Symmetric Inclined Grid Mobility Analyzer

SIGMA

an improved instrument for measuring
of charged particles below 7.5 nm in atmospheric air

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INTRODUCTION

The **S**ymmetric **I**nclined **G**rid **M**obility **A**nalyzer

SIGMA is a successor of the scanning mobility analyzers

IGMA (Inclined Grid Mobility Analyzer, 2002) and

BSMA (Balanced Scanning Mobility Analyzer, 2003).

Like the previous instruments, it is designed having in view applications in atmospheric aerosol nucleation research and makes possible simultaneous measuring of positive and negative air ion distribution in the mobility range of 0.032−3.2 $cm^2V^{-1}s^{-1}$ and in the size range of 0.4−7.5 nm.

Why a new instrument?

Time resolution and noise level of BSMA
are not good enough to:

1) detect 2−7 nm particles in non-nucleation situations,
2) measure vertical profile using a tower lift,

……..

Main improvements in SIGMA compared with BSMA are:

- increased sensitivity,
- improved time resolution,
- positive and negative ions are sampled from the same air and measured exactly simultaneously.

A technical improvement is
control of the instrument under Windows XP via USB.

INTRODUCTORY EXAMPLES

Previous experiments are descibed in:

Atmos. Chem. Phys., 9, 357–367, 2009
www.atmos-chem-phys.net/9/357/2009/

Atmospheric Chemistry and Physics

Negatively charged nanoparticles produced by splashing of water

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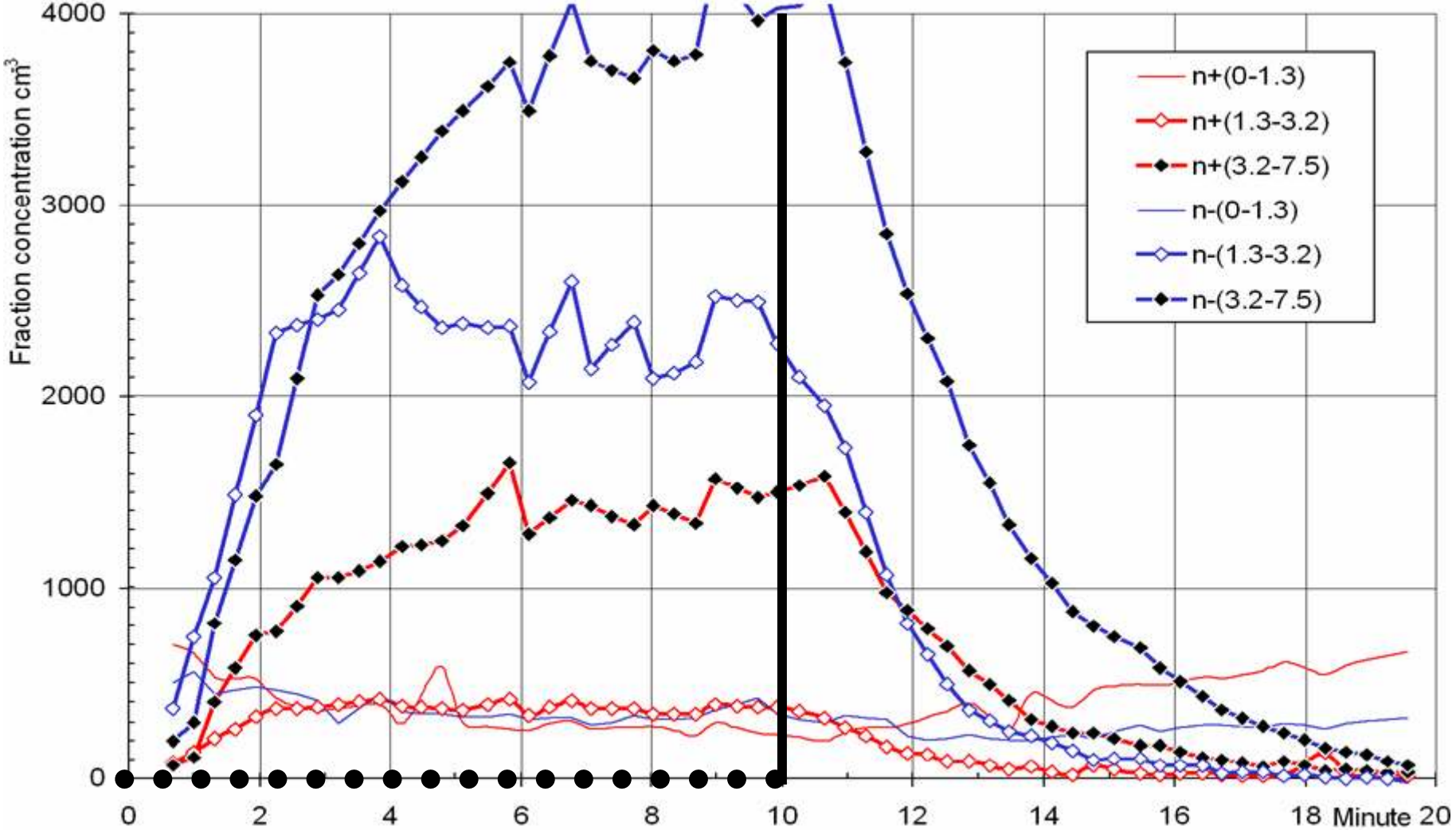
Received: 7 July 2008 – Published in Atmos. Chem. Phys. Discuss.: 1 September 2008
Revised: 10 December 2008 – Accepted: 11 December 2008 – Published: 16 January 2009

NB: dynamics of processes remained unknown because BSMA does not allow measuring time less than 5 minutes.

New experiments were carried out in the same 17 m^3 room,

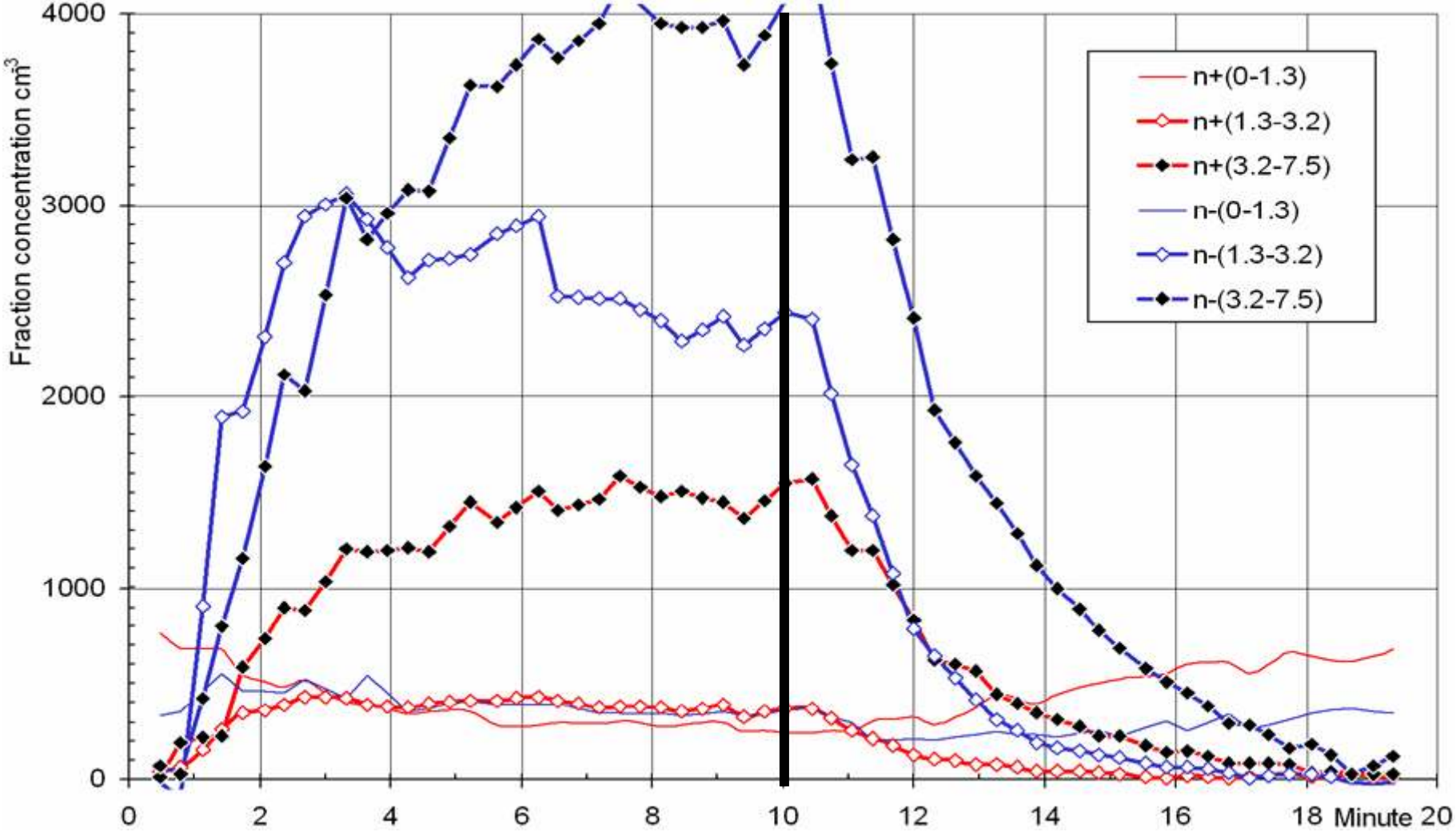
difference: BSMA was replaced by SIGMA.

Size fraction concentrations during a water jet experiment



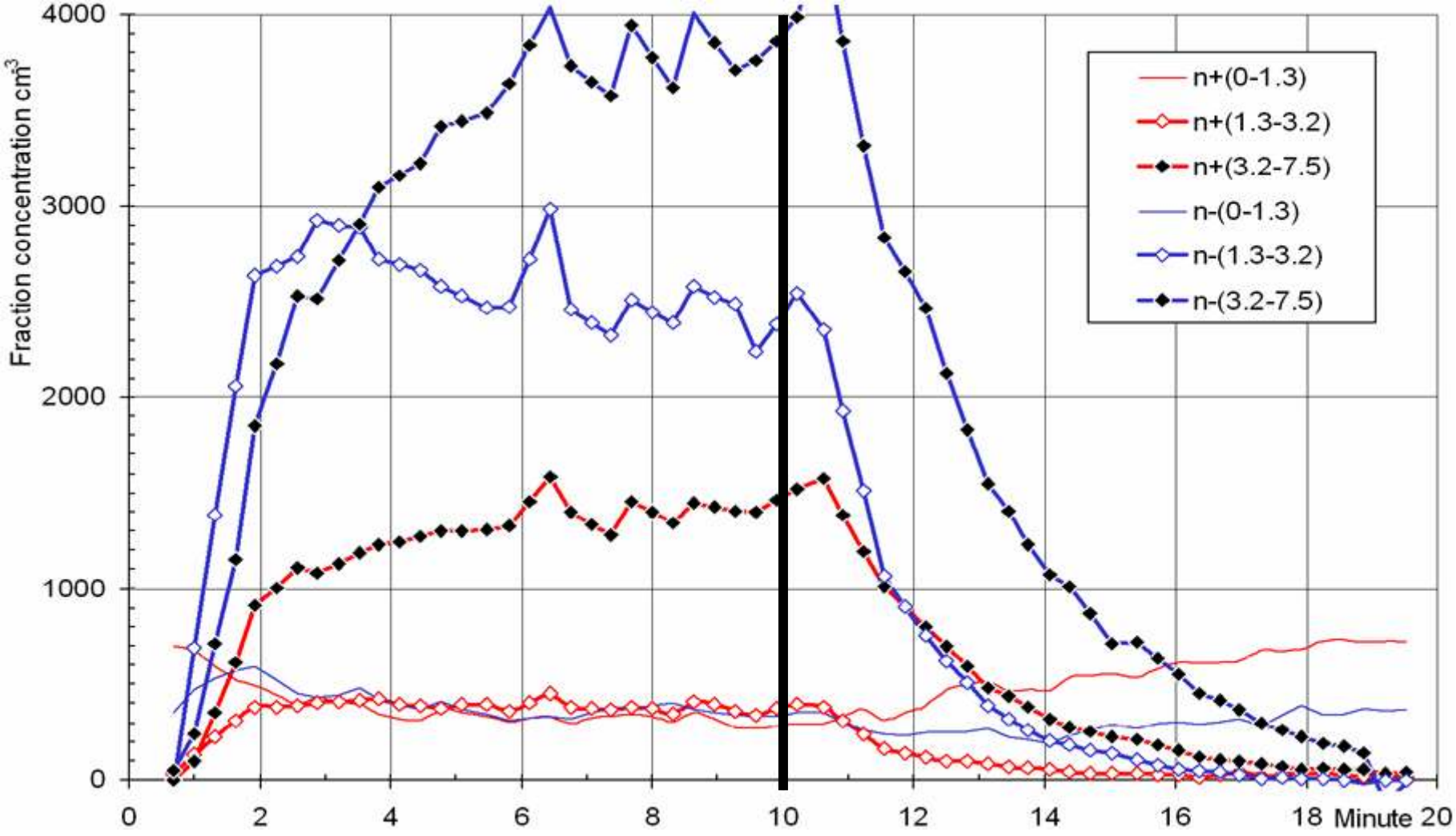
Experiment 20091028, 13:50-14:10
Water jet was turned on at 0 and closed after 10 minutes

Repeated:



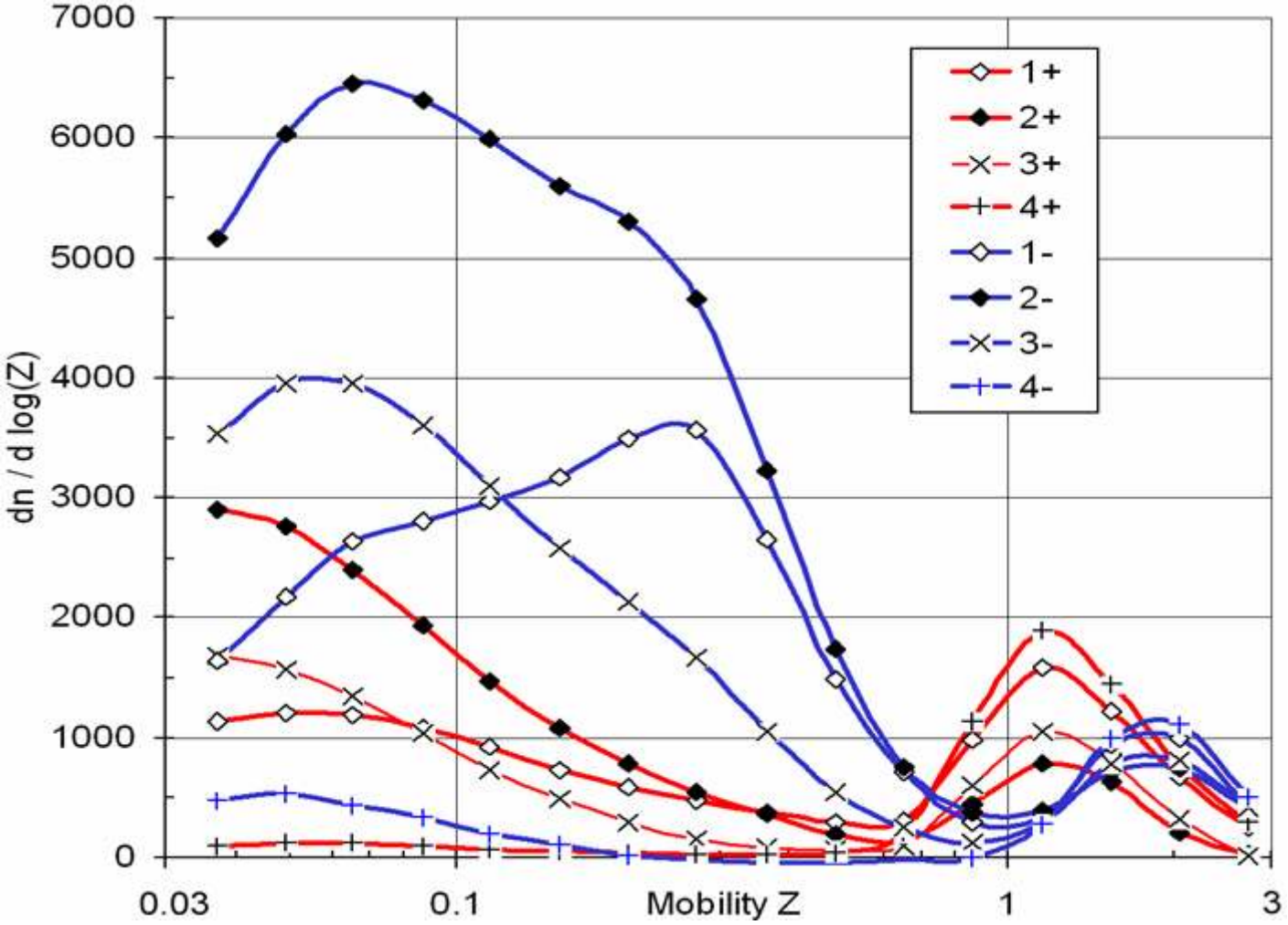
Experiment 20091028, 14:30-14:50
Water jet was turned on at 0 and closed after 10 minutes

Repeated:



Experiment 20091028, 14:50-15:10
Water jet was turned on at 0 and closed after 10 minutes

Mobility distribution for 4 five-minute phases

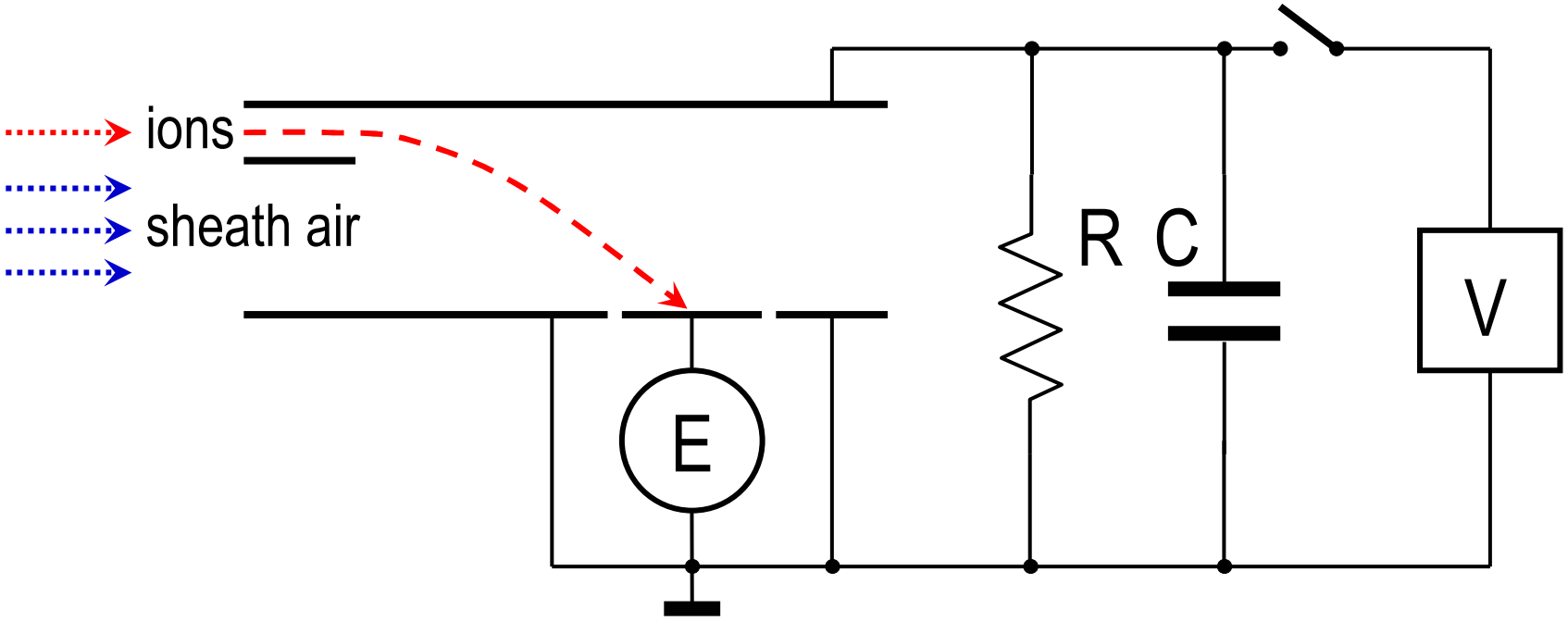


Water jet experiment 20091028, average of 4 runs during 13:50-15:10

Common distinctive properties of BSMA and SIGMA are:

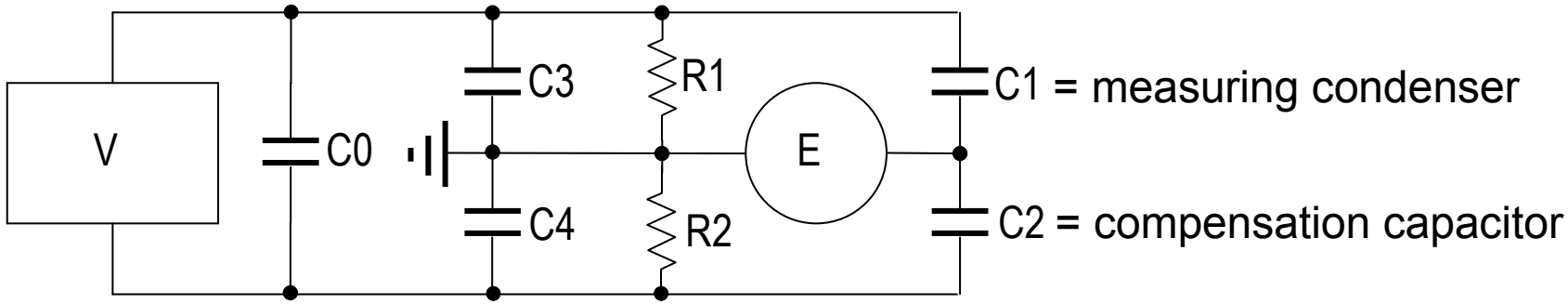
- High flow rate (30 dm^3/s) suppresses (but does not eliminate) the effect of external electric field and assures representative sampling of ions.
- The ions pass in the analyzer only through unaffected atmospheric air.
- Short passage time about 0.1 s and low heating of air less than 0.3 K suppress changing of the ions during the measuring.
- The scanning through full mobility range using single collector and varying only the voltage:
  1) allows calibrating the instrument using test ions of single mobility,
  2) guarantees that peculiarities in the mobility distribution are not generated by the technical troubles of individual channels.
- Low inlet loss of ions enables reliable estimating and numerical compensation of ion fraction concentrations.
- Temperature- and pressure- sensitive calibration coefficients are operatively adjusted during the measurement according to the readings of built-in meteorological sensors.

Principle of RC-scanning

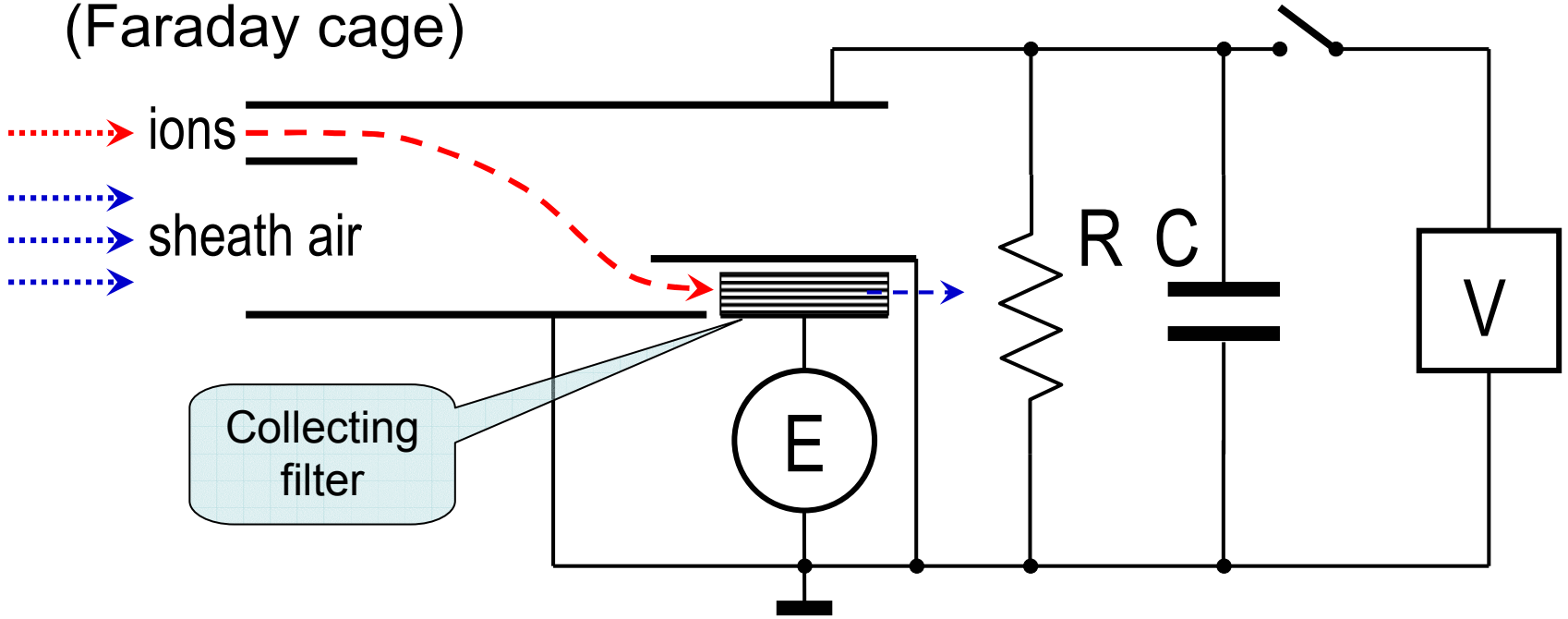


Methods of neutralizing the induced current

1. Erikson bridge or Komarov bridge



2. Shielded collector
(Faraday cage)



Scanning mobility analyzers of Tartu University

1975) UT-7509

1978) UT-7801

1991) UT-9105

2002) IGMA

2003) BSMA

2009) SIGMA

NB: First multichannel spectrometer of Tartu University was made **1972**.

UT-7509

Tammet, H.F., Hilpus, A.O., Salm, J.J., and Üts, E.J. (1977) An air ion spectrometer for the detection of some admictures in air (in Russian). *Acta Comm. Univ. Tartu* 409, 84–88.

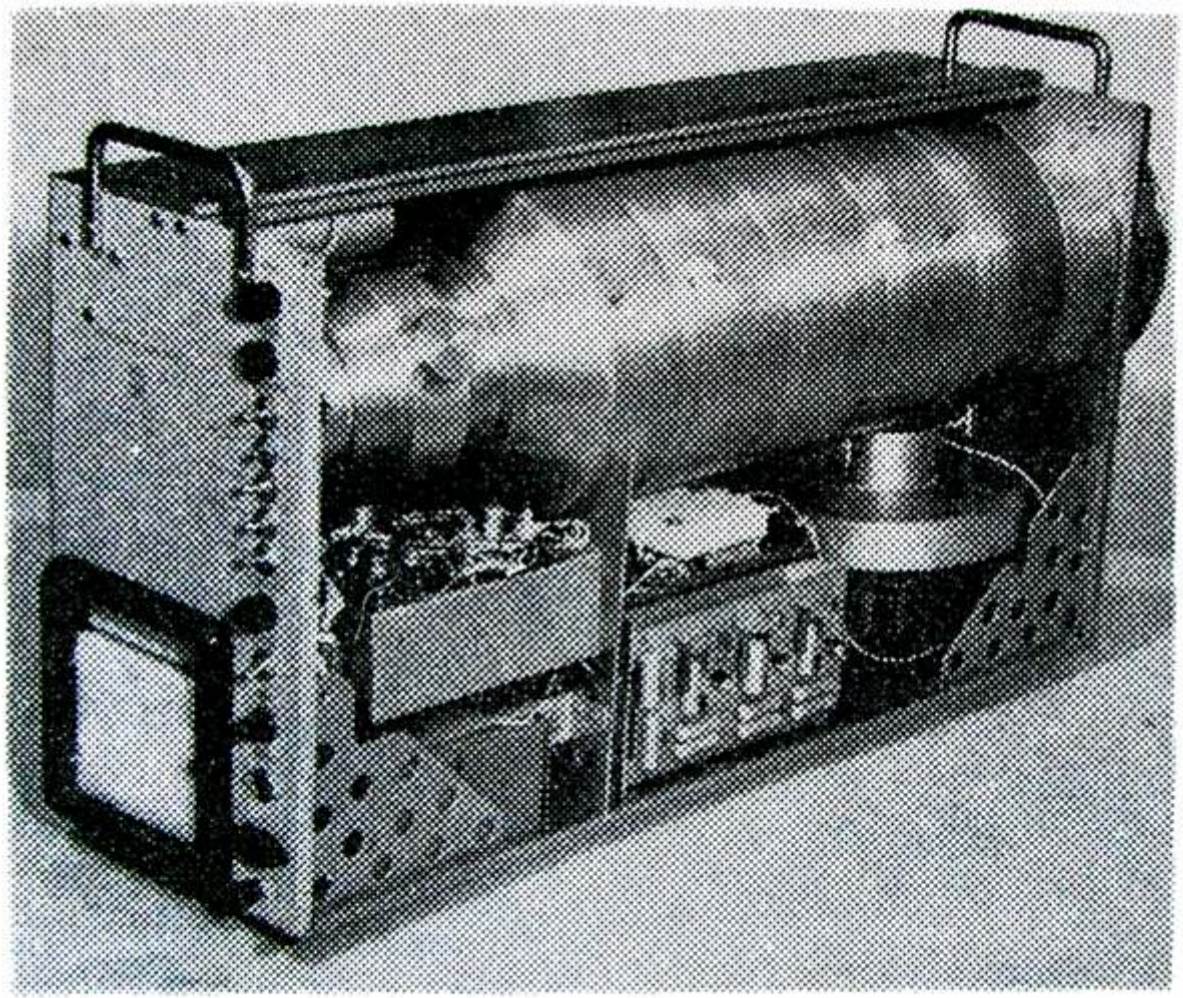


Рис.I.Спектрометр аэроионов UT-7509 со снятым кожухом

UT-7509

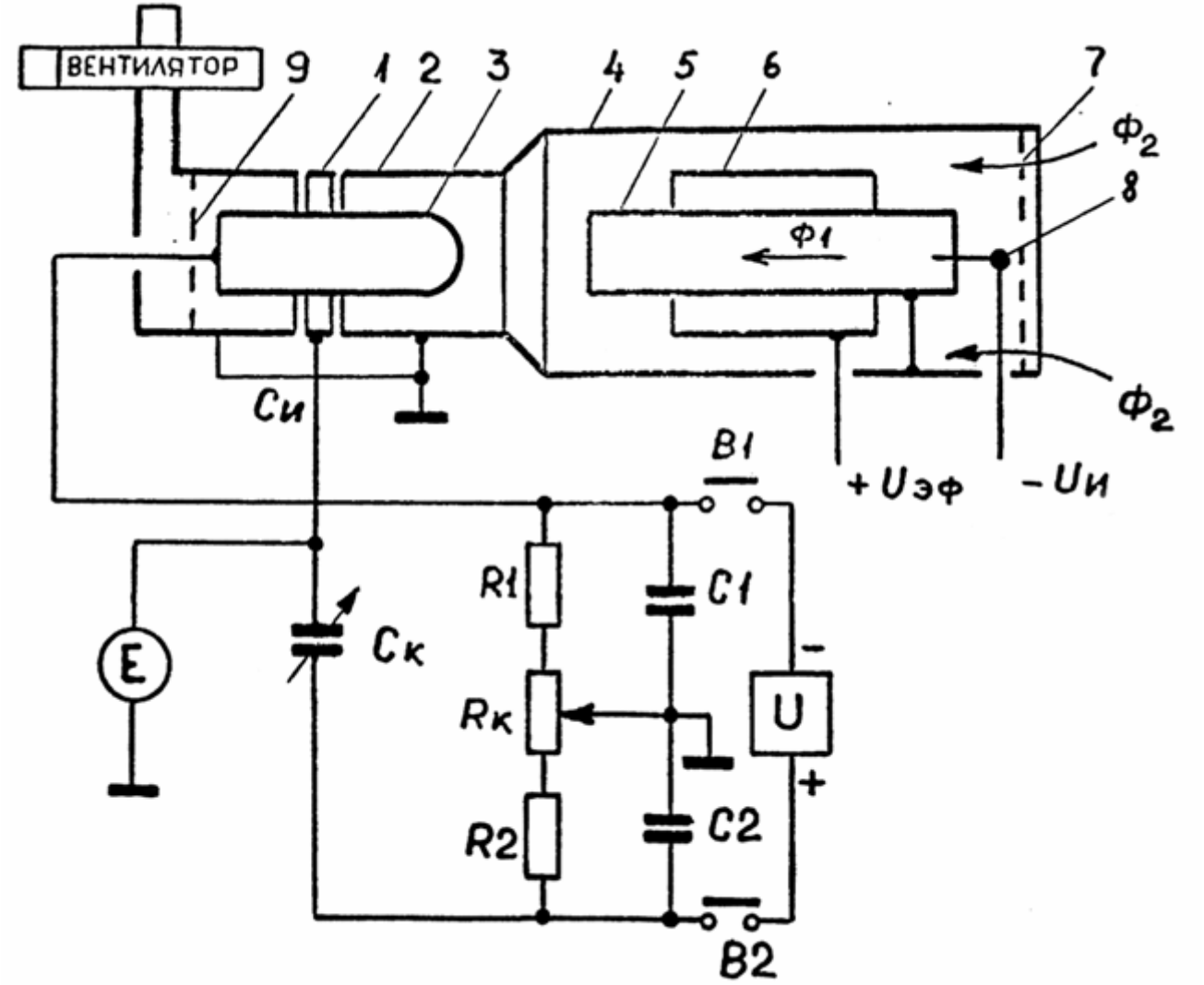
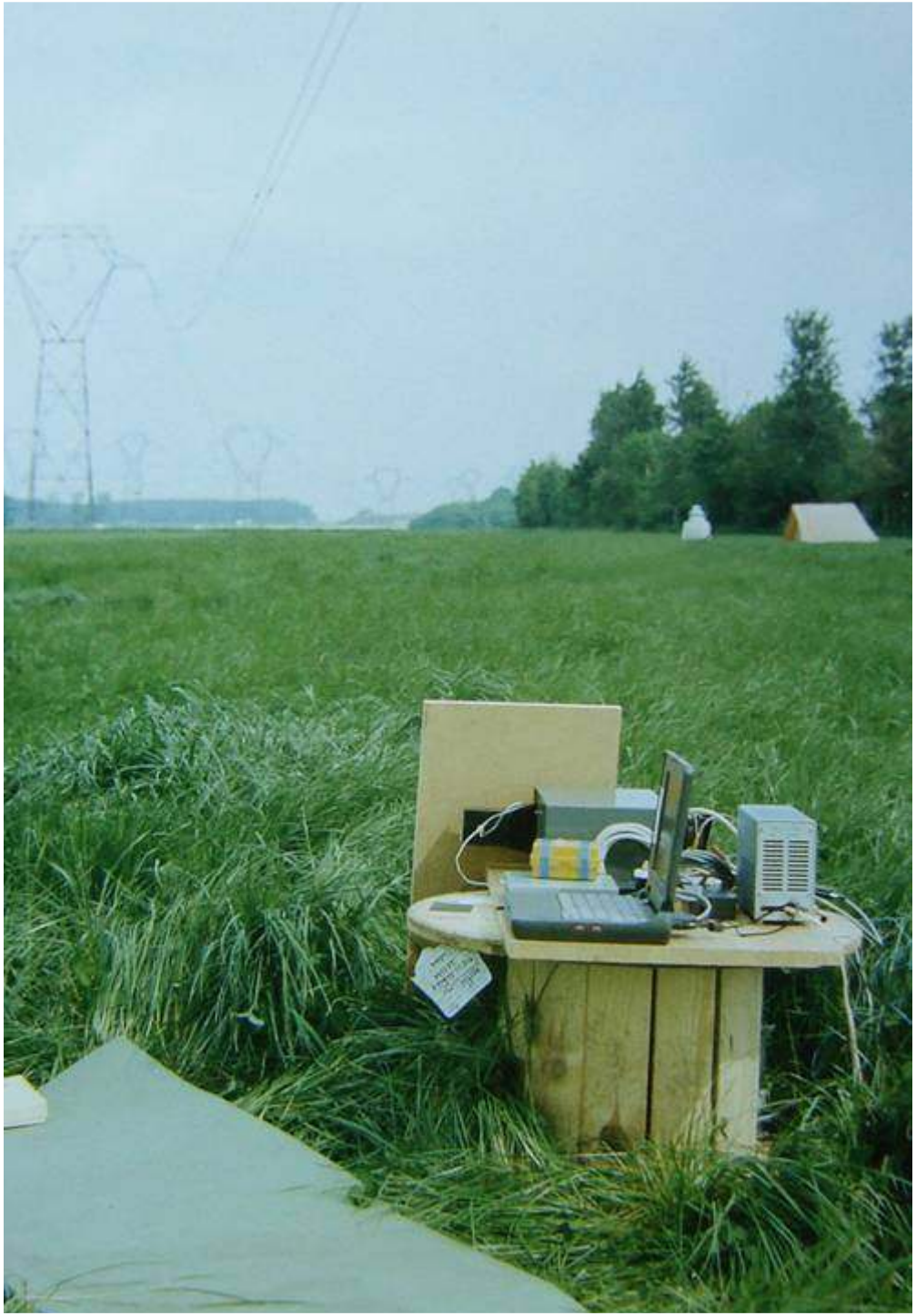


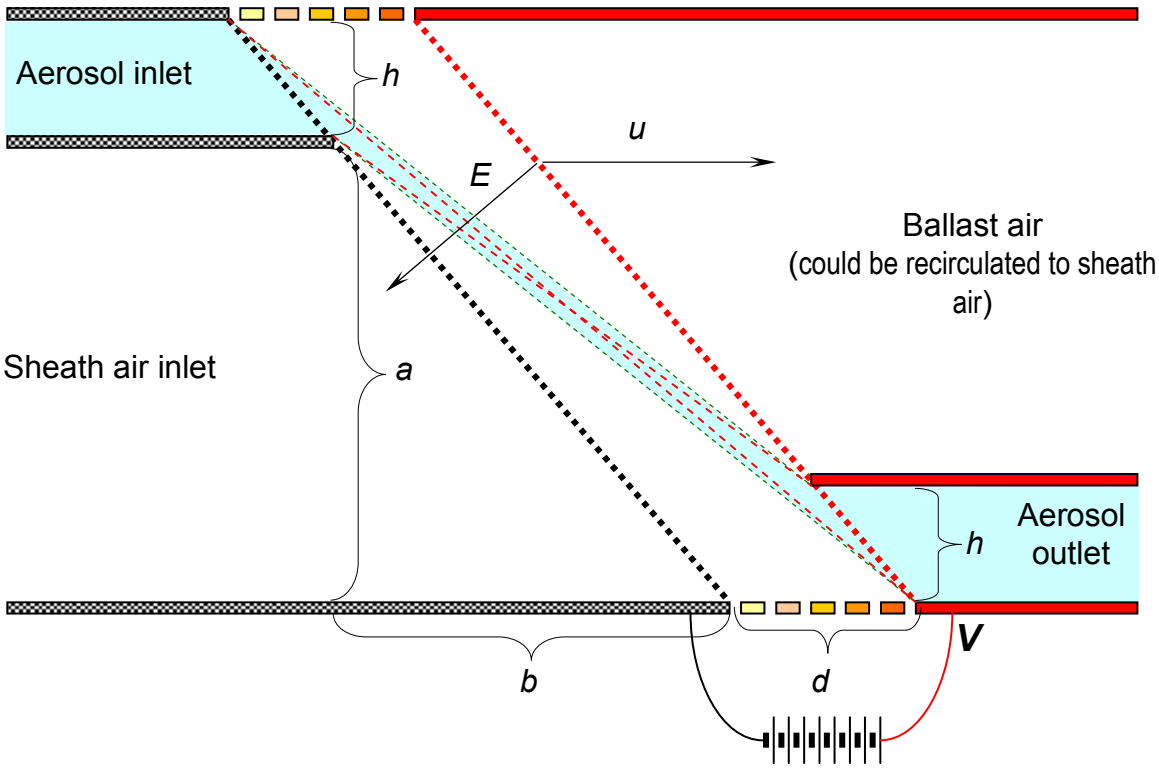
Рис.2. Функциональная блок-схема спектрометра аэроионов.

UT-7801

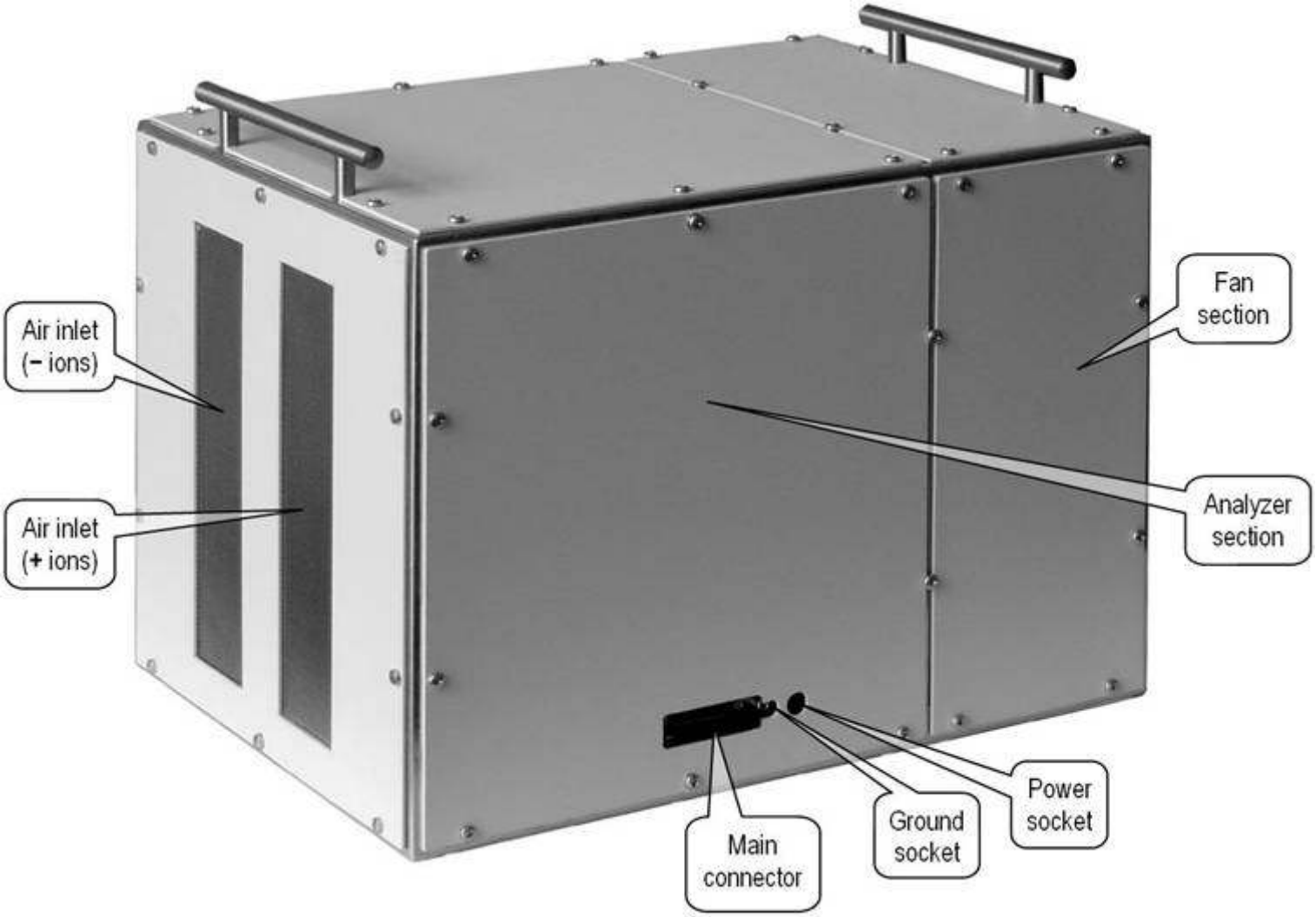
UT-9105

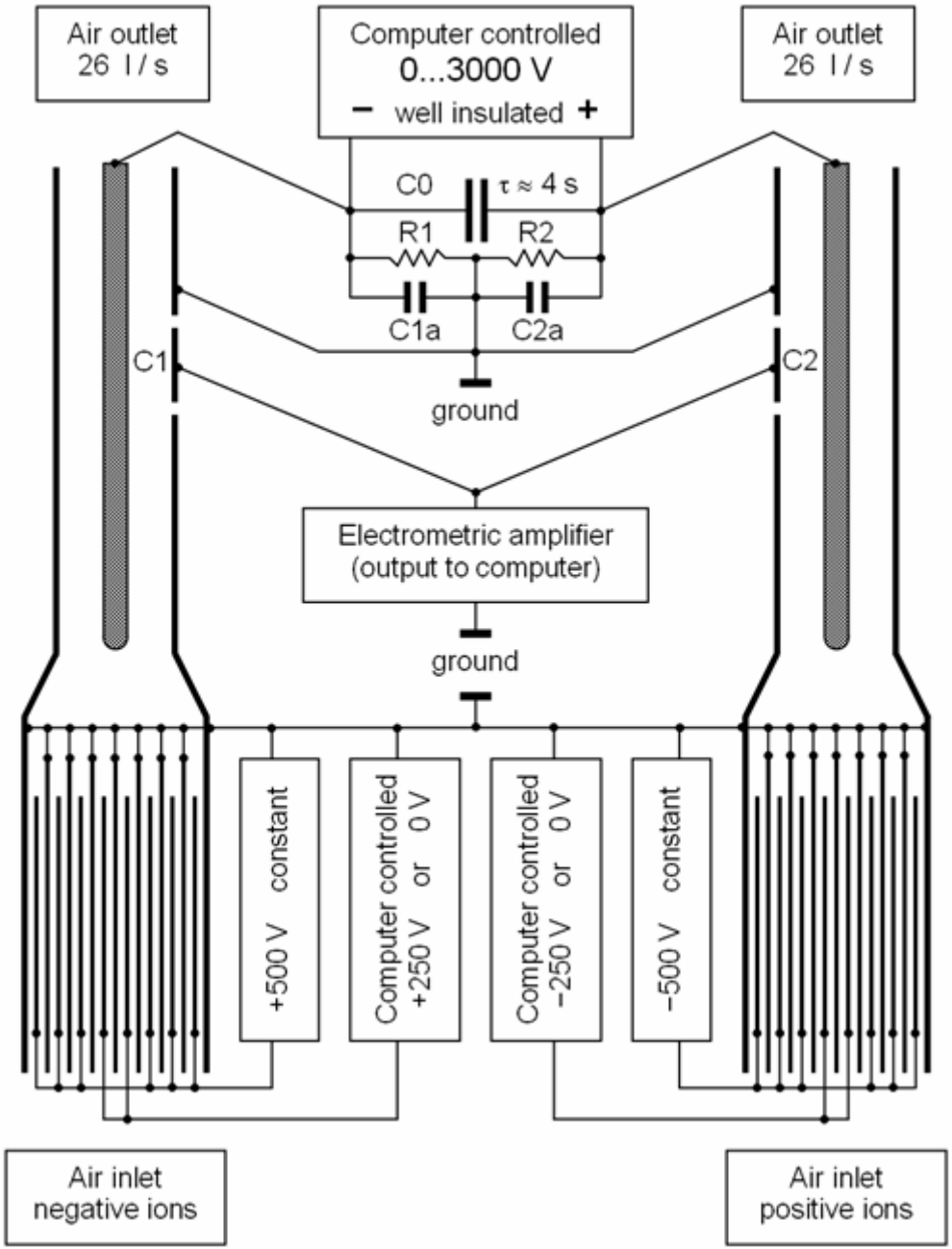


IGMA

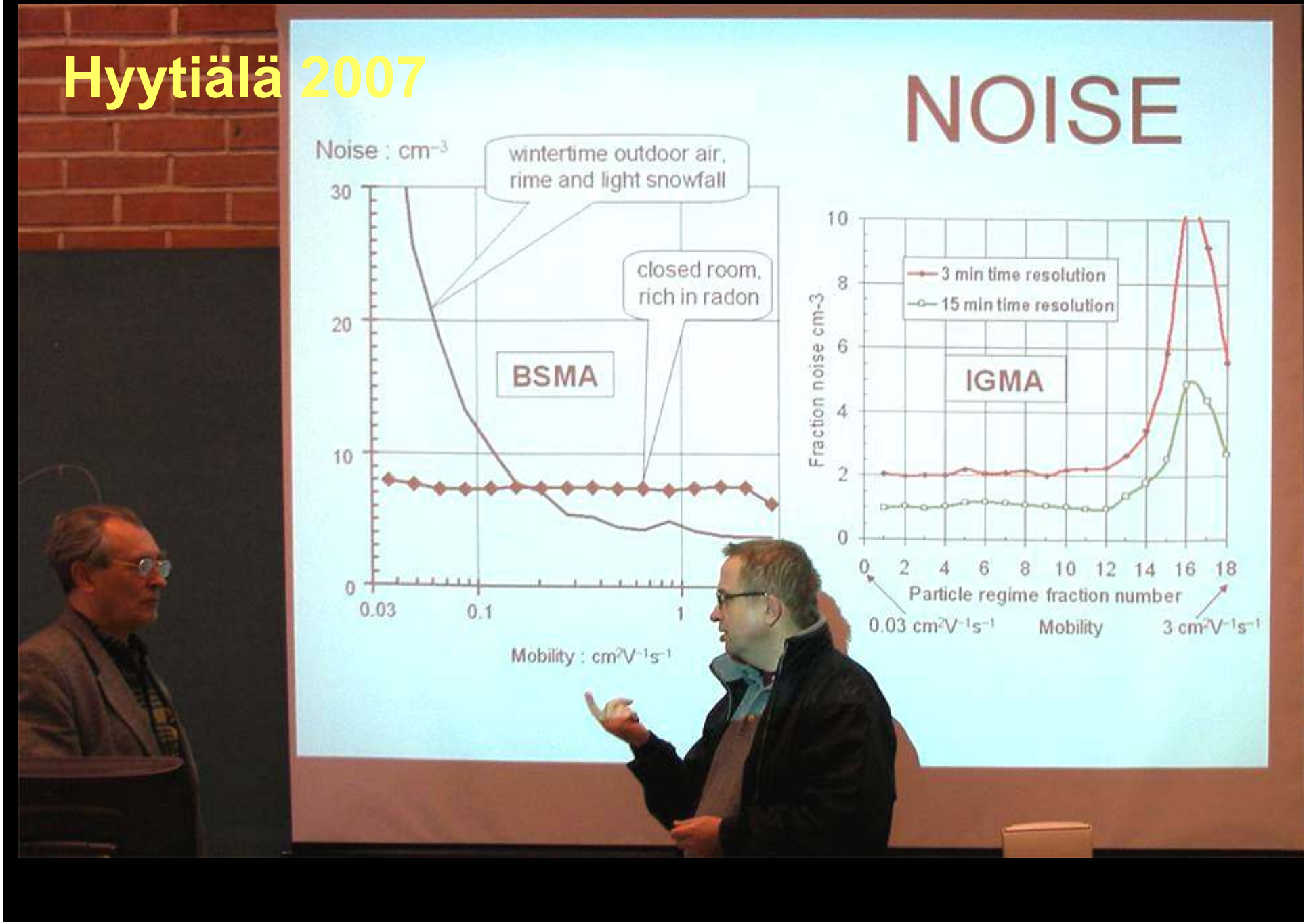

Aerosol inlet
h
u
E
Ballast air
(could be recirculated to sheath
air)
Sheath air inlet
a
Aerosol
outlet
h
V
b
d

BSMA

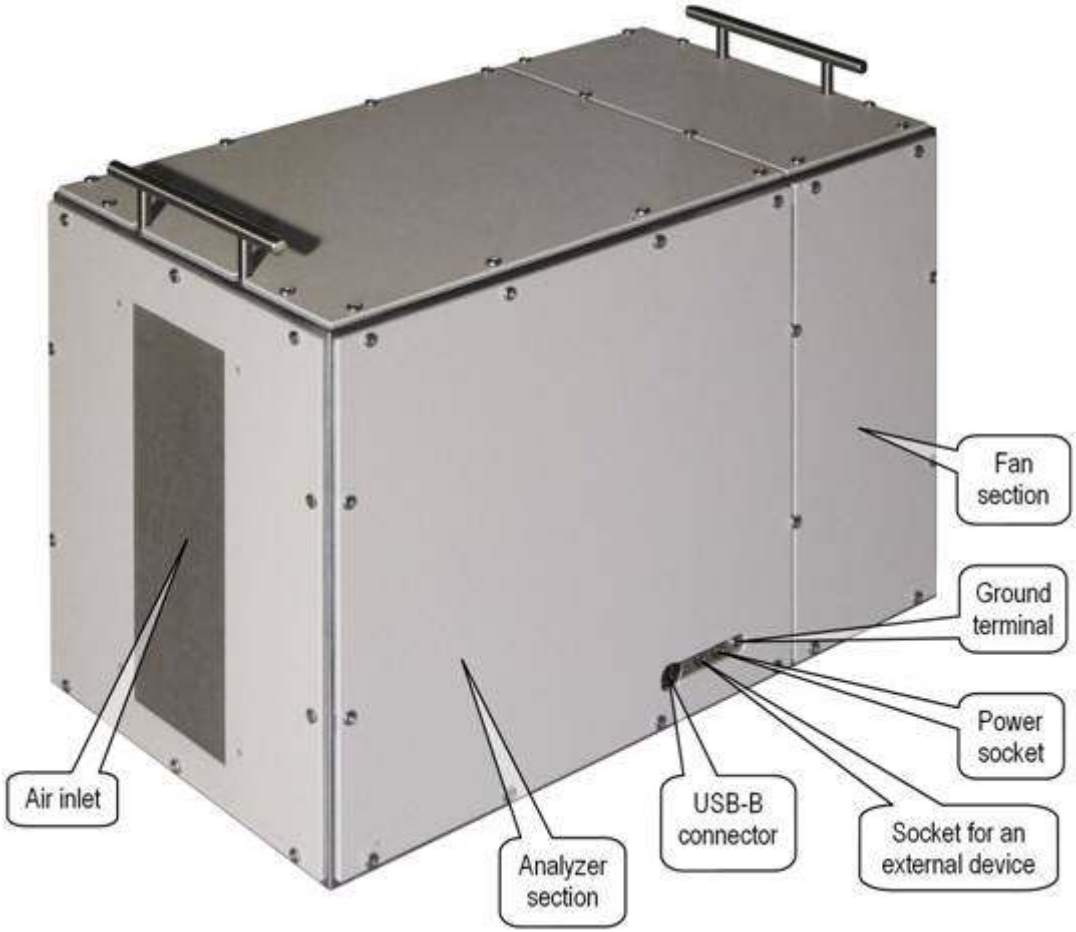

Air inlet
(− ions)
Air inlet
(+ ions)
Fan
section
Analyzer
section
Main
connector
Ground
socket
Power
socket

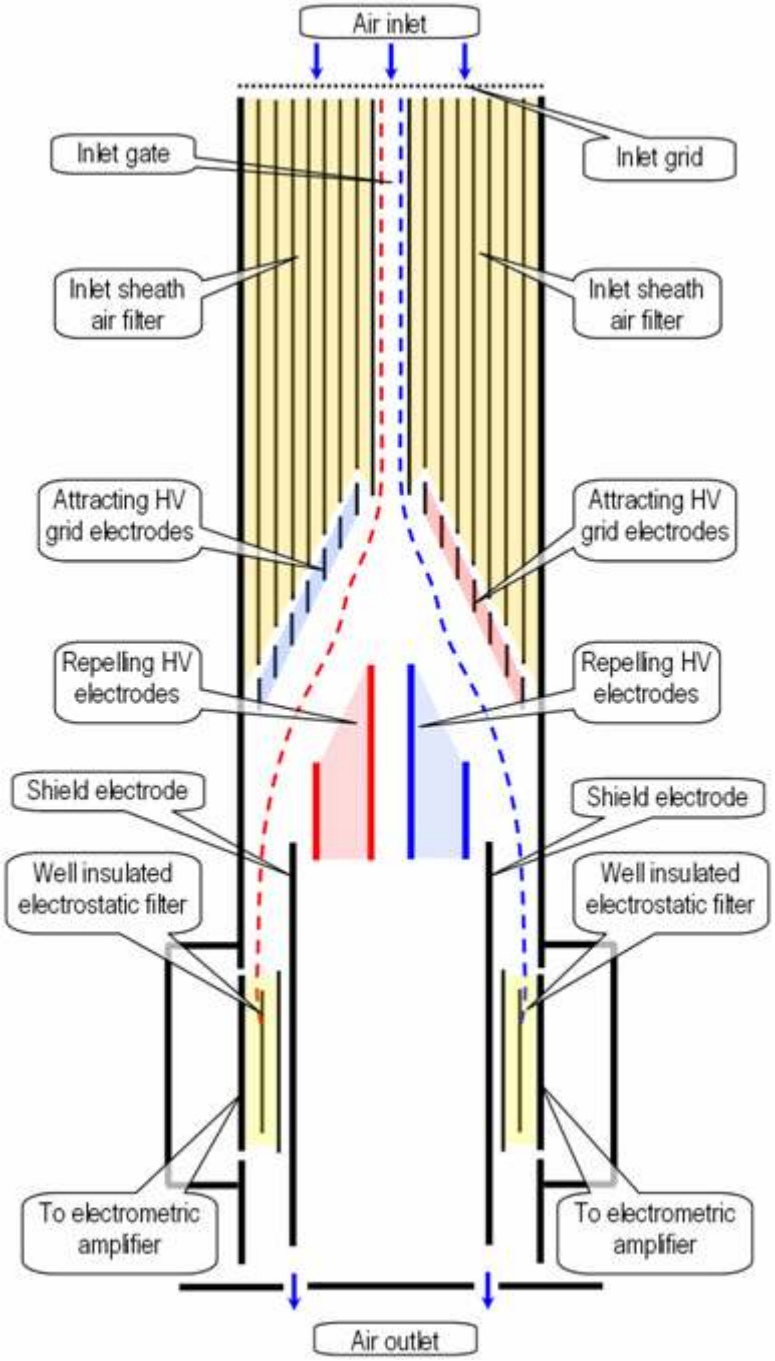

Air outlet
26 l / s
Computer controlled
0...3000 V
− well insulated +
Air outlet
26 l / s
C0
τ ≈ 4 s
R1
R2
C1a
C2a
C1
C2
ground
Electrometric amplifier
(output to computer)
ground
+500 V constant
Computer controlled
+250 V or 0 V
Computer controlled
−250 V or 0 V
−500 V constant
Air inlet
negative ions
Air inlet
positive ions

Hyytiälä 2007

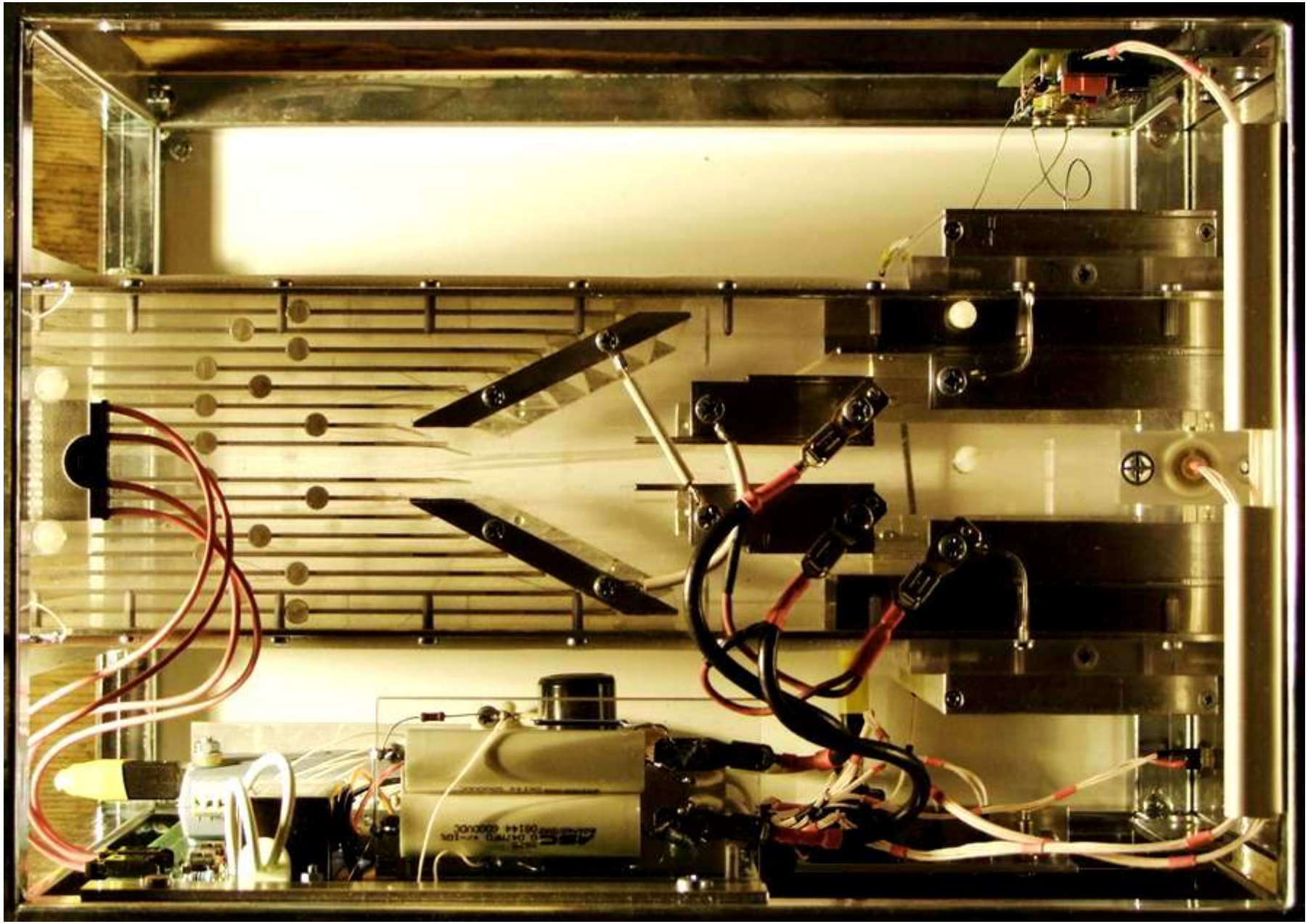


Outline of SIGMA

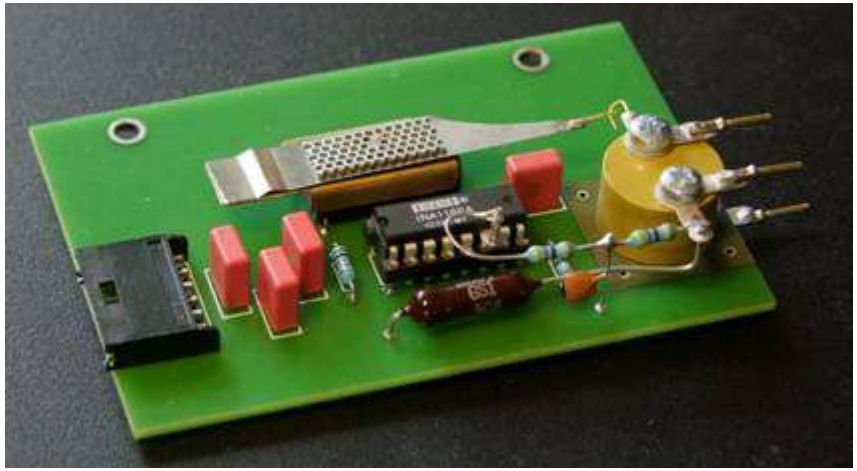


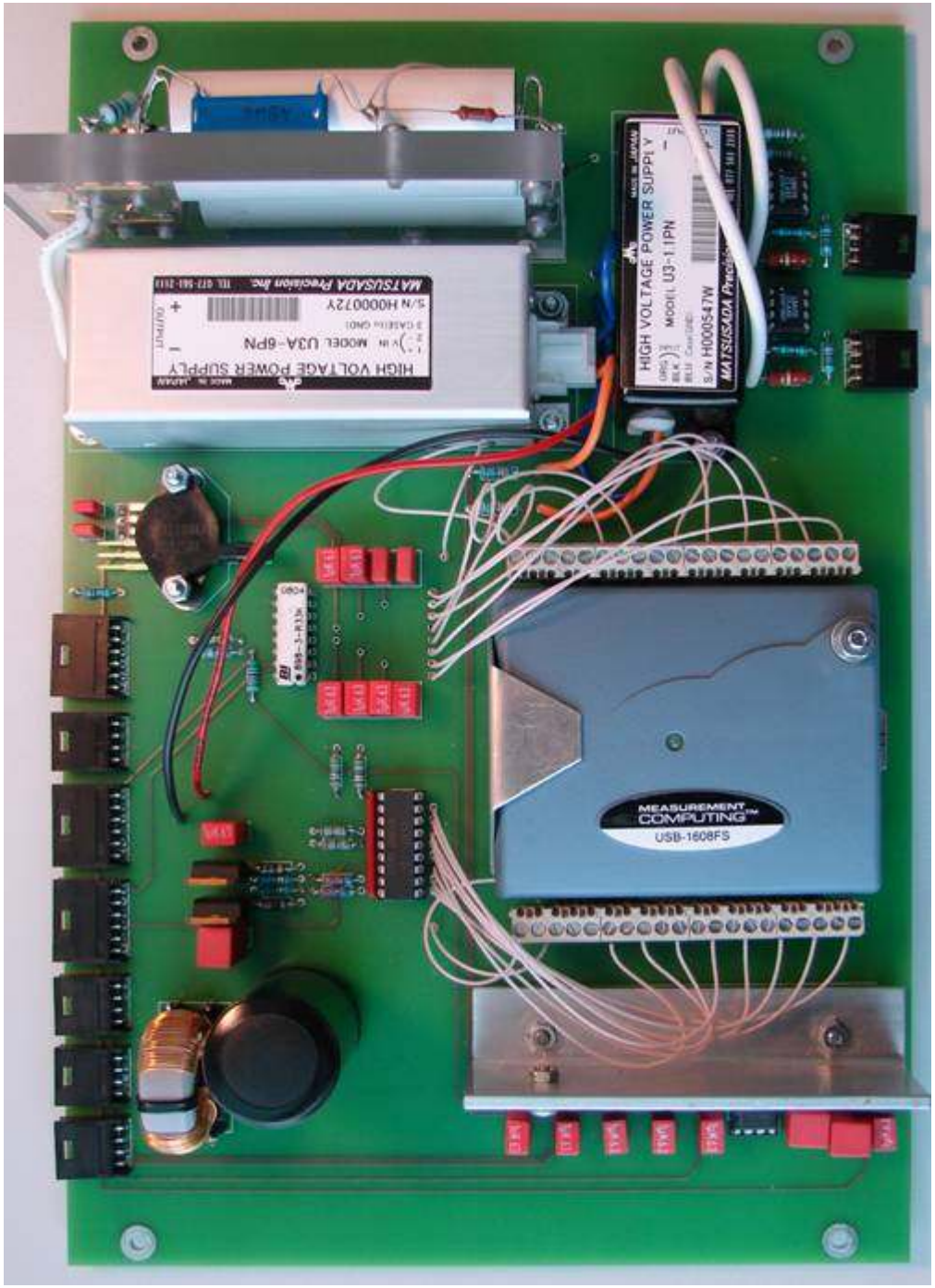


Top view of topless SIGMA



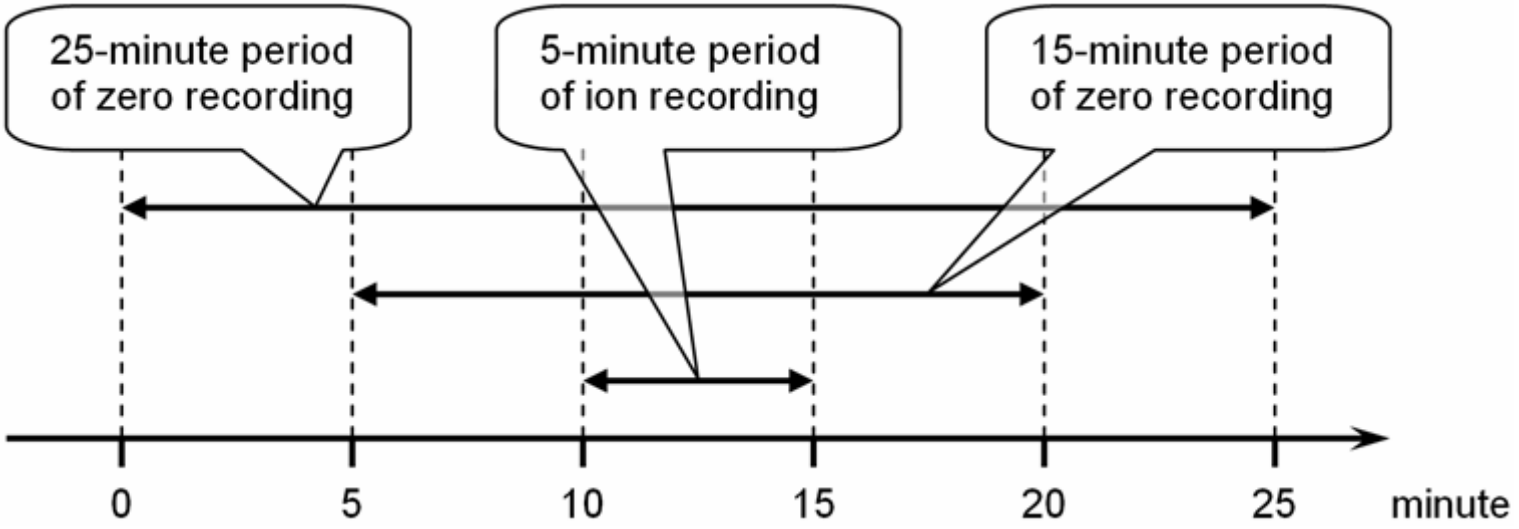
Electrometer and control board





Standard control algorithm

A 20-second scan begins with measuring of air temperature and pressure. Next the boundary voltages between mobility and size fractions are calculated and the HV capacitor is charged up to about 6000 V. The voltages of electrodes and electrometer outputs are measured about 100 times per second during the following exponential decrease of voltage. *Every third scan is performed with closed air ion inlet gate*. If the time crosses a full 5-minute border then the buffered data are processed. The open-gate signal is calculated for 5 minute period and the zero level is estimated according to closed-gate measurements during an elongated period of 15 or 25 minutes.



The method of *trimmed mean* is used in the data processing.
When calculating a *g*-trimmed mean the *g* smallest and *g* largest entries of the sample are excluded and the trimmed mean is found as the arithmetic average of remaining entries. The criterion of the optimum trimming is the roughness R of the intermediate ion mobility distribution:

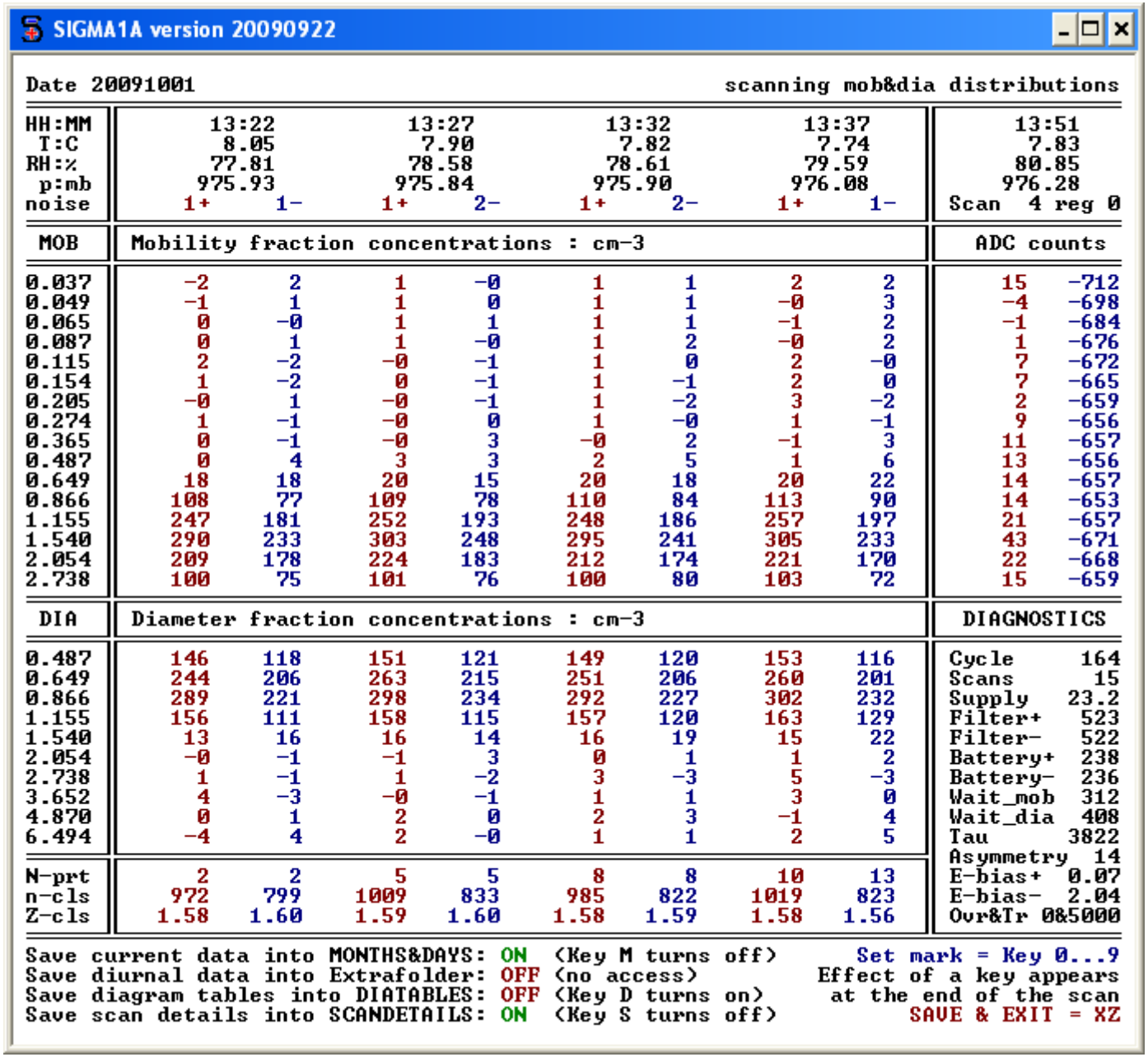
$$R = \sum_{i=3}^{8} \left(x_{i-2} - 4x_{i-1} + 6x_i - 4x_{i+1} + x_{i+2} \right)^2$$

where $x_1 \ldots x_{10}$ are measurements of mobility fraction concentrations of ions in the range of 0.032…0.56 $cm^2V^{-1}s^{-1}$.
The roughness is calculated for the:

- 0- to 4- trimmed means of open gate ion signal in the 5-minute period,
- 0- to 7-trimmed means of closed gate signal in the 15-minute period,
- 0- to 12-trimmed means of closed gate signal in the 25-minute period.

Finally, the trimmed means of minimum roughness are used for calculating the ion mobility and size distributions according to the difference between the open gate and closed gate measurements.

Examples



SIGMA1A version 20090922

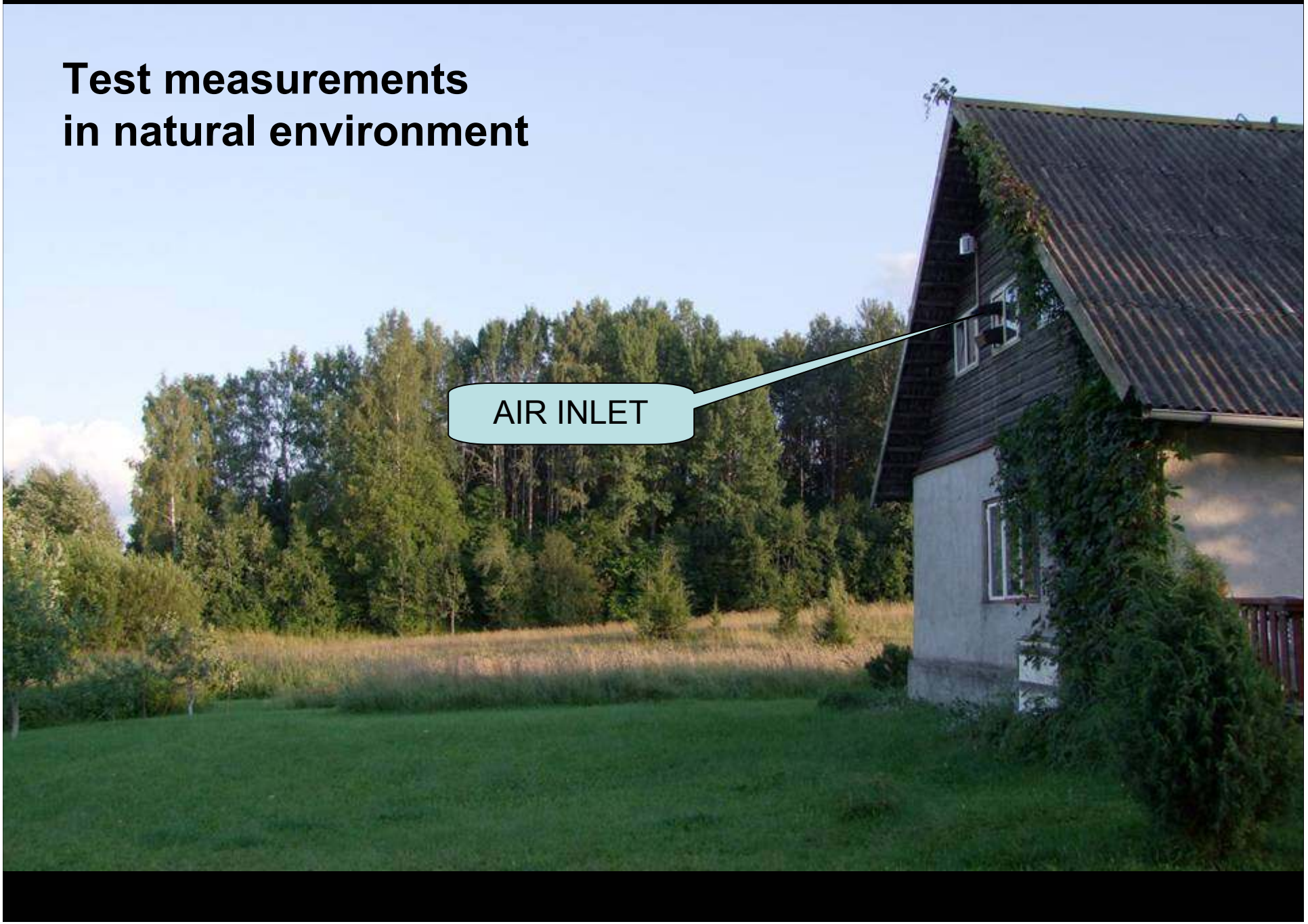
Date 20091001 scanning mob&dia distributions

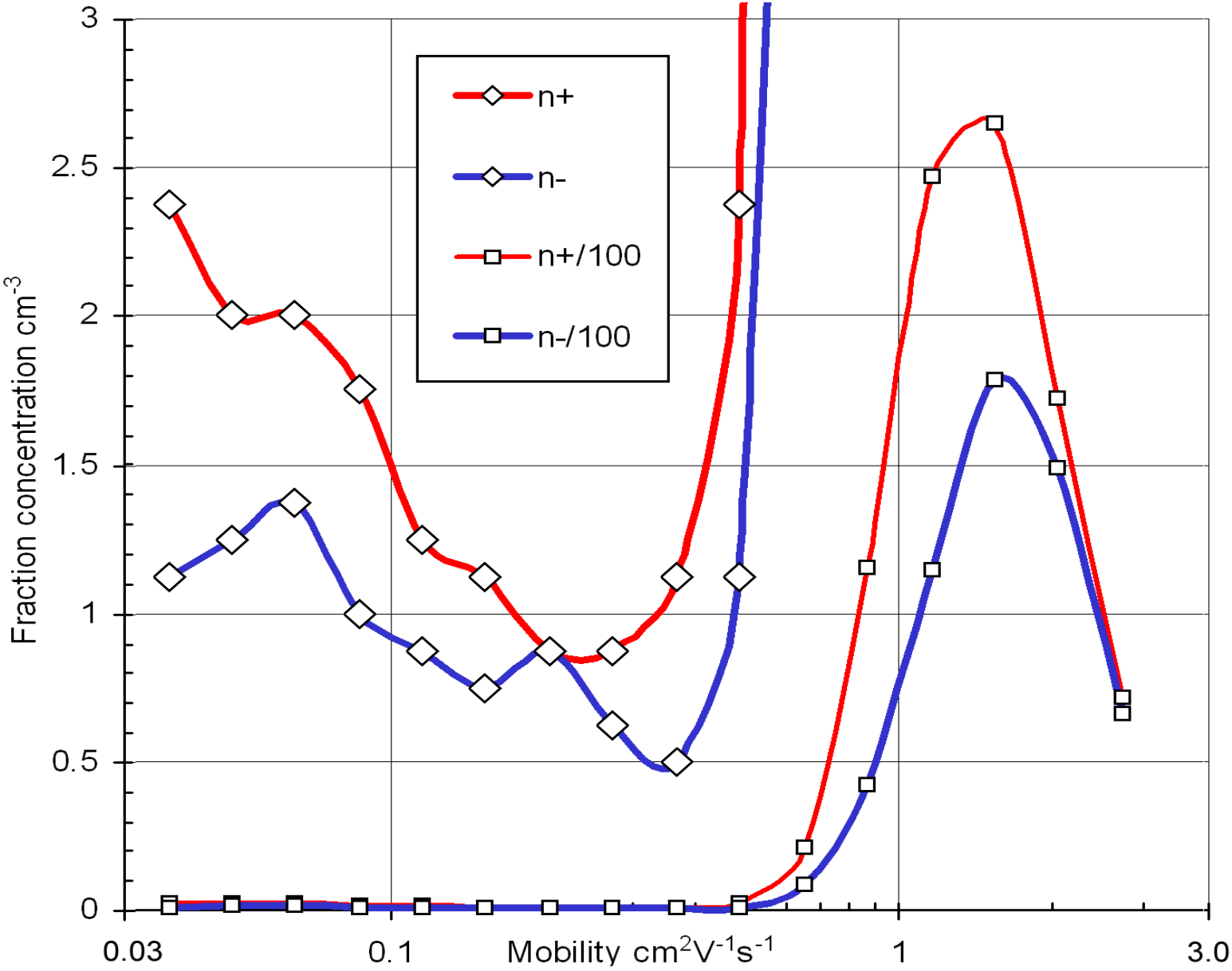
HH:MM	13:22		13:27		13:32		13:37		13:51
T:C	8.05		7.90		7.82		7.74		7.83
RH:%	77.81		78.58		78.61		79.59		80.85
p:mb	975.93		975.84		975.90		976.08		976.28
noise	1+	1-	1+	2-	1+	2-	1+	1-	Scan 4 reg 0
MOB	Mobility fraction concentrations : cm-3								ADC counts
0.037	-2	2	1	-0	1	1	2	2	15 -712
0.049	-1	1	1	0	1	1	-0	3	-4 -698
0.065	0	-0	1	1	1	1	-1	2	-1 -684
0.087	0	1	1	-0	1	2	-0	2	1 -676
0.115	2	-2	-0	-1	1	0	2	-0	7 -672
0.154	1	-2	0	-1	1	-1	2	0	7 -665
0.205	-0	1	-0	-1	1	-2	3	-2	2 -659
0.274	1	-1	-0	0	1	-0	1	-1	9 -656
0.365	0	-1	-0	3	-0	2	-1	3	11 -657
0.487	0	4	3	3	2	5	1	6	13 -656
0.649	18	18	20	15	20	18	20	22	14 -657
0.866	108	77	109	78	110	84	113	90	14 -653
1.155	247	181	252	193	248	186	257	197	21 -657
1.540	290	233	303	248	295	241	305	233	43 -671
2.054	209	178	224	183	212	174	221	170	22 -668
2.738	100	75	101	76	100	80	103	72	15 -659
DIA	Diameter fraction concentrations : cm-3								DIAGNOSTICS
0.487	146	118	151	121	149	120	153	116	Cycle 164
0.649	244	206	263	215	251	206	260	201	Scans 15
0.866	289	221	298	234	292	227	302	232	Supply 23.2
1.155	156	111	158	115	157	120	163	129	Filter+ 523
1.540	13	16	16	14	16	19	15	22	Filter- 522
2.054	-0	-1	-1	3	0	1	1	2	Battery+ 238
2.738	1	-1	1	-2	3	-3	5	-3	Battery- 236
3.652	4	-3	-0	-1	1	1	3	0	Wait_mob 312
4.870	0	1	2	0	2	3	-1	4	Wait_dia 408
6.494	-4	4	2	-0	1	1	2	5	Tau 3822
									Asymmetry 14
N-prt	2	2	5	5	8	8	10	13	E-bias+ 0.07
n-cls	972	799	1009	833	985	822	1019	823	E-bias- 2.04
Z-cls	1.58	1.60	1.59	1.60	1.58	1.59	1.58	1.56	Ovr&Tr 0&5000

Save current data into MONTHS&DAYS: ON (Key M turns off)
Save diurnal data into Extrafolder: OFF (no access)
Save diagram tables into DIATABLES: OFF (Key D turns on)
Save scan details into SCANDETAILS: ON (Key S turns off)

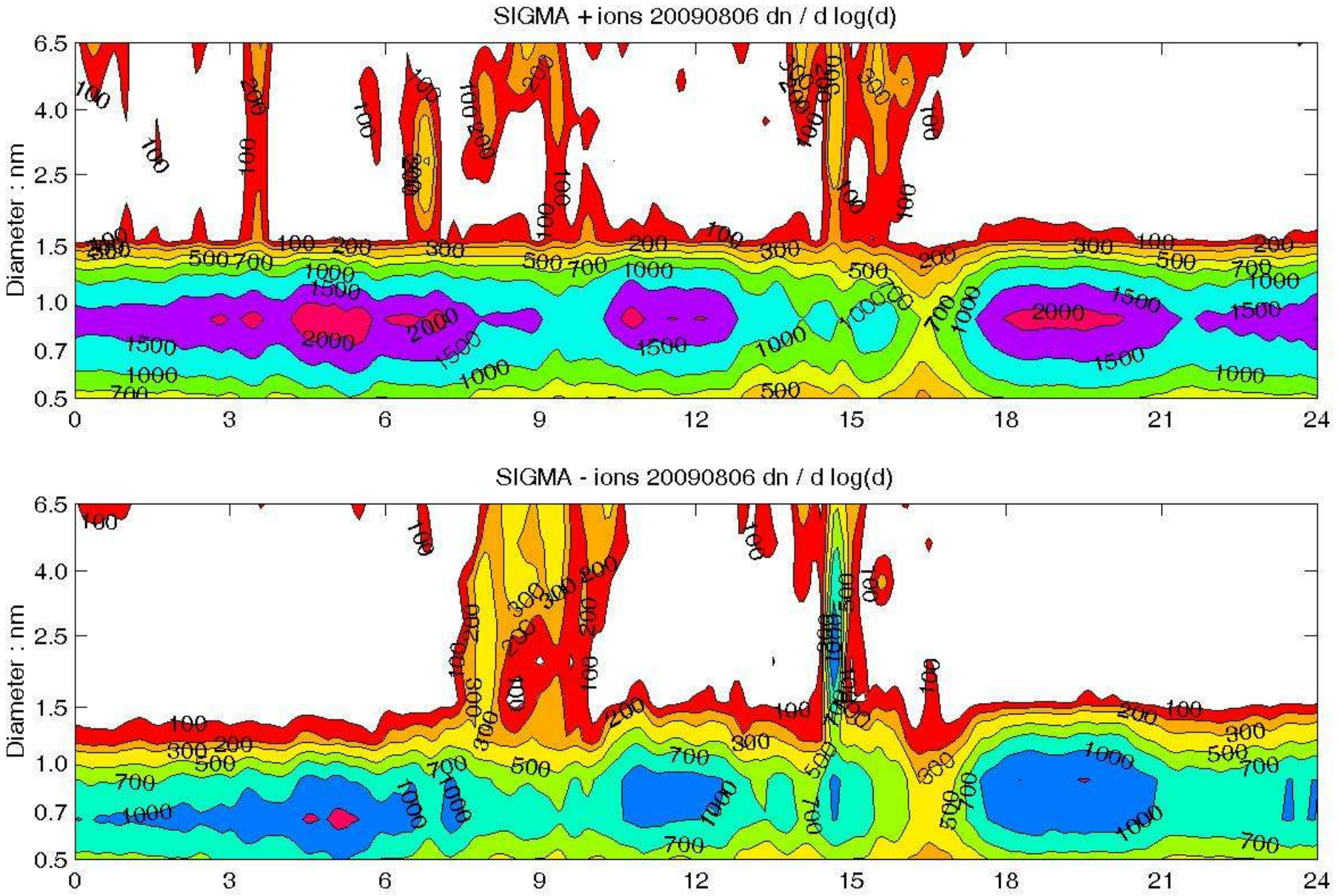
Set mark = Key 0...9
Effect of a key appears at the end of the scan
SAVE & EXIT = XZ

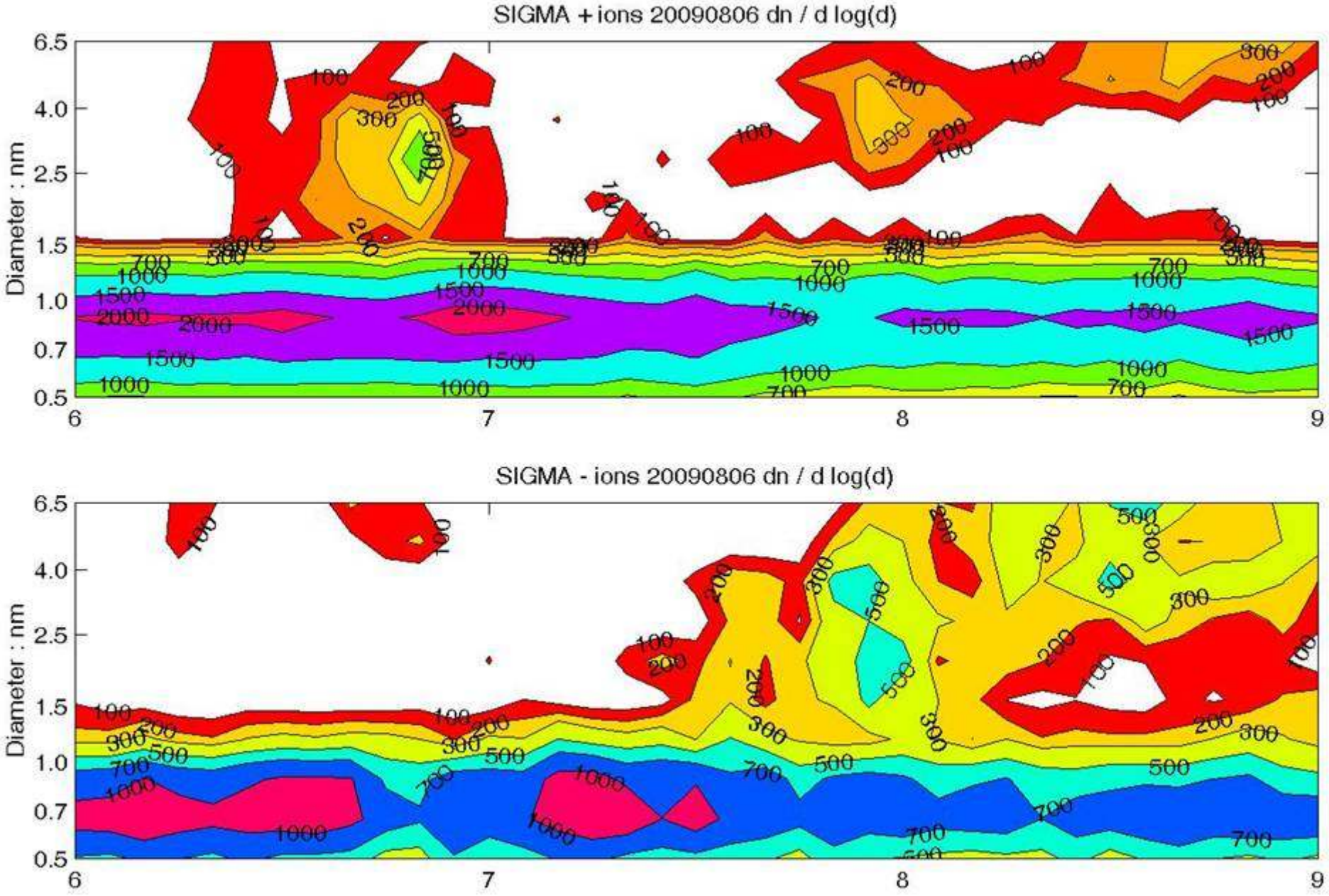
Test measurements in natural environment



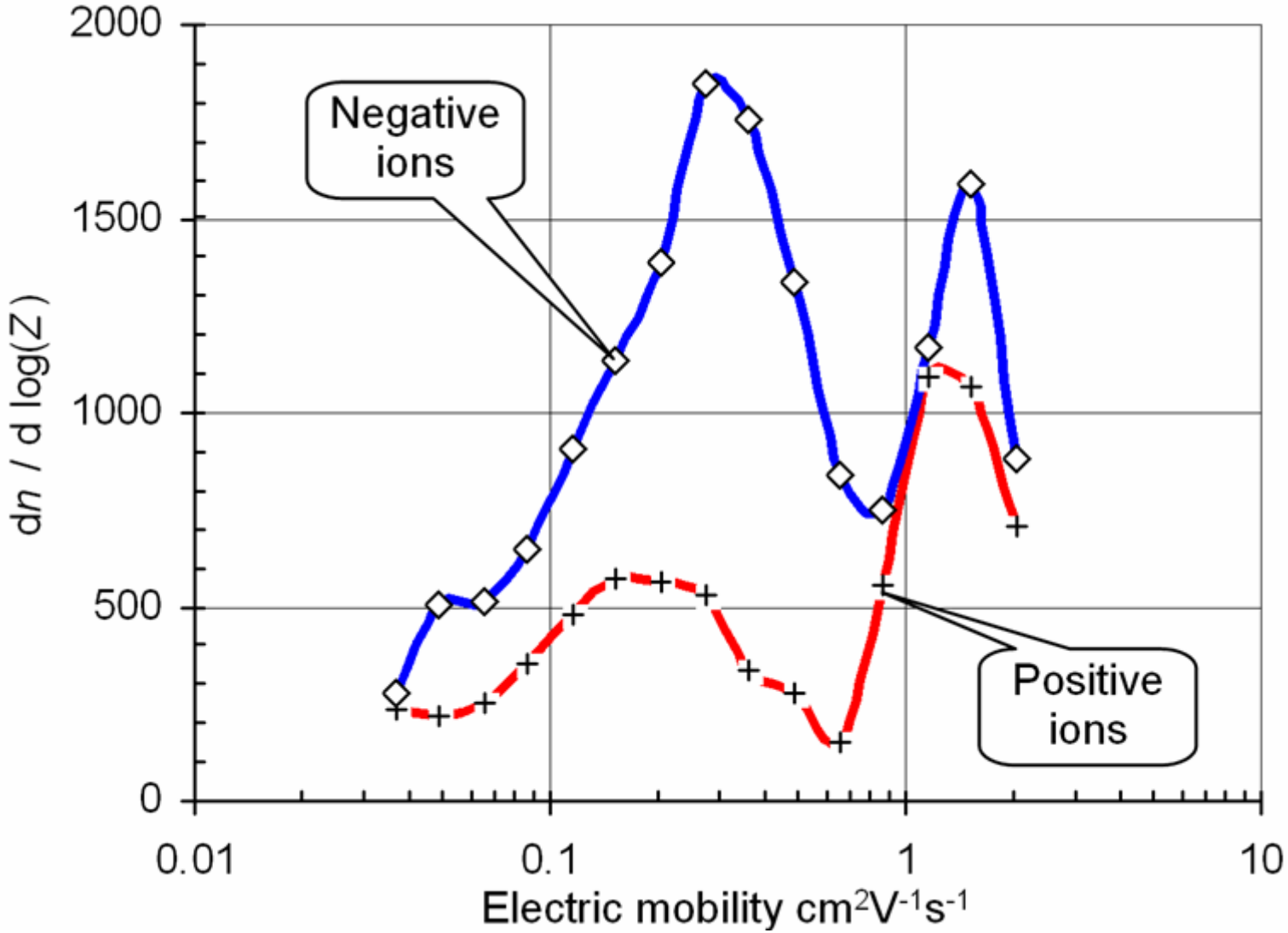


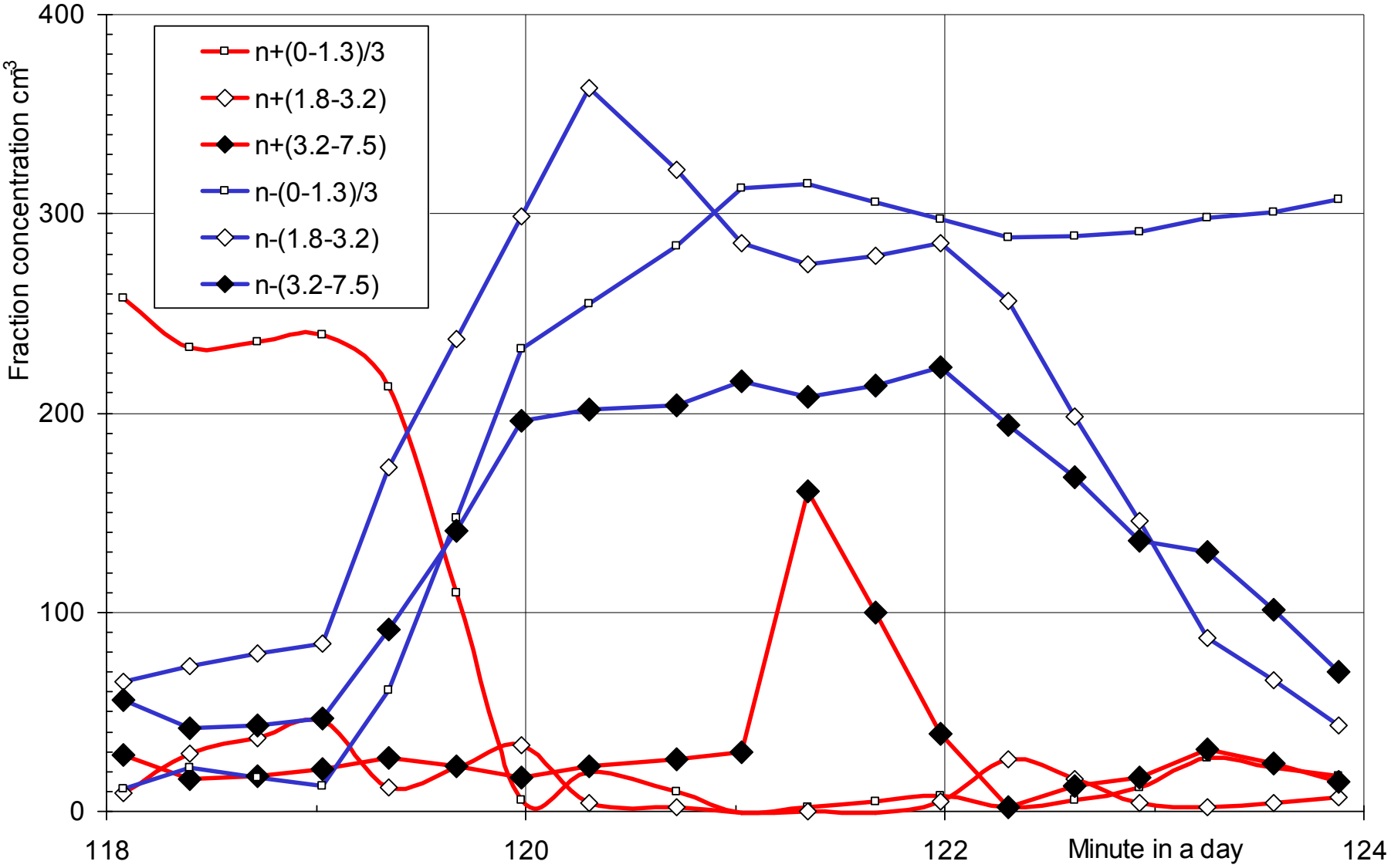
Mobility distributions presented by fraction concentrations, 20090920 16:00-24:00


SIGMA + ions 20090806 dn / d log(d)
Diameter : nm
6.5
4.0
2.5
1.5
1.0
0.7
0.5
0
3
6
9
12
15
18
21
24
SIGMA - ions 20090806 dn / d log(d)
Diameter : nm


SIGMA + ions 20090806 dn / d log(d)
Diameter : nm
6.5
4.0
2.5
1.5
1.0
0.7
0.5
6
7
8
9
SIGMA - ions 20090806 dn / d log(d)
Diameter : nm
6.5
4.0
2.5
1.5
1.0
0.7
0.5
6
7
8
9

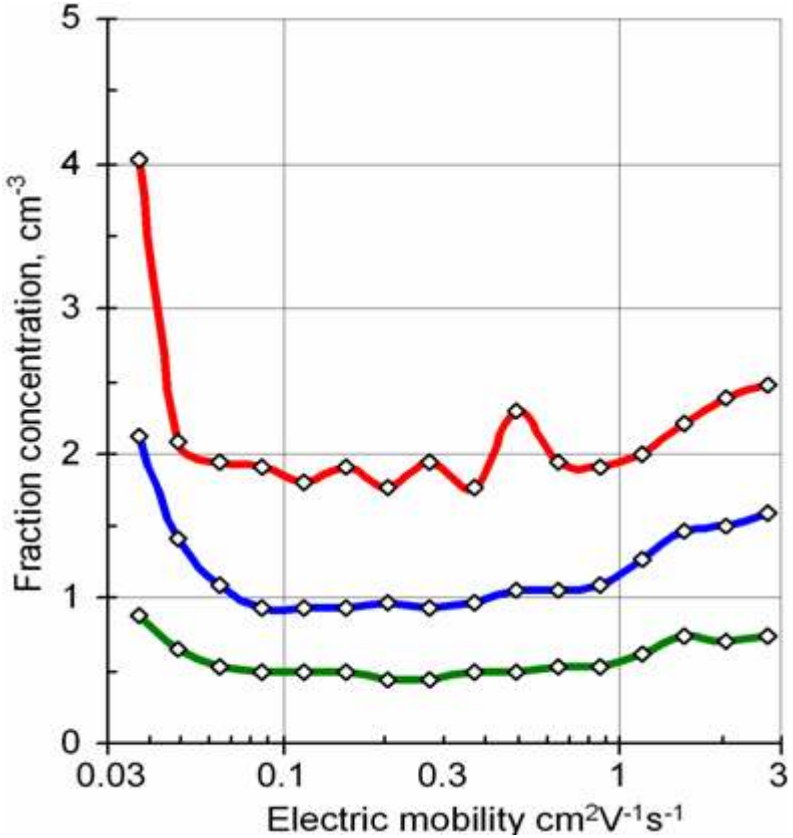
Raintime mobility distribution

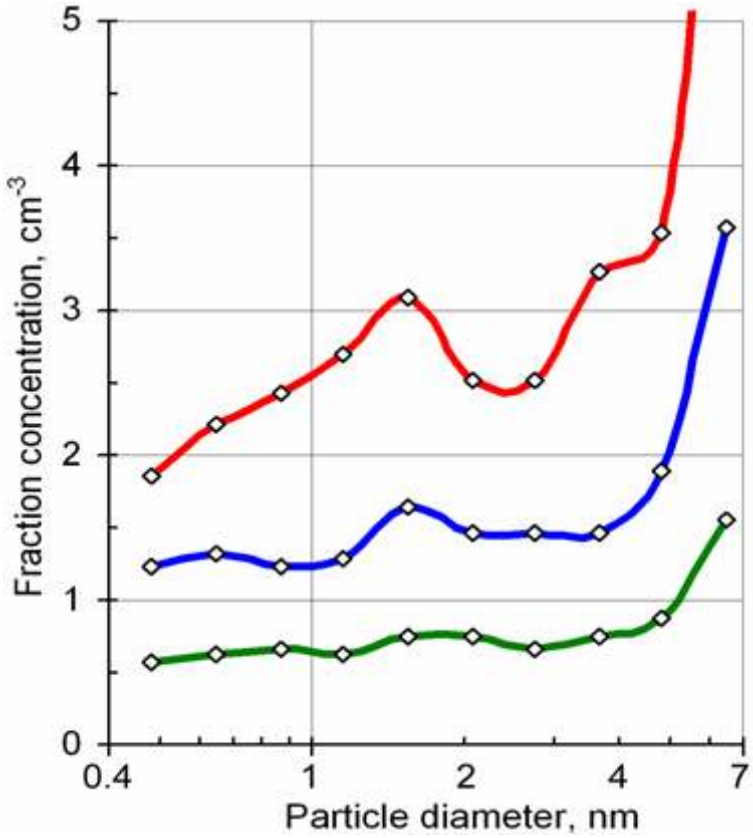




Size fractions during nocturnal thunderstorm shower Oct 01, 2009

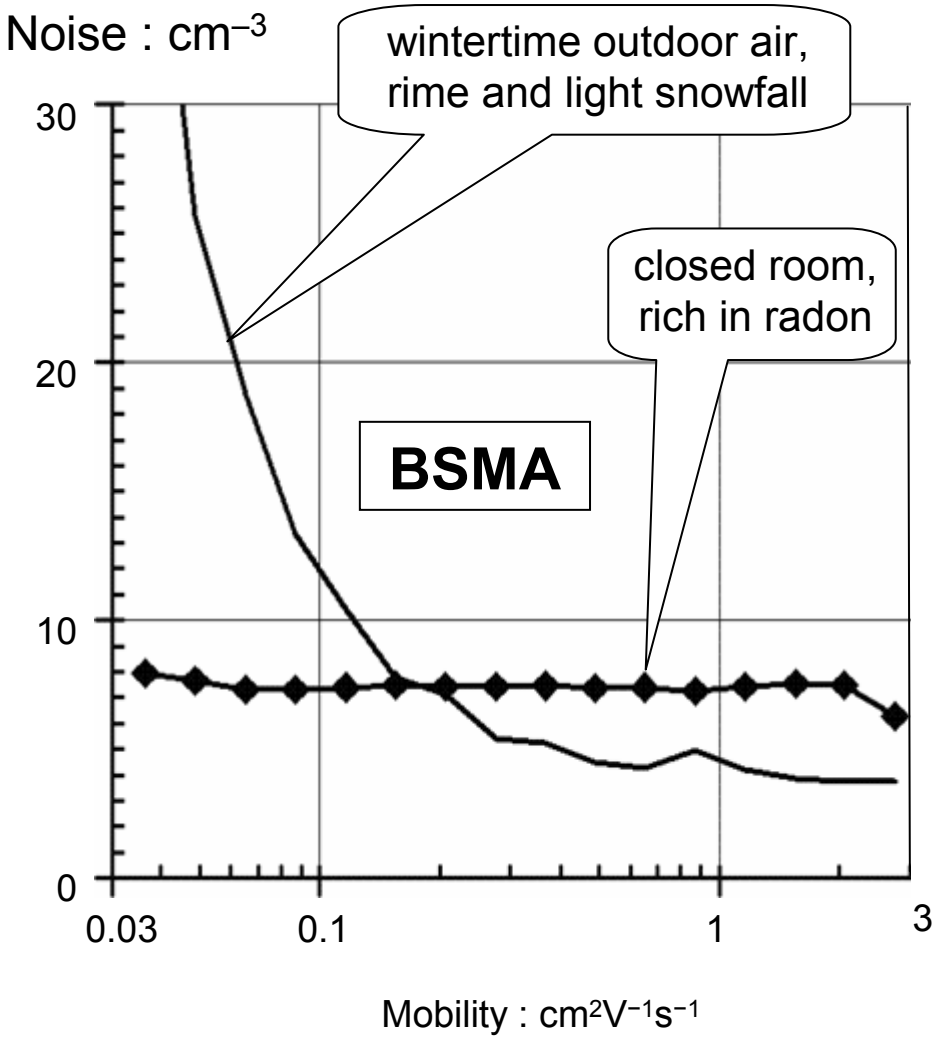
SENSITIVITY is limited by the level of random errors or noise in the fraction concentrations. The noise measurements were performed September 26-28 during strong wind, RH between 80 and 100% and drizzling rain from time to time. Only difference with standard measurement was permanently closed inlet gate.

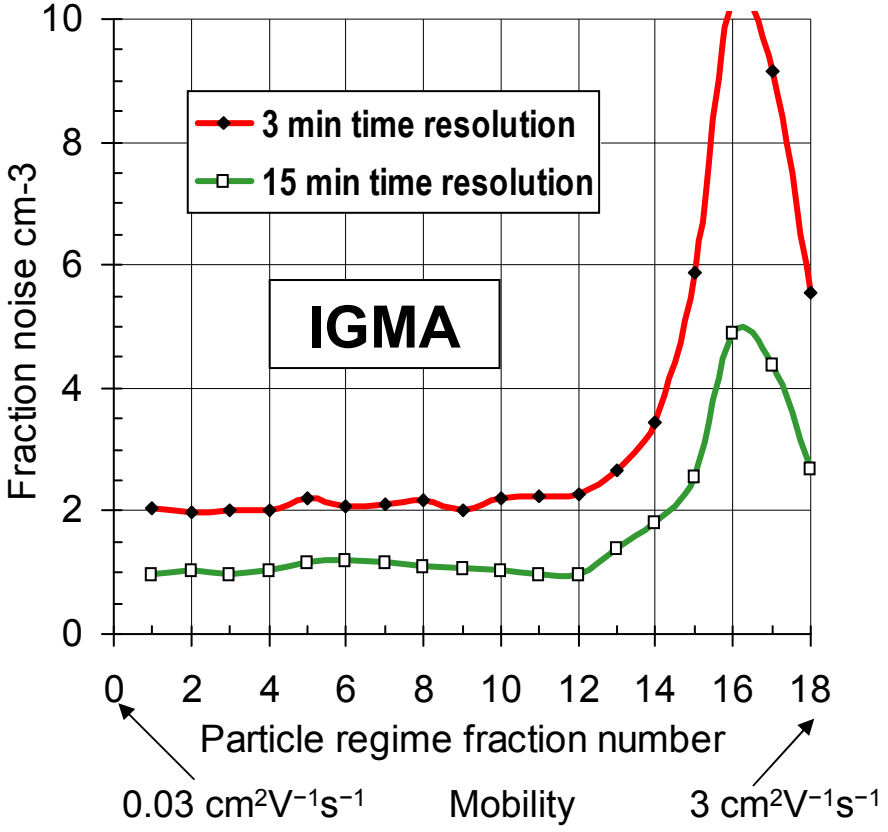


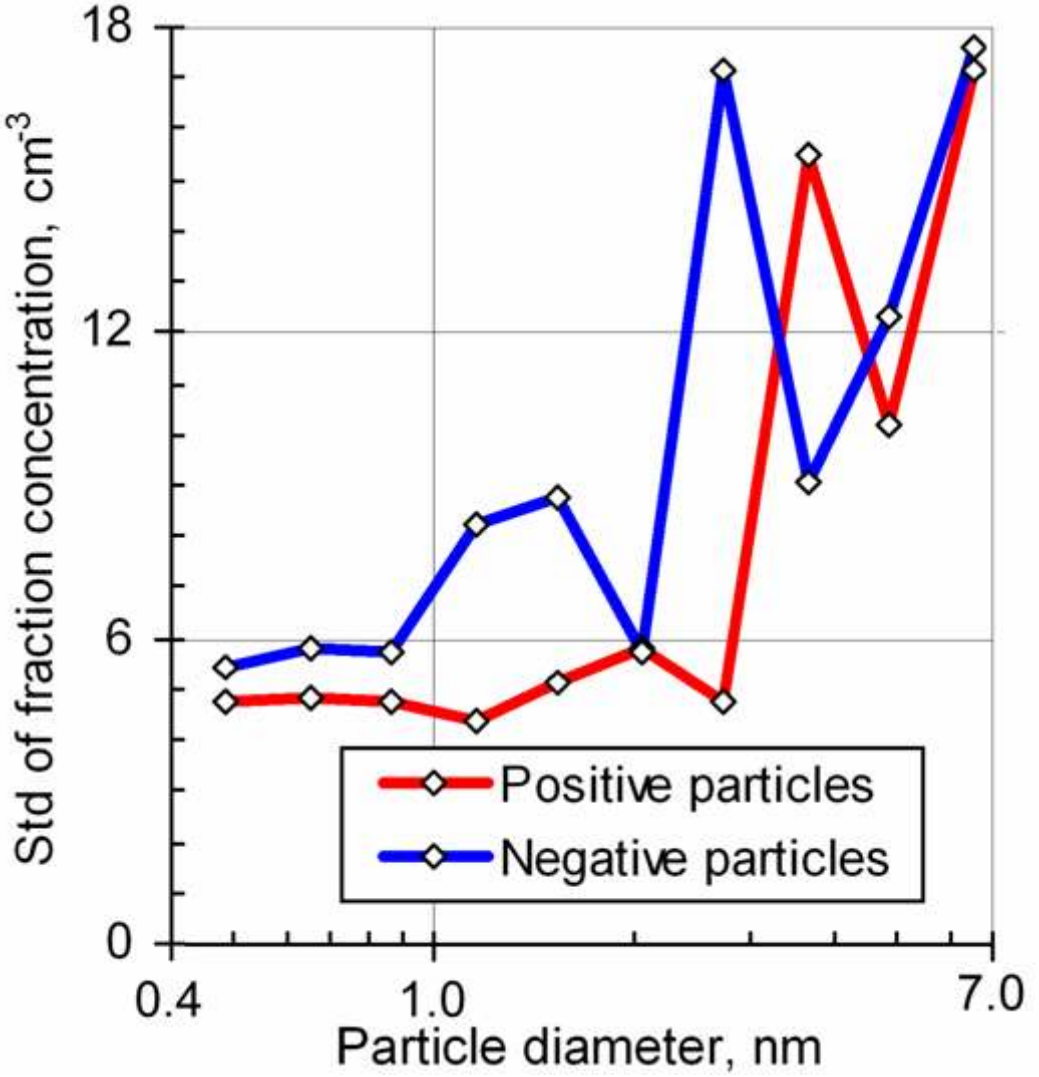


50%, 90% and 99% quantiles of fraction concentration absolute values at zero level of the real concentration.

NOISE


Noise : cm⁻³
wintertime outdoor air,
rime and light snowfall
closed room,
rich in radon
BSMA
30
20
10
0
0.03
0.1
1
3
Mobility : cm²V⁻¹s⁻¹


3 min time resolution
15 min time resolution
IGMA
Fraction noise cm-3
10
8
6
4
2
0
0
2
4
6
8
10
12
14
16
18
Particle regime fraction number
0.03 cm²V⁻¹s⁻¹
Mobility
3 cm²V⁻¹s⁻¹



Standard deviation of noise signal in size fraction concentrations in case of 20 s time resolution (4470 scans during field measurements Sept 27, 2009).

Additional information:

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


Thank you for attention