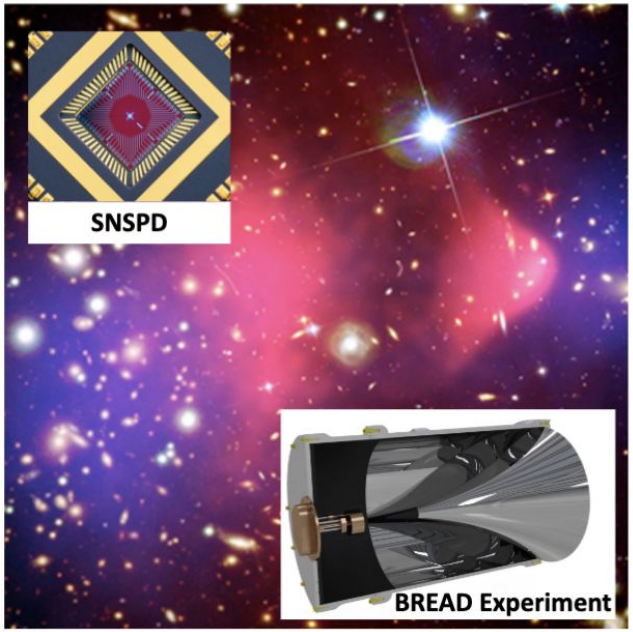
Towards Low Energy Threshold and Large Area SNSPDs for HEP Science



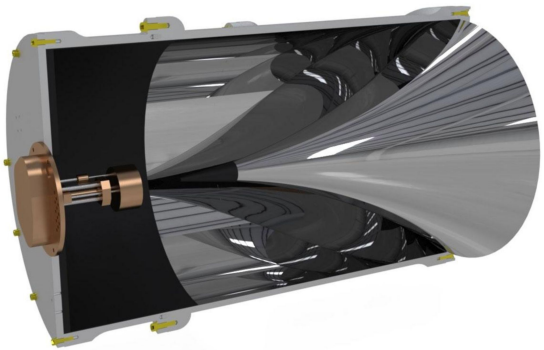
Cristián Peña, Si Xie, Boris Korzh, Christina Wang, Matt Shaw, Jamie Luskin, Sasha Sypkens, Leo Stefanazzi, Gustavo Cancelo

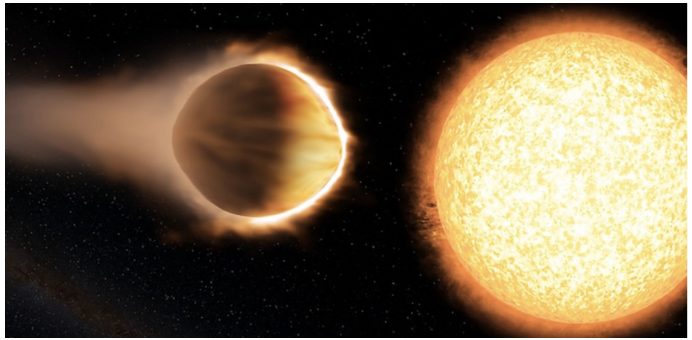
CPAD 2023 – Nov 9, 2023

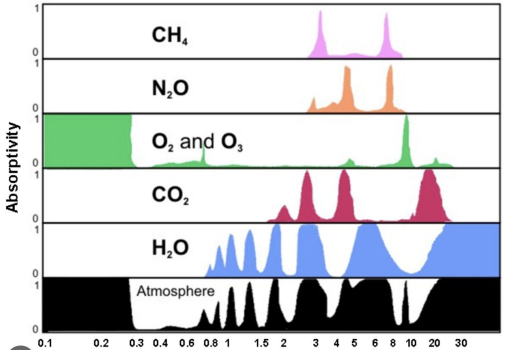
Mid-IR Photon Detection

- Until recently, efficient detection of Mid-IR (10-50μm) not possible
- Science impact is **broad** and **significant** !
- Critically enables:
  - **Sub-eV axion and dark matter detection**
  - Exoplanet transit spectroscopy
  - Monitoring of atmospheric, environmental, and biological processes via rotational modes of complex molecules

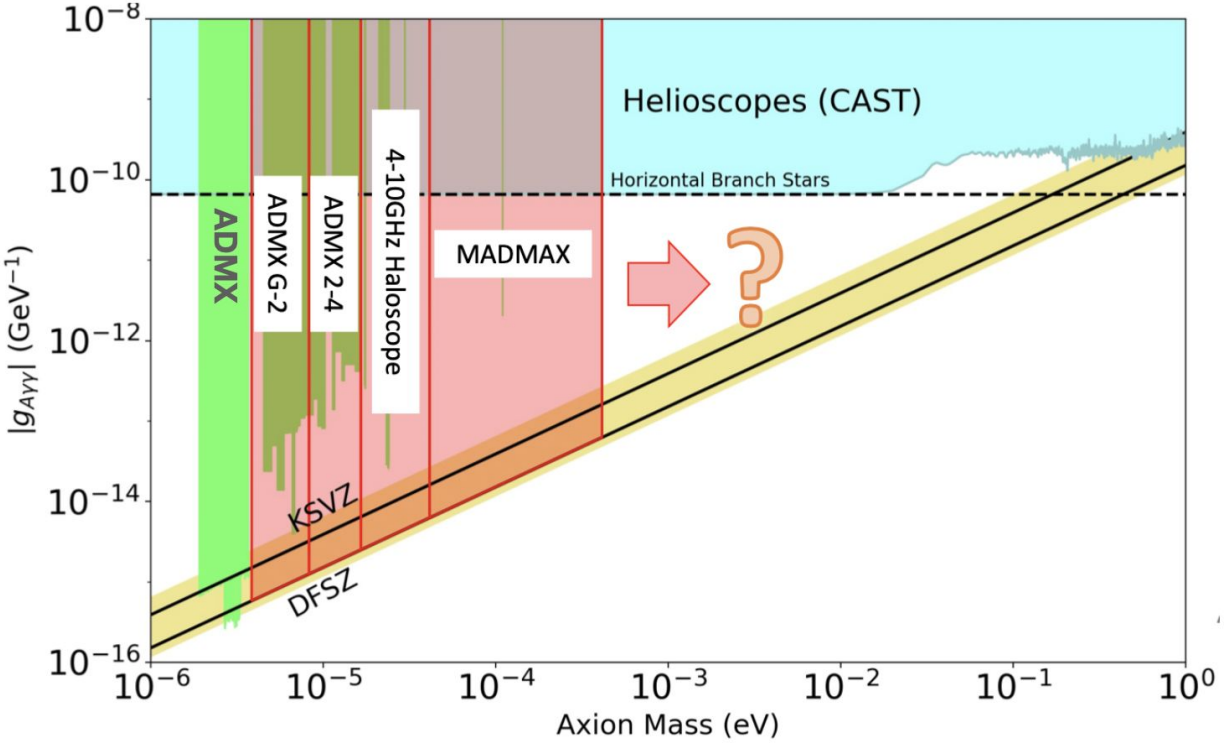
Focus of this talk







meV Axions are Unexplored

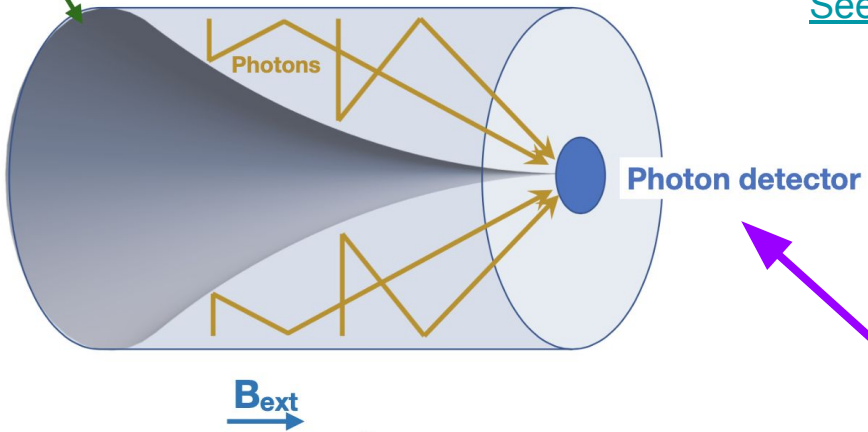


Axions solve the “strong CP” problem

And simultaneously a good dark matter candidate

BREAD Experiment

- Since an external B field is needed, its convenient to build a **cylindrical surface** that would fit in a solenoid
- A **parabolic mirror** is added to focus the photons to a vertex

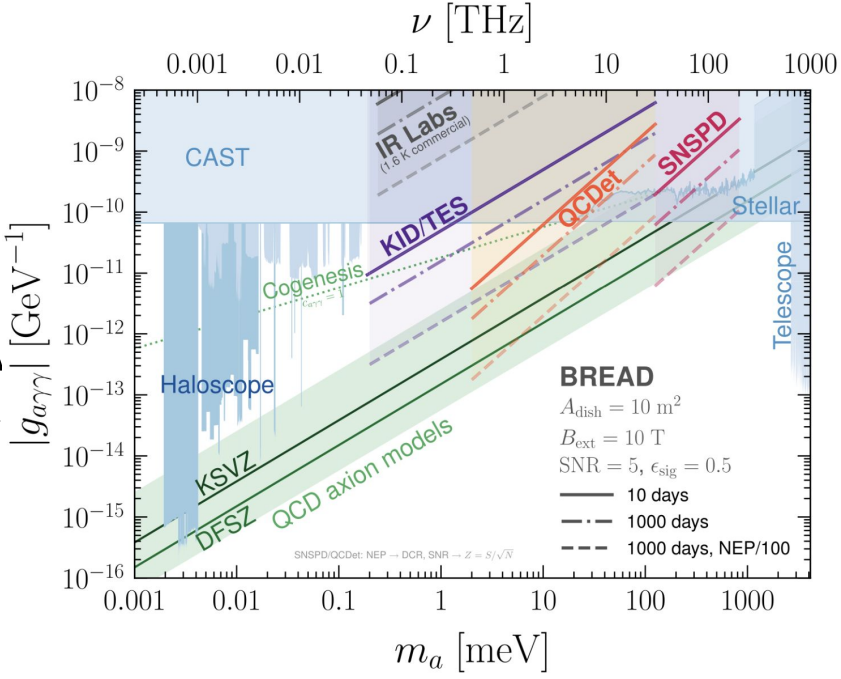


See C. Wang's talk on Friday

Mid-IR SNSPDs are the ideal detector for this application !

Desired Detector Specifications

- To fully exploit SNSPD technology for the BREAD experiment we need:
  - **Low threshold**:
    - 30μm photons detected ~ 0.04 eV
    - Aim below 50-60μm ~ 0.02 eV → go as low as achievable
  - **Large area** : towards ~ 5 mm^2
  - **Low Dark Counts** : below 10^{-5} Hz
  - **Time Resolution** : as low as possible to suppress particle background

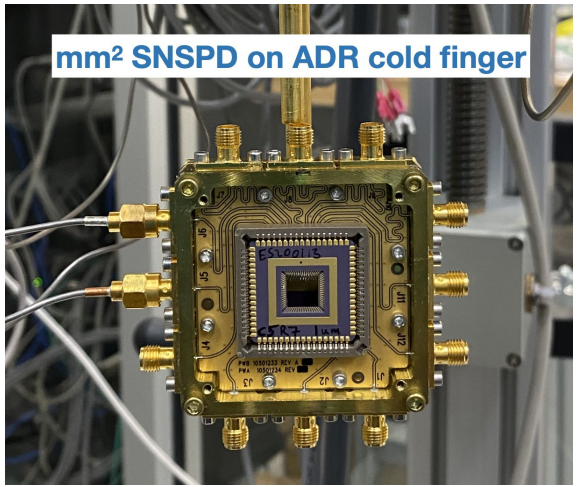


Awarded 2023 DOE Accelerate Initiative Project to develop these detectors

Testing Facilities @ Fermilab

- Adiabatic Demagnetization Refrigerator (ADR) available with 0.1K base temp
- New dedicated fridge @ FNAL for FDM testing capability implemented

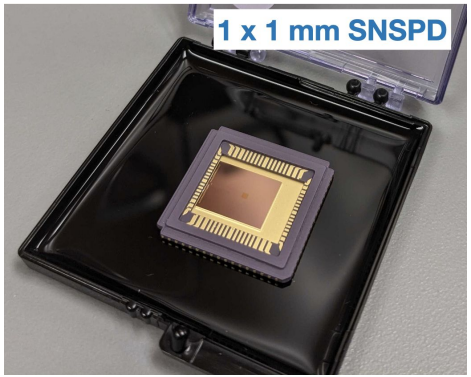
- Dilution Refrigerator delivery expected by April 2024
- New lab at Edwards Center (IERC) under construction – towards low energy threshold SNSPDs

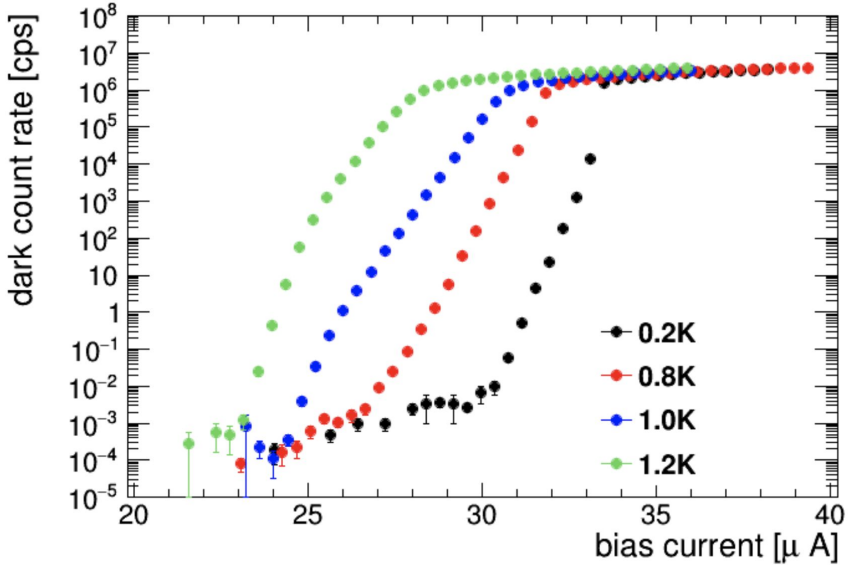


Latest Test Results

- Dark count rate and photon count rate characterization under way since 1 year ago
- Observed interesting temperature dependence

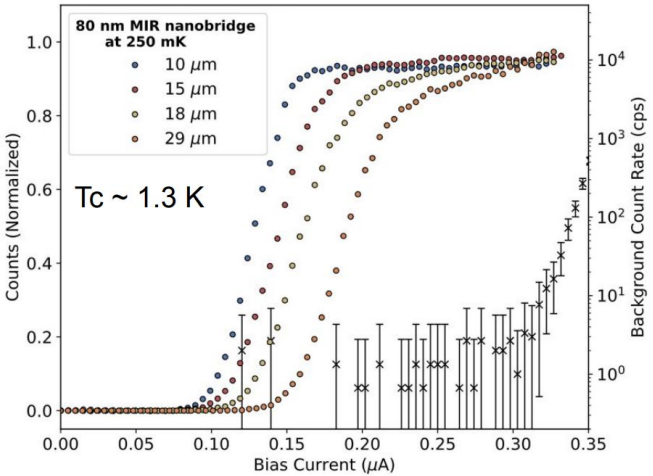
- Continuing tests with new 4-channel sensor and improved dark box

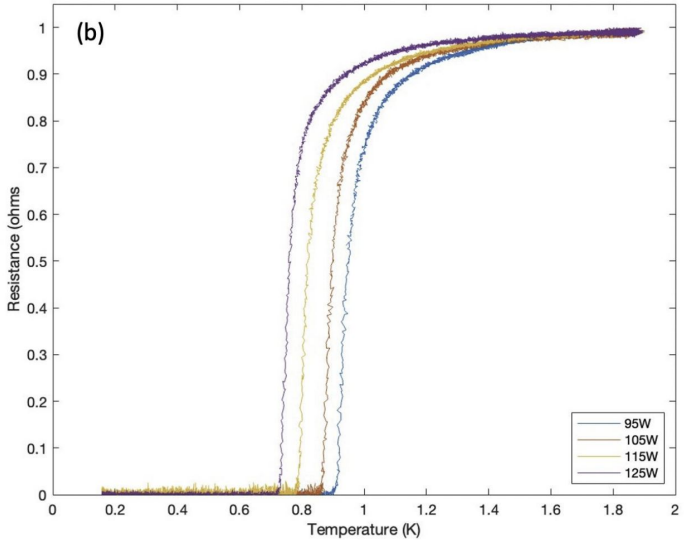




Towards Lower Energy Threshold

- Based on detailed experimentally validated simulations, energy threshold can be reduced in WSi nanowires by tuning the T_c via Si content
- Using this technique recently achieved sensitivity for λ up to 29 μm
- Further decrease in Tc being explored with co-sputtering of $W_{30}Si_{70s=}$ together with an aSi targets. Goal is to push energy threshold as low as possible



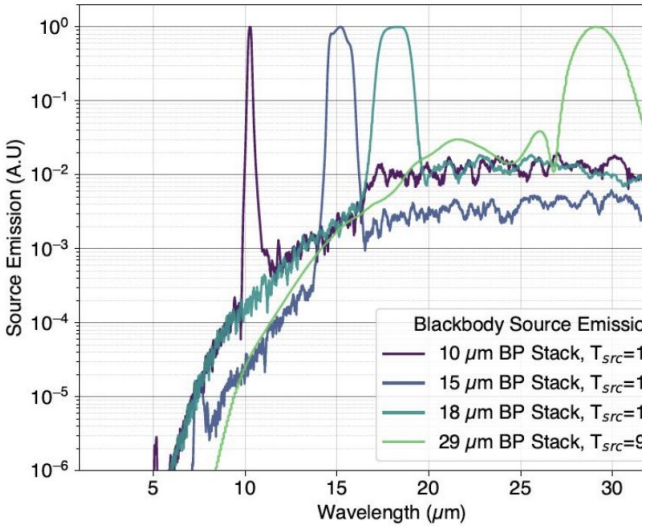


Thermal Source

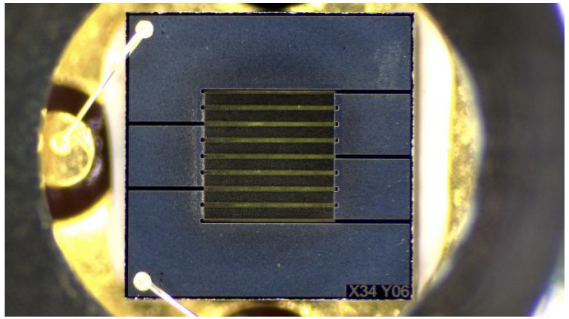
- A major challenge are photon sources with sufficiently low energy
- Realized that wide spectrum thermal sources coupled with narrow band filters is a practical and economical solution\

- COTS Filters exist up to 15 um

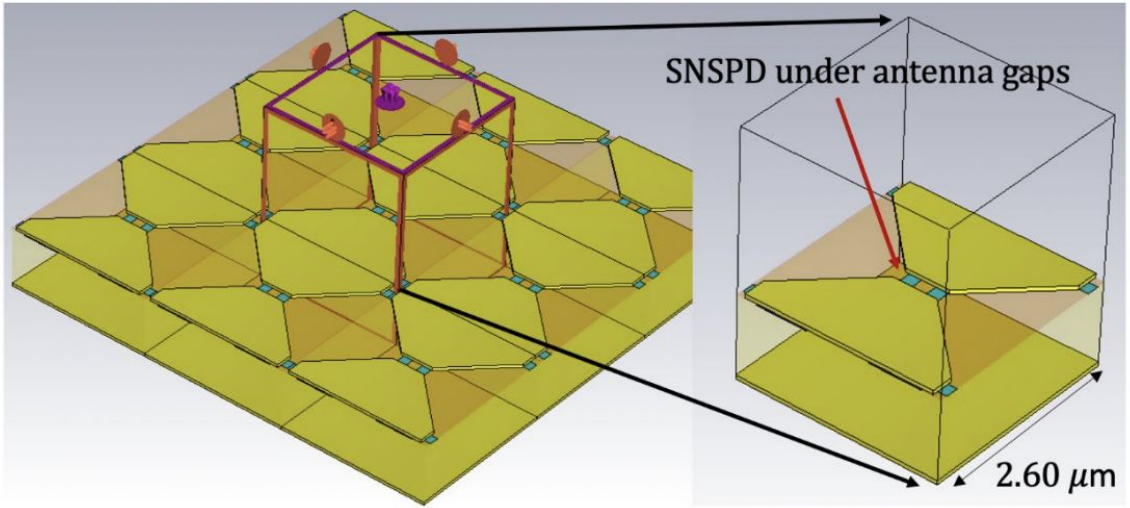
- Semi-custom commercial solutions exist for >15 μm filters
- JPL has capability to fabricate >20 μm filters

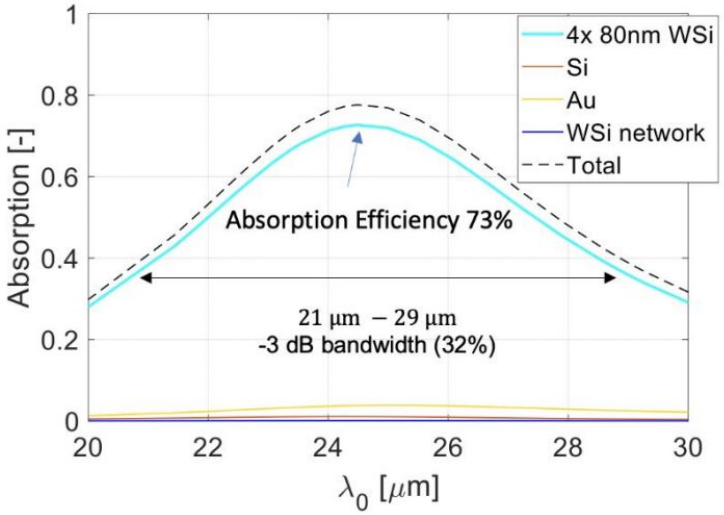


With reflector for collimation



Towards Large Areas: Antennas

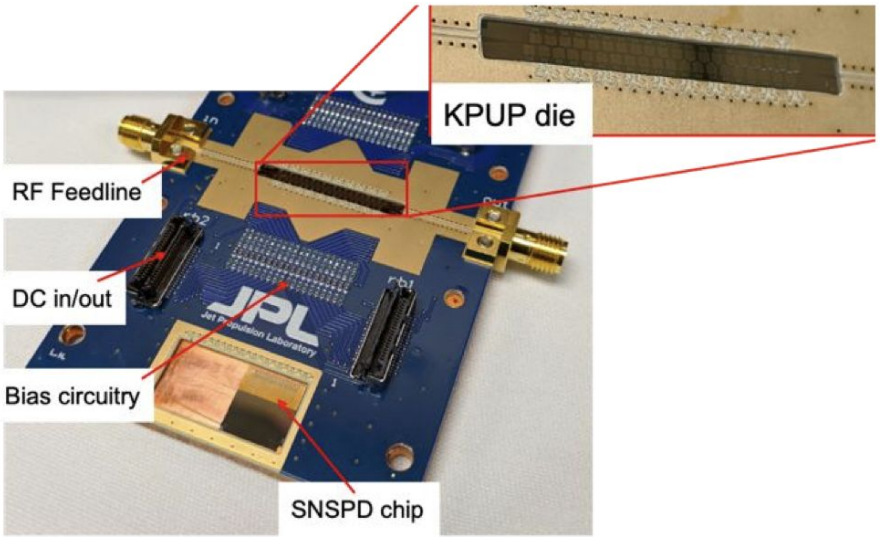


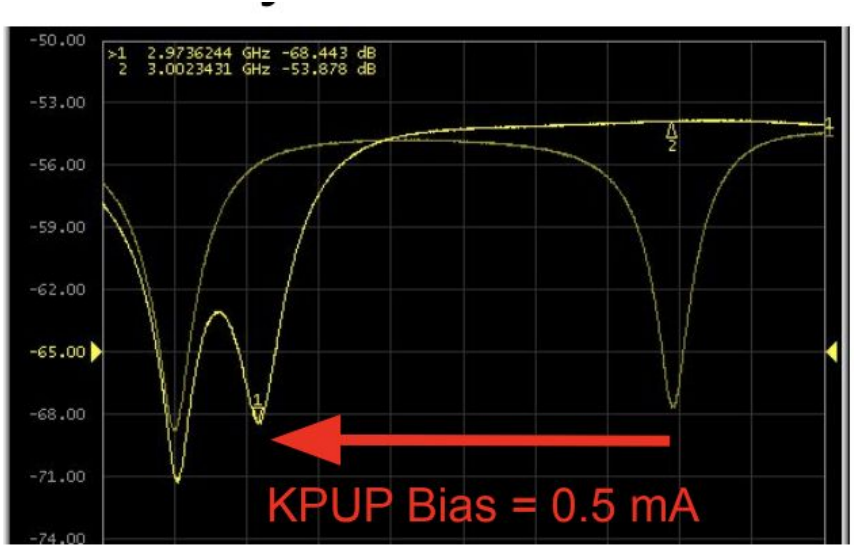


- Developing fabrication techniques for antenna structures at JPL
- Developing techniques to test and characterize coupling and detection efficiency

Resonator coupling

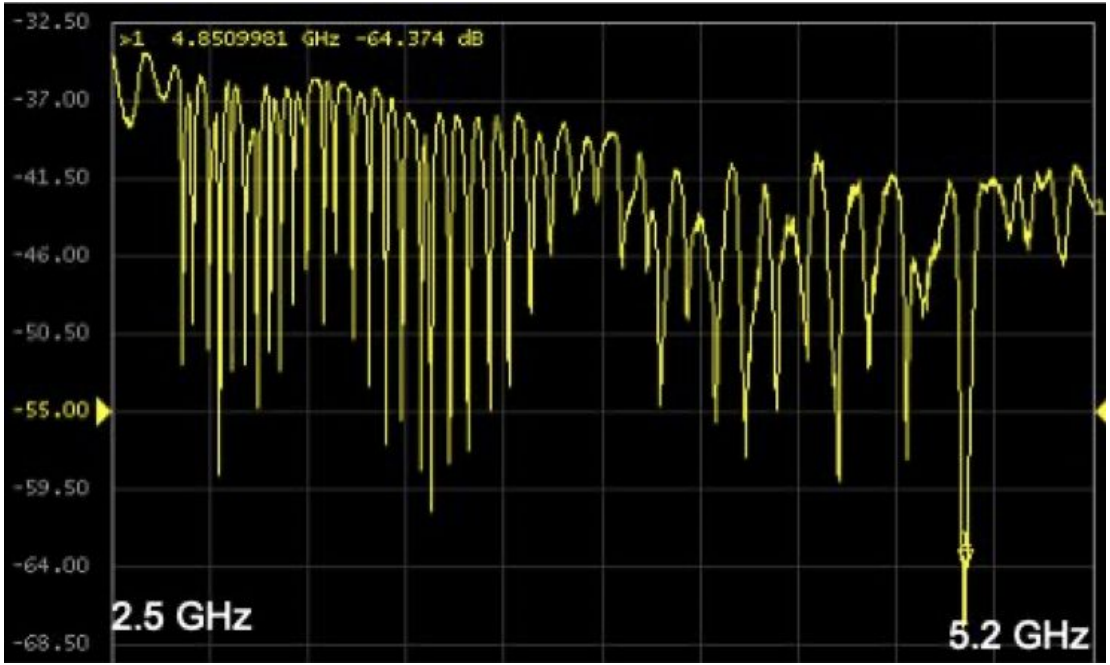
- Low Tc sensor must be operated at low bias current resulting in smaller signals → low noise amplification is a key requirement
- Use external resonator sensitive to current perturbations
- Signals induce small but detectable shift in the resonant tone frequency





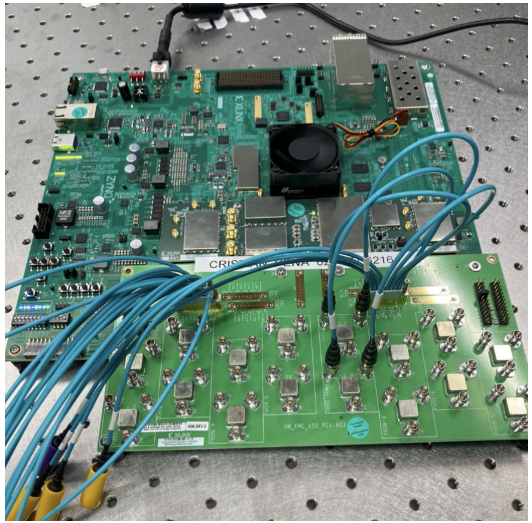
Frequency Division Multiplexing

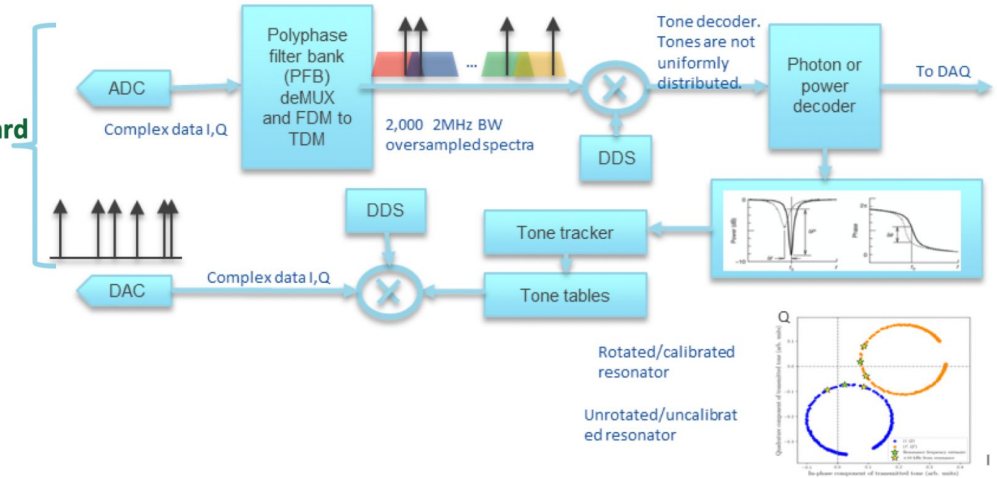
- Using this “nanowire resonance detector” (NRD) scheme, we can naturally enables FDM on a single RF line



Frequency Division Multiplexing

- Using this “nanowire resonance detector” (NRD) scheme, we can naturally enables FDM on a single RF line
- Using newest RFSoC technology from Xilinx, FDM can be naturally implemented in a scalable fashion



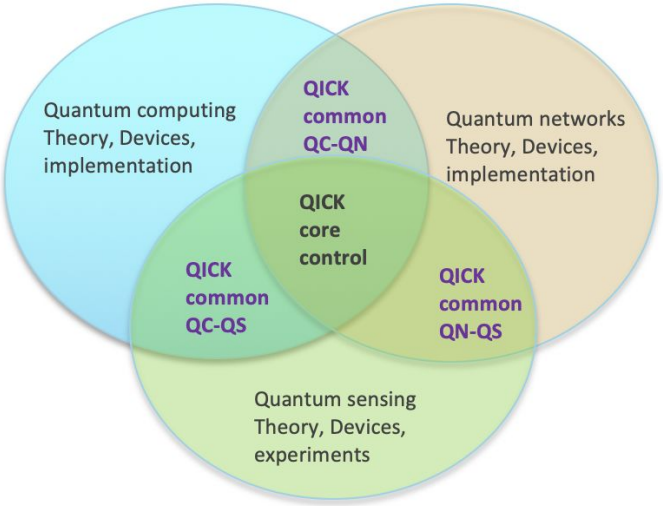


QICK Ecosystem

A comprehensive, control and readout system for QIS

– **Open source**: including hardware schematics/layouts, firmware, software.
See https://github.com/openquantumhardware https://qick-docs.readthedocs.io/en/latest/

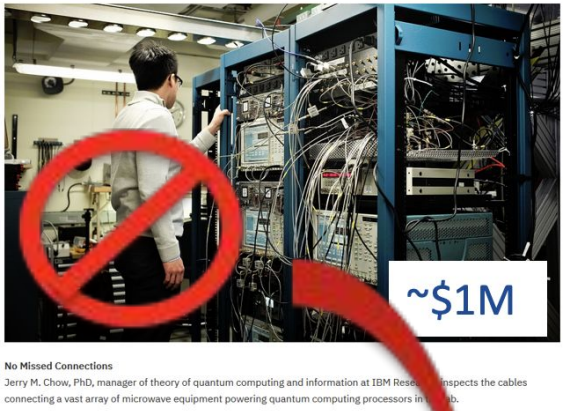
– Easy to use, Cost effective, Collaborative, Supported by a growing international community



QICK

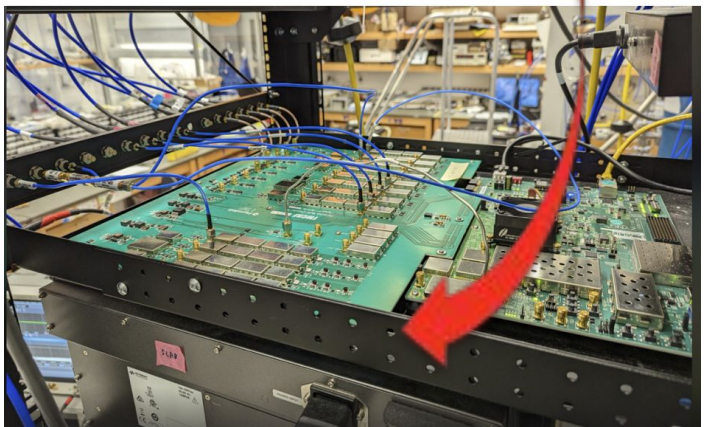
QICK: Quantum Instrumentation Control Kit

QIS before QICK w/off the shelf control

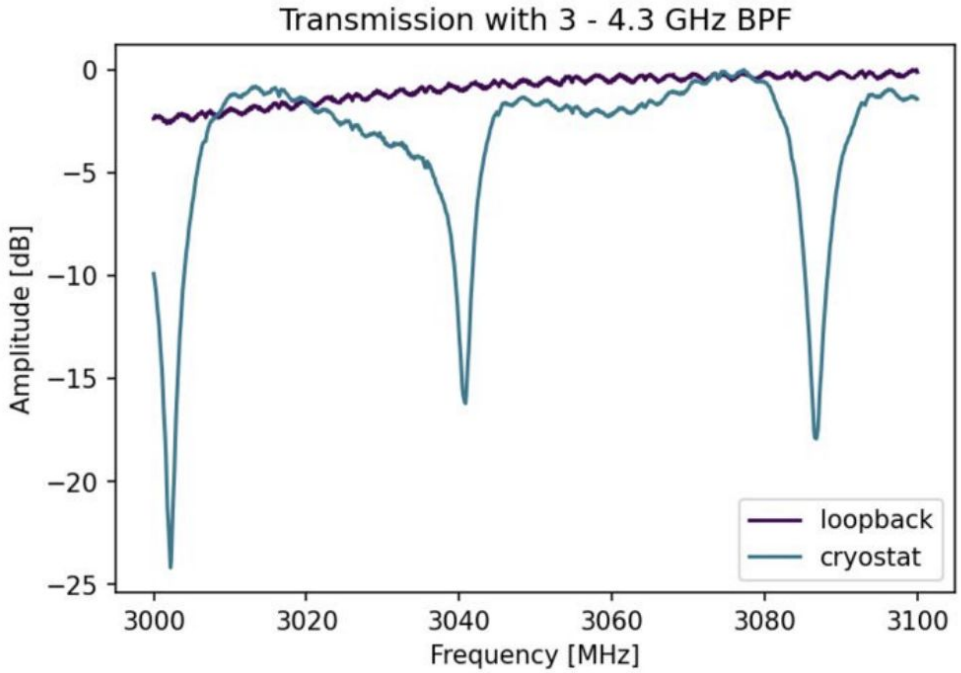


No Missed Connections
Jerry M. Chow, PhD, manager of theory of quantum computing and information at IBM Rese inspects the cables connecting a vast array of microwave equipment powering quantum computing processors in lab.

Control with QICK



First Detection with QICK-FDM



First resonances measured with QICK firmware on ZCU216

Sasha Sypkens

Summary

- Mid-IR Photon Detection has broad and significant impact on DOE & HEP science

- Presented key progress towards application for axion detection:
  - Pushing low energy threshold
  - Pushing large area coupling
  - Pushing scalable multiplexed readout