# Measurement of atmospheric aerosols using airborne digital cameras

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# Overview

- Background and theoretical information
- Current aerial image analysis
- Strategy for determining aerosol information
- Particle Chamber Setup
- Chamber Experiments
- Detailed data analysis
- Method application to aerial flights

# Background

- Images have been used to determine atmospheric turbidity (the loss of transparency in air due to particle scattering of light) and particle size ratios.
- Dissertation discussing the measurement of turbidity in an urban environment. [1]*(Damien Igoe. Analysing Urban Aerosols using a Digital Camera. Dissertation as submitted to the University of Southern Queensland.)*
- Research group utilized the Angstrom exponent to determine particle size ratios using digital cameras.([2] *Filipe Carretas, Frank Wagner, Fernando M. Janeiro. Atmospheric visibility and Angström exponent measurements through digital photography. Measurement 64 (2015) 147–156.*)
- Our goal is to further this research by applying these methods to aerial images and find ways to measure not only visibility but also particle density and particle size distribution.

# Theory

- We know how light propagates through the atmosphere.
- Beer-Lambert Law
  - Where "ρ" is the particle density
  - "$b_{ext}$" is the light extinction constant
  - "x" is the path length of light
  - "τ" is the optical depth
- Koshmieder's law gives visibility relationship
- Atmospheric visibility study gave numerator to be 3 rather than 3.912 for experimental purposes[18]

$$C(x) = e^{-x\rho b_{ext}} = e^{-\tau}$$

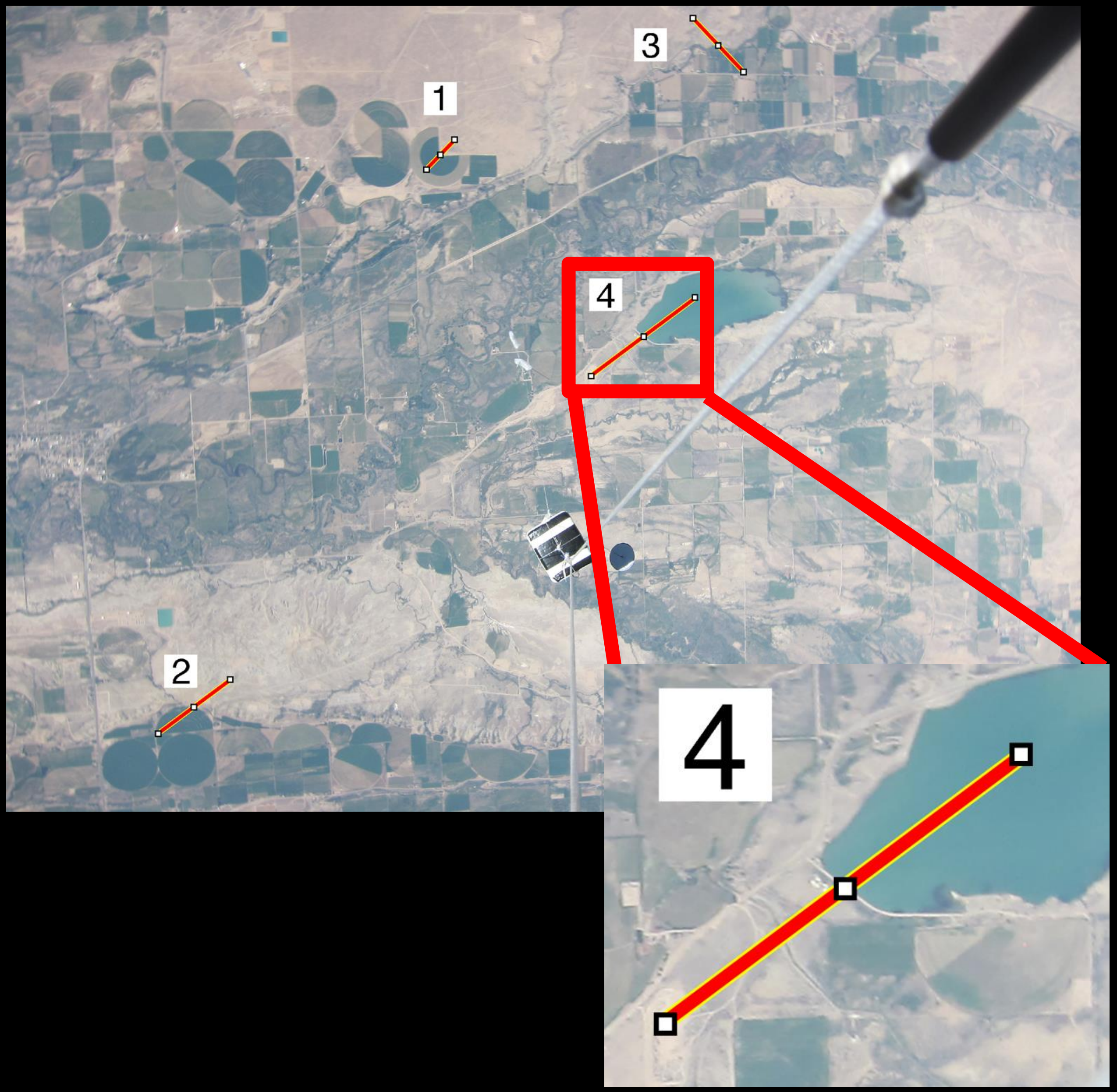
$$V = \frac{3.912}{b_{ext}}$$

# Aerial Analysis

- Photos taken during high altitude balloon flights may be able to determine atmospheric turbidity

- General turbidity can be determined by choosing a high contrast target and analyzing images taken at varying distances from the target

- Our goal is to use aerial images to determine particle density and ratios of “small” to “large” aerosols

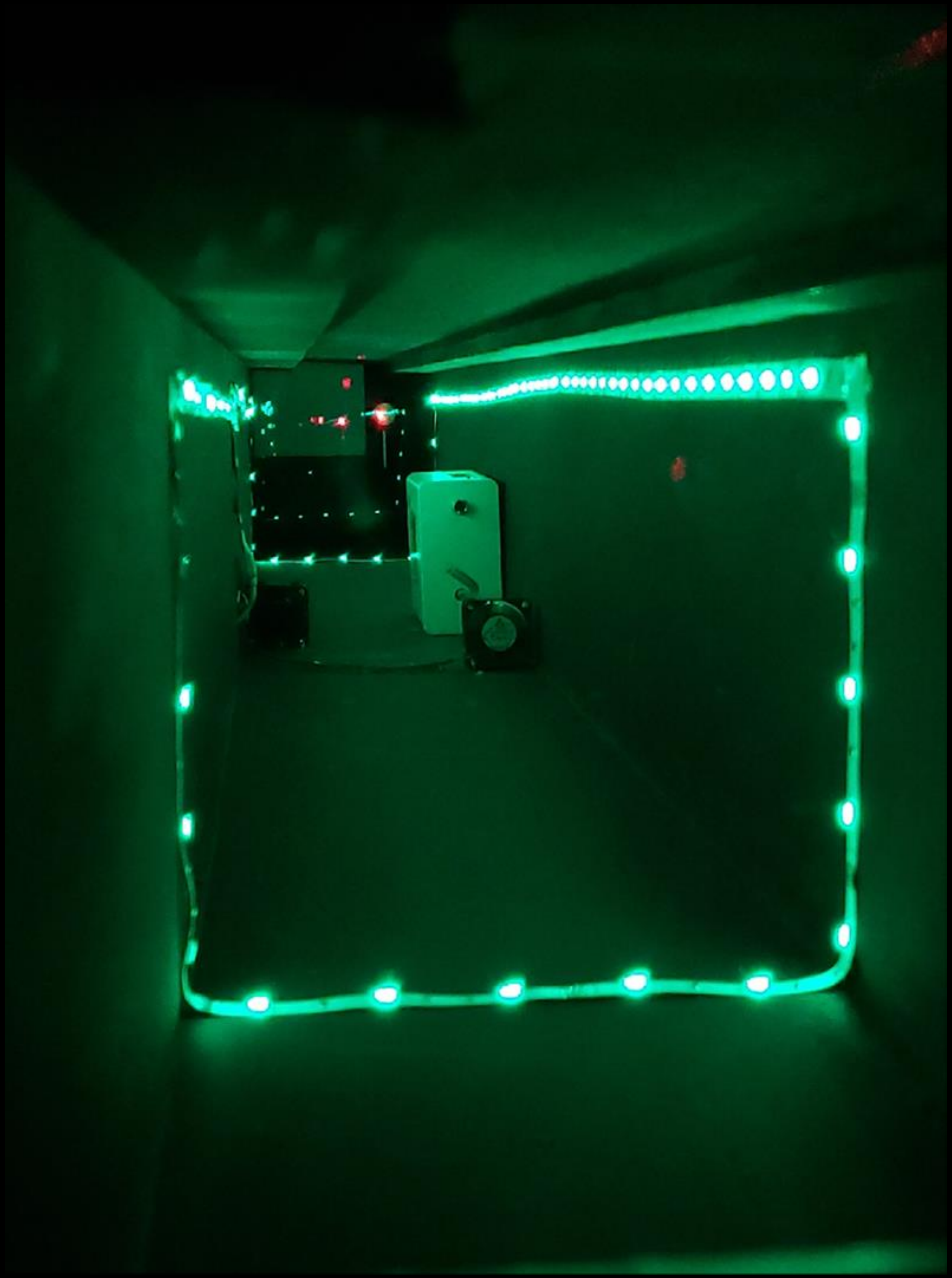


# Imaging in Laboratory Environment

- Use known particle density to find a correlation between image quality and air quality.
- Beer-Lambert Law says the relationship should look exponential.
- Experimentally solve for optical depth from Beer-Lambert Law and manipulate to get the extinction coefficient.
- Extinction coefficient can be used for finding the previously mentioned visibility and optical depth may be used to find particle distribution.
- Apply results to varying color channels of aerial images from varying altitudes to determine air quality  and particle density information.

# Particulate Chamber Setup

- 8 foot long chamber with optical glass on either end
- Fans to keep particles relatively evenly dispersed
- Capped outlet to insert pollutant
- Incense used to create “dirty air”
- Calibrated particle sensor inside the chamber
- Interior adjustable lights
- Camera focused at a black/white target on opposite sides of the chamber
- Laser transmission measurements



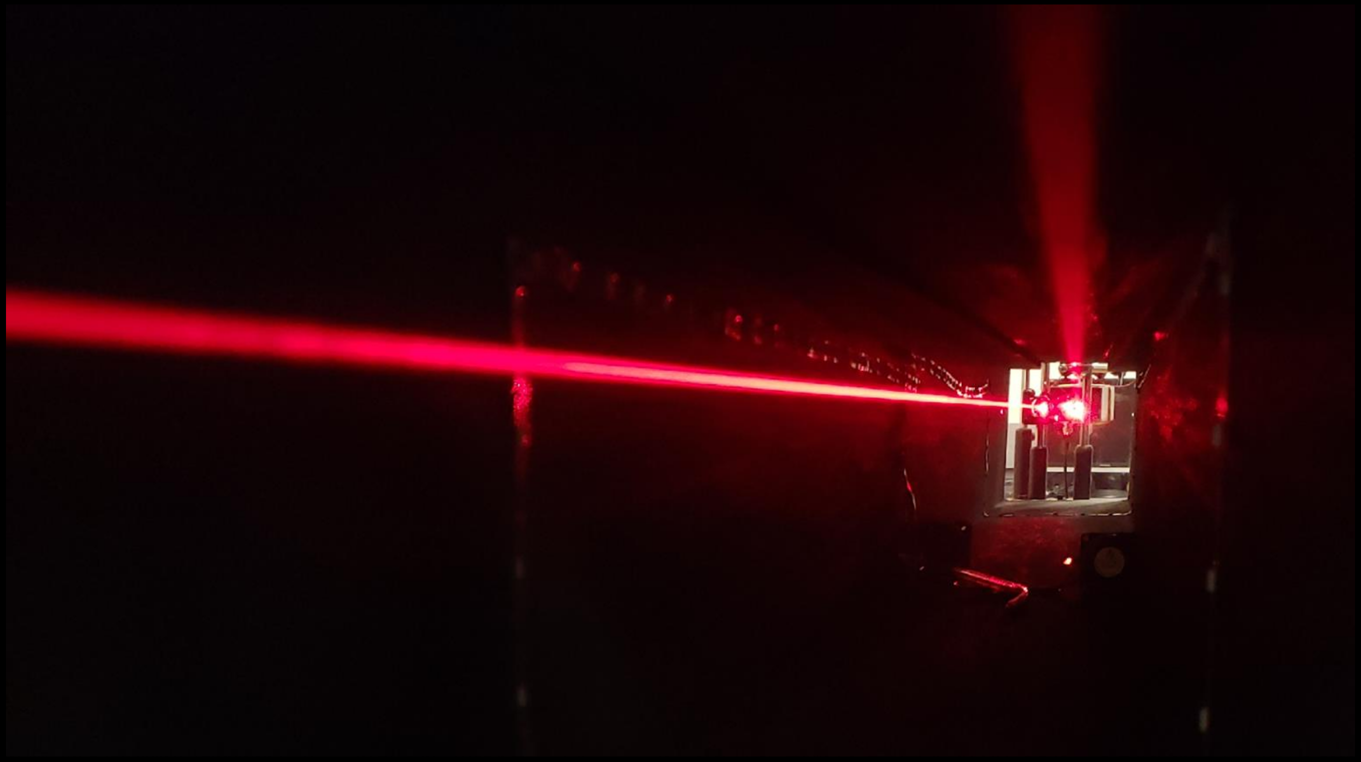


Photo Credit: Alex Lehr, WSU HARBOR Flight Team

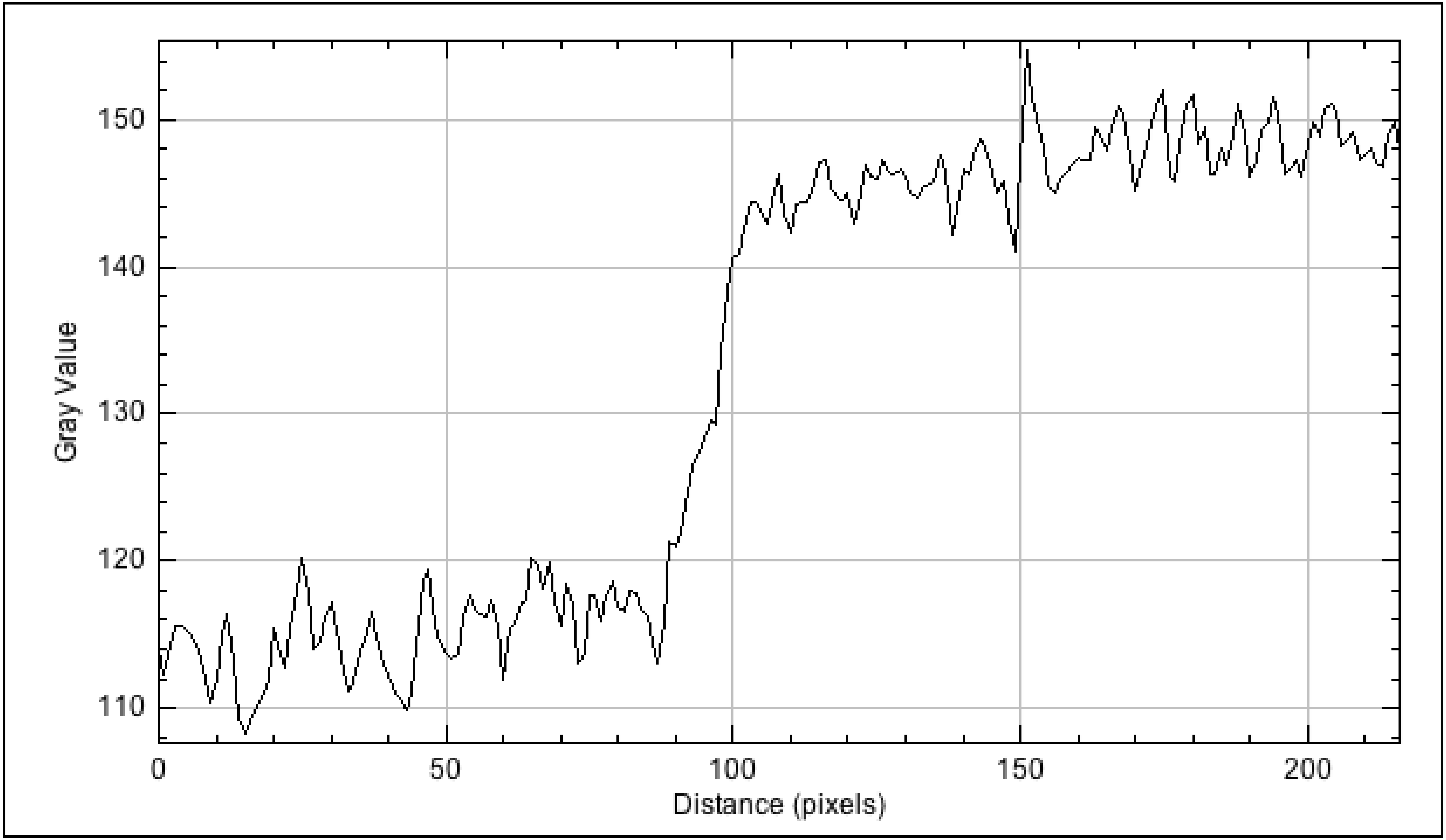
# Overall Results

- Compare fringe contrast calculations to several different particle density distributions including total amount of particles, a  total count weighted by particle sizes, and individual particle sizes.
- Images were taken in white, red, green, and blue light.
- The expected exponential curve could be seen in the red and green image analysis. The blue and white light gave more sporadic results which may be smoothed out with more data runs.
- The fringe contrast percentage stayed below 60% even with a clear, unpolluted chamber.

# Fringe Contrast Measurement

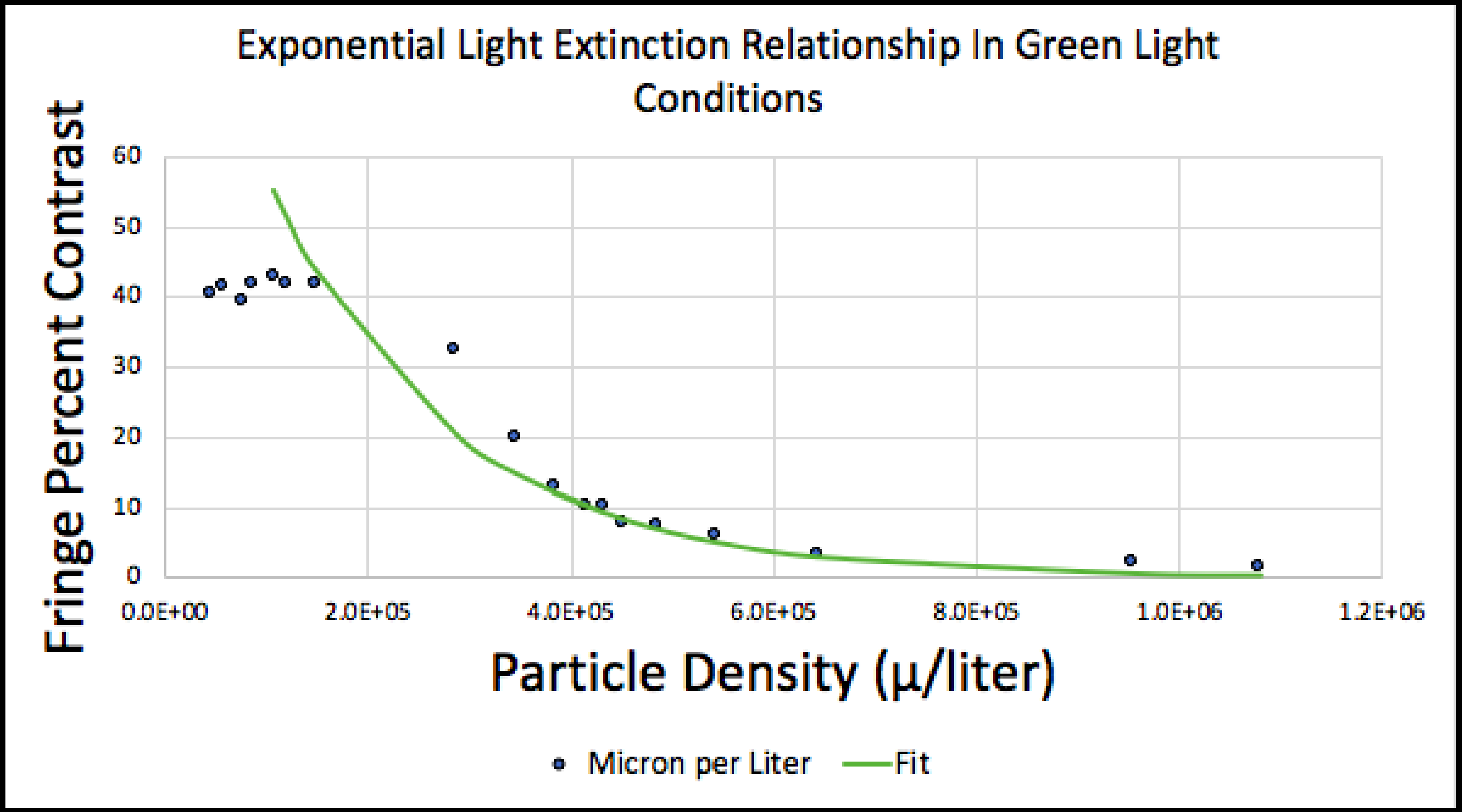
- Definitionally this is the difference in light and dark components divided by their sum.
- Contrast plot given by ImageJ photo analysis software
- Choose a contrast section of photo and have the software perform a contrast density plot

249.83x56.49 (613x355); 8-bit; 213K

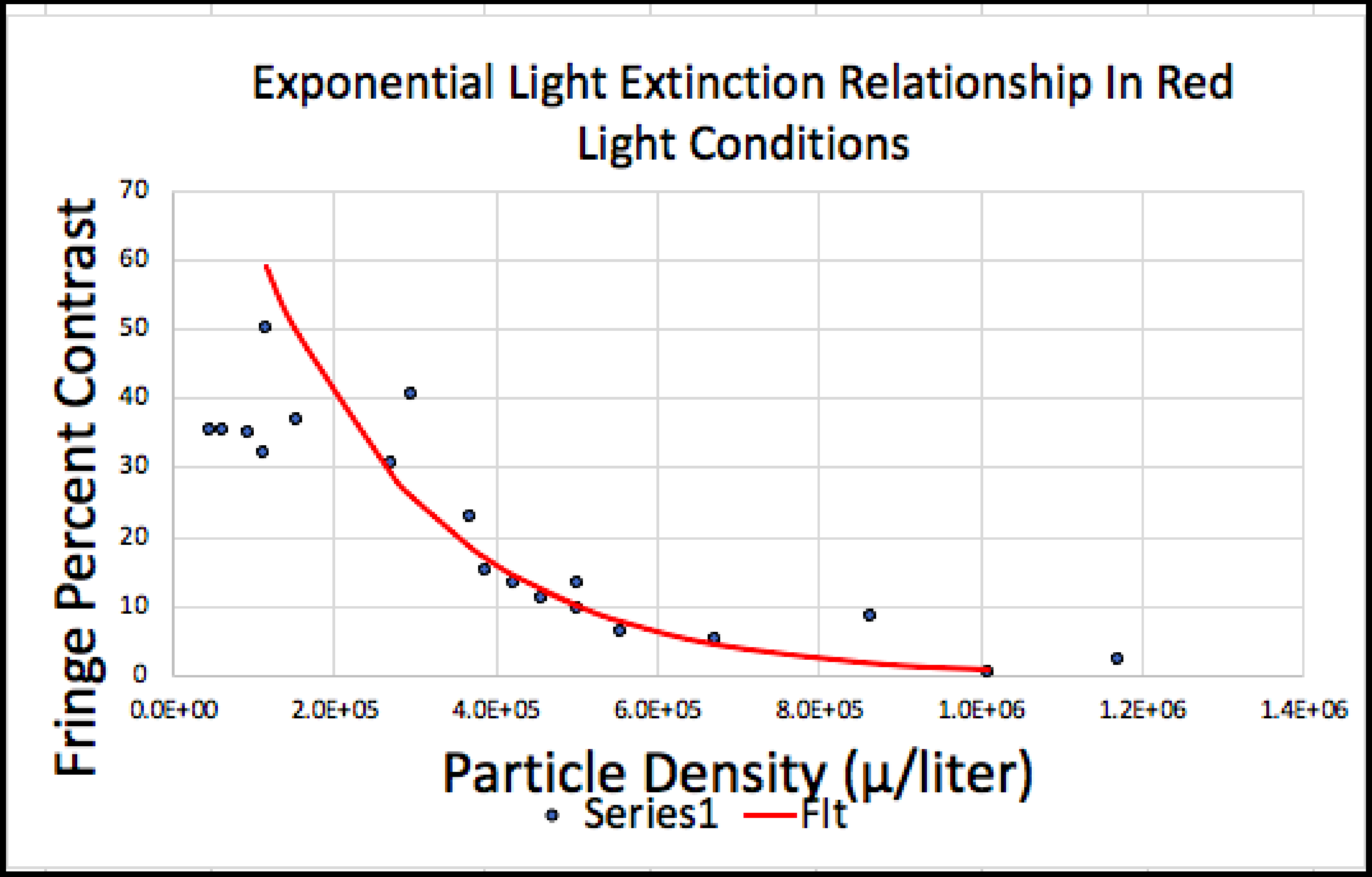



$$C(x) = \frac{I(x)_{max} - I(x)_{min}}{I(x)_{max} + I(x)_{min}}$$

$$b_{extGreen} = 2.3 \times 10^{-6}$$




$$b_{extRed} = 1.9 \times 10^{-6}$$



# Solving for Optical Depth

- Optical depth is a measure of how far light will travel before being completely dispersed by absorption and scattering

$$C(x) = e^{-x\rho b_{ext}} = e^{-\tau}$$

- This can be related to the Angstrom exponent which which gives particle size ratio information, visibility, and particle density.

$$\tau = \beta\lambda^{-\alpha}$$

# Angstrom Exponent Calculation

- Used to determine turbidity and ratio of small to large particles in the atmosphere
- Ranges from 0.5 to 2.5 with higher numbers indicating a greater smaller particle to large ratio [2]
- Used a spectrometer to find the center of the red and green bands of the LED's which were used for the wavelength dependence in the formula
- The angstrom exponent gives values between 0.9 and 1.5
- This result is reasonable where there are on average more than 17 times as many 0.3 micron particles than particles larger than 1 micron

$$\alpha = \frac{ln\frac{\tau_1}{\tau_2}}{ln\frac{\lambda_1}{\lambda_2}}$$

# Total Optical Density

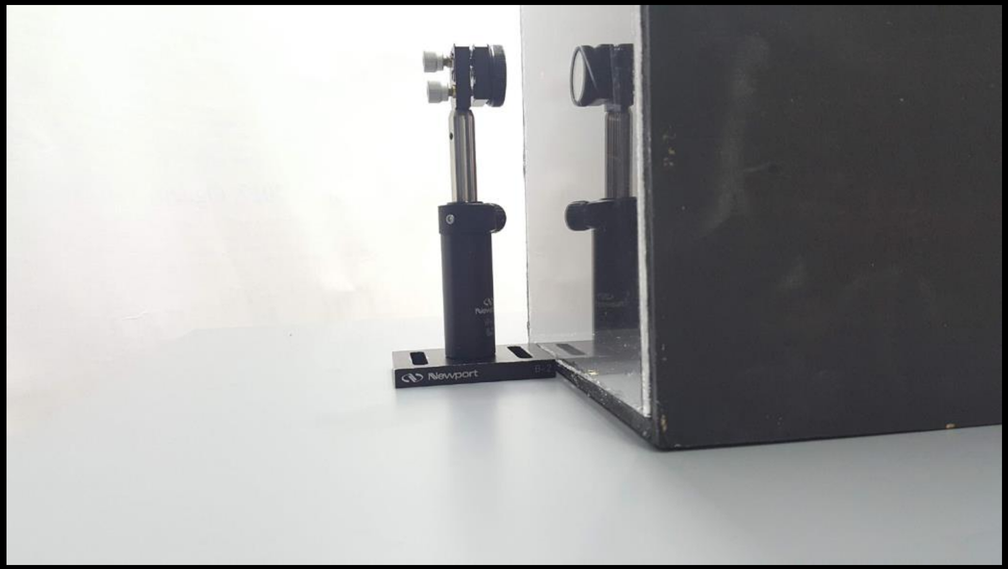
- Values smaller than 0.1 indicate less turbidity and 0.2 indicate higher turbidity
- Our values were between 0.5 and 1.5. This gives a relationship that be applied for any wavelength with a given density.
- This means contrast analysis of just two color channels can give the optical density for any wavelength, which in turn may be summed to give the total optical density.
- Even though we are unable to confidently solve for the optical density on the blue channel, we can use this relationship to give the total optical density of a system.

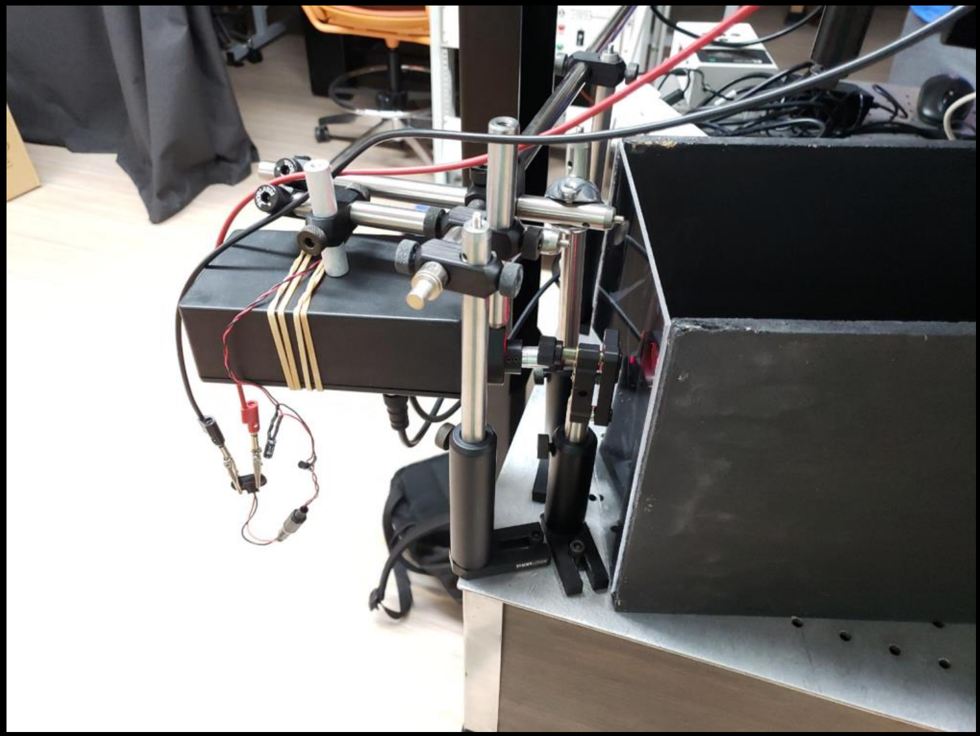
$$\beta = \tau \lambda^{\alpha}$$

$$\tau = \beta \lambda^{-\alpha}$$

# Laser Transmission

- Set up laser, beam splitter, mirror, and homemade dual diode sensor
- The diode 1 received the initial beam intensity from the laser and diode 2 received the beam which had traveled down and back through the chamber.
- Intensities were compared to get a transmission value

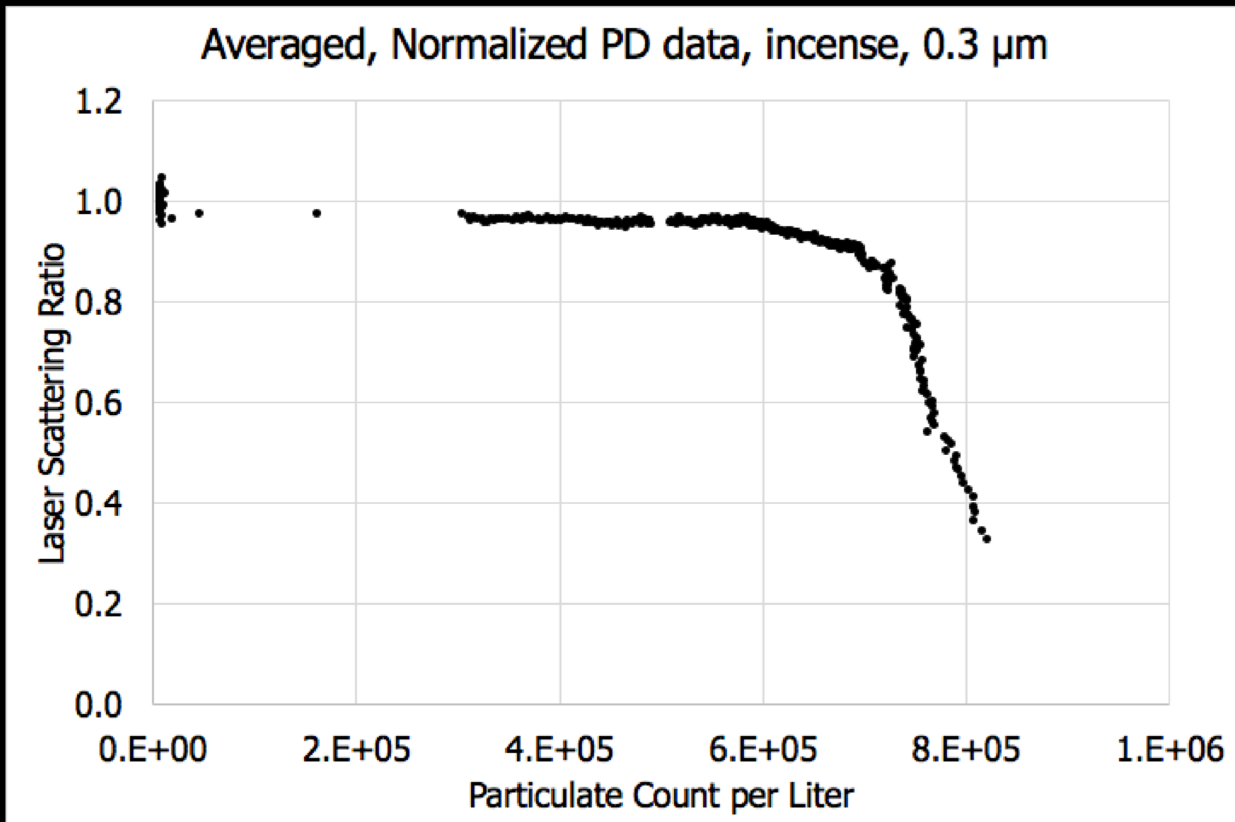


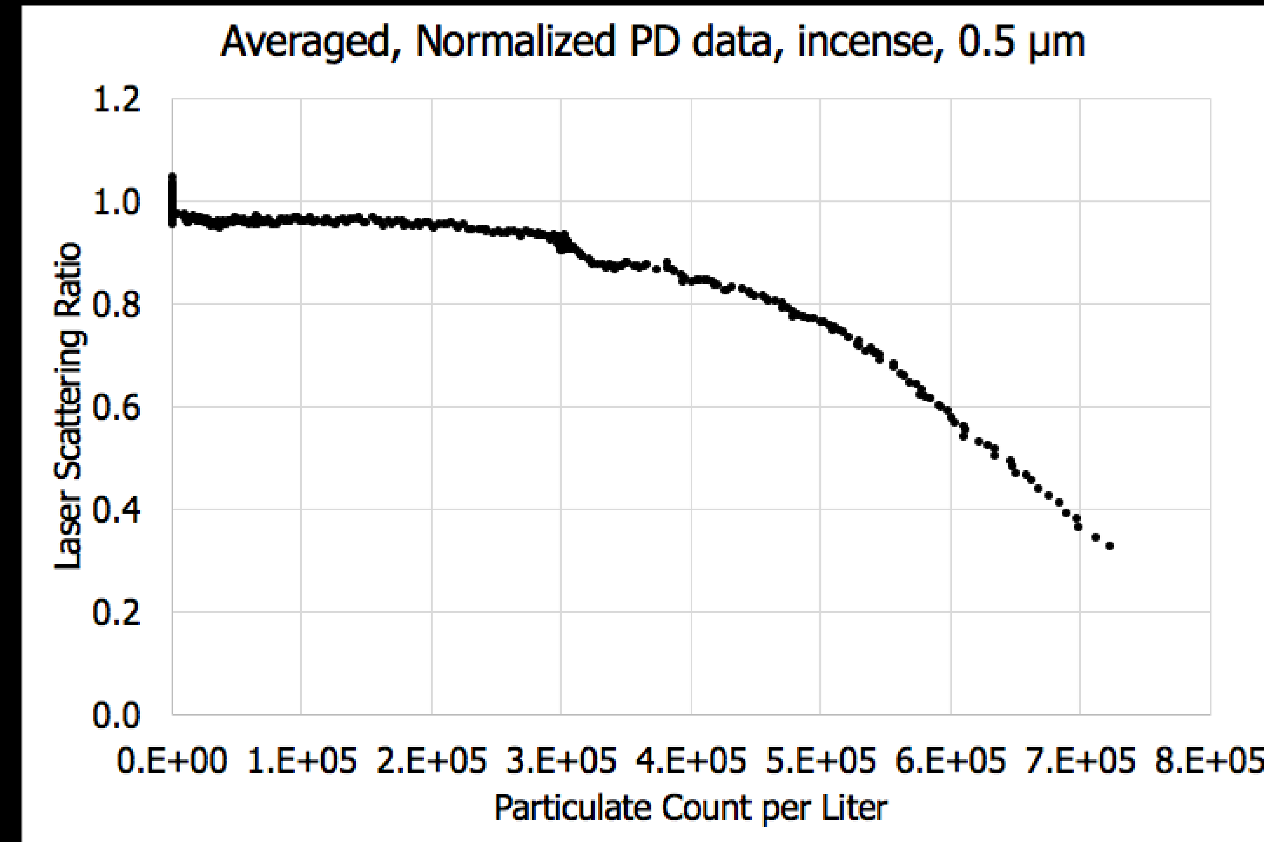


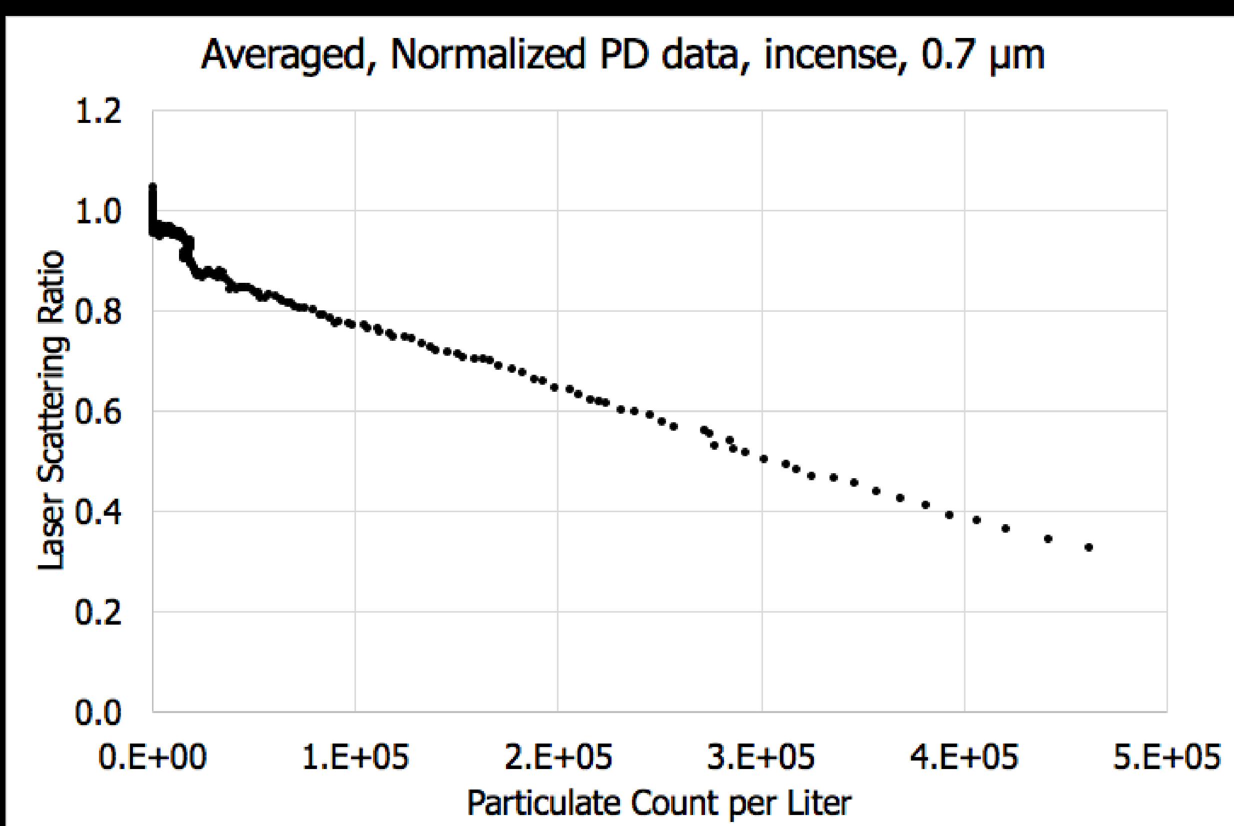
# Laser Optical Depth Calculation

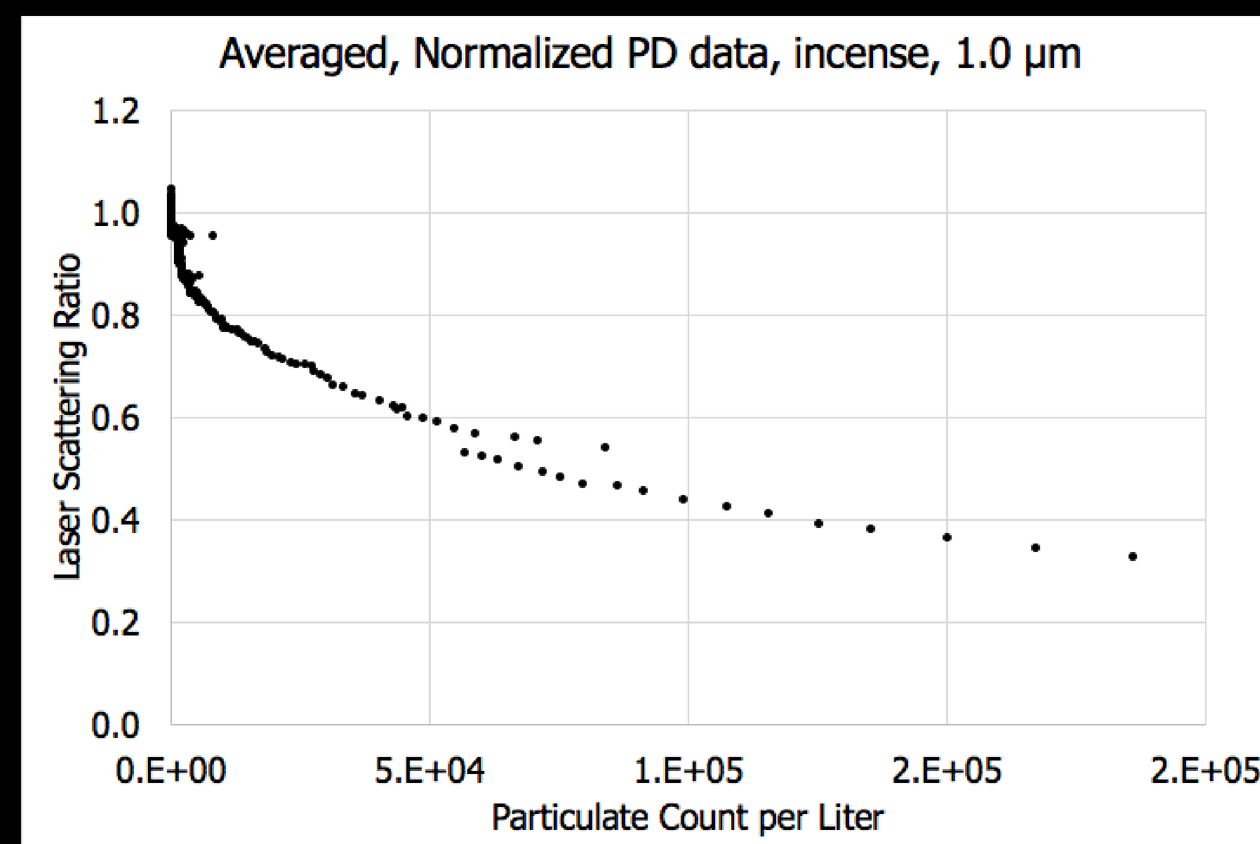
- Intensity change gives transmission which in turn gives the optical density.
- Compare these results with image analysis for validity of methodology

$$T = \frac{I}{I_0} = e^{-\tau}$$


Averaged, Normalized PD data, incense, 0.3 µm
Laser Scattering Ratio
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.E+00
2.E+05
4.E+05
6.E+05
8.E+05
1.E+06
Particulate Count per Liter


Averaged, Normalized PD data, incense, 0.5 µm
Laser Scattering Ratio
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.E+00
1.E+05
2.E+05
3.E+05
4.E+05
5.E+05
6.E+05
7.E+05
8.E+05
Particulate Count per Liter


Averaged, Normalized PD data, incense, 0.7 µm
Laser Scattering Ratio
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.E+00
1.E+05
2.E+05
3.E+05
4.E+05
5.E+05
Particulate Count per Liter


Averaged, Normalized PD data, incense, 1.0 µm
Laser Scattering Ratio
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.E+00
5.E+04
1.E+05
2.E+05
2.E+05
Particulate Count per Liter

# Summary of Image Data

- Fringe Contrast: Experimentally determined through image analysis. Gives intensity relationship bypassing resolution calculation. Gives general turbidity.
- Extinction Coefficient: Determined for green and red light from fringe contrast for a given particle density and distance.  Gives optical density for given distance and particle density.
- Optical Density: Experimentally calculated from fringe contrast and transmission measurements. Tells how far light will travel before being completely dispersed.
- Angstrom Coefficient: Calculated from optical density and wavelength. Gives ratio of large to small particles.
- Overall Transmission: Describes how much light is lost when traveling through a turbid environment for each particle density size distribution.

Applying chamber results to analyze aerial photos

# Application to high altitude images

- This method can be used for aerial flights where the parameters depend on distance and particle density.
- Using the same contrast analysis techniques as ground experiments, we can use photos with known distances from a high contrast target to determine optical depth experimentally which leads to particle density information.
- From aerial photographs, we can use these techniques to manipulate the color channels to get a better idea of what size and density of particles are polluting the atmosphere.

# Sources


- [1] Damien Igoe. Analysing Urban Aerosols using a Digital Camera. Dissertation as submitted to the University of Southern Queensland.

- [2] Filipe Carretas, Frank Wagner, Fernando M. Janeiro. Atmospheric visibility and Angström exponent measurements through digital photography. *Measurement* 64 (2015) 147–156.

- [3] Fernando M. Janeiro, Frank Wagner, Pedro M. Ramos, Ana Maria Silva. Atmospheric Visibility Measurements Based on a Low-Cost Digital Camera. Available from: Pedro M. Ramos.

# High altitude images analysis via color channels

- Images taken from small aircraft during high turbidity due to wildfire smoke
- Images from all different directions circling a single high contrast location at steady target distance
- Each image analysis will be used to confirm consistent results and to determine error in calculations