Measurements of Aerosol Particles

What is an aerosol ?

An aerosol is a dispersion of condensed, solid or liquid particles in suspension in a gaz.

Example:

Measurements of Aerosol Particles

What is the typical size of aerosol particles ?

From a few nanometers: a few molecules condensed

To precisely 72.87 meters

According to the standard in Toulouse

Measurements of Aerosol Particles

What is the typical size of aerosol particles ?

From a few nanometers: a few molecules condensed

To a few centimeters: hailstones

Measurements of Aerosol Particles

What means a distribution ?

The parameter of interest, F, for an aerosol can be

- the number concentration (cm^{-3})
- the extinction (km^{-1})
- the mixing ratio ($g\ kg^{-1}$ or $g\ m^3$)

…… any extensive property of a population of particles, with different sizes, mass, chemical composition,…...

A distribution, or spectrum, describes how that parameter is distributed over size, mass, …..

Measurements of Aerosol Particles

What means a distribution ?

x measures the particle property, size, mass,……

$F(x-,x+)$ is the parameter of interest, and $x-$, $x+$ are the smallest, largest x values

The spectrum is dF/dx

How to select x ?

As an example, F is the particle concentration: C

and x is the particle radius: r

$c(r)=dC/dr$ is the particle size spectrum

Measurements of Aerosol Particles

What means a distribution ?

$c(r)=dC/dr$ is the particle spectrum,

How would you define it ?

~~$c(r)$ is the concentration of particles with a radius between r and $r+dr$~~

$c(r)$ is the **concentration density** of particles at the radius r

$$(cm^{-3}\ \mu m^{-1})$$

Measurements of Aerosol Particles

How to measure a distribution ?

$c(r)=dC/dr$ is the particle spectrum,

But any instrument has a limited size resolution

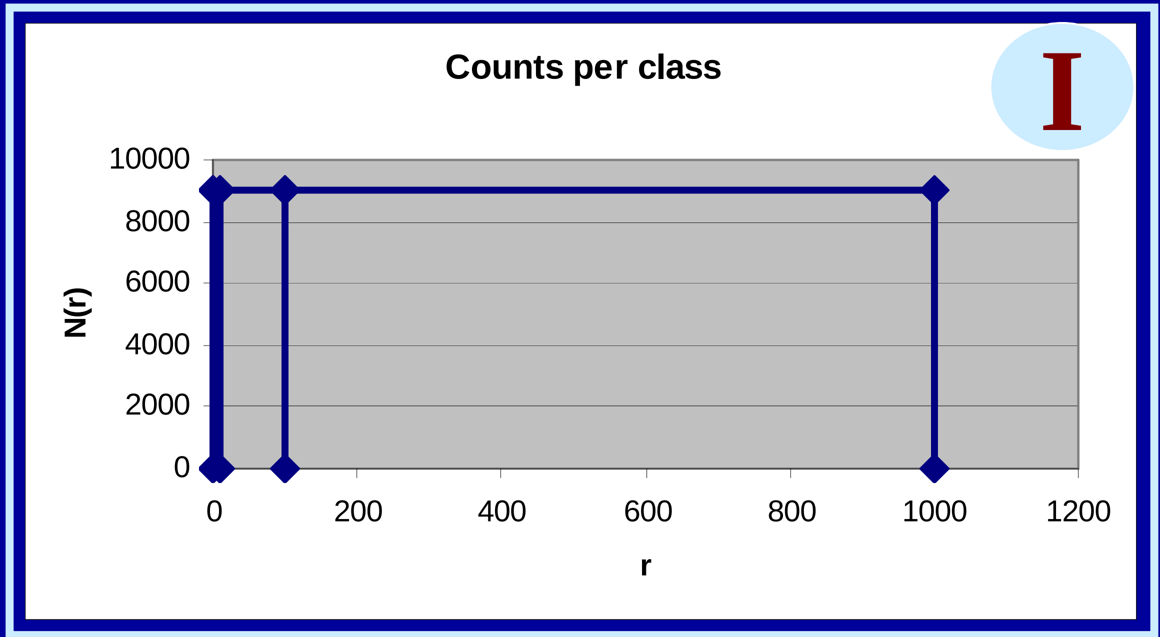
One can only approach $c(r)$ by measuring the concentration of particles in size classes, that have a finite width: $\Delta ri=ri_{max}-ri_{min}$

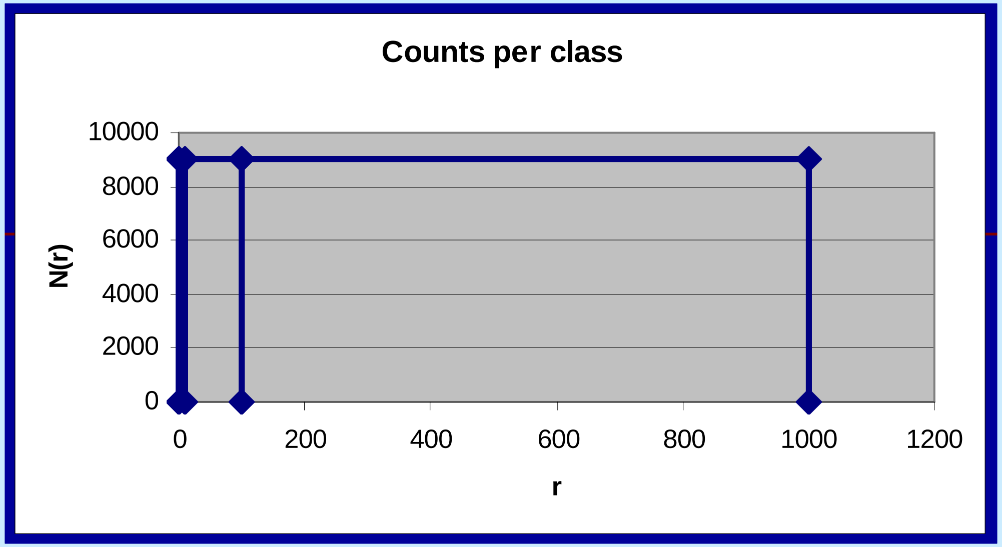
$$Ni \ \ (cm^{-3})$$

Measurements of Aerosol Particles

How to plot a distribution ?

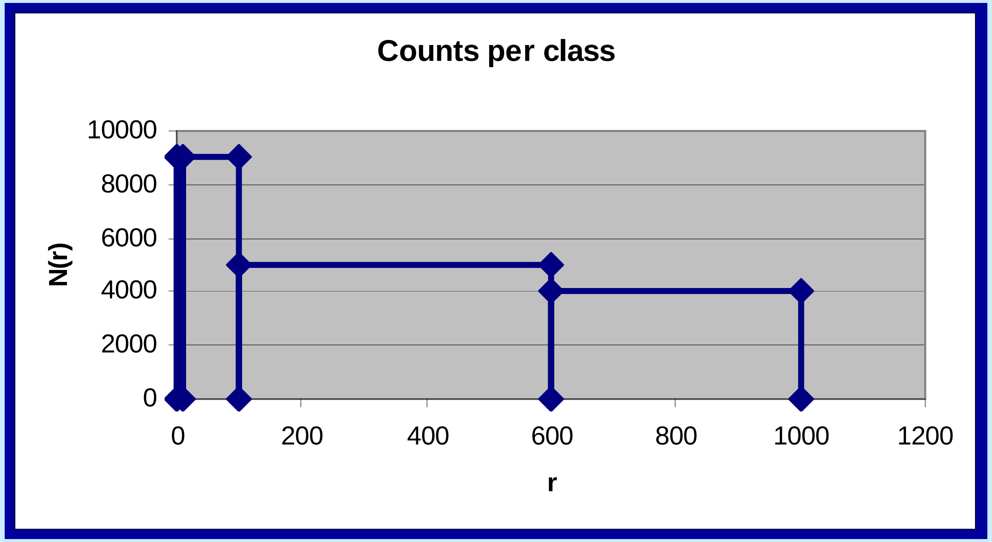
Size classes (µm)	Counts per class Ni
0.1-1	9000
1-10	9000
10-100	9000
100-1000	9000





Size classes (µm)	Counts per class Ni
0.1-1	9000
1-10	9000
10-100	9000
100-1000	9000

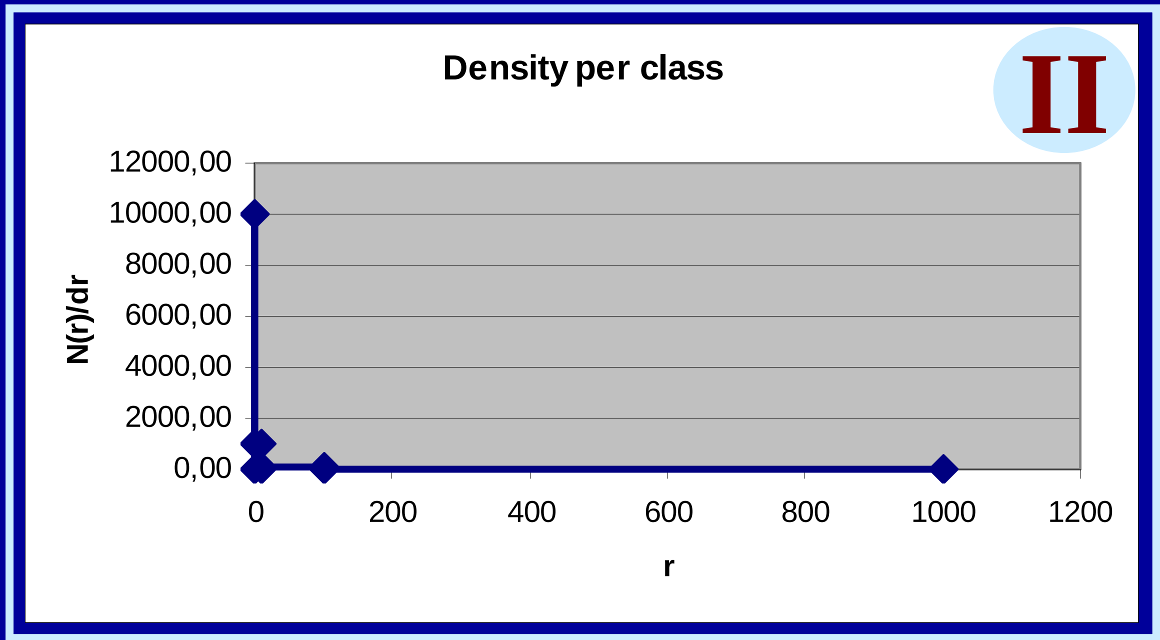
Δri	Ni
0.1-1	9000
1-10	9000
10-100	9000
100-600	5000
600-1000	4000



Measurements of Aerosol Particles

How to plot a distribution ?

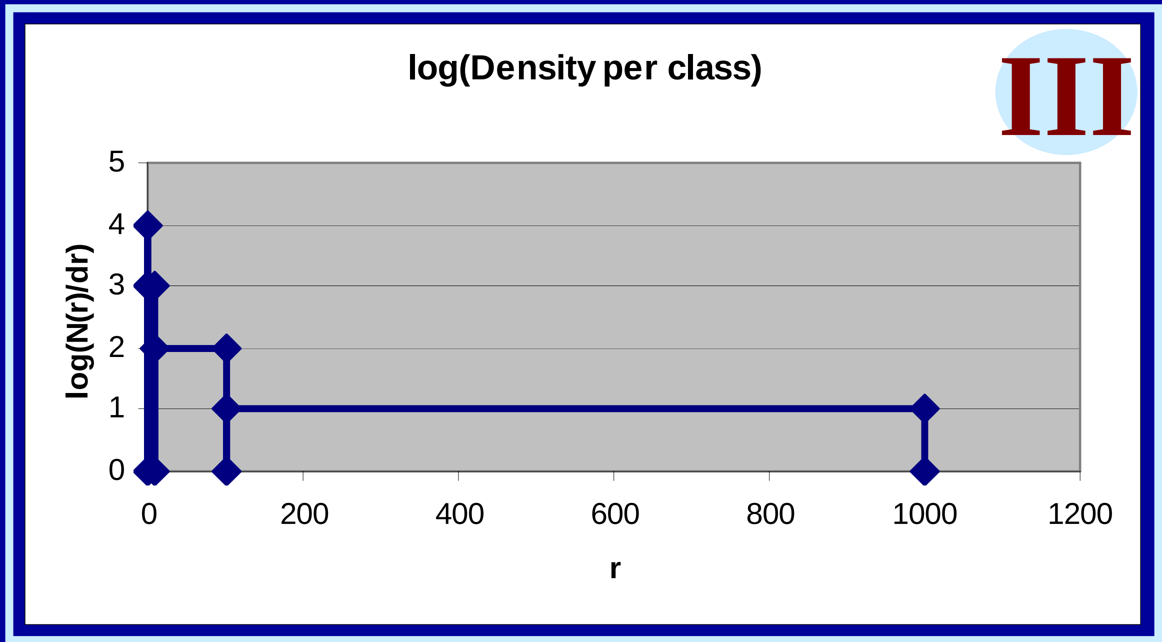
Size classes (µm)	Counts per class Ni	Ni/Δri (µm^{-1})
0.1-1	9000	10000
1-10	9000	1000
10-100	9000	100
100-1000	9000	10



Measurements of Aerosol Particles

How to plot a distribution ?

Size classes (µm)	Counts per class Ni	Log(Ni/Δri)
0.1-1	9000	4
1-10	9000	3
10-100	9000	2
100-1000	9000	1



Measurements of Aerosol Particles

How to plot a distribution ?

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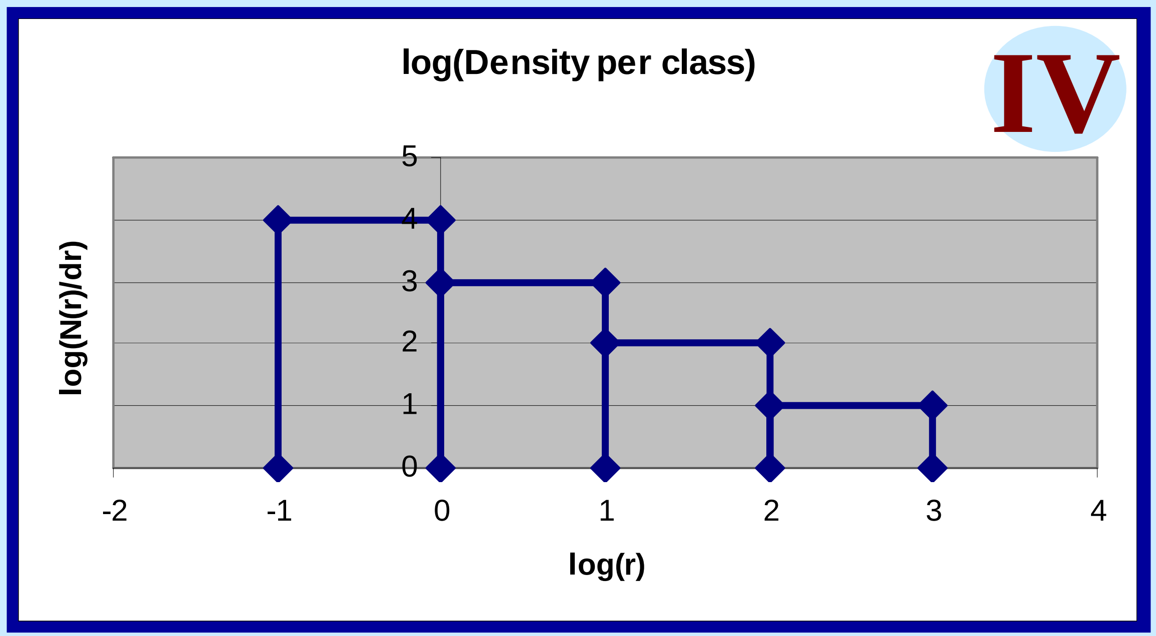
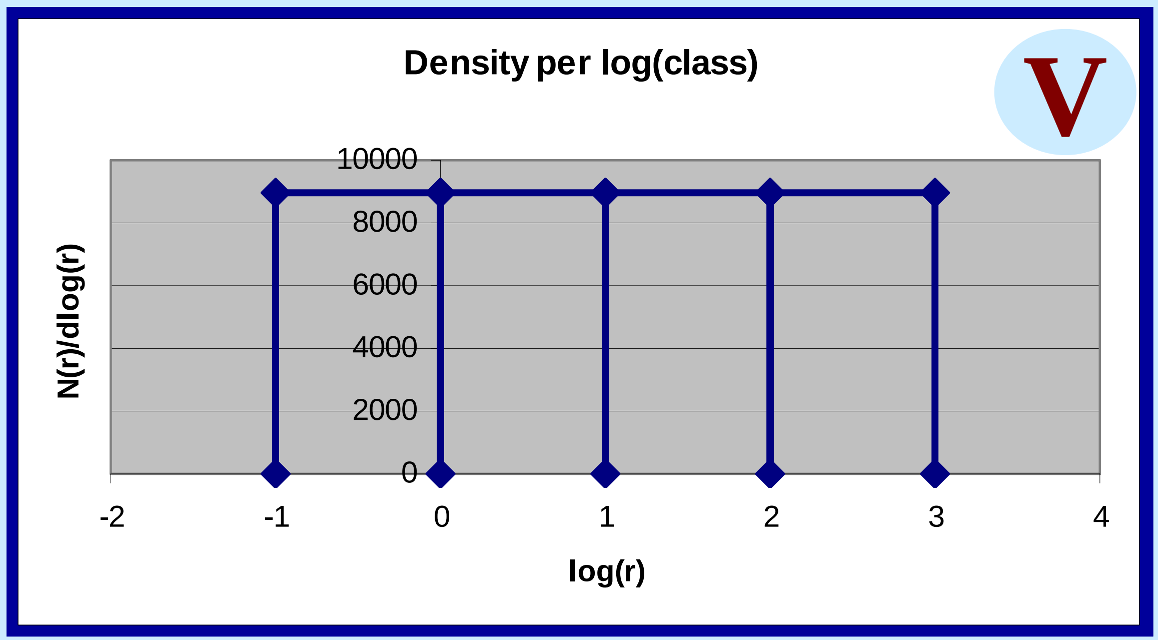


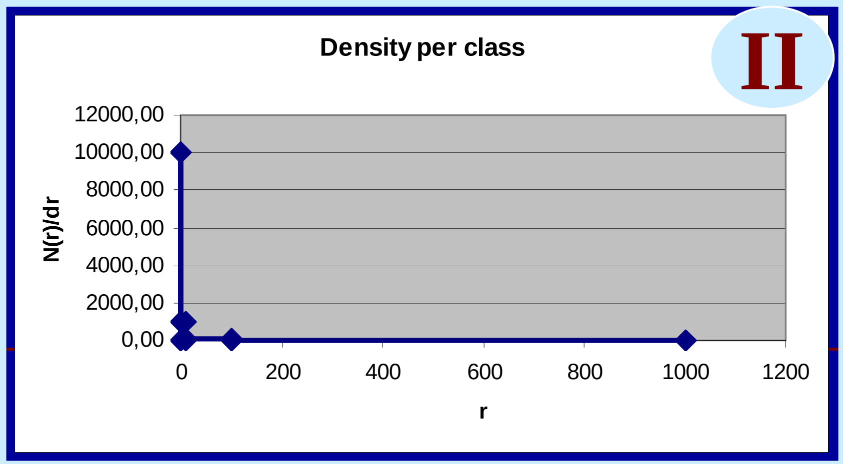
Measurements of Aerosol Particles

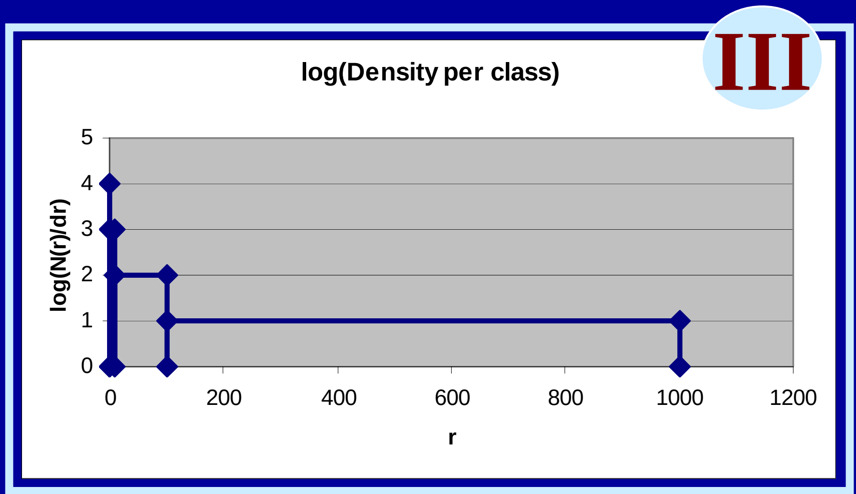
How to plot a distribution ?

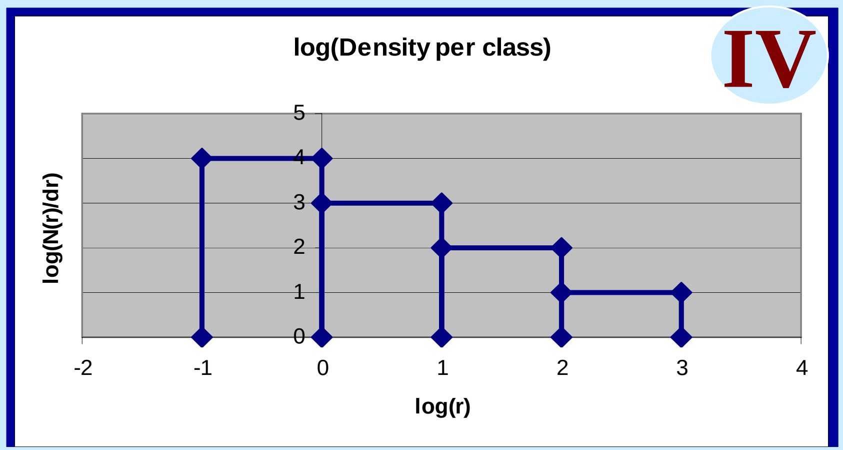
Size classes (µm)	Counts per class Ni	Ni/ Δlog(ri)
0.1-1	9000	9000
1-10	9000	9000
10-100	9000	9000
100-1000	9000	9000



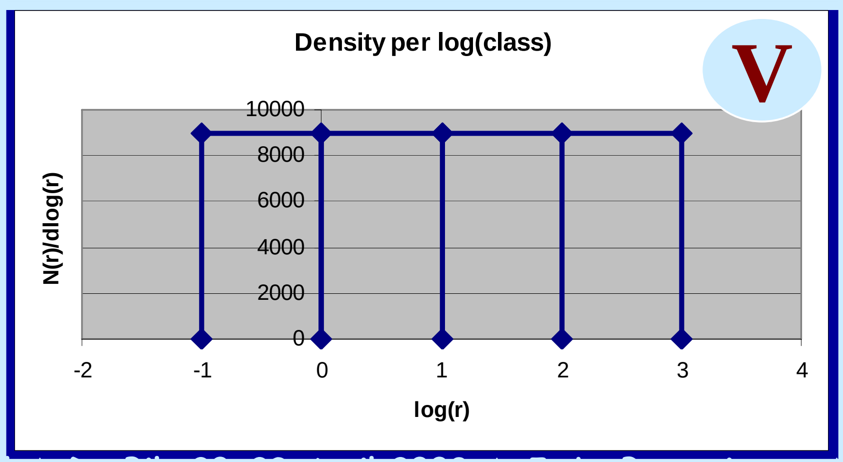
Better divide the number/class by the same unit as you use on the X axis







Δri	Ni
0.1-1	9000
1-10	9000
10-100	9000
100-1000	9000



Measurements of Aerosol Particles

How to measure a distribution ?

Particle Integrator: measures an integral property of an ensemble of particles.

Ex: phase function : $I(\theta)=\int i(\theta,r)c(r)dr$

Inverse $I(\theta)$ to get $c(r)$

Single particle counter: detects each particle as it crosses the sensitive section of the instrument, and measures its size. Cumulate counts until you have enough particles to build a statistically significant spectrum.

Measurements of Aerosol Particles

How to measure a distribution with a SPC ?
Spatial resolution/statistical significance

The uncertainty due to randomness of counting decreases as: $\mathbf{N^{-1/2}}$
An estimation based on 100 counts is within ±10%
An estimation based on 1000 counts is within ±3%

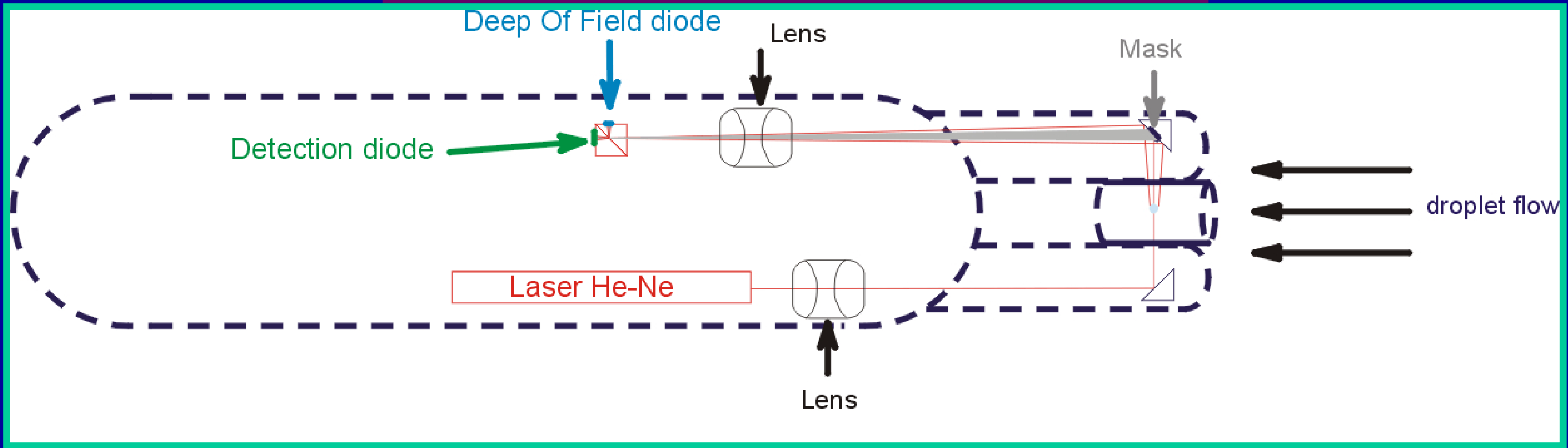
The aircraft moves while the counter is cumulating detected particles.

A measured spectrum is always a compromise between spatial resolution and statistical significance.

Measurements of Aerosol Particles

Microscale studies

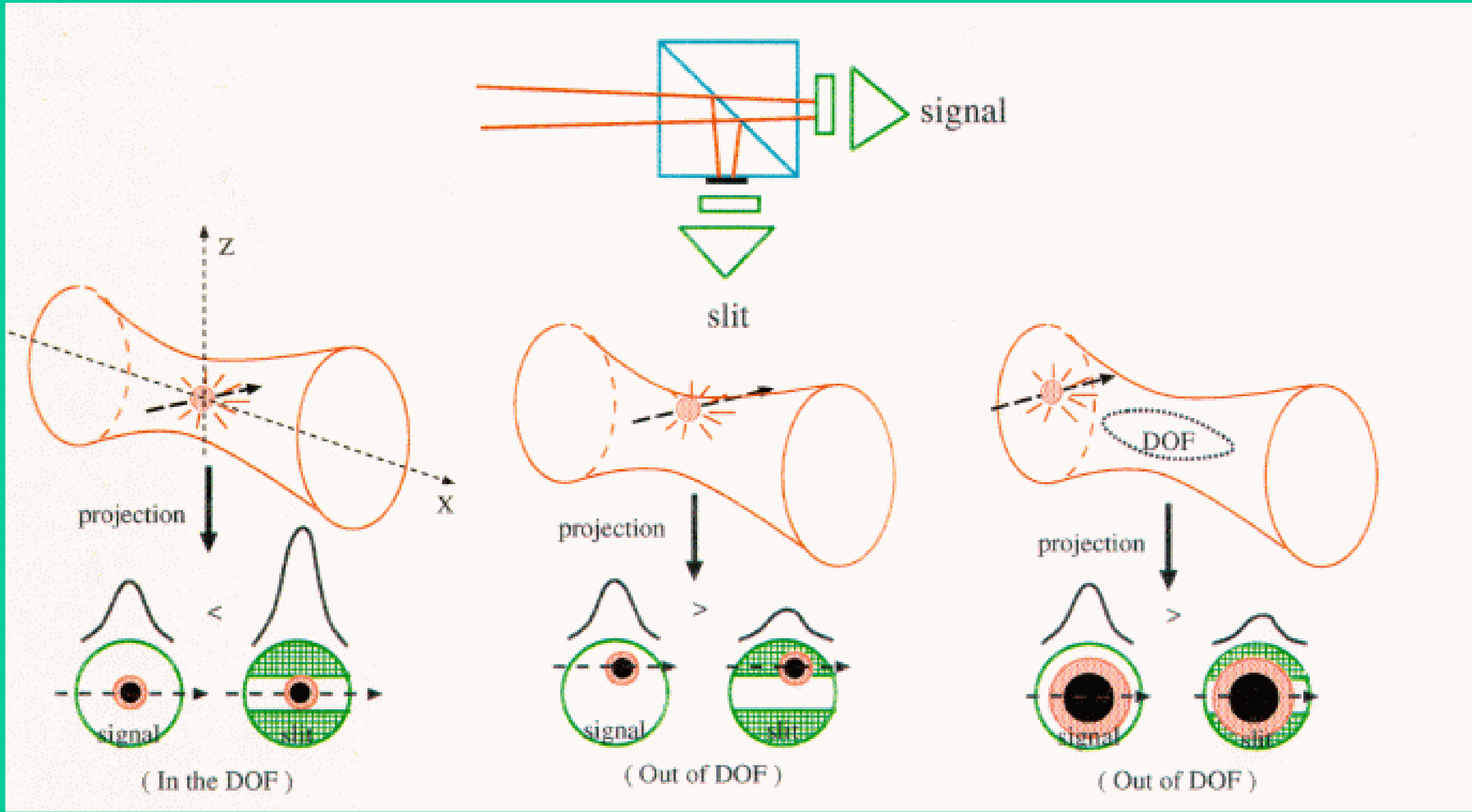
Overal schematics of the FSSP



Measurements of Aerosol Particles

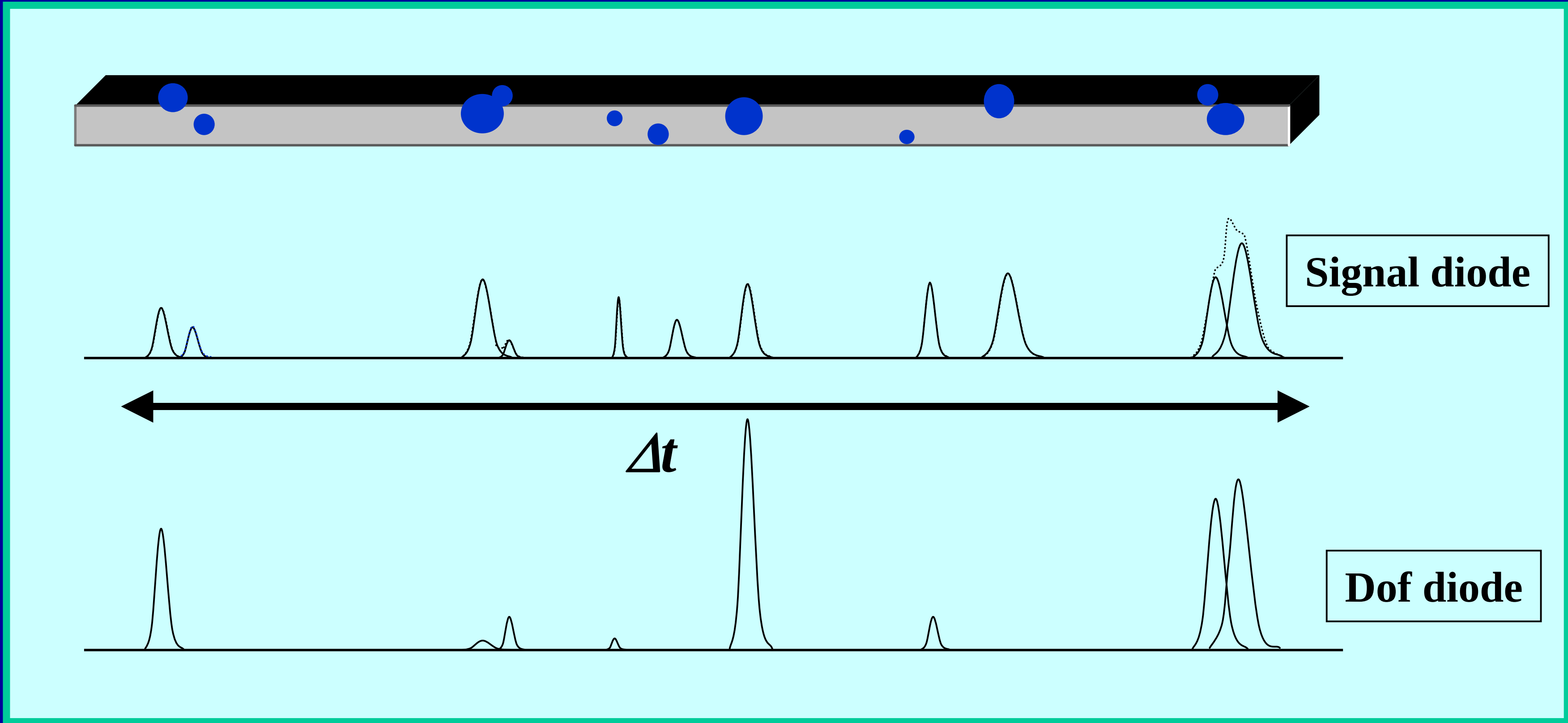
Microscale studies

Depth of field selection



Measurements of Aerosol Particles

Microscale studies

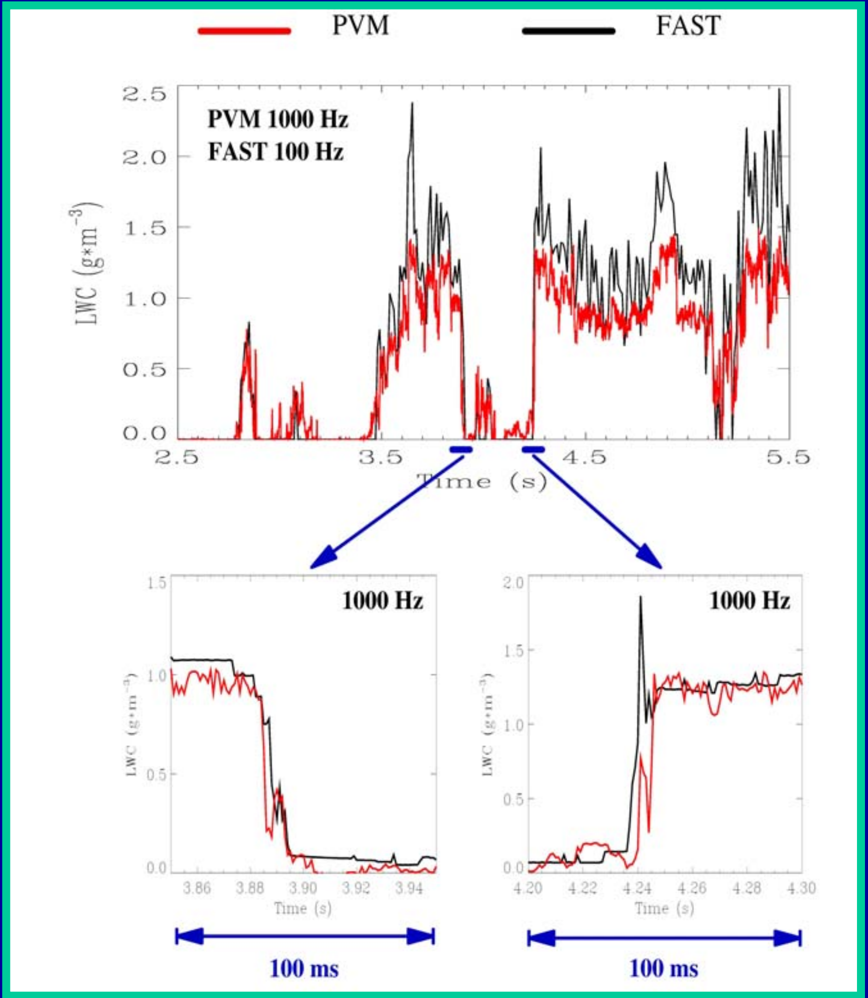


$N_i = n_i / (S\ v\ \Delta t)$

$q_c = 4/3 \pi \rho_w \sum N_i\ r_i^3 = 4/3 \pi \rho_w \sum n_i\ r_i^3 / (S\ v\ \Delta t)$

Measurements of Aerosol Particles

Microscale studies



The FSSP counts up to 100 000 particles per second, i.e. 100 m spatial resolution. 10 % are sized.

Processing at 100 Hz, i.e. 1 m spatial resolution, means about 100 particles available for calculation of LWC

At a higher sampling rate, finer spatial resolution, the estimation of LWC is noisy because of randomness of the counting process

Measurements of Aerosol Particles

Microscale studies

What is the maximum liquid water content measurable with a single particle counter in a cloud ?

1 gm^{-3}

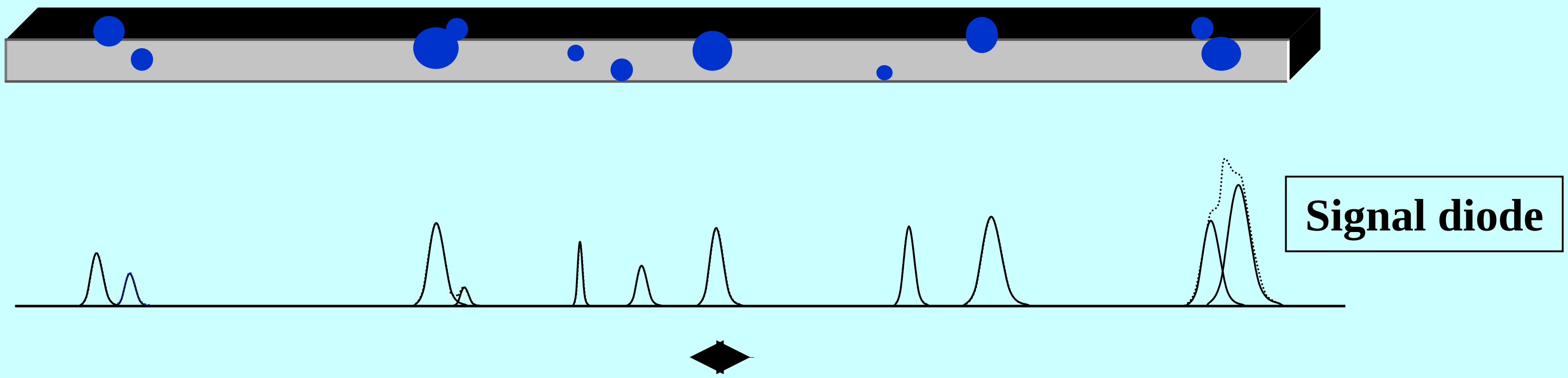
10 gm^{-3}

1000 gm^{-3}

10^6 gm^{-3}

Measurements of Aerosol Particles

Microscale studies



$\Delta t = 2\ 10^{-7}\ s$

$N_i = n_i / (S\ v\ \Delta t)$ $\quad q_c = 4/3 \pi \rho_w \sum N_i\, r_i^3 = 4/3 \pi \rho_w \sum n_i\, r_i^3 / (S\ v\ \Delta t)$

When $\Delta t < 0.1\ \mu s$, a sample shorter than the droplet diameter

The limit is q_{cmax} = *1000 kg* m^{-3}

Measurements of Aerosol Particles

Microscale studies

Counting particles is a random heterogeneous Poisson process

Each cloud traverse is a single realization of that random process

How is it possible to get a realistic estimation of the concentration (or LWC) from a single realization ?

The estimation based on N counts, approaches the expected mean concentration over the sample, within **$\pm N^{-1/2}$**

Is it possible to get a realistic estimation with fewer particles ?

YES **But it is not easy !**

Measurements of Aerosol Particles

Optimal estimation

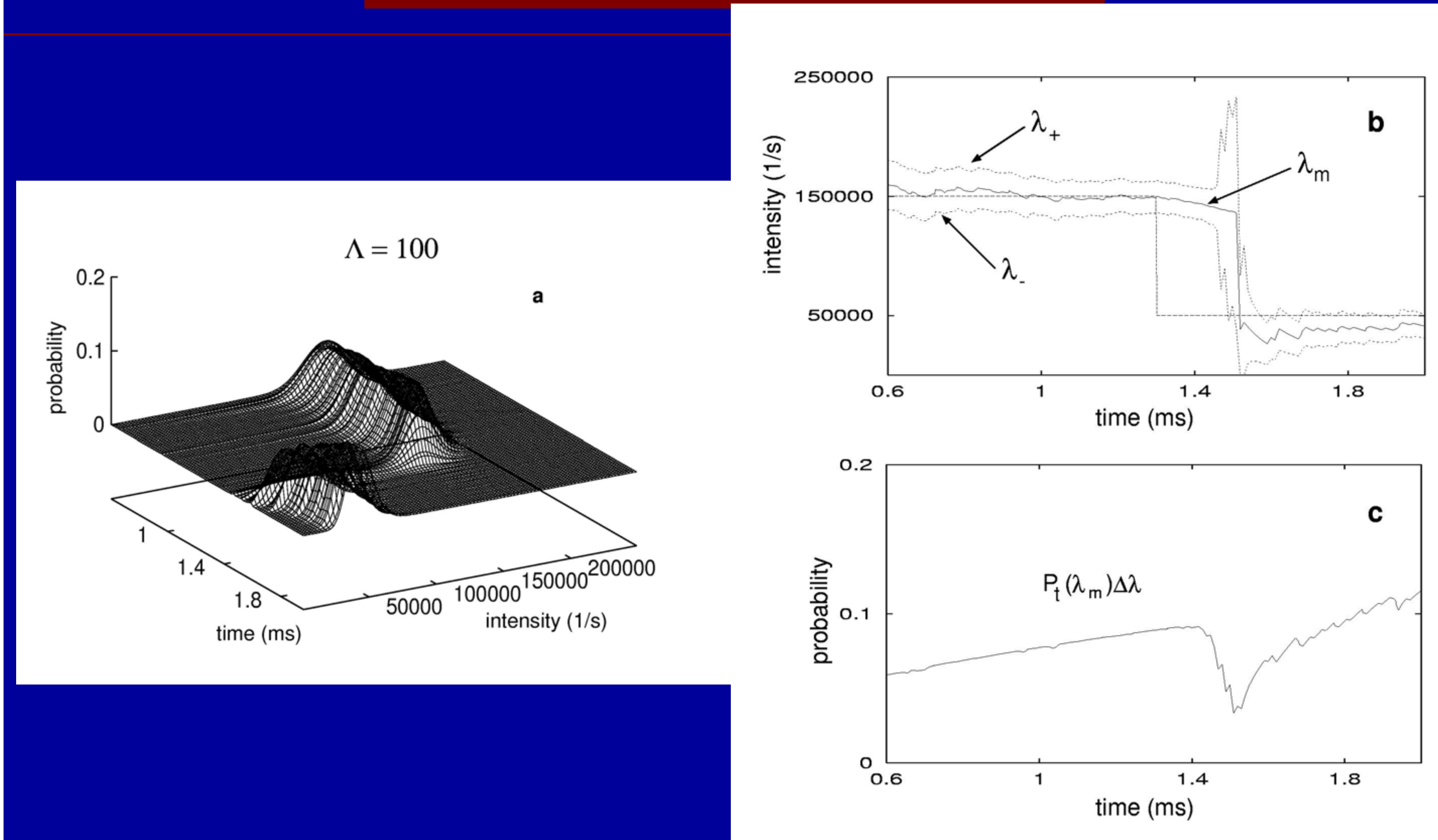
Optimal estimation allows to retrieve information based on a few counts, provided previous counts and statistical properties of the process driving concentration fluctutations.

It provides the probability density function of the possible solutions

A non-linear optimal estimator is well suited for the detection of sharp changes, such as at the cloud edge.

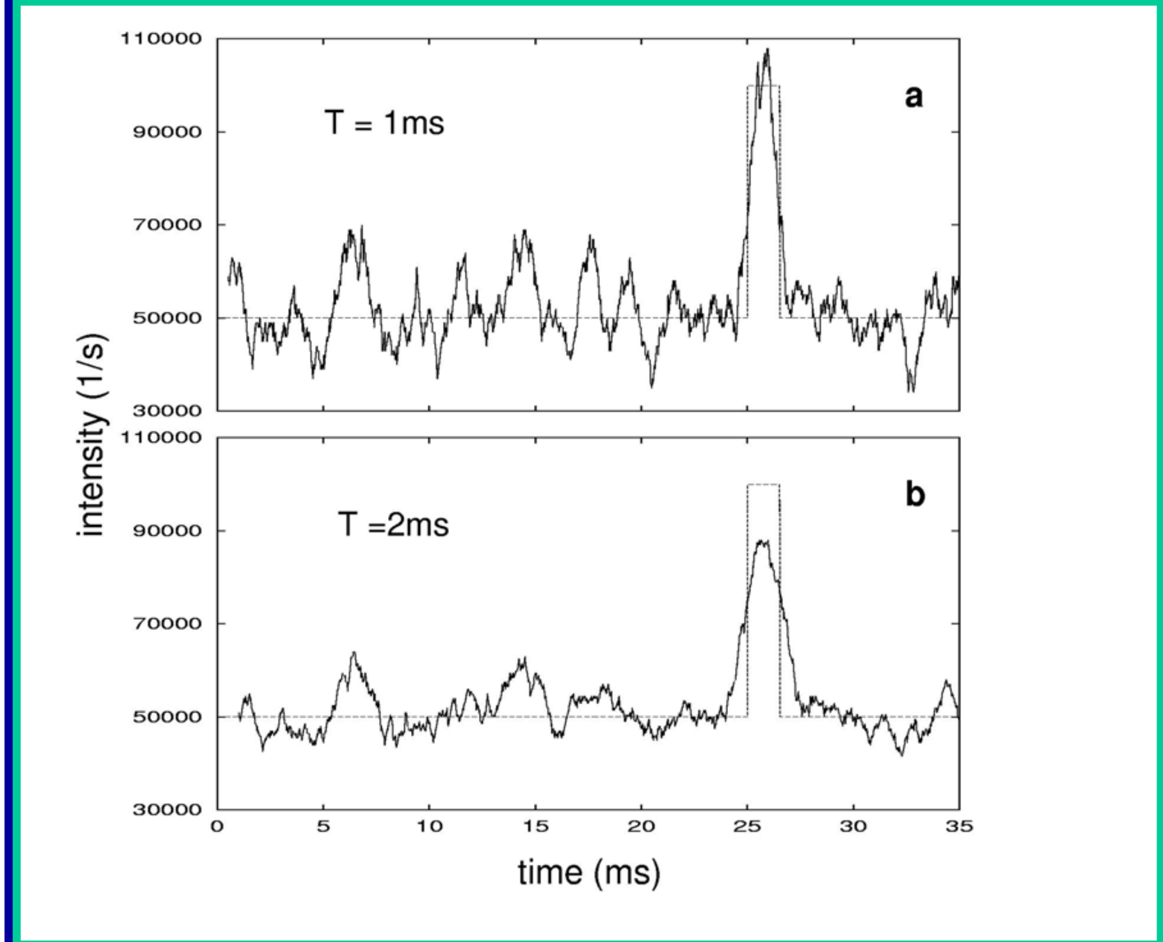
Measurements of Aerosol Particles

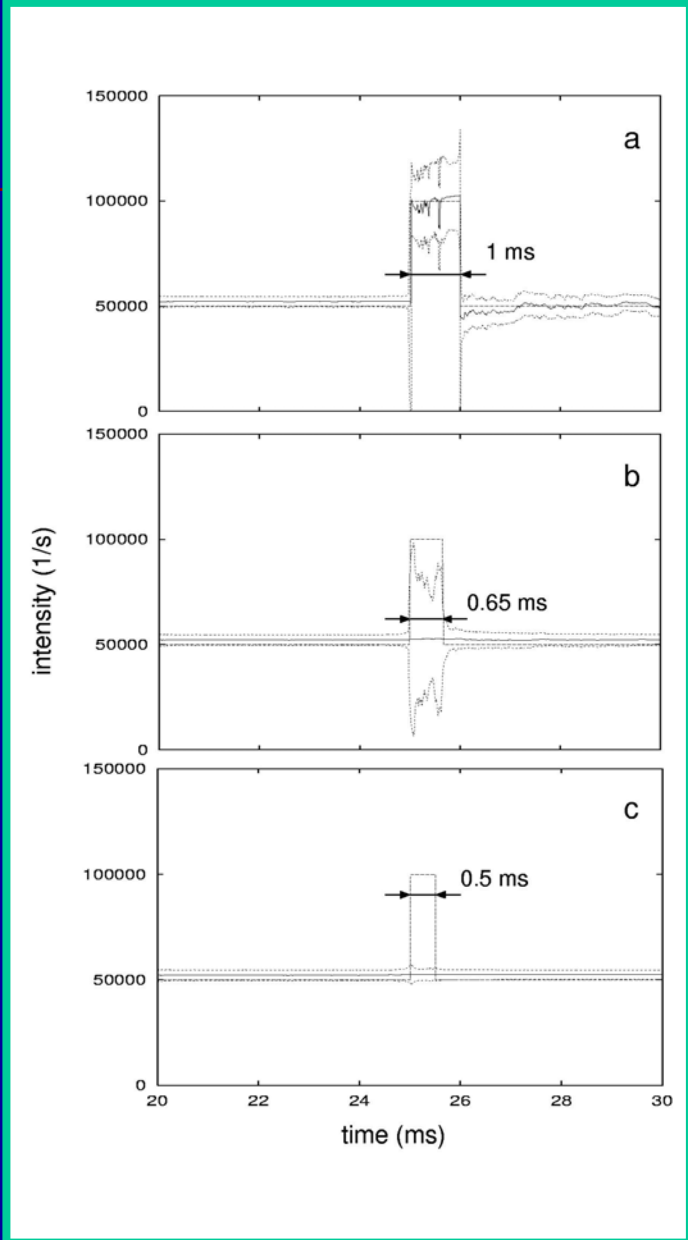
Optimal estimation



Measurements of Aerosol Particles

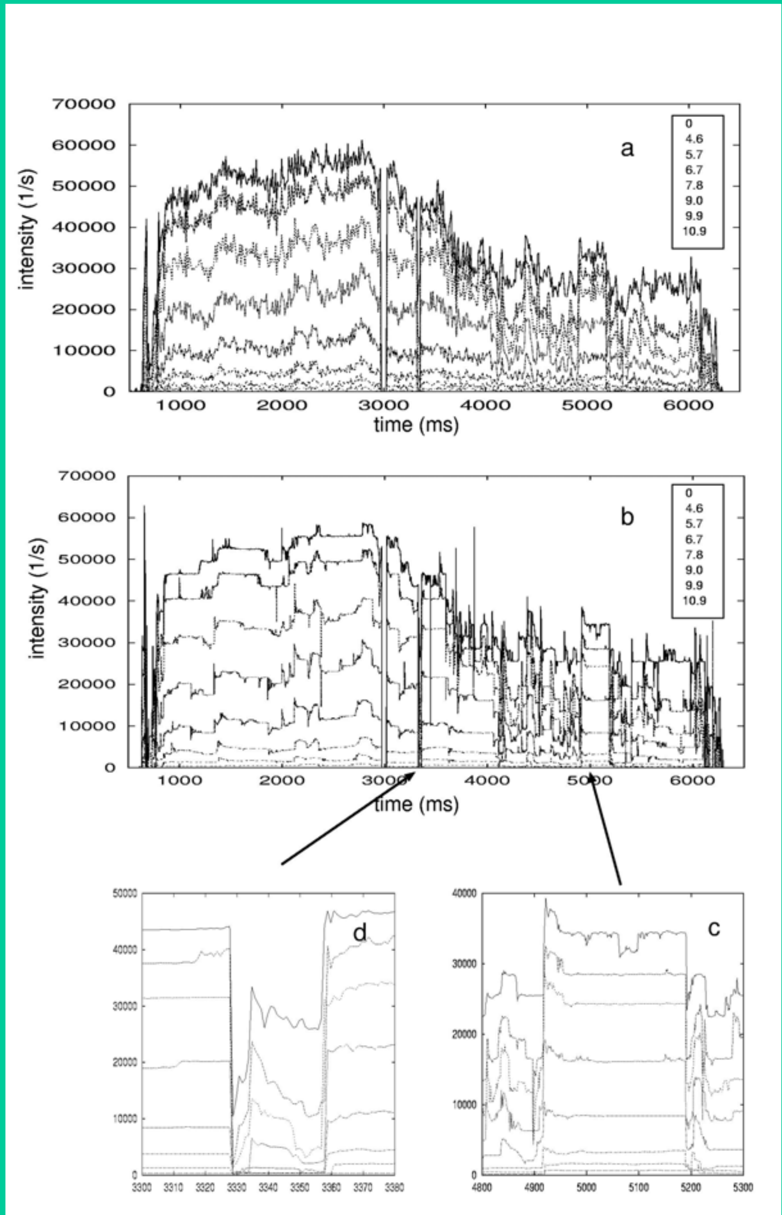
Optimal estimation





Measurements of Aerosol Particles

Optimal estimation



Measurements of Aerosol Particles

Another trick !!!!!

Extensive/Intensive Parameters

Measurements of Aerosol Particles

Impact of entrainment-mixing on cloud microphysics

In non-precipitating convective clouds, droplets are growing by water vapour diffusion, from cloud base to cloud top.

The liquid water content, however, is reduced each time drier air from the environment is entrained and mixed with the cloudy air.

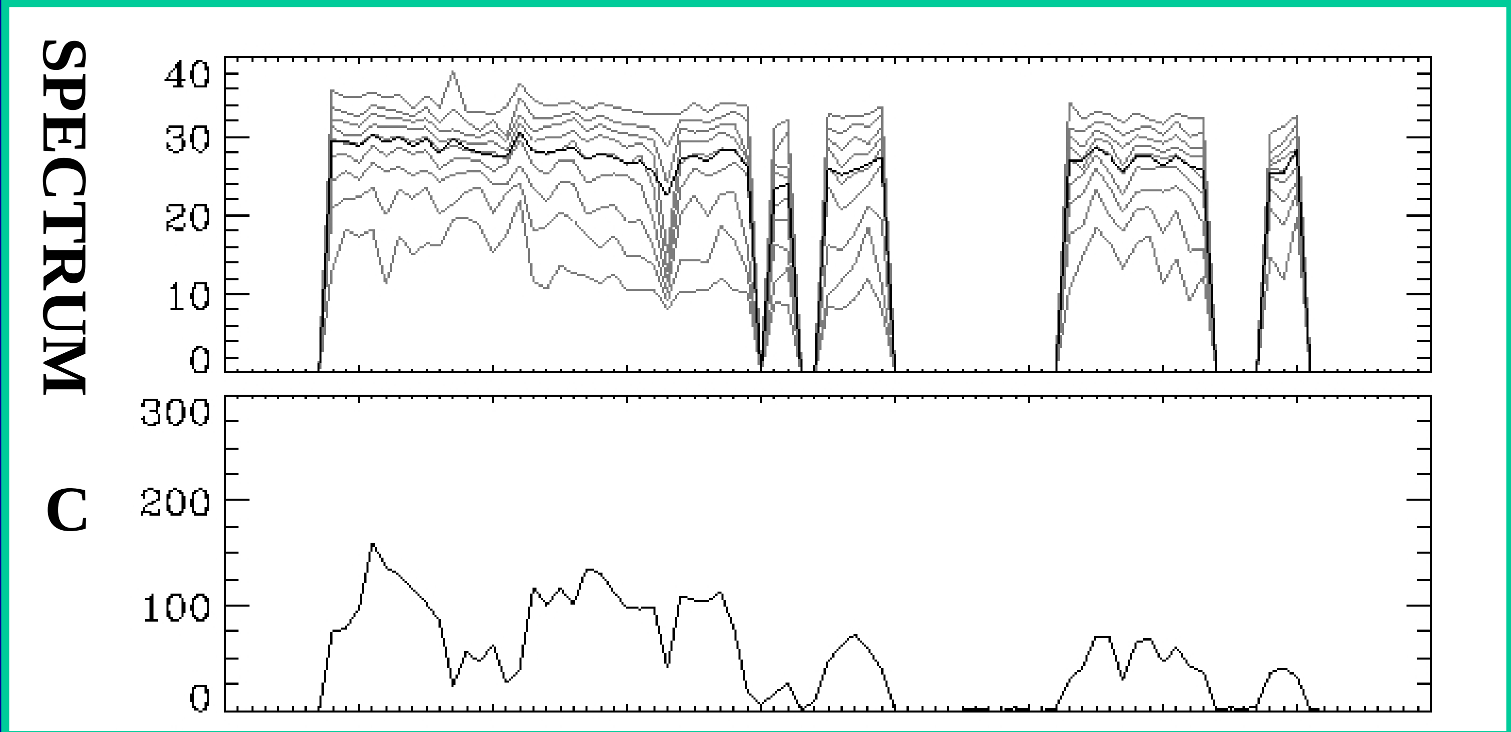
Is that LWC reduction accounted for by a decrease of the droplet sizes or a decrease of the droplet concentration ?

Most of in situ observations show that the concentration decreases, while the mean diameter is almost not affected by mixing

Measurements of Aerosol Particles

Impact of entrainment-mixing on cloud microphysics

Most of in situ observations show that the concentration decreases, while the mean diameter is almost not affected by mixing



Measurements of Aerosol Particles

Impact of entrainment-mixing on cloud microphysics

Explanation I:

If the time scale for turbulent homogeneization τ_T is much **shorter** than the droplet response time to evaporation τ_D , mixing is homogeneous, and droplet sizes shall decrease.

If , the time scale for turbulent homogeneization τ_T is much **longer** than the droplet response time to evaporation some droplets are totally evaporated, but the remaining ones are unaffected, because they finally mix with pre-moistened entrained air. Mixing is heterogeneous

Measurements of Aerosol Particles

Impact of entrainment-mixing on cloud microphysics

Explanation II:

The droplet spatial distribution in regions affected by entrainment-mixing is heterogeneous, with pure cloudy air filaments, intertwinned with clear air filaments.

Pure cloudy air: $[N_a ; \phi_{va}^3]$ and diluted air: $N_d << N_a$ and $\phi_{vd}^3 << \phi_{va}^3$

When cumulating counts over a heterogeneous section

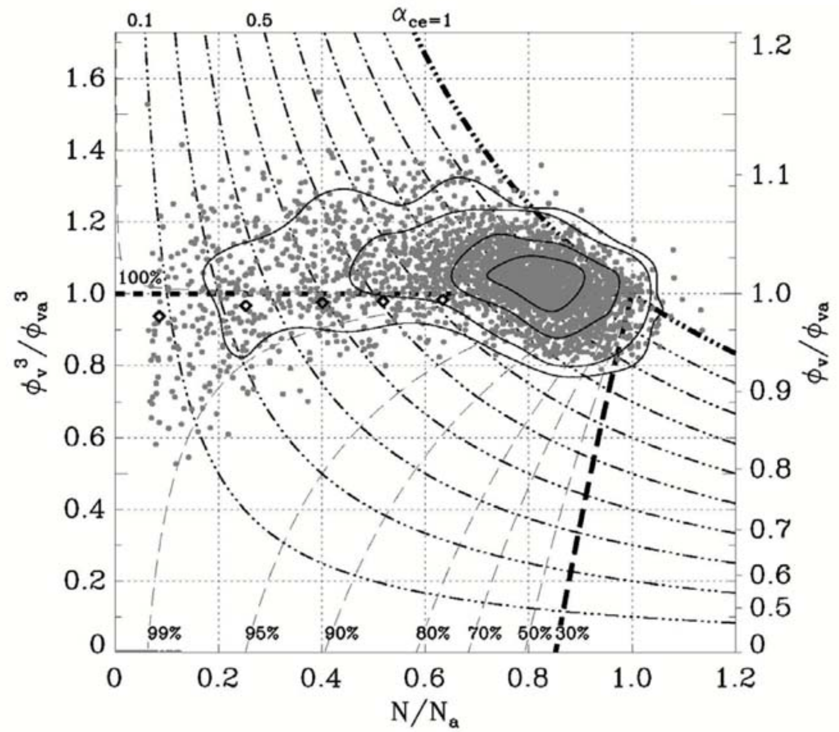
$N = 0.5N_a + 0.5N_d \approx 0.5N_a$ and $\phi_v^3 = (0.5N_a\phi_{va}^3 + 0.5N_d\phi_{vd}^3)/N \approx \phi_{va}^3$

The spatial heterogeneity affects extensive parameters, while intensive parameters are only slightly reduced

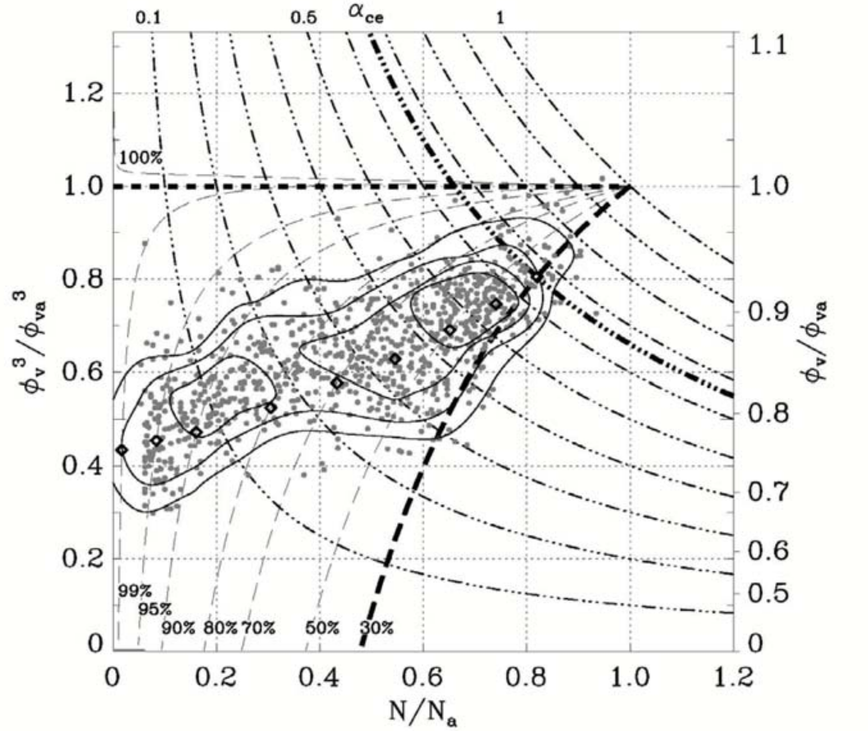
Measurements of Aerosol Particles

Impact of entrainment-mixing on cloud microphysics

Explanation I:



DYCOMS-II Sc : $\tau_T = 17$ s $\tau_D = 0.8$ s



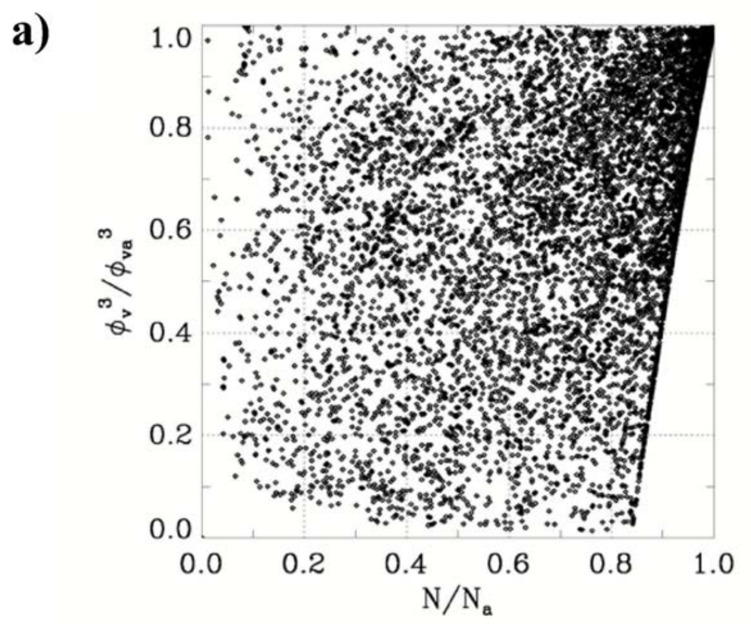
SCMS Cu : $\tau_T = 1.7$ s $\tau_D = 3.2$ s

Measurements of Aerosol Particles

Impact of entrainment-mixing on cloud microphysics

Explanation II:

$N = 0.5N_a + 0.5N_d \approx 0.5N_a$ and $\phi_v^3 = (0.5N_a\phi_{va}^3 + 0.5N_d\phi_{vd}^3)/N \approx \phi_{va}^3$



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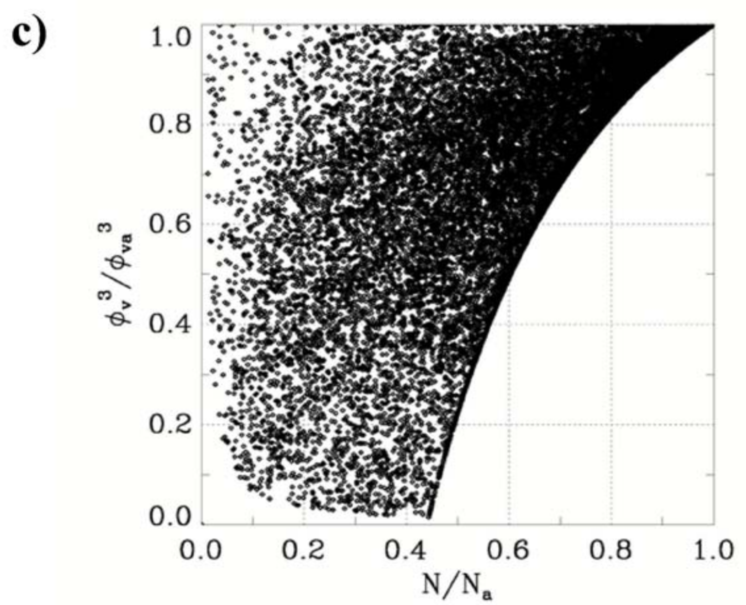

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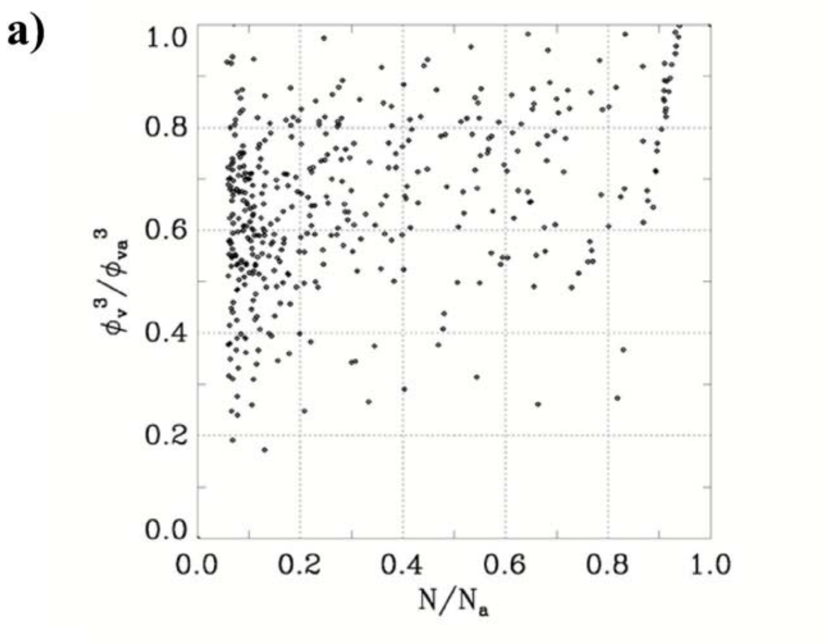
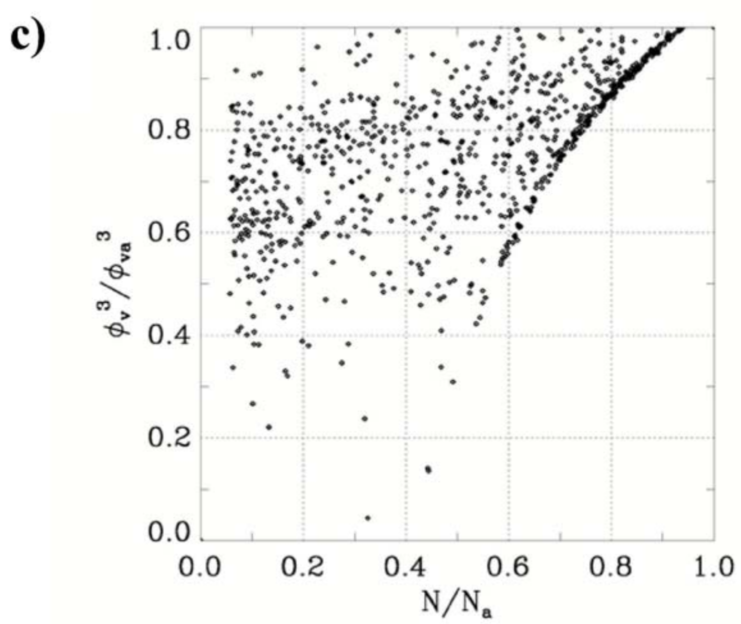
Measurements of Aerosol Particles

Impact of entrainment-mixing on cloud microphysics

Explanation II:

$$N = 0.5N_a + 0.5N_d \approx 0.5N_a \text{ and } \phi_v^3 = (0.5N_a\phi_{va}^3 + 0.5N_d\phi_{vd}^3)/N \approx \phi_{va}^3$$





SCMS Cu : τ_T = 1.7 s τ_D = 3.2 s

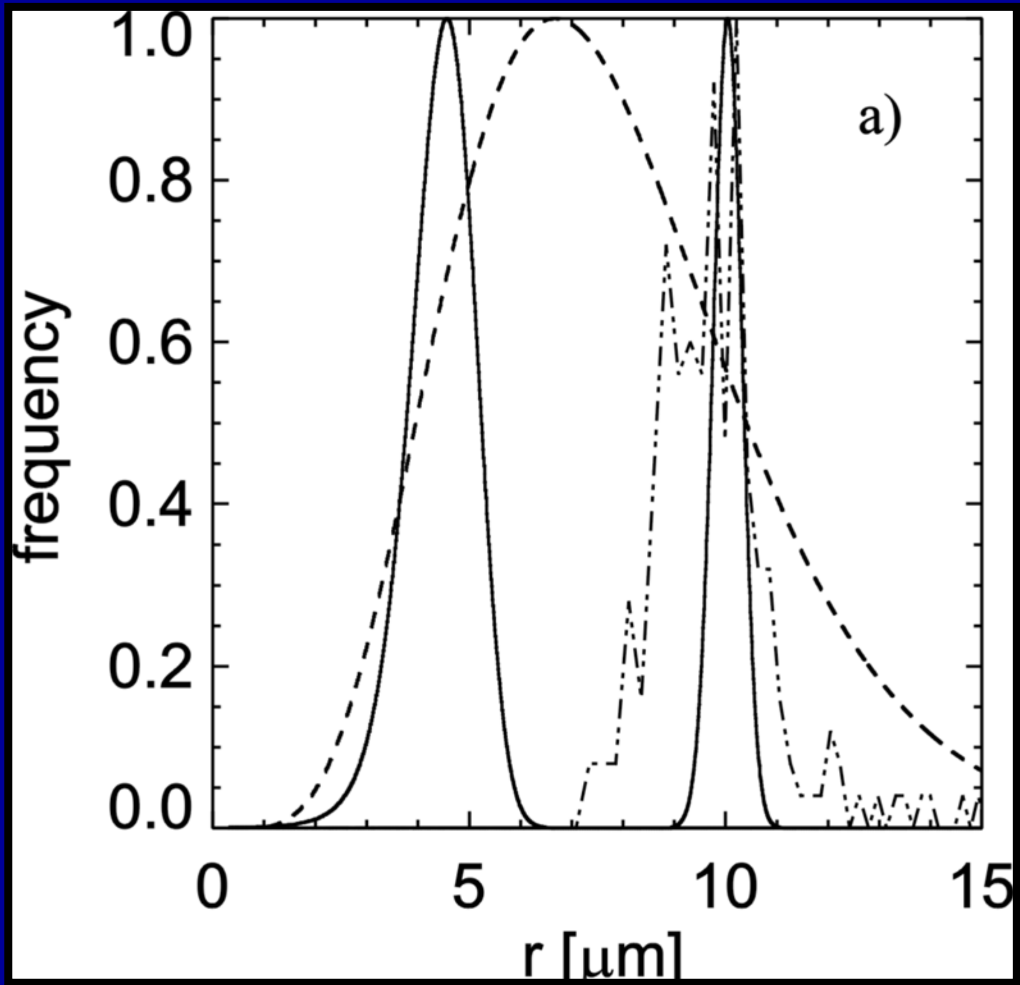
Measurements of Aerosol Particles

Spatial resolution/statistical significance

PHASE I: Observations

Locally, cloud drop spectra are narrow

When averaged over long distances, they approach a nice Gamma or Lognormal distribution shape



Measurements of Aerosol Particles

Spatial resolution/statistical significance

PHASE II: Modelling: Bulk Parameterizations

Detailed microphysics 1 to 3-D (50 to 200 variables)

↓

Divide the drop spectrum in two parts

r<20 µm: droplets (floating) $q_c=\sum 4/3\pi\rho_w n_i r_i^3$

r>20µm drops (precipitating) $q_r=\sum 4/3\pi\rho_w n_i r_i^3$

↓

Bulk microphysics (2 variables: q_c, q_r)

Measurements of Aerosol Particles

Spatial resolution/statistical significance

PHASE II: Empirical Parameterization of the Collection Process

Detailed microphysics simulation 1 to 3-D (50 to 200 variables)

↓

For each model grid, at each time step

Calculate $dq_r/dt=-dq_c/dt$ from droplets only: Autoconversion

Calculate $dq_r/dt=-dq_c/dt$ from droplets with drops : Accretion

↓

Derive empirical fits for

$$[dq_r/dt]_{AUTO}=\alpha q_c^{\beta}$$

$$[dq_r/dt]_{ACC}=\gamma\, q_c^{\delta} q_r^{\eta}$$

Measurements of Aerosol Particles

Spatial resolution/statistical significance

PHASE II: Analytical solution of the Collection Process

$$df(m)/dt = \int K(m', m-m') f(m') f(m-m') dm' d(m-m')$$

Assuming K behaves nicely and f(m) can be approximated by a nice analytical function, such as Gamma or Lognormal

Derive analytical solutions for

$$[dq_r/dt]_{AUTO} = \alpha q_c^{\beta}$$

$$[dq_r/dt]_{ACC} = \gamma\, q_c^{\delta} q_r^{\eta}$$

Measurements of Aerosol Particles

Spatial resolution/statistical significance

PHASE II: Analytical solution of the Collection Process

$$df(m)/dt = \int K(m',m-m')f(m')f(m-m')dm'd(m-m')$$

K measures the probability for a drop of mass m' to collect a drop of mass m-m', when they are randomly mixed
The Gamma or Lognormal functions represent drop properties averaged over 10s of km

What is the probability of collision of 2 drops, when they are 10 km apart?

Measurements of Aerosol Particles

Thank you for your attention !