



Upconversion Nanoparticles for In-depth Super Resolution Imaging and Ultra-strong Nanoscale Optical Trapping

Fan Wang, University of Technology Sydney

The OSA Imaging Optical Design Technical Group Welcomes You!

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Dr. Maryna L. Meretska



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Our Technical Group at a Glance

Our Focus

- Physics of linear optical materials, processes, devices, & applications
- 2000 members

Our Mission

- To benefit YOU
- Webinars, social media, publications, technical events, business events, outreach
- Interested in presenting your research? Have ideas for TG events? Contact us at: TGactivities@osa.org.

Where To Find Us

- Website: <https://www.osa.org/fd>
- Facebook: <https://www.facebook.com/groups/OSAImagingOpticalDesign/>
- LinkedIn: <https://www.linkedin.com/groups/8113351/>

Today's Speaker



Dr Fan Wang

POSITIONS

Lecturer, School of Electrical and
Data Engineering

Core Member, IBMD - Initiative for
Biomedical Devices



Dr. Fan Wang is an Australian Research Council DECRA fellow and the UTS Chancellor's Postdoctoral Research Fellow, working on nanophotonics and biophotonics research. Dr. Wang has published over 56 peer-reviewed journal articles with an h-index of 27 (Google Scholar) and over 2624 citations.

Dr. Wang obtained his Ph.D. from the University of New South Wales in Australia in 2014. From 2013 to 2015, he worked as a Postdoctoral Research Fellow in Prof. Jagadish's group at the Australian National University studying semiconductor nanowires. Since 2015, Dr. Wang joined the ARC center of excellence for nanoscale biophotonics at Macquarie University. From 2017, Dr. Wang joined Prof. Dayong Jin's group in UTS to lead the biophotonics team. From 2020, Dr Wang joined the School of Electrical and Data Engineering as a lecturer to establish his nano-optoelectronics group.



Today's talk

UPCONVERSION NANOPARTICLES FOR IN-DEPTH SUPER RESOLUTION IMAGING & ULTRA-STRONG NANOSCALE OPTICAL TRAPPING

20 November 2020 • 18:00 EST

OSA Imaging
Optical Design
Technical Group

OSA Nonlinear
Optics
Technical Group

**Upconversion nanoparticles for
in-depth super-resolution
imaging and strong
nanoscale optical
trapping**



Dr. Fan Wang

Chancellor's Postdoctoral Research Fellow
ARC Discovery Early Career Researcher Fellow

Upconversion nanoparticles for in-depth super-resolution imaging and strong nanoscale optical trapping



Dr. Fan Wang

Chancellor's Postdoctoral Research Fellow
ARC Discovery Early Career Researcher Fellow





Biophotonics

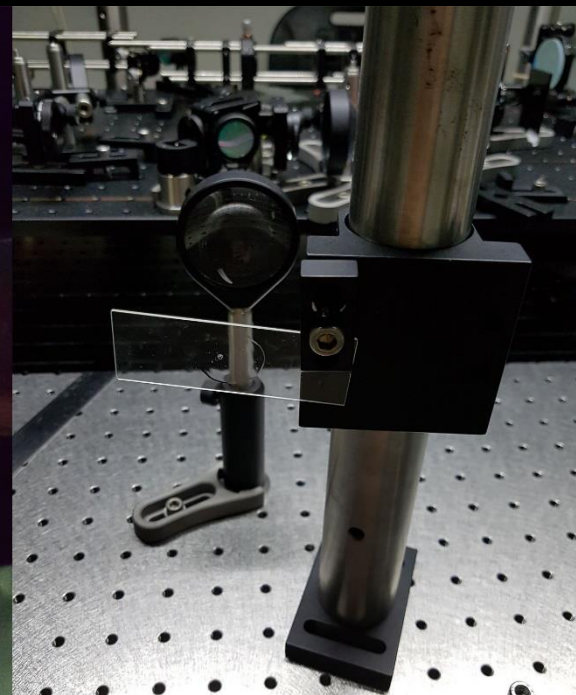
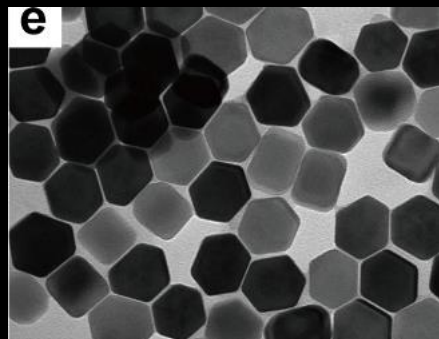


Material
Science



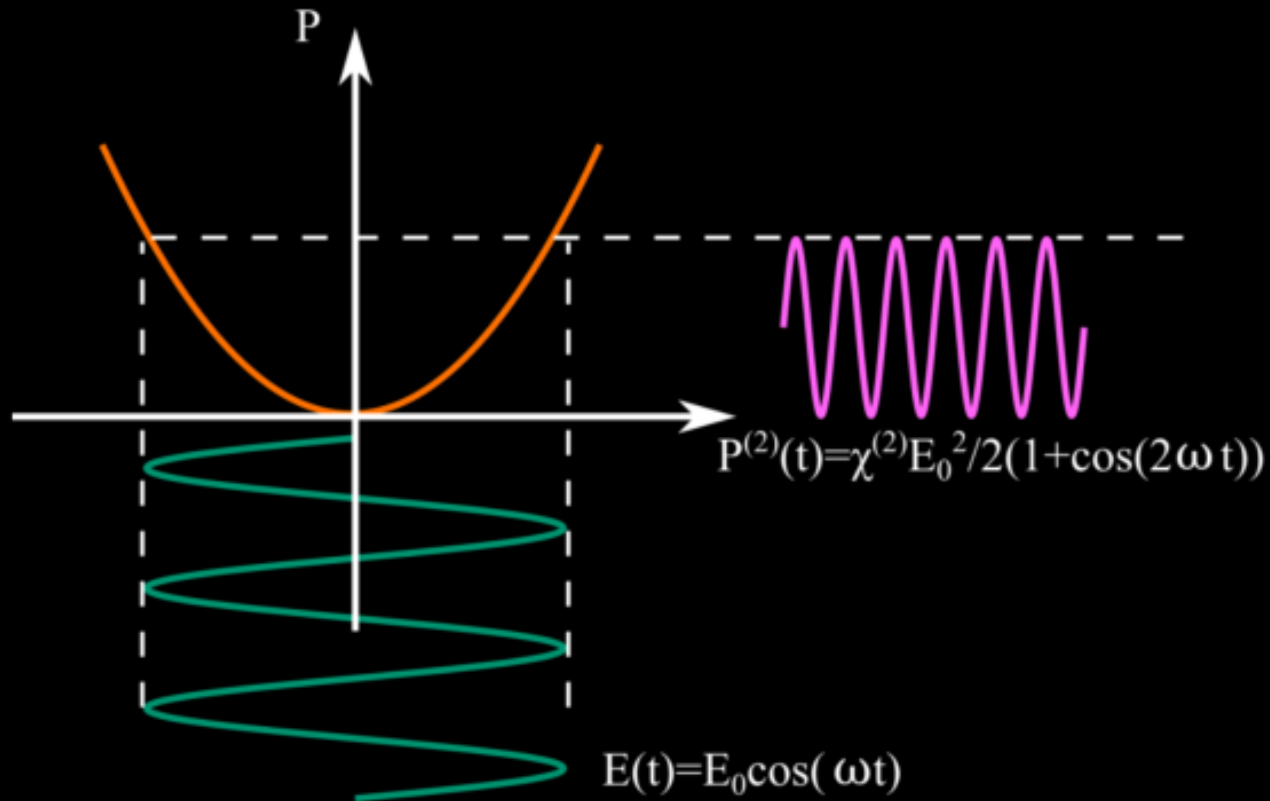
Photonics
Devices

Upconversion nanoparticles (UCNP)

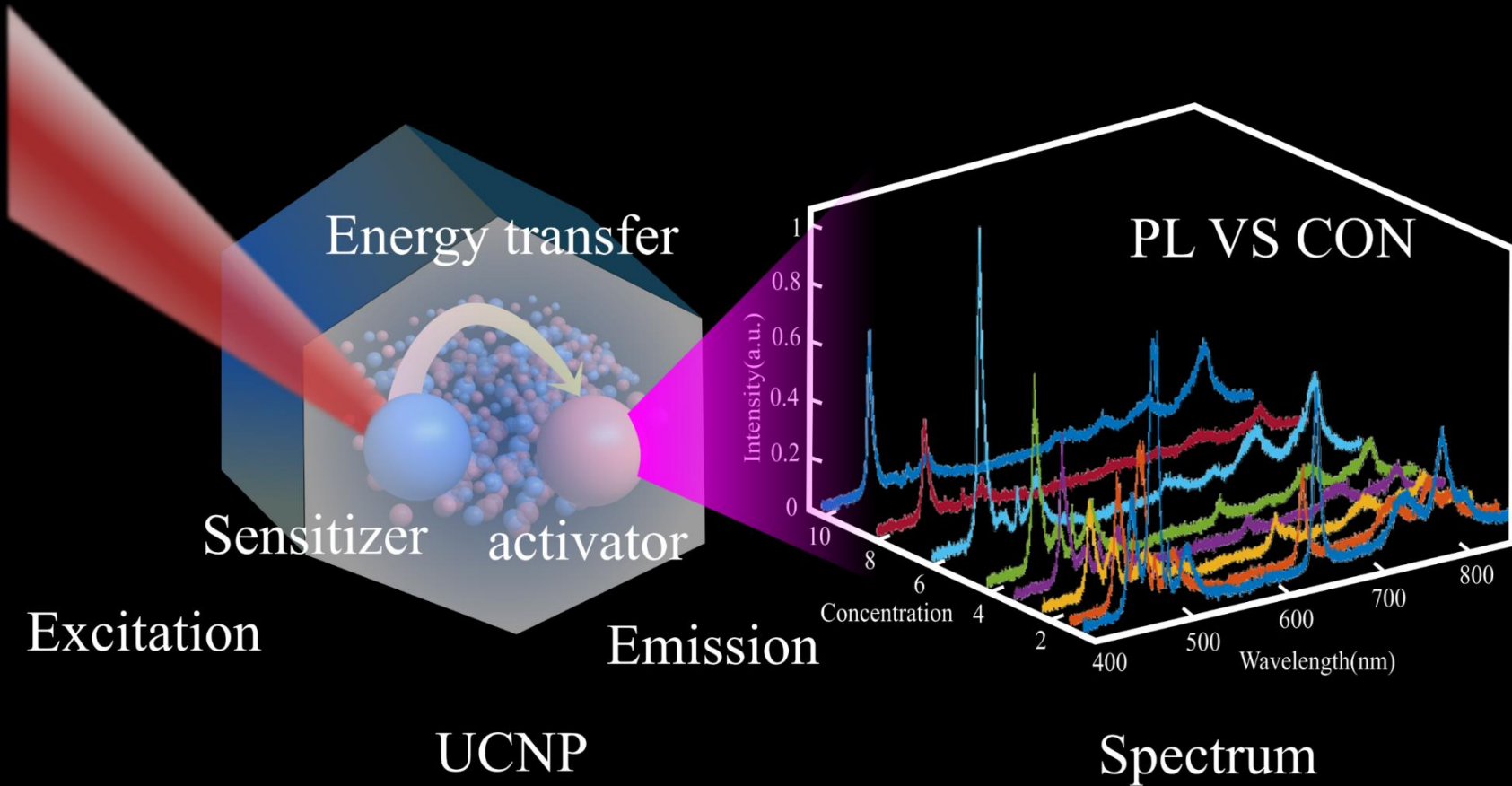


Nonlinear photo-response

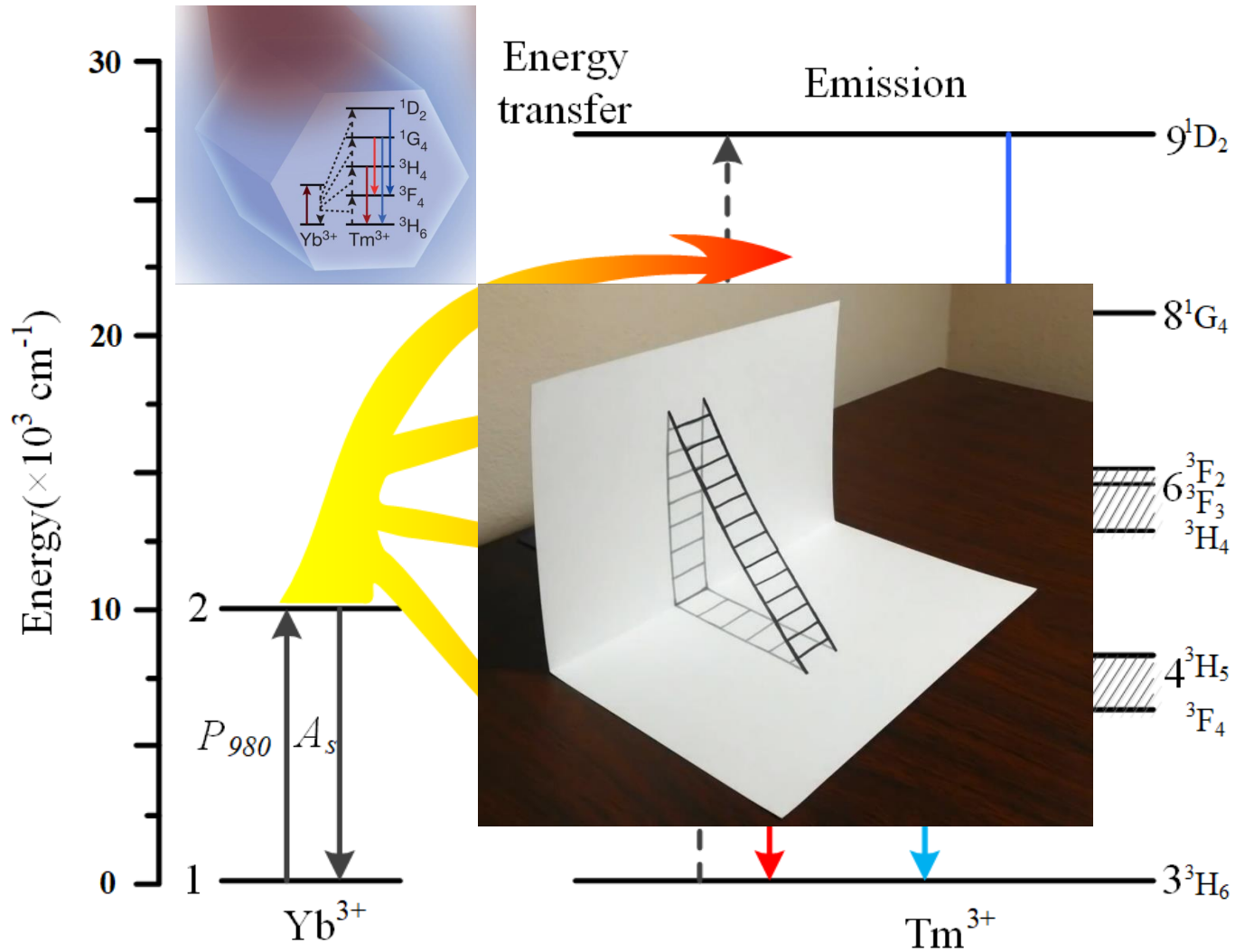
$$\mathbf{P} = \varepsilon_0 [\chi^{(1)} \mathbf{E} + \chi^{(2)} \mathbf{E}^2 + \chi^{(3)} \mathbf{E}^3 + \dots]$$



Upconversion nanoparticles (UCNP)



Upconverting nonlinear photo-response



Upconverting nonlinear photo-response

$$\frac{dn_1}{dt} = -c_1 n_1 n_{S2} + a_{21} w_2 n_2 + a_{31} w_3 n_3 + a_{41} w_4 n_4 + a_{51} w_5 n_5 - k_{41} n_1 n_4 - k_{31} n_3 n_1 - k_{51} n_5 n_1$$

$$\frac{dn_2}{dt} = c_1 n_1 n_{S2} - c_2 n_2 n_{S2} - a_{21} w_2 n_2 + a_{32} w_3 n_3 + a_{42} w_4 n_4 + a_{52} w_5 n_5 + k_{41} n_1 n_4 + 2k_{31} n_1 n_3$$

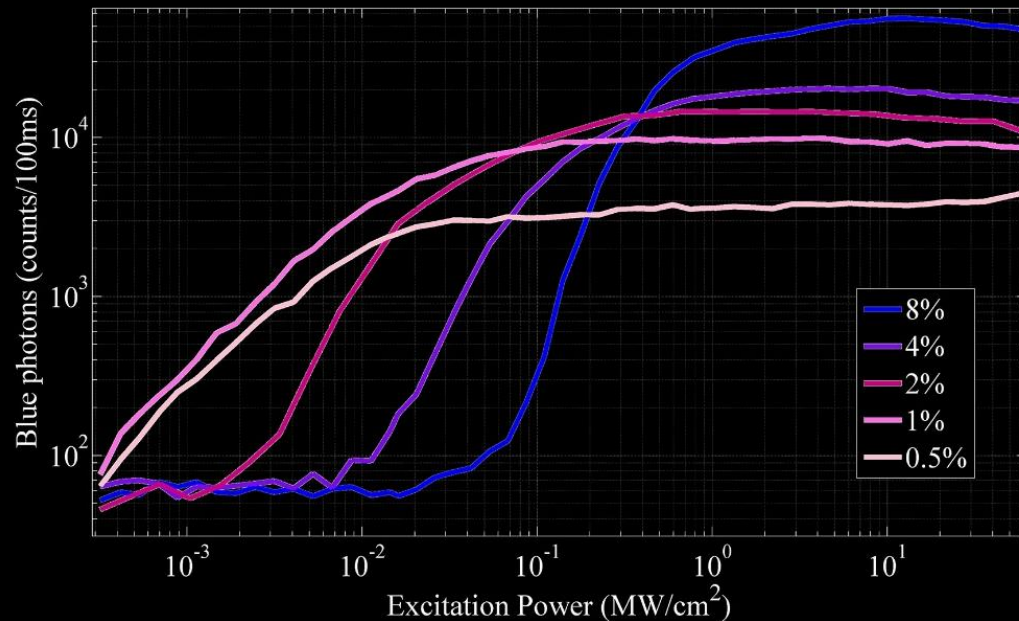
$$\frac{dn_3}{dt} = c_2 n_2 n_{S2} - c_3 n_3 n_{S2} - (a_{31} + a_{32}) w_3 n_3 + a_{43} w_4 n_4 + a_{53} w_5 n_5 + 2k_{51} n_5 n_1 + k_{41} n_4 n_1 - k_{31} n_3 n_1$$

$$\frac{dn_4}{dt} = c_3 n_3 n_{S2} - c_4 n_4 n_{S2} - (a_{43} + a_{42} + a_{41}) w_4 n_4 + a_{54} w_5 n_5 - k_{41} n_1 n_4$$

$$\frac{dn_5}{dt} = c_4 n_4 n_{S2} - (a_{54} + a_{53} + a_{52} + a_{51}) w_5 n_5 - k_{51} n_1 n_5$$

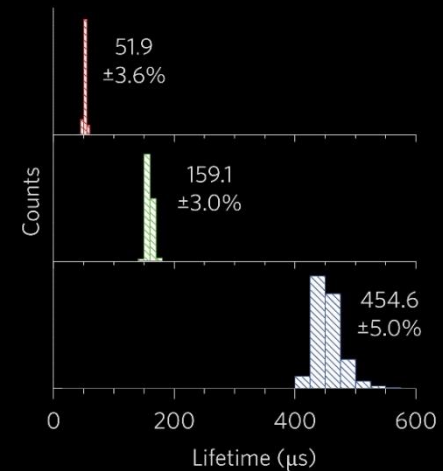
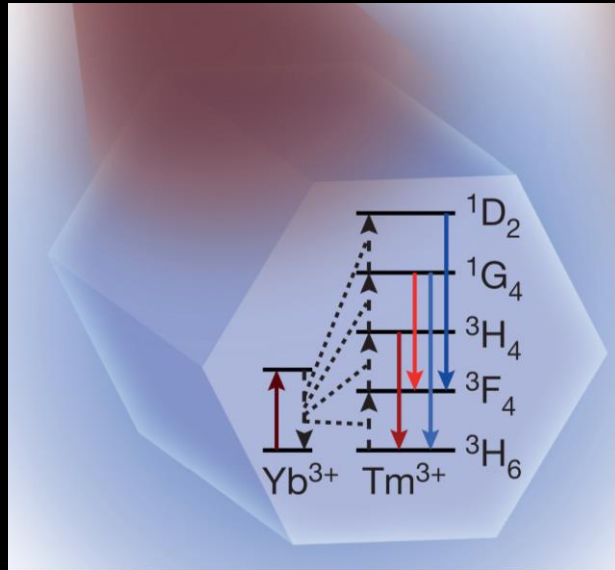
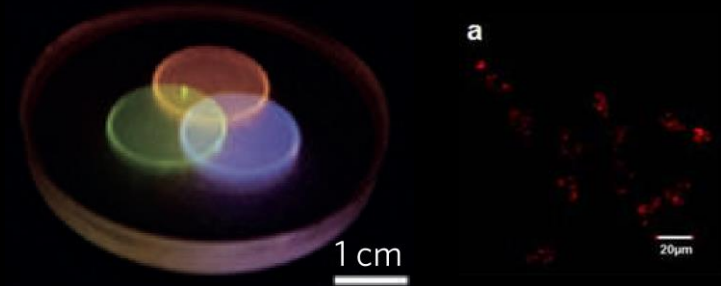
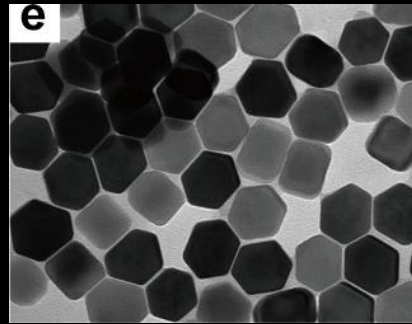
$$\frac{dn_{S2}}{dt} = P_{980} n_{S1} - w_{S2} n_{S2} - (c_1 n_1 + c_2 n_2 + c_3 n_3 + c_4 n_4) n_{S2}$$

- Cross relaxation
- Super linear
- Saturation
- Multi-energy levels

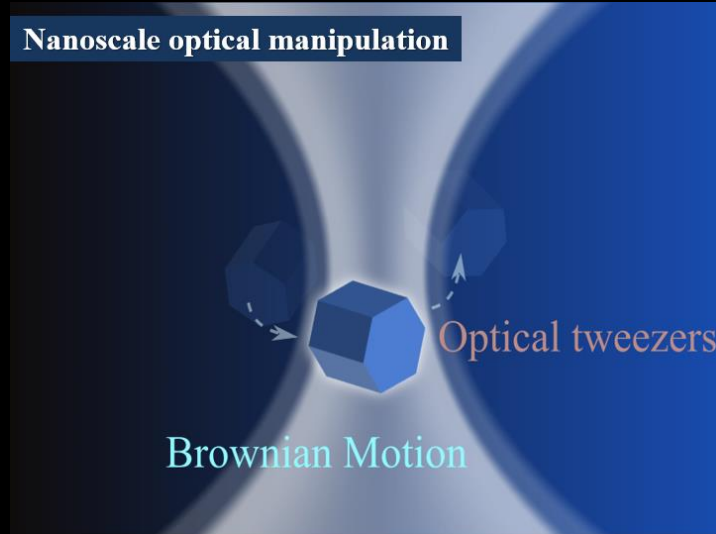


Upconversion nanoparticles (UCNP)

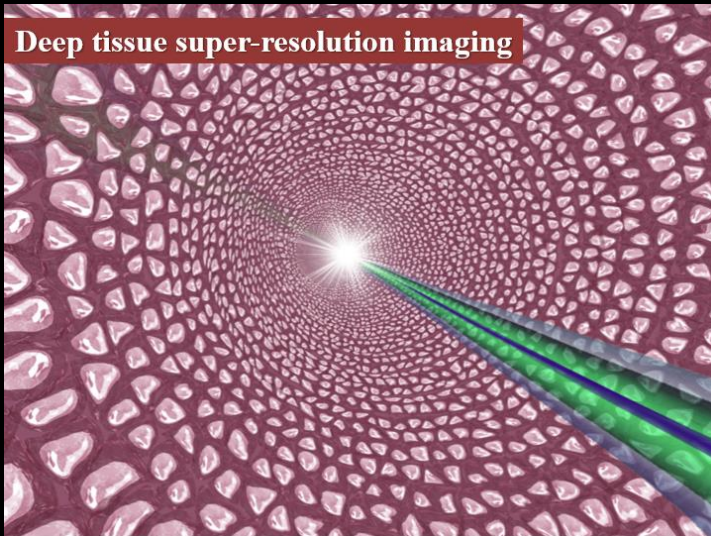
- Anti-stokes emission
- Multi-emission color
- No quenching
- No blinking
- Uniform
- Cross relaxation
- Duo-NIR
- Nonlinear response



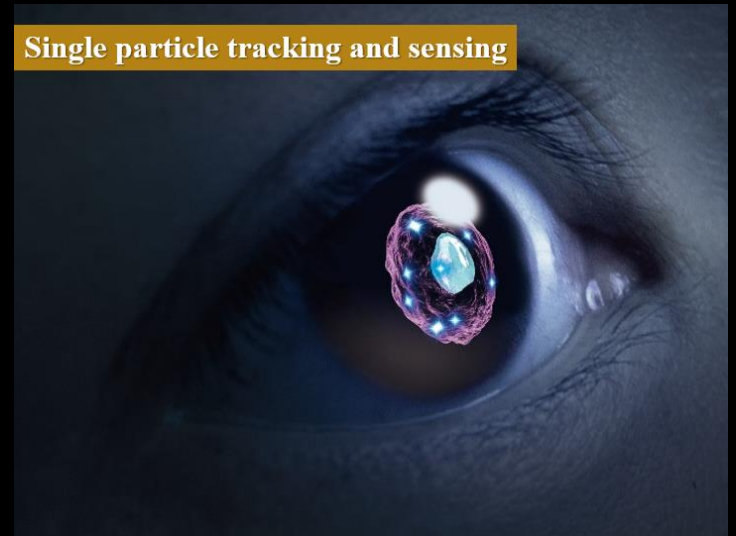
Nanoscale optical manipulation



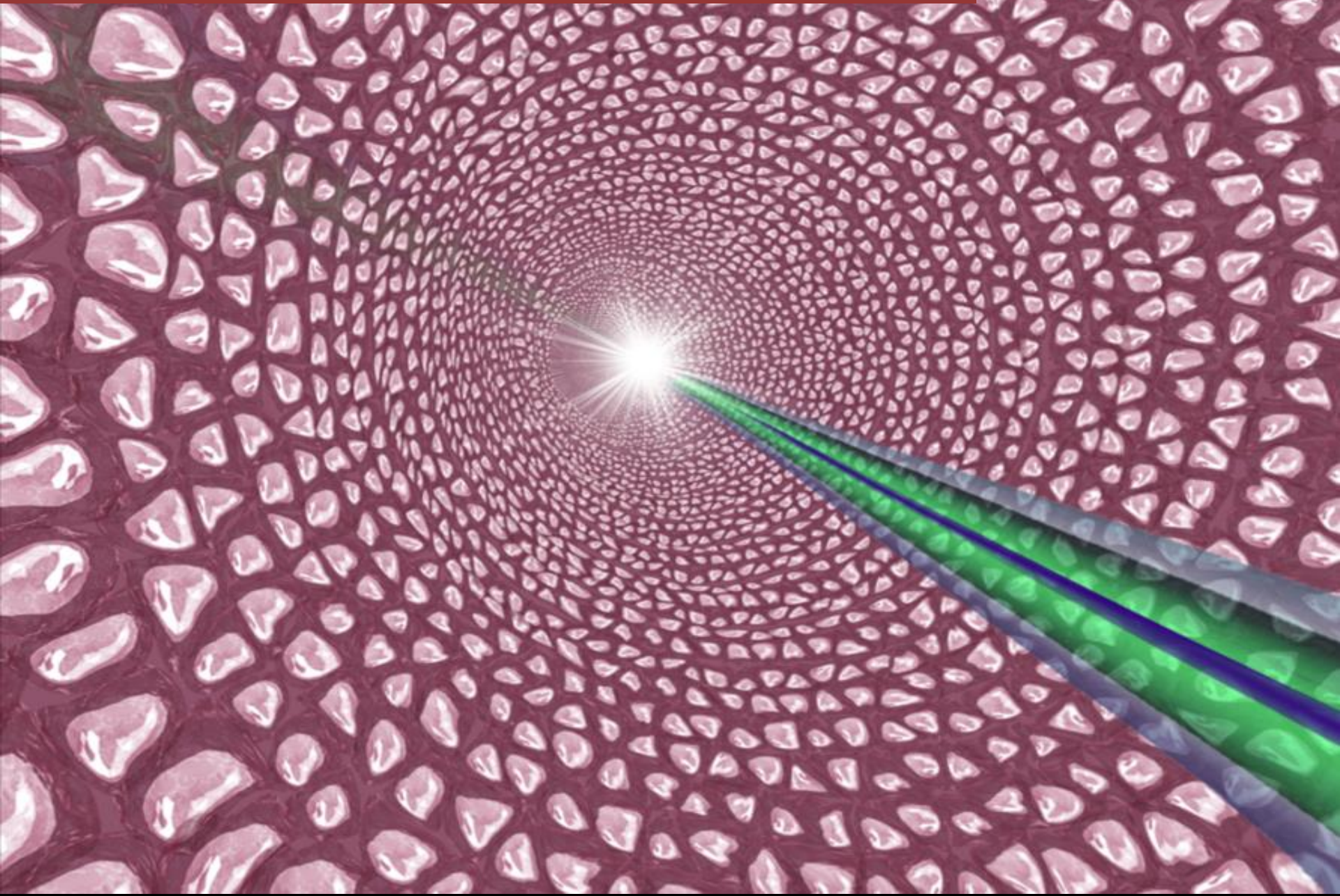
Deep tissue super-resolution imaging



Single particle tracking and sensing



Deep tissue super-resolution imaging



Small Molecules Proteins, Antibodies Genes Viruses

Super-resolution Microscopy

2014 NOBEL PRIZE IN CHEMISTRY: WHAT YOU NEED TO KNOW

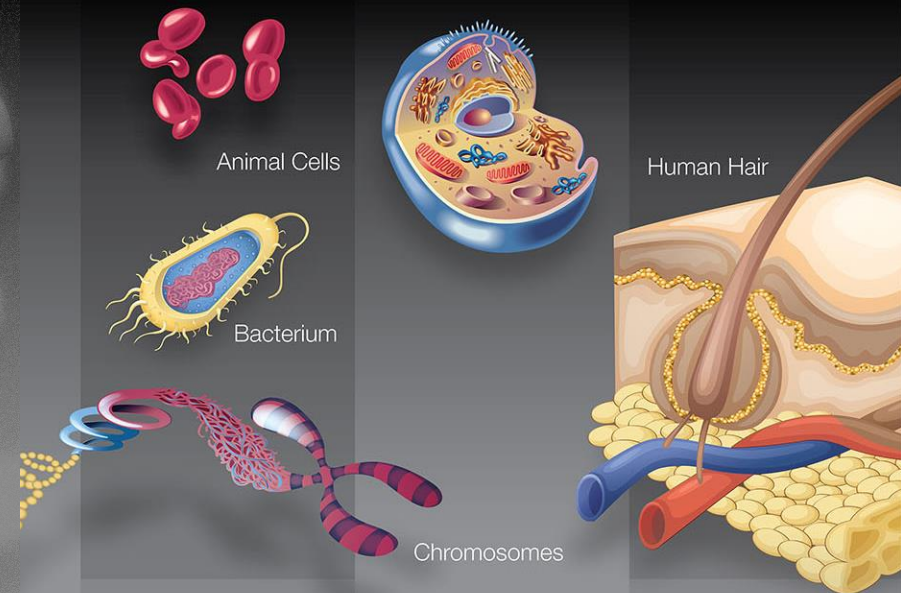


THE WINNERS

Eric Betzig

Stefan Hell

William Moerner



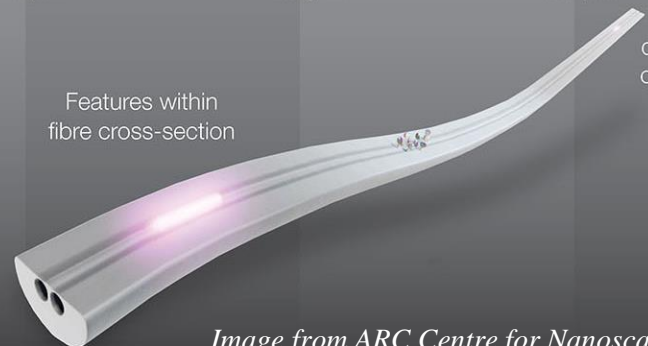
1 μm

10 μm

100 μm

Features within
fibre cross-section

Outer
diameter of
optical fibre



???



Resolution

Depth

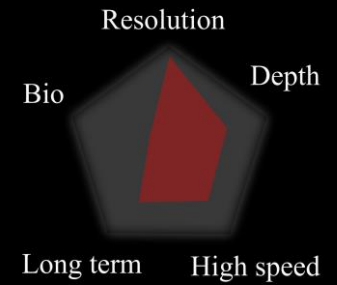
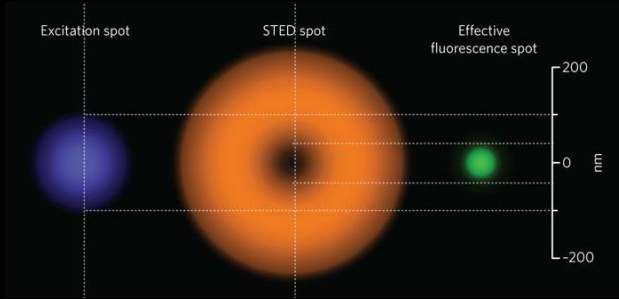
Bio

Long term

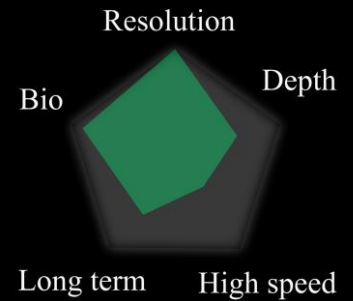
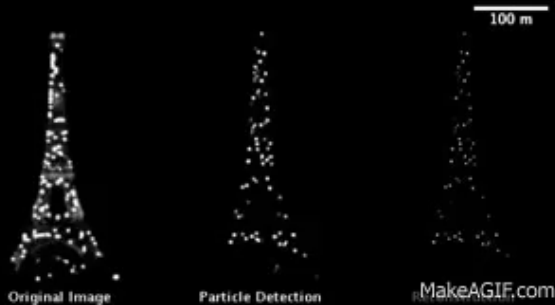
High speed



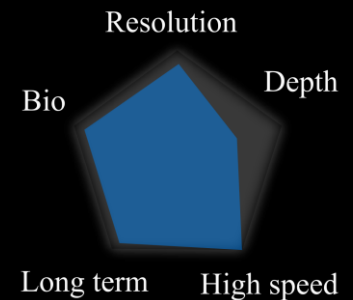
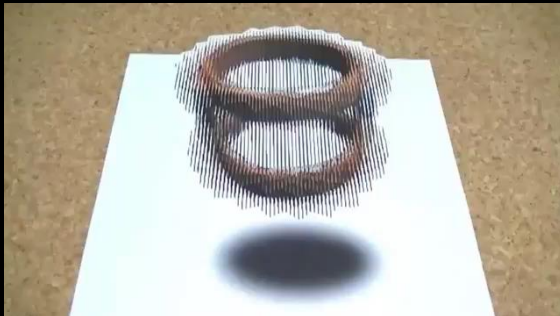
Stimulated emission depletion (STED)



Stochastic optical reconstruction microscopy (STORM)

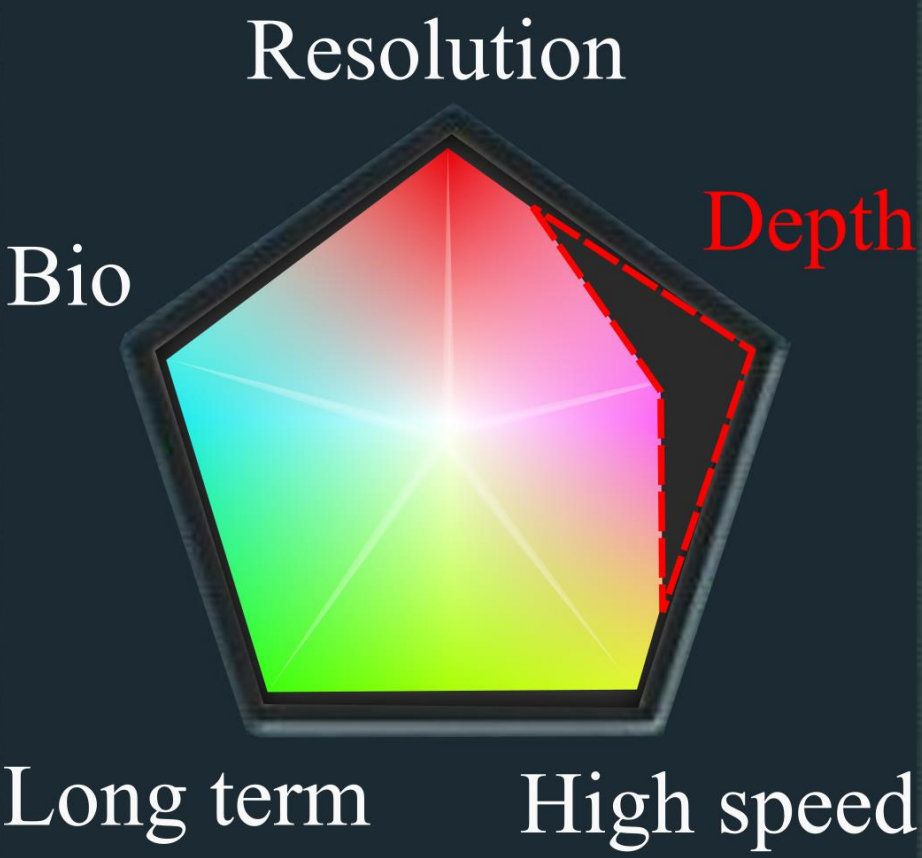


Structured illumination microscopy (SIM)



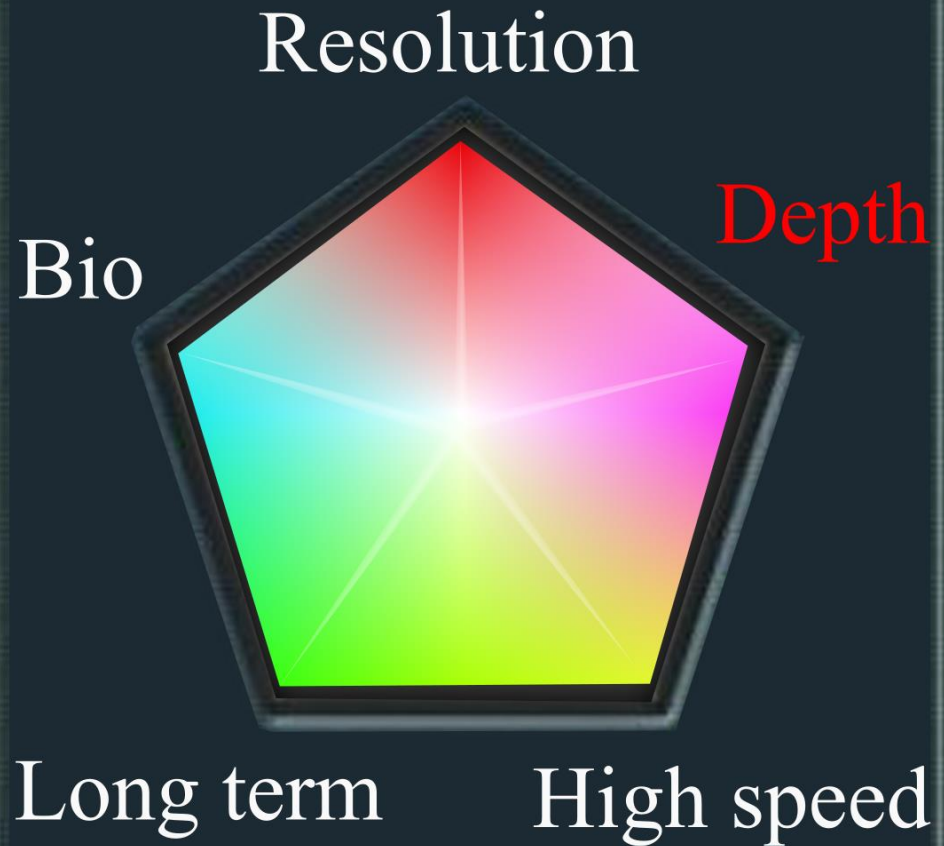
Problem: working depth

???

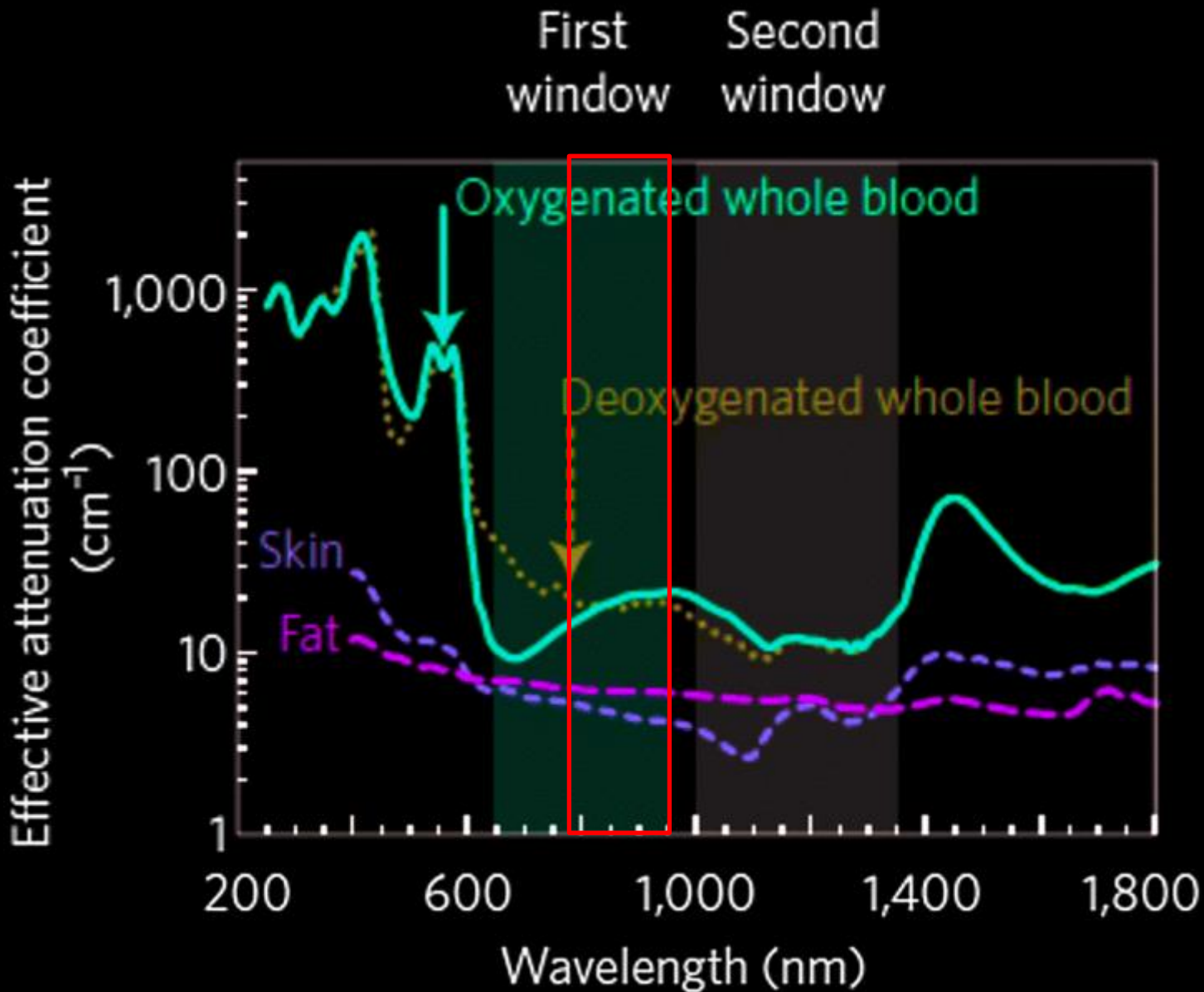


Problem: working depth

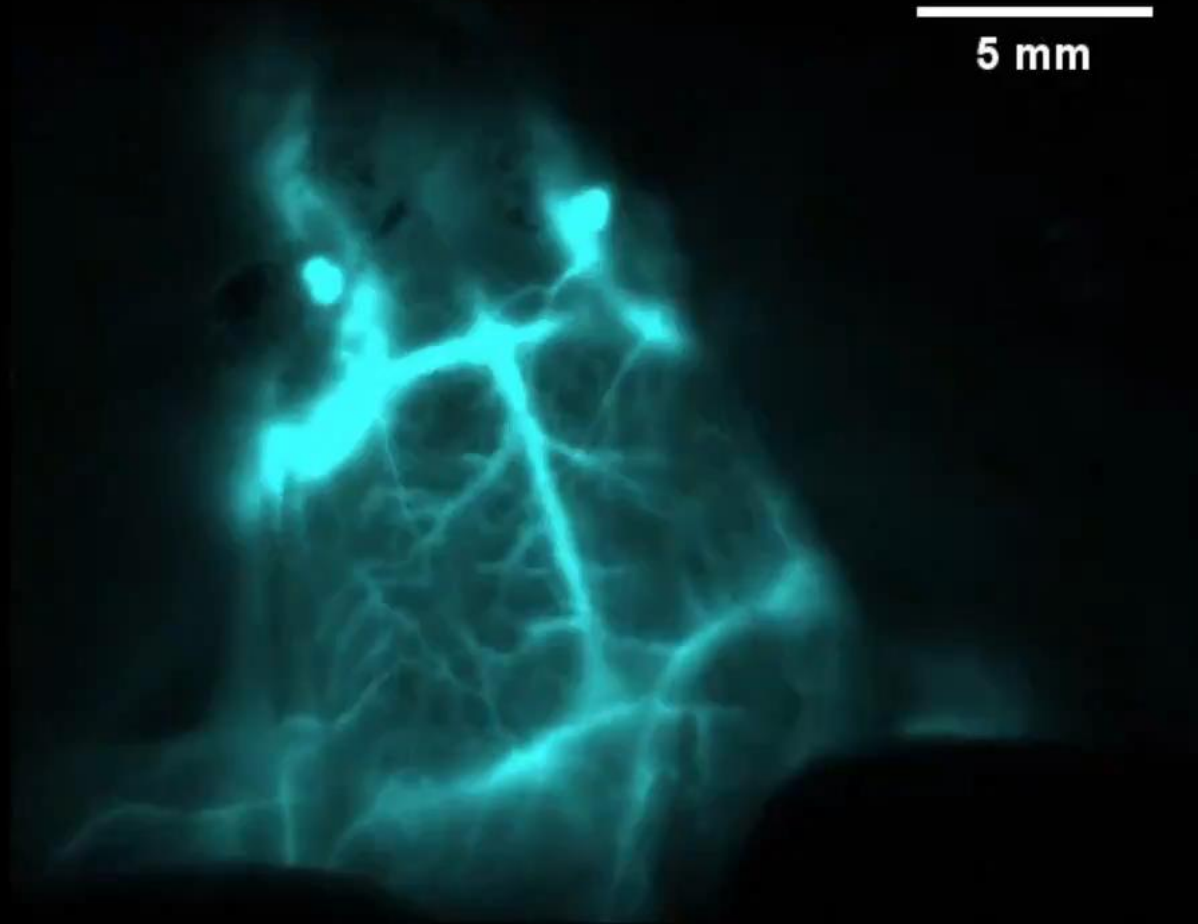
NIR Probe



Biological window



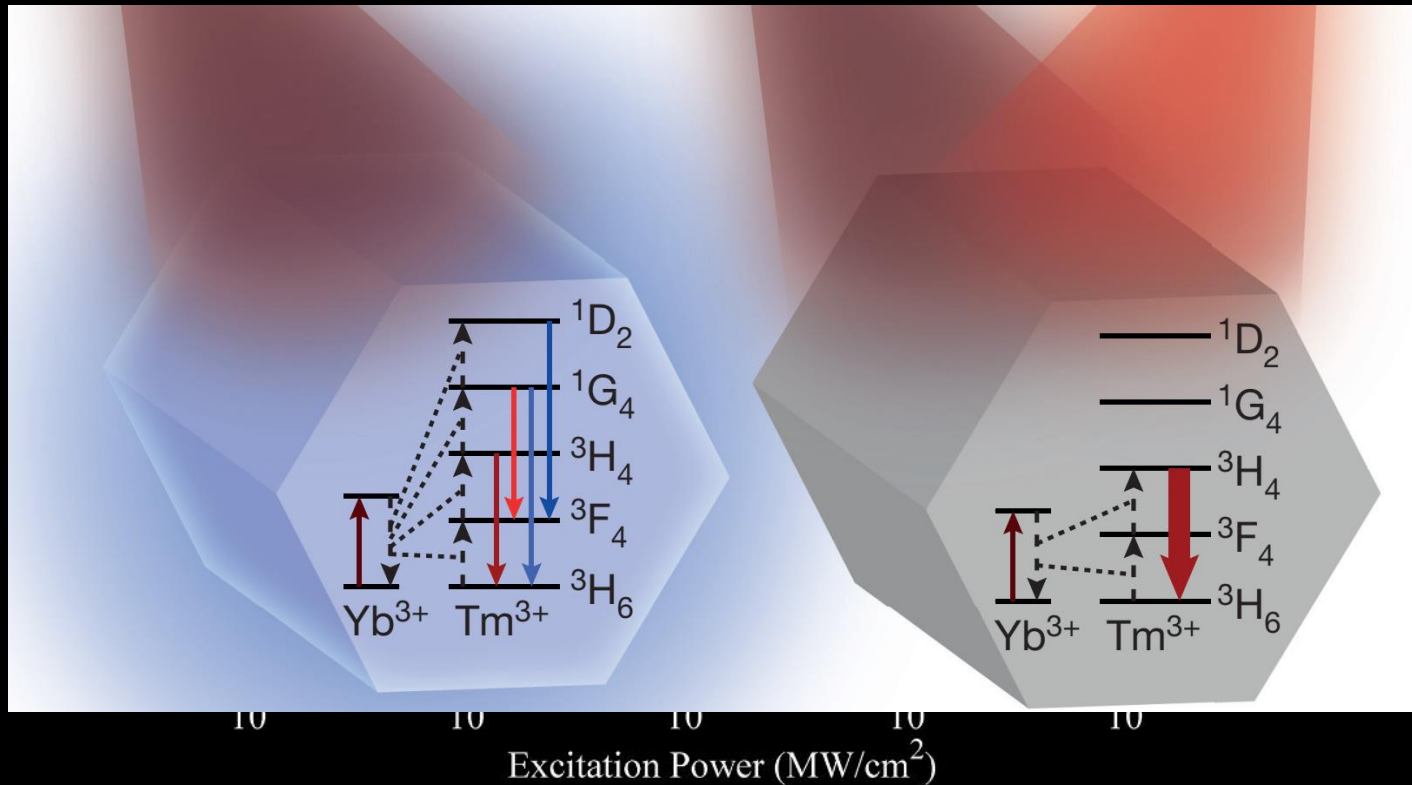
Deep-tissue biocompatible probe






How to make it super-res?

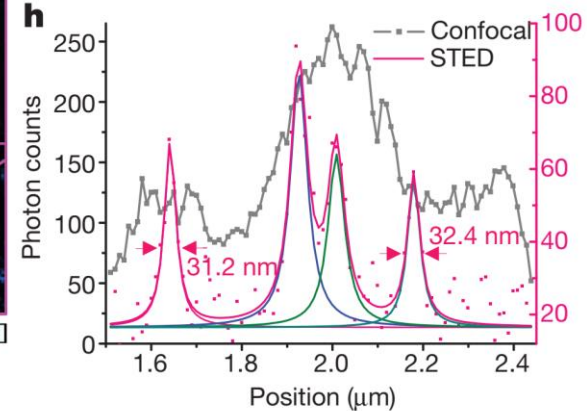
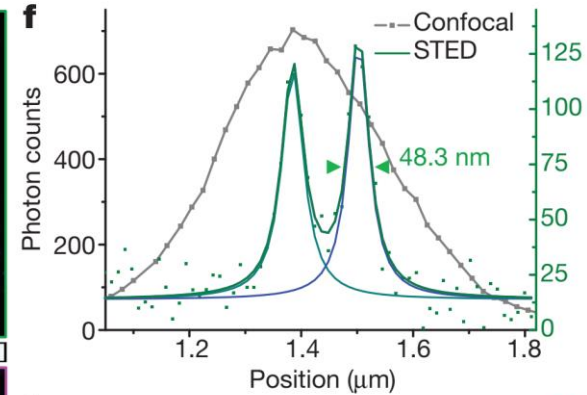
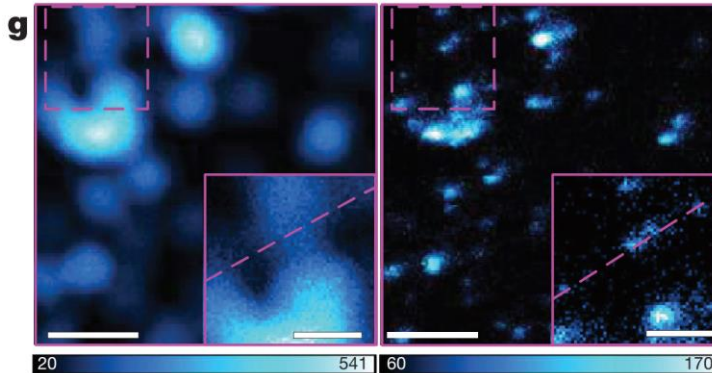
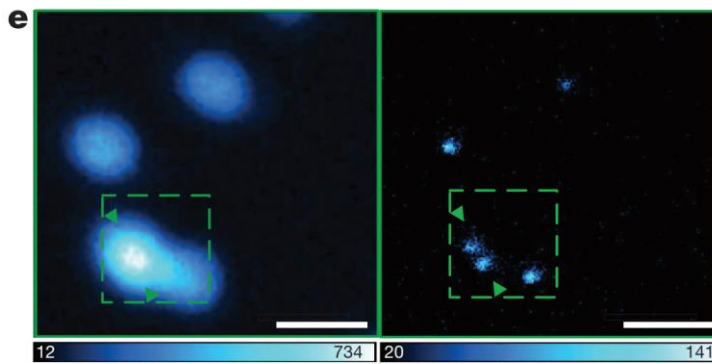
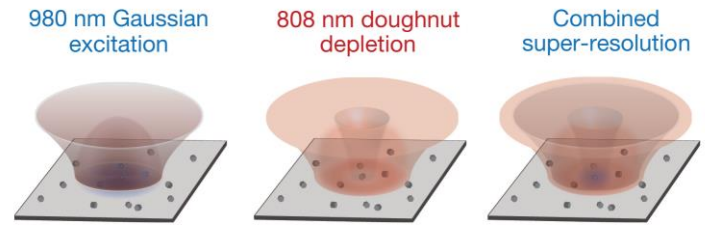
Upconverting nonlinear photo-response

- Cross relaxation
- Super linear
- Saturation
- Multi-energy levels



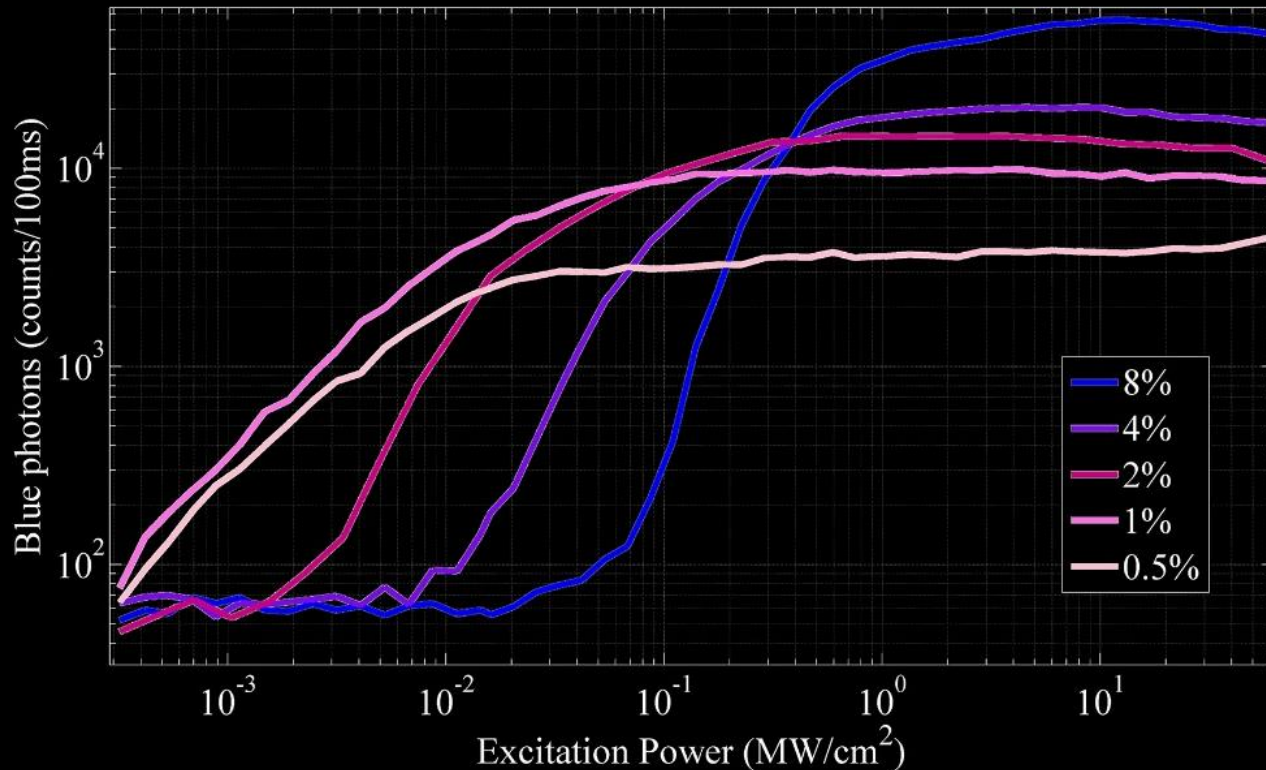
Amplified stimulated emission in upconversion nanoparticles for super-resolution nanoscopy

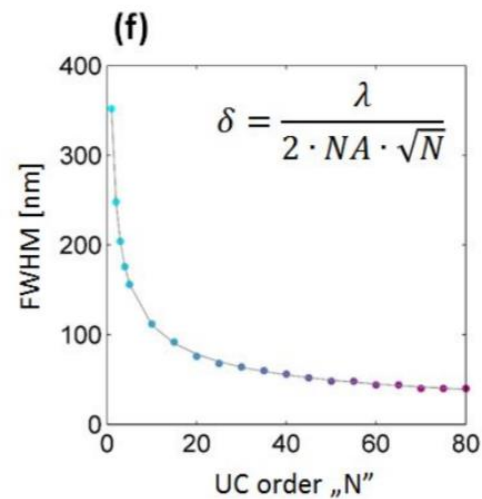
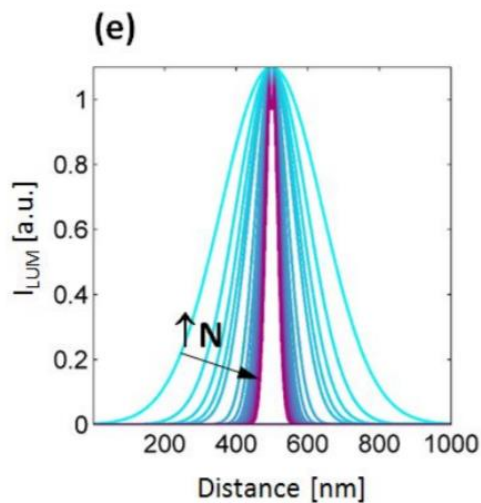
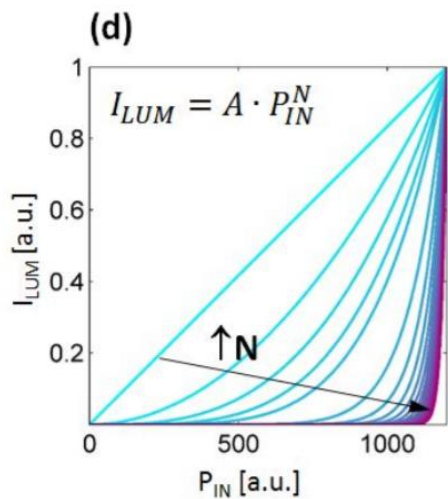
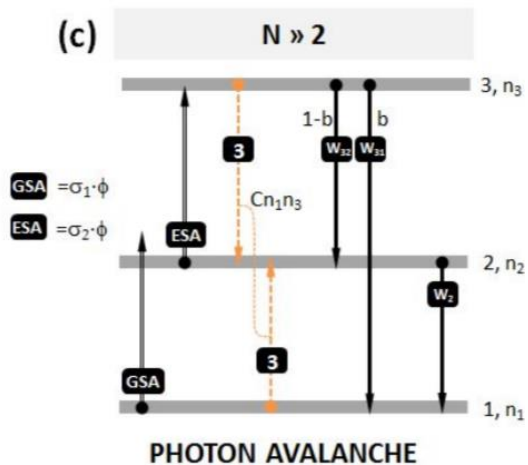
Yujia Liu, Yiqing Lu , Xusan Yang, Xianlin Zheng, Shihui Wen, Fan Wang, Xavier Vidal, Jiangbo Zhao, Deming Liu, Zhiguang Zhou, Chenshuo Ma, Jiajia Zhou, James A. Piper, Peng Xi  & Dayong Jin 

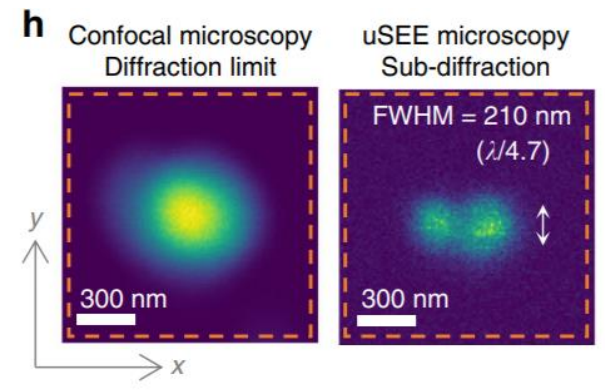
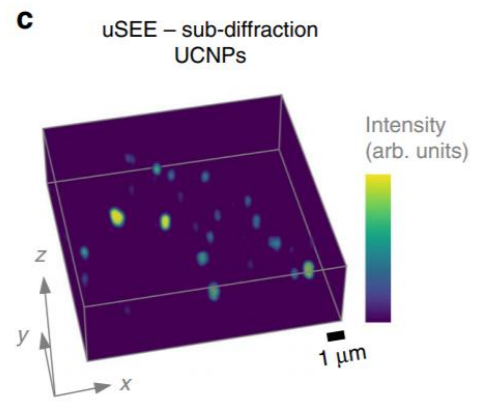
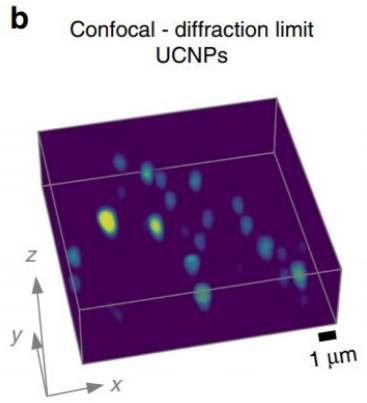


Upconverting nonlinear photo-response

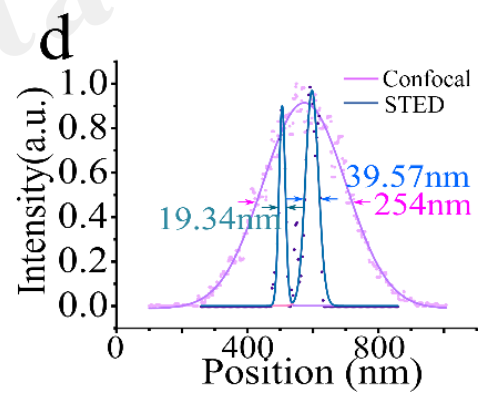
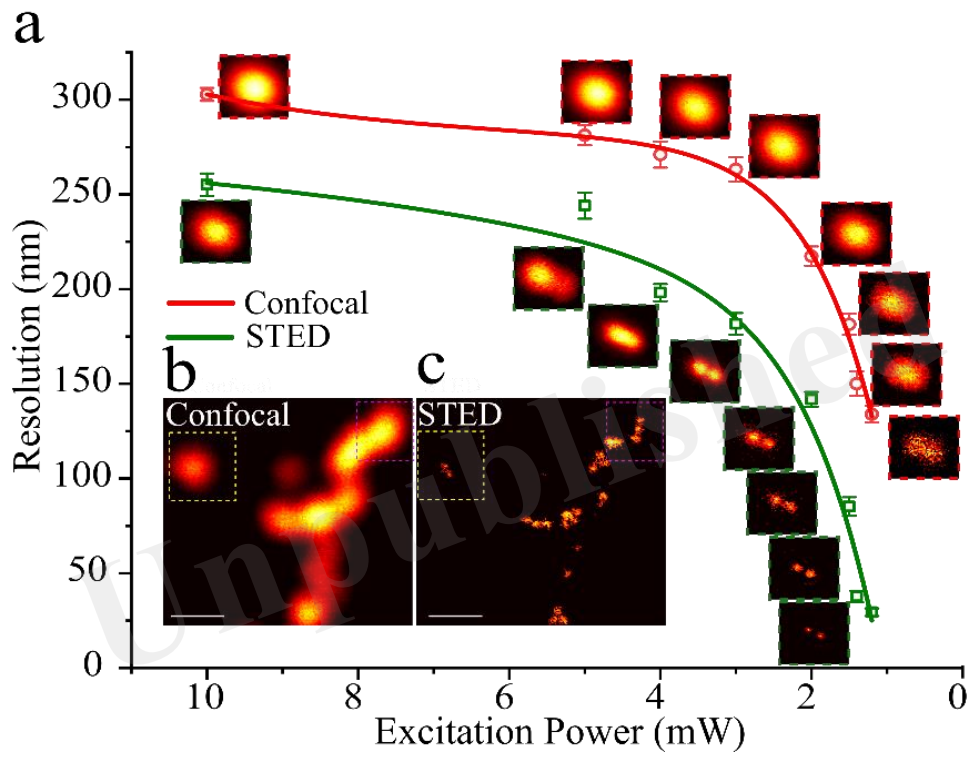
- Cross relaxation
- Super linear
- Saturation
- Multi-energy levels







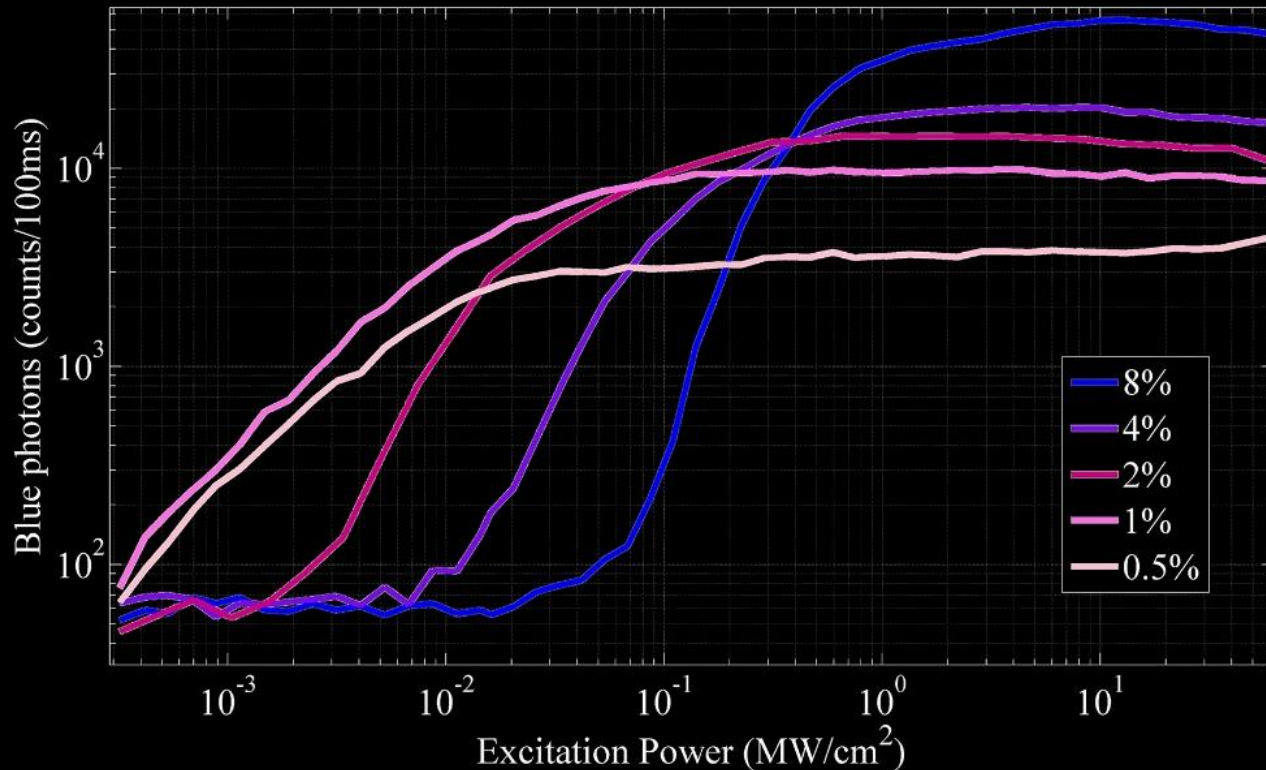
Denkova et al, Nature Communication, 10, 3695 (2019)



Challenge: Visible light to NIR

Upconverting nonlinear photo-response

- Cross relaxation
- Super linear
- Saturation
- Multi-energy levels





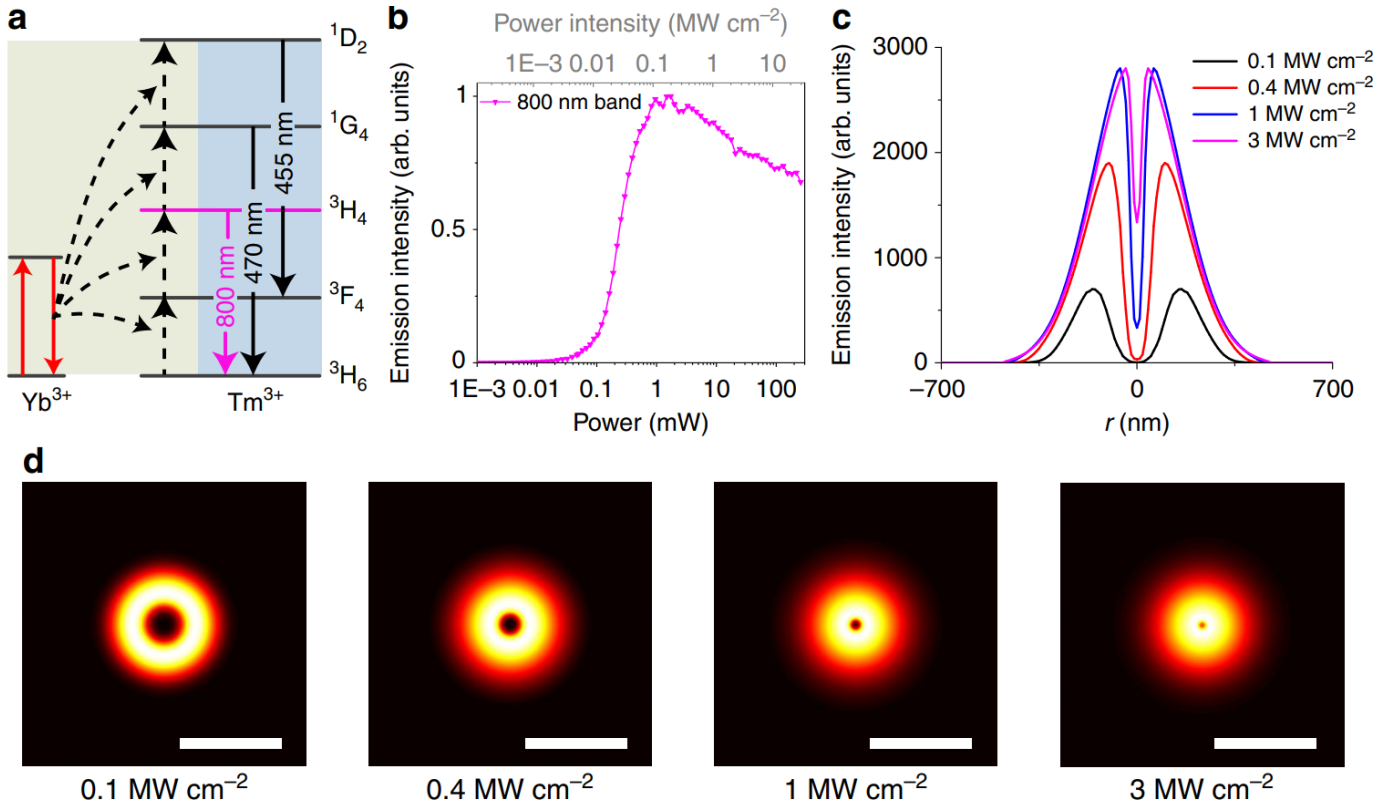
ARTICLE

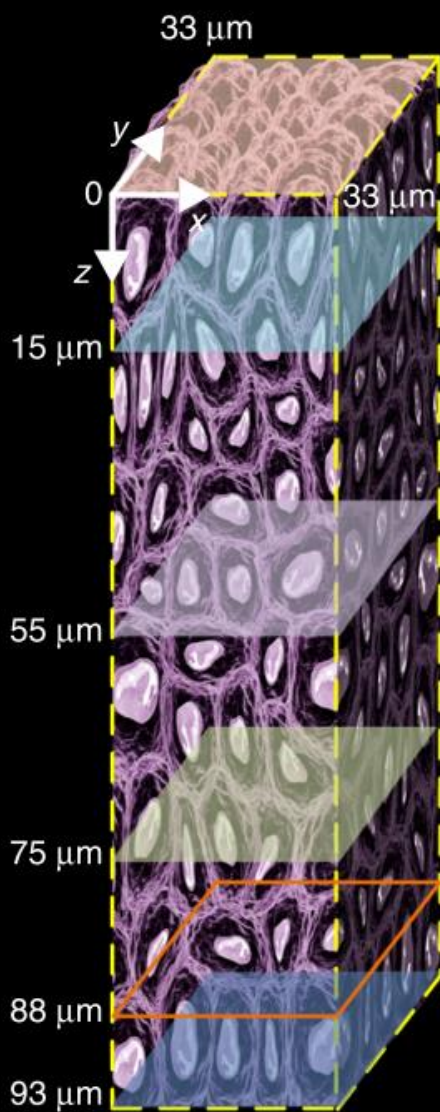
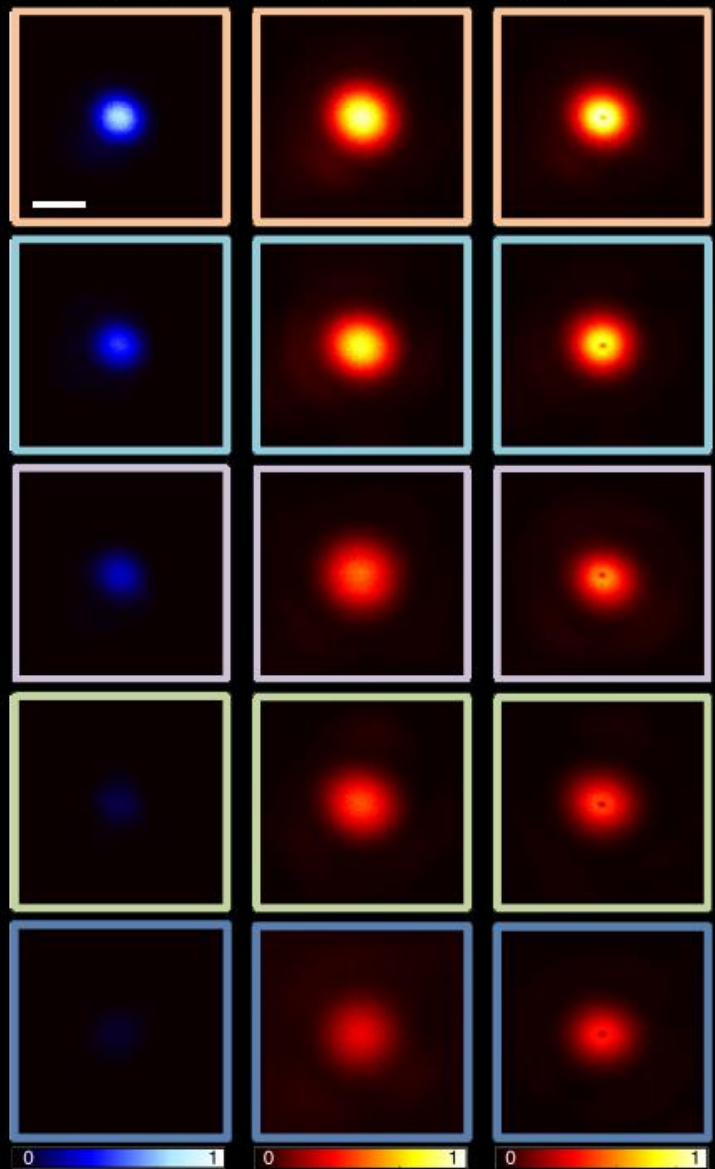
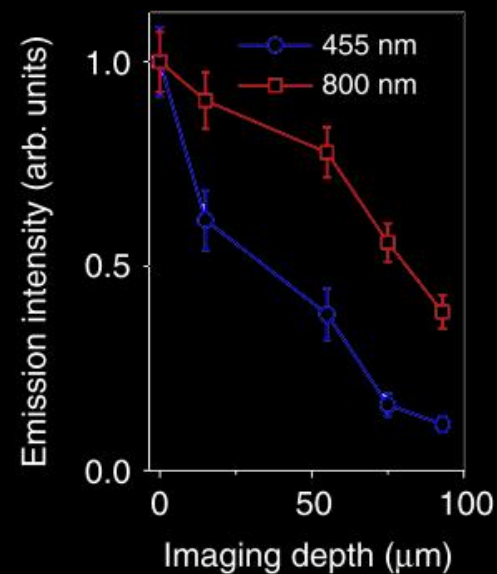
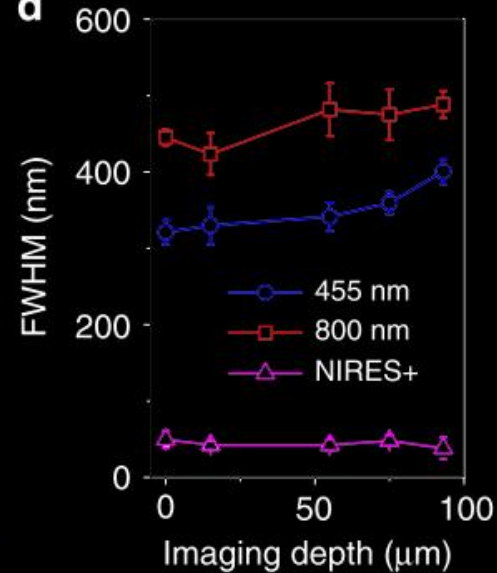
DOI: 10.1038/s41467-018-05842-w

OPEN

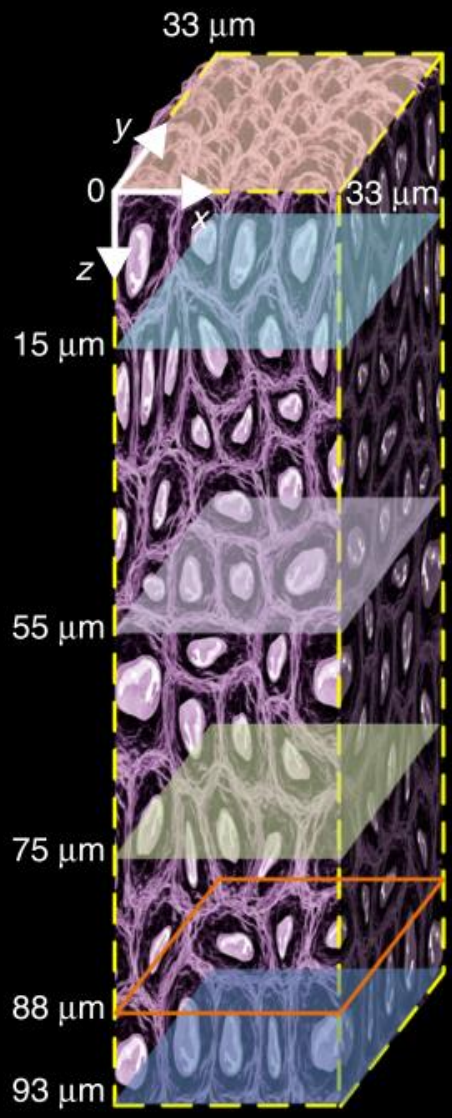
Multi-photon near-infrared emission saturation nanoscopy using upconversion nanoparticles

Caohao Chen¹, Fan Wang¹, Shihui Wen¹, Qian Peter Su¹, Mike C.L. Wu², Yongtao Liu¹, Baoming Wang¹, Du Li¹, Xuchen Shan¹, Mehran Kianinia¹, Igor Aharonovich¹, Milos Toth¹, Shaun P. Jackson², Peng Xi³ & Dayong Jin^{1,4}

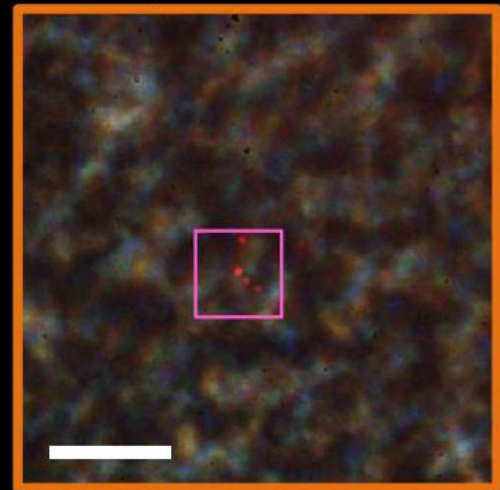


a Mouse liver tissue slice**b** 455 nm 800 nm 800 nm NIRES**c****d**

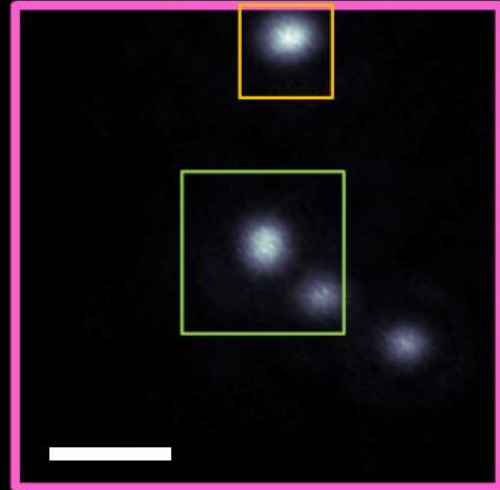
a Mouse liver tissue slice



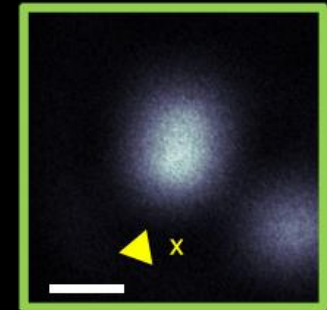
a 88 μm depth wide field



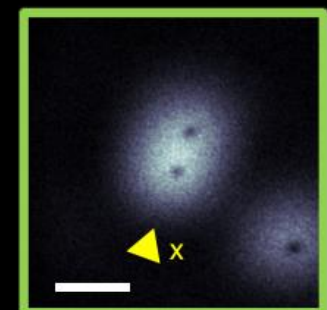
b Confocal



d Confocal



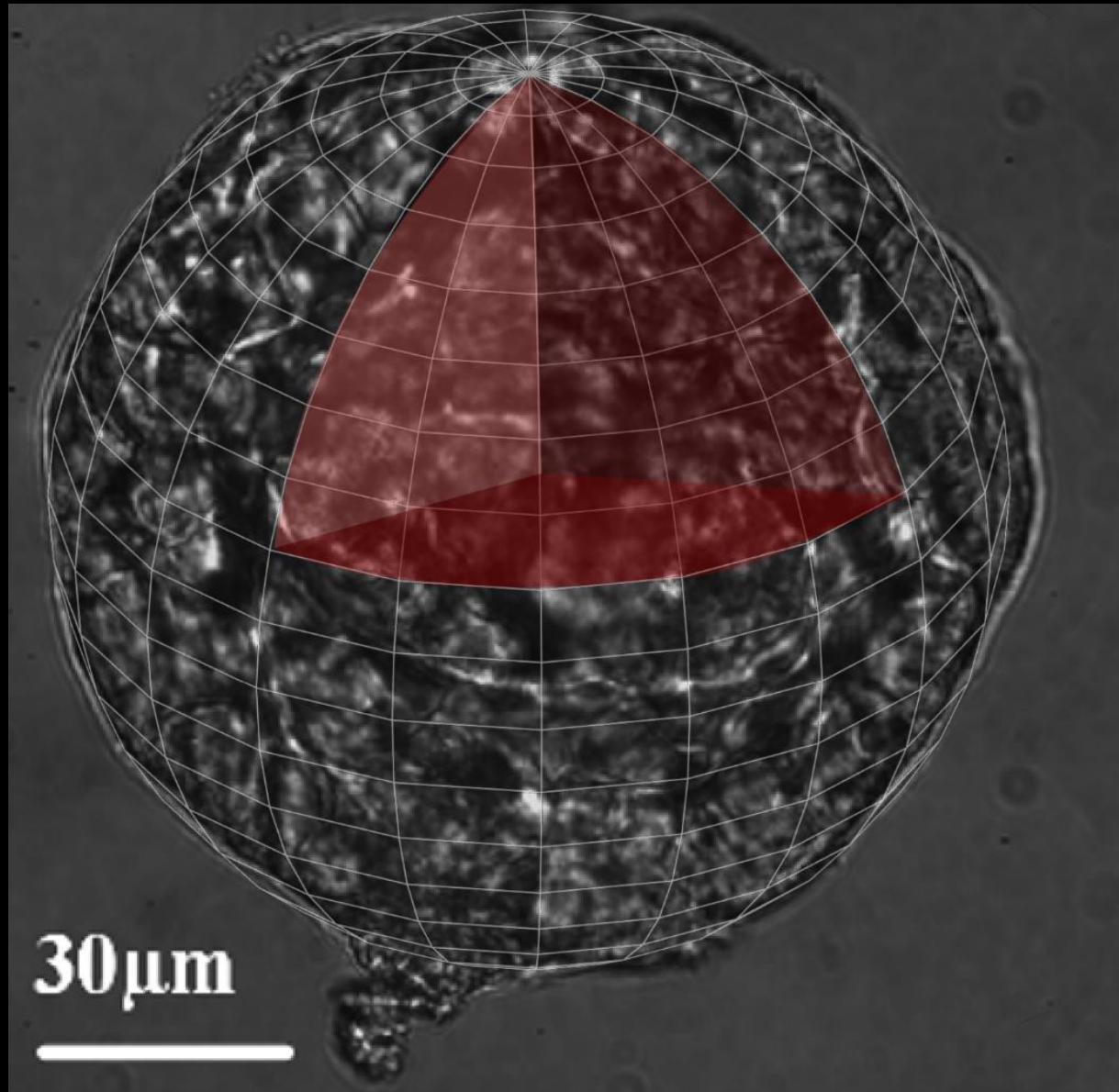
f NIRFS



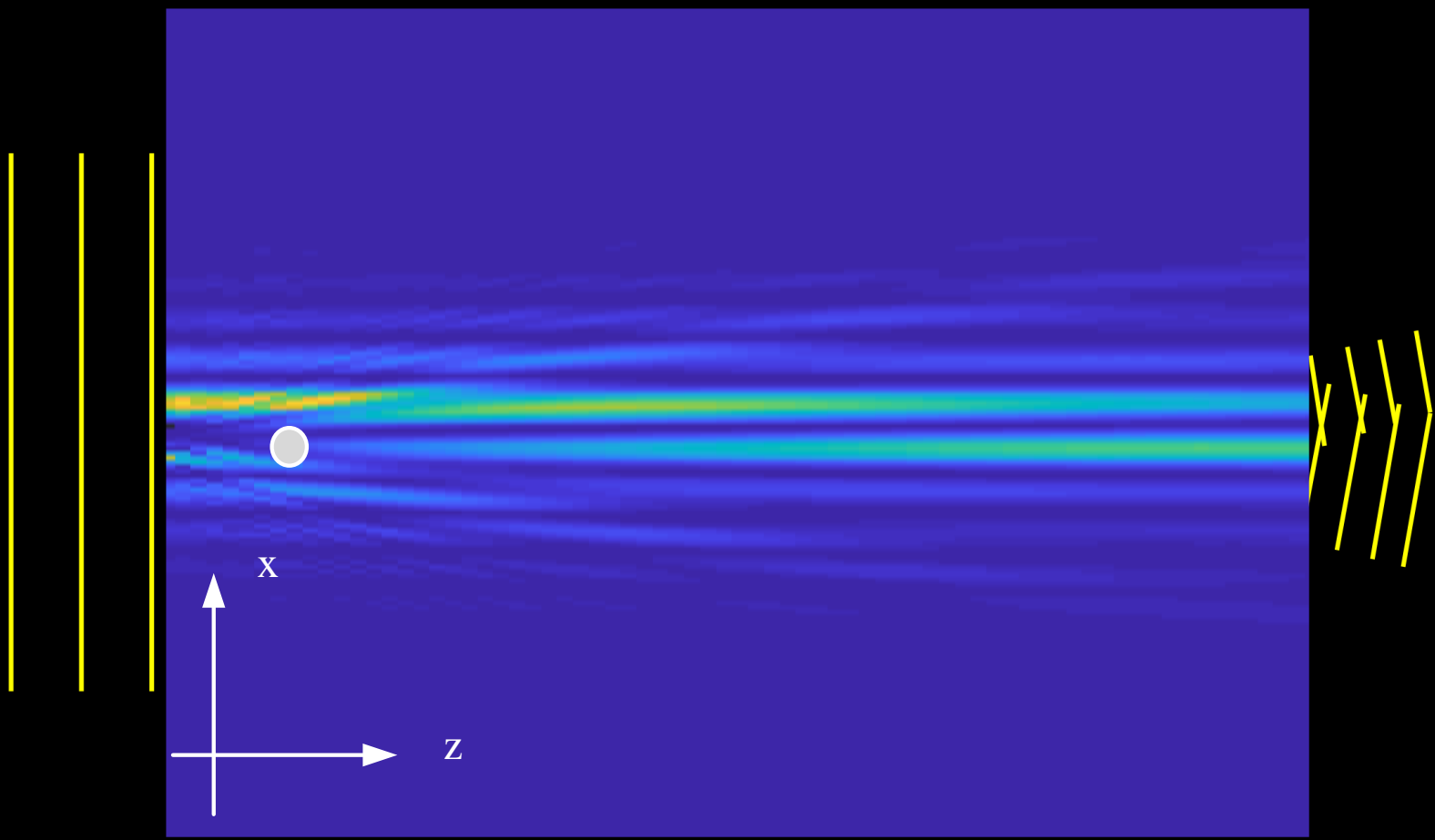
h NIRFS+

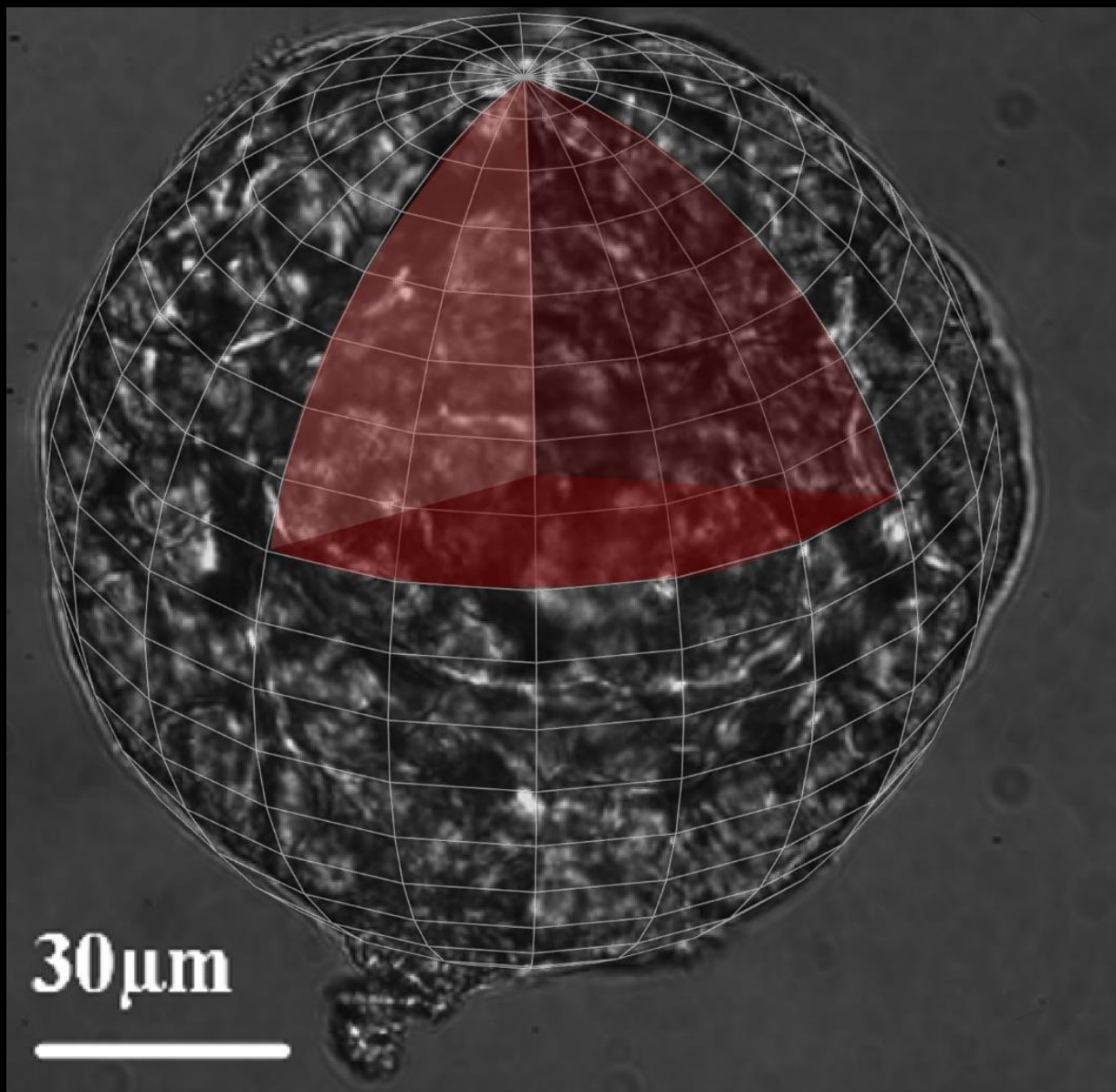


Deep tissue super-resolution imaging



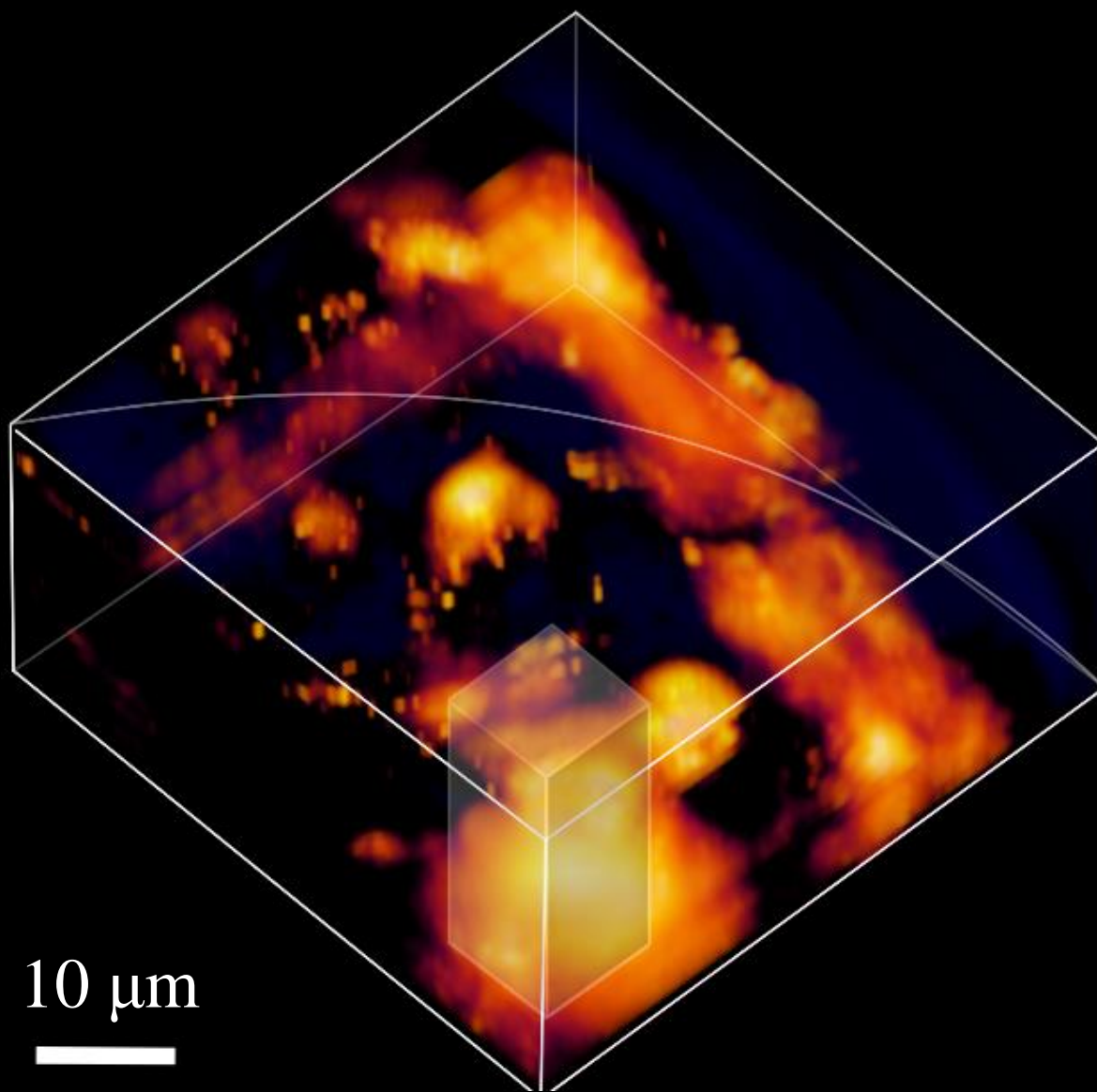
Bessel-LG beam

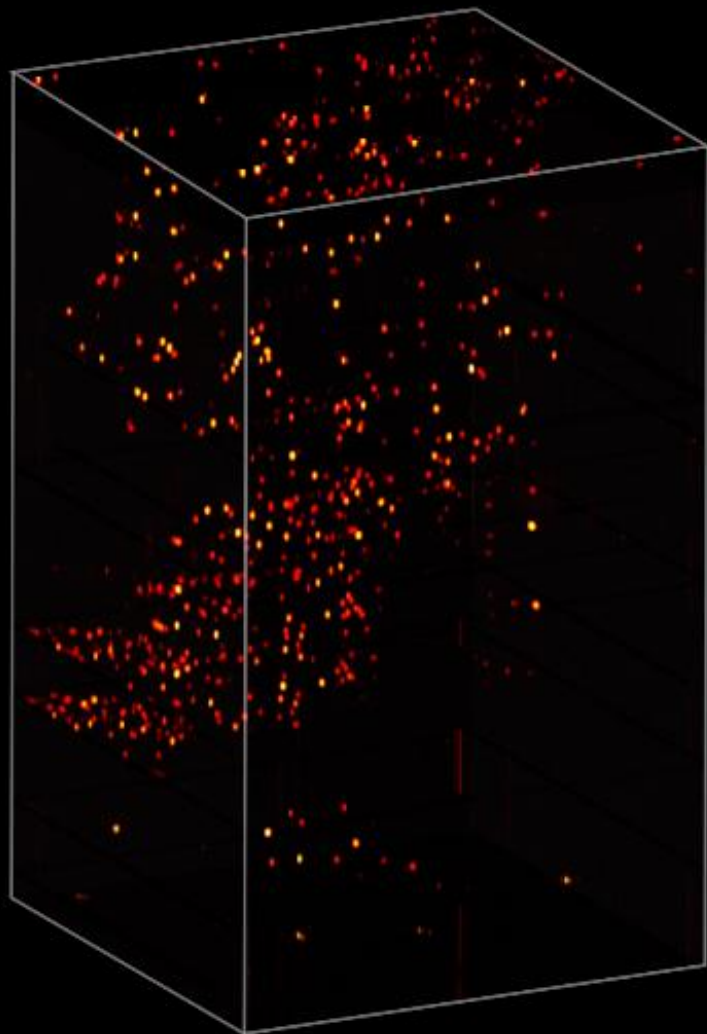






Yongtao Liu



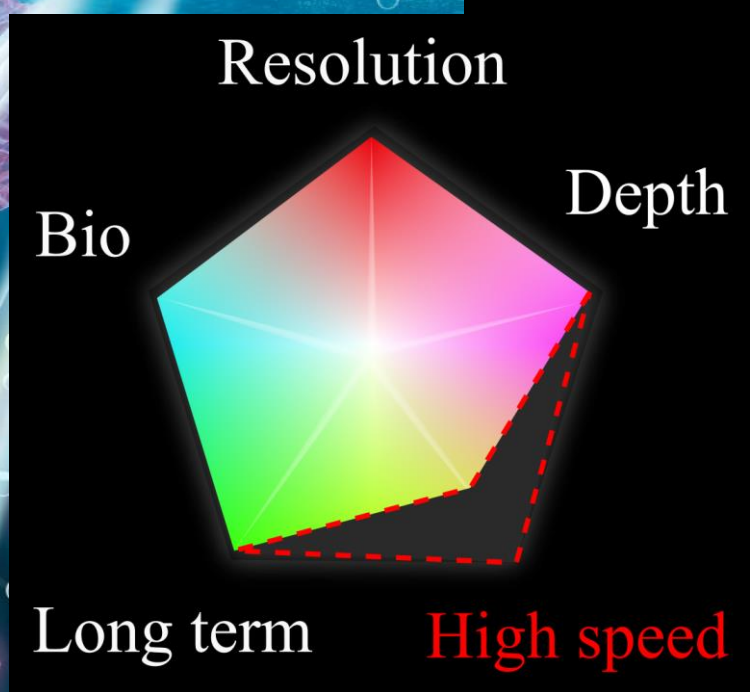
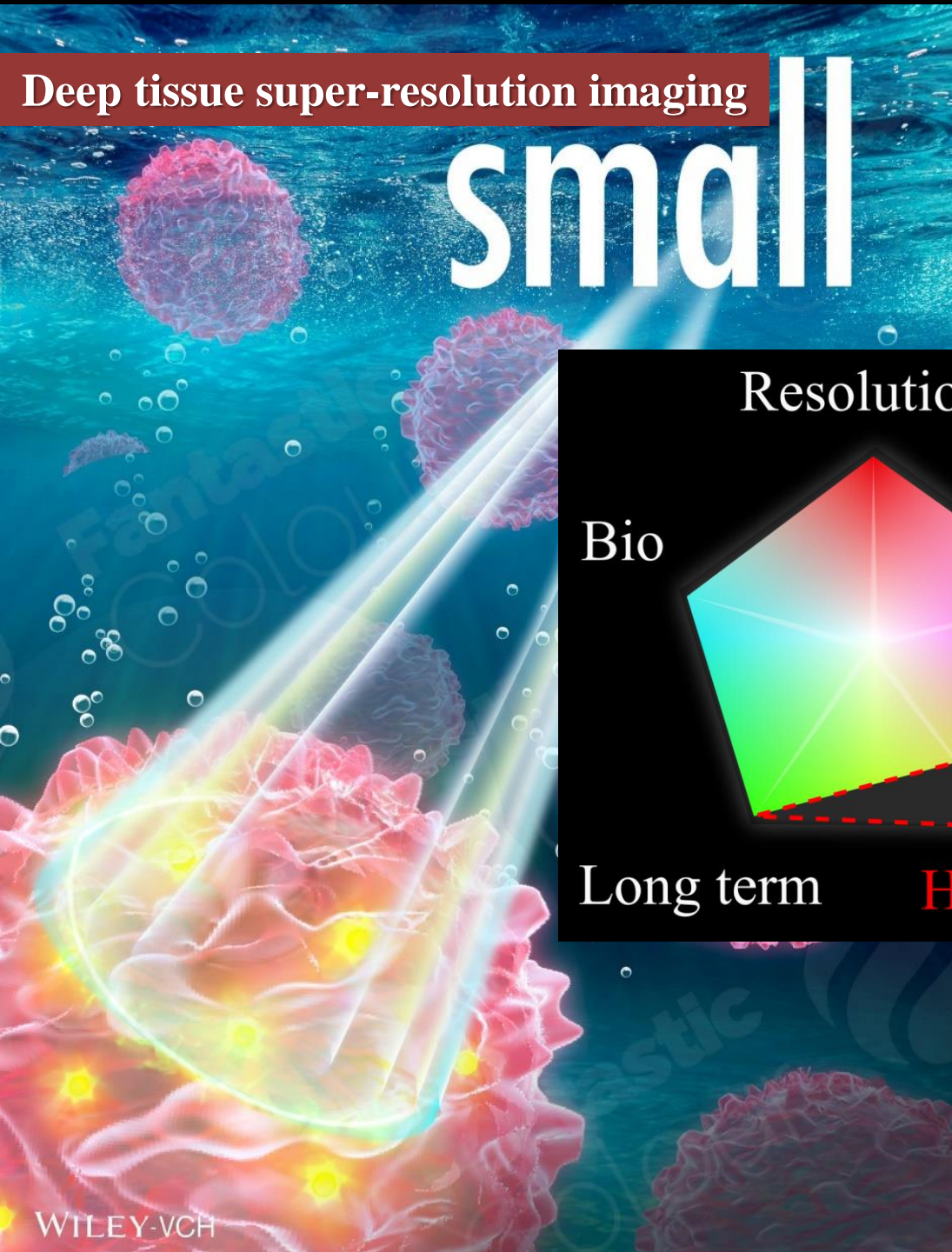


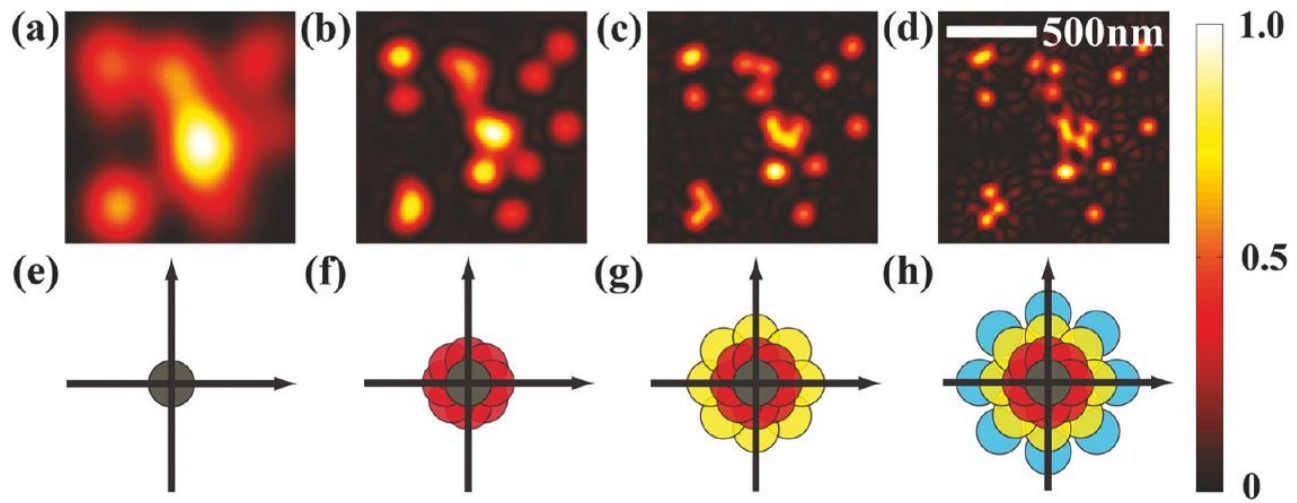
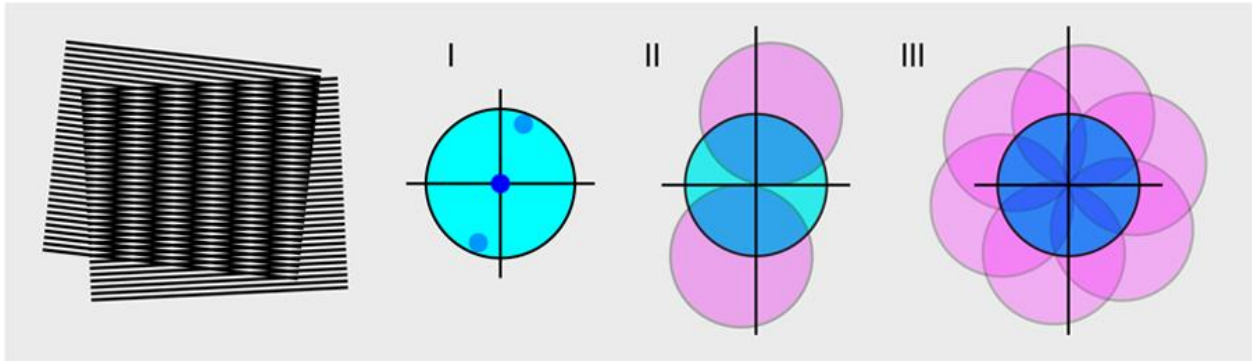
5 μm



Deep tissue super-resolution imaging

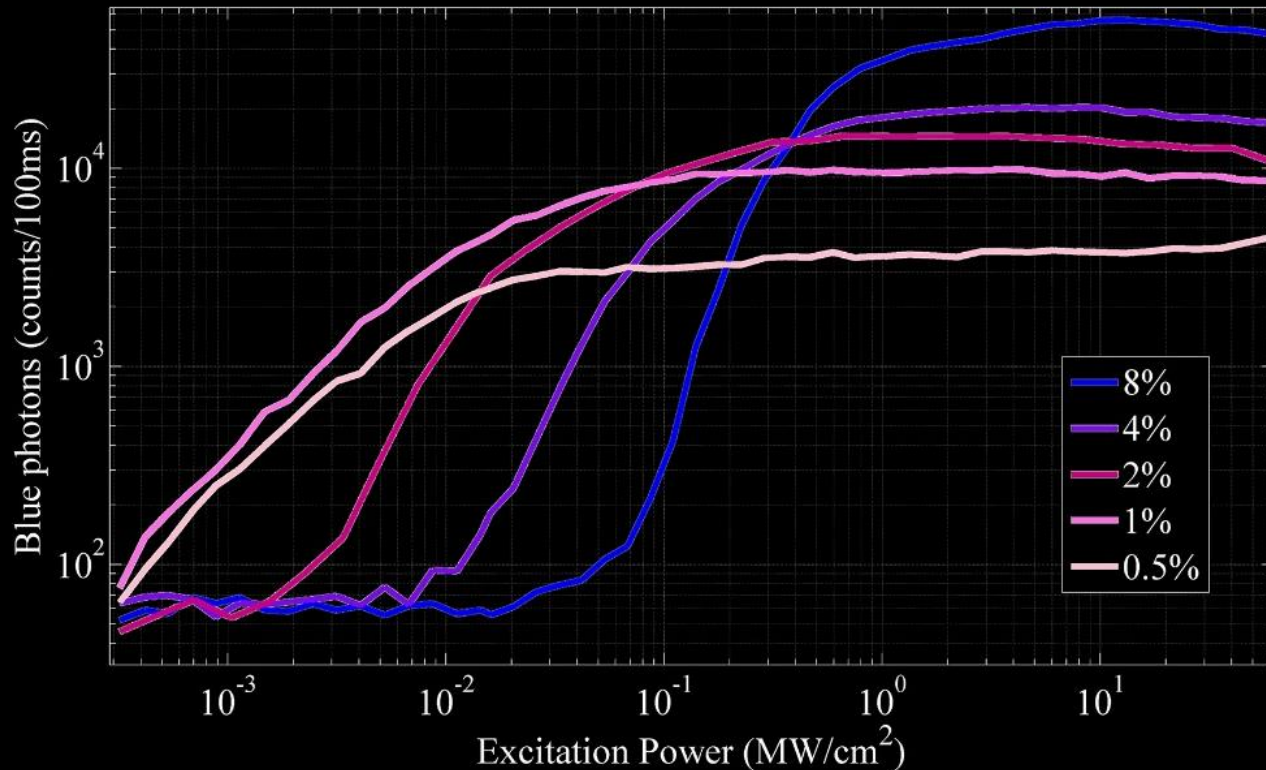
small





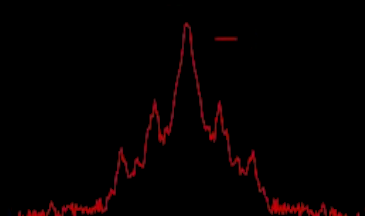
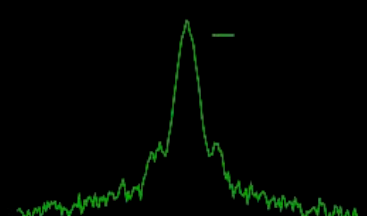
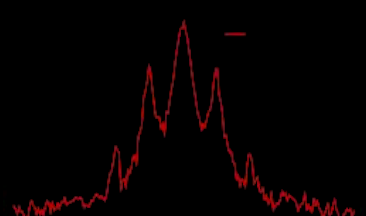
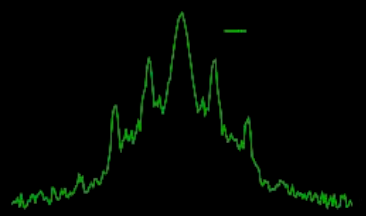
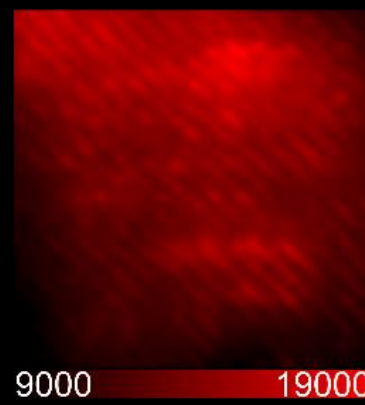
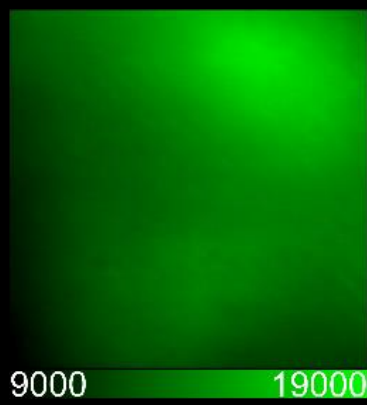
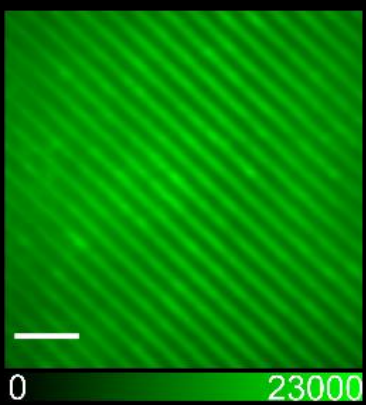
Upconverting nonlinear photo-response

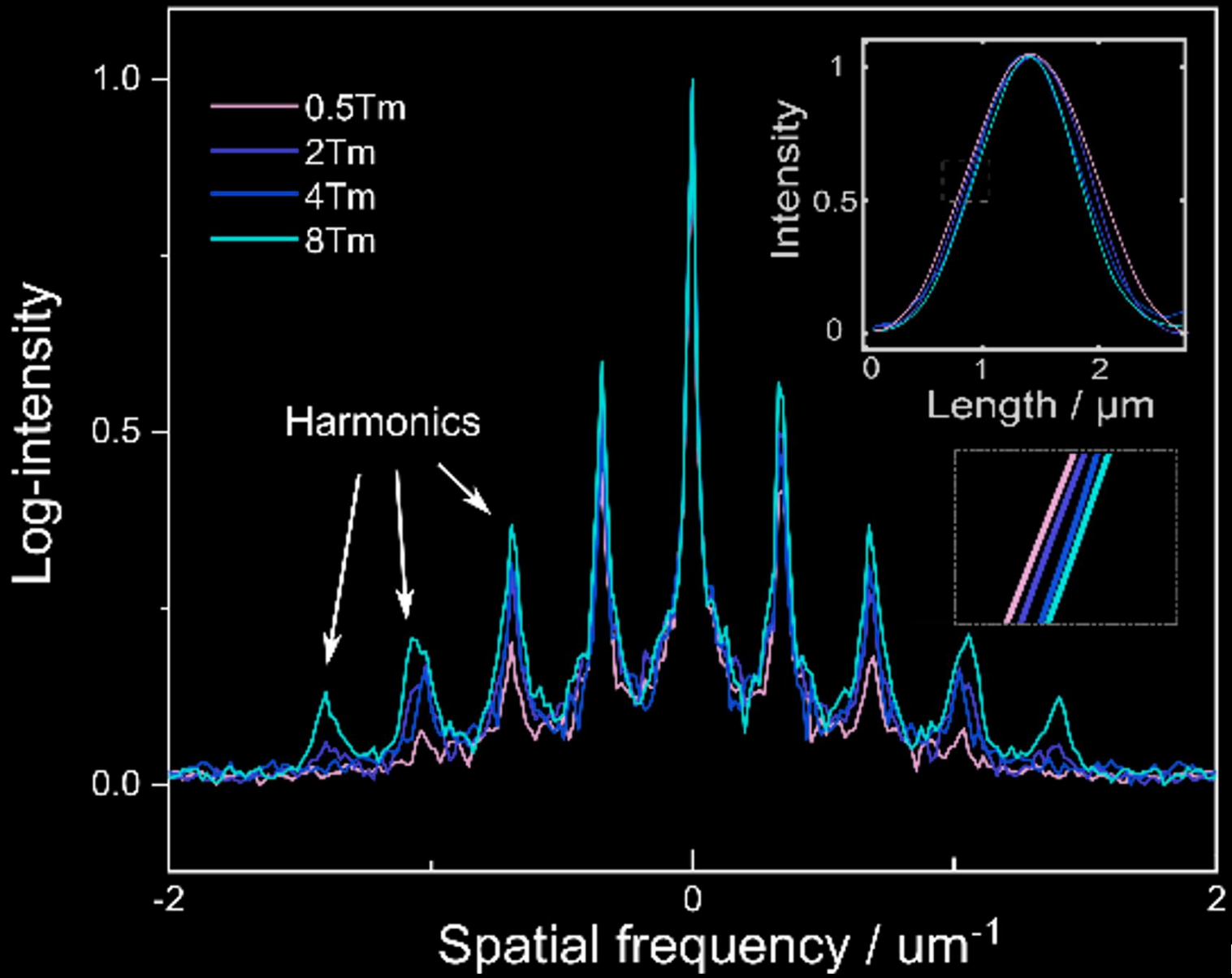
- Cross relaxation
- Super linear
- Saturation
- Multi-energy levels



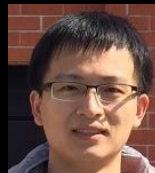
Without tissue

With tissue

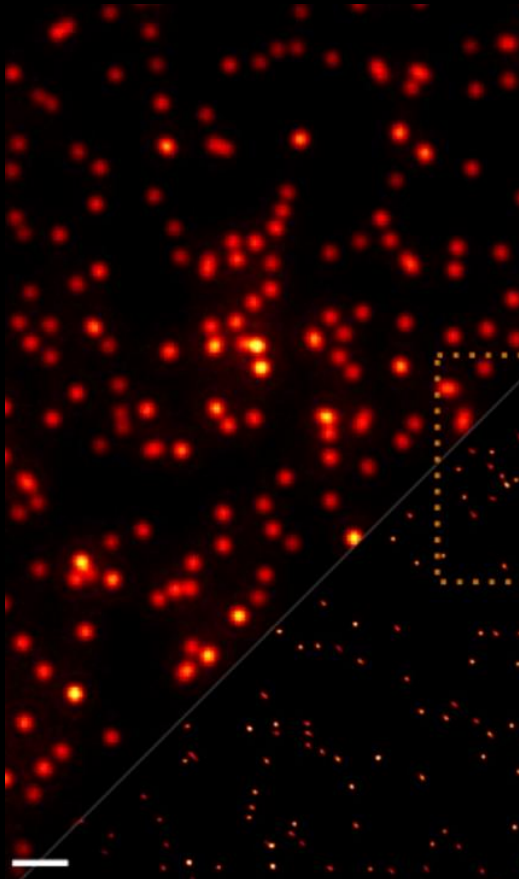




130nm resolution; 1Hz imaging rate for 30x30 μ m;
through 51 μ m thick tissue



Baolei Liu

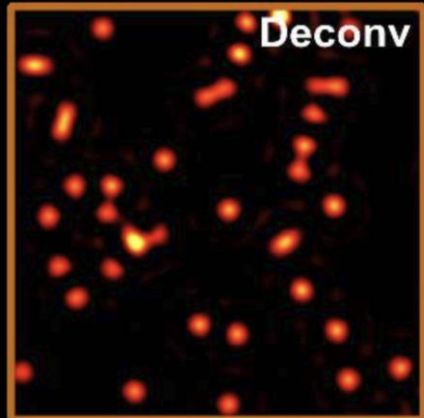


NANO LETTERS

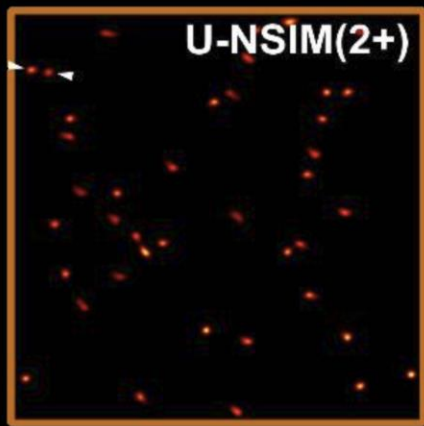
XXXX XXXX
Volume XX, Number XX
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F

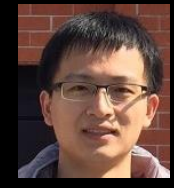


M

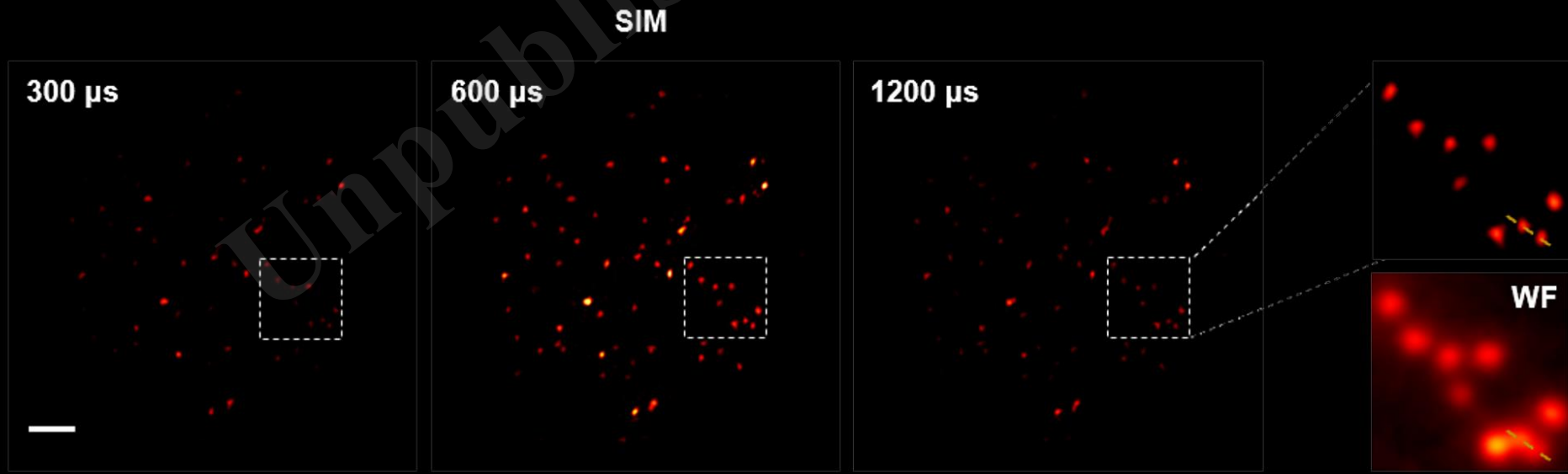
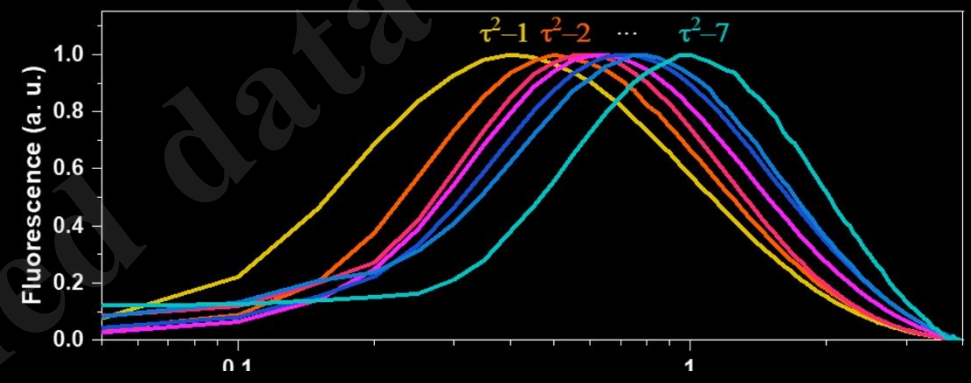
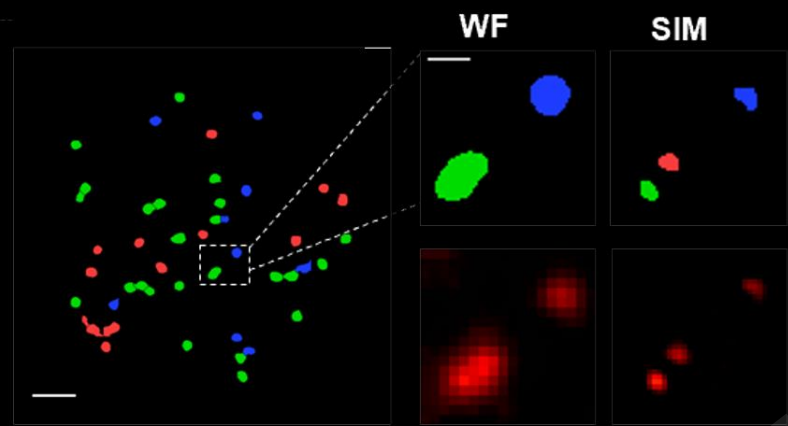




Jiayan Liao

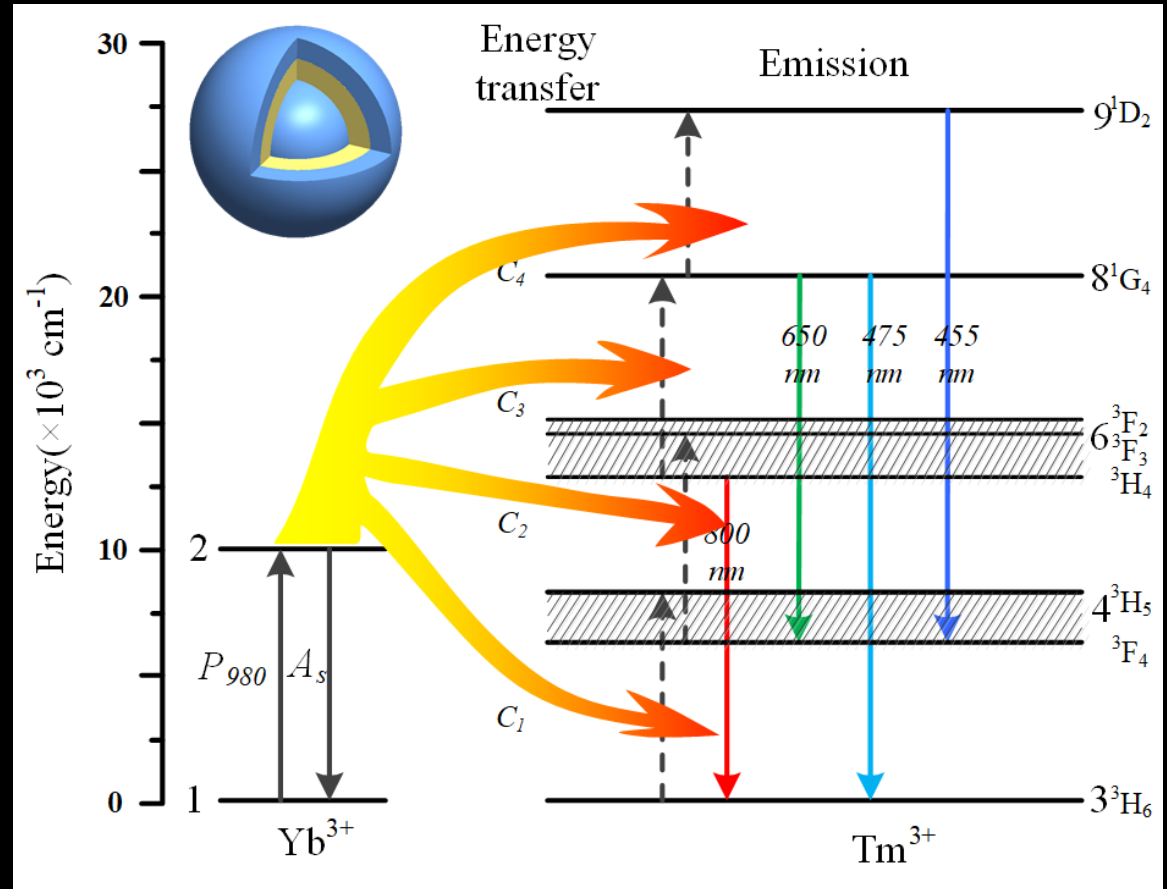


Baolei Liu

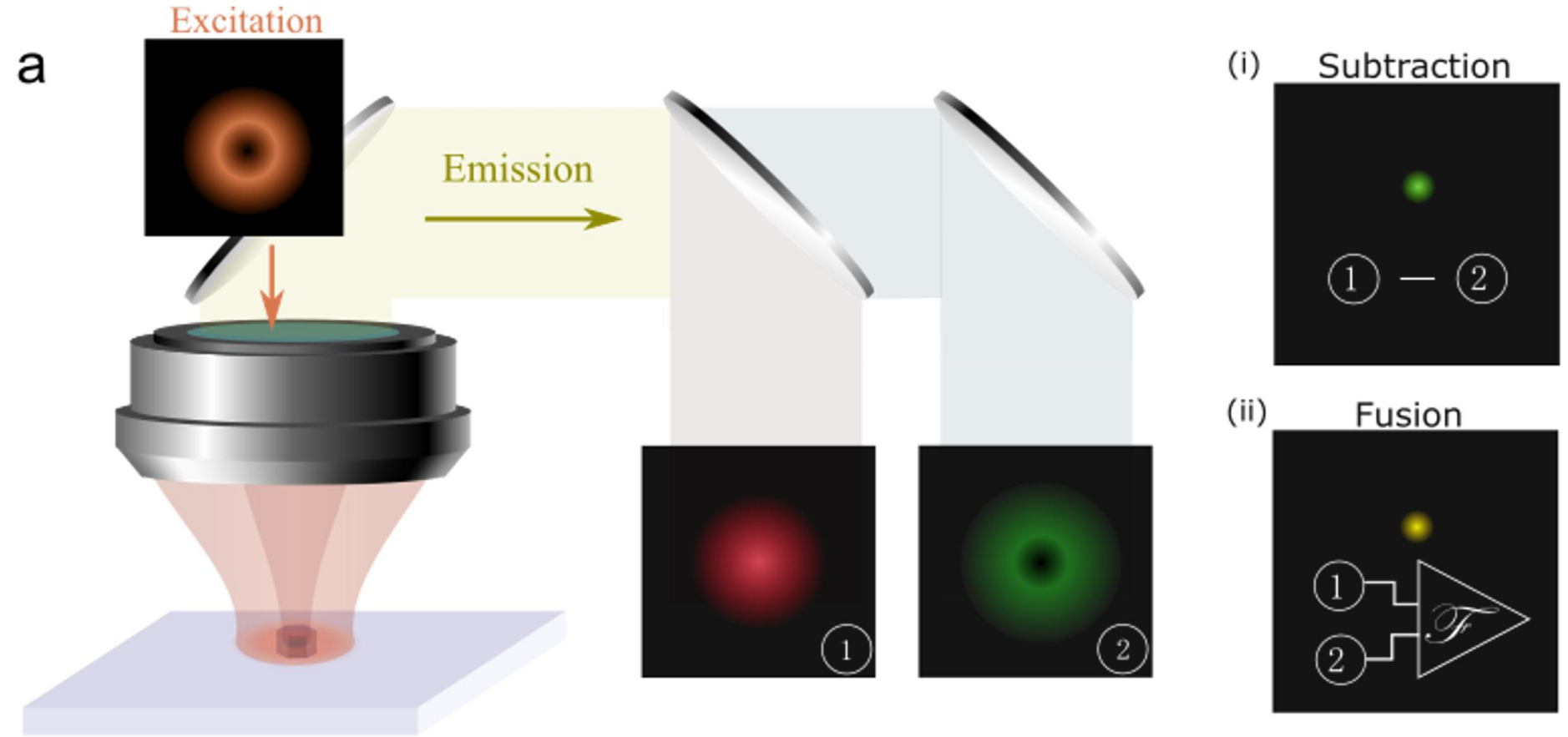


Upconverting nonlinear photo-response

- Cross relaxation
- Super linear
- Saturation
- Multi-energy levels

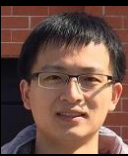


Multi-energy levels' response

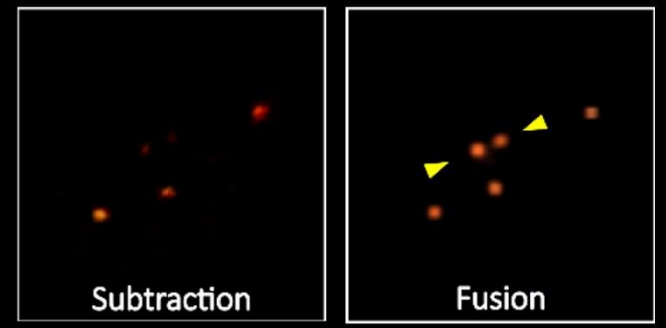
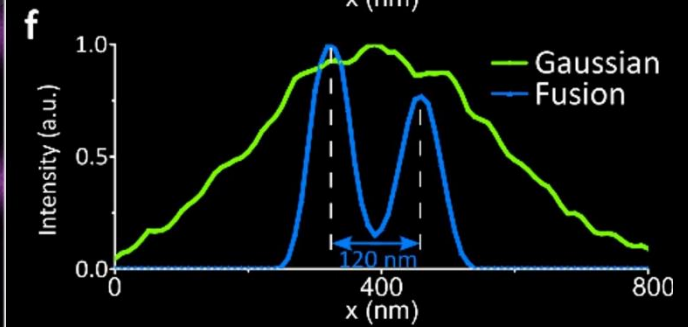
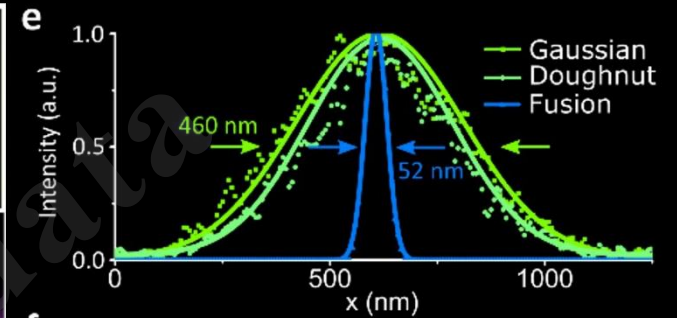
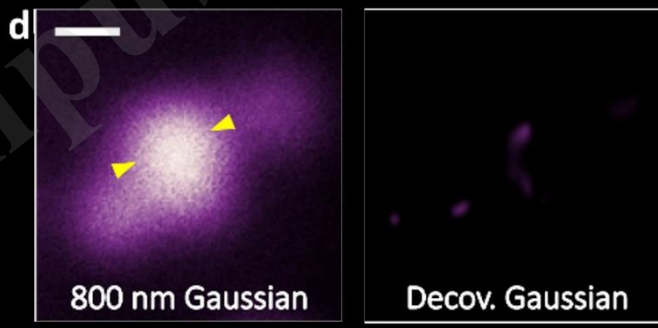
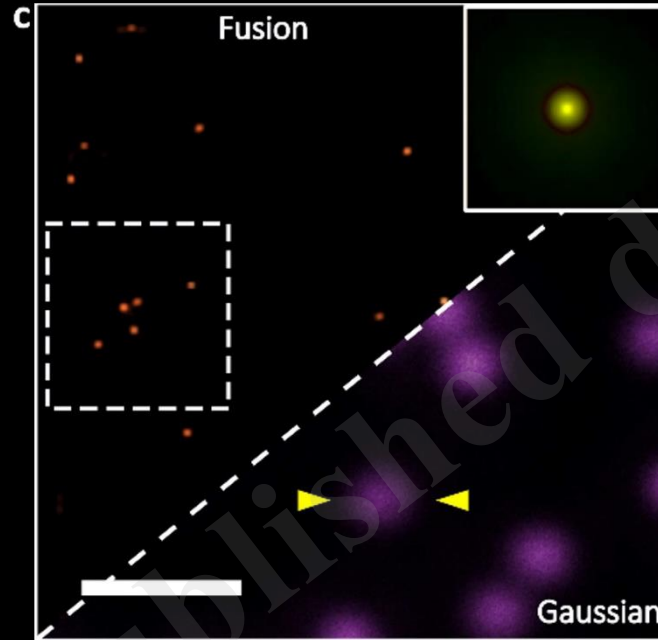
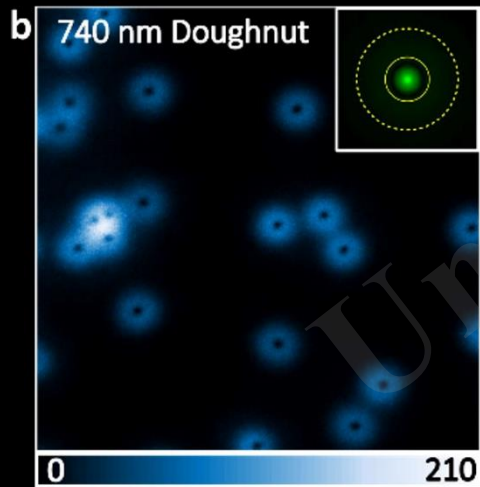
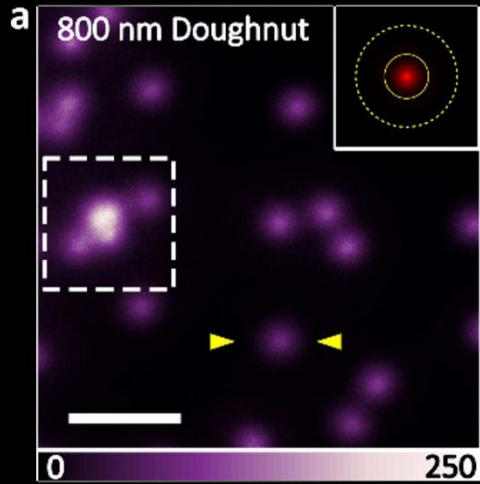




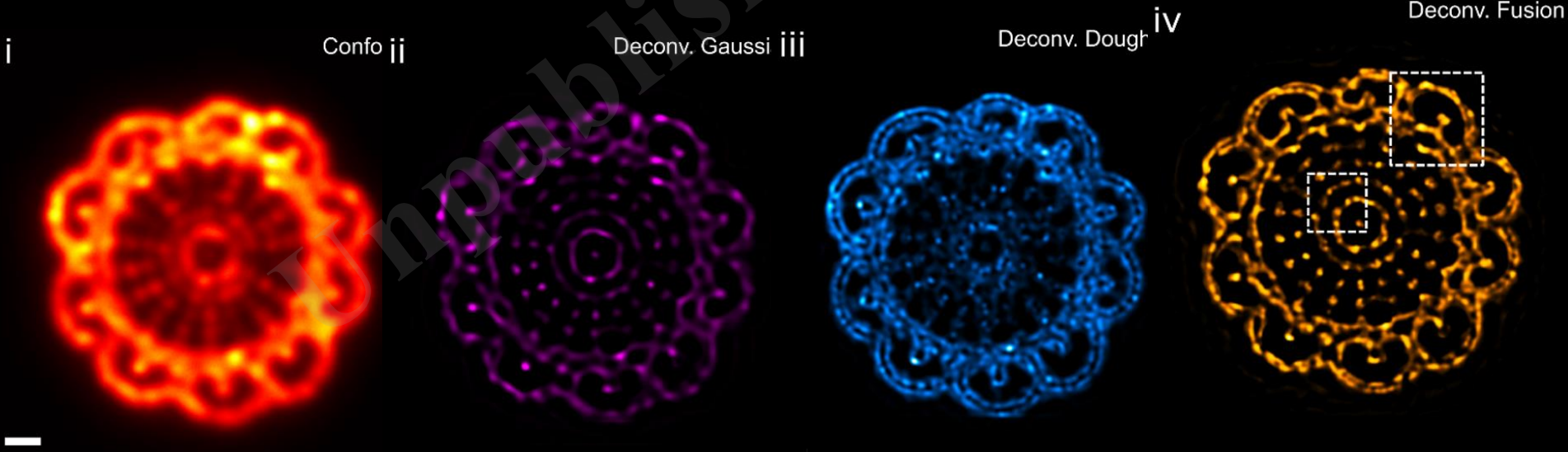
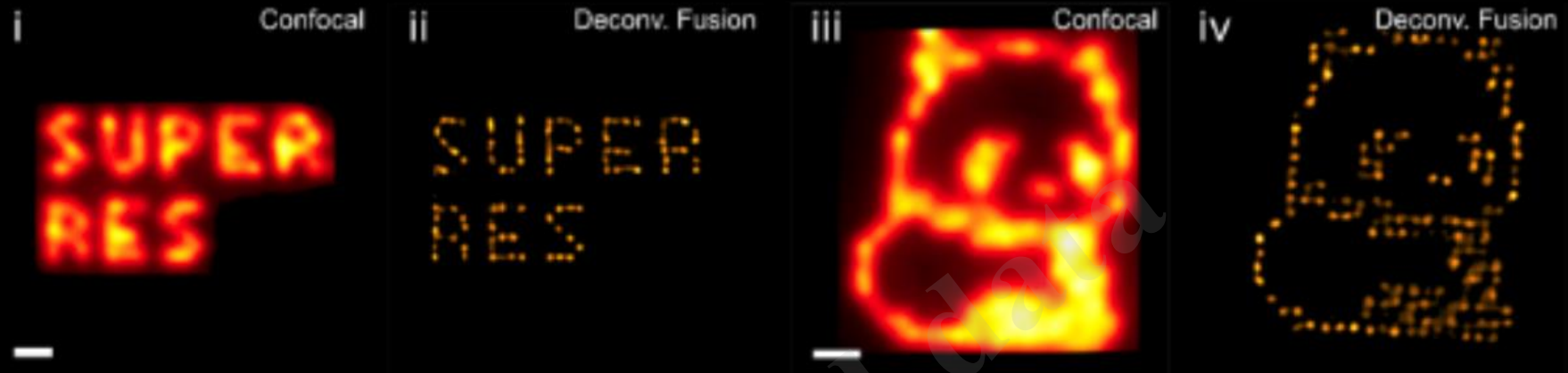
Caohao Chen



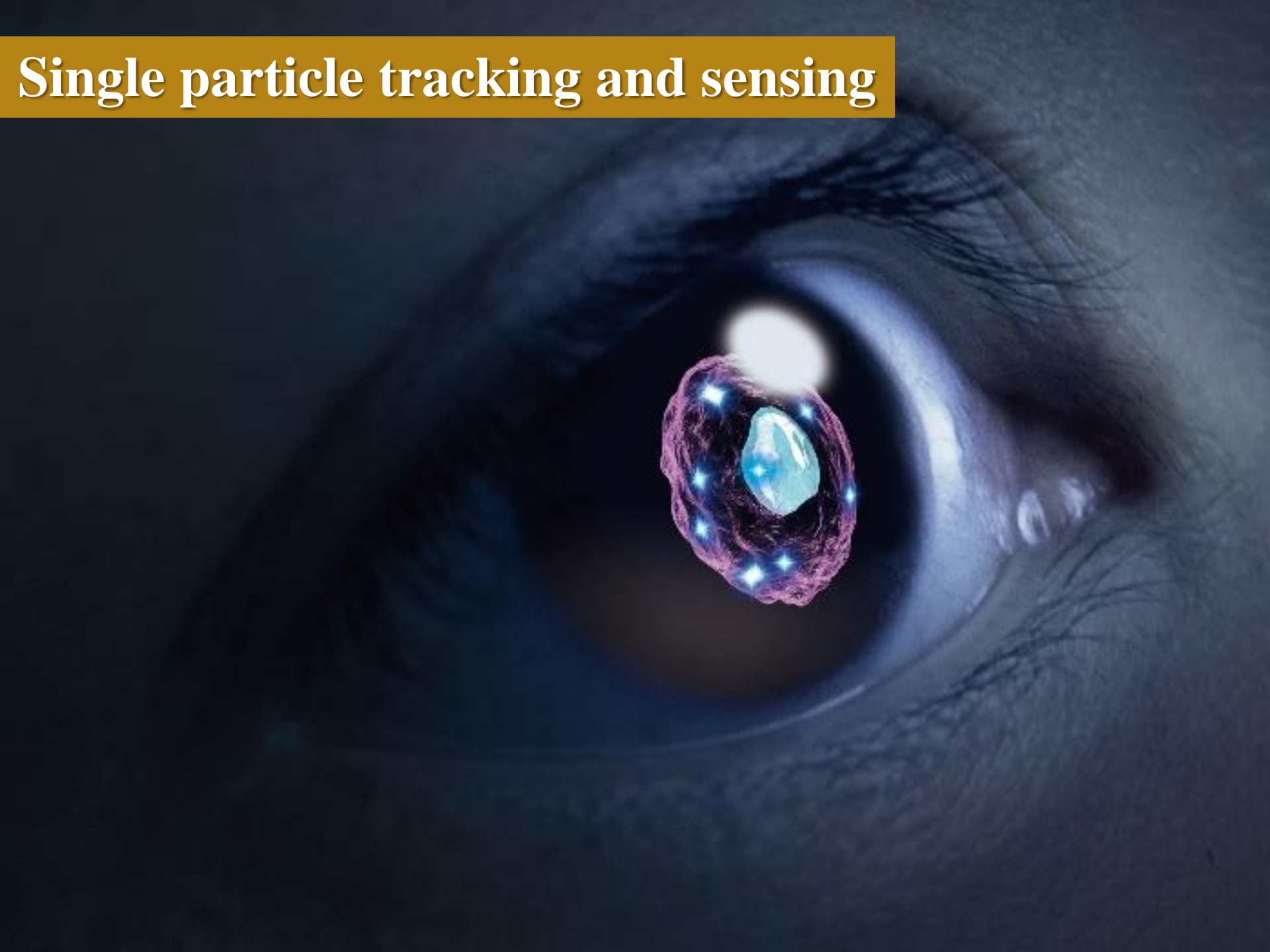
Baolei Liu



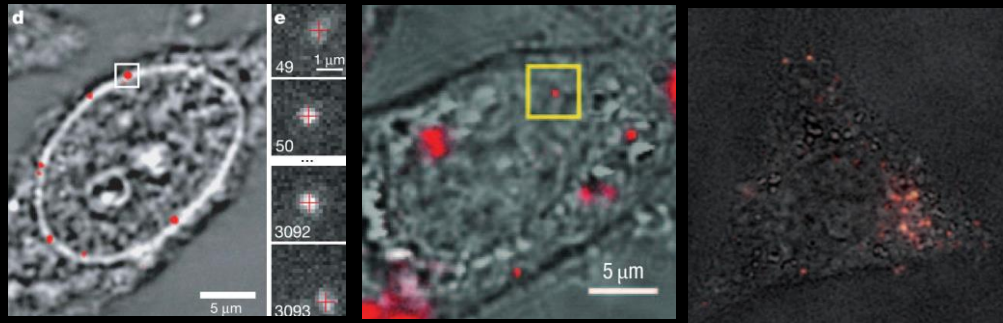
Single scanning Fourier Fusion imaging



Single particle tracking and sensing



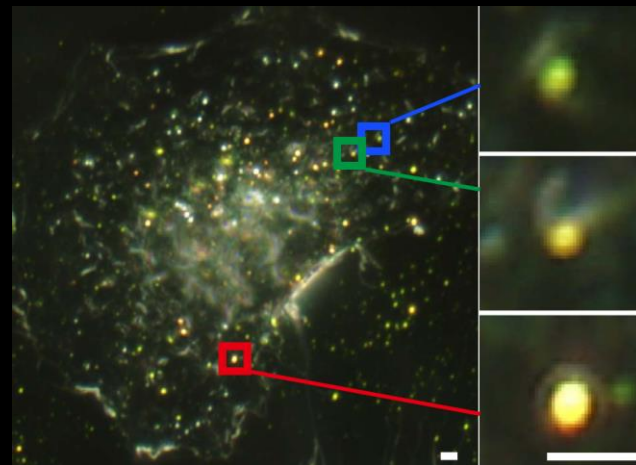
Tracking but no single



Need EMCCD



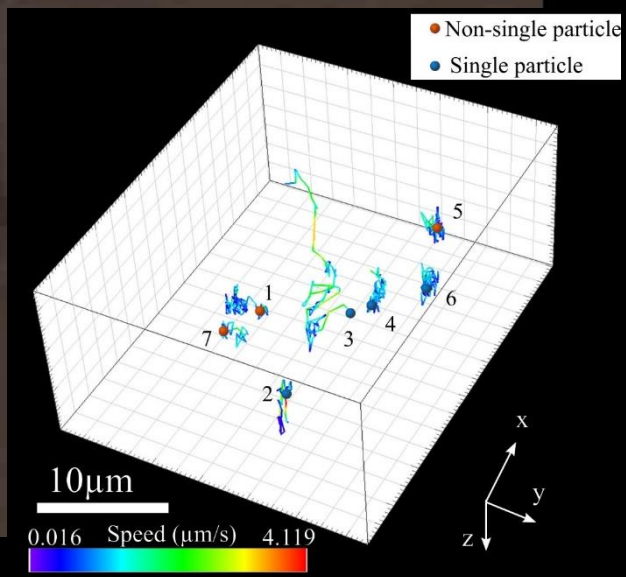
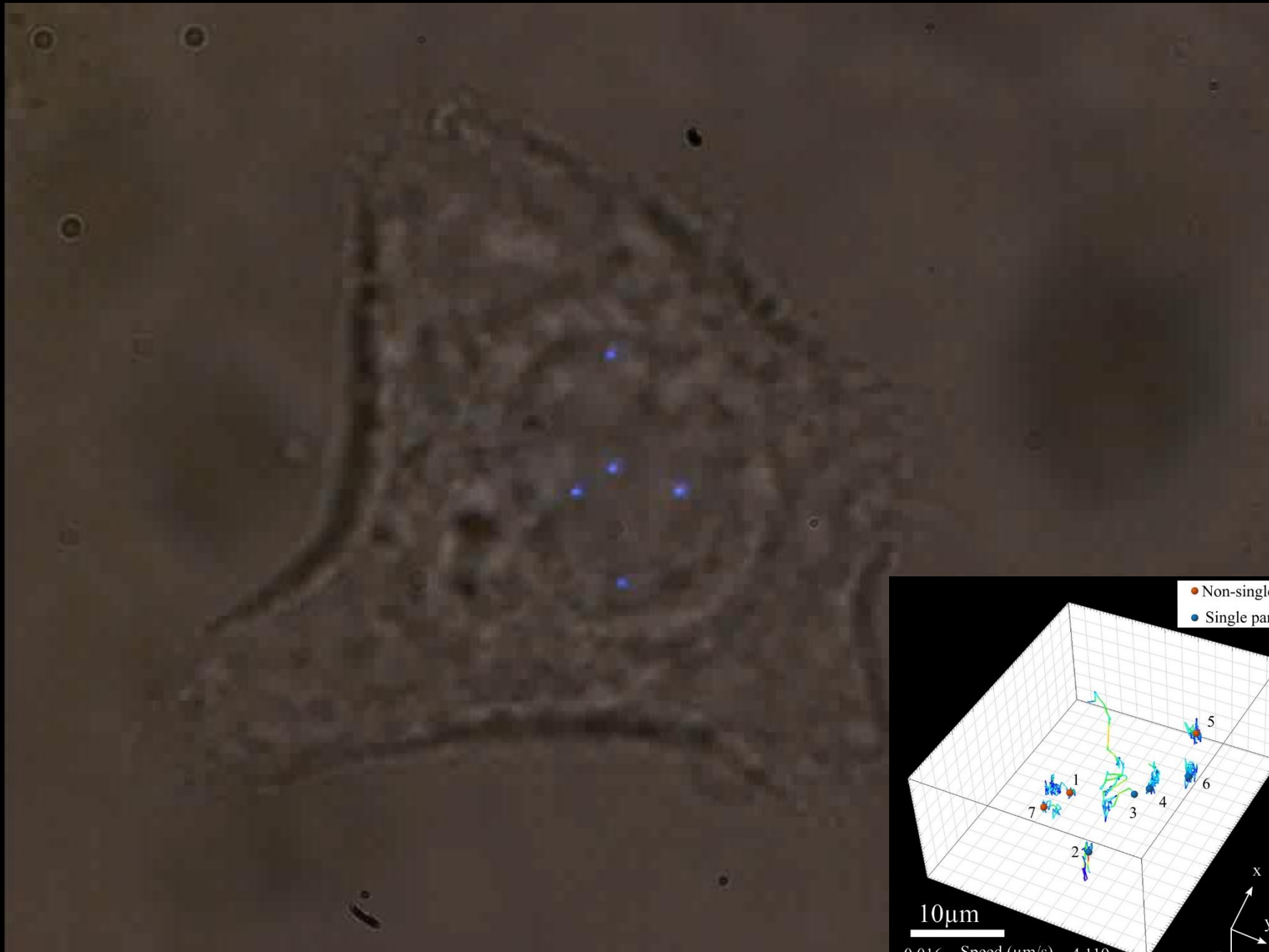
Background & noise

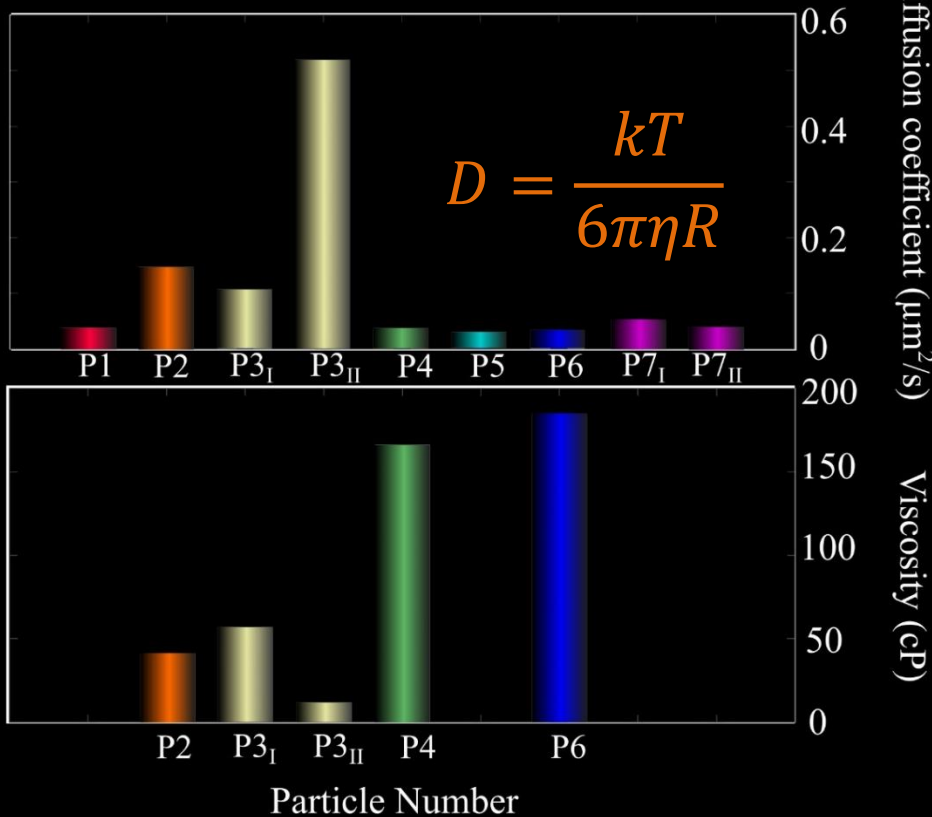
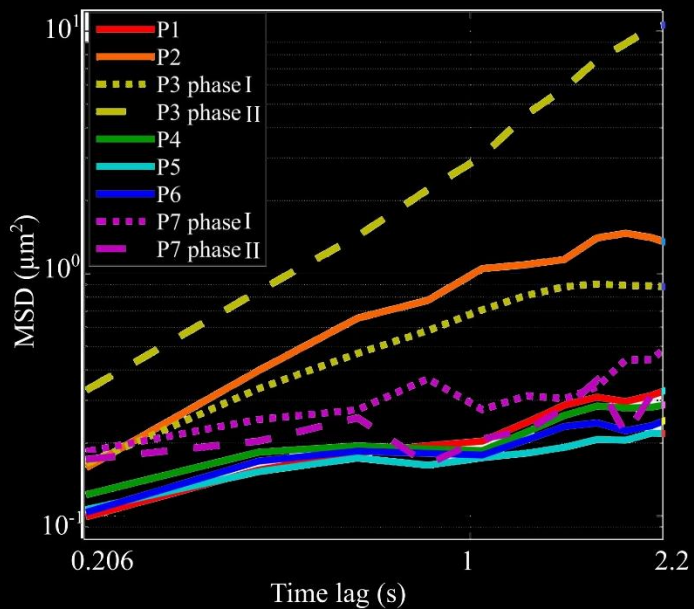
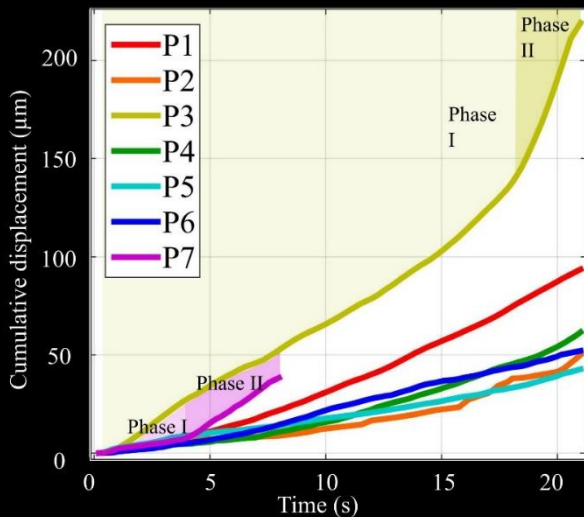


Simple
Fast

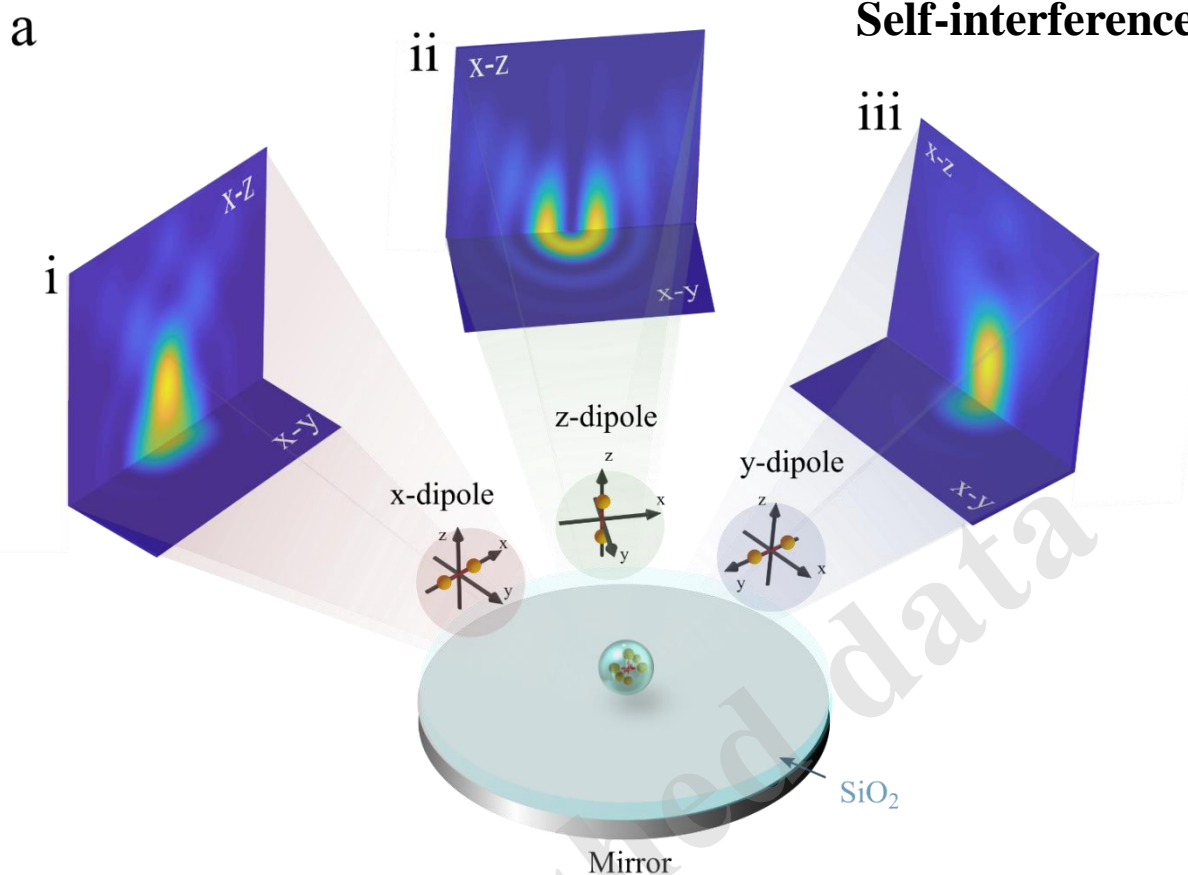
Long-term stable,
No background

Single nanoparticle Distinguishable
Naked eye visible sensitivity

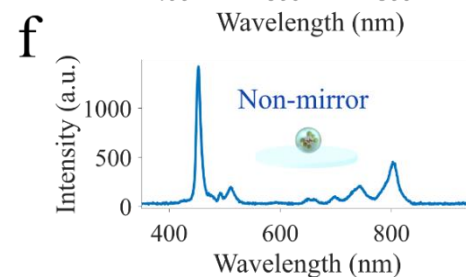
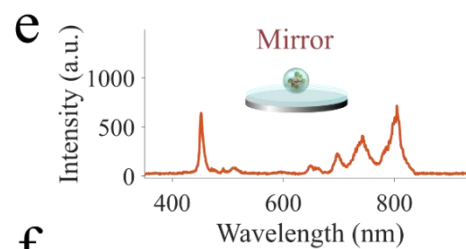
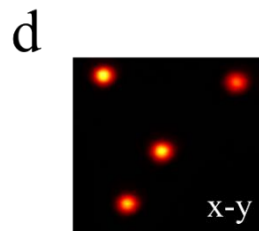
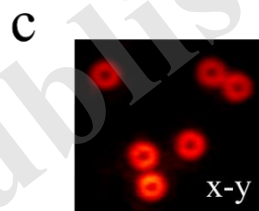
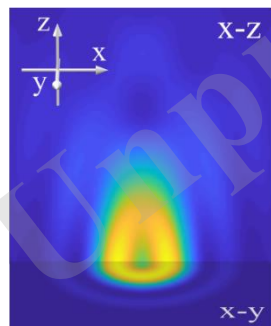


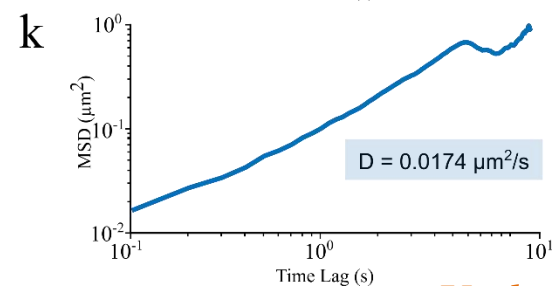
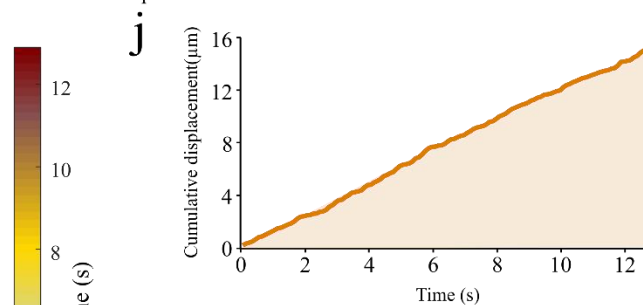
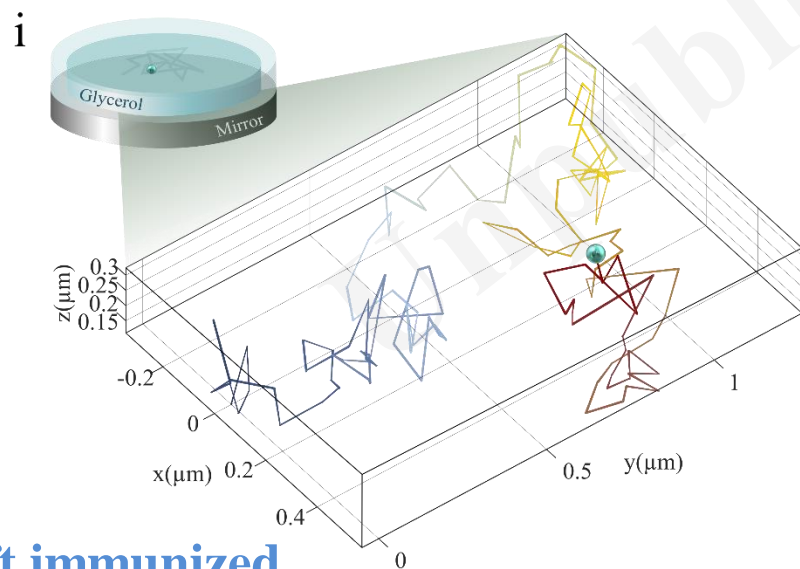
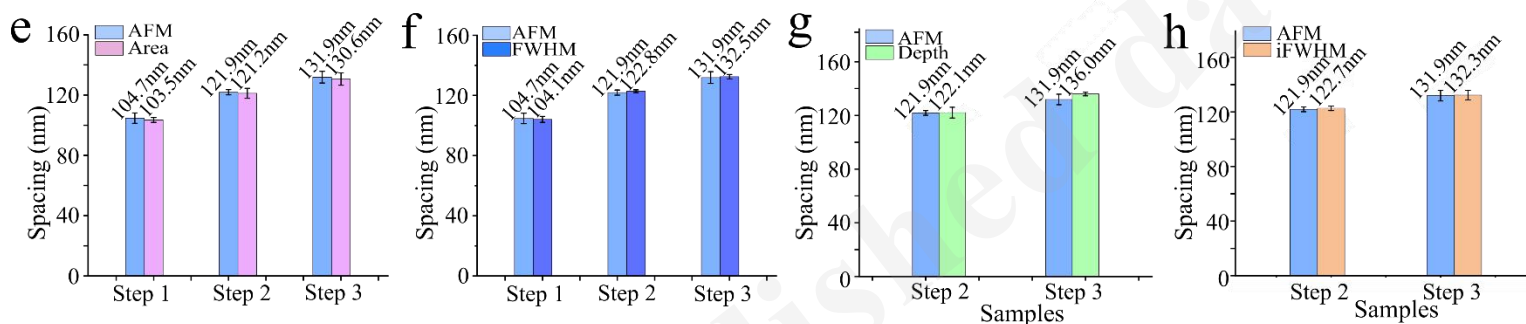
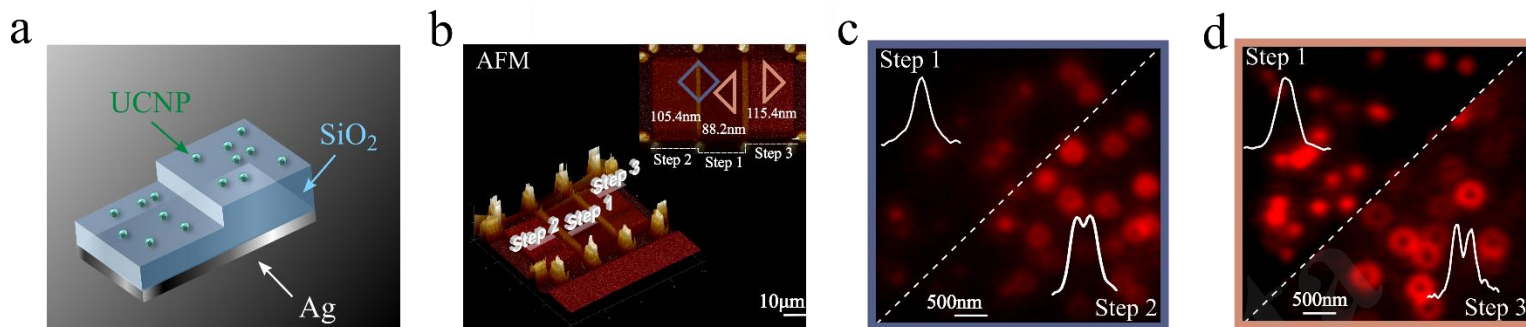






b x,y,z dipoles





Drift immunized



Nanoscale optical manipulation



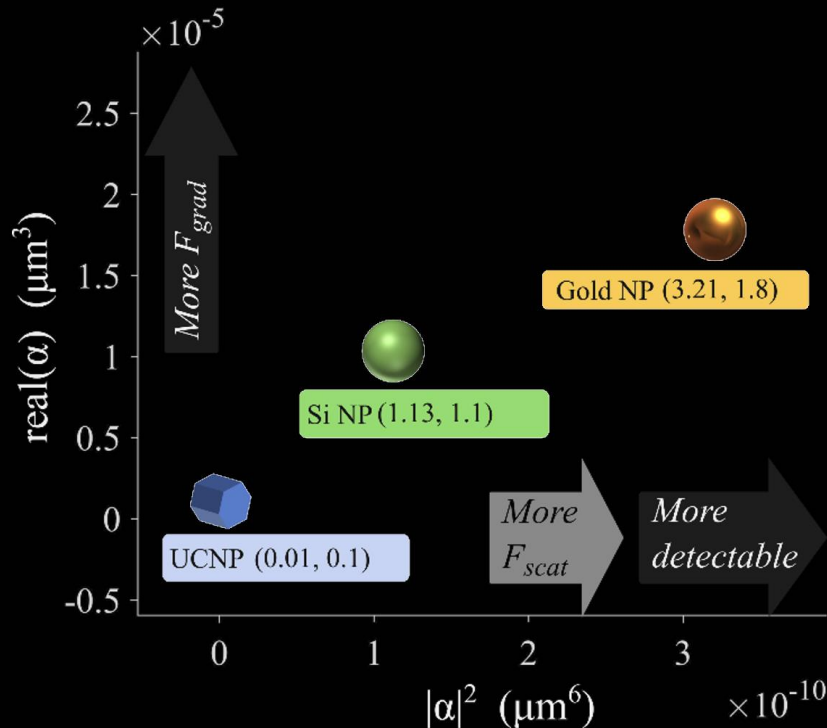
Optical tweezers

Brownian Motion

Rayleigh region: Gradient force + Scattering force



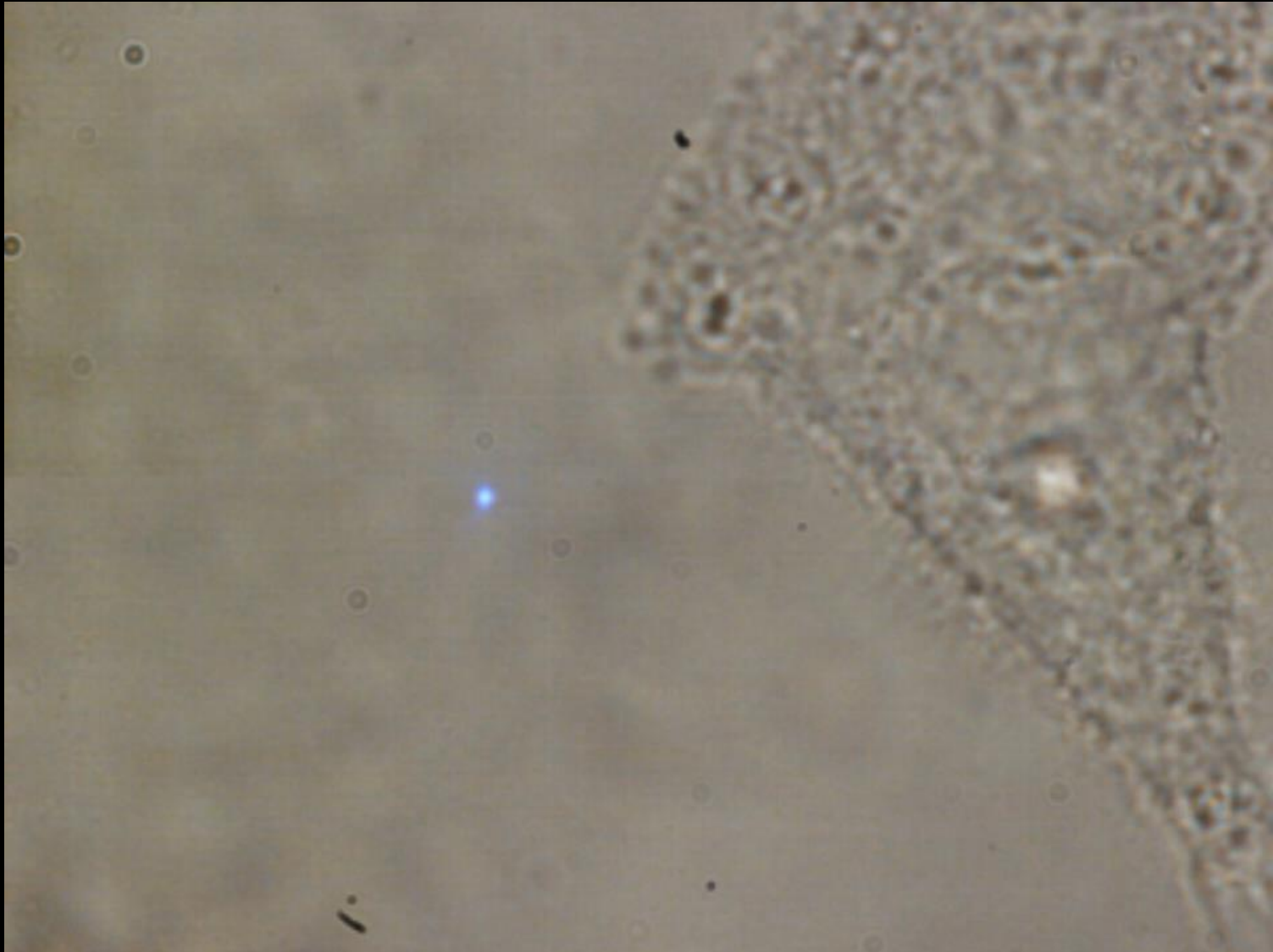
Nanoscale optical manipulation



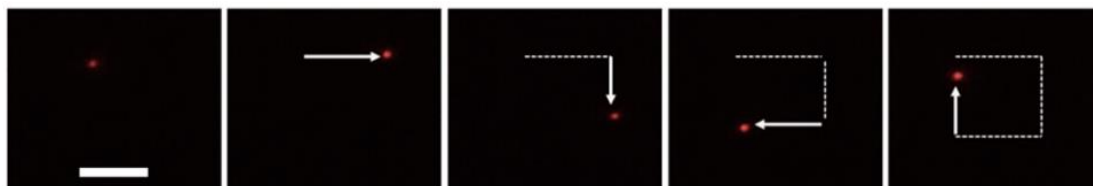
$$F_{grad} = \frac{2\pi n_2}{c} \text{Re}(\alpha) \nabla I$$

$$C_{scat} = \frac{8}{3} \pi k_m^4 |\alpha|^2$$

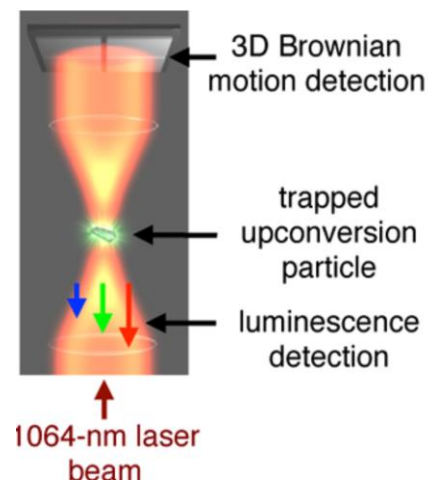
Nanoscale optical manipulation



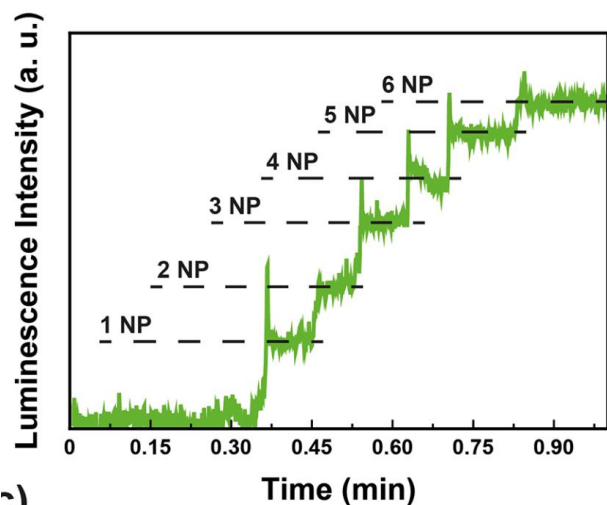
Nanoscale optical manipulation



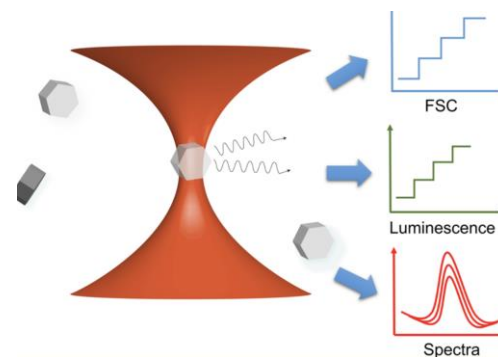
P. Rodríguez-Sevilla et al, Nano Lett. 2015, 15, 5068–5074



Flavio M. Mor et al. ACS Photonics 2014, 1, 12, 1251–1257

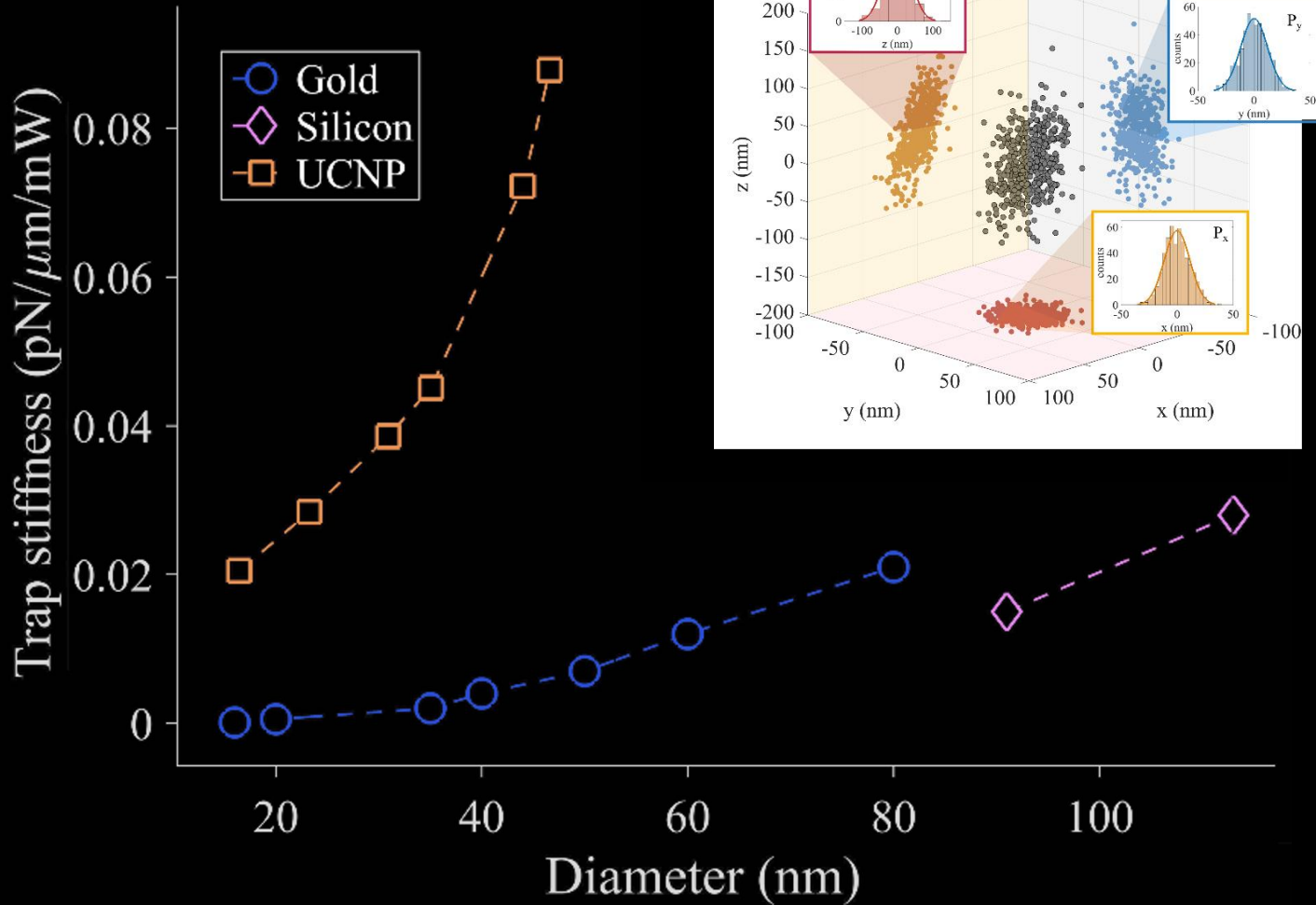


Rodríguez-Sevilla, P. et al. Nano Lett. 18, 602–609 (2018).



Y Kang, et al., J. Phys. Chem. C 2019, 123, 15, 10107–10113

Nanoscale optical manipulation



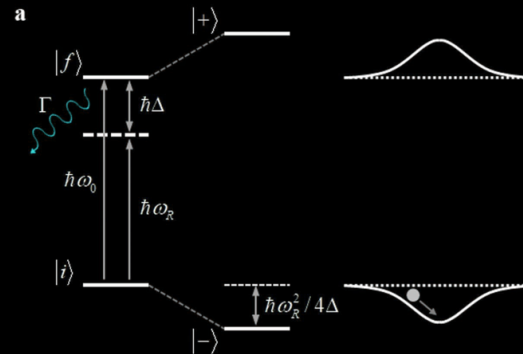
Electrostatic enhanced force

Nanoparticle

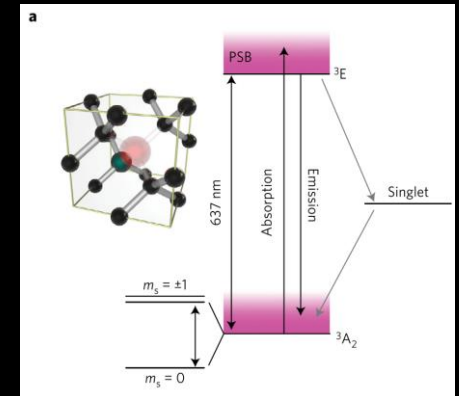
Surface Charge



Near-resonant radiation force



Super-radiance enhanced force

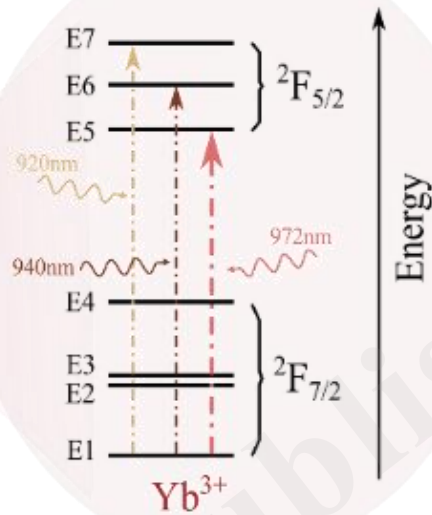
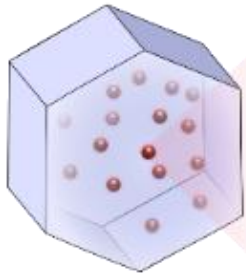


Nanoscale optical manipulation

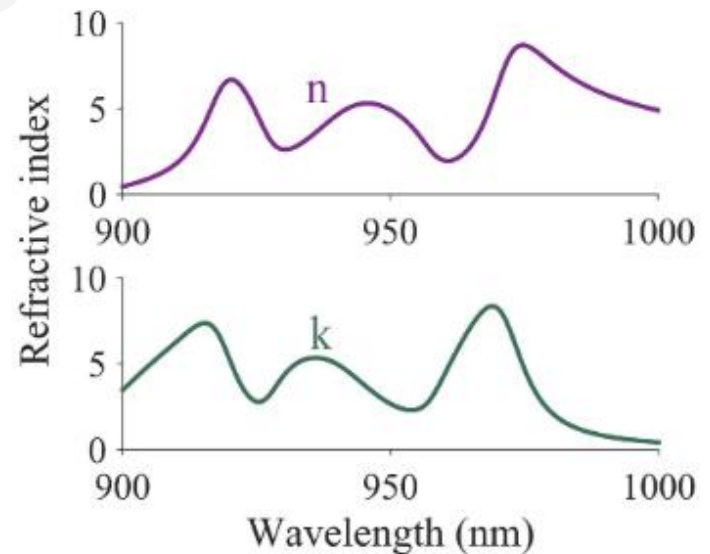
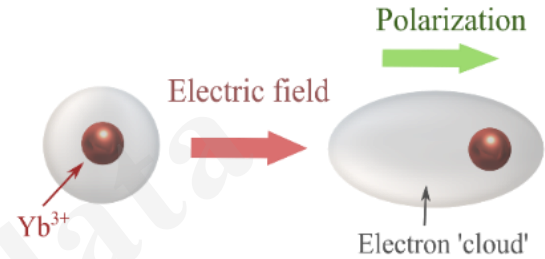
X. Shan

a

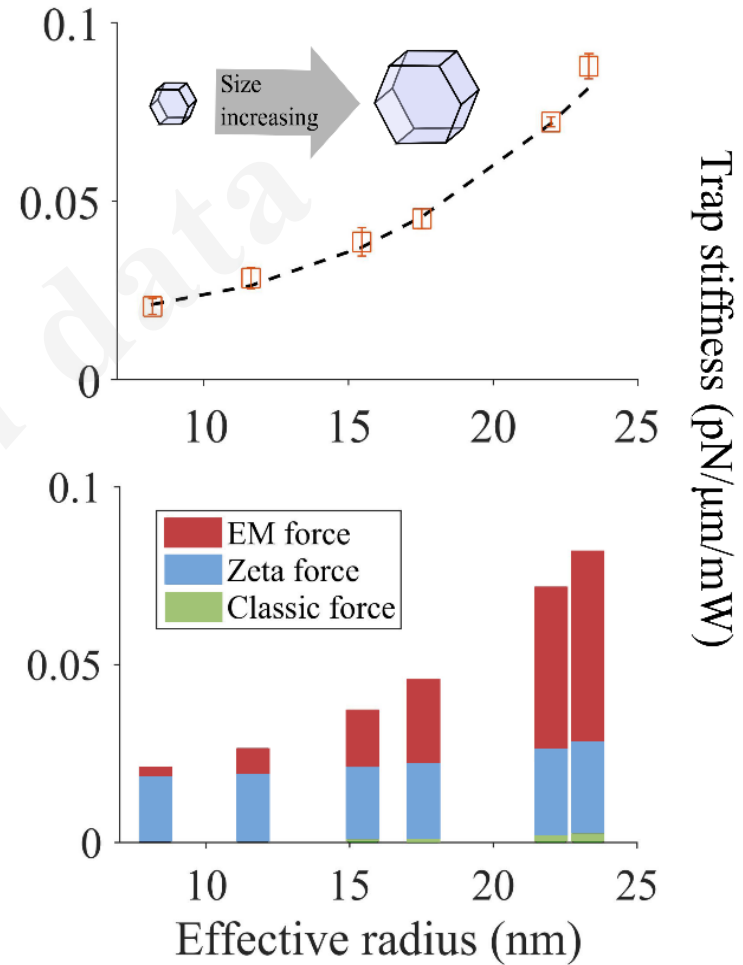
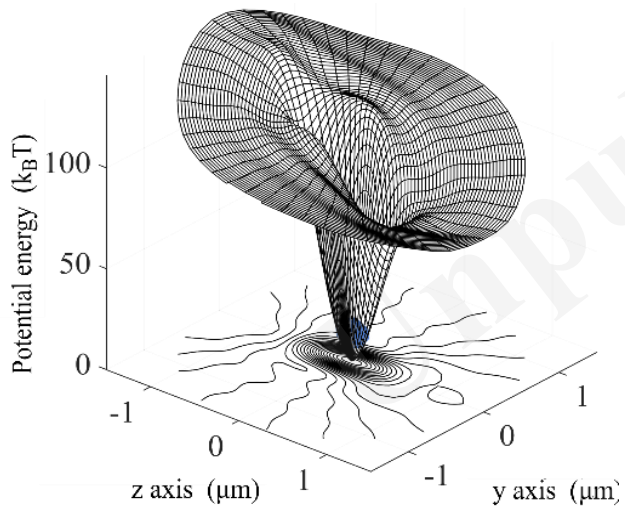
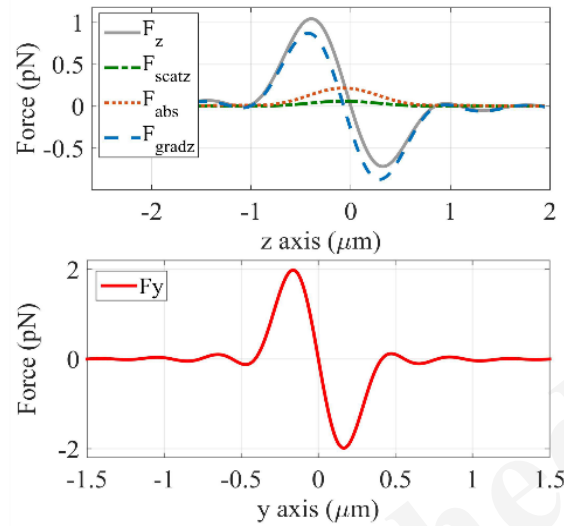
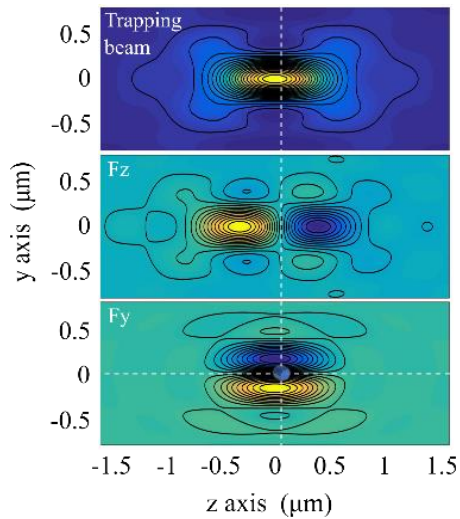
NaYF₄:Yb/Er



Hamonic oscillator model



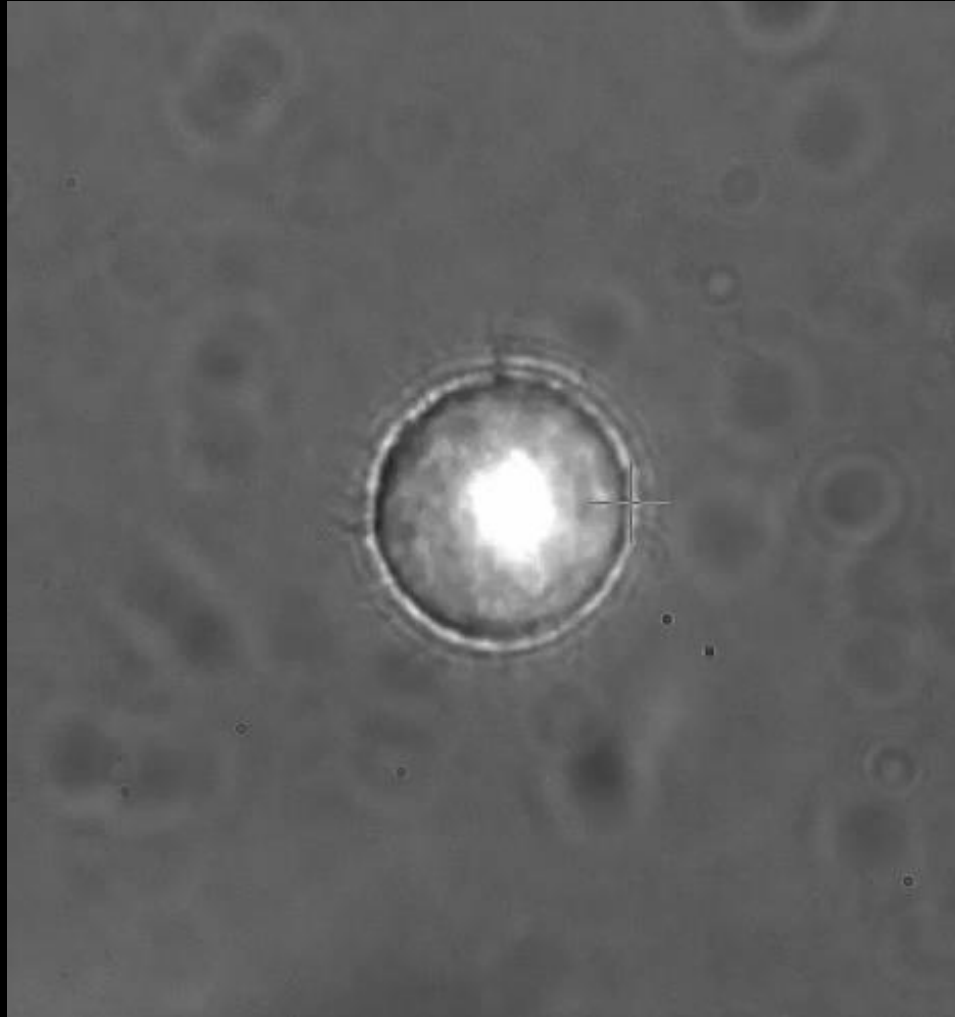
Lanthanide-ion resonance trapping



Nanoscale optical manipulation



X. Shan



Optical tweezers

- UCNP-optical trapping
 - Highest force for Nanoparticle
 - Attonewton force sensor



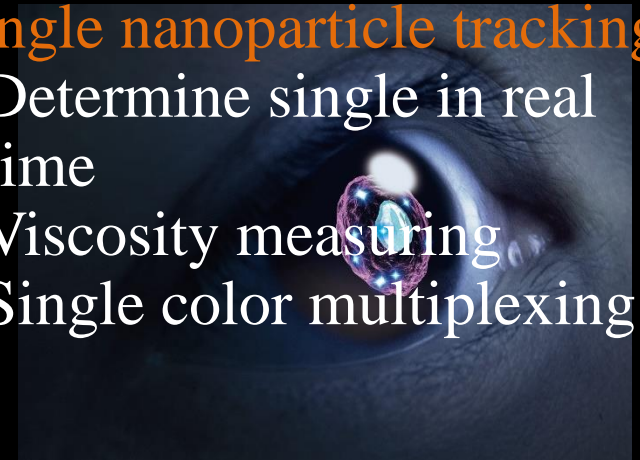
Super-resolution imaging

- UCNP nanoscopy
 - Near-infrared emission saturation nanoscopy
 - Orgnoid imaging



Single particle tracking & sensing

- Single nanoparticle tracking
 - Determine single in real time
 - Viscosity measuring
 - Single color multiplexing



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Mr. Chaohao Chen
Mr. Xuchen Shan

Alumni:

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Dr Chao Mi
Dr Laixu Gao

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UNSW: *Dr. Peter J. Reece, Prof Matina Stanzel*

ANU: *A/Prof. Lan Fu, Prof. Hark Hoe Tan, Prof. Chennupati Jagadish A/Prof. Yuerui Lu*

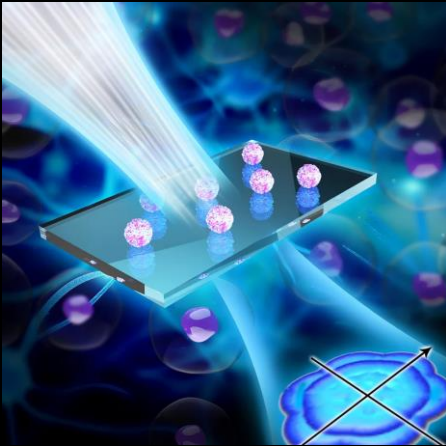
USYD: *Prof Shun Jackson, Dr Lining Ju*



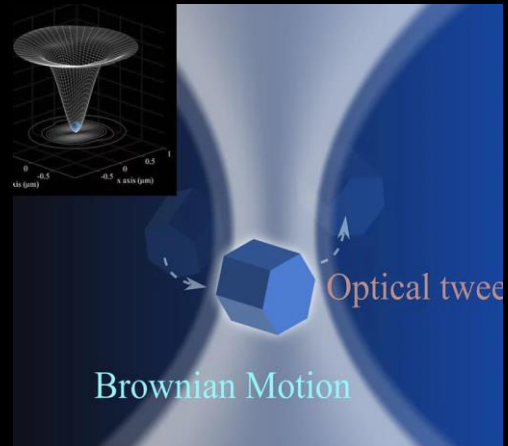
International scholarship available

Contact email: fan.wang@uts.edu.au

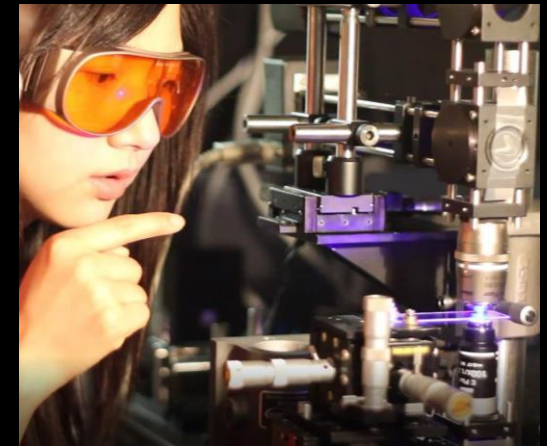
On-chip Super-res



Biological laser cooling



Super-resolved Characterization



Thanks

