National Physical Laboratory

Activities to improve calibration for PM mass concentration and black carbon measurements in the EMPIR programme

AAMG meeting, RSC

14th December 2017

What is EMPIR?

- EU co-funded projects with metrology focus
- Coordinated by EURAMET (European Association of National Metrology Institutes)
- Environment calls 2010, 2013, 2016 …

Aerosol metrology (AEROMET), led by PTB (Germany) (Burkhard Beckhoff) 1/6/17 – 31/5/17

Partners:

BAM, Germany
DFM, Denmark
LNE, France
NPL, United Kingdom
DTI, Denmark
IJS, Slovenia
LUND, Sweden
NTUA, Greece
TROPOS, Germany
Bruker, Germany

CMI, Czech Republic
INRIM, Italy
NILU, Norway
CIEMAT, Spain
FORCE, Denmark
IRSN, France
MTA-EK, Hungary
PMO, Italy
UNICAS, Italy
METAS, Switzerland

Aerosol metrology (AEROMET)

1. To develop reproducible reference methods for PM_{10} and $PM_{2.5}$, including the design and building of a demonstration chamber system using representative generated aerosols.

2. To establish traceable validated methods for the major components of particulate matter such as elemental and organic carbon, total carbon, anions and cations and major metals (arsenic, cadmium, mercury, nickel).

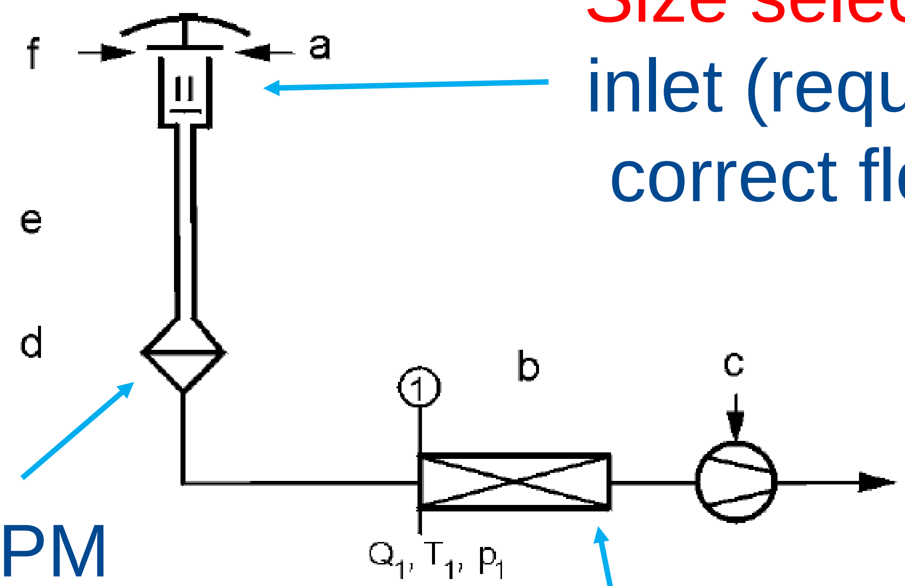
3. To develop validated calibration procedures for Mobility Particle Size Spectrometers for ambient measurements in the size range up to 1000 nm, and Condensation Particle Counters in support of standardisation.

4. To develop traceable and reliable analytical techniques (such as electron, optical, x-ray, infrared spectroscopy and mass spectrometry), including flexible particle sampling techniques, for quantifying particle compositions in the field, and in particular for real time analysis.

PM_{10} and $PM_{2.5}$ – the calibration problem

Correct value is defined by the reference method (EN 12341)

Size selective inlet (requires correct flow)



Collection of PM on filters for weighing

Flow control (for correct size selection and known sampled volume)

PM_{10} and $PM_{2.5}$ – the calibration problem

Factors affecting the measured PM weight:

- Effect of humidity on filter material
- Effect of humidity on hygroscopic PM
- Loss of filter material
- Effect of temperature during sampling, storage and transport on semi-volatile material (eg ammonium nitrate)
- Chemical reactions on the filter
- balance drift, static electricity …..

PM_{10} and $PM_{2.5}$ – the calibration problem

EN16450 – Automated measuring systems

Laboratory Tests – 2 instruments of the same pattern

- Repeatability at zero & span
- Flow accuracy and stability
- Effect of variables (temperature, humidity, voltage)

Field Tests – 2 instruments of the same pattern

- 4 comparisons carried out at a minimum of 2 sites with:
  - variable composition of the PM fraction, with high and low fractions of semi-volatiles
  - high and low air temperature and humidity
  - large variations of wind speed to cover the impact on sampling inlet performance

Equivalence with the reference method must be demonstrated with real ambient aerosol over long periods

PM_{10} and $PM_{2.5}$ – the AEROMET proposal

1. To develop reproducible reference methods for PM_{10} and $PM_{2.5}$, including the design and building of a demonstration chamber system using representative generated aerosols.

Chamber parameters: controlled humidity, temperature
flow rate, homogeneity, duration

Aerosol properties: non-volatile and semi-volatile
hygroscopic and non-hygroscopic
realistic particle size (especially important for optical instruments)

Likely sources: Arizona test dust; CAST soot + organic coating;
atomised ammonium sulphate and nitrate

PM_{10} and $PM_{2.5}$ – the AEROMET proposal: controlled properties of test aerosol

AEROMET
Aerosol metrology for atmospheric science and air quality

Property	Aim	Notes/quantification
Particle size at low sizes	No unrepresentative large concentration of particles below ~300 nm	To match “aged” aerosol, unless specifically to test performance with fresh aerosol.
Particle volatility	Representative of the volatility in the specified test condition.	X% reduction in mass concentration when the aerosol is heated to Y°C
Particle hygroscopicity	Representative of the hygroscopicity in the specified test condition.	X% change in filter mass concentration when the humidity is changed from X to Y% at Z°C
Particle density	Representative of the particle density in the specified test condition.	Most important if the test condition is to represent an industrial site with many metallic particles.
Particle mass concentration	Representative of the specified test condition. Higher priority to “limit value” levels i.e. 50 µg/m^3 for PM_{10}.	
Temperature	Representative of the temperature in the specified test condition.	
Humidity	Representative of the humidity in the specified test condition.	

PM$_{10}$ and PM$_{2.5}$ – the AEROMET proposal: suggested test conditions

Property	Roadside, winter episode	Roadside, winter, non-episode	Roadside, summer episode	Roadside summer non-episode
Particle size at low sizes	Median >300 nm	Median >300 nm	Median >300 nm	median >300 nm
Particle volatility	high	low	high	Low
Particle hygroscopicity	high	low	high	Low
Particle mass concentration	PM2.5: 40 $\mu g/m^3$ PM10: 70 $\mu g/m^3$	20 $\mu g/m^3$ 40 $\mu g/m^3$	40 $\mu g/m^3$ 70 $\mu g/m^3$	20 $\mu g/m^3$ 40 $\mu g/m^3$
Temperature	~ 10˚C	~ 10˚C	~ 30˚C	~ 30˚C
Relative humidity	80%	80%	40%	40%

Comments are welcome

EMPIR Black Carbon
led by NPL (UK) (Paul Quincey)
1/7/17 – 30/6/20

Partners:

TROPOS (Germany)
PTB (Germany)
NCSR Demokritos (Greece)
METAS (Switzerland)
FHNW (Switzerland)
PSI (Switzerland)
LNE (France)
FMI (Finland)

Black carbon basics

EMPIR BLACK CARBON

1 Aerosol optical absorption, filter-free. Unit Mm^{-1}
→ **equivalent black carbon** $\mu g/m^3$
using a conventional mass absorption cross-section

2 Aerosol optical absorption, filter-based. Unit Mm^{-1}
→ **equivalent black carbon** $\mu g/m^3$
using a conventional mass absorption cross-section and an empirical correction for filter effects

Directly relevant to climate change; rapid and sensitive indicator of primary combustion sources for air quality and atmospheric science

3 Aerosol optical absorption, corrected for enhancement by internally-mixed non-absorbing material, absorption by non-carbon material, particle size etc. Unit Mm^{-1}
→ **black carbon** $\mu g/m^3$

using a "correct" mass absorption cross-section

A much more complicated problem, potentially providing much more detailed information

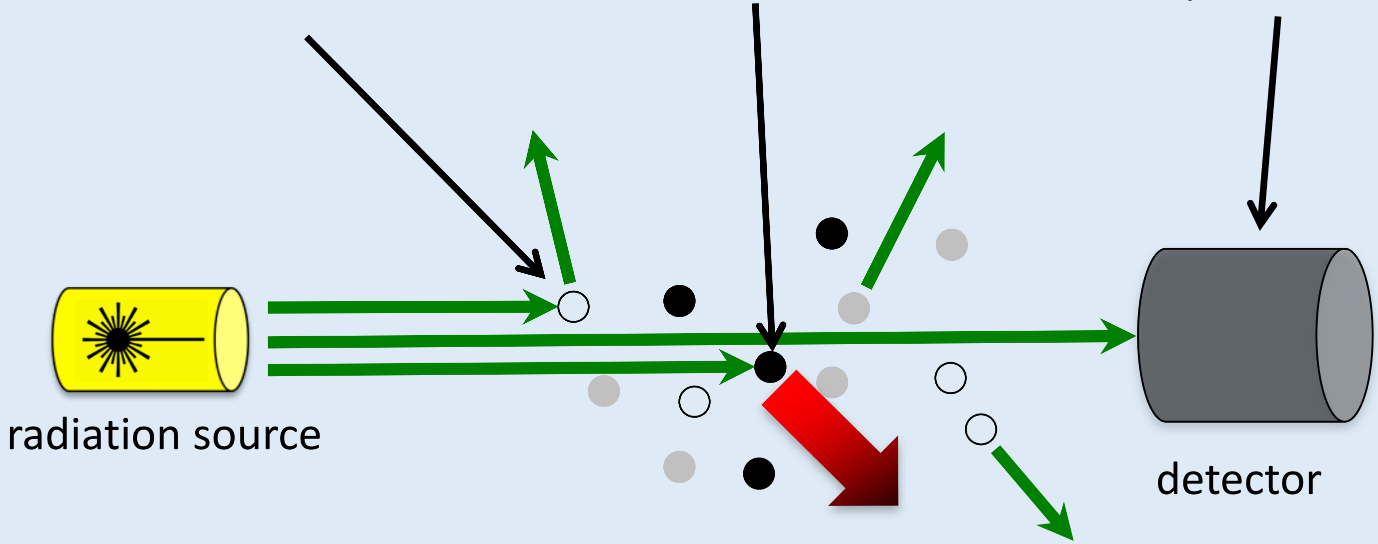
NON-FILTER-BASED aerosol light absorption

scattering + absorption = extinction

light is scattered in other directions

light is absorbed and transformed (e.g. to heat, …)

light is attenuated (extinction) due to absorption and scattering



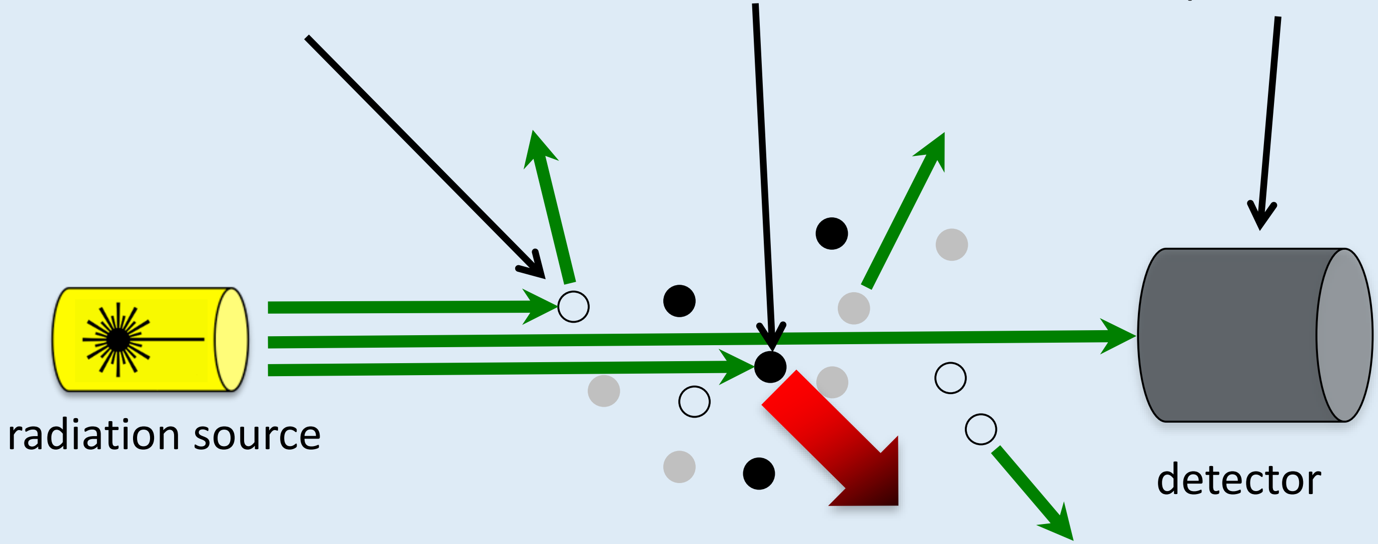
Direct: photoacoustic or photothermal interferometry

Indirect: extinction minus scattering

EMPIR BLACK CARBON

NON-FILTER-BASED aerosol light absorption

scattering	+	absorption	=	extinction
light is scattered in other directions		light is absorbed and transformed (e.g. to heat, …)		light is attenuated (extinction) due to absorption and scattering

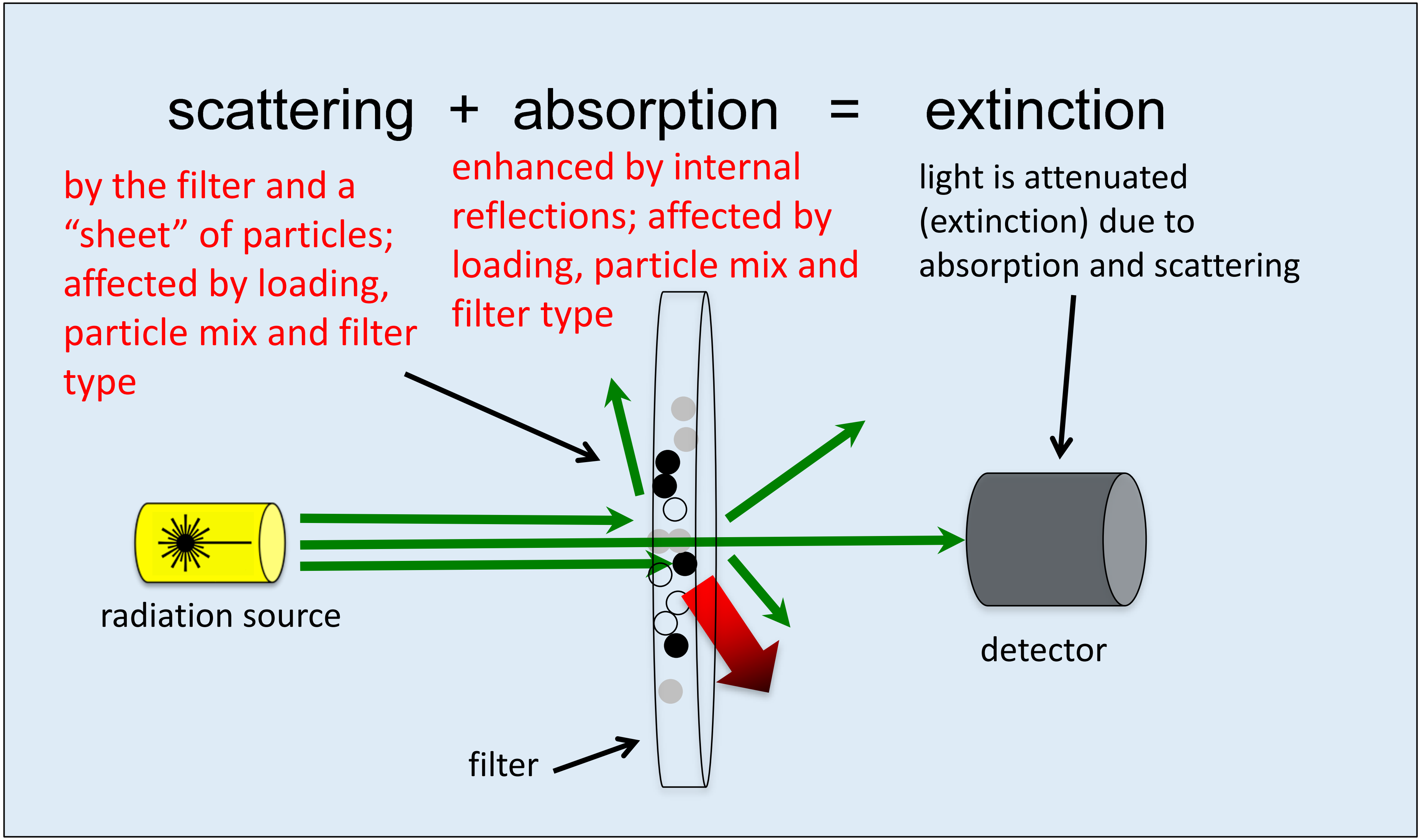


Direct: photoacoustic or photothermal interferometry

Traceability to SI is possible

Indirect: extinction minus scattering

EMPIR BLACK CARBON



FILTER-BASED aerosol light absorption instruments

EMPIR BLACK CARBON

FILTER-BASED aerosol light absorption instruments

EMPIR BLACK CARBON

The determination of aerosol absorption is affected by different filter types,

***and by different particle types for each type of filter*.**

It is **not** possible to apply a general calibration factor (traceability)

But it **is** possible to apply a calibration factor for specific particle types (standardisation)

Key project aim: definition of suitable particle types, and validation of a field calibration method

FILTER-BASED aerosol light absorption instruments – what particles to use for calibration ?

Key properties:

particle size (affecting penetration into the filter)

Single Scattering Albedo (ratio of scattering to extinction)

Two “opposite” ambient particle types are needed, to avoid accidental accuracy

Likely source: variations of CAST soot + organic coating

The focus of the project

EMPIR BLACK CARBON

1 Aerosol optical absorption, filter-free. Unit Mm^{-1}
→ equivalent black carbon $\mu g/m^3$ Traceable

using a conventional mass absorption cross-section

2 Aerosol optical absorption, filter-based. Unit Mm^{-1}
→ equivalent black carbon $\mu g/m^3$ Standardised

Directly relevant to climate change; rapid and sensitive indicator of primary combustion sources for air quality and atmospheric science

3 Aerosol optical absorption, corrected for enhancement by internally-mixed non-absorbing material, absorption by non-carbon material, particle size etc.
Unit Mm^{-1}
→ black carbon $\mu g/m^3$

using a "correct" mass absorption cross-section

A much more complicated problem, potentially providing much more detailed information

Aerosol metrology (AEROMET)

www.aerometproject.com

EMPIR Black Carbon

www.empirblackcarbon.com

Thank you

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