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AEROSOL AGENT DETECTION USING SPECTROSCOPIC CHARACTERIZATION

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ABSTRACT. We present here a brief description of our efforts to develop optical spectroscopic characterization and classification methods for air-borne biological particles. While the bulk of our experimental investigation has used laser-induced fluorescence in conjunction with incident laser elastic scattering, we have also developed novel methods for generating, handling, interrogating and collecting aerosol particles. A method known as a Structured Trigger Beam (STB) for obtaining optical measurements from individual aerosol particles that are normalized with respect to the instrument response function is described here. Our latest results will be included in our presentation.

1. Introduction

Detection of chemical and biological agents that would most likely be dispersed as aerosols has become a critical component of modern defense capability. Under a Defense Threat Reduction Agency supported program, the NRL Optical Sciences Division has recently developed advanced ambient air monitoring and aerosol classification technologies based on laser interrogation and spectroscopy. These optical characterization measurements are performed on individual aerosol particles entrained in a continuous air stream as they move past the sensor focal volume at rates up to 10,000 per second. Multiple laser beams at three wavelengths are used to interrogate the aerosol particles. Six of the beams are generated by one continuous-wave visible wavelength diode laser and collectively provide position and velocity information of the aerosol particles. Subsequently, each particle is illuminated with one or two pulsed ultraviolet (UV) lasers. If the particle is composed of biological material, characteristic fluorescent emission will result from the UV laser excitations. The UV-laser-induced fluorescence (UV-LIF) signals are recorded in discrete spectral channels, as are the elastic scattering intensities. Up to 14 optical measurements are obtained from each particle. These data values are used to classify and differentiate the particles into potential-threat or non-threat categories.

2. Spectral Discrimination

Figure 1 shows a scatter-plot survey of UV-LIF signatures from particles from eight separate populations with different compositions as described in the legend and elsewhere

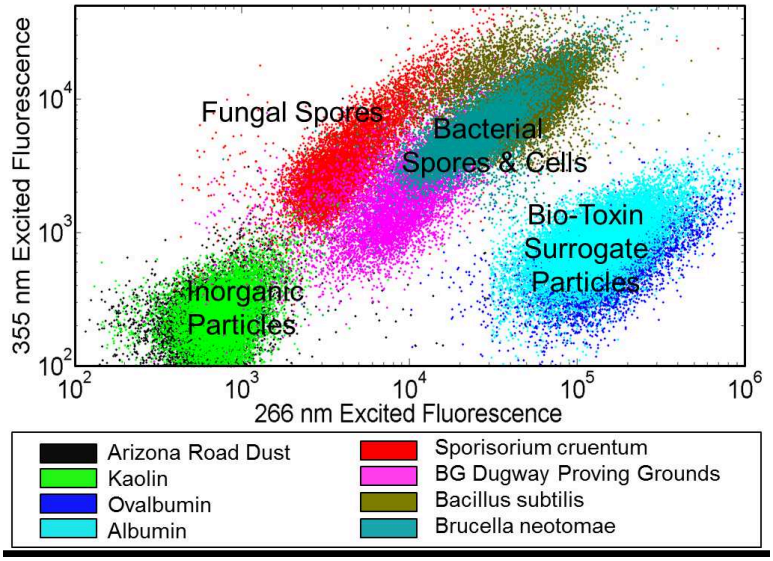

Figure 1. An illustration of the separation observed in measured UV-LIF emission intensities in two spectral channels from lab-generated populations of aerosol particles representing four broad groups: inorganic ambient background particles, fungal spores, bacterial particles (spores or cells) and bio-toxin surrogates (proteins). The eight specific example compositions are color-coded in the legend.

[1]. The data shown are the emission intensities from two of five excitation-emission channels. All of the aerosol particles shown here are approximately one micron in diameter, and each point on the plot represents a single particle. One can easily see that significant discrimination is obtained for four broad categories of different materials including those relevant to biological agents. However, the spread in these particle data includes variation in instrument optical collection efficiency and laser illumination of the particle depending on its location in the sensor focal volume. In an effort to improve discrimination, we have recently implemented a new design to remove variability due to particle position from the raw data.

3. Instrument Design

The basic optical design has been previously published [1], and contains greater detail than can be accommodated here. The original design uses a single separate continuous-wave laser beam as a trigger to indicate the presence of an aerosol particle entering the instrument. Most recently, this trigger beam has been split into a set of six spatially structured beams that provide data on the specific position and velocity of each particle. This arrangement, referred to as a Structured Trigger Beam (STB) [2] provides the ability to

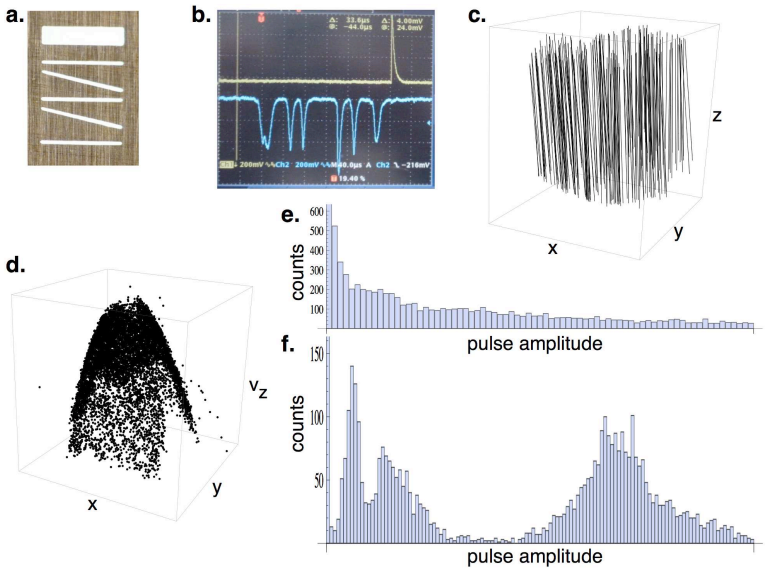

Figure 2. Different aspects of the structured trigger beam (STB) are shown starting with: (a) the high precision mask used to generate the six beams, (b) a typical oscilloscope trace (blue trace) showing the six-pulse signature as a particle passes through each of the beams, (c) 3-dimensional particle trajectories for an ensemble of particles created from STB data, (d) the corresponding velocity (vz) profile from that particle ensemble, (e) uncorrected LIF pulse height data from test particles, and (f) the same LIF data as in (e), corrected now using the STB data, and revealing the presence of three distinct fluorescence populations.

reduce the spread of the fluorescence and elastic scattering data used to characterize the particle.

By knowing the precise particle location, the instrument response function due to spatially dependent laser beam intensity profiles and optical collection efficiency can be normalized. Figure 2 shows the precision mask (a) used to generate six spatially distinct STB laser beams, and a typical oscilloscope trace (b) of a particle passing through the beams (lower, blue trace). The particle position and velocity is coded into the relative positions of these six pulses generated by the particle passing through each beam. Figure 2c shows typical x-y-z trajectories for an ensemble of particles calculated from the STB data, while Fig. 2d. shows the (parabolic) distribution of flow velocities for the same particles as a function of their position (x-y) in the flow cross section. Finally, the effectiveness of the STB positional data to normalize fluorescence intensities can be seen by comparing Fig. 2e to Fig. 2f. Figure 2e shows a histogram of un-normalized (raw) fluorescence pulse height data, while Fig. 2f shows the same data normalized for spatial position instrument response. The result clearly shows the presence of three distinct test populations of fluorescent particles that was previously completely obscure.

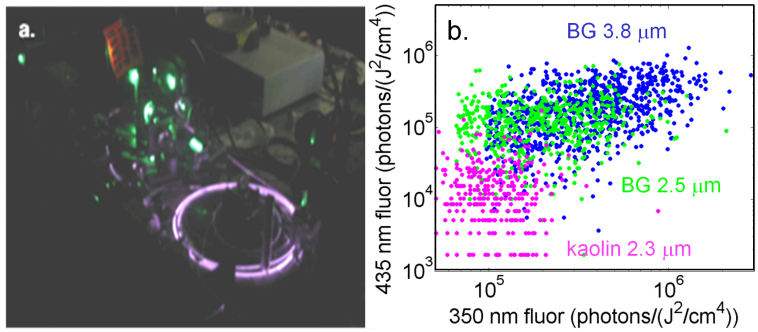

Figure 3. (a) is a photograph of a unique, mode-locked fiber laser developed to provide a continuous train of short (<500 fs) pulses of light for aerosol particle interrogation. The laser fundamental wavelength can be either doubled to 526 nm (green) or quadrupled to 263 nm (UV) very efficiently. (b) Because of its high peak power, two-photon absorption of the laser green light results in UV fluorescence from aerosol particles of bacterial spores (BG clusters of 2.5 and 3.8 micron diameters) compared to non-fluorescent mineral particles (kaolin) of similar size as shown in this scatter plot.

4. Future directions

In the past year, we have also developed customized UV laser light sources that offer certain advantages, such as greater energy efficiency, over the commercially available laser systems employed so far (e.g. 266 and 355 nm wavelength lasers). Figure 3.a. shows a photograph of a NRL developed, mode-locked fiber laser that provides high-intensity pulses (< 500 fs in duration) at a 41 kHz repetition rate [3]. The photograph shows the coiled optical fiber laser (as bright purple) as well as its 2^{nd} harmonic converted light (as green). The fiber laser pulse intensities are sufficiently high that two-photon absorption can be used to effectively pump fluorescence. The plot in Fig. 3b shows UV fluorescence intensities in two spectral bands, similar to Fig. 1, from three different populations of aerosol particles. These data are the first published [3] observations of emission due to multi-photon absorption from bacterial aerosol particles.

References

[1] V. Sivaprakasam, A. Huston, C. Scotto and J. Eversole, "Multiple UV Wavelength Excitation and Fluorescence of Bioaerosols", *Opt. Express*, **12**, 4457-4466, (2004); V. Sivaprakasam, H-B. Lin, A. L. Huston, and J. D. Eversole, "Spectral characterization of biological aerosol particles using two-wavelength excited laser-induced fluorescence and elastic scattering measurements", *Opt. Express.* (accepted).

[2] W. D. Herzog, S. M. Tysk, et. al., "Measurement of aerosol particle trajectories using a structured laser beam", *Appl. Opt.* 46, 3150-3155 (2007).

[3] W. Lou, M. Currie, V. Sivaprakasam, and J.D. Eversole, "Green and ultraviolet pulse generation with a compact, fiber laser,chirped-pulse amplification system for aerosol fluorescence measurements" *Rev. Sci. Instrum.* **81** (9) 2010; V. Sivaprakasam, J. Lou, M. Currie, and J. D. Eversole, "Two-photon excited fluorescence from biological aerosol particles," *JQSRT* (2010) (accepted).

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