Recent Advances in Coded Aperture Correlation Holography

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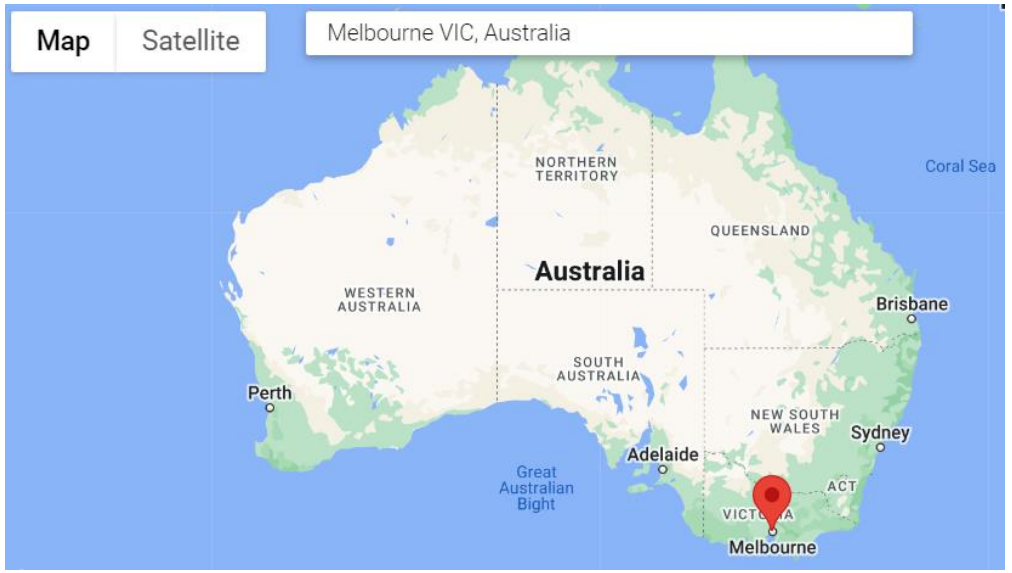
Where are we located?



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1632

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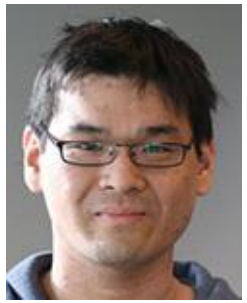
Adj Assoc Professor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Dr. Yuval K
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Outline

- Incoherent digital holography
- Coded aperture imaging technology
- Coded aperture correlation holography
- Interferenceless coded aperture correlation holography
- Reconstruction methods
- Aperture engineering
- New capabilities and applications

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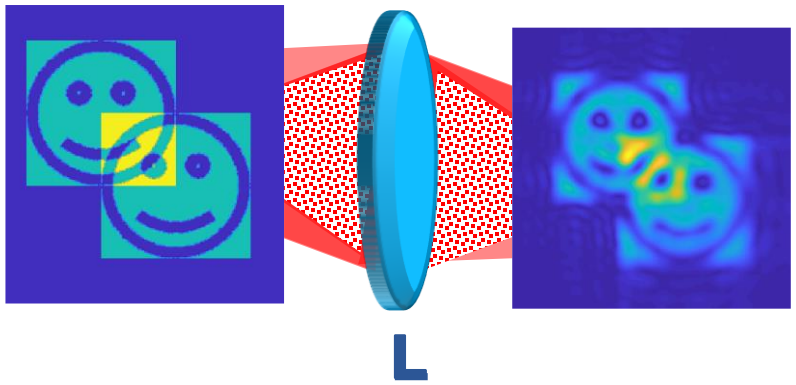
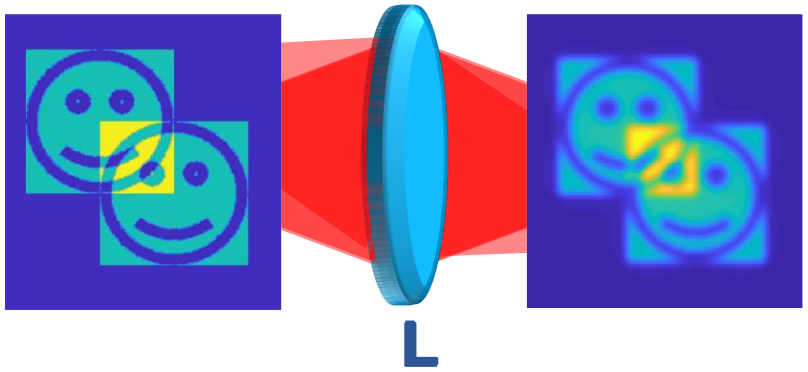
Coherent vs Incoherent imaging

Coherent Imaging	Spatially incoherent Imaging
Needs a coherent light source such as laser	Low cost LEDs or natural light
Suffers from speckle noise	No speckle noise
Edge ringing effects	No edge ringing effects
Narrow bandwidth of MTF	Twice the bandwidth of MTF of coherent light



A coherent imaging system is linear in complex amplitude.



An incoherent imaging system is linear in intensity.

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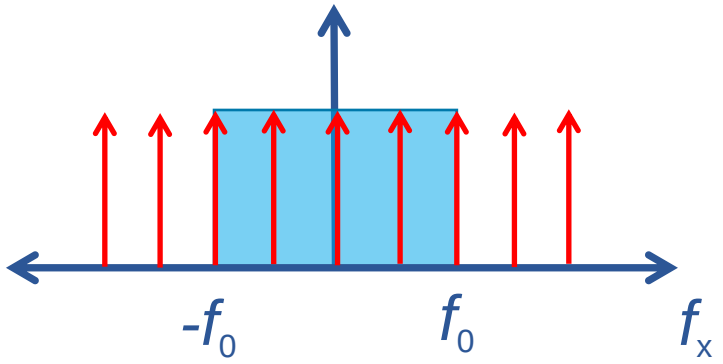
Coherent vs Incoherent imaging

Coherent systems

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

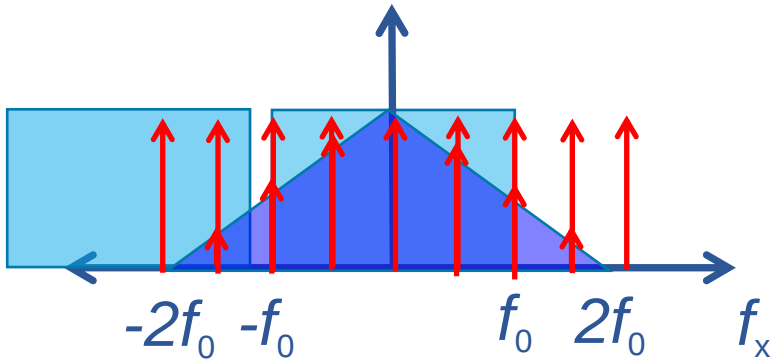
$$\Im\{I_i\} = [HG_o \otimes HG_o]$$

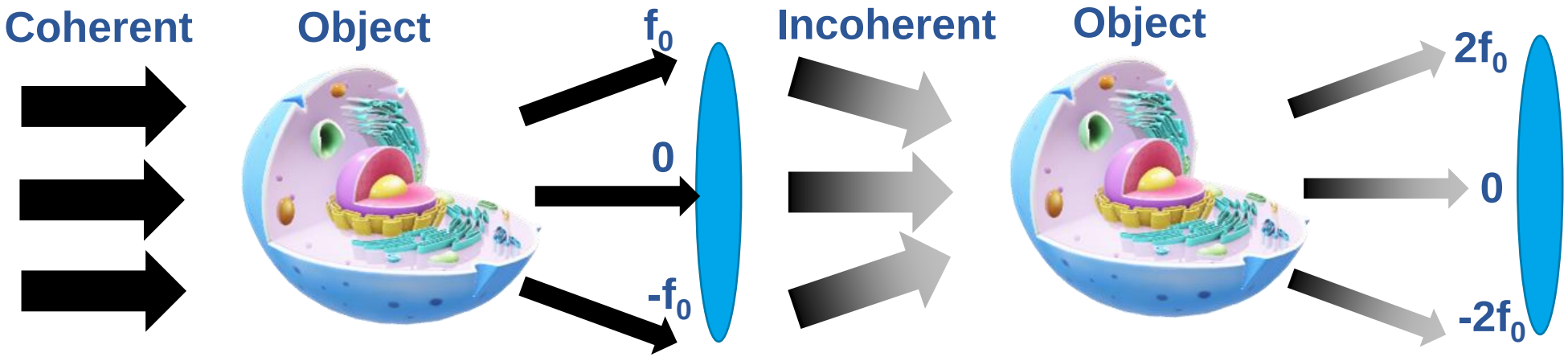


Incoherent systems

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

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





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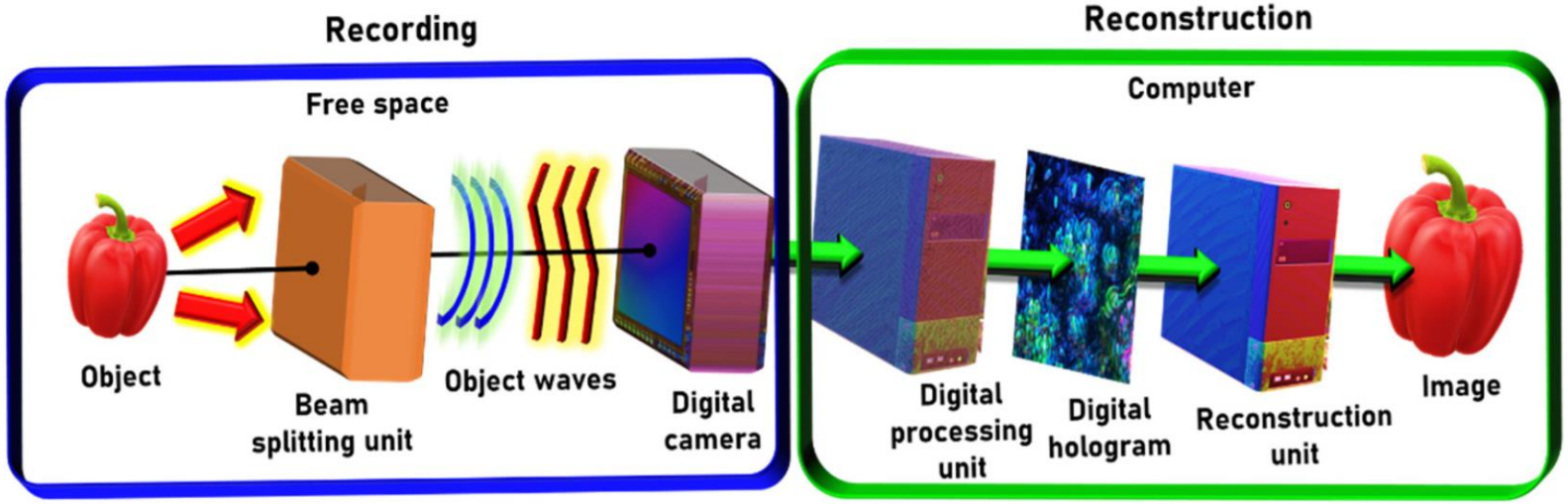
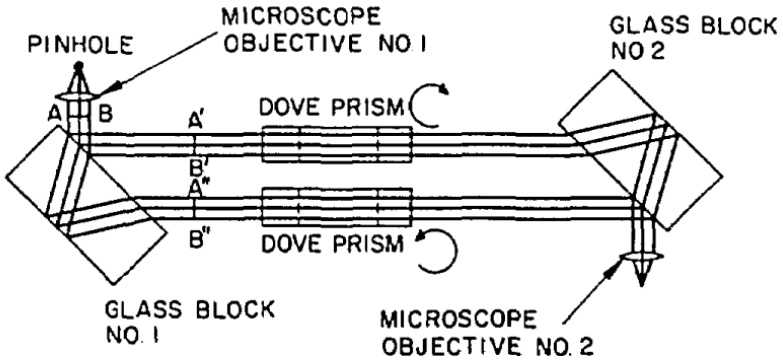
Principle of Incoherent holography

Incoherent digital holography



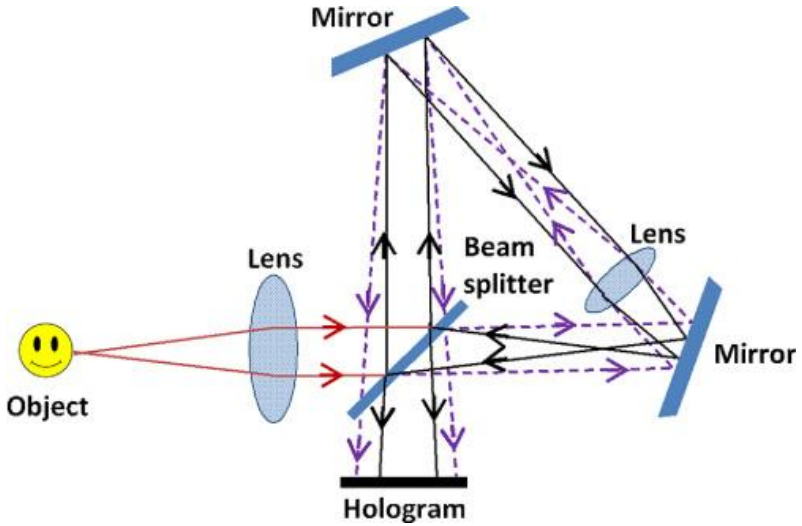
Rosen, et. al. J. Imaging, 7, 197 (2021)

Rotational shearing interferometer



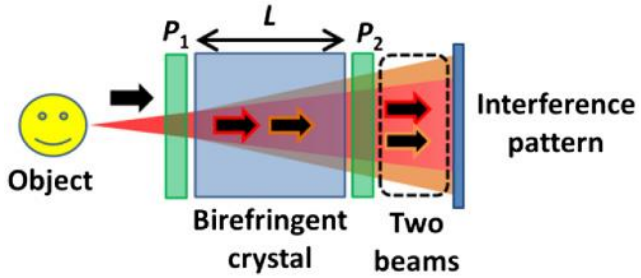
M. V. R. K. Murty and E. C. Hagerott, Appl. Opt. 5, 615 (1966)

Triangle interferometer



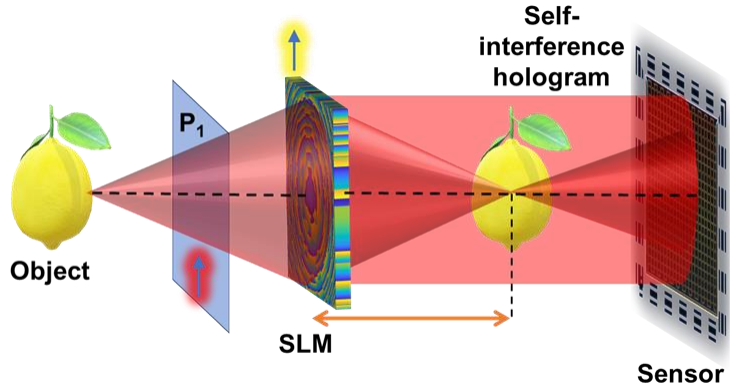
Rosen, et. al. Adv. Opt. Photon. 11, 1 (2019)

Conoscopic holography



*G. Y. Sirat, J. Opt. Soc. Am. A **9**, 70 (1992).*

Fresnel incoherent correlation holography



*J. Rosen and G. Brooker, Opt. Lett. **32**, 912 (2007).*
J. Rosen and G. Brooker, Nat. Photonics 2, 190 (2008).

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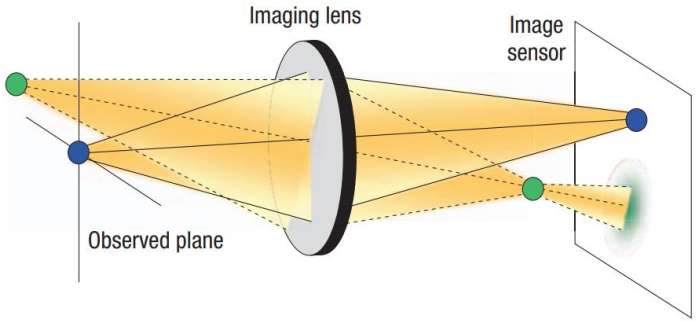
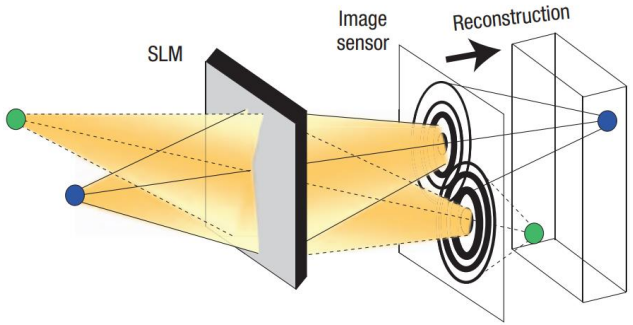
Fresnel incoherent correlation holography

Incoherent digital holography

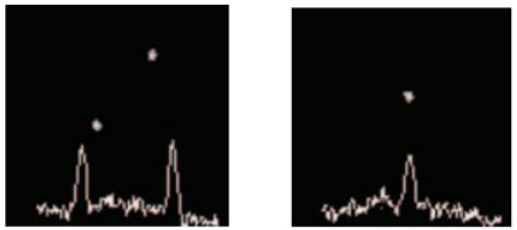


Conventional imaging



FINCH

Reconstruction results



38 µm

84 µm

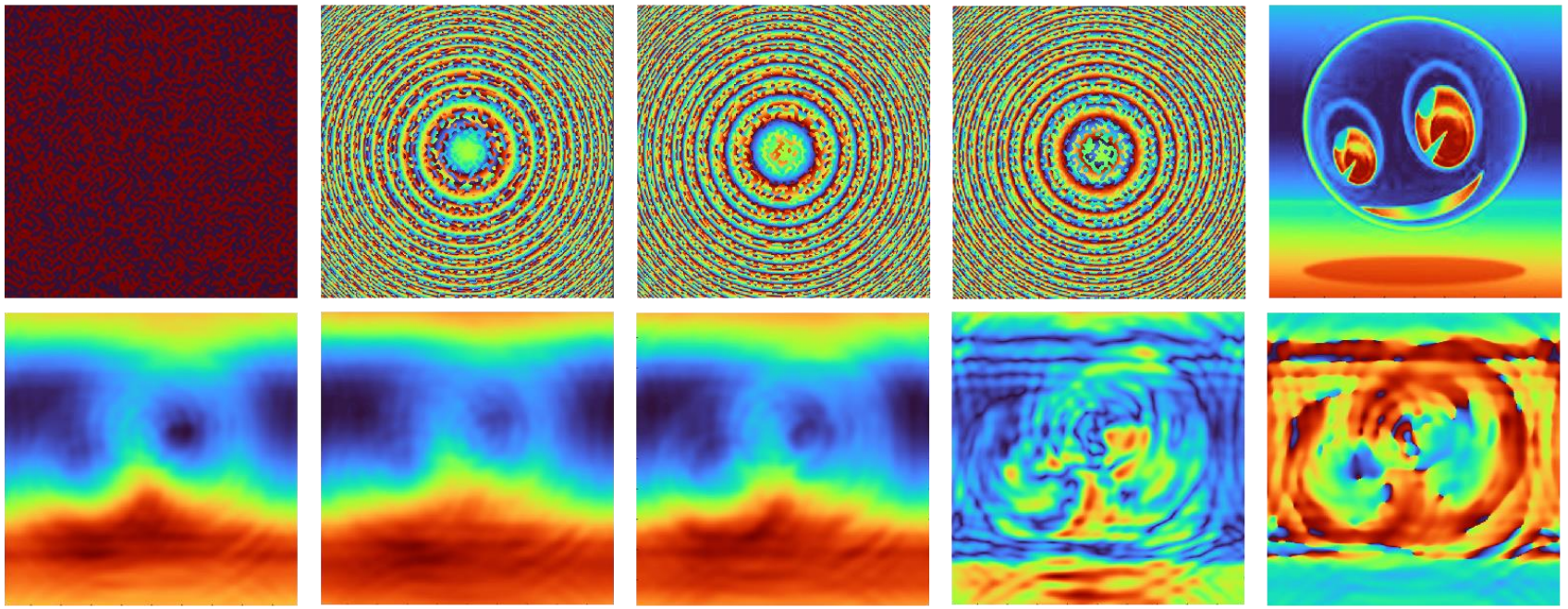
Binary random phase mask

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

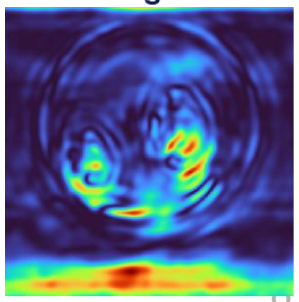
Object hologram 2 Theta = 120 degrees

Object hologram 3 Theta = 240 degrees

Amplitude of complex hologram

Phase of complex hologram

Rosen J, Brooker G. Nature Photonics. 2008;2(3):190-5.



Reconstruction result

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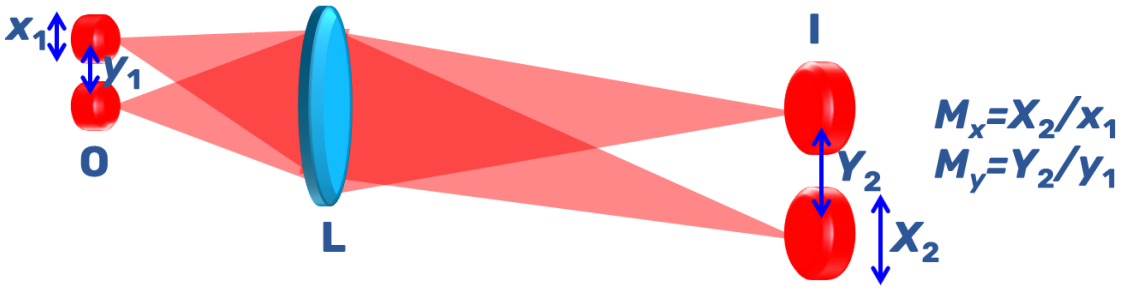
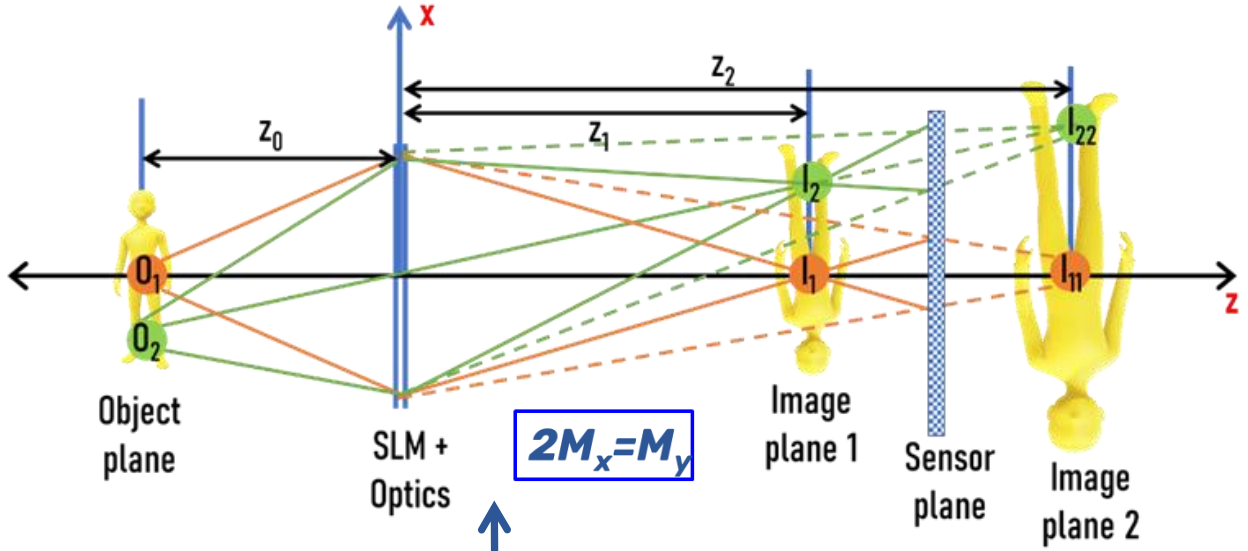
Lagrange invariant condition and super resolution

Incoherent digital holography

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

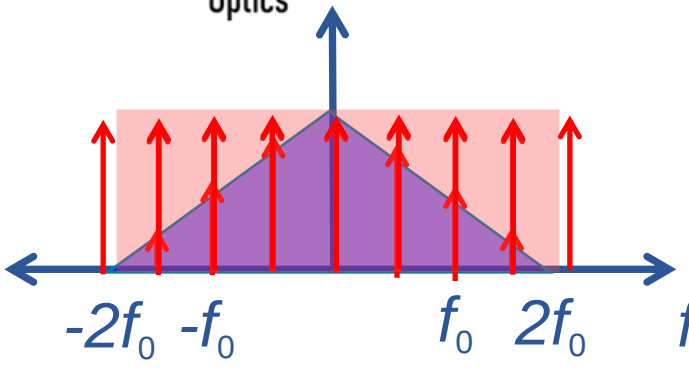


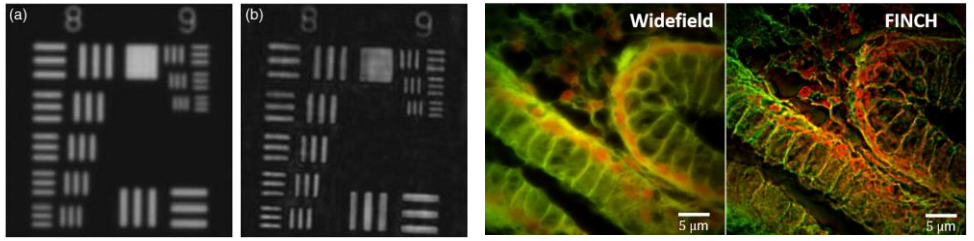


$M_x=M_y$ **Lagrange Invariant condition satisfied.**

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

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





G. Brooker, N. Siegel, V. Wang, and J. Rosen, Opt. Express 19, 5047 (2011).

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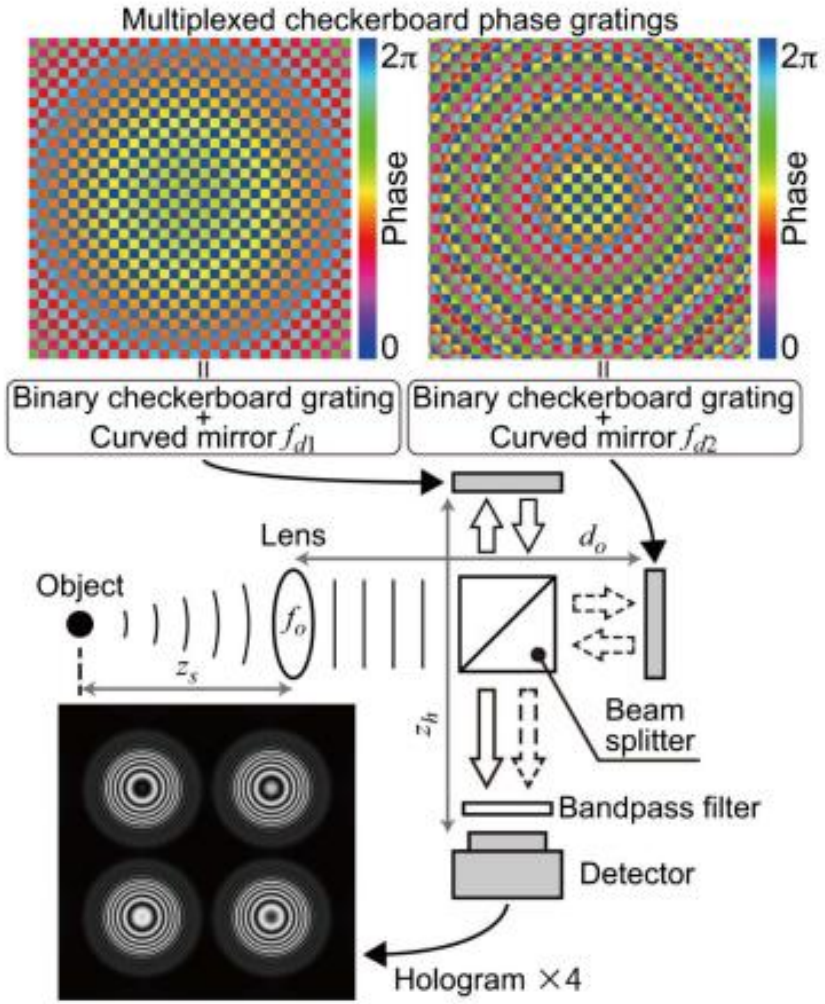
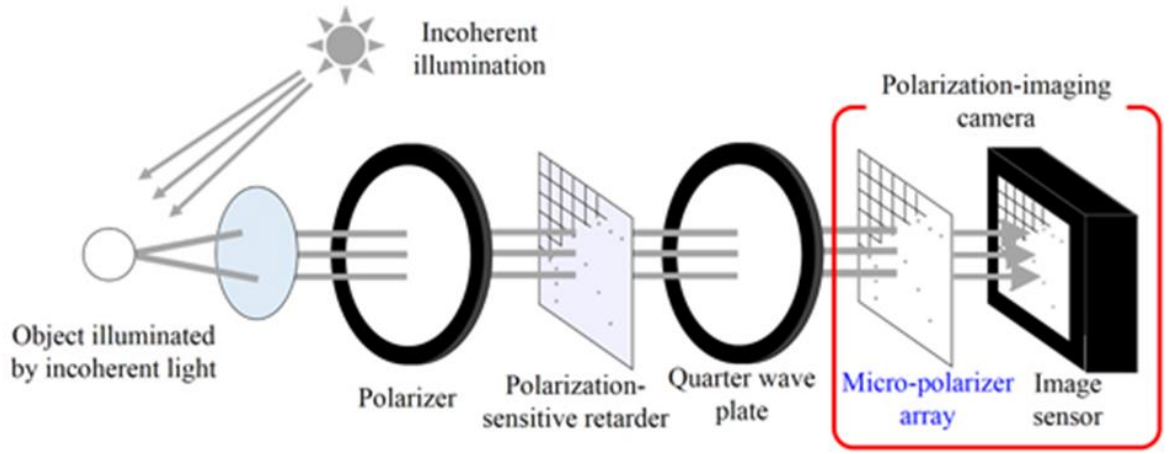
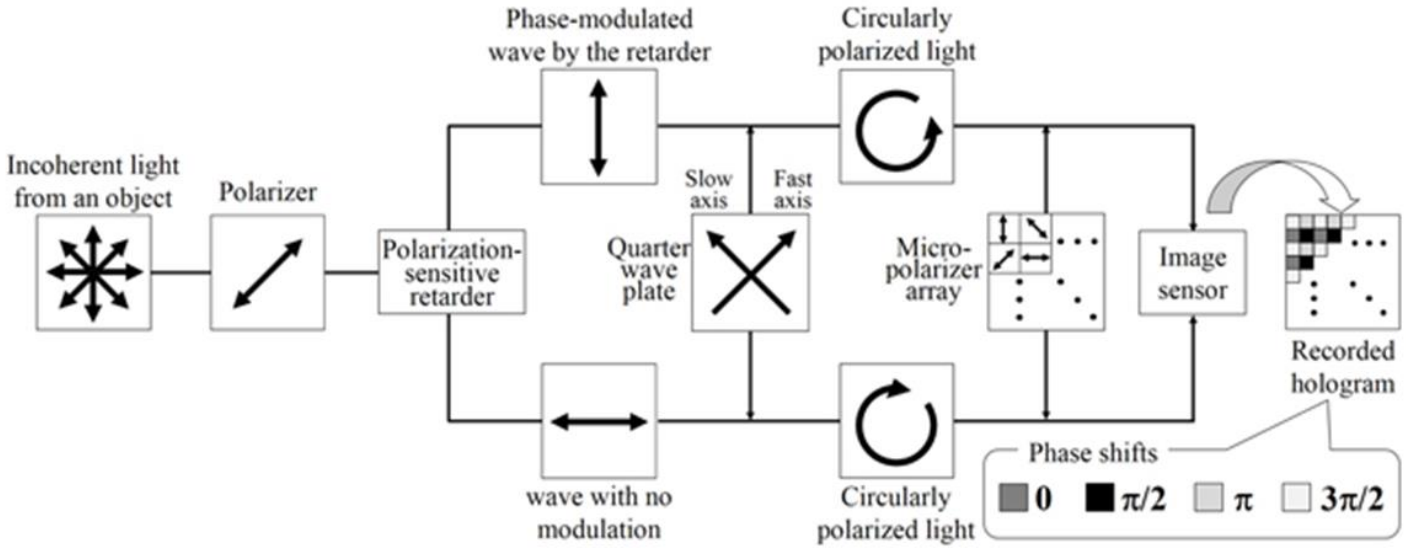
Evolution of FINCH – Time resolution

Incoherent digital holography



Nobukawa, et. al. Opt. Lett. 43, 1698-1701 (2018)





Tahara et. al. Opt. Lett. 2011;36:3254.

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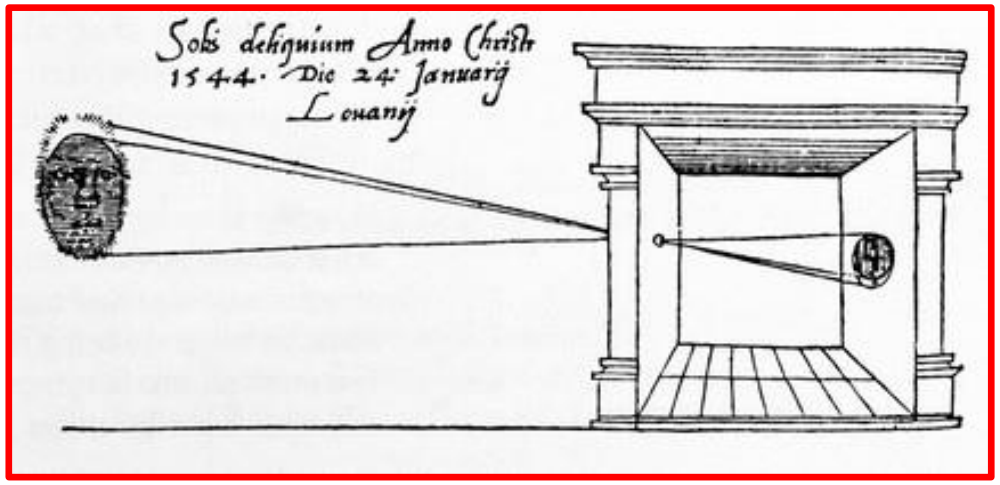
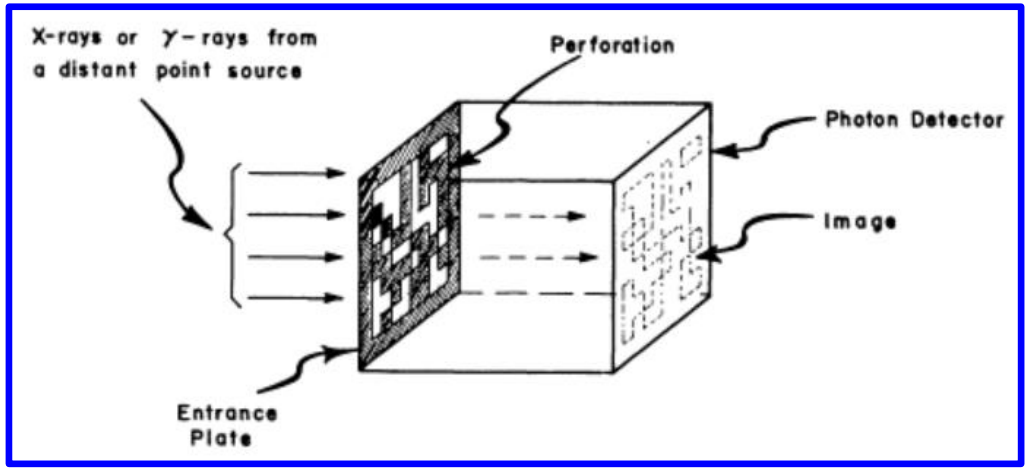
History of coded aperture imaging

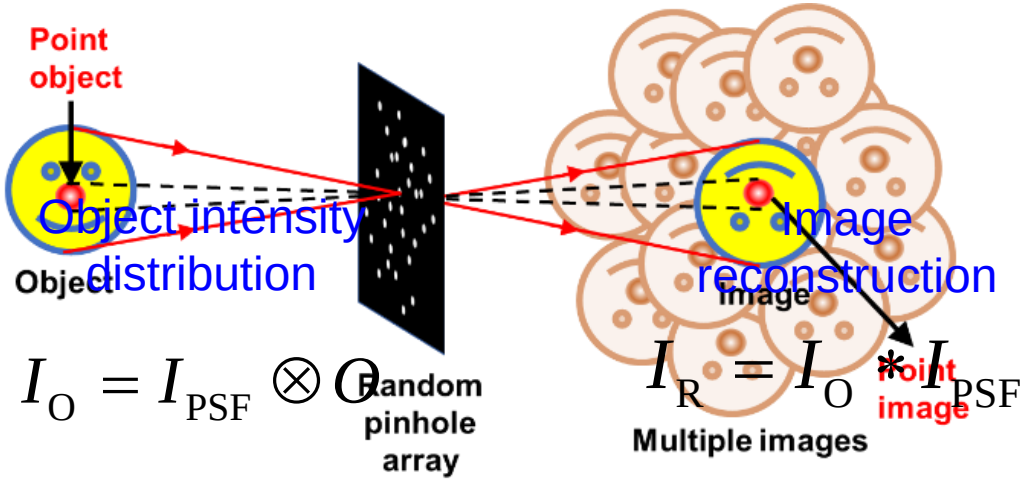
Coded aperture imaging technology

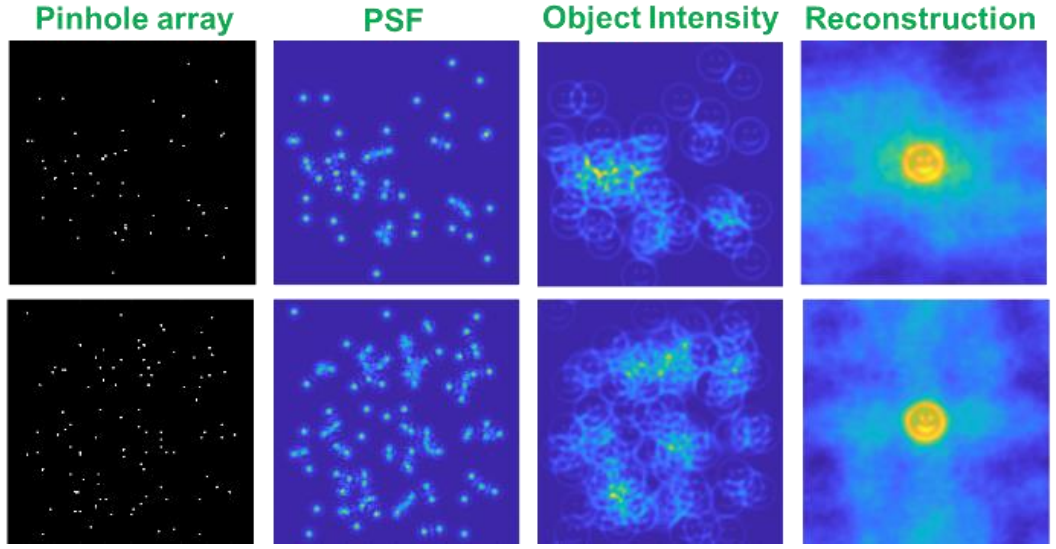


Gemma Frisius' 1545 book De Radio Astronomica et Geometrica



Dicke, Astrophysical Journal, vol. 153, p.L101 (1968)





A. Vijayakumar and J. Rosen, Photonics spectra Magazine March 2020

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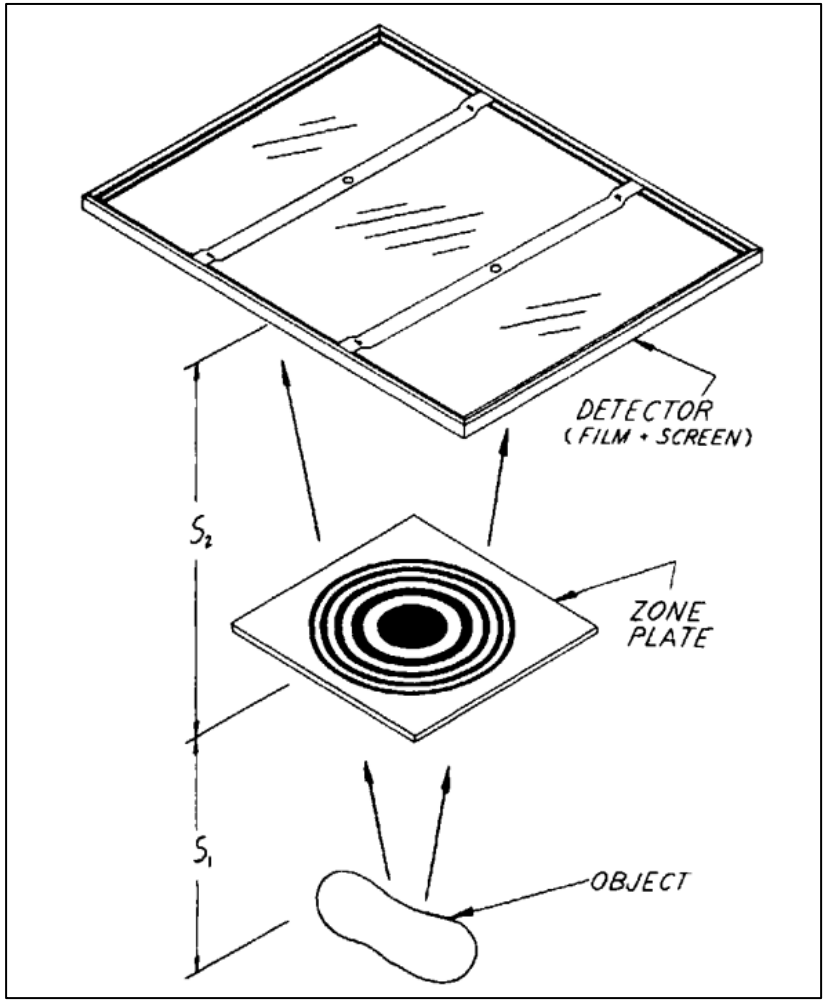
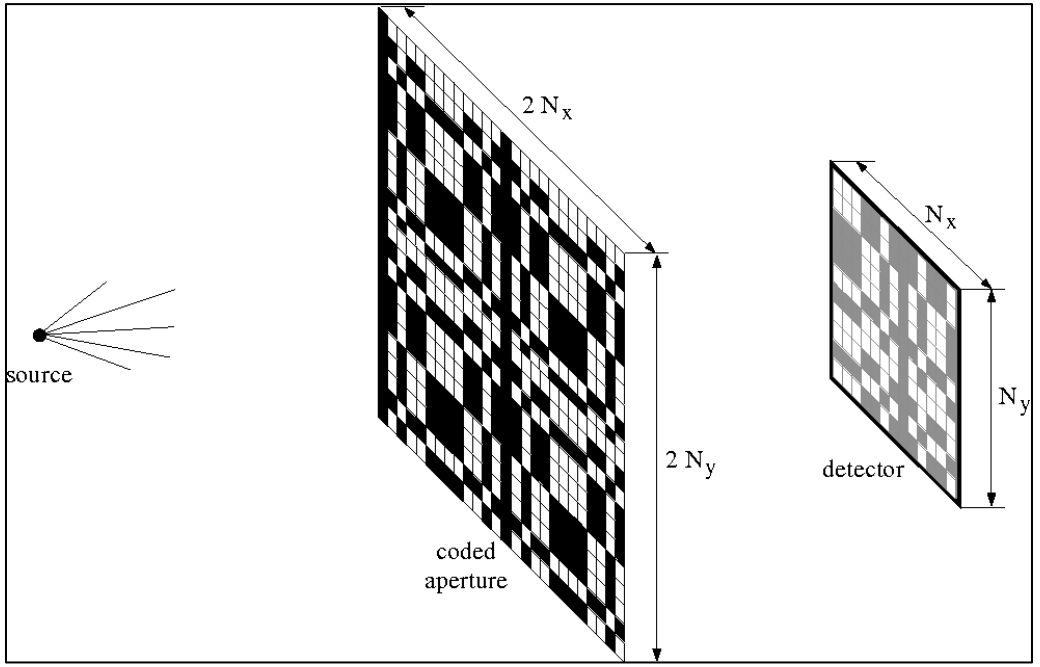
Coded aperture Imaging methods

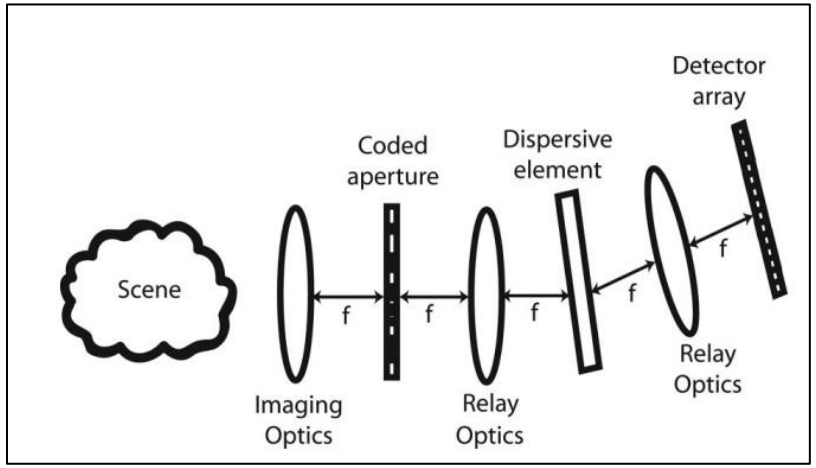
Coded aperture imaging technology



Tipton, et. al. Radiology, 112(1), 155–158.



Busboom, et. al. Experimental Astronomy,8, 97–123 (1998)



Wagadarikar, et. al.Appl. Opt. 47, B44-B51 (2008)

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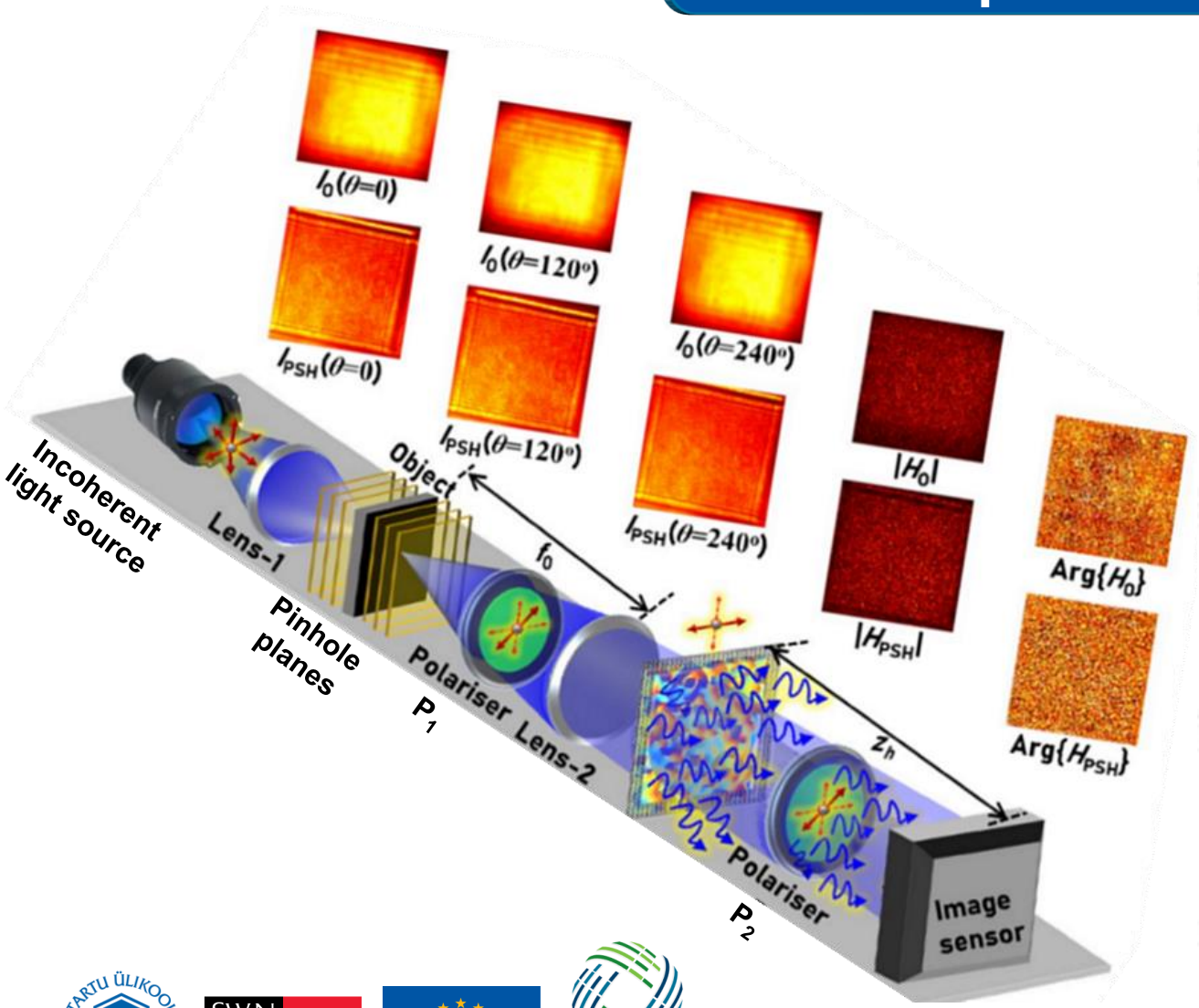
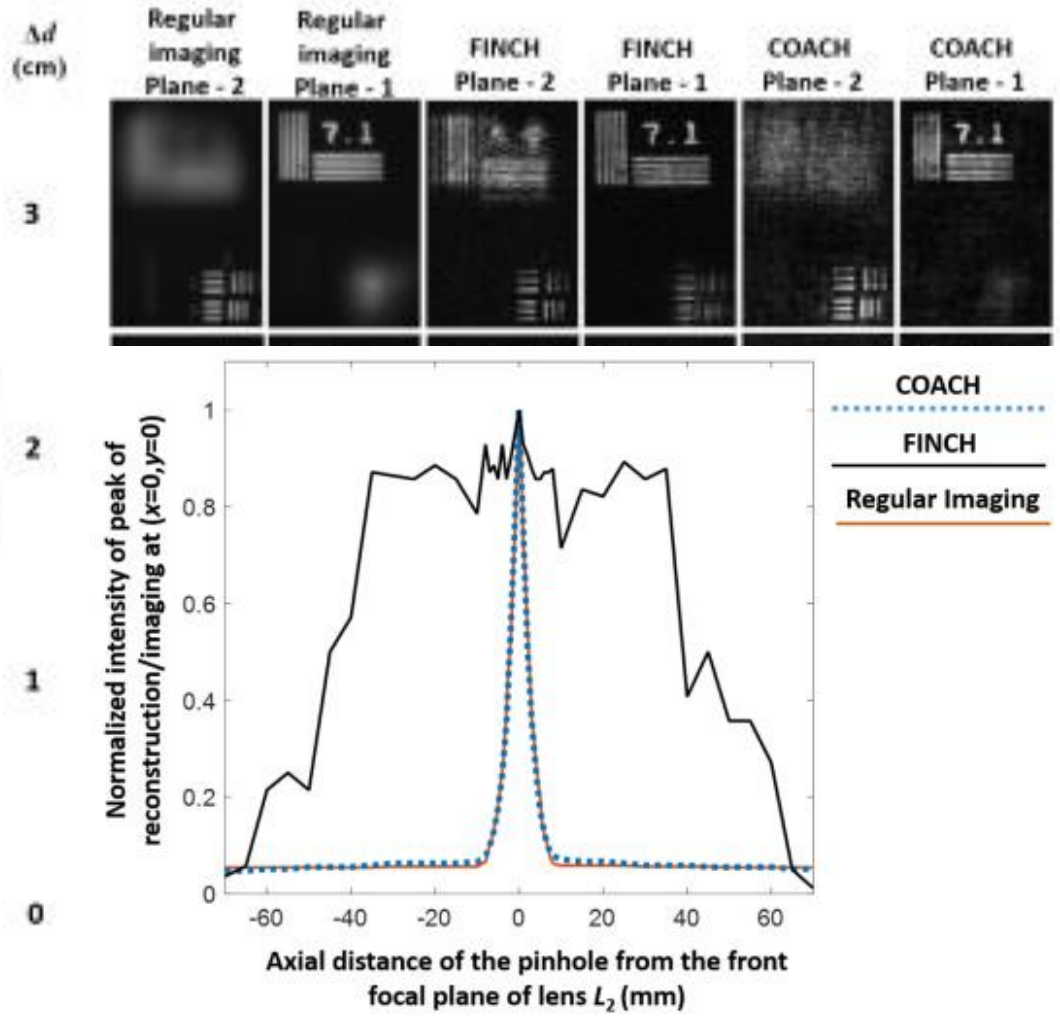
Incoherent digital holography meets coded aperture Imaging technology

Coded aperture correlation holography (COACH)





Vijayakumar, et. al. Opt. Express 24, 12430-12441 (2016)

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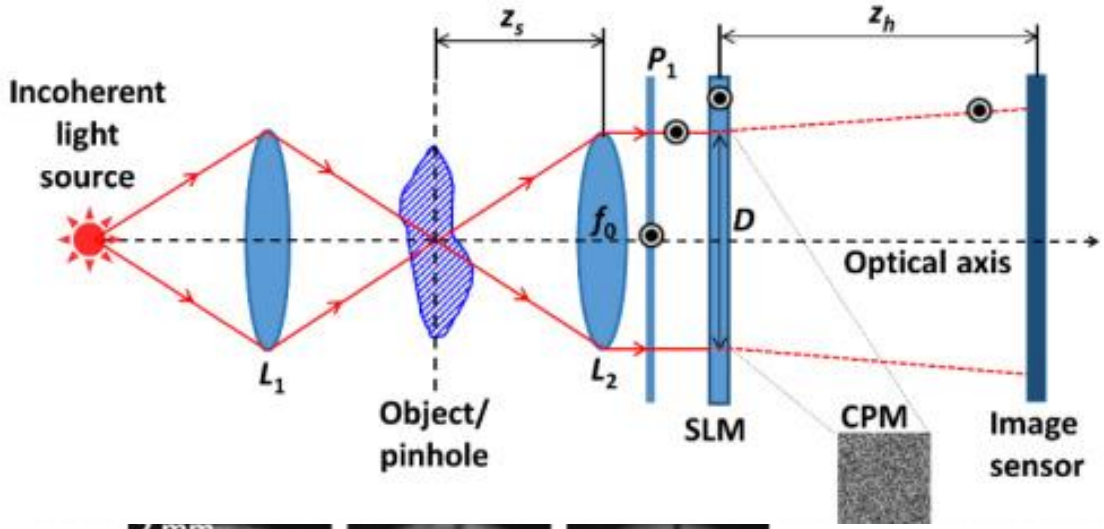
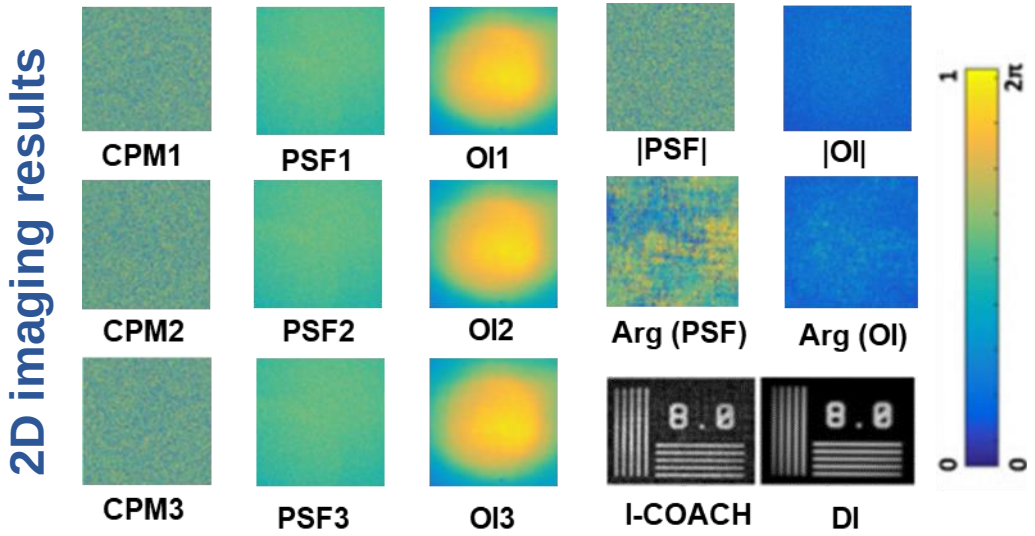
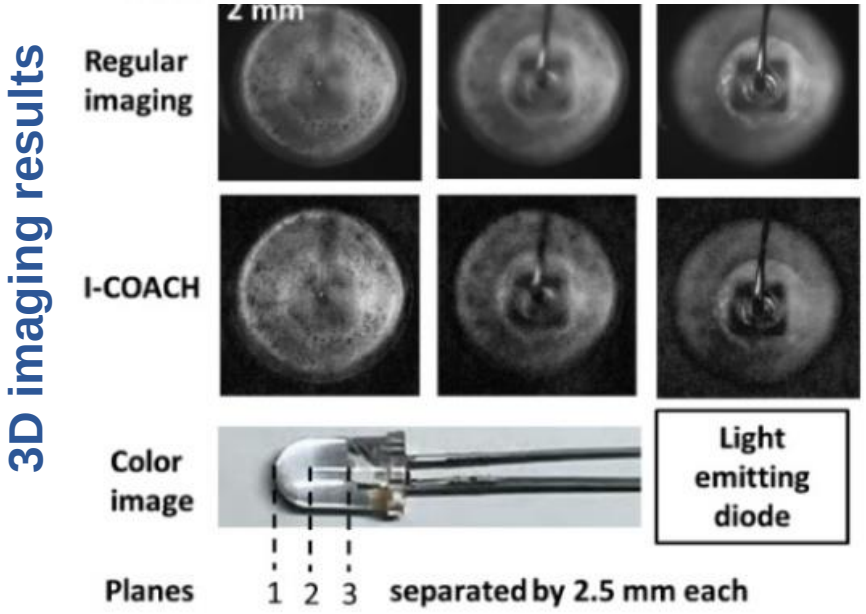
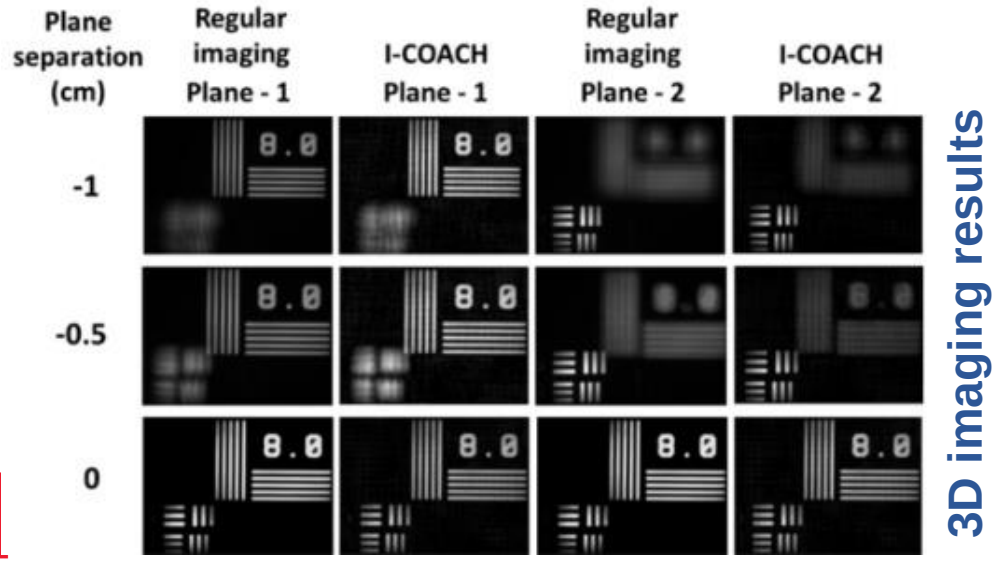
Incoherent holography without two-beam interference

Interferenceless COACH (I-COACH)









Vijayakumar, et. al. Opt. Express 25, 13883-13896 (2017)

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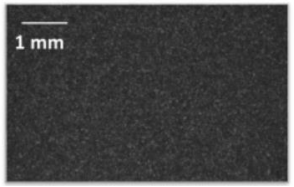
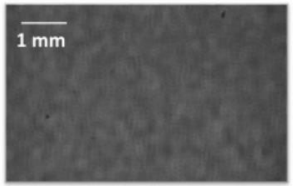
Non-Linear Reconstruction

Reconstruction methods

- Lucy Richardson algorithm
- Phase-only filter
- Matched filter
- Regularized filter
- Deep learning
- Wiener filter



PSF



OI

$$I_{\mathrm{IMG}} = I_{\mathrm{OBJ}} * I_{\mathrm{PSF}}$$

$$I_{IMG} = \mathcal{F}^{-1}\left\{\left|\tilde{I}_{OBJ}\right|^{o}\exp\left[i\cdot\arg\left(\tilde{I}_{OBJ}\right)\right]\left|\tilde{I}_{PSH}\right|^{r}\exp\left[-i\cdot\arg\left(\tilde{I}_{PSH}\right)\right]\right.$$

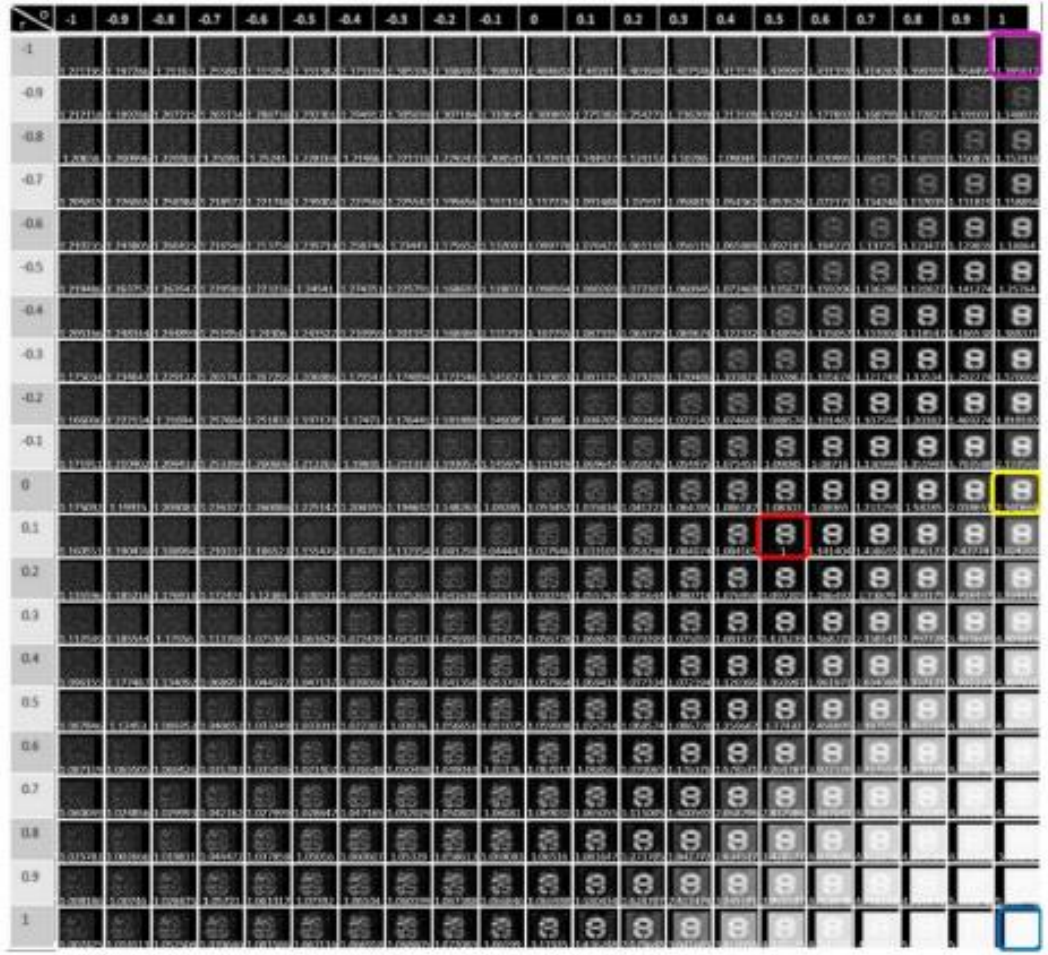


Figure of merit - Entropy

- Matched filter
- Inverse filter
- Phase-only filter
- NLR

Rai, et. al. Opt. Express 26, 18143-18154 (2018)

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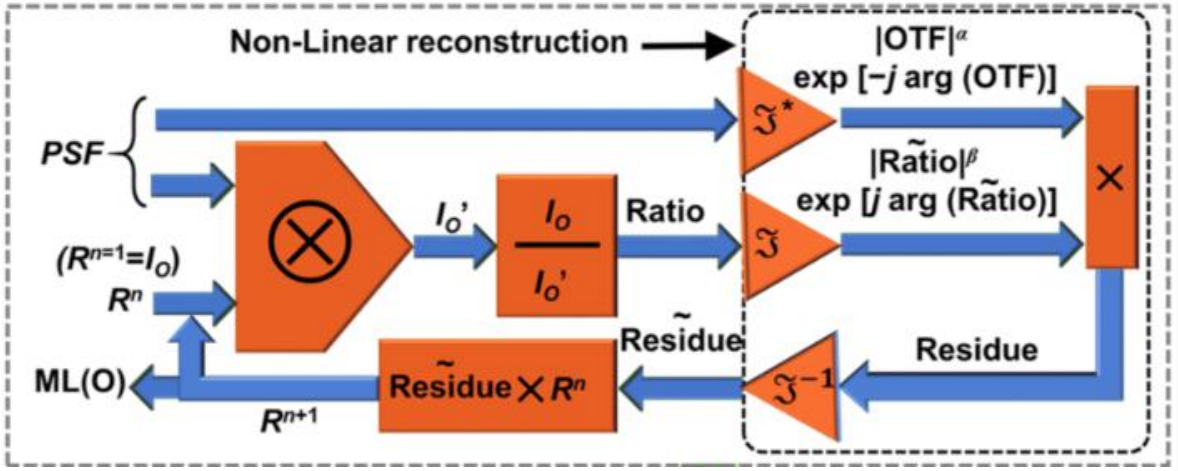
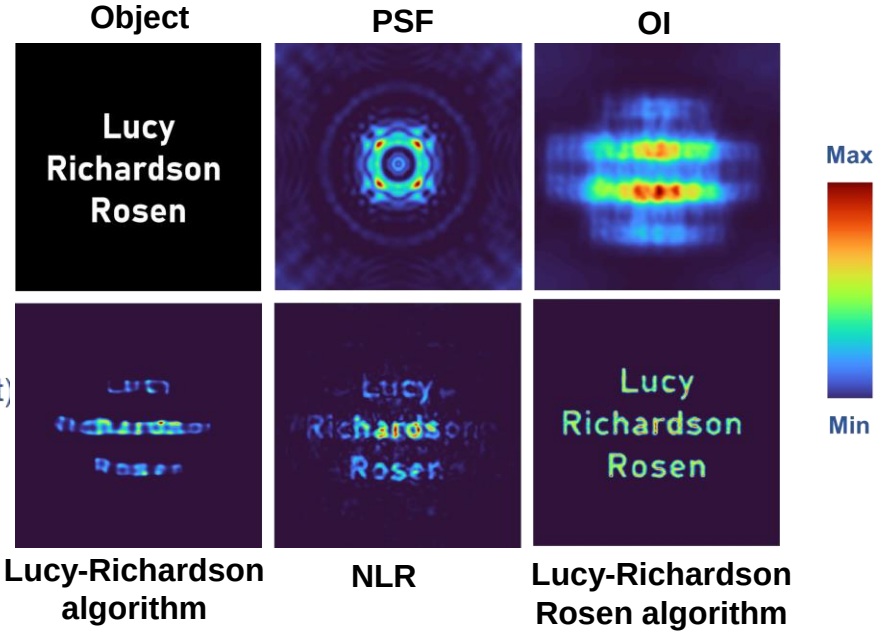
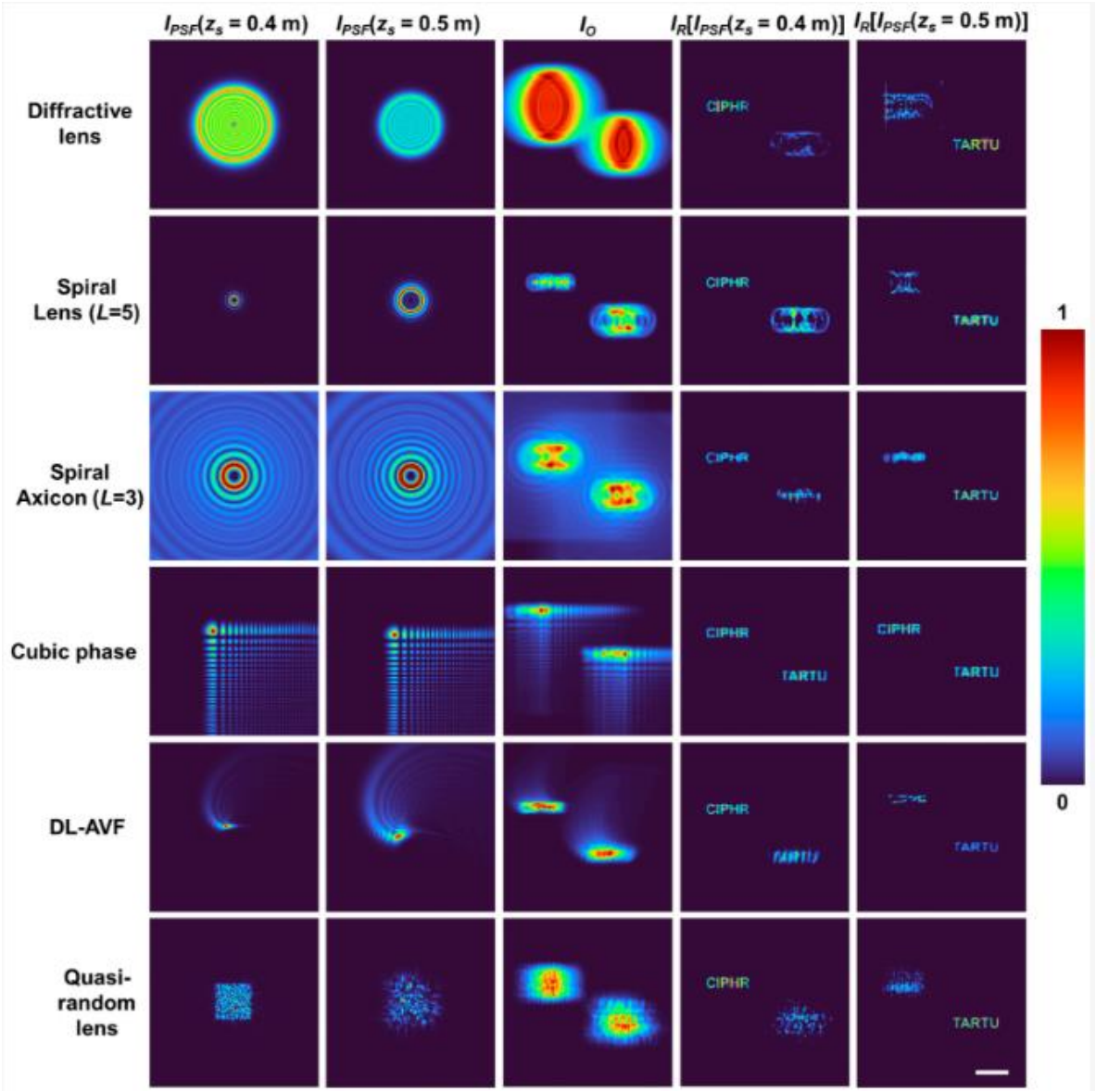
Lucy – Richardson – Rosen algorithm

Reconstruction methods



Ms. Agnes PIX
(Doctoral student)





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Ignatius Xavier, A.P.; Photonics 2023, 10, 987.

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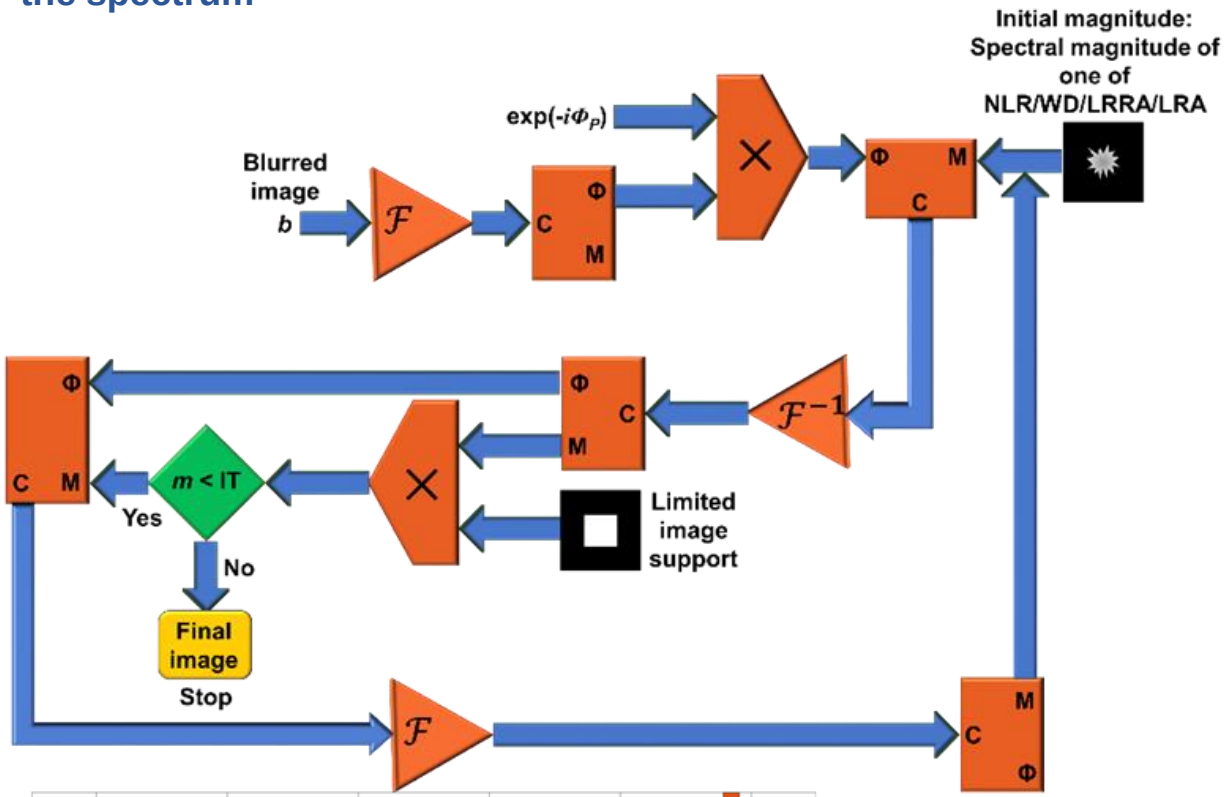
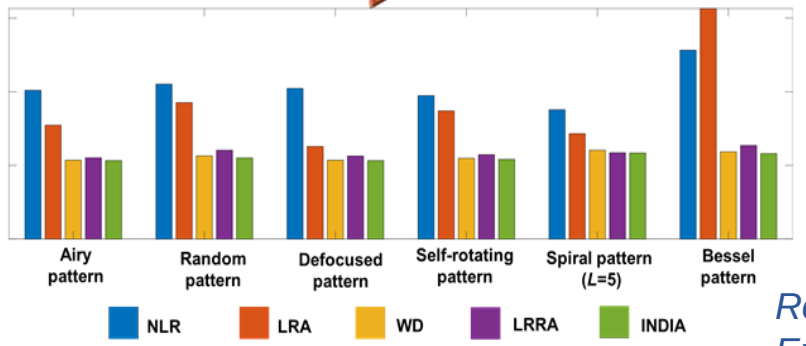
Incoherent Nonlinear Deconvolution using an Iterative Algorithm (INDIA)

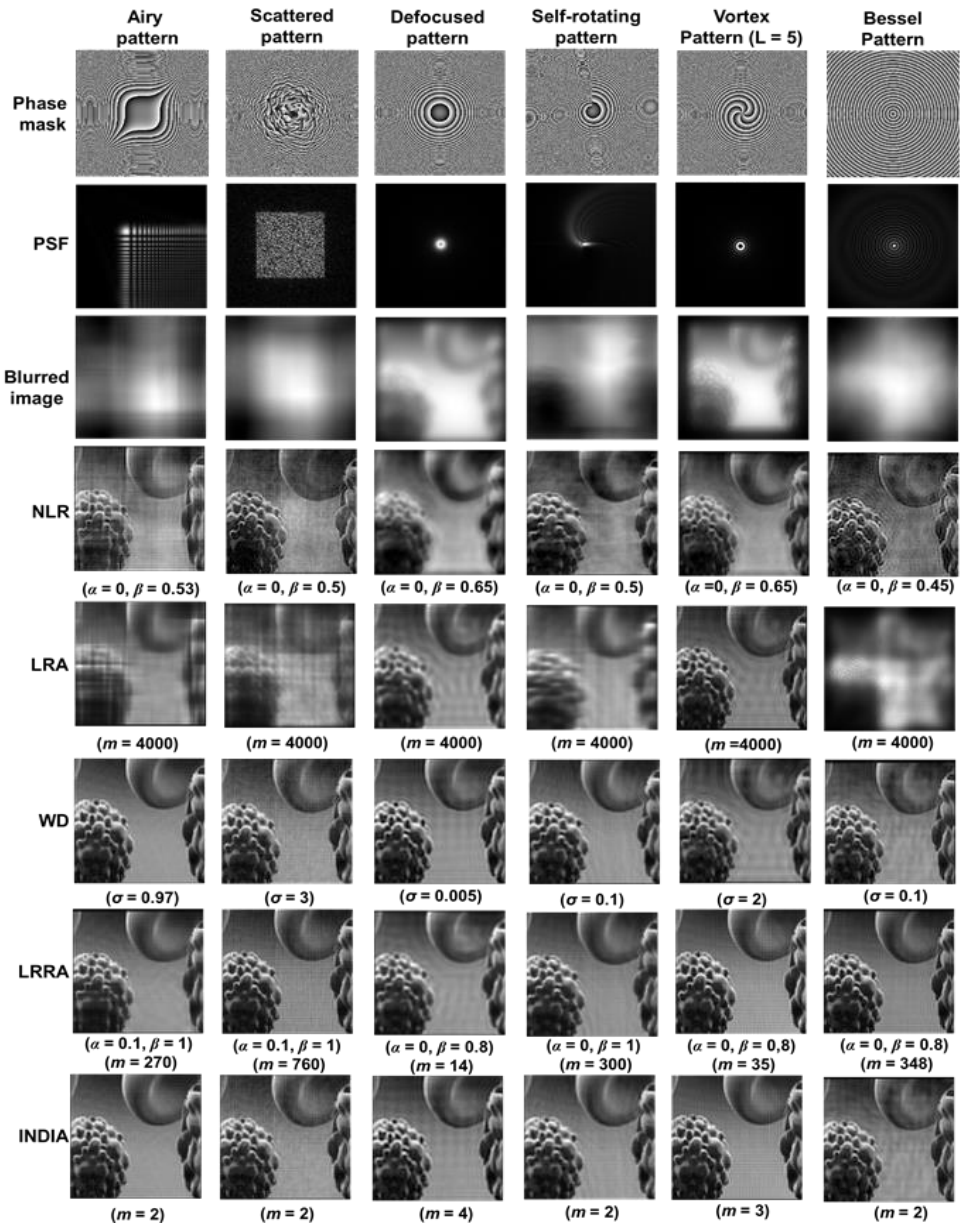
Reconstruction methods

Majority of an object's information is present in the phase of the spectrum





RMSE



Rosen. J and Anand. Opt. Express 32, 1034-1046 (2024)

Outline

- Incoherent digital holography
- Coded aperture Imaging technology
- Coded aperture correlation holography
- Interferenceless coded aperture correlation holography
- Reconstruction methods
- Aperture engineering
- New capabilities and applications

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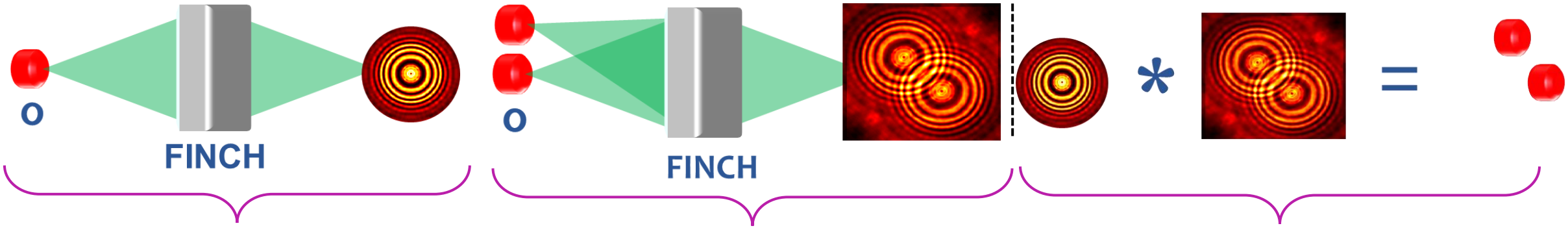
FINCH as a Coded Aperture Imaging System

Aperture Engineering + Advanced capabilities



PSF | **OI** | **Cross-correlation**

Optical microscope images

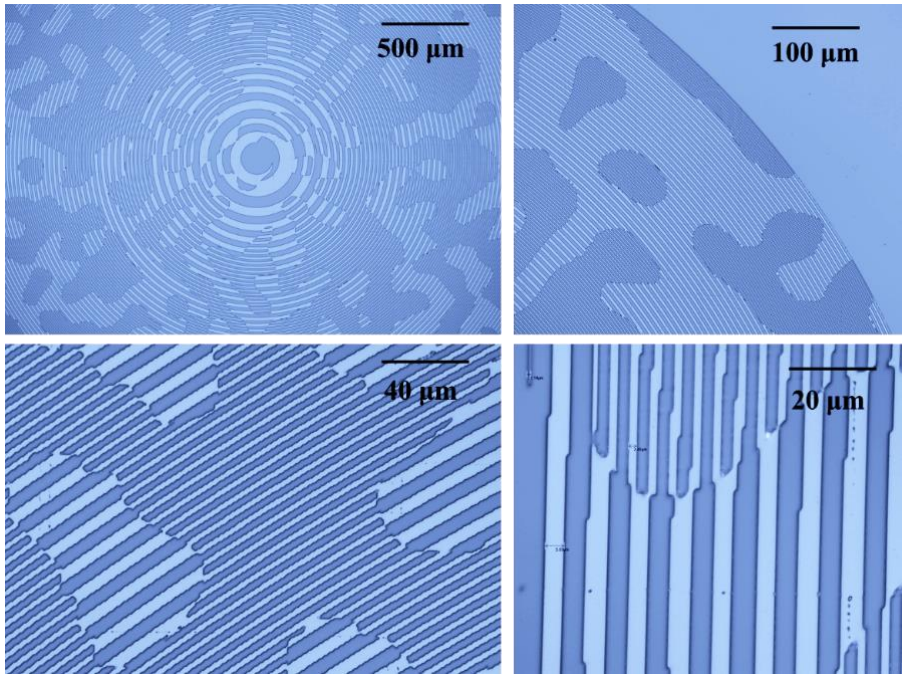
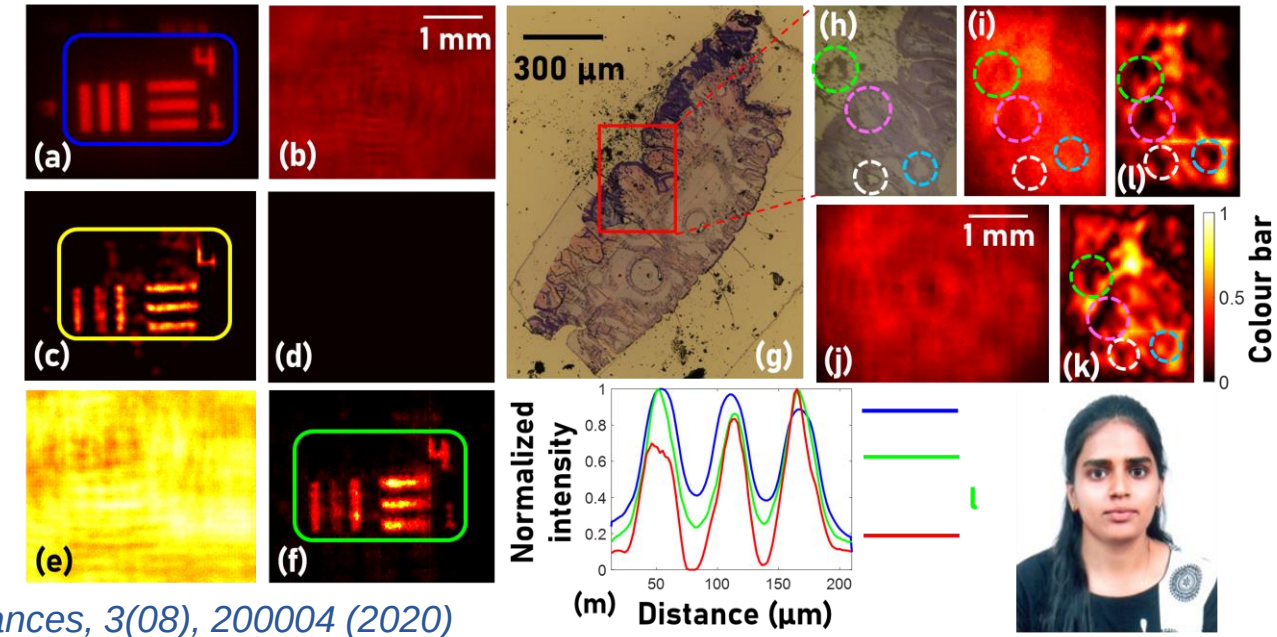


Image reconstruction



Anand, et. al. Opto-Electronic Advances, 3(08), 200004 (2020)

Arockiaraj, et. al. J. Opt, 26, 3 (2024)

Ms. Francis GA
(Doctoral student)

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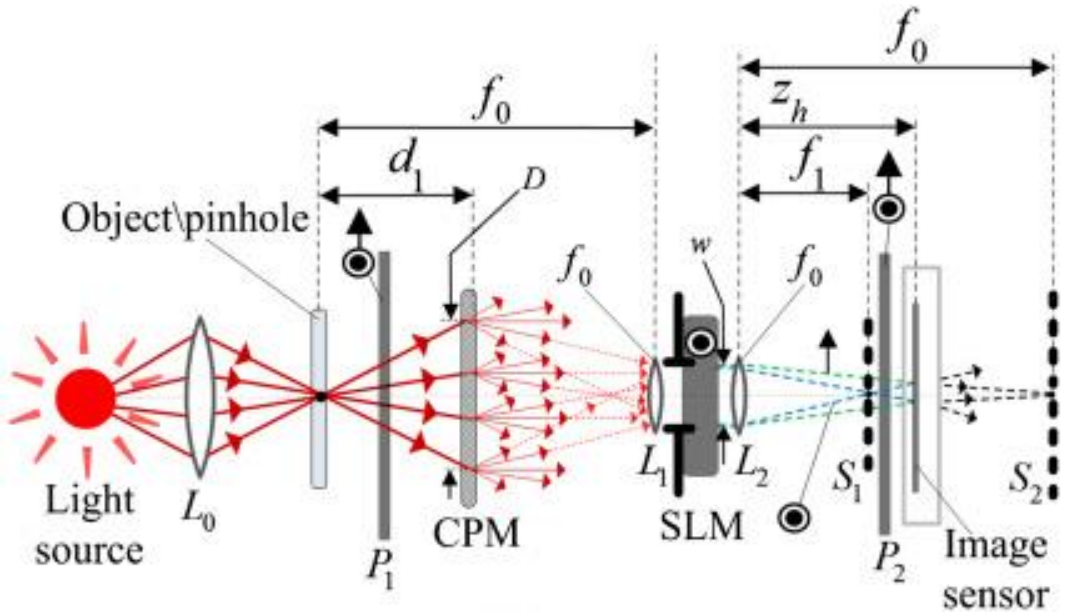
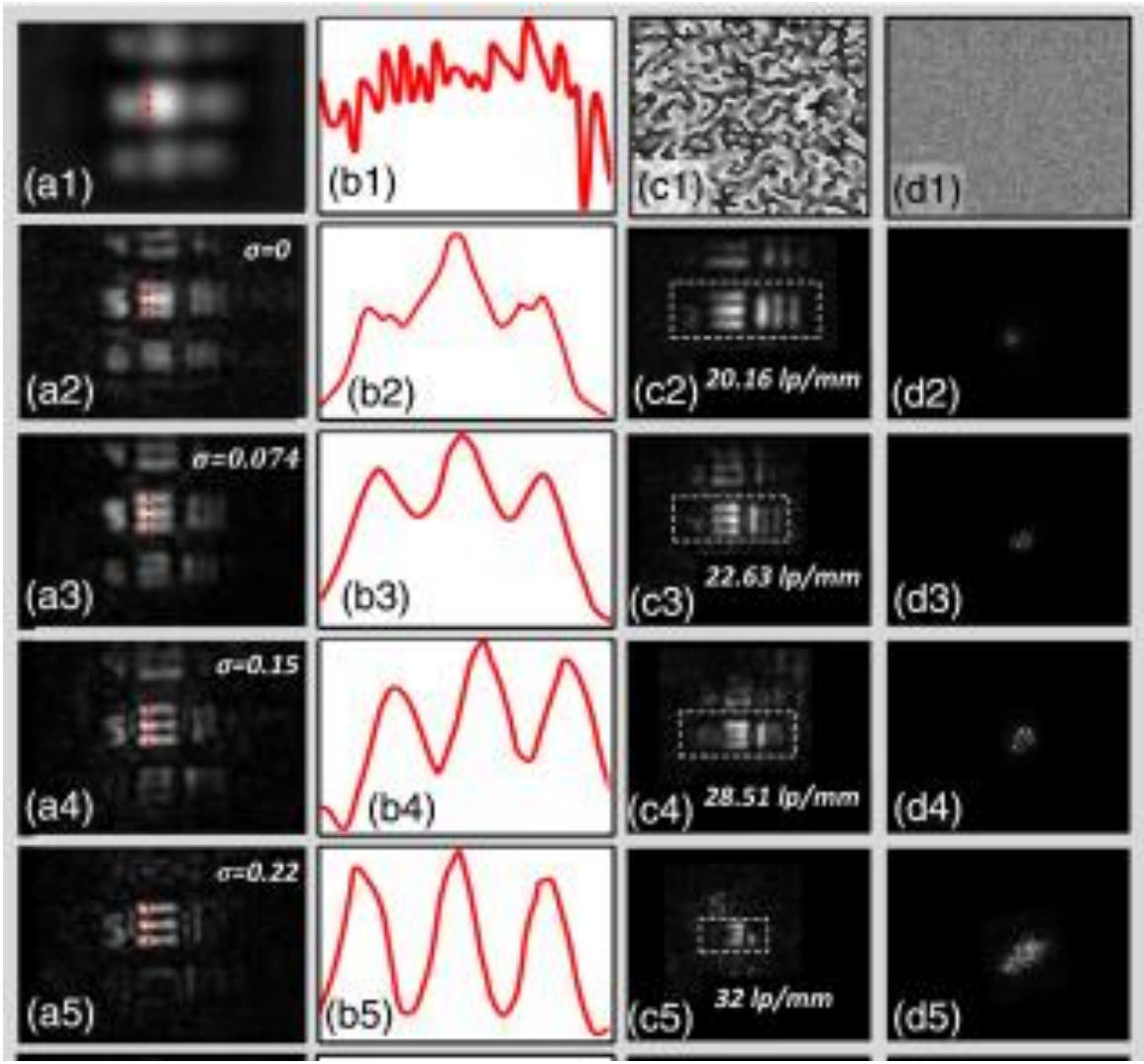
FINCH-COACH Super Resolution System

Aperture Engineering + Advanced capabilities





Resolution enhancement of an order (10 times) was demonstrated

Y. Kashter, A. Vijayakumar, and J. Rosen, Optica 4, 932-939 (2017).

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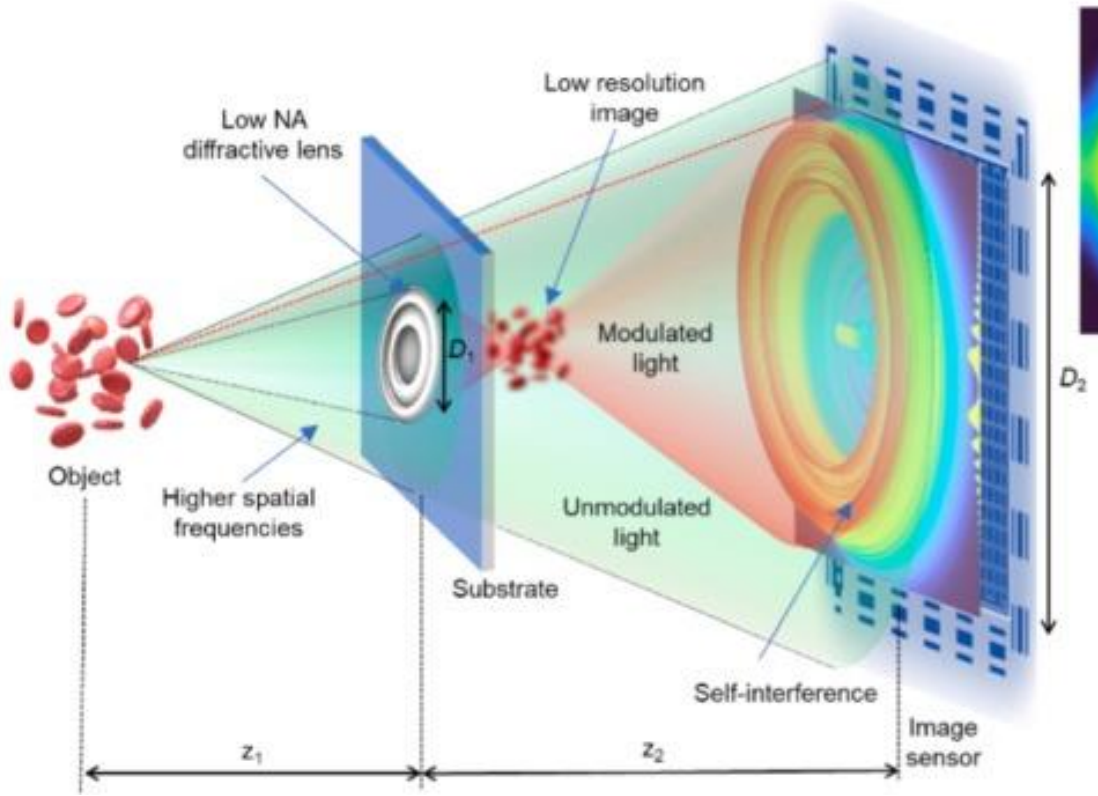
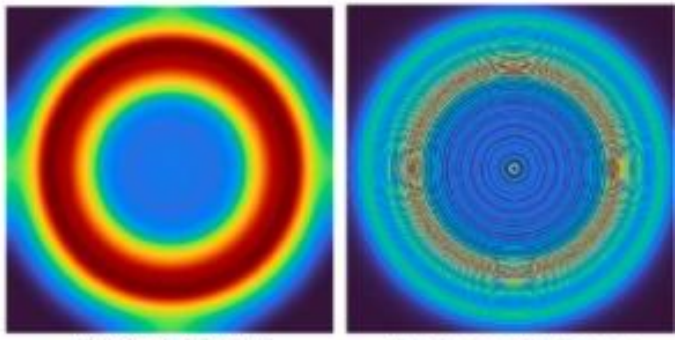
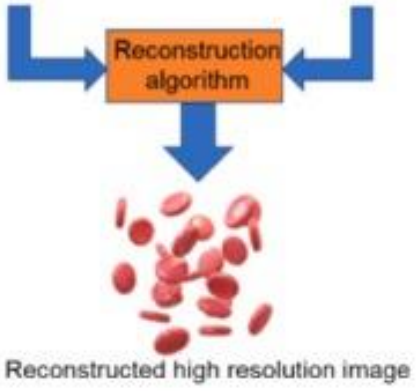
Self Wavefront Transverse splitting Holography

Aperture Engineering + Advanced capabilities

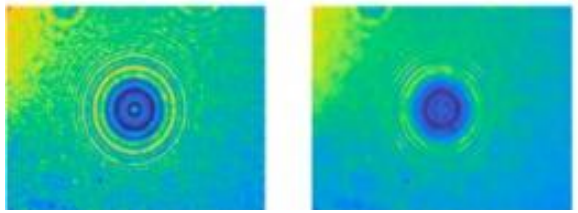






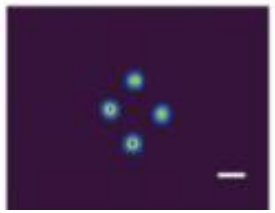
Ms. Narmada J
(Doctoral student)

Resolution enhancement of an order (10 times) was demonstrated

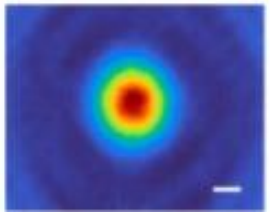


PSF

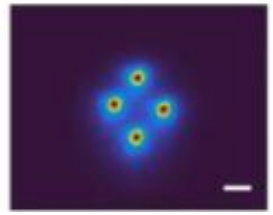
OI



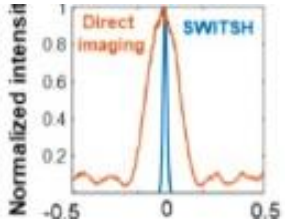
Direct imaging
Full aperture



Direct imaging
Limited aperture



SWITSH
Limited aperture



A. Bleahu, et. al. Results in Physics 52, 106839 (2023)

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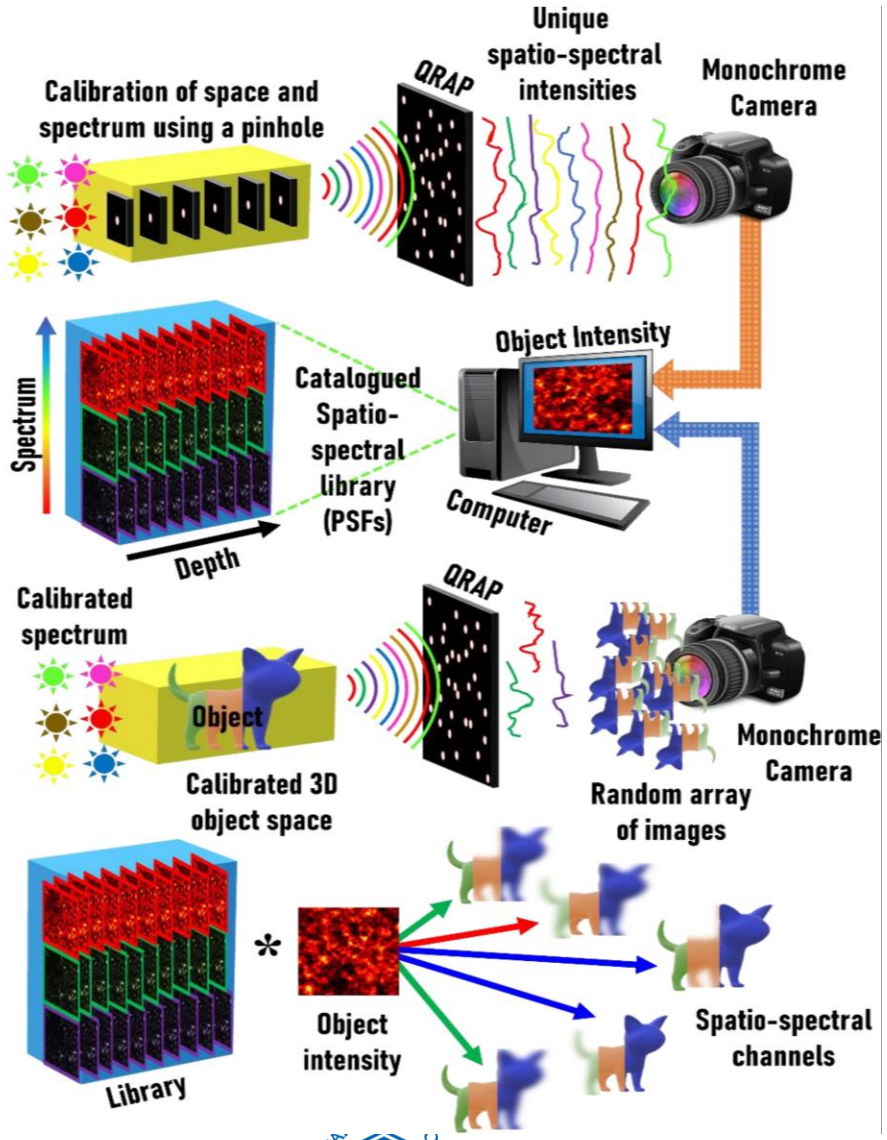
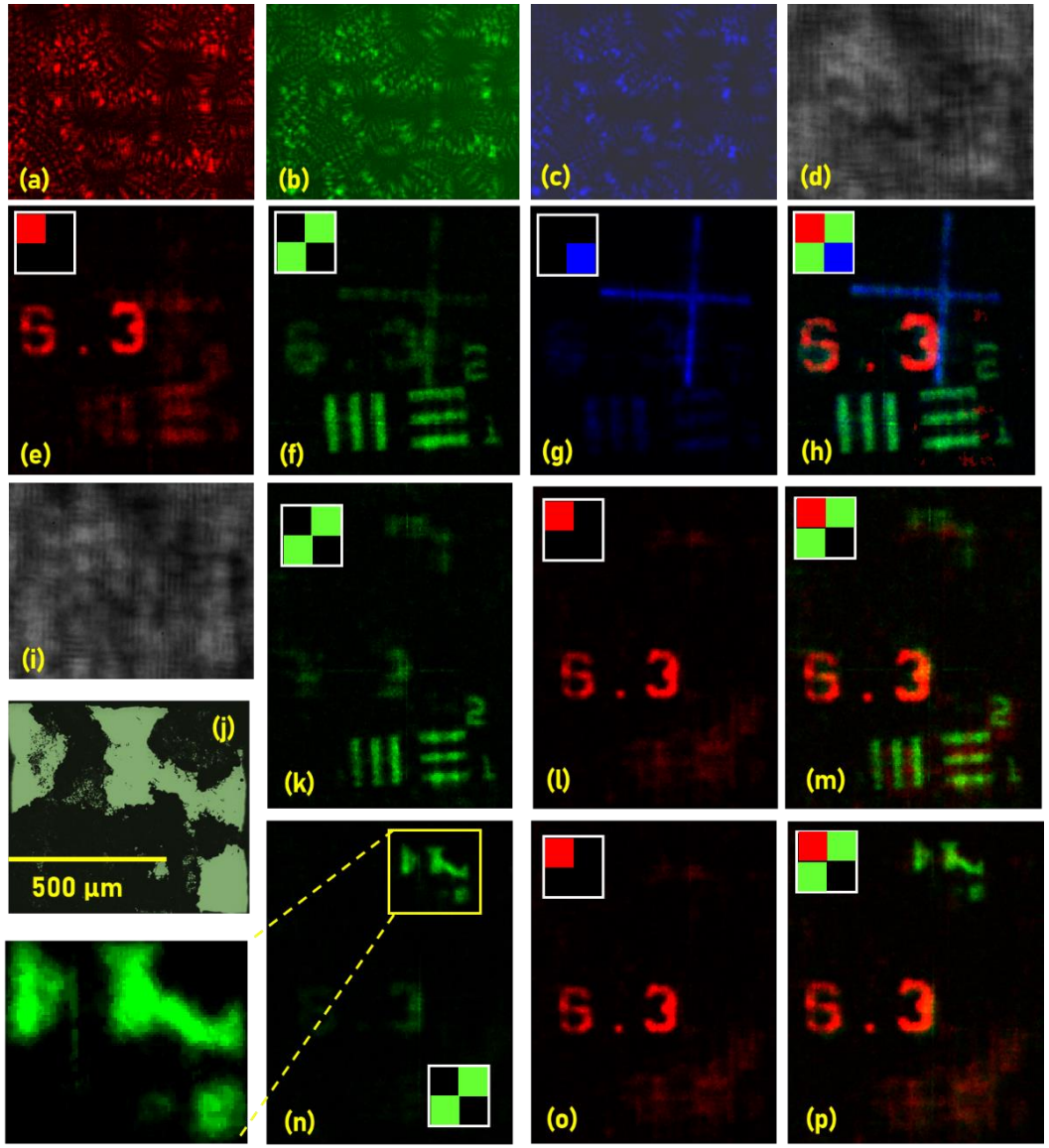
5D Imaging system in 3D space, spectrum and time

Aperture Engineering + Advanced capabilities





Anand, et. al. Sci. Rep. 3, 10, 1 (2020).

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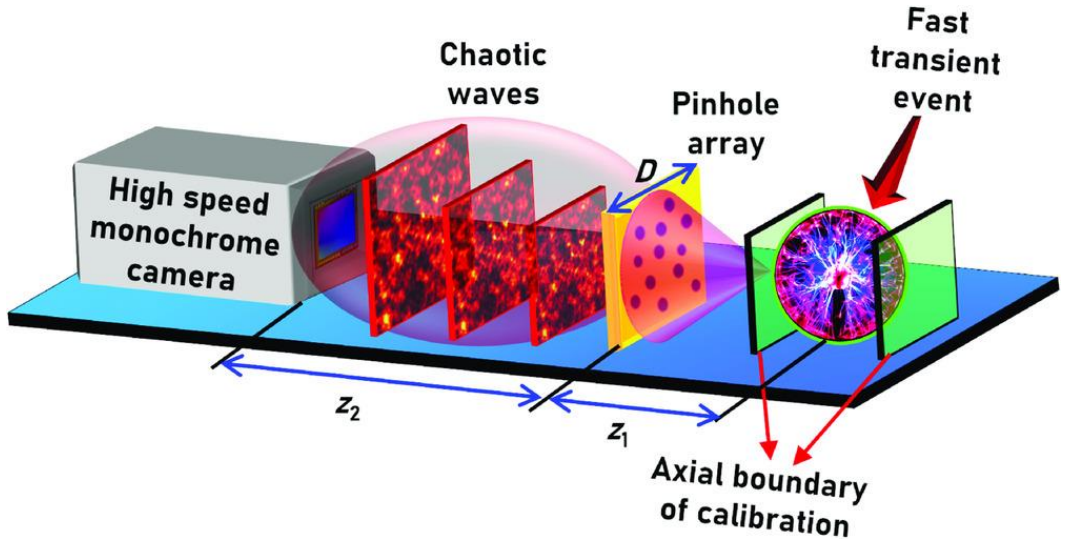
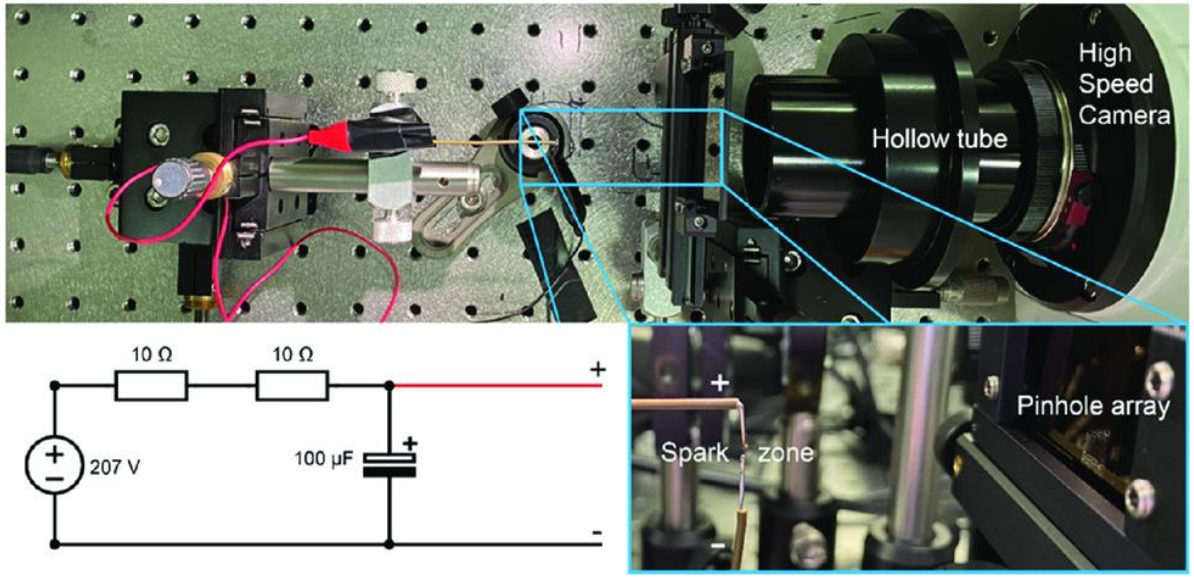
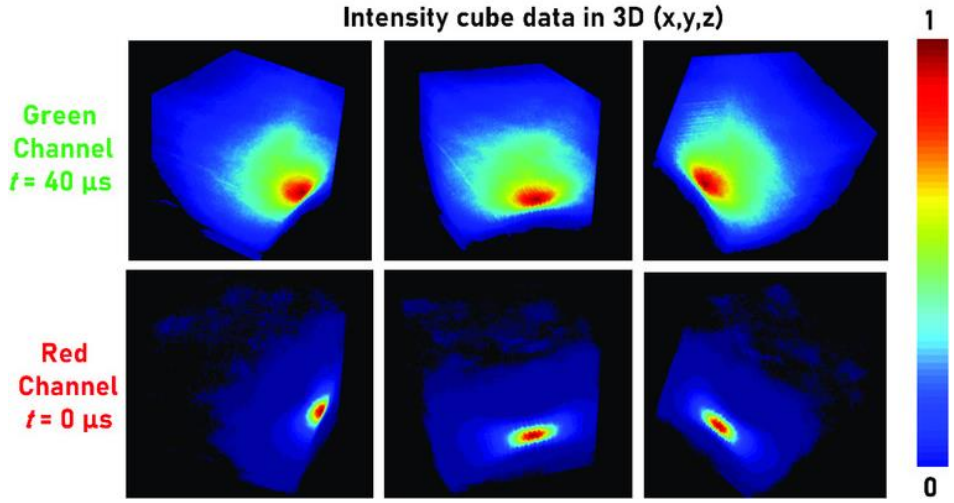
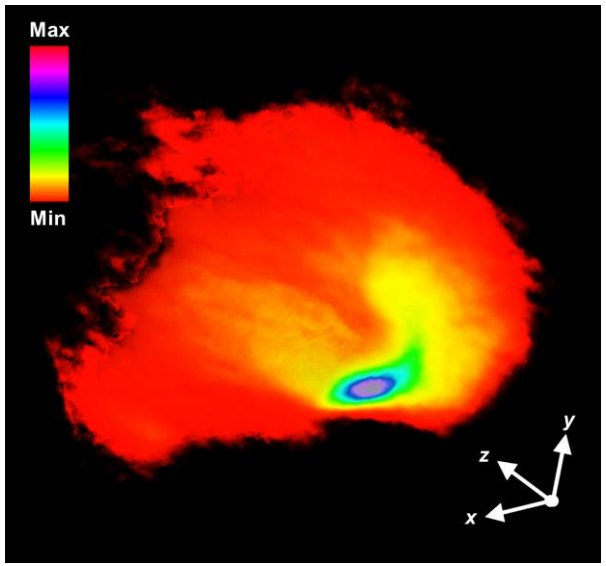
Single Shot Tomography

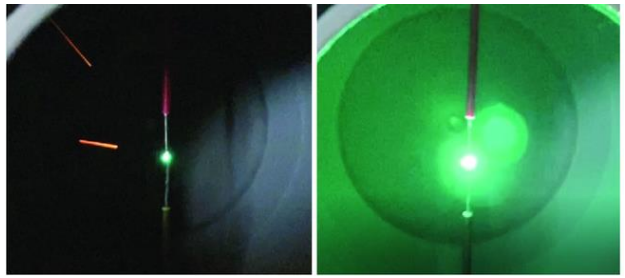
Aperture Engineering + Advanced capabilities











Anand, et. al. Advanced Photonics Research 2.2 (2021): 2000032

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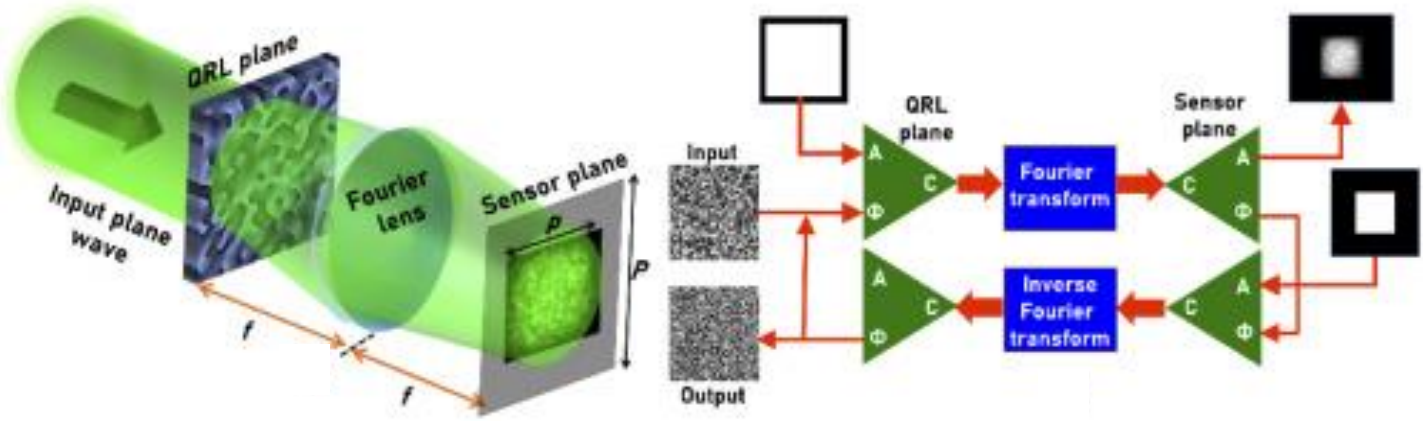
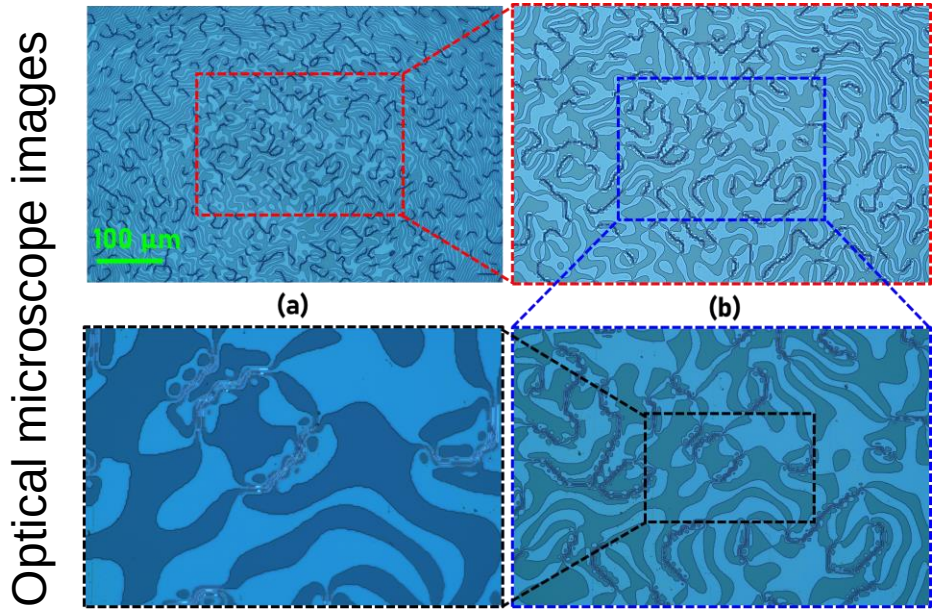
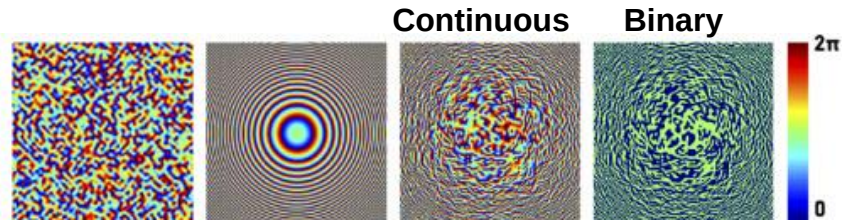
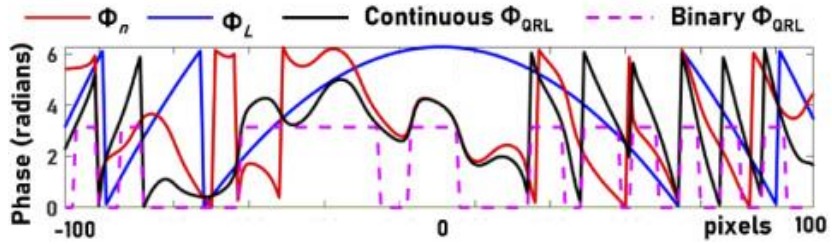
5D imaging with a quasi-random lens

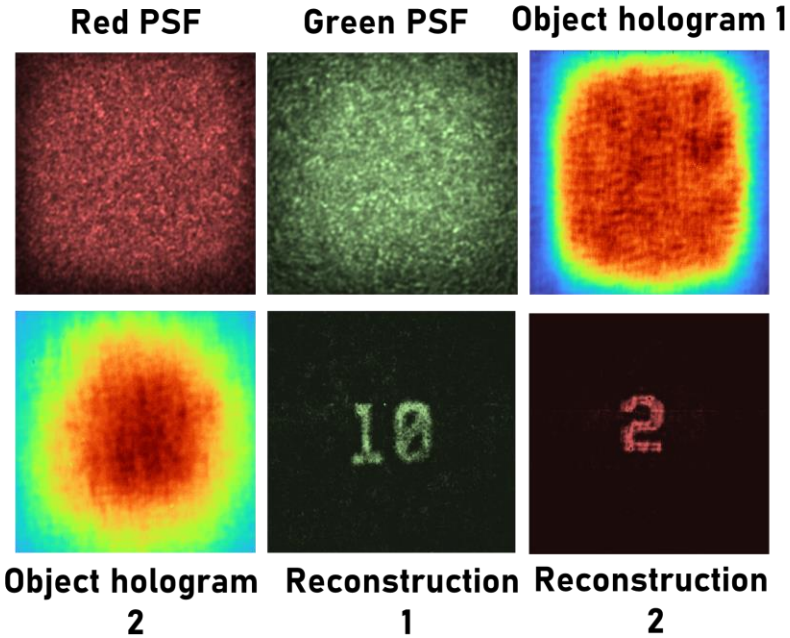
Aperture Engineering + Advanced capabilities











Anand, et. al. Opt. Express 29, 15551-15563 (2021)

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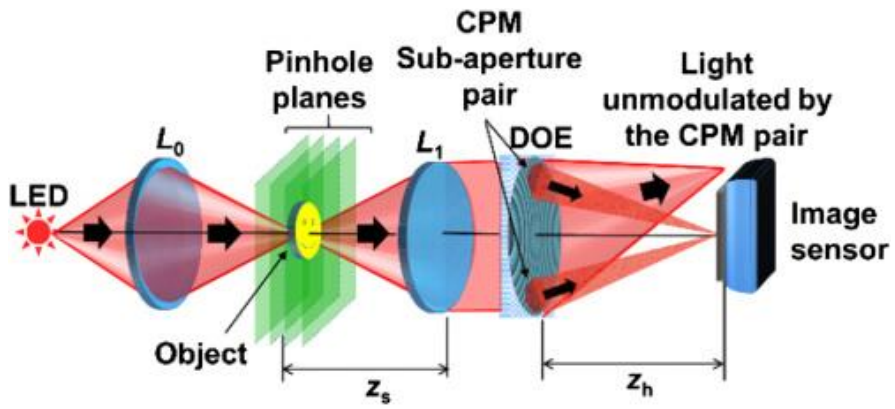
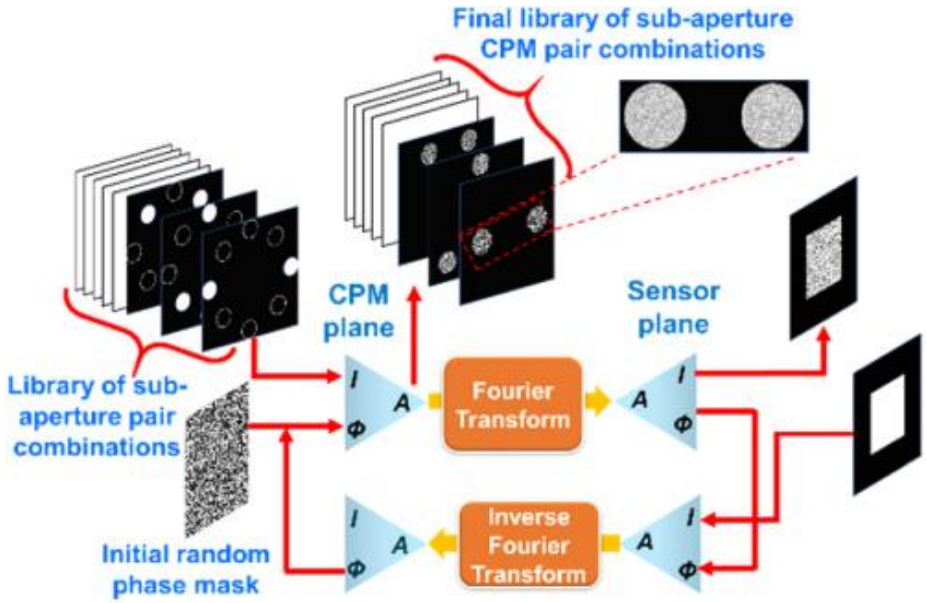
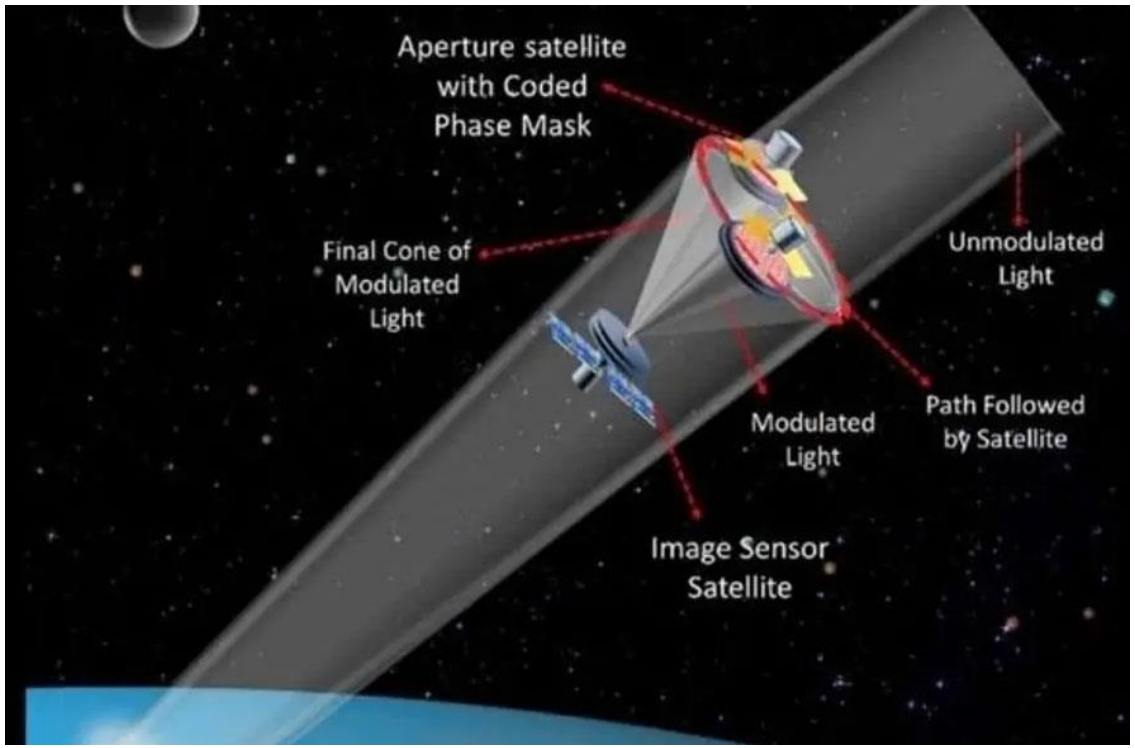
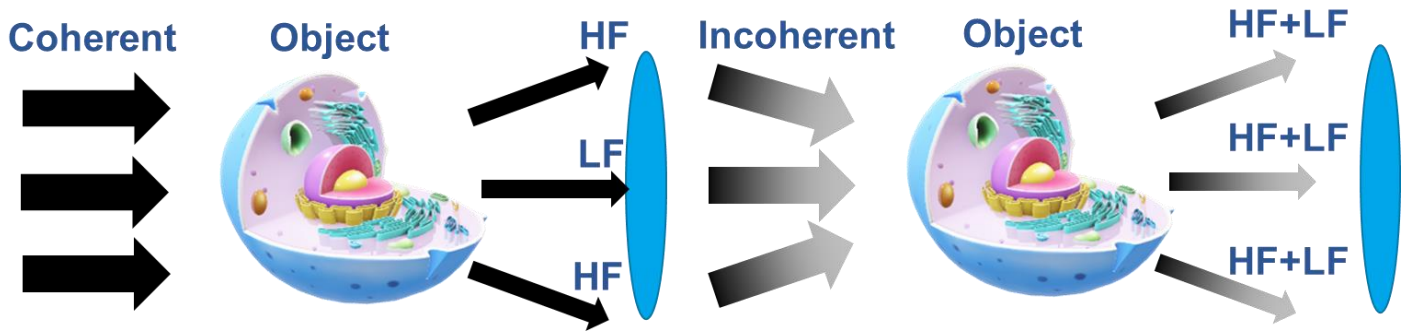
Satellite Telescope with I-COACH

Aperture Engineering + Advanced capabilities









A. Bulbul, A. Vijayakumar, and J. Rosen, Optica 5, 1607-1616 (2018)
J. Rosen, A.Vijayakumar and A. Bulbul, US patent 11,445,125 (2023) Granted

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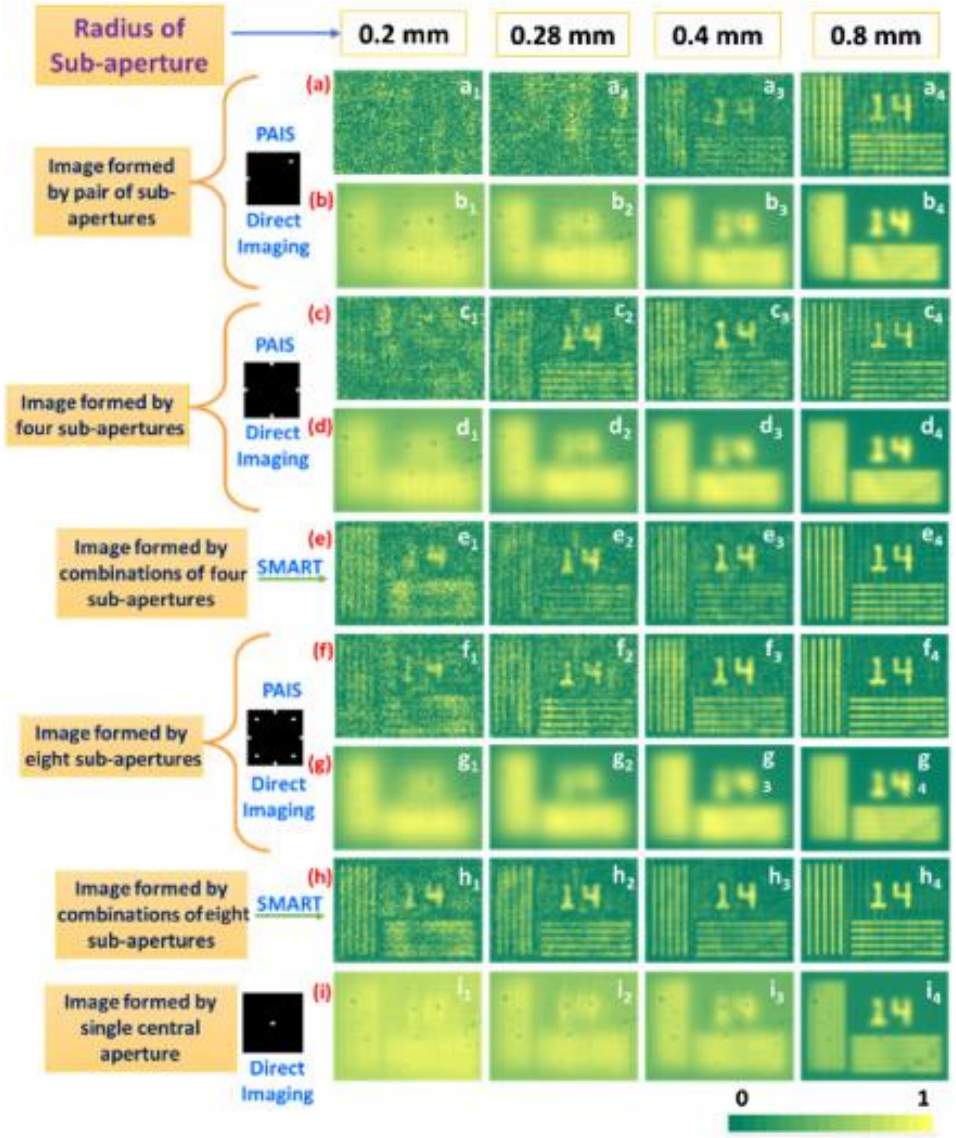
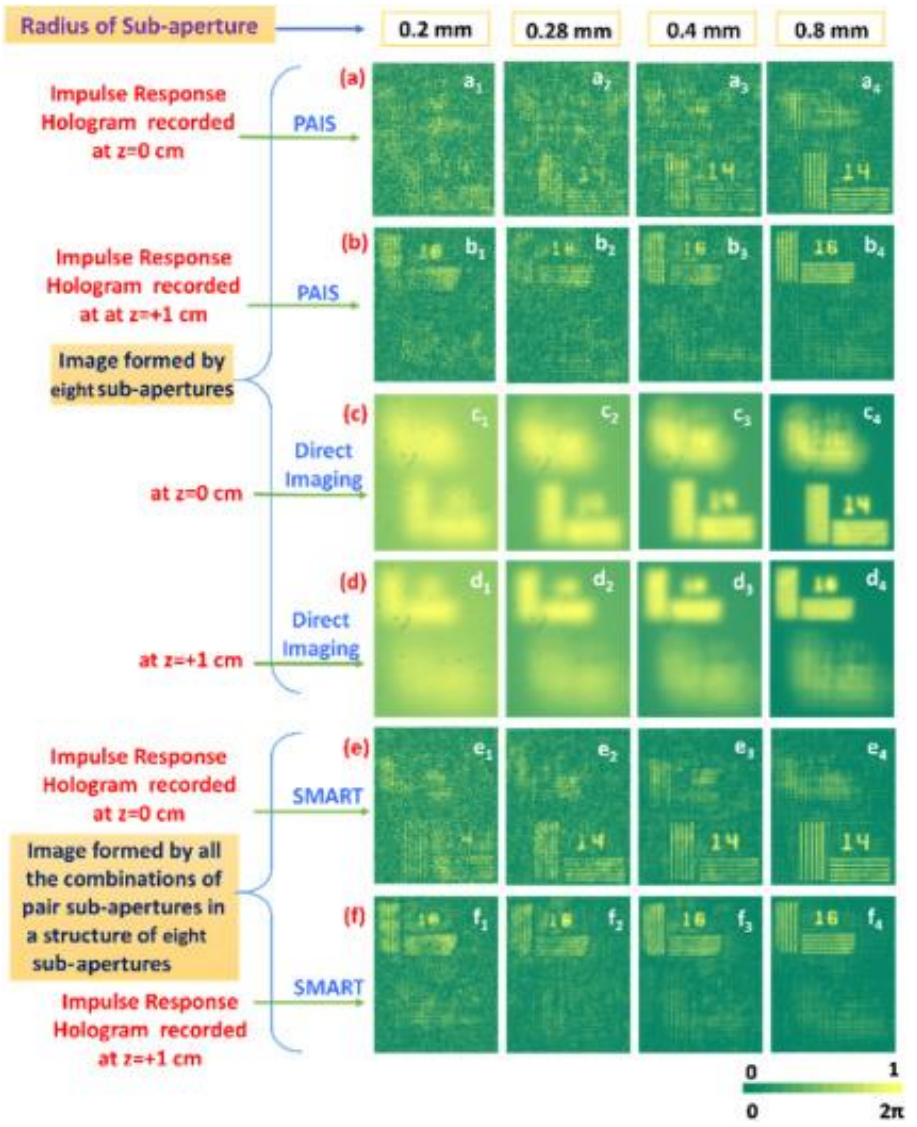
Satellite Telescope with I-COACH

Aperture Engineering + Advanced capabilities





A. Bulbul, A. Vijayakumar, and J. Rosen, Optica 5, 1607-1616 (2018)
J. Rosen, A.Vijayakumar and A. Bulbul, US patent 11,445,125 (2022, Granted)

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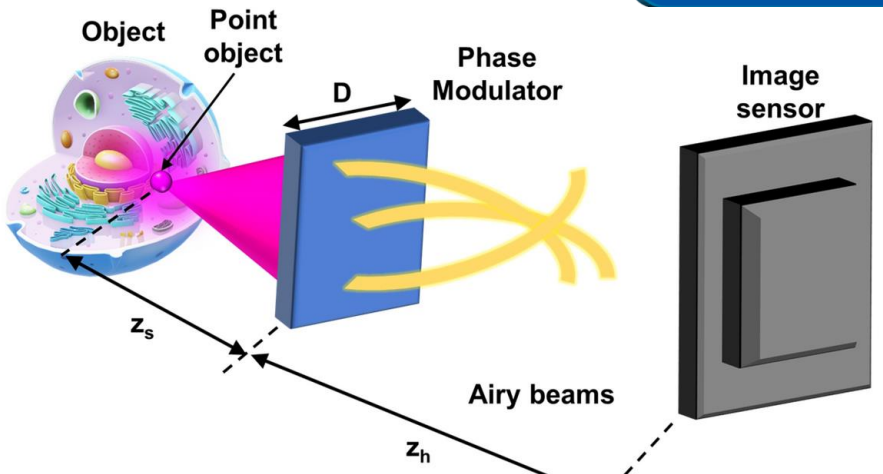
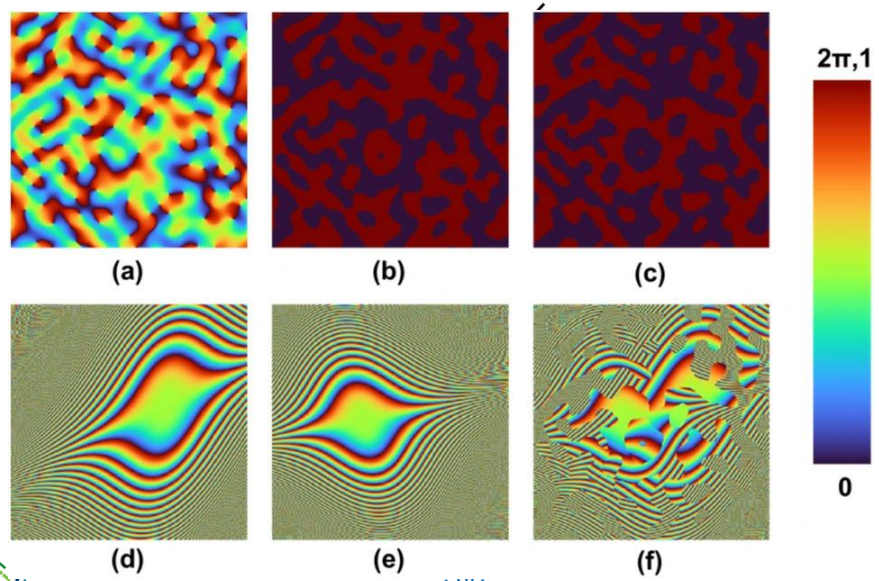
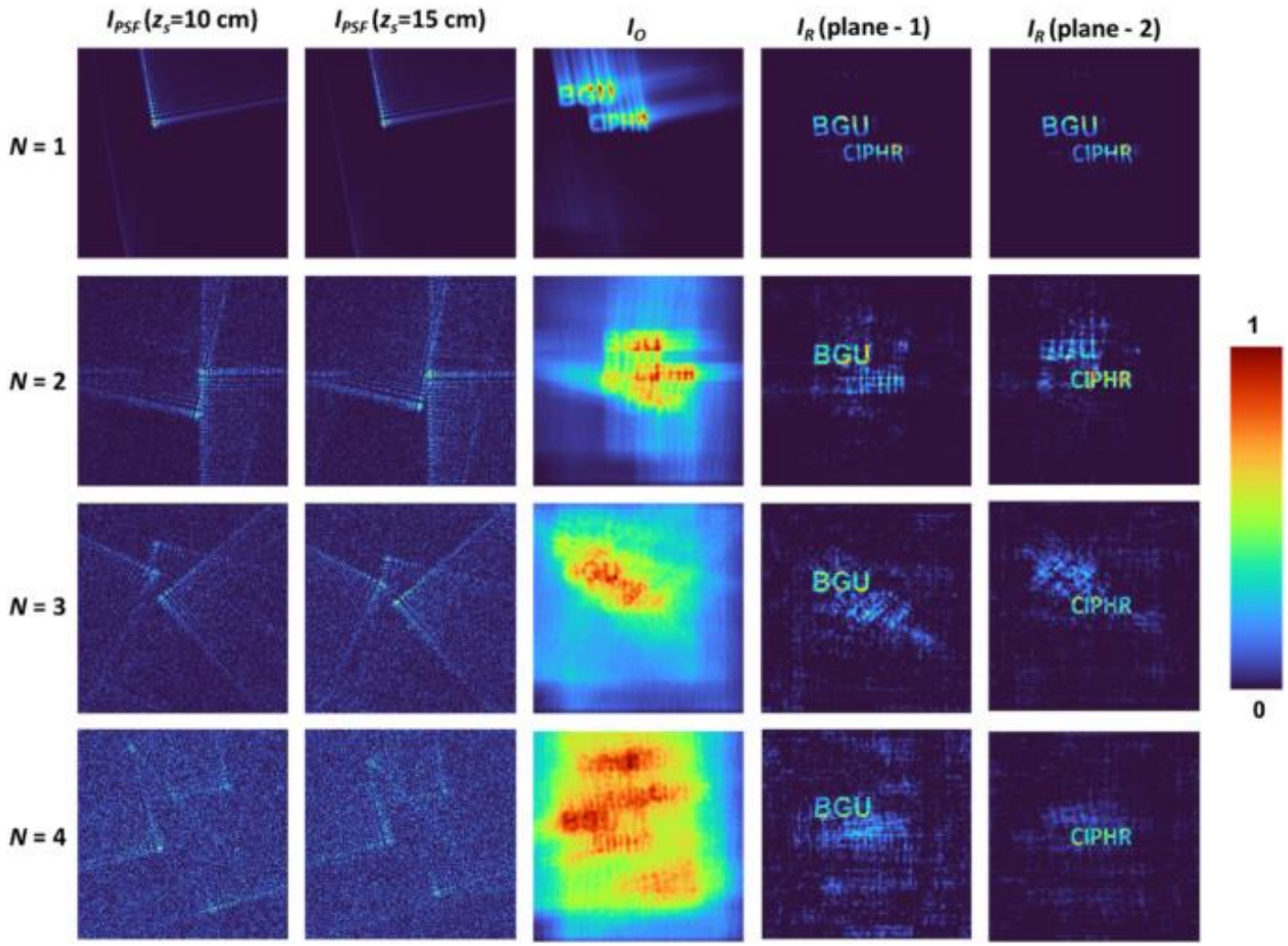
Tuning axial resolution independent of lateral resolution – Airy beams ensemble

Aperture Engineering + Advanced capabilities







Kumar, R., Anand, V. & Rosen, J. Sci Rep 13, 2996 (2023).

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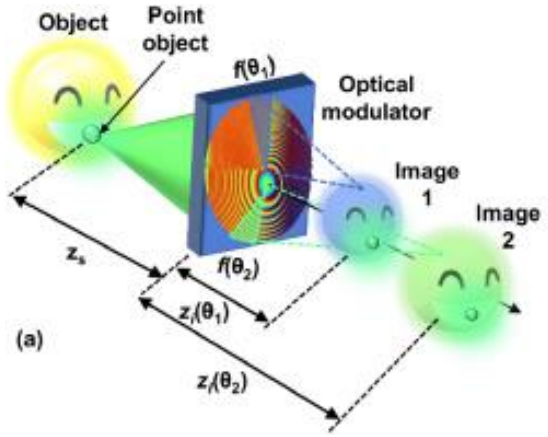
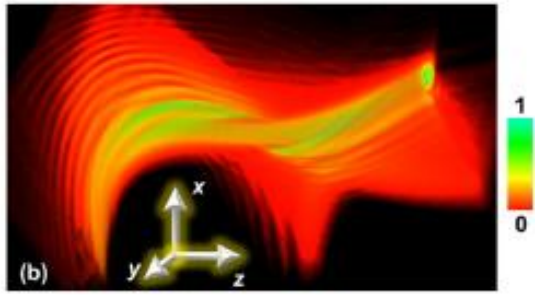
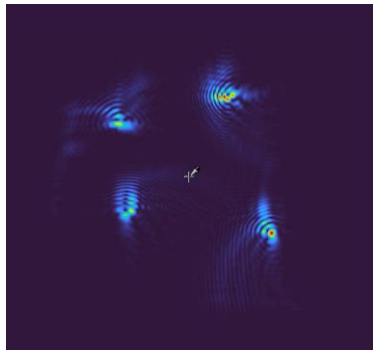
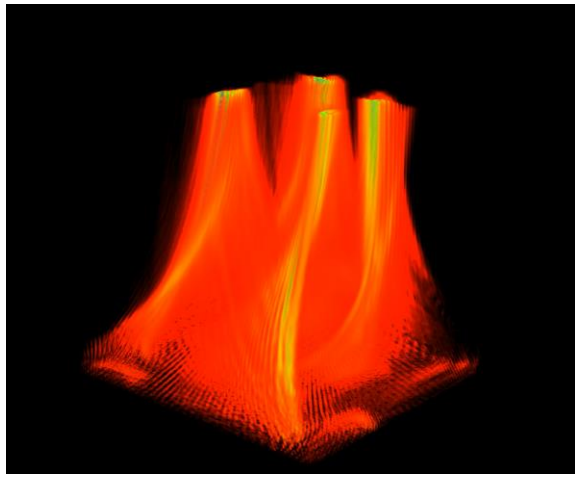
Tuning axial resolution independent of lateral resolution – Self-rotating beams ensemble

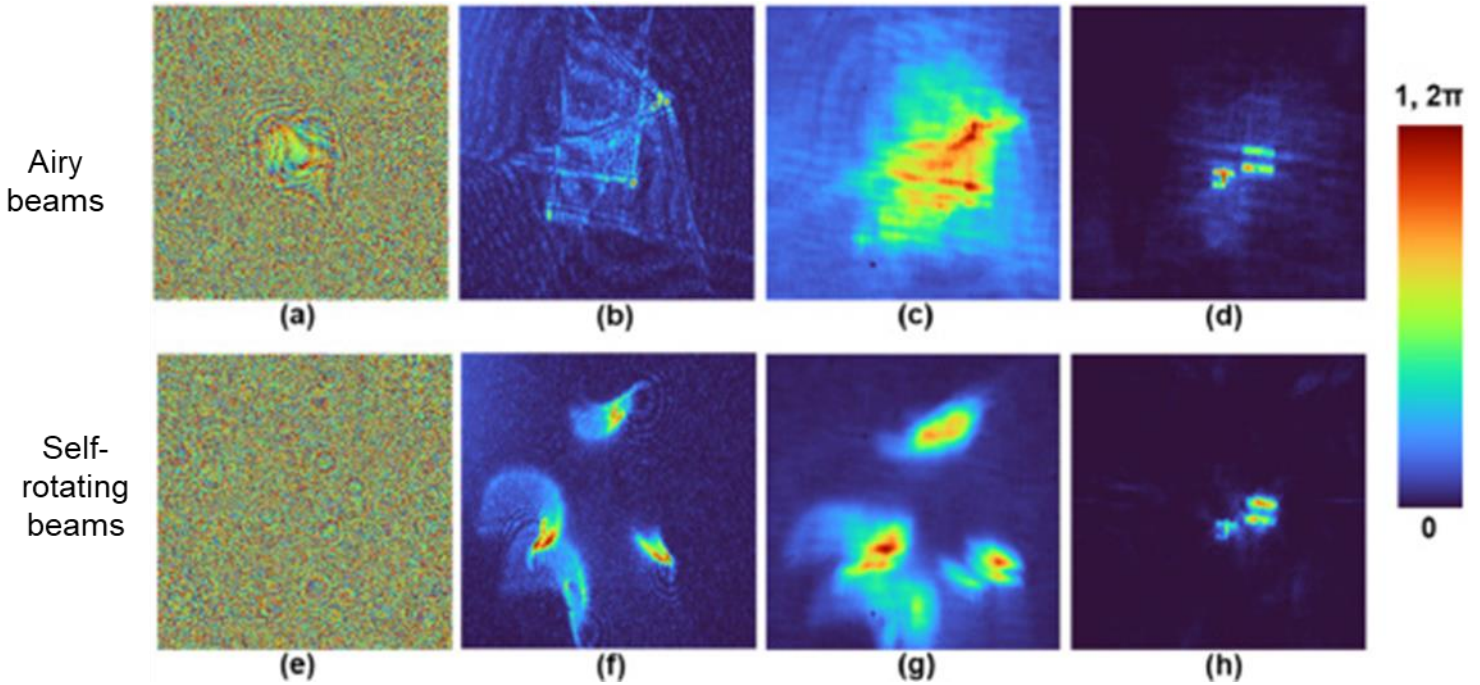
Aperture Engineering + Advanced capabilities











Bleahu, et. al. Opt. Express 31, 26120-26134 (2023)

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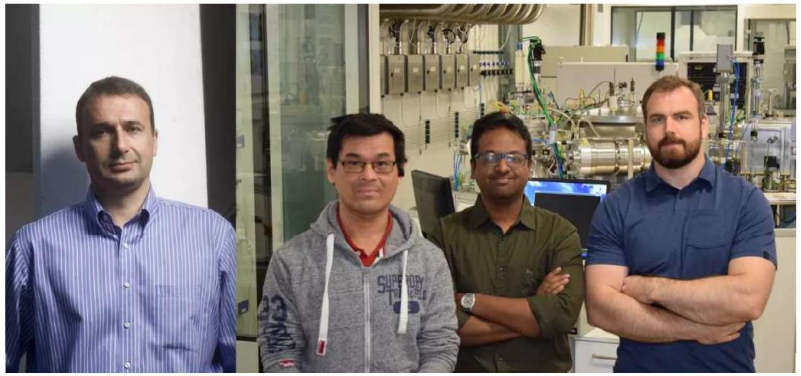
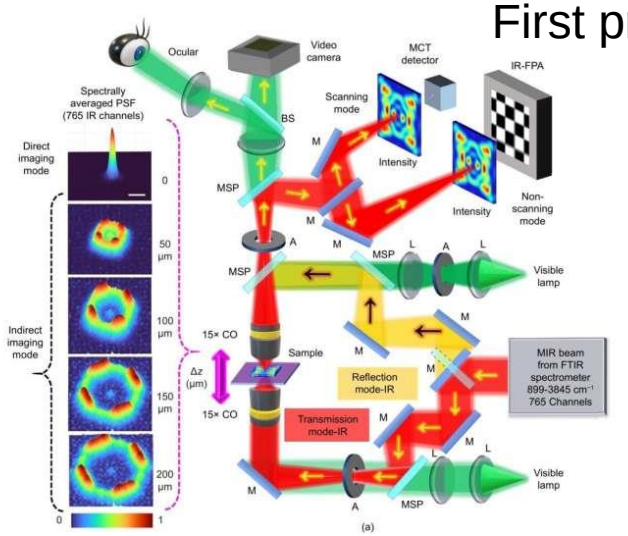
News on Coded Aperture Imaging

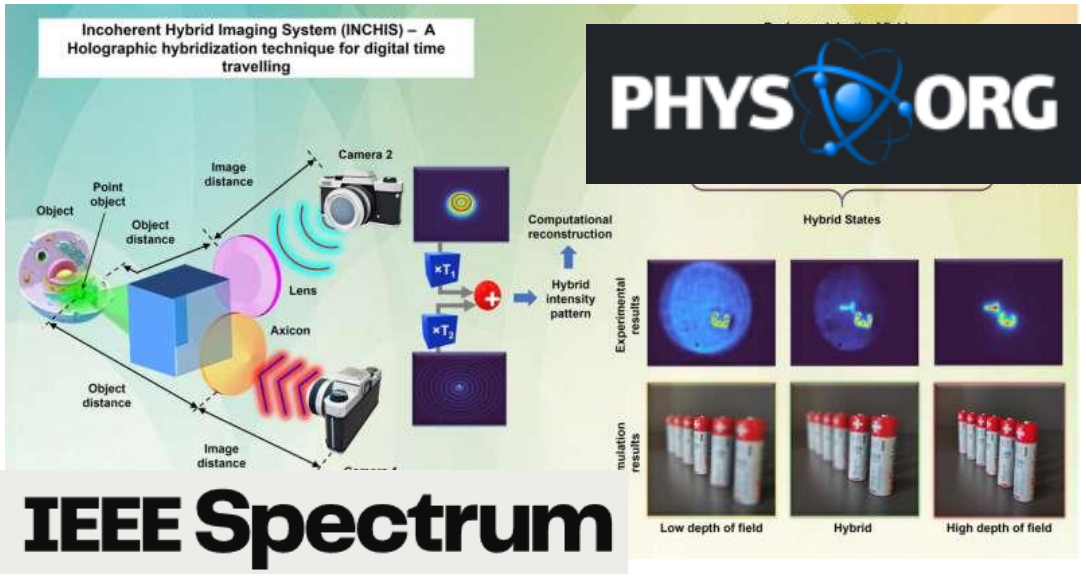
作者简介



FINCH as CAI – Cover page of Chinese Optics Letters and Opto-Electronic Advances cash prize and outstanding research award (2021), First prize from RAITH systems



Lucy-Richardson-Rosen algorithm in Phys. Org, Spectroscopy news and Hot paper in 2022.



Depth of field tuning after recording pictures and videos – IEEE spectrum news and Phys. Org - 2023

Satellite telescope – Phys. Org, India Times and Economic Times in 2019

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Collaboration network

Holography and structured light


Joseph Rosen (BGU)


Boaz Jessie Jackin (KIT)


Pierre Magistretti (KAUST)


Ravi Kumar (SRM-AP)


Andrew Forbes (WITS University)


Naresh Reddy (Latvia University)


Hasan Yilmaz (Bilkent University)


Etienne Brasselet (Bordeaux University)


Manoj Kumar (Kobe University)

Advanced Manufacturing and Nanophotonics


Saulius Juodkazis (Swinburne)


Aile Tamm (Tartu University)


Kaupo Kukli (Tartu University)


Mangirdas Malinauskas (Vilnius University)


Darius Gailevicius (Vilnius University)


Elena Ivanova (RMIT University)

Medical imaging and bioinformatics


Scott Singh (Scott Laser Piles and Fistula Center)


Milling Tania (Rajas College)

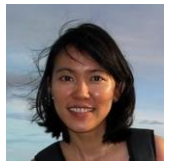

Andres Salumets (Tartu Univ)


Zoltan Vilagosh (Baroondara Health Center)

Deep Learning


Rajesh Sharma, Tartu University

Synchrotron imaging


Jitraporn Vongsvivut, Australian synchrotron

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Joint Activities

- Summer School 2024/2025
- International Conference 2025
- Dual Doctoral degree
- International Master degree
- Joint Research
- Joint Grant Consortium Applications – ERC
- Joint Estonian Grant Applications

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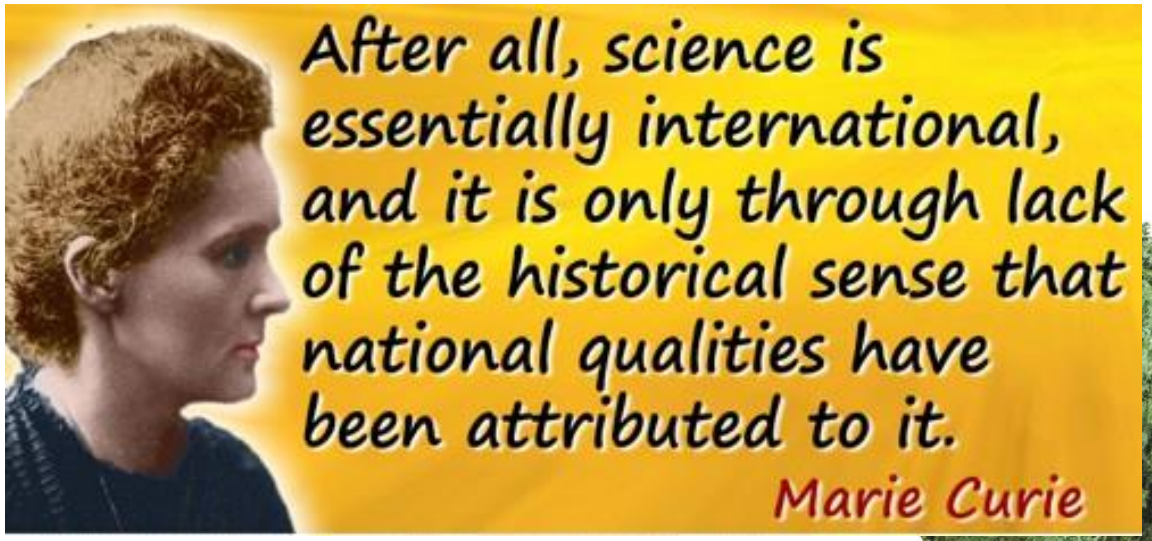

unitartu

tartuuniversity

Funded projects (PhD and Postdoc positions)