LTC Summer 2020
Investigation of unexpected rings in laser beam profile

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1 Introduction

Initially, the goal of this project was to complete a lab from PHY 300 on measuring the waist of a Gaussian beam by clipping the beam with a razor blade and measuring changes in intensity. The CPS635R Collimated Laser Diode Module from Thorlabs was used in this experiment, and it was quickly realized that the beam from this module was not Gaussian. The beam was shone through a single convex lens, magnifying the intensity profile and allowing it to be observed by eye on a wall behind the lens. Instead of having a Gaussian profile, there were visible rings, as seen below:

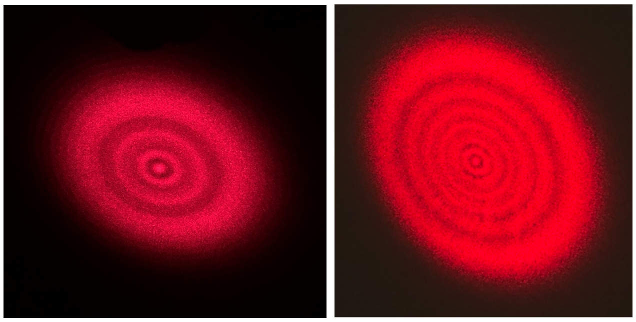

Figure 1: Images of beam after being magnified by a lens taken with an iPhone camera

It is assumed that the lens simply magnified the beam and that it had no effects on the intensity profile besides scaling it up. Further investigation should be conducted to verify this assumption.

After observing these rings, the goal of this project shifted to documenting this phenomenon. It was observed that the number of rings changes depending on the distance between the laser and the lens but not the laser and the wall. The intensity profile pattern did not change depending on the distance between the lens and the screen but simply got larger. Two experiments were conducted. In the first, the relationship between the distance of the laser from the lens and the number of rings in the profile was studied. The experimental setup is shown in the figure below:

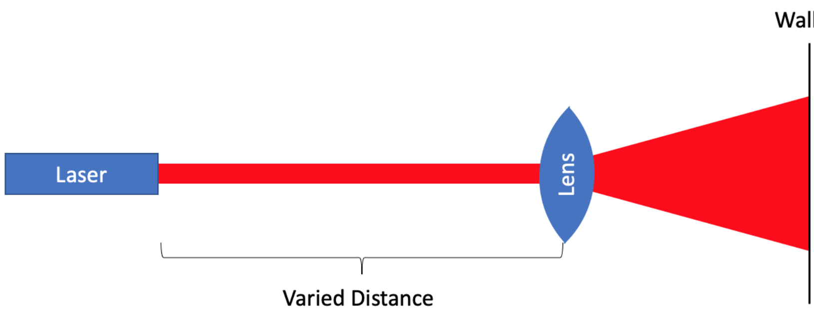

Figure 2: Experiment 1 setup

In the second, the intensity profile of the beam was analyzed at various distances. An iPhone camera was used to capture photographs of the beam intensity profile projected onto a wall. The distance between the laser and the lens was varied. Numerical data for the intensity profile was extracted from each image and fitted to a Gaussian curve using a Mathematica notebook written with the help of Professor Dominik Schneble. The experimental setup is shown in the figure below:

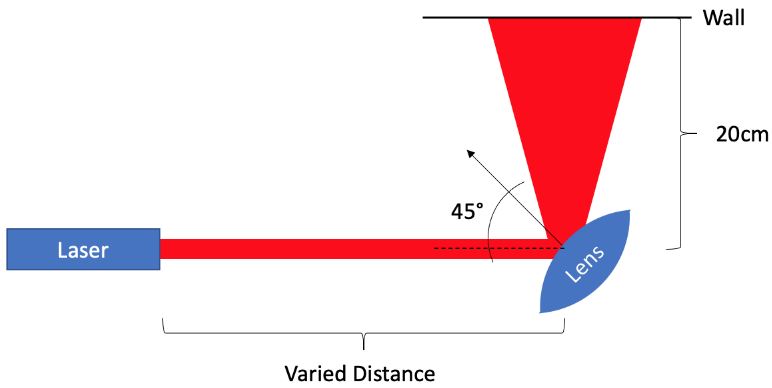

Figure 3: Experiment 2 setup

In the second experiment, the lens was placed at an angle of 45° because it was found while conducting the first experiment that the beam was reflected several times within the lens, and the resulting beams had different numbers of rings. This is shown in the figure below:

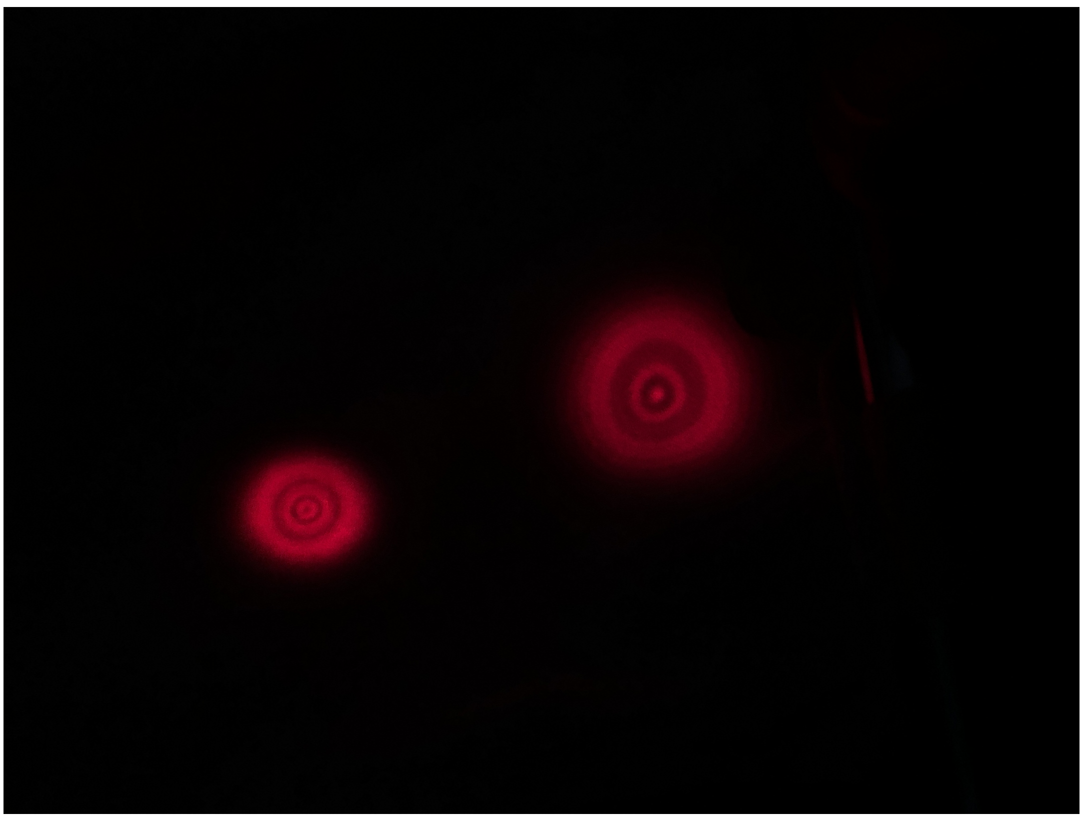

Figure 4: Two beam spots with different numbers of rings on the wall behind laser. It is speculated that the spot on the left is the reflection off of the near side of the lens as it is brighter, and the spot on the right is the reflection off of the far side of the lens.

Further investigation of this phenomenon would be interesting as it might disprove the assumption that the lens does not alter the intensity profile in a non-negligible way besides magnifying it. In this experiment, the lens was placed at 45° as this allowed for horizontal separation between successive reflected beams. The beam reflected off of the near side of the lens was the one photographed.

In the process of collecting data, it was found that Thorlabs had documentation of the beam profile of the CPS635R Collimated Laser Diode Module on their website [1]. A screenshot has been included below:

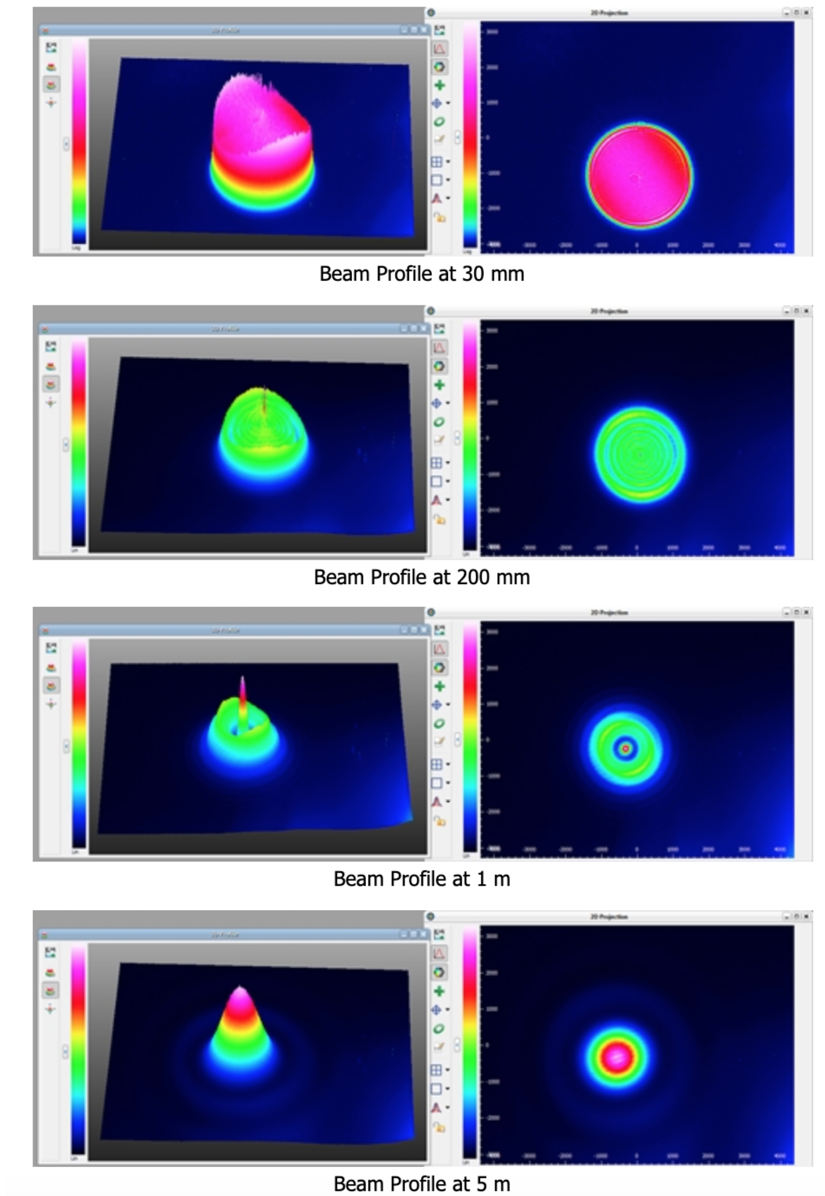

Figure 5: Screenshot of Thorlabs documentation of the beam profile evolution of the CPS635R Collimated Laser Diode Module

The website also contained the following writeup: "The output of the CPS635R is circularized using a series of specially designed apertures. These apertures, which each have a geometry designed to clip the propagating beam, create very little near-field noise, and, when compared to typical apertures, reflect less light back to the diode output. A consequence of this design is Airy diffraction, which is created from clipping the sides of the beam. The photos below show how the interference changes as a function of the beam propagation distance from the output aperture. In the near-field you can see the spatial intensity variations. However, after 5 meters of beam propagation, the intensity profile becomes more Gaussian. Please note that the scale does not change in the images below."

This confirmed that the laser module should not have a Gaussian profile at the distances at which it was first measured. For future optics kits, it should be noted that the beam profile for this laser is not approximately Gaussian until after 5 meters of propagation. Thorlabs also has three different types of 635nm lasers listed along with the CPS635R on their website which all have elliptical Gaussian profiles and might be better than the CPS635R for future optics kits in the LTC.

2 Experiment 1

2.1 Procedure

1: The laser was shone through the lens onto a wall behind it. The first measurement was done with the laser very close to the lens. The distance between the laser and the lens was recorded and the number of rings was counted. The experimental setup is shown below:

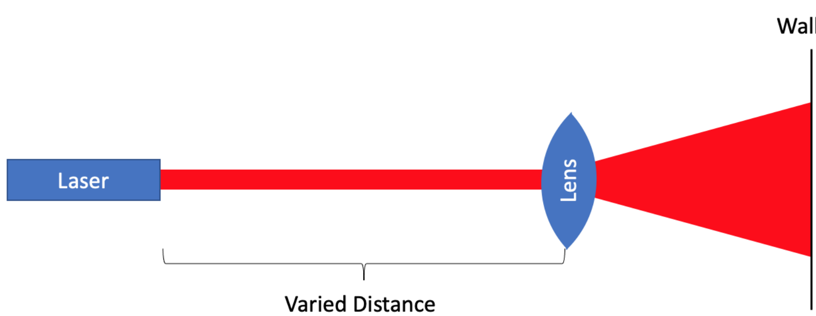

Figure 6: Experimental setup

2: The laser was then slowly moved away from the lens. As the laser was moved backwards, new rings would emerge outwards from the center of the circle. Measurements for a full new ring were taken when that central spot was brightest and measurements for half-integer ring numbers were taken when the dark spot in the center of the pattern was darkest. Measurements stopped when the number of rings was too high to be discernible.

3: This experiment was conducted for four lenses of different focal lengths to find a relationship between focal length and ring number. There was a 35mm, 20mm, 90mm, and an 80mm lens.

2.2 Data

Below is a graph of ring number vs distance between the lens and the laser.

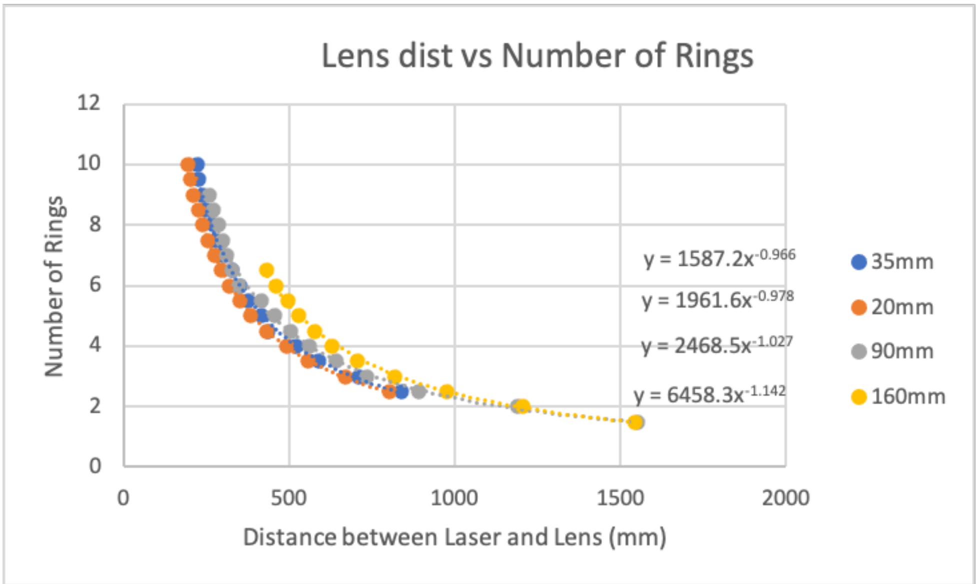

Figure 7: Graph of Data from Experiment 1

It was found that there was no large noticeable change in the behavior of the ring number between lenses with different focal lengths. The 160mm lens did seem to have a higher ring number than the other lenses at distances less than 1000mm, which indicates that further investigation is necessary.

In the process of conducting this experiment, was also found that beams reflected from the different surfaces of the lens had different numbers of rings.

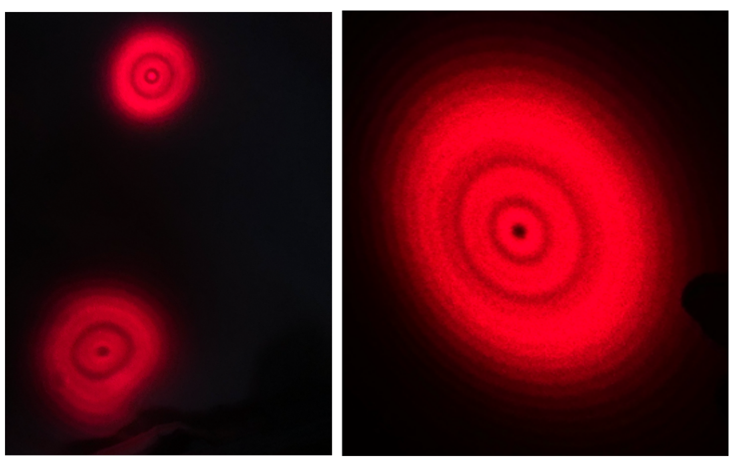

Figure 8: Reflections from different surfaces of the 160mm lens resulted in different numbers of rings

While observing the 3.5 fringe image (right) with the 160mm lens, two images were observed on my laundry hamper behind the laser (left). The bottom spot on the left appears warped only because it is projected onto an uneven surface. The two spots in the image on the left are likely caused by reflections from either surface of the lens. Due to the fact that the top spot is brighter and less displaced from the original source, it can be assumed that this spot is caused by the beam reflected by the near side of the lens. The bottom spot is likely from the beam transmitted through the near side of the lens and reflected from the far side. Additionally, the bottom spot has a dark splotch in the bottom left which is likely due to imperfections in the glass, supporting the assumption that it has traveled through the lens. It is notable that the ring numbers vary between each spot. On the right, the ring number is 3.5. The external reflected spot has 3 rings and the internal reflected spot has 2.5. The width of the lens is very small in relation to the distance necessary to transition between 2.5, 3.5 rings, which was measured to be 27cm. This indicates that the reflection and transmission does have some effect on the profile. Further investigation is needed.

3 Experiment 2

3.1 Procedure

1: The experimental setup is shown below:

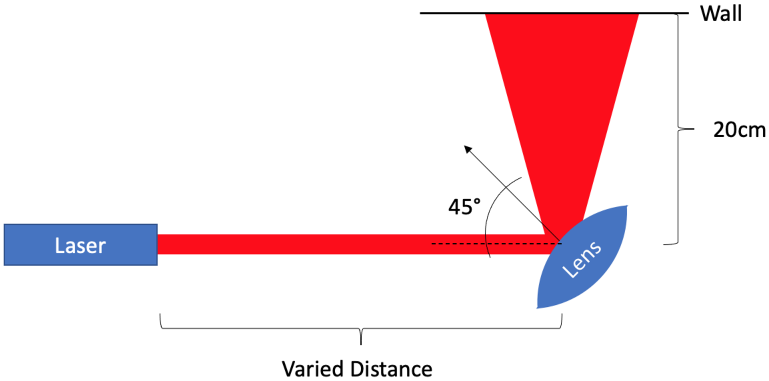

Figure 9: Experimental setup

2: The beam profile from reflection from the near side of the lens was photographed with an iPhone. The iPhone's camera brightness was adjusted to ensure that the brightest parts of the image didn't overload the camera's sensors and create a flat top. Below, one can see the comparison of two images of the same beam spot at 184cm where the brightness was properly and not properly adjusted:

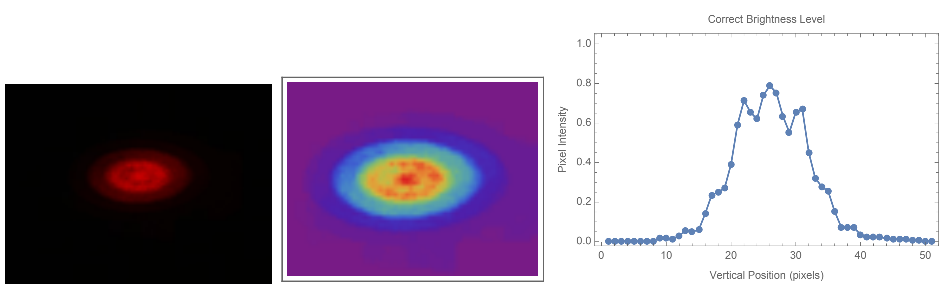

Figure 10: Image where pixels are not oversaturated

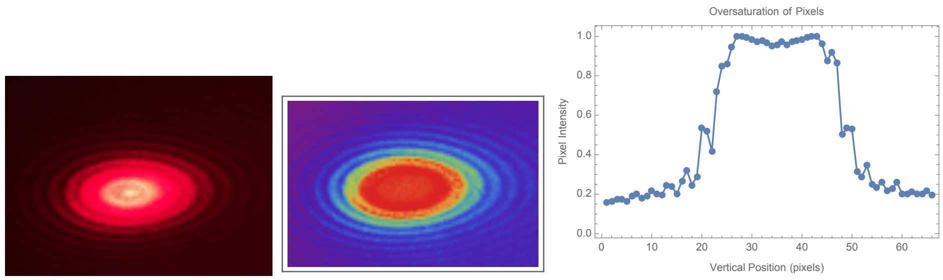

Figure 11: Image where pixels are oversaturated

3: A photograph was taken of the beam spot with the laser diode at distance of 3cm, 26cm, 72cm, 164cm, 348cm, and 716cm from the lens. These numbers were chosen by taking an arbitrary small distance of 3cm for the first measurement and adding it to the propagation distance after the lens for a total of 23cm. Between each measurement, this distance was doubled to 46cm, 92cm, etc. For the beam spot at 184cm, 368cm, and 736cm, the beam was reflected off of a thin sheet of plexiglass 0.5cm thick at 45° to reduce the beam intensity as the image overloaded the camera even at its lowest brightness setting.

4: To analyze an image, the value of the red channel for each pixel was extracted. Because the beam has a 635nm wavelength, red should be the dominating color in the beam and its intensity should be proportional to that of the actual beam. These value corresponding to each pixel ranges between 0 and 1. Because the lens was only rotated along the vertical axis relative to the beam path, the beam was distorted only along the horizontal axis. Therefore, a column of pixels was chosen through the center of the beam to identify its 2D intensity profile.

5: To compare each intensity profile to a gaussian profile, the graph of the column of pixels was studied. Points that appeared to fit a gaussian profile were identified and all others were discarded. A gaussian curve was fitted to the chosen points.

3.2 Data

On the following page are the raw photographs and their analysis. A vertical column from the middle of each image was selected arbitrarily. The values for pixel intensity vs vertical position were plotted and fitted to a Gaussian curve in order to observe how the beam becomes an increasingly better approximation of a Gaussian beam.

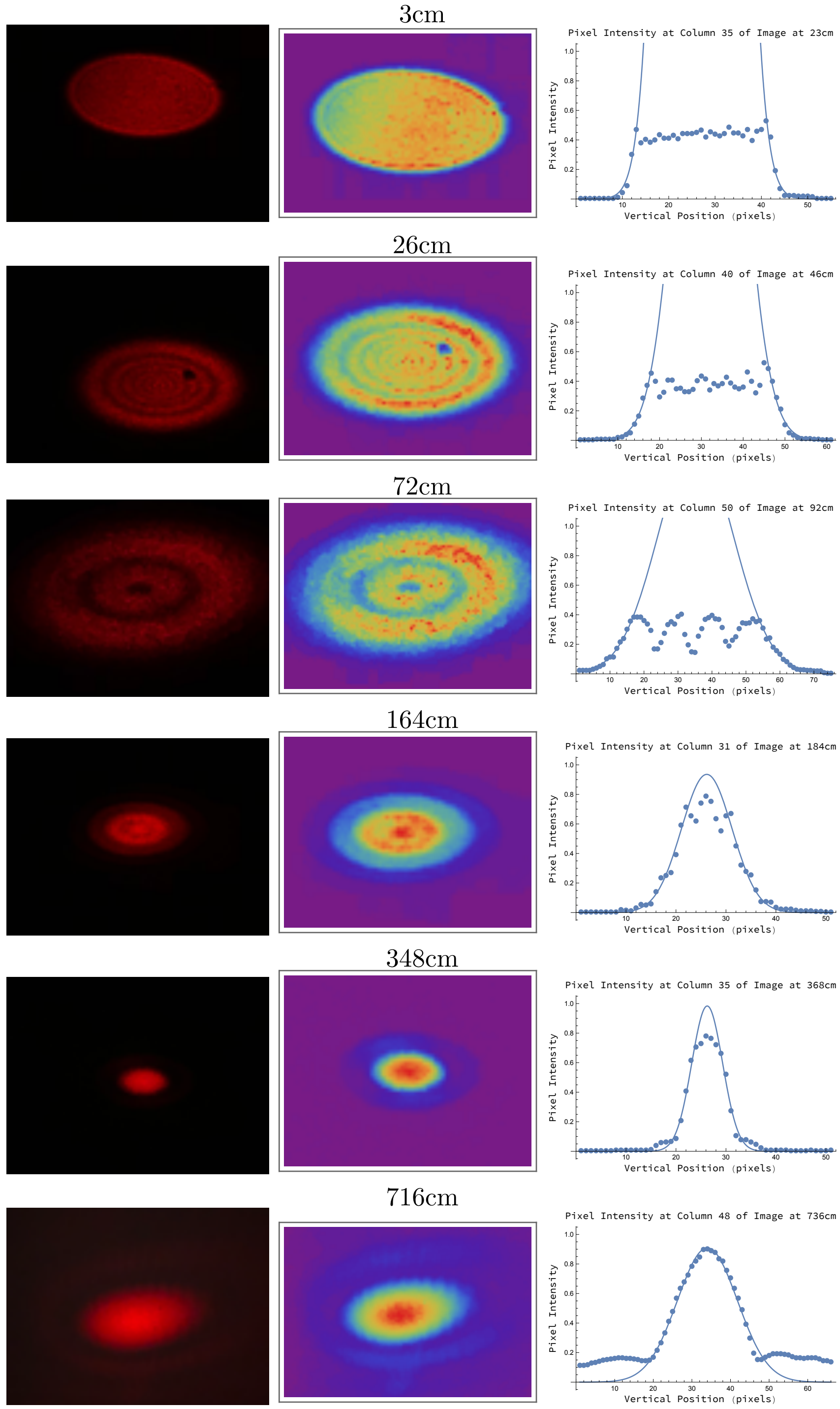

Figure 12: Image Data of Intensity Profile at Various Distances

It does appear that after 5m of propagation, the beam profile is approximately Gaussian. The collected photographs do seem to match the Thorlabs documentation quite well when comparing Figure 8 to Figure 4. The profiles at 3cm both show a beam with a high number of rings such that the beam is approximately a flat top. The beam starts out with a high number of rings and the ring number gradually decreases over distance until a good Gaussian approximation is achieved. It would be interesting to redo this experiment and use the same propagation distances as given by Thorlabs.

4 Conclusion

The most important result to come out of this project is the understanding that the CPS635R Collimated Laser Diode Module is not approximately Gaussian until 5m of propagation. Between 0 and 26cm, the beam is closer to being a flat-top. Thorlabs has three different types of 635nm lasers listed along with the CPS635R on their website which all have elliptical Gaussian profiles. Perhaps these would be better suited for future Gaussian optics kits in the LTC.

The evolution of the beam has now been documented. As a next step, it would be interesting to understand the physics behind the evolution. Thorlabs was not willing to show the exact design of the module, but at least it is known that the beam is created by being clipped by sequential apertures. There must also be further investigation into how the lens alters the beam as different numbers of rings were observed in the beams reflected by the near side and far side of the lens as well as the beam transmitted through.

References

[1] “Compact Laser Modules with Phono Jack.” (2020) *Thorlabs*, https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=1487