In situ measurements of chemical and physical parameters of various traffic related particles under cruise conditions

J. Schneider[1], V. Scheer[2], U. Kirchner[2], R. Vogt[2]

[1] Max Planck Institute for Chemistry Mainz
[2] Ford Forschungszentrum Aachen GmbH

During a 4-day measurement project in situ measurements of various aerosol and gas phase compounds were performed with the Ford Mobile Laboratory (FML) on various roads. The focus was set on truck chasings, but the data set also includes motorway background, rural roads, and inner city data. The FML was equipped with an aerosol mass spectrometer, a Photo-acoustic Soot Sensor, CPC, SMPS and gas analyzers for NO, NOx and CO2. The truck chasing data were obtained when following a truck on the motorways at an average distance of 100 m. Individual passenger car chasing was not possible on motorways, since passenger cars are allowed to travel much faster than the FML. When no direct truck chasing took place, data obtained on motorways were defined as "motorway background". Data was also sampled in a suburban region, in small cities and on the city ring road in the inner city of Aachen. The averaged number concentration values of the individual drives for the four main categories ("truck chasings", "motorway background", "rural regional road", "Aachen city") show large differences. Particle number concentrations are highest during truck chasings, while the motorway background concentrations are comparable to the values measured in the inner city of Aachen. The rural regional road concentrations are markedly lower. The mass based particle quantities as black carbon, organics, and sulfate behave different: The sulfate mass concentrations are very constant, almost independent on the measurement location and are therefore most likely dominated only by background aerosol and not influenced by traffic exhaust. The mass concentrations of the non-refractory organic compounds as well as those of black carbon are highest under city traffic conditions. Since the number concentration in the city traffic is not higher than on the average motorway background, the particles emitted under city conditions are larger, or must contain a larger fraction of organic material than under motorway traffic conditions. Black carbon mass concentrations show also higher values during the truck chasings, similar to the number concentrations. The mass of the non-refractory organics is not significantly elevated. Thus, the freshly emitted particles from trucks under high speed condition contain only low amounts of unburned hydrocarbons but a large fraction of soot. A smaller subset of the truck chasings also shows a "nucleation mode" at diameters around 30 nm. It is assumed that these nucleation events are triggered by sulfuric acid/water nucleation and that the organic vapours condense on these nucleation cores.

In situ measurements of chemical and physical parameters of various traffic related particles under cruise conditions

J. Schneider[1], V. Scheer[2], U. Kirchner[2], R. Vogt[2]

[1]Particle Chemistry Department, Max Planck Institute for Chemistry, Mainz, Germany

[2]Ford Research Center, Aachen, Germany

Introduction

Motivation:

- **Public debate on traffic related particles (PM10) (European Legislation)**
- **Health effects of exhaust particles still an issue (composition ?)**
- **Diesel cars increasing in Germany (1993: 19%, 2003: 27 % with respect to mileage).** *Source: DIW-Wochenbericht 41/2004*
  Overall Diesel car consumption in 2003: 11 x 10^6 L / year
- **Trucks: 16 x 10^6 L / year (Germany, 2003)**

Objective of this study:

***in situ*-characterization of particle emissions from various sources :**

- **trucks**
- **motorway background**
- **rural road background**
- **inner city traffic**

Instrumentation (1)

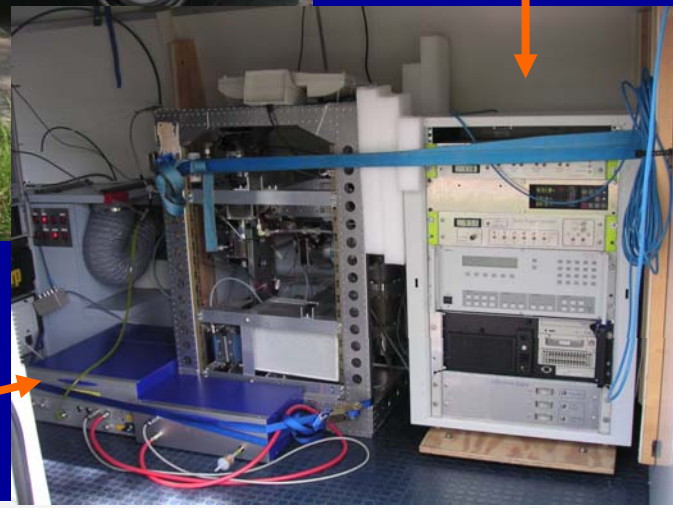
Ford Mobile Laboratory (FML)

Gas sensors

SMPS

Micro Soot Sensor

AMS



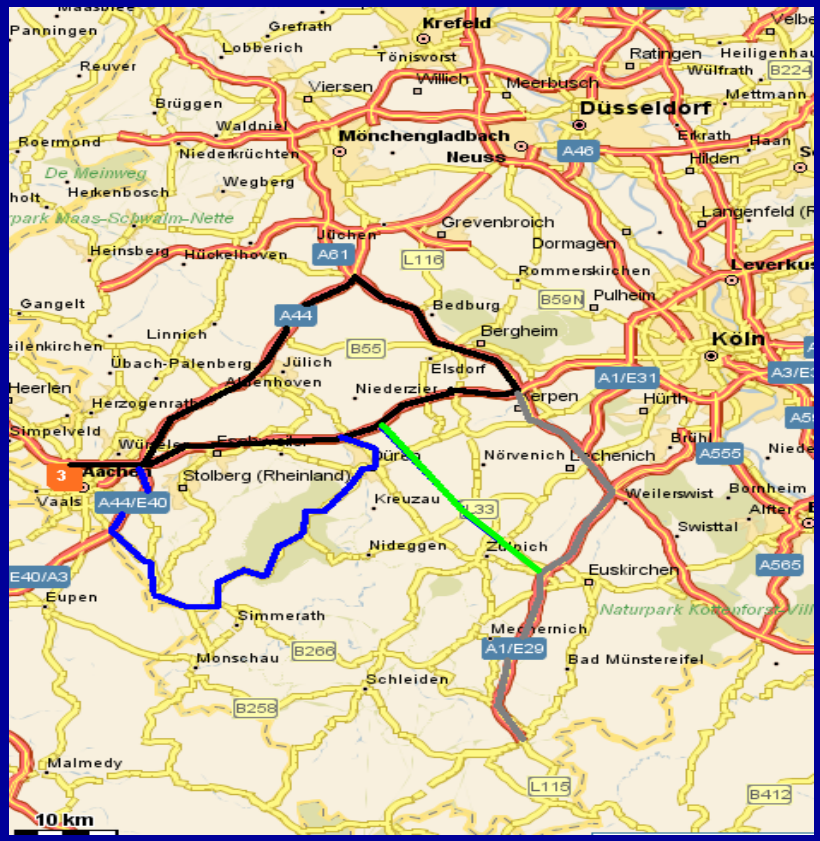
Instrumentation (2)

Instrument	Measured quantity	Time resolution
CPC (3022, TSI)	Particle number conc.	5 sec
Micro Soot Sensor (483, AVL)	Black carbon mass	1 sec
Aerodyne AMS	Non-refractory particle mass and size distribution	30 sec
SMPS (3934L, TSI)	Particle size distribution	2 min
Met. Sensors	Temp., RH	1 sec
Chemiluminescence detector (CLD)	NO_x, NO, NO_2	1 min
NIR-detector	CO_2	1 s

Instrumentation (3)

Digital Camera installed behind windshield
used to categorize traffic situations / truck chasing events.

Location



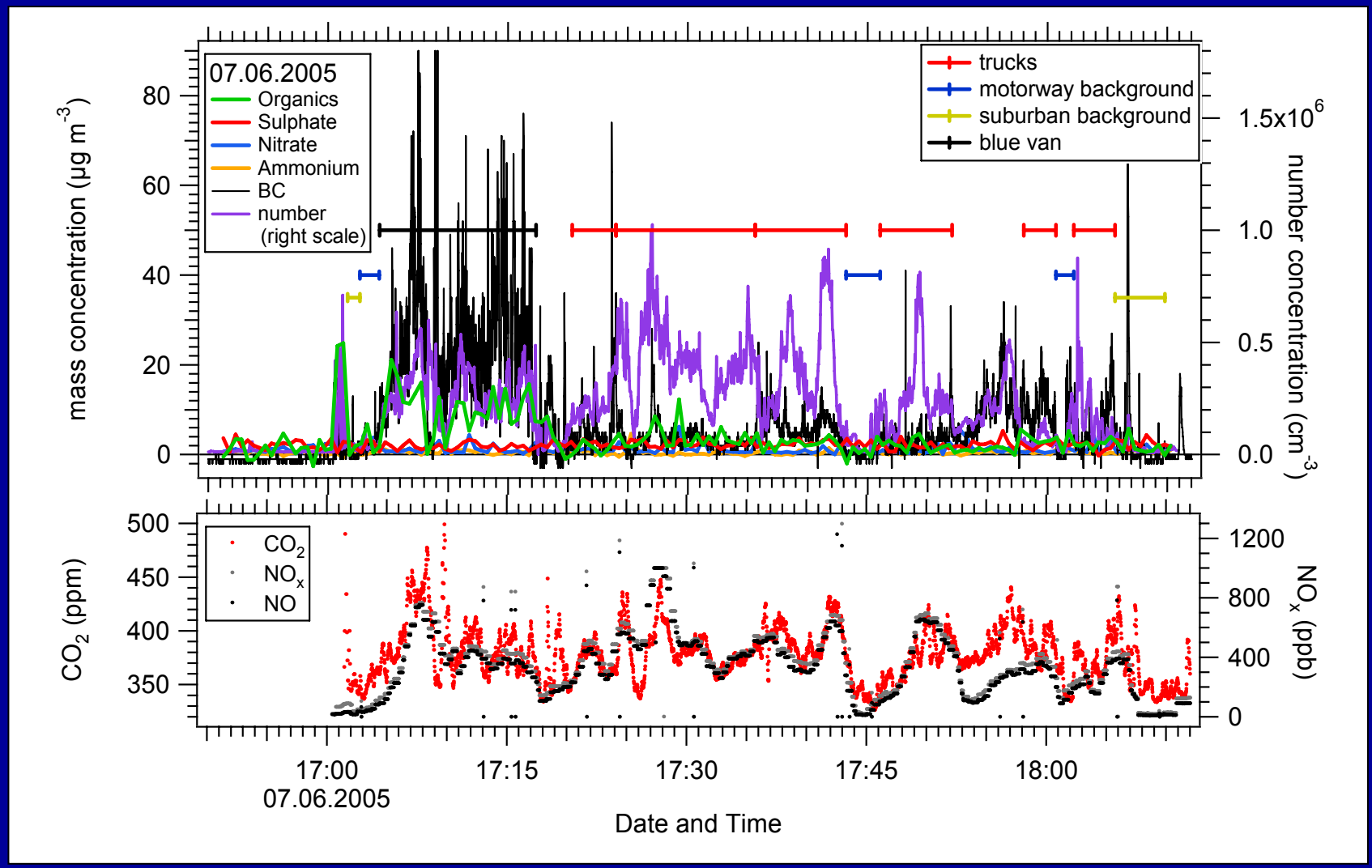
Black: motorway data on A44, A61, and A4 between Aachen, Jüchen, and Kerpen

Grey: motorway data on A61, A1

Green: rural road, June 08 (afternoon)

Blue: rural road, June 10

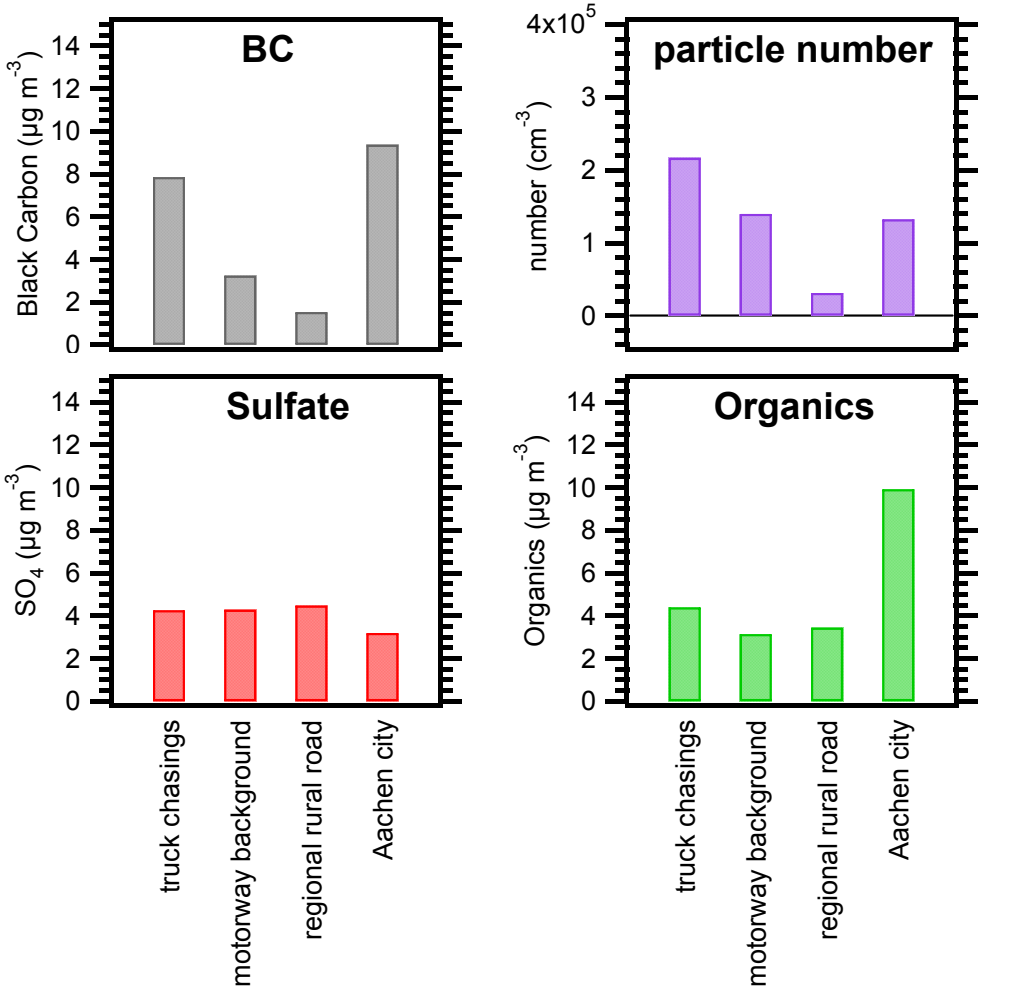
Example: time series of measured parameters



Data Categories

Category	Accumulated time
Truck chasing on motorway	302 min
Motorway background	106 min
Regional road rural	71 min
Inner city Aachen	28 min
Suburban/small city	52 min
Regional road suburban	5 min

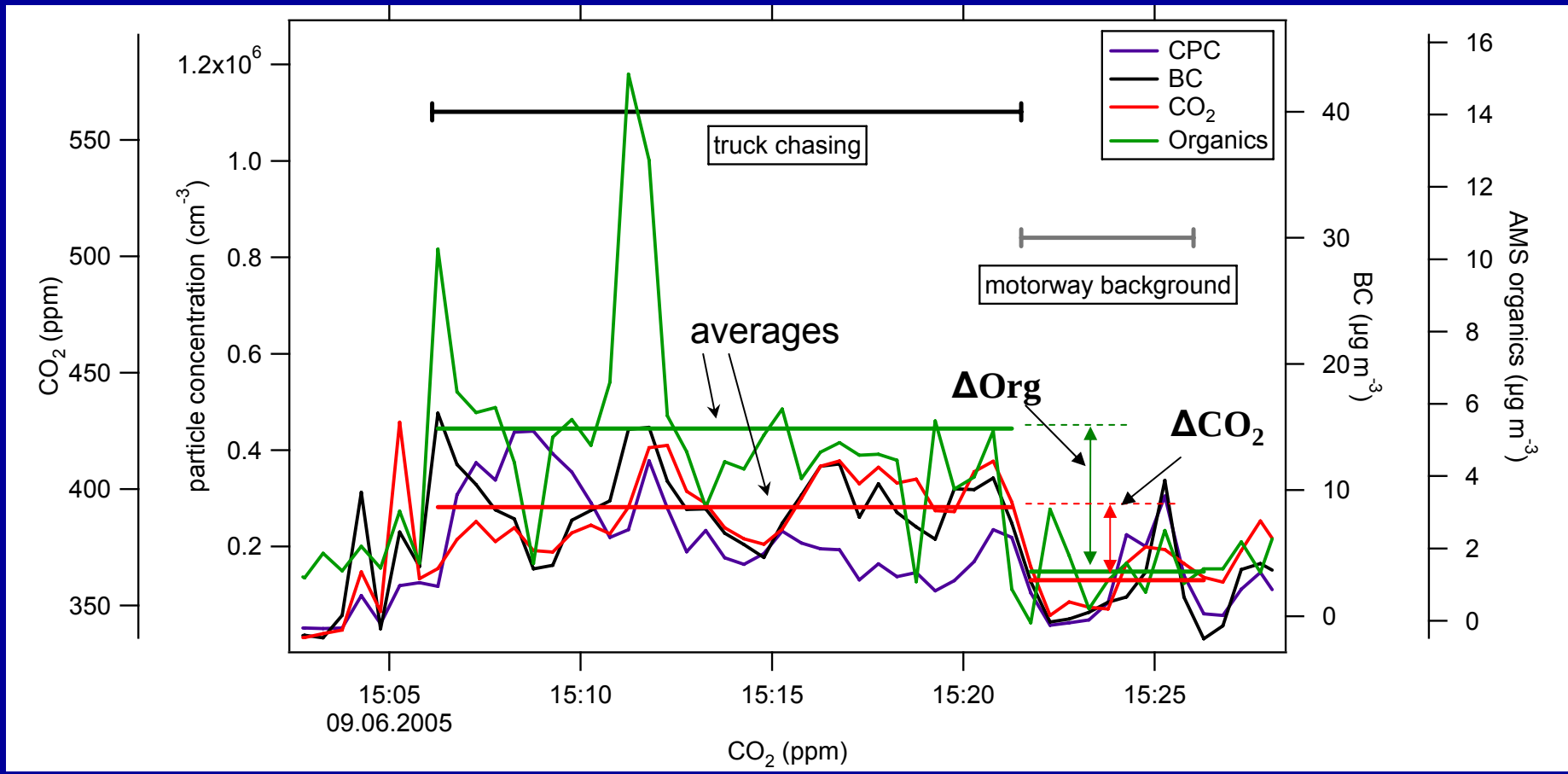
Summary - particle concentrations



- **Sulfate not influenced by traffic**
- **Highest black carbon (BC) and organics in Aachen city**
- **BC significantly increased during truck chasing**
- **Highest particle number during truck chasing**
- **Particle number increased in motorway background and Aachen city**

Example: Time series & emission indices

Determination of ΔCO2, ΔOrganics etc.: 050609 - afternoon



Conversion into emission per kg fuel: Diesel fuel: carbon mass fraction ≅ 0.86 (source: DOE)
Assumption: all C → CO_2
→ 1 kg fuel produces 3.15 kg CO_2

Emission indices

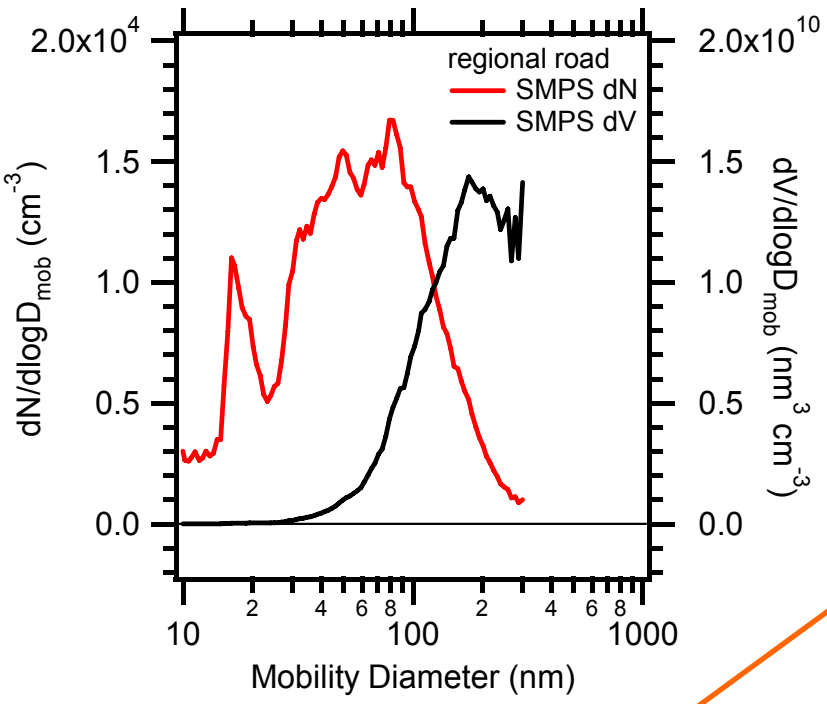
050609 - afternoon

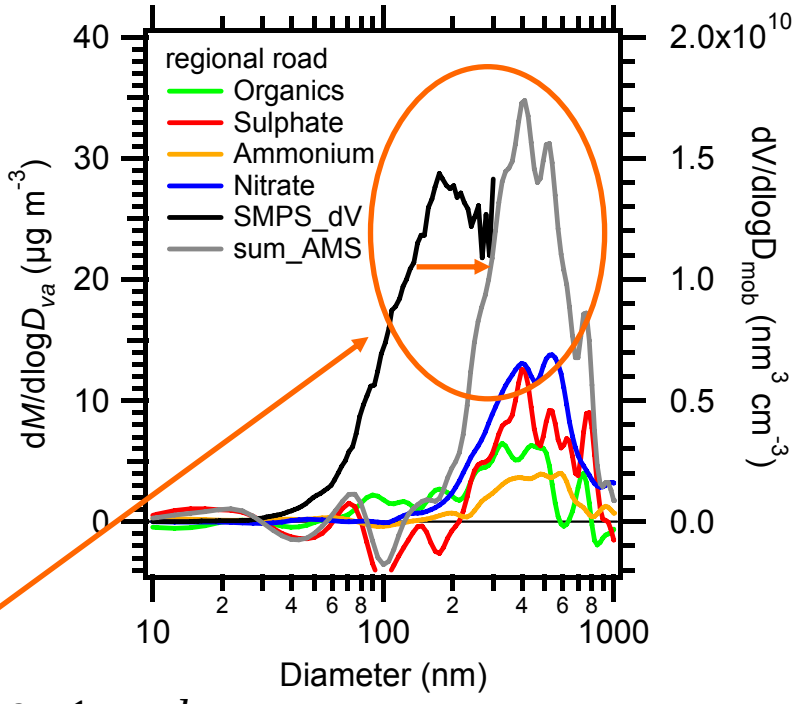
On-road fuel specific emission ratios for heavy duty diesel trucks

truck	Particle number (kg fuel)$^{-1}$	BC mg (kg fuel)$^{-1}$	Organics mg (kg fuel)$^{-1}$	NO_X g (kg fuel)$^{-1}$
1	--	183.6	47.2	43.7
2	2.42e+15	423.7	174.2	25.4
3	--	233.4	35.4	16.3
4	1.02e+16	311.2	222.0	31.8
5	--	1160.5	187.8	9.82
6	--	452.6	211.8	10.4
7	6.20e+15	78.5	101.6	53.9
8	1.52e+16	43.1	134.1	4.62
9	1.33e+17	--	1296.9	91.9

Size distributions (1)

Rural regional road (10.06.2005)



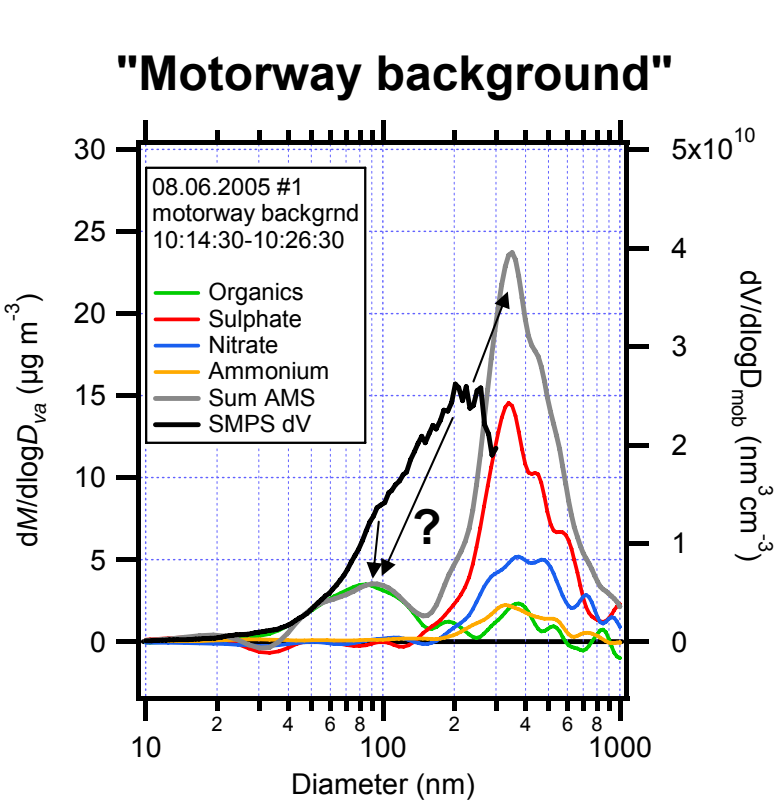


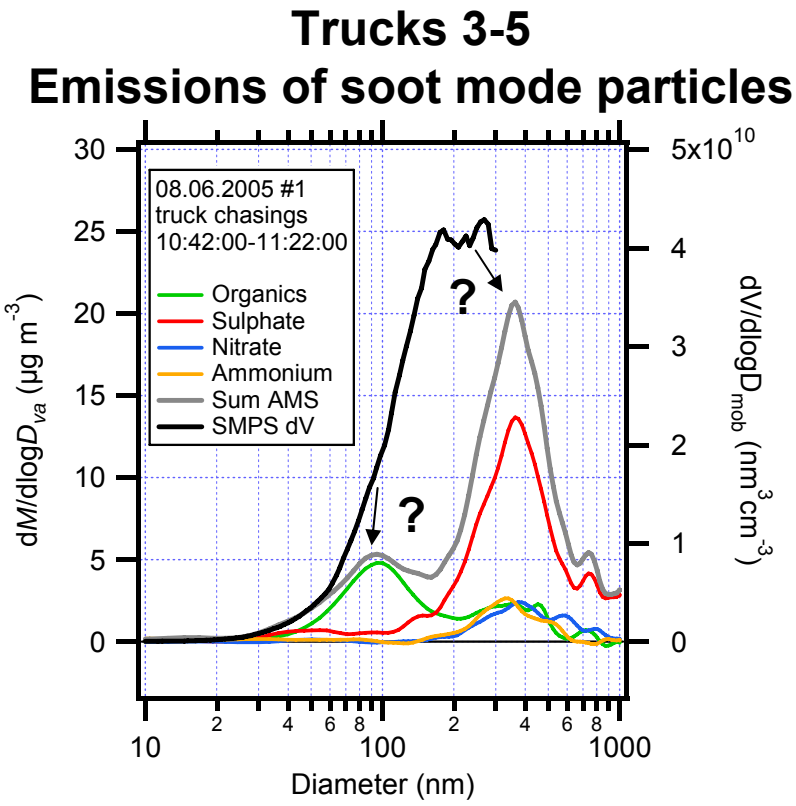
AMS & SMPS: $\rho_{eff} = \frac{\rho_p}{\rho_0}\frac{1}{\chi} = \frac{d_{va}}{d_{mob}} \approx 2\,g\,cm^{-3}$

- **Particle composition typical for accumulation mode particles in rural background already containing organics and sulfate.**
- **Comparing SMPS and AMS data gives effective density of ~ 2 g cm^{-3}**

Size distributions (2)

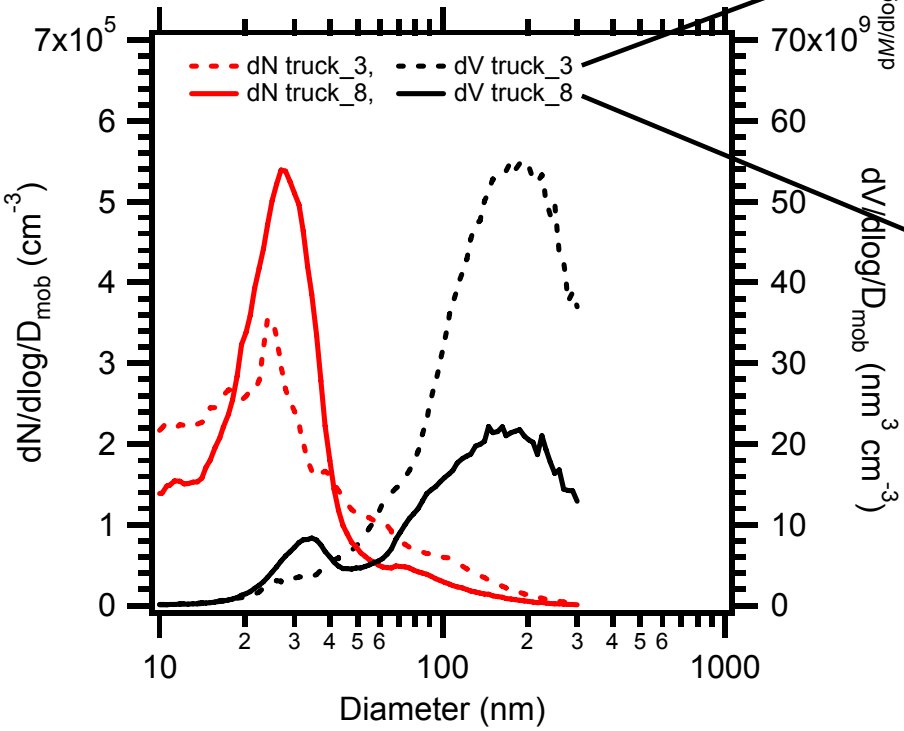
08.06.2005 a)

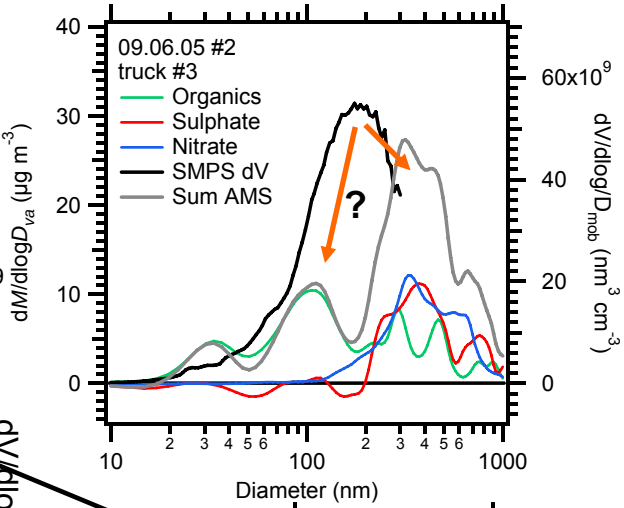


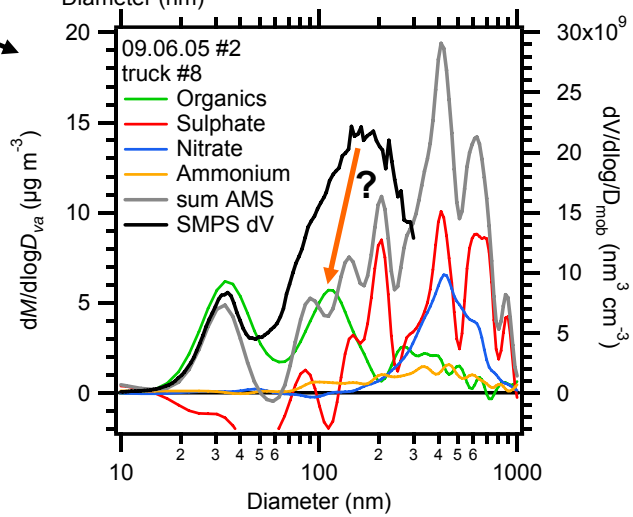


- **Effective density interpretation difficult (accum. mode density ~ 2 g/cm-3)**
- **Motorway background contains a certain amount of organics in soot mode particles.**
- **Truck emissions without pronounced nucleation mode contain organics in soot mode.**

09.06.2005 b)
Emissions of soot mode and nucleation mode particle





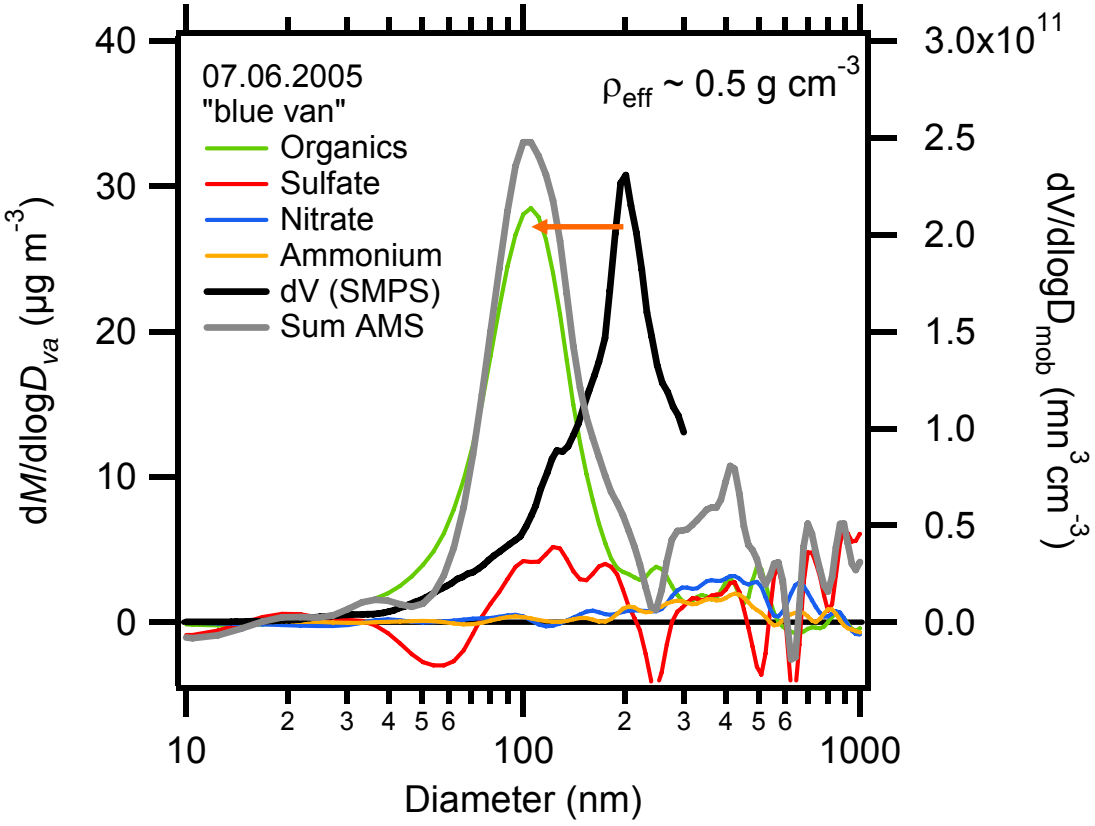


- **Truck emissions with nucleation mode have significant organics within the nucleation mode (density ~1 g/cm^{-3}), besides the soot mode (density <1 g cm^{-3}).**
- **No sulfate in nucleation mode => nucleation particles formed by organics**

Special Events: „Blue van“

07.06.2005

- **High BC and elevated organics emissions and low particle number**



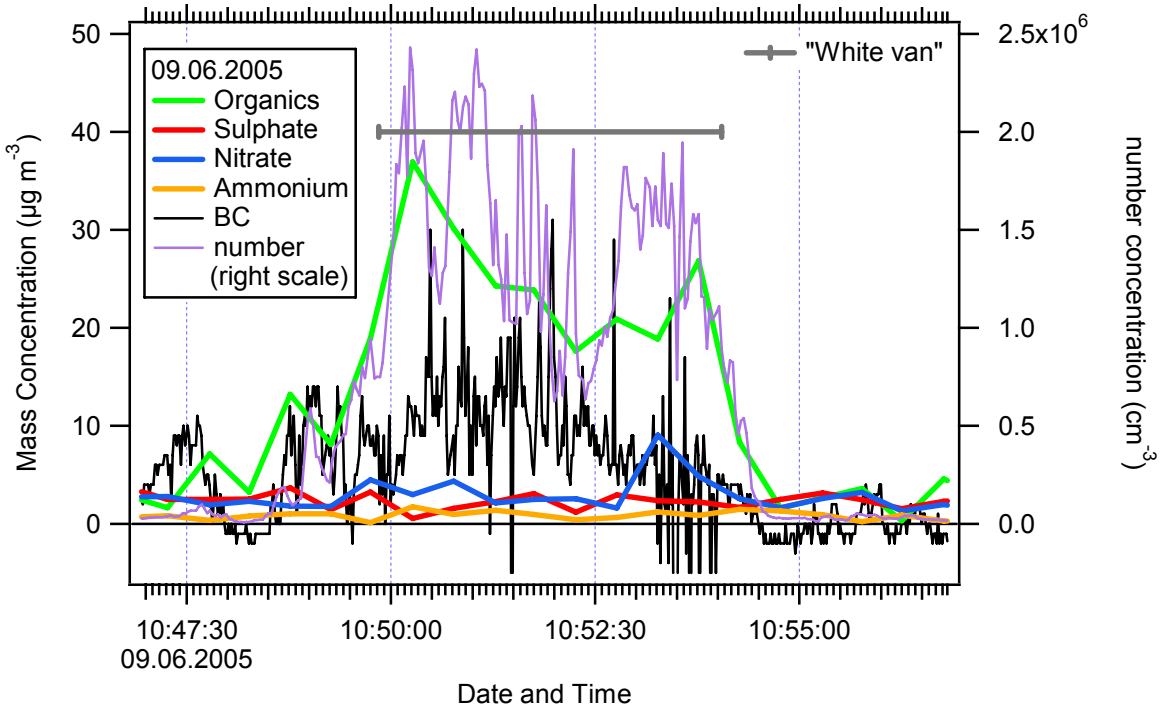
07.06.2005 „Blue van"

AMS & SMPS:

$$\rho_{eff} = \frac{\rho_p}{\rho_0}\frac{1}{\chi} = \frac{d_{va}}{d_{mob}}$$

- **Organics contained in soot mode**
- **Effective density ~ 0.5 g cm-3**
- **No nucleation**

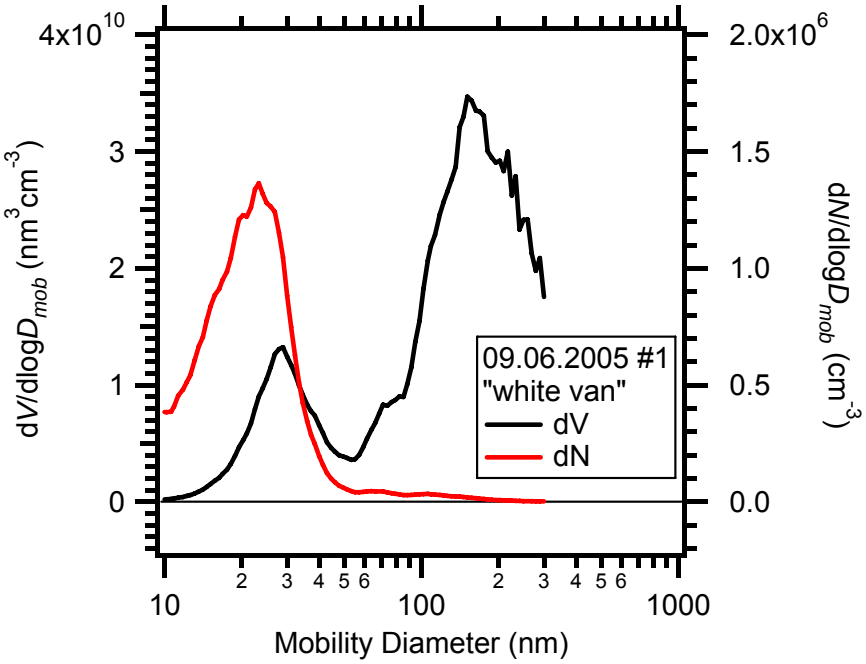
Special Events: „White van“

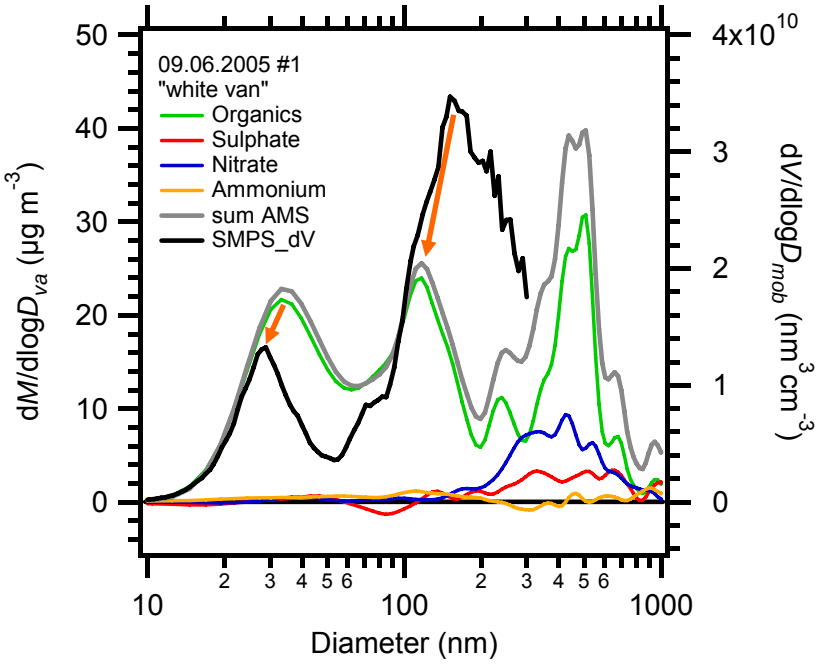


09.06.2005 a)

- **High organics and high particle number emissions with moderate BC emission**

09.06.2005 a) „White van"





- Organics contained in nucleation mode and soot mode
- No sulfate in nucleation mode => nucleation particles formed by organics

Conclusions (1)

- Successful measurements with all instruments during 6 measurement drives on 4 days
- Particle number concentrations and mass concentrations for BC, sulfate, organics, separated into 4 major different categories:
  Motorway background, truck chasings, Aachen City, regional rural road
- Pronounced differences between these categories:
  Highest number concentrations during truck chasing, highest BC and organics mass in Aachen City, lowest number and BC concentration on rural road
- Sulfate total mass concentration not influenced by traffic

Conclusions (2)

- Emission indices for BC, organics, NOx and particle number from trucks (calculated from ΔCO_2):

BC:	43 – 1160	mg/(kg fuel)
Organics:	35 – 1300	mg/(kg fuel)
NOx:	5 – 92	g/(kg fuel)
Particle number:	2E15 – 1E17	#/(kg fuel)

- Mass size distributions: Organic mass distribution shows clear indication for traffic influence during truck chasing: Nucleation mode at ≈ 30 nm and soot mode at ≈ 100 nm.
- No sulfate found in nucleation mode particles => nucleation particles in HD exhaust formed by organics.
- Combination of mobility diameter and vacuum aerodynamic diameter allows to infer an effective density, but interpretation is difficult for complex mixture of different particle types, with different densities and physical morphologies.

Acknowledgments

Thomas Böttger (MPI-C Mainz)
for technical assistance

James Allan (U Manchester) and others
for the AMS analysis software