Improvements in Rayleigh and Raman Scattering Imaging Using a Phase Conjugate Mirror

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Overview

- Describe Rayleigh and Raman Scattering
- Discuss methods of boosting signal
- Demonstrate benefits of Phase Conjugate Mirror
- Explain polarization of light
- Show various experimental setups
- Discuss results

Flow Imaging

- Combustion dependent on mixture of fluids
- Small length and time scales
- Increase efficiency
- Two important methods
  - Rayleigh Scattering
  - Raman Scattering

Rayleigh Scattering

- Elastic scattering of light
  - No energy transferred
  - Incident and scattered light are same wavelength
- Species independent
- Highest intensity of molecular scattering methods
- Intensity of scattered light is a function of Rayleigh scattering cross section and number density
  - Reactants chosen to give constant scattering cross section in flame
- Can be used to calculate density, temperature, and flame width

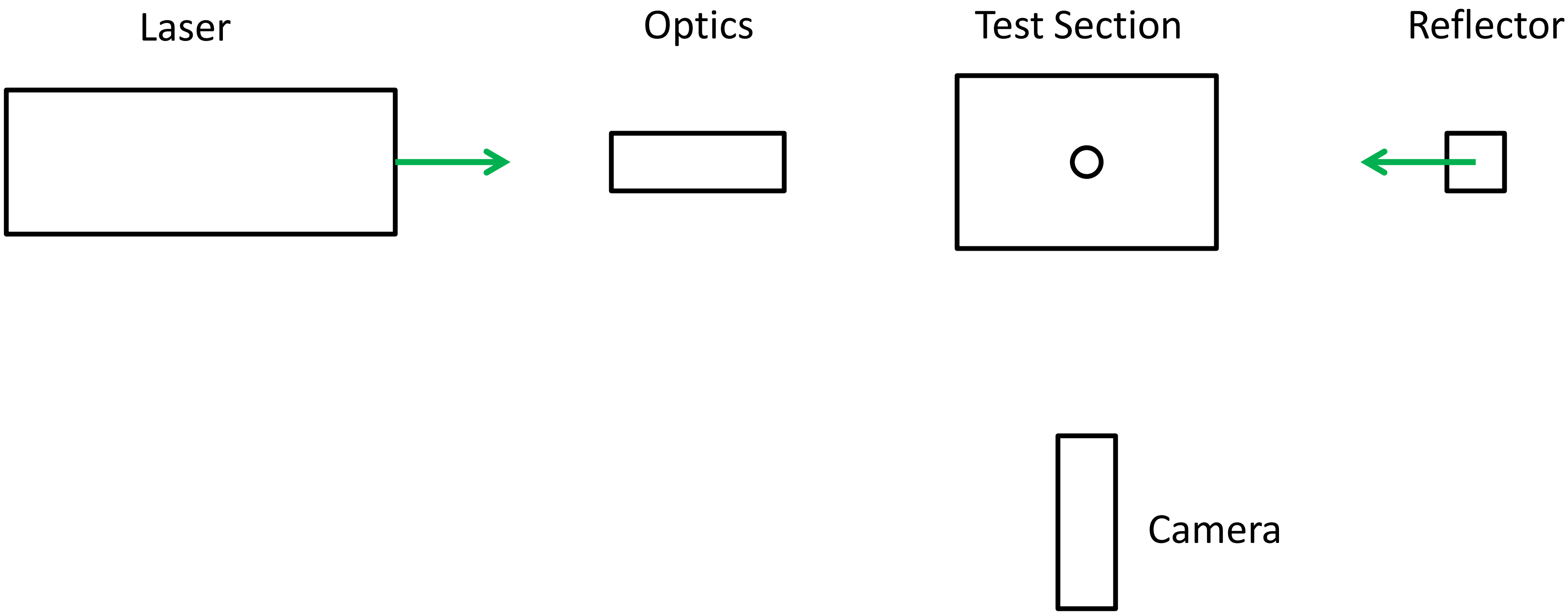
Raman Scattering

- Inelastic scattering of light
  - Energy transferred during scattering process
  - Shift in frequency of light dependent on energy states of molecule
- Species dependent
- Intensity of scattered light 3 orders of magnitude smaller than Rayleigh Scattering
- Can be used to calculate mixture fraction and temperature

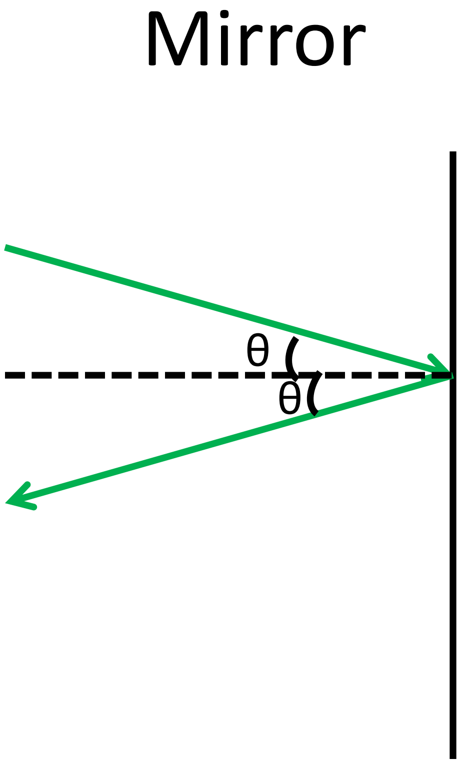
Boosting Signal

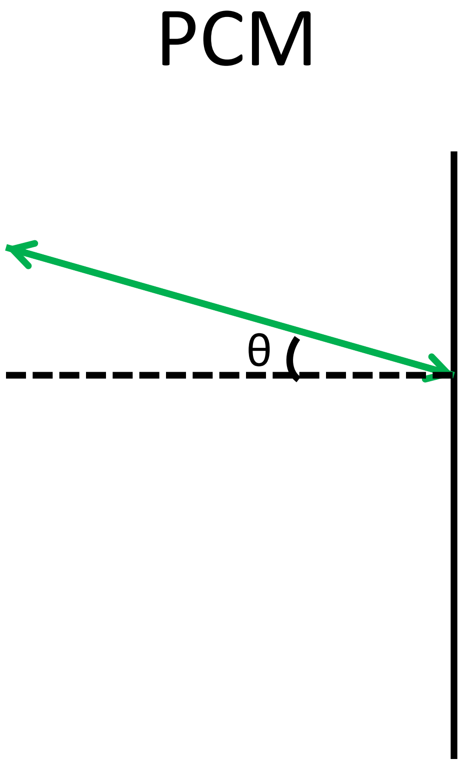
- Multiple laser system
  - Complicated
  - Expensive
- Multipass laser system
  - Impossible to align conventional mirror
  - Refraction causes beam steering
  - Can’t send beam back into laser

Multipass Laser System

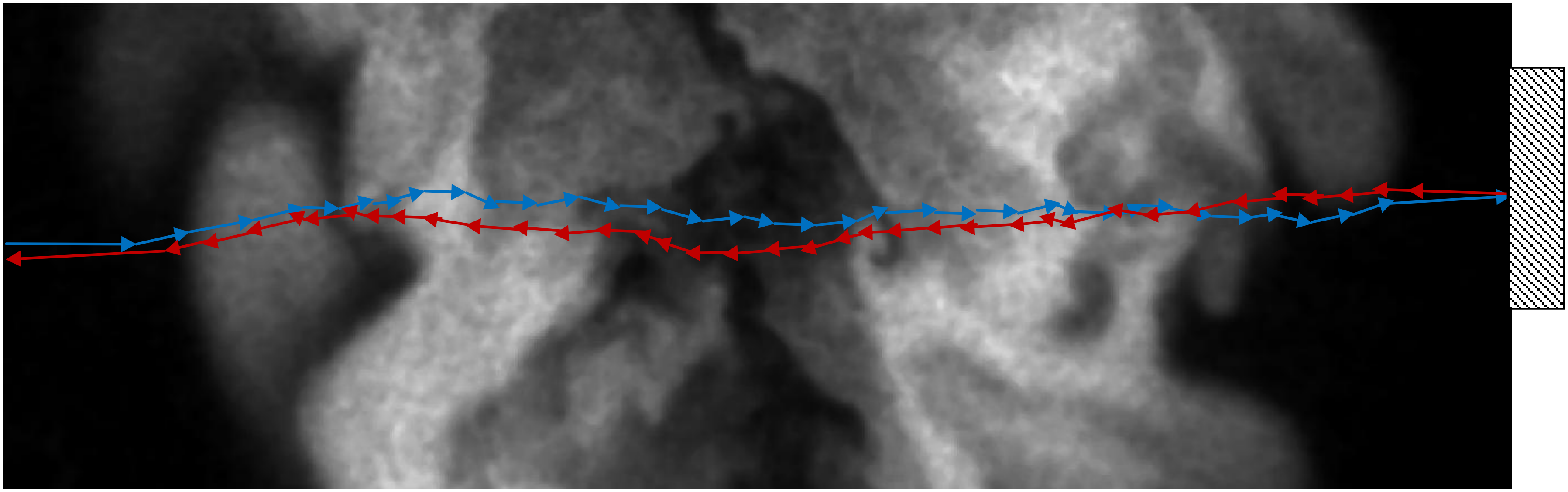


Reflection vs. Retroreflection





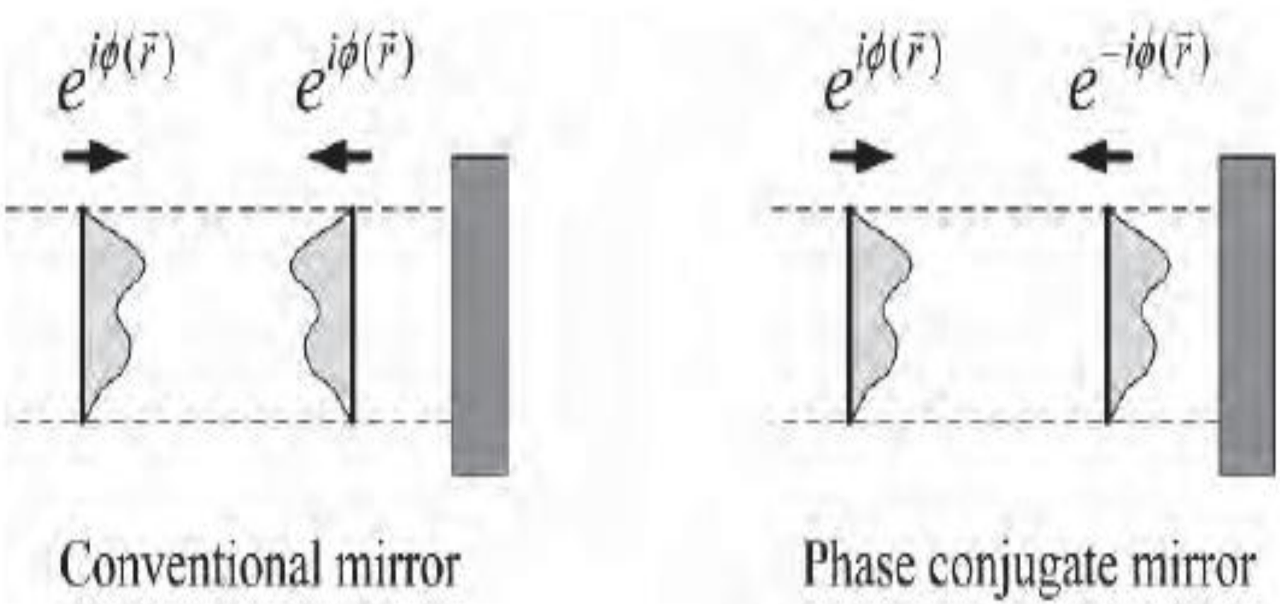
Beam Steering



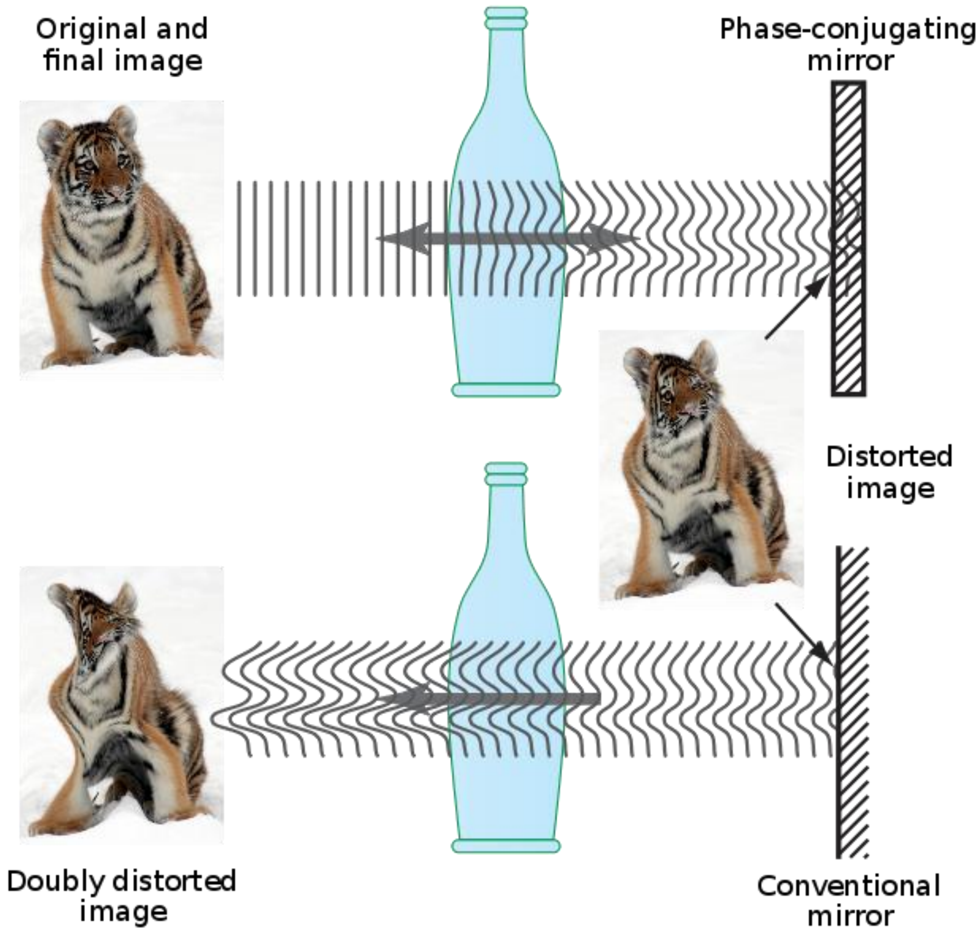
Phase Conjugate Mirror

- Uses stimulated Brillouin scattering to retroreflect beam
  - Beam creates sound waves via electrostriction and is then retroreflected from those waves
- Reverses propagation and phase directions of beam
- Avoids the degradation of spatial resolution from beam steering
- Easy to align
- Amount of light reflected is dependent on incident energy.

Mirror vs. PCM



Mirror vs. PCM

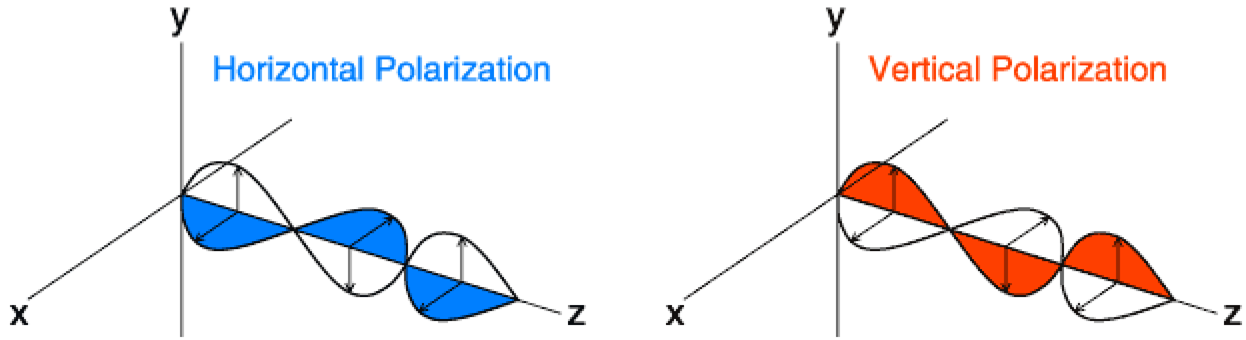


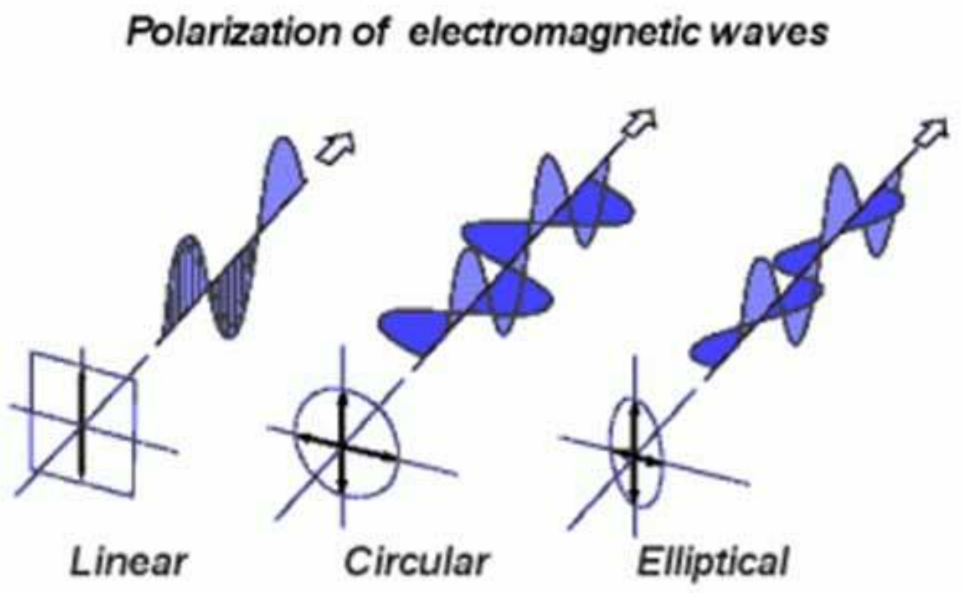
3. Phase Conjugate Principle. Wikimedia Commons.

Research Goals

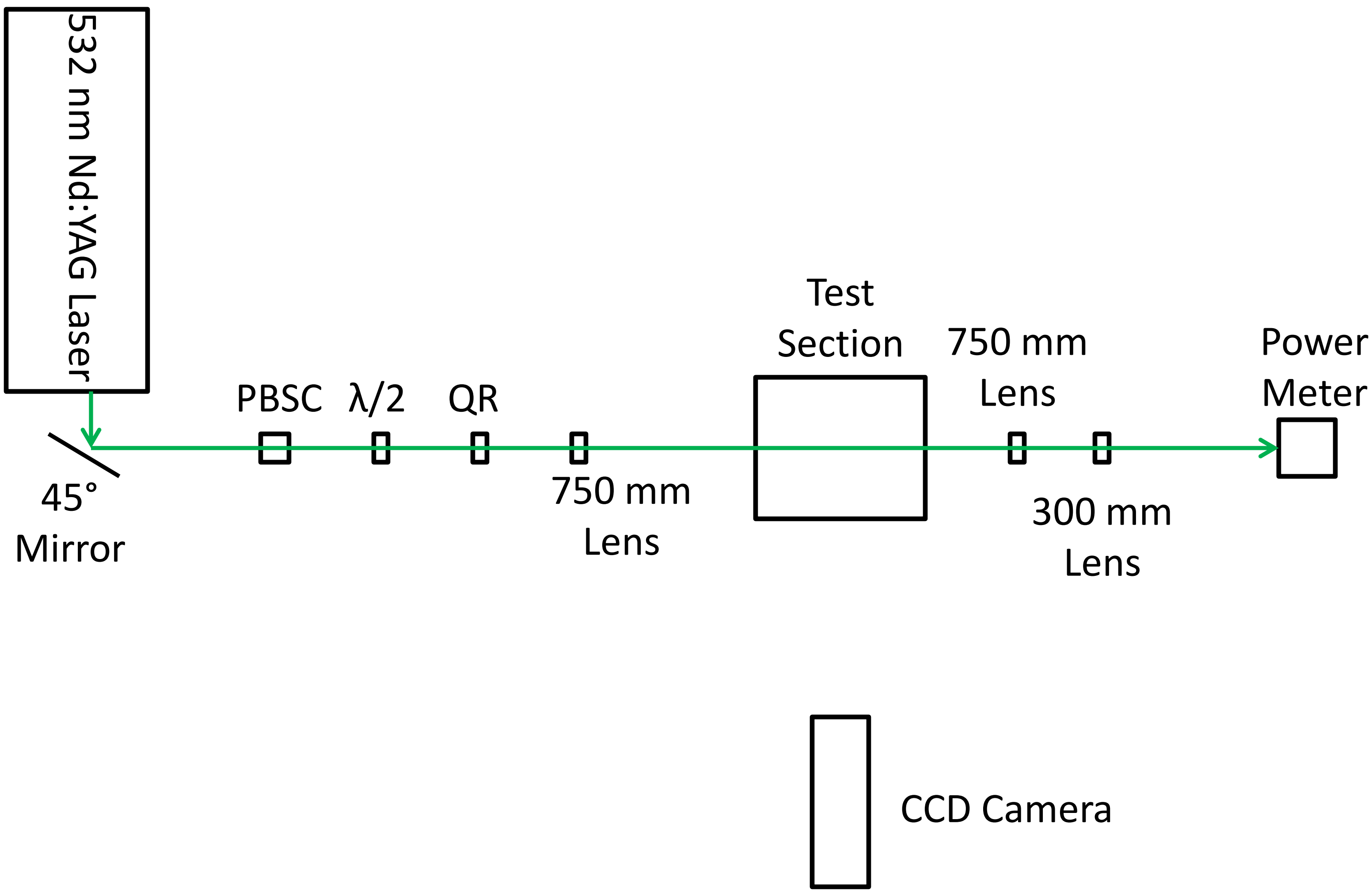
- Proof of concept using Rayleigh Scattering
- Single pass, PCM double pass, and mirror double pass experimental setups
- Perform Rayleigh scattering measurements in air and a turbulent flame
- Compare signal counts to measure boost in signal from double pass systems
- Compare beam width to measure degradation of spatial resolution from double pass systems

Polarization of Light

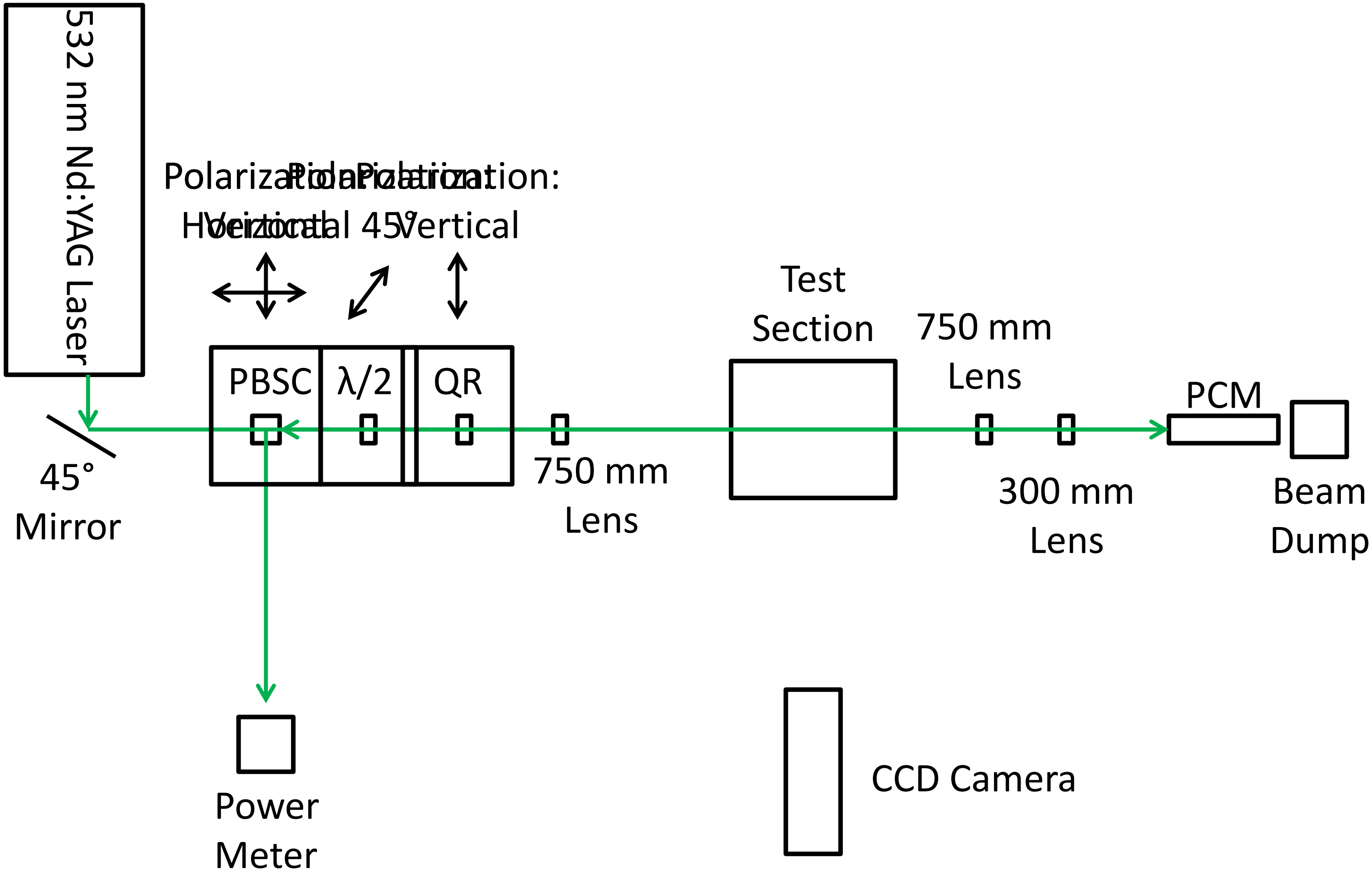




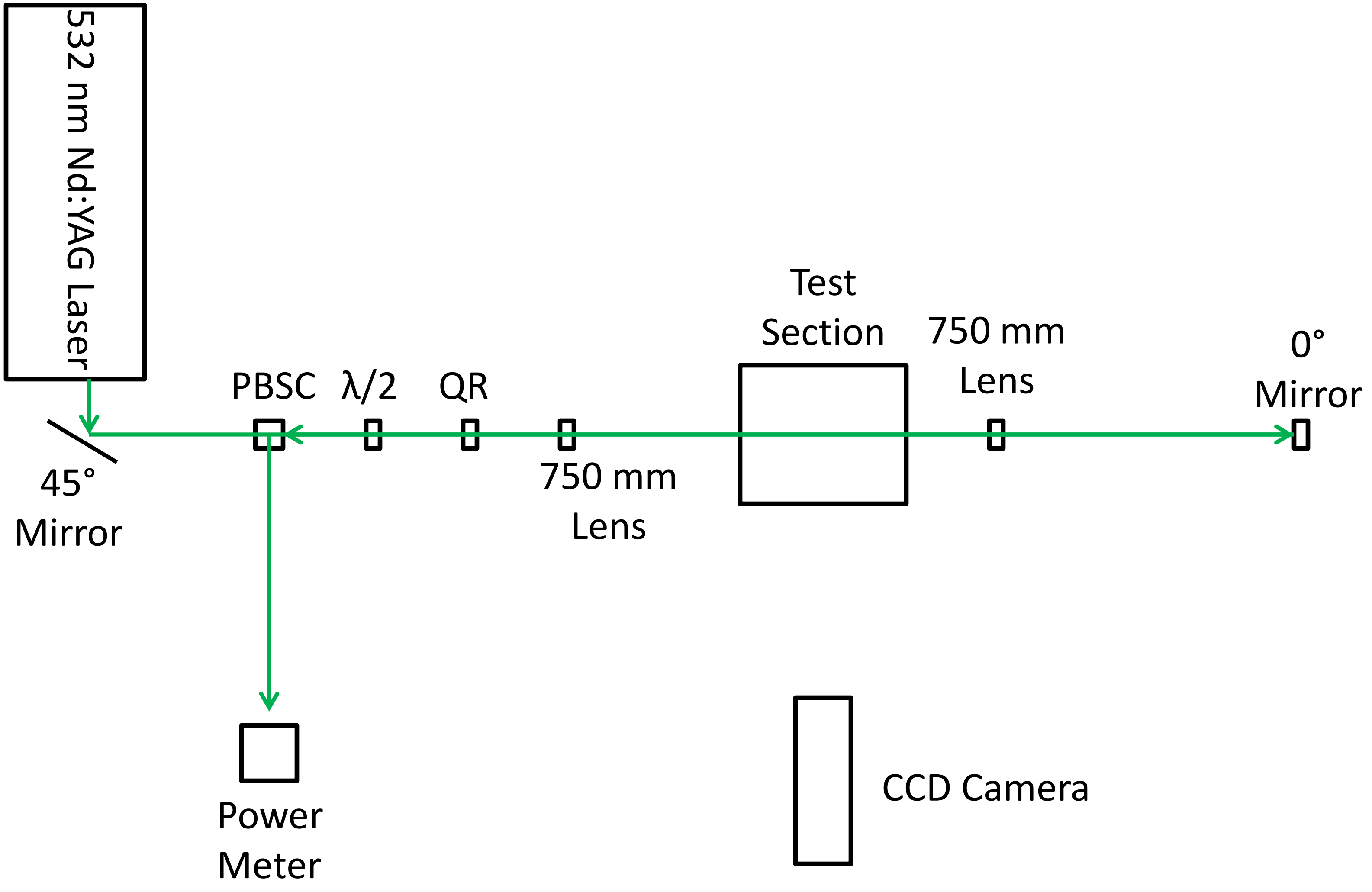
Experimental Single Pass



Experimental Setup PCM



Experimental Setup Mirror



Methods

- Measurements taken at 10 Hz
- Energy of 80 mJ per pulse
- Flame measurements taken at x/d=30
- 500 uncorrelated images per experimental setup
- Power measurements taken simultaneously to measure boost in signal
- Resolution of 9.82 microns per pixel
- Beam width was calculated using $1/e^2$

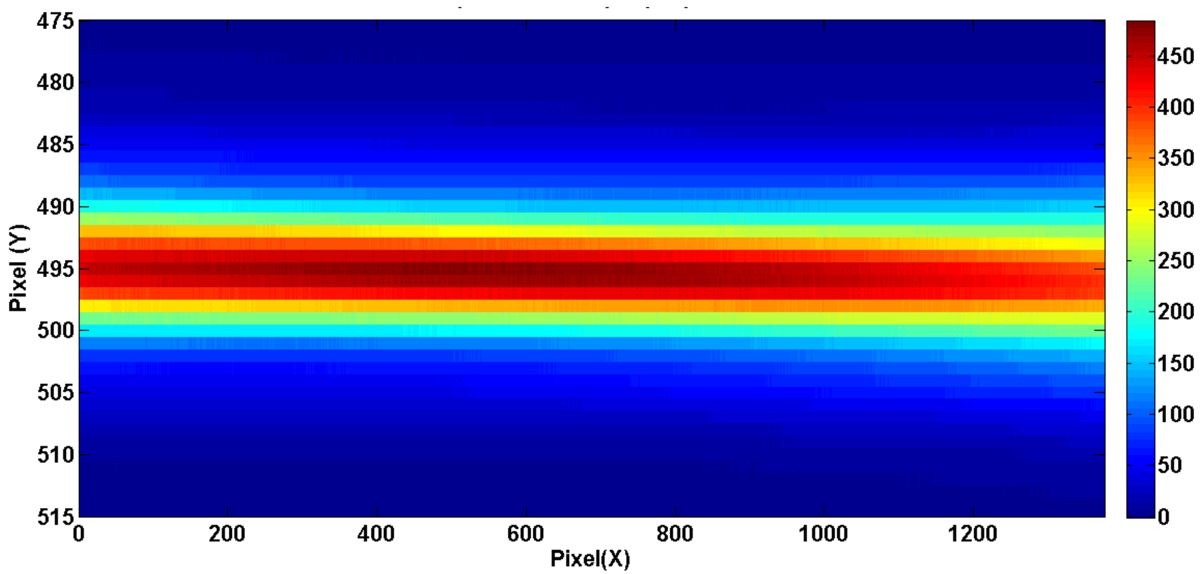
Results in Air

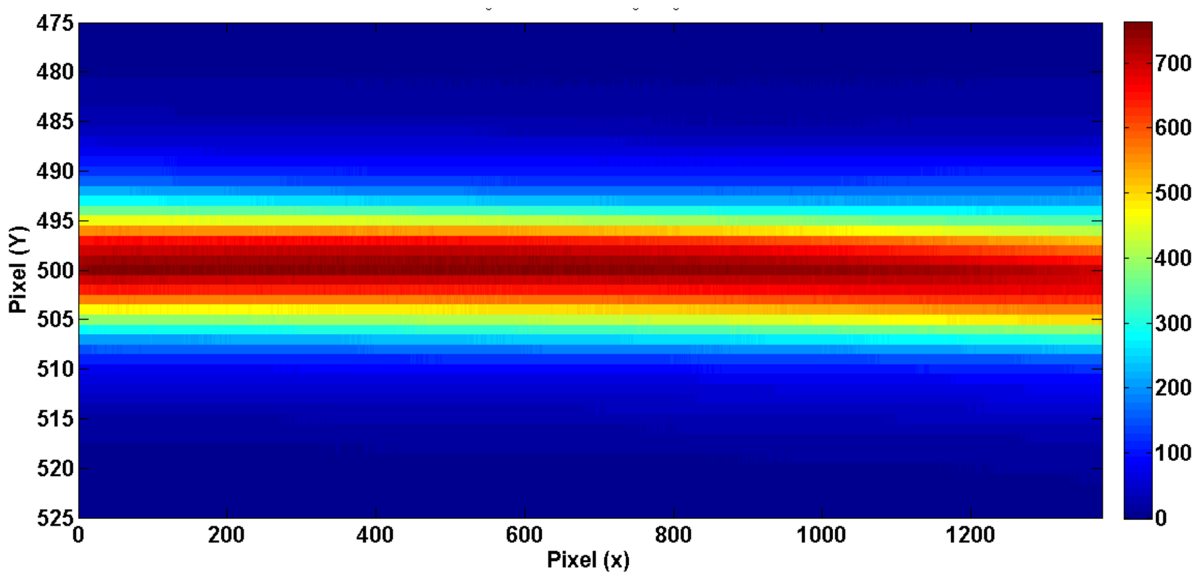
- Single Pass
  - Beam width of 15.55 pixels or 152.39 microns
- Mirror
  - Signal boosted by 81%
  - Beam width increase of 3.546 pixels or 34.751 microns
  - Beam width increase of approximately 22%
- PCM
  - Signal boosted by 49%
  - Beam width increase of 3.006 pixels or 29.4 microns 18.556
  - Beam width increase of approximately 19%

Results in Flame

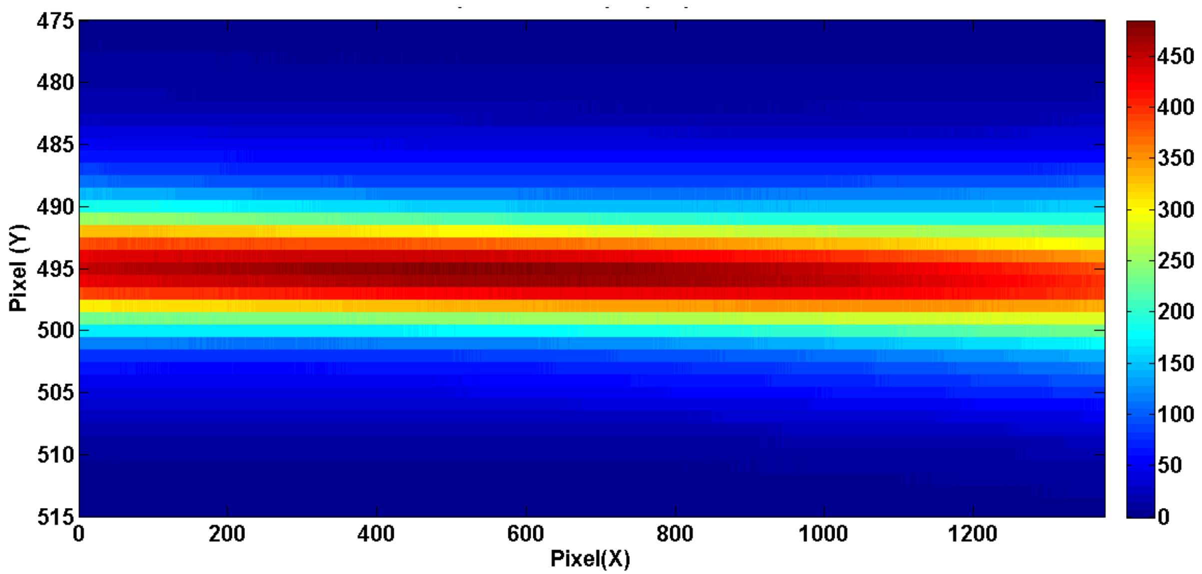
- Single Pass
  - Beam width of 18.572 or 182 microns
- Mirror
  - Signal boosted by 78%
  - Beam width increase of 10.198 pixels or 99.94 microns
  - Beam width increase of approximately 55%
- PCM
  - Signal boosted by 48%
  - Beam width increase of 0.722 pixels or 7.076 microns
  - Beam width increase of 4%

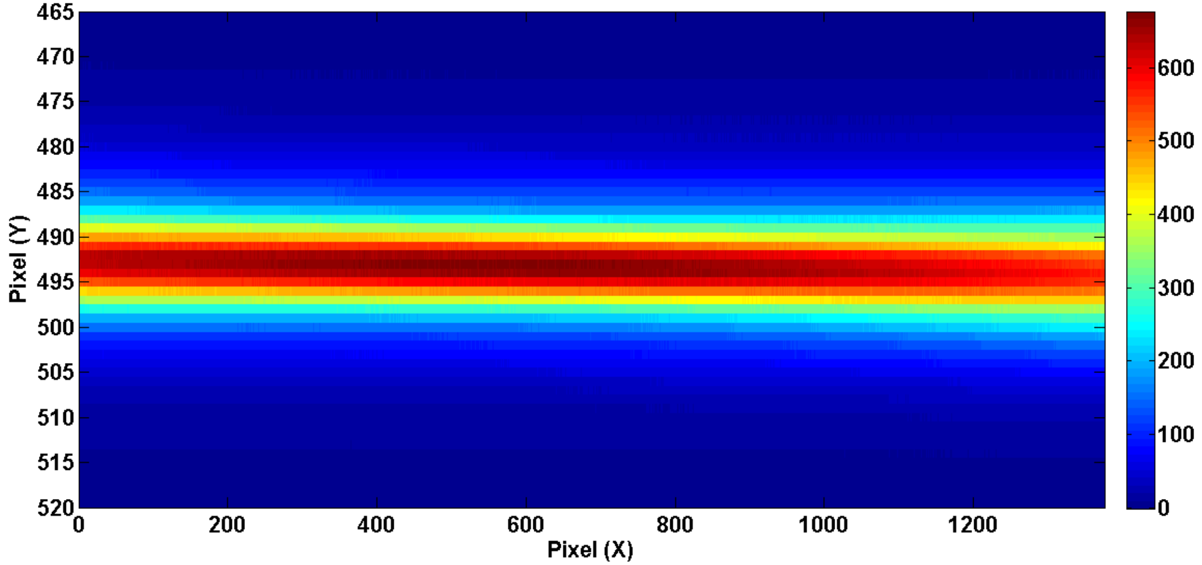
Beam Image Single Pass vs. Mirror Air



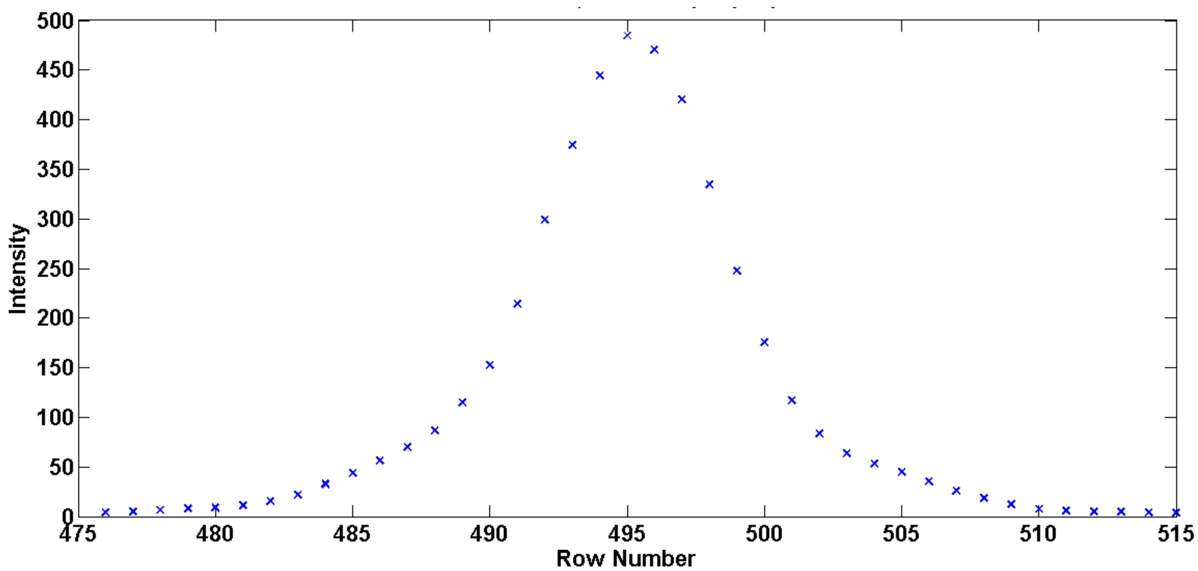


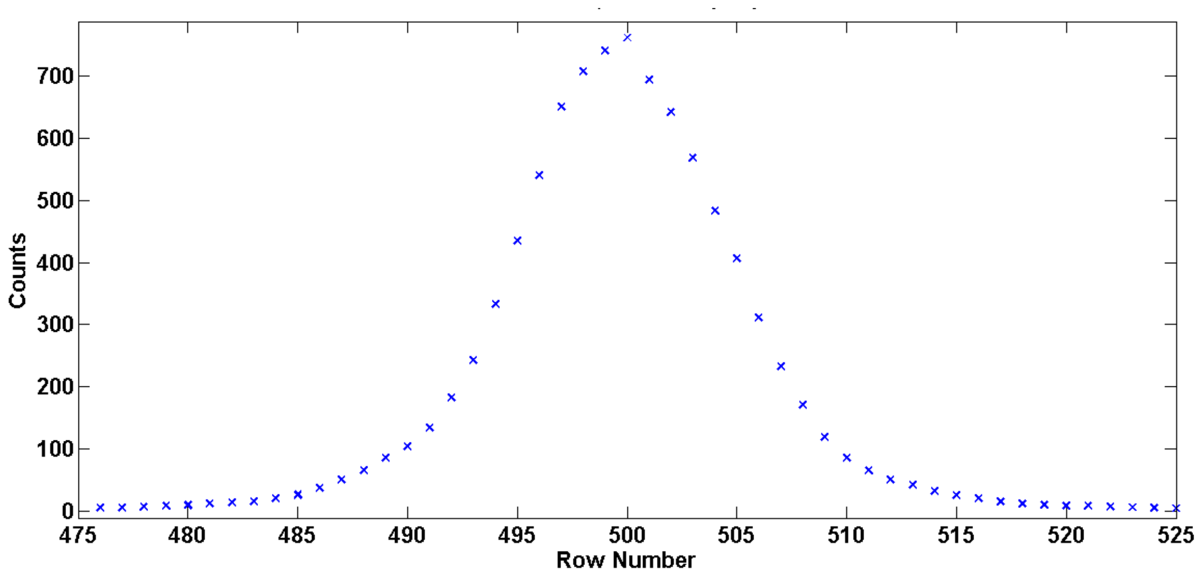
Beam Image Single Pass vs. PCM Air



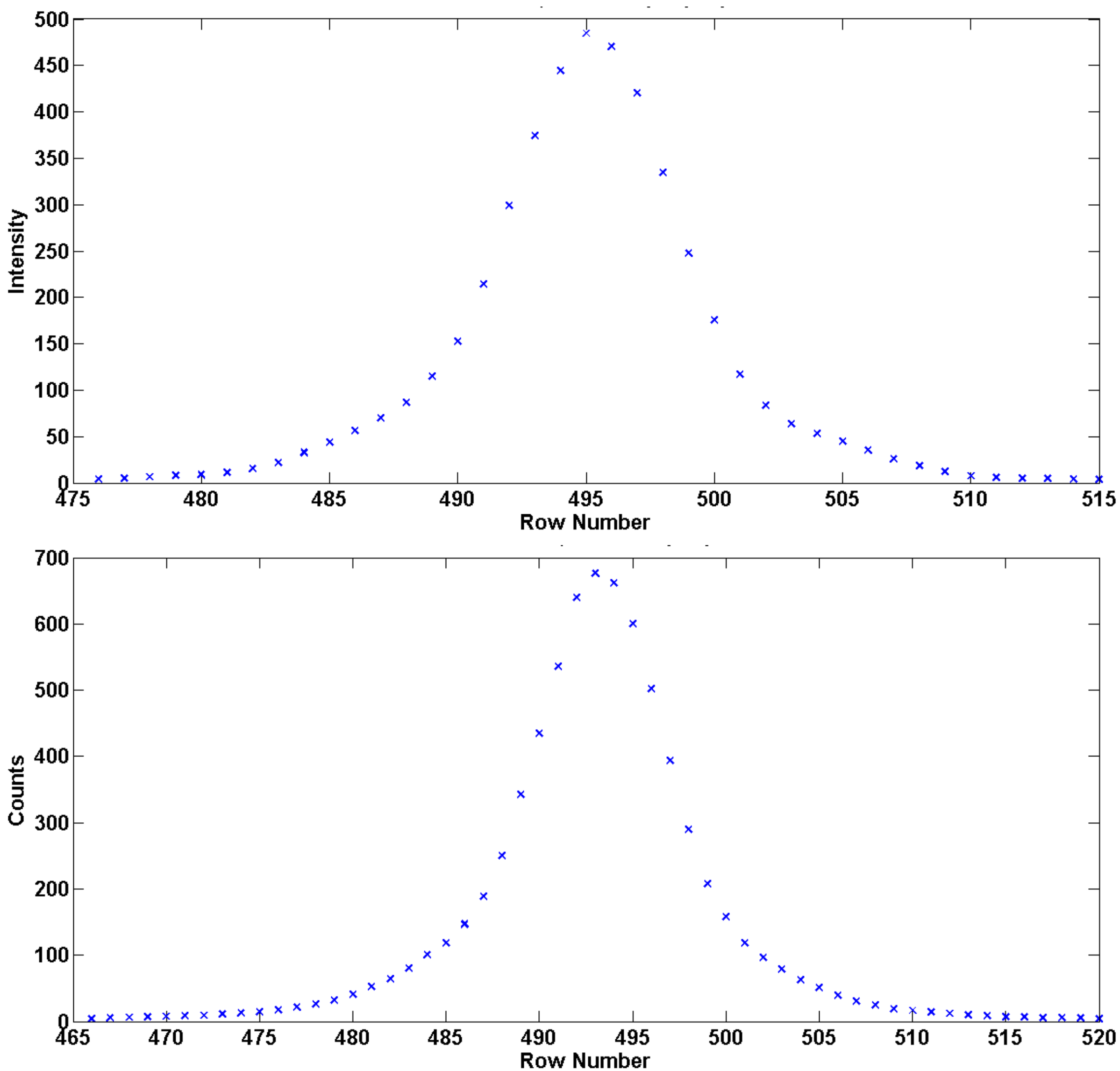


Beam Profile Single Pass vs. Mirror Air

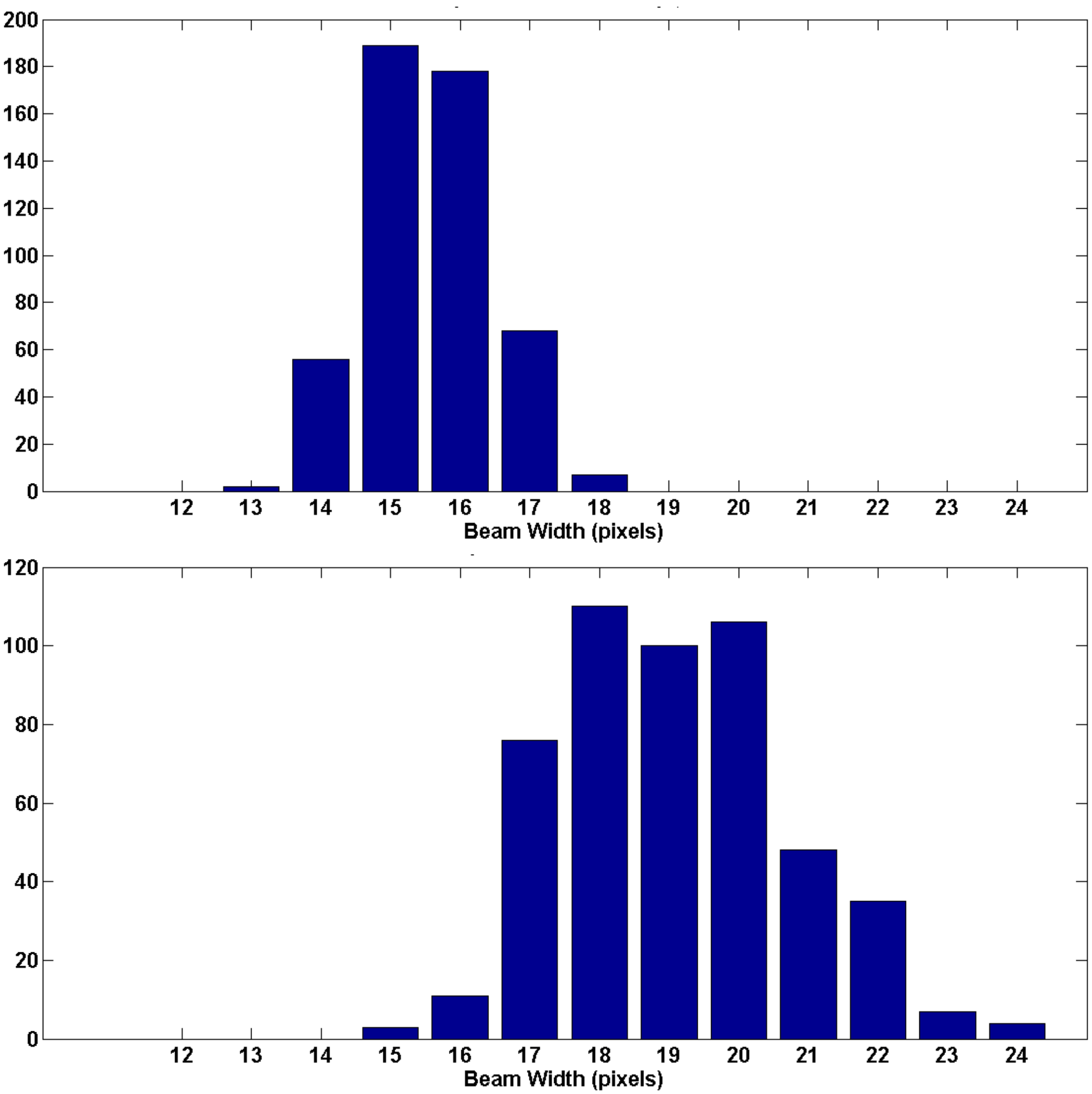




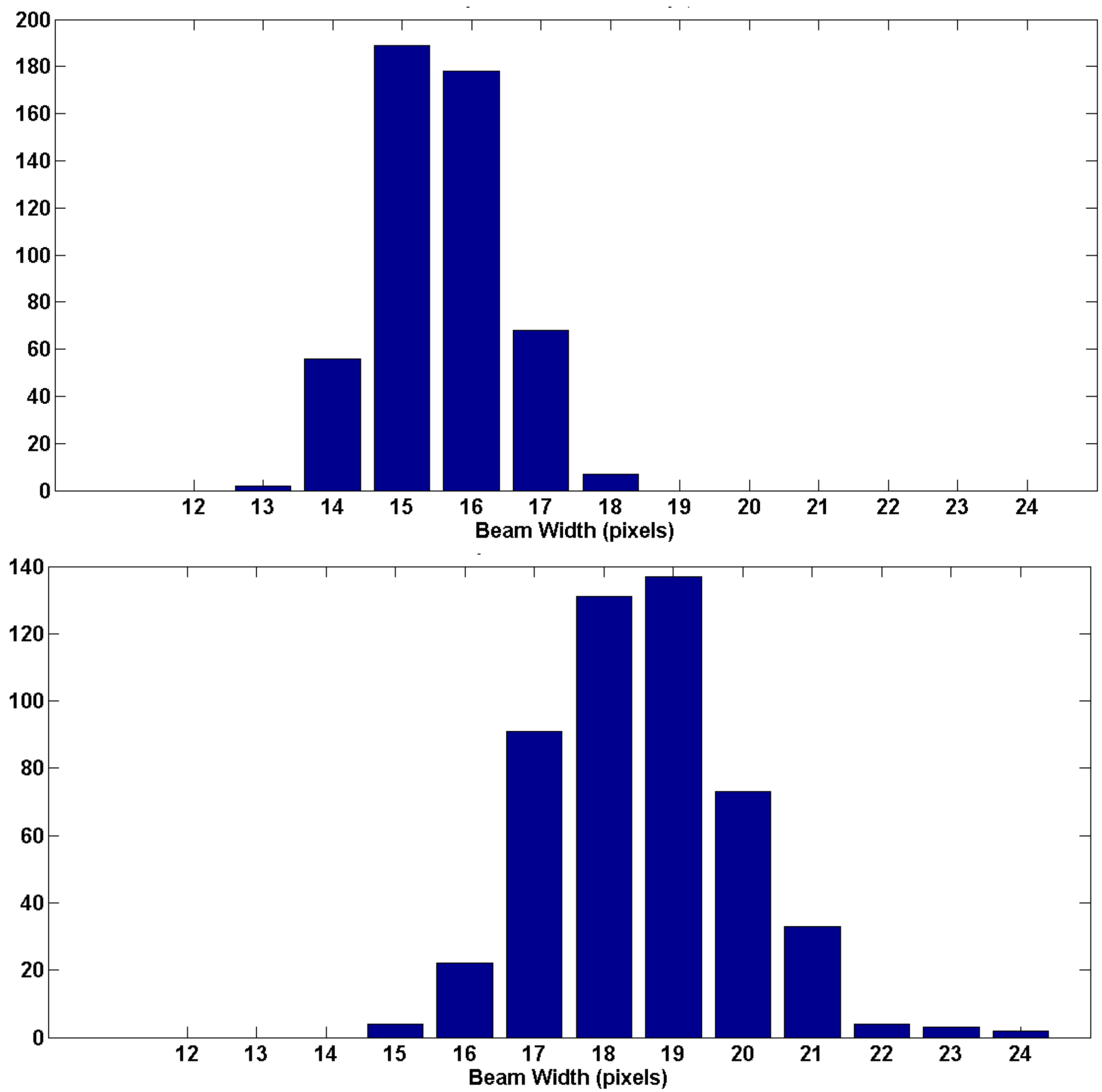
Beam Profile Single Pass vs. PCM Air



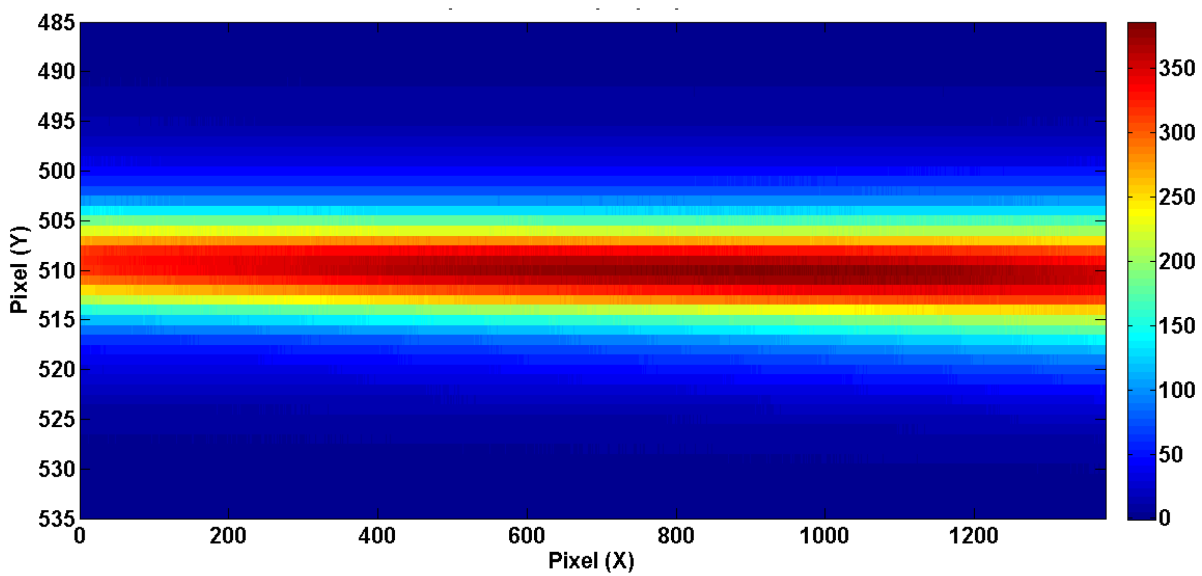
Beam Width Single Pass vs. Mirror Air

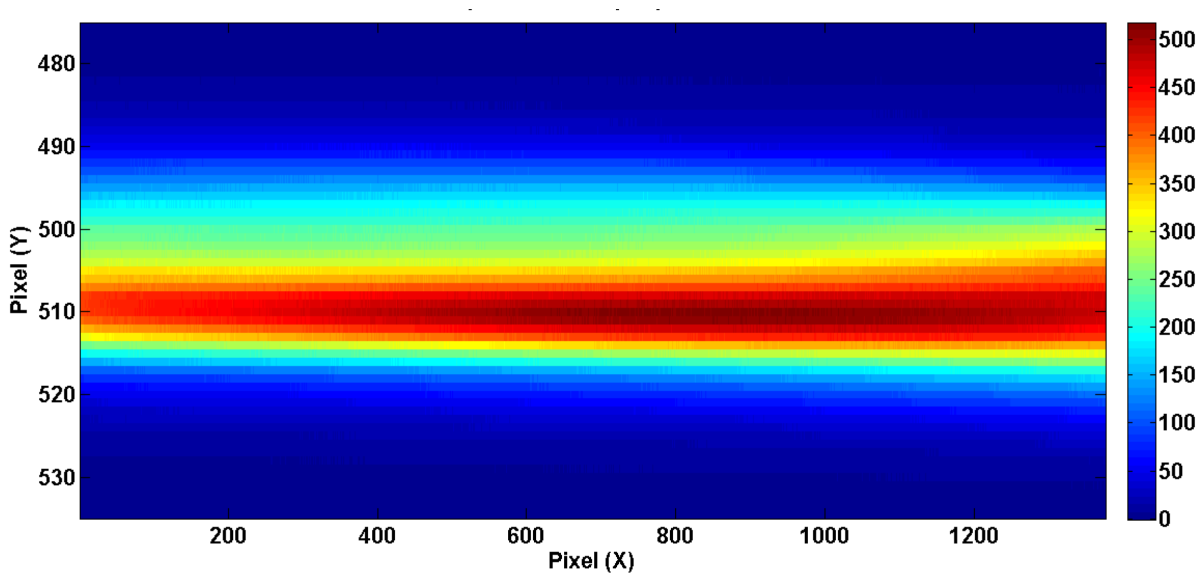


Beam Width Single Pass vs. PCM Air

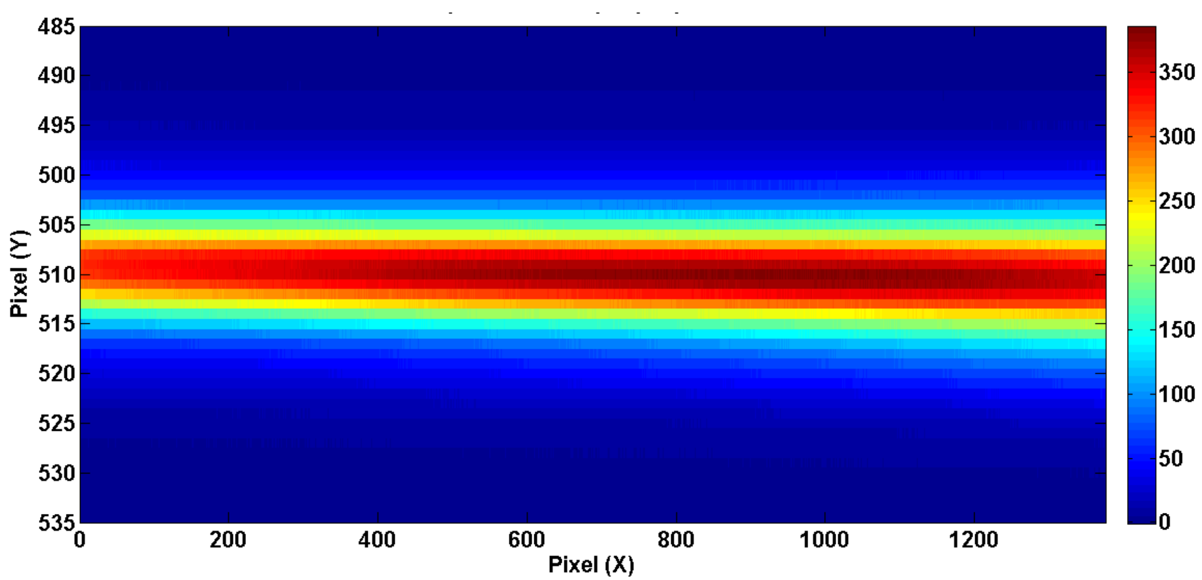


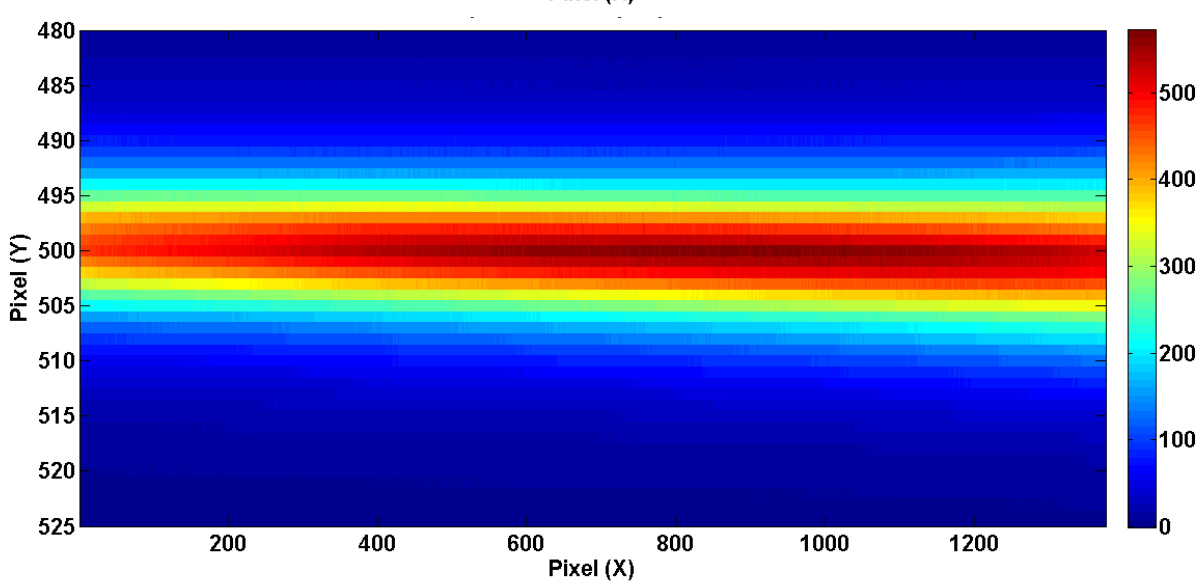
Beam Image Single Pass vs. Mirror Flame



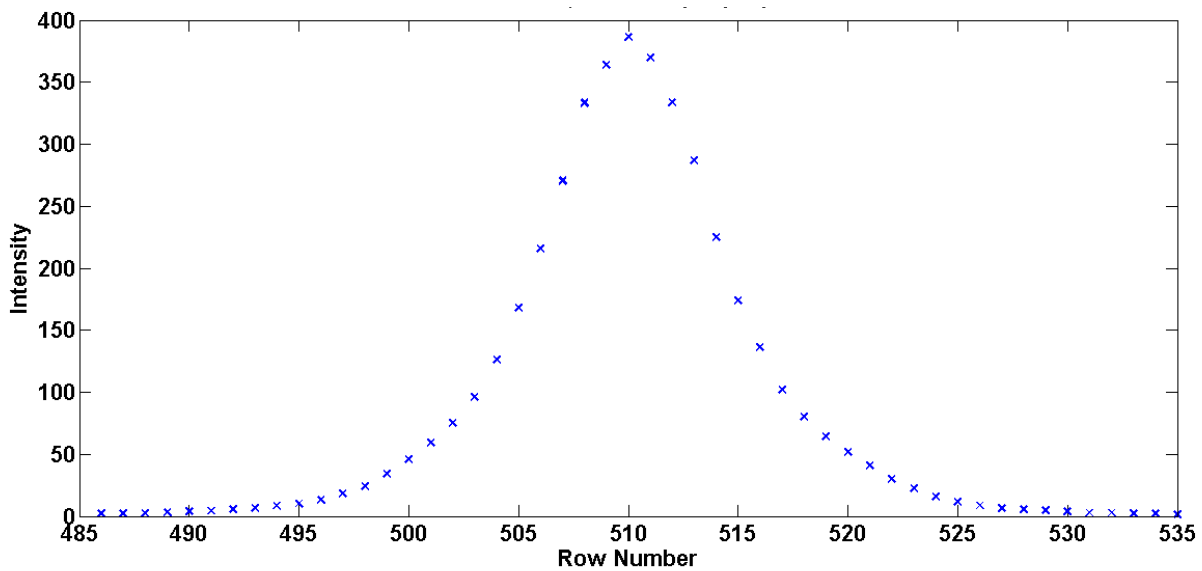


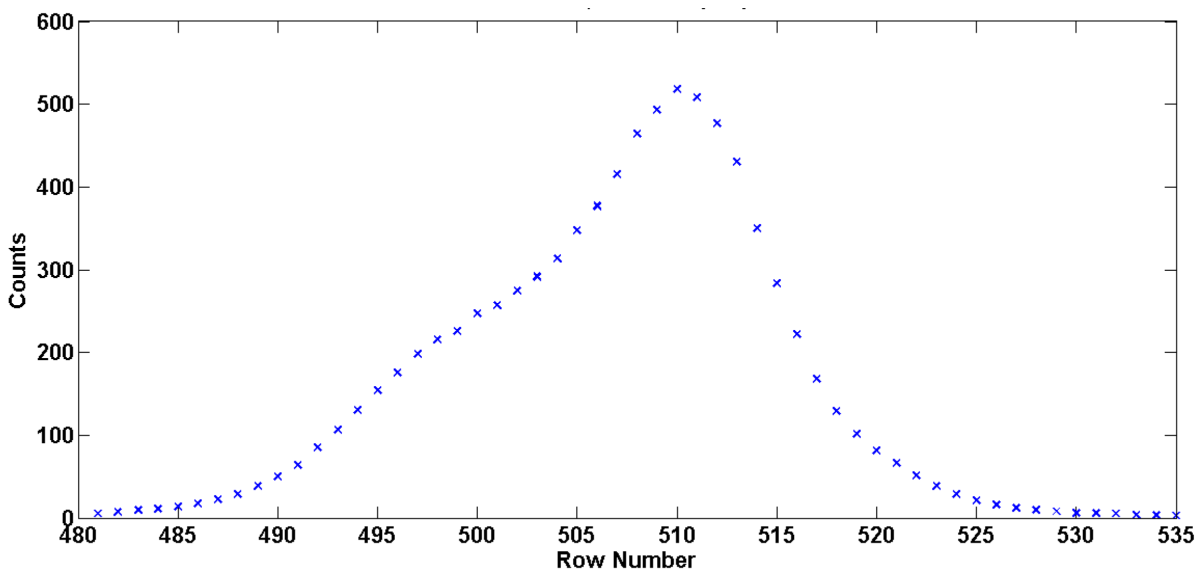
Beam Image Single Pass vs. Mirror Flame



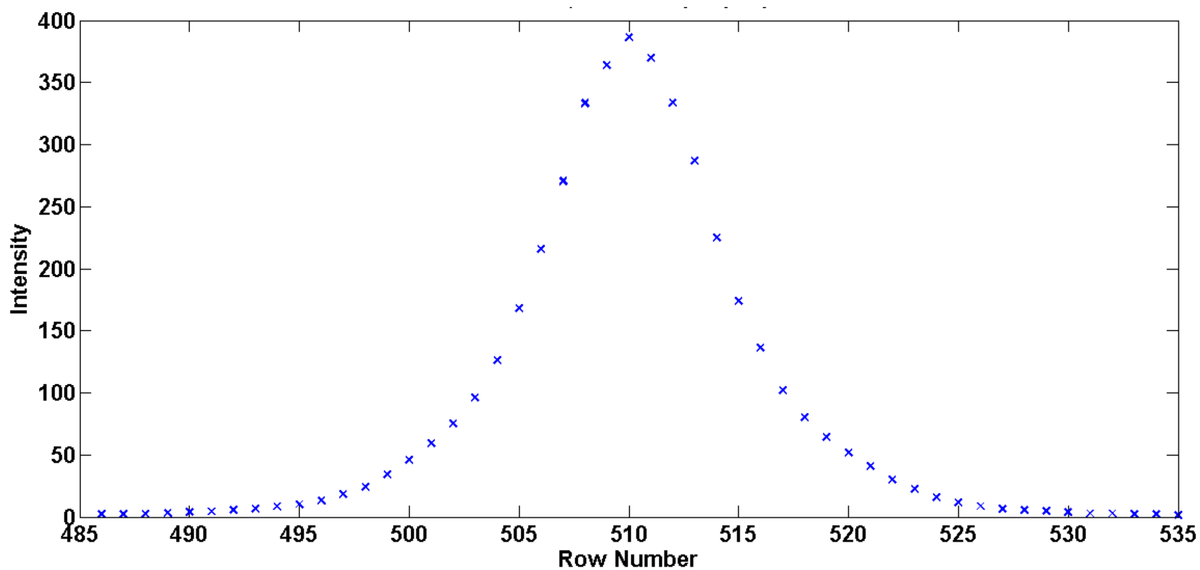


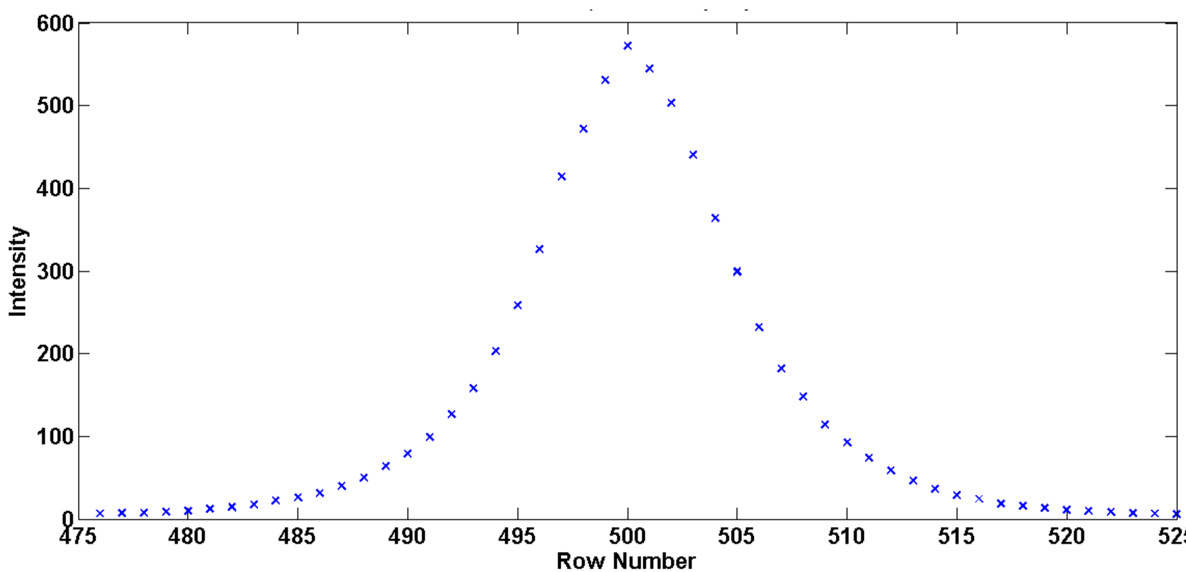
Beam Profile Single Pass vs. Mirror Flame



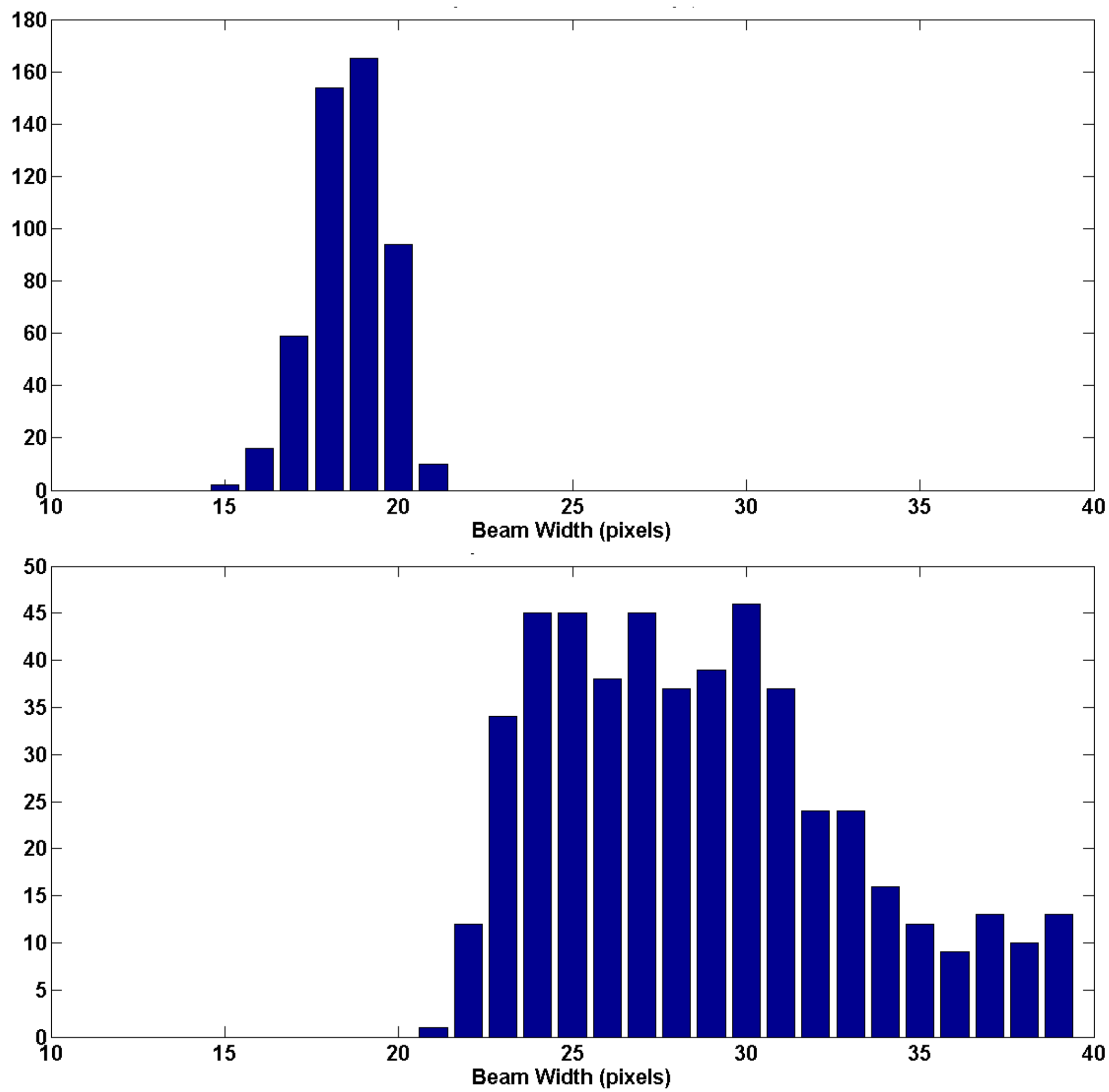


Beam Profile Single Pass vs. PCM Flame

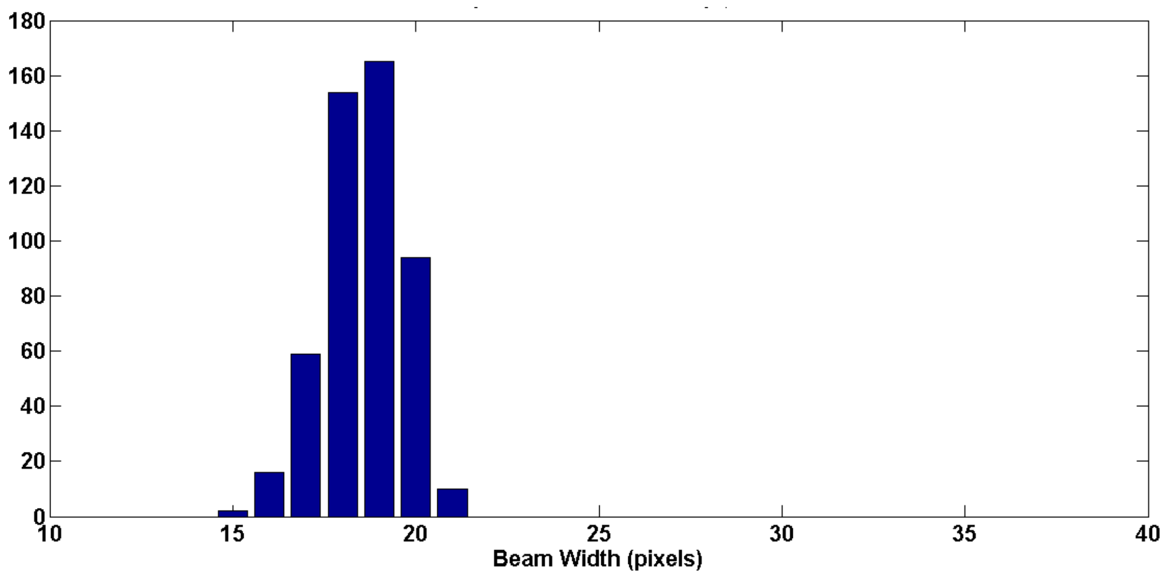


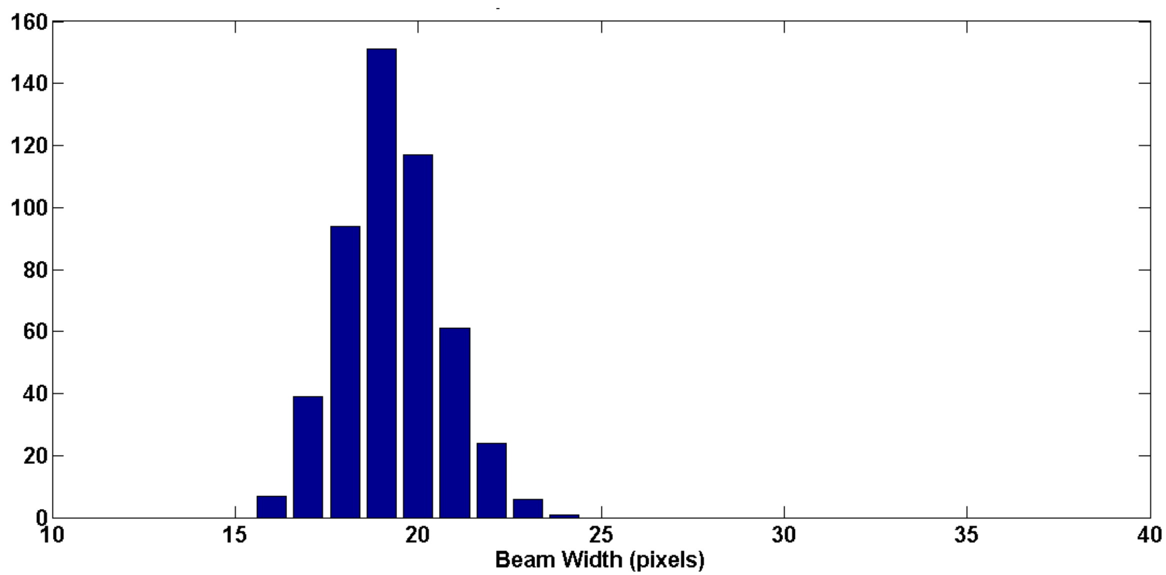


Beam Width Single Pass vs. Mirror Flame

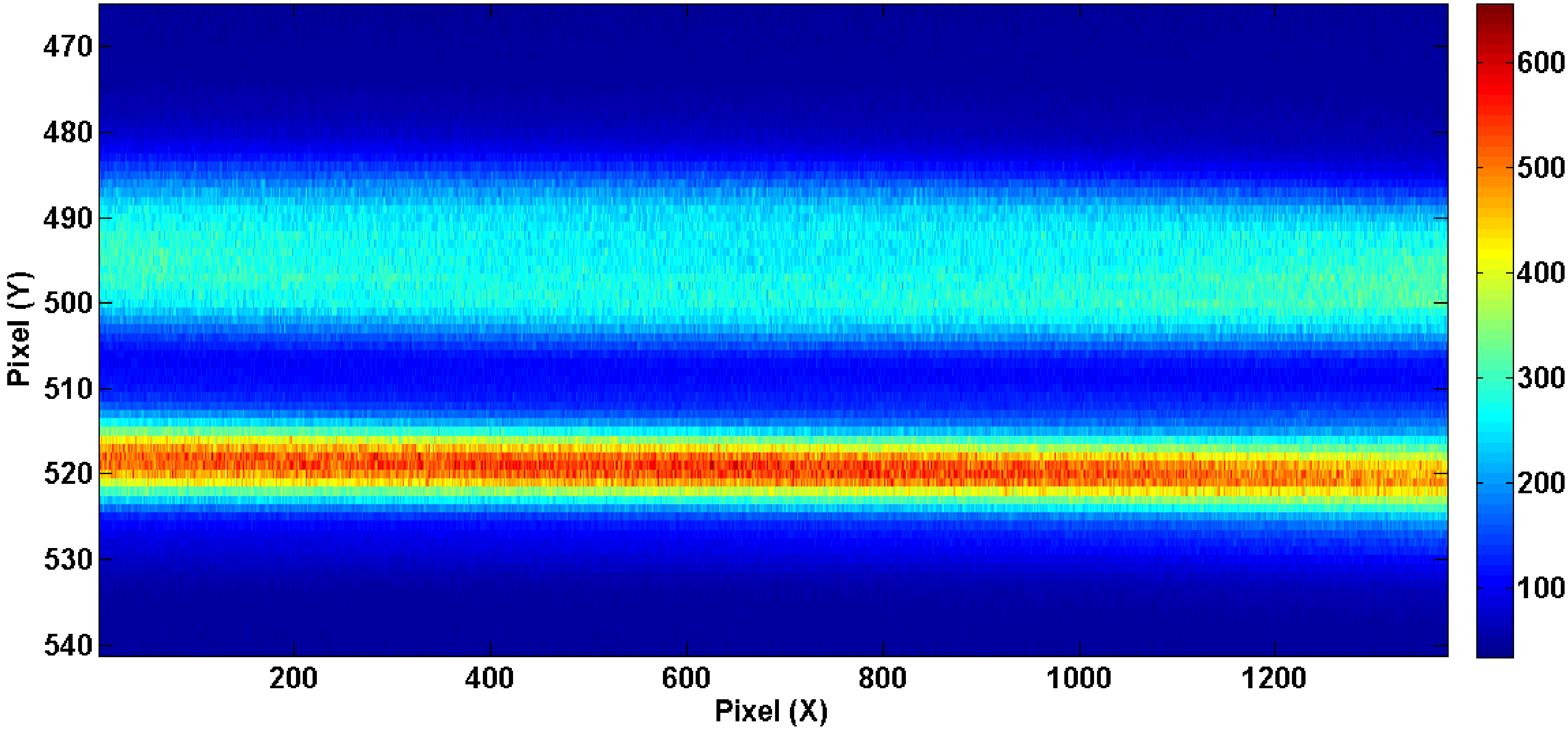


Beam Width Single Pass vs. Mirror Flame





Instantaneous Mirror Measurement in Flame



Conclusions

- The mirror was more successful in boosting the signal of the Rayleigh scattering measurement in both air and the flame
- The PCM was more successful in boosting the signal of the Rayleigh scattering measurement without degrading the spatial resolution of the flame measurement
- There is an unknown energy transfer mechanism occurring in the PCM

Acknowledgements

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- Frederik Fuest
- All the other members of TCRL
- Friends and Family

Questions?