Spaceborne lidar technology developments at the European Space Agency

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Abstract. The European Space Agency is carrying out a development programme for spaceborne lidars, which are candidate instruments for forthcoming Earth Explorer satellite missions for remote sensing of the Earth. Mission analyses and scientific studies have been carried out and developments of critical lidar technologies have been performed. The paper reports about the ATLID and ALADIN development programs and gives an overview of the other technology studies.

1. Introduction

The attraction of spacebome lidars for disciplines such as meteorology, climatology and environmental sciences is widely recognised {1}. Such instruments offer the potential for high-accuracy range-resolved measurements of atmospheric parameters with global coverage
The European Space Agency (ESA) has for some years supported a programme for satellite-borne lidar instruments which has included both mission and scientific studies and technology developments. In the process of defining the next ESA research missions for Earth observation, a backscatter lidar has been proposed as part of an Earth Radiation mission and a Doppler wind lidar has been proposed as the key-instrument of an Atmospheric Dynamics mission {2}. In addition, ESA is supporting developments of advanced technologies for Differential Absorption Lidar (DIAL) and Doppler wind lidar.

2. ATLID: the spaceborne Atmospheric Lidar

The front-runner of ESA lidar developments is a backscatter lidar based on all solid-state laser technology called ATLID (ATmospheric LIDar) {3}. ATLID is designed primarily to provide satellite measurements of cloud top height in day- and night-time conditions. In addition ATLID will be capable of measuring the heights of cloud bottoms for thin clouds and the extent of the Planetary Boundary Layer (PBL) and of aerosol banks. These atmospheric features can be measured up to 20 km height with a range resolution of 50 m and a height restitution accuracy of ± 100 m (3 σ). In order to provide 3-D mapping of atmospheric features, ATLID telescope is linearly scanned transversely to the direction of the spacecraft velocity. The scan angle of ± 23.5° at an orbit height of 800 km results in a swath width on the ground of 700 km. With a footprint of 140 m diameter, and operating at 100 pps, the instrument can obtain more than 100 measurements within a 100 x 100 km^2 area. ATLID layout is shown in Fig. 1.

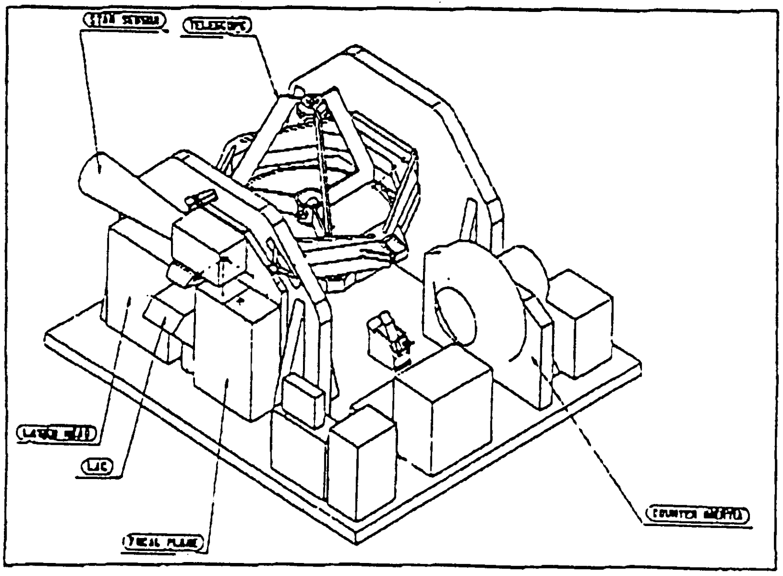


Fig.1: ATLID instrument layout; transmit/received beam paths are shown.

The present design of the instrument was tailored to the accommodation on ENVISAT remote-sensing satellite, in view of a potential future ENVISAT re-flight. A non-scanning design of ATLID is presently proposed for the Earth Radiation mission, for which a different spacecraft concept is foreseen. The elimination of the scanning is mostly dictated by the need of exploiting at best the synergy between ATLID and the cloud radar, which is part of the basic instrument package of the satellite.
The transmitter laser for ATLID is a diode-pumped Q-switched Nd:YAG laser operating at 1.064 μm wavelength, which emits laser pulses of 100 mJ energy and 20 ns duration at 100 Hz pulse repetition frequency. The laser emits a near-TEM_{00} beam of good spatial quality (M^2=1÷1,5) and pulse-to-pulse stability (2%) and shows an electrical-to-optical efficiency of 6.5%. The laser diode power supply provides the high current pulses and shows an efficiency up to 74%. Heat removal from the laser head is provided by a capillary-pumped two-phase loop that is coupled to a radiator mounted on the anti-sun face of the satellite.
The lag-angle effect due to the scanning is compensated by a mechanism in the transmitter chain. The backscattered radiation is collected by a 60 cm lightweight Cassegrain telescope, which has an estimated mass of 10 kg. The primary mirror is realised in C-SiC, coated with a SiC vapour-deposited layer, and has a non-hygroscopic CFRP structure.
The telescope is mounted on a one-axis scanning mechanism, suspended between two liquid-lubricated bearings, designed to a lifetime of 1.8 10^7 cycles. The scanning-induced torque is compensated by a fly-wheel and satellite inaccuracies in attitude restitution are compensated by a fine star-sensor.
Focal plane optics direct the incoming photons to the detection chain via an ultra-narrow bandwidth filter for background rejection. The selected filter is a Fabry-Perot Interferometer, which transmits up to 63 % of the return signal within a bandwidth of 0.21 nm. A Lyot filter has been also investigated but resulted less robust and more critical in meeting the accuracy and stability requirements.
The detection module is based on a silicon APD, DC-coupled to a low-noise trans-impedance amplifier , integrated on the same hybrid circuit. To perform the twin roles of cloud top height and aerosol density measurement, the return signal is pre-processed in parallel by a peak detection chain and a radiometric chain,
The estimated mass and power consumption of ATLID are 240 kg and 450 W, respectively.
Breadboarding of key-units, including the laser head and its power supply, the telescope, the scanning mechanism, the detection chain front-end, the thermal control system and the filters for background radiation rejection are being carried out by a wide industrial consortium {3}, led by Matra Marconi Space (France). A novel algorithm for signal retrieval under low SNR conditions has been also evaluated {4}. The technology effort shall be completed in the next future by the integration of the key subsystems (transmitter, receiver, pointing mechanism and telescope).

3. ALADIN: the European spaceborne Doppler wind Lidar

The second corner-stone instrument of ESA lidar programme is ALADIN (Atmospheric LAser Doppler Instrument), a coherent Doppler wind lidar aimed at measuring winds in the troposphere and lower stratosphere on a global scale. To take advantage of early flight opportunities, a Doppler wind lidar concept based on CO_2 laser technology is considered the most appropriate, due to its present higher technological maturity.
The instrument has been configured to measure radial wind speed profiles in clear air. Its accuracy ranges from 1 m/s in the PBL to 5 m/s at 15 km height, with a measurement reliability of 95%. The instrument line-of-sight scans a swath width of 800 km from an orbital height of about 500 km, sampling a grid of observation cells of 200 x 200 km dimension. Step-scanning of the telescope line-of-sight to a fixed number of positions allows increased SNR through shot-averaging, and also eliminates the need for lag-angle compensation which is associated with conical scanning.

Two parallel industrial studies for ALADIN {5,6,7} have been performed in to define instrument concepts. A single-mode CO_2 laser source of 10-15 J pulse energy, based on pulse-sustainer discharge technique, was selected as the most appropriate. Coupled to this, a telescope aperture of 50 to 70 cm is needed. The proposed step-scanning concept can be implemented either by means of a steerable mirror in front of the telescope{6} or by switching the line-of-sight among telescope sub-elements in the focal plane{7}, as it has been proposed by the two parallel Pre-phase-A studies. The receiving chain is based on a heterodyne detection scheme, and advanced frequency estimation algorithms based on adaptive filters for retrieving the wind velocity have been proposed {8}. ALADIN mass is of the order of 500 kg and power consumption about 1.5 kW. Accommodation on a dedicated satellite flying in a helio-synchronous dawn-dusk orbit or, alternatively, on the International Space Station has been evaluated for a research/demonstration mission. The present baseline for the Atmospheric Dynamics mission foresees the accommodation of ALADIN on the International Space Station. A sketch of the ALADIN instrument concepts generated by the two parallel studies is shown in Fig. 2

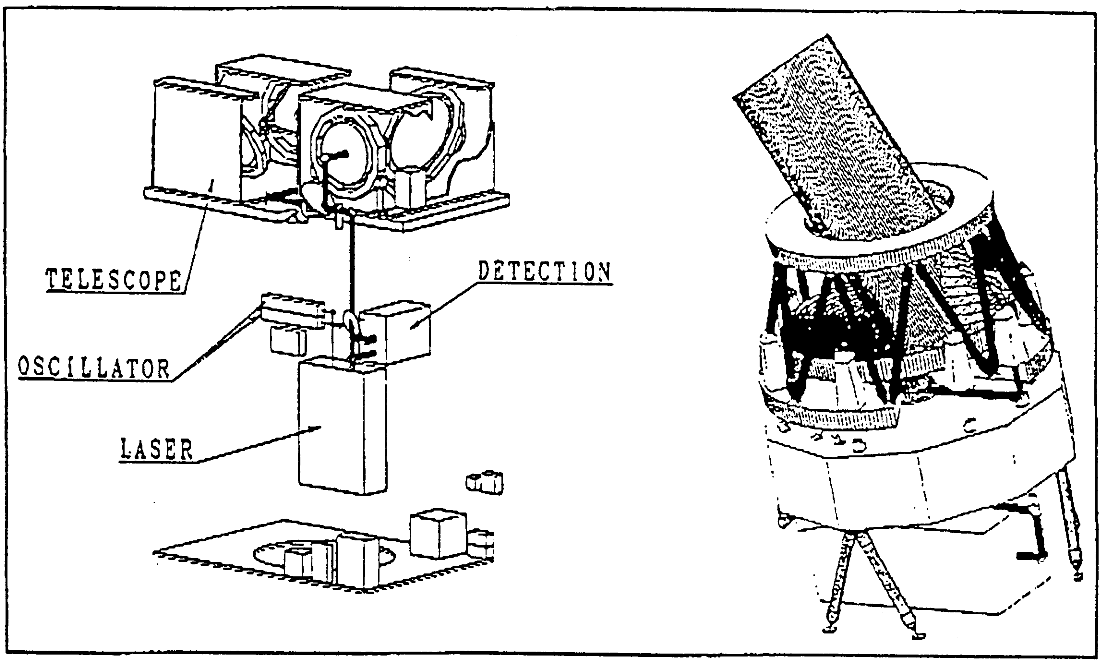


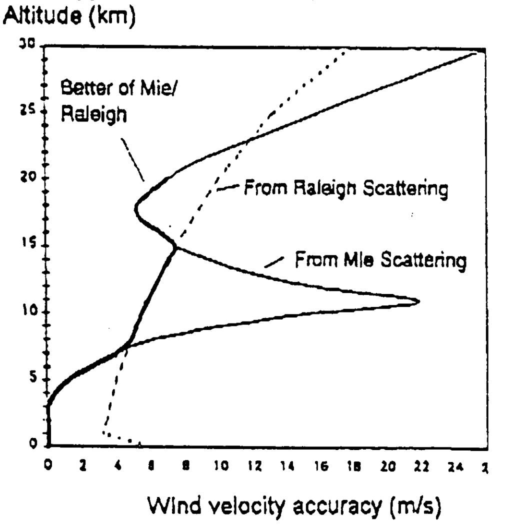
Fig.2: ALADIN instrument concepts. Steerable mirror scanning (left) and shared primary telescope step-scanning (right)

Enabling key-technologies for ALADIN are being breadboarded. A CO_2 single-mode laser transmitter, based on electron-beam sustained discharge, has delivered 11.3 J per pulse in 5 µs at 10 Hz rate. Lifetime has been demonstrated to exceed $6 \cdot 10^7$ pulses on a single extended sealed run {9}. The pulser-sustainer technique has been also investigated and shows promise of efficient all-solid-state excitation {10}. Support studies on signal processing aspects have been also carried out, confirming the validity of accumulation techniques with adaptive frequency estimation algorithms. A high-energy pulser-sustainer laser transmitter and an heterodyne receiver operating at 10 µm are proposed for forthcoming technology demonstration.

4. Lidar technology developments.

Developments looking towards the longer term are focused upon a project for a combined DIAL/Doppler wind lidar that operates at 2 µm wavelength. The objectives are the range-resolved measurement of water vapour concentration in the lower troposphere to an accuracy of better than 10% and high accuracy wind measurements in the planetary boundary layer (2 m/s). The core of the instrument concept consists of an all-solid-state Tm,Ho:YAG transmitter laser emitting 1 Joule energy and a coherent receiver. Design of the Q-switched injected-seeded master oscillator is currently underway. Experiments on phase-conjugate beam correction mirrors at 2 µm have demonstrated reflection efficiencies greater than 60% using stimulated Brillouin scattering in $SnCl_4$ {11}. Towards development of the receiver, measurements of heterodyne mixing efficiency at 2 µm have recently been undertaken, and breadboarding of the detection chain is currently underway.

Additionally, a wind measuring lidar based on incoherent detection and operating in the ultra-violet is also being investigated in two parallel studies. The attraction of incoherent lidar as compared to coherent lidar is that the alignment tolerances are somewhat more relaxed. Two receiver concepts are under investigation. One concept is based upon Mie returns and consists of a Fizeau interferometer combined with a light-intensified CCD. The second receiver concept measures winds from Rayleigh returns using a dual edge technique interferometer {12}. Since the reflection from the blocking filter for the Mie receiver may be used by the Rayleigh receiver, wind measurements at high altitude based on Rayleigh returns and at low altitude based on Mie returns may be obtained simultaneously. The accuracy profile vs. height resulting from such a combined detection technique is shown in fig.3.



INSTRUMENT CONCEPT

Energy:	1 Joule (@ 355 nm)
PRF:	20 pps
Tel. aperture:	1 m
Shot cluster area:	35 * 35 km^2
Swath width:	600 km
Orbit height:	520 km
Horiz. cell size:	200 km * 200 km
Height resol.:	1 km

Fig.3: Velocity accuracy measurements vs. altitude employing either Mie and/or Rayleigh returns at 355 nm

5. Conclusions

The European Space Agency aims at the deployment of a satellite-based lidar system in the next decade. ATLID, a backscatter lidar and ALADIN, a coherent Doppler wind lidar are the focus of this development programme. In parallel, new enabling technologies and other instrument concepts are investigated, in view of future missions after years 2010.

6. References

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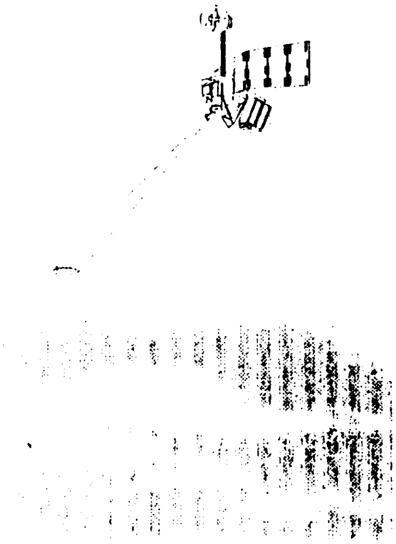
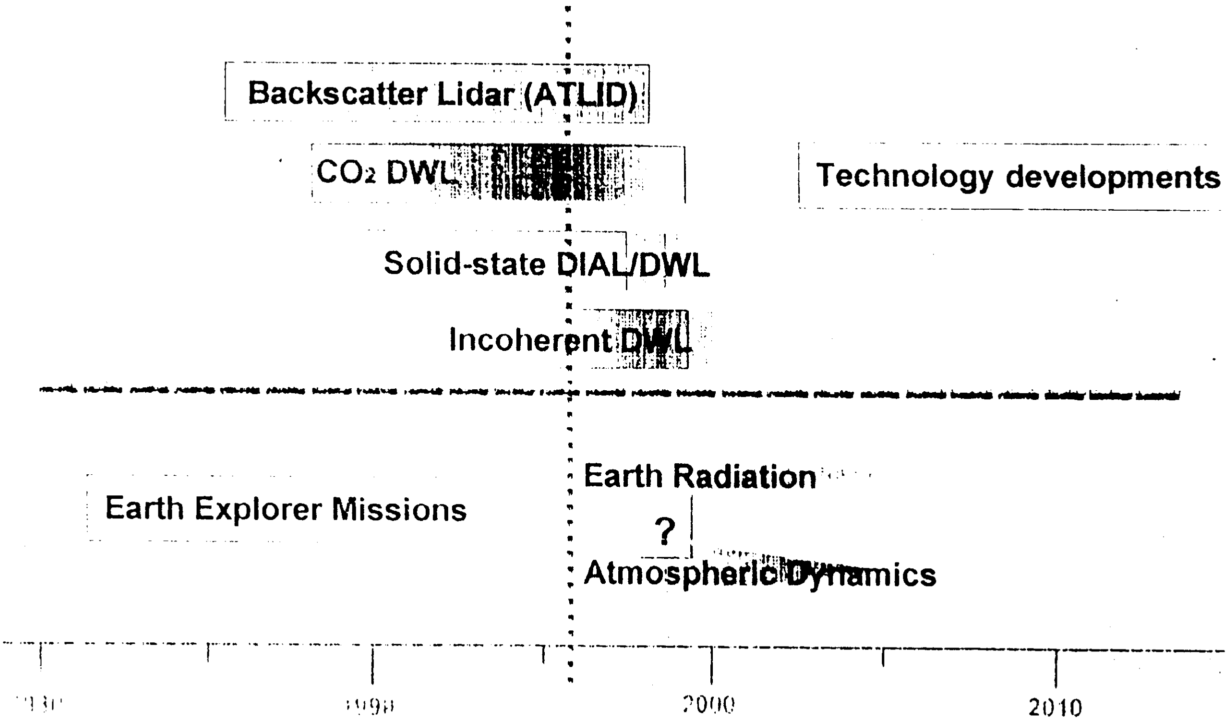


International Workshop on Spaceborne Lidars 1996 - Technology and applications - Hakone, Dec. 15th-18th 1996

International Workshop on Spaceborne Lidars 1996 - Technology and applications - Hakone,

Overview of Spaceborne Lidar activities



Backscatter lidar for Earth Radiation Mission

The **Backscatter Lidar** for the Earth radiation mission **will evolve from** the technology development program of ATLID (ATmospheric LIDar), the European Backscatter lidar.

The need for exploiting at best the synergy between the cloud radar and the lidar calls for a **non-scanned** instrument, whose line-of-sight can be always kept aligned to the cloud-radar bore-sight. The loss of the swath coverage is acceptable within the objectives of the Earth Radiation Mission.

System **advantages of a non-scanned solution** are

- mass reduction (Δm ~ 45 kg)
- prime power requirement reduction (ΔP~ 60 W)
- increased compactness and robustness
- possibility of using larger telescope aperture (90 cm, proposed)
- cost reduction

An increase of the requirements for thin cloud detection is also foreseen ($\tau = 0.1$)

ATLID: the European Backscatter lidar

ATLID - the European backscatter lidar - was the first lidar being developed by ESA, due to its advantageous balance between system complexity, technology maturity and scientific return.

From **1992**, the present **ATLID** development phase was initiated, aiming at an instrument design compatible with the accommodation on ENVISAT.

From **1994** a wide programme of development of critical technologies is running, with the aim of demonstrating the key-units of **ATLID** instrument.

<u>**ATLID** scientific objectives</u>:

- Thick clouds top height,
- Thin clouds top and bottom height,
- Cirrus optical depth and depolarisation
- Planetary Boundary Layer top height and optical depth

<u>Present ATLID concept mostly fulfils observation requirements of **ERM backscatter lidar**</u>. Further assessment of ATLID technology shall be carried out within the Phase-A study of the Earth Radiation mission.

ESA Earth Explorer Missions

The next ESA's research satellite initiative for Earth Remote Sensing is based on a series of nine missions, the **Earth Explorer Missions**.

The missions have been evaluated by the scientific community and **four** of them have been proposed and selected for a **Phase-A study**, possibly to run in 1997-1998.

The four Earth Explorer Missions candidate for early implementation are:
- Gravity Field and Steady-state Ocean Circulation
- Atmospheric Dynamics
- Earth Radiation
- Land-Surface Processes and Interactions

Two of them embark as a corner-stone instrument a **spaceborne lidar**:
- Earth Radiation: Backscatter lidar
- Atmospheric Dynamics: Doppler wind lidar

ESA Earth Radiation Mission

The **Earth Radiation Mission** intends to provide a picture of the 3-D spatial and temporal structure of **radiative transfer** in the Earth's atmosphere and to quantify the impact of clouds and aerosol fields on **radiation balance**.

For the space segment of the Earth Radiation mission the following instruments have been proposed :
- a Broadband Radiometer (BBR)
- a Visible/Infrared Cloud Imager (CI)
- a Cloud Profiling Radar (CPR)
- a **Backscatter Lidar (BL)**

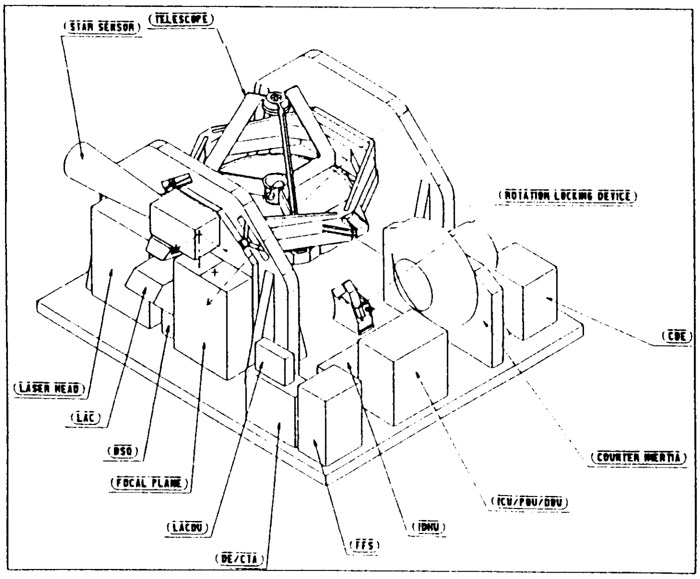
ATLID REQUIREMENTS

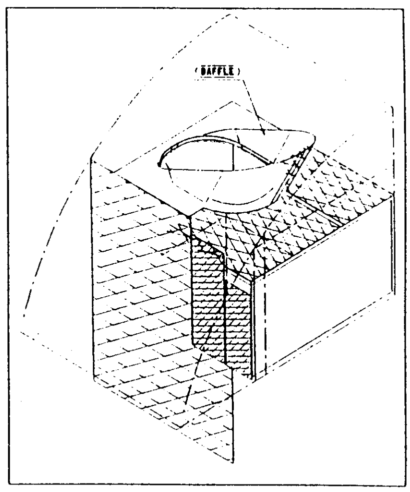
ORBIT	- Inclination - Type - Altitude		Polar 98° Helio-synchronous 800 km	
SCAN GEOMETRY	- Full Swath width - Scan angle		700 km (along-track) ± 23.5°	
SAMPLING REQS.	- Observation range - Footprint diameter - Height restitution acc. - Vertical resolution (nadir) - Shot spacing - Shot location accuracy[2]		0 < h < 20 km 100 m< d < 500 m 100 m 50 m < 50 km ± 2000 m (3σ)	
MISSION REQS.	-Operation mode - Lifetime		Day/night continuous 3 years	
RADIOMETRIC REQS.	**Feature**	**Meas.type**	**Hor.cell size**	**SNR[2]**
	Cloud top	single-shot[1]	20 x 20 km	4 (3)
	PBL	averaged	100 x 100 km	6
	Cirrus depol.	averaged	100 x 100 km[2]	6 (3)
	Cirrus τ	averaged	100 x 100 km[2]	20 (3)

[1] only for cumulus /cumulonimbus clouds - Altostratus, and cirrus averaged

[2] Requirements for ERM: Shot location accuracy, 35 x 35 km cell size, SNR in brackets

ATLID INSTRUMENT LAYOUT





ATLID PREDICTED PERFORMANCE-1

OVERALL INSTRUMENT

Interface parameters:

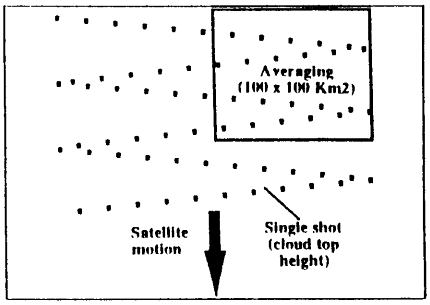
* Mass: 240 kg (< 200 required) - To be reduced with better accommodation (anti-sun face)
* Power consumption: 443 W BOL/ 498 W EOL (<500 W required)
* Data rate: 1.06 Mbps (2.26 Mbps for two chains)
* Volume envelope: 1.6 x 1.35 x 1.1 m^3 (radiator not included)

Geometric performance:

Parameter	Predicted	Required
Vertical resol. (Nadir)	**40 m**	50 m
Height rest.acc. (3σ)	**± 100 m#**	±100 m
Shot spacing	**< 50 km**	< 50 km
Shot location rest. acc.	**± 1 km (3σ)**	± 1 km (3σ)
Footprint diam. (nadir)	**140 m**	100÷500 m

At Nadir:±31 m(Aerosols),+79/-25 m(Clouds).At swath edge:±79m(A),+97/-103m(C)

Scan pattern:



ATLID PREDICTED PERFORMANCE-2

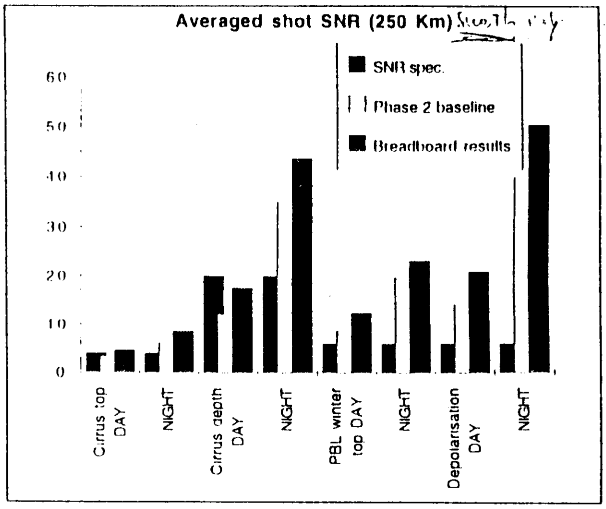
Pointing performance:

- S/C Pointing error: <18 μrad[1] (14 req.)
- S/C Pointing rate:< 12 μrad/s (18 req.)

Optical performance:

- Optical efficiency (Tx/Rx):0.4
- Internal FOV: 640 μrad
  (600 with present BB results)

Radiometric performance:



1 Due to SAR Antenna overshoot in the pattern of Envisat disturbances

ATLID TEAM

Atlid

22 Companies and Institutions
from
9 ESA member states

Mgmt & Overall instr. design and engineering
MMS-F (F)

MATRA MARCONI SPACE

Tx chain engineering
GFSA (I)

Laser head
GFSA (I) with Quantel(F), ENOSA (E), Norsk EO (N)

Laser diode power supply
DASA-Dornier (D)

Laser head thermal ctrl.
MMS-UK (UK) with NLR and Bradford Eng.(NL)

Rx chain engineering
MMS-F (F) & DASA Dornier (D)

BREADBOARDS

Detection chain I
MMS-F (F) with EG&G (Can), TPD (NL)

Detection chain II
DJO (D) and EG&G (Can)

Fabry-Perot filter
DASA (D) and Tecoptics (UK)

Lyot-Solc filter
DASA(D) & Carl Zeiss Jena (D)

Coatings
DASA (D) & Jenoptik (D)

Opto-mech.chain eng.
MMS-F (F)& DASA Dornier(D)

Telescope
Carl Zeiss Jena with CZO, DASA, PTS, MAN & Jenoptik (D)

Scan mechanism
ORS (A) with Oerlikon Contraves and Laben (I) and VTT (Fin),

ATLID LASER HEAD

Transmitter chain
Includes 2 **laser heads**, *LPS*, Q-switch el., BSO, Beam exp.

Laser head characteristics
- Diode-pumped Q-switched Nd:YAG operating at 1064 nm
- Operation with 100 mJ pulses at 100 Hz (PRF adjustable in 90 ÷110 Hz range)
- Side-pumped slab (8stacks,7 bars each; 84 mJ/bar)
- Zigzag path in the slab for thermal lensing compensation
- Folded unstable resonator with super-gaussian output coupler.

Laser head BB main performance

- Pulse Energy:	97 ± 1 mJ
- Pulse Energy stability:	< 5% (15 s)
- Laser linewidth	< 0.1 nm (± 0.01 nm)
- Pulse duration:	20 ns
- Polarization:	Linear (50:1)
- Mode structure:	Near-TEM_{00} (M^2 = 1.5), multi-mode longitudinal
- Beam dimension:	2.9 x 4.2 mm (Near-field)

ATLID INSTRUMENT CONCEPT

Transmitter:
- Diode-pumped, Q-switched Nd:YAG laser,
- Power-oscillator laser, 100 mJ/pulse @ 100 Hz, λ=1.064 μm.

Receiver:
- Fabry-Perot Filter + Avalanche Photodiode detection chain.
- 2 concepts studied: trans-impendance amplifier and resetable integrator.

Scanning concept:
- One-axis sinusoidal scanning telescope (±23.5°)
- Contra-rotating flywheel to compensate for induced torques.

Telescope:
- 0.6 m aperture, afocal Cassegrain telescope
- Lightweight primary mirror (SiC-coated C-SiC)
- Refocusing mechanism (intermediate focus) needed !

Alignment / pointing:
- Lag-angle compensated by dedicated mechanism on laser boresight
- Fine star sensor for assisting laser LOS restitution.

Thermal control:
- Capillary-pumped two-phase loop.
- Two radiators, one foldable (based on Envisat accommodation)
- Fixed thermal baffle around telescope cavity (tight thermal control)

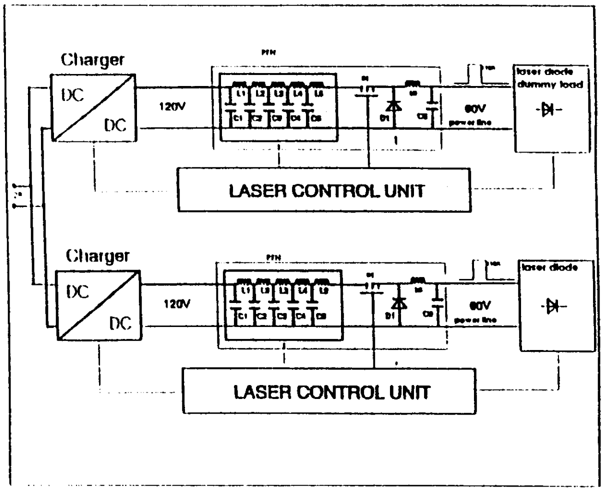
Calibration:
- Without extra hardware: background radiometric calibration. Laser LOS and Rx/Tx LOS re-alignment , receiver defocus compensation, against long term misalignment effects

LASER DIODE POWER SUPPLY

LPS PERFORMANCE

- Pulse power: 2 x 5 kW peak
- Pulse voltage:59 V
- Pulse current:2 x 85 A
- Pulse duration:200 ± 20 μs (adjustable)
- Pulse stability:2 μs
- PRF:100 Hz
- Overall efficiency:74% (73% req.)
- Temperature test range:-20° ÷ +50 °C
- EMC test: compliant in all modes

LPS BLOCK DIAGRAM



LASER HEAD THERMAL CONTROL

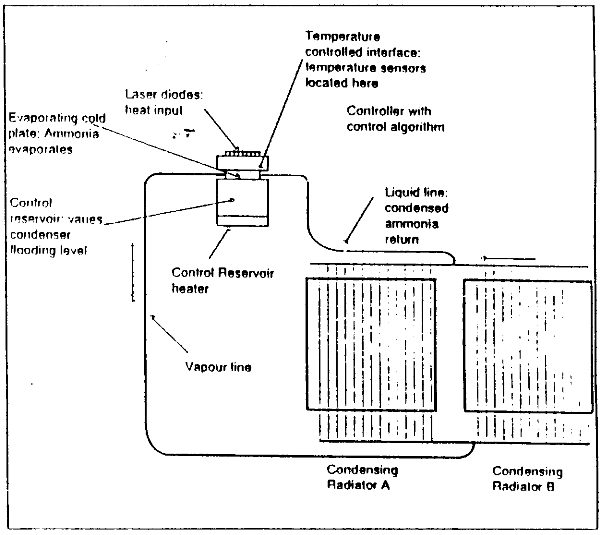
LHTC BB CHARACTERISTICS

- Capillary-pumped two-phase loop (NH_3)
- Evaporating cold plate: sintered Ni wick
- Reservoir: liquid level compensation
- Radiating surface (2 x 1.22(h)x1.6(l) m^2)

LHTC BB PERFORMANCE

- T interface stability: 0.7°C over thermal cycle simulating orbital conditions
- Capillary pumping demonstrated at 1 g.
- Heat loads: 147 ÷ 332 W (operational)
- Evaporator/reservoir stiffness: 200 Hz (1st freq.)
- Radiators stiffness: 100 Hz and 84 Hz (1st freqs.)

LHTC BLOCK DIAGRAM

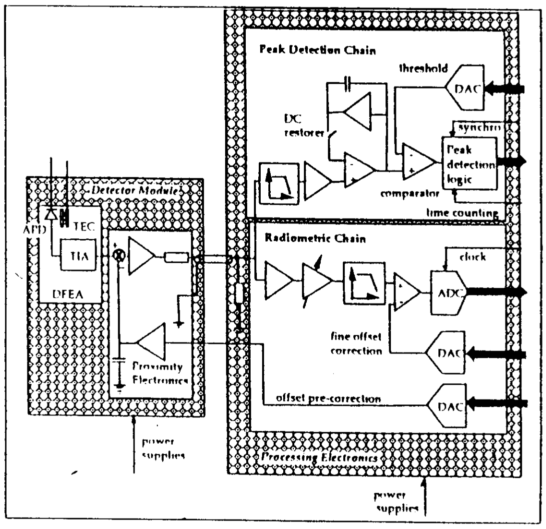


DETECTION CHAIN I

DETECTION CHAIN BB CHARACTERISTICS

- Si-APD and TIA integrated on a hybrid.
- Temperature stabilization with TEC (25°C)
- DC-coupled amplifier and offset correction
- Peak detection chain: high-speed for precise timing of cloud-top/high-energy signals
- Radiometric chain: low-noise, capability of reconstructing cloud profile (filtering/sampling).
- Programmable gain in radiometric chain for test aims (0.75 ÷ 15)
- Filter cutoff frequency and ADC sampling frequency variable for performance evaluation
- Potential for space qualification

BLOCK DIAGRAM



DETECTION CHAIN I - BB PERFORMANCE

PARAMETERS	REQUIREMENTS	PERFORMANCE
Signal dynamic range	5 ÷ 2000 pW	OK
Background dynamic range	0.1 ÷ 230 pW	OK
Sampling frequency	>3 MHz	4 MHz
SNR-day cirrus[1] (S=60pW,Bg=230 pW)	> 1.2 (goal:1.5)	**1.57**
SNR-night cloud[1] (S=620 pW)	> 9 (goal:10)	**13.1**
Datation Accuracy/Probability[2]	325 ns/95%	0÷325 ns/99% (Nadir)
Detection Prob.[2] (PFA=$3.5 \cdot 10^{-4}$)	-	
Linearity error	3% over 12 bits	**< 1.2%**
Gain stability	-	0.3 % (1 hour)

[1] Radiometric chain SNR @ 1.5 MHz cut-off Bessel Filter - [2]Peak detection chain @ 500 pW signal

FILTER BREADBOARDS

PARAMETERS	REQUIREMENTS	FABRY-PEROT	LYOT-SOLC
Center wavelength	1064.15 (STP)	1064.49(vacuum)	1064.49(vacuum)
Spectral Bandwidth	0.2 nm (FWHM)	*0.21* nm	0.19 nm
Peak transmission	> 0.5	0.63 (*0.48* after test)	0.66 (0.57 after test)
Center wavelength stability	<±0.01 nm (0÷40°C)	No temp.stab.needed	Temp.stab. ±0.1 K
Equivalent blocking bandwidth	0.28 nm (0.3÷1.2μm)	*0.35 nm*	*0.33 nm*
Effective aperture	30 mm	OK	OK
FOV	±5.3 mrad	OK	OK
WFE	<λ/10 rms @1.06 μm	OK[#]	OK[#]

Critical area: long-term stability of filter performance (center λ, transmission, bandwidth)

The **Fabry-Perot filter** has been selected as **baseline** due to its more compact and robust design.

[#] Marginal due to non-optimum quality of blocking filter

TELESCOPE BREADBOARD

TELESCOPE BB CHARACTERISTICS

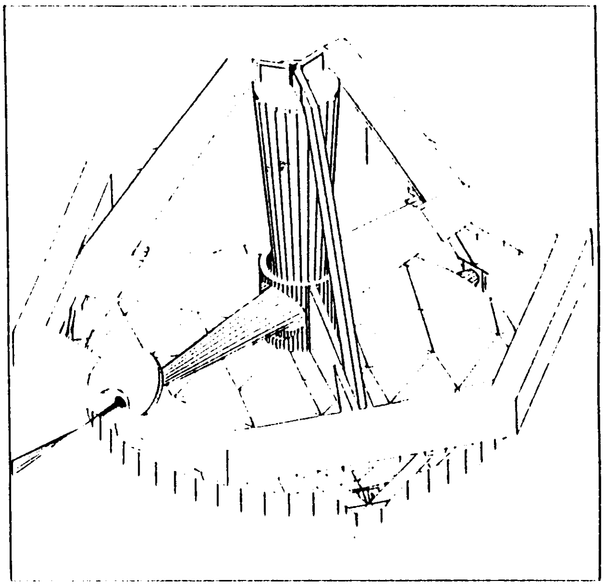
- Cassegrain telescope
- Clear aperture 600 mm
- C-SiC primary mirror
- CVD coated 100 μm SiC
- Non-hygroscopic CFRP barrel
- Zerodur 85.9 mm secondary mirror
- Folding mirror 45°

TELESCOPE PERFORMANCE

- Predicted total optical transm.: 0.887
- Predicted equiv. focal length: 5657.7 mm
- Required optical quality: $d_{99\%}$=450 μm
- Roughness: < 10 nm rms (2nm, sample test)
- Primary mirror mass: 5.7 kg
- Telescope mass: < 9 kg

Polishing of SiC-coated samples OK
BB (M1+ISM) to be completed (4/97)

TELESCOPE LAYOUT



SCAN MECHANISM BREADBOARD

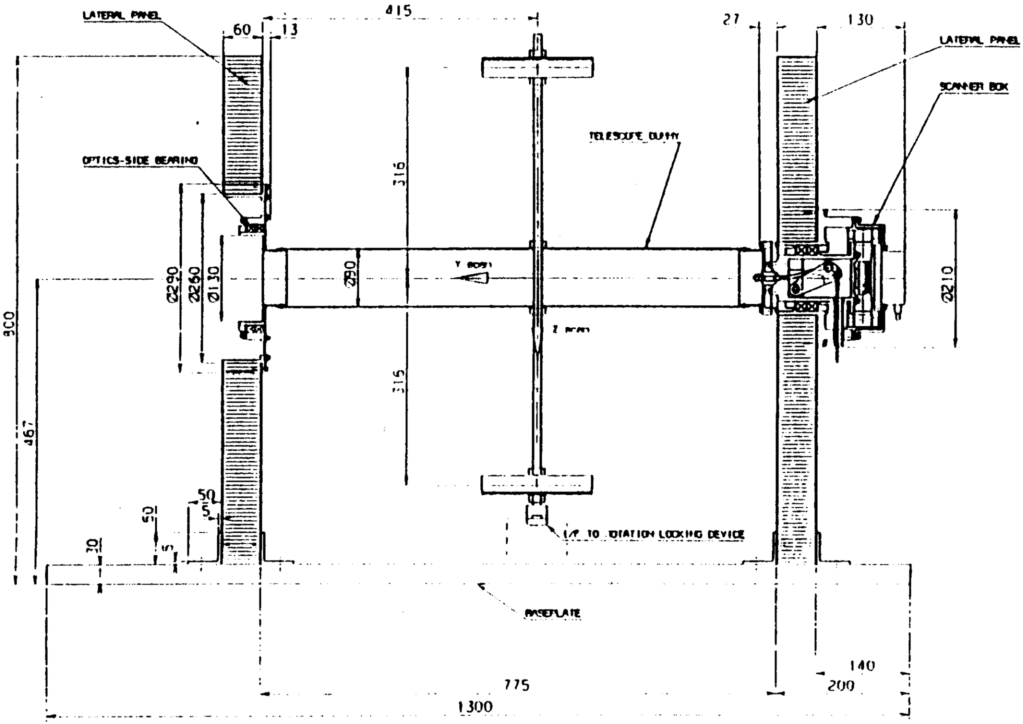
SCAN MECHANISM BB CHARACTERISTICS

The scan mechanism BB is composed by:
- **Dummy telescope** (15 kg, 1 mm CoG eccentricity)
- Contra-rotating **flywheel** (9 kg)
- Torque **motors**: 2-phase redundant windings (2.6 Nm)
- **Encoder**: 21-bit resolution
- Telescope and flywheel ball **bearings**: pre-loaded - lubricated (Fomblin Z25)
- **Controller**: based on 32-bit DSP AD-21020
- Support structure

SCAN MECHANISM BB TEST

- Each part tested, assembly integrated
- Off-line bearings life-test (9 months, T_{amb}, 10^{-5} mbar)

SCAN MECHANISM BREADBOARD LAYOUT



ATLID: The Next Future

EARTH RADIATION MISSION:

- Phase-A Study of the mission <u>should</u> start mid '97 (duration 2 years)
- The ERM Backscatter Lidar shall be designed during Phase-A Study.

ATLID TECHNOLOGY PROGRAM:

- A second stage of ATLID technology development has been approved in the frame of GSTP-2 program
- Objective: validation of the technology and the internal interface of the three main subsystems:
  * TRANSMITTER CHAIN
  * RECEIVER CHAIN
  * POINTING/SCANNING ASSEMBLY
  * TELESCOPE/OPTICAL SUB-SYSTEM
- Available breadboards will be refurbished and reused
- New items will be built and the chains assembled integrated and tested.
- Duration: 2 years: 1997-1999

ONE STEP AHEAD:

Upon approval of the mission, a FM of ATLID could be developed to meet the launch date of the first Earth Explorer satellite (2003).

ESA Atmospheric Dynamics Mission

The Atmospheric dynamics mission aims at providing the users with observation of **tri-dimensional wind fields in clear air** (above or in absence of thick clouds).

The importance of this mission resides in the major deficiency of wind data in the current meteorological operational observing networks. The **assimilation** of such data **into NWP models** would lead to a an improvement of in objective analyses and hence in NWP.

The Atmospheric dynamics mission would also provide data for **climatological research** for the quantification of climate variability, validation and improvements of climate models and process studies relevant to the climate change.

The key-instrument for the Atmospheric Dynamics mission is a Doppler wind lidar, **ALADIN** (Atmospheric LAser Doppler Instrument).
ALADIN is a CO_2 coherent DWL and is presently considered for accommodation on the International Space Station.

Requirements

Wind data accuracy comparable with the current radio-sonde network: 2-3 ms^{-1} up to 15 km altitude
Data reliability of 95%
Measurement distribution equal to that of current assimilation model grid size: 50 * 50 * 1 km

Mission Concept

Payload power consumption	≤ 1 kWatt
Platform:	ERS-type at altitude of 480 km or international Space Station Alpha at altitude 340 - 460 km

Instrument Concept

The main instrument within the Atmopheric Dynamics Mission is a coherent CO_2-laser based Doppler Wind Lidar with the following characteristics:

Transmitter Laser Energy	15 Joules
Pulse Repetition Rate	8 pps (max)
Burst-Period to Off-Period Ratio	0.25
Spectral Width	750 kHz
Lifetime	3 years (2*10^8 shots)
Telescope Diameter	80 cm
Line of Sight	2 step-scanned lines of sight, at 30° to Nadir

Instrument Performance

1500 reliable line of sight wind profiles within 12 hours

CO_2 Laser coherent DWL technology

The BB of the **e-beam sustained CO_2 laser**, operating at λ = 9.25 μm has reached a high level of engineering and it has demonstrated outstanding performance and a good reliability:

- Pulse energy: 11 J, single mode
- Pulse length: 5 μs
- PRF: 1 Hz
- Efficiency : 8.5% discharge-optical; 5% overall
- Lifetime 6.5 10^7 pulses demonstrated
- Beam quality: 2 x diffraction limit demonstrated
- Low dissociation

A laboratory breadboard of a **spiker-sustainer CO_2 laser** has been realised and tested, with promising results (the source is in principle scalable up to 10 J):

- 6.5 J multimode in 1 μs pulse; 5 J in 7 μs
- Efficiency: 11%
- Novel pulser-sustainer discharge circuit: only 10% of sustainer energy is passing through the pulse transformer
- All solid-state pulser option (magnetic circuit, no thyratron): 2.5 J in 3 μs.
- Dissociation rate better than self-sustained source.

Combined DIAL/DWL with solid-state laser technology

Objectives

An instrument capable of combined wind and water-vapour monitoring from space would provide valuable information on the global energy budget concerning evaporation, tranport and condensation processes. An instrument with the potential for such measurements is a coherent DWL/DIAL operating at a wavelength of ~ 2 μm. Towards this goal, ESA has been investigating potential instrument concepts and developing the required basic technologies.

Instrument Requirements

• Orbit	International Space Station (orbit inclination 51°)
• Horizontal distribution:	Cluster size 35 * 35 km Cell size 200 * 200 km Swath width > 600 km
• Vertical distribution	Resolution of 500 m within planetary boundary layer
• DIAL	10% accuracy
• DWL	1 line of sight per measurement cluster 2ms^{-1} accuracy with >80% reliability (10 km)

Combined DIAL/DWL with solid-state laser technology

Instrument Overview

- Transmitter Lasers: Dual Injection-seeded Q-switched TmHo:YAG, 1 Joule each
- Scanning: Across track scanning (constant Doppler shift)
- Power requirement: 1.7 kW
- Overall Mass: 655 kg

Technology Development

Whilst many sub-systems are demanding in a combined coherent DIAL/DWL, technology developments are presently focussed on the DWL receiver and transmitter laser.

Recently Completed Activities

- RIN of 2 µm local oscillator laser neglible beyond 10 MHz (below -170 dBm/Hz)
- Influence of receiver optics alignment on heterodyne efficiency at 2 µm
- Phase conjugate reflectivity at 2 µm of 60% in $SnCl_4$ for pulse energy of 50 mJ

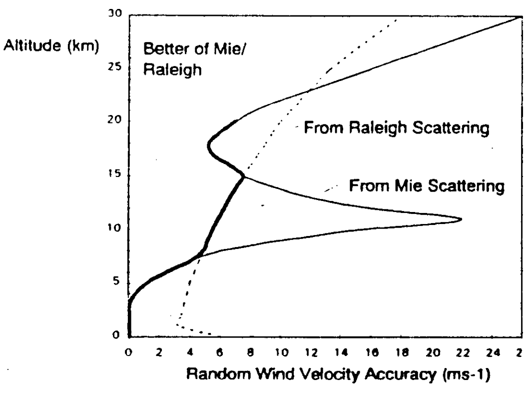
Ongoing Activities

- Noise tests on InGaAsP photodiode and preamplifier
- Phase-noise measurements of diode-pumped 2 micron laser
- Development of injection seeded 70 mJ, diode-pumped TmHo:YAG laser

UV Incoherent Doppler Wind Lidar

Objectives

ESA is currently funding two parallel studies to prepare the receiver technology for an all-solid-state space-borne Doppler wind lidar operating in the ultra-violet (355 nm). This technology is seen by the Agency as potentially suitable for a second generation instrument. An attraction of operating at 355 nm is that accurate measurements can be achieved in conditions of high aerosol backscatter whilst useful, though lower accuracy, measurements can be achieved in conditions of minimal aerosol backscatter.



Instrument Concept

Energy	1 Joule (355 nm)
Pulse Repetition Rate	20 pps
Telescope Diameter	1 m
Shot cluster area	35 km * 35 km
Swath Width	600 km
Orbit Height	520 km
Horizontal Cell Resolution	200 km
Vertical Profile Resolution	1 km

UV Incoherent Doppler Wind Lidar

Status

Overall instrument concepts, parametric analyses and breadboard designs have been completed and the two teams are currently undertaking breadboard construction.

Receivers Undergoing Breadboarding

Receiver A

• Backscatter Source	Mie Scattering
• Interferometer Type	Fizeau
• Measurement Principle	Resolution of Spectra
• Detector	Micro-channel plate and CCD array

Receiver B

• Backscatter Source	Raleigh Scattering
• Interferometer Type	Fabry-Perot
• Measurement Principle	Double-edge
• Detector	2 measurement PMTs and locking PMT