Computational Imaging in Extreme Light

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QUANTUMARC
SCOTTISH FUNDING COUNCIL

EXTREME LIGHT

University of Glasgow

EXTREME LIGHT GROUP



Prof. Daniele Faccio

Professor in Quantum Technologies

30+ PhD/postdocs





Dr. M. Chiara Braidotti

Lecturer



Dr. Caroline Müllenbroich

Senior Lecturer



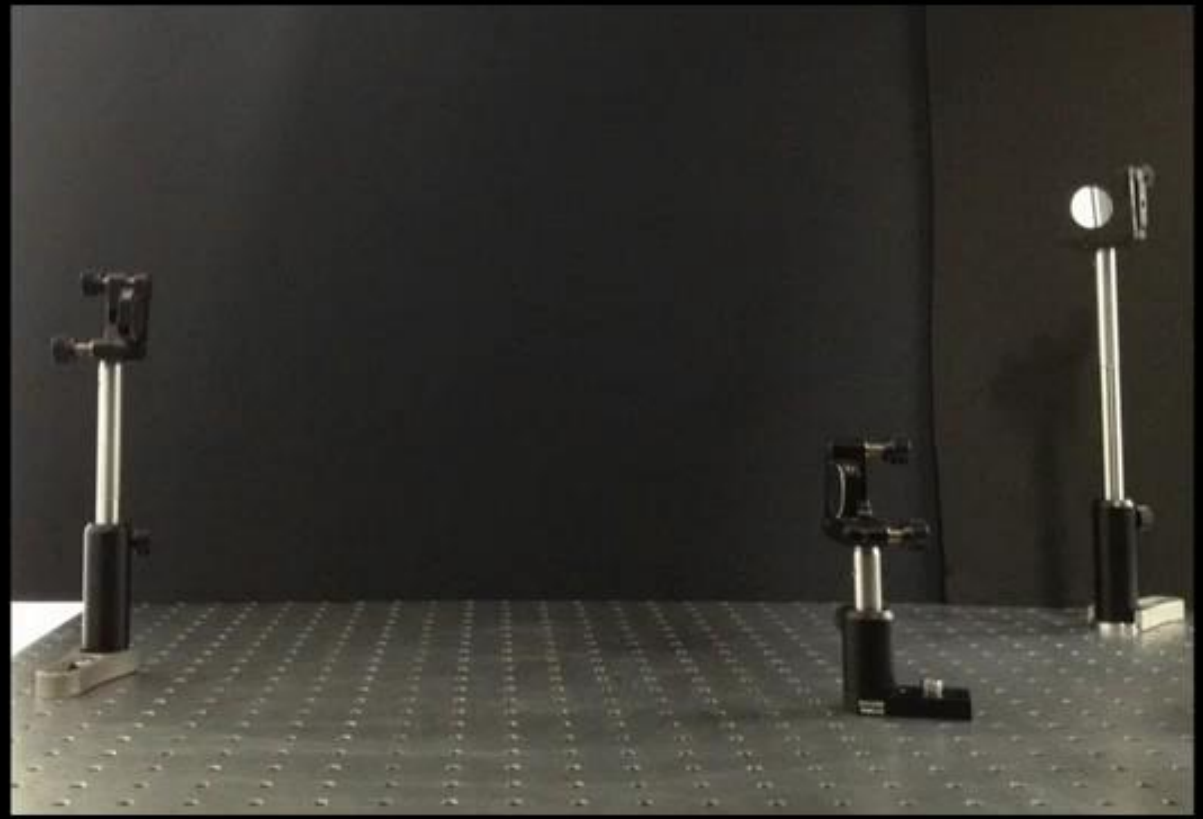
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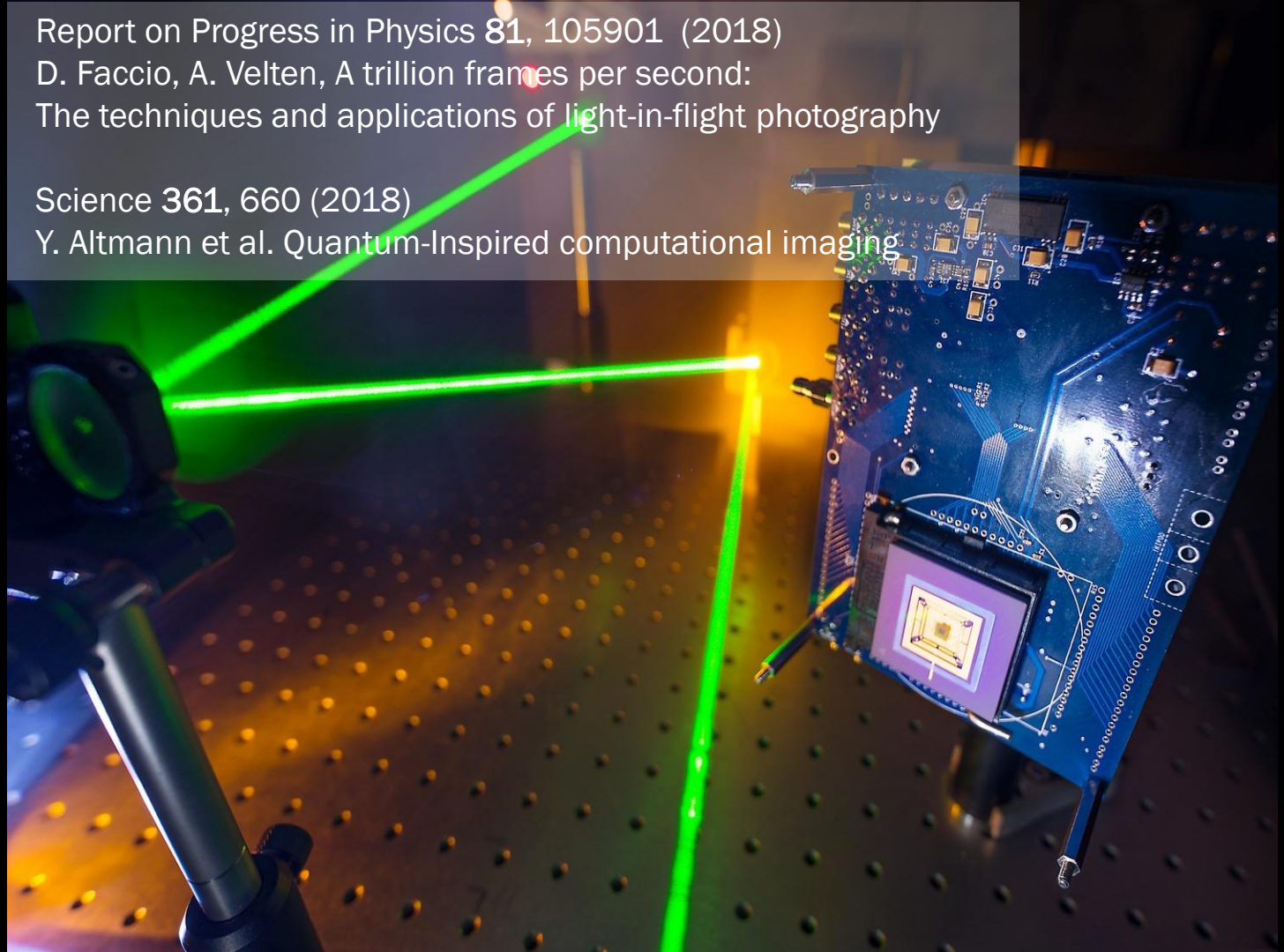
- Quantum optics
- Computational imaging
- Imaging through scattering media
- Nonlinear optics
- Optical analogues to gravity
- Optical metamaterials
- LiDAR – non line of sight imaging
- Optical Neuromorphics



Andreas Velten, MIT



Computational Time-of-Flight Imaging



Report on Progress in Physics **81**, 105901 (2018)
D. Faccio, A. Velten, A trillion frames per second:
The techniques and applications of light-in-flight photography

Science **361**, 660 (2018)
Y. Altmann et al. Quantum-Inspired computational imaging

SPAD Cameras

- Single photon sensitivity
- 10^6 frames per second
- Timing of photons down to 10^{-11}s

pi imaging



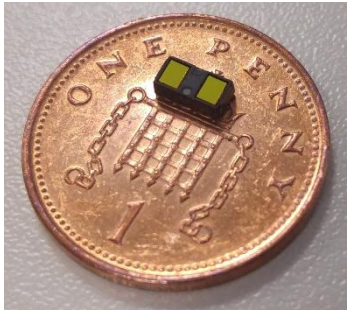
THE UNIVERSITY of EDINBURGH

Prof Robert Henderson

STMicroelectronics

PHOTON FORCE

Singular™ Photonics



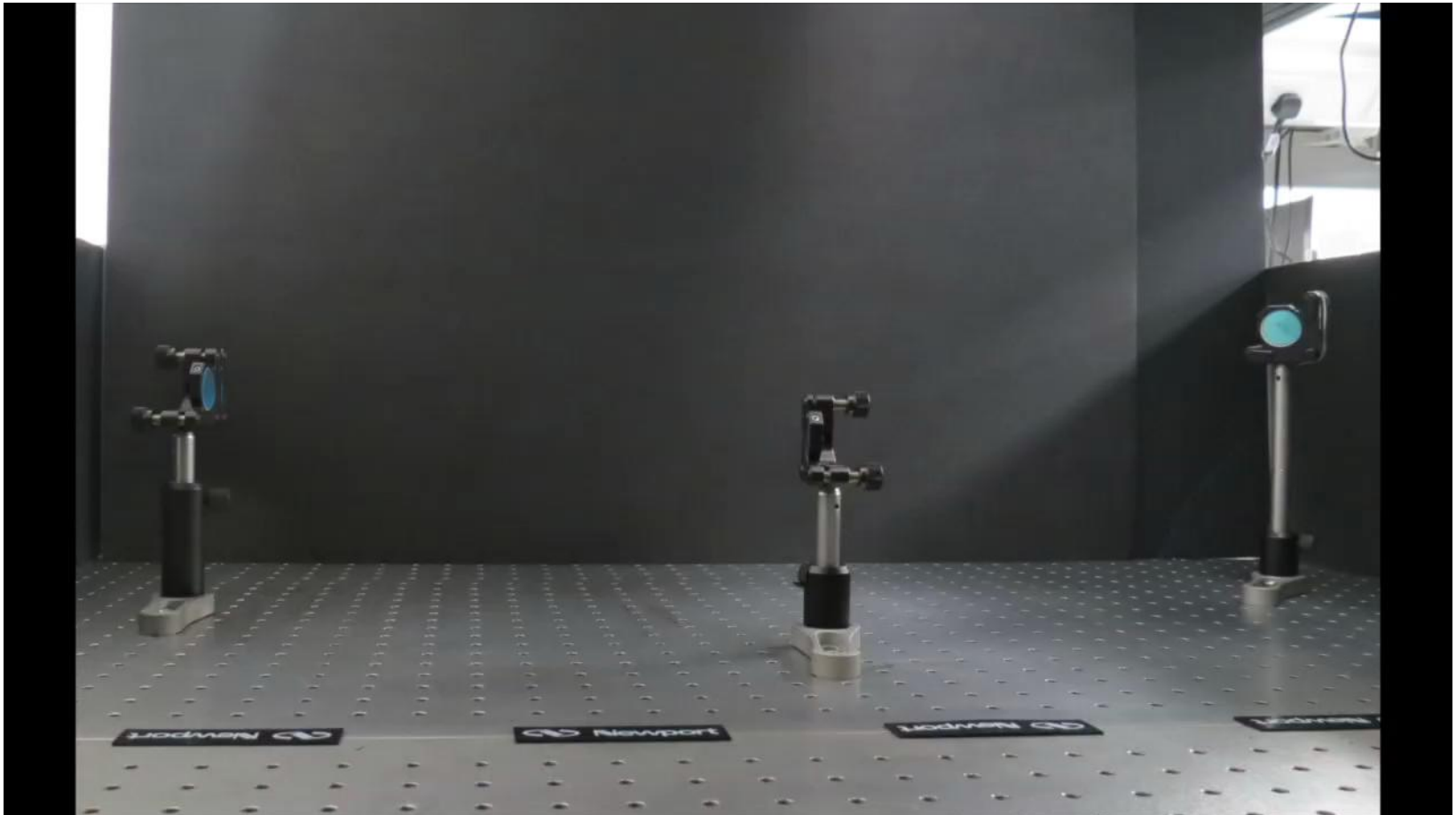


What can we do with this?

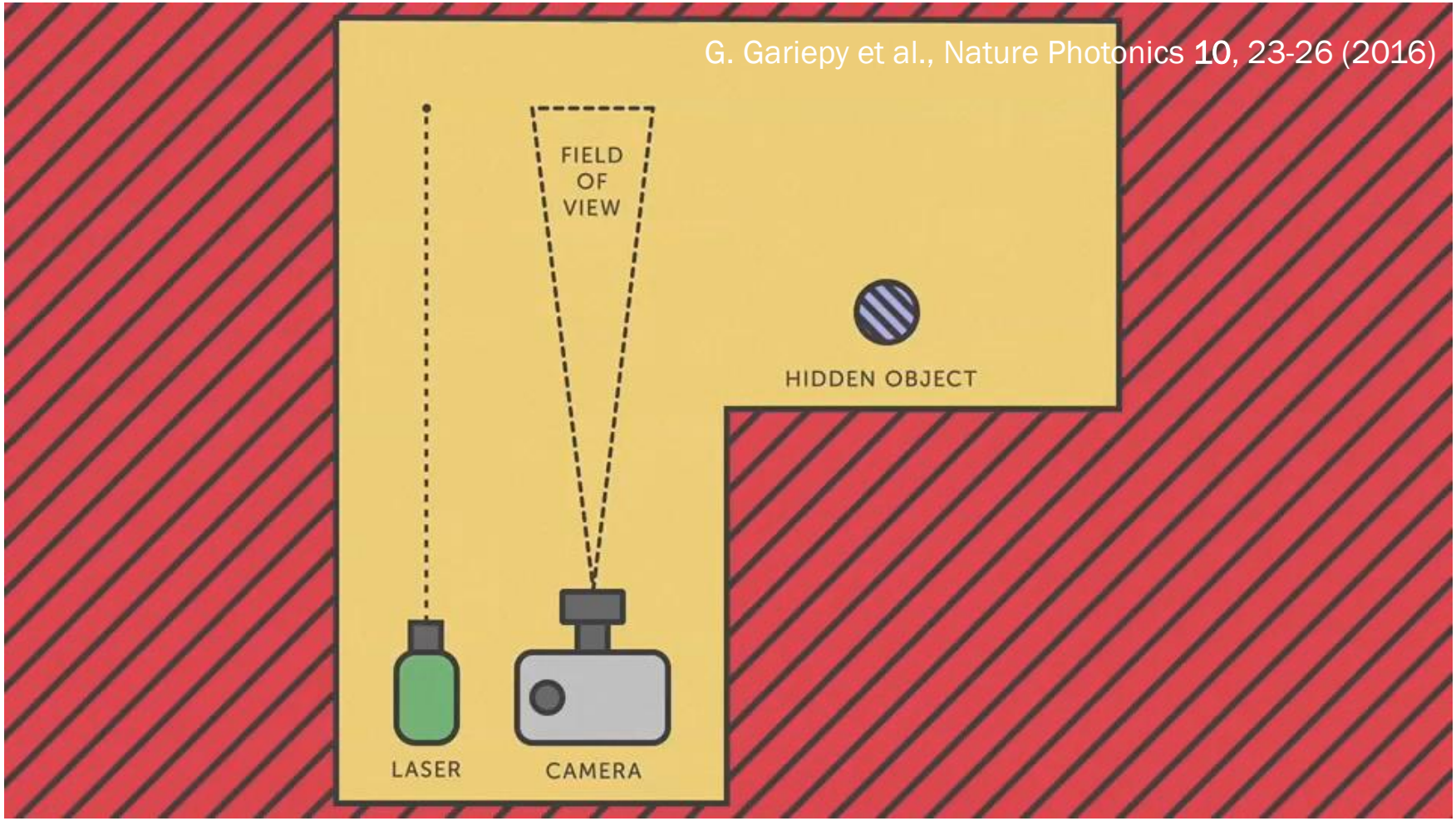
- Ranging/LiDAR/3D Imaging
- Image around corners
- Image without cameras
- Image through highly scattering/diffuse media
  - *Biological tissues*
- Fluorescence lifetime microscopy
- High speed speckle imaging for medical applications

Imaging around corners

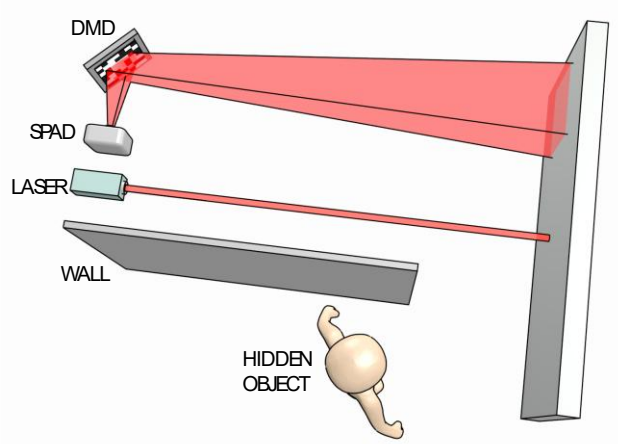
“laser echos” from beyond the field of view



G. Gariepy et al., Nature Photonics 10, 23-26 (2016)



Non-Line-of-Sight Imaging

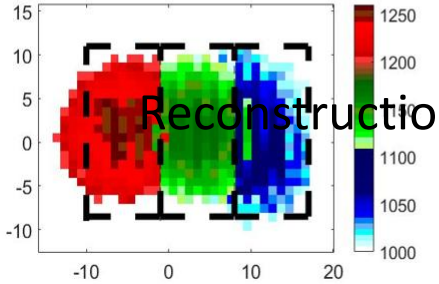


Hidden Scene

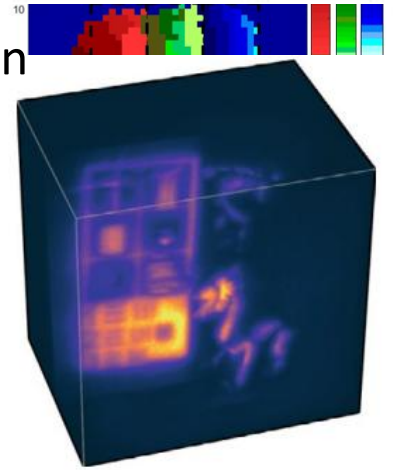




Reflectivity



Reconstruction



PHYSICAL REVIEW APPLIED **12,** 011002 (2019)

Letter | Editors' Suggestion | Featured in Physics

Non-Line-of-Sight Three-Dimensional Imaging with a Single-Pixel Camera

G. Musarra,[1,*] A. Lyons,[1] E. Conca,[2] Y. Altmann,[3] F. Villa,[2] F. Zappa,[2] M.J. Padgett,[1] and D. Faccio[1,†]

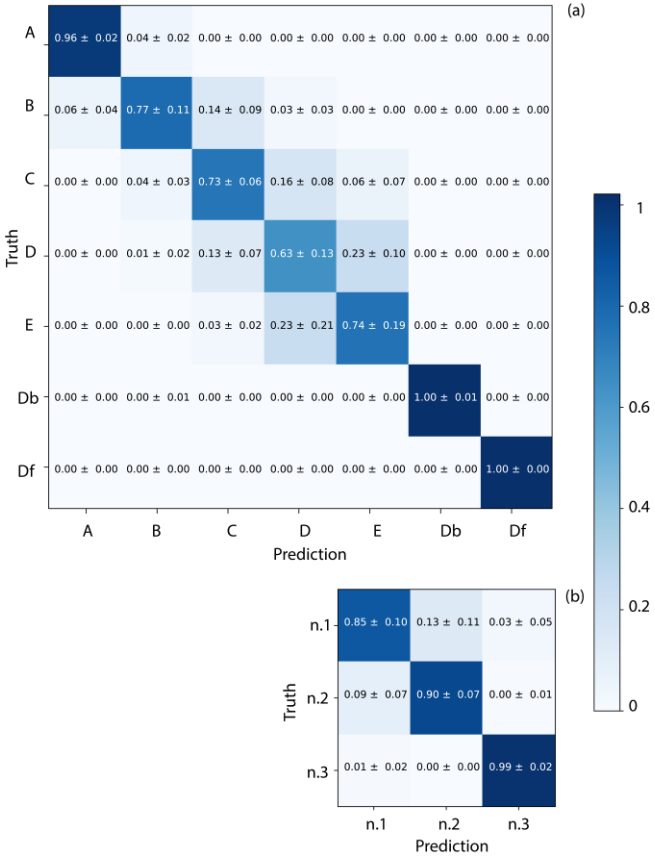
[1] *School of Physics & Astronomy, University of Glasgow, Glasgow G12 8QQ, United Kingdom*

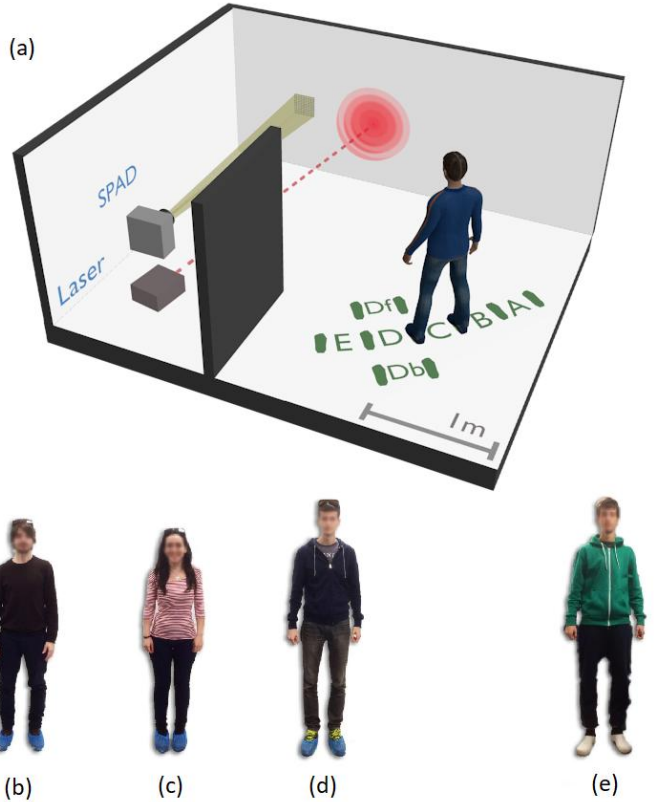
[2] *Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, 20133 Milano, Italy*

[3] *School of Engineering and Physical Sciences, Heriot-Watt University, Edinburgh EH144AS, United Kingdom*

D. Lindell et al. ACM Trans. Graph., 38, 4, 116. (2019).

Non-Line-of-Sight Imaging

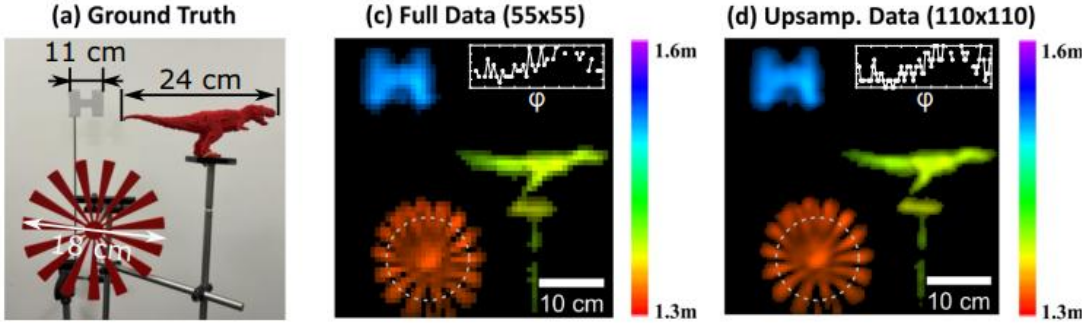


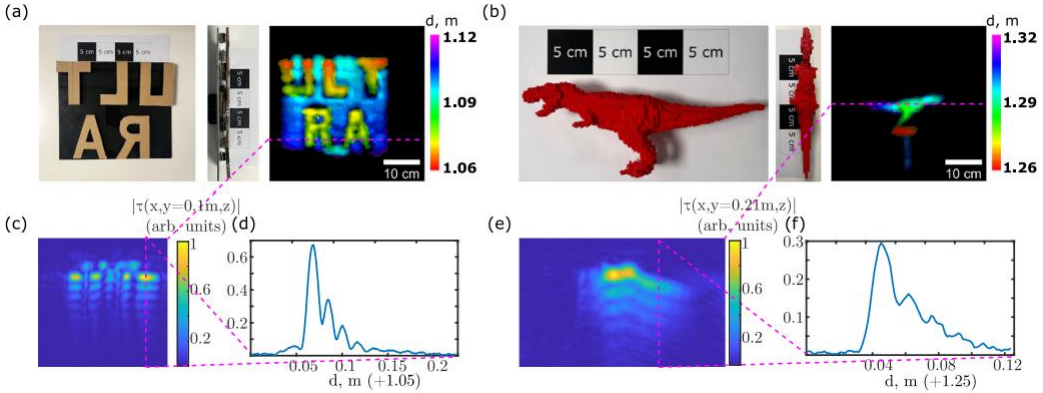


P. Caramazza et al. Sci. Rep. 8, 11945 (2018)

Non-Line-of-Sight Imaging

Ultrasound

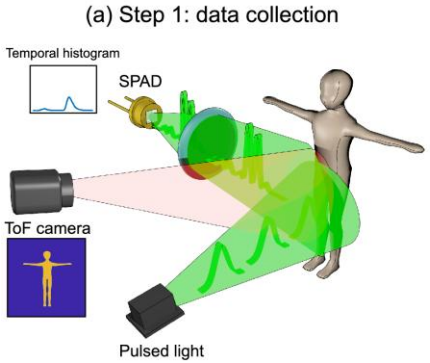


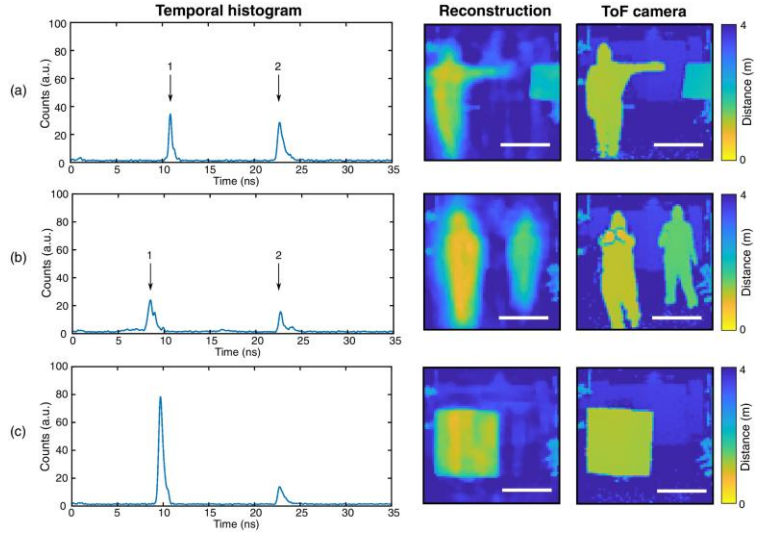


T. Li et al. Comms. Phys. 8, 432 (2025)

Imaging without cameras

Do I even need pixels?





- Measure time domain + 3D image
- Train neural net
- Throw away 3D image
- 3D imaging with only time + NN

900 Vol. 7, No. 8 / August 2020 / Optica Research Article

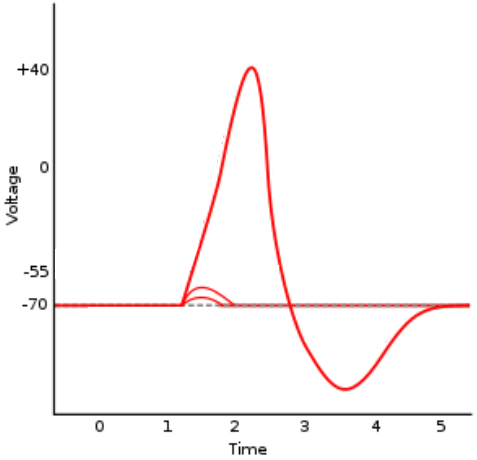
optica

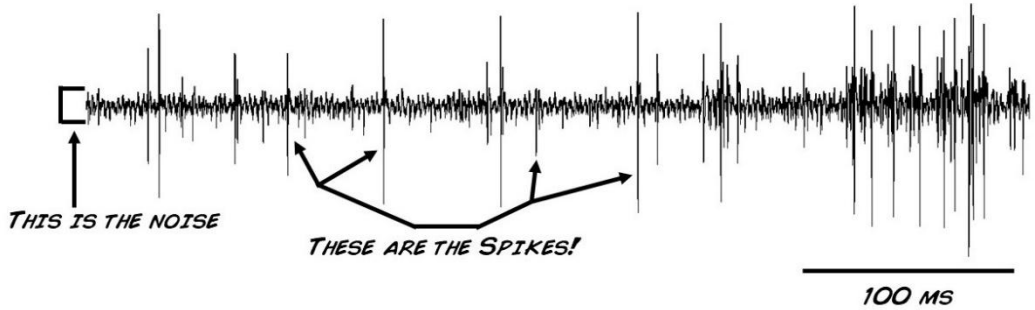
Spatial images from temporal data

Alex Turpin,[1,*] Gabriella Musarra,[2] Valentin Kapitany,[2] Francesco Tonolini,[1] Ashley Lyons,[2] Ilya Starshynov,[2] Federica Villa,[3] Enrico Conca,[3] Francesco Fioranelli,[4] Roderick Murray-Smith,[1] and Daniele Faccio[2,5]

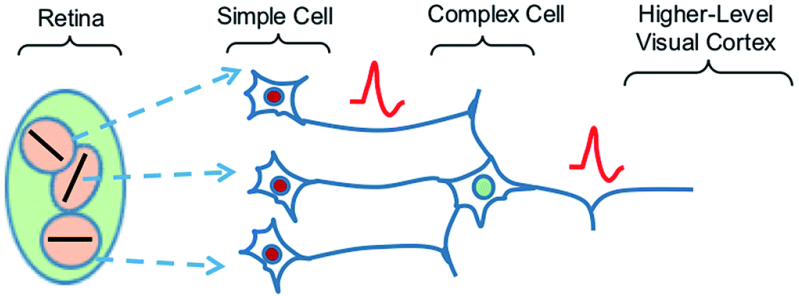
[1]School of Computing Science, University of Glasgow, Glasgow G12 8QQ, UK
[2]School of Physics & Astronomy, University of Glasgow, Glasgow G12 8QQ, UK
[3]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, 20133 Milano, Italy
[4]Department of Microelectronics, TU Delft, 2628CD, The Netherlands
[5]e-mail: daniele.faccio.@glasgow.ac.uk

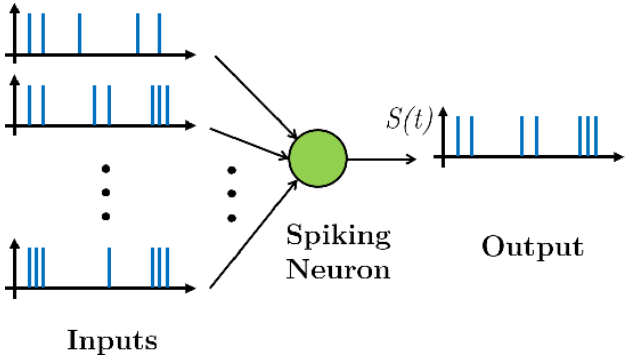
How do we process this information?





(a)



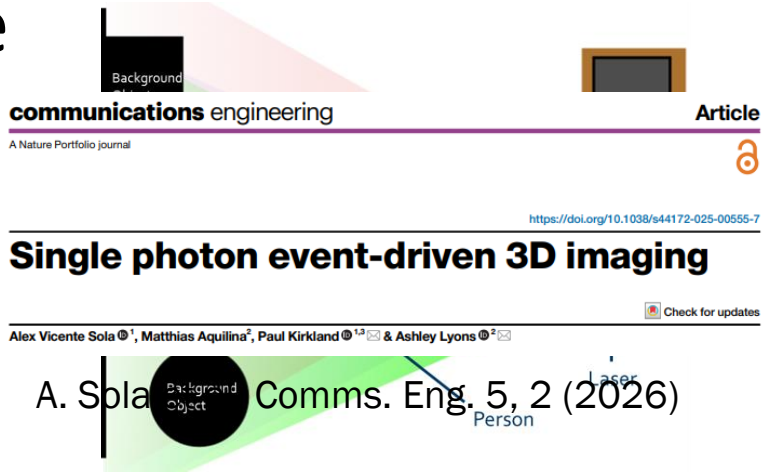


Imaging 1 photon at a time

Use the time domain to gain spatial information

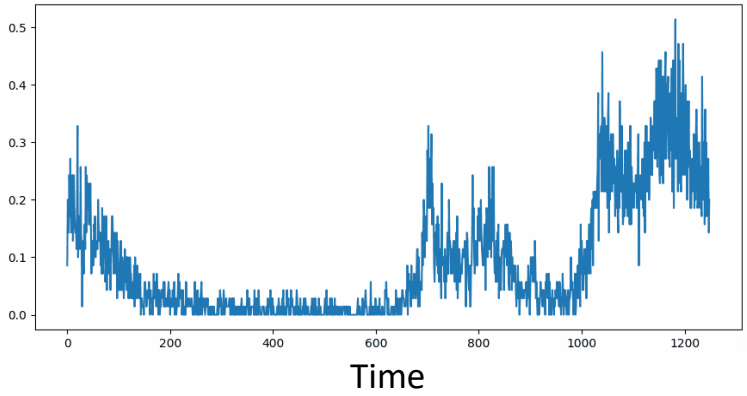
Turn single point sensors into 3D cameras
Make very small, very cheap cameras

Nanosecond latency

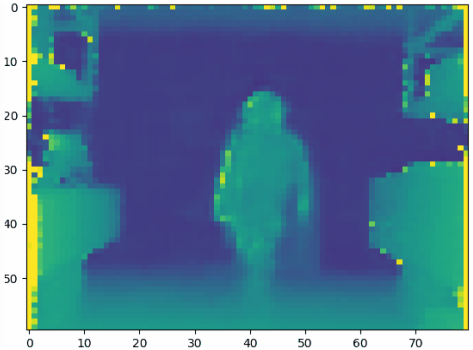


A. Sola et al. Comms. Eng. 5, 2 (2026)

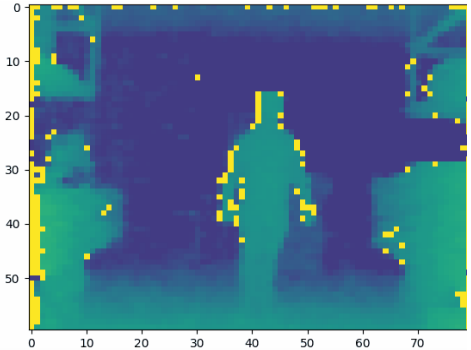
Single Pixel Measurement



Reconstruction

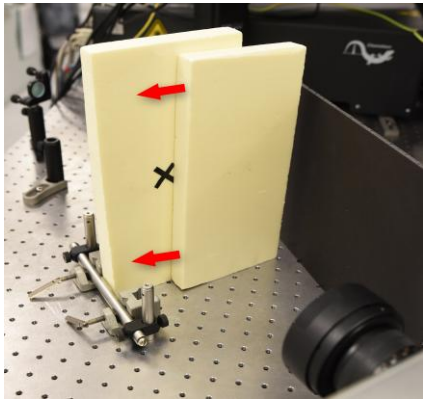


Ground Truth



Imaging inside the body

Imaging through diffusion

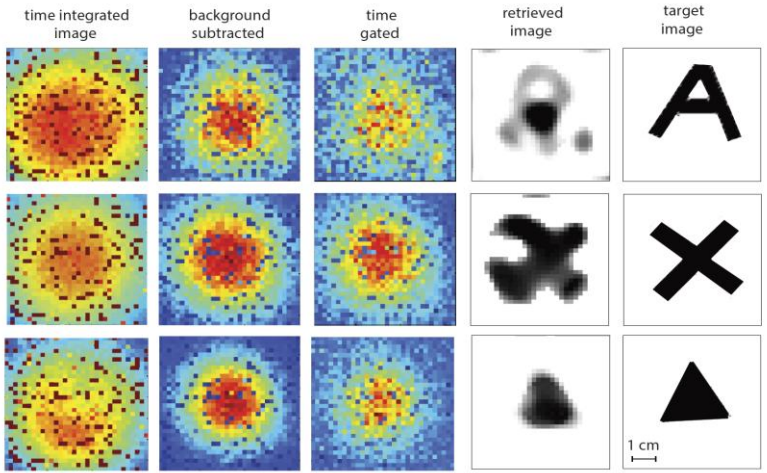


nature photonics
ARTICLES
https://doi.org/10.1038/s41566-019-0439-x

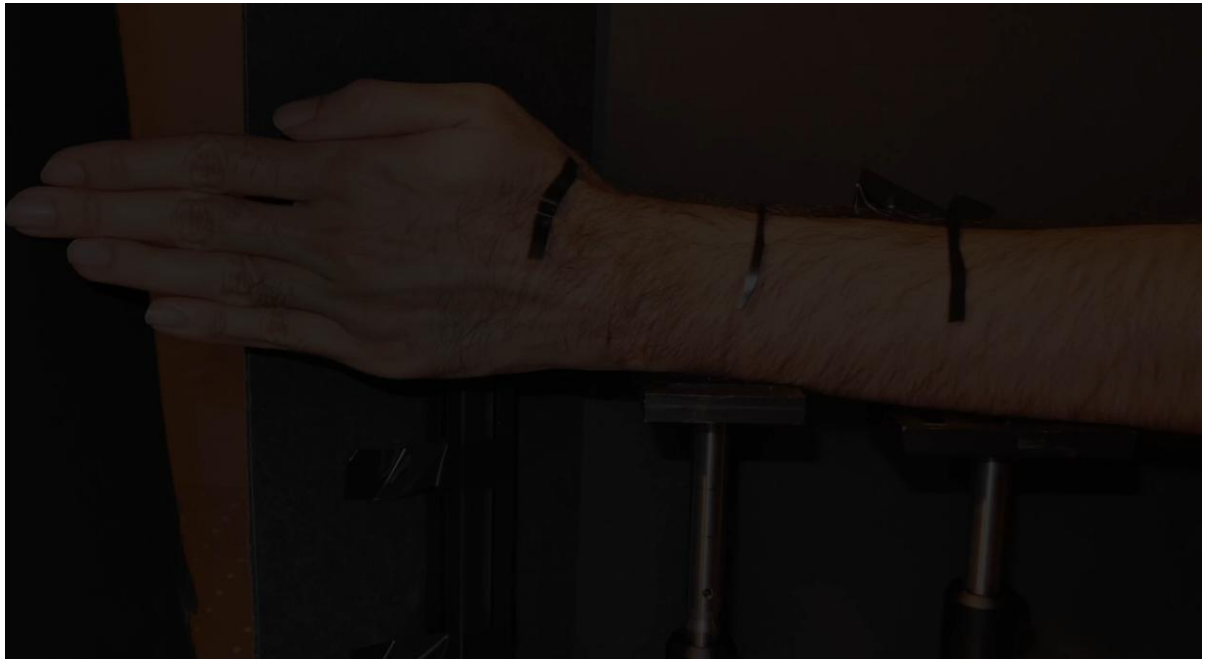
Computational time-of-flight diffuse optical tomography

A. Lyons et al., Nature Photonics 13(8), pp. 575-579 (2019)

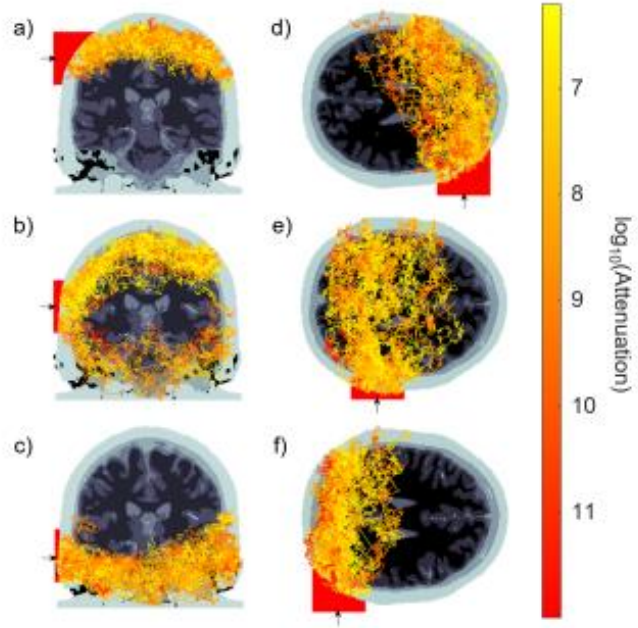




Seeing inside biological tissues



Can you take this further?



Can you get light through the adult human head?



NEUROPHOTONICS

RESEARCH PAPER

Photon transport through the entire adult human head

Jack Radford, Vytautas Gradauskas, Kevin J. Mitchell, Samuel Nerenberg, Ilya Starshynov, and Daniele Faccio*
University of Glasgow, School of Physics and Astronomy, Glasgow, United Kingdom

J. Radford et al. Neurophotonics 12(2), 025014 (28 May 2025)

Scatter Guiding

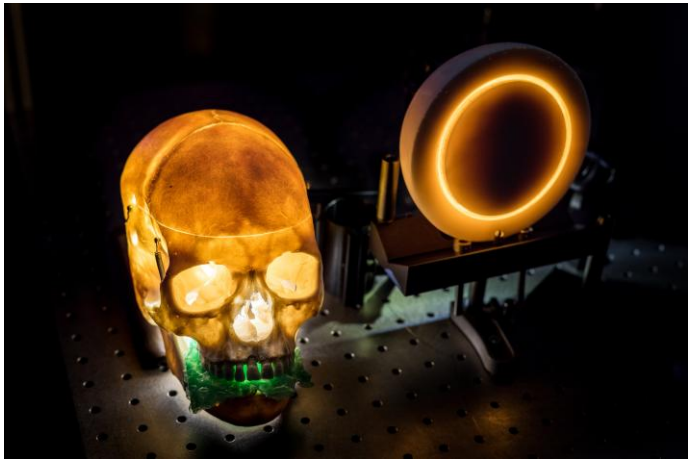
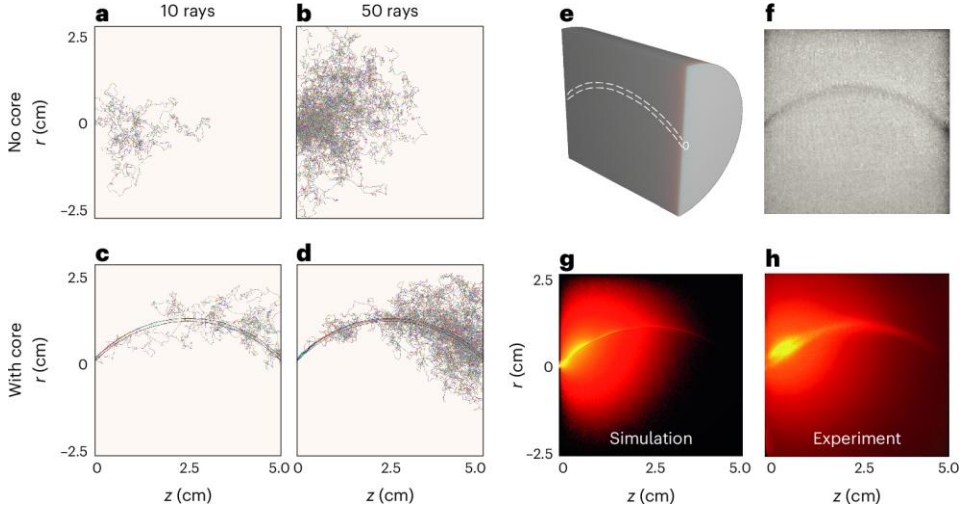


Photo credits: Kevin Mitchell



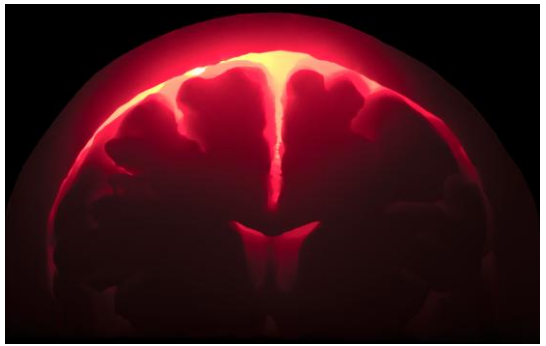
nature physics

Article

https://doi.org/10.1038/s41567-024-02665-z

Energy transport in diffusive waveguides

K. Mitchell et al. Nat. Phys. 20. 1955–1959 (2024)



FNIRS

Functional Near Infra Red Spectroscopy

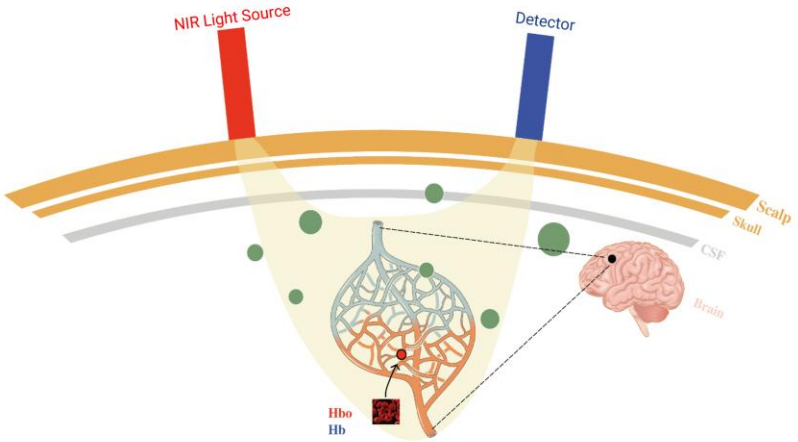


Image credit: Seenel Imaging

kernel



Measure blood deoxygenation at the superficial layers

Brain reading from a wearable device

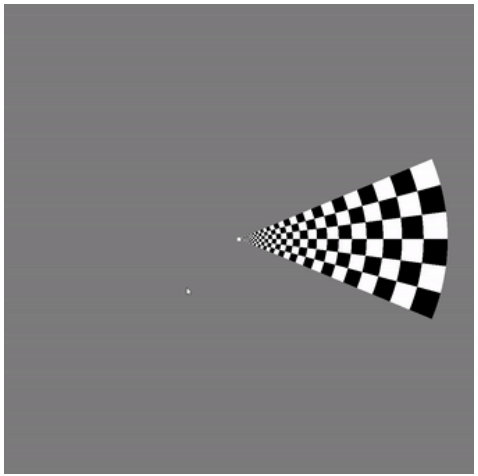

University of Glasgow
Extreme Light

FNIRS

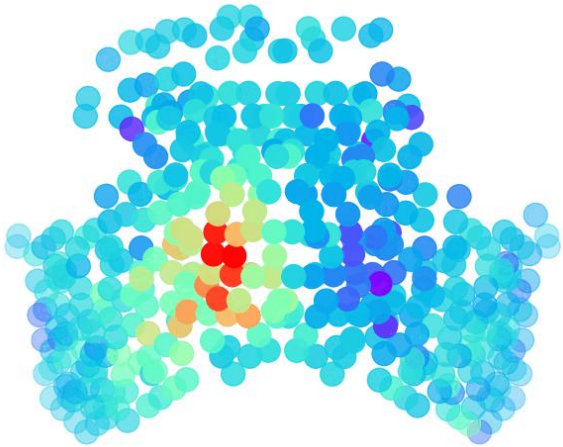
Functional Near Infra Red Spectroscopy

Retinotopic mapping

Visual Stimulus



Brain Activity

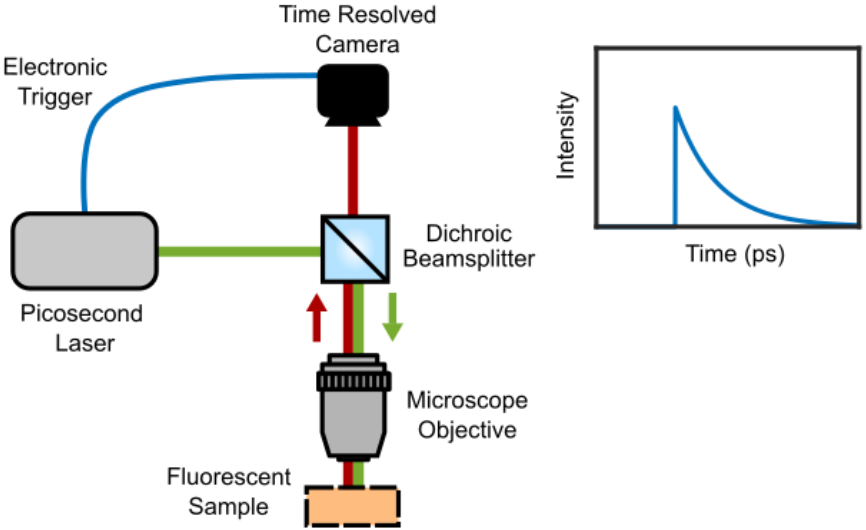


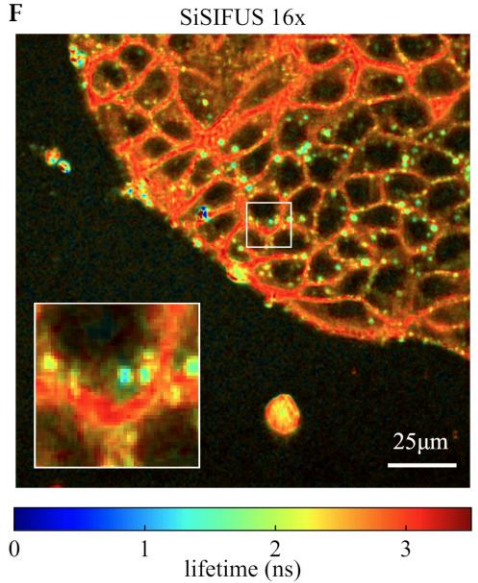
Fluorescence Lifetime Imaging Microscopy (FLIM)

Fluorescence Lifetime Imaging
FLIM

Process:

- Excite Fluorophore in bio-sample with ultrafast laser
- Measure exponential decay time using photon arrival time - *TCSPC*
  - *Gated Camera*





Fluorescence Lifetime Imaging

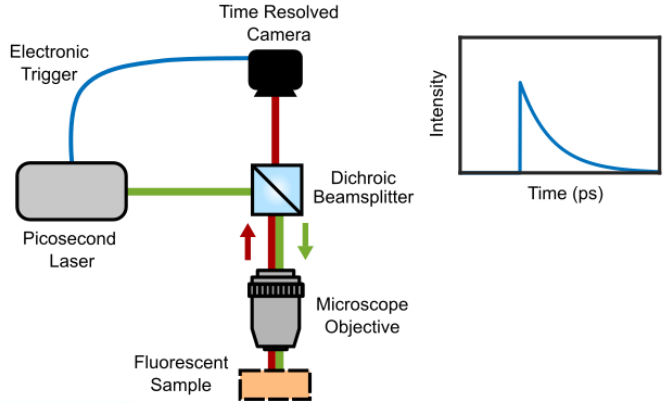
FLIM

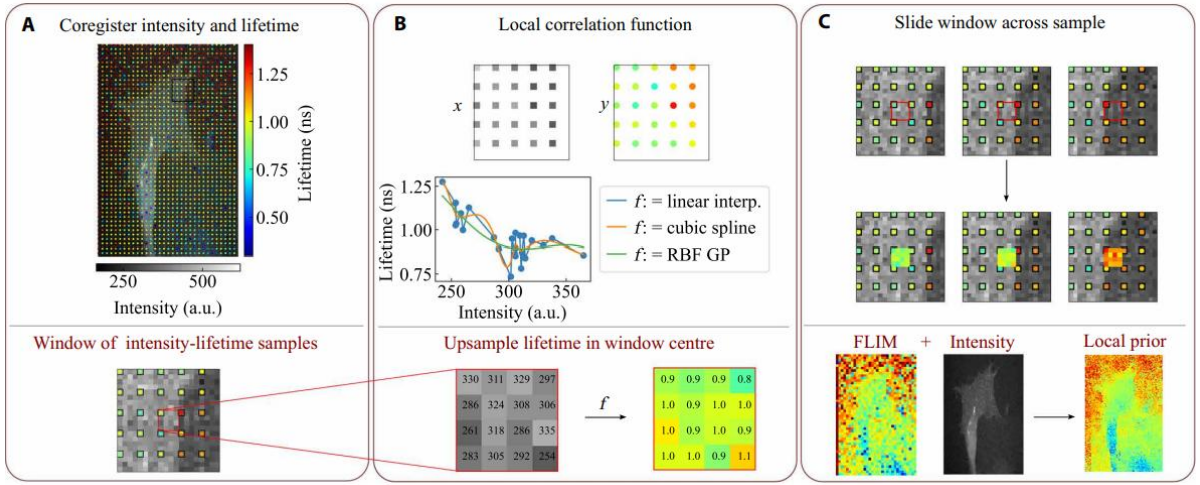
Improving the spatial resolution

Take 2 images

- High spatial res, no time domain
- Low spatial res, high-res time domain

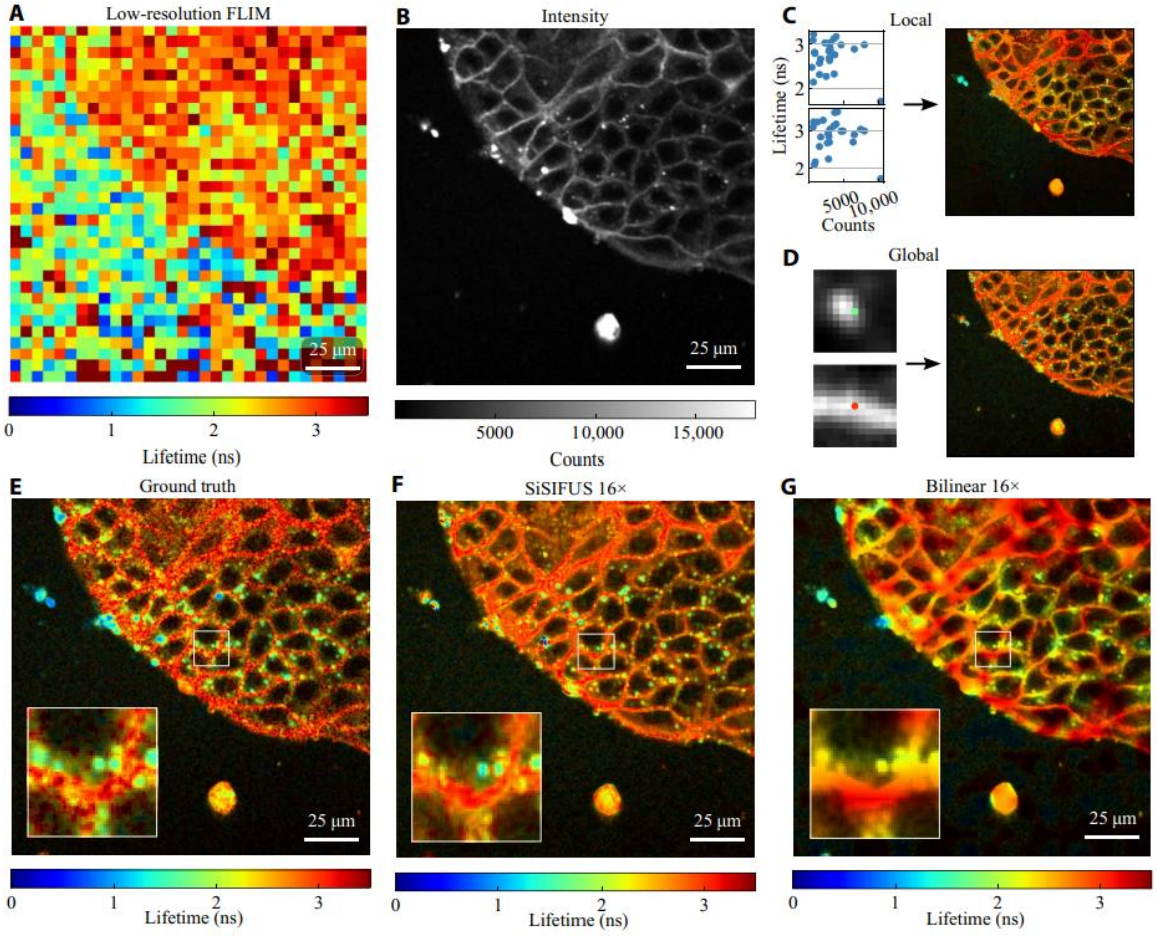
Computationally fuse





Fluorescence Lifetime Imaging

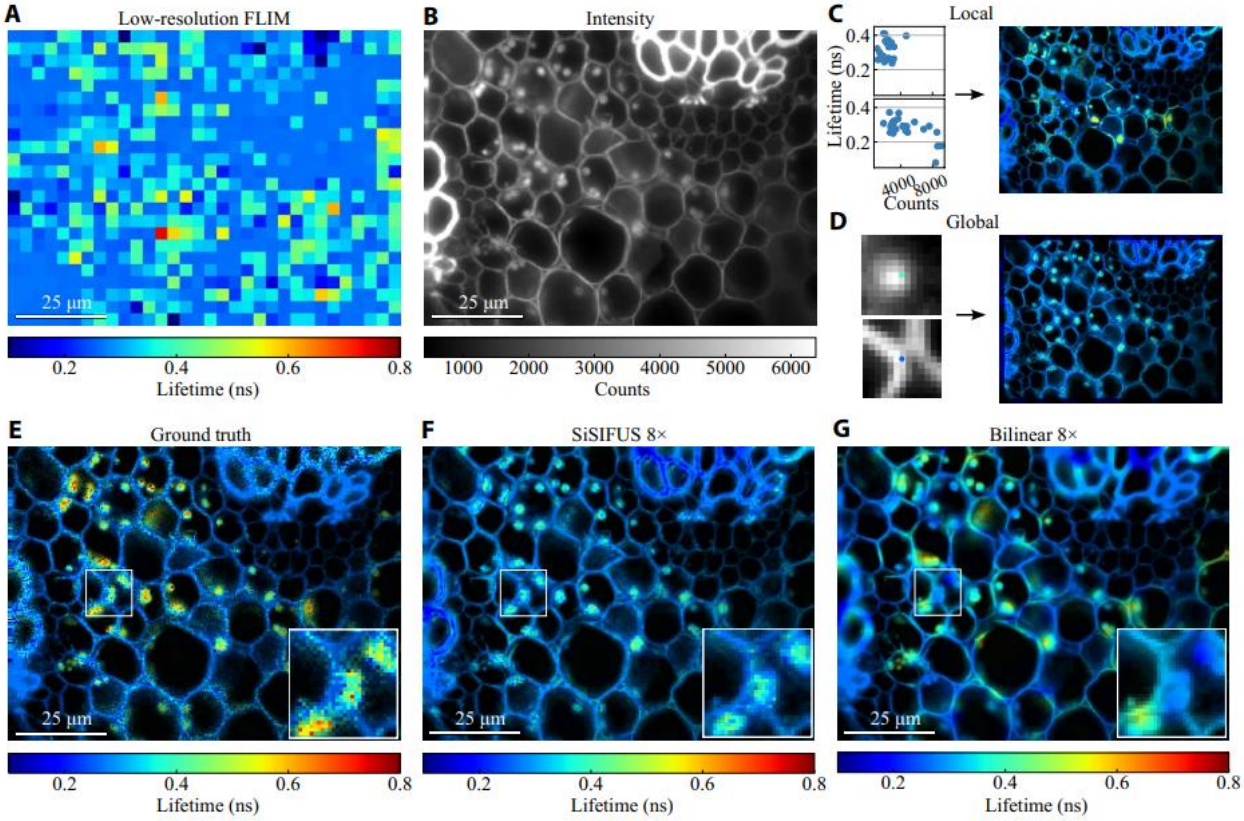
FLIM



V. Kapitany et al. Sci. Adv. 10, eadn0139 (2024)

Fluorescence Lifetime Imaging

FLIM



V. Kapitany et al. Sci. Adv. 10, eadn0139 (2024)

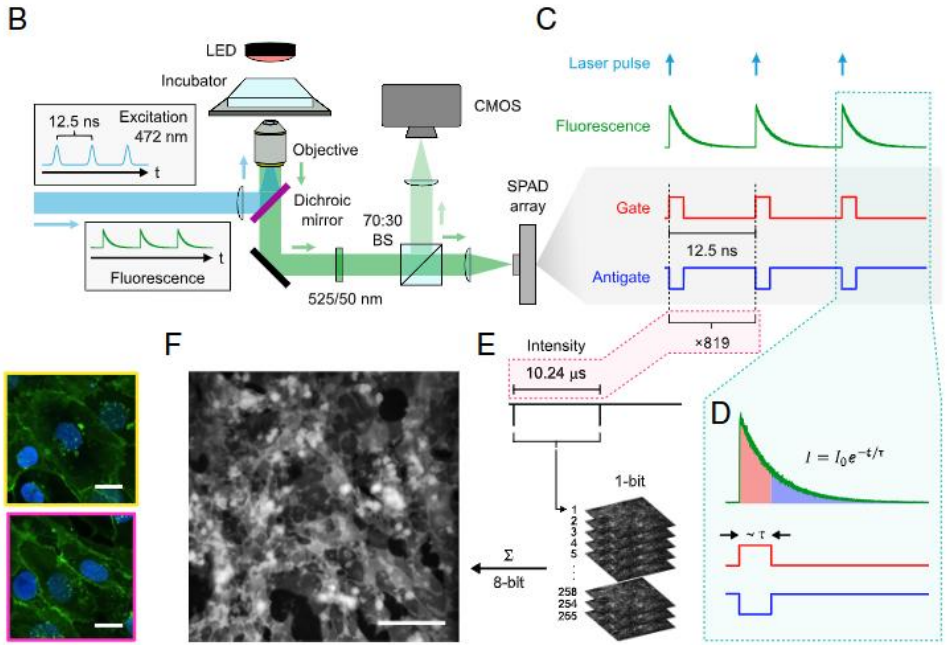
Fluorescence Lifetime Imaging

FLIM

Improving speed

Conventional FLIM systems:
- Scanning
- Around 1fps for 0.25Mpx

Our system:
- Widefield
- 200 fps at 0.25Mpx



Fluorescence Lifetime Imaging

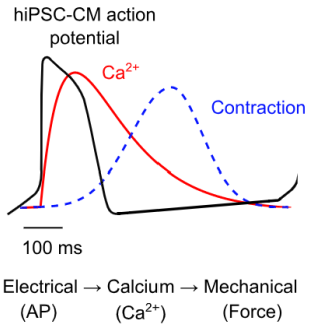
FLIM

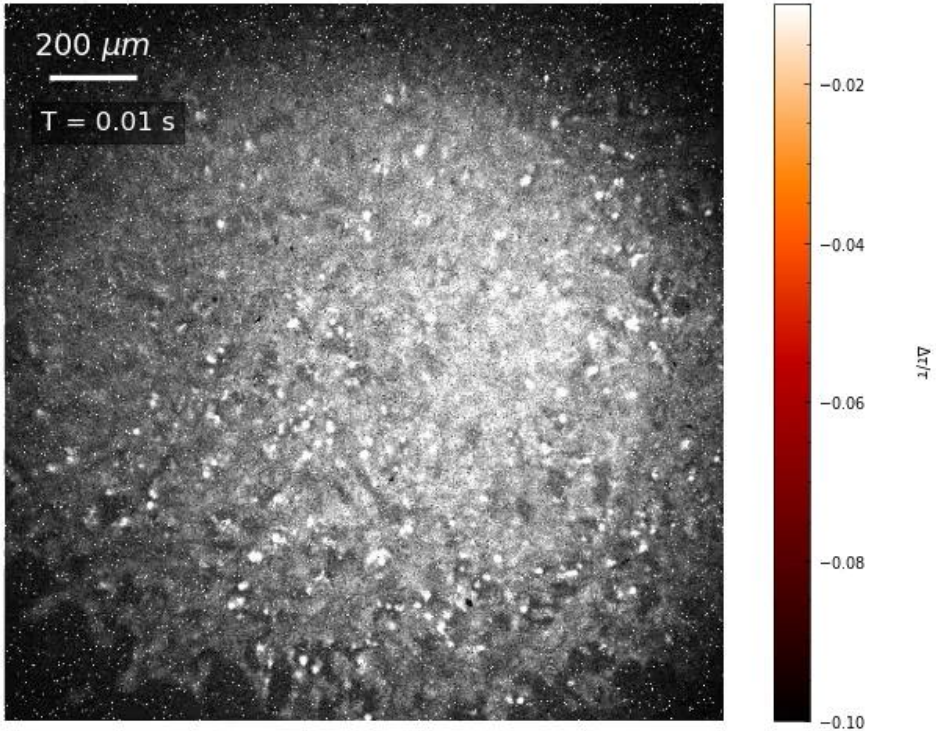
Improving speed

Conventional FLIM systems:
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Our system:
- Widefield
- 200 fps at 0.25Mpx

Electrophysiology in cardiomyocytes

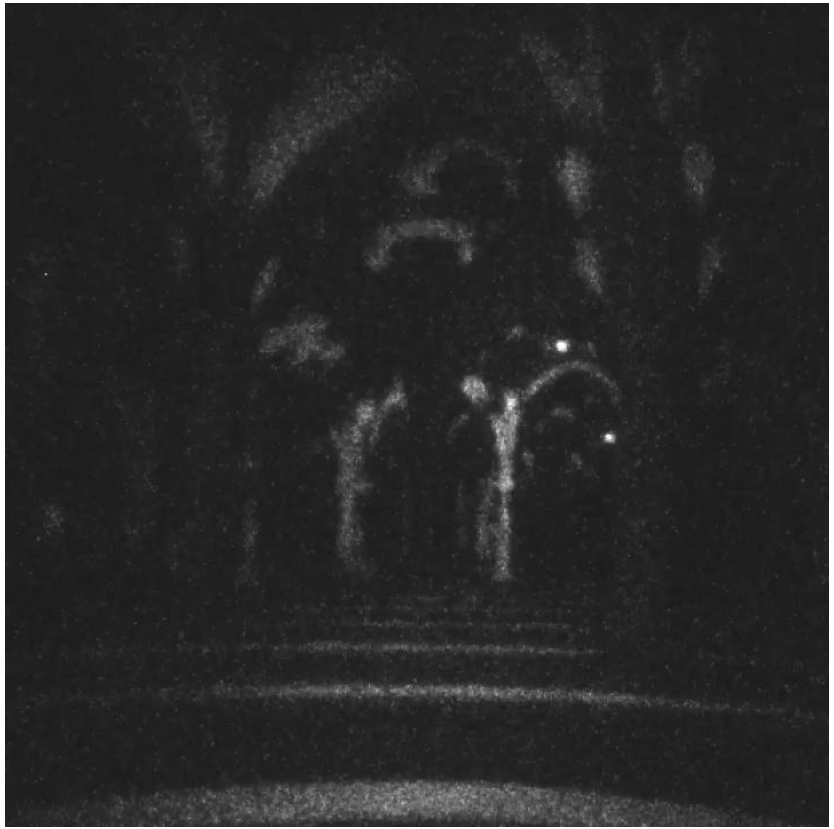




Finish with some art

Semiconductor

Ruth Jarman and Joe Gerhardt







Summary and Conclusions

EXTREME LIGHT

- Ranging/LiDAR/3D Imaging
- Image around corners
- Image without cameras
- Image through highly scattering/diffuse media
  - Biological tissues
- Fluorescence lifetime microscopy
- High speed speckle imaging for medical applications

extremelight.org.uk

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SCOTTISH FUNDING COUNCIL

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daniele.faccio@glasgow.ac.uk

CRACKING QUANTUM

University of Glasgow