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ATLID, ESA ATMOSPHERIC LIDAR DEVELOPEMENT STATUS

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ABSTRACT

The ATmospheric LIDAR ATLID[1] is part of the payload of the Earth Cloud and Aerosol Explorer[2] (EarthCARE) satellite mission, the sixth Earth Explorer Mission of the European Space Agency (ESA) Living Planet Programme. EarthCARE 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. This paper is presenting an updated status of the development of the ATLID instrument and its subsystem design. The instrument has recently completed its detailed design, and most of its sub-systems are already under manufacturing of their Flight Model (FM) parts and running specific qualification activities. 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.

1. Introduction to ATLID, the ESA ATmospheric LIDar.

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).

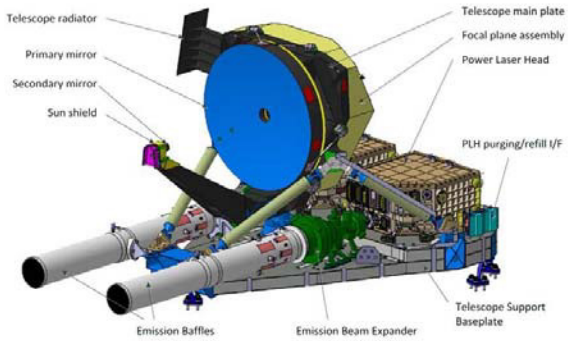

Fig. 1 – ATLID High stability assembly

The task of ATLID 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

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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.

2. ATLID Design

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. 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).

2.1. ATLID emitter chain design

The emitter chain includes the laser Transmitter Assembly (TxA), the Emission Beam Expander (EBEX), and the emission baffle. The TxA consist of a Reference Laser Head (RLH), a Power Laser Head (PLH) and its Transmitter Laser Electronics (TLE). The RLH provides the stable seed laser and frequency tuneability to the PLH which is a diode pumped Nd:YAG single-mode laser emitting at 355 nm. The PLH consists of a Master Oscillator, a Pump Unit and a Harmonic Conversion stage doubling and tripling the laser frequency. The laser head includes also a Beam-Steering Mechanism (BSM) finely adjusting the emission line-of-sight to continuously maintain emission / reception co-alignment in flight, based on information acquired in the reception chain by a Co-Alignment Sensor (CAS). With a power consumption of 300W the transmitter (implementing innovative mini loop heat pipes for cooling) delivers pulses of more than 38 mJ UV energy with duration of about 30 ns at a pulse repetition frequency of 51Hz. The laser transmitter has also stringent spectral requirements with a spectral linewidth below 50 MHz and a 25 GHz spectral tuneability range. The EBEX, sealed and pressurized as the TxA, is then used to expand the laser beam in order to meet the divergence requirement and minimize the laser fluence on the last diopter exposed to vacuum. This allows to mitigate the risk of Laser Induced Contamination (LIC) and the correspondent degradation of the instrument performance over its operational lifetime in space.

2.2. ATLID receiver chain design

The receiver chain includes the receiver telescope, the receiver optics, the science channels detection chain, the ATLID Control and Data Management Unit (ACDM). The ATLID telescope is an afocal Cassegrain with 620mm primary mirror diameter, made of Silicon Carbide to ensure high stability.

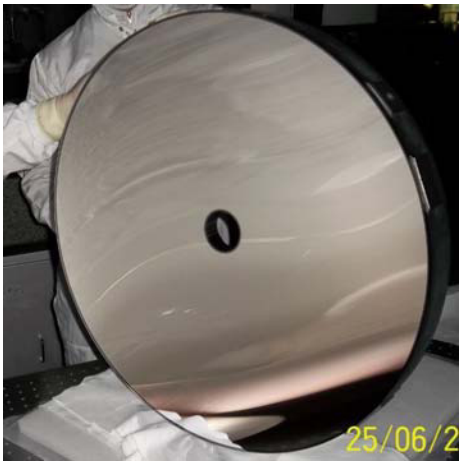

Fig.2 – ATLID Primary mirror (Airbus DS, Boostec, Safran/Reosc)

The receiver optics goes from the telescope output to the detector fiber entrances. It includes the entrance filtering optics (narrow interference filter with less than 1 nm bandwidth), the blocking filtering optics (spatial filtering with a field-stop delimiting the 65 µrad field-of-view), and two spectral filtering units: the background Fabry-Perot etalon used to finely filter the Earth background light, and the High Spectral Resolution filter (combining an optical prism assembly for the channels separation and a high resolution Fabry–Perot etalon).

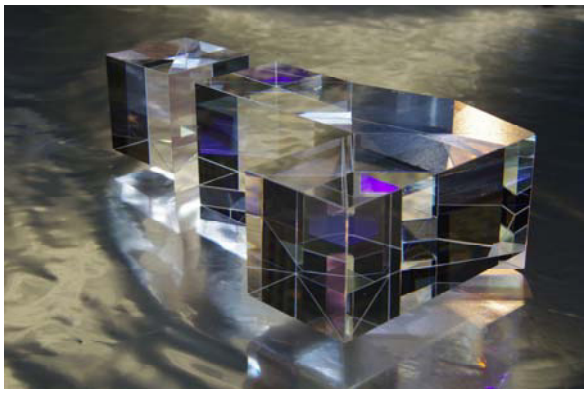

Fig.3 – HSRE prisms used for channel differentiation (RUAG, TSESO)

The signal is transported to the detectors by means of fibre couplers, allowing deporting the whole detection chain on the anti-sun wall for passive cooling. Part of the flux is split at focal plane assembly entrance and imaged on the CAS which provides laser spot position information. The detection chain, composed by the three Memory CCDs and the Instrument Detection Electronics, is 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 (< 3e- rms per sample). Finally the ACDM provides full autonomy in operation management, ensures the synchronization between laser emission and backscatter signal acquisition, the data processing and data stretching toward the spacecraft, the thermal regulation functions, the co-alignment control loop as well as the beam steering mechanism commanding, the TM/TC and observability management.

3. Industrial Consortium and Development Status

Airbus Defense and Space SAS (Airbus DS) is the prime responsible for the procurement, integration and verification of ATLID instrument and its subunits. While the ATLID system critical design review has only been recently completed, many of the subunits have already passed their qualification phases and some are already at their flight readiness status.

3.1. ATLID emitter chain development

Selex ES, as prime of the Laser Transmitter, has been developing an extensive set of hardware models as full scale breadboard used for validation and correlation with developed numerical models, and a PLH LIC test model. While the laser transmitter is largely inheriting from the Aladin instrument development for the AEOLUS mission, a significant evolution of the laser design lies in the fact that ATLID power laser head is sealed and pressurized (improving tolerance to LIC). Significant achievements have been made in the last years, including the development and the testing of a Power Laser Head Structural and Thermal Model. The model used for qualification of the housing sealing demonstrated the feasibility to meet the 3 years lifetime in orbit. The integration of a Power Laser Head Qualification Model has progressed with the assembly and testing (opto-mechanical stability confirmed after environmental testing) of the Master Oscillator section. After completing a successful qualification test campaign at Quantel Laser the Laser Amplifier has been also integrated and as soon its functional testing is successfully completed it will be followed with the integration of the UV section.

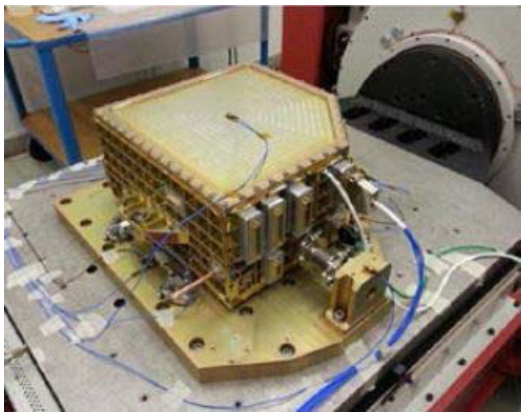

Fig.4 – PLH STM (Selex ES)

In parallel, the development of the Transmitter Electronics, supported by two engineering models, is progressing and one model was already delivered to Airbus for early function verification at instrument level. In parallel, soldering qualification is being performed, taking into account lessons learnt on Aladin electronics

boards development. An extended programme for qualification of coatings, and in particular for the verification against Laser Induced Damage effects, is taking place in specialized laboratories at DLR and ESTEC. These tests are performed to coatings from optics existing throughout the entire transmitter chain (including IR and UV when relevant). The BSM assembly being developed by CEDRAT and SODERN is based on an Engineering Qualification Model (EQM) followed by the manufacturing and testing of the 2 flights models to be integrated in the Power Laser Heads. The EQM passed successfully mechanical and thermal vacuum environmental testing. Electronics coupling tests demonstrated its sub-microradian accuracy performance, just before being delivered to Airbus DS. The Emission Beam Expander by SODERN relies on two groups of lens designed as a Galilean beam expender type, inside a sealed and pressurized unit and expanding the laser beam to 120mm diameter. This requires large brazed windows, large lenses mounts development with stringent requirements in WFE, high transmission and qualification for laser irradiation. The development of the EBEX has been supported by a number of qualifications activities (large lens mount, brazed windows) successfully concluded and the FM units parts are now under integration.

3.2. ATLID receiver chain development

The receiver development is now well advanced, some Flight Models (FM) already available or ongoing manufacturing. The silicon carbide FM telescope mirrors are already coated and polished and have been assembled and aligned on its main structure. The Entrance Filtering Optics (polarisation control and narrow bandpass interference filter) and the Blocking Filter (spatial filtering) developed by Bertin Technologies in a proto-flight approach, are fully assembled and already completed their qualification test sequence. The two Fabry-Perot etalons flight models are currently under manufacturing phase at TSESO, with very challenging requirements (only a few nanometers parallelism are tolerated over a 40 mm distance), and RUAG Space will undergo their performance and environmental campaign during 2015. The Fibre Coupler Assemblies, developed by Bertin Technologies, have completed their successful qualification at QM level, and FMs assembly is ongoing. The Co-Alignment Sensor (CAS), developed by CRISA and aiming at measuring the retro-reflected laser spot with better than 1/10 pixel accuracy, completed its mechanical and thermal qualification sequence and already initiated the FM manufacturing. The ATLID Control Data and Management unit successfully passed its manufacturing review and it is now near its integration completion.

3.3. ATLID mechanical and thermal units development

ATLID mechanical and thermal functions are of particular complexity due to the large number of units, the strong dissipation from the laser source, and the interface to a carbon fibre panel. The high stiffness and high stability required for the Stable Structure Assembly (developed by APCO) supporting the telescope and the laser heads impose thick double-stages CFRP sandwich panel and strong titanium brackets. The large dissipation (above 600 W) of the units together with the inhomogeneity of materials (aluminium for electronics, carbon-fibre for interface panel) requires for the housing structure assembly a complex assembly of aluminium sandwiches, aluminium structure, titanium blades and brackets, and carbon-fibre panel designed by Airbus Defence and Space. The critical design reviews of the structures and cooling systems are now passed, and the qualification on breadboards of critical technologies (high load inserts, embedded titanium mounts) is approaching its completion.

4. CONCLUSIONS

The ATLID instrument is well progressing into its Phase C/D with the qualification and development of its subunits, many of which are already at FM level. ATLID will fly on the EarthCARE satellite which is scheduled for launch early 2018. EarthCARE, as well as the ESA wind mission AEOLUS, are paving the way for space LIDAR missions, capable of providing the scientific community with the measurements required for a better understanding of the atmospheric physics and climate evolution.

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