CVPR 2018

Computational Imaging for Self-Driving Vehicles

Jan Kautz Ramesh Raskar Achuta Kadambi Guy Satat

Computational Imaging for Self-Driving Vehicles

Jan Kautz

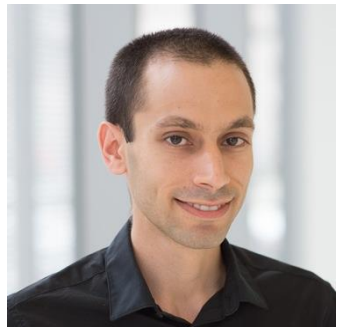
NVIDIA

Ramesh Raskar

MIT

Achuta Kadambi

MIT



Guy Satat

MIT

Computational Imaging

Self Driving Cars

Novel Sensors

LIDAR

Challenging Weather

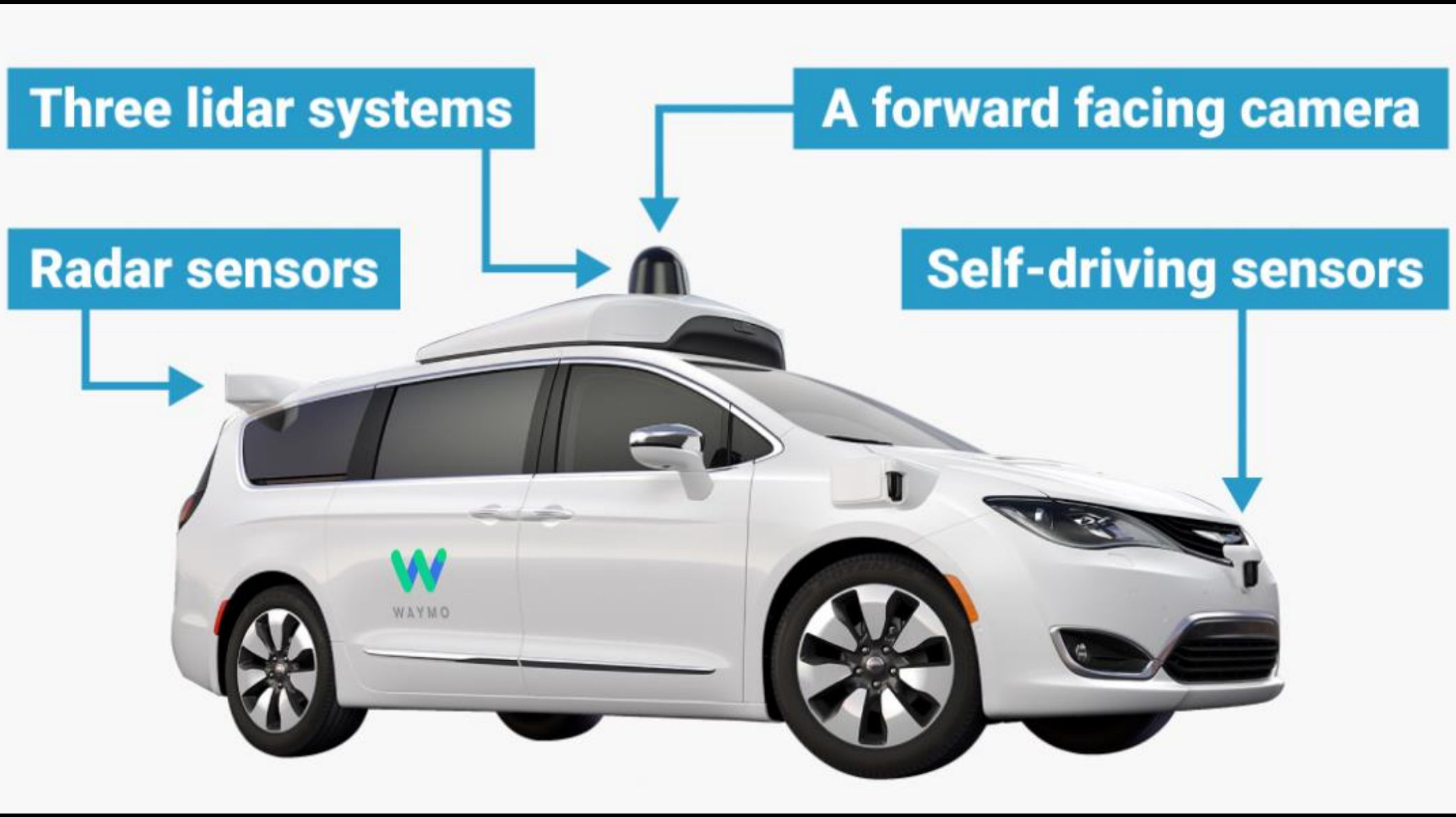
Open Problems

Deep Learning

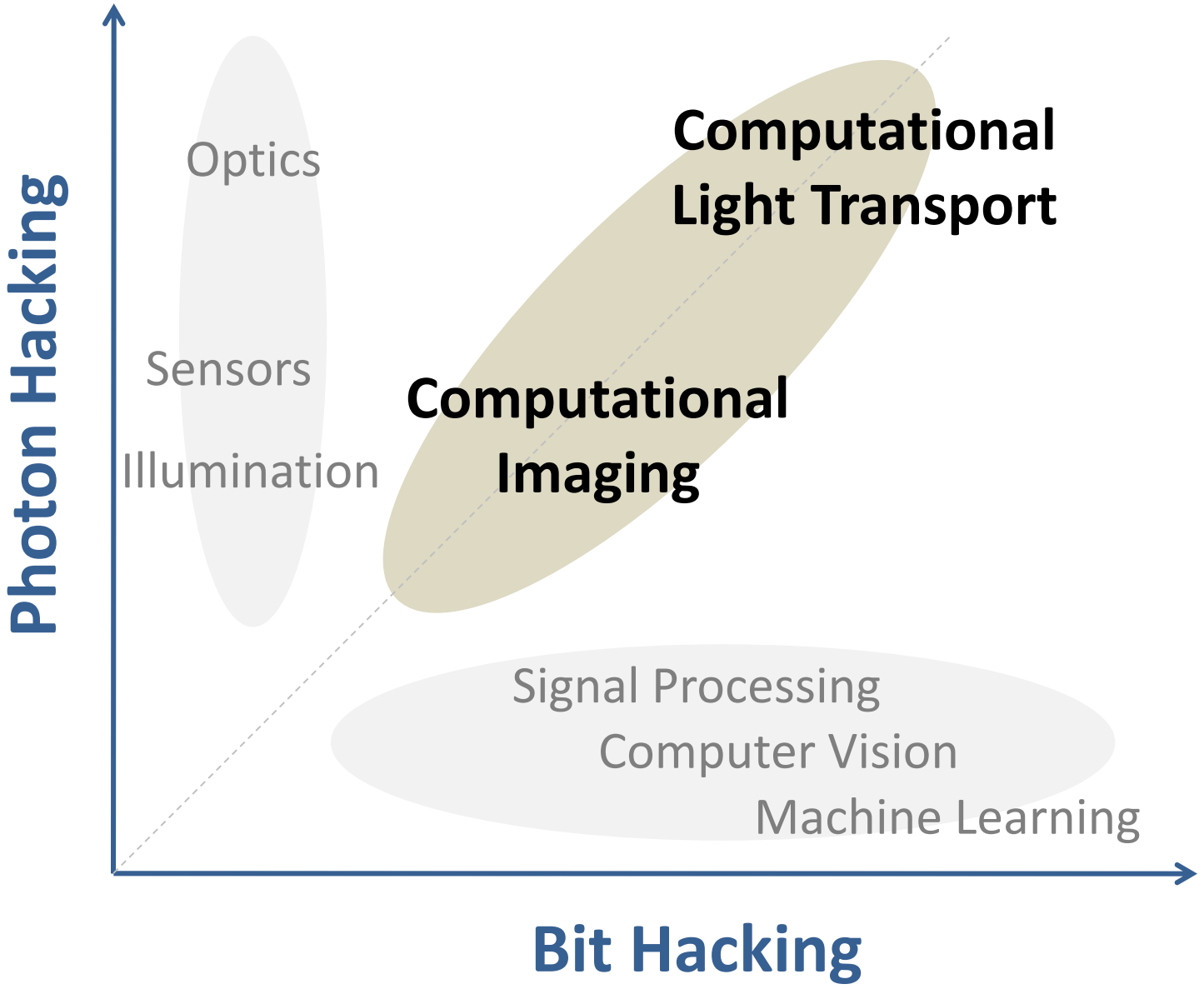
Course Schedule

imagingav.media.mit.edu

13:30 – 13:50	Course Introduction *Ramesh Raskar (MIT)*
13:50 – 15:00	Existing Sensors and Their Limits *Guy Satat (MIT), Achuta Kadambi (UCLA)*
15:00 – 15:10	Break
15:10 – 15:50	Emerging 3D Sensors *Achuta Kadambi (UCLA)*
15:50 – 16:30	Imaging in Bad Weather *Guy Satat (MIT)*
16:30 – 16:40	Break
16:40 – 17:20	Deep Learning-based Computational Imaging *Jan Kautz (NVIDIA)*
17:20 – 17:30	Conclusion and Open Problems

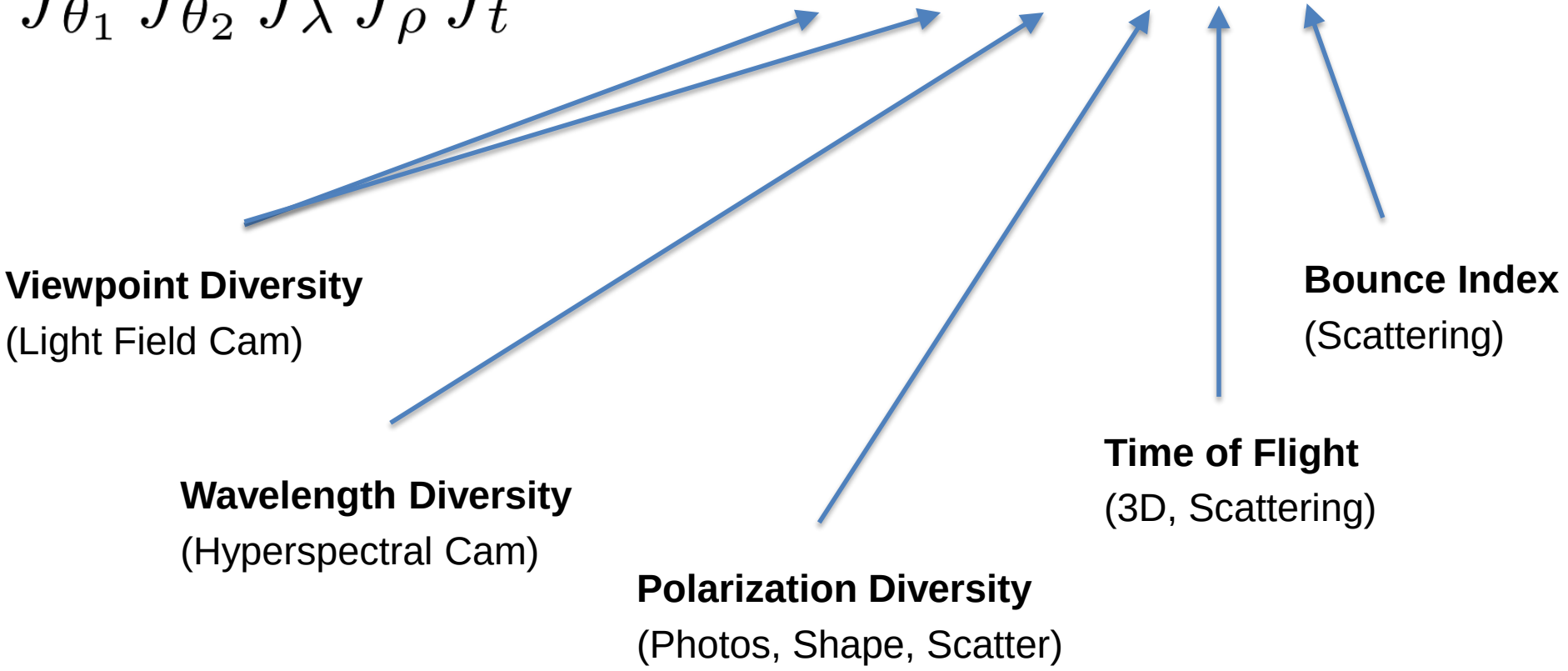

Three lidar systems
A forward facing camera
Radar sensors
Self-driving sensors
WAYMO

	Classification	Resolution	Localization	Cost	Any Weather
Radar	✓	✗	✗	✓	✓
Sonar	✗	✗	✗	✓	✓
Camera	✓	✓	✓	✓	✗
LiDAR	✓	✓	✓	✗	✗


Photon Hacking
Optics
Sensors
Illumination
Computational
Light Transport
Computational
Imaging
Signal Processing
Computer Vision
Machine Learning
Bit Hacking

Plenoptic Light Transport

$$I(x,y) = \int_{\theta_1}\int_{\theta_2}\int_{\lambda}\int_{\rho}\int_{t} \Sigma_n I(x,y,\theta_1,\theta_2,\lambda,\rho,t,n)$$



Adelson and Bergen "The Plenoptic Function…" MIT Press 1991

Shower Curtain: Diffuser

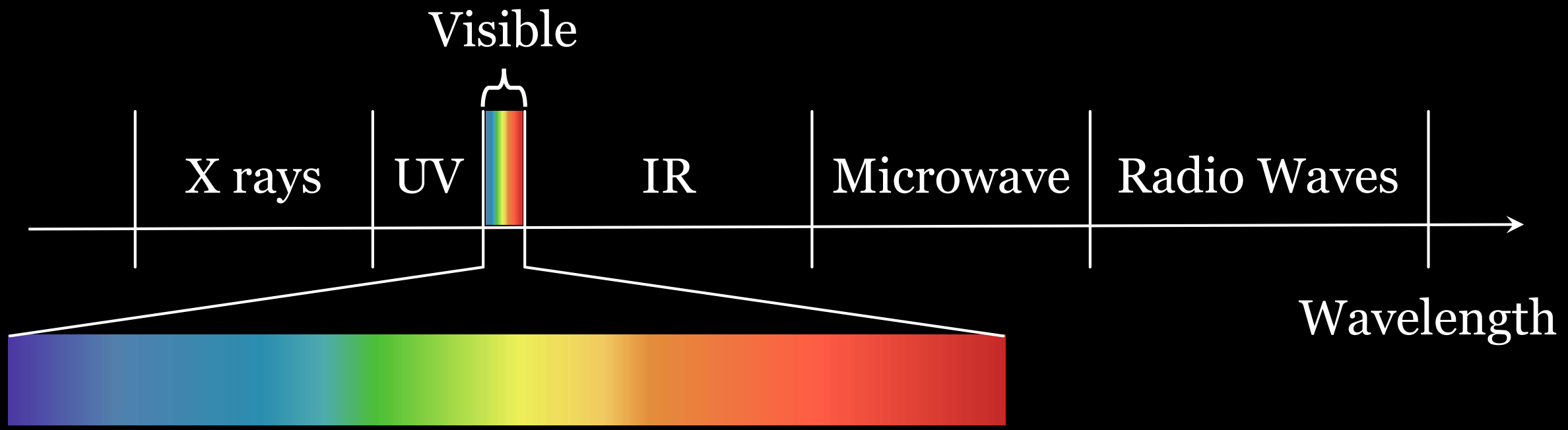
Courtesy of Shree Nayar. Used with permission.
Source: http://www1.cs.columbia.edu/CAVE/projects/separation/occluders_gallery.php

Shower Curtain: Diffuser

Courtesy of Shree Nayar. Used with permission.
Source: http://www1.cs.columbia.edu/CAVE/projects/separation/occluders_gallery.php

Direct

Global

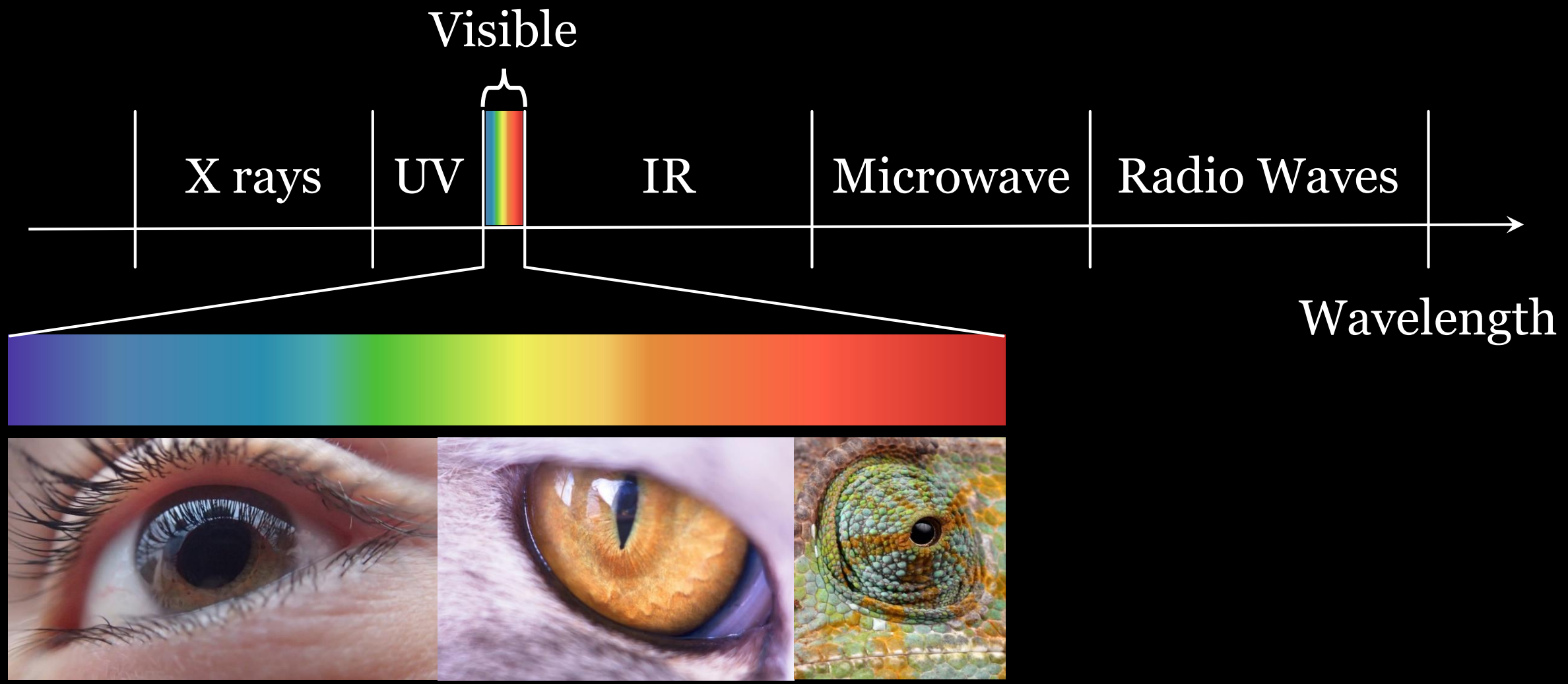


- Resolution
- Optical Contrast
- Non ionizing
- Availability of fluorophores

Optical Contrast

Visible light

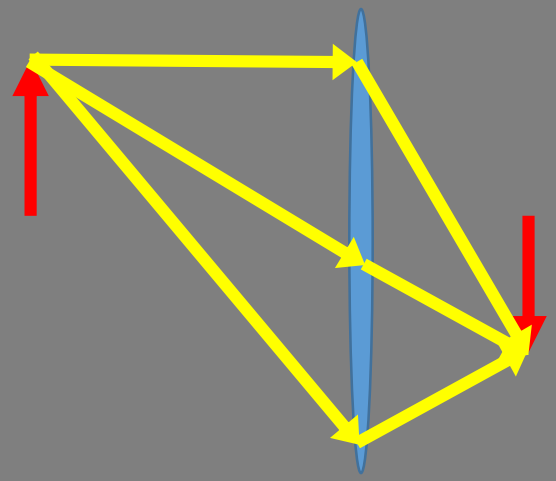
X-Ray

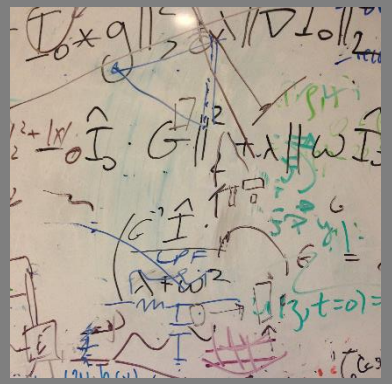

Visible
X rays
UV
IR
Microwave
Radio Waves
Wavelength

Light Interaction

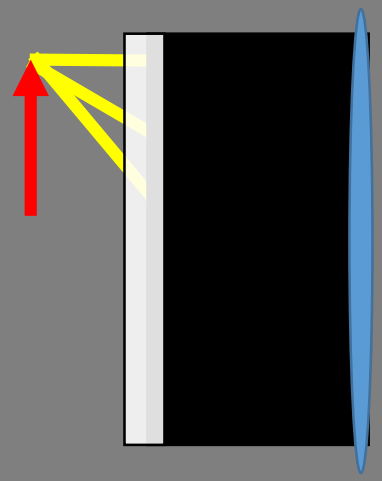
Object

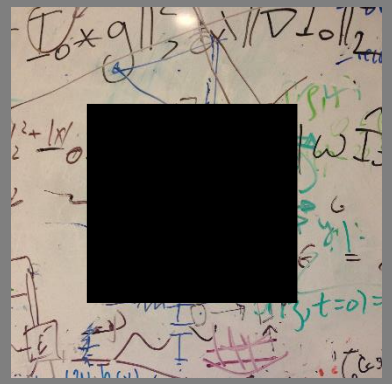
Lens



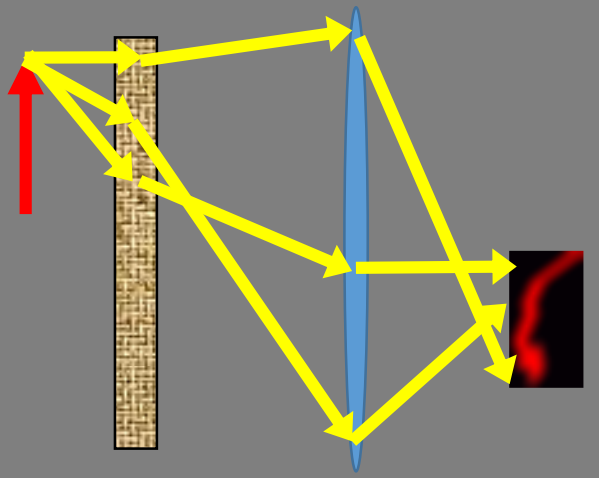


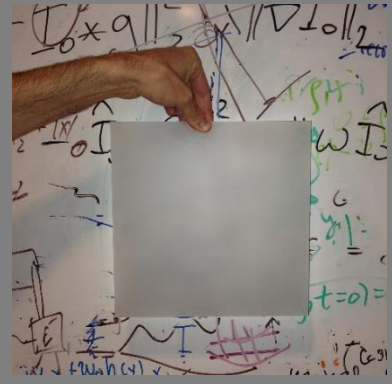
Absorption





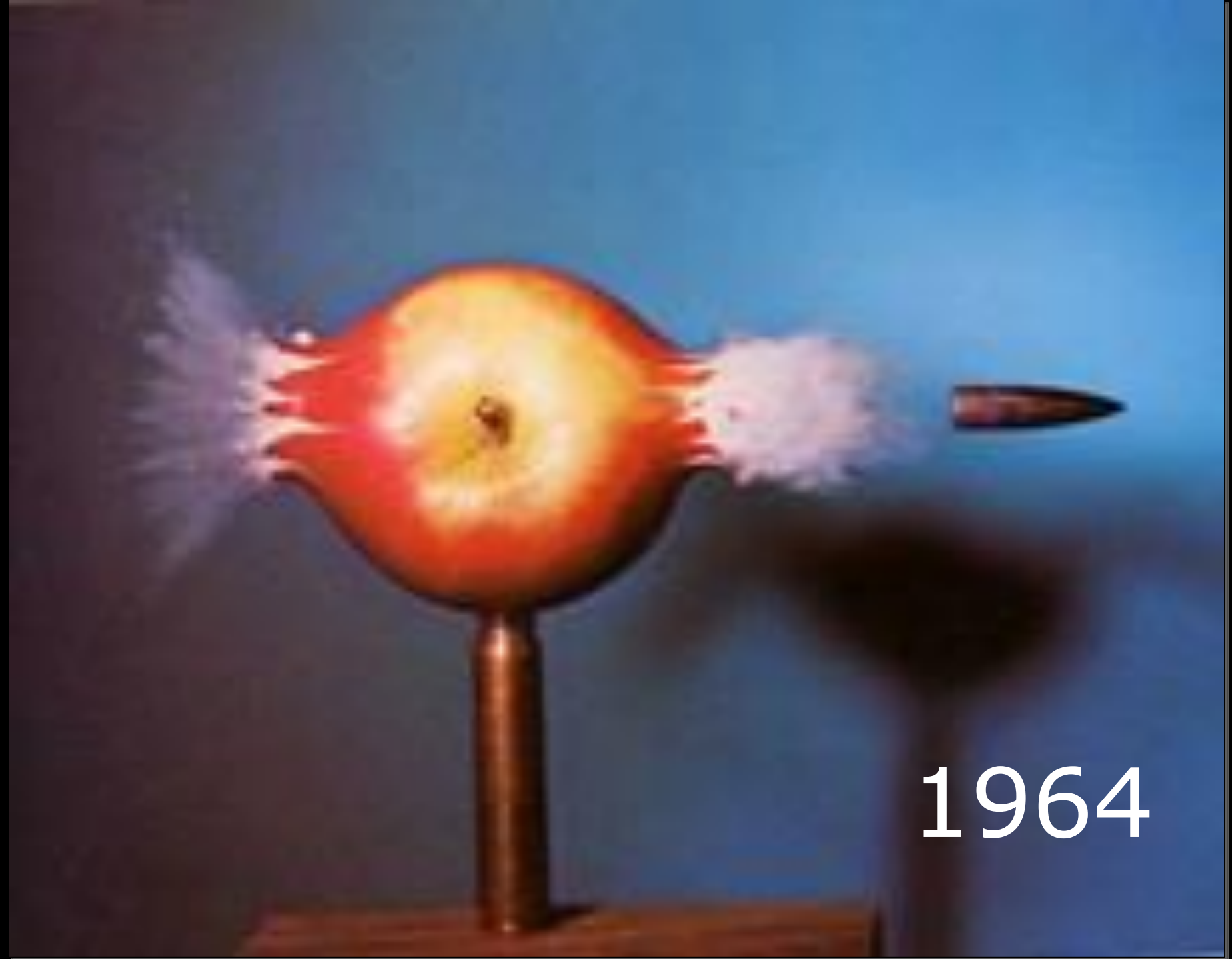
Scattering

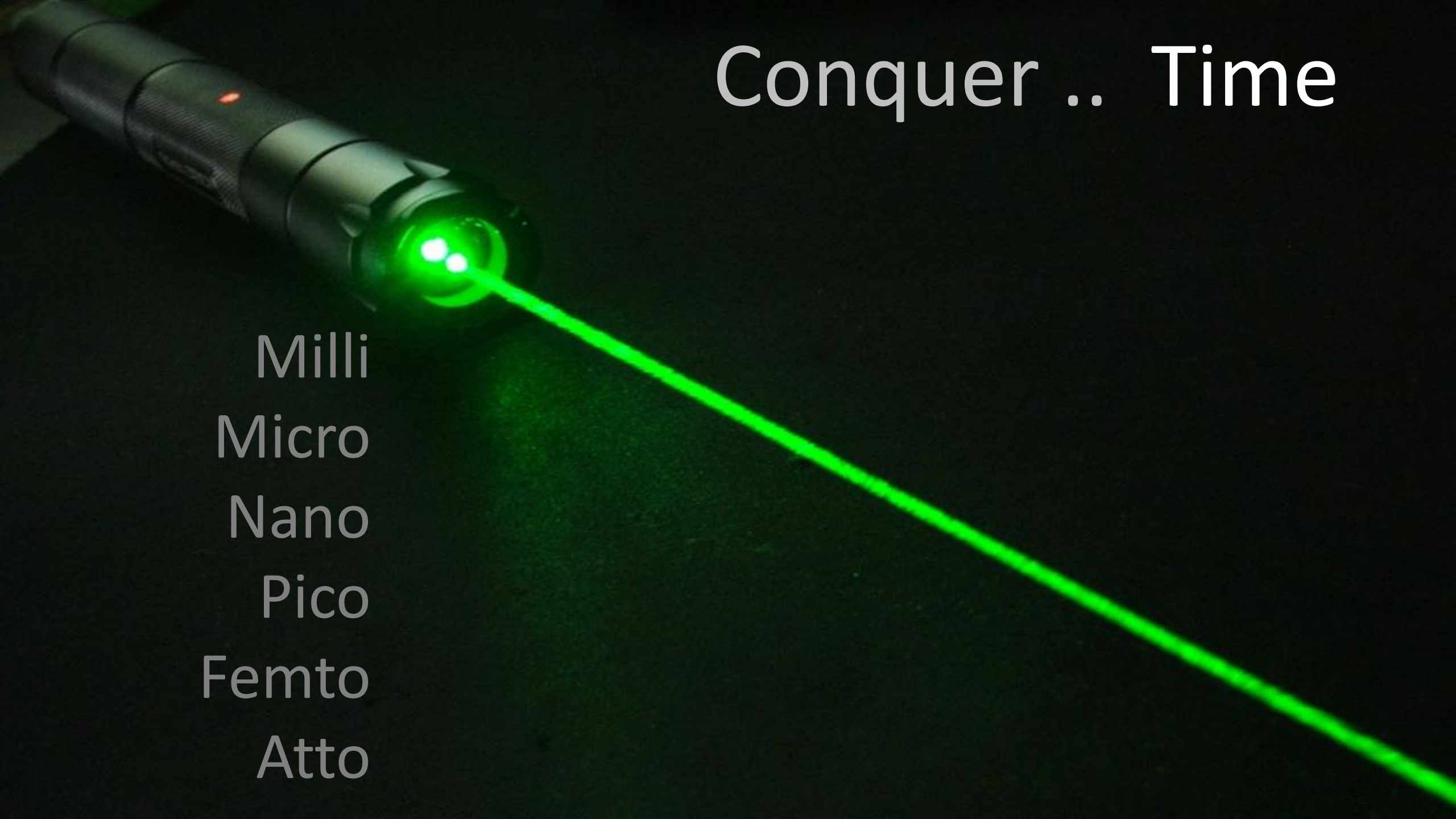


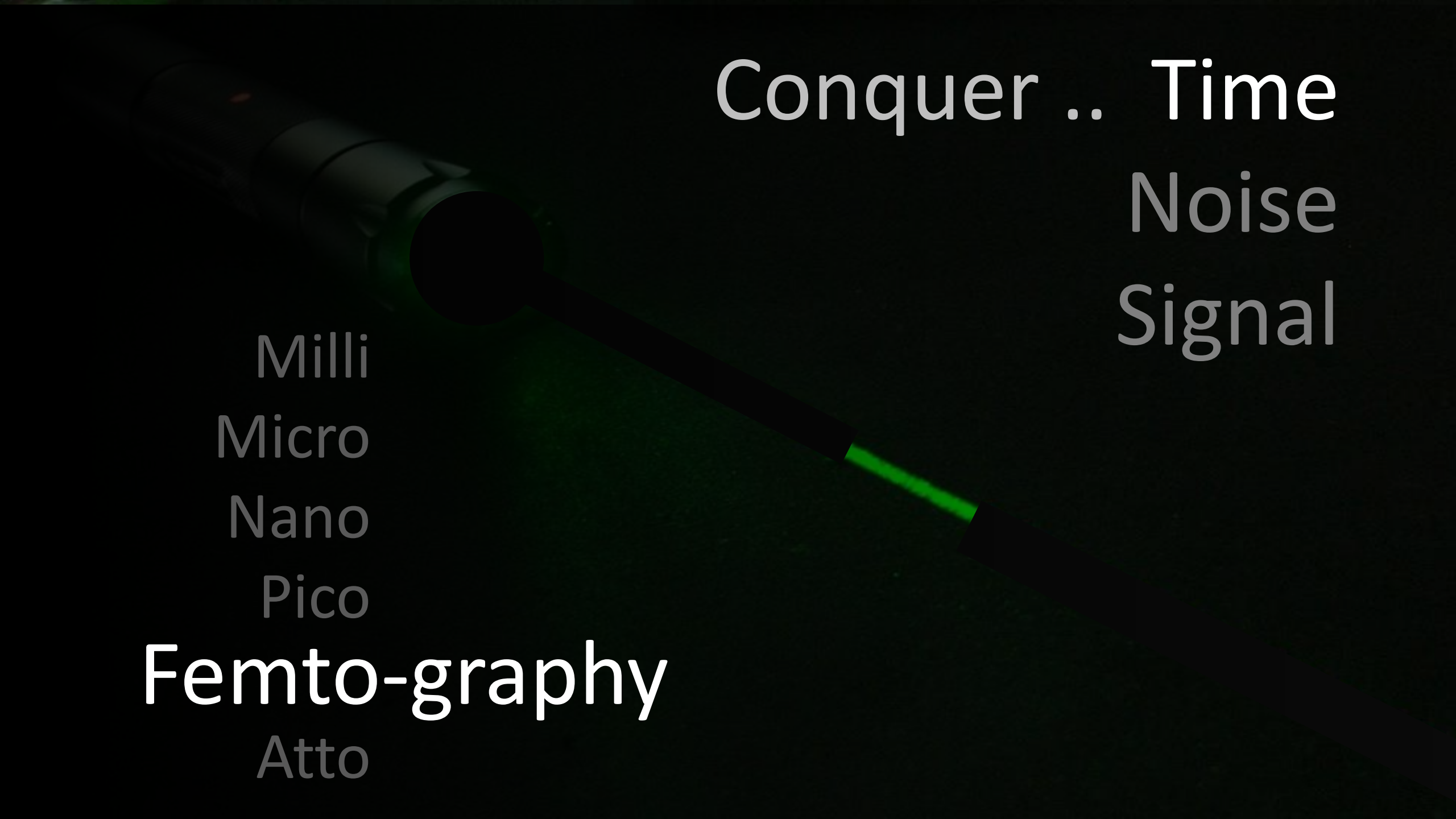


Diffraction
Dynamic Range
Descattering

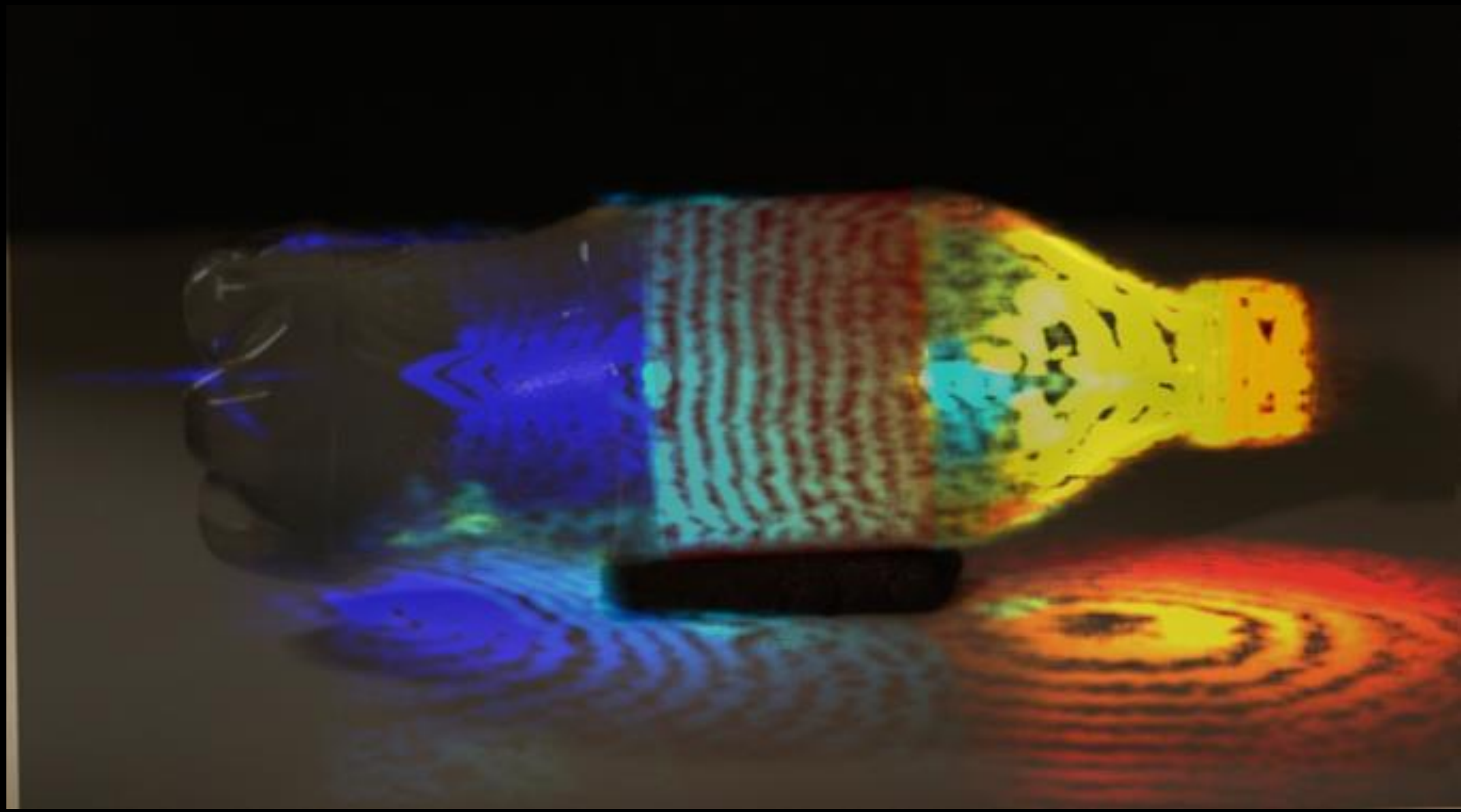
Defocus
Depth

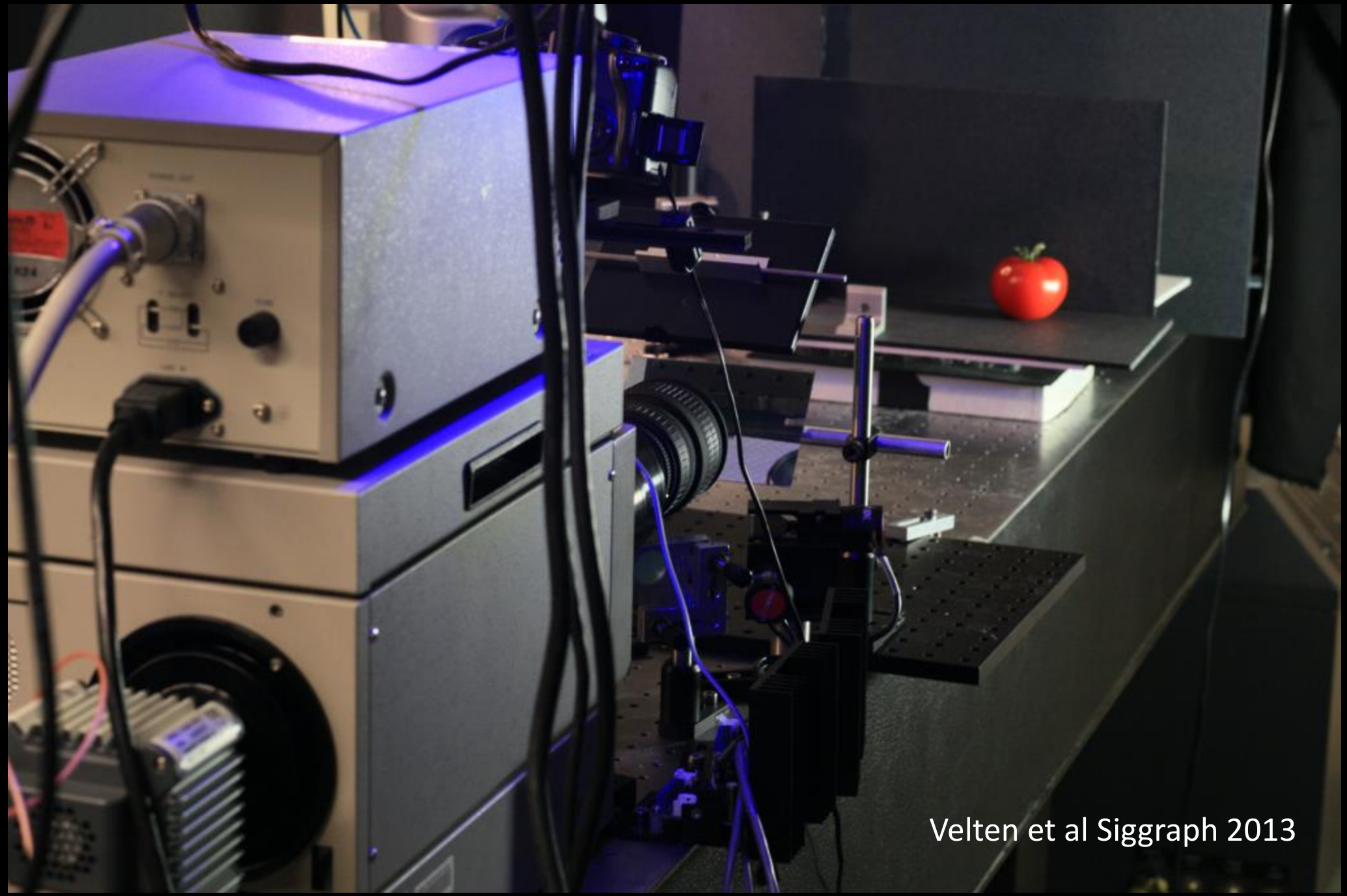

1964

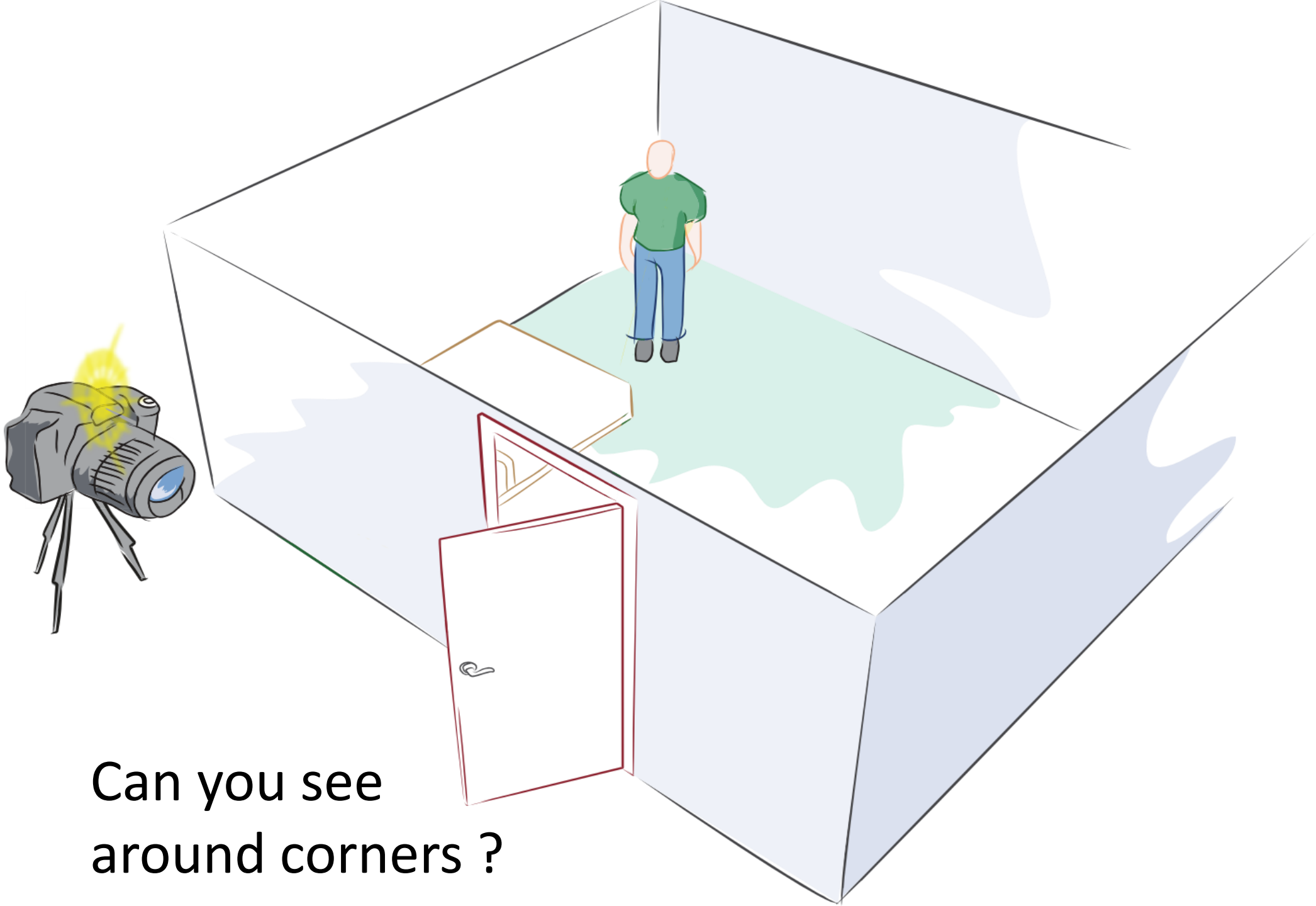

Conquer .. Time
Milli
Micro
Nano
Pico
Femto
Atto


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

Light in Slow Motion ..

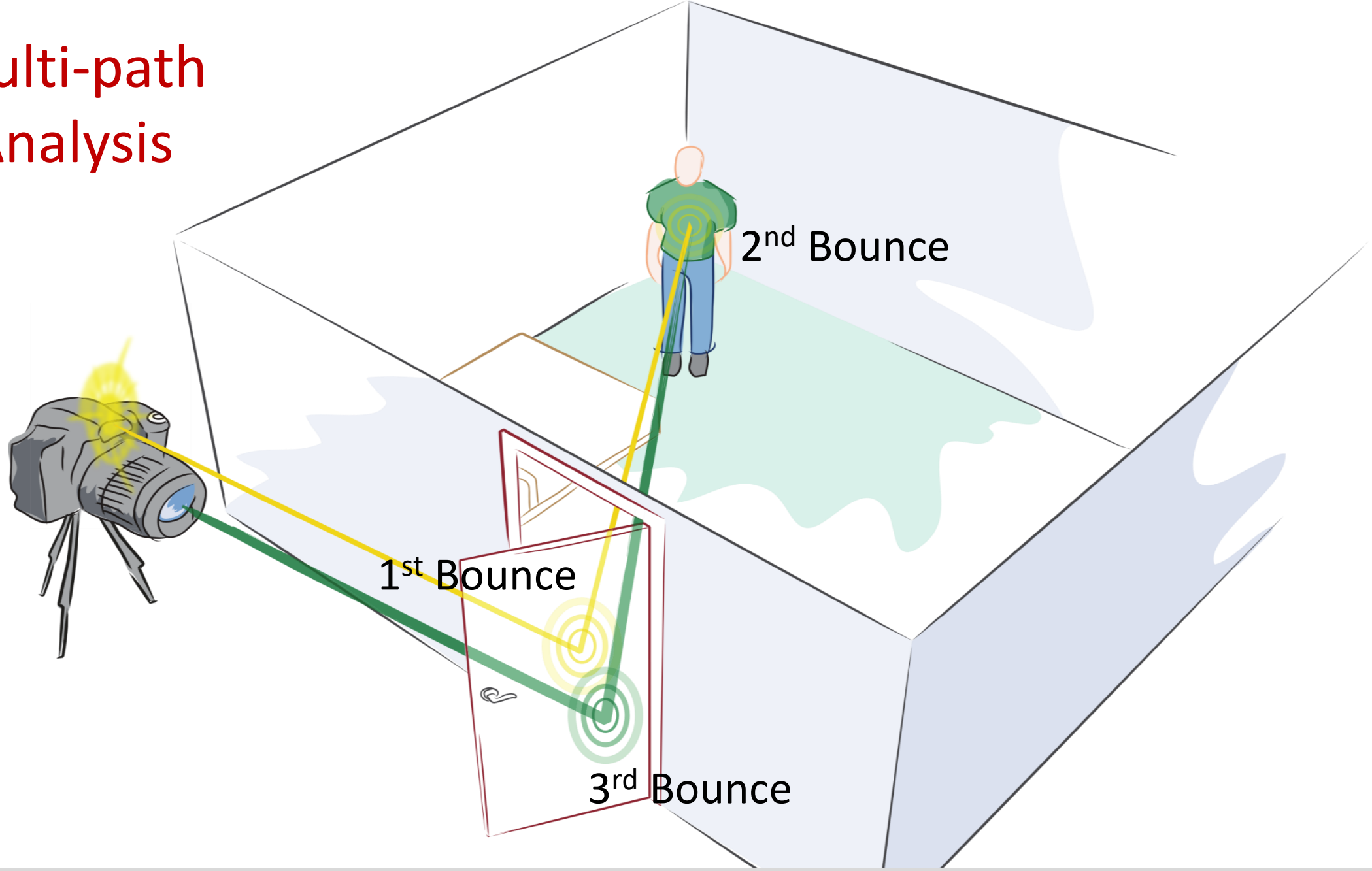



Velten et al Siggraph 2013



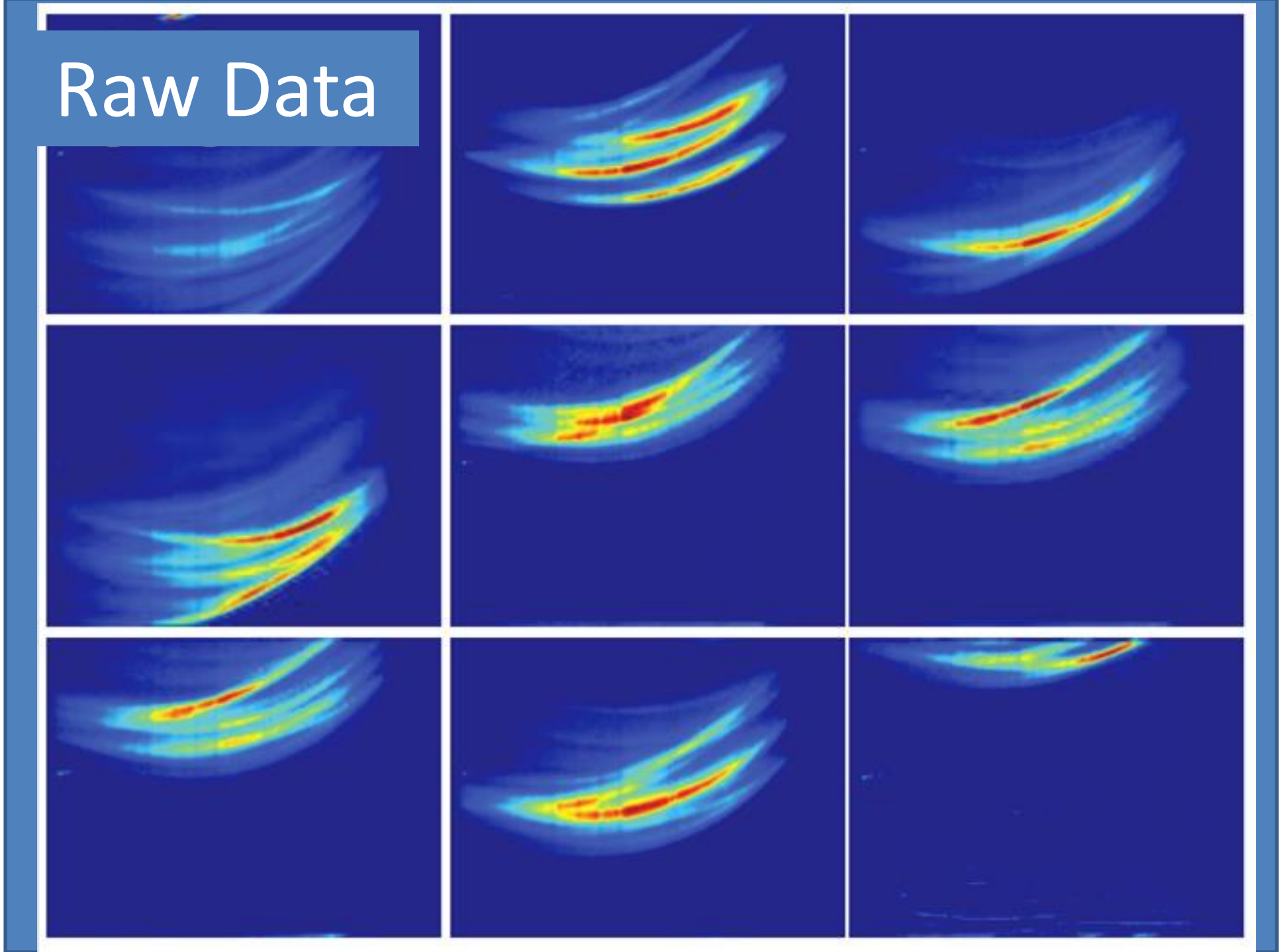
Can you see
around corners ?

Multi-path Analysis

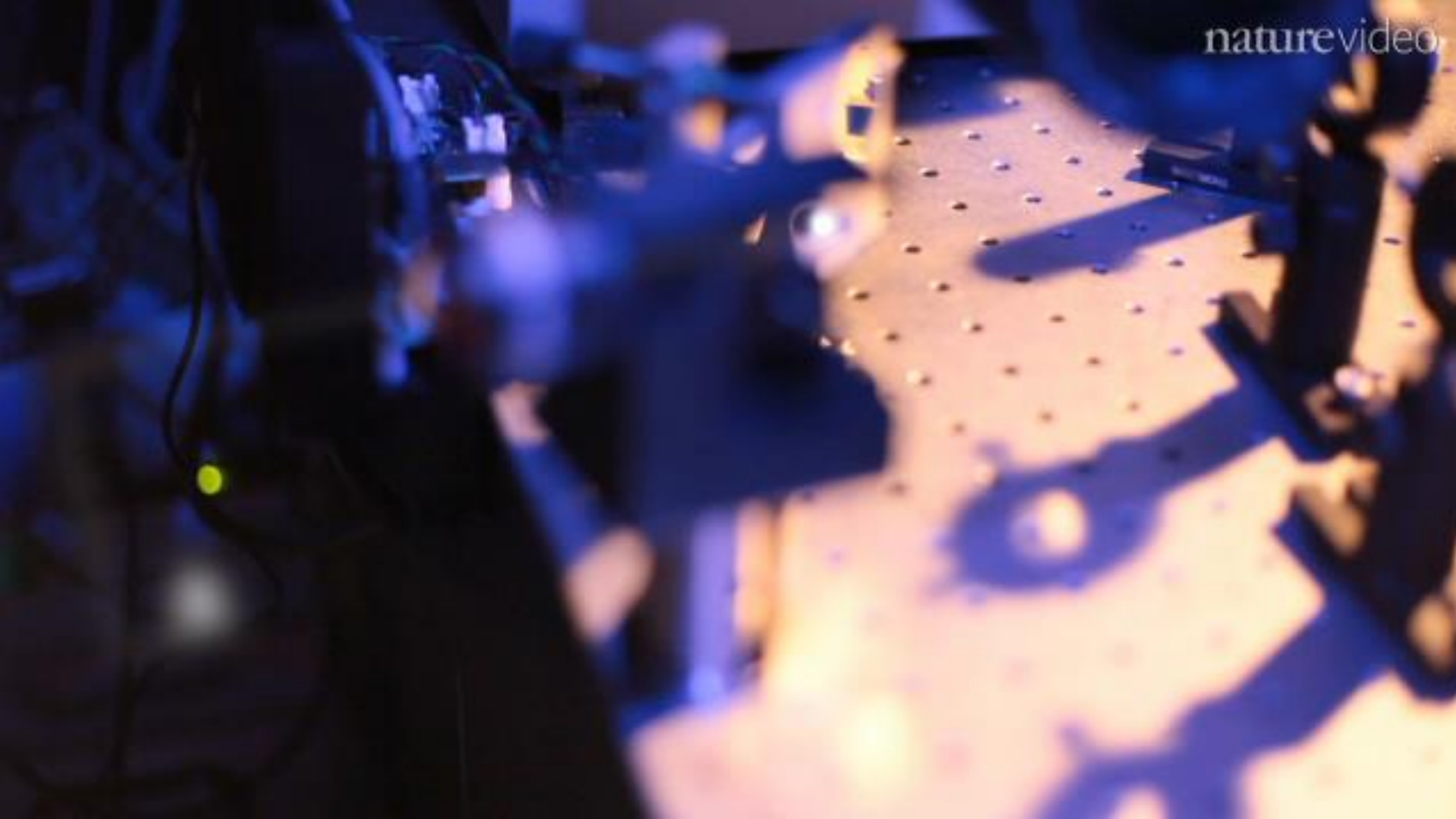


Velten et al. Nature Comm 2012

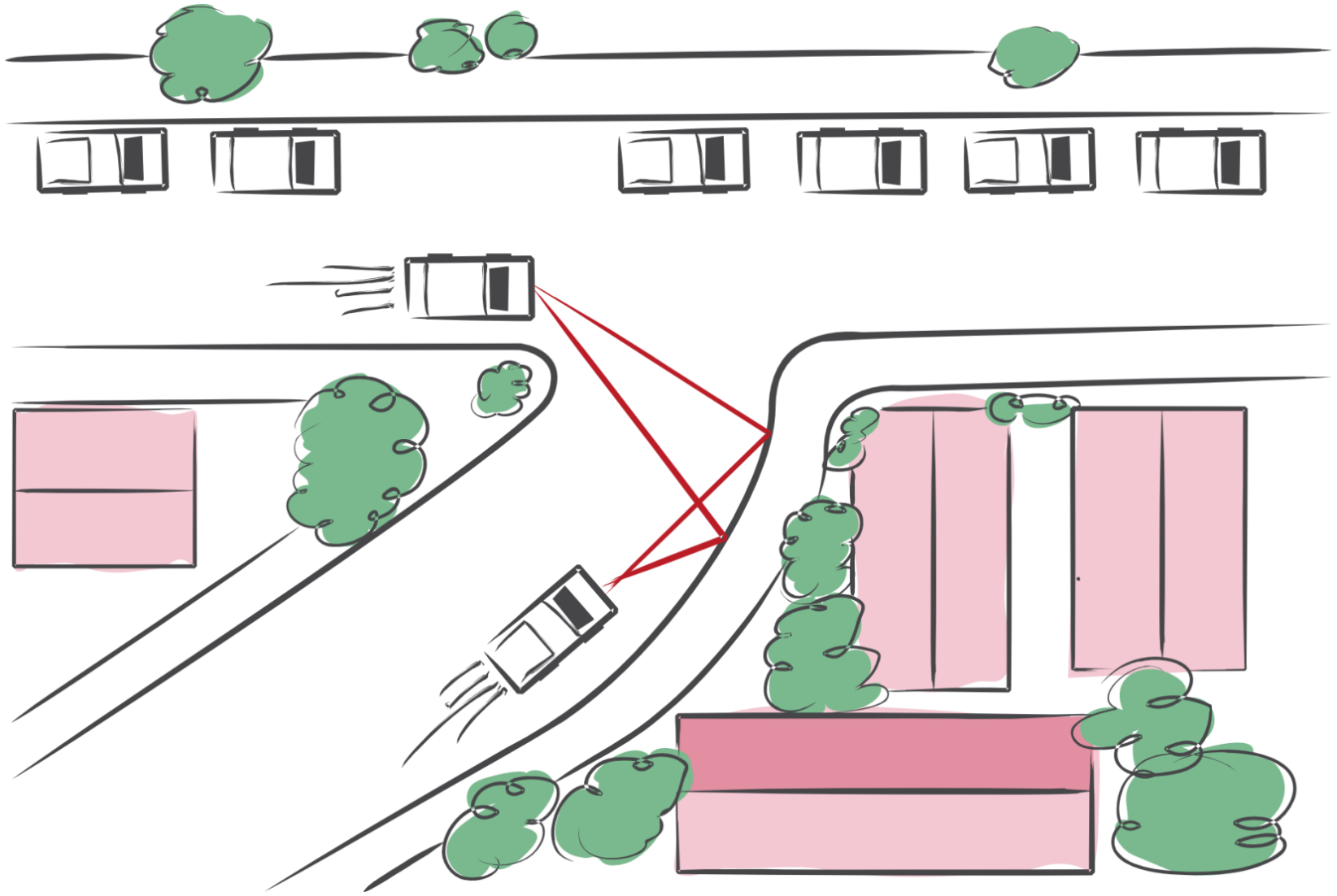
Raw Data



Velten et al, Nature Communications 2012

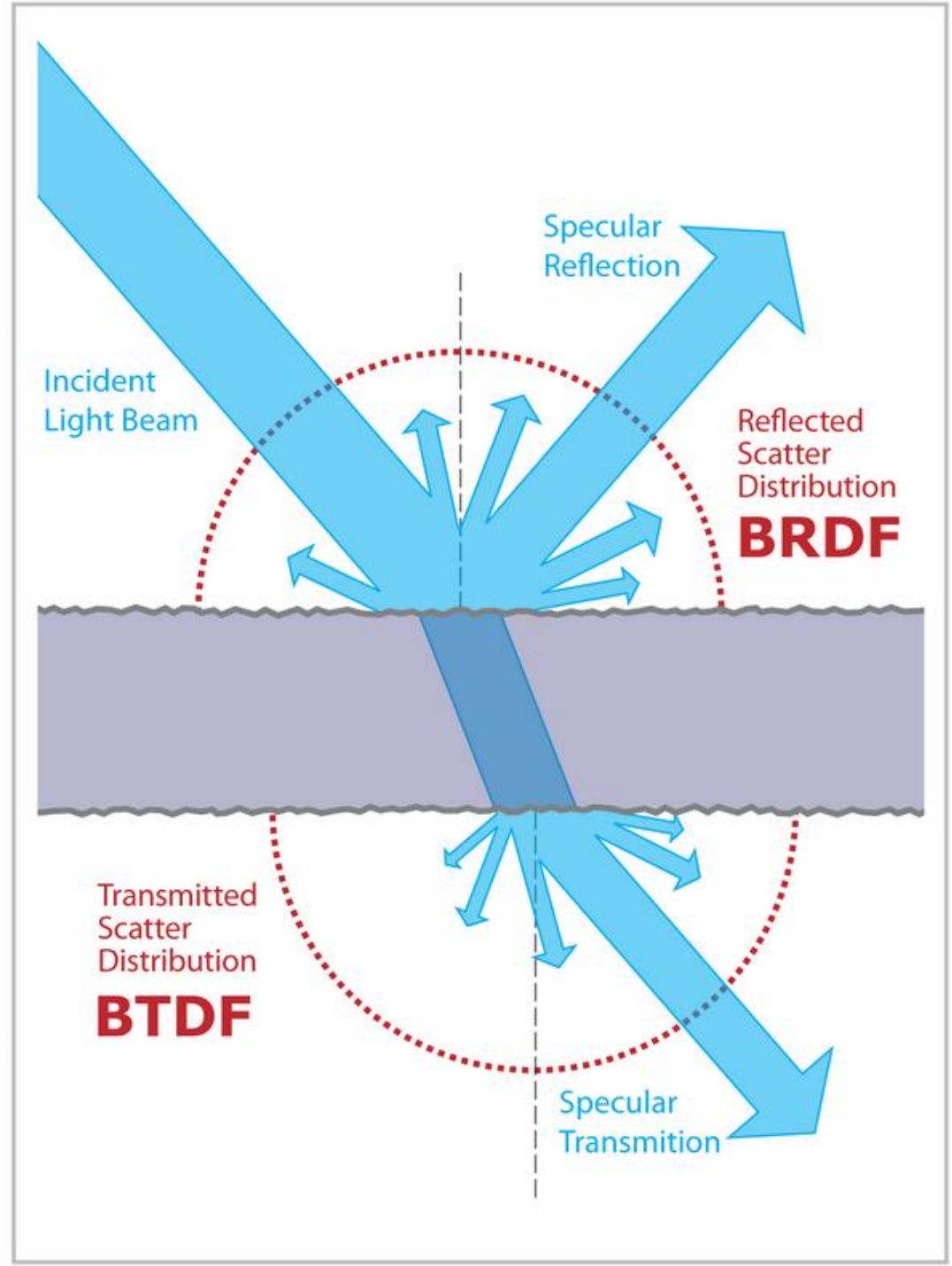

naturevideo

Collision avoidance, robot navigation, …

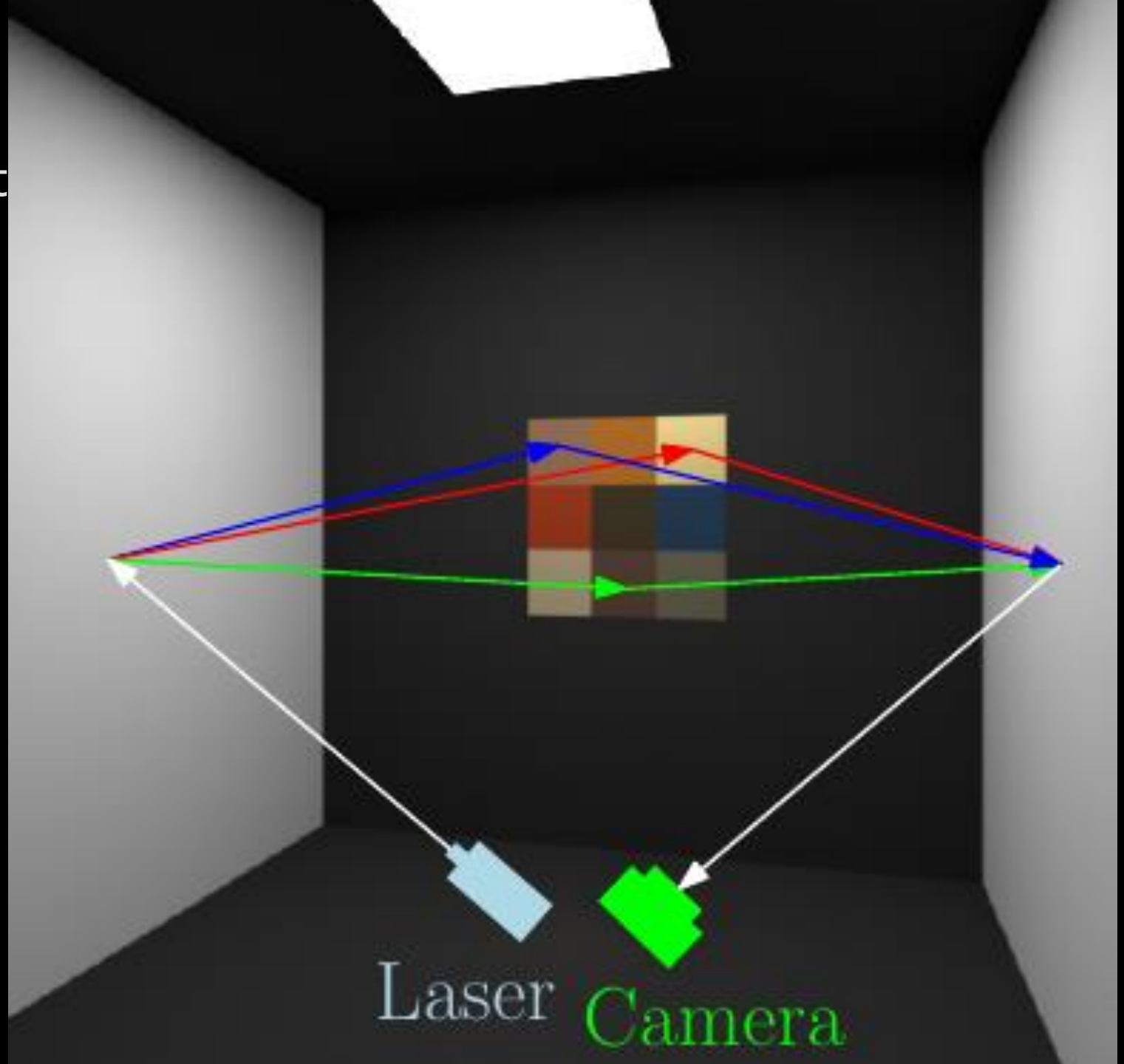


DARPA REVEAL Program by Dr. Predrag Milojkovic

Identify Materials

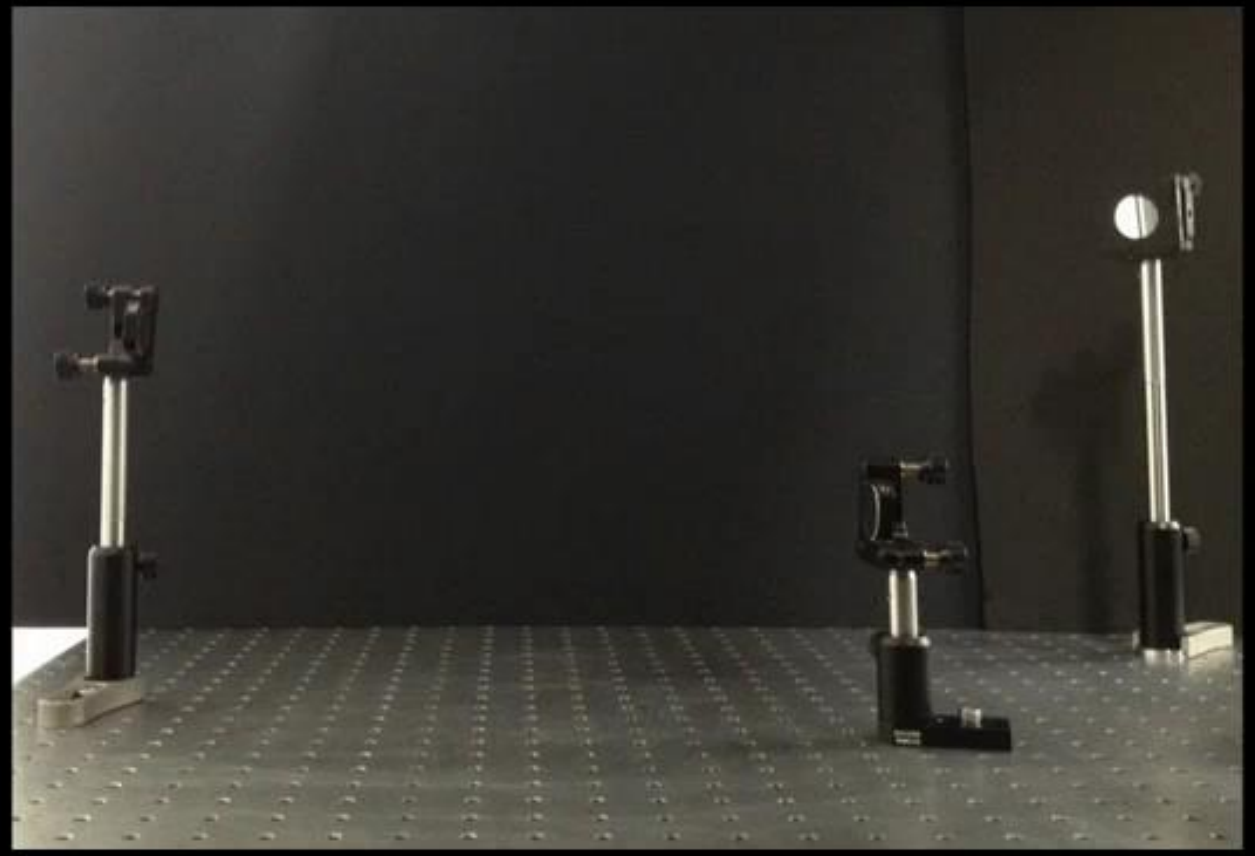

Specular
Reflection
Incident
Light Beam
Reflected
Scatter
Distribution
BRDF
Transmitted
Scatter
Distribution
BTDF
Specular
Transmition

BRDF from a single viewpoint



Naik, Zhao, Velten, Raskar, Bala,
(SIGGRAPH Asia 2011)

Single Photon Sensitive Imaging (SPAD)



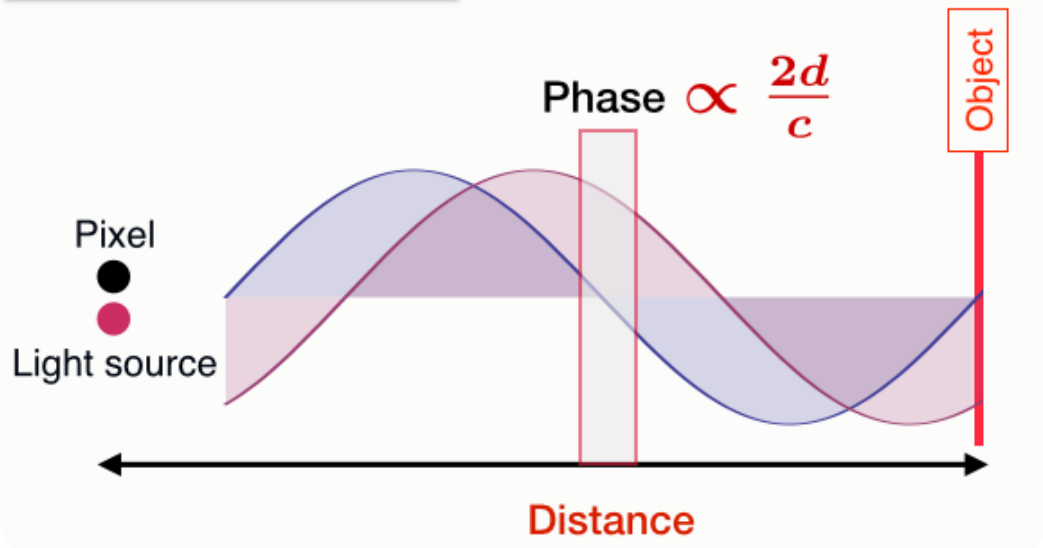
Gariepy et al. Nature Comm (2015)

Time-of-Flight Imaging Sensors

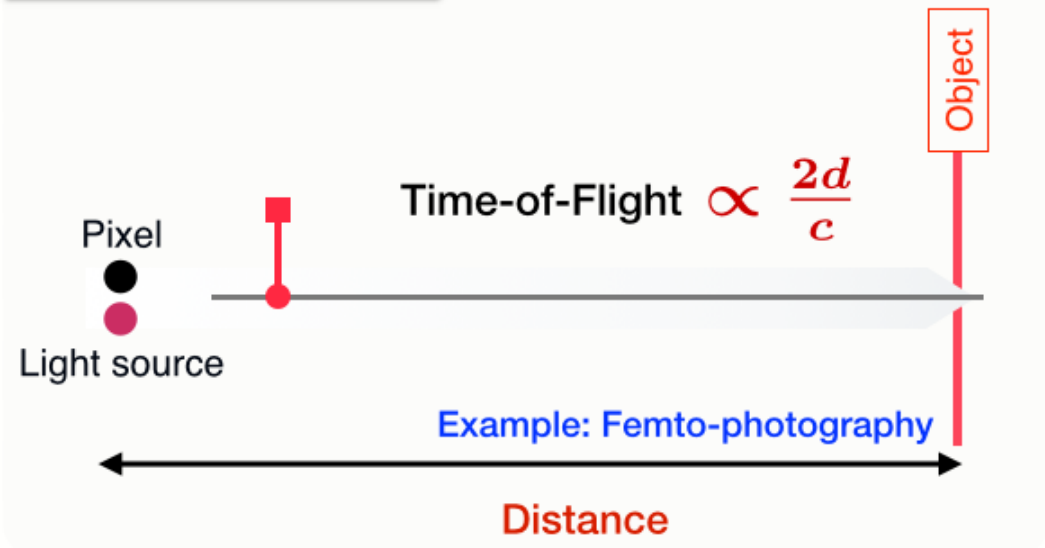
Time-of-Flight Sensors: Computes depth based on speed of light (aka SONAR with light.)

Time-of-Flight Principle: Distance of object is proportional to time traveled by light

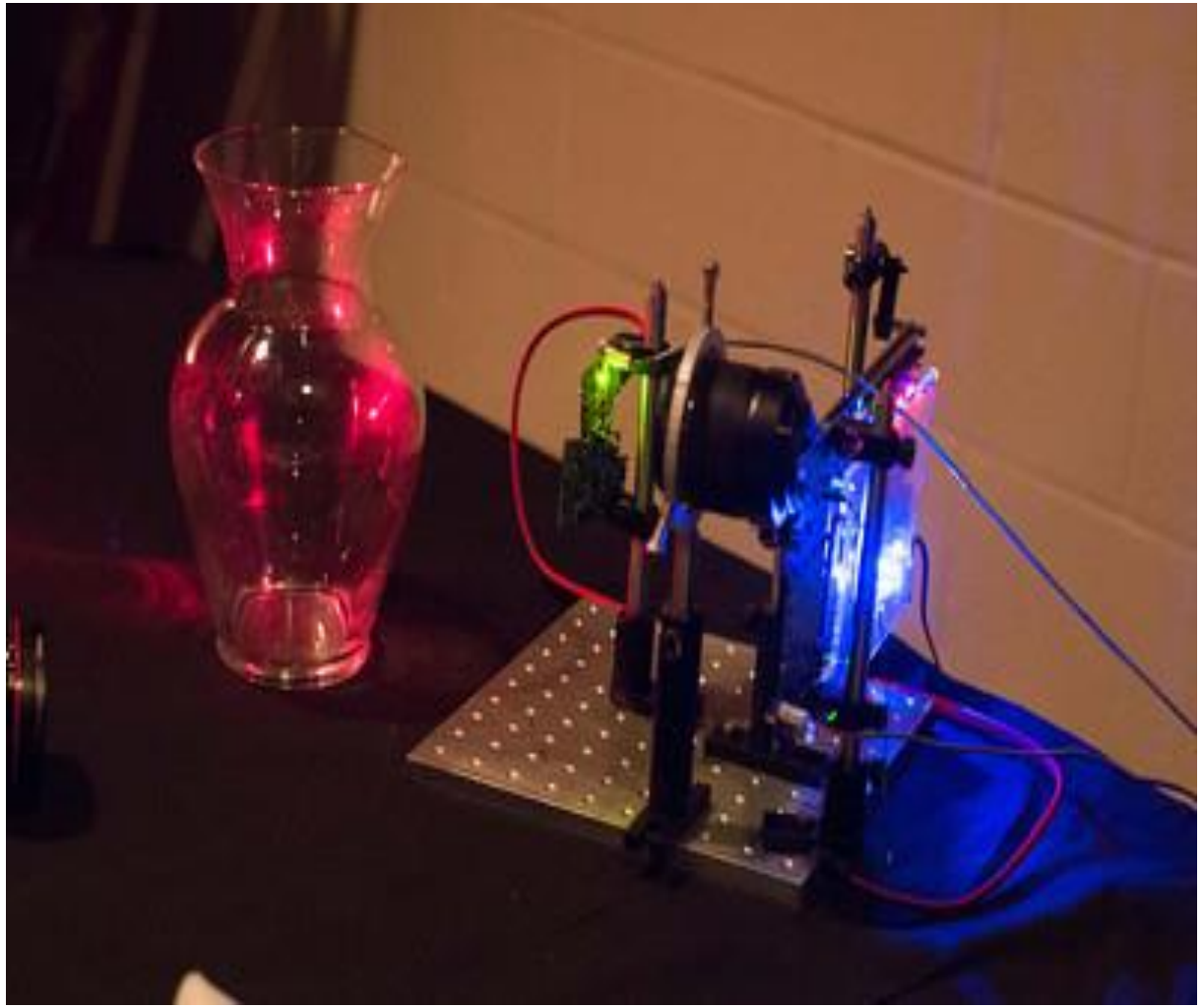
Continuous Wave ToF



Pulsed/Impulse Based ToF

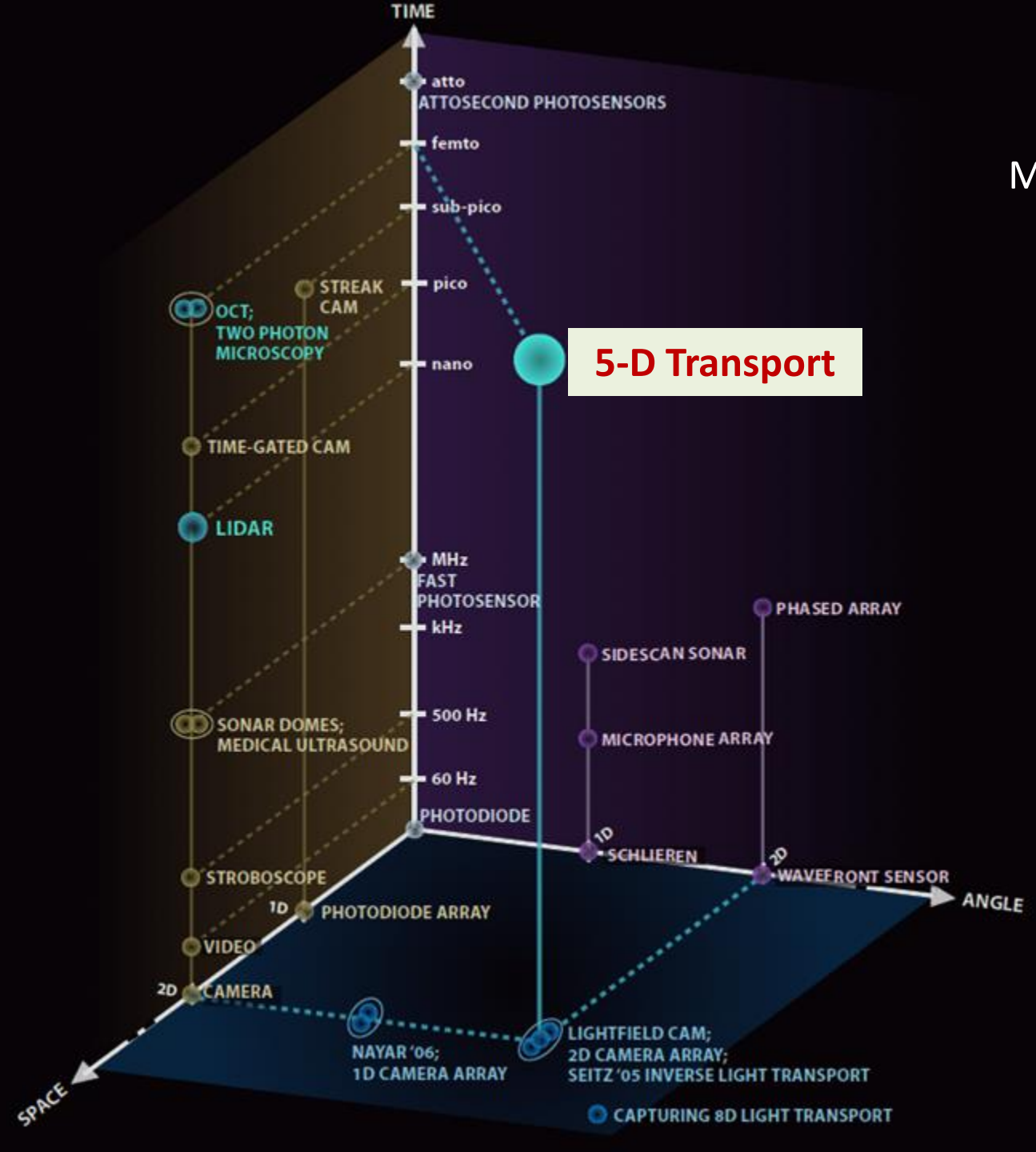


Nanophotography



[Kadambi et al 2013]

Multi-Dimensional Light Transport



Question: How does Imaging influence Autonomy?

Level 0: Driver only: the human driver controls everything independently,

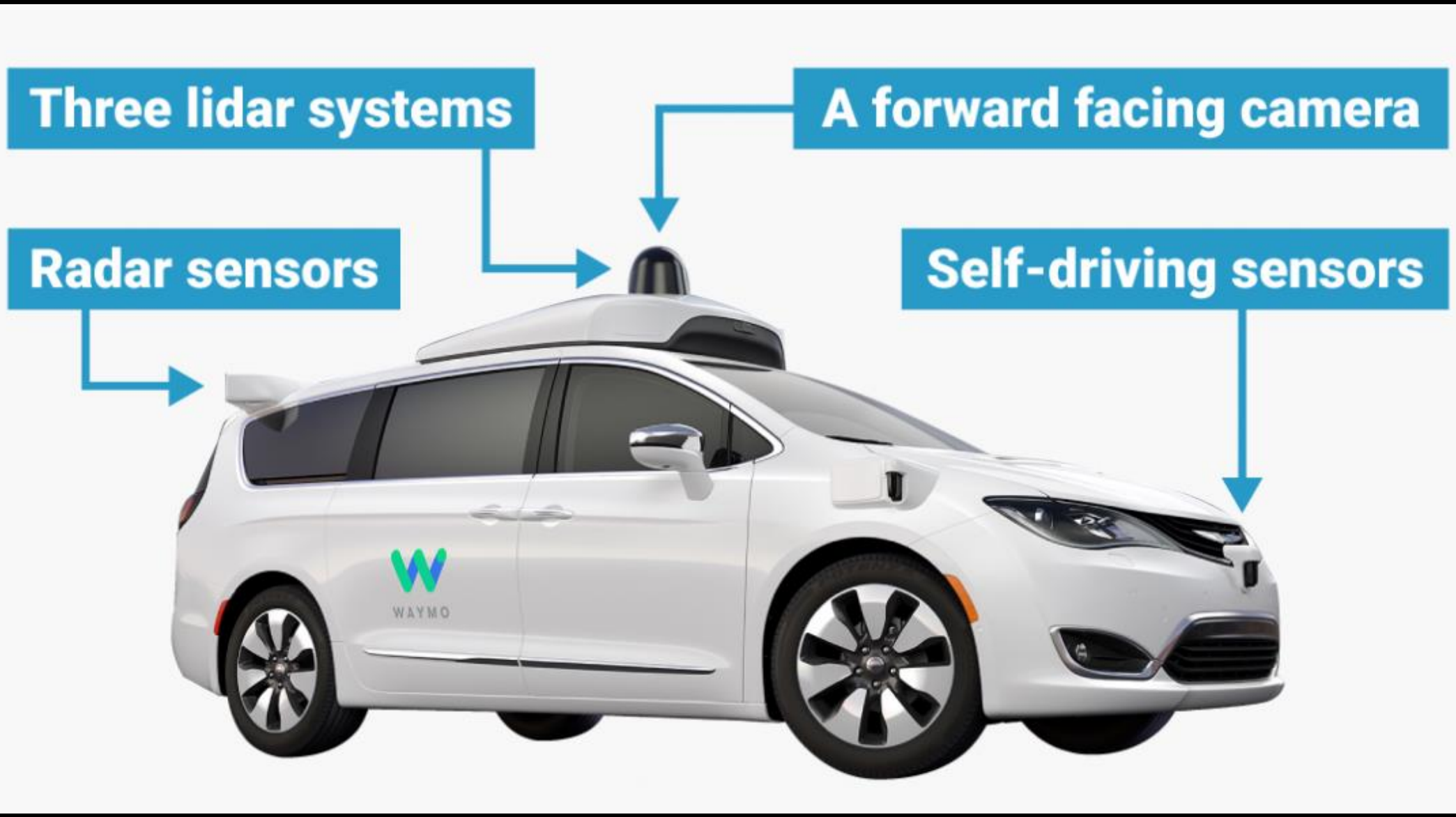
Level 1: Assisted driving: assistance systems help during vehicle operation (Cruise Control, ACC).

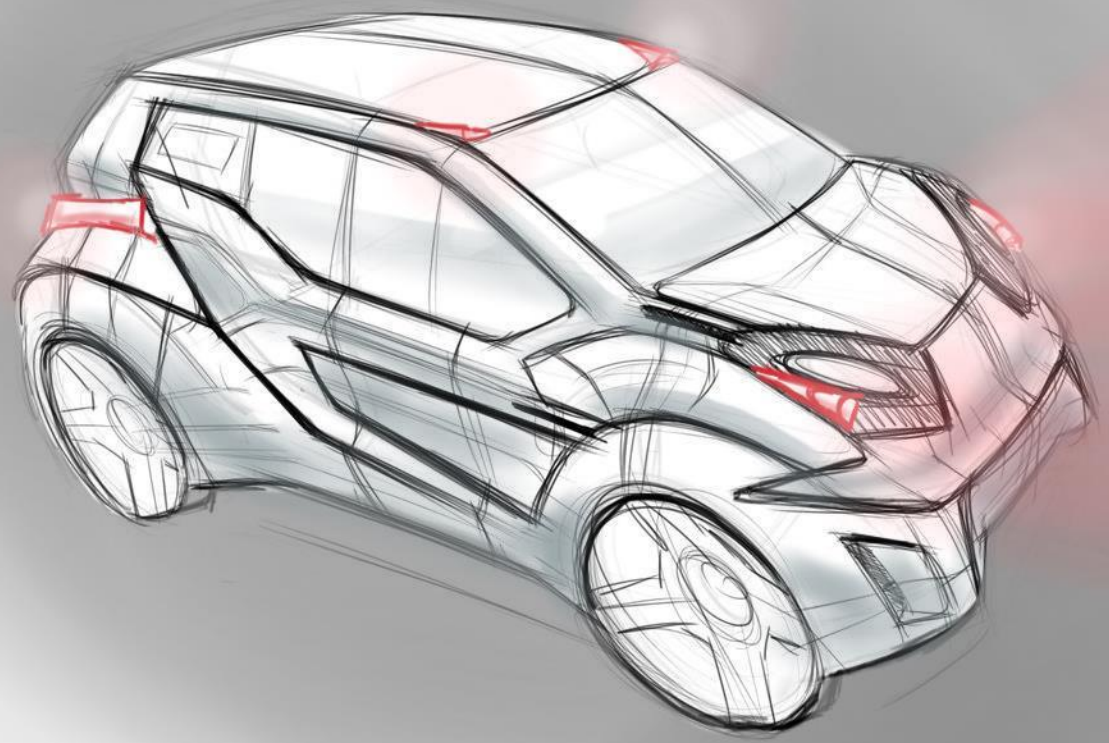
Level 2: Partial automation: the operator must monitor the system at all times.

Level 3: Conditional automation: the operator monitors the system and can intervene when necessary.

Level 4: High automation: there is no monitoring by the driver required. Vehicles are designed to operate safety-critical functions and monitor road conditions for an entire trip. However, the functions do not cover all every driving scenario.

Level 5: Full automation: operator-free driving.


Three lidar systems
A forward facing camera
Radar sensors
Self-driving sensors
WAYMO



Kadambi, Bhandari et al

Course Schedule

imagingav.media.mit.edu

13:30 – 13:50	Course Introduction *Ramesh Raskar (MIT)*
13:50 – 15:00	Existing Sensors and Their Limits *Guy Satat (MIT), Achuta Kadambi (UCLA)*
15:00 – 15:10	Break
15:10 – 15:50	Emerging 3D Sensors *Achuta Kadambi (UCLA)*
15:50 – 16:30	Imaging in Bad Weather *Guy Satat (MIT)*
16:30 – 16:40	Break
16:40 – 17:20	Deep Learning-based Computational Imaging *Jan Kautz (NVIDIA)*
17:20 – 17:30	Conclusion and Open Problems

CVPR 2018

Computational Imaging for Self-Driving Vehicles

Jan Kautz Ramesh Raskar Achuta Kadambi Guy Satat