CMB detectors

Ari Cukierman

SLACmass Neutrino Meeting

Jul. 8, 2020

Neutrino physics from CMB measurements

Presentation from Yuuki Omori and Jessie Muir
CMB-S4 Science Book

- Effective number of neutrino species (N_eff)
  - Sensitive to sterile neutrinos and other light particles
- Sum of neutrino masses

→ Large sky areas at CMB-dominated frequencies (~70-240 GHz) with ~arcmin resolution → large-aperture (5-10 m) telescopes **with lots of detectors**

Optical depth τ from scattering during reionization

- Changes overall normalization of CMB anisotropies

→ Measure large-scale (ell < 20, few-degree resolution) polarization → small-aperture (25-75 cm) telescopes **with lots of detectors**

CMB experiments for dummies

CMB experiments for dummies

Telescope

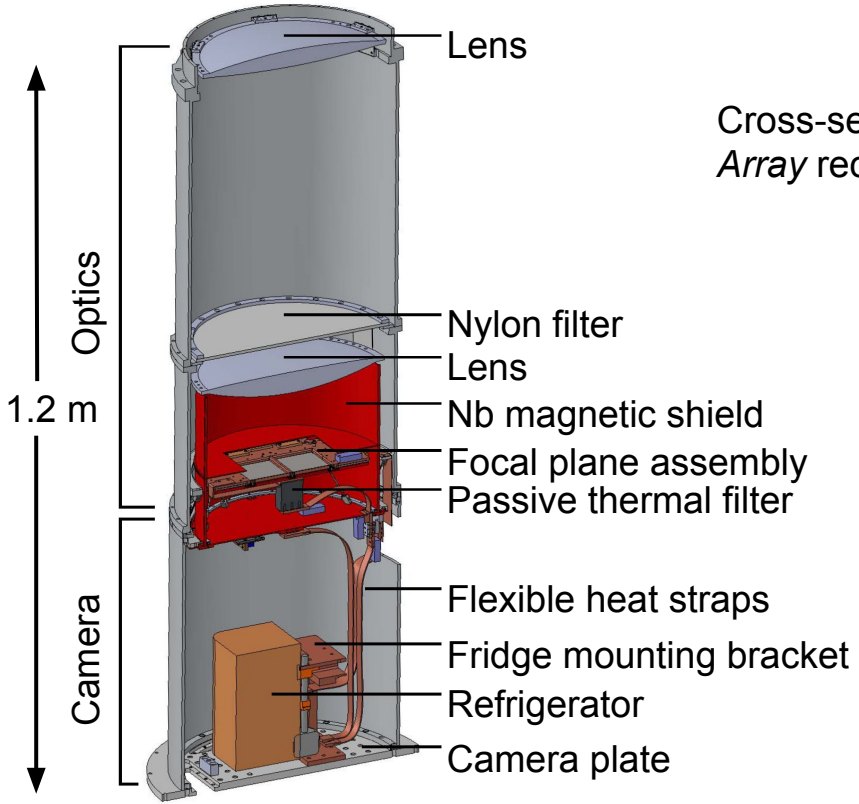
South Pole Telescope (SPT)

BICEP3

CMB experiments for dummies

Telescope

Receiver



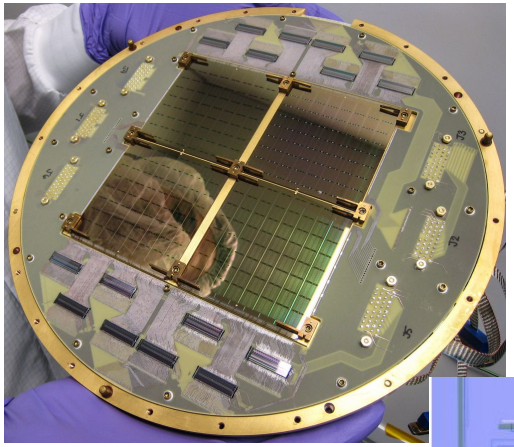
Cross-section CAD of *Keck Array* receiver

CMB experiments for dummies

Telescope

Receiver

Focal plane



Keck focal plane
(250 mK)

Slot antennas +
transition-edge
sensors (TESs)

CMB experiments for dummies

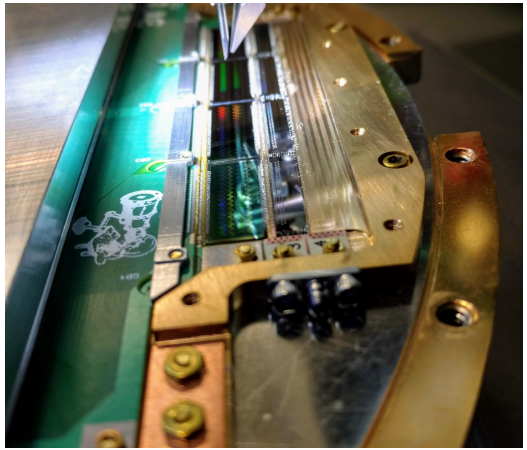
Telescope

Receiver

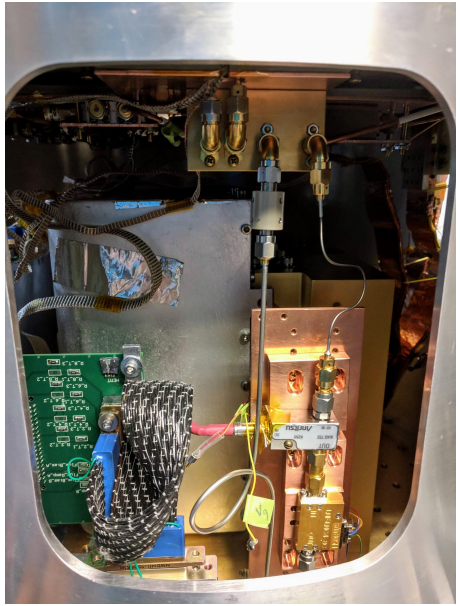
Focal plane

Readout

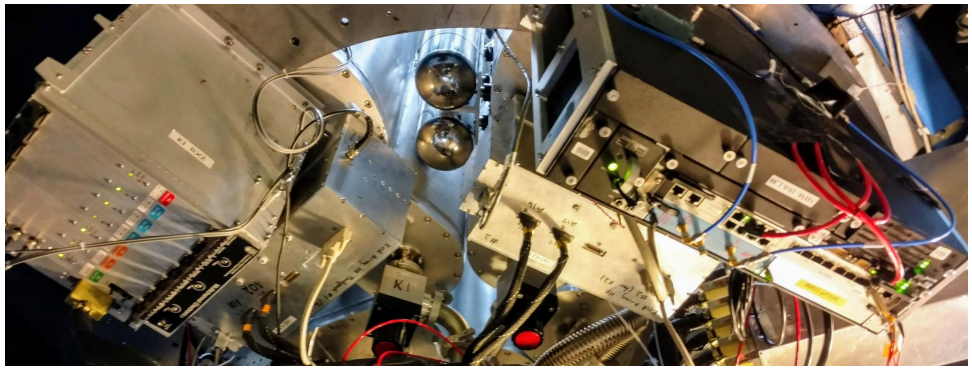
Cryogenic multiplexing components (250 mK)



Intermediate-temperature (4-50 K) amplifiers, leads, etc.



Room-temperature electronics



CMB experiments for dummies

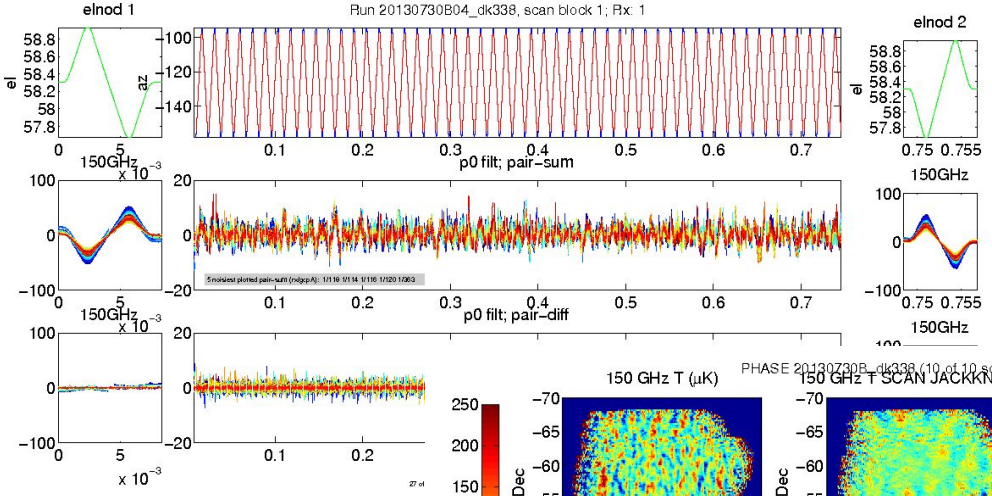
Telescope

Receiver

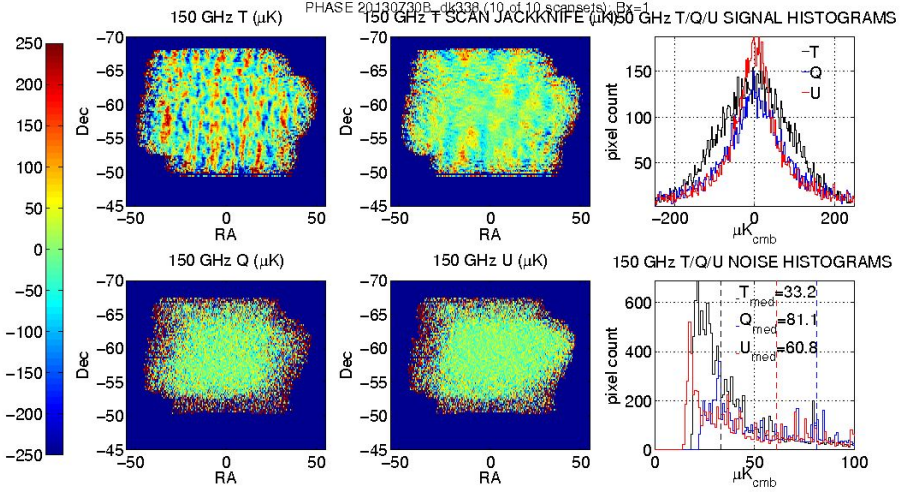
Focal plane

Readout

Data



Time-ordered data (TOD)



Per-observation maps

CMB experiments for dummies

Telescope

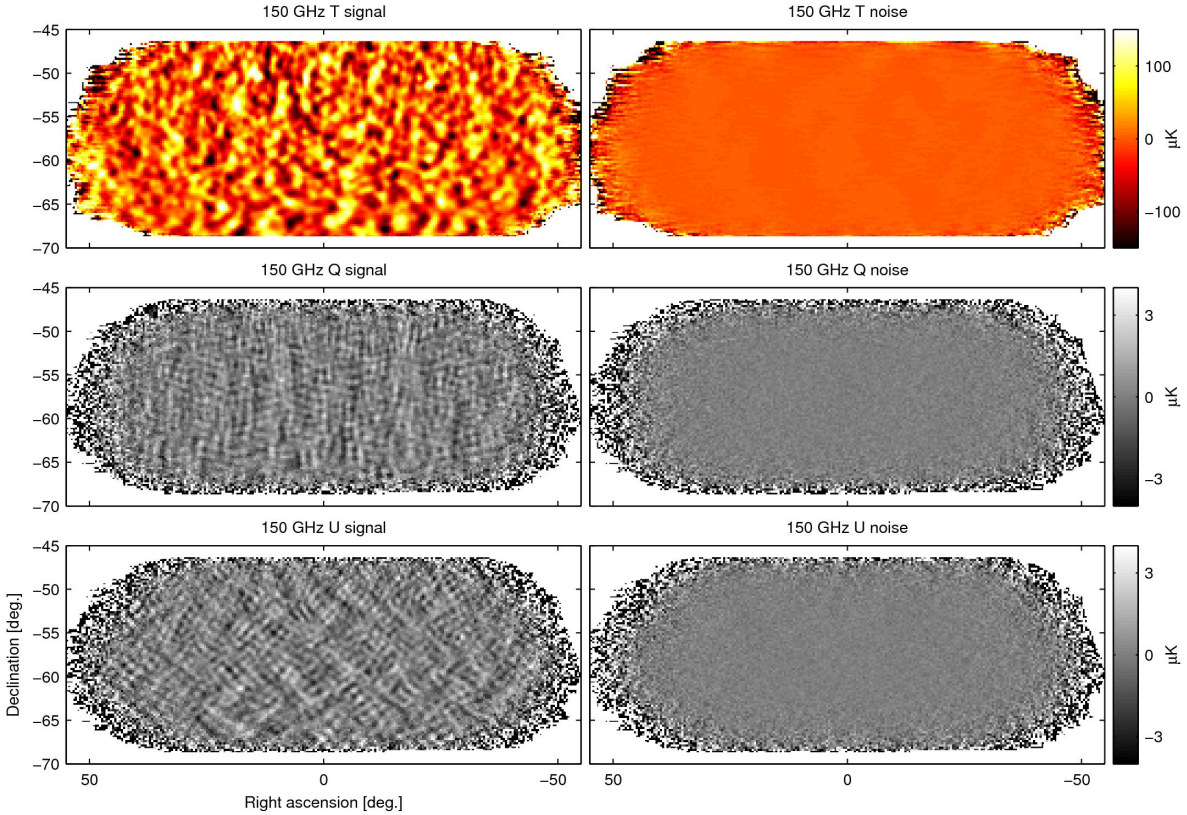
Receiver

Focal plane

Readout

Data

Maps



CMB experiments for dummies

Telescope

Receiver

Focal plane

Readout

Data

Maps

The fun doesn’t stop there, but I will.

- Simulations
- Foreground cleaning
- Power spectrum
- Non-Gaussian statistics
- Cosmological parameter estimation
- Cross correlation

CMB **detectors** for dummies

CMB detectors for dummies

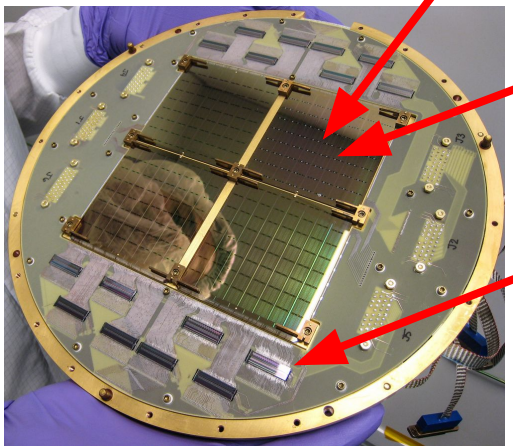
CMB photons

Telescope optics couple radiation to focal plane

Antenna couples radiation to transmission line

Bolometer (detector) converts radiation to heat

Readout circuit converts temperature to current



Keck Array focal plane

CMB-S4 Technology Book

Detector fabrication

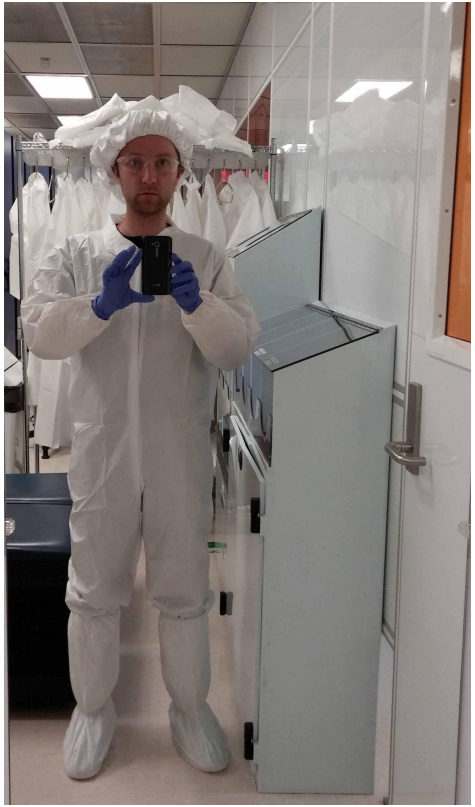
Class-100 clean rooms

~10-layer process

UV photolithography

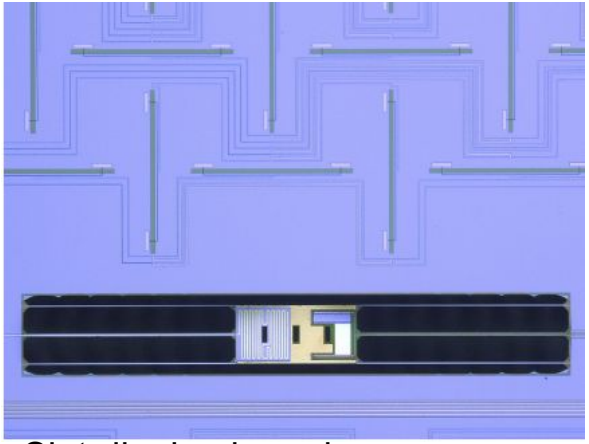
- Smallest features are ~0.5 um

CMB fabrication sites have been Berkeley, NIST (Boulder), JPL, Argonne

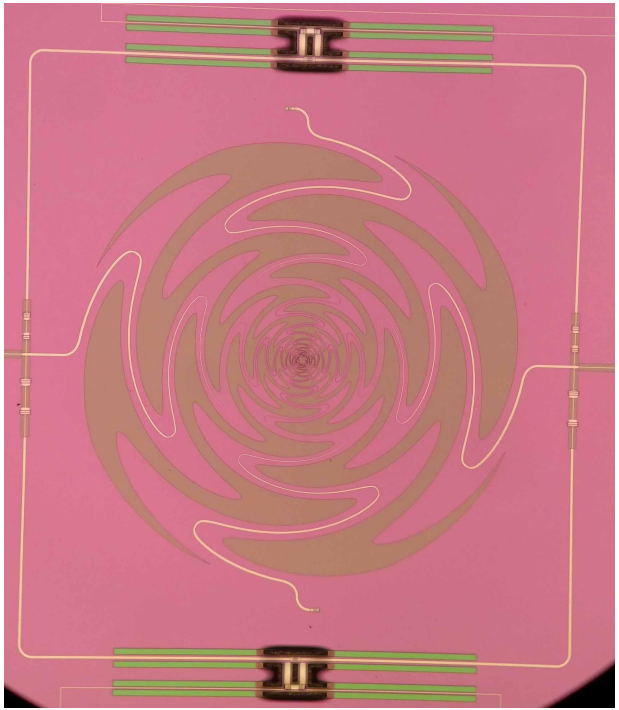


Portrait of the artist as a third-year graduate student

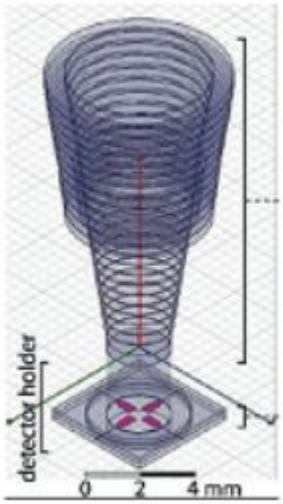
Antennas

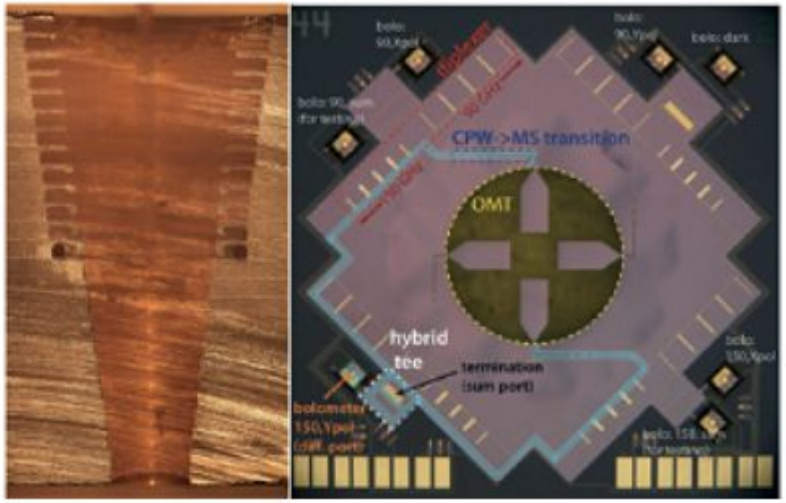


Slot-dipole phased array



Sinuous antenna

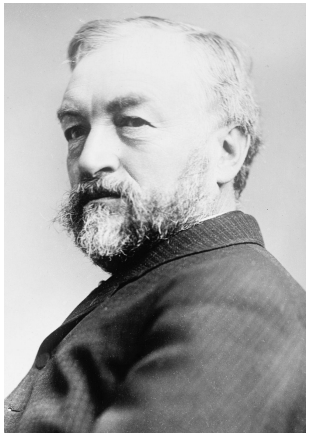




Feedhorn coupled to orthomode transducer

Bolometers

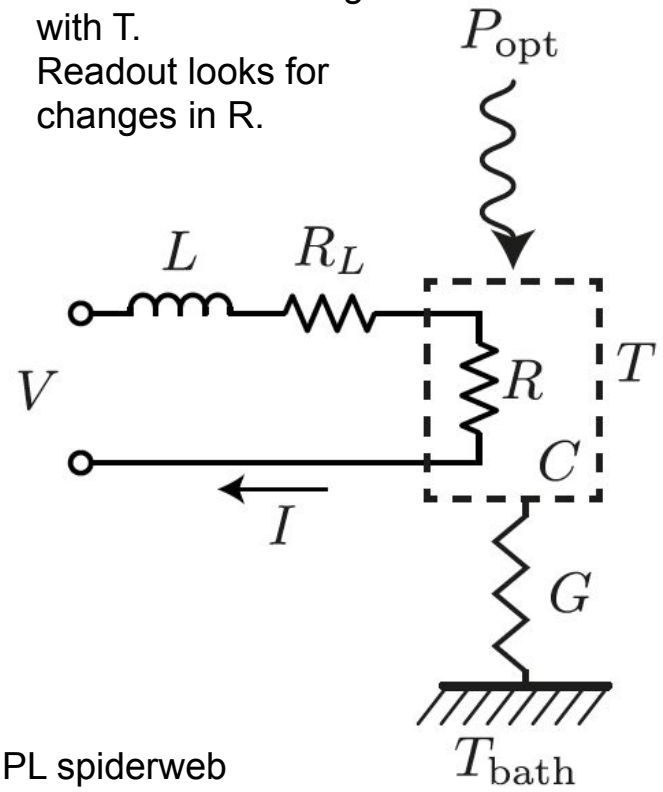
*Oh, Langley devised the **bolometer**.*
It's really a kind of thermometer
That can measure the heat
From a polar bear's feet
At a distance of half a kilometer.



Samuel P. Langley (1834-1

JPL spiderweb bolometer

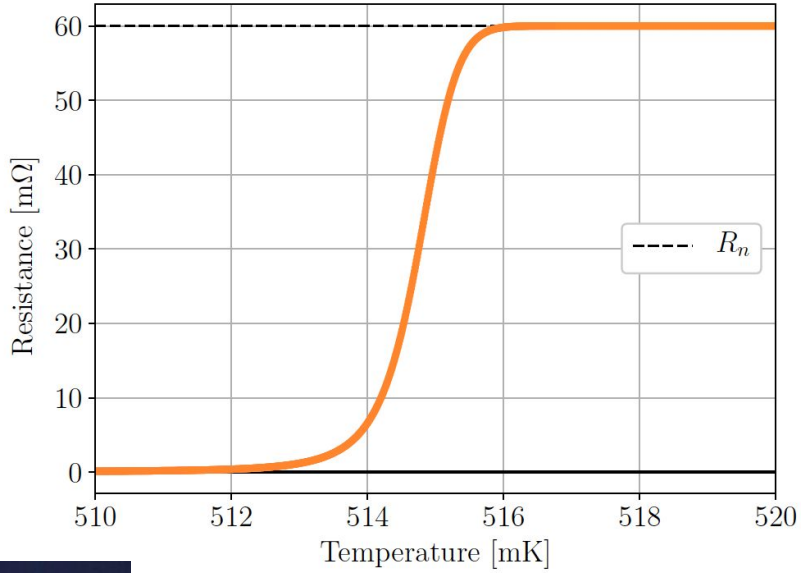
Thermistor R changes with T.
Readout looks for changes in R.

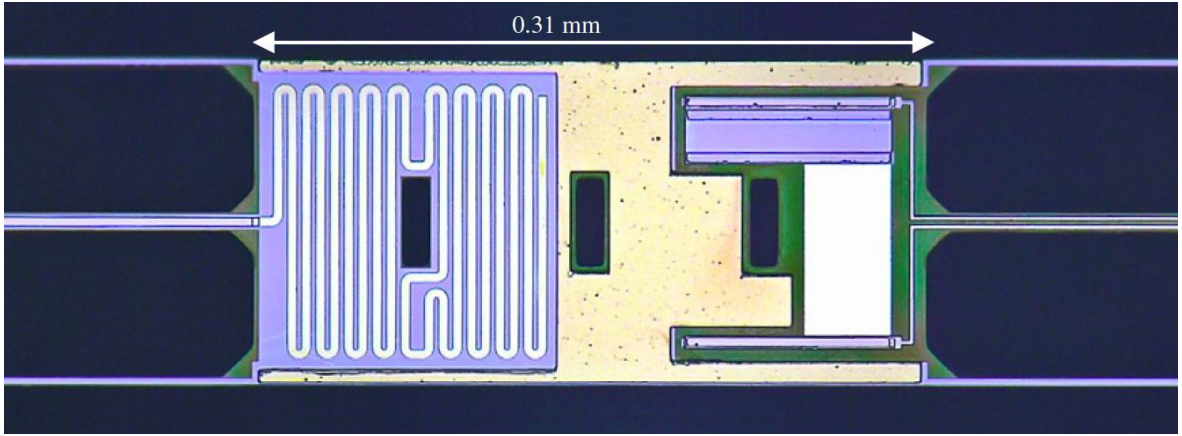


Transition-edge sensor (TES)

Irwin, Hilton, 2005

Steep temperature dependence near superconducting transition



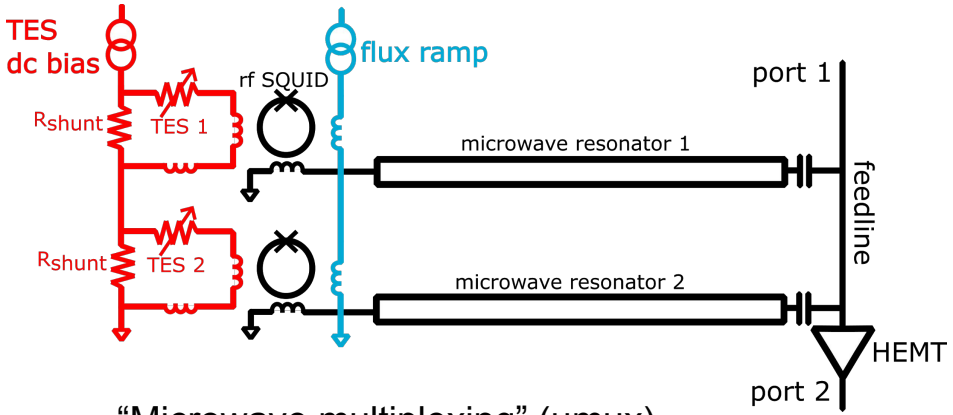


BICEP TES

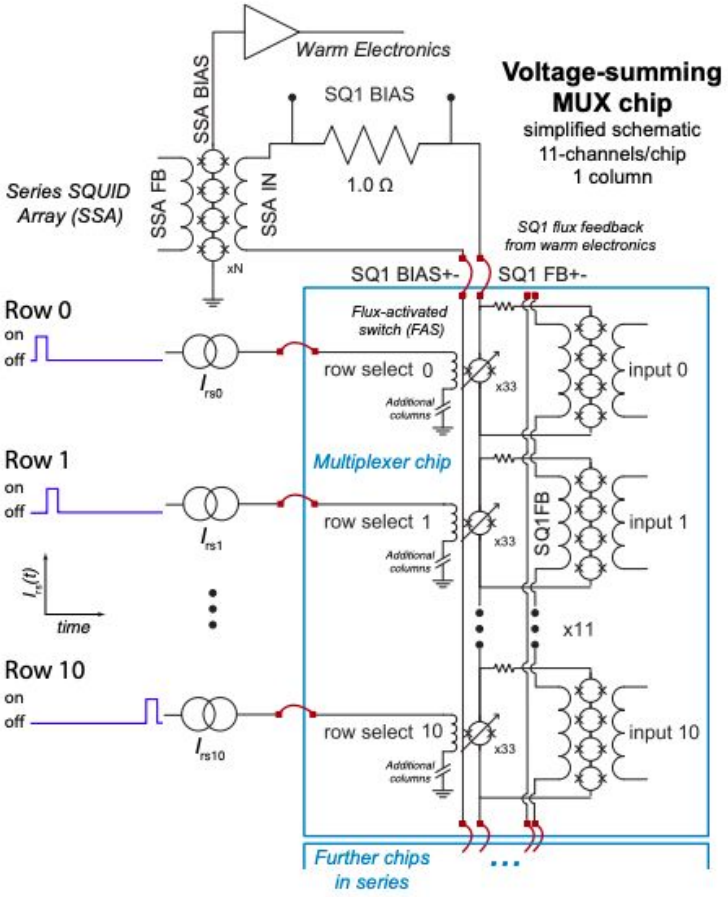
Readout multiplexing

Address multiple (50-2000) detectors with a single cable

→ Simplification + thermal insulation



"Microwave multiplexing" (μmux)



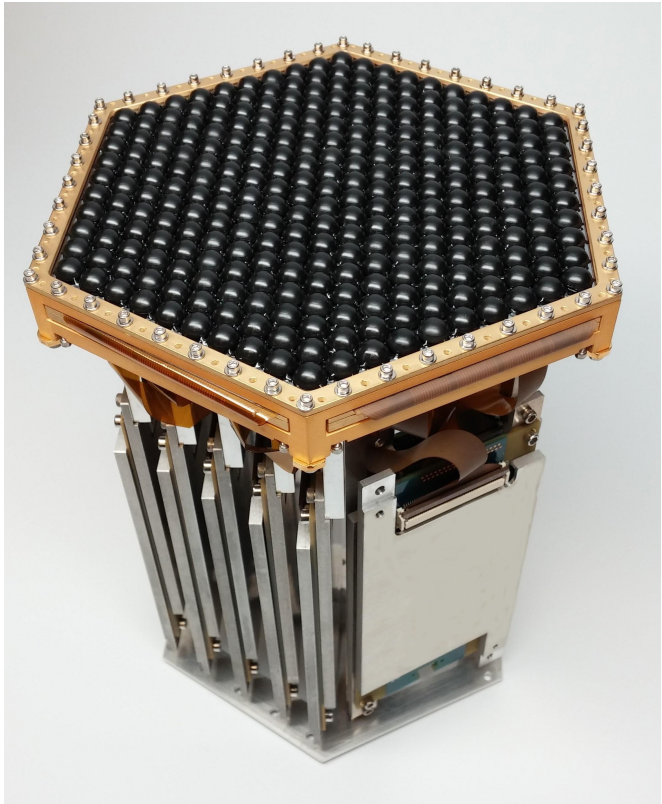
Time-division multiplexing (TDM)

Detector arrays

O(1000) TESs per wafer

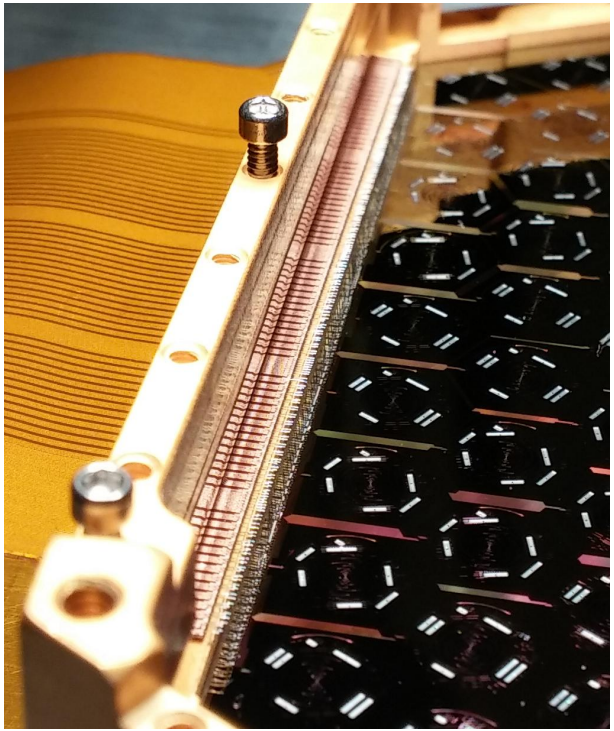
6” wafer fabrication

“Detector module” integrates detectors with cryogenic readout components



POLARBEAR-2 detector module

Lots of wire bonds bring TES leads off wafer



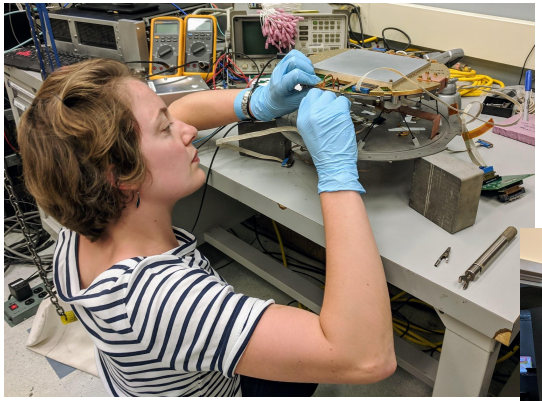
Integration and testing

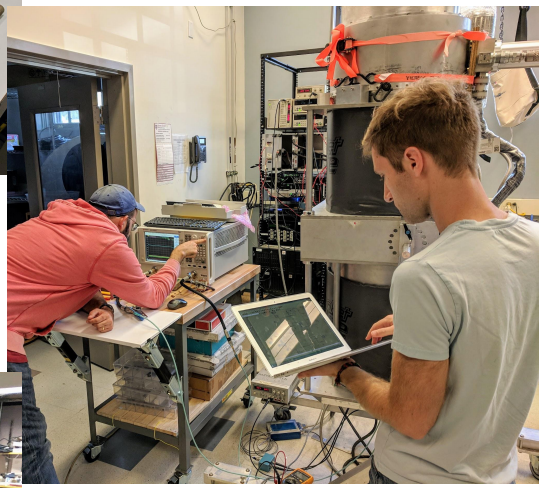
Install detectors and readout in cryostat

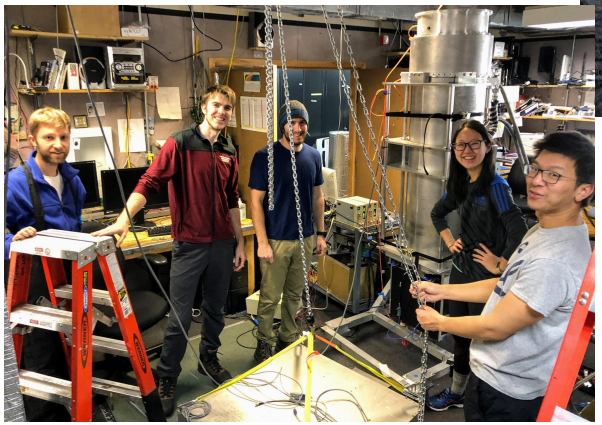
Cool to O(100 mK)

- Takes days/weeks

Test TESs, readout, data handling, control software, antennas, microwave circuitry, cryogenics, etc.







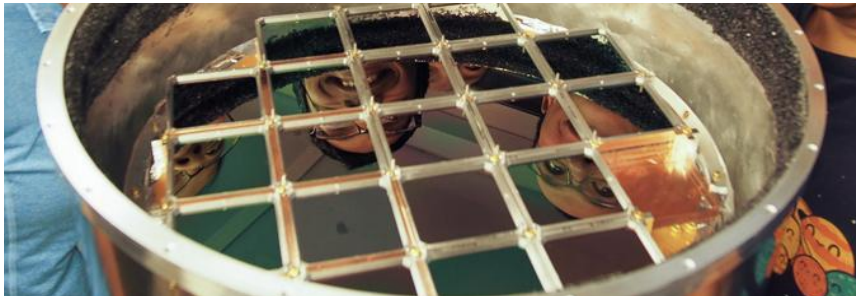
SLAC/Stanford

Integration & testing

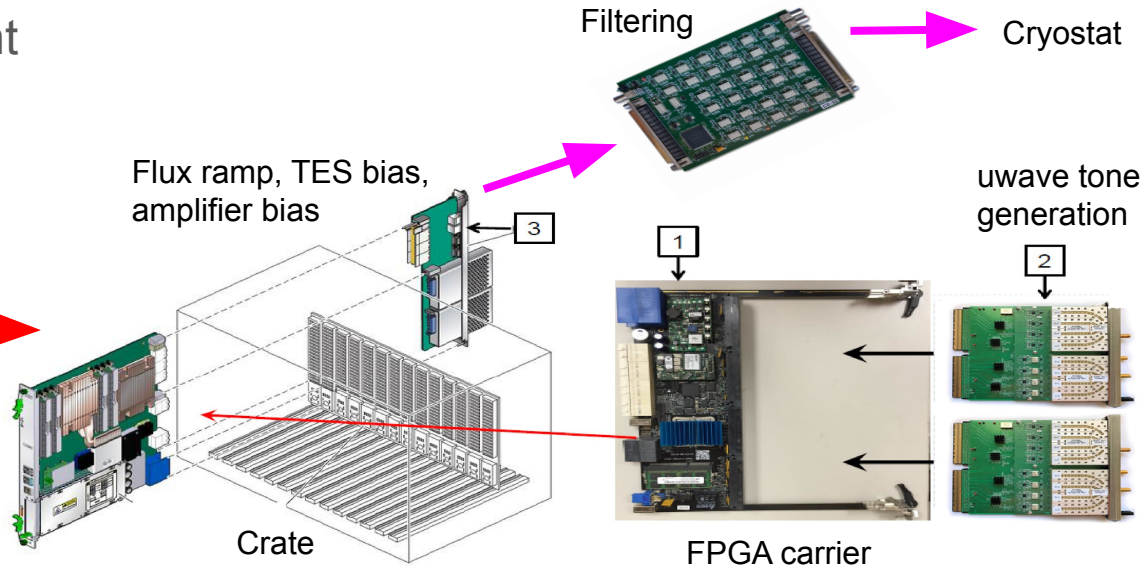
- Chao-Lin Kuo, Zeeshan Ahmed
- BICEP3 integration
- BICEP, SPT testing and technology development

Microwave multiplexing (umux)

- Kent Irwin, Zeeshan Ahmed, Joe Frisch
- SMuRF electronics
- Testing
- Development



BICEP3 focal plane



Cosmic neutrino background

Cosmic neutrino background (CνB)

Neutrinos decouple at t ~ 1 s (T ~ 1 MeV)

- Freestreaming neutrinos form CνB
- Cosmic neutrinos dominate at T ~ meV today

Tritium endpoint

- Distinguish beta decay from neutrino capture
- Look for electrons beyond the tritium beta-decay endpoint
- Must resolve the endpoint (similar to neutrino mass experiments)

PTOLEMY

- ~100 g tritium → O(10) events per year