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Photothermal interferometry for the *in situ* measurement of aerosol light absorption

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Introduction & motivation

- Aerosol particles in the atmosphere affect health, visibility and climate.
- Soot or black carbon (BC) particles are highly efficient light absorbers that are emitted by combustion processes.
- BC mass loadings are commonly quantified by measuring the light absorption of deposited particles on fibrous filters and applying large empirical correction factors. The most widely used instrument is the aethalometer, produced by Magee Scientific.
- We are developing a robust field-deployable instrument using photothermal interferometry (PTI), which measures aerosol absorption in situ. With this method calibrated absorption measurements can be obtained, with better accuracy and less artifacts.

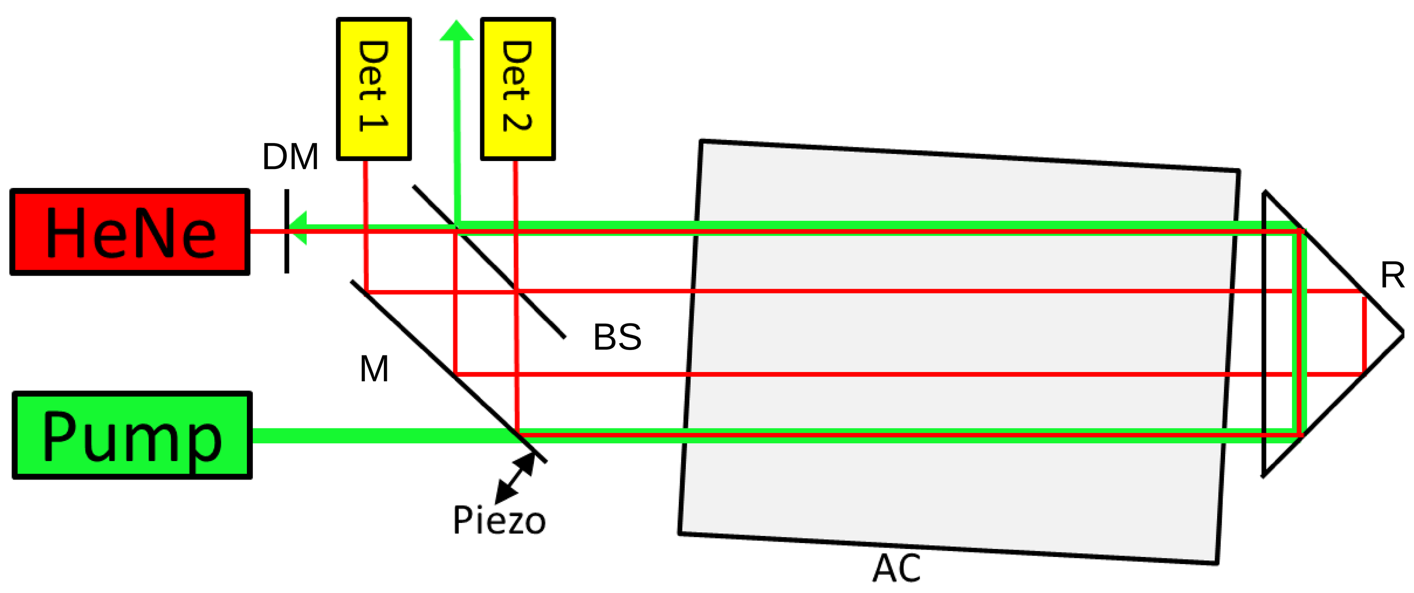

Figure 1. Example folded Jamin configuration photothermal interferometry setup. Light absorption is measured via the refractive index change in the sample gas induced by a pump light source. In this configuration the pump beam is directed along the probe beam path to maximize overlap of the two beams. BS=beam splitter, M=mirror, AC=aerosol chamber, DM=dielectric mirror and R=retroreflector.

Advantages and challenges

- Interferometry is an incredibly sensitive technique, with a theoretical (shot noise) lower detection limit of the phase change $\Delta\Phi$ of 1×10^{-8} rad.
- The particles are measured *in situ* and therefore the measurements are free from support effects and the related corrections.
- The interferometer response can be internally calibrated using a gas mixture with known light absorption.
- PTI can therefore be used to calibrate other BC measurement devices.
- PTI measurements are very sensitive to noise and require extensive mitigation strategies.
- Few suitable calibration gases are available.
- It is difficult to couple pump (laser) energy into the experiment without also introducing more noise.

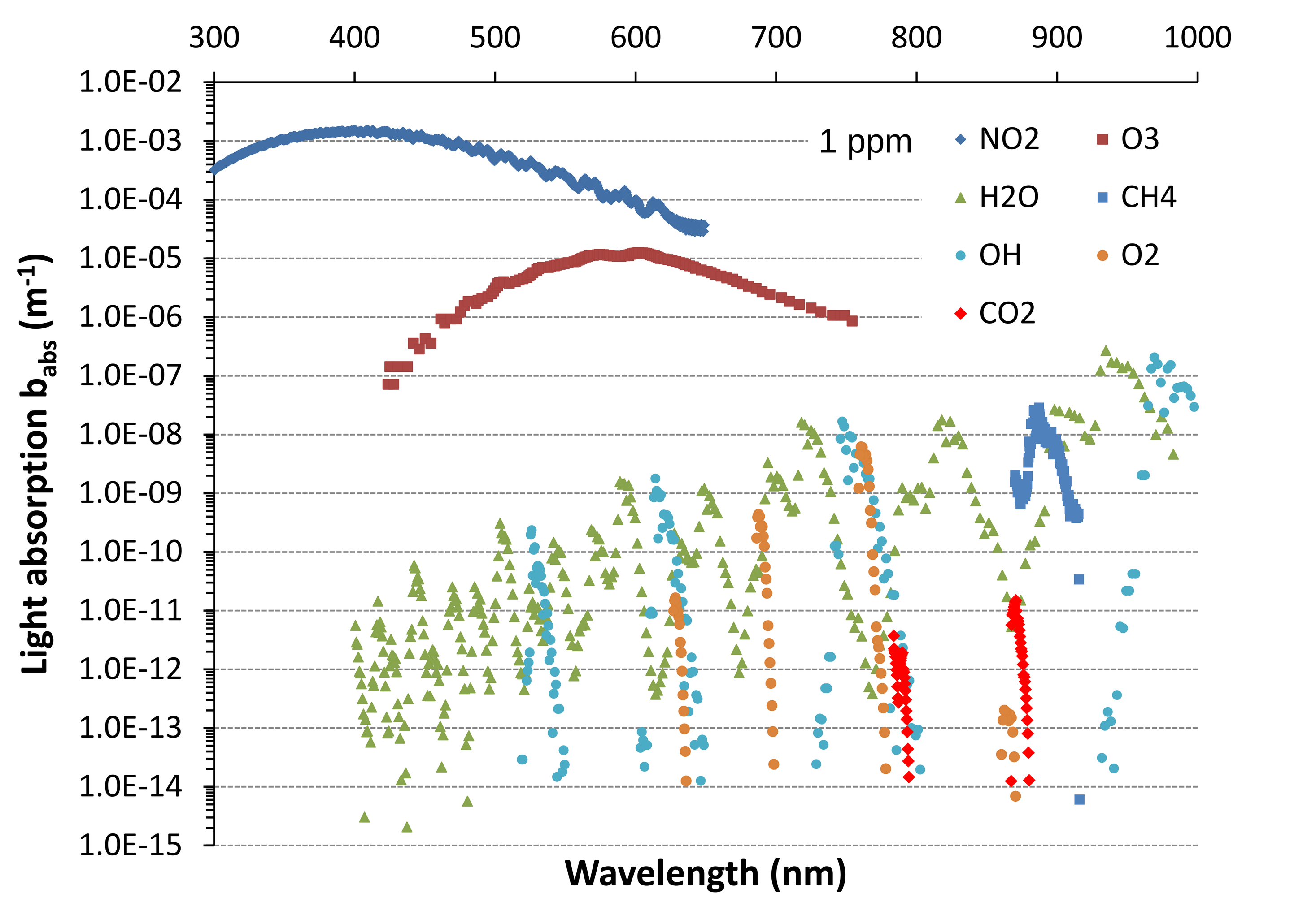

Figure 3. Averaged absorption data for a range of potential calibration gases. Absorption is calculated for 1 ppm of gas.

Photothermal interferometry

- In interferometry two waves are superimposed and the resulting interference pattern allows the measurement of the differences in the two beam paths.
- Photothermal interferometry involves the measurement of heat (-thermal) following the absorption of light (photo-).
- One arm of the interferometer is filled with an aerosol sample and irradiated with light pulses from a pump laser.
- Upon absorption of the light the particles heat up and subsequently transfer this heat to the surrounding gas, changing the refractive index.
- It is this change of refractive index that is measured with the interferometer (i.e. the sample and reference beam interfere and the phase shift of the sample beam is measured).

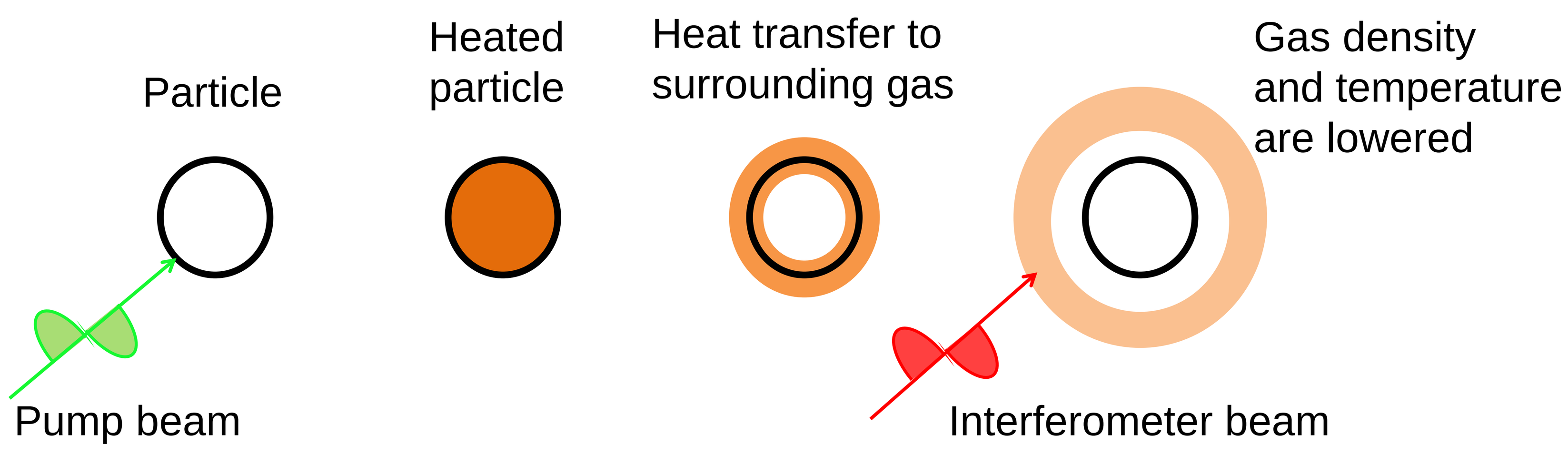

Figure 2. Principle of photothermal interferometry. Particles absorb light and transfer heat to the surrounding gas, which is detected by interferometry.

Goals

- The relation between phase change and absorption is:

$$\Delta\varphi = \frac{2\pi(n-1)}{\lambda \cdot T \cdot \rho \cdot c_p} \cdot \frac{l \cdot P}{A} \cdot b_{abs}\, \Delta t$$

- The $\Delta\Phi$ theoretical limit is about 10^{-8} rad, so we aim practically to reach 5×10^{-7} rad.
- Primary and secondary internal calibration for a stand alone system that can be used to calibrate other instruments.

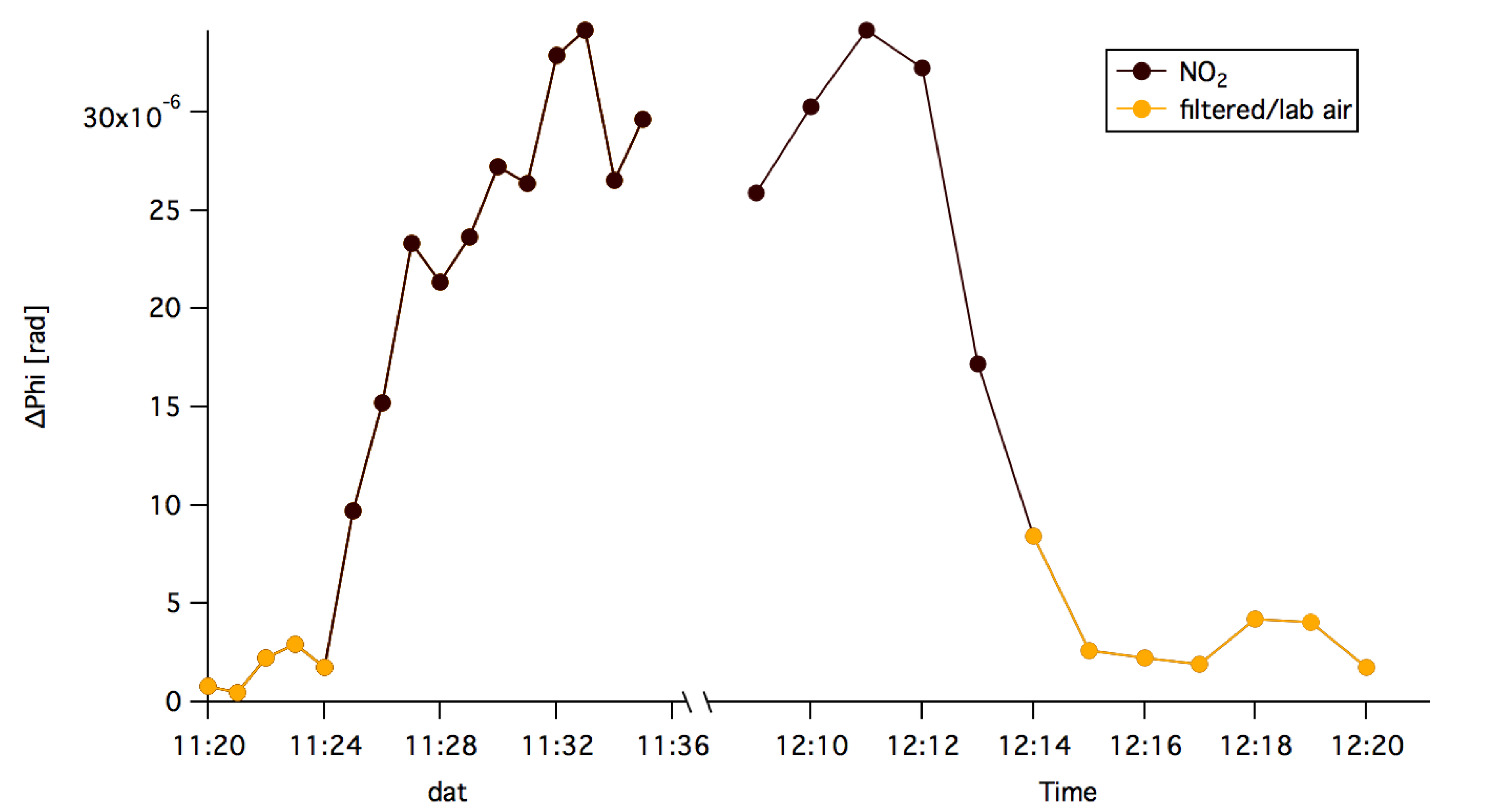

Figure 4. Typical measurement of 1 ppm NO_2 (absorption coefficient 345 Mm^{-1} at 25° C, 1000 mbar and 1 ppm) with the photothermal interferometer prototype.

Conclusions

- A photothermal interferometer built from OEM components has been tested.
- Continuing assessment of several interferometer configurations.
- Current $\Delta\Phi$ noise is 1.1×10^{-6} rad (10 s average).
- Limit of detection (LOD) is about 35 Mm^{-1} (Fig. 4). The goal, in order to be competitive, is to achieve LOD 1 Mm^{-1}.

The interferometer absorption measurement allows **comparison with and validation of aethalometer-type instruments. This results in a better accuracy** of aerosol absorption measurements for the community.