Optimization of a Single Particle Soot Photometer for Metallic Particle Detection and Differentiation

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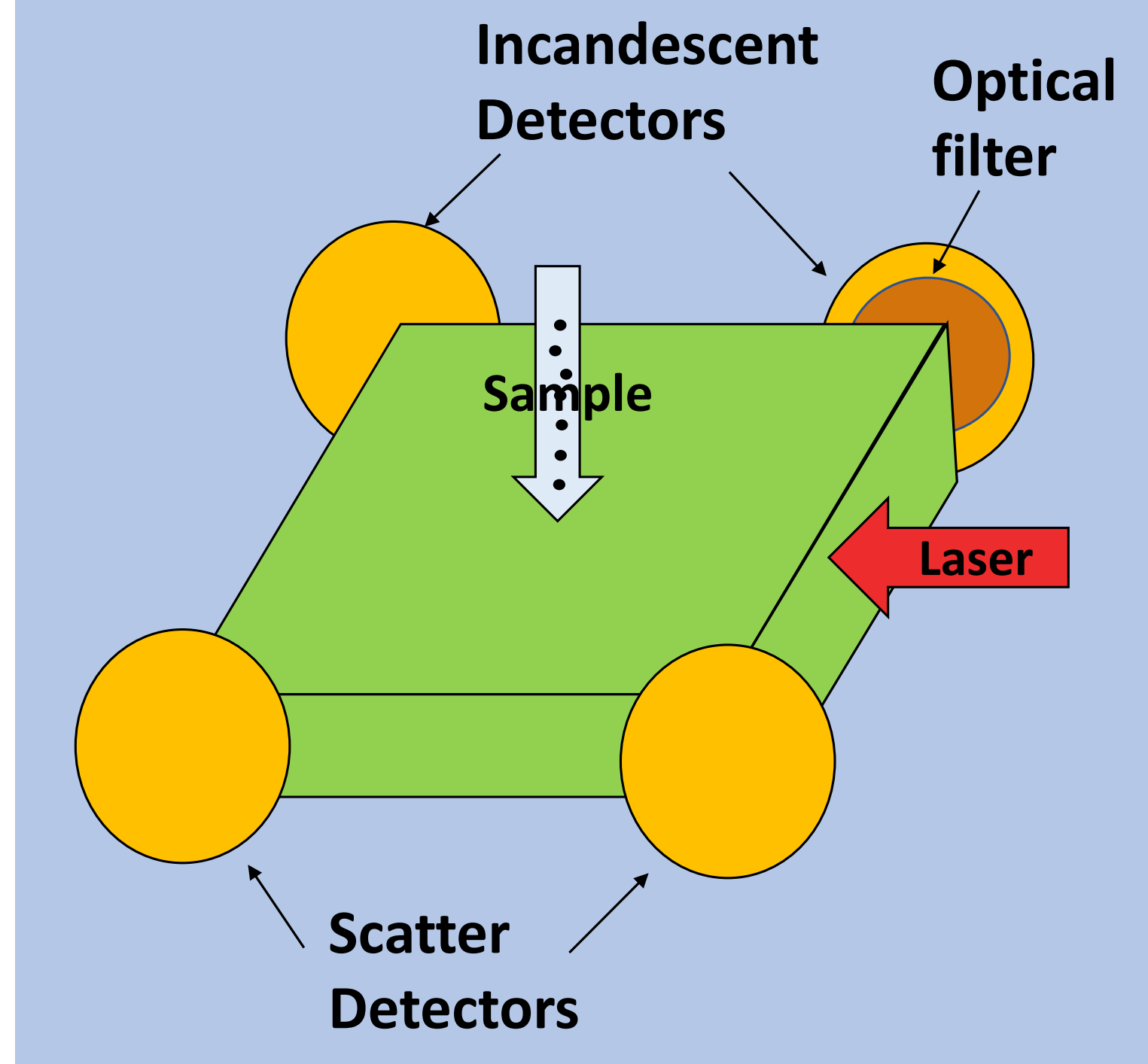
Background

Single Particle Soot Photometers (SP2) are typically used for measurements of atmospheric black carbon, by using a laser to vaporize particles causing them to emit incandescence and scattering signals. One important measurement from these signals is the color ratio (ratio between the two incandescent detectors) which indicates the particle's composition. While black carbon has a color ratio of 1, metallic particles commonly have a lower color ratio because the color ratio relates to the boiling temperature of the material. A recent study shows that they were able to use optical filters to make a distinction between metallic particles and black carbon[1]. This experiment is an attempt to recreate those results and further define this process.



This is a simplified model of the SP2, component connections not depicted accurately, for understanding the basic elements and layout of the instrument. An optical filter is placed between one of the incandescent detectors and the rest of the instrument.

Objectives

- Maintain a safe working environment while handling potentially hazardous airborne particles.
- Determine the minimum laser current required to completely incandesce the metallic particles.
- Determine the incandescence efficiency of the metallic samples
- Modify the SP2 using optical filters to differentiate the color ratios of various metallic particles.

Method

Modifications to the SP2 were made by adding different longpass optical filters which filter out light below a certain wavelength. Four materials were tested to see how the filter effected their color ratio.

Variables

Materials: Magnetite, Hematite, Fullerene Soot, and Gold

Filter Type (in nm): 500, 515, 540, 560, 580, 600, and 620

Size Selection: From 100 nm to 700 nm

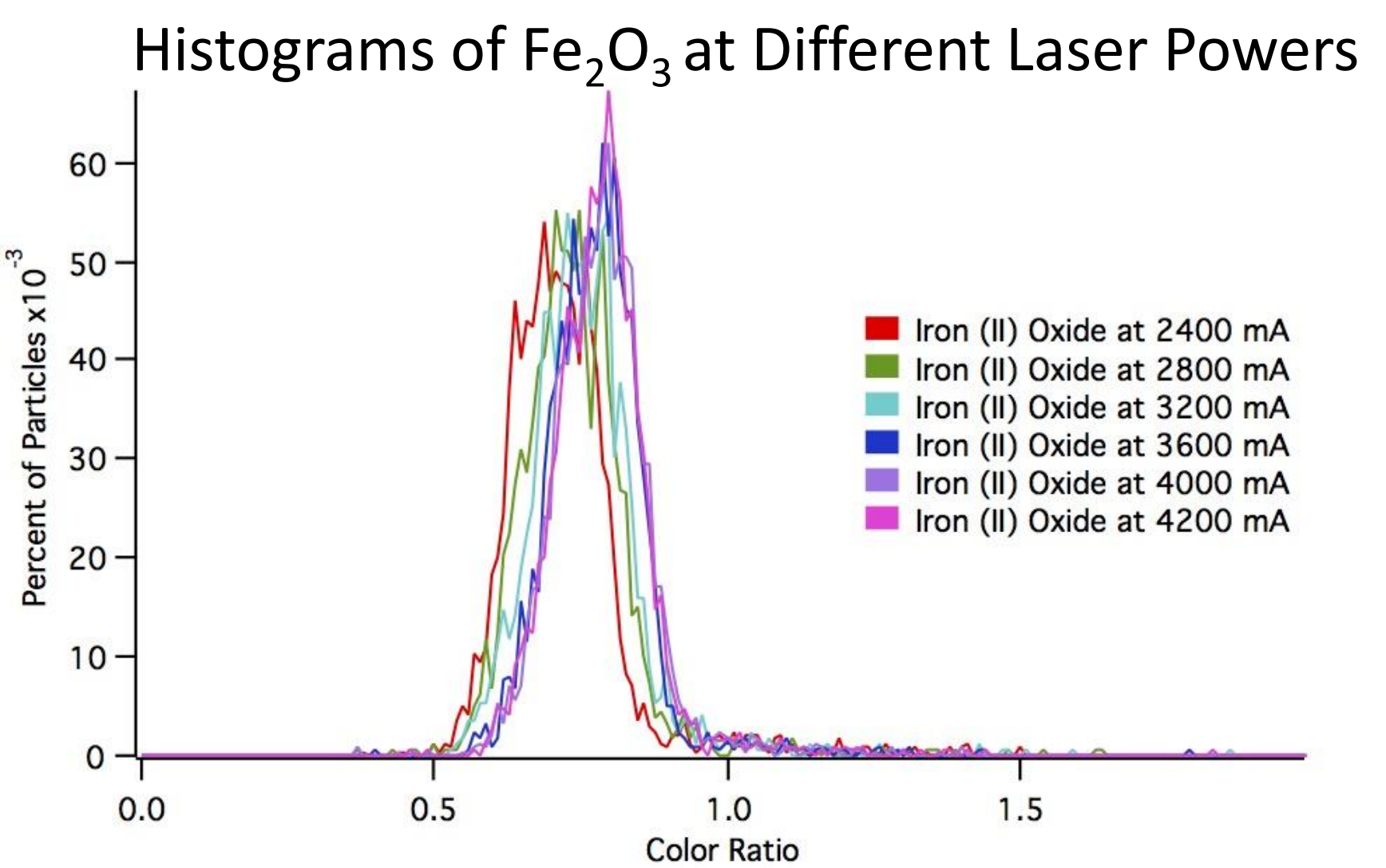
Before beginning the filter tests, a power analysis was conducted to determine the minimum power required to fully incandesce each particle.

The efficiency of each material was tested by putting the sample through a DMA to select a specific size of particles. At each size the number of incandescent particles in relation to scatter particles, particles without measurable incandescence, was measured to give an indication of what percentage of particles incandesced.

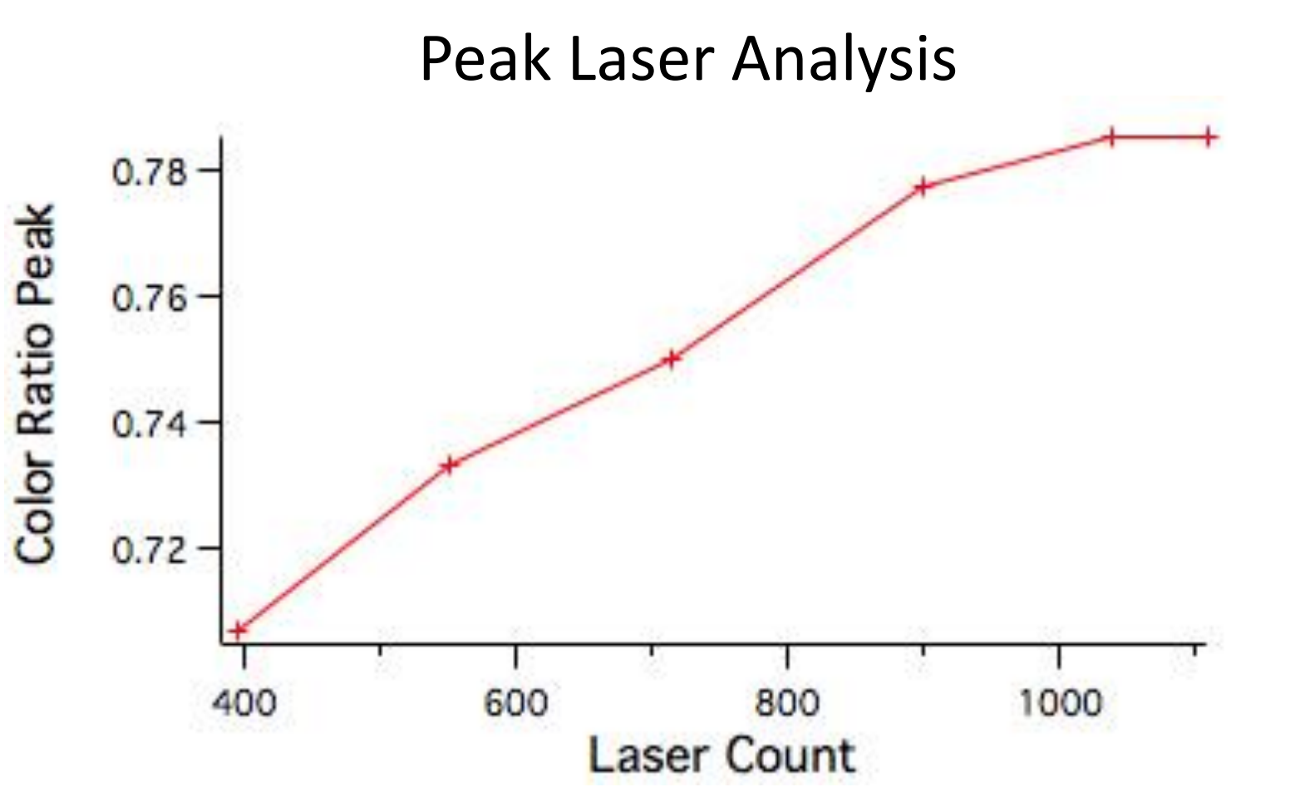
Results

To determine the laser current required to fully incandesce the particle trials were conducted at six different laser currents (see graph right). Since color ratio is not dependent on laser current, the color ratio should be approximately the same when particles completely incandesce. This was repeated for each material.

Histograms of Fe_2O_3 at Different Laser Powers



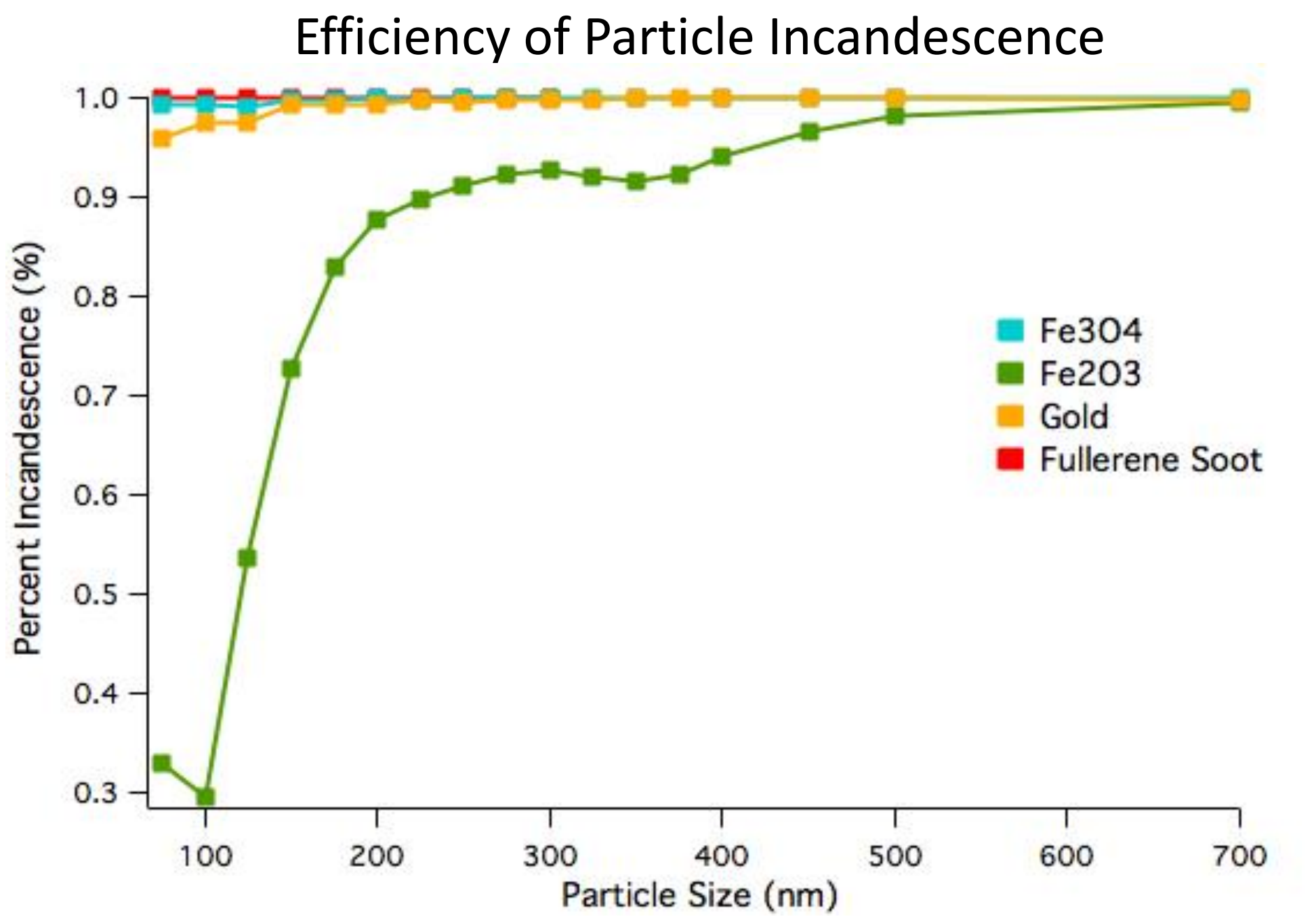
Peak Laser Analysis

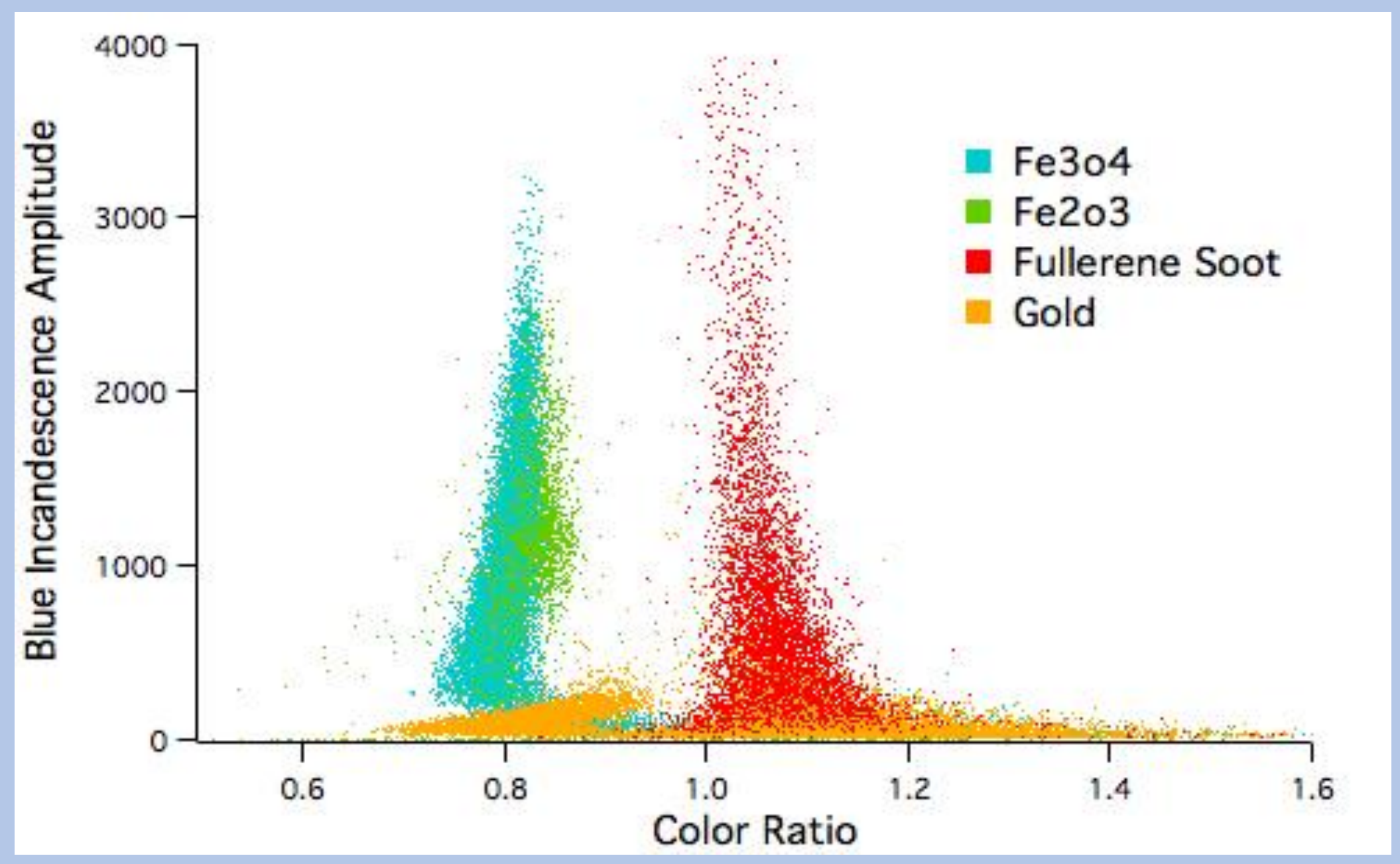


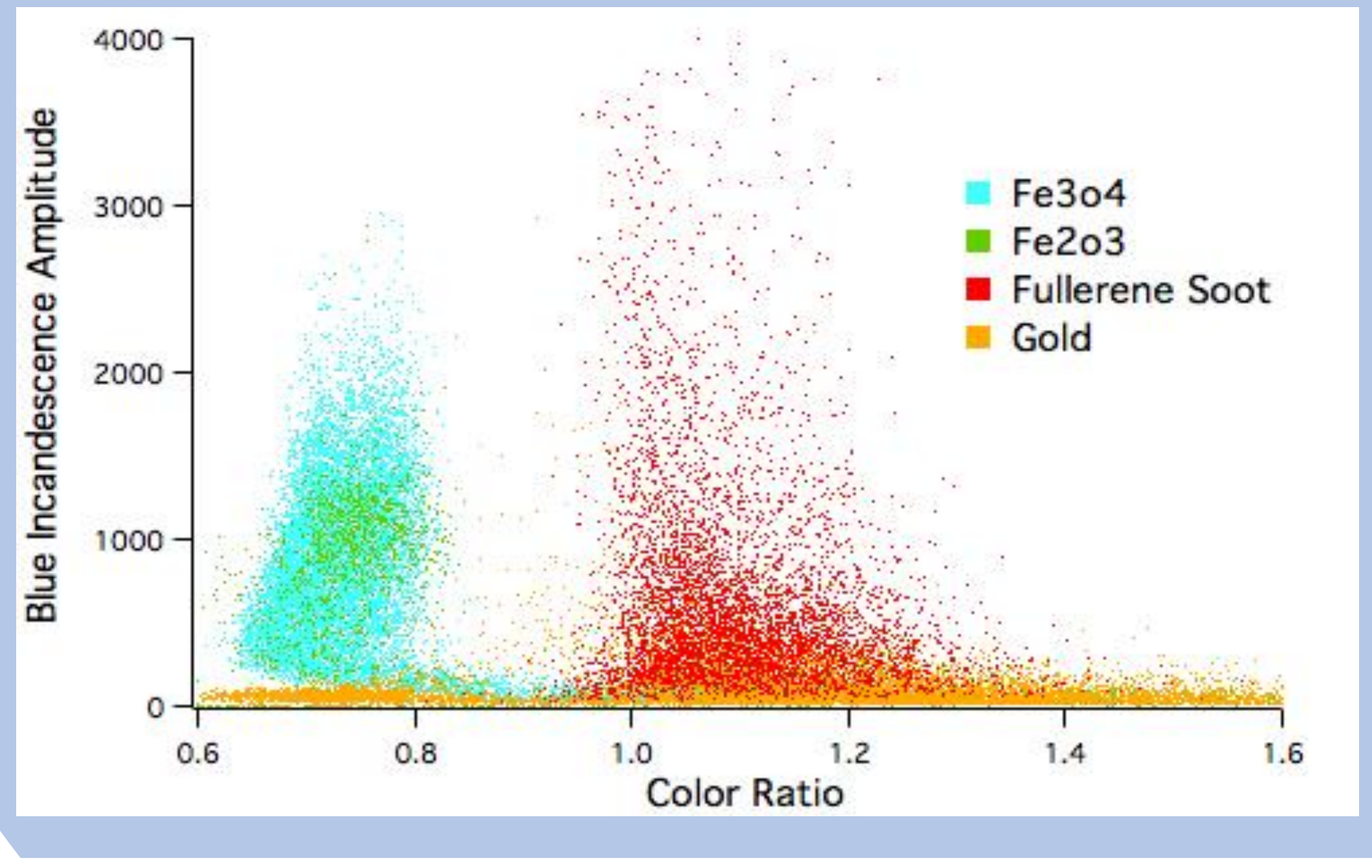
The color ratio curves where fitted and the peaks were determined. The graph to the left is of the peaks over different laser powers (based on scattering counts of a 220 nm PSL standard). This curve begins to level off around 900 counts or 3600 mA. Other materials leveled off at or before 3600 mA, so subsequent tests were conducted at 3600 mA.

The graph to the right, shows the efficiency (incandescence divided by total particles measured) of different materials versus particle sizes. The size of the particles were selected using a DMA before putting the selected sample through the SP2.

Efficiency of Particle Incandescence

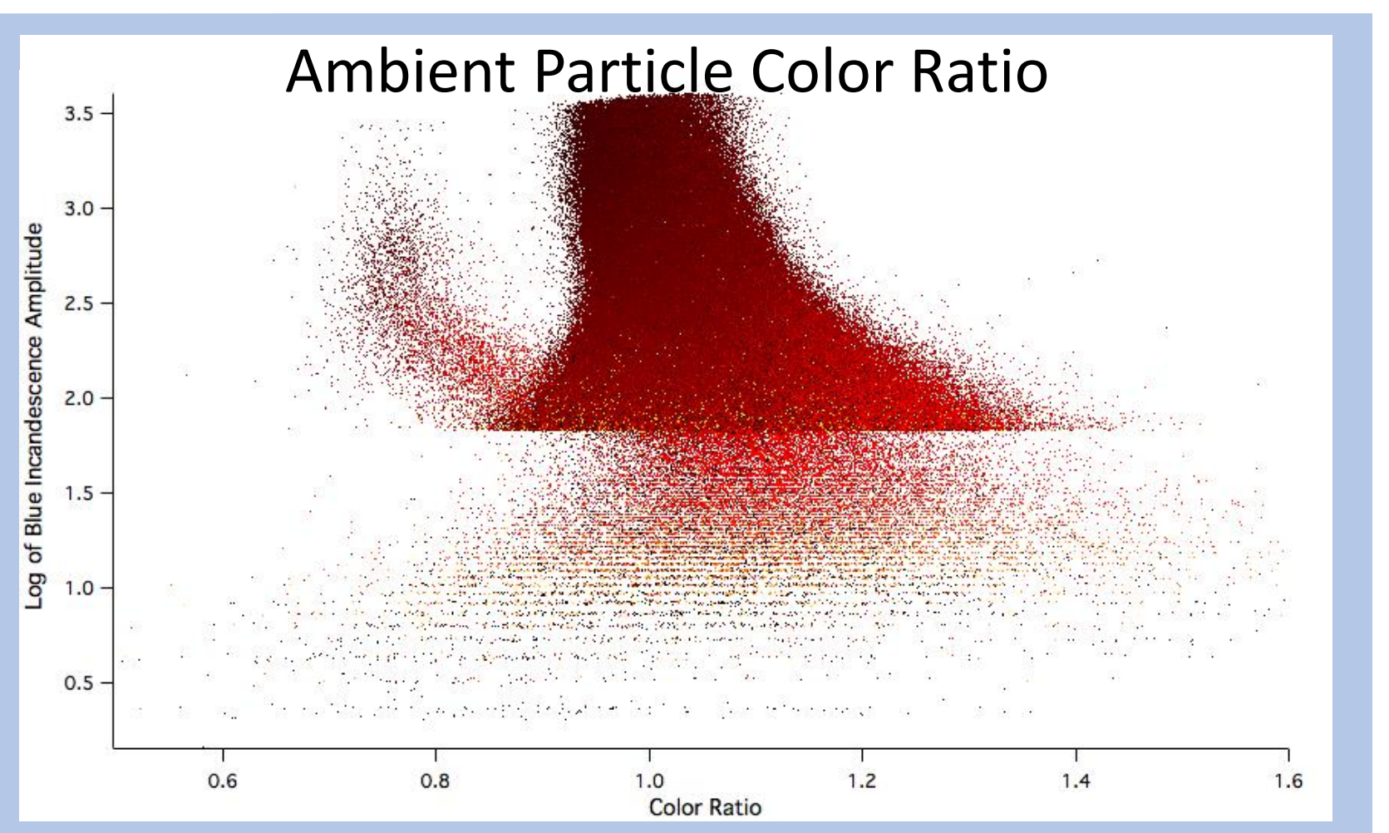






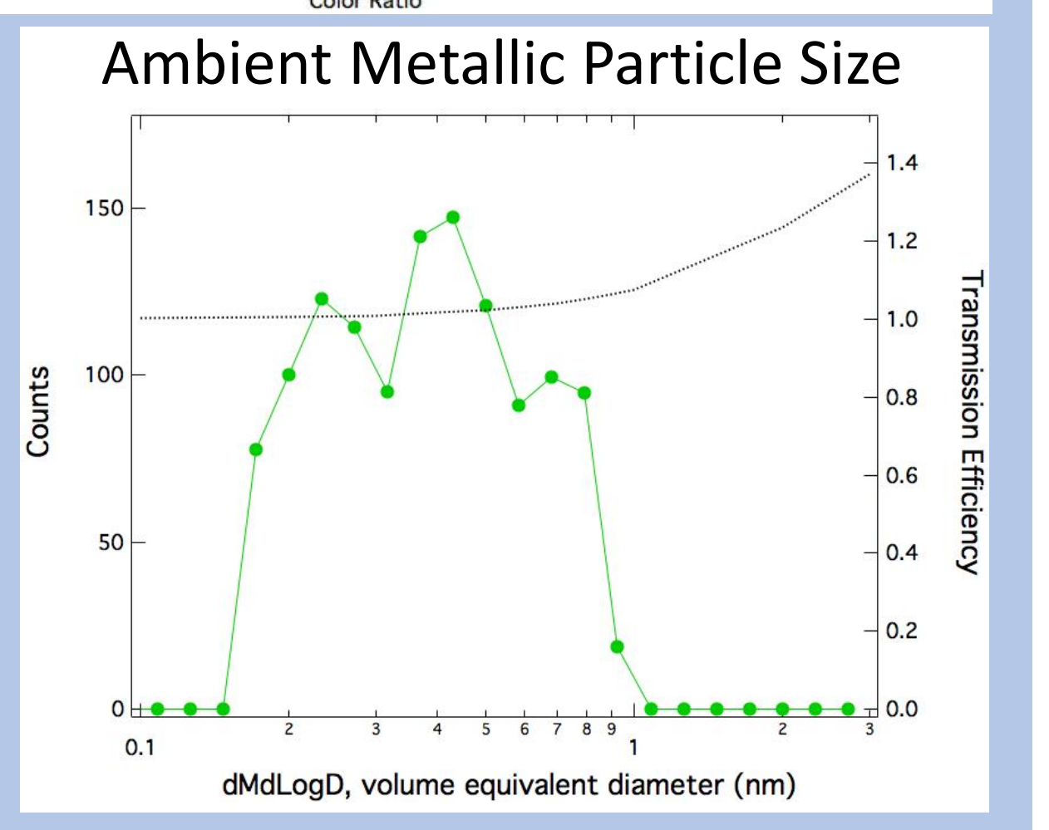
These two graphs show the color ratio for different materials in relation to their blue channel incandescence peak. The samples in the top graph were taken without a filter and the lower graph had a 540 nm. Each dot represents a particle that incandesced in the SP2. The vertical coordinate is the maximum incandescence of the particle. This type of graph was made for each filter, 540 nm is merely an example of the trends seen. Adding an optical filter that filtered out light below a specific wavelength increased the contrast between the red and blue channels, but also decreased the total light measured. The decreased signal strength was more detrimental than the increased contrast between the channels in this SP2 system.

Ambient Particle Color Ratio



Ambient data was collected from Boulder, Colorado over a 45 hour period. The large volcano shaped section in the middle is black carbon (with a lower detection limit at the horizontal line). The small section to the right are the metallic particles. The points below the horizontal line are small carbon particles that were coated. The metallic particle mass distribution is smaller than a sample previously measured in Japan[1]. The dotted line shows how efficiently the particles reach the detector. It is unlikely that the large particles are present but not reaching the detector.

Ambient Metallic Particle Size



Discussion

The magnetite (Fe_3O_4) and gold both incandesce efficiently while hematite (Fe_2O_3) becomes more efficient as it increases in size. This shows that if unknown data is taken and metallic particles are measured, then the number of particles measured is similar to the concentration in the sample. With a maximum color ratio of 0.9 and minimum blue amplitude of 68 Magnetite is correctly identified 96.5%, Hematite is identified 83.6%, and black carbon is not misidentified. While it is more challenging to distinguish metallic particles from one another, additional techniques would need to be developed, they can be differentiated from black carbon. In Boulder, CO there are some metallic particles present and they have relatively small diameters. These metallic particles are potentially hazardous, because they contribute to climate change and may be detrimental to human health. One study indicates that Magnetite nanoparticles in the human brain are linked to Alzheimer's disease[2]. Further study of these particles and the identification is needed.

References

1. Yoshida, Atsushi, et al. "Detection of light-absorbing iron oxide particles using a modified single-particle soot photometer." *Aerosol Science and Technology*50.3 (2016): 1-4.
2. Maher, Barbara A., et al. "Magnetite pollution nanoparticles in the human brain." *Proceedings of the National Academy of Sciences* 113.39 (2016): 10797-10801.

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