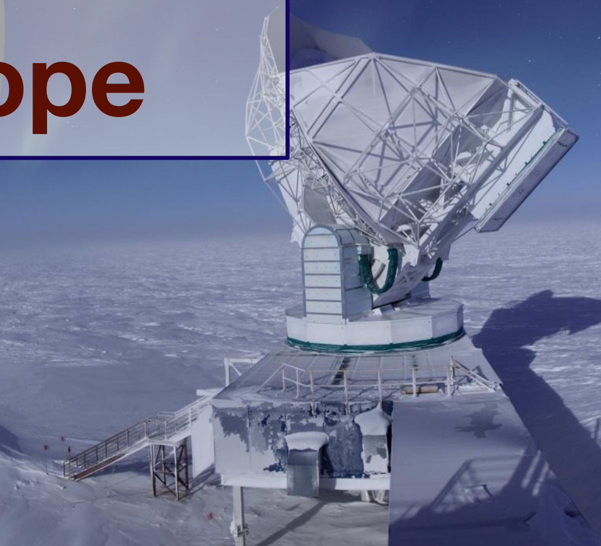


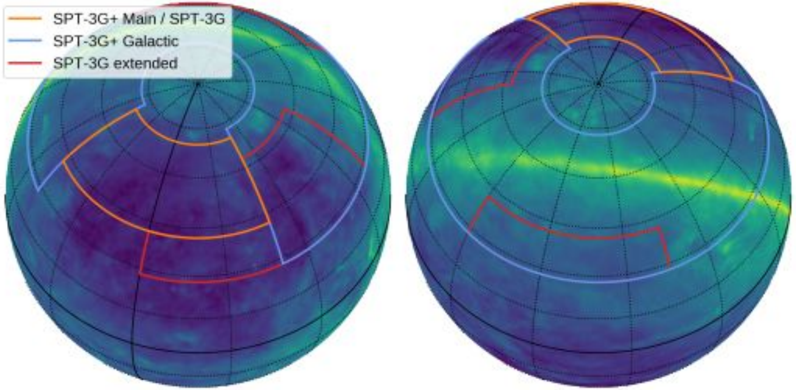
MKID development for the SPT-3G+ camera on the South Pole Telescope

Karia Dibert
(for the SPT-3G+ collaboration)
CPAD 2023

Images:
J. Gallicchio, T. Cecil

SPT-3G+: A new camera for the South Pole Telescope

J. Gallicchio



A. Anderson

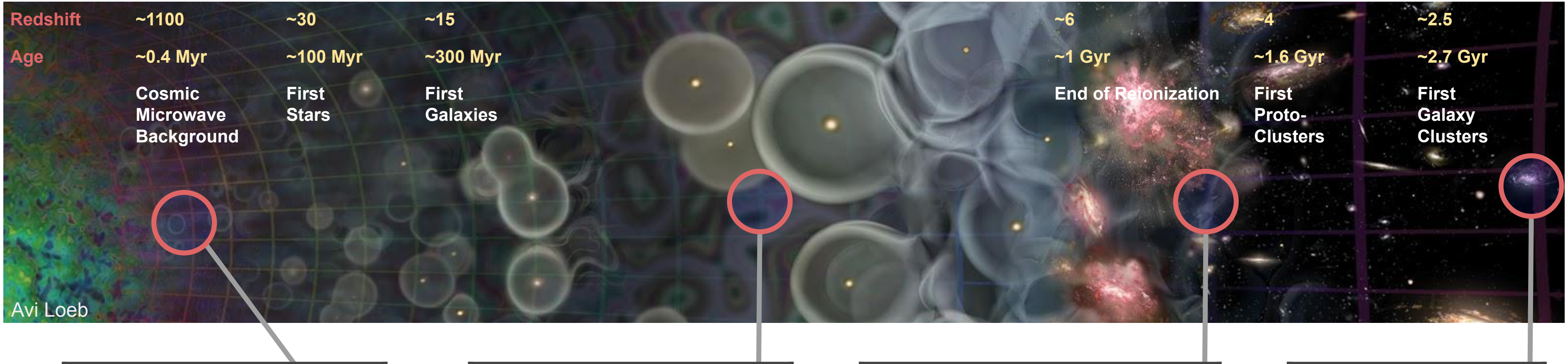
The South Pole Telescope

- 10-meter millimeter/submillimeter telescope that observes the Cosmic Microwave Background (CMB)
- Uniquely dry & stable South Pole atmosphere is ideal for CMB observations.
- Currently equipped with SPT-3G camera:
    - Observes the CMB at 95, 150 and 220 GHz
    - 14,000 TES bolometers

SPT-3G+ Survey

- High-frequency, high-sensitivity complement to the SPT-3G dataset!
    - Will observe at 220, 285, and 345 GHz
- On-sky demonstration of detector technology
    - The camera will consist of 34,000 Microwave Kinetic Inductance Detectors (MKIDs)

SPT-3G+ Science



Recombination

First detection of Rayleigh scattering of the CMB, a new probe of cosmic expansion and ionization history.

Reionization

Constrain the time and duration of reionization via the kinematic Sunyaev-Zel’dovich effect.

Galaxy & Cluster Growth

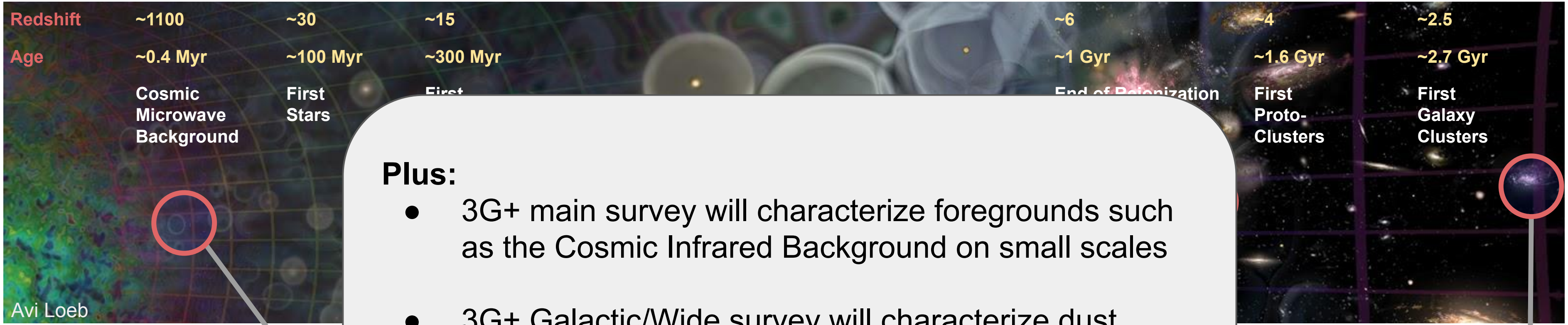
Detect dusty emission from very distant massive galaxies and clusters to learn more about their formation and evolution.

Cluster Finding

Identify new galaxy clusters via the thermal Sunyaev Zel’dovich effect.

Anderson, et al. 2022 - arXiv:2208.08559

SPT-3G+ Science



Plus:

- 3G+ main survey will characterize foregrounds such as the Cosmic Infrared Background on small scales
- 3G+ Galactic/Wide survey will characterize dust emission for wide-field lensing reconstruction and study small-scale galactic magnetic fields
- 3G+ will extend SPT transient measurements into the VRO/LSST area at mm/sub-mm wavelengths

Recombination

First detection of Rayleig
scattering of the CMB, a
new probe of cosmic
expansion and ionization
history.

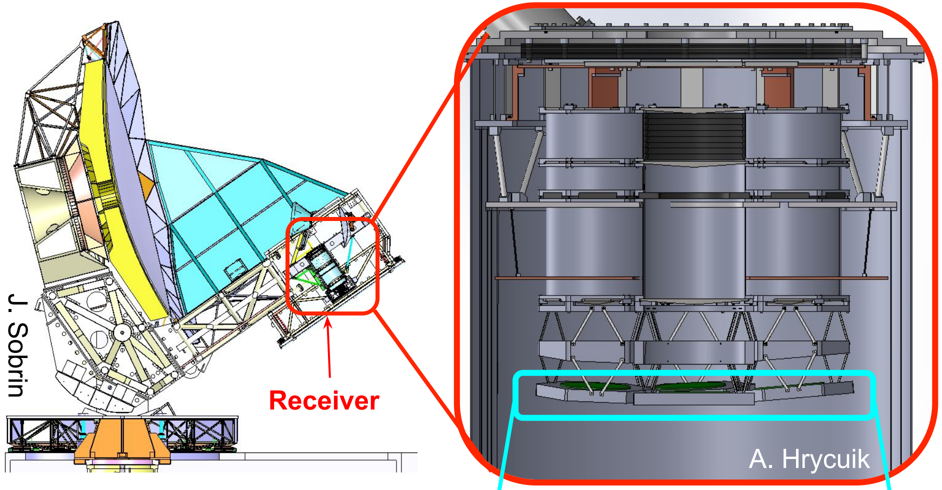
Cluster Finding

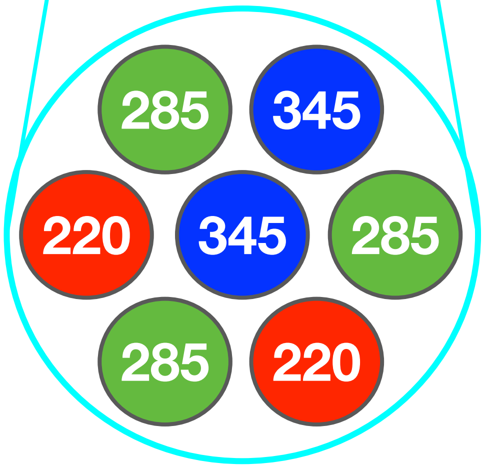
Identify new galaxy clusters via the thermal Sunyaev Zel’dovich effect.

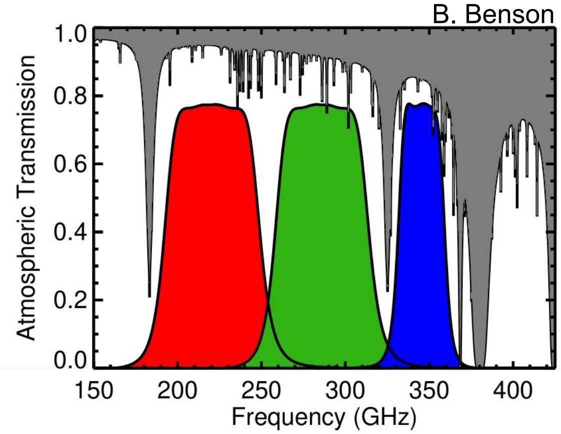
Anderson, et al. 2022 - arXiv:2208.08559

SPT-3G+ Receiver

- Seven separate optics tubes, each illuminating a wafer of 4800 monochroic polarization-sensitive MKIDs.
    - MUX goal is 800 detectors per 500 MHz readout bandwidth, or 6 feedlines per wafer.
    - **34k total detectors.**
    - Readout with McGill RF-ICE system modified for MKID readout (Rouble, et al. 2023 - arXiv:2310.07657)
- Separate optics tubes allow for individual wafer upgrades - potential future platform for Line Intensity Mapping (see talk by K. Karkare)

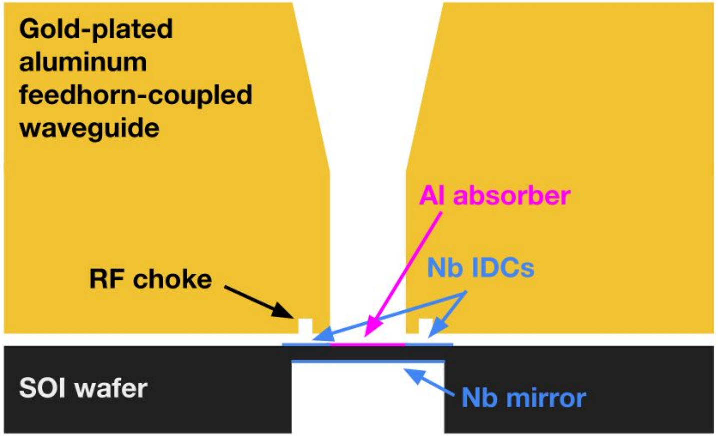




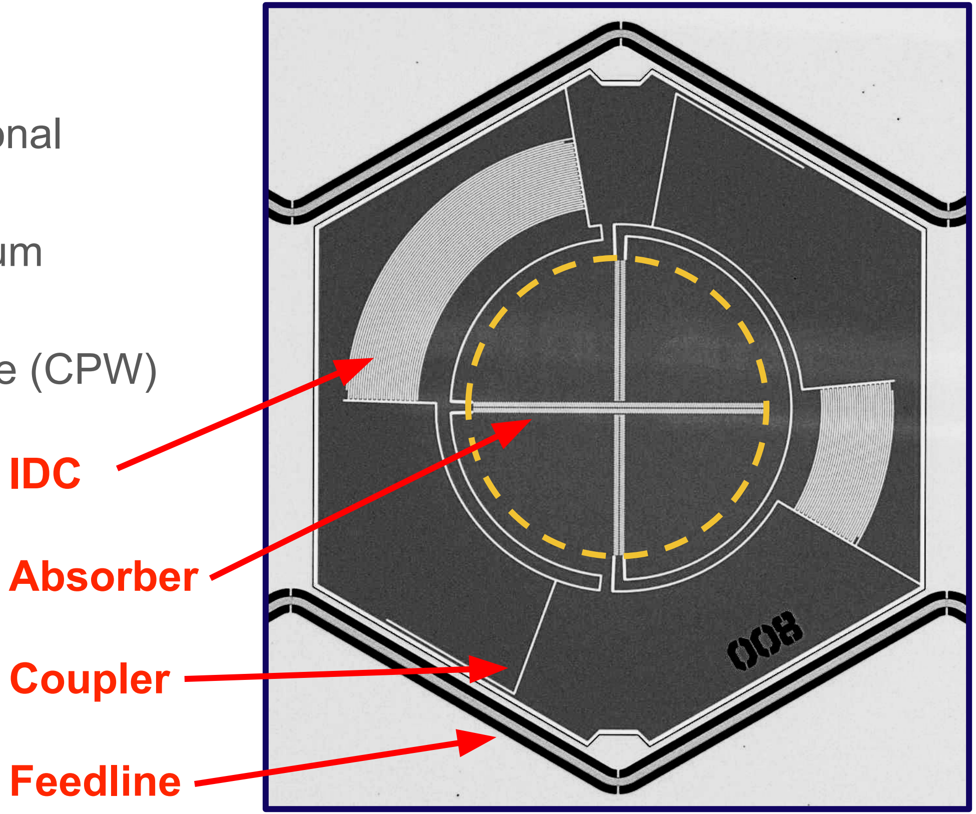


Pixel design

- Feedhorn-coupled single-frequency direct-absorber MKID
- 2x detectors per pixel, coupled to orthogonal polarization modes
- Aluminum inductors/absorbers and niobium interdigitated capacitors (IDCs)
- Feedline is a niobium coplanar waveguide (CPW)

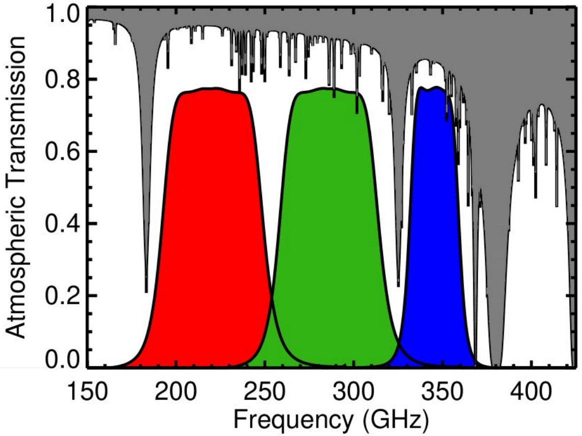


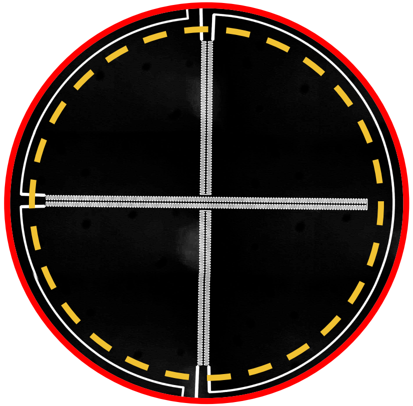
Dibert, Barry et al. 2022 - arXiv:2111.04816



Absorber design

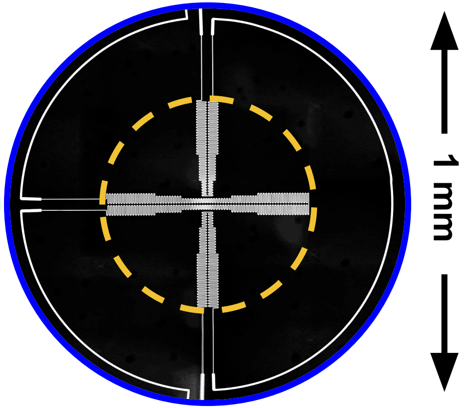
- Aluminum inductors meander to achieve the necessary volume to support the expected optical load (~5-10 pW) at the South Pole.
- Simulations indicate good (~80-90%) optical coupling and low (~2-3%) cross-polarization pickup.





220 GHz

285 GHz



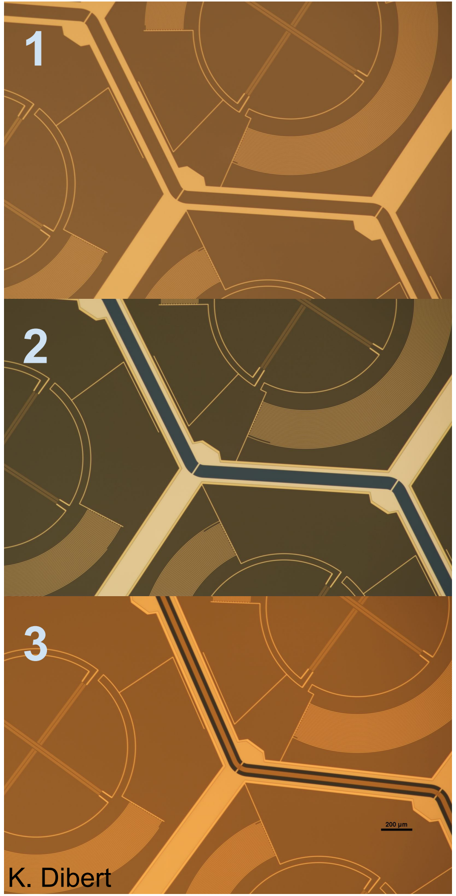
345 GHz

Images: B. Benson, T. Cecil, K. Dibert

Device fabrication

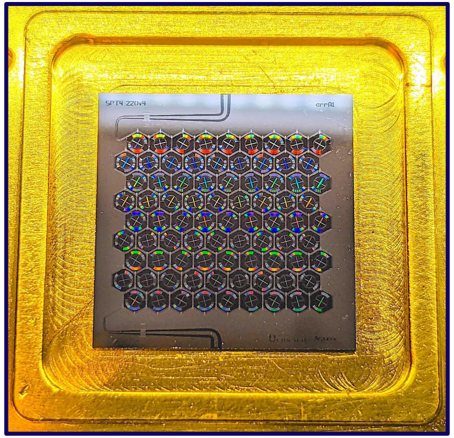
- Device fabrication process:
  - Inductors/absorbers (30nm Al)
  - IDCs, ground plane, CPW bridges (120nm Nb)
  - Bridge layer (150nm SiO2) ← *for now!*
  - Feedline (200nm Nb)
- Initial prototypes are fabricated at UChicago (me), and larger arrays of chips/subarrays are fabricated at Argonne.
  - Eventually, deployment-grade arrays will be made at Argonne
- More work at Argonne on SPT-3G+ fab:
  - Galvanic contact via NbN interface and SiN membrane stepdown (Cecil, et al. 2023, arXiv:2304.00973)
  - Response of two-level-system noise to IDC geometry (Pan, et al. 2023, arXiv:2304.01133)
  - Effect of varying inductor linewidth on resonant frequency scatter (Li, et al. 2022, arXiv:2203.17244)

CPW fabrication process

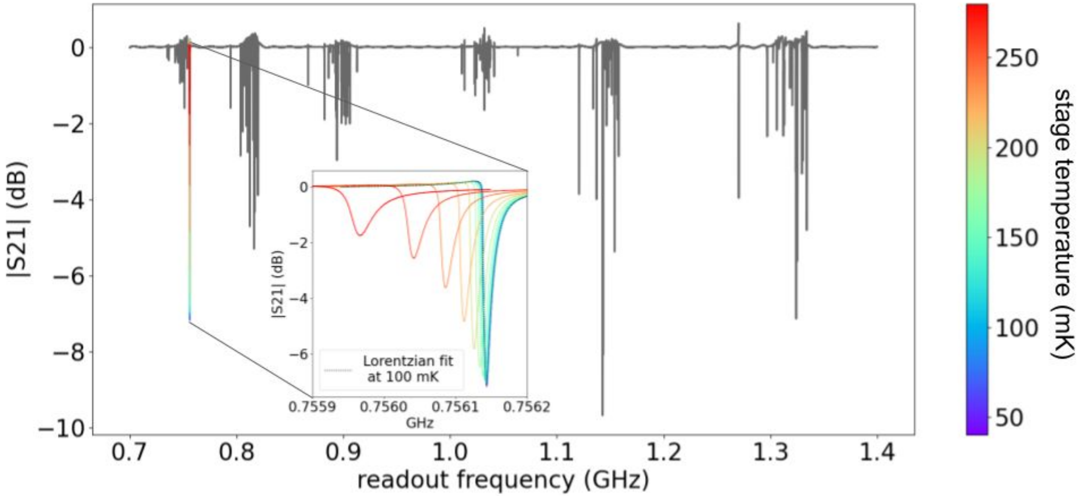


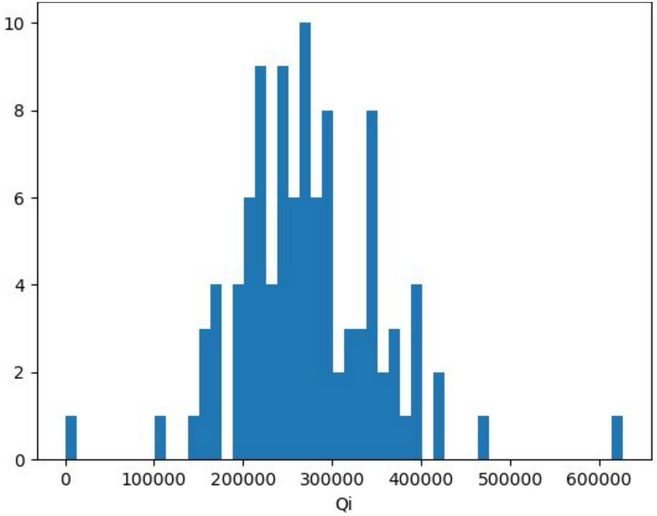
K. Dibert

Dark tests look good for 1x1 inch chips!



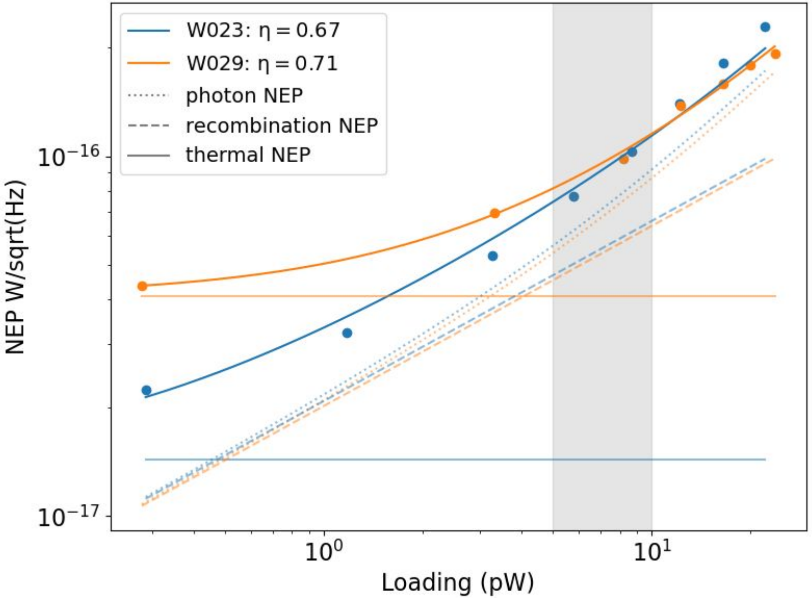
Repeatedly achieved mean Qi > 100k and the expected response to stage heating from these test chips, each with 50-80 pixels.

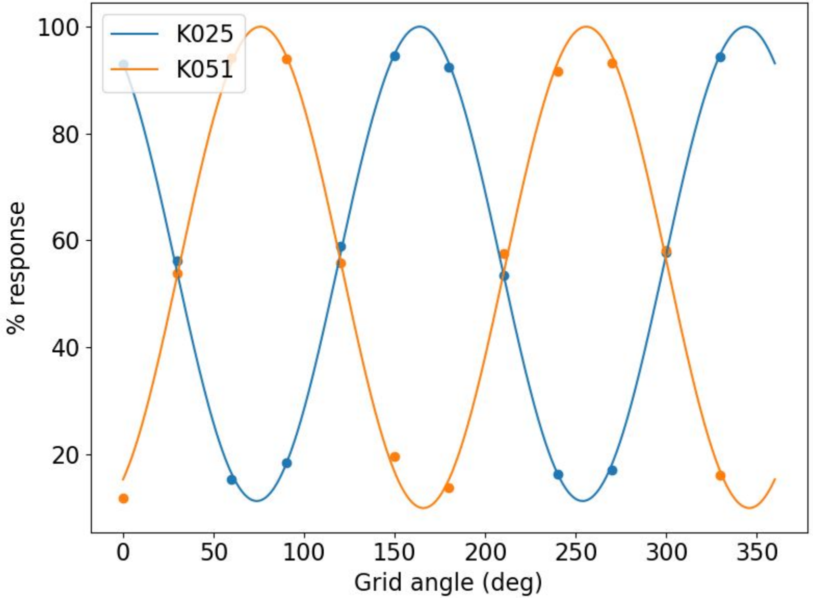




Optical testing for 220 GHz

Dibert, et al. 2023 - arXiv:2304.01158

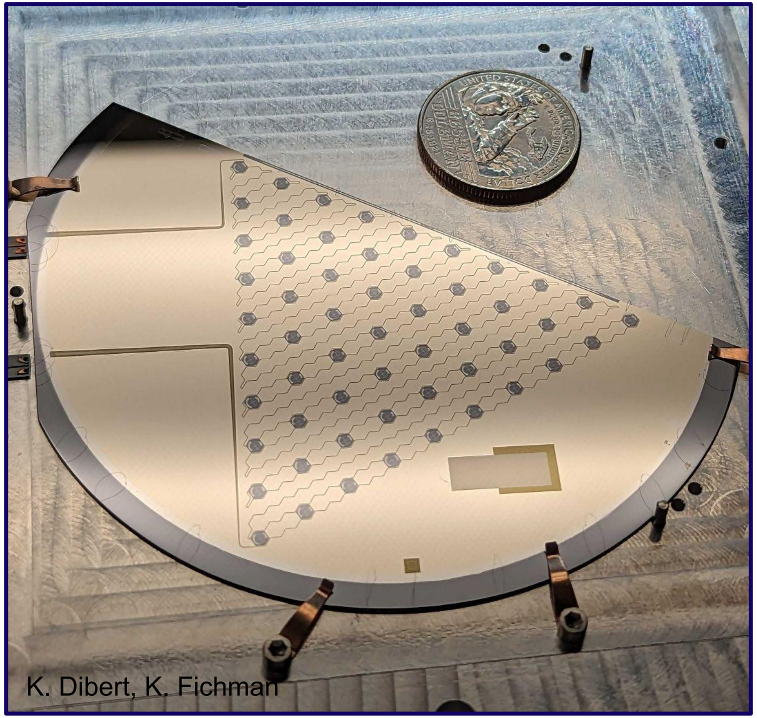




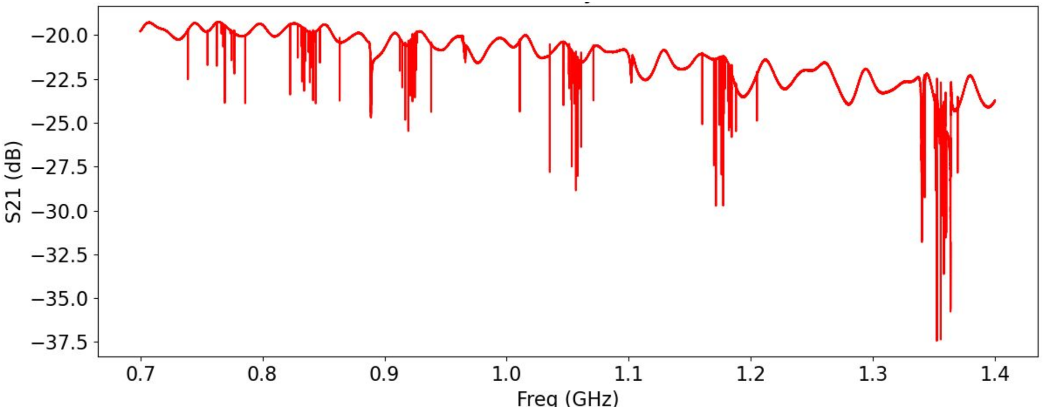
- We see background-dominated response from 220 GHz detectors at the expected SPT optical loading (grey band).
- Fit to NEP vs loading gives ~70% optical efficiency (from feedhorn to detector).

- We see the expected response to polarization angle for two orthogonally-aligned detectors
- Cross-polarization pickup of < 10% (conical feedhorn included)

Scaling up to deployment-sized arrays



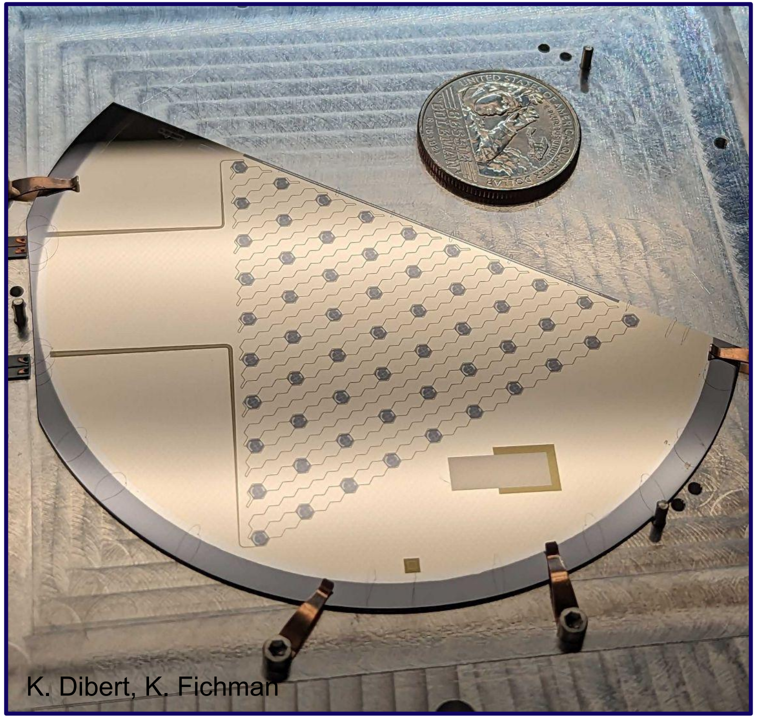
1/7 filled triangle subarray feedline test
UChicago 100mm wafer



Mean Qi ~ 200k
Yield 91% (101/110)

Same as the 1x1 inch chips, so add more pixels!

Scaling up to deployment-sized arrays


K. Dibert, K. Fichman

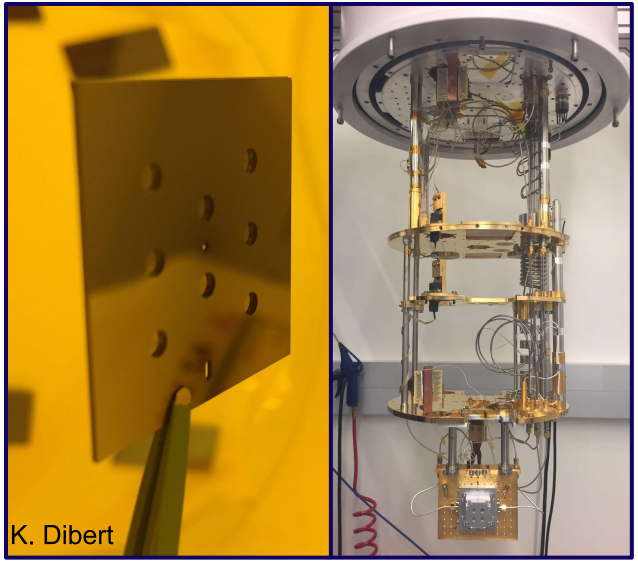
1/7 filled triangle subarray feedline test
UChicago 100mm wafer


New!

T. Cecil

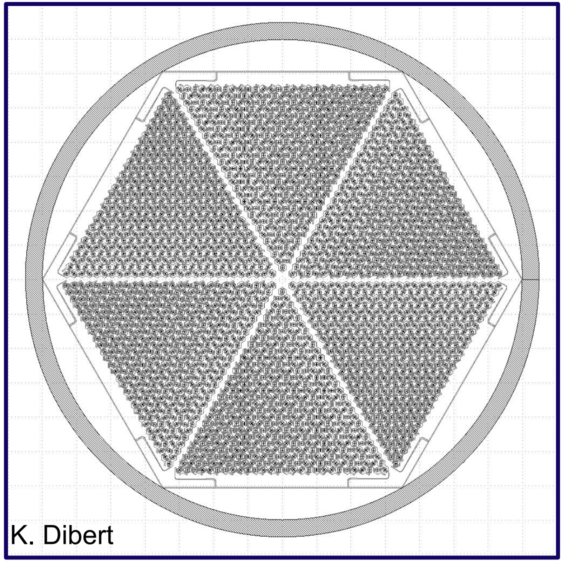
1/4 filled triangular subarrays for 3 bands
Argonne 150mm wafer

Upcoming plans


K. Dibert

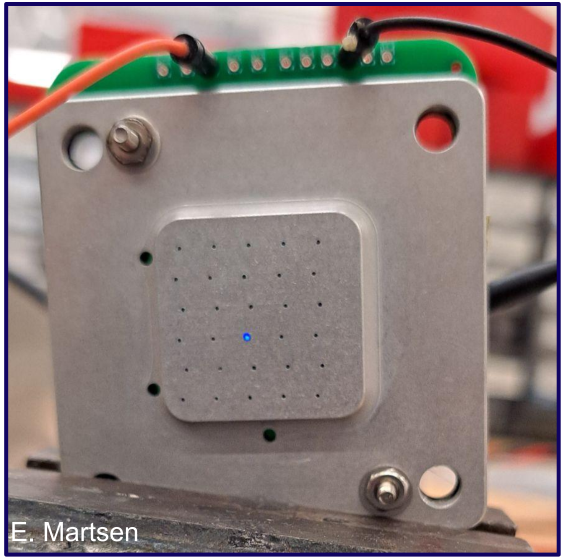
Fabrication and optical testing of 345 GHz and 285 GHz prototype chips on appropriate SOI wafers.

- Repeat the process that we did for 220 GHz!


K. Dibert

Fabrication and dark testing of fully-filled subarrays.

- 150mm wafers will be fabricated at Argonne!


E. Martsen

Pixel identification via LED mapper for post-fabrication IDC trimming - necessary for mux goals.

Thank you!

Argonne
NATIONAL LABORATORY

Berkeley
UNIVERSITY OF CALIFORNIA

Fermilab

SLAC

CARDIFF
UNIVERSITY
PRIFYSGOL
CAERDYDD

McGill
UNIVERSITY

THE UNIVERSITY OF CHICAGO

University of Colorado
Boulder

CfA

Email: krdibert@uchicago.edu