Lidar evolution over the last 30 years

Pierre H. FLAMANT

Institut Pierre Simon Laplace
Laboratoire de Météorologie Dynamique
École Polytechnique, France

Foreword

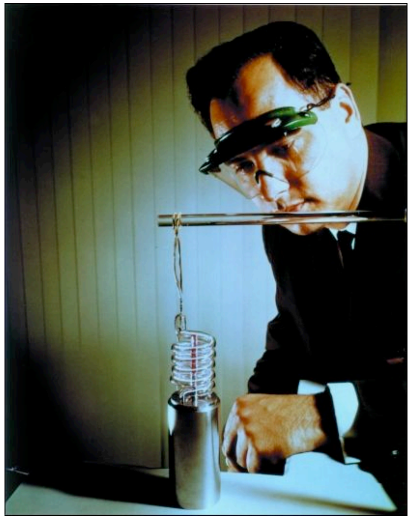
- A lidar evolution, the lidar evolution or my lidar evolution
- As witness and to be an actor
- Confrontation of what's going on world wide and how to get involved to be part of it

1. Prehistory of Lidar

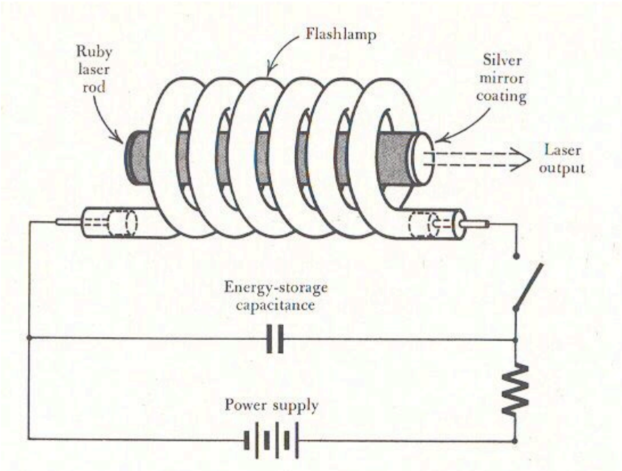
"Down the Lidar-Hole"

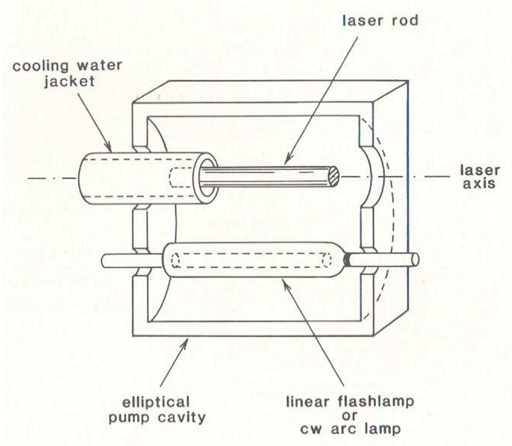
"Lidar, you said lidar,
how bizarre it is!"

1960: Year "1" of the laser Era



T. H Maiman





When the first working laser was reported, it was described as "a solution looking for a problem". Initially, the laser was called an invention looking for a job

LIDAR before LASER

(*g*) *Automatic ceiling light projector*

A development from the daytime ceilometer described above is the automatic recording ceiling light now used quite extensively by the United States Weather Bureau. In this device, the modulated beam is projected vertically and the photocell, or photoelectric telescope, at the other end of the base line scans from 0° elevation to the vertical in the plane of the light beam (Fig. 147). The angle at which the photocell receives an impulse from the spot on

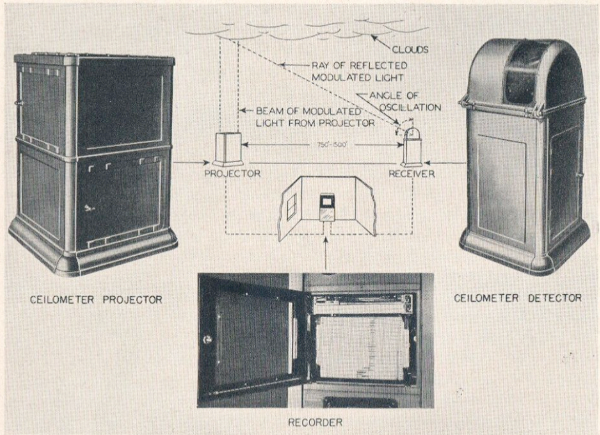


FIG. 147. Automatic ceilometer system. (Courtesy of Crouse-Hinds Company of Canada, Limited)

the cloud ceiling is recorded automatically in terms of ceiling height on a recorder usually placed remotely in the Weather Bureau office.

(*h*) *Ceiling alarm*[9]

An apparatus similar to the daytime ceiling projector, but with a much smaller light source, is used to give a visible or audible signal when the ceiling drops below any selected value at night; and the same apparatus may also be used to measure the ceiling at night without the necessity of locating the spot visually. The light source is an 85-watt mercury lamp at the focus of a 16-inch parabolic mirror, throwing a narrow vertical beam of modulated light. The photoelectric telescope differs from that used in the daytime ceiling projector in making use of an electron multiplier tube (type 931) instead of an

[9]Private communication from the Instrument Division, United States Weather Bureau.

ordinary phototube. The ingenious electrical circuit discriminates against random pulsations in favor of the 120-cycle current produced in the multiplier tube by the modulated light; and the output of the amplifying tubes is proportional to this current. It can be measured on a meter when the instrument is used to measure ceilings, or used to operate a relay when it is desired to use it as a ceiling alarm.

Fig. 148 will make clear the operation of the ceiling alarm. The photoelectric telescope is set to the angle corresponding to the ceiling below which an alarm is to be given. As long as the ceiling is higher than this value, the field of view of the telescope includes a volume of air which is strongly illuminated by the projector; and enough light is always scattered into the telescope from this volume of air to hold open the contacts of a back-contact relay

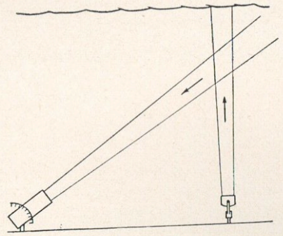


FIG. 148. Illustrating the principle of the ceiling alarm.

connected to the amplifier. If the clouds come lower, no part of the field of view of the telescope is strongly enough illuminated by the projector to hold up the relay, which closes, actuating the alarm. Failure of the projector or the detector is also immediately announced.

(*i*) *Pulse methods of cloud-ceiling measurement*

(i) *Light*

Experimental devices using a pulse of light—"lidar" so to speak—have been made in France and in Great Britain. The ceiling is given, as in radar, by timing the period between emission and receipt of the reflected light pulse. Using a high-voltage spark to produce a short (one microsecond) light pulse at the focus of a large mirror and detecting the pulse reflected from the clouds by a photocell at the focus of a second mirror, ceilings up to 18,000 feet in daytime have been measured in England.[10] An apparatus of this sort is produced commercially in France.

(ii) *Radar*

Not only the base of the lowest cloud (the ceiling) but the tops and bases of multiple superimposed cloud decks can be detected by the use of a one-

[10]Jones, F. E., *J. Roy. Aeron. Soc.*, **53**(1949):437-448.

Bistatic cw search light

"lidar" so to peak

W. E. K. Middleton and A. F. Spilhaus, 1953: "Meteorological instruments"

Earliest Search Light Works

1014 Mr. E. H. Synge *on a Method of*

References.

(1) Morris-Jones and Evans, Phil. Mag. iv. p. 1302 (Dec. 1927).
(2) Carpenter, H. C., *Zeit. für Metallkunde*, iv. p. 300 (1913).
(3) Guertler, *Zeit. Anorg. Chem. SI.* p. 418 (1906).
(4) Grime and Morris-Jones, Phil. Mag. vii. p. 1113 (June 1929).
(5) Stephens and Evans, Phil. Mag. viii. no. 48 (July 1929).
(6) Stephens, Phil. Mag. viii. no. 50, p. 286 (September 1929).
(7) James and Tunstall, Phil. Mag. xl. p. 233 (August 1920).
(8) Ogg, Phil. Mag. xlii. p. 163 (1921).
(9) Persson and Westgren, *Zeit. für Phys. Chem.* cxxxvi. p. 208 (September 1928).

January 1930.

XCI. *A Method of Investigating the Higher Atmosphere.* *By* E. H. Synge *.

REGULAR balloon observations of the upper atmosphere, as may be seen from the tables in any book on meteorology, do not extend beyond 20 km., at which height the density is from $\frac{1}{12}$ to $\frac{1}{14}$ that at sea-level. The density is falling rapidly at this point, and it is improbable that balloon observations could be carried to a much greater altitude. They must certainly fail long before that interesting region is attained, at about 50 km., where the density is about $\frac{1}{1000}$ that at sea-level and the pressure similar to that at which electrical discharge in vacuum tubes takes place most readily. It is quite probable that the ionization of the lower atmosphere may be controlled by conditions here, so that a means of recording variations in the atmosphere at these altitudes might be of considerable importance to meteorologists. So far as the writer is aware the only method suggested for obtaining records at such altitudes has been that of sending up powerful rockets, loaded with apparatus, which, after recording the conditions at the height reached, would descend to the earth by means of parachutes †. The difficulties of this method are numerous and obvious, and it does not seem that any attempt has been made to obtain records in this way. The following method, on quite different lines, is, however,

* Communicated by the Author.
† R. H. Goddard, "A Method of Reaching Extreme Altitudes," Smithsonian Misc. Collections, vol. lxxi. no. 2 (1921).

Phil. Mag., 9, 1014 (**1930**)

Investigating the Higher Atmosphere. 1015

available to determine certain properties and variations of the upper atmosphere, as far as a density from $\frac{1}{1000}$ to $\frac{1}{10,000}$ that at sea-level. Nearly all the apparatus required exists in sufficient quantity; there are no formidable technical difficulties to be surmounted; and the theory appears quite unassailable.

The method depends on the scattering of light by the molecules of a gas; for a gas of constant composition this scattering is proportional, to a high approximation, to the density of the gas, and inversely proportional to the fourth power of the wave-length of the light. Thus, supposing the composition of the atmosphere to be unchanged at the heights investigated, its density at these heights will be known, after making various corrections, if we can project a sufficiently strong beam of light to allow of the light scattered in a given region being detected and measured by photo-electric apparatus after collection by a large reflector.

The sky of night is, of course, by no means perfectly dark, and even if we select the darkest part of the sky on a clear moonless night as a background, the light scattered by the beam of a single searchlight at any considerable height will be quite imperceptible to the eye. For instance; taking figures for the searchlight from Glazebrook's 'Dictionary of Applied Physics'; for the molecular scattering from Schuster and Nicholson's 'Optics'; and for the sky from Russell, Dugan, and Stewart's 'Astronomy,' it appears that, at a height of 30 km., where we may suppose the density to be about $\frac{1}{50}$ that at sea-level, the light scattered from the beam of a 36-inch searchlight, with the most powerful arc, will only add about 1 part in 200 to the brightness of the darkest part of the sky. This proportion, although perfectly imperceptible to the eye, can be detected by photo-electric apparatus, which is sensitive to a difference of 1 part in 1000.

This is the case of a single searchlight, but the method involves the concentration of a large number of searchlights upon the same region in the upper atmosphere. The effect is additive. In the case considered, if a single searchlight enables a reading to be made with a probable error of 10 per cent., then ten searchlights will reduce the probable error to about 1 per cent. This leaves out of account various important considerations—for instance, the steadiness of the arcs and the absorption of the light by

516 JOHNSON, MEYER, HOPKINS AND MOCK

10- to 12-km region. Fig. 3 shows a curve taken on August 22, 1939, up to ten km, together with a good example of a transparent cloud at 12 km. The dotted part of the curve was estimated from deflections of the cathode-ray oscillograph since the cloud was moving too rapidly to allow a complete delineation of the curve.

Other nights showed the presence of a varying absorption or scattering of fairly rapid period. Fig. 4 shows the signal-variation at 16 km on the night of September 5, 1939, together with the variation in noise level.

In the present work no attempt was made at great accuracy. The accuracy of the observations could be made very good by using a monitor receiver set a height of four km, since it is felt that a varying absorption takes place below this height and because of known variations in transmitter-output. It would also be very advantageous to use a receiver with a lower f number in order to improve the optical imagery and to allow the use of filters. If measurements are to be made at great heights it would be necessary to use a longer base-line in order to increase the resolution. The effect of changing the base-line is shown in Fig. 1. However, changing the base-line from 5.8 to 22 km also decreases the sensitivity about tenfold.

It is possible to predict the increase in height which would be possible with an improved system. If a 60-inch aluminized receiver and a 60-inch aluminized transmitter with 18-mm carbons were used, together with a (K−O)-cell at the receiver and a 22-km base-line, it would be possible to gain at a maximum a factor of 100 in sensitivity. This should make observations possible to a height of 70 to 80 km. Greater heights with poor resolution would be possible from the 5.8-km base-line.

The ultimate usefulness of this method is unknown, but it appears that it may be adapted to the study of a number of important atmospheric problems. Such problems are the occurrence with height of water-vapor, turbulence, winds, dust, fluorescence, and absorption. One of the most interesting problems of meteorological importance is the study of the distribution of ozone in the atmosphere. Since ozone has a strong absorption-band from about 2500A to 3300A, it would be possible to compare the scattering from this region with that above 3400A. This can be done by the use of two receivers using a sodium and potassium oxide cell, respectively.

ACKNOWLEDGMENTS

The authors are indebted to Dr. M. A. Tuve and Dr. O. R. Wulf as well as to many other colleagues in Washington for discussion and loan

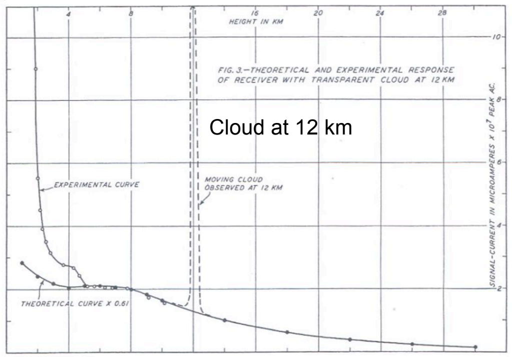


FIG. 3.

"The measurements of light scattered by the upper atmosphere from a search-light beam, **1939**, JOSA

Earliest Pulsed Lidar with no Laser

La Météorologie, July/September, **1946**

Cloud ranging by light pulses

ALTIMÉTRIE DES NUAGES PAR IMPULSIONS LUMINEUSES[1]

par R. BUREAU
Directeur du Laboratoire National de Radioélectricité.

Il est important de mesurer d'une manière rapide et précise la hauteur des nuages aussi bien le jour que la nuit. Le système décrit ci-après est basé sur la mesure du temps de parcours d'une brève et puissante impulsion lumineuse dirigée vers le nuage et renvoyée par lui comme un écho. Un premier appareil conçu en 1938 a fonctionné en 1940 jusqu'au mois de juin. Un second appareil a été construit en 1945. L'auteur donne les principaux résultats et un certain nombre d'exemples. Il signale ensuite les applications possibles de ce matériel.

I. — INTRODUCTION

La mesure précise, rapide et fréquente de la hauteur des nuages est depuis longtemps réalisée par l'emploi d'un projecteur lumineux à faisceau vertical et par la mesure de l'angle de site sous lequel on voit à distance la tache formée par le faisceau sur les nuages. Malheureusement ce procédé n'est applicable que dans l'obscurité. C'est pourquoi nous avons imaginé dès 1934 d'en étendre l'application aux heures de jour en utilisant de la lumière modulée. Des expériences entreprises avec des moyens de fortune en janvier 1935 avaient prouvé qu'une solution était possible dans cette voie ([2]). Les expériences durent être mises au ralenti jusqu'en décembre 1938. A cette époque nous avons proposé et provoqué des recherches sur une autre méthode basée sur la mesure du temps de parcours d'une impulsion lumineuse transmise verticalement à partir du sol et renvoyée par les nuages vers le sol. Des expériences étaient rendues possibles par l'existence d'un matériel de mesure des échos fournis par une impulsion lumineuse, matériel établi dans d'autres buts. René Barthélemy a fait récemment l'historique de ces expériences ([3]). Dès le mois de février 1940 un appareil fut mis en fonctionnement régulier à proximité de Paris et des mesures à heures fixes de la hauteur des nuages furent utilisées quotidiennement par l'Office National Météorologique jusqu'aux premiers jours de juin de la même année. Les expériences furent brutalement interrompues, le matériel et la documentation dispersés, et c'est seulement en décembre 1944 que nous entreprîmes la reconstitution des appareils.

([1]) Communication présentée à la Société Météorologique de France, le 18 juin 1946

([2]) C'est ce procédé qui a, six années plus tard, été employé et mis au point aux Etats-Unis.

([4]) *C. R.*, 222, 1946, p. 450.

II. — PRINCIPE DE L'APPAREIL

Au foyer d'un miroir parabolique M d'axe vertical (fig. 1) se trouve un éclateur constitué par deux tiges de tungstène, avec un dispositif de réglage de l'écartement. Une troisième électrode destinée à l'amorçage, est reliée à un transformateur élévateur de grand rapport dont le primaire peut, à l'aide de l'interrupteur I, être fermé sur une source de tension convenable.

Les deux électrodes principales sont reliées aux bornes d'une batterie C de condensateurs de 32 μF de capacité totale, chargée à l'aide d'un système

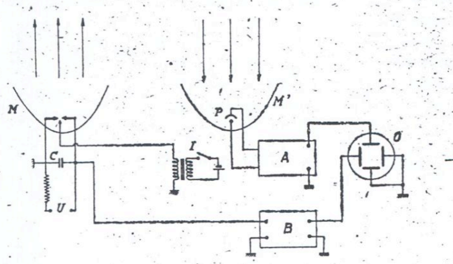
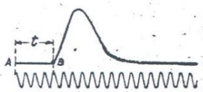


Fig. 1.

d'alimentation U, à partir du secteur alternatif, à une tension de 6.000 volts. Lorsqu'on ferme l'interrupteur I, l'étincelle pilote qui jaillit entre l'électrode d'amorçage et une électrode principale, déclenche la décharge de la batterie C dans l'éclateur. Par la diminution de la longueur des connections et par une disposition symétrique, on réduit la self-induction aux bornes de C de manière à avoir une décharge aussi peu oscillante et aussi brève que possible.

On obtient donc ainsi au foyer de M une impulsion lumineuse très intense d'une durée de l'ordre de 10 microsecondes, la puissance mise en jeu étant del'ordre de 40 mégawatts. Le pinceau vertical donné par le miroir produit une tâche lumineuse sur le nuage à télémétrer. La lumière diffusée reçue par un second miroir parabolique M′, placé à une trentaine de mètres de M, est concentrée sur une cellule photo-électrique placeé en son foyer. Le courant donné par la cellule est appliqué à l'amplificateur A dont la sortie attaque les plaques de déviation verticale d'un oscillographe cathodique O. D'autre part, l'étincelle de départ, agissant par l'intermédiaire du dispositif B sur l'autre système de plaques, déclenche le balayage horizontal du spot de l'oscillographe. Par un réglage préliminaire convenable des circuits, l'origine de



- Fig: 2 -

Robert Bureau

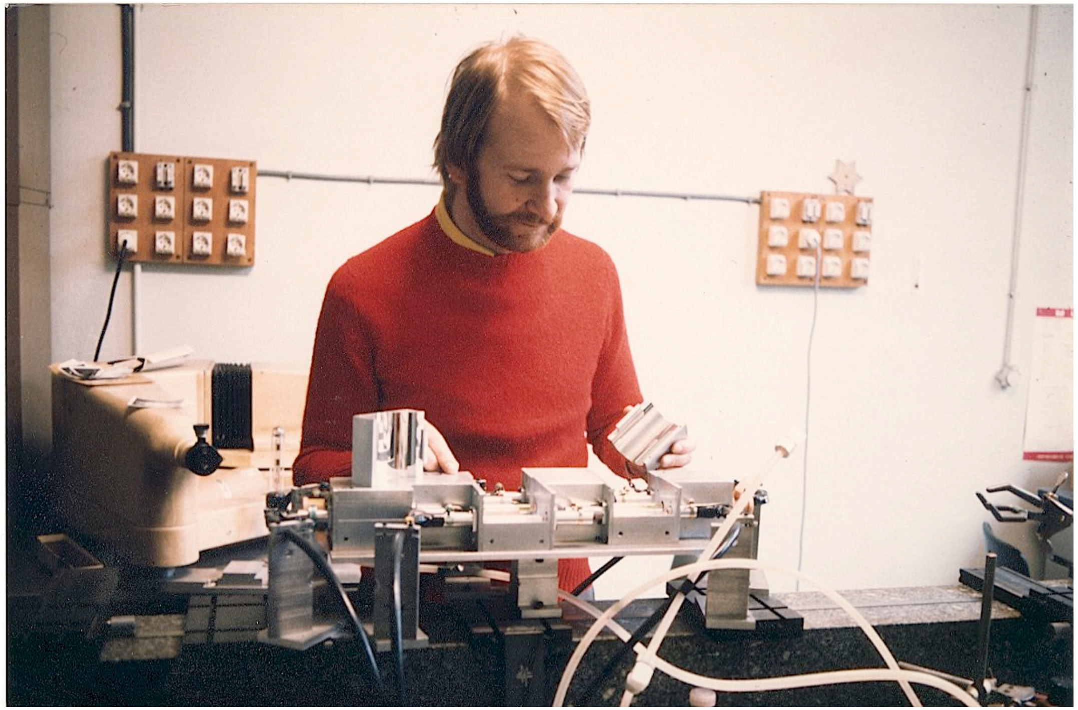
René Barthélemy

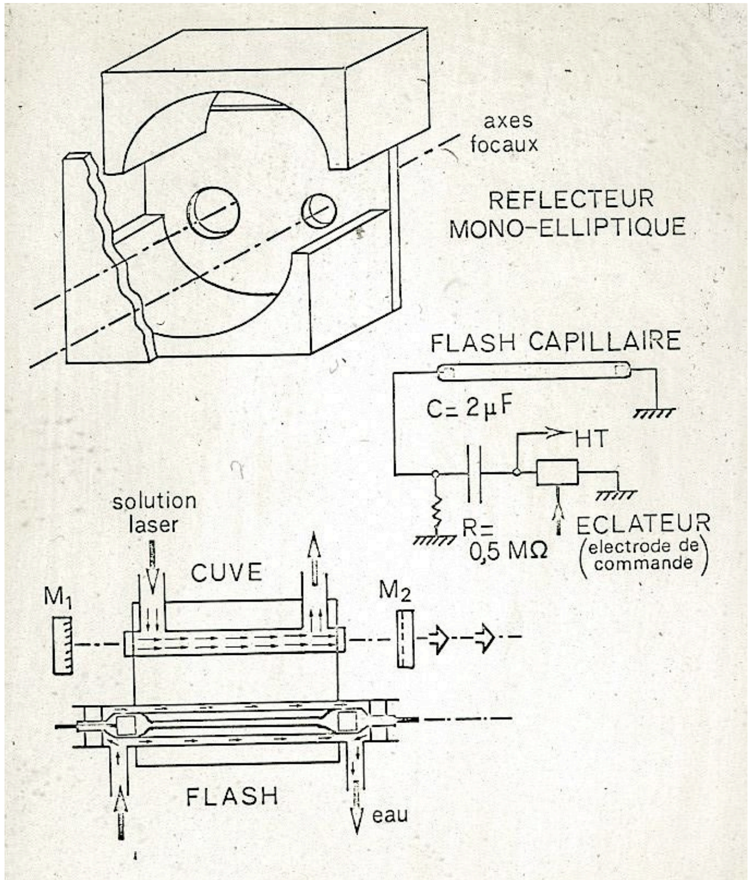
Work started in 1934, stopped in 1940

2. Elastic Backscatter lidar started in the 60's

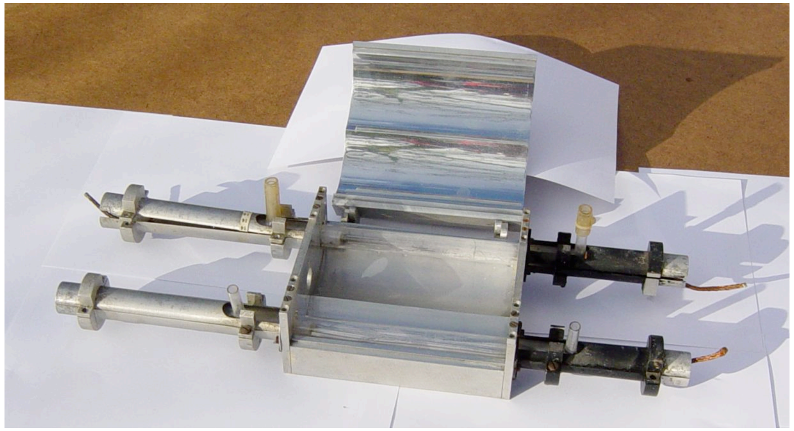
1980 - till now

Pulsed Dye Laser in the 70's





Lidar Atmospheric Applications at OHP



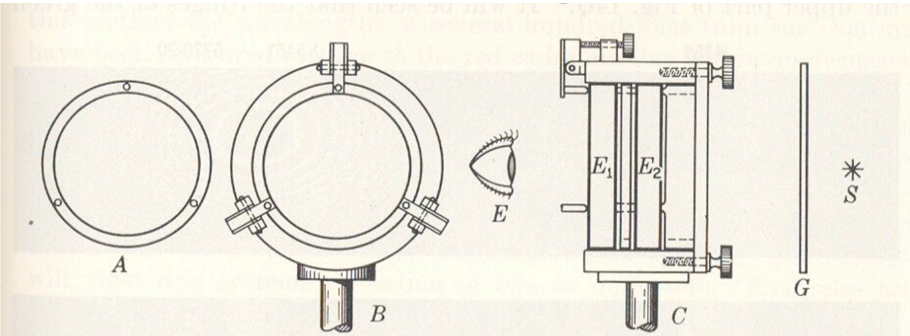
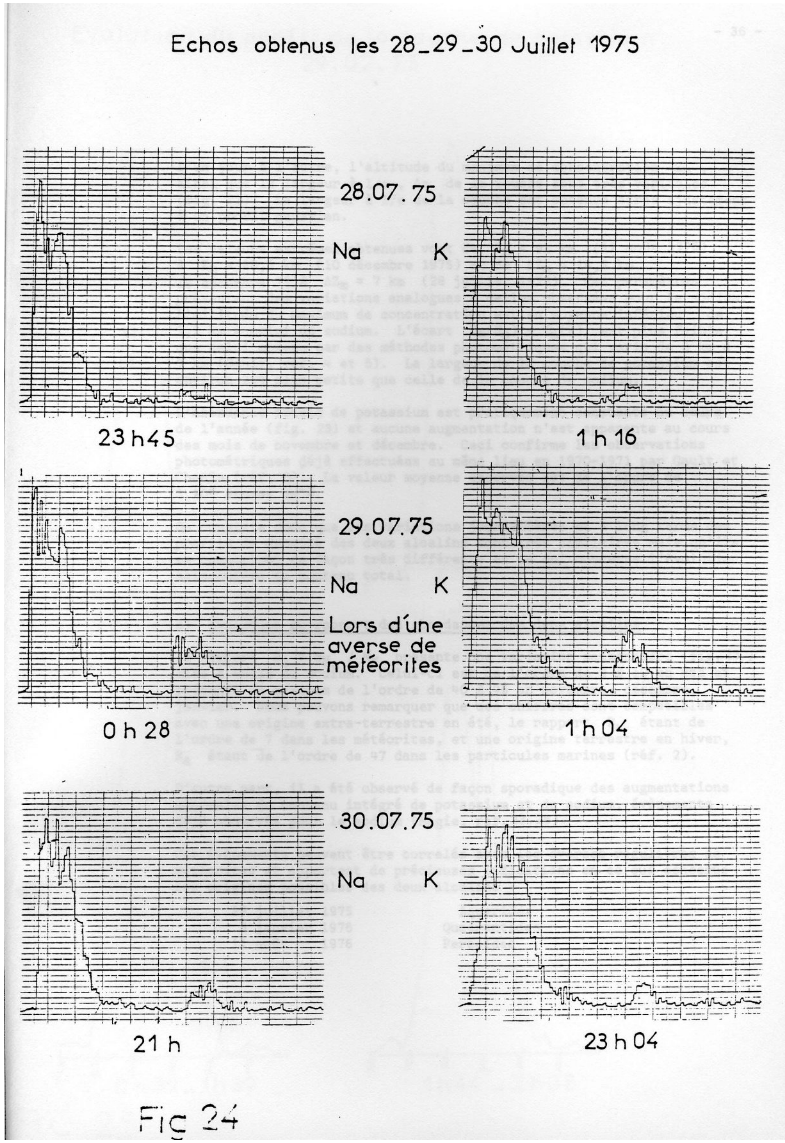
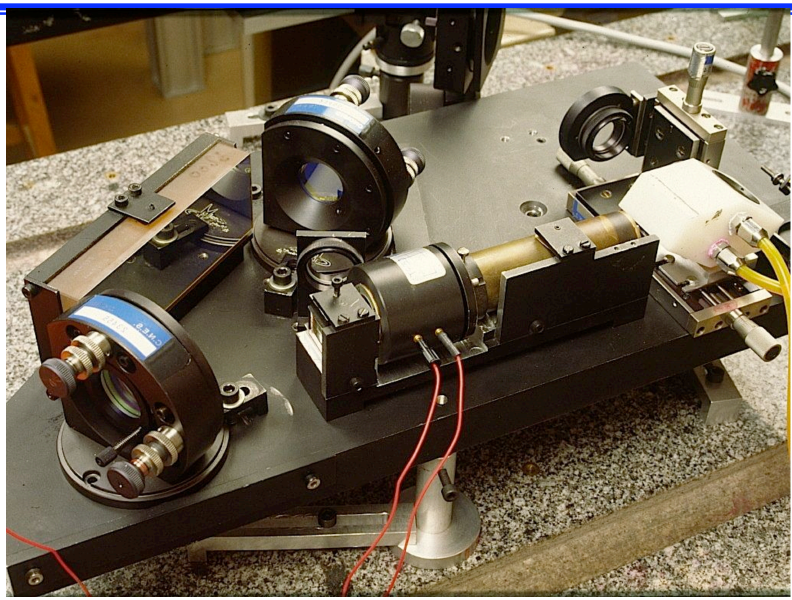
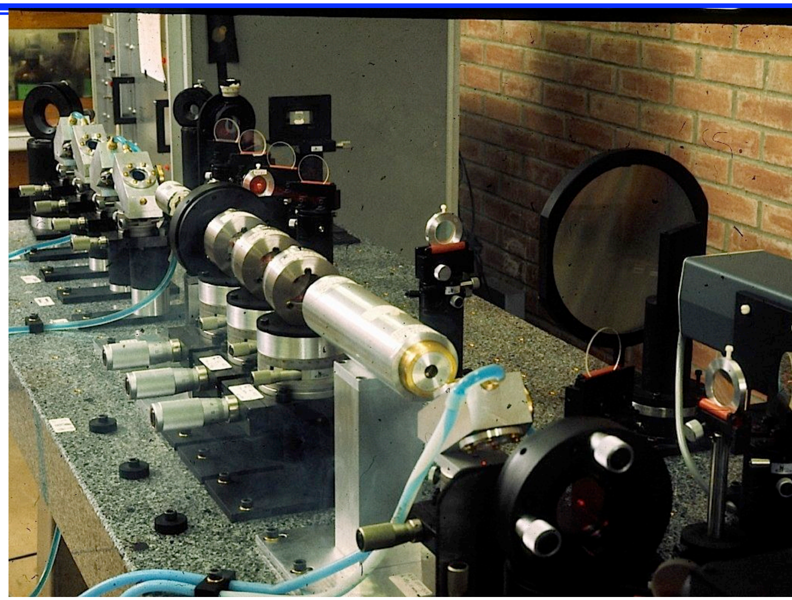
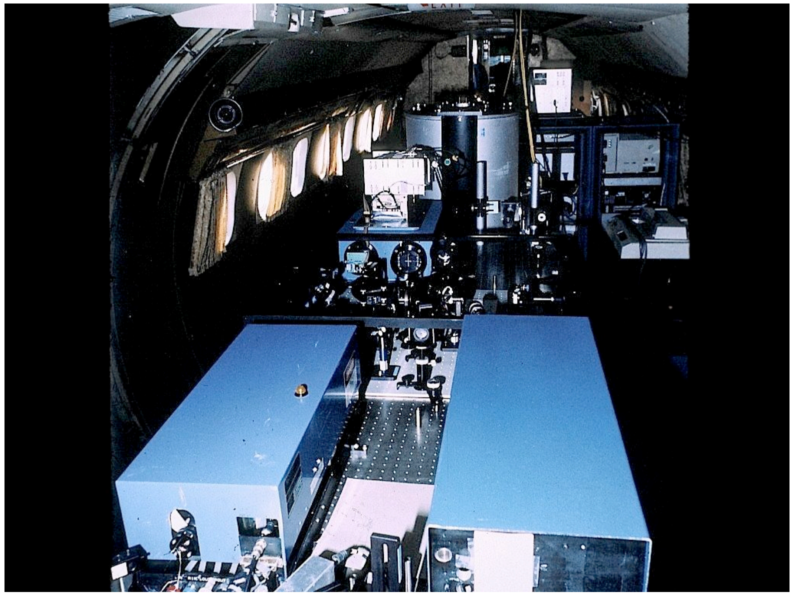


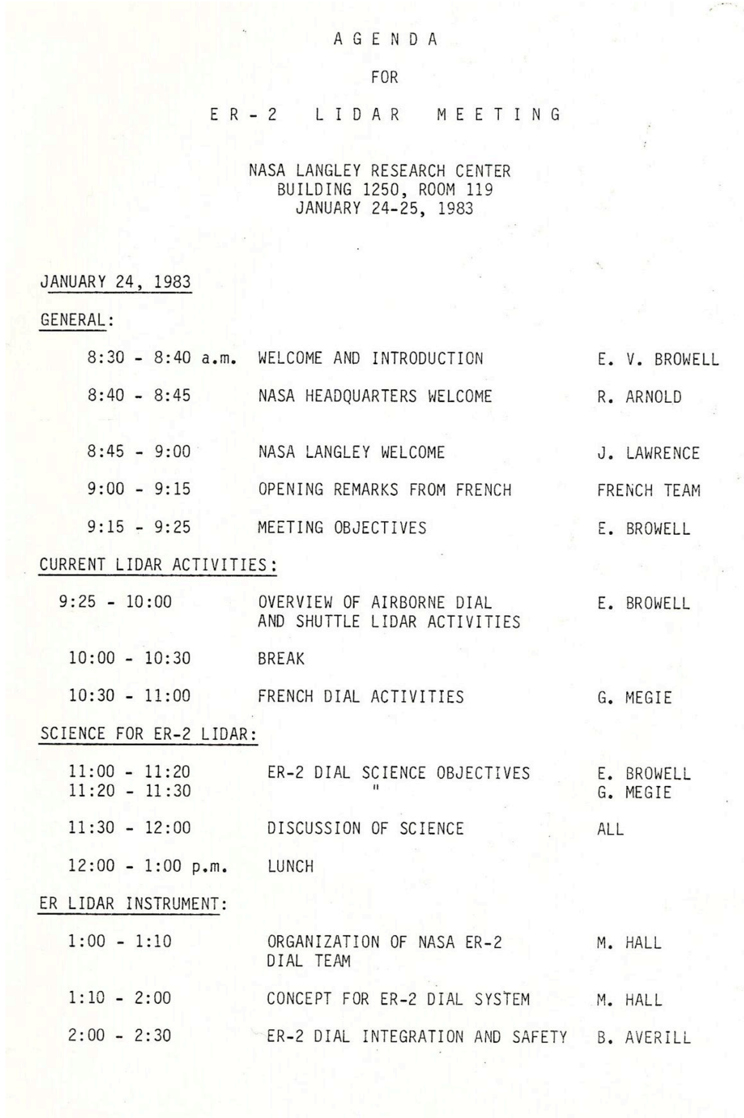
FIG. 140. Mechanical details of a Fabry-Perot etalon, showing spacer ring, adjusting screws, and springs.



Lidar Atmospheric Applications


Looking for an Aircraft, desperately



A G E N D A

FOR

E R - 2 L I D A R M E E T I N G

NASA LANGLEY RESEARCH CENTER
BUILDING 1250, ROOM 119
JANUARY 24-25, 1983

JANUARY 24, 1983

GENERAL:

8:30 - 8:40 a.m.	WELCOME AND INTRODUCTION	E. V. BROWELL
8:40 - 8:45	NASA HEADQUARTERS WELCOME	R. ARNOLD
8:45 - 9:00	NASA LANGLEY WELCOME	J. LAWRENCE
9:00 - 9:15	OPENING REMARKS FROM FRENCH	FRENCH TEAM
9:15 - 9:25	MEETING OBJECTIVES	E. BROWELL

CURRENT LIDAR ACTIVITIES:

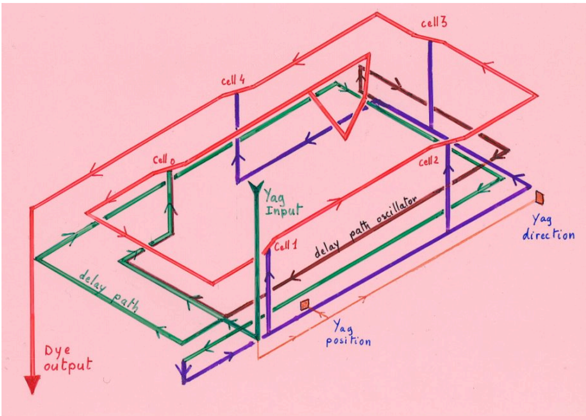
9:25 - 10:00	OVERVIEW OF AIRBORNE DIAL AND SHUTTLE LIDAR ACTIVITIES	E. BROWELL
10:00 - 10:30	BREAK	
10:30 - 11:00	FRENCH DIAL ACTIVITIES	G. MEGIE

SCIENCE FOR ER-2 LIDAR:

11:00 - 11:20	ER-2 DIAL SCIENCE OBJECTIVES	E. BROWELL
11:20 - 11:30	"	G. MEGIE
11:30 - 12:00	DISCUSSION OF SCIENCE	ALL
12:00 - 1:00 p.m.	LUNCH	

ER LIDAR INSTRUMENT:

1:00 - 1:10	ORGANIZATION OF NASA ER-2 DIAL TEAM	M. HALL
1:10 - 2:00	CONCEPT FOR ER-2 DIAL SYSTEM	M. HALL
2:00 - 2:30	ER-2 DIAL INTEGRATION AND SAFETY	B. AVERILL



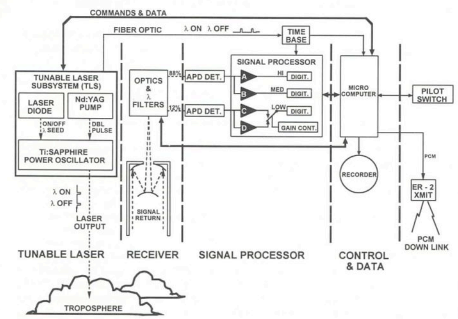
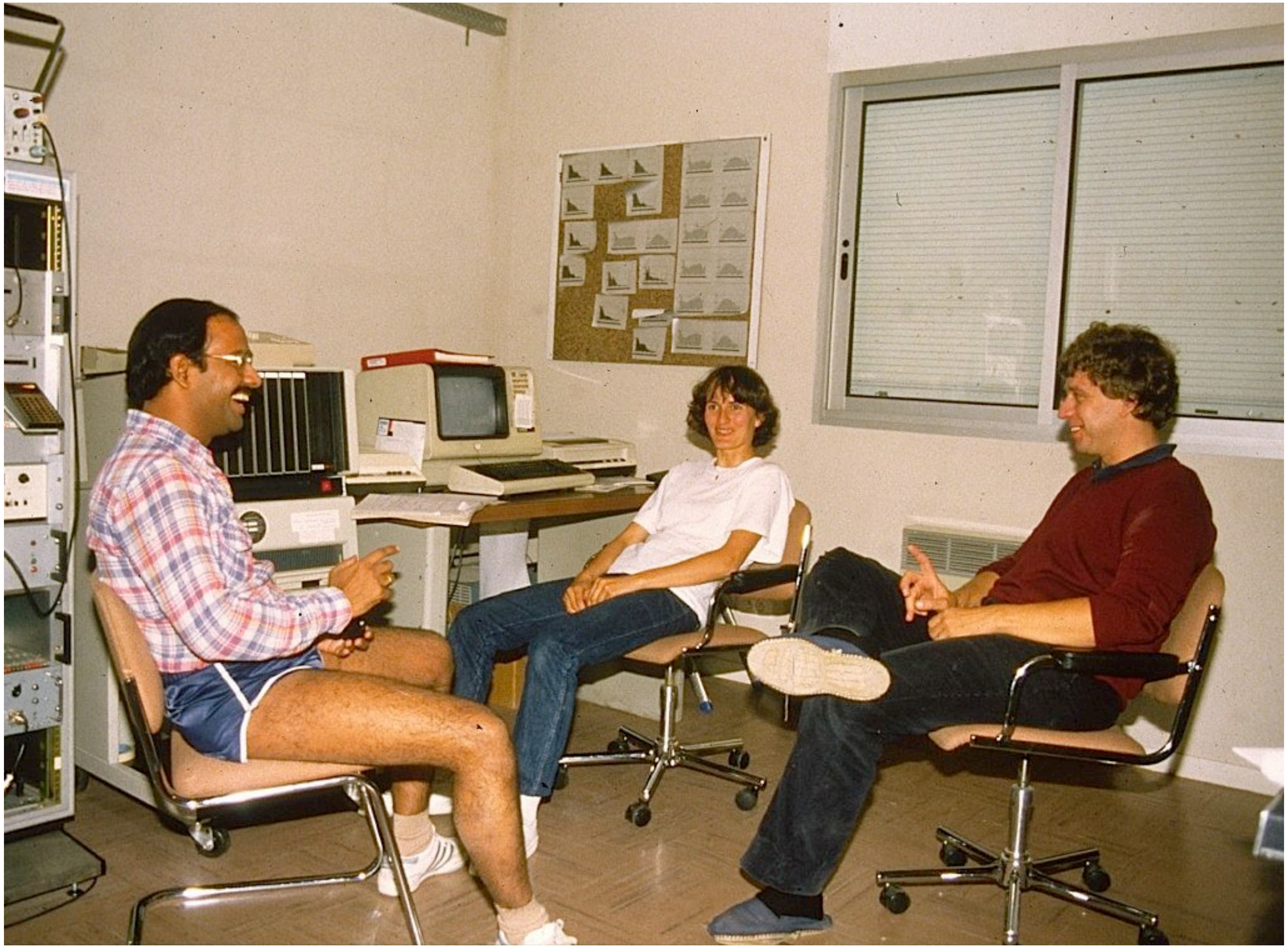


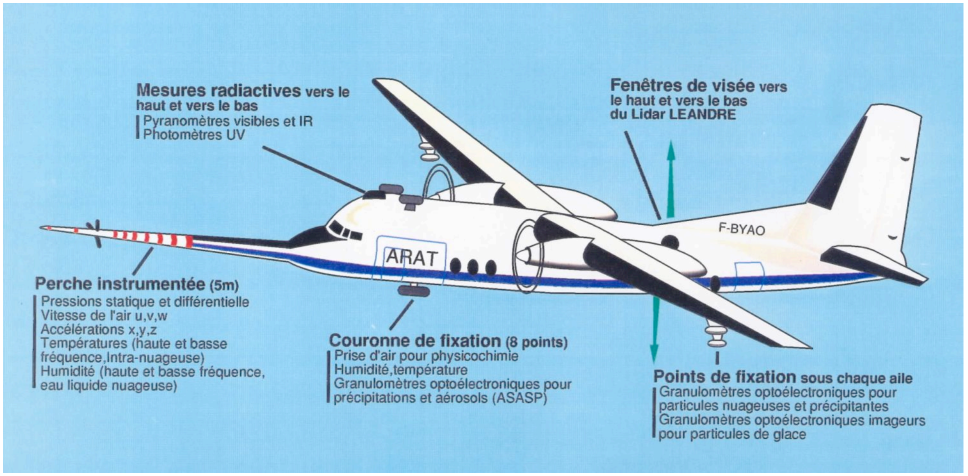
Fig. 1. LASE System Block Diagram

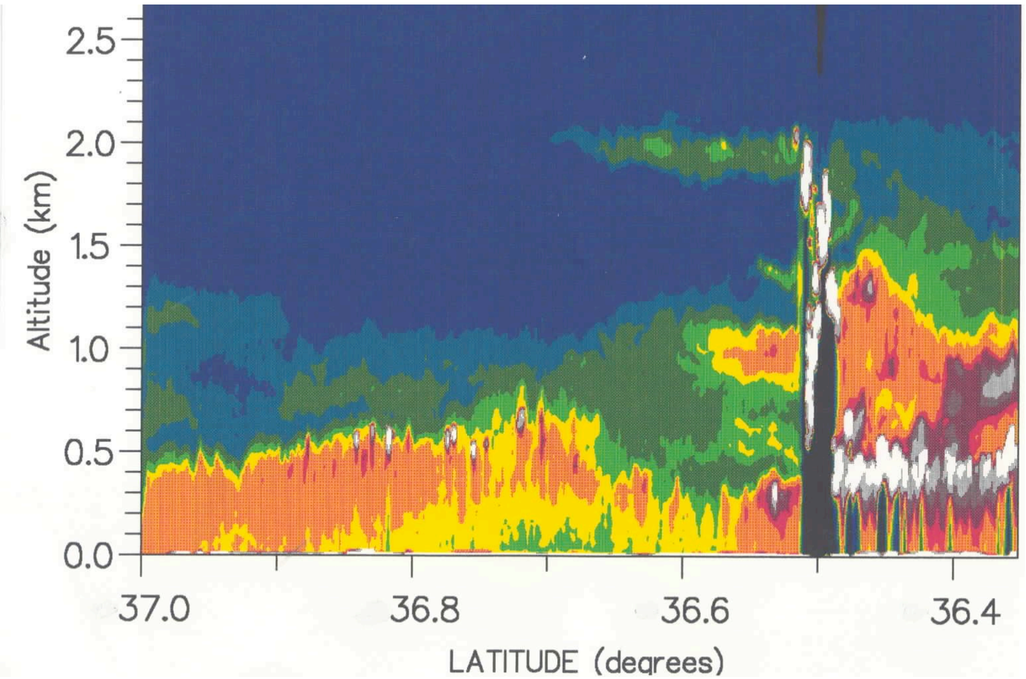
As shown in Figure 1, LASE is divided into four main parts: Tunable Laser Subsystem (TLS), Receiver Subsystem (RCS), Signal Processor Subsystem (SPS) and

1984 at the New Lidar Station at OHP

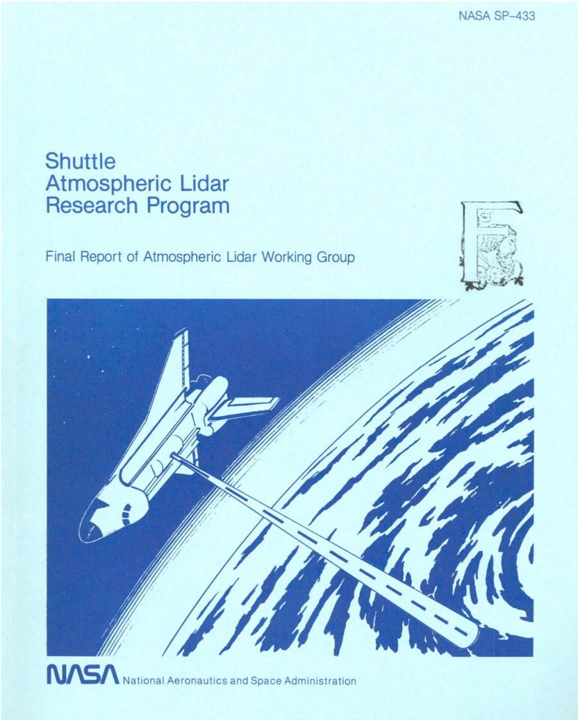


1986: French Airborne Lidar Program

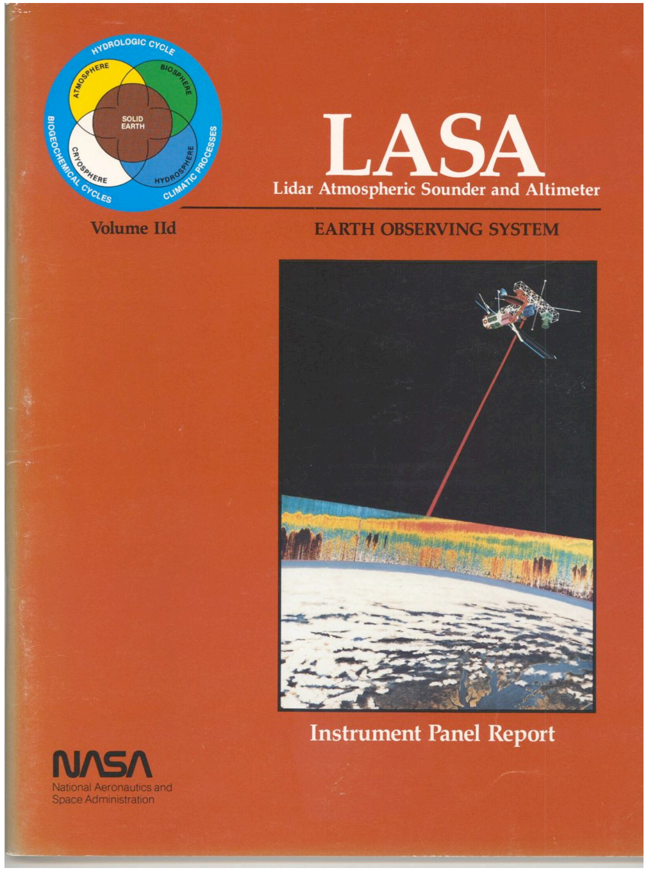




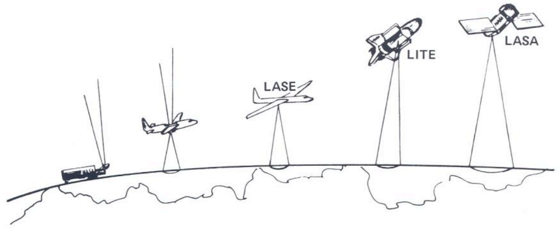
NASA on Atmospheric lidar in Space



1979



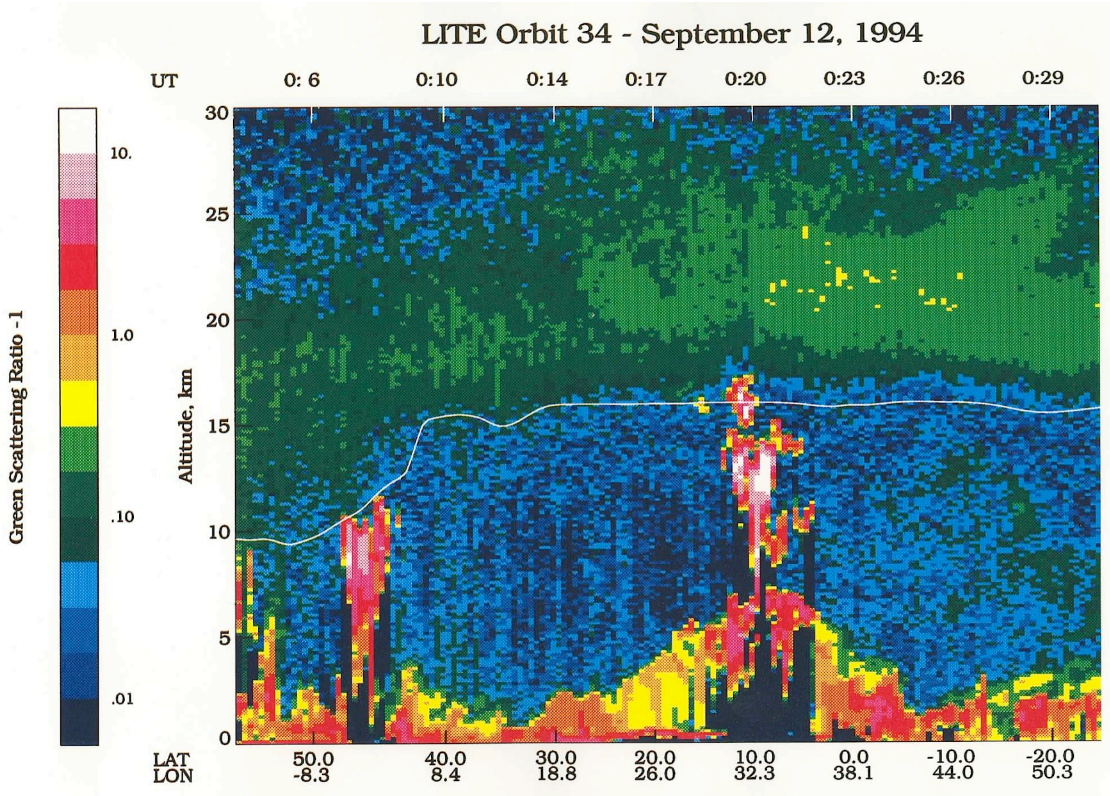
1989



	FIRST MEAS.	λ's	LASER (Tunable*)	MEAS. SPECIES
GND Based 48 in.	1970	2	Ruby (694 nm, 347 nm)	Aerosols/Molecular Backscatter, Water Vapor
Aircraft Electra/990	1978	3	Ruby, YAG, YAG/Dye (1060, 720*, 694, 600*, 530, 347, 300* nm)	Aerosols/Water Vapor/ Ozone
LASE/ER-2	1988	3	Alexandrite (720*)	Water Vapor/Aerosols
LITE/Shuttle	1988	3	YAG (1060, 530, 355 nm)	Aerosols/Density/T
LASA/Eos	1994	≧3	–	Aerosols/Clouds/Altimetry Density/Water Vapor/T

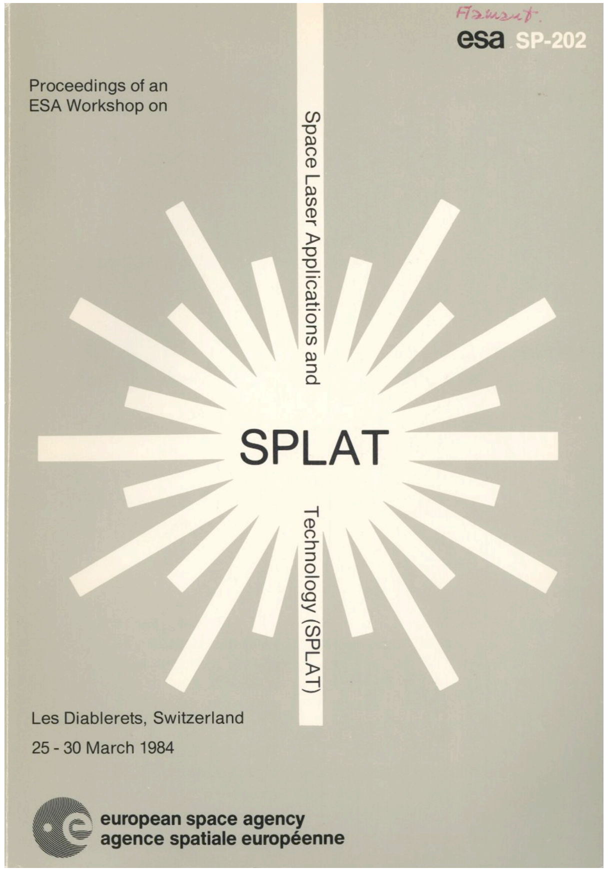
Figure 76. NASA lidar atmospheric measurements evolution.

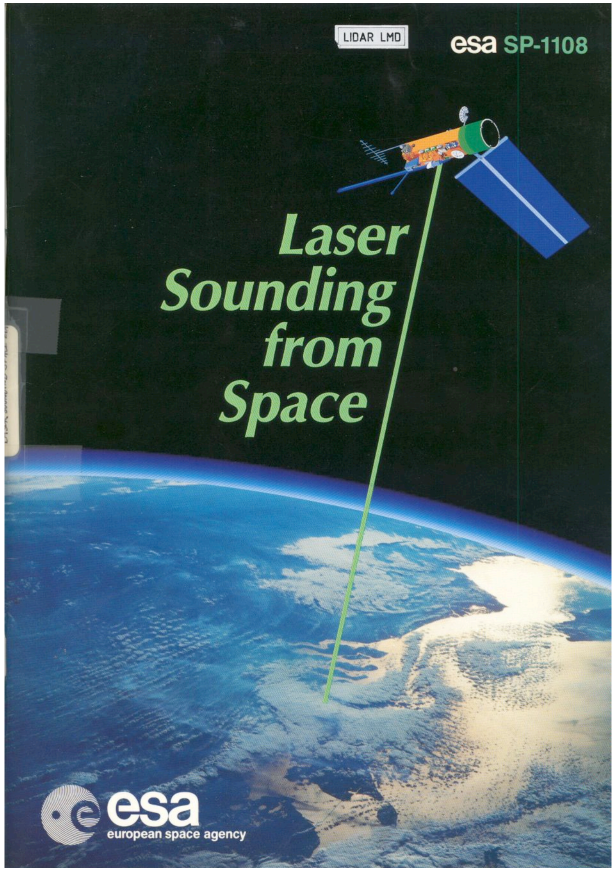
1994: NASA LITE mission in space

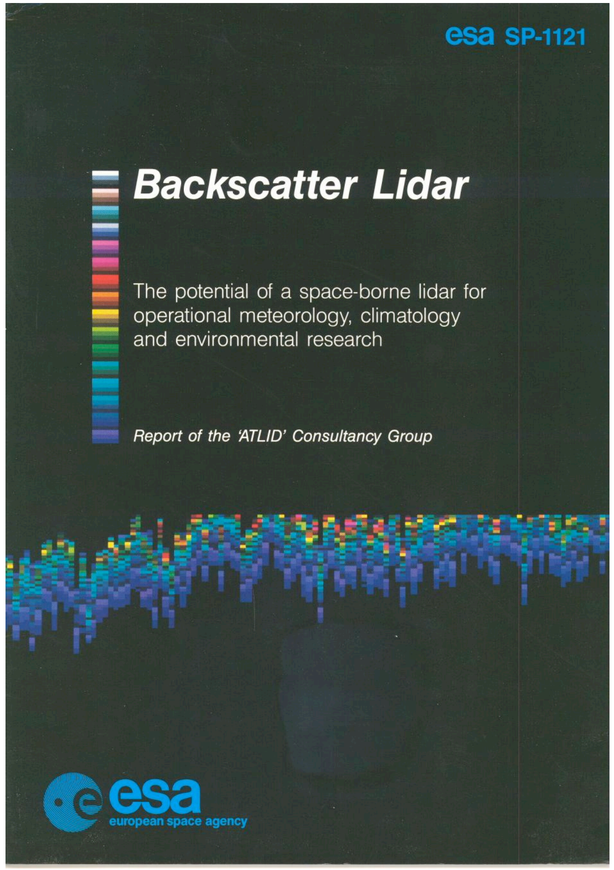


2006: CALIPSO in A-Train

ESA on the road of lidar in space







1984

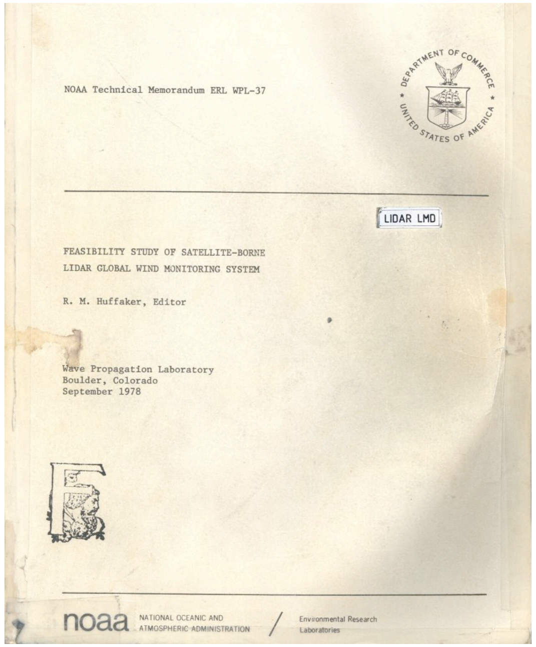
1989

ATLID in EarthCARE, a joint
venture between ESA and JAXA
as ESA 3rd Earth Explorer Mission
to be launch in 2013-2015

3. WIND lidar

1981 - till now

WINDSAT !!! Meeting with Milt HUFFAKER


NOAA Technical Memorandum ERL WPL-37

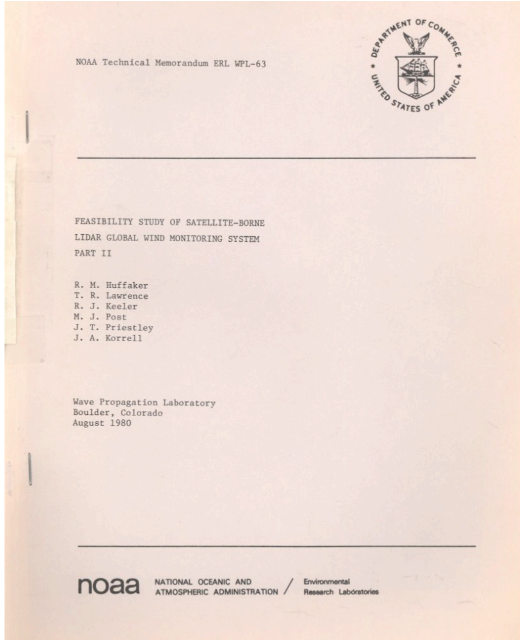
LIDAR LMD

FEASIBILITY STUDY OF SATELLITE-BORNE
LIDAR GLOBAL WIND MONITORING SYSTEM

R. M. Huffaker, Editor

Wave Propagation Laboratory
Boulder, Colorado
September 1978

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

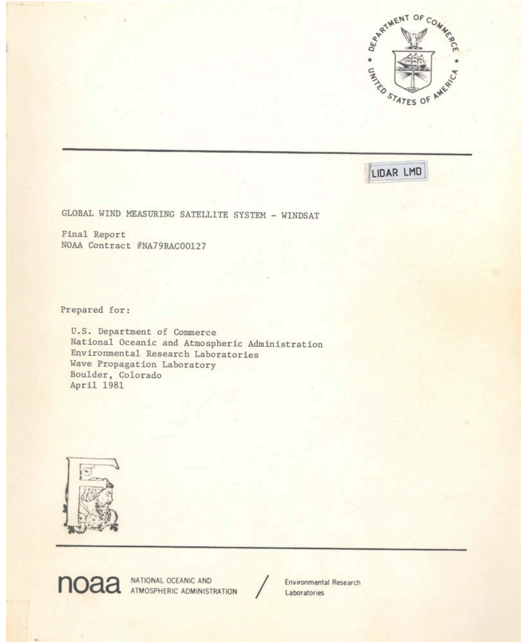

NOAA Technical Memorandum ERL WPL-63

FEASIBILITY STUDY OF SATELLITE-BORNE
LIDAR GLOBAL WIND MONITORING SYSTEM
PART II

R. M. Huffaker
T. R. Lawrence
R. J. Keeler
M. J. Post
J. T. Priestley
J. A. Korrell

Wave Propagation Laboratory
Boulder, Colorado
August 1980

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories


LIDAR LMD

GLOBAL WIND MEASURING SATELLITE SYSTEM - WINDSAT

Final Report
NOAA Contract #NA79RAC00127

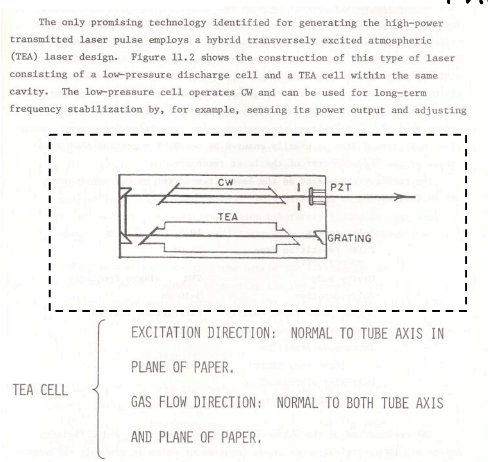
Prepared for:

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Wave Propagation Laboratory
Boulder, Colorado
April 1981

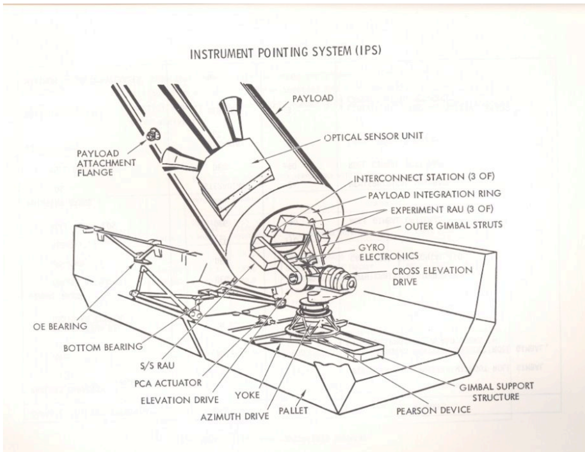
noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

Transmitter laser

The shuttle, the CO2 laser and great expectations


The only promising technology identified for generating the high-power transmitted laser pulse employs a hybrid transversely excited atmospheric (TEA) laser design. Figure 11.2 shows the construction of this type of laser consisting of a low-pressure discharge cell and a TEA cell within the same cavity. The low-pressure cell operates CW and can be used for long-term frequency stabilization by, for example, sensing its power output and adjusting

TEA CELL
EXCITATION DIRECTION: NORMAL TO TUBE AXIS IN PLANE OF PAPER.
GAS FLOW DIRECTION: NORMAL TO BOTH TUBE AXIS AND PLANE OF PAPER.



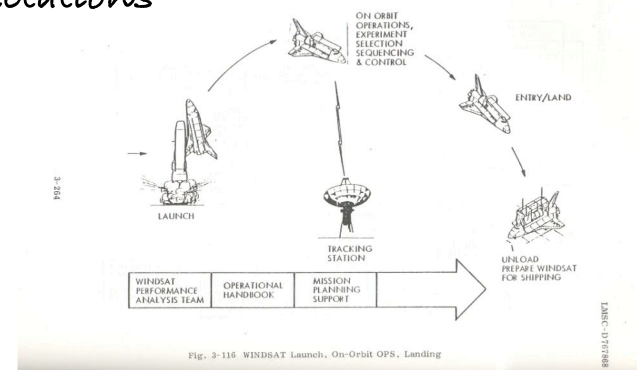
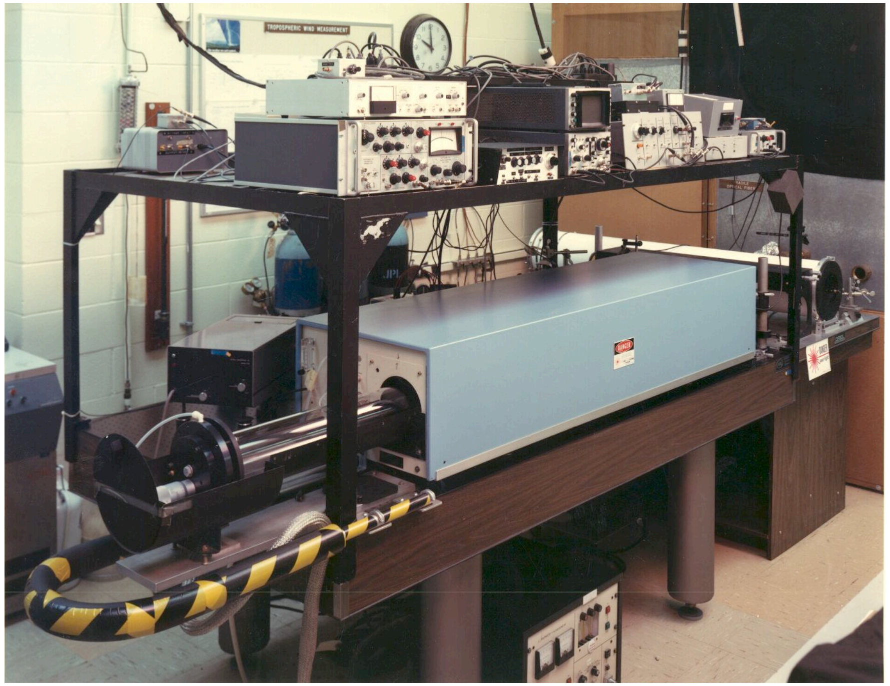
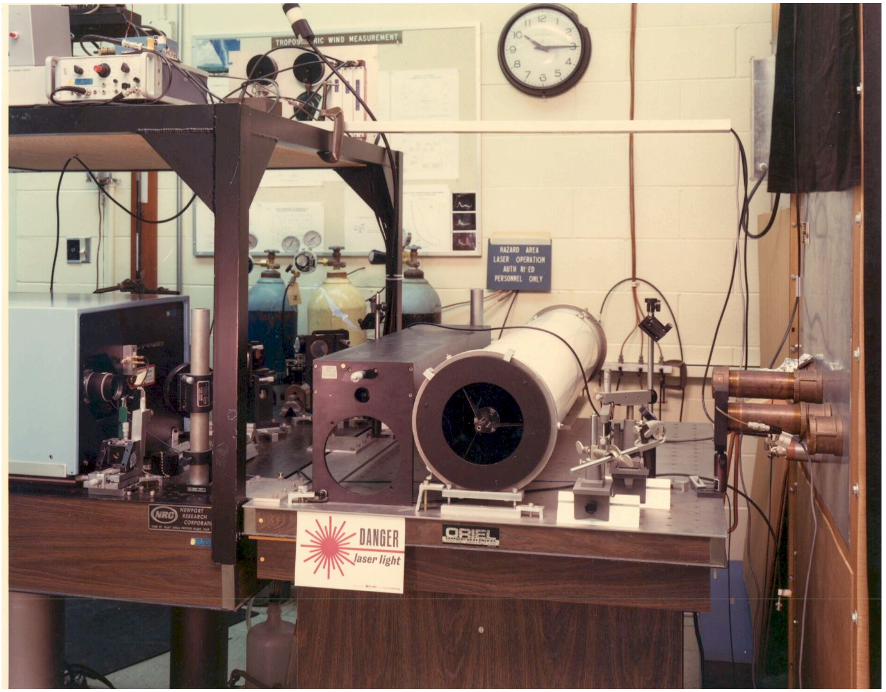


Fig. 3-116 WINDSAT Launch, On-Orbit OPS, Landing

Si non é véro é ben trovato

1981-1982 at JPL: Pulsed CO_2 Lidar



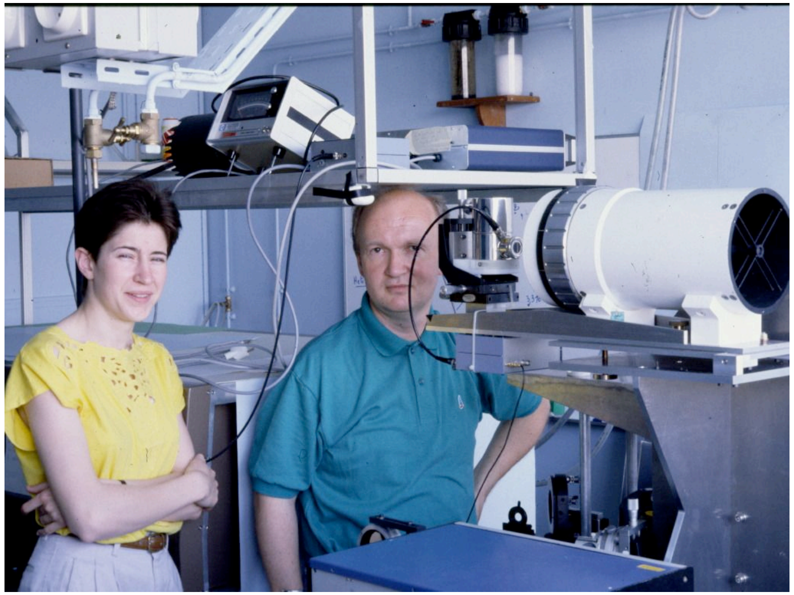


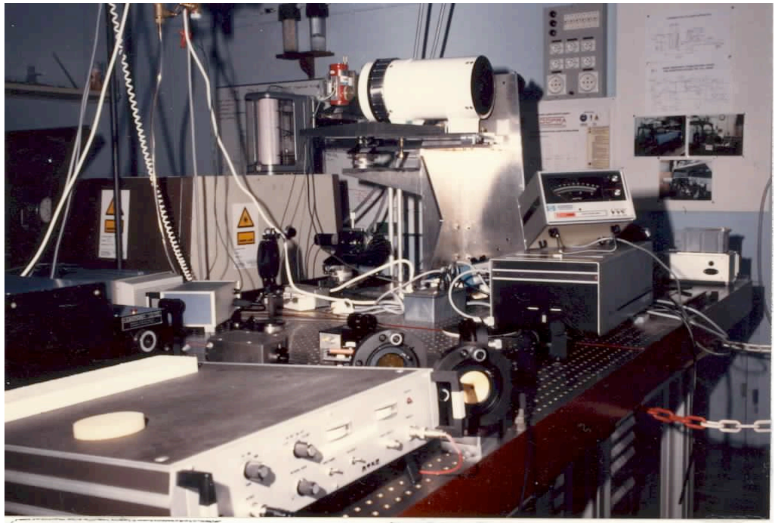
1982: Target work for Calibration

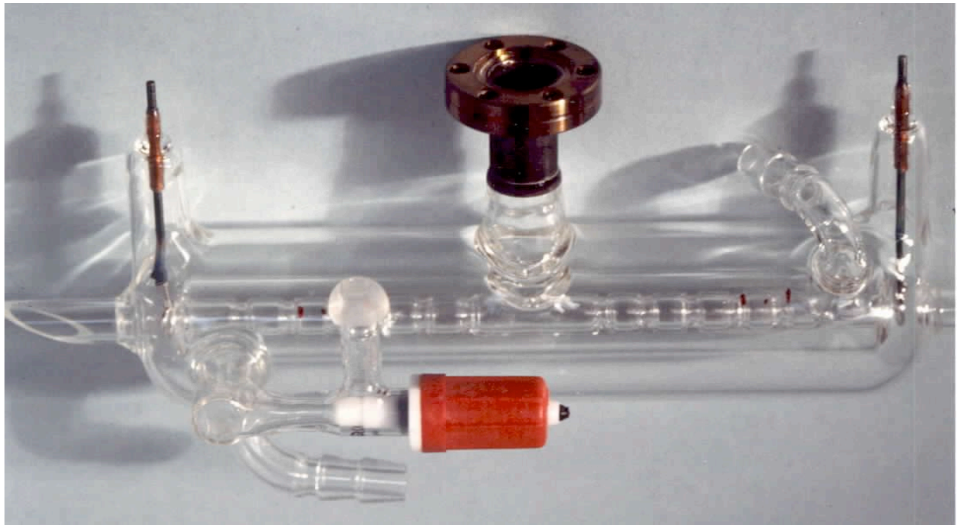
1985: CLRC in Malvern

1987: NAIL at NCAR

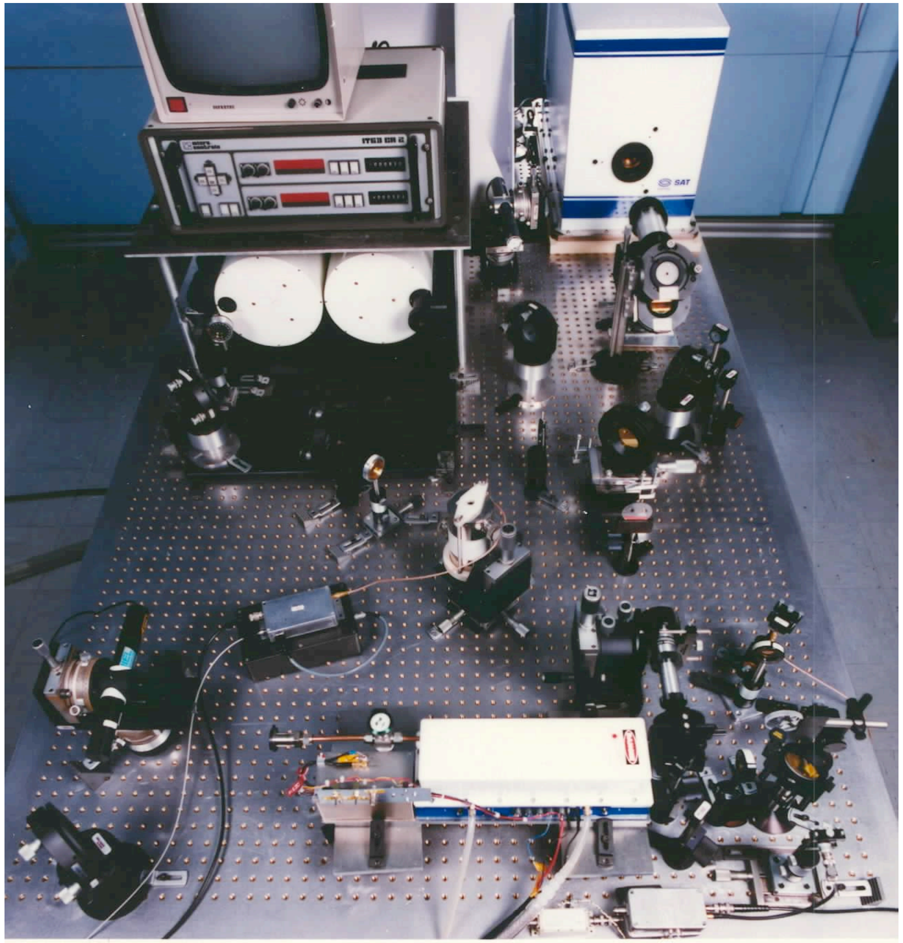
1987: beginning of CO_2 lidar for Wind at LMD

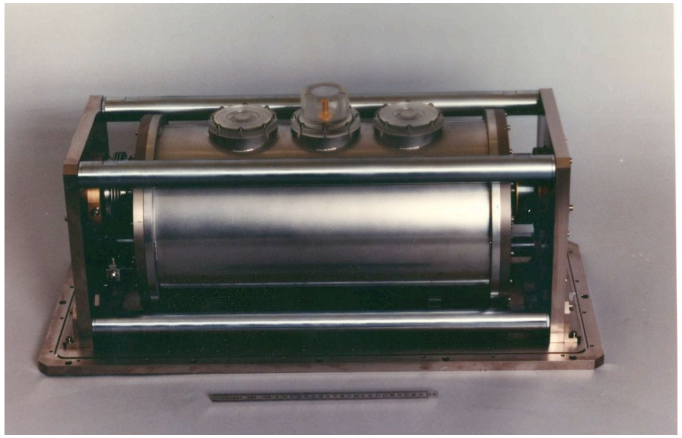


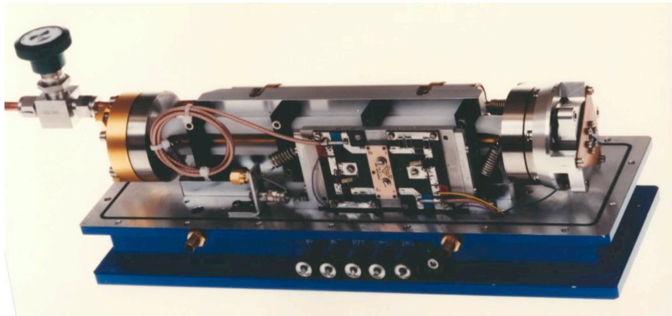




New technologies !

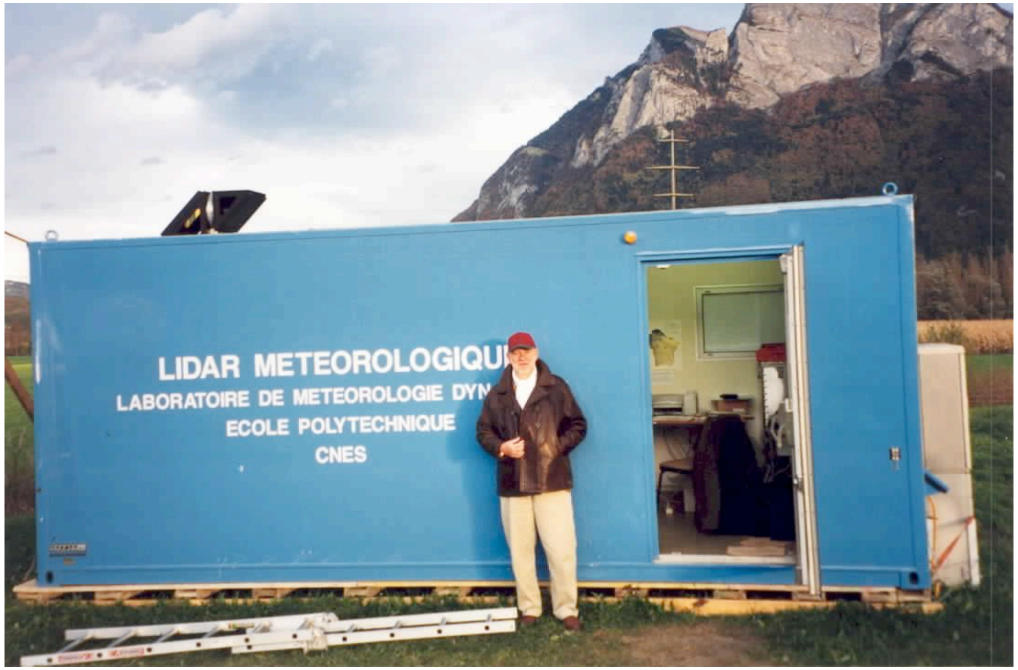




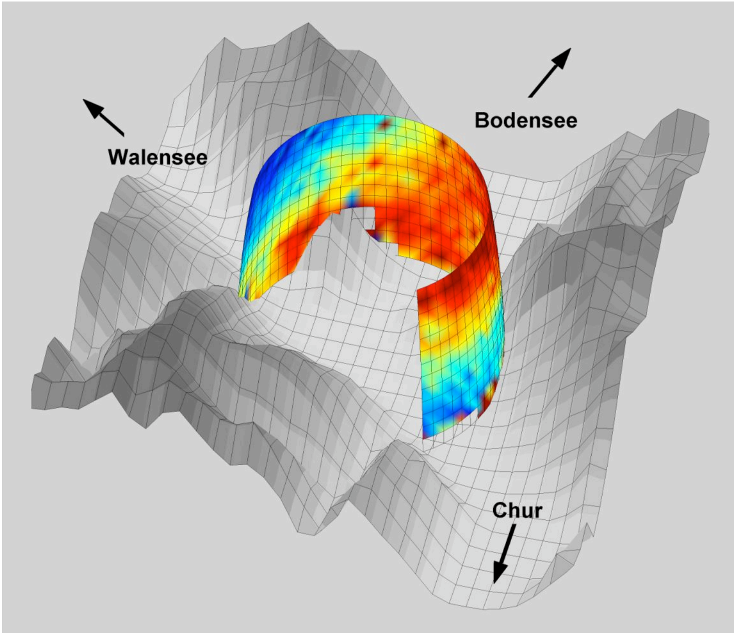


PhD work for thesis
Articles in peer review journals

1999: Mesoscale Alpine Program

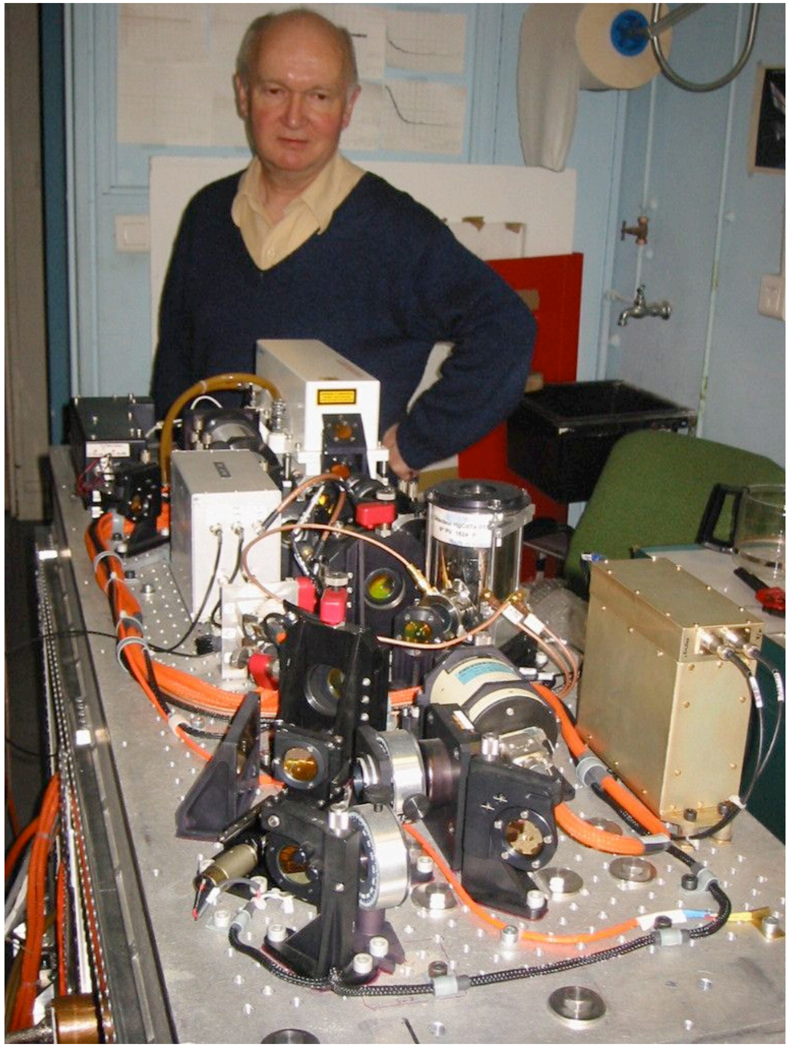


- The Transportable Wind Lidar in the Rhine valley, for the study of Foehn circulation
- Mono-static scanning Doppler Lidar
- CO_2 transmitter & heterodyne detection

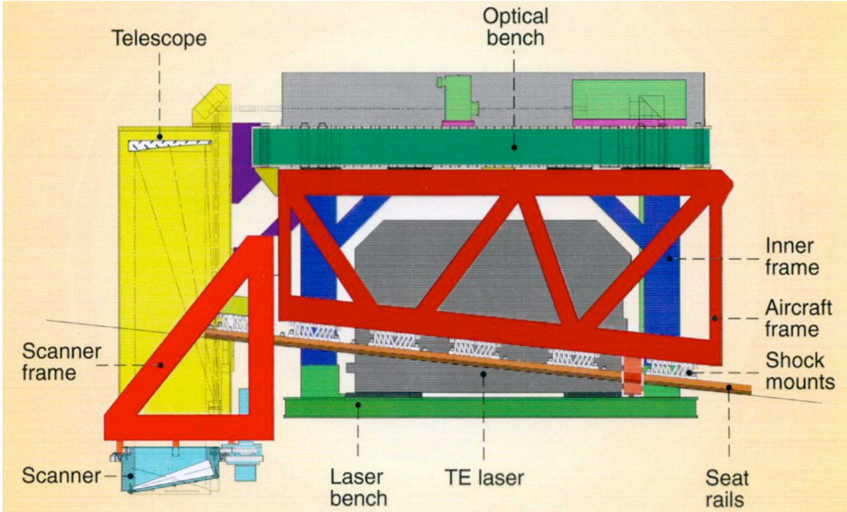


Thanks to Alain Dabas

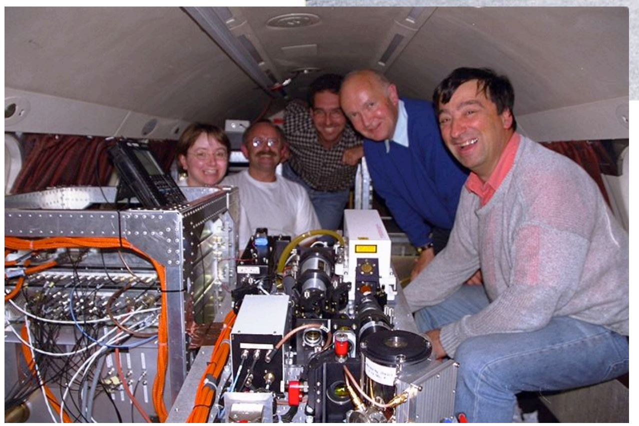
The Franco-German WIND airborne Lidar



The artisan and the master piece



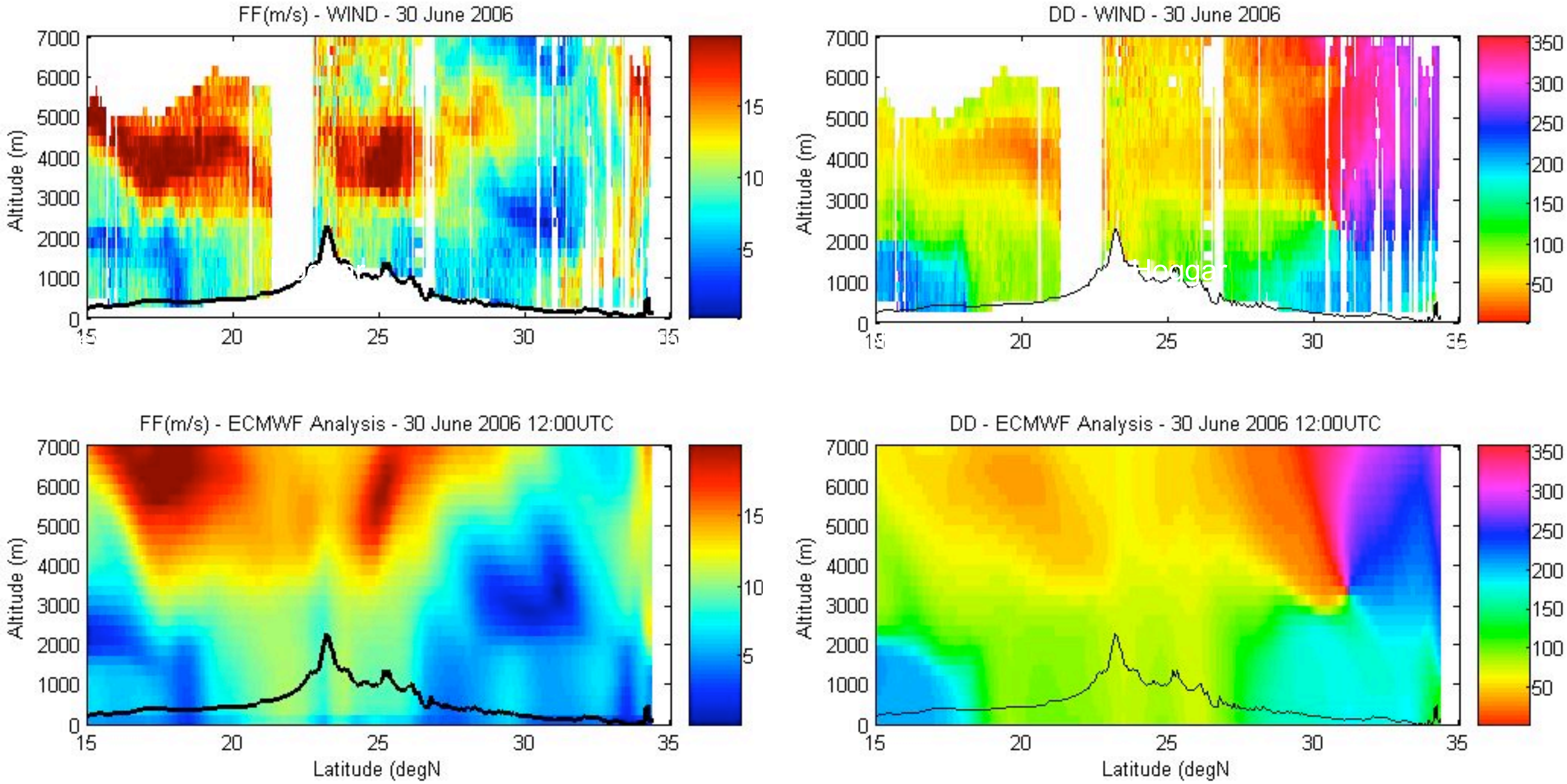
1999 at DLR: WIND 1st flight



Waiting for the good, and then the MAP field campaign the same year, …

2006: WIND in AMMA

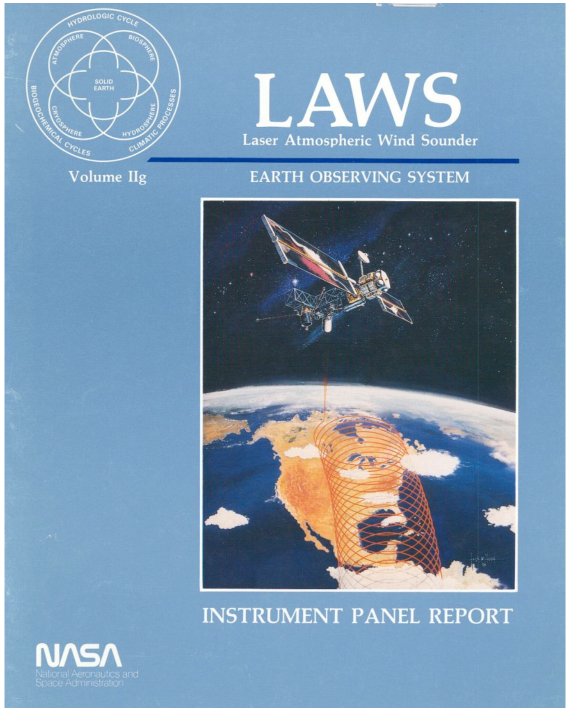
African Monsoon



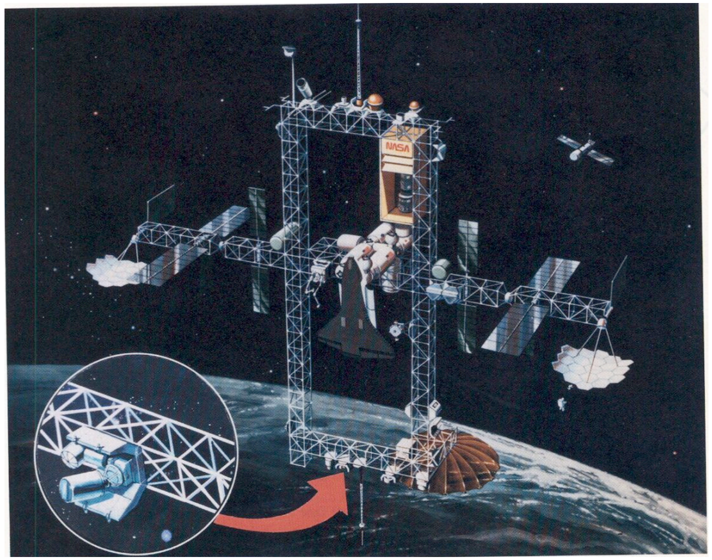
The clue and beauty of a lidar probing the wind field in the depth of atmosphere

Thanks to Alain Dabas

NASA on the Road of WIND lidar in Space



1987



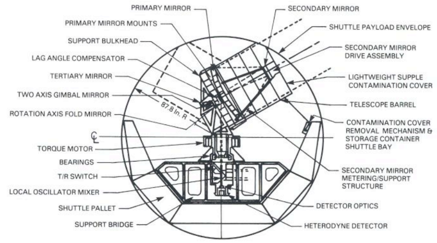


Figure 24. Side view of recommended lidar design mounted on the Space Shuttle pallet.

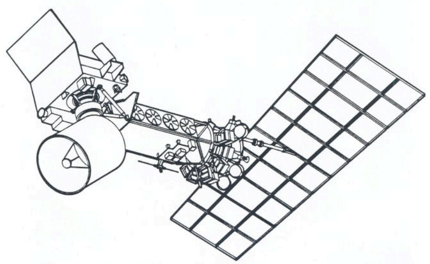


Figure 25. Windsat free flyer.

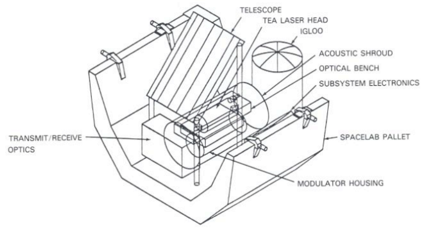
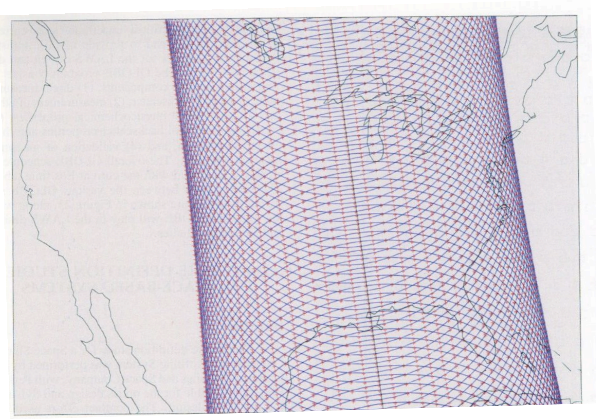


Figure C.5. SCALE configuration.



NASA-NOAA Working Group
on Space Based Lidar Wind
Led by Wyman BAKER

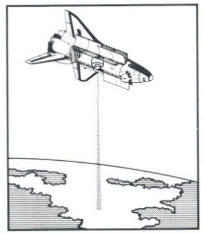
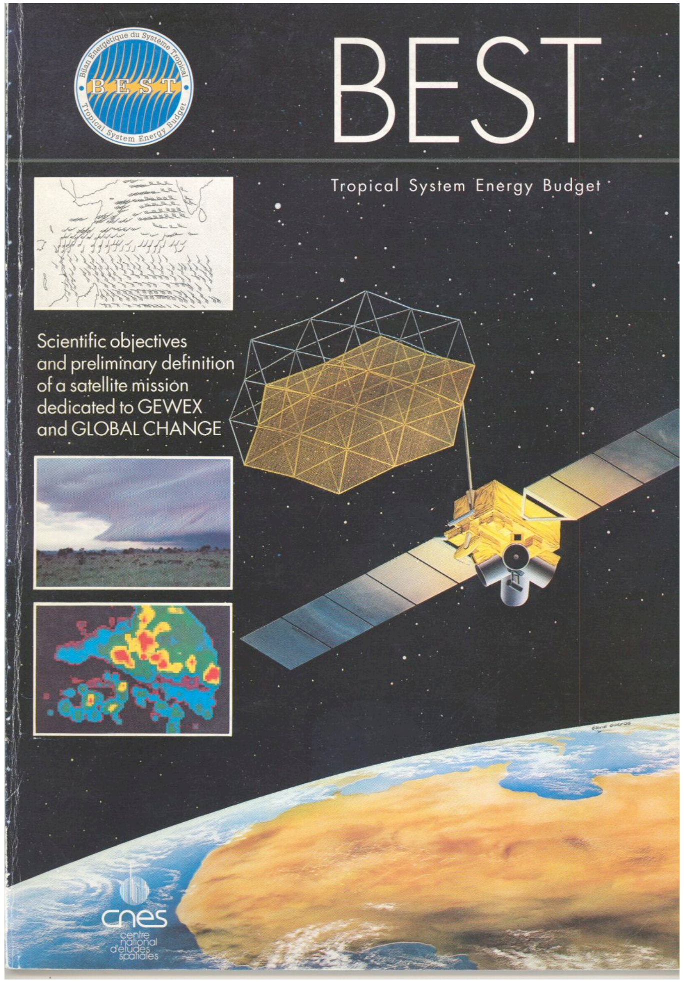


Figure C.6. SCALE scan pattern.

1989: BEST study by CNES



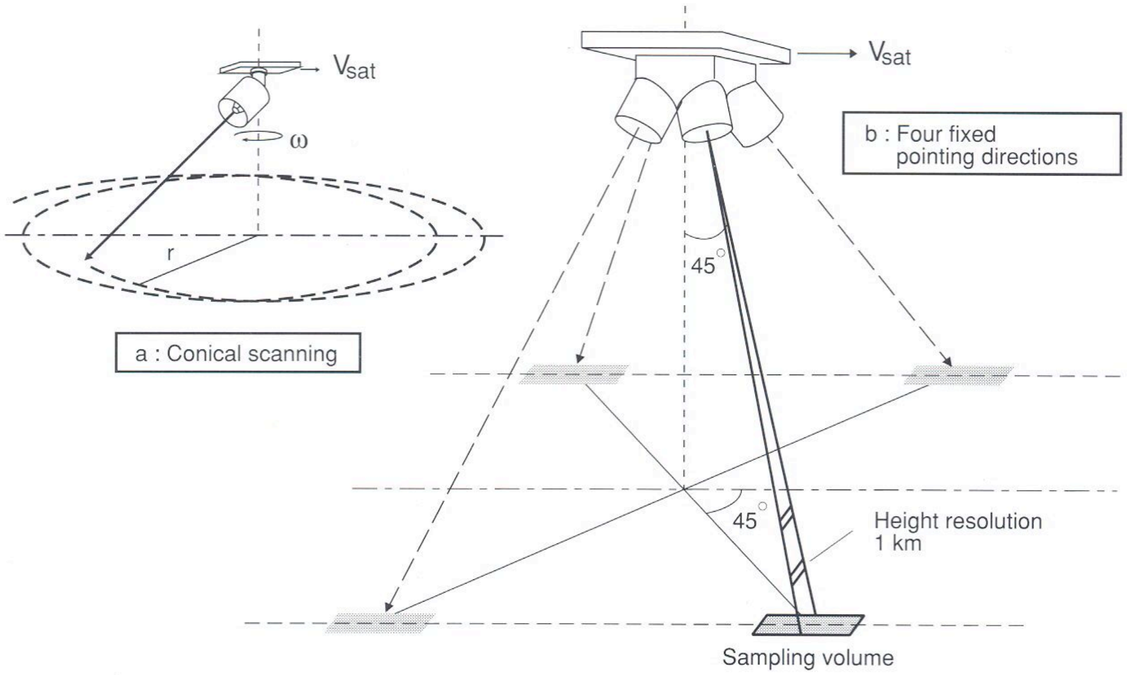
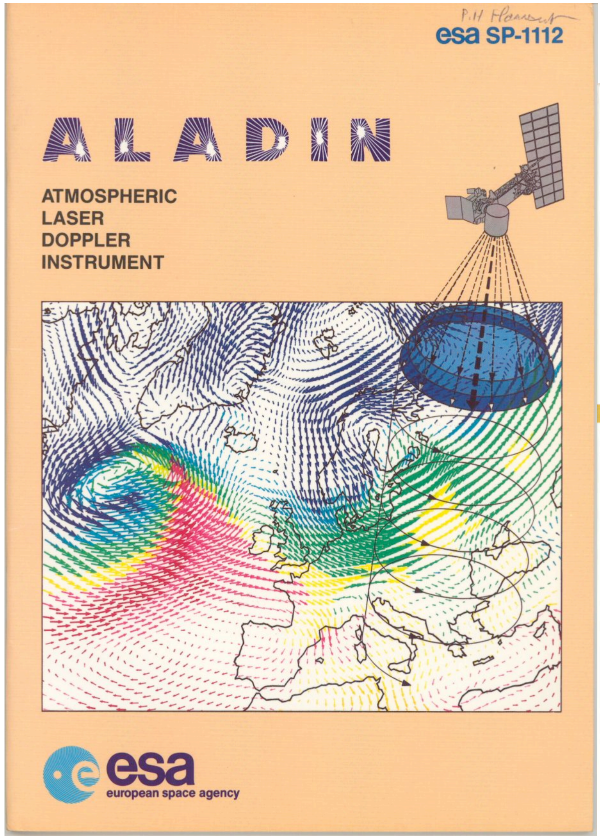


Figure 16 : *Pointing configurations.*

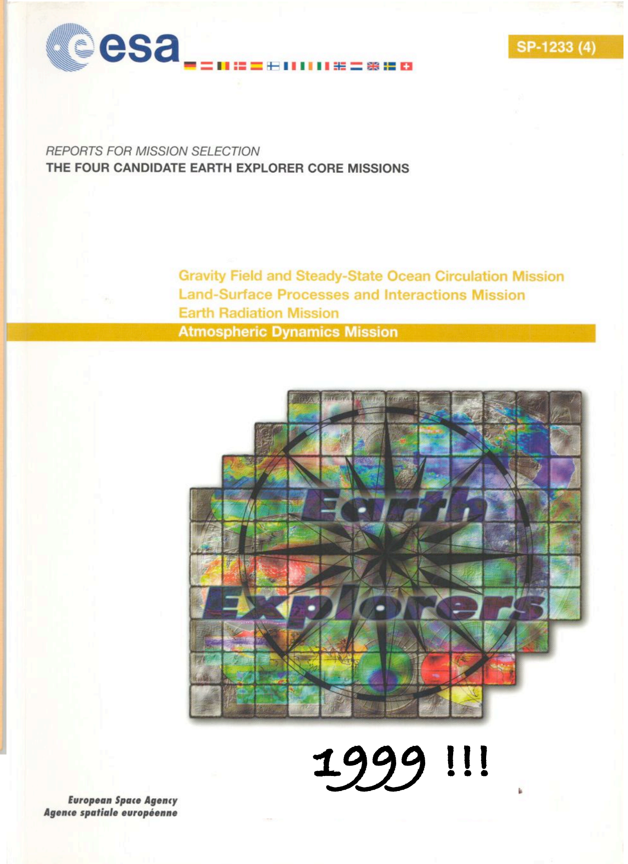
Wind lidar

- still CO2 laser transmitter & heterodyne detection
- 4 fixed LOS

ESA on the road of WIND lidar in space



1989



1999 !!!

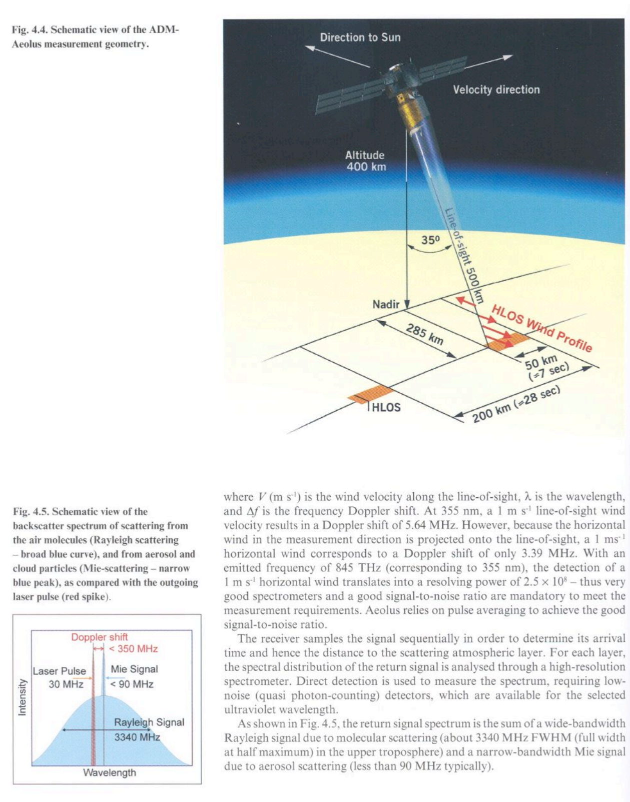


Fig. 4.4. Schematic view of the ADM-Aeolus measurement geometry.

Fig. 4.5. Schematic view of the backscatter spectrum of scattering from the air molecules (Rayleigh scattering – broad blue curve), and from aerosol and cloud particles (Mie-scattering – narrow blue peak), as compared with the outgoing laser pulse (red spike).

where V (m s^{-1}) is the wind velocity along the line-of-sight, λ is the wavelength, and Δf is the frequency Doppler shift. At 355 nm, a 1 m s^{-1} line-of-sight wind velocity results in a Doppler shift of 5.64 MHz. However, because the horizontal wind in the measurement direction is projected onto the line-of-sight, a 1 ms^{-1} horizontal wind corresponds to a Doppler shift of only 3.39 MHz. With an emitted frequency of 845 THz (corresponding to 355 nm), the detection of a 1 m s^{-1} horizontal wind translates into a resolving power of 2.5×10^8 – thus very good spectrometers and a good signal-to-noise ratio are mandatory to meet the measurement requirements. Aeolus relies on pulse averaging to achieve the good signal-to-noise ratio.

The receiver samples the signal sequentially in order to determine its arrival time and hence the distance to the scattering atmospheric layer. For each layer, the spectral distribution of the return signal is analysed through a high-resolution spectrometer. Direct detection is used to measure the spectrum, requiring low-noise (quasi photon-counting) detectors, which are available for the selected ultraviolet wavelength.

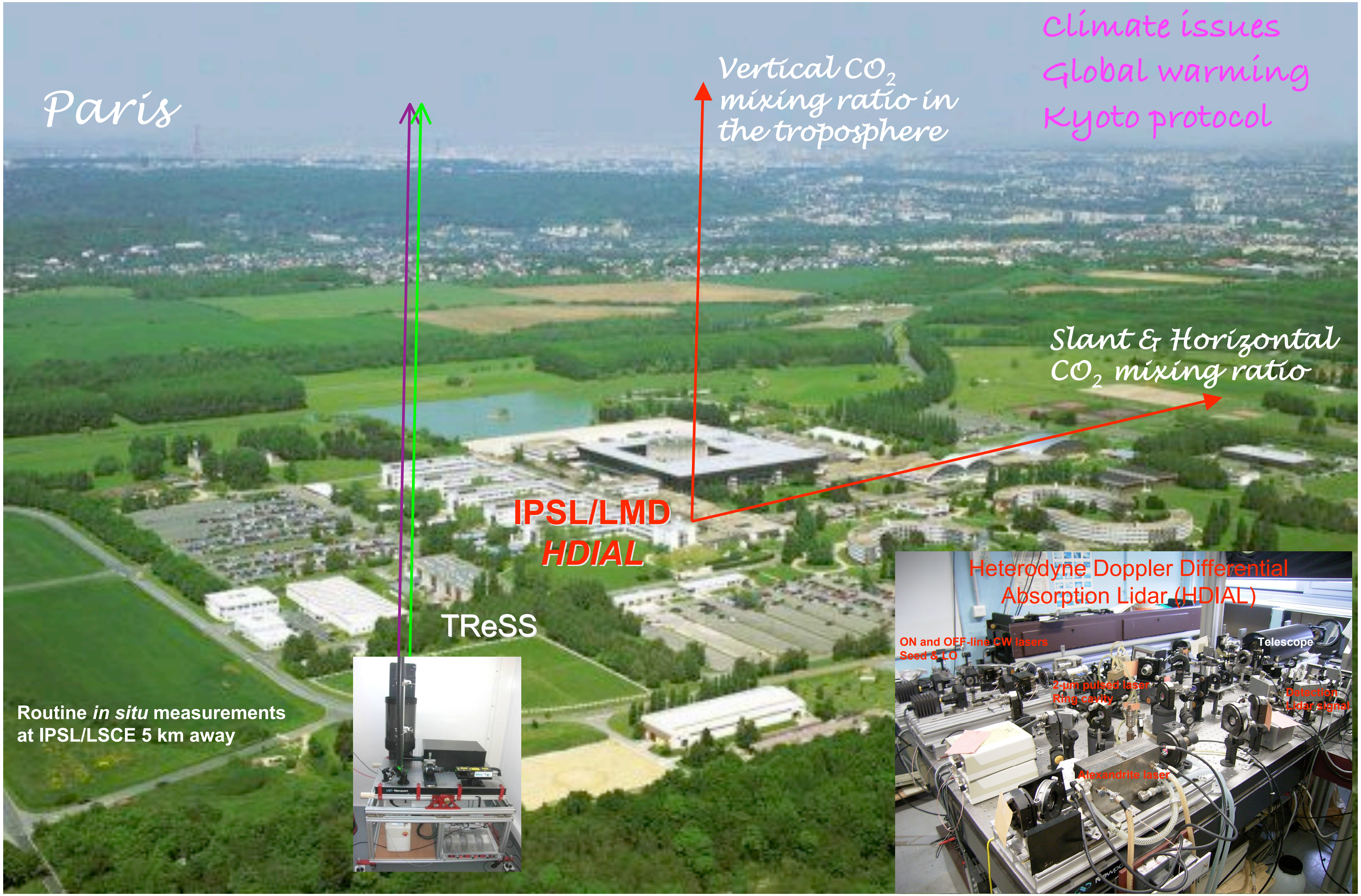
As shown in Fig. 4.5, the return signal spectrum is the sum of a wide-bandwidth Rayleigh signal due to molecular scattering (about 3340 MHz FWHM (full width at half maximum) in the upper troposphere) and a narrow-bandwidth Mie signal due to aerosol scattering (less than 90 MHz typically).

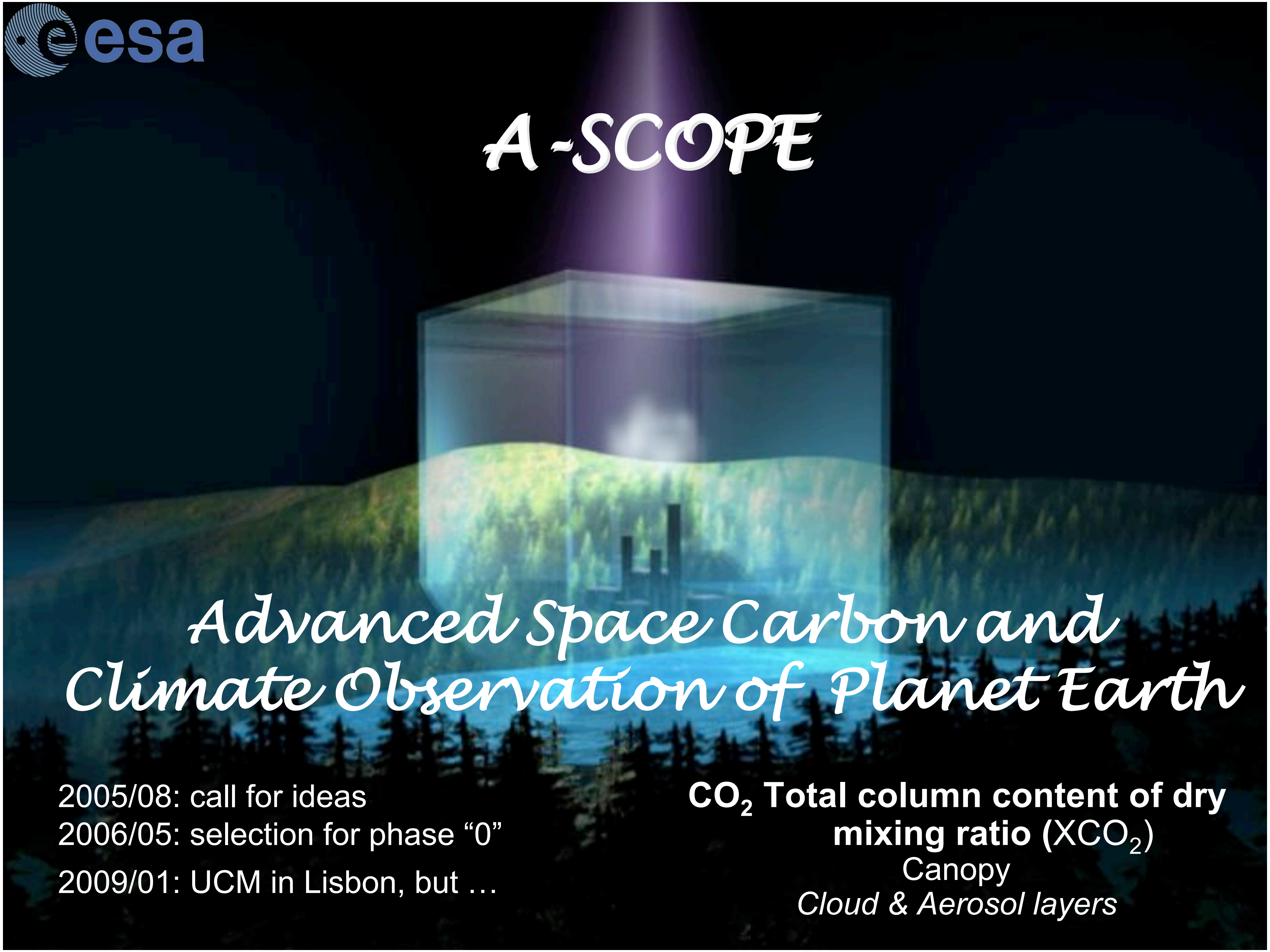
Atmospheric Dynamic Mission (ADM-Aeolus)
2nd Earth Explorer Mission for a launch in 2011
HSR Rayleigh-Mie backscatter lidar at 355 nm with direct detection

4. New story about greenhouse gases and atmospheric CO_2

starting in 2003

Since 2003 : CO_2

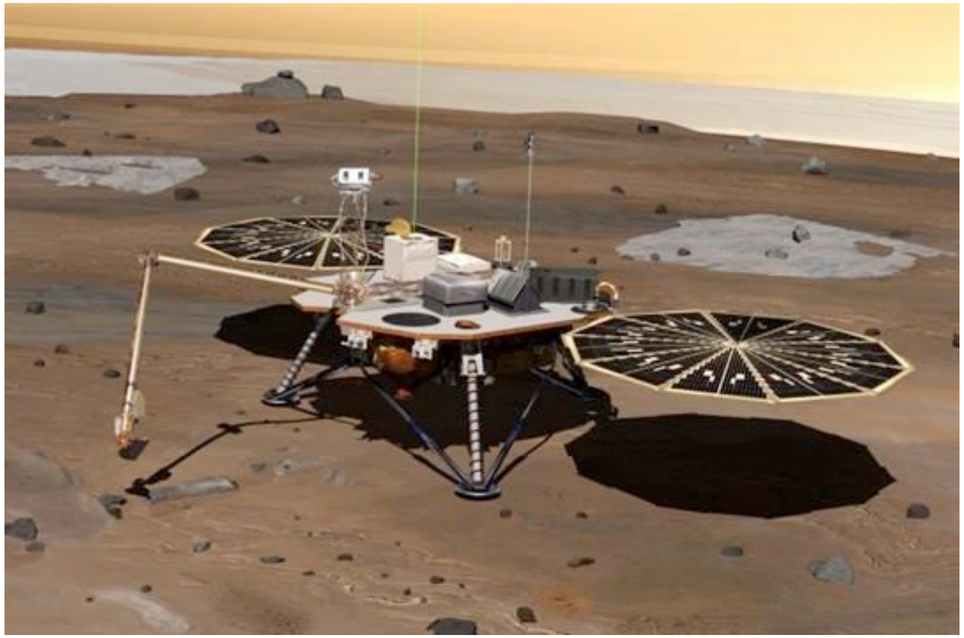


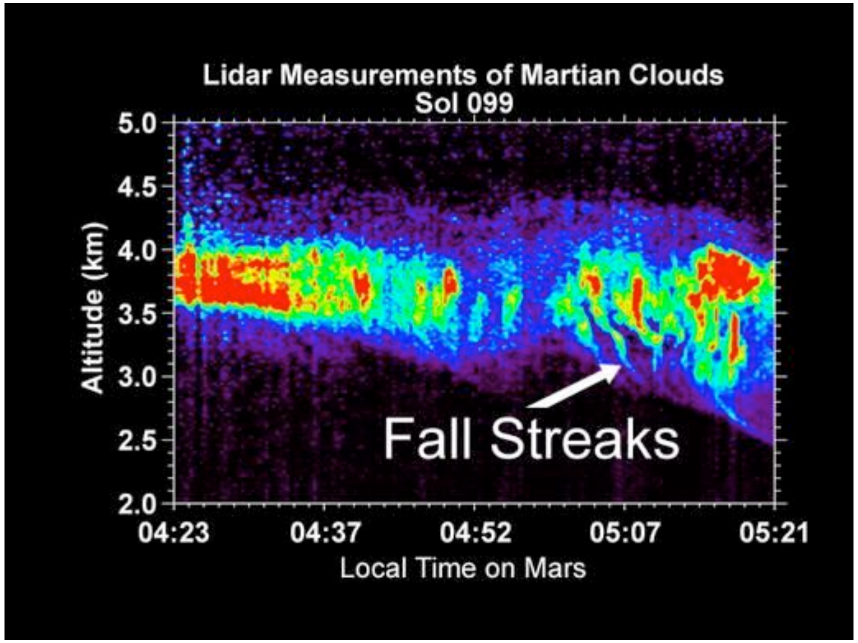

A -SCOPE
Advanced Space Carbon and Climate Observation of Planet Earth
2005/08: call for ideas
2006/05: selection for phase “0”
2009/01: UCM in Lisbon, but …
CO_2 Total column content of dry mixing ratio (XCO_2)
Canopy
Cloud & Aerosol layers

Internal WShop on CO_2 Lidar Remote Sensing

A new Frontier

Go "Mars" or somewhere else





To make a long story short about Space Lidar

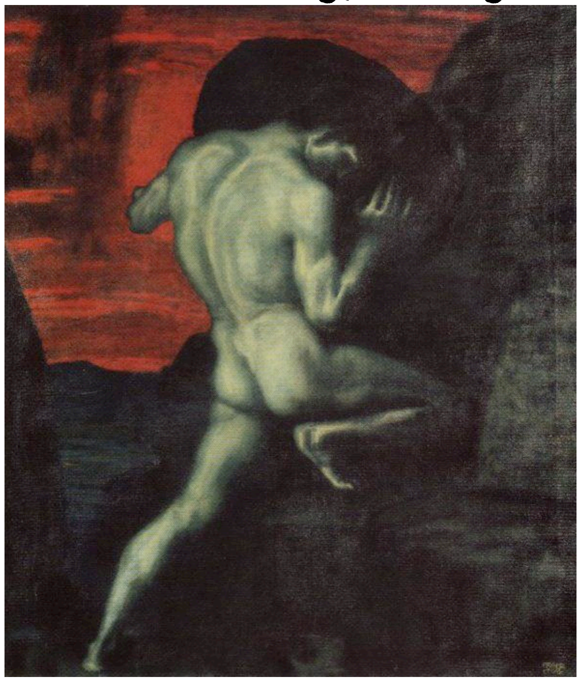
Step 1

Ingenuity
ingenuousness
Great expectations

Please ... let me draw a lidar

Step 2

Hard work (Sisyphus myth)



a few

Step 3-A

Heaven !!!

MAJORITY

Step 3-B

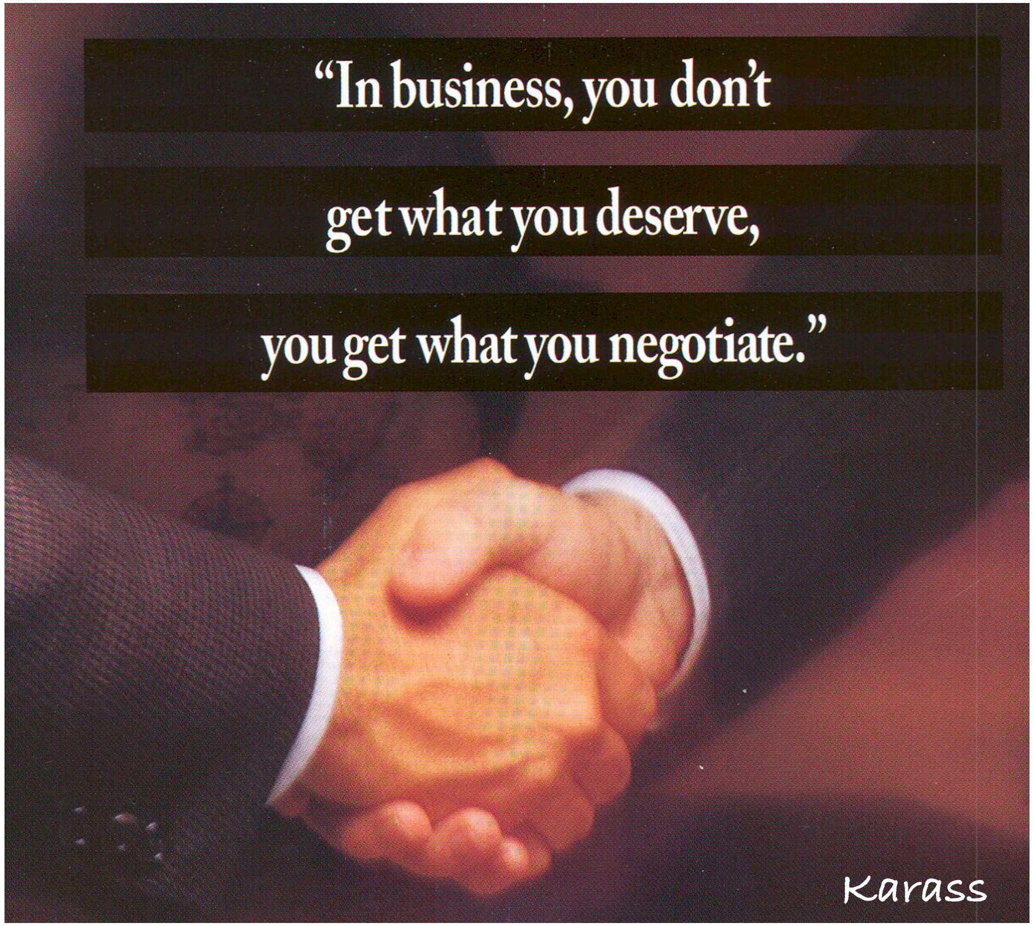
Bitterness and frustration

"The Tartar Steppe" syndrome

A novel by Dino Buzzatti

A pan-European group of officers, stationed at an outpost as they await in vain an enemy that may not even exist. And on the D day when a dust cloud appears at horizon their time is over and they leave the citadel for ever ...

By way of Conclusion



But, what about space research business ?

Happy Present and Bright Future

- CALIPSO (NASA/CNES) since 2006
- ADM-Aeolus (ESA) for a launch in 2011
- Earth-CARE (JAXA/ESA) for a launch in 2013-2015
- ICE-Sat II (NASA)

- A-SCOPE / ASCEND. What about a C-Train ?
- ACE (in 2 or 3 steps)

Acknowledgments

A big thank you to **Claude Loth**

and thank you to all **my students** that made my story real and true

The works were supported by **CNES, CNRS + ANR** and **ESA**

Postscriptum

A world without a Lidar! It's the most curious thing I ever saw in all my life!

In 2005, at the 13 CLRC in Kamagura, Japan I am posing for a picture with my favorite "lidar Star" who sent me on the road of wind lidar!

In memoriam Gérard Mégie

who sent me on the road of lidar for the best of it