计算光学成像与光信息处理技术前沿

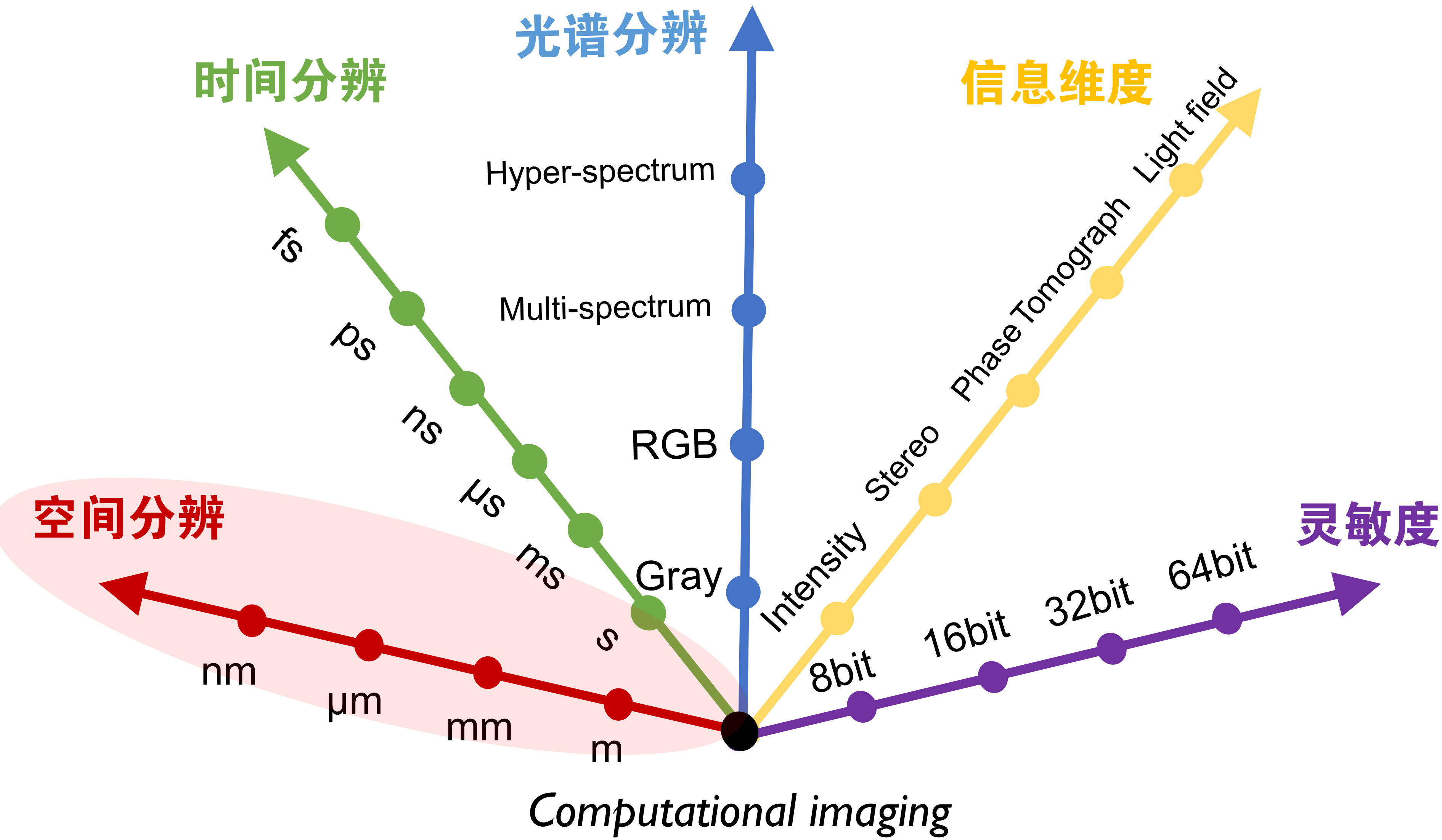
（第7讲）

左 超

南京理工大学电光学院光电技术系

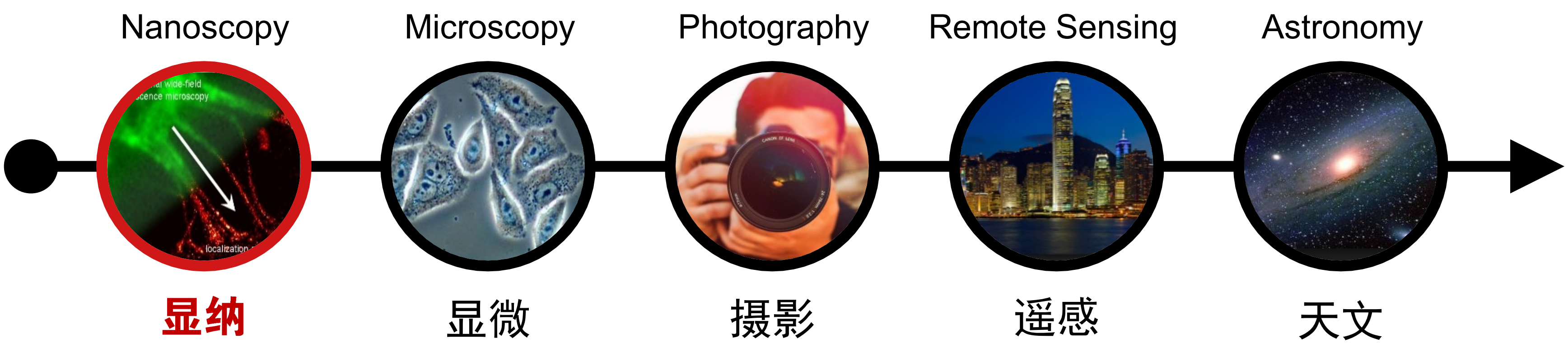
Jiangsu Key Laboratory of Spectral Imaging & Intelligent Sense (SIIS)
Nanjing University of Science and Technology,
Nanjing, Jiangsu Province 210094, China

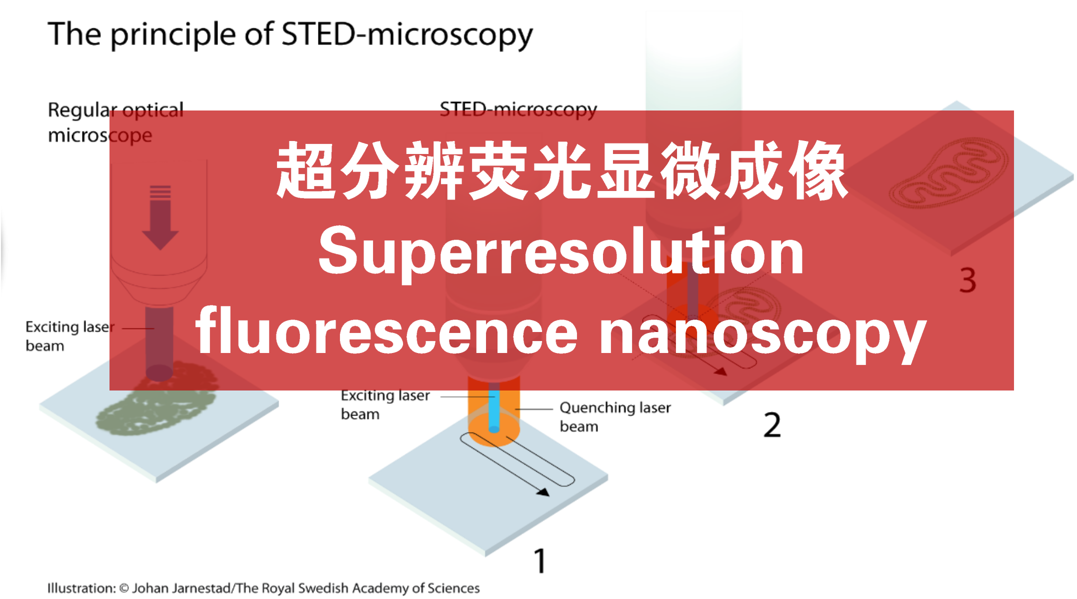
What is *computational imaging*?



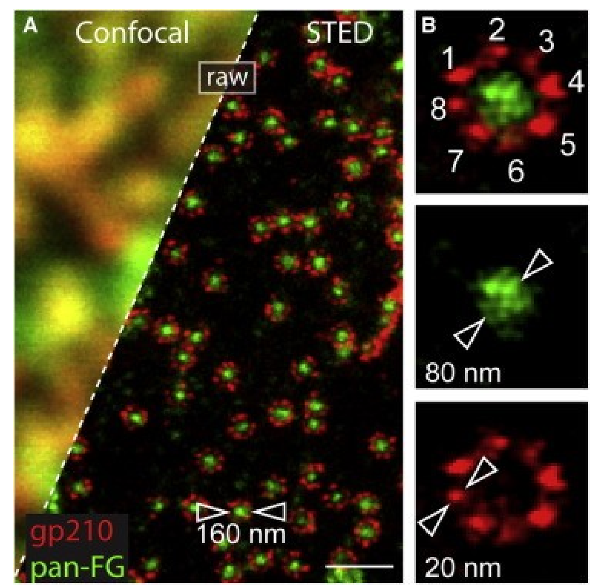
Why *computational imaging*?

空间分辨





超分辨荧光显微成像
Superresolution fluorescence nanoscopy



Why *computational imaging*?

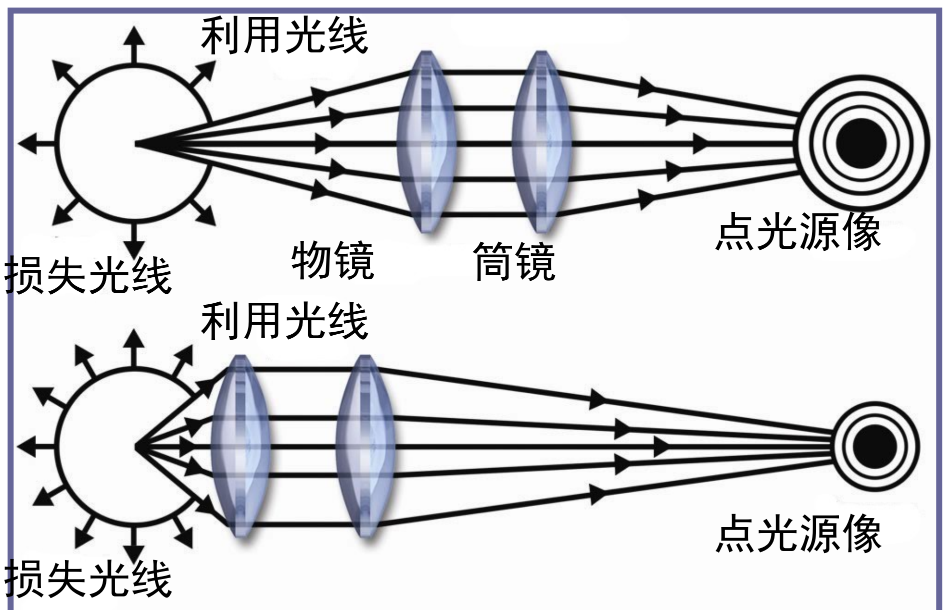
物镜的分辨率

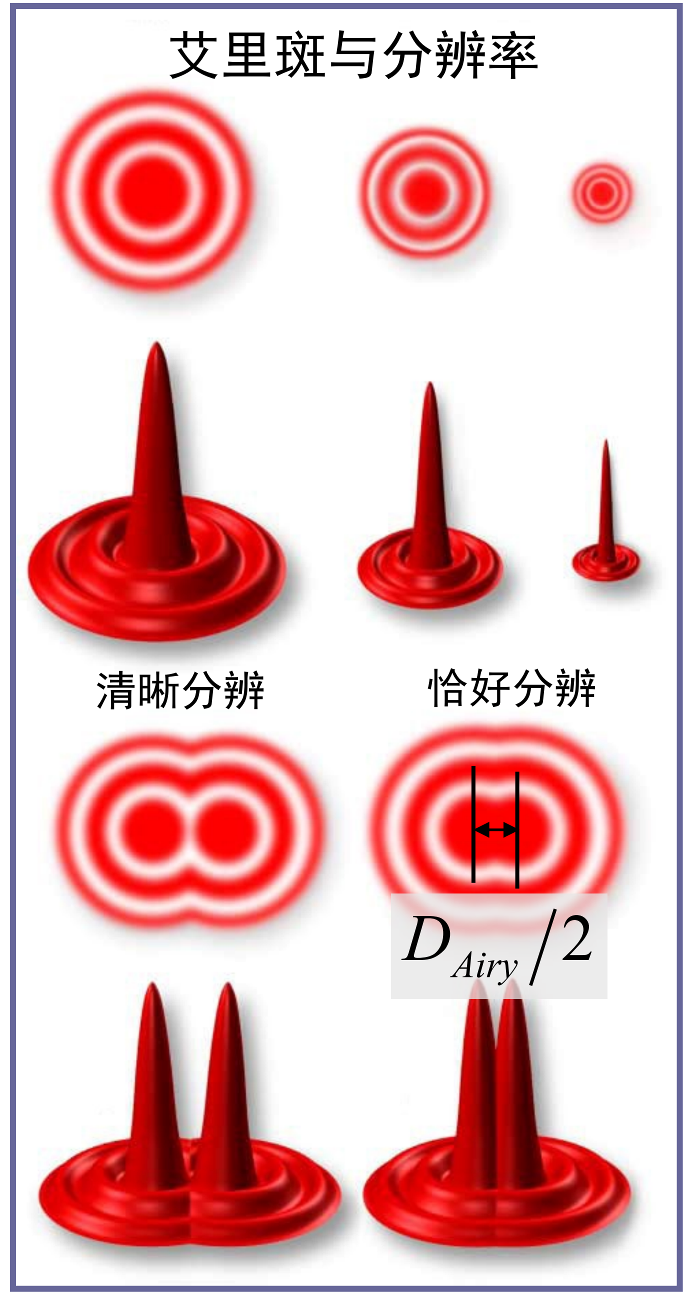
——分辨率与放大倍数没有关系！

分辨率（半径） $= 0.61\lambda / N.A. = 1.22\ \lambda F\#$

λ：　光的波长（550 nm）
NA：物镜的数值孔径

	分辨率	N.A.
干镜	大约300 nm	0.95
油镜	大约200 nm	1.40





Why *computational imaging*?

空间分辨

Nanoscopy　Microscopy　Photography　Remote Sensing　Astronomy

显纳　显微　摄影　遥感　天文

Eric Betzig
(born 1960)
H. Hughes Medical Institute
USA

Stefan W. Hell
(born 1962)
Max Planck Institute
Germany

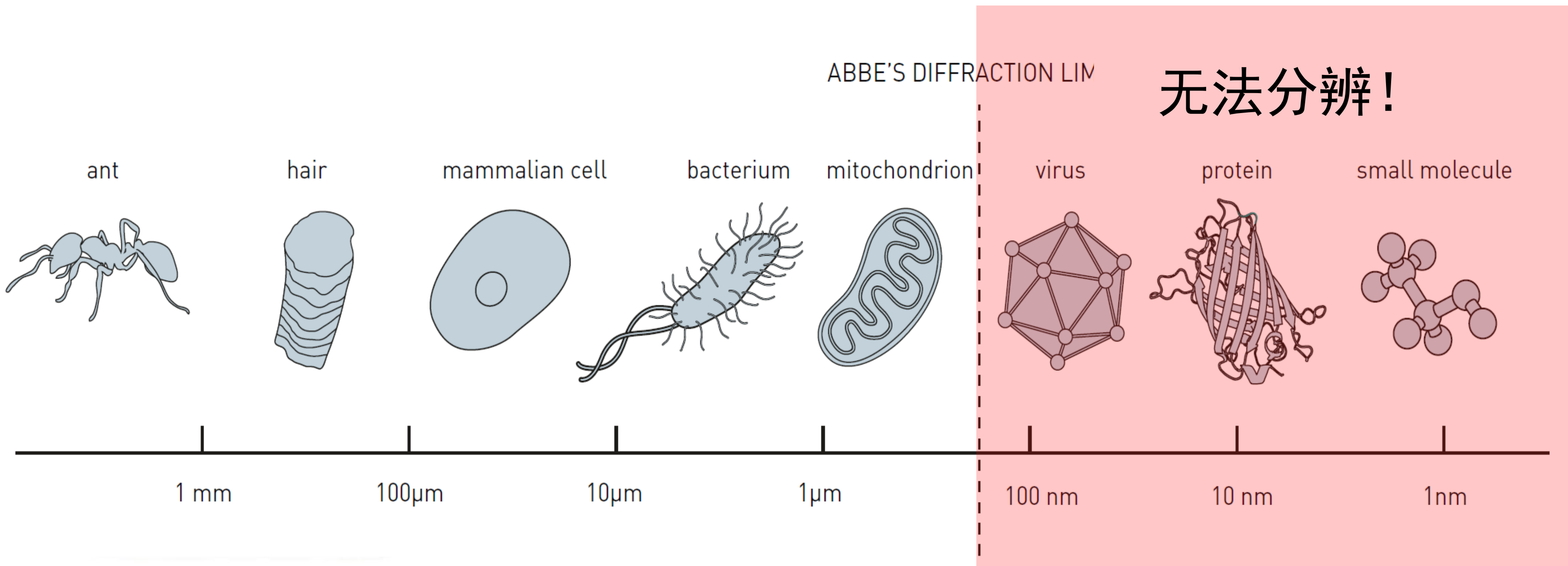
William E. Moerner
(born 1953)
Stanford University
USA

https://www.nobelprize.org/prizes/chemistry/2014/press-release/

Why *computational imaging*?

超分辨荧光显微镜

– 分辨率可以超越衍射极限



一个荧光蛋白分子激发形成的艾里斑尺寸约200nm

https://www.nobelprize.org/prizes/chemistry/2014/press-release/

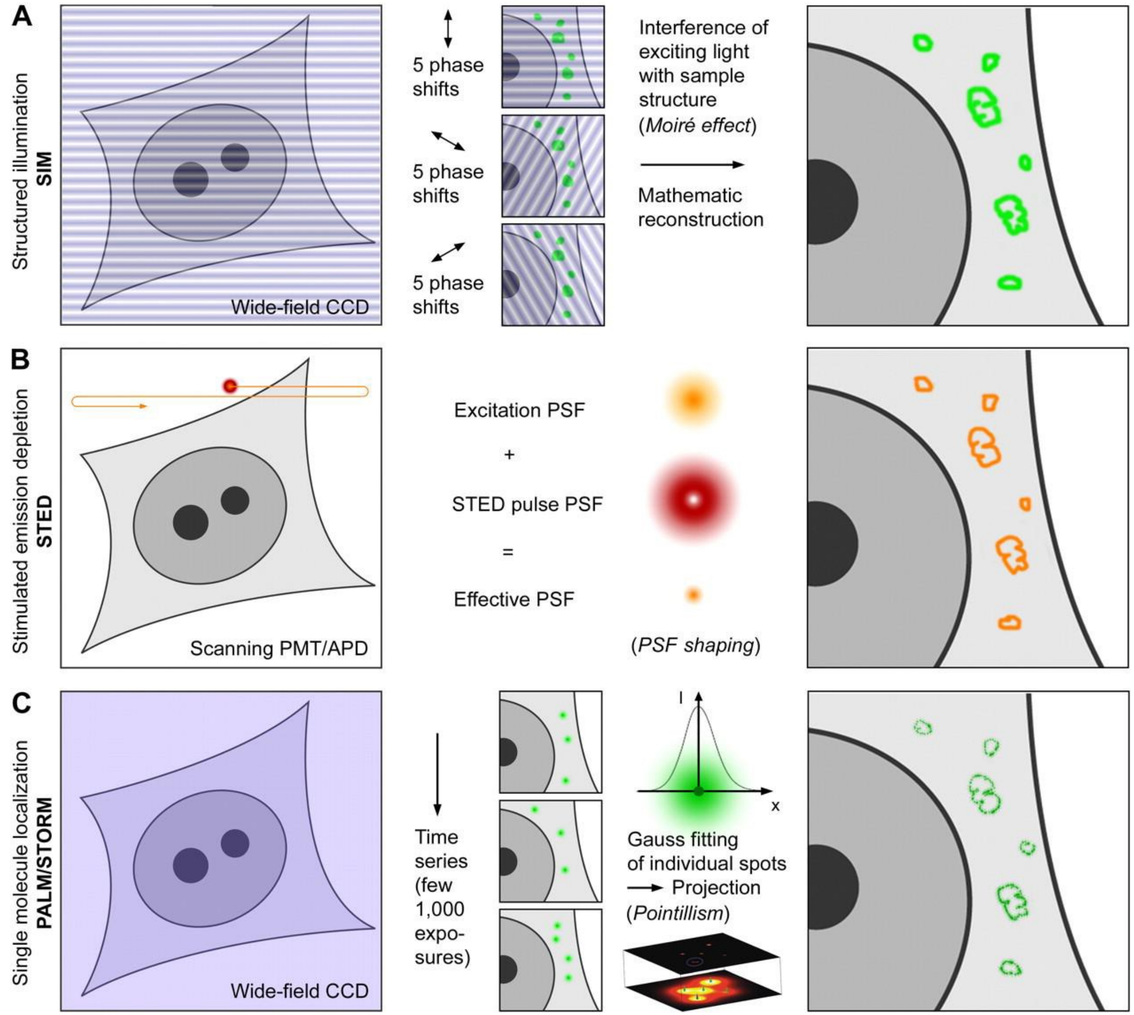
Why *computational imaging*?

超分辨荧光显微镜 – 分辨率可以超越衍射极限

结构光照明（SIM）

受激辐射光淬灭（STED）

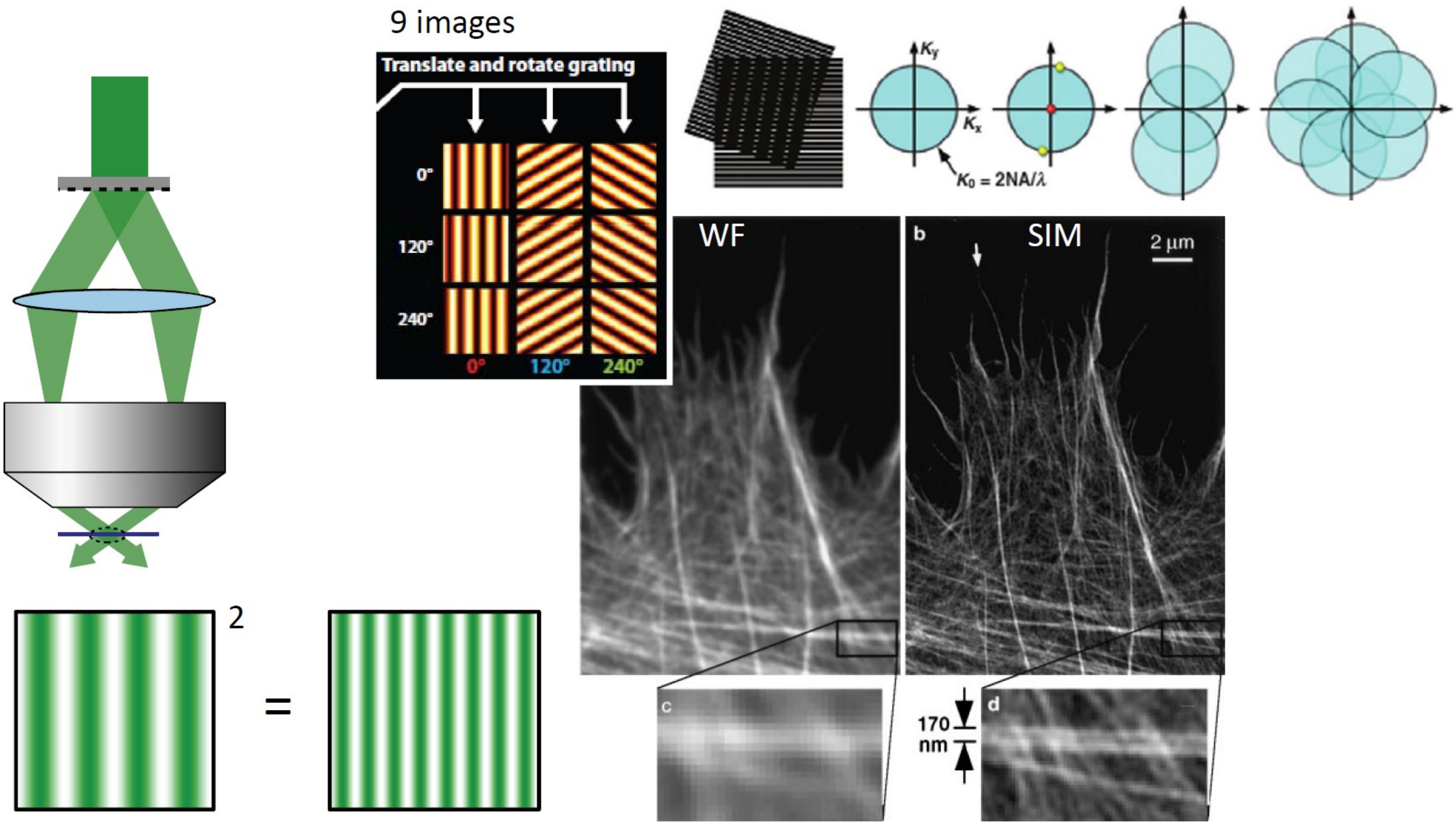
单分子定位（PALM/STORM）



Lothar Schermelleh, Rainer Heintzmann, Heinrich Leonhardt, The Journal of Cell Biology Jul 2010, 190 (2) 165-175;

Why *computational imaging*?

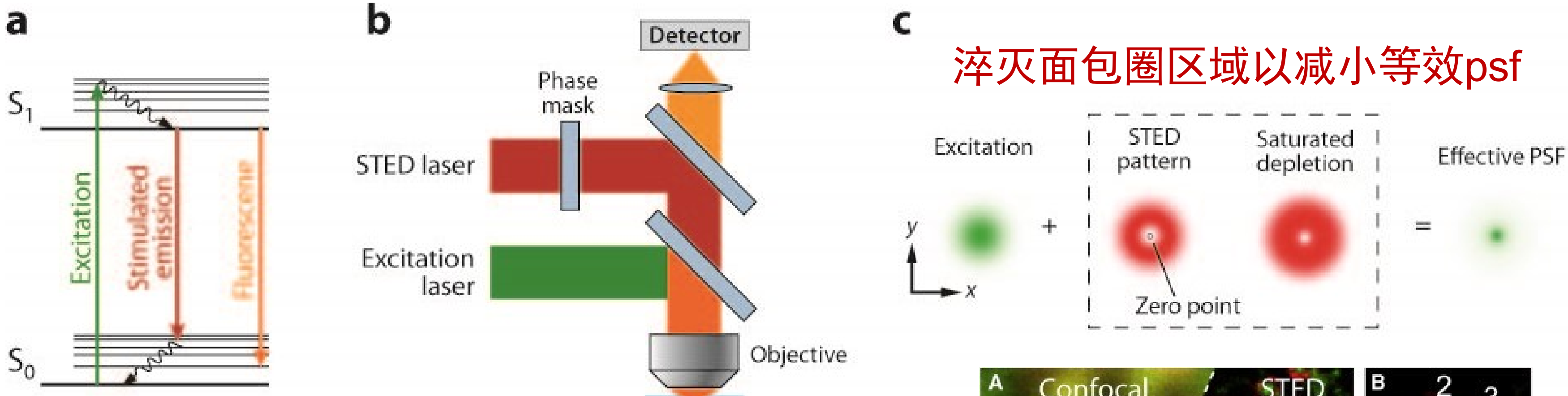
超分辨荧光显微镜SIM – 分辨率可以超越衍射极限

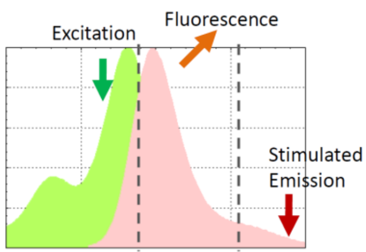


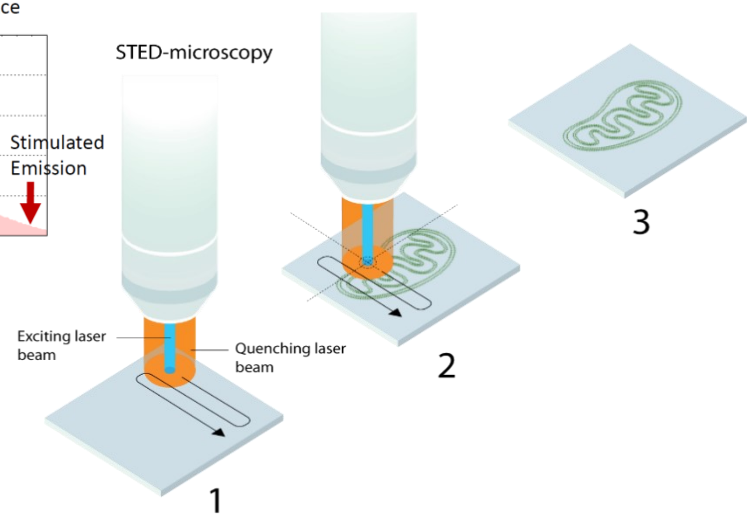
Gustafsson, M. G. (2000), Journal of Microscopy, 198: 82-87.

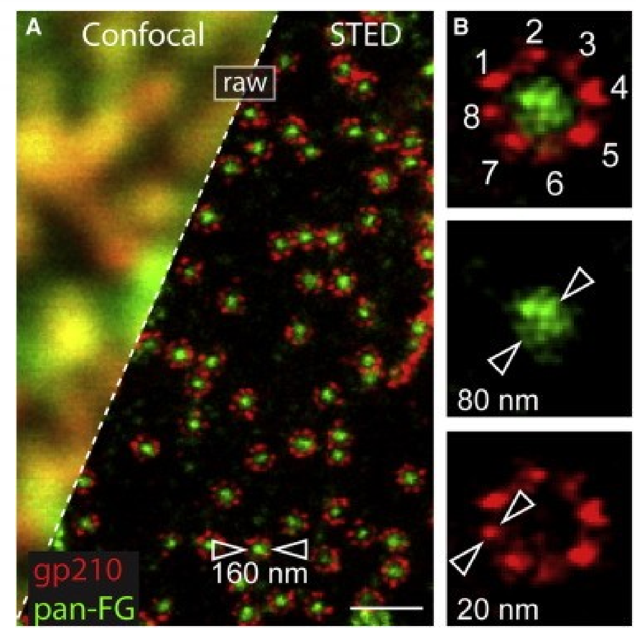
Why *computational imaging*?

超分辨荧光显微镜STED – 分辨率可以超越衍射极限





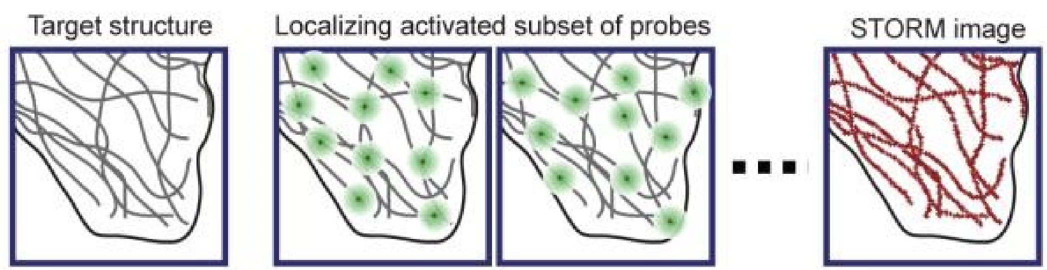


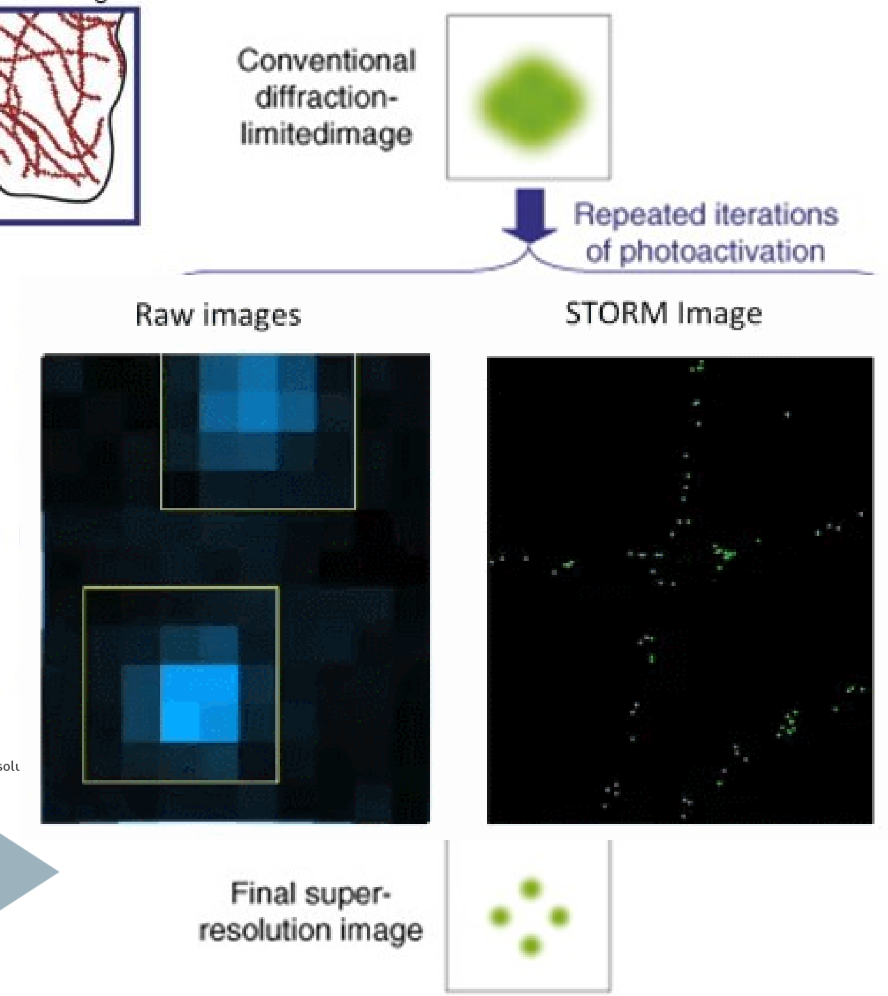


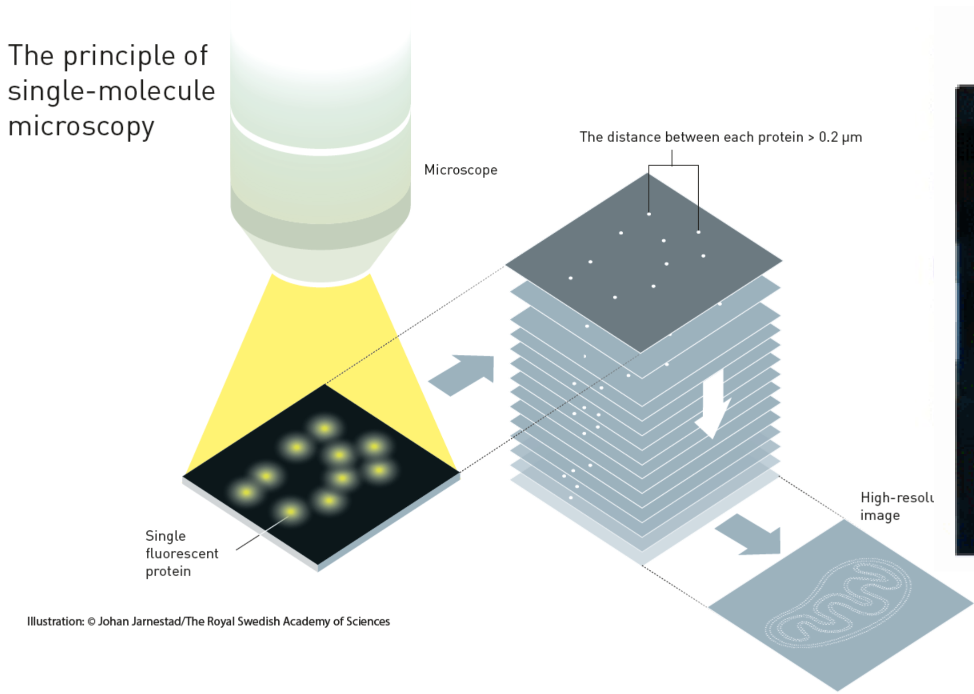
Stefan W. Hell, Science Vol. 316, Issue 5828, pp. 1153-1158

Why *computational imaging*?

超分辨荧光显微PALM/STORM –超越衍射极限







Michael J Rust, Mark Bates & Xiaowei Zhuang, Nature Methods volume 3, pages 793–796 (2006)

Why *computational imaging*?

超分辨荧光显微镜 – 分辨率超越衍射极限

Eric Betzig
(born 1960)
H. Hughes Medical Institute USA

ERIC BETZIG

U.S. citizen. Born 1960 in Ann Arbor, MI, USA. Ph.D. 1988 from Cornell University, Ithaca, NY, USA. Group Leader at Janelia Research Campus, Howard Hughes Medical Institute, Ashburn, VA, USA.

http://janelia.org/lab/betzig-lab

Stefan W. Hell
(born 1962)
Max Planck Institute Germany

STEFAN W. HELL

German citizen. Born 1962 in Arad, Romania. Ph.D. 1990 from the University of Heidelberg, Germany. Director at the Max Planck Institute for Biophysical Chemistry, Göttingen, and Division head at the German Cancer Research Center, Heidelberg, Germany.

www3.mpibpc.mpg.de/groups/hell

William E. Moerner
(born 1953)
Stanford University USA

WILLIAM E. MOERNER

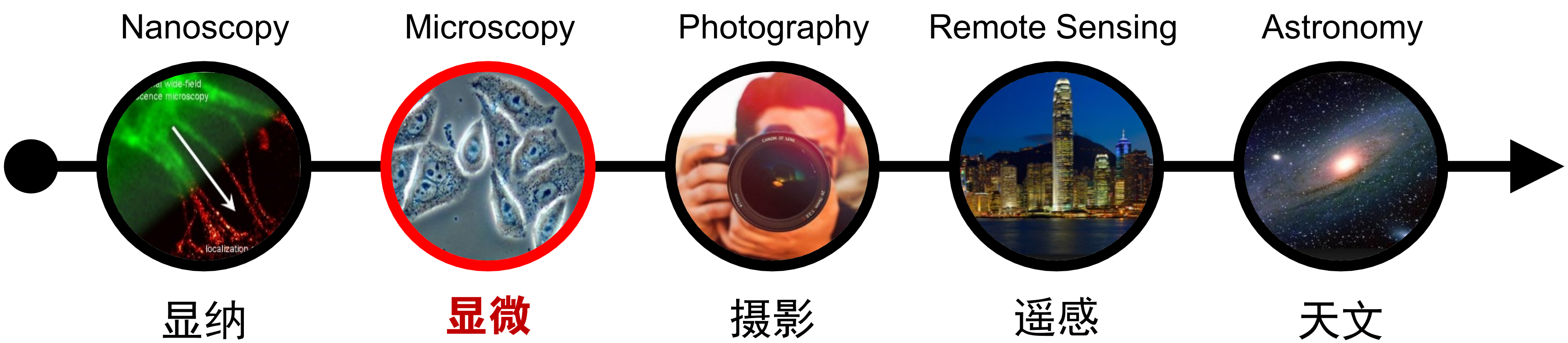
U.S. citizen. Born 1953 in Pleasanton, CA, USA. Ph.D. 1982 from Cornell University, Ithaca, NY, USA. Harry S. Mosher Professor in Chemistry and Professor, by courtesy, of Applied Physics at Stanford University, Stanford, CA, USA.

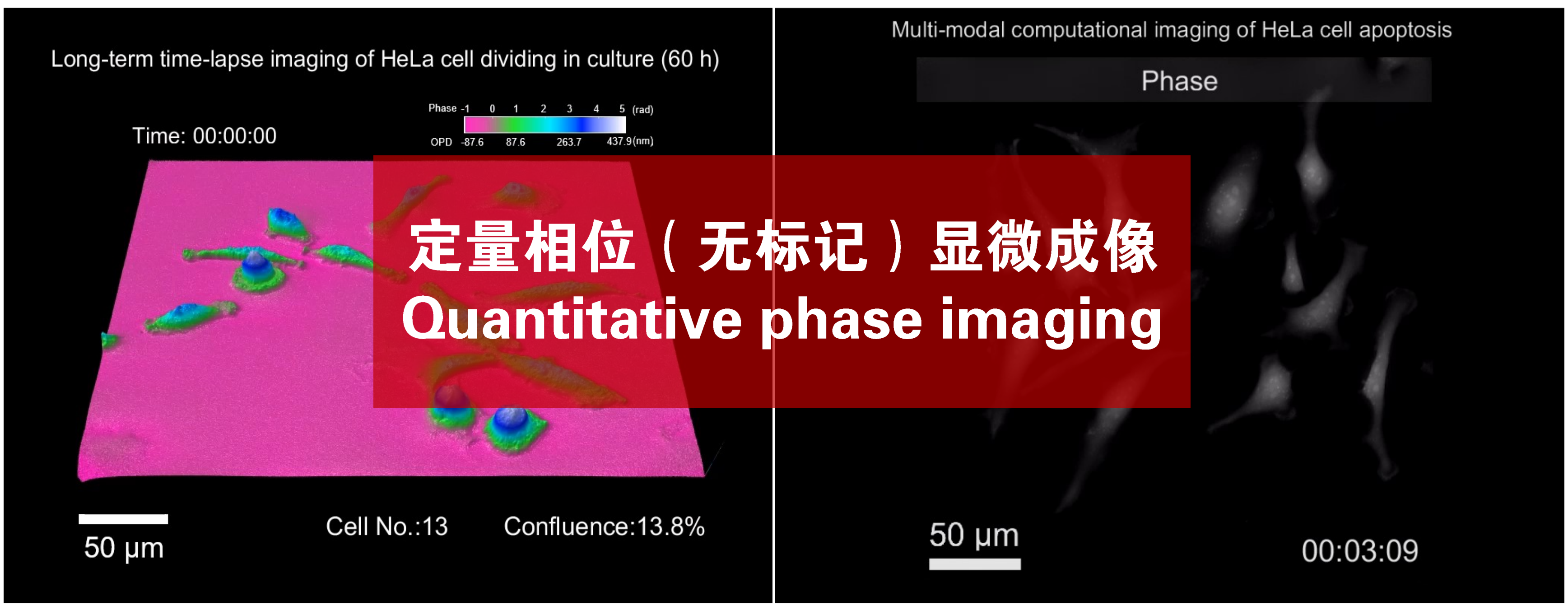
http://web.stanford.edu/group/moerner

https://www.nobelprize.org/prizes/chemistry/2014/press-release/

Why *computational imaging*?

空间分辨





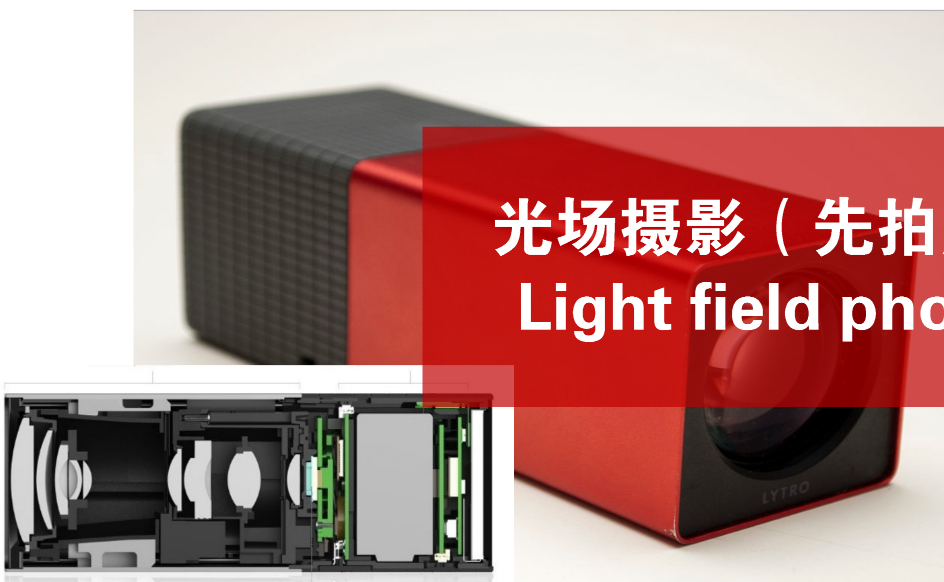
C Zuo, J Sun, J Li, J Zhang, A Asundi, Q Chen Scientific Reports 7, 7654, (2017).

Why *computational imaging*?

空间分辨

Nanoscopy | Microscopy | Photography | Remote Sensing | Astronomy

显纳 | 显微 | **摄影** | 遥感 | 天文



光场摄影（先拍照后聚集）
Light field photography

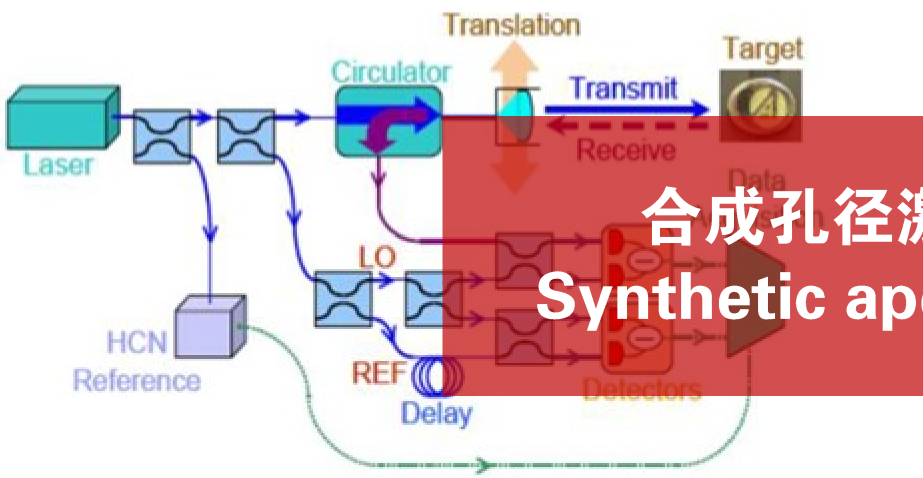
https://en.wikipedia.org/wiki/Light-field_camera

Why *computational imaging*?

空间分辨

Nanoscopy　Microscopy　Photography　Remote Sensing　Astronomy

显纳　显微　摄影　**遥感**　天文



合成孔径激光雷达
Synthetic aperture lidar

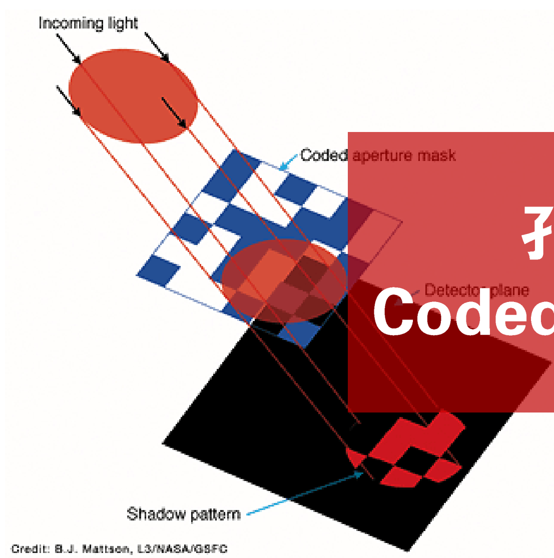
Beck S M, Buck J R, Buell W F, et al..Applied Optics, 2005, 44(35): 7621–7629.

Why *computational imaging*?

空间分辨

Nanoscopy　Microscopy　Photography　Remote Sensing　Astronomy

显纳　显微　摄影　遥感　**天文**



孔径编码（无透镜）成像

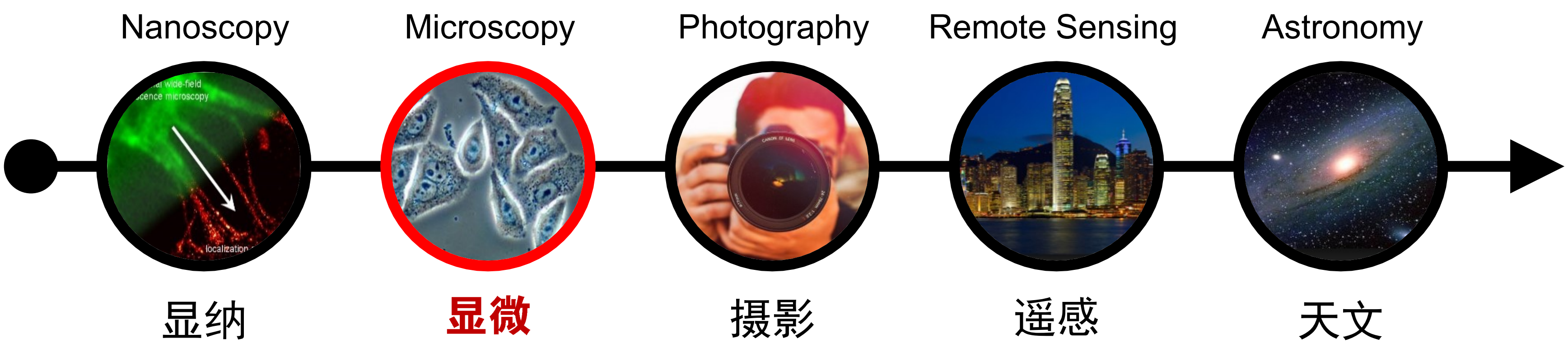
Coded aperture les–free imaging

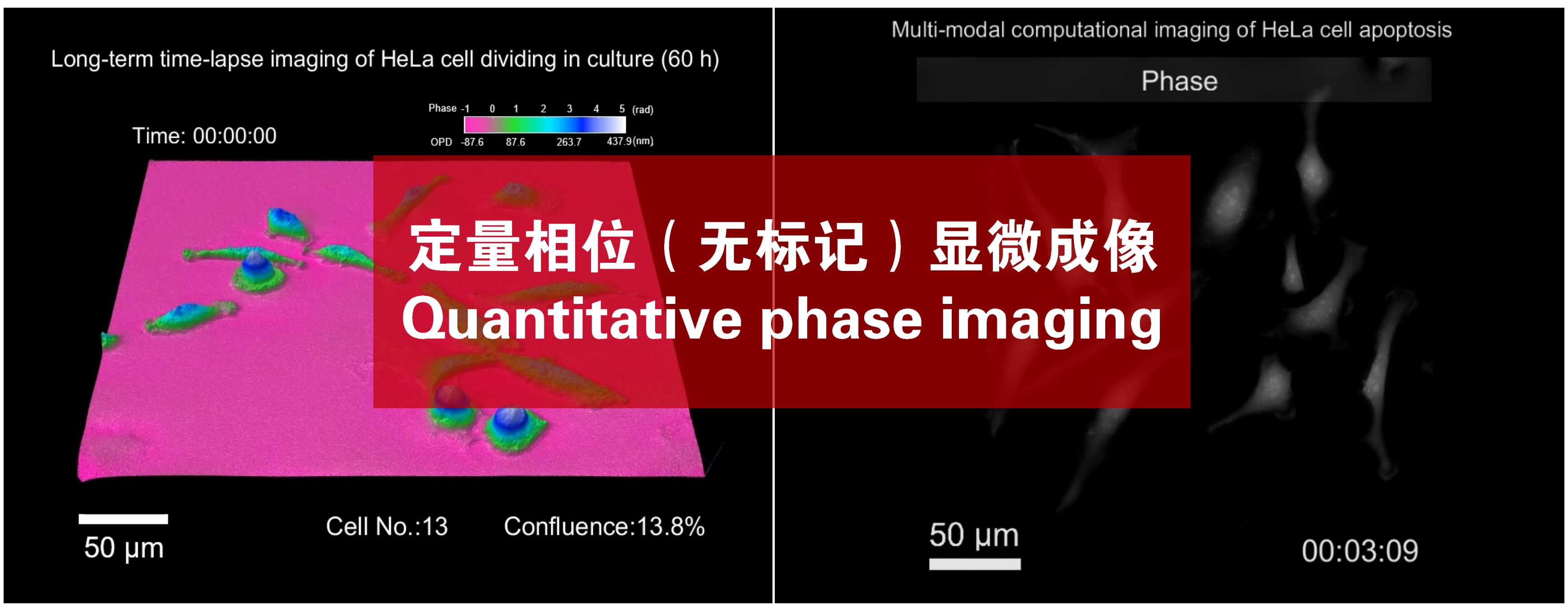
JEM-X FM2 Mask　　JEM-X Mask Coded detail: "island"

https://en.wikipedia.org/wiki/Coded_aperture

Why *computational imaging*?

空间分辨





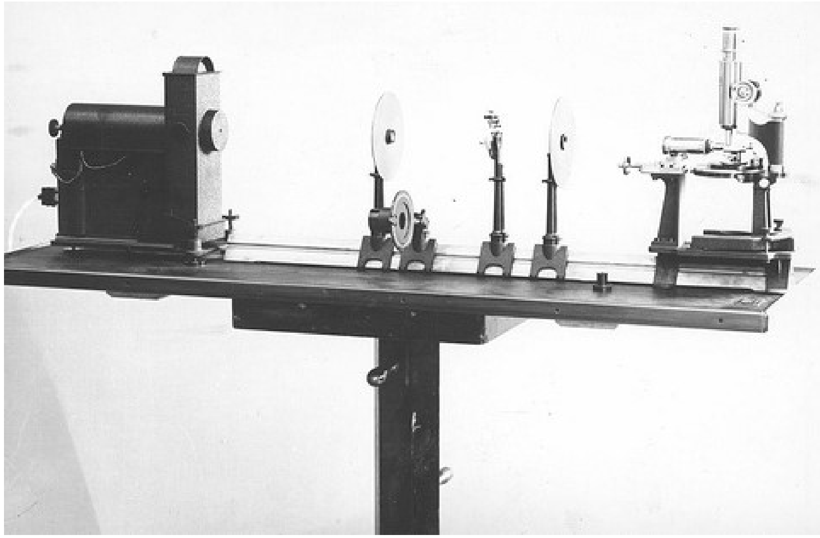
定量相位（无标记）显微成像
Quantitative phase imaging

C Zuo, J Sun, J Li, J Zhang, A Asundi, Q Chen Scientific Reports 7, 7654, (2017).

Computational microscopy

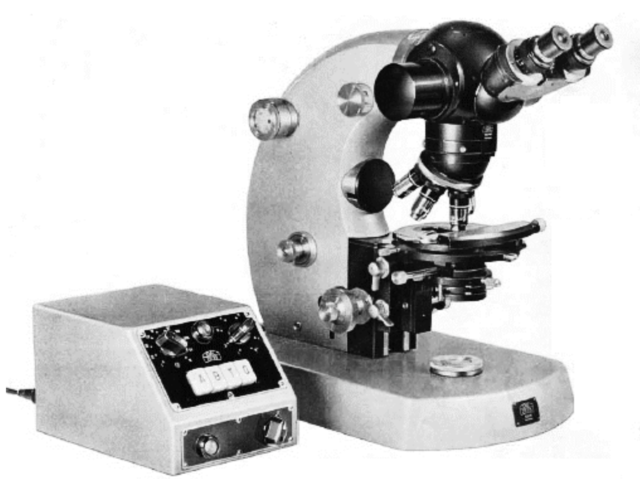
与显微成像相关的诺贝尔奖	1925	Richard Zsigmondy	超显微镜（暗场）
	1953	Frits Zernike	相衬显微镜
	1971	Dennis Gabor	全息摄影
	1974	Martin Ryle	射电望远镜/合成孔径
	1981	Kai Siegbahn	电子光谱仪
	1981	Nicolaas Bloembergen Arthur Schawlow	激光光谱仪
	1986	Ernst Ruska	电子显微镜
	1986	Gerd Binning Heinrich Rohrer	扫描隧道显微镜
	2008	Osamu Shimomura Martin Chalfie Roger Y. Tsien	绿色荧光蛋白
	2009	Willaed S. Boylean George Smith	电荷耦合器件（CCD）
	2014	Eric Betzig Stefan W. Hell William E. Moerner	超分辨率荧光显微成像
	2017	Jacques Dubochet Joachim Frank Richard Henderson	冷冻电镜
	2018	Arthur Ashkin	光学镊子

Van Leeuwenhoek’s microscope, 1670



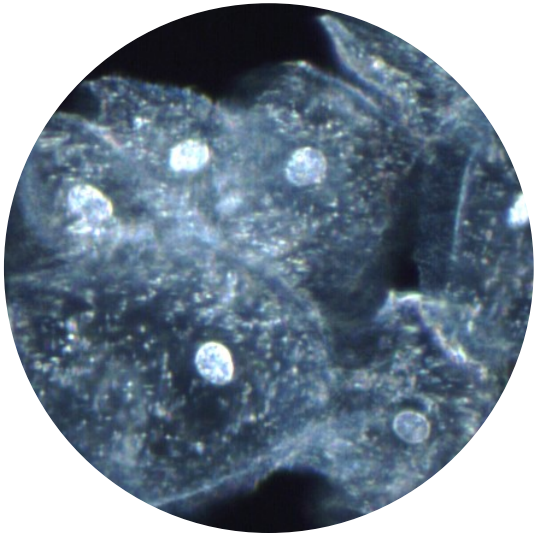
Dark field (Ultra) microscope
R. Zsigmondy, 1903

Phase contrast microscope
F. Zernike, 1932

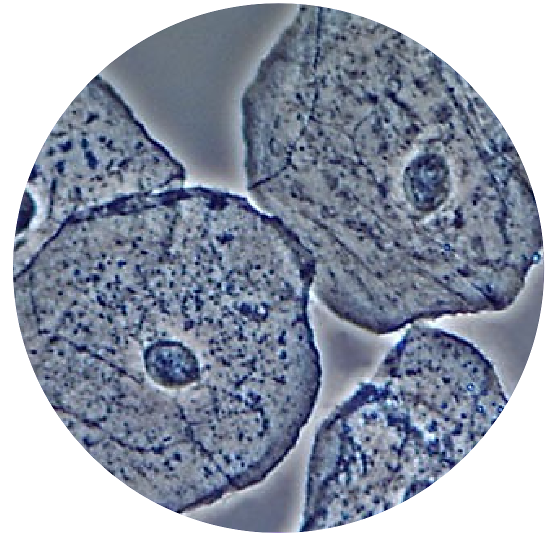


Fluorescence microscopy
O. Shimomura, M. Chalfie and R. Tsien
early 20th century

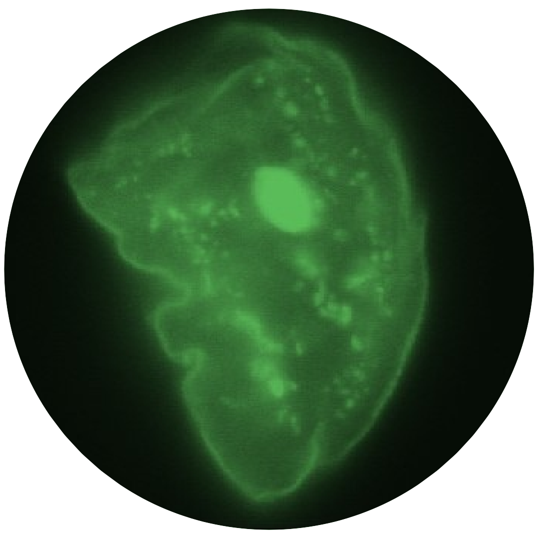
Superresolution fluorescence microscopy
E. Betzig, S. W. Hell and W. E. Moerner
late 20th century



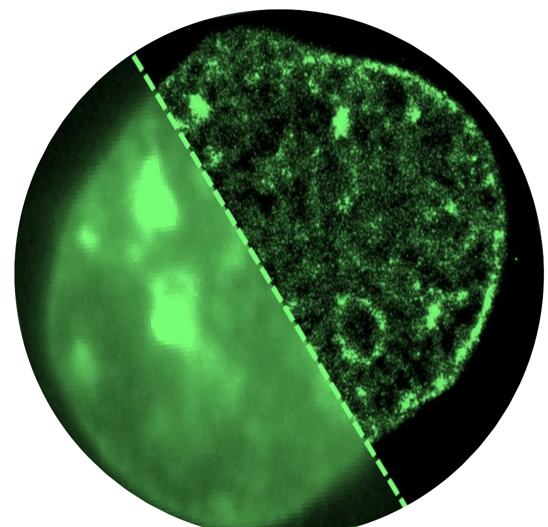
Dark field (Ultra) microscope
R. Zsigmondy, 1903



Phase contrast microscope
F. Zernike, 1932



Fluorescence microscopy
O. Shimomura, M. Chalfie and R. Tsien
early 20th century



Superresolution fluorescence microscopy
E. Betzig, S. W. Hell and W. E. Moerner
late 20th century

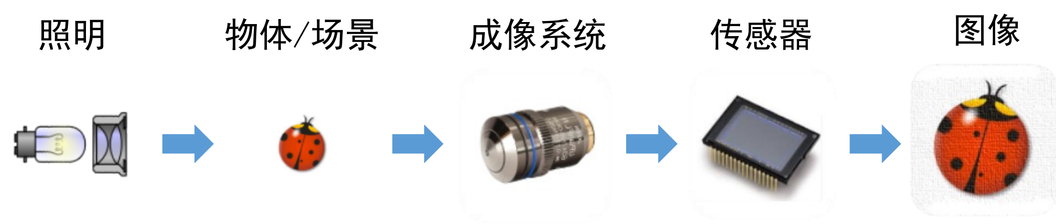
Nobel Prize for Chemistry, 1925
R. Zsigmondy

Nobel Prize for Physics, 1953
F. Zernike

Nobel Prize for Chemistry, 2008
O. Shimomura, M. Chalfie and R. Tsien

Nobel Prize for Chemistry, 2014
E. Betzig, S. W. Hell and W. E. Moerner

主要瓶颈问题：无标记非干涉相位显微成像



传统透镜式光学成像系统

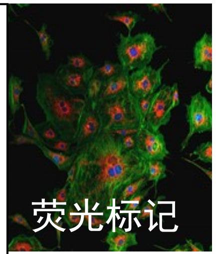
传统透镜式成像

点对点光强信号探测

微观局限:

无法定量探测相位

大部分生物细胞无色透明，成像依赖染色标记

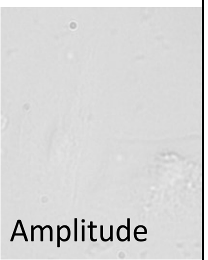


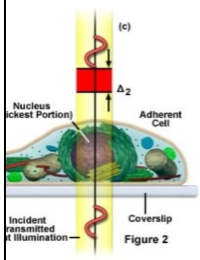
侵入

(Inv

成像

-free)





2014年12月

Nature Method

PERSPECTIVE

Live-cell mass profiling: an emerging approach in quantitative biophysics

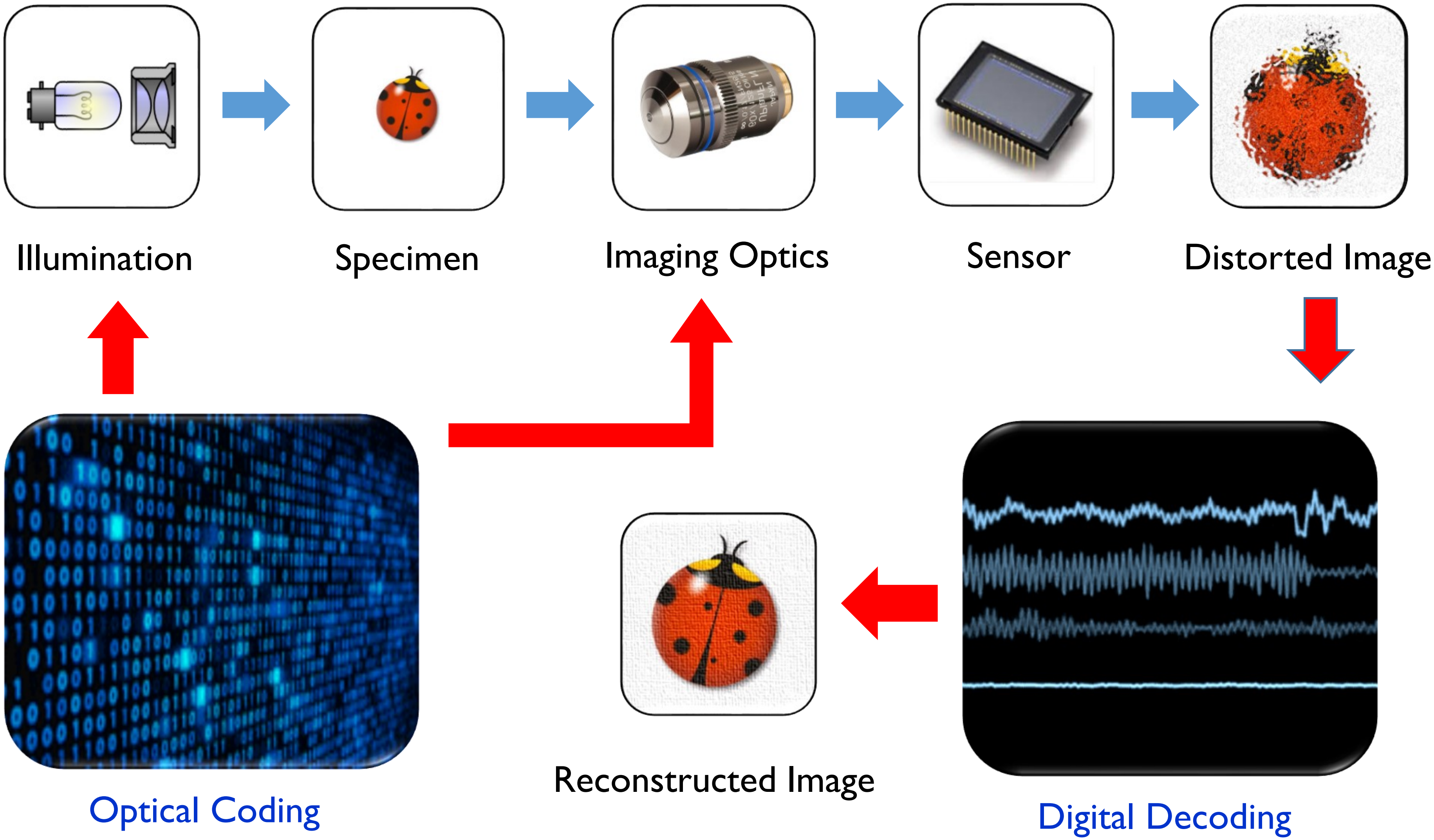
Thomas A Zangle[1] & Michael A Teitell[1–6]

is selling a system based on ptychography for quantitative phase imaging of biological samples[62]. There are several DHM systems available through Phase Holographic Imaging (Sweden), Lyncée Tec (Switzerland), 4Deep Inwater Imaging (Canada) and Ovizio Imaging Systems (Belgium).

Future technological developments will likely focus on resolution improvement, integration with other imaging modalities and the use of quantitative phase information in new ways, as has been done in the past with extensions to the measurement of intracellular transport[49,70]. The development of quantitative phase imaging in living tissue would be a remarkable advance, as it would allow for cell growth quantification … whole organisms. Single-cell mass …

“定量相位成像技术”将是未来实现下一代无标记细胞成像的一项重大进展 (remarkable advance)

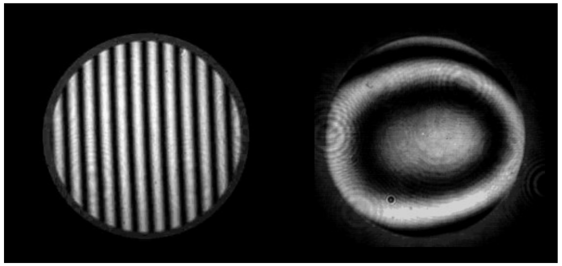
Computational microscopy



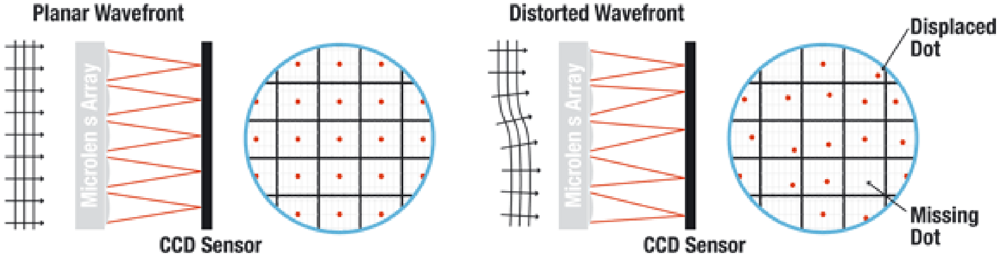
Phase measurement

Interference based method

- Interferometry
- Digital holography
- ….



Shack-Hartmann wave-front sensor



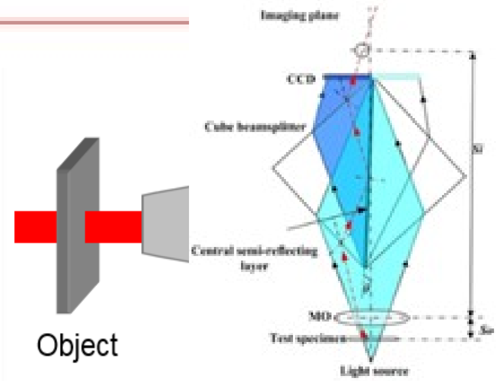
Phase retrieval

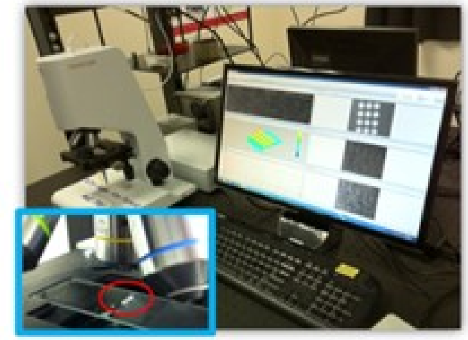
- Iterative: Gerchberg–Saxton etc.[1,2]
- Direct: Transport-of-intensity equation[3]

[1] J. R. Fienup, Appl. Opt. 21, 2758-2769 (1982).
[2] R. W. Gerchberg and W. O. Saxton, Optik 35, 237–246(1972)
[3] M. Reed Teague, J. Opt. Soc. Am. 73, 1434-1441 (1983) .

传统全息摄影技术

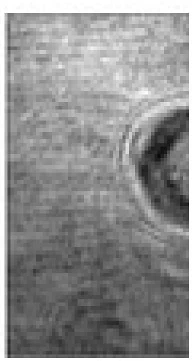
数字全息显微 Digital Holographic Microscopy (DHM)





Digital Recording

正置共路干涉数字全息显微镜

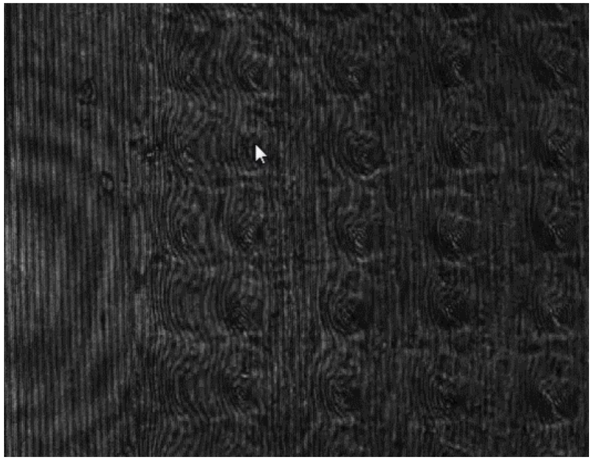


Amp

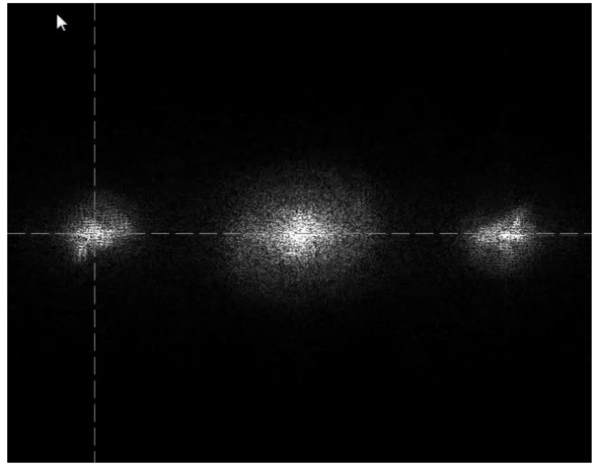
merical nstruction

倒置透射数字全息显微镜

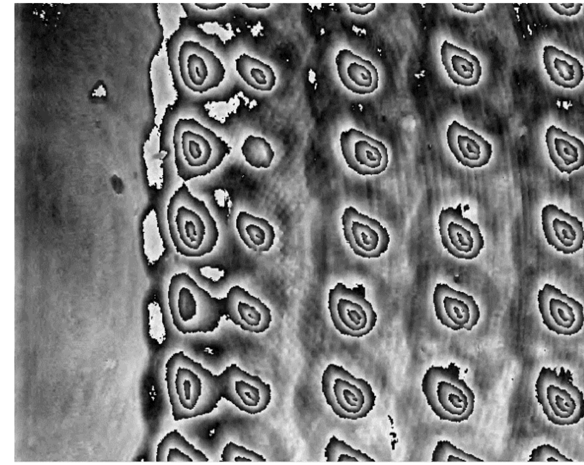
数字全息显微 Digital Holographic Microscopy (DHM)



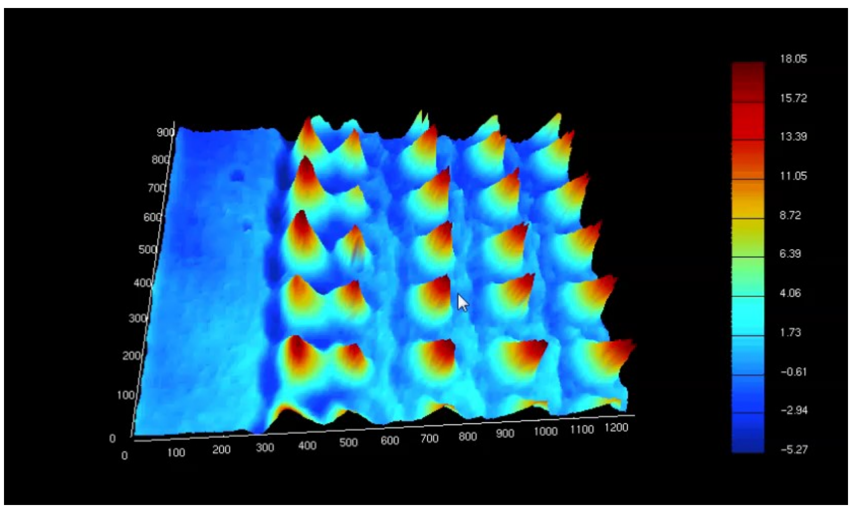
Hologram



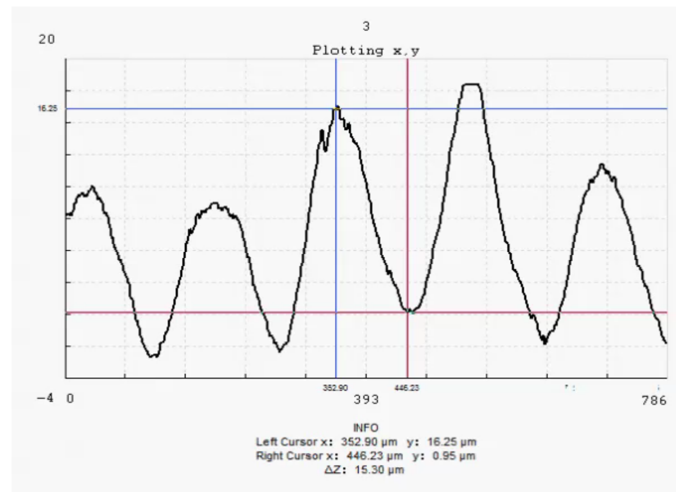
Fourier



Phase



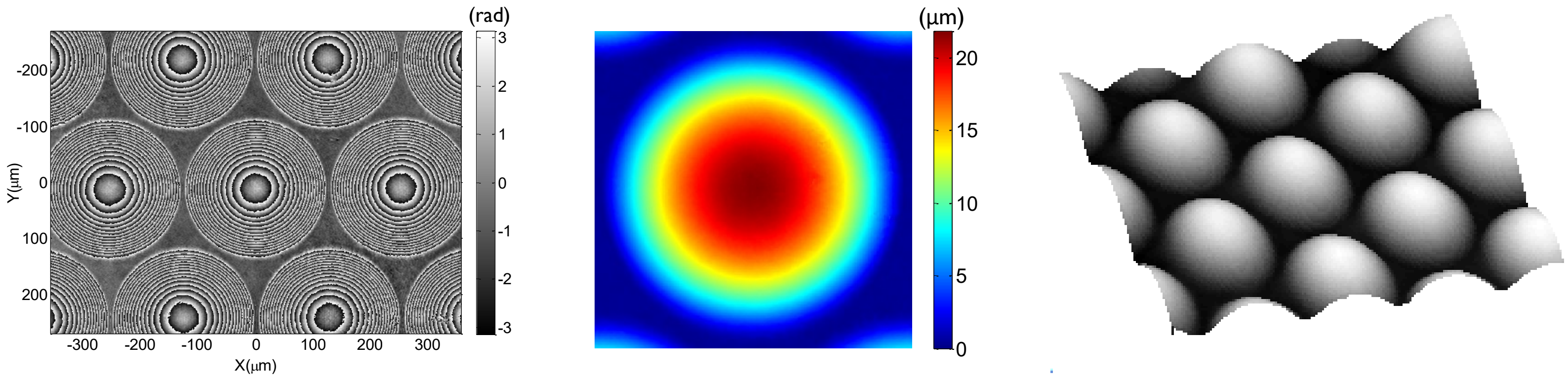
3D Profile



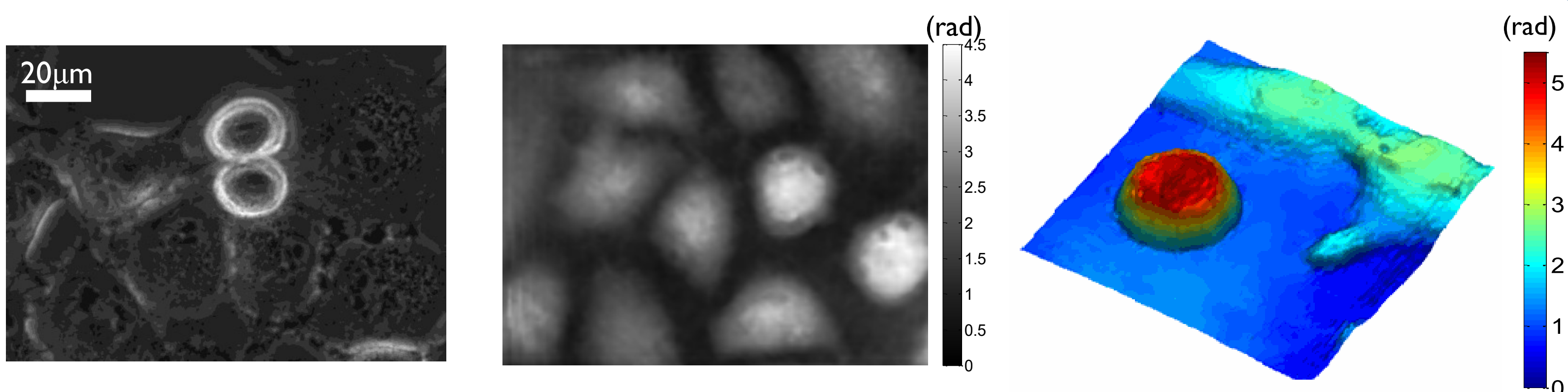
Line Profile

C. Zuo, Q. Chen, W. Qu and A. Asundi, *Chapter 3: Digital Holography for Three-Dimensional Metrology: Principles, Methods, and Applications*, in Ella Myers (ed.) *Advances in Digital Holography Research*. ISBN: 9781608764747.

数字全息显微 Digital Holographic Microscopy (DHM)



Micro-optics Metrology



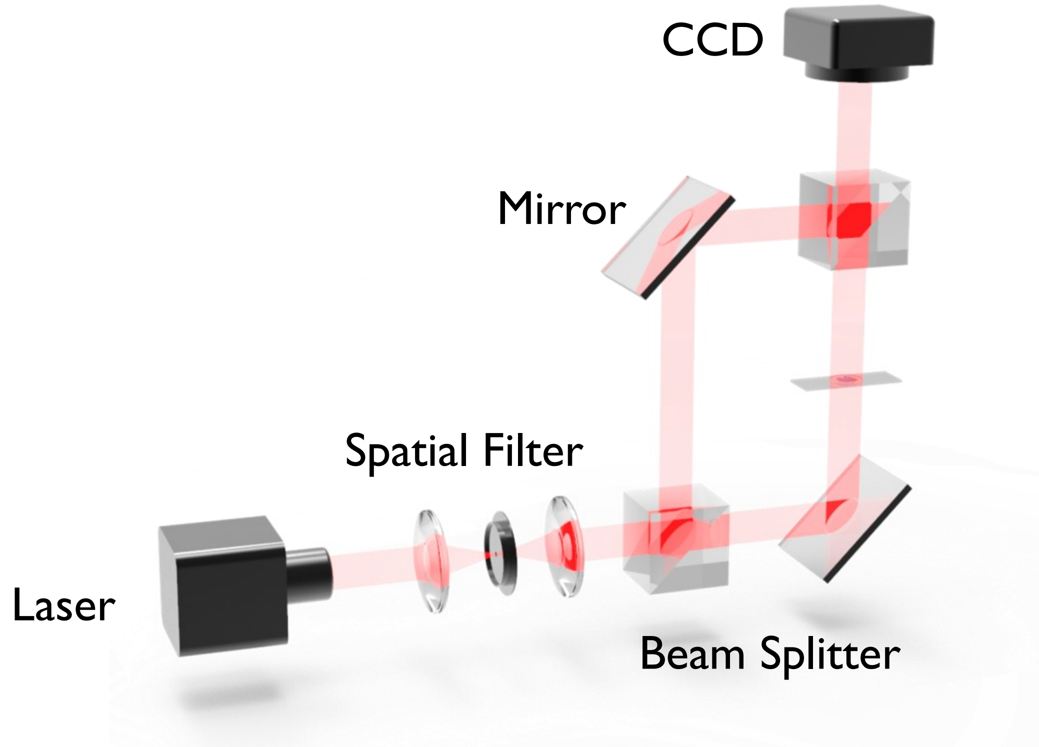
Bio-applications

C. Zuo, Q. Chen, W. Qu and A. Asundi, *Chapter 3: Digital Holography for Three-Dimensional Metrology: Principles, Methods, and Applications*, in Ella Myers (ed.) *Advances in Digital Holography Research*. ISBN: 9781608764747.

数字全息显微镜

南京理工大学
NANJING UNIVERSITY OF SCIENCE & TECHNOLOGY

FSM-Precision



飞时曼数字全息显微镜（我国**首台**商业化数字全息显微镜）

数字全息显微镜

南京理工大学
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FSM-Precision

飞时曼数字全息显微镜（我国**首台**商业化数字全息显微镜）

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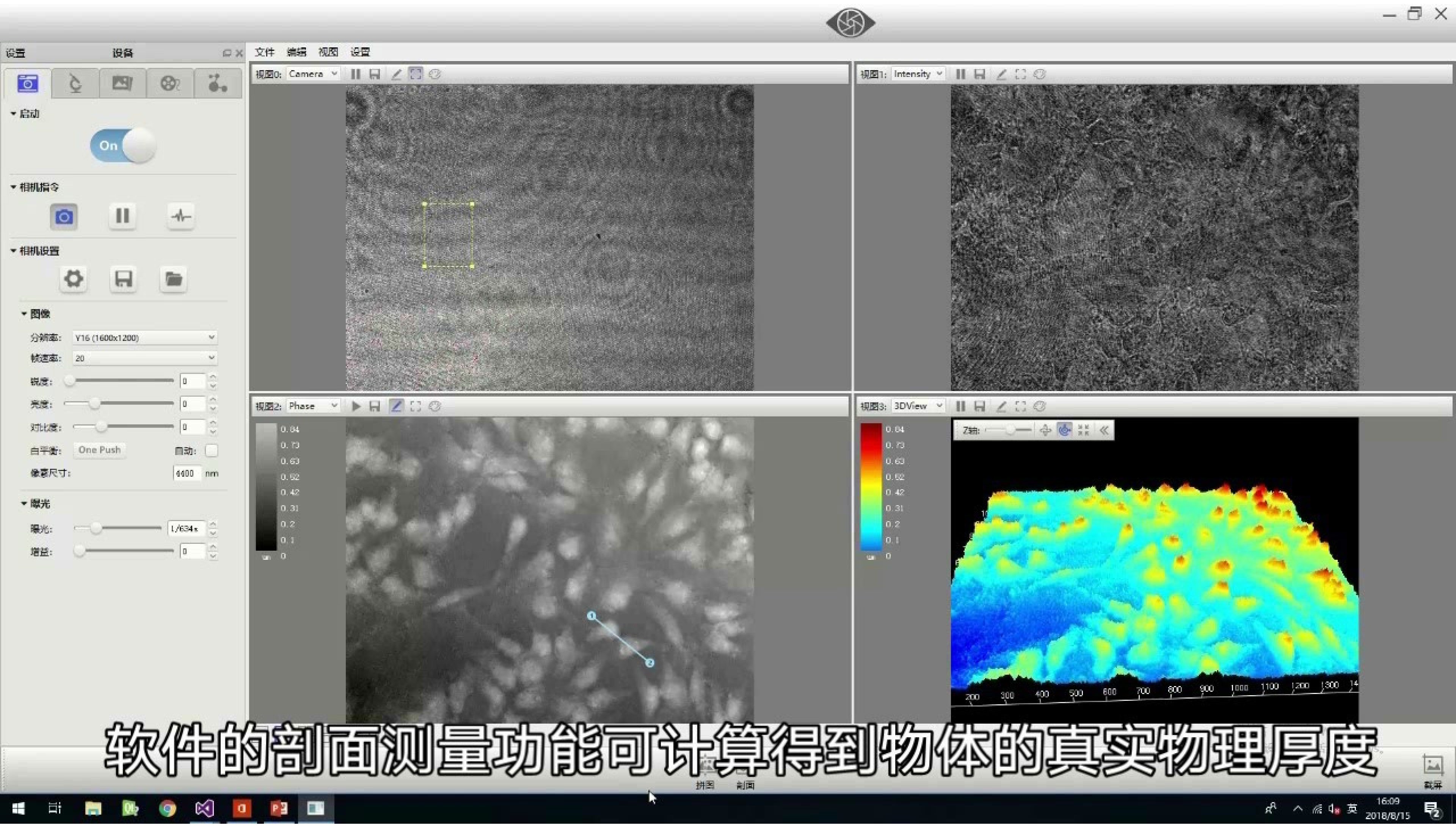

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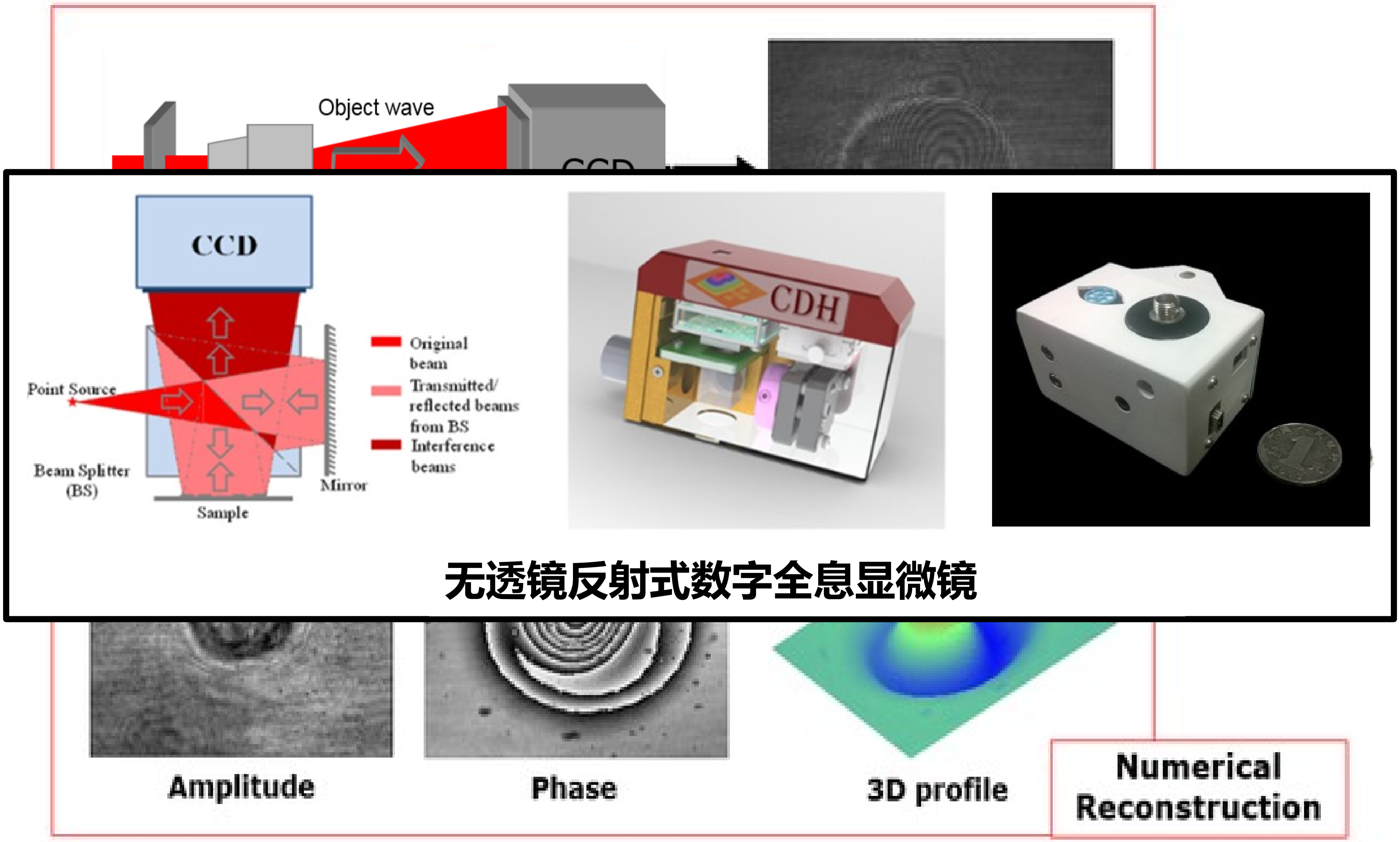
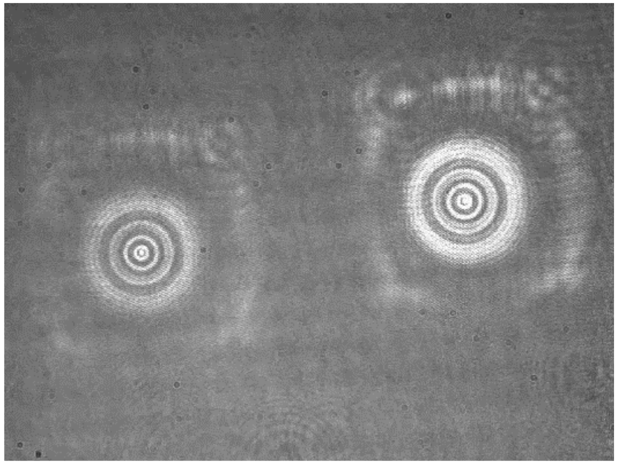
无透镜全息显微 Lensless Holographic Microscopy

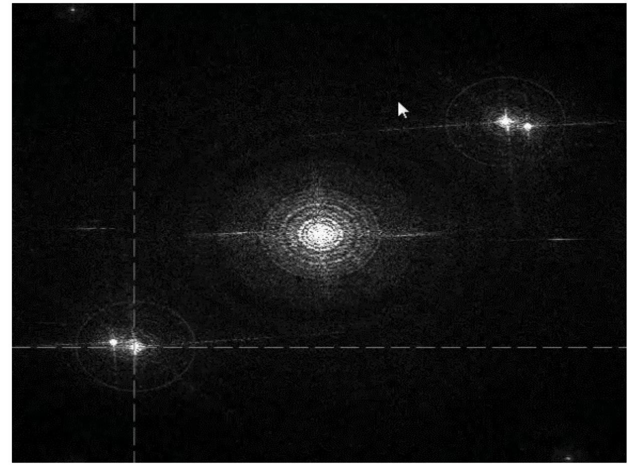


C. Zuo, Q. Chen, W. Qu and A. Asundi, *Chapter 3: Digital Holography for Three-Dimensional Metrology: Principles, Methods, and Applications*, in Ella Myers (ed.) *Advances in Digital Holography Research*. ISBN: 9781608764747.

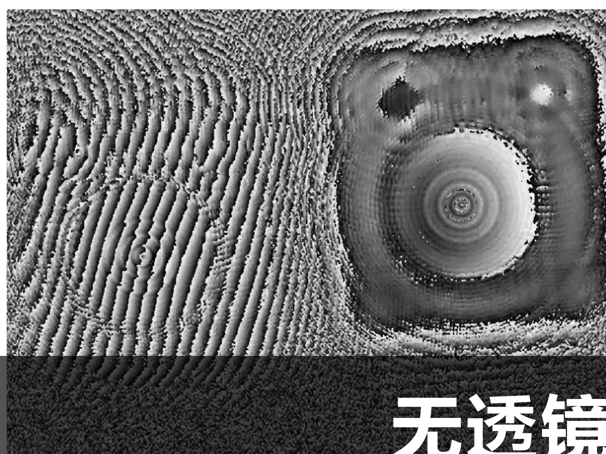
无透镜全息显微 Lensless Holographic Microscopy

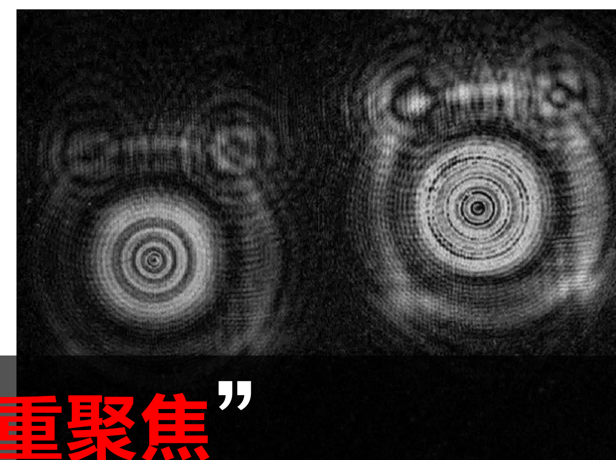


Hologram



Fourier





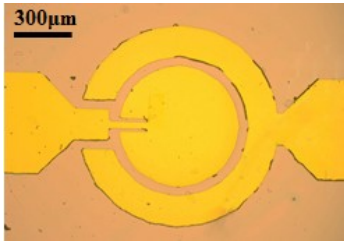
无透镜“数字重聚焦”

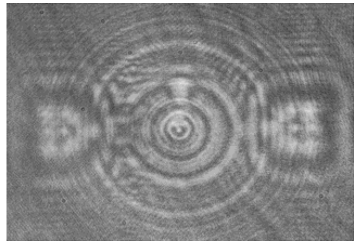
Phase (digital refocusing)

Intensity (digital refocusing)

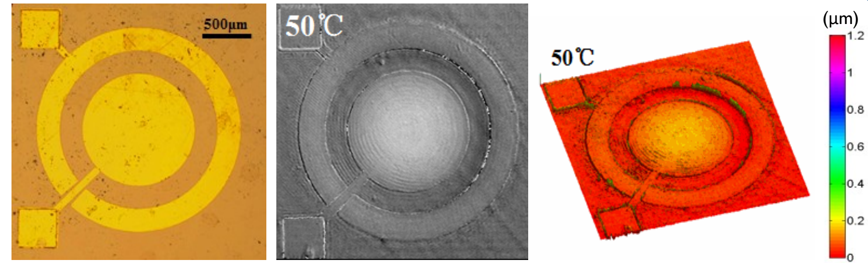
C. Zuo, Q. Chen, W. Qu and A. Asundi, *Chapter 3: Digital Holography for Three-Dimensional Metrology: Principles, Methods, and Applications*, in Ella Myers (ed.) *Advances in Digital Holography Research*. ISBN: 9781608764747.

无透镜全息显微 Lensless Holographic Microscopy



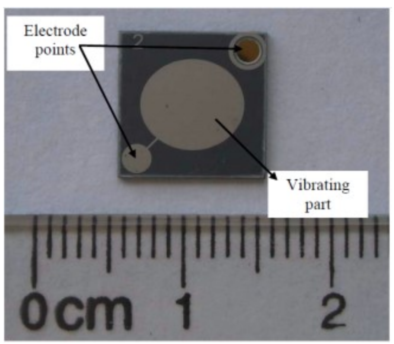


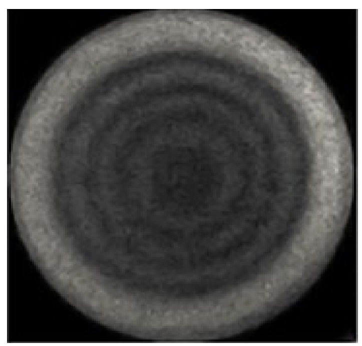
3D Profiling and Measurements

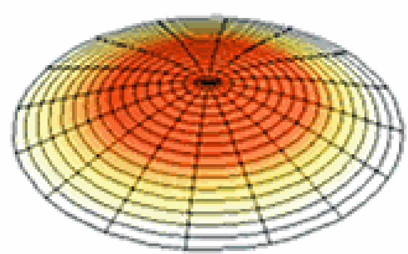


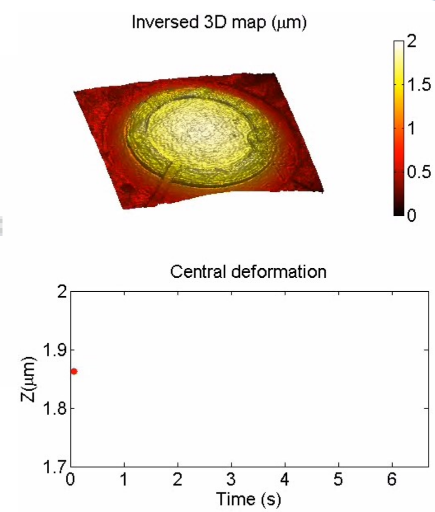
Displacement and Deformation

MEMS and Nano-metrology







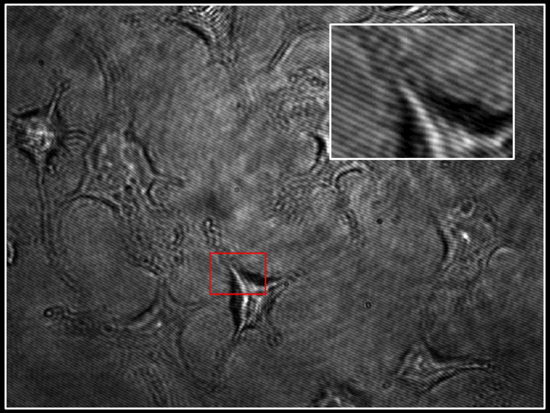


Vibration and Dynamic Measurements

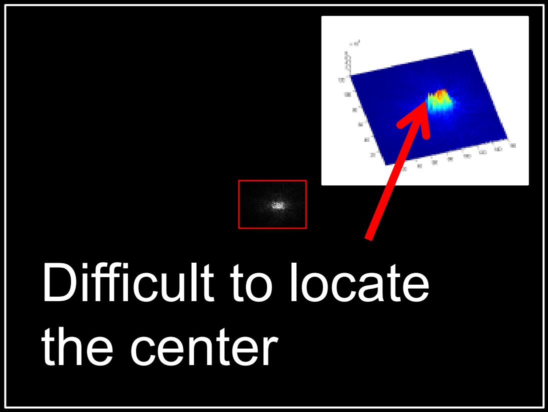
C. Zuo, Q. Chen, W. Qu and A. Asundi, *Chapter 3: Digital Holography for Three-Dimensional Metrology: Principles, Methods, and Applications*, in Ella Myers (ed.) *Advances in Digital Holography Research*. ISBN: 9781608764747.

A. Asundi, *Digital Holography for MEMS and Microsystem Metrology*, Wiley-vch Verlag, Ed. Weinheim, 2011

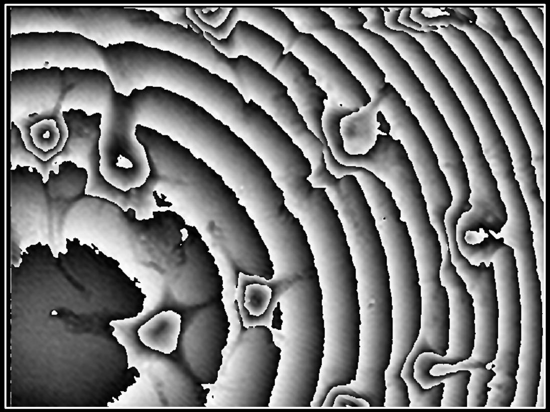
Phase aberration compensation



The quadratic aberration induced by MO broadened the spectrum



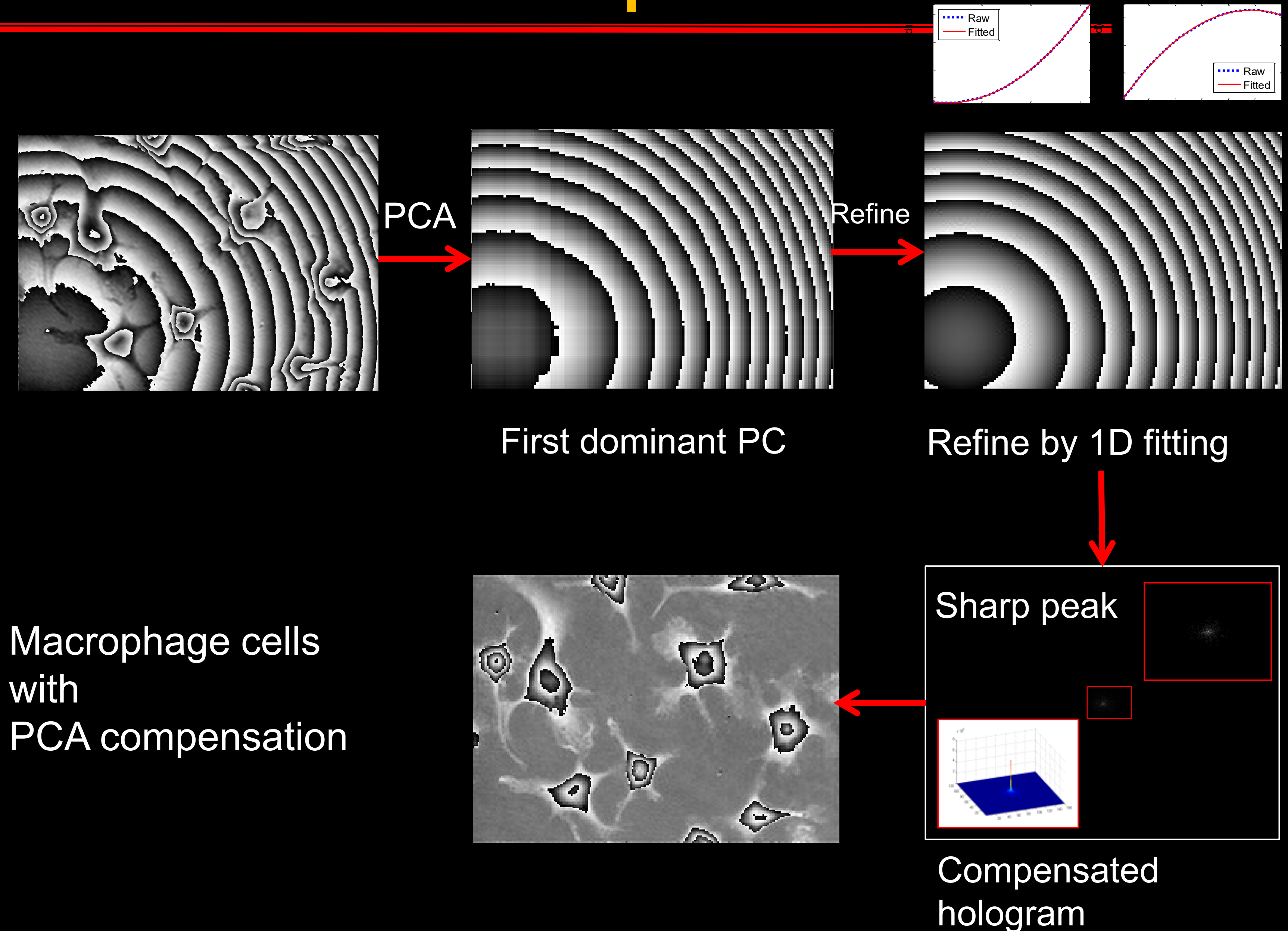
Difficult to locate the center



Both tilt and defocus are fail to compensated by spectrum centering

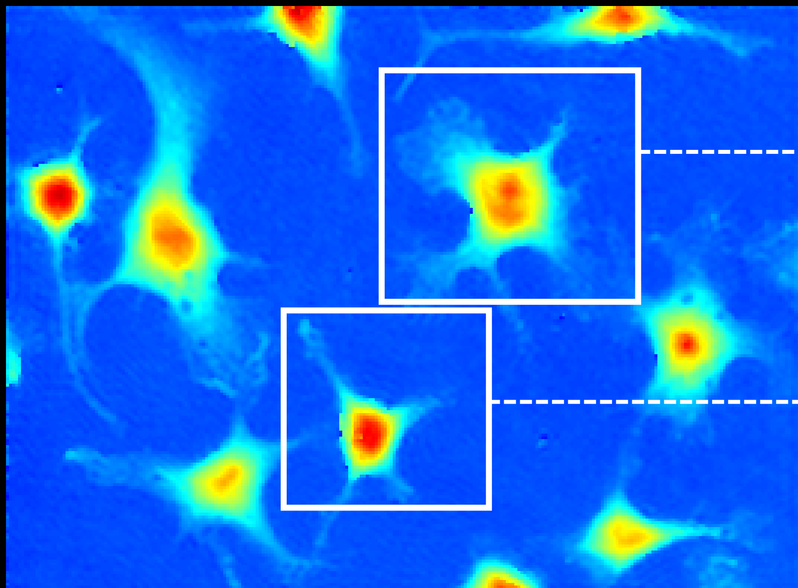
Macrophage cells without phase compensation

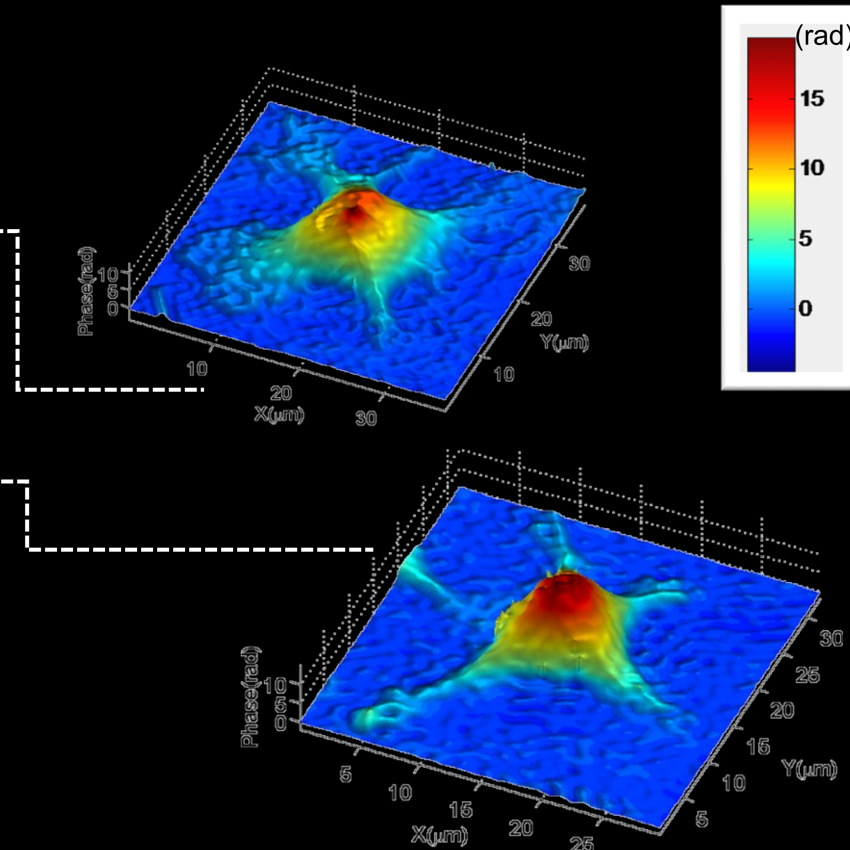
Phase aberration compensation



C. Zuo, Q. Chen, W. Qu, A. Asundi, Optics Letters **38**, 1724-1726 (2013).
J. Sun, Q. Chen, Y. Zhang, and C. Zuo, Optics Letters **41**,1293-1296 (2016).

Phase aberration compensation





Macrophage cells with
PCA phase compensation

C. Zuo, Q. Chen, W. Qu, A. Asundi, Optics Letters **38**, 1724-1726 (2013).
J. Sun, Q. Chen, Y. Zhang, and C. Zuo, Optics Letters **41**,1293-1296 (2016).

Thank you