Superconducting Nanowire Single Photon Detectors for Dark Matter Detection and HEP

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Jet Propulsion Laboratory
California Institute of Technology

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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
- Andrew Beyer
- Boris Korzh
- Emma Wollman
- Ioana Craiciu
- Ryan Briggs

Postdocs
- Gregor Taylor
- Emanuel Knehr
- Jamie Luskin (Maryland)
- Sahil Patel (Caltech MS)
- Sasha Sypkens (Arizona State)

Graduate Students
- Andrew Mueller (Caltech APh)
- Sahil Patel (AEA)
- Gregor Taylor (Caltech)

Join us!
Always recruiting postdocs, students, nanofabrication engineers

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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)

![Graph showing high efficiency](image)


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


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

![Graph showing UV to Mid-IR operation](image)


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

![Large array format](image)


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

![Graph showing high time resolution](image)

Taylor et al, *arXiv* (2023)

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

![Graph showing high event rate](image)


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Particle-like DM Search: Electron Recoil in GaAs

- Larger pixel size
- Up to 16mm active area
- Higher fill factor

New GaAs 10 mm x 10 x 4 mm
0.4 cm3 ~2g

Light-tight packaging with external reflectors

Dark Matter (mass ~MeV)


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

4x4 mm area for 1 µm

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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SNAP Devices with Low-Tc WSi
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- 80 nm 2 SNAP with impedance matching tapers with 750mK Si Rich film
SNAP Devices with Low-Tc WSi

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

![Graphs showing 80nm 2 SNAP and Single 80nm Wire behaviors](image)
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!

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