Polarized multi-wavelength multiple-field-of-view/imaging Lidar: Experimental results and optical properties retrieval

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Defence R&D Canada – Valcartier
Scientific Literature
DRDC Valcartier SL 2011-565
November 2011

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Polarized multi-wavelength multiple-field-of-view/imaging Lidar: Experimental results and optical properties retrieval

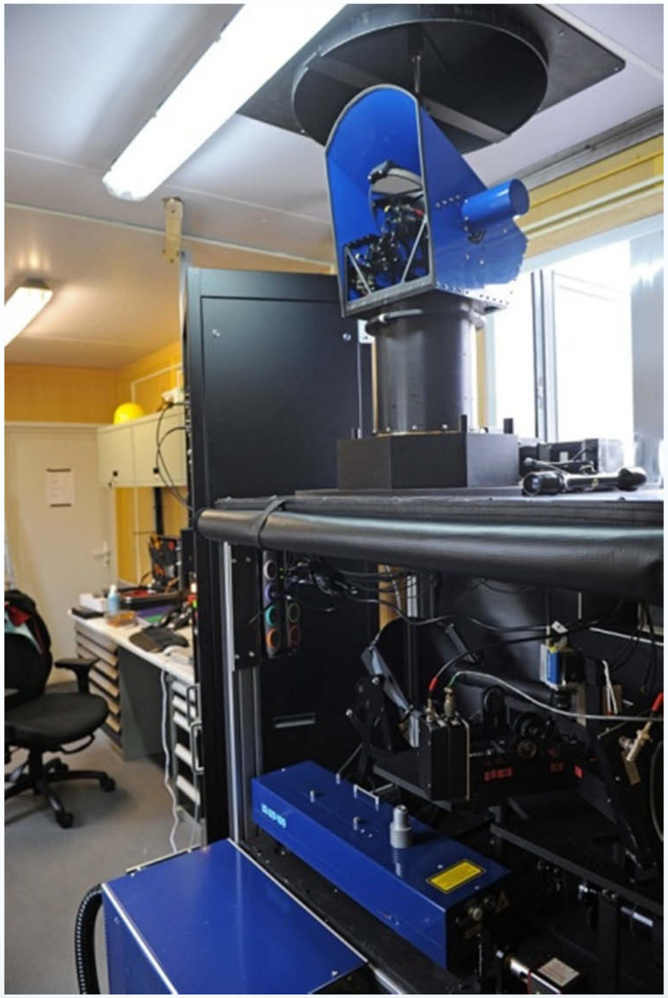
LIDAR Observations of Optical and Physical Properties (LOOPP) Workshop - November 2011

Gilles Roy
George Fournier

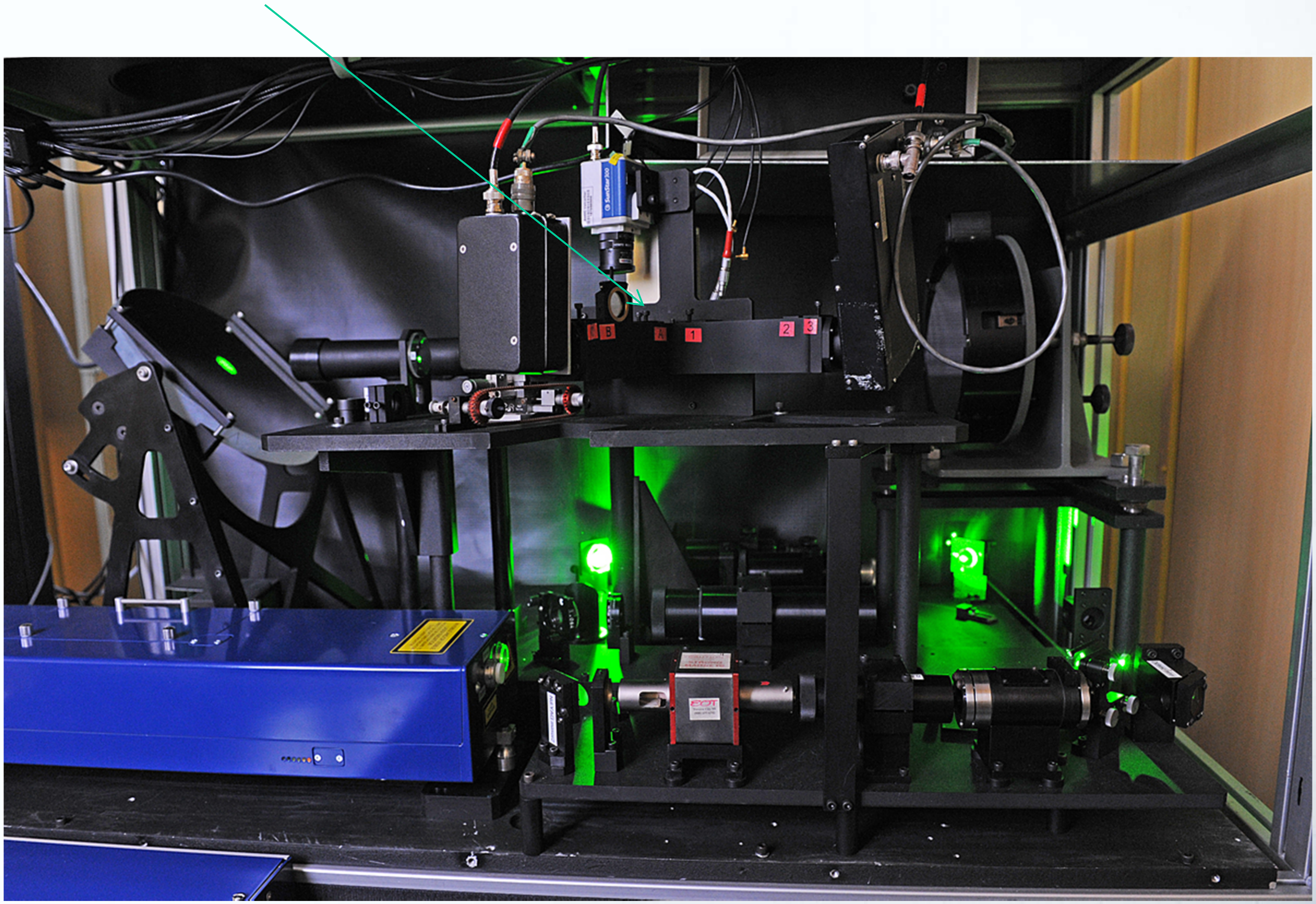
Presentation Plan

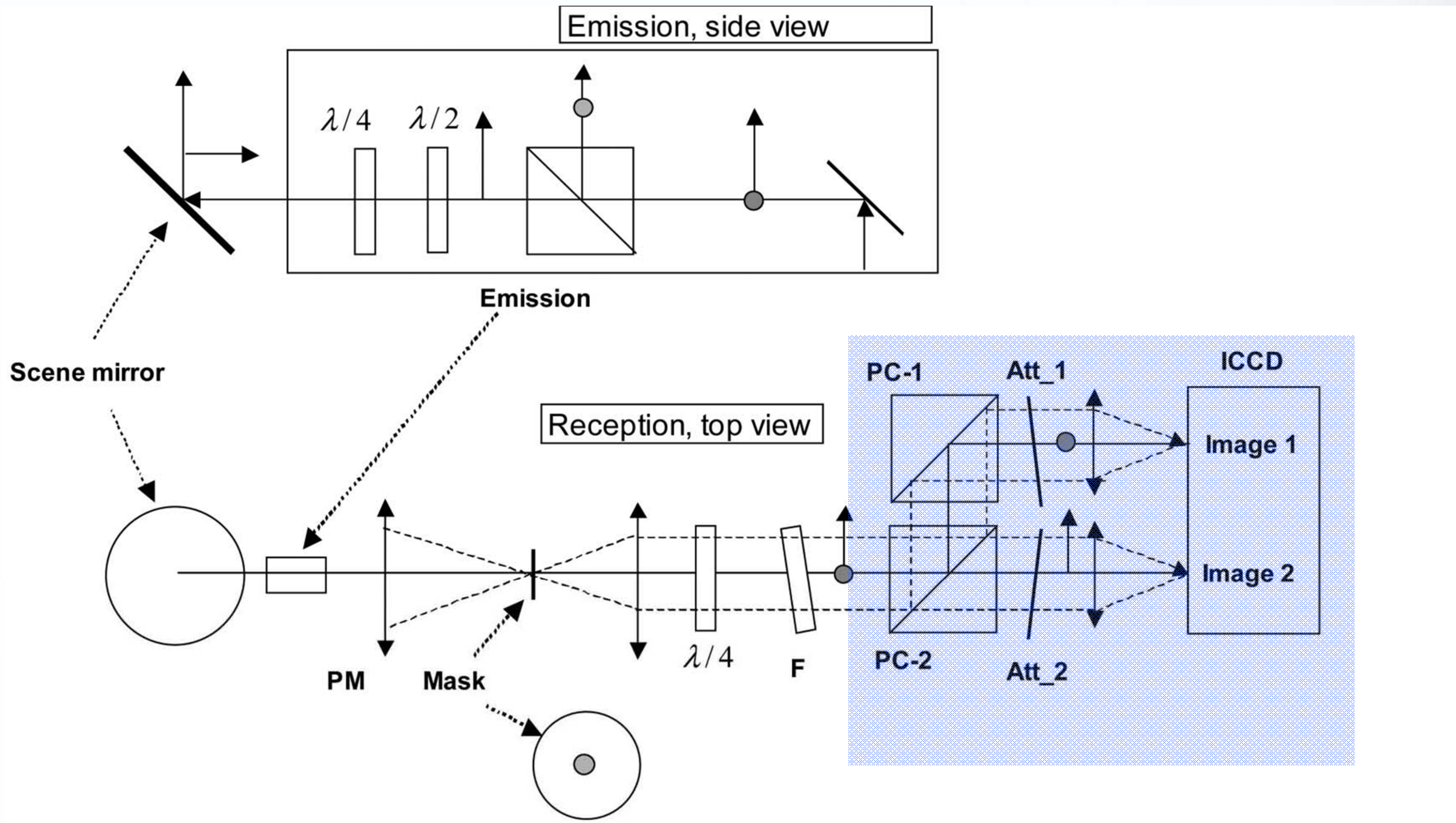
- Modular Hardware Lidar
- Multiple Field-of-view polarimetric lidar and Particles sizing
- Bioaerosol depolarization discrimination
- Adverse weather lidar
- Biofluorescence lidars
- Adaptation to oceanographical studies

Modular Lidar



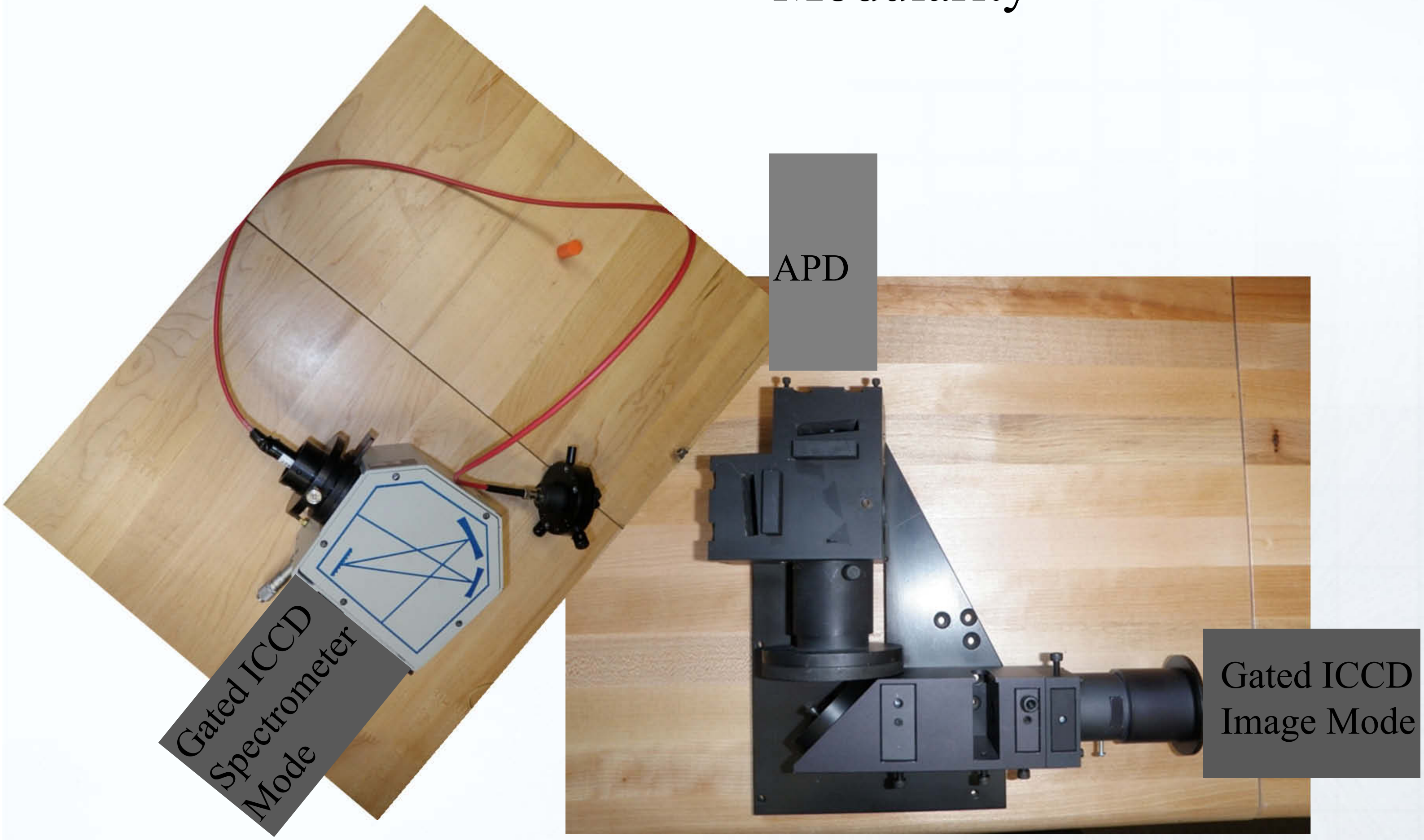
Modular detection modules





PM: 20 cm parabolic mirror; F: 532 nm inteference filter; PC_1 and PC_2: polarization cube beam splitter; Att_1 and Att_2: attenuators

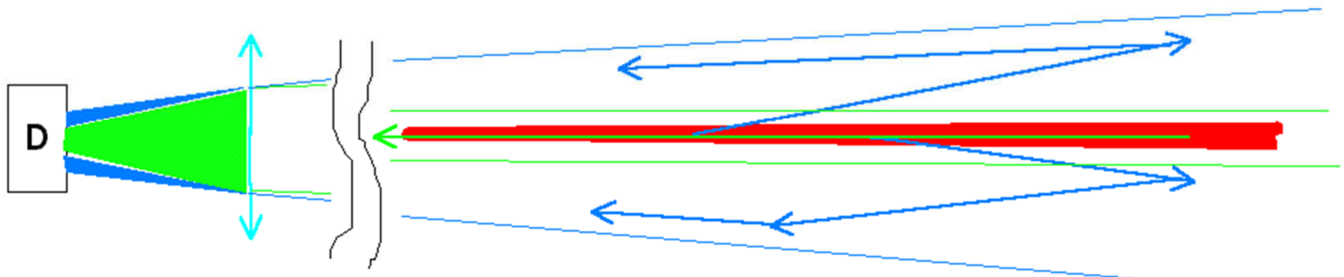
Modularity

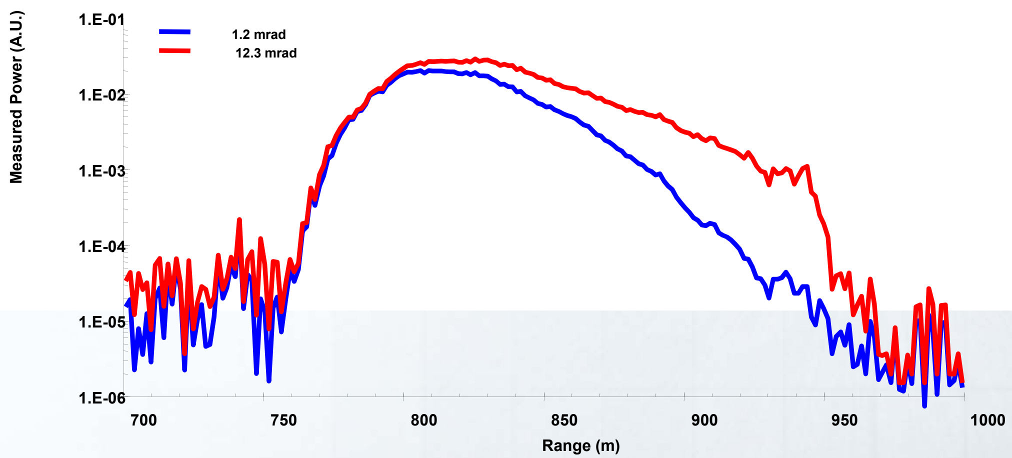


Realizations and proof of concepts

-Particle sizing

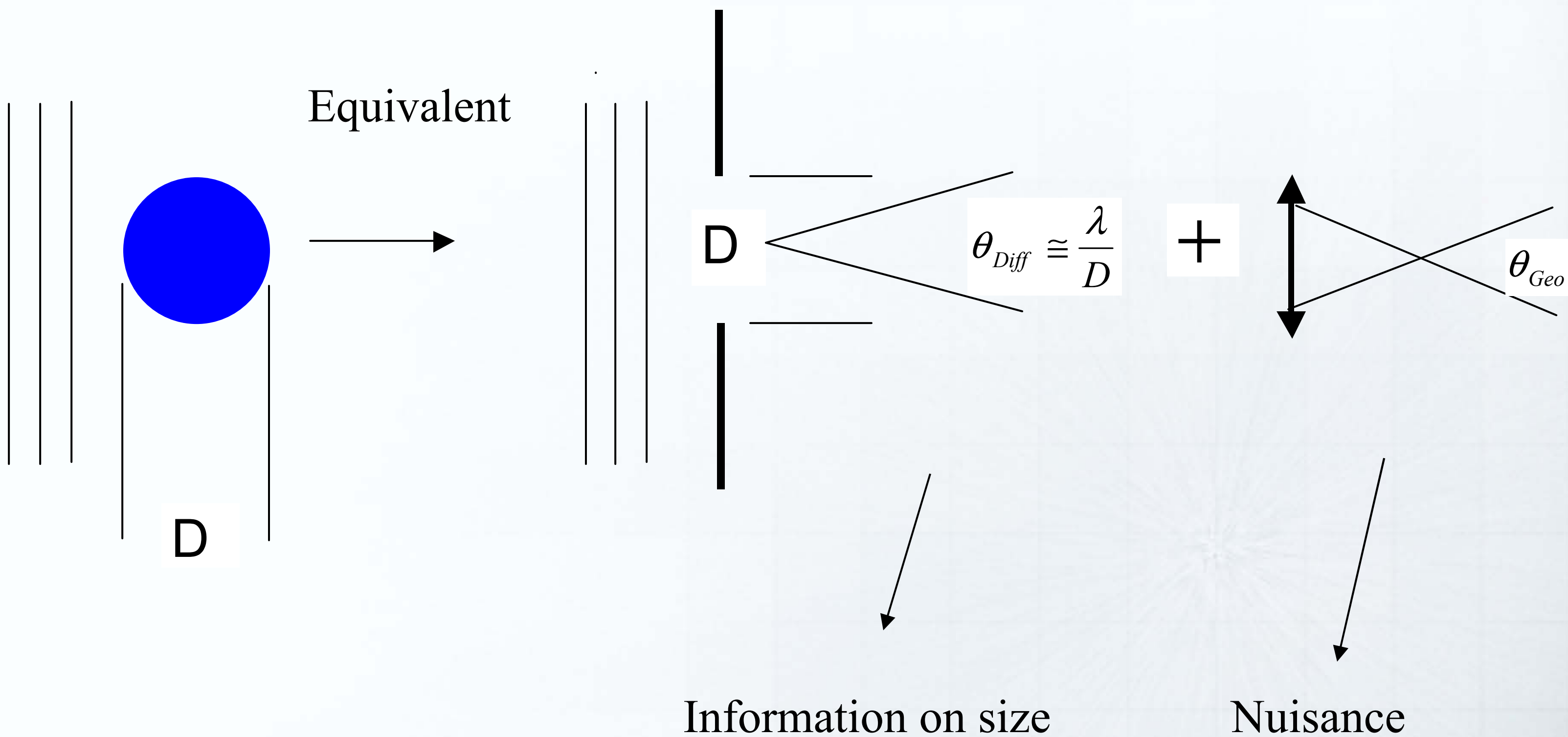
Multi-Field-of-View Lidar principle

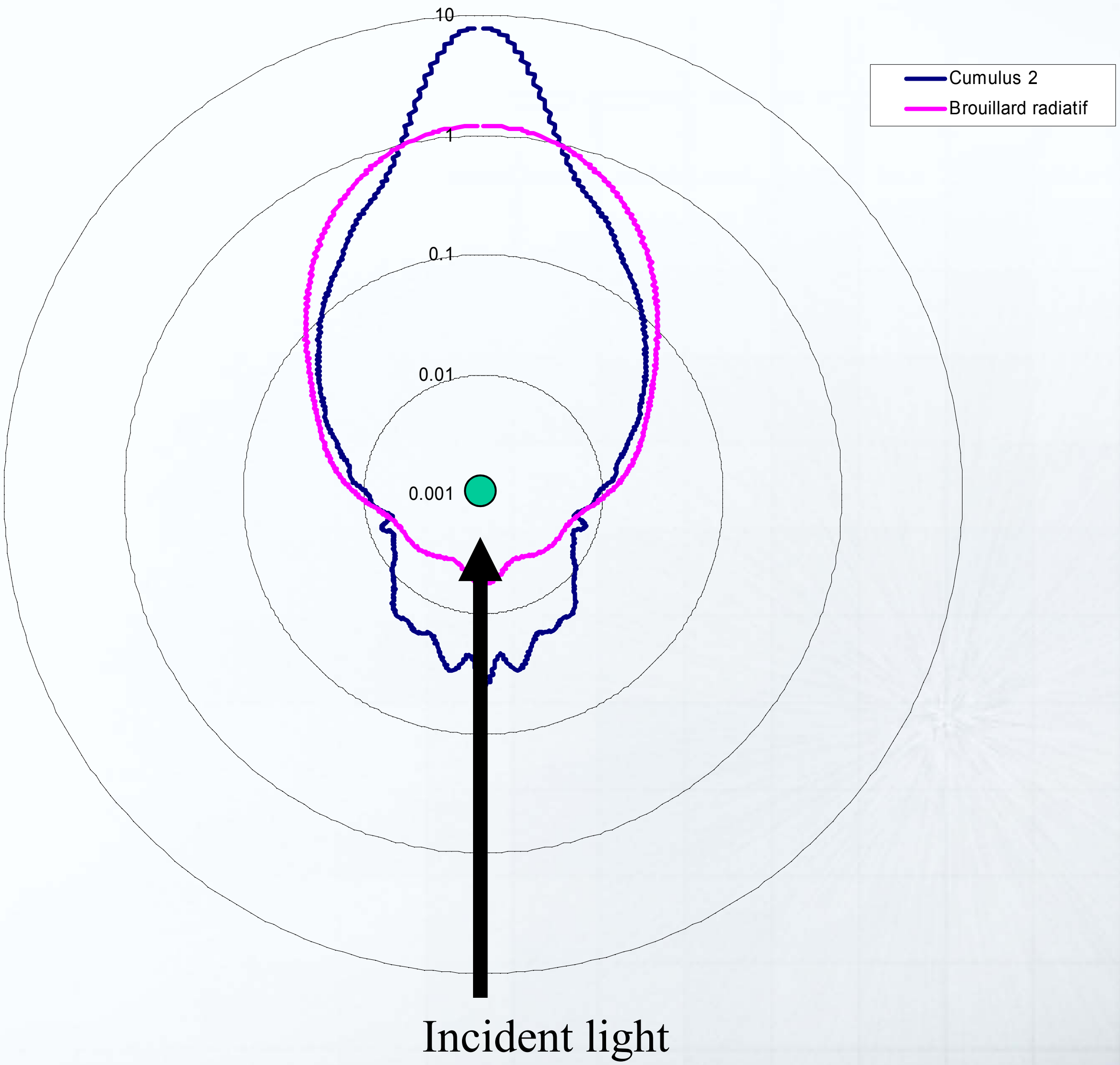




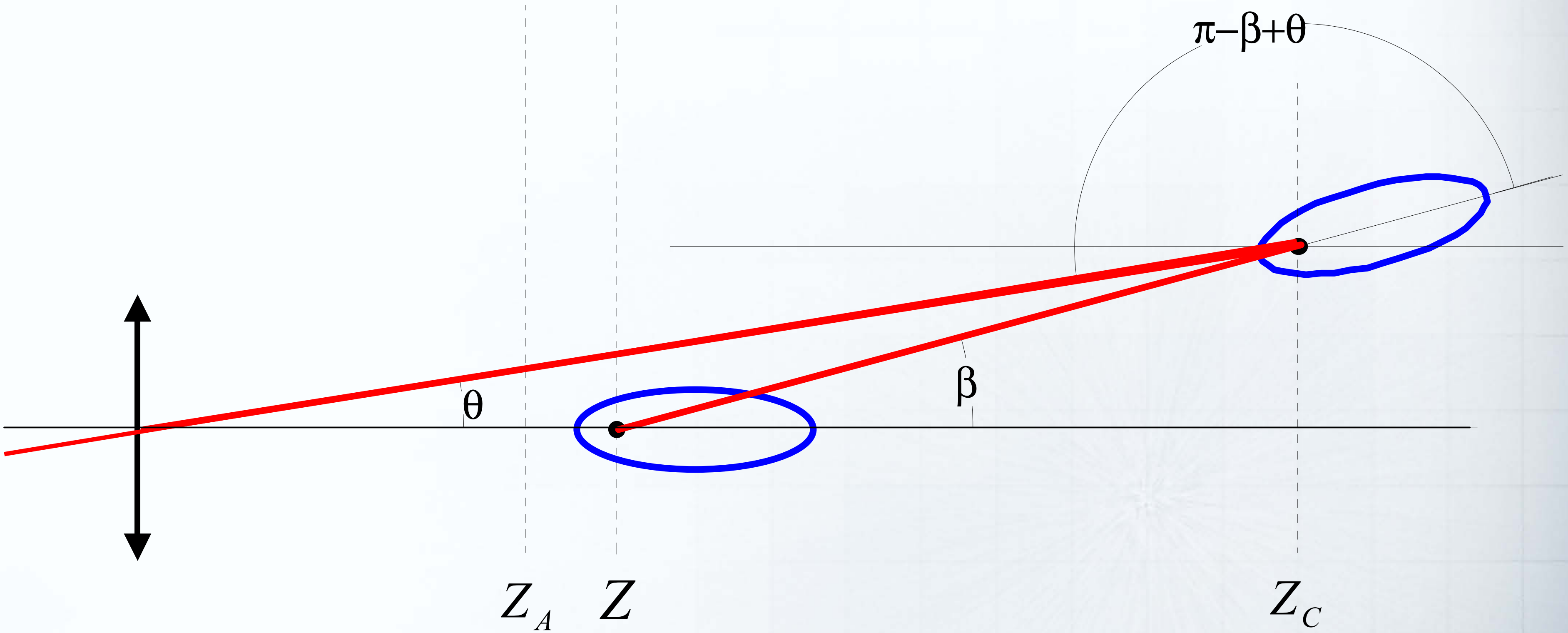
Why is there information on size?

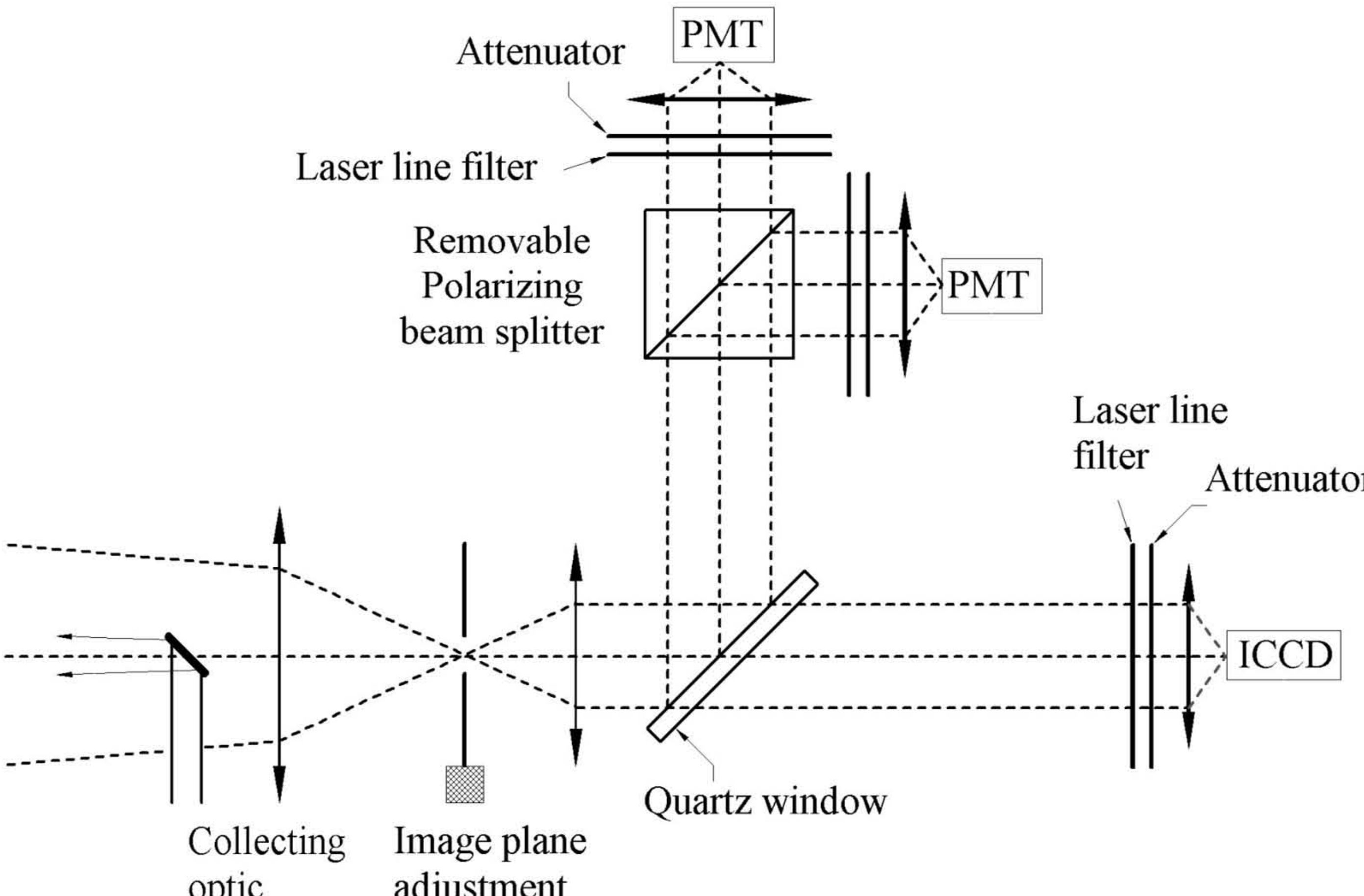
Forward scattering

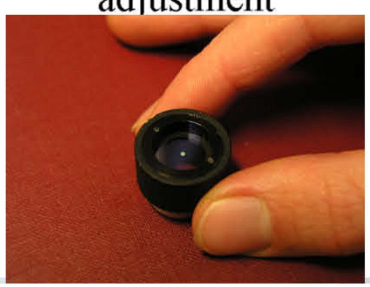


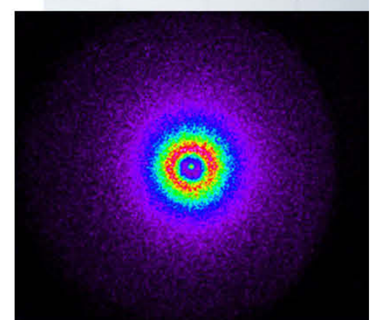

10
1
0.1
0.01
0.001
Cumulus 2
Brouillard radiatif
Incident light

Second Order Scattering Model

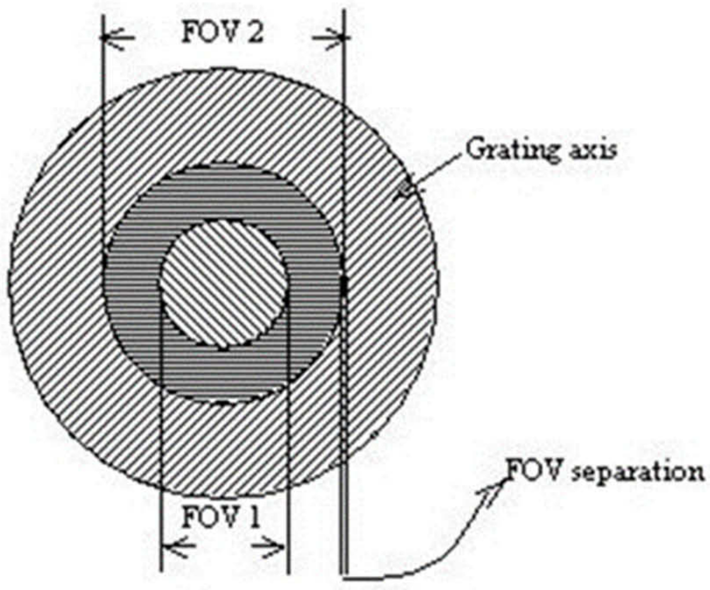



Attenuator
PMT
Laser line filter
Removable
Polarizing
beam splitter
PMT
Laser line
filter
Attenuator
ICCD
Quartz window
Collecting
optic
Image plane
adjustment

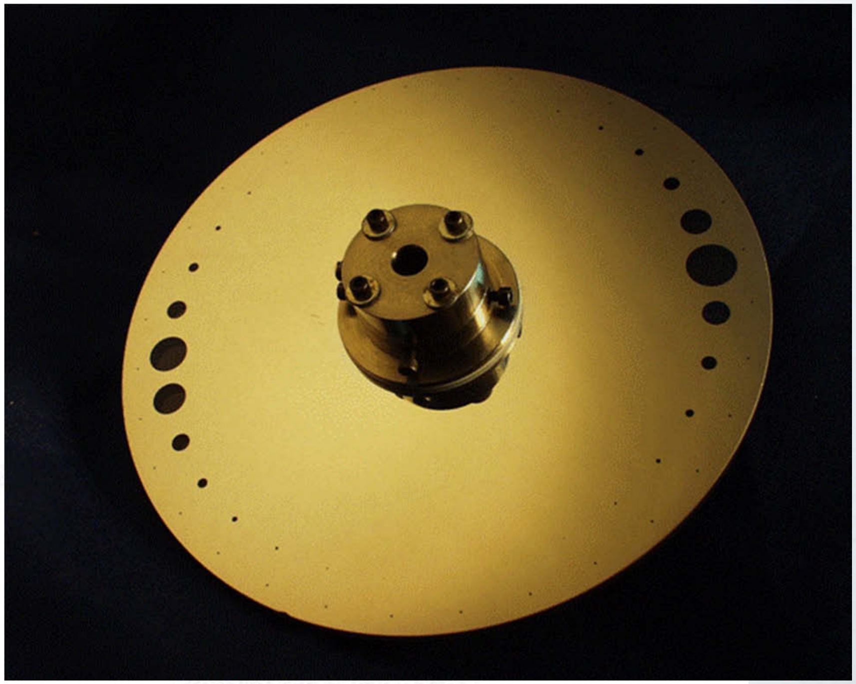




Two design concepts: sequentials and HOE



a) Front view of HOE



Sequential

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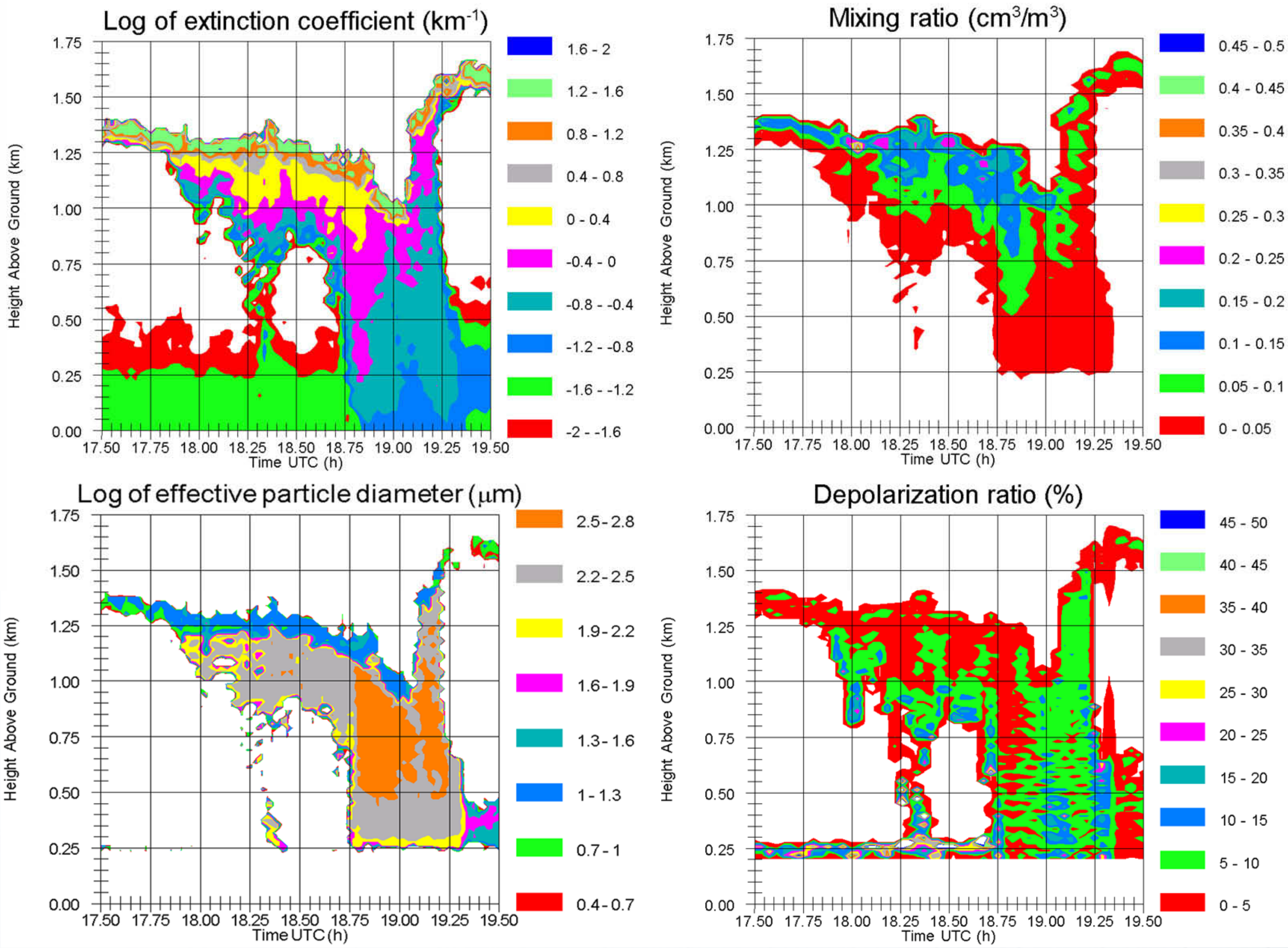
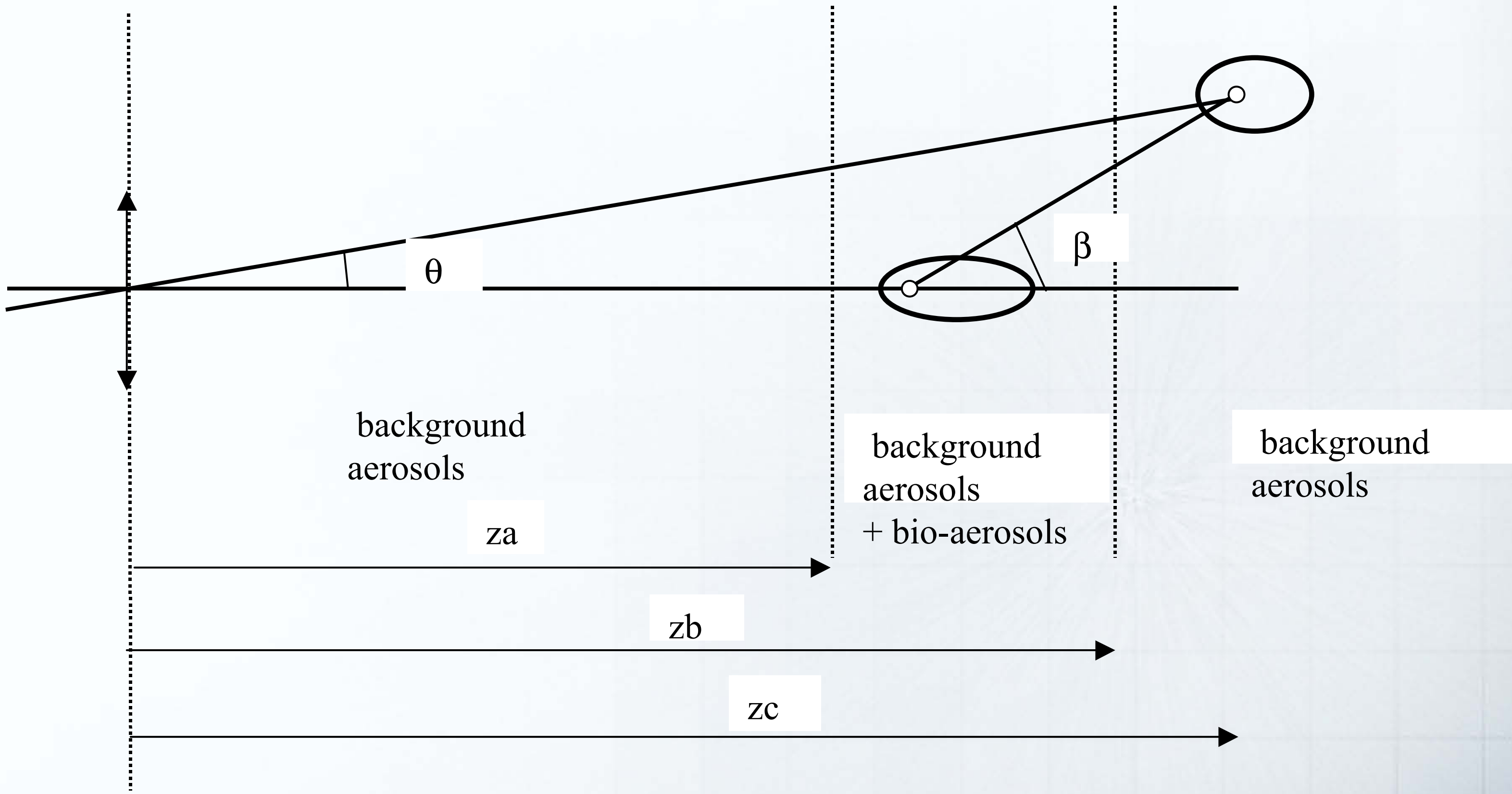
MFOV Lidar - Retrieved Cloud & Precipitation Parameters
10 December 2003

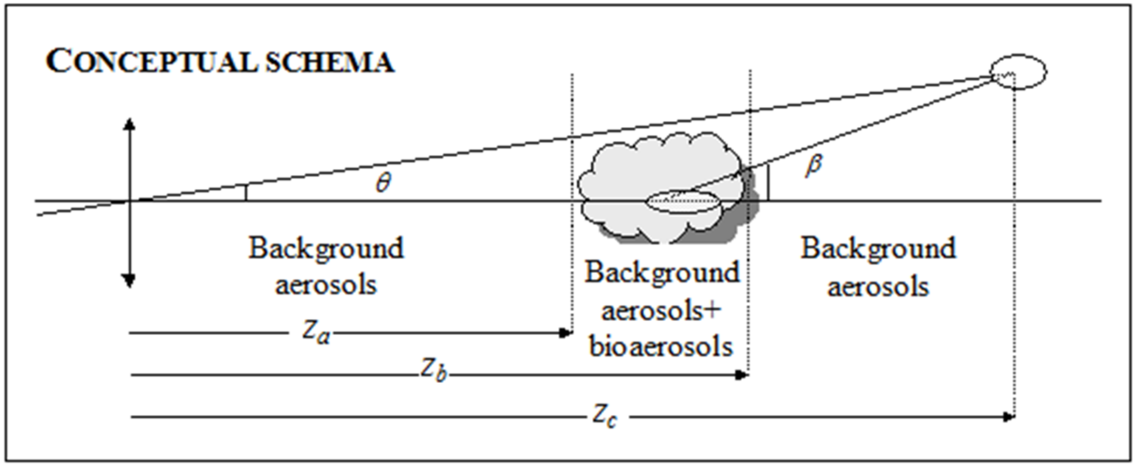


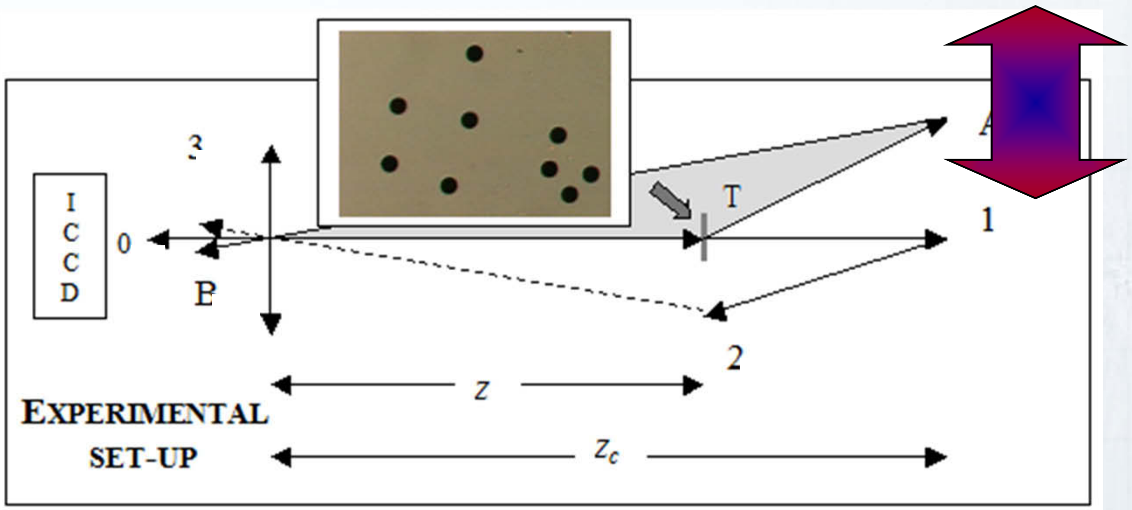
Bioaerosols

Determination of size and concentration of very thin aerosol layer

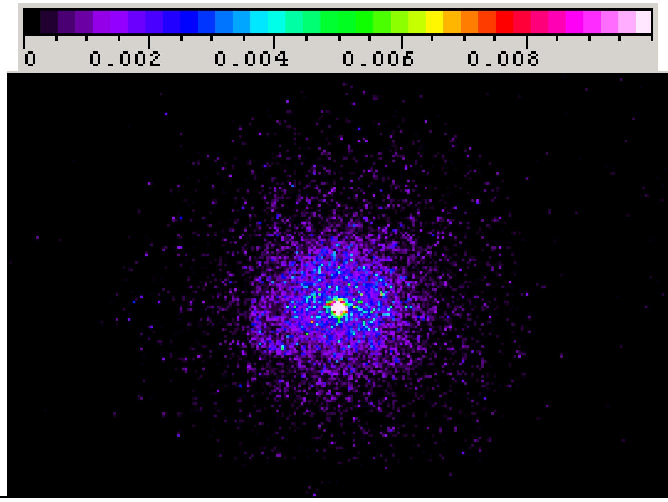


Experimental validation

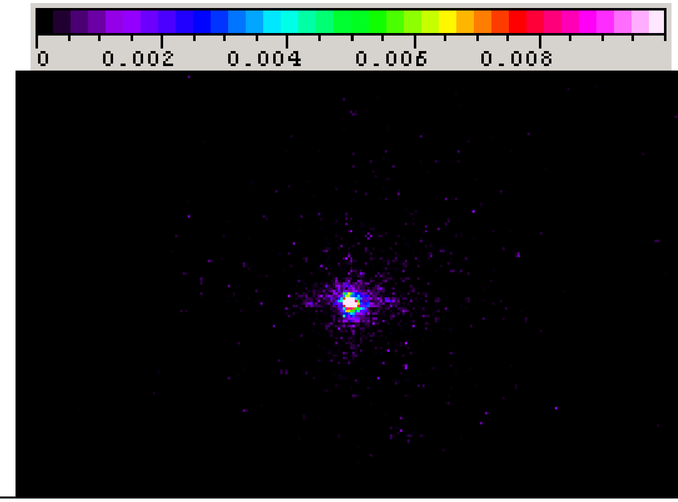




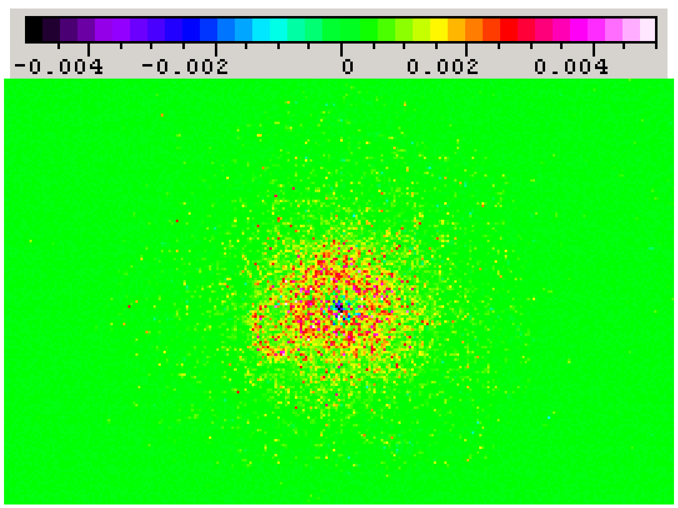
$$\frac{P_D\left(z_c,\theta_{i+1}-\theta_i,\alpha_b>0\right)}{P_s\left(z_c,\theta_s,\alpha_b>0\right)}$$

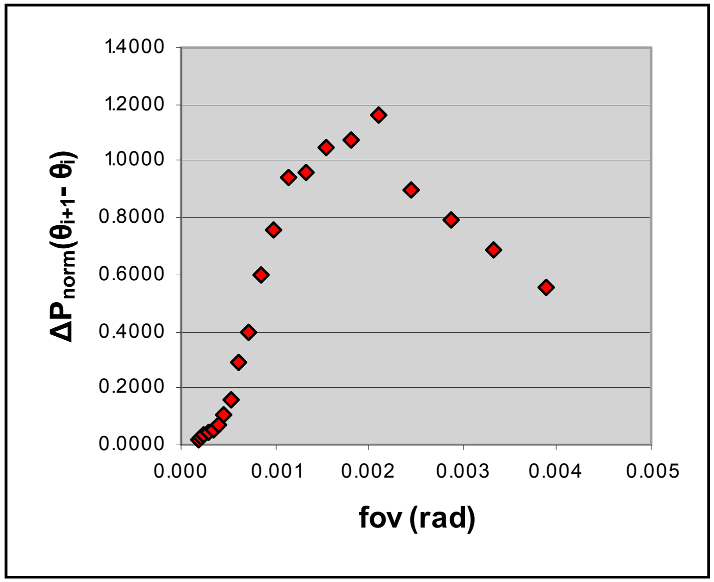


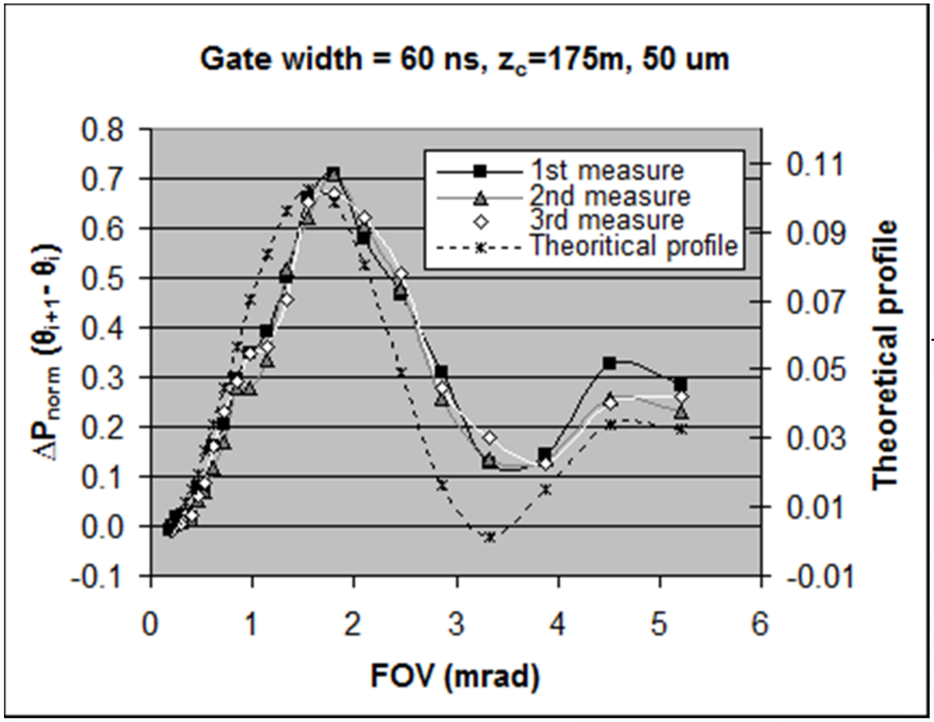
$$\frac{P_D\left(z_c,\theta_{i+1}-\theta_i,\alpha_b=0\right)}{P_s\left(z_c,\theta_s,\alpha_b=0\right)}$$



$\Delta P_{norm}(\theta_{i+1}-\theta_i)$







D=46.6µm -6.8%

D= 48.5 µm -3.0%

D= 47.0 µm -6.0%

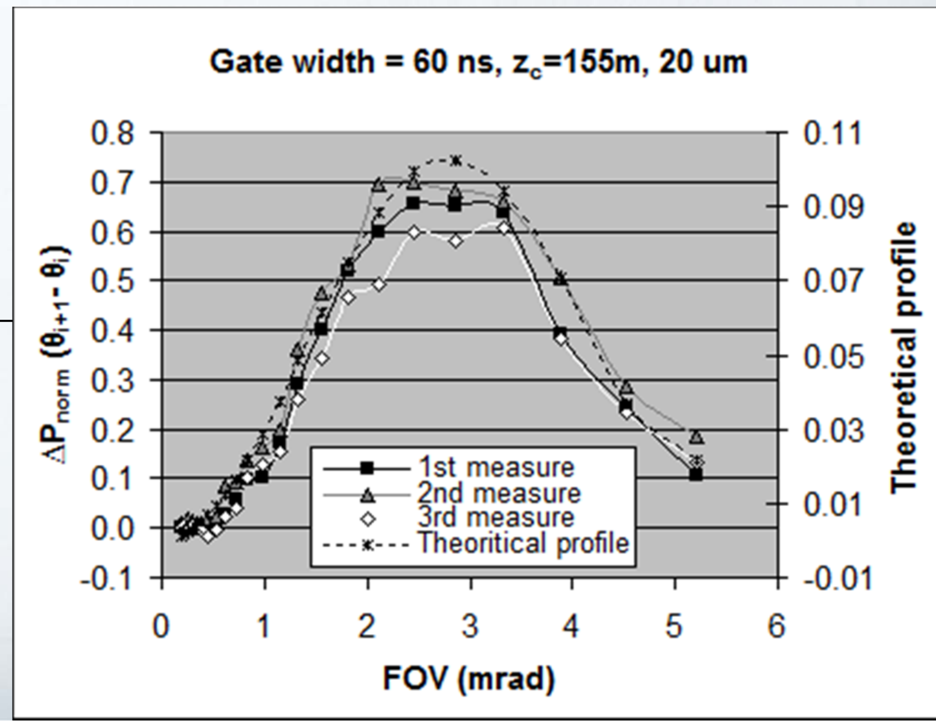
Optical depth: 0.04 +/- 10%

D=21.9 µm +9.3%

D= 21.9 µm +9.7%

D= 23.4 µm +16.8%

Optical depth: 0.04 +/- 10%



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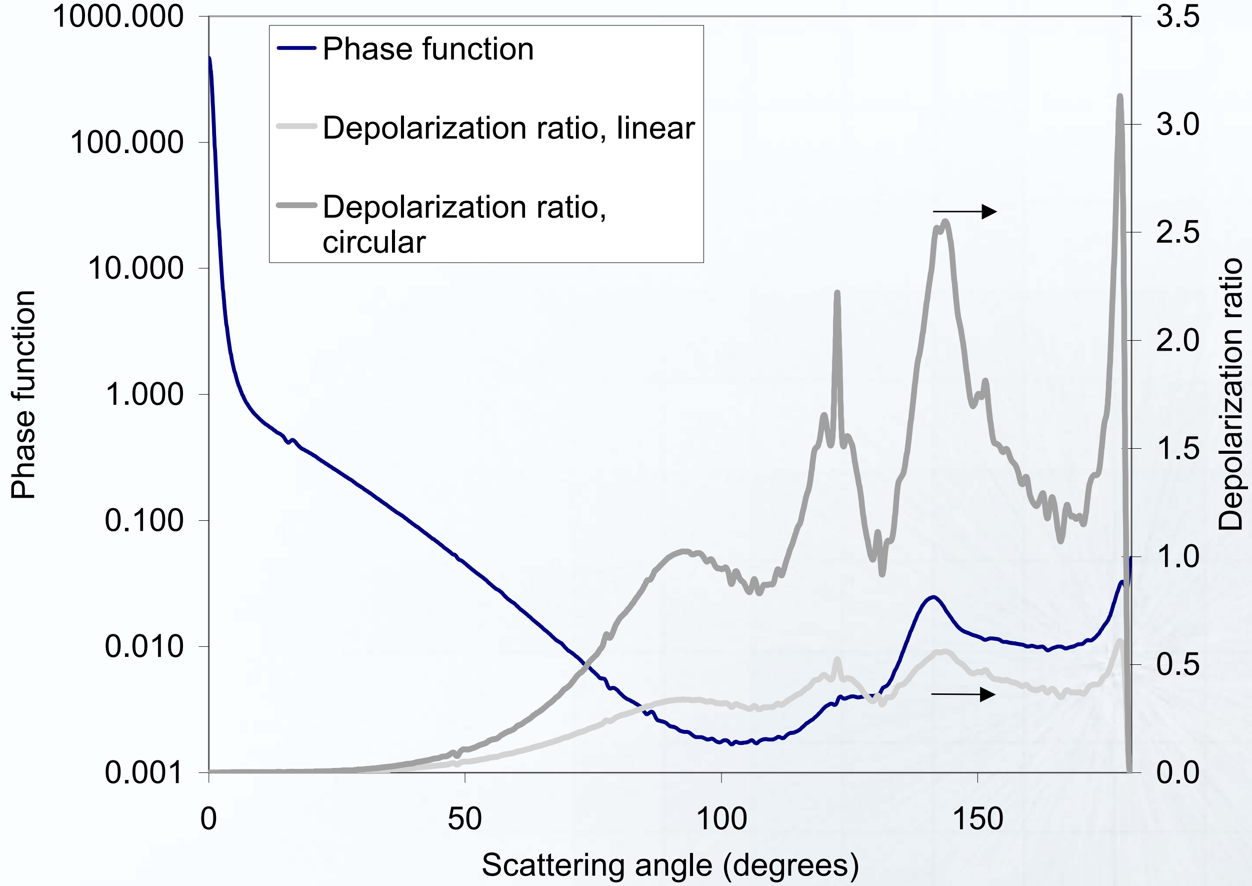
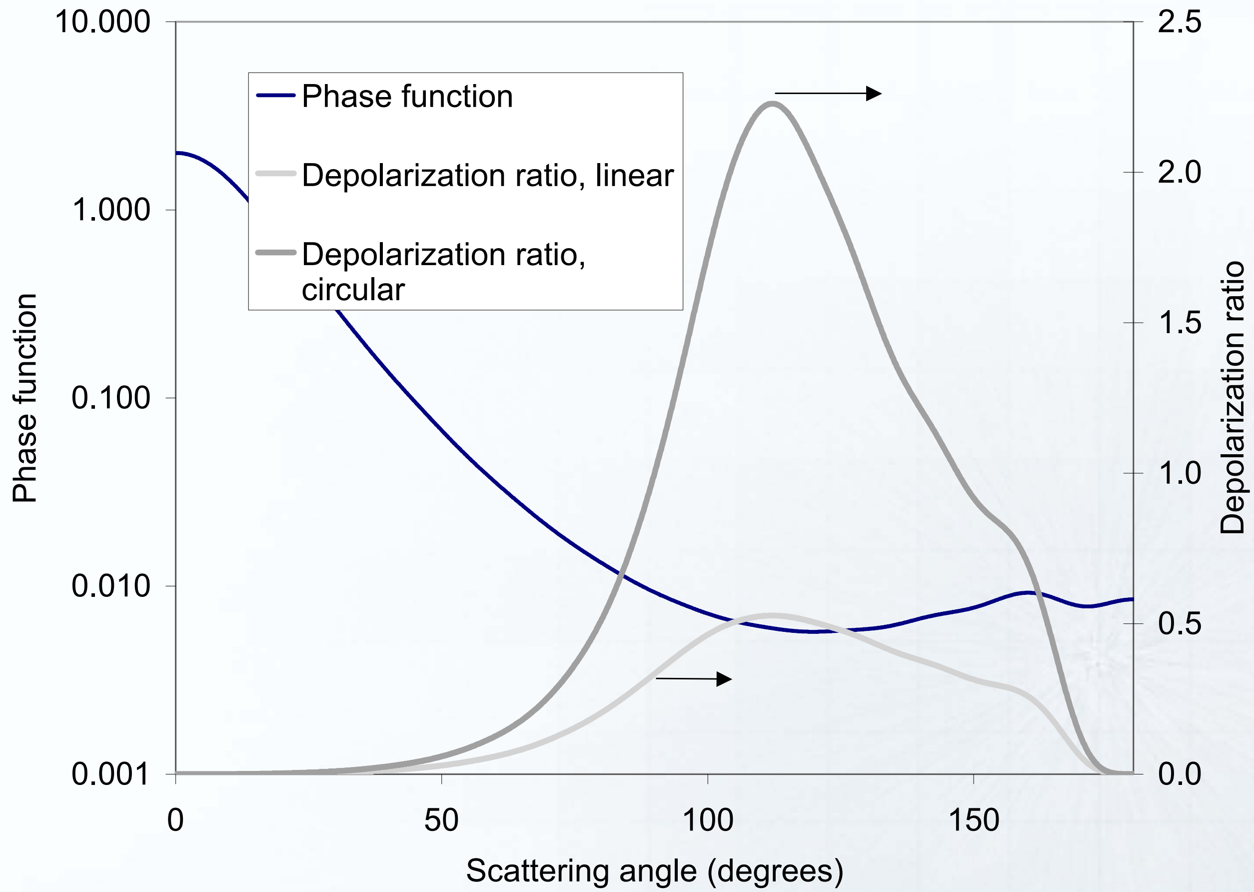
Measure on Pollen

Pollen type	Elm		Timothy	
Measurement technique	**Photo**	**Lidar**	**Photo**	**Lidar**
Mean Diameter (µm)	26.8	29.1	34.3	35.5
Standard deviation (µm)	2.4	1.5	1.5	3.2

Polarization and Multiple scattering


Phase function
Depolarization ratio, linear
Depolarization ratio, circular
1000.000
100.000
10.000
1.000
0.100
0.010
0.001
0
50
100
150
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Phase function
Depolarization ratio
Scattering angle (degrees)


10.000
1.000
0.100
0.010
0.001
Phase function
Phase function
Depolarization ratio, linear
Depolarization ratio, circular
2.5
2.0
1.5
1.0
0.5
0.0
Depolarization ratio
0
50
100
150
Scattering angle (degrees)

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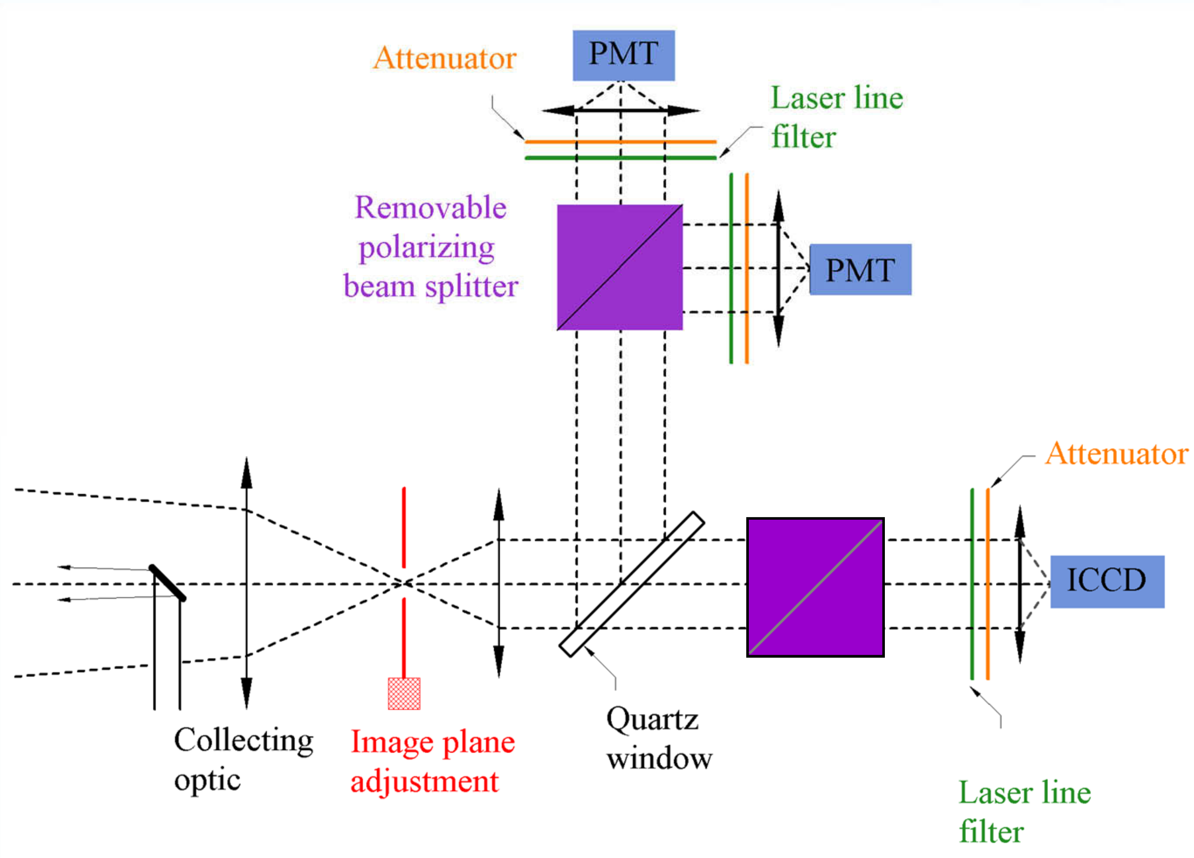
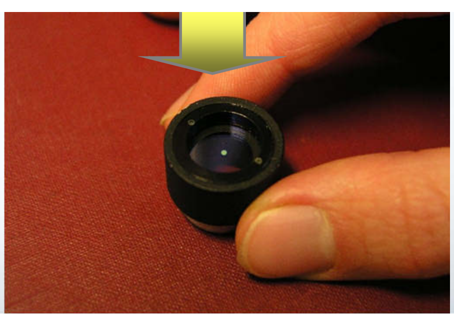
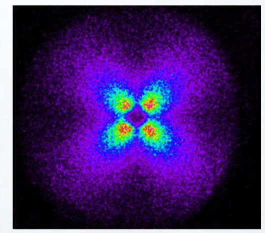
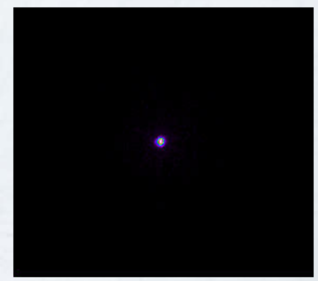
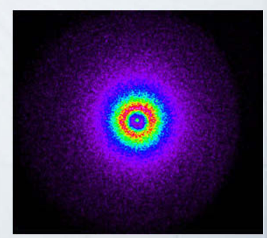
Observation with a gated ICCD





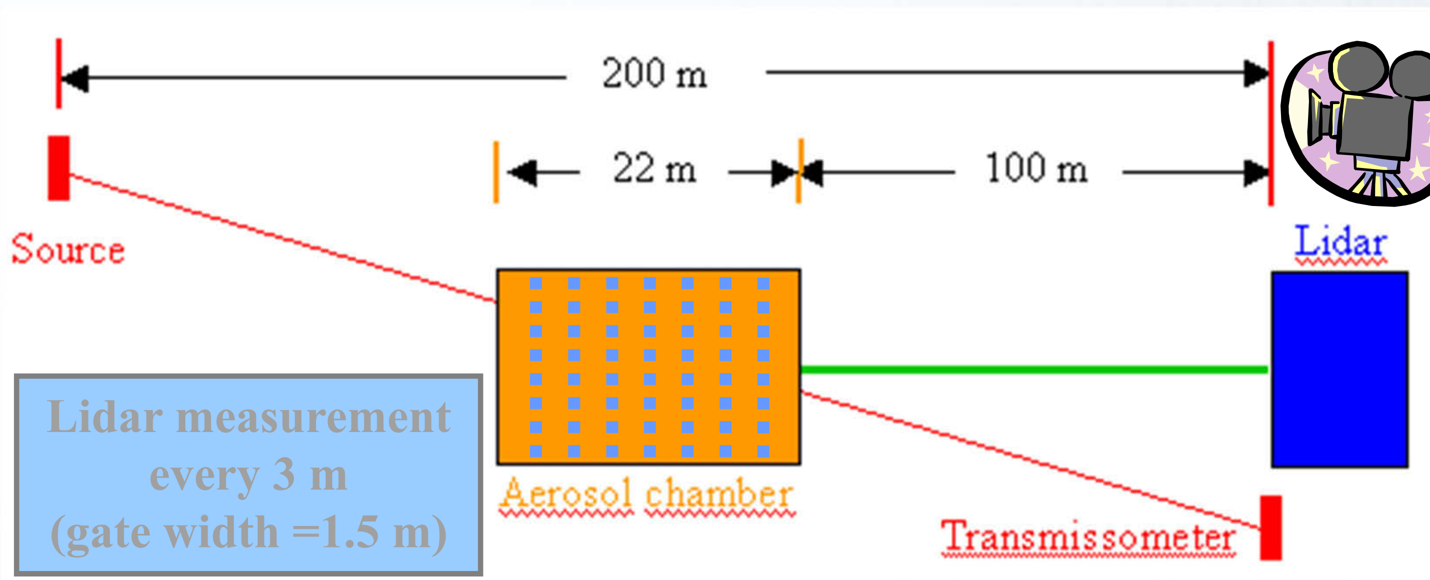




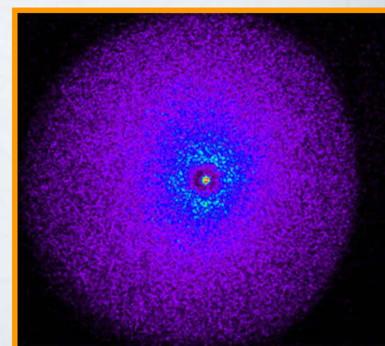


Measurement Method

- 2 dissemination systems used to generate water droplets (6 µm) and oil droplets (0.8 µm)
- Mixing fans operated to ensure a good homogeneity inside the chamber

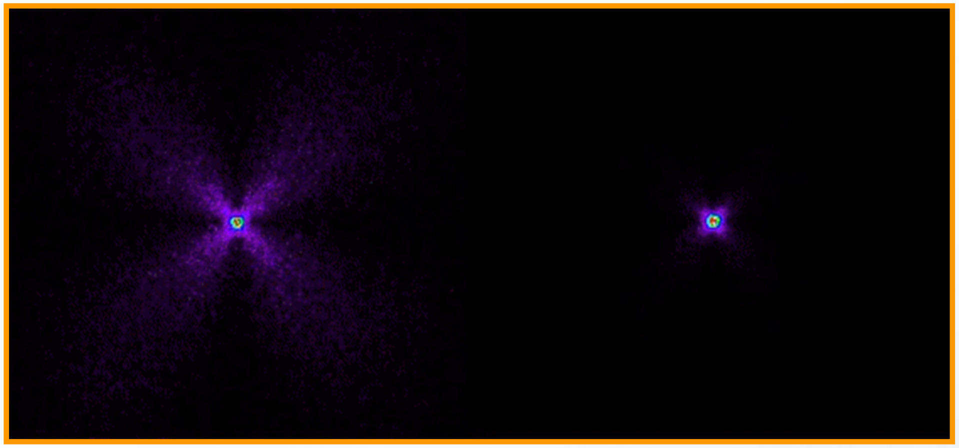


On ICCD

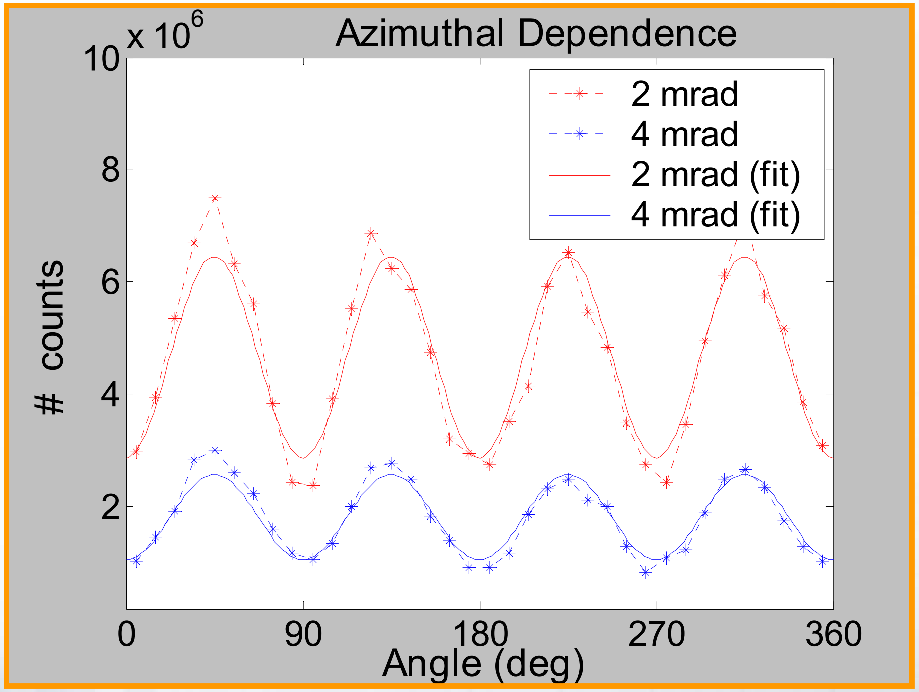


Study of the azimuthal dependence of the cross-polarized returns

Fog oil droplet
(0.8 um)



Water droplet
(6 um)



Fitting curve

$$I = a_z * \cos\ (4\ \phi) + b_z$$

Relation between contrast and optical depth

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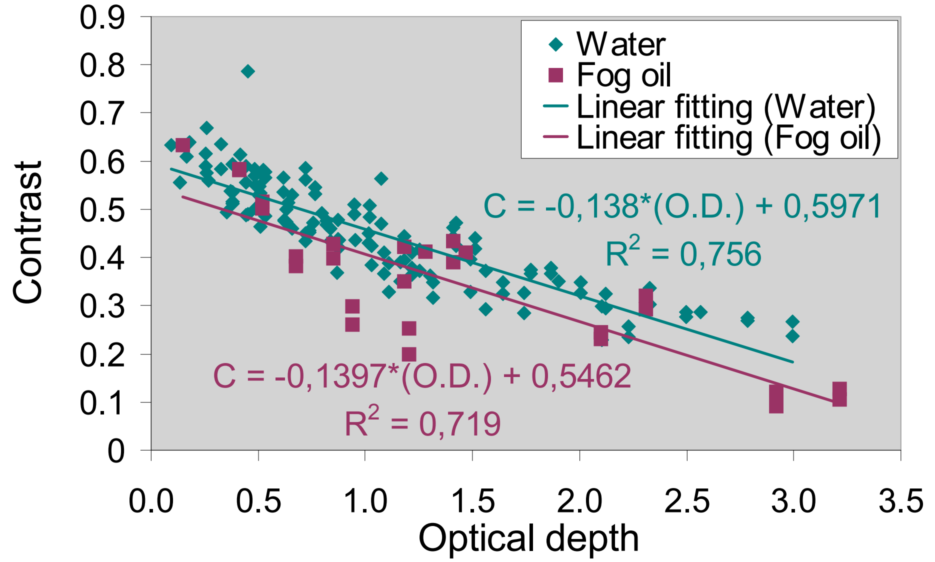


Contrast calculation :

$$C(\theta_z) = \frac{(I_{max} - I_{min})}{(I_{max} + I_{min})} = \frac{-a_z}{b_z}$$

Optical depth calculation :

T = Transmission through the chambrer

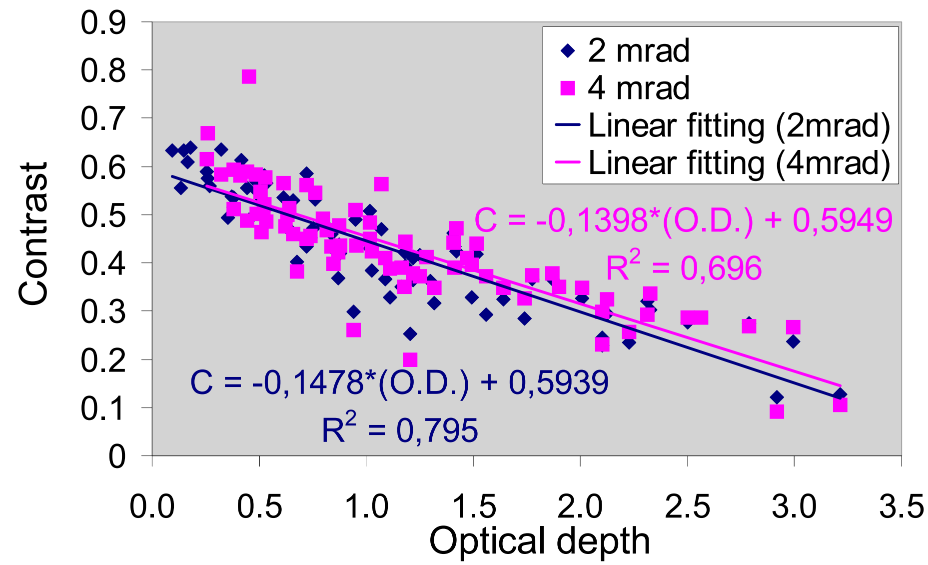
z = Penetration distance

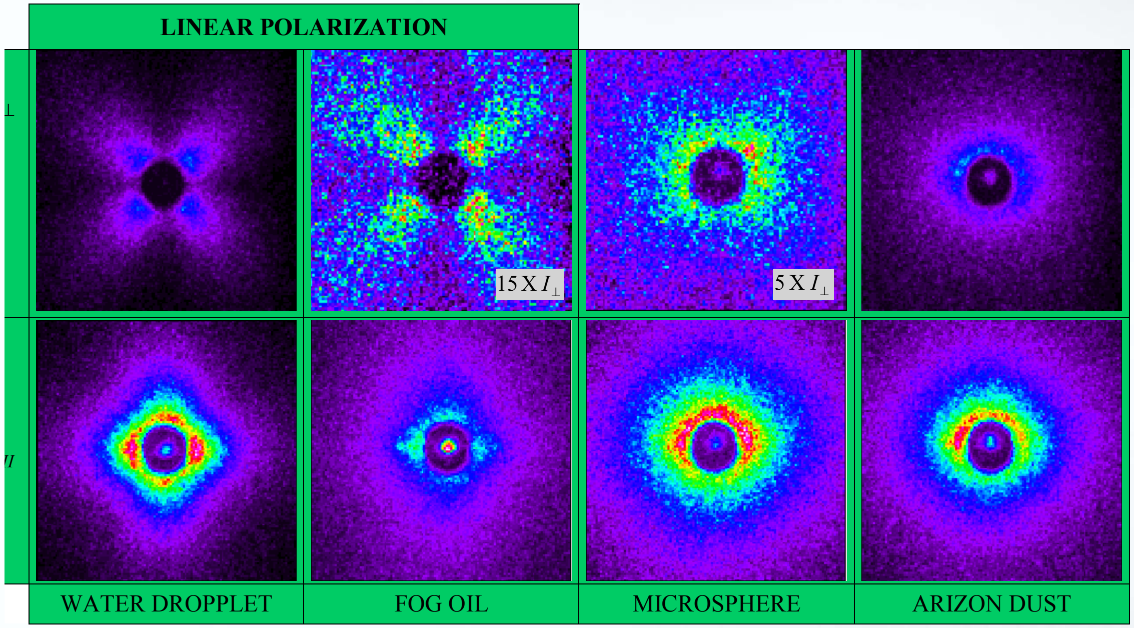
$$O.D._z = \frac{-z}{22} \ln T$$

Contrast decreases quasi-linearly with o.d.

Independent :

- Droplet size
- Fov (2 et 4 mrad)



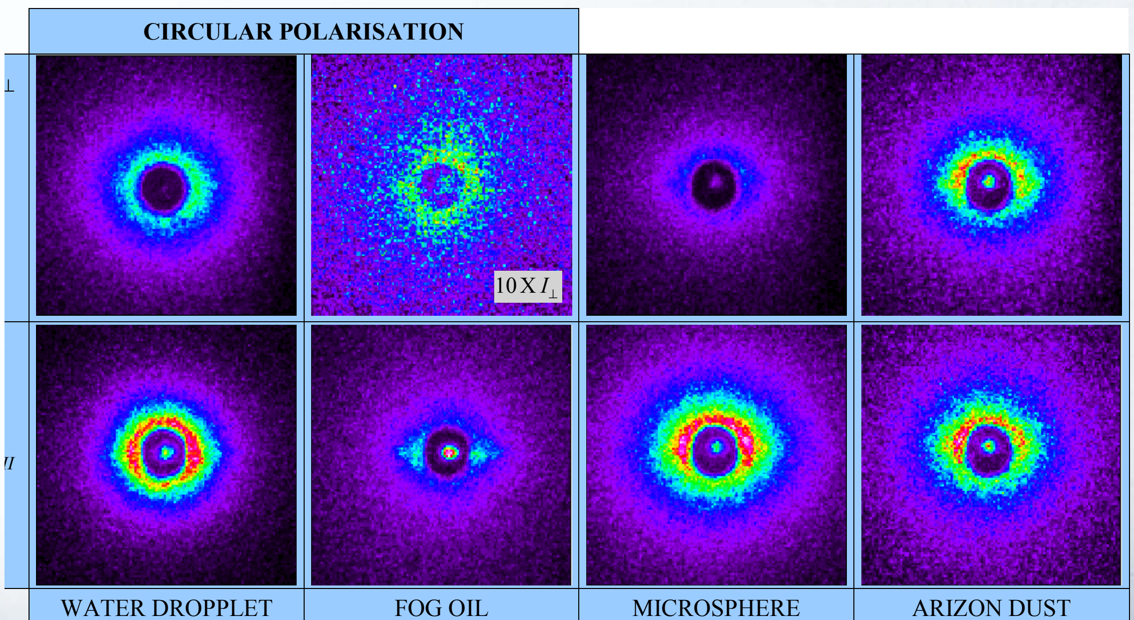


Perpendicular;

Secondary

Parallel;

Principal



Perpendicular;

Parallel

Parallel;

Principal

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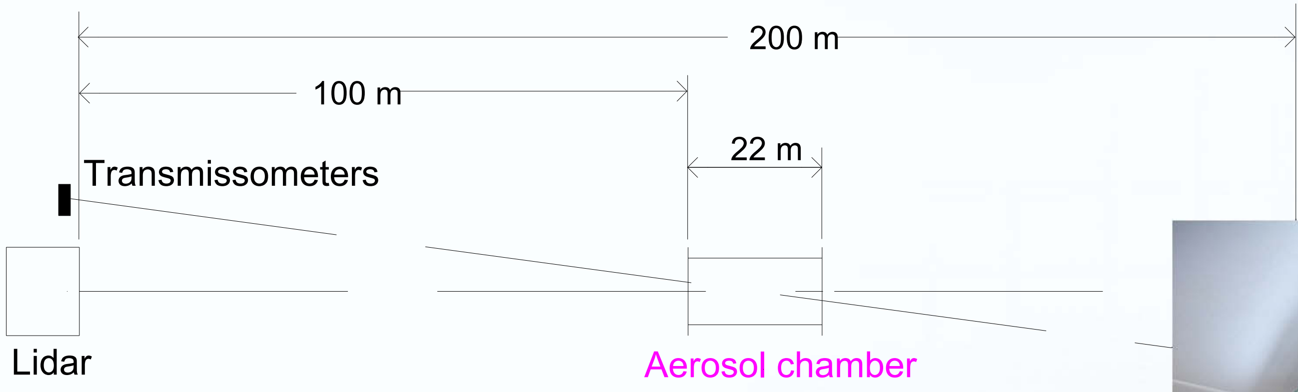
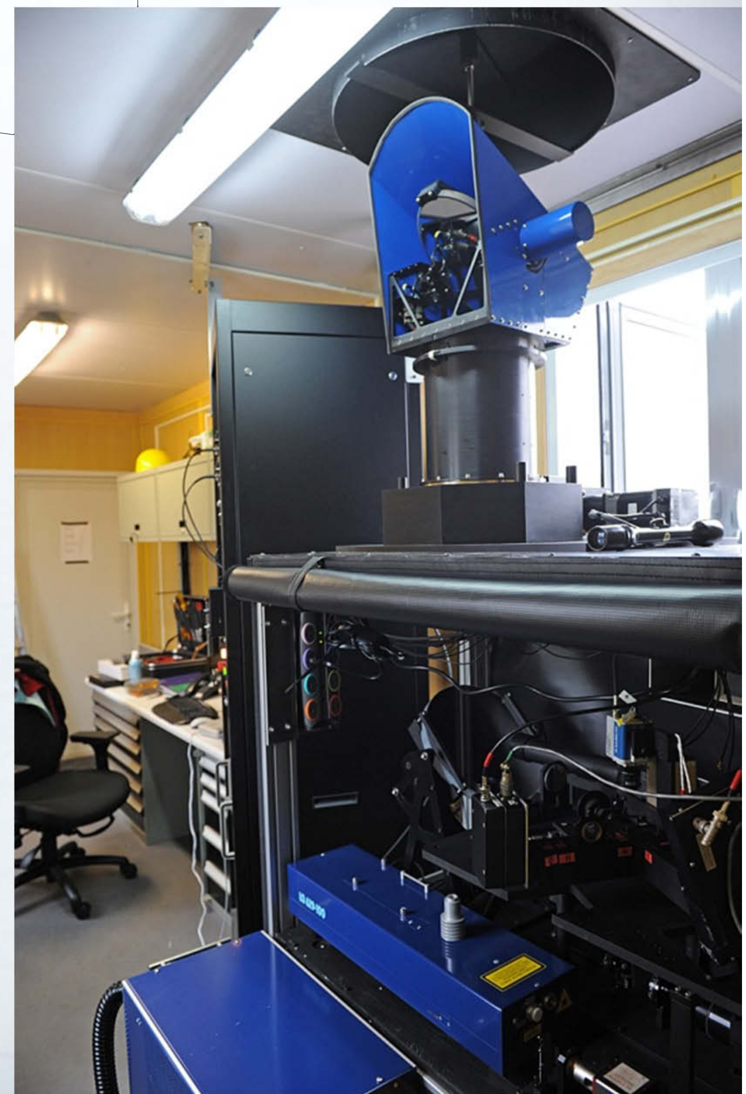
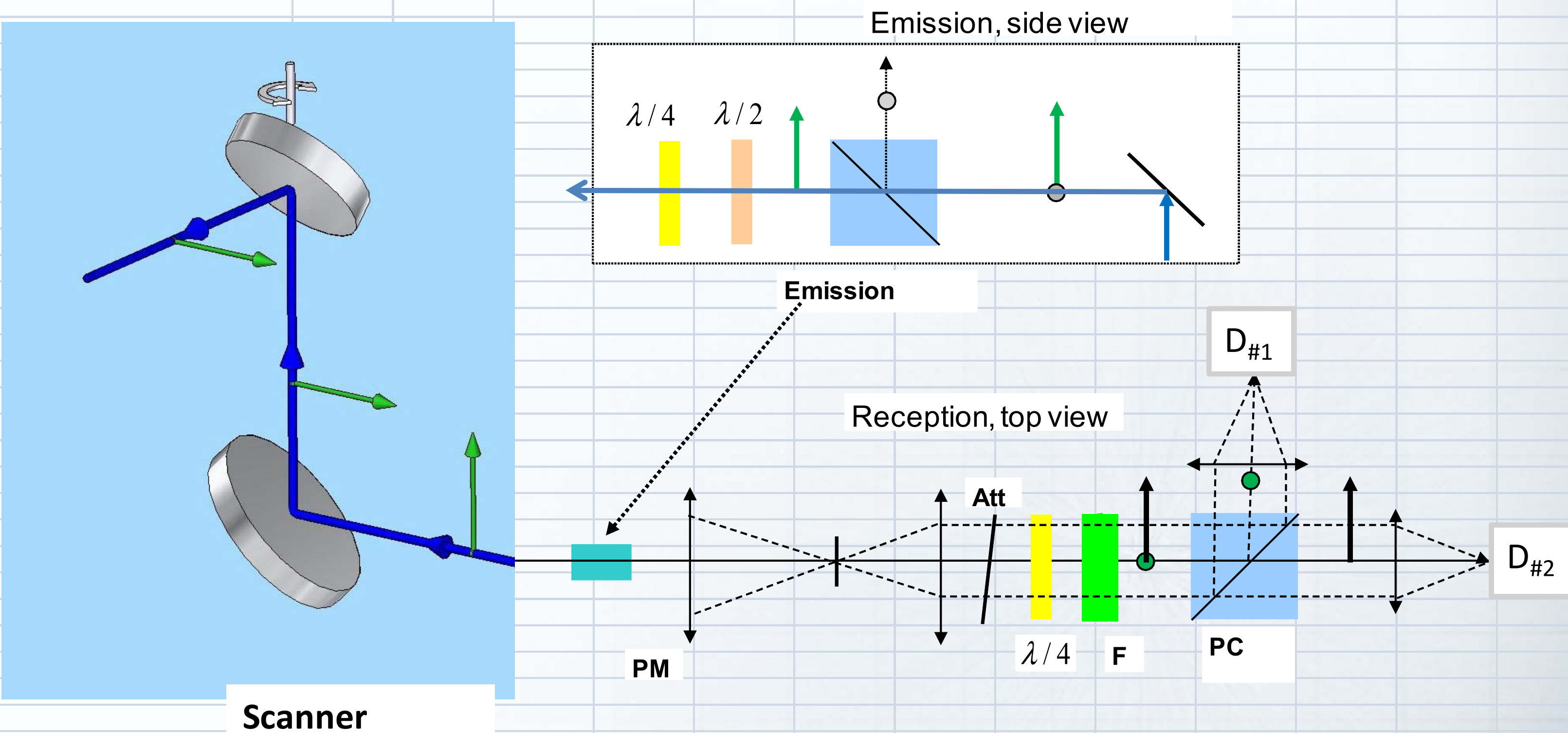
On the information content of linear and circular depolarization signatures of bioaerosols

- Could the information content and discrimination power be increased if circular polarization measurement was added to linear polarization existing measurement?

- Is it worthwhile to develop lidar with full Stokes parameter measurement capabilities for randomly oriented aerosols?


200 m
100 m
22 m
Transmissometers
Lidar
Aerosol chamber





PM: 20 cm parabolic mirror; F: inteference filter; PC: polarization cube beam splitter; Att: attenuator

Materials

Description		Pol. #	Size µm	Description		Pol. #	Size µm
Trees and shrubs	Mulberry, paper	1	8-10	Cultivated. Plants	Alfalfa	14	25-40
	Aspen	2	25-30		Mustard	15	-
	Birch, White	3	30-35	Grain Dusts	Barley	16	8-20
	Oak, White	4	25-30		Corn	17	8-20
	Elm, American	5	20-30		Wheat	18	8-25
	Poplar, White	6	20-30	Smuts	Oat	19	5-7
	Pine, Virginia	7	-		Wheat	20	5-8
Weeds	ragweed, short	8	20		Corn	21	-
	Plantain, English	9	20-25	Fungi	Neurospora intermedia	22	-
	Sagebrush, common	10	-		Penicillium chrysogenum	23	-
	Mugwort, Common	11	15-25	Grasses	Rye, Perennial	24	20-30
Flowers	Sunflower	12	-		Timothy	25	35-40
	Daisy, Ox-Eye	13	24-30	Road Dust	ARD	26	1-10
					AFD	27	1-10
				Glass Beads	GB	28	1-5
				Graphite	GR	29	1-5

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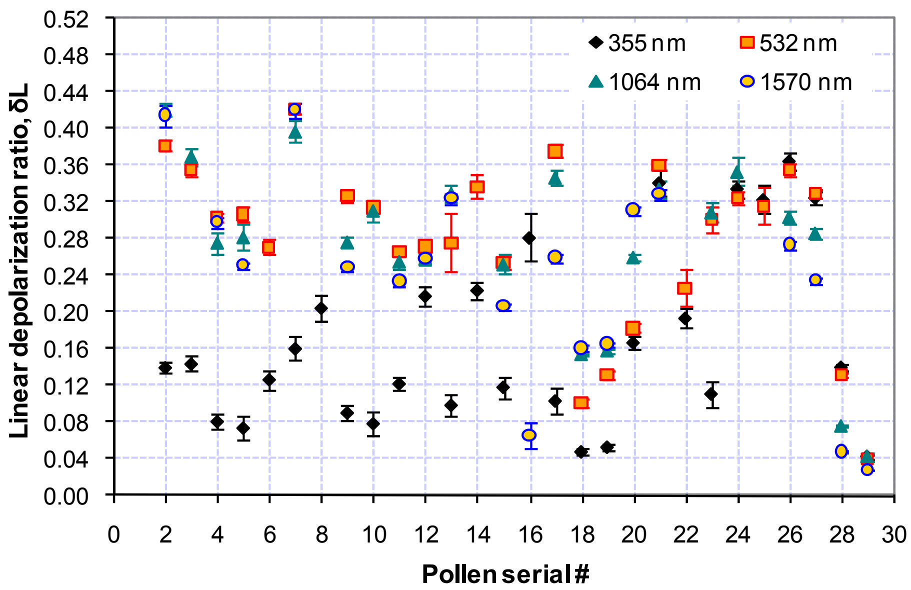
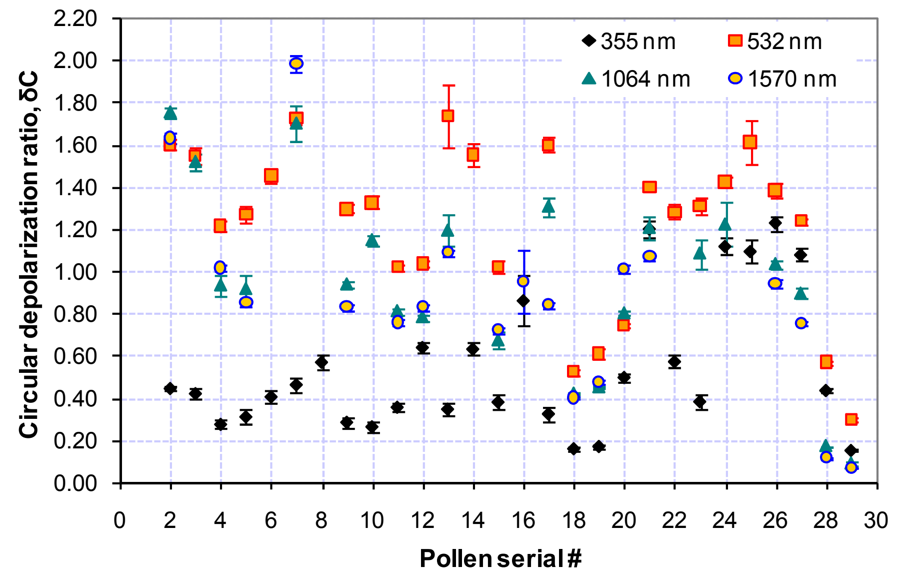
Linear and circular depolarization ratio measurement





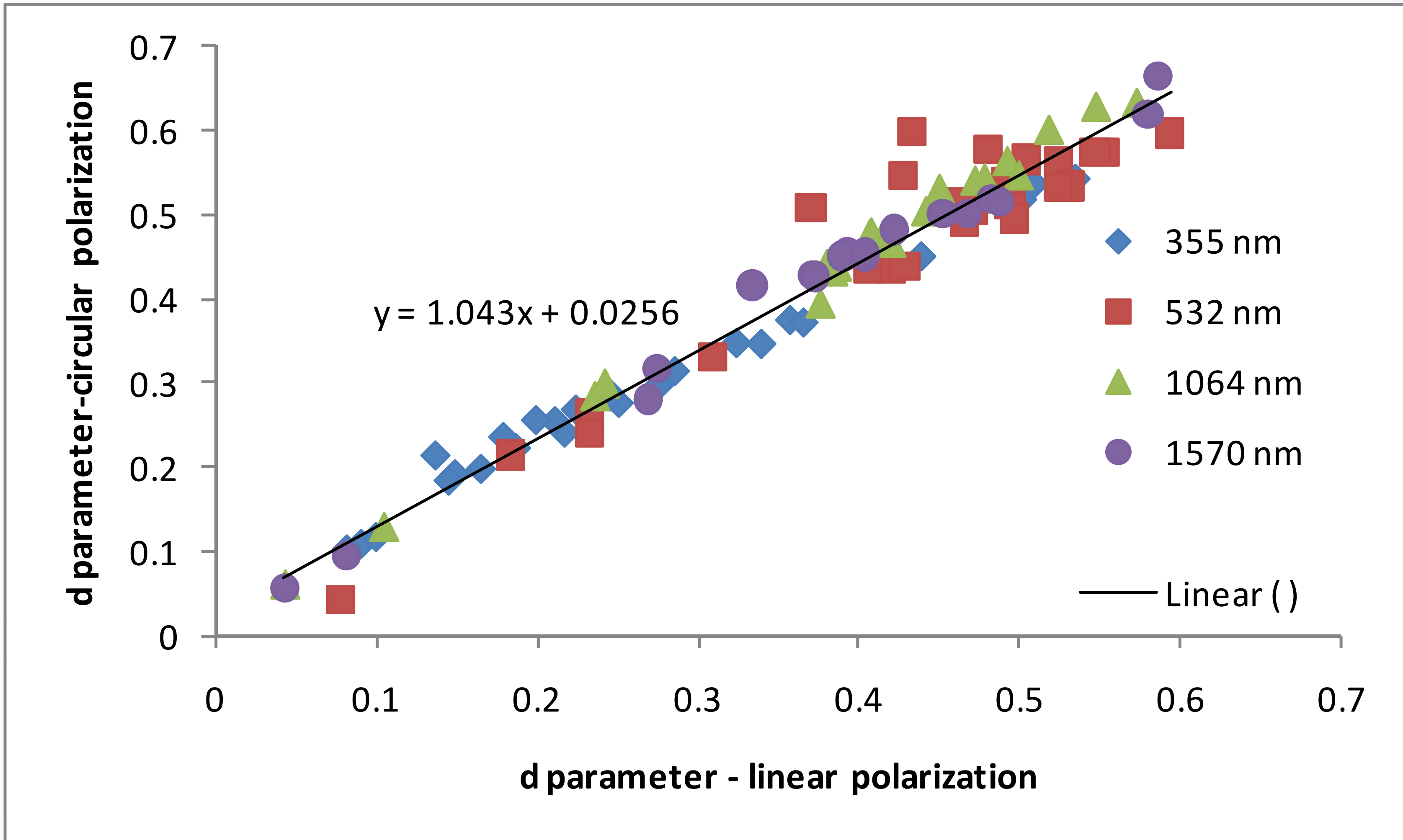
Scattering matrix for randomly oriented materials

$$M_{atm} = p(180^o)\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1-d & 0 & 0 \\ 0 & 0 & d-1 & 0 \\ 0 & 0 & 0 & 2d-1 \end{pmatrix}$$

$$d = \frac{2\delta_{Lin}}{1+\delta_{Lin}} = \frac{\delta_{Cir}}{1+\delta_{Cir}}$$

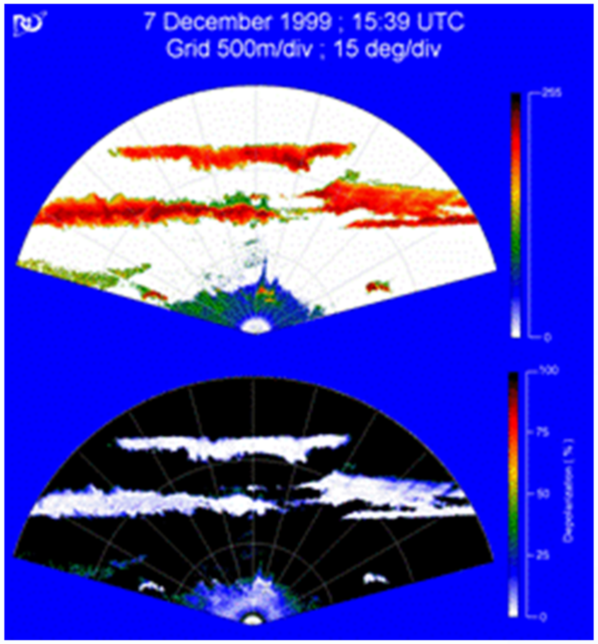
$$\delta_C = \frac{2\delta_L}{1-\delta_L}$$

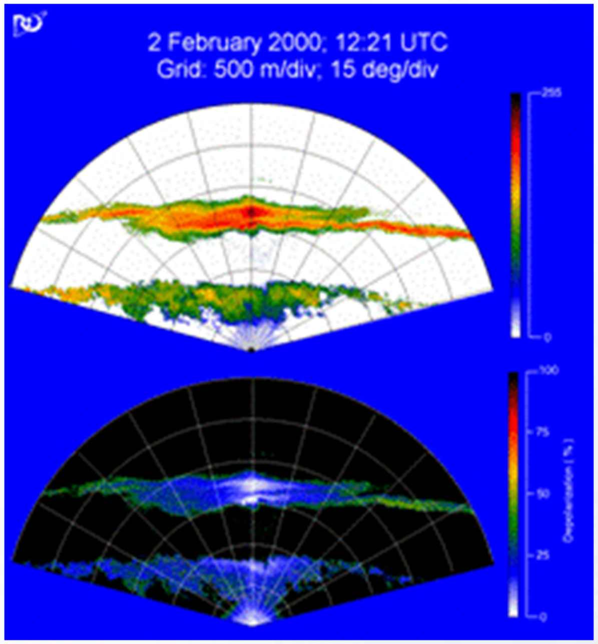
Depolarization parameter

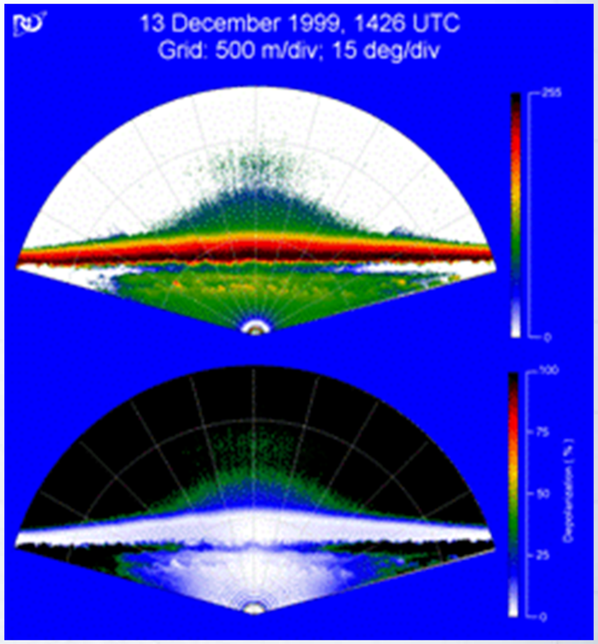


Scanning adverse weather lidar

Examples of sky scans

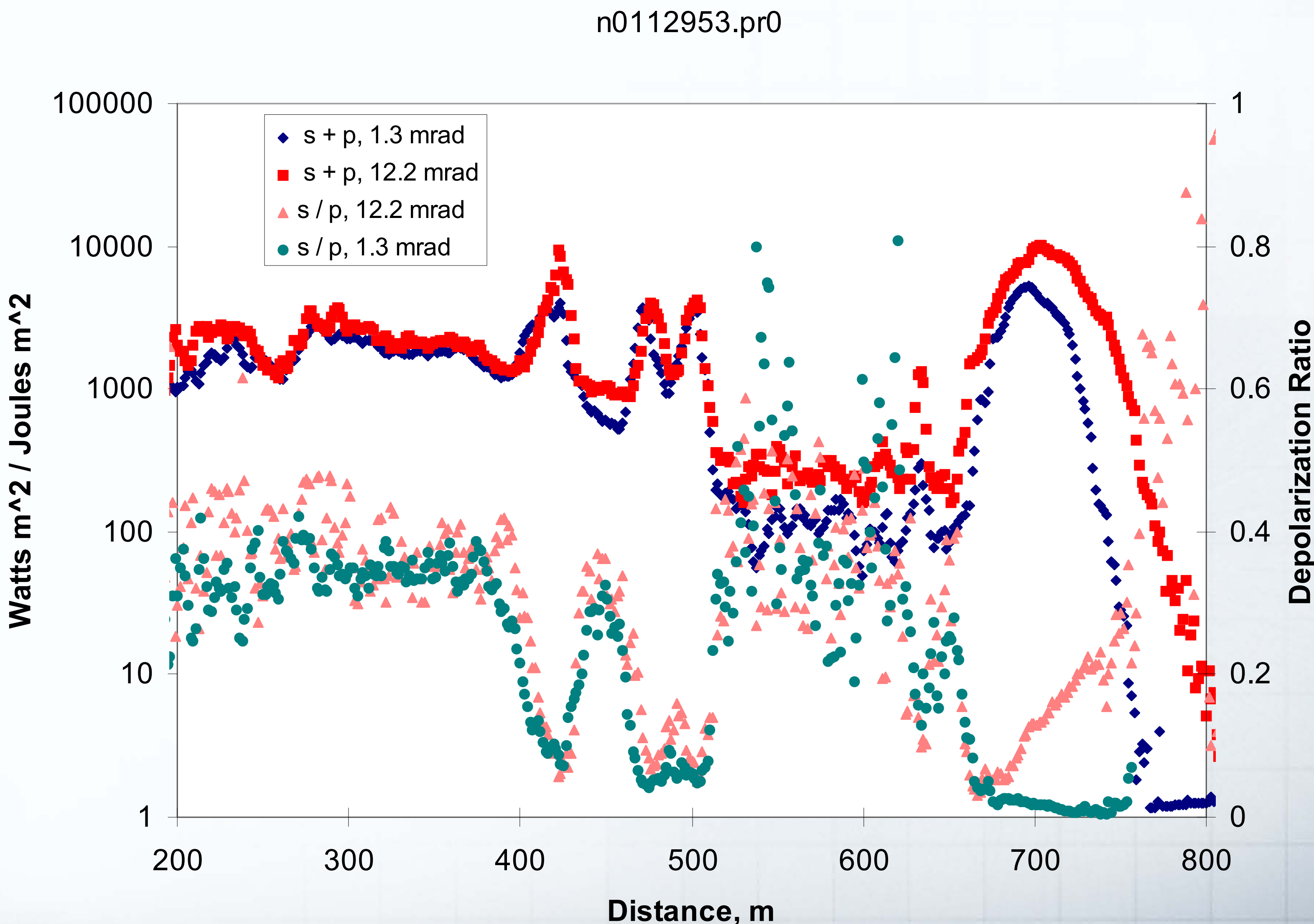






2 water cloud layers | **2 ice cloud layers** | **Cloud layer & Fog**

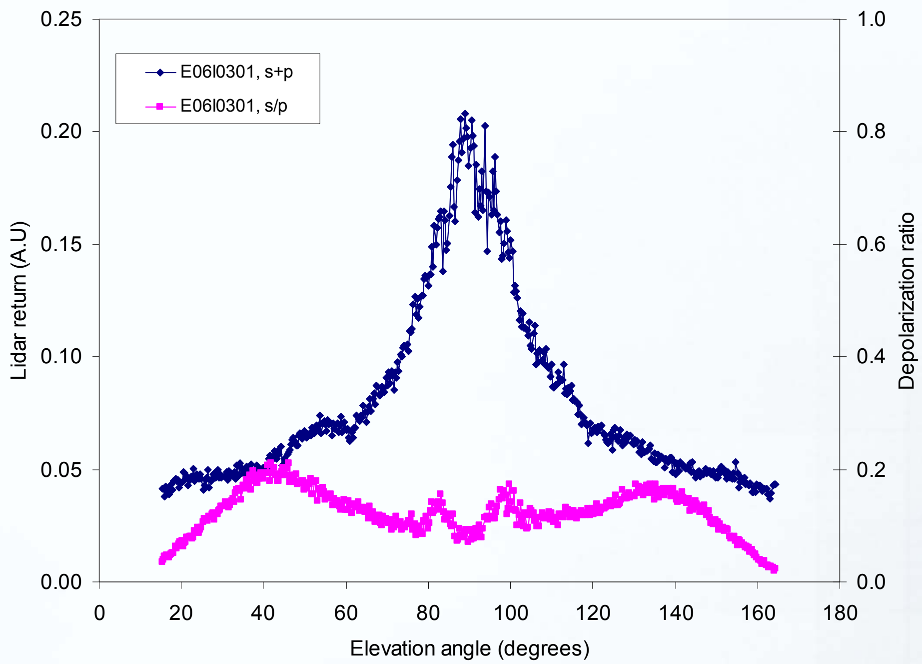
Snow and clouds

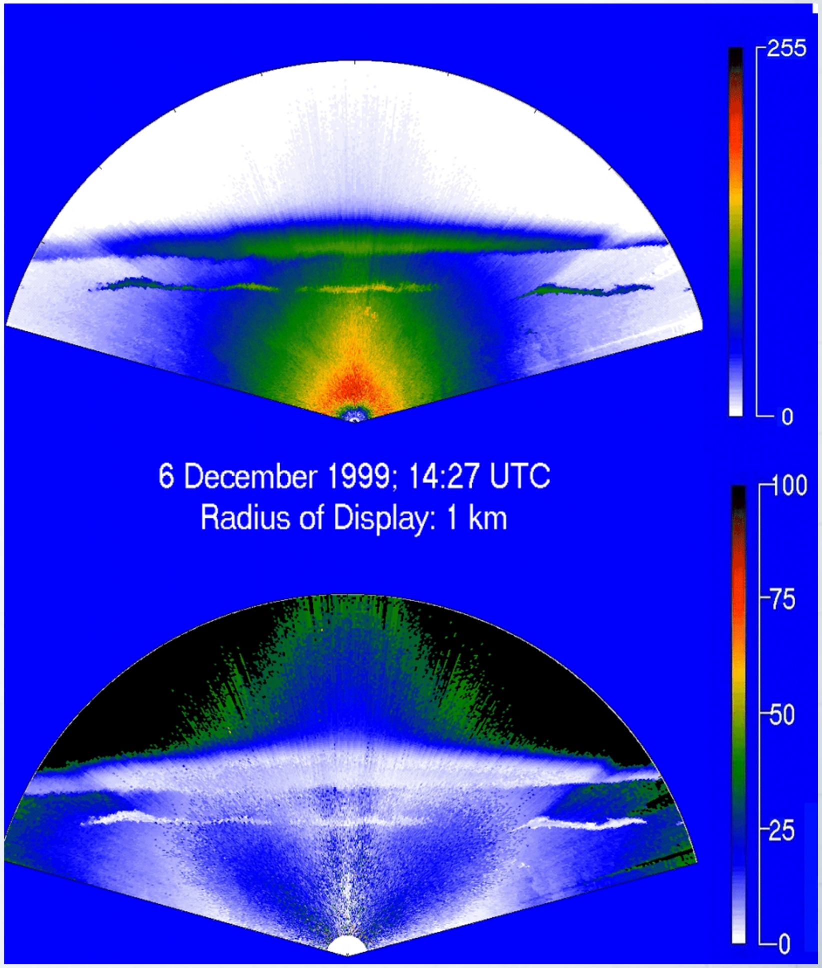


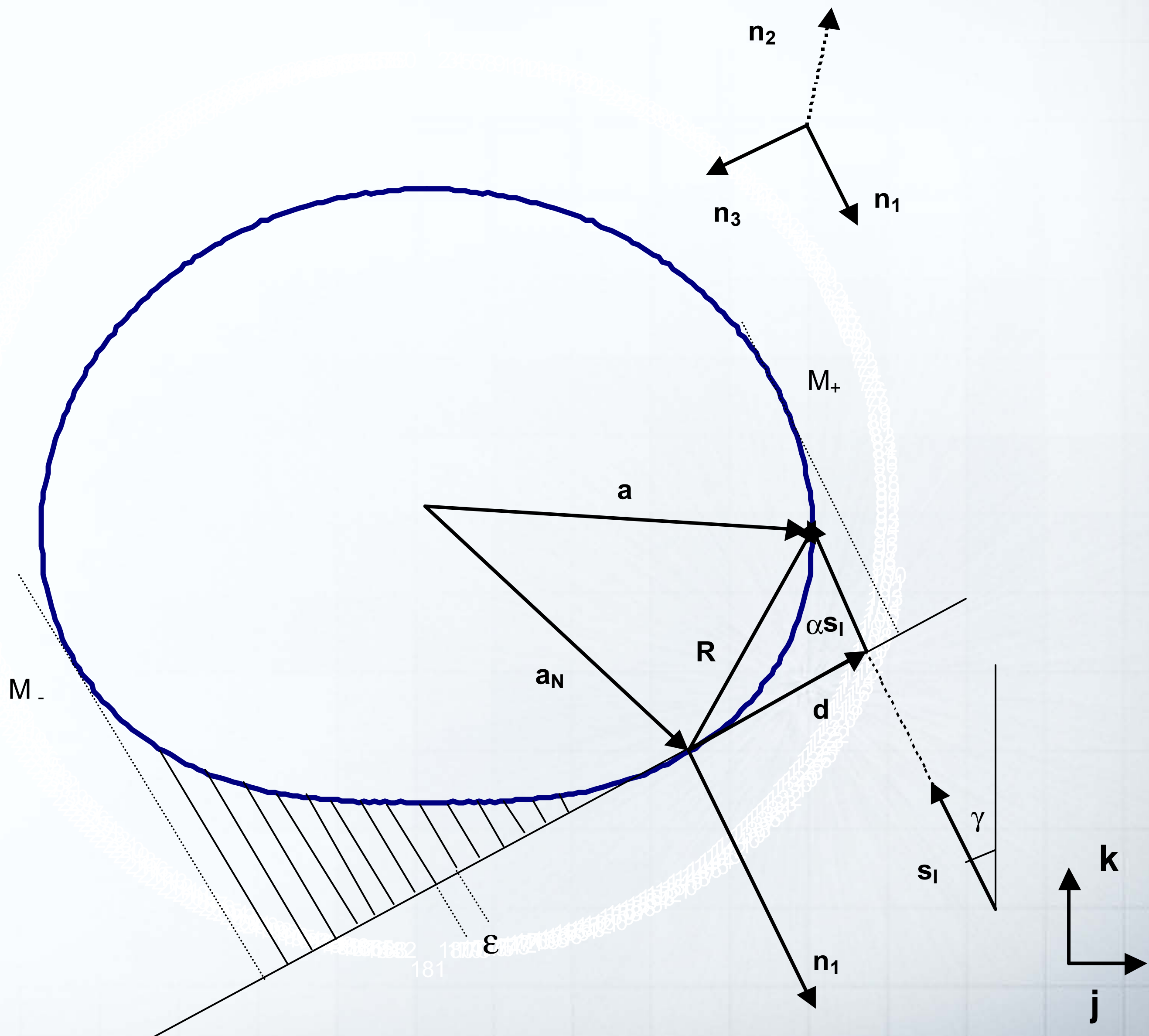
Rain and clouds layers

At 400 et 550m

Temperature: 6°C






n2
n3
n1
M+
a
R
aN
αsl
d
M -
ε
γ
sl
k
j
n1

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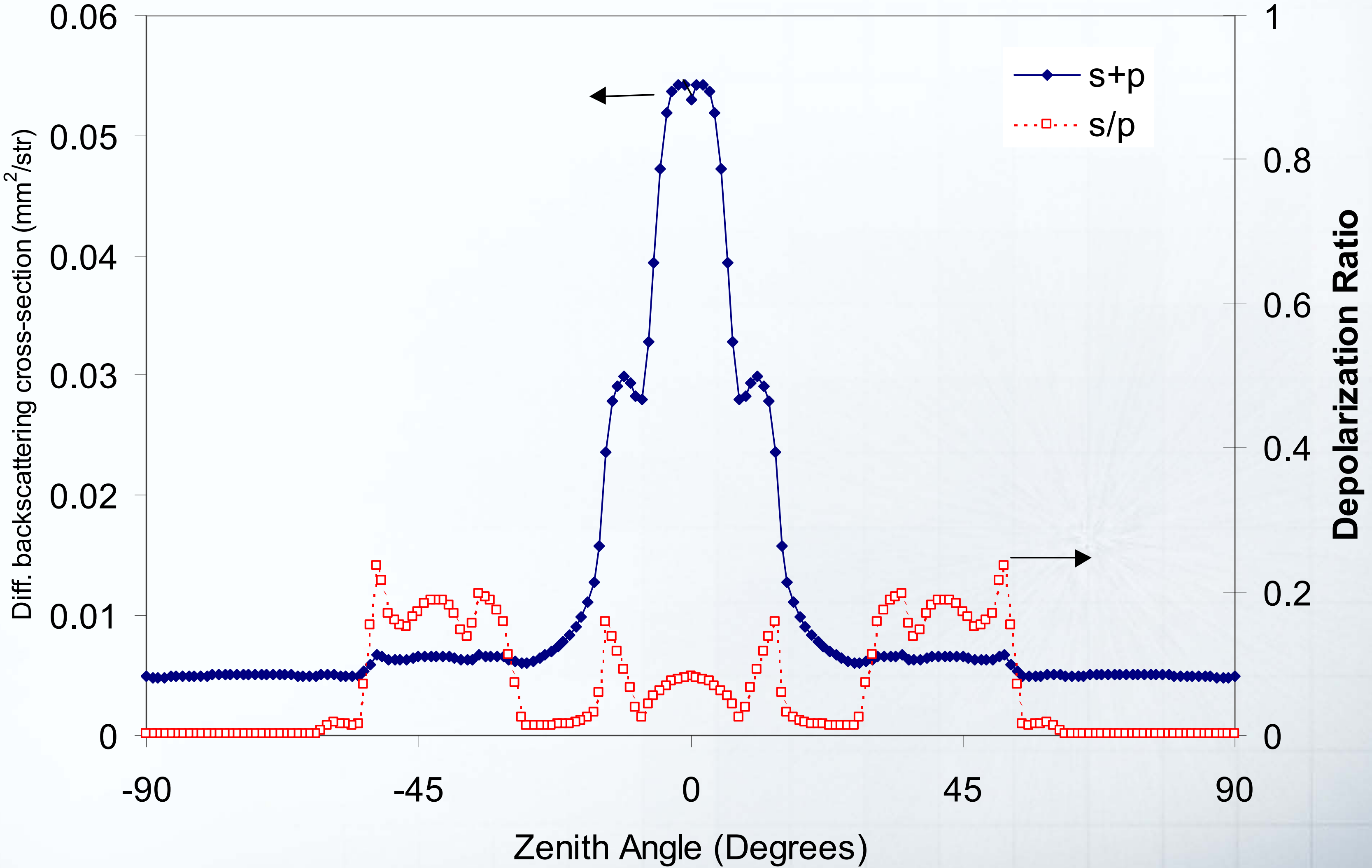
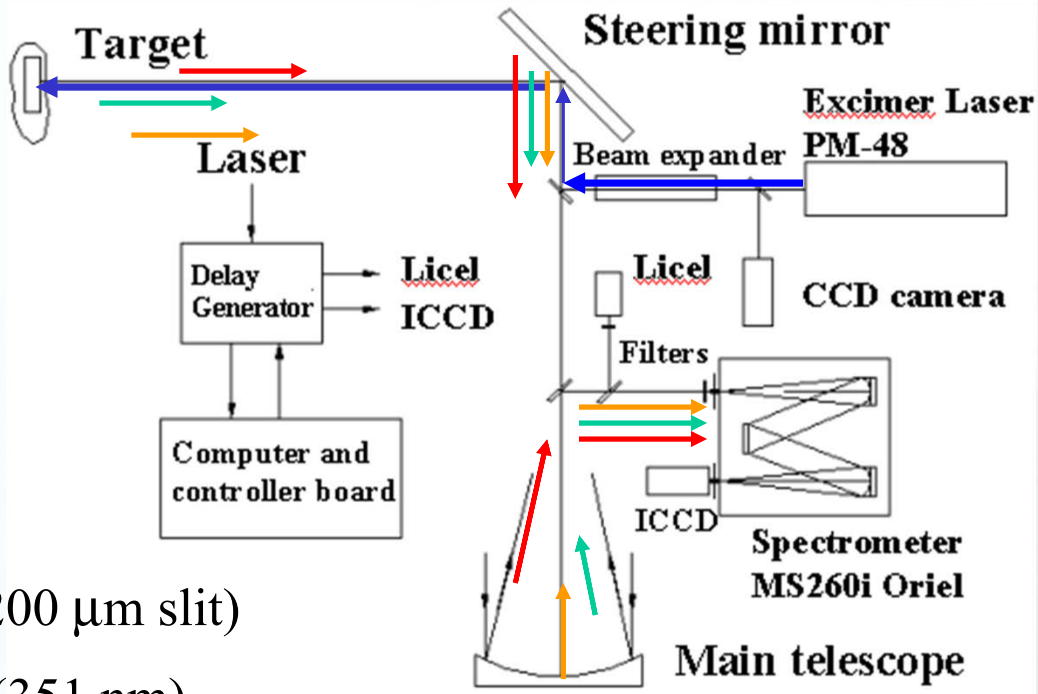
$(5*0.61^2*p(\pi)_{0.61} + 3*1^2*p(\pi)_1 + 1*1.5^2*p(\pi)_{1.5)})*\pi/(4*9)$

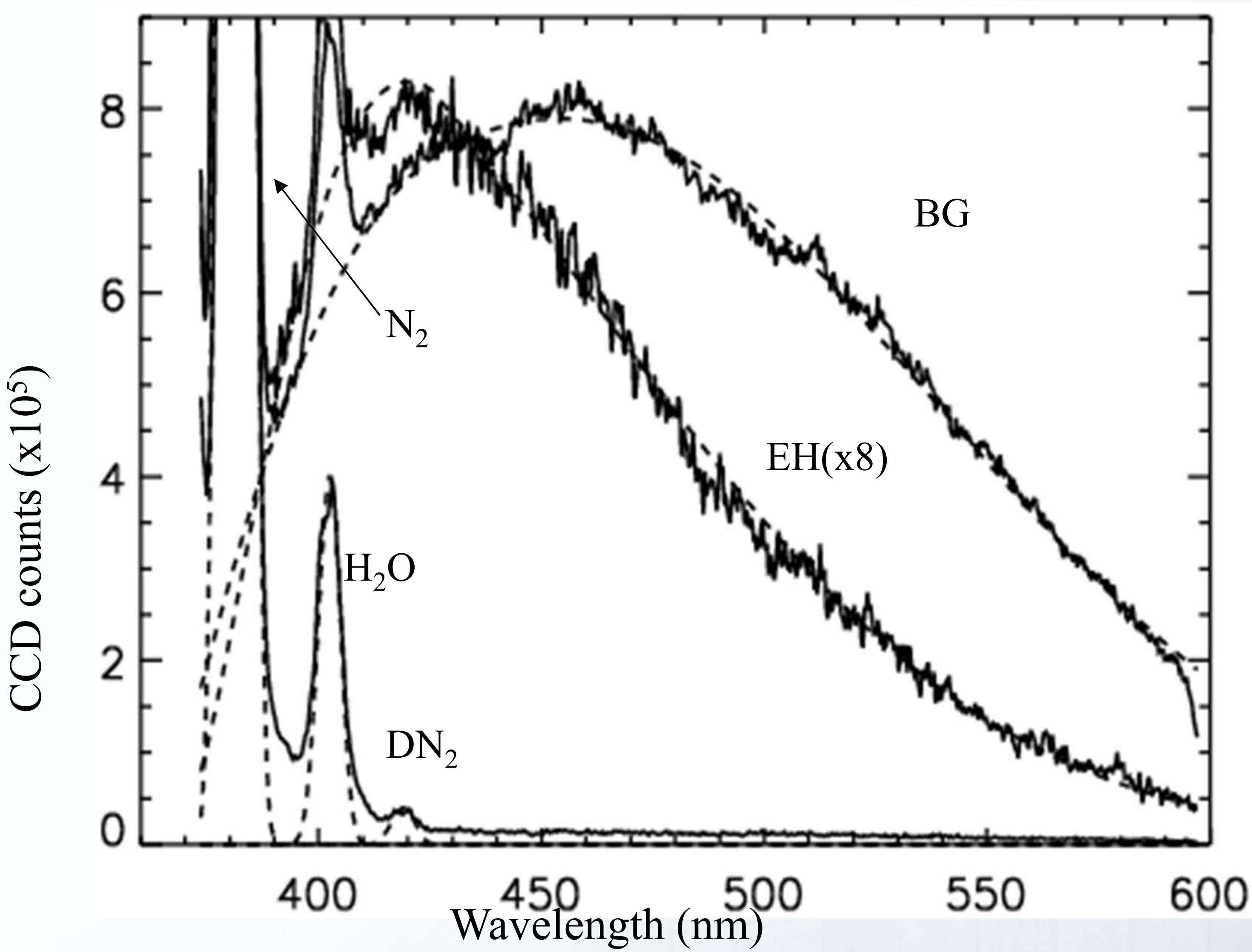


Gated Biofluorescense

Schematic SINBAHD Diagram

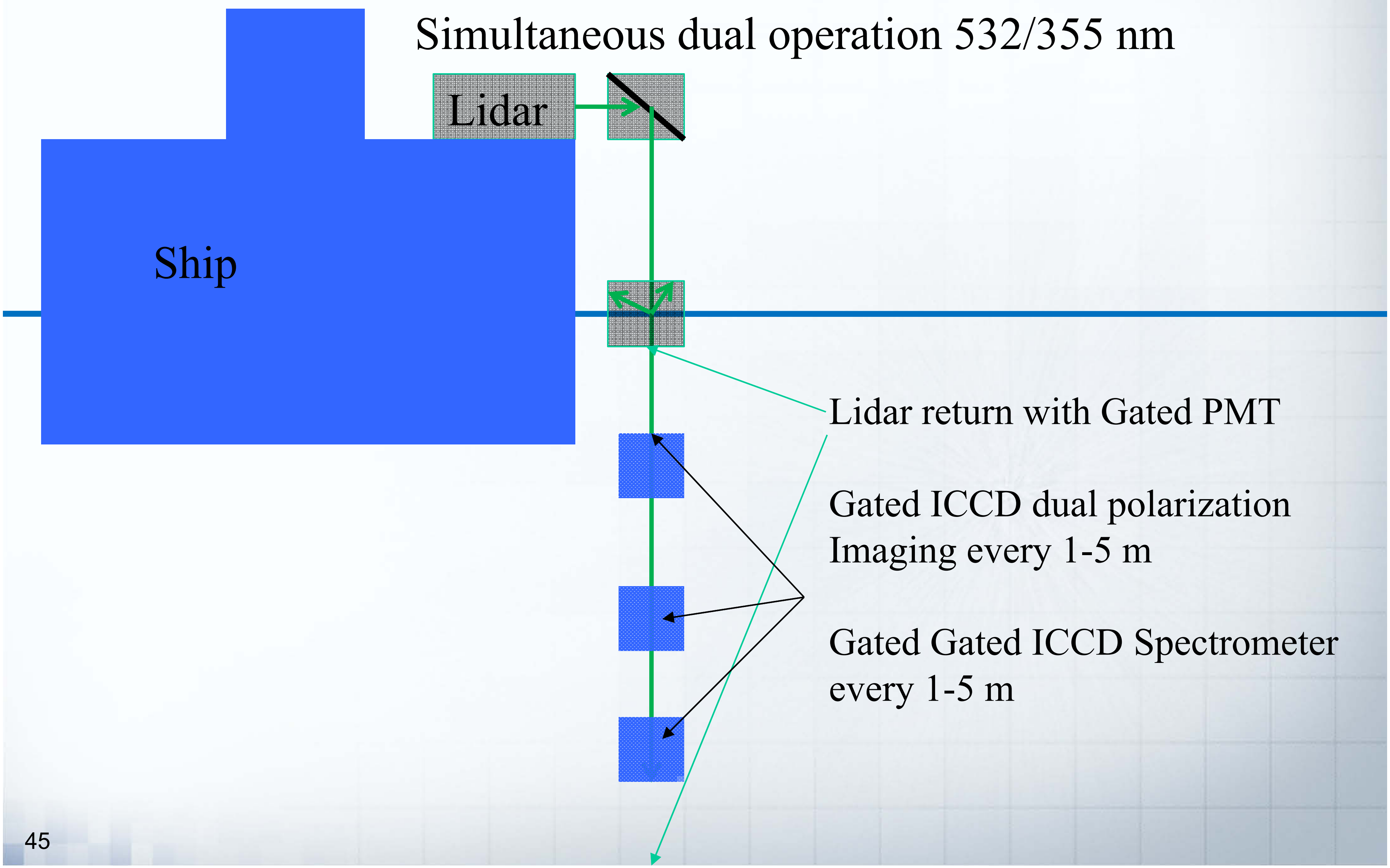


- Aperture: 12 inches
- FOV (1D): 150 µrad (200 µm slit)
- Laser power: 25 Watts (351 nm)
- Laser wavelength: 308 nm and 351 nm
- Two channels of collection (backscatter and fluorescence)
- Spectral interval of collection: 300-600 nm (resolution: 1-10 nm)



8
6
4
2
0
400
450
500
550
600
CCD counts (x10^5)
Wavelength (nm)
N2
H2O
DN2
BG
EH(x8)

Adaptation to oceanographical studies



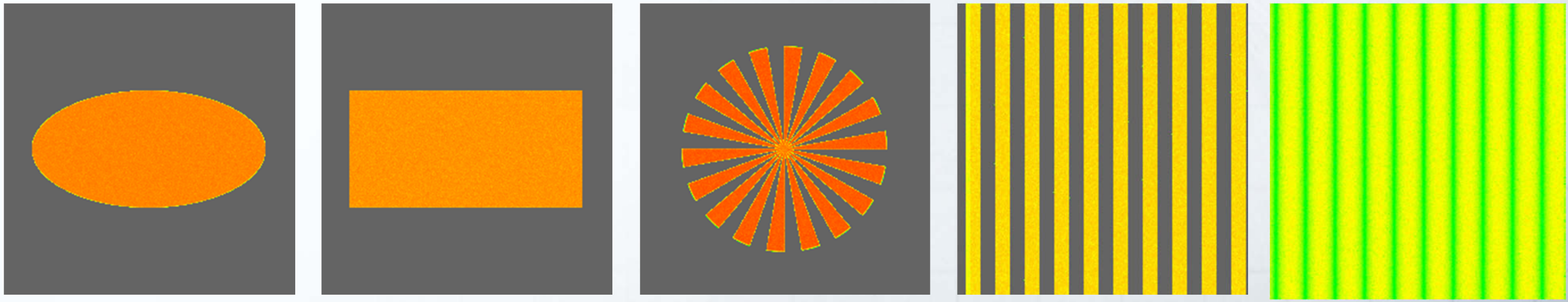
The Undique Monte-Carlo Simulator

- The Undique Imaging Monte-Carlo simulator is made to reproduce the behaviour of a Flash Ladar system.
- It is made of a laser source, a camera, a propagation media, and a target.
- The characteristics of each component can be adjusted to reproduce the desired system.
- Polarization management capacity was recently added to the simulator.

The Undique Monte-Carlo Simulator

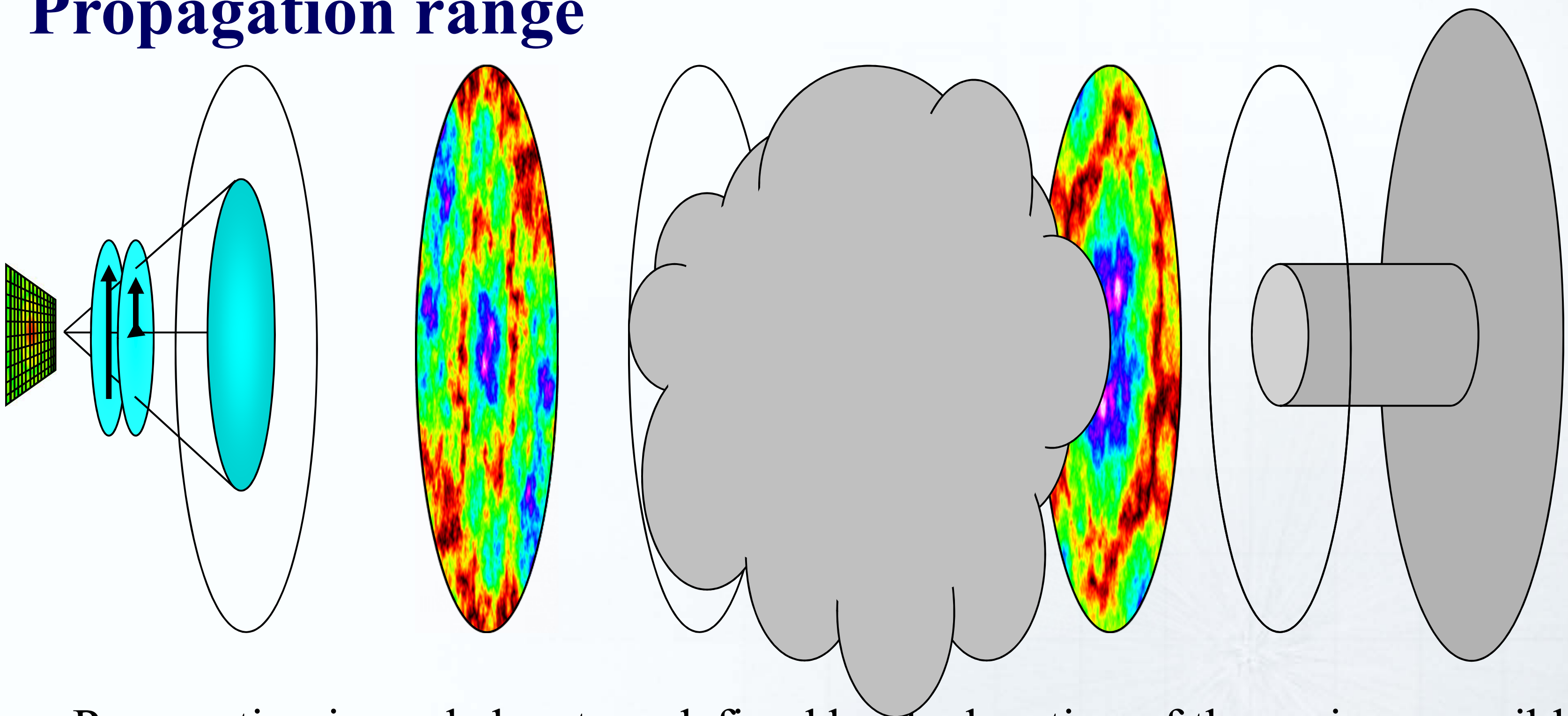
The source

- The source can be coaxial with the receiver or anywhere else within the maximum range allowed.
- Multiple sources are possible (ambient sunlight)
- Sources can have pattern for various purposes.



The Undique Monte-Carlo Simulator

Propagation range



- Propagation is made by steps defined by the location of the various possible events: camera aperture, beginning of the target, target background, aerosol beginning, aerosol end, turbulence plane.
- The photons are sent from one plane to the next.
- It makes the simulations longer but allows easy addition of new types of interactions.

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DEFENCE DÉFENSE

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