Compressive Super-Pixel LiDAR for High-Framerate 3D Depth Imaging

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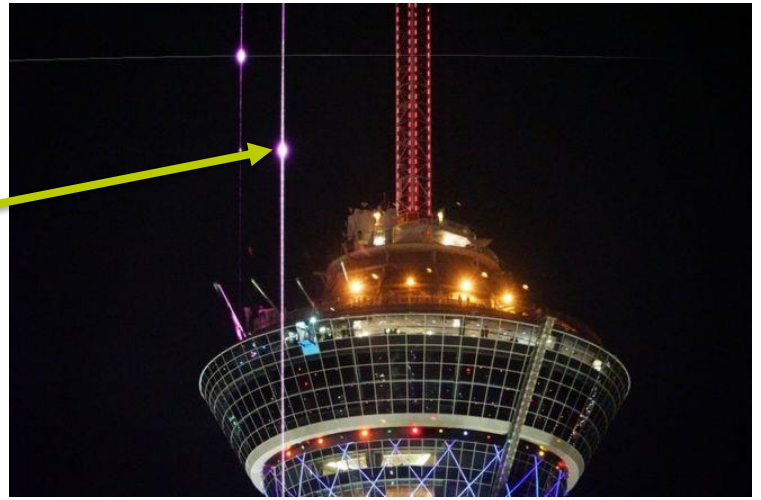
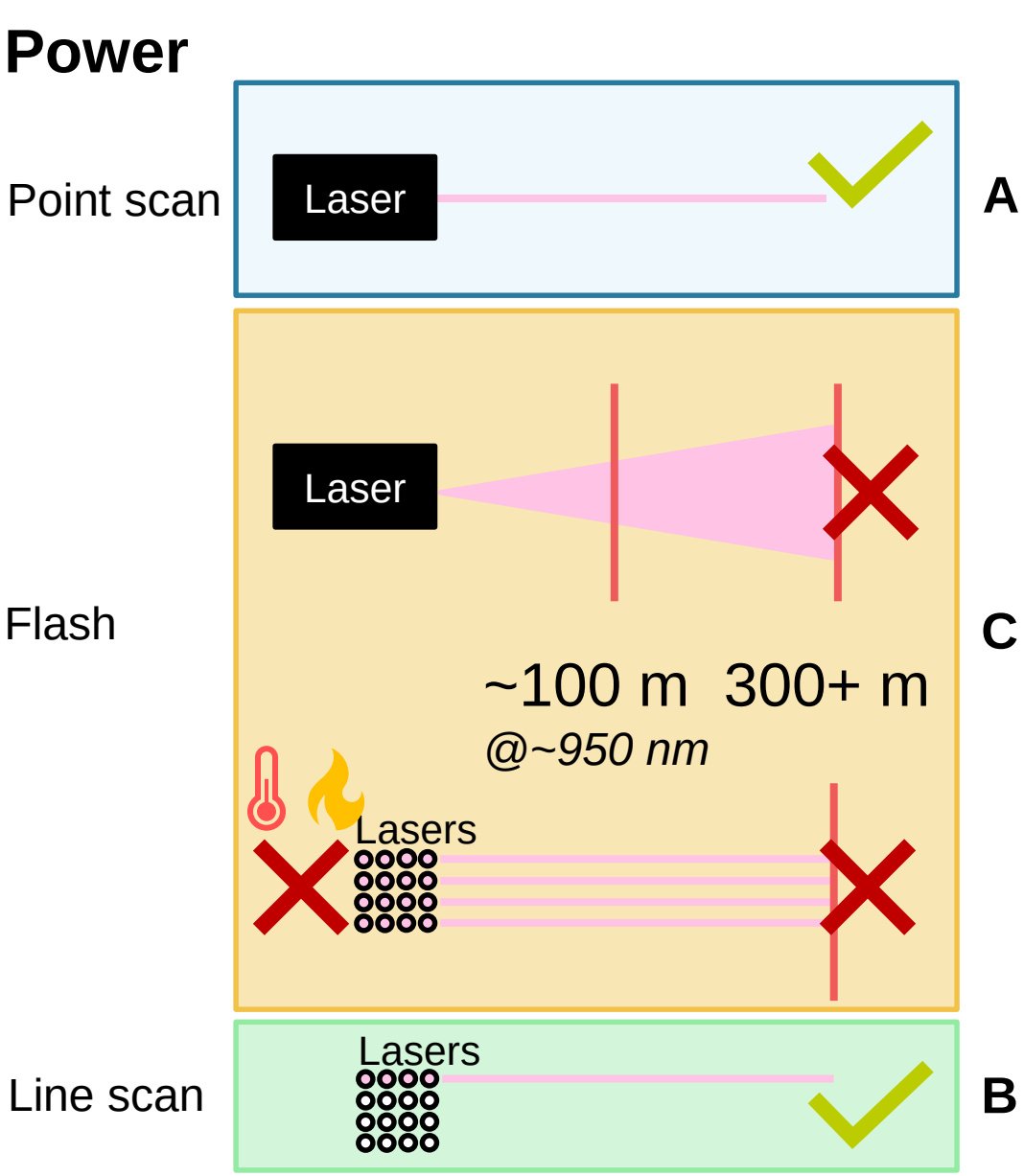
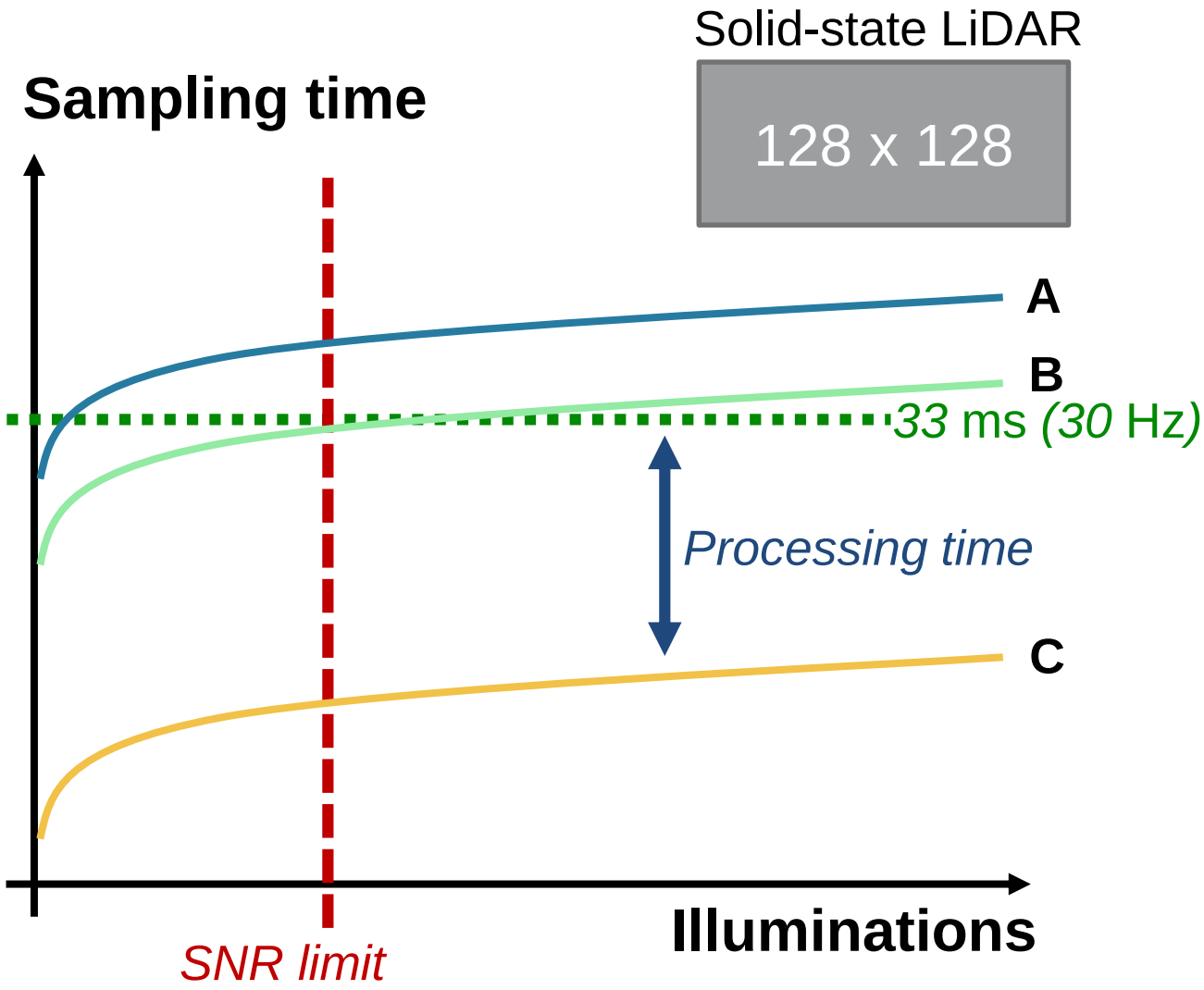
“Driverless car laser ruined camera” (BBC News, Jan 2019)



Can we make safe LiDAR systems?

LiDAR Problems





Overview

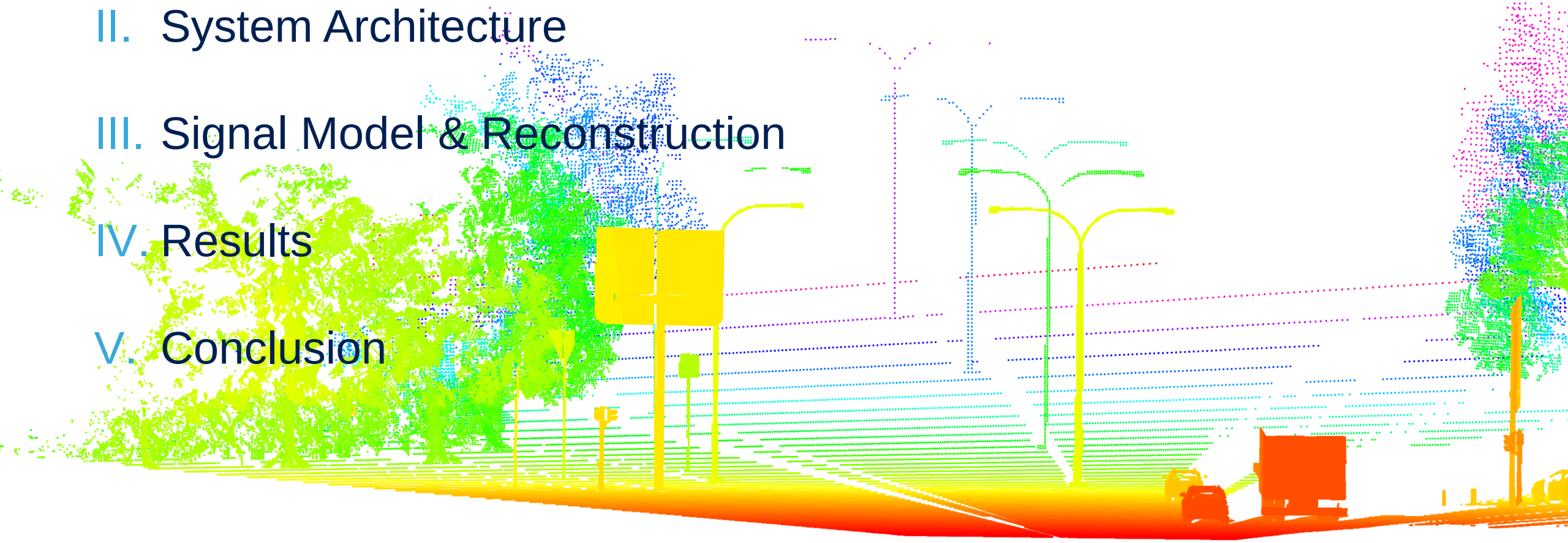
I. Compressed Sensing

II. System Architecture

III. Signal Model & Reconstruction

IV. Results

V. Conclusion



Introduction

Compressed Sensing (CS)

measurements | sensing matrix | signal

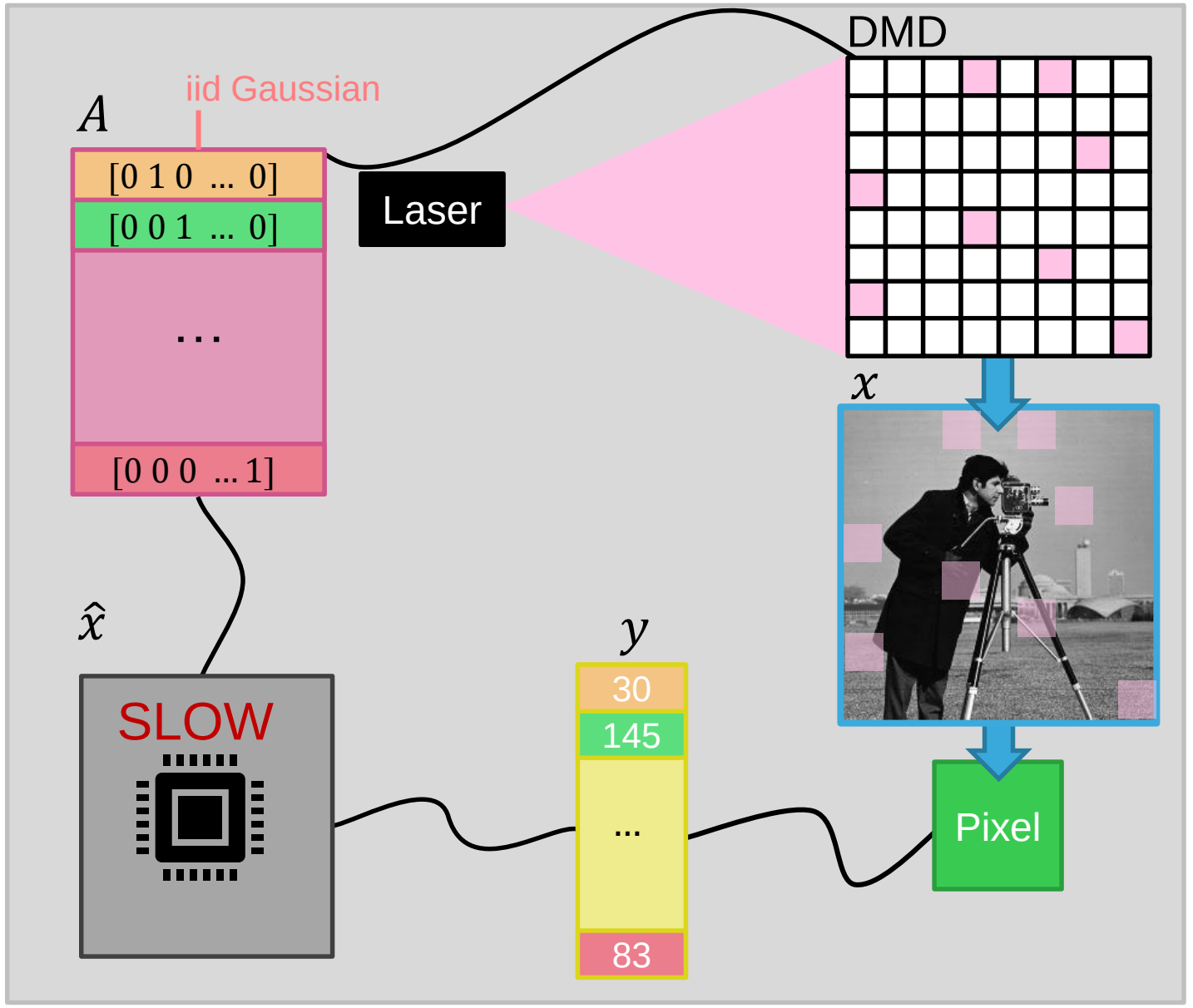
$$y = A: m \times n \; x$$

ℓ_1 or TV minimization

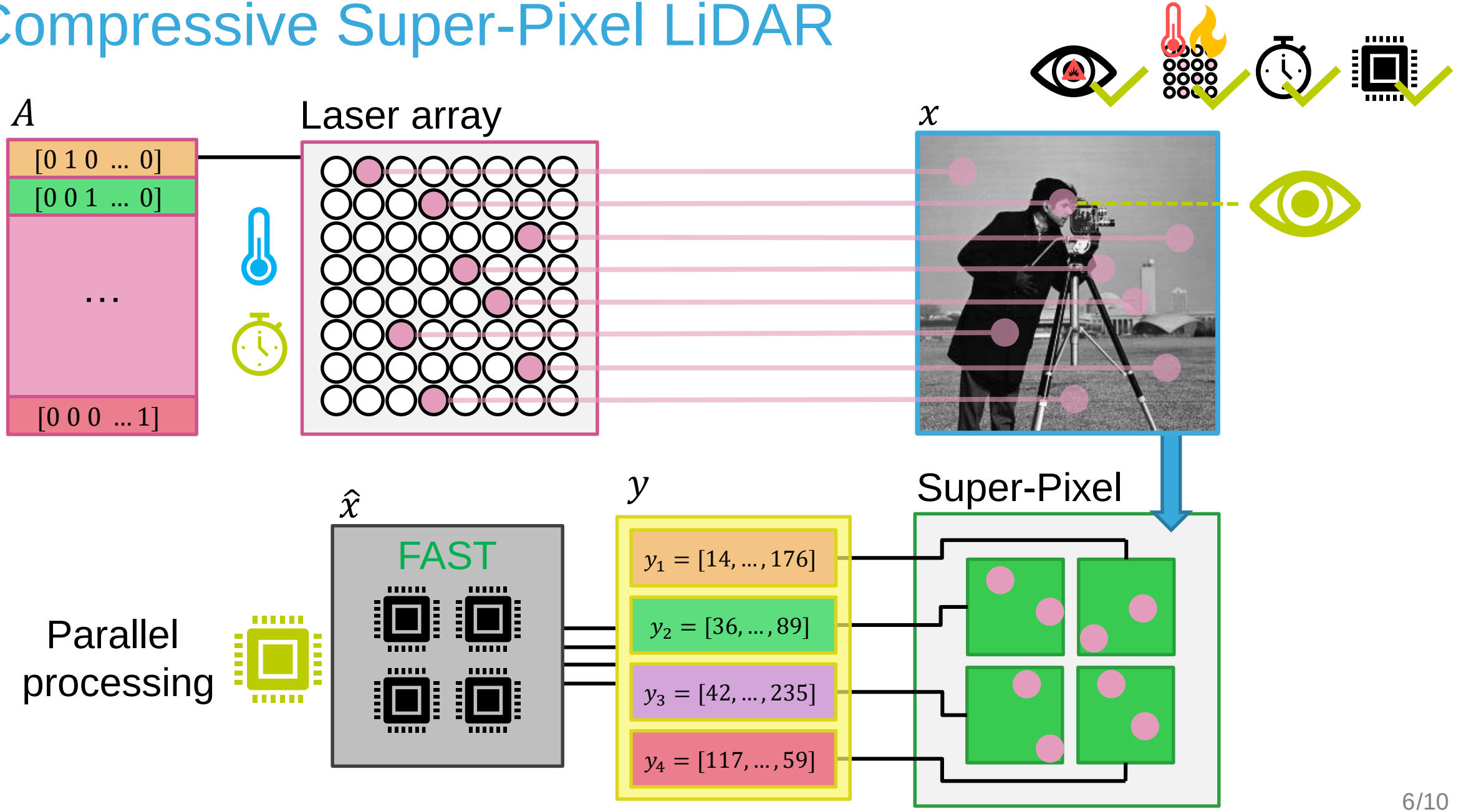
$$\hat{x} = \min_x \; \mathrm{TV}(x)$$
$$s.t. \quad \|y - Ax\|_2^2 < \epsilon$$

[Candès and Wakin 08', IEEE Signal Processing Mag]
[Duarte et al. 08', IEEE Signal Processing Magazine]
[Willet et al. 11', Optical Engineering]

Single Pixel Camera

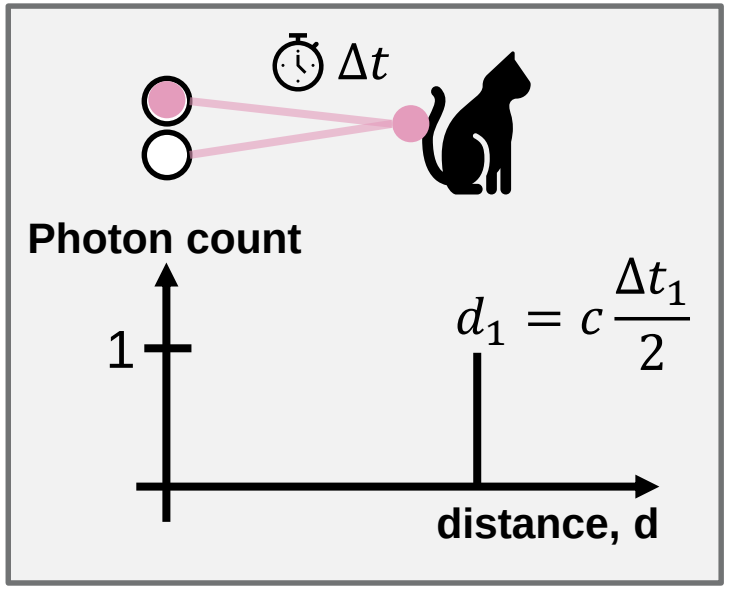


Compressive Super-Pixel LiDAR

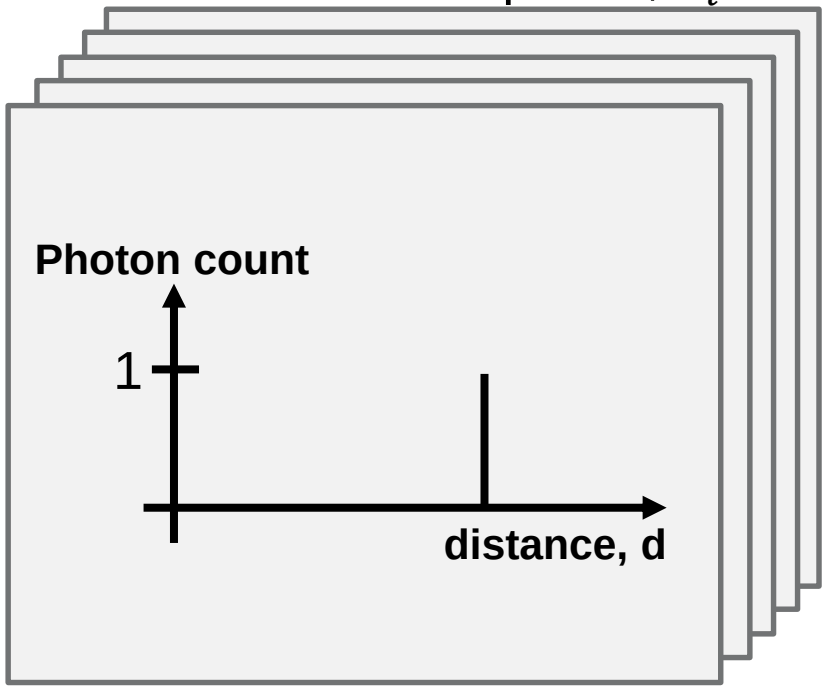


Signal Model

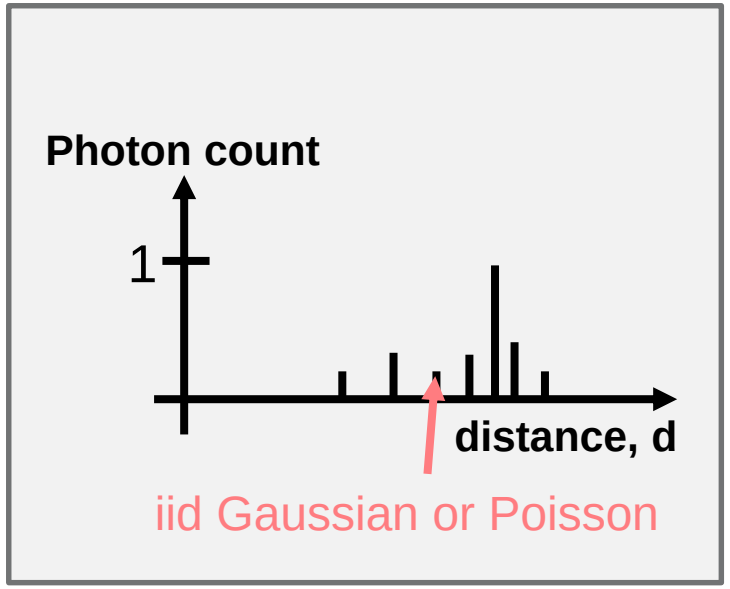
Ideal pixel i histogram, h_i



Observations at pixel i, $\tilde{h}_i$



Estimate for pixel i, $\hat{h}_i$



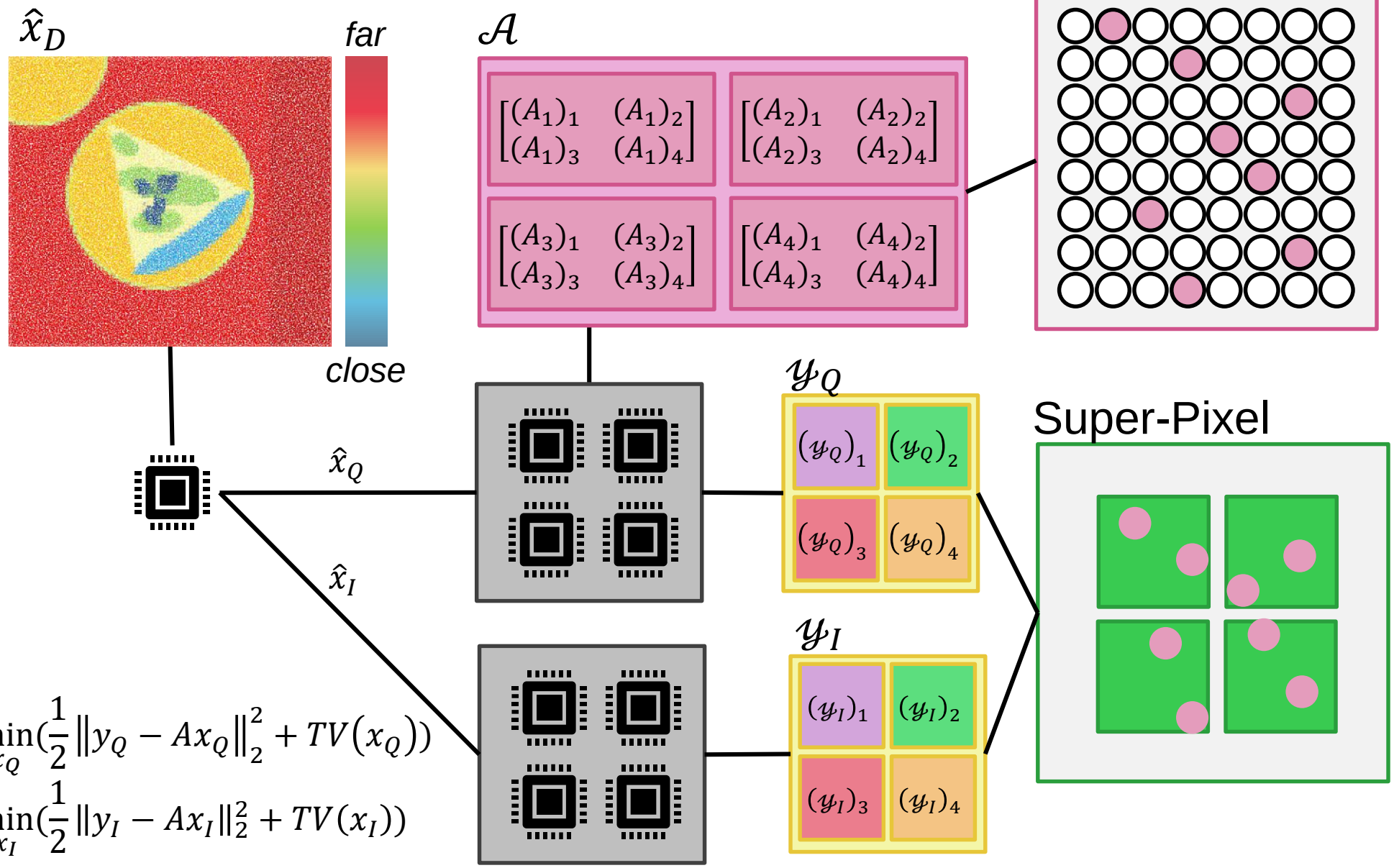
$$(x_D)_i = h_i \circ d$$

$$\text{Let } \hat{h}_i = \frac{\sum_k \tilde{h}_i^k}{\sum_k (\sum_p \tilde{h}_i^k(p))} =: \frac{(\hat{x}_Q)_i}{(\hat{x}_I)_i} \Rightarrow \hat{x}_D = \hat{h}_i \circ d$$

Assumption: $\hat{x}_Q$ and $\hat{x}_I$ are basis sparse or have small total variation (TV)

[Howland et al. 13', Optics Express]
[Duarte et al. 08', IEEE Signal Processing Magazine]

Reconstruction

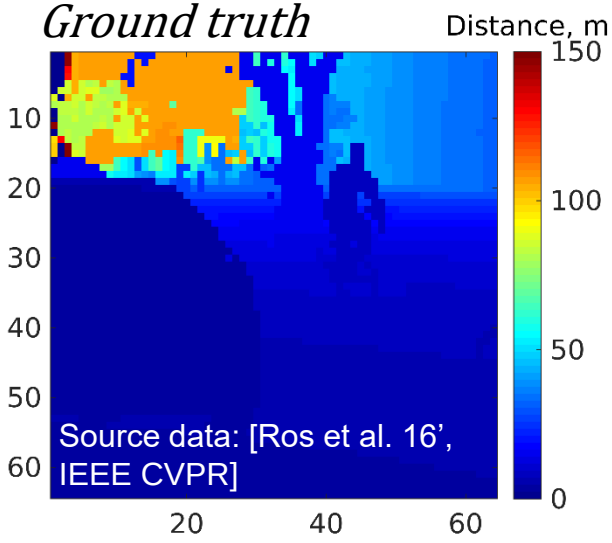


Results

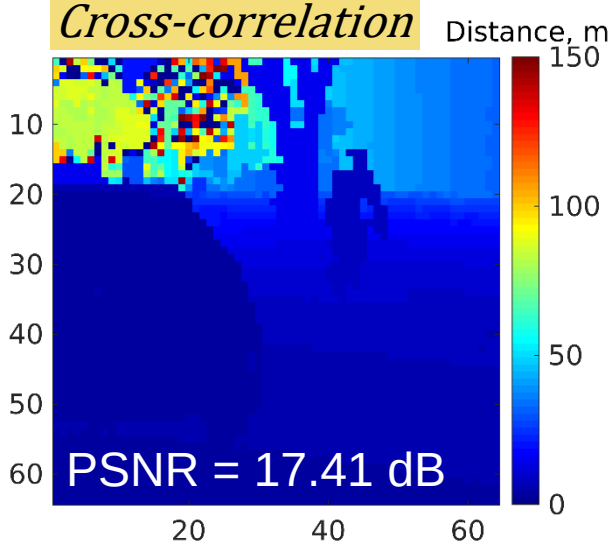
$(\hat{x}_D)_i = \max(f_i \star h_i)$
f – instrumental function
$\star$ *- convolution operator*

all: sunlight at 1 klux

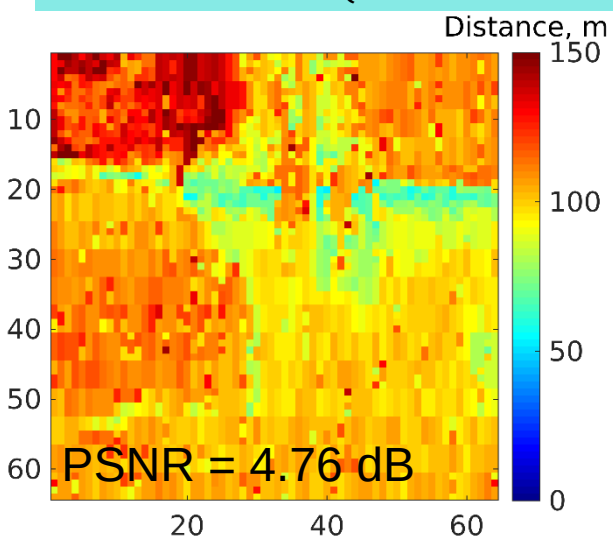
Ground truth

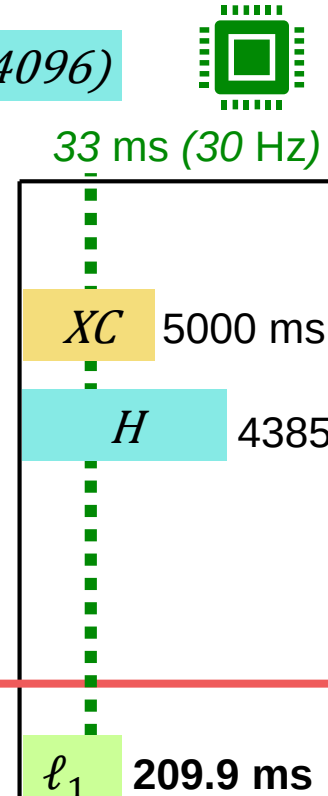


Cross-correlation



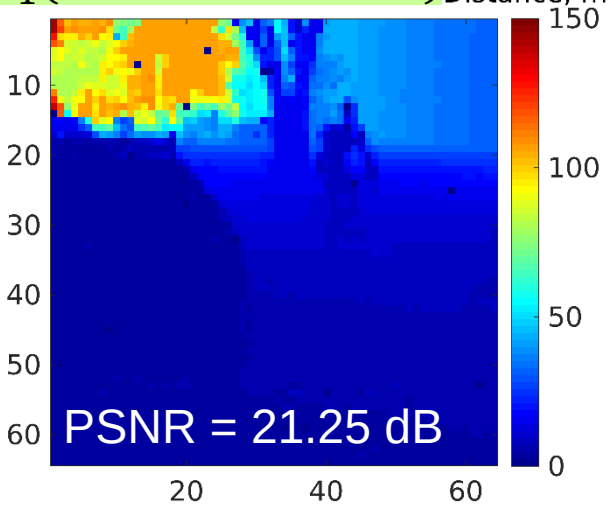
Howland et al. (m=3200 < 4096)



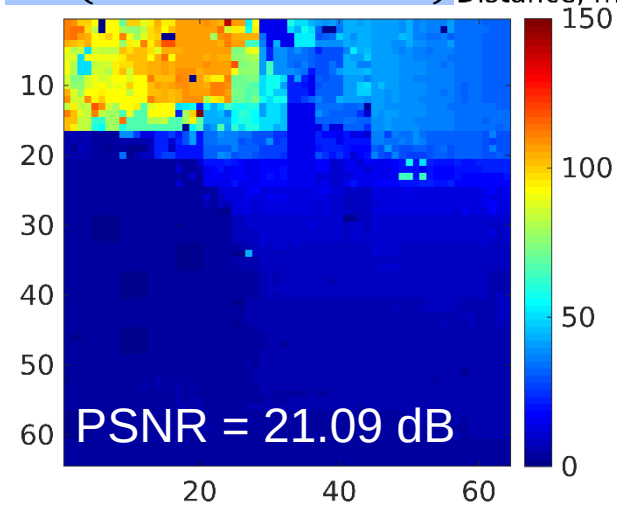


Our work:

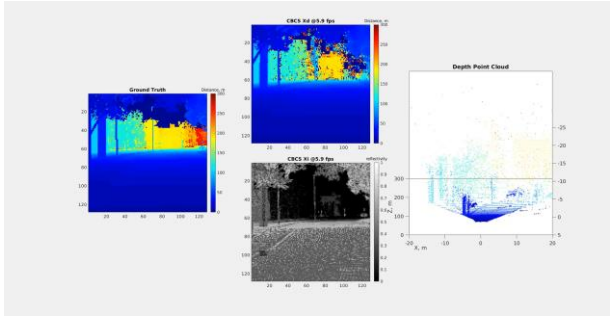
$\ell_1(m = 48 > n = 16)$



$TV(m = 4 < n = 16)$



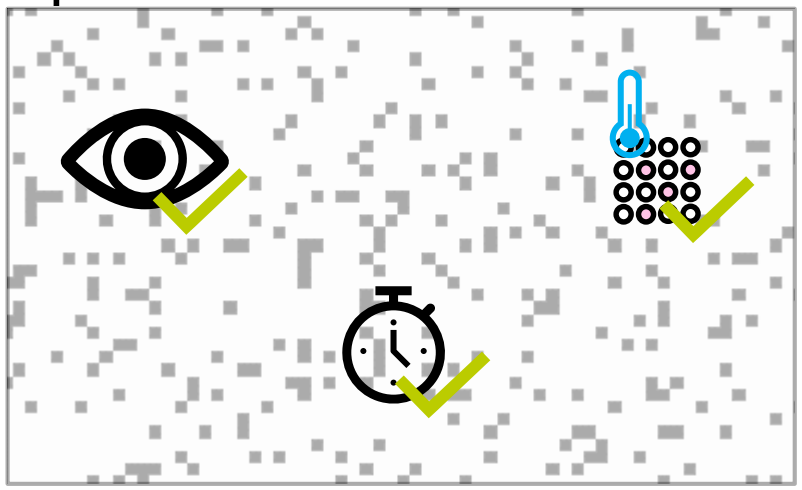
$Video - \ell_1\ on\ GPU$



Source data: [Gaidon et al. 16', IEEE CVPR]

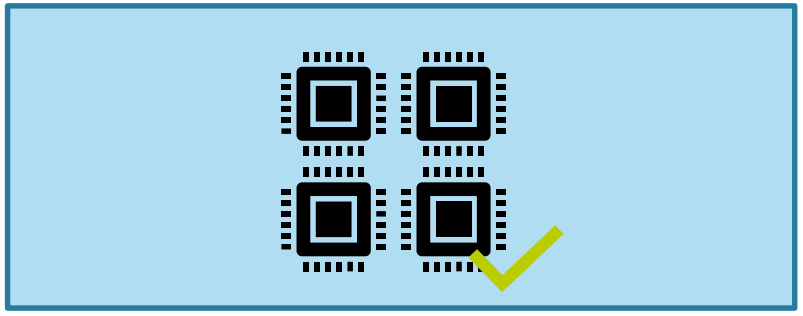
Can we make safe LiDAR systems?

Sparse illumination



- **Lower total laser power**
- **Fast sample time**

Parallelism



- **High frame rates**

YES!