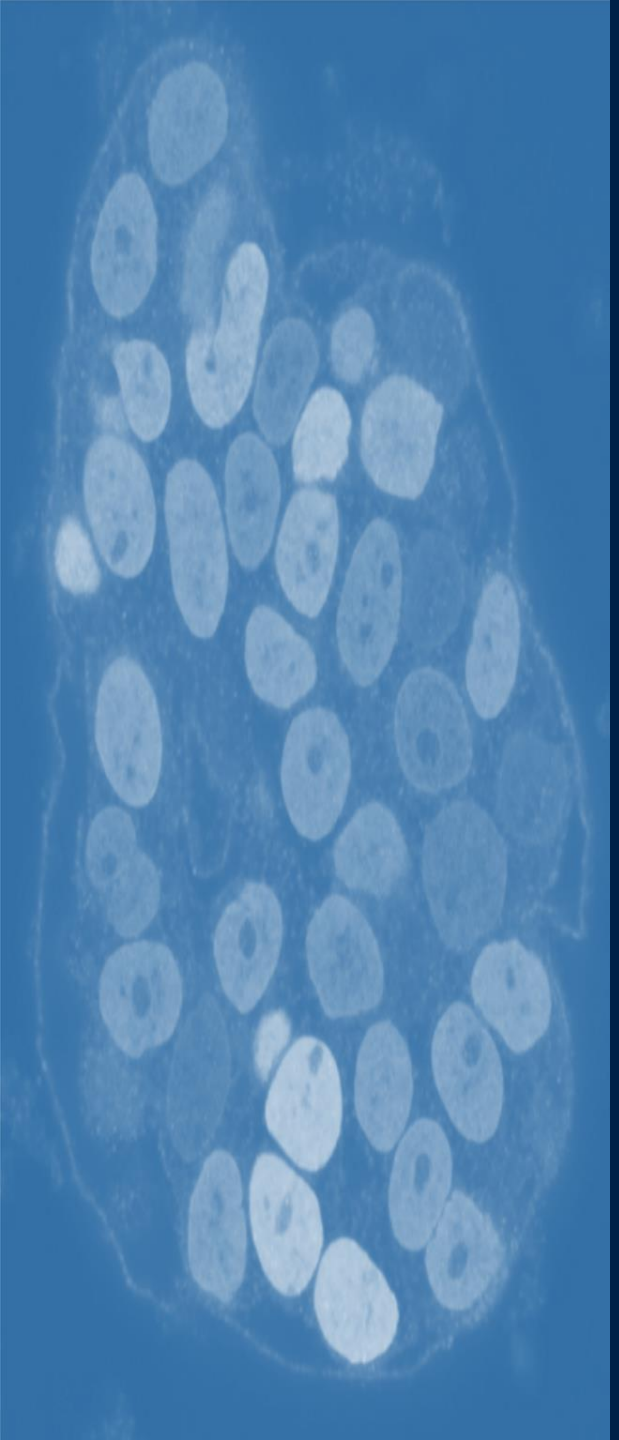


ESPCI PARIS | PSL

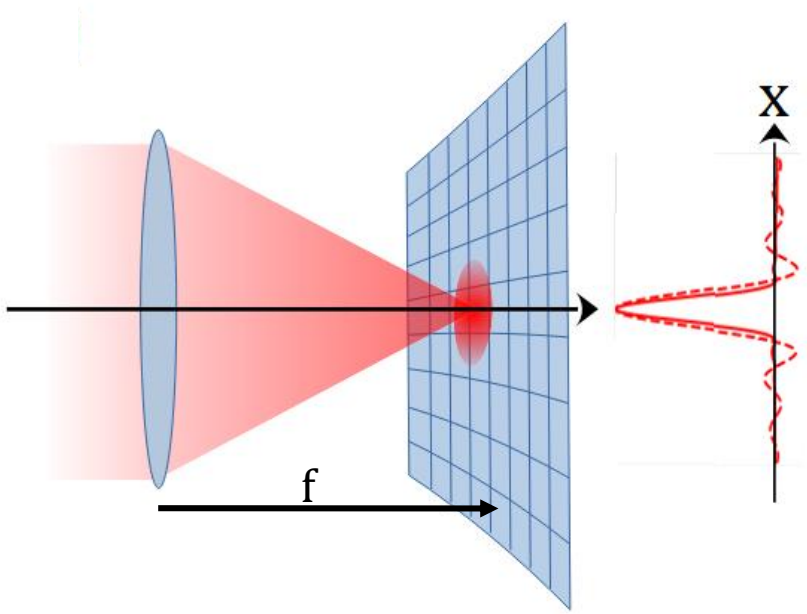
Superresolved imaging based on spatiotemporal wave-front shaping

Fabrice Lemoult

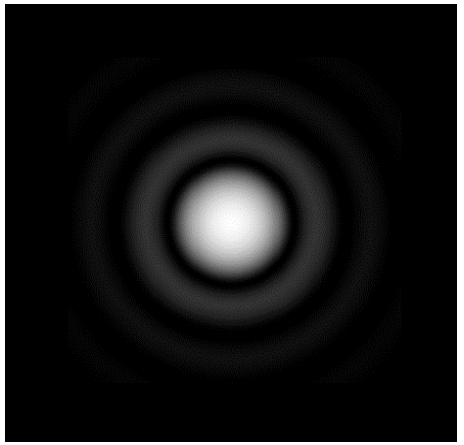
Guillaume Noetinger, S. Métais,
G. Lerosey, S. Popoff, M. Fink

Institut **Langevin**
ONDES ET IMAGES

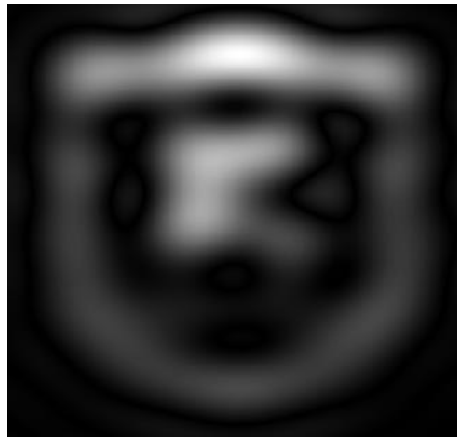
Diffraction limit and image resolution



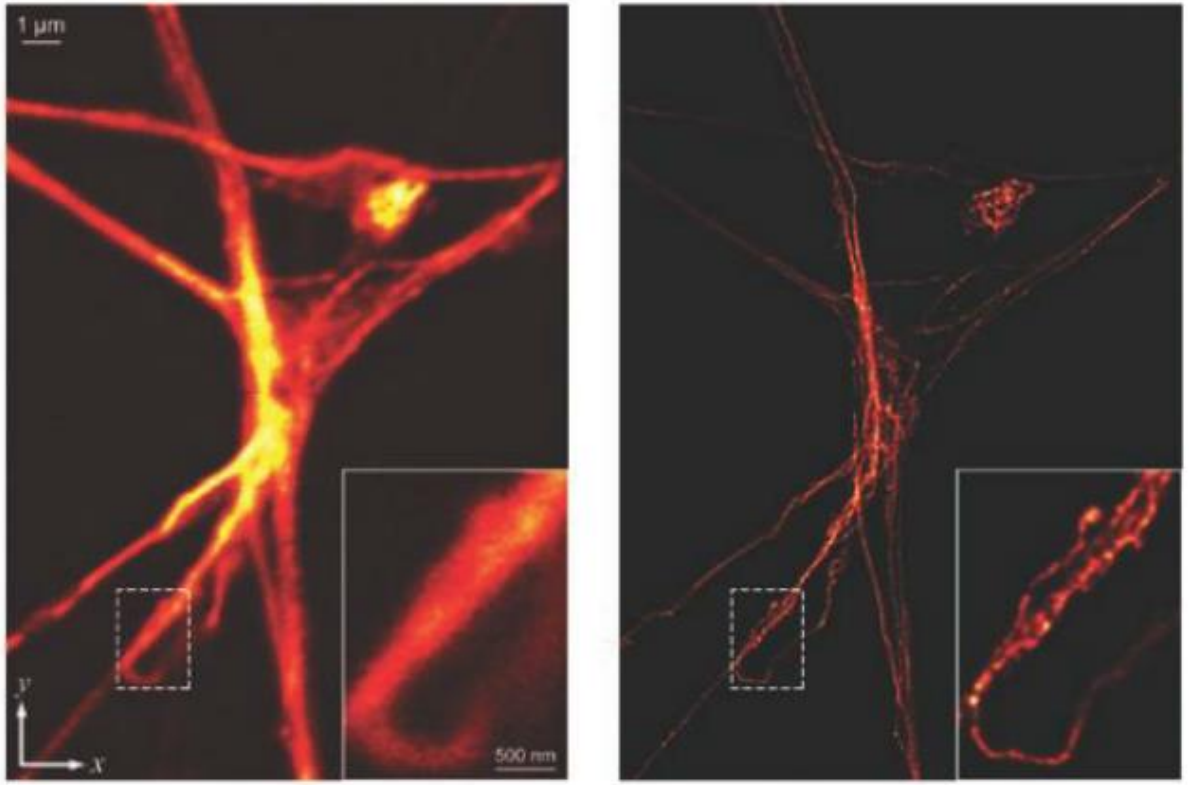
Tâche d'Airy = **PSF**

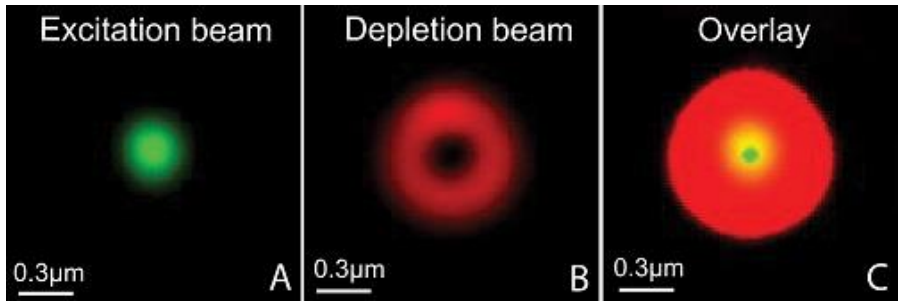


Largeur $l_{res} \approx {}^{\lambda}/_{2ON}$



An example of super-resolved imaging: STED



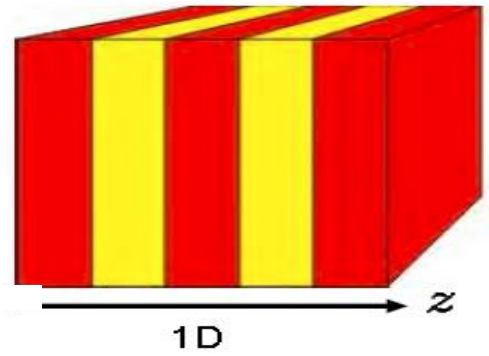


Exploiting non-linearity gives a sub-diffraction spot

MPI for Biophysical Chemistry, Medda, et al.

Space time modulations

Space material

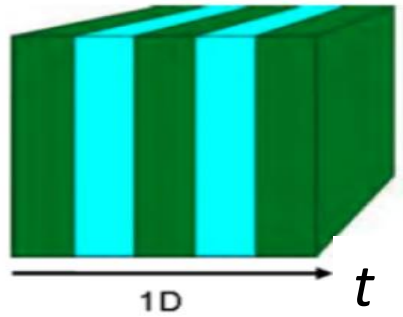


Multiple **reflections** and transmissions in space

Frequency is conserved

Phononic/photonic crystals…

Time material

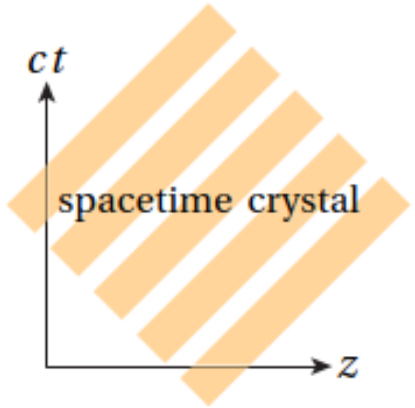


Multiple **reflections** and transmissions in time!

Momentum is conserved

Floquet crystals…

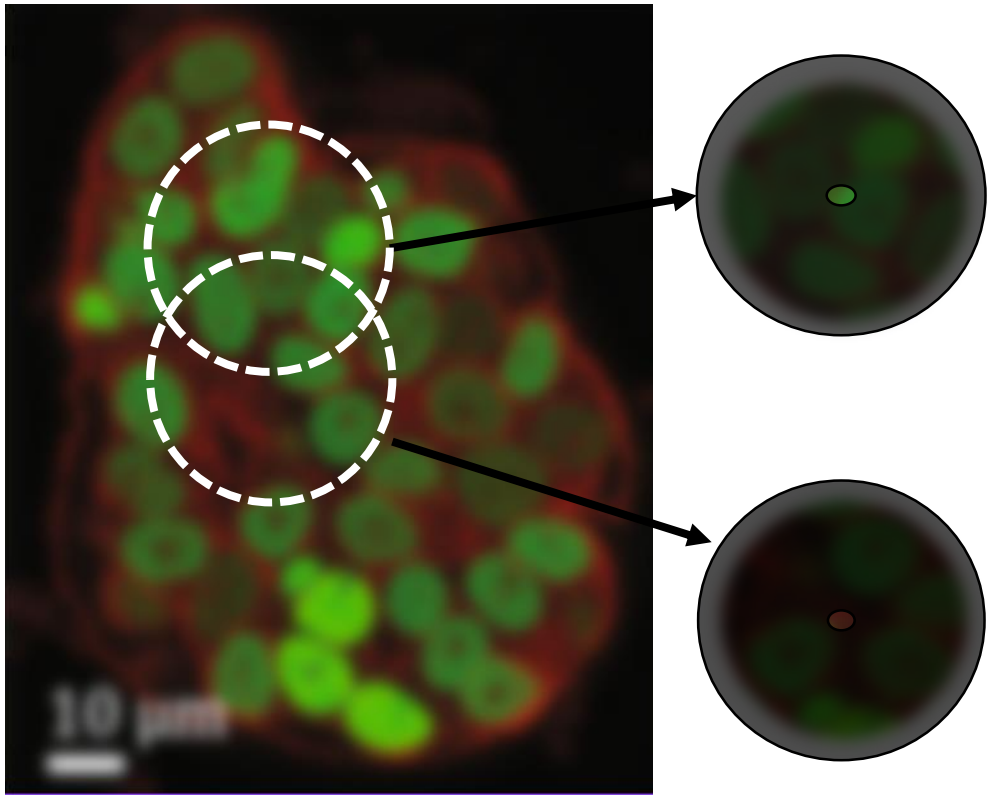
Space-time material



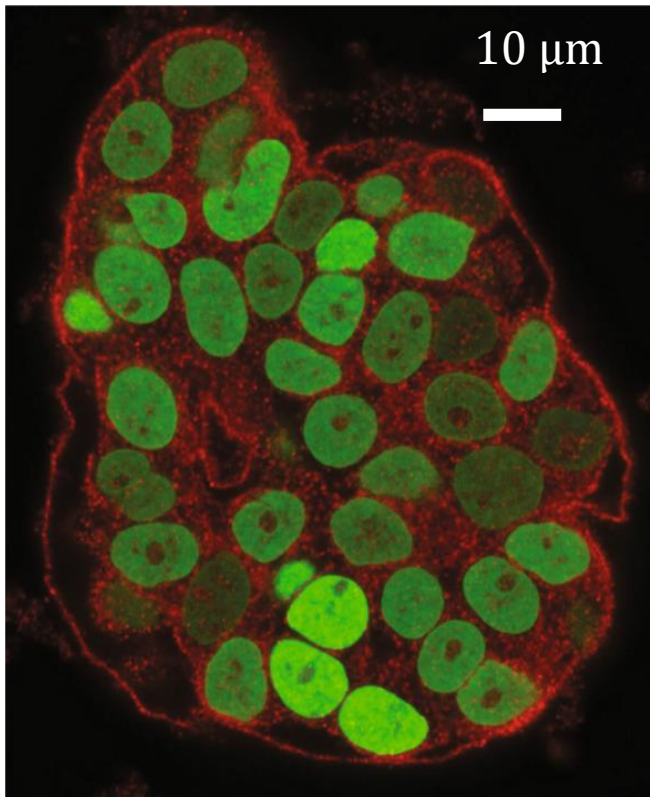
Multiple spatio-temporal refelctions and transmissions??

Neither frequency nor momentum are conserved!

Concept



Information @ the center
+ scanning

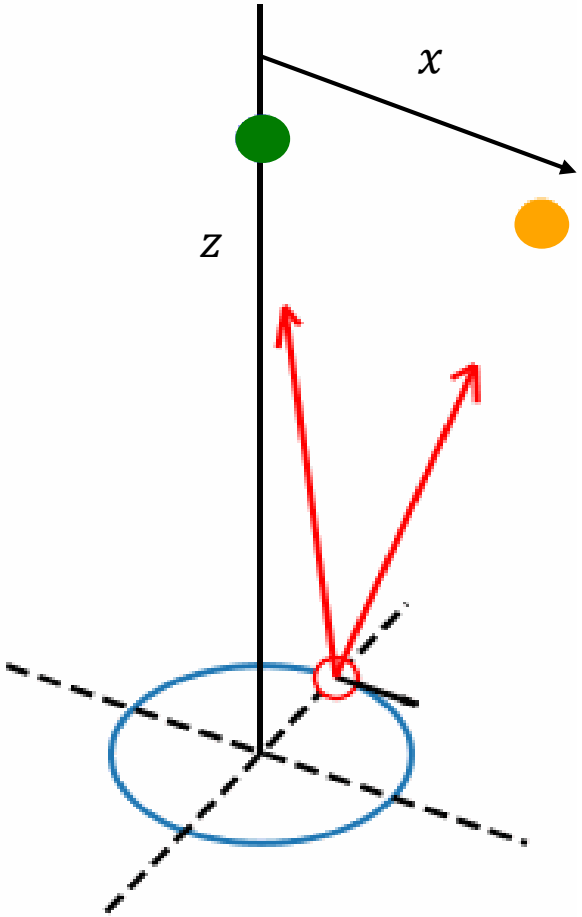


?

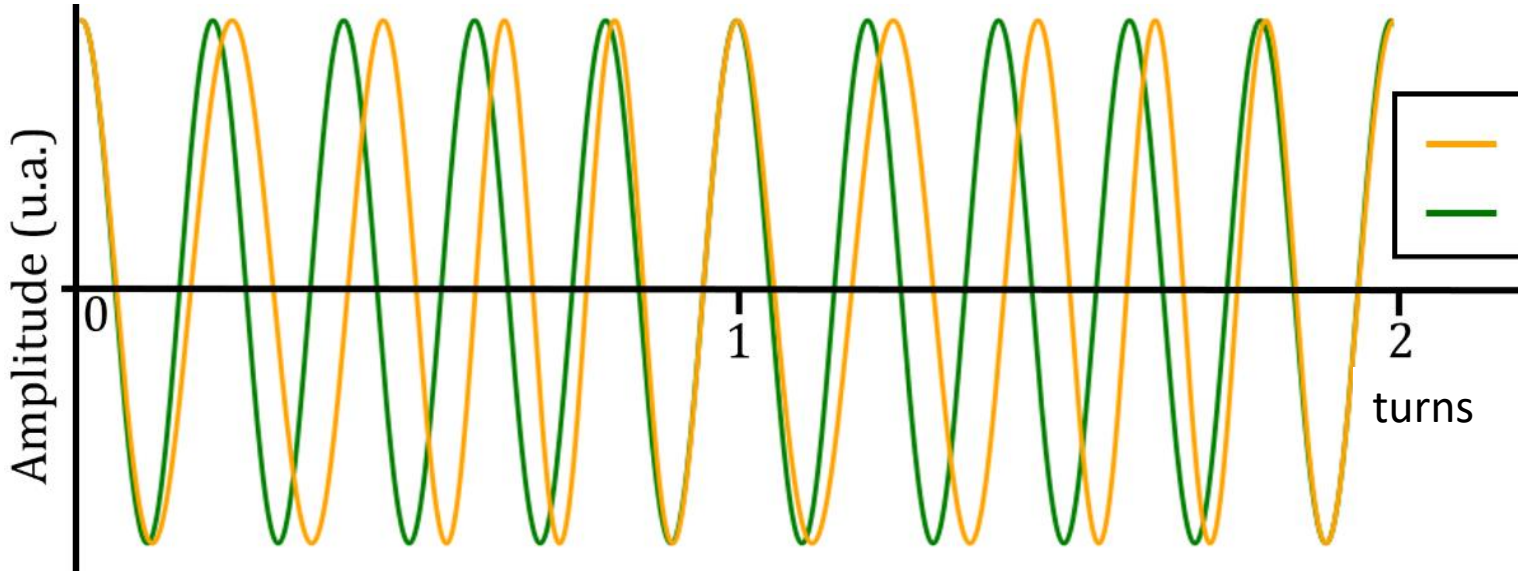
Pierre Bon et al.,
ACS Photonics 2022

Concept

Emitter
On-axis receiver
Off-axis receiver

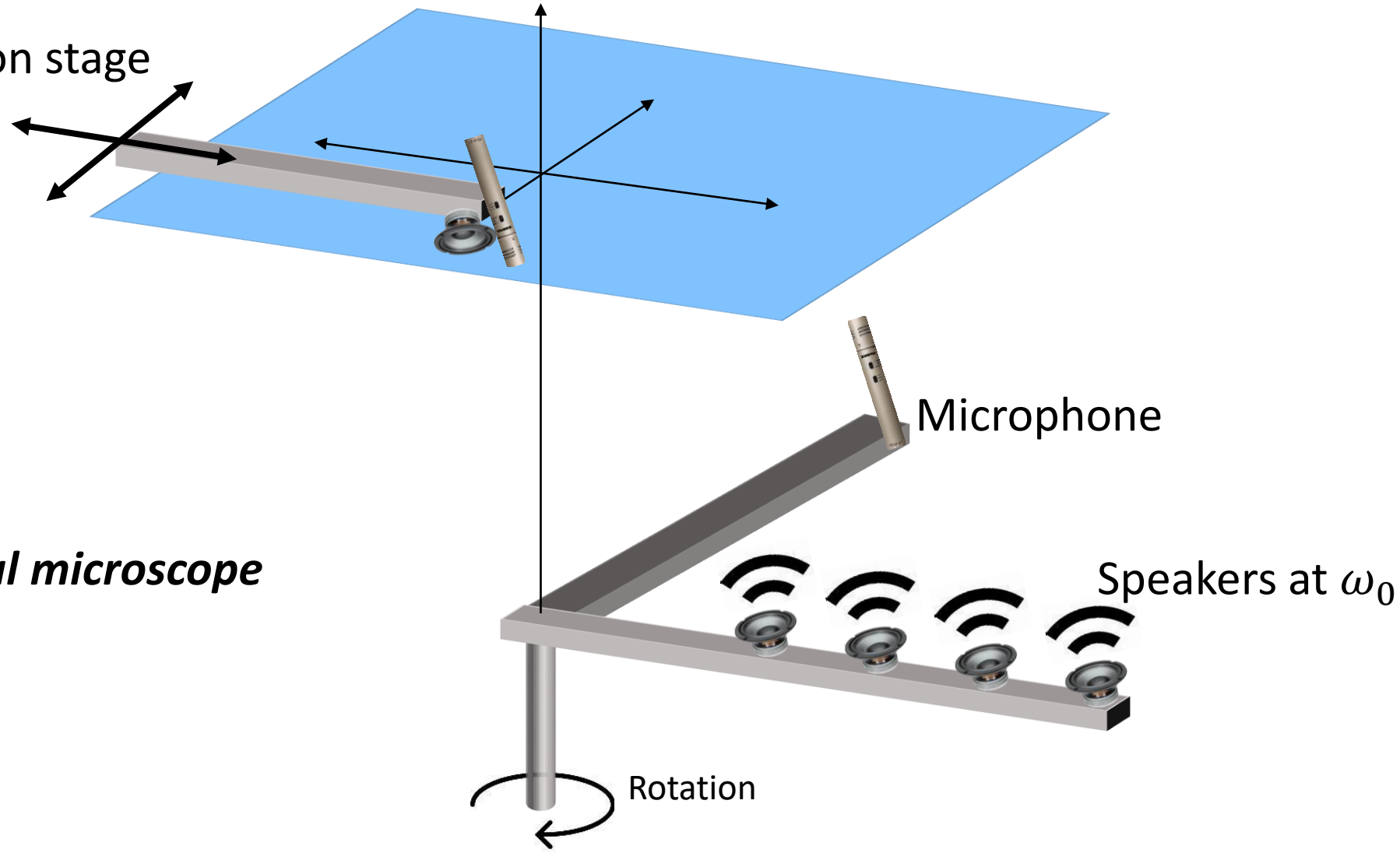


Doppler shift: $\Delta f(t) = -\frac{R\Omega x f_0 \sin(\Omega t)}{cz}$



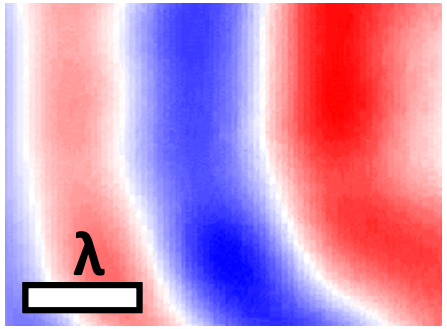
Similar to FM modulation

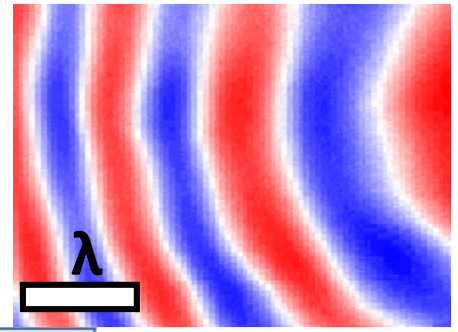
Proof of concept in acoustics

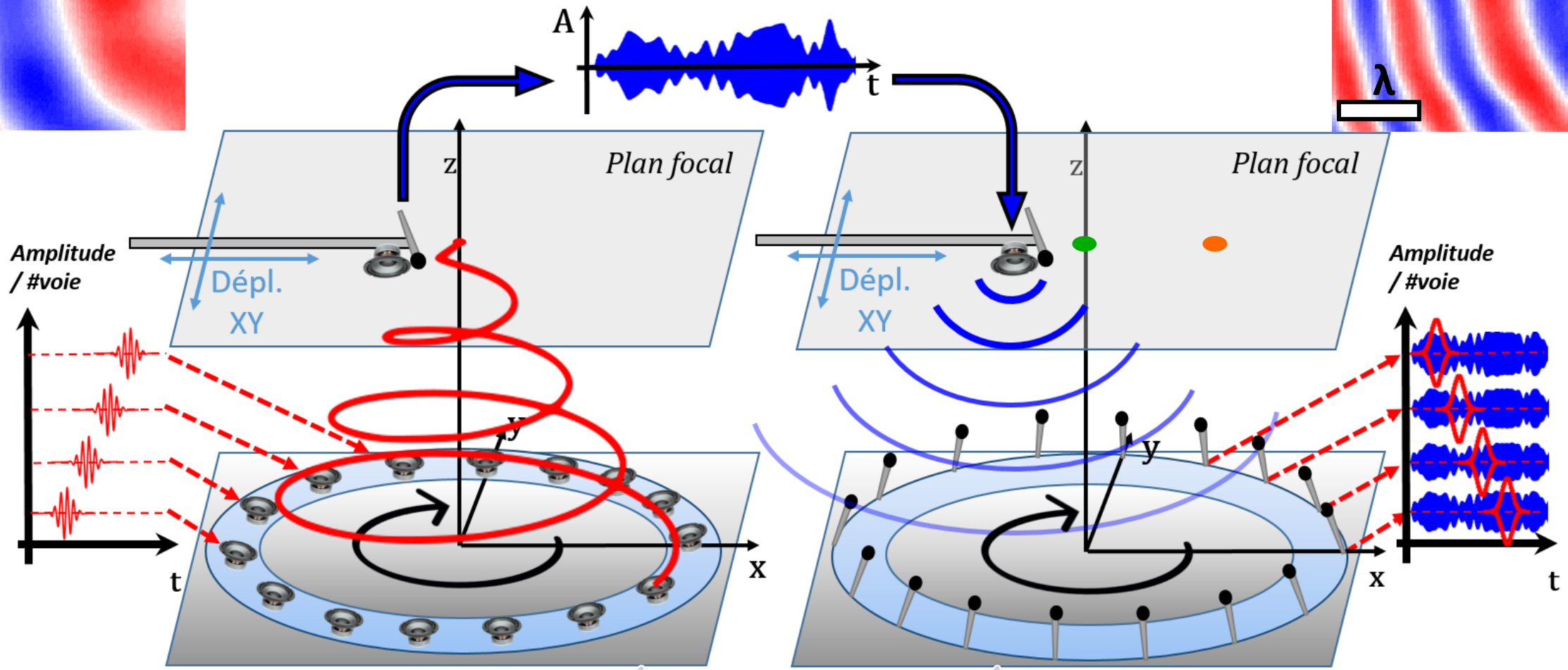


Acoustic confocal microscope

Improvement: spatiotemporal wavefront shaping







On-axis

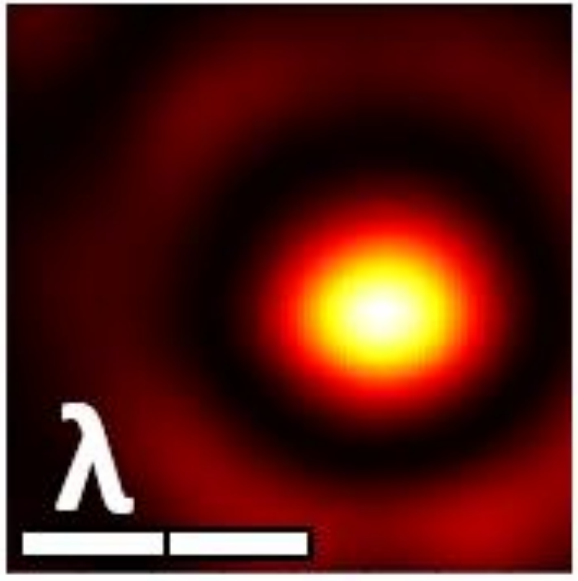
Off-axis

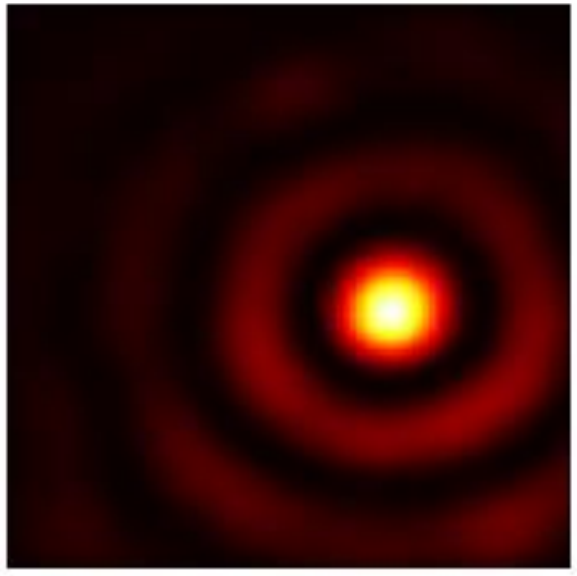
Image at @ ω_0

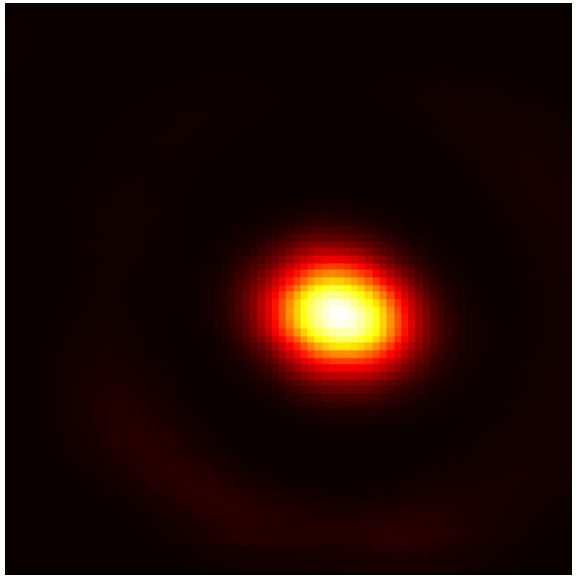
Focal plane

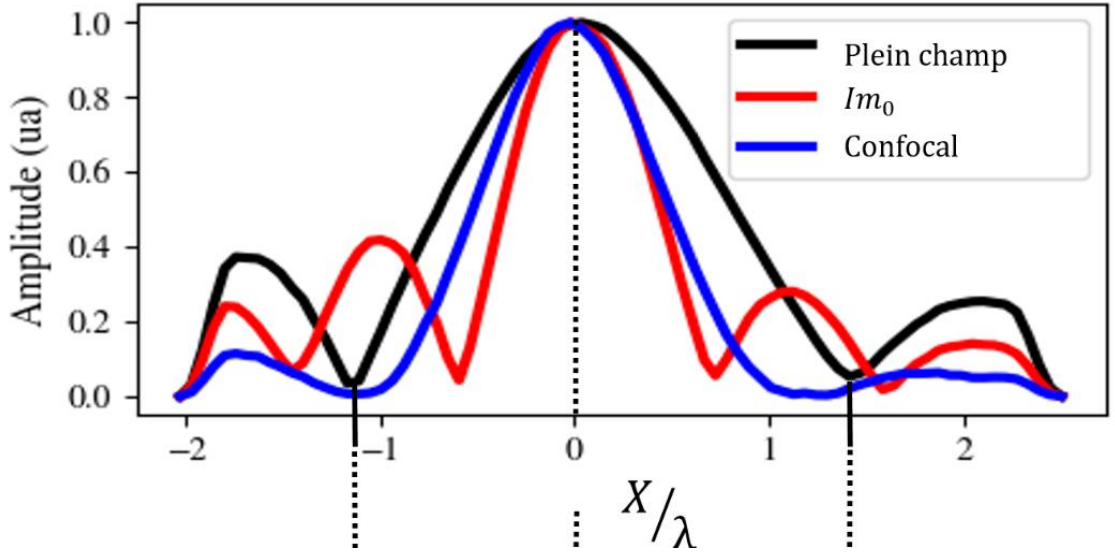
Backscattered

Confocal image

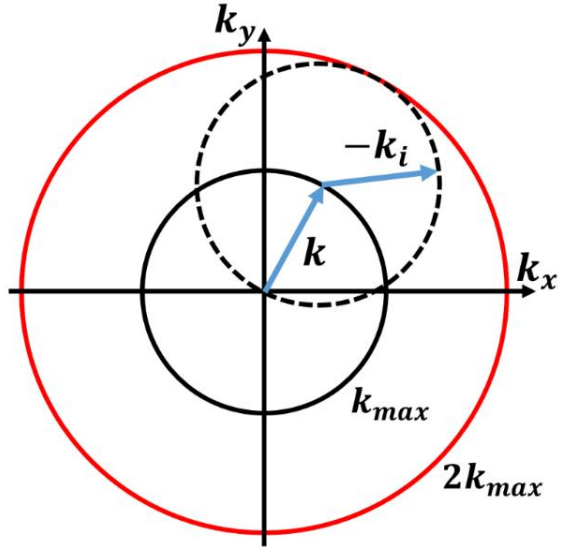








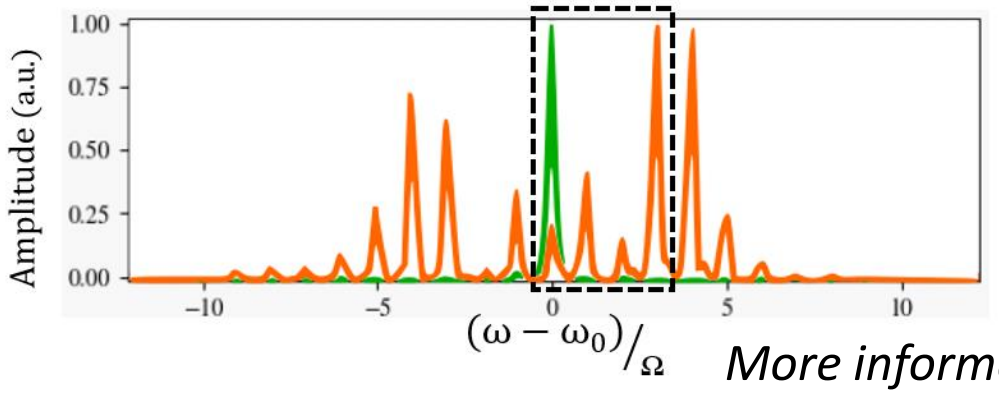
Improvement by a factor **2**



Multi-harmonic imaging

On-axis

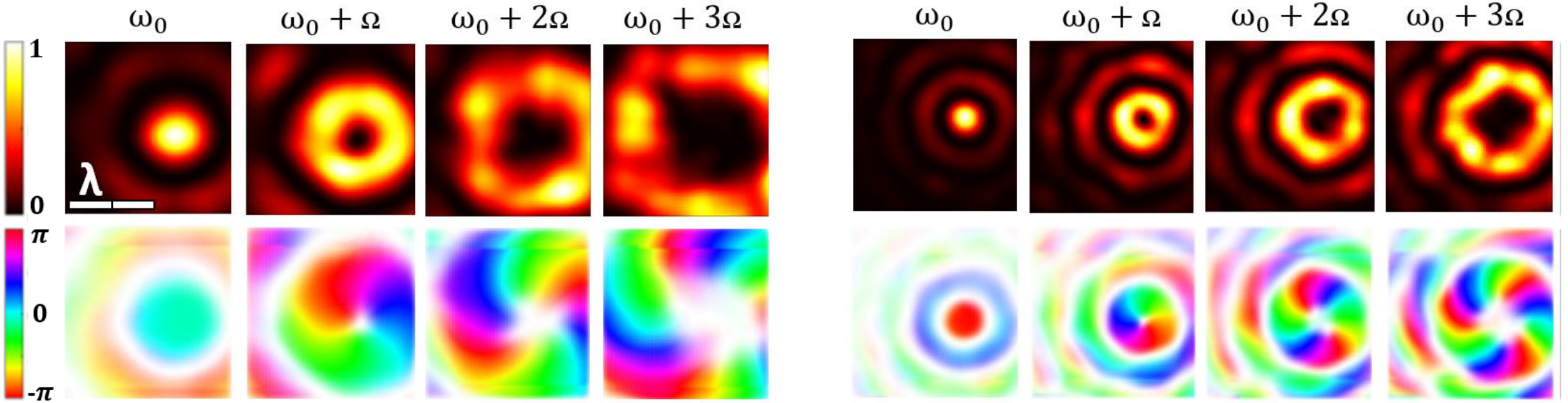
Off-axis



More information?

Focal plane

backscattered

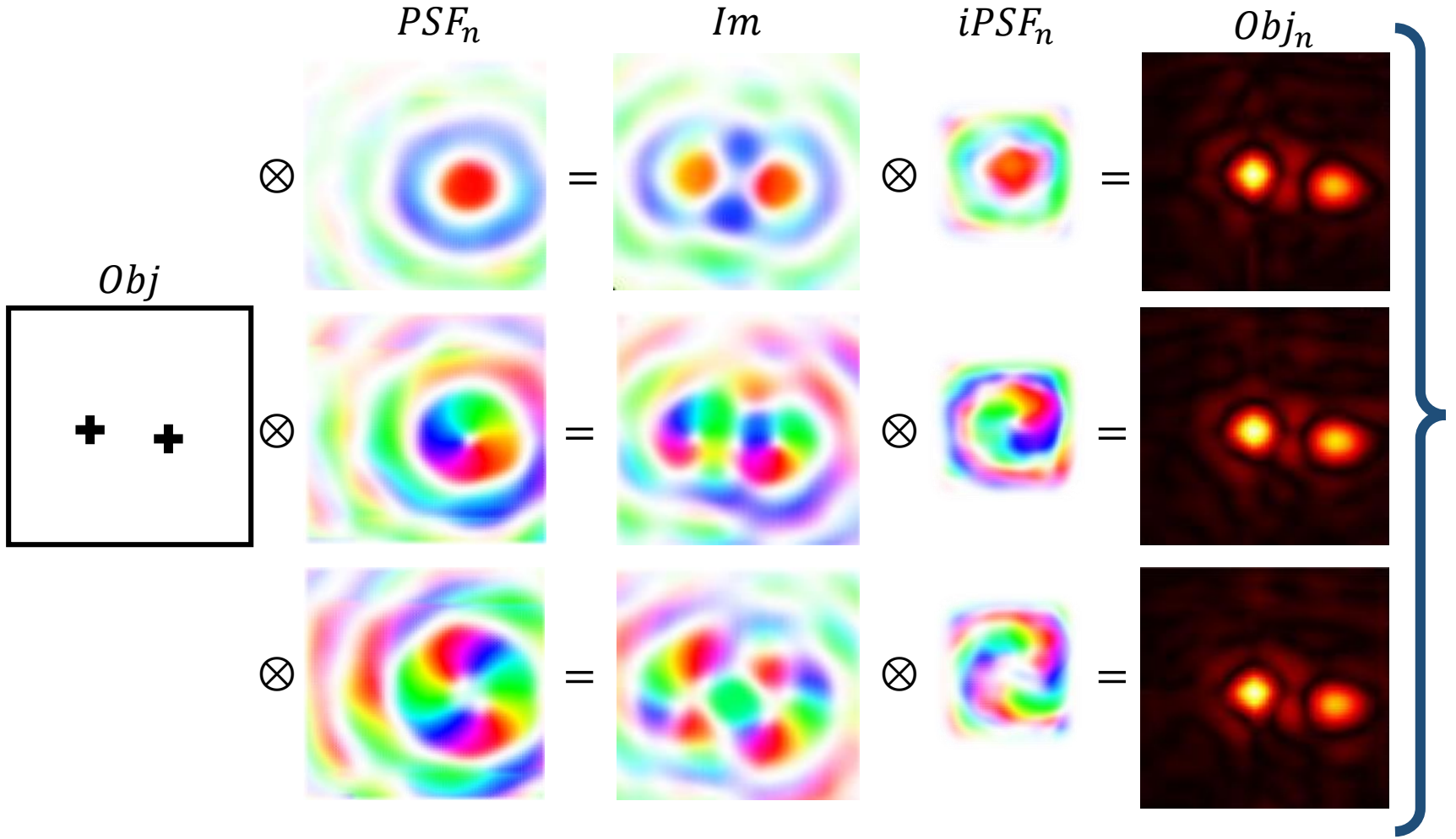


Multiplexing

$$Im_{\omega_0+n\Omega} = Obj \otimes PSF_{\omega_0+n\Omega}$$

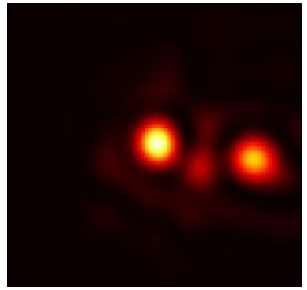
Image reconstruction

$$Im_{\omega_0+n\Omega} = Obj \otimes PSF_{\omega_0+n\Omega}$$

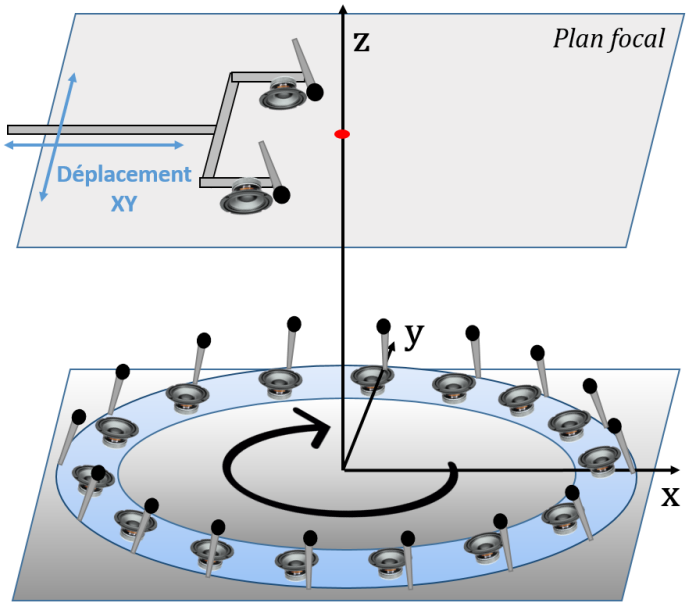


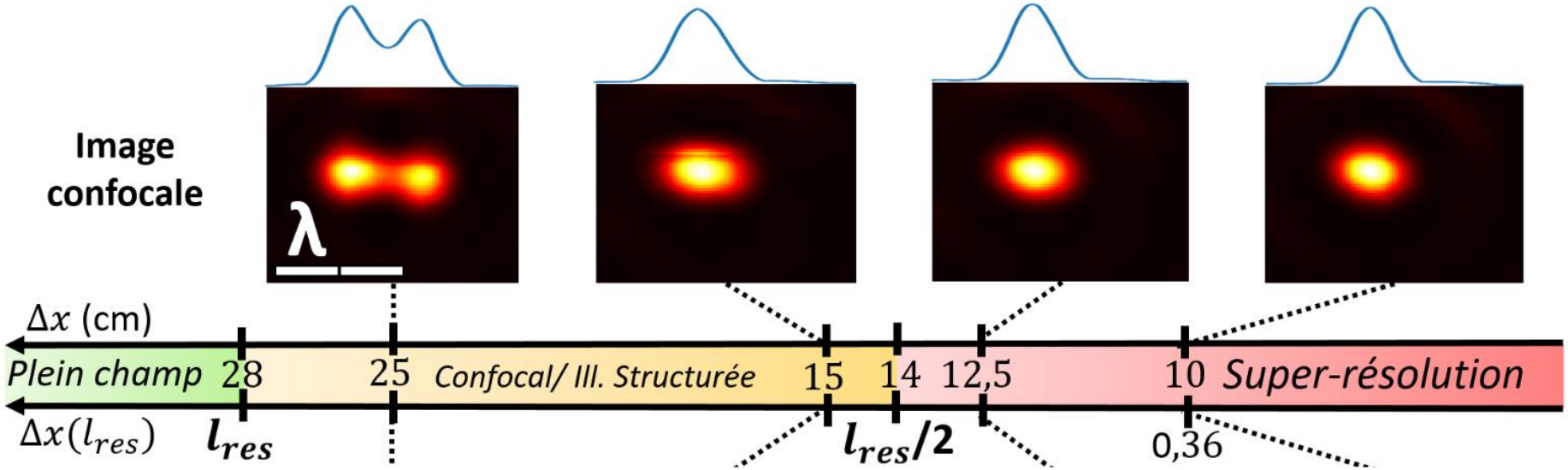
Sum of reconstructions

$$\boldsymbol{Obj_R = \sum_{-N}^{N} Obj_n}$$



Resolution improvement





Resolution :
+70% better than Confocal, +10% better than structured illumination

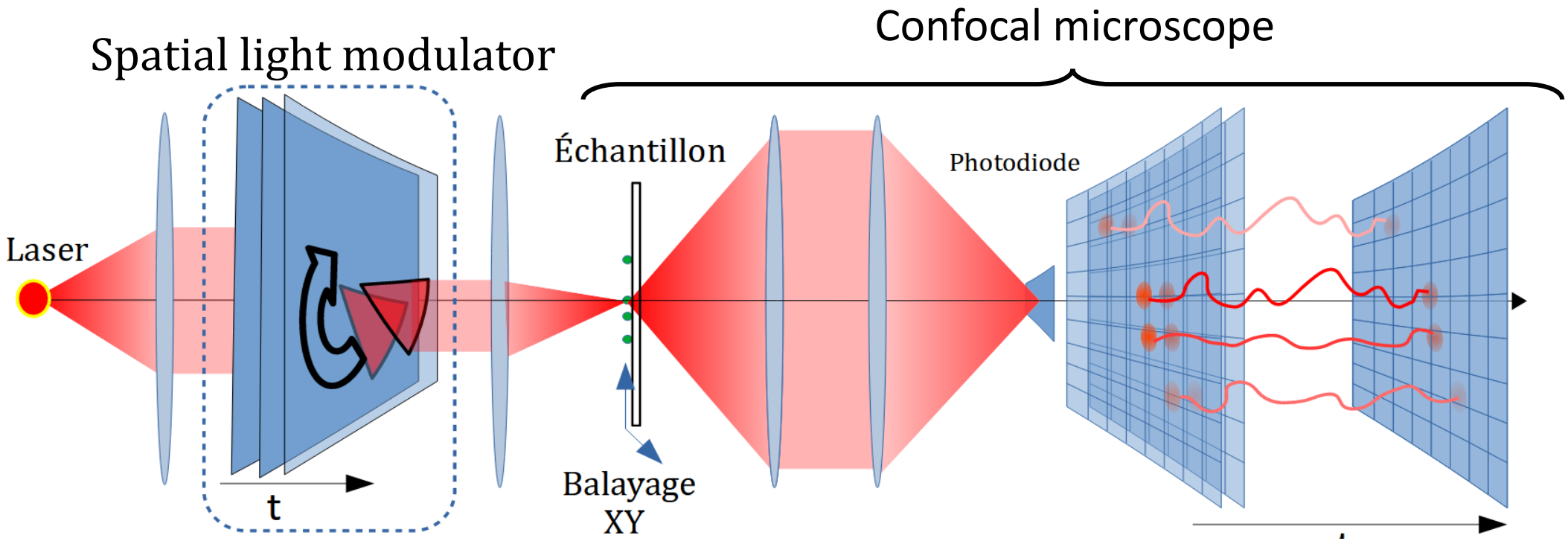
Is it transferrable to optics?

PHYSICAL REVIEW APPLIED **19,** 024032 (2023)

Superresolved Imaging Based on Spatiotemporal Wave-Front Shaping

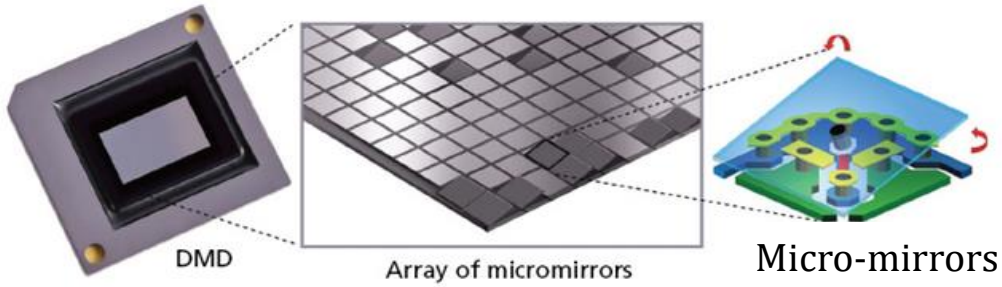
Guillaume Noetinger,[1] Samuel Métais,[2] Geoffroy Lerosey,[3] Mathias Fink,[1] Sébastien M. Popoff,[1] and Fabrice Lemoult[1,*]

Optics experiment

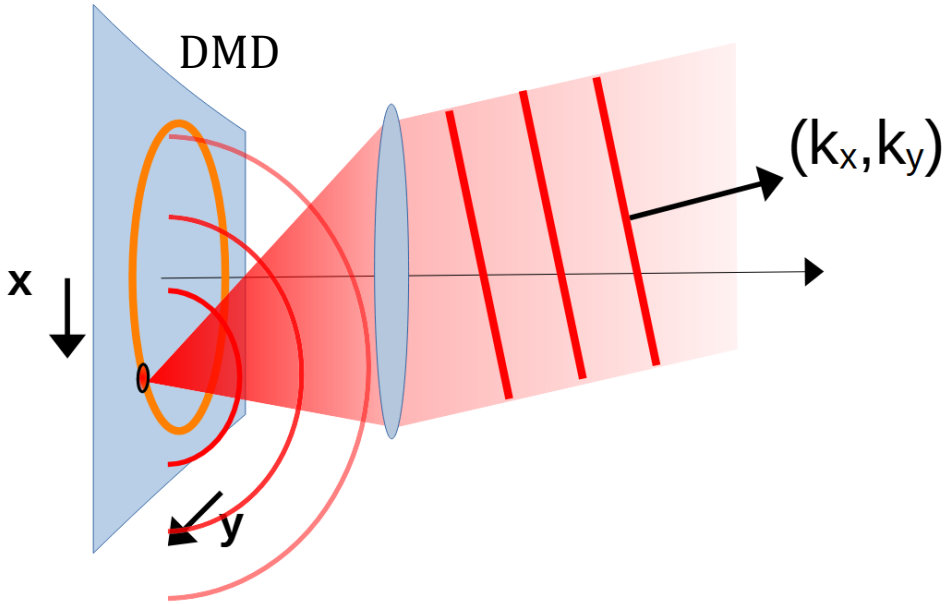


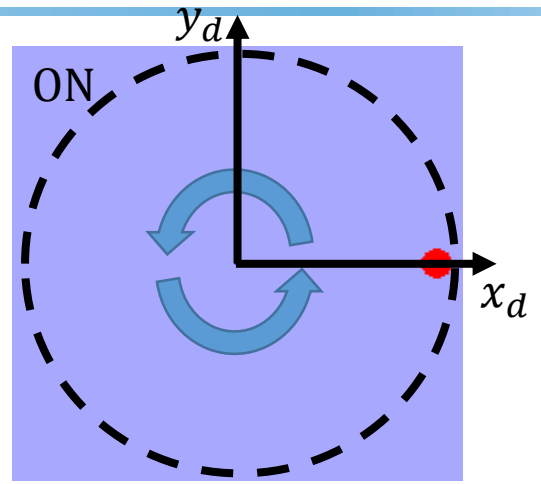
DMD (*Digital Micromirror Device*)

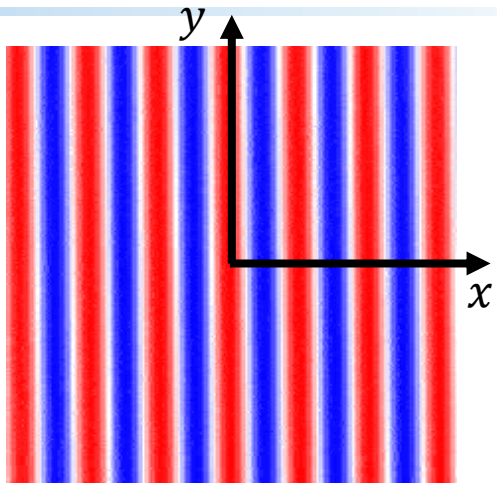
Resolution: 2 Mpx
Pixel: 10,8 µm
Rate: 11 kHz

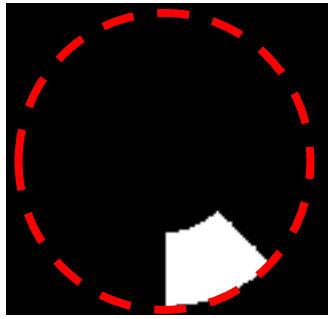


Difference with acoustics...

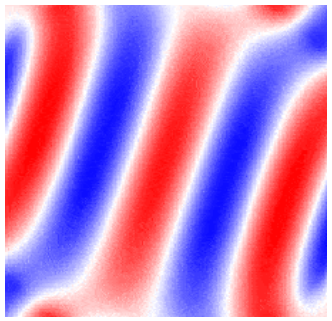


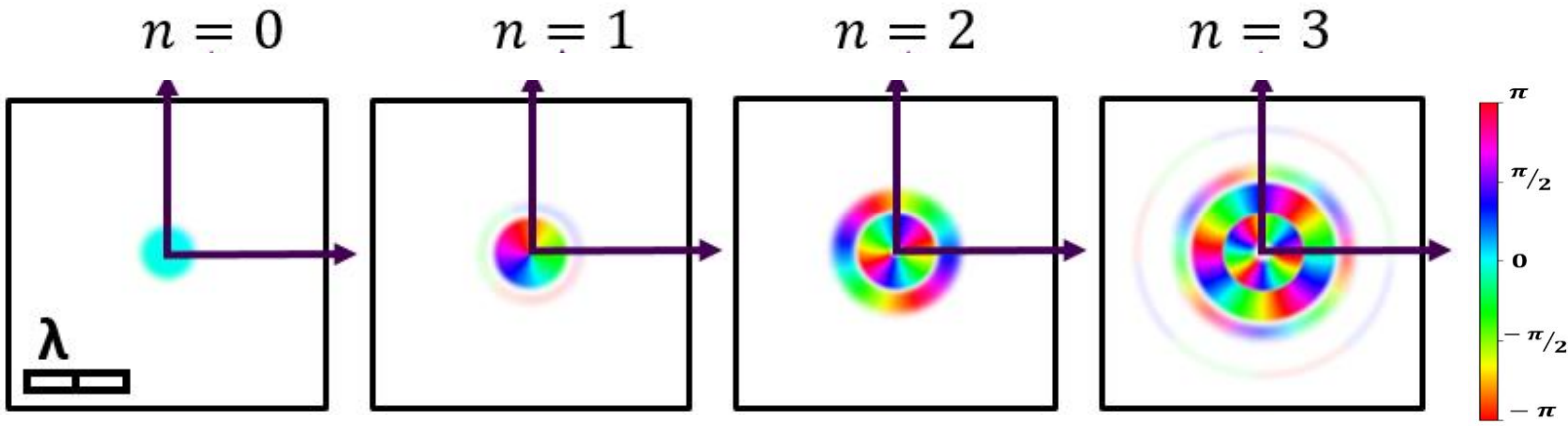






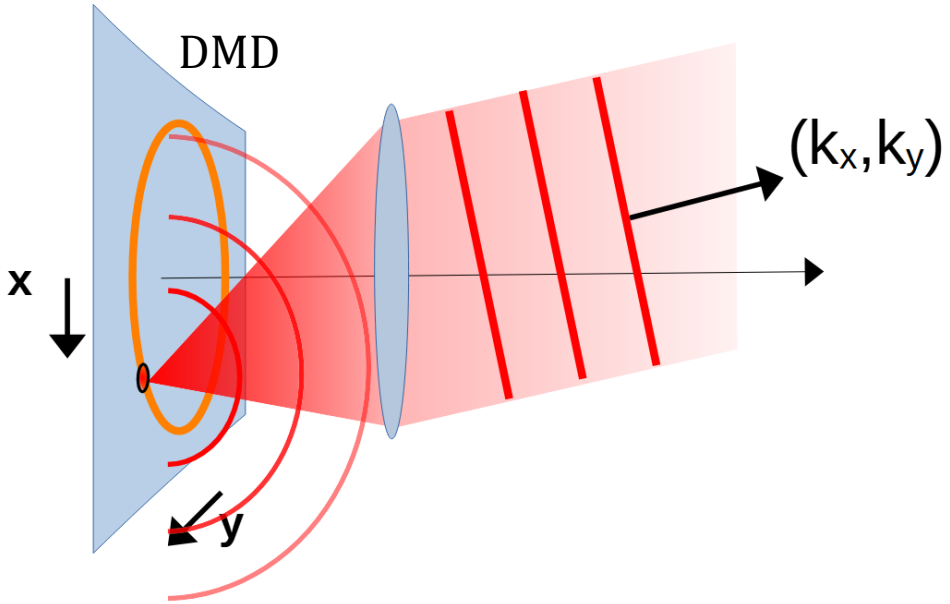
Focal plane

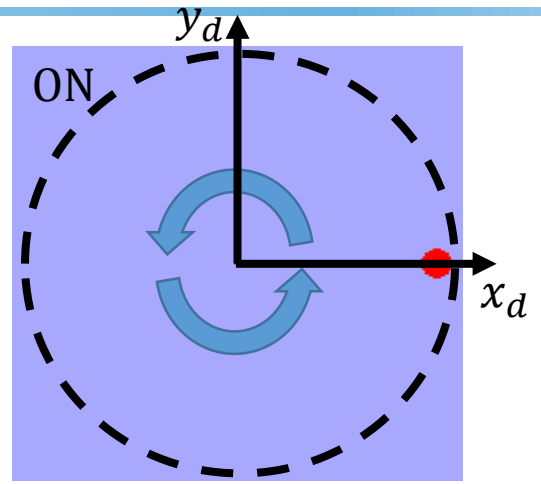


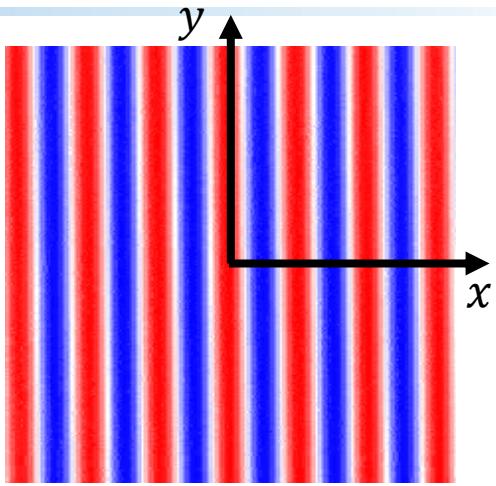


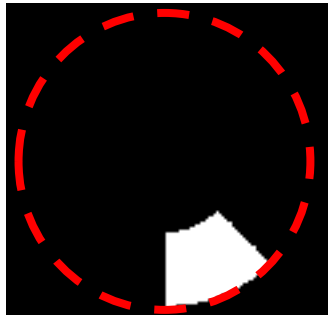
Similar to acoustics

Difference with acoustics...

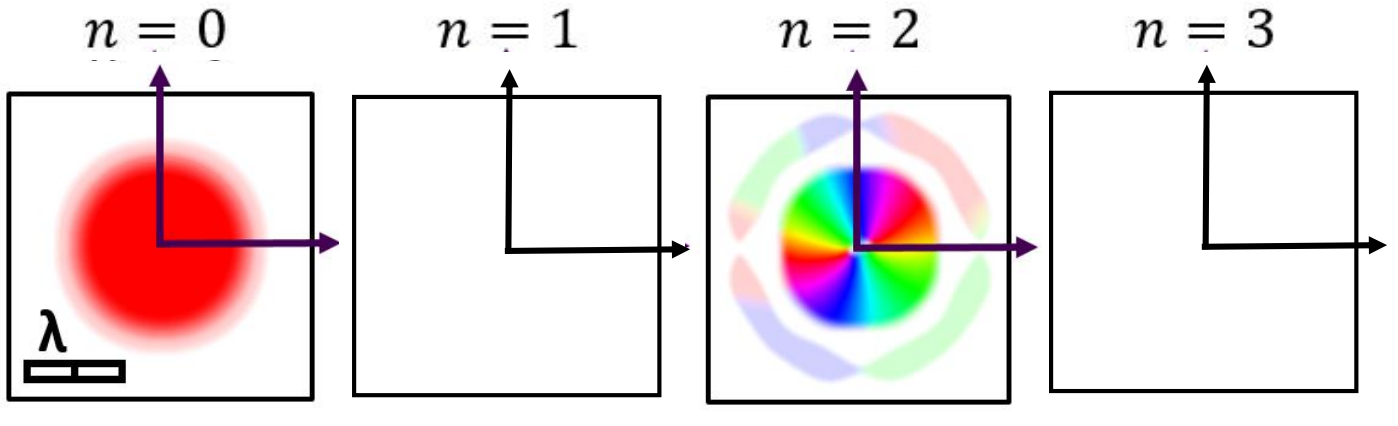






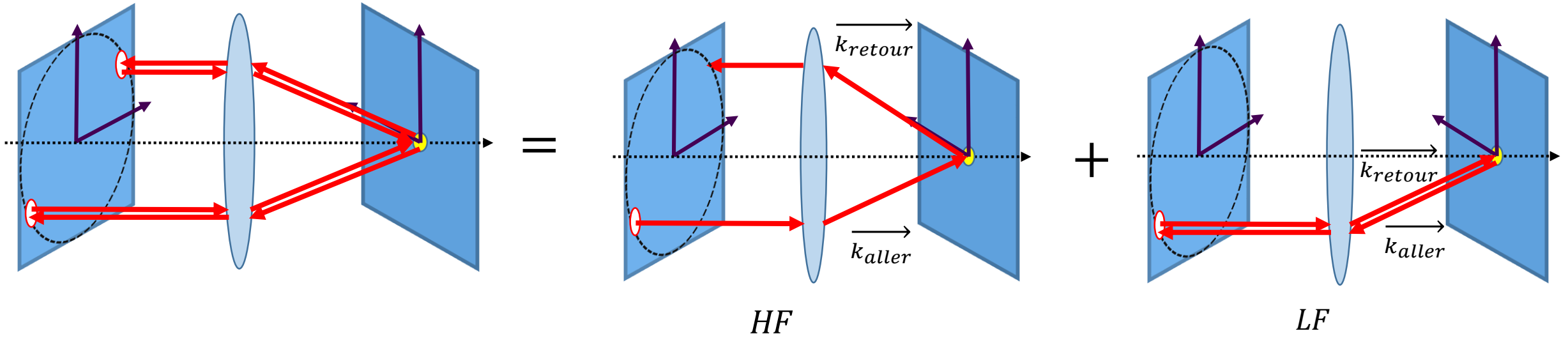


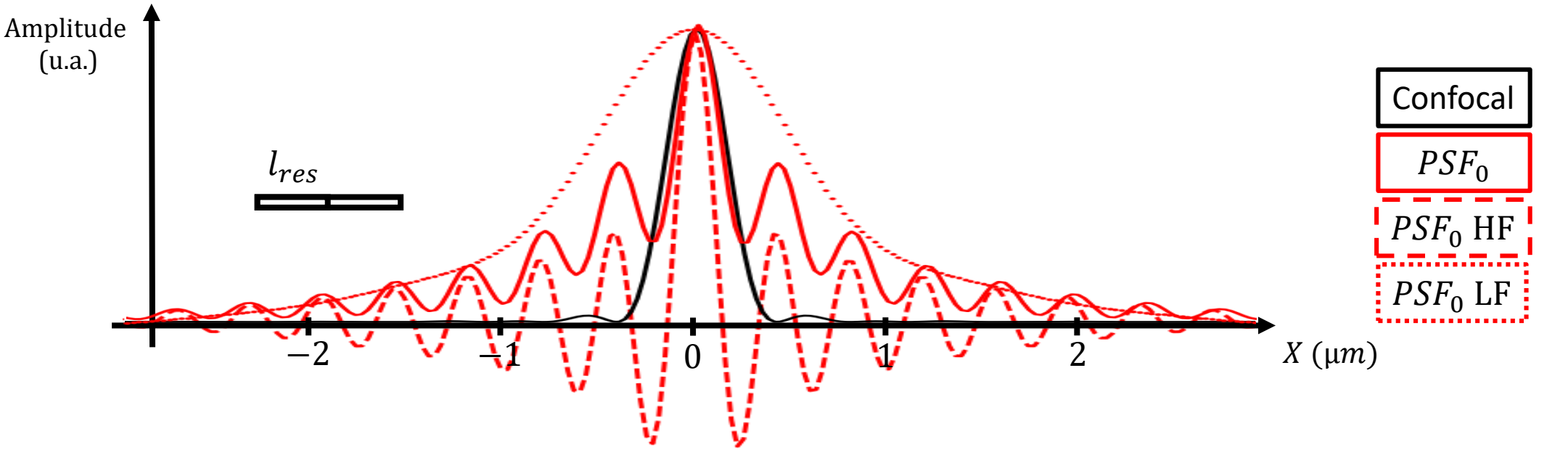
Backscattered signal



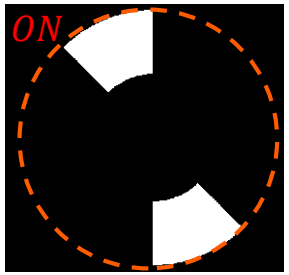
Big difference with acoustics

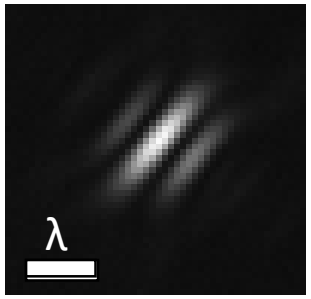
Intensity images without interferometric arm



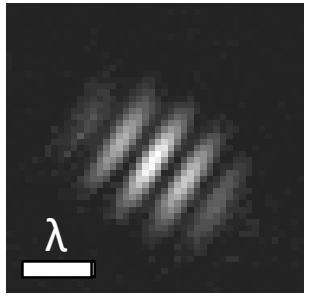


Optical experiment

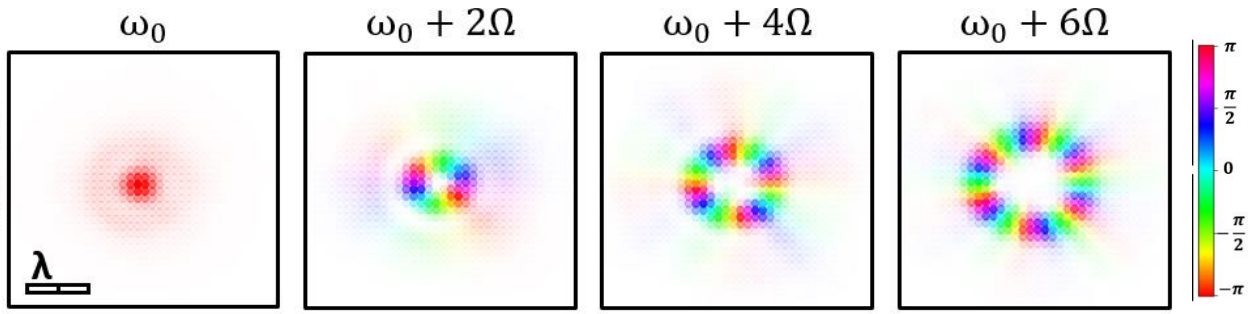


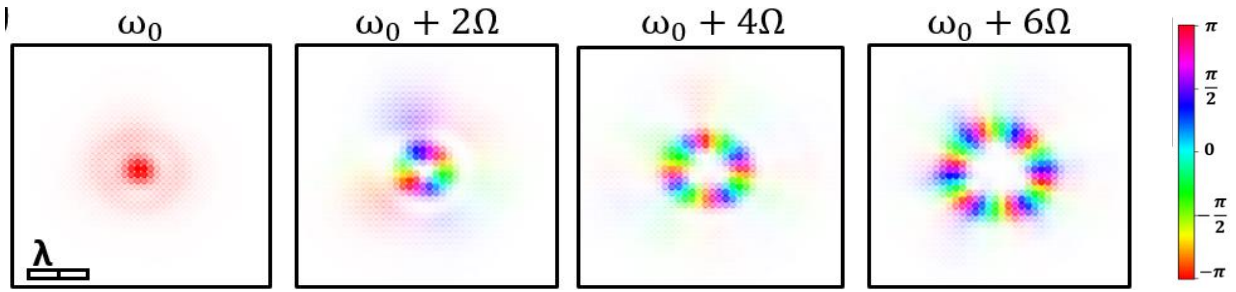


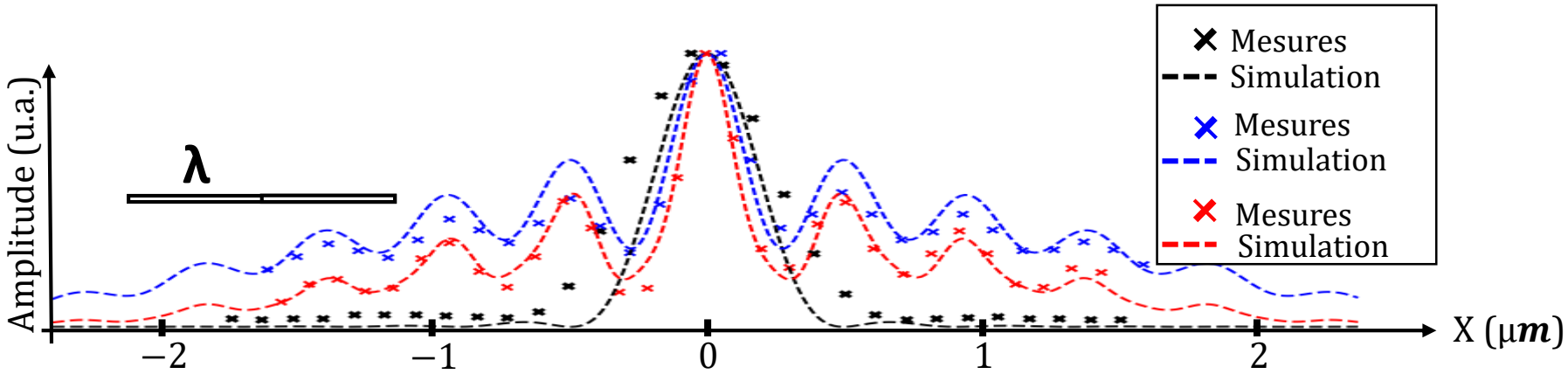
focal plane



backscattered

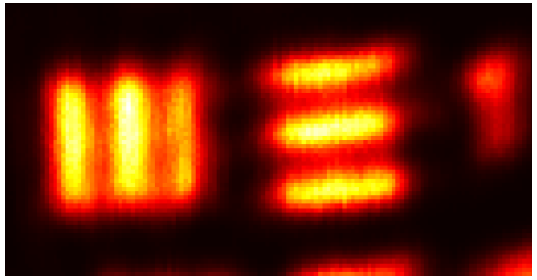




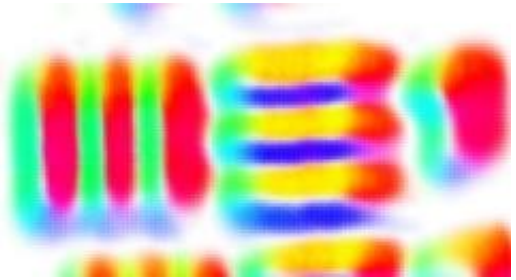


First optical images

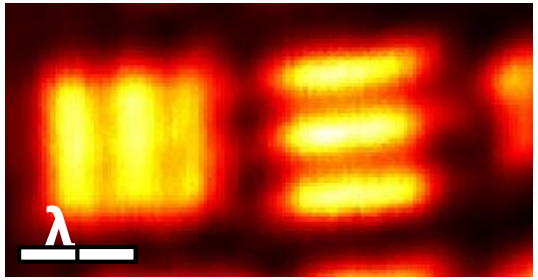
Im_0



Im_1



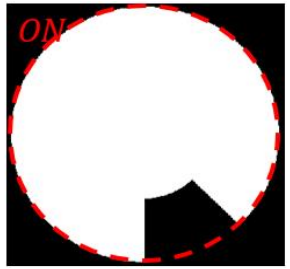
Confocal image



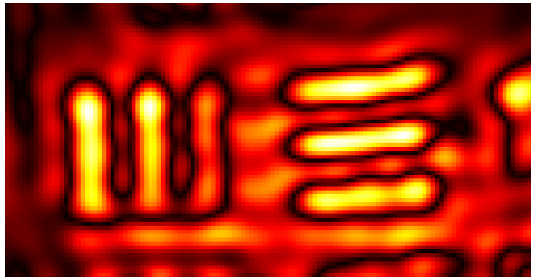
Groupe 11 element 1:

244 nm

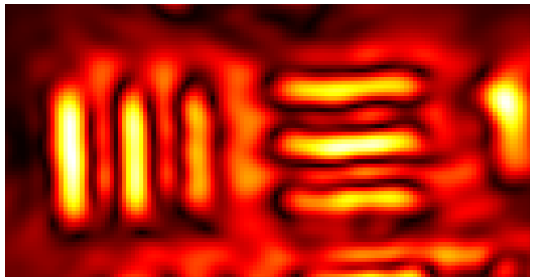
Reconstruction



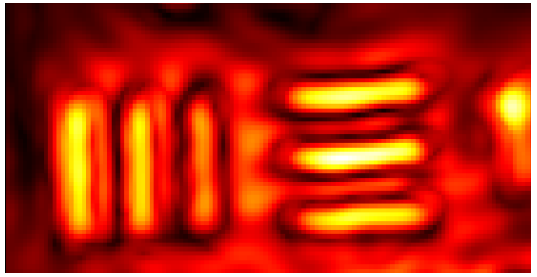
Obj_0



Obj_1



Reconstructed



Announcement

Actively looking for a postdoc starting in September

(who also accepts to teach 135 hours of laboratory works at ESPCI)

THANK YOU

PHYSICAL REVIEW APPLIED **19,** 024032 (2023)

Superresolved Imaging Based on Spatiotemporal Wave-Front Shaping

Guillaume Noetinger,[1] Samuel Métais,[2] Geoffroy Lerosey,[3] Mathias Fink,[1] Sébastien M. Popoff,[1] and Fabrice Lemoult[1,*]