NPL
National Physical Laboratory

Aerosol particle light absorption: bringing metrology to black carbon measurements

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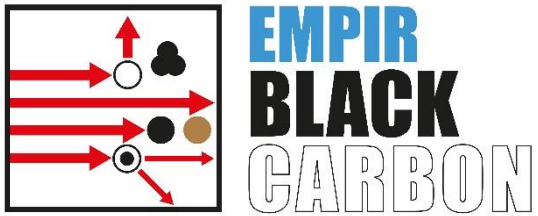
Gas and Particle Metrology Group

Cambridge Particle Meeting
15th June 2018

What do we mean by black carbon ?



In principle:

Black carbon (BC) is a useful *qualitative description* when referring to *light-absorbing carbonaceous* substances in atmospheric aerosol; however, for quantitative applications the term requires clarification of the underlying determination
[my italics]

Equivalent black carbon (EBC) should be used instead of black carbon for data derived from optical absorption methods, together with a suitable mass-specific absorption cross-section (MAC) for the conversion of light absorption coefficient into mass concentration.

[A. Petzold et al., “Recommendations for reporting black carbon measurements”, Atmos. Chem. Phys., 13, 8365-8379, 2013]

What do we mean by black carbon ?

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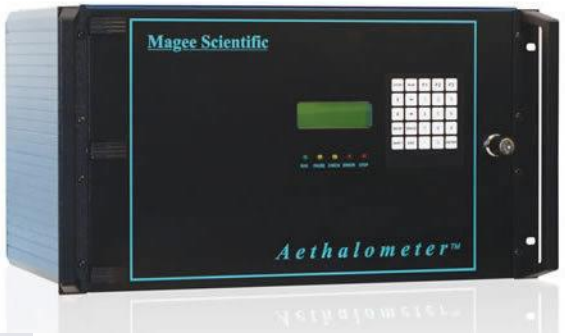
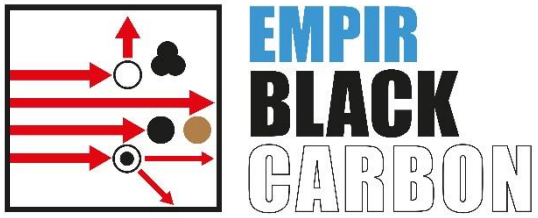
In practice:

(E)BC is an optical measure of airborne “soot” that can be made with:

- high sensitivity
- high time resolution
- simple, reliable instruments



Black carbon basics



1 Aerosol optical absorption, filter-free. Unit Mm^{-1}
→ **equivalent black carbon** µg/m^3
using a conventional mass absorption cross-section, e.g. 7.5 m^2/g

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

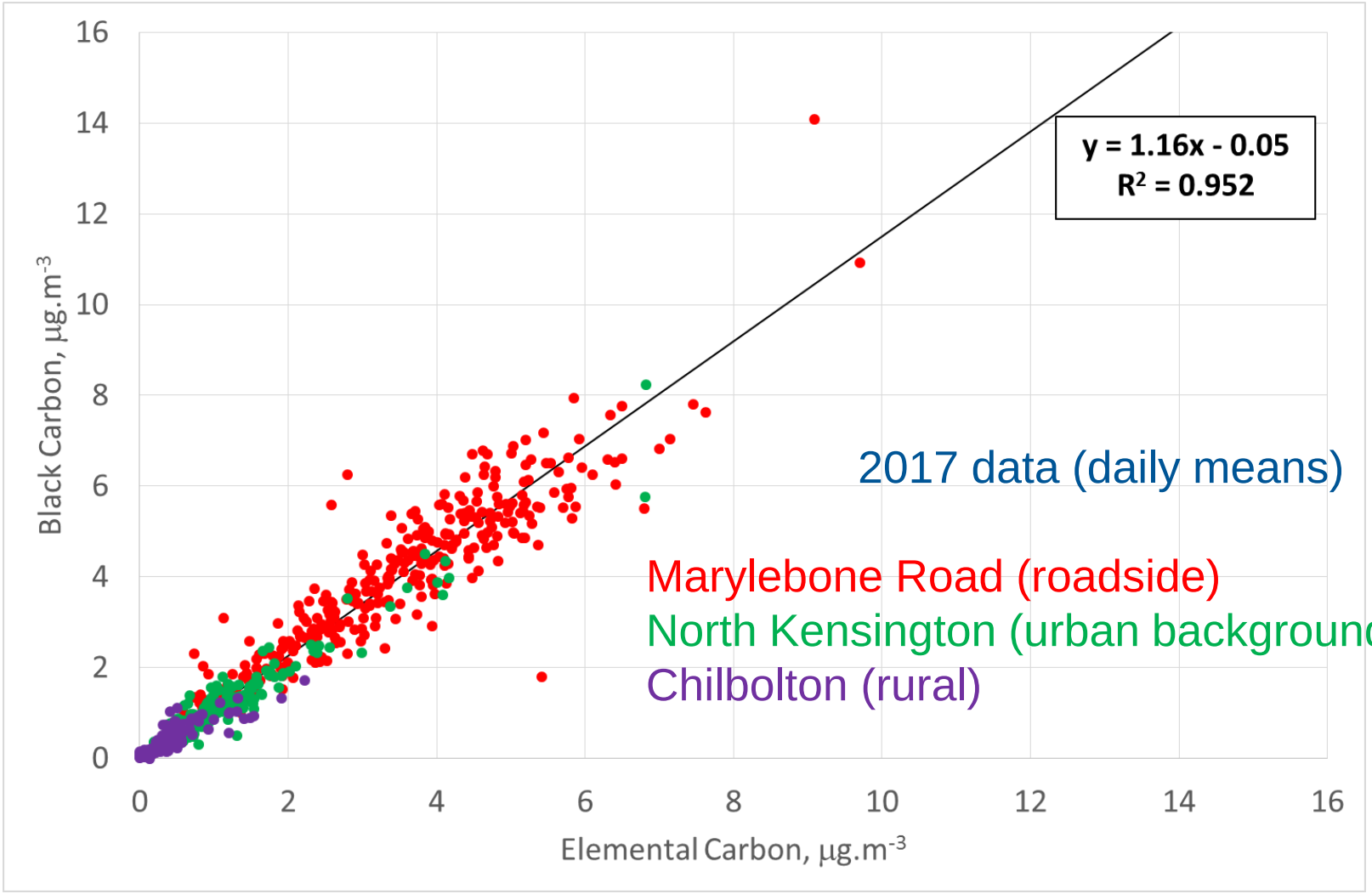
Directly relevant to climate change;

rapid and sensitive indicator of primary combustion sources for air quality and atmospheric science

"True" black carbon needs additional correction for:

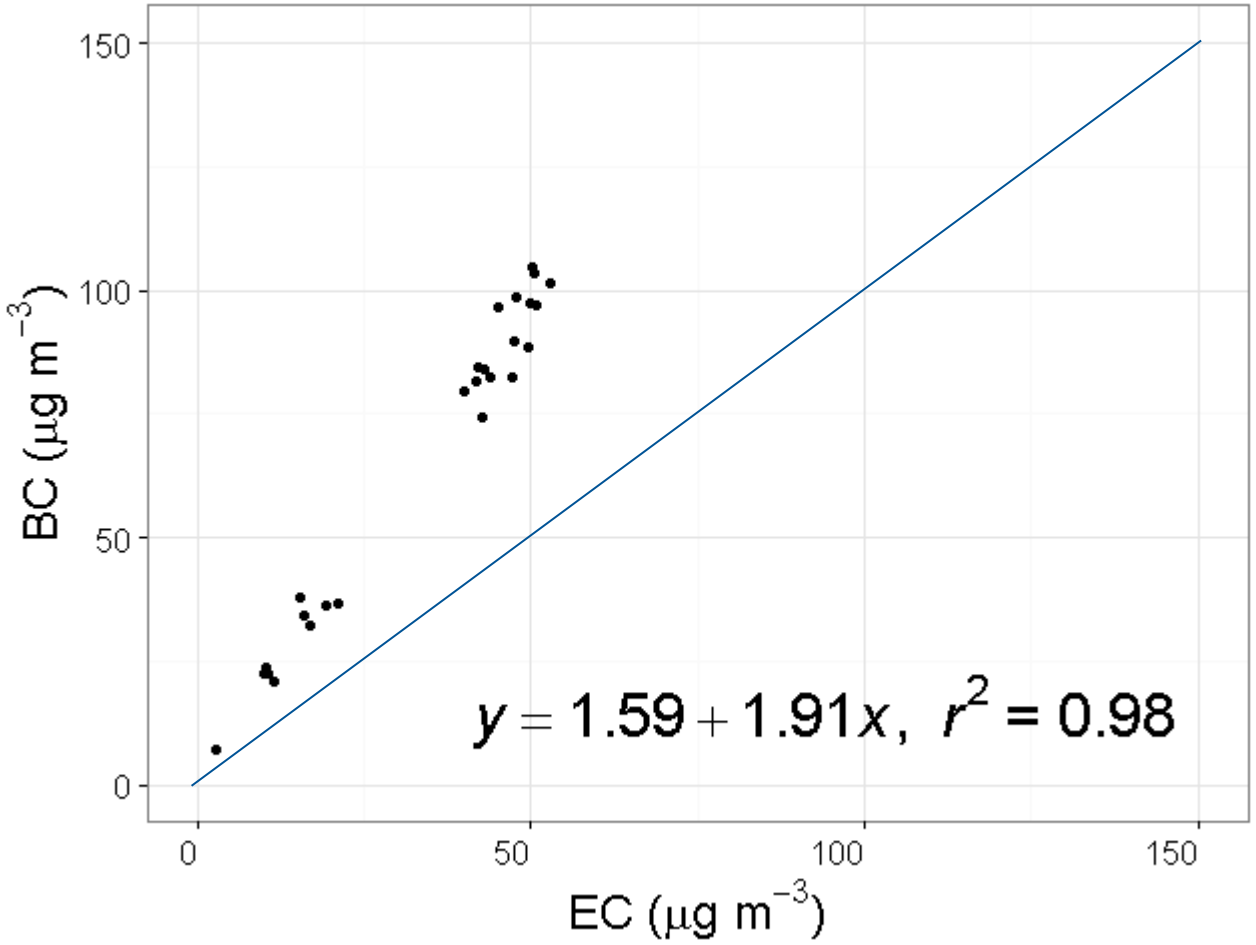
enhanced absorption by internally-mixed non-absorbing material,
absorption by non-carbonaceous material,
particle size etc.

Relation between Black Carbon and Elemental Carbon in ambient air



Data from the Defra Black Carbon network and the Defra Particles network, run by NPL with King's College London

Relation between BC and EC in the London Underground



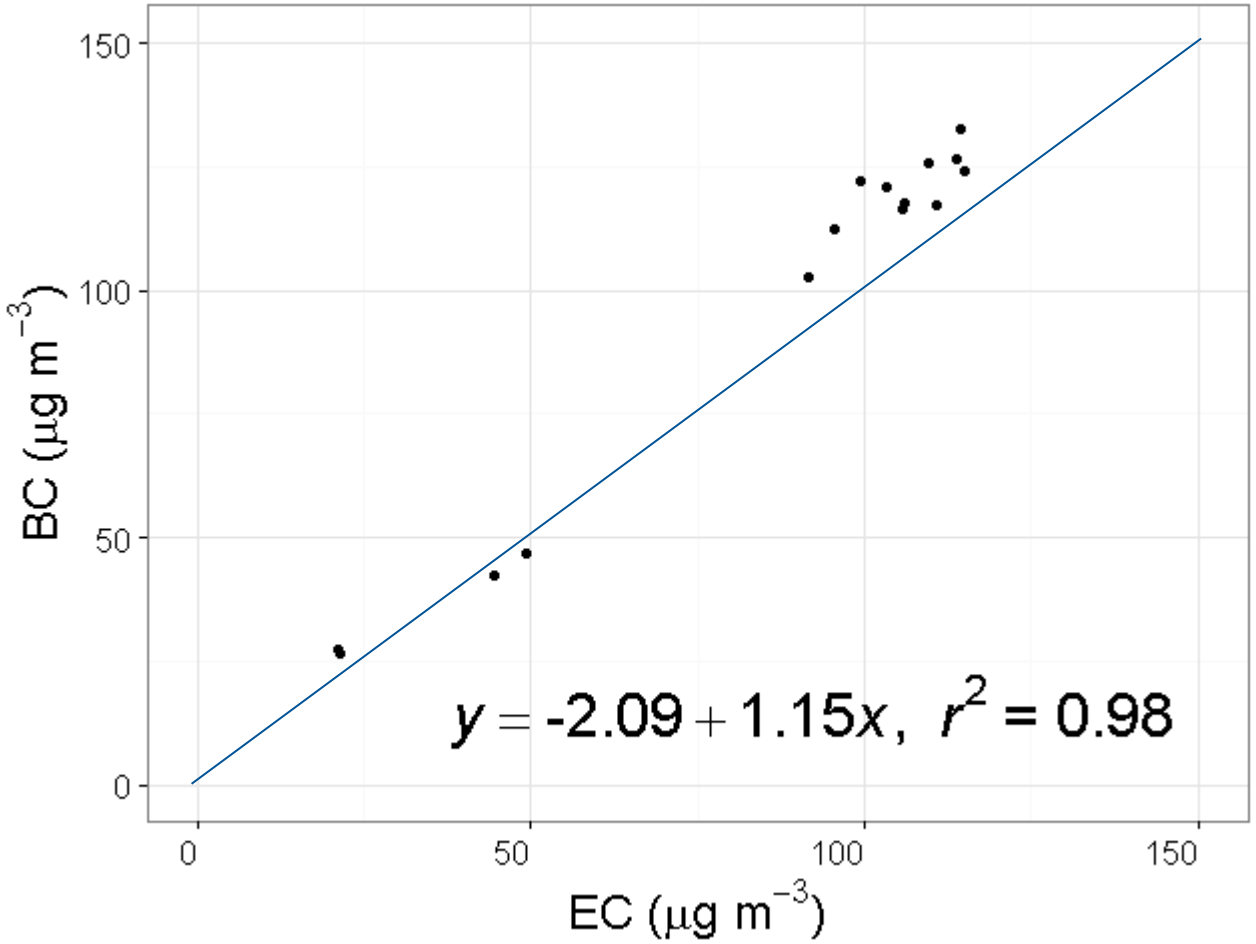
$PM_{2.5}$ inlets

High Fe concentration
BC overestimated

Large (non-combustion) graphitic particles
BC underestimated

Data from a PhD collaboration with King's College London

Relation between BC and EC in the London Underground



TSP inlets
(no size selection)

High Fe concentration
BC overestimated

Large (non-combustion) graphitic particles
BC underestimated

Data from a PhD collaboration with King's College London

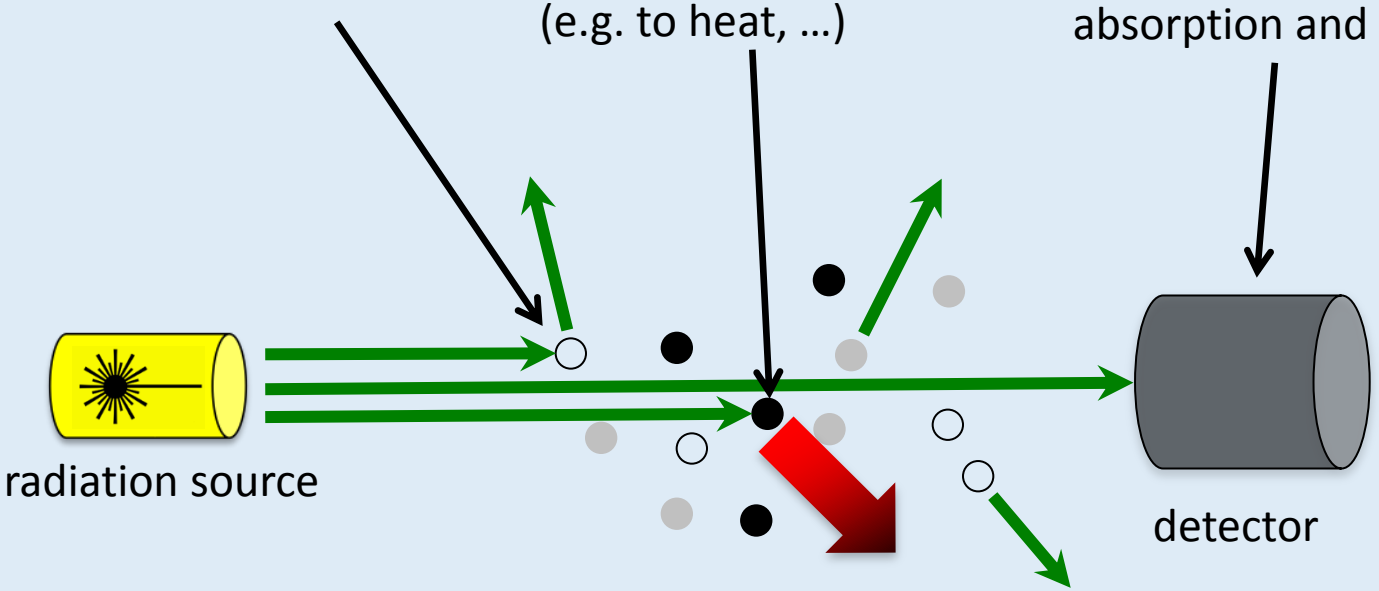
FILTER-FREE aerosol light absorption

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

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FILTER-FREE aerosol light absorption

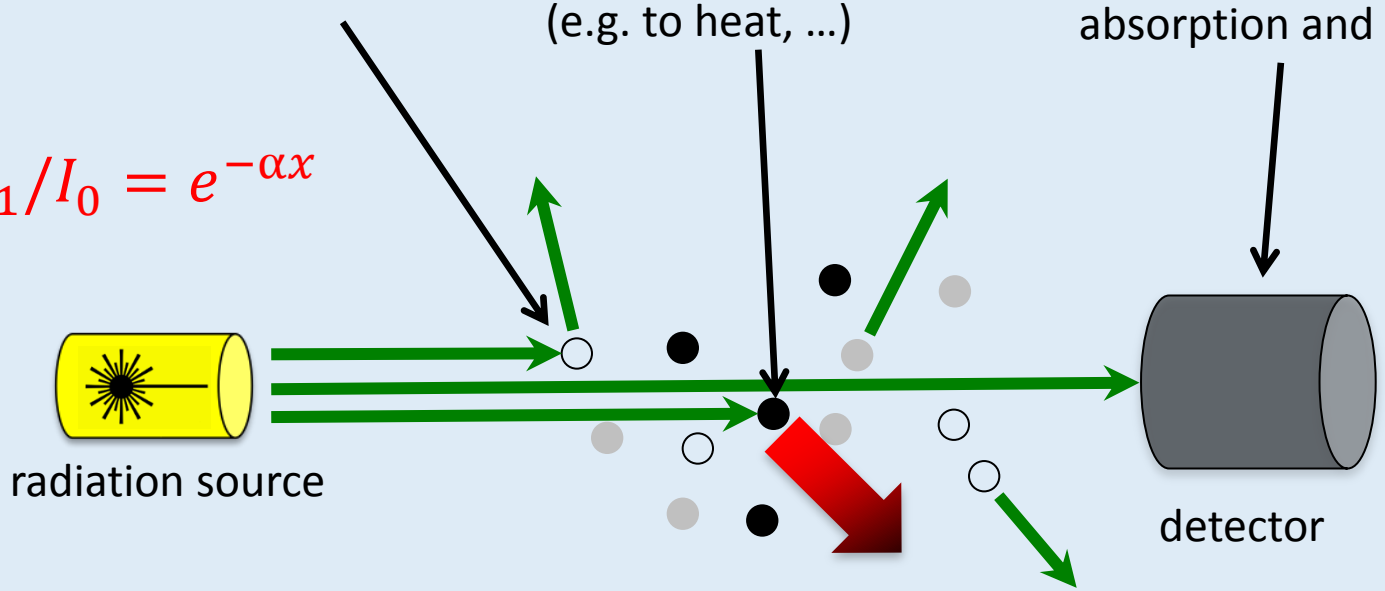
scattering + absorption = extinction

light is scattered in other directions

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

light is attenuated (extinction) due to absorption and scattering

$I_1/I_0 = e^{-\alpha x}$



Direct: photoacoustic or photothermal interferometry

Traceability to SI is possible

Indirect: extinction minus scattering

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FILTER-FREE aerosol light absorption

Uncertainty components include

Gaseous absorption (and scattering)

Absorption data for 1 ppm of various gases

(slide courtesy of Ernest Weingartner, FHNW)

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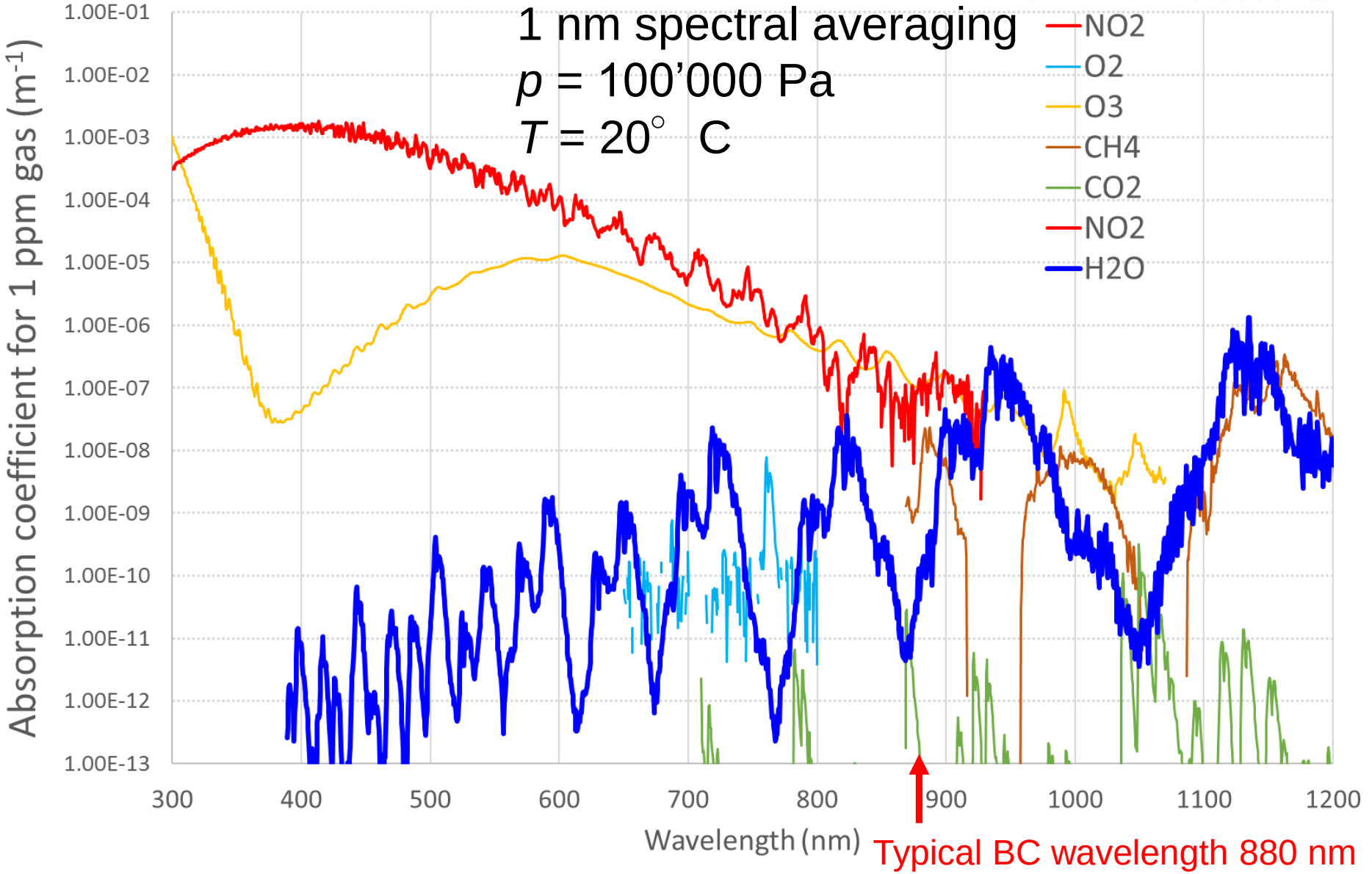
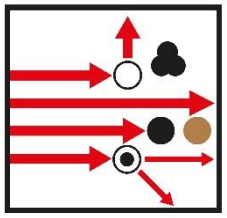


FILTER-FREE aerosol light absorption



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Uncertainty components include

<u>Gaseous absorption (and scattering)</u>

Mainly by H_2O, but also by NO_2 and O_3.

Are there benefits of moving reference instrument measurements to 770 nm (or another “water window” wavelength), so that any correction is minimised?

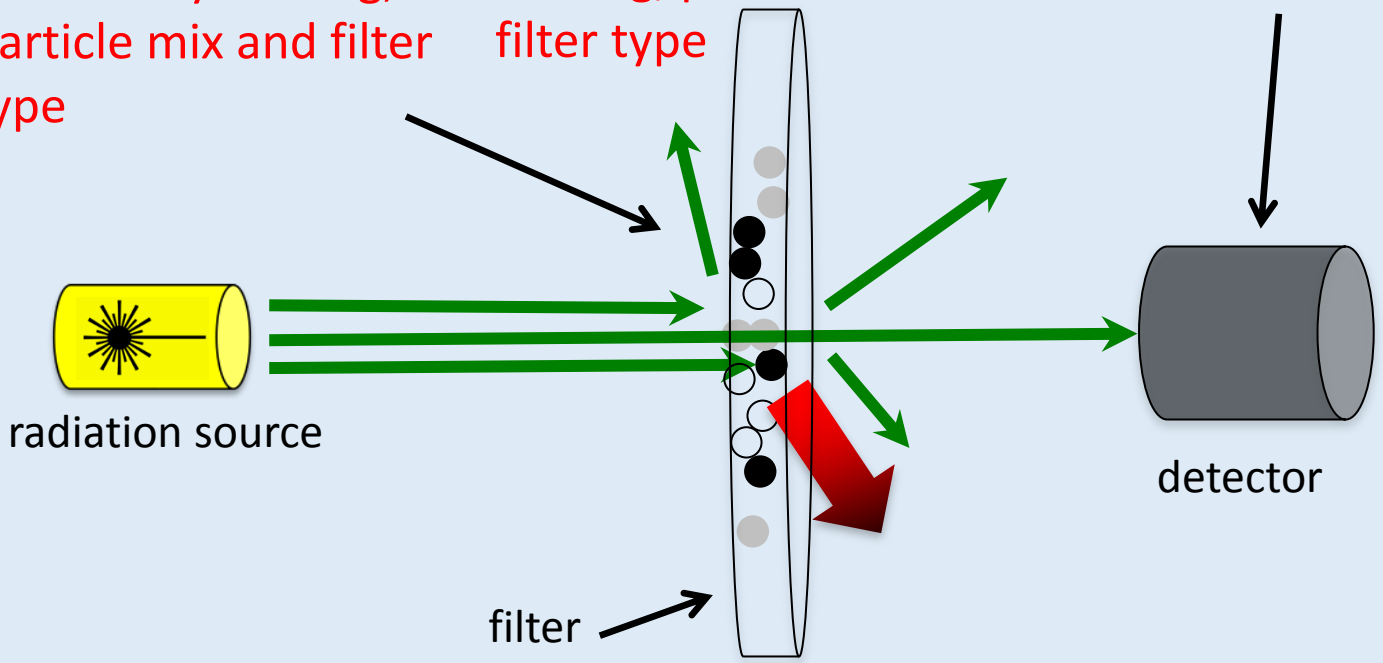
FILTER-BASED aerosol light absorption instruments

scattering + absorption = extinction

by the filter and a "sheet" of particles; affected by loading, particle mix and filter type

enhanced by internal reflections; affected by loading, particle mix and filter type

light is attenuated (extinction) due to absorption and scattering



e.g. aethalometer, MAAP, PSAP

Gaseous absorption is relatively unimportant

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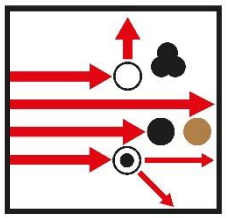
FILTER-BASED aerosol light absorption instruments



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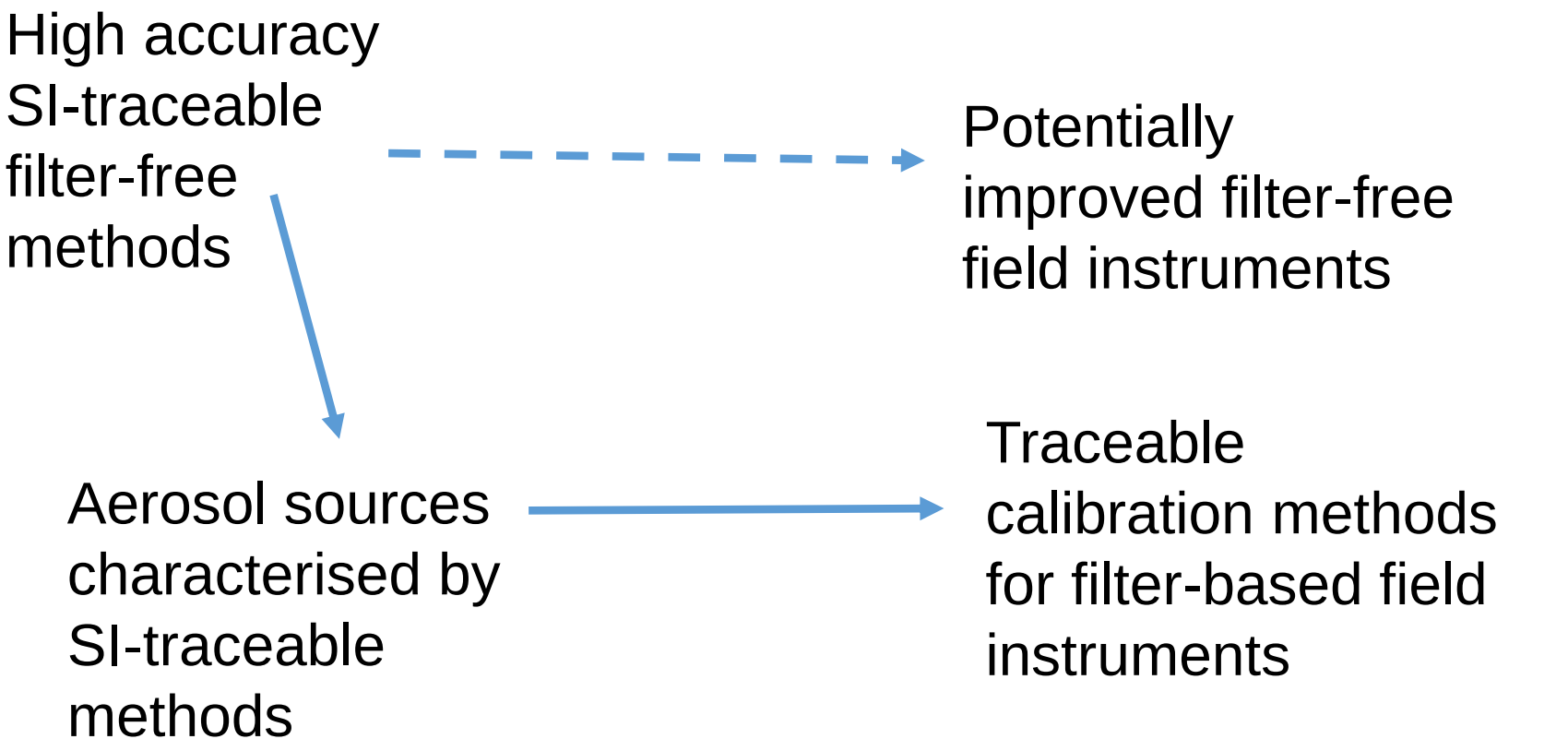
The determination of aerosol absorption is affected by different filter types,

and by different particle types for each type of filter.

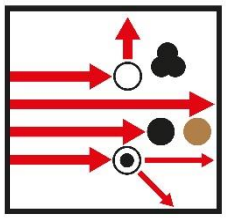
It is **not** possible to apply a general calibration factor (traceability)

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

Overall plan



FILTER-BASED aerosol light absorption instruments –



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What particles to use for calibration ?

“Pure black carbon” particles would lead to instruments giving the wrong answer with ambient air.

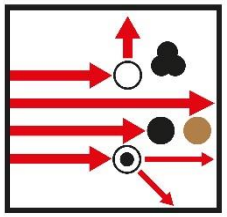
Two “extreme” particle types, representative of ambient air, are needed, to avoid accidental accuracy.

Key properties:

particle size (affecting penetration into the filter)

Single Scattering Albedo (ratio of scattering to extinction)

FILTER-BASED aerosol light absorption instruments –



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What particles to use for calibration ?

We propose two types of calibration aerosol:

(1) “fresh combustion particles”:
size 50 - 100 nm, SSA 0.4 – 0.6 at 550 nm

(2) “aged combustion particles”:
size 200 - 400 nm, SSA 0.7 – 0.9 at 550 nm.

In both cases, the absorption coefficient should cover the range from 0 to 50 Mm^{-1} at 880 nm.

Potential calibration sources: coated and uncoated soot

METAS

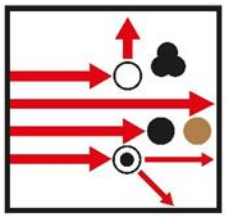

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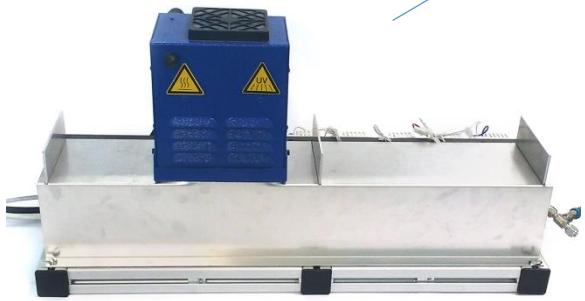
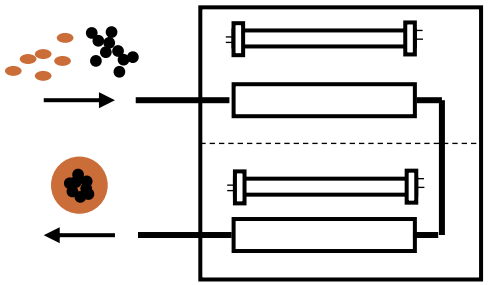
Photo-oxidation reactor (micro smog chamber)





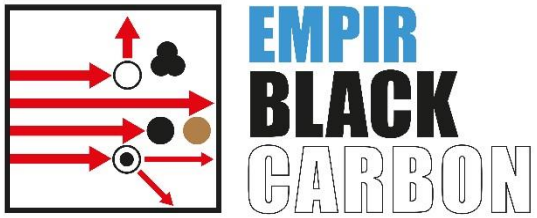
1st quartz tube (surrounded by 5 mercury lamps)-> production of O_3 by UVC light (up to 100 ppm)

2nd quartz tube (UVA, optional, for production of ·OH)

n|w University of Applied Sciences and Arts Northwestern Switzerland

Keller, A. and Burtscher, H. A continuous photo-oxidation flow reactor for a defined measurement of the SOA formation potential of wood burning emissions (2012), *J. Aerosol Science* **49**, 9-20

EMPIR Black Carbon project
1/7/17 – 30/6/20



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www.empirblackcarbon.com

Thank you

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