Real-time road field determination of ultra fine particulate matter

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Introduction

With respect to immission legislation, many European cities transgressed the threshold value of particulate matter exposure. Unfortunately, only the total mass of particles smaller than 10µm is restricted without distinguishing between different components. Epidemiological studies indicate that ultra fine particles of definite nature are significantly more dangerous than larger ones. Thus, simultaneous selective determination of mass and specific surface area is necessary to better appraise the exposure composition. Moreover, real-time characterization is important for potentially allocating single emission sources. A non-invasive measurement technique which fulfils these requirements is time-resolved laser-induced incandescence (TIRE-LII) which was integrated in a robust immission sensor (LI²SA). Its potential for particle determination in ambient air is shown on-road and at the roadside.

Measurement Setup

The basic principle of time-resolved laser-induced incandescence (TIRE-LII) is the rapid heating of the soot particles up to their vaporization temperature by means of a highly energetic frequency-doubled Nd:YAG-laser and the subsequent detection of the enhanced thermal radiation in a specific wavelength range. The soot mass concentration and the specific surface area, respectively the primary particle size can be determined online and in-situ by means of time resolved measurement. Under the assumption of sufficient laser irradiance, the maximal LII signal is proportional to the mass concentration. Therefore, the sensor is calibrated in comparison to coulometric filter analysis with the combustion aerosol standard (CAST). In contrast to conventional measurement devices, the system is only selective on elemental carbon (EC), as all other components are vaporized due to the high temperatures. For the characterization of the primary particle size, experimental signal decay times are compared to numerical calculations. Beside the LI²SA sensor for direct raw exhaust measurements also one for real-time immission determination up to 20 Hz was developed with a detection limit of 3$\mu g/m^3$.

Field Study

First investigations were carried out next to two different measurement stations, one located at a busy urban road, the other one based at a residential area next to a forest. In comparison to measurements using TEOM systems which determine the total mass of PM10 per hour, LI^{2}SA characterized the EC fraction averaged in the same time scale. Thereby, at the busy street the mean concentration of elemental carbon was always between 7 to 12 $\mu g/m^3$. Beyond this, due to the deviation of the non-traffic related particles the EC fraction lies always between 20-40% of the total mass. By means of time-resolved measurements (5Hz) short but high peak concentrations were detectable and unambiguous correlation to single vehicles were found when comparing to simultaneously recorded video tapes. Other investigations were conducted at school bus stops to appraise the exposure on pupils. It was found that short (2 to 6 s) but very high EC mass concentrations of about several hundred $\mu g/m^3$ occurred. This underlines the need for comprehensive equipping of buses with particulate traps. Mobile studies on the road showed the exposure on drivers inside and outside the car whereas the mean EC mass concentration inside the vehicle was approximately doubled. Thereby, as expected, specific surface area and primary particle sizes are in the same range. Furthermore, high concentrations at traffic congestions or start ups at traffic lights and street crossings can be seen, as well as typical concentration courses inside and after a tunnel.

Summary

In the framework of this field study, portion and size of diesel soot emission in urban environment has been characterized using a modified LI^{2}SA soot sensor, which is selective on elemental carbon, the content reduced by diesel particle filter. Its underlying measurement principle is based on time-resolved laser-induced incandescence technique, temporally evaluating the enhanced thermal radiation after rapid laser heating. Observations have been carried out mobile in a light van and at the roadside of arterial urban roads, motorways and tunnels. Thereby, the impact of traffic congestion and the influence of different vehicles could be shown by means of real-time (up to 5 Hz) monitoring in and outside of the car. Furthermore, very high peak concentrations of several hundred µg/m³ at bus stops have been investigated, which indicated the need for comprehensive equipping with particulate traps. The obtained results demonstrate the advantages of portable specific online measurement instruments, which are able to characterize directly and unambiguously the exposure at a wide range of locations.

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Zürich 15.-17.08.2005

Motivation

2005: Commencement of European Immission Legislation

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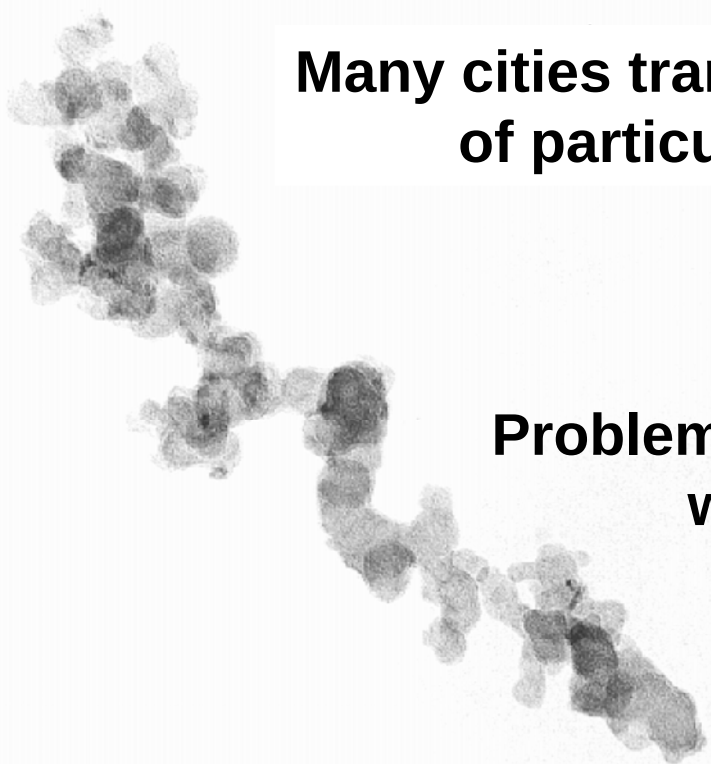

Many cities transgressed threshold value of particulate matter exposure

⇩

Problem: Only total mass (< 10µm) is restricted without distinguishing between different components

Motivation

1. Ultra fine particles are more dangerous than larger ones

→ **Determination of mass concentration in specific size ranges**

2. What kind of particles are measured?

→ **Selective Particle Determination**

3. Problem: Unknown emission source

→ **Real-time characterization**

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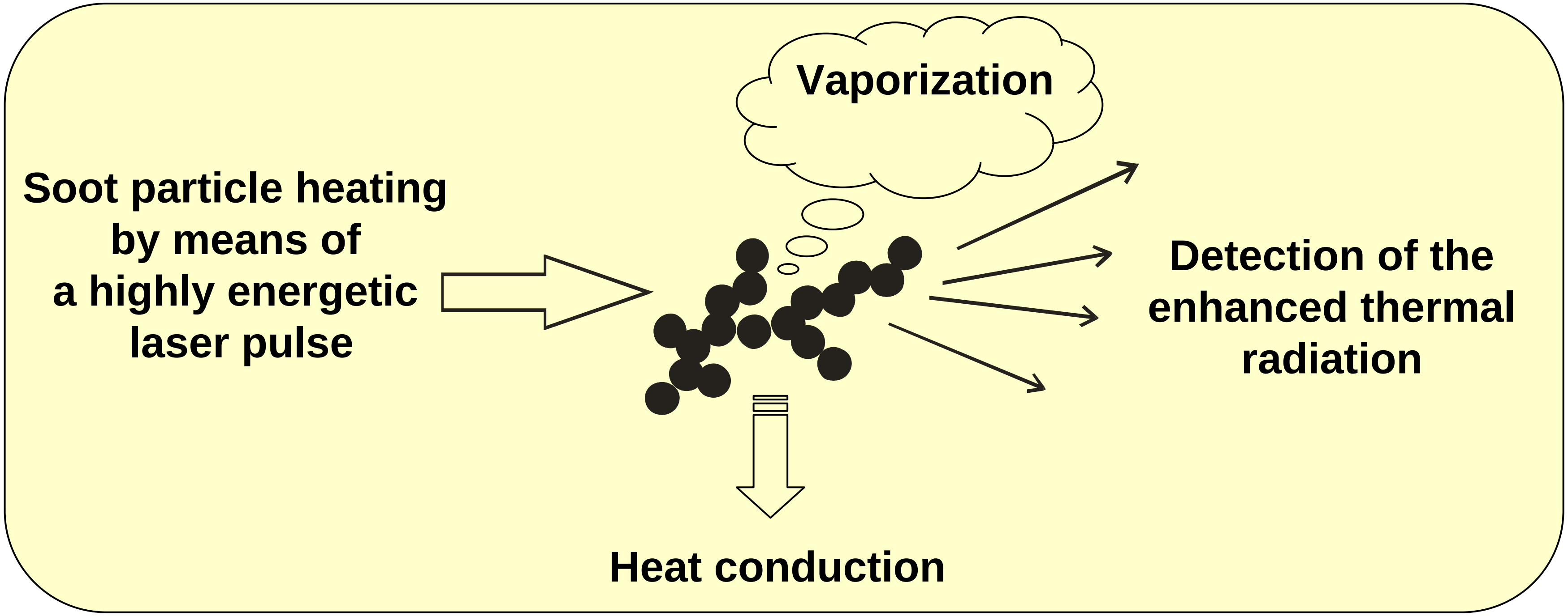
Time-Resoved Laser-Induced Incandescence (TIRE-LII)

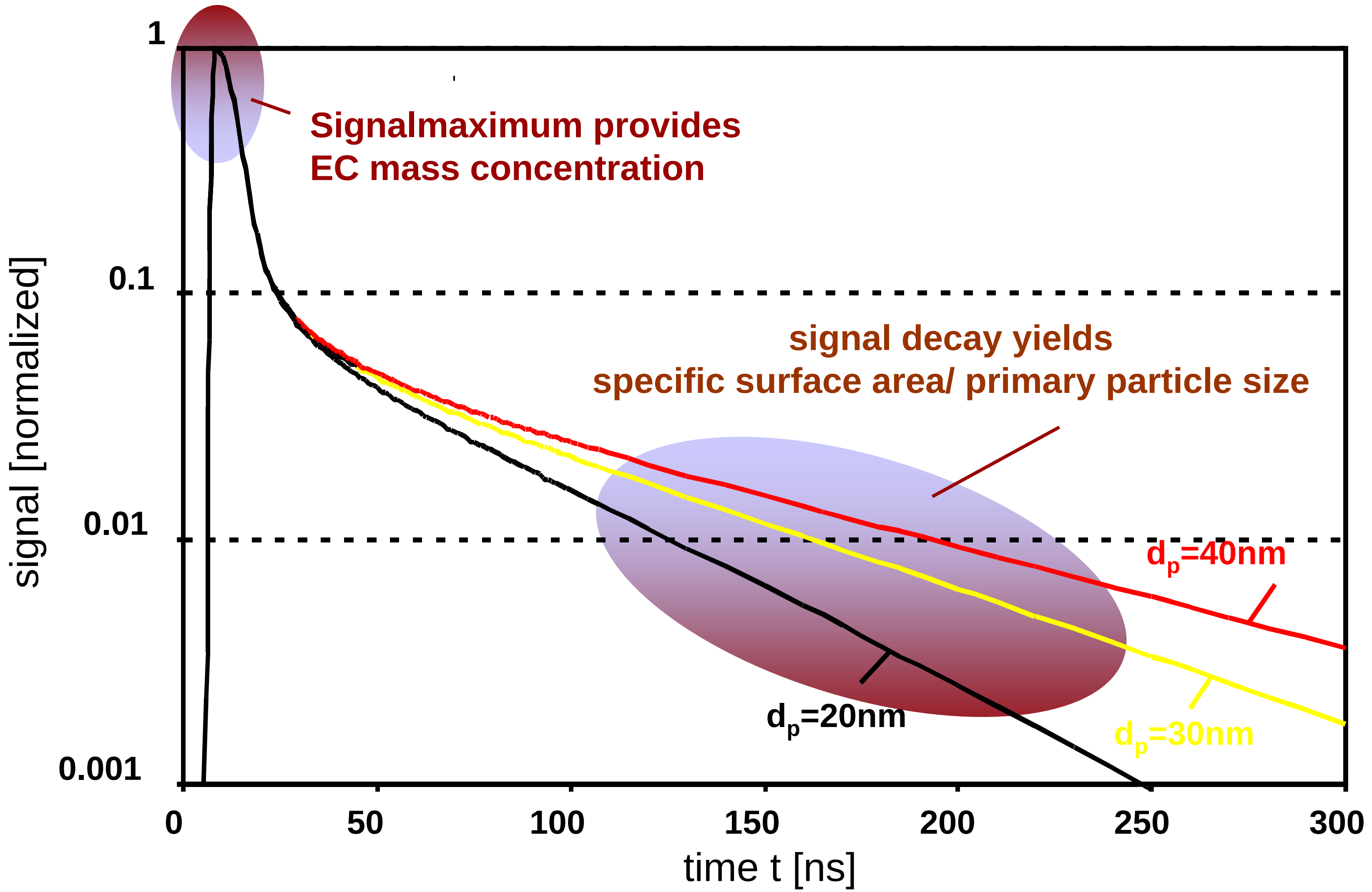
Principle of the LII technique



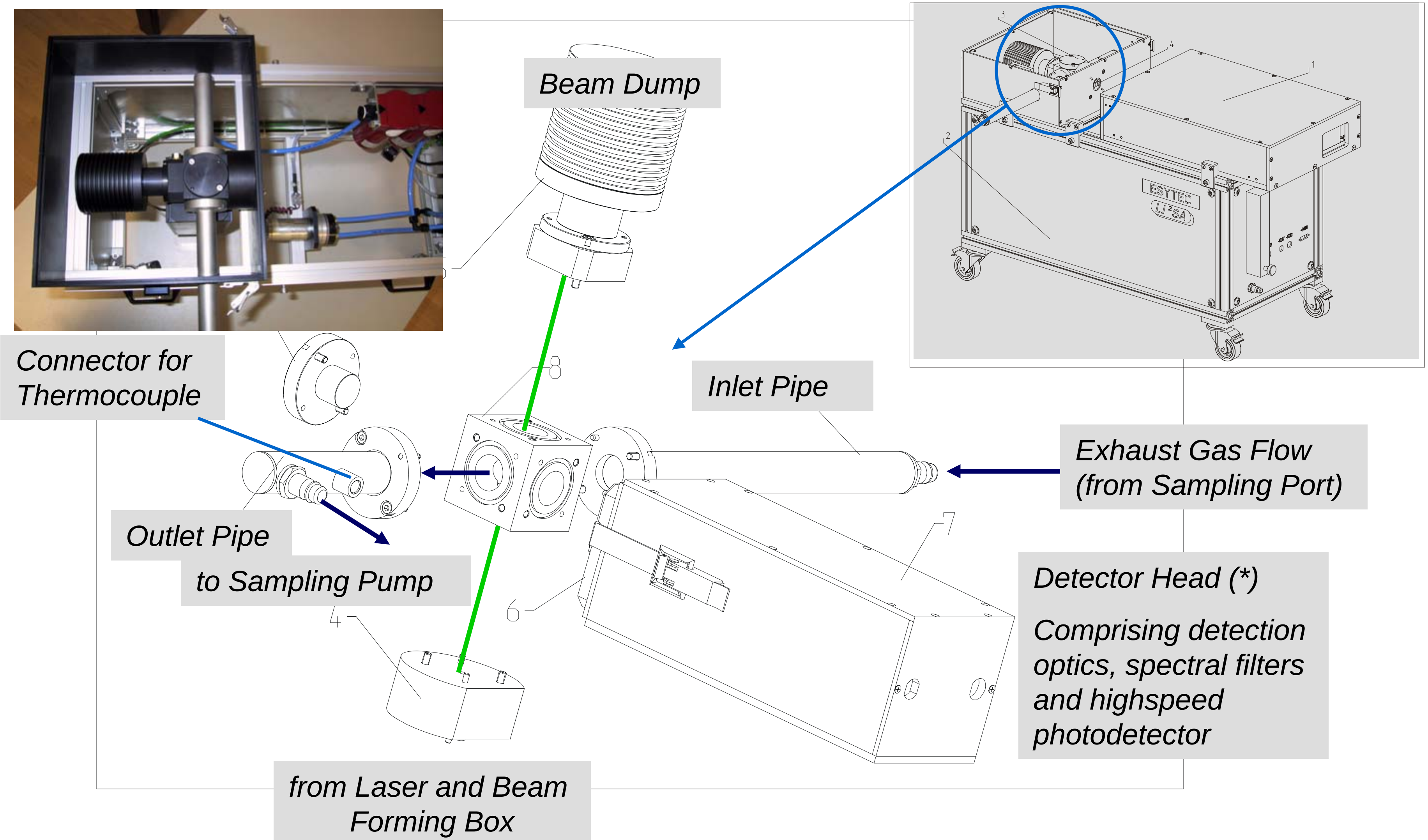
$$\underbrace{Q_{abs}\cdot\frac{\pi d_p^2}{4}\cdot E_i}_{Absorption}-\underbrace{\Lambda\cdot(T-T_0)\cdot\pi d_p^2}_{Heat\ conduction}+\underbrace{\frac{\Delta H_S}{M}\cdot\frac{dm}{dt}}_{Vaporization}-\underbrace{\pi d_p^2\int\varepsilon(d_p,\lambda)M_\lambda^b(T,\lambda)\cdot d\lambda}_{Thermal\ radiation}-\underbrace{\frac{\pi d_p^3}{6}\rho_S\cdot C_S\cdot\frac{dT}{dt}}_{Change\ of\ internal\ energy}=0$$

⇨ **Numerical Solution of the energy balance yields temporal signal course**

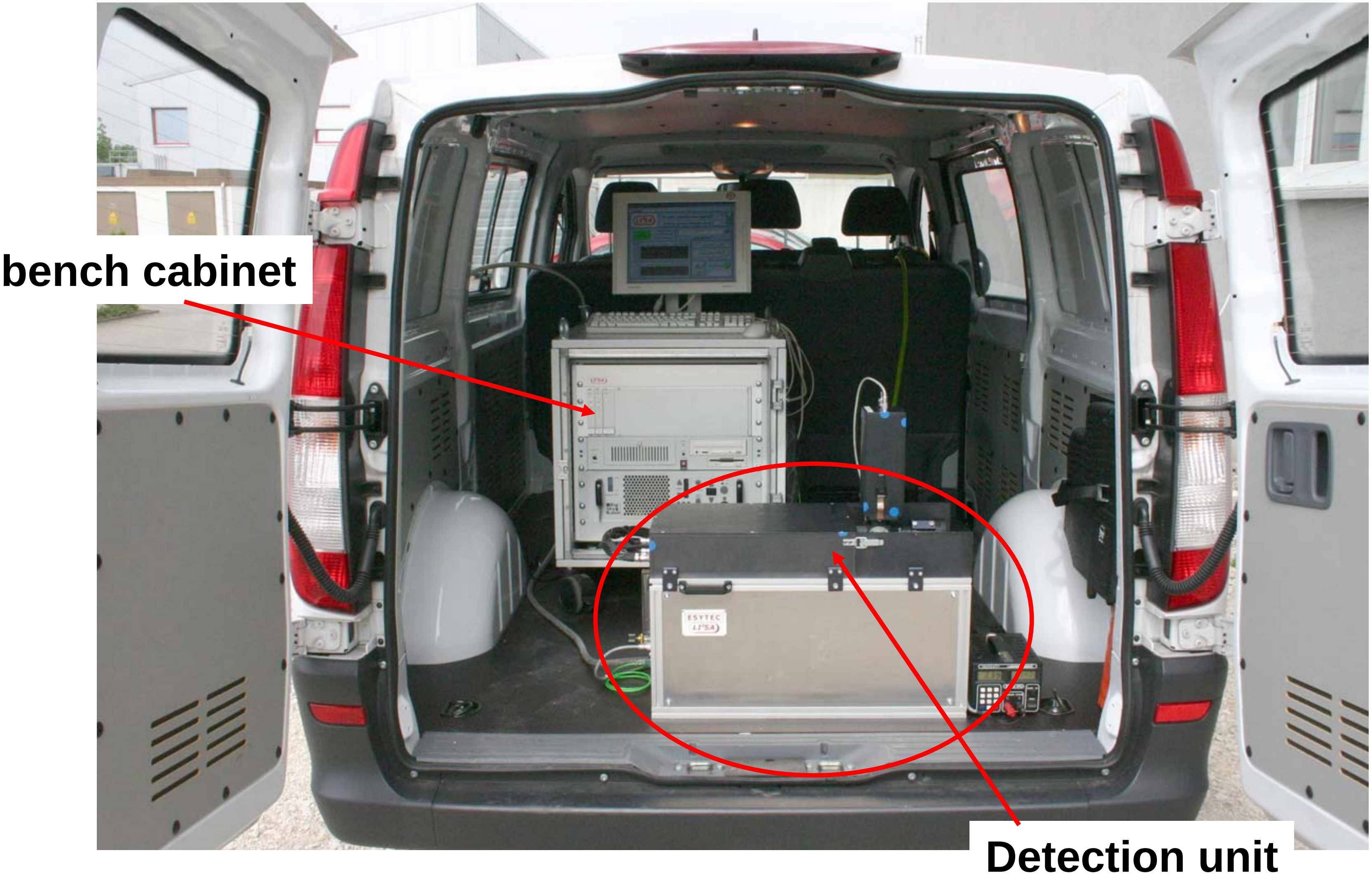
Principle of the LII technique



LI²SA-Immission-Sensor



Measurement setup: Mobile unit



Roadside measurements

LTT ERLANGEN

City of Erlangen

↙ ↘

busy urban road | ***residential area***

EC fraction of total mass ? | **Particle Emission source ?**

residential area

↙ ↘

PM 10

40-55 µg/m³

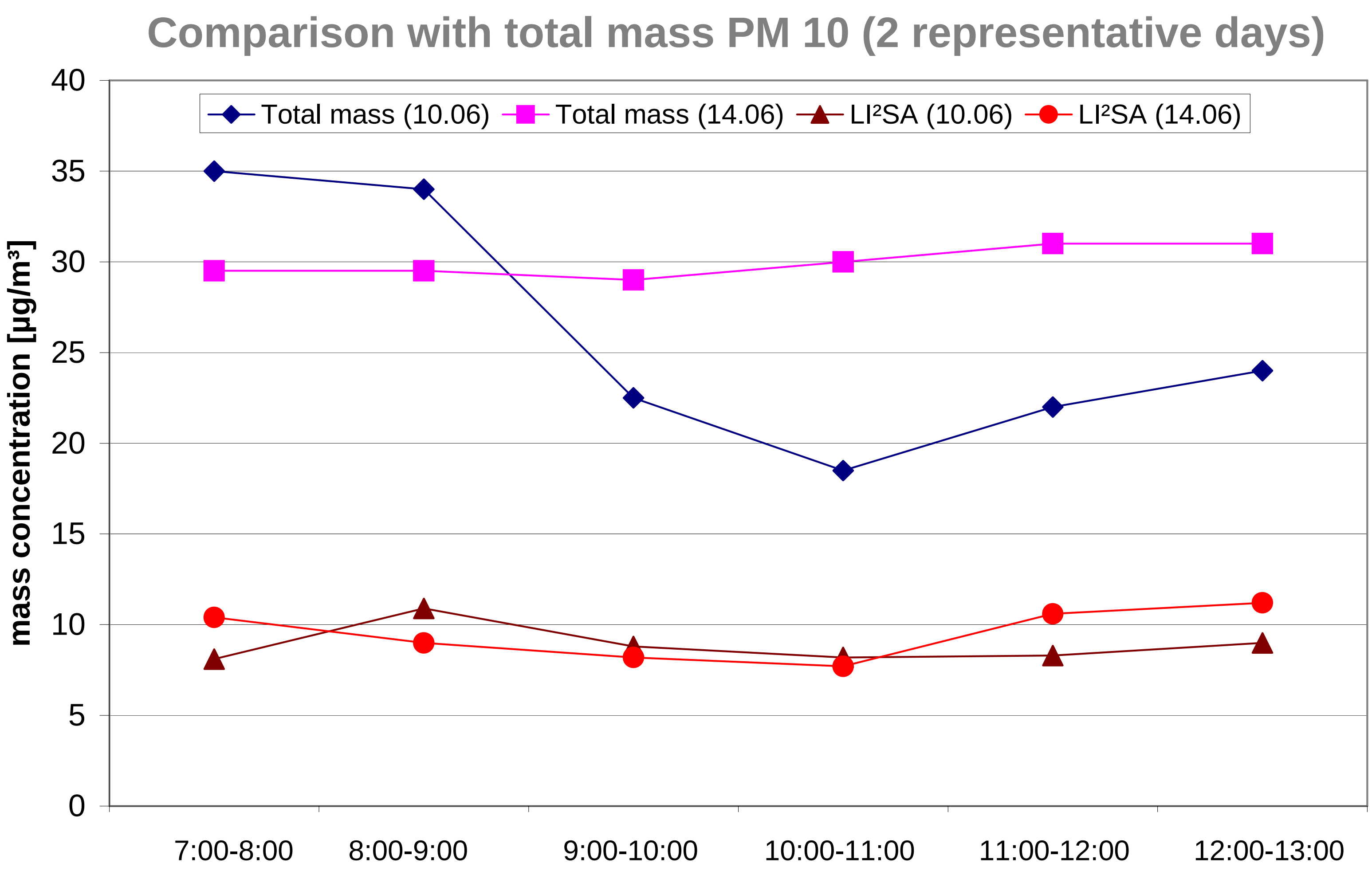
EC (LI²SA)

< 3 µg/m³

Comparison with sampling method (TEOM)

Roadside measurements

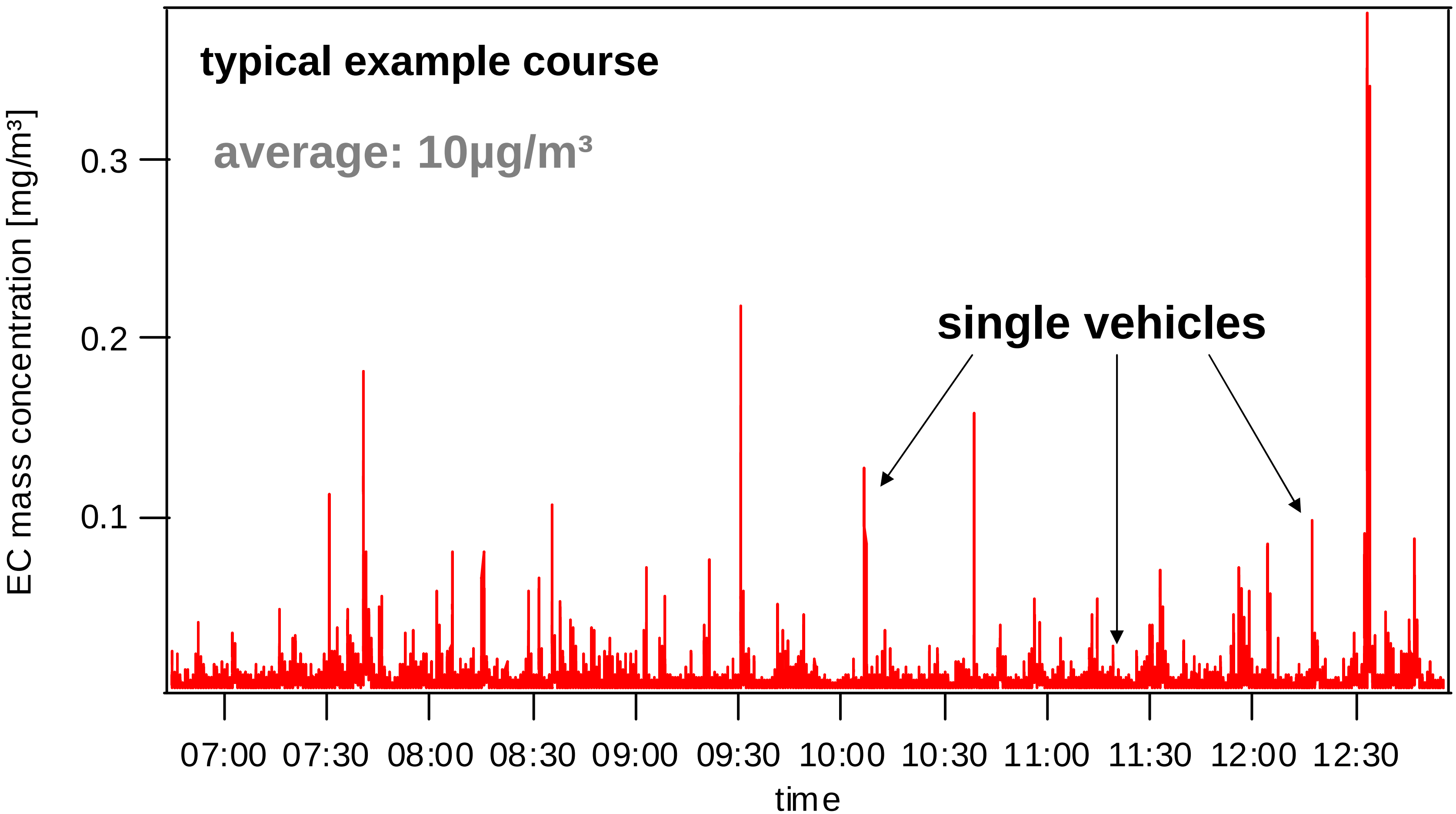
Erlangen: busy urban road



→ **EC fraction between 20 and 40% of total mass**

Roadside measurements

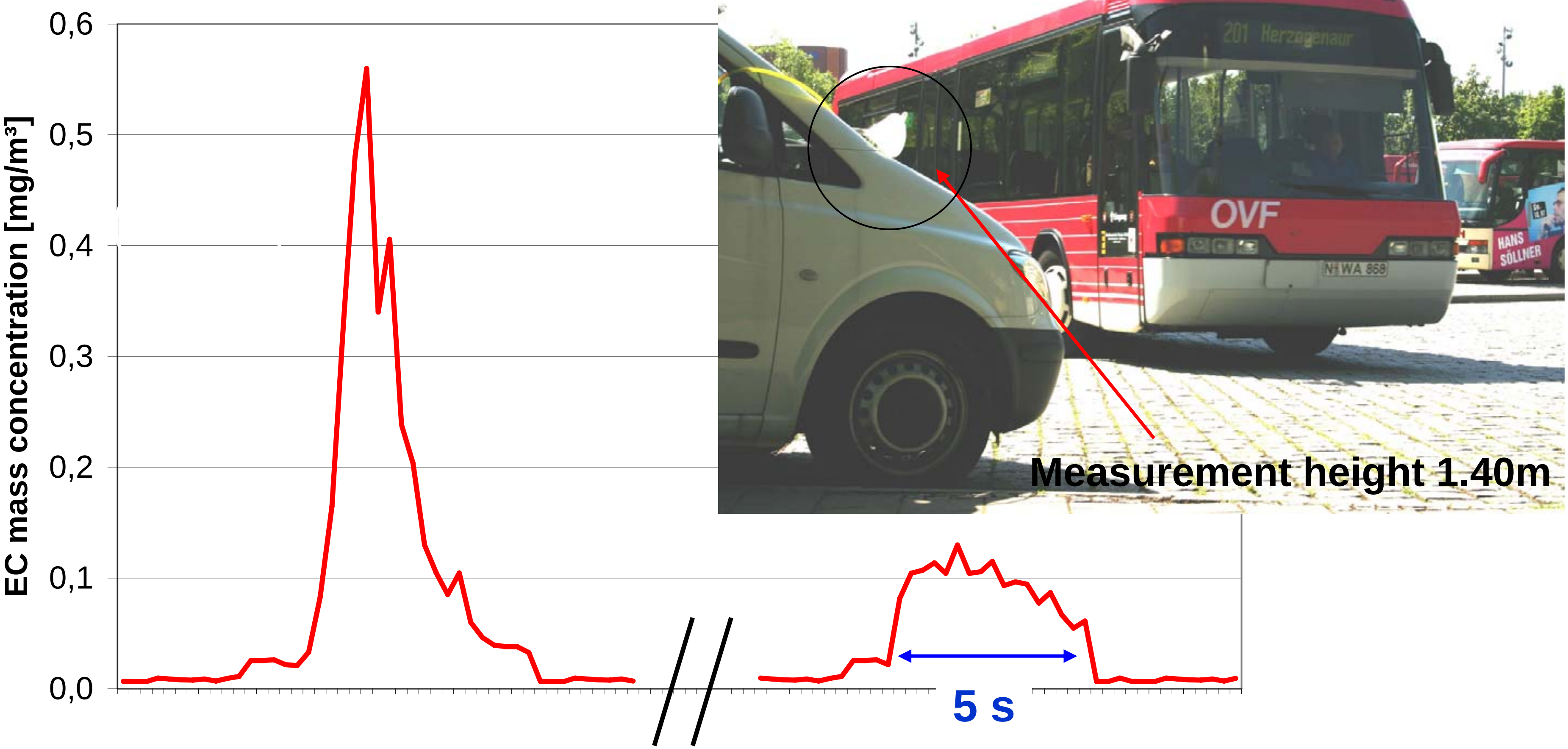
Erlangen: arterial urban road



→ **very high peak concentrations from specific vehicles**

Roadside measurements

School bus stops: Exposure on pupils

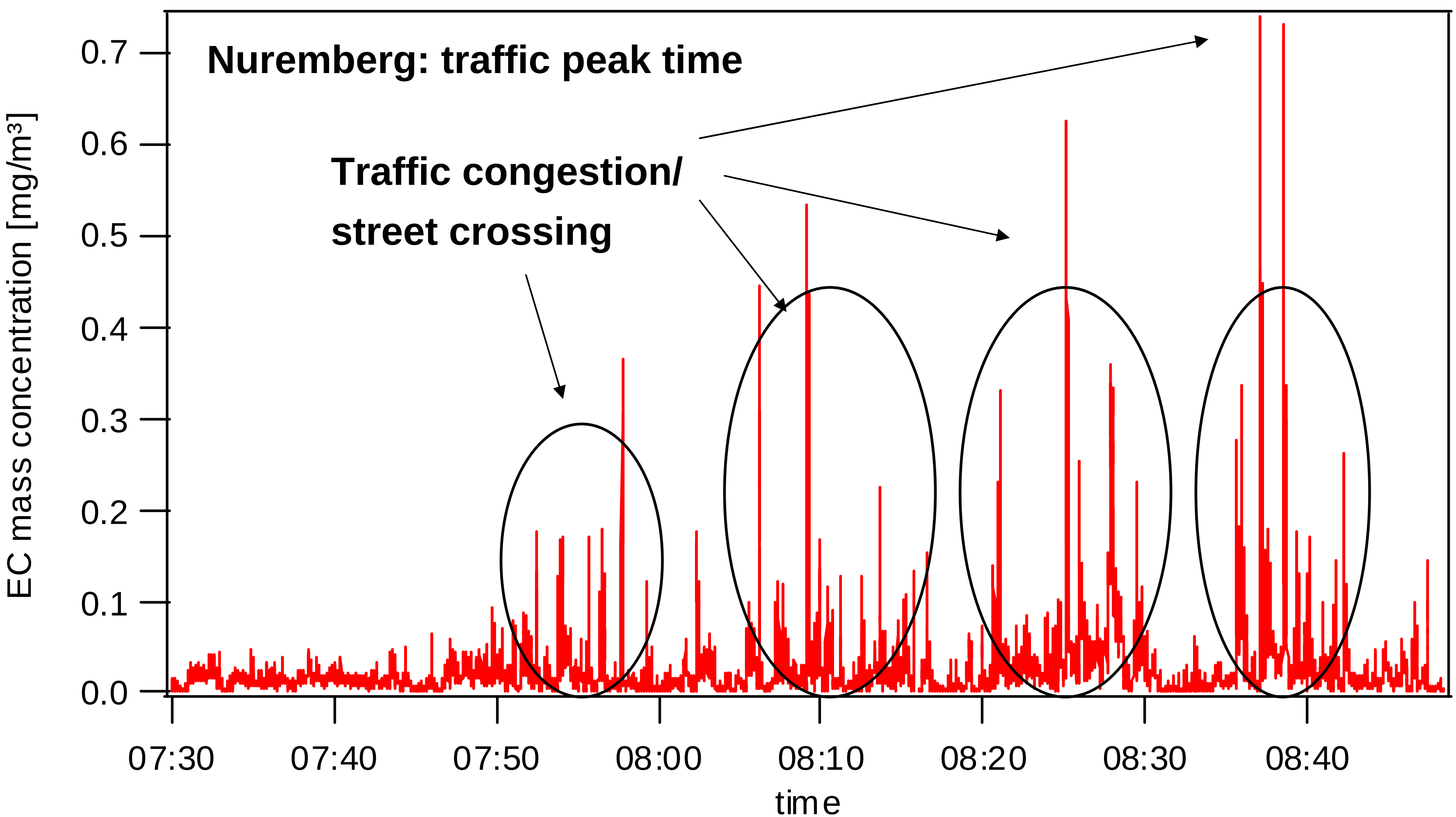


→ **short but very high exposure on children**

→ **DPF retrofit strongly recommended**

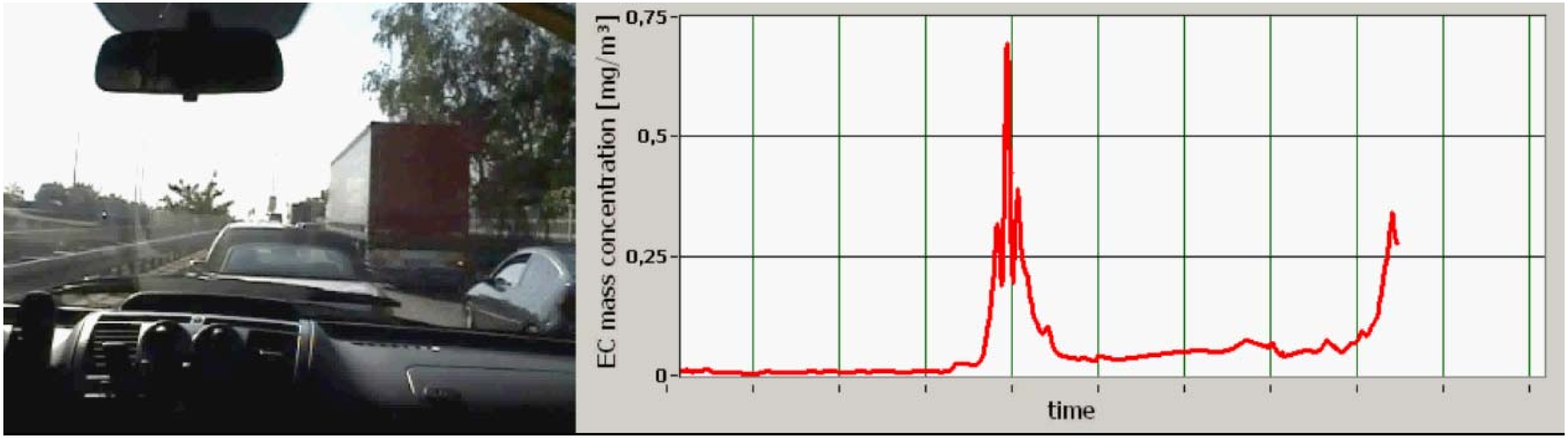
On the road: outside the car

EC exposure during on-road measurements?



On the road: outside the car

Nuremberg: traffic congestion



→ **unambiguous correlation to specific vehicles**

On the road: inside the car

How many soot particles do a driver breathe?

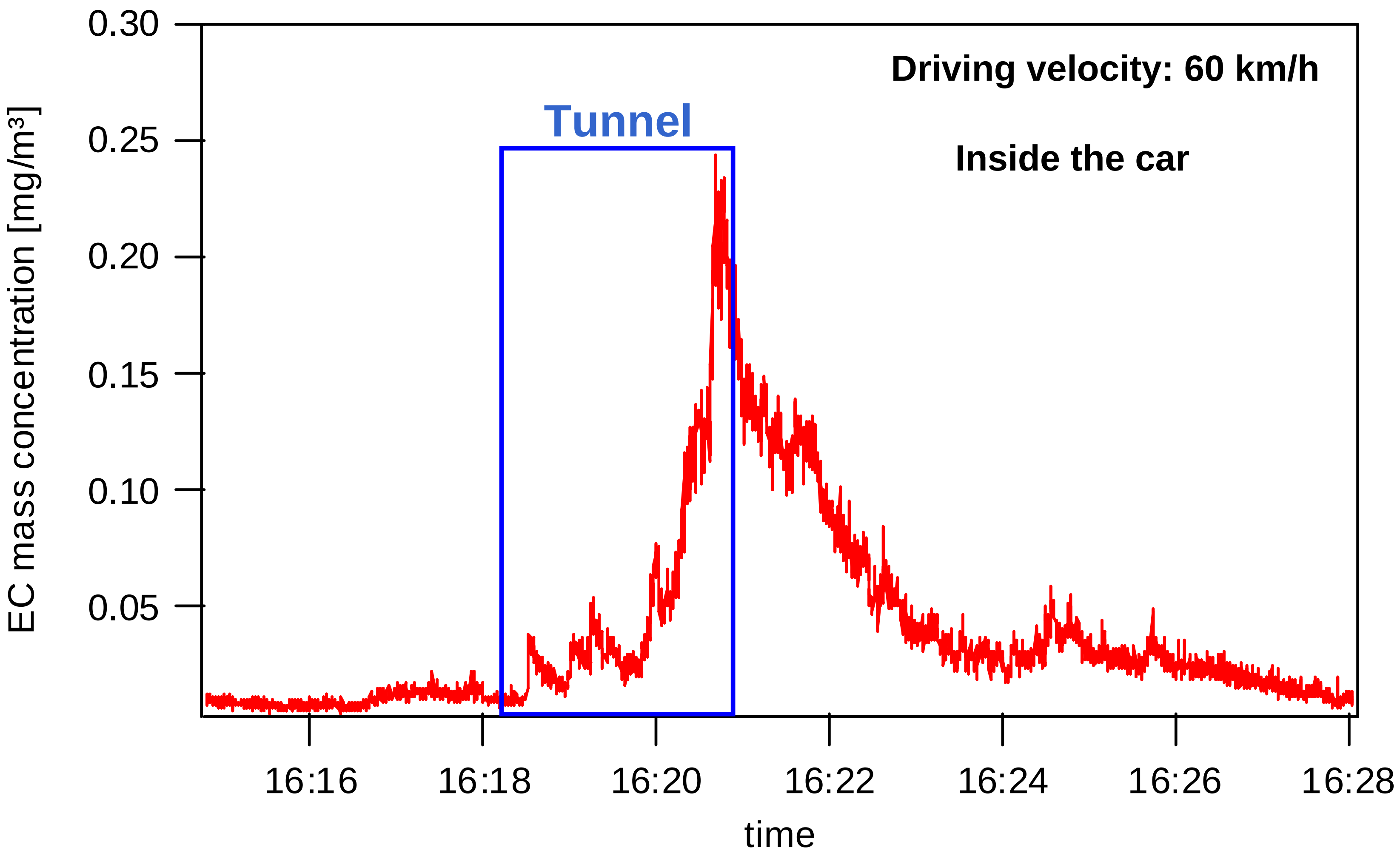
Nuremberg: traffic peak time

Comparison outside and inside the car

	Outside the car	Inside the car
Mean EC mass concentration [µg/m³]	8 - 10	19 - 28
Maximum EC mass concentration [µg/m³]	up to 820	max 120
Specific surface area [m²/mg]	0,361 - 0,067	0,279 - 0,071
Primary Particle size [nm]	11 - 50	13 - 47

→ **permanently higher mass concentrations inside the car in comparison to outside measurements**

On the road passing a tunnel



→ **long term exposure also after the tunnel**

Summary and outlook

Summary

- → **Real-time Determination of EC mass concentration and specific surface area**
- → **Allocation of peak concentrations to single specific vehicles possible**
- → **Higher mean concentrations inside the car detectable**

Outlook

- → **Optimization of detection limit (<1µg/m³)**
- → **Recent research: Investigation of after-treatment systems directly in the raw exhaust**