Phase-space tomography for measuring partially coherent fields of light sources

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Outline

- Introduction
- Goals
- Experiment design
- Experiment setup
- Results
- Discussion and conclusion
- Future work
- Acknowledgement

Introduction

- Ambiguity function
  - Definition

$$A(x', z; p') = \left(\frac{k}{2\pi}\right) \int W\left(x - \frac{x'}{2}; x + \frac{x'}{2}, z\right) e^{-ikx \cdot p'} dx \qquad (1)$$

  - Cross-spectral density

$$W(x_1, x_2; z) = \langle U^*(x_1; z) U(x_2; z) \rangle \qquad (2)$$

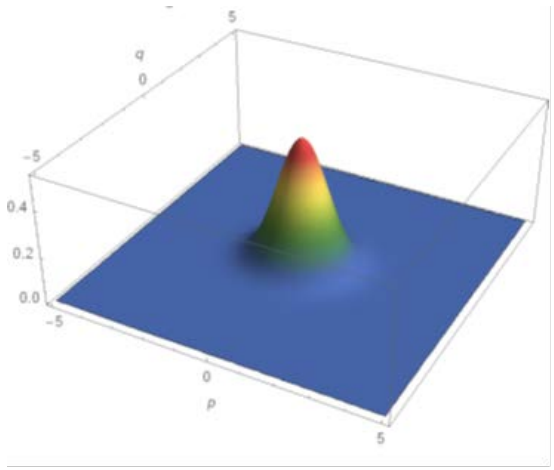
  - Spectral density

$$S(x; z) = W(x, x; z) = \langle |U(x; z)|^2 \rangle \qquad (3)$$

- Properties
  - Propagation in systems follows ABCD transformation

- Relation to Wigner function

$$A(x', z; p') = \left(\frac{k}{2\pi}\right) \iint B(x, z; p) e^{ik(x' \cdot p - x \cdot p')} dx dp \qquad (4)$$

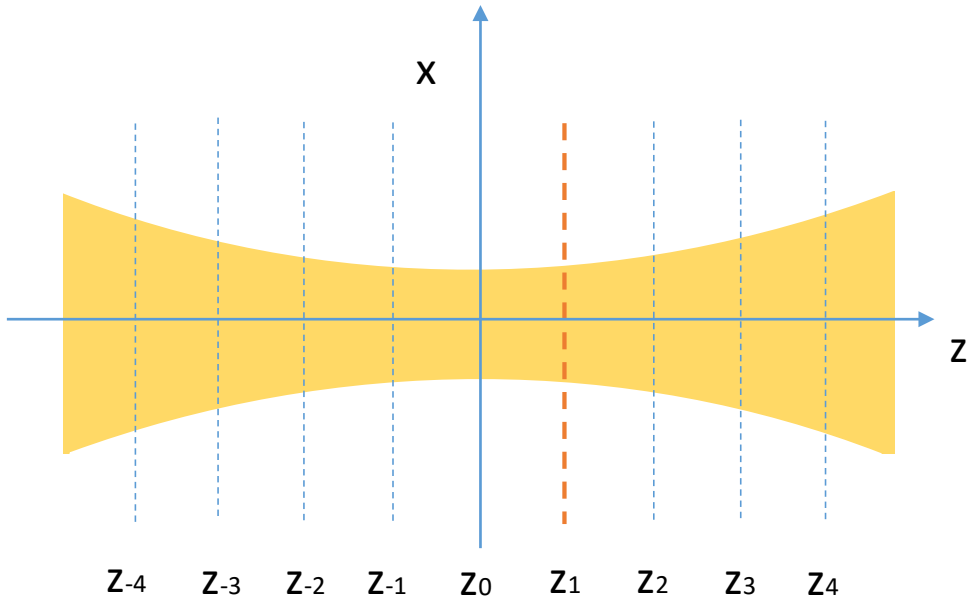


Eq 1-4, Cho and Alonso, Ambiguity function and phase-space tomography for nonparaxial fields, Opt.Soc.Am. 2011

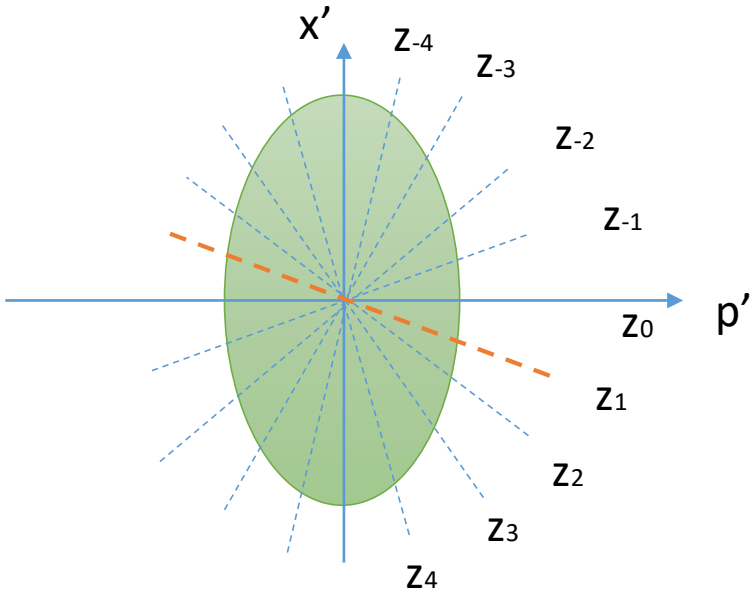
Introduction

- Phase-space tomography in paraxial and non-paraxial region
  - Tu and Tamura, 1998
  - Cho and Alonso, 2011

$$A_{np}(-zp', 0; p') = \frac{k}{2\pi} \int S(x, z) \exp(-ikp'x)\, dx \quad (5)$$



Two-dimensional space distribution*

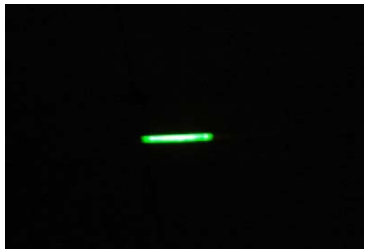


Phase space distribution*

Eq 5, Cho and Alonso, Ambiguity function and phase-space tomography for nonparaxial fields, Opt.Soc.Am. 2011

Goals

1. Measure field distributions for light sources
   - 2D free space
   - Non-paraxial field



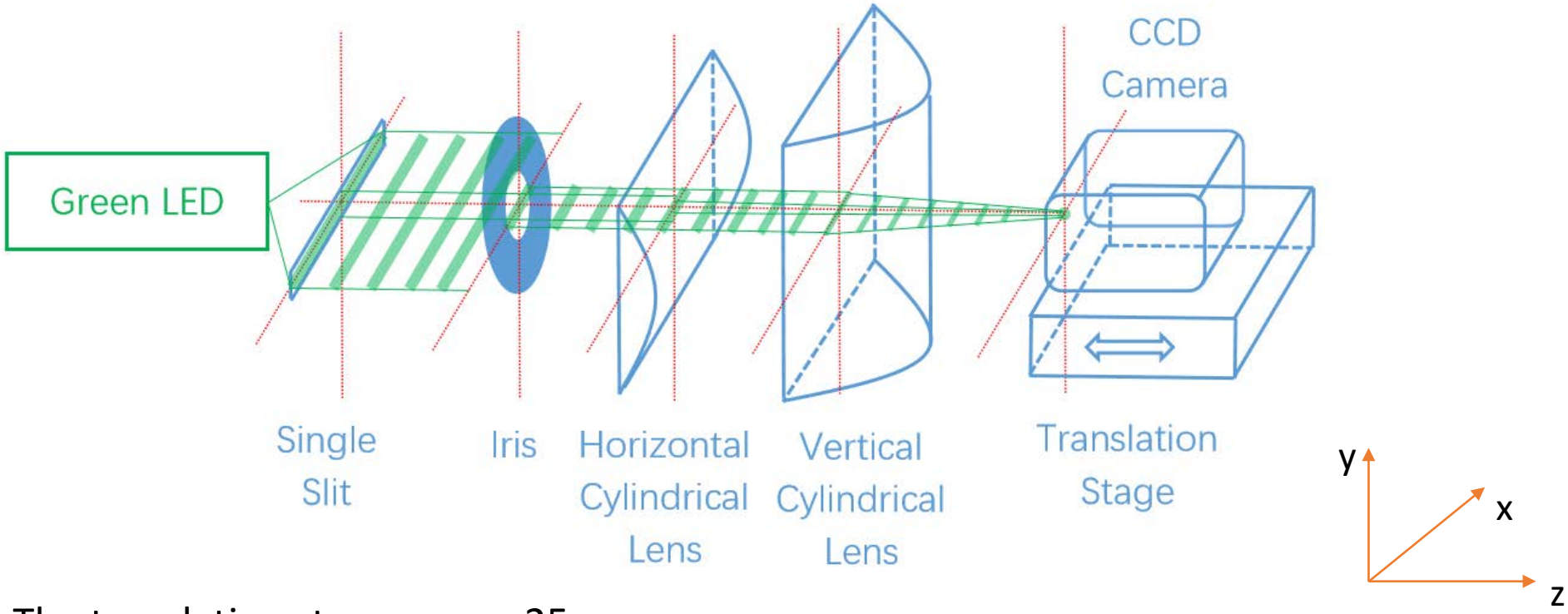
A representative linear field of laser

2. Construct ambiguity functions
3. Analyze the field distributions and their ambiguity functions

Experiment Design

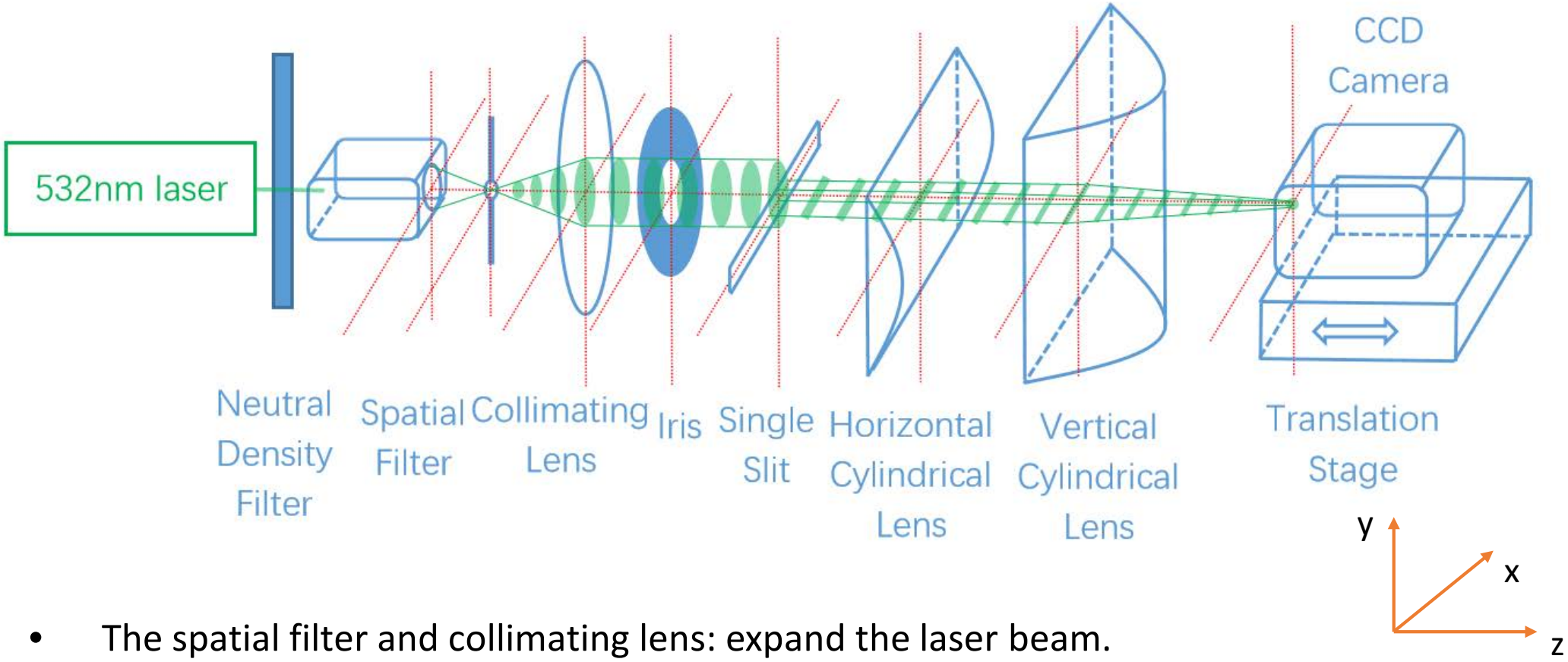
- Sources: laser, green LED, white LED, incandescent lamp
- Detector: CCD arrays
- Apply lenses to create a linear image area similar to the waist of laser field

Experiment Design



- The translation stage range: 25mm.
- z direction increment: 200μm, 500 μm
- The match of the two cylindrical lens focus light to the CCD camera
- 1st lens: for obtaining a horizontal 2D filed in transverse plane
- 2nd lens: large power for a non-paraxial transverse field
- Non-paraxial angle: >5°

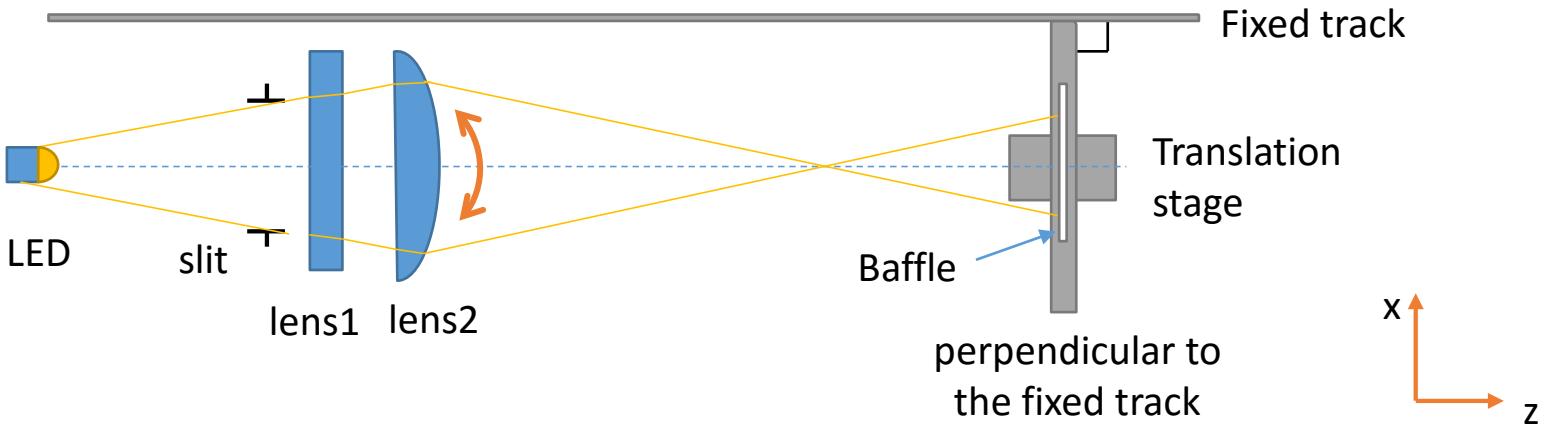
Experiment Design



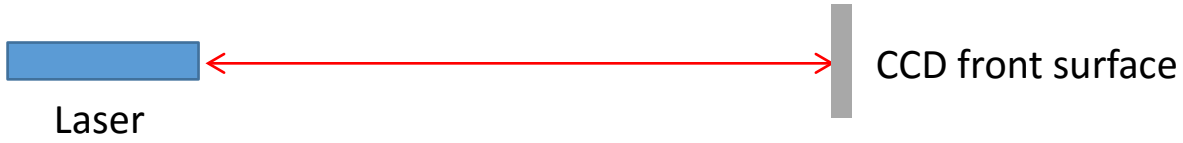
- The spatial filter and collimating lens: expand the laser beam.
- Neutral density filter: avoid saturation of the CCD camera.
- Non-paraxial angle: >5°

Experiment Design

- Alignment
  - Adjust cylindrical lens2 to make sure the beam centered at different z position

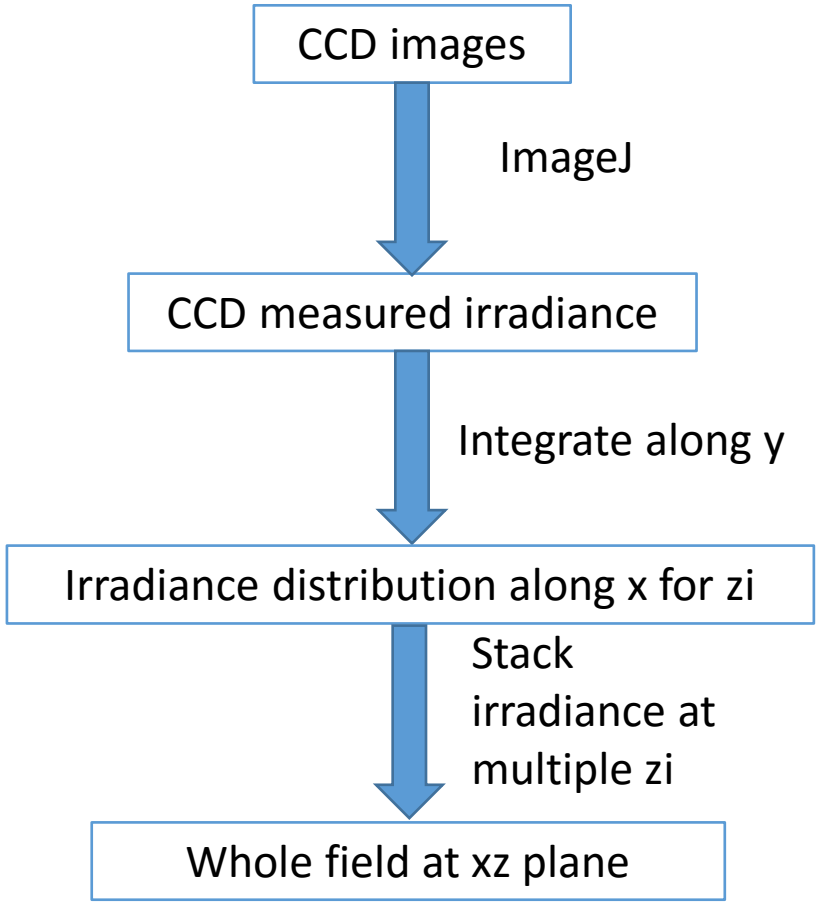


  - Switch baffle to CCD and align the CCD by a laser.

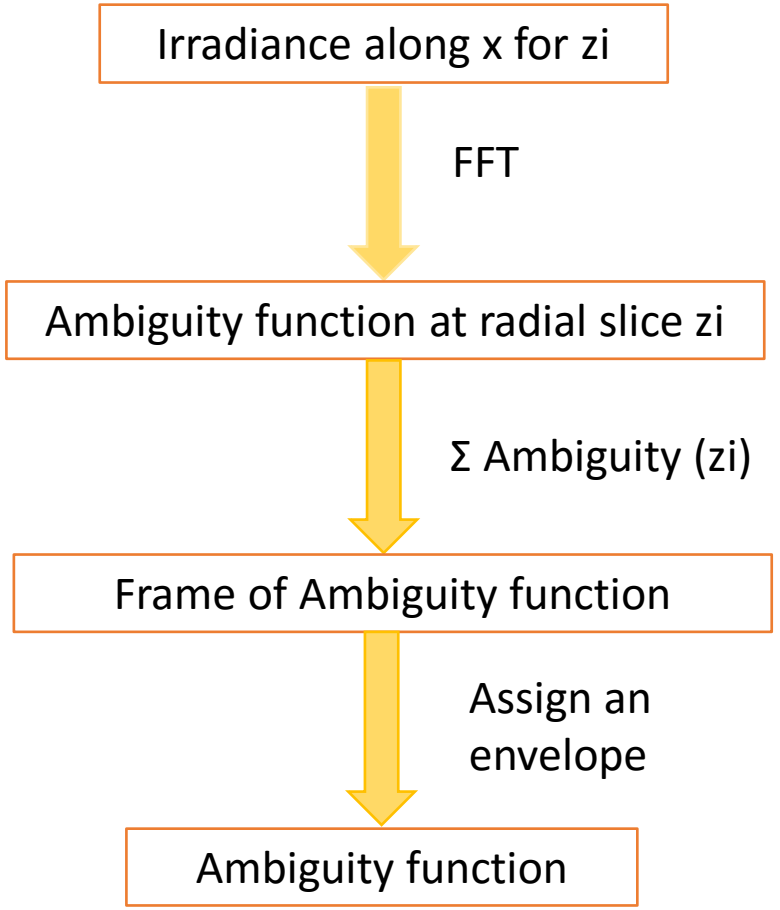


Experiment Design

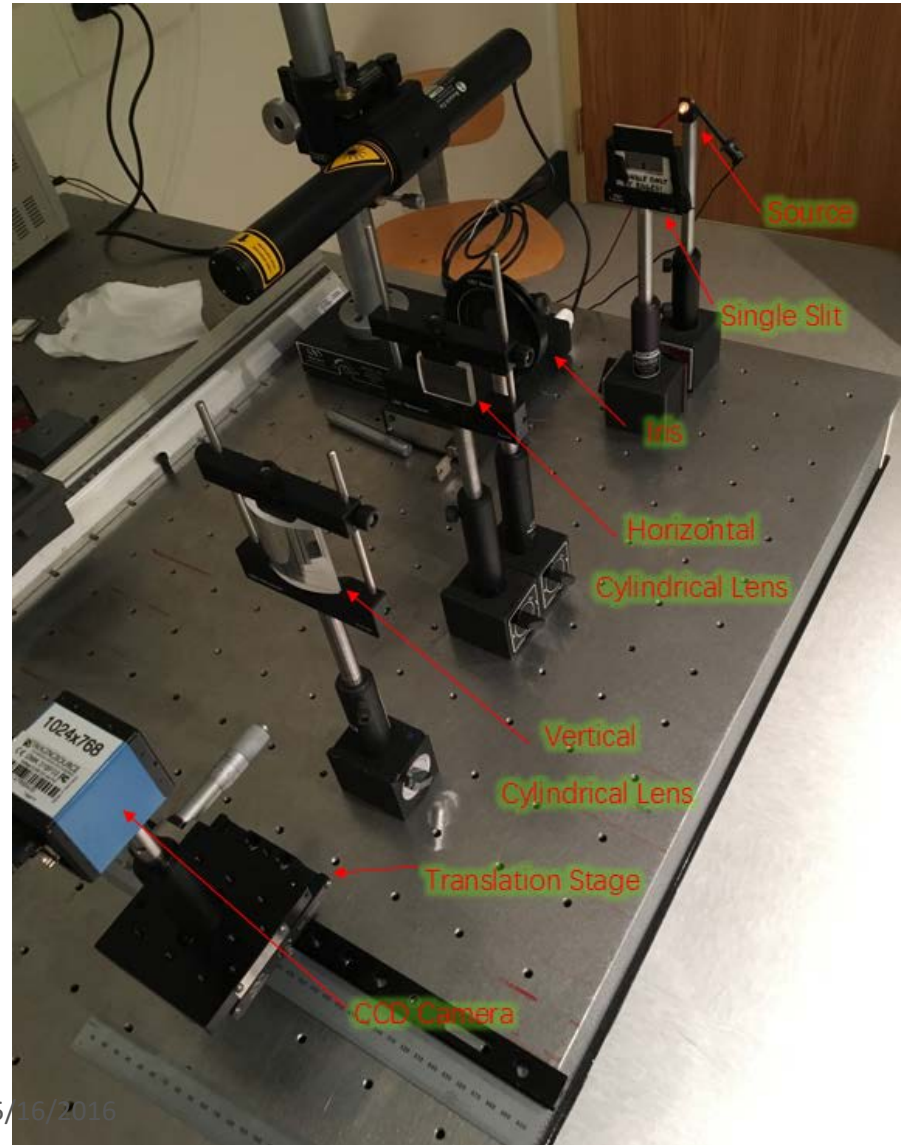
- Field construction

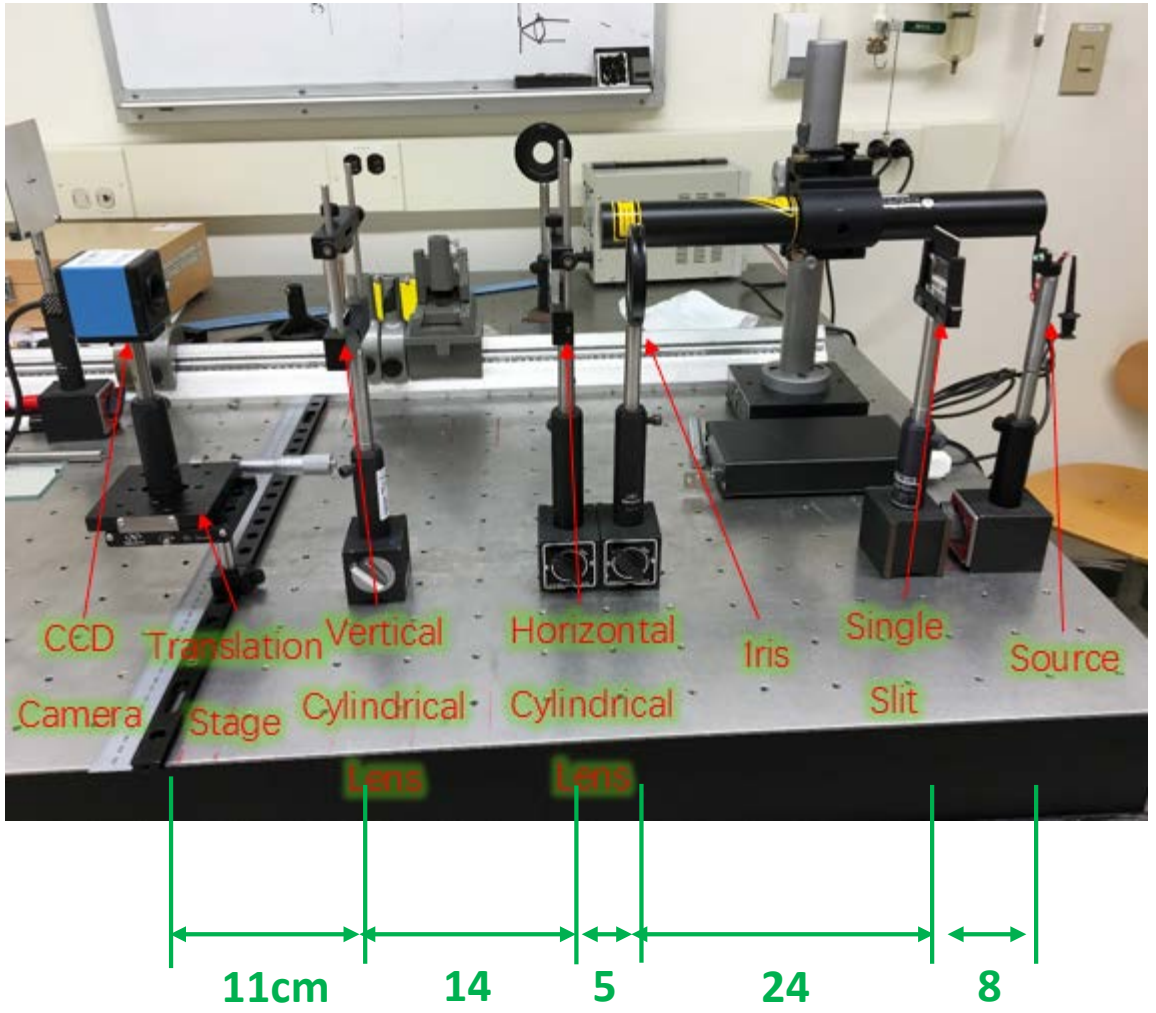


- Ambiguity function

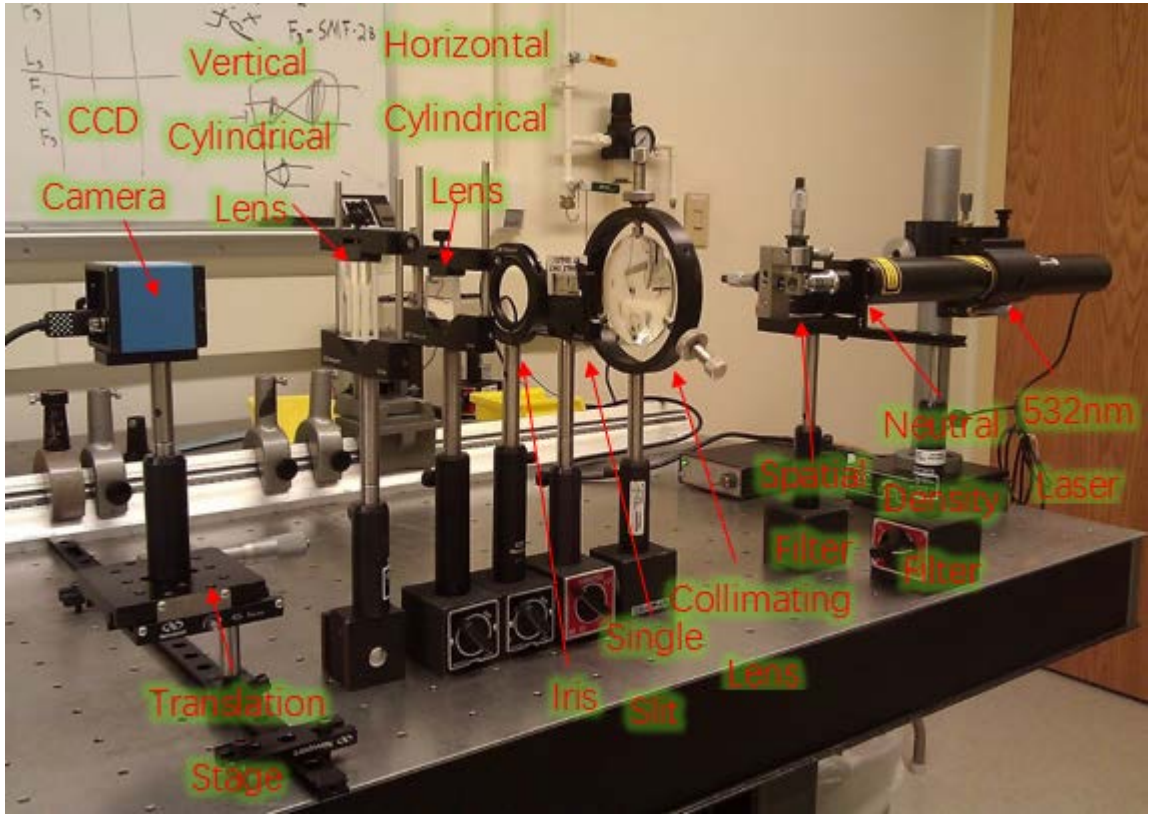


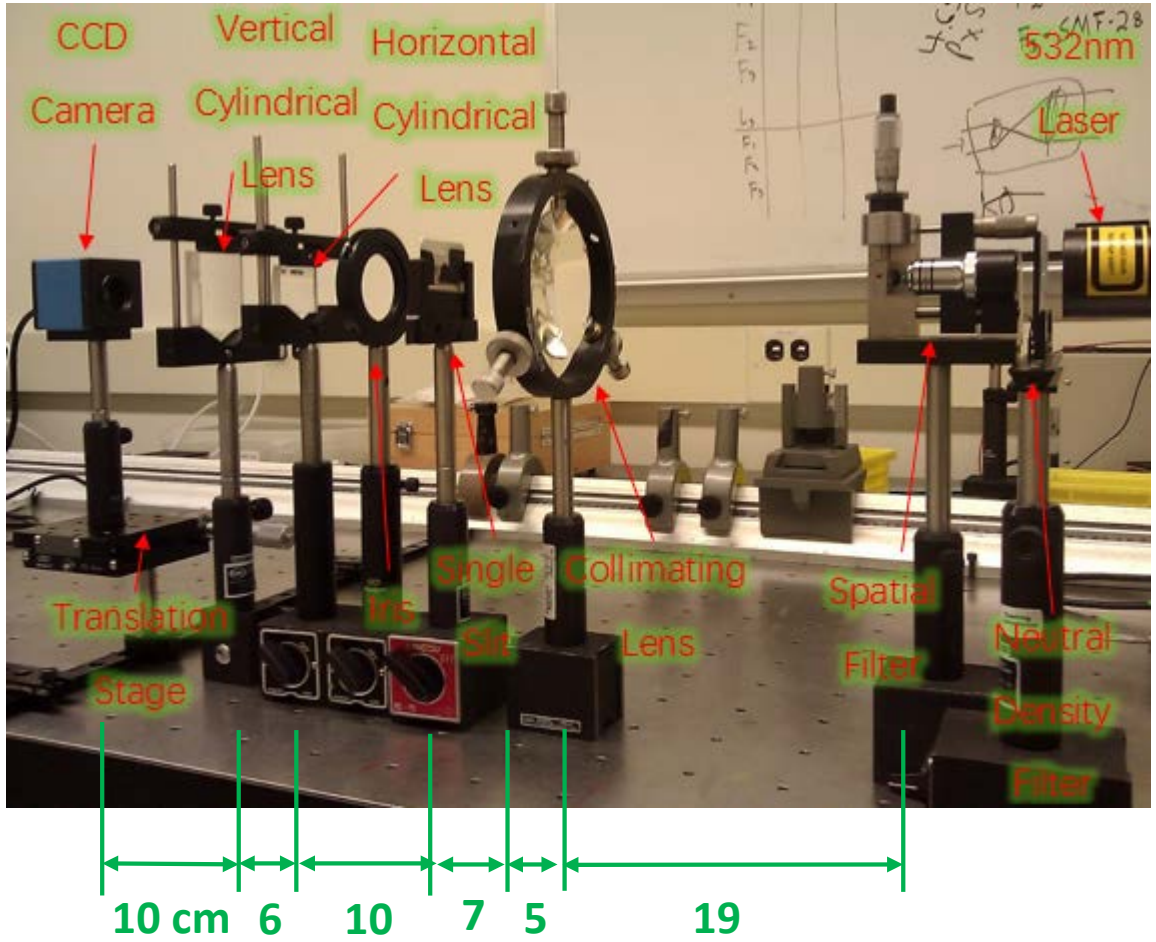
Experiment setup-LEDs, Incandescent Bulb



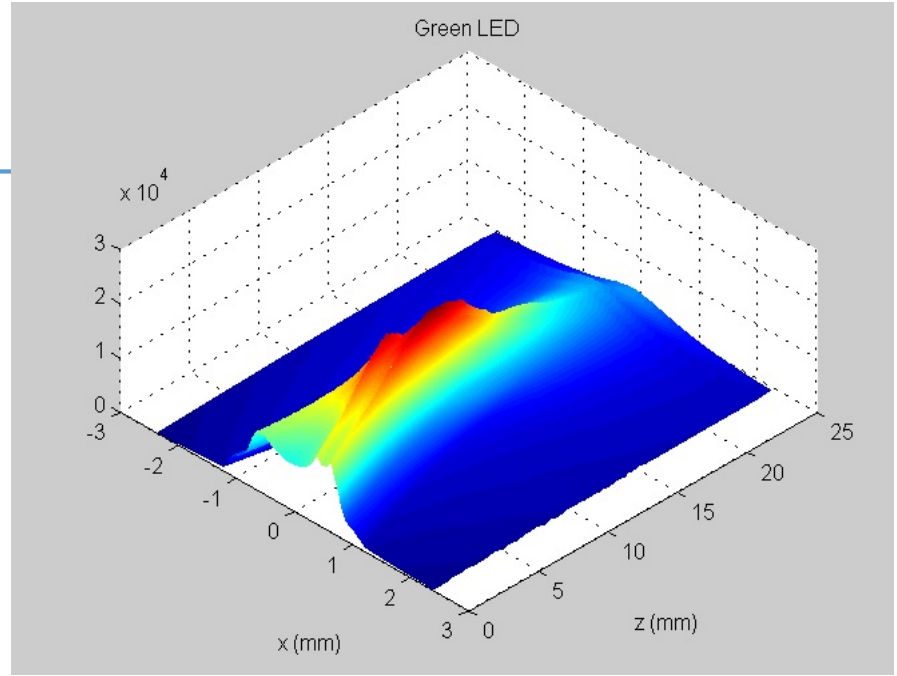


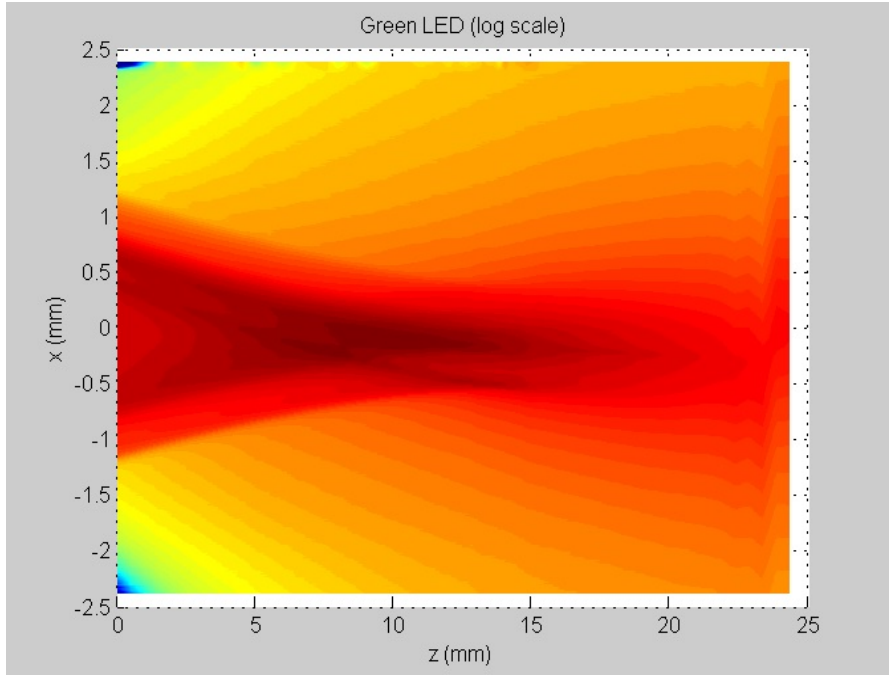
Experiment Setup-Laser Source





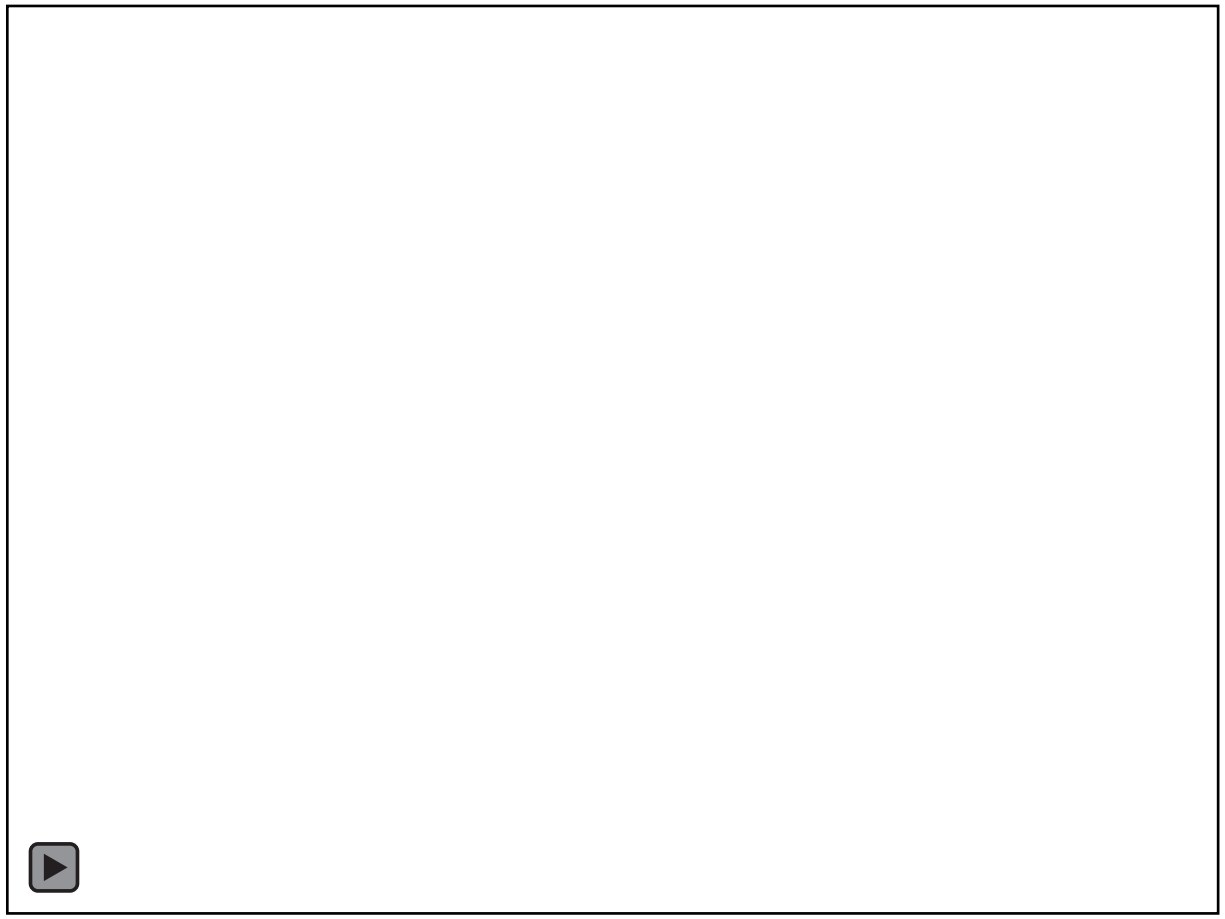
Results for Green LED



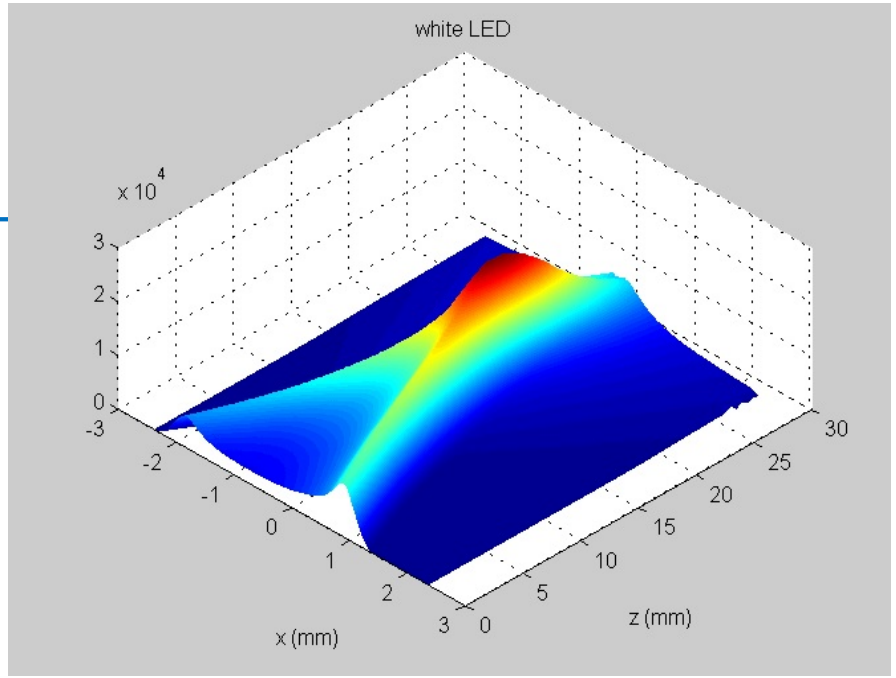


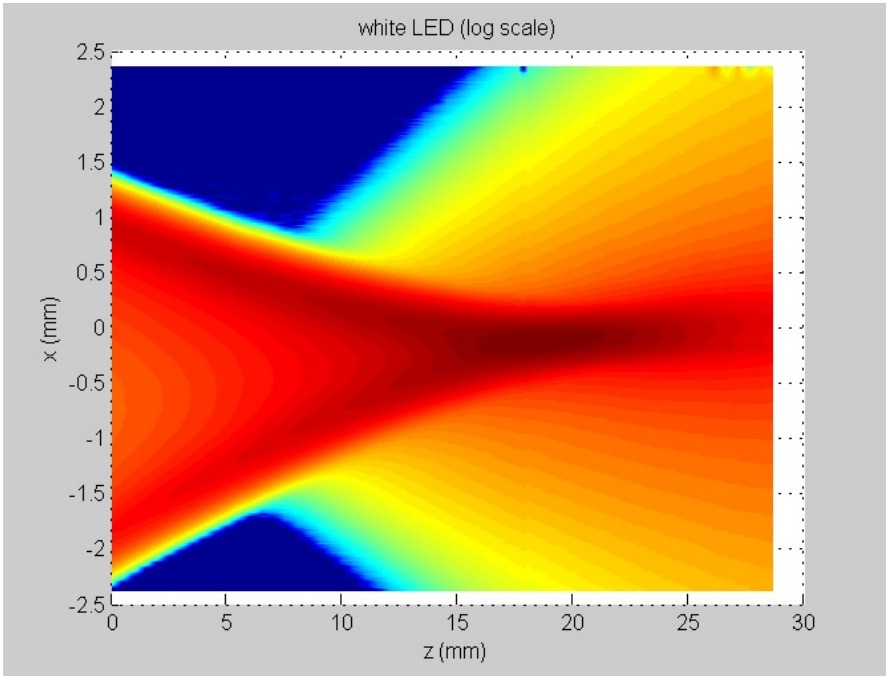
Working Voltage: 2.7 V

Results for White LED

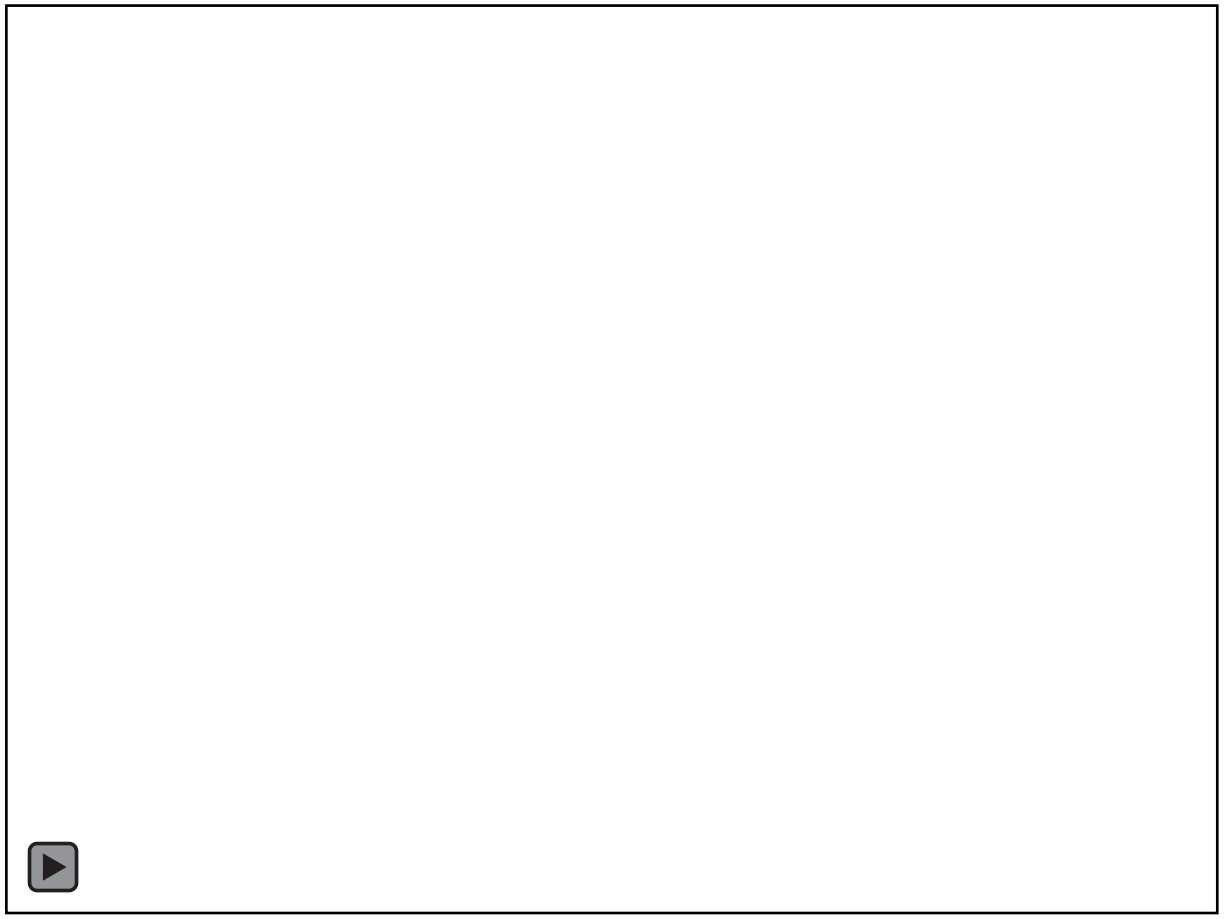


Working Voltage: 3.0 V

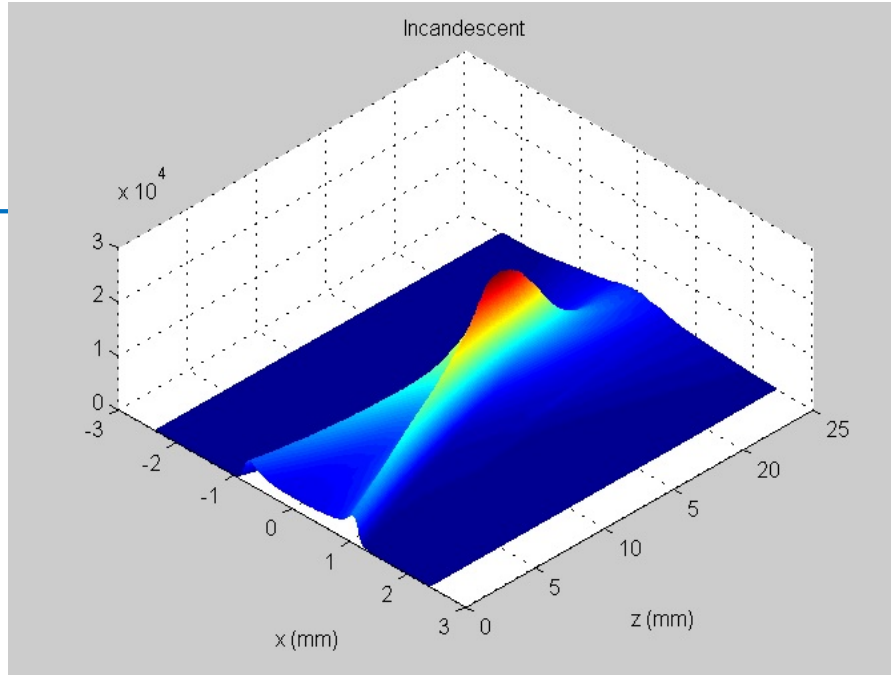


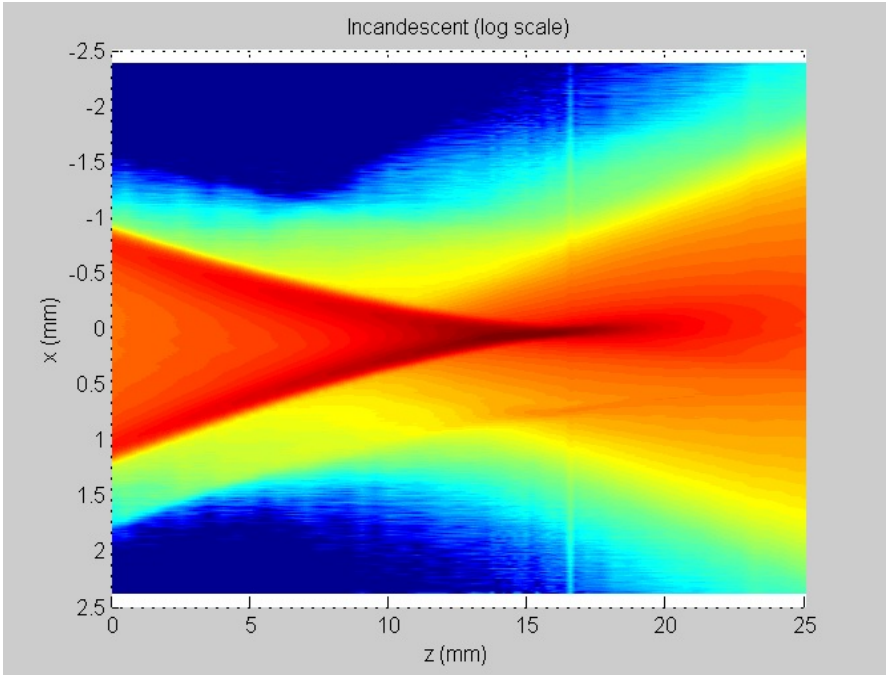


Results for Incandescent Light Bulb

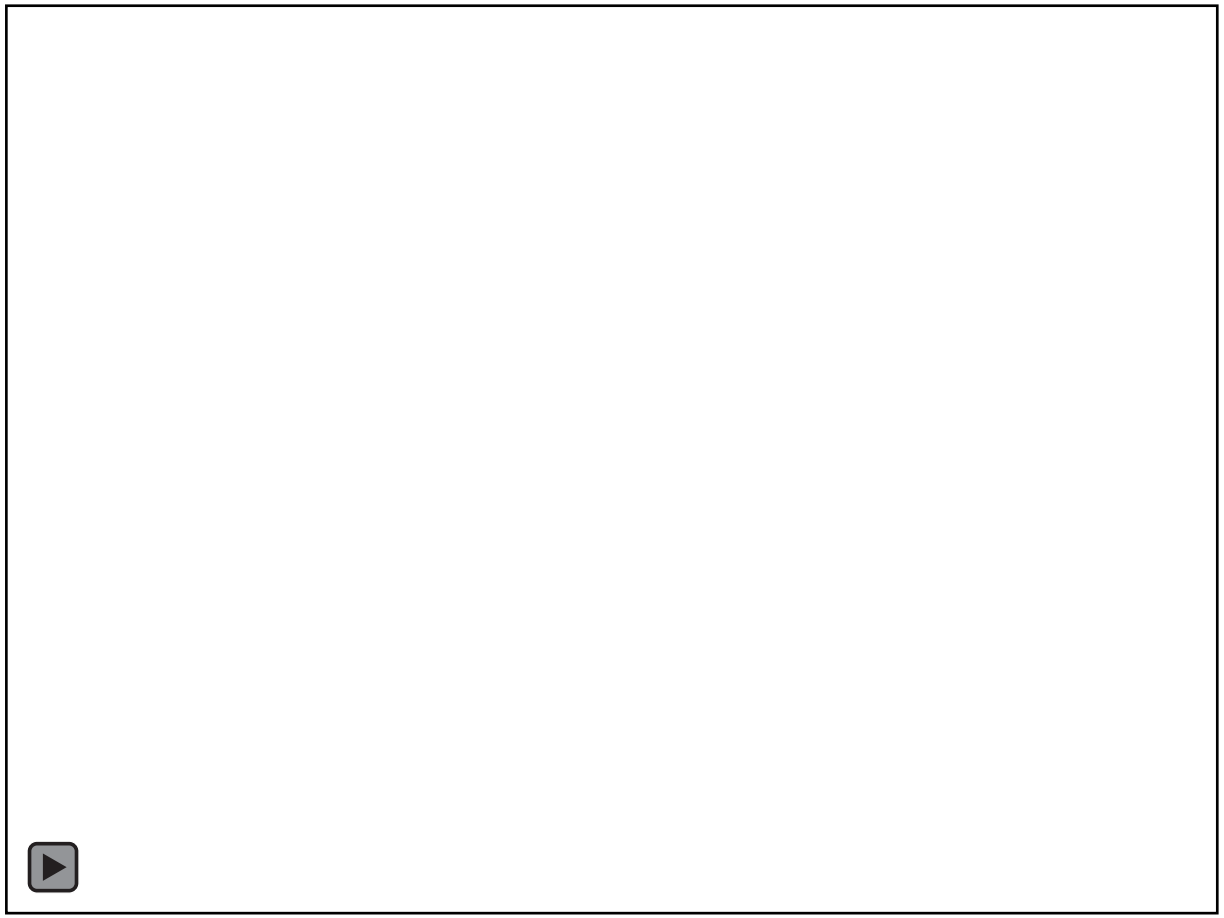


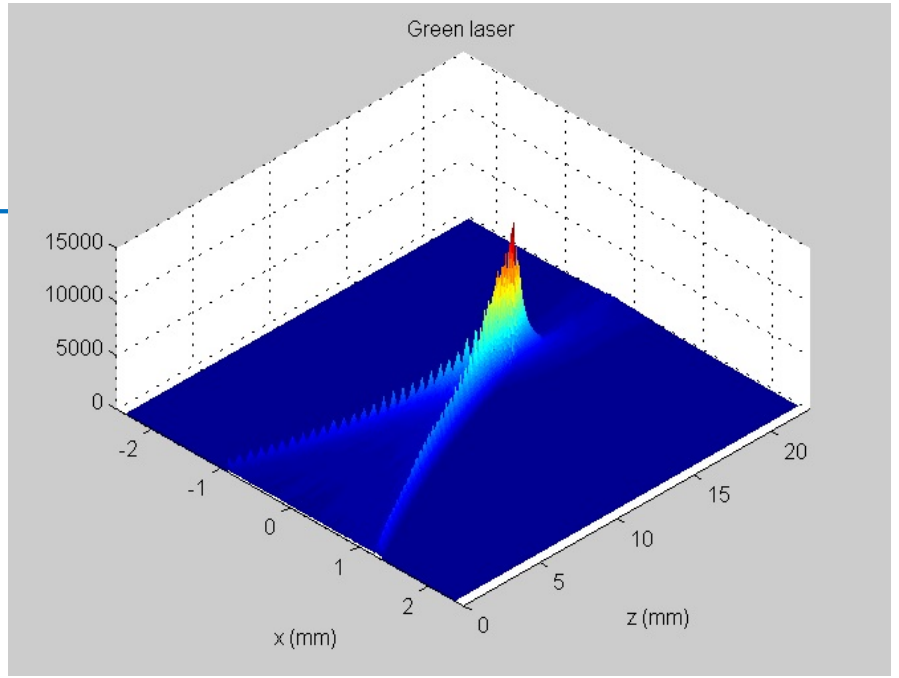
Working Voltage: 1.0 V

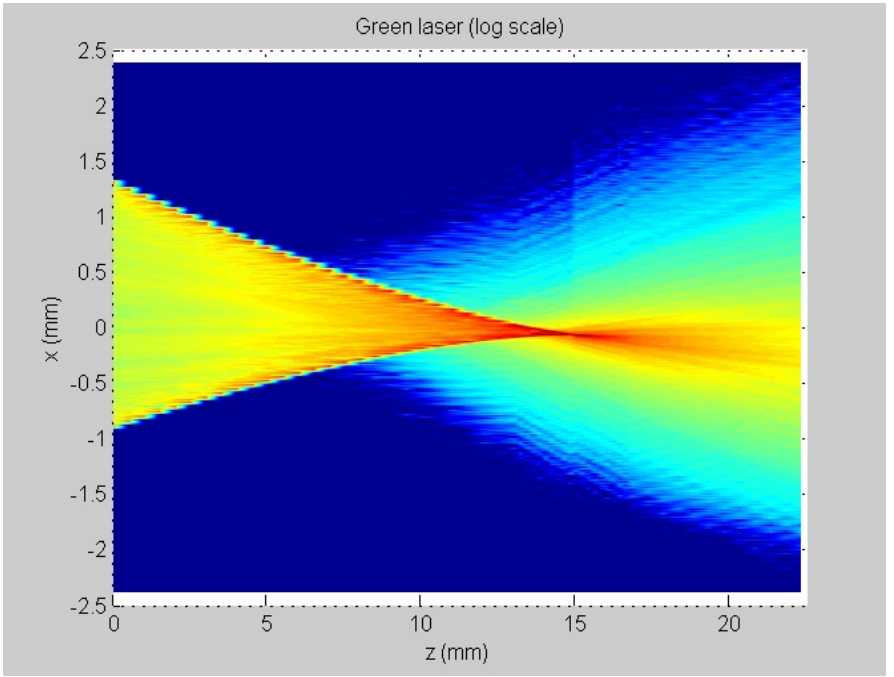




Results for Green Laser

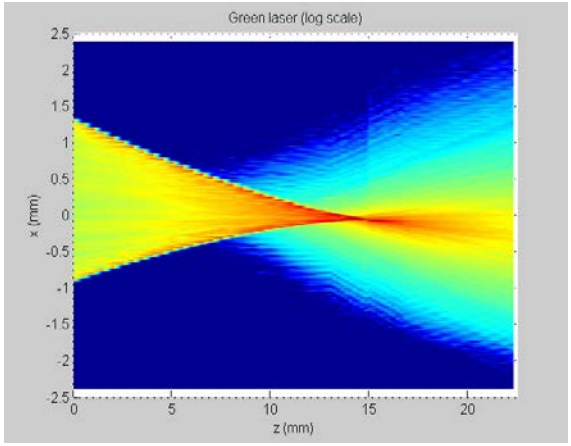




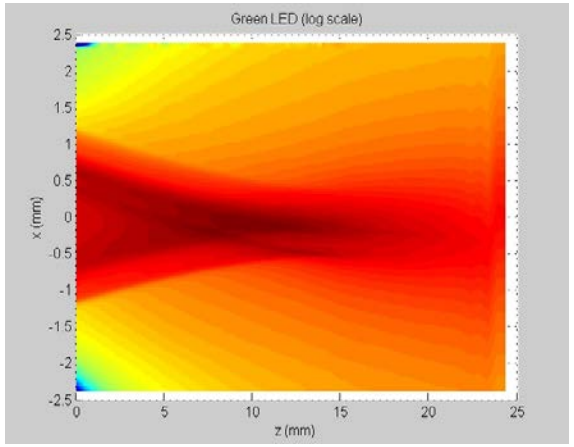


Laser Power: 1 mW

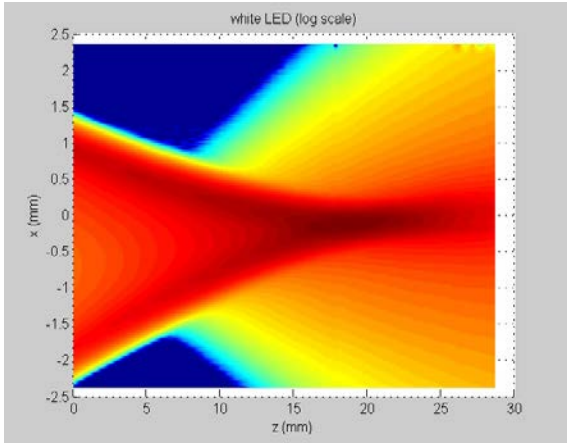
Compare between difference sources



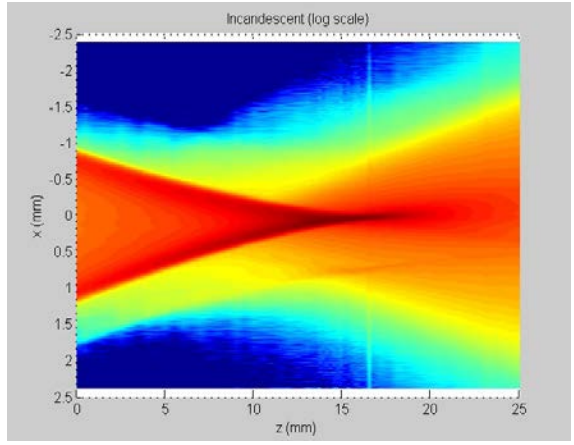
Green Laser



Green LED



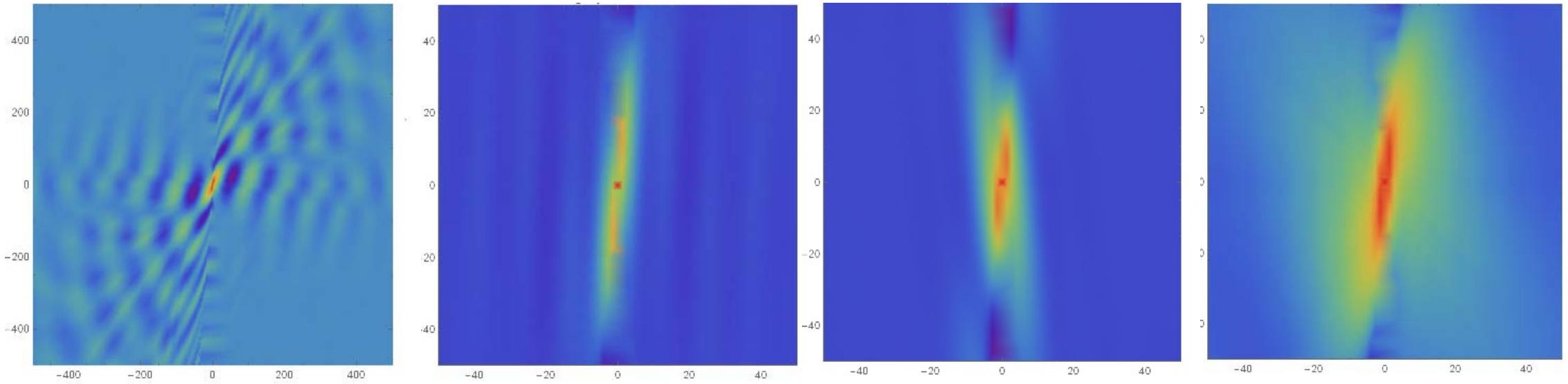
White LED



Incandescent

- The laser field has a relatively sharp edge.
- Certain amount of light of Green LED falls outside the CCD
- The field for incandescent light bulb has blurred edge and relatively slow gradient of the transverse field distribution.

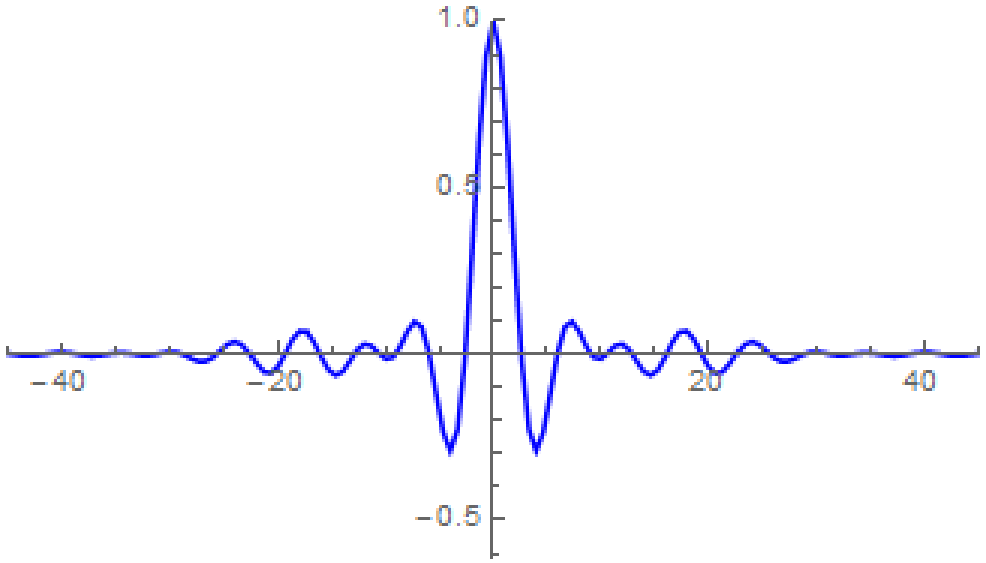
Ambiguity Function of the fields



Laser Green LED White LED Incandescent

- All ambiguity functions show that the optical system has spherical aberration.
- The scanning range of the field covers most of the ambiguity function except for those close to y-axis.

Ambiguity Function of the Incandescent lamp



Cross section of the Incandescent light bulb ambiguity function at z=0

Incandescent light bulb can be seen as a Lambertian source. The Wigner function of Lambertian source is,

$$W(x,p) \sim rect\left(\frac{x}{2x_{max}}\right) rect\left(\frac{p}{2ksin\theta_{max}}\right)^*$$

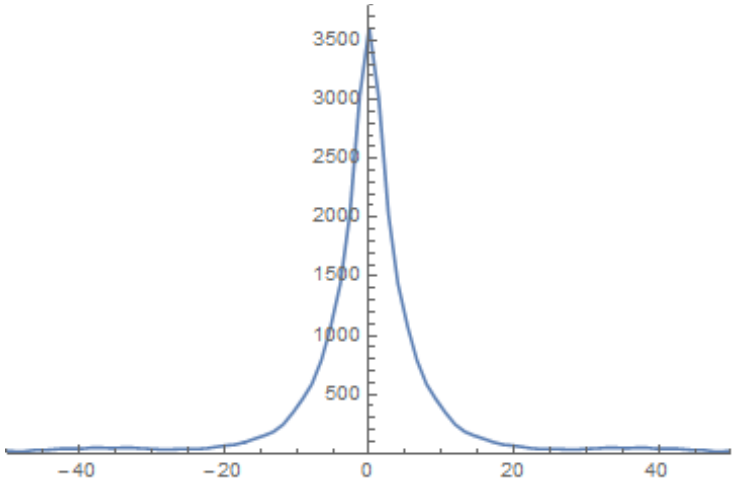
The Ambiguity function can be seen as Fourier transform of the Wigner function,

$$A(x',p') \sim sinc(2x_{max}x')sinc(2ksin\theta_{max}p')$$

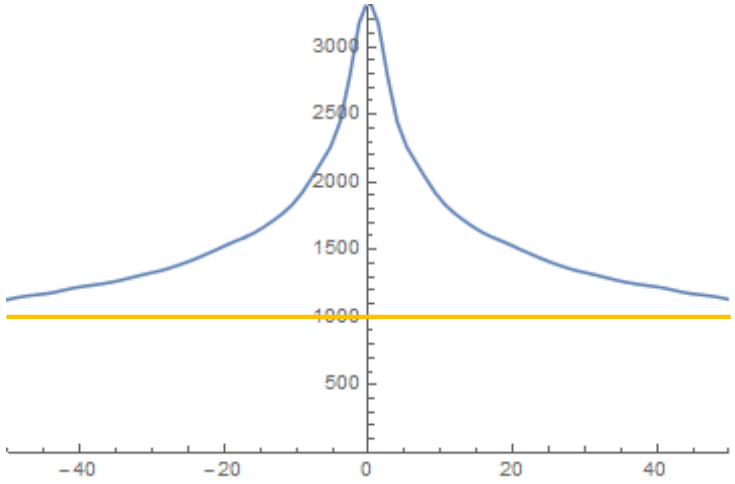
Our experiment result agrees with the theory.

*Bastiaans M J. Application of the Wigner distribution function in optics[J]. The Wigner Distribution—Theory and Applications in Signal Processing, 1997: 375-426.

Ambiguity Function of the Laser



Measured cross section of laser Ambiguity function at z=22.3(mm)



Measured cross section of the laser Ambiguity function at z=0

- Near the image point, the laser image is only focused on limited number of pixels, thus the distribution is close to a delta function. The cross section of the Ambiguity function shows a tendency to be a constant independent of the location in space.

Discussion and Conclusions

- An optical path has been set up to measure the transverse field distribution of different light sources.
- Through Fourier transform of the field, Ambiguity functions of light sources are obtained.
- The incandescent lamp provides the widest Ambiguity function and the green LED provides the narrowest one.
- Oscillations are strong in the Ambiguity function of laser and the green LED. Oscillations tend to wash out in the Ambiguity functions of the white LED and the incandescent lamp.
- Ambiguity functions might be good indicators of the coherent level of light sources.

Discussion and Conclusions

- Error sources
  - Misalignment of the two cylindrical lens;
  - Saturation of the CCD camera;
  - Loss of light signal outside the CCD.

- Future work
  - Adjustments of lens distance and focal lengths in the next experiment.
  - Improvement of measurement quality by applying a CCD with higher dynamic range and temperature control.
  - Calculation of Wigner function and cross spectral densities.

Acknowledgement

- Per Adamson (Institute of Optics, University of Rochester)
- Professor.John Marciante (Institute of Optics, University of Rochester)
- Professor. Miguel Alonso(Institute of Optics, University of Rochester)

Thank you!

Measured non-paraxial fields angles

	Non-paraxial angle(degree)
Laser	9
Green LED	11
White LED	7
Incandescent	9