Passive Inter-Photon Imaging

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CVPR 2021

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Conventional Image Sensors

Charge-Coupled Imaging Devices: Experimental Results

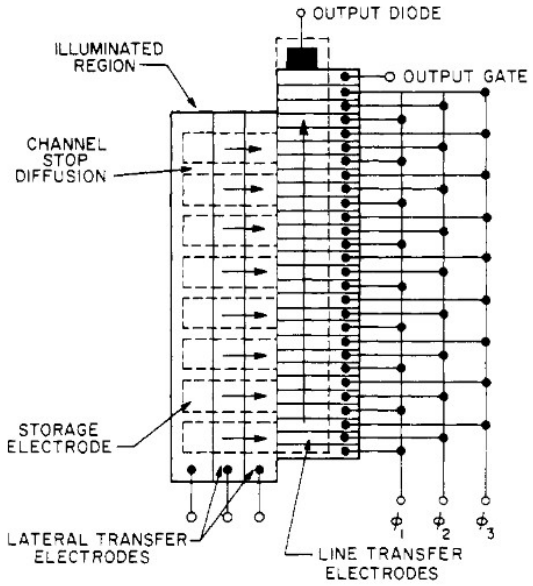
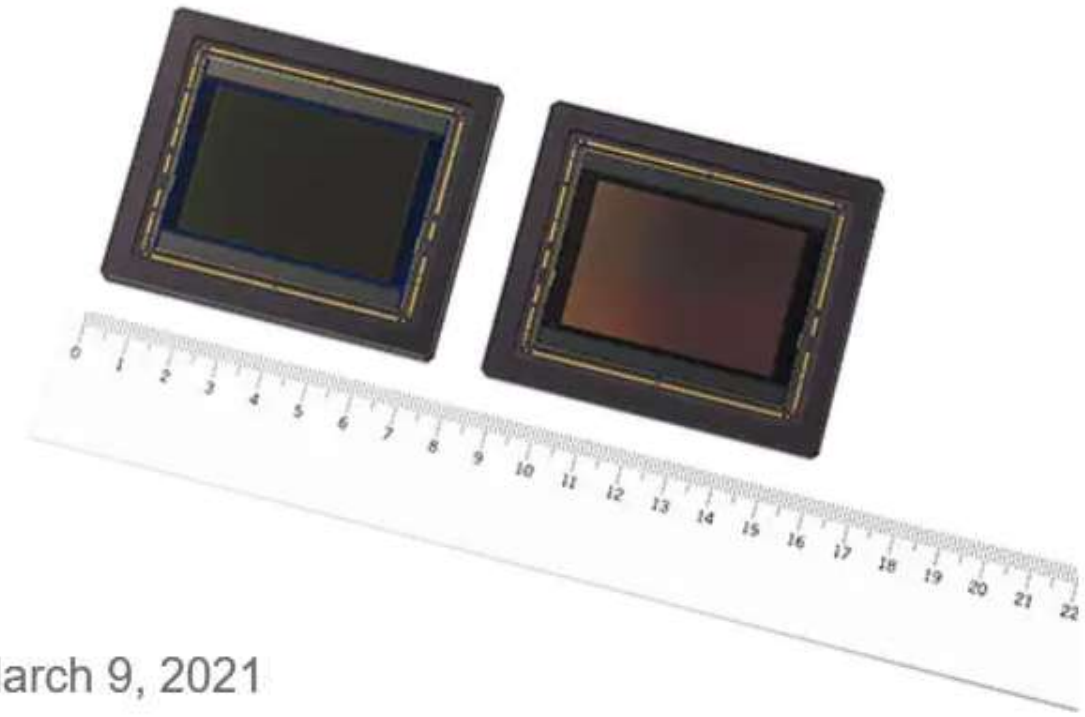


Fig. 6. A schematic diagram of a charge-coupled line imaging device with lateral transfer to eliminate shuttering.

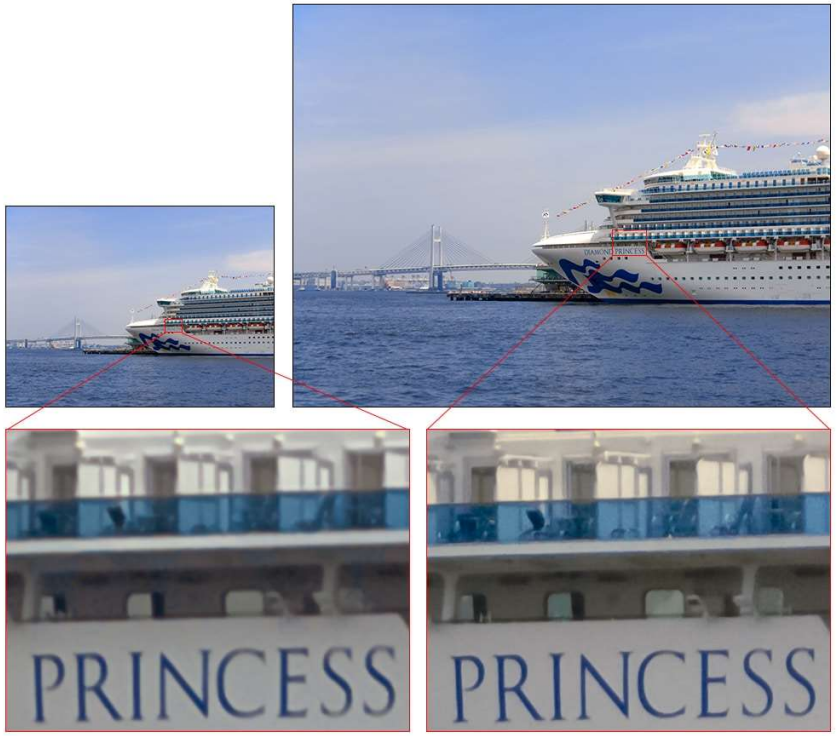
Fig. 5. Reproduction of a photograph demonstrating gray scale made using the 96-element CCD as a line scan imaging device. The device scan direction is horizontal and the image was mechanically scanned in the vertical direction. The operating frequency was 1 MHz.

Conventional Image Sensors

Sony to Release Large Format CMOS Image Sensor with Global Shutter Function and Industry's Highest Effective Pixel Count of 127.68 Megapixels

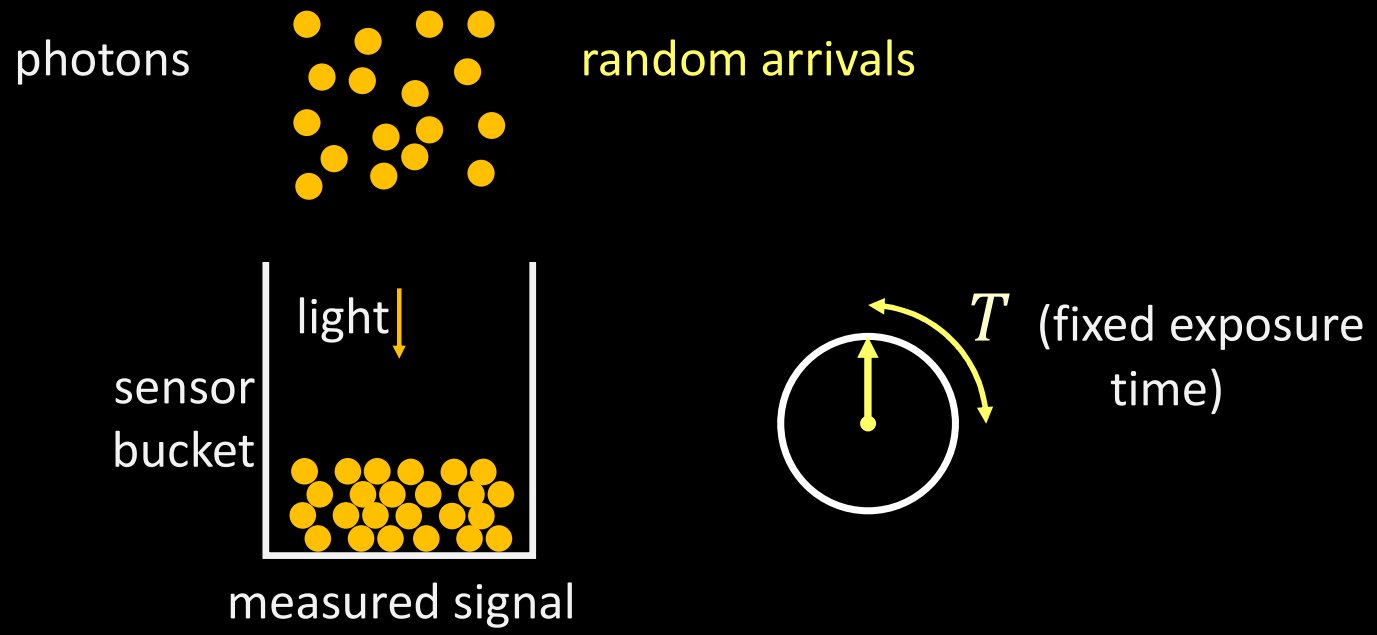


March 9, 2021

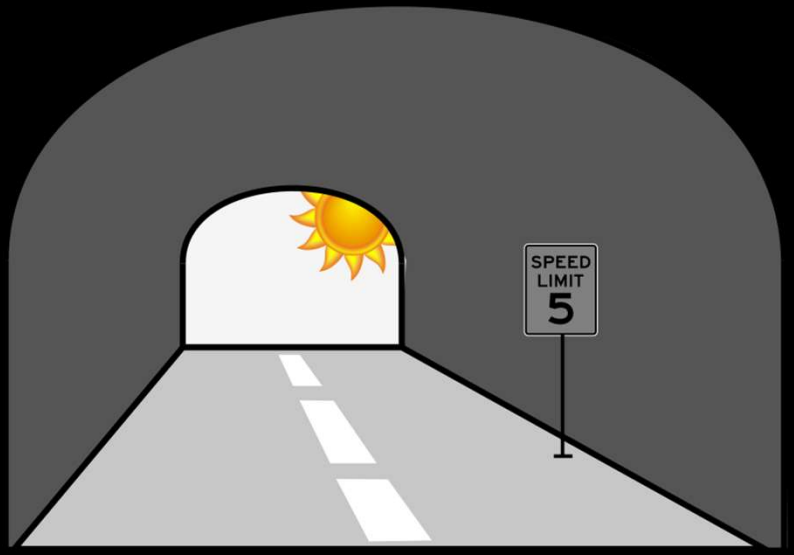


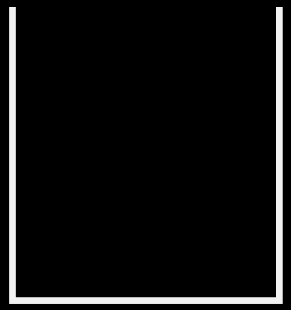
https://www.sony.com/en/SonyInfo/News/Press/202103/21-021E/

Conventional Image Sensor Pixel



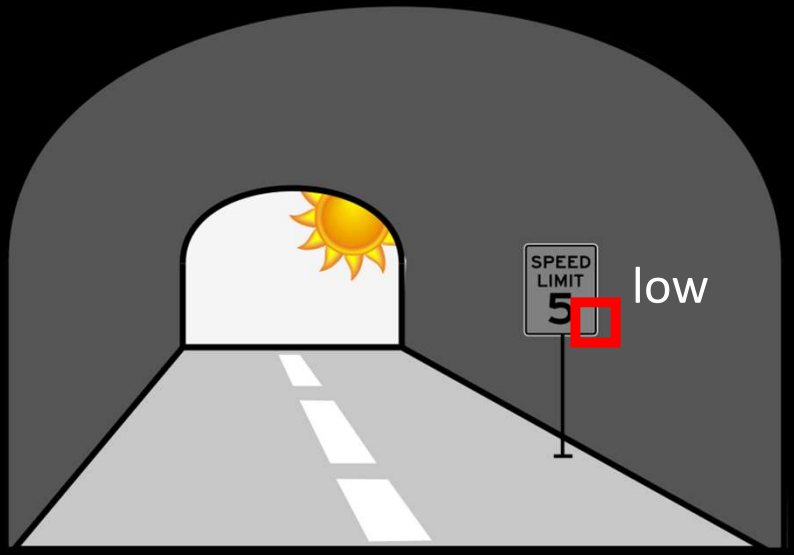
Conventional Image Sensor Pixel

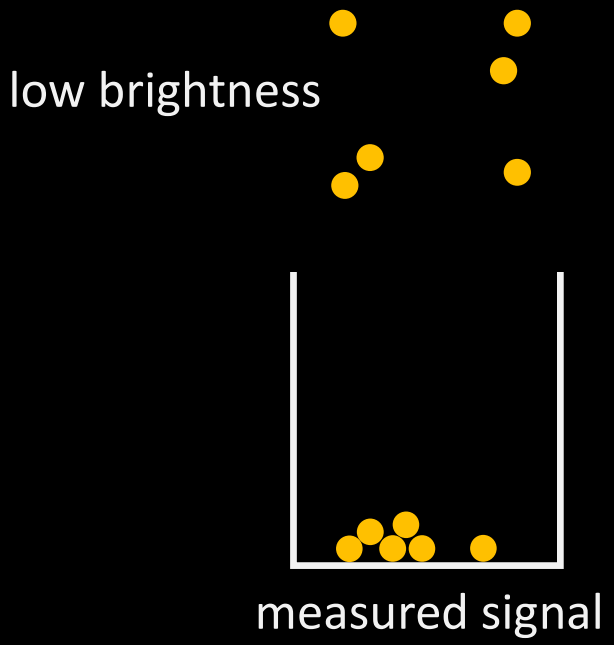




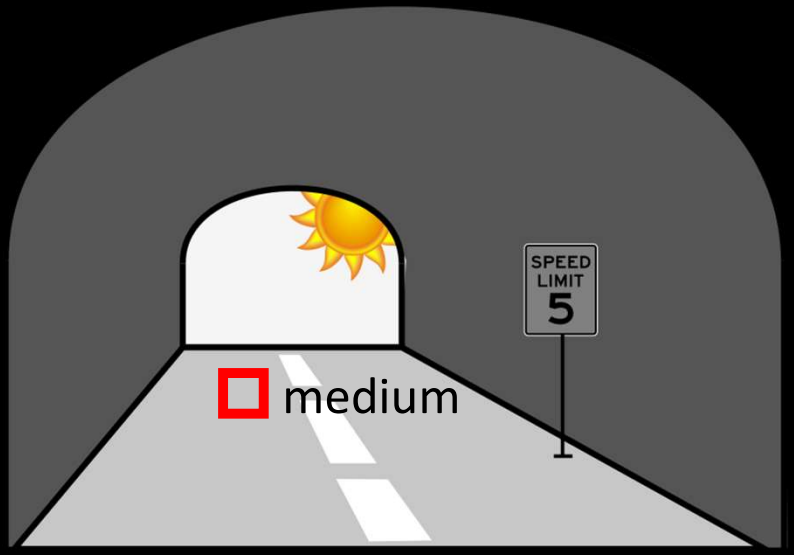
measured signal

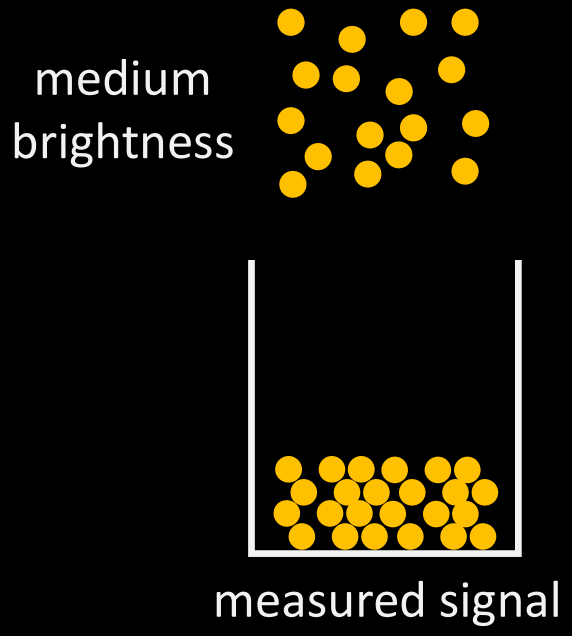
Conventional Image Sensor Pixel



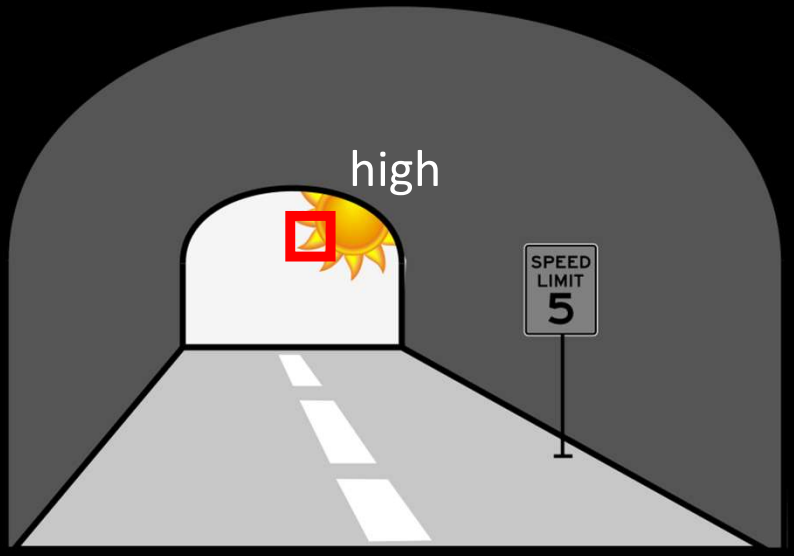


Conventional Image Sensor Pixel

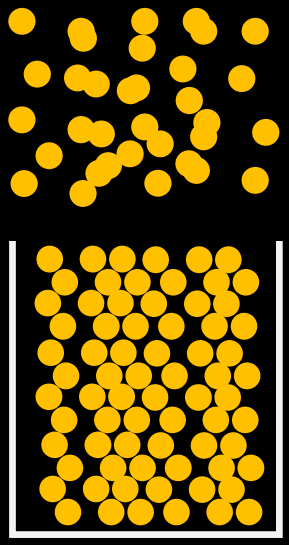




Conventional Image Sensor Pixel

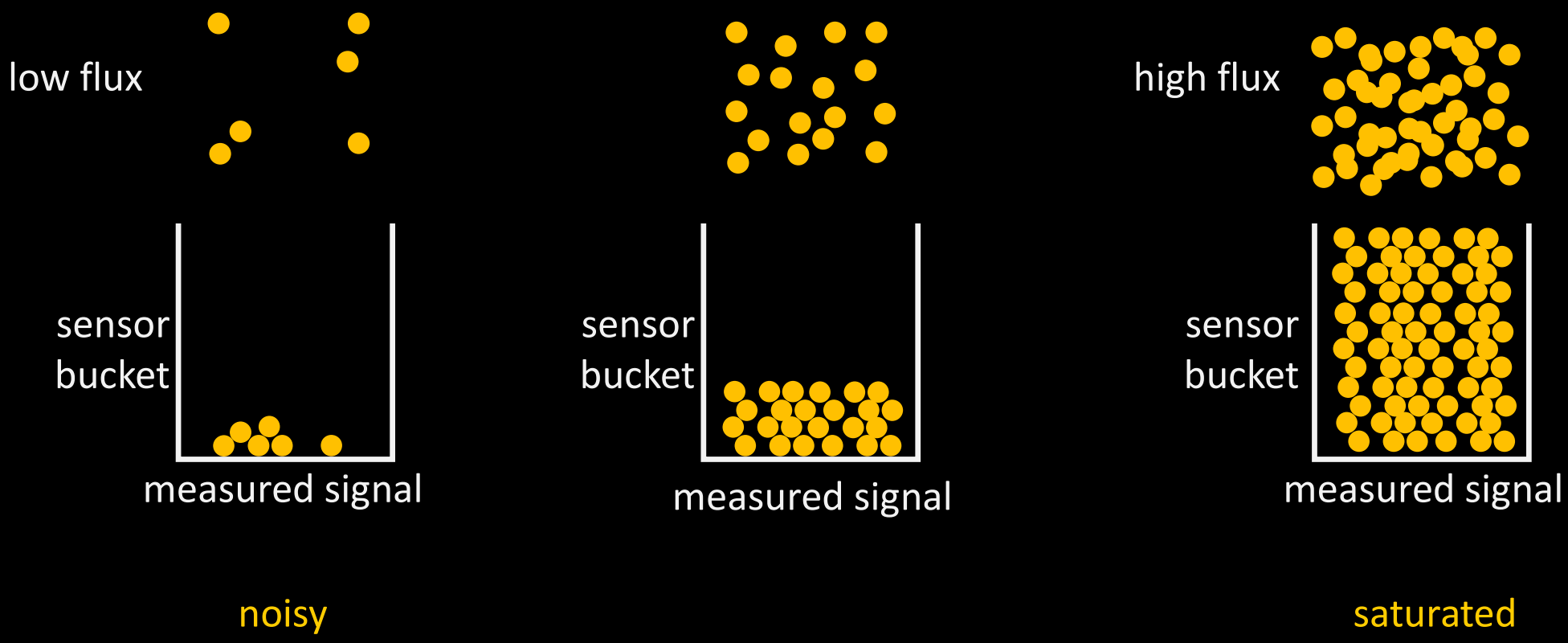


high brightness

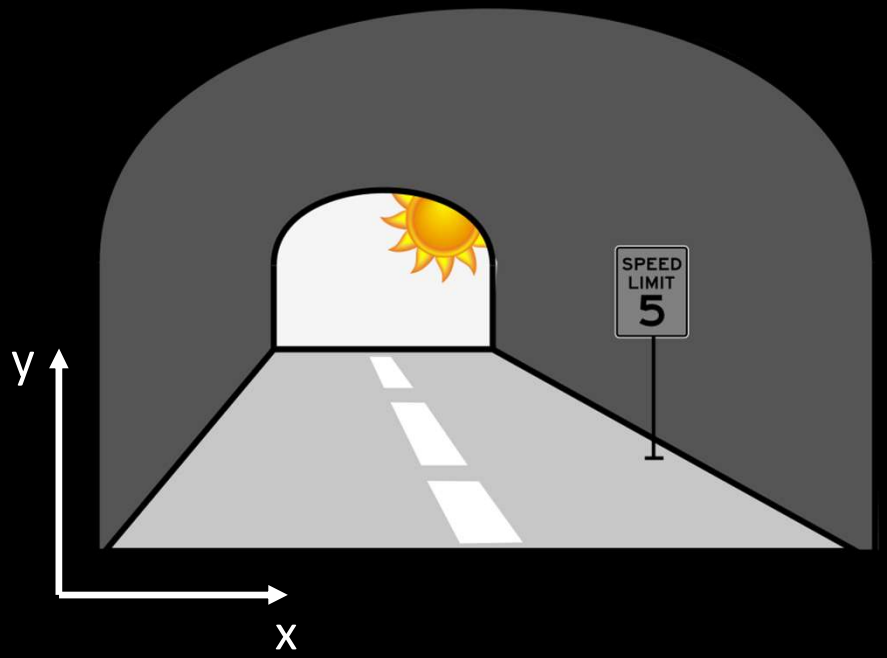


measured signal

Conventional Image Sensor Pixel



Photon Arrival Timelines



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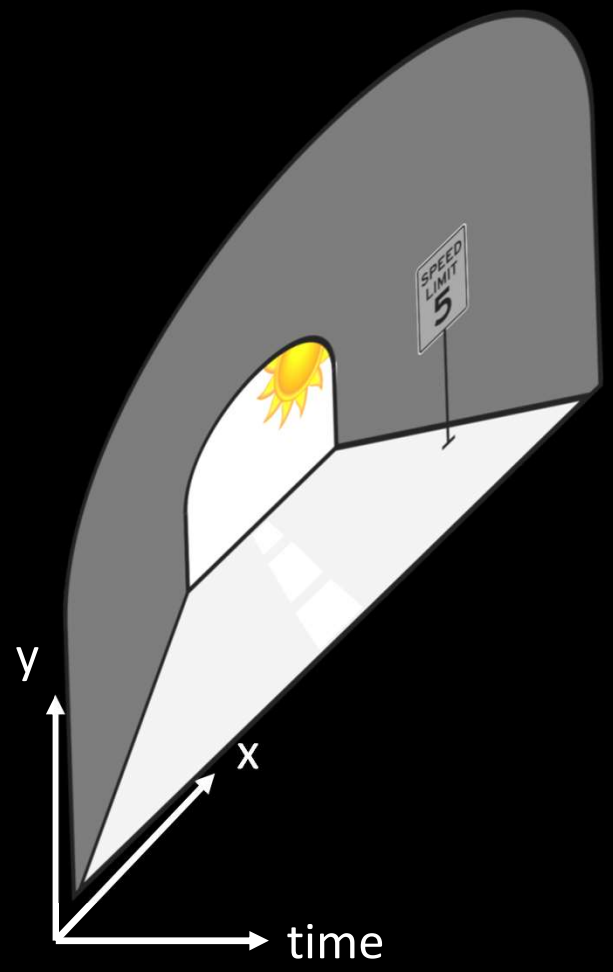

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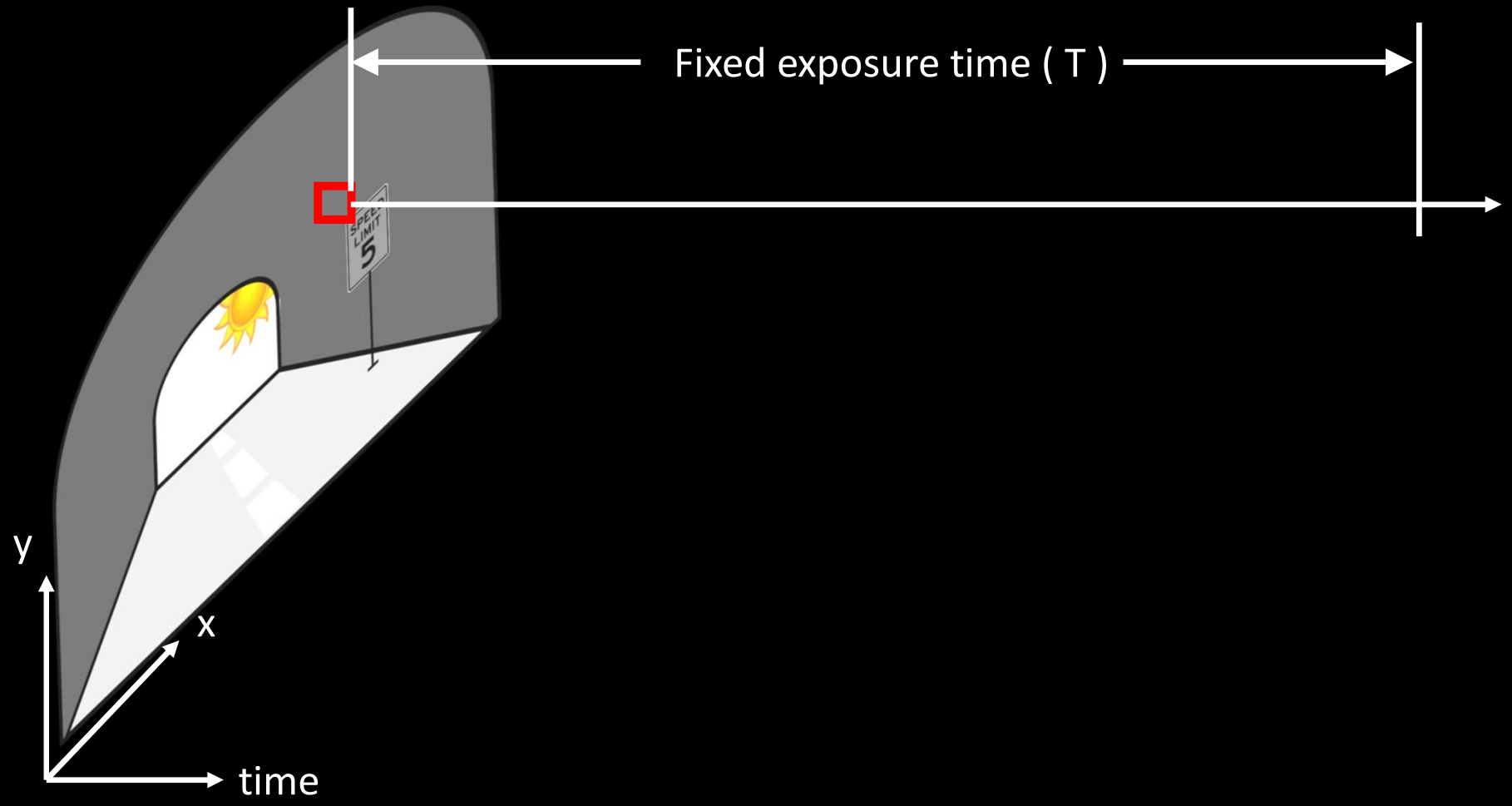

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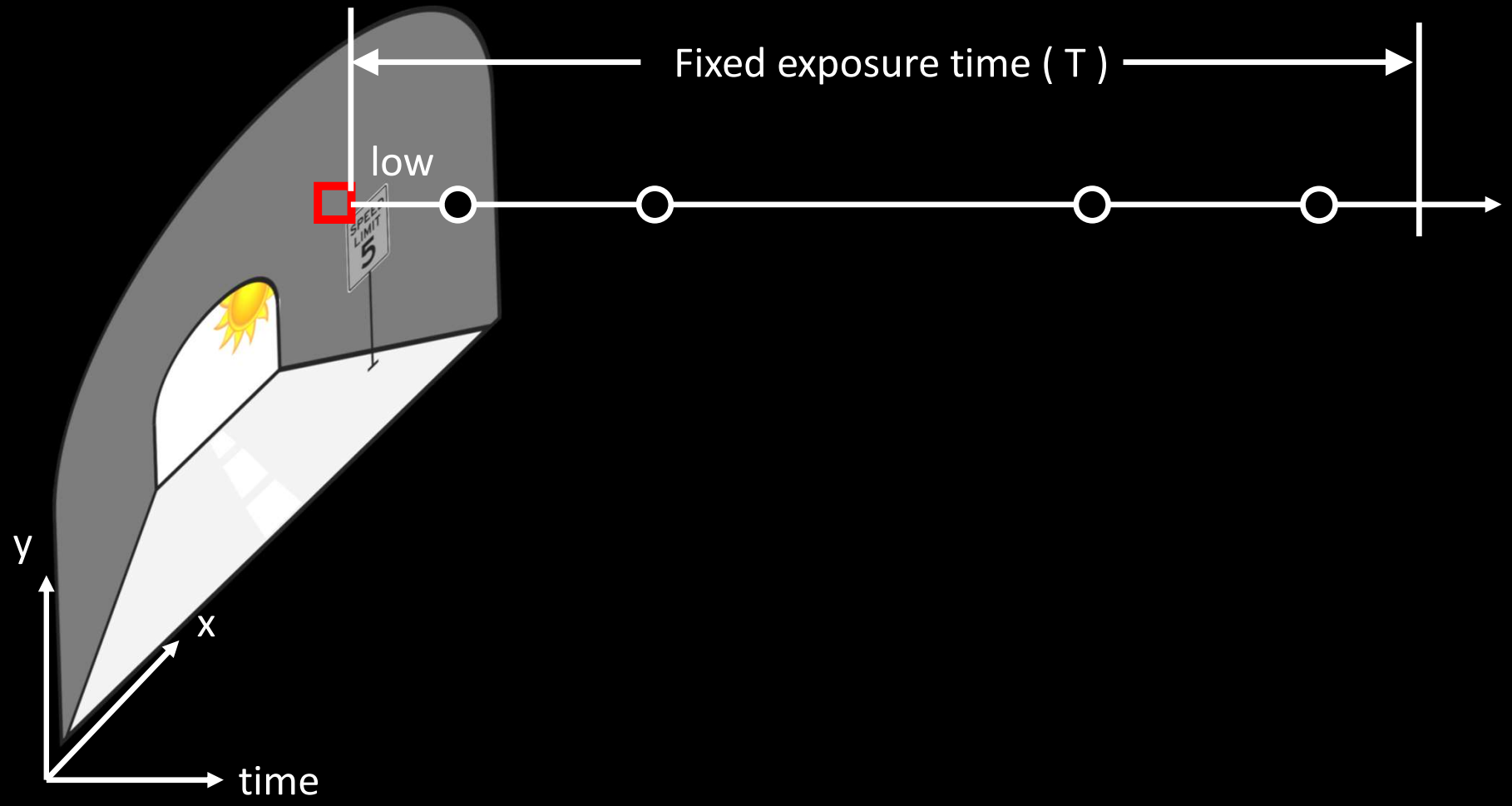

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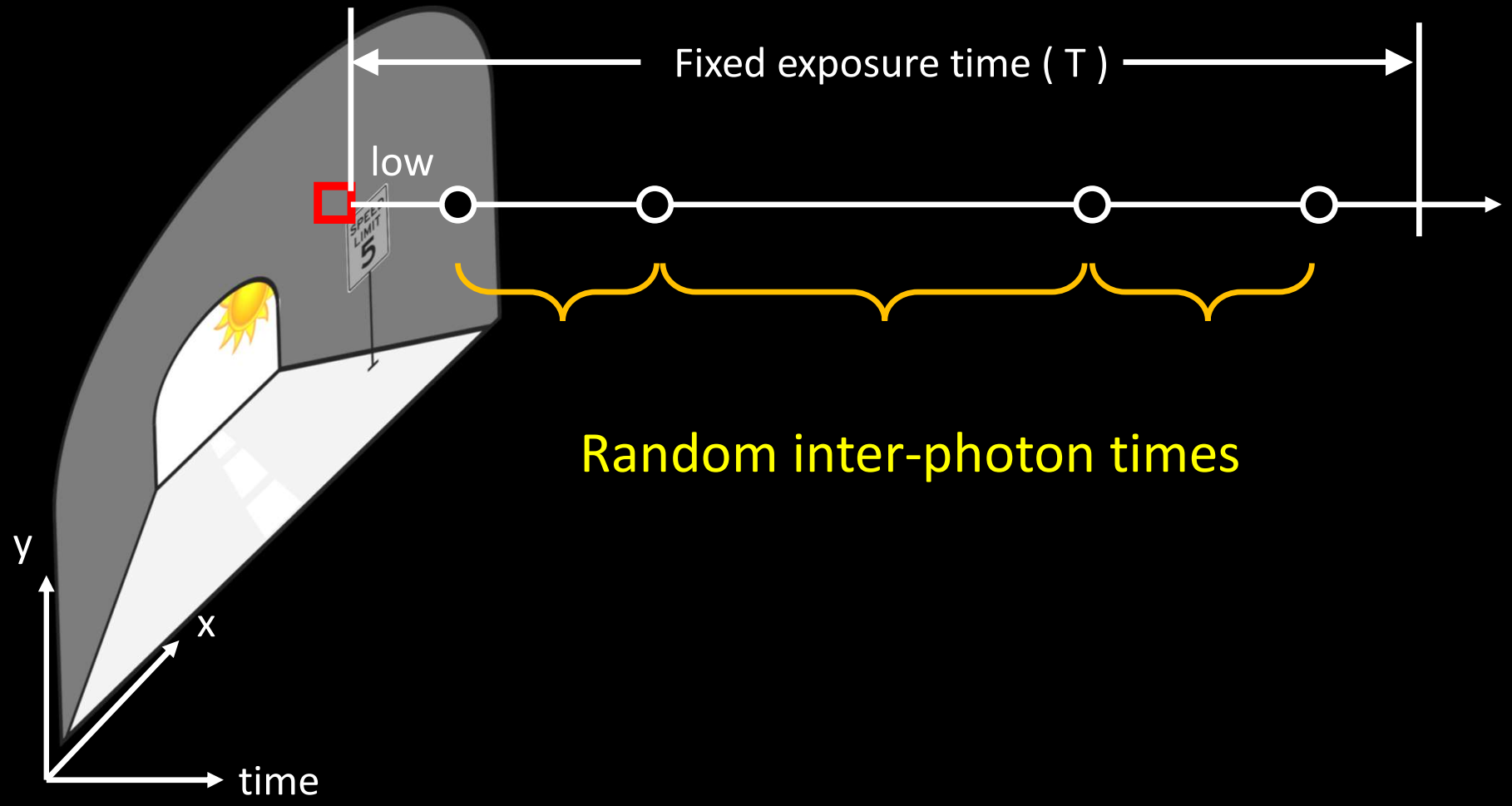

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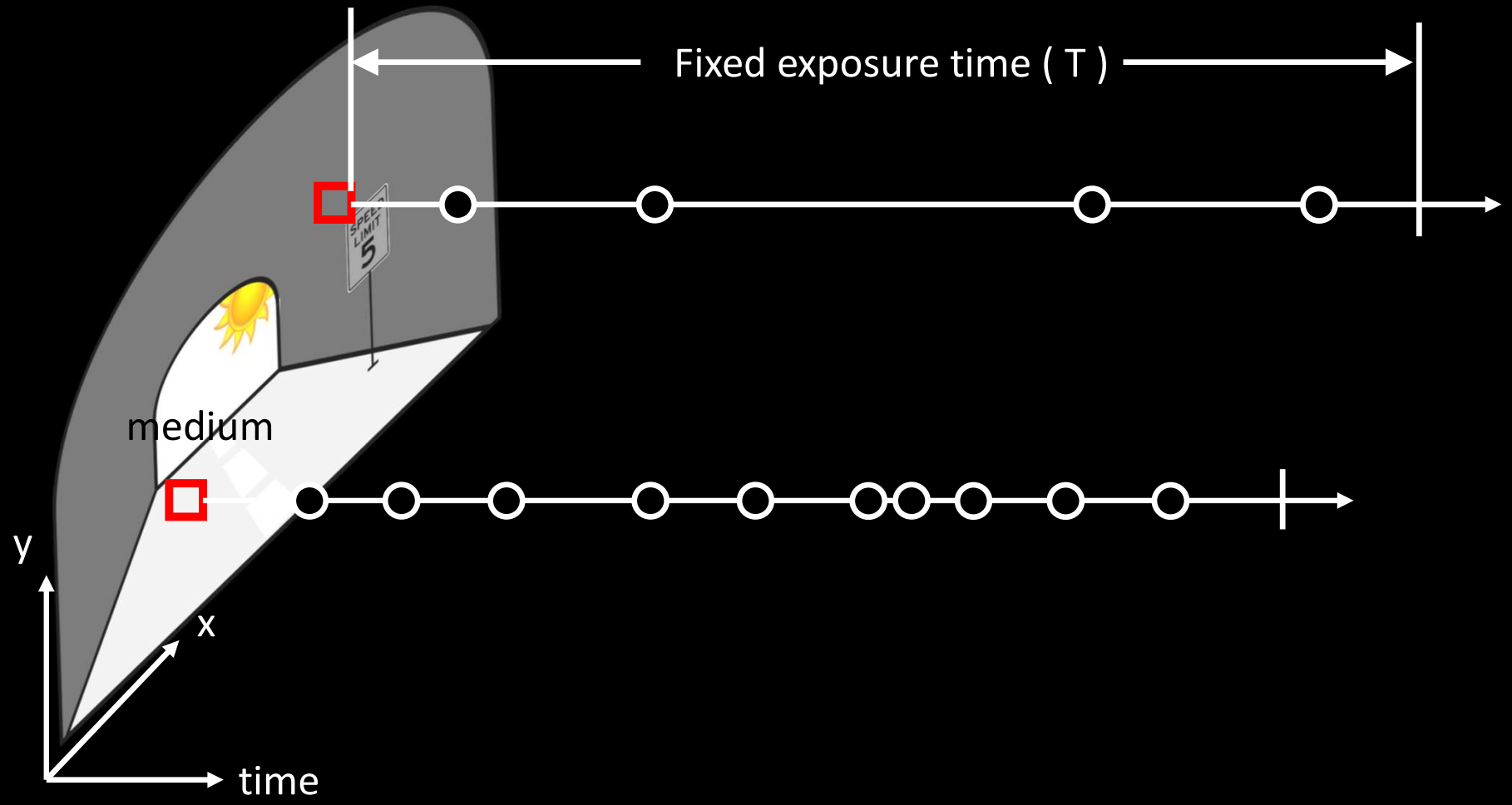
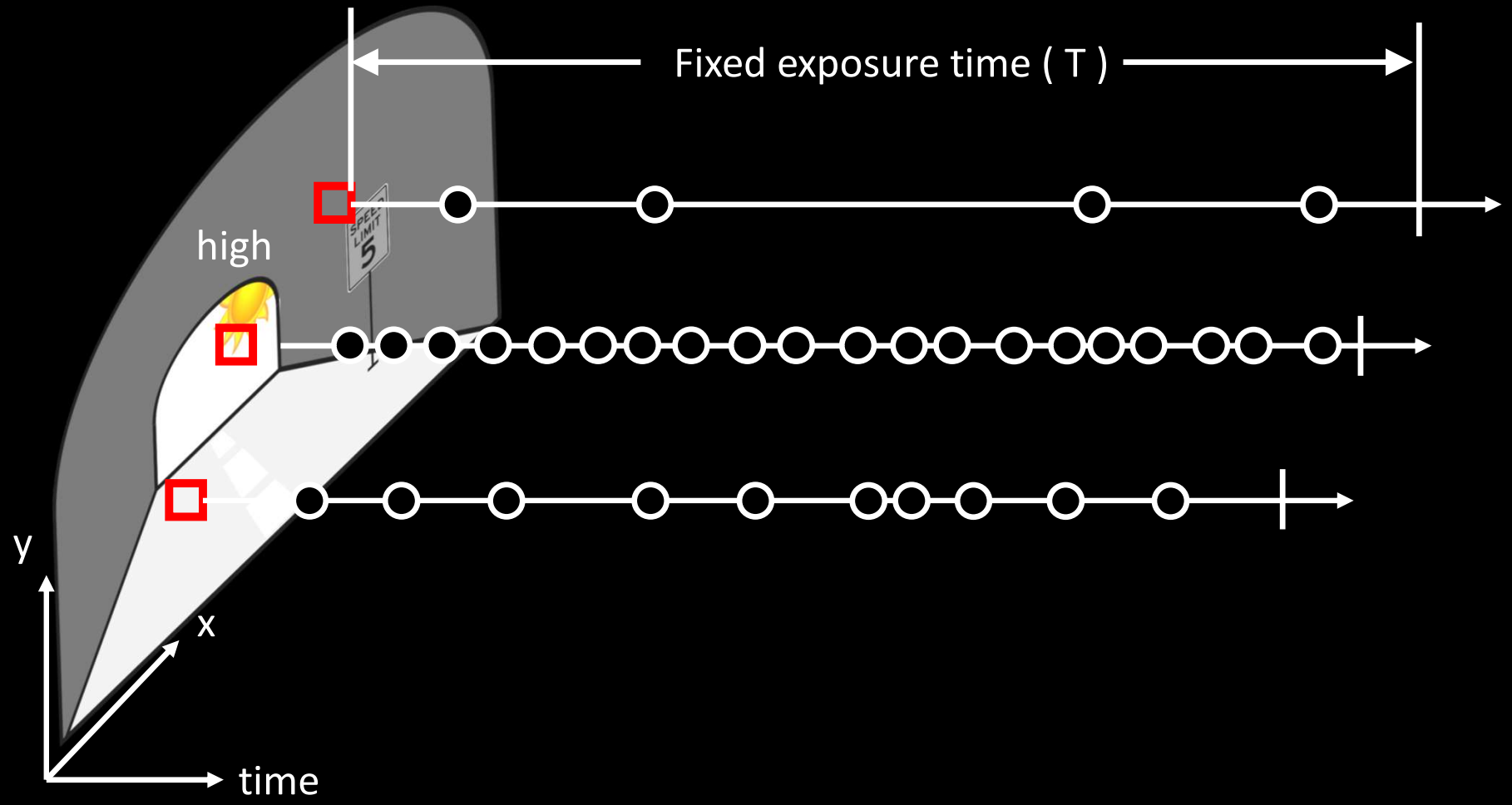
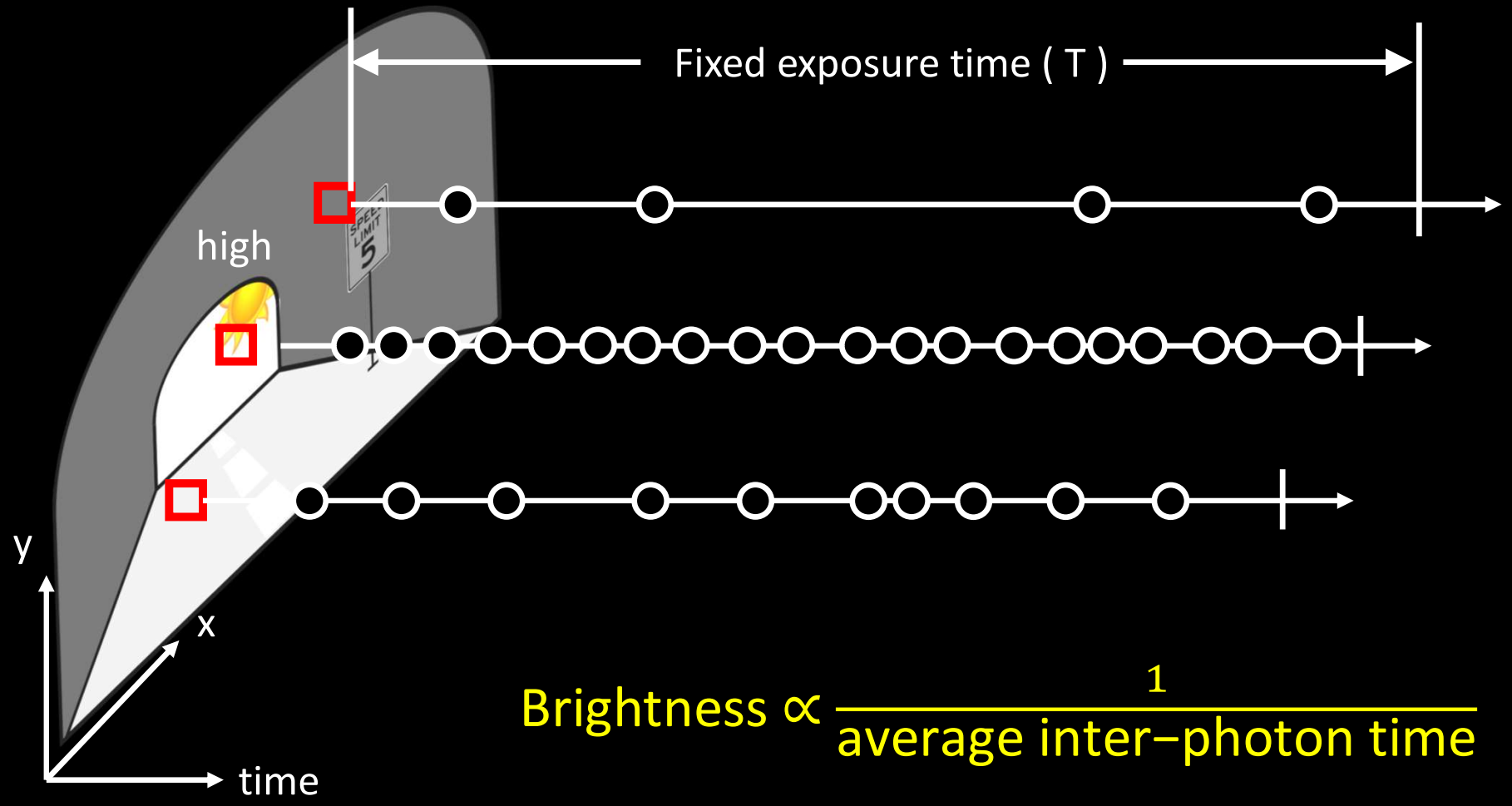


Photon Arrival Timelines



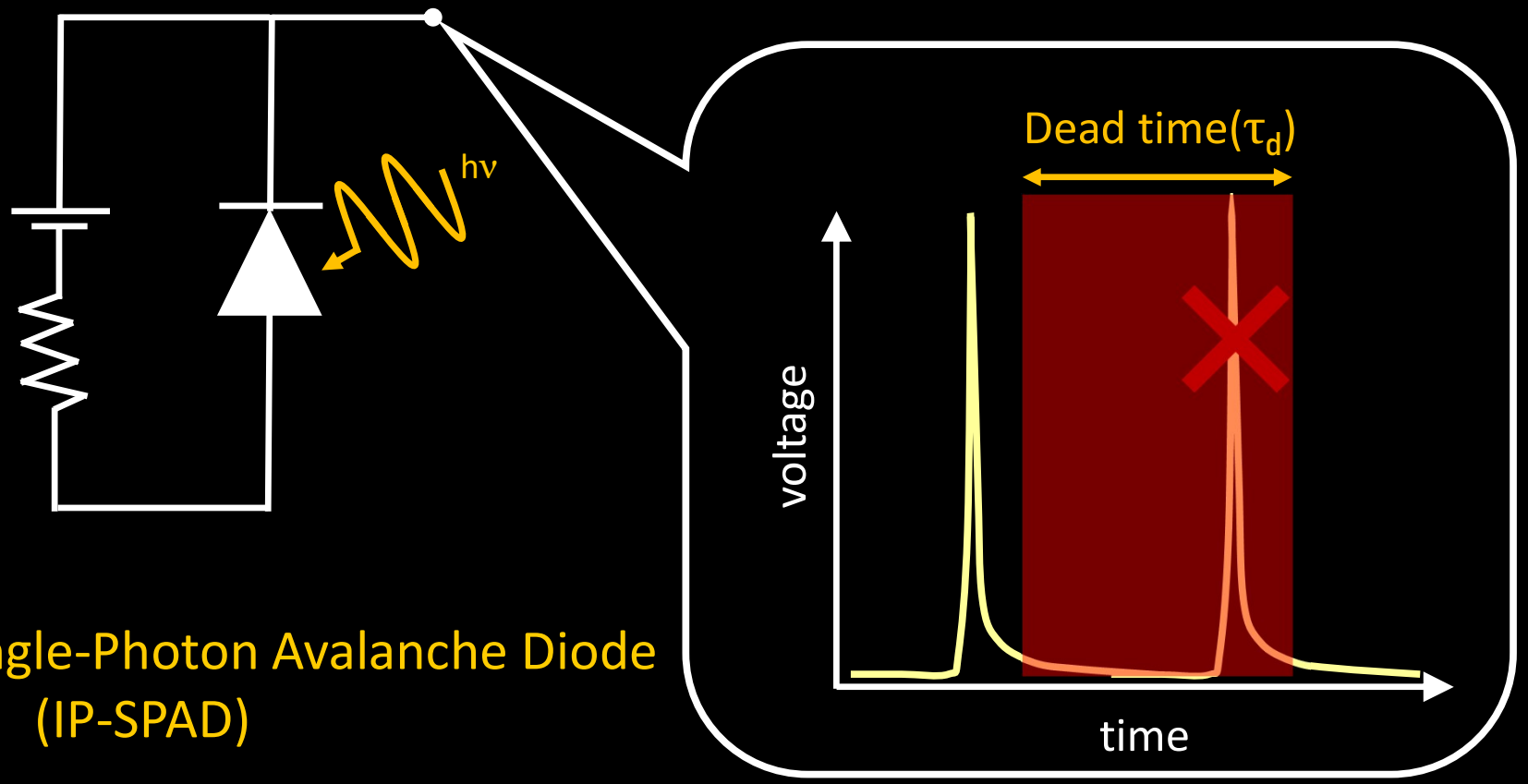
Flux from Inter-Photon Timing?



$$\text{Brightness} \propto \frac{1}{\text{average inter-photon time}}$$

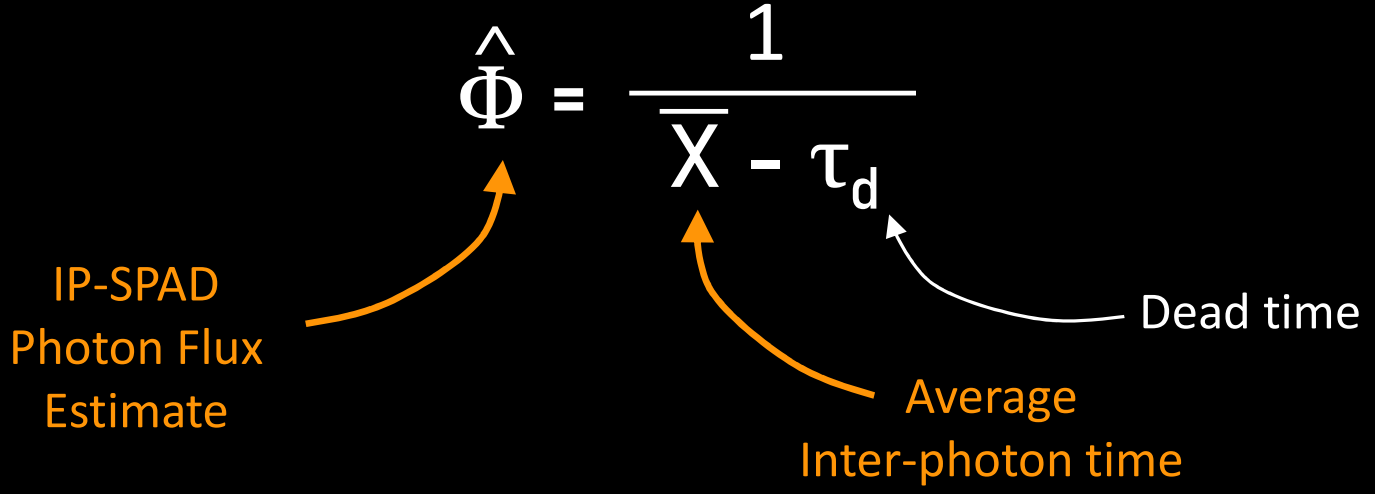
Inter-Photon Imaging in Practice

Measuring Inter-Photon Timing in Practice



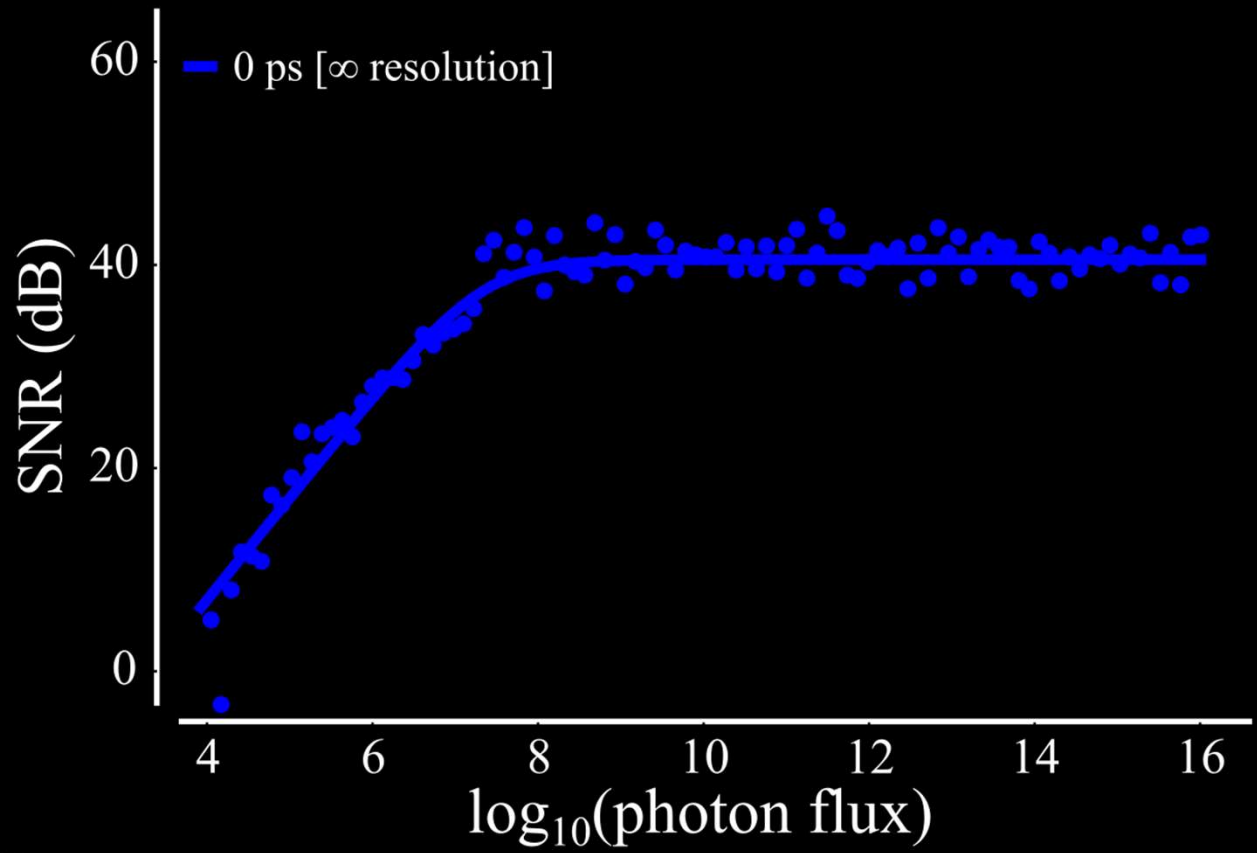
Inter-Photon Single-Photon Avalanche Diode (IP-SPAD)

IP-SPAD: Flux Estimator



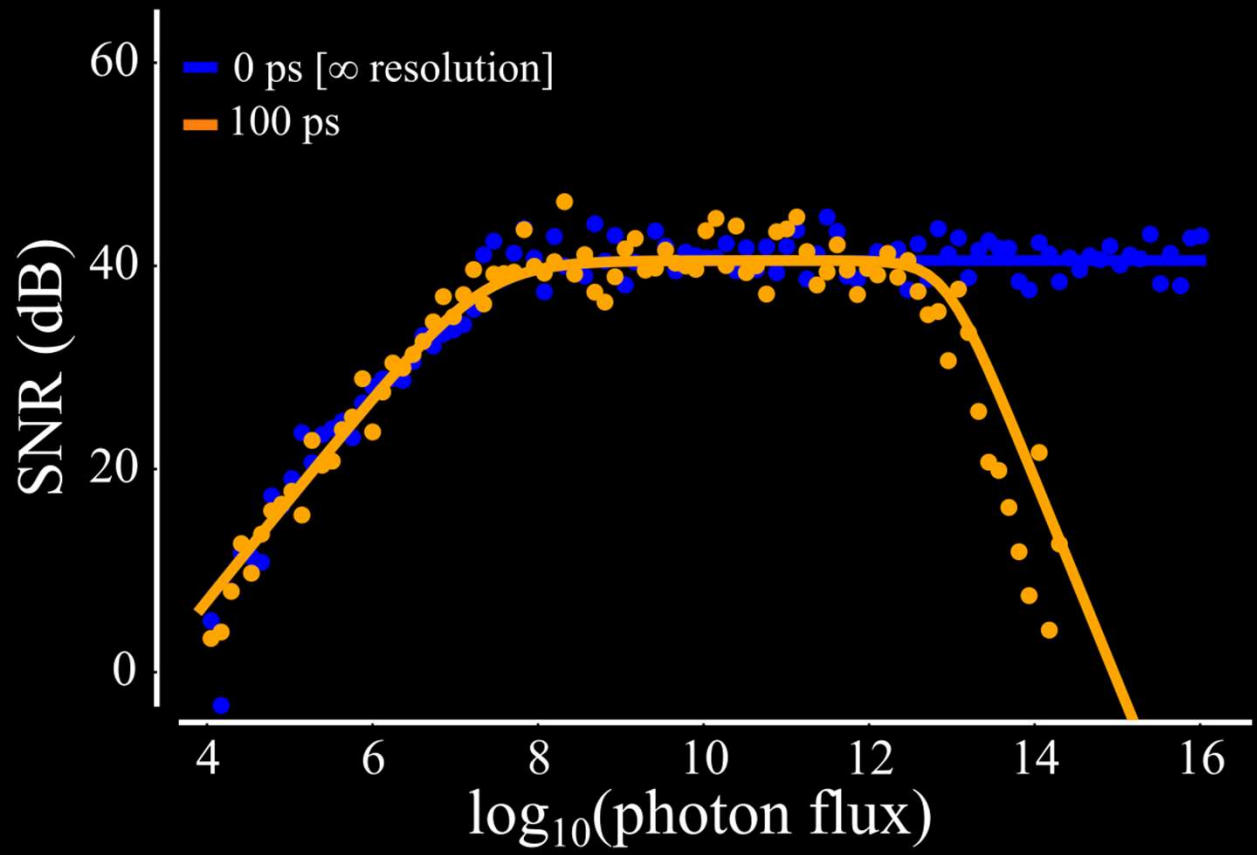
Non-linear mapping

IP-SPAD: Signal-to-Noise Ratio (SNR) Analysis



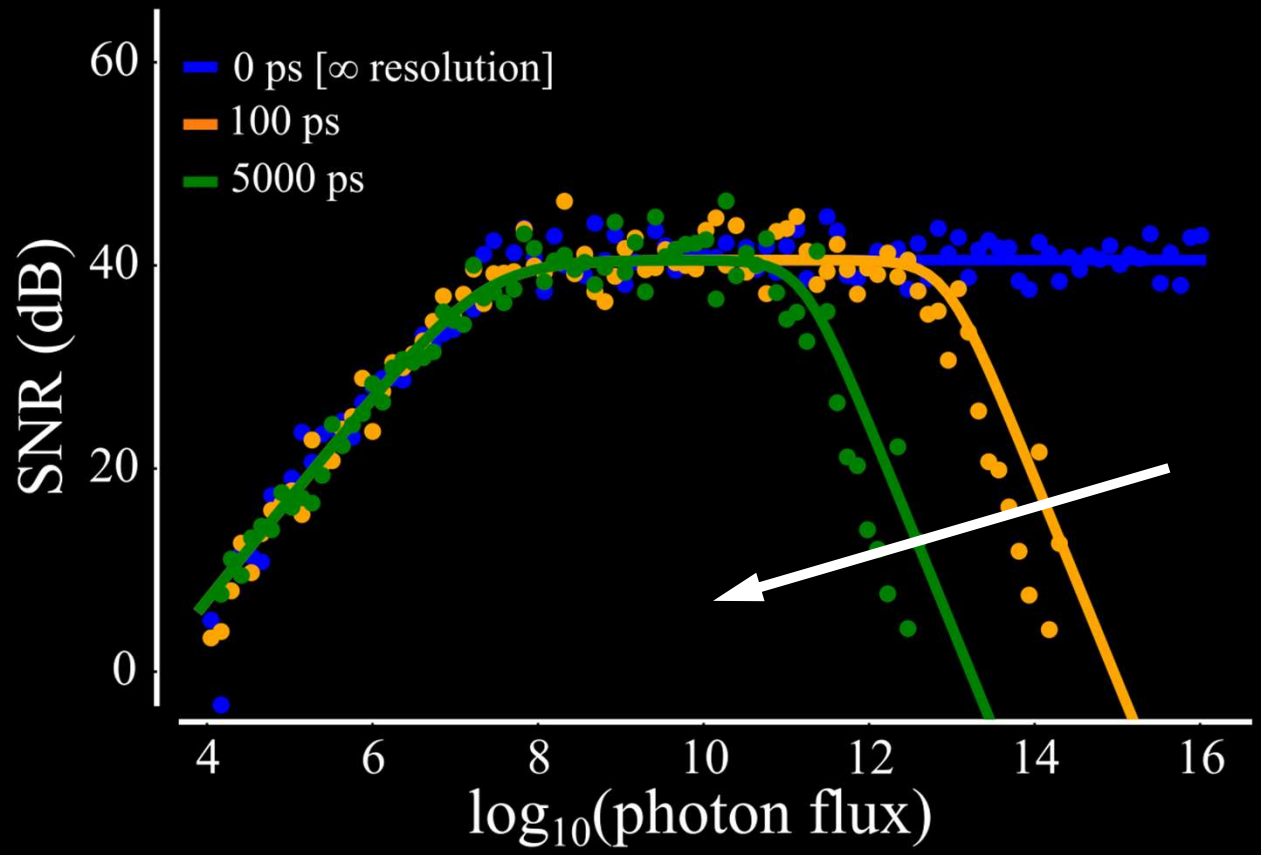
T = 5ms, τ_d = 150ns

IP-SPAD: Signal-to-Noise Ratio (SNR) Analysis



T = 5ms, τ_d = 150ns

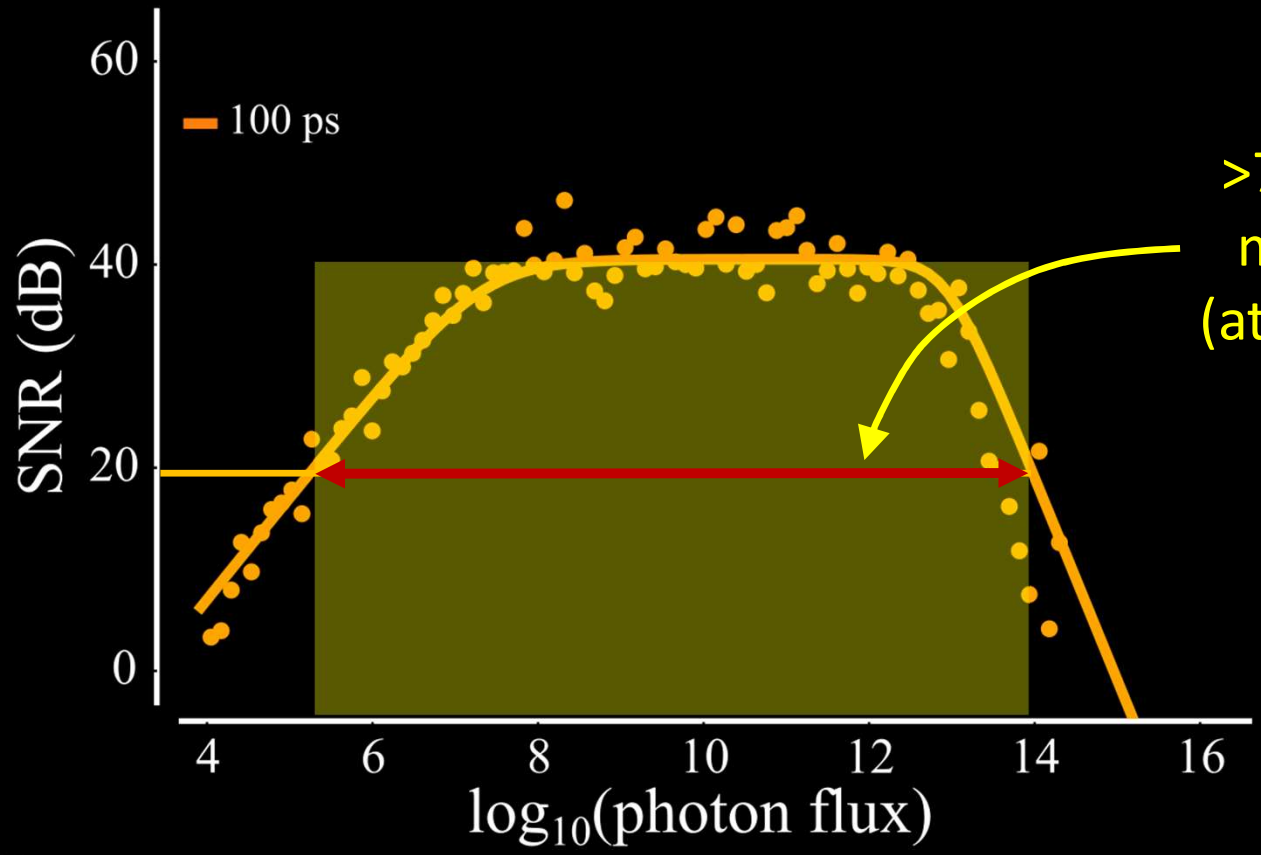
IP-SPAD: Signal-to-Noise Ratio (SNR) Analysis



Decreasing time resolution

T = 5ms, τ_d = 150ns

IP-SPAD: Signal-to-Noise Ratio (SNR) Analysis



>7 orders of magnitude (at 20dB SNR)

T = 5ms, τ_d = 150ns

Experiment Results

Experiment Tunnel Scene

Experiment Tunnel Scene: Result

Conventional Camera

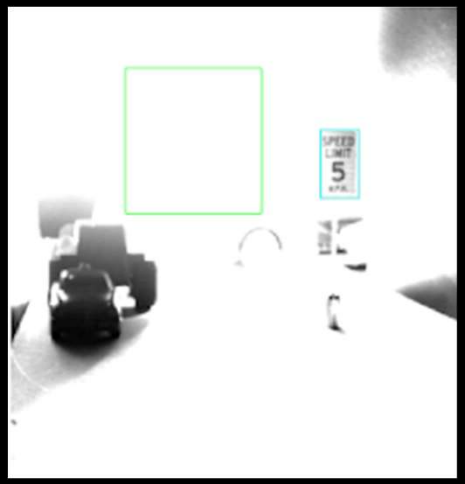
IP-SPAD [Proposed]

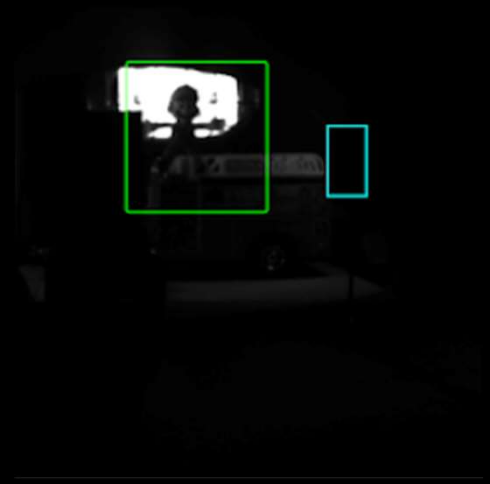
Long exposure (5 ms)

Mid exposure (0.5 ms)

Short exposure (0.005 ms)

Single exposure (5 ms)





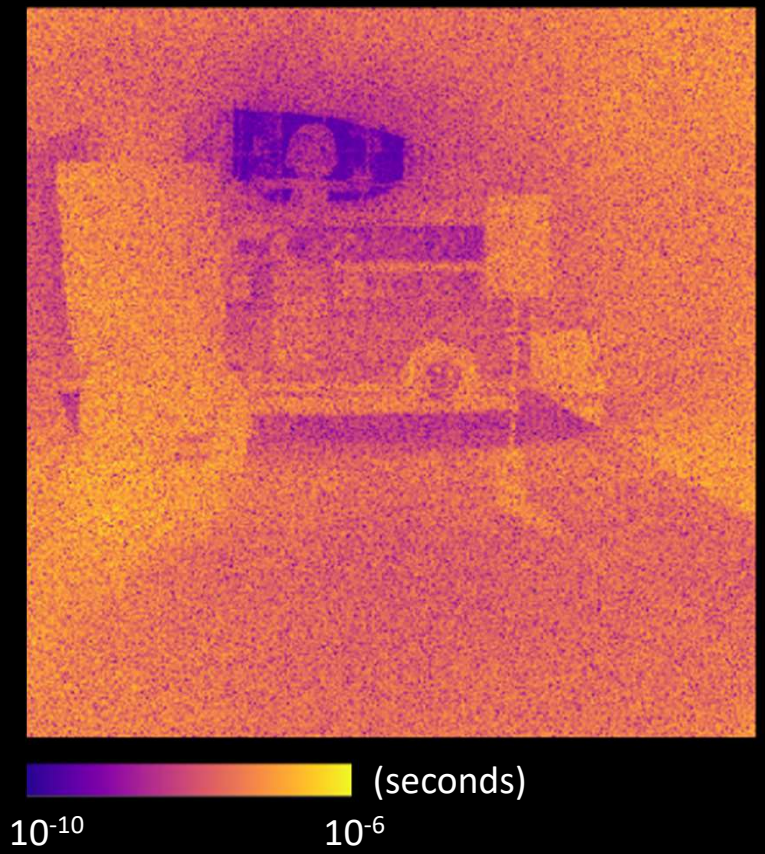
IP-SPAD Imaging with Low Photon Counts

IP-SPAD with Few Photons

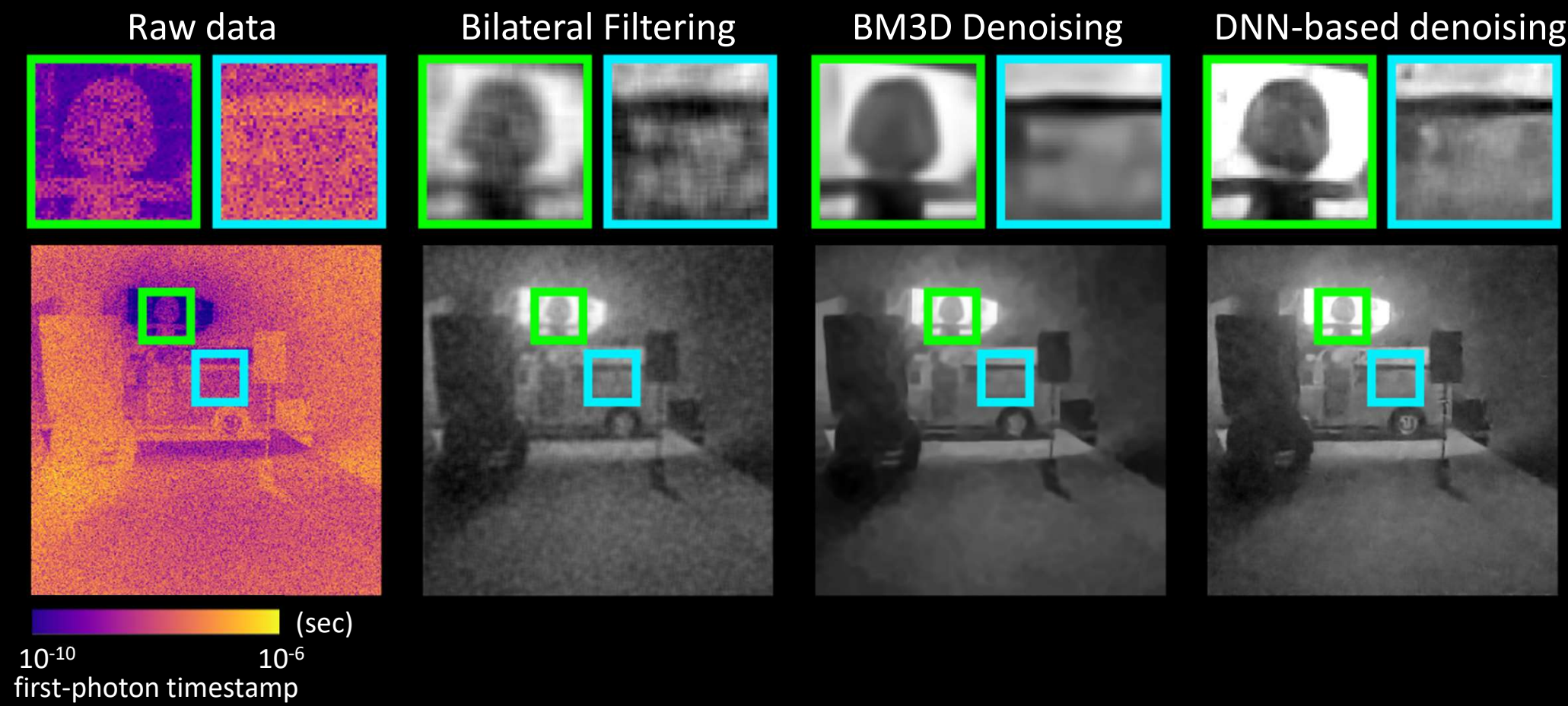
What if we only get 1 photon per pixel?

IP-SPAD Imaging with 1 Photon Per Pixel

First-photon Timestamp Image



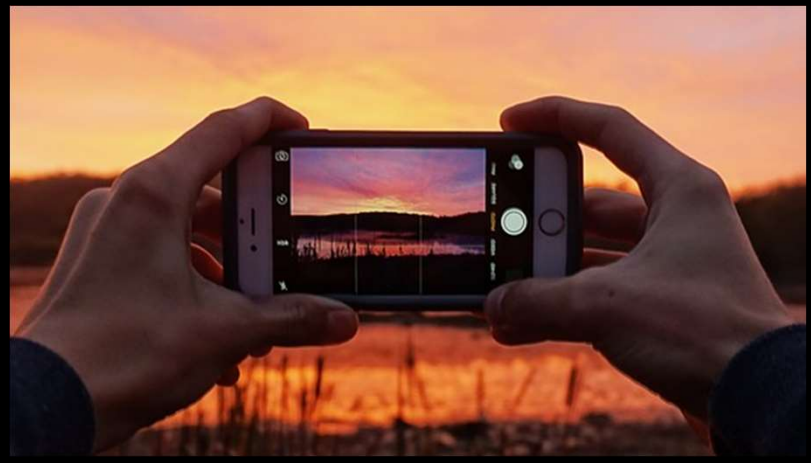
IP-SPAD Imaging with 1 Photon Per Pixel



Implications

Cincinnati Observatory

Schunk Lightweight Arms: Bin-picking
https://www.youtube.com/watch?v=GPPEStcDrFE



IP-SPAD Imaging: SPADs as General-Purpose, Passive Sensors

https://wisionlab.cs.wisc.edu/project/ip-spad/