National Institute of
Advanced Industrial Science
and Technology
AIST

7/22/2016

Optical vortex laser measurement

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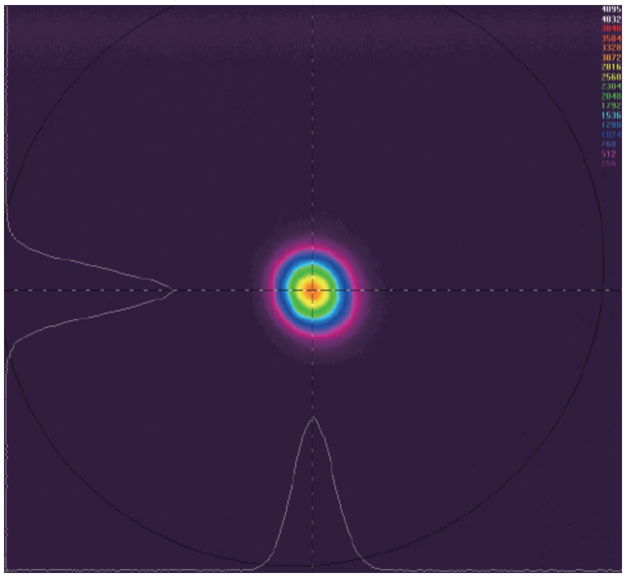
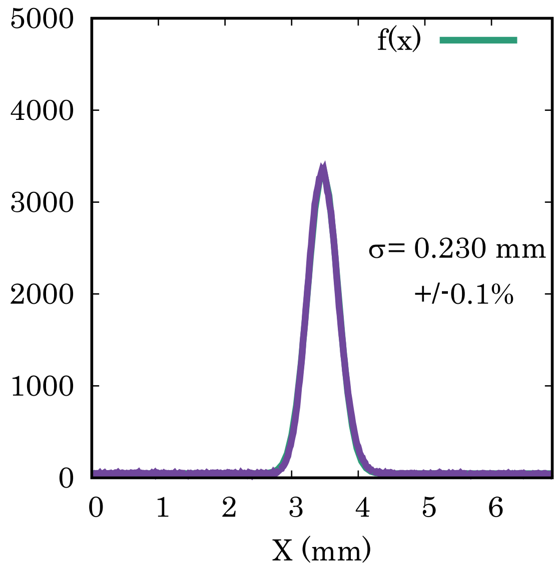
Laser and CCD camera

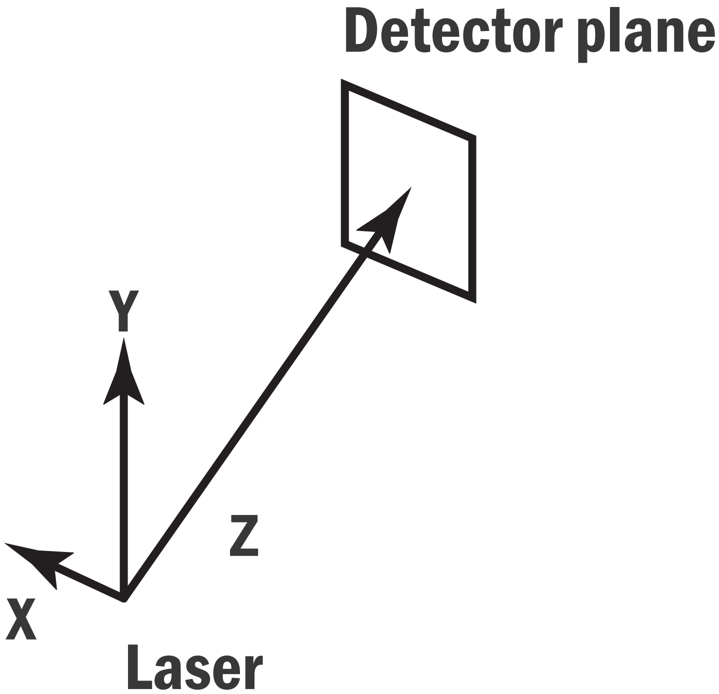
Laser: World Star Tech
Wavelength: 532 nm
Power: < 5 mW
Beam size: 0.54 mm (H), 0.59 mm(V) at FWHM

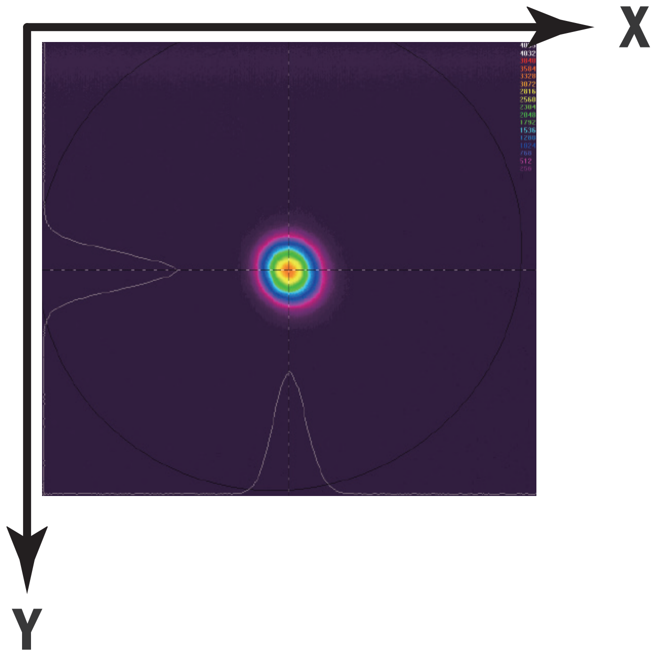
Camera: COHU, Model 4812
Pixel size: 0.0135 mm/px
Pixel: 512 (H), 480 (V)





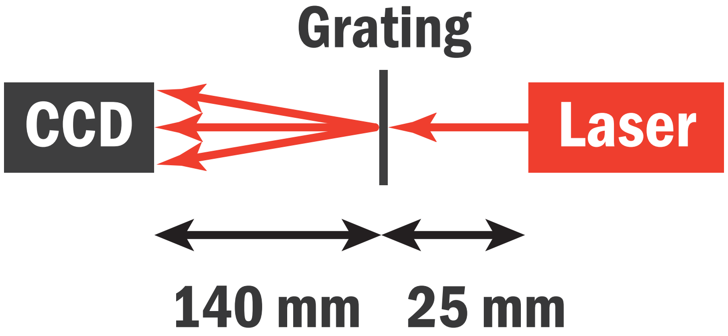
Coordinate system

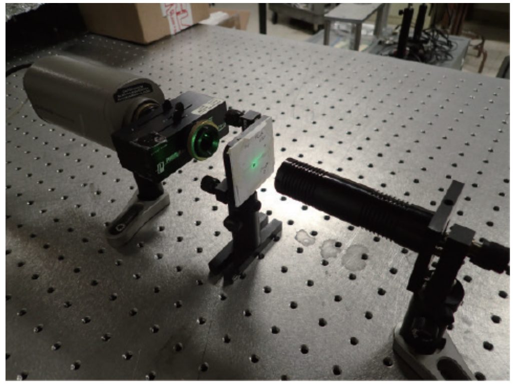




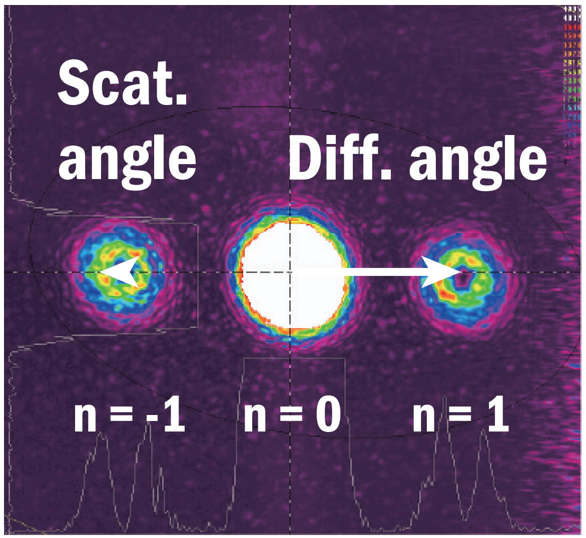
Coordinate system of the calculated result should be reversed to compare with the measurement results.

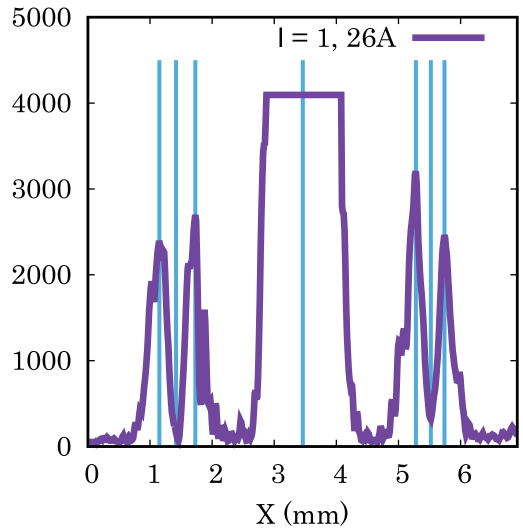
Diffraction pattern





OAM value = m×n
(m is the charge of grating, n is the diffraction order)





List of gratings

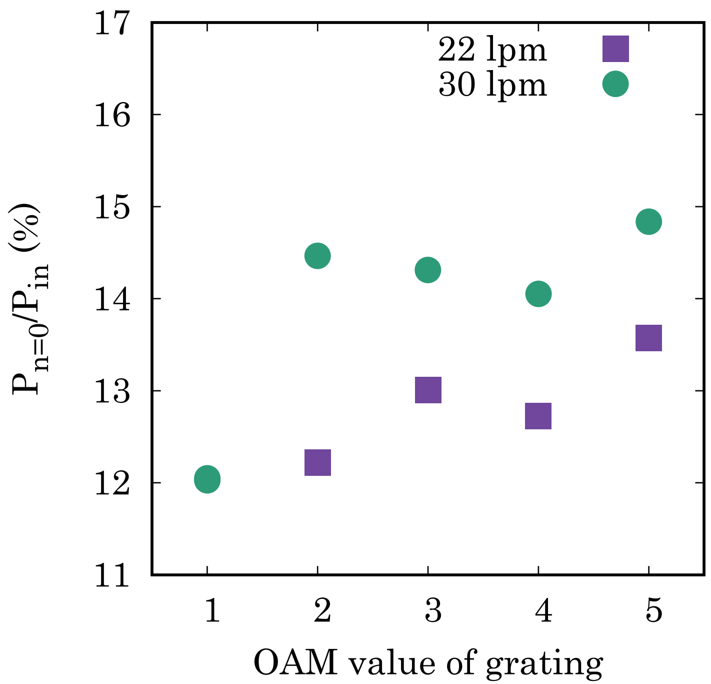
Grating #	Charge, m	Lines /mm	Diff. angle (mrad)	Scat. angle (mrad)
27A	1	30 ± 2	13.9 ± 0.4	1.8 ± 0.3
26A	1	30 ± 2	14.7 ± 0.1	2.1 ± 0.2
24A	2	30 ± 2	14.8 ± 0.1	2.2 ± 0.3
2A	2	22 ± 2	10.6 ± 0.1	2.3 ± 0.2
34A	3	30 ± 2		
9A	3	22 ± 2		
35A	4	30 ± 2		
10A	4	22 ± 2		
33A	5	30 ± 2		
11A	5	22 ± 2		
29A	10	30 ± 2		

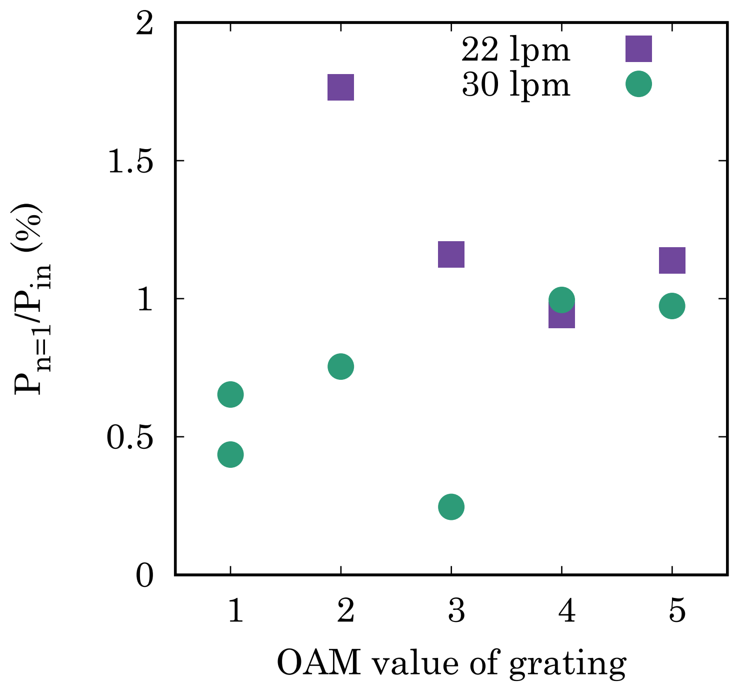
Lines per mm was measured with a optical microscope and microscale.

Charge, m = 2

Power measurement

Pin = 4.59 mW
Power of diffracted beam (n = 0 and n = 1) was measured.



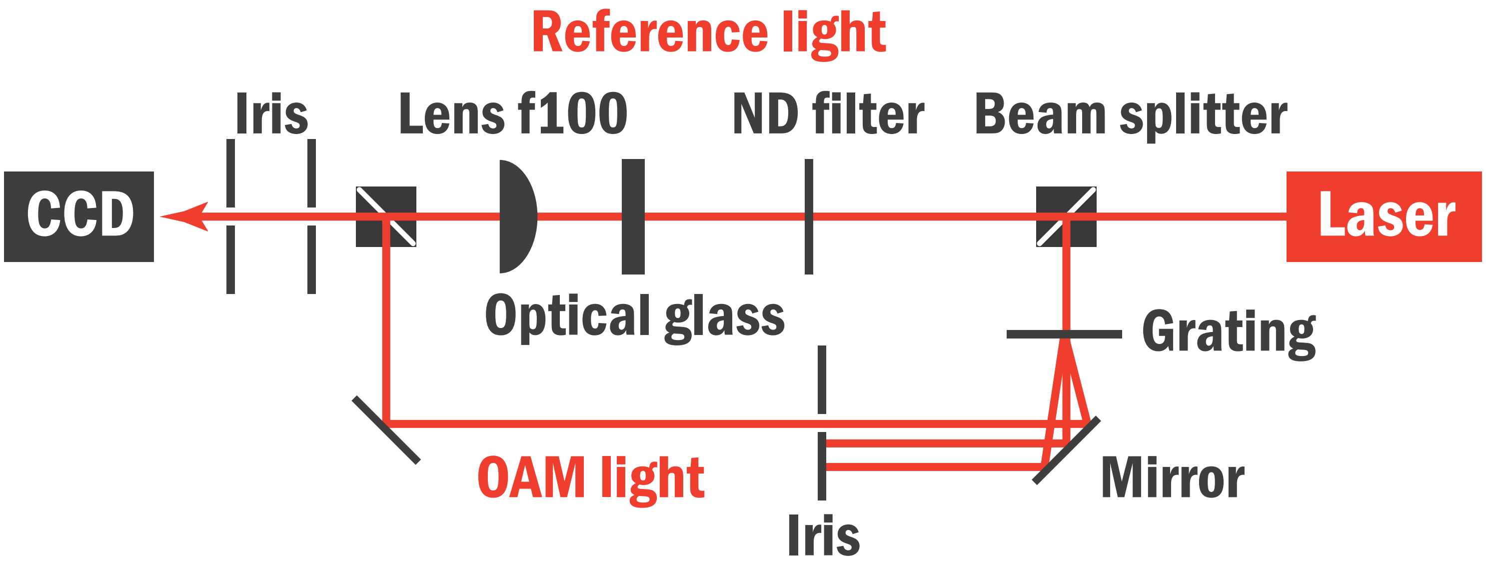


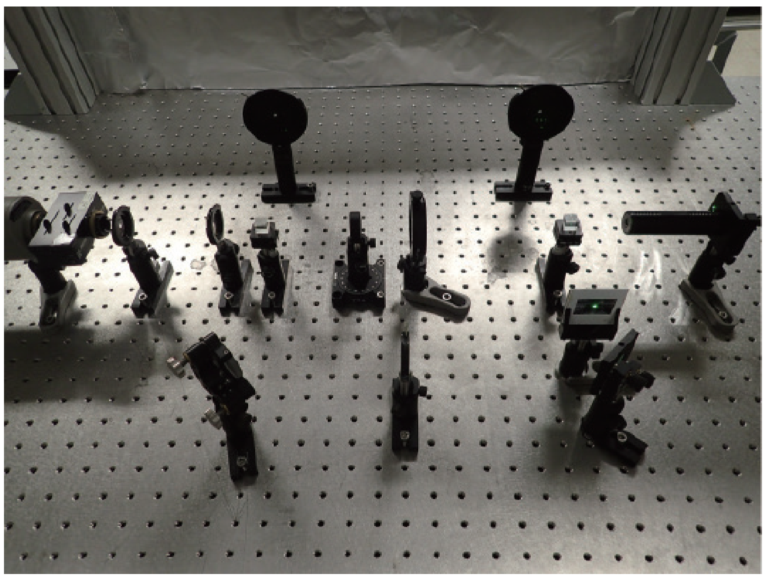
Power of non diffracted beam increases as the lpm is large.
Power of n=1 beam increases as the lpm in small (except OAM = 4) and differs even if same OAM value (OAM =1).

Interference pattern measurement

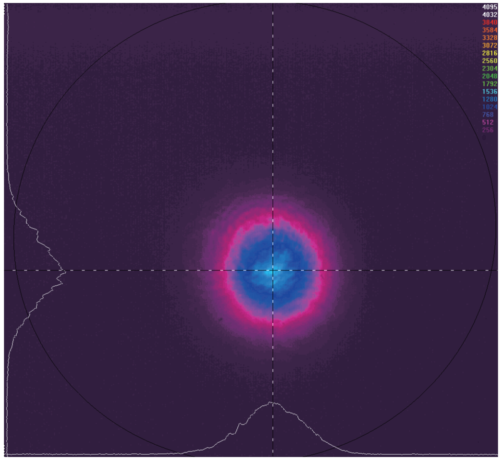
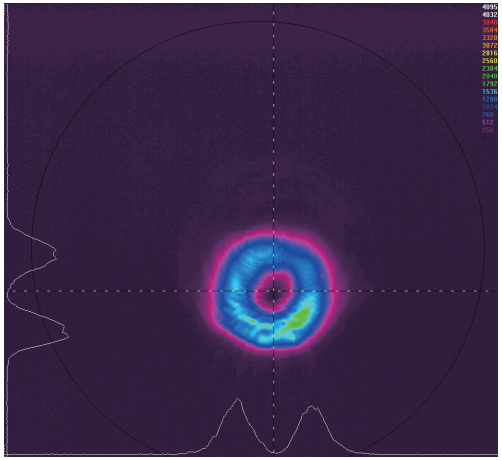
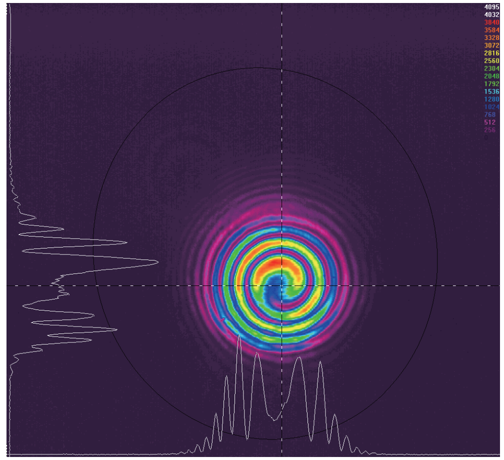
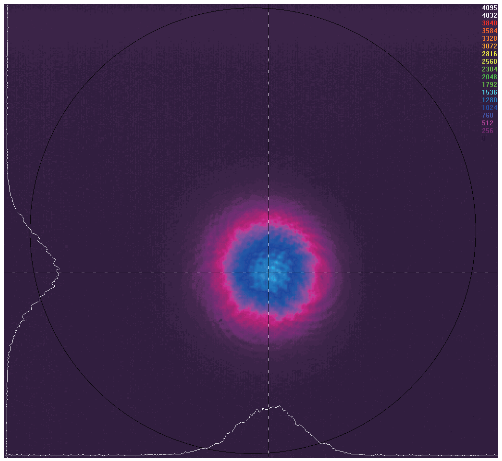
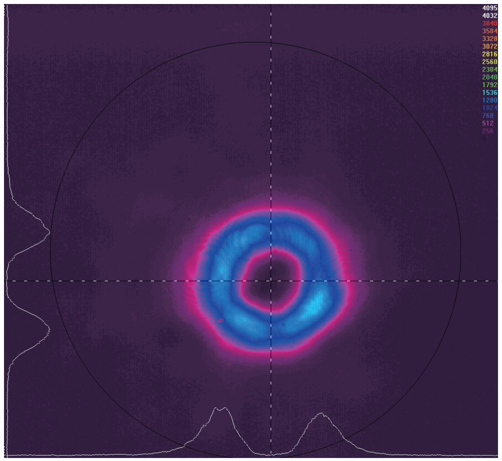
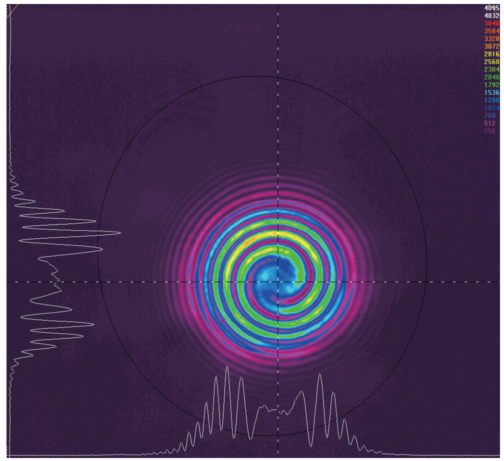
1. OAM + reference (R = 215 mm)
2. OAM + reference (R = ∞)
3. OAM (double gratings) + reference (R = 215 mm)
4. OAM + OAM

Interference pattern with lens





Interference pattern

OAM value	Reference light	OAM light	Interference
-1			
-2			

Calculation of interference pattern

Interference between two different electric fields

$$E_1 \exp\left(i\phi_1\right) \qquad E_2 \exp\left(i\phi_2\right)$$

$$I = \left|E_1 \exp\left(i\phi_1\right) + E_2 \exp\left(i\phi_2\right)\right|^2 = E_1^2 + E_2^2 + 2E_1E_2 \cos\left(\phi_1 - \phi_2\right)$$

Gaussian beam (reference light)

$$E = E_0 \frac{\omega_0}{\omega(z)} \exp\left(-\frac{r^2}{\omega^2(z)}\right) \exp\left\{-i\left(kz + k\frac{r^2}{2R(z)} - \psi(z)\right)\right\}$$

$$\omega(z) = \omega_0 \sqrt{1 + \left(\frac{z}{z_R}\right)^2}$$ **Beam radius**

$$R(z) = z\left\{1 + \left(\frac{z_R}{z}\right)^2\right\}$$ **Rradius of curvature of the beam's wavefront**

$$z_R = \frac{\pi \omega_0^2}{\lambda}$$ **Rayleigh range**

$$\psi(z) = \tan^{-1}\left(\frac{z}{z_R}\right)$$ **Gouy phase**

$$\omega_0 = 0.053 \text{ mm}$$ **Waist size when the laser is focused by a f100 lens**

Laguerre Gaussian beam (OAM light)

$$E = \frac{C}{\sqrt{1+\left(z/z_R\right)^2}}\left(\frac{r\sqrt{2}}{\omega(z)}\right)^{|m|} L_p^m\left(\frac{2r^2}{\omega^2(z)}\right)\exp\left(-\frac{r^2}{\omega^2(z)}\right)$$

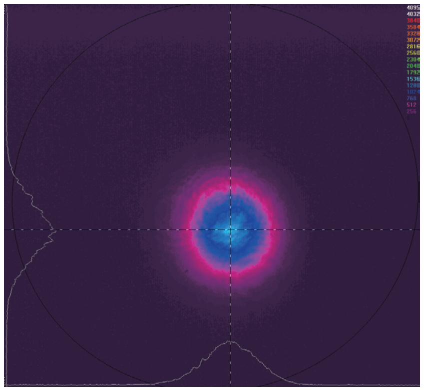
$$\times \exp\left\{-i\frac{kr^2 z}{2\left(z^2+z_R^2\right)}\right\}\exp\left(-im\phi\right)\exp\left\{i\left(2p+m+1\right)\tan^{-1}\frac{z}{z_R}\right\}$$

$L_p^m(x)$ **Laguerre polynominal, m is OAM value**

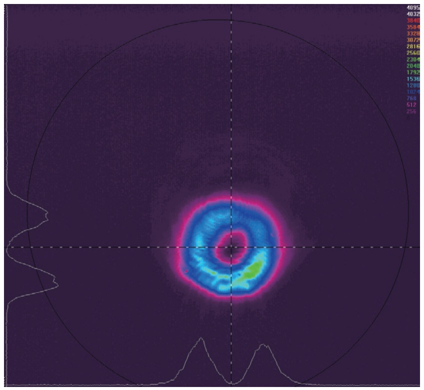
$$L_0^m(x)=1$$

Interference pattern: OAM = -1

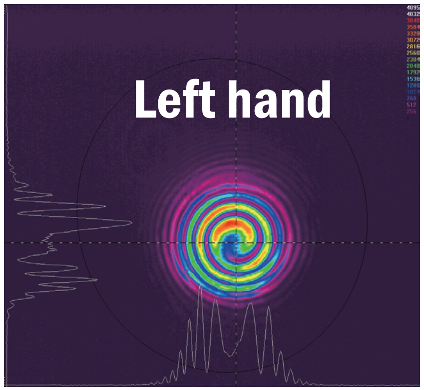
Reference light

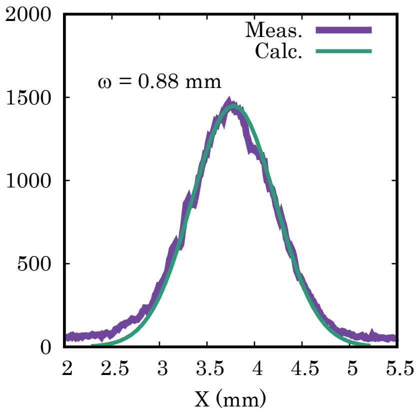


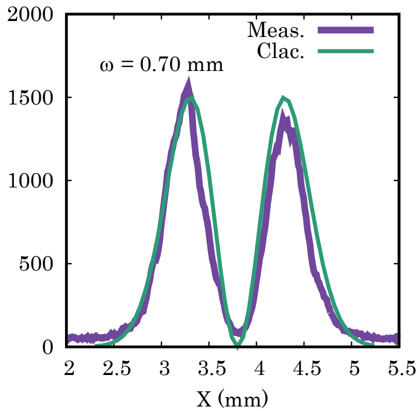
OAM light

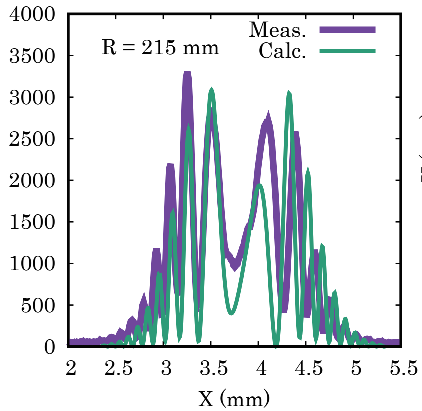


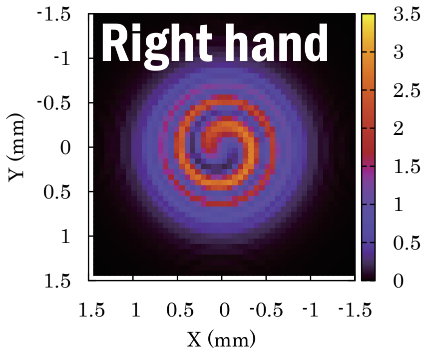
Interference





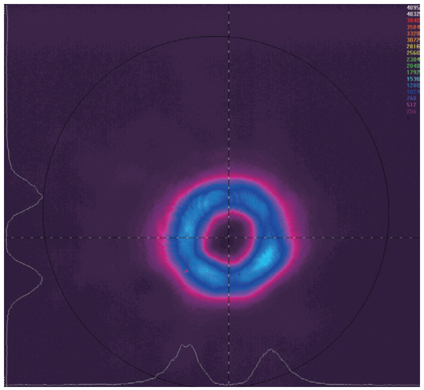




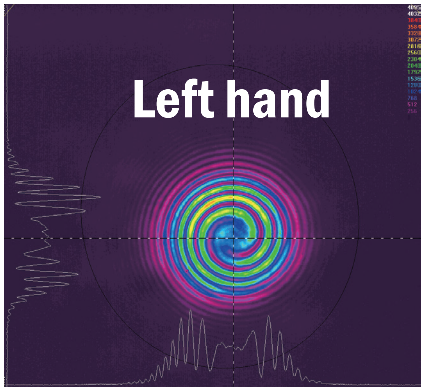


Interference pattern: OAM = -2

OAM light

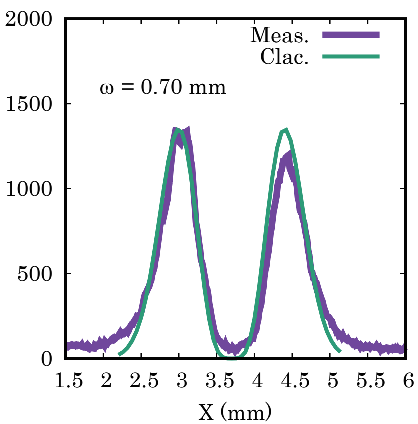


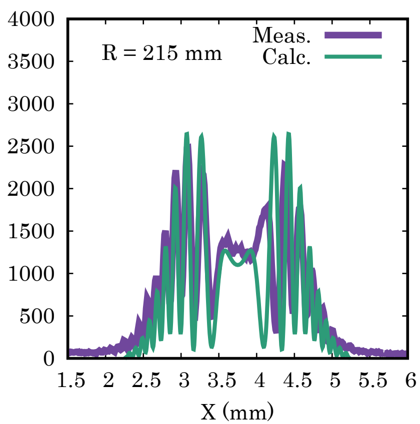
Interference

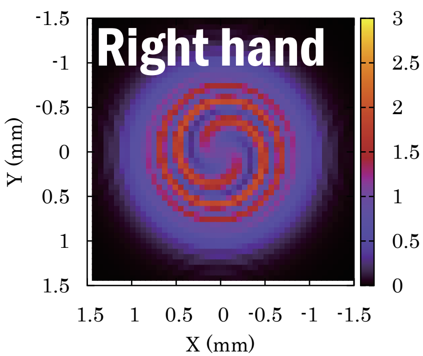


OAM value is inverted. Why?

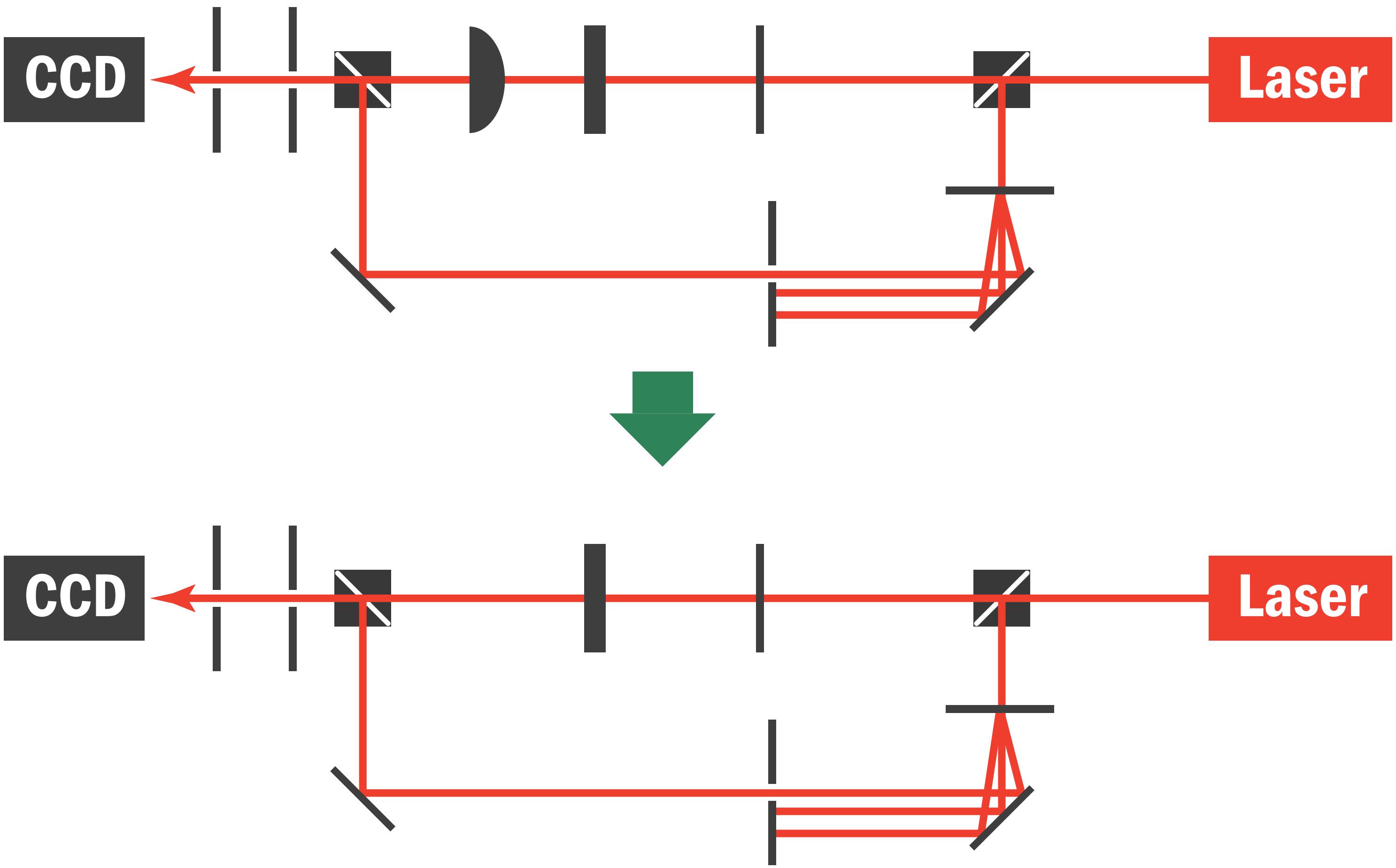
But, we can explain the spiral interference pattern. This is due to a finite curvature of the wave front.





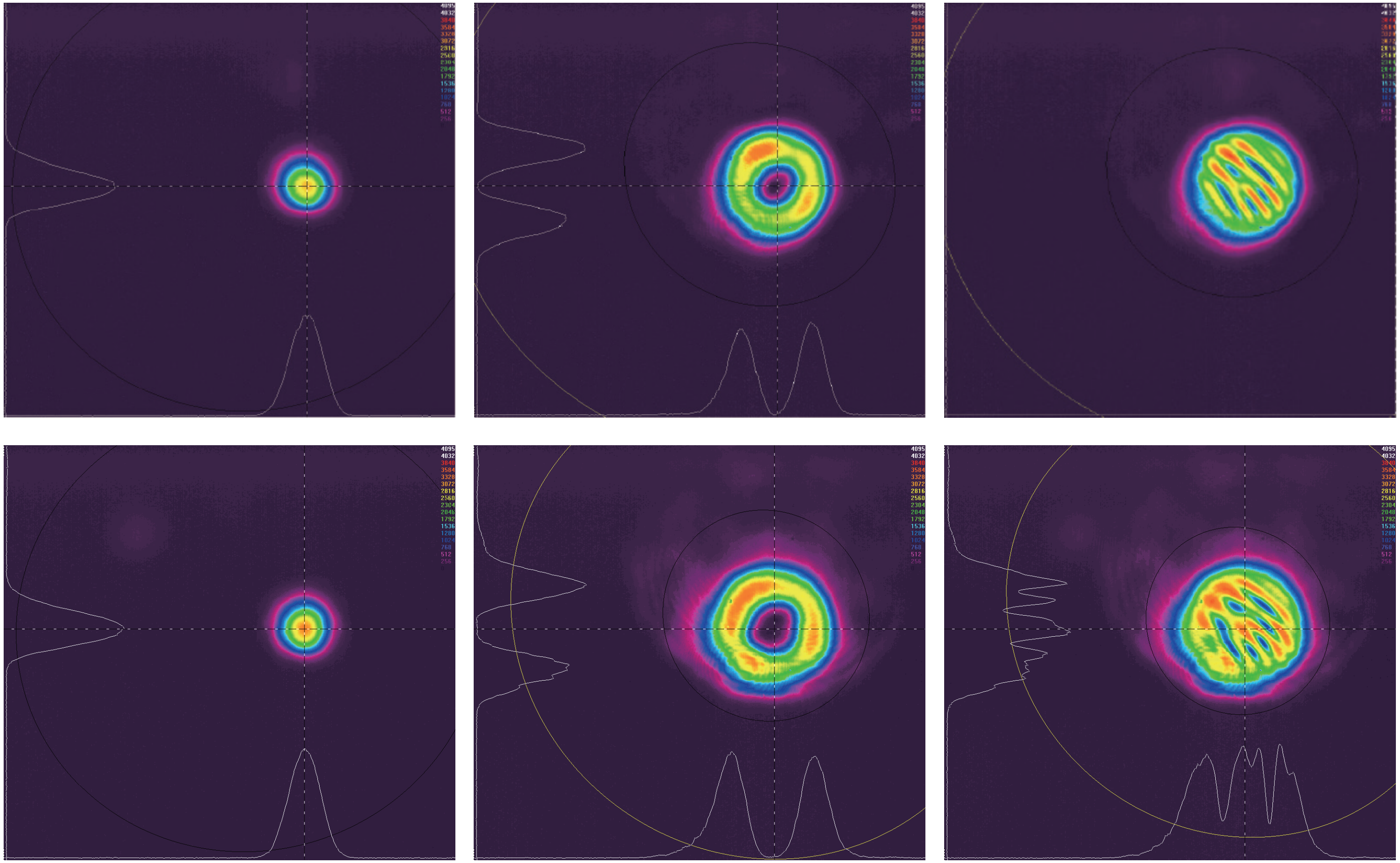


Interference pattern without lens



Interference pattern w/o lens

OAM value	Reference light	OAM light	Interference
-1			
-2			



I cannot understand why the interference pattern become fork, but..

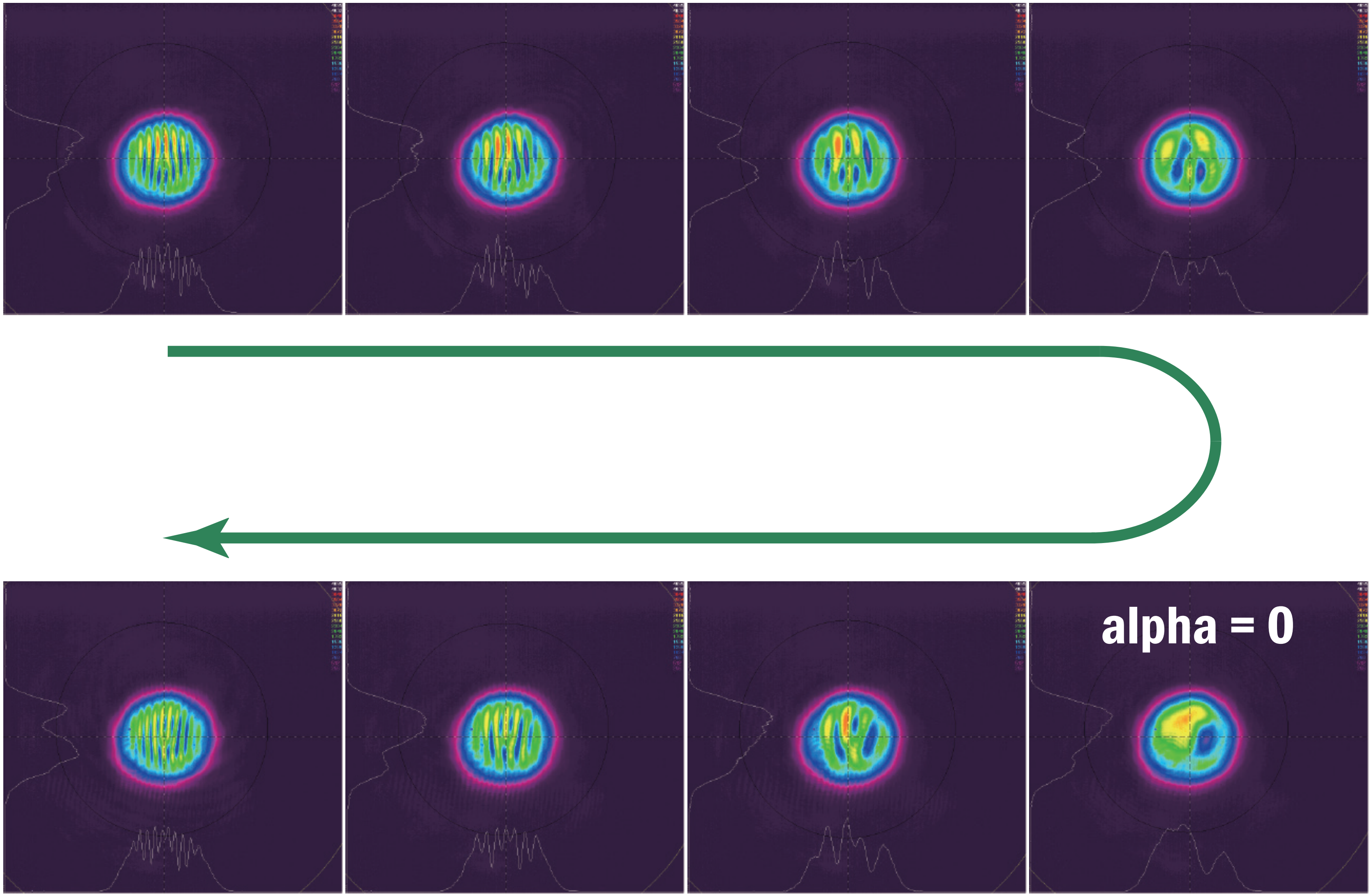
Interference pattern w/o lens

If the beam intersects another beam at angle, alpha, Gaussian beam can be expressed as

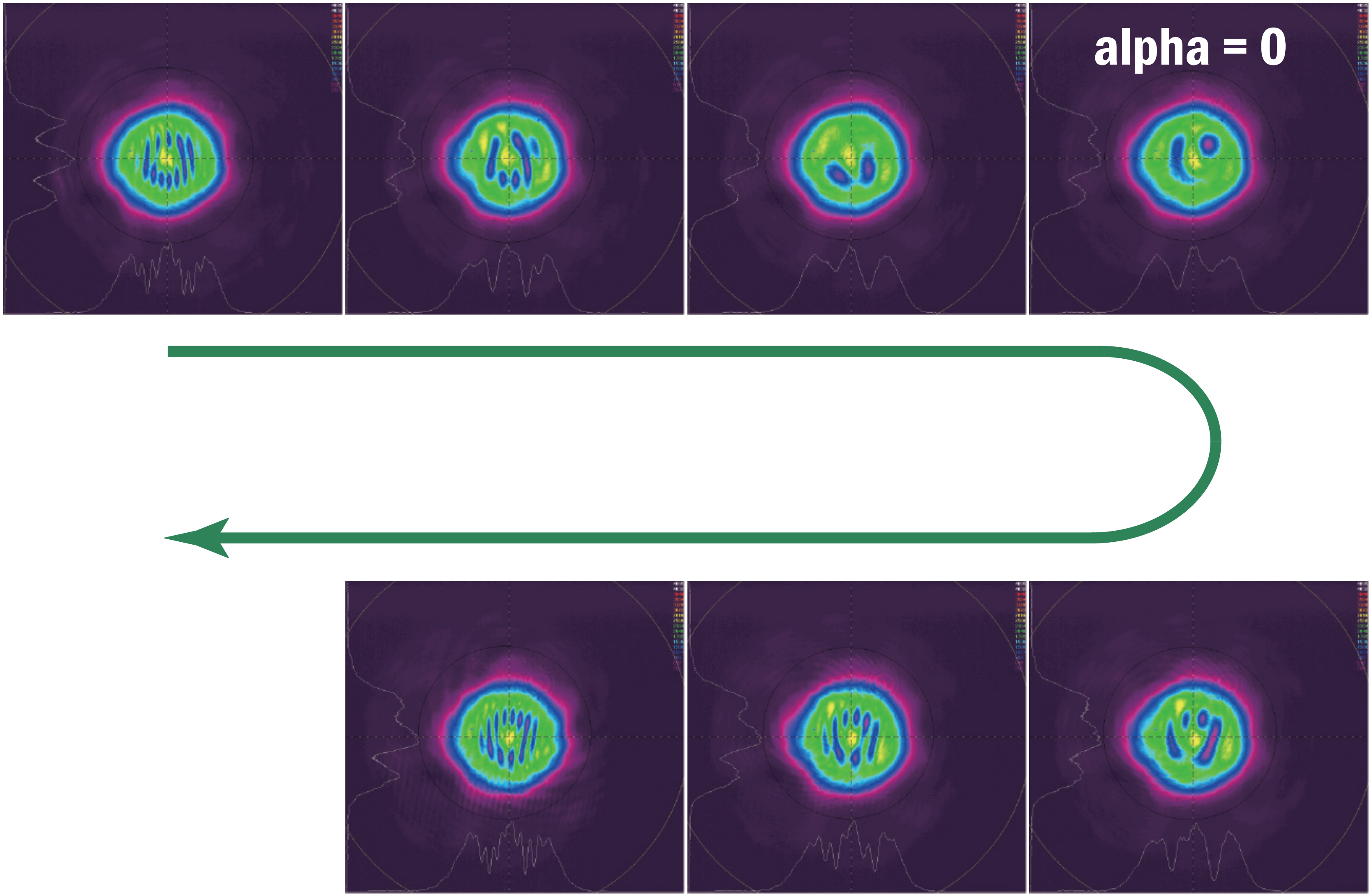
$$E = E_0 \frac{\omega_0}{\omega(z)} \exp\left(-\frac{r^2}{\omega^2(z)}\right) \exp\left\{-i\left(kz\cos\alpha + kx\sin\alpha + k\frac{r^2}{2R(z)} - \psi(z)\right)\right\}$$

The term kxsin(alpha) induce fork interference pattern, and the pattern will change by the value of alpha.

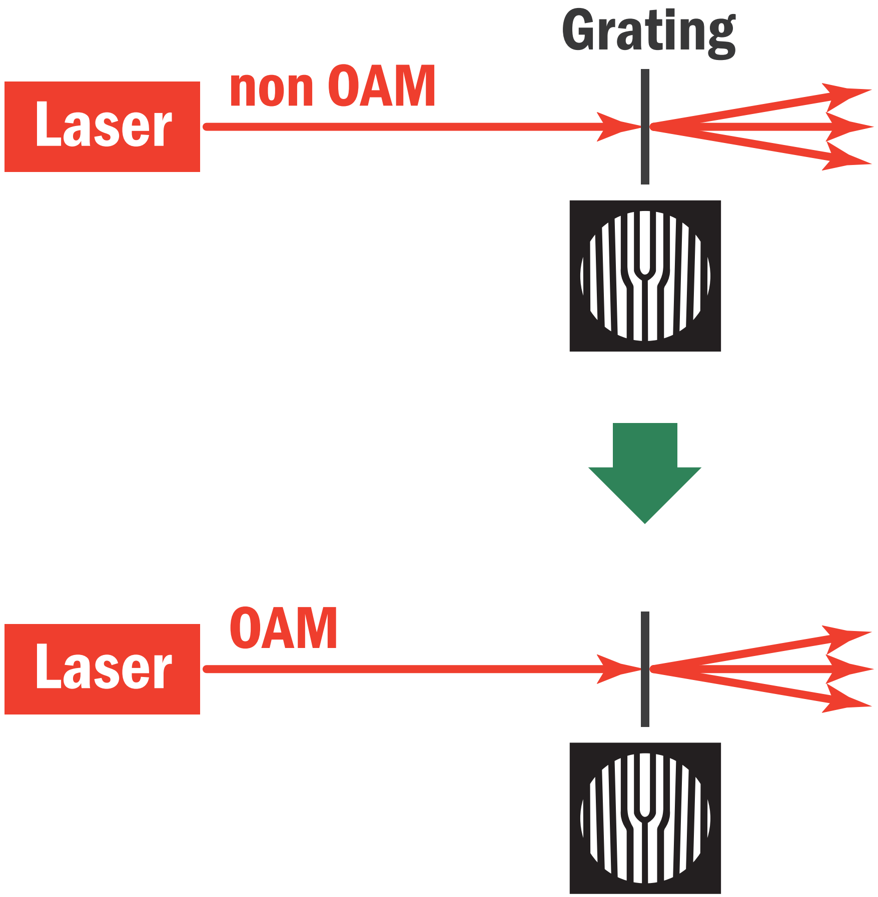
Changing crossing angle: OAM = -1



Chaning crossing angle: OAM = -2



What will happen if OAM laser injects

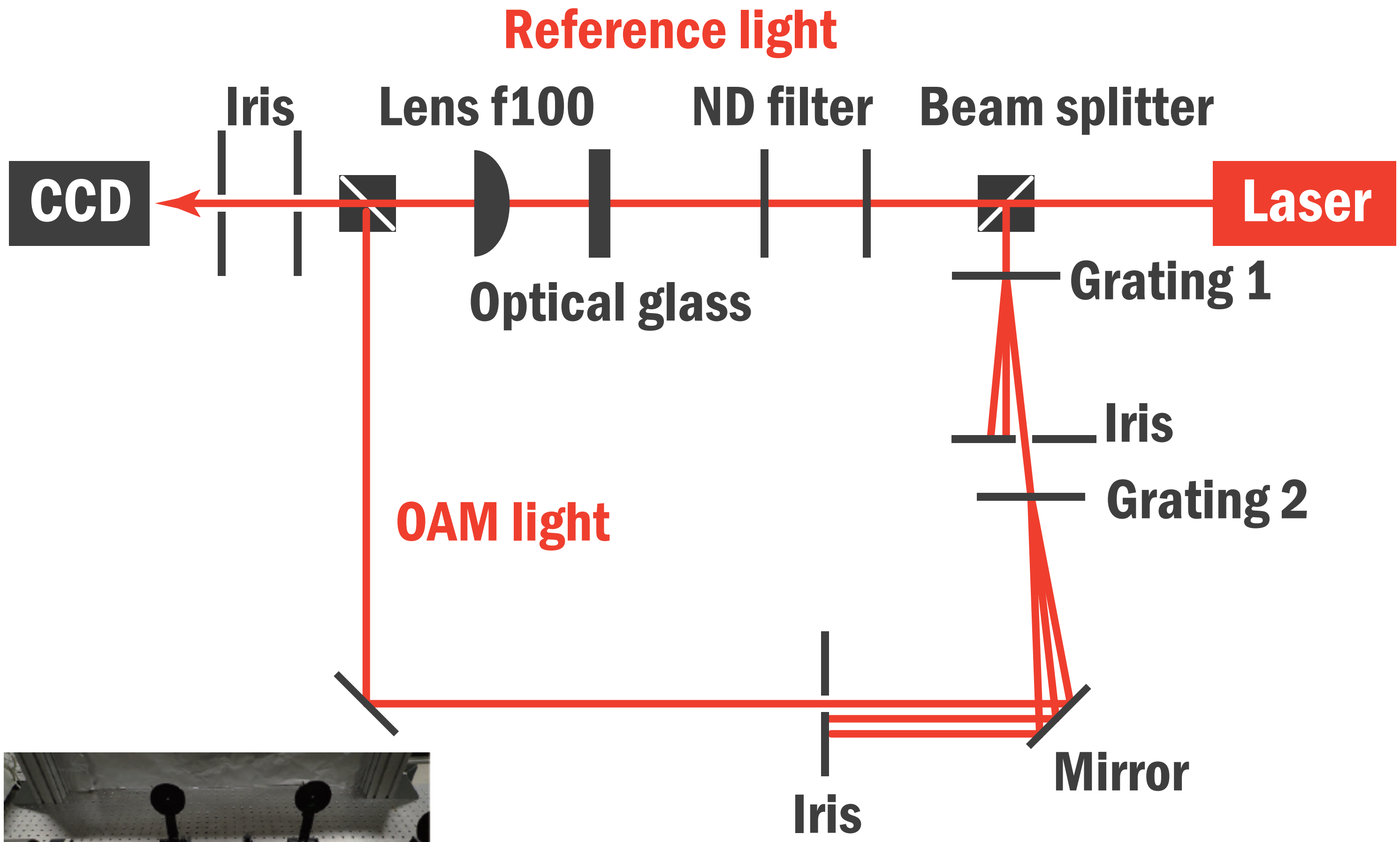


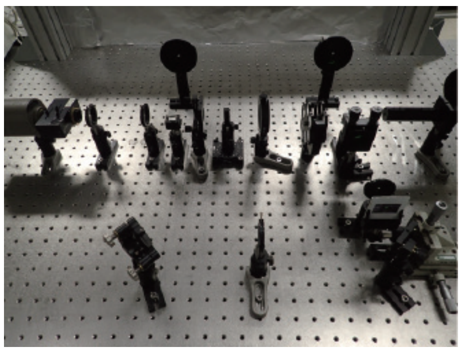
OAM = m × n

m: the charge of grating
n: the diffraction order
n=0, ±1, ±2, ...

OAM = ??

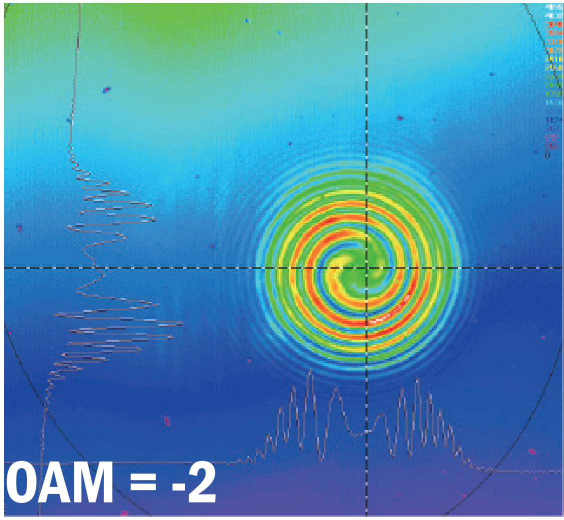
Interference pattern using double gratings



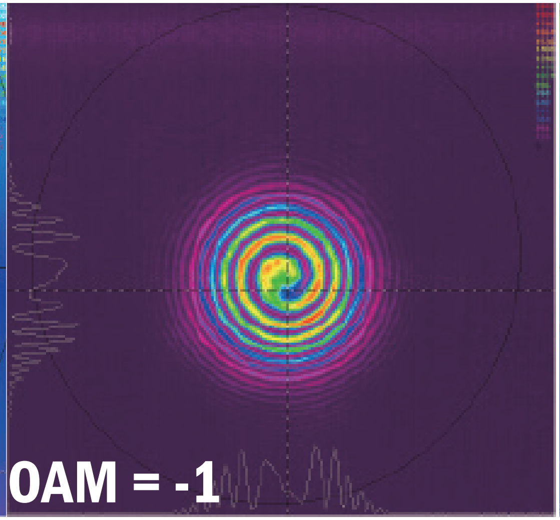


Interference pattern

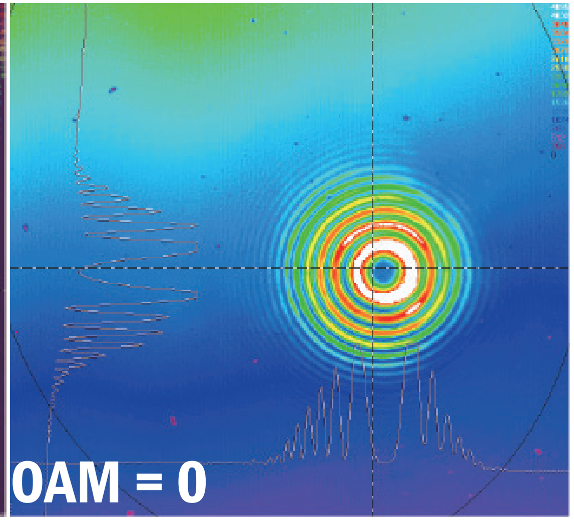
OAM G1 = -1
OAM G2 = -1



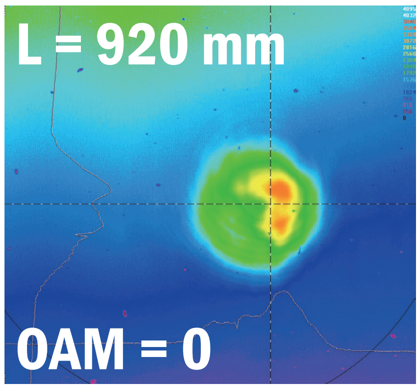
OAM G1 = -1
OAM G2 =0

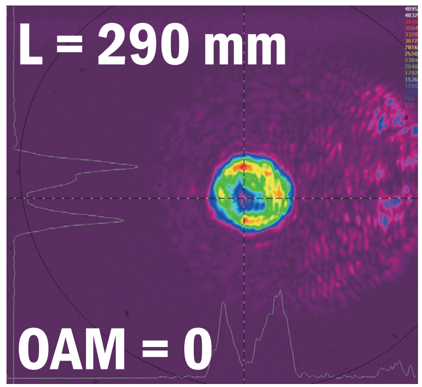


OAM G1 = -1
OAM G2 =+1



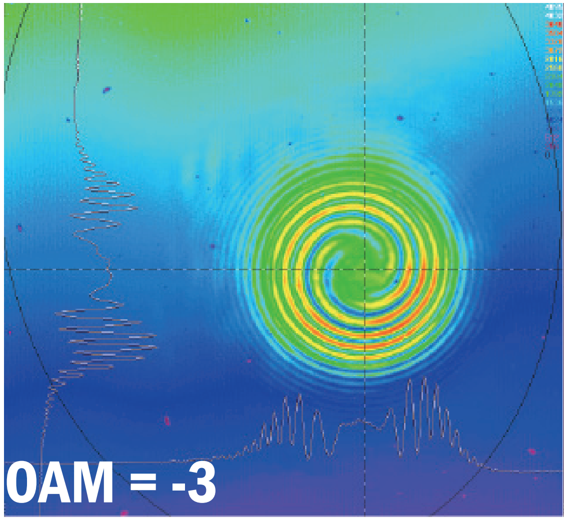
Profile of the beam from G2



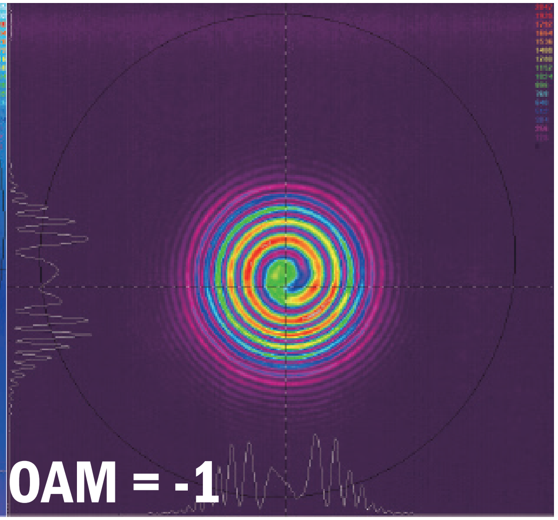


Interference pattern

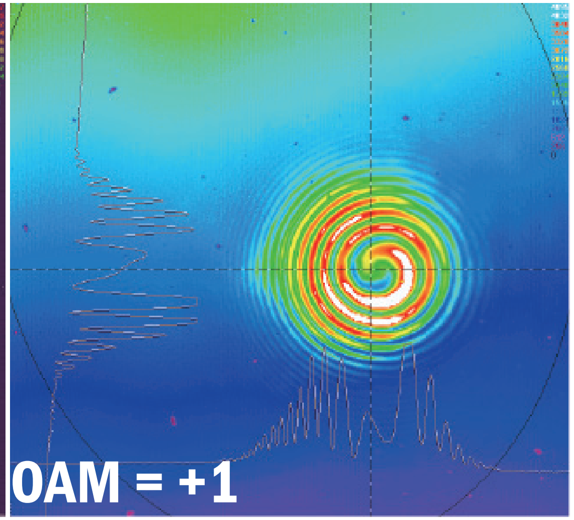
OAM G1 = -1
OAM G2 = -2



OAM G1 = -1
OAM G2 = 0

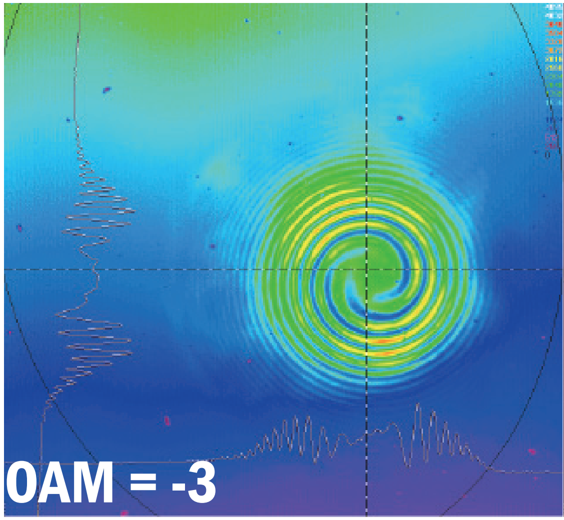


OAM G1 = -1
OAM G2 = +2

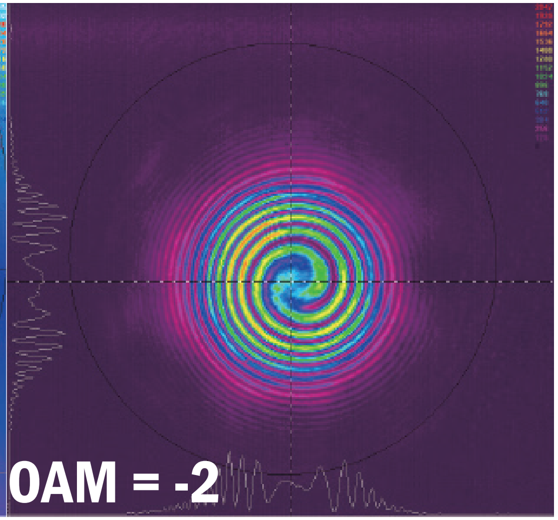


Interference pattern

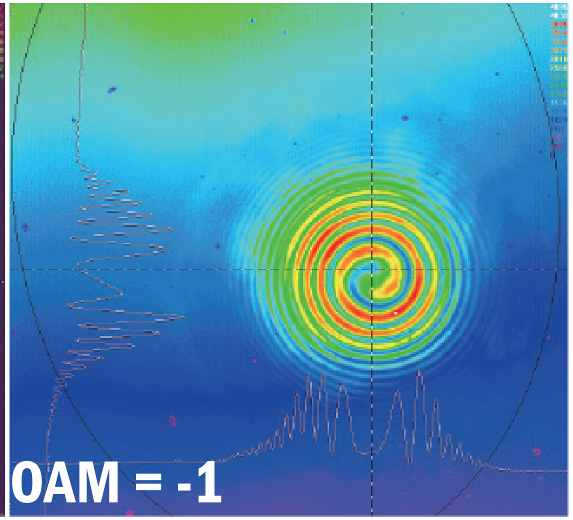
OAM G1 = -2
OAM G2 = -1



OAM G1 = -2
OAM G2 =0

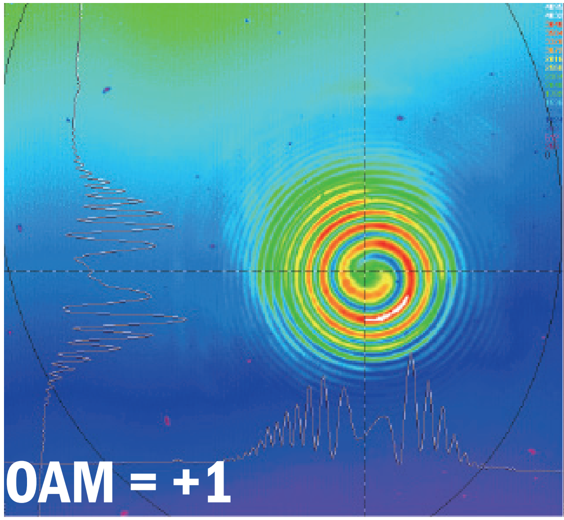


OAM G1 = -2
OAM G2 =+1

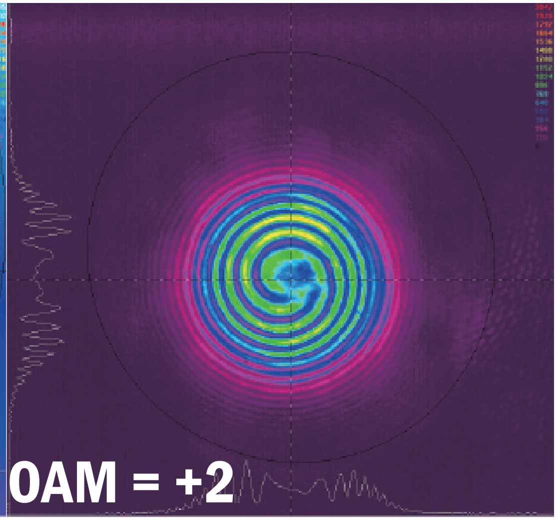


Interference pattern

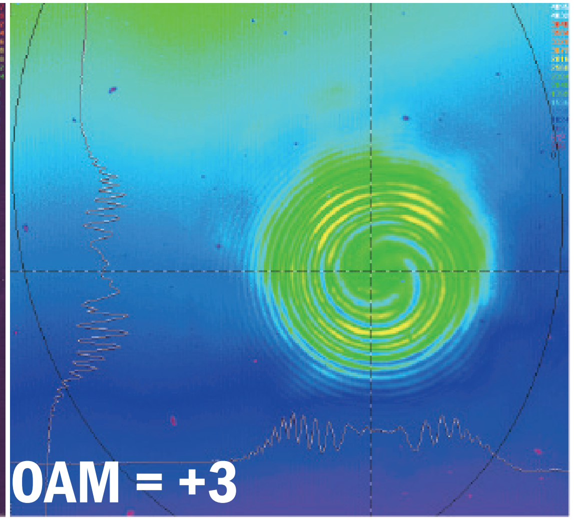
OAM G1 = +2
OAM G2 = -1



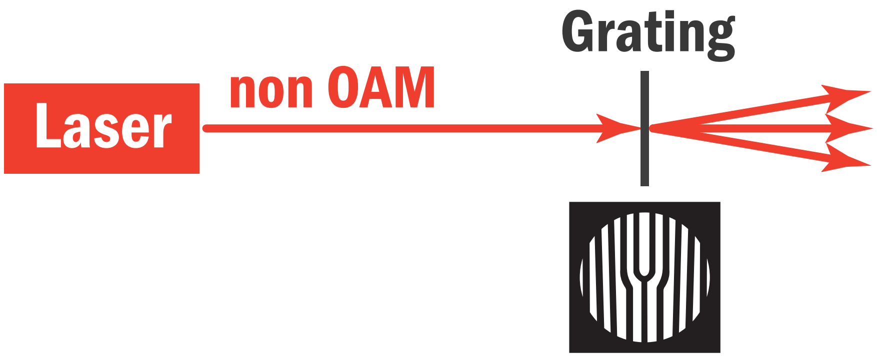
OAM G1 = +2
OAM G2 = 0



OAM G1 = +2
OAM G2 = +1



Interference pattern



OAM = m × n

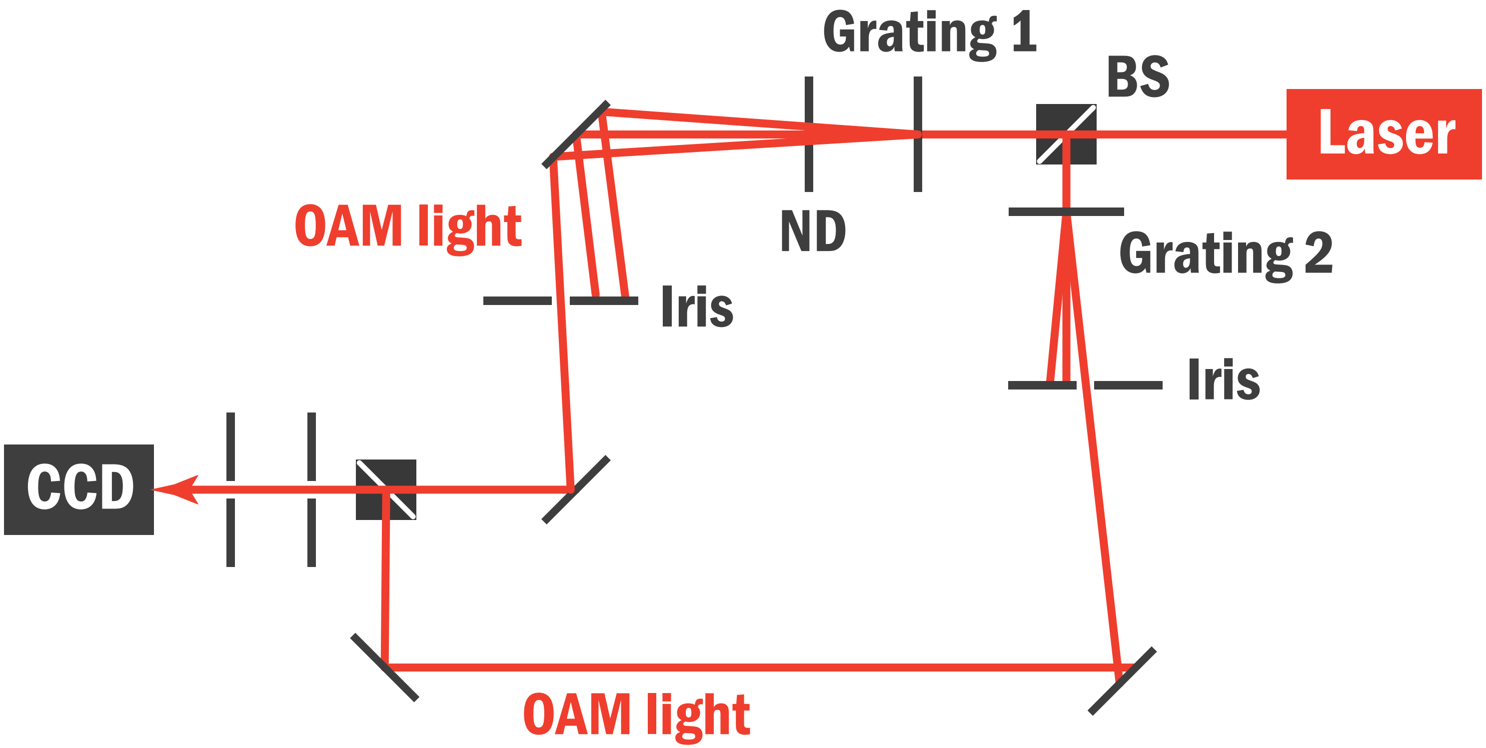
m: the charge of grating
n: the diffraction order
n=0, ±1, ±2, ...

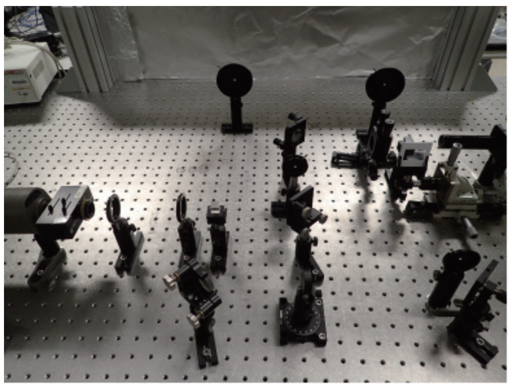
OAM = m1+m2 × n

m2: the charge of grating
n: the diffraction order
n=0, ±1, ±2, ...

OAM value is preserved.

Interference pattern between OAM laser

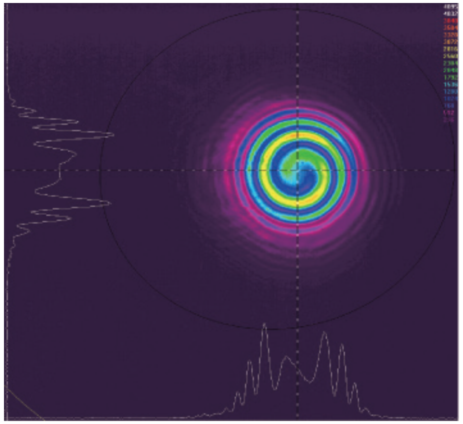




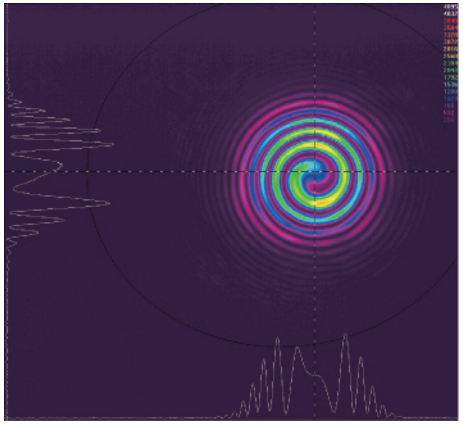
Interference pattern with reference laser

OAM value = -1: Right hand spiral interference is produced

OAM laser from G1 and reference laser (without G2)



OAM laser from G2 and reference laser (without G1)

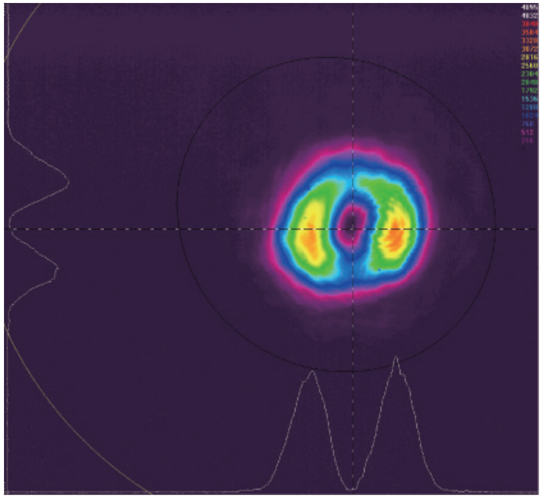


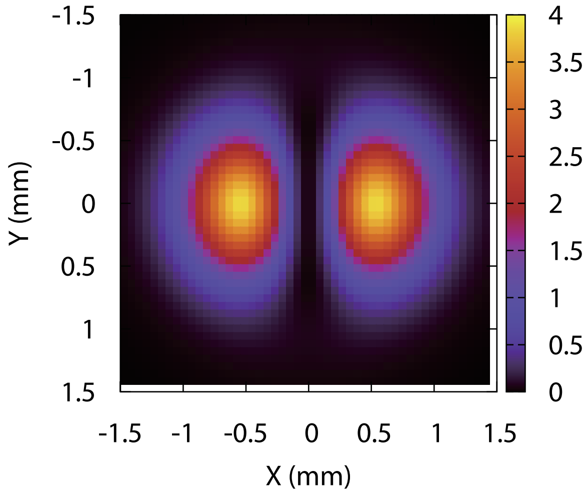
OAM value from G2 is inverted.

Interference pattern

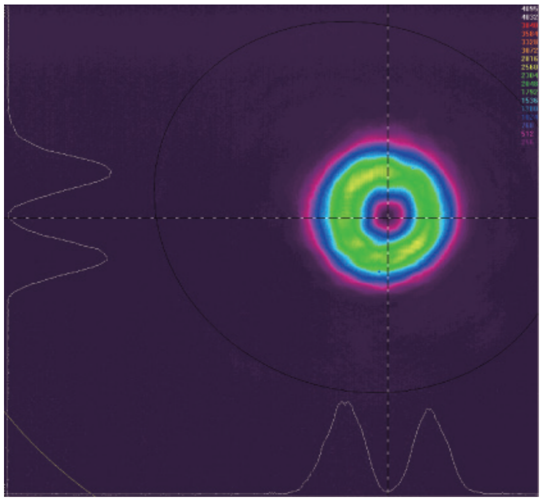
OAM value (value of G2 is inverted from the actual value)

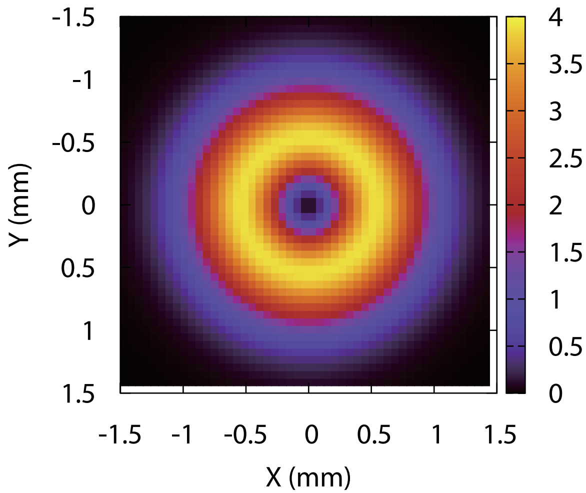
G1 = -1
G2 = +1





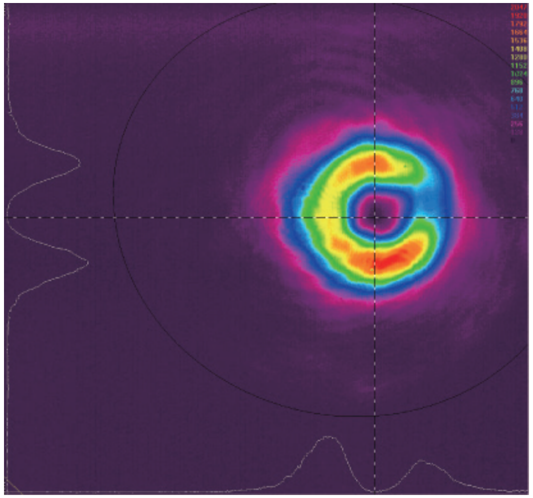
G1 = -1
G2 = -1

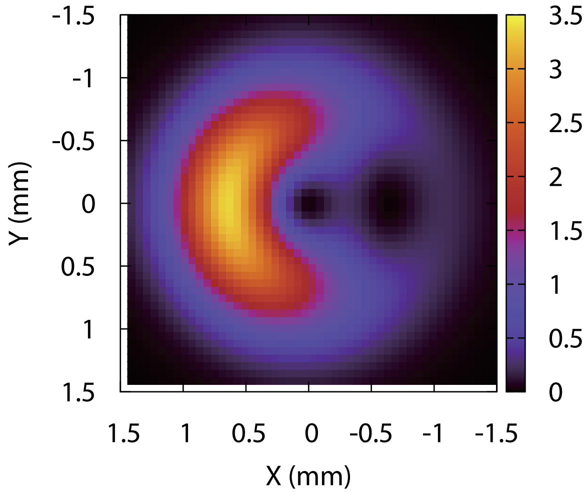




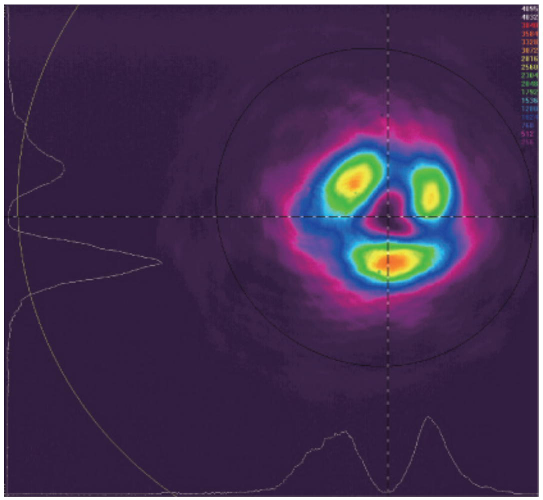
Interference pattern

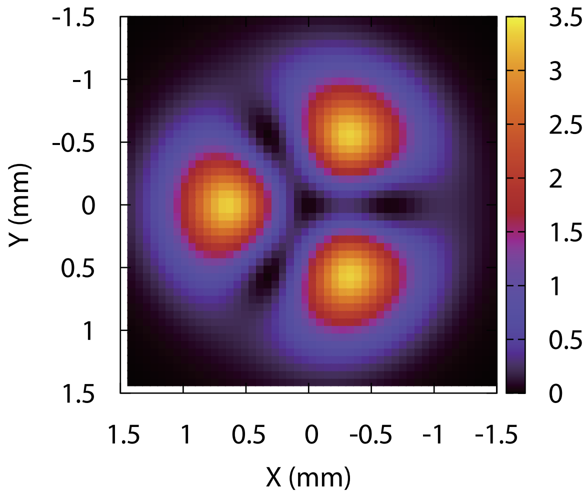
G1 = -1
G2 = -2





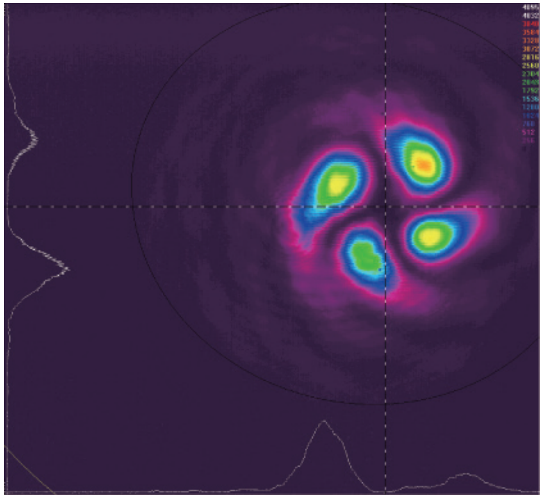
G1 = -1
G2 = +2

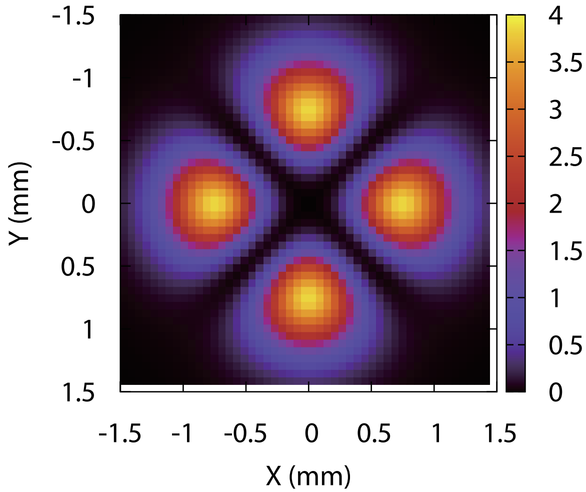




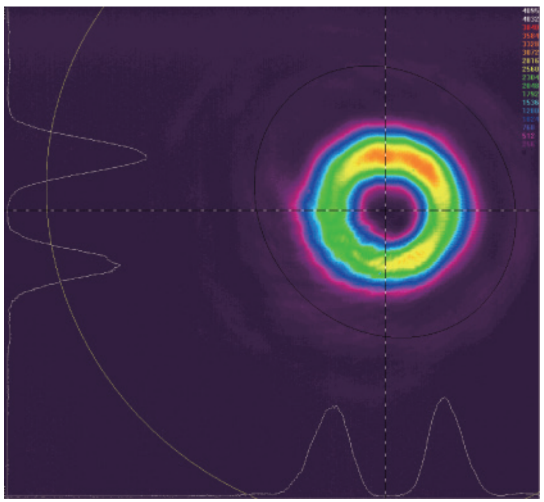
Interference pattern

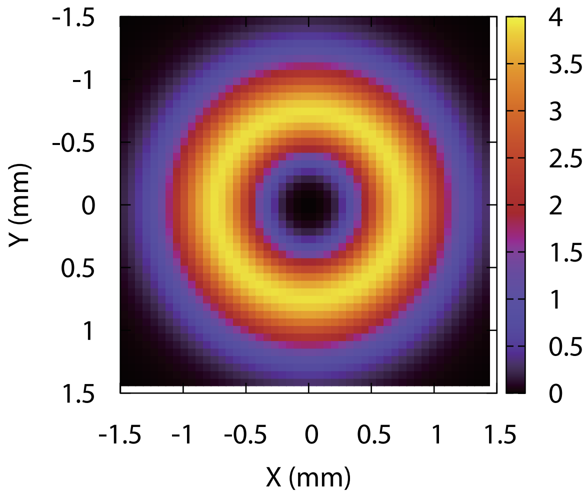
G1 = -2
G2 = +2



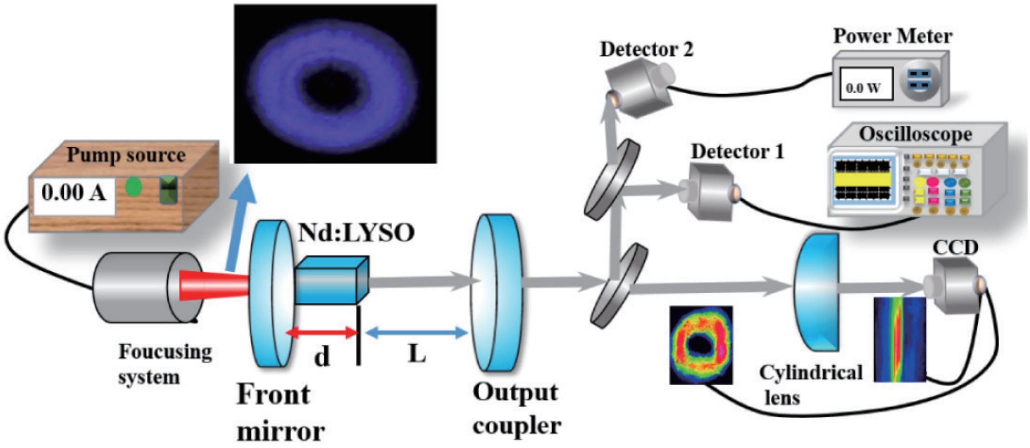


G1 = -2
G2 = -2

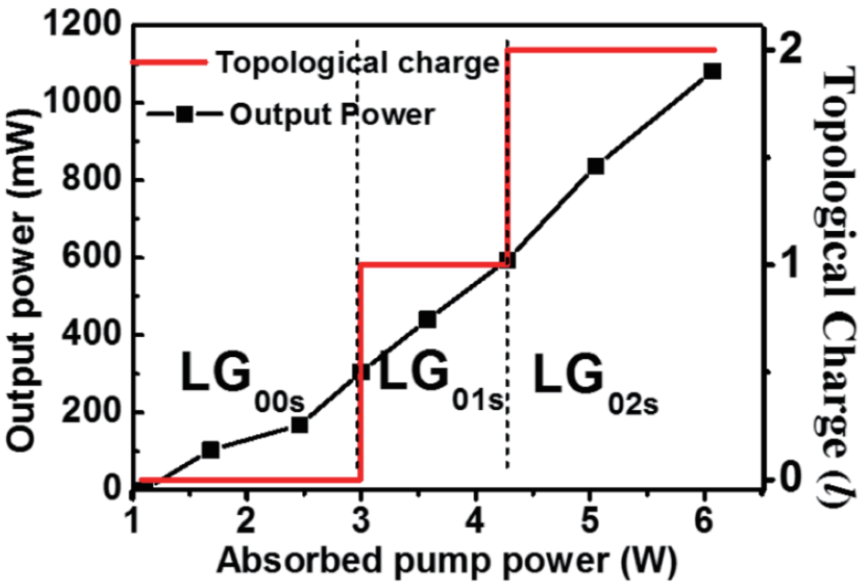


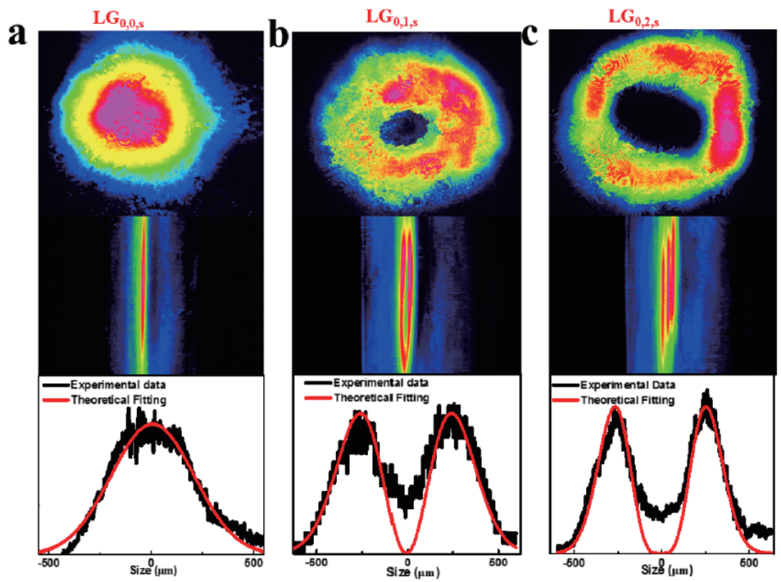


Fabry Perot cavity with OAM laser



Self-mode-locked Laguerre-Gaussian beam with staged topological charge by thermal-optical field coupling

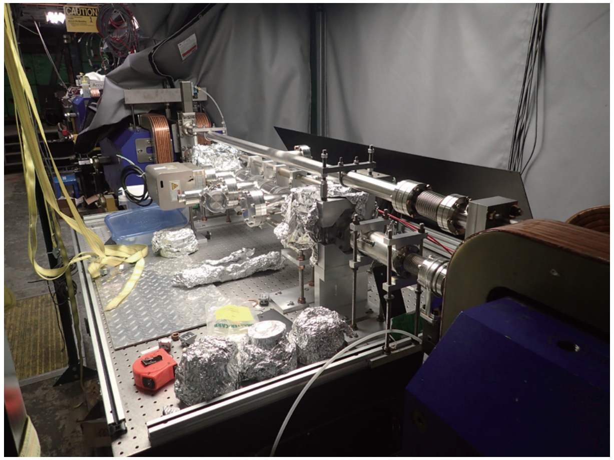




Y. Zhang et al., Opt. Exp., 24 5514 (2016).

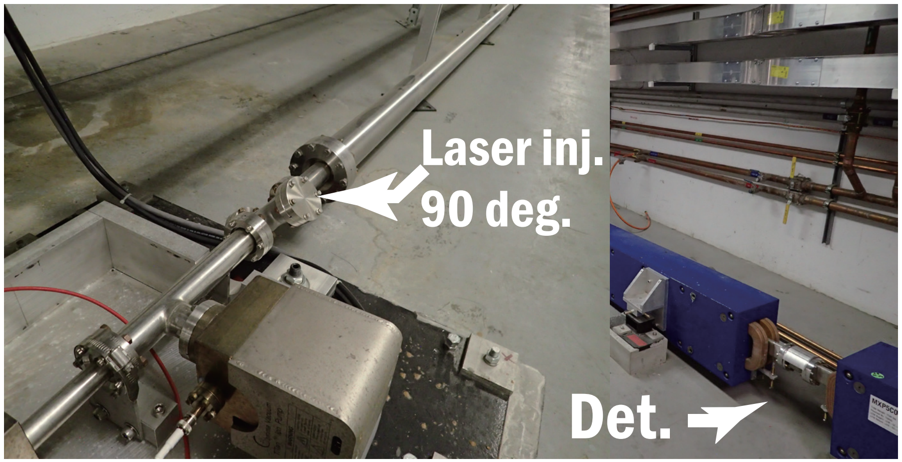
Hall A, C or Hall D?

Hall A, C



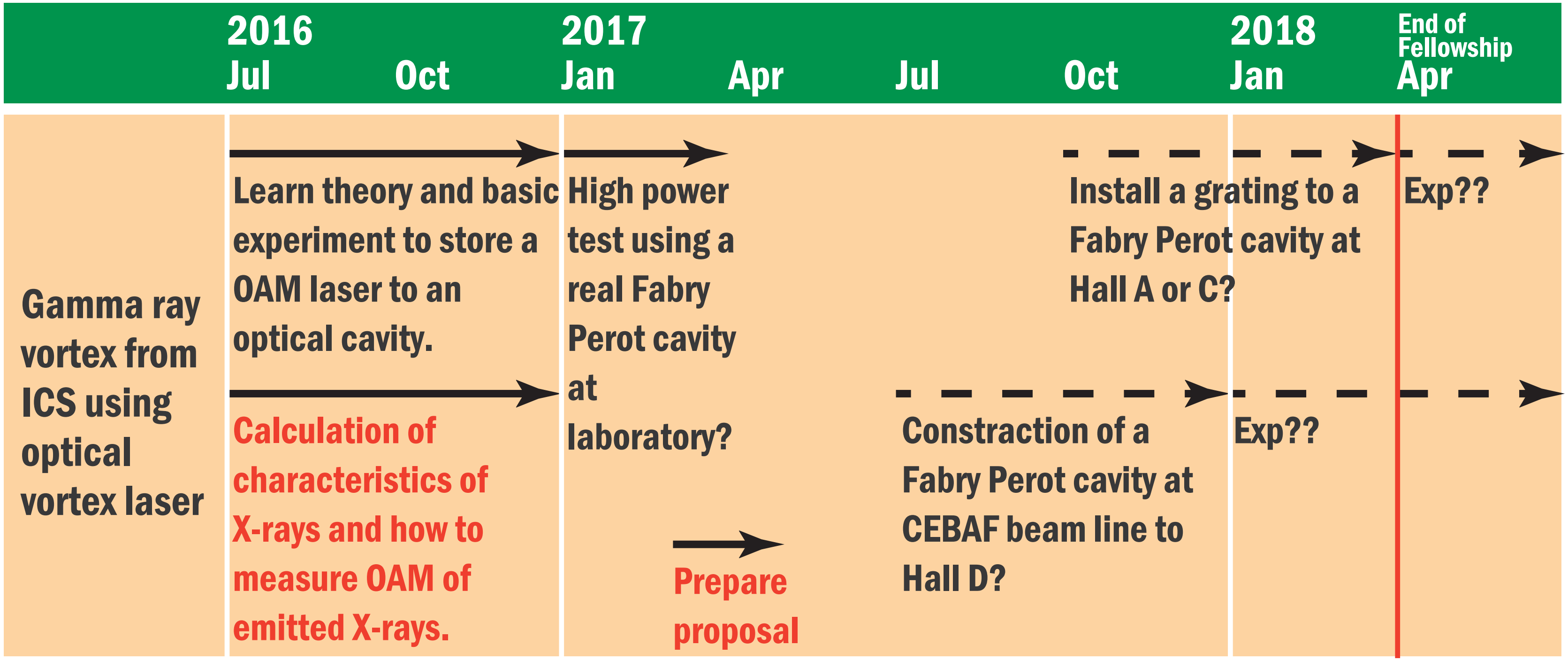
Merit:
Low cost (polarimeter exists).
Demerit:
Many restriction?

Beam line to Hall D



Merit:
Free access.
Demerit:
High cost? (Laser injection sysytem should be constructed.)

Schedule


2016
Jul
Oct
2017
Jan
Apr
Jul
Oct
2018
Jan
End of Fellowship
Apr
Gamma ray vortex from ICS using optical vortex laser
Learn theory and basic experiment to store a OAM laser to an optical cavity.
High power test using a real Fabry Perot cavity at laboratory?
Install a grating to a Fabry Perot cavity at Hall A or C?
Exp??
Calculation of characteristics of X-rays and how to measure OAM of emitted X-rays.
Prepare proposal
Constraction of a Fabry Perot cavity at CEBAF beam line to Hall D?
Exp??