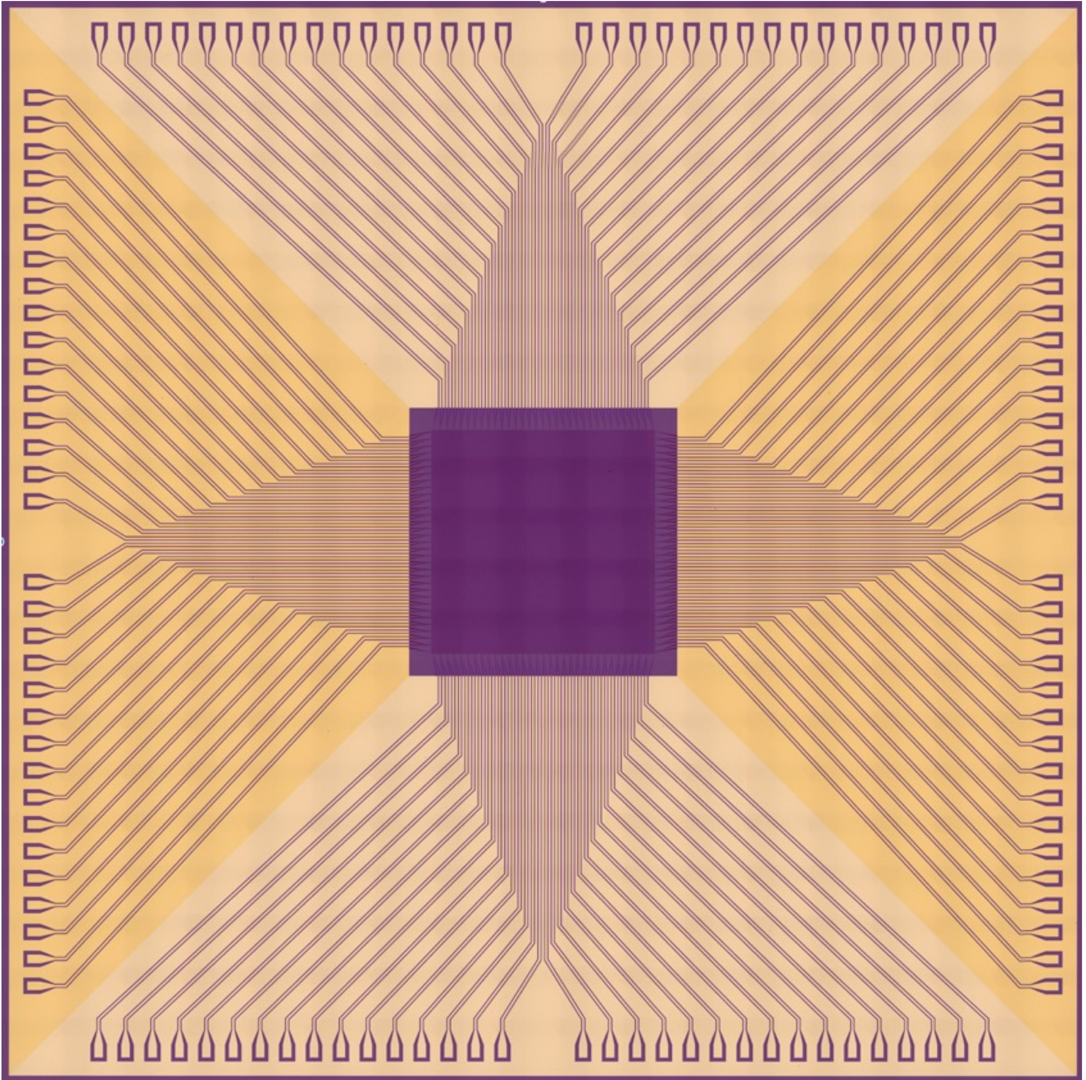


Superconducting Nanowire Single Photon Detectors for Dark Matter Detection and HEP

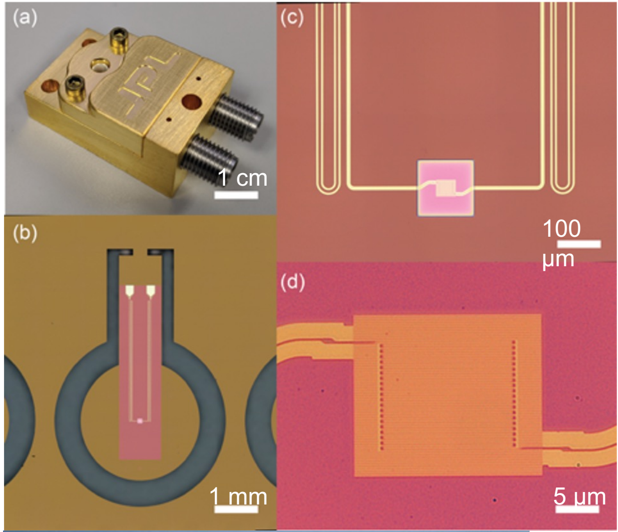
Matt Shaw
Jet Propulsion Laboratory

7 November 2023
CPAD Workshop, SLAC

Jet Propulsion Laboratory
California Institute of Technology

JPL Superconducting and Quantum Devices Group

- **Superconducting Nanowire Single Photon Detectors**
- Microwave Kinetic Inductance Detectors
- Kinetic Inductance Traveling-Wave Parametric Amplifiers
- Quantum Capacitance Detectors
- Transition-Edge Sensors for Cosmic Microwave Background
- Thermopile Arrays for Earth and Planetary Science
- SIS and HEB Mixers for Terahertz Astronomy
- Superconducting Circuits for Quantum Computing



JPL has been a world leader in superconducting detector technology development since 1981

JPL SNSPD Development Team

JPL Staff Researchers


Matt Shaw


Emma Wollman


Boris Korzh


Andrew Beyer


Bruce Bumble


Jason Allmaras


Ioana Craiciu


Ryan Briggs

Postdocs


Gregor Taylor

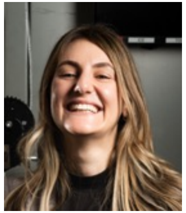

Emanuel Knehr


Dan Shanks


Fiona Fleming (Heriot-Watt)

Graduate Students


Andrew Mueller (Caltech APh)


Jamie Luskin (Maryland)


Sahil Patel (Caltech MS)


Sasha Sypkens (Arizona State)

Key Collaborators

California Institute of Technology 1891

NIST

Photon Spot

Fermilab

NASA Goddard Space Flight Center

Berkeley Lab

University of California San Diego

BU

Heriot Watt University

University of Glasgow

JPL

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Matt Shaw


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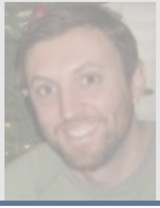

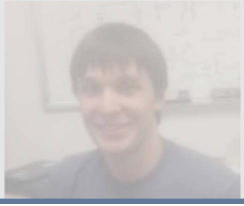


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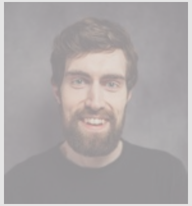
Emanuel Knehr

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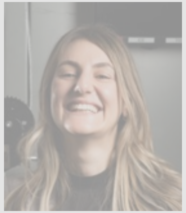
Jamie Luskin (Maryland)


Sahil Patel (Caltech MS)


Sasha Sypkens (Arizona State)

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Always recruiting postdocs, students, nanofabrication engineers

mattshaw@jpl.nasa.gov

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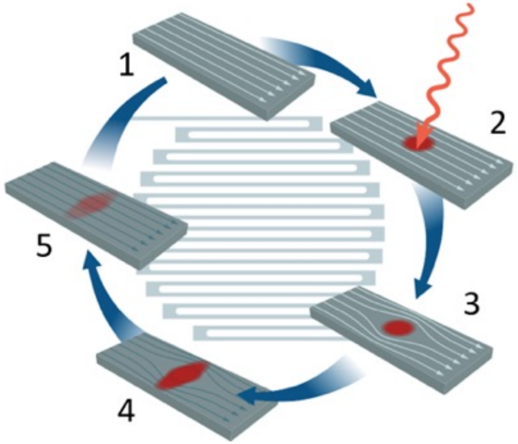
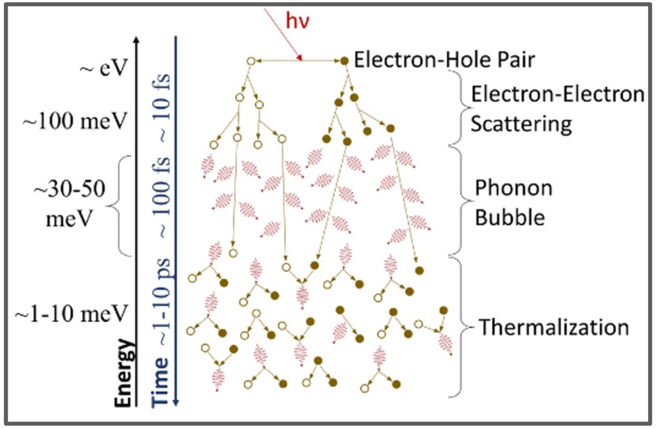
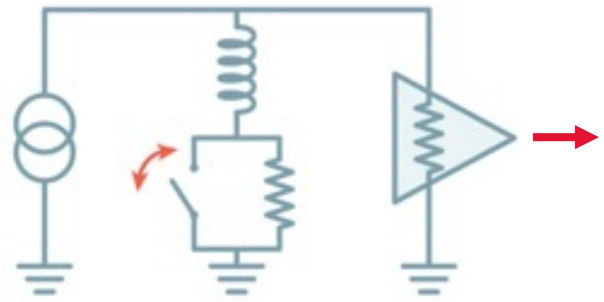
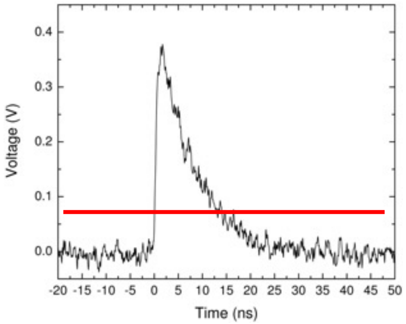
Superconducting Nanowire Single Photon Detectors

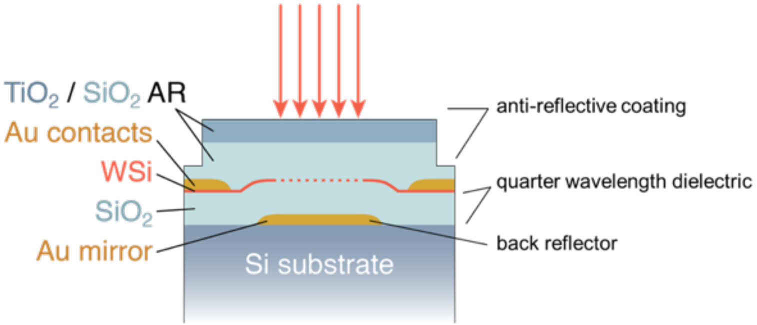




- Time-resolved single photon counting from UV to mid-IR
- Truly digital detection mechanism – reduced drift and zero read noise
- World-leading detector performance
- Operating temperature 1-4 K in most cases

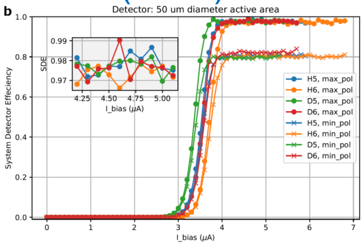






Present State of The Art in SNSPDs

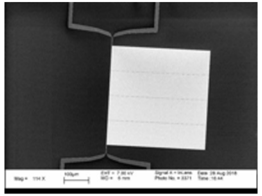
High Efficiency
98% SDE @ 1550 nm (NIST)

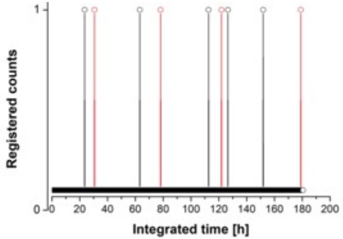


Reddy et al, *Optica* (2020)

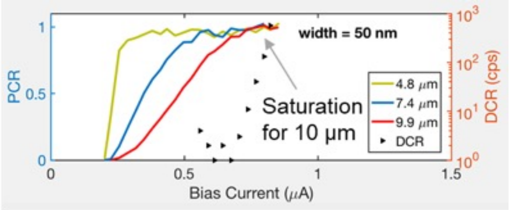
Low Dark Counts
6e-6 cps (MIT/NIST)

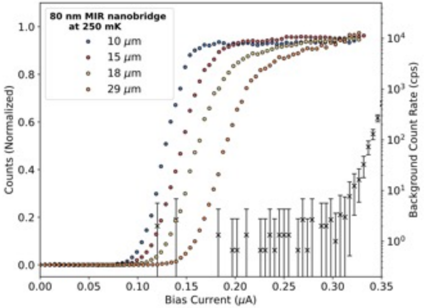
Chiles et al, *Phys. Rev. Lett.* (2022)





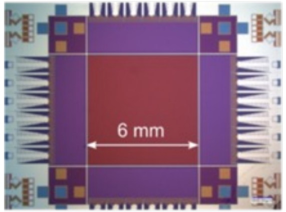
UV – Mid-IR Operation
Photon counting from 0.1 - 29 μm (JPL/MIT/NIST)

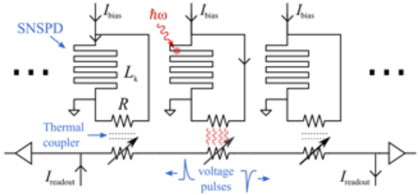




Taylor et al, *arXiv* (2023)

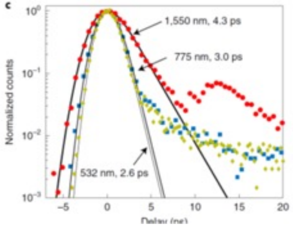
Large Array Formats
400 kpix with time-domain multiplexing (NIST/JPL)

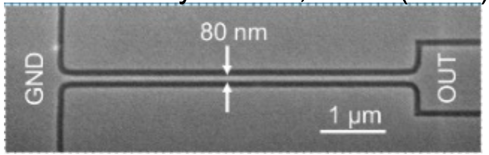




Oripov et al, *Nature* (2023)

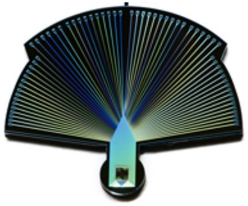
High Time Resolution
2.6 ps FWHM (MIT/JPL/NIST)

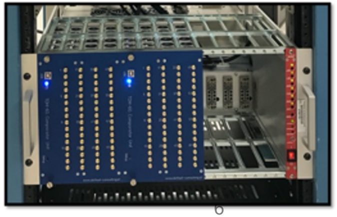




Korzh et al, *Nature Photonics* (2020)

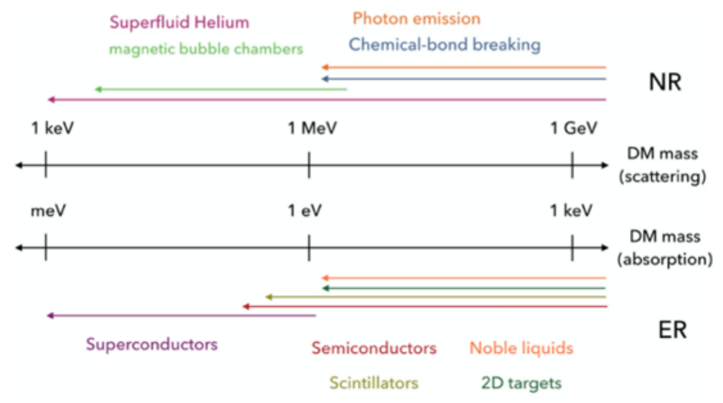
High Event Rate
1.5 Gcps in 32-element array (JPL)



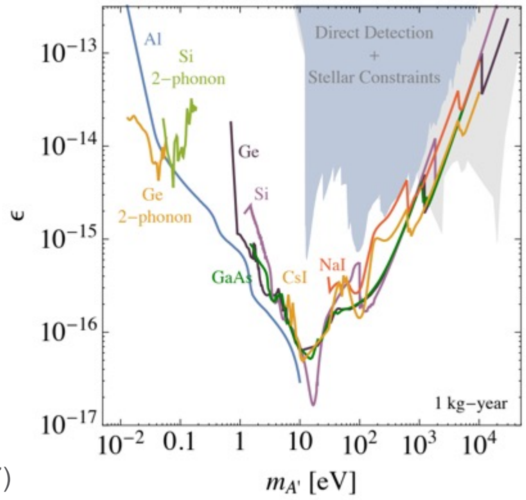


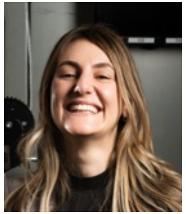
Craiciu et al, *Optica* (2023)

Particle-like DM Search: Electron Recoil in GaAs

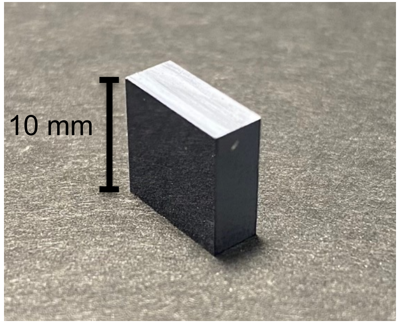


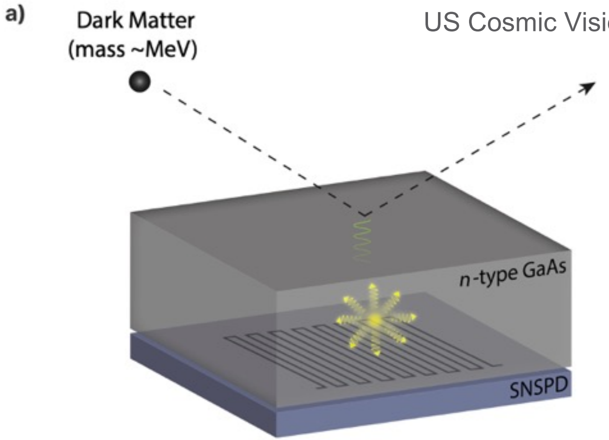
US Cosmic Visions Report (2017)

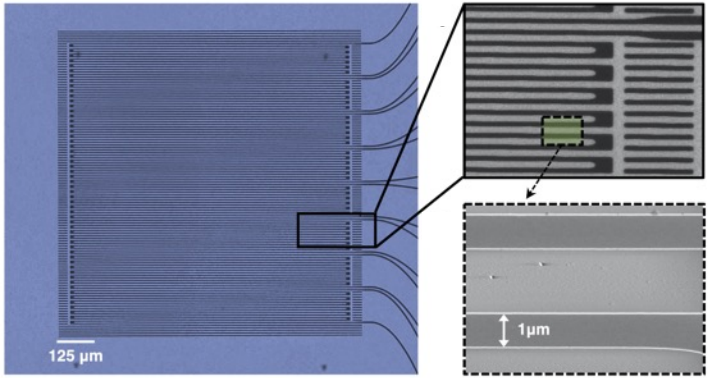


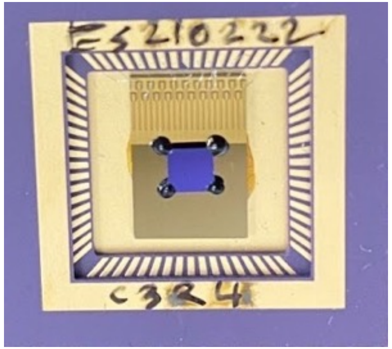


Jamie Luskin (Maryland)





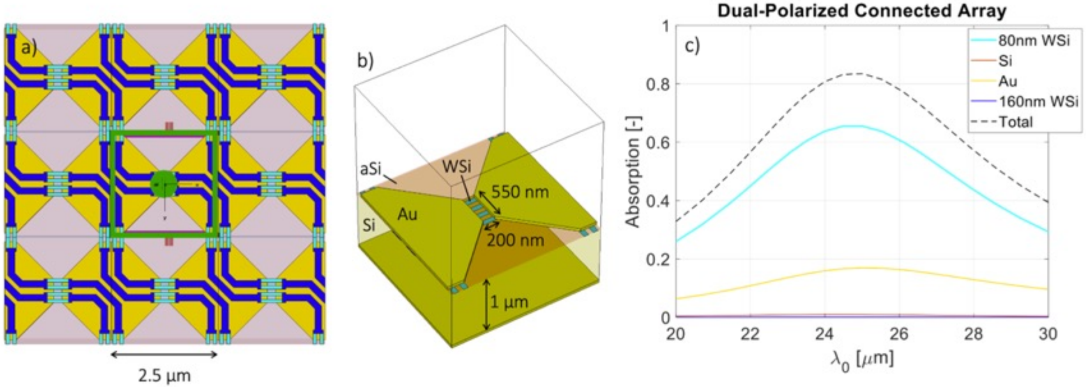


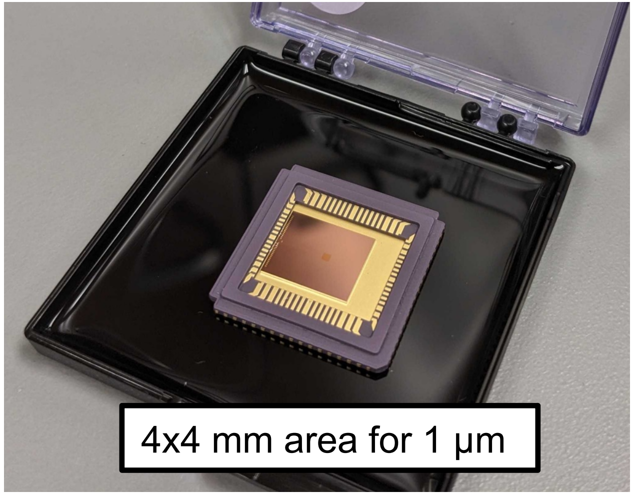


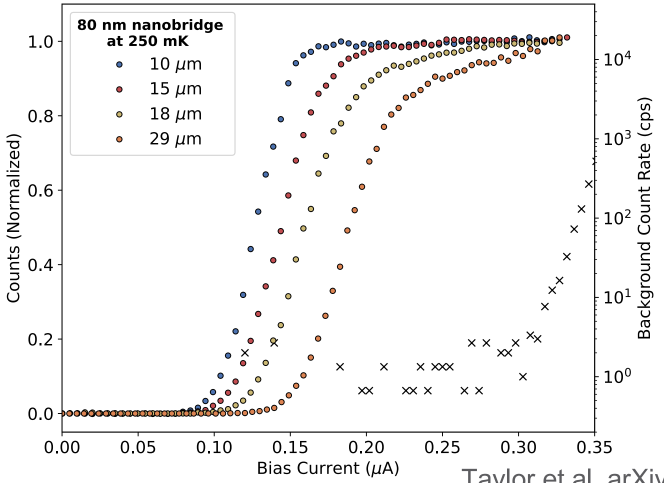
Luskin et al, Applied Phys Lett (2023)

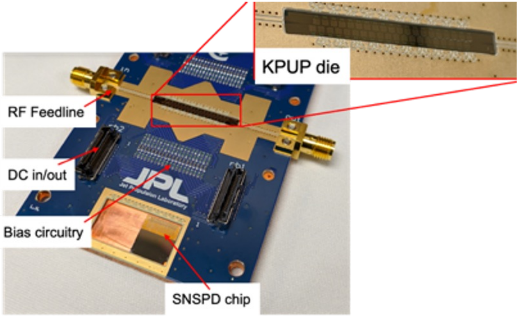
SNSPDs for BREAD

- Delivering large-area SNSPDs for 1 μm
- Developing large arrays at longer wavelengths (10 - 30 μm) and pushing energy threshold lower



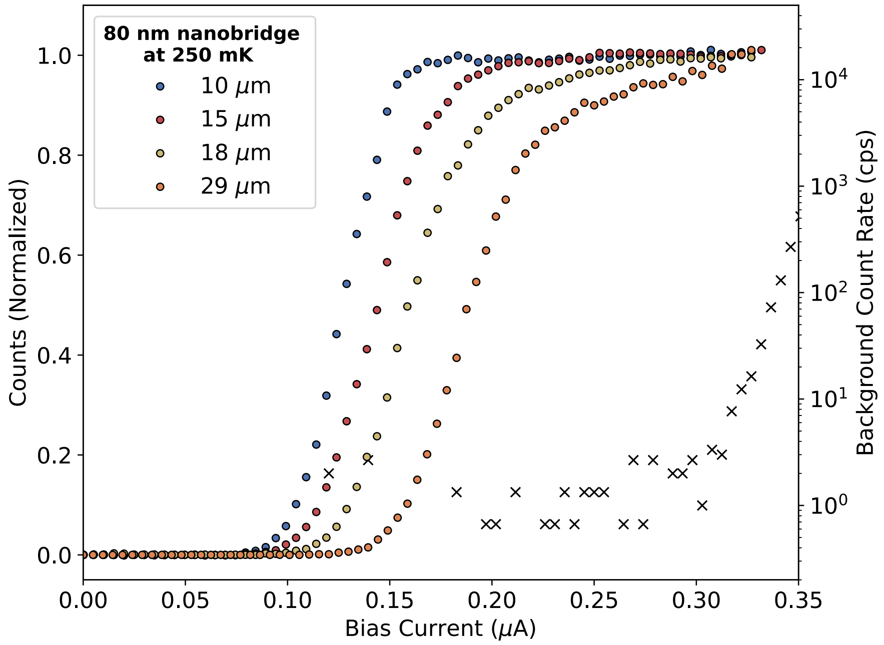


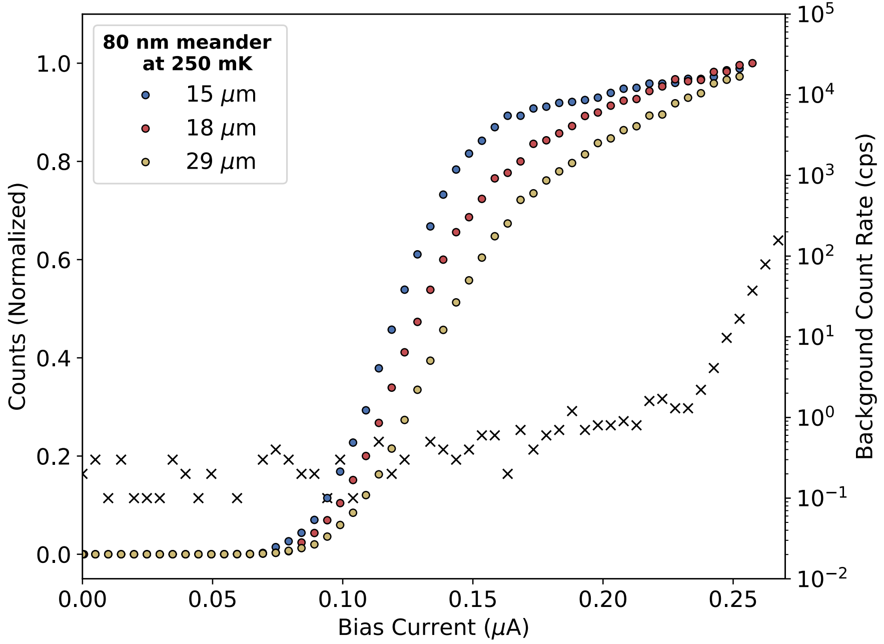




Taylor et al, arXiv (2023)

Single Photon Sensitivity up to 29 μm (41 meV)



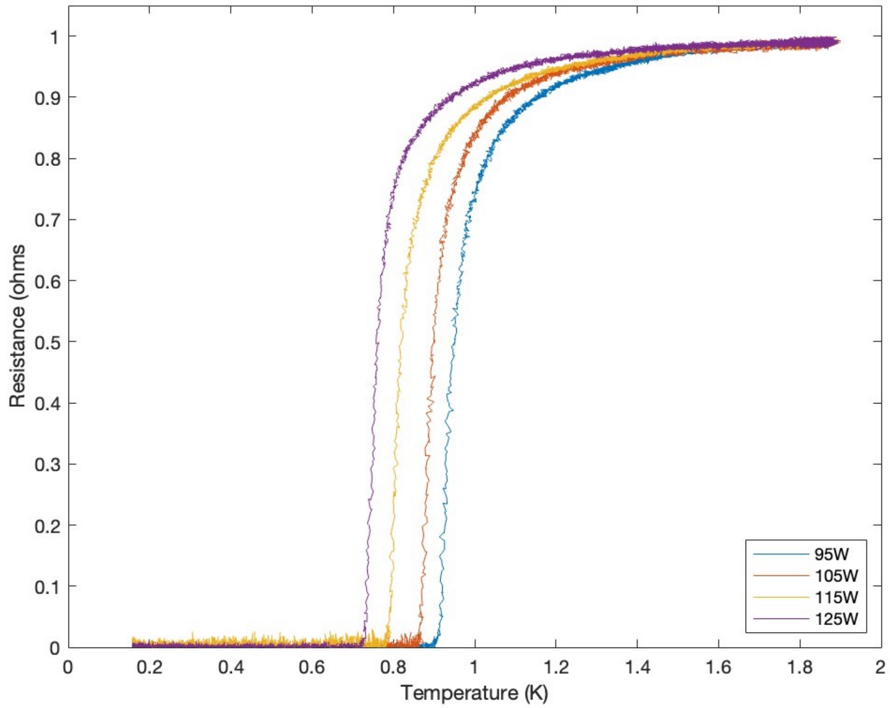


- SNSPD nanobridge with Si-rich WSi for reduced superconducting gap energy (1.3 K Tc, 80 nm nanobridge)
- Now fabricating WSi devices with an 800 mK Tc for even lower energy threshold

Pushing to Lower Wavelengths

- Co-Sputtering Wsi (30:70) target with Si Target to further increase Si content

- Targeting Tc of 800mK while maintaining a thicker film to make fabrication easier



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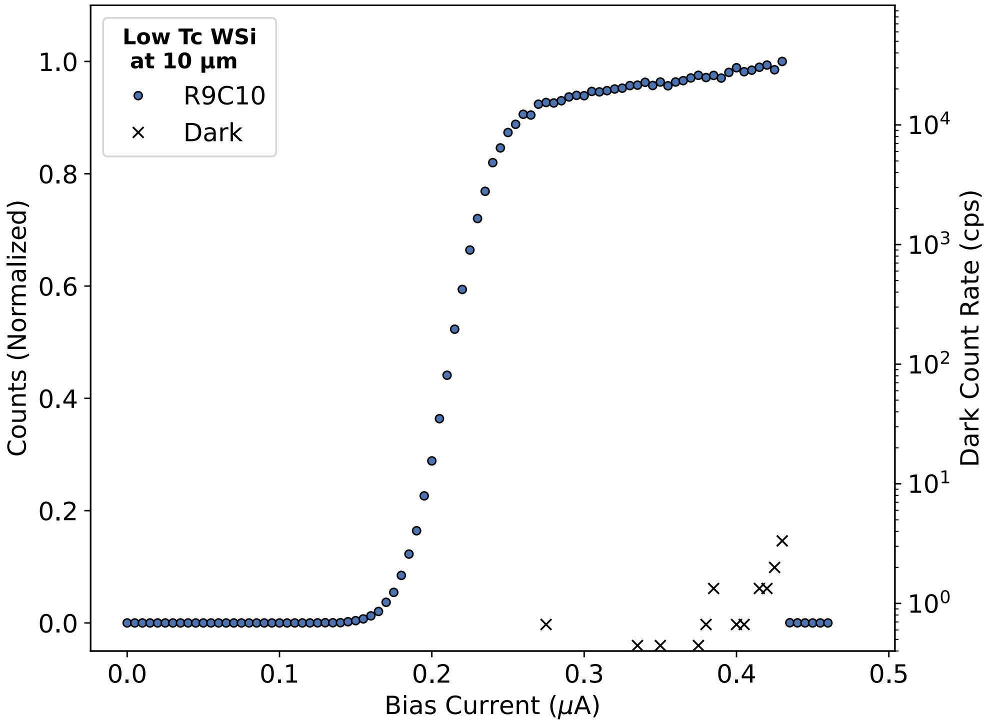
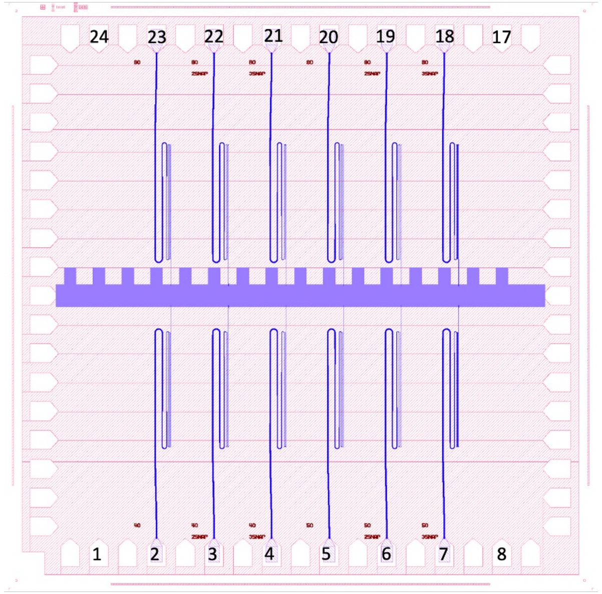
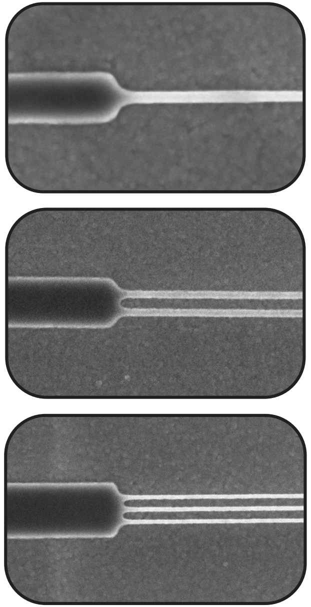
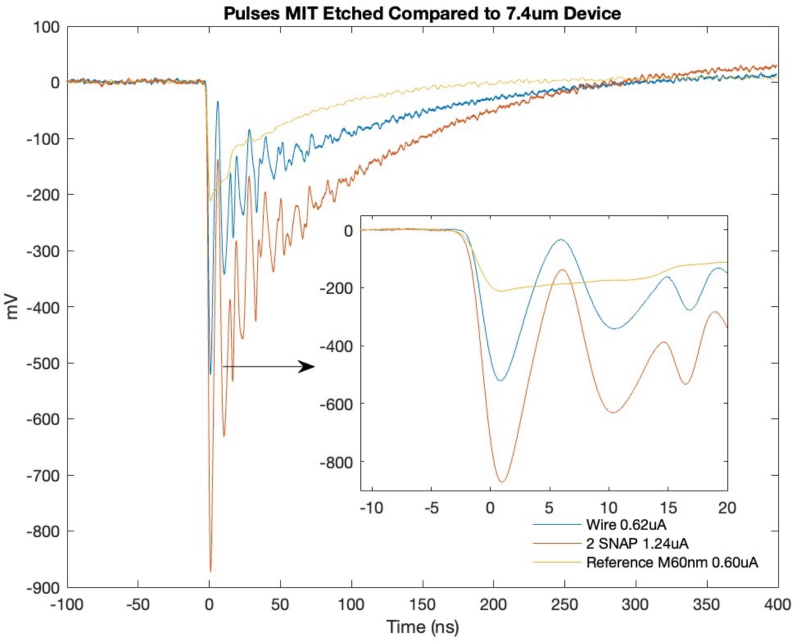


NIST MIT JPL

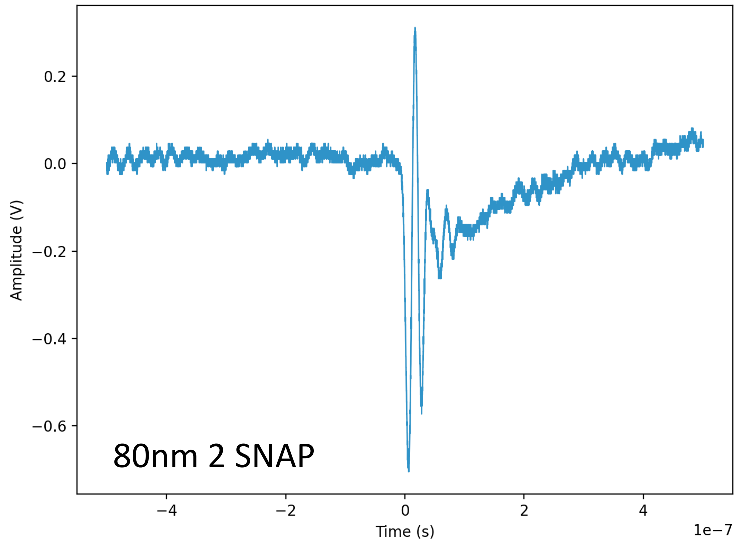
SNAP Devices with Low-Tc WSi

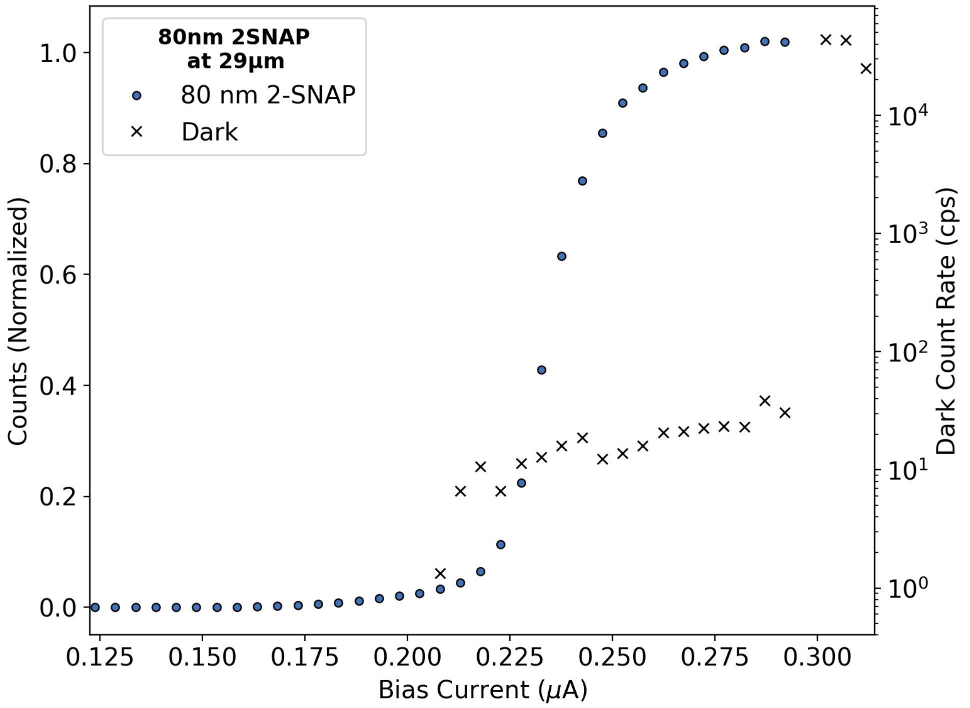






SNAP Devices with Low-Tc WSi

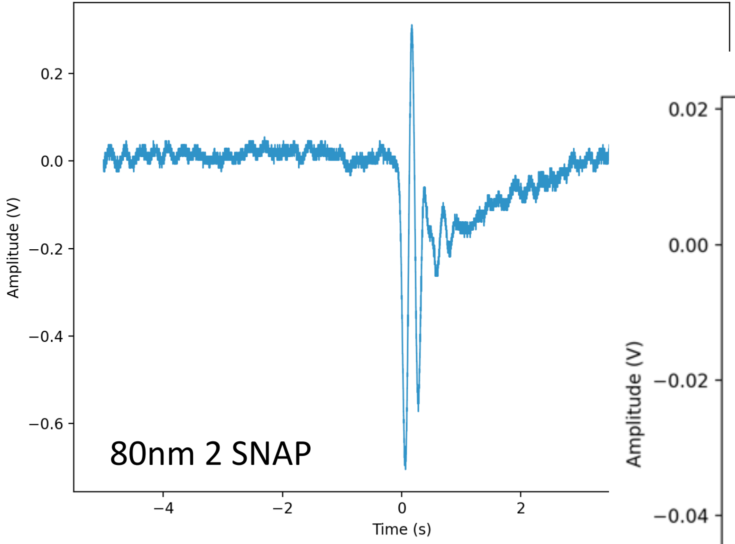


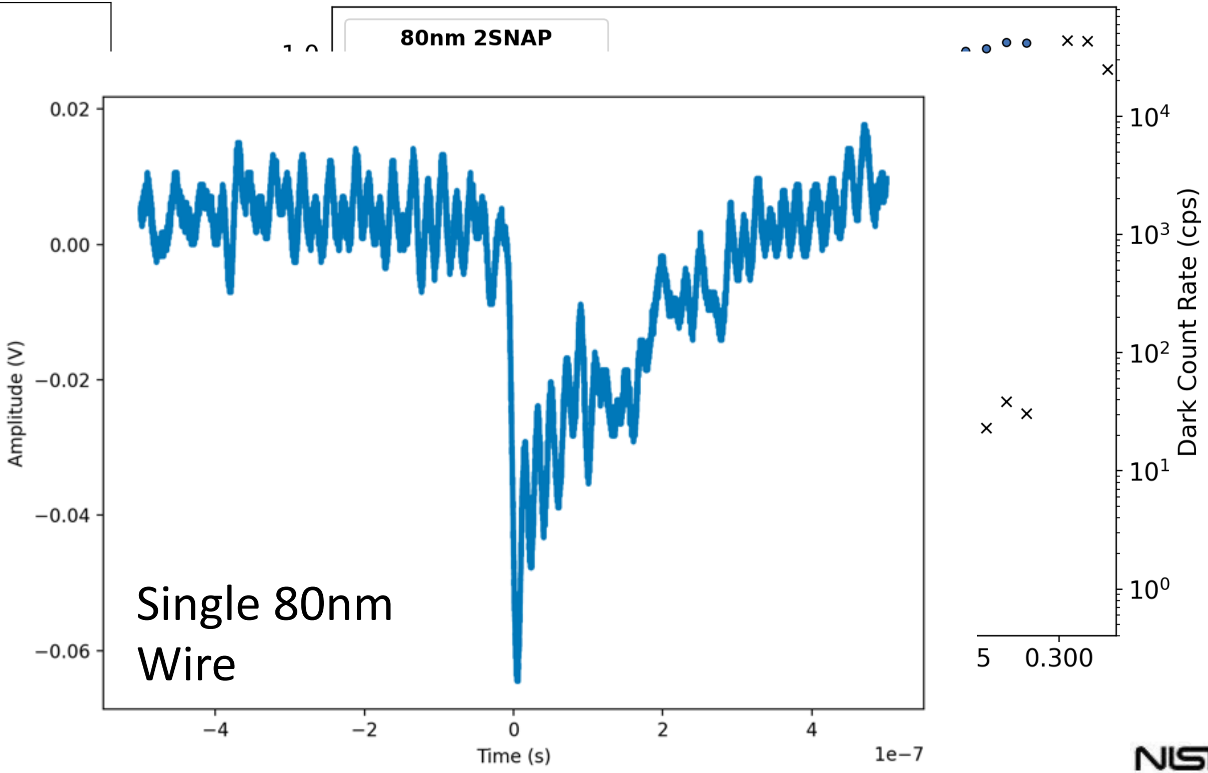


- 80 nm 2 SNAP with impedance matching tapers with 750mK Si Rich film

NIST
MIT
JPL

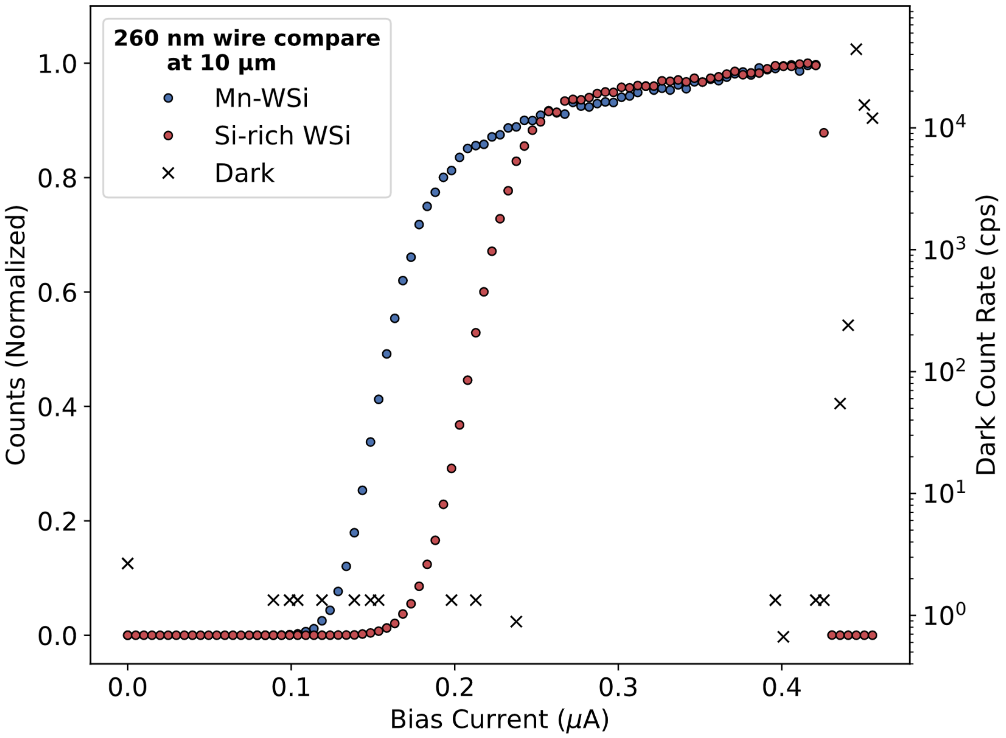
SNAP Devices with Low-Tc WSi





- 80 nm 2 SNAP with impedance matc
  750mK Si Rich film

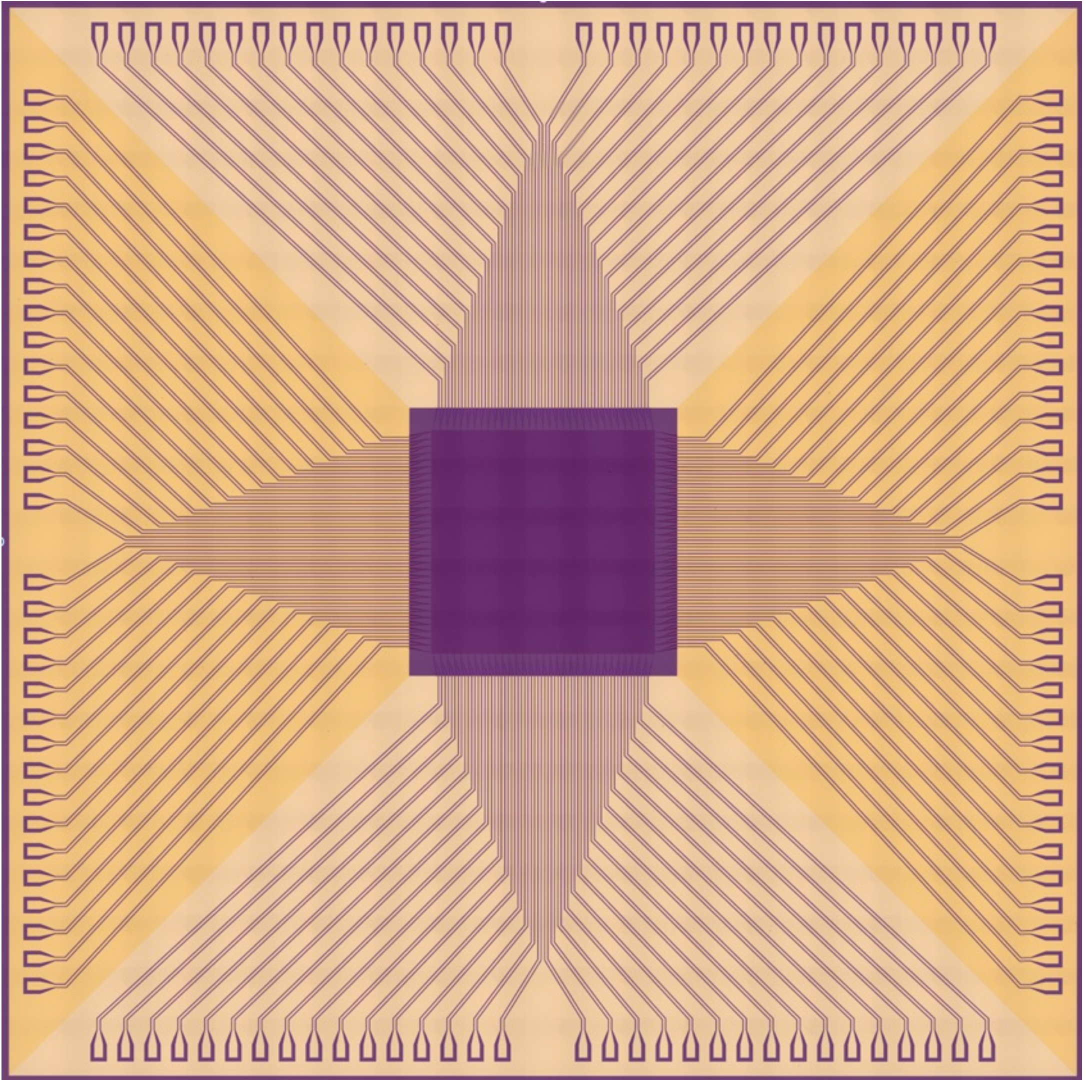
Mn Doped WSi for Longer Wavelengths



- Dilute magnetic impurities create additional disorder in thin films, to enhance energy sensitivity
- Curves above compare devices with same resistivity and critical temperature (800 mK)

Technology Development Path for Low-Threshold SNSPDs

- Materials development to push energy threshold even lower
- Efficient optical coupling at mid- and far-infrared wavelengths with antennas
- Frequency domain multiplexing using kinetic inductance parametric upconverter
- Calibrated efficiency measurements at mid- and far-infrared wavelengths
- Improved understanding and mitigation of low-energy backgrounds
- **Integration into dark matter experiments**



Thanks for your attention!

mattshaw@jpl.nasa.gov

Jet Propulsion Laboratory
California Institute of Technology