Generation of intense few-cycle pulses from the visible to the mid-IR

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Goals

<u>Axicon</u>

- Generate an aligned Bessel Beam with an Axicon
- Propagate a Bessel Beam through a Hollow Core Fiber (HCF) and measure the power
- Quantitatively characterize our experimental Bessel Beams

<u>Generation of mid-IR fs pulses</u>

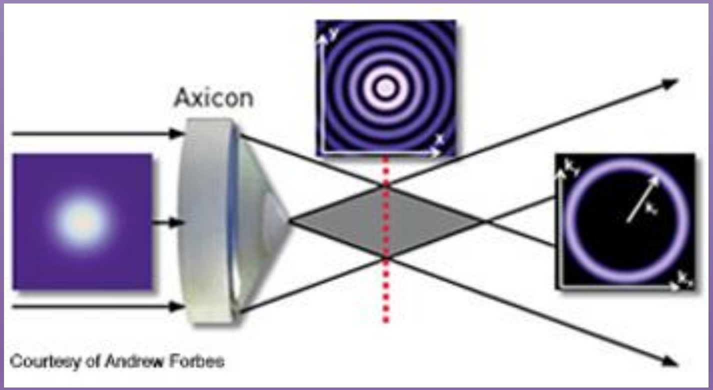
- Create a setup to prove the generation of mid-IR pules (5 -10 μm) with femtosecond pulses
- Measure efficiency as a function of angle of the Difference Frequency Generation (DFG) type II crystal in mid-IR region

<u>Motivation for Both Projects</u>

To study strong field physics in the mid-IR range

Axicon Terminology

- Axicon: conical lens that can be used to create a Bessel Beam
- Bessel Beam: a circular beam with ring like structure
- Hollow Core Fiber: a glass rod with a small hollow core that is used to guide light



Top: osa-opn.org Right: solidworks.com

Axicon Terminology

- Few cycle pulse: A pulse of light that has few optical cycles

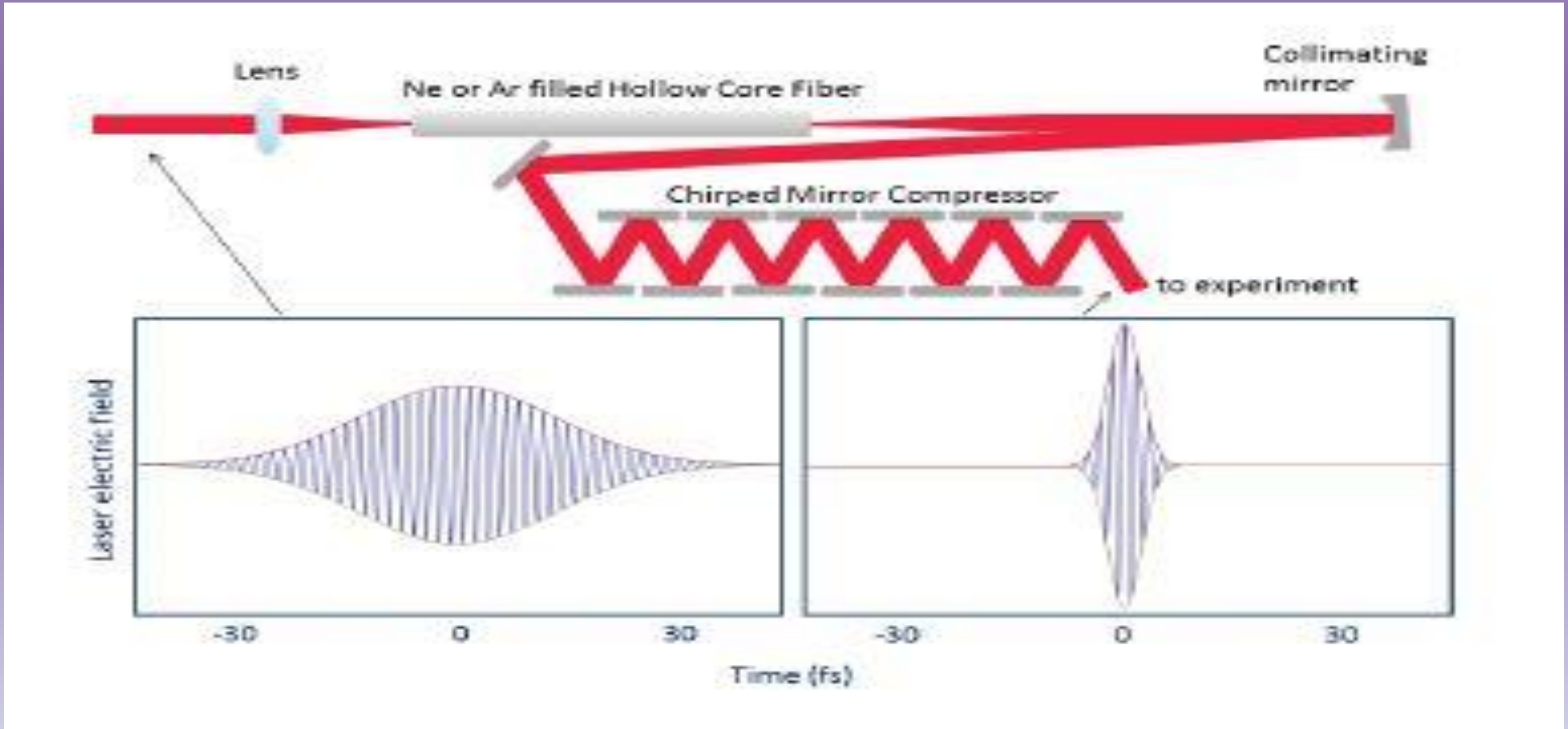
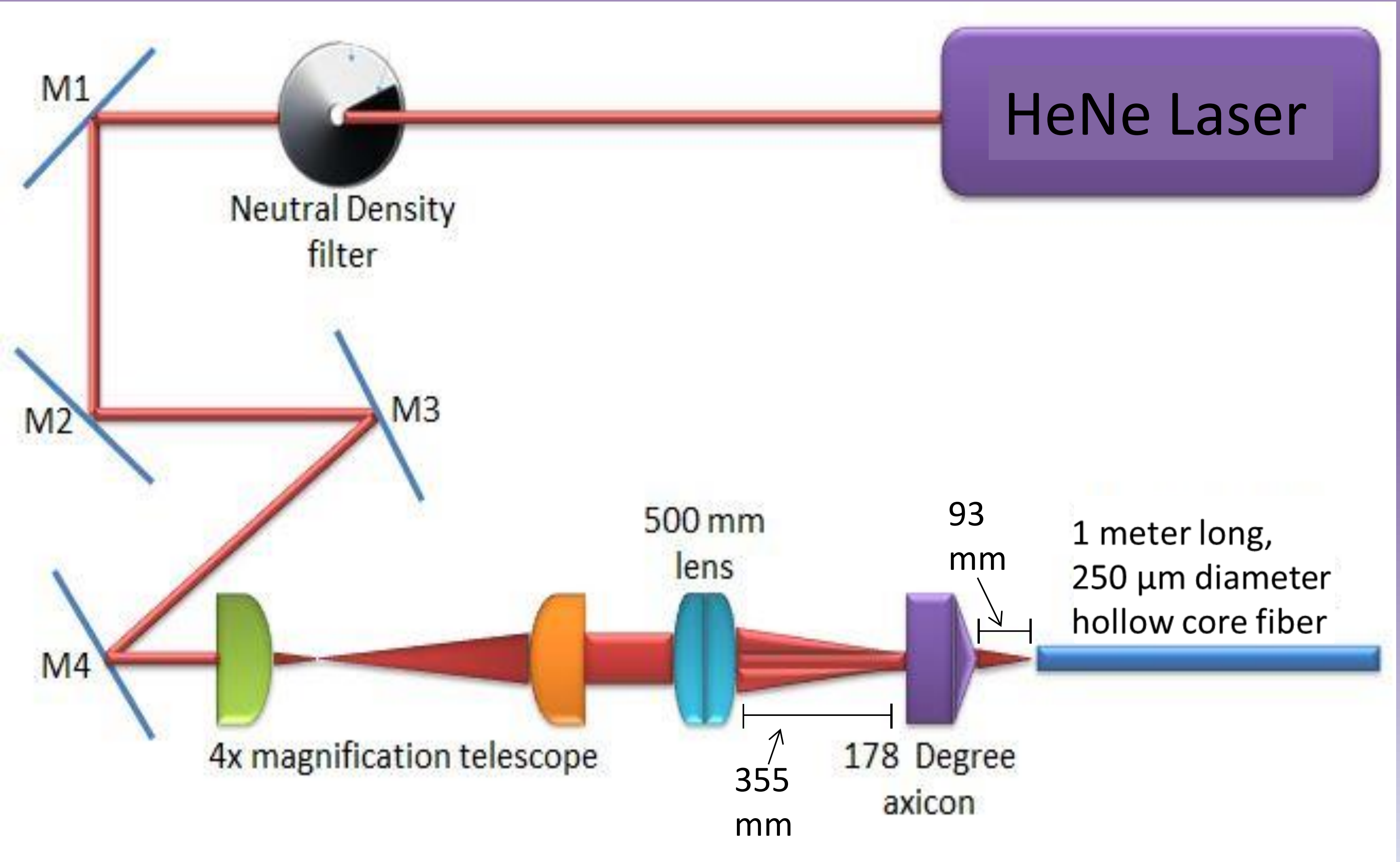


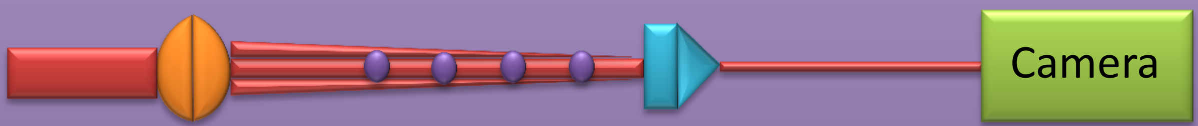
Diagram from Dissertation by Nora Kling (2013)

Axicon Setup

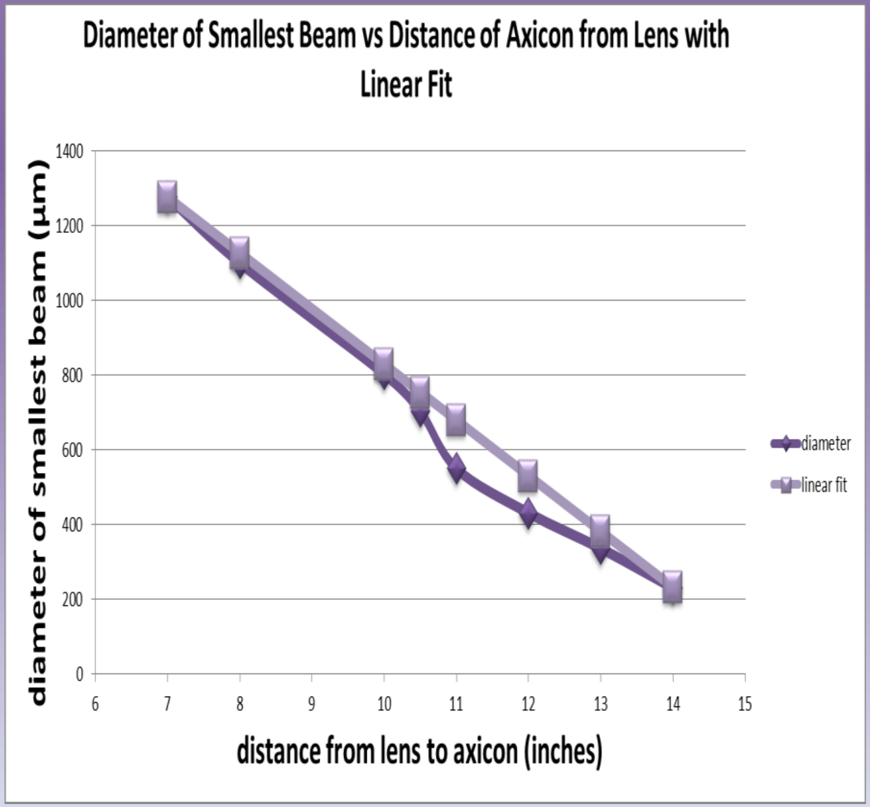


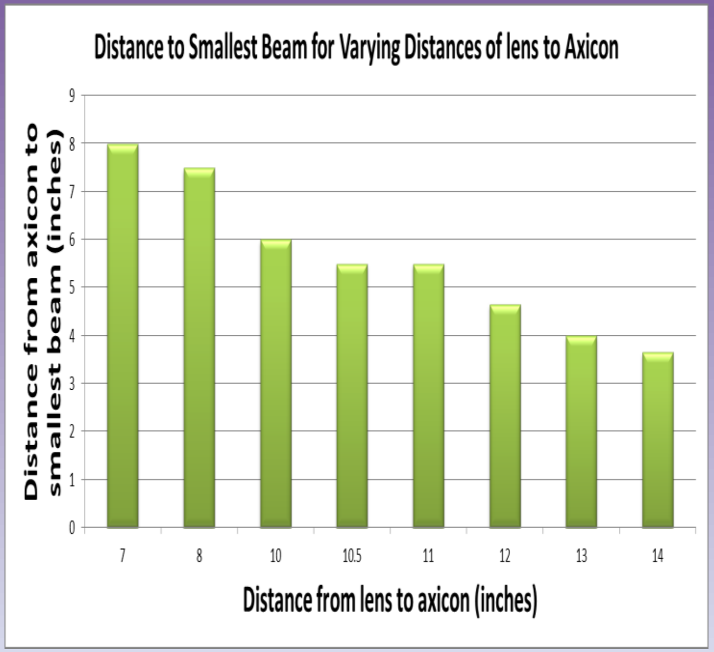
Determining Axicon and Fiber Distance

- Needed a beam smaller than 250 μm entering fiber



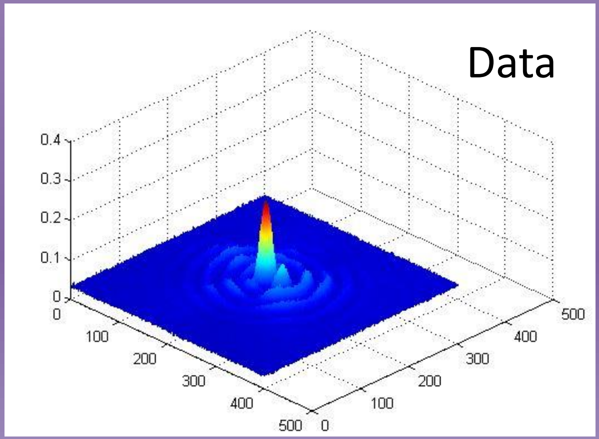
Bessel Image from rsc.org

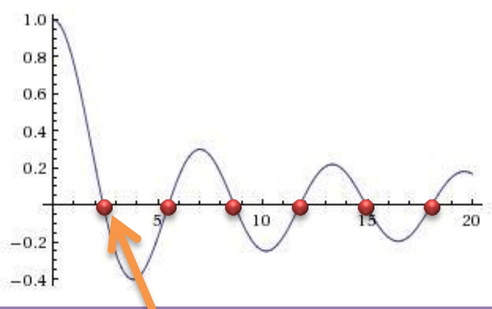




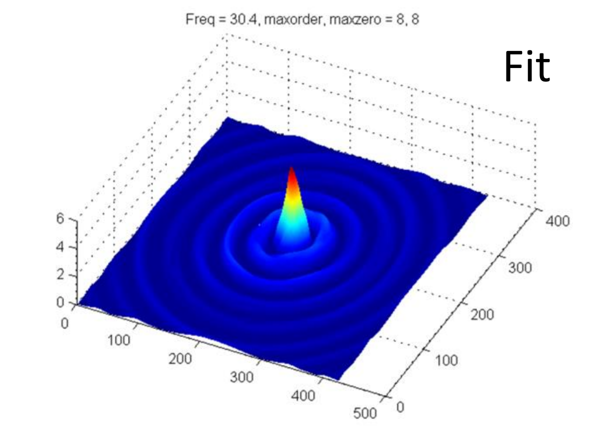
Theoretical Analysis

1. Created a program in Matlab to make a nice 2-d quantified representation of a Bessel Beam





Bessel zeros of zeroth order Bessel Function



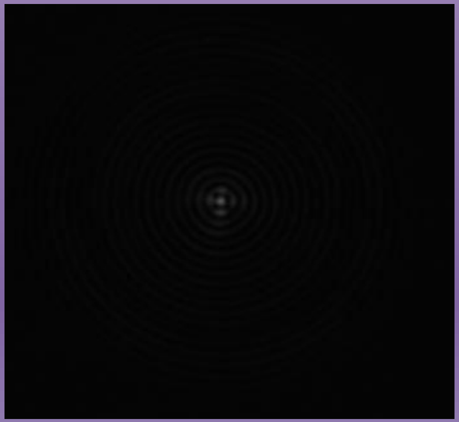
$$S(r,\theta) = \left| \sum_{m=0}^{M} \sum_{n=0}^{N} c_{nm} J_n(\alpha_n^m r/p) e^{in\theta} \right|^2$$

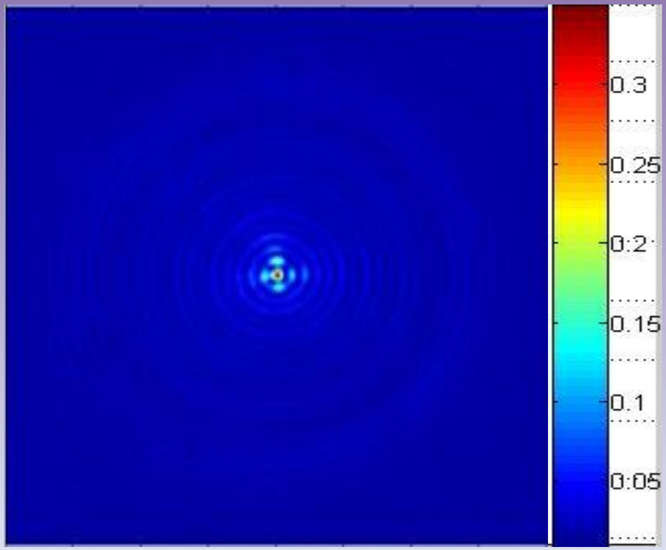
$$c_{nm} = \int_0^a \int_0^{2\pi} J_n(\alpha_n^m r/p) e^{in\theta} \sqrt{S(r,\theta)}\, r\, dr\, d\theta$$

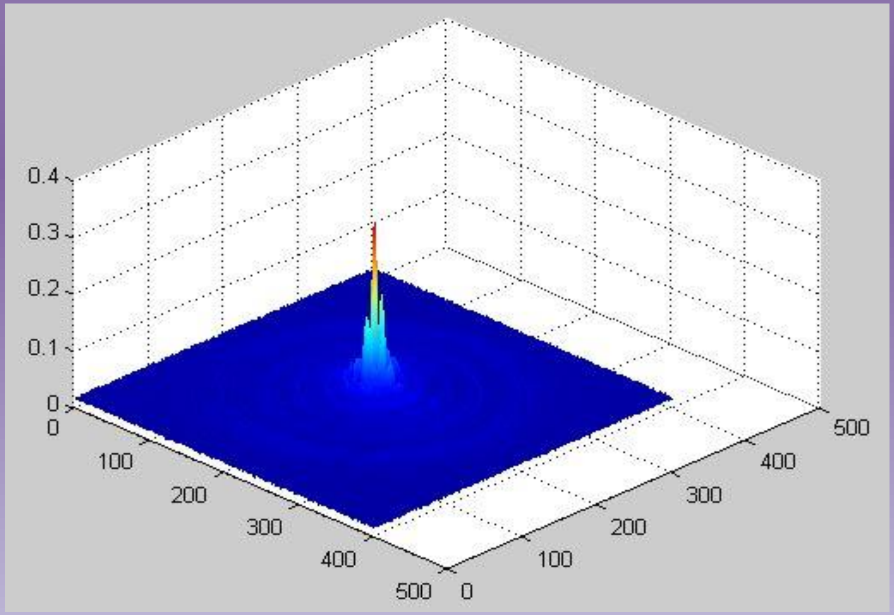
$S(r,\theta)$ = experimental distribution
J_n = n^{th} order Bessel Function
α_n^m = m^{th} Bessel zero of J_n
p = scaling constant for Bessel zeros
c_{nm} = coefficients retrieved from program

Data Analysis

2. Created a program in Matlab to programmatically analyze the data and give a nice color scheme

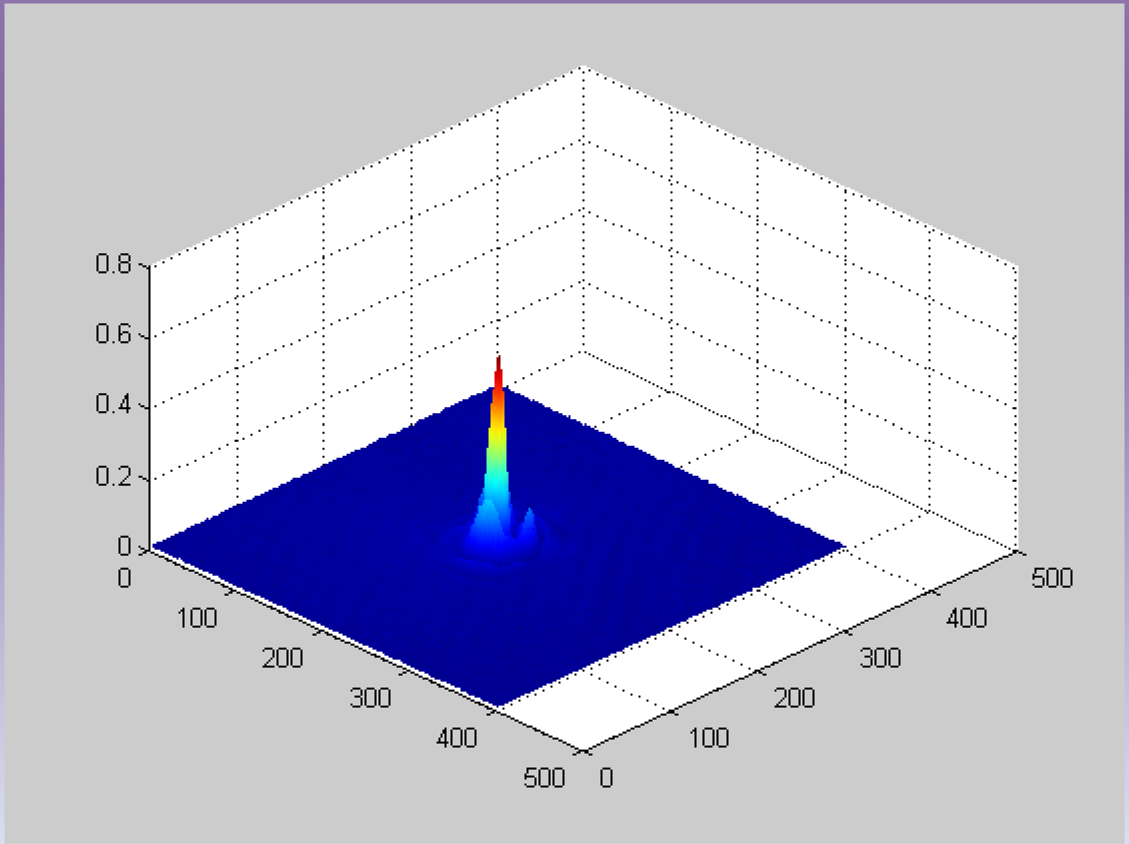


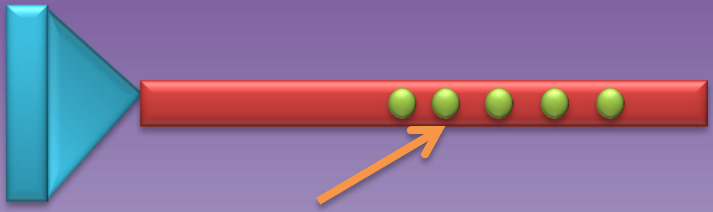




Data Analysis

3.Created a Matlab program to make a video of the propagation of a Bessel Mode after an axicon.





Pictures taken at 2.5 mm steps along propagation from 155 mm to 200 mm

Axicon Results

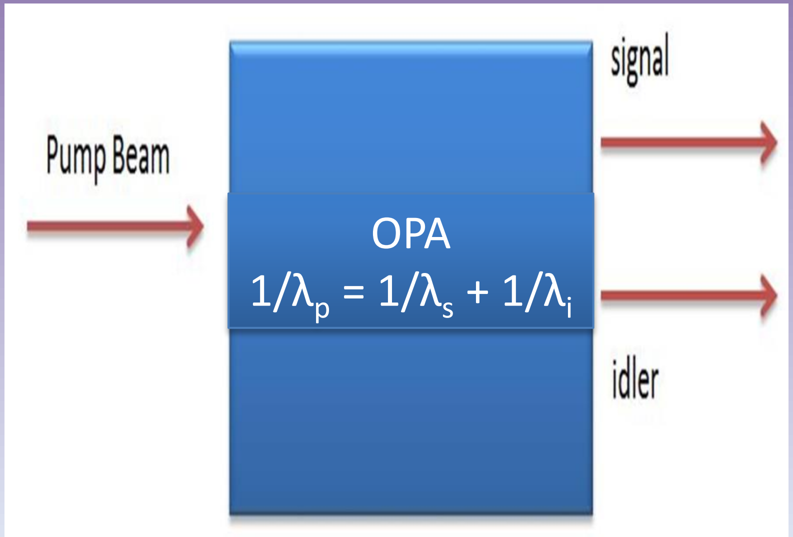
Power before fiber = 3.72 mW with axicon and 4.03 mW without axicon

Inner Diameter (µm)	Transmitted Power (mW)	Efficiency (%)
250	2.08	55.9
300	0.36	9.7
350	0.78	21.0
400	0.77	20.7
450	0.48	12.9
500	0.40	10.8
500 mm lens	2.32	57.6

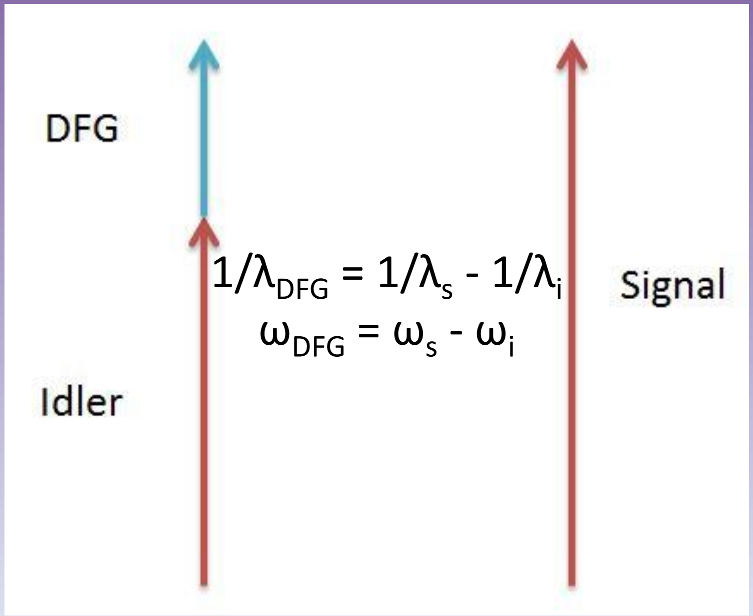
300 – 500 µm fibers are new and a different brand . It is not conclusive whether they are bad fibers or not.

Mid-IR fs Pulse Generation Terminology

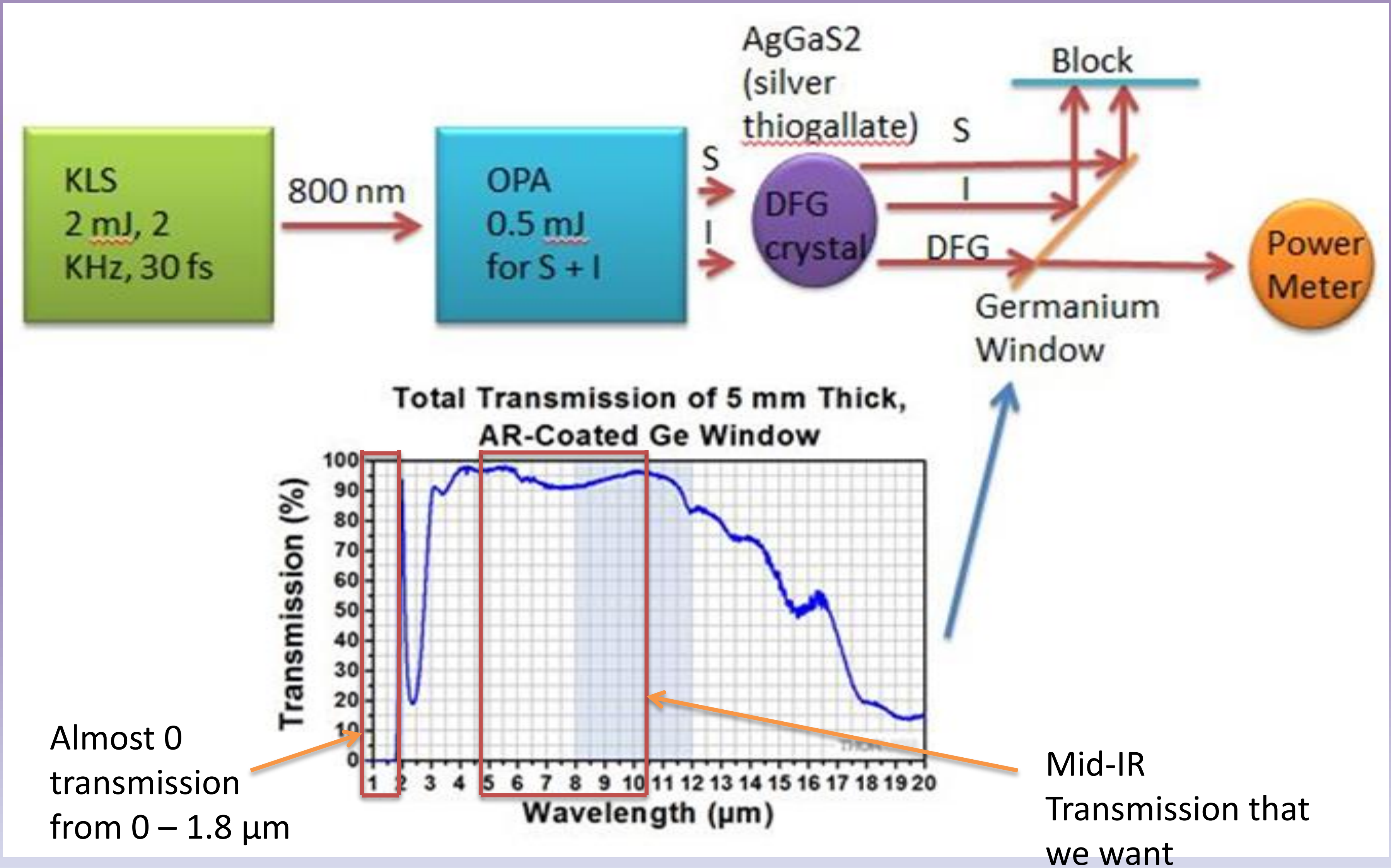
- Optical Parametric Amplifier (OPA): Non-linear device that takes pulsed laser light and for our case produces two beams; a signal (1050 – 1550 nm) and an idler (1600 – 2500 nm); Signal and Idler are about 40 – 50 fs



- Difference Frequency Generation (DFG): takes two beams (signal and idler) and for our case creates one beam (3-12 µm)



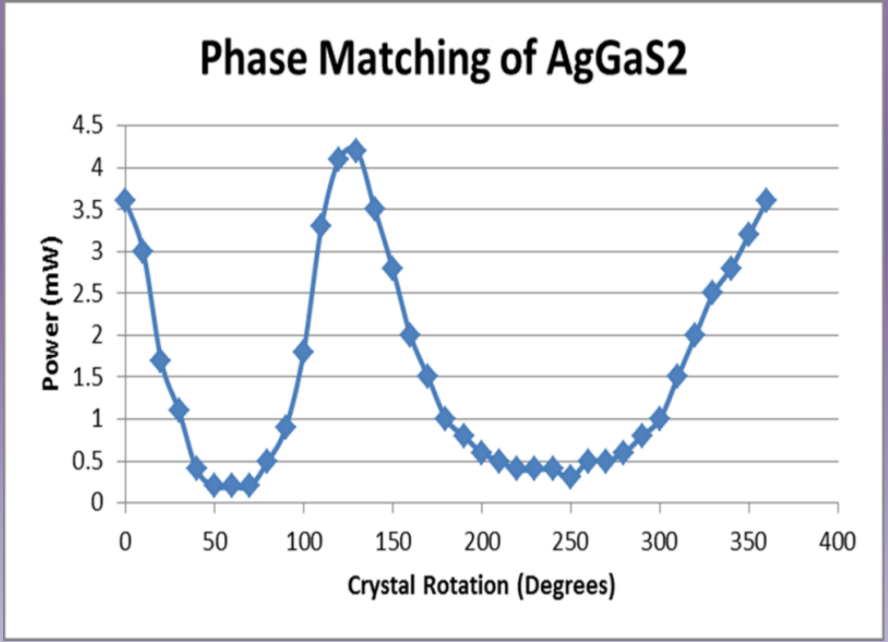
Mid-IR fs Pulse Generation Setup



Transmission graph from thorlabs.com

Mid-IR fs Pulse Generation Results

- Showed generation of mid-IR fs pulses through crystal with Phase Matching



$1/\lambda_{DFG} = 1/\lambda_s - 1/\lambda_i$

Beam	Wavelength (nm)
Signal	1490
Idler	1750
Mid-IR fs pulse	9200

- Signal and Idler achieve optimum phase matching at 0 (or 360) and 130 degrees

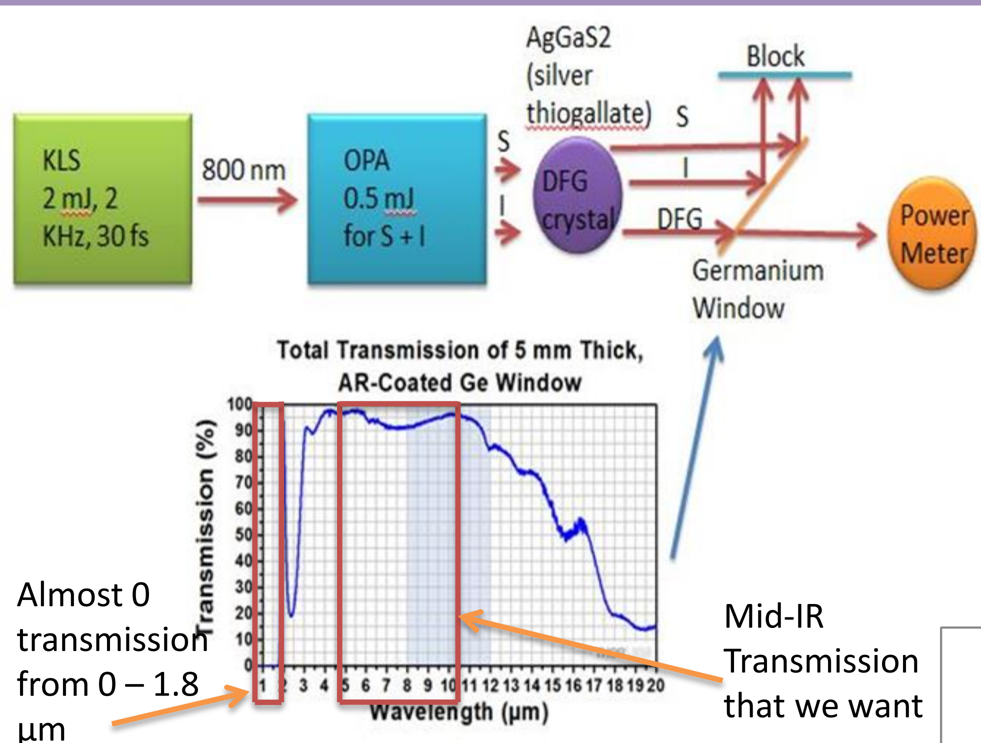
Mid-IR fs Pulse Generation Results

- With tuning and crystal rotation of 134 degrees:

$1/\lambda_{DFG} = 1/\lambda_s - 1/\lambda_i$

Observed Phenomena	Results
Maximum Power of generated Mid-IR fs pulse	10.5 mW
Wavelength of signal at max power	1450 nm
Wavelength of idler at max power	1705 nm
Energy Split	66% signal 34% idler
Wavelength of generated Mid-IR fs pulse at max power	9700 nm sub 100 fs pulse

Mid-IR fs Pulse Generation Results



$$1/\lambda_{DFG} = 1/\lambda_s - 1/\lambda_i$$

Beam	Wavelength (nm)
Signal	1450
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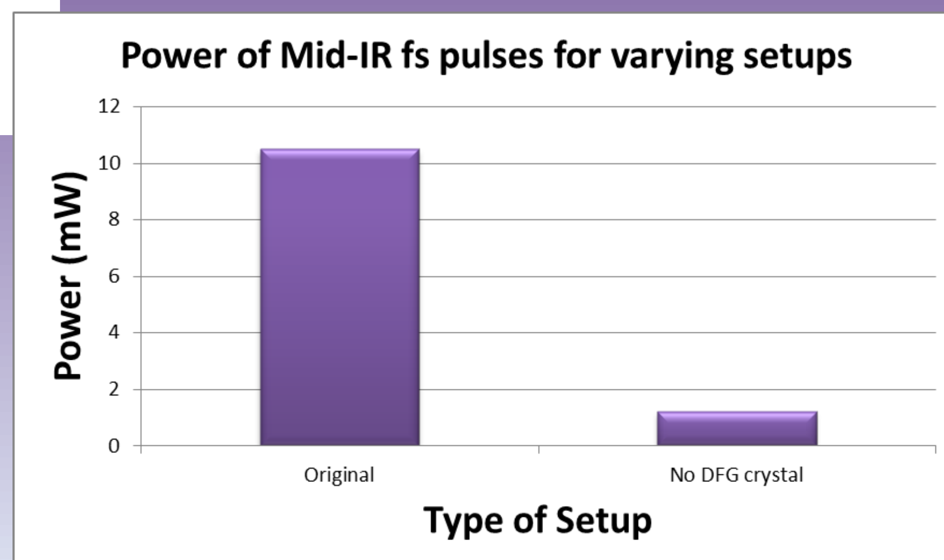
Mid-IR fs pulse	9700



Conclusion

Axicon

The Bessel Beam from the axicon coupled through a 250 µm fiber almost as well as just the lens.

Mid-IR fs pulse generation

We were able to create 10.5 mW light at close to 9.7 µm (mid-IR) sub 100 fs pulses which is an awesome result.

Future

Axicon

- We expect to improve the transmission efficiency by changing the focusing conditions and the fiber diameter.
- As soon as the Bessel Beam travels through the fiber more efficiently, we can use this method to have more efficient spectral broadening for fs pulses.

Mid-IR fs pulse generation

- We are going to adjust our Mid-IR fs pulse generation setup to better control the phase matching of the signal and idler in order to create higher power Mid-IR fs pulse beams.
- We are going to attempt the Mid-IR fs pulse setup in HITS

Acknowledgements

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