Lidar instruments for ESA Earth observation missions

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1. INTRODUCTION

Lidar systems offer a wide range of capabilities for the remote detection and monitoring from space of the atmosphere and its constituents as well as for the measurement of certain land or sea surface parameters. Therefore, the development of advanced lidar systems for space applications and their evaluation by airborne or ground based test campaigns is considered an important strategic element of the Agency’s Earth Observation Programme. ESA has been supporting the development of laser systems for remote sensing since the early eighties. By exploiting various properties of the interaction between the signal and the matter, surface, atmosphere, dedicated target, observations can be performed that are of relevance for various Earth Science disciplines and applications.

The Atmospheric Lidar (ATLID) measures the signal backscattered by clouds and aerosols to determine essential data for the study of the Earth radiation budget, its distribution and divergence. It is considered candidate for flight on the former named ERM mission (Earth Radiation Mission), now called EarthCARE. A similar sensor will be launched on the Calipso/CENA mission of NASA and CNES. Even if not selected for flight yet, the technology development for ATLID has been essential for other missions such as ADM-Aeolus and in general for European efforts on lidars.

The ALADIN Lidar for the Atmospheric Dynamics Mission provides direct observation of wind profiles by measuring the Doppler shift induced by the motion of molecules and aerosols. ALADIN is under development for launch in 2007 onboard the ADM-Aeolus satellite. The usefulness of ALADIN data for NWP makes it a promising candidate for continuation in follow-on rugged operational systems.

Studies of an Ice Topography Observing System, using a laser altimeter early considered for implementation on the Topography Earth Explorer mission, was later abandoned in favour of microwave option (Cryosat) for the better performance of the latter and in view of NASA’s selection of GLAS for Icesat.

The sounding of atmospheric composition with active techniques has been considered in the past especially for water vapour and to lesser extent in Europe for ozone. A
mission concept, WALES, is being considered as candidate Earth Explorer Core Mission. Other concepts had been proposed, including proposals to ESA, like the Carbosat proposal to the second cycle of Earth Explorer Core Missions, featuring a DIAL for derivation of profiles of CO₂ concentration.

It is expected that the measurement capabilities of DIAL lidars and similar differential spectroscopy laser instruments, will attract more and more interest from the scientific community, resulting in new upcoming missions proposals.

2. AEOLUS

AEOLUS has been selected for implementation as the second core mission of the Earth Explorer Core missions of ESA’s Living Planet programme. It is scheduled for launch in 2007, for a three-year mission, to study the Atmospheric Dynamics. Aeolus will provide measurements of tropospheric wind profiles on a global scale, with accuracy of 1 m/s below 2 km and 2 m/s above 2 km.

The core space element of ADM-AEOLUS is ALADIN (Atmospheric Laser Doppler Instrument), a direct detection Doppler Wind Lidar (DWL) incorporating a fringe-imaging receiver (analyzing aerosol and cloud backscatter) and a double-edge receiver (analyzing molecular backscatter). The instrument sends a high energy laser pulse at 355 nm towards the atmosphere, which is backscattered by aerosol particles (Mie scattering) and molecules (Rayleigh scattering). The frequency Doppler-shifted backscattered signal is analyzed through the high-resolution spectrometer and by direct detection techniques.

The Lidar functional architecture is organized in four main functions: the Transmitter, the transmit/receive Telescope, the Receiver, and the ACDM (Aladin Control and Data Management).

The transmitter assembly is based on a diode-pumped tripped Nd:Yag laser emitting 150mJ pulsed energy at 355 nm. It will be operated in burst mode with 100 Hz PRF during 7 second, every 28 seconds. There are two fully redundant transmitters, each including two laser heads (Power Laser Head, and Reference Laser Head) and a transmitter laser electronic (TLE).

The Telescope is an afocal Cassegrain with 1.5 m entrance pupil. All-SiC construction is proposed for the mirrors and the M1-M2 tripod link, mainly motivated by consideration of mass saving and geometrical stability.

The receiver assembly includes the transmit/receive switch (polarization-based), a set of relay optics and diplexers for beam transports and laser reference calibration, a blocking interference filter, the Mie and Rayleigh spectrometers, the two Detection Front-end Units (DFUs). Both spectrometers are used in conjunction with a thinned back-illuminated Si-CCD detector working in an accumulation mode (Astrium patent), which allows photon counting and provides very high quantum efficiency.

Figure 2: Aladin instrument architecture

3. EarthCARE

The Earth Clouds, Aerosols and Radiation Explorer mission has been proposed as a candidate for the future Earth Explorer Core missions of ESA’s Living Planet programme. The mission major objective is to determine, in a radiatively consistent manner, the global distribution of vertical profiles of cloud and aerosol field characteristics. The EarthCARE payload is composed of four instruments: an Atmospheric backscatter Lidar (ATLID), a Cloud Profiling Radar (CPR), a Multi-Spectral Imager (MSI) and a Broad Band Radiometer (BBR).

ATLID will provide vertical profiles of the physical parameters of aerosols (e.g. optical depth), and the altitude of the highest cloud top. The requirements applicable to ATLID are presented in table 1. A single wavelength (355 nm) lidar with High-Spectral Resolution receiver separating Rayleigh (molecular) and Mie (cloud and aerosol particles) backscattered has been selected as baseline.
Table 1: ATLID observation requirements

<table>
<thead>
<tr>
<th></th>
<th>Mie co-polar channel</th>
<th>Rayleigh channel</th>
<th>Mie cross-polar channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cirrus optical depth</td>
<td>0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Backscatter sr(^{-1}) m(^{-1})</td>
<td>8 (10^{-4})</td>
<td>2.6 (10^{-5})</td>
<td></td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>100 m</td>
<td>300 m</td>
<td>100 m</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>10 km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required Accuracy</td>
<td>50%</td>
<td>15%</td>
<td>50%</td>
</tr>
</tbody>
</table>

This wavelength allows relatively high pulse energy to be used without infringing on eye safety. A small footprint of around 20 m is favoured to minimise the multiple scattering effects and reduce the solar background noise by reducing the telescope field of view. An additional cross-polarisation channel is implemented.

**Instrument concept**

The agency conducted two phase A’s under prime responsibility of ALCATEL space and ASTRIUM to study both mission and instrument concepts. ATLID laser concept is a diode-pumped frequency tripled Nd:YAG similar to ALADIN with reduced requirements, as the energy required is 20-25 mJ with a pulse repetition frequency of 70-100 Hz. Operations during daylight are made possible thanks to a filter train, interference filter plus etalons, reducing drastically the background level.

The Rayleigh and Mie backscatter separation is obtained at receiver level thanks to a single narrow bandwidth (spectral bandwidth 0.2 to 0.5 pm) etalon, so-called the High Spectral Resolution etalon, featuring high peak transmission. The working principle of the receiver detection is depicted in Figure 3.

4. **WALES**

The WAter vapour Lidar Experiment in Space mission has been proposed as a candidate for the future Earth Explorer Core missions of ESA’s Living Planet programme. The mission is to provide improved insights into the distribution of atmospheric water vapour and information on aerosols in the troposphere and lower stratosphere relevant to climate change studies, atmospheric modelling and chemistry studies and to numerical weather forecasting. It is a single payload mission operating a nadir viewing Differential Absorption Lidar (DIAL) instrument.

The measurement requirements for WALES are presented in table 2. Direct detection DIAL operated in the 935 nm spectral range is the most suitable concept to provide low statistical errors and bias.

Table 2: WALES observation requirements

<table>
<thead>
<tr>
<th>PBL</th>
<th>Low Troposphere</th>
<th>High Troposphere</th>
<th>Low Stratosphere</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical domain</td>
<td>0-2 km</td>
<td>0-5 km</td>
<td>5-10 km</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>1 km</td>
<td></td>
<td>2 km</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>25 km</td>
<td>100 km</td>
<td>150 km</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>0.01-15 g/kg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Random error</td>
<td>&lt; 20 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bias</td>
<td>&lt; 5%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The DIAL technique compares the attenuation of two laser pulses emitted at different wavelength. The on-line wavelength falls on the centre of a water vapour absorption line and the off-line wavelength falls on the line wing, where absorption is significantly reduced.

The large dynamic range of water vapour is addressed with a DIAL instrument by using different on-line wavelengths \(\lambda_1, \lambda_2, \lambda_3\) with different (water vapour) attenuation cross-sections, and one off-line wavelength \(\lambda_4\), as depicted in Figure 5.
The different on-line wavelengths possess different penetration depths, thus allowing for measurements in different altitude intervals. The strongly absorbing water vapour lines are used for higher altitudes and the weakly absorbing lines are used for lower altitudes (high water vapour concentration).

**Instrument concept**

The agency conducted two phase A’s under prime responsibility of ALCATEL Space and ASTRIUM ltd. to study mission and instrument concepts. These studies are now completed. Two instrument concepts have been proposed and are both based on the emission of 4 wavelengths, serving as 3 pairs of on- and off-line wavelengths. They are depicted in figure 7. The main subsystems are:

- 2 transmitter units capable of emitting 2 wavelengths each, plus one unit in cold redundancy,
- Separate telescopes to transmit the different wavelengths,
- One or three large telescope providing a collection aperture of 2 to 3m²,
- Four direct detection receivers with blocking filters to reduce the background noise level,
- Instrument control electronics. The instrument provides 50 m vertical sampling from ground to 16 km altitude and less than 1 km horizontal sampling.

Two different emission and measurement modes were proposed, the burst mode were the 4 wavelengths are emitted in a cascade way with a time separation of 100μs and a continuous mode where wavelengths are emitted each 10ms but with different line of sight directions to allow sampling of the same atmospheric volume by the 4 emitted wavelengths. This last operation mode features advantageous receiving concept by in-field separation but requires sophisticated active alignment and satellite pointing.

**Transmitter system**

The DIAL measurement principle does not require radiometric calibration. However, accurate control of the transmitted wavelengths is required. Knowledge of both the absolute wavelength and the transmitter spectral shape determines the achievable systematic measurement error (bias). The requirements applicable to the laser system are given in the table 3.

The transmitter system is made of 3 identical units each emitting 2 wavelengths, one unit being implemented in cold redundancy. A transmitter unit consists of 2 elements, the pump unit and the laser source. The pump unit is a frequency doubled Nd:YAG laser operating at 532nm emitting pulses of 300-350mJ and could re-use most of ALADIN laser developments.
Table 3: Requirements applicable to the laser system

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of wavelengths</td>
<td>4 wavelengths to be transmitted as a burst of 4 pulses</td>
</tr>
<tr>
<td>Laser pulse energy</td>
<td>75 mJ</td>
</tr>
<tr>
<td>Pulse repetition frequency (double pulse)</td>
<td>25 Hz</td>
</tr>
<tr>
<td>Inter pulse separation within burst</td>
<td>200 μs</td>
</tr>
<tr>
<td>Wavelength range</td>
<td>935 nm</td>
</tr>
<tr>
<td>Laser frequency accuracy and stability</td>
<td>&lt; 60 MHz</td>
</tr>
<tr>
<td>Laser linewidth</td>
<td>&lt; 160 MHz</td>
</tr>
<tr>
<td>Laser spectral purity within 1GHz</td>
<td>&gt; 99.9%</td>
</tr>
</tbody>
</table>

The pump pulses are routed to one of the two independent laser sources; Ti:Sapphire laser has been identified as promising candidate to provide high spectral purity and high pulse energy in the 920-950 nm band.

In addition, to ensure high spectral purity, the laser source must be injected with a laser seeder based on external cavity diode laser or a DFB/DBR diode laser. The long-term frequency stabilisation can be achieved by using water vapour cells and wavemeters.

**Receiver system**

The receiver concept consists of a large aperture telescope, a spectral pre-selection unit and four receiver channels, each including a high resolution spectral filter stage and a detector assembly. Two concepts were proposed for the telescope, a single aperture of 1.75 m diameter and a tri-pupil concept of an equivalent 2.1 m diameter.

The narrow bandwidth etalon (~40 pm bandwidth) is a key element in the receiver chain to separate any particular wavelength and block the background radiation. The detector could consist of Avalanche Photo Diode providing both high efficiency and low noise in the required spectral band, an alternative solution is the newly developed L3CCD from E2V Technology that provides photon-counting capabilities.

**5. Lidar Technologies and instrument pre-developments**

**ALADIN Pre-Development Model**

Following the selection for implementation of the ADM/Aeolus mission and the development risk analysis performed during phase A, a pre-development programme for the ALADIN instrument was undertaken to reduce the technical and programmatic risks of the mission. The objectives of this pre-development programme are to validate the technologies used in the flight design, evaluate the flight-worthiness of its major equipment and critical component and verify the overall instrument performance. The pre-development programme encompasses:

a) A laser transmitter programme, including

- Two parallel developments of laser breadboards to demonstrate the feasibility of a diode-pumped frequency tripled Nd:YAG laser providing 150 mJ per pulse at 355 nm, operating in burst mode with 100 Hz PRF during 7 seconds, every 28 seconds.

- Testing of commercial continuous laser diodes and commercial pulsed laser diode arrays used respectively for pumping the seeder, and the oscillator and the amplifier stages of the laser transmitter.

- Separate studies of specific technology improvements (e.g. optimisation of frequency tripling efficiency, solid-state phase-conjugation mirrors)

b) A lidar receiver programme, consisting of a full Pre-Development Model (PDM) of the receiving part of the instrument, in a system and sub-system configuration as representative as possible of the design, materials and building techniques of the flight model.

One of the laser breadboards is being reconditioned for integration with the PDM, to allow end-to-end test of the lidar system after completion of the performance tests of the optical receiver. The PDM will later be
refurbished as airborne lidar and be used in the preparation and validation of the Aeolus mission.

The PDM is a functional representative model of the receiver part of the ALADIN instrument, composed of engineering model units going from the receiver/transmitter optics to the detection chain. All the critical sub-units (optical bench, Mie and Rayleigh spectrometers, detection front end unit, accumulation CCD) have been manufactured and successfully characterized. Key receiver sub-systems architecture, as the high resolution spectrometers, are shown on figure 10 together with pictures of the developed units. The main characteristics of both spectrometers are also provided in table 4 and 5.

The PDM programme includes as well the design, manufacturing and test of the detection electronic unit at breadboard level (video chain, sequencer, and interfaces).

<table>
<thead>
<tr>
<th>Table 4: Mie spectrometer characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design parameters</td>
</tr>
<tr>
<td>Free spectral range</td>
</tr>
<tr>
<td>Useful spectral range</td>
</tr>
<tr>
<td>Peak transmission</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
</tbody>
</table>

Table 5: Rayleigh spectrometer characteristics

<table>
<thead>
<tr>
<th>Design parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free spectral range</td>
</tr>
<tr>
<td>Peak spectral spacing</td>
</tr>
<tr>
<td>Peak transmission</td>
</tr>
<tr>
<td>Resolution</td>
</tr>
</tbody>
</table>

After completion of the alignment of all units on the Optical Bench Assembly (OBA), the PDM has been submitted to environmental tests. First, thermal vacuum tests have been run to simulate the in-orbit environment, to simulate the performance range (+15 °C +25 °C) and the non-operating temperature (-20 °C +50 °C). Radiometric, spectral, geometrical, stability and thermal tests have been run. Second, the PDM has successfully passed mechanical tests at qualification levels for quasi-static (25 g), sine and random (5 g) tests for two axes, one of which was considered the most critical one. The results are in line with the flight model needs.

The full ALADIN PDM configuration consists of coupling the OBA with its detection electronics to the selected laser breadboard and associated electronics. A functional and performance test campaign will then be run on the full ALADIN PDM to conclude the assembly integration and verification of the ALADIN PDM. The results of these tests will demonstrate the validity of the design and the expected performance of the instrument. This is a key step in securing the path to the flight instrument.

**Titanium Sapphire laser transmitter breadboard**

The WALES laser transmitter has been identified as the most critical technology and ESA initiated in 2002 two contracts with ALCATEL space and Galileo Avionica for the development of this key component. Different technologies were traded in the frame of the contracts, namely: OPO, Ti:Sapphire and Raman lasers. Both contracts indicate the the Ti:Sa laser technology as the most mature and promising to fulfil both required power and spectral requirements.

The developed breadboards consist of a laser unit emitting two wavelengths in the 935-936nm spectral range as identified for WALES. The requirements applicable to the breadboard are those already mentioned in table 1.

The laser breadboard is made of high energy Ti:Sa oscillator pumped by a frequency doubled Nd:Yag together with two seeders stabilised on water vapour lines bringing the spectral quality. Alternatively, the Ti:Sa laser could be made of a low energy oscillator coupled with an amplifier.
The transmitter breadboards are now being built; the injection seeder together with its stabilisation unit has already shown good performance meeting the requirements. First results for the injected laser should be available by April 2004.

Nd:Mixed Garnet laser transmitter breadboard
As part of the TRP, the agency has also initiated studies on solid-state laser technology known as Nd:Mixed Garnet laser in order to assess the suitability of the technology to provide multiple wavelength emission in the spectral domain identified for WALES. The technology has been recently the subject of intensive research and development in academia and industry. Two contracts involving Astrium Gmbh with german research institutes and CESI have been started late 2002. The activity aims at developing the crystals and to build a high-energy breadboard laser. Radiation testing on crystals has already taken place and the studies should be completed by November 2004.

Development of a frequency stabilisation scheme
A key driver for the spectral performance of the laser is the injection seeder together with its frequency stabilisation insuring the long-term wavelength accuracy and stability required to emit in the water vapour absorption line. The overall frequency stabilisation unit is a complex sub-system requiring detailed studies and breadboard, as four stabilised wavelengths have to be provided to the WALES transmitter.

ESA is now running contracts, as part of the Technology and Research Programme, to breadboard a complete scheme for the stabilisation of 4 laser injection seeders under the prime responsibility of CSO-SAGEIS, Observatoire de Neuchatel and Intune Technologies. The activities will be completed by end 2004 and have already established a concept.

Development of high resolution optical filter technology
Narrow bandwidth optical filtering is a key element of many LIDAR instruments and is used to spectrally filter the incoming signal and reduce the intensity of background radiation. The objective of the work under the prime contractor ship of AEA Technology together with Hovemere Ltd. is to develop the technology for a narrow bandwidth, high-resolution optical filter suitable for use in future LIDAR instruments, such as WALES.

At the heart of the HRF design is a Capacitance Stabilised Fabry-Perot Etalon (CSE) that provides the narrow bandwidth spectral filtering. A key feature of the CSE is its ability to dynamically control the separation between the two étalon plates, allowing the filter to be tuned to different wavelengths and allowing the parallelism between the two plates to be accurately controlled. The CSE will have a tunable range of 9 nm.

A schematic diagram of a Capacitance Stabilised Etalon, as used on a previous programme, is shown in Figure 13.

In order to obtain the high value of finesse necessary to achieve the narrow transmission bandwidth, considerable care is required in the manufacture of the étalon plates. In fact, achieving a required overall finesse of better than 150 necessitates manufacturing the plates with a defect finesse better than 220, which in turn requires a plate flatness in excess of \( \lambda/300 \) (at 630 nm).

This High Resolution Filter (HRF) is currently being manufactured and, once built, will be put through a complete environmental and performance qualification campaign. The HRF programme is expected to complete its manufacturing phase around the turn of the year proceeding to the test phase during February 2004. The
programme is scheduled for completion during June 2004.

Table 6: High resolution filter expected performance

<table>
<thead>
<tr>
<th>Central Wavelength</th>
<th>935.5 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working Aperture</td>
<td>50 mm</td>
</tr>
<tr>
<td>CSE Free Spectral Range</td>
<td>4 nm</td>
</tr>
<tr>
<td>CSE Plate Reflectivity</td>
<td>98.8 %</td>
</tr>
<tr>
<td>CSE Plate Flatness (target)</td>
<td>1/300</td>
</tr>
<tr>
<td>CSE Plate Defect Finesse</td>
<td>220</td>
</tr>
<tr>
<td>CSE Plate Overall Finesse</td>
<td>160</td>
</tr>
<tr>
<td>Acceptance Angle</td>
<td>± 4 mrad</td>
</tr>
<tr>
<td>Transmission Bandwidth</td>
<td>25 pm</td>
</tr>
<tr>
<td>Overall Transmission</td>
<td>50 %</td>
</tr>
<tr>
<td>Tuning Range</td>
<td>9 nm</td>
</tr>
<tr>
<td>Background Rejection</td>
<td>10^6</td>
</tr>
</tbody>
</table>

6. Future lidar instruments

As part of its activities to prepare for a long-term program in Earth Observation, the European Space Agency is now promoting studies with the objective to provide a background for and pave the way towards the definition of a spaceborne lidar systems to monitor greenhouse gases and also atmospheric pressure and temperature.

Several initiatives have been undertaken to assess the feasibility of monitoring CO2 and other greenhouse gases by active optical sensors from space in the context of the Kyoto protocol. Proposals for missions have been made in the USA and Europe. The CELSIUS mission was proposed for implementation within the frame of NASA’s ESSP. It would have used laser absorption spectroscopy (LAS) to obtain column integrated CO2 densities. In order to meet the end objectives of an Integrated Carbon Observing System the measurement of concentration profiles would be very beneficial. The CARBOSAT mission was proposed as candidate to the second cycle of Earth Explorer Core Missions but not selected at the time for lack of technological maturity. It indeed proposed to use a challenging differential absorption lidar (pulsed) to obtain accurate profiles of CO2 concentration.

The Agency is initiating system and instrument studies to first assess the potential to overcome the principle limitations of the existing passive sounding concepts by a Laser based instrument measuring the CO2 column/profile. Instrument concept and performance will be derived. Another study is extending the range of applications to the monitoring of greenhouse gases as CO2, CH4, N2O and also pressure and temperature profiles. The study is aiming at studying future lidar and DIAL concept. Instrument concepts will be derived and a review of available technologies will be essential for the definition of the future main directions of the system, technology and pre-development activities for the next generation of lidar instruments.

Future technology development

Depending on their application Lidar’s are based upon the use of the backscatter, Doppler effect, or differential absorption (DIAL). The systems can operate in a wide range of wavelength either in Continuous Wave, modulated or in pulsed mode, both coherent and incoherent.

In any case, the standard building blocks of a Lidar system are:
- Transmitter chain, including laser and pump laser
- Receiver chain, including filters, local oscillators (in case of a coherent system), detectors
- Optical system, including beam forming optics and transmit/receive telescopes
- Beam pointing system
- Control and data processing electronics
- Power supply
- Thermal control
- Structure

Those building blocks comprise generic technologies and instrument specific technologies. The main generic technology elements are:
- Detectors (CCD, APD, InGaAs detectors,…)
- High resolution filters (tunable, fixed…)
- Lasers and pump sources (tunable, fixed, local oscillators, power amplifiers,…)
- Optical systems (beam forming optics, large lightweight telescopes,…)
- Pointing systems (motors, encoders, bearings,…)
- Signal processors
- Modulators

The development of generic and instrument specific technologies as well as the definition of Lidar instrument concepts is tuned to the developing user requirements and, thus, performed in close dialogue with all user groups concerned.

The programmatic supporting the development of instrument specific technologies and instrument concepts is mainly driven by the short-term user needs. The generic technology developments, however, have to be defined taking into account long term technology trends that might prepare the development of future
system concepts and are, therefore, less driven by the short term planning considerations.

ESA is therefore initiating a range of technology development activities as part of its Technology Research Programme and Earth Observation instrument pre-developments. These activities are focussed on two main objectives: one, to develop advanced technologies to improve the performance or reduce the resource requirements of presently baselined lidar concepts, the second, to prepare advanced lidar concepts to cope with the forthcoming requirements and user needs for Atmospheric research, meteorology, climatology and environmental research. Figure 14 is summarizing the running and planned activities. The developments results will constitute a broad base to support the future programme implementation resulting from mission selection.

Figure 14: development planning for future lidar instruments

7. Acknowledgments
The authors would like to thank the industrial teams in charge of the fore-mentioned contracts and studies.

8. References