Proposal for Multi-Wavelength Absorption-Reference

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Soot aerosols

Workshop on measurement methods and perspectives
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Mitglied der Leibniz-Gemeinschaft

TROPOS
Leibniz Institute for Tropospheric Research

Overview

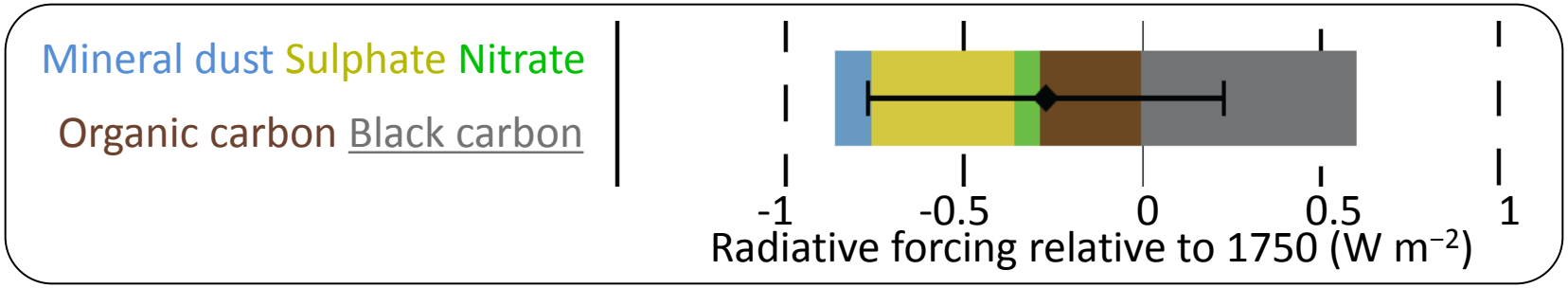
- Introduction
- Uncertainty in measurements
- Performance criteria for reference systems
- Proposal for a multi-wavelength absorption reference system
- First results
- Summary & Outlook

Introduction

- Statements on **Radiative Forcing by aerosol-radiation-interaction (RF_{ari})** in the 5th assessment report of IPCC (AR5)

- *"The assessment for RF_{ari} is **less negative** than reported in AR4 because of a **re-evaluation of aerosol absorption**. The **uncertainty estimate is wider** but more robust."*

- *"The RF_{ari} is caused by multiple aerosol types"*



Black carbon has a large impact on radiative forcing

- Multi-wavelength absorption is used for quantifying **Black carbon(soot),** Organic carbon, and Mineral dust

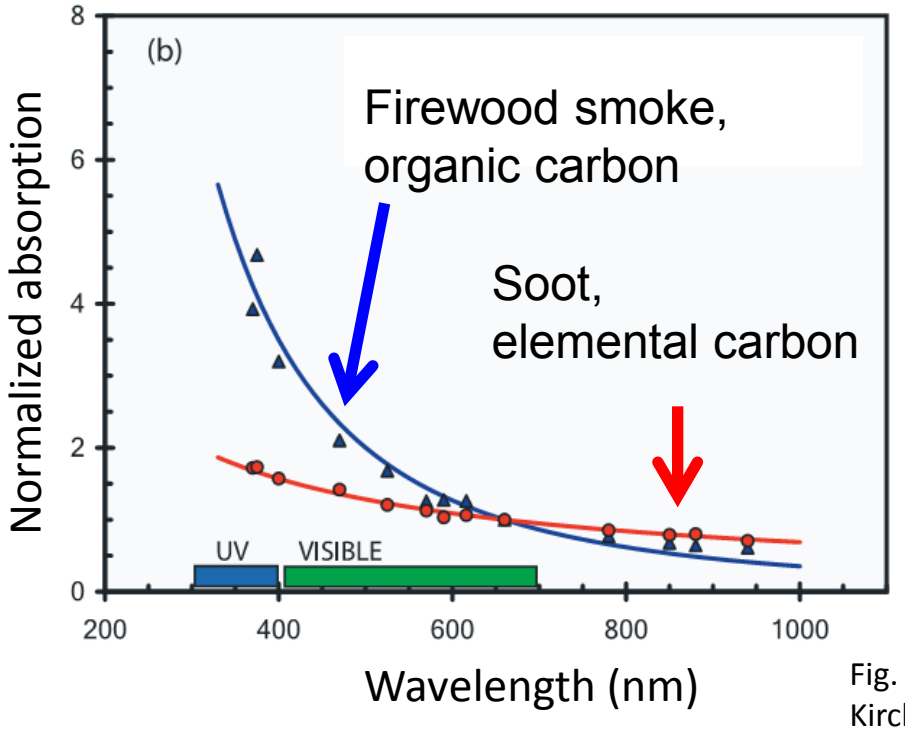


Fig. adopted from Kirchstetter et al. (2008)

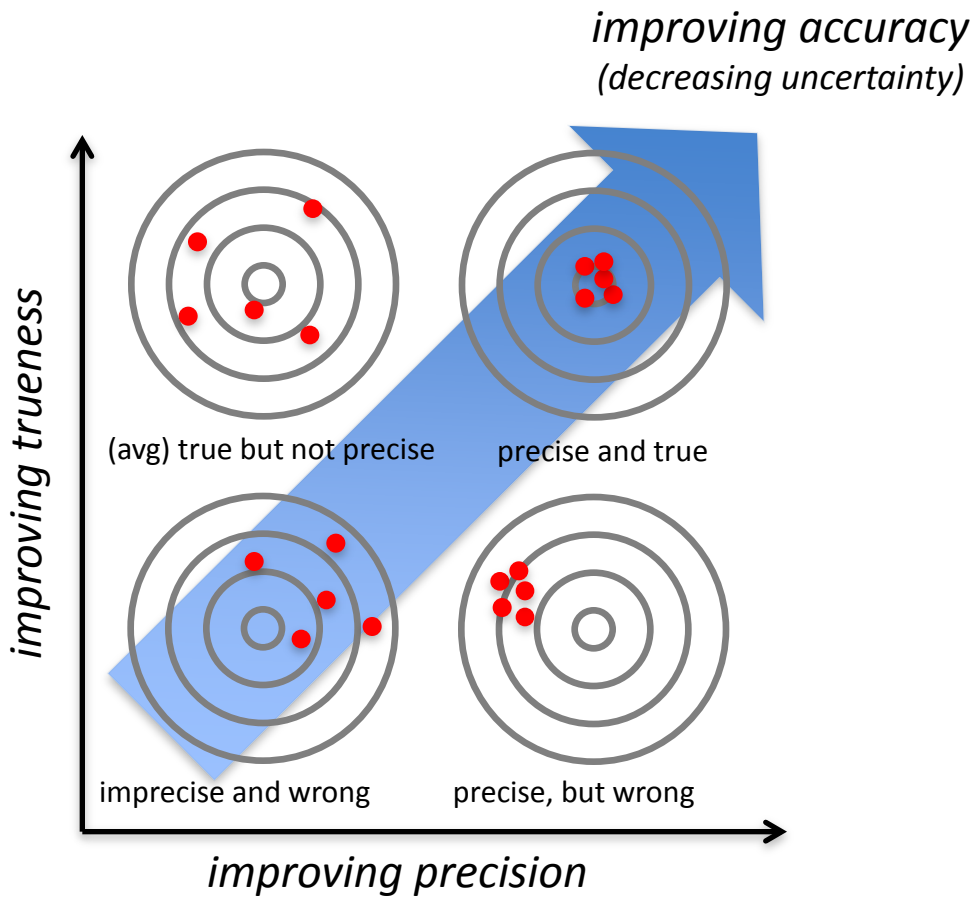
- Instrument intercomparison workshops have shown **large differences between instruments** measuring (multi-wavelength) absorption

Need for a **Reference System** for calibration and quality assurance

Uncertainty in measurements

- Inconsistent use of terms led to the “**g**uide to the expression of **u**ncertainty in **m**easurements” (GUM), published by ISO / 1993, 1995
- For comparison of measurement techniques the terminology must be clarified

The correct use of terms visualized by *target analogy*



ISO 5725-1

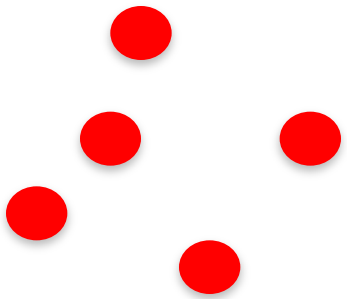
Trueness: The closeness of agreement between the average value obtained from a large series of test results and an **accepted reference value.**

Precision: The closeness of agreement between independent test results obtained under stipulated conditions.

Accuracy: The closeness of agreement between a test result and the **accepted reference value.**

Note: The accepted reference often is considered to be the 'true value'

Situation without having an accepted reference



true?

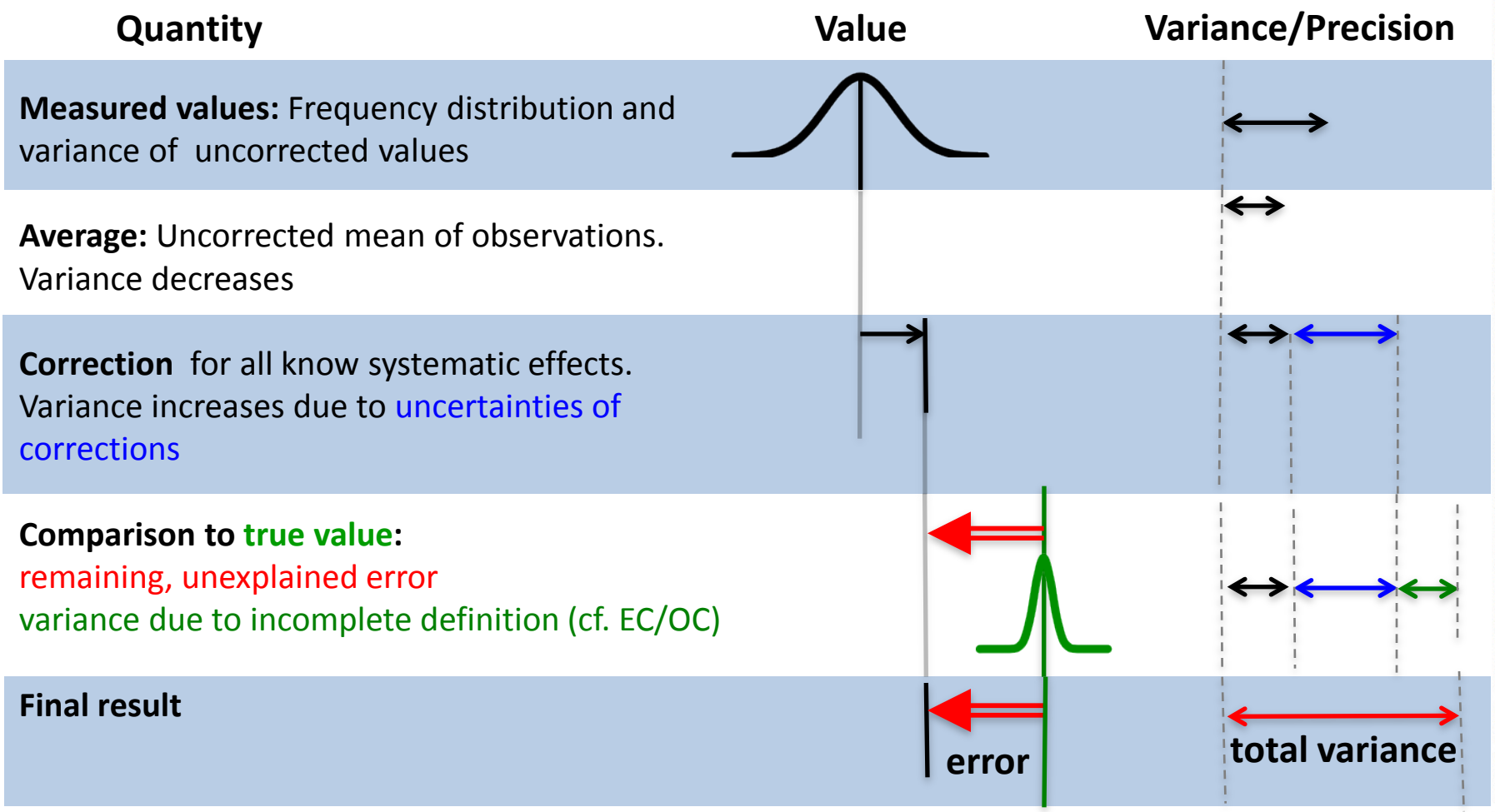
precise?

wrong?

imprecise?

According to GUM it is impossible to make any statement on uncertainties without having an accepted reference!

Performance criteria for reference measurements



Minimization of systematic errors is the major criteria for reference systems!

Note on Calibration and Reference Materials

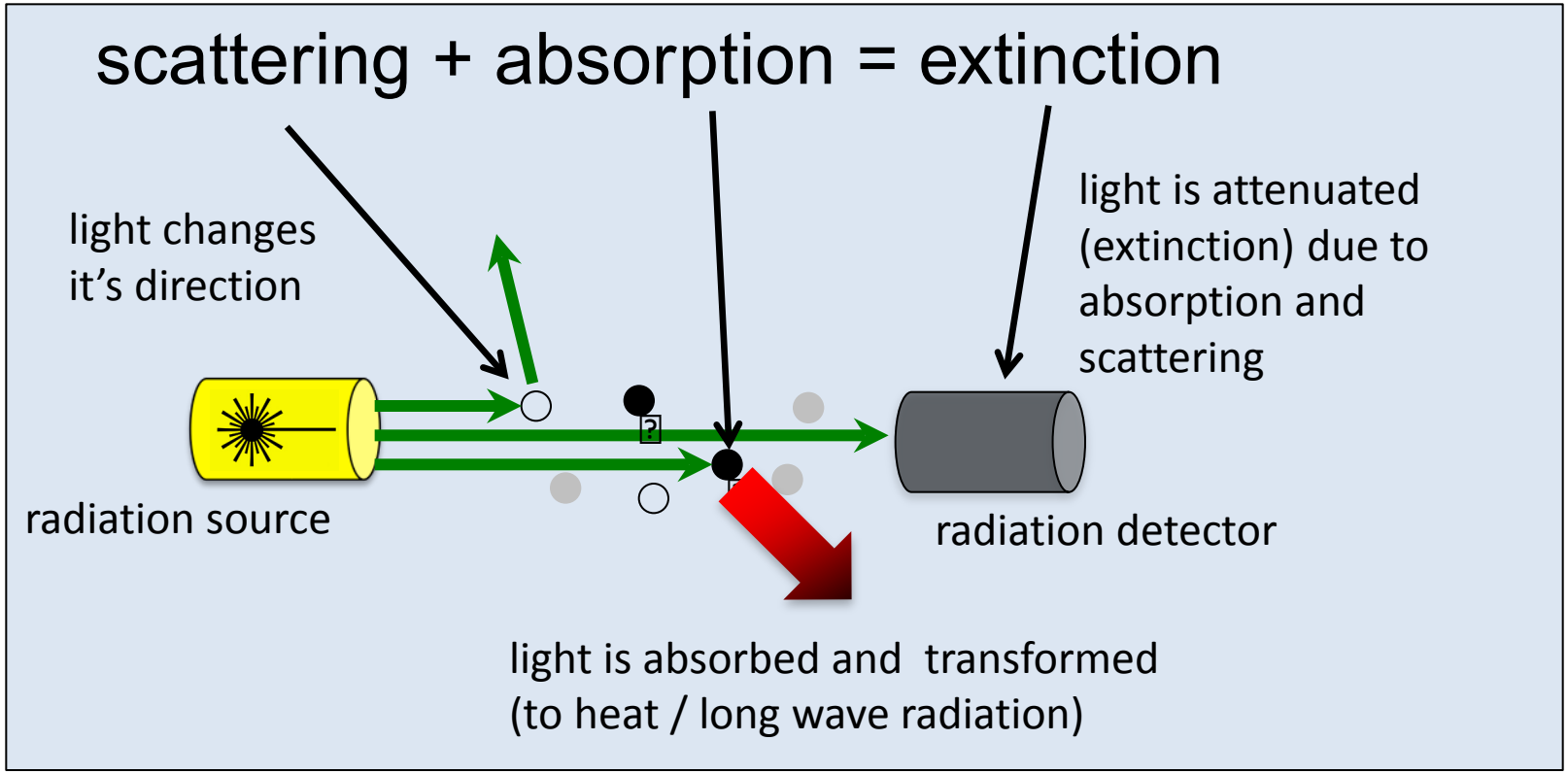
- **Certified Reference Materials** are ‘controls’ or standards used to check the quality and **metrological traceability** of analytical measurement methods, or for the **calibration** of instruments.

- For particle absorption there is
  no accepted reference material

- **A reference system must be based on fundamental principles,** because of this lack of having reference materials.

Proposal for an absorption reference system

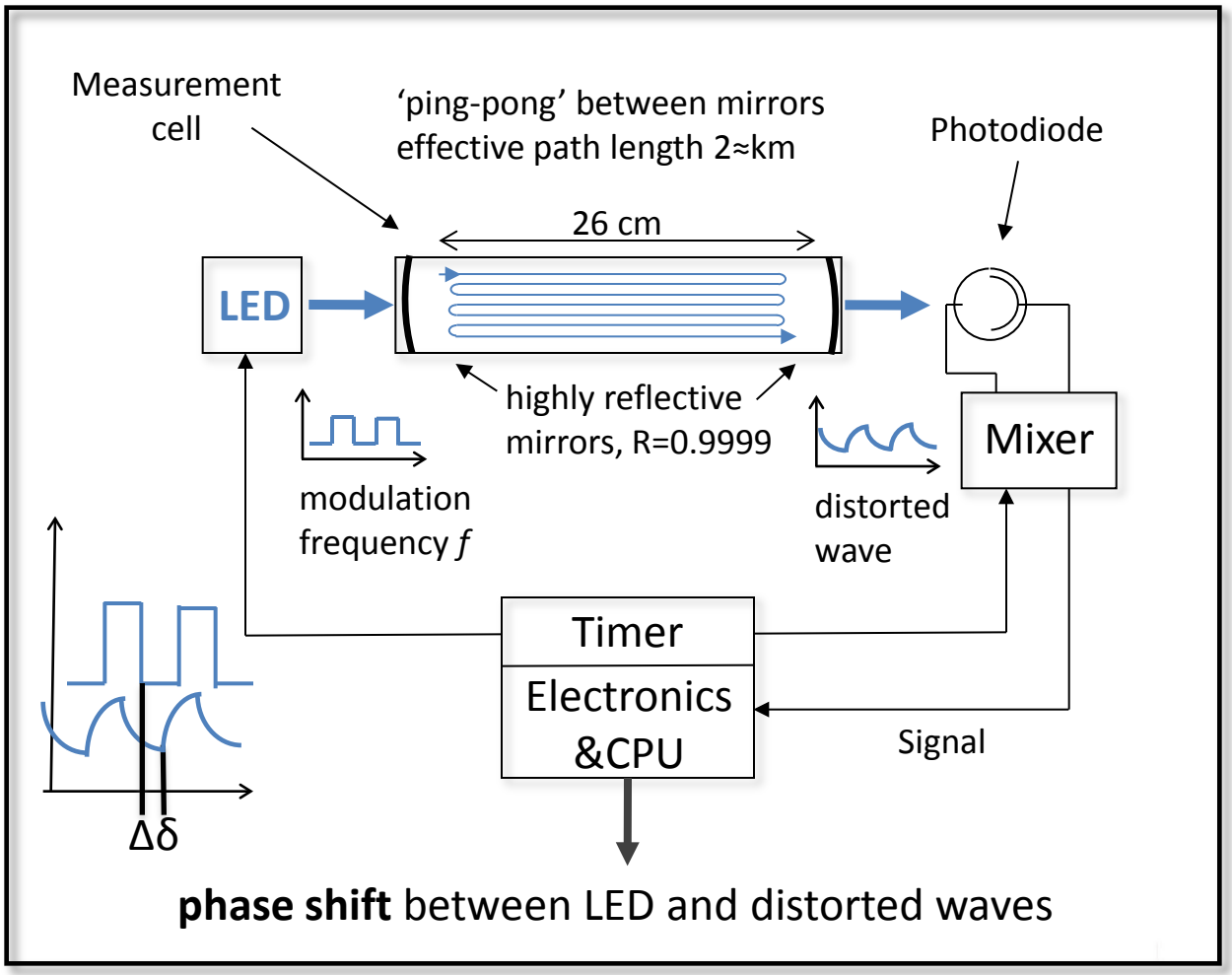
The absorption reference methods is based on fundamental principles of optics



Absorption is determined by measuring scattering and extinction

absorption = extinction-scattering

Extinction measured with Cavity Attenuated Phase Shift (CAPS)



Schematic adopted from Kebabian et al. (2007)

Extinction is a function of the phase-shifts

$$\sigma_{ext} = \left[\cot\delta - \cot\delta_0\right] \cdot \left(2\pi\, f/c\right)$$

- δ phase shift — measurement with particles
- δ_0 baseline phase shift — measurement without particles
- f modulation frequency — system constant
- c speed of light — natural constant
- L cell length — system constant

Measurement with CAPS provide an absolute value, requiring no calibration!

Nephelometer measure the light scattered in **all directions**

ideal nephelometer
exponent = 1.0

Intensity scattering function
particle property

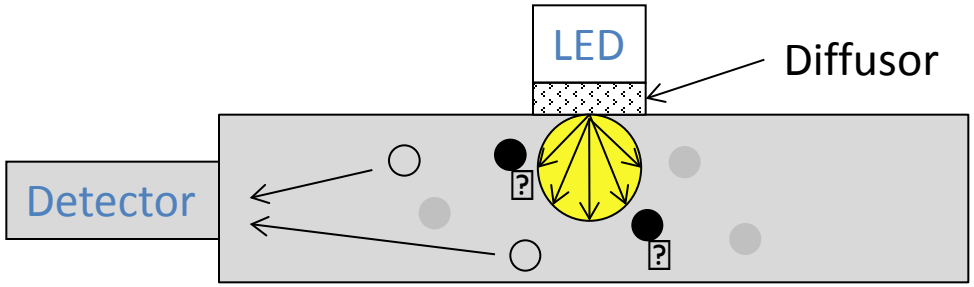
ideal nephelometer
integration from 0 to 360°

$$\sigma_{sca} = c \cdot \int_{0}^{\leq 45^\circ} \int_{10^\circ}^{170^\circ} \sin(\theta)^{1.1} I(\theta)\, d\theta\, d\varphi$$

actual nephelometer
compensation by calibration constant c

ideal nephelometer
integration from 0 to 180°

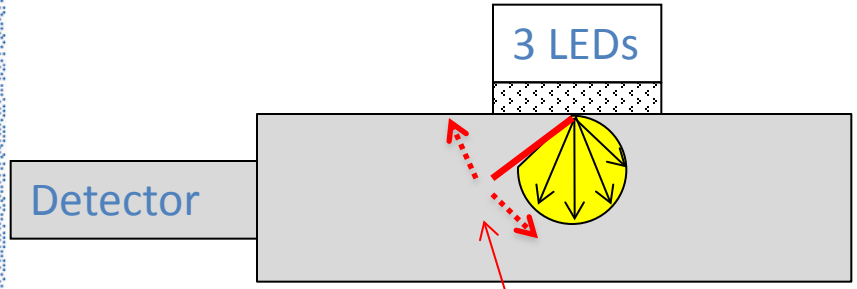
correction needed
to account for imperfect θ-integration



Measurement cell is illuminated with diffuse light

Nephelometers need to be **calibrated and corrected**

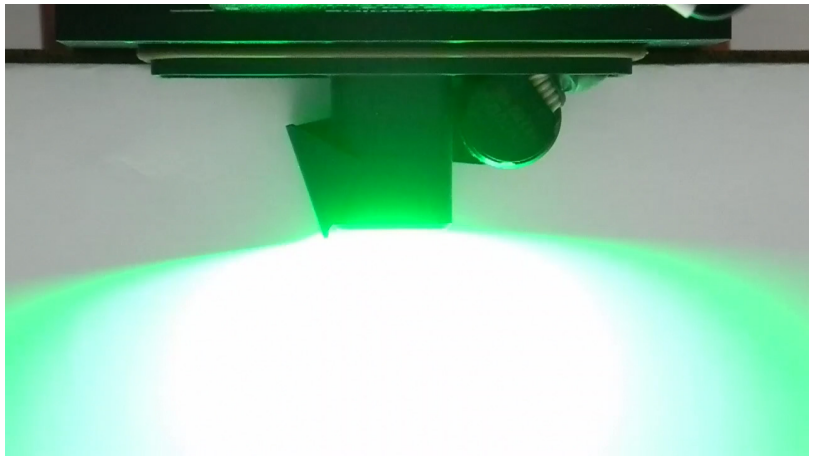
The multi-wavelength polar nephelometer Aurora4000

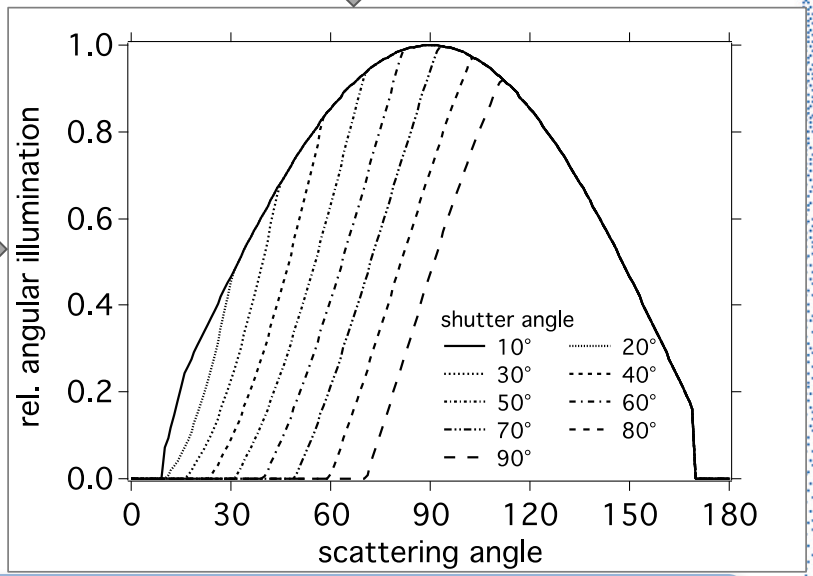


$$\sigma_{sca} = c \cdot \int_{0}^{\leq 45^\circ} \int_{10^\circ}^{170^\circ} \sin^{\approx 1.1}(\theta)\, I(\theta)\, d\theta\, d\varphi$$

variable shutter:
starting angle of integration
varies between 10 and 90°

instrumental angular sensitivity function

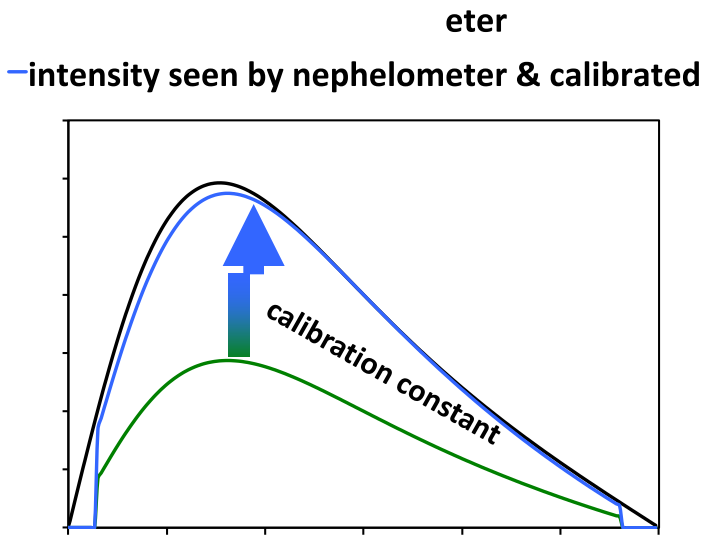


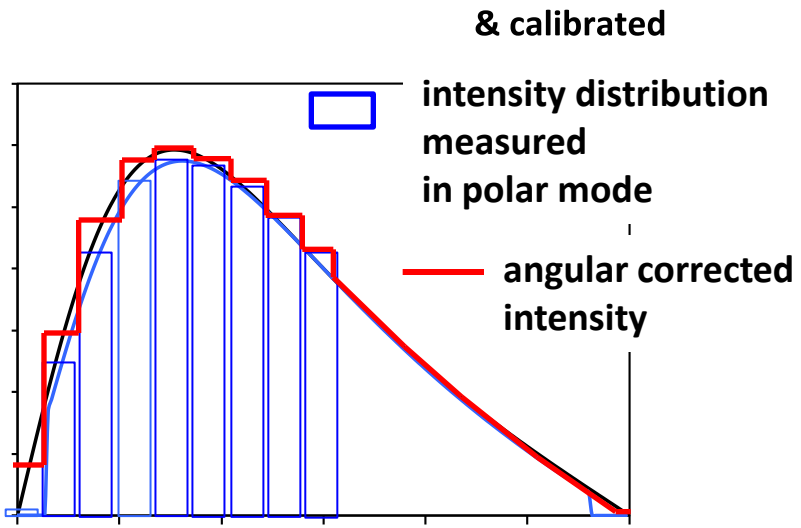


Polar-mode allows an angular scanning of the scattered intensity I(θ)

Calibration and correction of nephelometers

The value of the scattering coefficient is represented by the area under the plotted angular intensity distribution



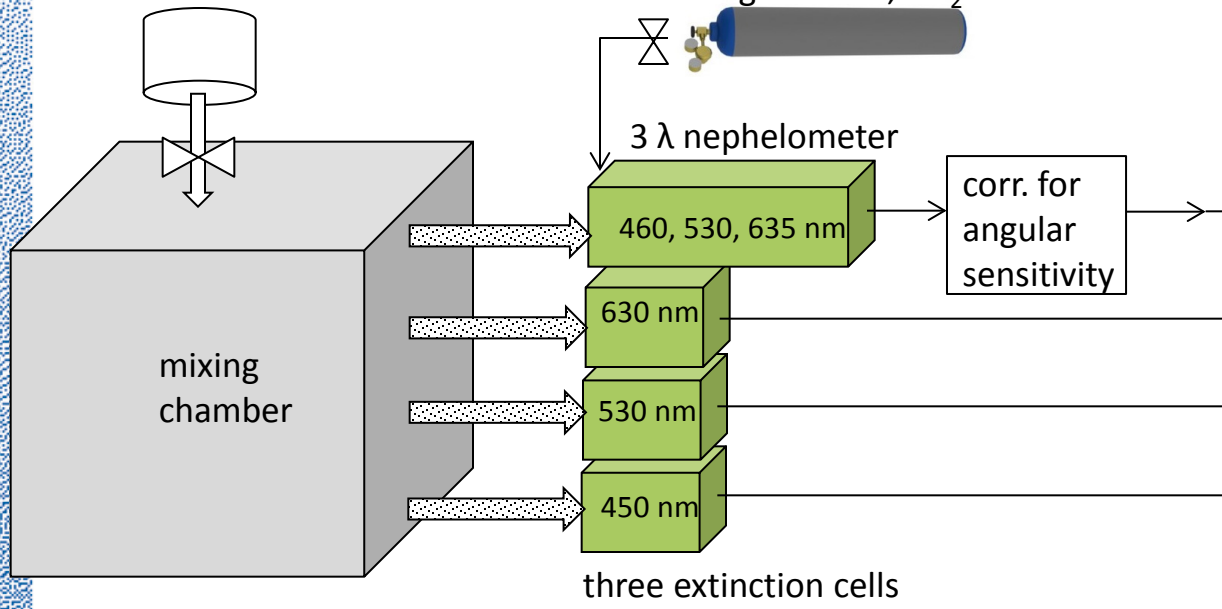


- **Calibration with gases of know scattering coefficients (e.g. CO_2)**
- **Intensity from polar measurements are corrected using the know angular sensitivity function**

Setup for measurements of extinction and scattering

Aerosol generators for

- ❑ non absorbing particles
- ❑ absorbing particle



Calibration and Characterization

1. Calibration
   - gas calibration
   - white particle check
2. Noise
   - particle free (filtered) air
3. Repeatability
   - repeat steps 1-3
4. Derive precision and accuracy

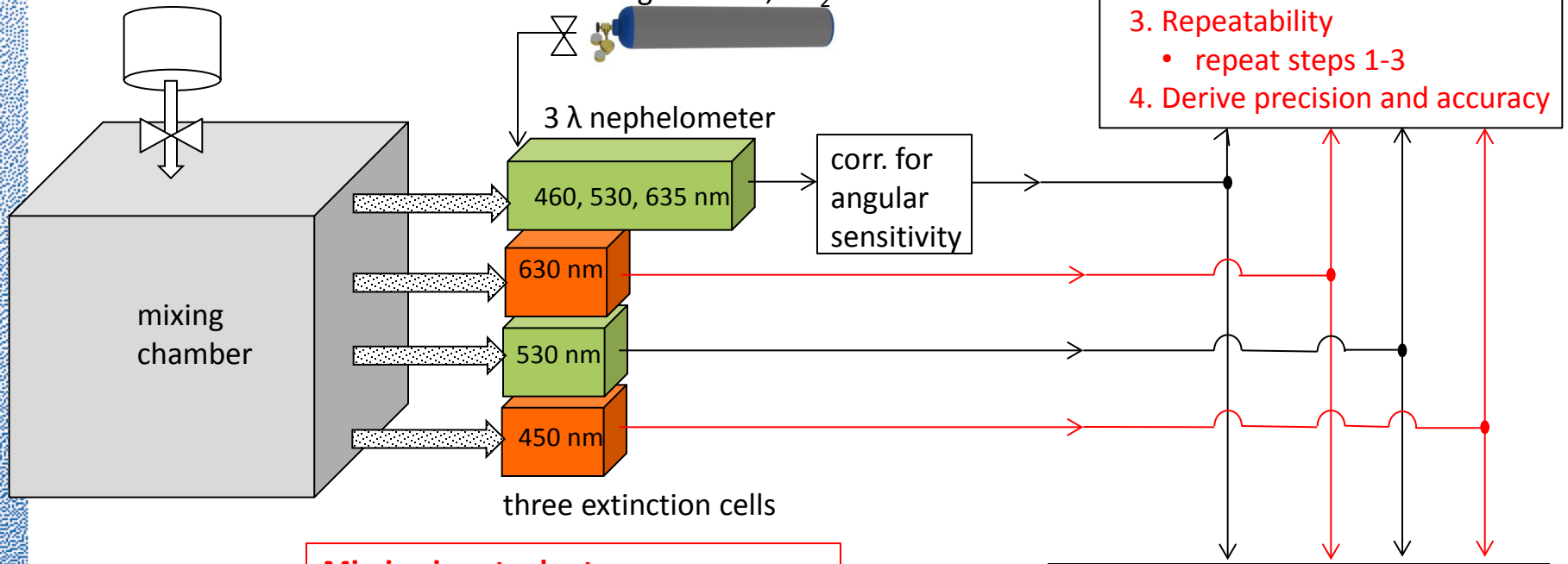
1. Generate ‘test aerosol’
2. Derive reference absorption
3. Compare to instrument under test

“Use as reference methods”

Setup for measurements of extinction and scattering

Aerosol generators for

- ❑ non absorbing particles
- ❑ absorbing particle



Missing in actual setup:

- ❑ Two extinction cells are not yet installed.
- ❑ Tests for Repeatability precision and accuracy not yet done

Calibration and Characterization

1. Calibration
   - gas calibration
   - white particle calibration
2. Noise
   - particle free (filtered) air
3. Repeatability
   - repeat steps 1-3
4. Derive precision and accuracy

1. Generate ‘test aerosol’
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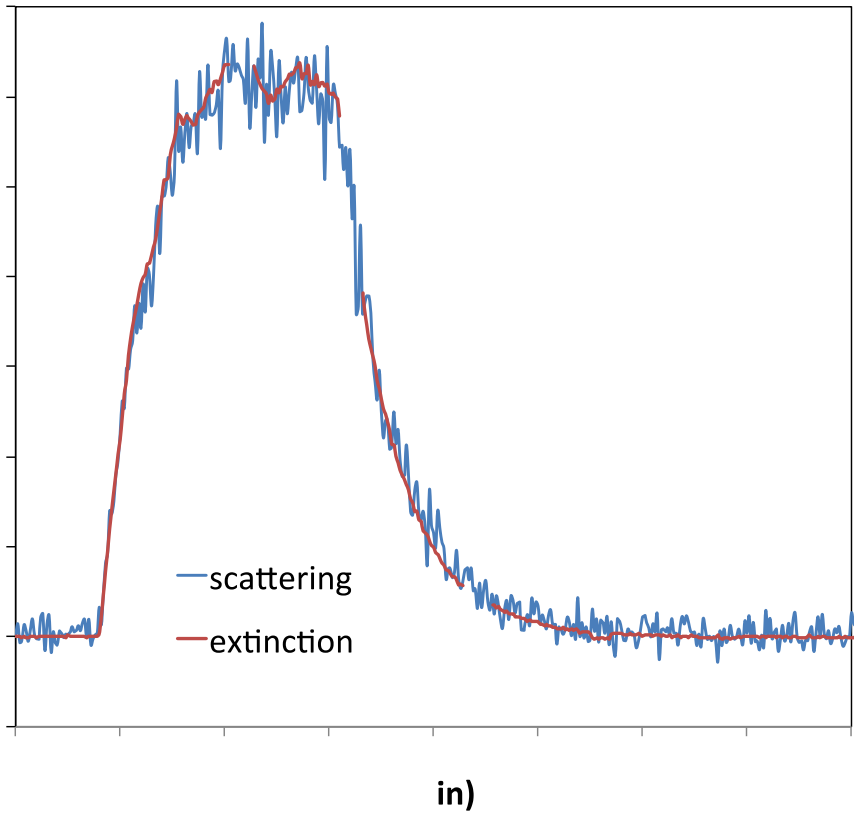
“Use as reference methods”

First results for single wavelength reference

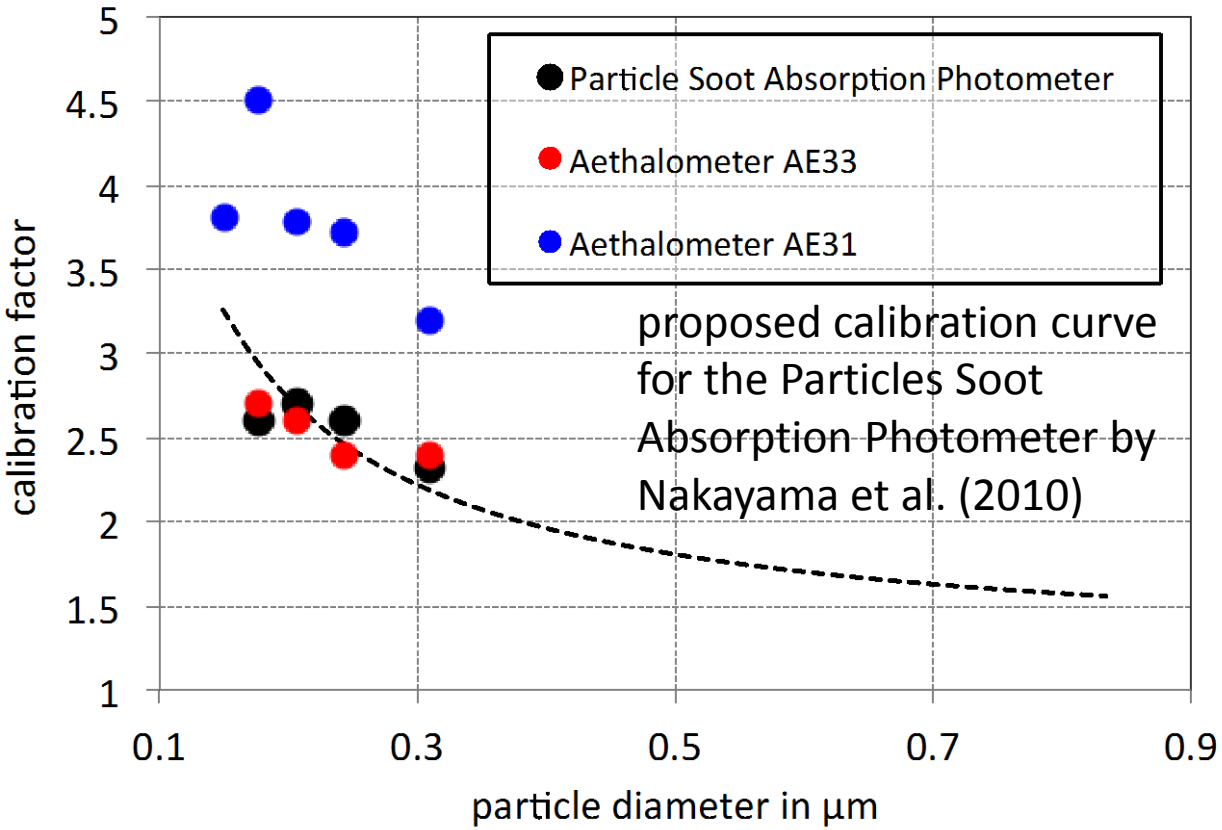
Performance test of extinction and scattering measurements for non-absorbing particles (extinction = scattering)



Instruments agree with in 2%.
The proposed uncertainty in scattering is 3%.

Results from the ACTRIS-2013 workshop

- Calibration of Filter Based Absorption Photometers of types Aethalometer and PSAP
- Reference absorption = Extinction - Scattering



Calibration factors of Filter based absorption photometers depends on the particle size.

Summary and Outlook

- The proposed setup does not require a *reference material for absorption*
- Absorption is traceable back to SI-units
- The proposed method for multi-wavelength reference absorption was tested successfully for a single wavelength
- Setup for three wavelength will be completed in Oct. 2014
- Performance and repeatability will be tested. Standard operating procedures will be developed.
- Series of experiments for calibrating ‘filter based’ multi-wavelength absorption photometer are planned in 2015.