

# Microwave multiplexing on the Keck Array



Ari Cukierman (Stanford University)

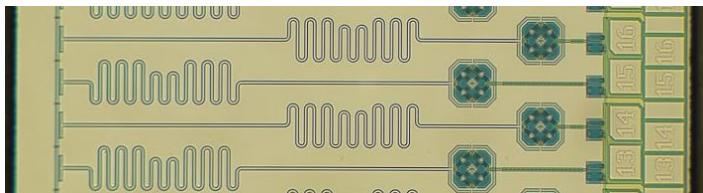
Z. Ahmed, S.W. Henderson, E.Y. Young, C. Yu,  
H.-M. Cho, J.M. D'Ewart, D. Barkats, D. Brown, S.  
Chaudhuri, M.I. Dierickx, B.J. Dober, J. Dusatko, S.  
Fatigoni, J.P. Filippini, J.C. Frisch, G. Haller, M.  
Halpern, G.C. Hilton, J. Hubmayr, K.D. Irwin, K.S.  
Karkare, E. Karpel, S.A.S. Kernasovskiy, J.M.  
Kovac, S.E. Kuenstner, C.L. Kuo, D. Li, J.A.B.  
Mates, S. Smith, M.T. St. Germaine, J.N. Ullom, L.  
Vale, D.D. Van Winkle, J. Vasquez, L. Zeng, and the  
BICEP/Keck Collaboration

Low Temperature Detectors, Milan  
Jul. 24, 2019

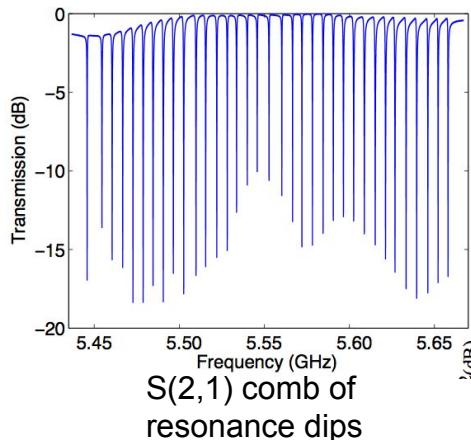
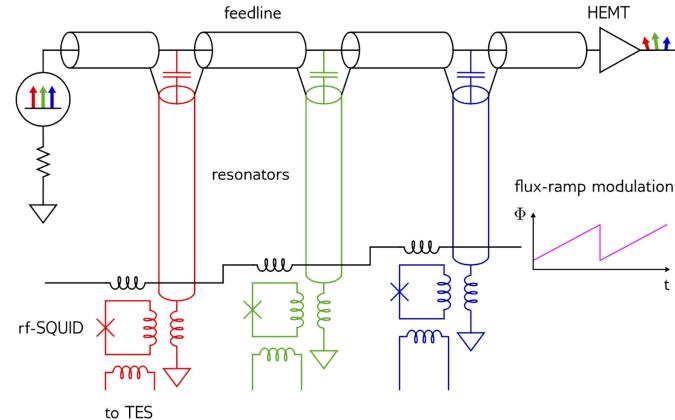
Ari Cukierman, *Microwave multiplexing on the Keck Array*

# Microwave multiplexing (umux)

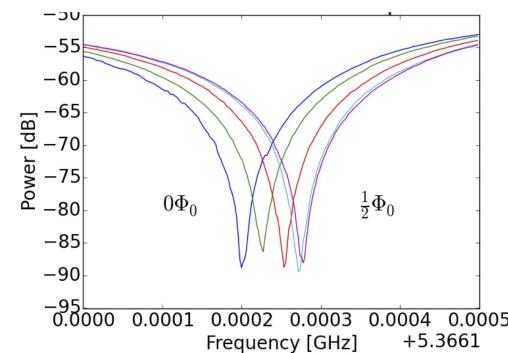
- GHz frequency multiplexing for DC-biased TESs
  - TES current controls resonance frequency
  - Modulate to higher frequencies ( $\sim 10$  kHz)
    - Avoid TLS noise and linearize SQUID response
  - 4-8 GHz
    - CMB:  $\sim 2000\times$
    - x-ray:  $\sim 200\times$
- Fabrication: **Brad Dober's talk later this morning**



Fabricated resonators and SQUIDs



S(2,1) comb of resonance dips

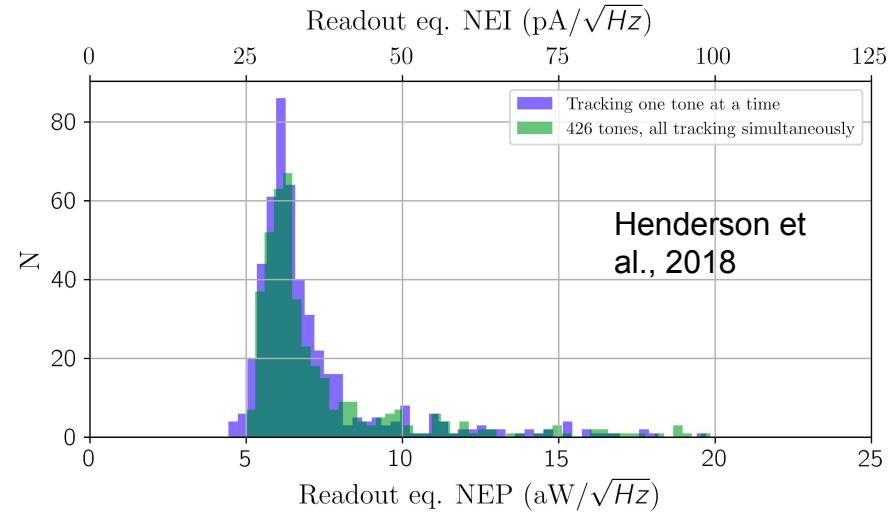
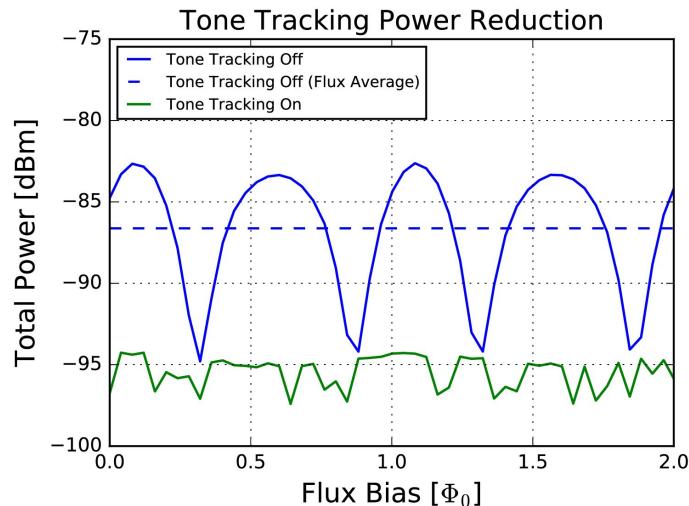


Magnetic flux shifts resonance

# Tone tracking with SMuRF (SLAC Microresonator RF) electronics

- Enables high channel counts ( $> 100x$ )
- Probe tone follows resonance as it shifts
- Lowers power entering HEMT
  - Linear amplification

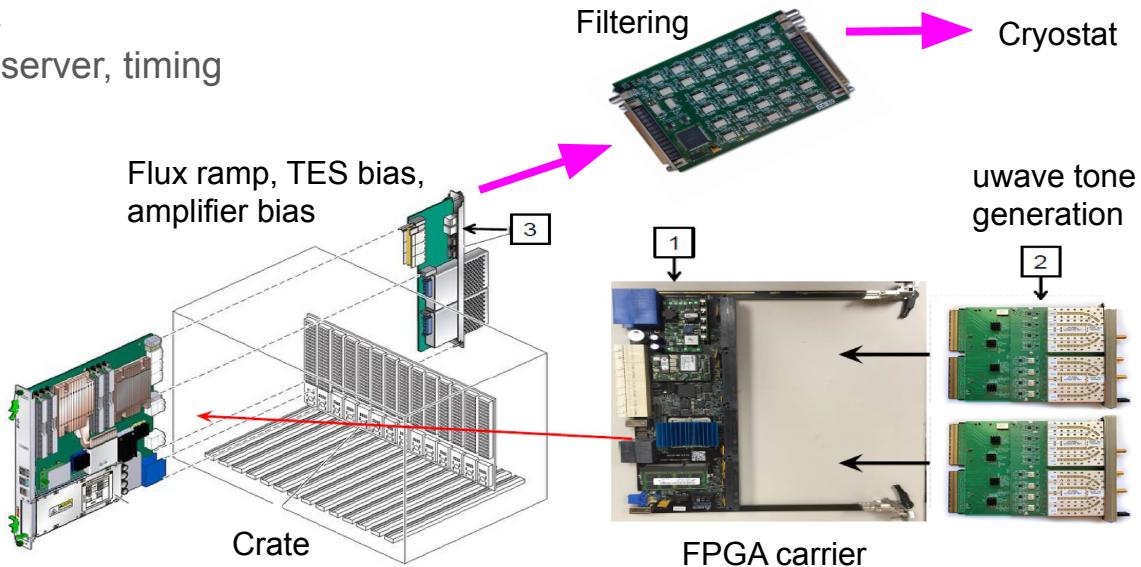
Kernasovskiy et al., 2018



Noise comparison with 426 individual tones and with all on simultaneously  
→ same performance

# SMuRF

- 3328 channels over 4-8 GHz
- Computation on FPGA
- Integrates with control server, timing and DAQ

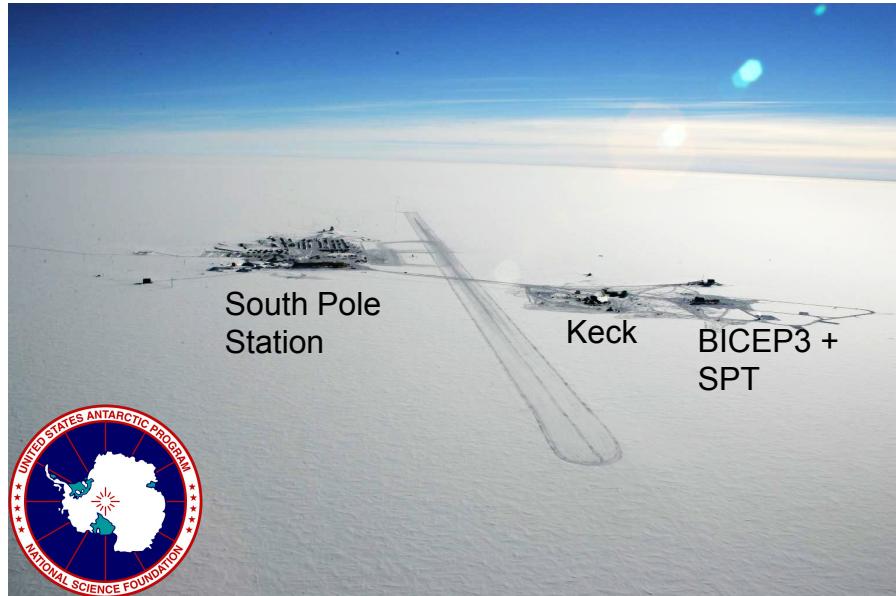


# Keck Array

- CMB polarimetry from the South Pole
  - Targeting degree-scale B-modes
  - Five BICEP2-like receivers
  - 100, 150, 220, 270 GHz
- ~500 TESs per receiver
  - Time-domain multiplexing (TDM) readout
    - One receiver now with umux



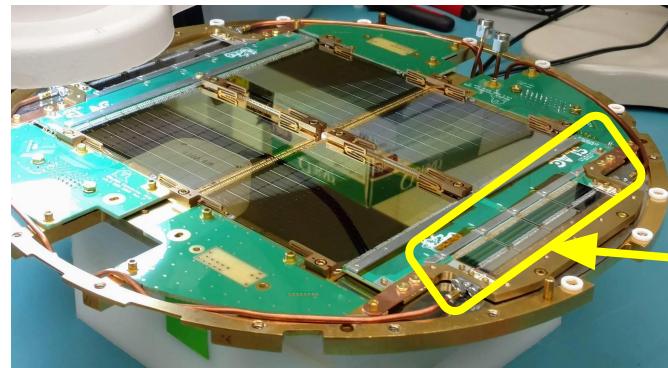
Five Keck receivers observe from  
the same mount



# umux on BICEP/Keck

- On-sky umux demo
  - Increase technology readiness
  - Understand challenges early
    - Systematics: **Cyndia Yu poster 291**
- Retrofit a Keck receiver with umux
  - TDM → umux
  - Microwave plumbing
  - Resonators
    - Some issues with collisions, low Q
    - 5-6 GHz
  - Shunt-resistor network
  - ~120 optically active TESs

Microwave plumbing in Keck receiver



Keck focal plane with microwave resonators

RF module

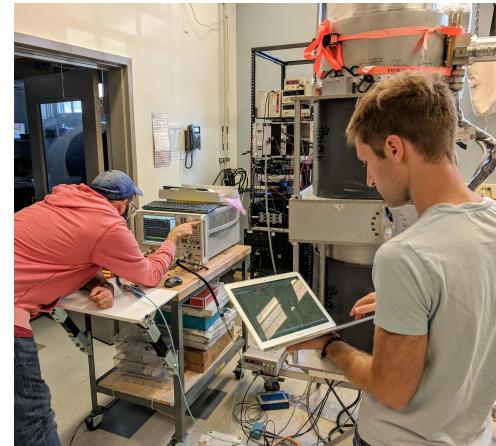
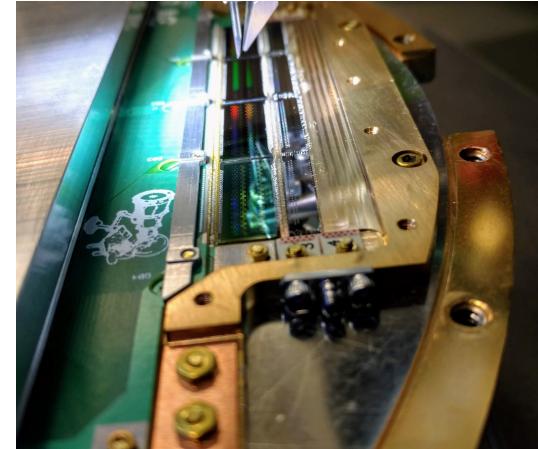
# Testing in North America

- RF modules
  - Integrate resonators and shunt resistors
- Rehybridize Keck focal plane
- Harvard testing with Keck replica
  - SMuRF installation
  - Retrofit Keck receiver
  - gcp integration (telescope control and DAQ)
  - Dark and optical testing

Focal-plane assembly at Harvard



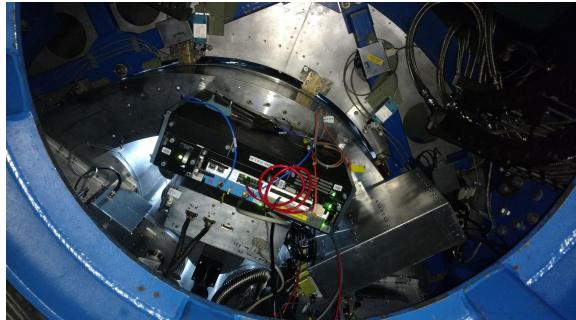
umux RF module: resonators and TES bias resistors



Resonator and TES characterization at Stanford and Harvard

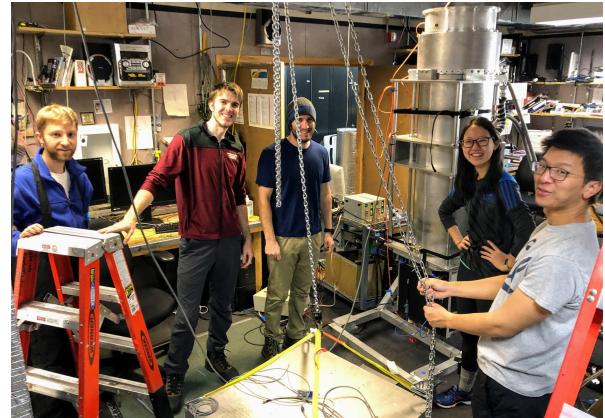
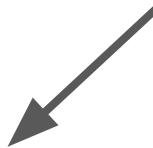
# Pole deployment

- umux parts shipped to Pole
- Retrofit Keck receiver at Pole
- SMuRF installation
  - Integration with Keck DAQ and control
    - SMuRF server intercepts commands
  - SMuRF crate replaces TDM electronics
- In-lab dark/optical testing
- Mount installation
- Beam mapping
- Observations



SMuRF crate  
attached to Keck  
receiver

In-lab (MAPO) testing at Pole

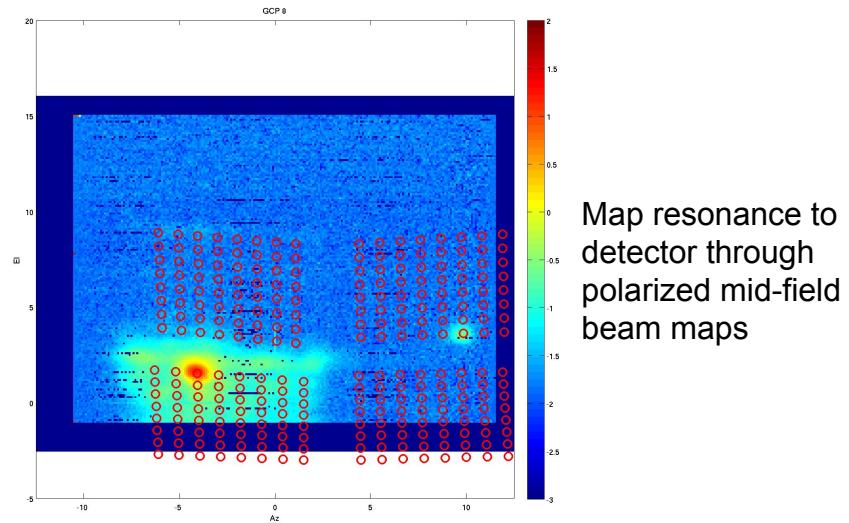


Installing umux receiver  
in Keck mount

# System development

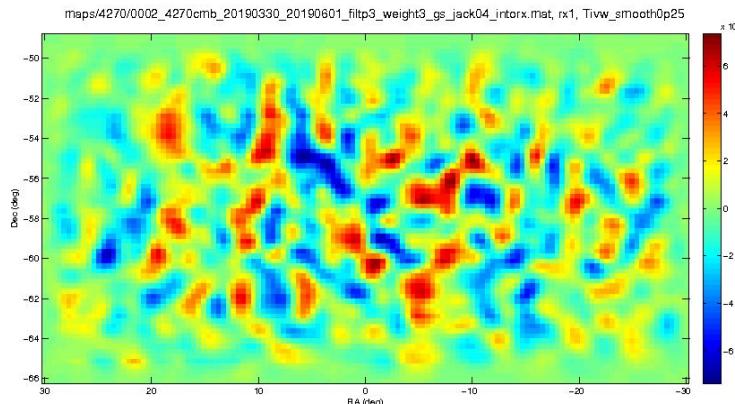
- **pysmurf** development
  - User-level software to control detectors and microwave tone generation
- Speed up resonator tuning
  - Needed to keep up with Keck observation schedule
- Mapping detectors
  - Frequency space to physical space

```
[In [1]: import pysmurf  
[In [2]: S = pysmurf.SmurfControl()
```



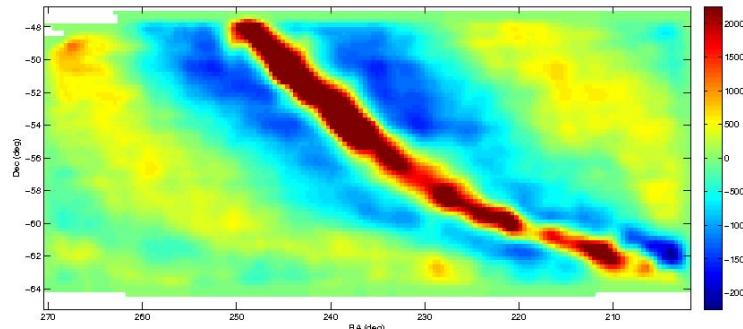
# What did we demonstrate?

- End-to-end umux system
  - Fully integrated with Keck control, DAQ and analysis
- Preliminary maps
- Polarization + sensitivity + systematics analyses on the way



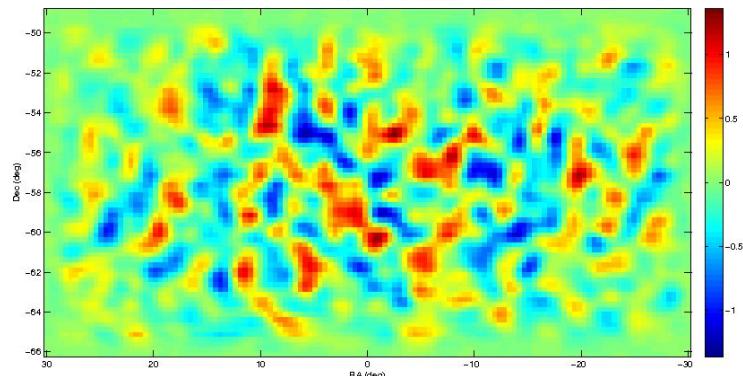
CMB temperature with Planck 143 GHz

maps/4270/real\_4270gal\_20190330\_20190601\_filtp3\_weight3\_gs\_jack04\_intorx.mat, rx1, T\_smooth0p25



Milky Way at 150 GHz with umux

maps/4270/real\_4270cmb\_20190330\_20190601\_filtp3\_weight3\_gs\_jack04\_intorx.mat, rx1, Tivw\_smooth0p25

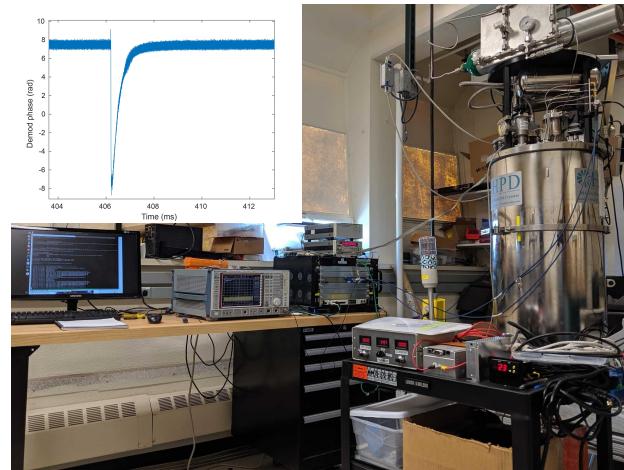
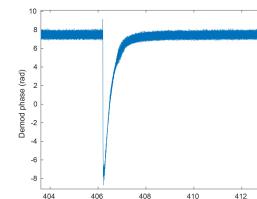


CMB temperature with Keck 150 GHz with umux

# Future of SMuRF

- CMB
  - Simons Observatory
    - Heather McCarrick's talk later this morning
  - BICEP Array 220/270 GHz
- X-ray
  - LCLS-II (Large Coherent Light Source) at SLAC
  - Future satellite missions
- Non-TES LTDs

CMB SMuRF at Princeton, Mar. 2019



X-ray SMuRF at NIST, Jun. 2019

# Questions



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