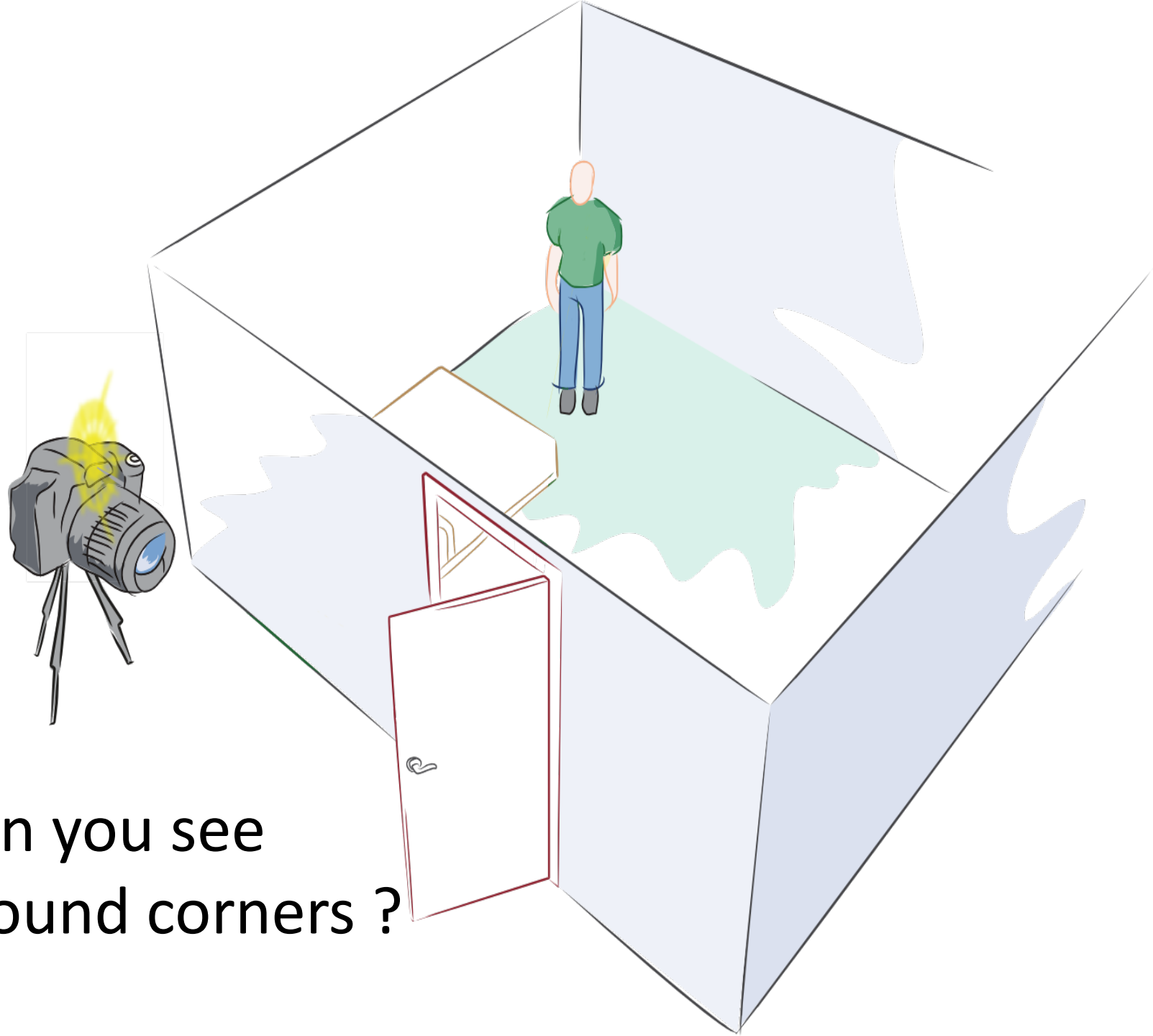
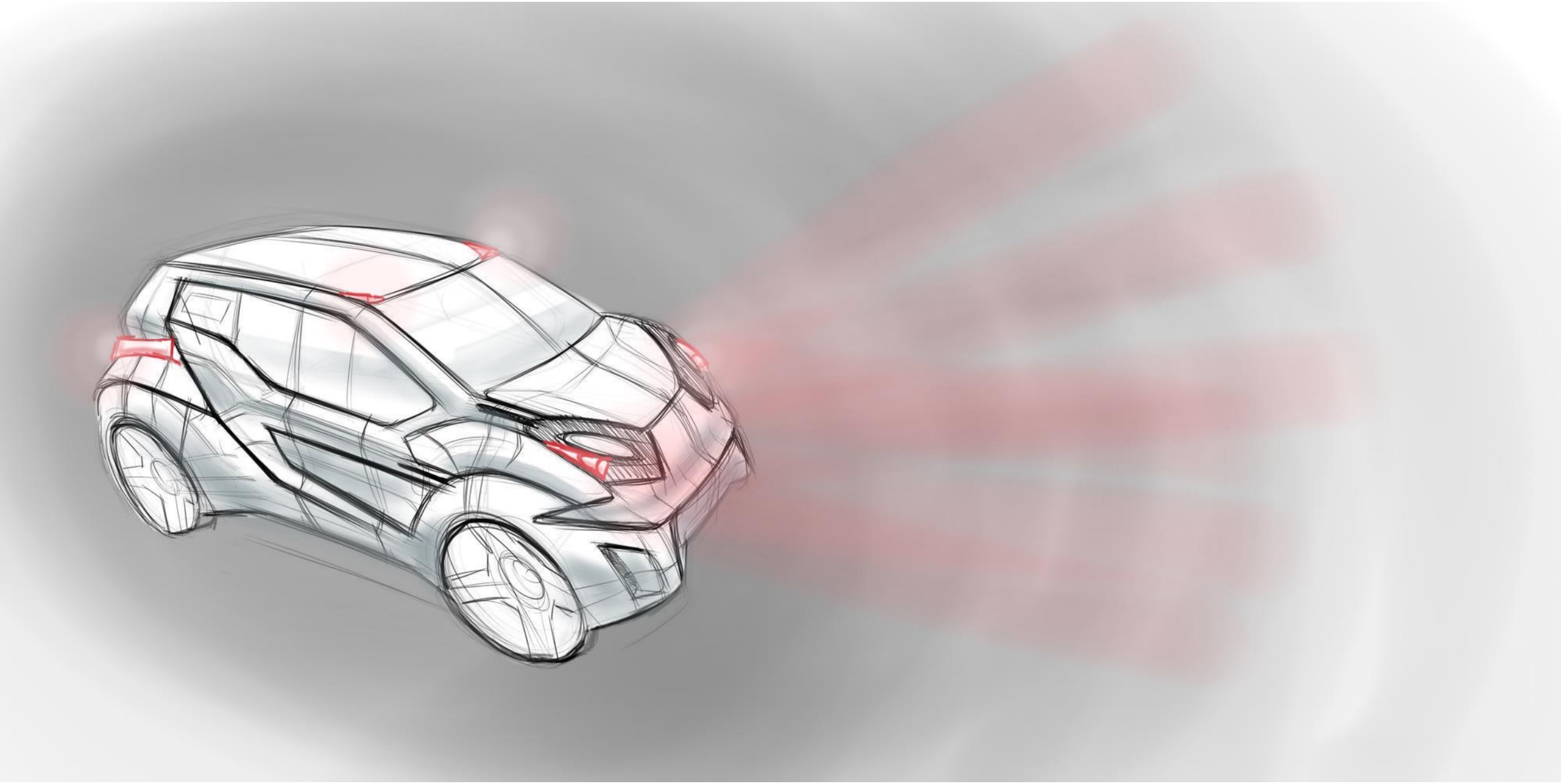
Making Invisible Visible

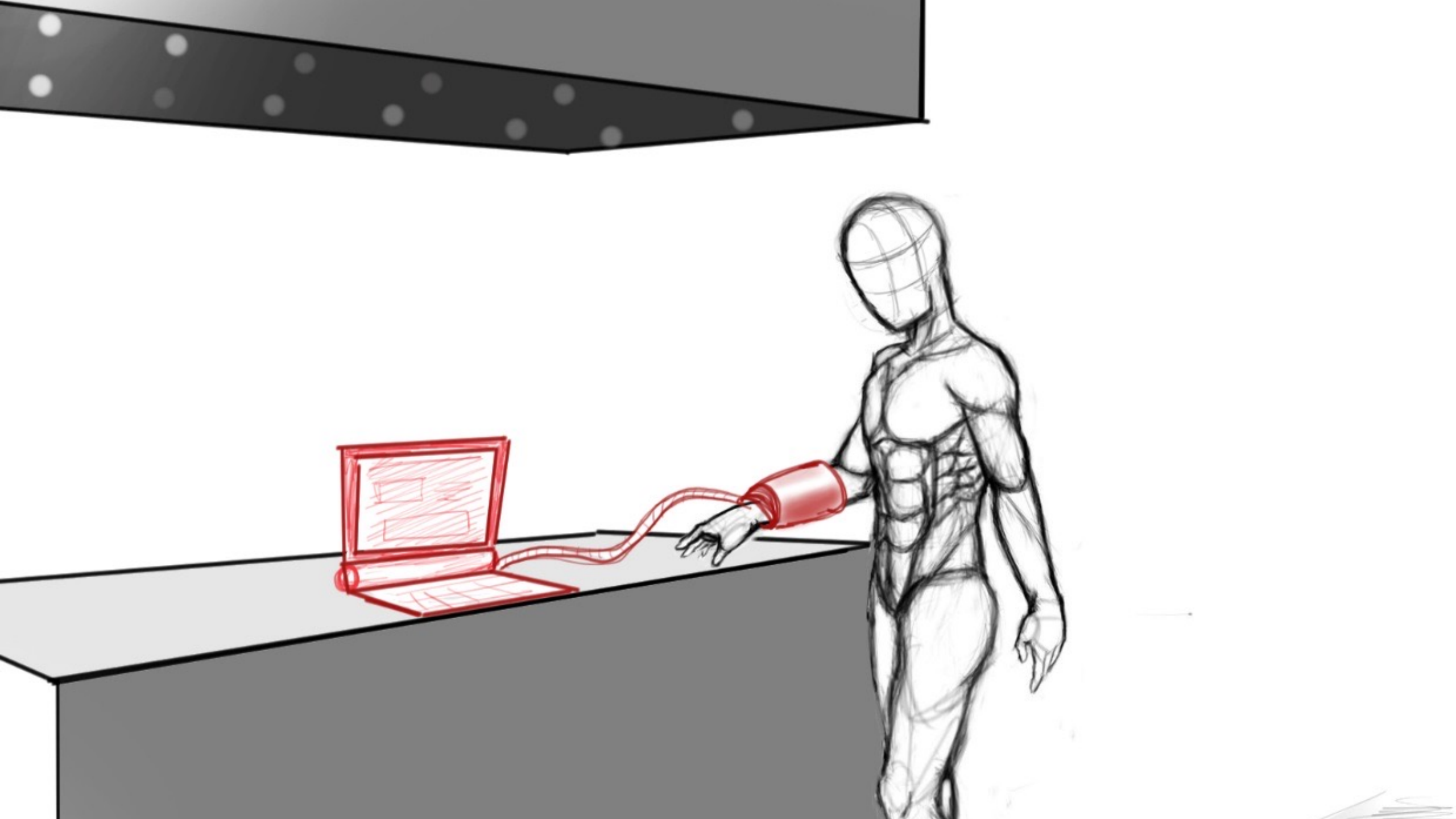
Inside, Around and Beyond

Ramesh Raskar
Associate Professor
MIT Media Lab



Can you see
around corners ?





MIT Camera Culture Grp

Summer course: tiny.cc/mitcourse

People:

Head: Professor Ramesh Raskar
Administrative Staff: Margaret Church

Head of Innovation and New Ventures:
John Werner

Research Staff
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Post-Doctoral Researchers
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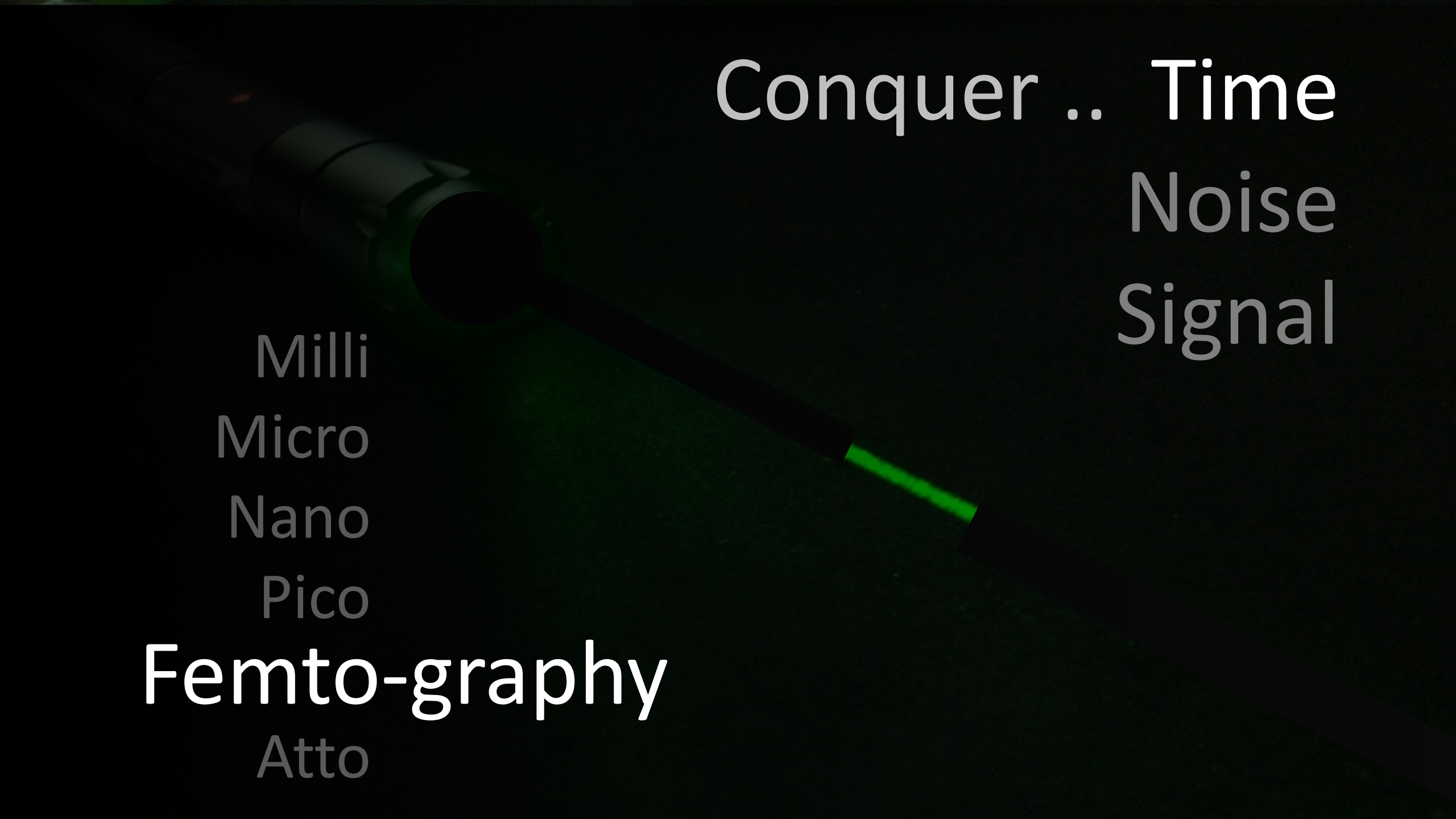
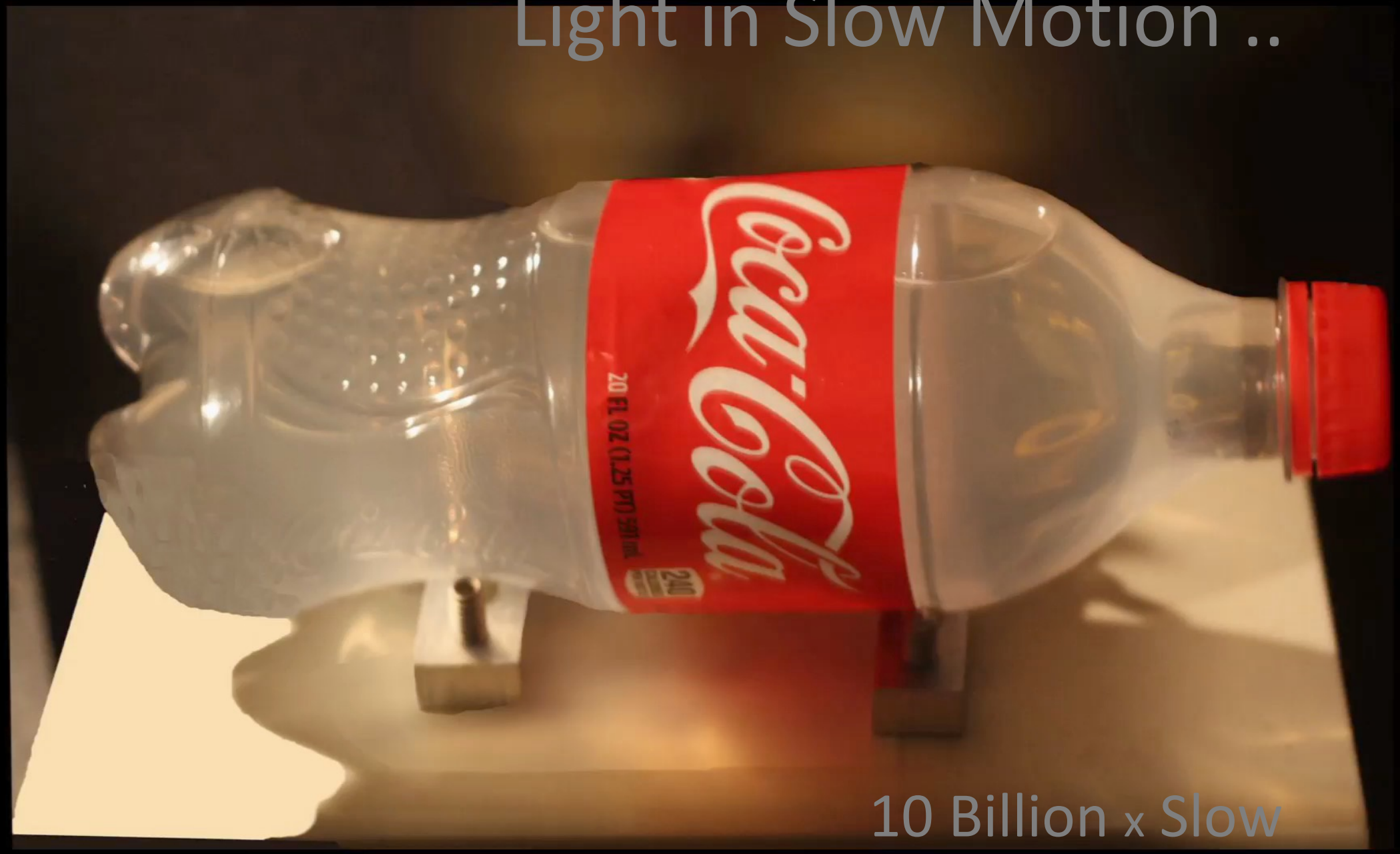
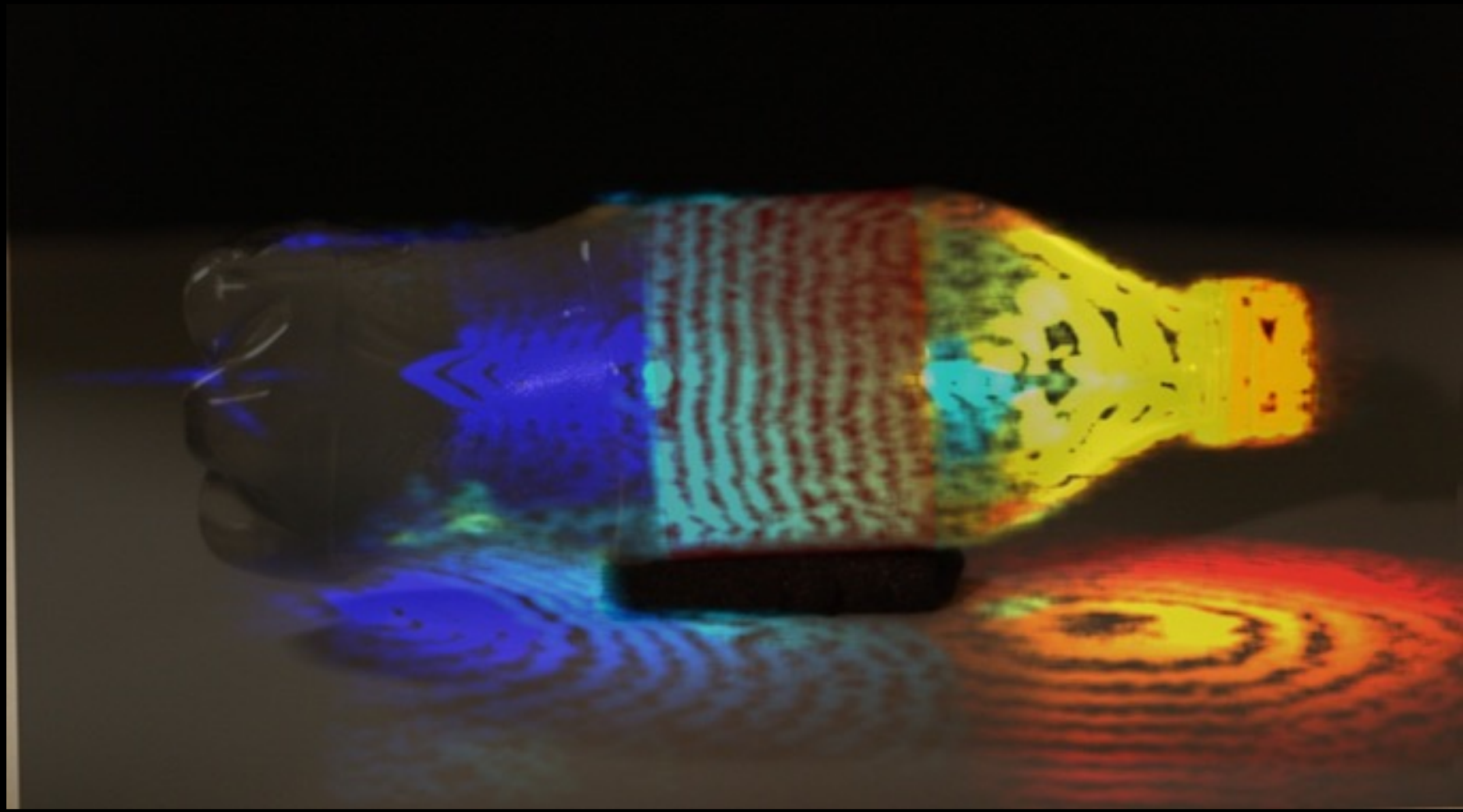
Visiting Researchers & Students
In Kyu Park, Eduardo Bayro-Corrochano, Mingjie Zhang, Yun Zhang, Jamie Schiel

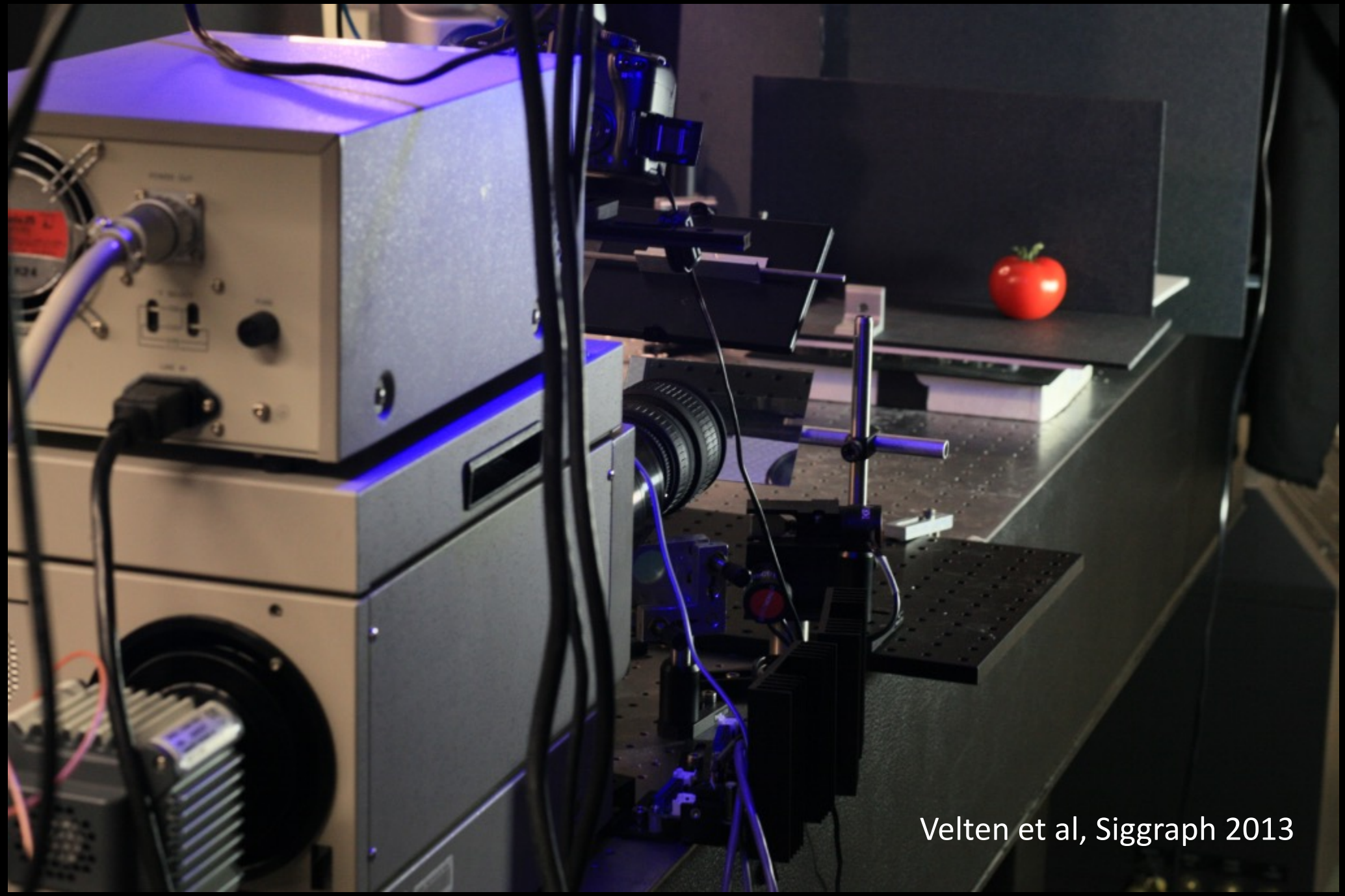

Conquer .. Time
Milli
Micro
Nano
Pico
Femto
Atto


Conquer .. Time
Noise
Signal
Milli
Micro
Nano
Pico
Femto-graphy
Atto

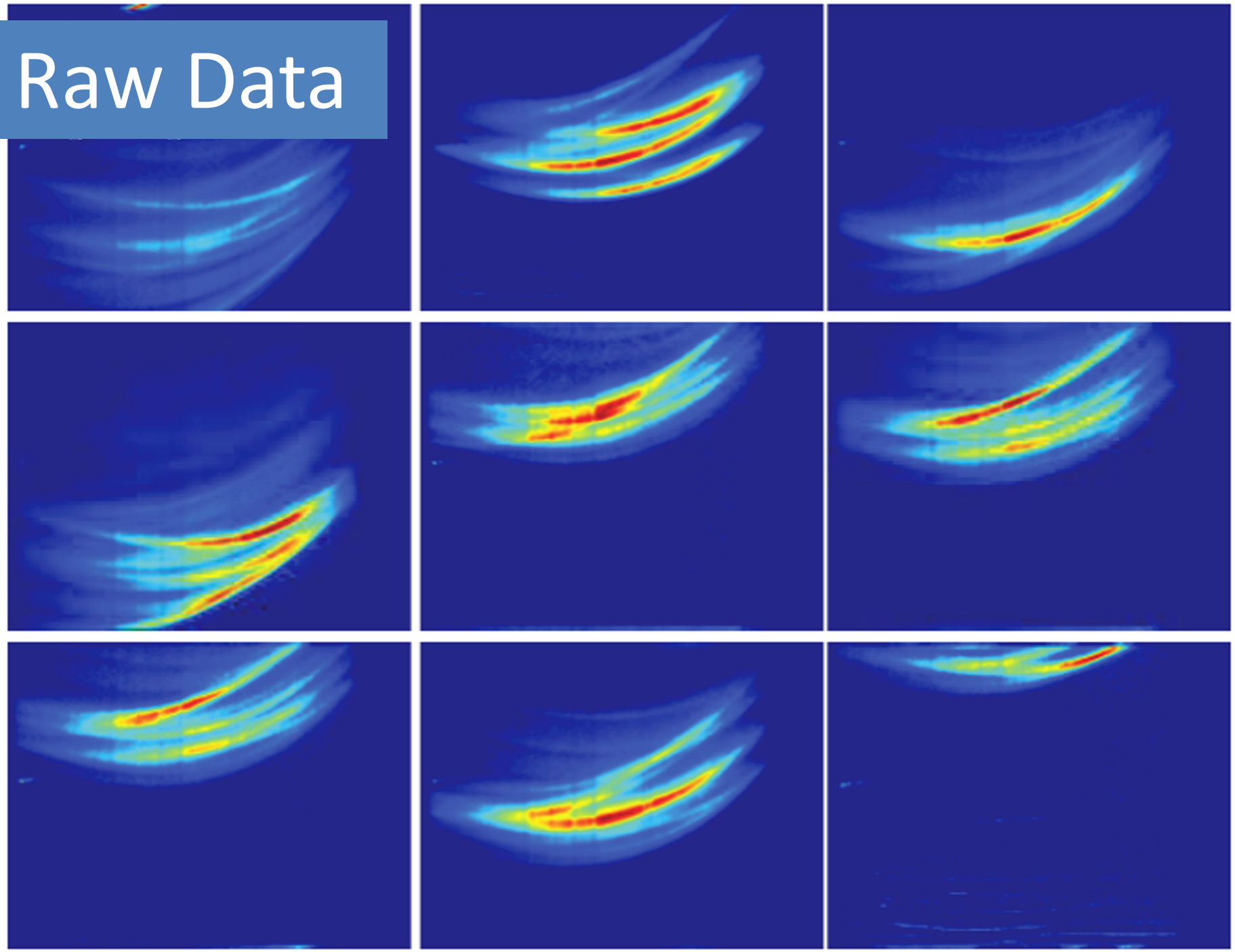
Light in Slow Motion ..

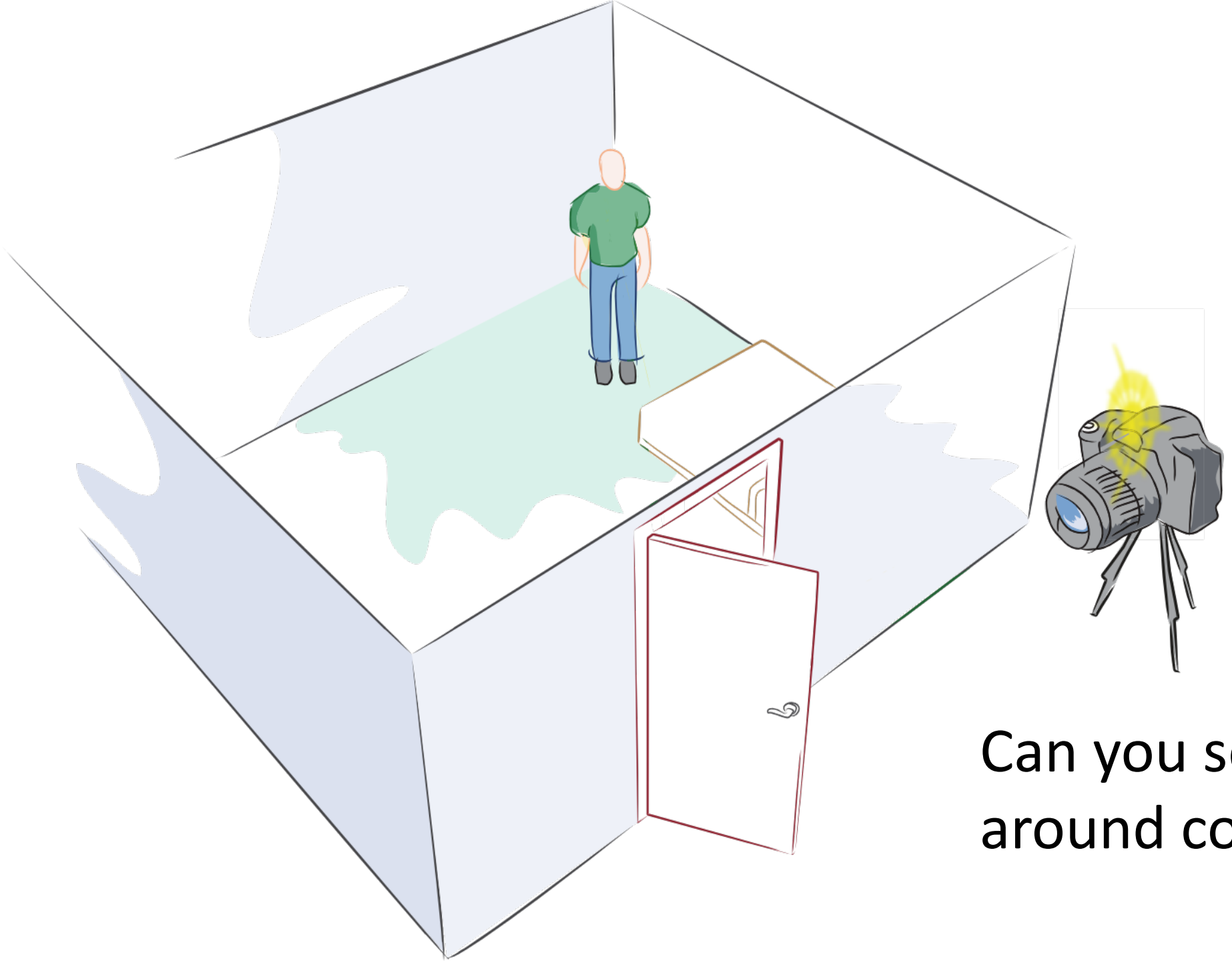





Velten et al, Siggraph 2013

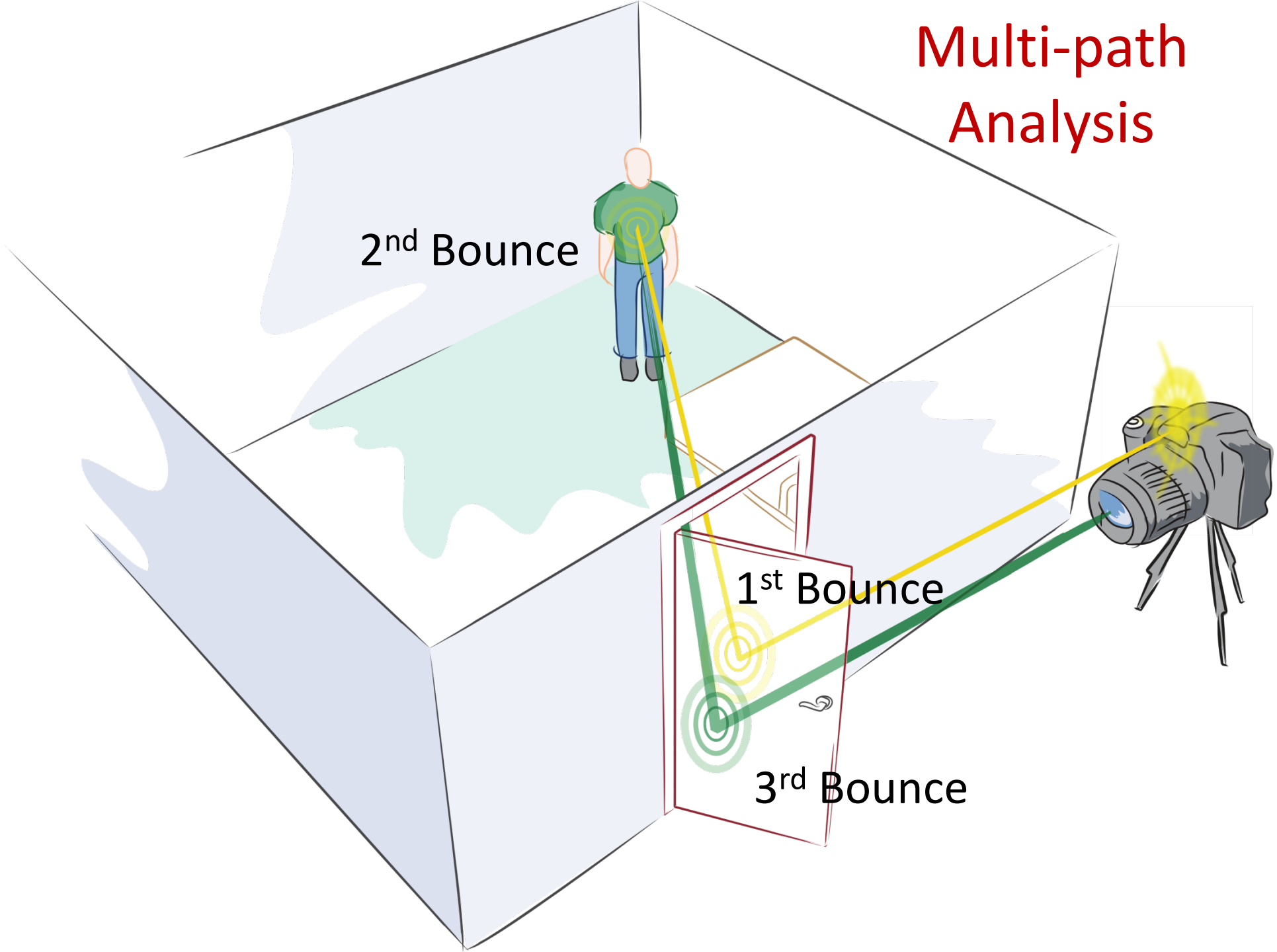
Raw Data

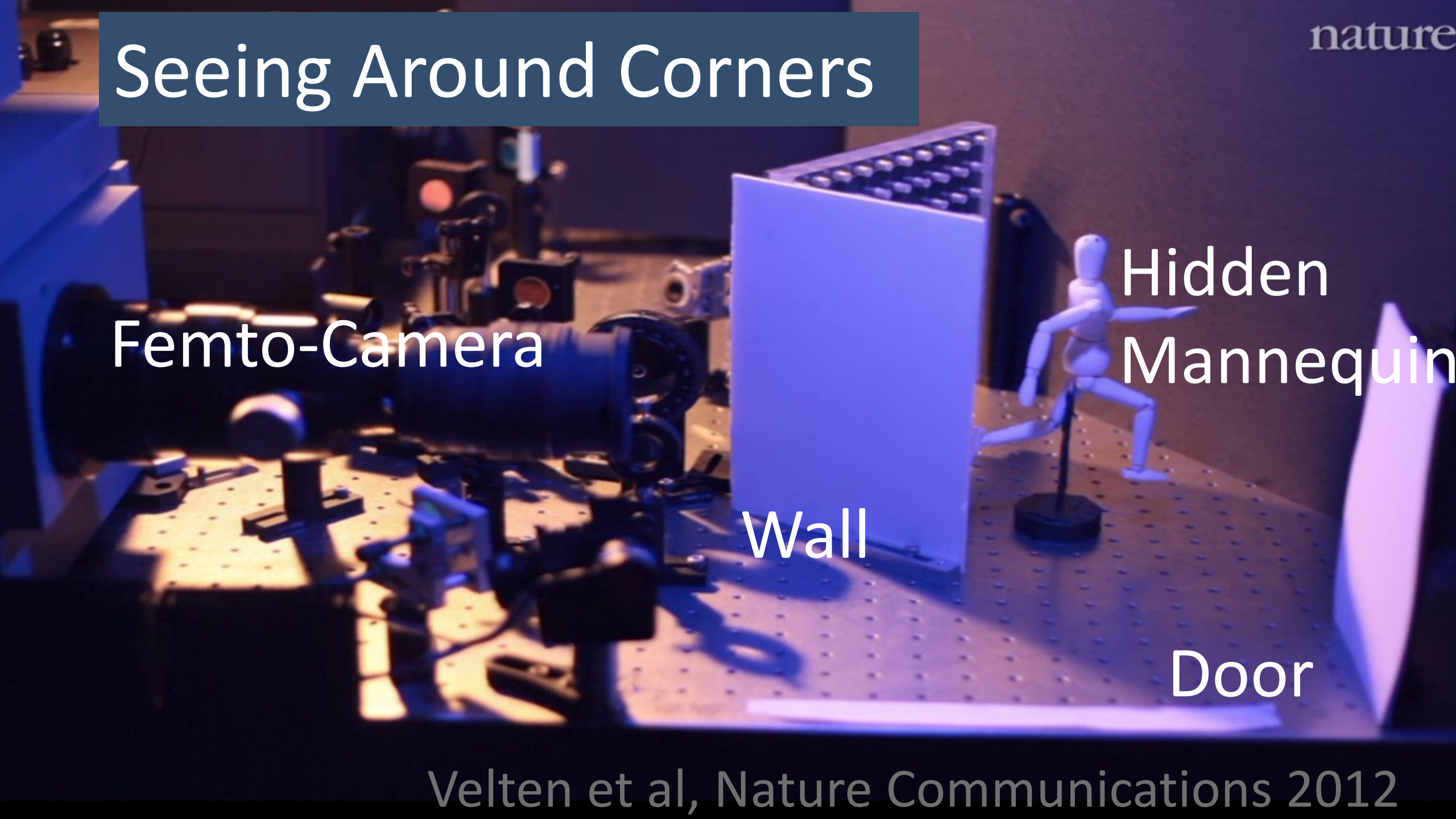


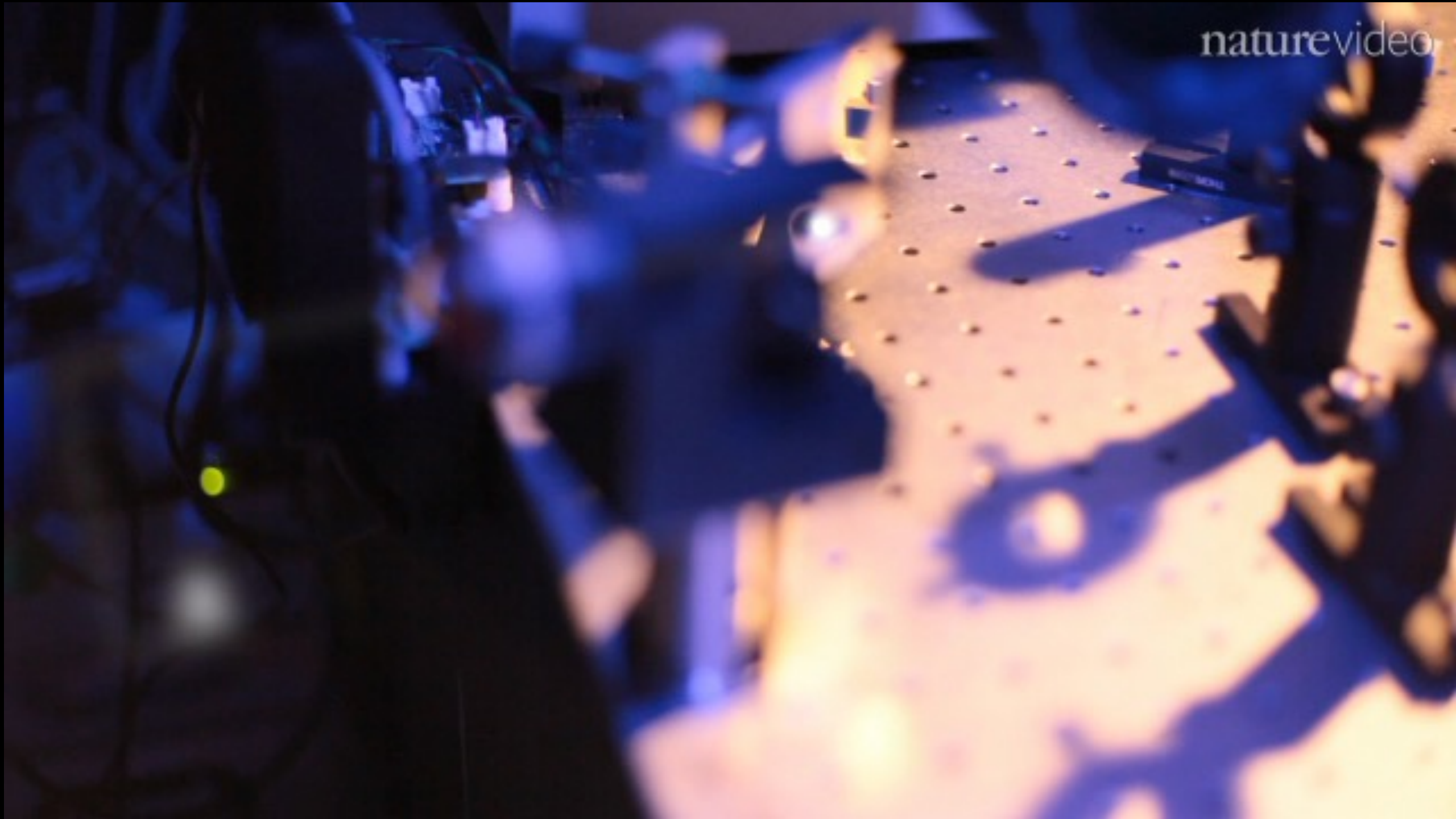


Can you see
around corners ?

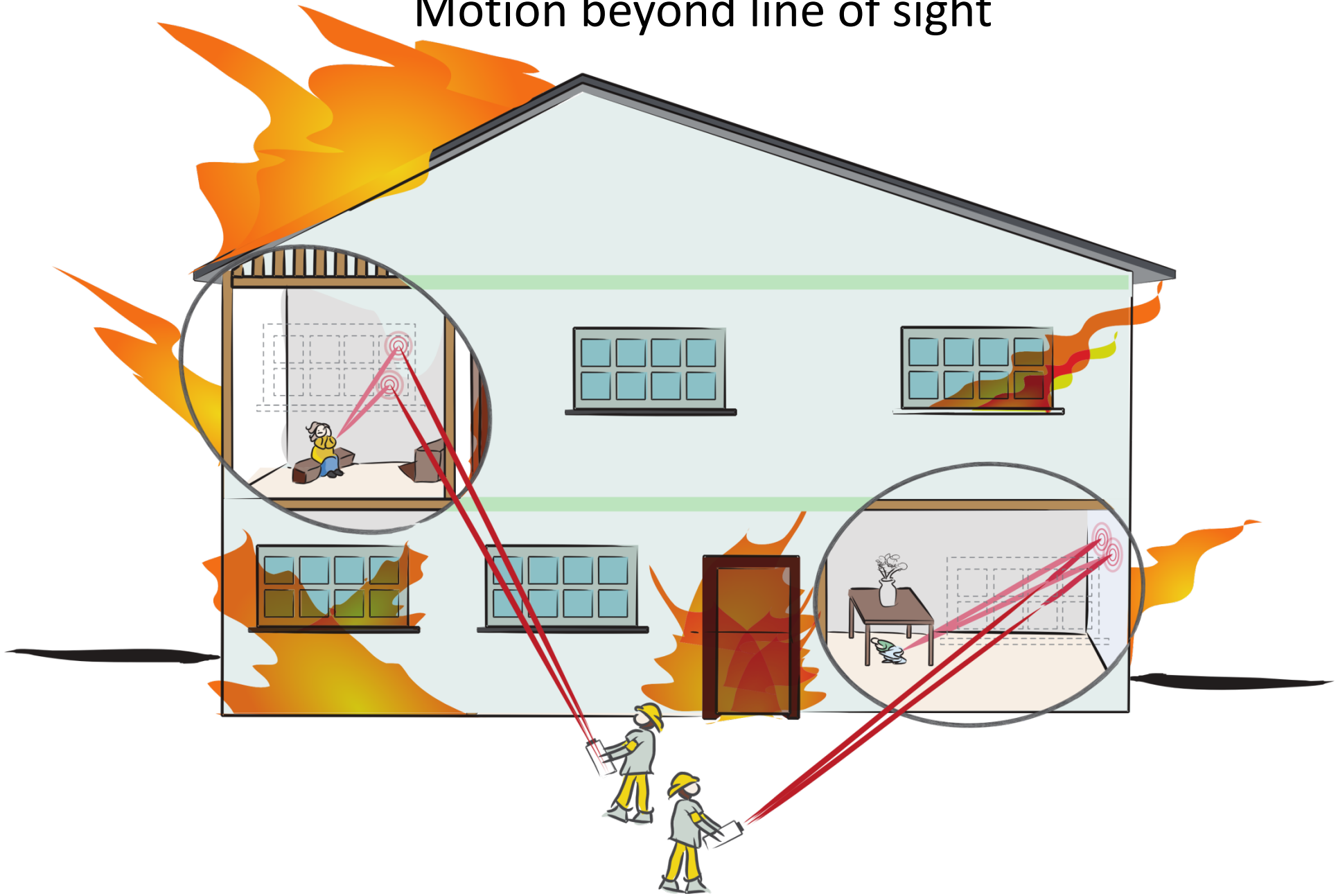
Multi-path Analysis




Seeing Around Corners
nature
Femto-Camera
Hidden
Mannequin
Wall
Door
Velten et al, Nature Communications 2012

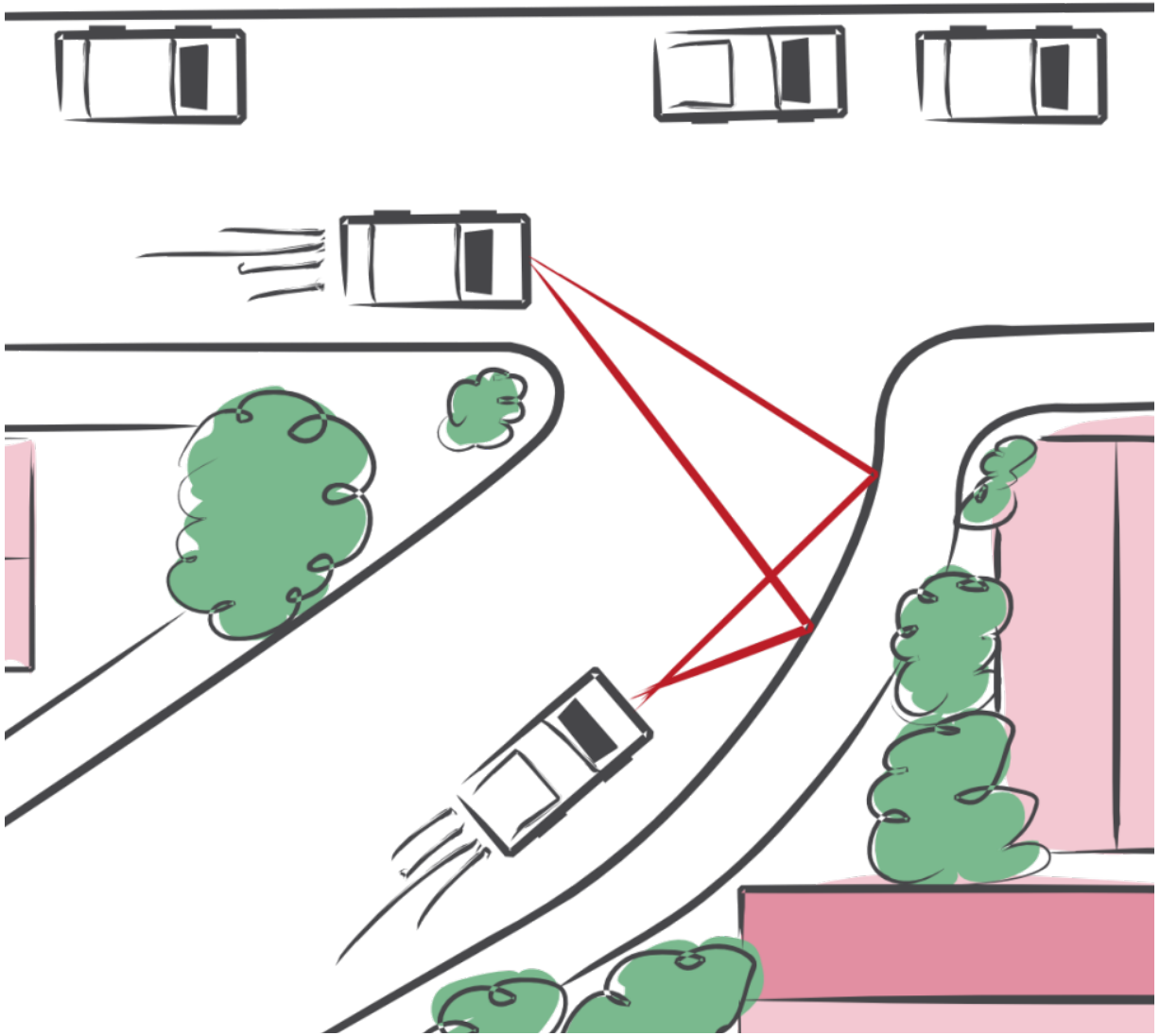

naturevideo

Motion beyond line of sight



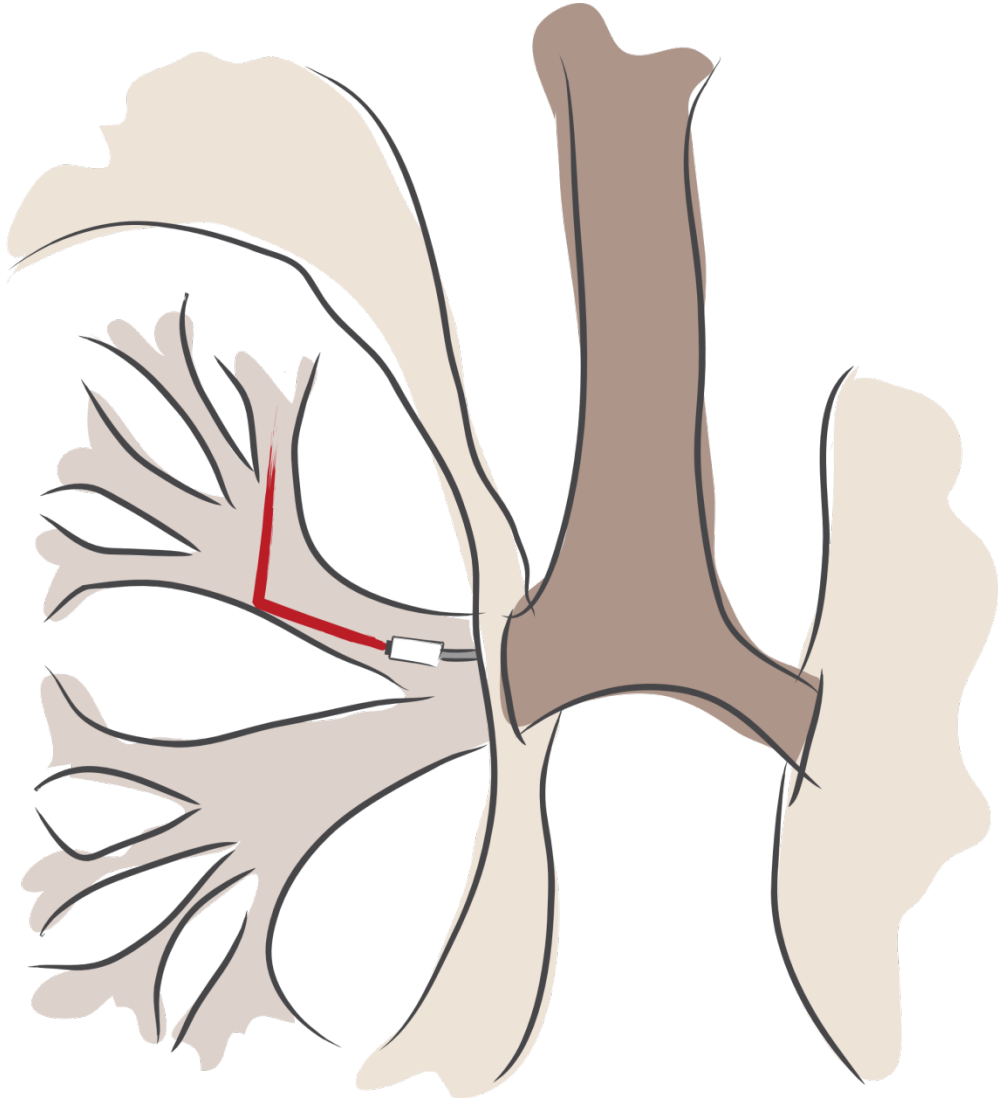
Pandharkar, Velten, Bardagjy, Lawson, Bawendi, Raskar, CVPR 2011

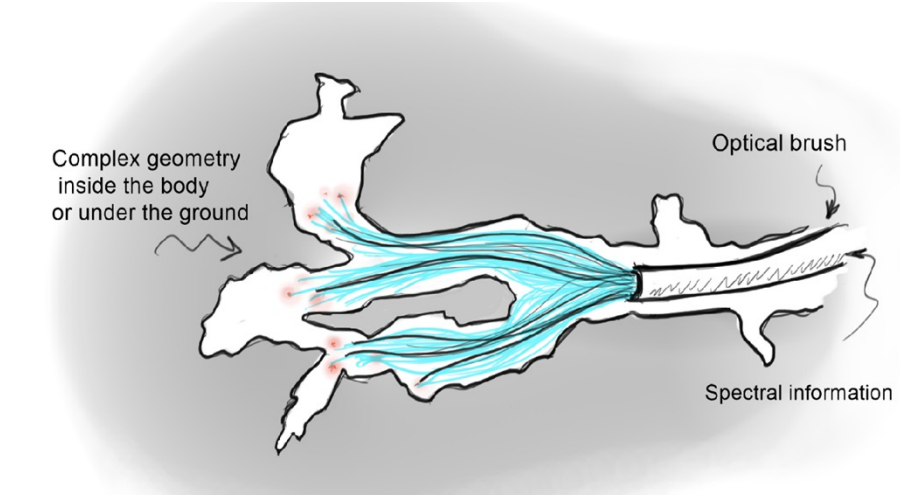
Collision avoidance …



DARPA REVEAL Program $28M

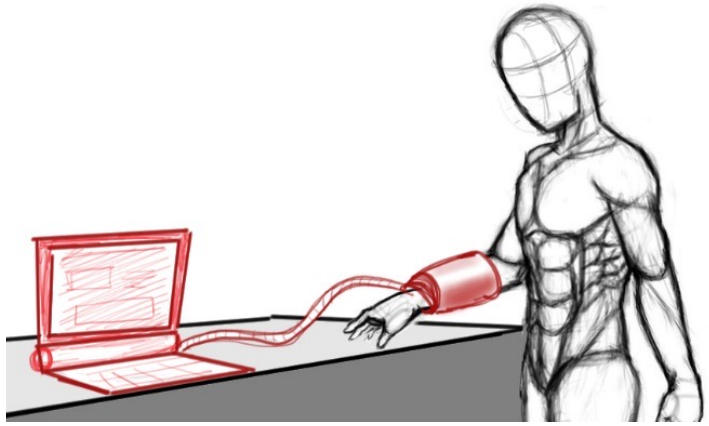
Femto-Photography Endoscope





Optical Jumbled Brush Endoscope

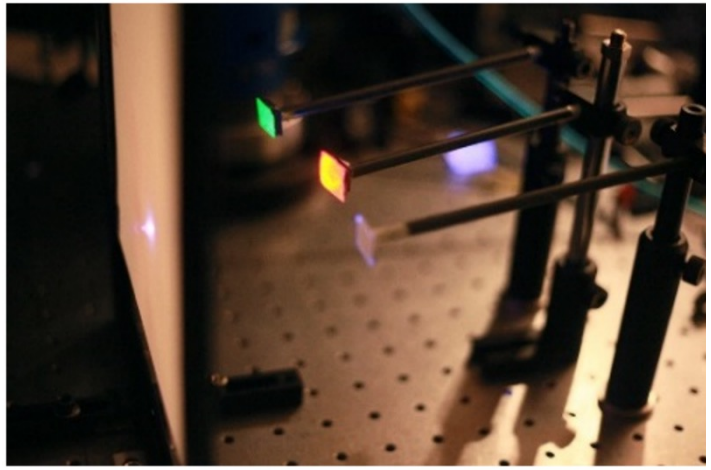
Heshmat, Nature SciRep16



Cellular resolution at 5mm

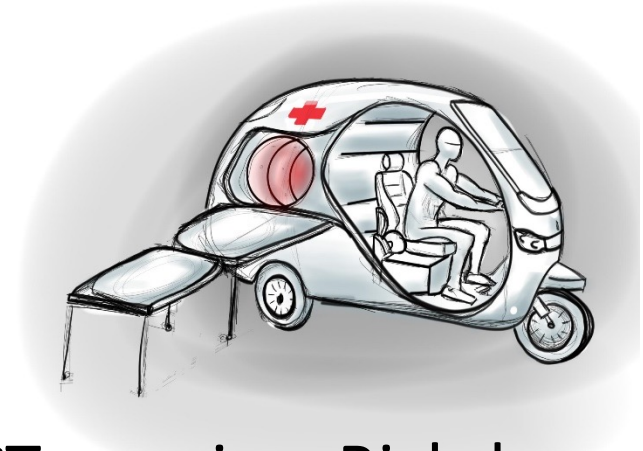
NSF Moonshot

Satat, Nature Comm 15



FLIM Location behind Tissue

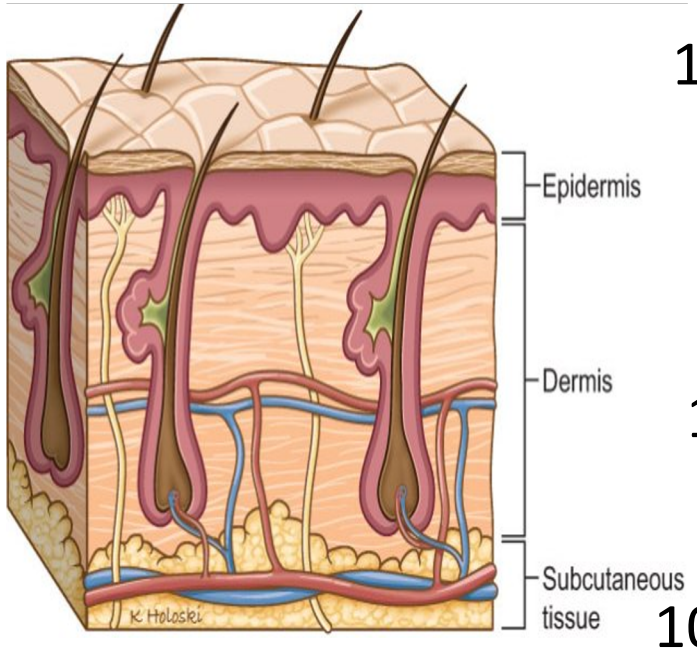
Satat, Nature SciRep 17



CT-scan in a Rickshaw

Kadambi 17

‘All Photon’ Imaging for Tissues



Surface

10 um

100 um

1 mm

10 mm

100 mm

Depth

● Confocal

2/3 photon

OCT

Ballistic Limit

Computational Photoscatterography

Photo-acoustic Limit

1 um

10 um

100 um

1mm

Spatial Resolution

Carnegie Mellon University

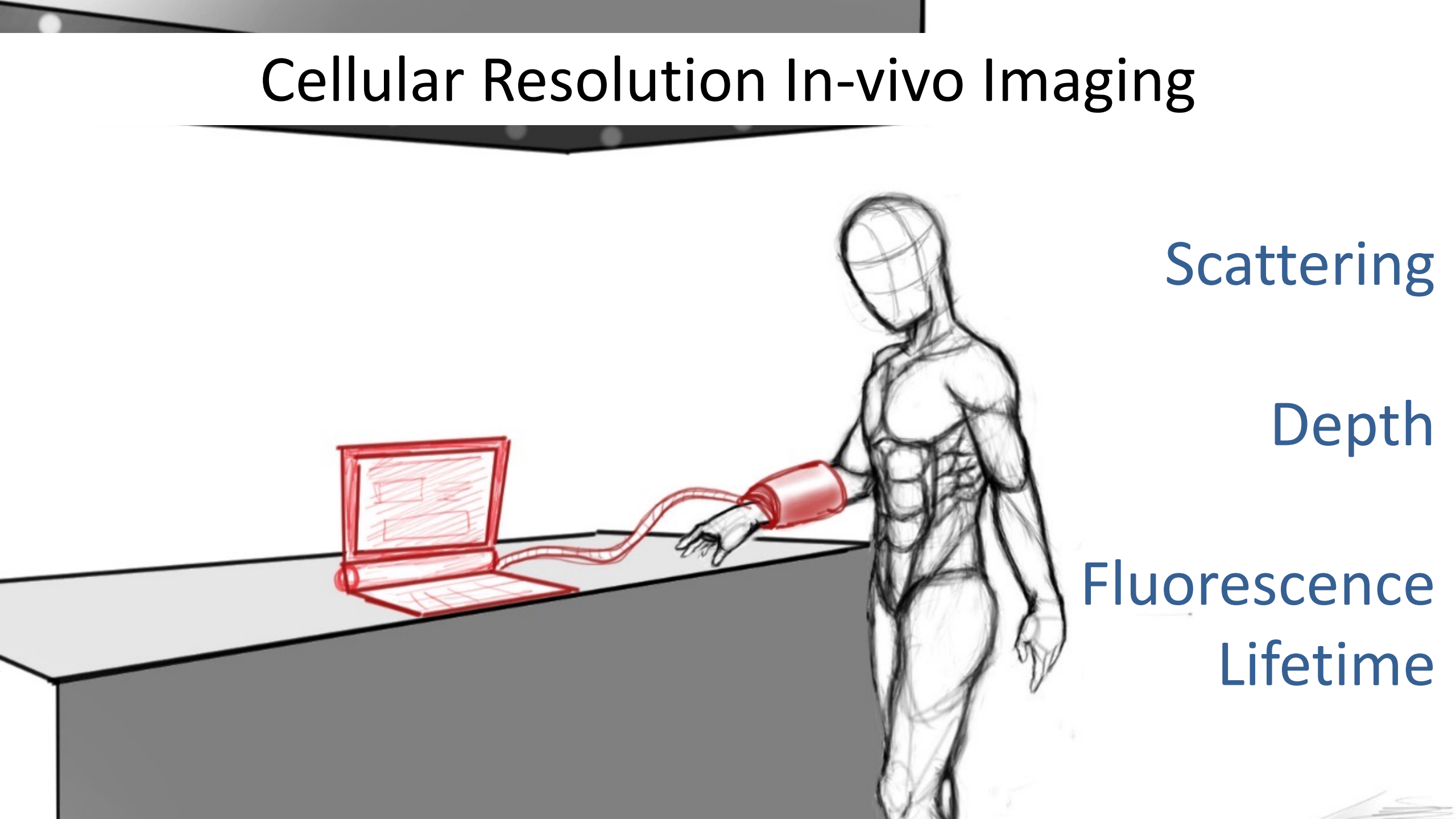
Massachusetts Institute of Technology

HARVARD UNIVERSITY

CORNELL UNIVERSITY FOUNDED A.D. 1865

NSF Expedition 2017-2022

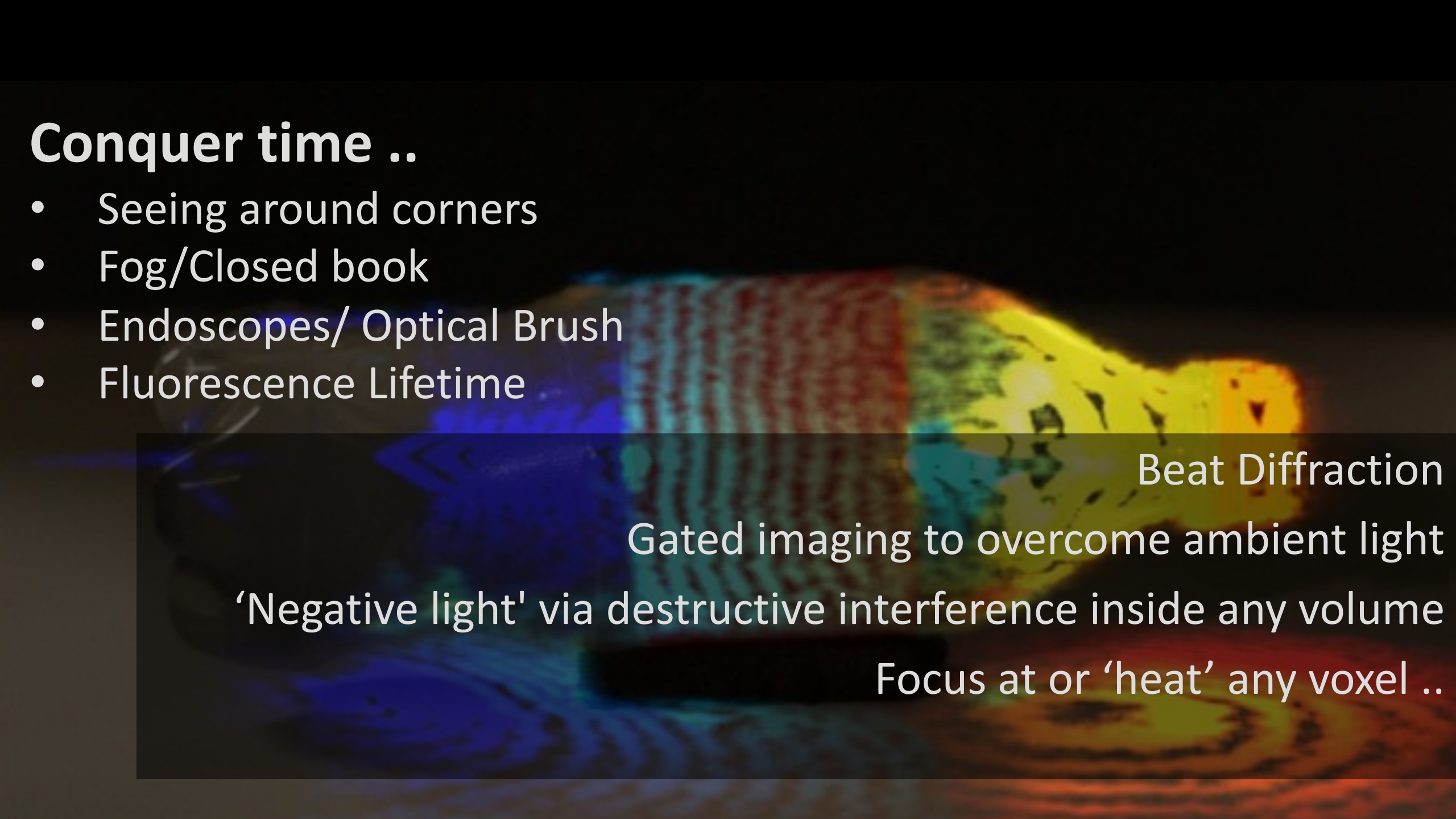
Cellular Resolution In-vivo Imaging



Scattering

Depth

Fluorescence Lifetime



Conquer time ..

- Seeing around corners
- Fog/Closed book
- Endoscopes/ Optical Brush
- Fluorescence Lifetime

Beat Diffraction

Gated imaging to overcome ambient light

‘Negative light' via destructive interference inside any volume

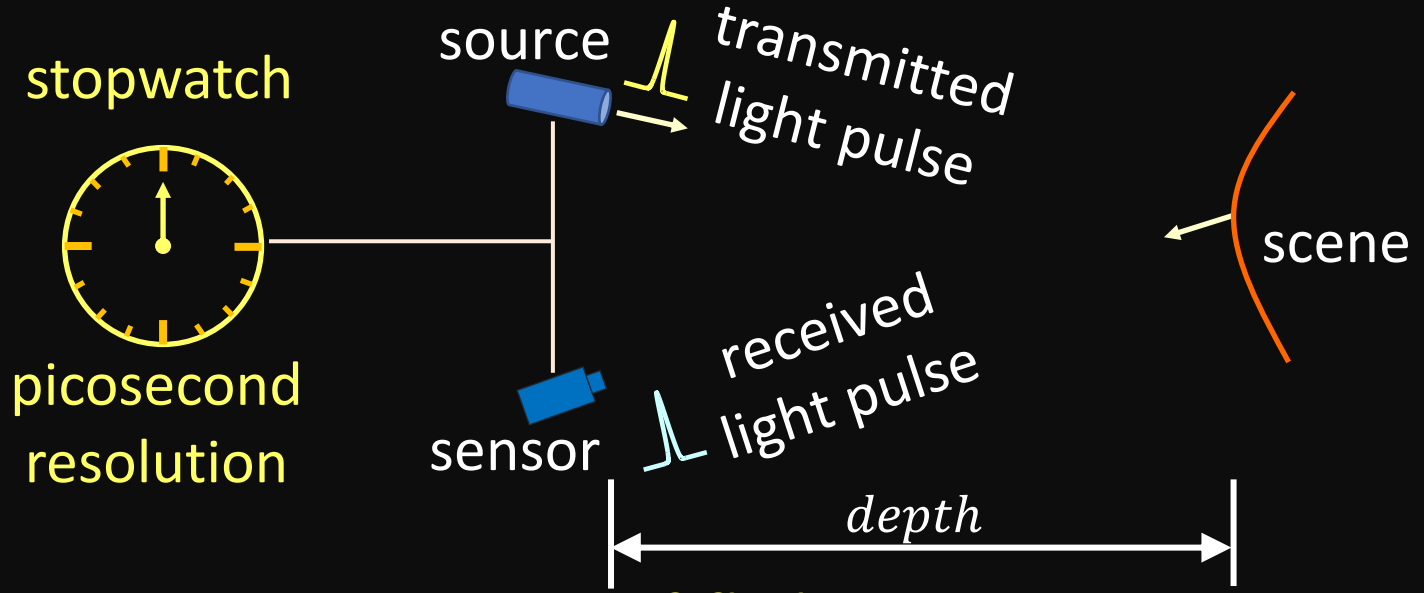
Focus at or ‘heat’ any voxel ..

SPAD

Single-Photon Camera: 3D Imaging

single photon

(single-photon sensor)



Time-of-flight 3D Camera

$$2 \times depth = c \times \tau$$

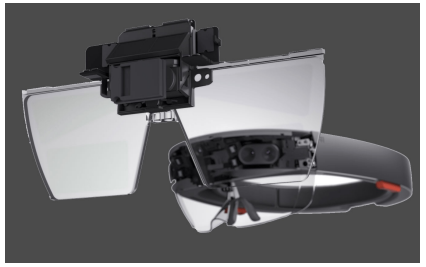
speed of light

time-of-flight (round trip)

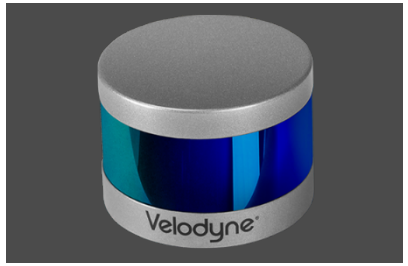
Time-of-Flight 3D Cameras

Commercial Devices

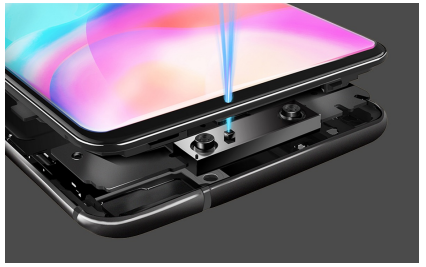
Kinect 3D Camera



AR/VR Headsets



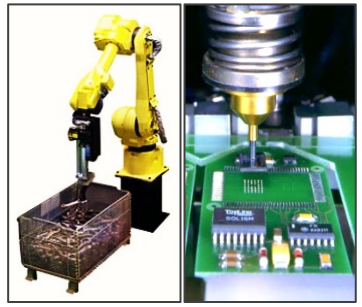
LiDAR



Smartphones

Applications

autonomous cars



industrial automation

augmented reality

extreme robotics

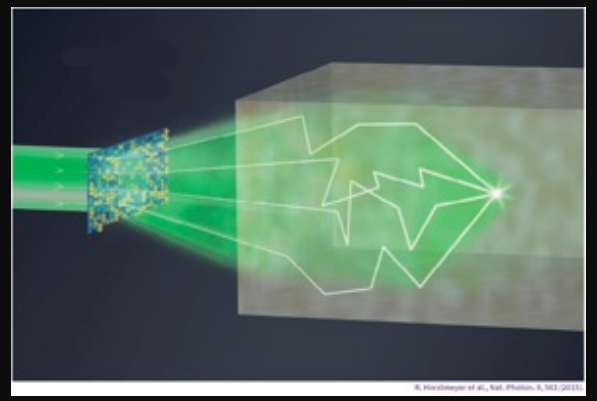
Microsoft Kinect v4, Hololens 2 (www.microsoft.com)
Velodyne VLP-16 velodynelidar.com
TOF Sensors https://wccftech.com/apple-tof-sensor-2019-android-flagships-getting-support/
www.magicleap.com/, http://www.upi.com/

Single-Photon Cameras: Active Imaging

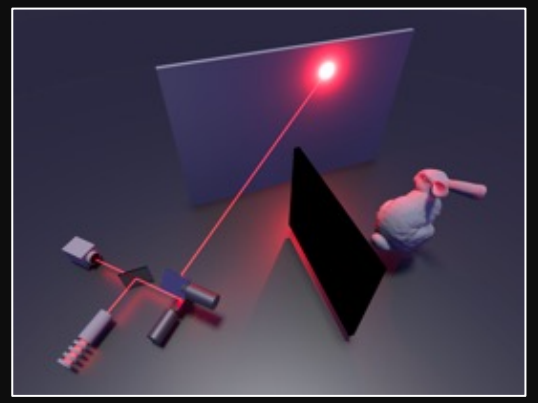
3D Imaging

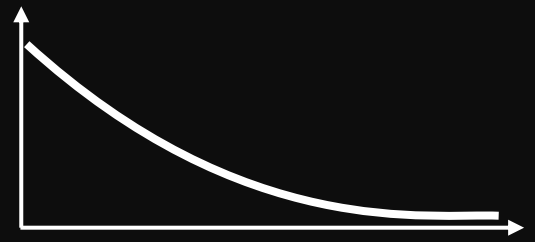
Fluorescence Microscopy

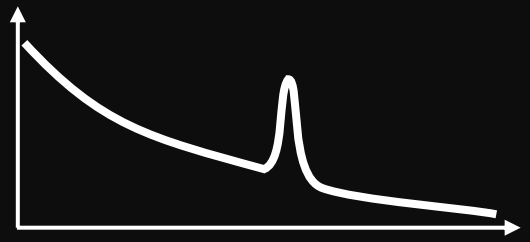
Scattering media

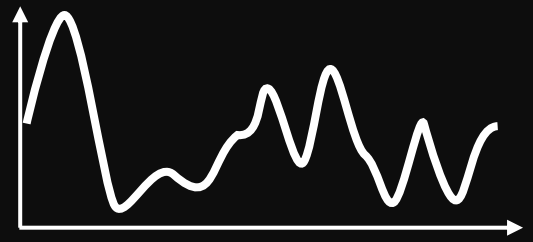


NLOS Imaging







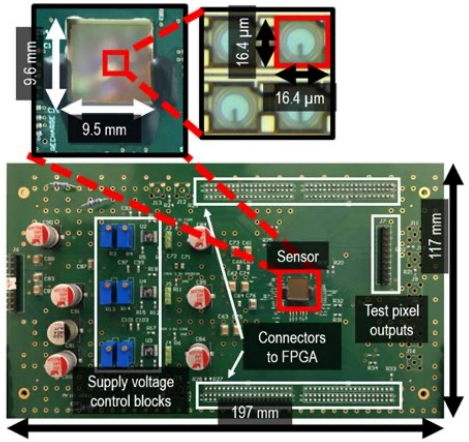


Asynchronous acquisition for other active imaging applications

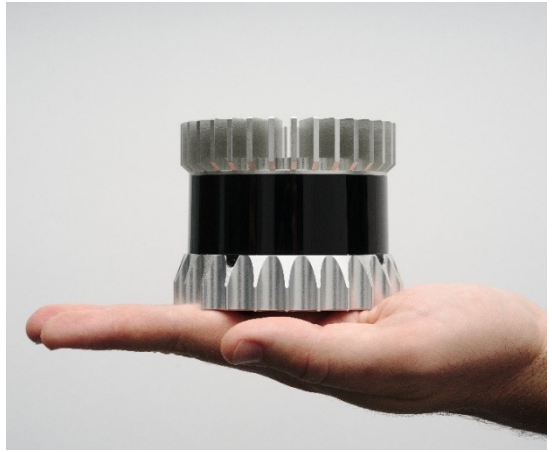
images courtesy: http://www.noao.edu/, http://www.futurahma.it/ , http://www.computationalimaging.org/, http://www.upi.com/ , www.openmv.io

Single-Photon Cameras

MPD



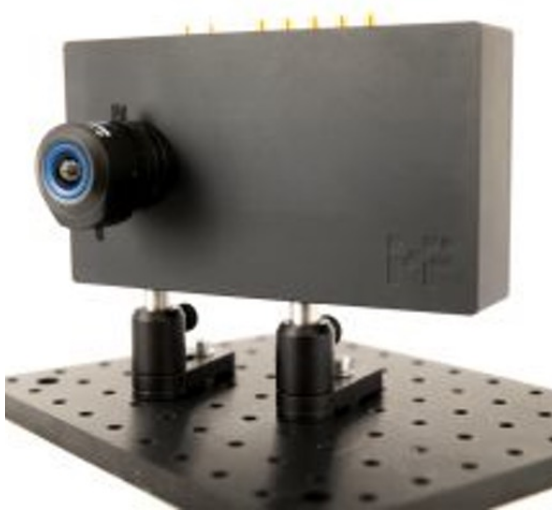
SwissSPAD2 EPFL



Ouster LiDAR

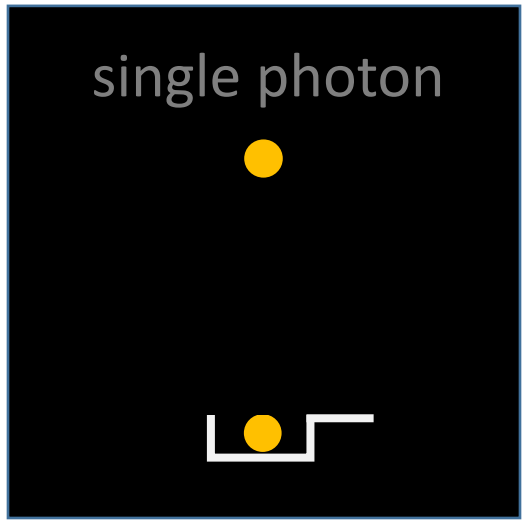
Voxtel, Inc.

Gigajot



PhotonForce

Single-Photon Cameras: Attractive Features



Extreme Sensitivity

25°C

Room Temperature Operation

CMOS compatible
Low cost, Compact

SPAD for Passive Imaging

Low Light

High Dynamic Range

Fast Motion

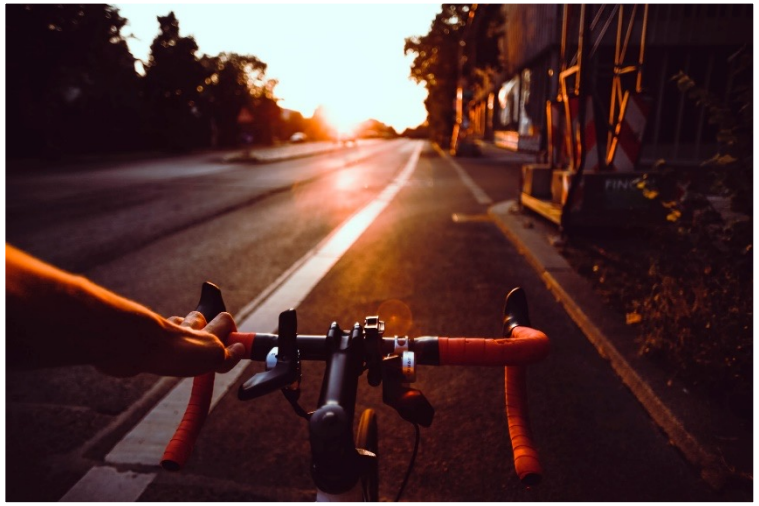
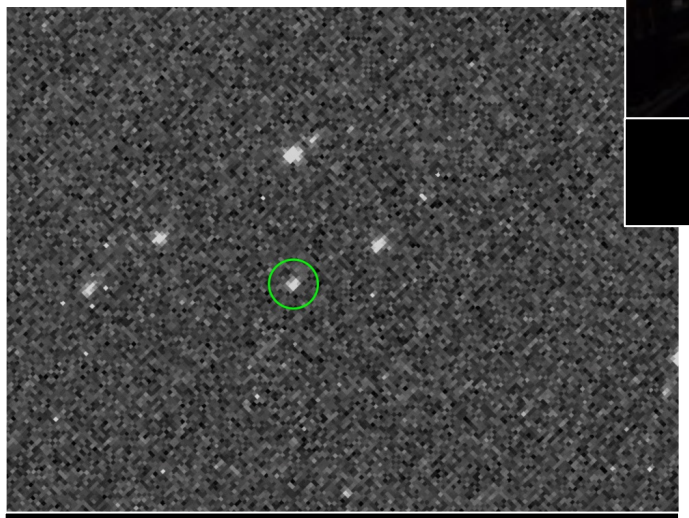


Photo by Mehmet Kürşat Değer, Adam Śmigielski, and Flo Karr on Unsplash

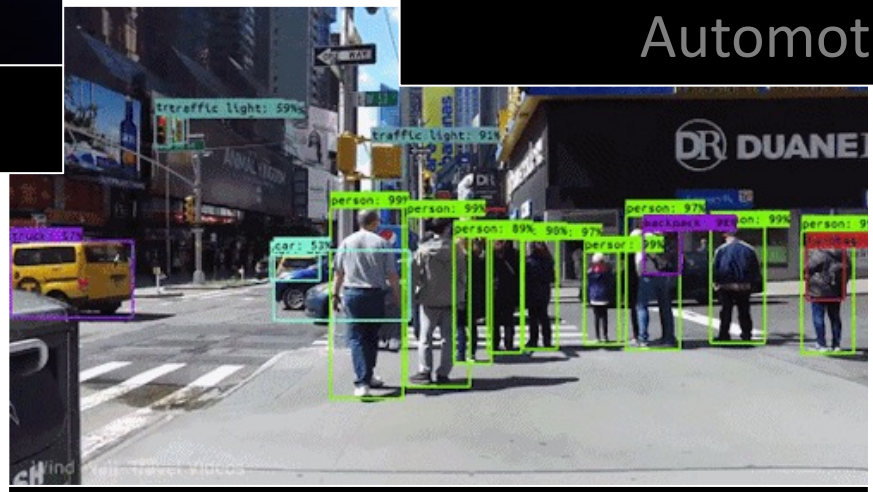
Single-Photon Camera: Limited to the Dark?



Astronomy

Face recognition

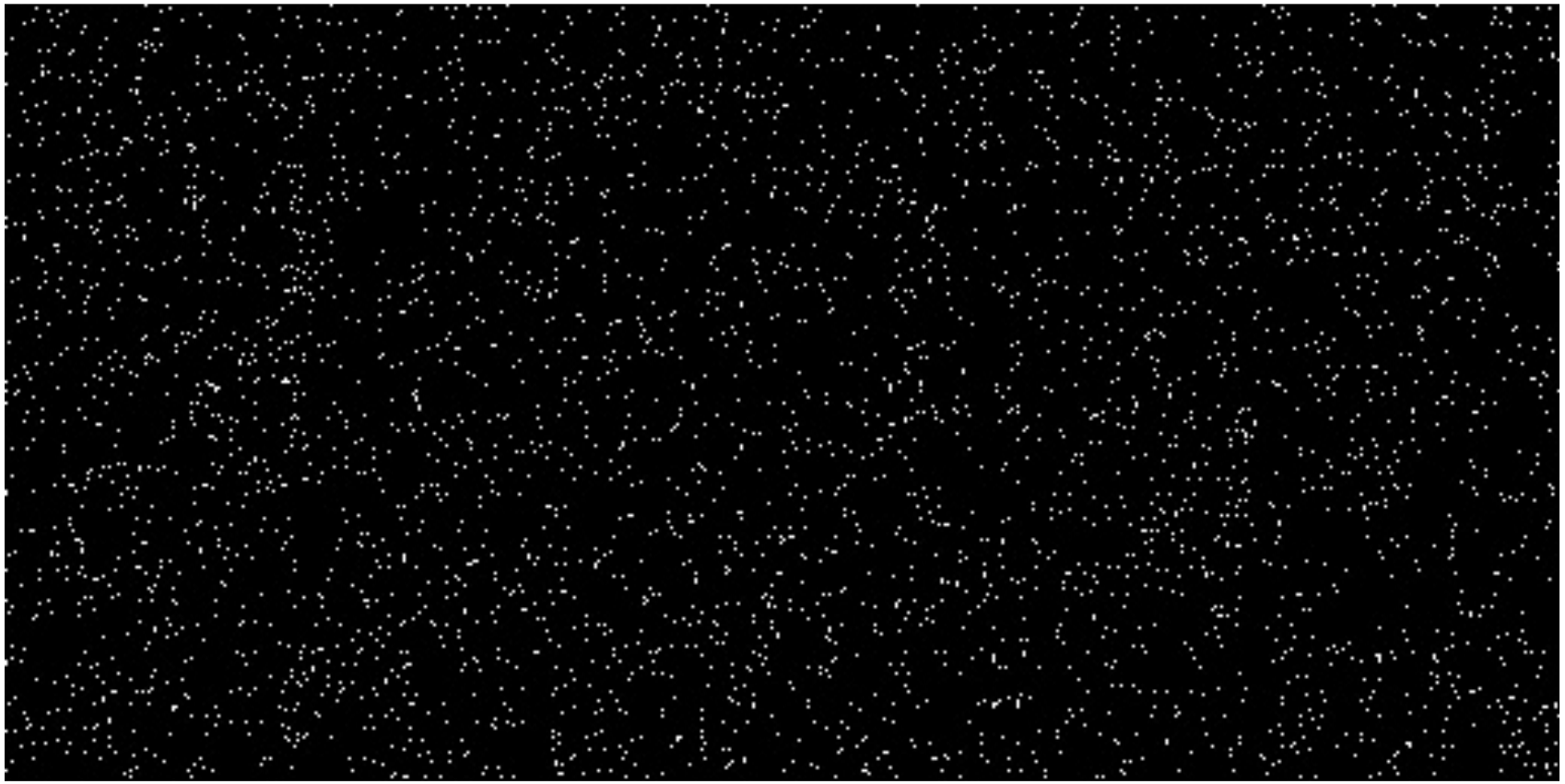
Automotive



Object recognition

Dark → Bright

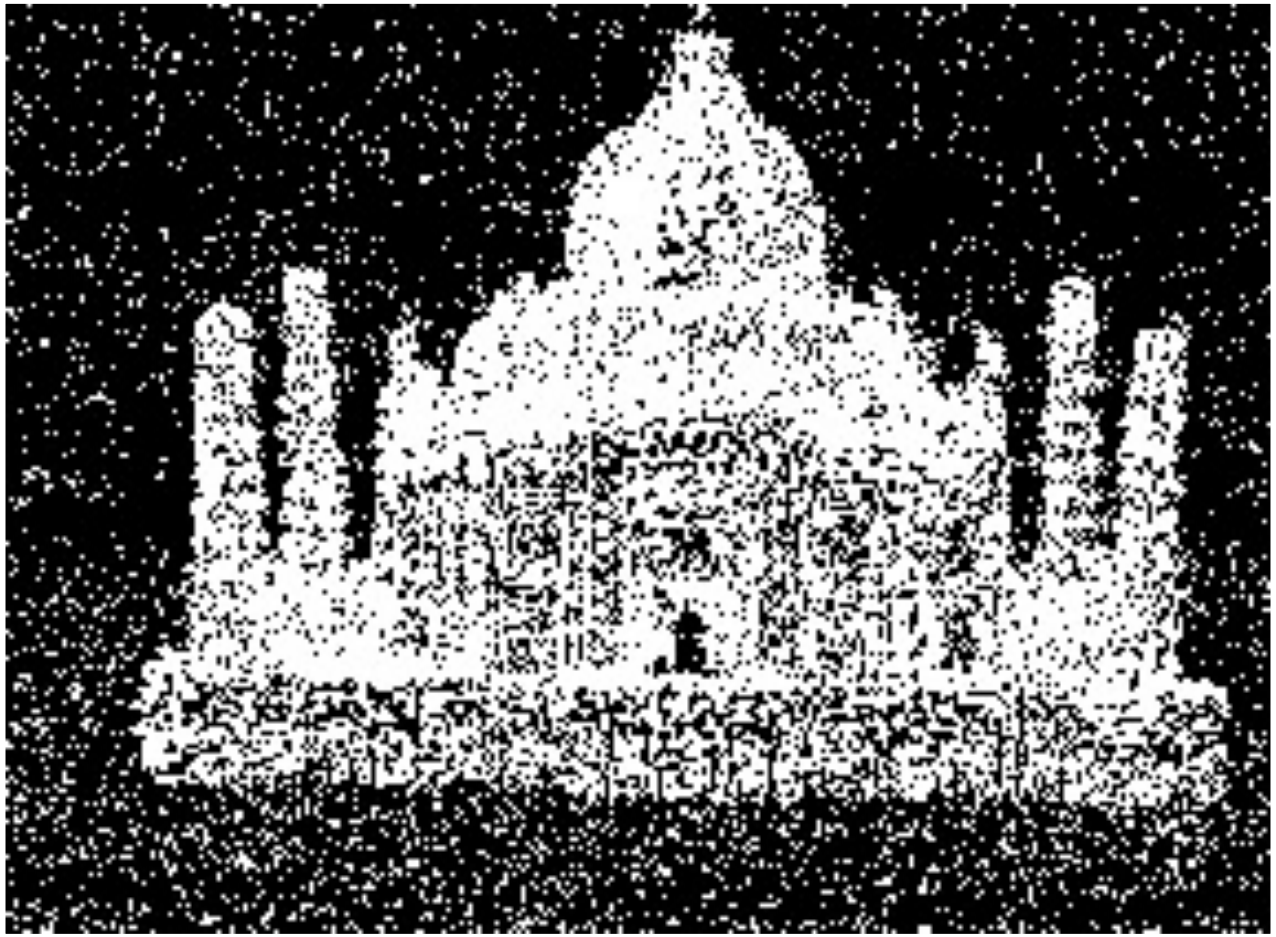
Photography in Ultra Low-Light



0.03 photons-per-pixel per frame (2000 frames)

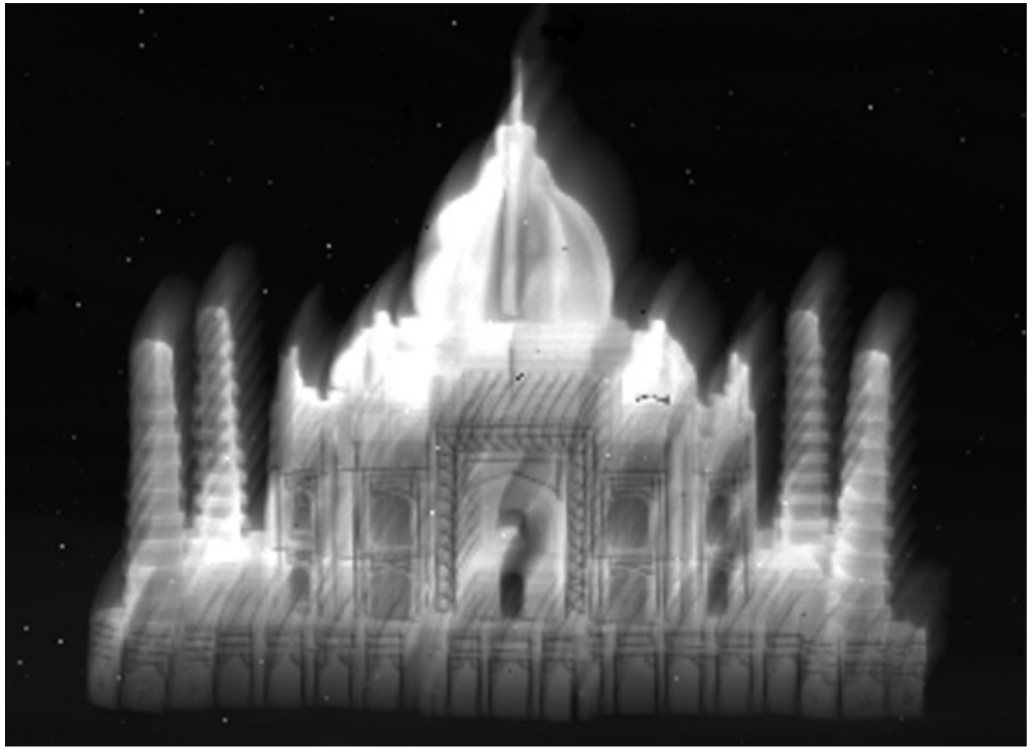
Mohit Gupta
Assistant Professor
UW Madison

Complex Geometry



Complex Geometry

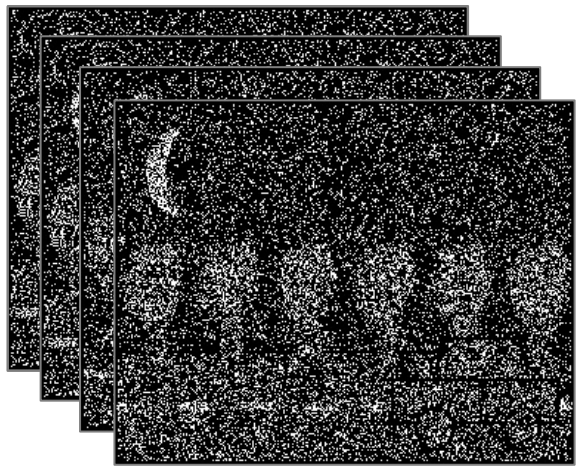
Naive Averaging



With Align & Merge

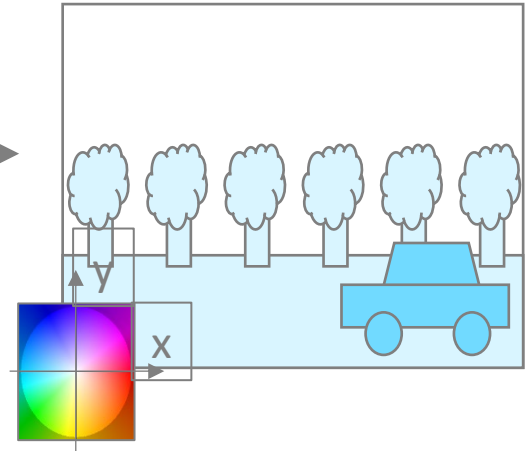
Quanta Burst Photography: Overview

Quanta Burst
(stochastic and binary)



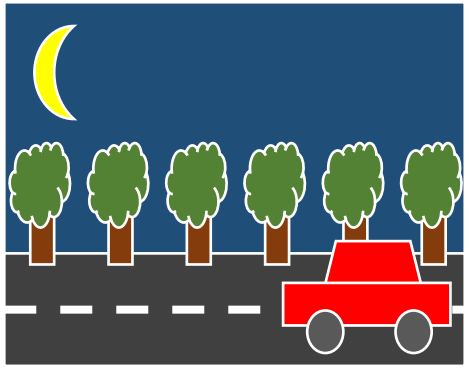
Align

Per-frame Motion



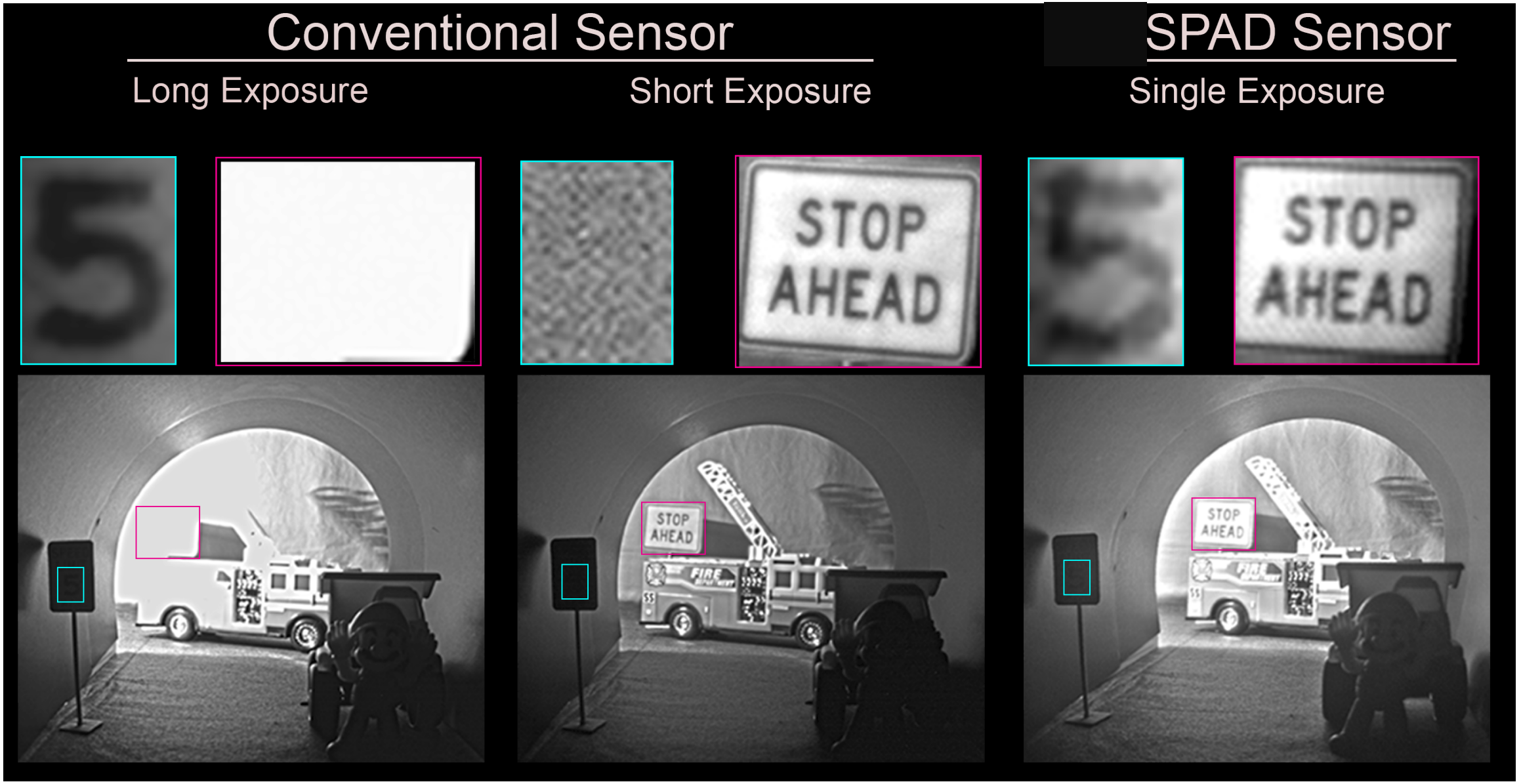
Merge

High-Quality Image



Low blur and noise
High dynamic range

Comparison with Conventional CMOS Sensor



ubicept

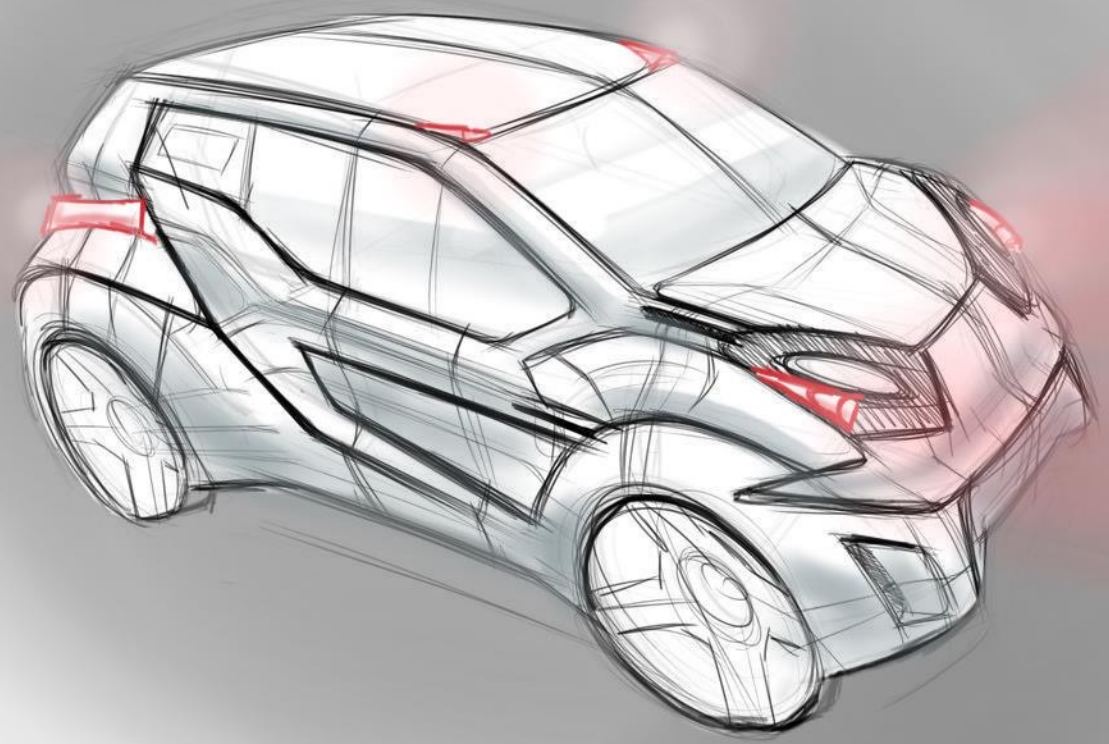
Light has a story

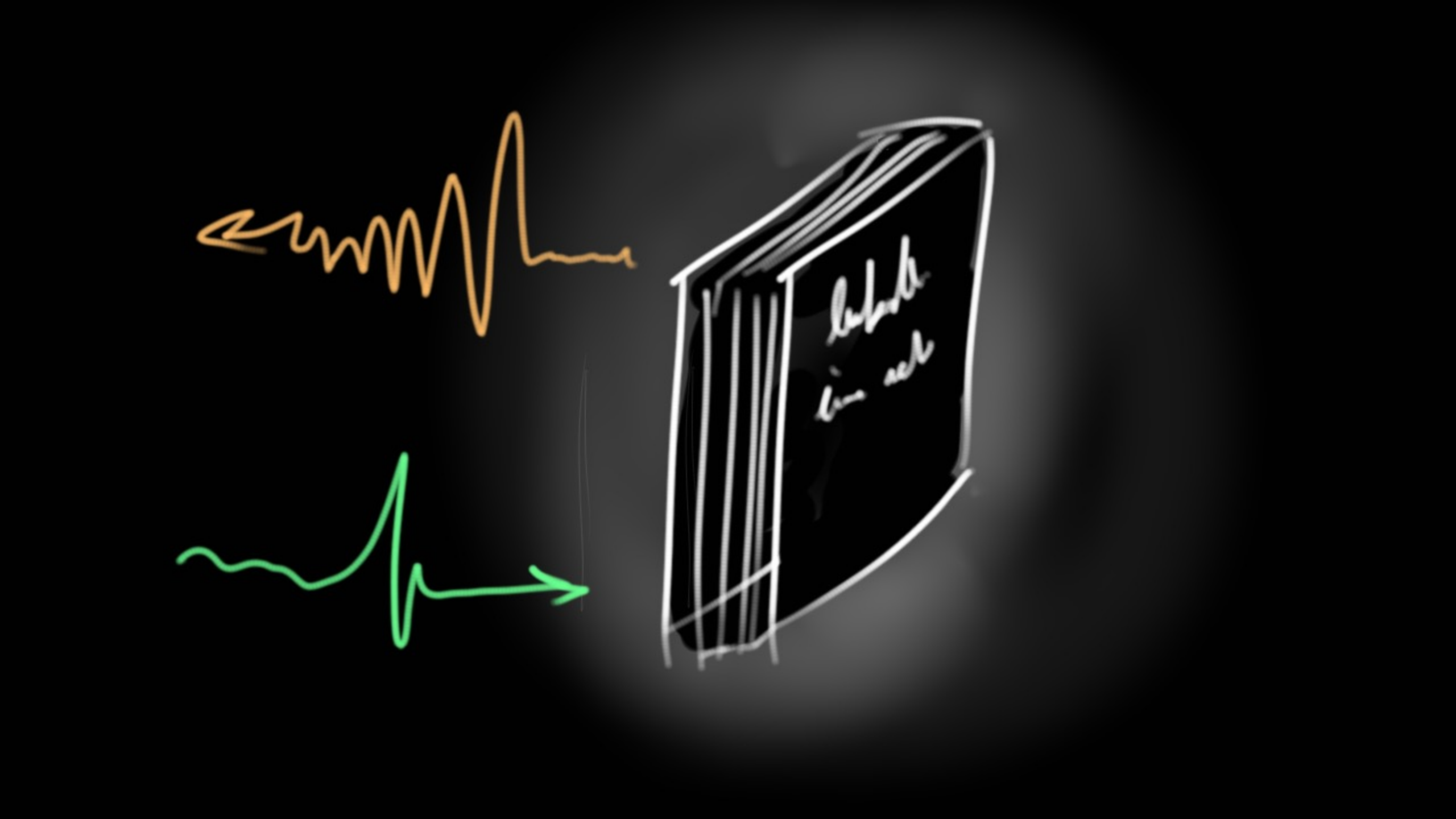
Revolutionary Computer Vision with Single Photon Detectors

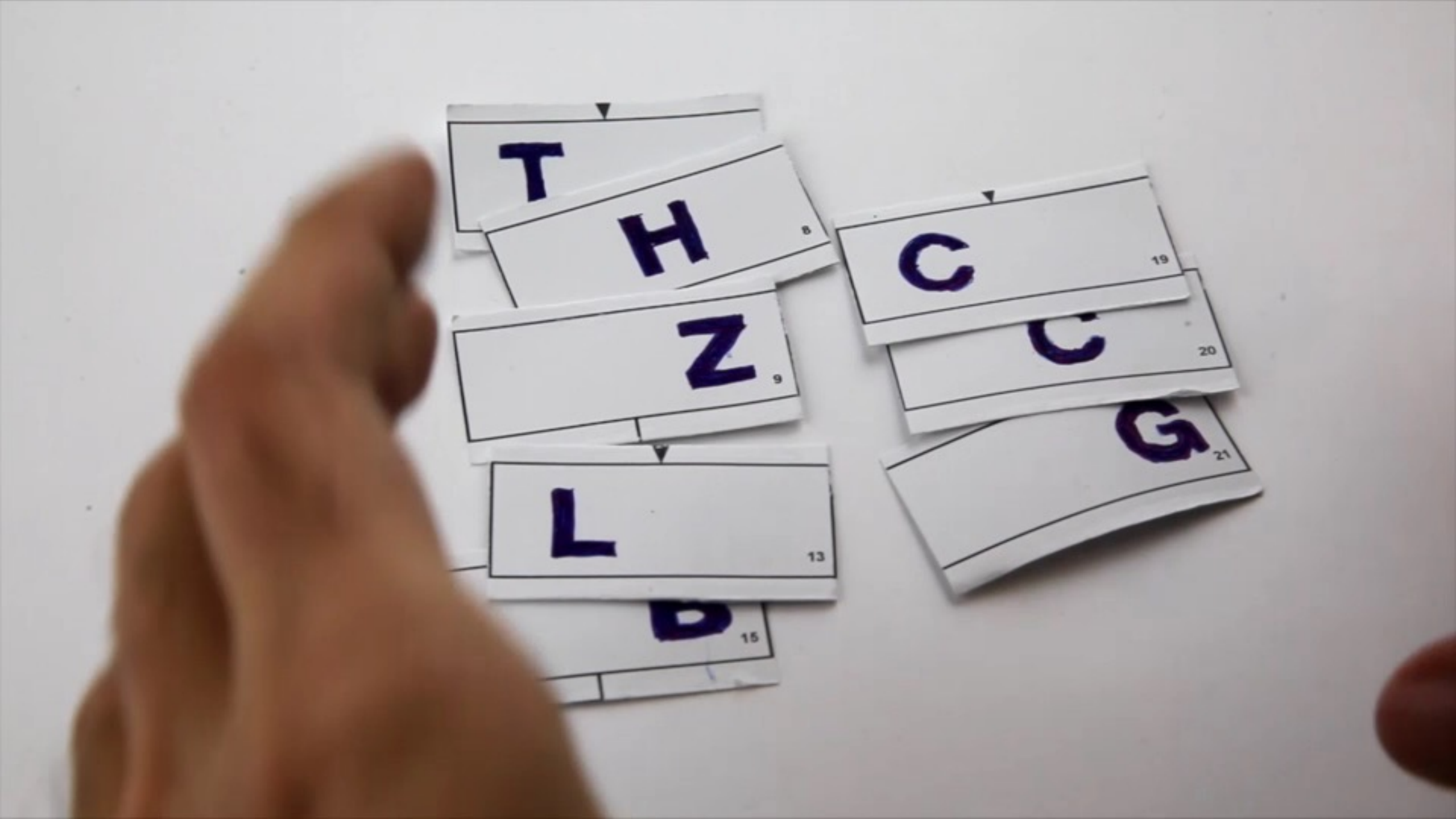
sebastian@ubicept.com

Sebastian Bauer, CEO

Invisible Objects






T
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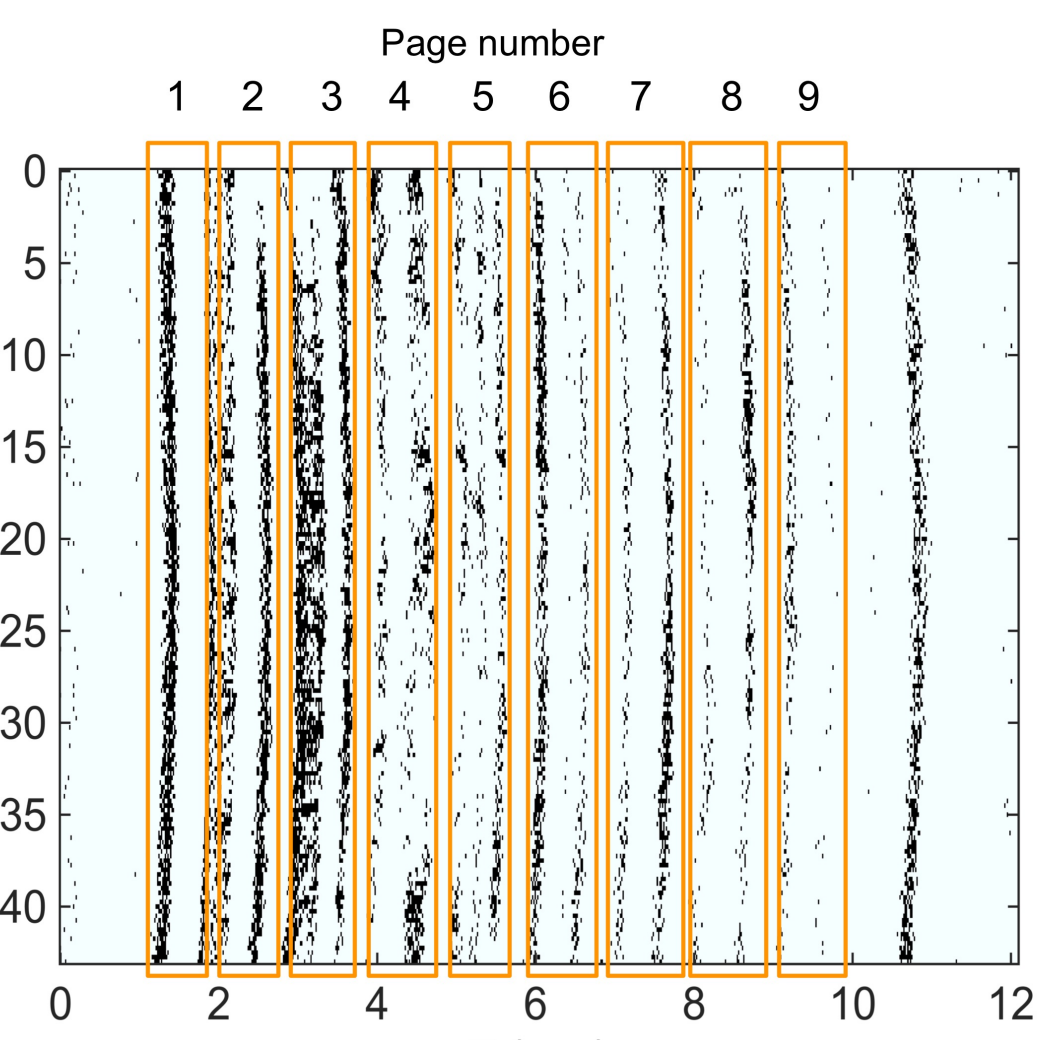
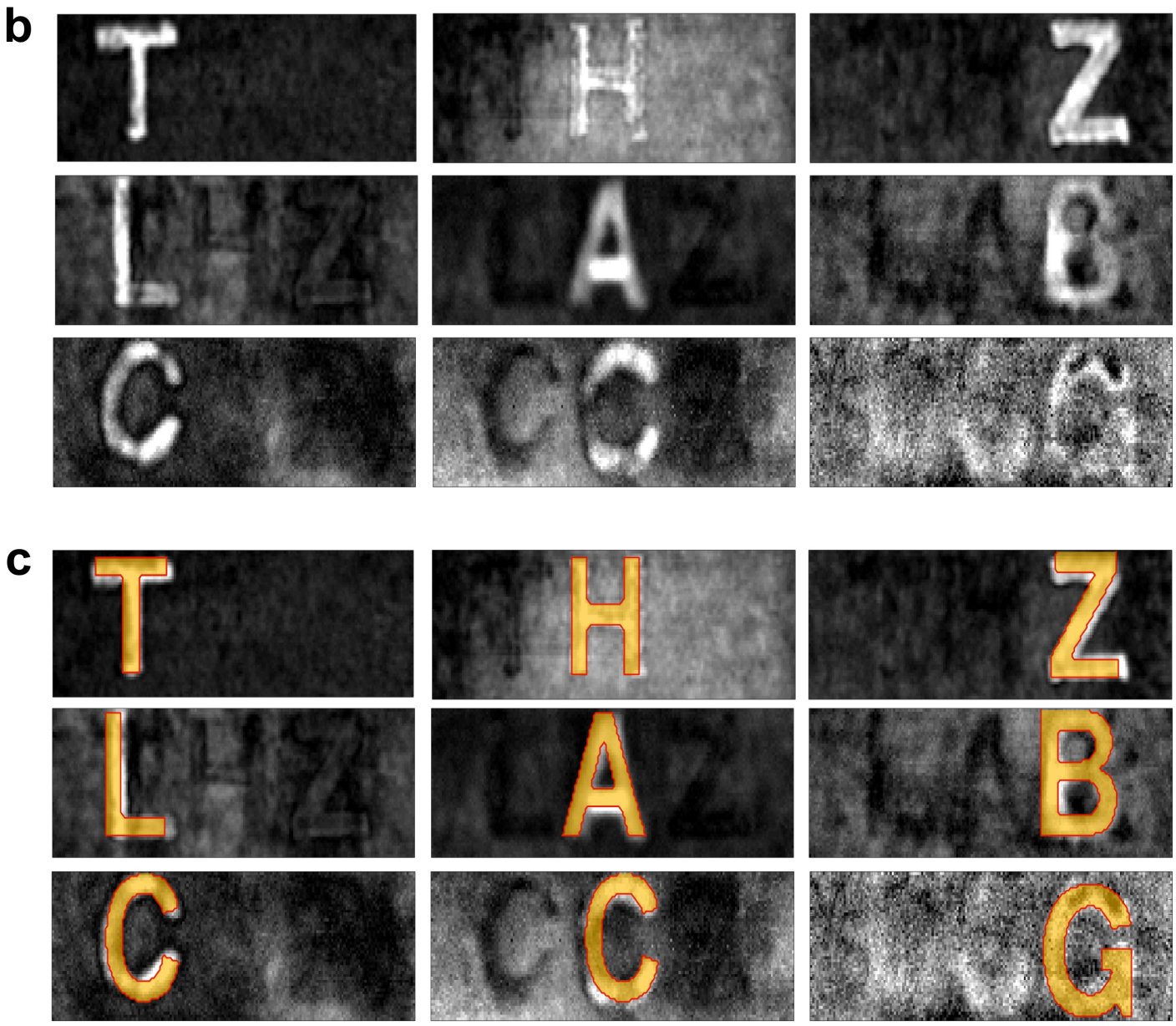
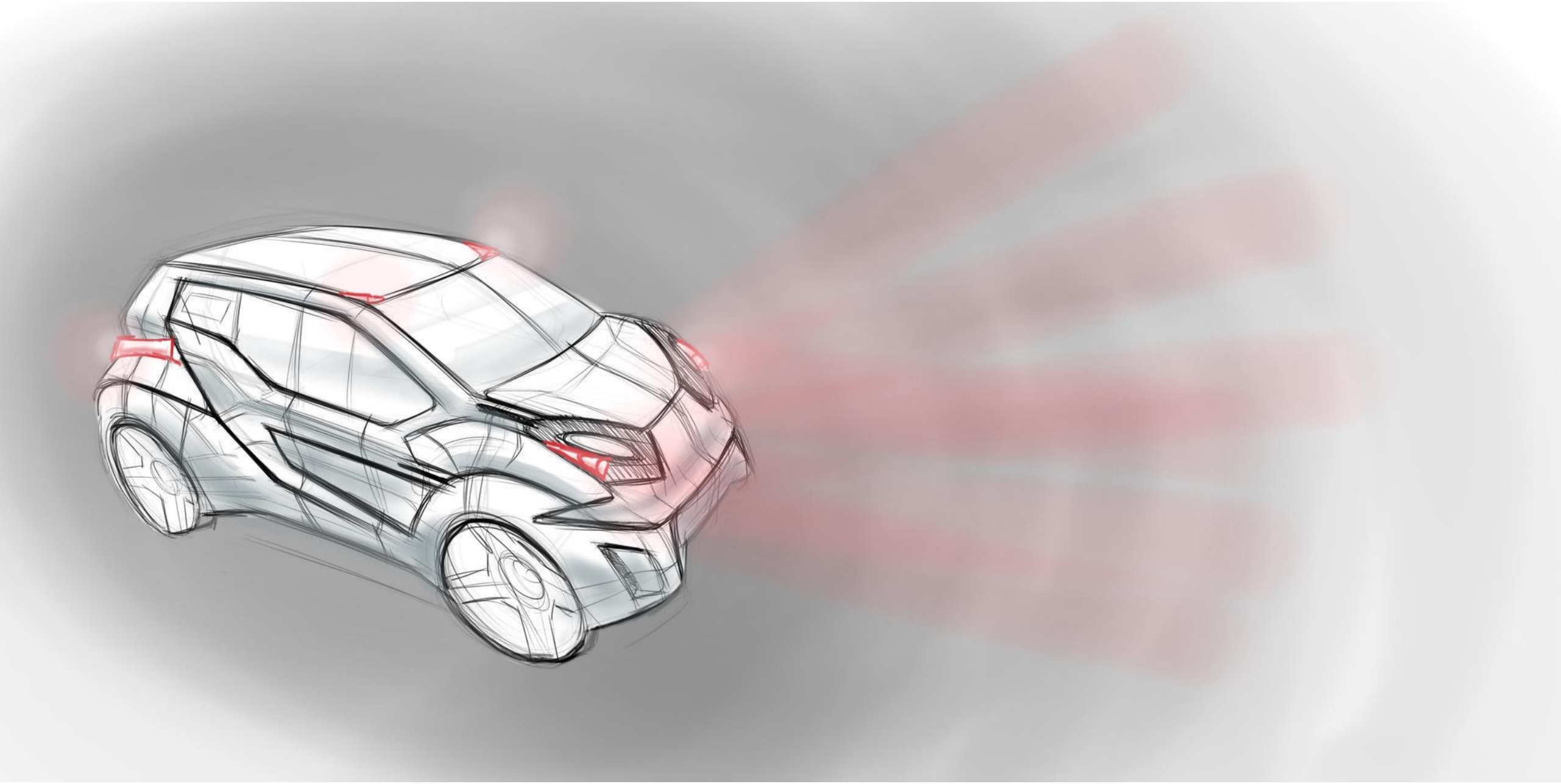
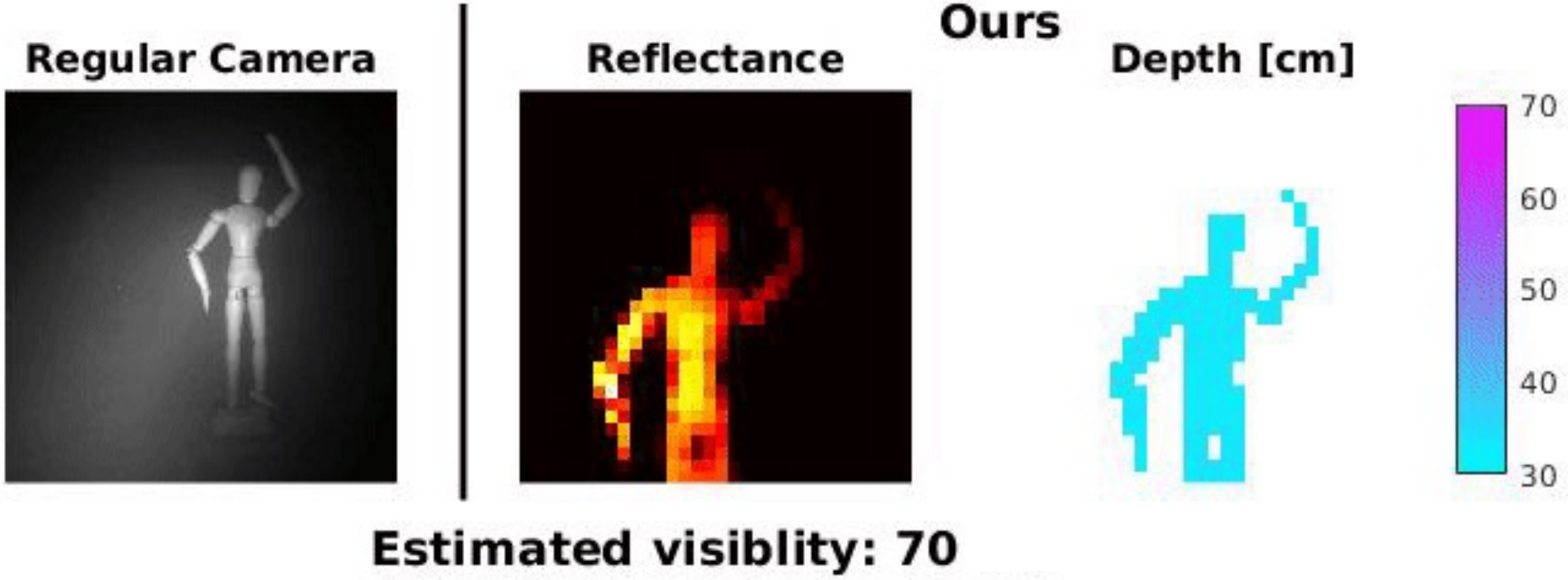




Sanchez, Heshmat, Reza, Romberg, Raskar 2015



Seeing thru Fog



Satat, Maeda, Tancik, Raskar, *ICCP* 2018

Fog + Object Model

$$f_T(t) = P(B)f_T(t|B) + P(S)f_T(t|S)$$

Photon Timing

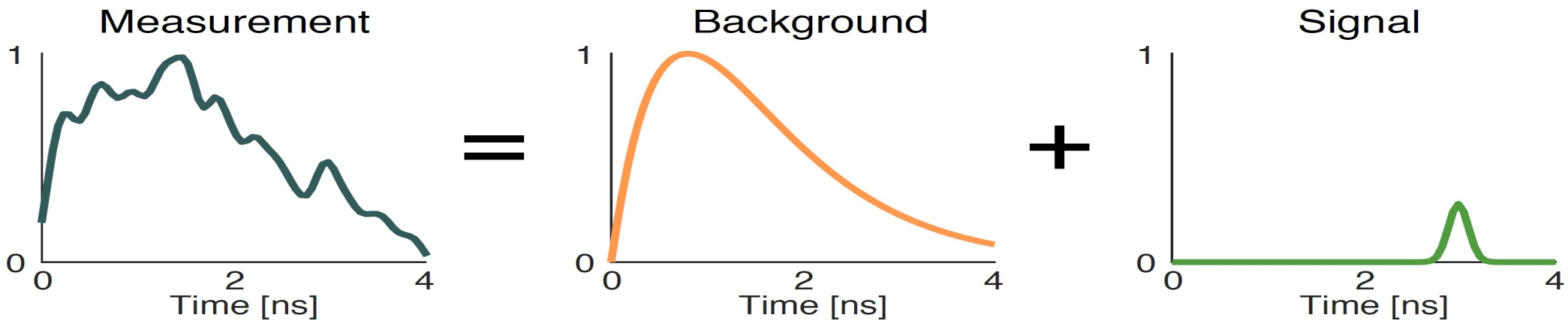
background photon

Gamma distribution

Object photon

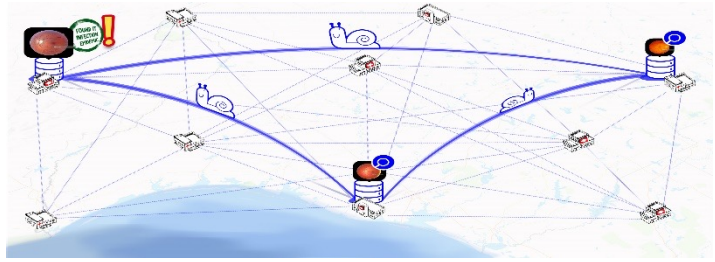
Normal distribution

depth and reflectance



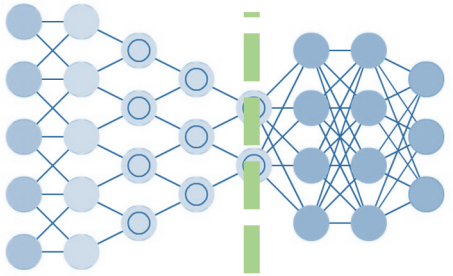
Making Invisible Visible | Summer course tiny.cc/mitcourse

Data



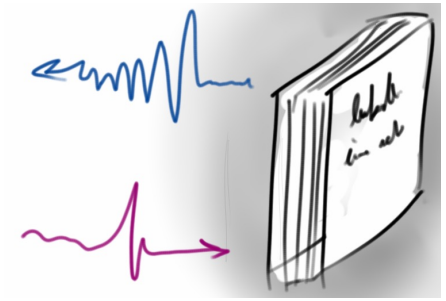
Auto-ML

Split Learning

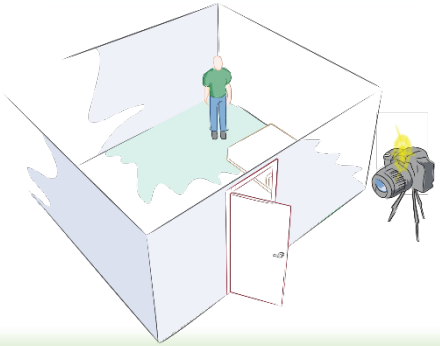


Data Markets

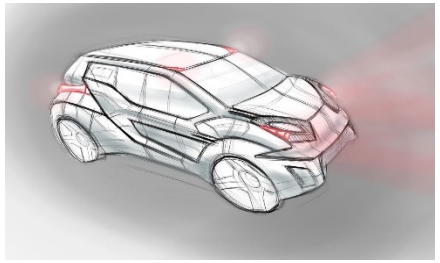
Objects



Book

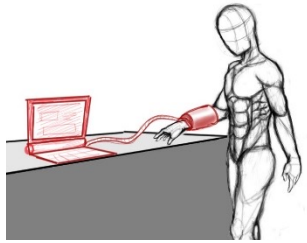


See around corners



Fog

Inside



Tissue Imaging

Eye Selfie

CAT-scan

Making Invisible Visible

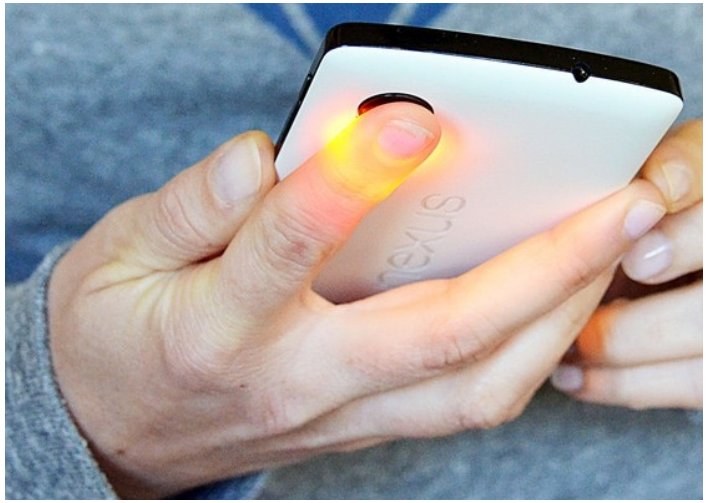
Inside, Around and Beyond

Ramesh Raskar
Associate Professor
MIT Media Lab

END$_1$

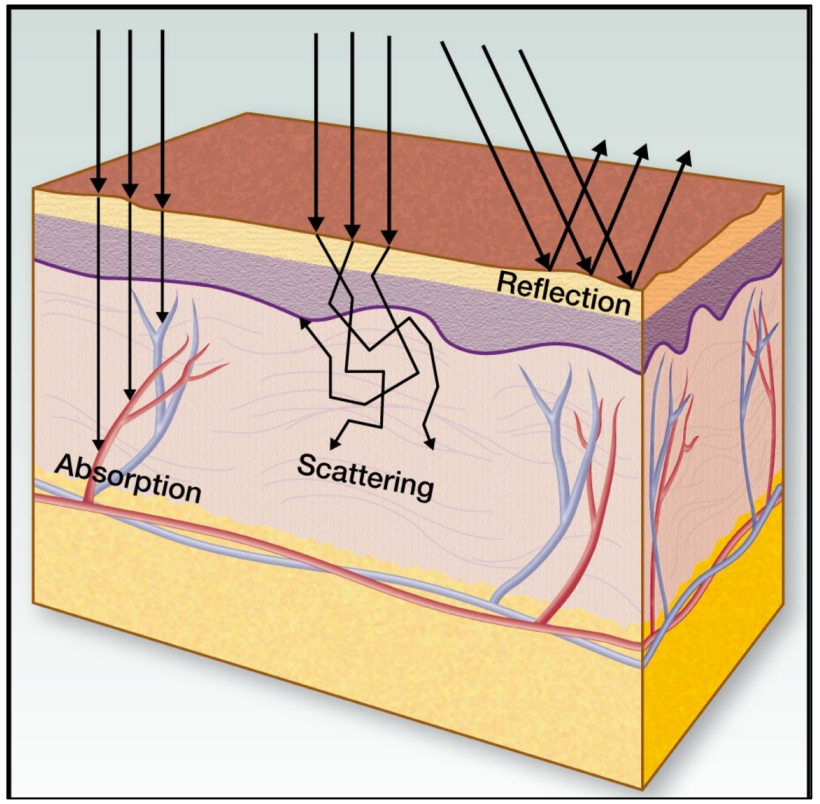
Break the Scattering Barrier

Opportunity



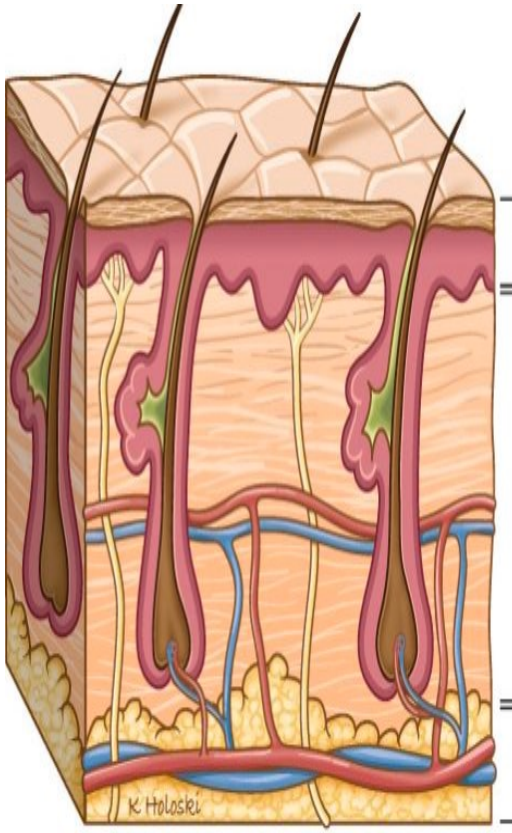
+ Light travels deep inside the body
+ It is non-ionizing (400-1100nm)
+ Cheap to produce and control

Scattering Barrier



– Most pass-through photons are scattered
– Avg 10 scattering events per mm
– By 50mm, avg 500 scattering events !
– Large-scale inverse problem with low SNR

Success with Each Millimeter



Depth	Applications
<1mm	• Skin cancer diagnosis • Burn wound assessment • Melanoma diagnosis • Skin graft assessment
1-5 mm	• Pressure ulcer evaluation • Microvascular blood flow assessment in diabetic foot ulcers • Diagnosing anemia & ICU shock
5-20 mm	• Vascular health in diabetics • Subcutaneous abscess/tumor screening

There are 99 ICD-10 codes for skin and subcutaneous tissue conditions. And many conditions like diabetes show symptoms in micro- and macro-vasculature below skin.