CMOS Pixelated Detectors

For Multi-probe Radiography

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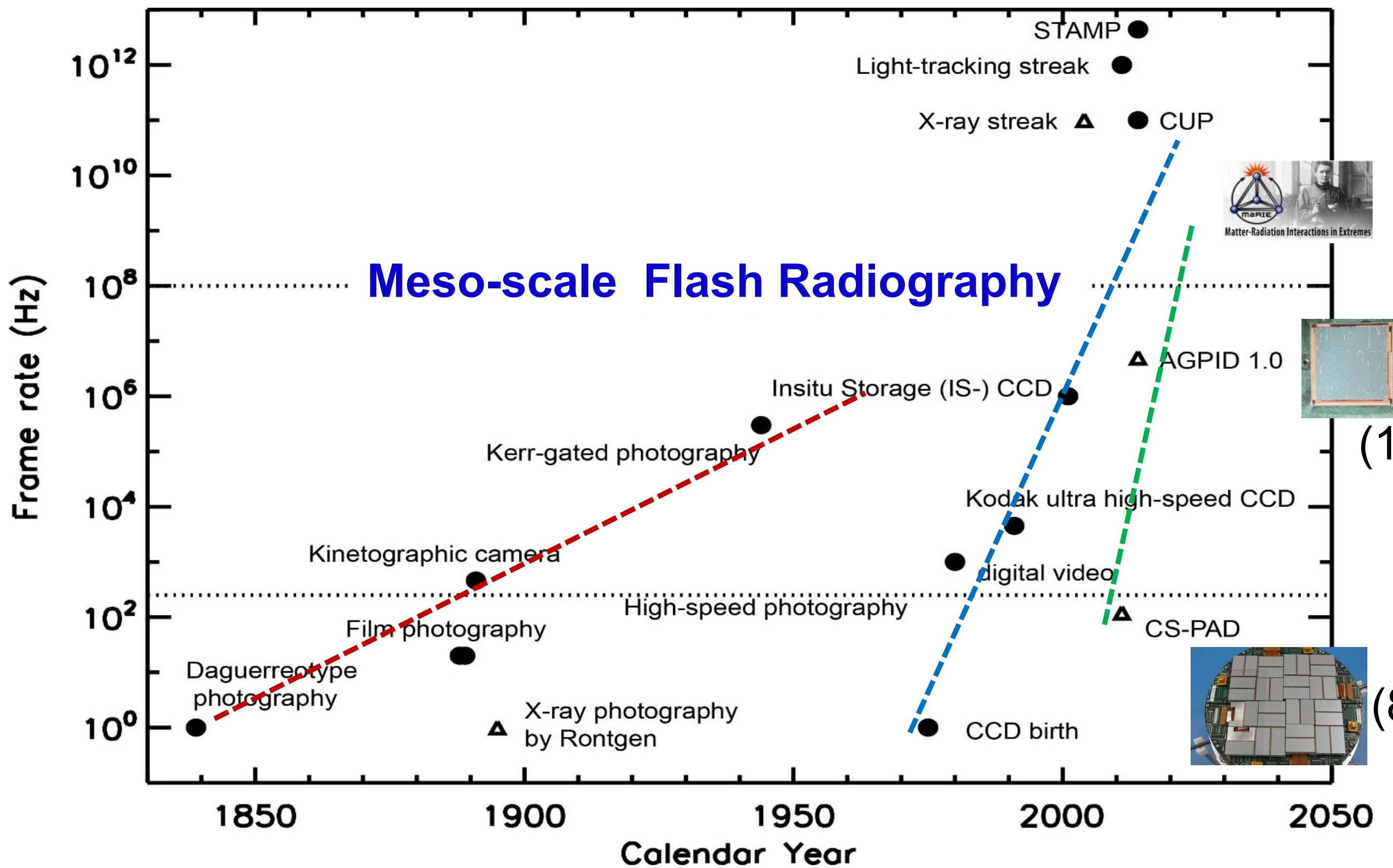
Ultrafast Detectors & Applications (**UDA**) institutions

UNCLASSIFIED

Outline

- **Motivations**
  - Flash radiography
  - High-speed imaging for dynamic experiments
  - ‘6H’ frontiers
- **Recent progress & highlights**
  - Electronics-driven: CMOS sensors
  - (Photonics-driven)
  - Materials-driven: Scintillators (primarily)
  - X-Ray Applications
  - Neutron work in progress
- **Summary**

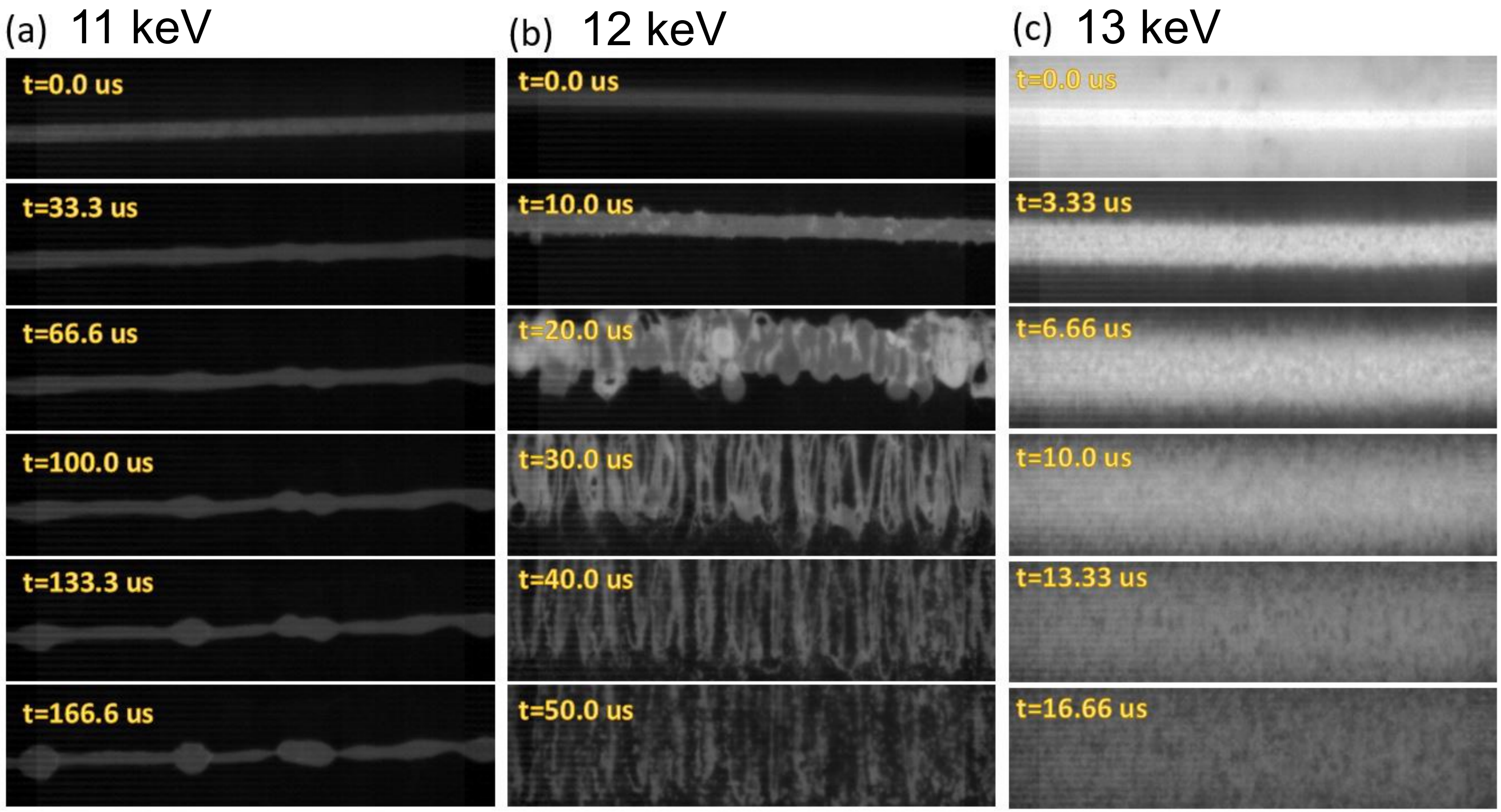
Evolution of high-speed imaging as of ~ 2017



(12 keV)

(8 keV)

In need of better temporal resolution

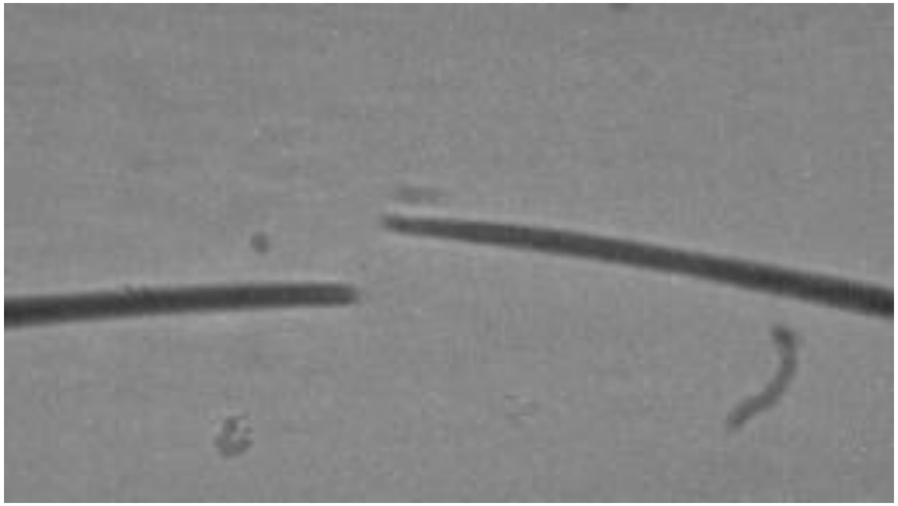


Fluid phase — "Phase explosion"

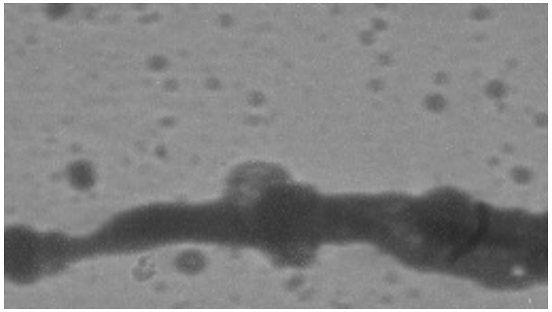
$T \sim T_0$ — $T > T_0$

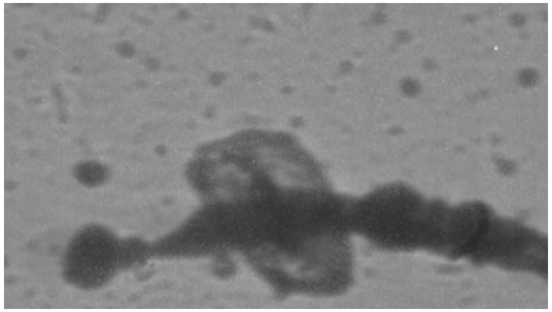
Sechrest *et al*, Appl. Phys. Lett. **117** (2020) 124102.

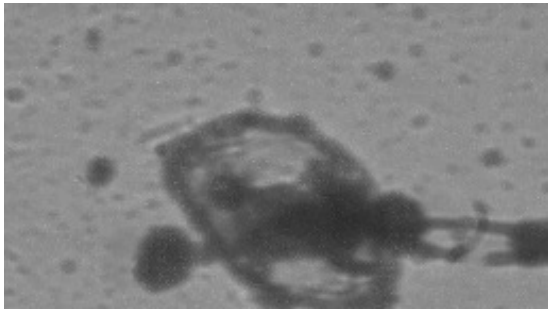
In need of 3D information: X-ray experiment @ APS



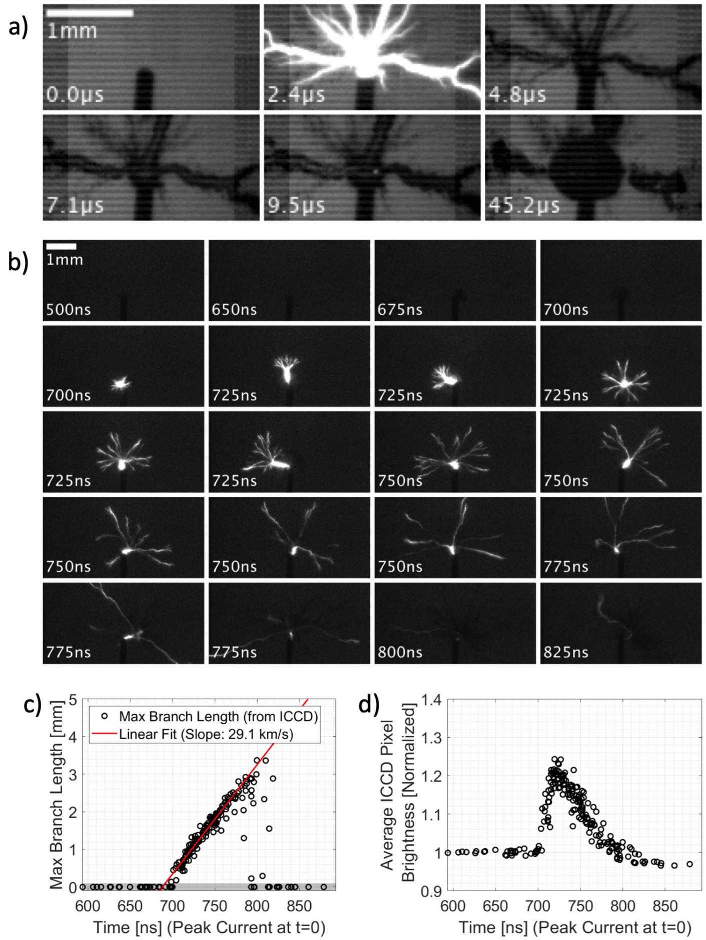
~ 100 kfps

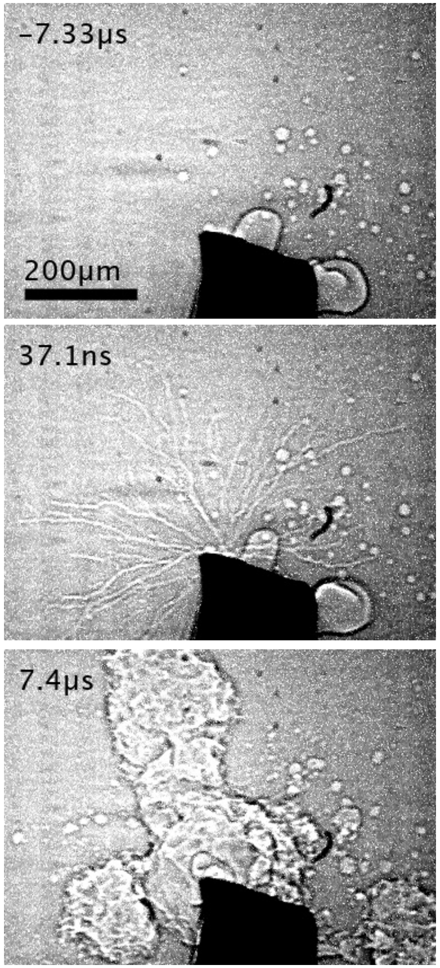






In need of Large FoV: X-ray experiment @ APS

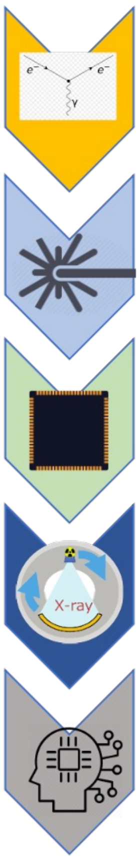




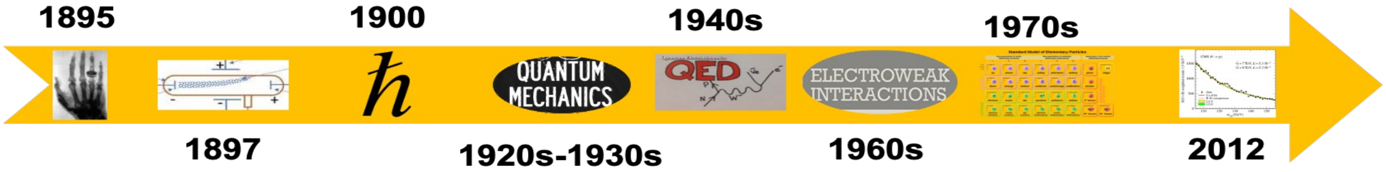
‘Lightening in water’

Campbell *et al*, Phys. Rev. Res. 3 (2021) L022021

Open problems in Flash Radiography



PHYS



SRCE Overcome limitations in source intensity, coherence, emittance

DETR “ 6H ” Frontiers

METH Maximization of information yield through novel materials, hardware (optics), and configurations (lensless imaging)

DATA Efficient algorithms, faster processing, noise rejection, automation

Appl. Opt. 16 (2022) RDS1-RDS4

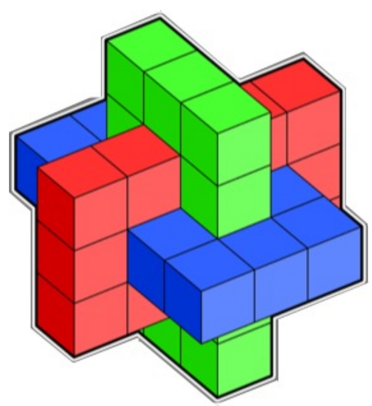
‘6H’ frontiers

High dimensional space optimization

- High-energy photons (20 keV +)
- High photon flux (10^7 + per pulse, sub-ns duration)
- High-efficiency /sensitivity (50% +)
- High temporal resolution (< 75 ns -)
- High spatial/pixel resolution (1-100 um -)
- High Data Volume

X-ray source

architecture

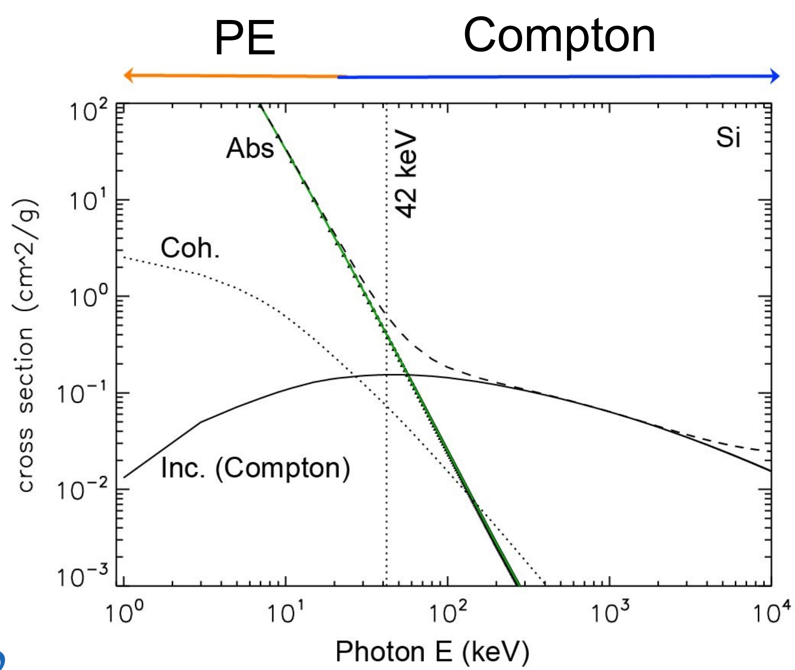


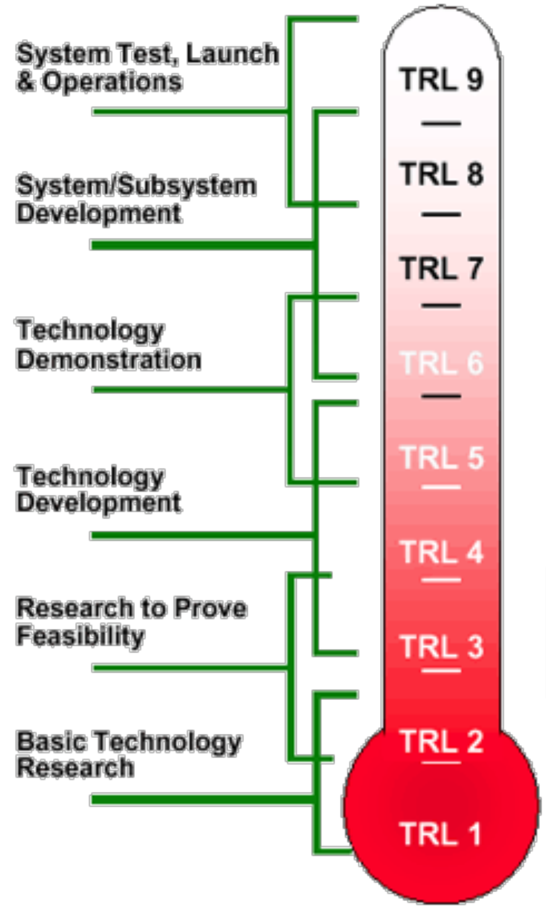
Sensor materials

Data

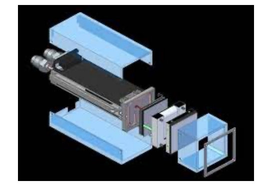
High-speed X-ray Cameras & prototypes

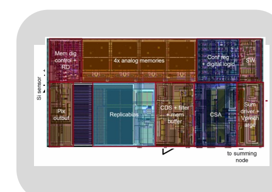
- **Hybrid CMOS**
- **Highest TRL Driven by near-term needs /light sources**





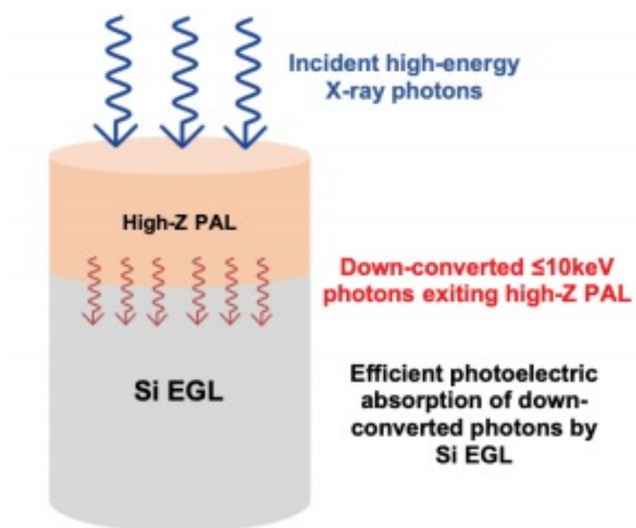
ePix (SLAC)

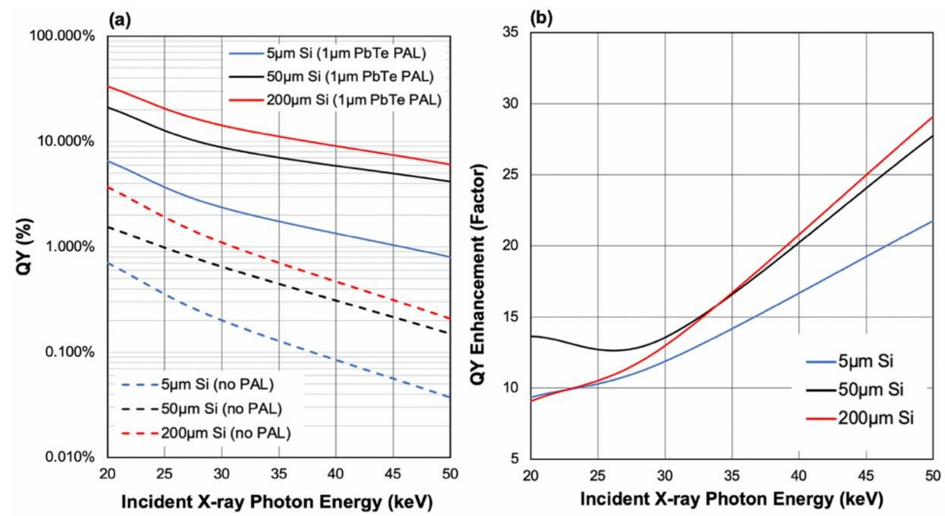




SparkPix (SLAC)

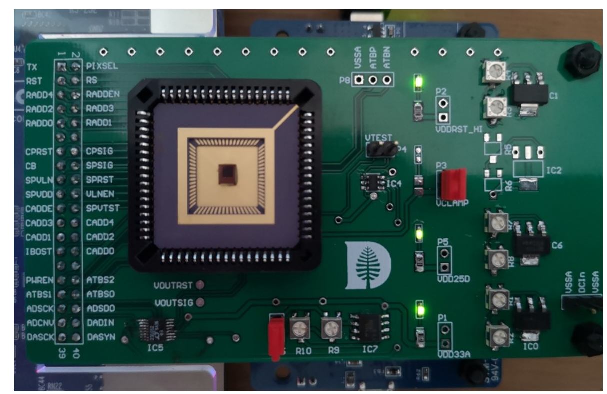
PAL layer integration with CMOS sensor





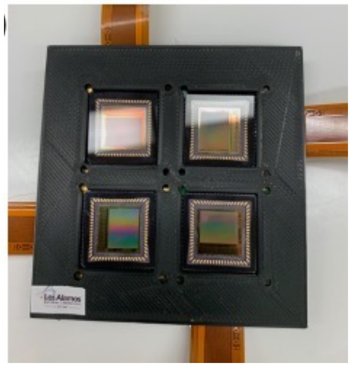
Pixel-level hybridization

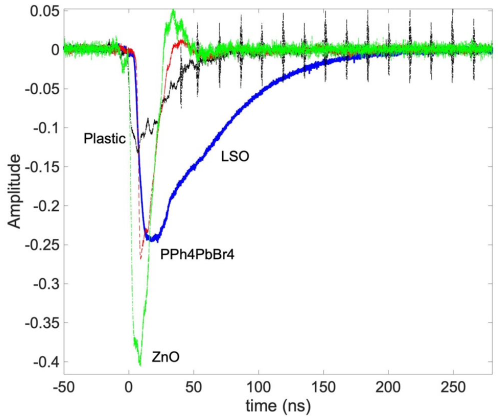
Lee *et al*, Instruments 5 (2021) 17

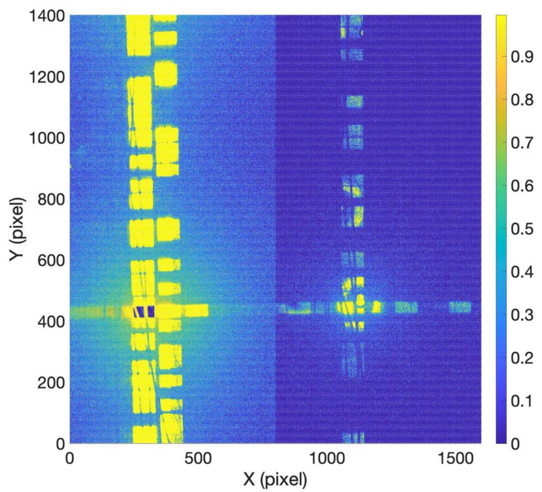


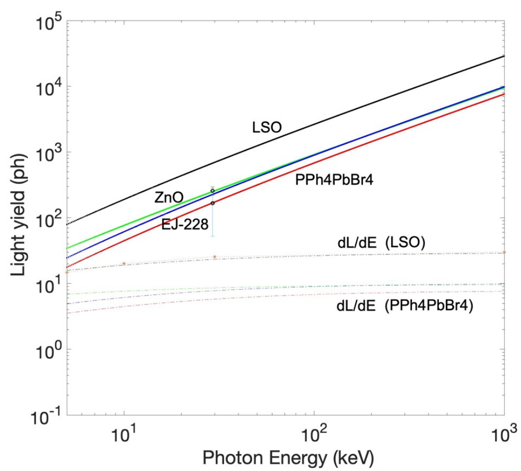
Yue et al, (2021)

Large FOV: Billion-pixel X-ray cameras (BiPC-X)





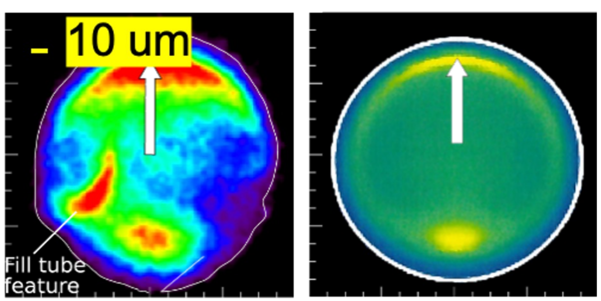




Wang *et al*, Rev. Sci. Instrum. 92 (2021) 043708

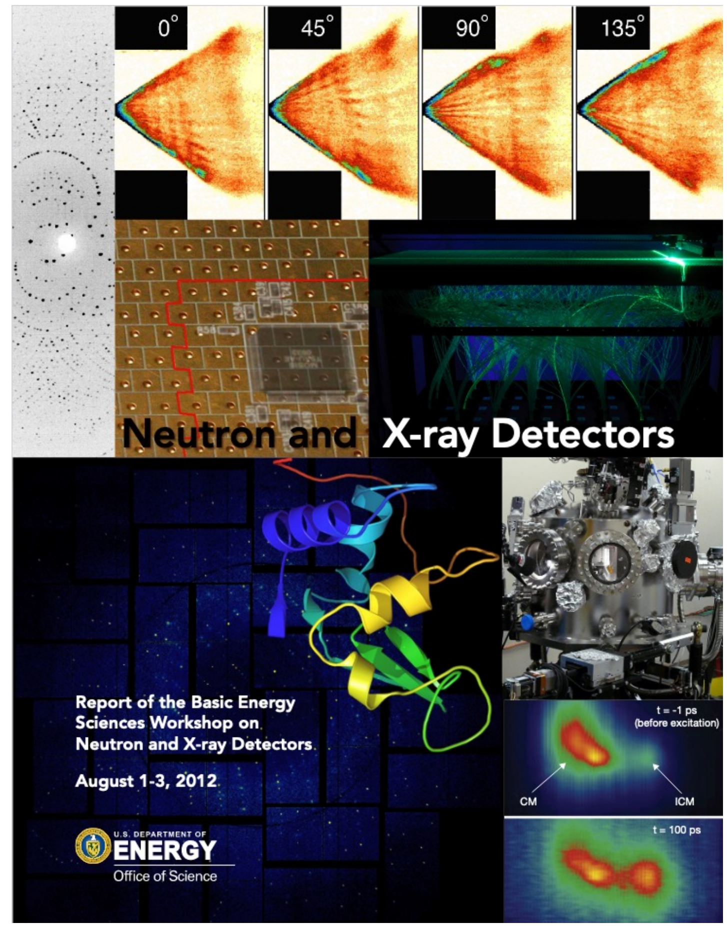
Some challenges with hardware centric approach

- Long development cycle
- High cost
- Imperfect results

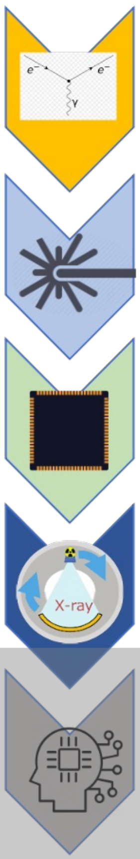


EXPERIMENT SIMULATION

D. J. Schlossberg et al, PRL (2021)



Open problems in Flash Radiography



Overcome limitations in source intensity, coherence, emittance

" 6H " Frontiers

Maximization of information yield through novel materials, hardware (optics), and configurations (lensless imaging)

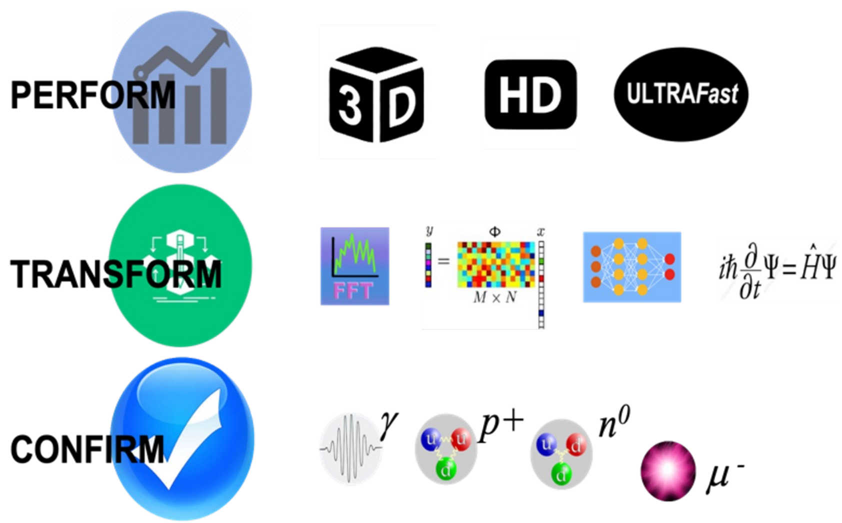
DATA

Efficient algorithms, faster processing, noise rejection, automation

Appl. Opt. 16 (2022) RDS1-RDS4

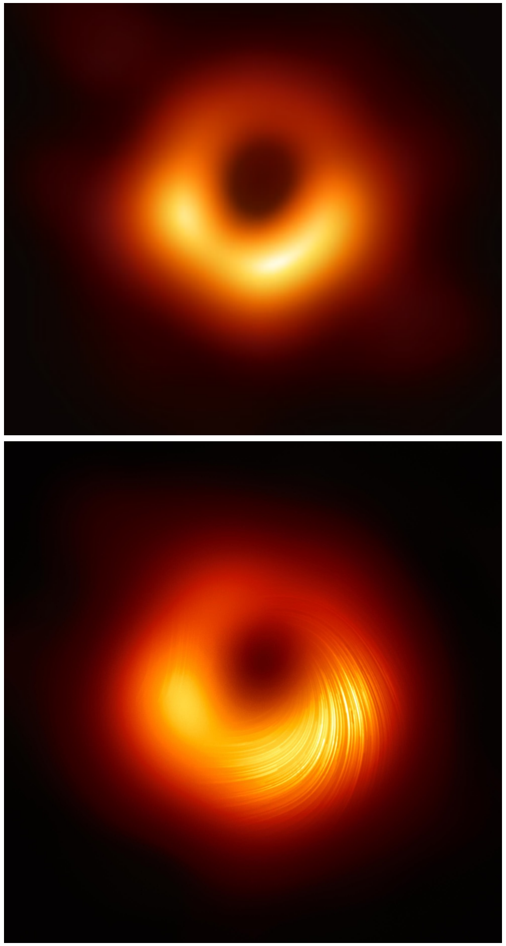
High data volume ~ large dynamic range

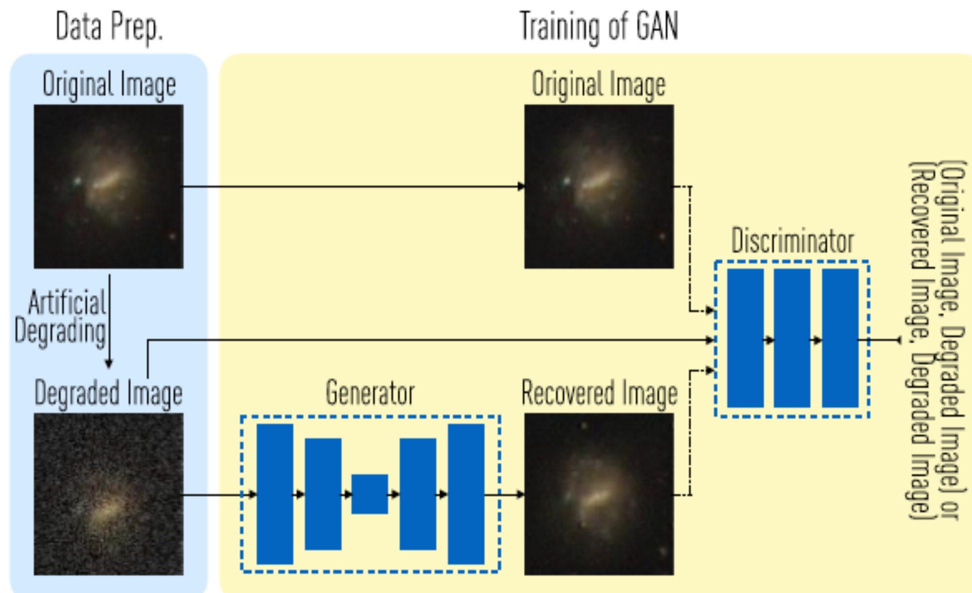
- Single photon sensitivity and > 10^5 photons per pixel within the same image
- Large FOV and resolution in a single device
- Image interpretation using theory or simulations
- Calibration data depend on a number of control parameters
- Noise
- …



Super – resolution in astronomy

M87

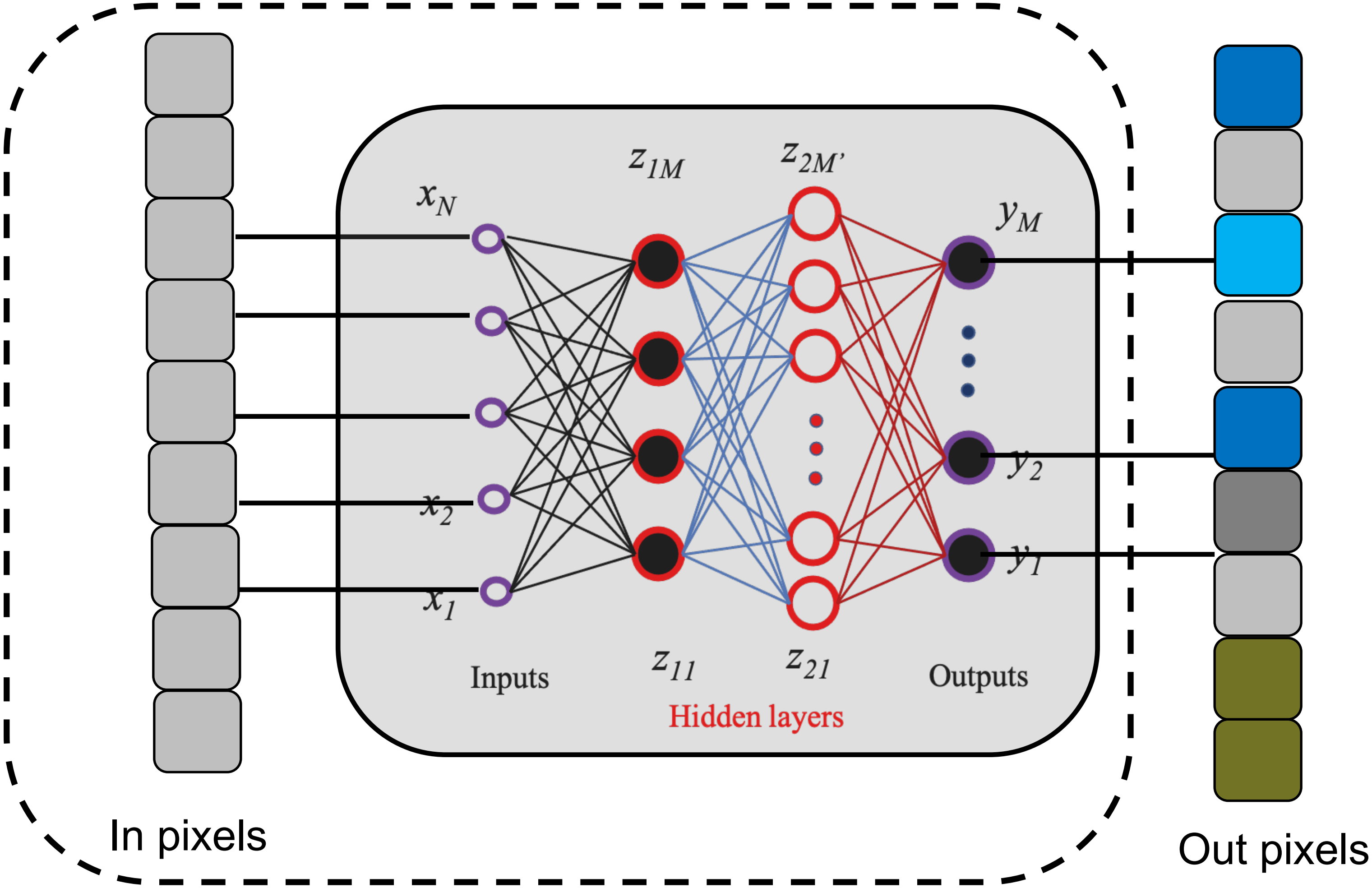




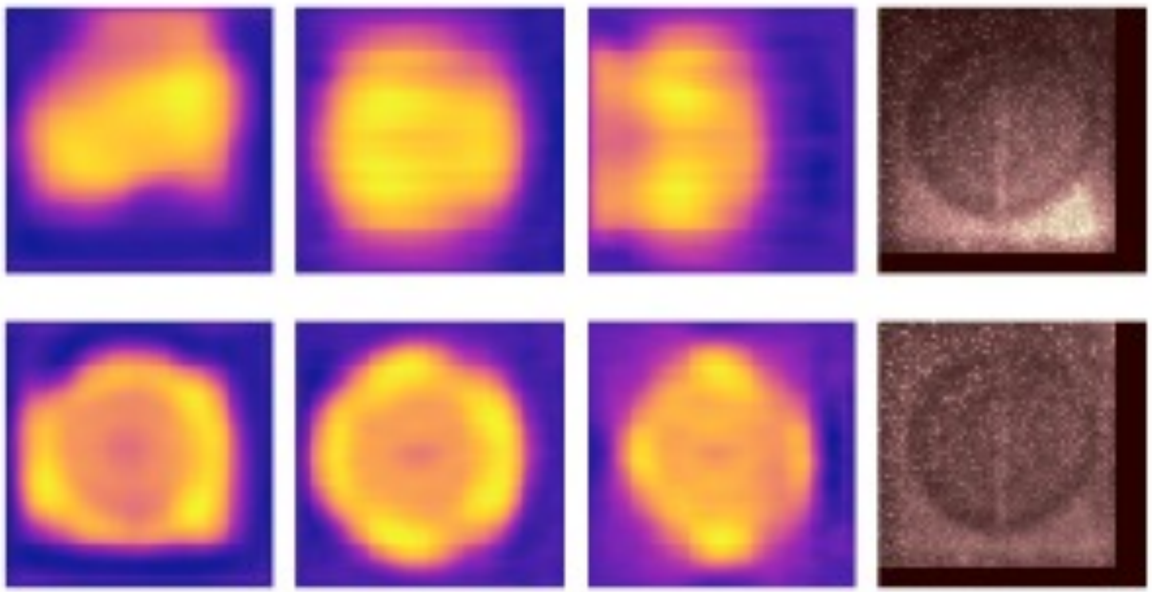
Schawinski et al, MNRAS 467 (2017) L110

The Event Horizon Telescope Collaboration *et al. Astrophys. J. Lett.* **875**, L1 – L4 (2019).

Φ–Cam Architecture based on Neural Network



3D reconstructions of X-ray images sensitive to noise



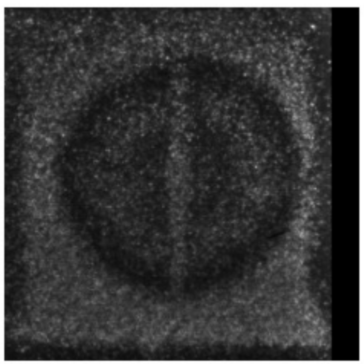
B. T. Wolfe et al, RSI 92 (3) (2021) 033547.

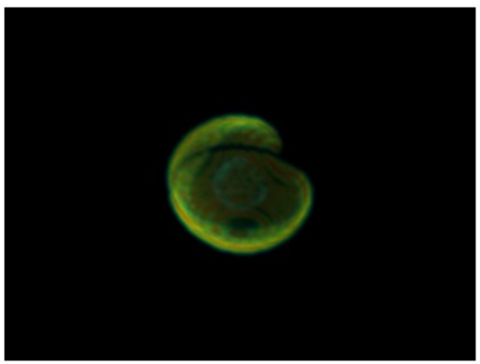
Model sensitivity studies

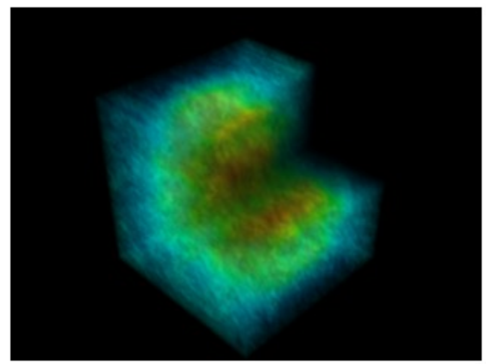
AttSets

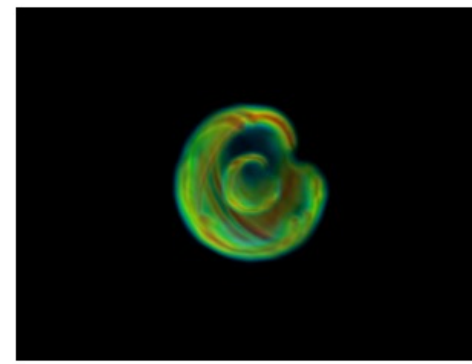
Transformable Bottleneck Networks(TBN)

Multiview Decomposition Network(MVD)





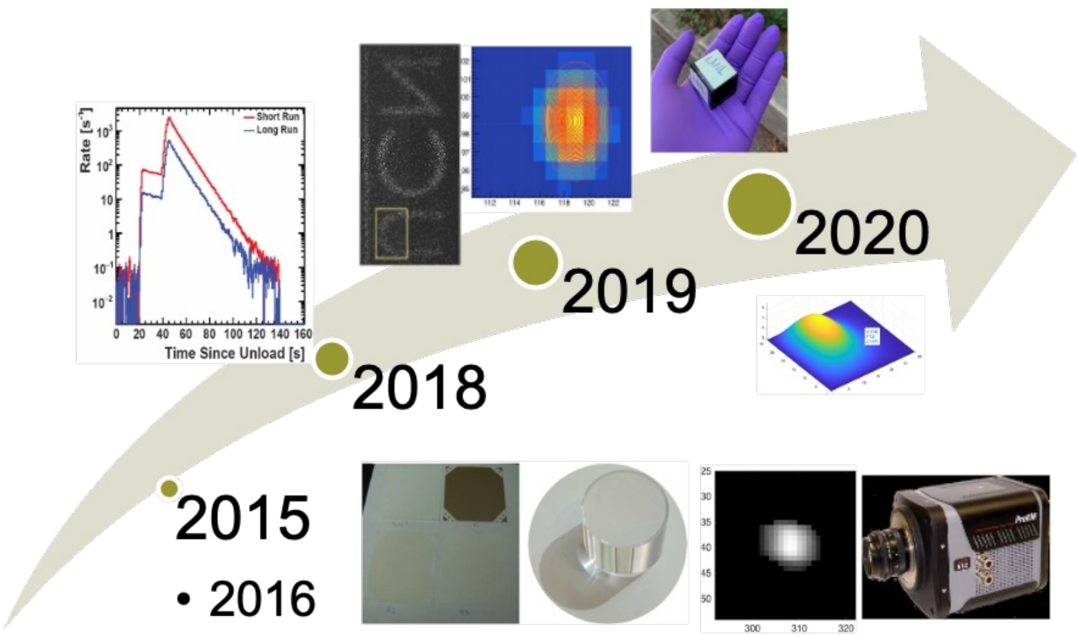




Wolfe et al, https://arxiv.org/abs/2206.02564

Neutron highlights

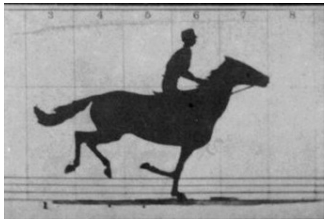
- **See Simon Spannagel (DESY) Talk**
  - -- Shanny Lin (LANL/ Texas Austin)



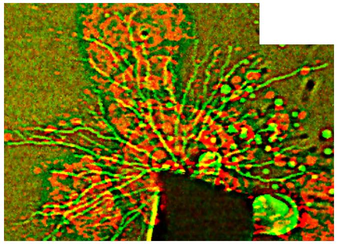
Sub-micron resolution

~ λ UCN

Summary



- **Flash X-ray radiography**
  - With roots in Flash photography
- **Recent trends** (hard-ware driven)
  - CMOS technology & device physics (legacy of the Moore's law)
  - Material discoveries (scintillators, nanomaterials),
  - Multiprobe radiography
- **Emergent opportunities** (data-driven)
  - data science, machine learning
  - Experimental validation
  - Broad application potentials → **Multiprobe Radiography**



Acknowledgement

Thank you !

Work supported in part by *LANL Office of Experimental Science (C2, C3)*, *LDRD*, NNSA *LRGF*, NNSA *SSAP, DoE SC*