FINCHing objects with a super-resolution – Fundamentals to Applications

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This Project has received funding from the European Union' s Horizon 2020 research and innovation programme under grant agreement No 857627 (CIPHR)

11th November 2022 – Raman Optronics Webinar Series 2022

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OUTLINE

- Fundamental differences between imaging with coherent and spatially incoherent light
- Fresnel incoherent correlation holography (FINCH)
- Lagrange invariant condition and super resolution
- Evolution of FINCH during the years
- Applications and Challenges in the FINCH technology
- Single camera shot FINCH
- Conclusion and future perspectives

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Fundamental differences between imaging with coherent and spatially incoherent light

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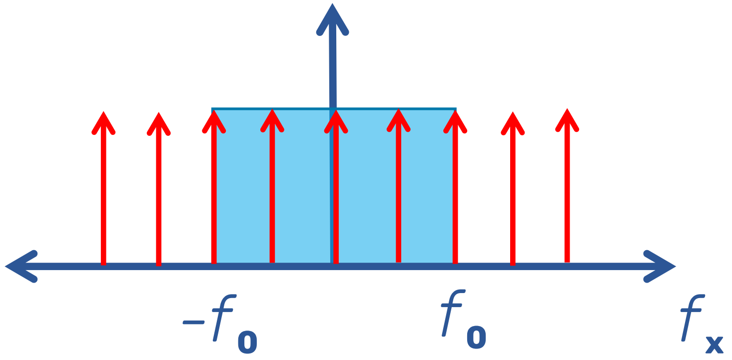
Fundamental differences between imaging with coherent and spatially incoherent light

Coherent systems

$$I_i = \left| h \otimes U_o \right|^2$$

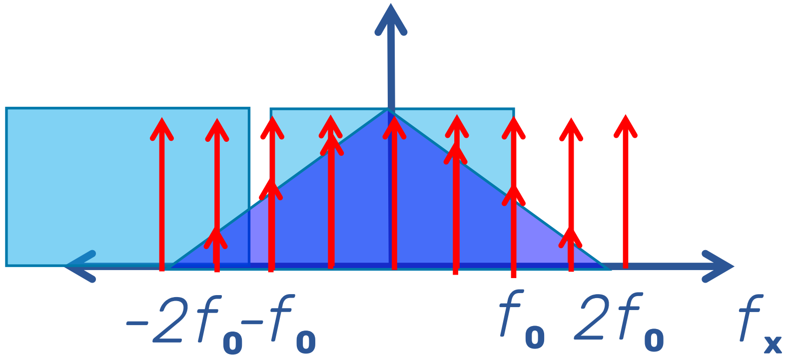
$$\Im\{I_i\} = \left[H G_o \otimes H G_o \right]$$

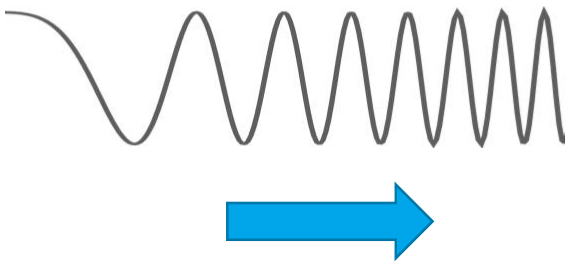


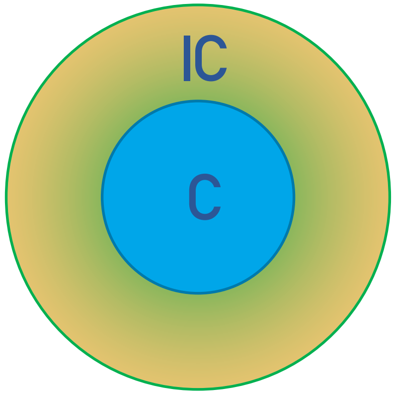
Incoherent systems

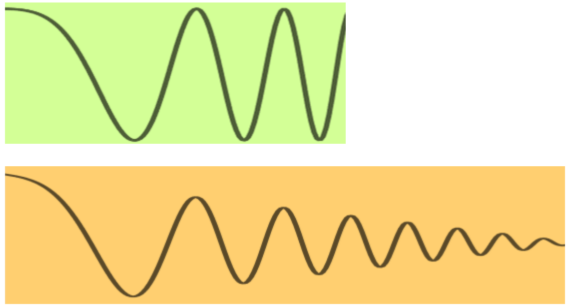
$$I_i = \left| h \right|^2 \otimes I_o = \left| h \right|^2 \otimes \left| U_o \right|^2$$

$$\Im\{I_i\} = \left[H \otimes H \right] \left[G_o \otimes G_o \right]$$









Fourier Optics – J. W Goodman

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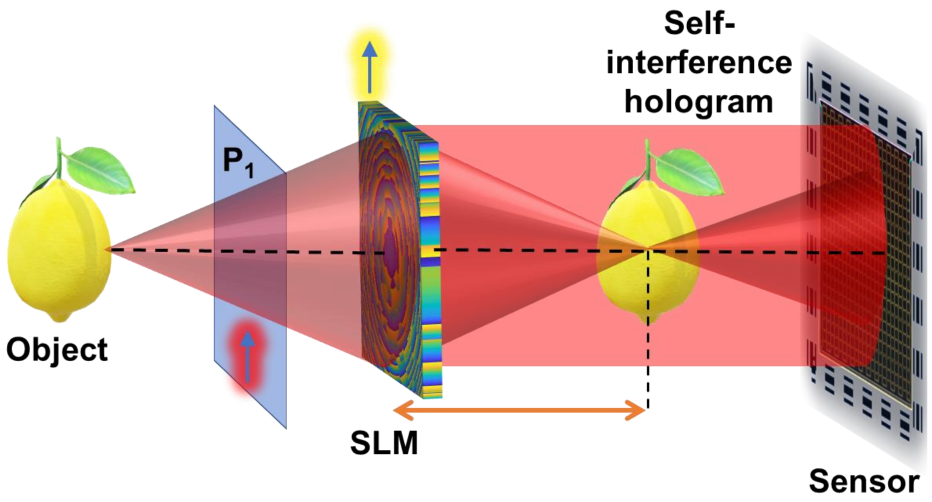
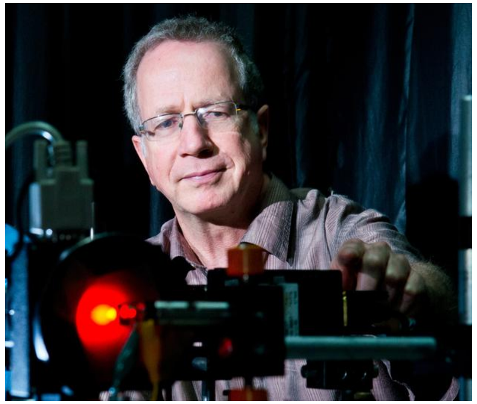
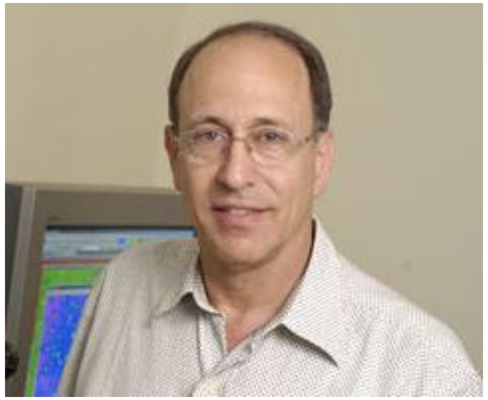
Fresnel incoherent correlation holography (FINCH)

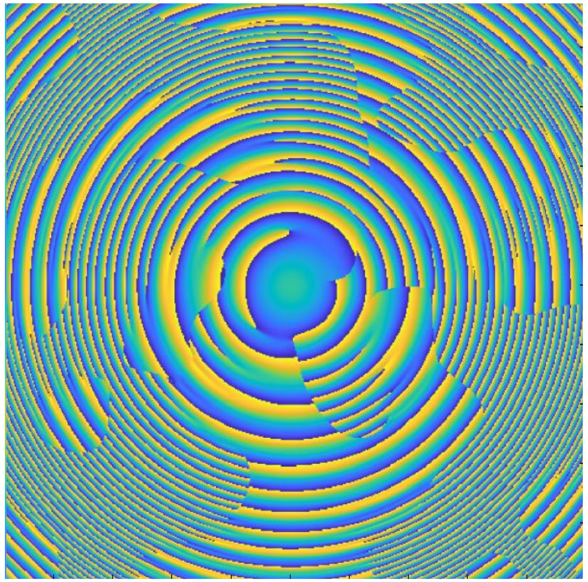




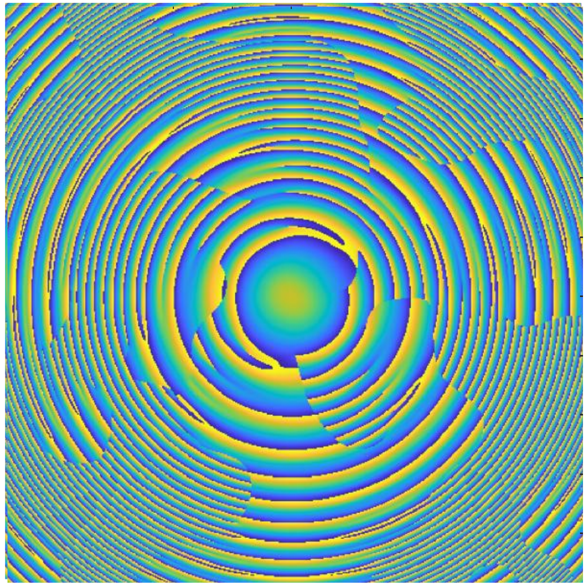
Prof. Joseph Rosen
Ben Gurion University (Israel)



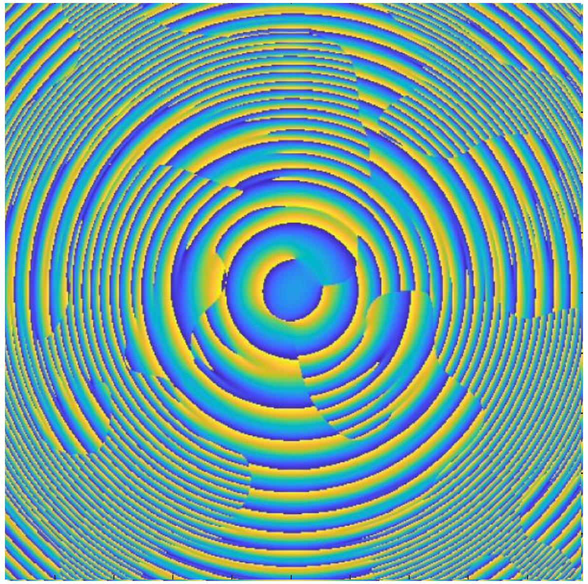
Prof. Gary Brooker
John Hopkins University (USA)



Random phase mask
Theta = 0 degrees



Binarized random phase mask
Theta = 120 degrees



Lens
Theta = 240 degrees

Opt. Lett. 32, 912-914 (2007)

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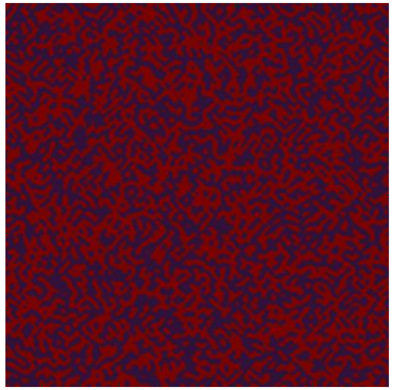
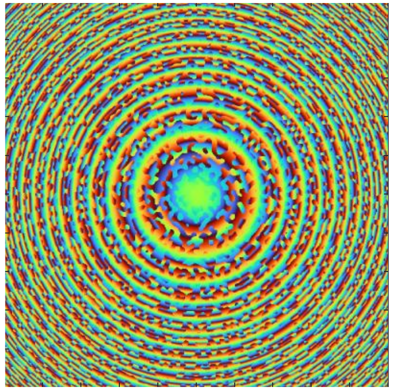
Fresnel incoherent correlation holography (FINCH)

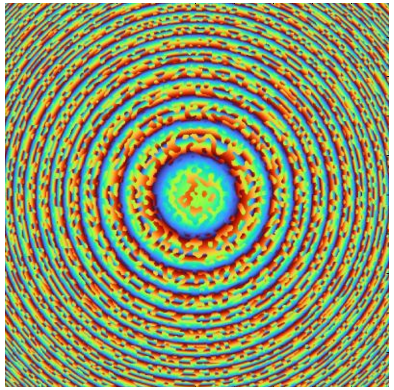
Binary random phase mask



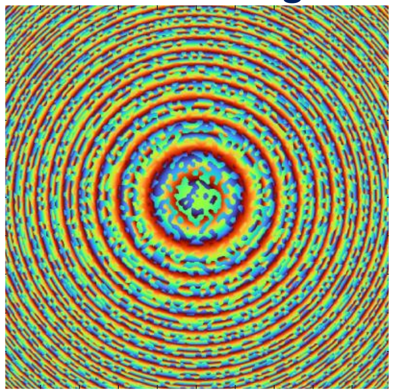
Phase mask 1
Theta = 0 degrees



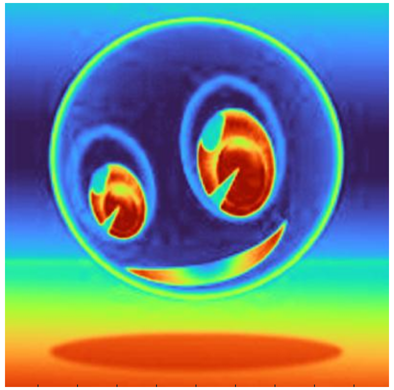
Phase mask 2
Theta = 120 degrees

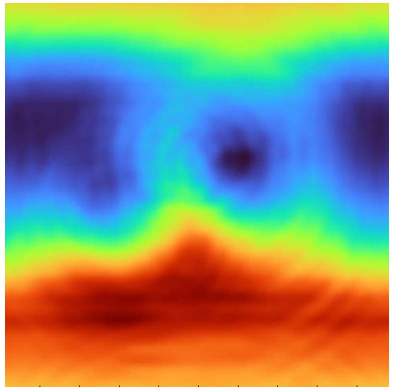


Phase mask 3
Theta = 240 degrees

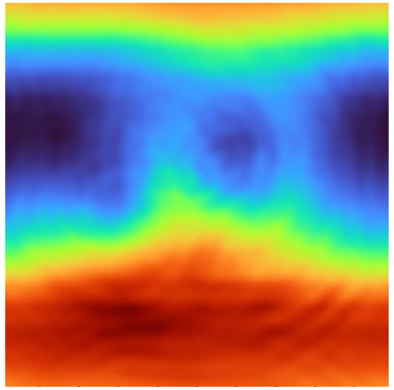


Test object

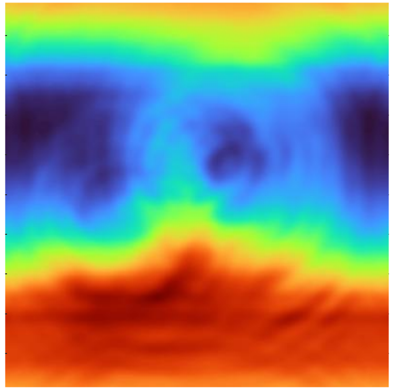




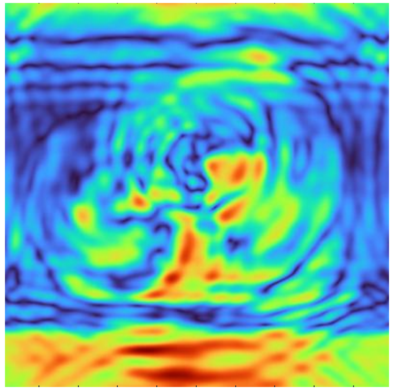
Object hologram 1
Theta = 0 degrees



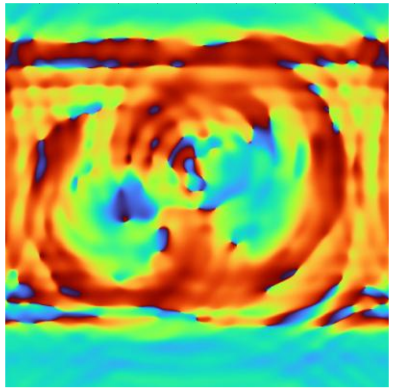
Object hologram 2
Theta = 120 degrees



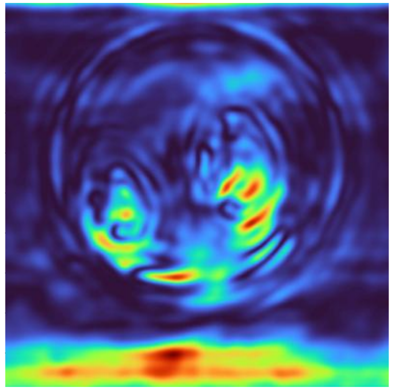
Object hologram 3
Theta = 240 degrees



Amplitude of complex hologram



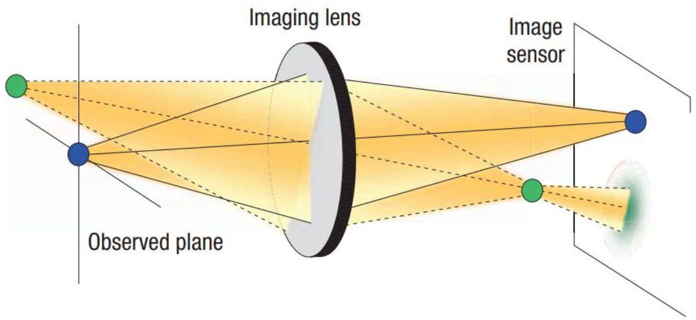
Phase of complex hologram



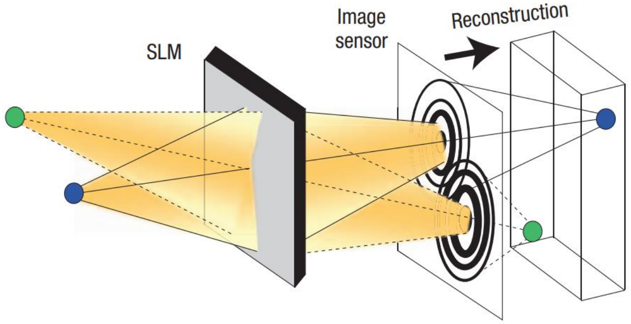
Reconstruction result

Opt. Lett. 32, 912-914 (2007)

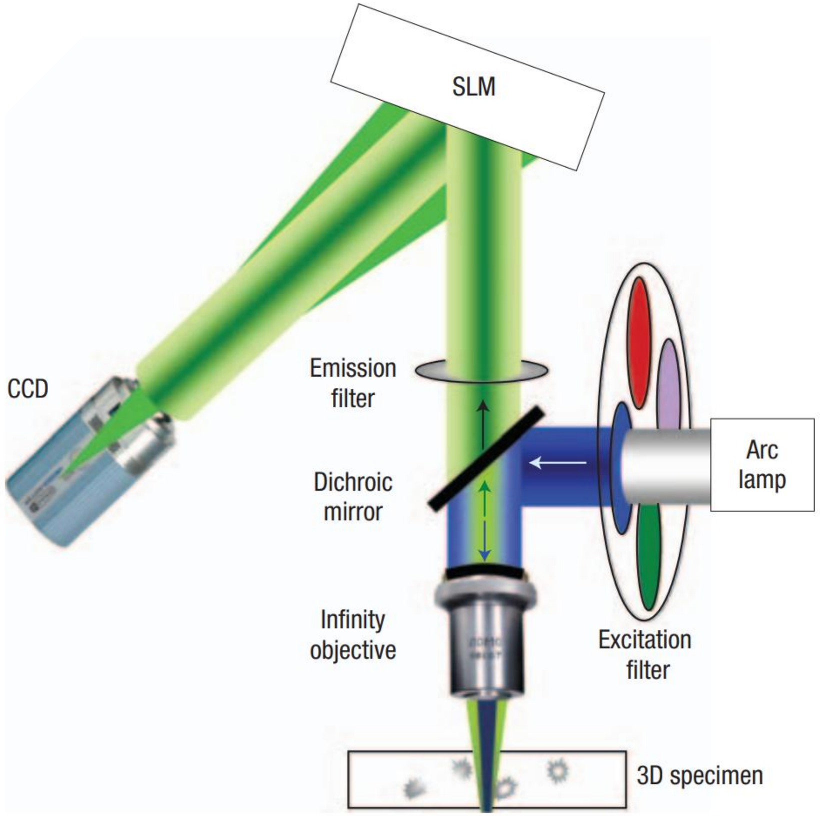
Fresnel incoherent correlation holography (FINCH)



Conventional imaging

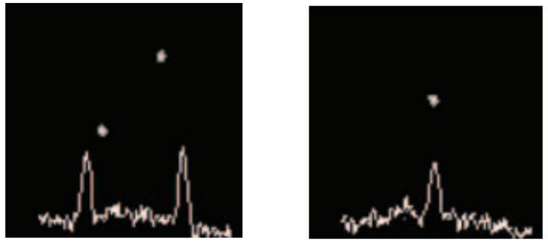


FINCH

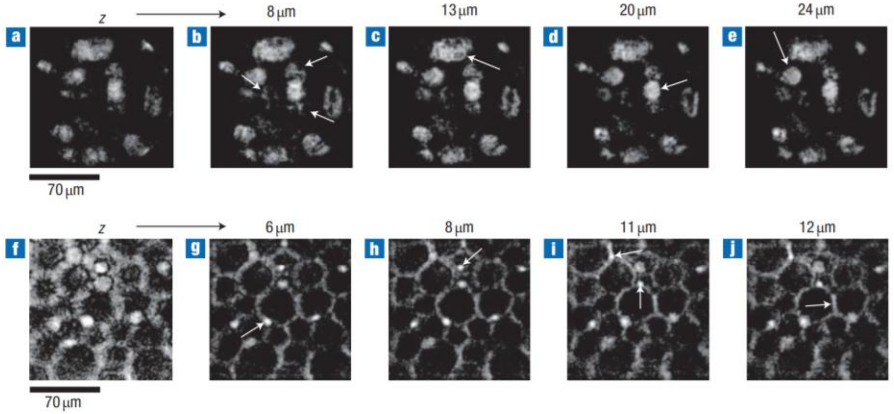


FINCH-Scope

Reconstruction results



38 µm **84 µm**



Nature Photonics. 2008;2(3):190-5.

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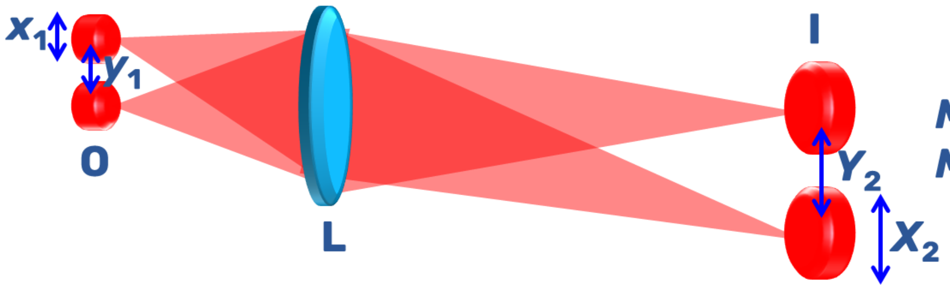
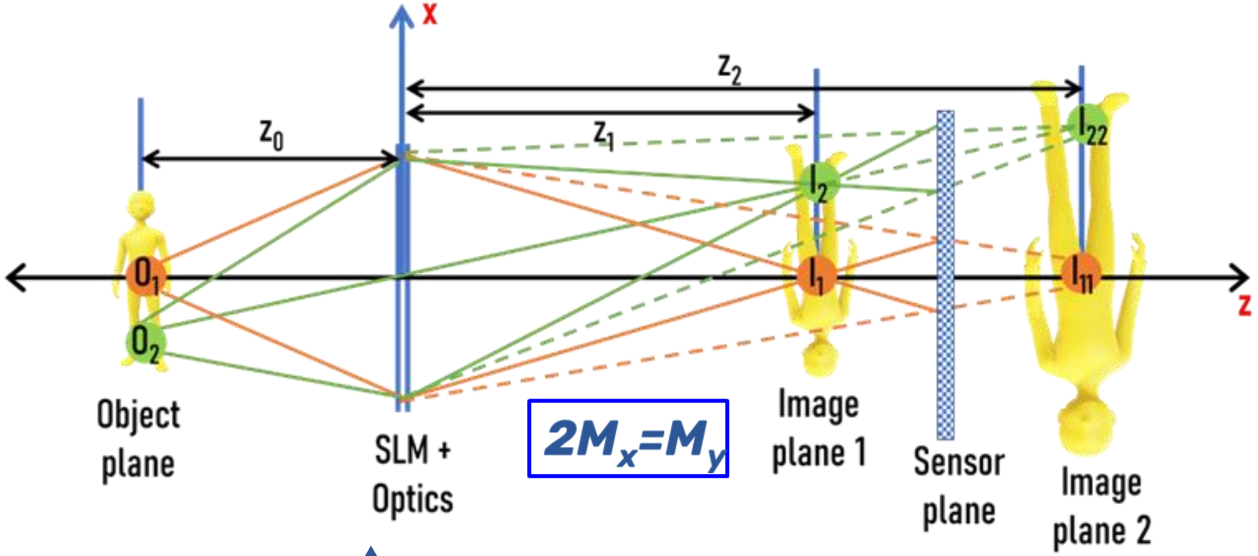
Lagrange invariant condition and super resolution

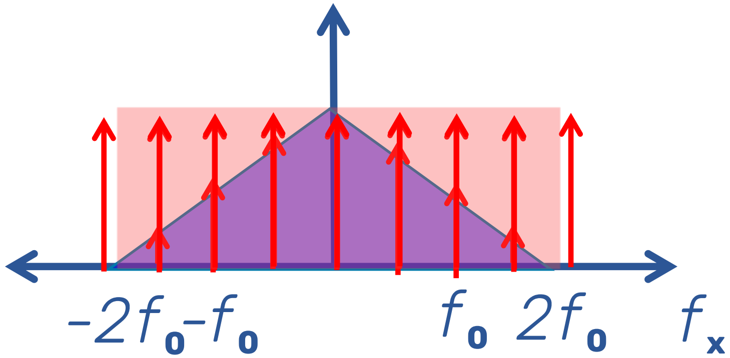
Lagrange Invariant condition also called as Smith–Helmholtz formula states that the magnification between two points is same as magnification of the point.

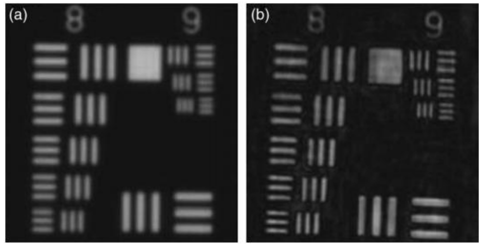


$M_x=X_2/x_1$
$M_y=Y_2/y_1$



$M_x=M_y$ Lagrange Invariant condition satisfied.





$M_x \neq M_y$ Lagrange Invariant condition not satisfied.

$M_x<M_y$ Lagrange Invariant condition not satisfied and super resolution.

Opt. Express 22, 29048-29066 (2014).

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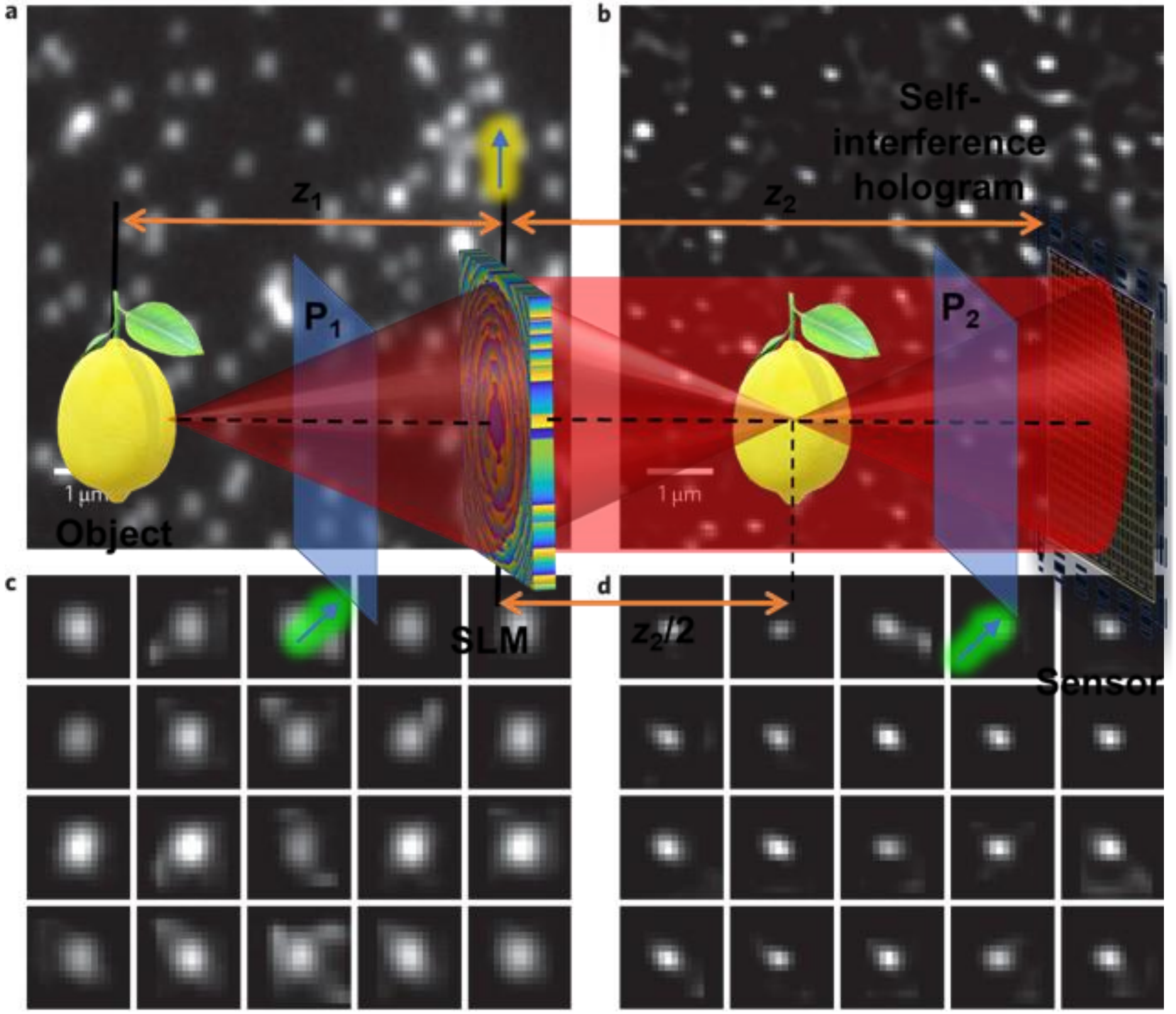
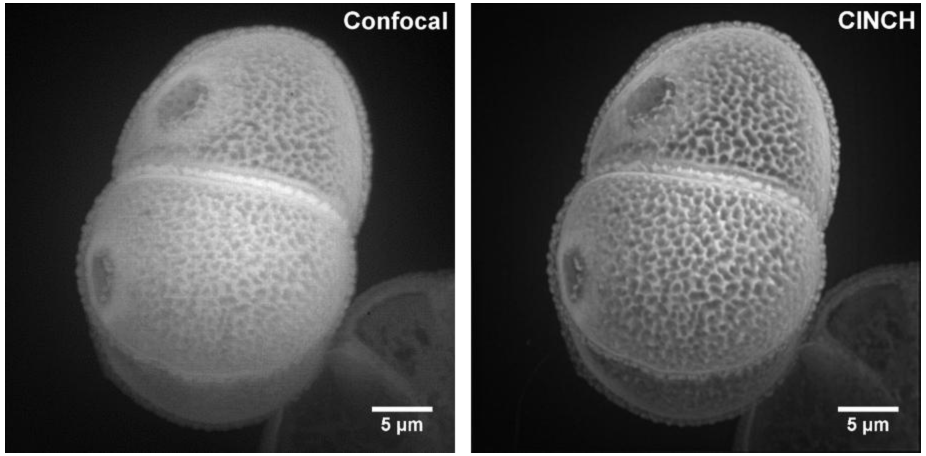
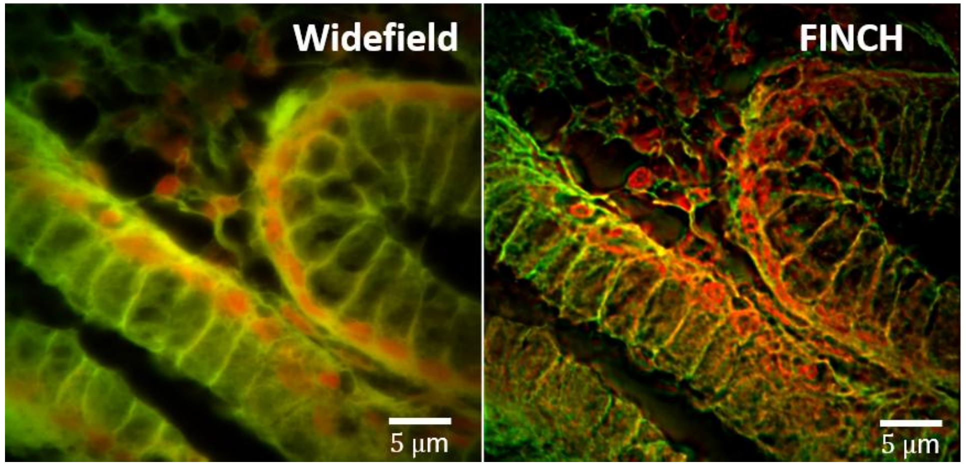
Lagrange invariant condition and super resolution

Wide field fluorescence microscopy

FINCH







Fundic stomach fluorescence

Nature Photonics 10, 802–808 (2016) and Celloptic Inc

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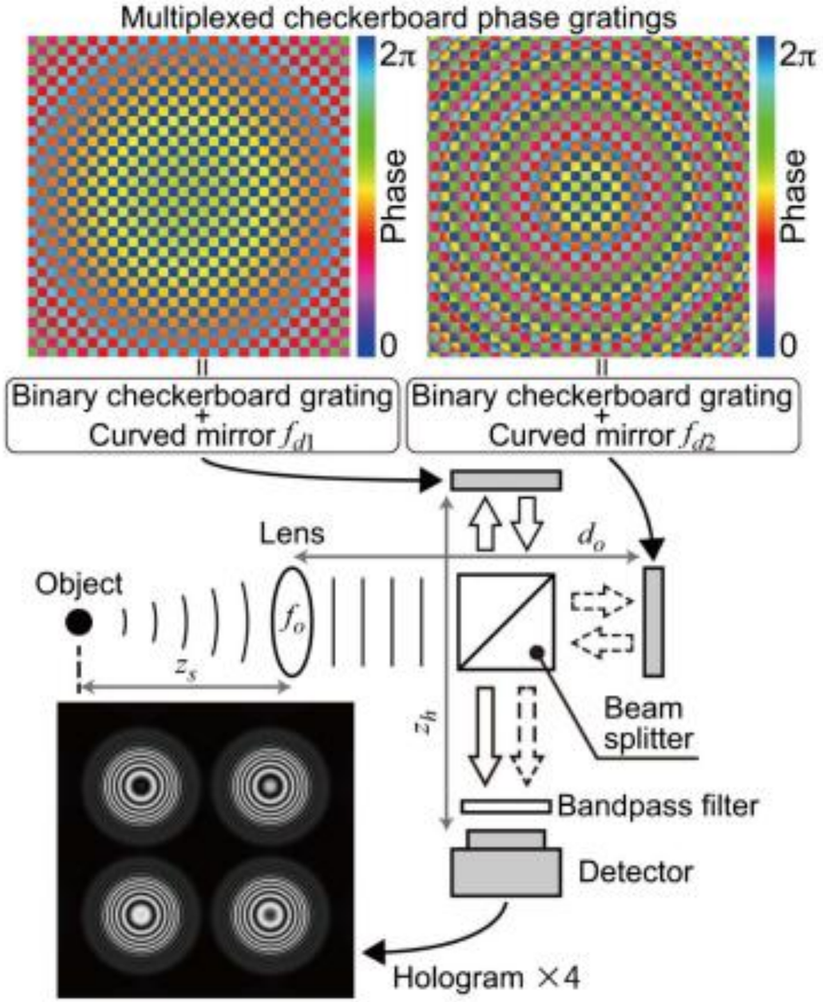
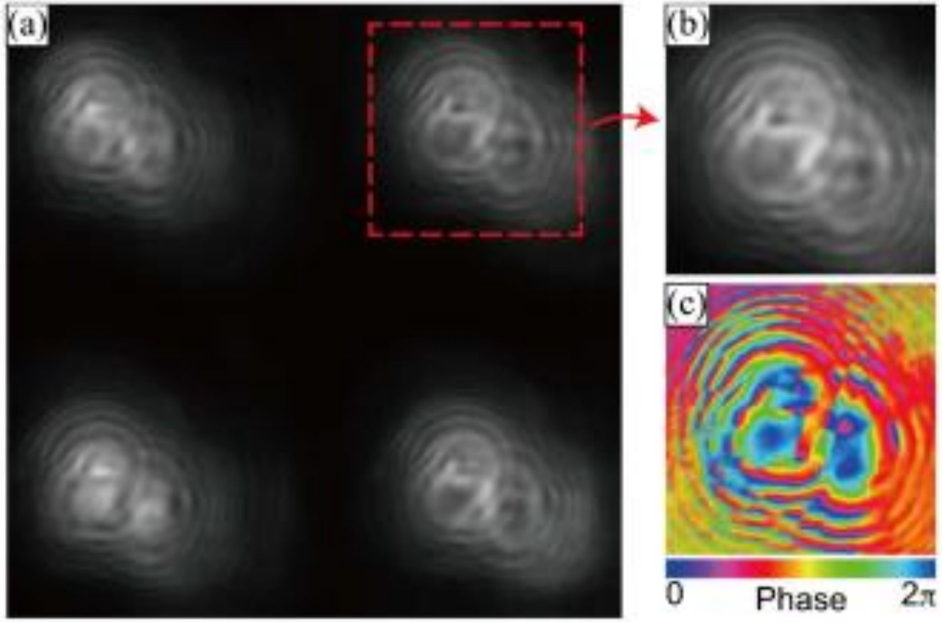
Evolution of FINCH

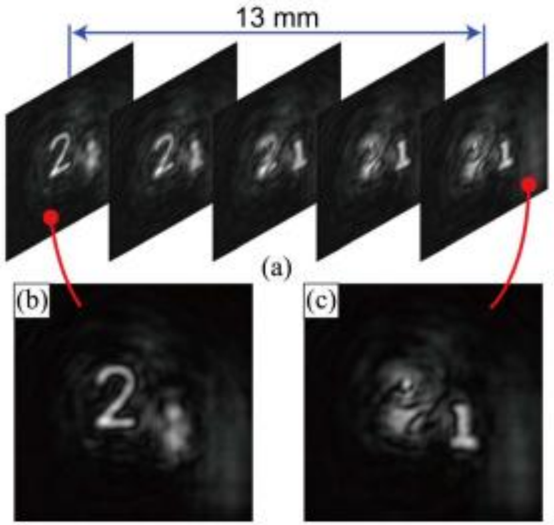
Optical configuration



Holograms



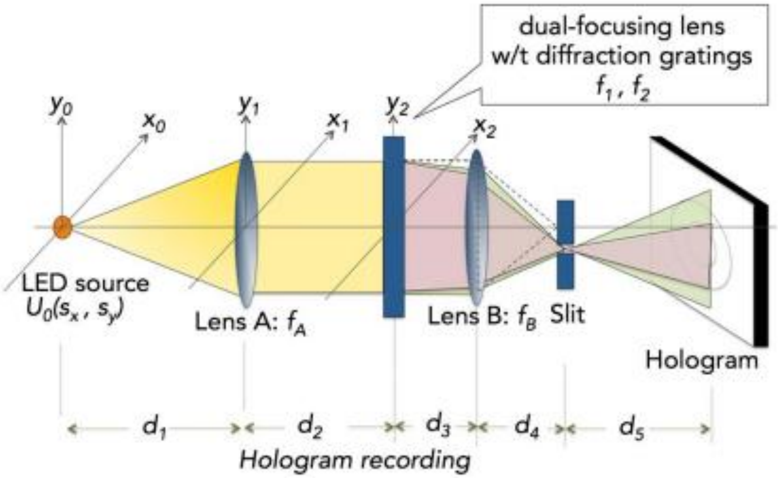
Reconstruction results



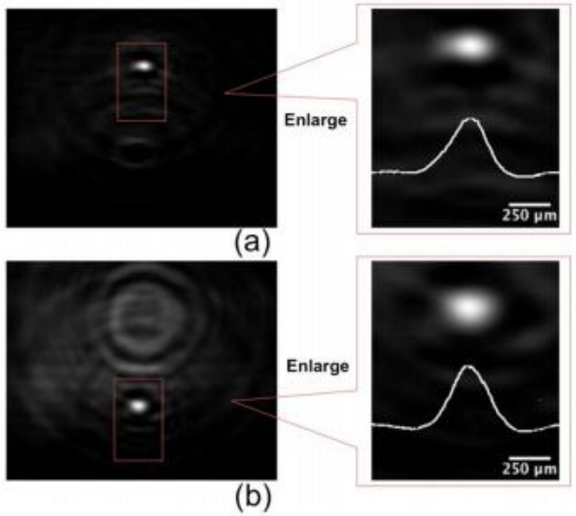
Opt. Lett. 43, 1698-1701 (2018)

Evolution of FINCH

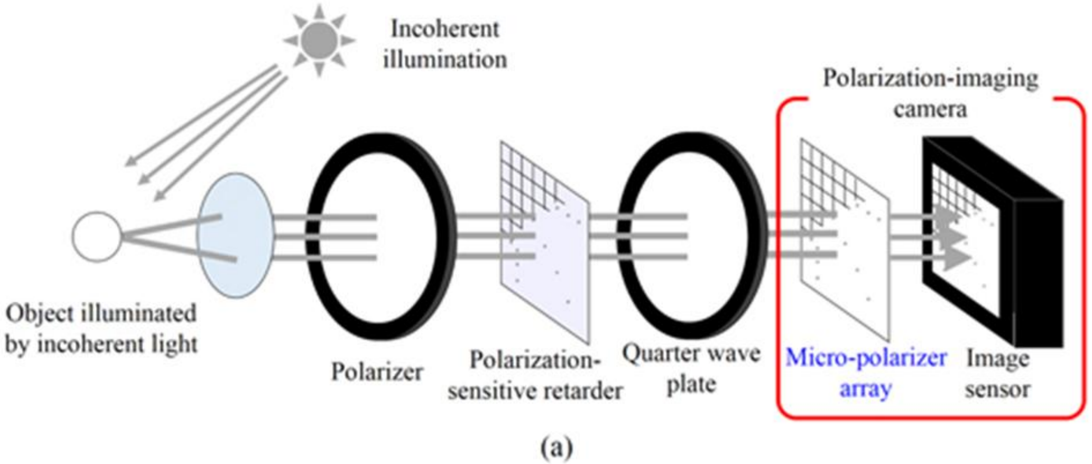
Optical configuration



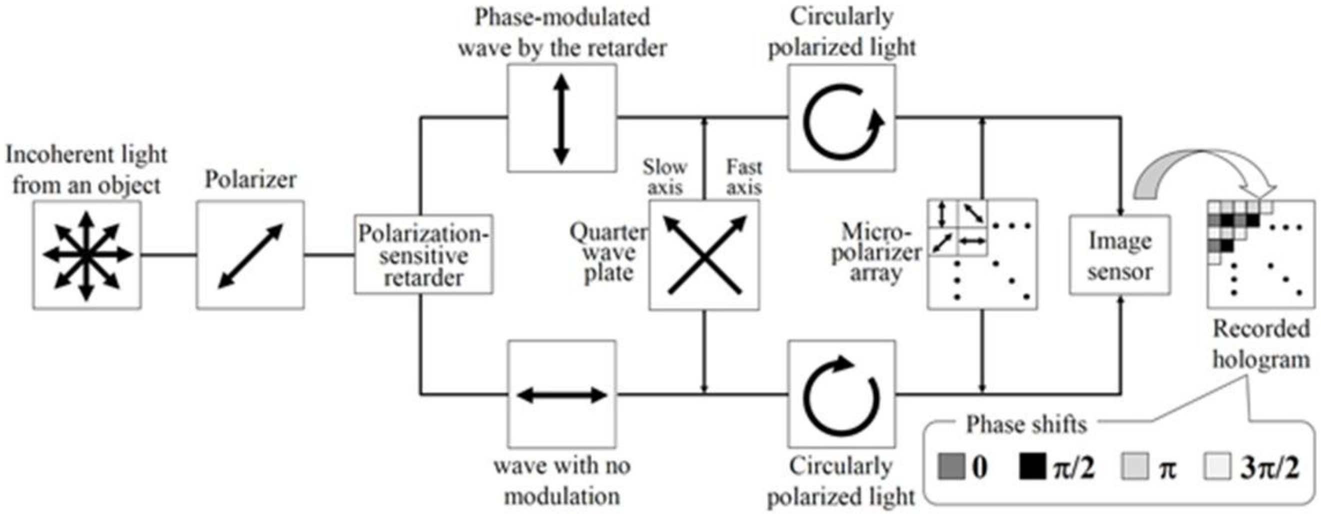
Reconstructions



Opt. Lett. 42, 383-386 (2017)



Reconstruction



Optics letters. 2011;36(16):3254-6.

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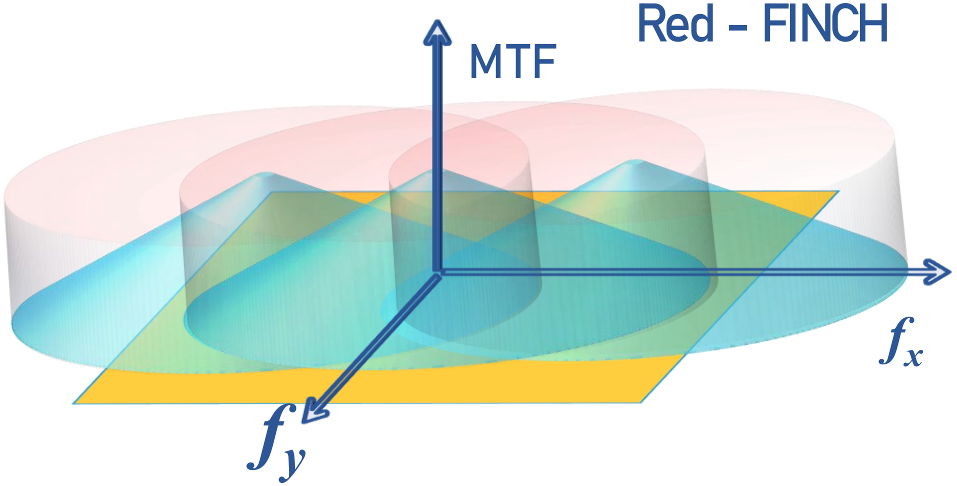
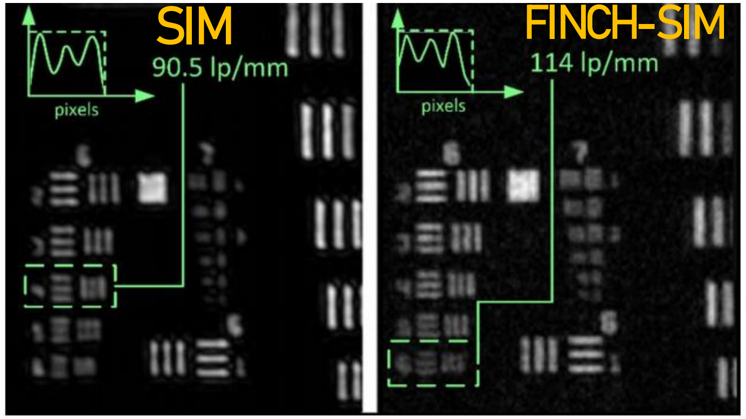
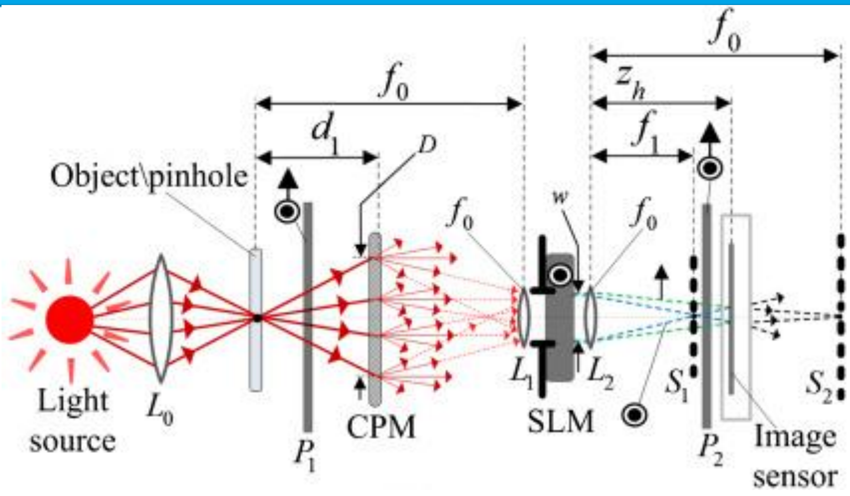
FINCH as a resolution booster

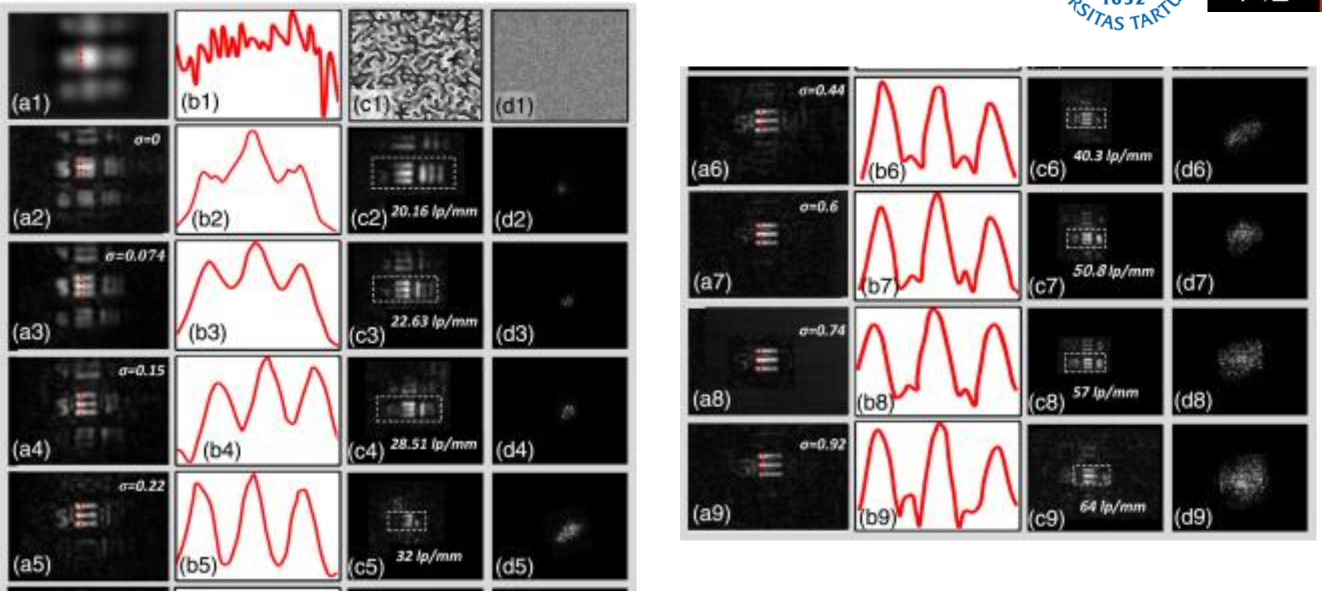
Blue – Direct imaging,
Red – FINCH





Opt. Lett. 41, 1558-1561 (2016).





Optica 4, 932-939 (2017)

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Linear imaging systems – Vending machine concept

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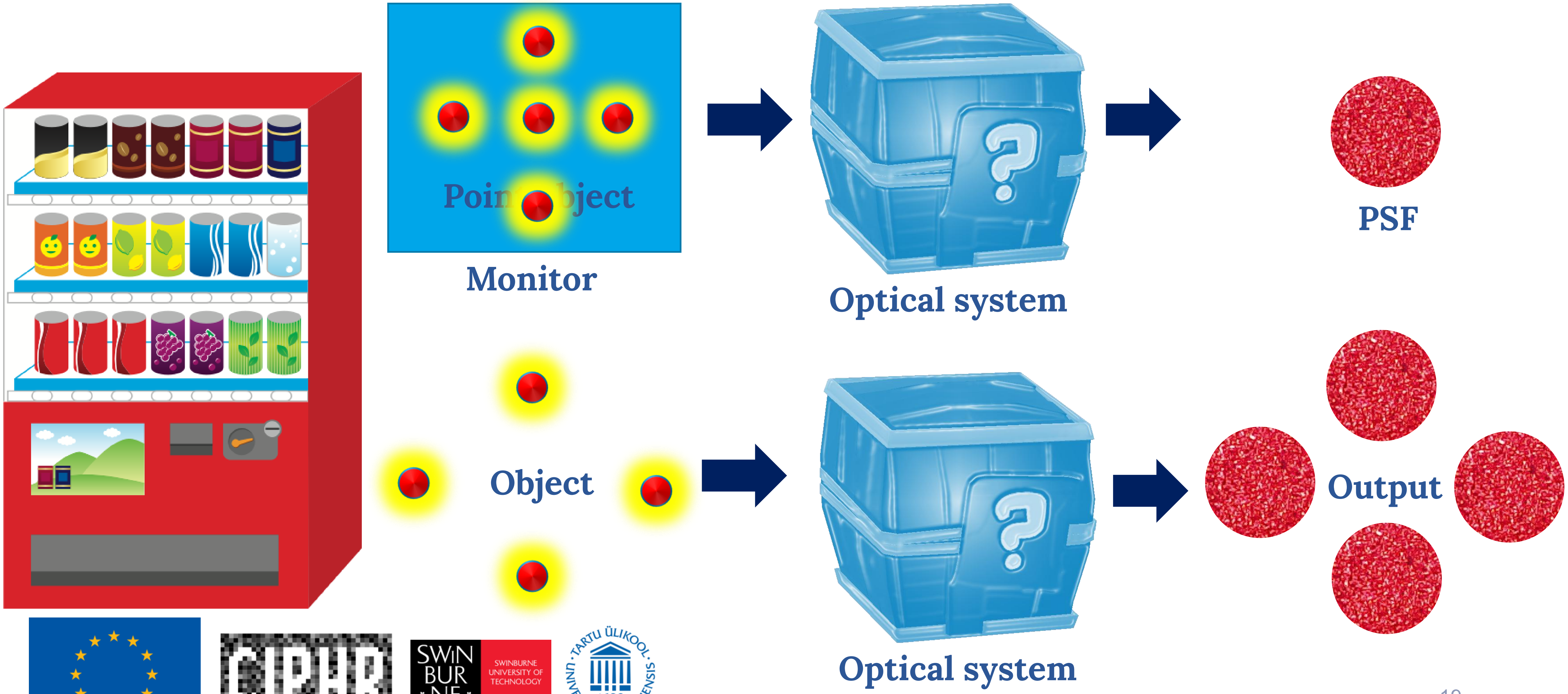
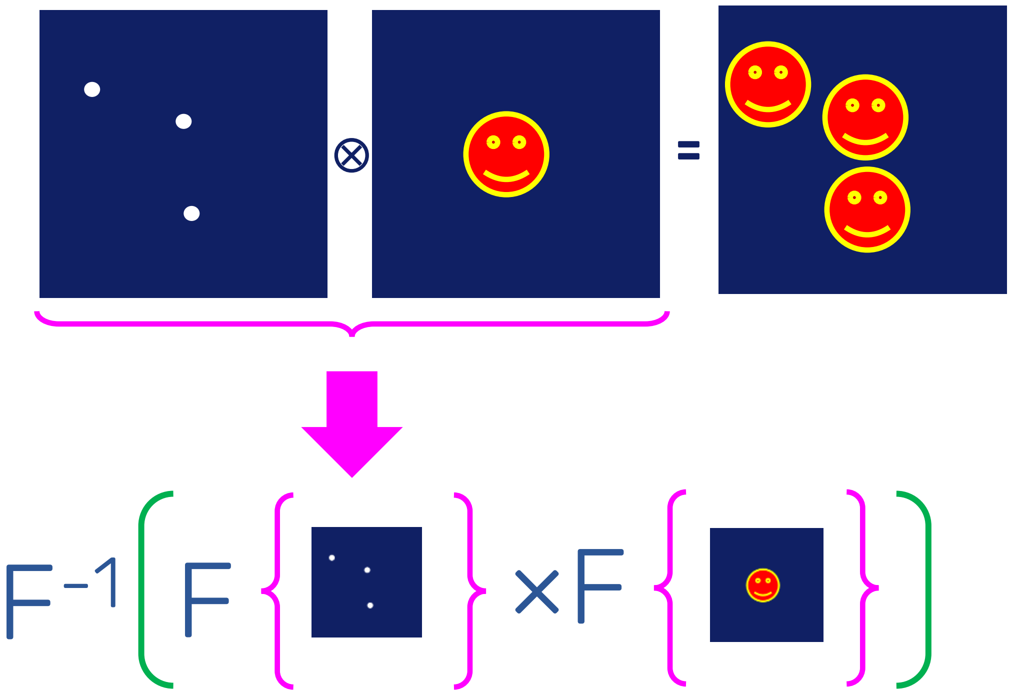
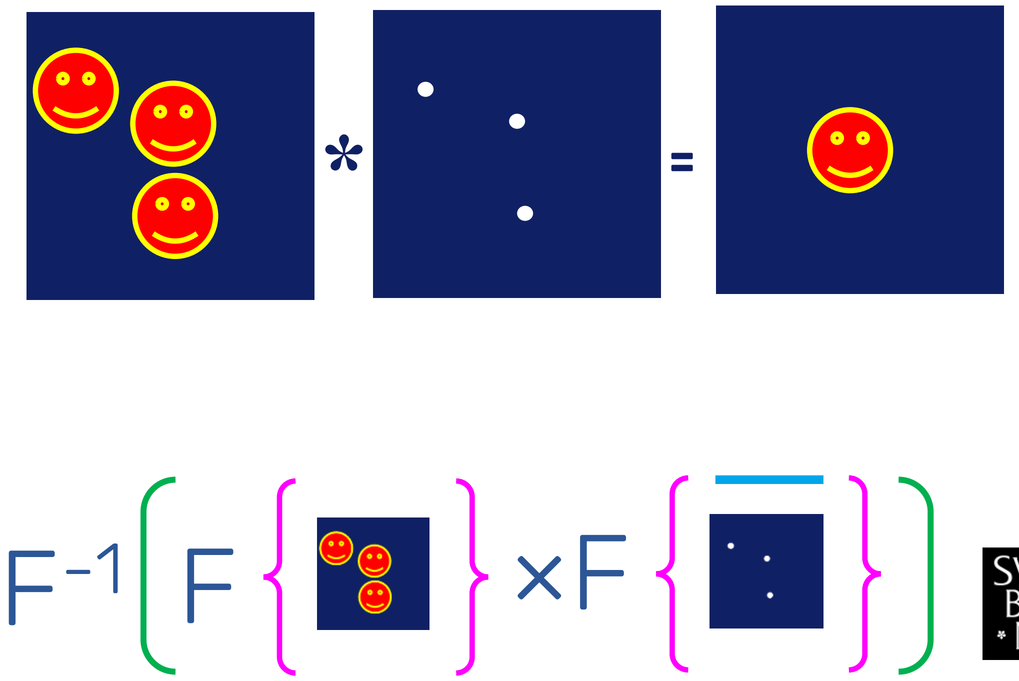
Linear imaging systems – Vending machine concept



Convolution & Correlation – Mathematical form



Convolution



Correlation

Complex conjugate

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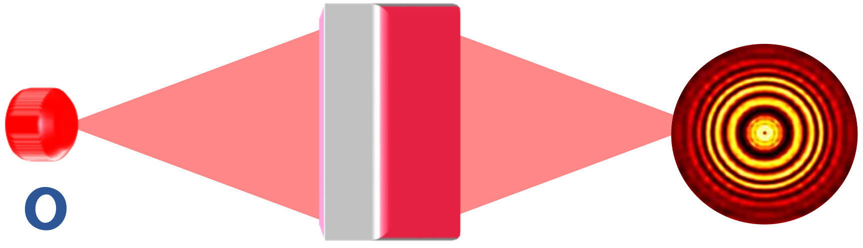
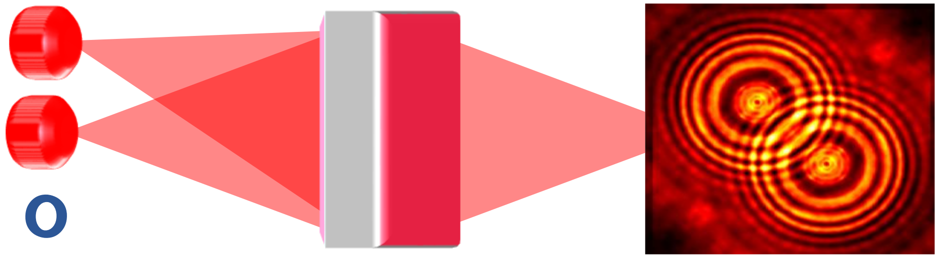
Single camera shot FINCH



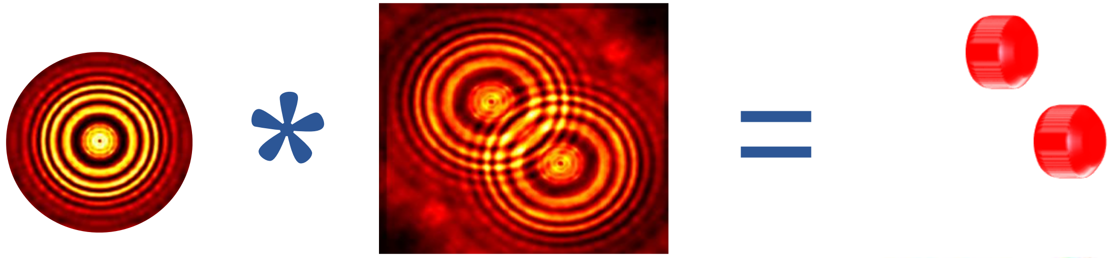
O

FINCH



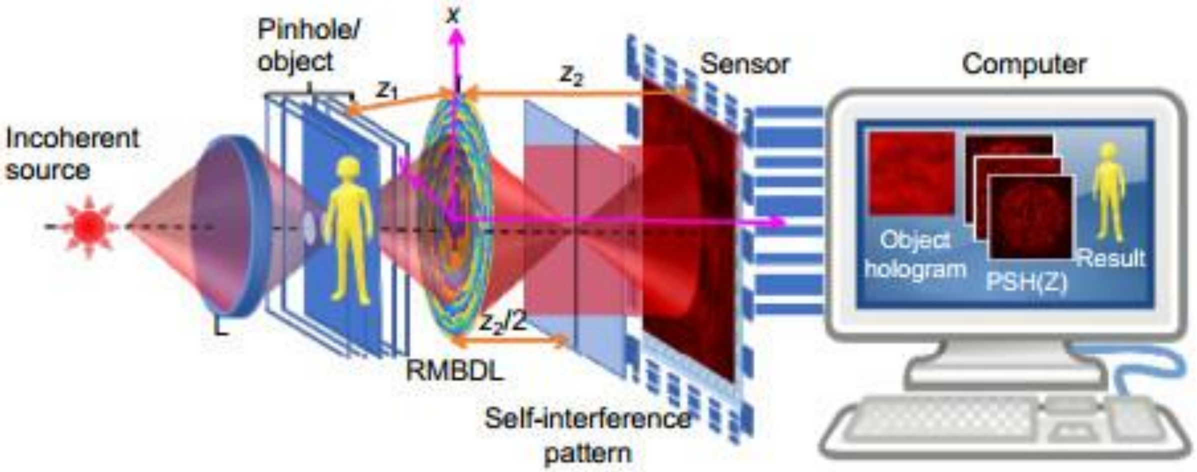
O

FINCH



$*$ Correlation operator

Optical configuration



Opto-Electron Adv 3, 200004 (2020).

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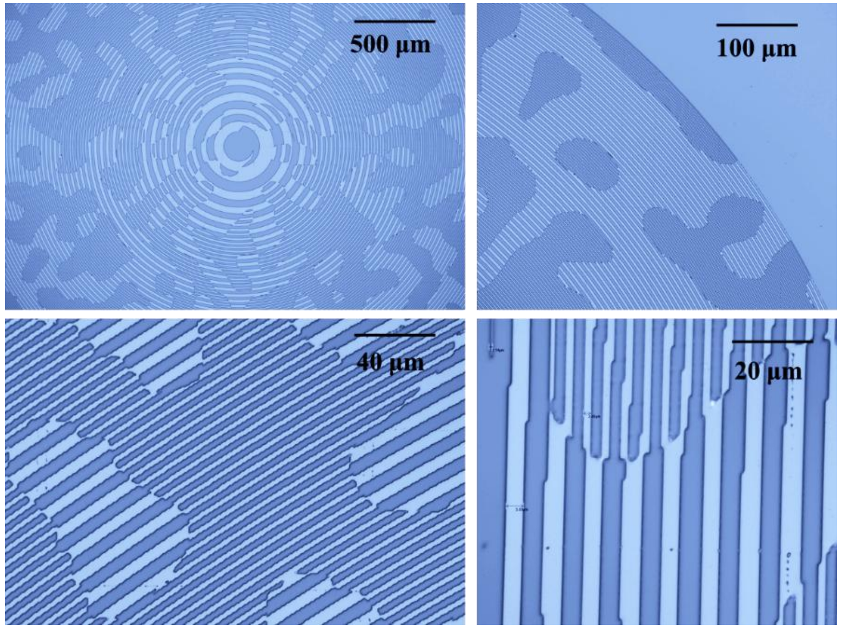
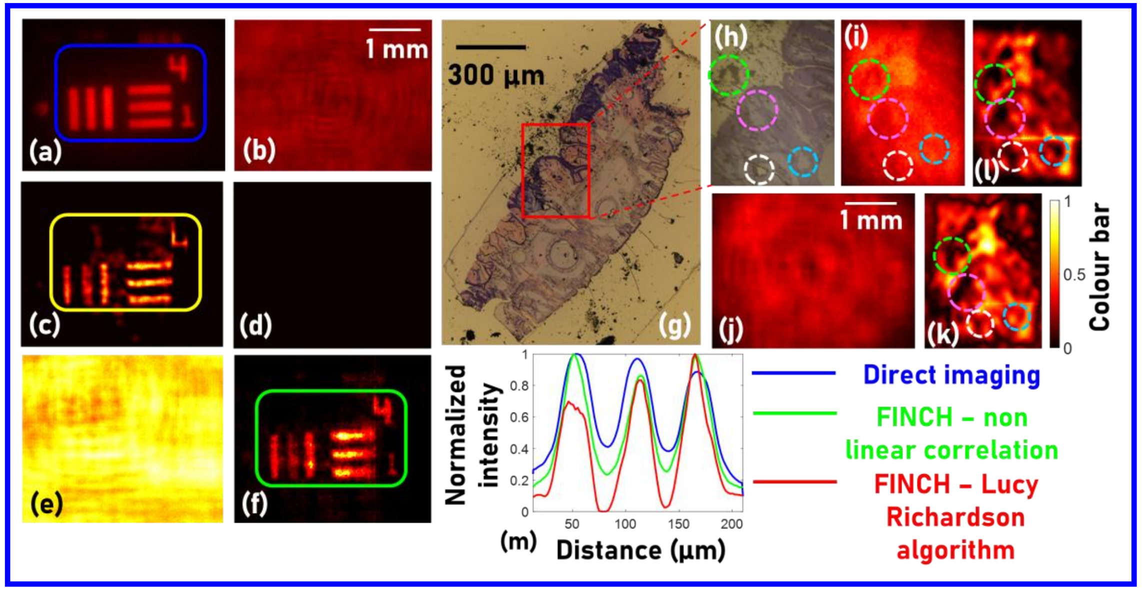
Single camera shot FINCH

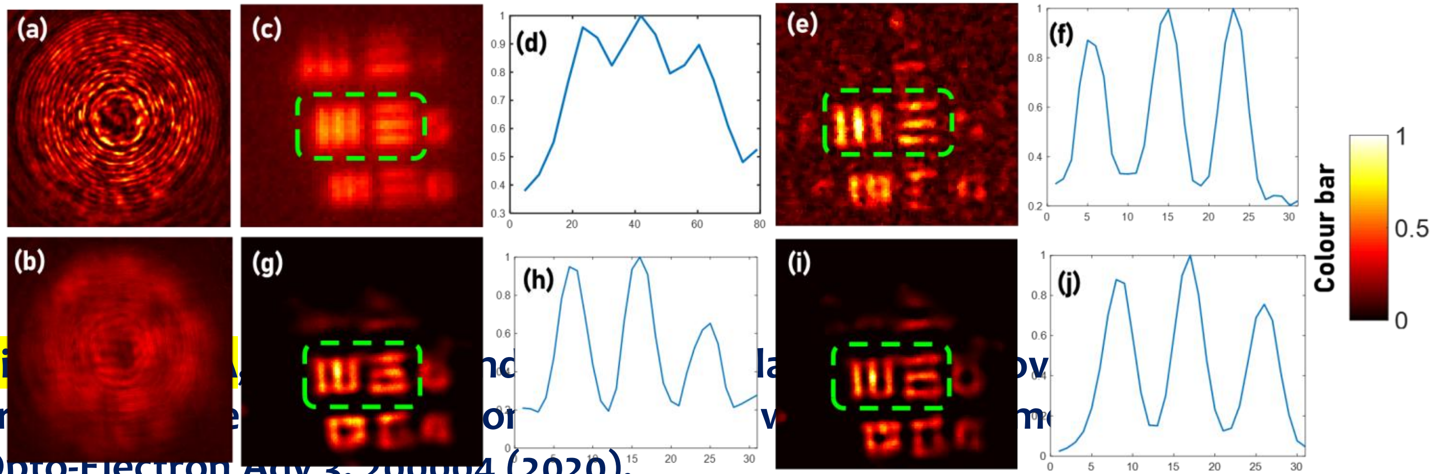
Fabrication results



Single plane results

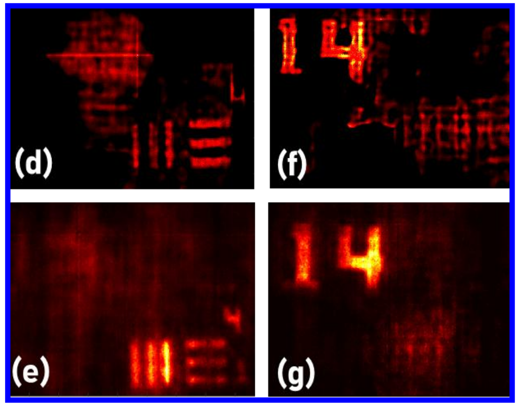


Super resolution demonstration



Opto-Electron Adv 3, 200004 (2020).

3D reconstruction



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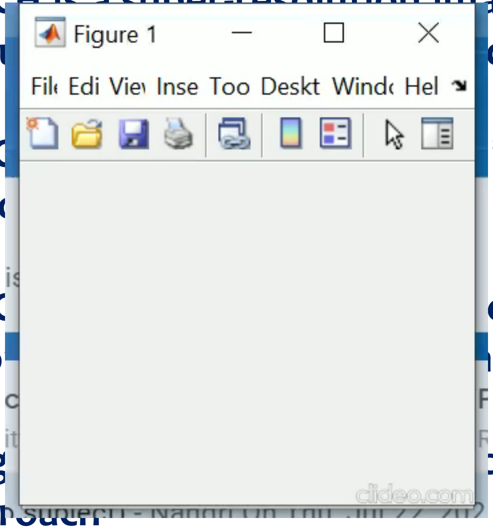
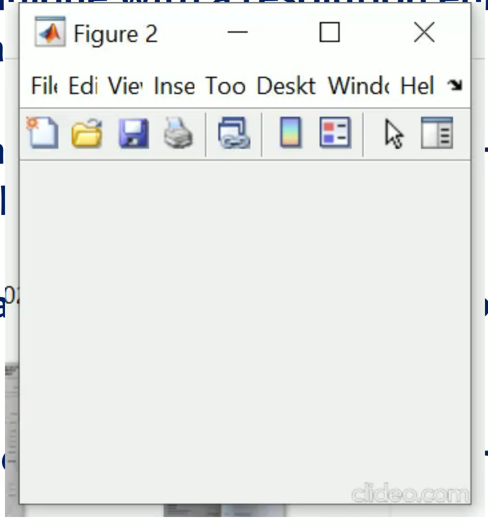
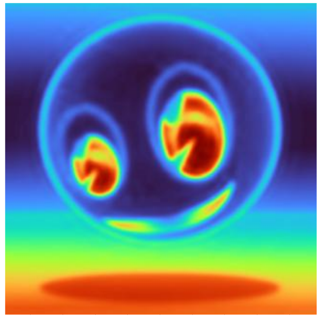
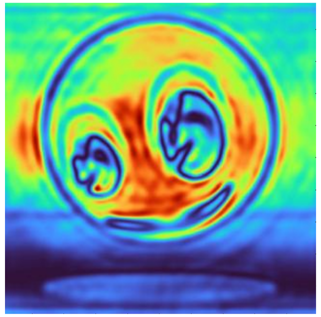
Conclusion

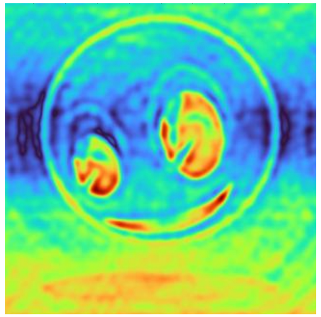
- FINCH is a super-resolution imaging technique with a resolution enhancement of abou direct ima
- FINC ization an and Brool H and CINCH at Cell
- FINC ee camera bject info SLM.
- Sing ccessfully rn recognition appr

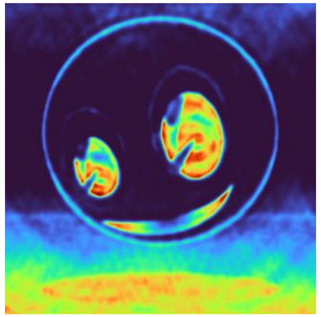





Direct imaging

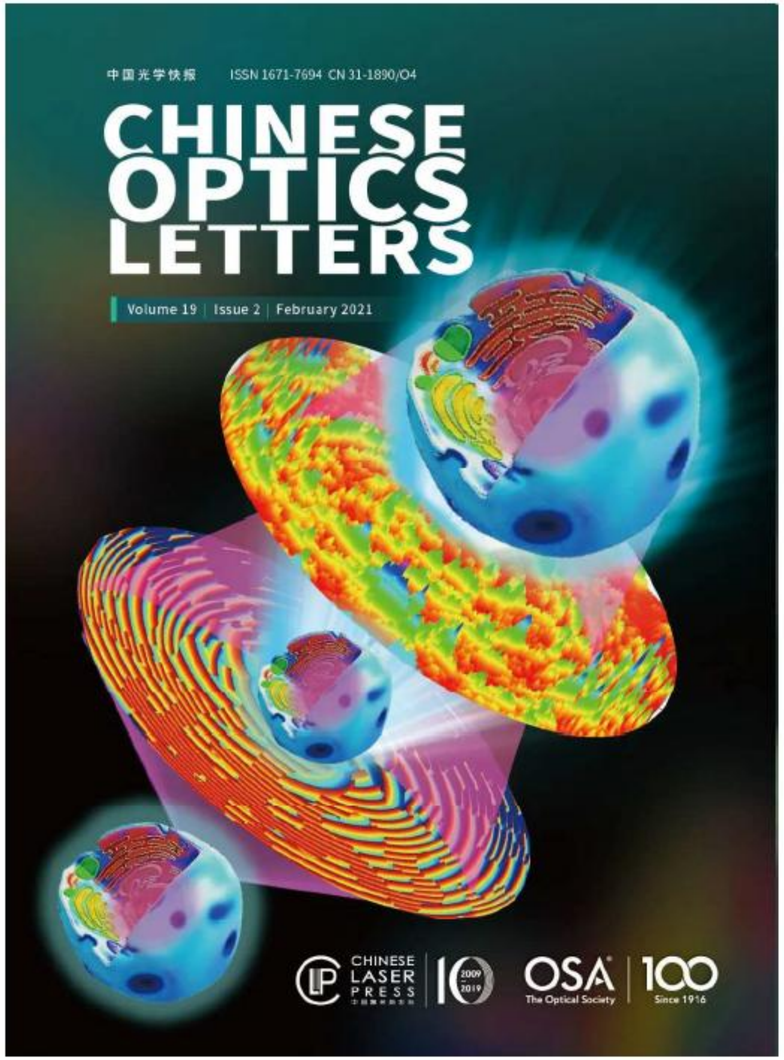

FINCH (3 shots)


FINCH (1 shot) and NLR

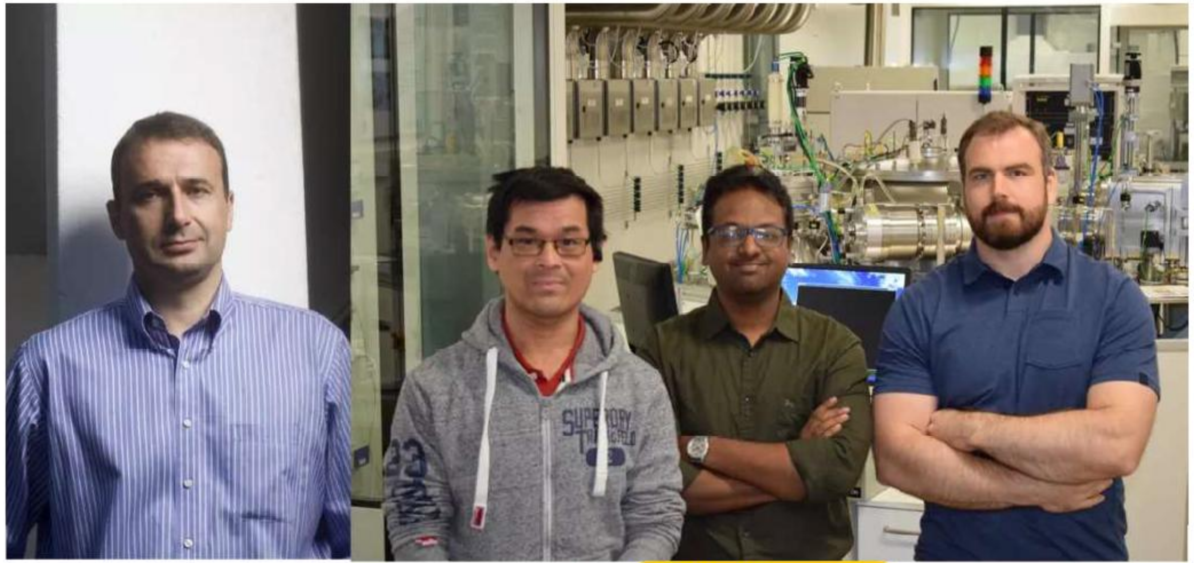

FINCH (1 shot) and LRRA

Future works

- A new reconstruction algorithm – Lucy-Richardson-Rosen algorithm is developed to achieve single shot in FINCH.
- CIPHR group and Prof. Rosen looking into AI based reconstruction possibilities from single shot.

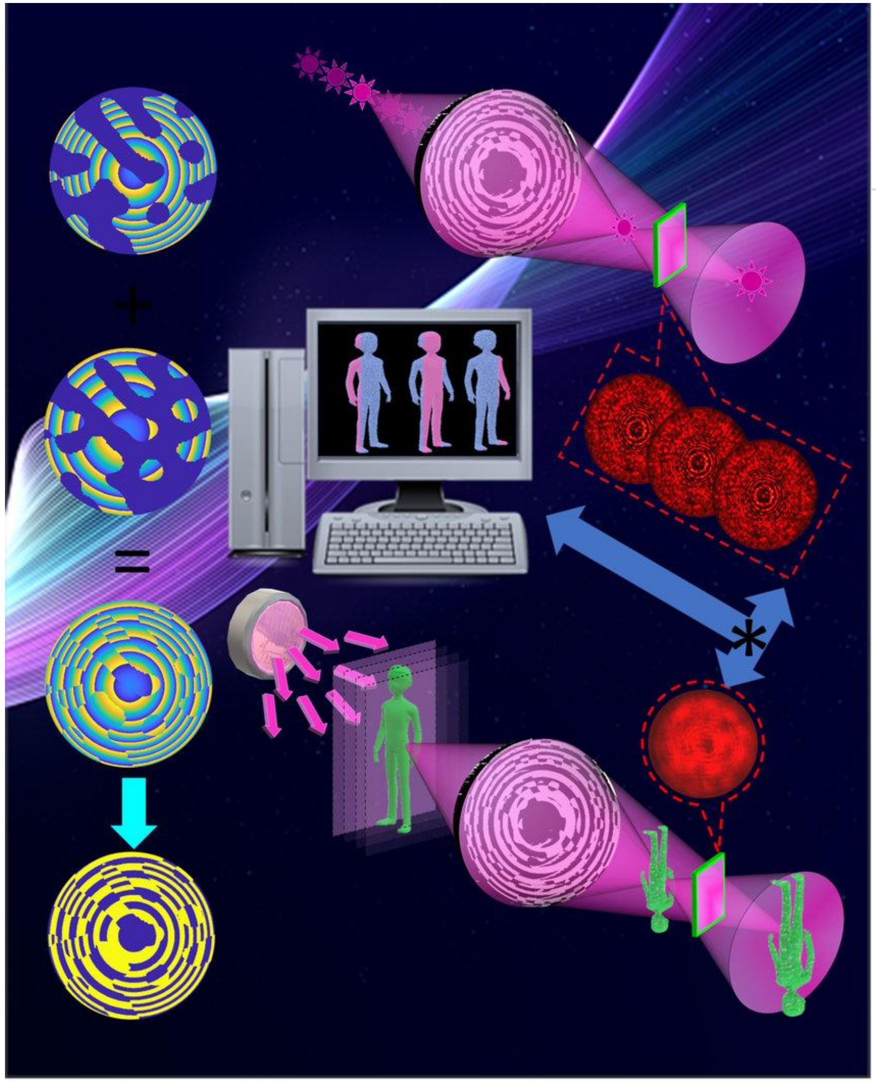


作者简介



Prof. Saulius Juodkazis Dr. Soon Hock Ng Dr. Vijayakumar Anand Dr. Tomas Katkus

Vijayakumar Anand博士（右二）专注于全息领域，并拓展该领域在生物医疗和激光加工的新应用。



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as the time-resolution of FINCH. The authors have demonstrated FINCH using a single passive multifunctional diffractive optical element consisting of randomly multiplexed diffractive lenses with different focal lengths for the first time. The multifunctional diffractive optical element has been fabricated using nanolithography and the technique has been successfully demonstrated in a highly compact optical configuration on resolution targets and biological samples.

Dr. Vijayakumar Anand from the research group of Prof. Saulius Juodkazis at Swinburne University of Technology has redefined a well-known incoherent imaging technique called as Fresnel incoherent correlation holography (FINCH) using the fundamental principles of linear systems. FINCH systems have a resolving power 1.5 times higher than that of equivalent lens based incoherent direct imagers and twice that of a coherent direct imager. For this reason, FINCH has been widely used to build super resolution fluorescence microscopes and also used as a resolution enhancer by coupling it with other super resolution techniques such as structured illumination. The super resolution in FINCH also demands many stringent requirements such as special optical configuration, active and passive optical elements such as spatial light modulator, polarizers and lenses and has lower axial and temporal resolutions. This cumbersome requirements and lower axial and temporal resolutions often prevent the wide applicability of FINCH. In this study, the researchers have redefined FINCH in a new light and have succeeded in transferring the enormous optical load consisting of active and passive optical components to nanofabrication and computational optics. Consequently, they were able to realize FINCH with a single diffractive optical element fabricated using nanofabrication. This approach has converted the bulky, expensive and heavy FINCH into a compact, low-cost and light weight version. Furthermore, the new approach has also improved the axial and

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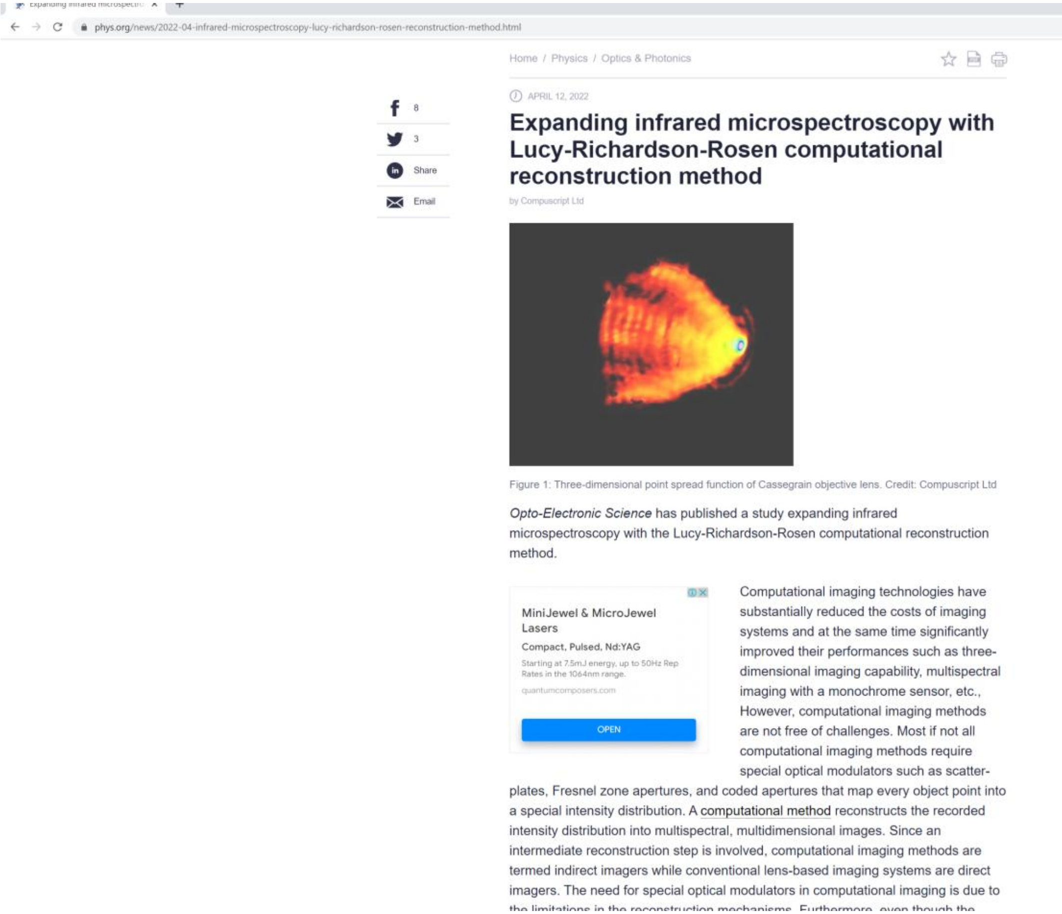
phys.org/news/2022-04-infrared-microspectroscopy-lucy-richardson-rosen-reconstruction-method.html

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APRIL 12, 2022

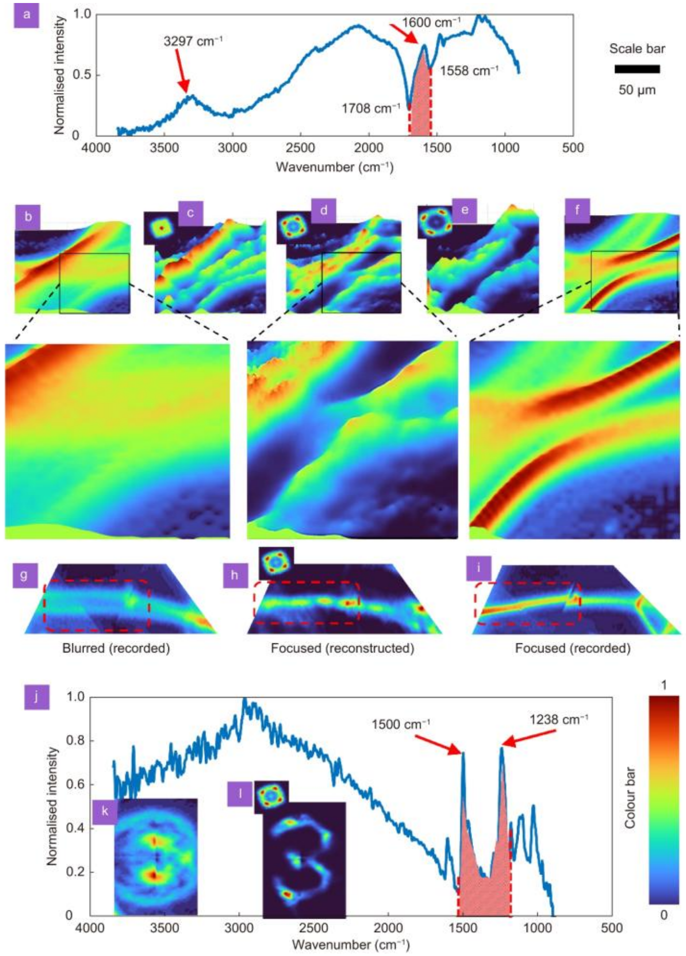
Expanding infrared microspectroscopy with Lucy-Richardson-Rosen computational reconstruction method

by Compuscript Ltd

Figure 1: Three-dimensional point spread function of Cassegrain objective lens. Credit: Compuscript Ltd

Opto-Electronic Science has published a study expanding infrared microspectroscopy with the Lucy-Richardson-Rosen computational reconstruction method.

Computational imaging technologies have substantially reduced the costs of imaging systems and at the same time significantly improved their performances such as three-dimensional imaging capability, multispectral imaging with a monochrome sensor, etc., However, computational imaging methods are not free of challenges. Most if not all computational imaging methods require special optical modulators such as scatter-plates, Fresnel zone apertures, and coded apertures that map every object point into a special intensity distribution. A computational method reconstructs the recorded intensity distribution into multispectral, multidimensional images. Since an intermediate reconstruction step is involved, computational imaging methods are termed indirect imagers while conventional lens-based imaging systems are direct imagers. The need for special optical modulators in computational imaging is due to the limitations in the reconstruction mechanisms. Furthermore, even though the



Vijayakumar Anand et al, Single-shot mid-infrared incoherent holography using Lucy-Richardson-Rosen algorithm, *Opto-Electronic Science* (2022). DOI: 10.29026/oes.2022.210006

Funded projects
(PhD, Masters and Bachelor thesis)

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Questions ???

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