present gaps in the current spatial and temporal coverage should be filled by extending the existing measurement systems.
- Long-term validation of satellite observations: in order to ensure the accuracy and

consistency of satellite measurements, sustained quality-assurance measures, over the entire lifetime of satellite sensors, are essential.

- Validation of vertical profile data from satellite observations: a set of high-performance scientific instruments using ground, aircraft and balloon platforms, possibly operated on campaign basis, must be maintained to provide the crucial validation data.

For all these reasons, a launch of ALTIUS before 2016 is our target.

2 MISSION AND PAYLOAD REQUIREMENTS

It is worth keeping in mind that nadir-looking instruments are characterized by a high horizontal sampling along the tracks and a poor vertical sampling. On the contrary, limb pointing instruments shall offer a much better vertical resolution be it at the price of a limitation in geographical sampling, mostly determined by the orbital parameters and the measurement rate.
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 sampling similar to that of an occultation instrument but with coverage similar to that of a backscatter instrument

Since the pioneering work of the SOLSE/LORE [1] experiment, 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].

Also, the limb scattered light recorded by the upper and lower bands of the GOMOS detector (on board ENVISAT) has been investigated in order to develop an efficient inversion algorithm [5].

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 [6].

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.

Table 1 shows the scientific targets of the ALTIUS mission : the atmospheric species are defined according to their priority for the mission, their atmospheric region of interest, the target total error in retrieved profiles, the spectral range to be covered for their measurement, the measurement method and the required geophysical spatial resolution of the final product (concentrations) along the LOS (Δz), perpendicular to the LOS and parallel to the horizon (Δy) and vertically (Δx).
The atmospheric regions are defined following the IGACO [7] report: UT (Upper Troposphere : 5km to tropopause), LS (Lower Stratosphere : from tropopause up to 30km), US (Upper Stratosphere : 30km to 50km), MS (Mesosphere : >50km).

Table 1 ALTIUS geophysical requirements

Priority	Species	Atmosph. region	Total error (%)	Spectral range (nm)	Limb	Stellar Occultation	Solar occultation	Spatial res. ($\Delta z,\Delta y,\Delta x$) (km)
A	O_3	UT/LS	5	550-650,1020	x	x	x	500,10,1
	O_3	US	5	300-350/550-650	x	x	x	500,10,1
	O_3	MS	20	250-300, 1260-1280	x*	x	x	500,NA,1
B	NO_2	LS/US	30	450-550	x	x	x	500,50,2
	CH_4	UT/LS	20	1600-1800	x	x	x	500,50,2
	H_2O	UT/LS	20	900-1800	x	x	x	500,50,2
	CO_2	UT/LS	2	1550-1600			x	500,50,2
	BrO	UT/LS	20	320-360	x		x	500,50,1
C	OClO	UT/LS/US	25	320-400	x**	x	x	500,NA,1
	NO_3	LS/US	25	662		x		500,NA,1
	aerosol/PSC	UT/LS	25	250-1800	x	x	x	500,20,1
	O_2	MS	30	1260-1270/1530		x	x	500,NA,5
	PMC	MS	50	250-1800	x	x	x	500,20,1
	T°				x		x	

The primary 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 250-270 nm (Hartley band) in the mesosphere in occultation mode only. In limb mode, measurement will also be performed within the spectral range 290-330 nm which overlaps the Huggins and Hartley bands and allows to cover the altitude range 25-60 km. 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).

The global coverage shall have 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 shall be a spectral imager capable of observing the atmospheric limb in the UV (250-400 nm), VIS (400-800 nm) and NIR (800-1800 nm) domains, with a resolution better than 10 nanometers for VIS and NIR; and better than 2.5 nm for UV. For each wavelength range, a distinct Acousto-Optic Tunable Filter (AOTF) will be the preferred technology to perform observations of selectable small wavelength windows. Ideally, a typical set of 10 wavelength domains shall be recorded in 1 second to record sufficient spectral information content about the priority 1/priority 2 chemical species with a maximal geographical resolution. However, the measurement time shall be possibly increased up to 50-100 s in the worst case to improve the S/N ratio of the measurement. Also, pixel binning (up to 100) shall also be possible for the same purpose at the price of a reduced transversal resolution.

In its main observation mode, ALTIUS shall be a limb remote sounder using spectral imagery and has to be inserted in a LEO circular helio-synchronous orbit (650-700 km) with a descending node at 10:00-10:30 am and allowing for a 3-day revisit time, which are close to the ENVISAT orbital parameters.

For a limb imager, the impact on the geophysical interpretation will be very different if the line-of-sight is along a parallel or along a meridian where larger concentration gradients are expected to occur (e.g. at the edge of the polar vortex).

Information about the horizontal gradients will be obtained from a side limb observation and will be mainly influenced by the spacecraft velocity and the acquisition time.

A proven observation technique is “hyper-spectral” remote sounding, where typically nadir-looking instruments are used to build a spectral hypercube consisting of pixel maps at different wavelengths. The acquisition mode of this hypercube is influenced by the spectrometer/detector technology. A grating or prism is combined with a 2D-detector of which one dimension is associated with wavelength, whereas the other dimension is a spatial dimension. The third dimension of the hypercube is constructed by some scanning process.

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 instrument shall be basically an imager with the limb itself as scope (Fig 1). 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), such as using: (1) background stars in the scene and (2) satellite star tracker information.

The use of an imager instead of using a scanning procedure is highly beneficial for the geometrical calibration of the observed scene.

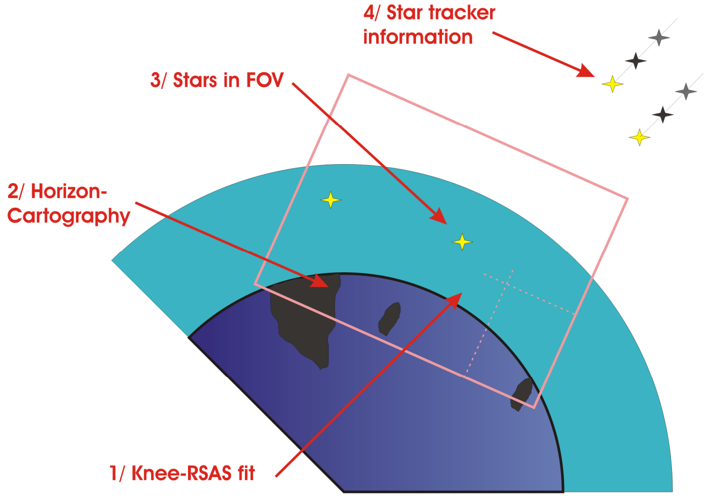

Figure 1 The attitude registration in limb observation mode is performed by the combination of the star tracker information, the position of stars in FOV and geographic features.

Atmospheric remote sensing will be operated in three different geometries: limb view, solar and stellar occultations as illustrated by Fig 2:

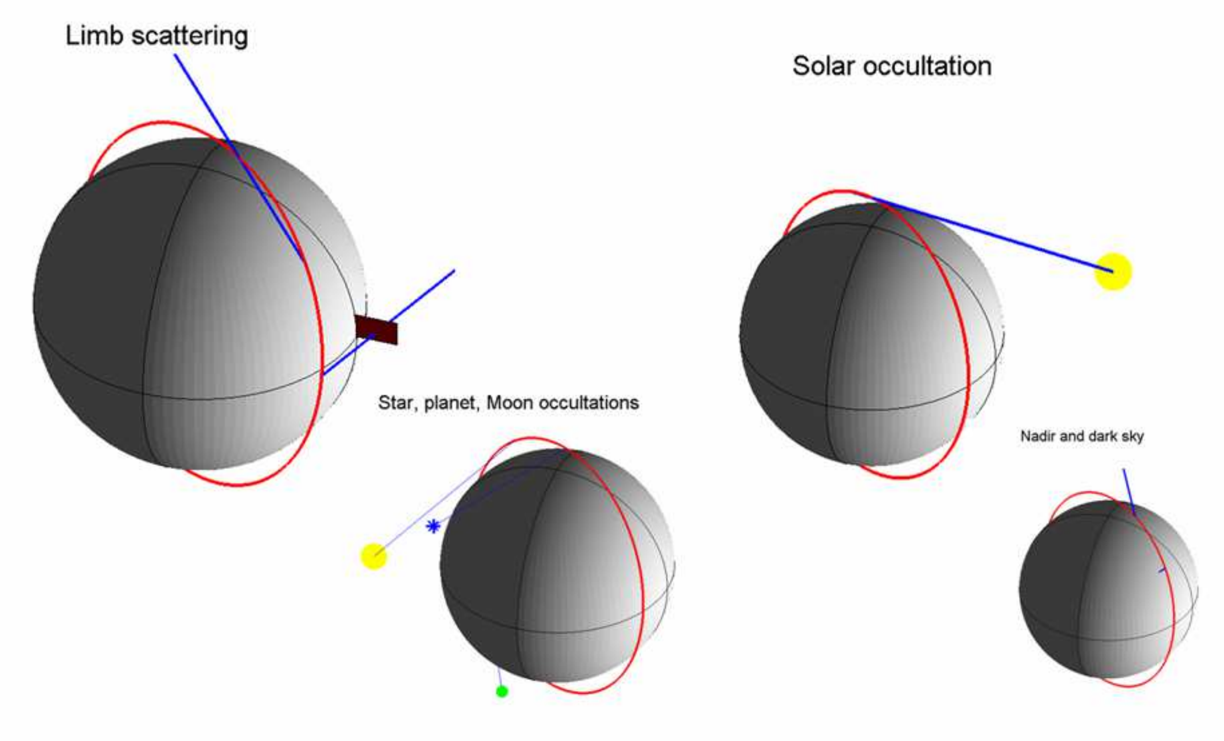

Figure 2 The three observation geometries of ALTIUS: limb, solar and stellar occultations.

Table 2 gives a summary of the ALTIUS technical requirements.

Table 2

Geophysical targets		
Atmospheric objectives from highest priority to lowest.	1. Global measurement of the ozone concentration vertical profiles with an accuracy of 5 % between 10 and 50 km, and of 20 % between 50 km and 100 km. 2. NO_2, CH_4, H_2O, BrO concentration vertical profiles with an 10-30 % accuracy between 10 and 50 km 3. OClO, NO3, aerosol-PSC concentration vertical profiles with an 20-30 % accuracy between 20 and 30 km; mesospheric O2 and PMC	
Instrumental requirement		
Independent spectral modules	UV (250-400 nm) Visible (400-800 nm) NIR (800-1800 nm)	Resolution better than 10 nm in the Visible and NIR. Resolution better than 2.5 nm in the UV. High mission resilience wrt to module failure
Spectrometer	One acousto-optical tunable filter (AOTF) imager per spectral range	KDP crystal in UV TeO2 crystal in Visible and NIR

Measurement modes	Limb observation: scattered solar light in bright limb Stellar occultation: dark limb only Solar occultation: at terminator (high latitudes)	
Pointing accuracy	100 µrad	
Pointing precision	100 µrad	Vertical sampling of about 600 meters (corresponding to twice the pointing precision)
FOV	0.1 x 0.1 rad	
Pixel field at tangent height	about 0.5 x 0.5 km	
Spatial dynamical range	10 000 -100 000	
Spectral dynamical range	1000	
Orbital Characteristics		
Orbit	LEO circular helio-synchronous orbit	revisit time: 3 days
	Descending node at 10:00-10:30	typical altitude range: 650-700 km
Global coverage	Resolution of 5° in latitude, 10° in longitude.	
General Characteristics		
Launch date	<= end 2015	
Mission duration	3-5 years	A 6 month commissioning phase is also scheduled.
Spacecraft Characteristics		
Satellite type	Dedicated platform (micro-satellite)	High manoeuvrability and autonomy
Operability	Dedicated to a single payload to run nominal and particular mission scenarios.	
Pointing speed	Average rate for changing pointing direction of 1° per second and per axis	
Minimal notification time before measurement	12 hours	High reactivity
Data Characteristics		
Bright limb observation		
Typical number of bright limb observations per orbit (1-10 sec)	50	Over half an orbit (bright side). S/N ratio may be increased by horizontal pixel binning and acquisition time (< 50-100 sec)
Typical number of spectral images per observation in the UV spectrum	4	
Typical number of spectral images per observation in the visible spectrum	4	
Typical number of spectral images per observation in the IR spectrum	4	
Imaging on the entire detector	yes	Usable detector subrange may depend on spectral module
Star occultation		

Typical number of star/planet occultations per orbit	10	
Typical number of observation per occultation	50	
Typical number of spectral images per observation in the UV spectrum	4	
Typical number of spectral images per observation in the visible spectrum	4	
Typical number of spectral images per observation in the IR spectrum	4	
Imaging on the whole detector	No	Windowing with possible on-board preprocessing
Typical number of solar occultations per orbit	2 (Sunset and Sunrise)	
Typical number of observation per occultation	50	
Typical number of spectral images per observation in the UV spectrum	4	
Typical number of spectral images per observation in the visible spectrum	4	
Typical number of spectral images per observation in the IR spectrum	4	
Imaging on the whole detector	No	Windowing with possible on-board preprocessing
Detector size	512x512 pixels	
Dynamical range	>=14 bits	
Number of images	600 full images and 7200 windowed images	
Daily contact time for downlinking	50°North Station (Redu: >=35 min)	
ALTIUS ground segment		
Mission segment, containing the Mission Operations Centre (AMOC)	Responsible for the mission planning of the ALTIUS project	
ALTIUS Science and Payload Operations (ASPO)	combined operational science and payload segment, located at BIRA-IASB. Data processing and archiving will be operated in ASPO.	ASPO has to contain the Science Operations Centre (ASOC) that has to be responsible for the operational planning of the ALTIUS project
Science team	Scientific advisory group for the scientific planning of the ALTIUS project through the definition of a Science Master Plan (SMP).	

3 CONCEPTUAL DESIGN

A prototype matching the current optical specifcations of the visible spectral channel was designed by the company OIP and manufactured by IASB. The only differences with ALTIUS are the use of COTS parts and a linear optical design made of lenses instead of a folded optical path made of mirrors. This visible channel breadboard was tested against compliance to requirements by OIP from September 2010 to January 2011 where a final review of the tests results took place at ESA and concluded to the acceptance of the breadboard. A complementary objective was decided to demonstrate the measurement capabilities of atmospheric trace gas concentration profiles.
The breadboard remote sensing capabilities were recently tested in harsh conditions by observing the turbulent plume of a waste incinerator near Toulouse (France) at a distance of 3.5 km (Fig 3). From successive pictures at two well-chosen wavelength pairs, we could detect the presence of NO2 within the smoke and estimate its concentration nearby the stack outlet. The total measurement time was only 10 seconds.

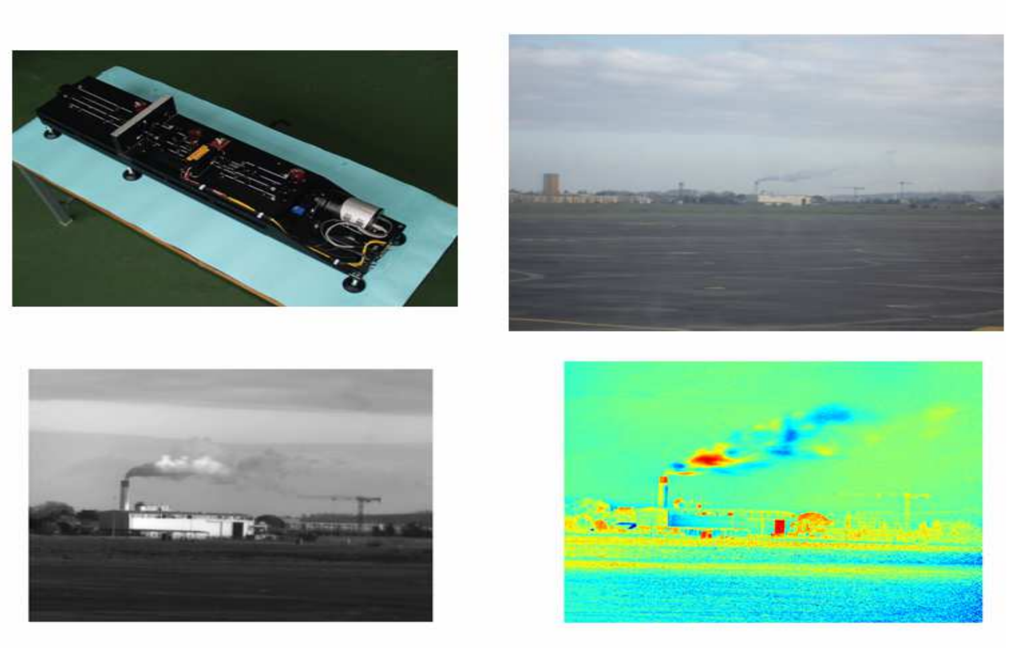

Figure 3 Top: ALTIUS visible breadboard (left); handheld camera picture of the oberved scene (right). Bottom: snapshot at 645 nm (left) . Differential measurement in the NO_2 band (right).

The optical design of the ALTIUS payload has similar arrangements in all the channels. This construction consists of the following components (Fig 4):

1. Front Optics (FO) – for NIR and VIS: it is an objective that constructs from 3 off-axis mirrors. The VIS channel also has a lens in front the objective. For UV there are 2 modules (StO and BL); each contains its own mirror objective.
2. AOTF Module – that consists of the AOTF unit with front and back polarizers and also 2 folding mirrors.
3. Back Optics (BO) – this part includes relay optics that are based on mirrors. This optics was arranged in the same folding configuration for all the channels in order to enable similar mechanical benches.

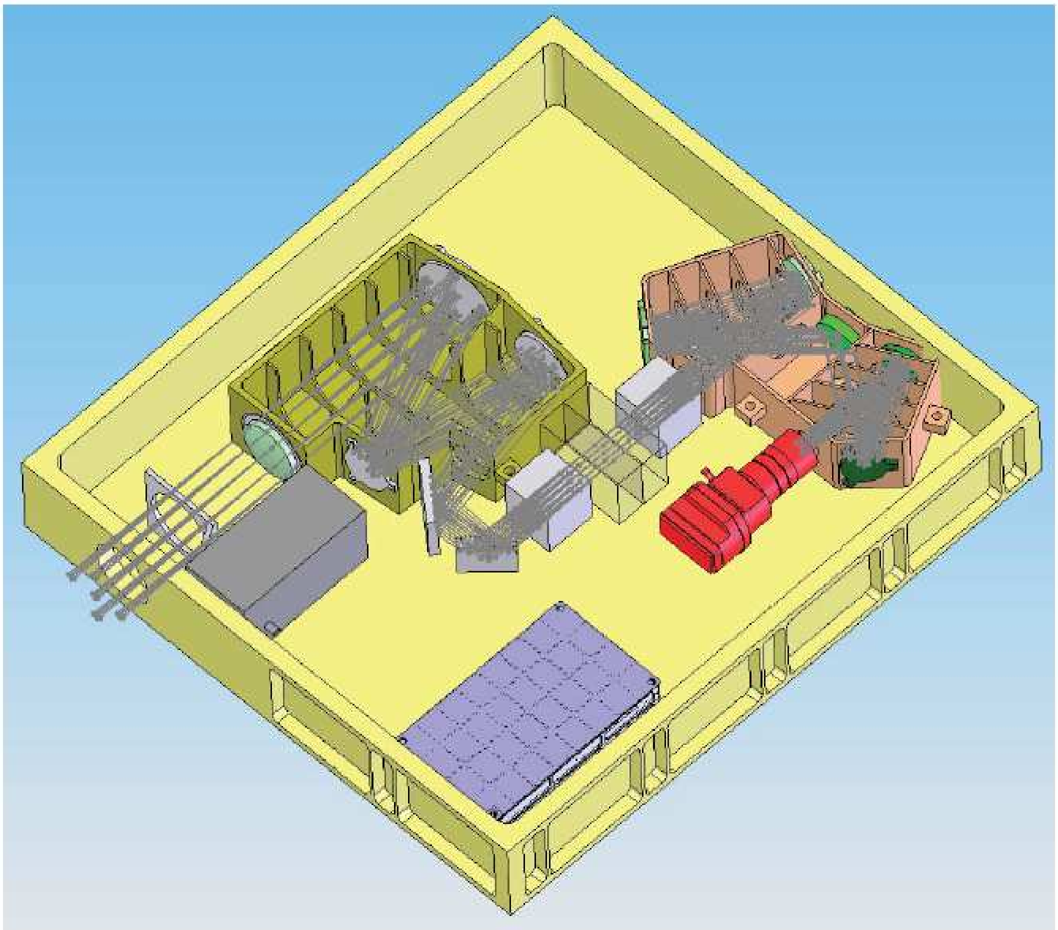

Figure 4: Conceptual design of the ALTIUS visible channel. Notice the neutral filter mechanism after the aperture in order to perform solar occultation measurements.

Hereafter we present the system conceptual design as reviewed at the end of the B0 phase (actually a phase A consolidation).
The payload has increased in size (height) after the conceptual design, meaning a need for the two vertical internal S/C panels to be moved more apart This would have had a considerable impact on the overall S/C structural stiffness. The original PROBA spacecraft baseline is including an internal “H” structure, meaning an additional internal panel in between and perpendicular to the other two panels.
Putting the payload at the top of the S/C allows togo back to the original “H” structure resulting in a S/C with more stiffness and less mass. An additional advantage of the new accommodation is that the spacecraft design is more independent from the height of the instrument. A limited change in height of the instrument can be done without a complete redesign of the spacecraft (see Fig 5)

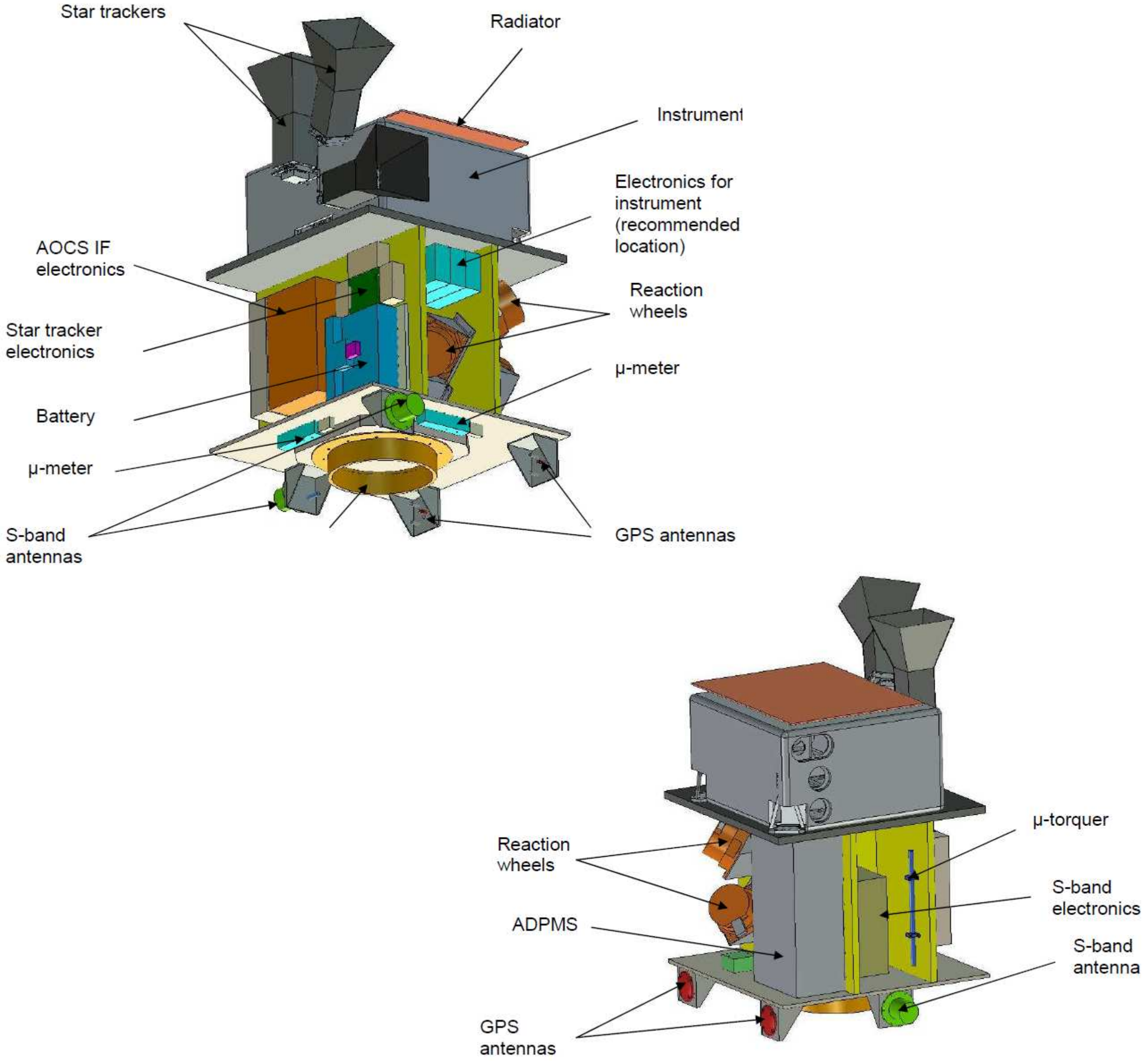

Figure 5: Preliminary spacecraft accomodation

4 SUMMARY

The ALTIUS mission has successfully passed a phase B0 review and is ready for a phase B that should lead to a full PDR.

The payload concept design was performed to meet scientific requirements with an opto-mechanical concept (improve SNR, image quality, reduce number of mechanisms, fit into the available envelope), a thermal concept (thermal stability, reduction of the detector noise) and an electrical preliminary design. The SNR performance meet most of the scientific requirements and the payload budgets were established for mass, power and data rate.

The spectrometer technology used in the visible and NIR channels will be based on AOTF devices using TeO_2 crystals. The development of a UV-AOTF with a KDP crystal is still ongoing and the selected spectrometric technique for this channel has not yet been decided.

The platform design is based on a PROBA microsatellite concept and all studies have demonstrated a positive budget for power, pointing, data rate and memory, link and processing. A simple thermal balance analysis has been performed to support P/L thermo-elastic study. Finally, it is worth mentioning that an ALTIUS Scientific Advisory Group (ASAG) has been set up with a participation of international experts in the field of atmospheric remote sensing.

Figure 6: Artistic view of the ALTIUS spacecraft close to the terminator.

5 ACKNOWLEGDMENTS

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