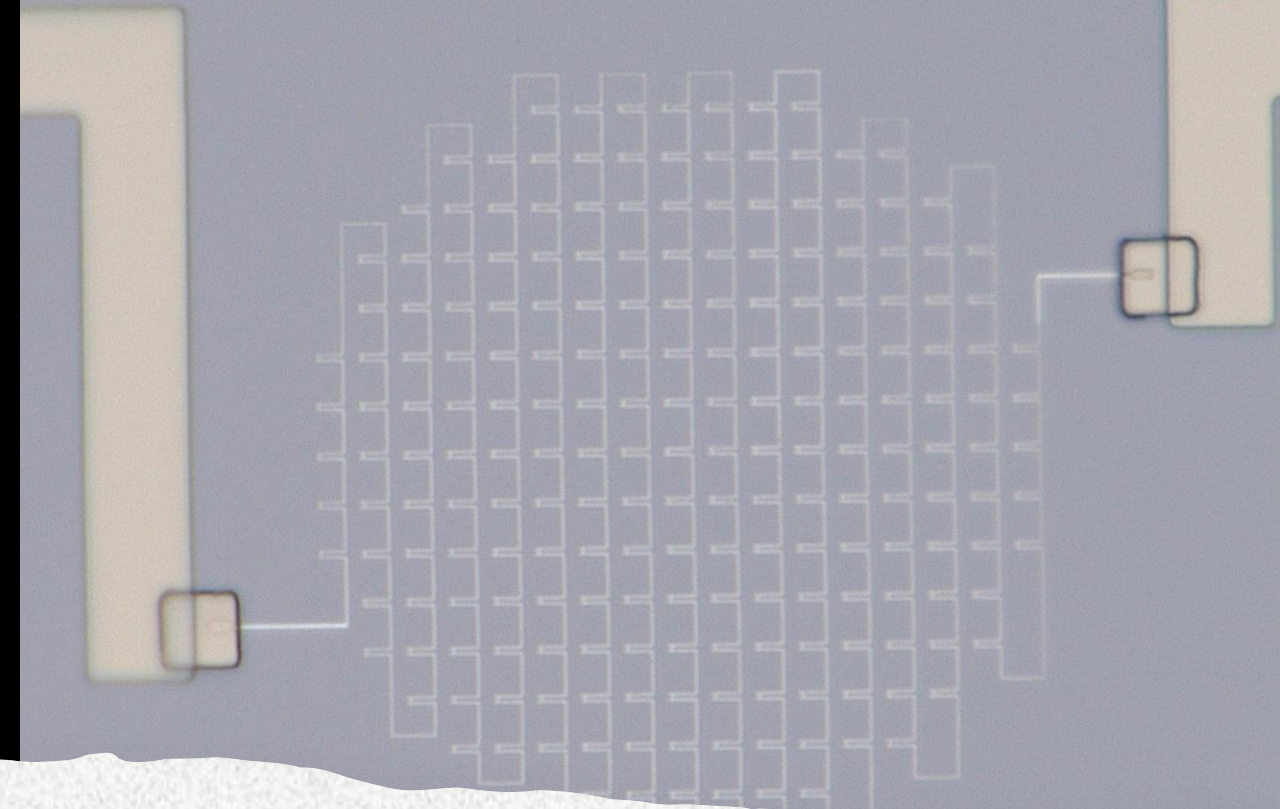
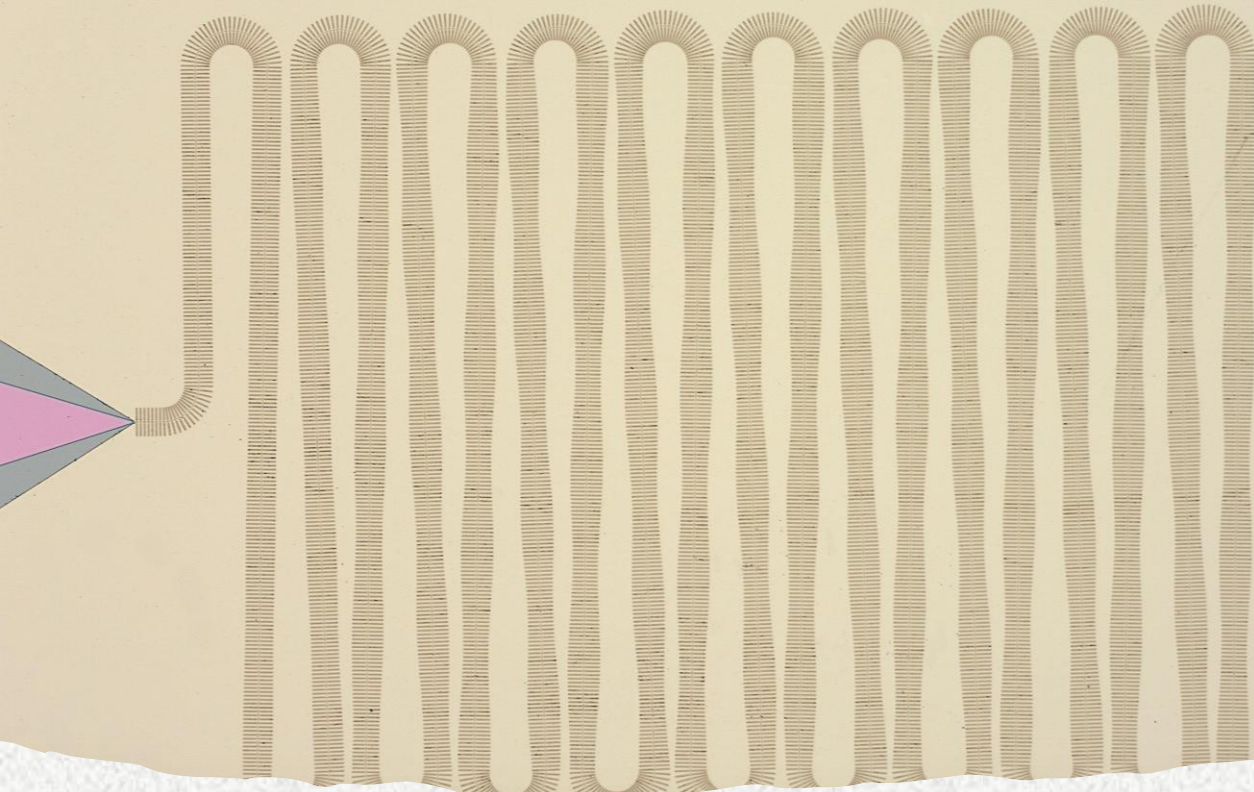




Kinetic Inductance Quantum Sensing Technologies for THz HEP and Dark Matter Searches

Chris Albert

CPAD 2026 | Seattle, Washington

10/22/2026



Jet Propulsion Laboratory
California Institute of Technology



The THz Science Landscape

1 THz (4meV / 300um)

10 THz (40meV / 30um)

100THz (400meV / 3um)



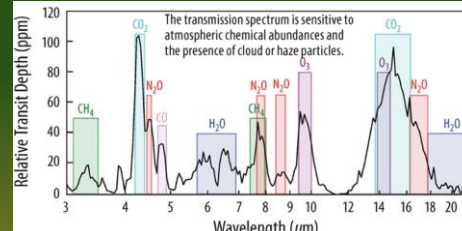
Astrophysics



- Galaxy evolution
- Cosmic Molecules
- Protoplanetary disk formation

Exoplanet Spectroscopy

Meixner+ 2021



The transmission spectrum is sensitive to atmospheric chemical abundances and the presence of cloud or haze particles.

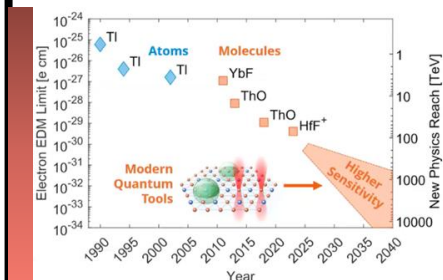
Dark Matter

THz Gap in Axion / Hidden Photon Searches

Strongest unprobed signal in QCD axion band

QUALIPHIDE-FIR

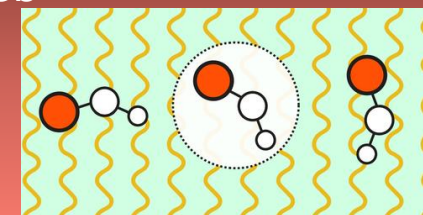
Quantum Sensing



Hutzler lab, Caltech

1-100 THz Transitions in Engineered Molecules

- Testing fundamental symmetries
- Quantum information and control

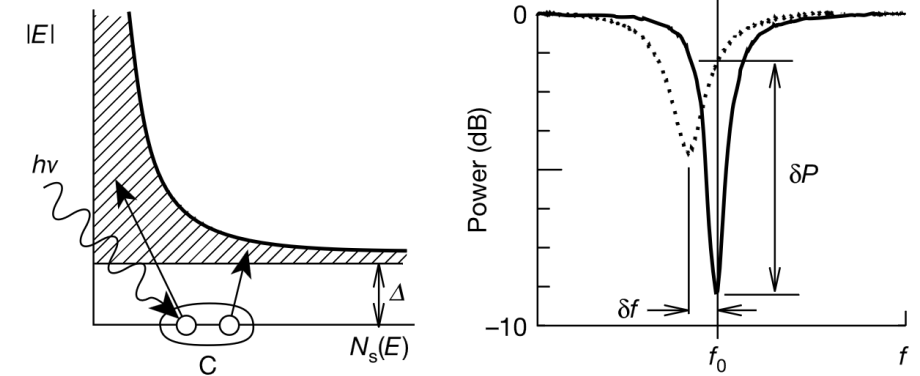


Takahashi+ 2023

Kinetic Inductance Detector Design and Sensitivity Optimization

Day+ 2003

- KIDs are superconducting LC resonators. Absorbed photons break cooper pairs (creating quasiparticles), increasing kinetic inductance L_k and lowering the resonant frequency.



Measured Signal:
$$\delta x \equiv \frac{\delta f_{\text{res}}}{f_{\text{res},0}} = -\frac{1}{2} \frac{\delta L_k}{L} \propto \frac{\alpha N_{\text{qp}} \tau_{\text{qp}}}{V}$$

Annotations for the equation:

- L_k / L_{tot} (points to $\delta L_k / L$)
- $\#$ of quasiparticles (points to N_{qp})
- quasiparticle lifetime (points to τ_{qp})
- Inductor volume (points to V)

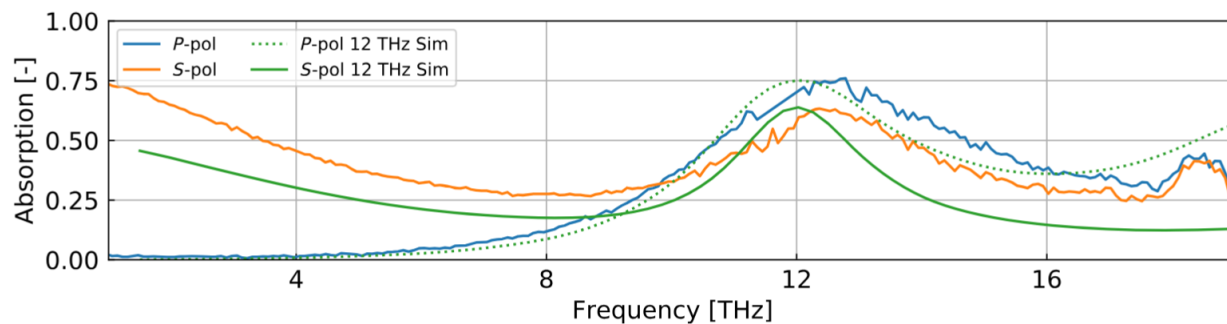
- Main design parameter to increase sensitivity: **Small Inductor Volume (V)**
 - Also design for high α . For a given absorber design, adjust fabrication to maximize τ_{qp}

TLS capacitor noise constant w.r.t. V :
$$\text{SNR}_{\text{TLS}} \propto \frac{\alpha}{V}$$

Amplifier noise:
$$S_{\text{amp}}^{1/2} \propto \frac{\alpha}{\sqrt{V}} \quad \text{SNR}_{\text{amp}} \propto \frac{1}{\sqrt{V}}$$

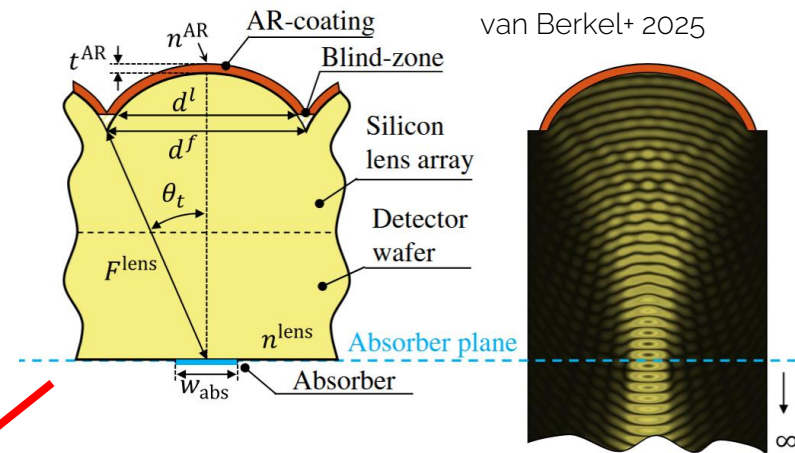
12 THz KID Design

- Developed for PRIMA, supports astronomical background limited observations
- Lenslet-coupled, 75-micron diameter aluminum resonant absorber
- Absorber designed to produce a resonance at 12 THz in for both polarizations

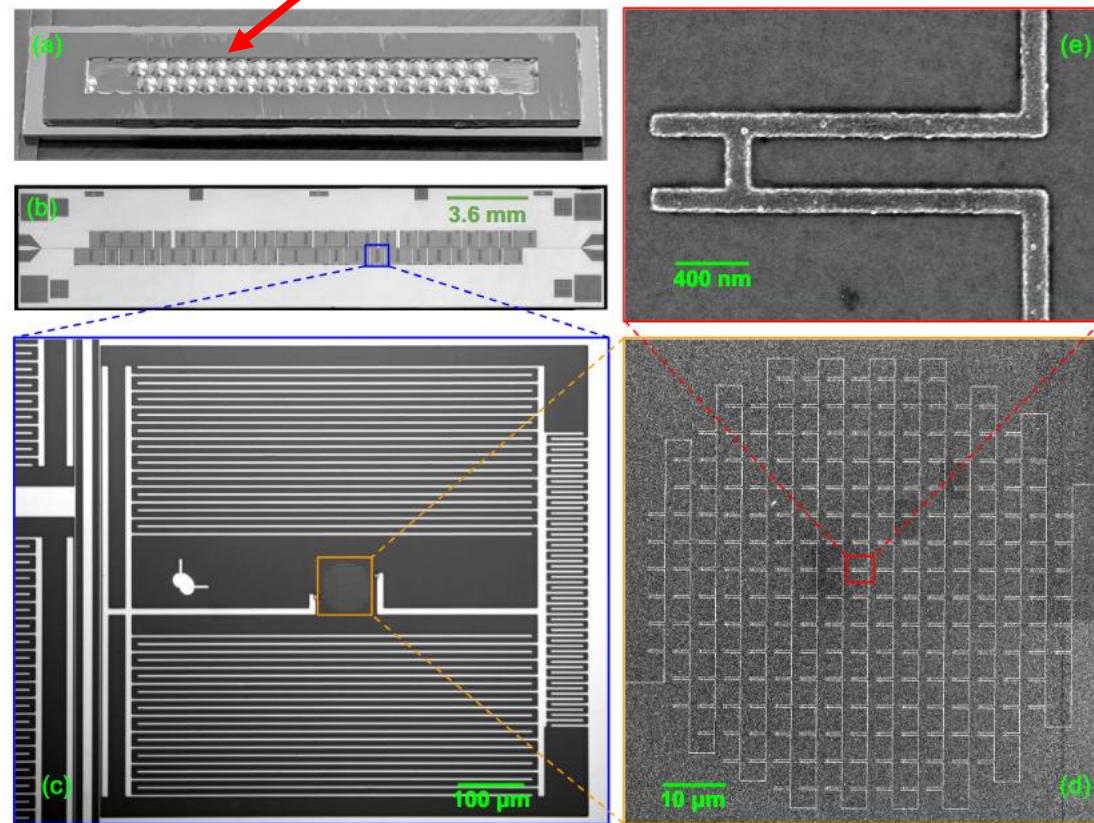


10/22/2026

Chris Albert



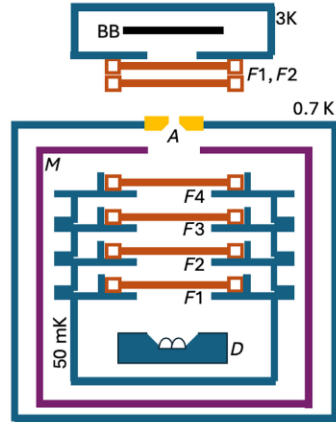
van Berkel+ 2025



Day+ 2024

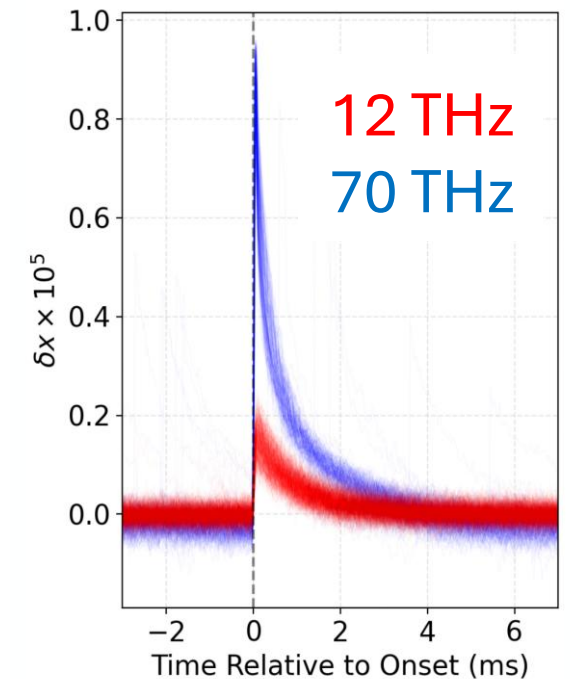
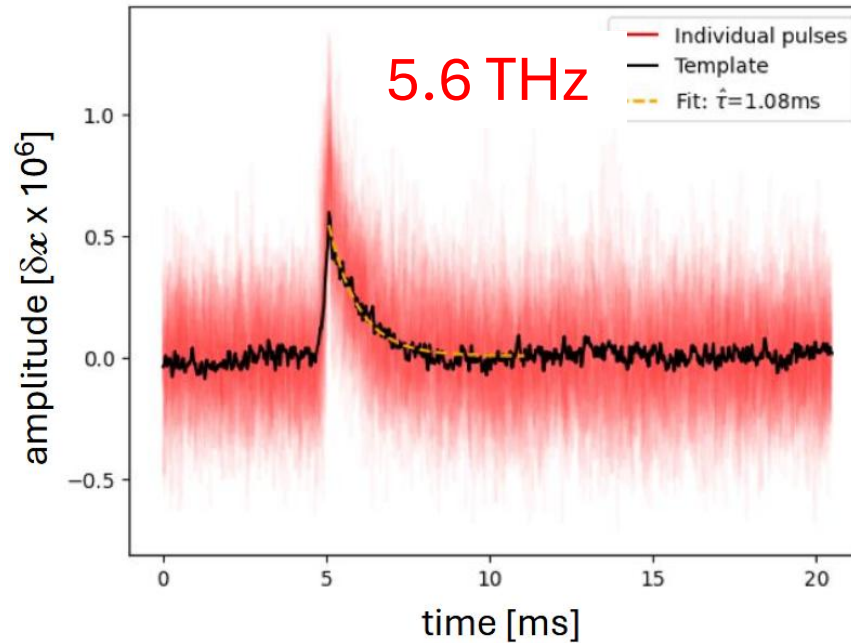
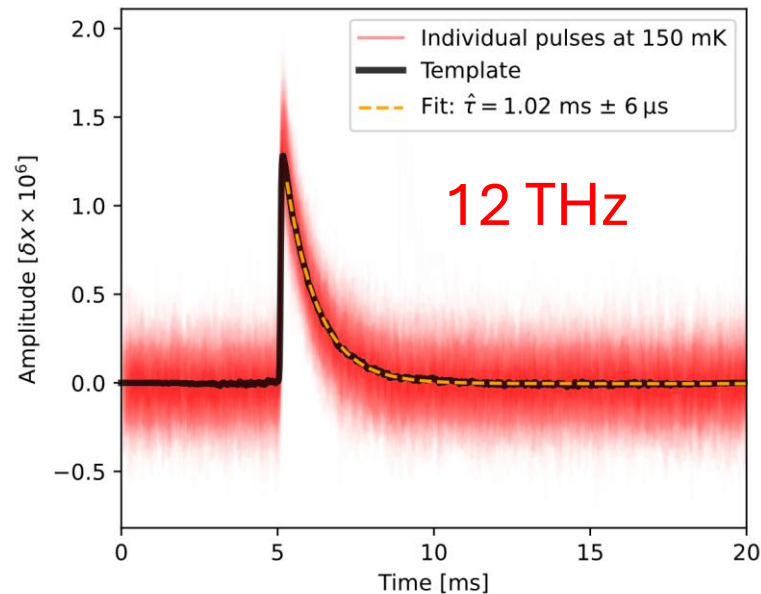
4

Demonstrated energy resolution from 5.6-70 THz



- 5.6 THz photons and 12 THz photons from different filter configurations with a black body emitter
- 70 THz photons from an infrared LED
- Currently working to extend this to 3.4 THz photons from a quantum cascade laser

Day+ 2024



Hidden Photon Dark Matter Dish Searches

Hidden photons:

- Hypothetical massive vector bosons in a hidden/dark sector
- Weakly mix with the Standard Model EM field (kinetic mixing parameter χ)
- A small part of the local DM energy density is stored in an oscillating SM electromagnetic field.

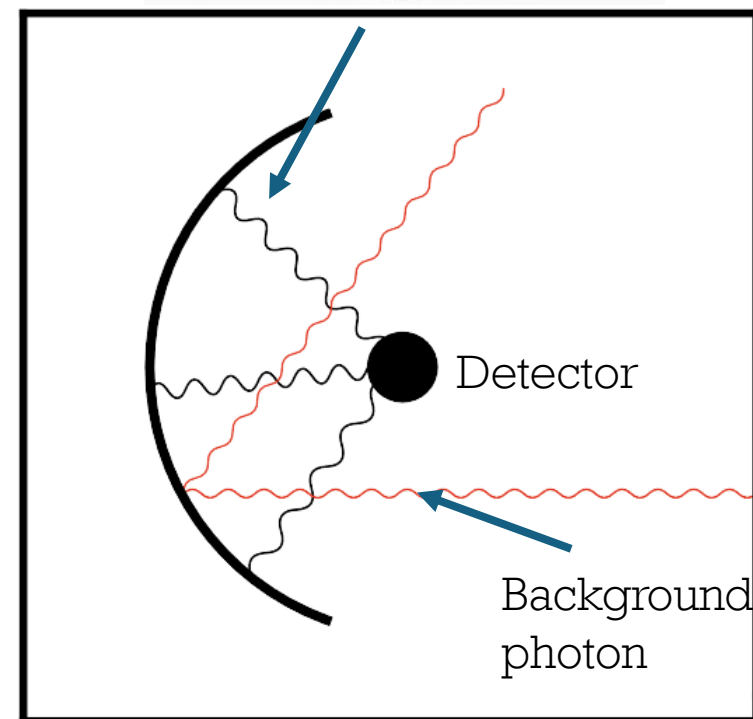
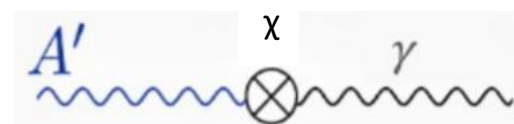
Couples to SM $\rightarrow$
Couples to HP $\rightarrow$

$$\begin{pmatrix} \mathbf{E} \\ \mathbf{E}_{\text{hid}} \end{pmatrix} = \mathbf{E}_{\text{DM}} \begin{pmatrix} -1 \\ 1/\chi \end{pmatrix} \exp(-i(\omega t - \mathbf{k}_0 \mathbf{x}))$$

Boundary conditions at a conductive surface require converted photons to emit normal to the surface.

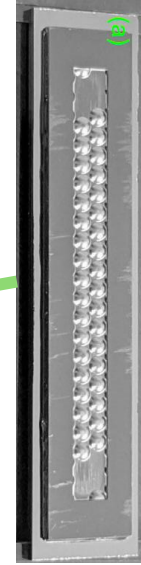
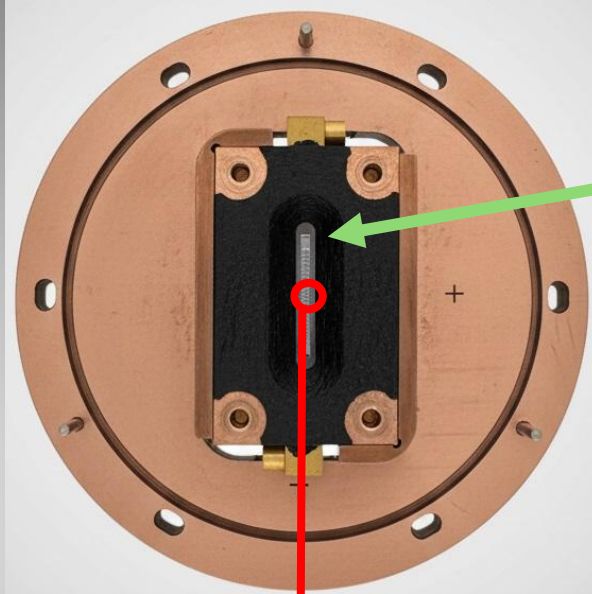
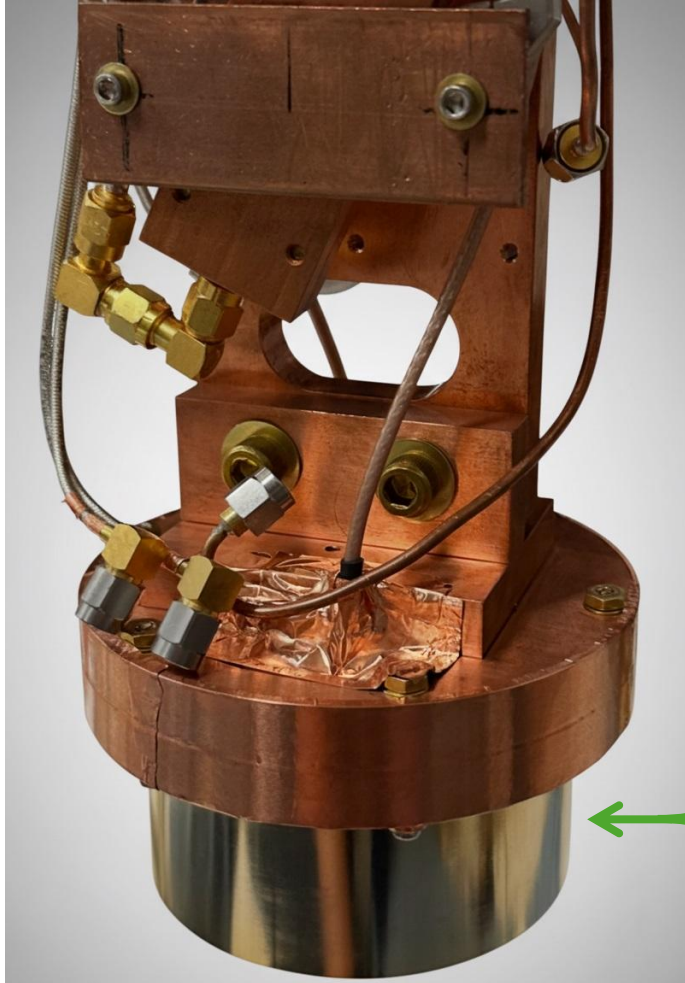
- Broadband
- Add B field to look for axions

Photons converted from HPs

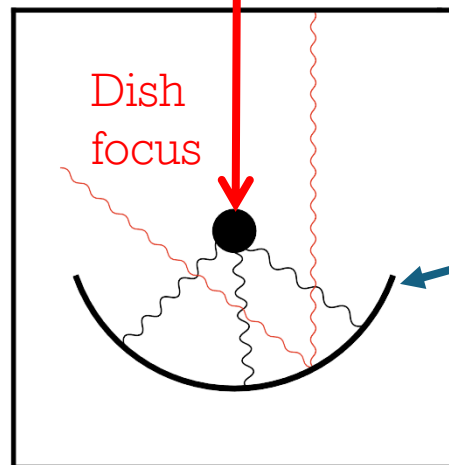


Horns+ 13

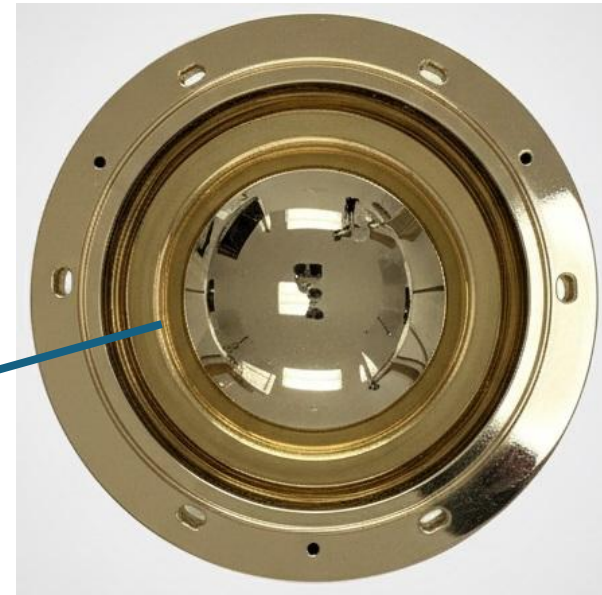
QUALIPHIDE FIR



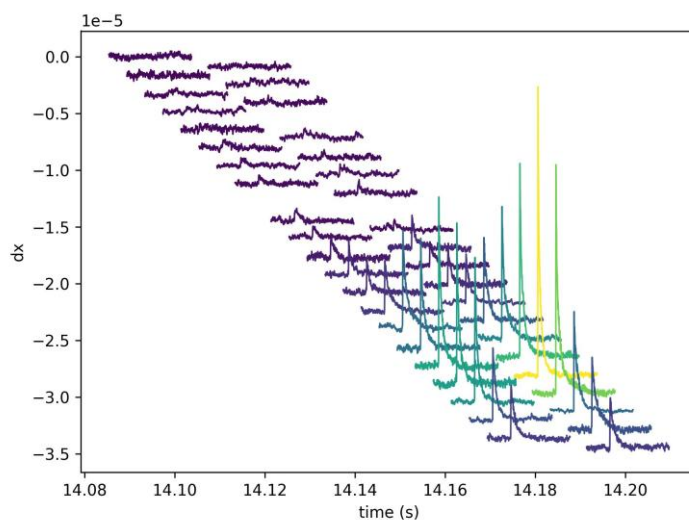
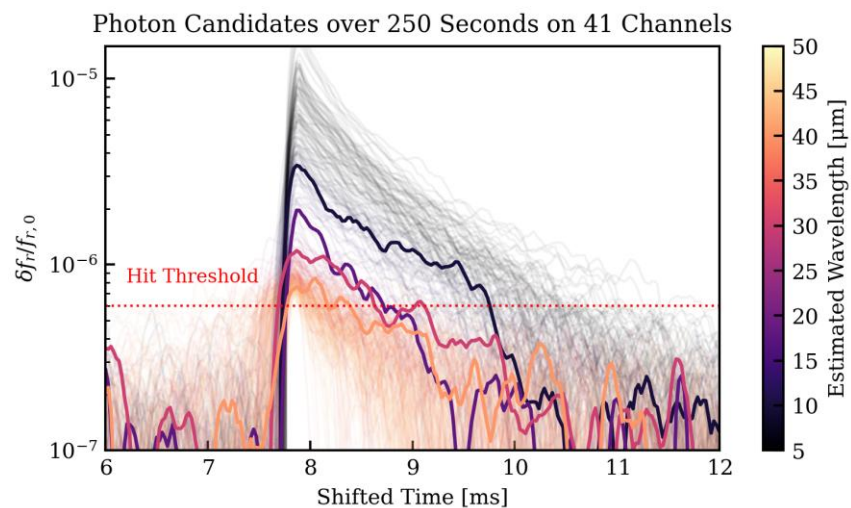
- 1 in-focus pixel
- 40 off-focus pixels allow for coincident-event vetoing and in-situ background monitoring



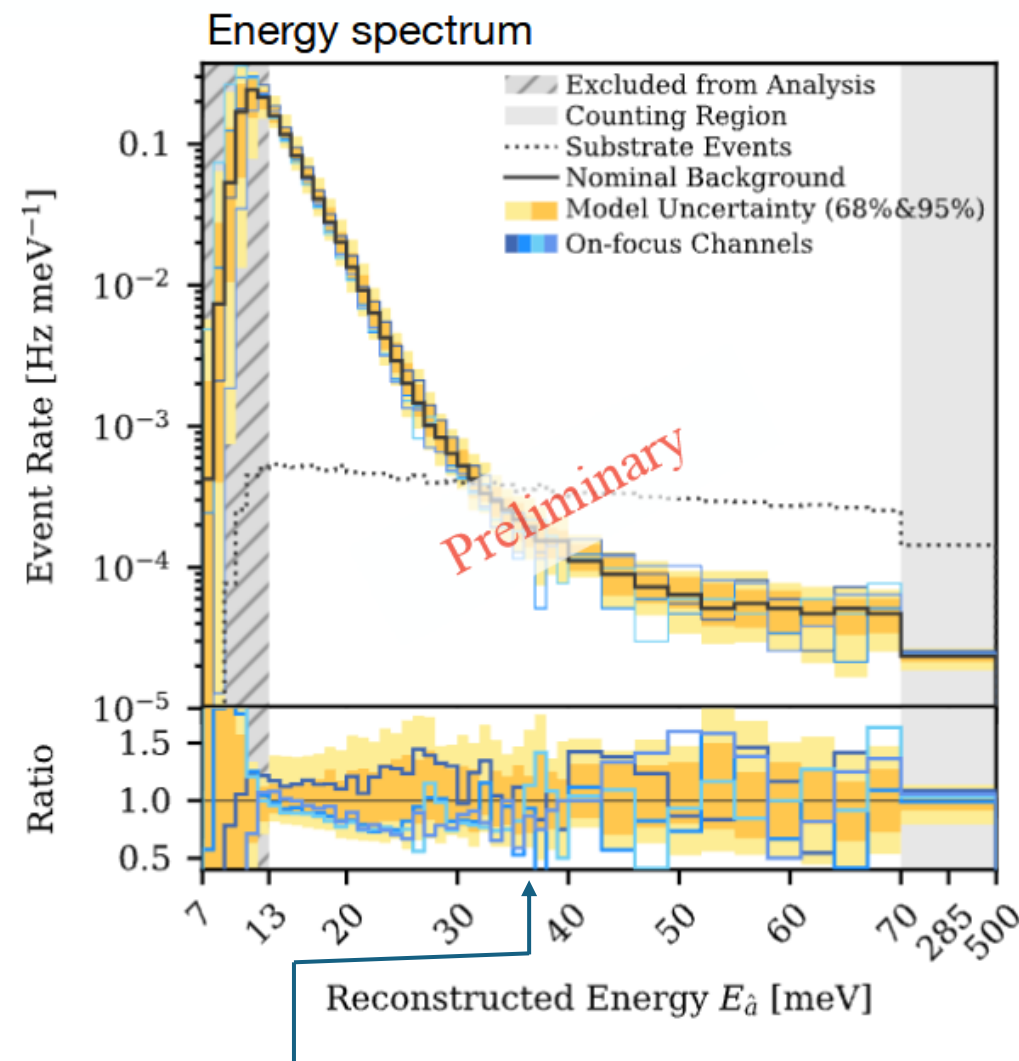
Dish



QUALIPHIDE FIR

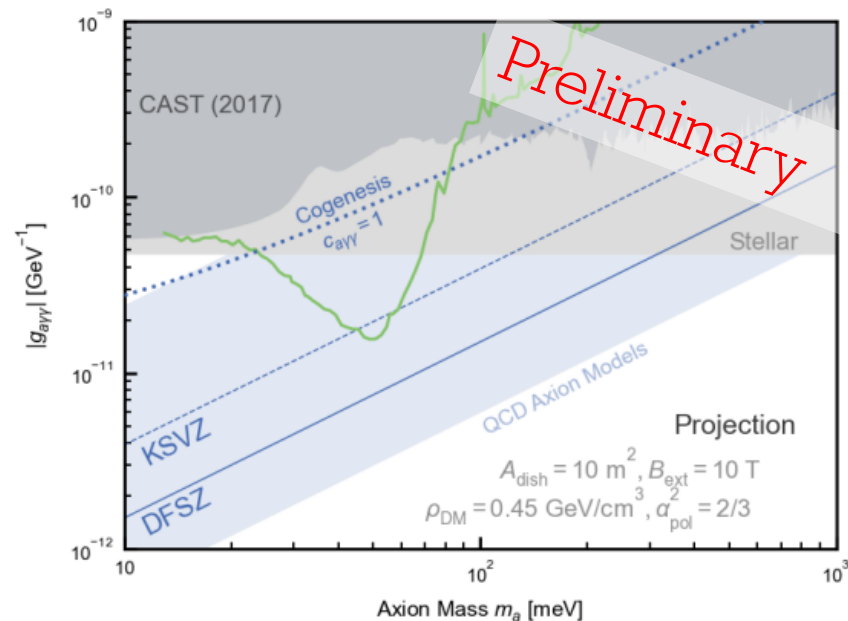
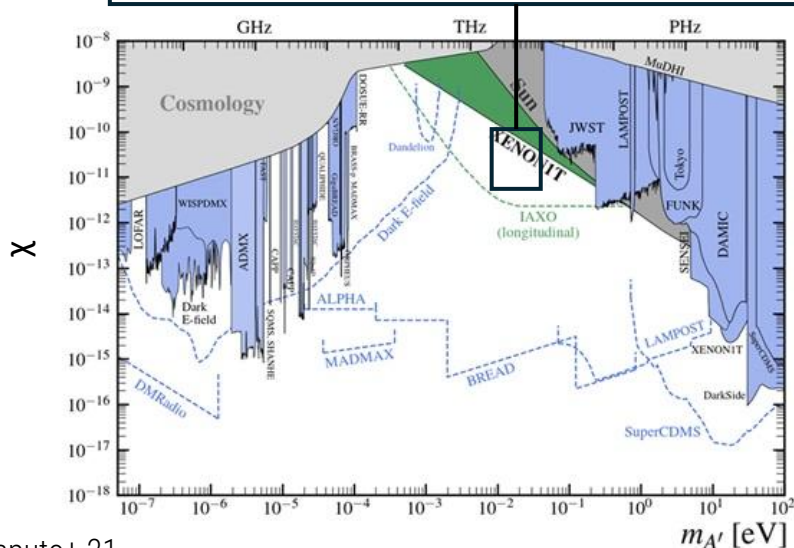
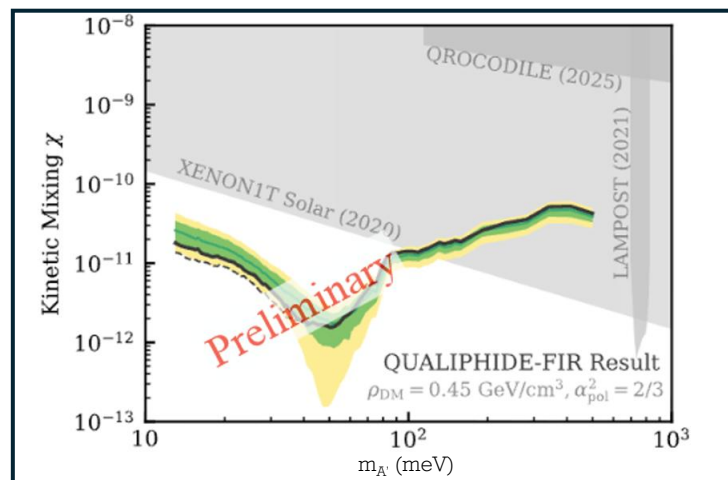


Cosmic ray
seen in
(staggered)
timestreams
across array

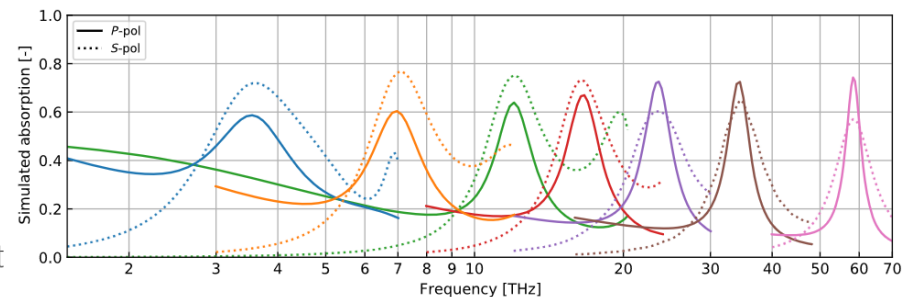


Debye energy of Al. In principle, can resolve single phonons.

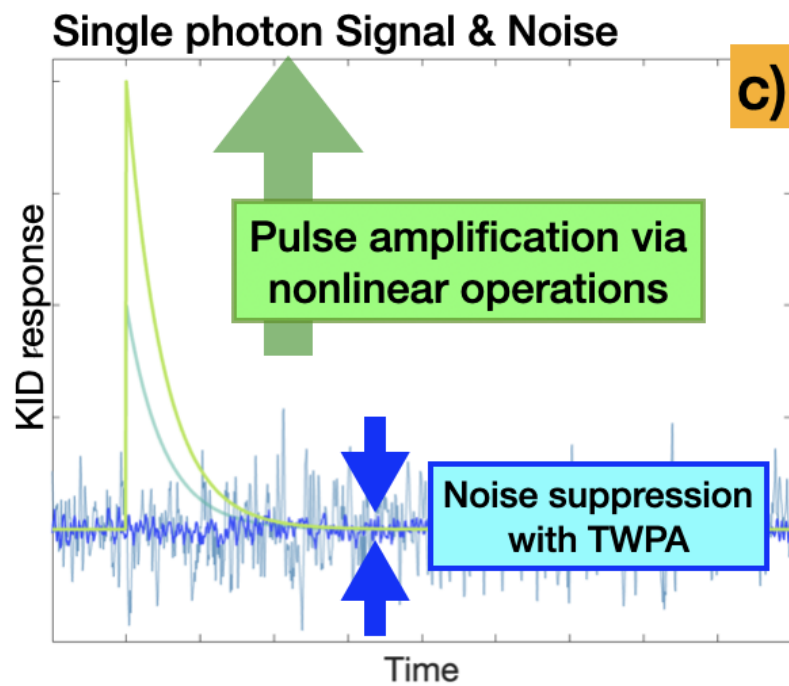
QUALIPHIDE FIR Projections



- Projected Axion exclusion limit if our measurement was in the BREAD experimental setup.
- The peak sensitivity is controllable by tuning the KID's absorber.

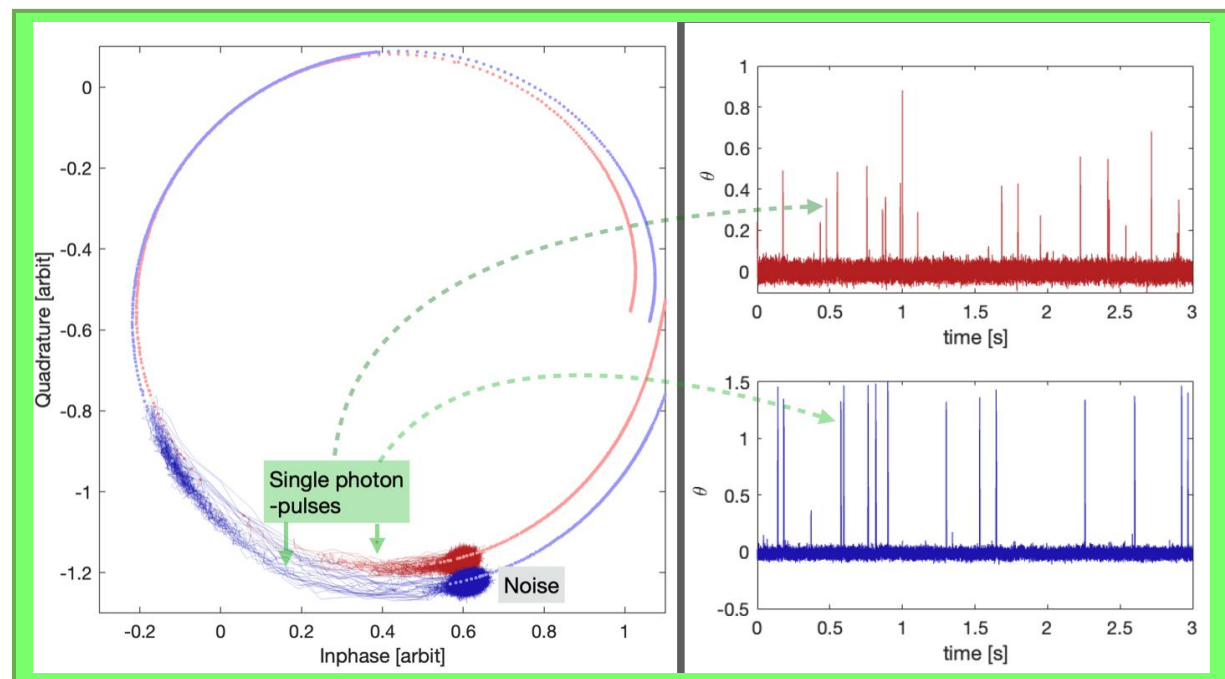
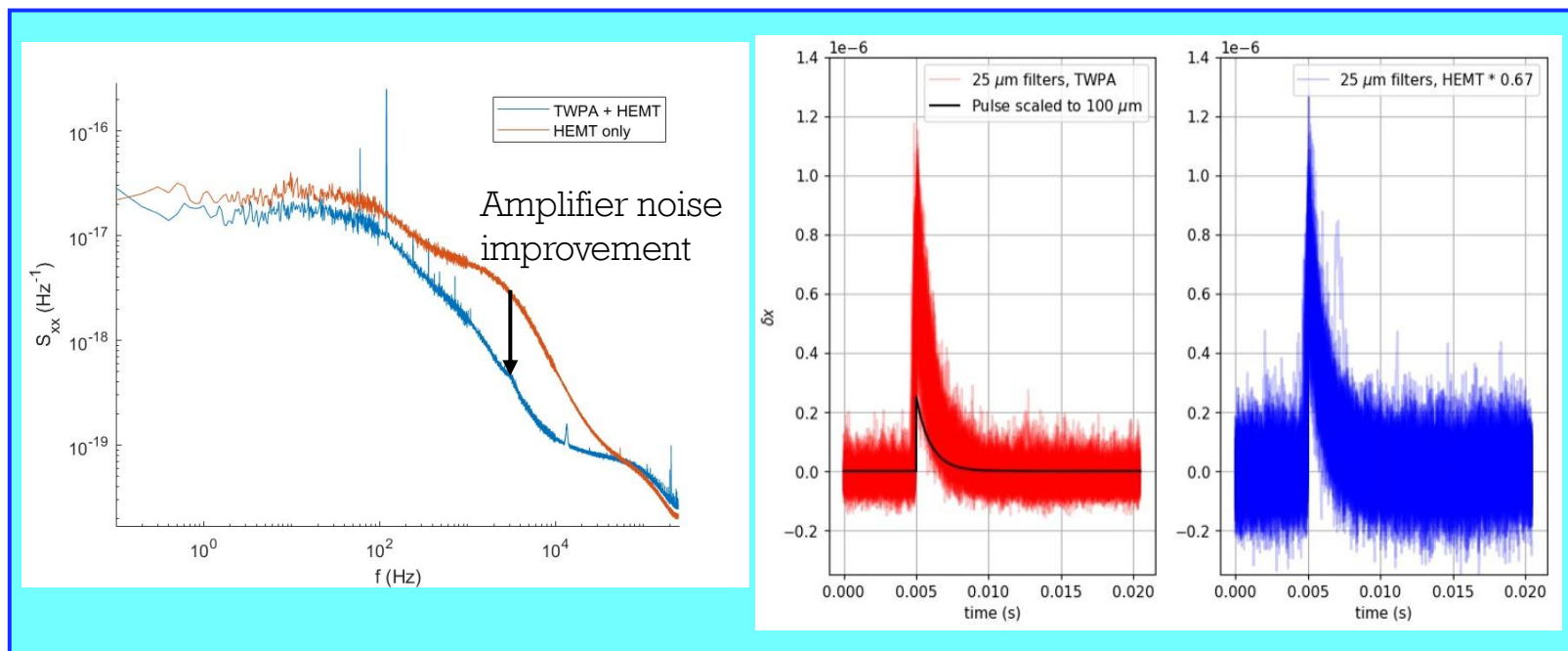


Increasing single photon SNR

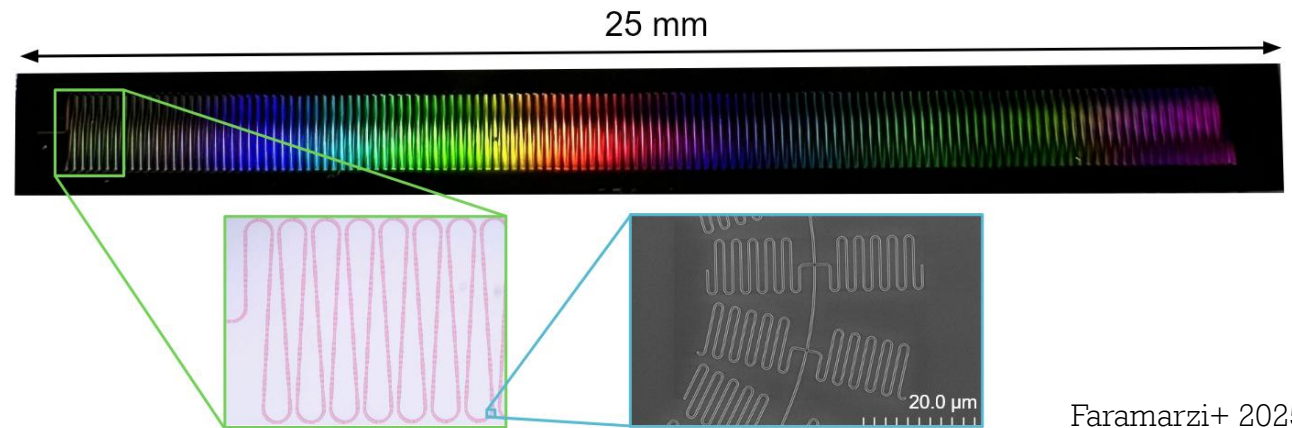


More amplified pulses in

- Rouble+ 2026 (arXiv:2608.23902)
- Basu Thakur+ [In preparation]



KI TWPA_s



Faramarzi+ 2025

- Nonlinearity in the kinetic inductance of a super conducting film mixes pump and signal tones, distributed across length of transmission line

$$\mathcal{L}(I) = \mathcal{L}_0(1 + (I/I_*)^2 + (I/I_4)^4 + \dots)$$

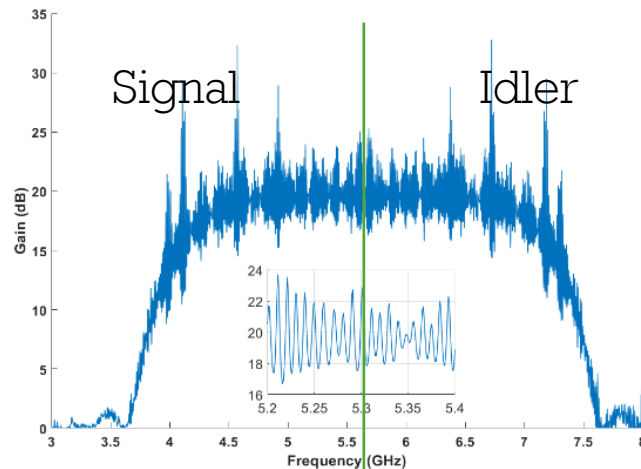
- More broadband, less sensitive to B fields, and relatively easier to fabricate than JPAs

3 wave mixing

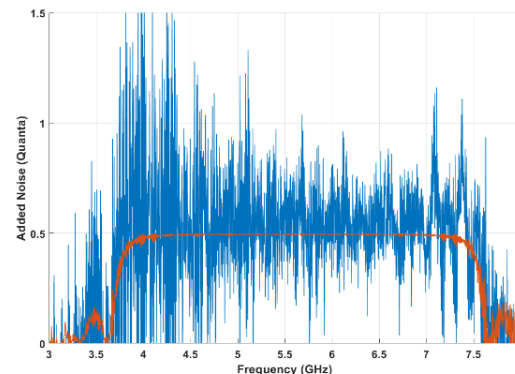
1 pump photon → 1 signal + 1 idler

4 wave mixing

2 pump photons → 1 signal + 1 idler

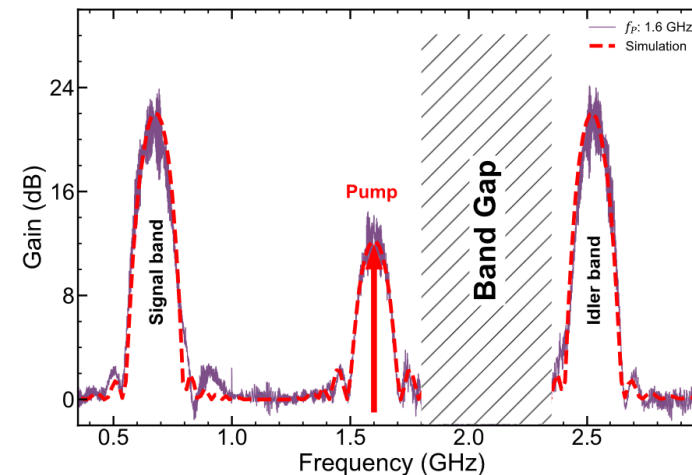


10/22/2026



Klimovich+ 2023

Chris Albert



Faramarzi+ 2025

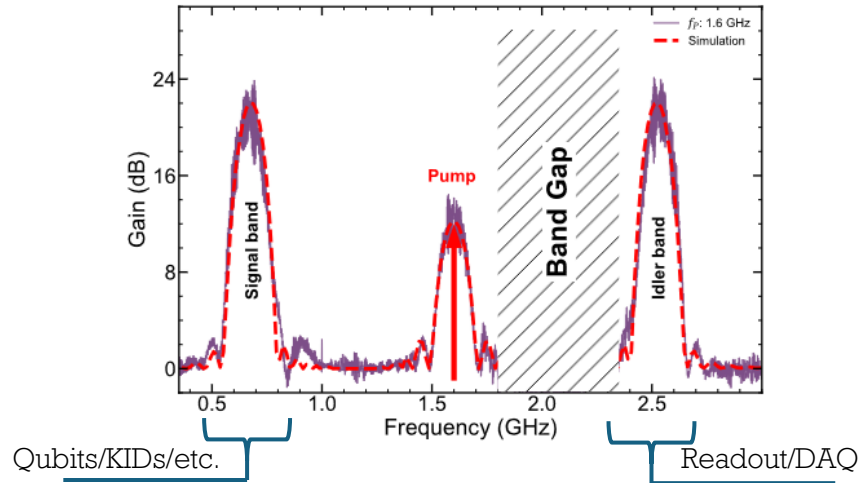
Current designs achieve ~2x bandwidth by tuning the dispersion relation to be less aggressive in suppressing power coupled into higher order modes

11

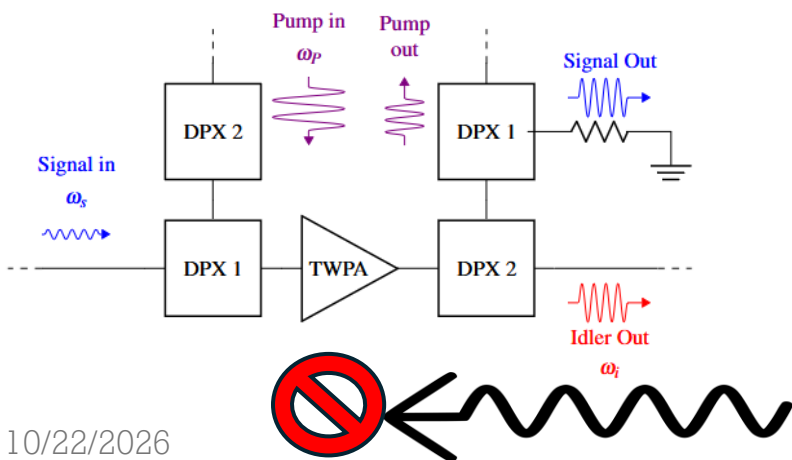
Frequency Translating KI TWPA's

Faramarzi+ 2025

(a)



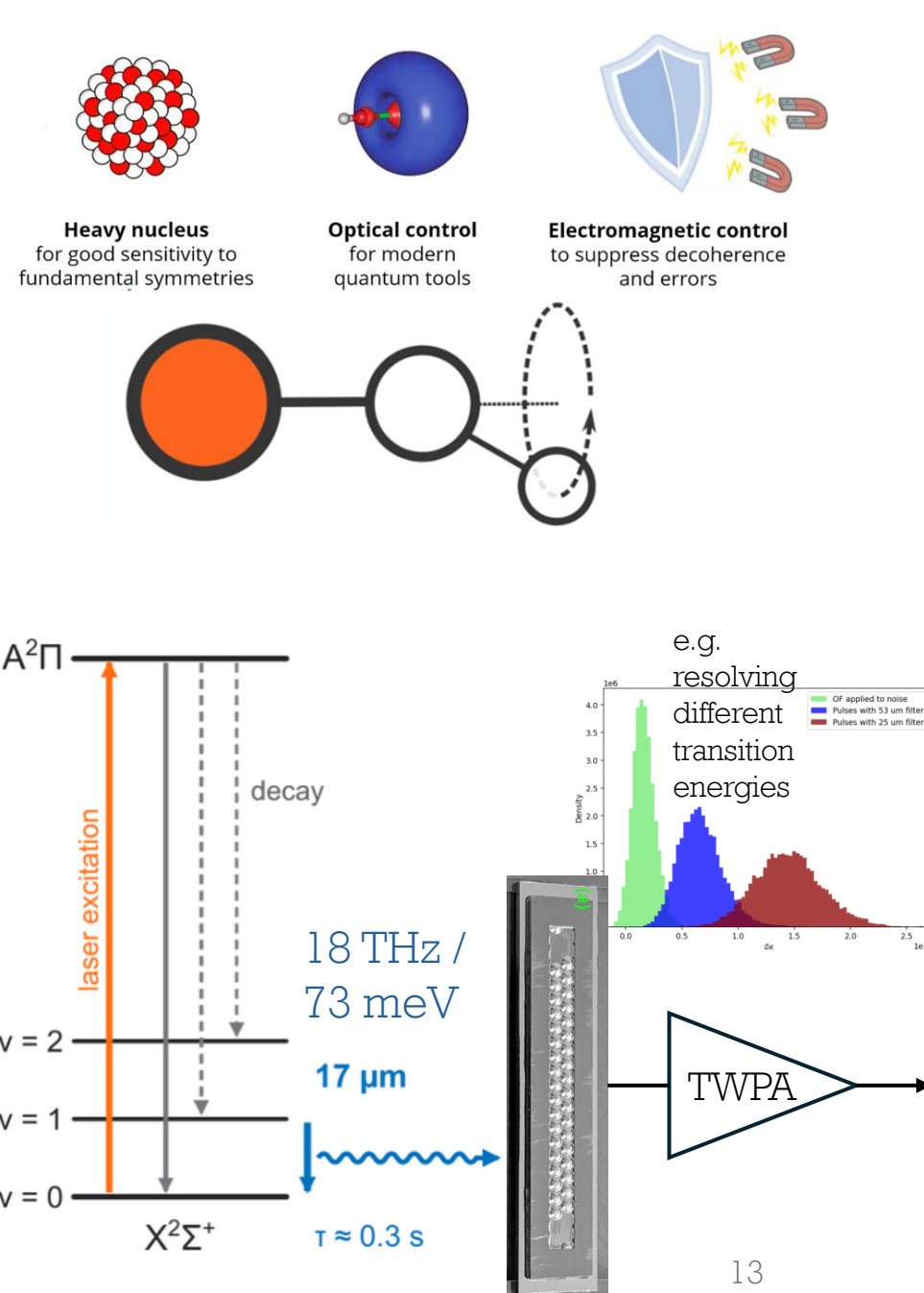
(b)



- Provides intrinsic isolation of the device from the warm output:
 - Out-going signal band is terminated cold so you only get 1 quanta of noise.
 - The idler out cannot be translated in reverse back into the signal input.
- Minimize disturbances to qubits from HEMT/output line
- Translating to higher frequencies allows sub-GHz devices to be compatible with commercially available cryogenic isolators

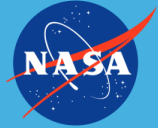
Engineered Molecules

- Polyatomic molecules for probing fundamental symmetries
 - Large internal electric fields $\rightarrow$ amplifies EDM sensitivity
 - Octupole-deformed nuclei for probing hadronic CP violation
- Quantum control: design molecules around an optical cycling center that allows for precise control with laser cooling
 - KID arrays resolve the energy of single photons emitted during decay to map branching ratios and close the cycling loop.



Acknowledgements

TWPA and PRIMA KID Development



Jet Propulsion Laboratory
California Institute of Technology

Peter Day, Ritoban Basu Thakur, Andrew Beyer,
Byeong Ho Eom, Charles (Matt) Bradford, Chris
Curwen, Henry (Rick) LeDuc, Jonah Hoffman,
Jonathon Hunacek, Marc Foote, Mary Kreidel,
Pierre Echternach, Reinier Janssen, Ryan
Stevenson



Chris Albert, Elijah Kane, Logan Foote,
Steve Haily-Dunsheath



Thomas Stevenson



Washington
University in St. Louis

Lanqing Yuan, Karthik Ramanathan, Andrew
Bear, Chris Cappiello, Jacob Harris, William Ho



Alejandro Simon, Karl Berggren



Nikita Klimovich



Arjun Ghosh

Engineered Molecules



Nick Hutzler