Cloud Extinction Probe:
calibrations and results of measurement

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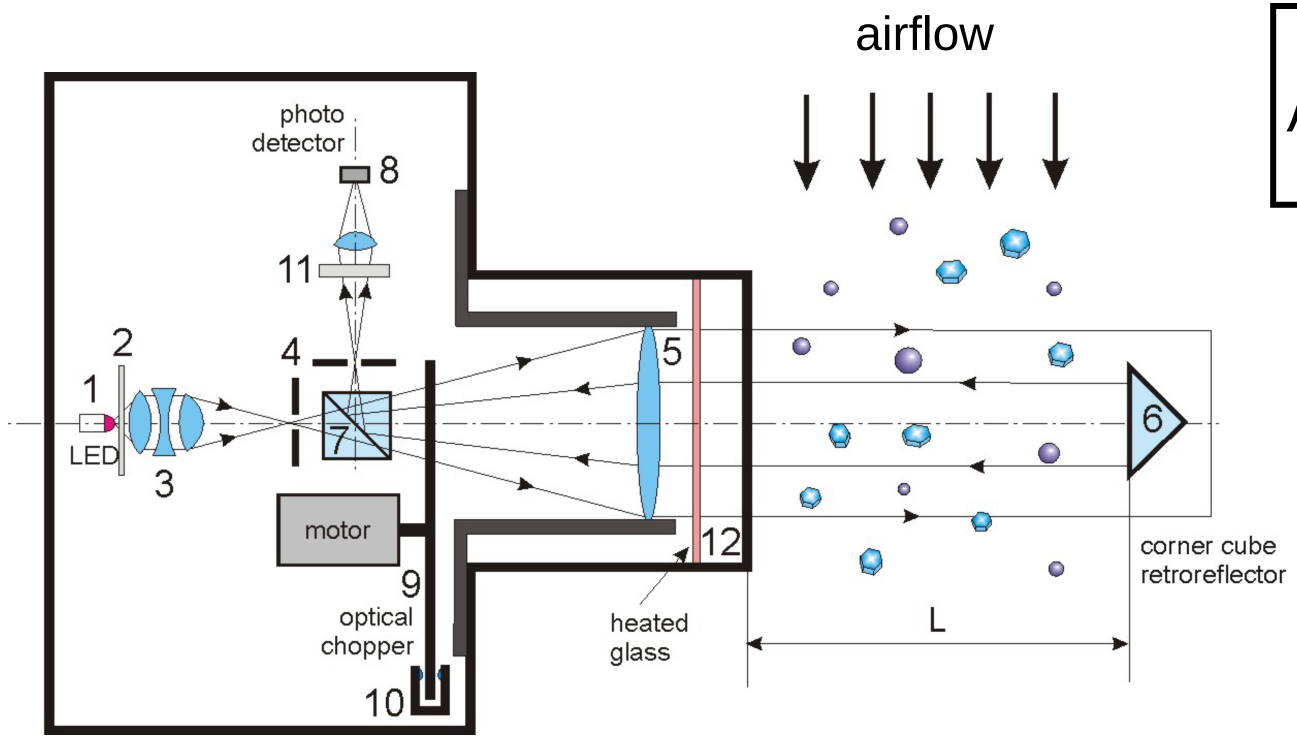
Cloud Extinction Probe

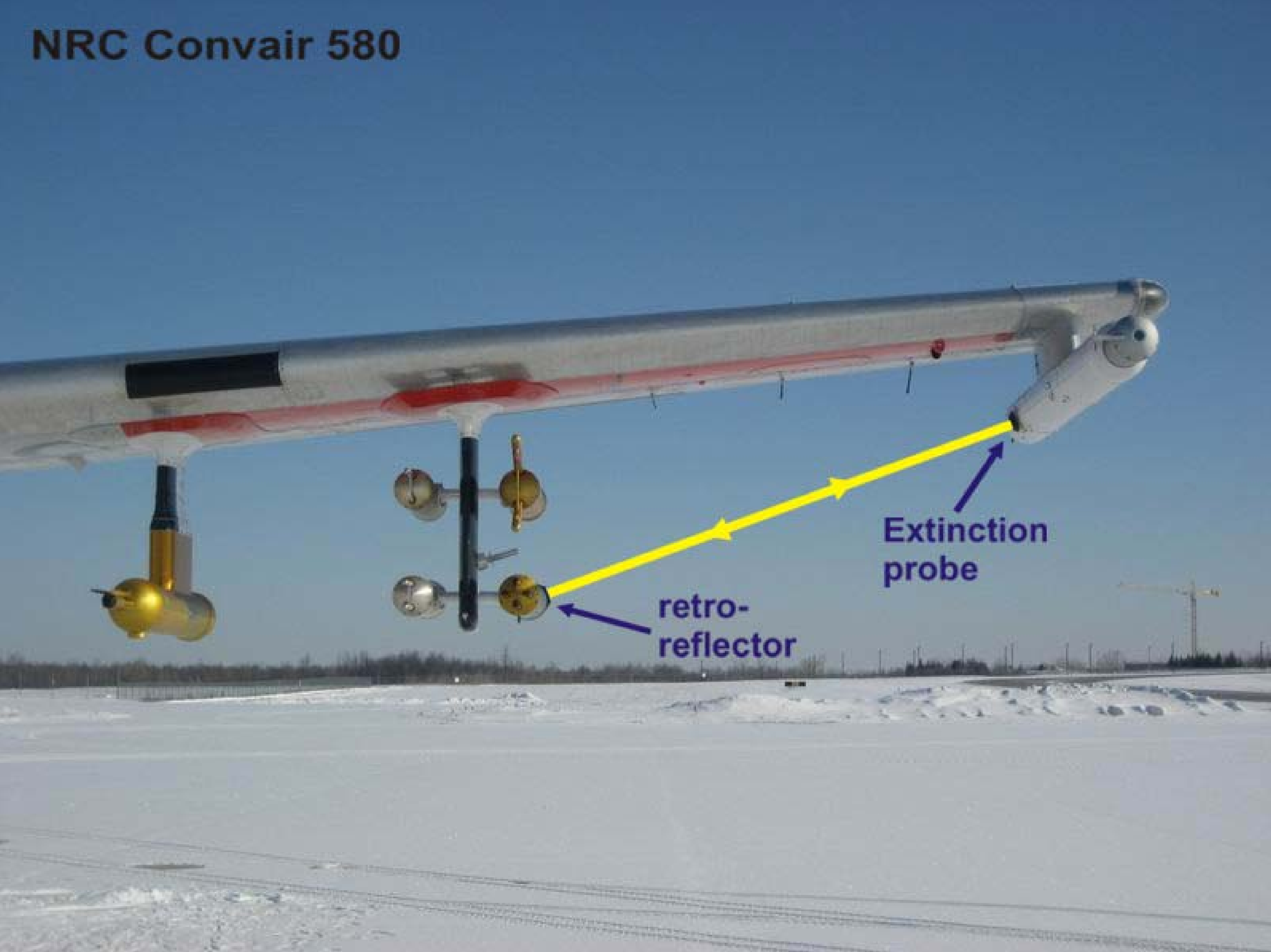
Schematic diagram of the optical unit of the Cloud Extinction Probe

Beer's law

$$\beta_{CEP} = -\frac{1}{2L} \ln \frac{I}{I_0}$$



(1) LED λ=0,635μm
(2) diffuser
(3) condenser
(4) pinhole
(5) objective
(6) cone cube retroreflector
(7) beamsplitter
(8) photodetector
(9) optical chopper
(10) optocouple
(11) filter
(12) front heated glass


NRC Convair 580
Extinction probe
retro-reflector

Specifications of Cloud Extinction Probe

Range:	$0.2km^{-1} < \beta < 200km^{-1}$
Sample area:	$60cm^2$
Rate of sampling:	$1.5\ m^3/s$
Receiving aperture:	0.6^o
Optical base:	2.5 m x 2
Data rate:	10Hz

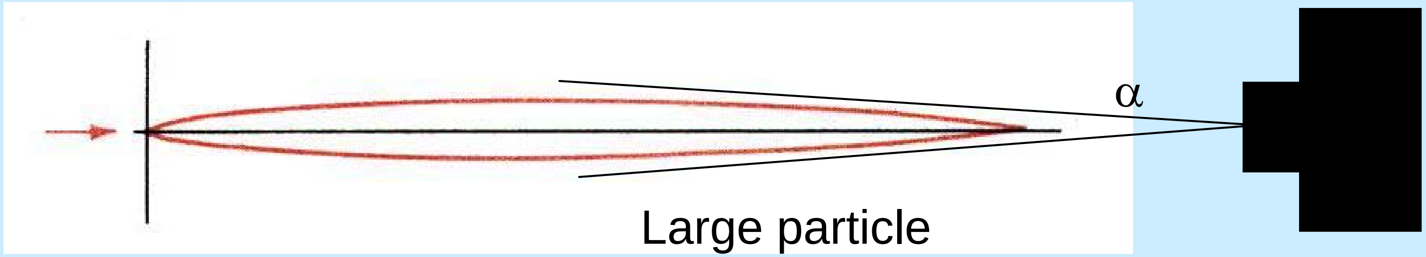
Insensitive to shattering

Non-coherent illumination

All-weather operation: -60C<T<+40C, 100mb<P<1000mb

Calibrations

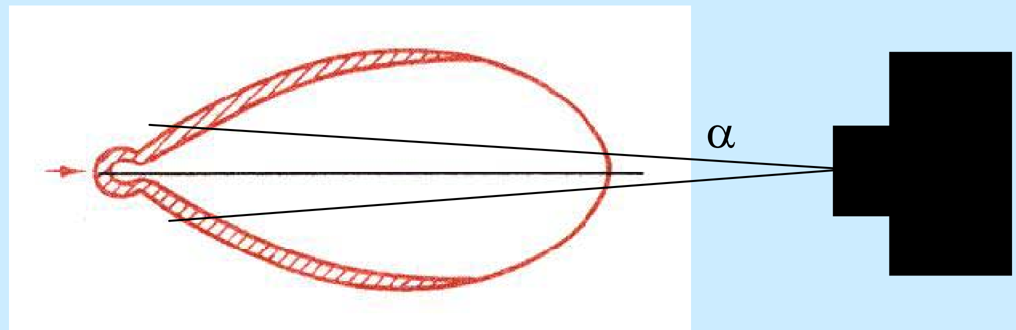
The effect of forward scattering on the extinction coefficient measurements



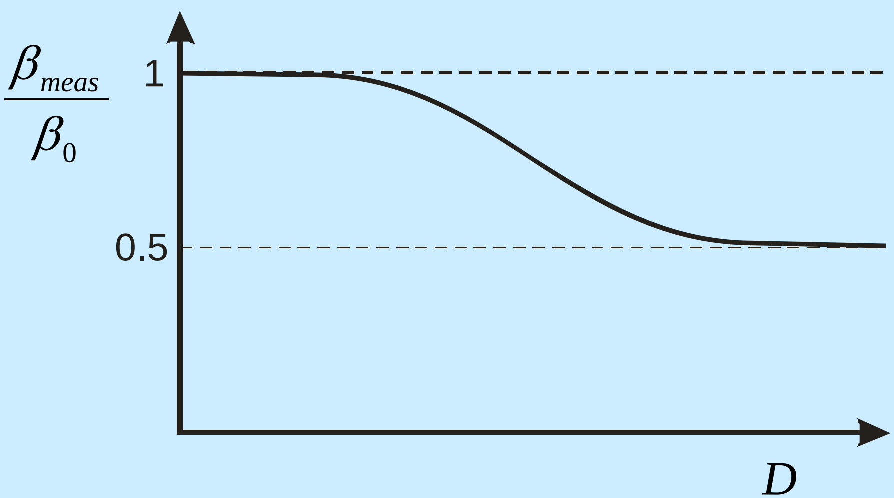
Large particle

Gumprecht and Sliepevich, 1953

Deepak and Box, 1978



Small particle



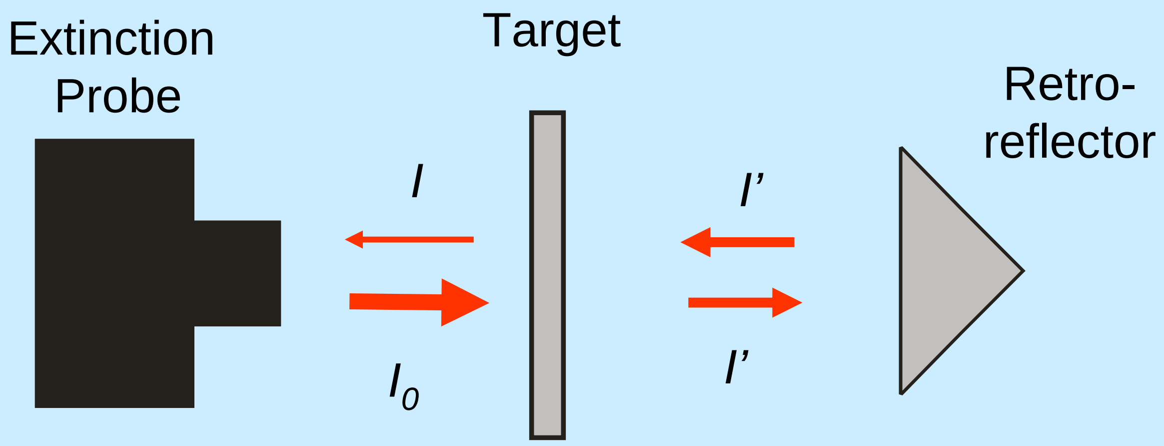
$$\beta_{meas} \leqslant \beta_0$$

The measured extinction coefficient is no higher than the actual extinction coefficient

- There are no techniques for the calibration of transmissometers and extinctiometers

- Absence of calibrating standards, e.g. monodisperse particle clouds with predetermined concentration

Experimental Schema



Instrumental extinction efficiency

single pass

$$\frac{I_0 - I}{I_0} = \frac{QS}{S_0}$$

double pass

$$\frac{I_0 - \sqrt{I_0 I}}{I_0} = \frac{QS}{S_0}$$

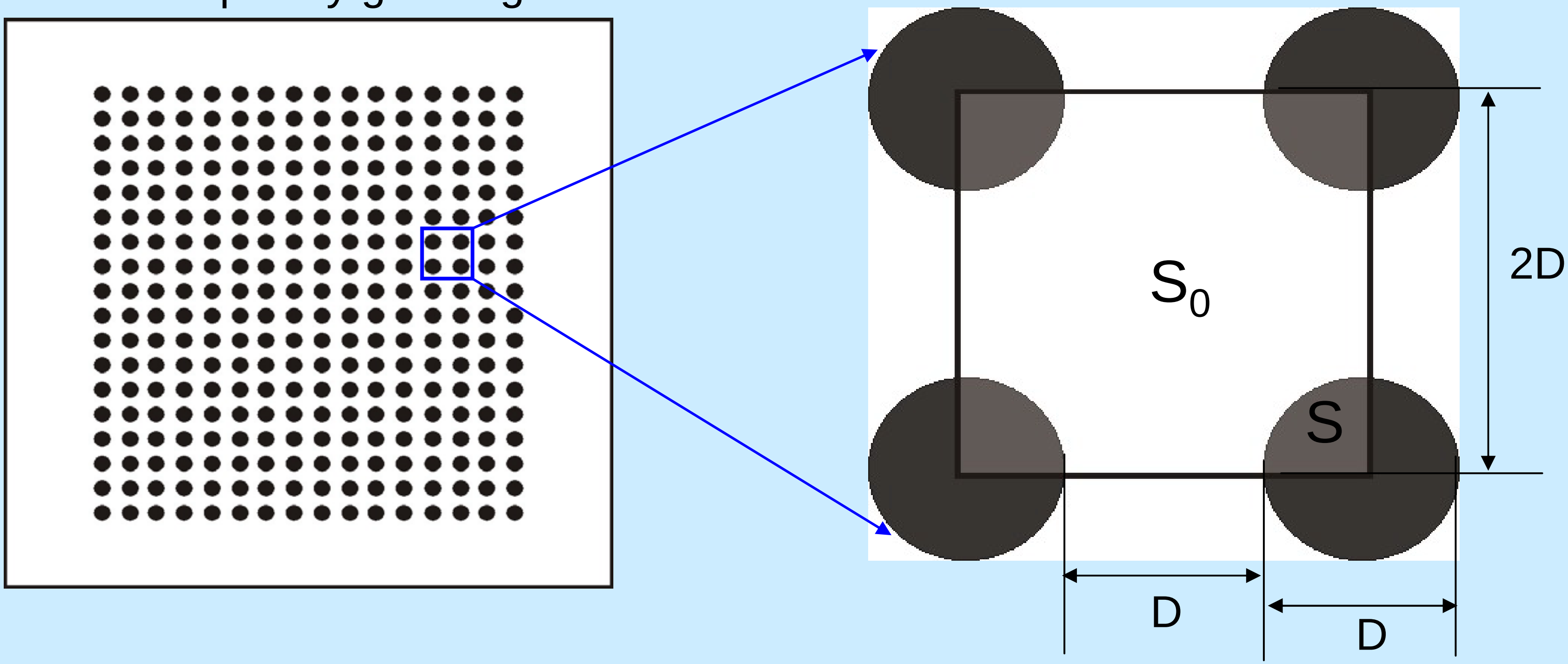
=>

$$Q(D) = \frac{1 - \sqrt{\dfrac{I}{I_0}}}{\dfrac{S}{S_0}}$$

$Q \approx 2$ extinction efficiency theoretical value

Proposed calibrating technique

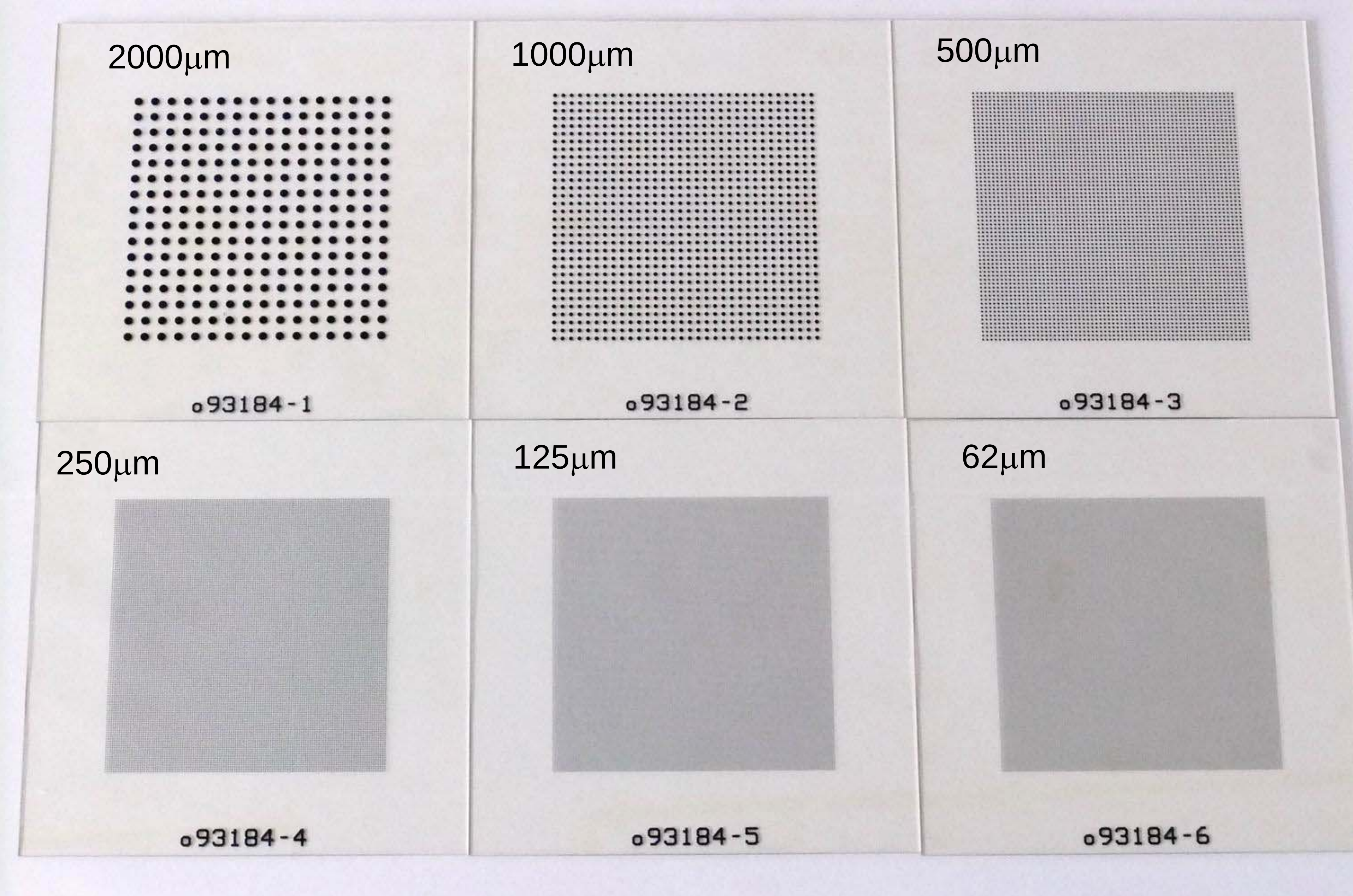
Fixed frequency grid targets



$$\frac{S}{S_0} = \frac{\pi}{16}$$

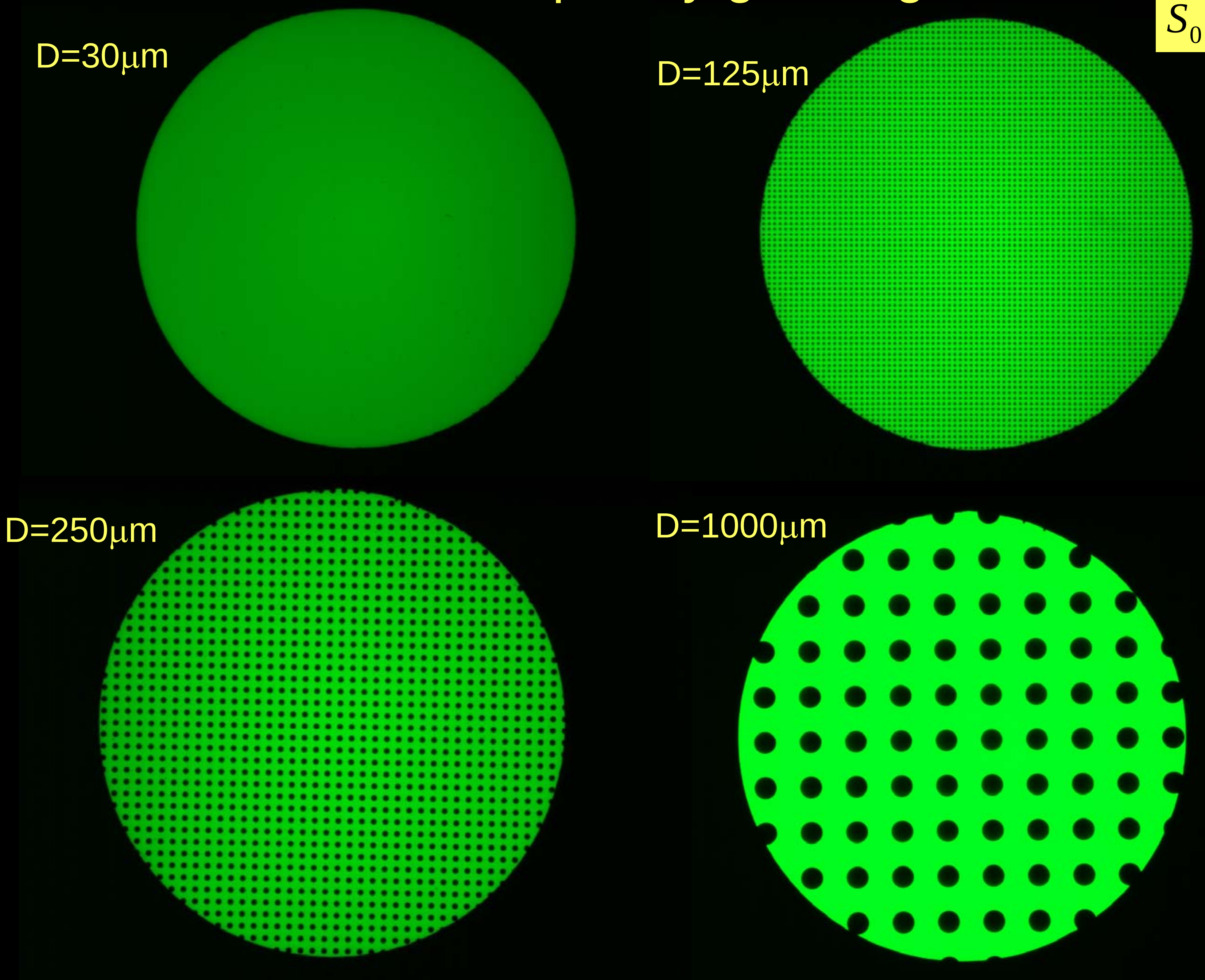
Fixed frequency grid targets
(custom made)

$$\frac{S}{S_0} = \frac{\pi}{16}$$

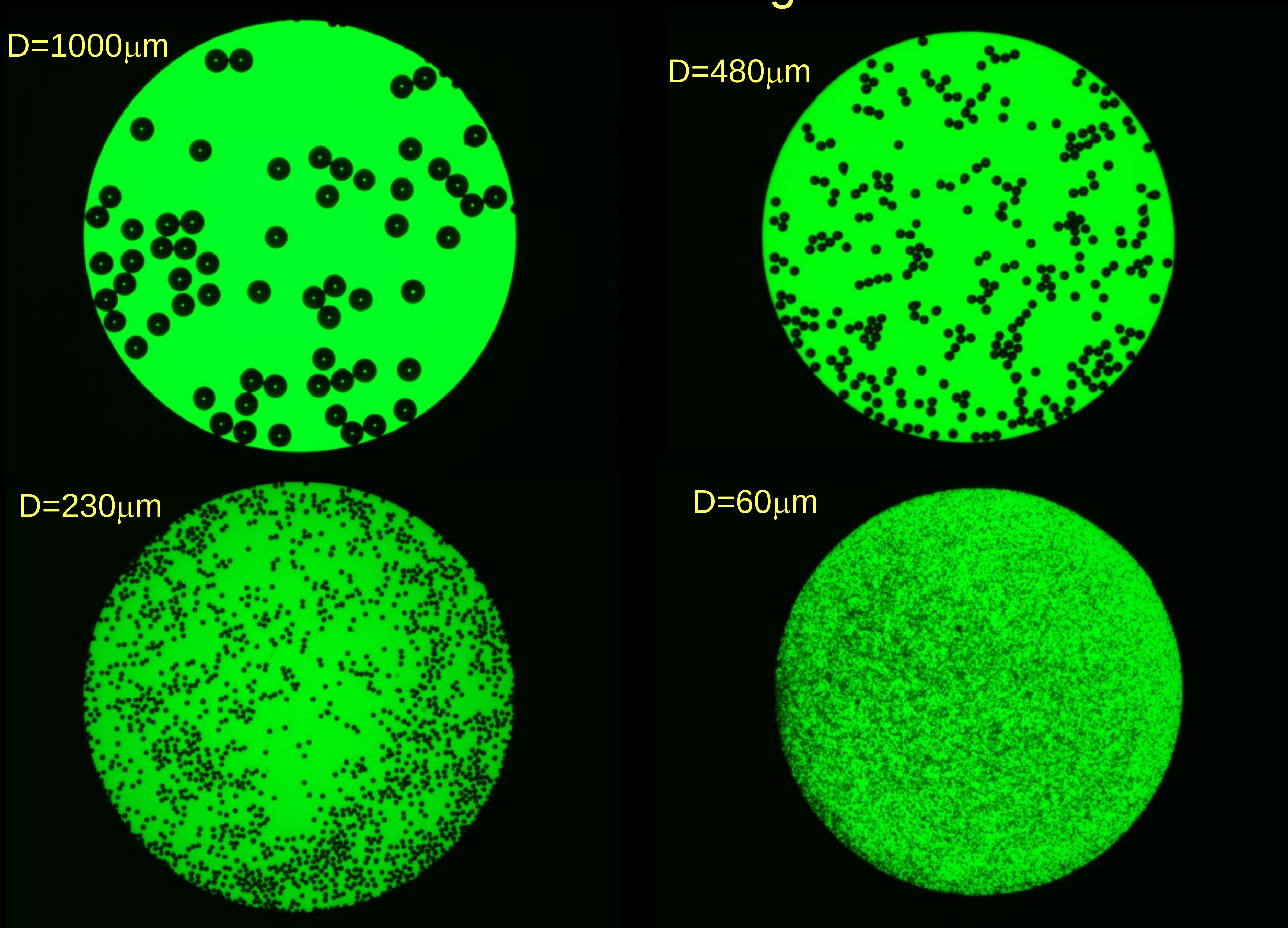


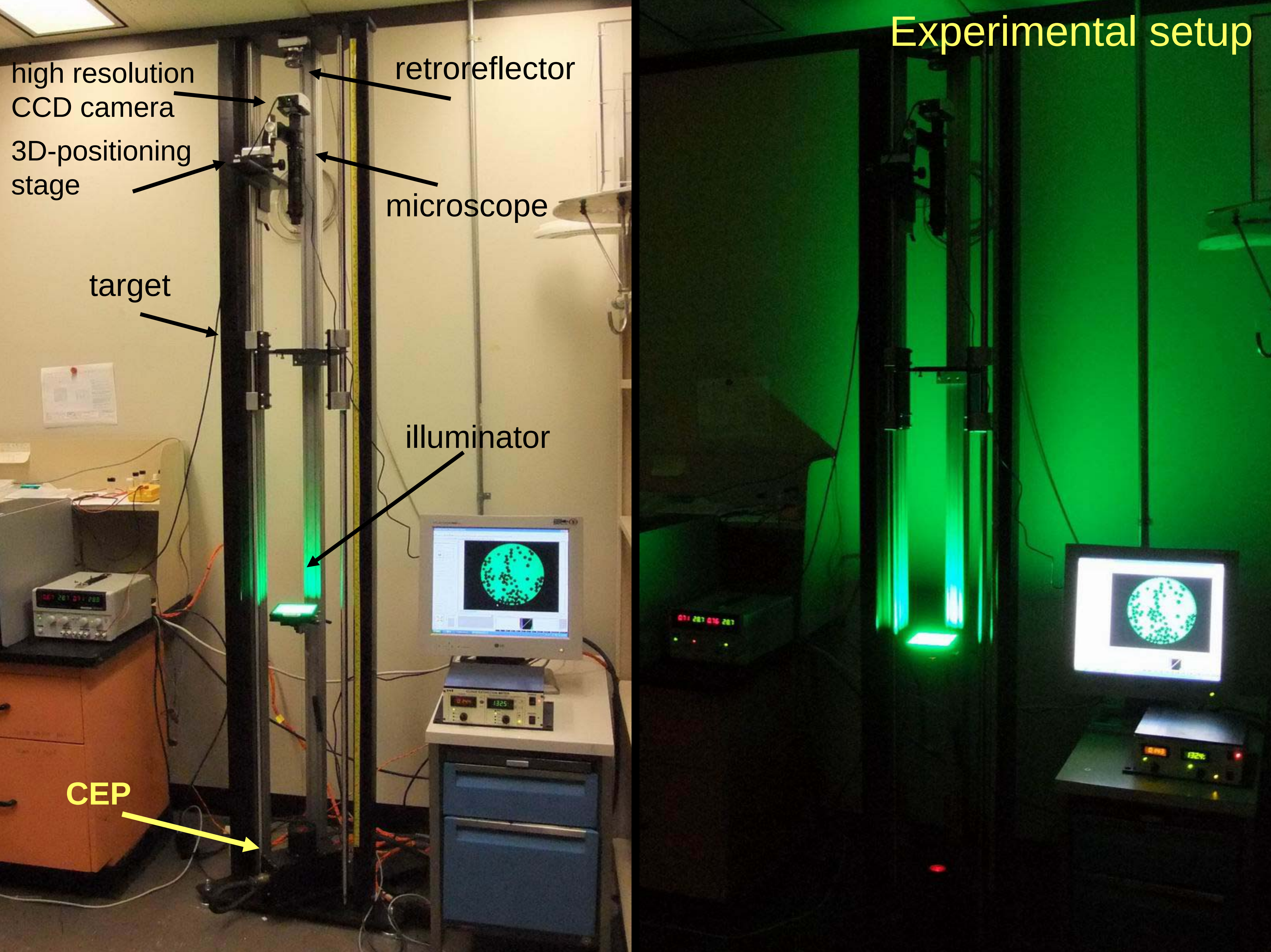
Fixed frequency grid targets

$$\frac{S}{S_0} = \frac{\pi}{16}$$

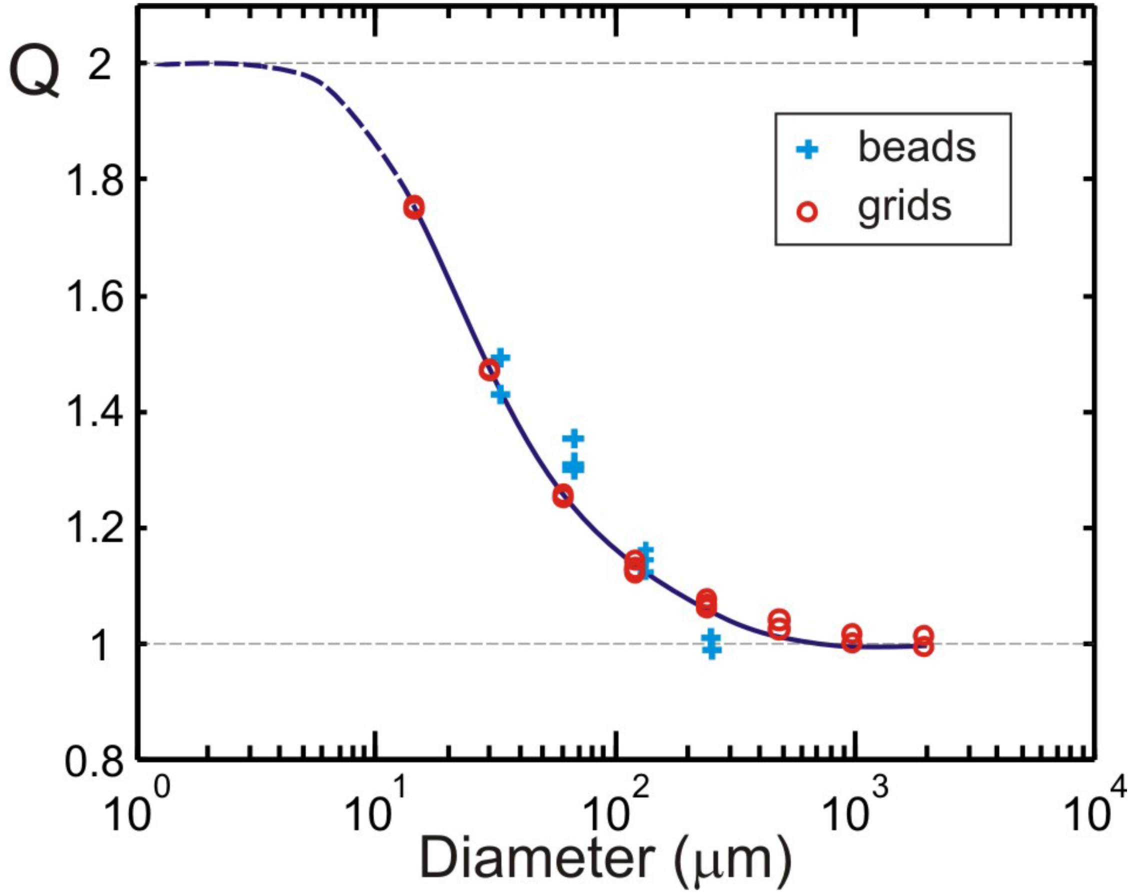


Glass bead targets

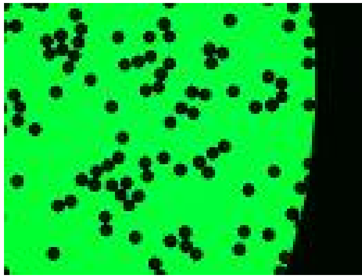



Experimental setup
high resolution
CCD camera
retroreflector
3D-positioning
stage
microscope
target
illuminator
CEP

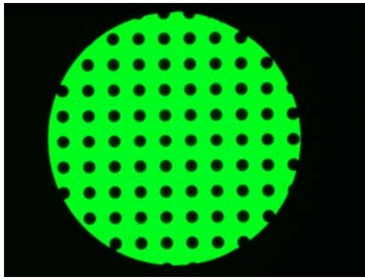
Results of calibrations



diffraction limit

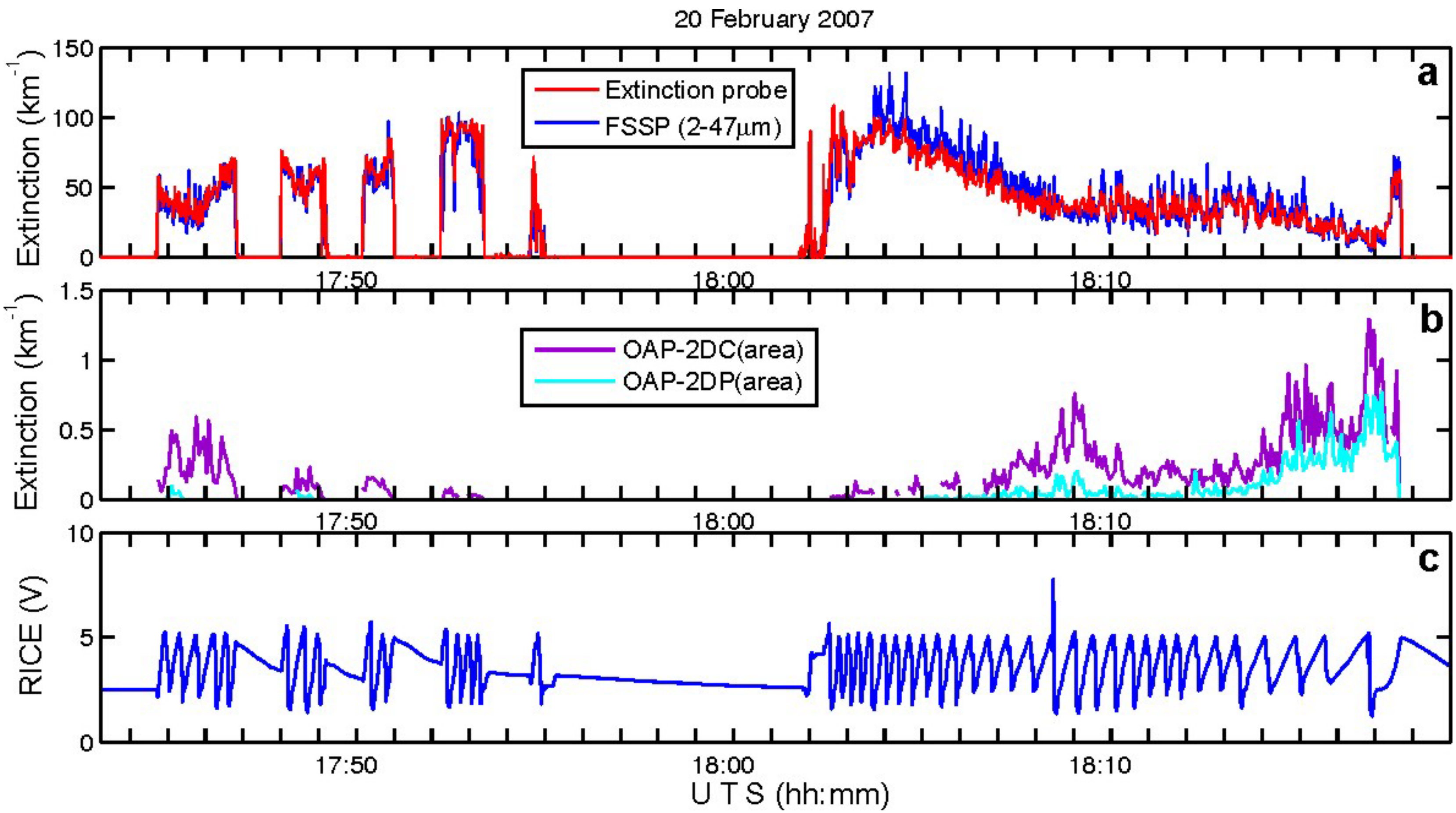


geometrical optics limit



Performance
and
results of measurements

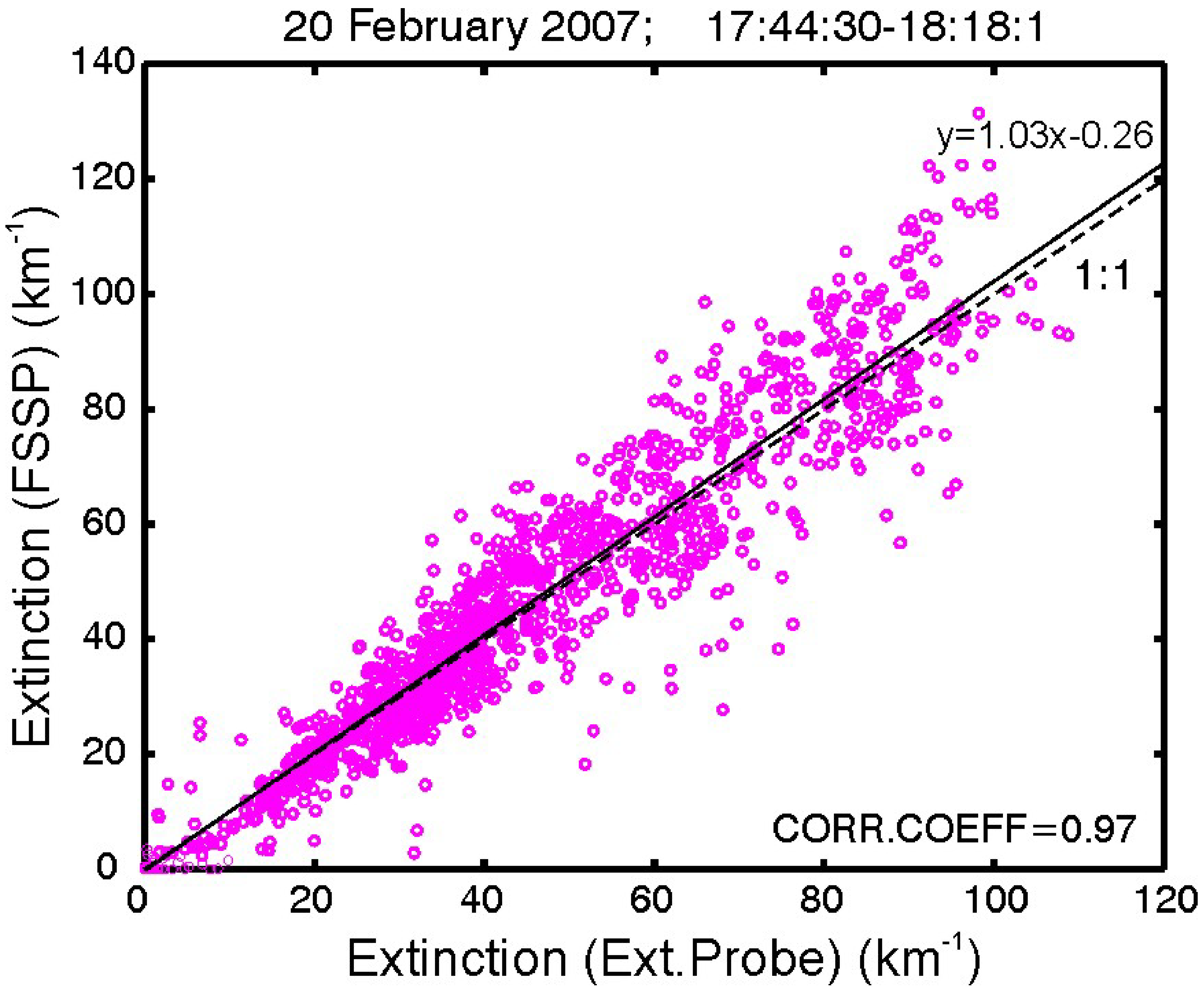
Liquid clouds



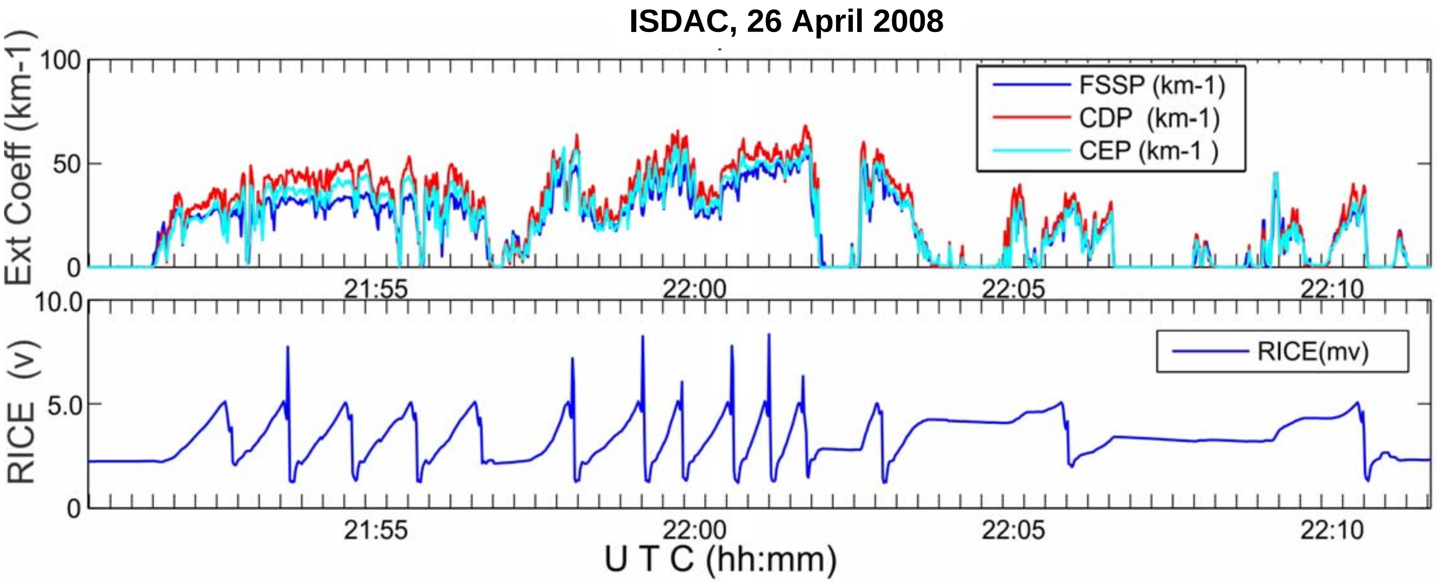
$$\beta_{FSSP} = \frac{\pi Q}{4}\sum_{j=1}^{15} n_j D_j^2$$

calculation of the extinction coefficient from FSSP measurements

Liquid clouds



Extinction coefficient measurements in liquid clouds during ISDAC

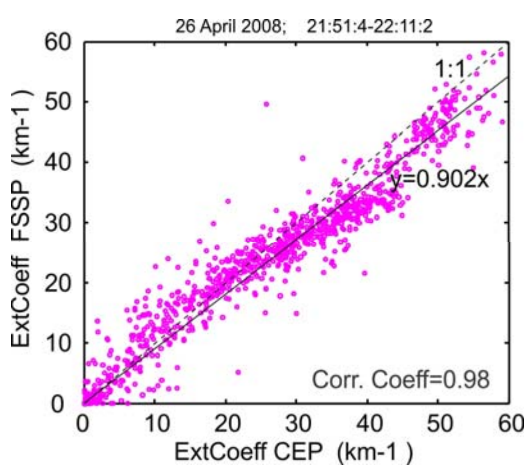


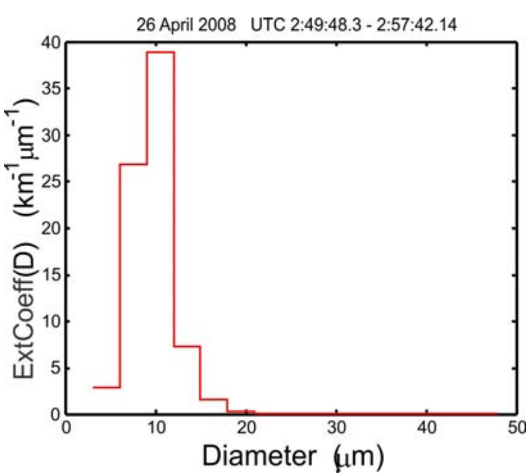
$$\beta_{meas} = \frac{Q_{instr}}{LA_0} \sum_j A_j$$

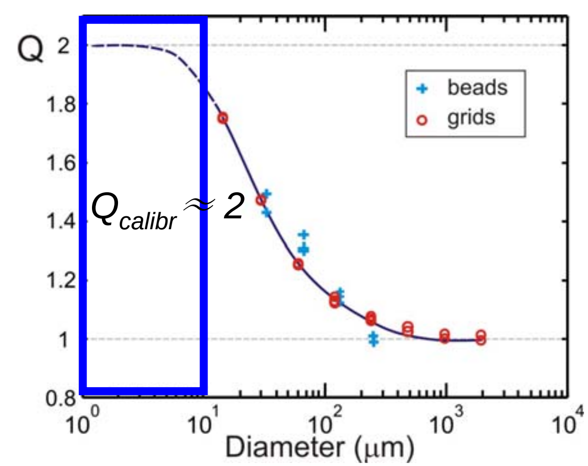
$$Q_{instr} = 2$$

$$Q_{calibr} \approx 2$$

$$Q_{instr} = Q_{calibr}$$





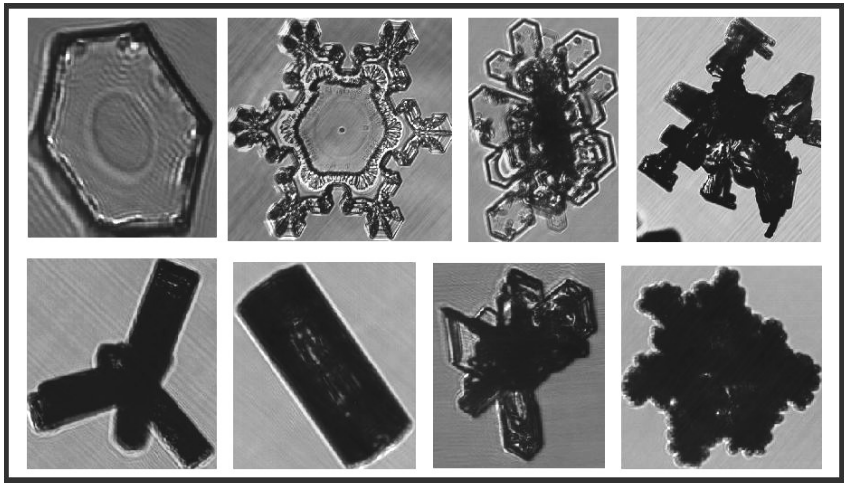


Extinction coeff. in liquid clouds measured by CEP and particle probes is in agreement with laboratory calibrations.

Size-to-area conversion technique (conventional)

$$A = aL^b$$

L-*A* parameterization



Examples of variety of different ice habits

single habit particles

$$\beta = Qa\sum_j n_j L_j^b$$

multiple particle habits

$$\beta = Q\sum_i a_i \sum_j n_{ij} L_{ij}^{b_i}$$

L particle size
A particle area
$Q \approx 2$ extinction efficiency

$0.05 < a < 0.63$
$1.4 < b < 2$

Range of changes of a and b for different ice particle size ranges and habits

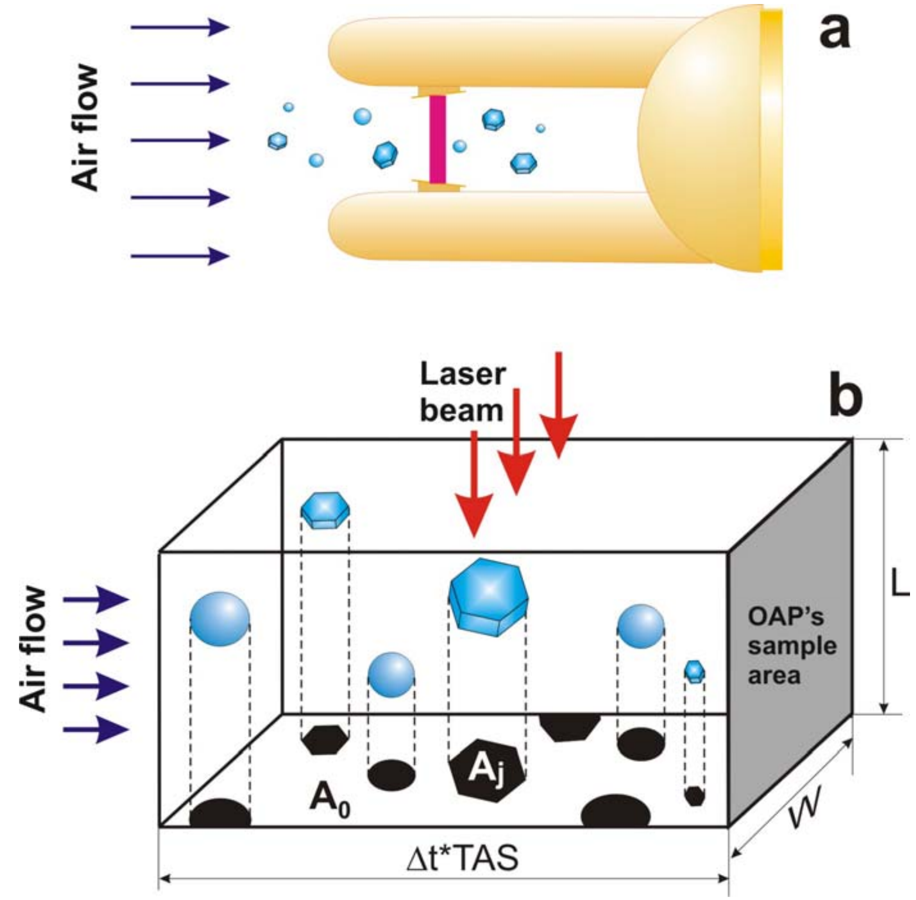
Techniques for calculations of the extinction coefficient from 2D imagery

Shadow-Area Technique (Korolev, 2008)

$$\beta_{OAP} = \frac{Q}{LA_0}\sum_j A_j$$

$$\boxed{\beta_{OAP} = \frac{Q}{LWU\Delta t}\sum_j A_j}$$

L length of the sample area
W width of the sample area
U air speed
$Q \approx 2$ extinction efficiency



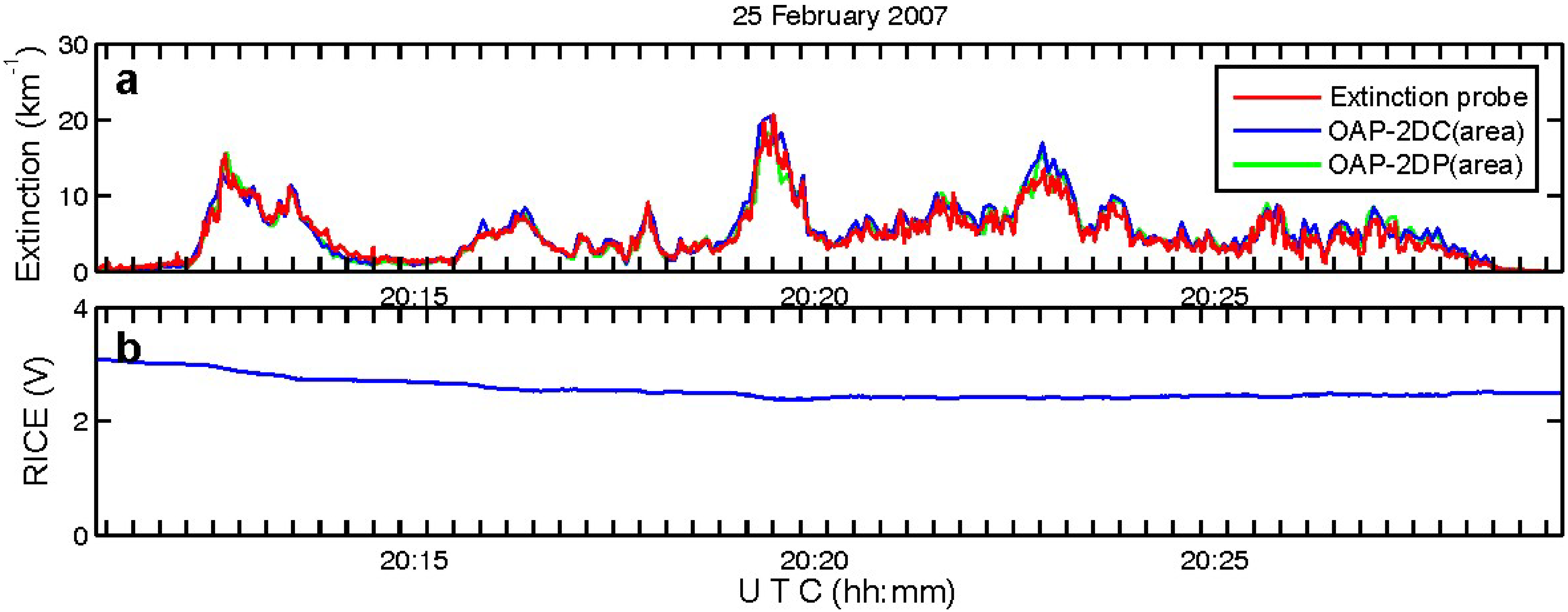
ASSUMPTIONS:

1. Ice particles with D<100μm have low contribution to the extinction coeff.
2. The measured 2D images preserve the aspect ratio of the particle shadowgraphs

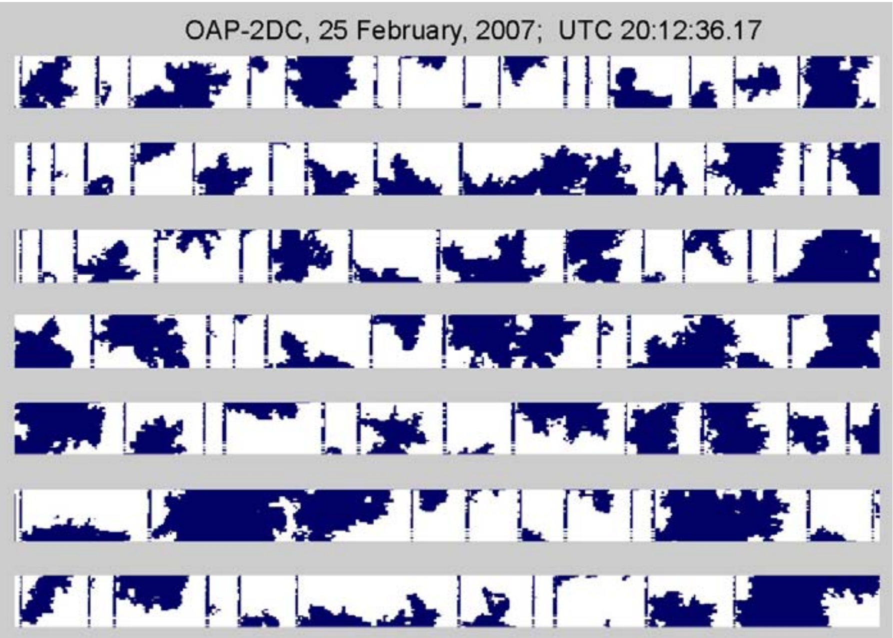
ADVANTAGES:

1. Free of errors related to partial images
2. Does not require multiple 2D probes to cover entire particle size range

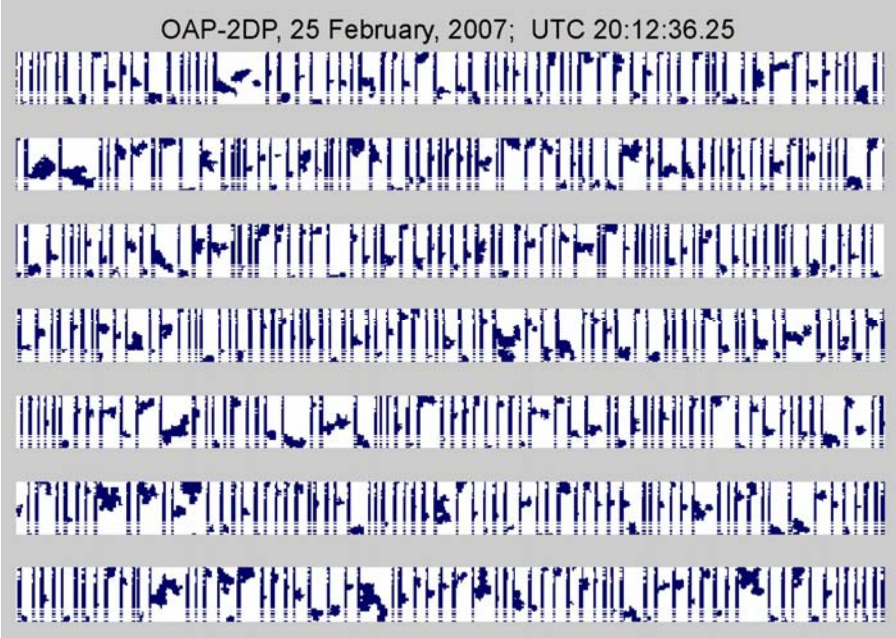
Ice clouds



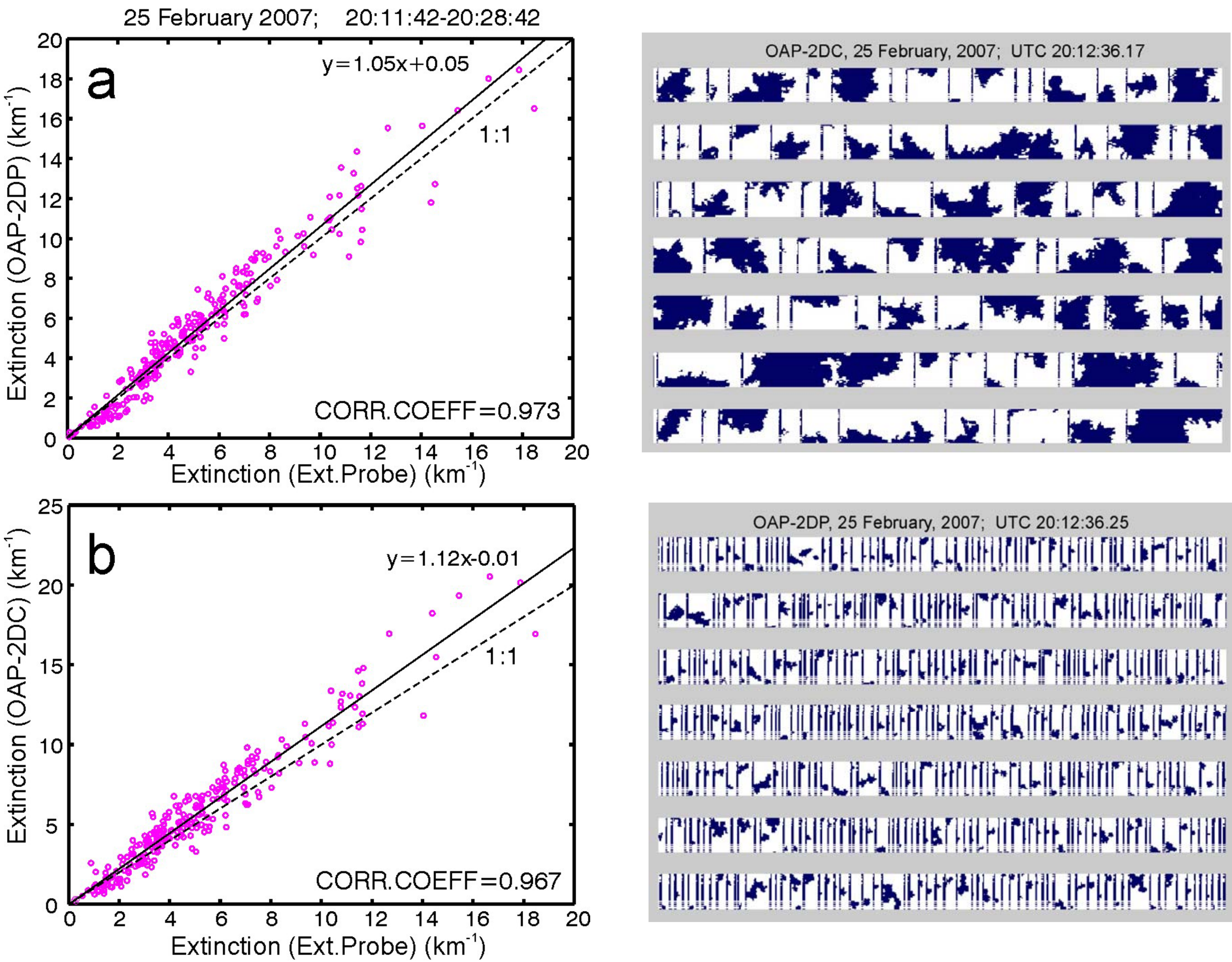
25 February 2007
a
Extinction (km^{-1})
30
20
10
0
Extinction probe
OAP-2DC(area)
OAP-2DP(area)
20:15
20:20
20:25
b
RICE (V)
4
2
0
20:15
20:20
20:25
U T C (hh:mm)



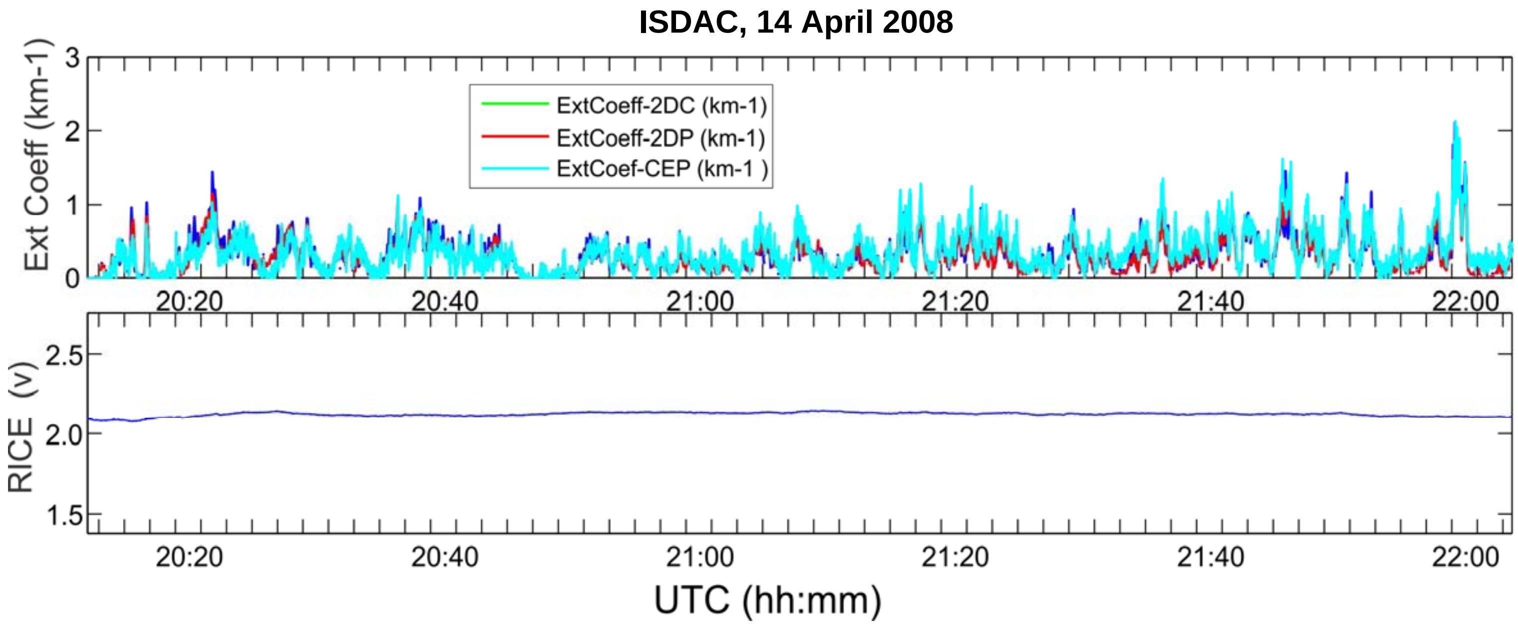
OAP-2DC, 25 February, 2007; UTC 20:12:36.17

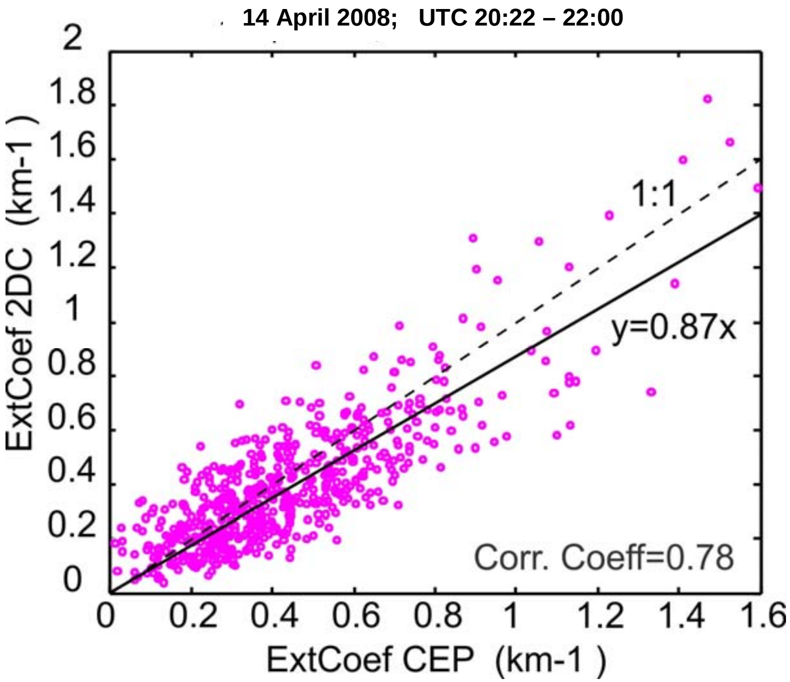


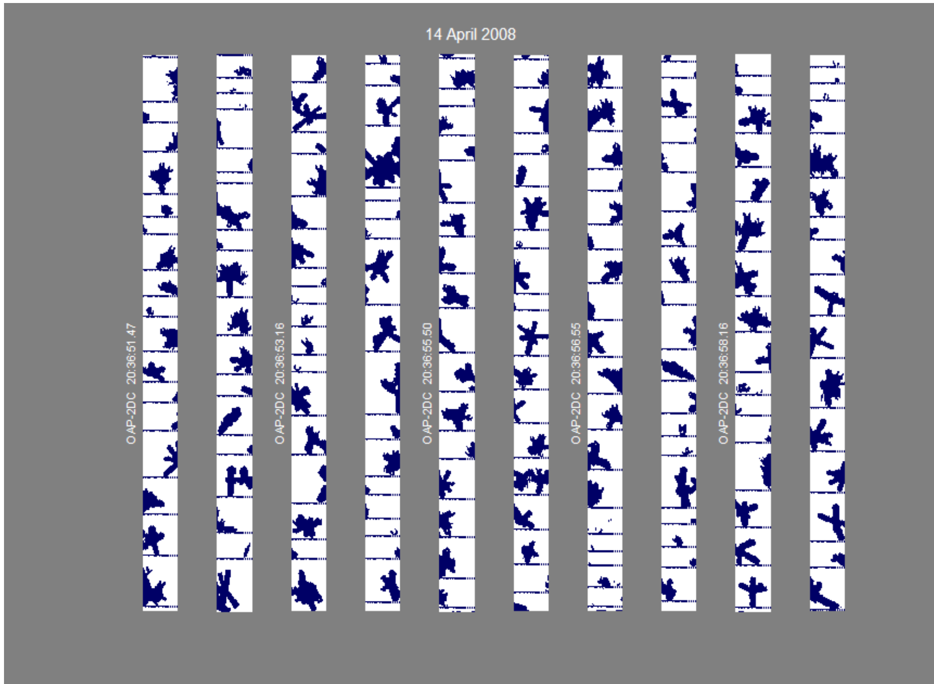
OAP-2DP, 25 February, 2007; UTC 20:12:36.25


25 February 2007; 20:11:42-20:28:42
a
y=1.05x+0.05
1:1
CORR.COEFF=0.973
Extinction (OAP-2DP) (km^{-1})
Extinction (Ext.Probe) (km^{-1})
0
2
4
6
8
10
12
14
16
18
20
OAP-2DC, 25 February, 2007; UTC 20:12:36.17
b
y=1.12x-0.01
1:1
CORR.COEFF=0.967
Extinction (OAP-2DC) (km^{-1})
Extinction (Ext.Probe) (km^{-1})
0
5
10
15
20
25
OAP-2DP, 25 February, 2007; UTC 20:12:36.25

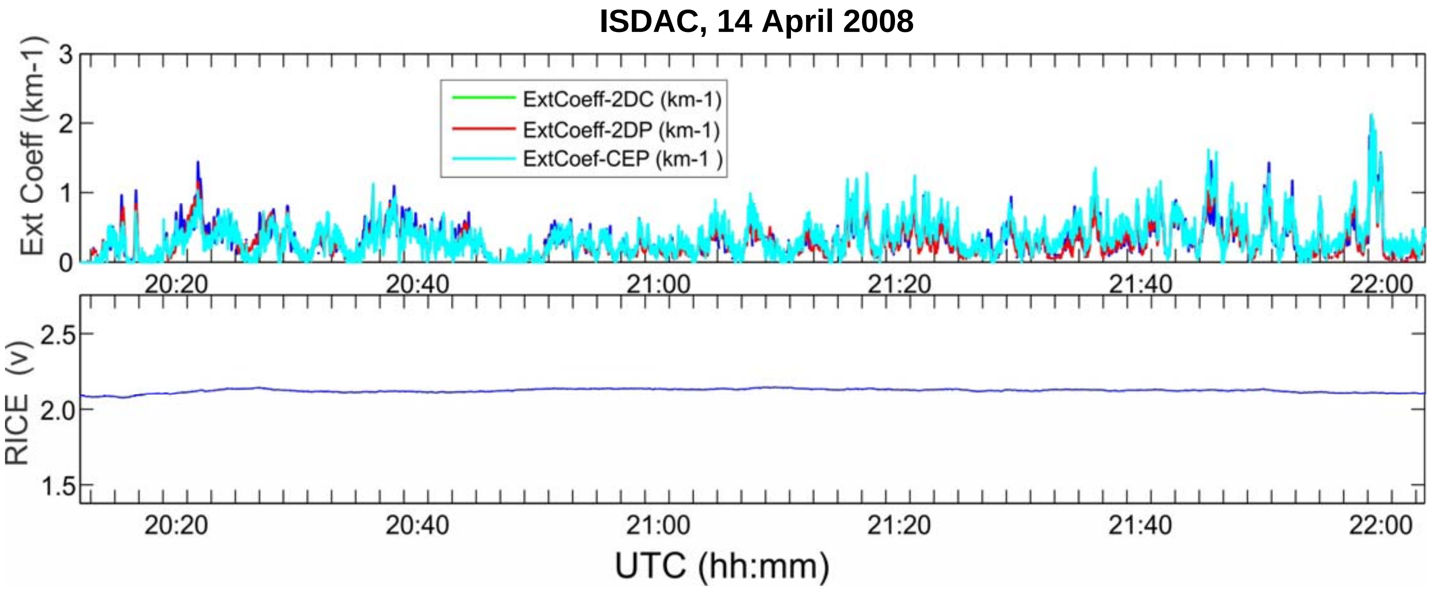
Extinction coefficient measurements in ice clouds during ISDAC







Extinction coefficient measurements in ice clouds during ISDAC

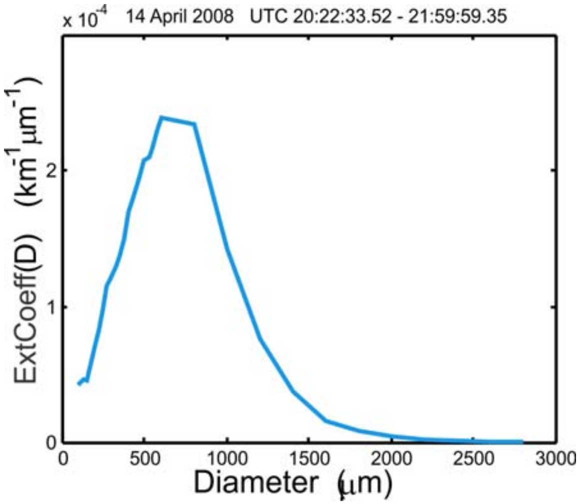


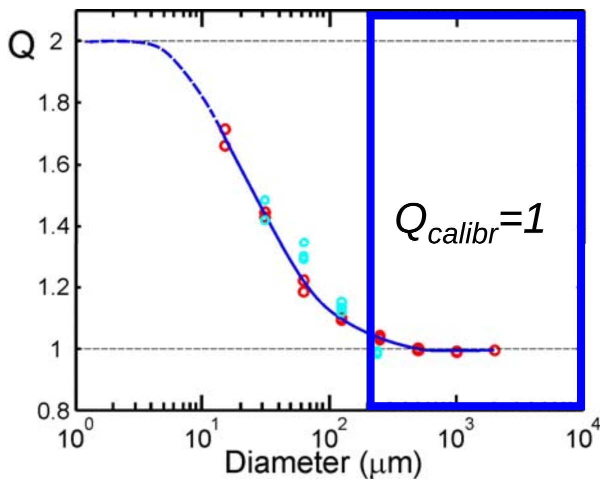
$$\beta_{2D} = \frac{Q_{instr}}{LA_0} \sum_j A_j$$

Q_{instr}=2

Q_{calibr}=1

$Q_{instr} \neq Q_{calibr}$





Extinction coeff. in liquid clouds measured by CEP and particle probes is in agreement with each other, but contradict laboratory calibrations.

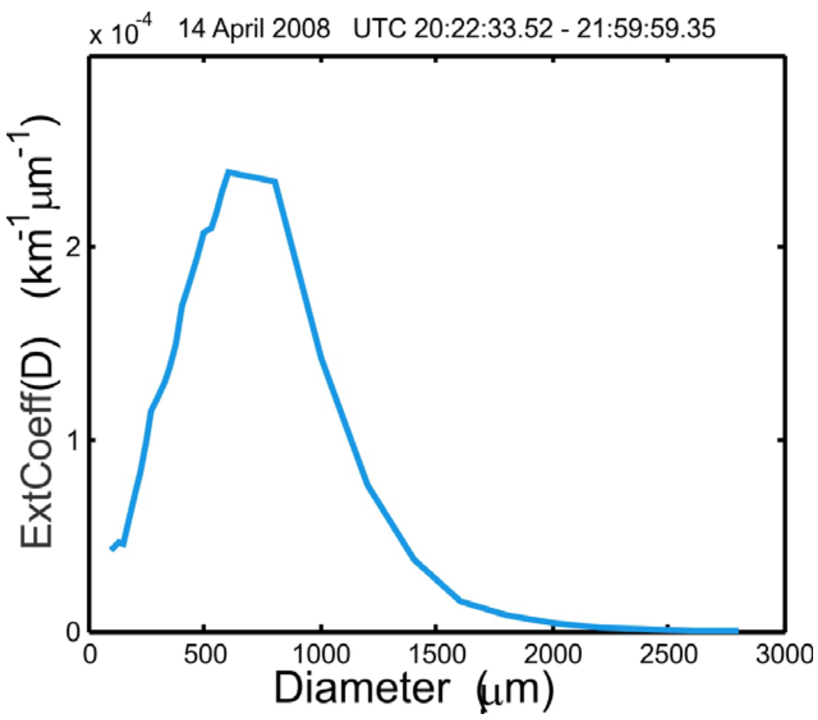
Conclusions

1. Extinction coefficient measured by CEP in liquid clouds agrees well with that derived from particle probes in assumption that Q=2.
This result is in agreement with the laboratory calibrations.

2. Extinction coefficient measured by CEP in ice clouds agrees well with that derived from 2D probes in assumption that Q=2.
This result contradicts the laboratory calibrations.

Hypothesis #1

Issues with particle size distribution measurements: e.g. shattering, oversizing, etc.



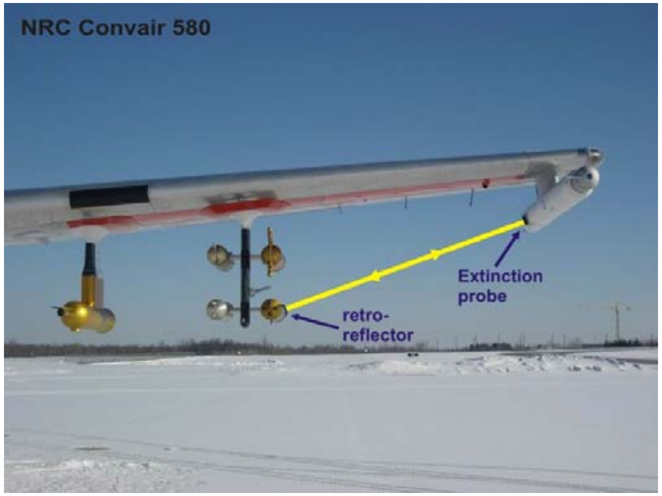
- Antishattering tips were used during ISDAC. Shattering cannot explain factor 2 difference.

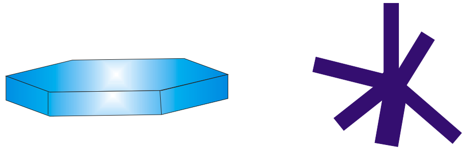
- To explain factor 2 error in particle area, the sizing error should be factor 1.4.

Hypothesis #2

Particle orientation. Extinction coefficient measured in horizontal and vertical directions are different in ice clouds.

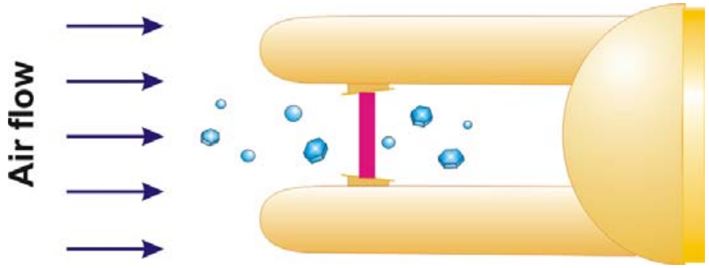
CEP measures extinction coeff. in ~horizontal direction

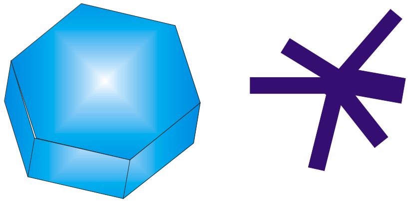




Particle projection viewed by CEP

2D probes measure extinction coeff. in vertical direction

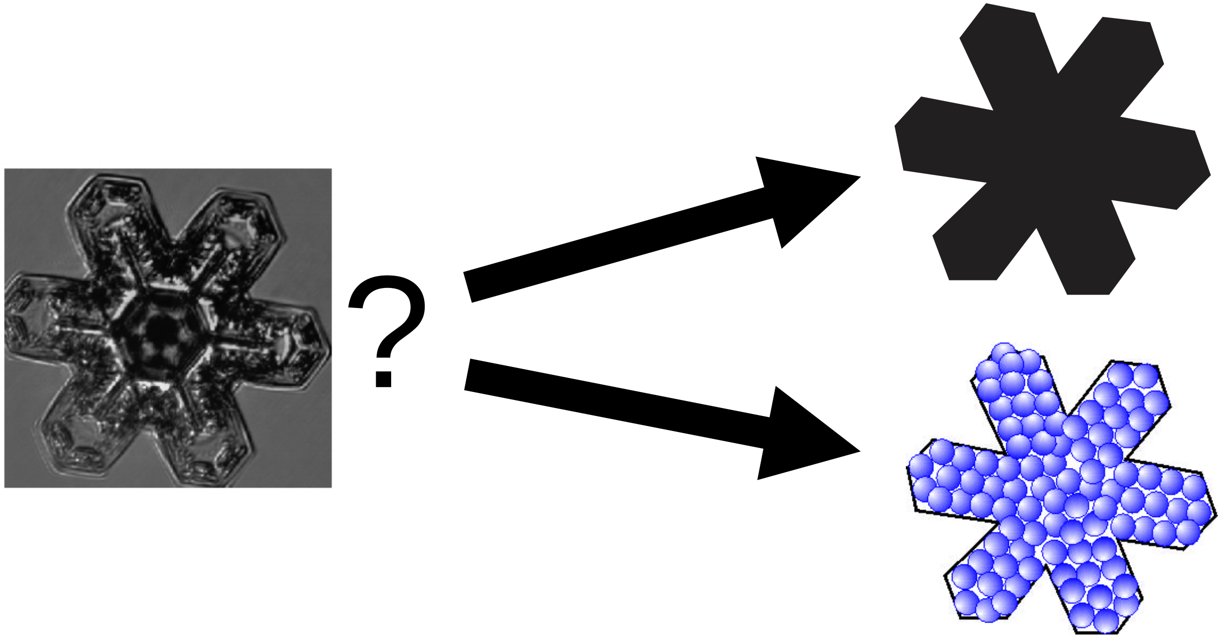




Particle projection viewed by 2D probes

Hypothesis #3

Ice particles attenuate light like an ensemble of small particles, rather than one big opaque screen.



Conclusive remarks :

1. Do we understand ice particle measurements?

2. Do we understand how ice particles scatter light?

Acknowledgements:

ACRF DOE proposal: “**Parameterization of Extinction Coefficient in Ice and Mixed-Phase Arctic clouds during the ISDAC Project**“ proposal # “09-5755“