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A new instrument prototype for aerosol light absorption measurements

T. Isolabella(1), M. Brunoldi(1), P. Prati(1), D. Massabò(1),
V. Bernardoni(2), V. Vernocchi(3) and F. Parodi(3)

(1) *Dipartimento di Fisica, Università di Genova, INFN, Sezione di Genova - Genova, Italy*
(2) *Dipartimento di Fisica, Università di Milano, INFN, Sezione di Milano - Milano, Italy*
(3) *INFN, Sezione di Genova - Genova, Italy*

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Summary. — The prototype for an innovative instrument has been built and validated at the Department of Physics, University of Genoa. The purpose of the instrument is to measure the light absorption properties of atmospheric aerosol sampled on a filtering support, over a wide spectral range with a high wavelength resolution. The preliminary tests of the prototype have been carried out on aerosol produced in an atmospheric simulation chamber. The performance of the prototype has been validated against the previously assessed Multi Wavelength Absorbance Analyzer (MWAA), with a scatter plot slope of $A = 0.95 \pm 0.03$, and a coefficient of determination of $R^2 = 0.97$. Preliminary results show the data analysis possibilities that an instrument with a high spectral resolution can offer.

1. – Introduction

Particulate Matter (PM) is present in the atmosphere in many forms, which differ from one another in size, shape, chemical composition and origin [1]. It has effects on climate, human and animal health, and on visibility [2].

It is established that different aerosol components have different light interaction properties. Some species, such as carbonaceous aerosol and mineral dust, absorb radiation in different bands [3, 4]. While it is known that some PM components have an effect on the energy balance of the Earth through light absorption and scattering, the uncertainty on this effect and its wavelength dependence are still largely unknown [5].

To address this issue, the prototype of a new instrument for measurements of light absorption on PM samples has been built at the Department of Physics, University of Genoa. The prototype, named BLAnCA (Broadband Light Analyzer of Complex Aerosol), can retrieve the absorbance of a PM sample gathered on a filter support over a wide spectral band with a high wavelength resolution.

2. – Prototype description

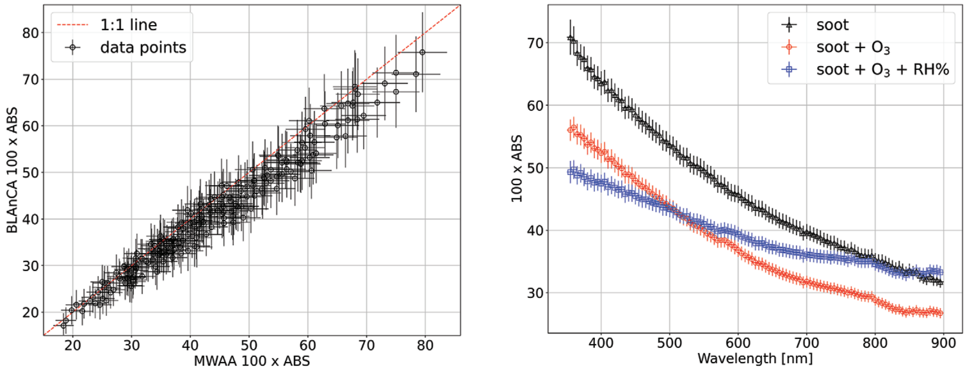
Light emitted from a Spectrolight Mighty Light Plus lamp, with a roughly black-body spectrum peaked around 700 nm, is carried through a light guide and collimated on a PM loaded filter mounted on an optical post. Transmitted and forward-scattered radiation is collected by a fibre-optic cable placed in the forward hemisphere at 0° with respect to the beamline. Backscattered radiation is collected by two fibre-optic cables placed at 125° and 165°, following the approach detailed in [6]. Light is transported to a high-resolution spectrometer (Avantes HS2049XL-EVO) connected to a PC. Spectral data is then processed following a data analysis scheme, based on [6], to extrapolate the absorbance of the sample in a wavelength range between 350 nm and 900 nm, with a resolution of 5 nm.

3. – Sample preparation

In order to test BLAnCA operation, we produced filters loaded with synthetic soot, used as proxy for pure Black Carbon (BC). A Mini Inverted Soot Generator (MISG, Argonaut Scientific Corp.) was used to generate soot through controlled propane combustion [7]. Soot was injected into ChAMBRe [8], the atmospheric simulation chamber located at the Genoa division of the National Institute for Nuclear Physics (INFN). We injected soot aggregates with an aerodynamic diameter $d < 1\,\mu$m (PM1) using a cyclone inlet. Three different sets of samples were produced by exposing soot particles to different atmospheric conditions inside the chamber. The first set was sampled with clean-air conditions (*i.e.*, no soot exposition and 30% relative humidity (RH)). In the second set, soot was exposed to O_3 (≈1300 ppb). Finally, for the third set, O_3 (≈1300 ppb) was generated, and relative humidity increased to about 90% inside the ChAMBRe volume. The soot concentration at the start of the sampling was about $1000\,\mu$ g m^{-3}. These concentrations were obtained in real-time with three Photoacoustic Extinctiometers, connected to the simulation chamber. We sampled each set on fifteen 47 mm quartz fibre filters using a low-volume sampler working at 10 L min^{-1}.

4. – Prototype validation

The data collected with BLAnCA has been validated against measurements obtained with the Multi-Wavelength Absorbance Analyzer (MWAA) [9]. The two instruments share many similarities in their working principle and data analysis model, therefore BLAnCA can be compared to the MWAA without any limiting assumptions. In order to directly compare the absorbance (ABS) values measured by the two instruments, we restricted the operation of BLAnCA to the five wavelengths at which the MWAA operates, which are 375, 407, 532, 635 and 850 nm. The absorbance of each filter in the entire set of 45 samples was measured with both instruments. The result of the comparison is displayed in fig. 1(a), with a red dashed line showing the ideal performance. The slope of the linear regression between BLAnCA and MWAA data is $A = 0.95 \pm 0.03$, with $R^2 = 0.97$. As can be seen from the scatter plot and from the slope of the regression, BLAnCA slightly underestimates the absorbance values compared to the MWAA.



(a) (b)

Fig. 1. – Panel (a) shows the validation plot of BLAnCA against MWAA data; Panel (b) shows a comparison of the absorbance (ABS) of three corresponding samples of pure soot, soot with ozone, soot with ozone and high humidity.

5. – Preliminary results

The absorbance of the PM gathered on each sample was then measured with BLAnCA over its whole spectral range following the procedure detailed in sect. **2**. One example of these preliminary measurements is shown in fig. 1(b), where corresponding samples from each of the three sets are compared. The pure soot sample (black triangles) has the highest absorbance at any wavelength except for the infrared region, for $\lambda > 850$ nm. The sample of soot aged with ozone (red circles) has a very similar spectral absorbance to the pure soot sample, with the exception that it is uniformly lower, partly due to the lower initial soot concentration for the second set compared to the first one, and partly due to the ageing process. Furthermore, a small bump in the absorbance plot for the second set highlights an increased absorbance around $\lambda = 580$ nm. The sample of soot aged with ozone in a humid environment (blue squares) has a markedly different spectral behaviour than the two other samples. The curve is noticeably flatter, with the lowest absorbance of the three samples until $\lambda = 500$ nm and the highest absorbance beyond $\lambda = 850$ nm. Moreover, a similar bump to the one noticed for the second dataset, around $\lambda = 580$ nm, can be found in this sample too. The reason for the reported spectral features of the absorption is still under investigation, and can possibly be attributed to changes in the shape and coating of aerosol particles due to the different ageing processes.

6. – Conclusion

A new instrument prototype for light absorption measurements has been built and firstly validated. It can retrieve the light absorption properties of particulate matter gathered on a filter over a wide spectral band, from the near UV to the near IR. The prototype has been tested measuring three different synthetic carbonaceous particulate matter samples that were specifically produced for this purpose at the ChAMBRe facility. First, the comparison was restricted to the same five wavelengths available with the MWAA to have a direct benchmark for the performance of BLAnCA. It has been found that the new prototype underestimates absorbance measurements by $5\% \pm 3\%$ with respect to the MWAA. Investigating further, it will be possible to diminish any systematic effect that might cause this discrepancy. Finally, the full BLAnCA wavelength range was exploited, showing how the high spectral resolution measurements of absorbance can highlight features not accessible by a discrete wavelength instrument.

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