清華大學
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Conference OSA Biophotonics Congress

Tucson, AZ, USA

Snapshot Compressive Volumetric Light-sheet Microscopy

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Tsinghua University, Beijing, China

Apr 17, 2019

Goal and Challenge

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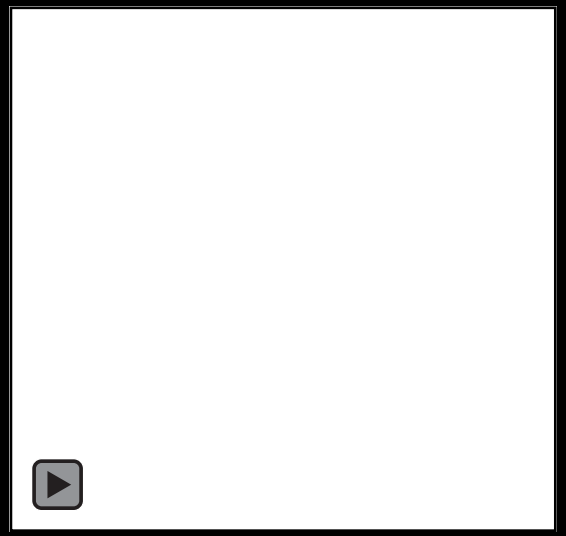
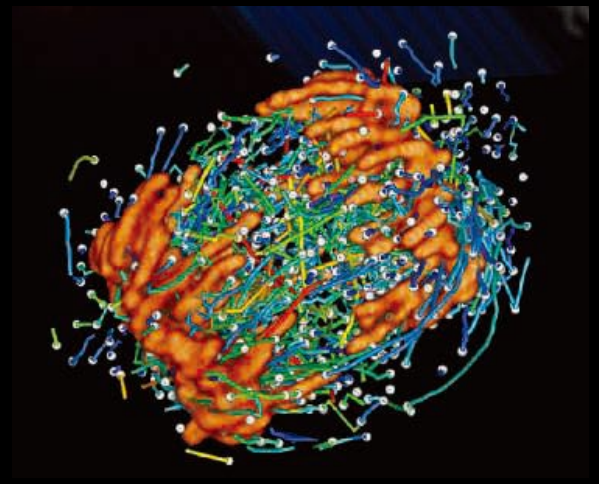
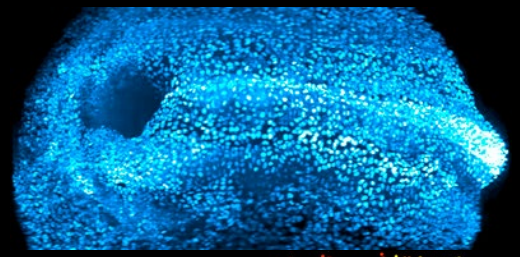


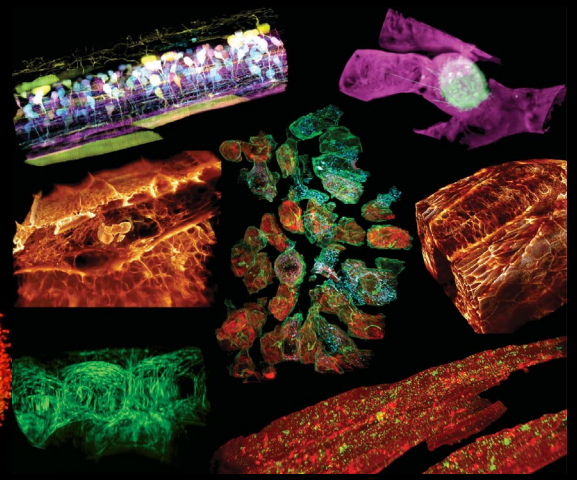
Keller, *Science* 2008



Chen, *Science* 2014

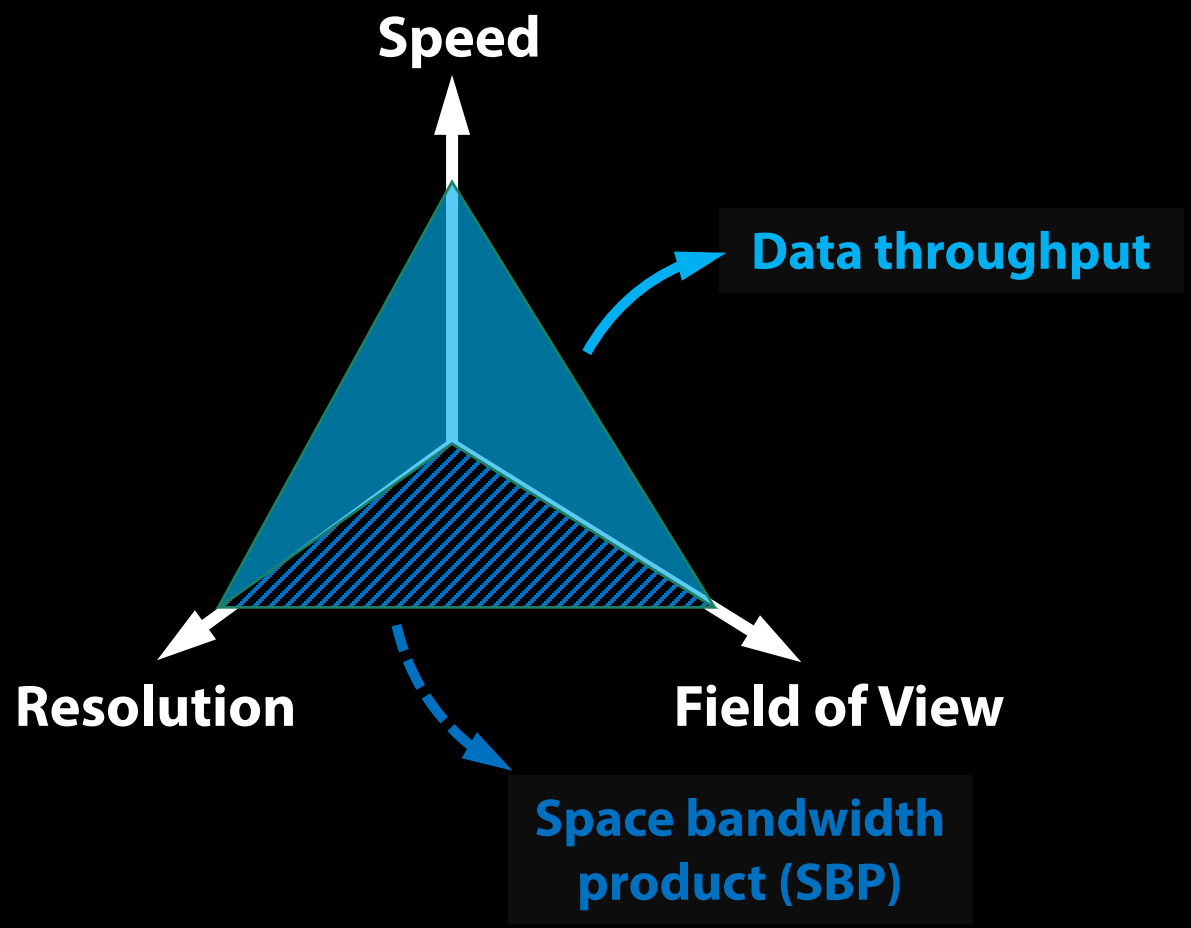


McDole, *Cell* 2018



Liu, *Science* 2018

High-speed 3D imaging of neural activity



Computational Imaging

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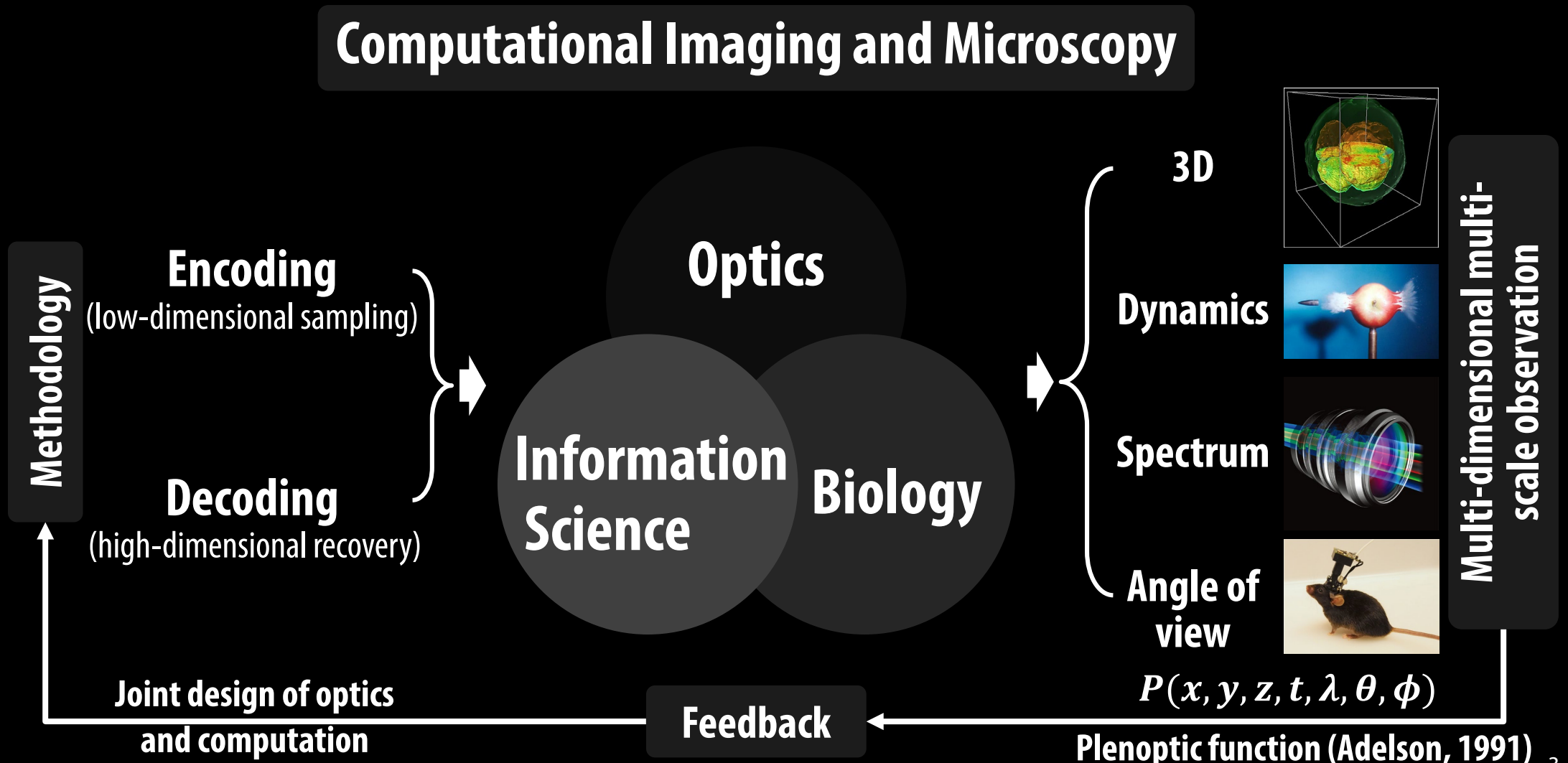

High-speed Imaging

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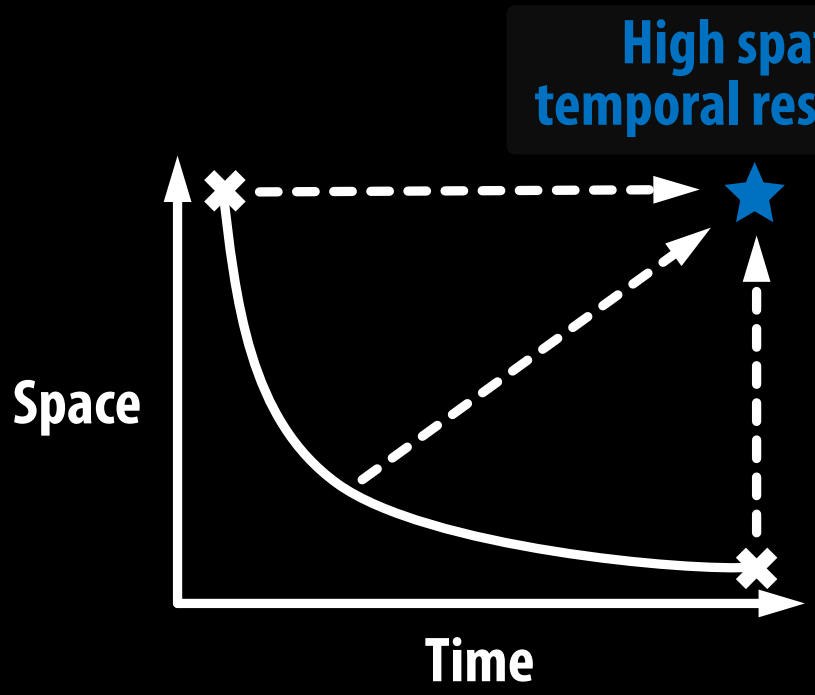
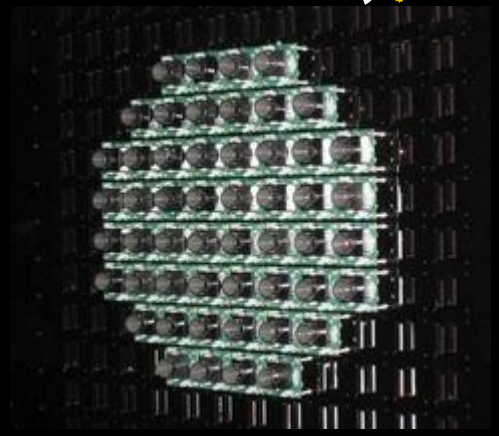
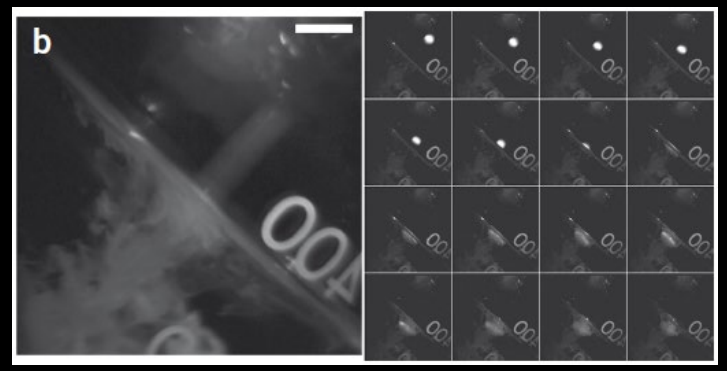


Camera array ✗ ✓



Wilburn, *CVPR* 2004

Temporal pixel multiplexing ✓ ✗



Bub, *Nat. Methods* 2010

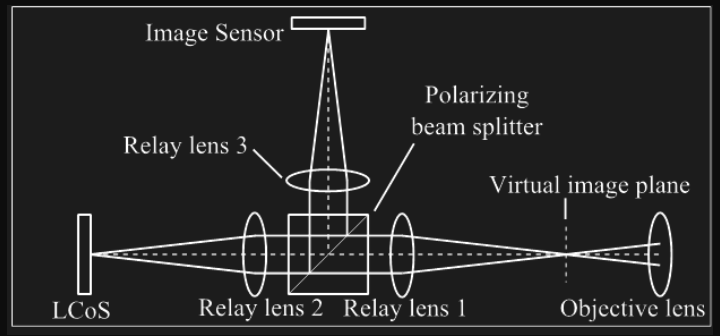
Hybrid system ✗ ✓

Ben-Ezra & Nayar, *TPAMI* 2004

Coded aperture

✓ Single-camera

✓ High-resolution



Hitomi, *ICCV* 2011; Liu, *TPAMI* 2014

High-speed Volumetric Imaging

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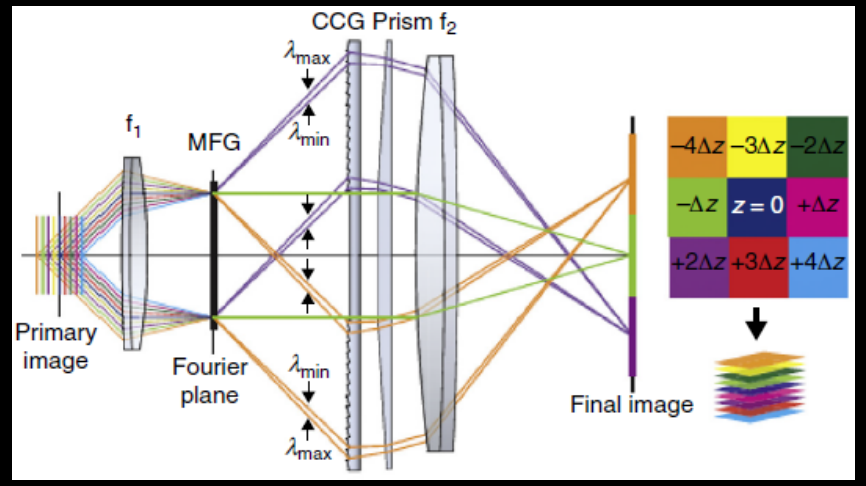
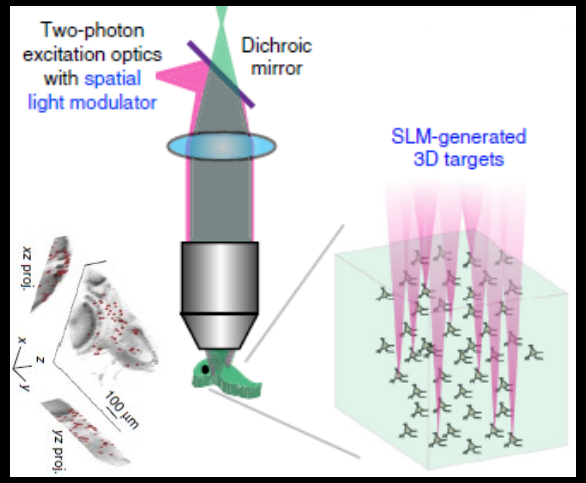
Multi-focal/-plane scanning ✔ ✗



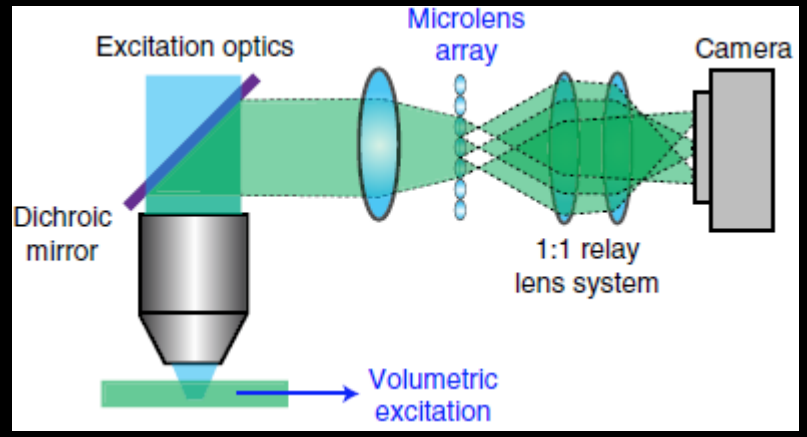
Abrahamsson, *Nat. Methods* 2012

Holographic 3D microscopy ✗ ✔



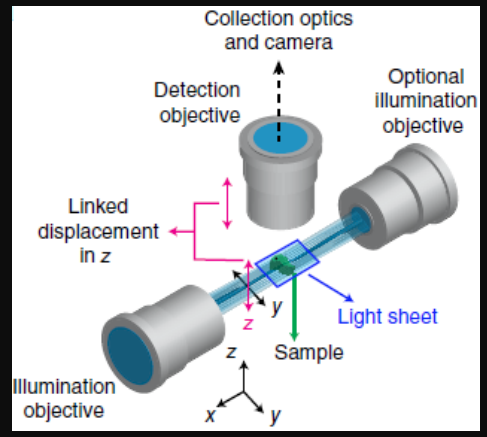
Quirin, *Front. Neural Circuits* 2014

Light field microscopy ✔ ✗



Levoy, *ACM ToG* 2006; Prevedel, *Nat. Methods* 2014

Light-sheet microscopy ✔ Wide-field ✔ Full-resolution



Ahrens, *Nat. Methods* 2013

Snapshot compressive imaging

Encoding

3D → 2D

Decoding

2D → 3D

High-speed volumetric light-sheet

Snapshot Compressive Imaging

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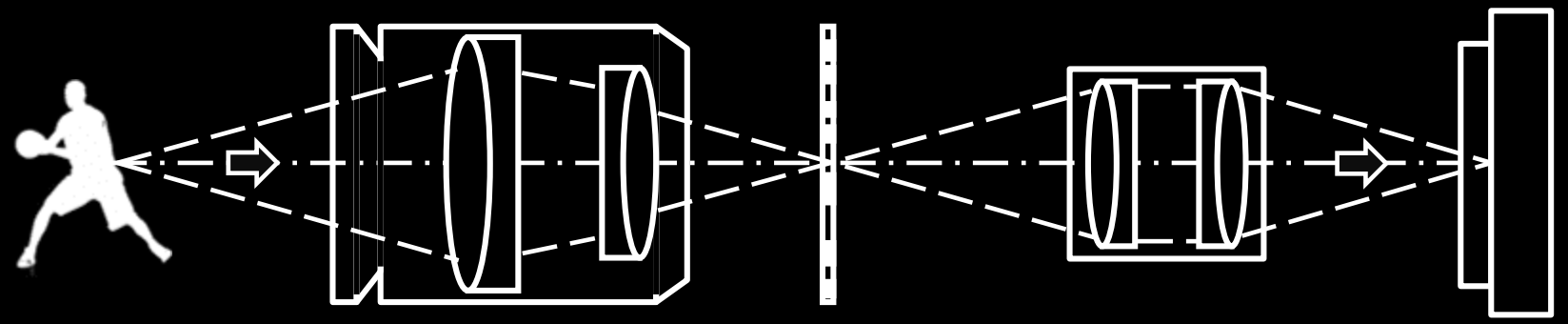


Scene

1,000 Hz

Objective lens

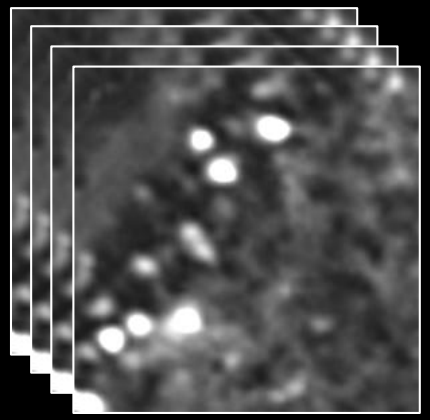
DMD

1,000 Hz

Relay lens

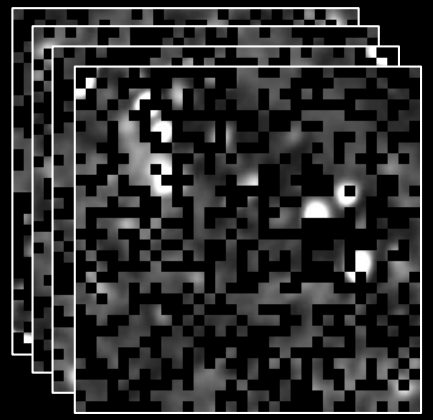
sCMOS

100 Hz



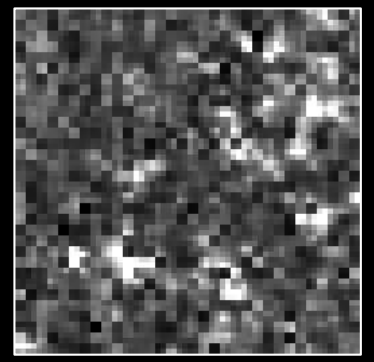
X_i

Encoding



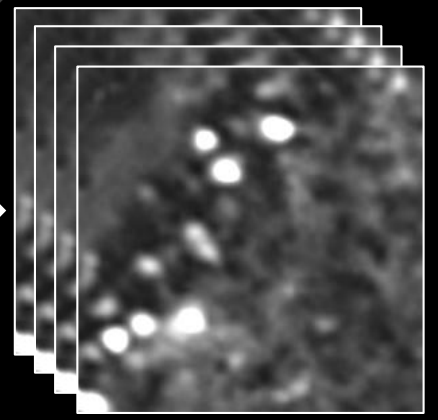
$X_i \odot C_i$

Capturing



$\sum X_i \odot C_i$

Decoding



Snapshot Compressive Imaging

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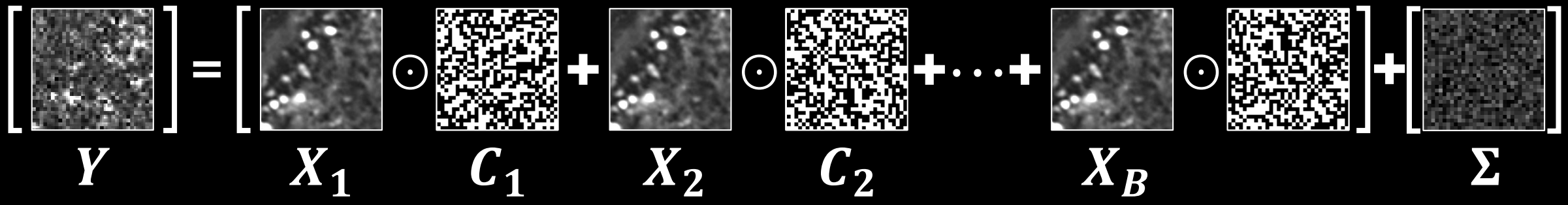
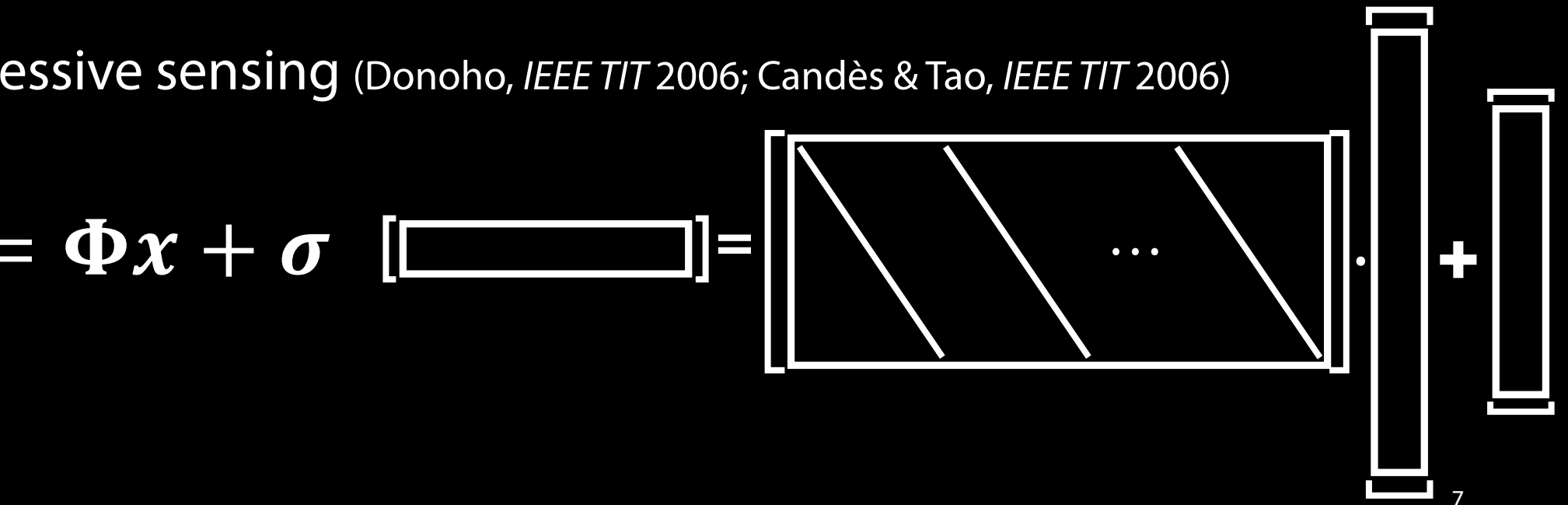
- Forward model



- Compressive sensing (Donoho, *IEEE TIT* 2006; Candès & Tao, *IEEE TIT* 2006)

$$\boldsymbol{y} = \boldsymbol{\Phi x} + \boldsymbol{\sigma}$$



Snapshot Compressive Imaging

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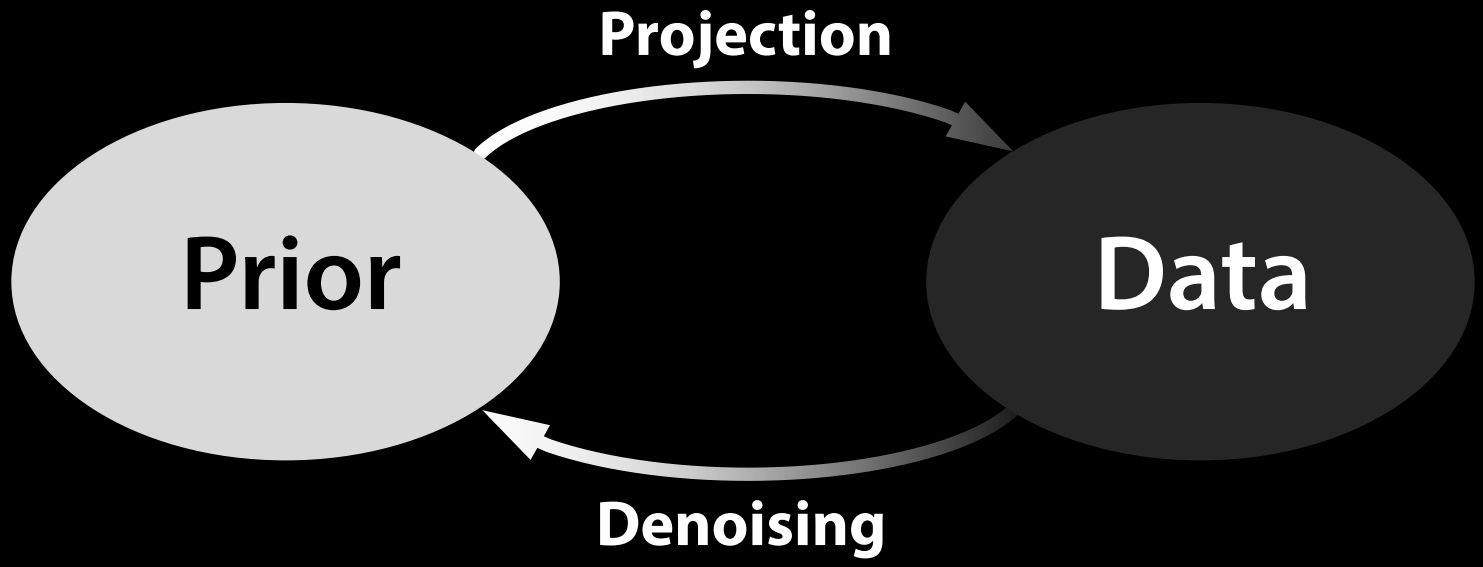
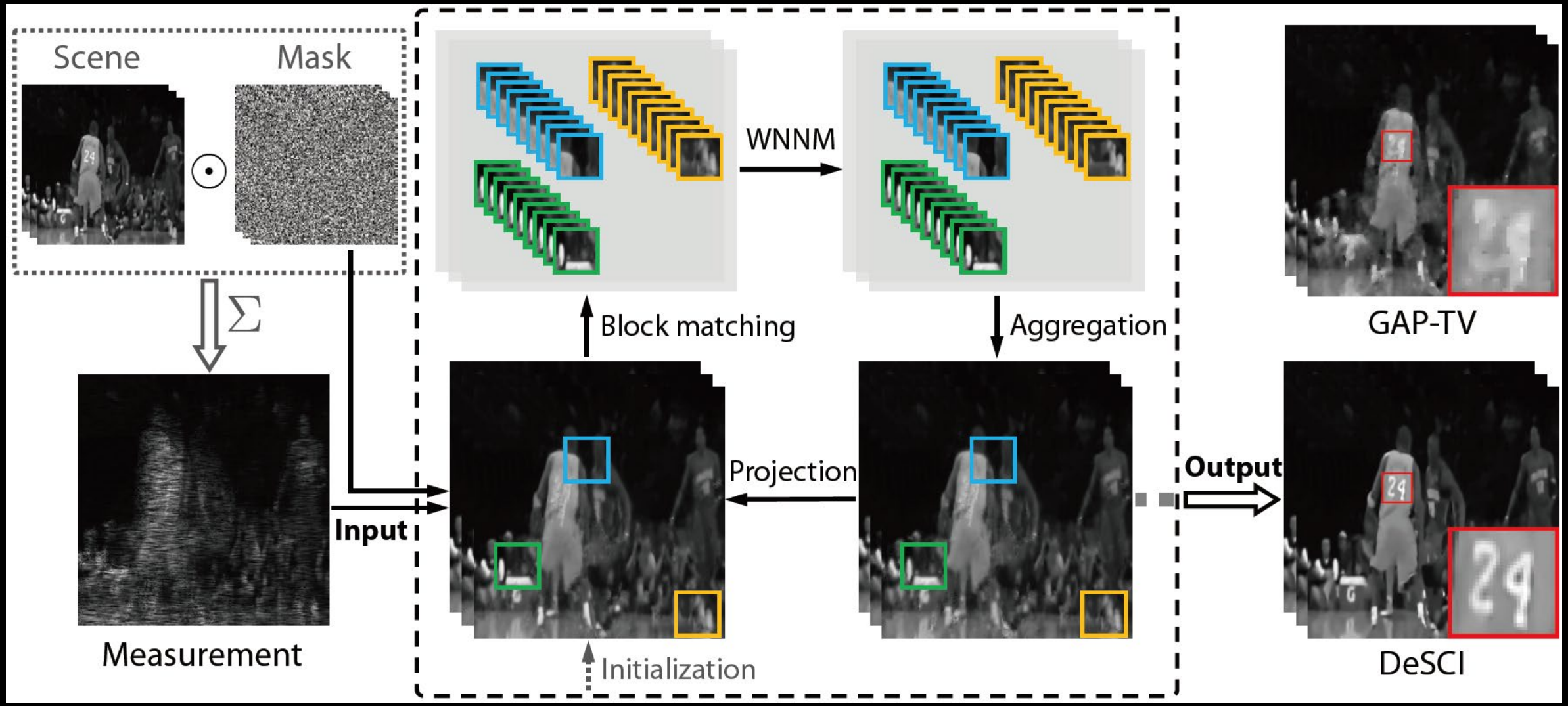
- Compressive sensing (Donoho, *IEEE TIT* 2006; Candès & Tao, *IEEE TIT* 2006)

$$\hat{\boldsymbol{x}} = \arg\min_{\boldsymbol{x}} \|\boldsymbol{y} - \boldsymbol{\Phi x}\|_2^2 + \boldsymbol{\lambda} \cdot \|\boldsymbol{x}\|_1$$

- Decompress snapshot compressive imaging (DeSCI)
  (Liu,* Yuan,* et al. *IEEE TPAMI* 2018)



Snapshot Compressive Imaging



Liu,* Yuan,* et al. *IEEE TPAMI*, doi:10.1109/TPAMI.2018.2873587

Snapshot Compressive Imaging

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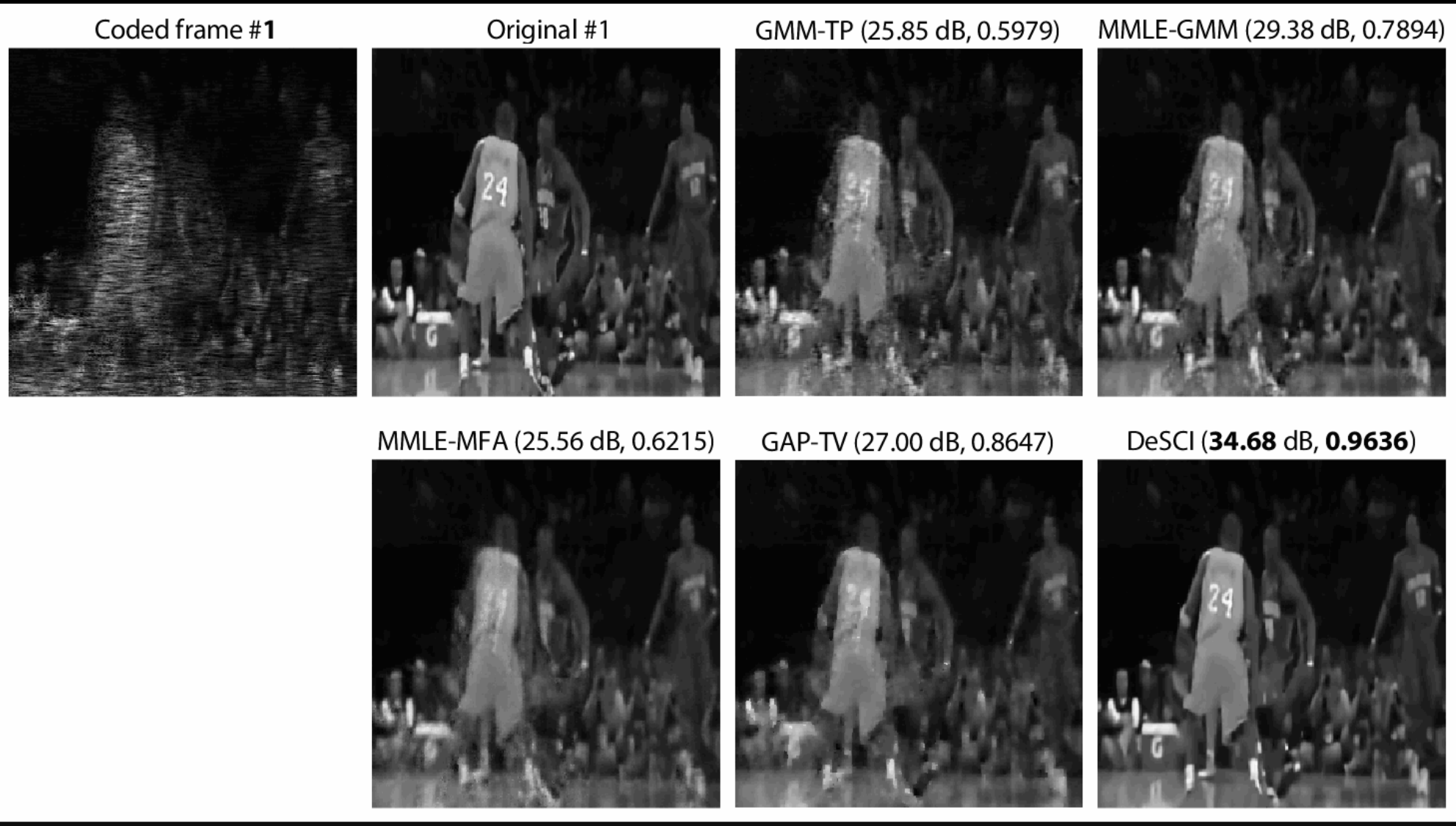

Liu,* Yuan,* et al. *IEEE TPAMI*, doi:10.1109/TPAMI.2018.2873587

Snapshot Volumetric Imaging

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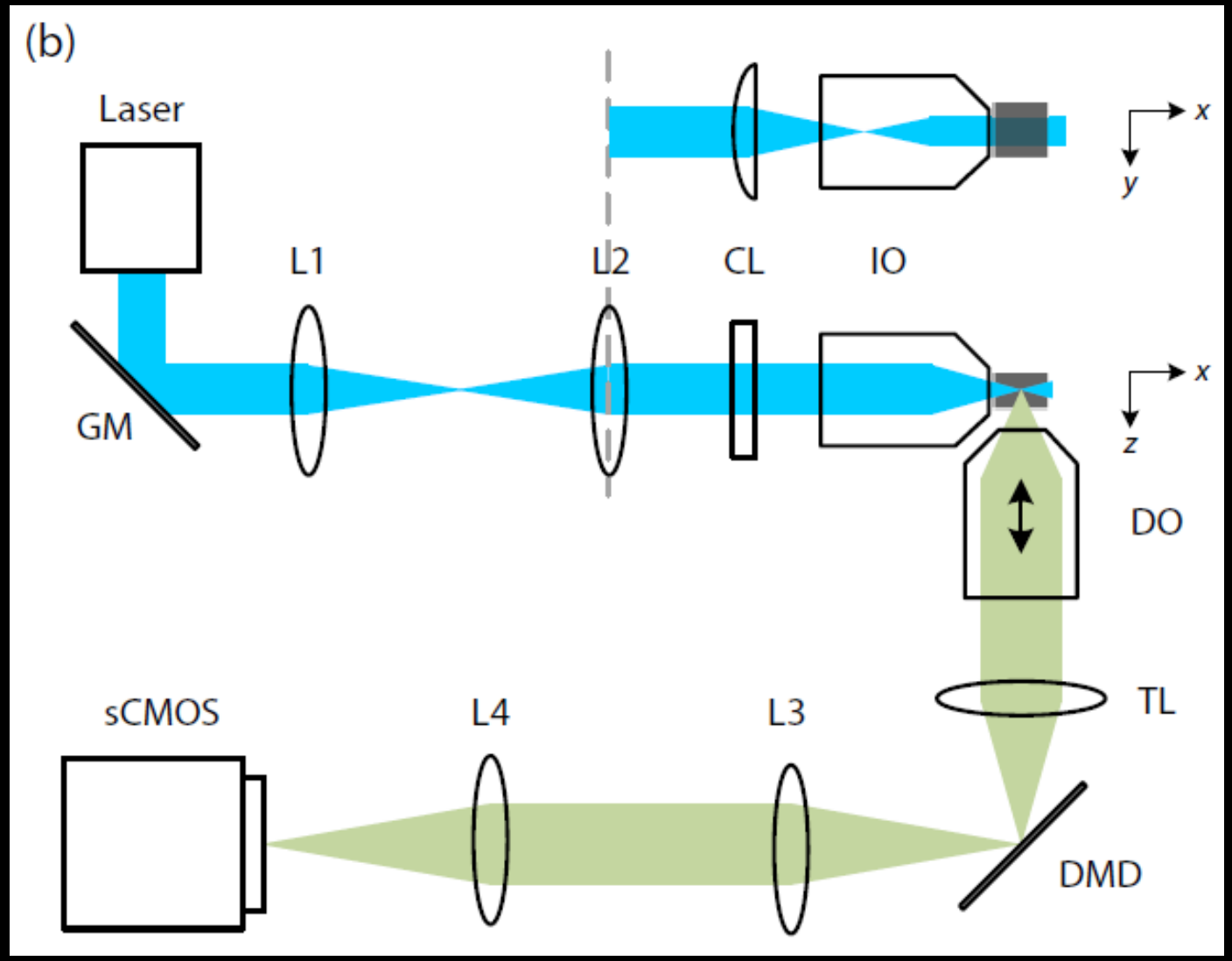

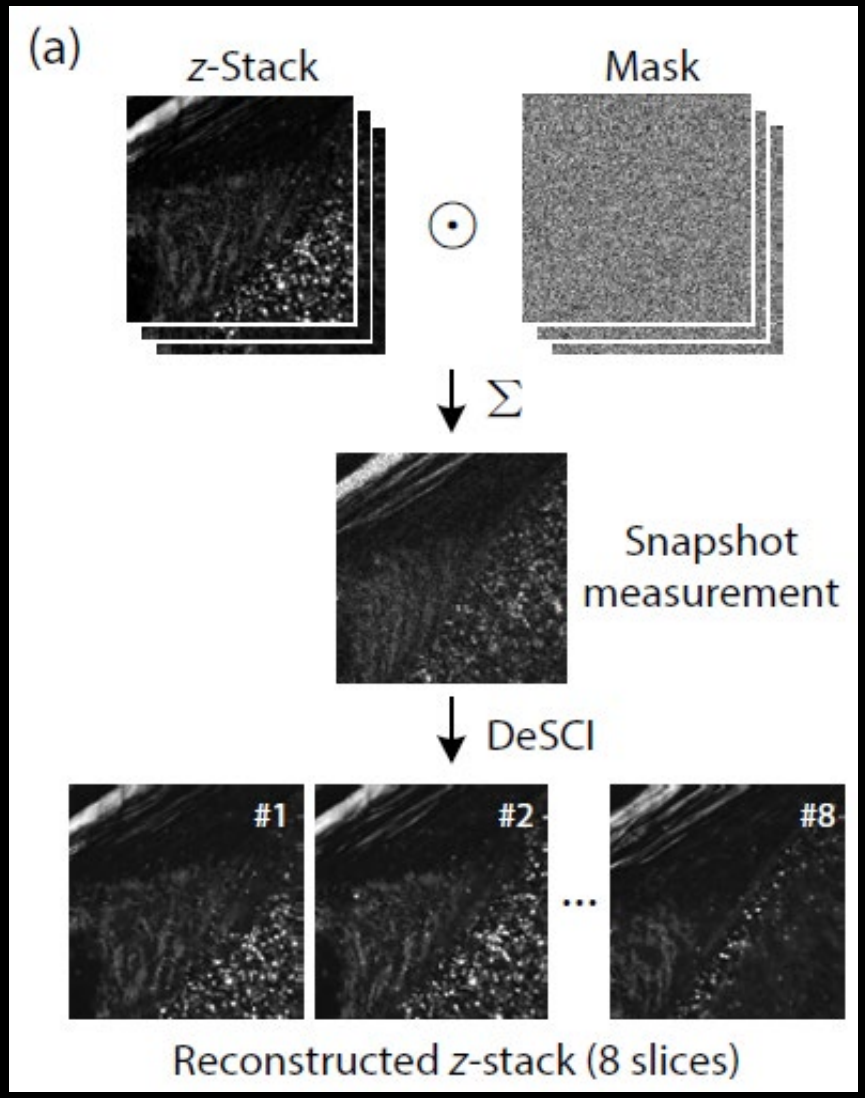

Snapshot Volumetric Imaging

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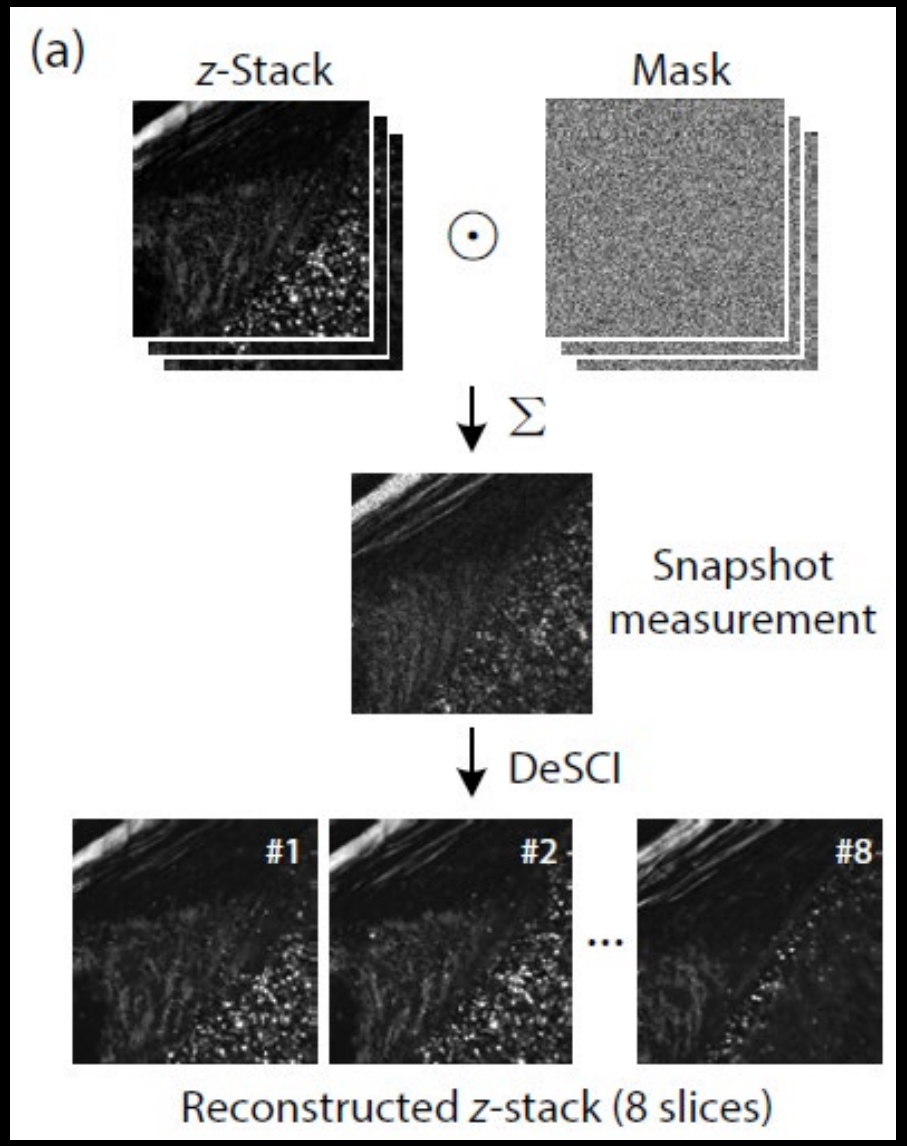

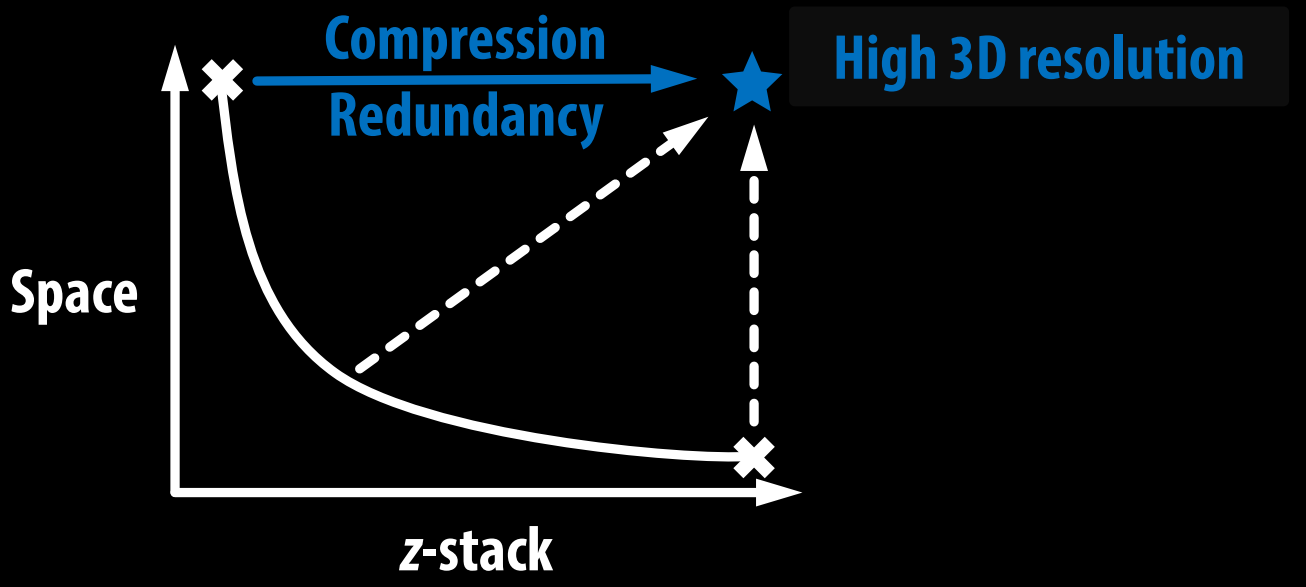

Snapshot Volumetric Imaging

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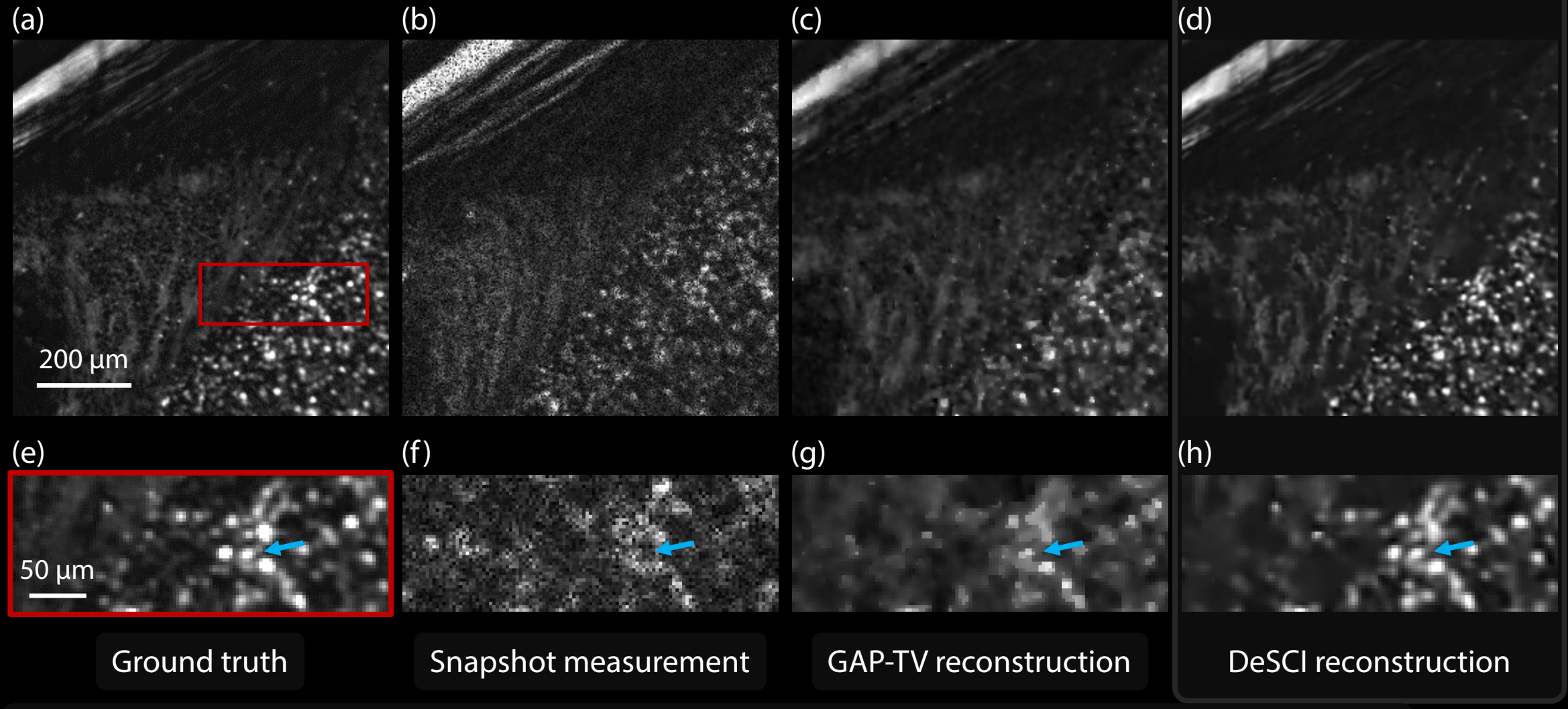

* Simulation results using images of a cleared mouse brain (CX3CR1-GFP) captured from a conventional LSM system. Eight *z*-stacks (pixel resolution of 256×256, *z*-step of 5.4 μm) are collapsed to a snapshot measurement.

Snapshot Volumetric Imaging

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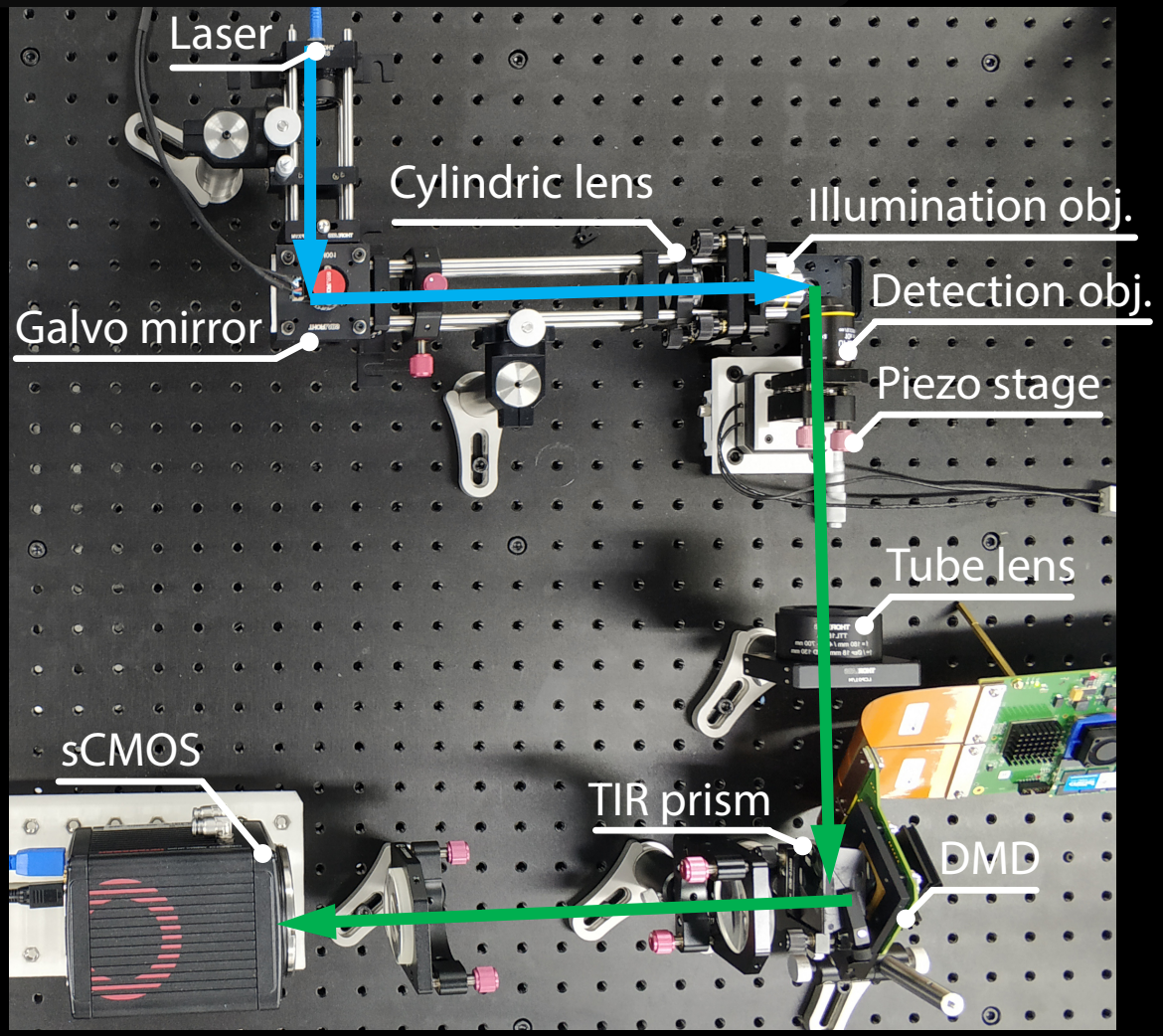
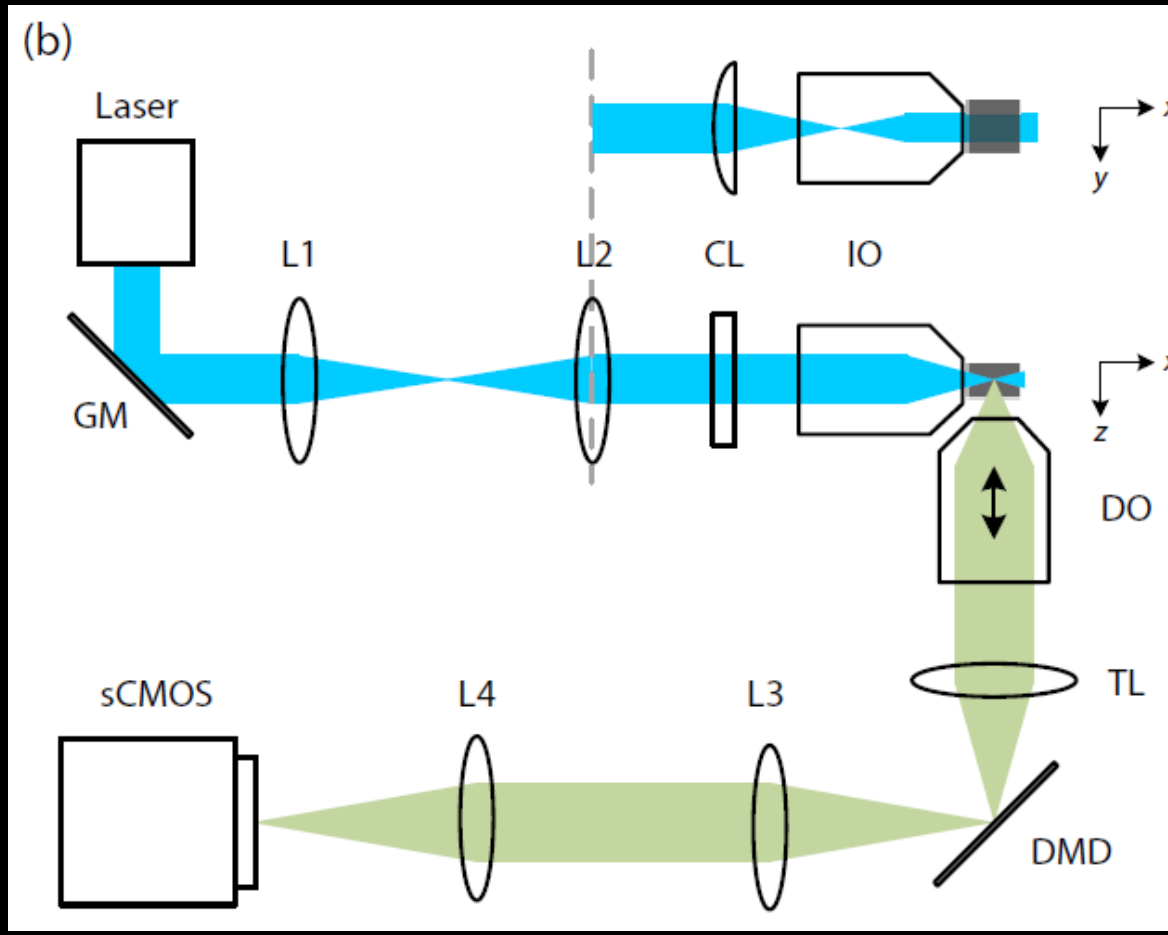
On-going SCV-LSM system …





Snapshot Volumetric Imaging

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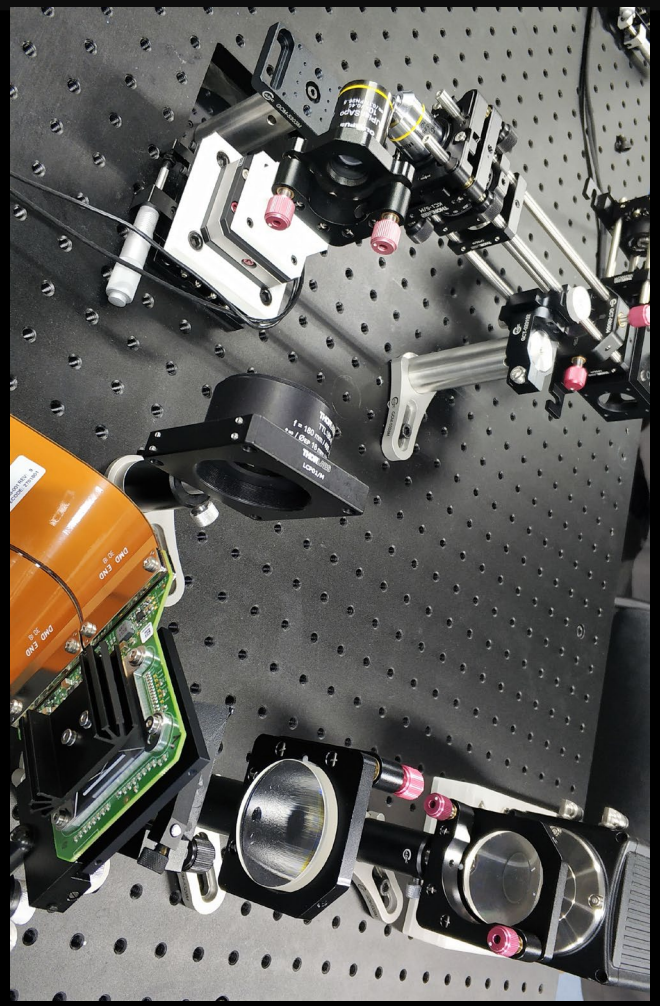
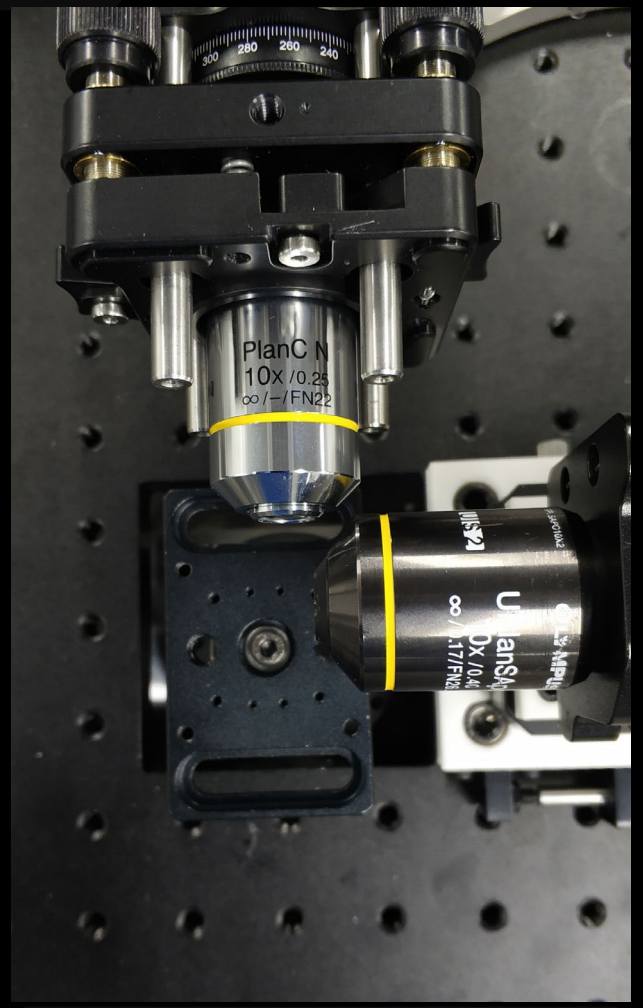
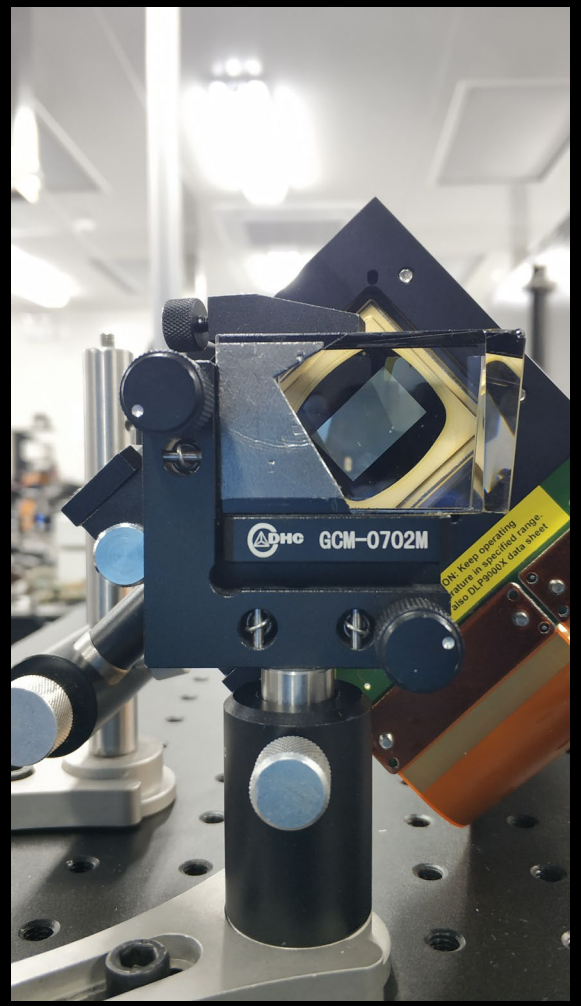
On-going SCV-LSM system …



Detection arm



Objectives and the sample



DMD and TIR prism

Summary (SCV-LSM)

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- Conclusion: SCV-LSM enables high-speed volumetric light-sheet microscopy at **20 Hz** with **50 axial planes**.
  - High-throughput (compressive high-speed, hyperspectral or light-field)

- Caveats:
  - The DMD blocks half of the light [Poisson noise] -> *Complementary acquisition with two sCMOS cameras*
  - Low spatial resolution [LSM] -> *Lattice light-sheet* (Chen, *Science* 2014)
  - Aberrations for *in vivo* observations -> *Adaptive Optics* (Liu, *Science* 2018)
  - Slow reconstruction (~1 hour for 256×256×8) -> *GPU acceleration and learning-based reconstruction* [***Deep learning***] (Weigert, *Nat. Methods* 2018)

Thanks to the lab!

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Artificial **I**ntelligence, **B**iological **I**ntelligence, and **C**omputational **I**maging

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Thank you!

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