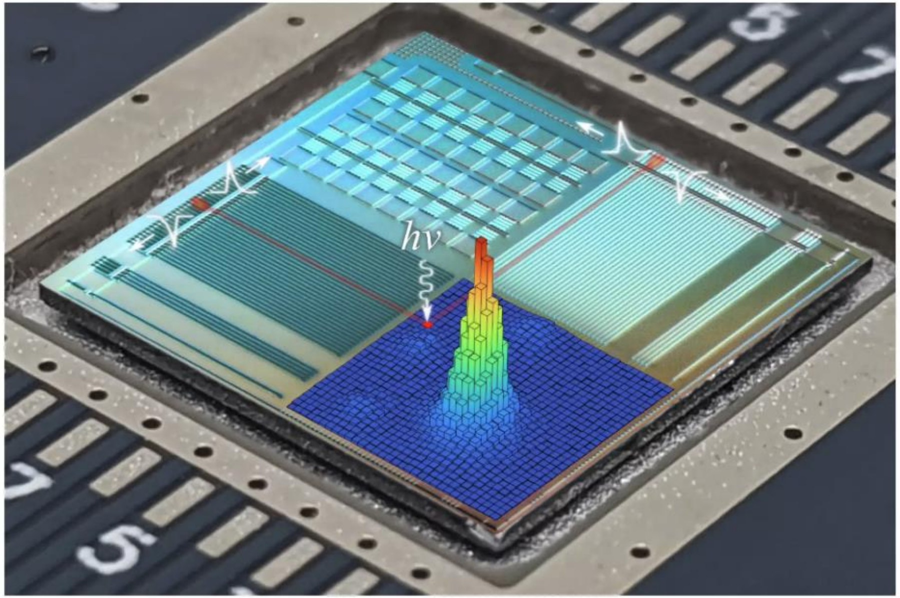
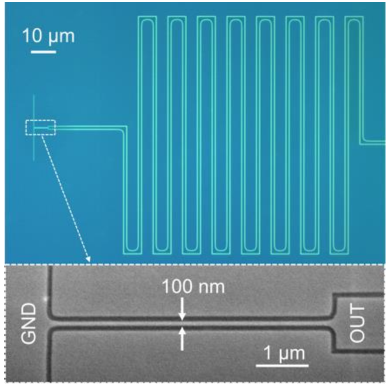
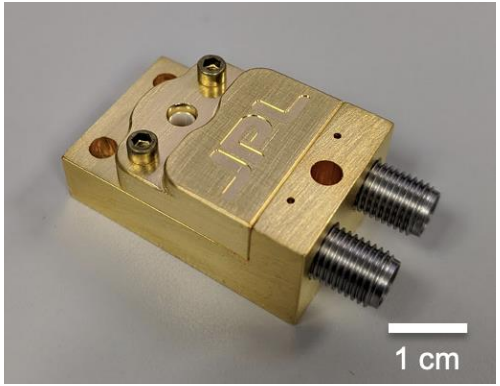






31st October 2024

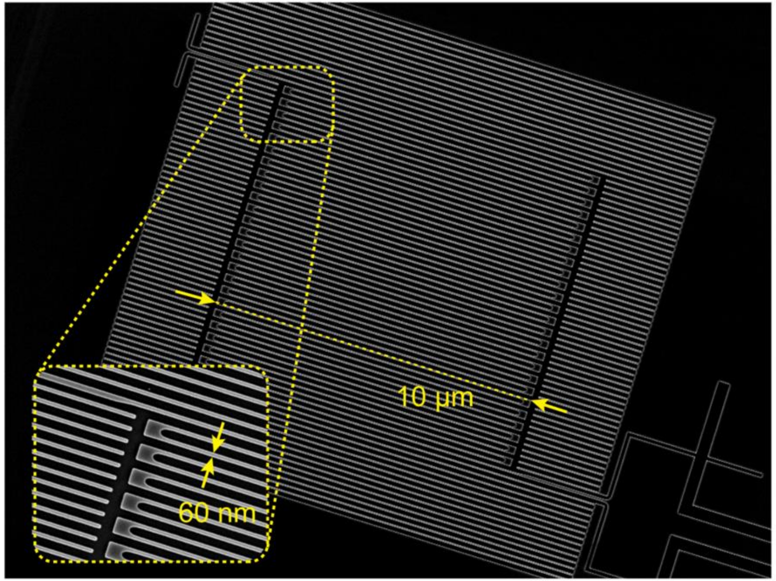
SNSPD Opportunities for Intensity Interferometry

Boris Korzh
University of Geneva, Switzerland
UNIVERSITÉ DE GENÈVE

boris.korzh@unige.ch
bkorzh@caltech.edu

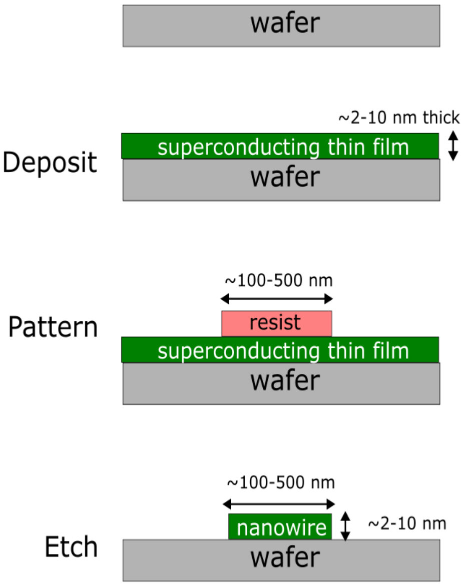
Jet Propulsion Laboratory
California Institute of Technology

Superconducting nanowire single-photon detector (SNSPD)



Single-pixel detector

Nanofabrication



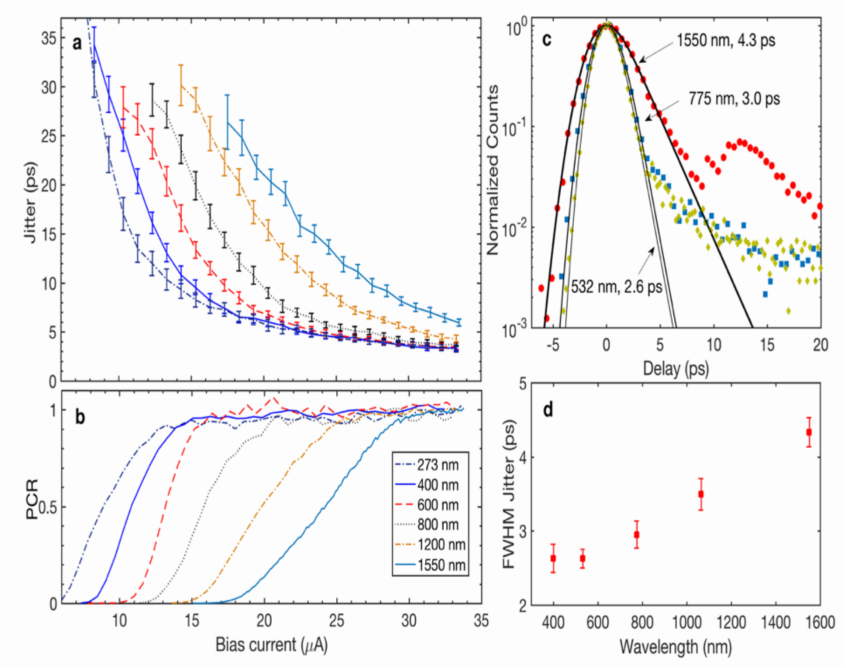
No need for full ‘Foundry’ process like SPADs
→ Easier to **tailor the devices for astronomy community**

Some select fabrication facilities (Academic and National Lab):

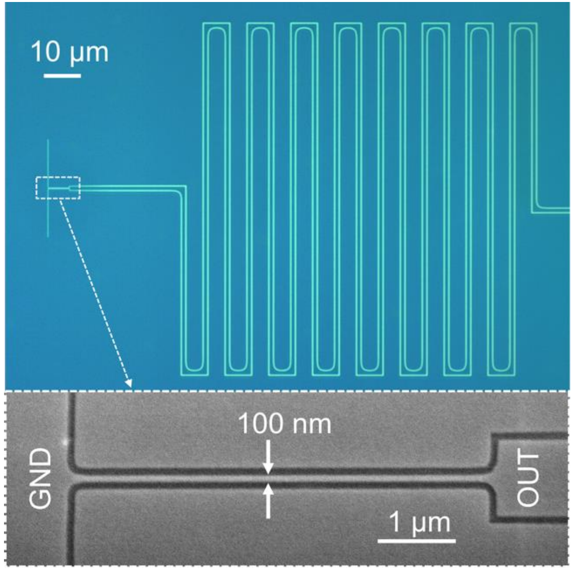
- Jet propulsion Lab, CA, USA
- NIST, Boulder, CO, USA
- MIT Nano, MA, USA
- NICT, Japan
- SIMIT, China
- EPFL, CMi, Switzerland
- TU Delft, Netherlands
- KIT, Germany
- KTH, Sweden
- …..

Goltsman, *et al*, ***APL* 79**, 705 (2001)

Record timing accuracy



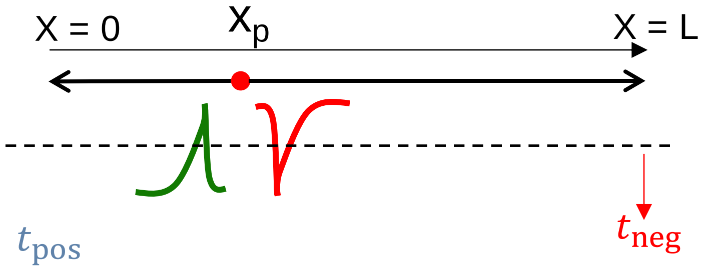
Probing the intrinsic timing jitter for first time (not limited by readout electronics)



Korzh, Zhao, Allmaras, Frasca *et al* ***Nature Photonics* 14,** 250-255 (2020)

Differential readout

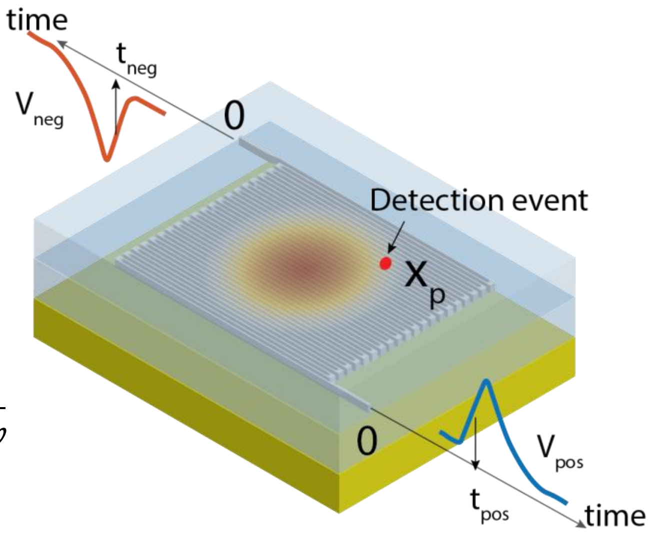
Geometric Effects (Slow speed → $v_{ph} \approx 0.01c$)



$$t_{pos} = \frac{x_p}{v}$$

$$t_{neg} = \frac{L - x_p}{v}$$

$$t_\Sigma = \frac{t_{pos} + t_{neg}}{2} = \frac{L}{2v}$$



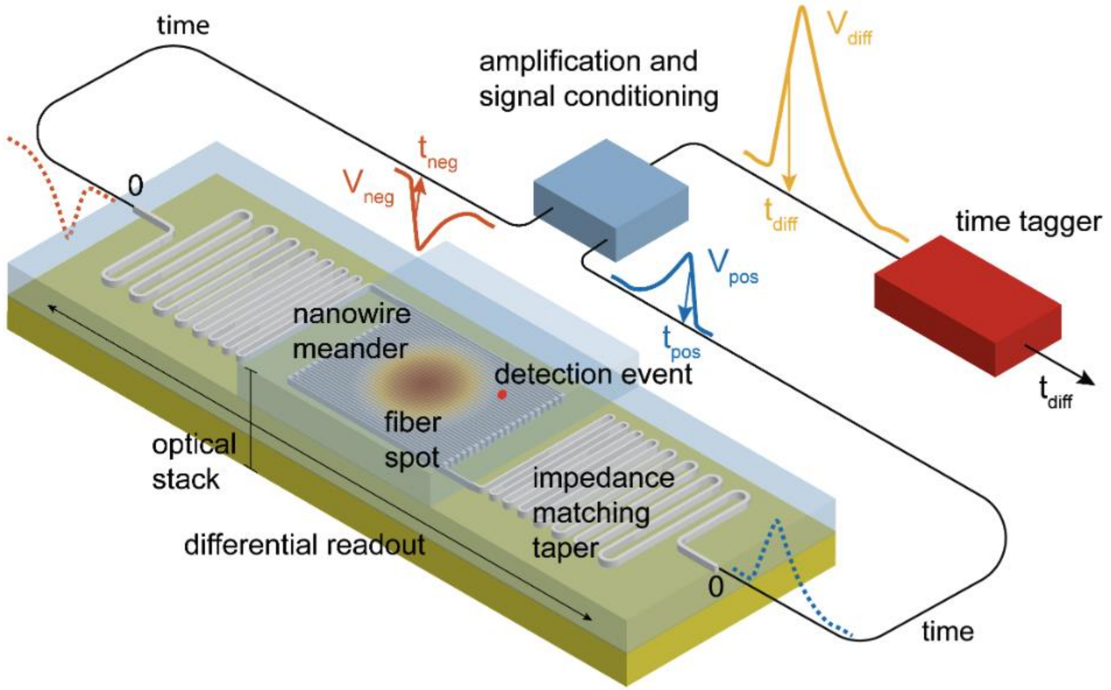
The detector jitter $\boldsymbol{j_\Sigma}$ is independent from x_p

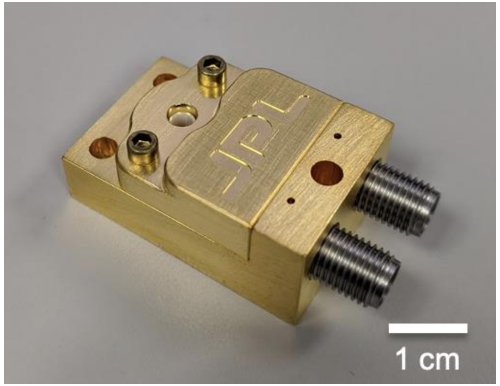
Geometric contributions are cancelled out!

Zhao, Qing-Yuan et al, ***Nature Photonics* 11**, 247 (2017)

Colangelo, Korzh, Allmaras, Beyer *et al*, ***PRApplied* 19**, 044093 (2023)

Practical single-pixel detectors

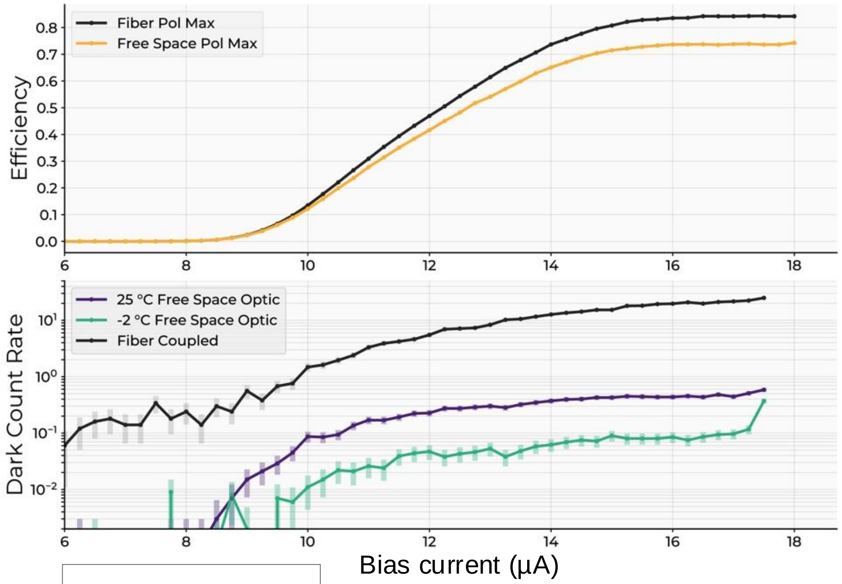




Colangelo, Korzh, Allmaras, Beyer *et al*, ***PRApplied* 19**, 044093 (2023)

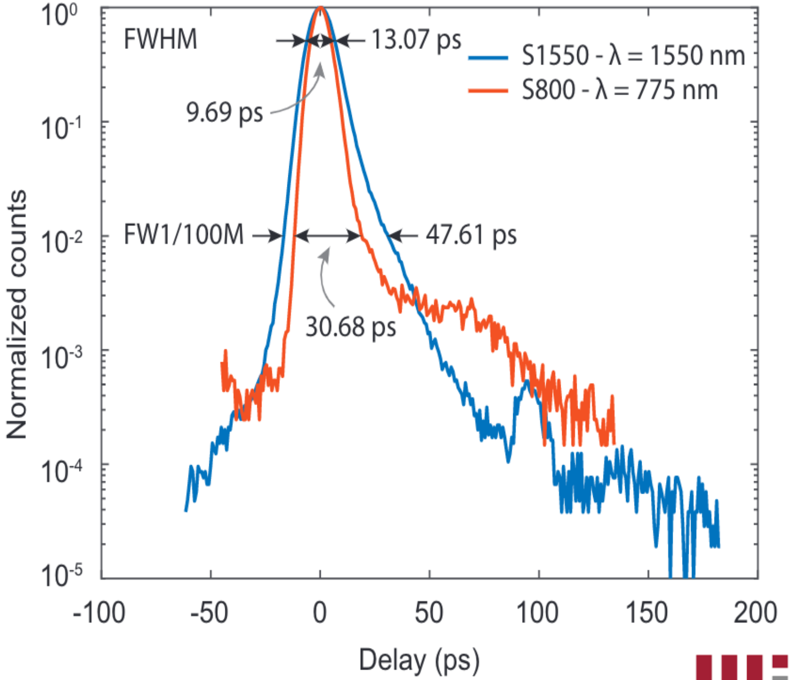
Combined metrics for fiber coupled detectors

High efficiency



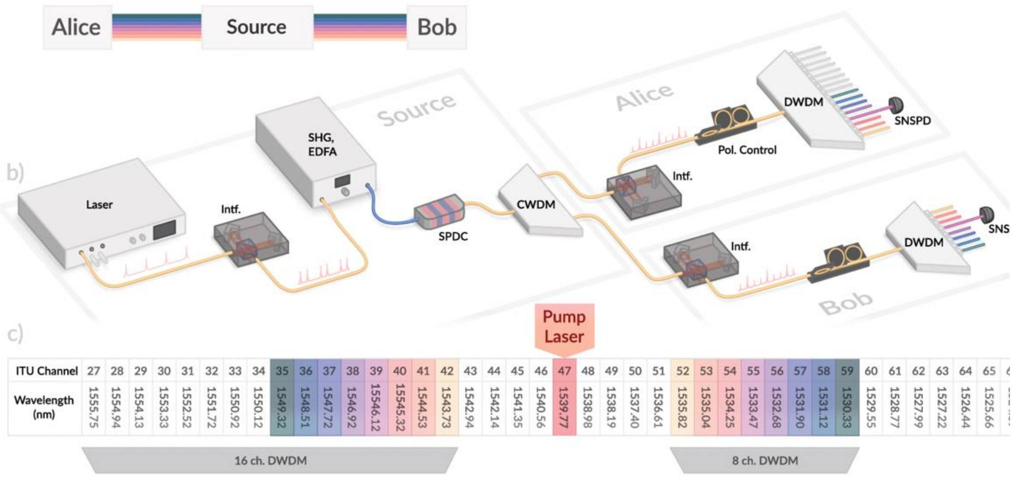
Low noise

Low ***system*** timing jitter

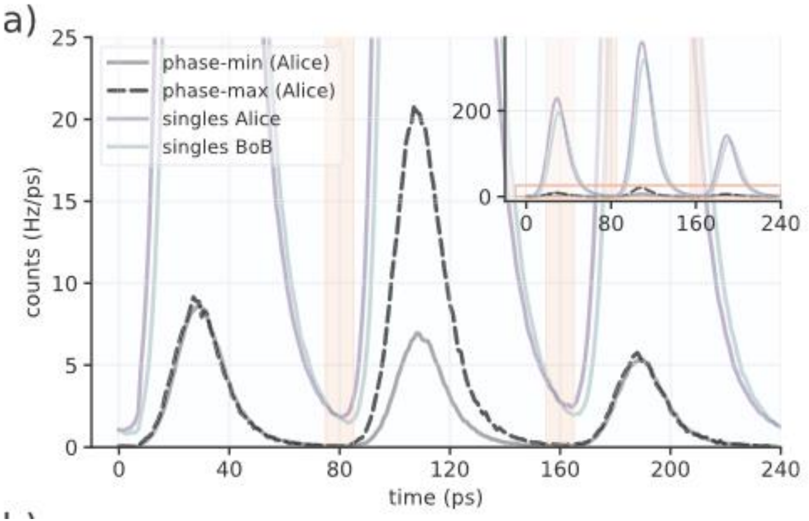


Colangelo, Korzh, Allmaras, Beyer *et al*, ***PRApplied*** **19**, 044093 (2023)
Mueller, Korzh, Runyan *et al*, ***Optica*** **8,** 1586 (2021)

Wavelength multiplexing around 1550 nm



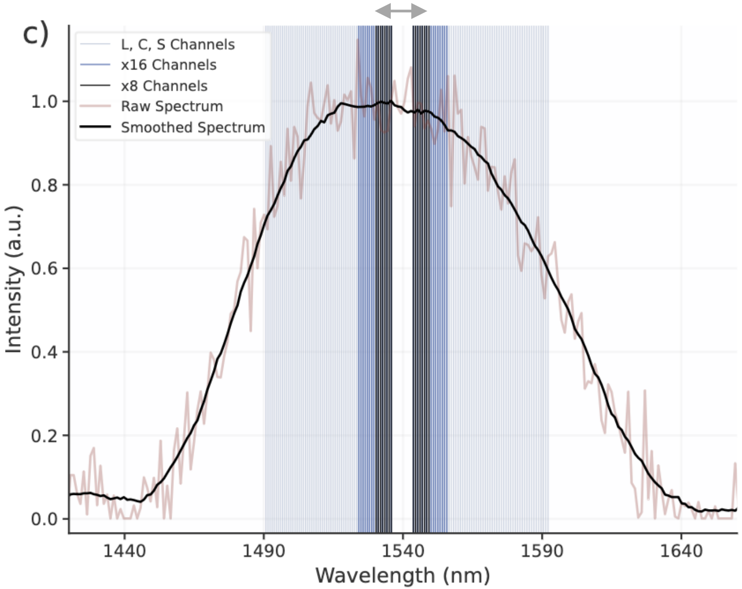
15 ps system response



Near Fourier-limited timing response
0.4 nm bandwith at 1550 nm → 10 ps-wide photons
Filter spacing **0.8 nm grid**

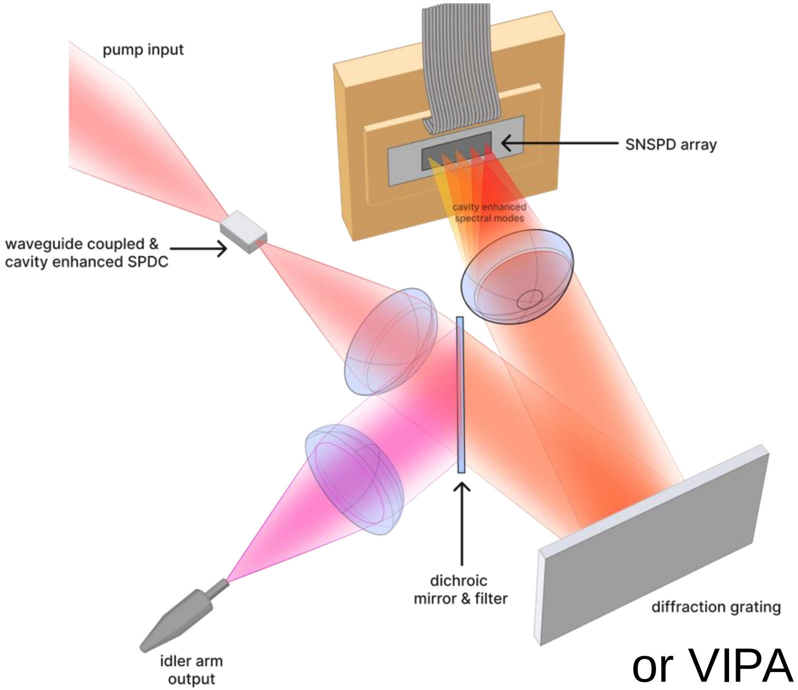
Mueller, Davis, Korzh, Valivarthi et al, ***Optica Quantum*** 2, 65 (2024)

Wavelength multiplexing



>40 channel fiber-coupled DWDM modules are commercially available

Future detector architecture



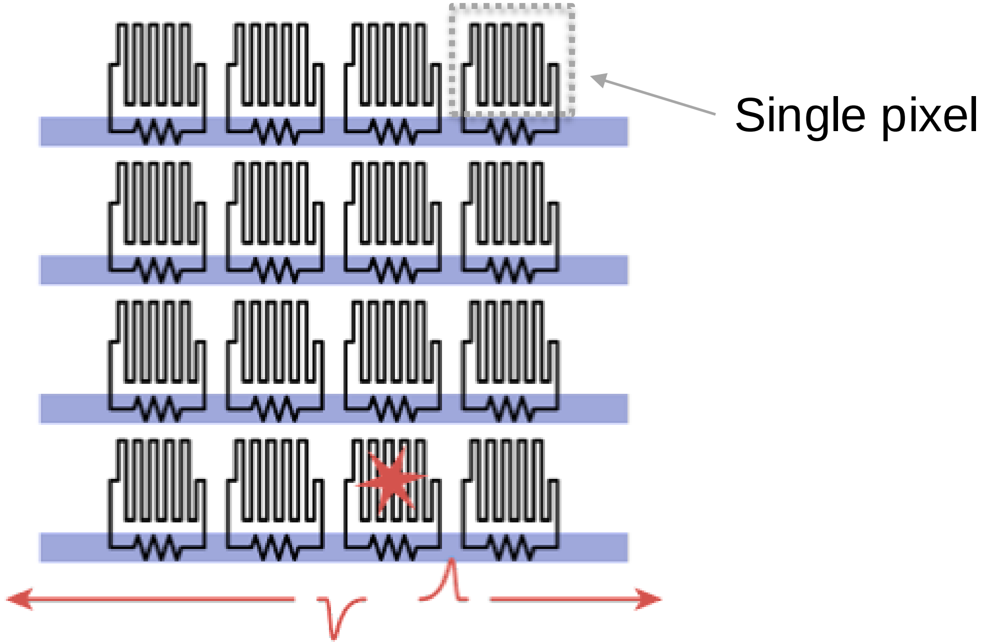
or VIPA

Pathway to 100 – 10,000 channels

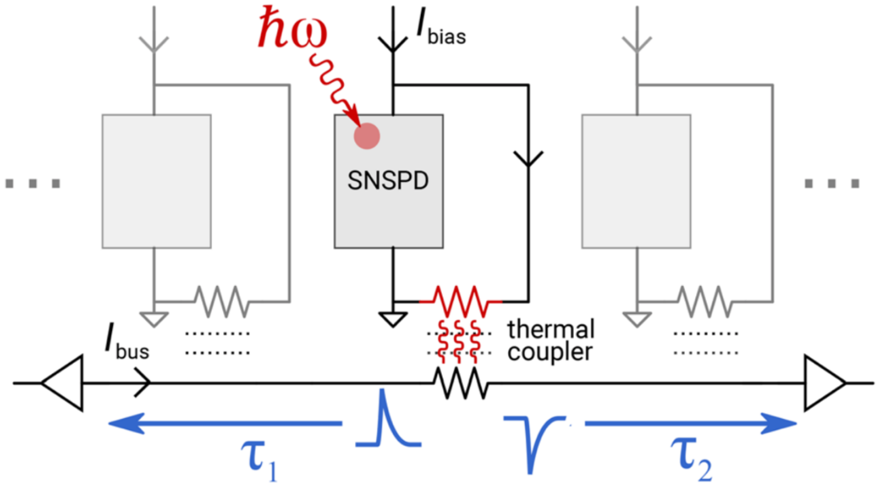
Mueller, Davis, Korzh, Valivarthi et al, ***Optica Quantum*** 2, 65 (2024)

How do we make a camera?

So far, most experiments only had access to single/few pixels…



Time-domain multiplexing

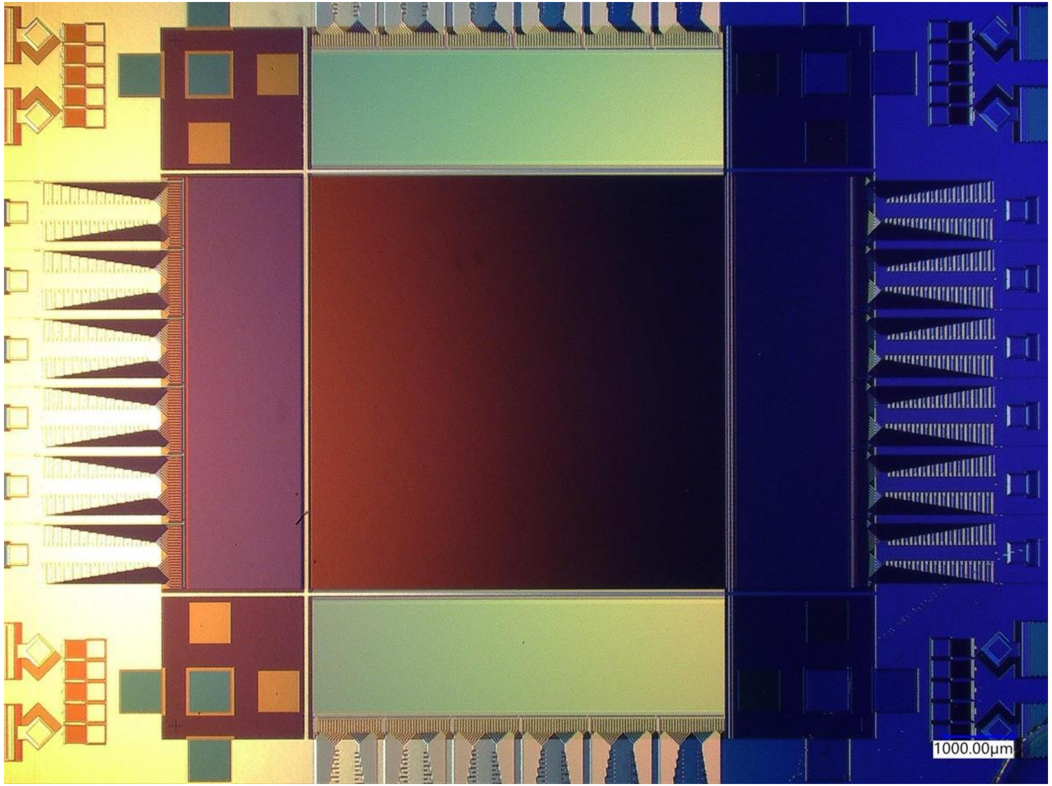


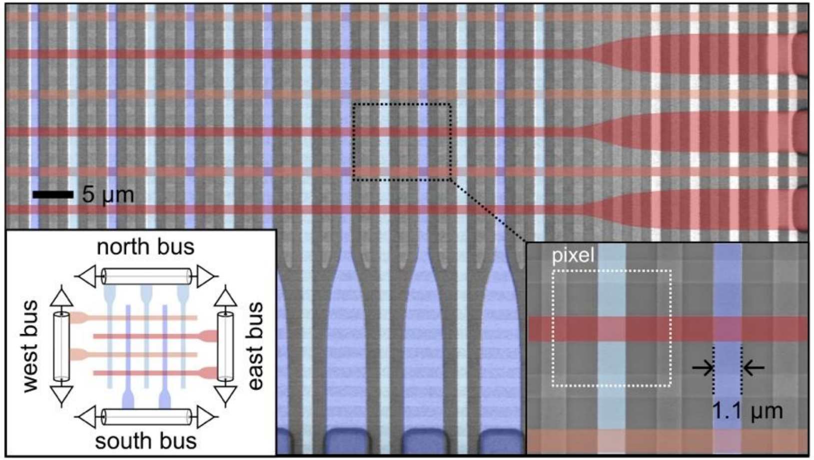
Time-of-flight difference in a superconducting bus

v_{ph} ≈ 0.01c (3 µm/ps) velocity helps us out this time!

→ 10 ps timing resolution enables 15 µm pixels to be resolved

400,000 pixel camera





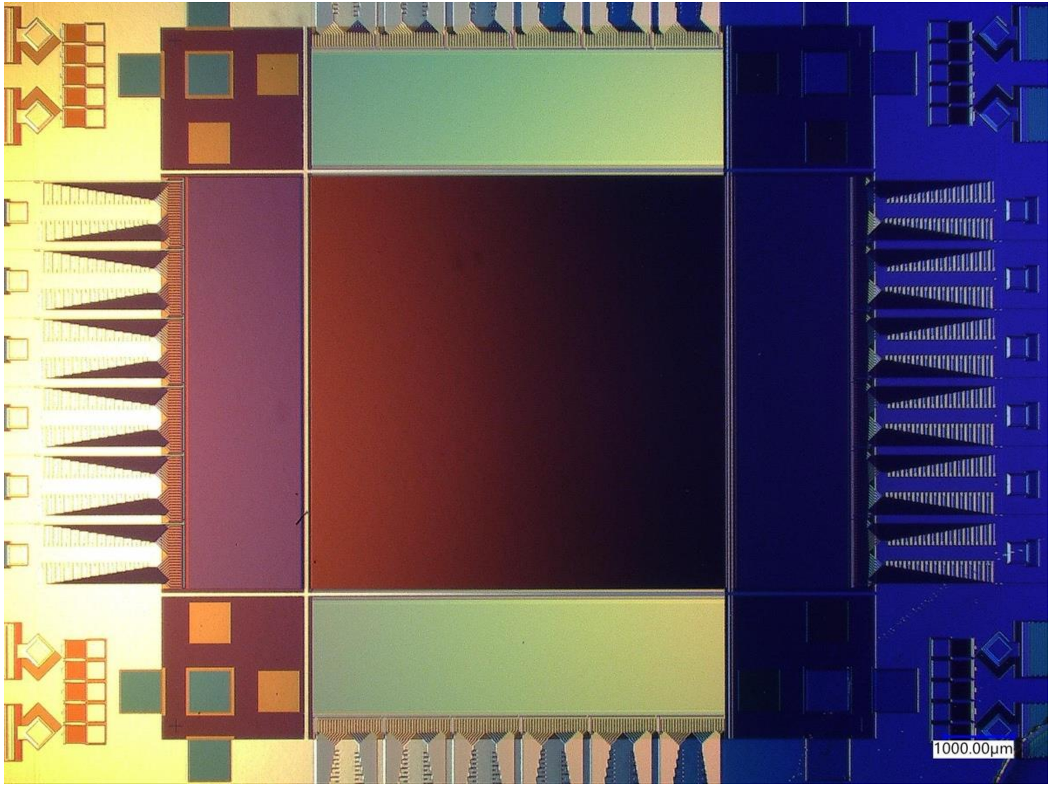
Performance
- Designed for UV-Vis
  - 4-10% efficiency
- Maximum count rates: 100 kcps
- 0.13 counts/sec background rate

Initially ***developed for photon starved*** applications:
- Extreme/deep-UV Astrophysics, **Earth-like exo-planet** imaging

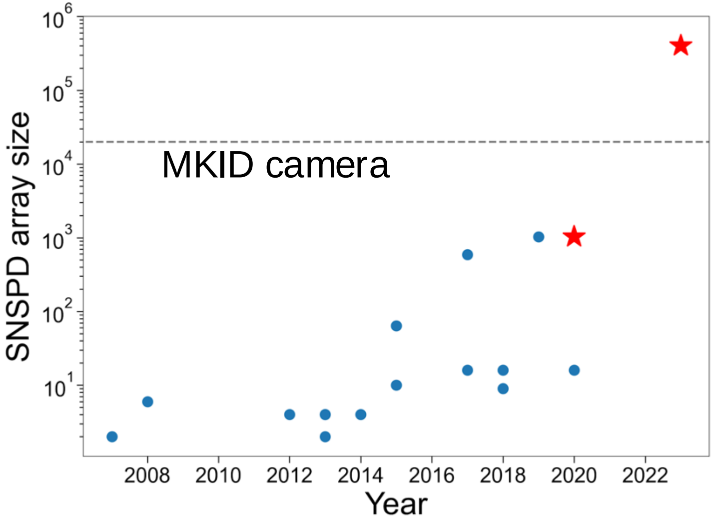
Fabricated at NIST

Oripov, Rampini, Allmaras, Shaw, Nam, Korzh, and McCaughan, ***Nature*** **622**, 730 (2023)

400,000 pixel camera



Largest superconducting camera by x20



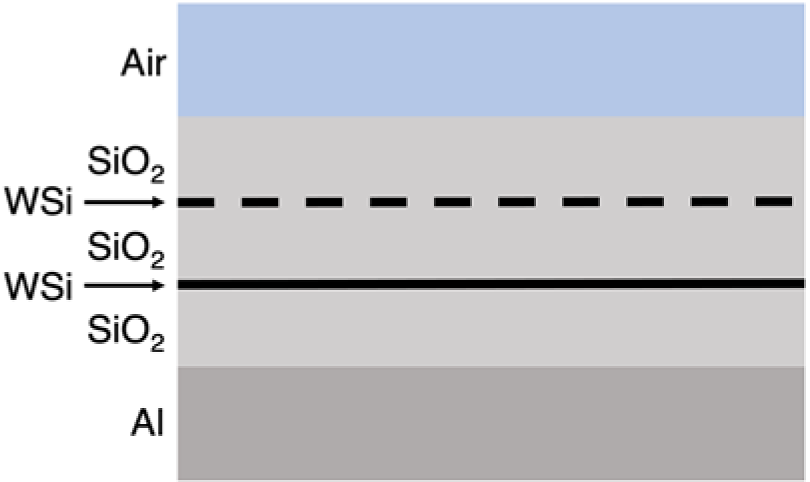
Future work

- Boost efficiency and sensitivity to long wavelength photons
- Increase count rates for practical applications

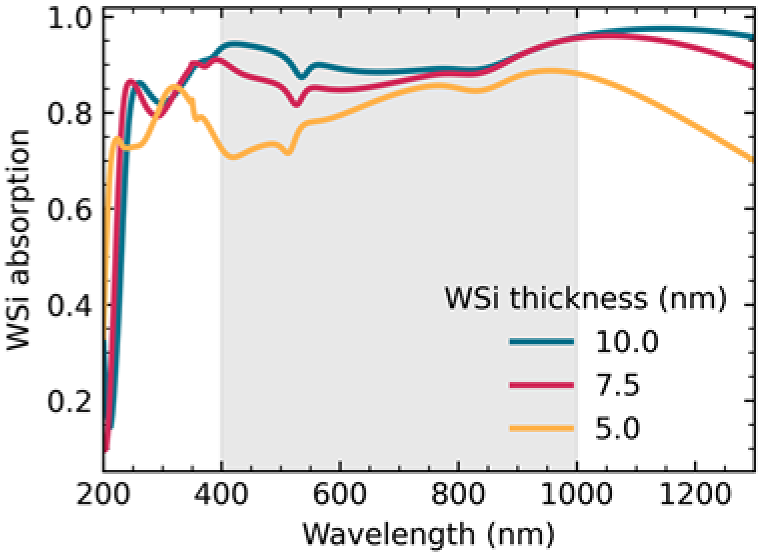
Fabricated at NIST

Oripov, Rampini, Allmaras, Shaw, Nam, Korzh, and McCaughan, ***Nature* 622**, 730 (2023)

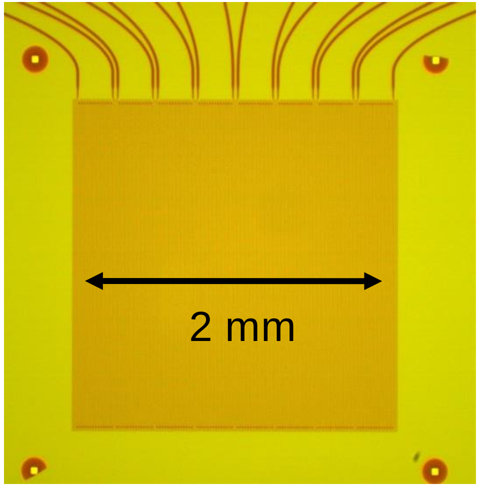
Expect broadband efficiency in future devices



Optical simulations



Large area ‘bucket’ detectors



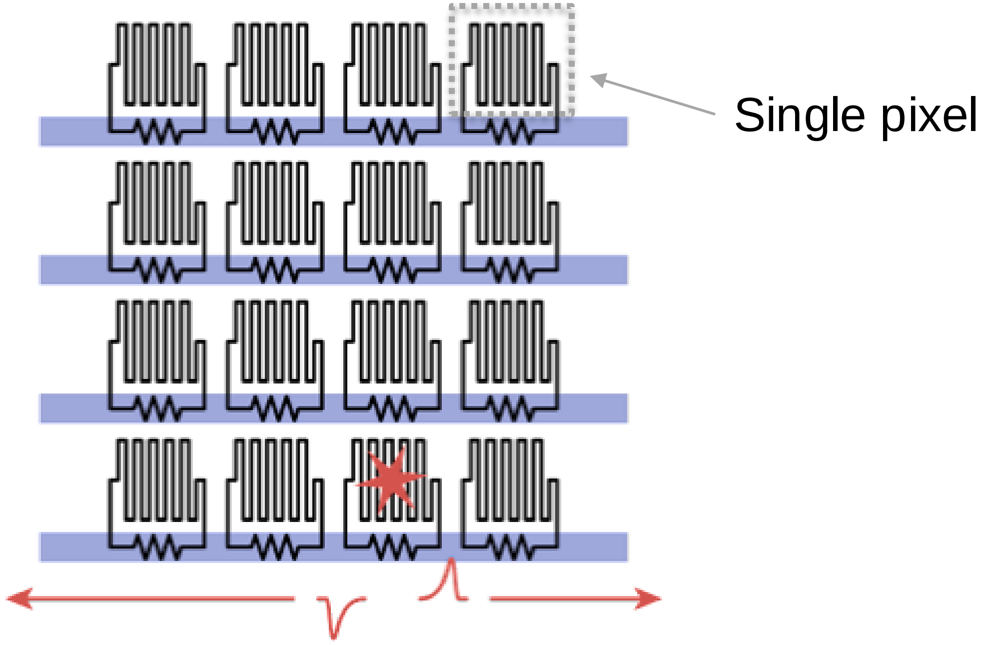
Fabricated with photolithography to better scalability

Goal: Superconducting analog of silicon-photomultiplier (Si-PM) and PMT …expected to reach x100 current active area

Luskin, Schmidt, Korzh, Beyer *et al*, ***Appl. Phys. Lett.*** **122**, 243506 (2023)

Considerations for Intensity Interferometry

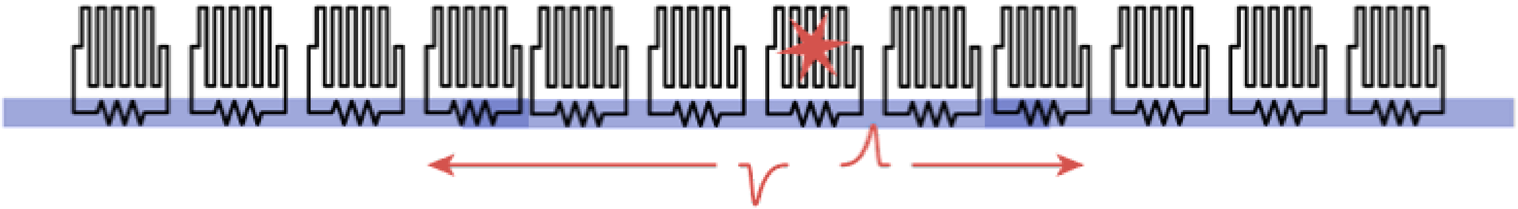
Better to avoid row-column architecture due to count rate limitation



Can could reach **10-50 Mcps per bus**

Considerations for Intensity Interferometry

Likely the best shape?

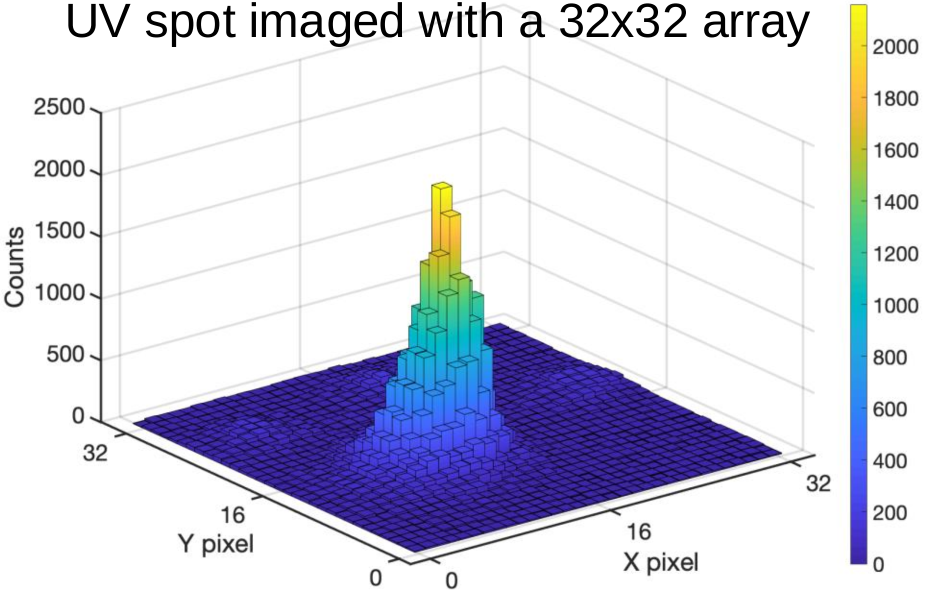


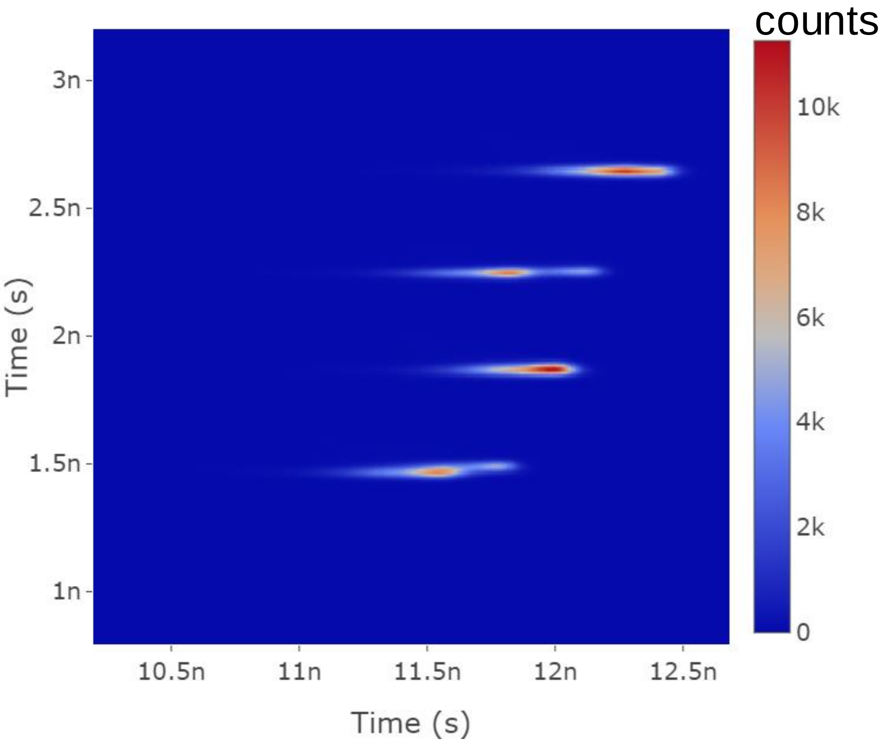
What would be useful in a phased approach?

	Number of channels	Count rate
Phase 1	256	100 Mcps
Phase 2	1,024	500 Mcps
Phase 3	4,096	3 Gcps

Timing jitter

UV spot imaged with a 32x32 array





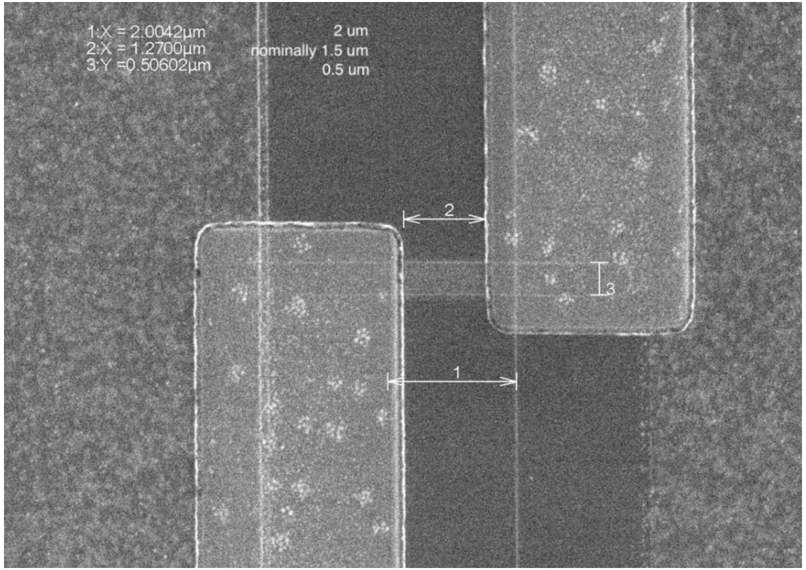
- In certain regimes it is **already <100 ps (FWHM)**
- Currently limited by single-ended coupling to heaters
- Versions being fabricated since, have implemented differential coupling

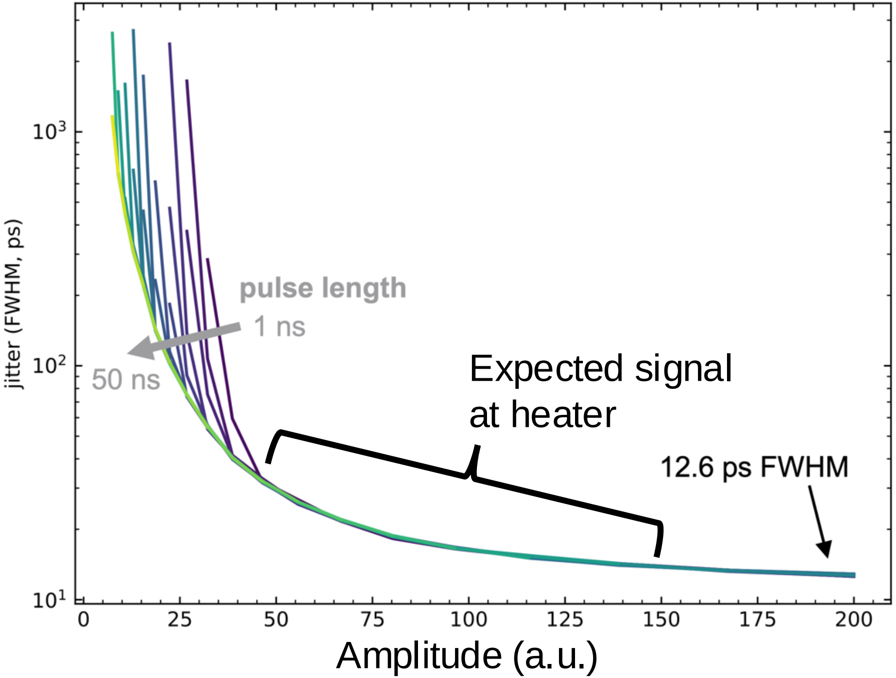
Thermal transduction expected to dominate

McCaughan, Zhai, Korzh, Allmaras *et al,* ***APL*** **121**, 102602 (2022)

Timing jitter

Differential heater test structure



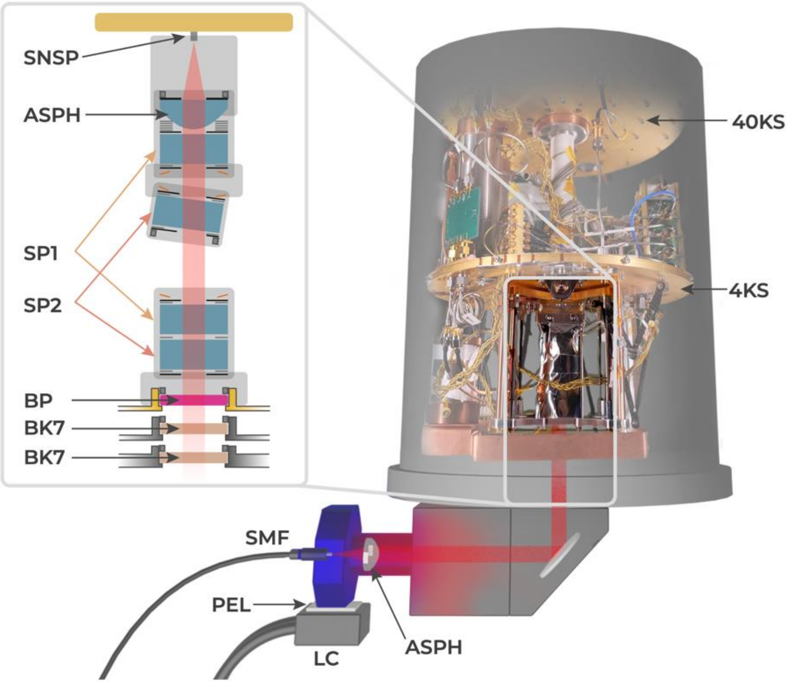


15-30 ps FWHM jitter looks feasible

JPL

Practical cryogenics

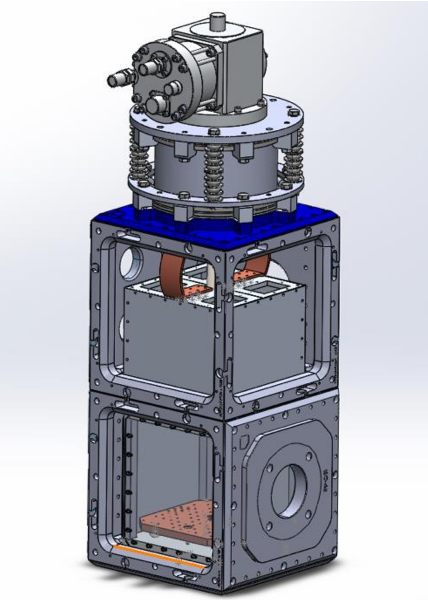
‘Hanging’ cryostat with cans



Modified PhotonSpot Inc. Cryostat

Mueller, Korzh, Runyan *et al*, ***Optica* 8,** 1586 (2021)

‘Bottom referenced’ cryostat with panels



- **Easy coupling to optical table**
- Off-the-shelf components where possible
- Vibration isolation
- Cost: <USD 50K in raw parts for 3 K version
- Design **will be made open-source** after validation

Summary

- SNSPDs provide a **flexible platform** for detector optimization
- **Single pixel fibre-coupled** devices
  - **Timing jitter <15 ps** for Fourier-limited timing
  - **775-1550 nm** demonstrated
- **Future devices** could hit the requirements for intensity interferometry
  - Sensitivity bands: 200-500 nm, **400-1000 nm**, 1000-1600 nm
  - High count rates: **>1 Gcps**
  - Number of channels: **>1,000**
    - Or **multimode collection** like PMT
  - Timing jitter: **<30 ps**
- Scalable free-space cryogenics are now available

Please send us your wishes and we'll make them ☺