Pulsed 1.55µm lidar for axial aircraft wake vortex detection

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UCL

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return on innovation

outline

- Introduction
- Lidar modeling
- Lidar design & build
- Field tests & results

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FIDELIO - EU (6th FTP) - 2005-2007

FIDELIO : Fiber laser Development for next generation Lidar Onboard detection system

Context

Increase aircraft safety during take off and landing

Objective

develop a coherent fibre laser lidar (1.5 micron wavelength) geared for the aerospace industry requirements, enabling on-board realisation of a LIDAR atmospheric hazard detection system

FIDELIO concept : onboard axial detection

Innovation

• Development of an «end to end» lidar modeling tool
• design and development of a pulsed fiber laser with high spectral brightness

Partners

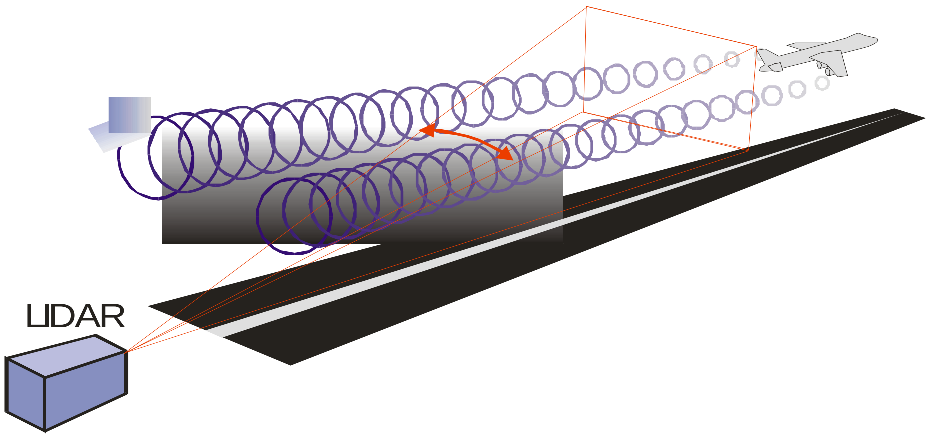
ELOP Industries (IL, coordinator, laser development & integration)
ONERA (FR, special fiber specifications, laser design, lidar development)
UCL (BE, real time signal processing & acquisition, wake-vortex modeling)
IPHT (DE, special fiber development)
Thales Avionics (FR, aircraft integration specifications)
Thales Research and Technology (FR, laser design)
CeramOptec GmbH (DE, fibre integration)
INESC Porto (PT, laser research)

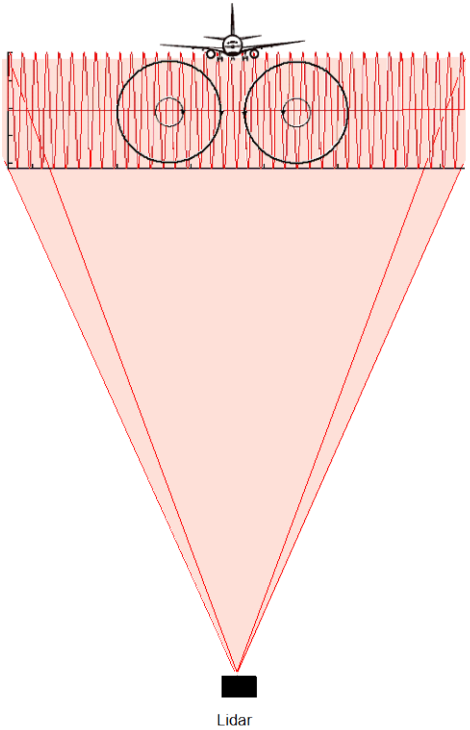
FIDELIO concept : onboard axial detection

Concept

- Axial detection
- Wake vortex detection thanks to spectral broadening
- At kilometer ranges
- At 1.5 µm

Feasibility demonstrated at 2 µm in MFLAME and IWAKE Programs





Advantages of 1.55 µm fiber systems

- Low electrical consumption :
  - Electrical to optical efficiency of the order of 10%
- Wavelength most favourable for eyesafe LIDAR designs
- IR fiber technology reliability
  - easy to adjust
  - mechanically reliable in a vibrating environment
  - 1.5 µm fiber coherent LIDARs have been successfully operated in flight
- Compactness
- Flexibility in terms of onboard installation
  - subsystems spatially far apart in the aircraft body
  - linked together using fiber optics

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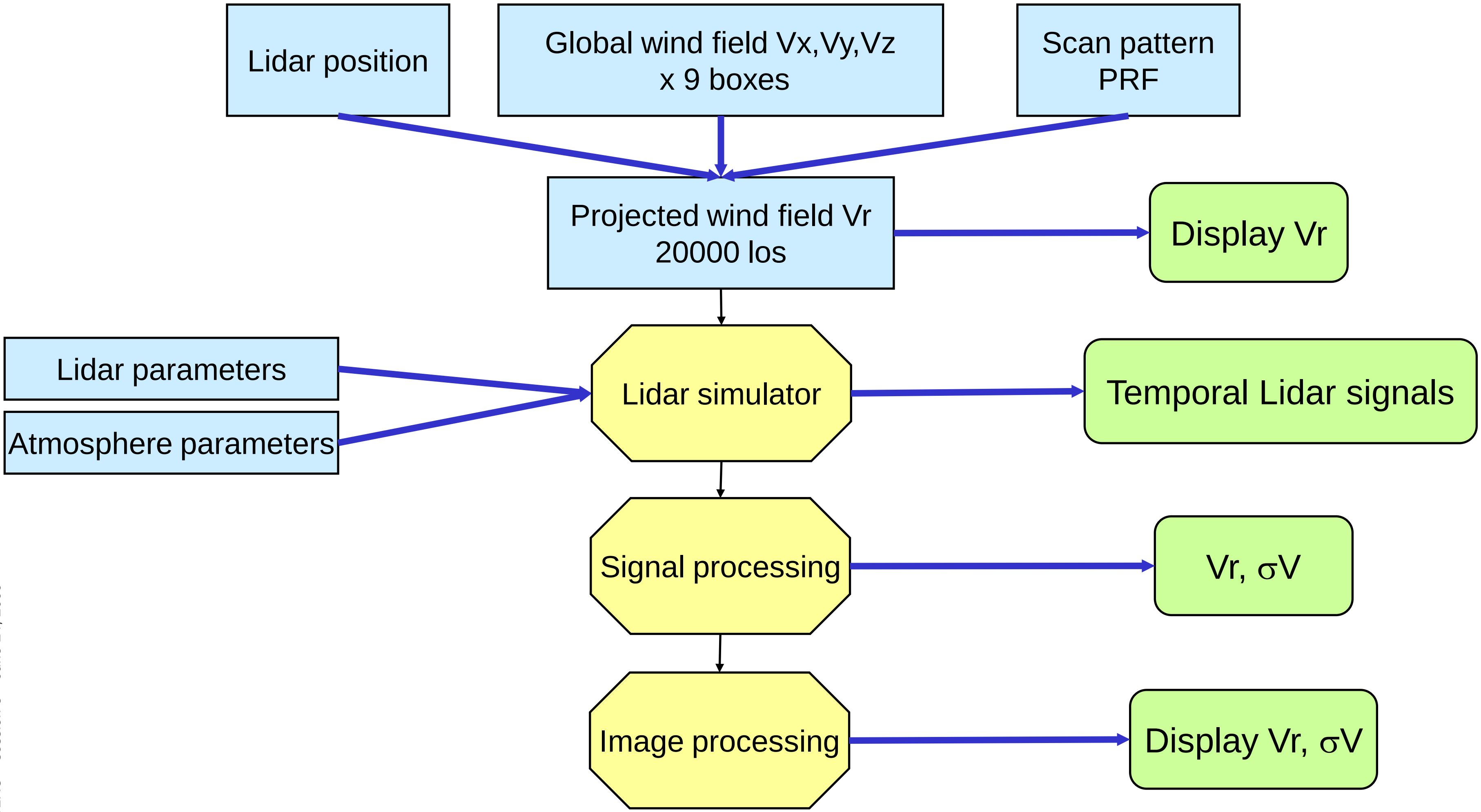
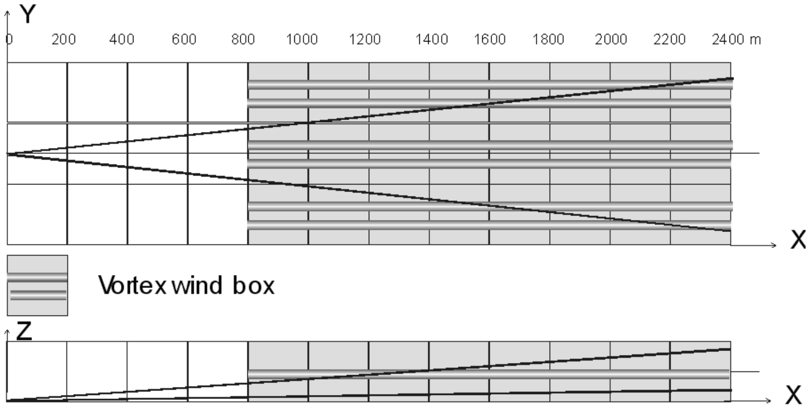
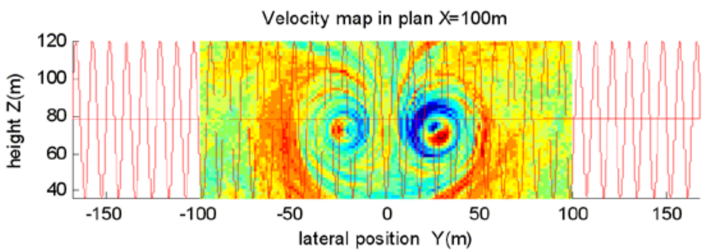
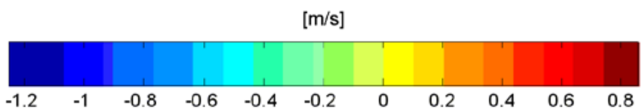
Lidar model flow chart



Axial detection
FIDELIO modeling



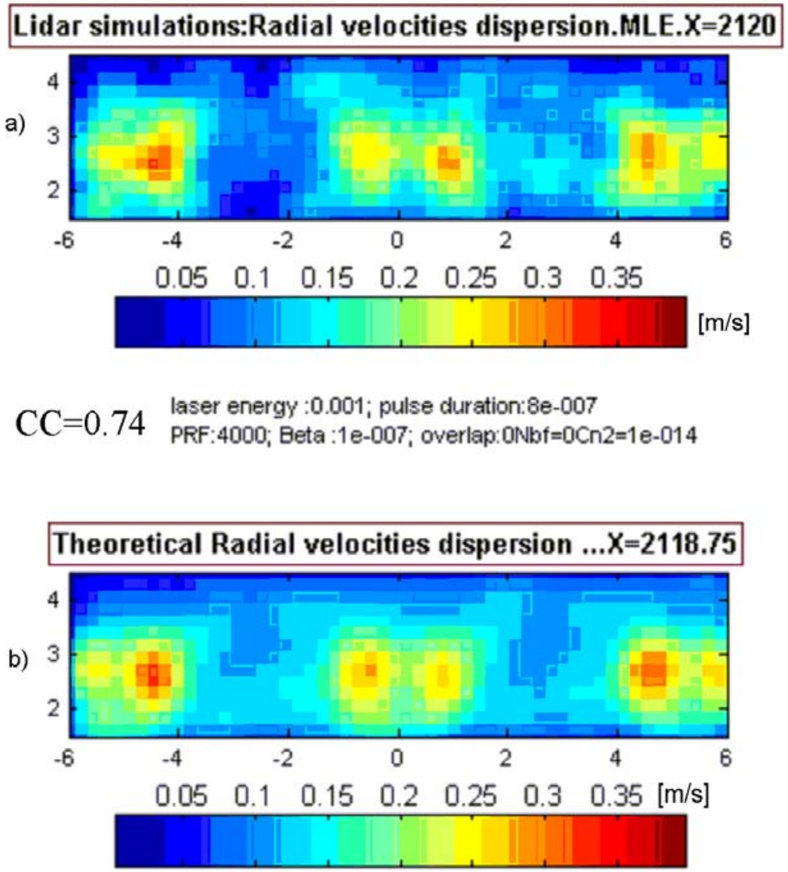


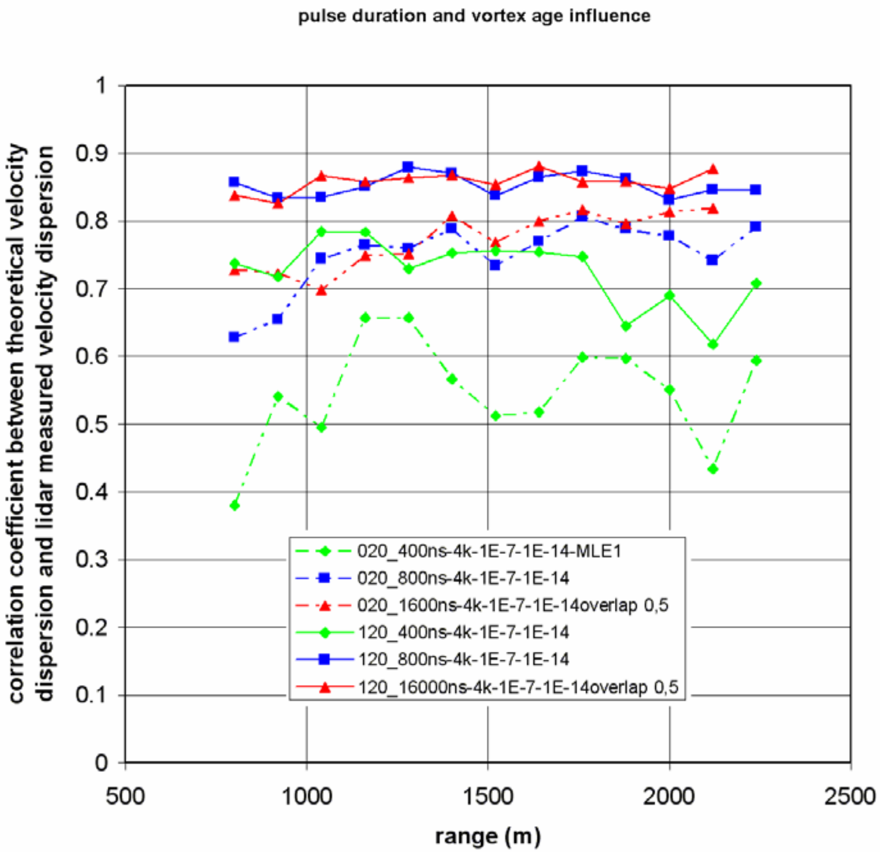


The lidar model takes into account :

- the observation geometry,
- the wake vortex velocity field,
- the scanning pattern,
- the LIDAR instrument,
- the wind turbulence outside the vortex,
- the signal processing.

FIDELIO modeling





CC: Normalized covariance of the two images

.... Young wake (20 s)

——— Old wake (120 s)

FIDELIO : modeling conclusions

- At medium range (>1 km), the vortex is easier to detect by measuring the spectrum broadening. These results confirm the IWAKE conclusions
- Longer pulse duration (800 ns) gives better results than the nominal value of 400ns and leads to a high velocity resolution
- The vortex is easier to detect at old ages than at young ones, since dissipation increases the velocity dispersion on the observation axis.
- A High PRF can compensate for a low laser energy. Indeed a high PRF value enables incoherent summation, reducing speckle effect and therefore gives a better velocity resolution.
- For PRF=4 kHz, E=1 mJ, nominal atmospheric conditions: the theoretical LIDAR range is 2400 m.
- For PRF=10 kHz, E=0.1 mJ, nominal atmospheric conditions : the theoretical LIDAR range is 1200 m.

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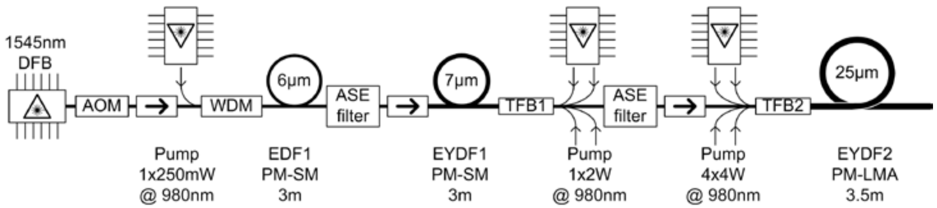
FIDELIO : laser research results

•Lab result :

- **750 µJ, 5 kHz, 1 µs pulses**, with 4 amplification stages, and a special fiber developed by IPHT (not used in the lidar demonstrator), excellent beam quality (**M^2=1.3**), **fully polarized**

• Integrated source used for Fidelio lidar test :

- 3 amplification stages with large core fiber .



- **120 µJ, 12 kHz and 800 ns pulses**, excellent beam quality (**M^2=1.3**), **fully polarized**

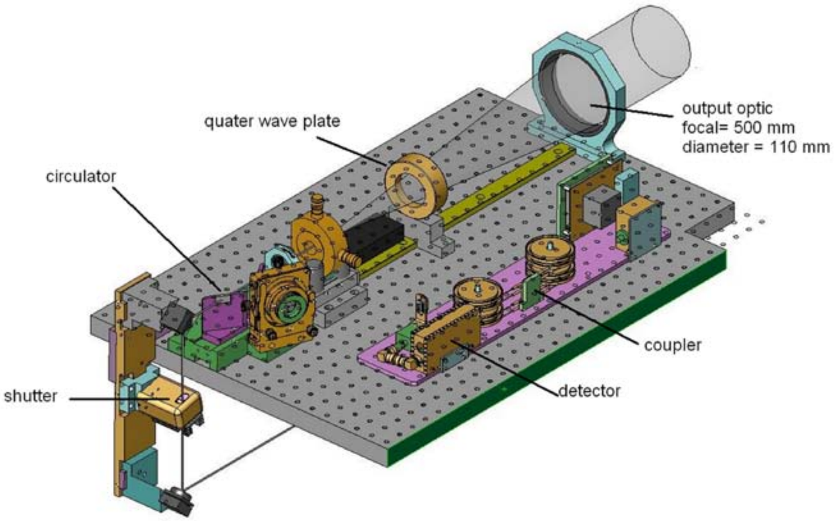
Laser source transfer to industry

Lab prototype 2007

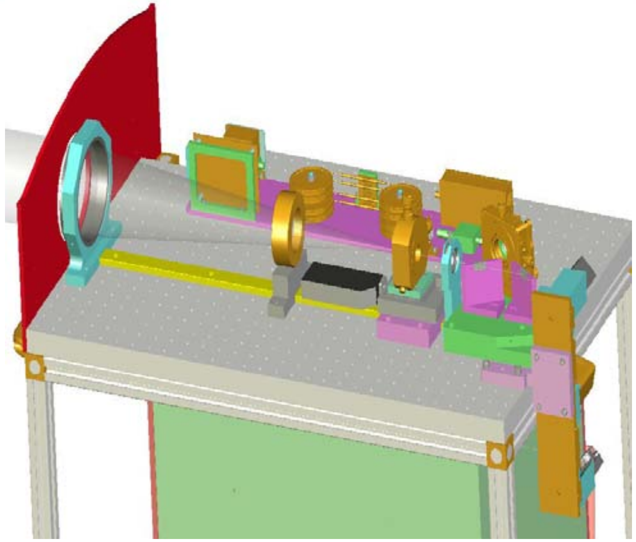
Energy:	100 µJ
Pulse duration:	800 ns
PRF:	12 kHz

Commercial laser
2009

Axial detection : lidar architecture

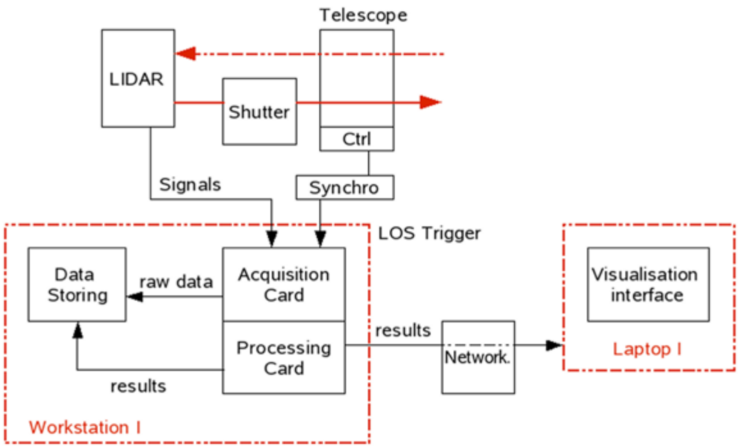


Front view



Rear view

Acquisition and real time display

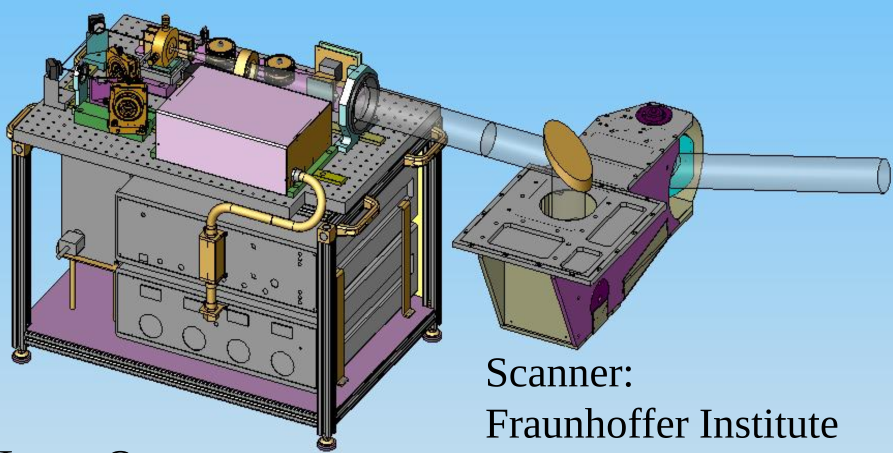


FIDELIO : architecture lidar

Lidar parameters

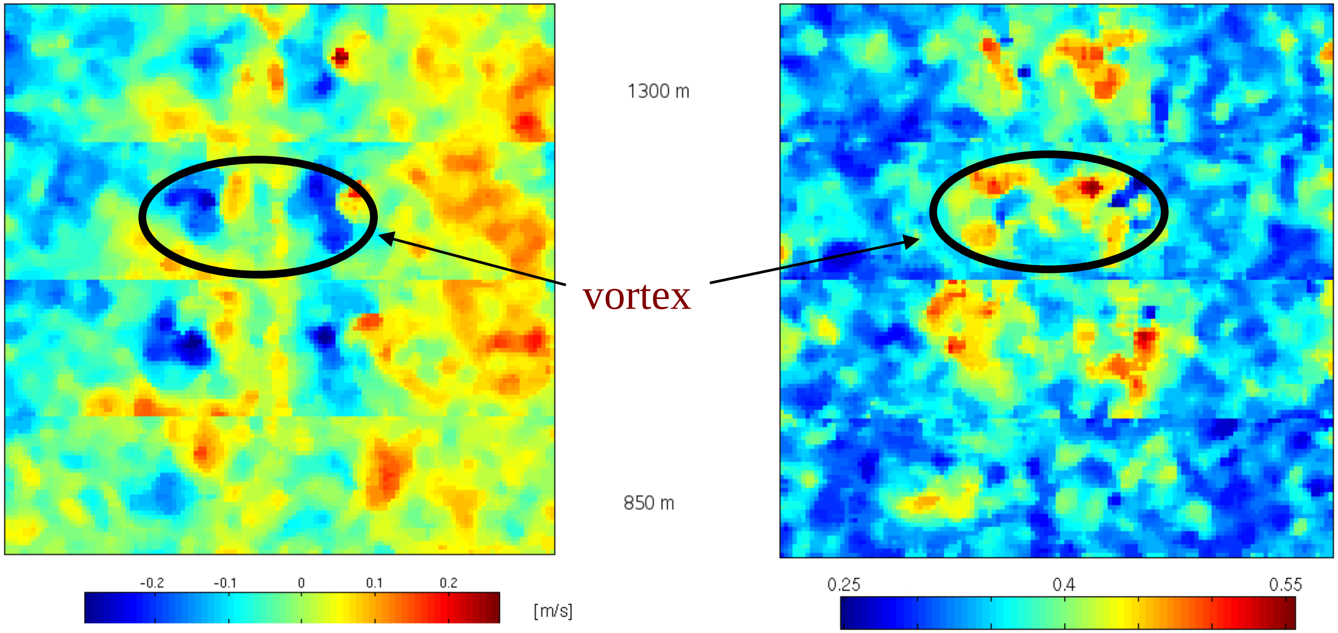
- wavelength: **1.55 µm**
- laser pulse energy: **0.1mJ**
- laser pulse duration: **800ns**
- laser: **10kHz**
- M2= **1.3**
- fully polarized

- WV range: **0.8 to 1.2km**
- Velocity resolution : **1 m/s**
- image frame rate: **0.2Hz**
- field of view: **12°x3°**



Signal processing: UCL
Real time display + velocity
dispersion post processing

Real time algoritms on simulated data



Wind velocity

Wind velocity dispersion

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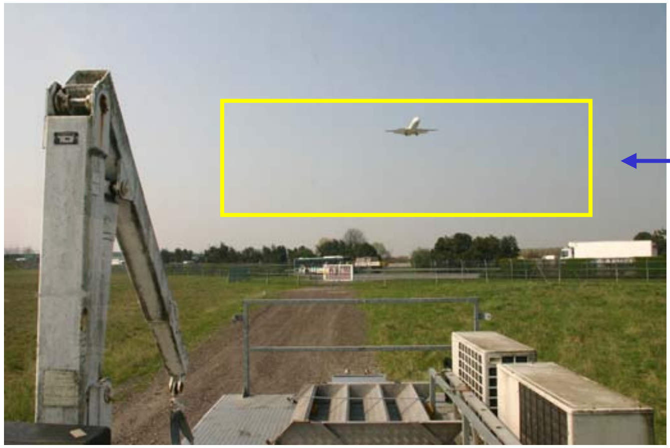
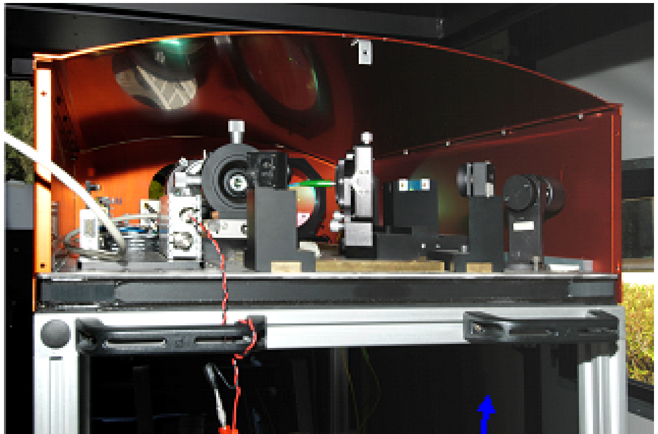
FIDELIO :Field tests at Orly airport (April 2008)



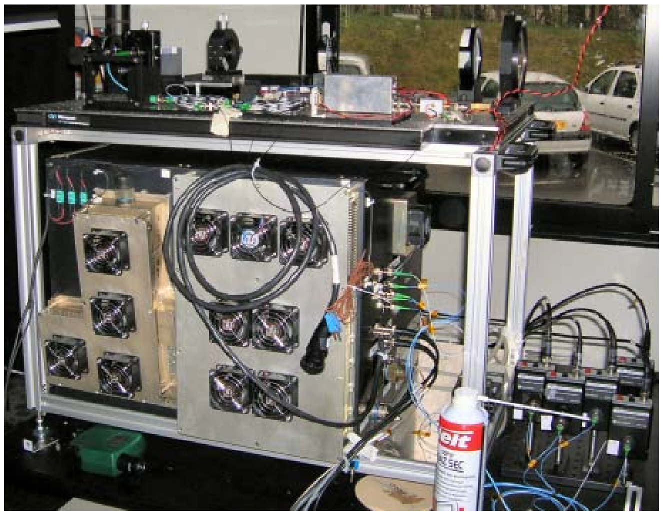
Lidar FoV



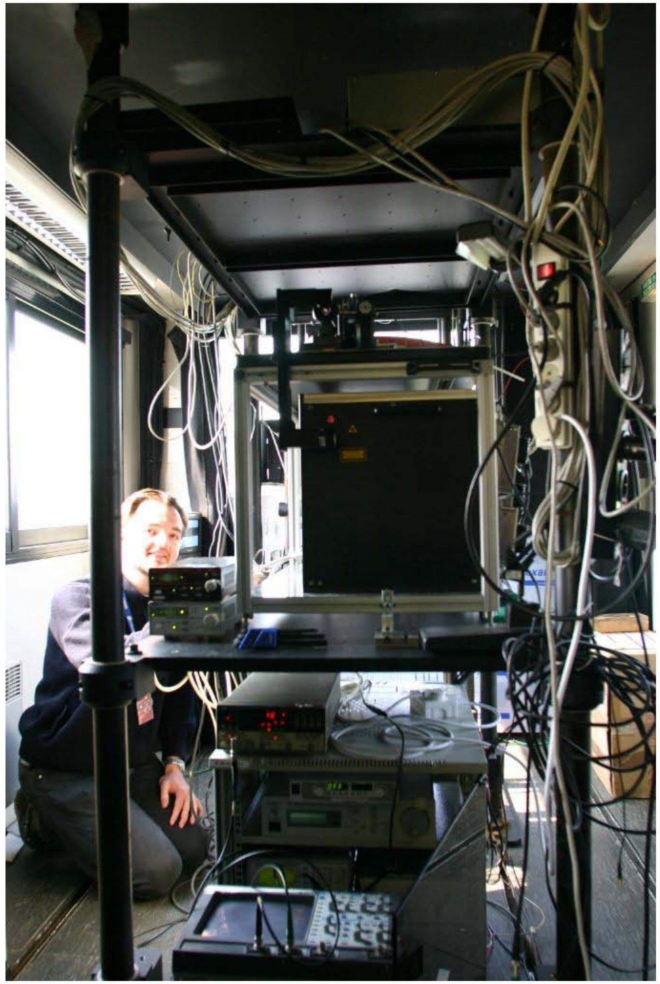
lidar head

viewed from rear

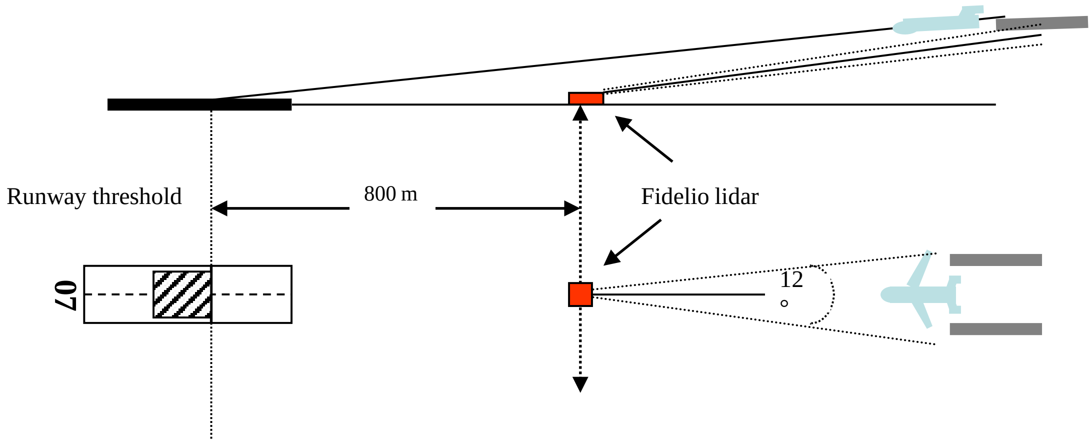
Laser location under the lidar head



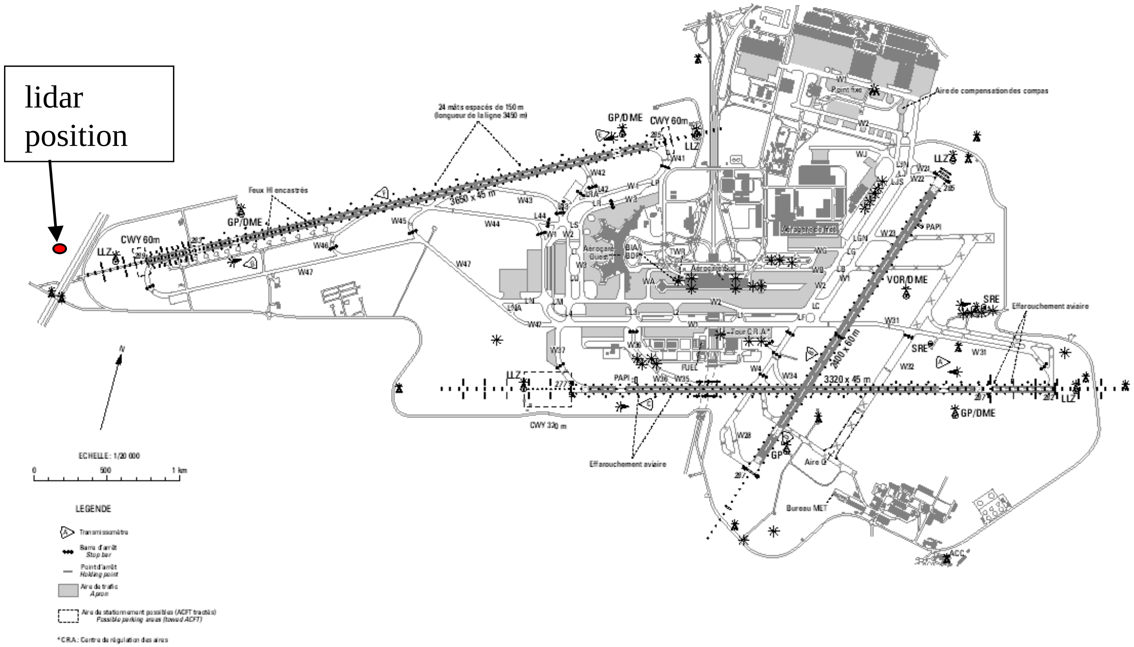
Lidar installed in Bemol lab



Orly set up



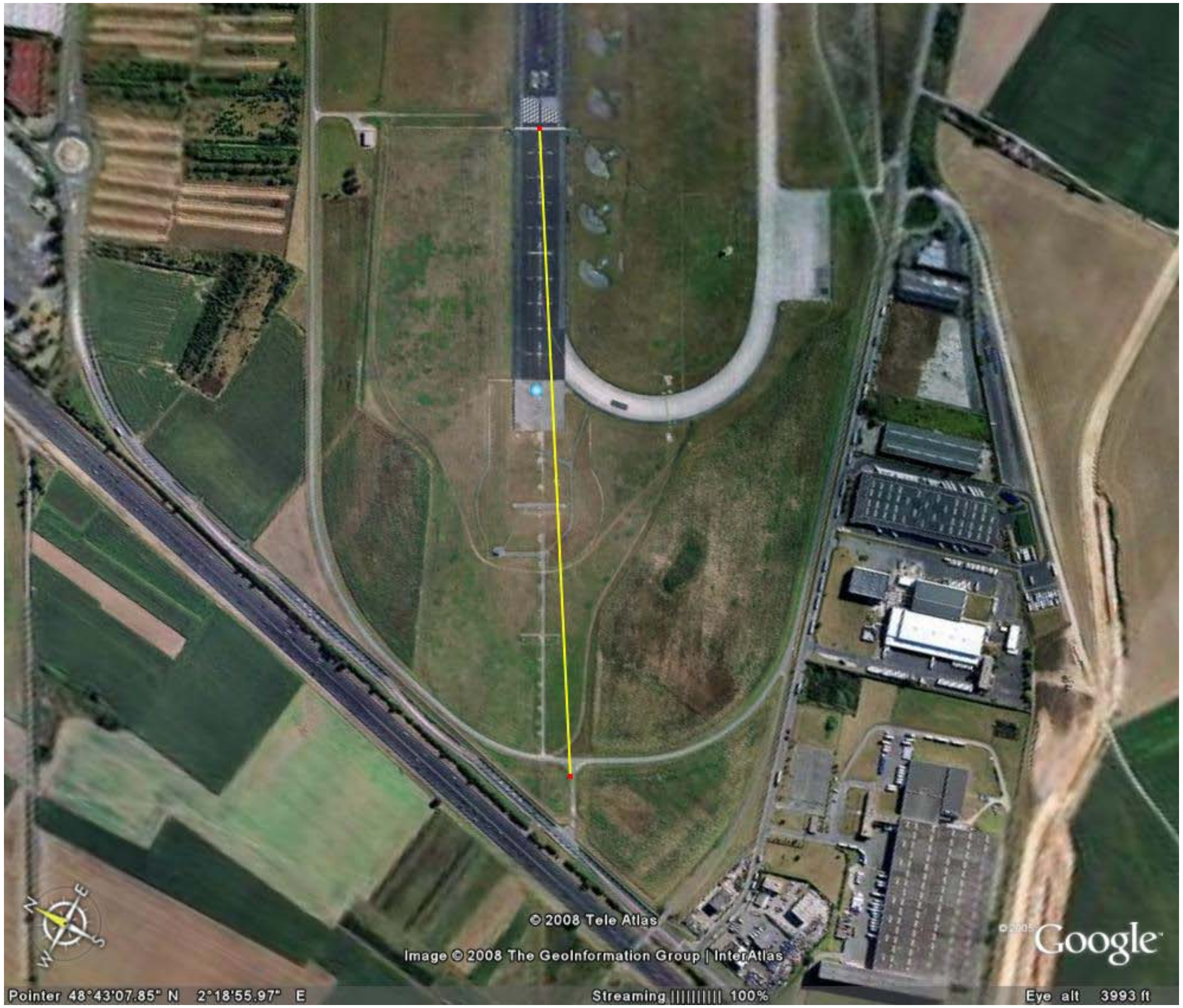
Runway threshold
800 m
Fidelio lidar
07
12
°



lidar position
GP/DME
CWY 60m
LLZ
VOR/DME
SRE
PAPI
FUEL
CWY 330 m
Effarouchement aviaire
Bureau MET
LEGENDE

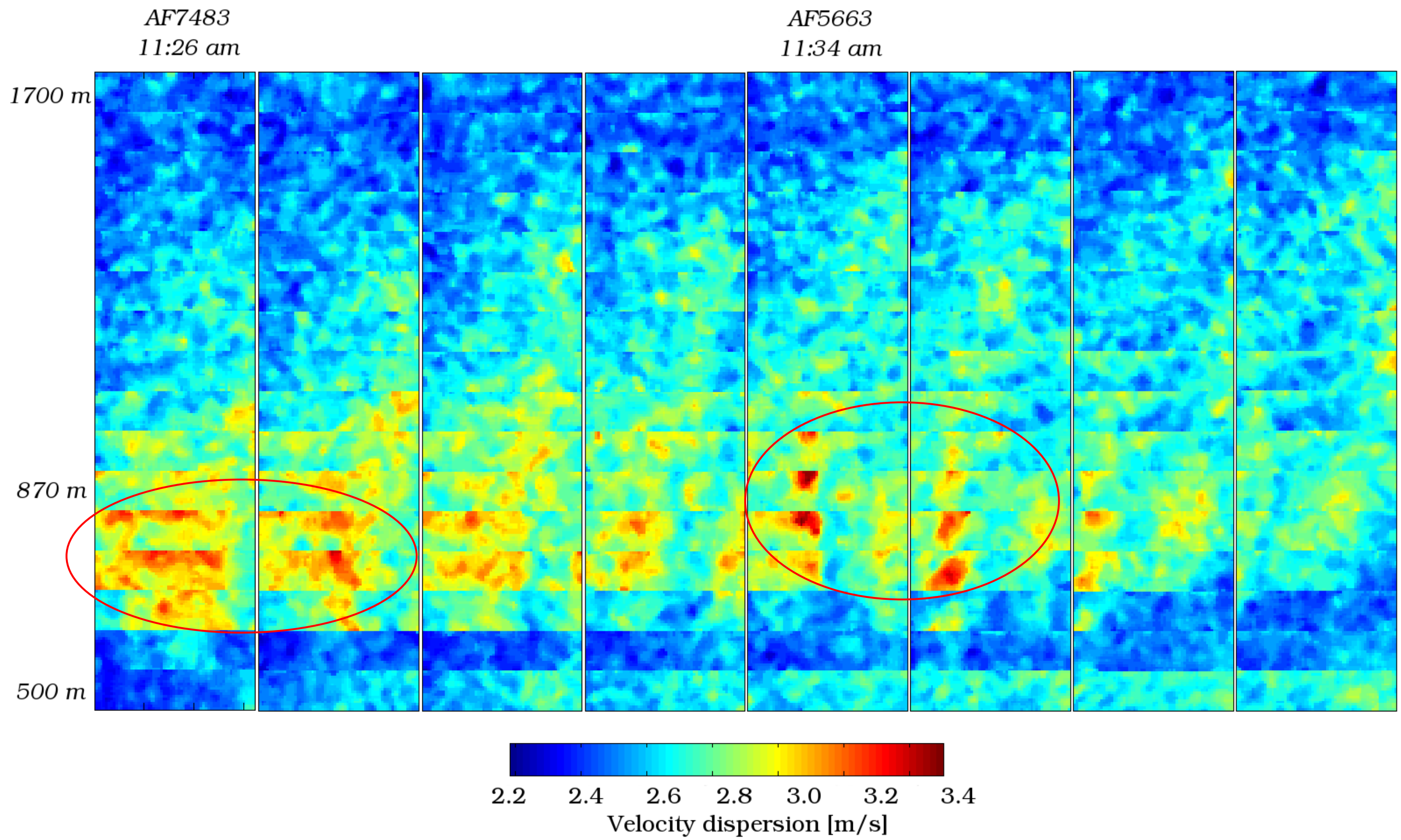
lidar position 2 runway 07

distance from runway threshold is 800 m



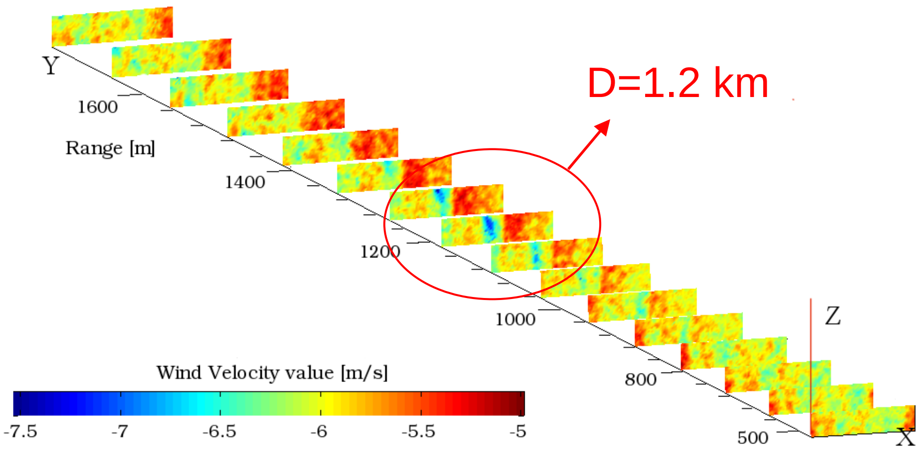
FIDELIO :Field tests

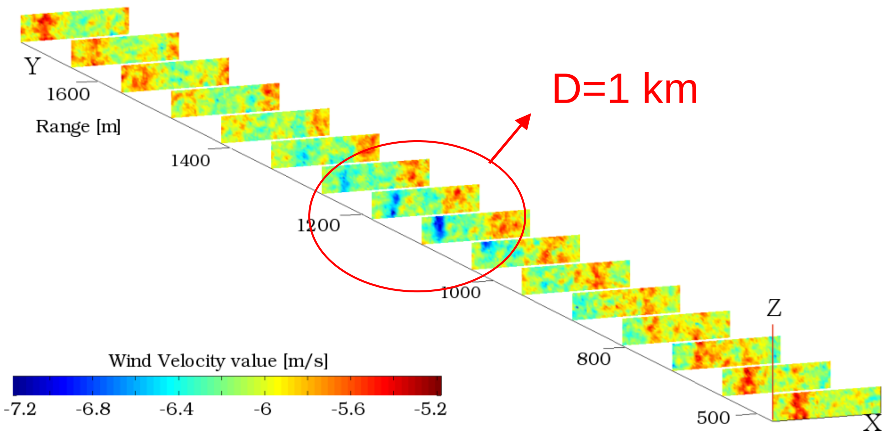
Wind velocity dispersion images computed after the passing of two successive aircrafts.
Each box represents the 3 x12 field of view image acquired at different ranges (vertical axis: 16 gates spaced with 75 m) and at different time (horizontal axis: 8 successive scans).



FIDELIO :Field tests

3D representation of wake vortex detection on two consecutive scans a few seconds after a B747 landing. Each rectangle corresponds to a range gate. The X axis represents the 12 horizontal field of view , Z axis the 3 vertical field of view and the Y axis the distance of the range gates.





Axial detection FIDELIO: Conclusions

- FIDELIO project has generated important advances in research and development on fiber laser technology:
  - An innovative high brightness pulsed 1.5µm laser source has been built, based on a MOPFA architecture with a large core fiber. The beam quality is excellent (M2=1.3). Achieved pulsed energy is **120µJ** with a pulse repetition frequency of **12kHz** and a pulse duration of 800ns. With a further amplification stage, **750µJ** pulses were obtained in the lab at **5kHz** and 1µs with excellent beam quality.
  - A Doppler heterodyne LIDAR has been developed based on the 120µJ laser source with a high isolation free space circulator. The LIDAR includes a real time display of the wind field. Wind velocity dispersion is post-processed.
  - Field tests were carried out at Orly airport in April 2008. Axial aircraft wake vortex signatures have been successfully observed and acquired at a range of 1.2km with axial resolution of 75m for the first time with fiber laser source.

Special thanks to

T.Peschel, Fraunhoffer institute, for the lending of IWAKE scanner