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# ATLID : ATMOSPHERIC LIDAR FOR CLOUDS AND AEROSOL OBSERVATION COMBINED WITH RADAR SOUNDING

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**ABSTRACT**

The atmospheric lidar ATLID is part of the payload of the joint collaborative satellite mission Earth Cloud and Aerosol Explorer (EarthCARE) conducted by the European Space Agency (ESA) and the National Space Development Agency of Japan (JAXA).

In December 2002, ESA granted Alcatel Space with a phase A study of the EarthCARE mission in which Alcatel Space is also in charge to define ATLID.

The primary objective of ATLID at the horizon 2011 is to provide global observation of clouds in synergy with a cloud profiling radar (CPR) mounted on the same platform. The planned spaceborne mission also embarks an imager and a radiometer and shall fly for 3 years.

The lidar design is based on a novel concept that maximises the scientific return and fosters a cost-effective approach. This improved capability results from a better understanding of the way optical characteristics of aerosol and clouds affect the performance budget.

For that purpose, an end to end performance model has been developed utilising a versatile data retrieval method suitable for new and more conventional approaches. A synthesis of the achievable performance will be presented to illustrate the potential of the system together with a description of the design.

## 1 MISSION REQUIREMENTS

The EarthCARE observations will be performed in a synergistic manner to make maximum use of the instruments flying the same satellite. As illustrated by the view of figure 1, the EarthCARE satellite payload embarks 2 active instruments namely:

- the ATmospheric LIDar (ATLID) to determine vertical profiles of aerosol physical parameters and, in synergy with the cloud profiling radar, vertical profiles of cloud physical parameters
- a Cloud Profiler Radar (CPR) for the retrieval of the micro and macroscopic properties of clouds

with 2 passive sounders:

- a BroadBand Radiometer (BBR) to measure short-wave and long-wave fluxes as a constraint of the radiative flux derived from the cloud aerosol profiles measured by the active instruments
- a Multi-Spectral Imager (MSI) to provide information of the horizontal structure of cloud fields in support of the vertical profiles measured by the active instrument

The Fourier Transform Spectrometer (FTS) originally planned has been discarded.

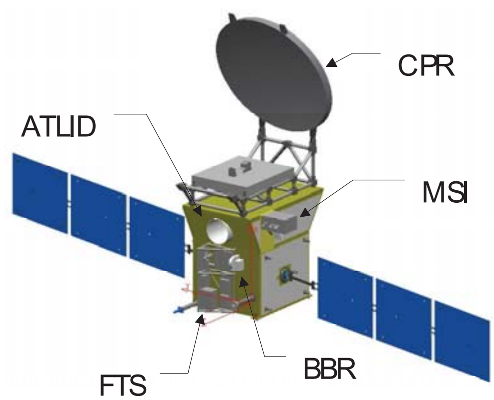



Fig. 1 Overview of EarthCare satellite

EarthCARE will be launched at the horizon 2011. The nominal orbit is Sun-synchronous with a local time at descending node at 10:30 hrs. The repeat cycle is chosen to have a less than 100 km between adjacent equator crossings.

ATLID provides a sequence of samples of the temporal profile, proportional to the laser pulse energy and collecting area. As shown by figure 2, the requirement driving the instrument resources is primarily focused on the measurement of cirrus physical properties in daytime condition assuming a dense cloud deck of unity albedo [1].

Table 1 indicates the characteristics of cirrus cloud applicable for the study . A 10 % depolarisation is assumed to assess the crosspolar channel with a significant increase of the backscatter.

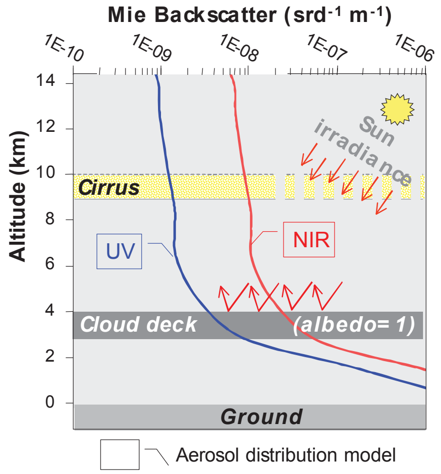



Fig. 2 Target for instrument sizing

| Component | Beta Cirrus ($m^{-1}$ $sr^{-1}$) | Depolar |
|---|---|---|
| Rayleigh | $8.0^{E}$-7 | 0% |
| Mie copolar | $8.0^{E}$-7 | 0% |
| Mie crosspolar | $2.6^{E}$-5 | 10% |

Table 1 Drivers for instrument sizing

## 2 INSTRUMENT CONCEPTS

2 instrument concepts has been studied:

– a Dual WAvelength Lidar (DWAL) probing the atmosphere simultaneously in the UV part of the spectrum (355nm) and the near infrared (1064 nm).

– a High Spectral Resolution Lidar (HSRL) operating with a single wavelength at 355 nm. The receiver separates Rayleigh (molecular) and Mie (Cloud and aerosol particles) backscatter return.

The principle is summarised by the schematics of figure 3 and discussed hereafter.

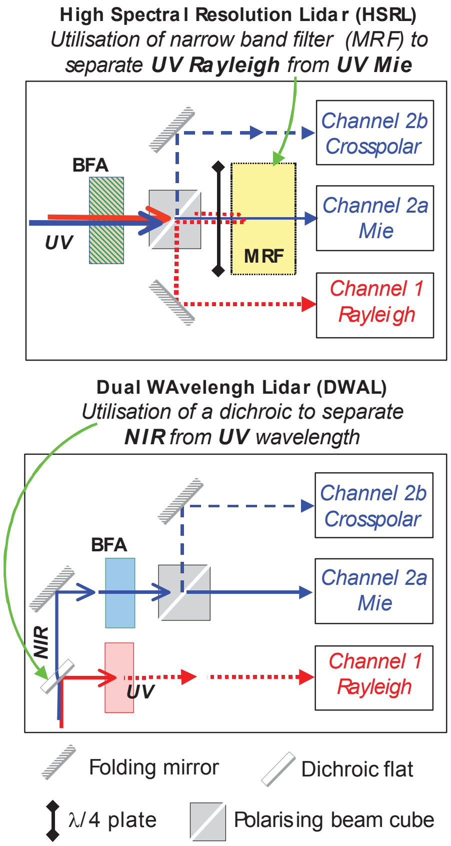



Fig. 3 Instrument concepts

In the DWAL layout a dichroic separates the infrared from the UV. The number of photons backscattered by the molecules at 1064 nm is almost 30 times lower than the one in the UV at 355 nm. In contrast the contribution of the cloud particles grows linearly with the wavelength because the backscatter coefficient remains invariant whilst the number of laser photons transmitted per joule varies proportionally to the wavelength.

This feature yields the aerosol backscatter to dominate in the IR. In each IR and UV channel, a background filter Assembly (BFA) rejects most of the spurious sunlight resulting from the illumination of the Earth atmosphere and ground floor. A Polarising Beam Splitter (PBS) implemented on the optical path of the IR channel separates the crosspolar from the copolar. In contrast, the whole UV signal is sent to channel 1 for acquisition.

In the HSRL, the input signal traverses first a BFA similar to the one implemented in the DWAL whose aim is rejecting the background prior to be intercepted by a PBS which splits the crosspolar and the copolar components.

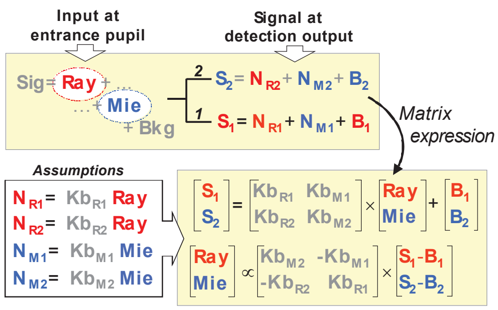
The crosspolar is acquired on channel 2b while the copolar is sent through a Mid Resolution Filter (MRF) whose bandwidth of 0.3 pm is narrow enough to let transmit the Mie spike but blocks the major part of the broadband Rayleigh reflected with the fraction of the aerosol backscatter not transmitted. A quarter wave plate implemented between the PBS and the MRF induces a rotation by 90° of the polarisation of the reflected signal which is deviated into channel 1 for acquisition.

## 3 PERFORMANCE BUDGETS

### 3.1 Methodology

A numerical model has been developed for the evaluation of the instrument performance with HSRL and DWAL concept. The bottomline identical for both concepts, relies on a square matrix approach in which the inputs Rayleigh and Mie at the pupil entrance of the instrument (noted respectively Ray and Mie) relate to the detection outputs, namely $S_1$ and $S_2$ by introducing a set of a priori known weighting coefficients shown in the box at the bottom of figure 2.

Simply inverting the square matrix once the background Bj is removed by subtraction thus retrieves the input components. For that purpose, this background is measured on a shot per shot basis before the laser beam penetrates the higher atmosphere and the measurement is repeated after the beam hits the ground floor.




$$\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \begin{bmatrix} Kb_{R1} & Kb_{M1} \\ Kb_{R2} & Kb_{M2} \end{bmatrix} \times \begin{bmatrix} Ray \\ Mie \end{bmatrix} + \begin{bmatrix} B_1 \\ B_2 \end{bmatrix}$$

$$\begin{bmatrix} Ray \\ Mie \end{bmatrix} \propto \begin{bmatrix} Kb_{M2} & -Kb_{M1} \\ -Kb_{R2} & Kb_{R1} \end{bmatrix} \times \begin{bmatrix} S_1-B_1 \\ S_2-B_2 \end{bmatrix}$$

Fig. 2 Methodology for retrieval

The weighting coefficients $Kb_{Rj}$ and $Kb_{Mj}$ define the efficiency by which the Rayleigh and Mie backscatter return are converted at the detection output of the channel 1 (j=1) and 2 (j=2).

With HSRL, these coefficients are carried out neatly by a radiometric calibration performed periodically on board the satellite. The calibration of the Rayleigh coefficients is performed with the return from the higher atmosphere. Above 40 km, the atmosphere is supposedly free of aerosol and scattering is simply due to the molecular content highly deterministic. In operation the Rayleigh coefficients can be determined with accuracy better than 3% limited by the uncertainty that the atmospheric temperature is known.

For the Mie coefficients the backscatter due to the particles is substituted by the exploitation of the ground echo itself. This return serves essentially to carry out the transmission /reflection properties of the MRF filters used to separate the Mie from the Rayleigh. Impact of the Doppler shift due to platform motion is thus circumvented as well as possible spectral shift of the transmitted laser line.

The UV channel of the DWAL is calibrated the same way. However unlike the HSRL, a difficulty lies in the extrapolation in UV of data gathered in the infrared and vice versa. Resulting from numerous observational and theoretical studies, a scaling appropriate for the spectral variation of the backscatter and shows that the backscatter β (and other related coefficients) is approximately related to the wavenumber 1/λ) according to a power law of the form:

$$\beta \propto (1/\lambda)^{\gamma} \qquad (1)$$

With exponent is the angstrom coefficient ranging from 4 for molecular scattering itself to zero as the particles become large compared to wavelength. Except for the molecules, the variability of the angstrom coefficient betrays the large variety of aerosol loading and particles to be encountered during mission. Equation 1 thus stresses the question of how reliable is an extrapolation from infrared to UV and reciprocally. The difficulty of setting a credible value for the angstrom coefficient poises heavily in the performance budget of the DWAL as highlighted in subsection (3.2).

For simulation, the ATLID Reference Model of Atmosphere established by ESA utilises a semi-empirical formula in which the angstrom coefficient derives from a climatological database of the atmosphere backscatter at the wavelength of 10.6 µm from regions of the Atlantic during the relatively clean atmospheric period 1988-1990. For cirrus cloud the angstrom coefficient is assumed equal to zero.

### 3.2 Retrieval accuracy

The accuracy by which the Rayleigh input (named Ray) is retrieved is given by Equation 2 as a function of the signal to noise ratio. In this formula, $err_0$ denotes a threshold error in relation to the calibration performance and reliability of assumptions in the wavelength extrapolation. The factor $r_M$ qualifies the contamination of the Rayleigh signal by the aerosol backscatter. $SNR_1$ and $SNR_2$ are the signal to noise ratio respectively at the output of channel 1 and 2.

$$\frac{\partial \mathrm{Ray}}{\mathrm{Ray}} \approx \frac{1}{(1-r_M)}\sqrt{\left\{\frac{1}{SNR_1^2}+\frac{r_M^2}{SNR_2^2}\right\}+err_0^2} \quad (2)$$

An equation similar for the Mie retrieval can be carried out by permuting index 1 with 2 and substituting in the formula $r_M$ by the Rayleigh contamination factor $r_R$.

The plots of figure 4 exhibit the amount of transmitted energy and collecting area to achieve the retrieval of Mie and Rayleigh with a certain accuracy at the bottom of the cirrus cloud., The blue and dashed red lines on the graphic refer respectively to the Rayleigh and Mie copolar.

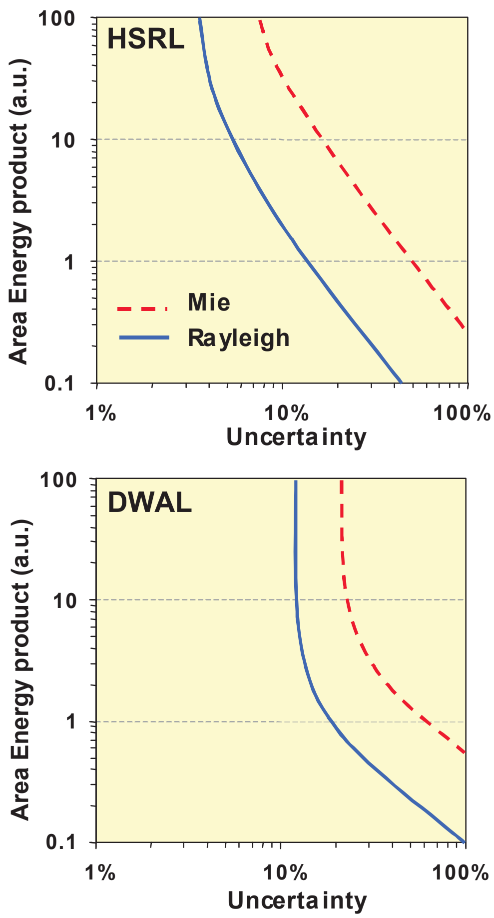



Fig. 4 Performance analysis

For sake of clarity the crosspolar is omitted because its measurement is not affected by the wavelength and is performed similarly in UV with the HSRL and infrared with the DWAL.

The curves evidence that the HSRL technique outperforms the DWAL whose performance is spoiled by a much higher threshold error. This error is put in evidence by the boundary values that the performance is restricted to about 12 % and 20% respectively for Rayleigh and Mie.

## 4 INSTRUMENT DESIGN

ATLID layout and operation mode is sketchily presented on figure 5.

The transmitter is a Nd-YAG laser operating at the third harmonic (354.8 nm). A master oscillator stabilised by an injection seeder emits the laser line. A single stage amplifier suffices to provide more than 25 mJ per shot with a pulse repetition frequency of 70Hz.

A beam expander shared with the half meter diameter receiving telescope magnifies the laser beam. This monostatic configuration ensures that the photons backscattered by the atmosphere are collected along the same axis as the laser beam. In this framework possible thermo-elastic deformation of structure and optics does not affect the collecting efficiency.

The telescope delivers a collimated beam which is sent through the Mie Rayleigh Separator Assembly (MRSA) housing the BFA and the MRF (See section 2). The filters are based on Capacitance Stabilised Etalon (CSE) whose gaps are actively controlled and finely adjusted by means of piezo actuators.

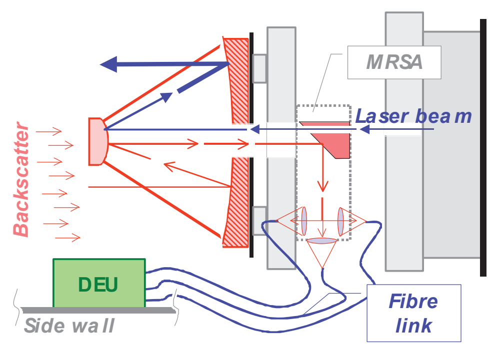



Fig. 5 ATLID principle

The characteristics of the filters are set for minimising the impact of Doppler shift caused primarily by satellite motion.

In the MRSA, the flux is dispatched between the 3 different channels according to the principle described in section 2. Then the flux exiting the MRSA is intercepted by focusing lenses and conveyed by fibre links to the focal plane detectors of the Detection Electronics Unit (DEU). These detectors are conventional photo multiplier tubes and to cope with the dynamics, the signal is acquired simultaneously in photo-counting and analogue modes. In this framework faint signal can be detected and large ground echo as well.

Once the instrument is assembled and tested, the whole is mounted together with the CPR and the passive sounders. A CAD overview of ATLID is shown on the figure 6 which highlights the compact design that the study concluded with.

The main instrument characteristics are gathered in table 2.

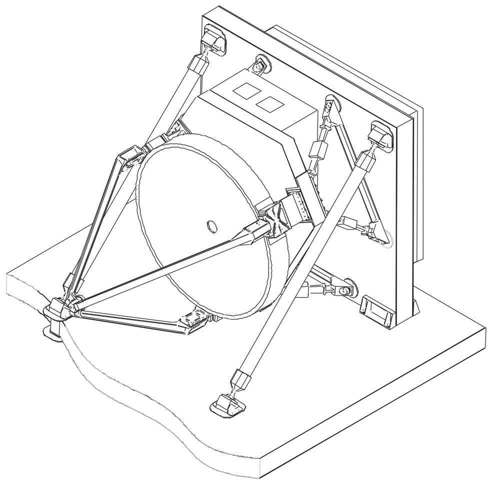


Fig. 6 ATLID CAD overview

| Parameters | value |
|---|---|
| Power consumption | 230 W |
| Mass | 130 kg |
| Vertical sampling | 100 m |
| Vertical range | 70 km |
| Data rate | 250 kbits/s |

Table 2 Main instrument characteristics

## 5 CONCLUSION

The study performed by ALCATEL SPACE for the atmospheric lidar of the EarthCARE mission led to select a design based on a novel methodology for probing the aerosol and clouds. The design relying on the utilisation of high spectral resolution filter features compactness and is less demanding in term of satellite recourses than the conventional approach requiring 2 wavelengths.

Moreover analysis of possibilities offered by the high spectral separation technique indicates a growth potential leading to upgrade the capability of ATLID at a slight expense of complexity.

## 6 REFERENCE

1. EEM-FP/2001-12-563/PS/ps, SoW, Phase A system study for the EARTH Clouds, aerosols and radiation Earth explorer core mission, 11 Feb 2002.

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