ICSO 2016

International Conference on Space Optics

Biarritz, France

18–21 October 2016

Edited by Bruno Cugny, Nikos Karafolas and Zoran Sodnik

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esa icso proceedings cnes

International Conference on Space Optics — ICSO 2016, edited by Bruno Cugny, Nikos Karafolas,
Zoran Sodnik, Proc. of SPIE Vol. 10562, 105621Q · © 2016 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2296136

ATLID, ESA ATMOSPHERIC LIDAR: MANUFACTURE AND TEST RESULTS OF INSTRUMENT UNITS

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INTRODUCTION

After the successful closure of the Critical Design Review (CDR), the development of the ESA (European Space Agency) ATmospheric LIDAR (Light Detection and Ranging) is now approaching the completion of the manufacturing and testing of all its units and the start of the full instrument integration and qualification campaign. The key units, that have already been manufactured and tested, and that are described in this paper include: the Housing Structure Assembly (HSA), the Stable Structure Assembly (SSA), ATLID telescope with M1 and M2 mirrors, Entrance Filter Optics (EFO) and Blocking Filter (BF), the Co-Alignment Sensor (CAS), the High Spectral Resolution Etalon unit (HSRE), Fiber Coupler Assembly (FCA), the Memory Charge-Coupled Device (MCCD) detectors, Instrument Detection Electronics (IDE), ATLID control and Data Management Unit (ACDM), Laser Cooling System (LCS), Beam Steering Mechanism (BSA), the Emitter Beam Expander (EBEX) and the Laser Transmitter (TxA). Considerable achievements have been achieved in the last year, with the completion of manufacturing, qualification and testing of most of ATLID units. For example the ATLID Power Laser Head (PLH) Proto-Flight Model (PFM), one of the most critical units, has been fully integrated and completed its qualification test campaign demonstrating to be compliant with its main performance requirements. The ATLID PLH PFM has demonstrated emission of UV pulsed laser radiation at 51Hz with pulse energy higher than 40mJ. With the delivery of the first units the ATLID instrument is now starting the instrument assembly and integration programme.

I. ATLID, THE ESA ATMOSPHERIC LIDAR:

A. The EarthCARE mission

The ATmospheric LIDAR ATLID[1] [2] is part of the payload of the Earth Cloud and Aerosol Explorer[3] (EarthCARE) satellite mission, the sixth Earth Explorer Mission of the European Space Agency (ESA) Living Planet Programme . EarthCARE, Fig 1, is a joint collaborative satellite mission conducted between ESA and the National Space Development Agency of Japan (JAXA) that delivers the Cloud Profiling Radar (CPR) instrument. The payload consists of four instruments on the same platform with the common goal to provide a picture of the 3D-dimensional spatial and the temporal structure of the radiative flux field at the top of atmosphere, within the atmosphere and at the Earth's surface. Clouds and aerosols are currently one of the biggest uncertainties in our understanding of the atmospheric conditions that drive the climate system. A better modelling of the relationship between clouds, aerosols and radiation is therefore amongst the highest priorities in climate research and weather prediction.

Fig. 1. Artistic view of EarthCARE satellite

EarthCARE aims to the determination of cloud and aerosol occurrence, structure and physical properties together with collocated measurements of solar and thermal radiation at a global scale. The mission goals are to retrieve vertical profiles of clouds and aerosols, and the characteristics of their radiative and micro-physical properties, to determine flux gradients within the atmosphere and fluxes at the Earth's surface. By measuring directly the fluxes at the top of the atmosphere while clarifying the processes involved in aerosol-cloud and cloud-precipitation-convection interactions will allow to include them correctly and reliably in climate and numerical weather prediction models. The EarthCARE satellite shall achieve its mission through the operation, individual and in synergy, of its four instruments: ATLID, the CPR, the Multi-Spectral Imager (MSI) and the Broad-Band Radiometer (BBR).

B. ATLID design and measurement principle

The task of ATLID, Fig 2, is to provide vertical profiles of optically thin cloud and aerosol layers, as well as the altitude of cloud boundaries. The measurements of ATLID are close to the nadir direction from a sun-synchronous orbit at 393 km altitude. These profile measurements have a vertical resolution of about 100 m from ground to an altitude of 20 km and 500m from 20km to 40km altitude. The instrument emits short laser pulses at a repetition rate of 51 Hz along the horizontal track of the satellite trajectory, so that several shots can be locally averaged to improve the signal to noise ratio. ATLID is a backscatter LIDAR instrument that uses the fact that interaction of light with molecules and aerosols leads to different spectra scattering effects. Whereas the Brownian motion of molecules induces a wide broadening of the incident light spectrum, the scattering with an aerosol does not affect the spectrum shape of the incident light. As a consequence, a simple means of separating the backscattering contributions consists in filtering the backscattered spectrum with a high spectral resolution filter centered on the emitted wavelength. This way the instrument is able to separate the relative contribution of aerosol (Mie) and molecular (Rayleigh) scattering, which allows the retrieval of the aerosol optical depth. Co-polarised and cross-polarised components of the Mie scattering contribution are also separated and measured on dedicated channels. The operating wavelength in the Ultra-Violet spectral range (355nm) was selected as the molecular scattering is high enough to measure accurate extinction profiles and aerosols/thin clouds thickness, and because laser technology (Nd:YAG laser with frequency tripling conversion) is available for operation in this spectral region.

ATLID is designed as a self-standing instrument reducing the mechanical coupling of instrument/platform interfaces and allowing better flexibility in the satellite integration sequence. The instrument is based on a bi-static architecture consisting of two independent main sections, the emitter chain and the receiver chain, Fig 2. The instrument functions are shared between a 'high stability' assembly (including the telescope, focal plane optics, and the optical emission chain), and a housing structure assembly (supporting the electronic units and their radiator, the detection chain and the harness). The instrument has already completed its detailed design, and most of its units Flight Model (FM) have been manufactured and are running, or already completed, its specific qualification activities.

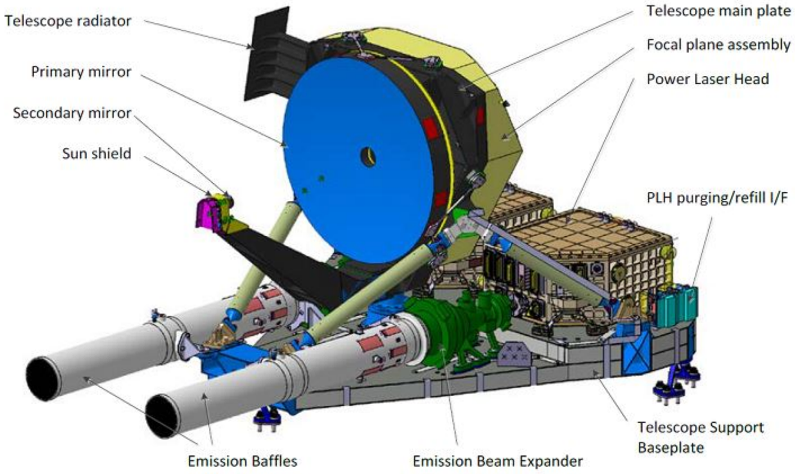

Fig. 2. High stability assembly of ATLID with both emission and receiver chains

II. ATLID KEY UNITS MANUFACTURING STATUS AND PERFORMANCE:

A. The emission chain:

The <u>Transmitter Assembly (TxA)</u> is the laser source for the ATLID LIDAR. It comprises a Power Laser Head (PLH), seeded via a fibre optic by a Reference Laser Head (RLH), Fig 3, and its associated Transmitter Laser Electronics (TLE). There are two fully redundant transmitters (in cold redundancy), each including both laser heads (PLH and RLH) and a Transmitter Laser Electronics (TLE). This ATLID core equipment has been designed and manufactured by LEONARDO, with a subcontract to TESAT for the RLH.

The PLH design is based on a diode-pumped tripled Nd:Yag laser providing a high energy pulse at 355 nm. It is operated in steady-state mode with 51 Hz pulse repetition frequency (PRF) during the nominal measurement mode. While the laser transmitter is largely inheriting from the Aladin instrument development for the AEOLUS mission [4], a significant evolution has been achieved by the fact that the ATLID PLH is sealed and pressurized in order to improve its tolerance to Laser Induced Contamination.

Two laser transmitter flight models have been manufactured. The first transmitter proto-flight model (PFM) has completed its qualification campaign and will be delivered in September. Cumulative shots reach above 150 MShots including a continuous burn in test during 4 weeks. This model demonstrated compliance with the main requirements: pulse energy is 43mJ (38mJ spec), pulse duration 34ns (35ns spec), output beam size 7.5x8.6mm² and laser beam divergence is 170µrad (spec 300µrad).The second TxA model has completed integration and will start environmental test in September.

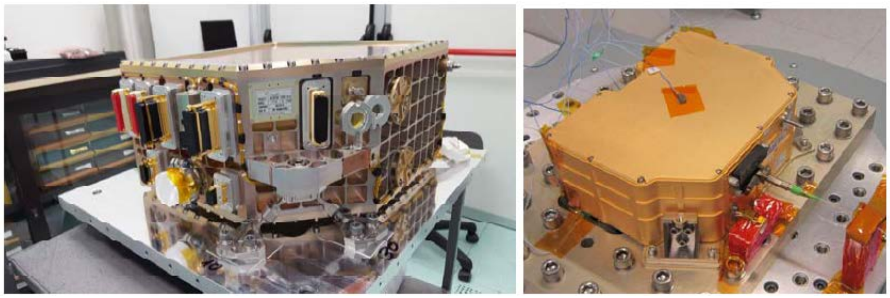

Fig. 3. Power Laser Head and Reference Laser Head flight models

The <u>Beam Steering Assembly (BSA)</u>, Fig 4, is a full custom frictionless lag-angle compensating mechanism using amplified piezo-actuators, dedicated to slightly tilt a mirror which reflects ATLID laser beam inside the PLH. According to commands sent by ACDM, the BSA enables to act on the laser beam direction along 2 directions within a +/-3 mrad range, to fulfil the co-alignment of both emitted and received beams with outstanding accuracy and stability (own closed loop control).

The two flight models (one for each emission chain) have been designed and manufactured by Sodern, and delivered in July 2015 and December 2015 with all performances compliant to the specified requirements.

Among its key performances, the resolution is better than 1 µrad, with a long term stability better than 90 µrad and a repeatability better than ± 30 µrad. The response time is < 90 ms for small displacements and < 250 ms for large ones.

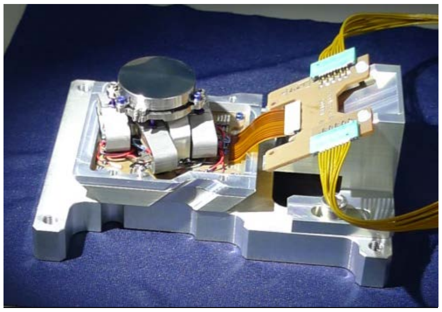

Fig. 4. Beam Steering Mechanism

The <u>Emission Beam Expander (EBEX)</u> , Fig 5, is used on the laser emission path to expand the laser beam to get the required output divergence. The unit concept is based on an afocal optics combination held into a sealed cavity filled with pure air at 0.5bar for minimizing LIC risk. The all-titanium structure is equipped with mat heaters, which allow a refocusing capability of 30nm/K. Other heaters bring a decontamination function for the output window.

The unit was developed by Sodern, with key technologies such as brazed windows and stable lens mounting without adhesive. The output window has a clear aperture of 120 mm and all optical elements are coated with qualified anti-reflection coatings made to withstand very high laser fluence at 355nm (>700mJ/cm^2) so to avoid laser induced damage (LID). The EBEX enlarges the laser beam by x6.7 with a transmission factor 97.5% and a WFE less than 30nm RMS (focus fit).

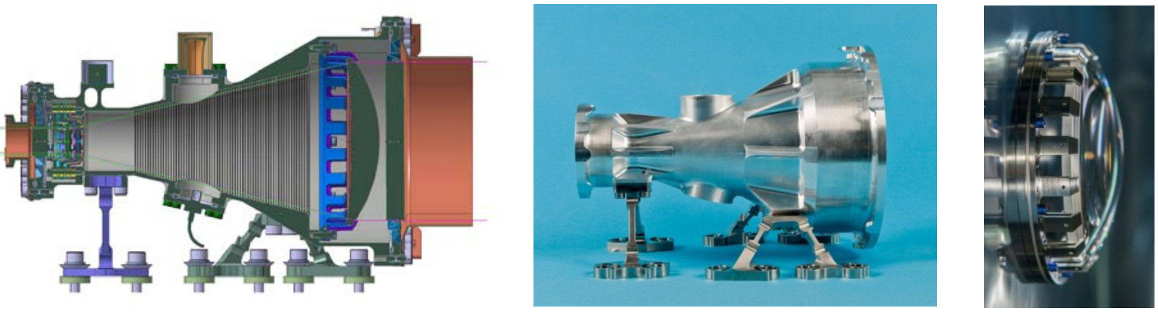

Fig. 5. From left to right: EBEX final design, EBEX body and front lens

The PLHs thermal control is ensured by the so-called Laser Cooling System (LCS). This thermal control system is a thermal bus which allows rejecting the power dissipation and insuring thermal stability of the ATLID PLH units. This joint Airbus DS / Euro Heat Pipes design is composed of two sets (one set for each PLH) of eight capillary mini-loop heat pipes, Fig 6, which extract the heat power dissipated at PLH level towards an aluminum honeycomb radiator panel through a golden stainless steel piping network.

To allow flight performances assessment through on-ground tests, this network has been first accommodated in a flat (2D) configuration to avoid gravity induced disturbances and submitted to a thermal vacuum test campaign in last July. It demonstrated the ability to start-up all the eight loops as well as properly perform the heat extraction and temperature regulation at PLH level.

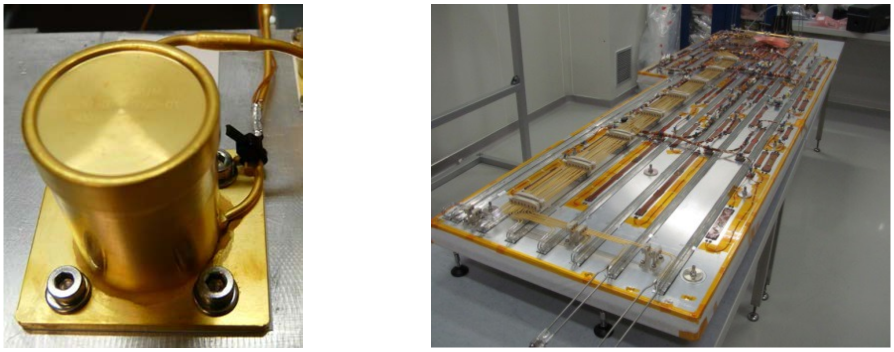

Fig. 6. Left : mini-loop heat pipe custom evaporator (PLH side)
Right: Piping network on the LCS radiator panel (condenser)

B. The receiver chain:

The optical configuration of ATLID telescope, Fig 7,consists in an afocal Cassegrain telescope made of two parabolic mirrors and a magnification ratio of x30. The mechanical structure and mirrors are all made of Silicon Carbide (SiC) in order to ensure long term mechanical stability. The input pupil diameter on M1 mirror is 620 mm and the output pupil diameter on M2 mirror is 20.7 mm. The telescope has been manufactured , integrated. qualified and tested with very good results: wave-front error (WFE, focus fit) < 55 nm rms, transmission > 96%

Fig. 7. ATLID telescope after final alignment

To enhance ATLID daytime performance the Entrance Filtering Optics (EFO) and the Blocking Filter (BF) , Fig 8, are implemented immediately at the output of the telescope in order to reject background light. The first one acts as a spectral filtering whereas the second provides a spatial filtering (field stop).

The EFO unit, composed of an interference filter and a half wave plate, aims at rejecting the earth solar radiance with a maximum efficiency without jeopardizing the peak transmission at laser wavelength, and at aligning the received linear polarisation axis with respect to the transmitted polarisation one.

EFO has been manufactured, qualified, tested at Bertin and its now integrated in the Focal Plane Assembly (FPA) on the telescope main plate. The main design drivers of EFO unit are met: low bandpass (0,8nm), high transmission factor (>90%) at laser wavelength and low WFE (15 nm rms, including defocus).

The BF not only blocks the background and stray light away of the useful field-of-view, but also includes the following functions: to transport, fold and enlarge the collimated beam; to image the pupil onto the spectrometers; and to define the instrument field of view. The BF has been manufactured, qualified, tested by Bertin and has been integrated on the optical bench. Results from BF unit testing have demonstrated compliance to its requirements: stability < 40 µrad, Transmission > 97 % and WFE (including defocus) < 70 nm rms.

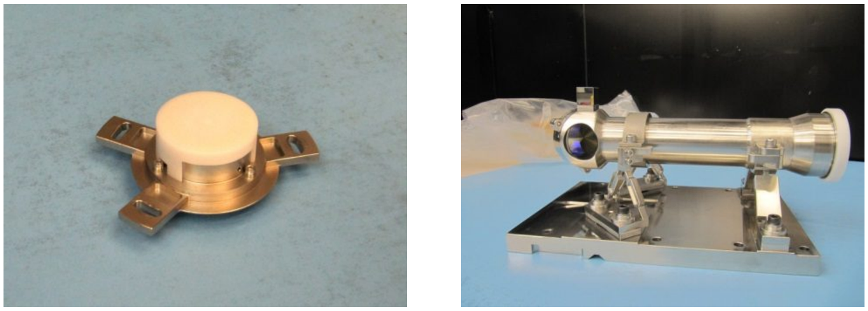

Fig. 8. Left: Entrance Filter Optics unit - Right: Blocking Filter unit

The Co-Alignment Sensor (CAS), Fig 9, is used in conjunction with the BSA to ensure the real-time control loop of the co-alignment of both emitter and receiver chains, which are optically decoupled in the ATLID bi-static configuration. The CAS is located in the FPA in between the EFO and the BF. A beam splitter derives approximately 7% percent of the incoming signal towards the co-alignment detector and thanks to a broad band rejection filter, it extends the EFO rejection range to ensure that the Earth background is filtered over the complete detector sensitivity spectral range. Focusing the input beam onto a dedicated Memory Charge-Coupled Device (MCCD) detector, operated by the CAS electronics, the spot image is transmitted towards the Instrument Detection Electronics (IDE), for further used by the ATLID Control and Data Management (ACDM) unit to derive the spot centroid and with that the knowledge of the laser beam direction in the receiver field of view.

The CAS equipment has been developed under CRISA responsibility, with partnerships with LIDAX, for the mechanical bench, Bertin for the optical assembly and INTA-LINES for integration and testing. It succeeded its environmental tests performed in summer 2016 and is to be delivered in September 2016.

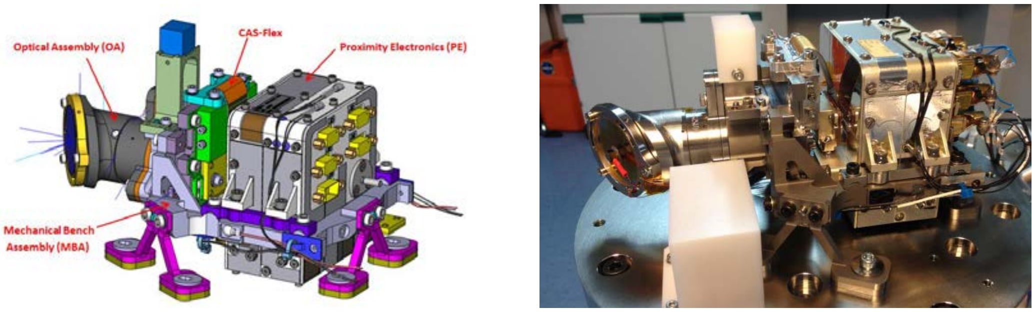

Fig. 9. Co-Alignment Sensor

The High Spectral Resolution Etalon (HSRE), Fig 10, filters the Mie and Rayleigh components of the backscatter signal routing it towards the relevant detection paths. Also, the Mie component is split in Mie co-polarised beam and Mie cross-polarised beam. The key performance of the HSRE is achieving the spectral transmittance on Mie-co-polarisation path with a full-width-half-maximum (FHWM) of 0.3pm and a peak transmission at 355nm up to 87%.

The unit concept is based on a Fabry-Perot (FP) etalon used in combination with polarisation beam-splitters (PBS) and quarter-wave plates. The Fabry-Perot etalon acts as a filter, transmitting only the narrow Mie signal and reflecting the wider Rayleigh signal.

The background rejection is completed by a prism placed at HSRE input allowing it to act as a monochromator in combination with the aperture stop located at the BF on one side, and at detection fiber coupling level after the HSRE on the other side.

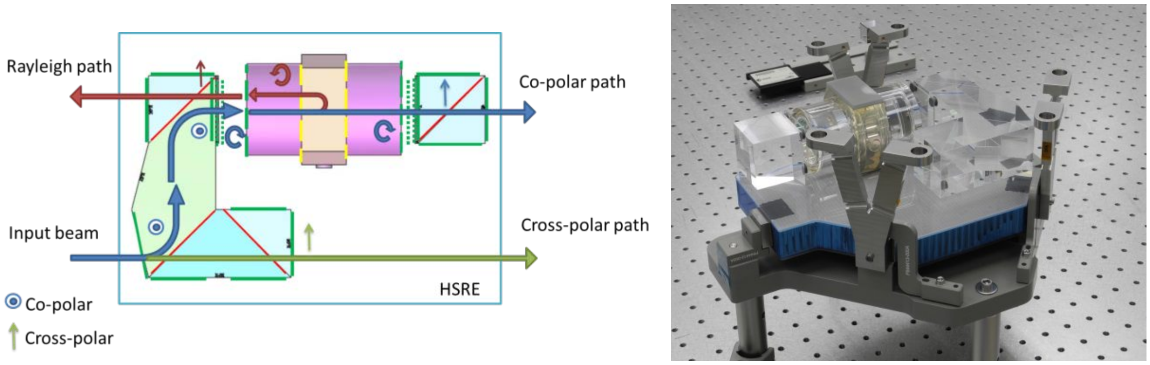

Fig. 10. HSRE functional scheme and HSRE unit

The unit was developed by RUAG Space System. Its structure is a composite base-plate with honeycomb and silica sheets. The PBS are silica prisms glued together. The cavity evacuated FP etalon manufactured by Thales-SESO includes silica plates polished at 10nm rms and optically contacted onto a spacer in Zerodur material with 10nm parallelism. The unit has free apertures of 35mm and weights 3kg. The PFM qualification testing is on-going.

To ease the cool-down of the science channels detectors down to -30°C, in order to minimize dark signal detection, they have been moved away from the FPA and are mounted on a dedicated external radiator. Then the optical signals of the three HSRE unit channels are transmitted to the detectors by the Fibre Coupler Assemblies (FCA). At the HSRE output, each beam is coupled into a multimode fibre with a collimating optics. Then each fibre is routed in the instrument to the corresponding Detector Fibre Assembly (DFA) where the fibre extremity is approached at 40µm from the Memory Charge-Coupled Devices (MCCD), Fig 11, for optimal coupling.

The FCA have been developed by Bertin Technologies. The units have completed their successful qualification at QM level, and FMs units have been fully tested and delivered.

The MCCD, developed by e2v, shall be able to measure single photon events to meet the worst case radiometric performance requirements. The selected design provides high response together with an extremely low noise thanks to on-chip storage of the echo samples which allows delayed read-out at very low pixel frequency (typically below 50 kHz). Combined with an innovative read-out stage and sampling technique, the detection chain provides an extremely low read-out noise (< 2e- rms per sample).

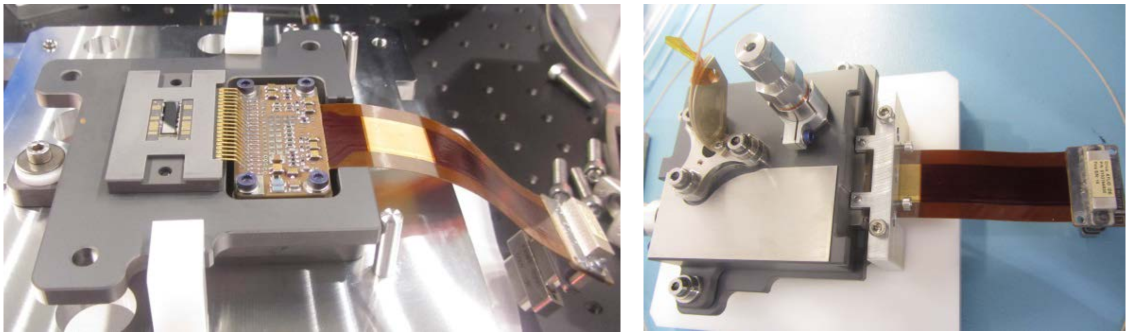

Fig. 11. Left: MCCD package; Right: Detector and Fibre Assembly

The Instrument Detection Electronics (IDE), Fig 12, unit is the equipment managing the four detection chains of the ATLID instrument (three for the science acquisitions and one for the co-alignment sensor). Therefore, its main objectives are to provide clocks, bias, and power to all the detectors, to acquire their video signals back and finally to send all those data to the ACDM.

The IDE has been designed, manufactured, tested and qualified by CRISA. The flight model was delivered in January 2016. One of the main challenging performances that have been achieved is the very low noise figure to cope with the science detection chain overall budget less than 2e-.

Fig. 12. Instrument Detection Electronics FM

C. System and mechanical units:

The ATLID Control and Data Management (ACDM) unit, Fig 13, represents the interface unit of ATLID Instrument with the EarthCARE spacecraft. Not only performing usual servitude activities (such as power conditioning, distribution and protection, MIL-STD-1553 bus interface (Remote Terminal), and TM/TC management), it manages also the ATLID operating principle by sending synchronization pulses towards TxA units (for laser pulses emission) and towards detection units (for backscattered signal acquisition sequence).

The ACDM unit performs also the following main functions: handling of monitoring and recovery action if needed, science data management and distribution, real-time co-alignment closed-loop processing from CAS image data to BSM control and instrument thermal control.

The ACDM is developed by TAS-UK, with Scisys Ltd as subcontractor for software development.

The digital core of the ACDM is powered by a LEON2 single chip processor running around 33.5MHz supported by several FPGAs. The software v2.0 qualification review has been held successfully in June 2016 followed by the Hardware/Software integration on ACDM FM unit. The validation of the FM unit shall start in September 2016 for a delivery in the following weeks.

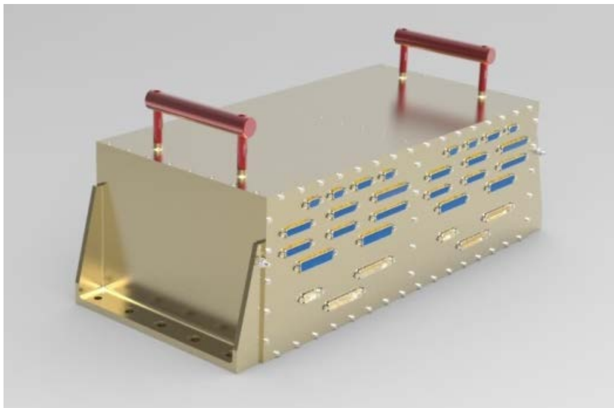

Fig. 13. ATLID Control and Data Management (ACDM) unit

Both transmitter and receiver chains optical parts are mounted on the Stable Structure Assembly (SSA), Fig 14, whose main role is to ensure their mechanical stabilities during the orbital life and particularly their co-alignment. Only the detectors, optically connected to the telescope FPA through fibers are outside, on the HSA.

This SSA is a light structure, weighting only 50kg compared to the 200 kg supported mass (submitted to 13g axial and 10g lateral accelerations), and with the approximate overall dimensions of 200 x 140 x 30 cm^3.

It is composed of a double stage 100 mm thick sandwich panel made of Carbon fiber skins and Aluminium honeycomb, supported by an isostatic mounting made of Titanium bipods. It is also equipped with two 1m long emission baffles with a very high cleanliness level inside, dedicated to protect the EBEX output window from contamination.

The SSA was designed and manufactured by APCO Technologies with Xperion GmbH for the large and thick composite sandwich panel. Thermal and mechanical qualifications were achieved at IABG premises in July 2016. These tests allowed demonstrating both key performances of a high stiffness (> 60 Hz lateral and > 80 Hz axial) in order to decouple the ATLID optical equipment from the launcher critical dynamic environment, as well as its high stability to cope with launch events and cyclic orbital thermal environment: as an example, the mechanical stability of the co-alignment of the reception chain wrt to the emission chain during one orbit is lower than 18µrad.

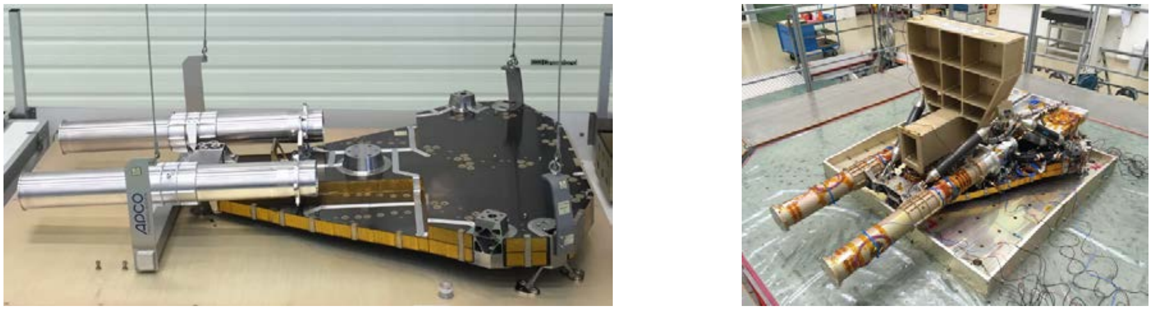

Fig. 14. Left: naked SSA with emission baffles;
Right: SSA equipped with dummies during its mechanical qualification campaign

The Housing Structure Assembly (HSA), Fig 15, is supporting all the ATLID electronic units and provides the ATLID instrument interfaces with the spacecraft. The HSA consists of 4 lateral walls connected to a bottom Interface Panel (IFP) through titanium feet and closed by a separated panel on top.

The IFP is supporting the fully equipped SSA and provides necessary spacecraft interfaces through titanium fittings. It is a 2.5 m² sandwich panel with aluminum honeycomb and carbon fiber skins. The lateral walls are supporting the receiver entrance baffle and several radiator panels with titanium blades. These radiator panels are a mix between aluminium frame and aluminium sandwich panels.

The ATLID dissipative units, such as IDE, RLH, TLE and ACDM are mounted directly on their dedicated radiator panel. In addition, the HSA supports the harness and the thermal hardware.

The HSA has been designed by Airbus DS design office and manufactured by Nexeya. It is to be delivered in September 2016 following environmental testing.

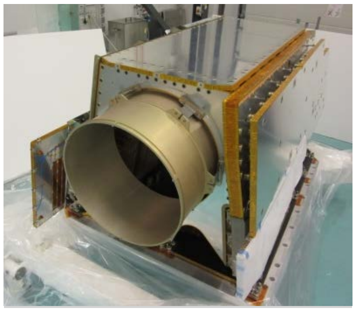

Fig. 15. PFM Housing Structure Assembly (HSA)

III. WAY FORWARD AND CONCLUSION

Considerable achievements have been reached in the last year with the completion of the manufacturing, qualification and testing of many ATLID units, in particular its laser transmitter. The ATLID instrument development follows a proto-flight approach, and several activities have been run in parallel at unit level to secure this approach. For example the delivery of the major instrument electronic units Engineering Models (EM) allowed the execution of the Electrical Engineering Model (EEM) programme. The ATLID EEM programme, allowed the verification of ATLID internal electrical interfaces, software functions, detection chain susceptibility to EMC, and co-alignment control loop function.

With the delivery of the first ATLID Flight Model (FM) units both the Optical Programme (OFM) AIT (Assembly, Integration and Testing) and the Detection Programme have been initiated. These two programmes are the precursors to the final ATLID PFM integration programme that shall be completed early 2017, immediately followed by the instrument performance and environmental test campaign.

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