

# “Summary” : SC/Quantum detectors

2 hr 45m

3 hr 30m

<

Sun 08/12

Mon 09/12

Tue 10/12

All days

>

Print

Full screen

Filter

15:00

MKIDs for CMB

Adam ANDERSON

Hall of Ideas I, Monona Terrace Convention Center

15:30 - 15:50

MKIDs and microwave spectrometry

Hall of Ideas I, Monona Terrace Convention Center

15:50 - 16:10

MKIDs for Visible and Near IR Wavelengths

Ben MAZIN

Hall of Ideas I, Monona Terrace Convention Center

16:10 - 16:30

Development of Large Scale CMB Detector Arrays at Argonne

Tom CECIL

Hall of Ideas I, Monona Terrace Convention Center

16:30 - 16:50

Readout for Multiplexed Superconducting detectors

Gustavo CANCELO

Hall of Ideas I, Monona Terrace Convention Center

16:50 - 17:10

Development of a Highly-Multiplexed TES Readout For Low Background Calorimeters

Dr. Ouellet JONATHAN

Fundamental Cosmology with Next-Generation Superconducting Millimeter-Wave Spectrometers

Dr. Kirit KARKARE

Superconducting Nanowire Single Photon Detectors For Optical Communication, QIS, and Fundamental Science

Matthew SHAW

18:00

Skipper CCDs for Cosmological Applications

Alex DRLICA-WAGNER

Hall of Ideas I, Monona Terrace Convention Center

18:00 - 18:15

<

Sun 08/12

Mon 09/12

Tue 10/12

All days

>

Print

Full screen

Filter

09:00

High-performance multilayer optical haloscope for a dark photon search

Dr. Jeffrey CHILES

Hall of Ideas I, Monona Terrace Convention Center

09:00 - 09:20

Superconducting nanowire single photon detectors and their performance in strong magnetic fields

Mr. Tomas POLAKOVIC

Nanowire Detection of Photons from the Dark Side

Dr. Ilya CHARAEV

Hall of Ideas I, Monona Terrace Convention Center

09:35 - 09:50

Superconducting Nanowire Single Photon Detectors: Applications from the UV to mid-infrared

Dr. Varun VERMA

Progress Towards Sub-eV Energy Thresholds with SuperCDMS Detectors

Dr. Noah KURINSKY

Hall of Ideas I, Monona Terrace Convention Center

10:05 - 10:25

Superconducting microwave resonator in a strong magnetic field for dark matter axion detection

Dr. Woohyun CHUNG

10:00

Microwave Photon Counting with Josephson Junctions

Prof. Robert MCDERMOTT

Hall of Ideas I, Monona Terrace Convention Center

11:00 - 11:20

Superconducting Qubits for an Axion Search

Akash DIXIT

Hall of Ideas I, Monona Terrace Convention Center

11:20 - 11:40

HeRALD: Dark Matter Direct Detection with Superfluid 4He

Harold PINCKNEY

Hall of Ideas I, Monona Terrace Convention Center

11:40 - 11:55

11:00

Dark Matter and Fundamental Physics Searches using Atomic Magnetometers

Dr. Young JIn KIM

Hall of Ideas I, Monona Terrace Convention Center

11:55 - 12:10

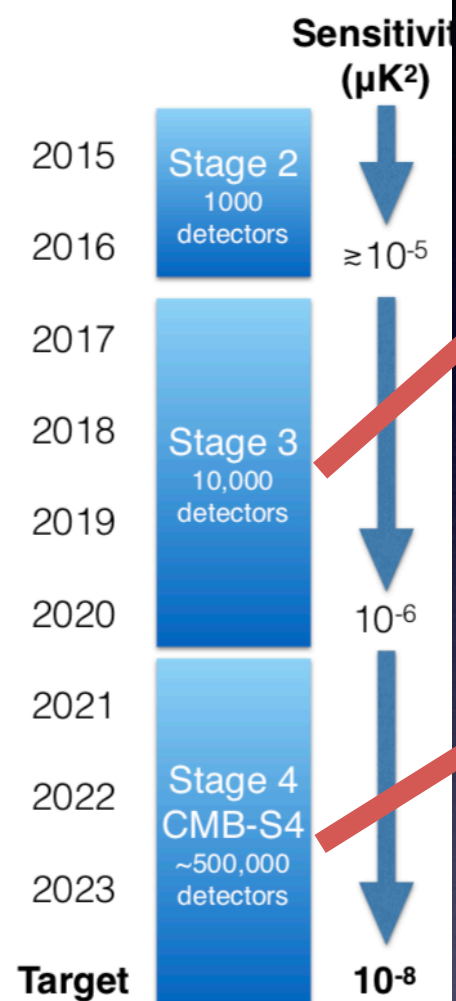
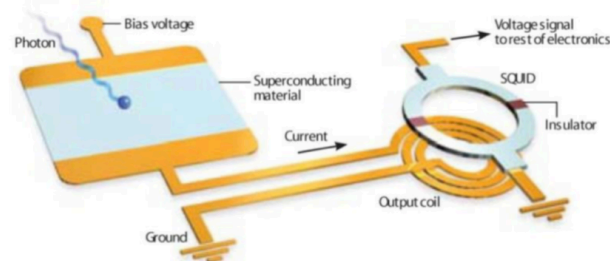
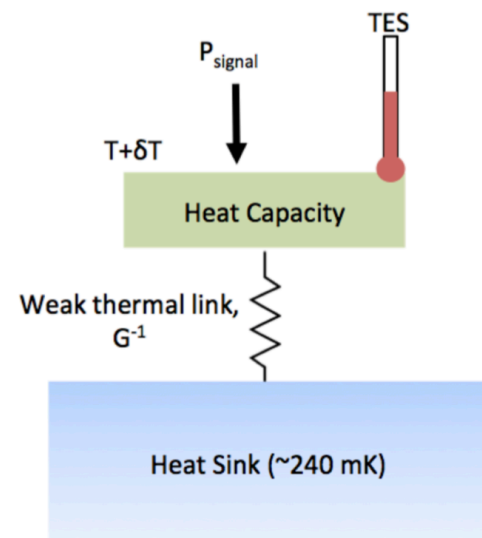
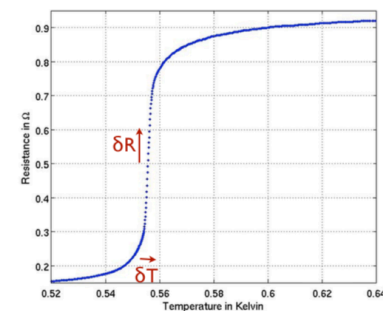
two long days with detectors for astronomy, dark matter and neutrinos... and photo-detectors in genera: TES, SNSPDs, MKIDs

J.Estrada (fnal)



# Transition Edge Sensors for CMB going BIG!

T.Cecil



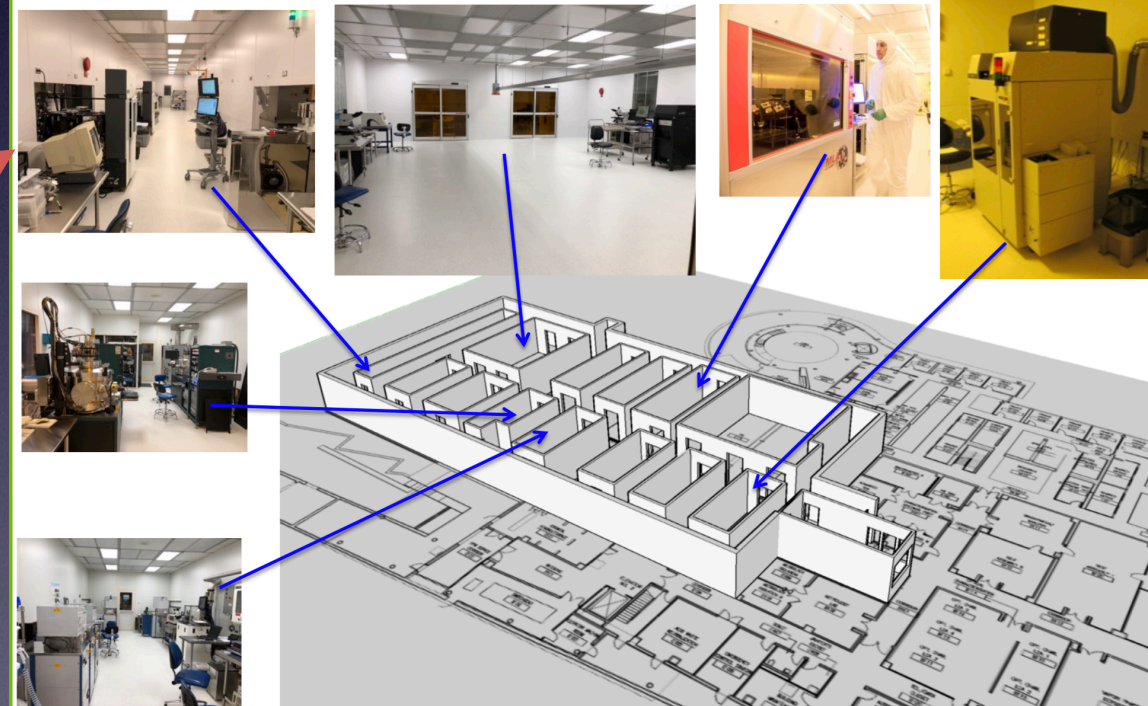
SPT-3G

16,260 detectors

Dual-Pol, multi-chroic pixel

Argonne

## MOVING TOWARDS CMB-S4 Fabrication Facilities



17,500 sq. ft. - Class 100-1000 - Bay-and-chase design

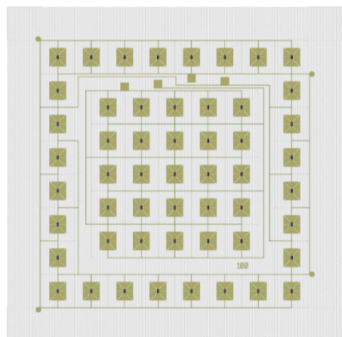


# TES in direct DM : going low!

N.Kurinsky

## R&D 'HVeV' Prototype Progress

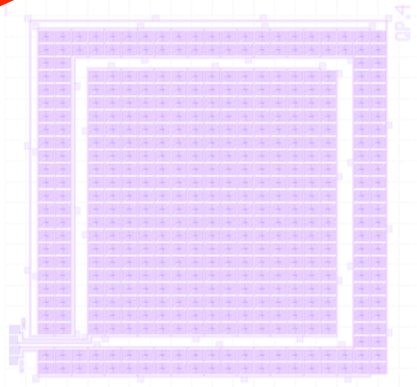
HVeV v1



Device: <https://arxiv.org/abs/1710.09335>  
DM: <https://arxiv.org/abs/1804.10697>

- 10 eV Resolution
  - 0.07 electron-hole pairs (140V)
- 3-5% energy efficiency
- 1 gram mass
- No position resolution
- ~1.2 Ohm Resistance
- ~55 mK Tc
- Amorphous Layer

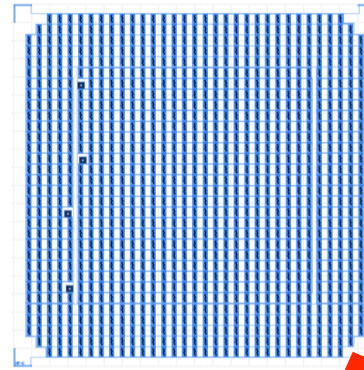
HVeV v1.5



Device: <https://arxiv.org/abs/1903.06517>

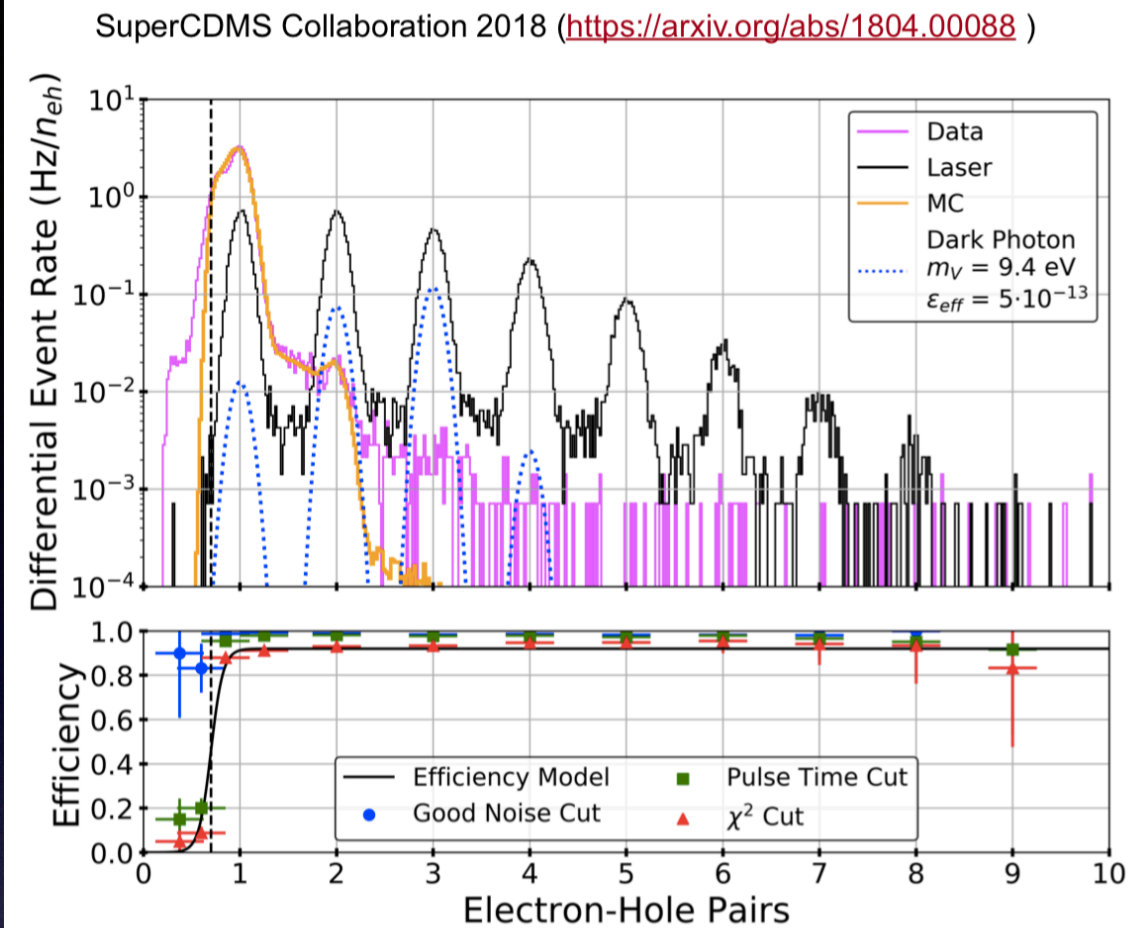
- 3 eV Resolution
  - 0.06 electron-hole pairs (50V)
- 25% energy efficiency
- 0.25 gram mass, contact-free design
- High position resolution
- ~400-900 mOhm Resistance
- 65 mK Tc
- No Amorphous Layer

HVeV v2 (NF-C)



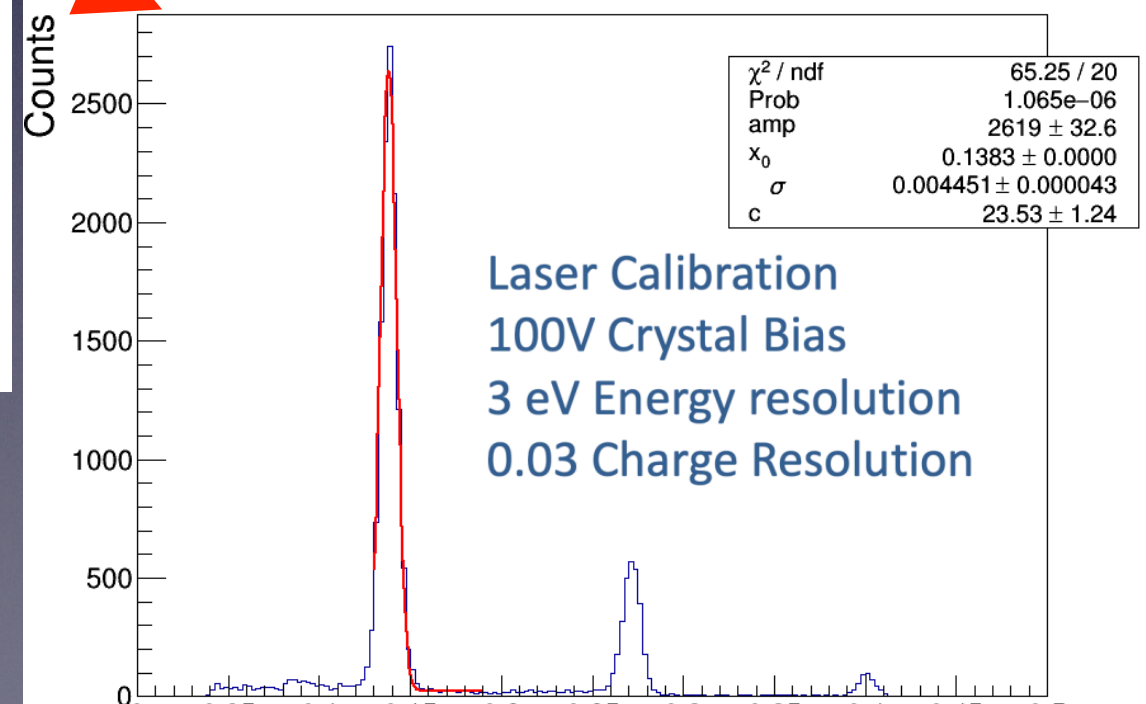
In Prep (TUNL, DM)

- 3 eV Resolution
  - <0.01 electron-hole pairs (100V)
- 25% energy efficiency
- 1 gram mass, backside contact
- High position resolution
- ~300 mOhm Resistance
- 65 mK Tc
- No Amorphous Layer



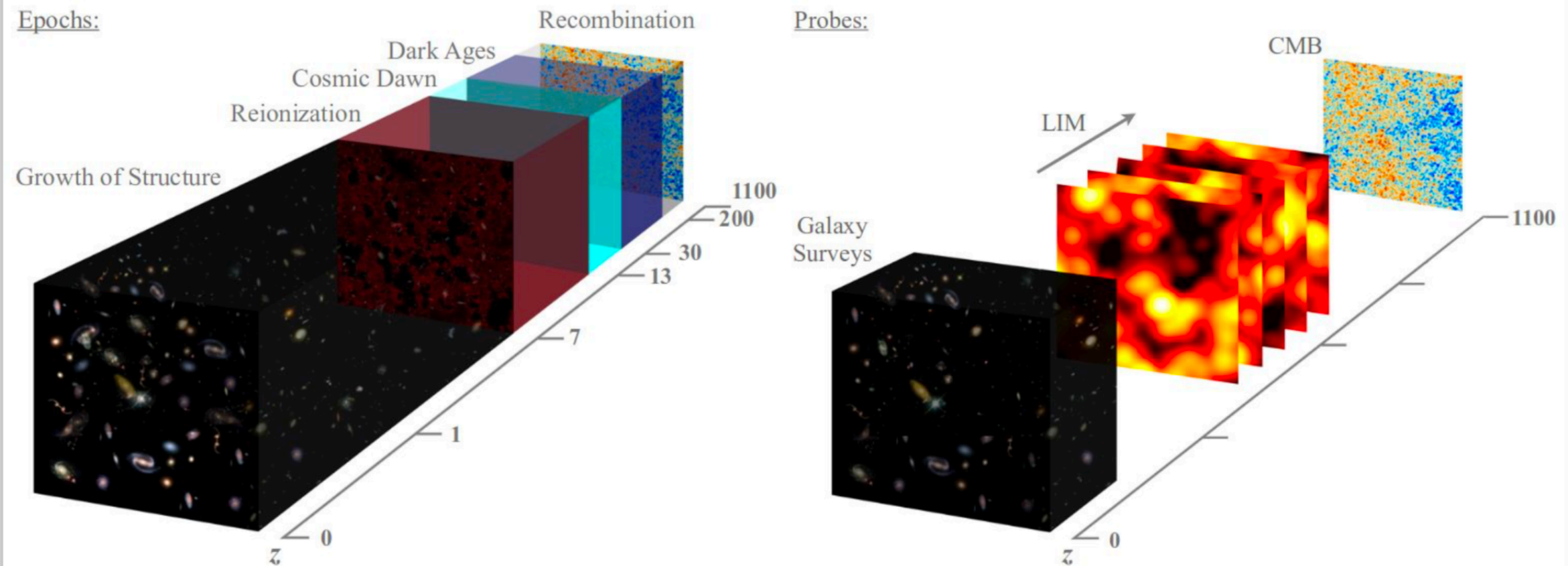
large R&D effort exploring several options,  
impressive progress

## HVeV v2: Combining Lessons





# K. Karkare : Line Intensity Mapping (with MKIDs)



Line intensity mapping white paper  
1903.04496

Galaxy surveys become extremely expensive at high redshift, as identifying individual faint objects above a threshold becomes more difficult.

## Cosmology at $z > 3$ : Expansion History

Using baryon acoustic oscillations, characterize the expansion history in the pre-acceleration era to the same precision as low- $z$  measurements

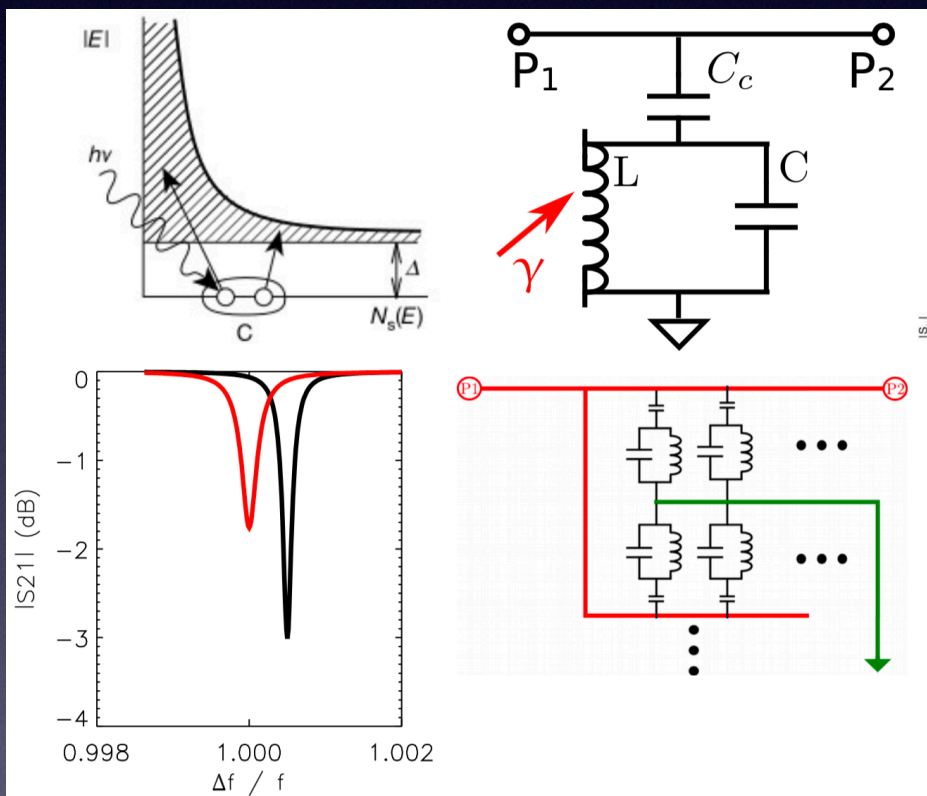


What kind of instrument do we need to measure cosmology / fundamental-physics with submm-IM?

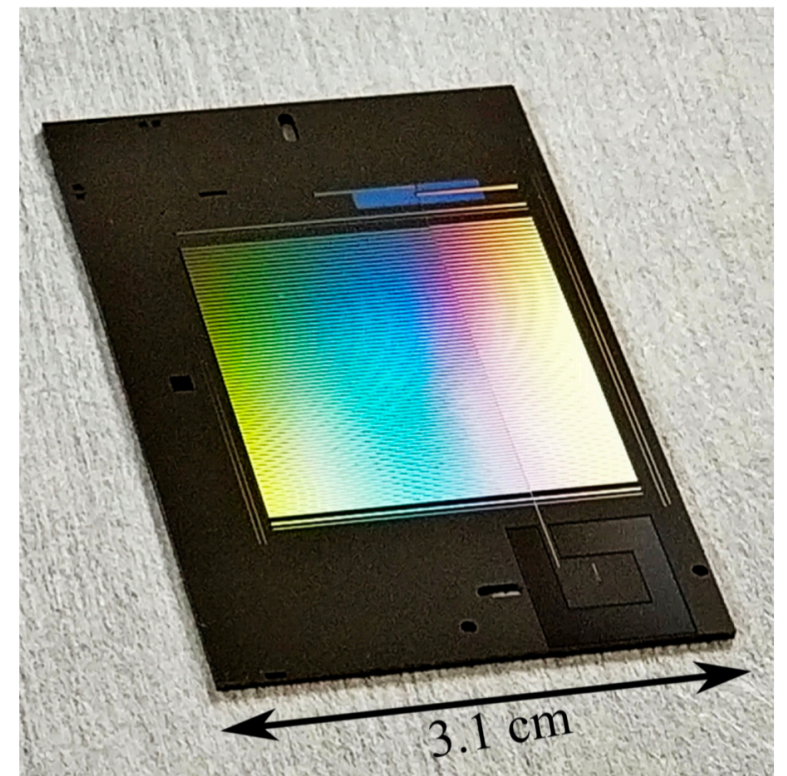
- Background-limited narrow band detectors with resolving power  $R \sim$  hundreds
- Hundreds of pixel-years on a 10m-class submm telescope.

MKIDs

deployment in January 2020



3 dual-pol pixels  
 $R=300$ , covering  
195-310 GHz



spectrograph on a chip!

E. Shirokoff



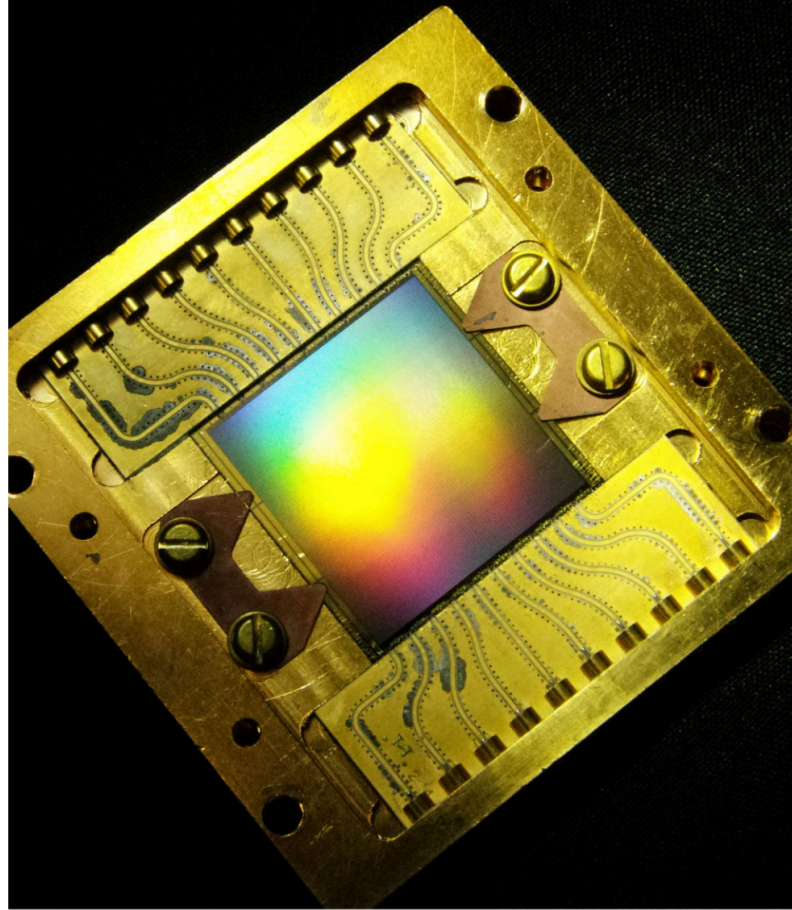
# MKIDs for optical and near IR

## B. Mazin

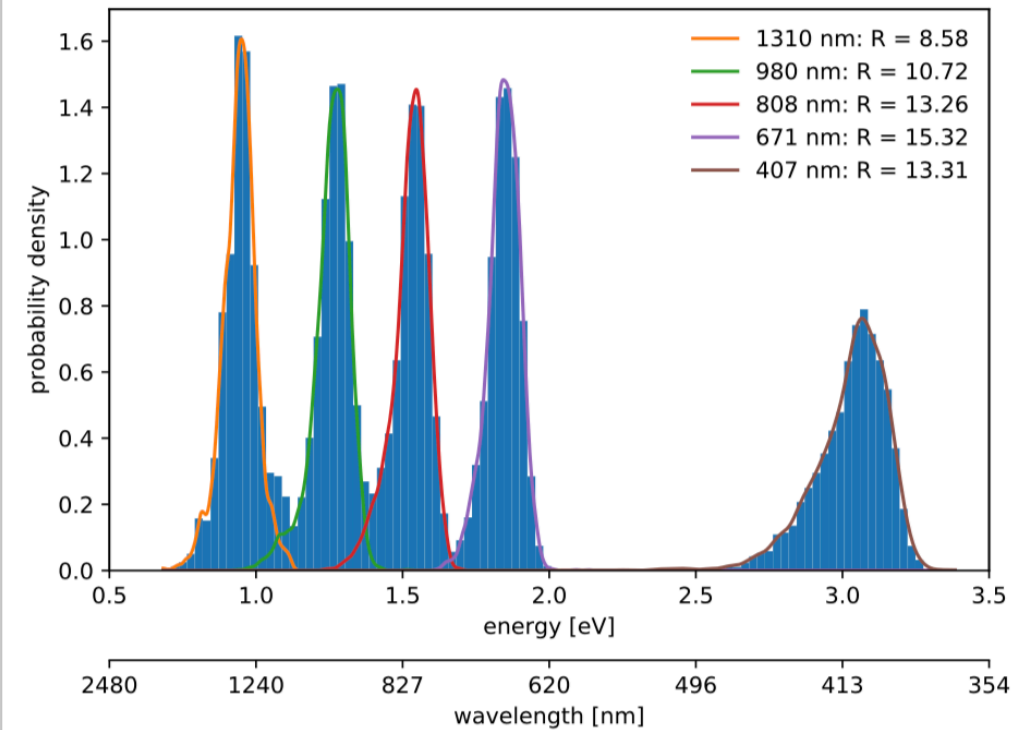
- 20 kpix PtSi MKID array for Subaru SCE<sub>x</sub>AO-MEC
- 140x146 pixels
- 150 micron pixel pitch
- 22x22 mm imaging area
- Pixel Yield ~85%
- $R \cong 10$  at 1 micron

Array fabricated at UCSB by P. Szypryt and G. Coiffard.

Szypryt et al. 2017, Optics Express



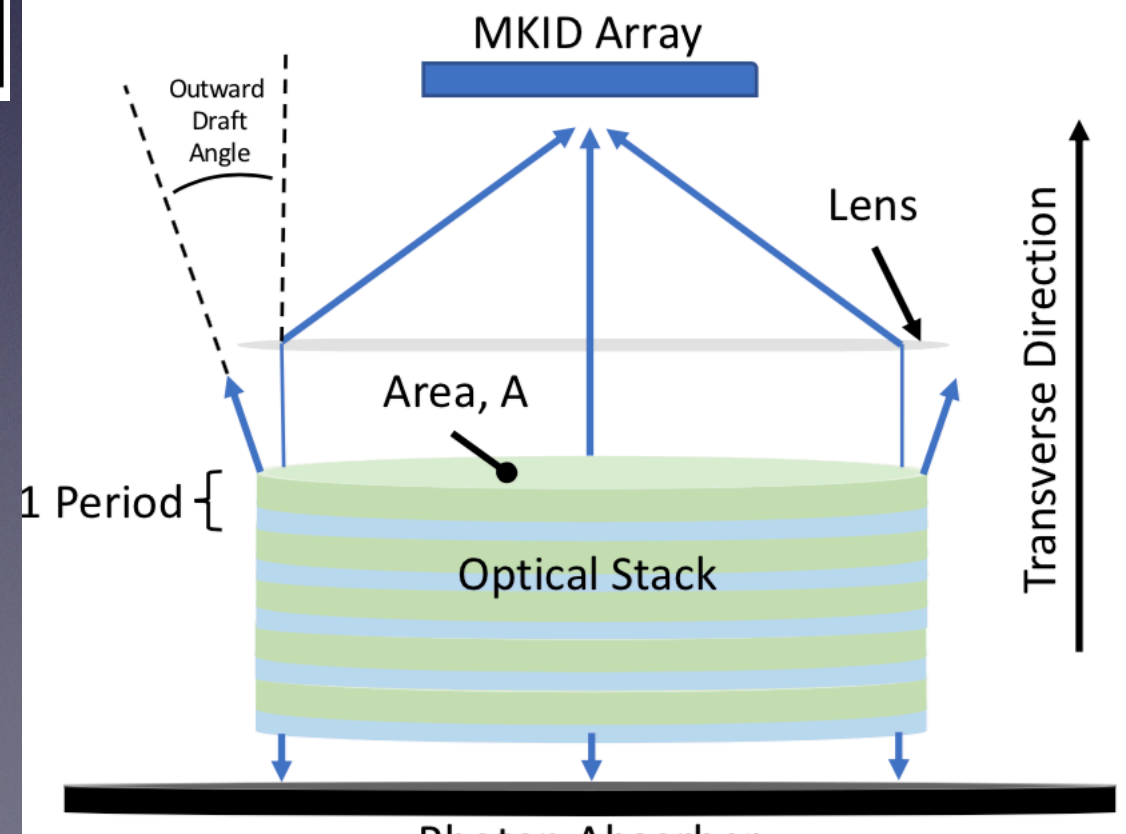
## improving resolution



Low  $Q_m$

20k channels of spectroscopy  
with  $R \sim 10 \dots$  at telescope

also for axion/dark photon  $\longrightarrow$



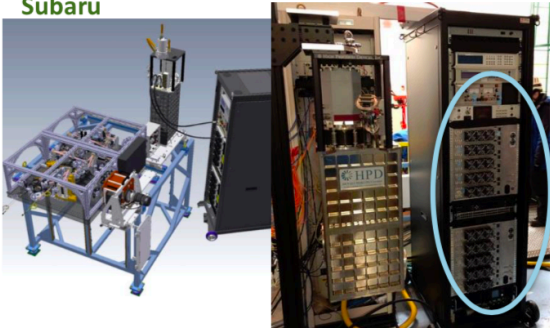


G. Cancelo  
electronics needed for these  
highly multiplexed arrays of  
MKIDs and TES

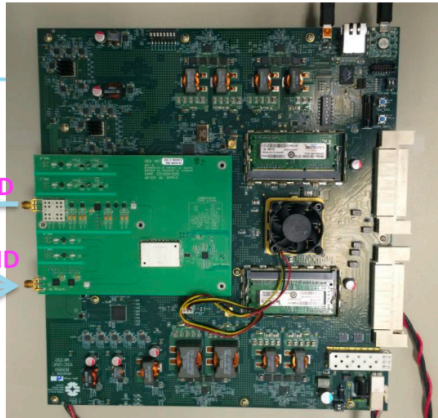
## FMESSI DAQ

Designed by  
Fermilab in  
2016.  
Production ~100  
Still in use

**MEC: 20K MKID**  
system operational  
at 8m telescope at  
Subaru



12 Gustavo Cancelo | Scalable 10 to 20 Kilo-pixel MKID Signal Generation and DAQ for Cosmology



- fMESSI main features:
- 1M photons/s per board.
- Noise: 12dB below HEMT.
- $<0.1\text{Hz}$   $1/f$  knee w/o compensation.
- 40 watts of power for the entire board running all ADCs and DACs at max sampling rate.
- Low cost: \$6/channel.

## DARKNESS 10Kpixels

On-sky, July 23 2016



fermilab

12/7/2019

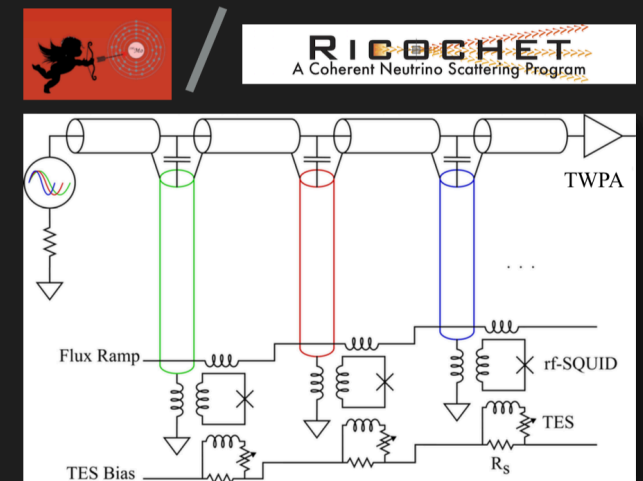
J. Ouellet  
quantum devices (TWPA) to improve the  
performance of these highly multiplexed  
systems

## Development of Next Generation Readouts

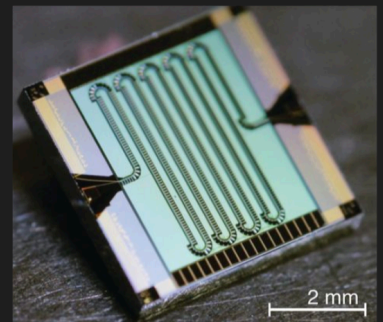
13

### rf Multiplexing Readout

- ▶ Multiplexing based on rf SQUIDs
  - ▶ Similar to HOLMES design
  - ▶ Multiplexing factors up to 100~1000s
  - ▶ Carrier frequencies in the ~GHz range
- ✗ Cannot use common TES bias line
  - ▶ Need one bias line per TES
- ✗ Signals need to travel the ~meter distance between the TES and SQUID un-mixed
  - ▶ Low background wiring only needs to have ~100 kHz bandwidth
- ✗ Magnetic flux & microphonics noise?
  - ▶ TWPA final amplification stage
    - ▶ Can achieve higher gain with SQL limited noise floor
  - ▶ Being developed at MIT as a collaboration between CUPID+Ricochet groups
    - ▶ Working with Lincoln Labs to design cold electronics
    - ▶ Testing NIST & SLAC designed warm readout electronics
  - ▶ No results yet, electronics are still being built



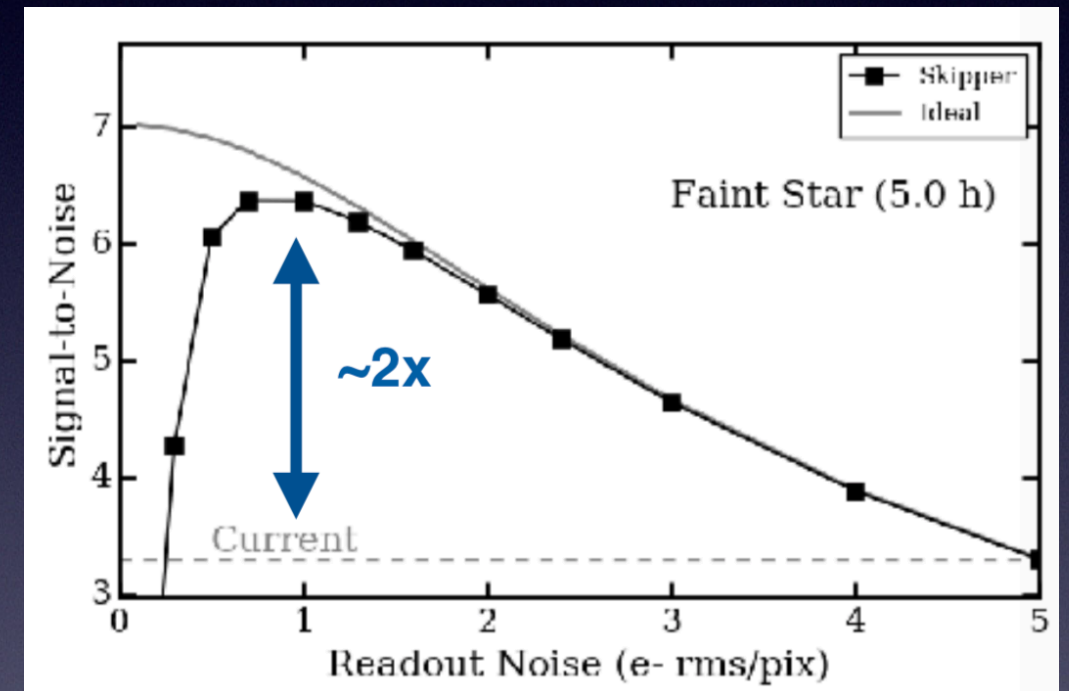
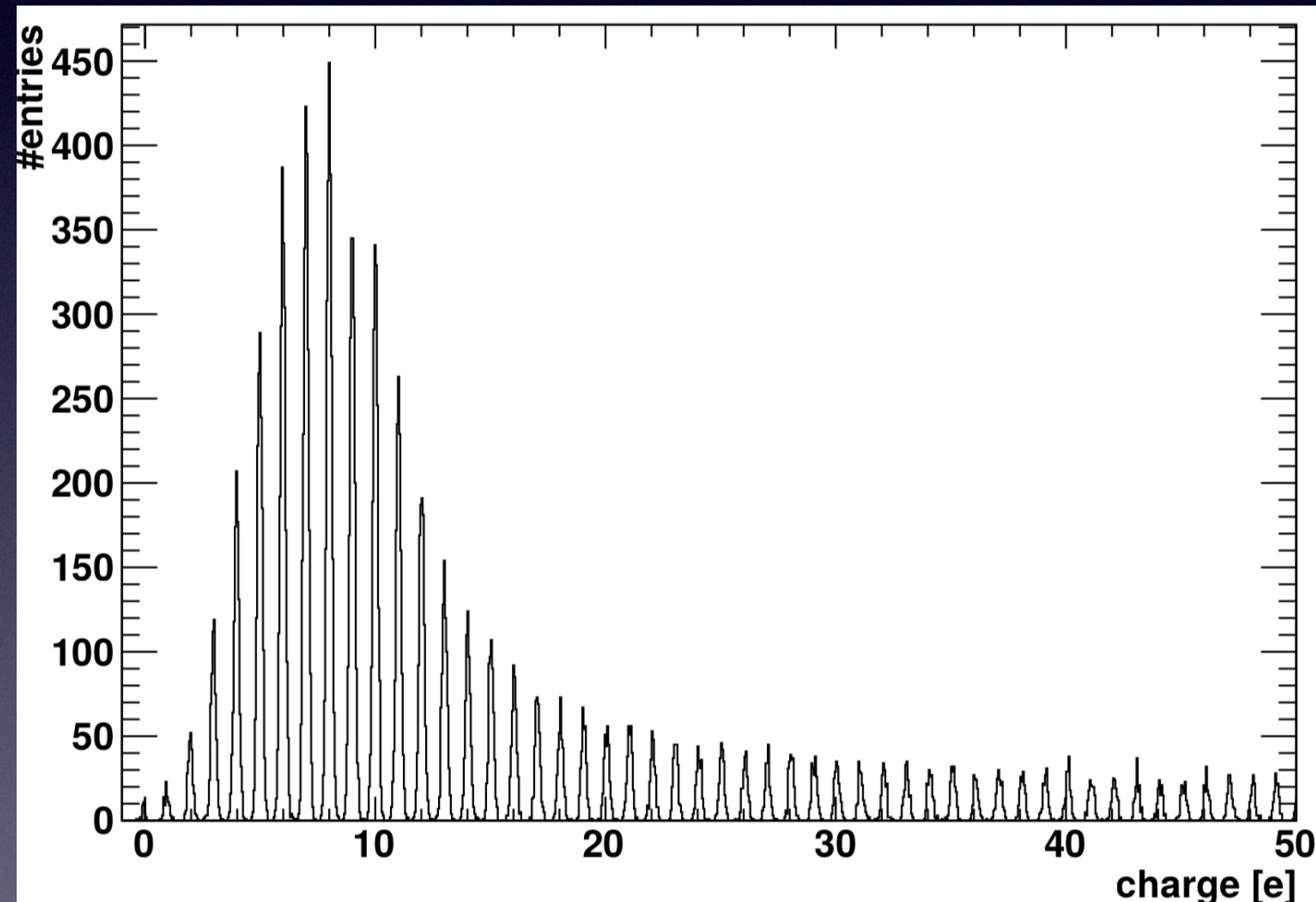
Appl. Phys. Lett 111 (24) 2017





## Summary: Skipper CCDs for Cosmology

- The Skipper CCD pitch...
  - Skipper CCDs allow you to **control readout noise** directly on a **pixel-by-pixel** basis
  - Configurable **per object** and **per exposure**
  - **Every CCD used for astronomical observations should be a Skipper CCD**

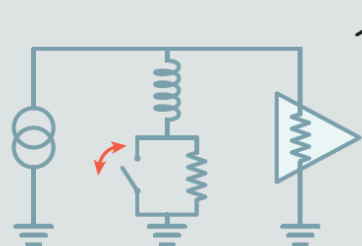


non destructive readout with skipper-CCD could  
enhanced cosmological observations



# M. Shaw started us on SNSPDs

Parameter	SOA 2019	SOA 2016	Group
Efficiency	98% @ 1550 nm	93% @ 1550	NIST
Dark Counts	< 1e-5 cps	< 0.1 cps	MIT
Energy	0.125 eV	0.250 eV	NIST/JPL/MIT
Timing Jitter	2.7 ps	16 ps	MIT/JPL/NIST
Active Area	0.92 mm <sup>2</sup>	0.058 mm <sup>2</sup>	NIST
Max Count Rate	1.2 Gcps	0.3 Gcps	JPL
Pixel Count	1024 (32x32)	64 (8x8)	NIST/JPL
Photon Number	1 from 2 or more	None	MIT
Operating Temp	4.3 K @ 1550	2.5 K @	Single Quantum



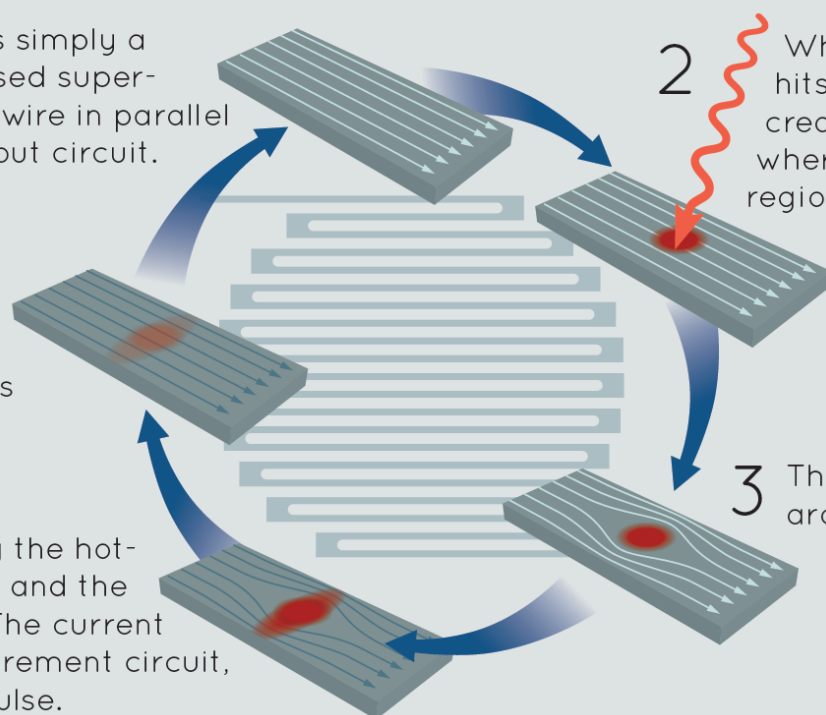
1 An SNSPD is simply a current-biased superconducting wire in parallel with a readout circuit.

2 When a photon hits the wire, it creates a hotspot, where a small region of the wire goes normal.

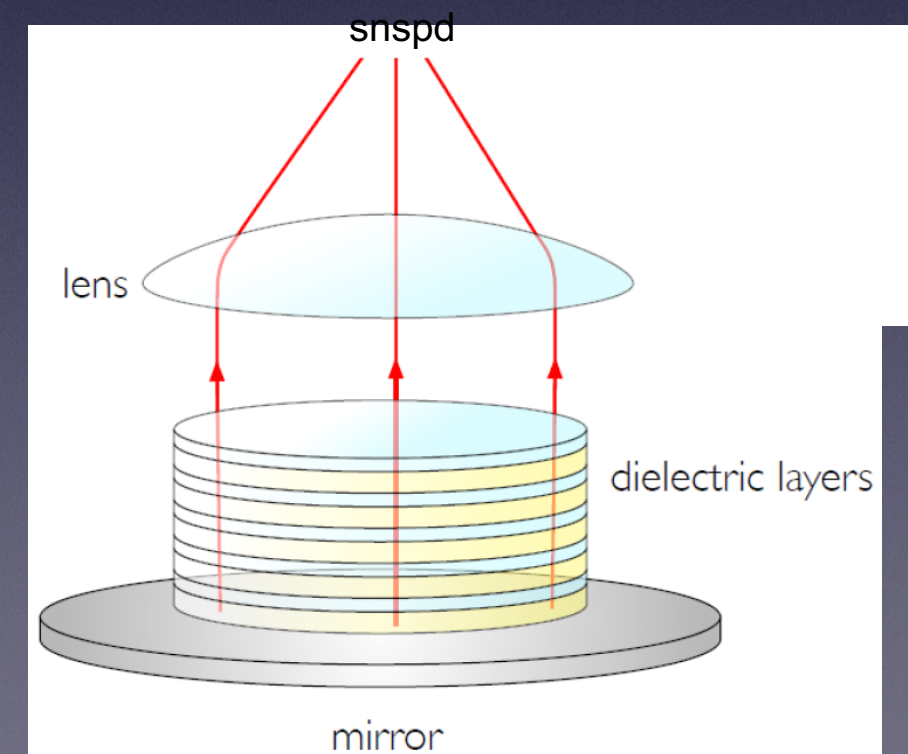
3 The current diverts around the hotspot.

5 With the current through the nanowire reduced, the hotspot cools off, returning the wire to its original state.

4 The current density surrounding the hotspot exceeds the critical current, and the entire wire width goes normal. The current is redirected through the measurement circuit, creating a detectable voltage pulse.



after [1] Gol'tsman et al. (2001)





perhaps these guys are having too much fun...

## NASA Deep Space Optical Communications (DSOC) Technical Demonstration Mission

Longest range demonstration of free-space laser communication by ~1000x

Demonstrating optical communications from deep space (0.1 – 2.7 AU) at rates up to 267 Mbps to validate:

- Link acquisition laser pointing control
- High photon efficiency signaling

Pre-Decisional Information -  
For Planning and Discussion  
Purposes Only

Psyche  
spacecraft

1550 nm  
downlink

Optical  
Platform  
Assembly

22 cm mirror  
4 W laser power

1064 nm  
uplink

### Ground Laser Transmitter

Table Mtn, CA  
1 m OCTL telescope  
5 kW laser power

### Ground Laser Receiver

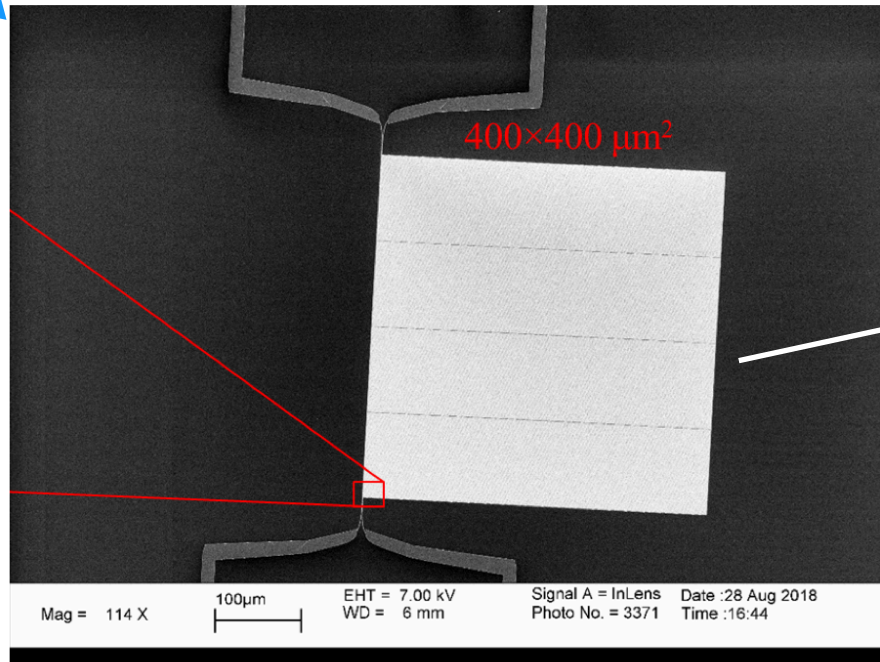
Palomar Mtn, CA  
5 m Hale telescope



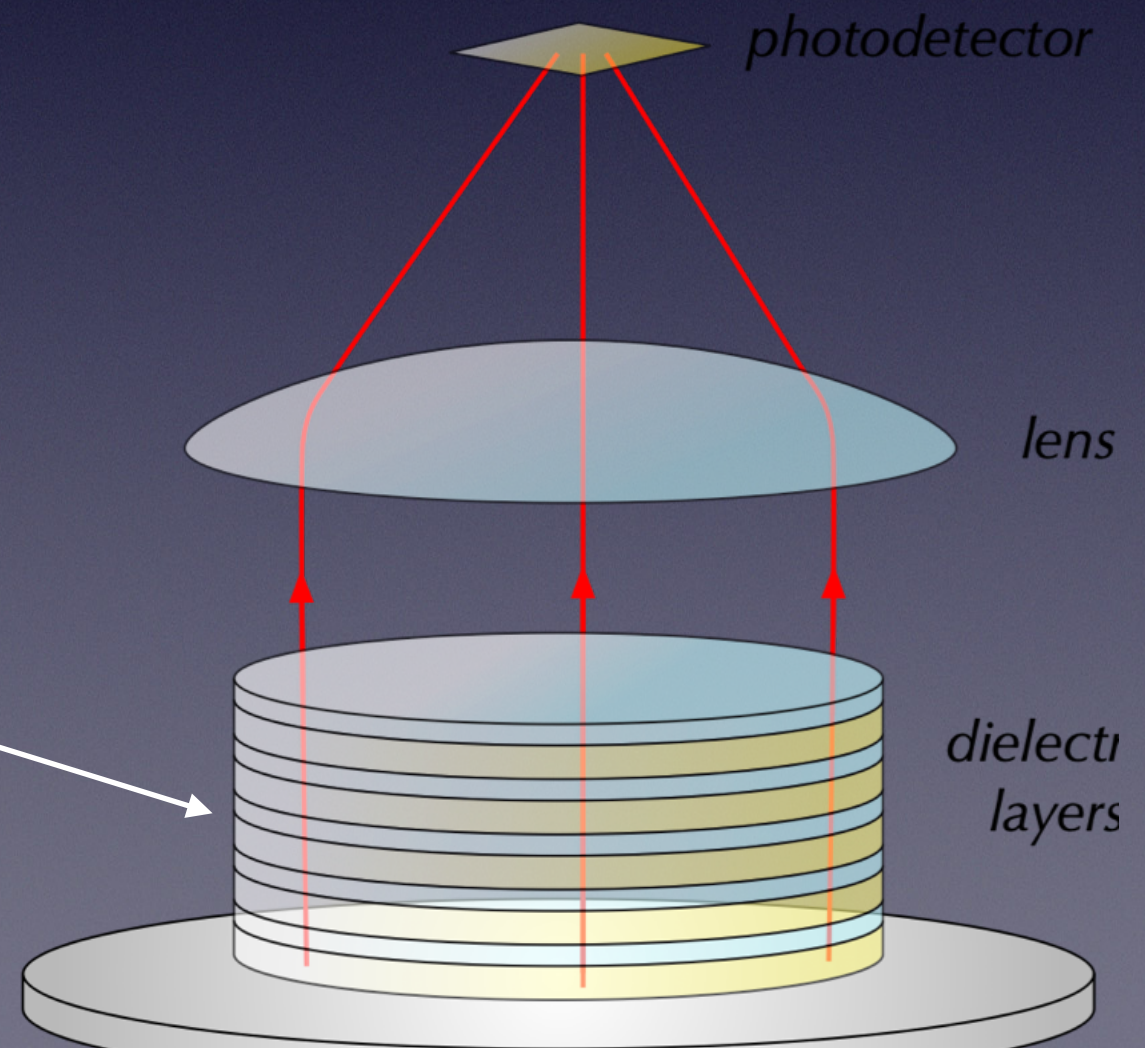
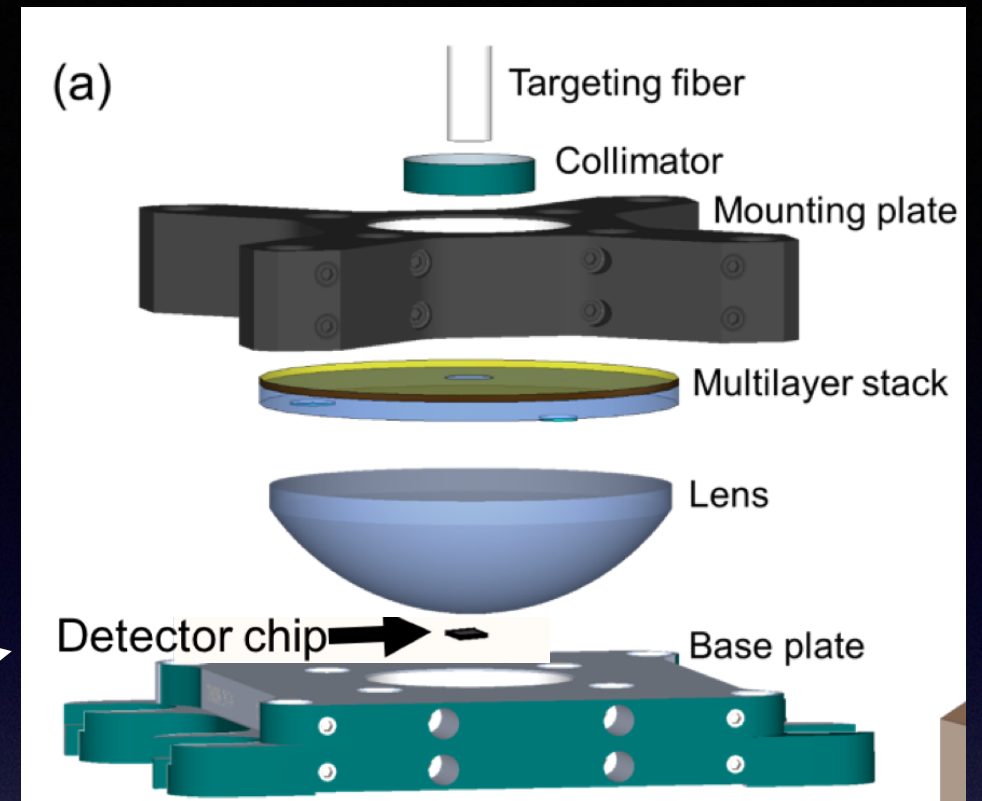
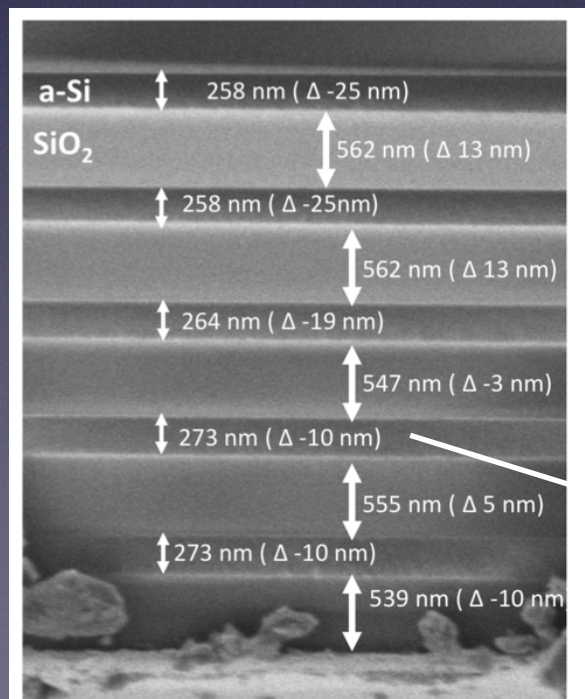
# J.Chiles SNSPD+haloscope

## Detector for optical haloscope

- See Ilya Charaev's talk at 9:35 AM
- $400 \times 400 \mu\text{m}^2$  detectors with  $10^{-5}$  Hz dark count rate



large detectors  
low dark  
current!



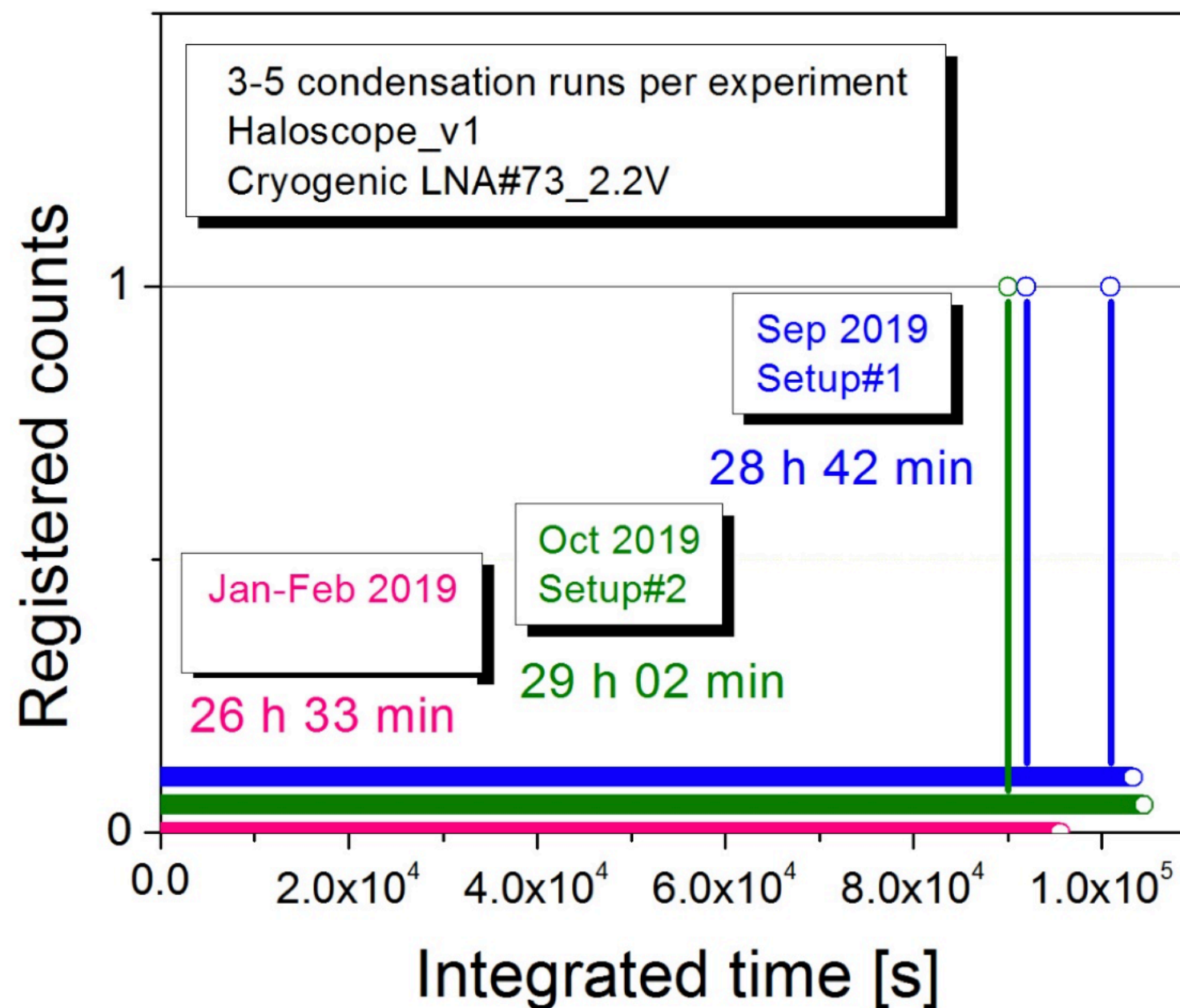


# I. Charaev

the SNPD detectors for haloscope  
(impressive dark count rate!)



## Dark-count experiment with optical haloscope

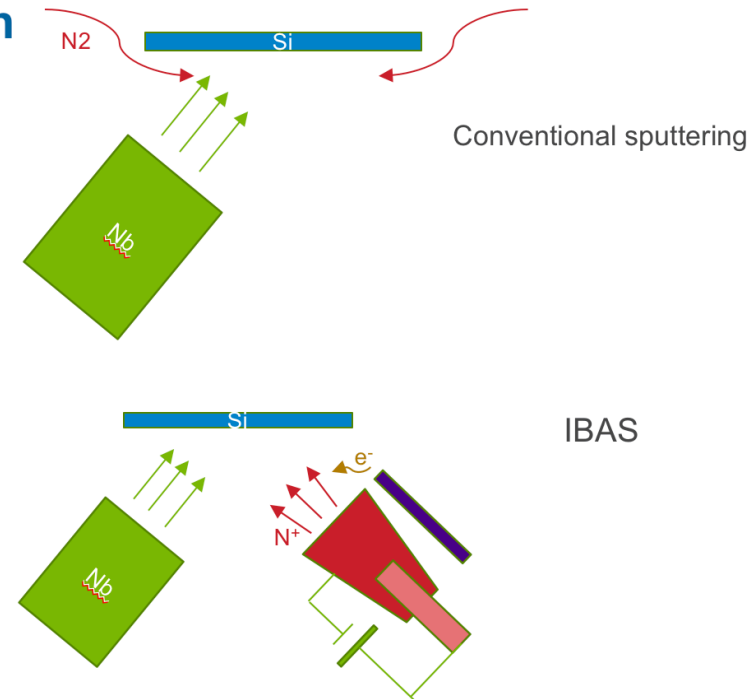




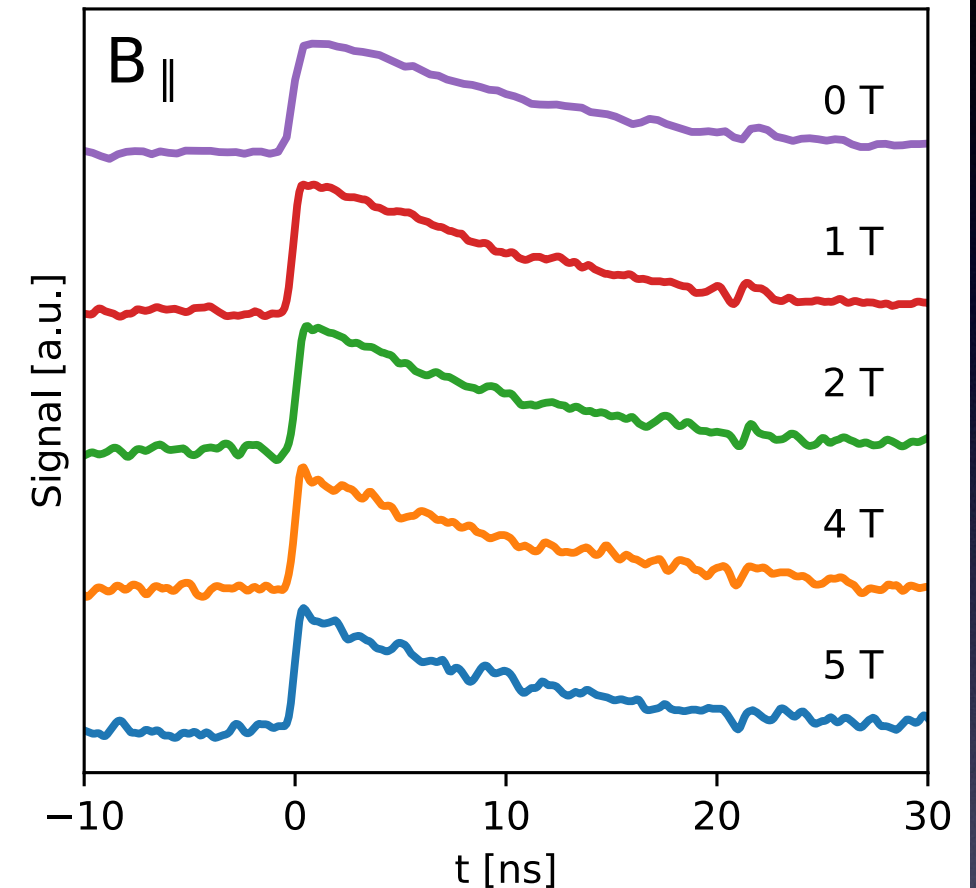
## ION BEAM ASSISTED SPUTTERING

### Technology developed as a solution

- Sputtering technique developed during NbN nanowire R&D
- Replaces passive N<sub>2</sub> gas with N plasma
- Increased in particle energy eliminates need for high temperatures
- Different momentum distributions allow for growth on non-epitaxial substrates
- Invention report ANL-IN-17-164
- Polakovic, *et. al.*, APL Mat (2018)



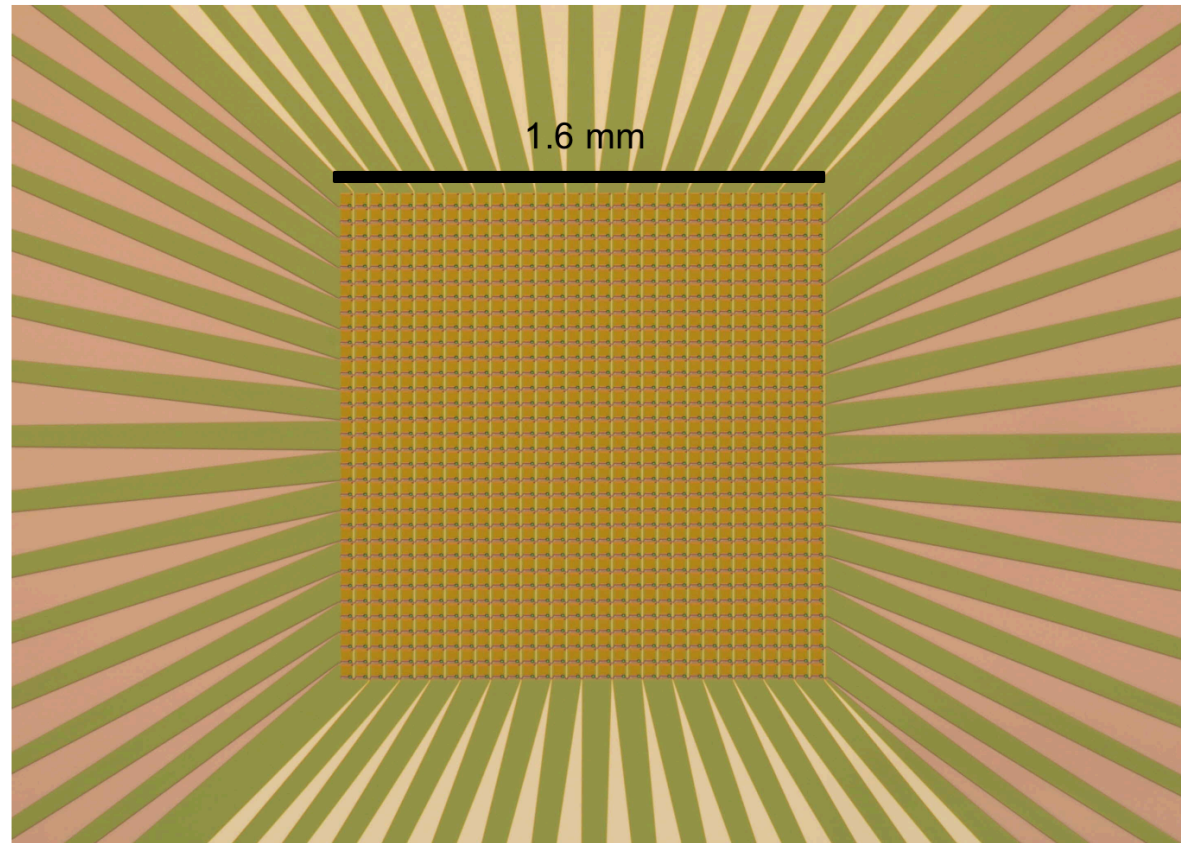
10



Developed a new technique for the fabrication of films that can operate in very high field.

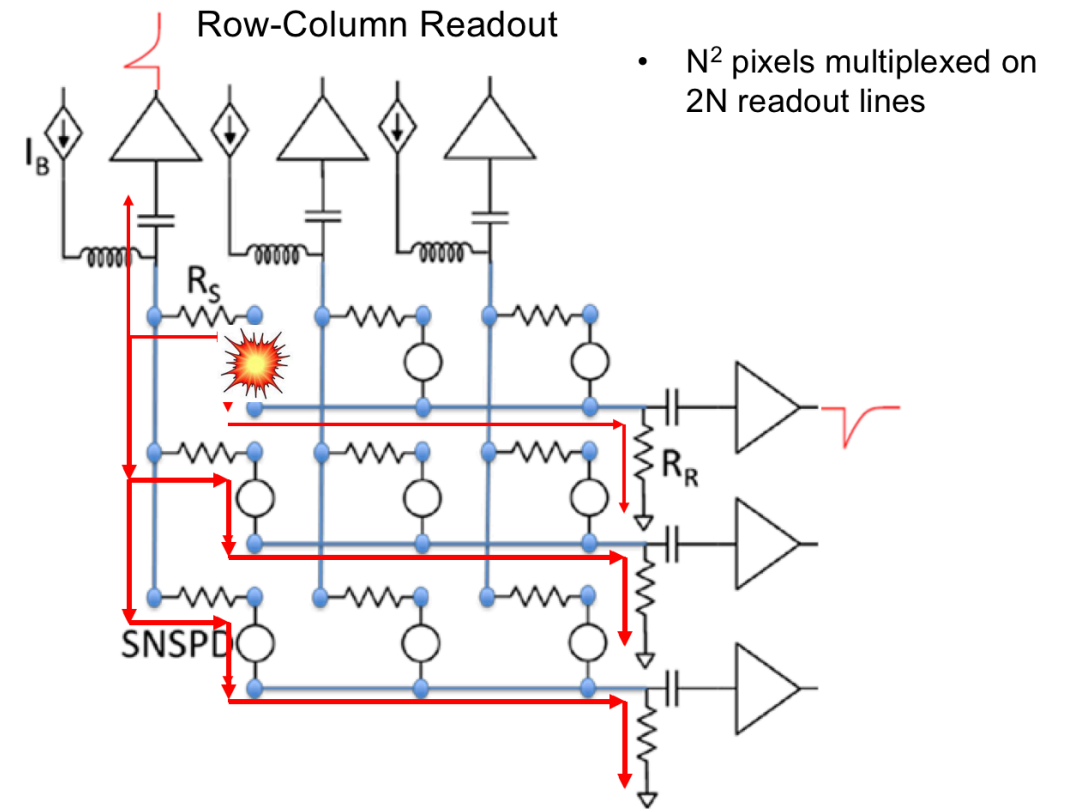


## Kilopixel (32 x 32) Array



NIST

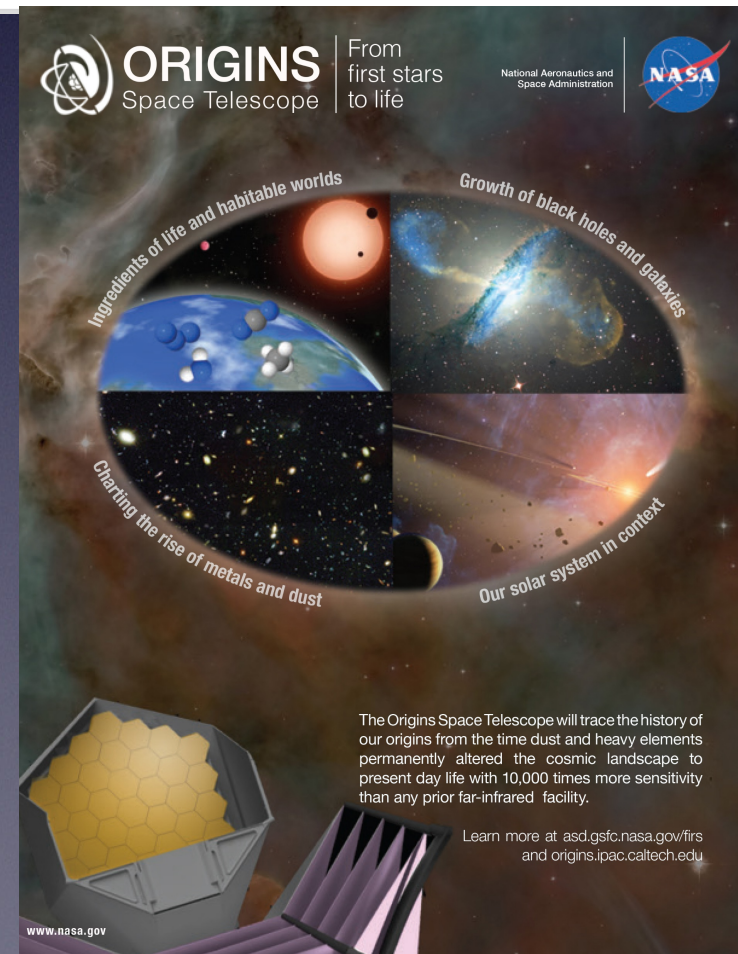
## Row-Column Readout for SNSPD Arrays



NIST

### Developments in SNSPDs at NIST/JPL

- Kilopixel scale arrays, megapixel arrays have been fabricated and will be tested in coming weeks
- Readout technology needs further development to make these large-format arrays practical (cryo-CMOS, single-flux-quantum or other types of superconducting logic for low-temperature signal processing)
- Optimization for the mid-infrared (up to 10  $\mu\text{m}$ )
- Optimization in the UV for integration with ion traps
- Potential for high energy physics experiments requiring high efficiency and timing resolution, but can tolerate small active areas



astronomy  
in the plans



# W. Chung speeding up axion search

- **Maximize Signal ( $B^2VQ$ )**
  - 25T 10cm bore HTS magnet by BNL (?)  $\sim \times 100$  faster scan
  - 12T 32cm bore LTS magnet by Oxford (2020)  $> \times 100$  faster scan
    - Higher frequencies without shrinking volume
      - Pizza Cavity (S. Youn)
      - Dielectric rings (TM<sub>030</sub> and TM<sub>050</sub>) (O. Kwon)
  - Improving Q-factor of cavity – YBCO cavity (D. Ahn)  $> \times 20$  faster scan
- **Minimize Noise ( $T_{\text{system}} = T_{\text{physical}} + T_{\text{amp}}$ )**  $\sim \times 100$  faster scan
  - Quantum Amplifier - SQUID and/or JPA
  - Optimize cryo-RF receiver chain

SC cavity could allow  
high B, in mixed state

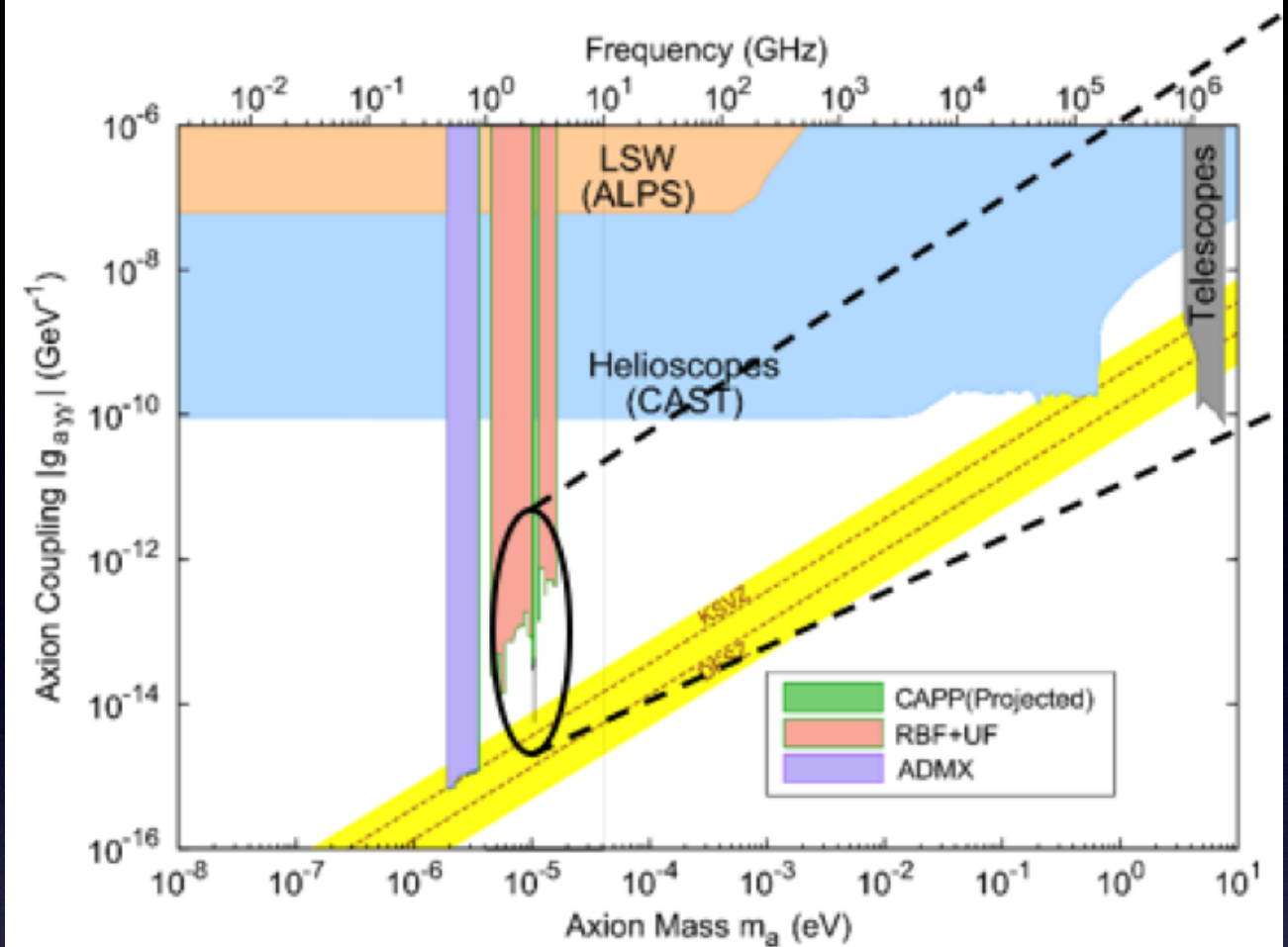
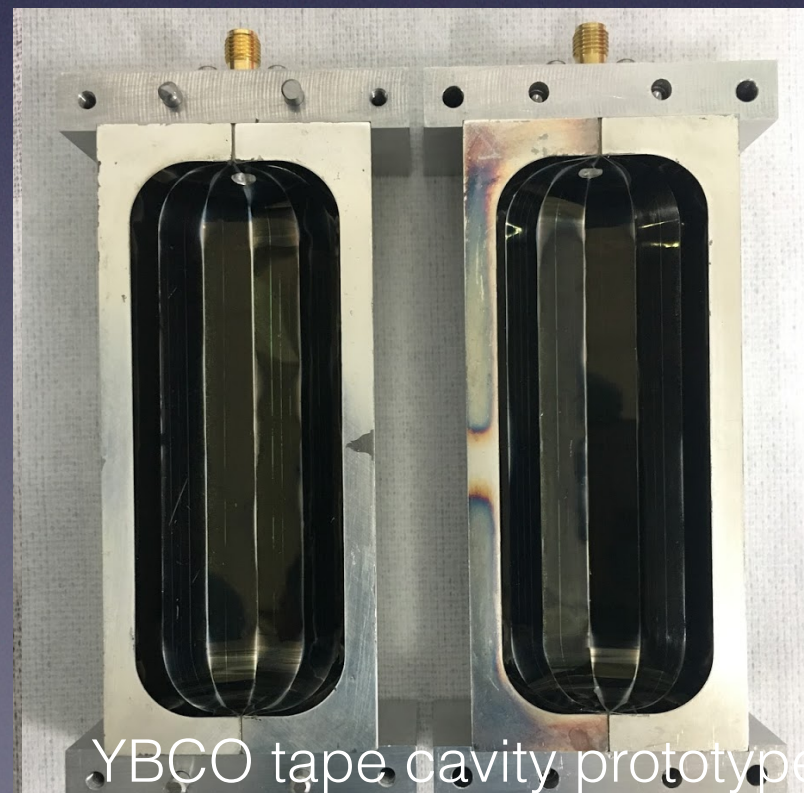
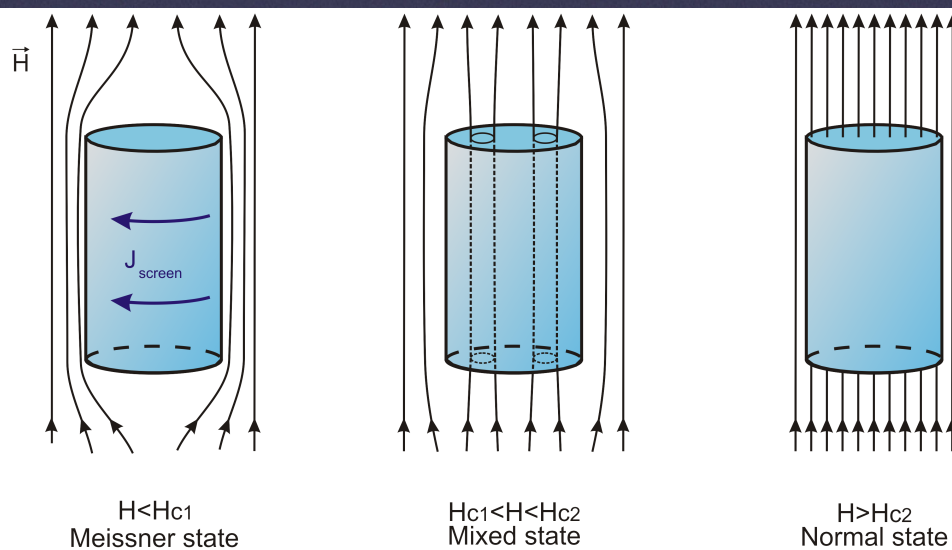
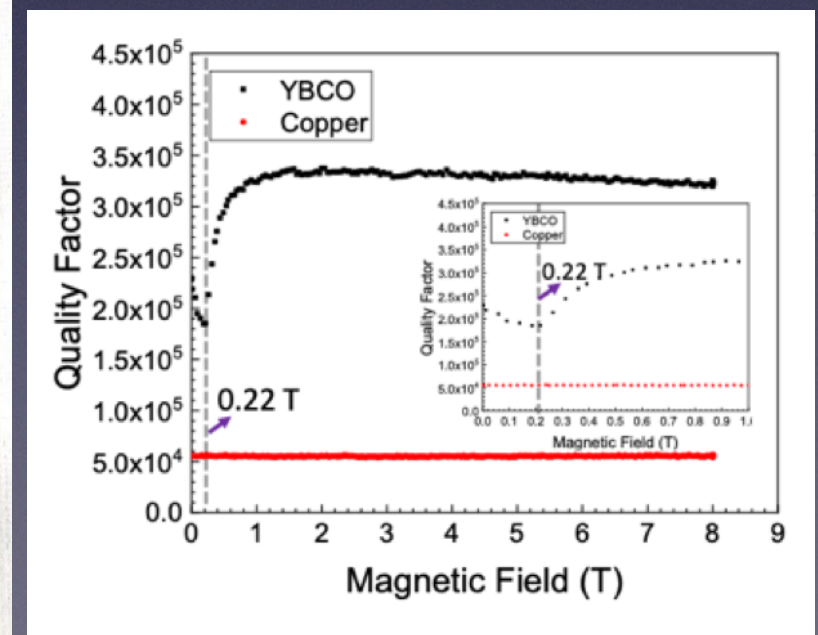


Figure 9: Exclusion plot showing CAPP-P... along with other haloscope experim

$$\frac{df}{dt} \sim B^4 V^2 C^2 Q_L T_{\text{syst}}^{-2}$$

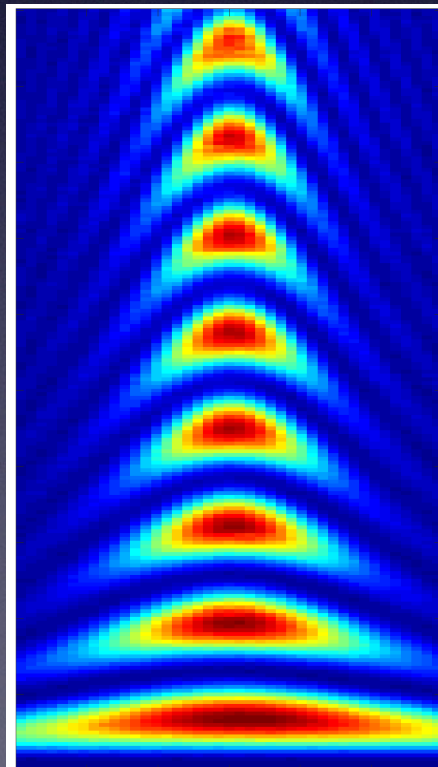
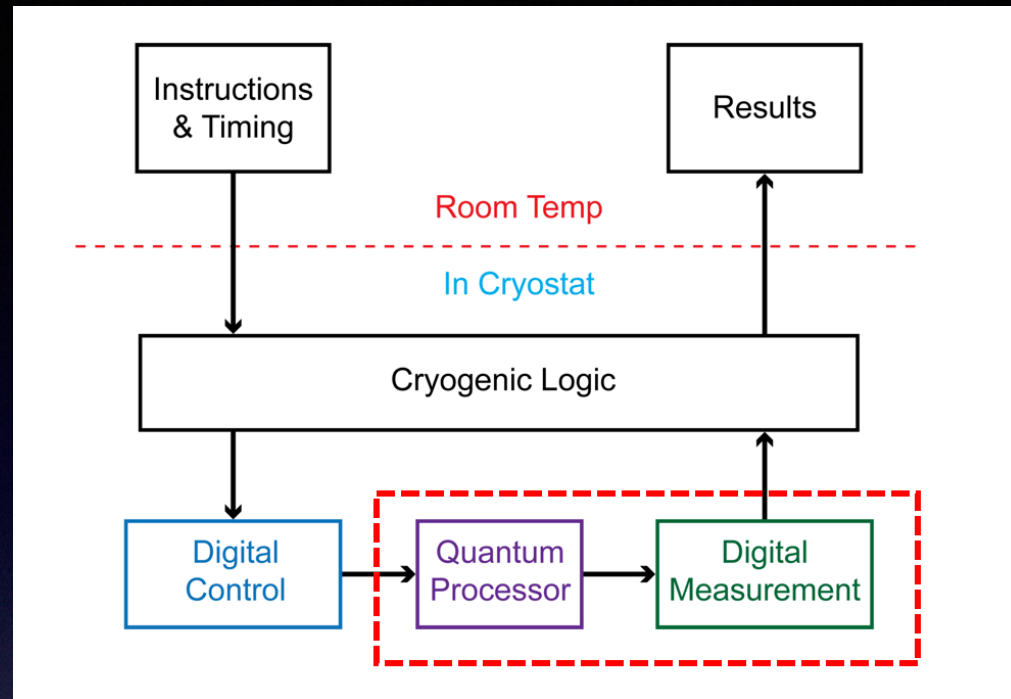


YBCO tape cavity prototype



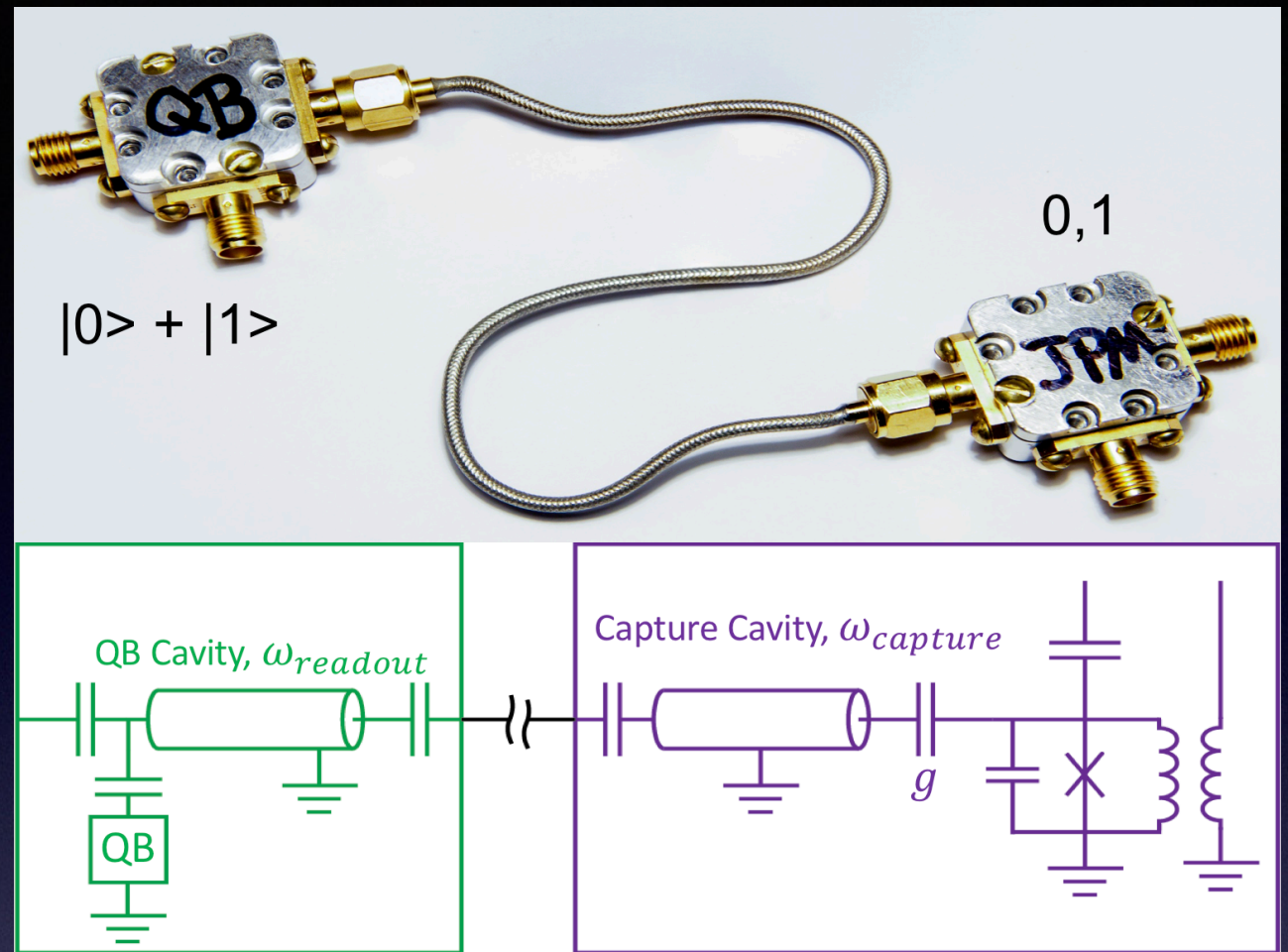
tested



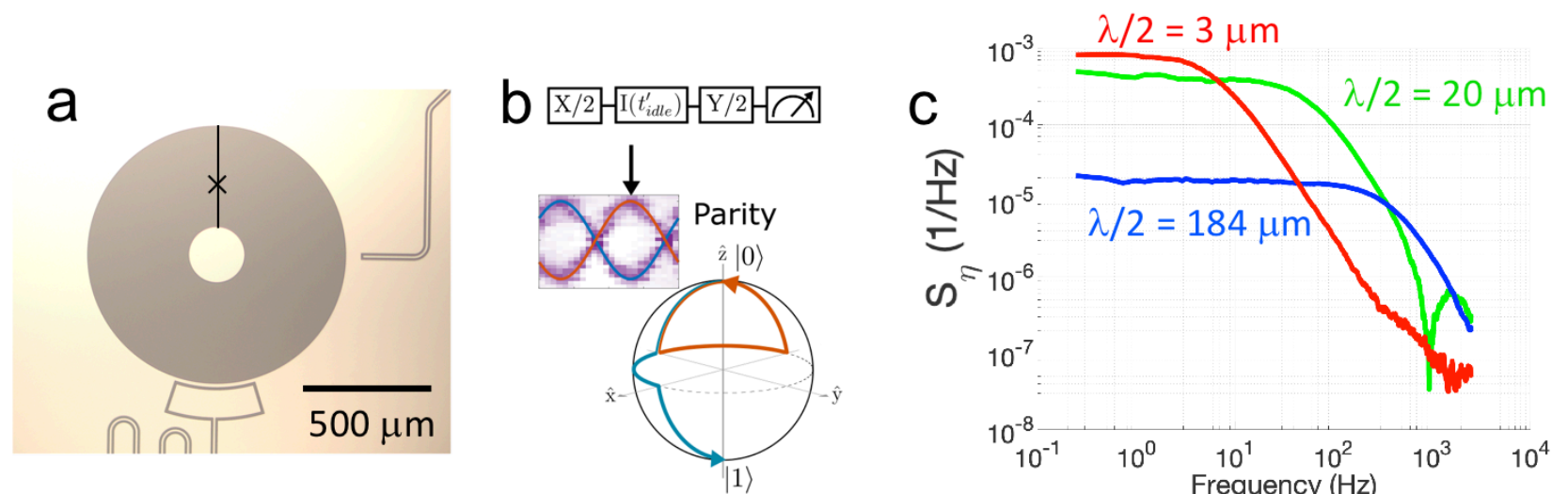


High-fidelity counter-based Qubit measurement

*Science* 361, 1239 (2018)



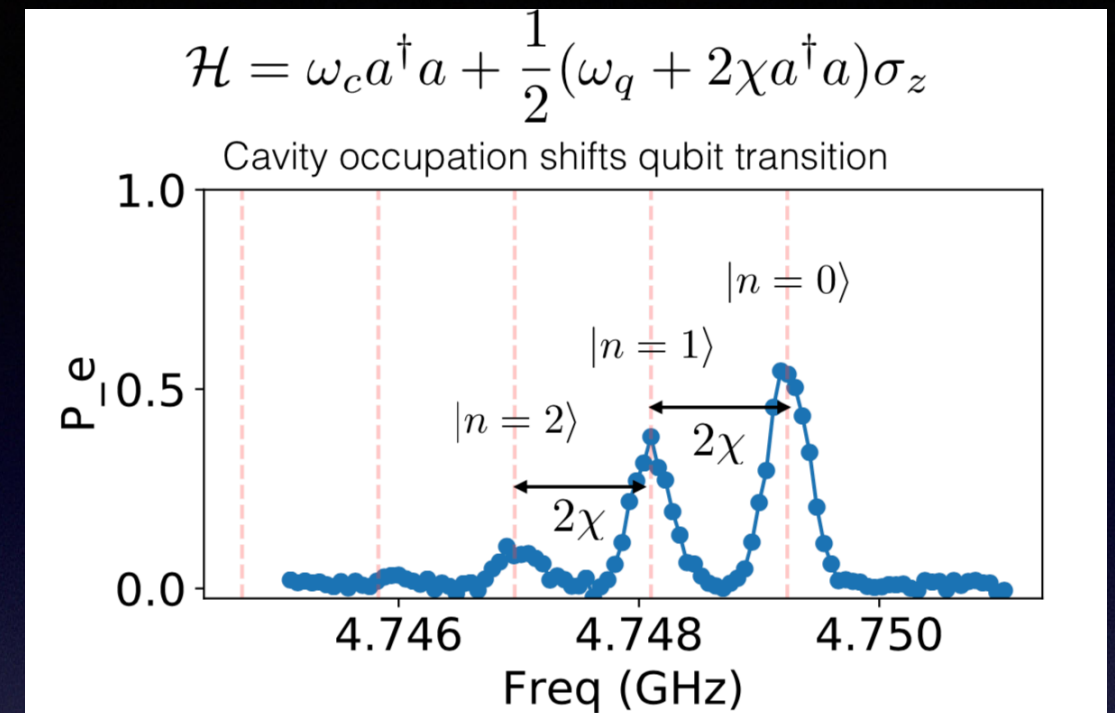
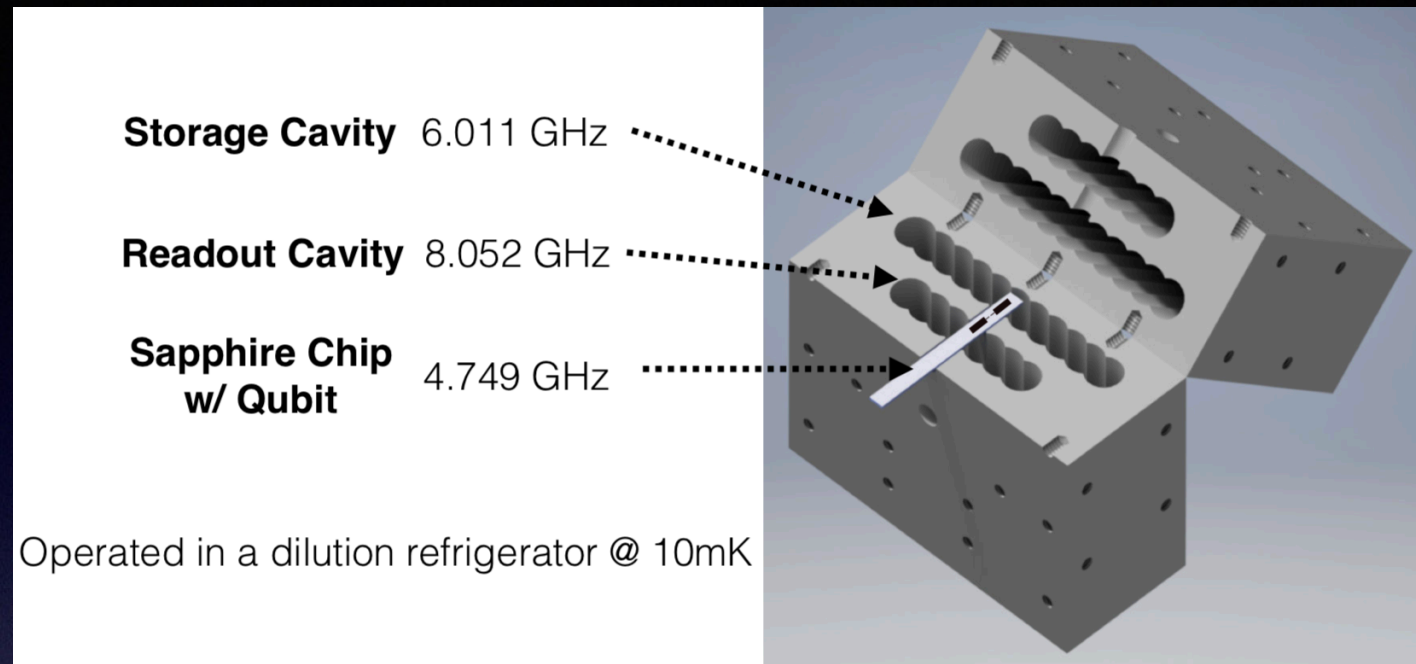
## QP Parity-based Detection of Transduced Photons



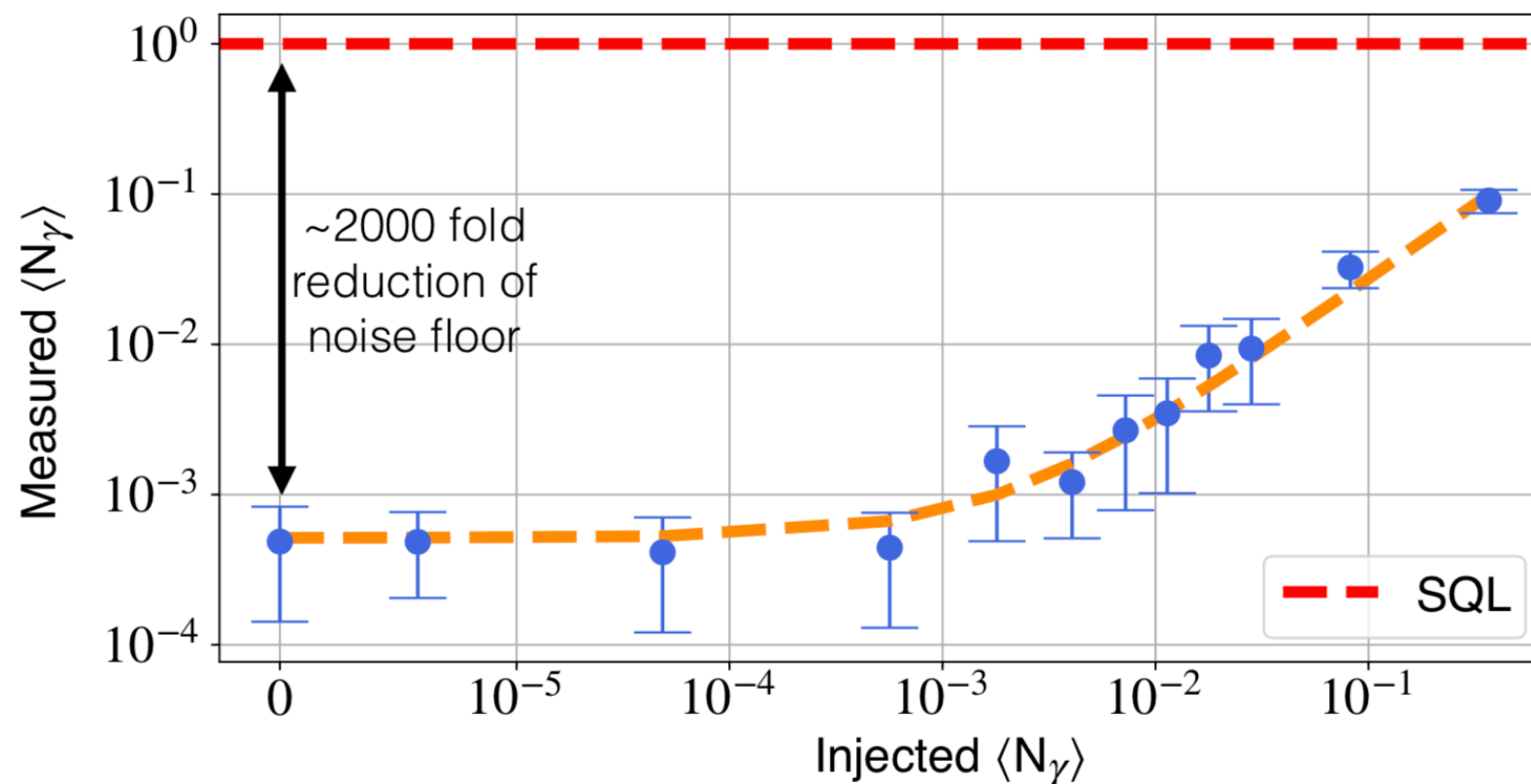
- Possible next-gen. axion detector (collaboration with A. Chou, FNAL)
- Accessible frequency range: 10 GHz to 10 THz



# A. Dixit: qubits for single photon detection in Axion search.



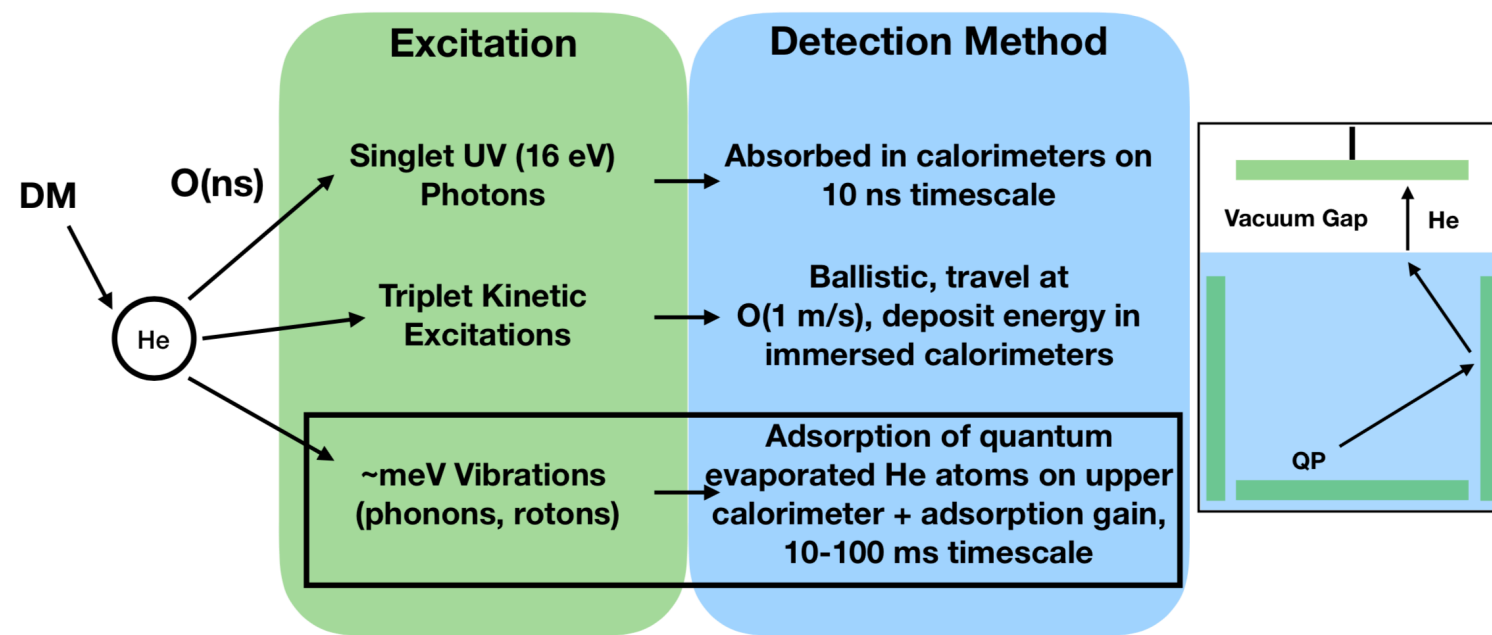
Detected Photon Occupation vs Injected Photon Occupation





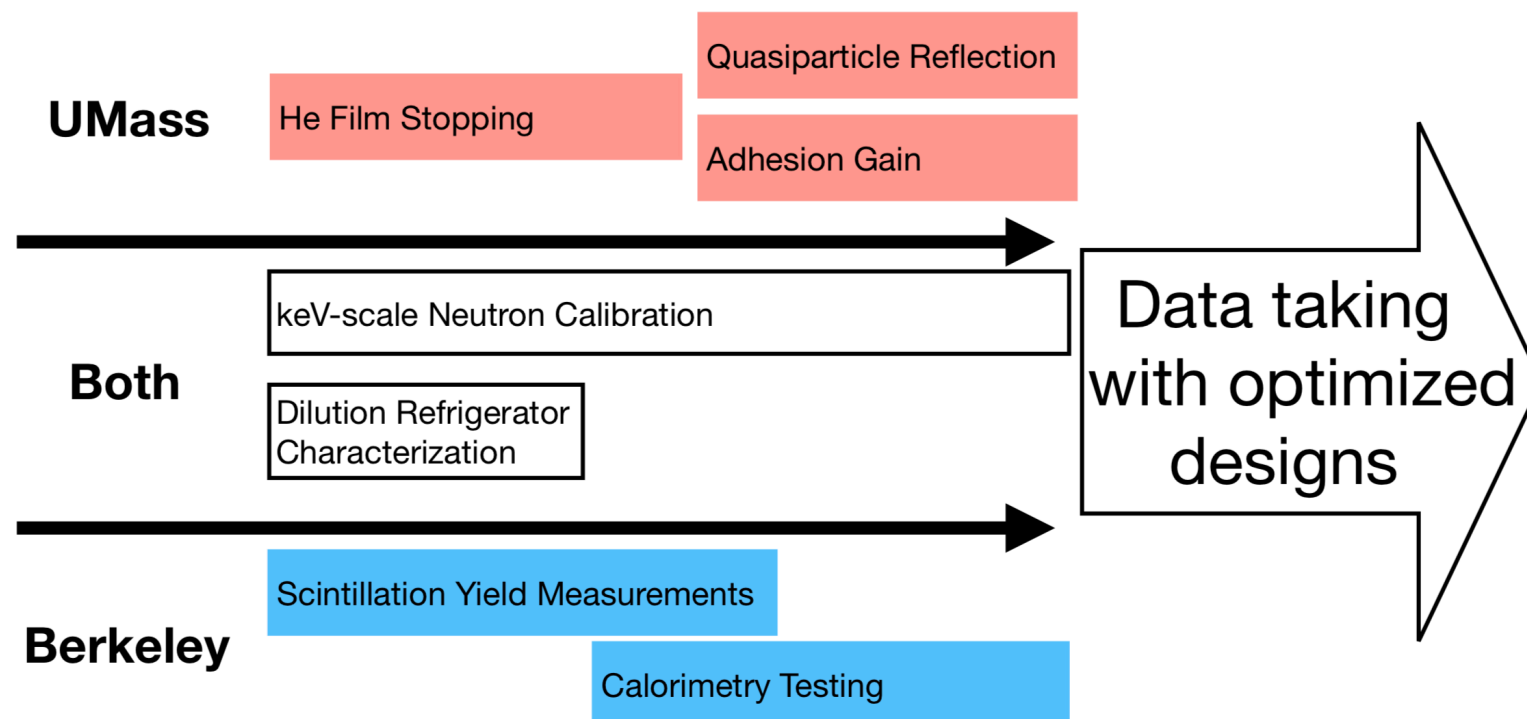
# Doug Pinckney : HeRALD

## Excitations in Superfluid 4He



Phys. Rev. D 100, 092007

## Next Steps



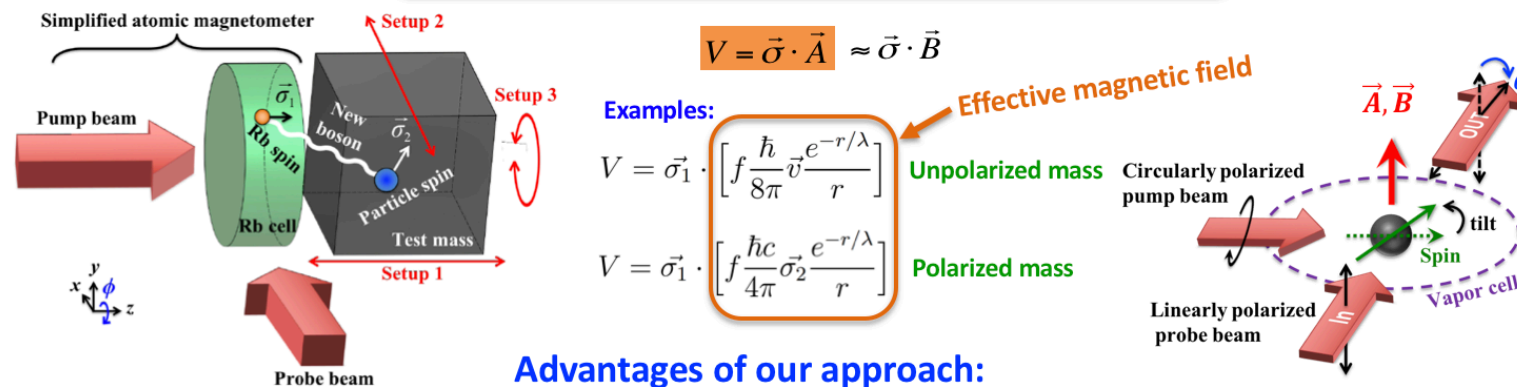


## dark matter search with atomic magnetometers

## LANL approach

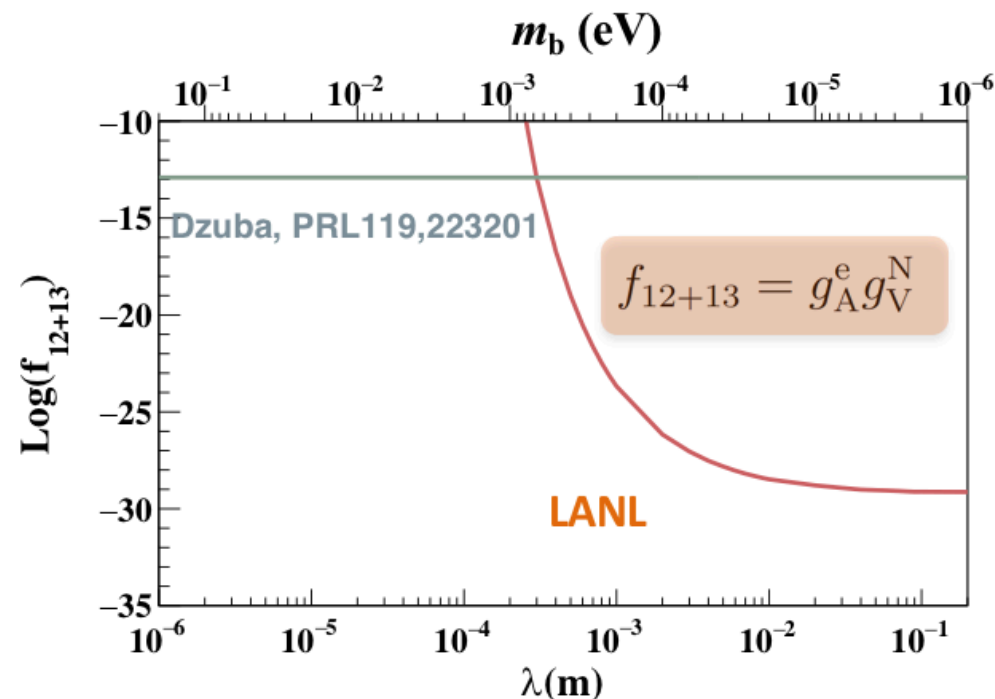
PHYSICAL REVIEW D **94**, 036002 (2016)

Search for exotic spin-dependent interactions with a spin-exchange relaxation-free magnetometer

P.-H. Chu,<sup>\*</sup> Y. J. Kim,<sup>†</sup> and I. Savukov

## Advantages of our approach:

- AM serves as both a source of electrons and a detector
- Simple experimental design; Cryogenic-free experiments
- Sensitive to all 15 spin-dependent interactions



Kim, Chu, Savukov, Newman, *Nature Comm.* **10**,  
2245 (2019)

recently  
published  
constraints