



Institute for Advanced  
Studies in Basic  
Sciences (IASBS),  
Zanjan, Iran



School of Nano Science,  
Institute for Research in  
Fundamental Sciences  
(IPM), Tehran, Iran



Multi-Dimensional  
Imaging and  
Detection Lab.

# 3D IMAGING

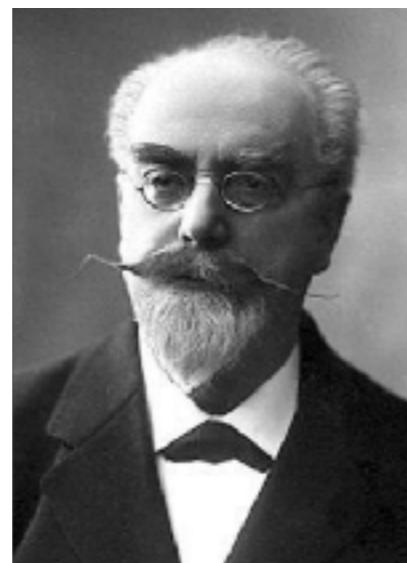
Ali-Reza Moradi

[moradika@iasbs.ac.ir](mailto:moradika@iasbs.ac.ir)

No Scanning

# 3D IMAGING

- ▶ Incoherent illumination
- ▶ Coherent illumination
- ▶ Integral imaging
- ▶ Digital holography



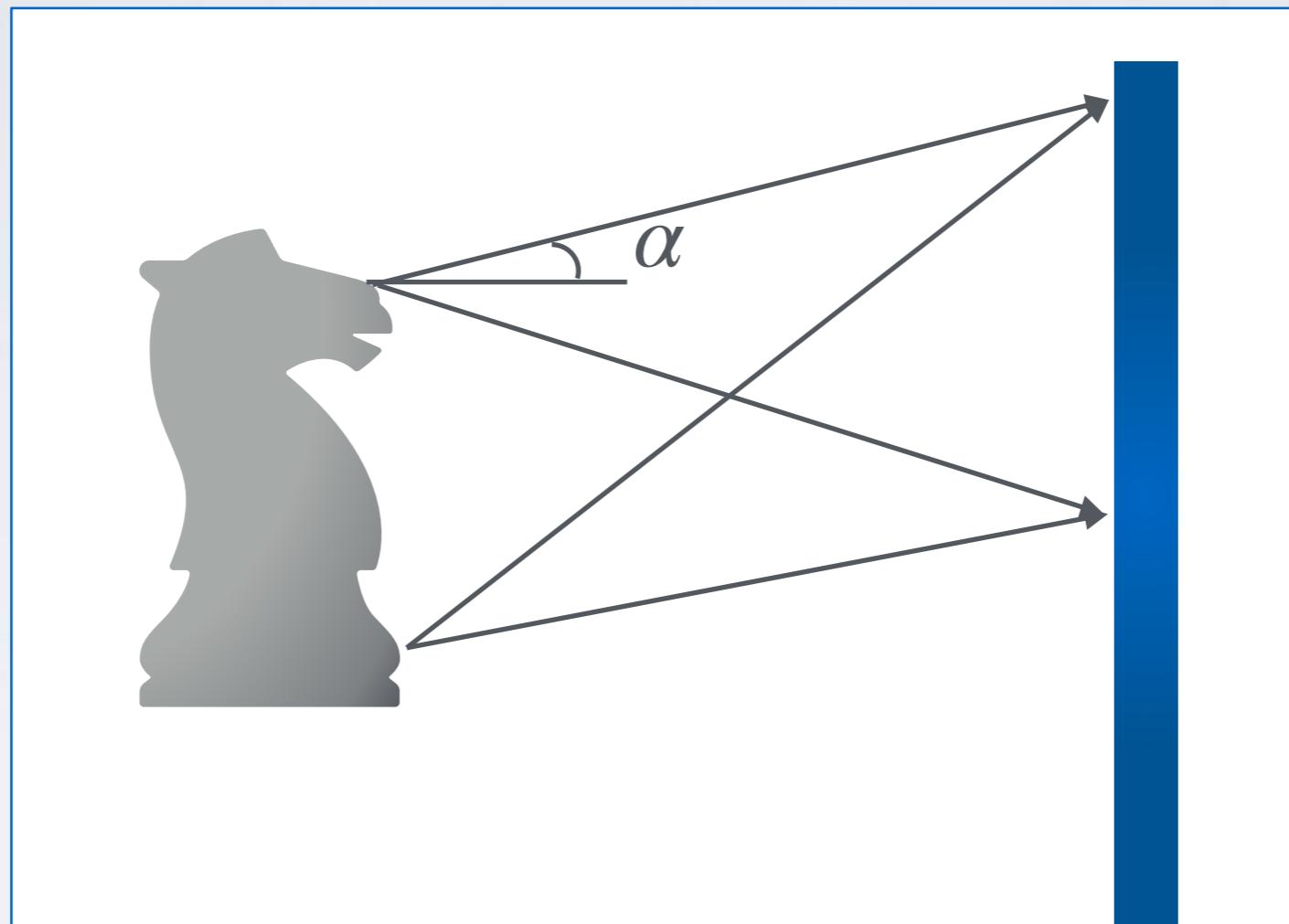
Integral Imaging: G. Lippmann 1908



Holography: D. Gabor 1971

# INTEGRAL IMAGING

- ▶ Plenoptic function:

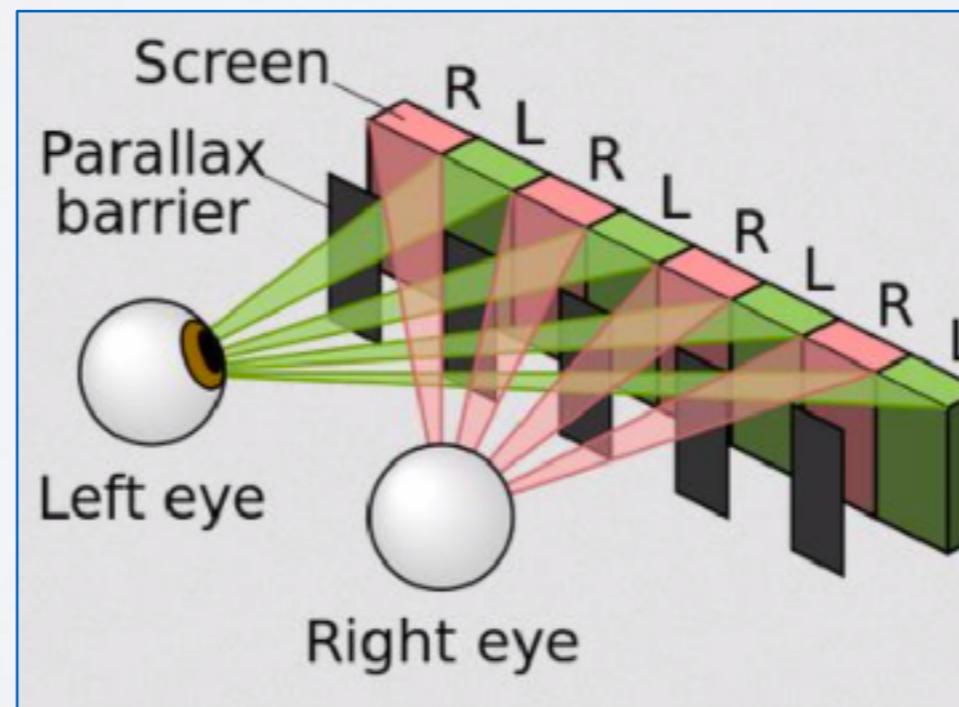
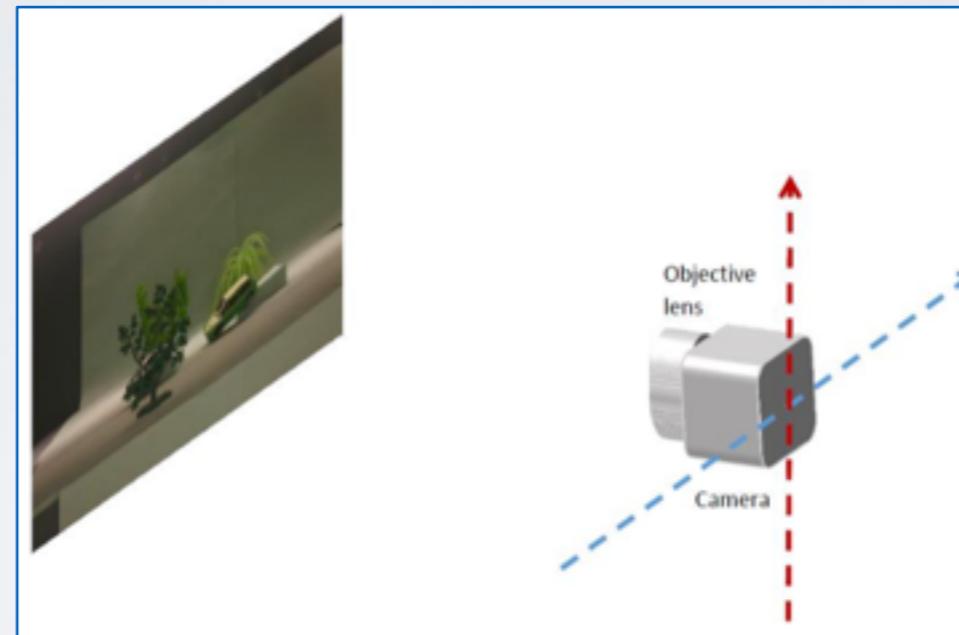


$$I(x, y, z = 0) = \int L(x, y, \alpha, \beta) d\alpha d\beta$$

Angular info is lost!

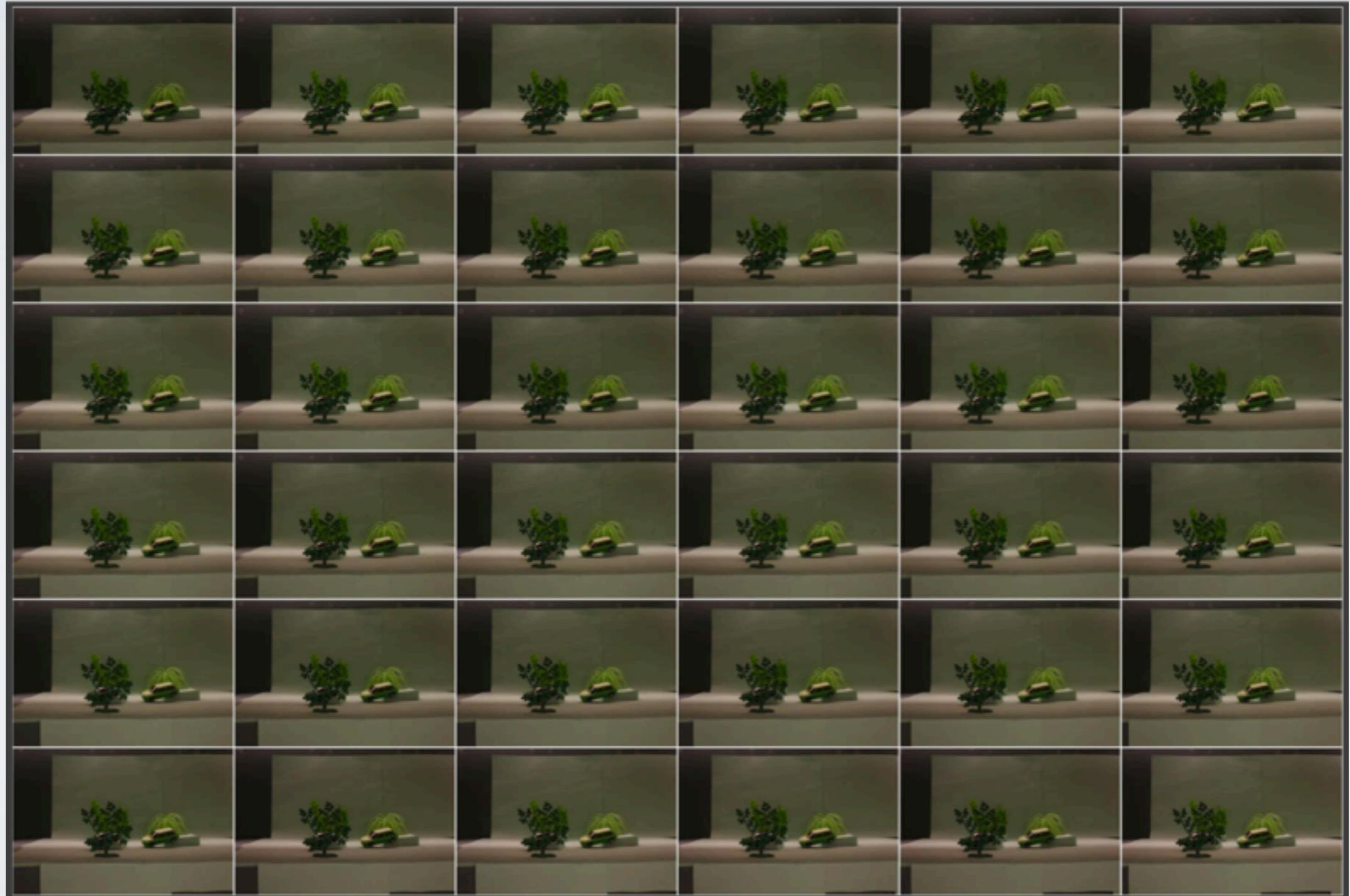
# INTEGRAL IMAGING

- ▶ Moving a single camera



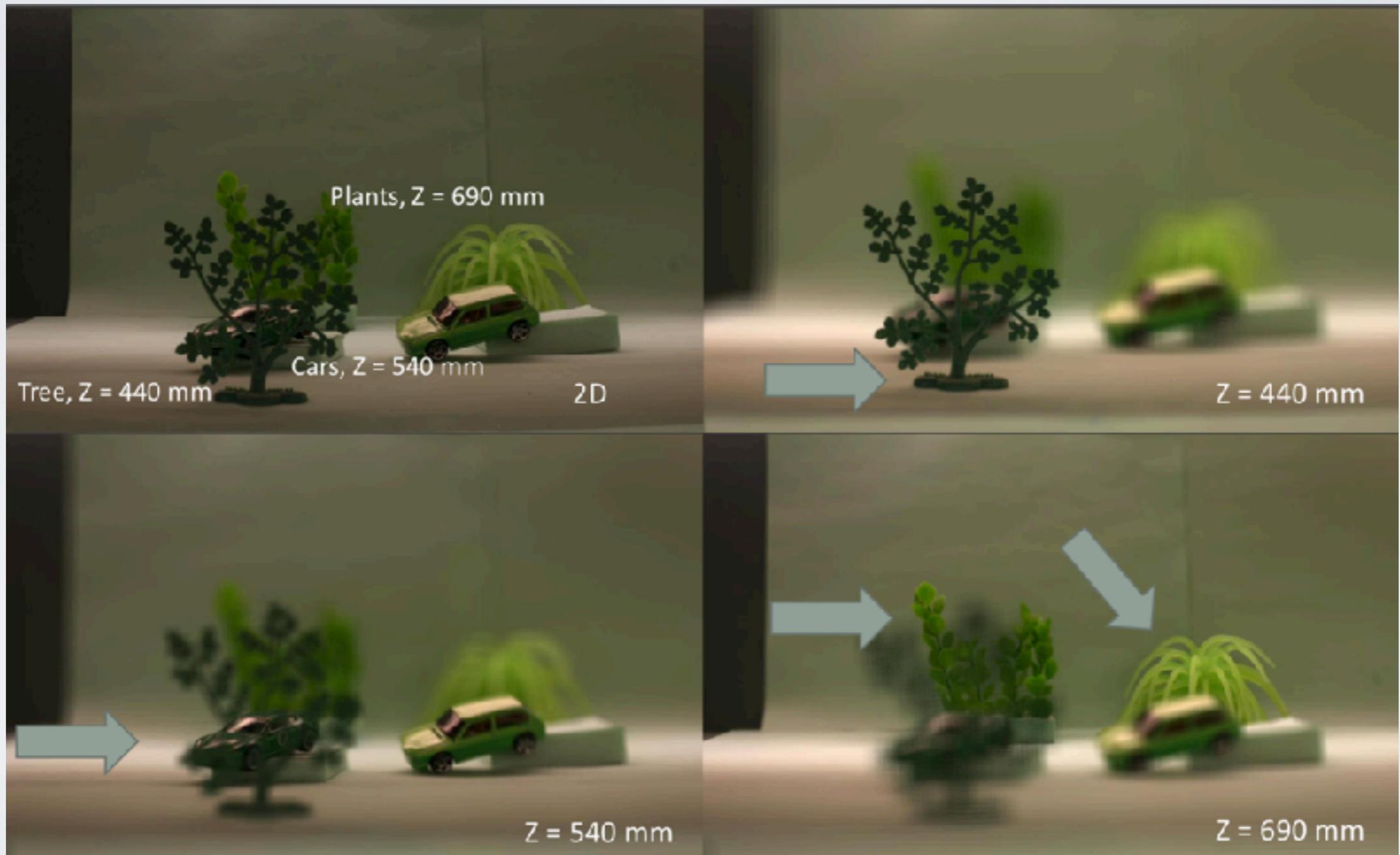
# INTEGRAL IMAGING

- ▶ Moving a single camera



# INTEGRAL IMAGING

- ▶ Moving a single camera



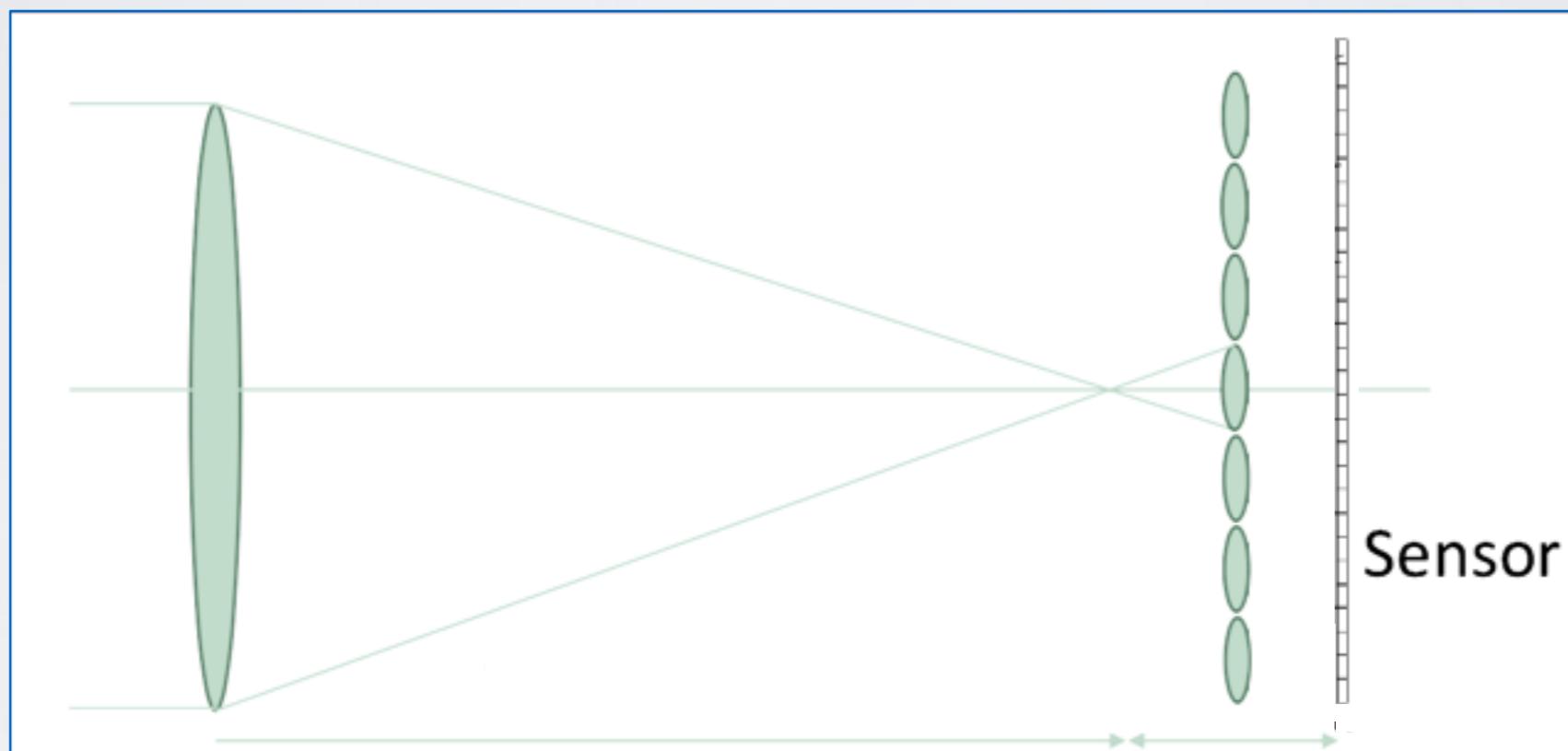
# INTEGRAL IMAGING

- ▶ Moving a single camera



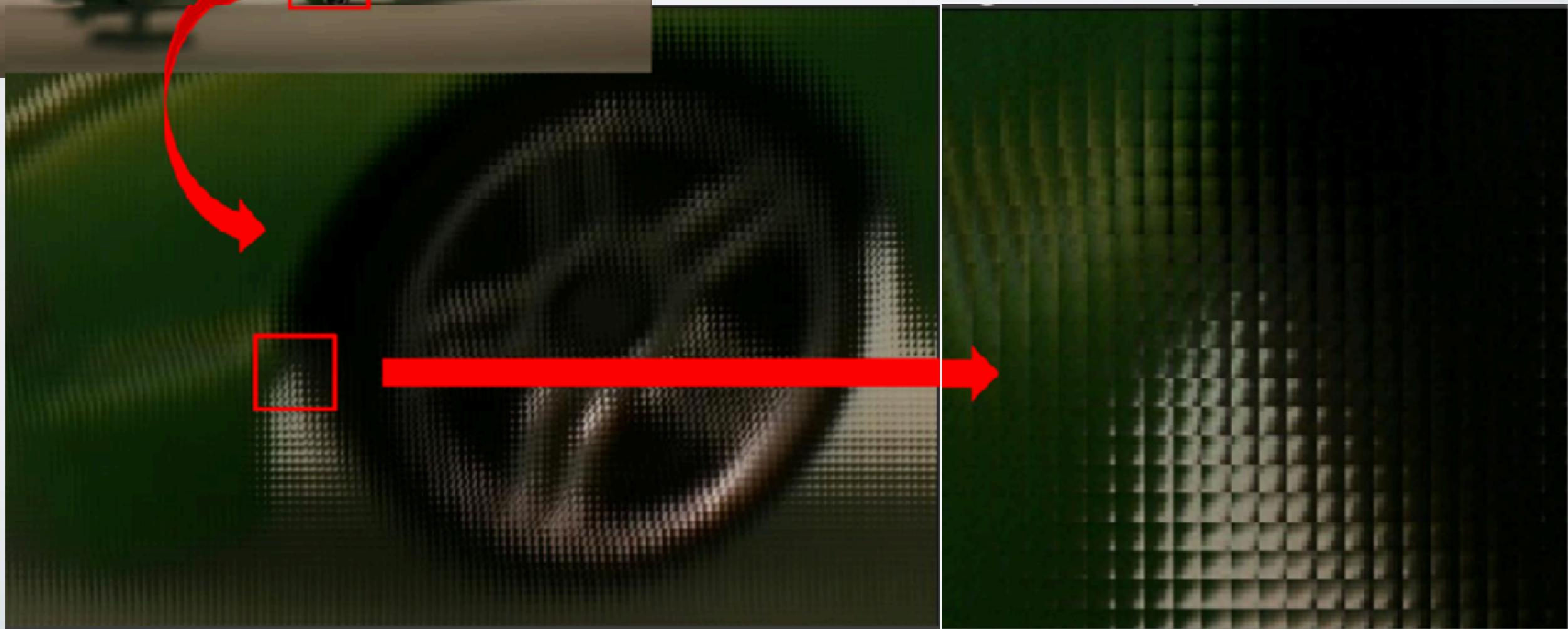
# INTEGRAL IMAGING

- ▶ Using a micro-lens array



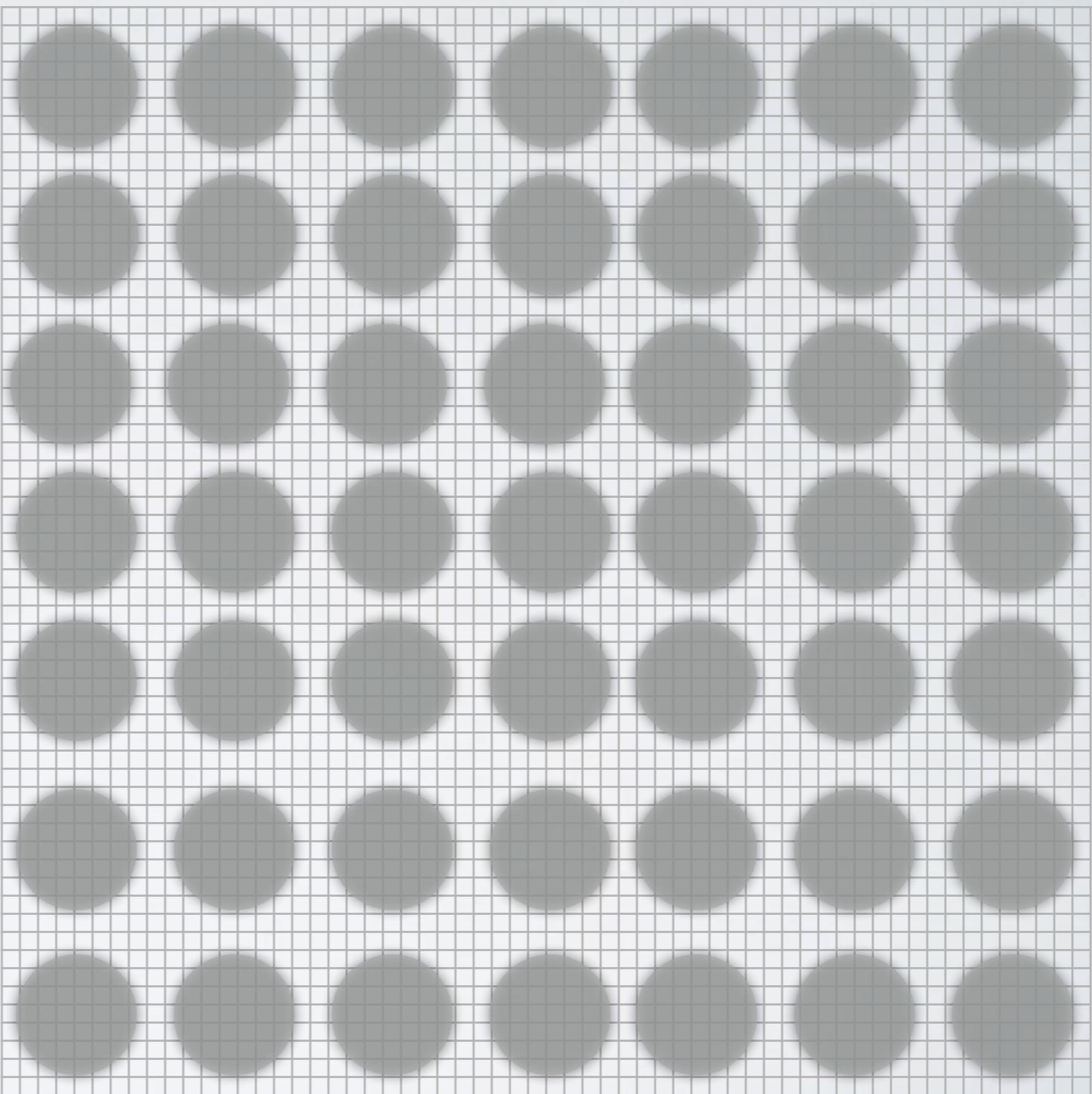
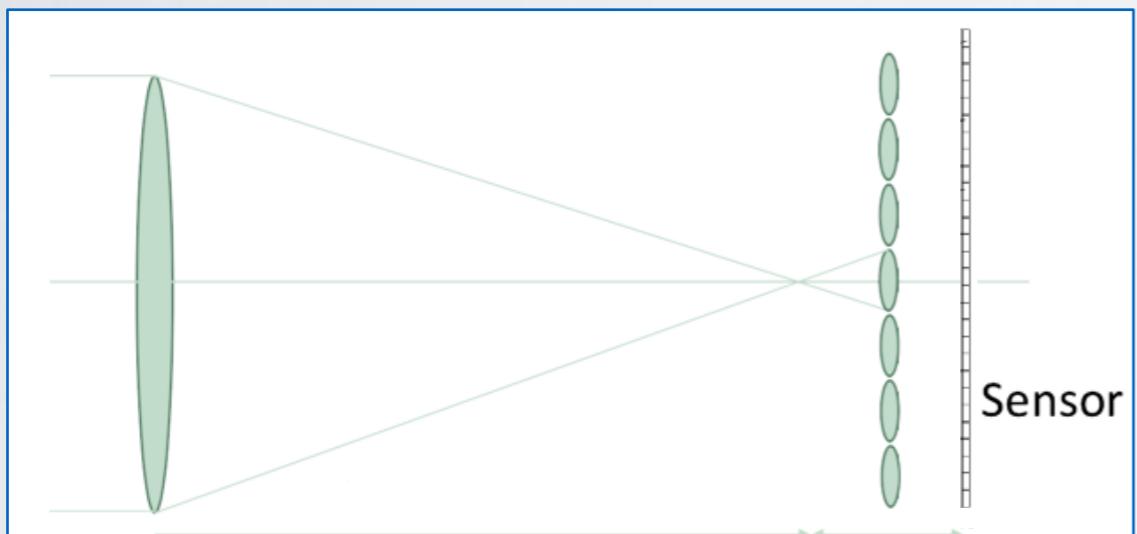
# INTEGRAL IMAGING

- ▶ Using a micro-lens array



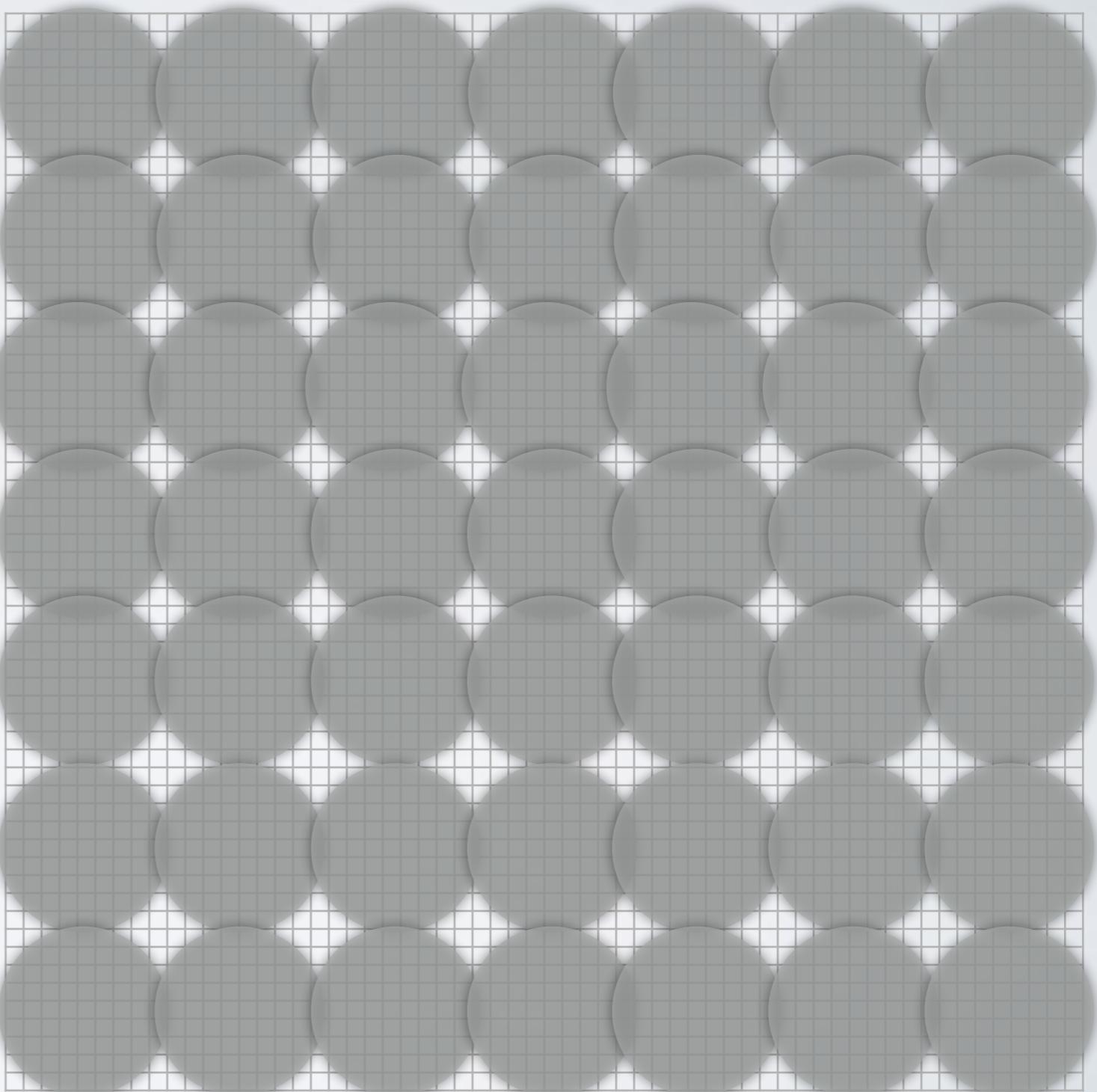
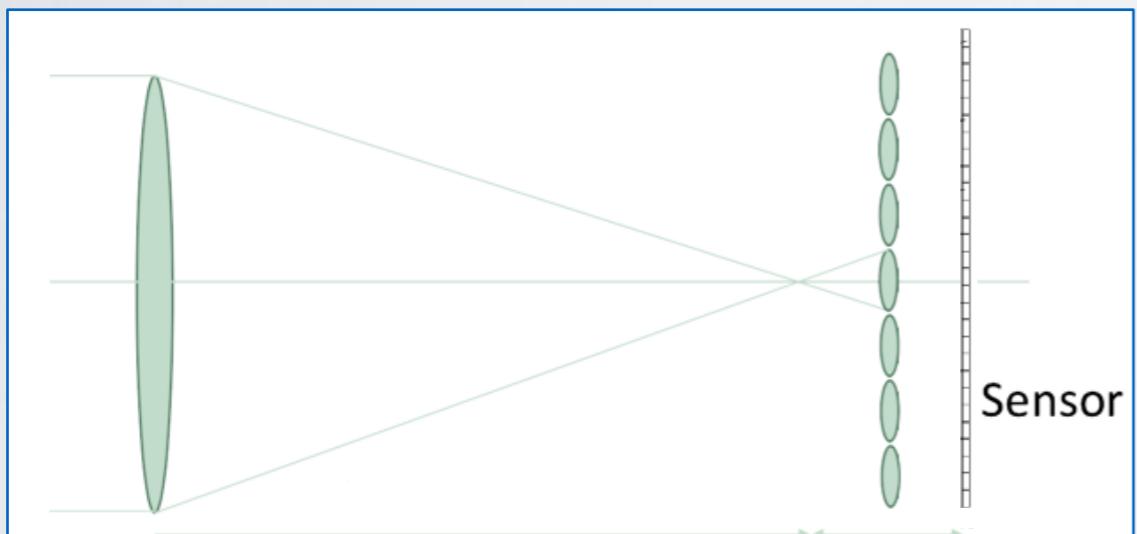
# INTEGRAL IMAGING

- ▶ Using a micro-lens array



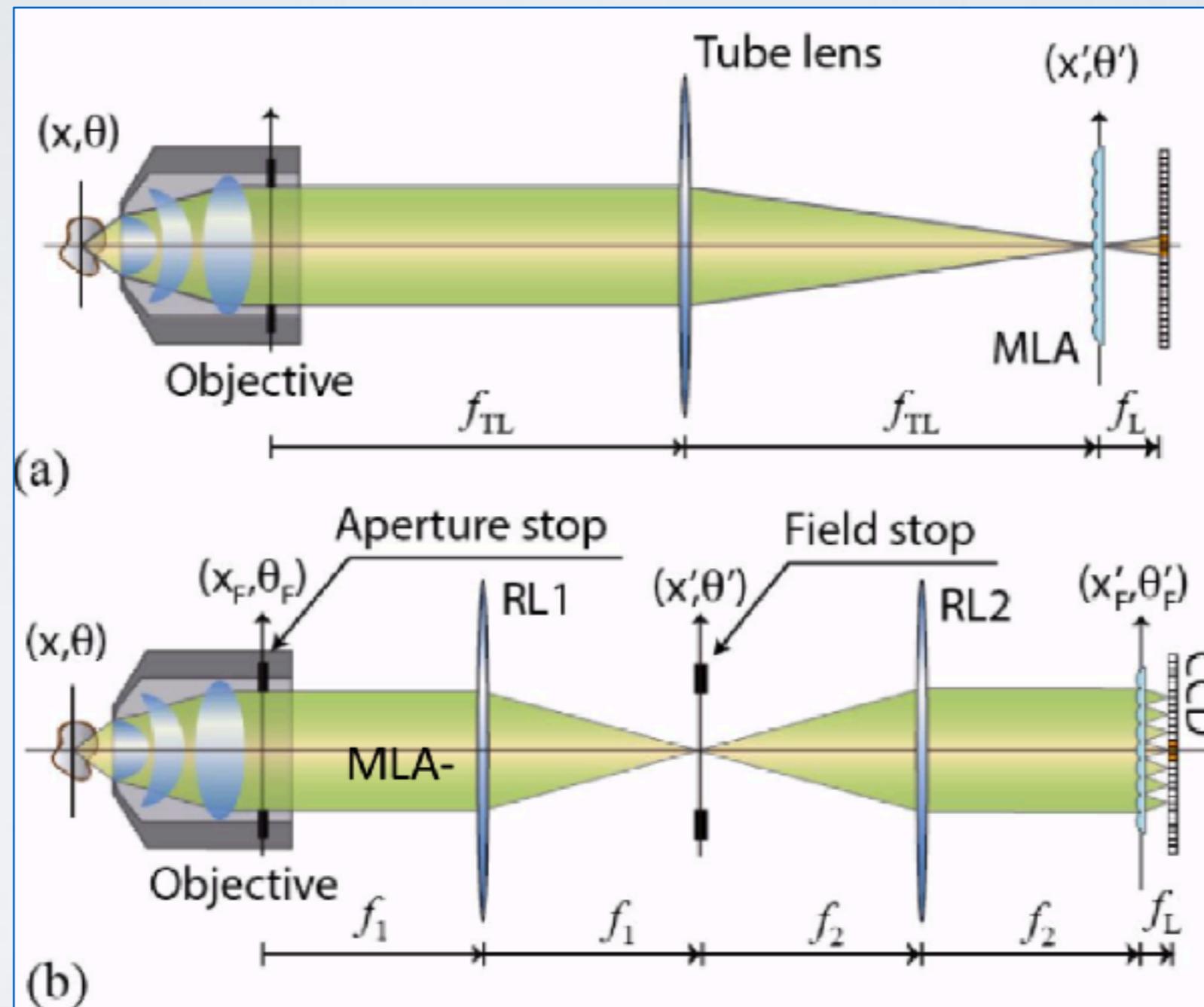
# INTEGRAL IMAGING

- ▶ Using a micro-lens array



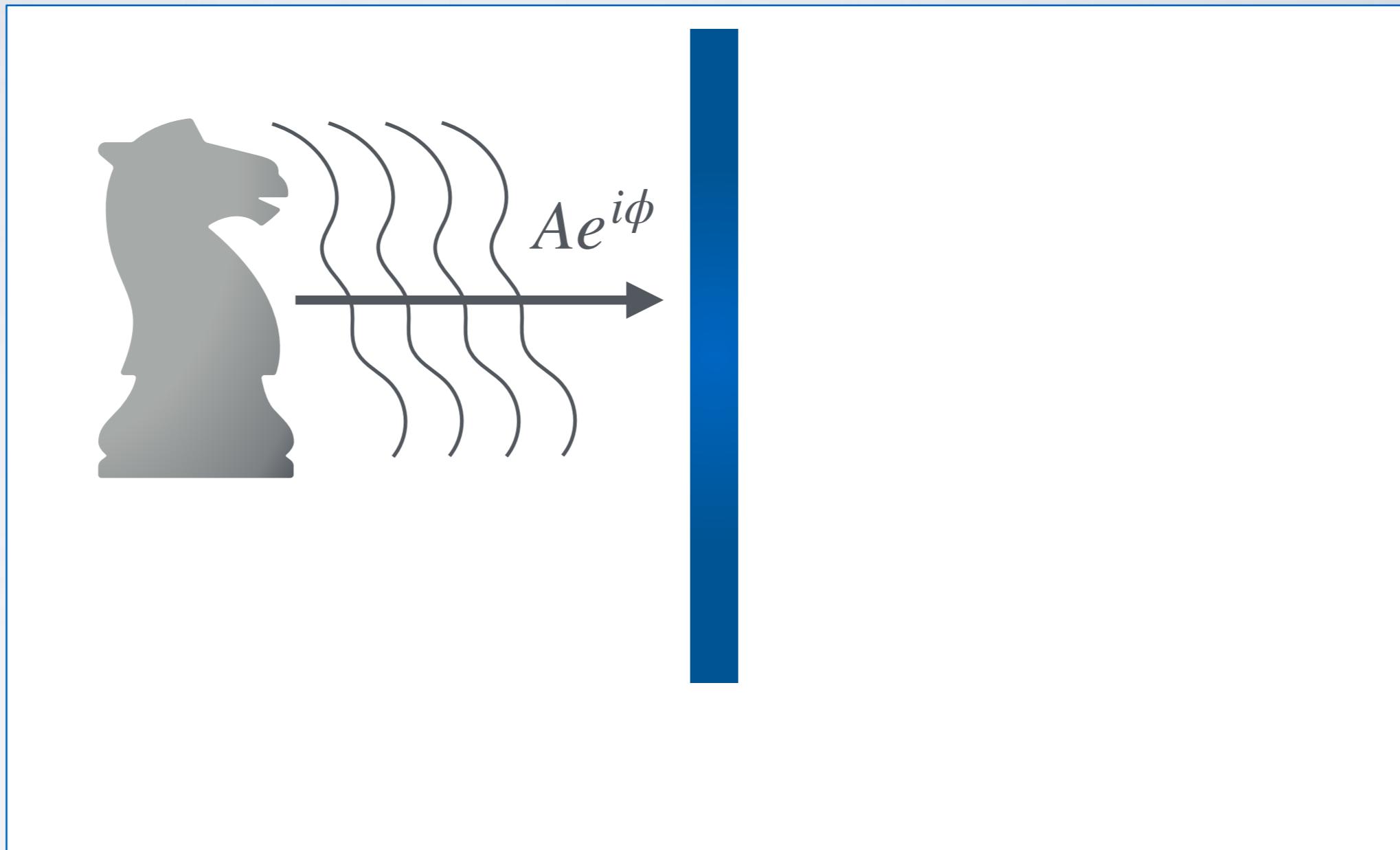
# INTEGRAL IMAGING

## ► II Microscopy



# HOLOGRAPHY

- ▶ Recording

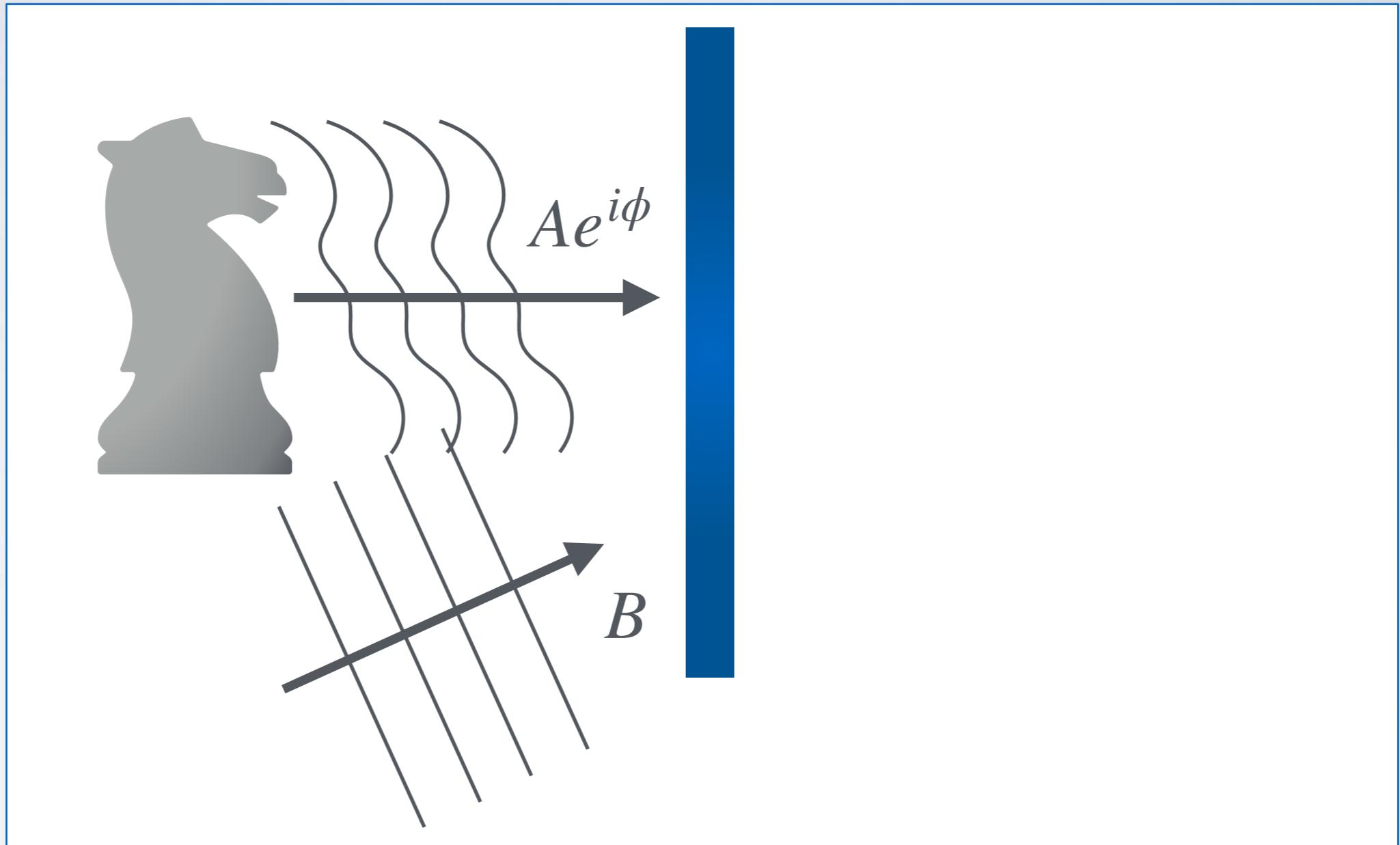


$$I_1 = A \ A^* \ e^{i\phi} \ e^{-i\phi} = |A|^2$$

Phase is lost!

# HOLOGRAPHY

- ▶ Recording



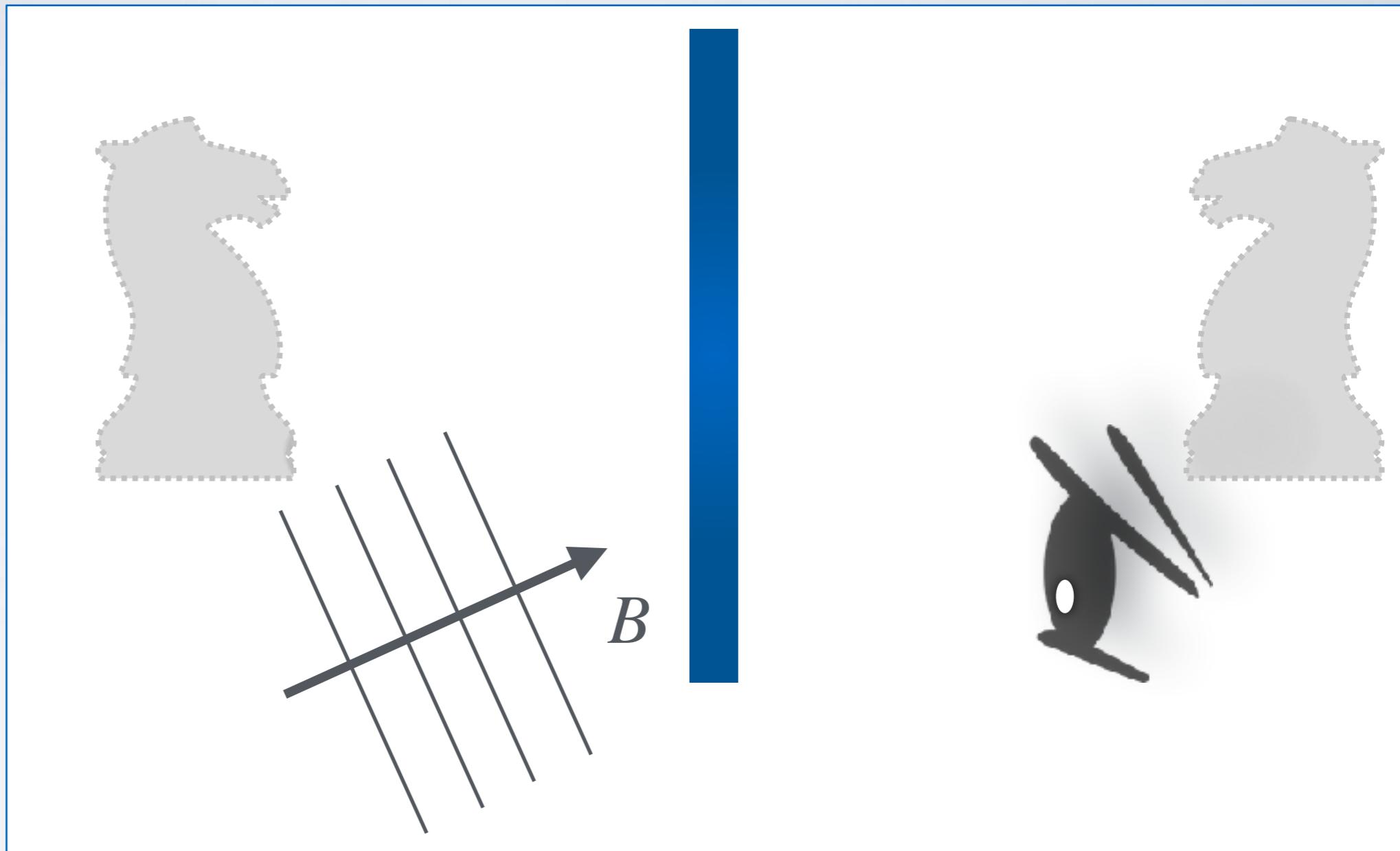
$$I_2 = (A e^{i\phi} + B)(A^* e^{-i\phi} + B^*)$$

$$= |A|^2 + |B|^2 + AB^* e^{i\phi} + A^* B e^{-i\phi}$$

# HOLOGRAPHY

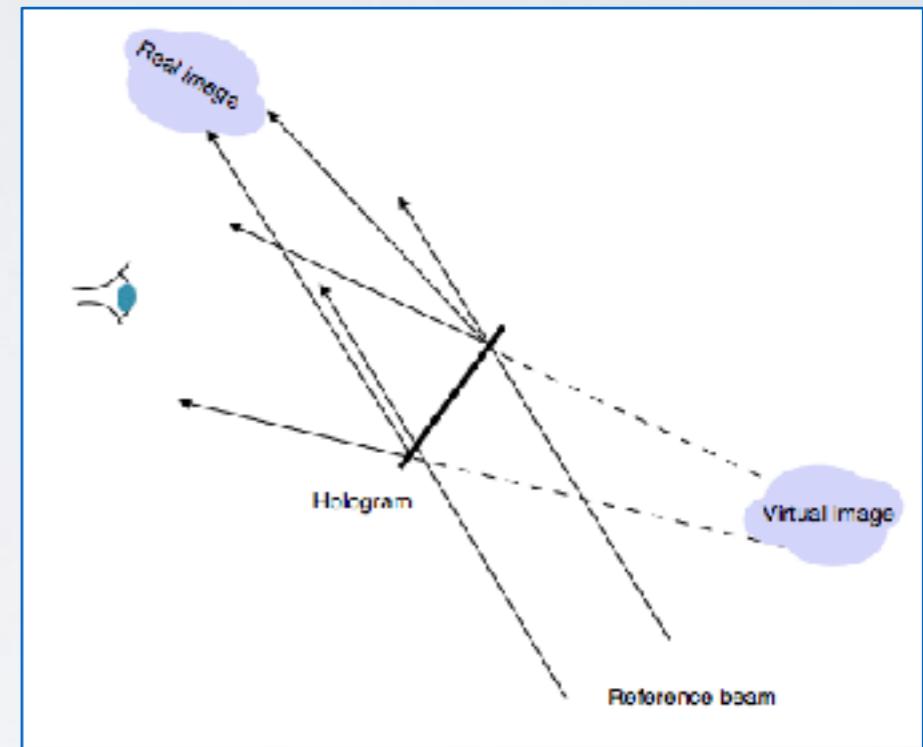
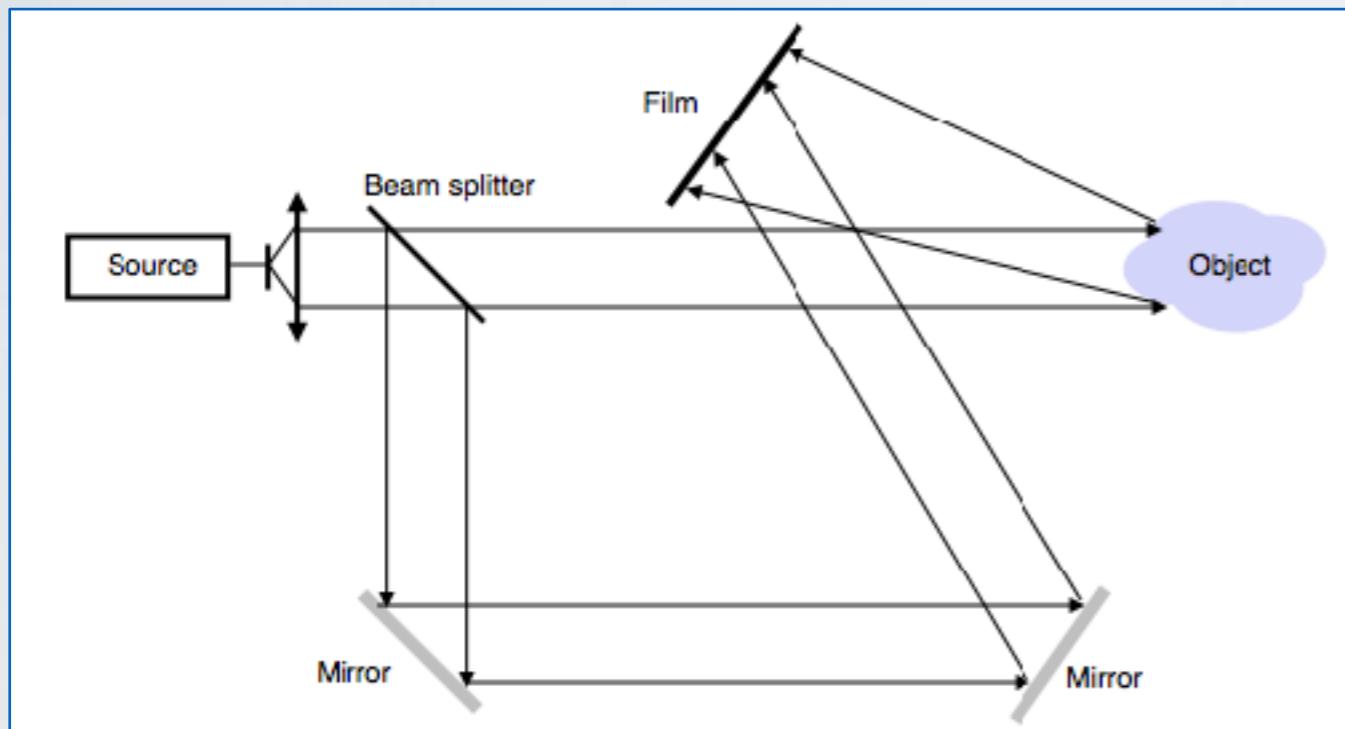
- Reconstruction

- Development
- Fixer Bath
- Rinsing
- Drying
- Illumination



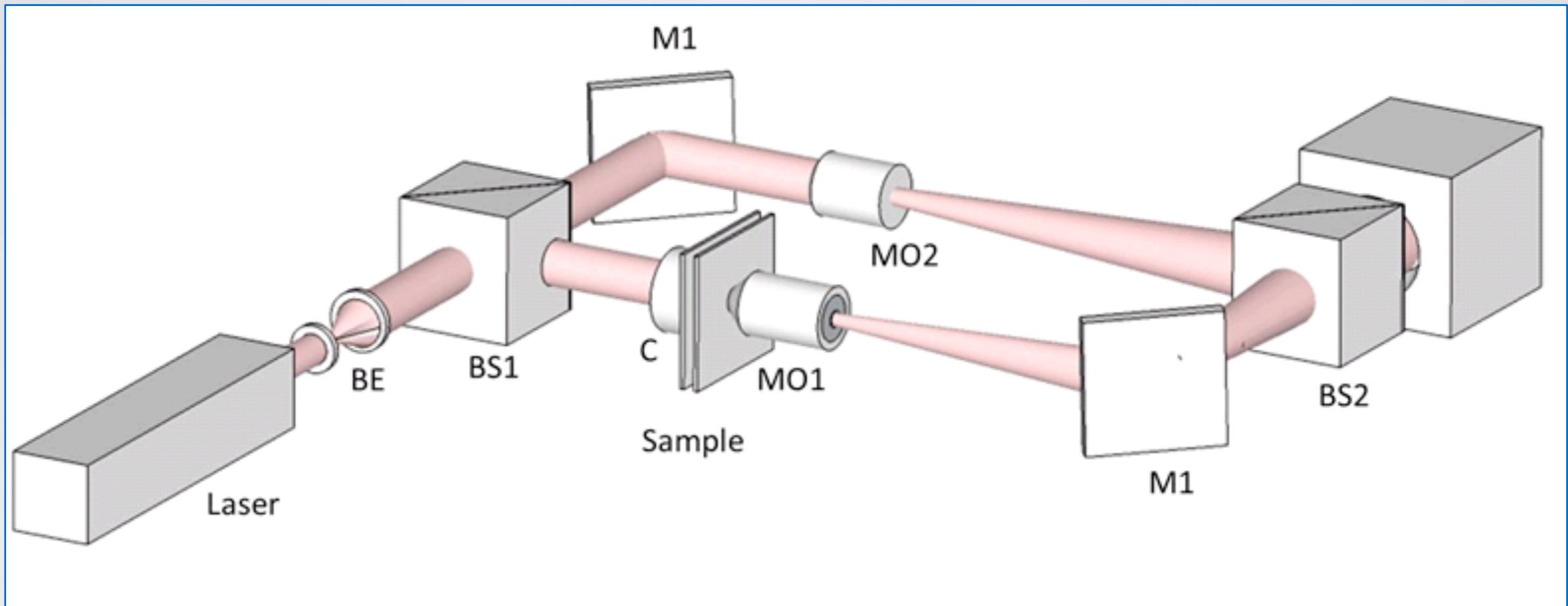
$$B I_2 = B |A|^2 + |BB|^2 + A |B|^2 e^{i\phi} + A^* B^2 e^{-i\phi}$$

# HOLOGRAPHY

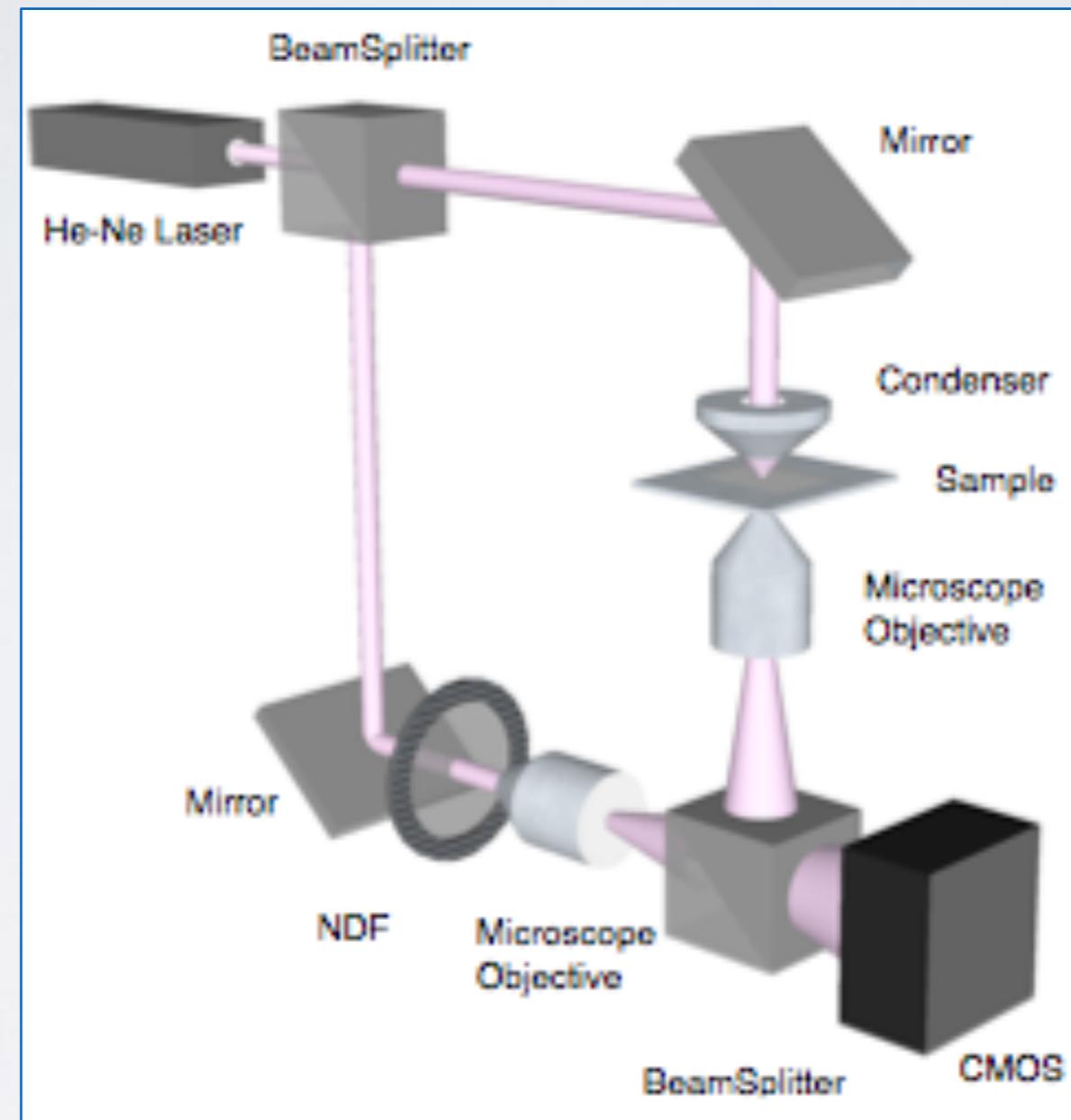


# DIGITAL HOLOGRAPHIC MICROSCOPY

- ▶ Experimental arrangement

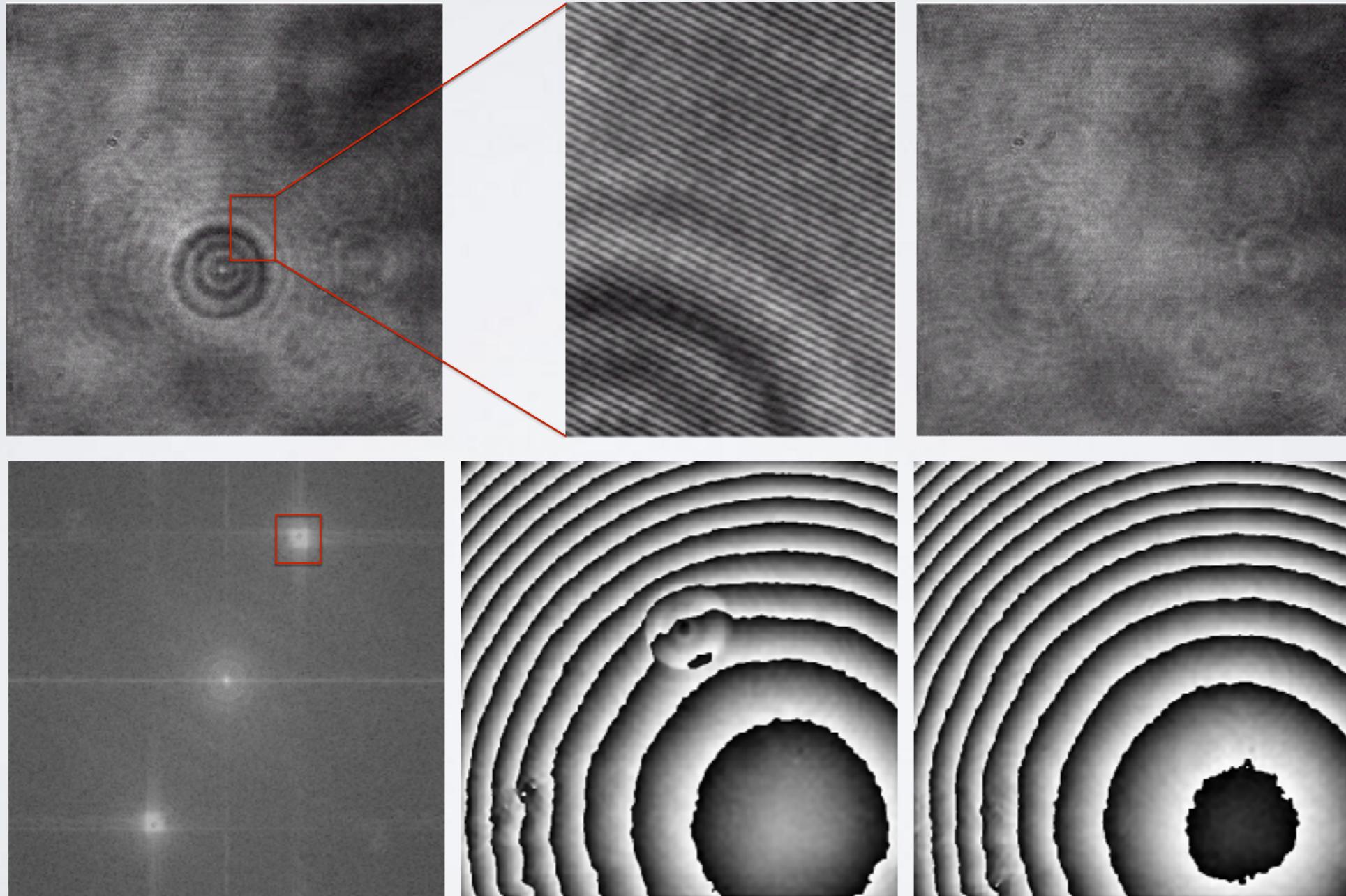


# DIGITAL HOLOGRAPHIC MICROSCOPY



# DIGITAL HOLOGRAPHIC MICROSCOPY

$$E_s^F(x, y, d) = \text{FT}^{-1}\{\text{[FT}\{E_s(x, y, 0)\}\text{]}^F e^{ikd\sqrt{1-\lambda^2 u^2 - \lambda^2 v^2}}\}$$

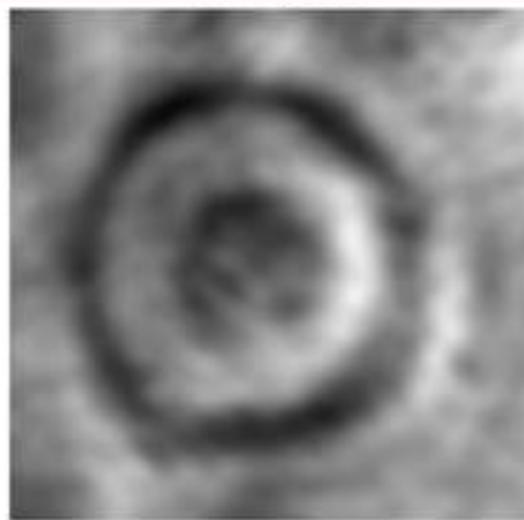
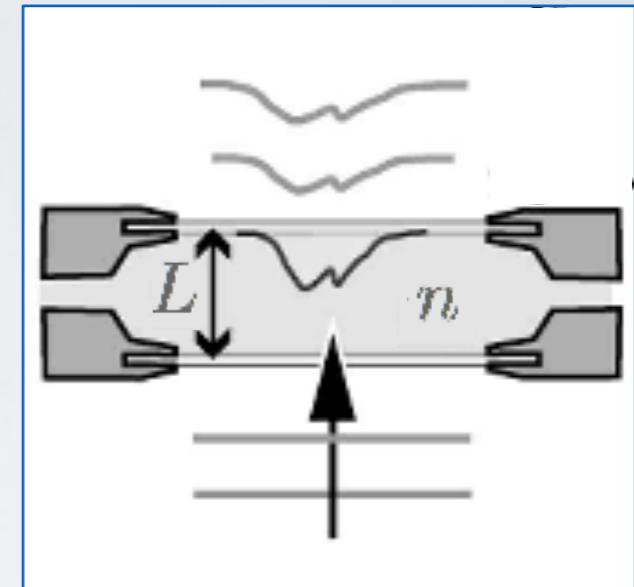


# DIGITAL HOLOGRAPHIC MICROSCOPY

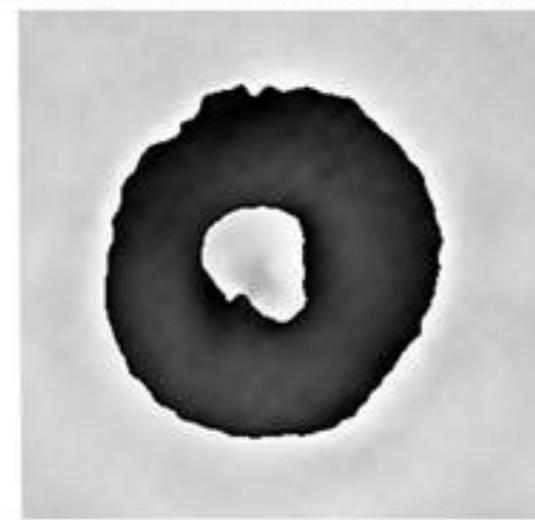
$$I_s(x, y, z) = |E_s^F(x, y, z)|^2$$

$$\phi_s(x, y, z) = \arctan \frac{\text{Im} E_s^F(x, y, z)}{\text{Re} E_s^F(x, y, z)}$$

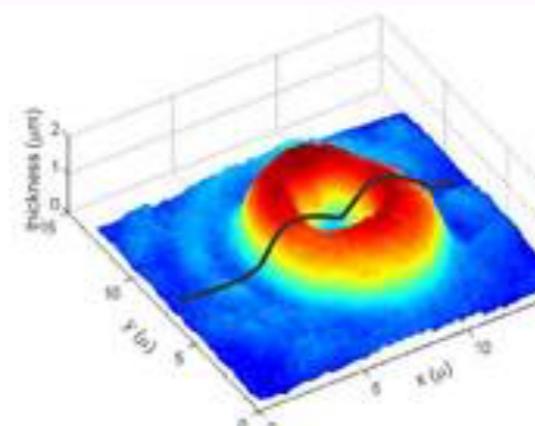
$$\phi_s(x, y) = \frac{2\pi}{\lambda} n(x, y) L(x, y)$$



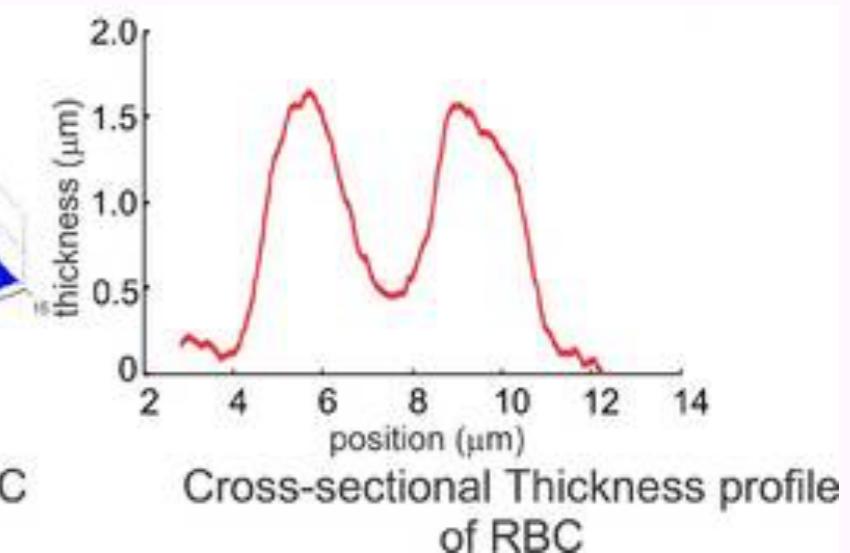
Reconstructed intensity



Quantitative phase contrast image



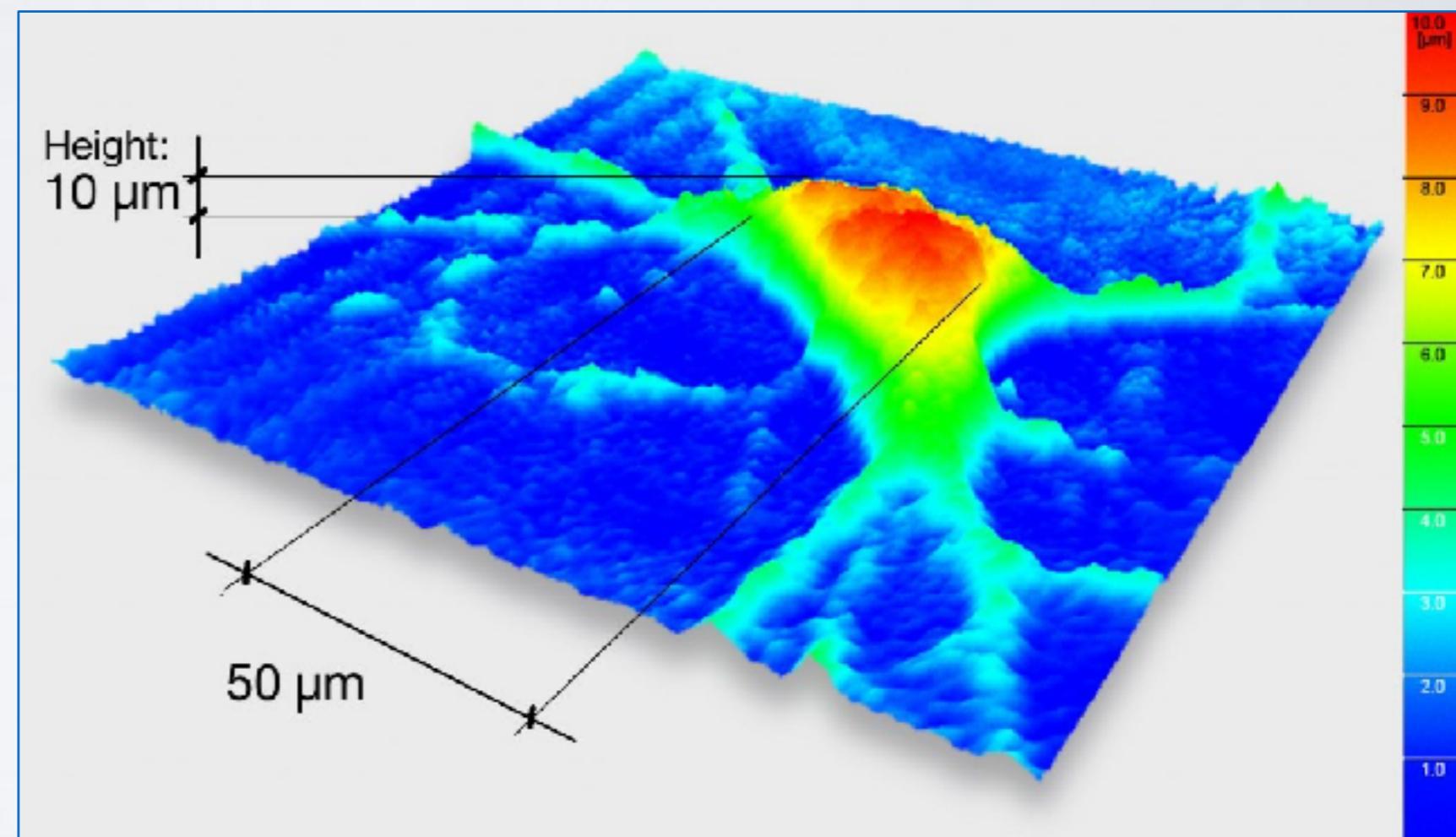
Thickness profile of RBC



Cross-sectional Thickness profile of RBC

# DIGITAL HOLOGRAPHIC MICROSCOPY

- ▶ High lateral resolution down to 300nm
- ▶ Nanometric thickness resolution
- ▶ No contrast agents
- ▶ Non-invasiveness
- ▶ No phototoxicity
- ▶ Speedy
- ▶ Dynamic
- ▶ Quantitative
- ▶ Multi-modal



# DHM APPLICATIONS

Transparent specimen:

- ▶ Biology applications
- ▶  $\mu$ Fluidics

Reflective specimen:

- ▶ Metallurgy and mechanical engineering applications

Any drawback?

# DIGITAL HOLOGRAPHIC MICROSCOPY

Technique improvement:

Self-referencing Setups

Super-resolution Techniques

Integration with other methodologies:

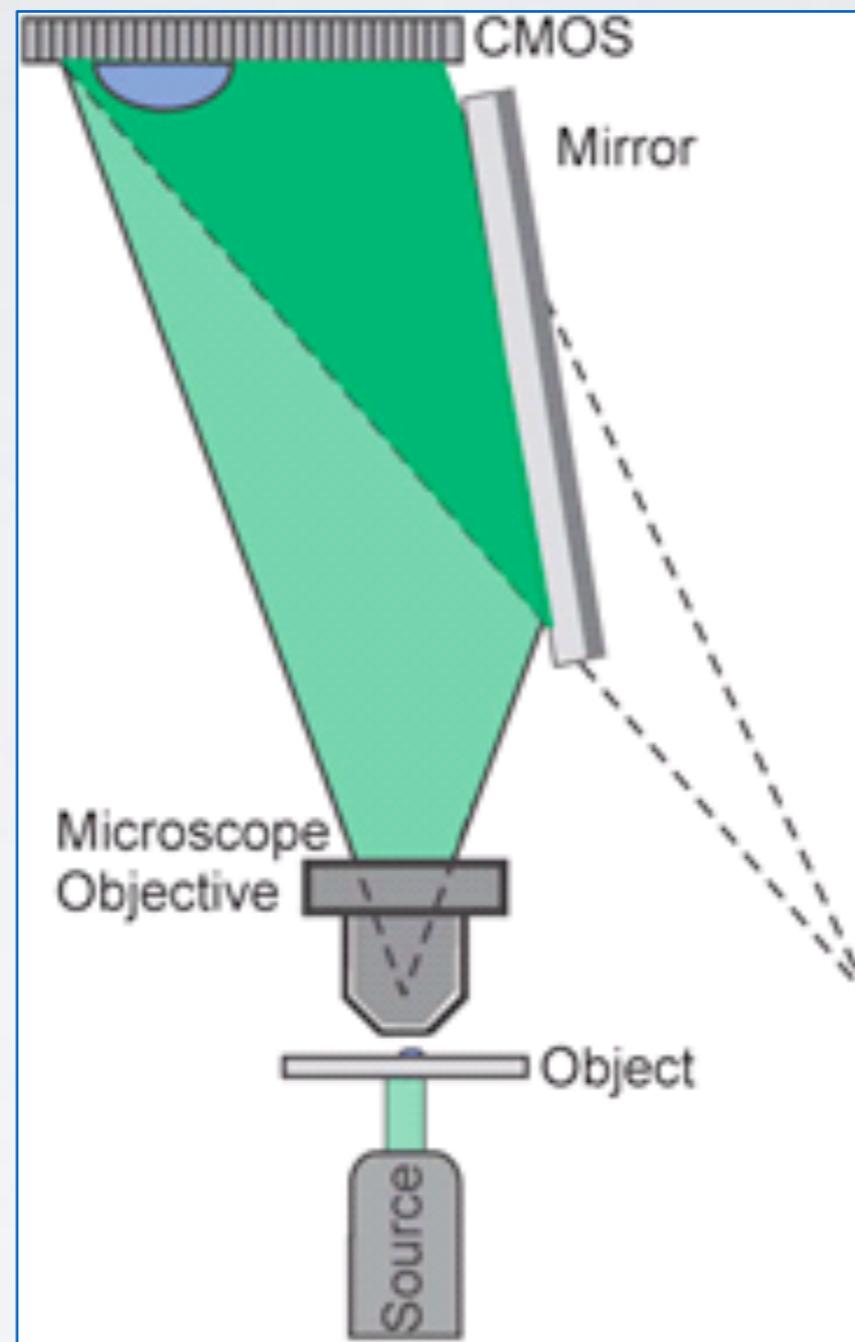
Optical/Acoustical Trapping

Fluorescent/Hyperspectral/ Thermal lens/... Microscopy

Spectroscopy Techniques

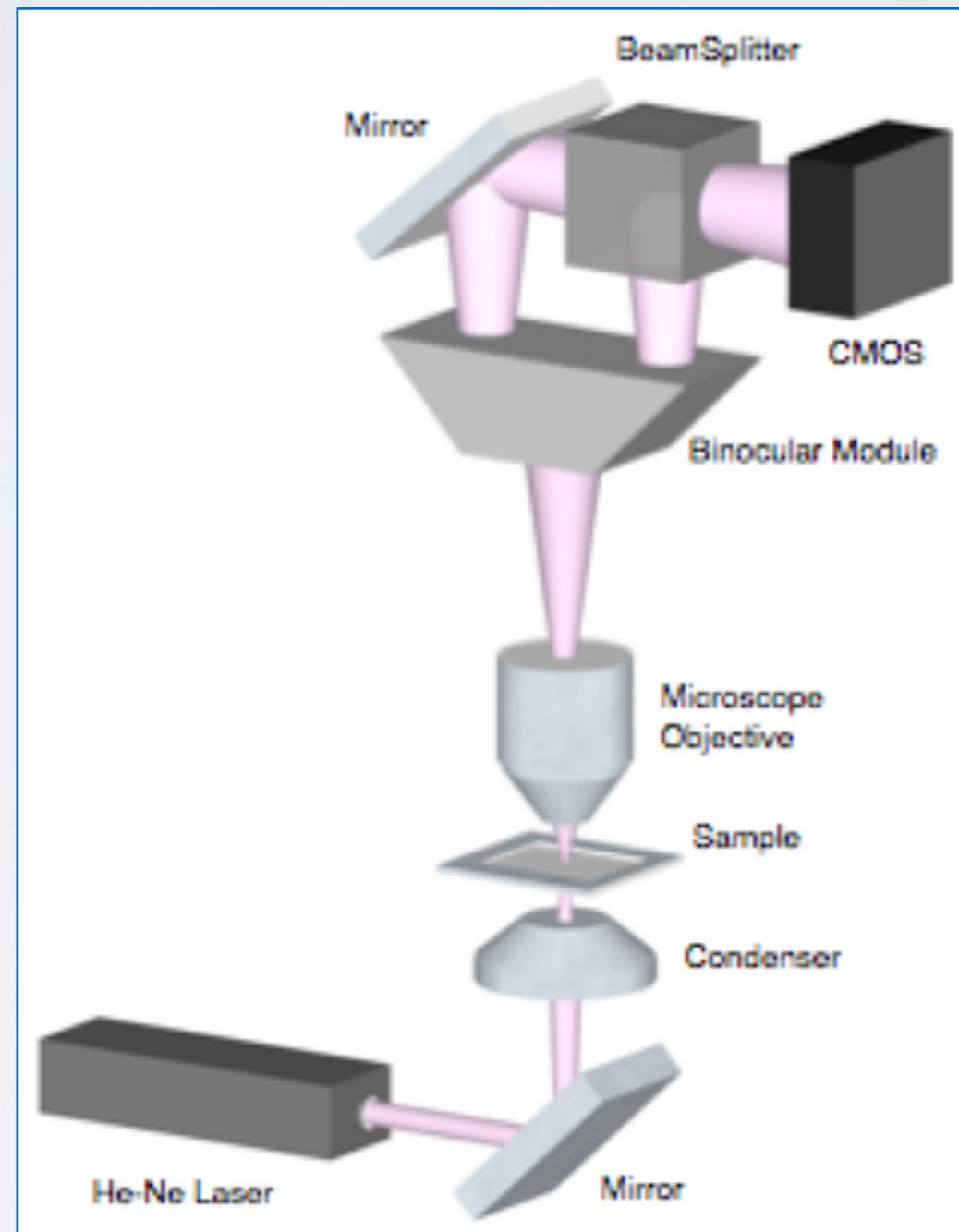
# SELF-REFERENCING SCHEMES

- ▶ Loyd's mirror



# SELF-REFERENCING SCHEMES

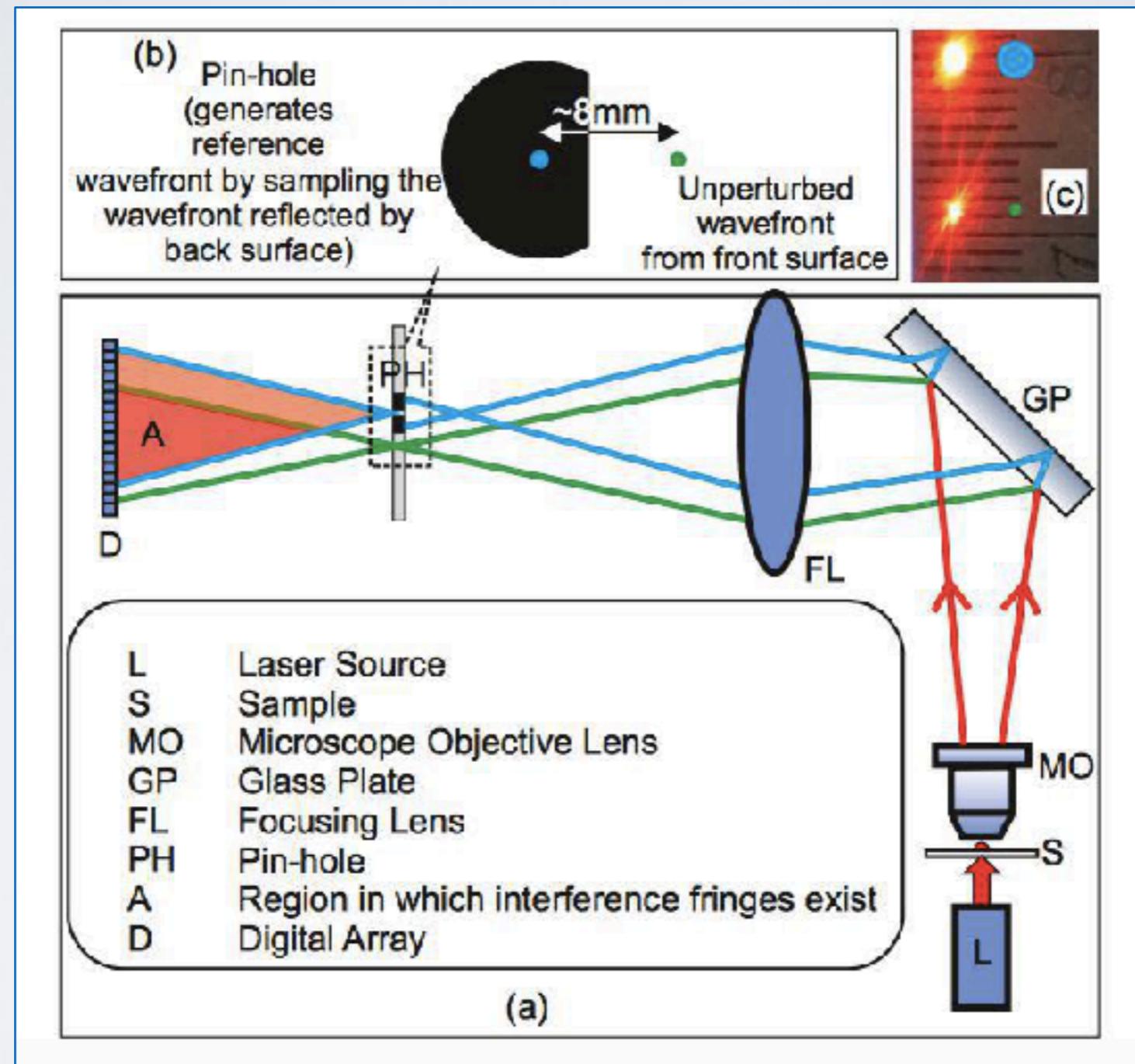
- ▶ Binocular module



S. Ebrahimi et al., Opt. Lett. 39(10), 2014

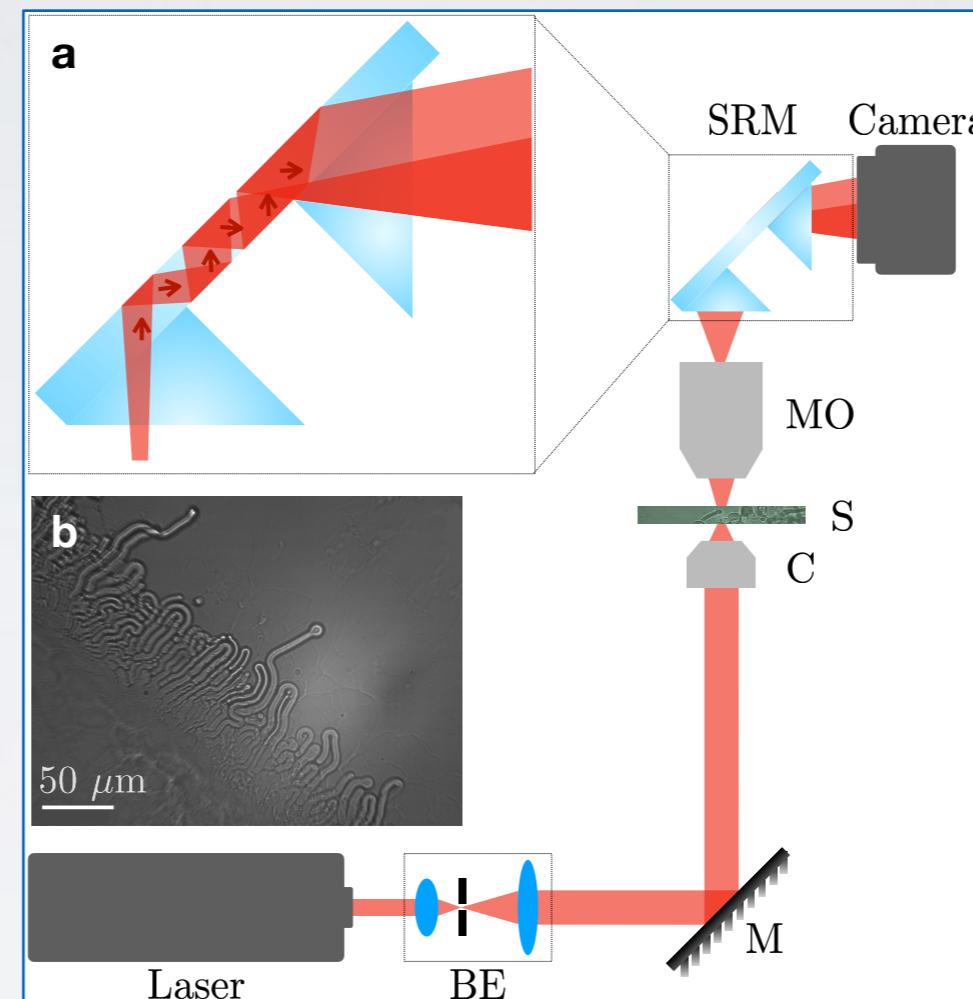
# SELF-REFERENCING SCHEMES

- Wide-field shearing



# SELF-REFERENCING SCHEMES

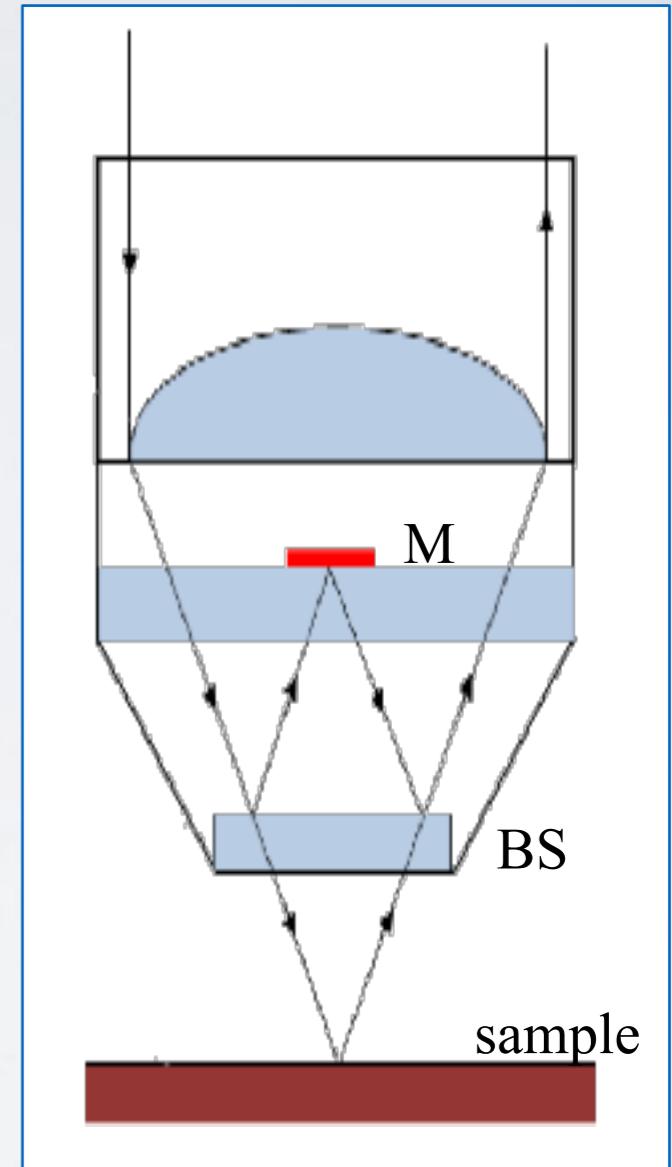
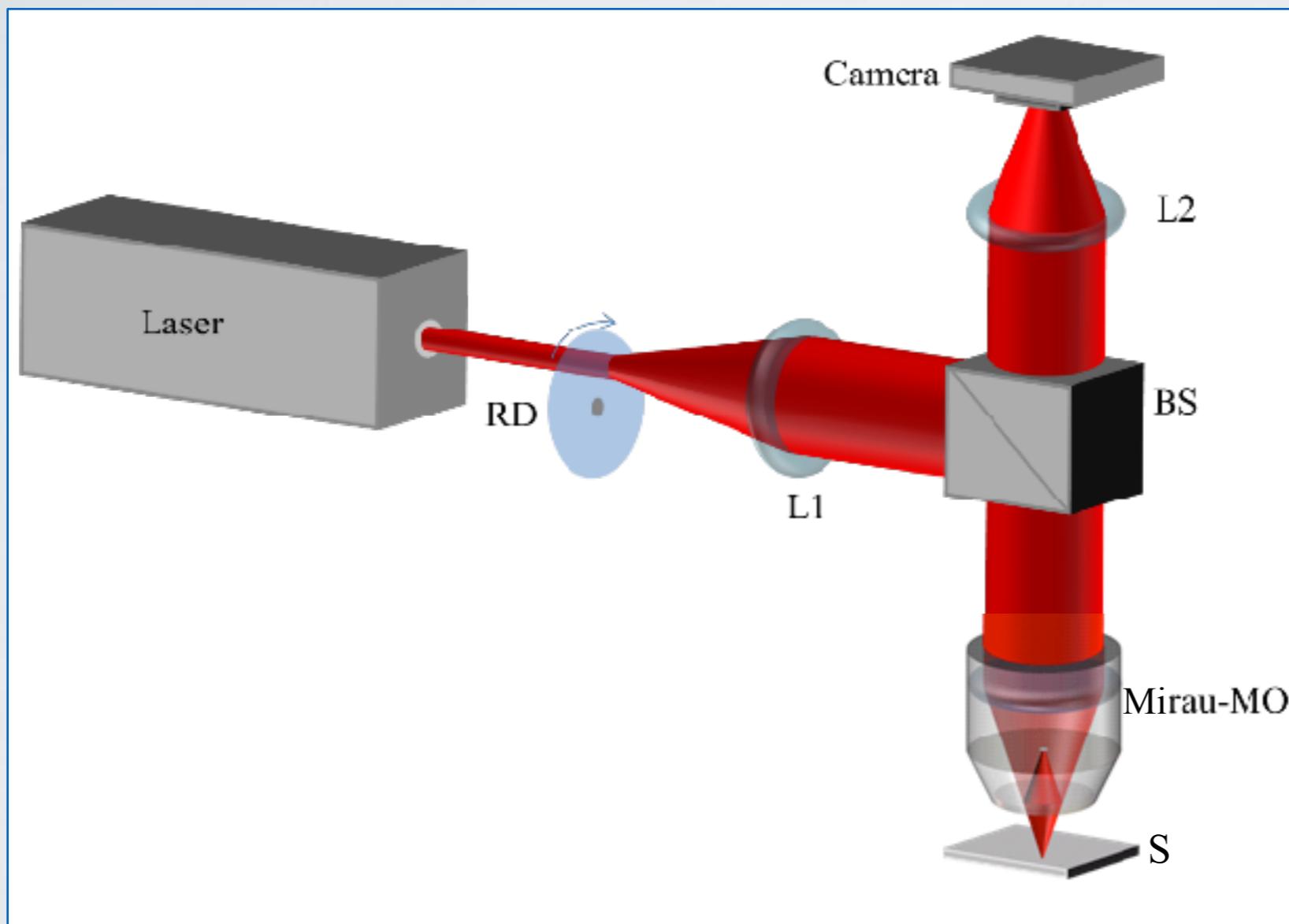
- ▶ Variable shearing



M.Allahpanahi et al., Biomed. Opt. Express. 11(10), 2020

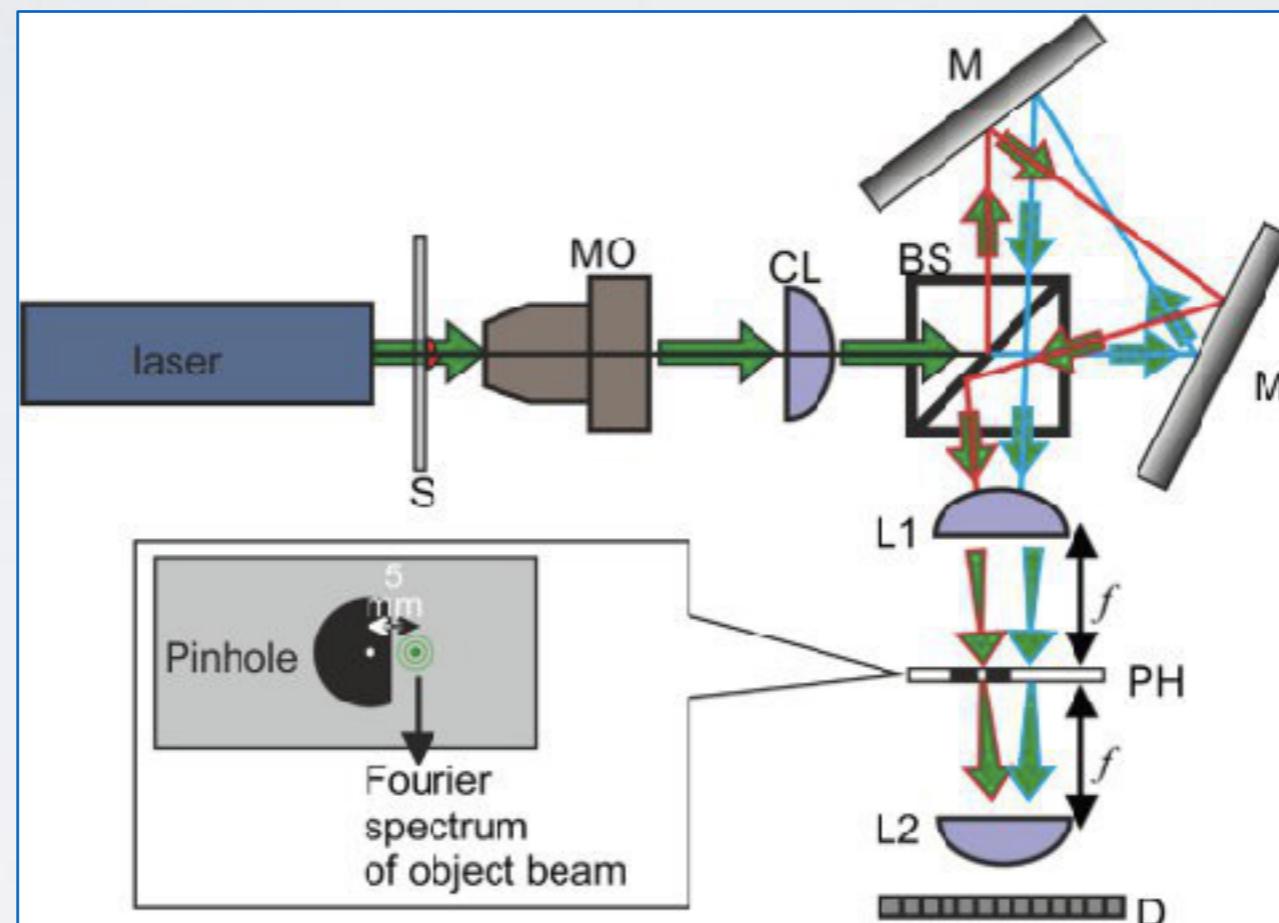
# SELF-REFERENCING SCHEMES

- ▶ Mirau



# SELF-REFERENCING SCHEMES

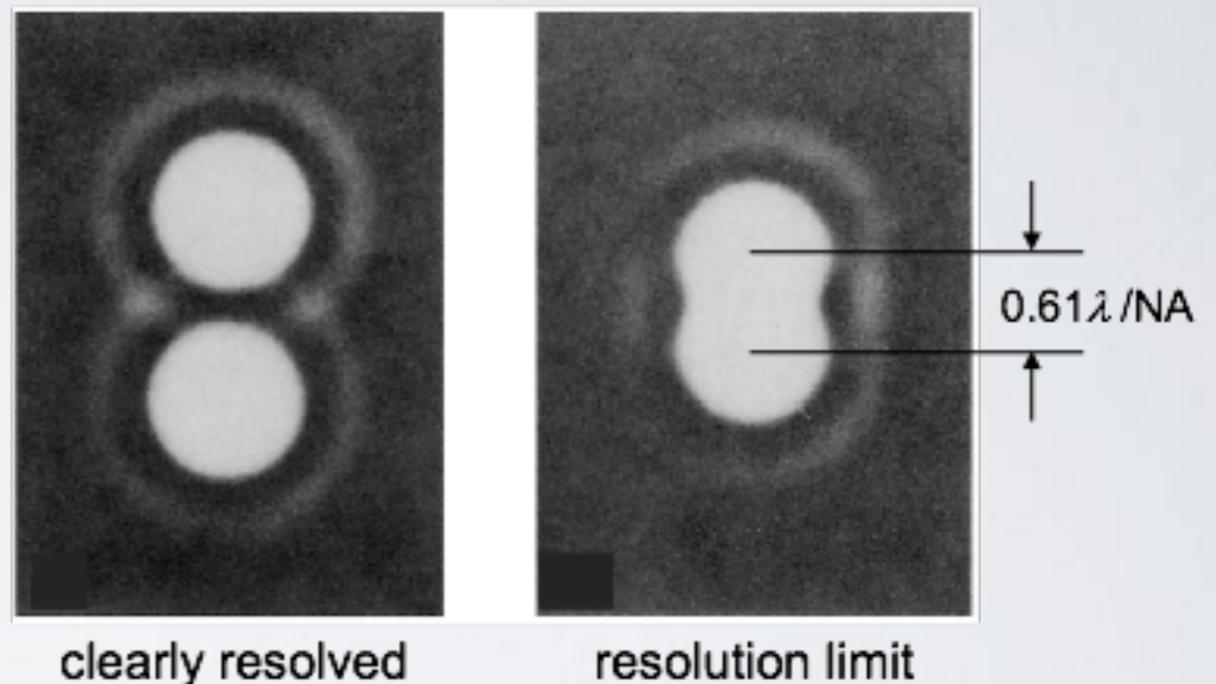
- Sagnac



S. Mahajan et al., Opt. Lett. 40(16), 2015

# SUPER-RESOLUTION TECHNIQUES

- ▶ Rayleigh criterion



Resolution  $\sim 0.61\lambda/NA$

Dry objectives:  $NA < 1.0$

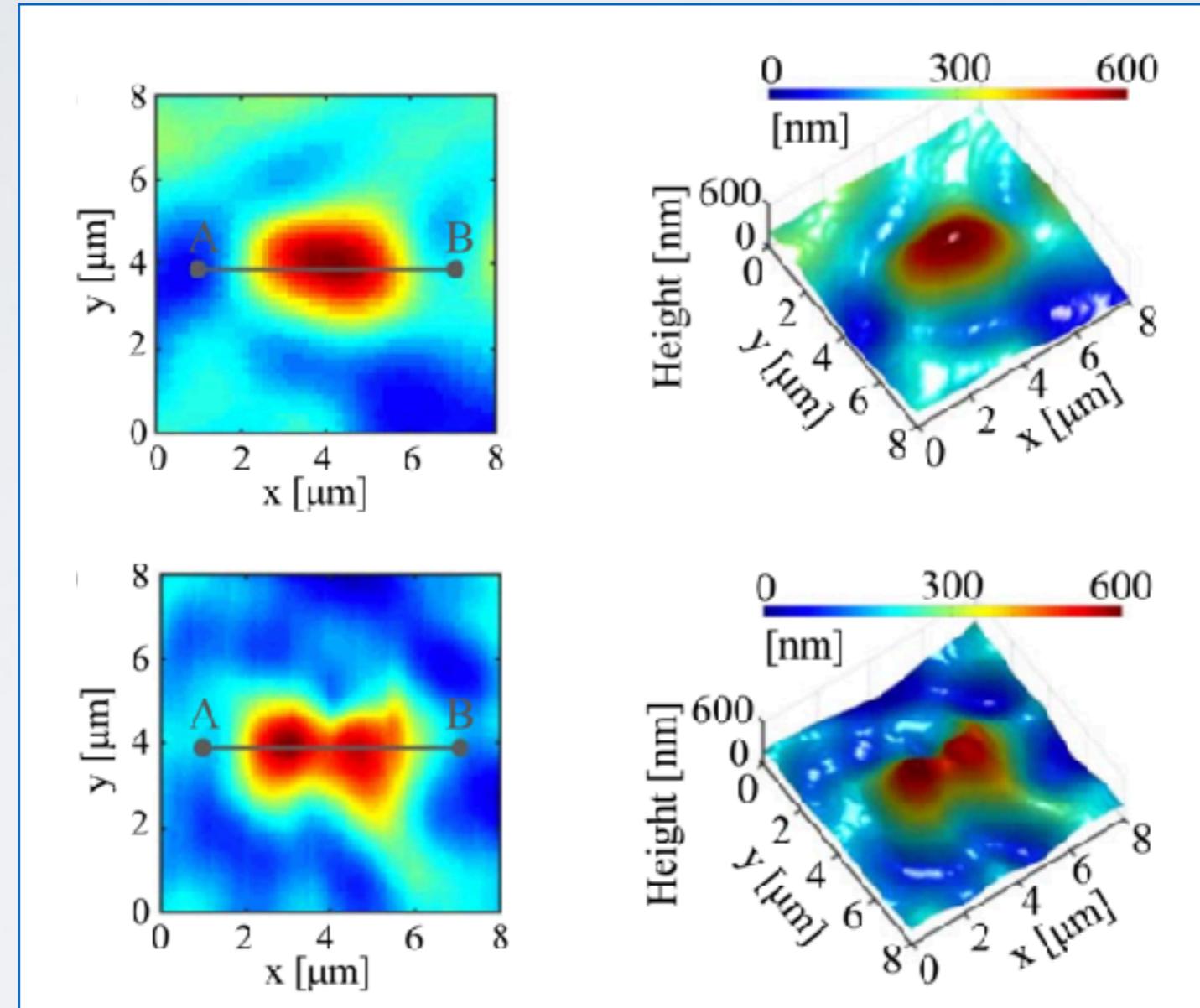
Medium immersion objectives:  $NA < 1.5$

# SUPER-RESOLUTION TECHNIQUES

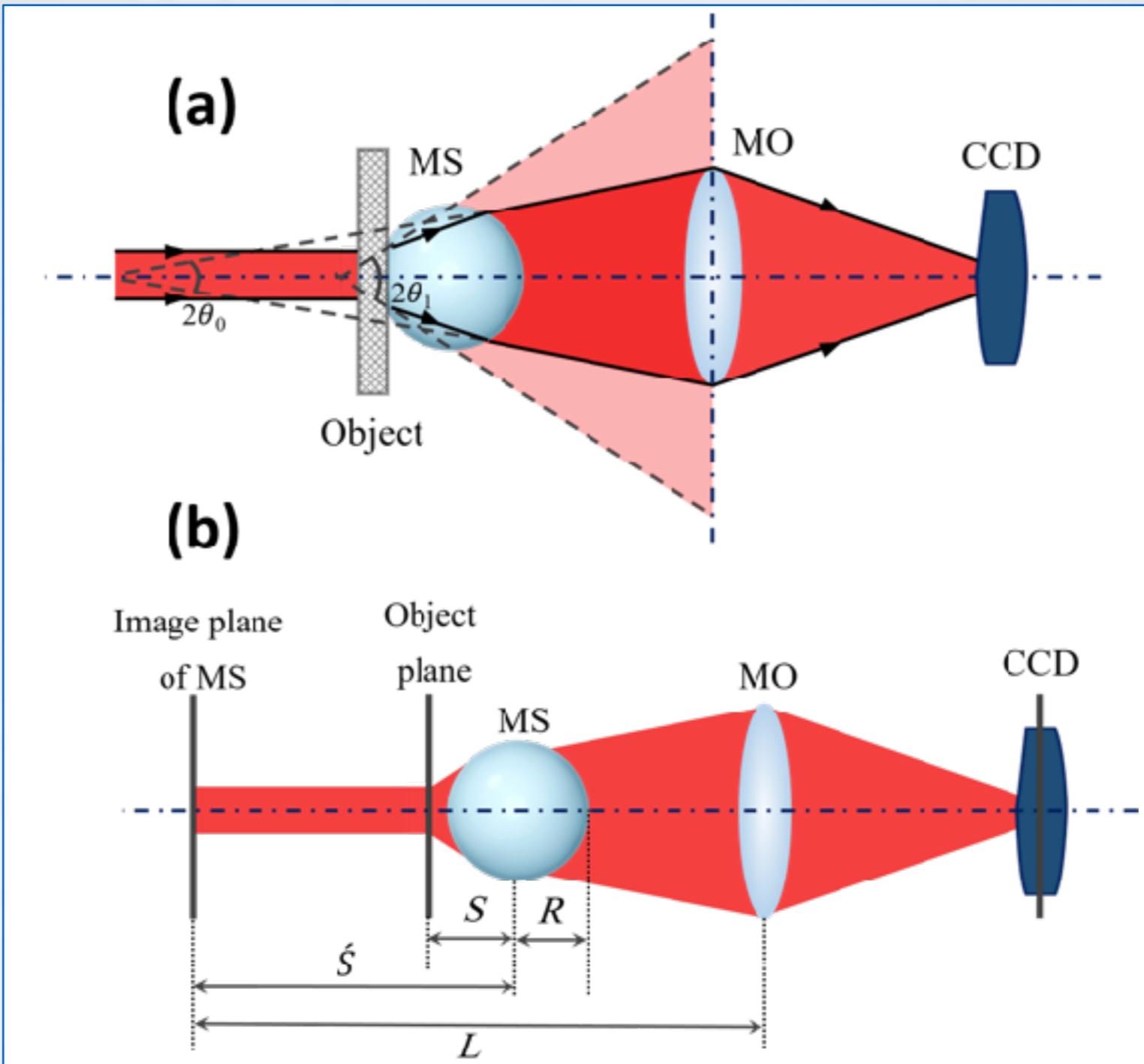
- Electron beam microscopes
- Diffraction free microscopies; Near field
- Clever ideas; SIM, PALM, STORM, STED,..
- Negative refractive index
- Geometrical super-resolution
- Micro-sphere assisted SR imaging
- Some of the SR techniques may be applied to DHM
- Microsphere assisted DHM
- Structured illumination DHM
- Oblique illumination
- Novel beams (Lagurre-Gaussian, Bessel, Airy)

# SUPER-RESOLUTION TECHNIQUES

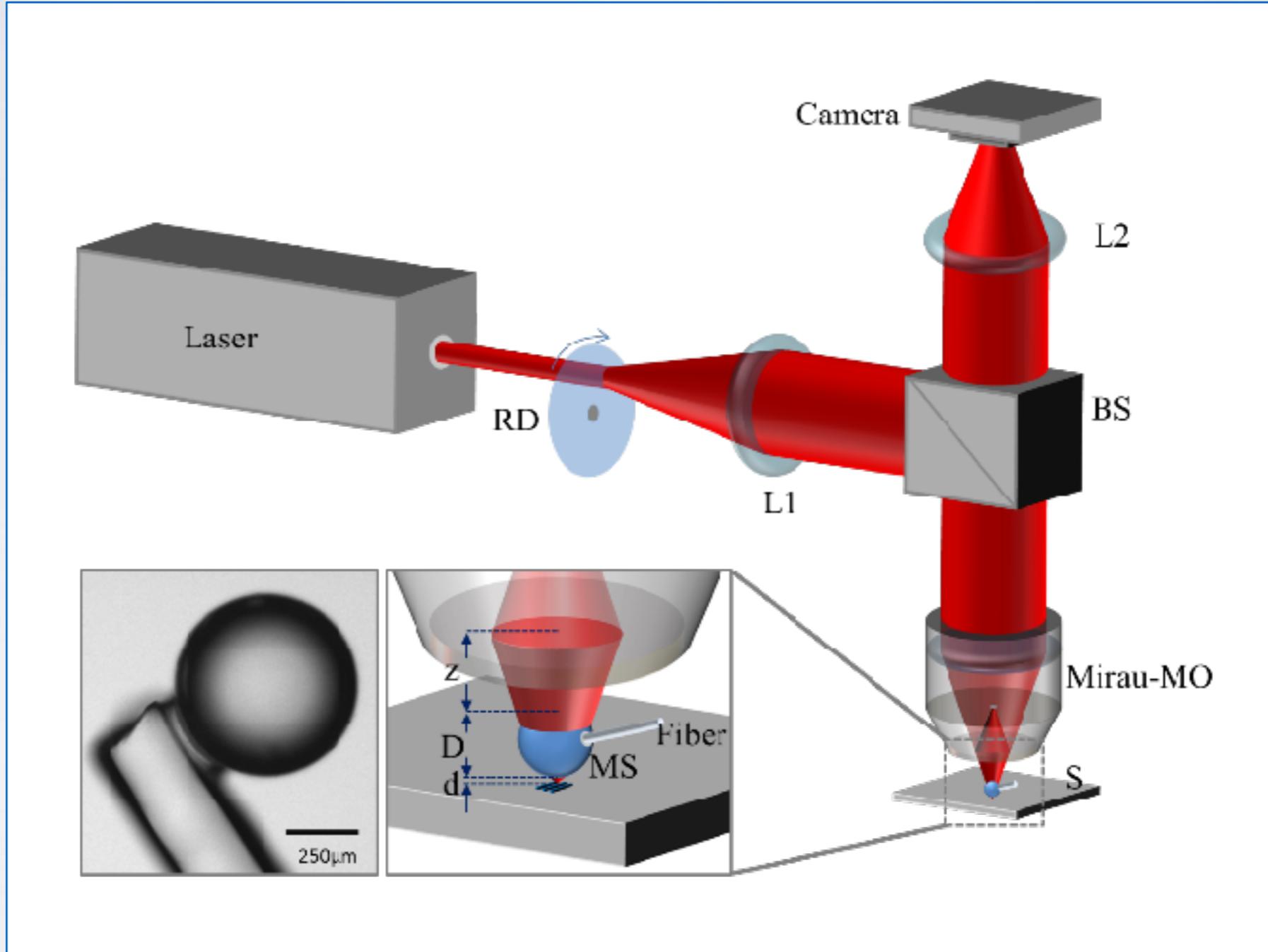
►



# SUPER-RESOLUTION TECHNIQUES



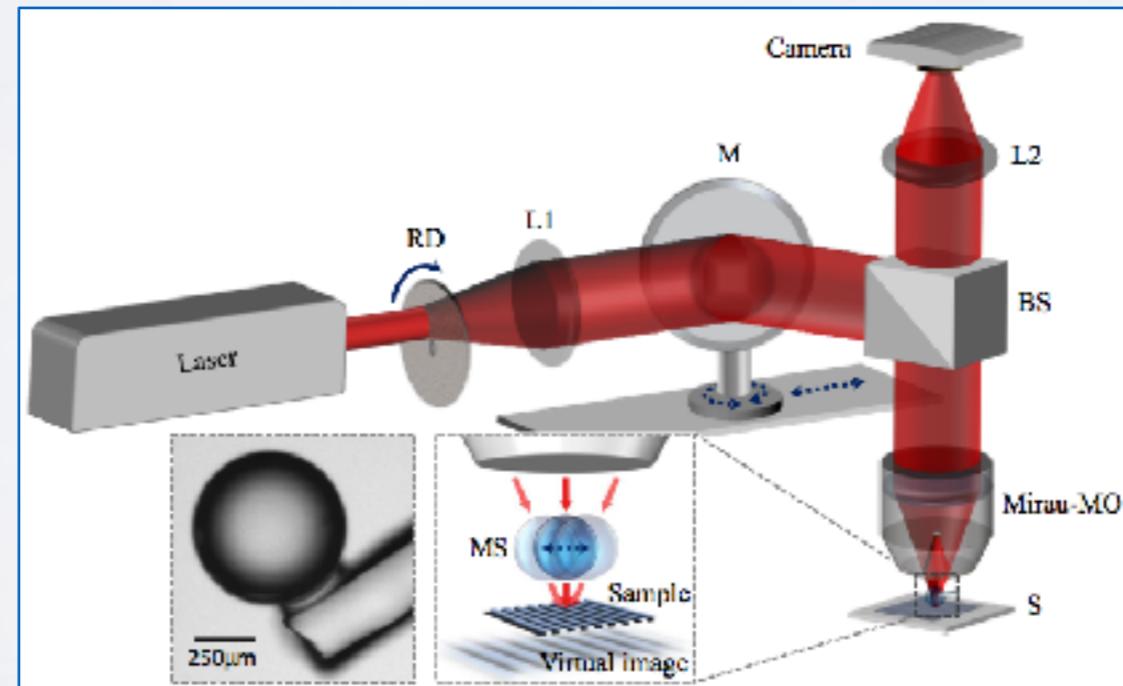
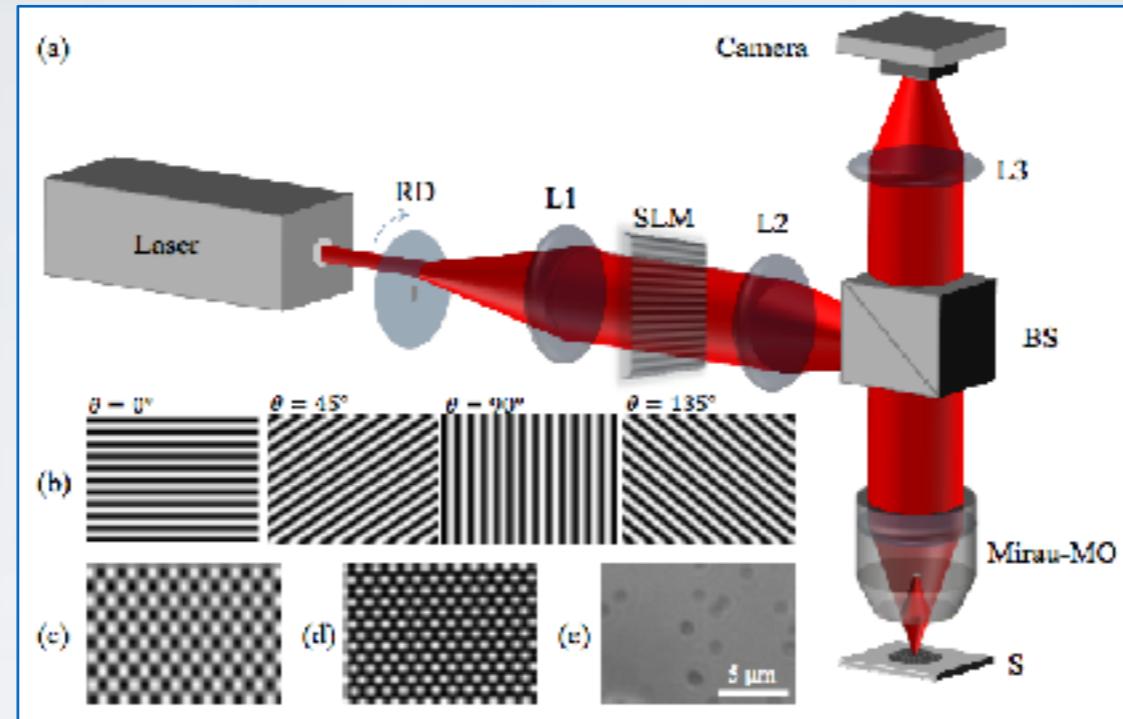
# SUPER-RESOLUTION TECHNIQUES



M.Aakhteh et al., Appl. Opt. 56(9), 2017

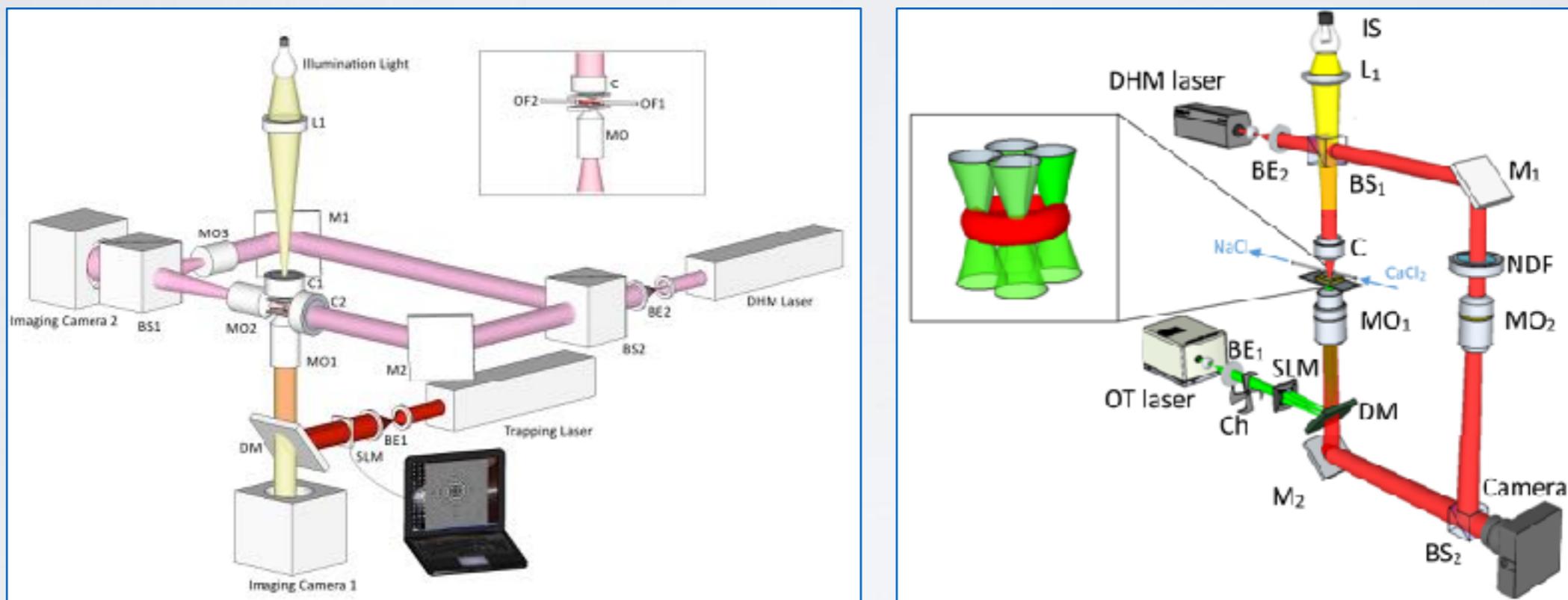
# SUPER-RESOLUTION TECHNIQUES

►



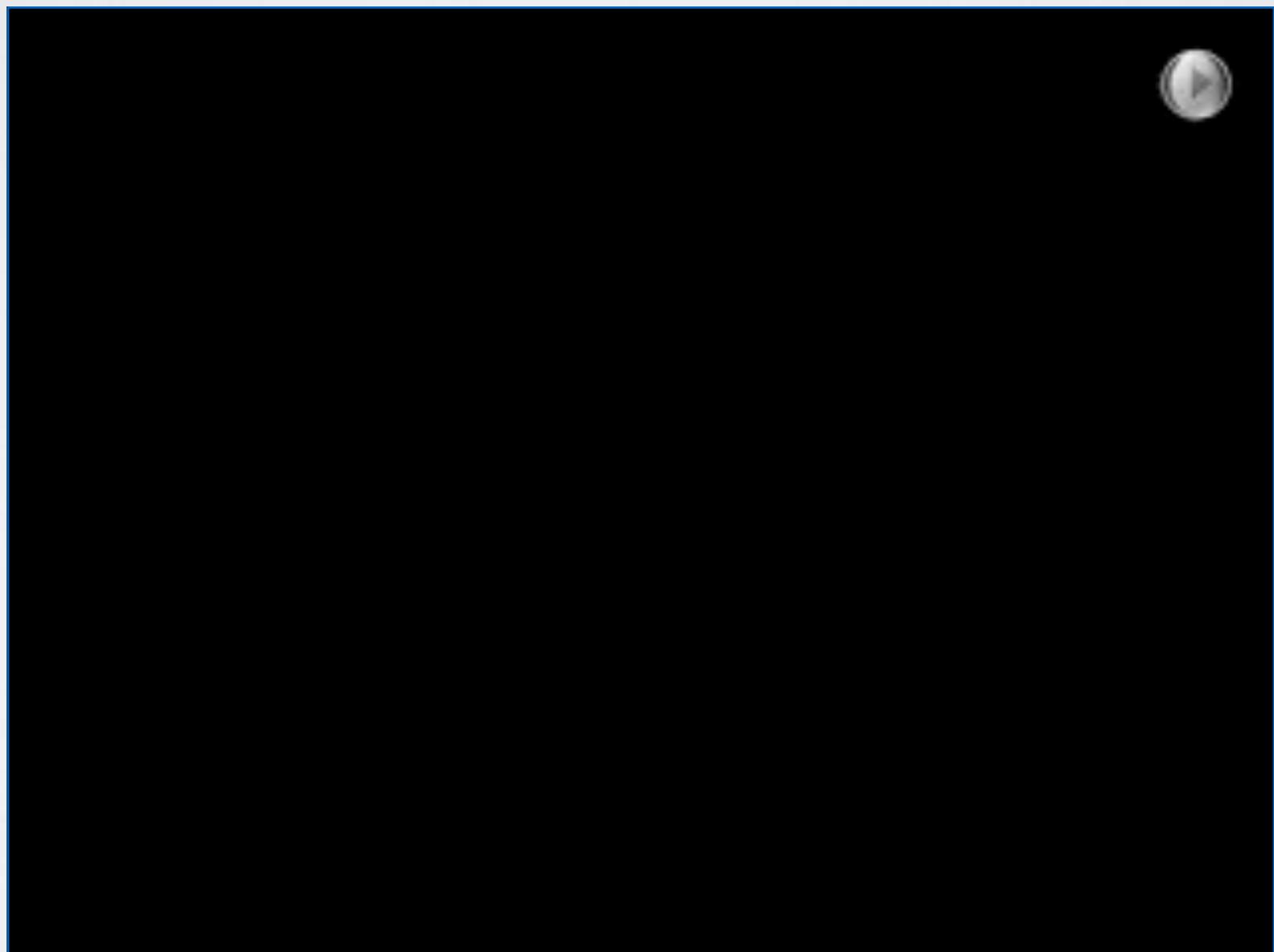
# DHM - OPTICAL TRAPPING

## ► Schemes



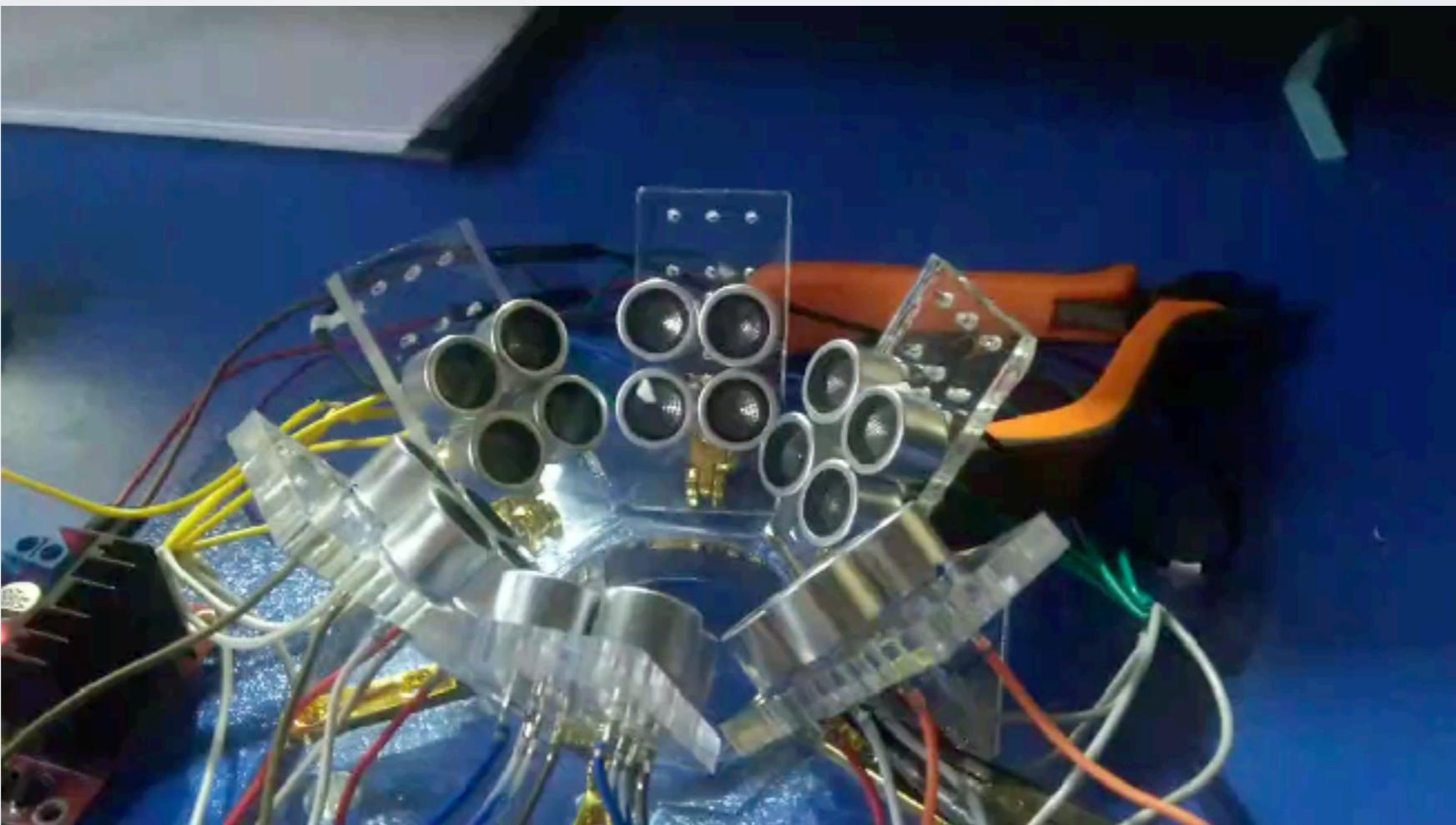
# DHM - OPTICAL TRAPPING

- ▶ RBC



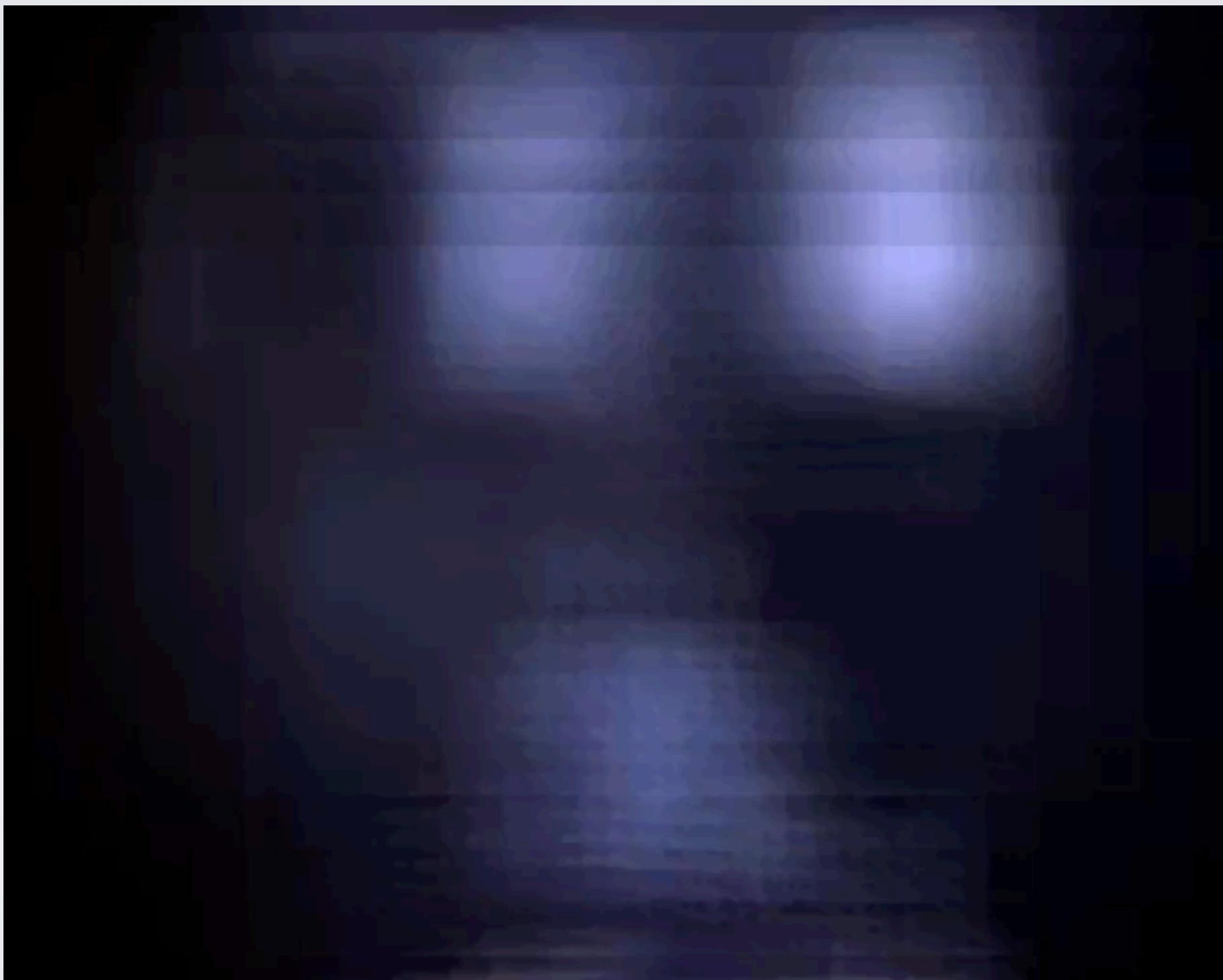
# DHM - ACOUSTICAL TRAPPING

- ▶ Schemes

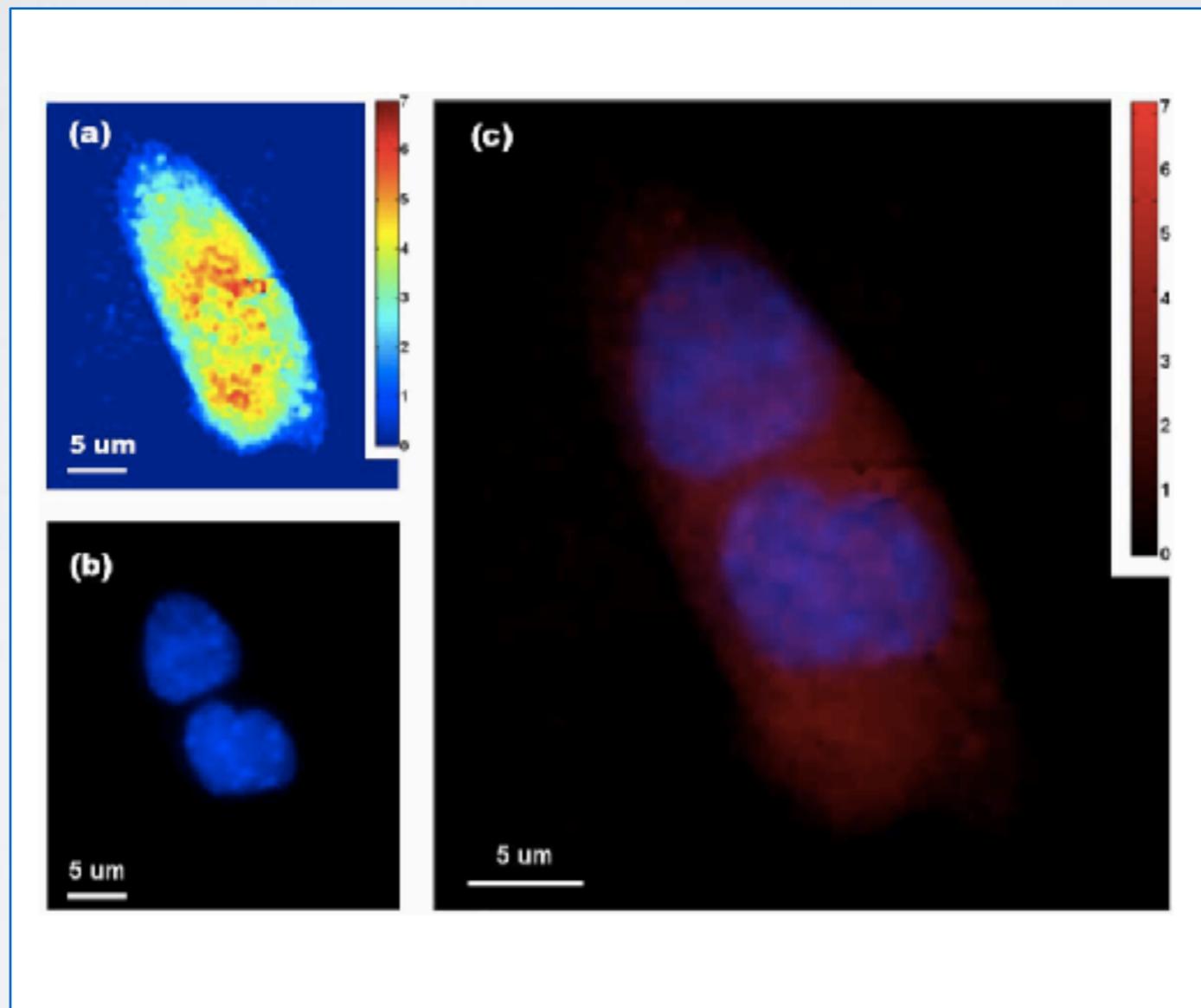


## II - ACOUSTICAL TRAPPING

- ▶ Schemes



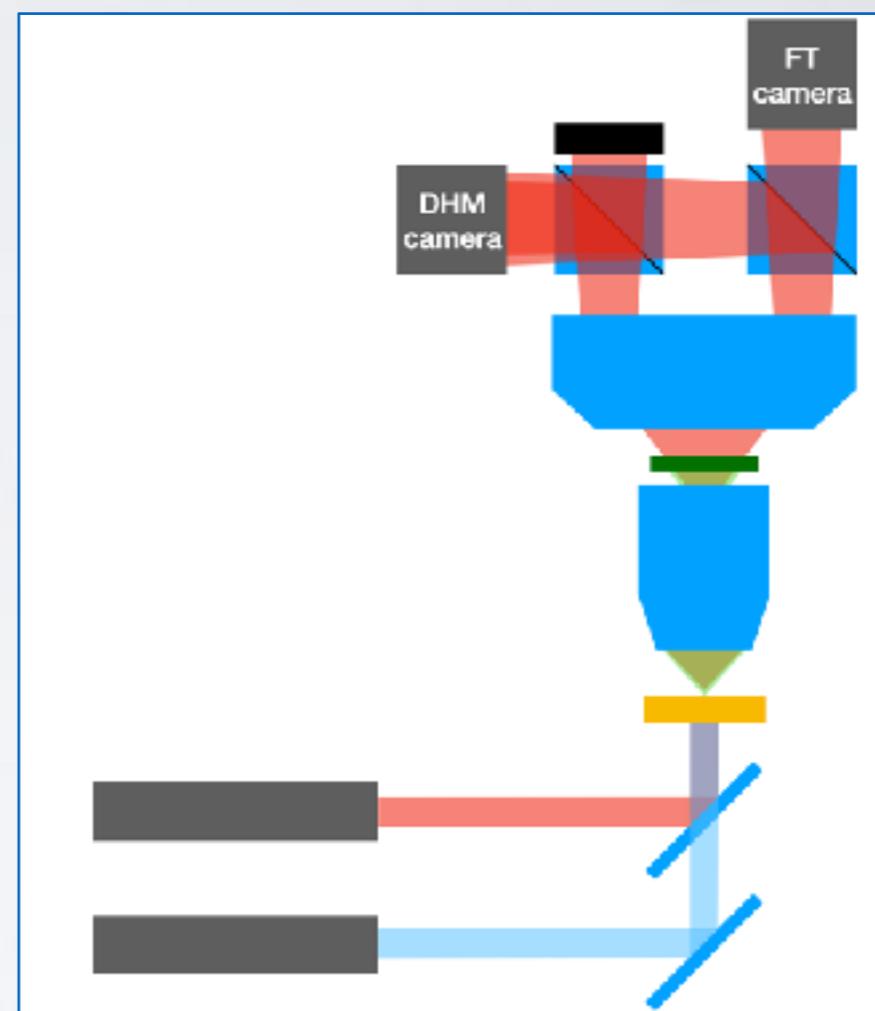
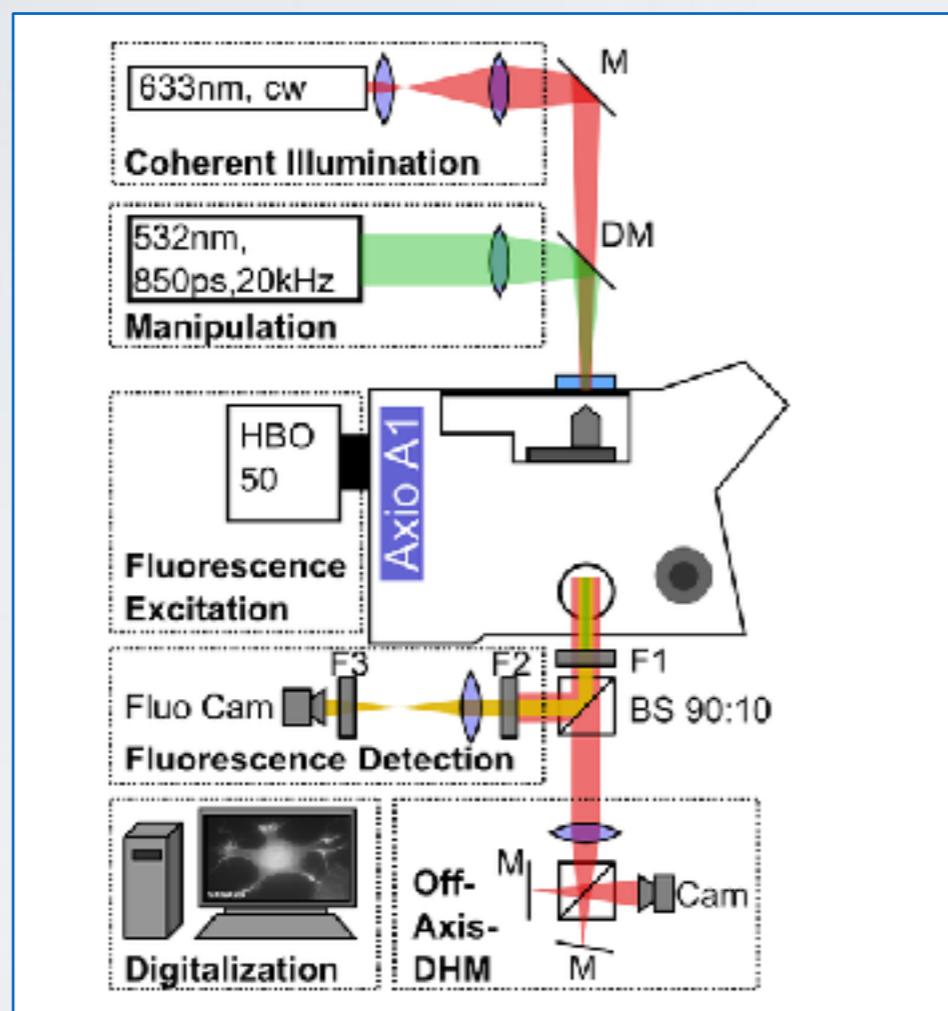
# DHM - FLUORESCENCE MICROSCOPY



X. Quan et al. Opt Rev (2015) 22:349–353

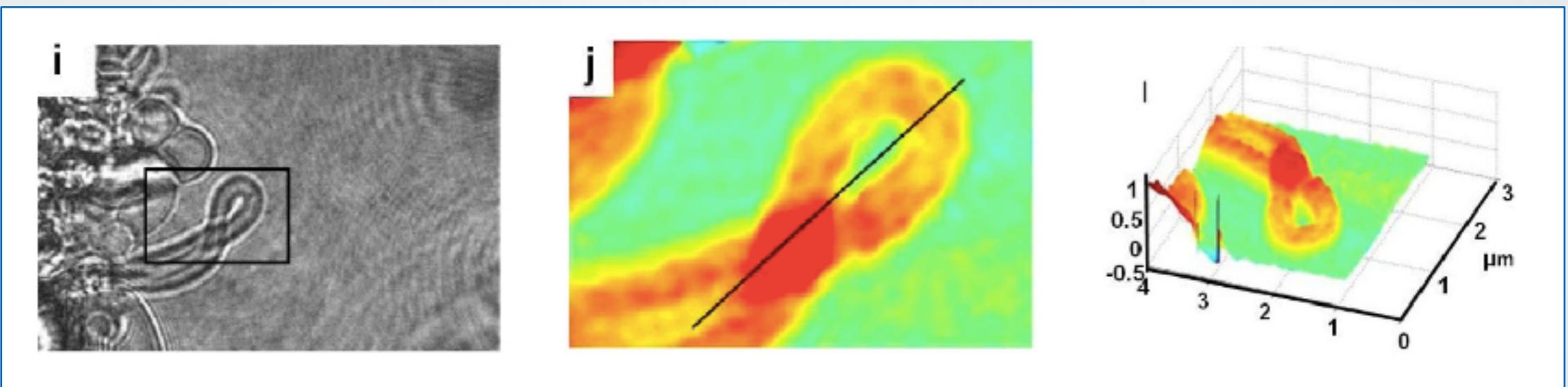
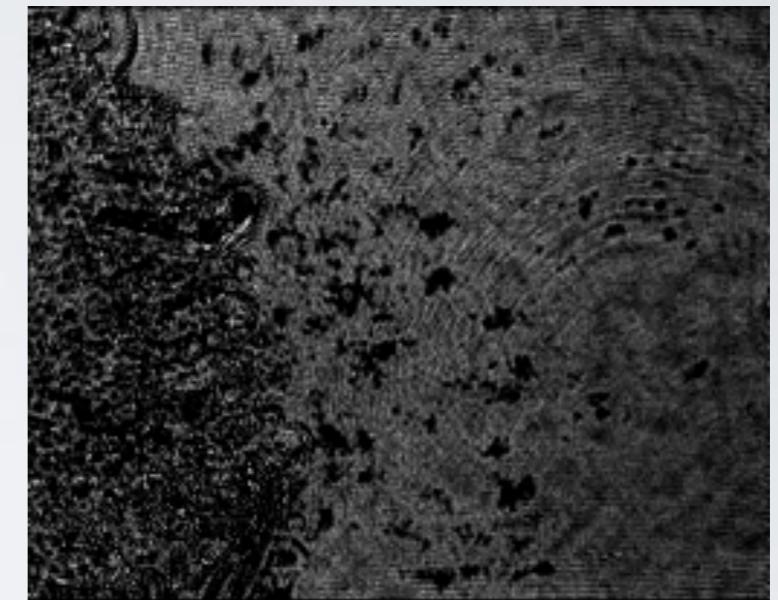
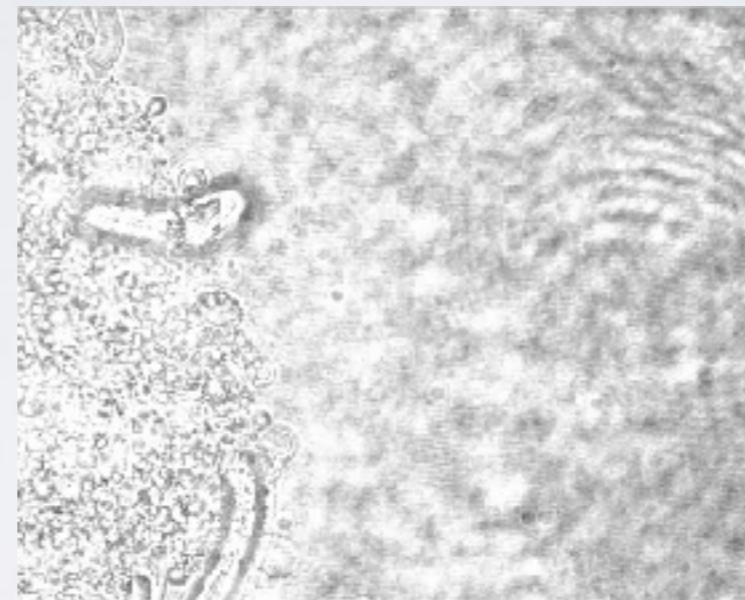
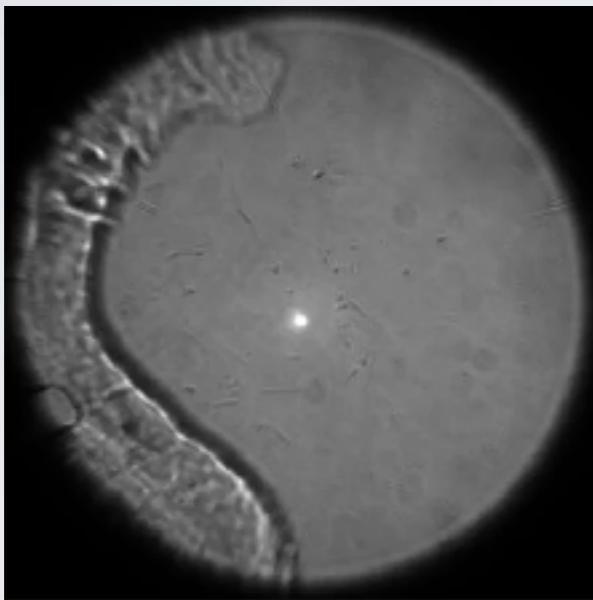
# DHM - FLUORESCENCE MICROSCOPY

## ► Schemes



# 3D IMAGING APPLICATIONS

- ▶ Myelin figures

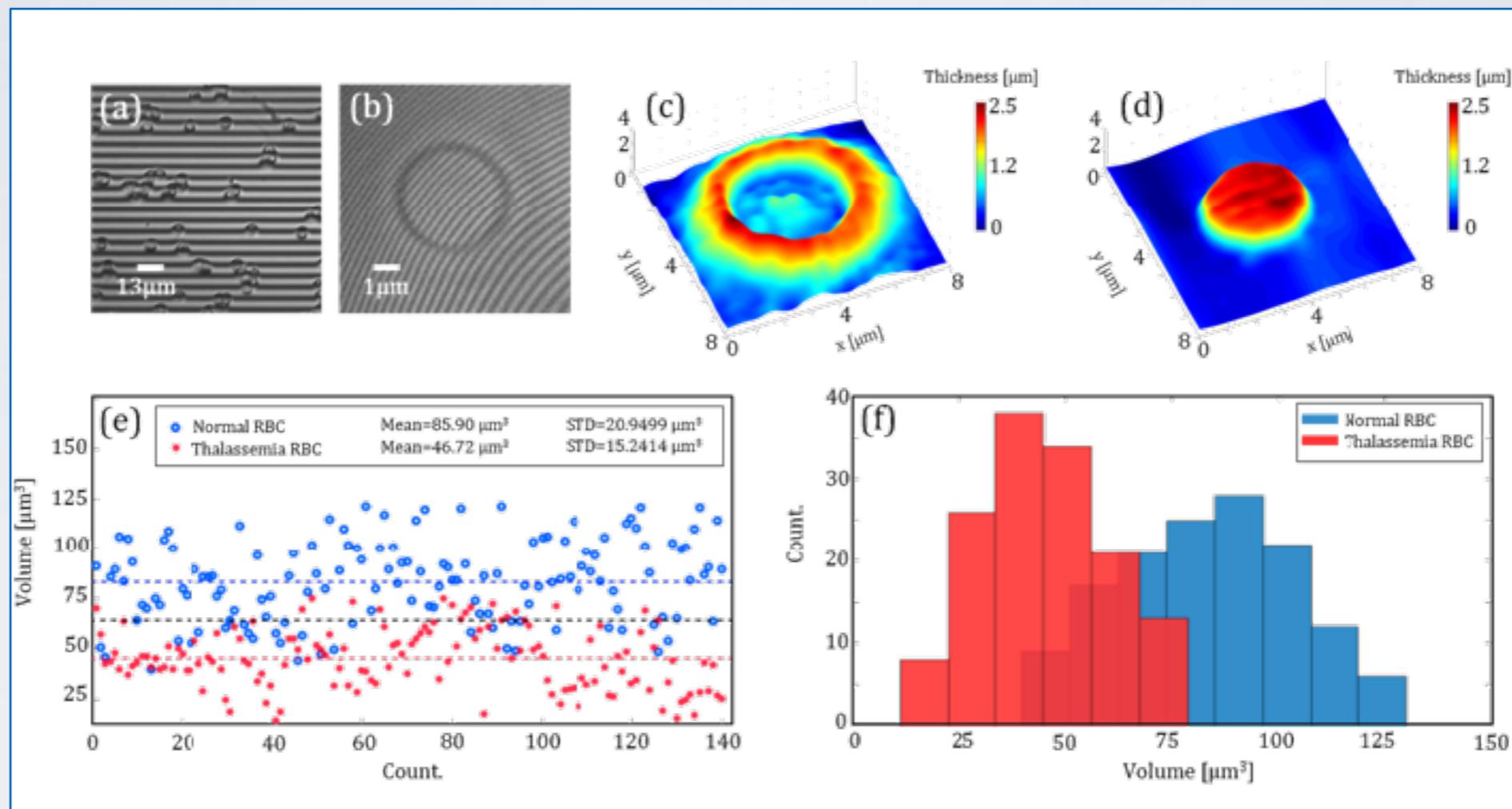


N. Fathi et al. Biomed. Opt. Express 11(11), 6324, 2013

Matt. Lett. 173, pp. 162-166, 2016

# 3D IMAGING APPLICATIONS

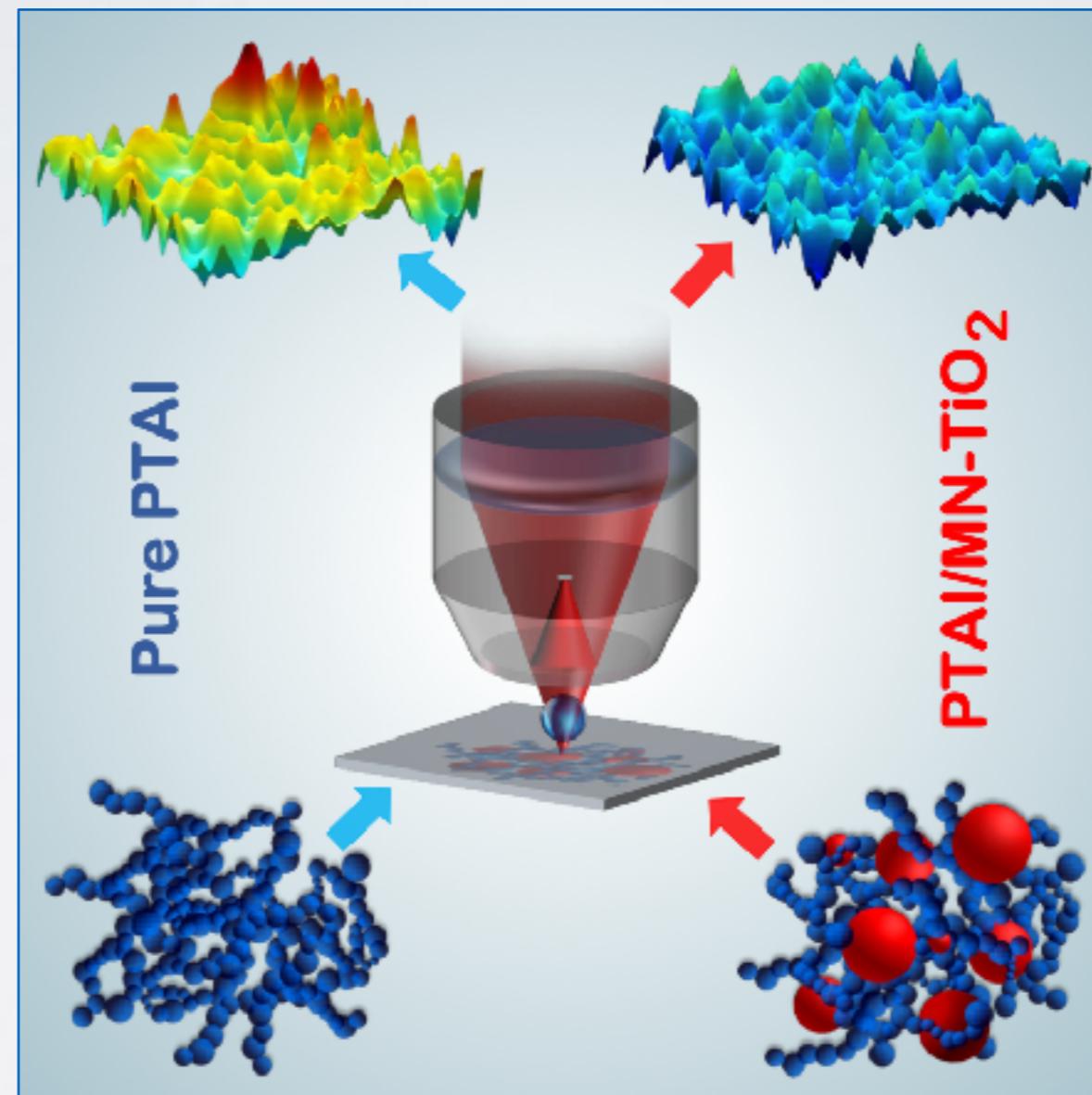
## ► RBCs



M.Aakhteh et al., Appl. Opt. 56(9), 2017

# 3D IMAGING APPLICATIONS

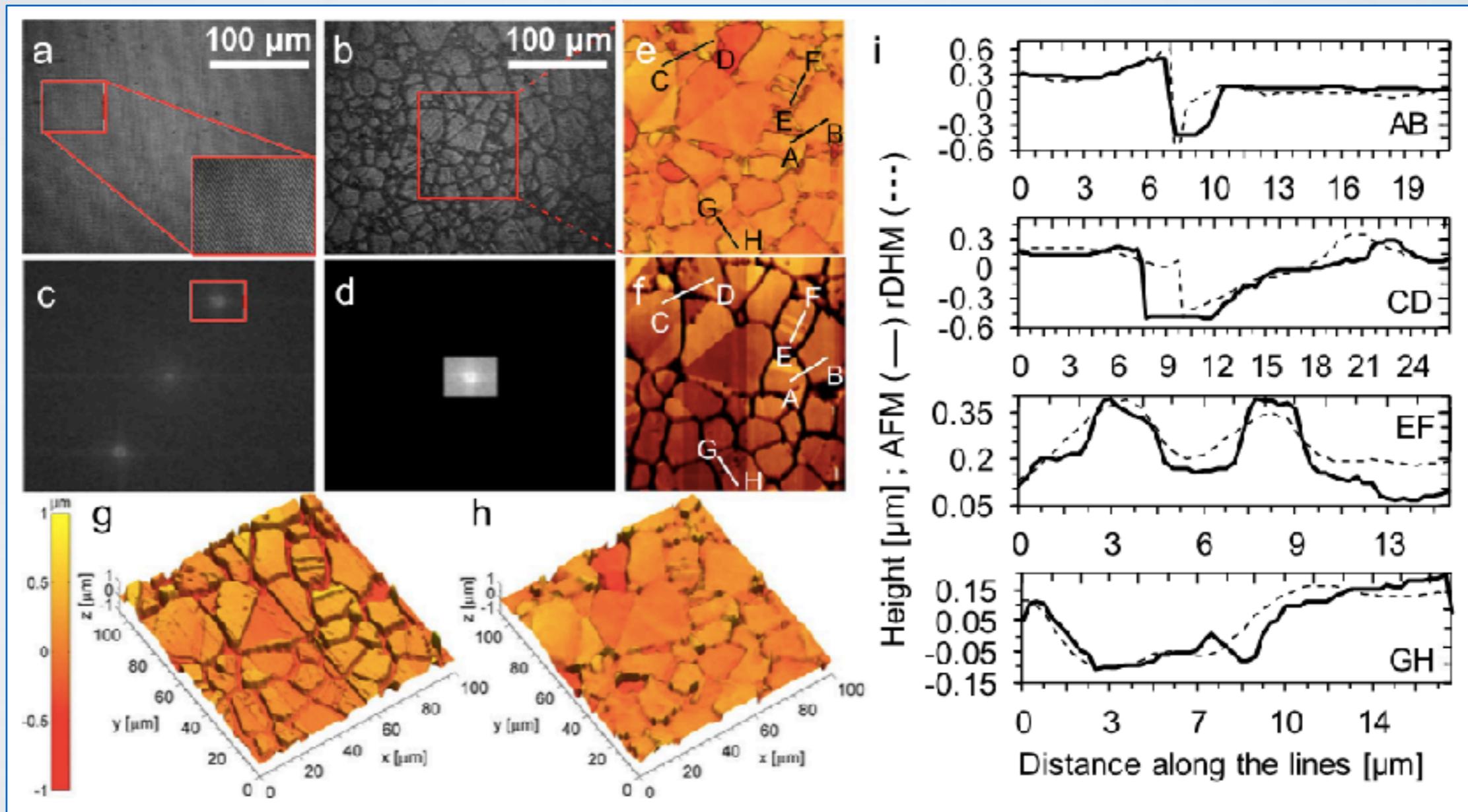
- ▶ Nano-composites



V.Abbasian et al. Ultramicroscopy 185C, pp. 72-80, 2018

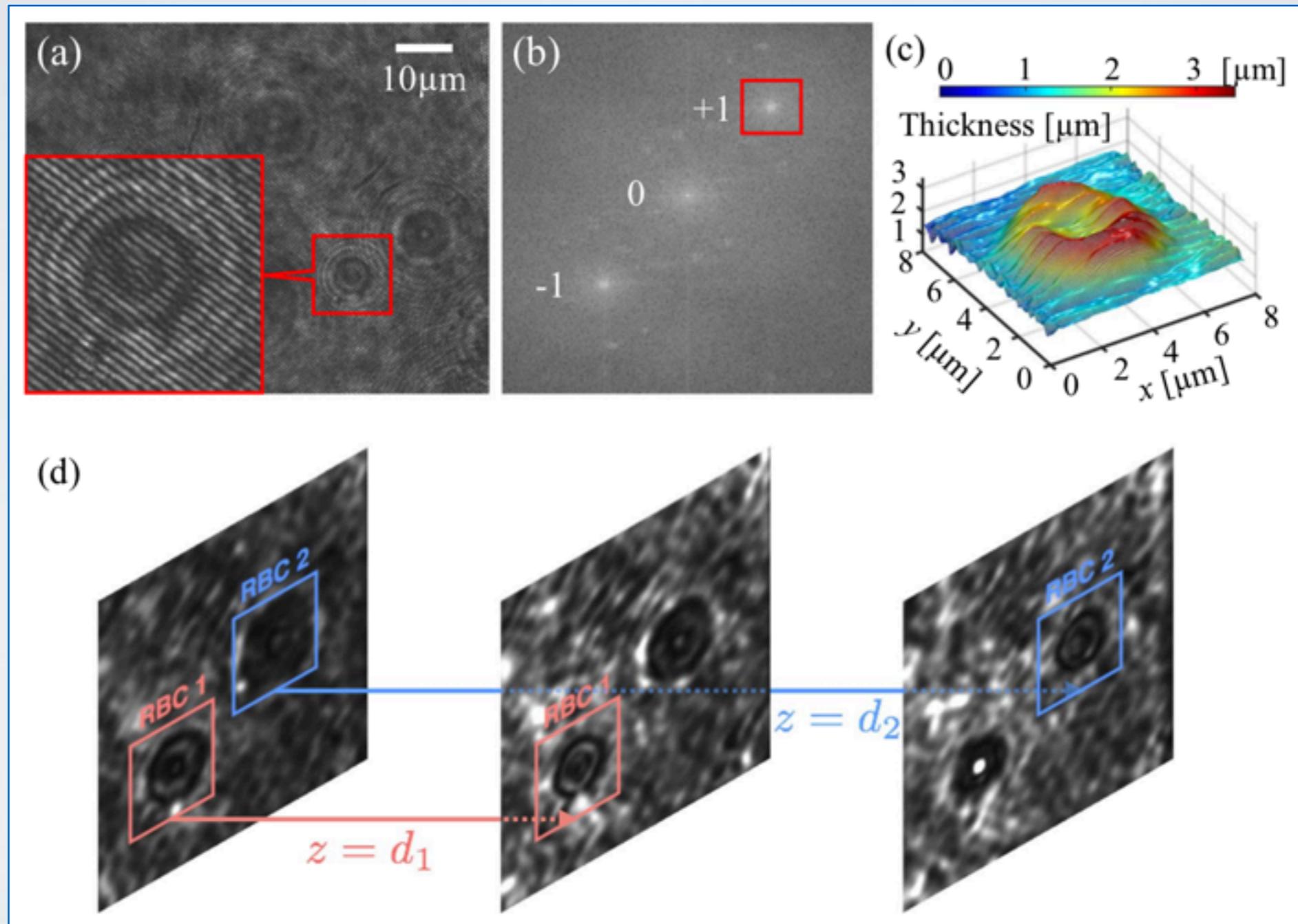
# 3D IMAGING APPLICATIONS

- Metallurgy samples



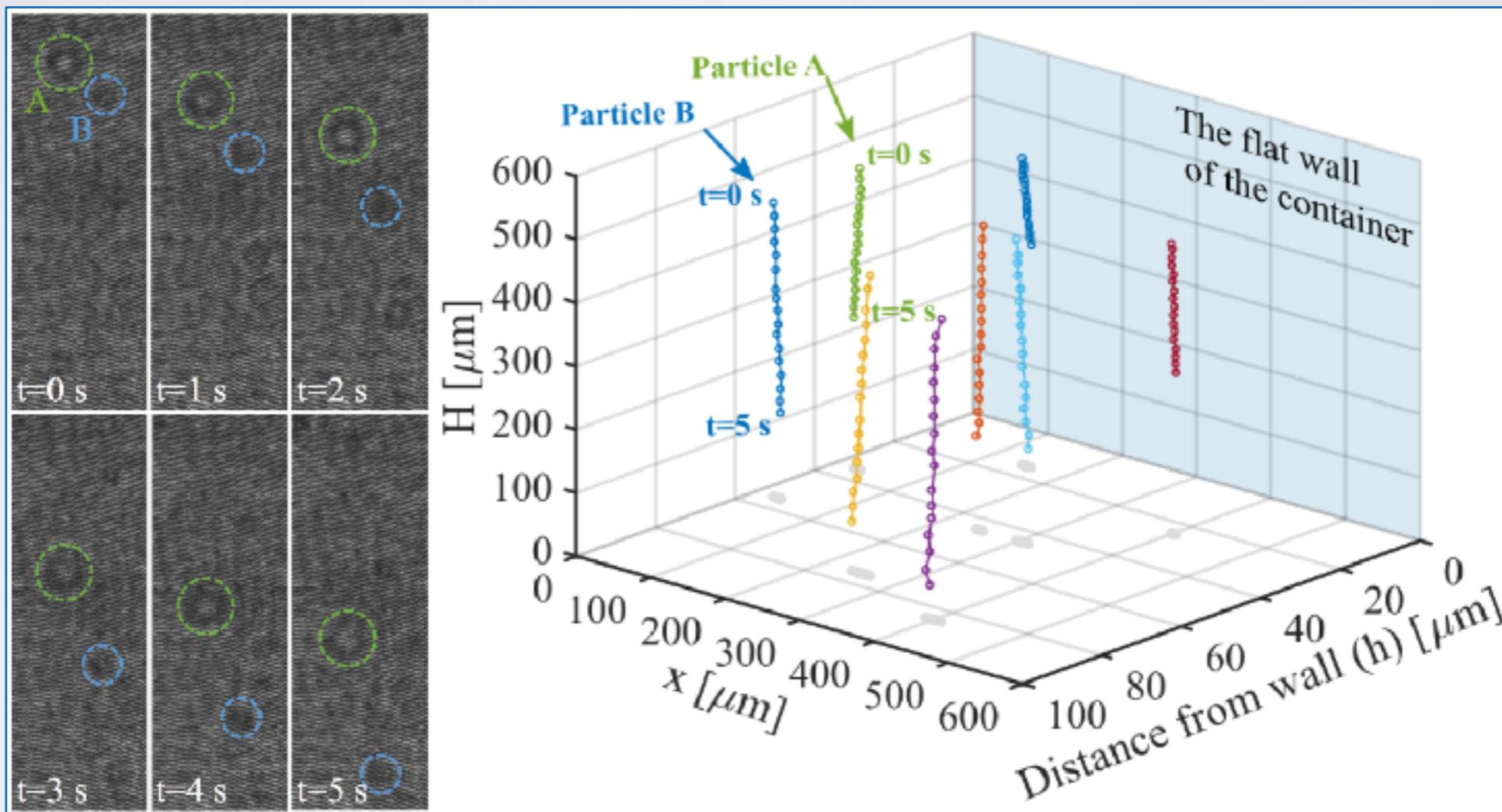
# 3D IMAGING APPLICATIONS

- Numerical focusing for 3D tracking



# 3D IMAGING APPLICATIONS

- Numerical focusing for 3D tracking



M. Charsooghi et al. Appl. Opt. 58(24), 2019



Institute for Advanced  
Studies in Basic  
Sciences (IASBS),  
Zanjan, Iran



Multi-Dimensional  
Imaging and  
Detection Lab.

The screenshot shows the homepage of the MDID laboratory's website. At the top, there is a banner with a grayscale microscopy image and the text "Institute for Advanced Studies In Basic Sciences Zanjan, Iran". Below the banner, the MDID logo is displayed. The main title "Multi-Dimensional Imaging and Detection Laboratory" is prominently shown. The page is divided into several sections:

- About Us**: Describes MDID's focus on 3D and multi-dimensional imaging approaches and scale management, mostly at microscale. It lists four main research directions:
  - Developing and improving the imaging methodologies
  - Integration of imaging techniques with each other and with other codes and simulation-based methods, toward multi-model modeling and enhanced detection
  - Applications to various phenomena in soft matter e.g. in biology, complex and microfluidics, and metallic specimens
  - Developing products and systems for diverse applications
- Featured Researches**: A grid of twelve images illustrating various research projects, including 3D reconstruction, particle tracking, and microscopic techniques.
- Contact**: Provides information about the laboratory's address (Biology Department, Institute for Advanced Studies in Basic Sciences, IASBS, 447, P.O. Box 45195-1411, Zanjan 45137-95311, Iran), contact email (mailto:mdid@iasbs.ac.ir), and phone numbers (+98 35 23015 2104 and +98 35 23015 2104).
- People**: A grid of 16 small portraits of the laboratory's staff members.



<https://iasbs.ac.ir/~moradika>



# Multi-Dimensional Imaging and Detection Laboratory

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[www.iasbs.ac.ir/~moradika/](http://www.iasbs.ac.ir/~moradika/)

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