THE ALTIUS PAYLOAD

L. Aballea[1], W. Moelans[1], L. De Vos[1], B. Luyssaert [2], B.Dierickx[2], D. Nevejans[3], E. Neefs[4], J VanHamel[4], D. Pieroux[4], E. Dekemper[4], F. Vanhellemont[4], D. Fussen[4]

[1] OIP, Westerring 21- 9700 Oudenaarde- Belgium,
+32 (0)55 33 38 11, ldv@oip.be
[2] Caeleste, Hendrik Consciencestraat 1 b -2800 Mechelen, Belgium
+32(0)15710513, bert.luyssaert@caeleste.be
[3] CONSERD, Krekelstraat 27 - 9052 Gent-Belgium, 09 222 63 69,
Dennis.Nevejans@conserd.net
[4] BIRA-IASB, Ringlaan 3 - 1180 Brussels- Belgium, 02 373 04 04,
Eddy.Neefs@oma.be

ABSTRACT

Since 2005-2006, the number of available space instruments atmospheric sounders with a high vertical resolution has dropped significantly having important consequence in the monitoring of long term trends for essential atmospheric species like Ozone. The ALTIUS (Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere) mission, inscribed in this frame, has been initiated to contribute to atmospheric trace gasses monitoring with high vertical resolution from space.

The ALTIUS mission will consist of a 2D spectral imager payload onboard a small satellite, PROBA type, flying over a Sun-Synchronous Orbit at an envisaged altitude about 700 km. The PI of the mission will be BIRA-IASB; Qinetiq Space will be mission prime and supplier of the satellite, and OIP will be the industrial prime contractor for the instrument.
The ALTIUS payload is a 2D spectral imager that will be developed for ESA to allow observing the Earth's atmospheric bright limb in an extended spectral region from the Ultraviolet to the NIR. In addition, the ALTIUS instrument will allow performing solar and stellar occultation observations in the dark limb, and will occasionally perform dark space and nadir (bright side) observations.

In the Visible (400-800nm) and NIR (900-1800nm) spectral range, the ALTIUS payload makes use of an Acousto-Optic Tunable Filter (AOTF). By scanning through the spectral domain of each channel, the AOTF will permit to perform observations with a spectral resolution better than 10 nm in a fast and flexible way.
In the UV range (250-400nm), the maturity of the UV-AOTF is not yet sufficient to guarantee successful operation within a short time frame in terms of development risk. For this spectral range, other filter technologies are under investigation.

The following topics were considered to be crucial for a successful ALTIUS project, and they are investigated during the phase B1 of the project:

- The Signal to noise ratio obtained at different wavelengths
- Payload performance
- Instrument calibration requirements
- Optimization of the instrument concept in terms of Engineering budgets

In this paper the preliminary concept of the ALTIUS instrument will be presented, as well as the goal and results of the presently ongoing phase B1.

1. AREA OF RESEARCH

Remote sounding from LEO satellites is the basis of the global monitoring of trace gas concentration profiles and trend assessments of the chemical composition of the Earth's atmosphere. Different observation methods can be combined that offer various advantages like geographical coverage, horizontal and vertical resolutions and calibration. The most known techniques are star/solar occultation, thermal emission sounding and limb scattering observation.

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 published for OSIRIS on board ODIN [2], for SCIAMACHY on board ENVISAT [3], and for the SAGE III mission before its premature end [4].
With the advent of imaging detectors, a simple method for wavelength multiplexing is made possible. In a diffraction grating instrument the rays corresponding to different wavelengths are dispersed inside the instrument, exit at different angles and are imaged at different detector locations. Different wavelengths fall on different elements of the detector in a direction perpendicular to the entrance slit of the instrument, and all wavelengths are recorded simultaneously. If a two-dimensional (array) detector is used, then spatial information can be obtained in the direction parallel to the entrance slit.
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]. It is highly desirable to achieve a full observation of the sounded limb region in order to calibrate the field-of-view with respect to the tangent altitude. The spectral filtering of the incoming radiance has then to be performed by some independent element along the optical path of the instrument. Apart from filter wheels and Fabry-Perot spectrometers, a very promising solution is obtained by the use of acousto-optic tunable filters (AOTF). The envisaged ALTIUS payload will make use of this spectral filtering technique.

2. ALTIUS SCIENTIFIC TARGETS.

The scientific targets of the ALTIUS mission are shown in Table 1. 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 spatial resolution[1] required (along the LOS (Δx), perpendicular to the LOS and parallel to the horizon (Δy) and vertically (Δz)).
The atmospheric regions are defined following the IGACO report: UT (Upper Troposphere: 5km to tropopause), LS (Lower Stratosphere: tropopause to 30km), US (Upper Stratosphere: 30km to 50km), MS (Mesosphere : >50km).
Priority A targets and their associated requirements represent the minimal objectives to be fulfilled to guarantee a successful mission. The scientific return of the mission can be further optimized if in addition priority B and C constituents can be retrieved with the mentioned accuracy.

[1] ALTIUS being a limb viewing instrument, the spatial resolution is defined with respect to the line of sight (LOS) and not with respect to the ground track at nadir.

Table 1. Scientific targets of the ALTIUS mission sorted by scientific priority

Priority	Species	Atmospheric region	Total error (%)	Spectral range (nm)	Limb	Occulta-tion	Spatial resolution (Δx,Δy,Δz) (km)
A	O_3	UT/LS	5	550-650,1020	x	x	500,10,1
	O_3	US	5	300-350/550-650	x	x	500,10,1
	O_3	MS	20	250-300, 1260-1280		x	500,NA,1
B	NO_2	LS/US	30	450-550	x	x	500,50,2
	CH_4	UT/LS	20	1600-1800	x	x	500,50,2
	H_2O	UT/LS	20	900-1800	x	x	500,50,2
	CO_2	UT/LS	2	1550-1600	x	x	500,50,2
	BrO	UT/LS	20	320-360	x		500,50,1
C	OClO	UT/LS/US	25	320-400		x	500,NA,1
	NO_3	LS/US	25	662		x	500,NA,1
	aerosol/PSC	UT/LS	25	250-1800	x	x	500,20,1
	O_2	MS	30	1260-1270/1530		x	500,NA,5
	PMC	MS	50	250-1800	x	x	500,20,1

3. THE ALTIUS MISSION

It is the aim of the mission to allow observation of 2-D images of the Earth atmosphere's bright limb. During such observation the instrument will cover an altitude range of 100 km at the earth Tangent point observing in the same time the atmosphere (approximately 100 km) as well as reference stars, and possible reference points (geographic features) located on the Earth's surface.

These observations will be performed sequentially in different randomly selectable small wavelength domains. In addition other observation modes will be available such as solar occultation at the terminator, stellar occultation in the dark limb, and occasionally dark space and nadir (bright limb) observations.

Therefore the ALTIUS instrument will operate in various modes in a broad wavelength range and with large differences in light intensity across the observed scenes.

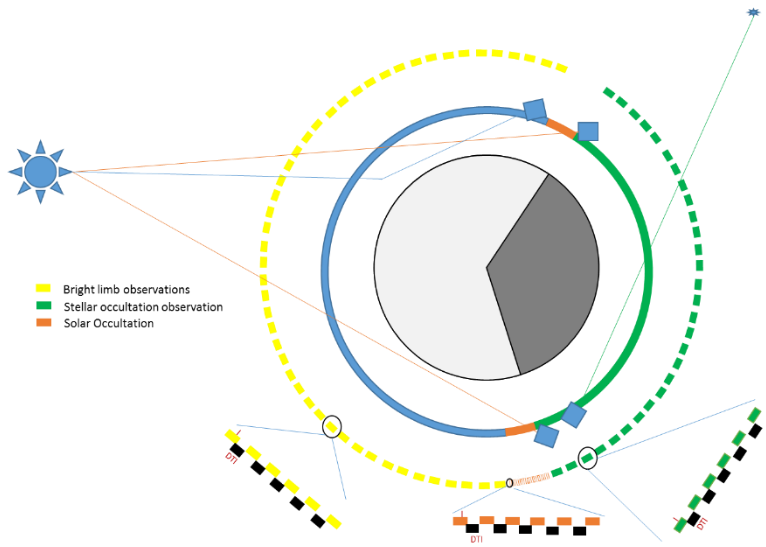

Fig. 1. Different observation modes for ALTIUS

Global coverage has to be performed in a delay equal or less than 3 days, with a resolution of 5 degrees in latitude and 10 degrees in longitude, which is a threshold requirement for the accuracy of present chemical assimilation models. The ALTIUS mission will follow a sun-synchronous orbit with an altitude of 668.5 km and a local time of 10:00, and will allow for a revisit time of 3 days.

4. THE ALTIUS PLATFORM.

The ALTIUS instrument will be mounted on a PROBA platform, currently under design at QinetiQ Space, in the frame of the PROBA-Next activity (Fig. 2). Unlike in previous PROBA platforms, the solar cell are all accommodated using deployable panels.
The spacecraft will be 3-axis stabilized. The stabilization will be done by 3 star trackers, 4 reaction wheels, a GPS receiver and 2 antennas, 3 magneto-torquers and 2 magnetometers. For communication, an S band receiver and transmitter, complemented by an X-band transmitter, will be used.

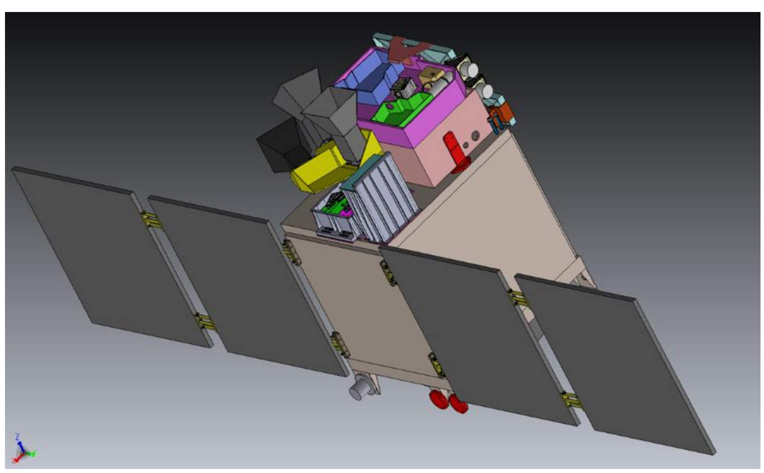

Fig. 2. PROBA spacecraft

The payload, which is composed of an optical bench and two electronic boxes, will be located on top of the S/C bus. The payload optical bench is isostatically mounted on the satellite's deck and interfaces the three Star trackers for optimized pointing performances. The payload electronic boxes are hard mounted onto the satellite’s deck.

The mission is currently foreseen to fit for a dual launch onboard a VEGA launcher. For the payload, the allocated mass is 56 kg and the average power budget over an orbit is 45 W.

5. THE ALTIUS PAYLOAD CONCEPT

5.1. General description

The ALTIUS payload overview diagram is shown in Fig. 3. 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.

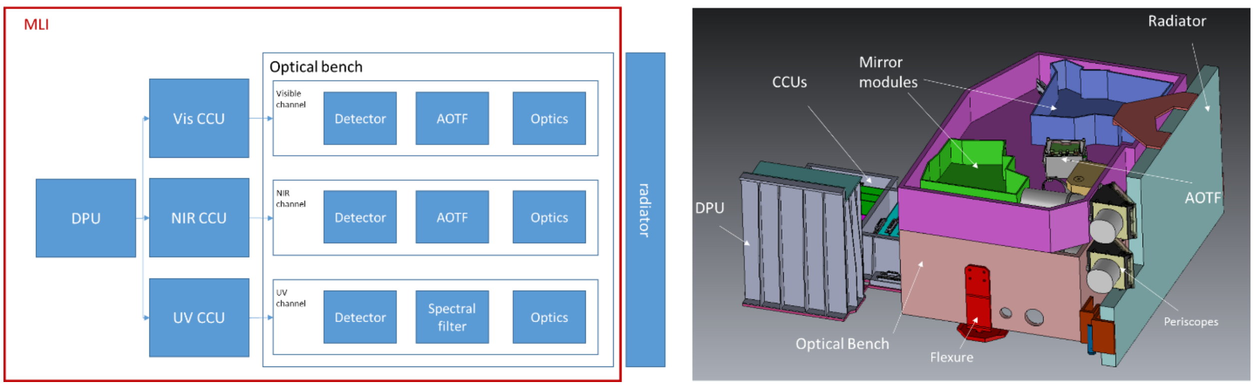

Fig. 3. ALTIUS payload block diagram (left) ALTIUS payload concept (right)

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.

5.2. 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

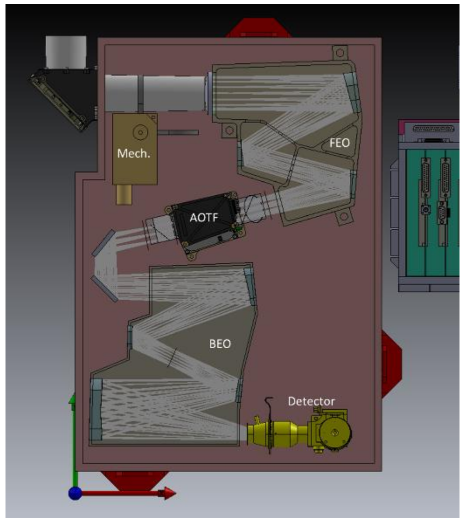

Fig. 4. ALTIUS NIR channel opto-mechanical design

The three optical channels of the ALTIUS payload will comply with the specifications as summarized in table 2.

Table 2: 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 mm^3

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 3. 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 3: 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 Fig. 5. The intermediate image from the FEO is located outside the AOTF crystal in order to reduce images non uniformity.

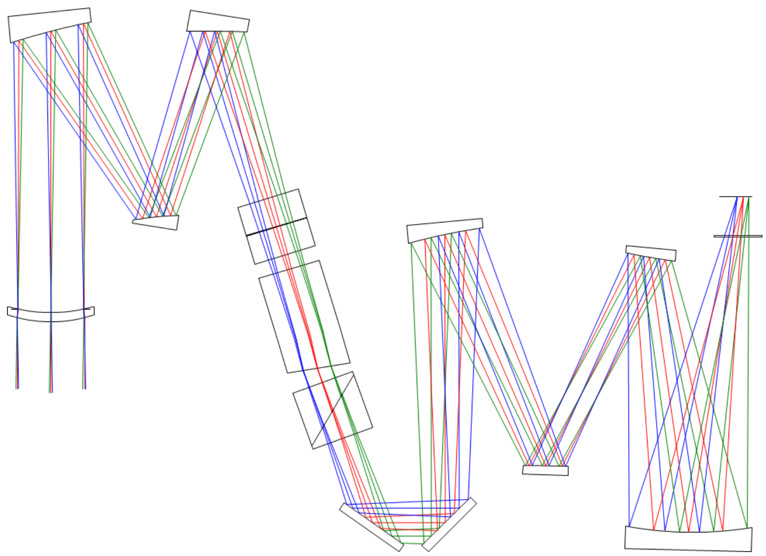

Fig. 5: Preliminary optical design of NIR channel.

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 are considered being respectively 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 have been currently submitted to the instrument PI and the Agency to select only one concept which will be worked out further.

5.3. 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 Fig. 6), 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.

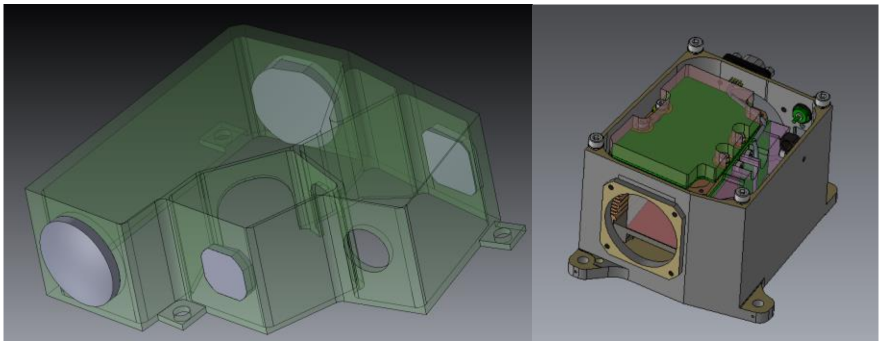

Fig.6: Opto-mechanical module (left) AOTF housing (right)

All these modules are mounted onto the optical bench structure of the instrument. The optical bench of the instrument is presented in Fig.7 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.

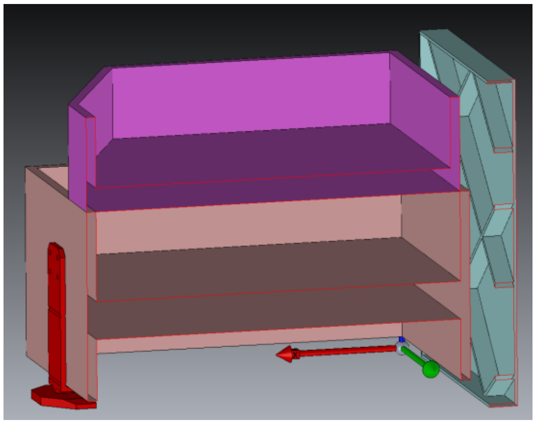

Fig. 7: Optical bench structure

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.

5.2. Electrical concept description

The main design drivers for the electrical part of the payload are the detectors and their temperature control, the control of the mechanisms, the AOTF RF drivers and the limited power availability on the PROBA platform. The electronics units of the ALTIUS payload concept are shown in Fig. 8.

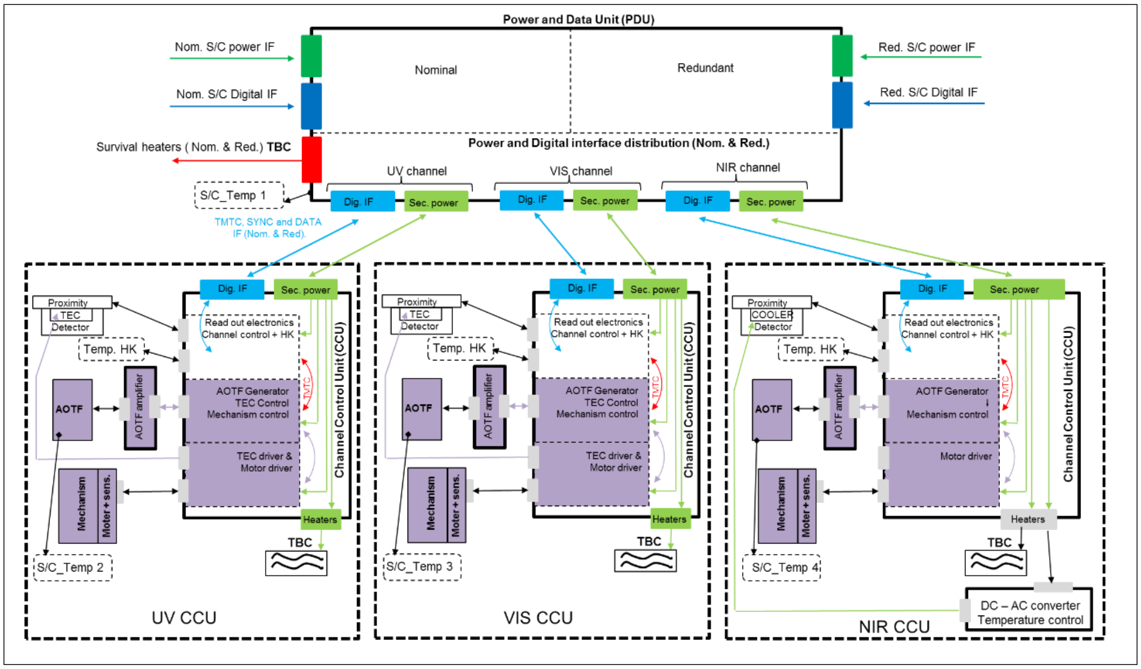

Fig. 8. Electrical concept of the ALTIUS payload

The DPU stores the entire script of actions to be performed by each channels during an orbit as received from S/C. The DPU distributes scripts subsets to be executed by the different CCUs (mechanism actuations, imaging…). The DPU is in charge of the data compression before transfer to the S/C on-board mass memory. The DPU provides also regulated power to all instrument subunits and heaters. It's a fully redundant unit at power and data level.

The CCU is composed of three PCBs:

- ROE: Doing detector setting and readout and also taking care of the general channel control
- ATMC: Doing the Spectral filter handling, detector temperature regulation and mechanism control
- Driver board: Steering the mechanism driving and the TEC

The CCU is the core electronics of each channel. It stores the subscript containing all informations to acquire several images and control the detector readout, the AOTF RF generation and amplification the mechanisms actuations and the detector temperature regulation via a TEC in UV and VIS or a Stirling cooler for the NIR. It communicates with the DPU and transfer raw data to it for compression.

The overall instrument electrical concept and command and control approach has been defined in order to preserve for the user an extended flexibility of imaging configurations and fulfill the different observations situation required for the mission.

5.3 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. 9. 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.

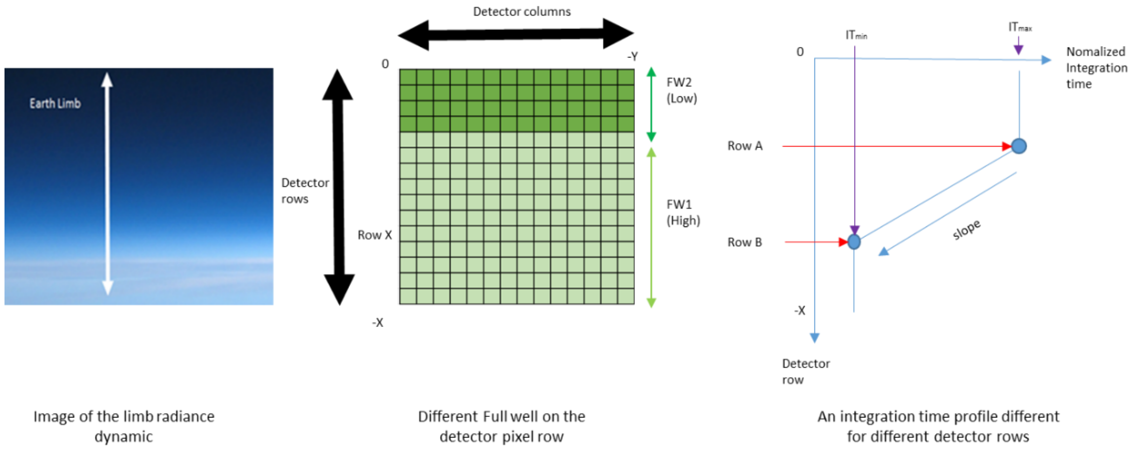

Fig. 9. Typical bright limb radiance dynamic and UV-VIS Detector properties, FW=full well

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[2]. 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.

[2] The HDR device from which ALTIUS pixel is inspired is currently under test at Caeleste.

6. REFERENCES

[1] McPeters et al. GRL, 27, 2597-2600, [2000]
[2] Haley et al. JGR, 109, doi:10.1029/2004JD004588 [2004]
[3] Brinksma et al. ACPD, 5, 4893-4928, [2005]
[4] Rault, JGR, 110, doi:10.1029/2004JD004970 [2005]
[5] von Savigny et al. ACPD, 5, 3701-3722, [2005]
[6] Dekemper et al. Appl Opt; 51(25):6259-67[2012]