A new mobility analyzer for routine measurement of atmospheric aerosol in the diameter range of 0.4−7.5 nm

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INTRODUCTION

The Symmetric Inclined Grid Mobility Analyzer SIGMA is arranged for study of initial stages of the atmospheric aerosol nucleation and it should:
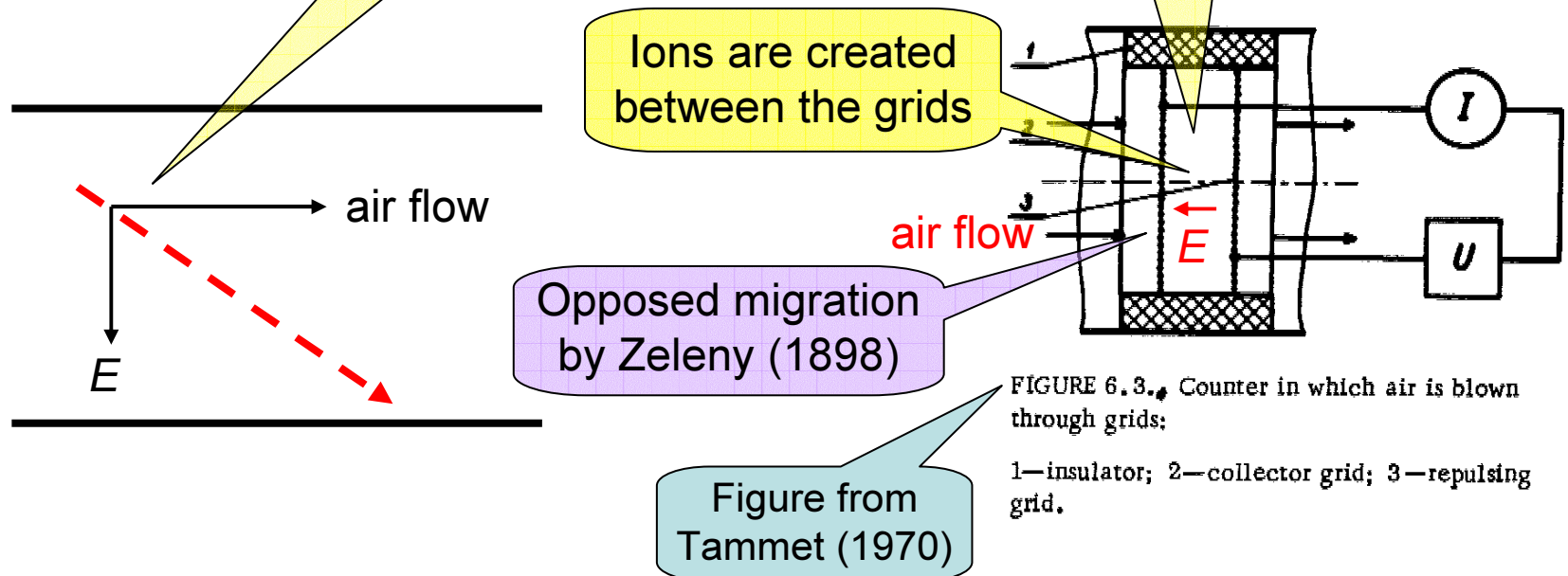
► be good for long-term routine measurements in natural atmospheric conditions,

► measure size distribution of small air ions and charged nanometer particles up to diameter of 7–8 nm,

► detect size fractions with low concentration down to $1\ cm^{-3}$,

► keep natural air temperature and humidity in the air tract during the measurement,

► minimize inlet distortions, which can be caused by the atmospheric electric field.

CLASSIC METHODS

The methods of transversal fields and of longitudinal fields were introduced in the Cavendish Laboratory at the end of 19th century under supervision of J.J. Thomson.

Ions are created between the grids

air flow

E

air flow

E

Opposed migration by Zeleny (1898)

Figure from Tammet (1970)

FIGURE 6.3. Counter in which air is blown through grids:

1—insulator; 2—collector grid; 3—repulsing grid.

The method of transversal fields is popular until today but the method of longitudinal fields was forgotten because it does not allow entering of ions from the outside air.

METHOD OF INCLINED FIELDS

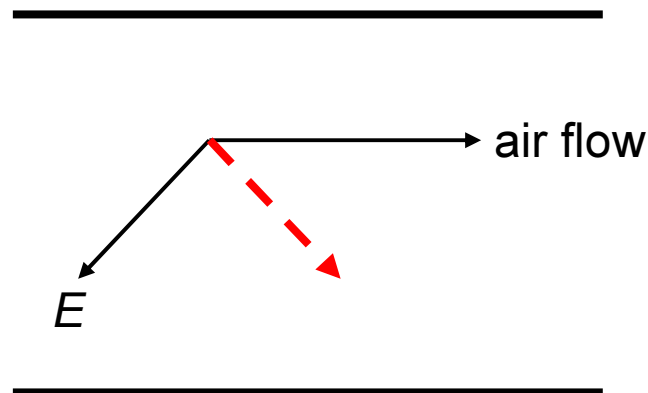## DRIFT DIFFERENTIAL MOBILITY ANALYZER

Ignacio G. Loscertales

Dep. Ingeniería Mecánica y Energética, Universidad de Málaga 29013, Spain

air flow

E

Loscertales (1998) showed that an intermediate configuration of fields allows to suppress the diffusion broadening of the transfer function.

Problem: how to carry out inclined fields in an actual instrument?

INCLINED GRIDS

Tammet, H. (1999) The limits of air ion mobility resolution.
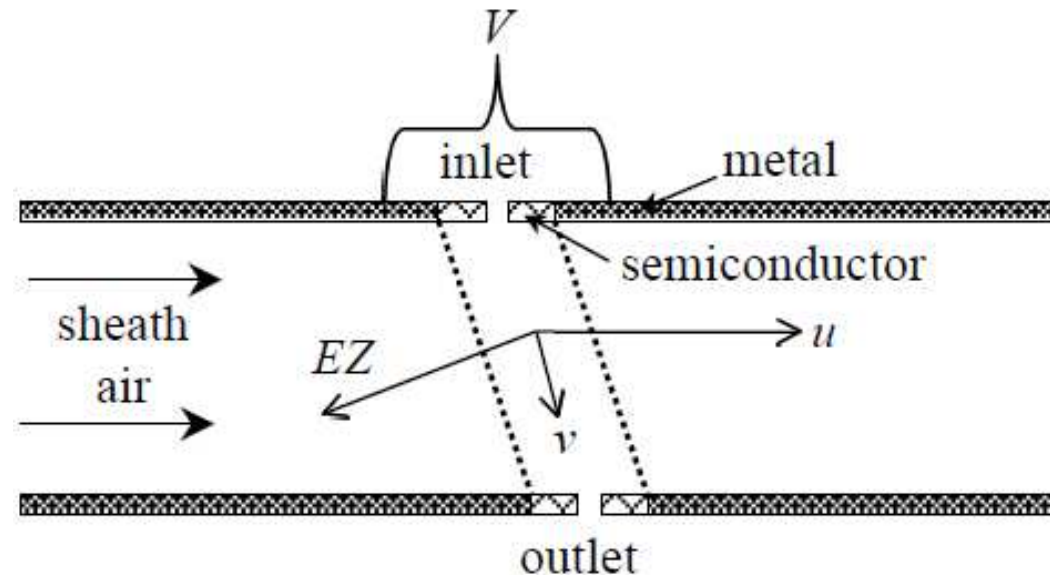*Proc. 11th Int. Conf. Atmos. Electr.*, NASA, Alabama, 626–629.

Figure 2. Mobility analyzer with inclined grids

Tammet, H. (2002) Inclined grid mobility analyzer: The plain model.
*Abstracts of Sixth International Aerosol Conference*, 2, 647–648.

Tammet, H. (2003) Method of inclined velocities in the air ion mobility analysis.
Proc. 12th Int. Conf. Atmos. Electr., Versailles, 399–402.

INCLINED POROUS ELECTRODES

Flagan, R.C. (2004) Opposed migration aerosol classifier (OMAC). *Aerosol Sci. Technol*. 38, 890–899.

Electrodes are inclined relative to the velocity of air flow
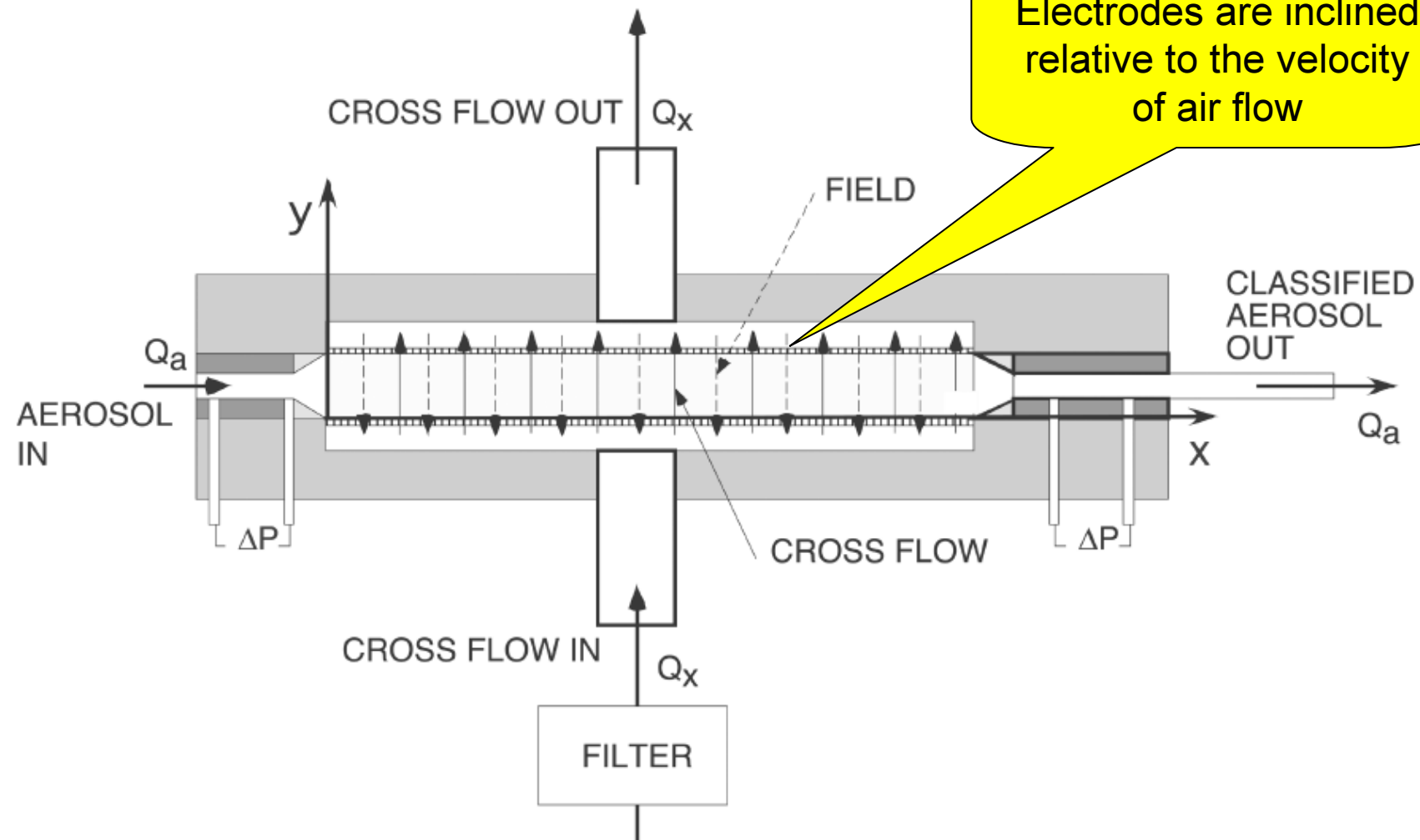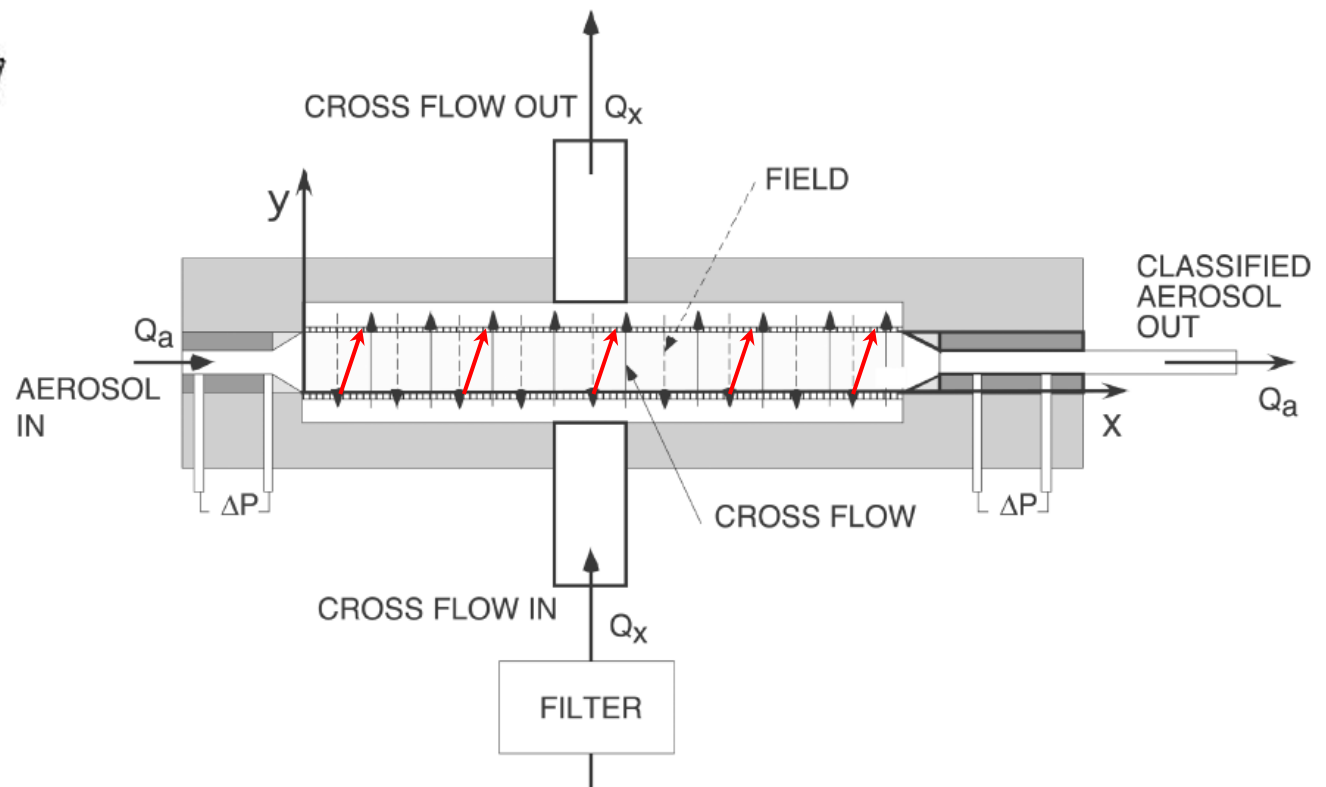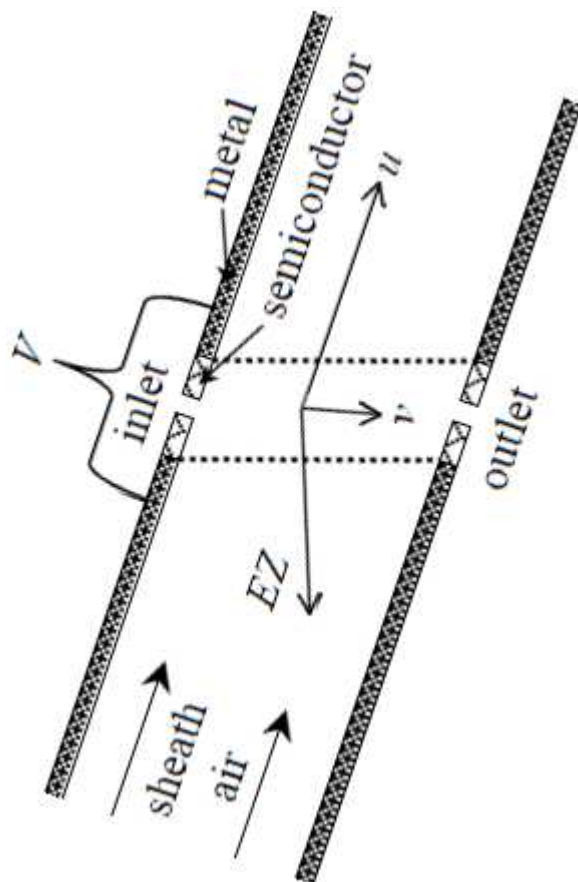
COMPARISON

IGMA: Tammet 1999
as rotated 71º

OMAC: Flagan 2004
with added red arrows

Grids are replaced by porous electrodes

Previous experience: IGMA
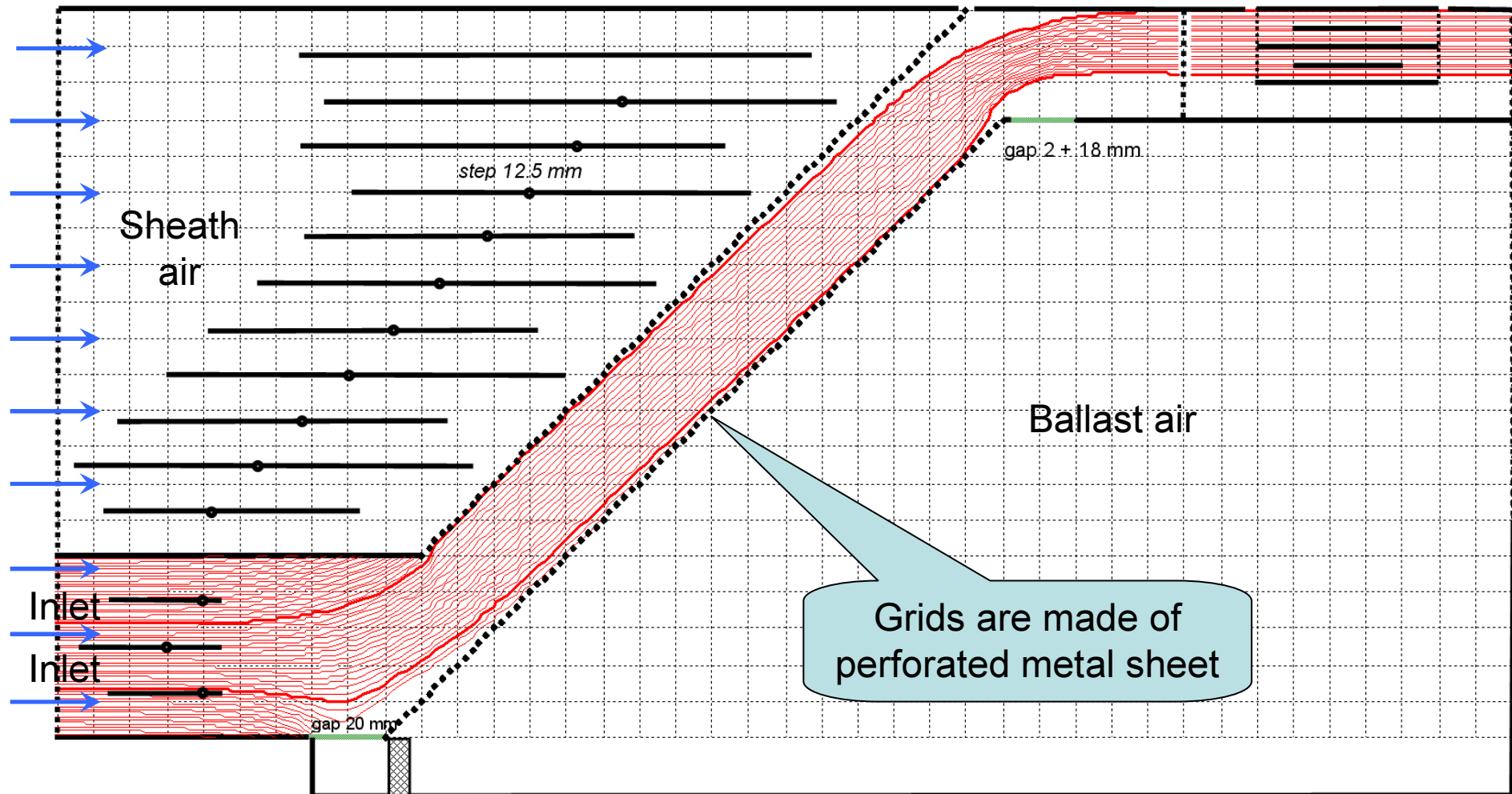
Manufactured 2002 and published 2003

Electrometric collector

Sheath air

step 12.5 mm

gap 2 + 18 mm

Ballast air

Inlet

Inlet

gap 20 mm

Grids are made of perforated metal sheet
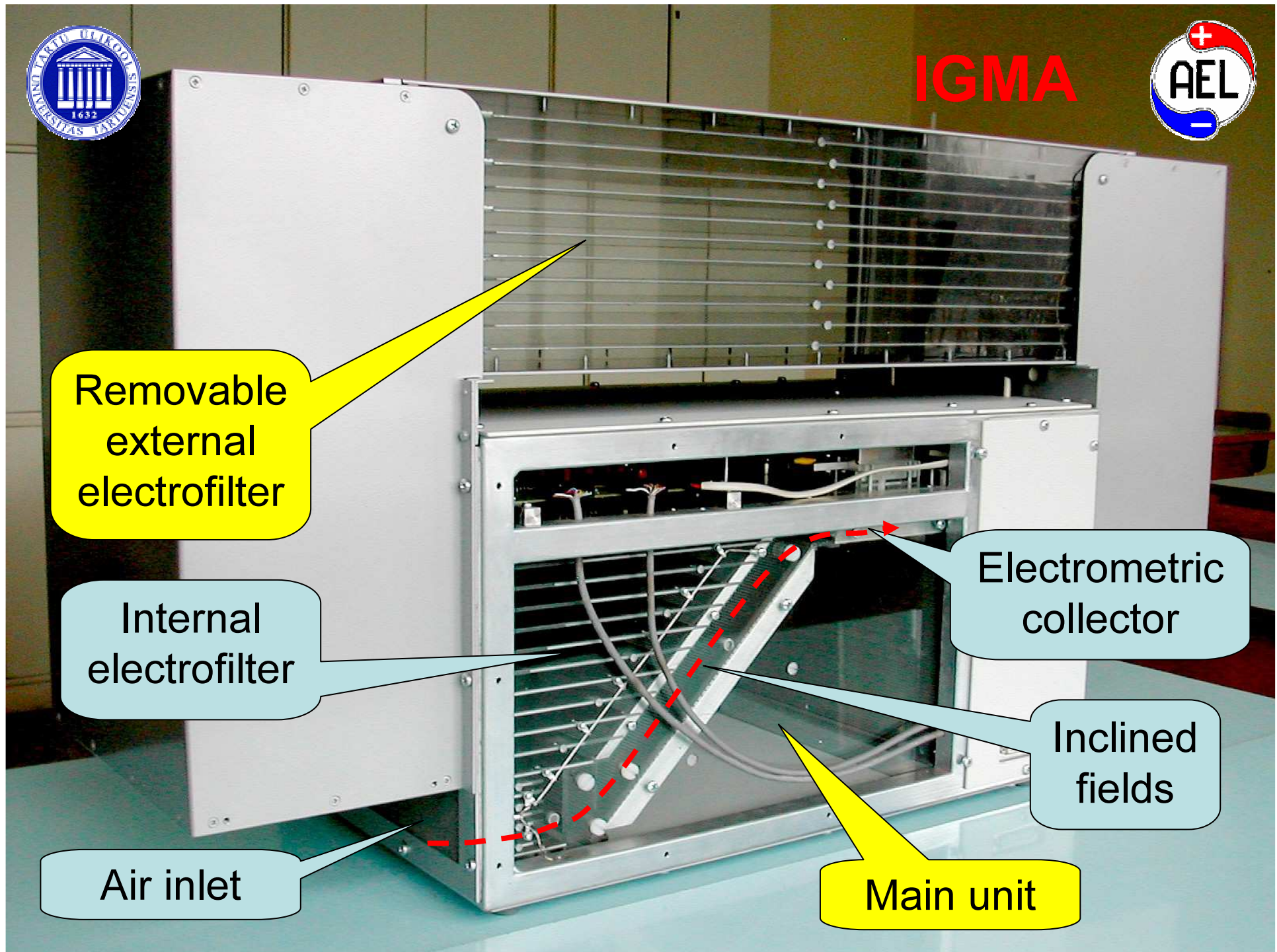
IGMA

Removable external electrofilter

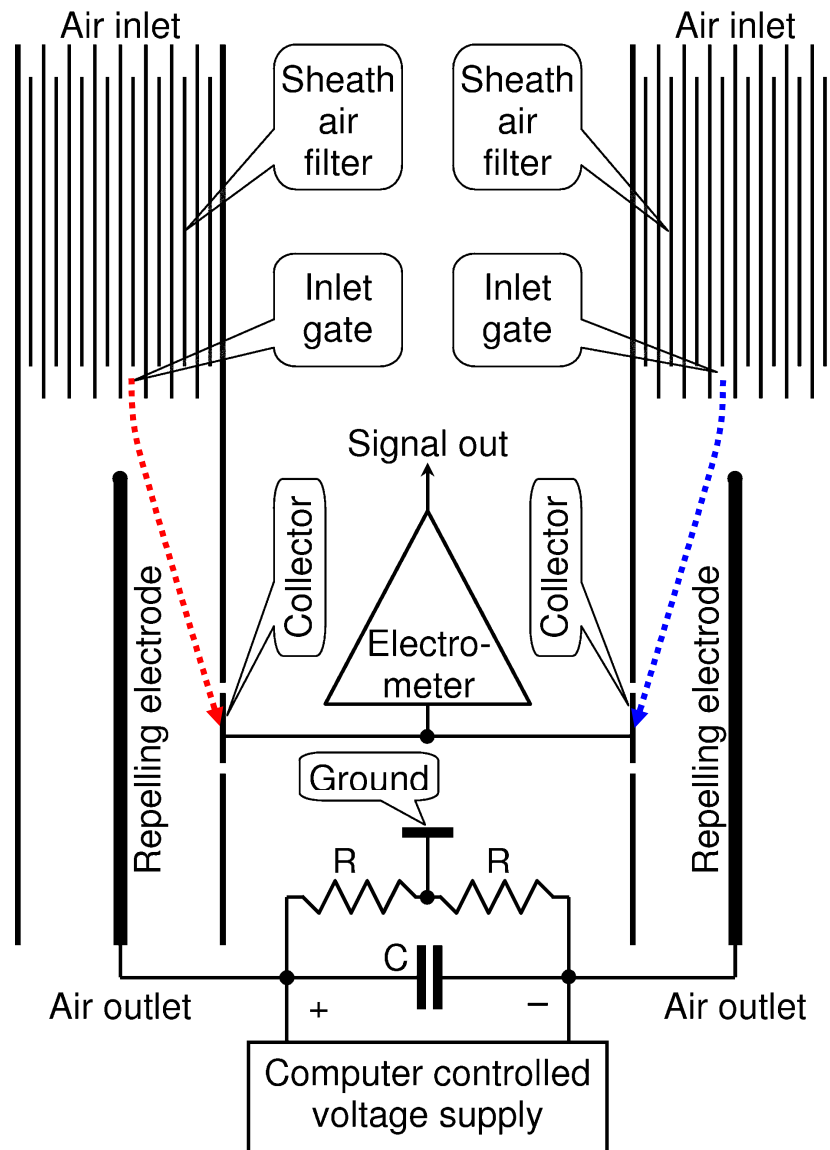Internal electrofilter

Electrometric collector

Inclined fields

Air inlet

Main unit

Previous experience: BSMA

Traditional *Erikson* method, electrostatic induction is suppressed by a balanced *Komarov* bridge.
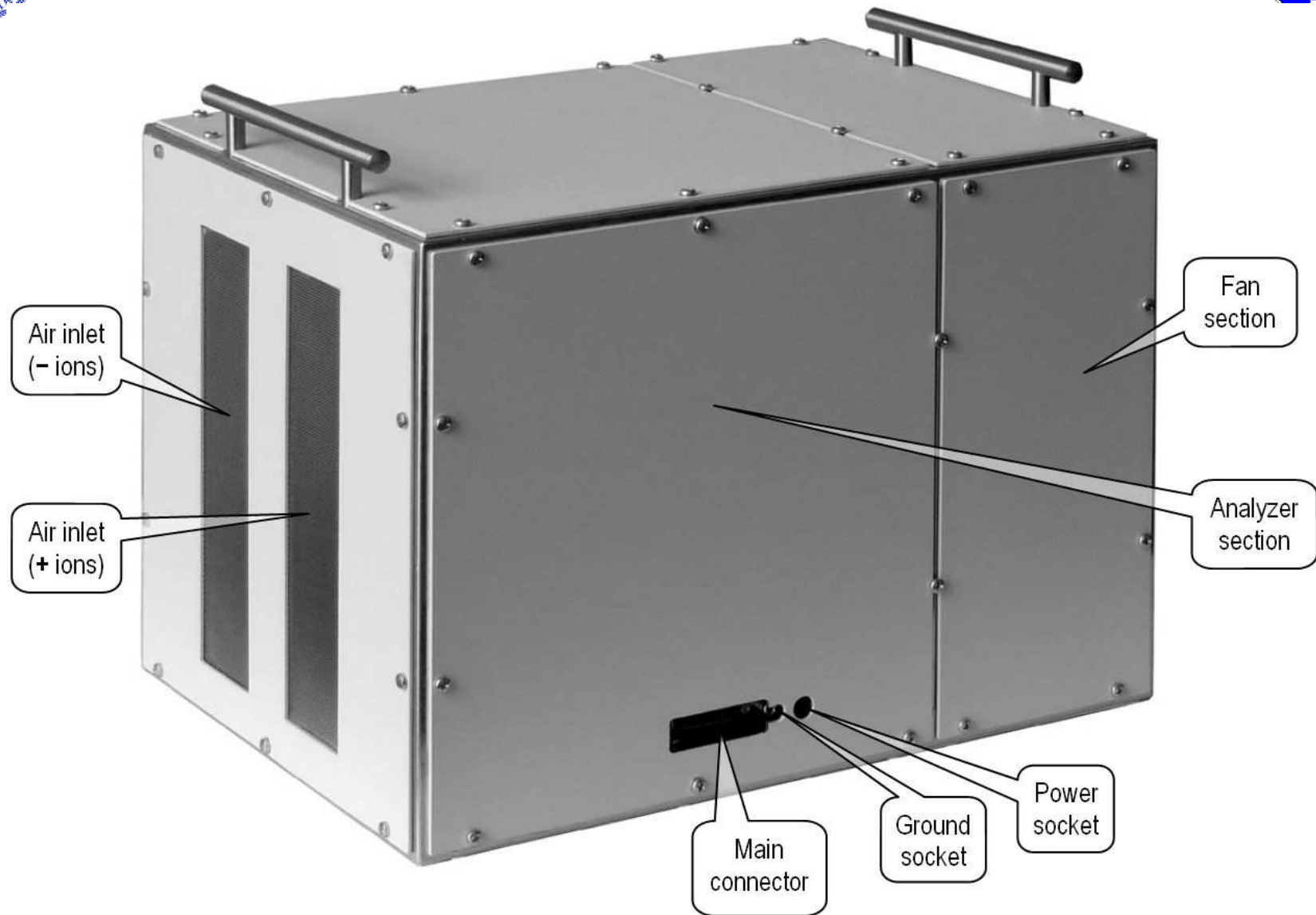
First BSMA was manufactured 2003 and published 2004–2006.

Long experience: routine measurements in Hyytiälä, Tartu, and Helsinki.

Main advantage:
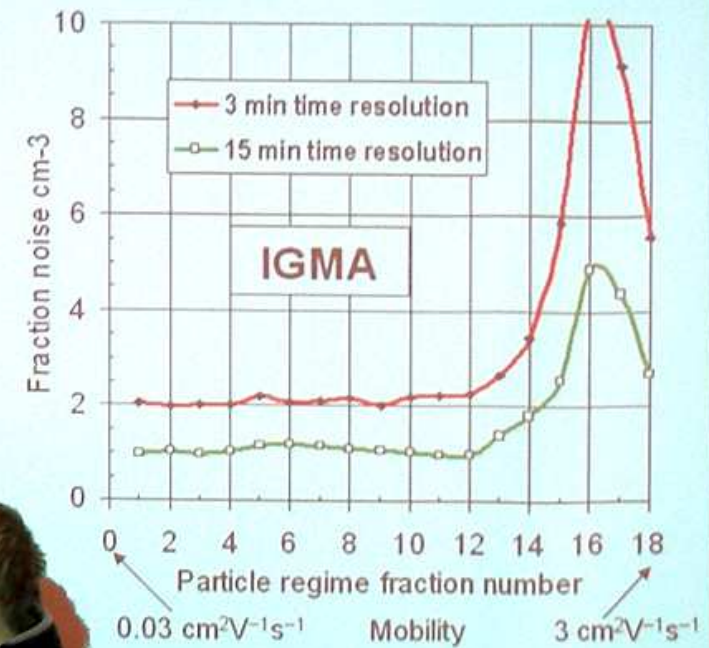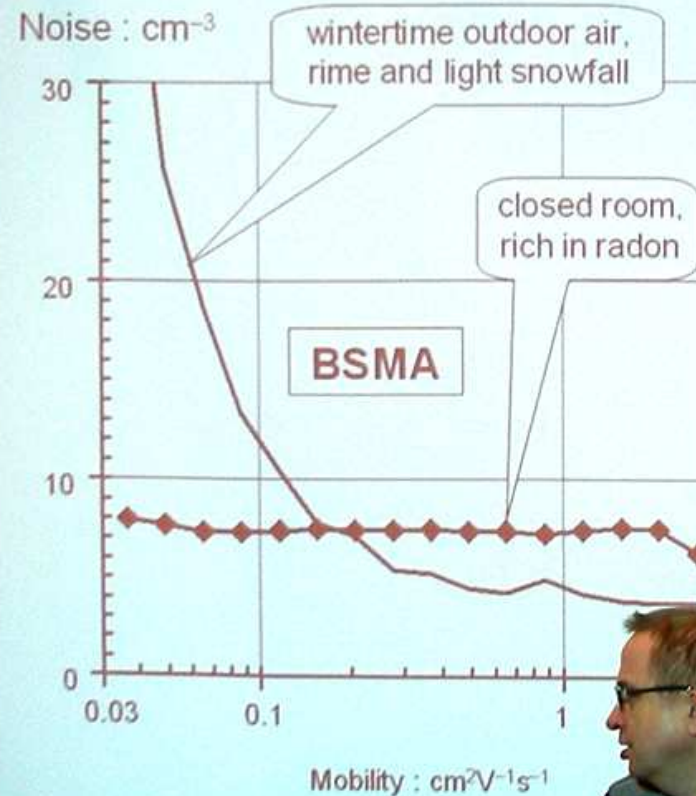the absolute calibration.

BSMA

Air inlet (− ions)

Air inlet (+ ions)

Fan section

Analyzer section

Main connector

Ground socket

Power socket

Discussion in Hyytiälä 2007

DECISIONS

► go back to the principle of IGMA,

► keep the mobility and size range as in approved instruments: 0.032–3.2 cm^{2}V^{-1}s^{-1} & 0.4–7.5 nm,

► increase sensitivity, especially in range of 2–5 nm,

► improve time resolution,

► provide reliability in long term atmospheric measurements equal or better than of the BSMA.

SIGMA

Fan section

Ground terminal

Power socket

Socket for an external device

USB-B connector

Analyzer section

Air inlet
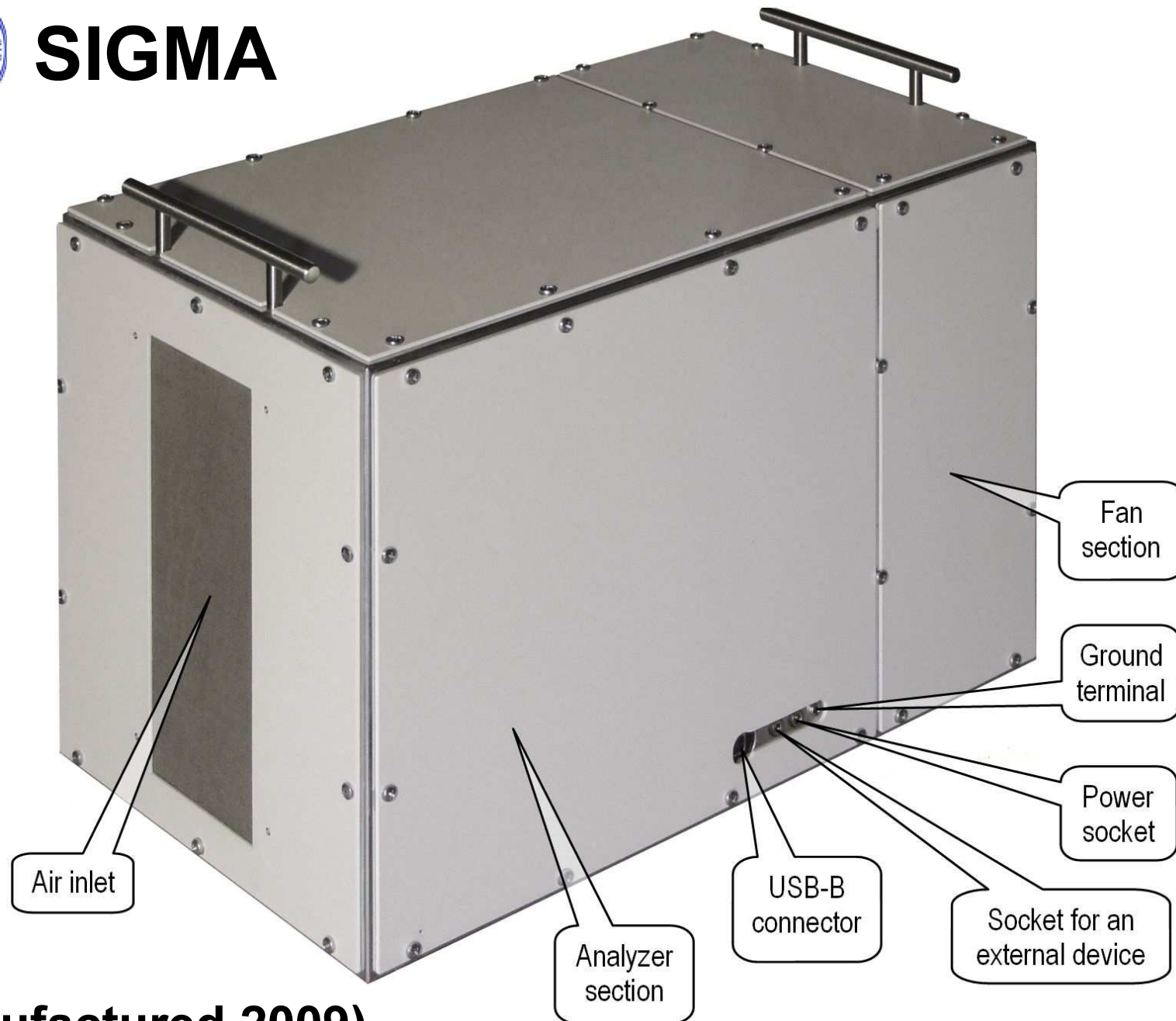
(manufactured 2009)

Analyzer
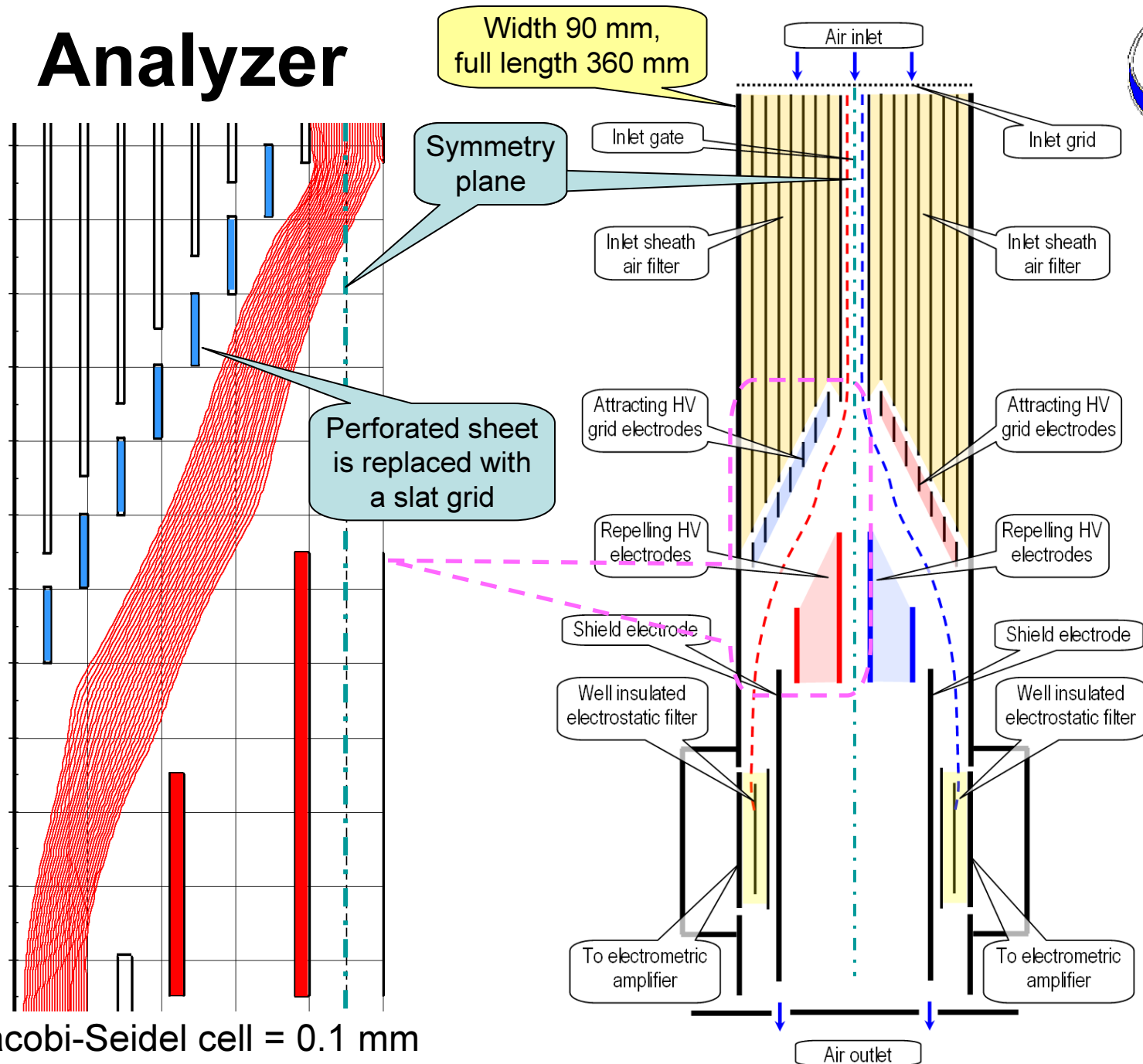
Width 90 mm, full length 360 mm

Symmetry plane

Perforated sheet is replaced with a slat grid

Configuration of electrodes is optimized using a numerical model

Jacobi-Seidel cell = 0.1 mm

Air inlet

Inlet gate

Inlet grid

Inlet sheath air filter

Inlet sheath air filter

Attracting HV grid electrodes

Attracting HV grid electrodes

Repelling HV electrodes

Repelling HV electrodes

Shield electrode

Shield electrode

Well insulated electrostatic filter

Well insulated electrostatic filter

To electrometric amplifier

To electrometric amplifier

Air outlet

Top view of topless SIGMA

CONTROL OF MEASUREMENT

Performance of the SIGMA substantially depends on manipulating the instrument by the computer and processing of the recorded signals under the supervision of the control program.

A 20-second scan begins with measuring of air temperature and pressure. Next the HV capacitor is quickly charged up to about 6000 V. Follows exponential decrease of voltage. The voltages of electrodes and electrometer outputs are measured about 100 times per second during a scan. Typically, every third scan is performed with closed air ion inlet gate and used for control of the zero level.

Carefully insulated collector filters are powered with internal batteries.

INLET LOSS

Inlet loss is numerically compensated using the semiempiric equations of heat and mass transfer. Relative adsorption depends on temperature, pressure, and mobility as

$$A = A_o \, (T / T_o)^{7/18} \, (p / p_o)^{1/6} \, (Z / Z_o)^{2/3}.$$

Calculation according to the parameters of SIGMA yields results for T_o = 273 K, p_o = 1013 mb and Z_o = 1 cm^{2}V^{-1}s^{-1}:

Normal loss on inlet grid A_{grid} = 1.1%,
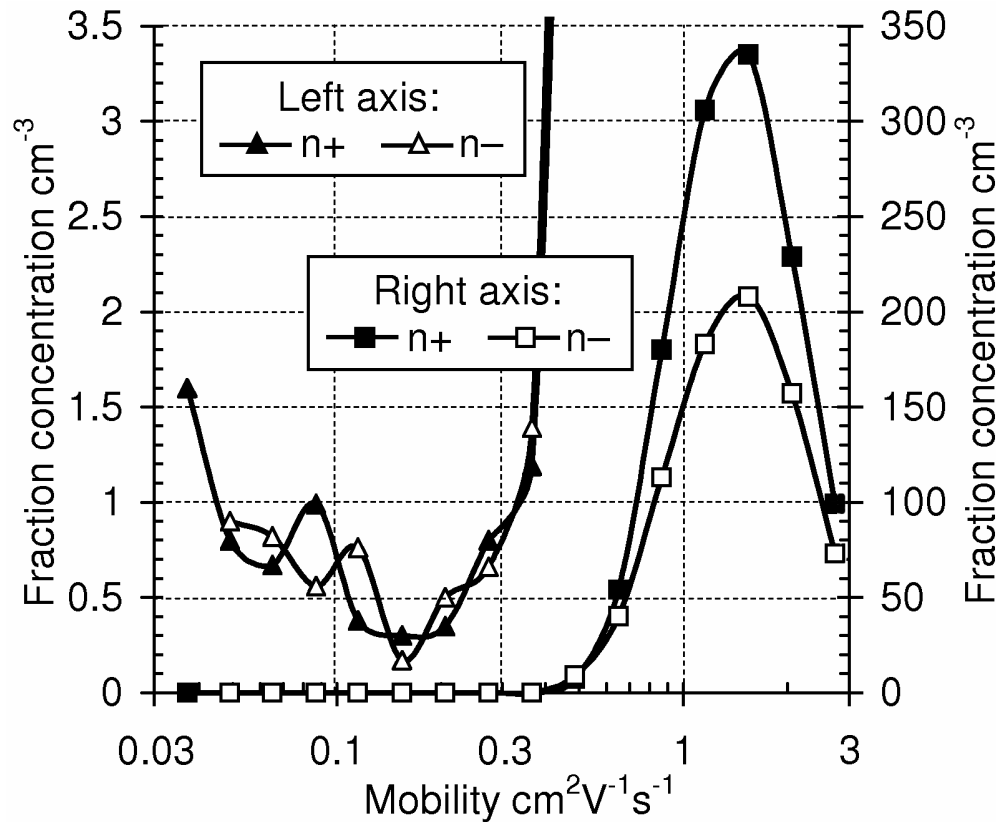Normal loss on inlet gate A_{gate} = 3.8%.

The concentrations of mobility fraction are numerically corrected:

$$f_{corrected} = f_{uncorrected} \, \exp \, (A_{grid} + A_{gate}).$$

The relative uncertainty of the fraction concentrations induced by the uncertainty of the 5% correction is about 20 times less than the uncertainty of the estimate of the relative adsorption A.
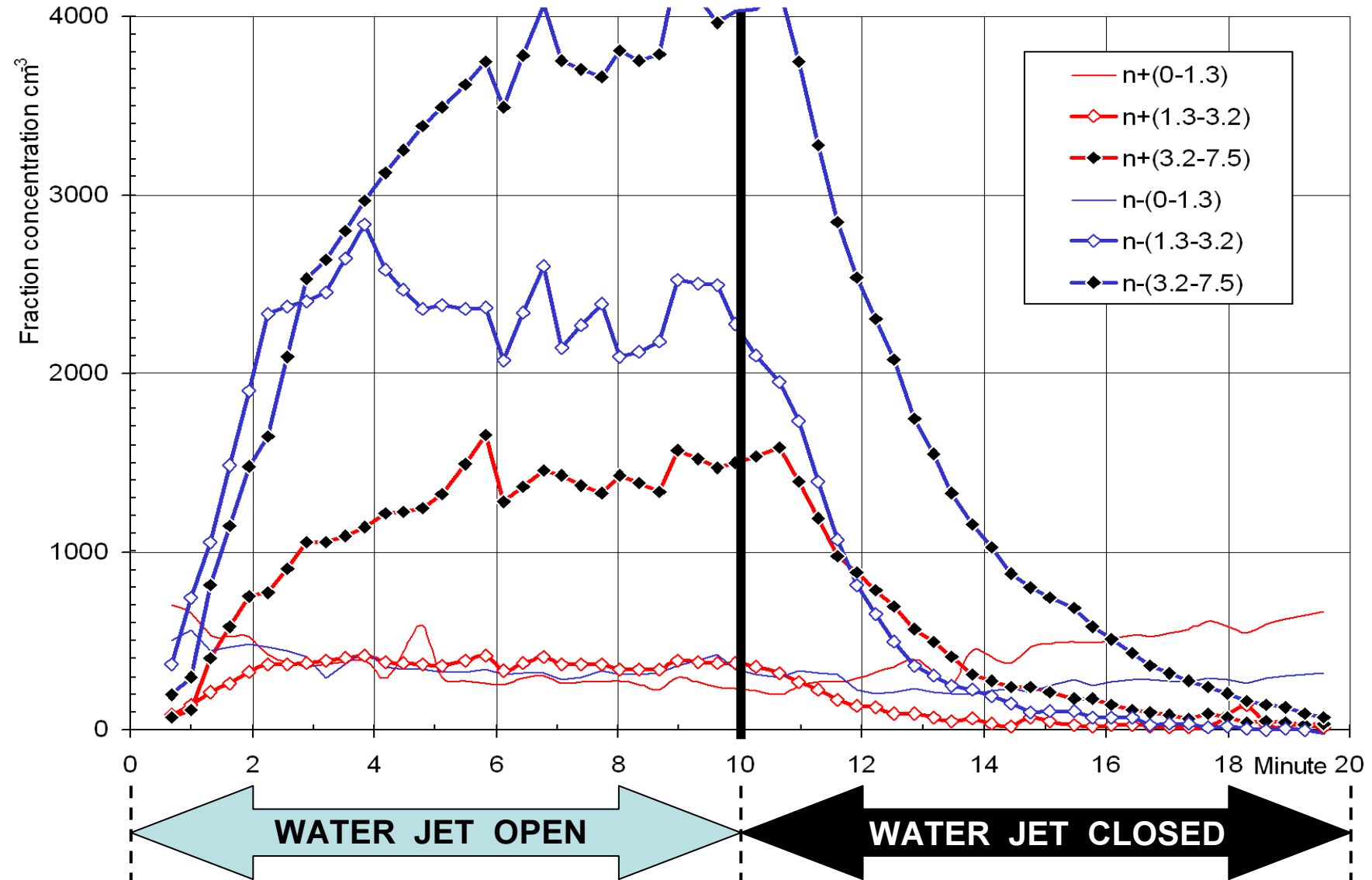
SENSITIVITY
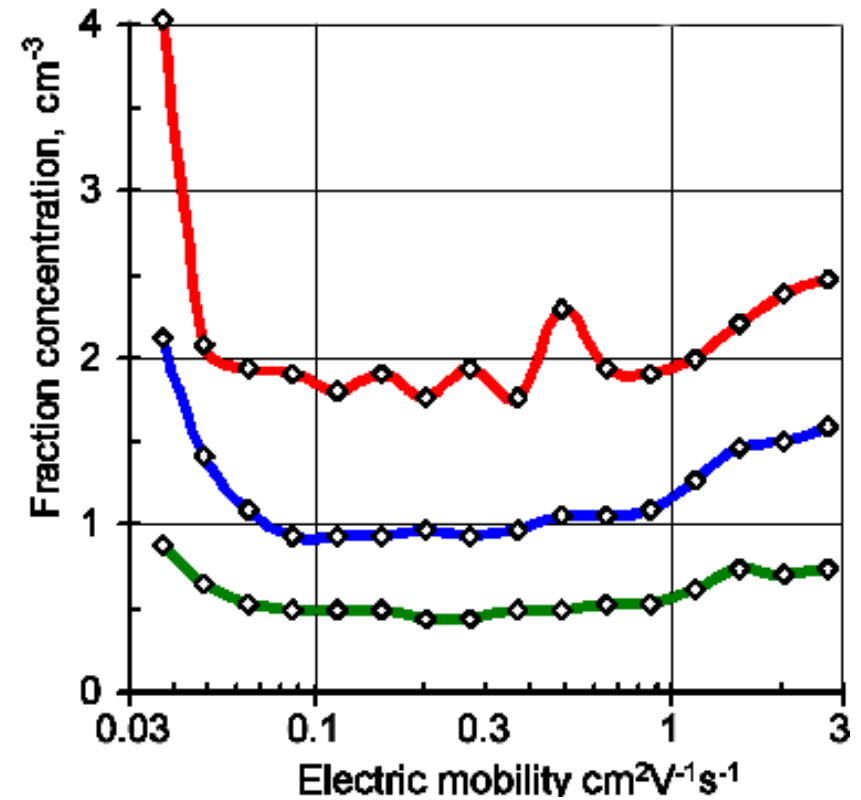
Mobility distributions presented
by fraction concentrations,
20090920 16:00-24:00

50%, 90% and 99% quantiles
of fraction concentration absolute values
at zero level of the real concentration.

TIME RESOLUTION

MOBILITY RESOLUTION

The diffusionless geometric transfer function has a triangular shape and the relative standard deviation $\sigma / Z = 0.115$. Brownian diffusion and smoothing by continuous scanning increases this parameter up to 0.15. Additional components of broadening the transfer function (e.g. turbulence) cannot be estimated by theoretical calculations. Experimental result: during measurements a nearly Gaussian peak with $\sigma / Z = 0.2$ was recorded. Thus the mobility resolution was estimated as:

$$0.15 \leq \sigma / Z \leq 0.2$$

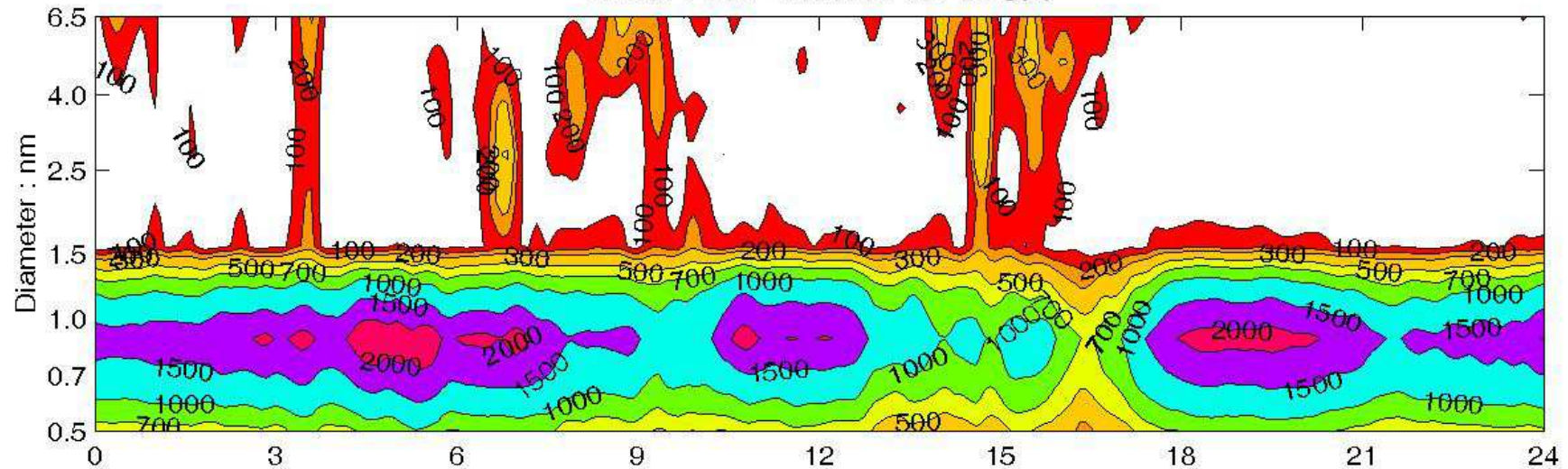$$2 \leq Z / \Delta Z_{1/2} \leq 3$$

$$4.5 \leq RFD \leq 7$$

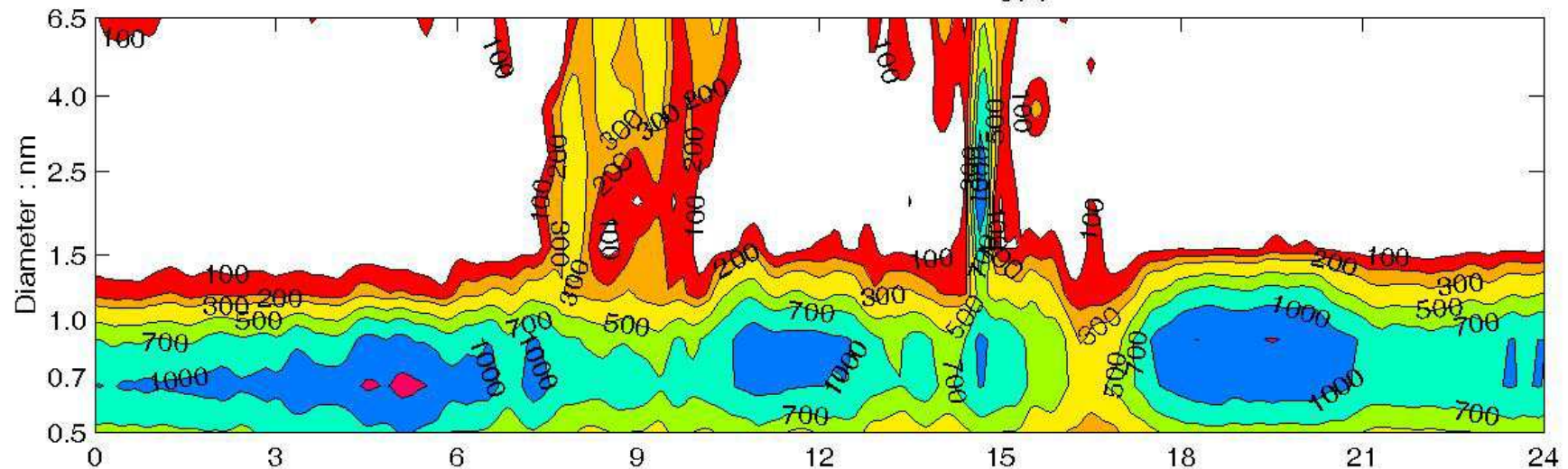(RFD = **R**esolved **F**ractions per **D**ecade)

EXAMPLE 1 (5 min time resolution)

SIGMA + ions 20090806 dn / d log(d)
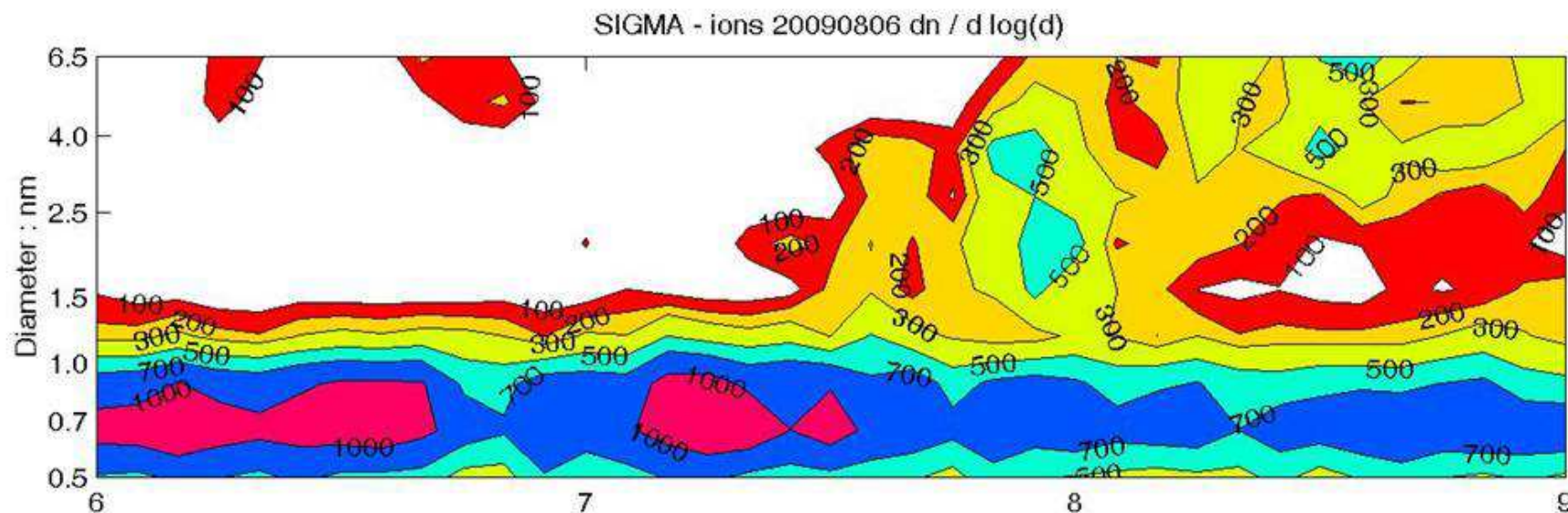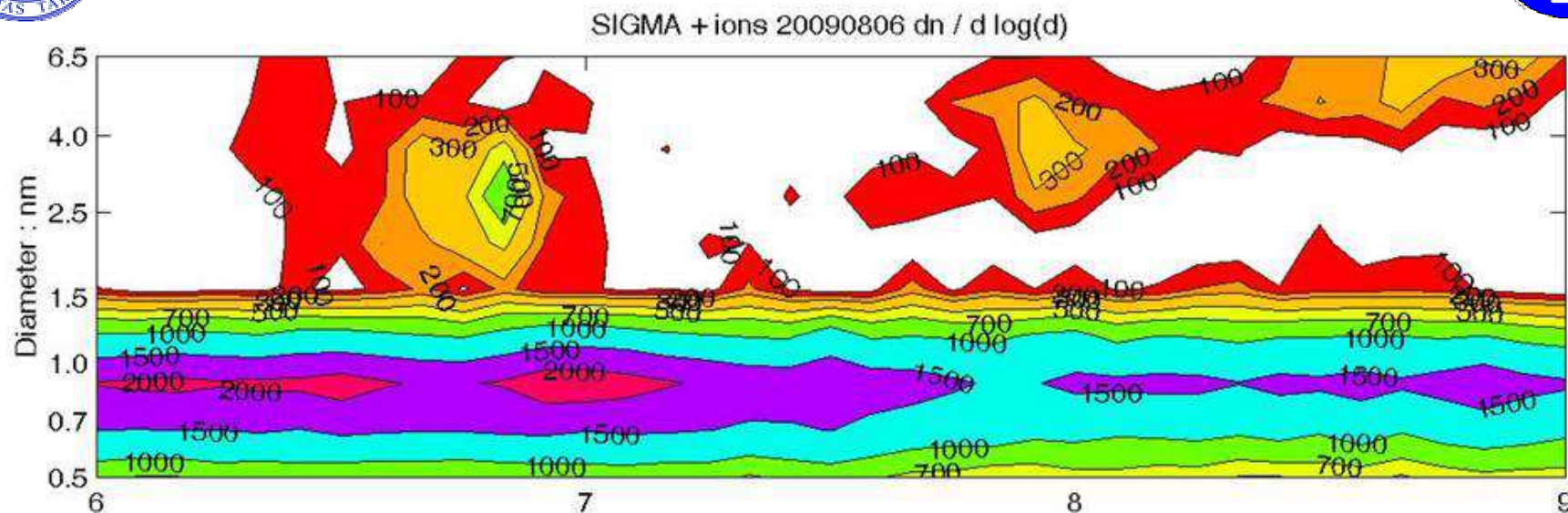
SIGMA - ions 20090806 dn / d log(d)

EXAMPLE 1a (excerpt from previous)

SIGMA + ions 20090806 dn / d log(d)

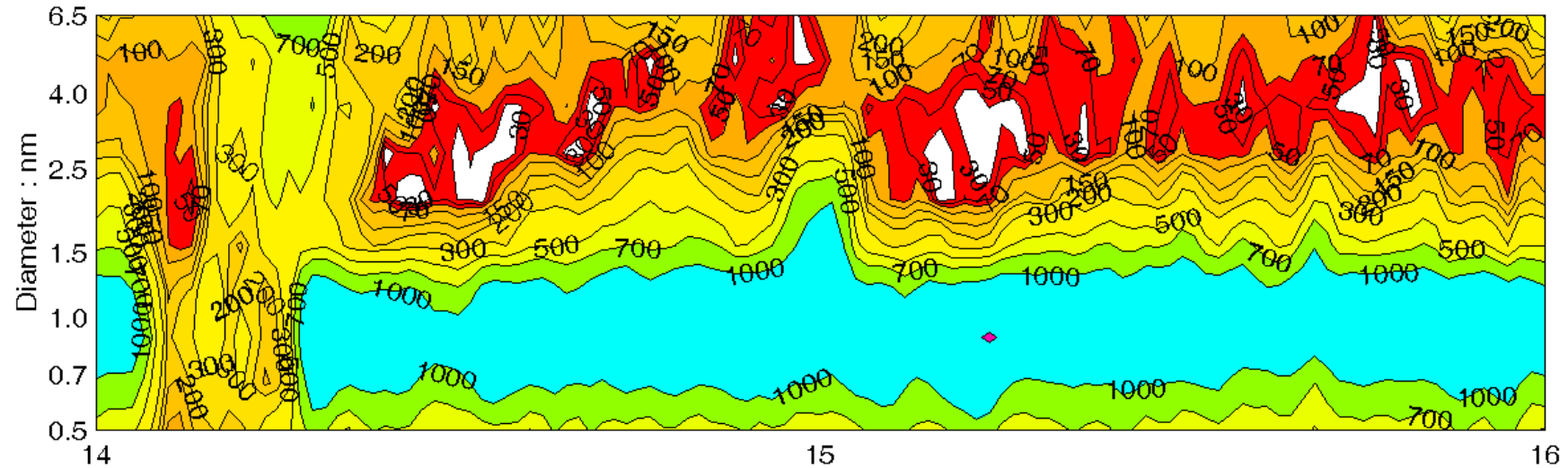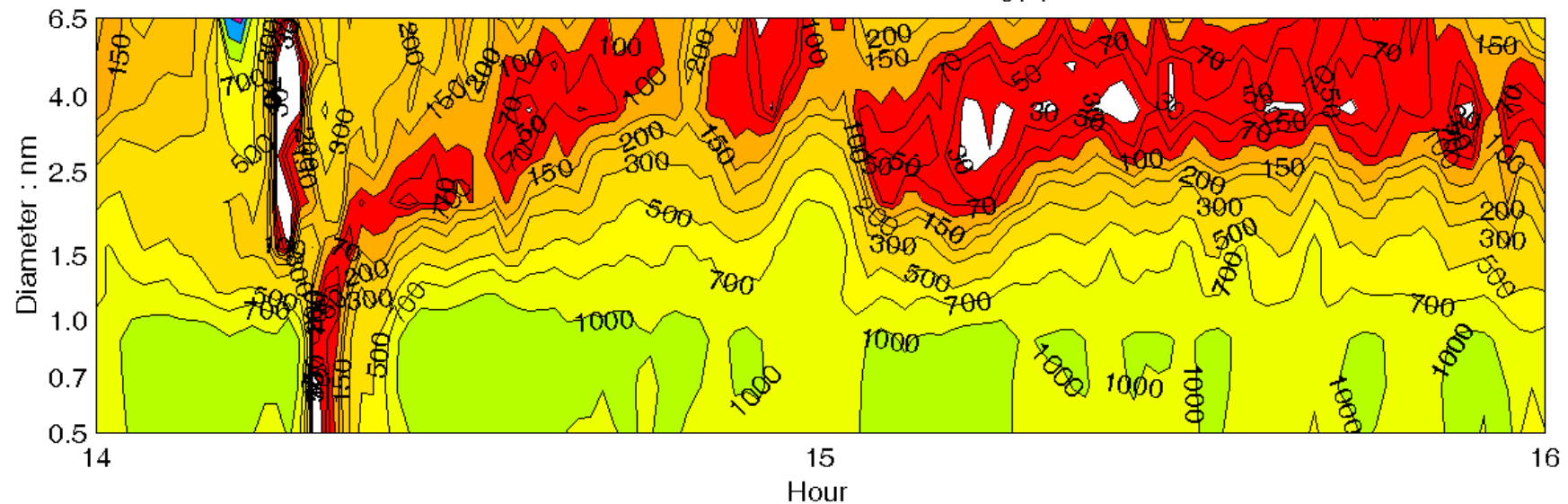SIGMA - ions 20090806 dn / d log(d)

EXAMPLE 2 (1 min time resolution)

SIGMA + ions 20100425 dn / d log(d)

SIGMA − ions 20100425 dn / d log(d)

CONCLUSIONS

Some essential properties of the instrument are:

➤ The positive and negative air ions are sampled from the same inlet air flow and measured exactly simultaneously.

➤ The sheath air is sucked into the instrument from the atmosphere together with the analyzed air and ions pass during the analysis only the unaffected atmospheric air.

➤ A high rate of air flow of about 30 dm^3/s and the isopotential principle suppress the disturbing effect of the external electric field and assure representative sampling of air ions.

CONCLUSIONS (continued)

➢ The loss of ions in the inlet tract is low and can be accurately corrected online.

➢ A short residence time of about 0.16 s and low heating of air less than 0.5 K suppress the risk of changing of the ions during the measurement.

➢ Standard control program records 16 fractions of atmospheric small and intermediate ions during every 5 minute cycle with random errors of about 1 cm^{-3}.

➢ Time resolution of 20 s is available at random errors in the mobility fraction concentrations of 4…10 cm^{-3}.

Get a copy of this presentation and additional information:

http://ael.physic.ut.ee/tammet/sigma

Thank You!