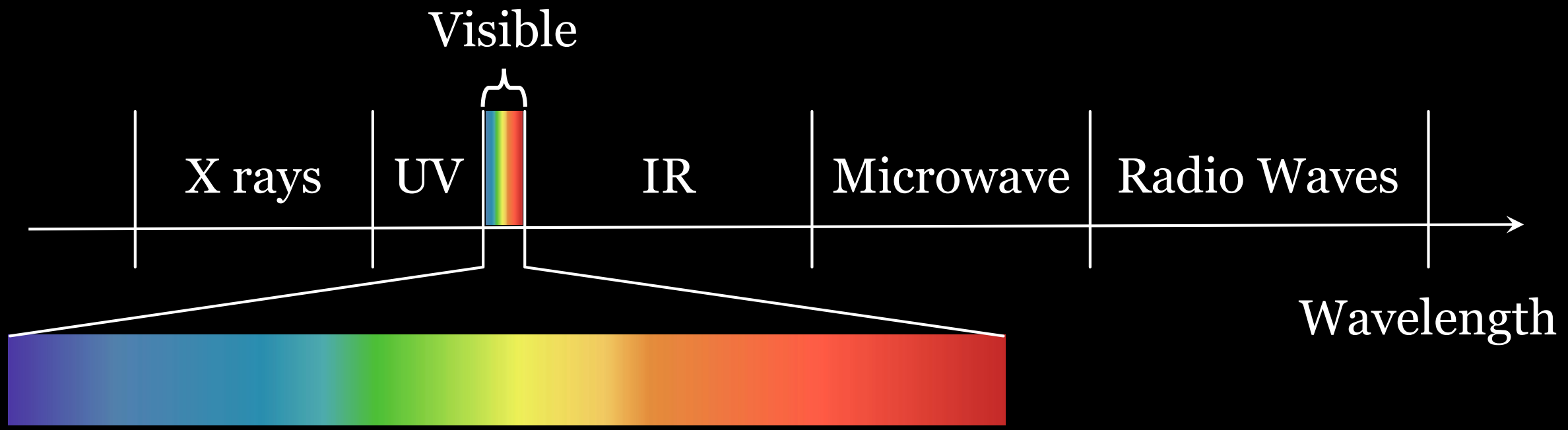
Seeing through Optical Barriers Using Visible Light

Guy Satat

May 25, 2017

AutoSens


Radar
Camera
Lidar



- Resolution
- Optical Contrast

Optical Contrast

Visible light

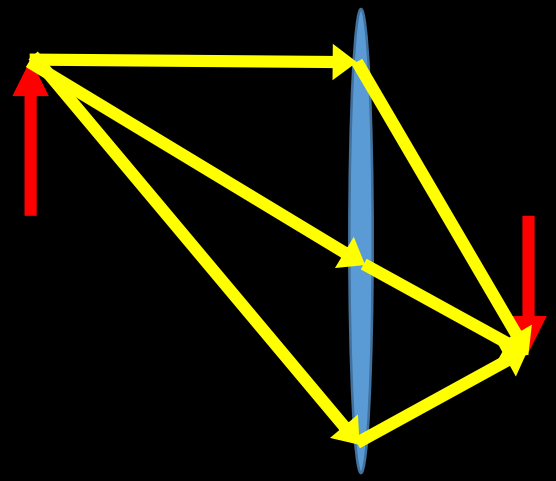
X-Ray

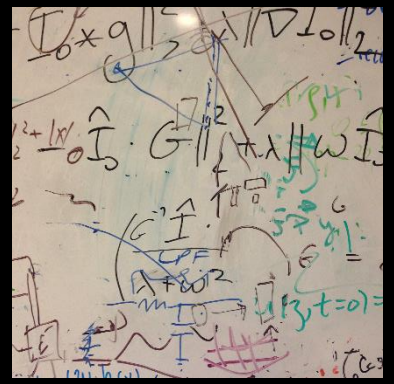
Light Scatters

Light and Matter in a Nutshell

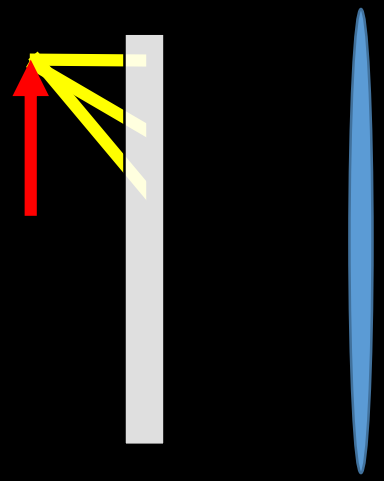
Object

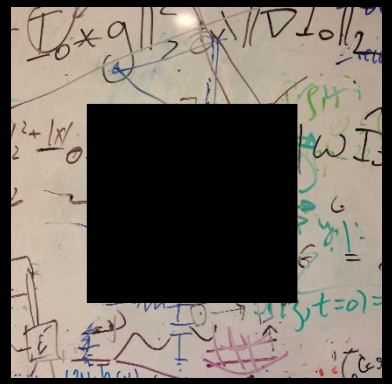
Lens



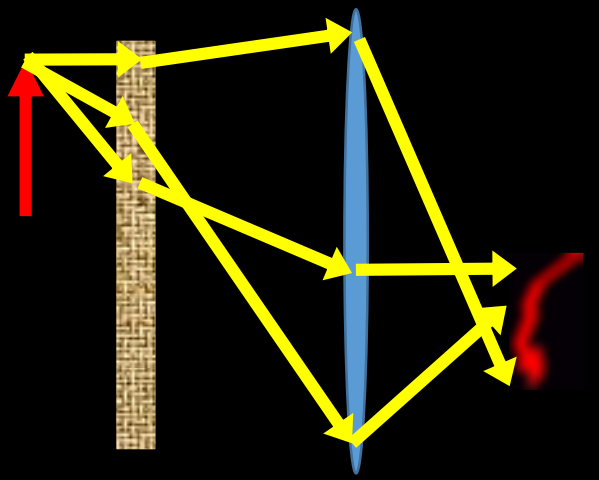


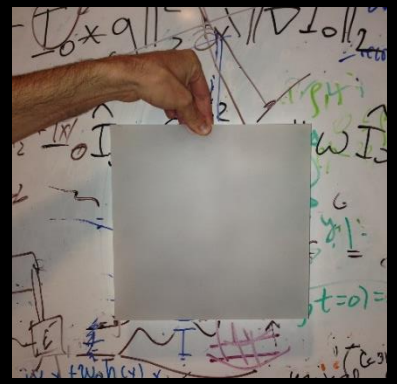
Absorption



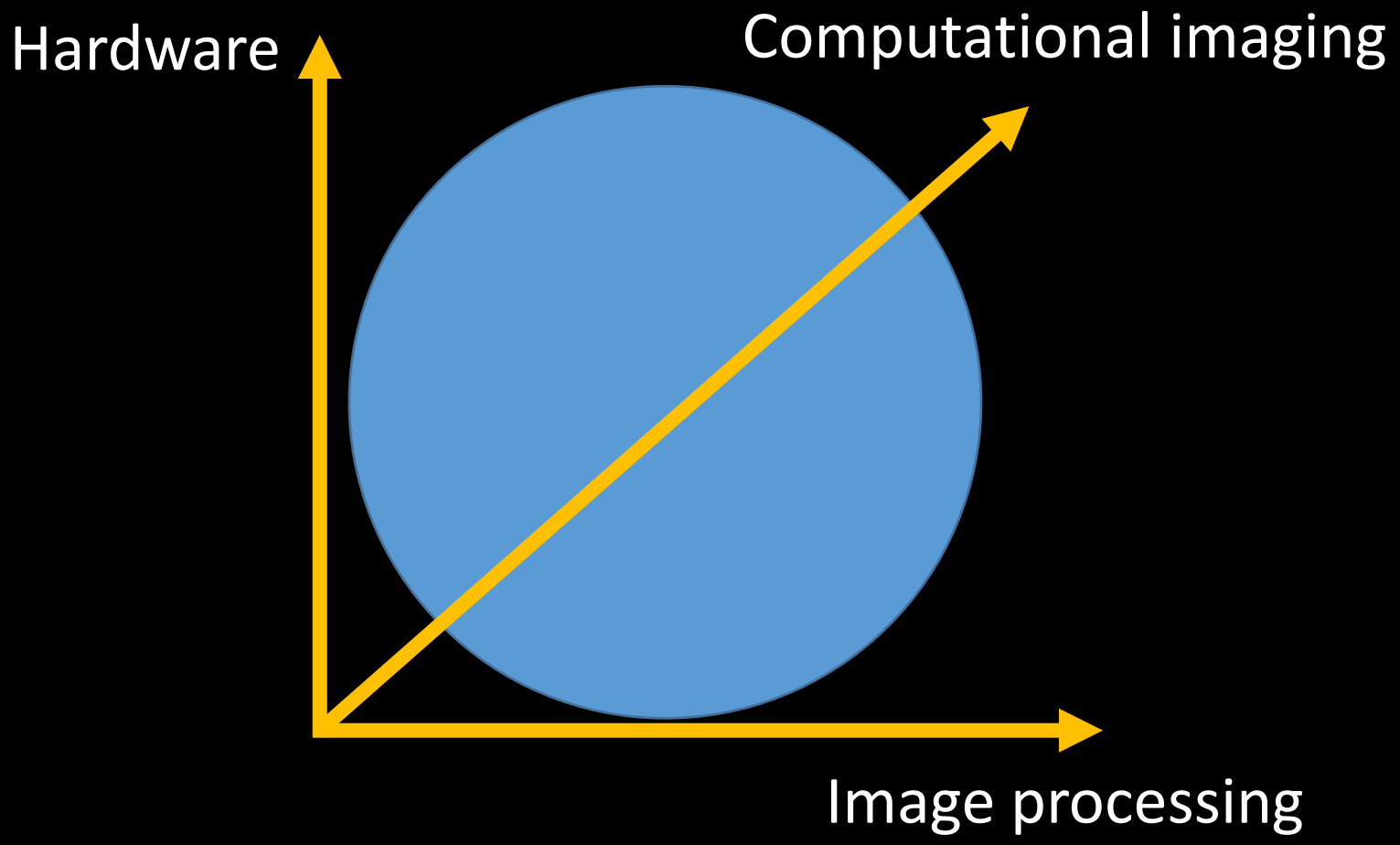


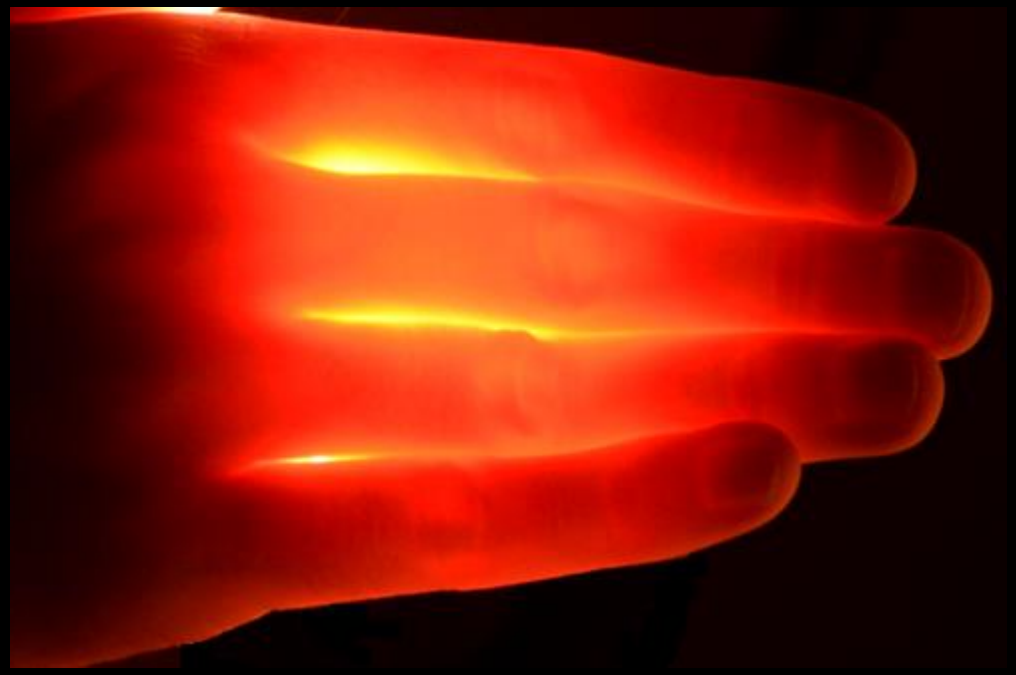
Scattering





How to Overcome Scattering





Lessons learned from seeing into the body

Information Carried by Light

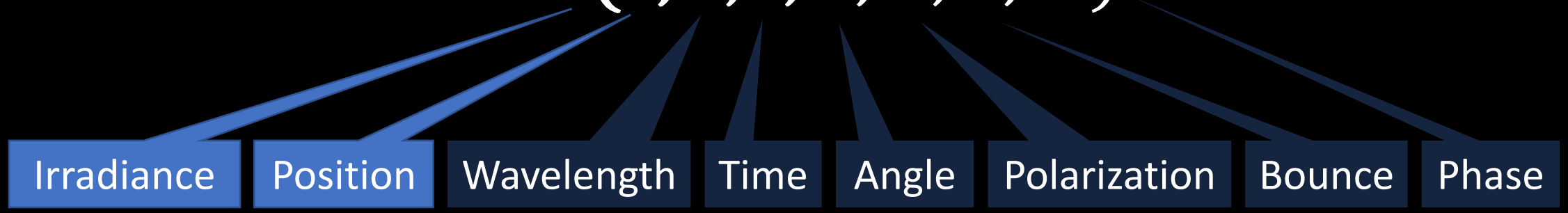
- The plenoptic function:

$$I(r, \lambda, t, \theta, P, n, \Phi)$$

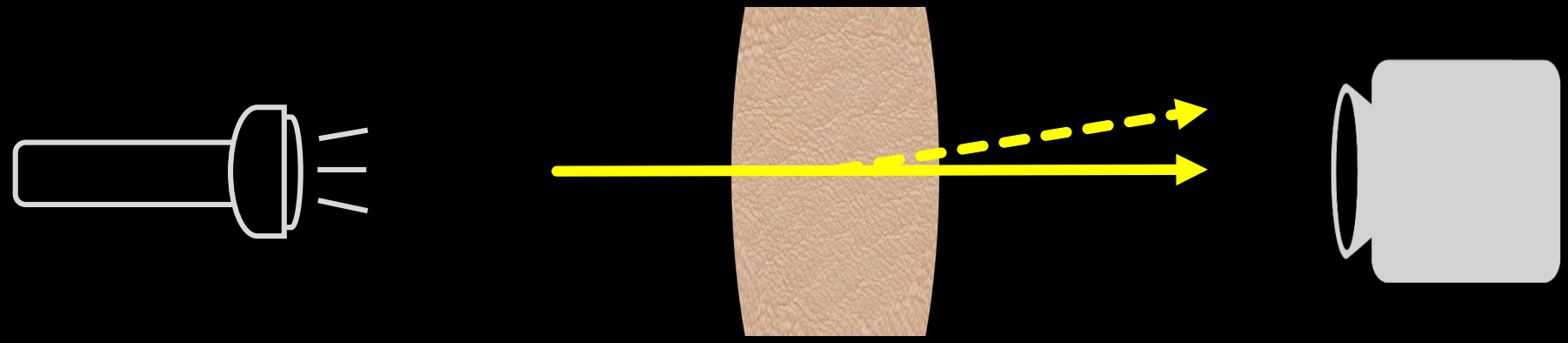
Information Carried by Light

- The plenoptic function:

$$I(r, \lambda, t, \theta, P, n, \Phi)$$



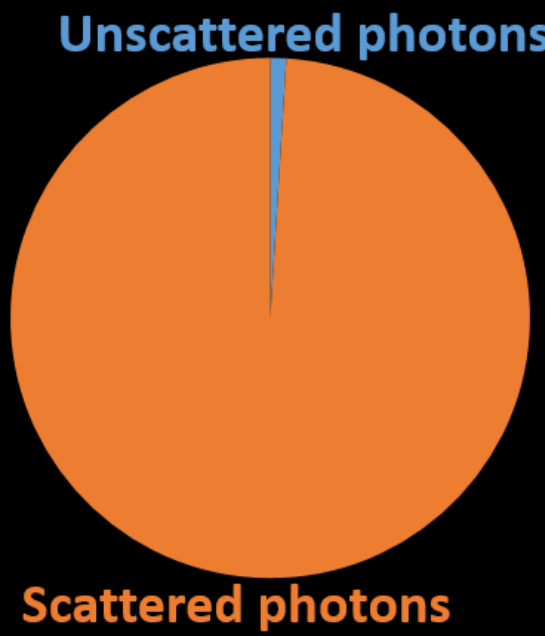
Optics Based Solutions



Photon gating:

- Angle
- Time
- Polarization

Not enough photons



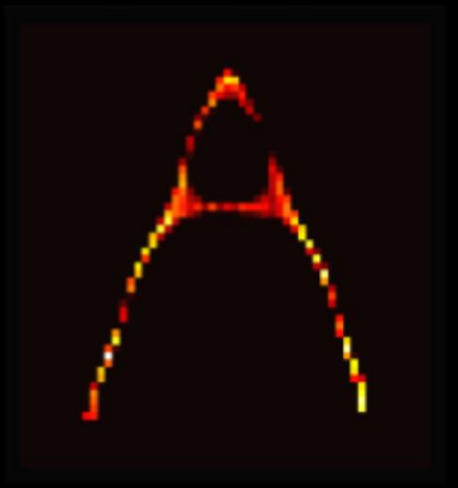
Use All Photons!

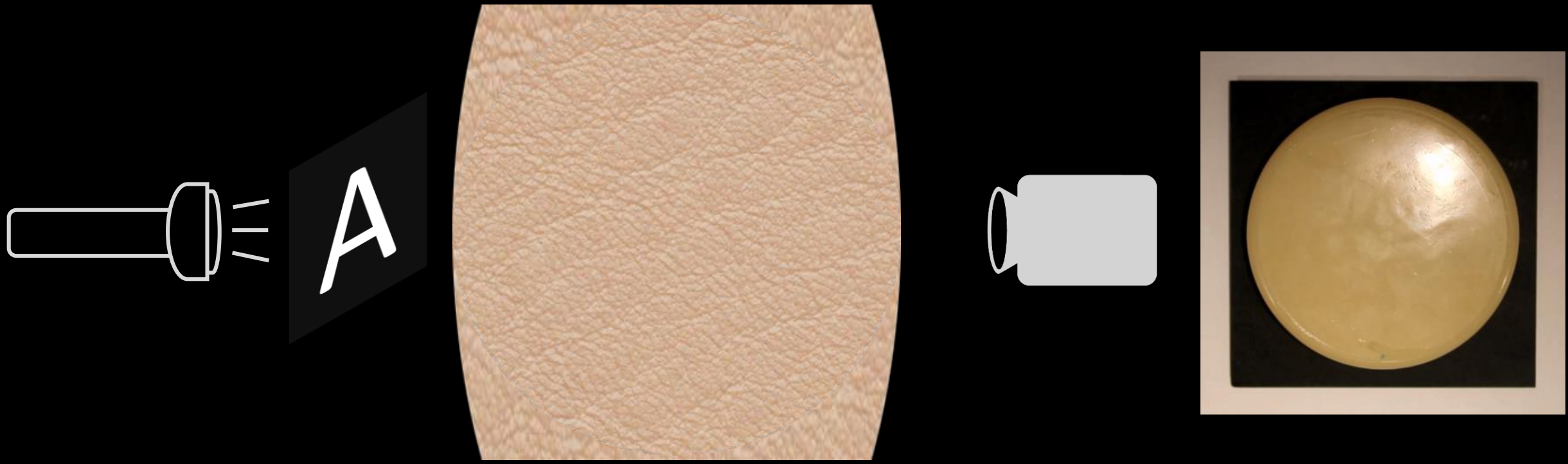
Computationally Invert Scattering

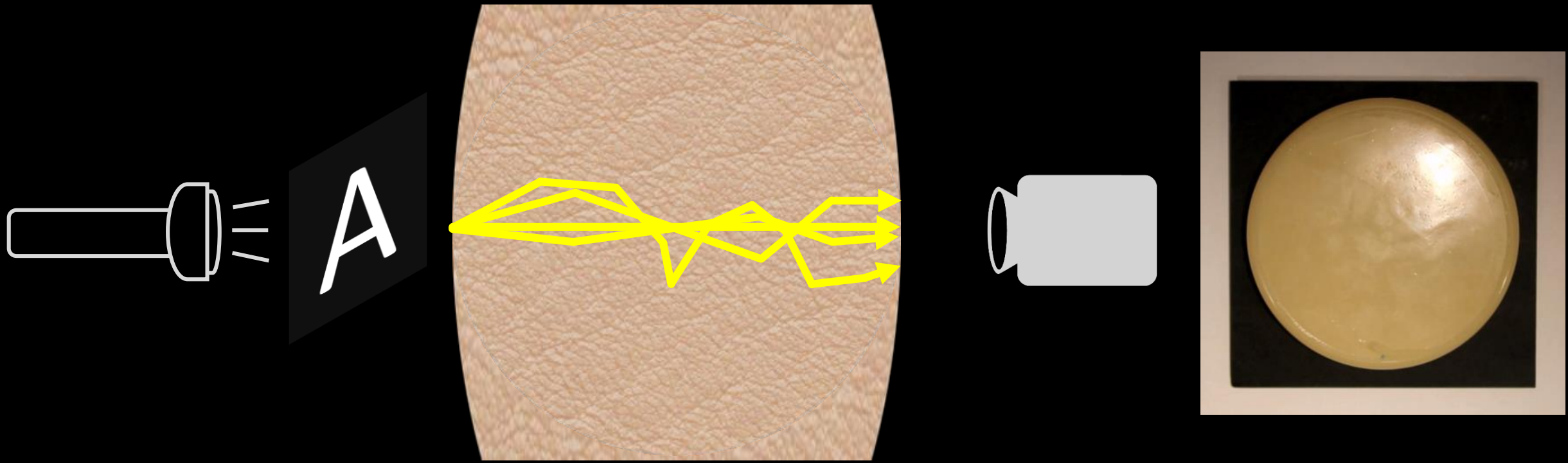
Satat, Heshmat, Raviv, Raskar *Nature Scientific Reports* 2016


A

- Estimate target
- Estimate scattering




A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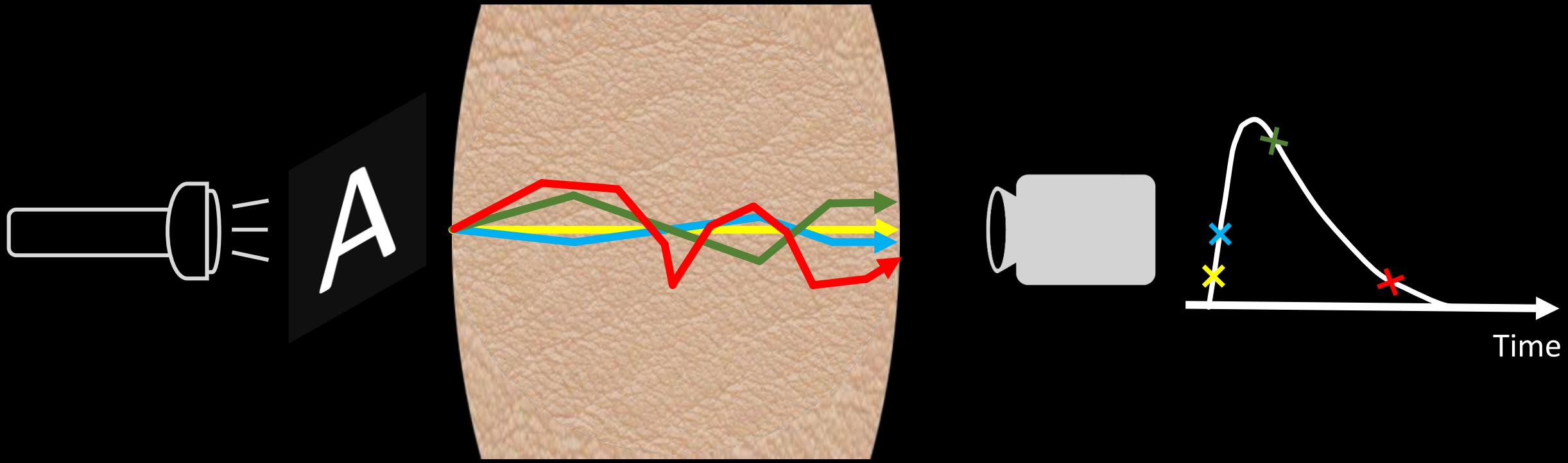
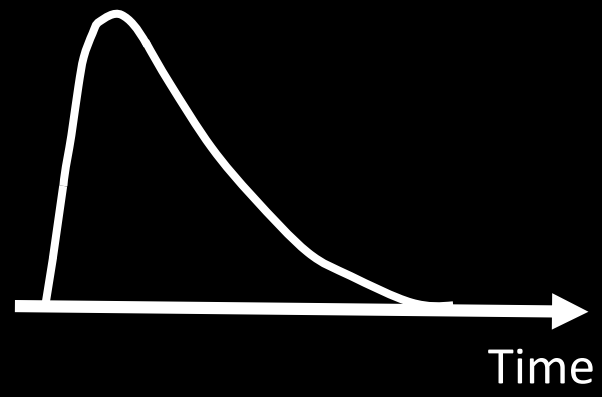

A
Time

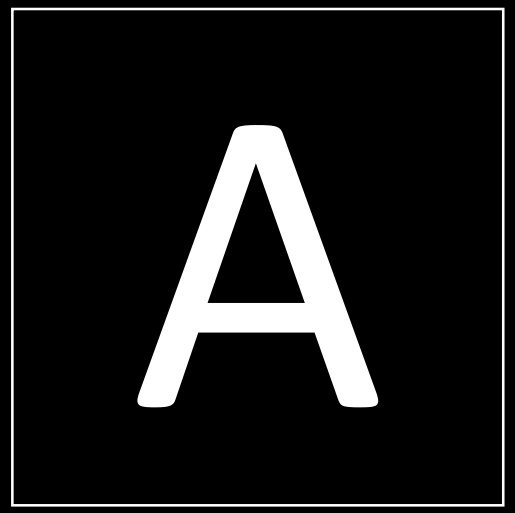
10,000,000,000 Slower

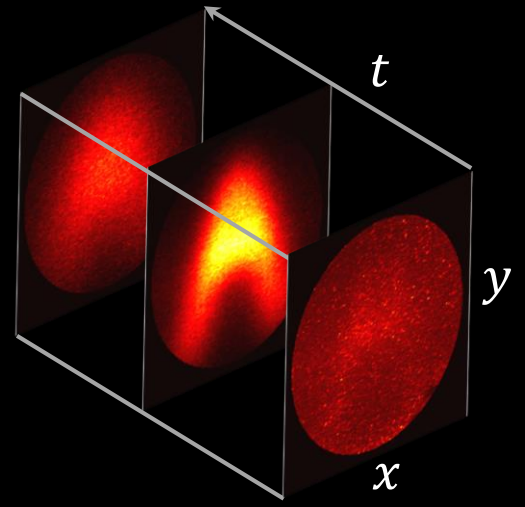


Scene

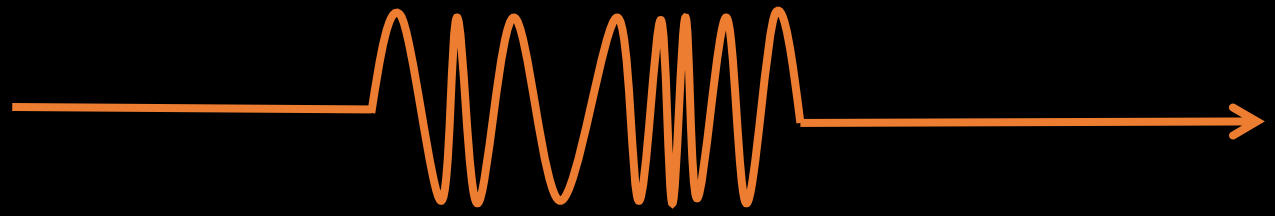
Scatterer

Measurement





Sharp
2D



Blurred
3D

$$s(x,y) \quad * \quad K(x,y,t) \quad = \quad m(x,y,t)$$

Estimating the Scattering - $K(x, y, t)$

- Point Spread Function
- Probabilistic interpretation:
  - Probability to measure photon at specific location and time
  - Bayes rule

$$K(x, y, t) = f_T(t)\, W(x, y|t)$$

Probability to measure a photon at time t

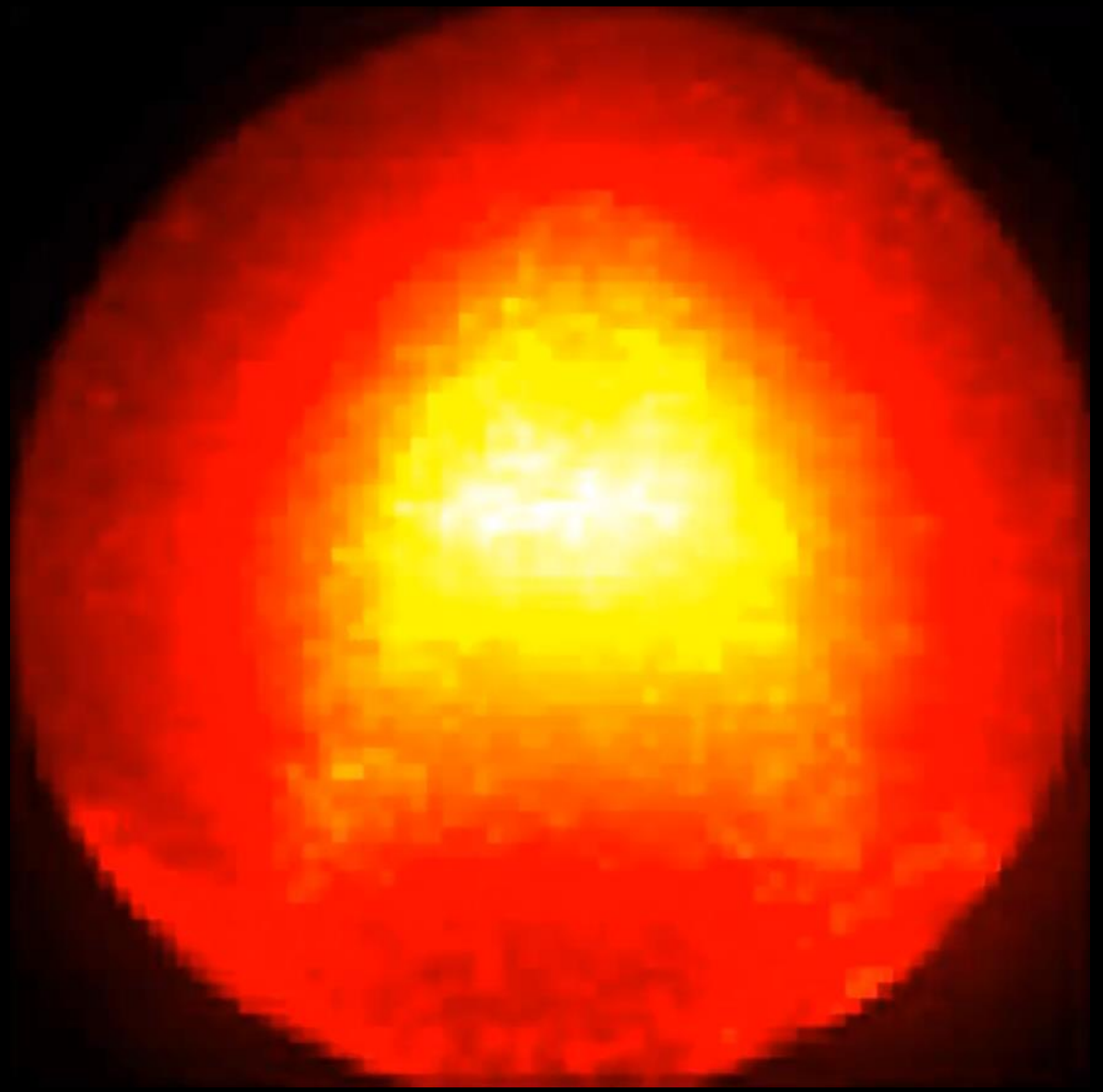
Given the time, probability to measure a photon at location x, y

Estimating the Scattering - $K(x, y, t)$

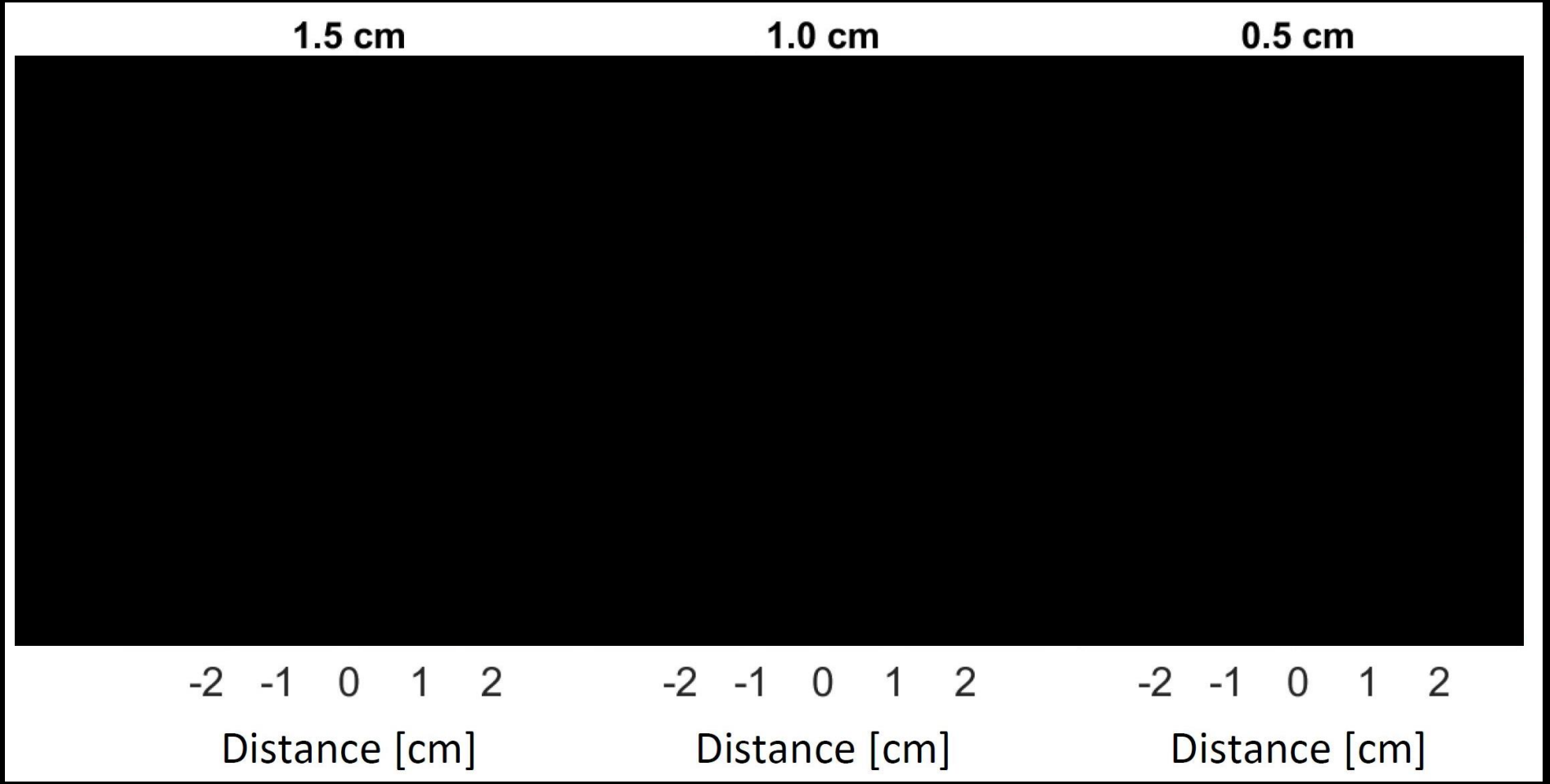
$$K(x, y, t) = f_T(t)\, W(x, y|t)$$

- $f_T(t)$, $W(x, y|t)$ – Easier to estimate

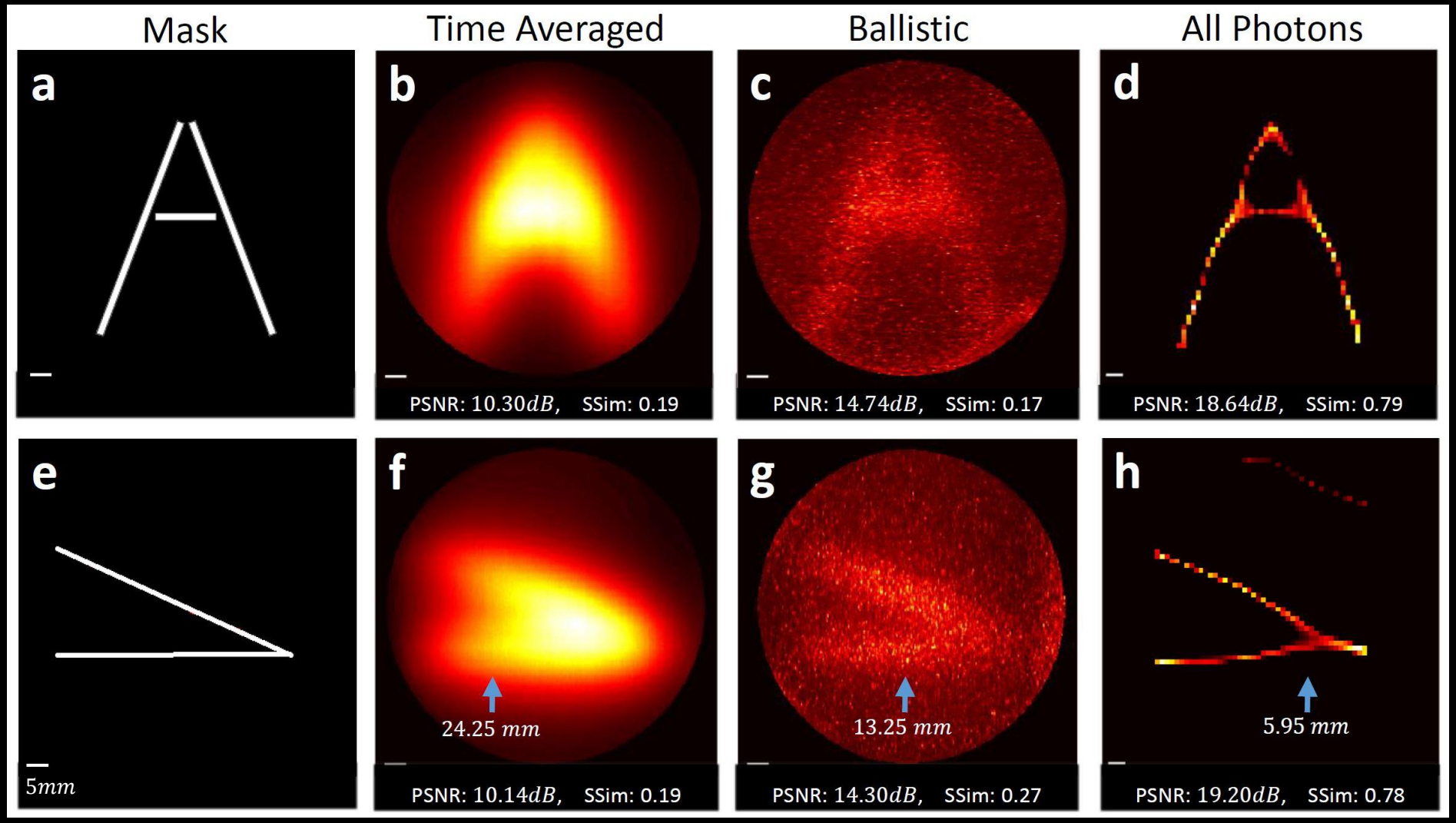
- Assumptions:
  - Enough samples to satisfy law of large numbers



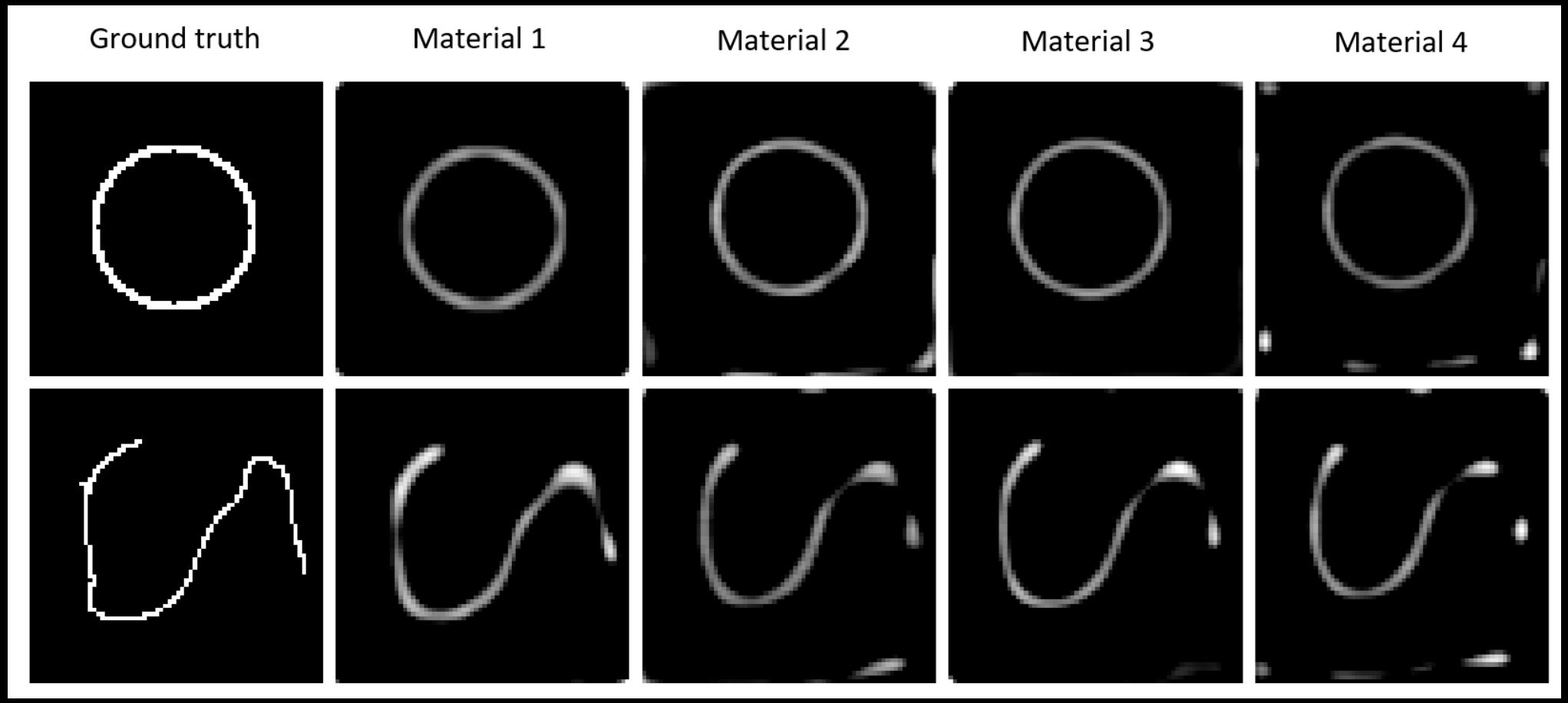
Recovery of Slits



Results


Mask
Time Averaged
Ballistic
All Photons
a
b
c
d
PSNR: 10.30dB, SSim: 0.19
PSNR: 14.74dB, SSim: 0.17
PSNR: 18.64dB, SSim: 0.79
e
f
g
h
5mm
24.25 mm
13.25 mm
5.95 mm
PSNR: 10.14dB, SSim: 0.19
PSNR: 14.30dB, SSim: 0.27
PSNR: 19.20dB, SSim: 0.78

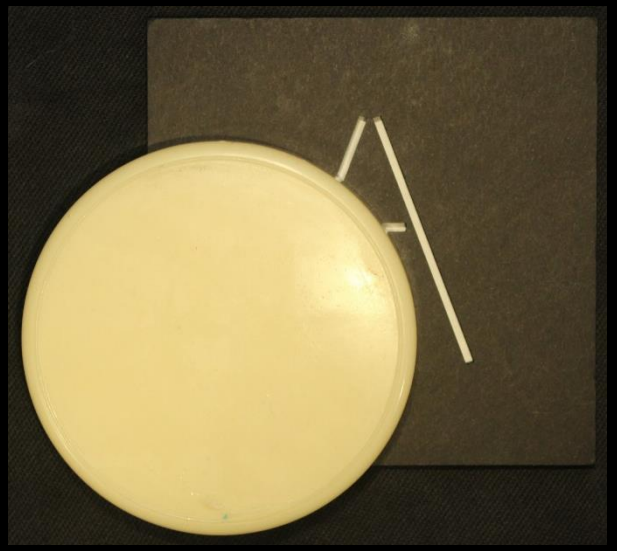
Invariant to Layered Material

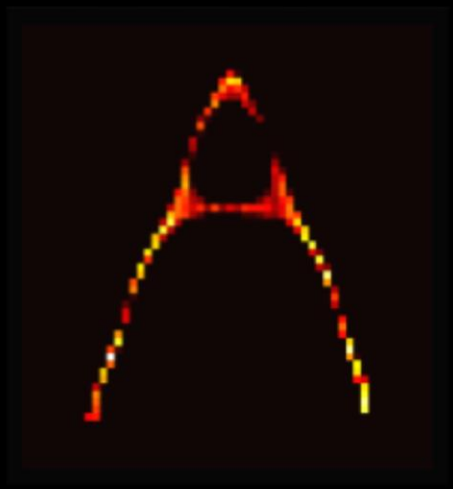


Satat, Heshmat, Raskar *COSI* 2017

Properties of All Photons Imaging

- Recovers scatterer and target
  - Calibration free
- Minimal assumptions
- Works with layered materials
- Doesn't require raster scan



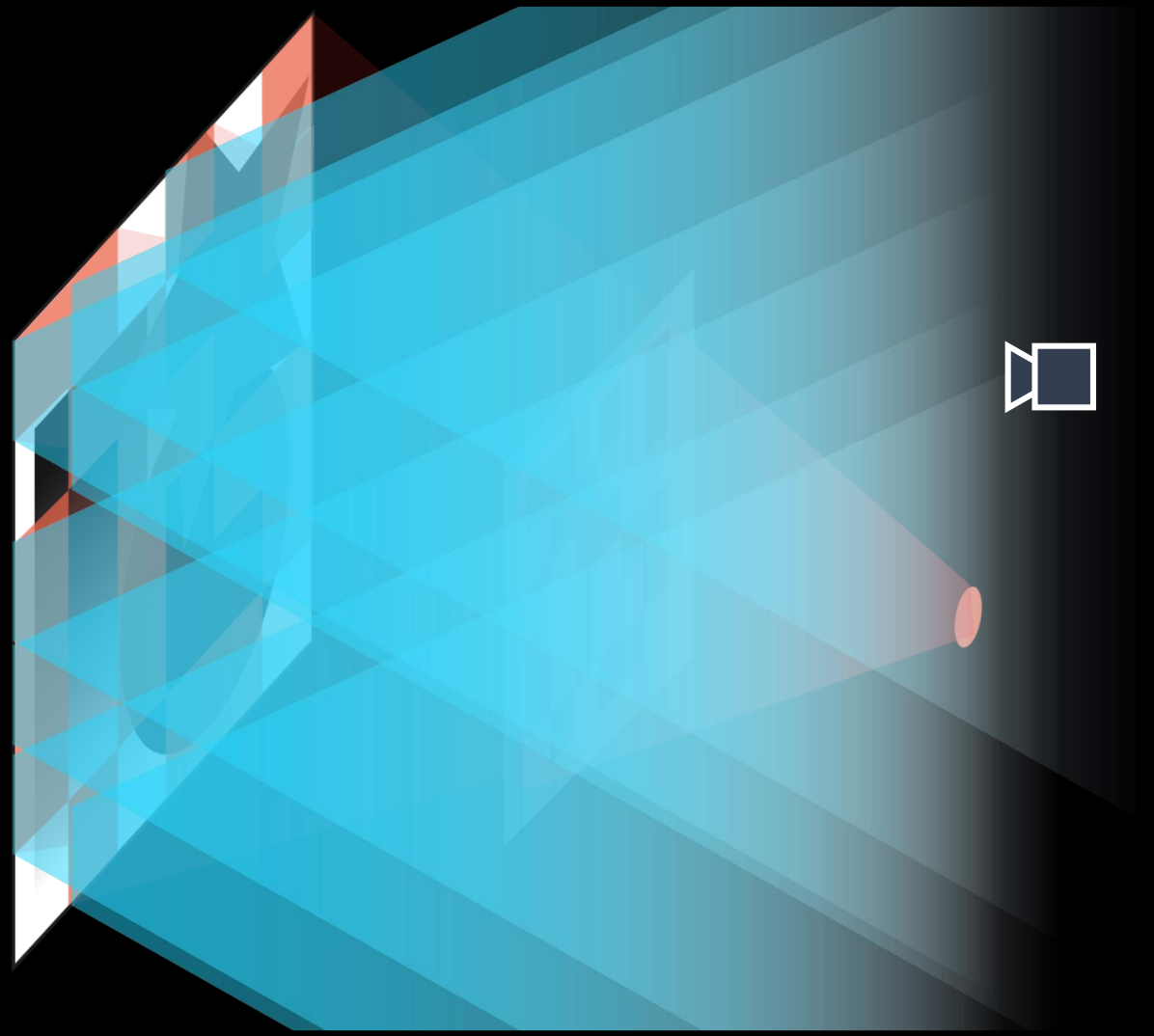


Challenges

Will It Scale?

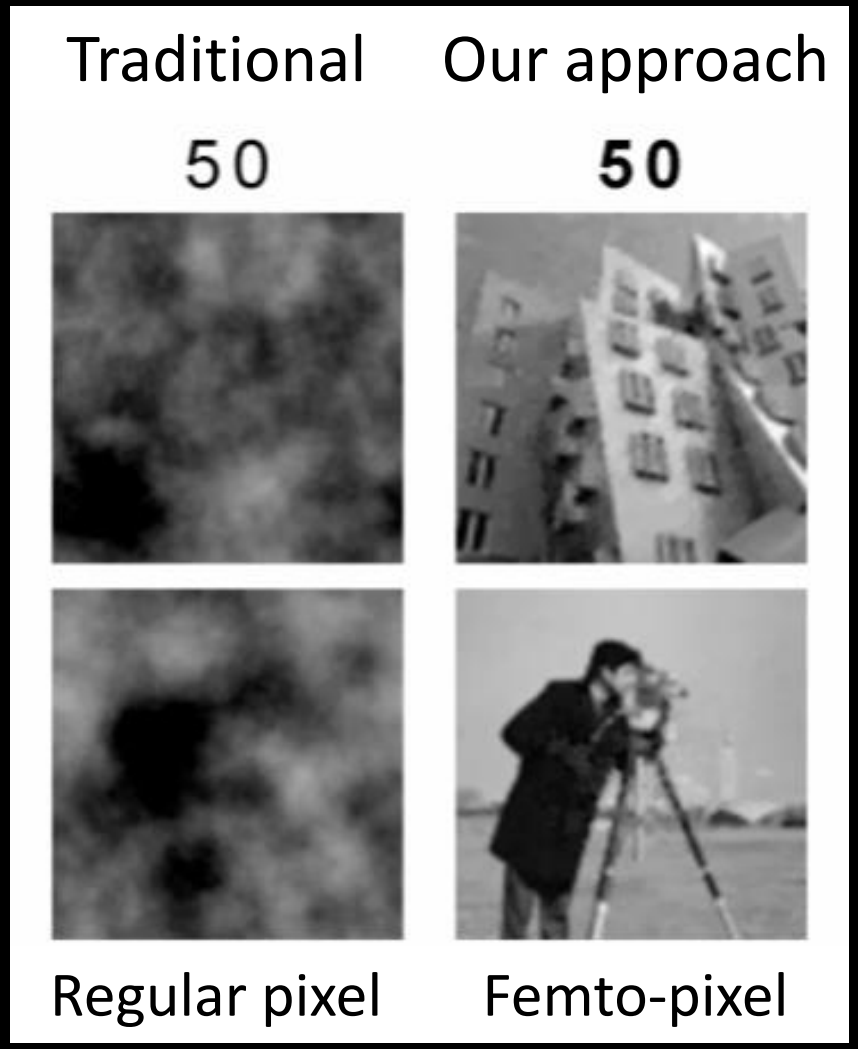
- Emerging sensors
- Can build on LIDAR
- Framework for low pixel count

Lensless Imaging with a Femto-Pixel

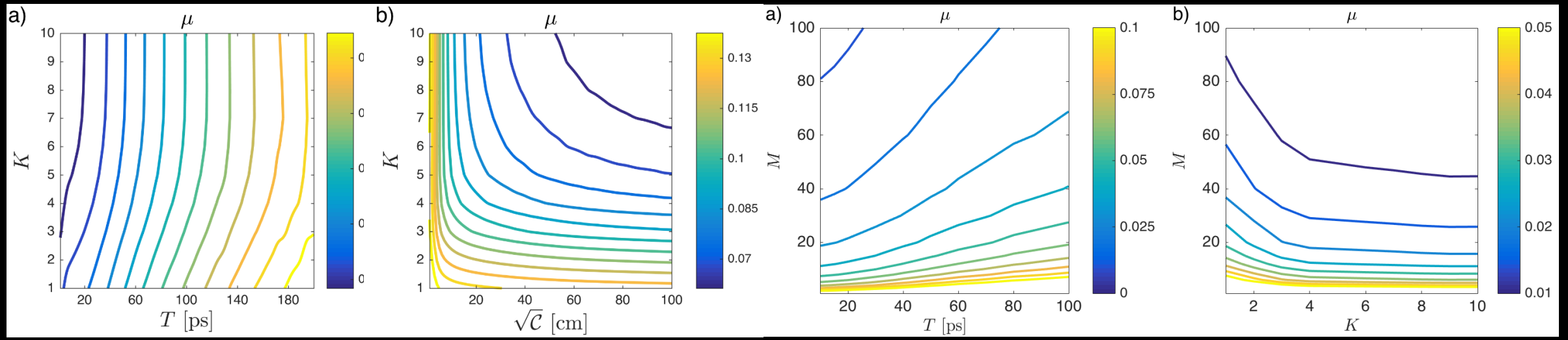


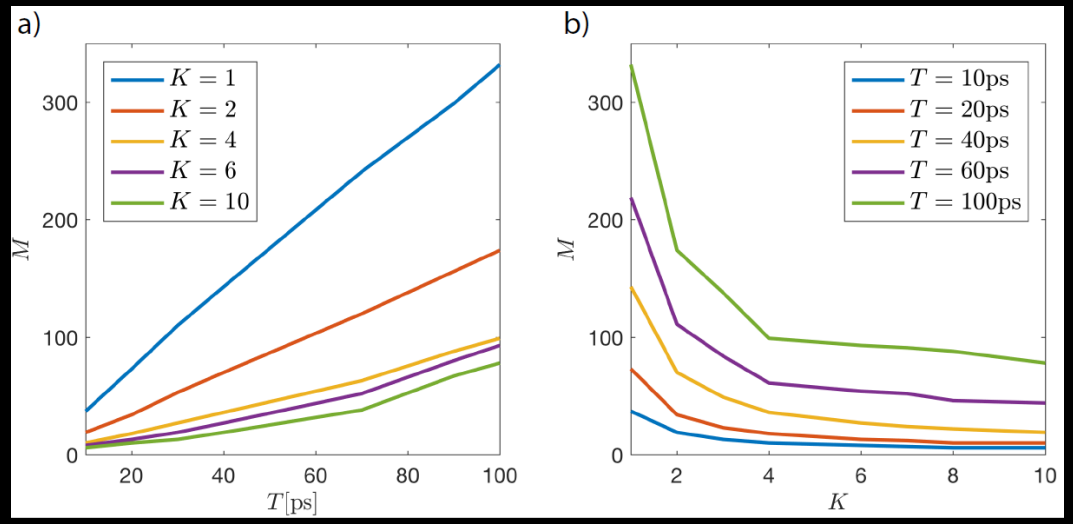
Satat, Tancik, Raskar *IEEE Trans. Computational Imaging* 2017

Lensless Imaging with a Femto-Pixel



Framework for Imaging with a Femto-Pixel





media.mit.edu/~guysatat
guysatat@mit.edu

Summary

- What if we could simply see through obstructions?
- Each photon has a story
- Super driver requires super vision

AutoSens