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,

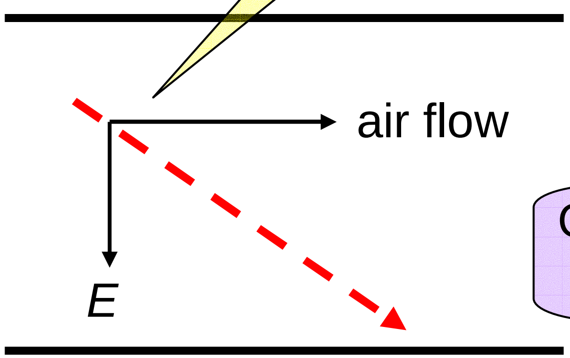
► detect size fractions with low concentration down to 1 cm^{-3},

► 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

Opposed migration by Zeleny (1898)

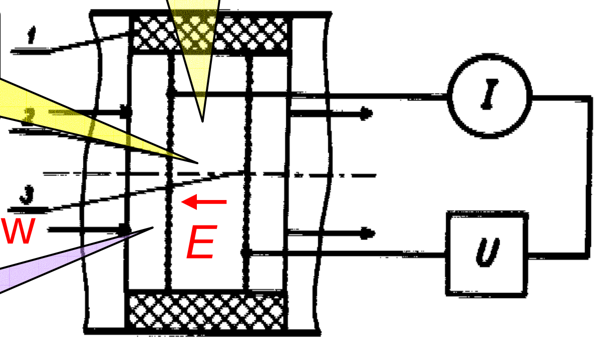


FIGURE 6.3. Counter in which air is blown through grids:

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

Figure from Tammet (1970)

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

Pergamon

J. Aerosol Sci. Vol. 29, No. 9, pp. 1117–1139, 1998

Printed in Great Britain
0021-8502/98 $19.00 + 0.00

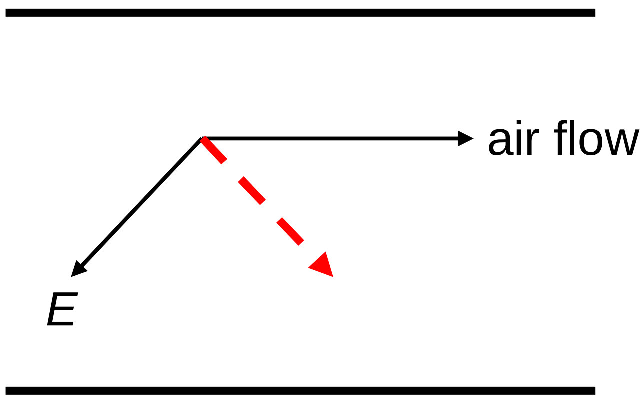
PII: S0021-2502(98)00031-7

DRIFT DIFFERENTIAL MOBILITY ANALYZER

Ignacio G. Loscertales

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

(*First received* 31 *October* 1997; *and in final form* 13 *February* 1998)



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.

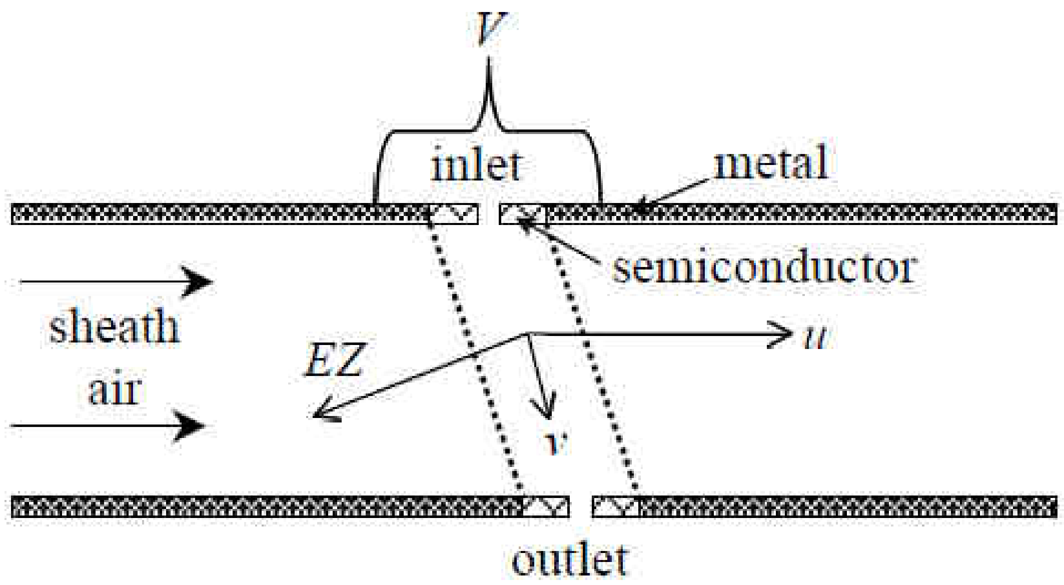


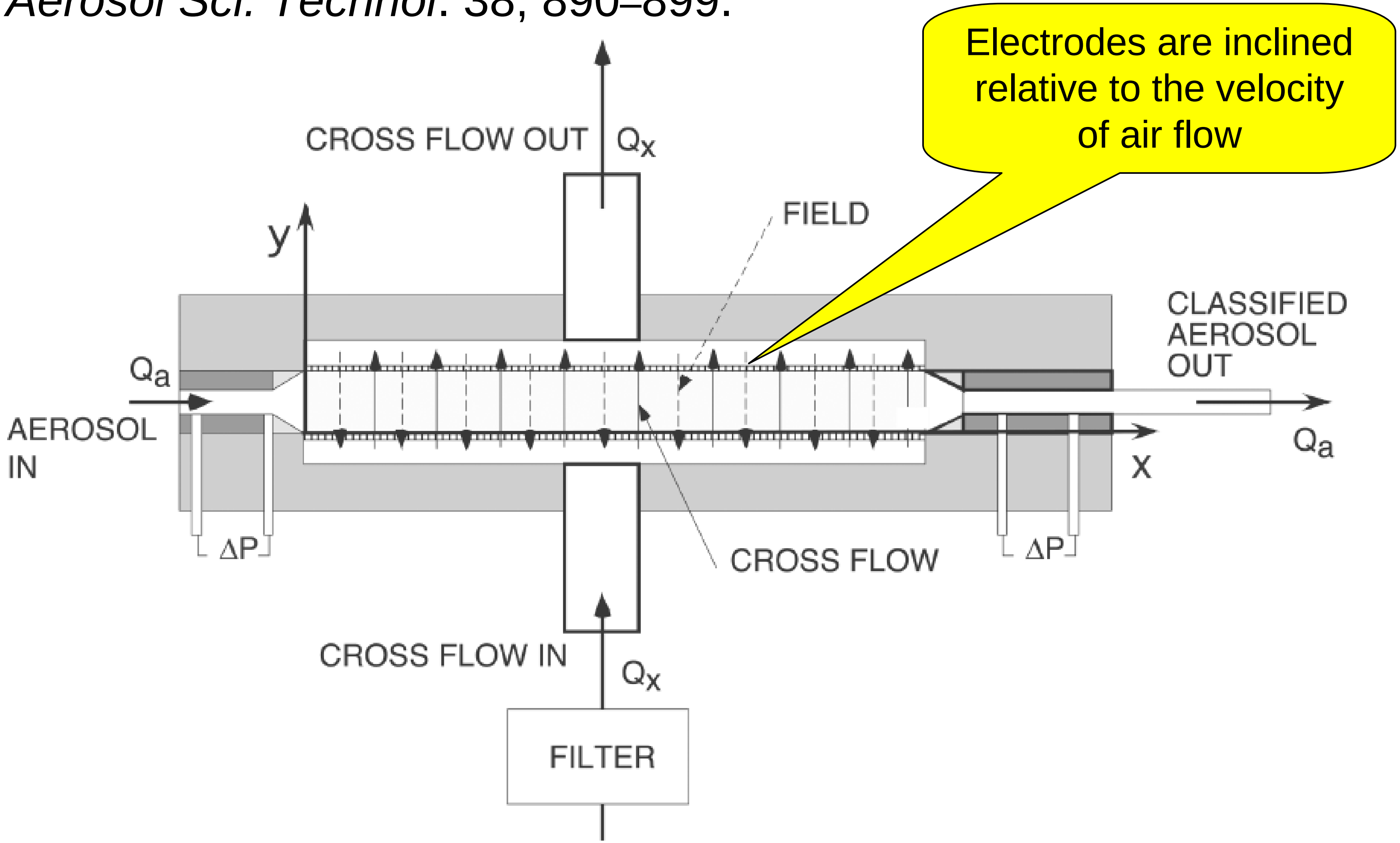
Figure 2. Mobility analyzer with inclined grids

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.

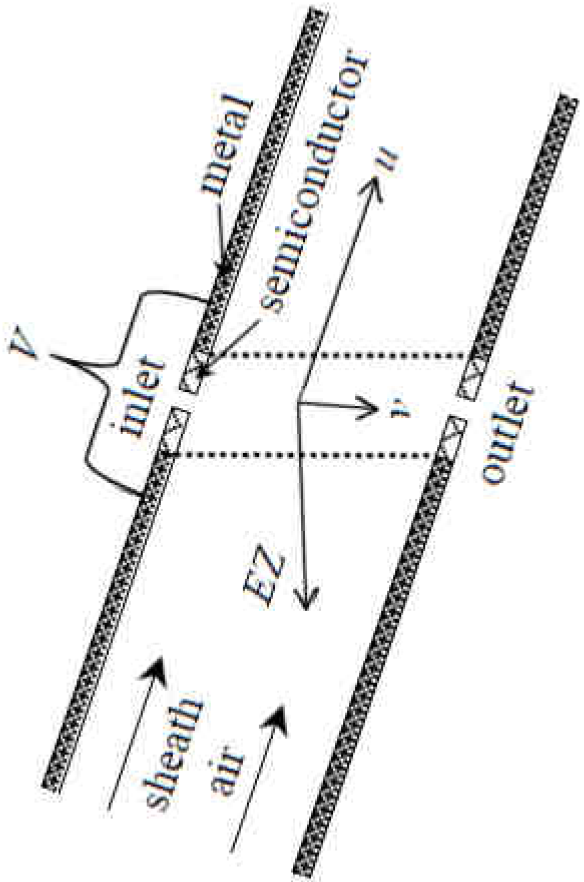
INCLINED POROUS ELECTRODES

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

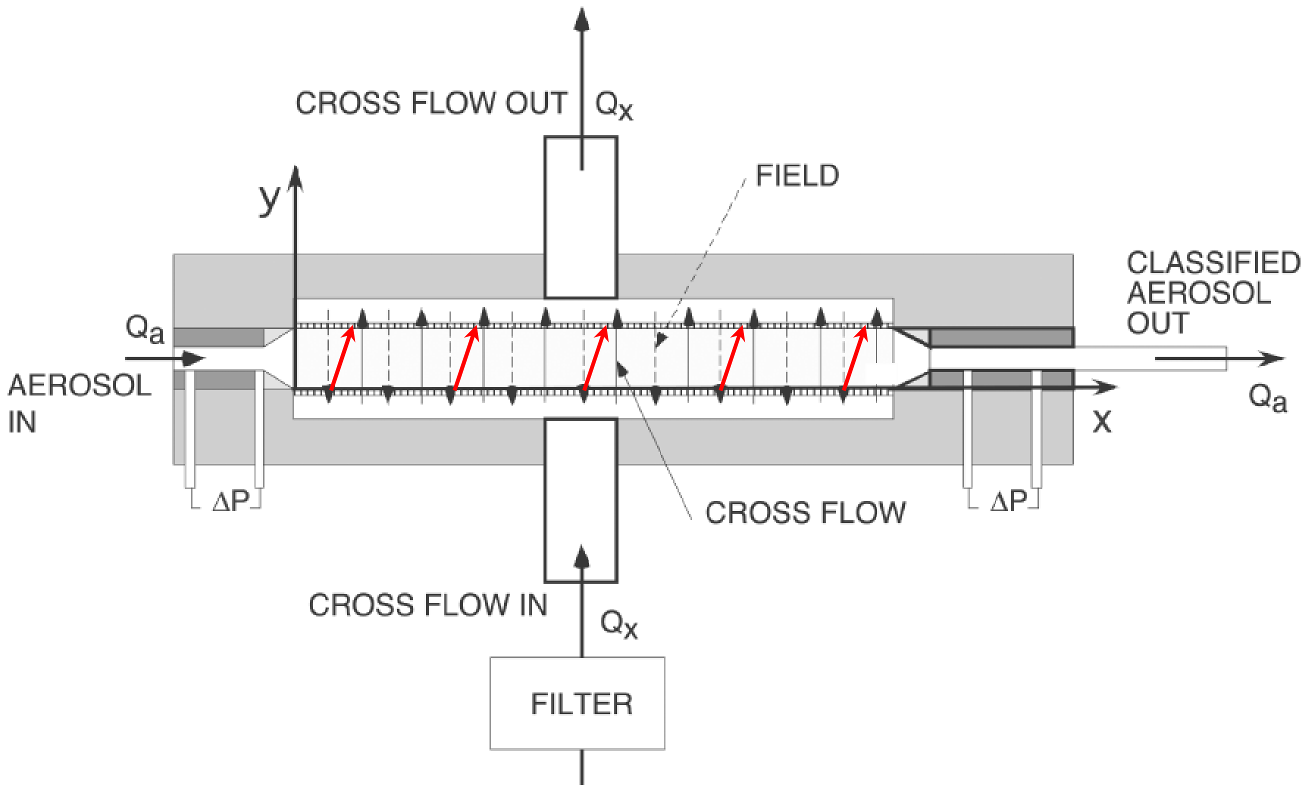


COMPARISON

IGMA: Tammet 1999
as rotated 71º



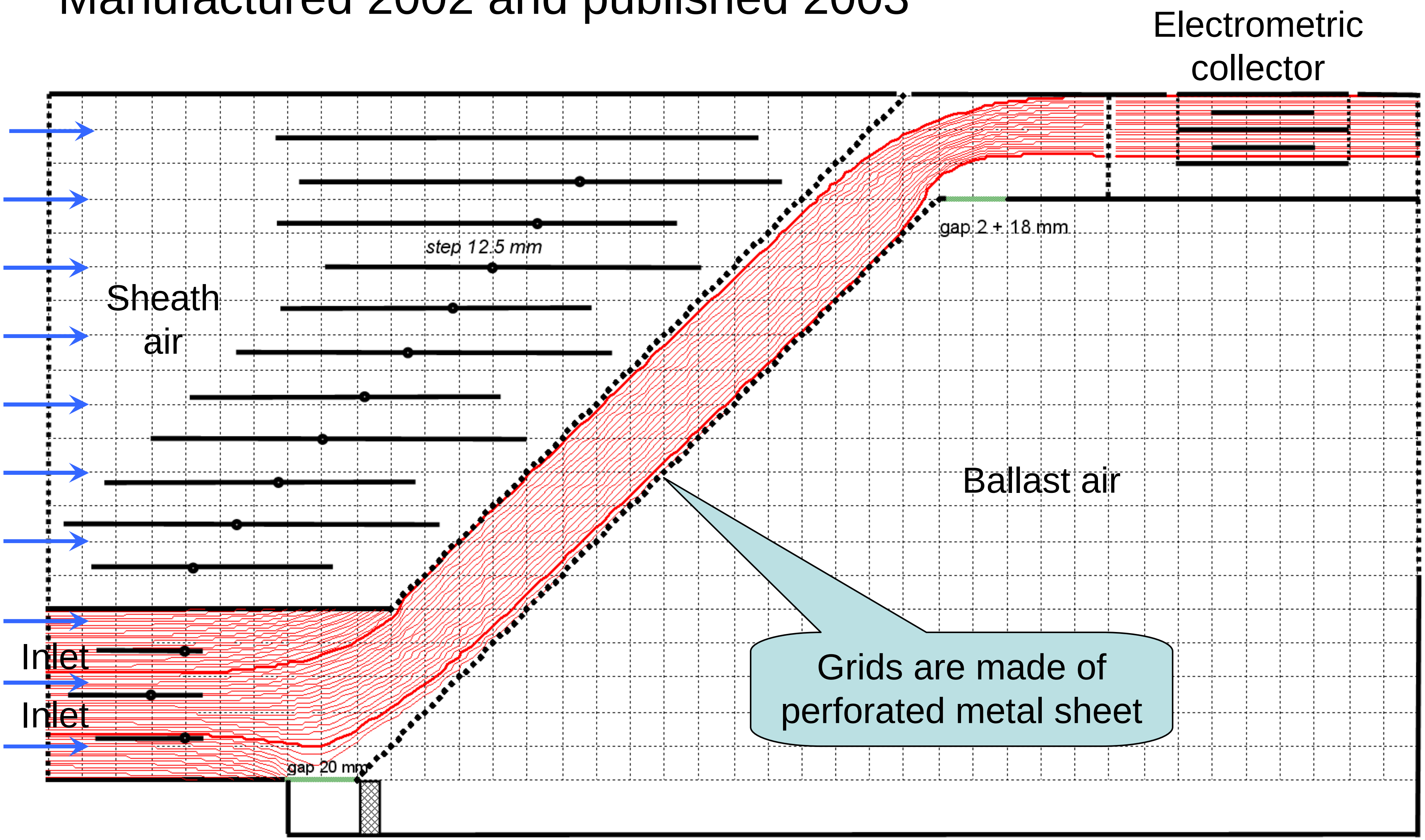
OMAC: Flagan 2004
with added red arrows

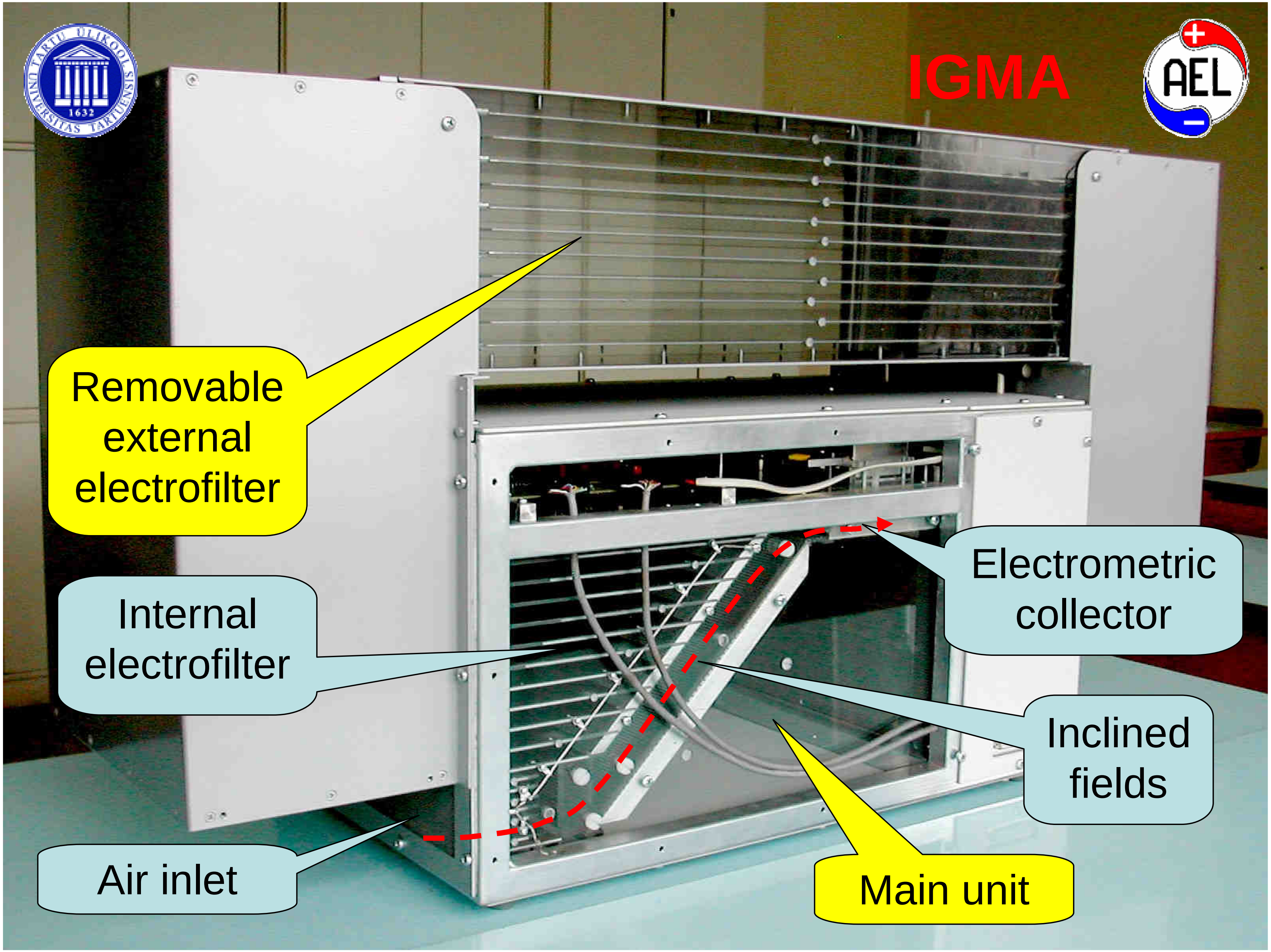


Grids are replaced by porous electrodes

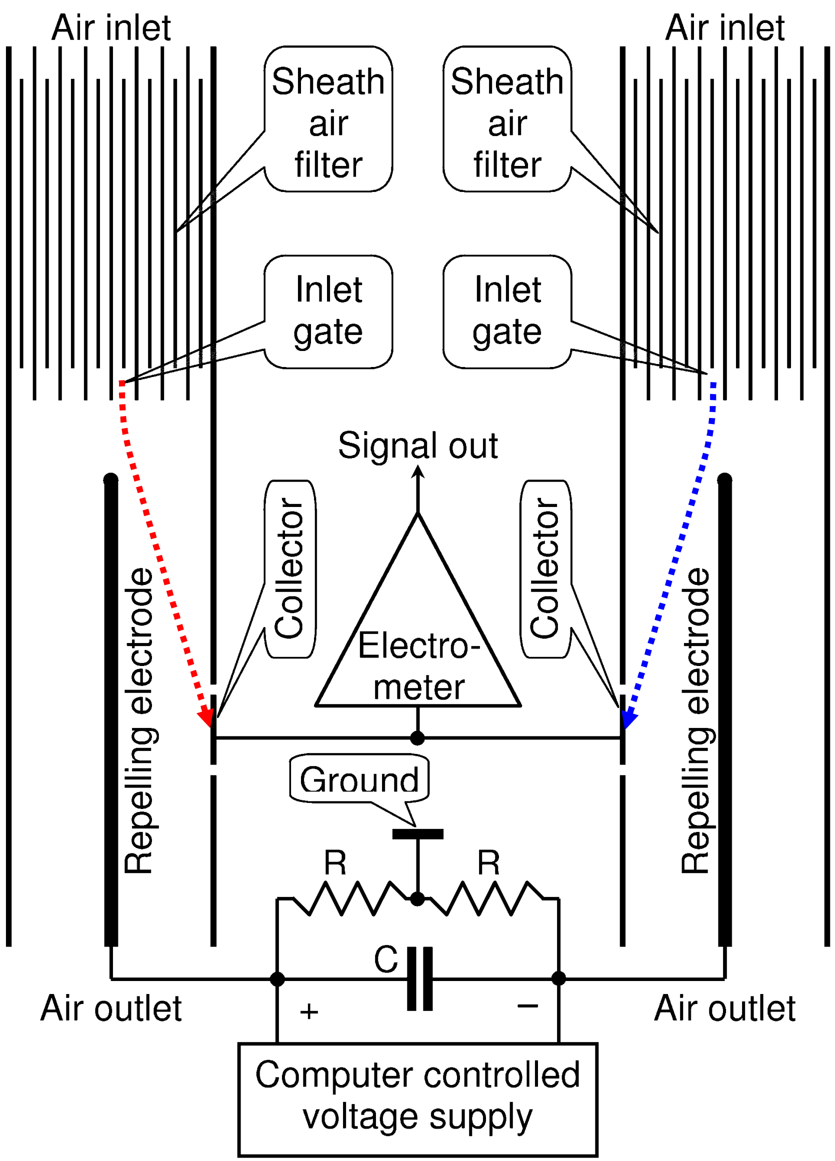
Previous experience: IGMA

Manufactured 2002 and published 2003




IGMA
AEL
Removable external electrofilter
Electrometric collector
Internal electrofilter
Inclined fields
Air inlet
Main unit

Previous experience: BSMA



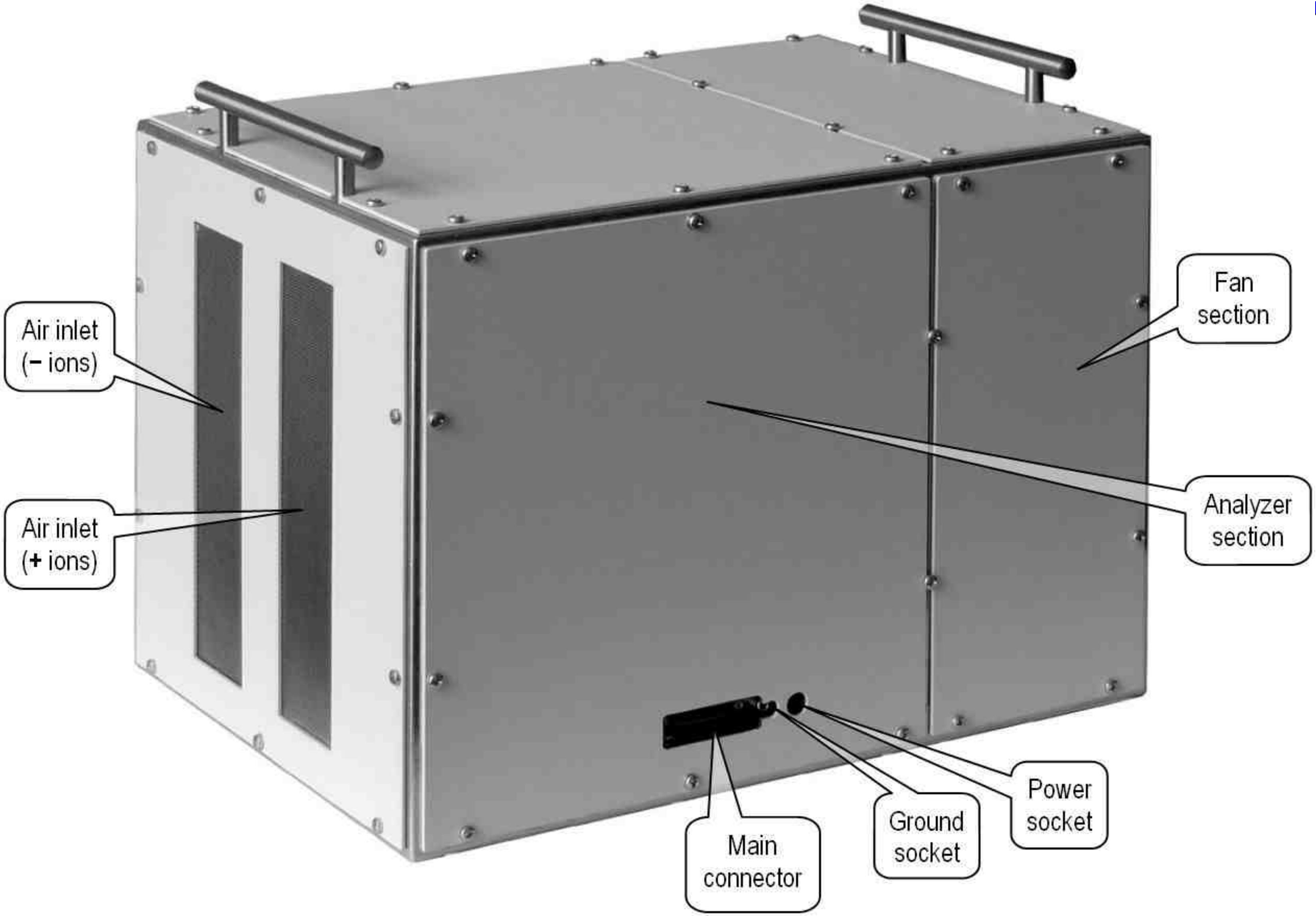
Traditional *Erikson* method, electrostatic induction is suppressed by a balanced *Komarov* bridge.

First BSMA was manufactured 2003 and published 2004–2006.

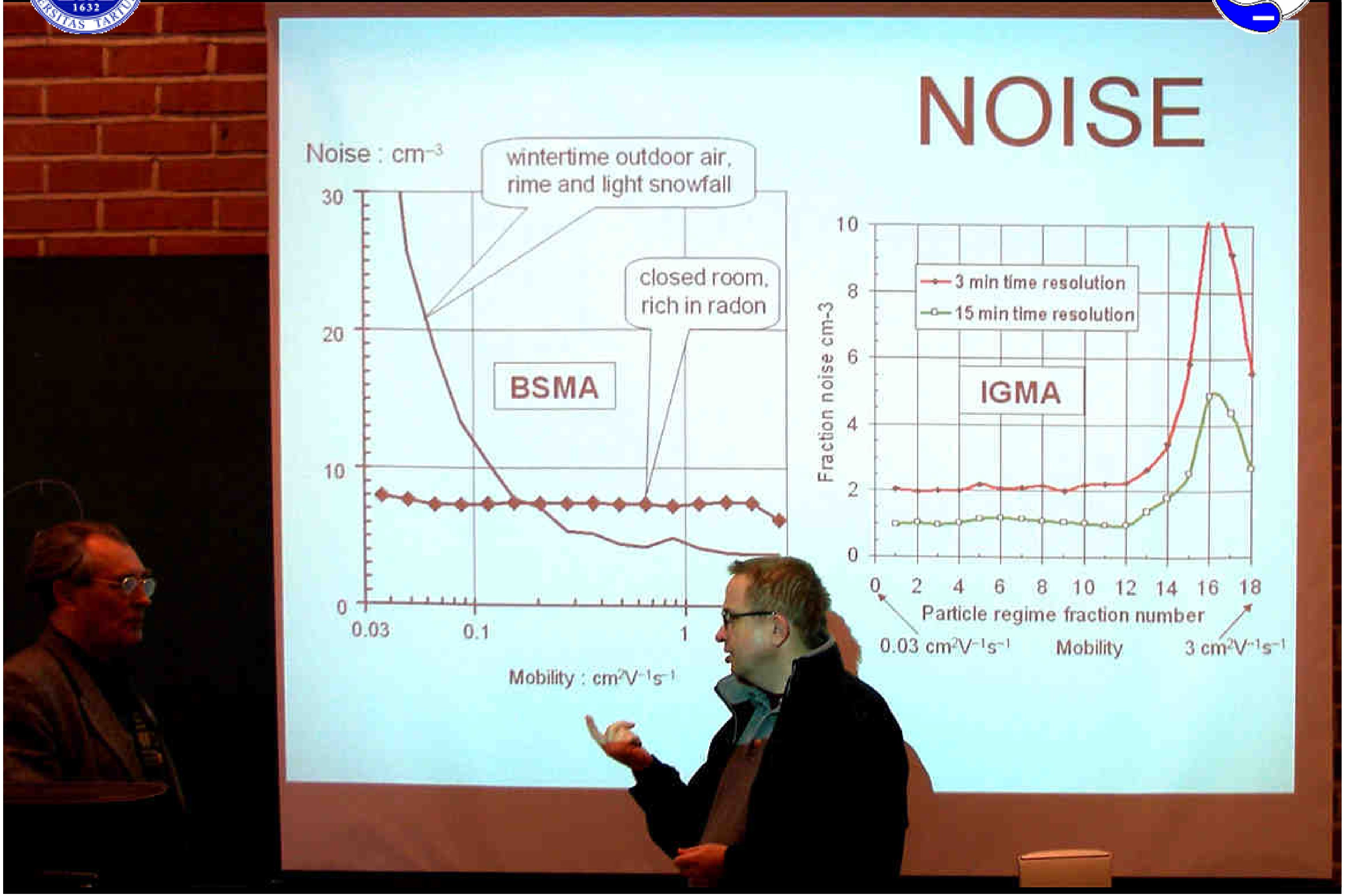
Long experience: routine measurements in Hyytiälä, Tartu, and Helsinki.

Main advantage:
the absolute calibration.

BSMA


Air inlet
(− ions)
Air inlet
(+ ions)
Fan
section
Analyzer
section
Main
connector
Ground
socket
Power
socket

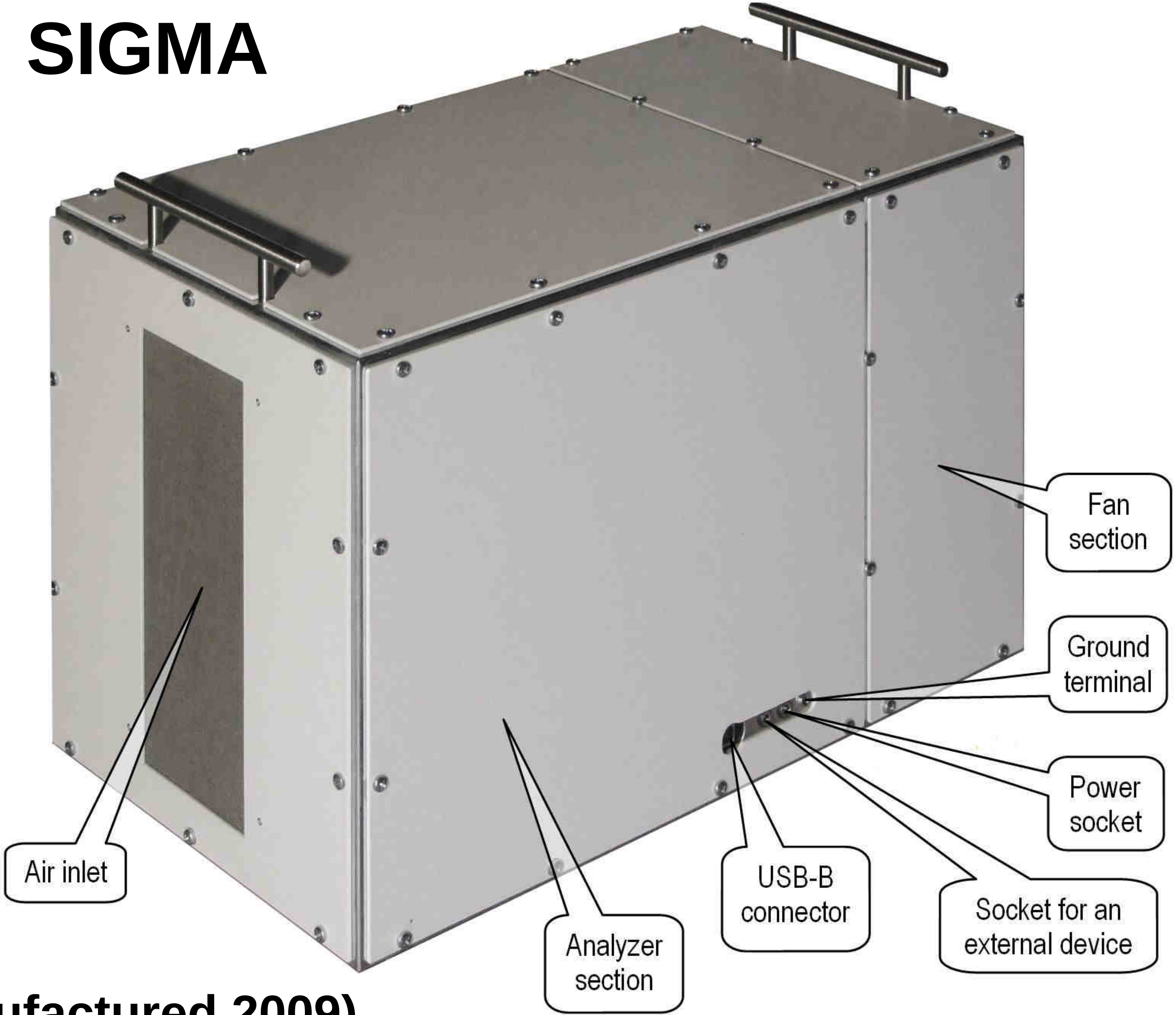
Discussion in Hyytiälä 2007



DECISIONS

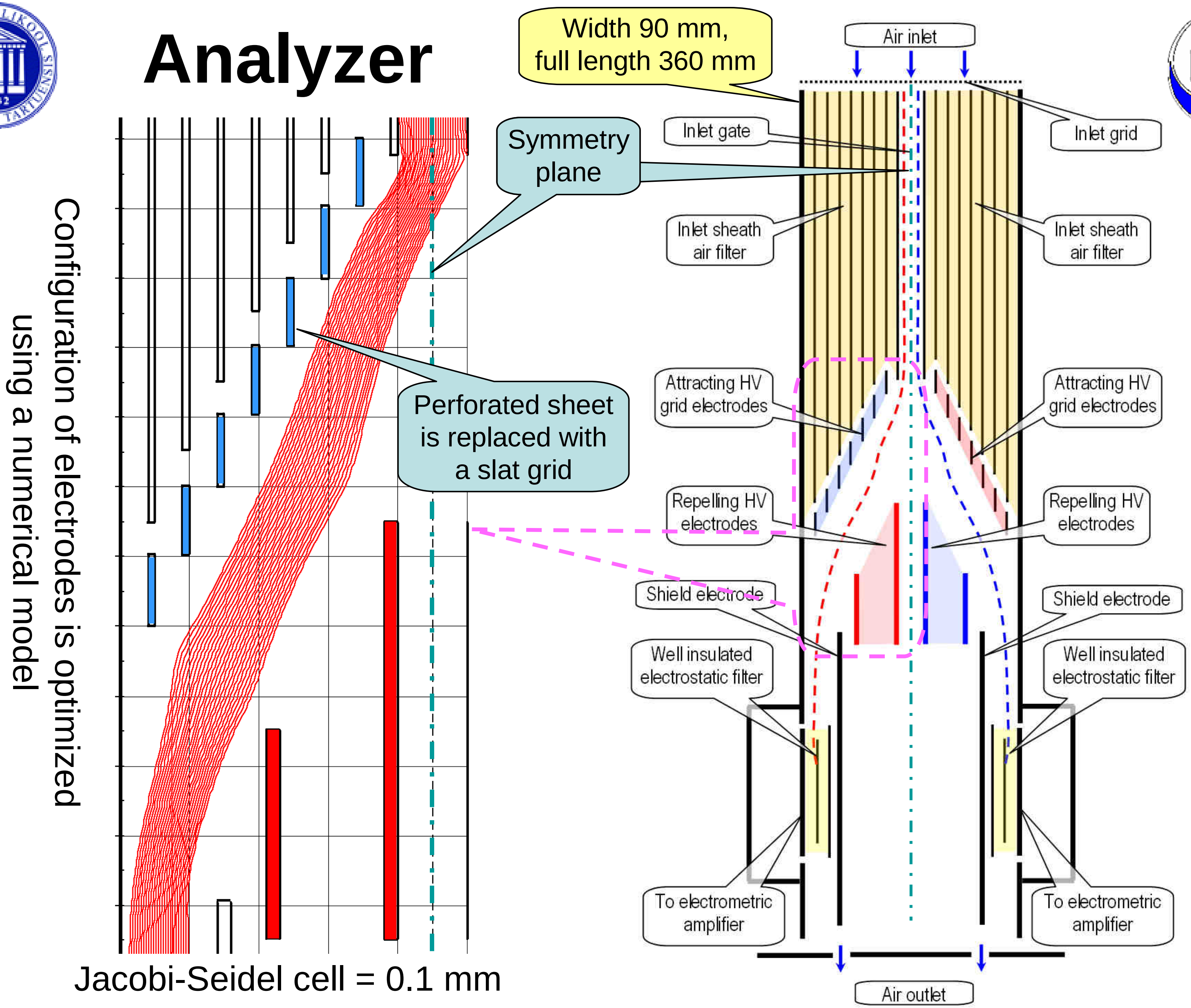
- go back to the principle of IGMA,
- keep the mobility and size range as in approved instruments: 0.032–3.2 $cm^2V^{-1}s^{-1}$ & 0.4–7.5 nm,
- increase sensitivity, especially in range of 2–5 nm,
- improve time resolution,
- provide reliability in long term atmospheric measurements equal or better than of the BSMA.

SIGMA



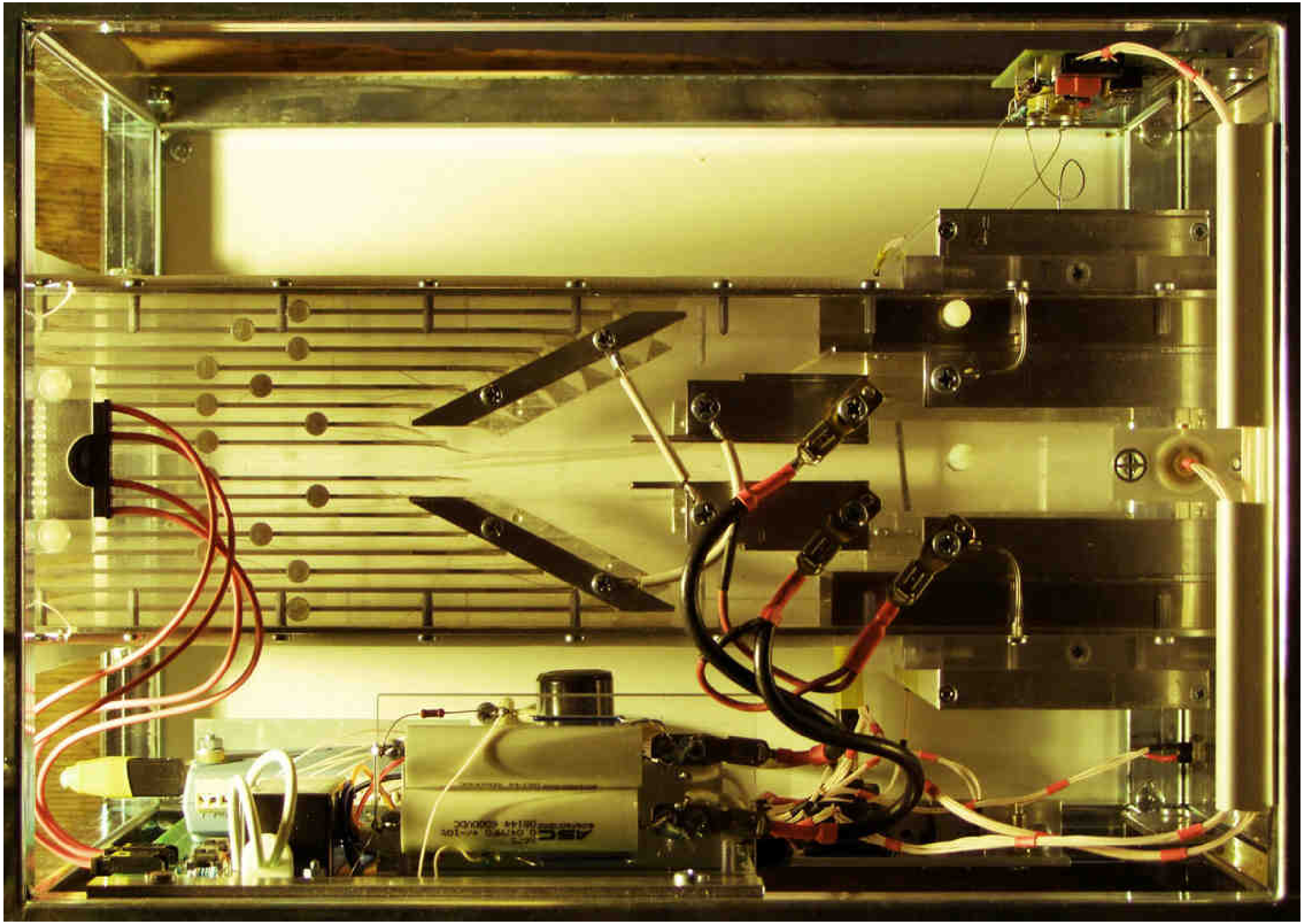
(manufactured 2009)

Analyzer

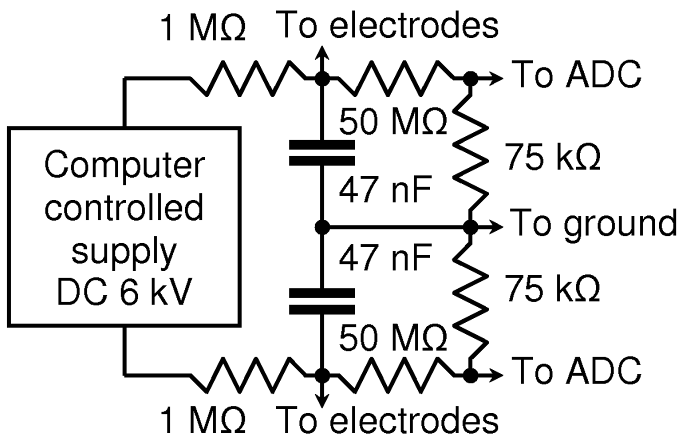


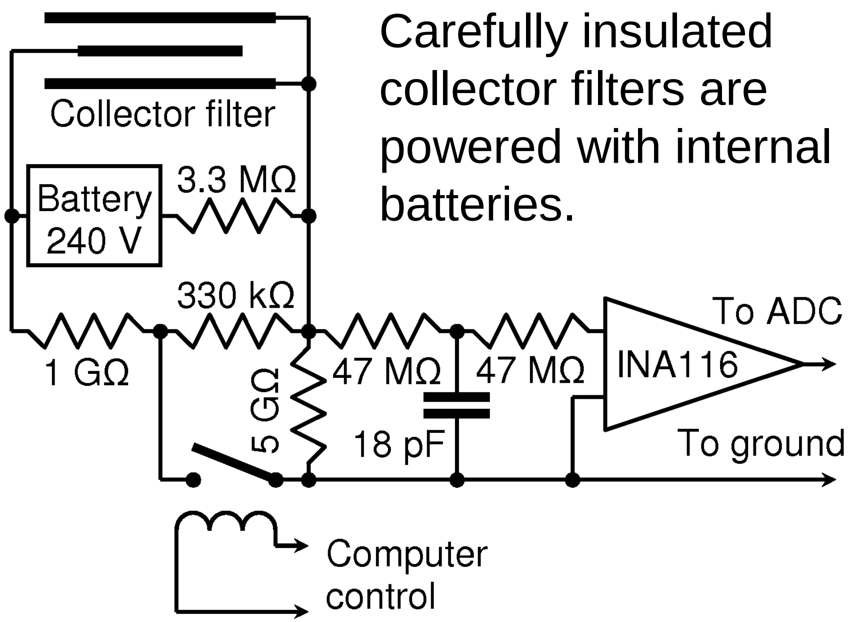
Jacobi-Seidel cell = 0.1 mm

Top view of topless SIGMA



CONTROL OF MEASUREMENT





Carefully insulated collector filters are powered with internal batteries.

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.

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}:

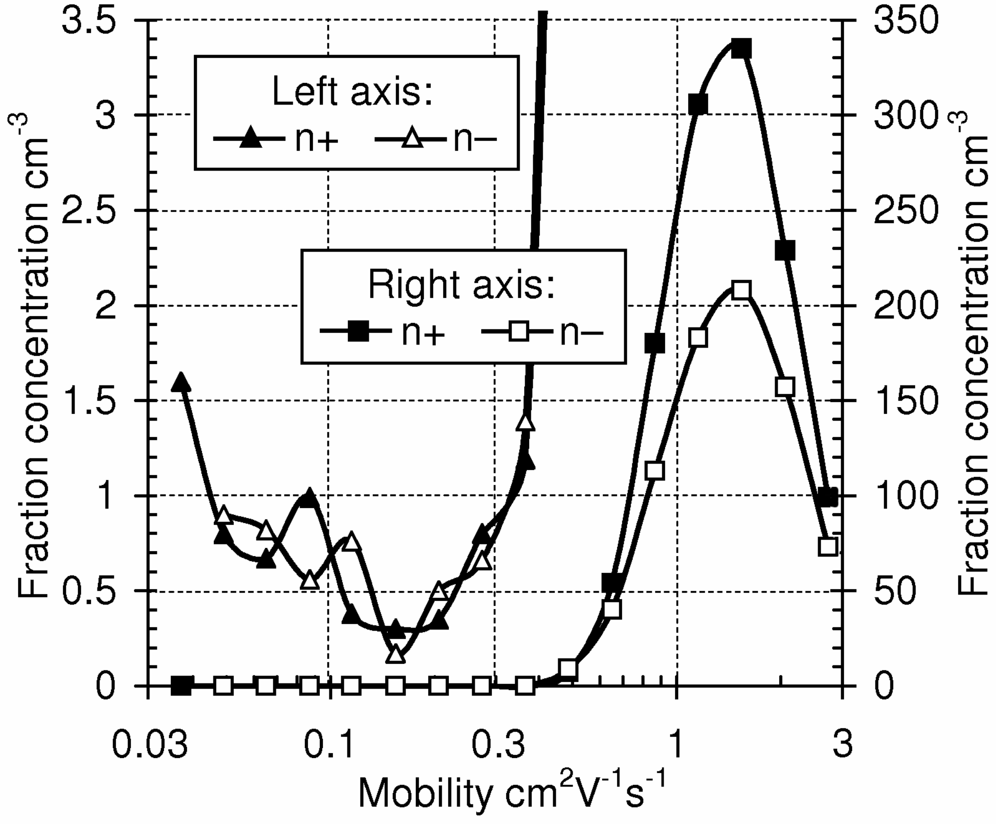
Normal loss on inlet grid A_{grid} = 1.1%,
Normal loss on inlet gate A_{gate} = 3.8%.

The concentrations of mobility fraction are numerically corrected:

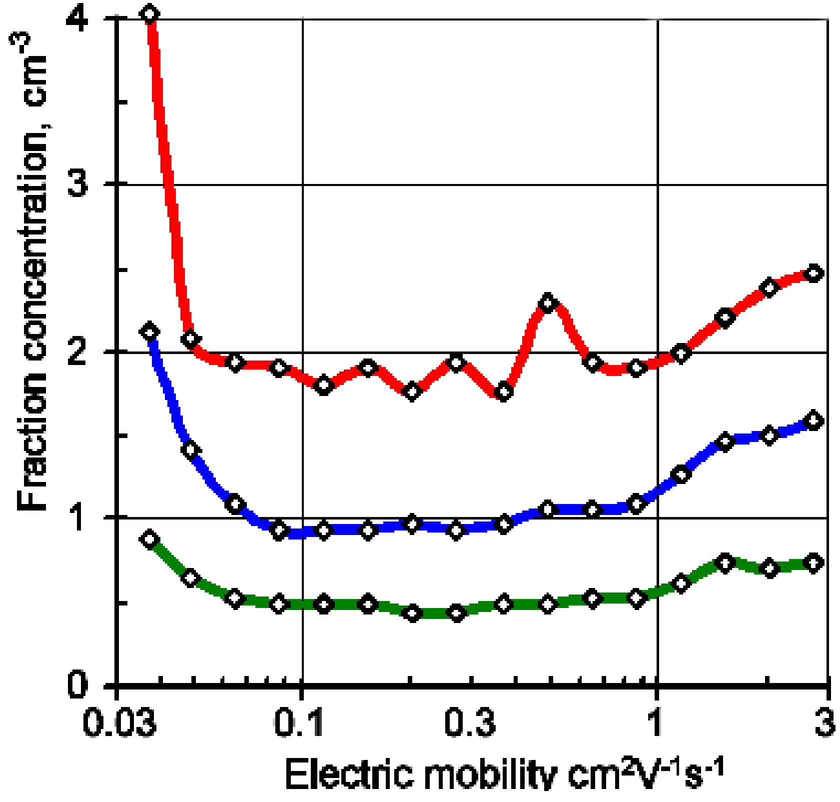
$$f_{corrected} = f_{uncorrected}\,\exp\,(A_{grid} + A_{gate}).$$

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

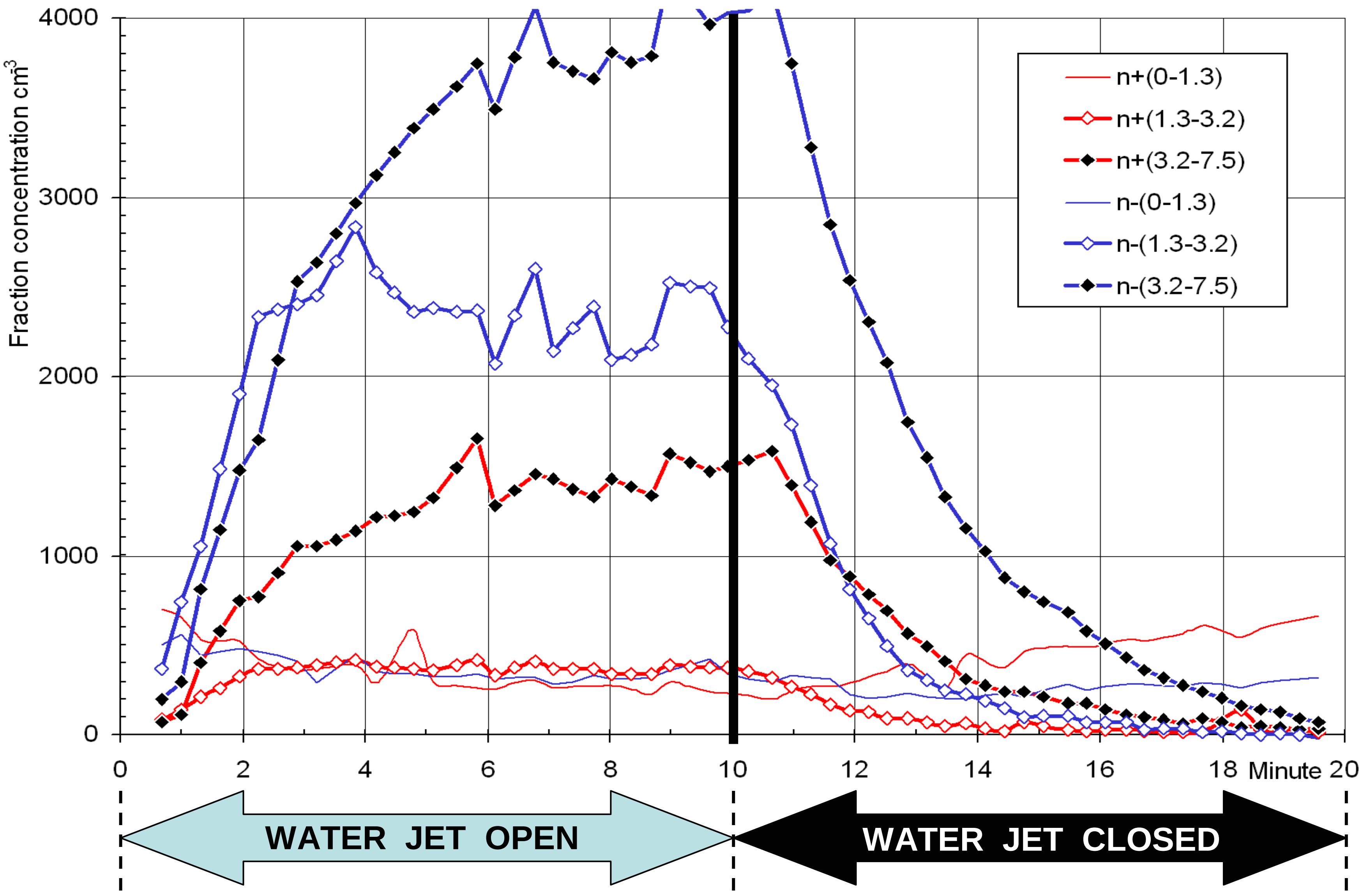


Mobility distributions presented
by fraction concentrations,
20090920 16:00-24:00



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:

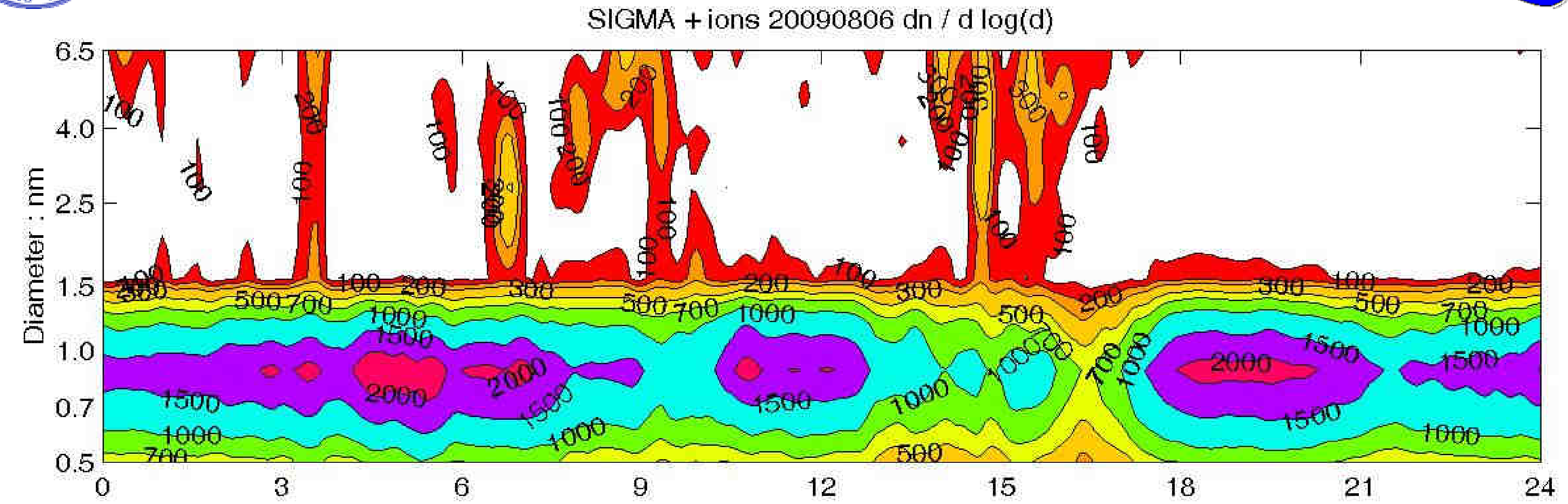
$$0.15 \le \sigma / Z \le 0.2$$

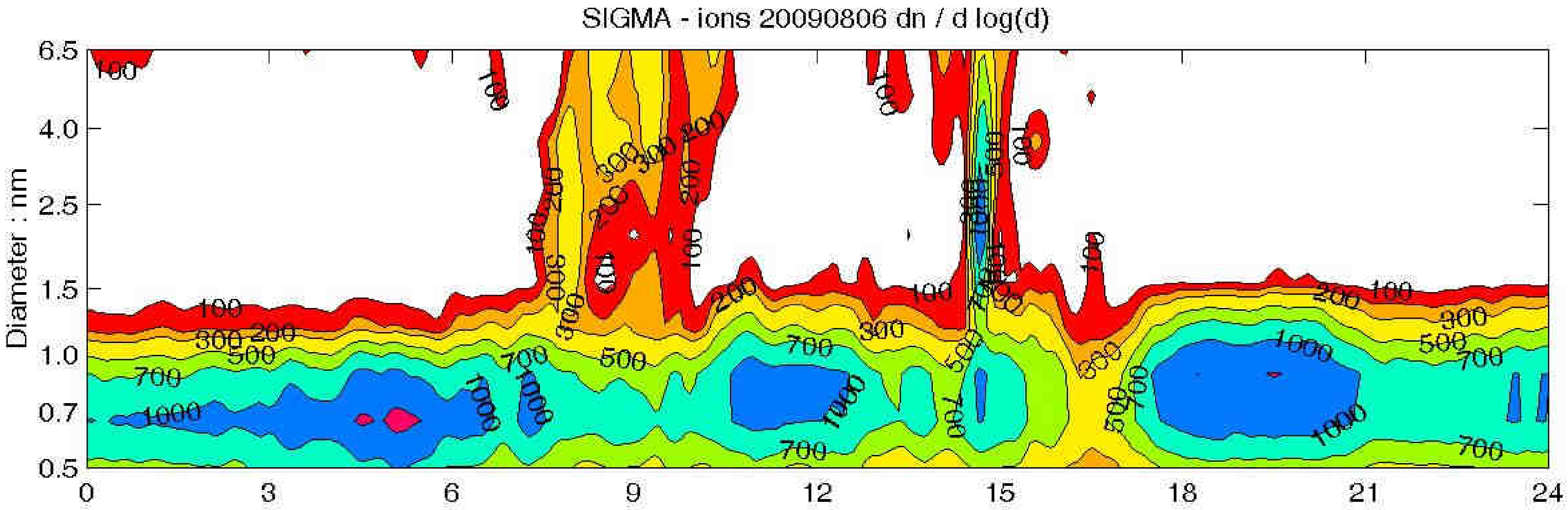
$$2 \le Z / \Delta Z_{1/2} \le 3$$

$$4.5 \le \mathrm{RFD} \le 7$$

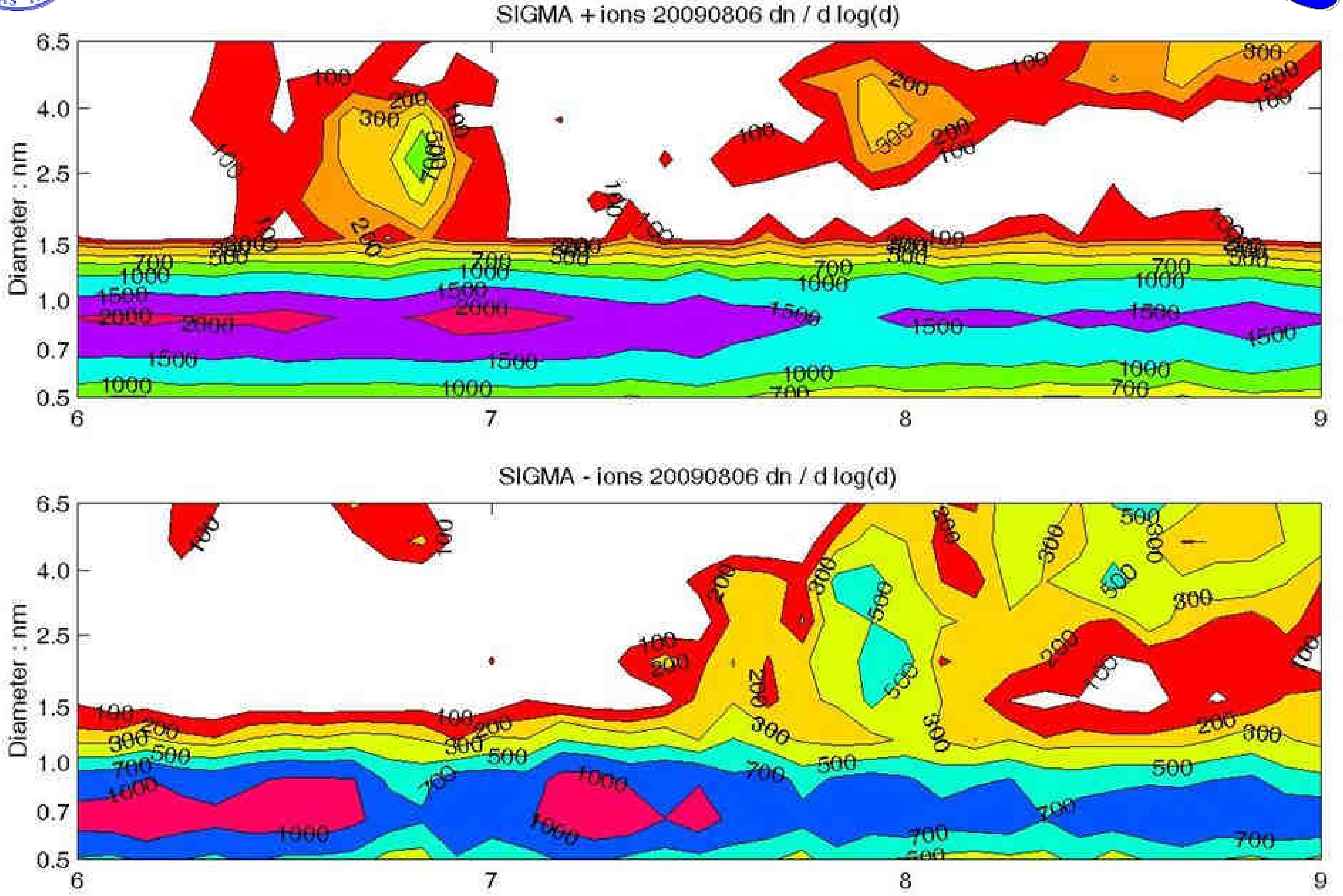
(RFD = **R**esolved **F**ractions per **D**ecade)

EXAMPLE 1 (5 min time resolution)

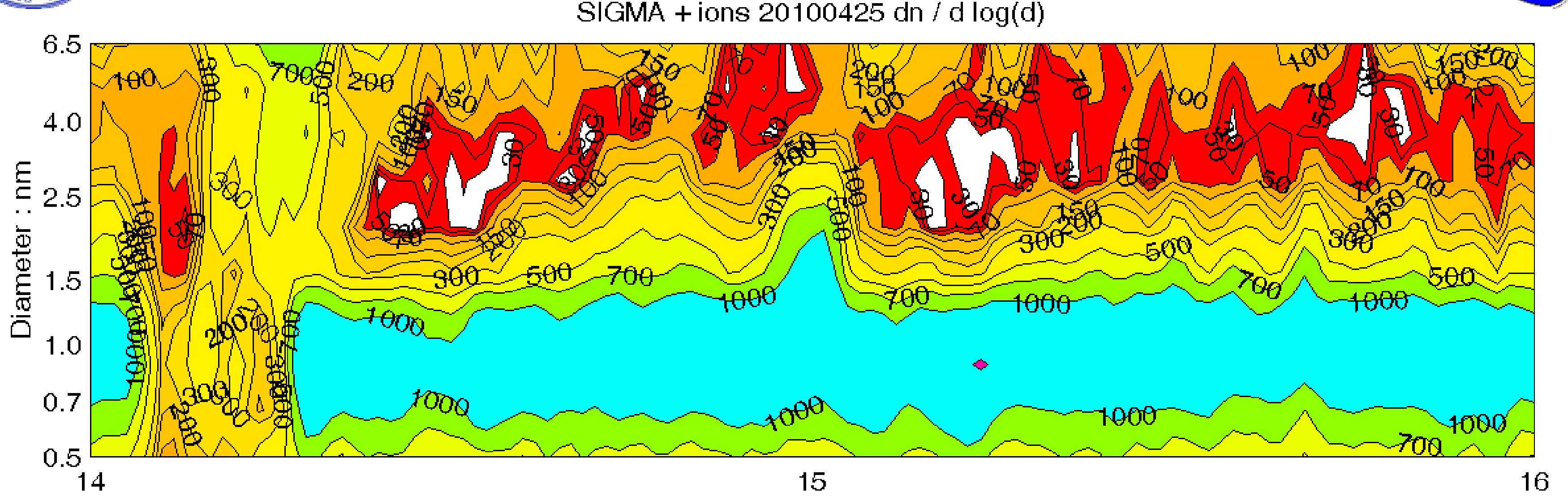


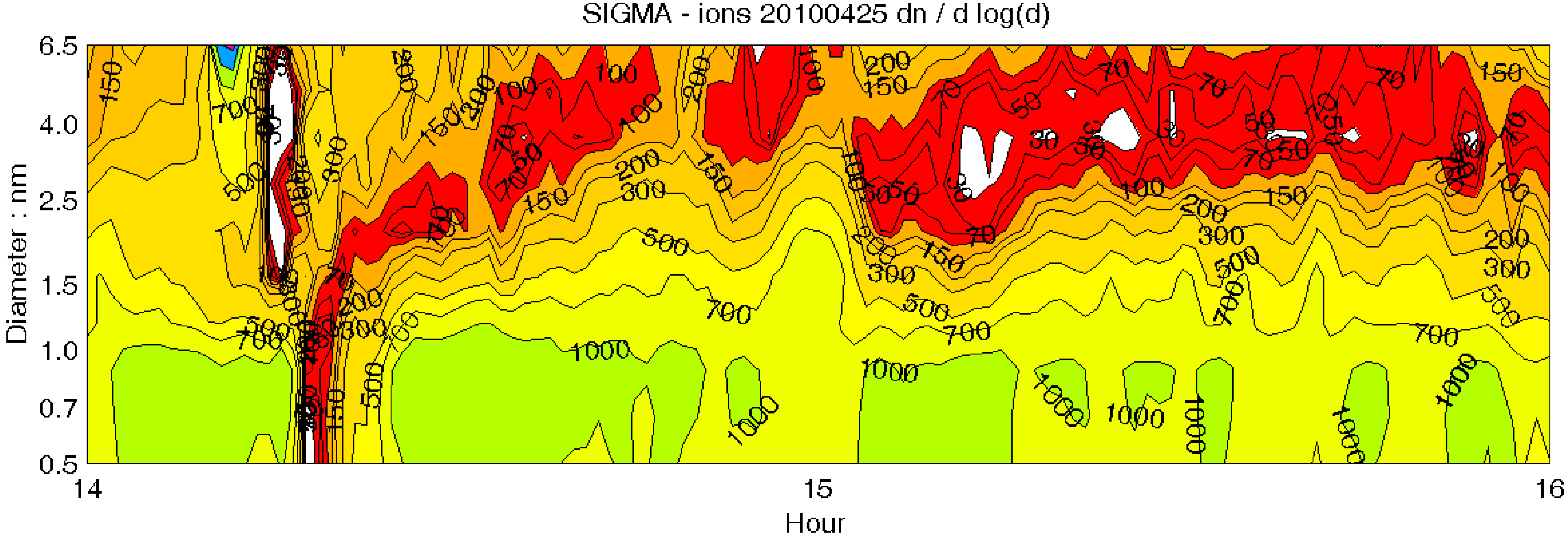


EXAMPLE 1a (excerpt from previous)



EXAMPLE 2 (1 min time resolution)





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}.

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Thank You!