Recent Advances in OIR MKIDs

Ben Mazin, Dec 2019

The UVOIR MKID Team:

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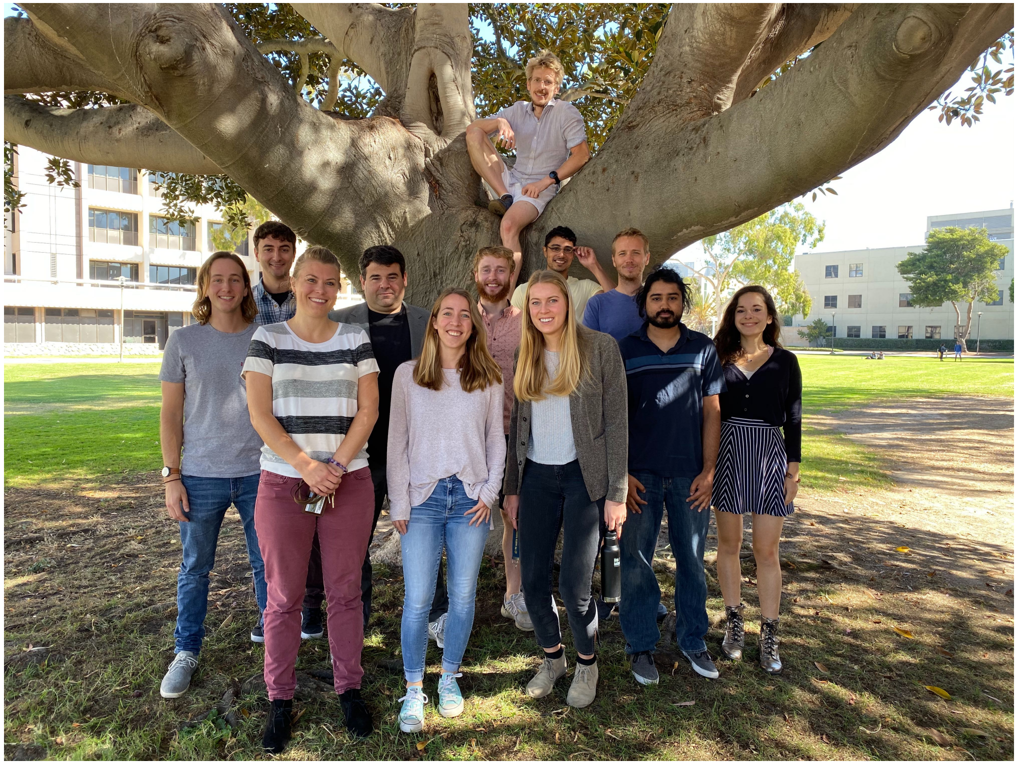
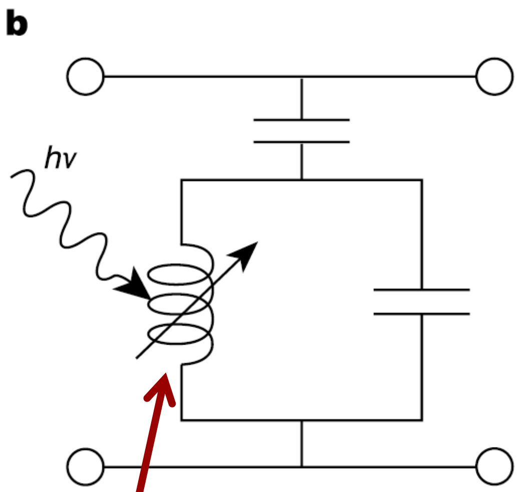
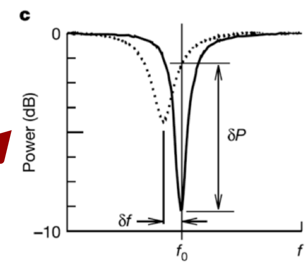
Subaru: Olivier Guyon, Julien Lozi
Caltech: Dimitri Mawet, Nem J.
JPL/IPAC: Seth Meeker, Bruce Bumble, Gautam Vashisht, Mike Bottom
Durham: Kieran O'Brien
Fermilab: Gustavo Cancelo, Juan Estrada
NIST: Paul Szypryt

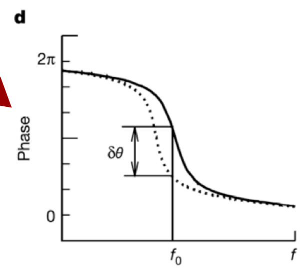


Mazin Lab
All of the wavelengths
All of the times
mazinlab.org

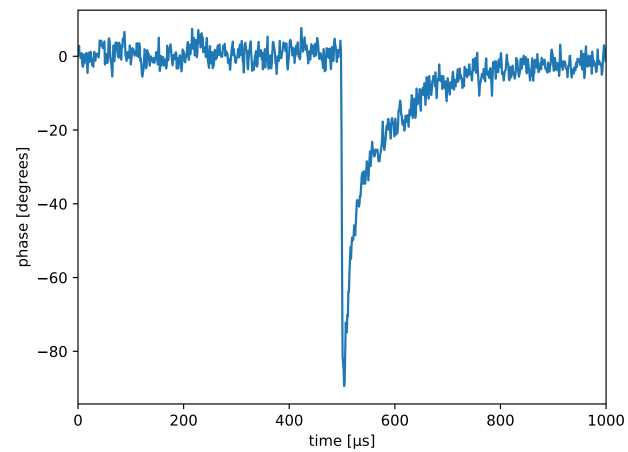
MKID Equivalent Circuit



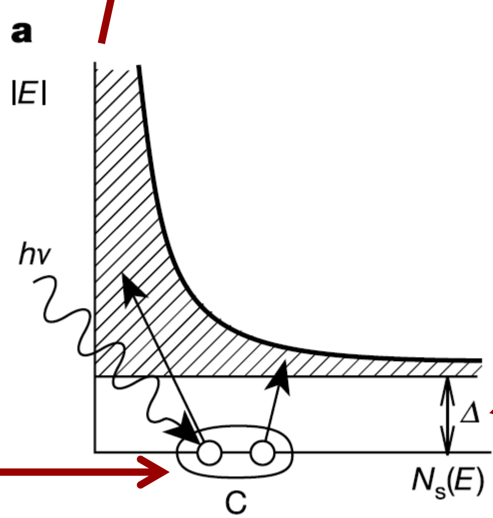




Typical Single Photon Event



Inductor is a Superconductor!



Cooper Pair

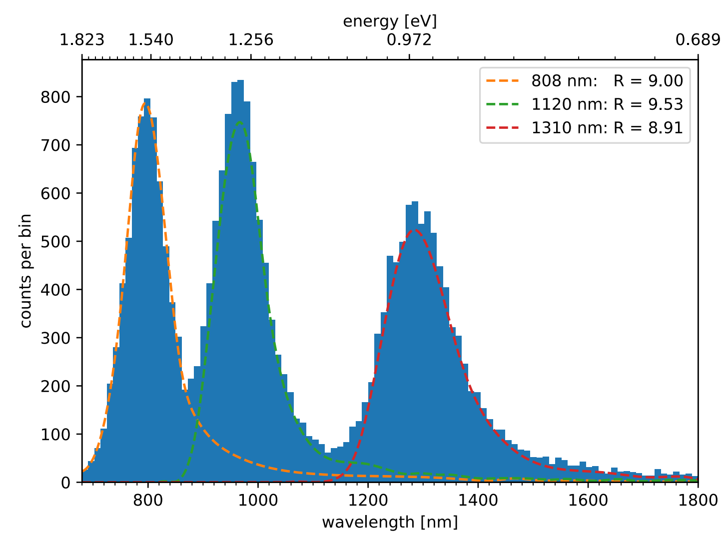
Energy Gap

Silicon – 1.10000 eV

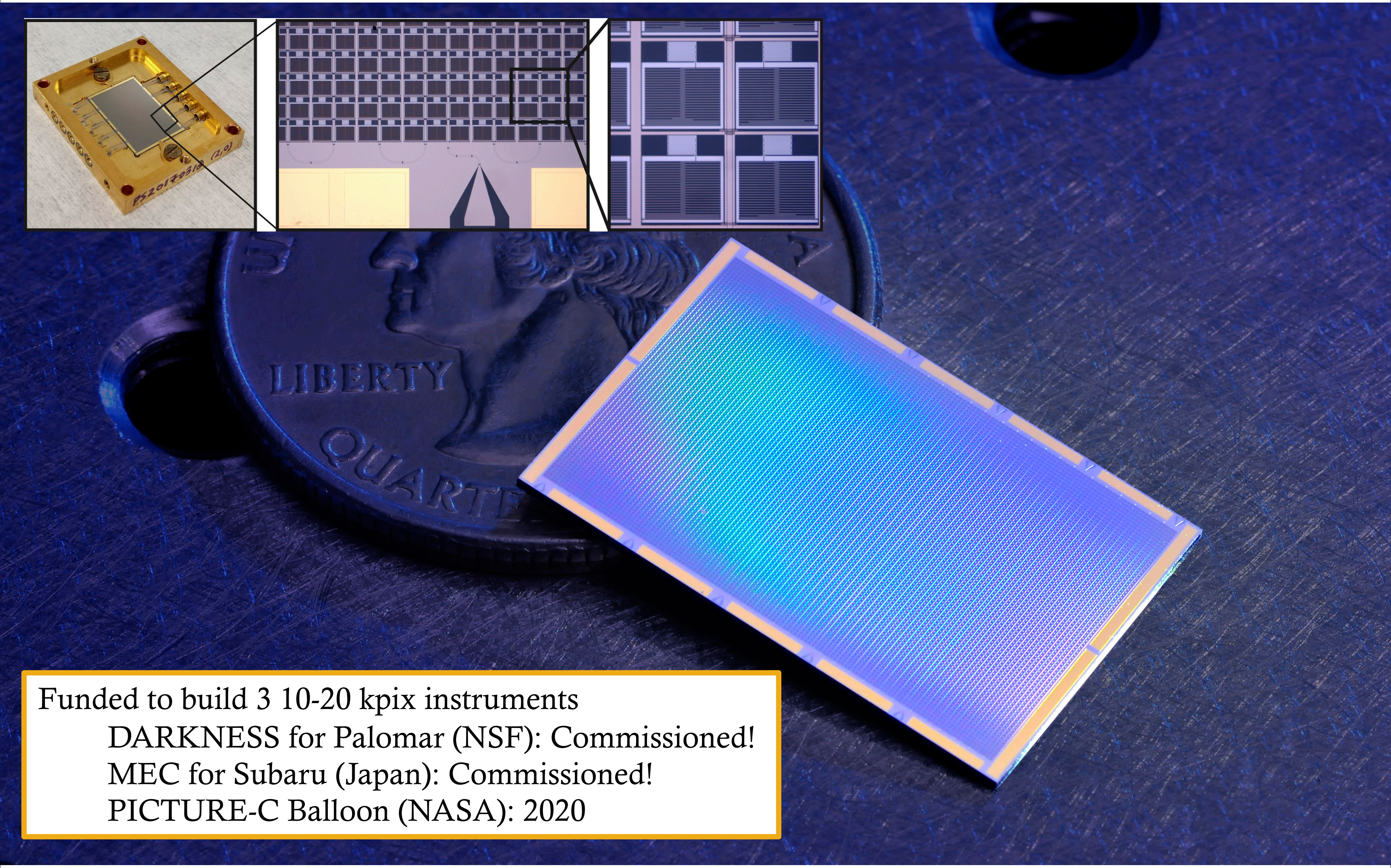
PtSi or TiN – **0.00013** eV

Energy resolution:

$$R = \frac{1}{2.355}\sqrt{\frac{\eta h\nu}{F\Delta}}$$



10 kpix DARKNESS Array

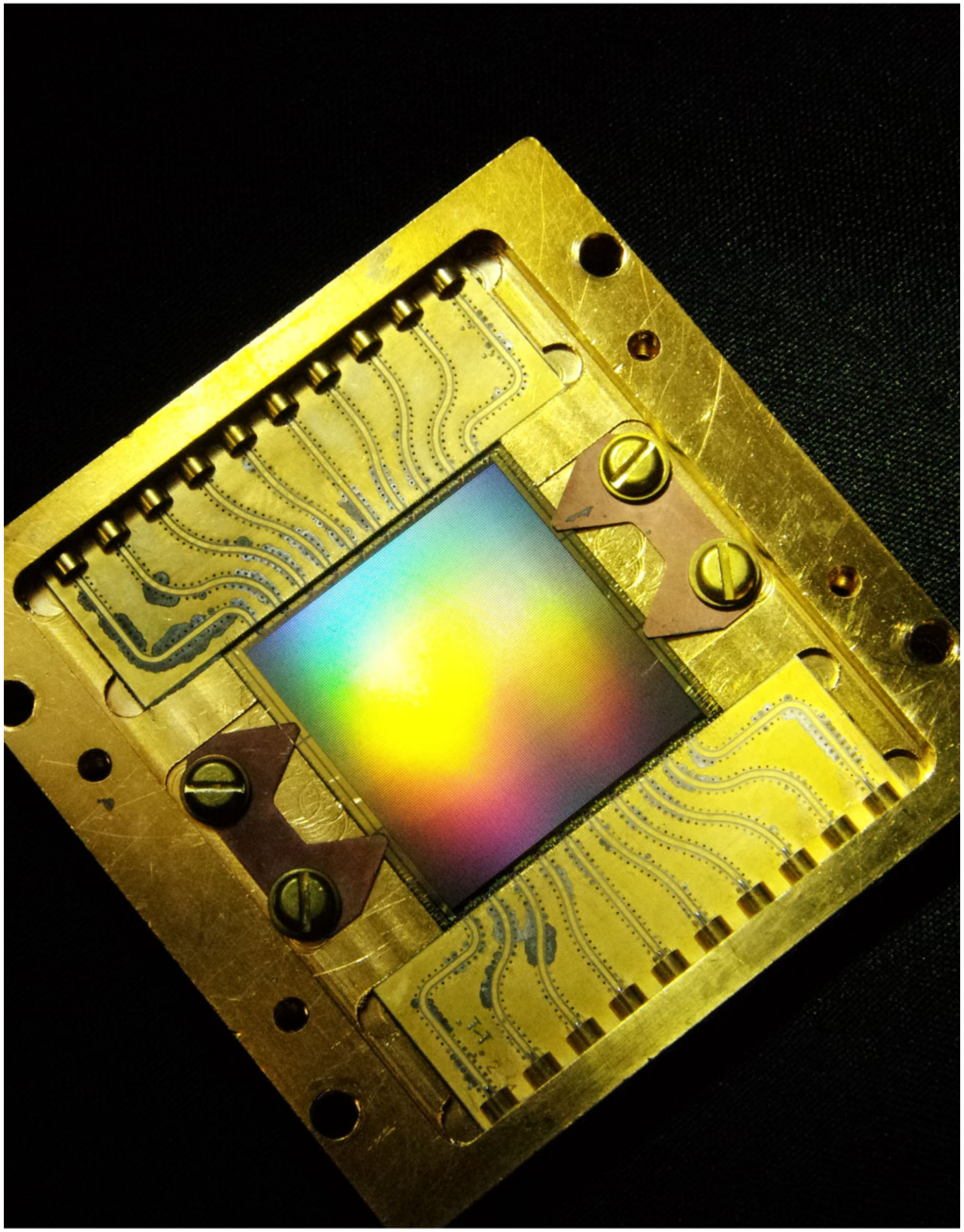


Funded to build 3 10-20 kpix instruments

- DARKNESS for Palomar (NSF): Commissioned!
- MEC for Subaru (Japan): Commissioned!
- PICTURE-C Balloon (NASA): 2020

MEC Array

- 20 kpix PtSi MKID array for Subaru SCExAO-MEC
- 140x146 pixels
- 150 micron pixel pitch
- 22x22 mm imaging area
- Pixel Yield ~85%
- R≅10 at 1 micron

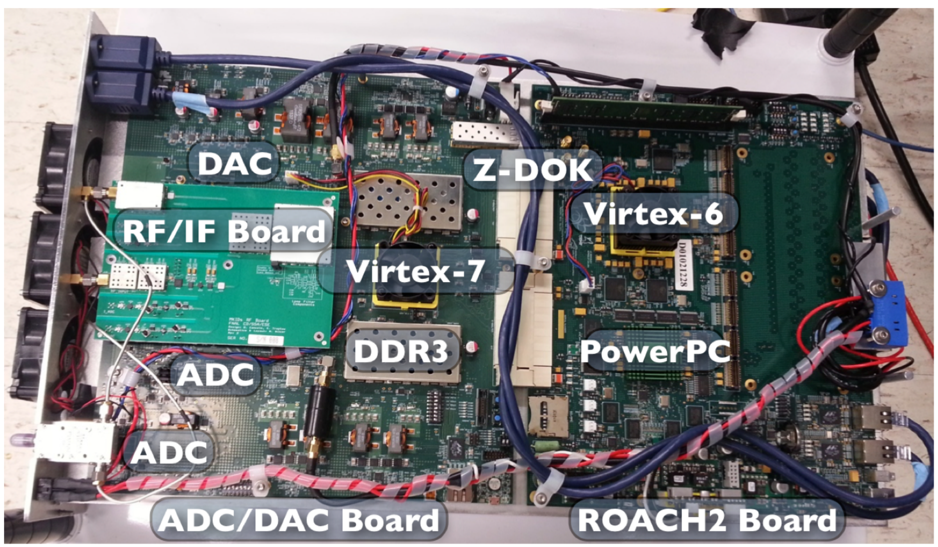


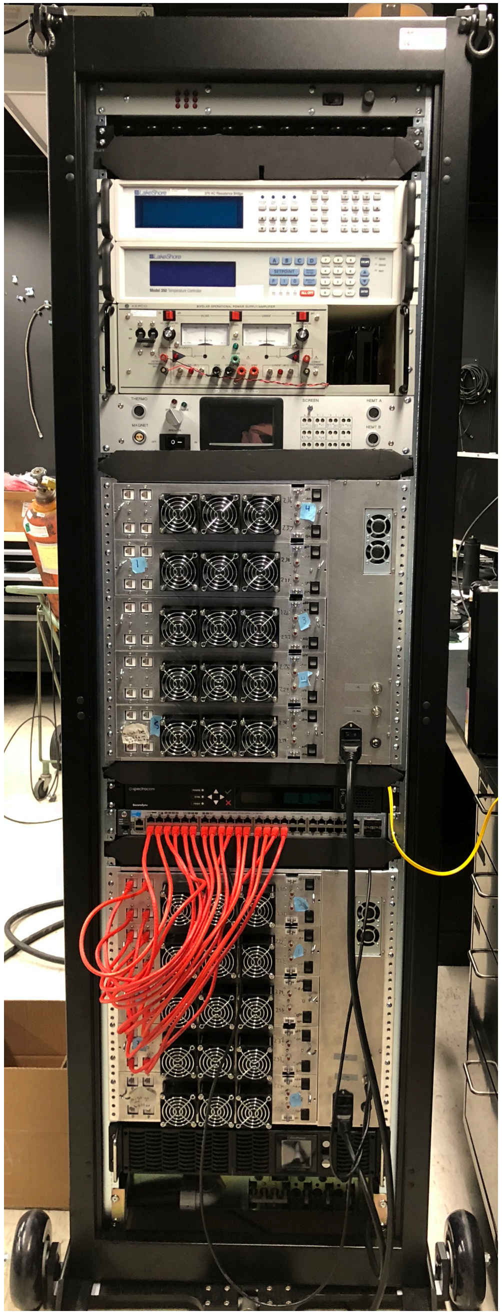
Array fabricated at UCSB by P. Szypryt and G. Coiffard.

Szypryt et al. 2017, Optics Express

MEC's Gen 2 Readout

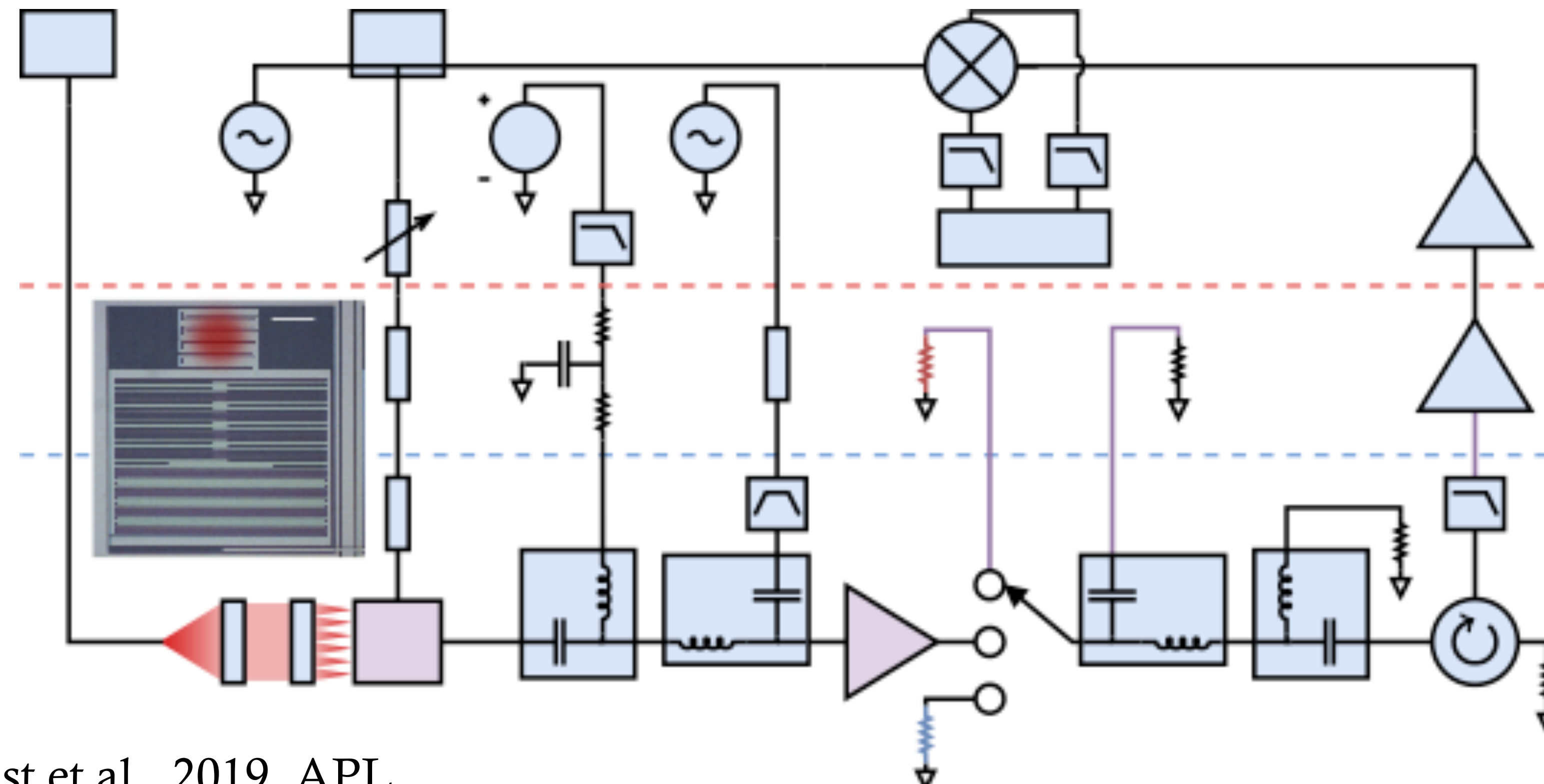
- Designed in collaboration with **Fermilab**
- Based on Casper ROACH2 (Virtex 6)
- Uses dual 2 GSPS 12 bit ADC
- Reads out 1024 pixels in 2 GHz
- 2 boards per feedline in 4-8.5 GHz band
  - scalable to 30+ kpix
- Air to Water/Glycol heat exchangers
- Cost: ~$5-10/pixel, excluding HEMT and FPGAs





Quantum Limited Parametric Amplifier

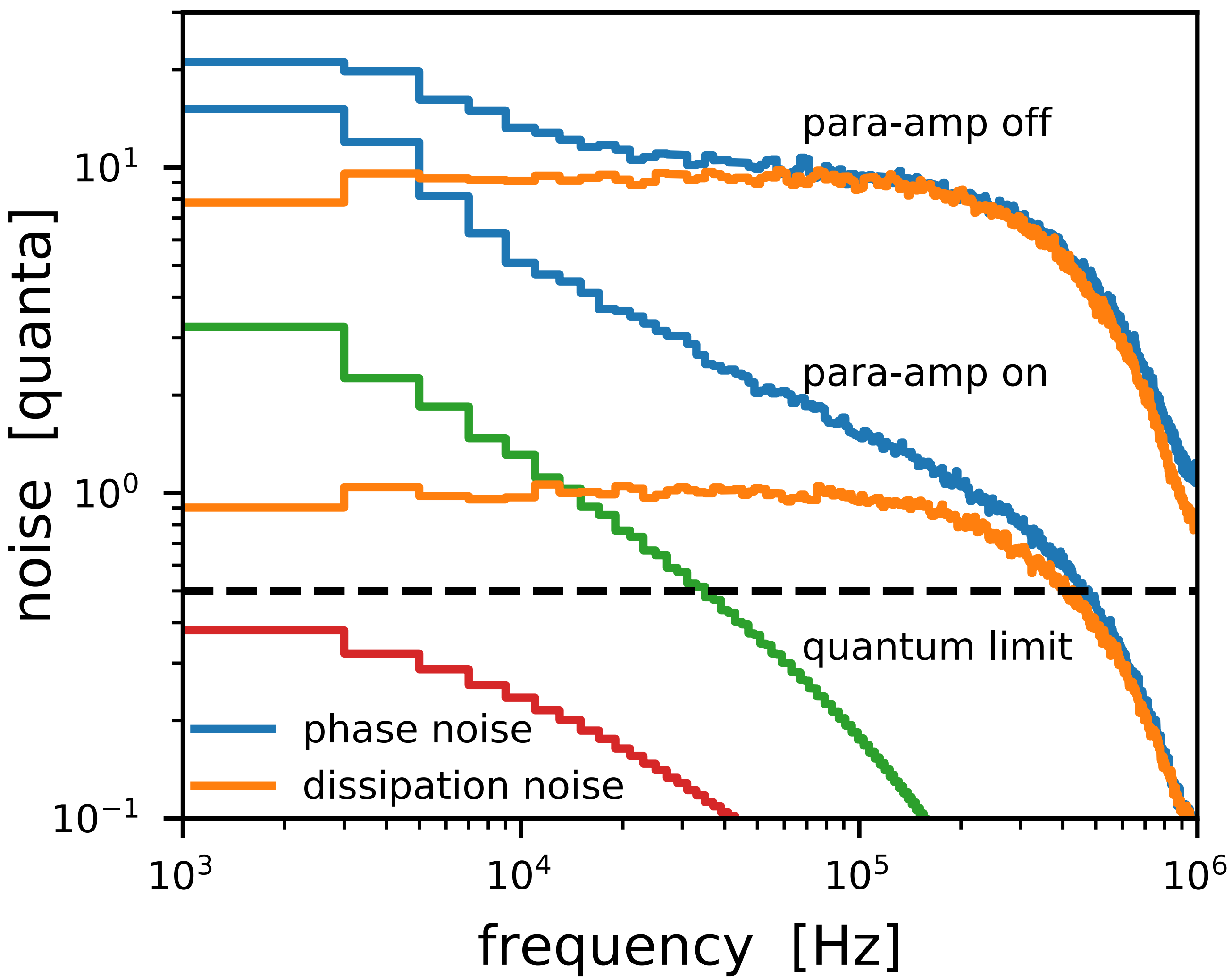
- Quantum limited travelling wave parametric amplifier (Peter Day will discuss later in the week) allows us to probe the noise of our resonators in ways we couldn't do before
  - Big difference over JPAs is operation at much higher input powers
  - Will eventually make their way into instruments, but some work needs to be done to reduce the number of components



Zobrist et al., 2019, APL

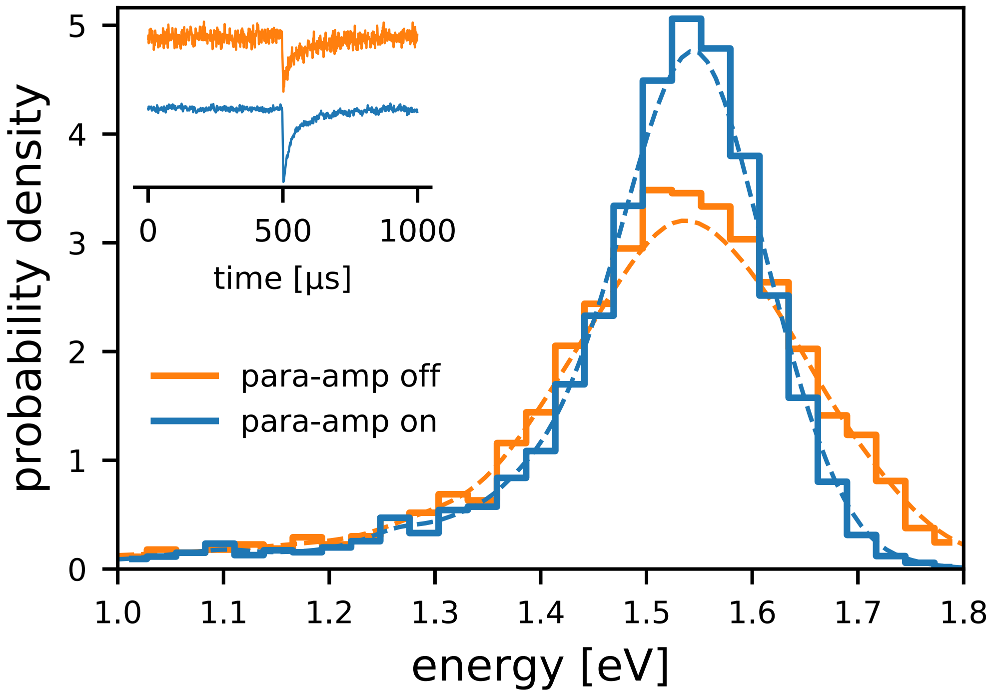
Para-amp + PtSi MEC Array

- Noise reduced as expected



Zobrist et al., 2019, APL

Spectral Resolution



Energy [eV]	Resolving Power [$^{E}/_{\Delta E}$]					
	Phase and Dissipation		Phase		Dissipation	
	Measured	Expected	Measured	Expected	Measured	Expected
1.53 (808 nm)	5.8 → 8.9	9.5 → 23	5.4 → 8.8	8.7 → 22	1.4 → 5.9	1.8 → 8.7
1.35 (920 nm)	7.4 → 9.4	10 → 24	6.6 → 9.1	9.7 → 23	1.4 → 5.8	1.7 → 7.8
1.27 (980 nm)	7.5 → 9.6	11 → 25	6.6 → 9.3	10 → 23	1.5 → 6.8	1.6 → 8.8
1.11 (1120 nm)	6.6 → 9.6	9.3 → 24	6.1 → 9.2	8.8 → 22	1.9 → 6.9	1.8 → 9.9
0.946 (1310 nm)	6.0 → 9.2	8.7 → 23	5.5 → 8.9	8.3 → 20	1.9 → 6.1	1.9 → 9.9

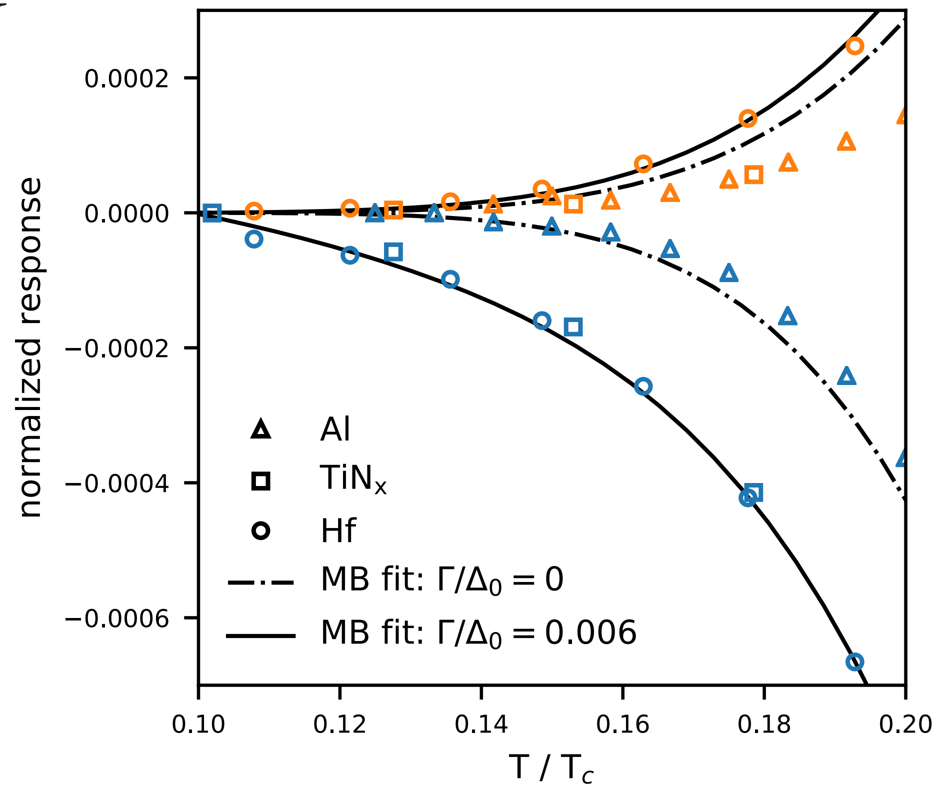
Zobrist et al., 2019, APL

Resolution Broadening

- Para-amp shows we are getting spectral resolution broadening from an unknown source
  - Geometric effects in the pixel (absorption location, gap variations)
  - Hot phonon loss into the substrate
- Best guess is hot phonon loss, backed up by new data from SRON (de Vissers, using aluminum on silicon)
- We are currently testing Hf MKIDs that are much thicker (200 nm vs 55 nm) which should lower hot phonon escape
  - Recently saw R=15.5 at 0.8 micron – best ever! $R_{expected}$ = 36!
- Engineering solutions to hot photon escape are being devised
- With para-amp, TLS noise starts to limit performance
  - Working on ways to decrease TLS noise by improving substrate cleaning and film deposition

Low Tc MKIDs - Hafnium

- We have developed Hf on sapphire resonators for MKIDs
  - We avoid Si substrates because having a semiconductor bandgap in our active wavelength range has proven to be very problematic
- Elemental superconductor, easier to deposit than PtSi
- Tc ~ 350-400 mK for best films (bulk Tc~130 mK)
- Superconducting properties resemble other high resistivity superconductors like TiN



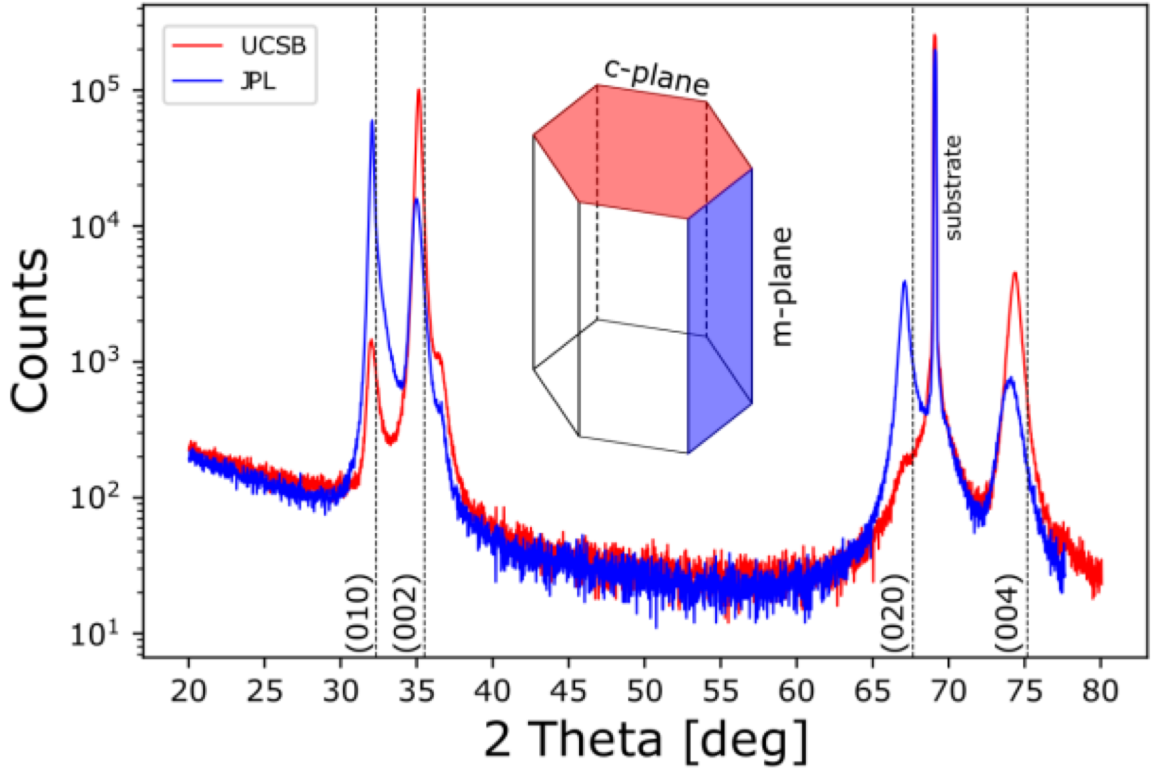
Freq. response: blue
Disp. response: orange

Hf Sputtering

- Hf Deposition conditions matter!

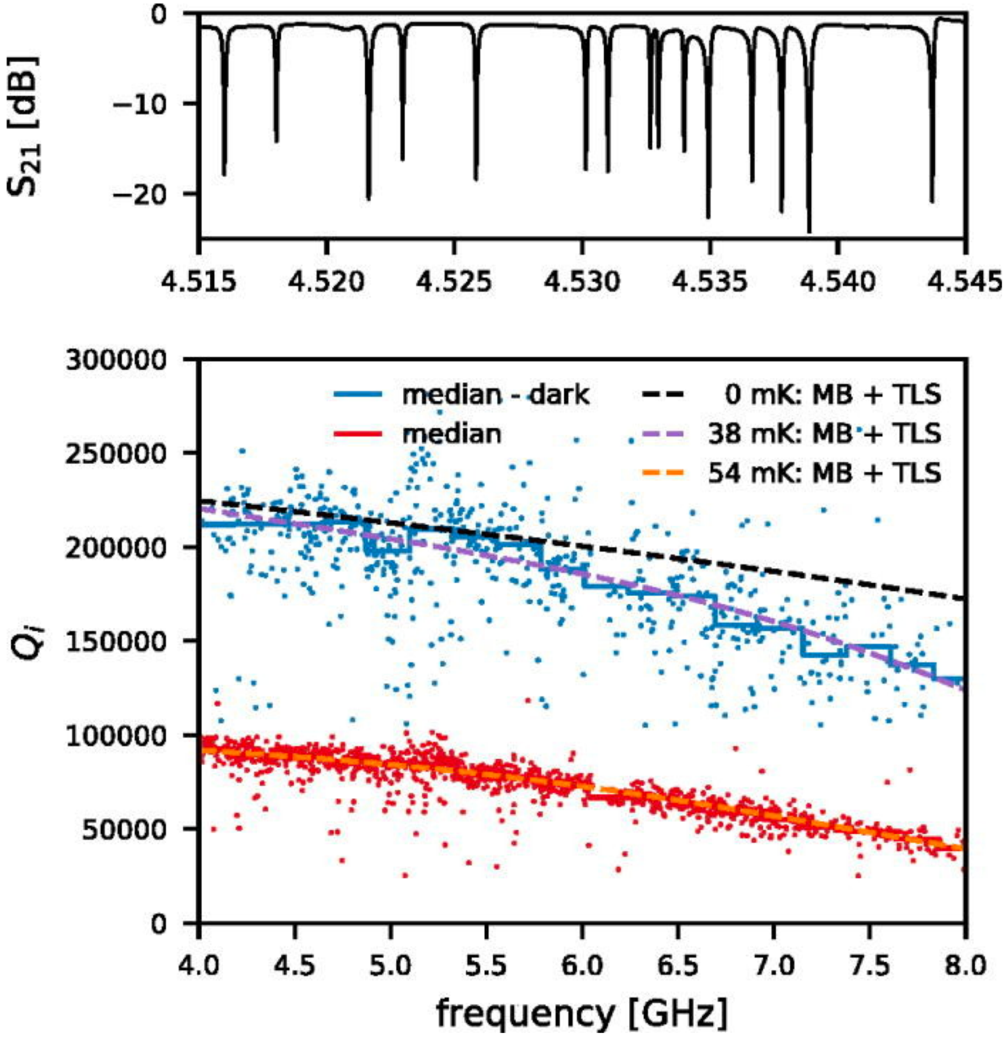
Crystallographic difference

Plane	JPL	UCSB
(010) m-plane	80.40%	1.32%
(002) c-plane	19.60%	98.68%



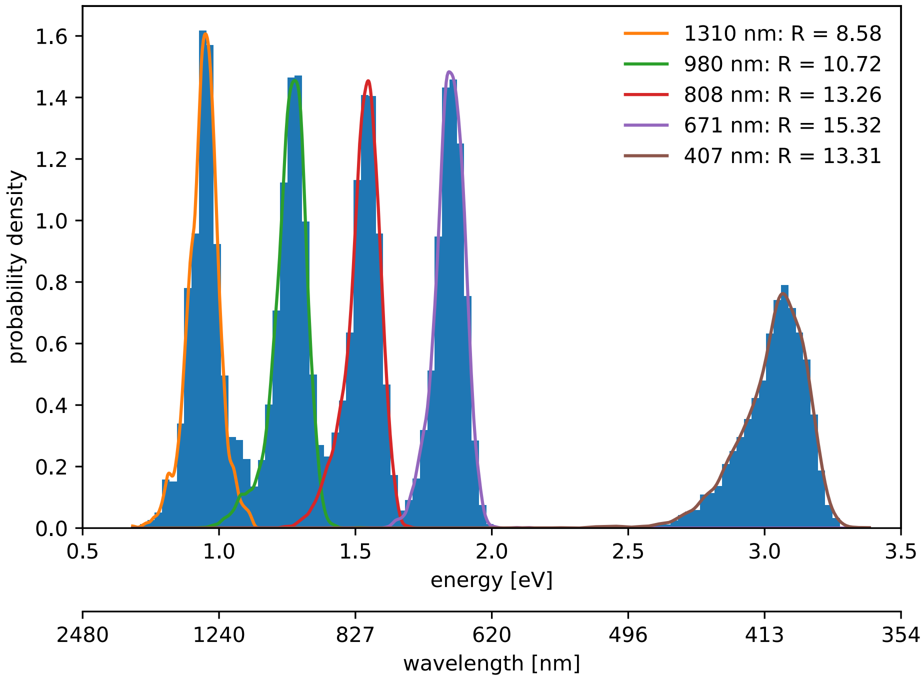
Gap Smearing

- Measurements consistent with various models that have some gap broadening mechanism

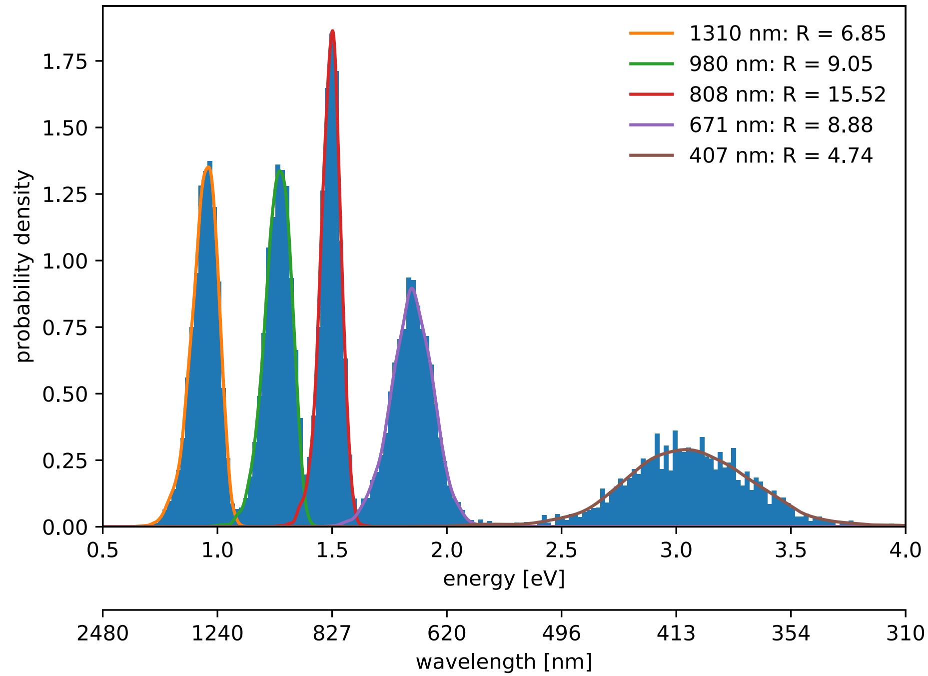


Hf OIR MKID Performance

- Already seeing better R than PtSi with para-amp



Low Q_m

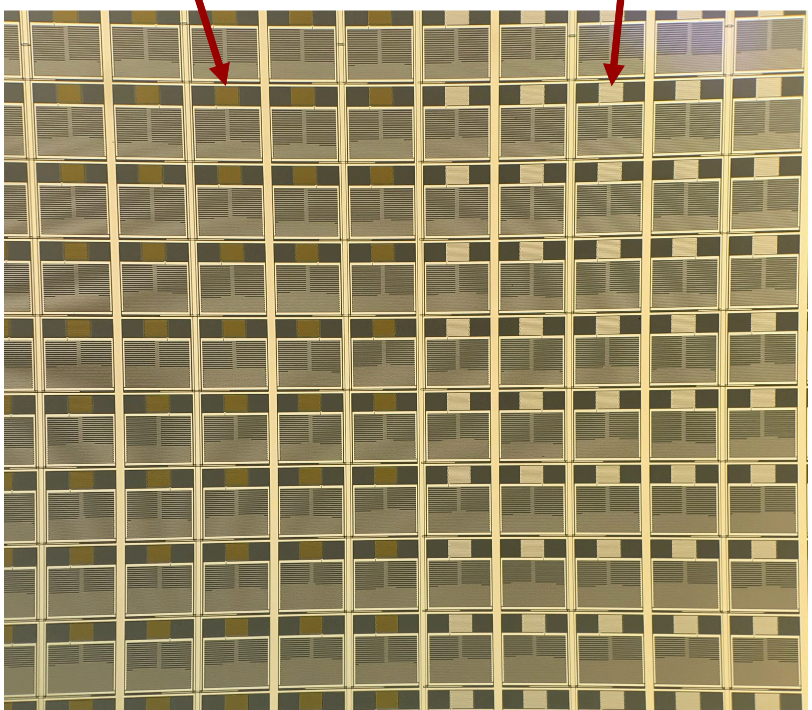


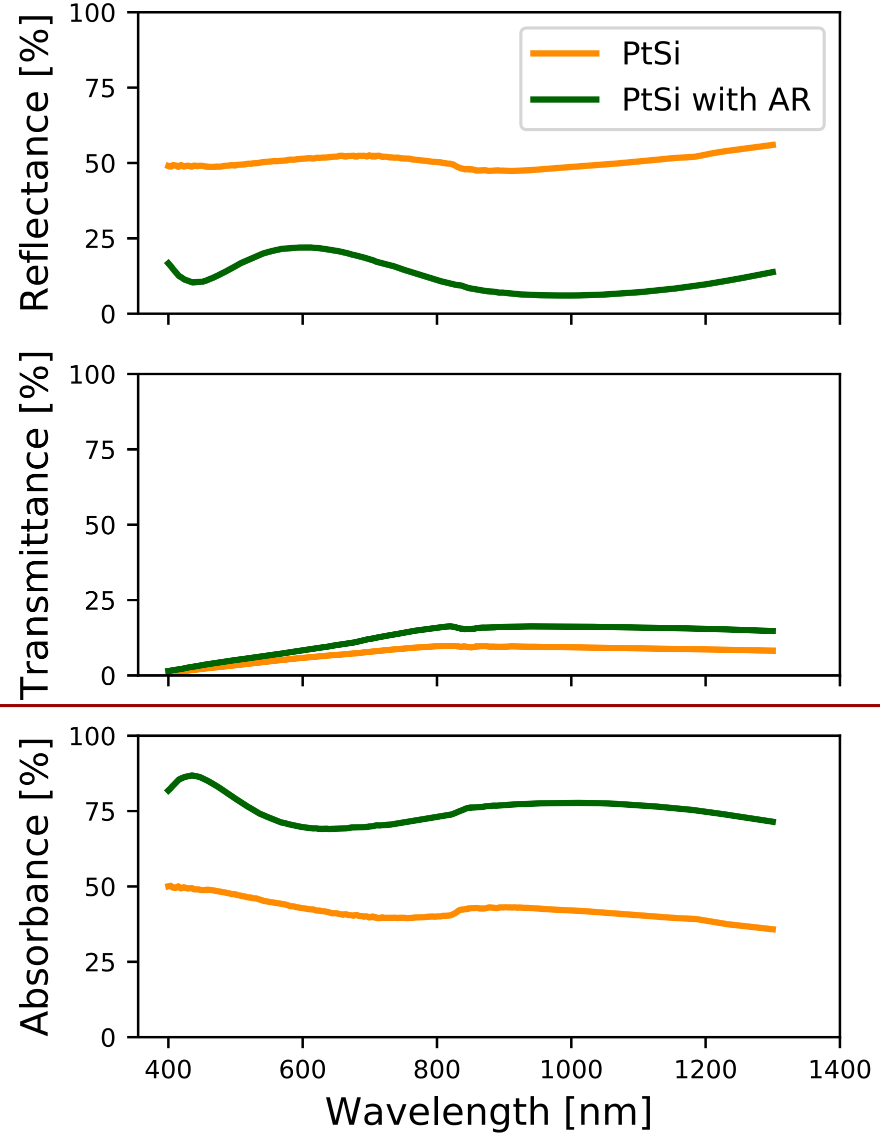
High Q_m

Quantum Efficiency

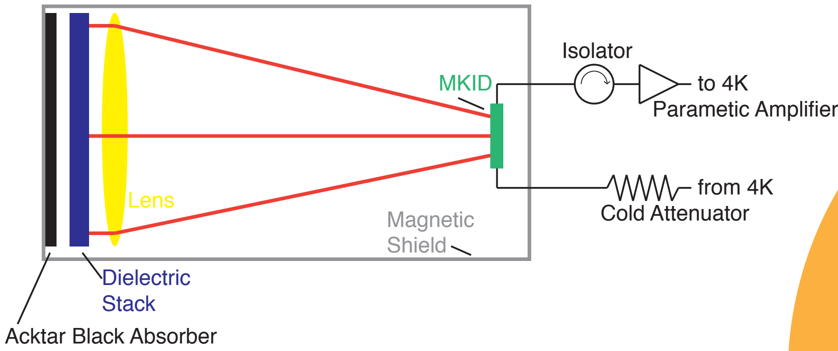
- QE increased with Anti-Reflection (AR) Coatings
- No degradation in Spectral Resolution R

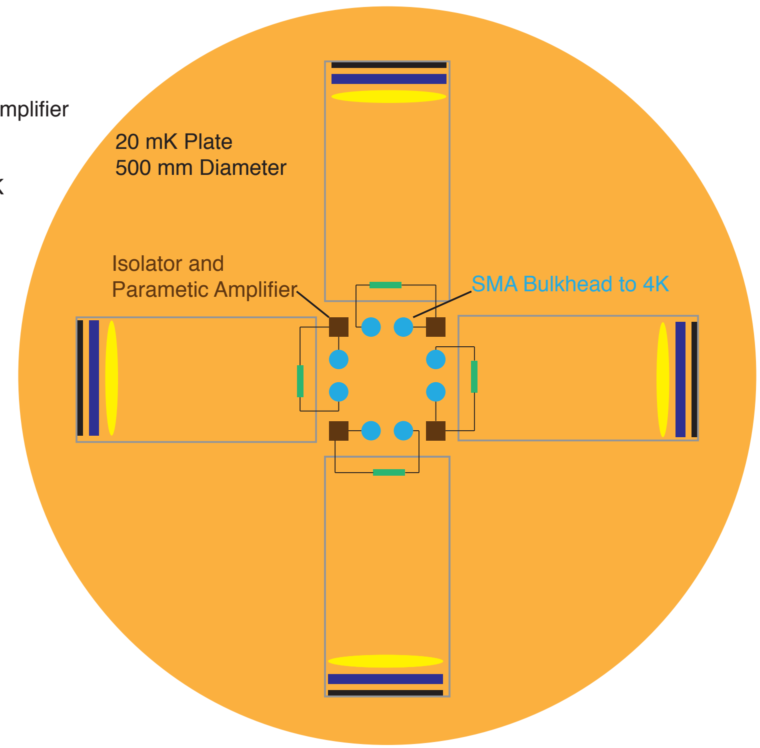
With AR | No AR

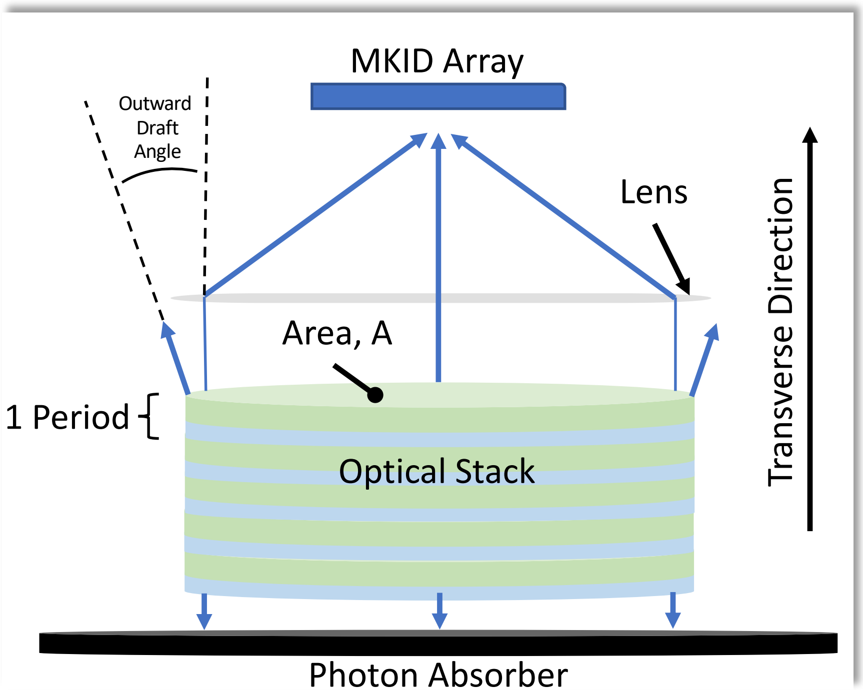




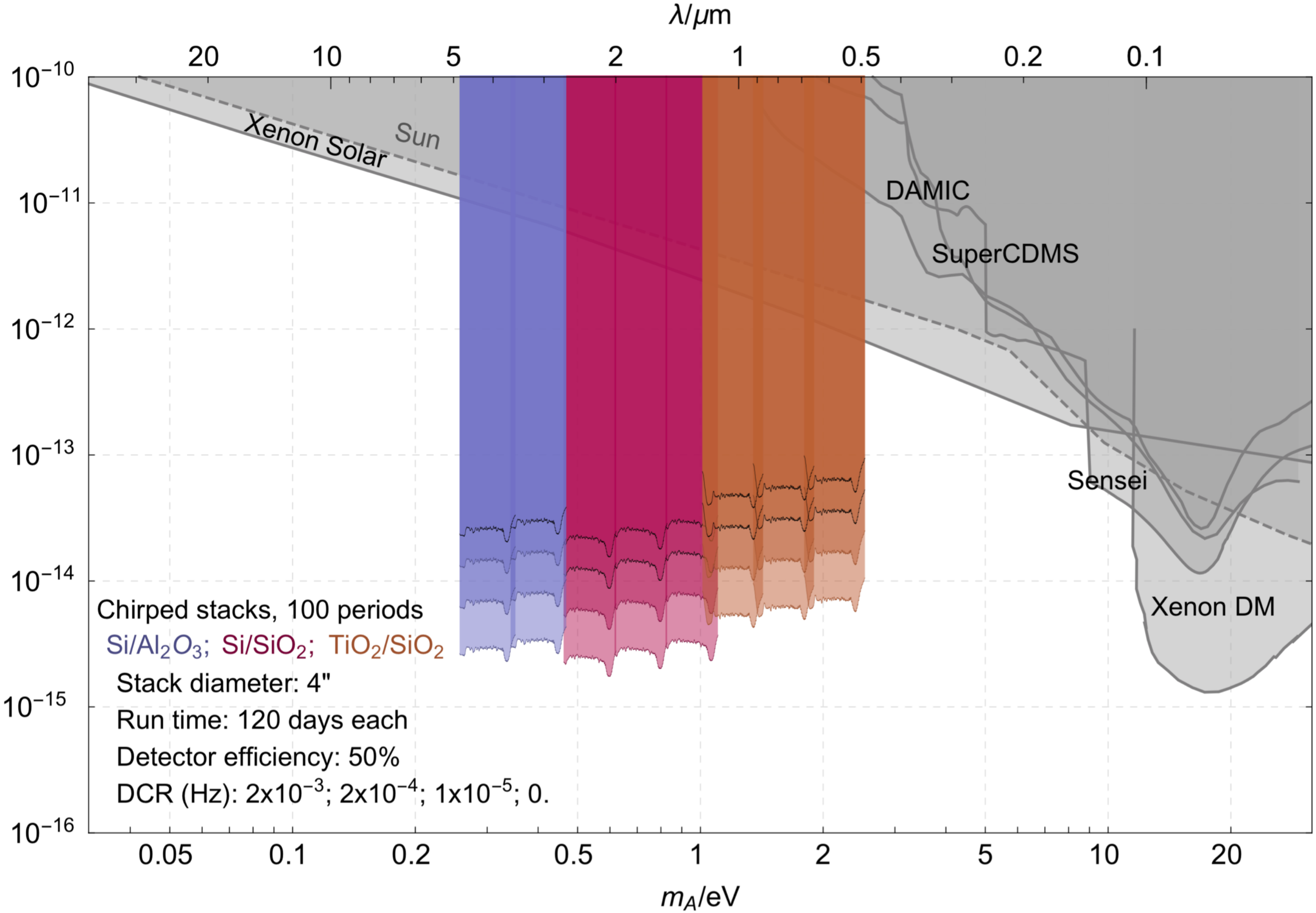
- **DEEPDISH**: Dark-matter Extended Energy Probe: Dielectric Infrared Superconducting Haloscope







- Just proposed to NSF Astroparticle (Second try, $1.75M)



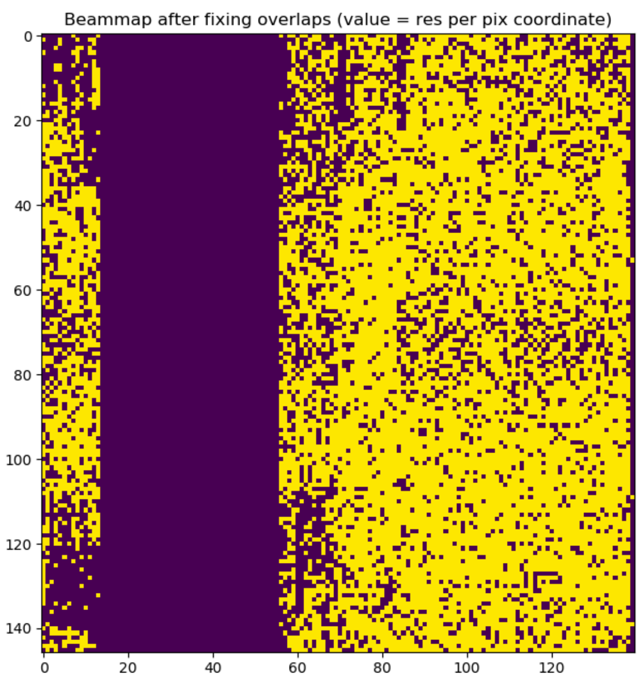
- MEC is a 20 kpix MKID Exoplanet Camera for Subaru SCExAO
  - SCExAO
    - Extreme AO
    - Lyot/PIAA/Vector Coronagraphs
  - Goal: Observe cold gas giants in reflected light

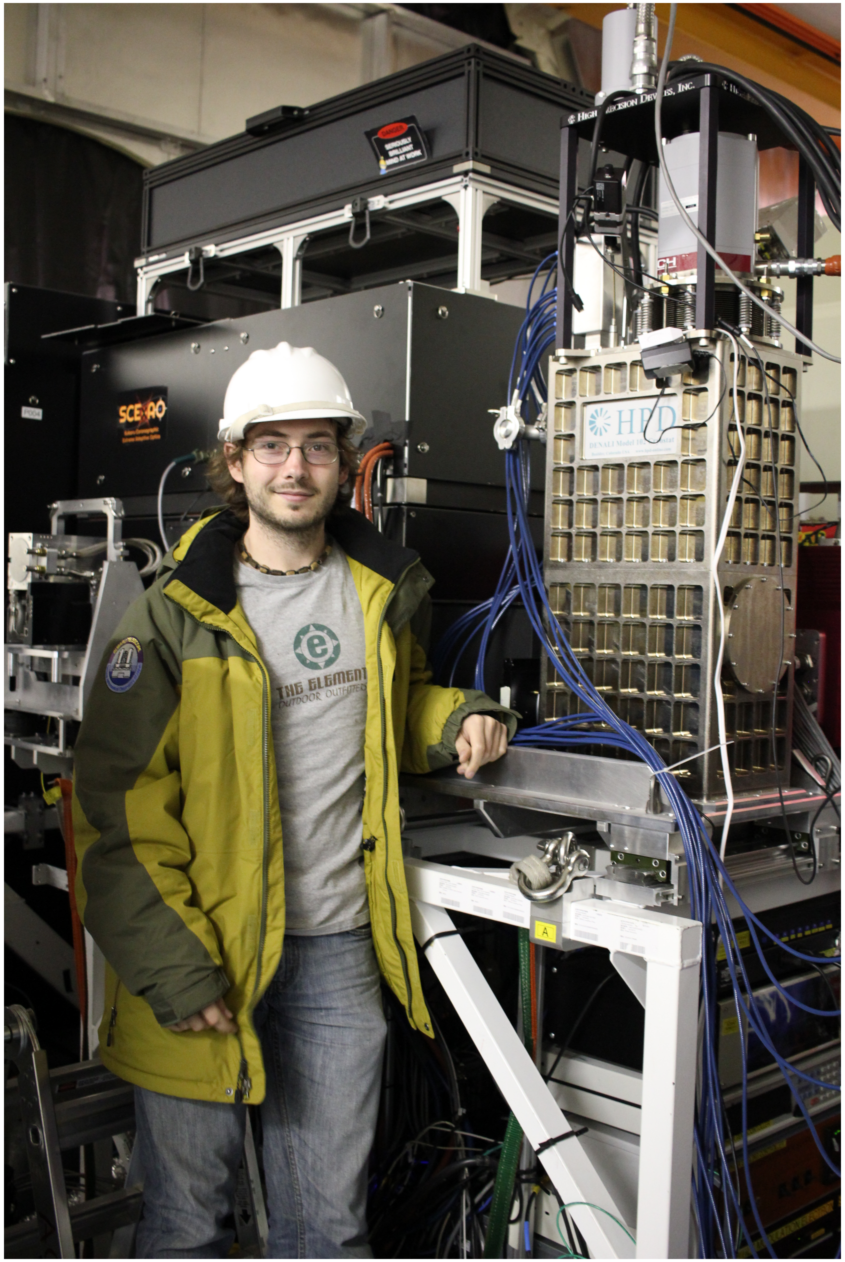
SUBARU TELESCOPE
National Astronomical Observatory of Japan

MEC was the thesis project of Alex Walter

MEC

- MEC has been operational for over a year
- We have done fully remote observing runs
- Achieving expected performance after a recent wiring upgrade





It works!

- Theta Orionis B