CMB instrumentation and detectors

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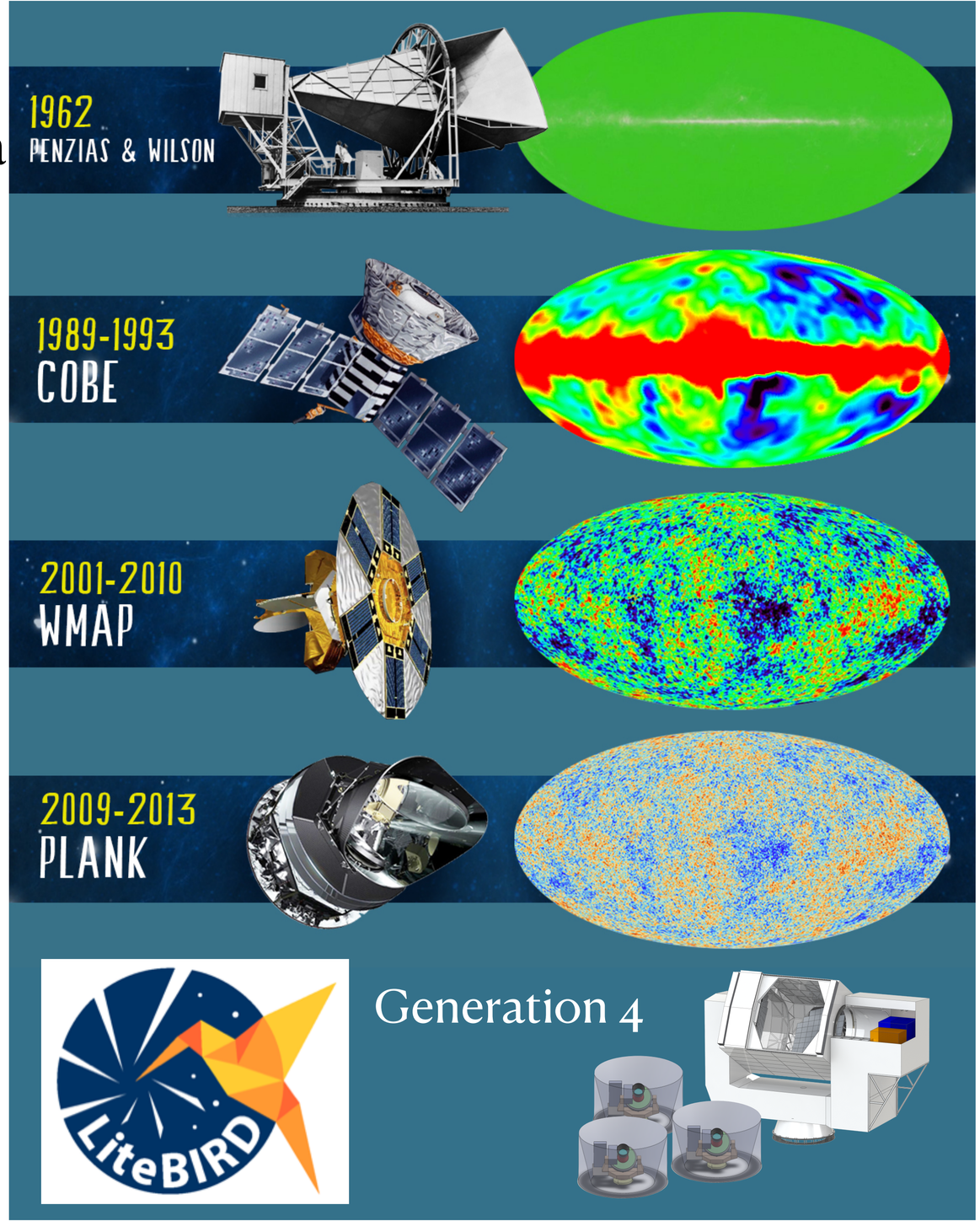
Horn antenna

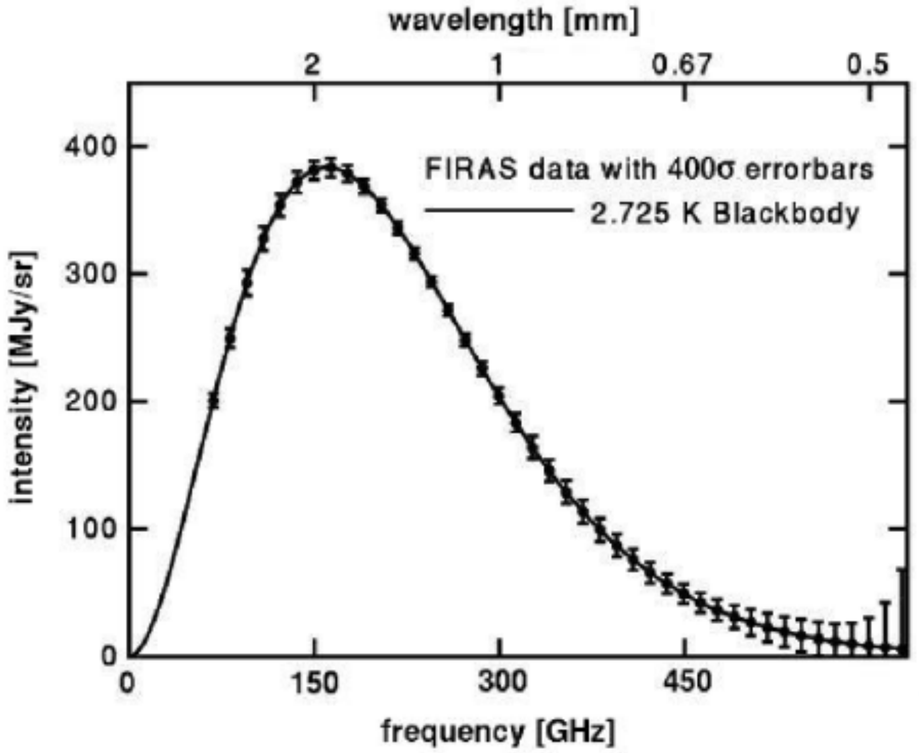
Microwaves Radiometer

Microwaves Radiometer

Antenna + bolometers (54 detectors)

Thousand Superconducting Transition Edge Sensor (TES)





- The energy of CMB photons

$$E_{CMB} = \sim 1 \text{ meV}$$

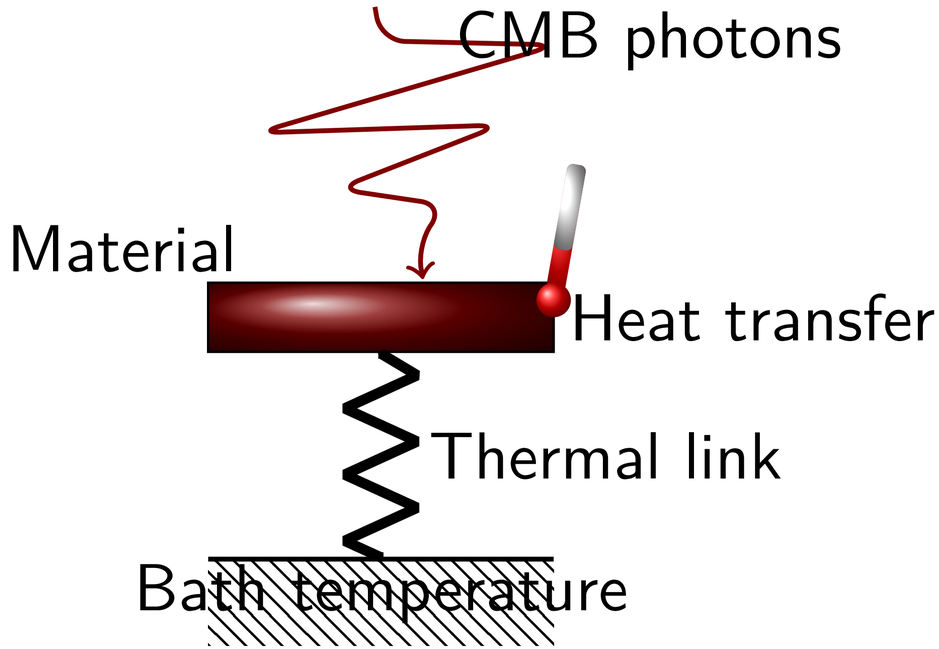
- CMB is a black body, the peak frequency

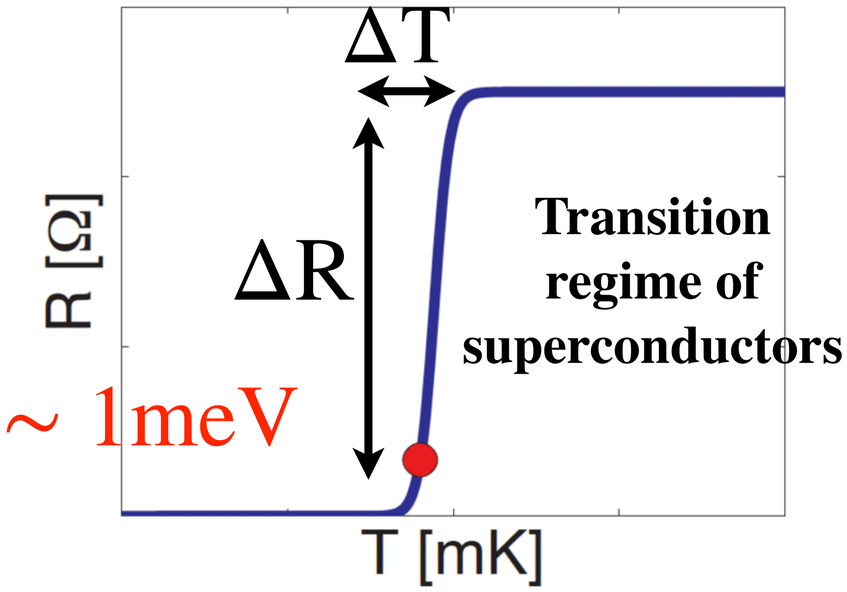
$$\nu_{max} \sim 150 \text{ GHz or}$$

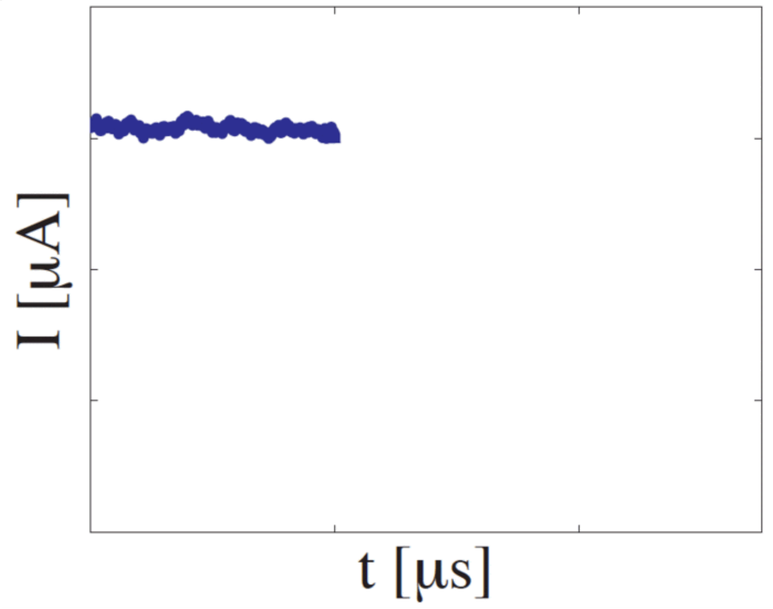
$$\lambda_{max} \sim 2 \text{ mm}.$$

Superconducting Transition Regime

Temperature measurement!

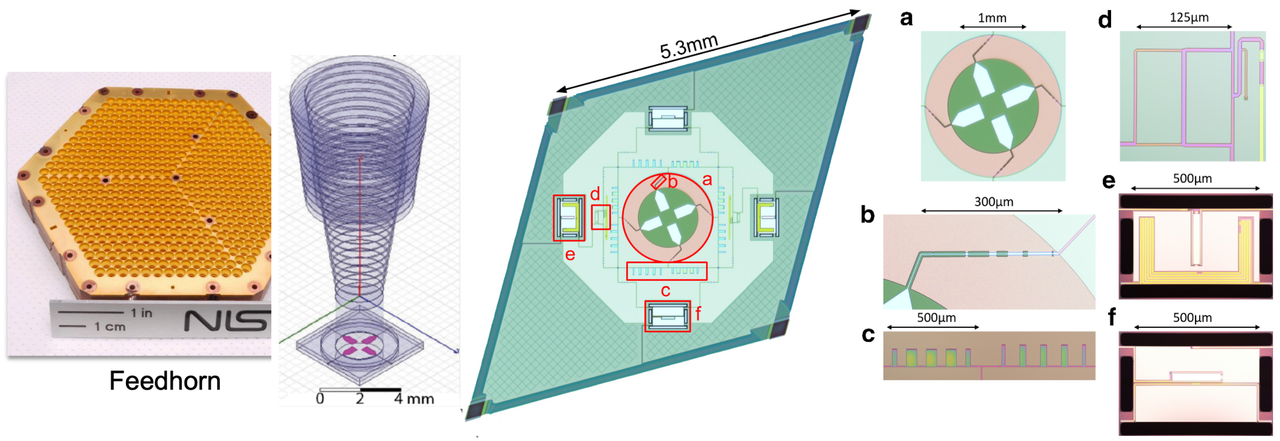




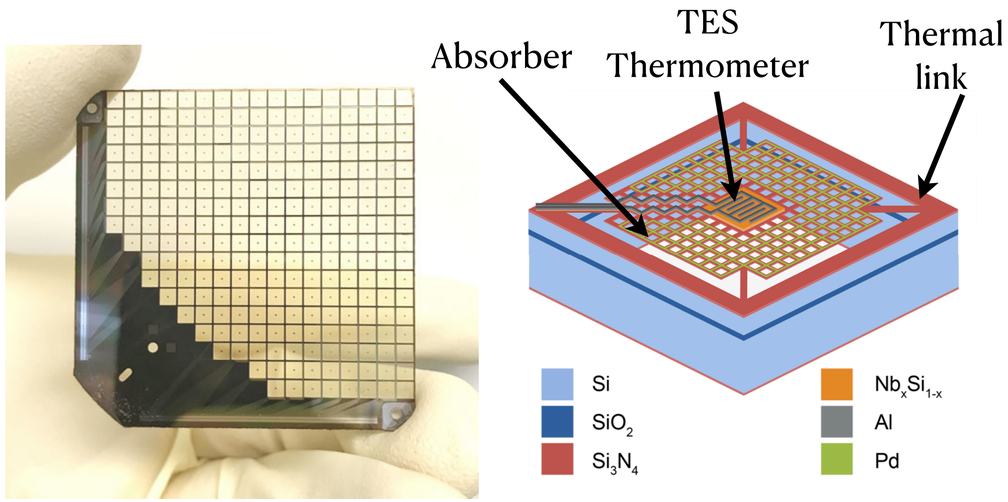


- **Transition Edge Sensor (TES)**: A thermometer made from a superconducting film operated near its transition temperature.

TES Array Technology (mm scale)

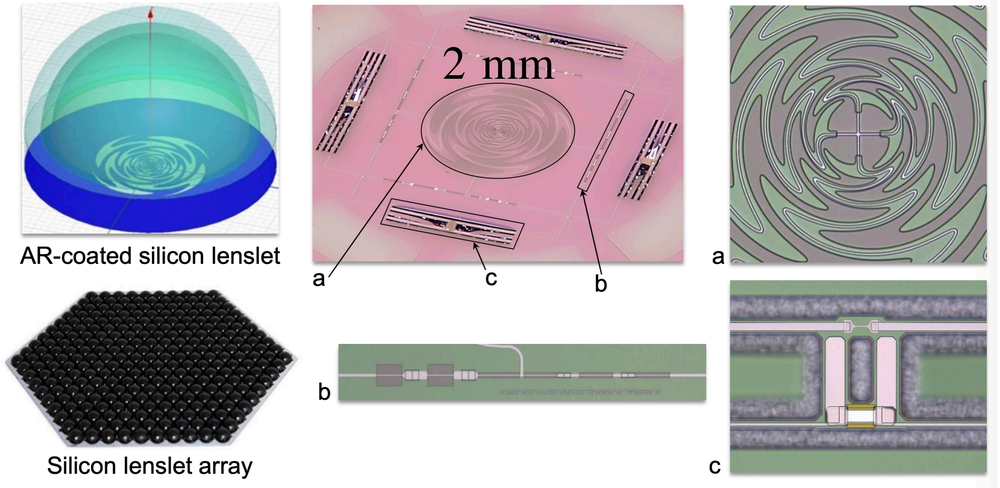


NIST: feed-horn technology: ACT, SPT, LiteBIRD (High frequency)

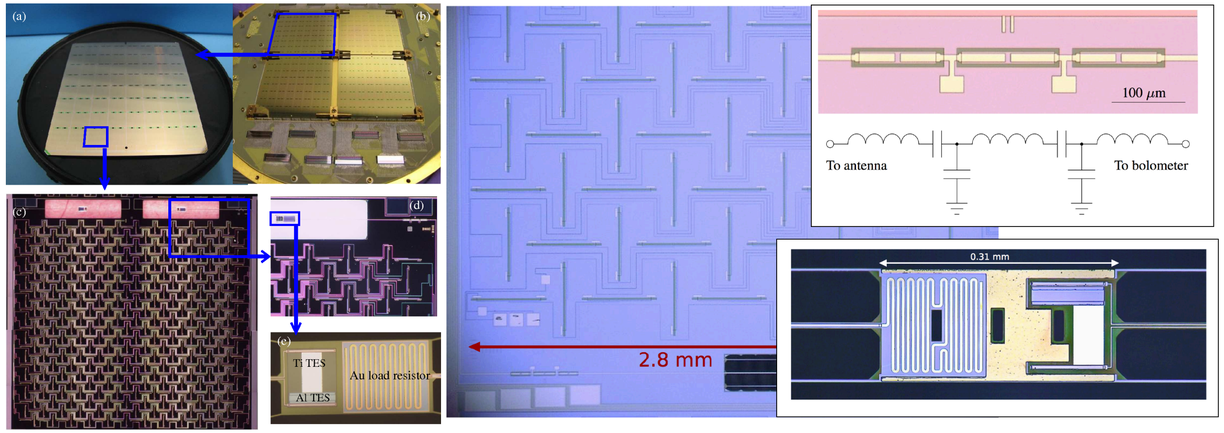


An array of 256 pixels, NbSi superconducting material (450 mK)

APC-France: no antenna technology: QUBIC

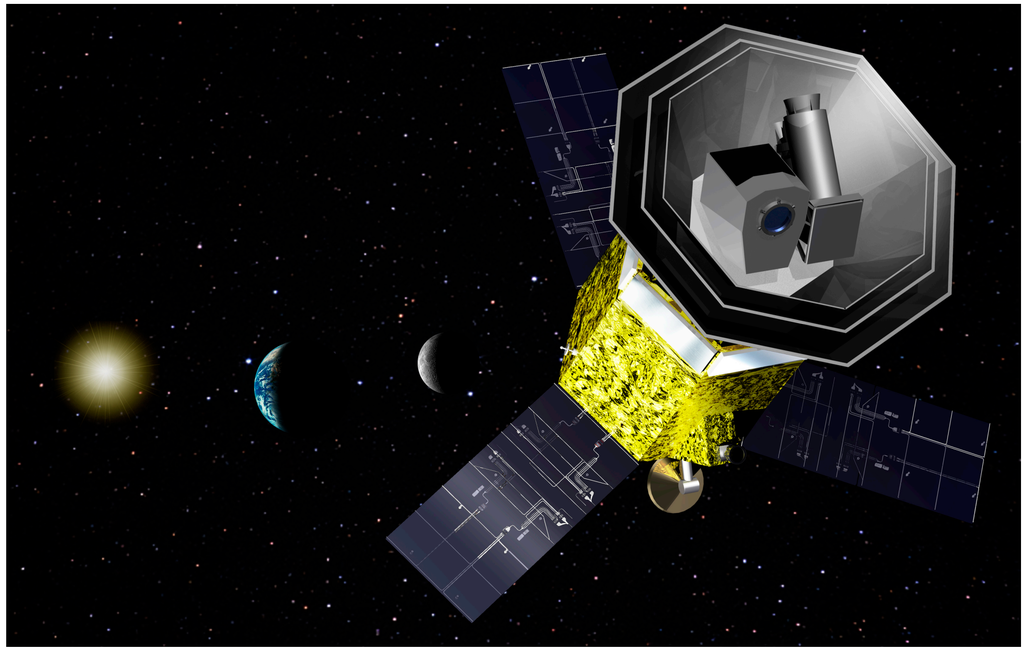


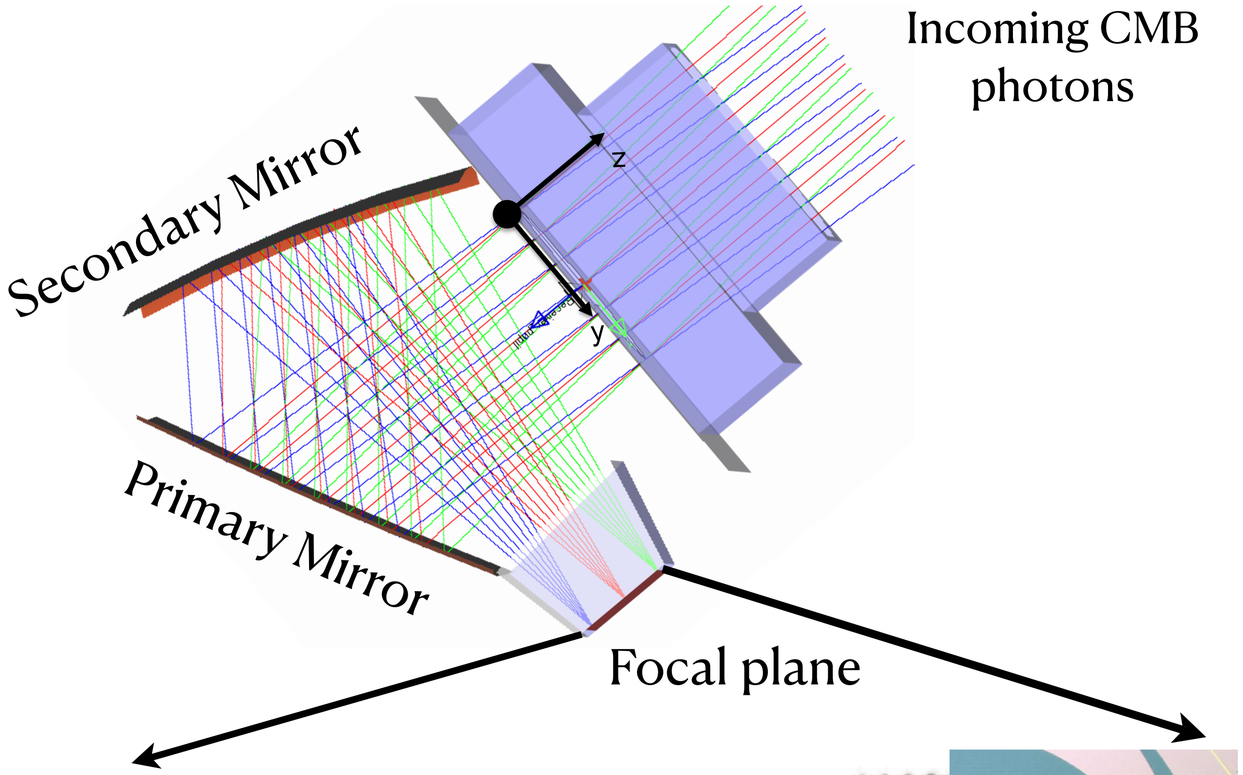
Berkeley: Planar sinuous antenna coupled TES: ACT, POLARBEAR, LiteBIRD (low-mid frequency)



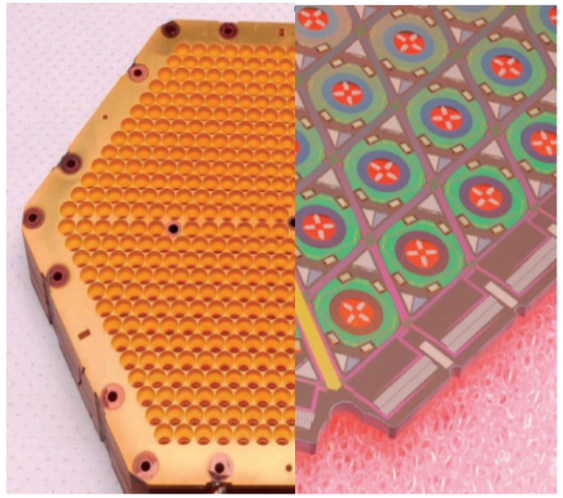
Caltech: Planar antenna coupled TES: BICEP/KECK

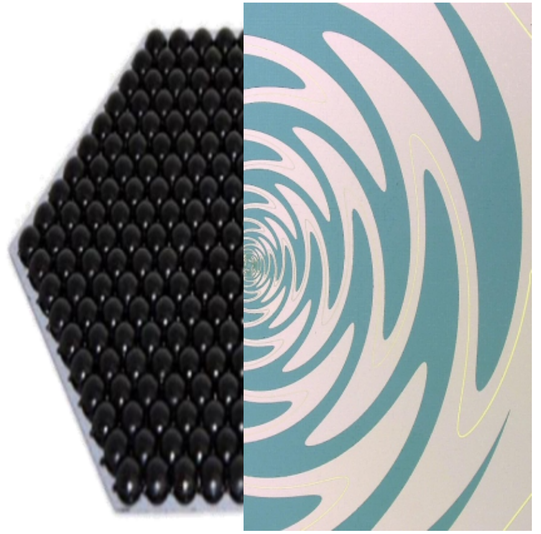
CMB space mission: LiteBIRD



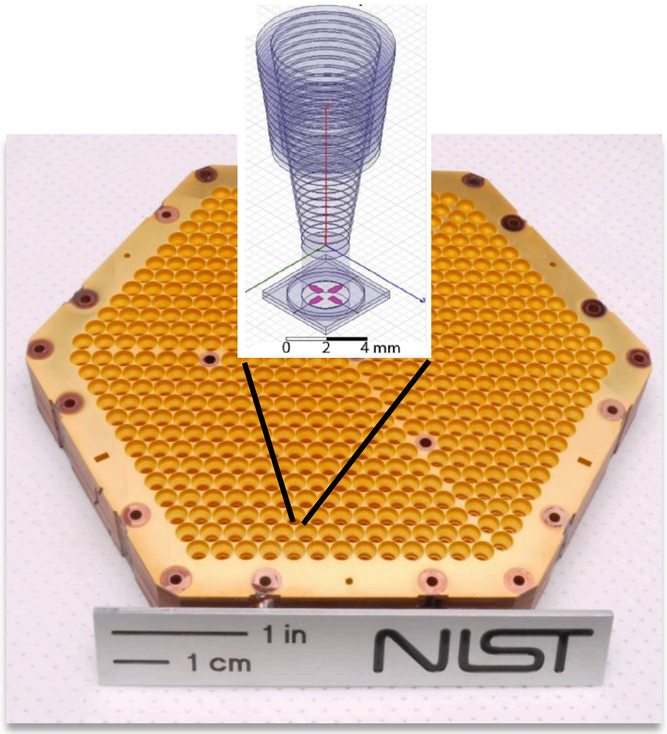


- **Two detector architectures: Feed horn and sinuous antenna**
- **Thousand TES detectors in the focal plane**

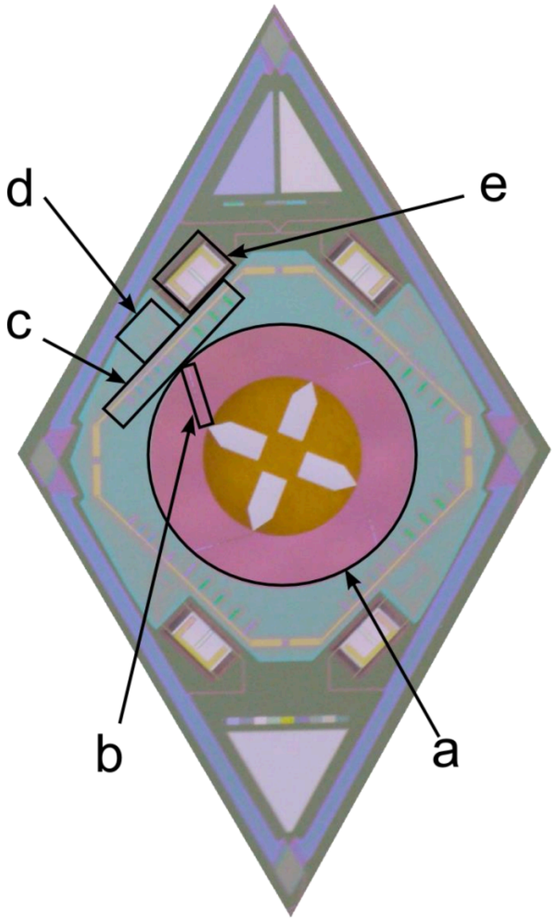


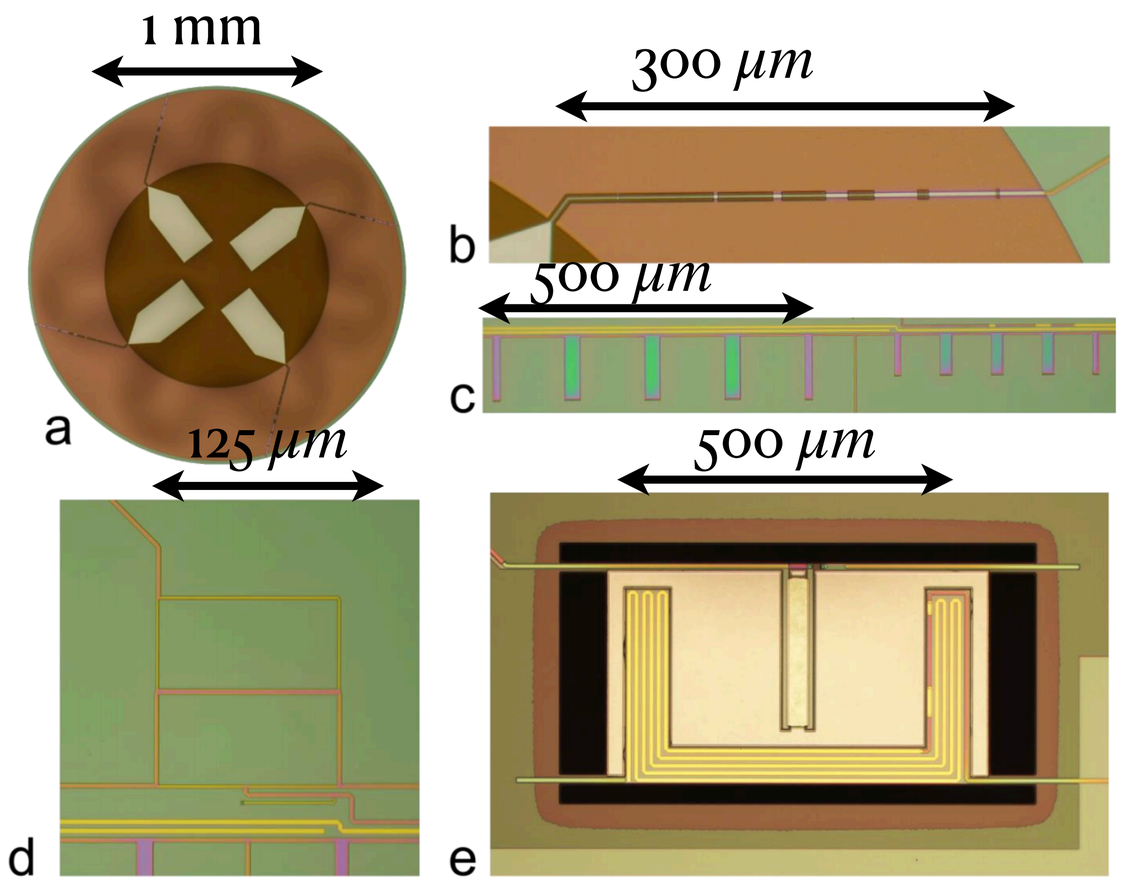


Horn-couple TES



Feedhorn

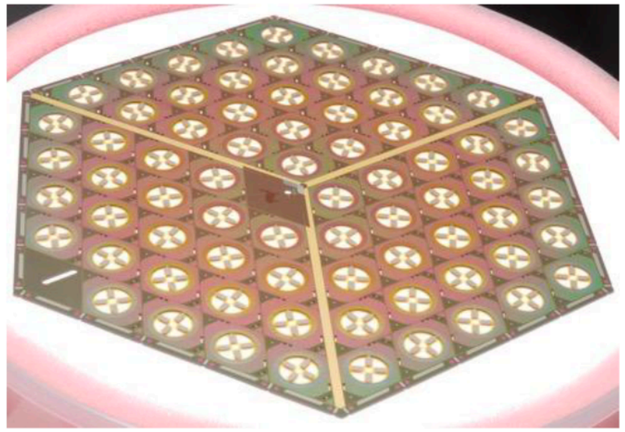




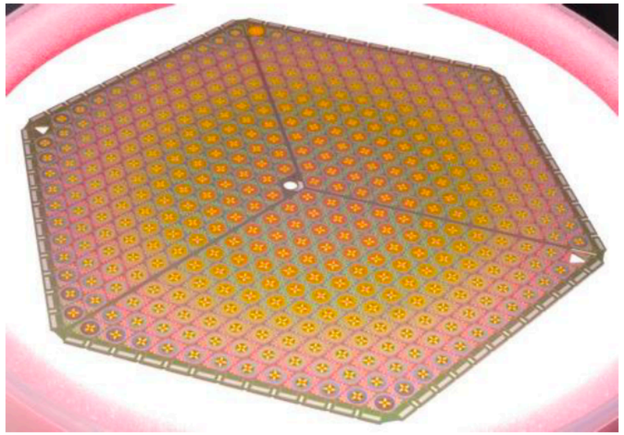
a) A planar polarization antenna.
b) Transmission lines.
c) Bandpass filters for multifrequencies per chip.
d) Hybrid tees which propagate the desirable mode.
e) TES: AlMn (160 mK).

Horn-couple detectors

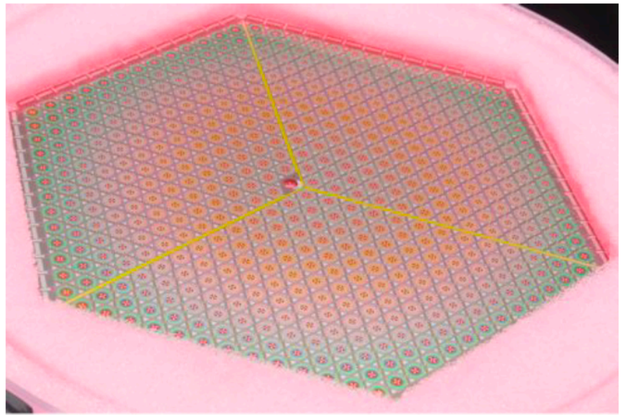
27/39GHz



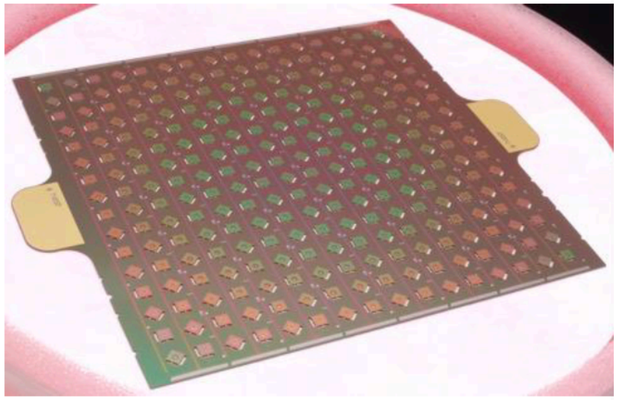
90/150GHz



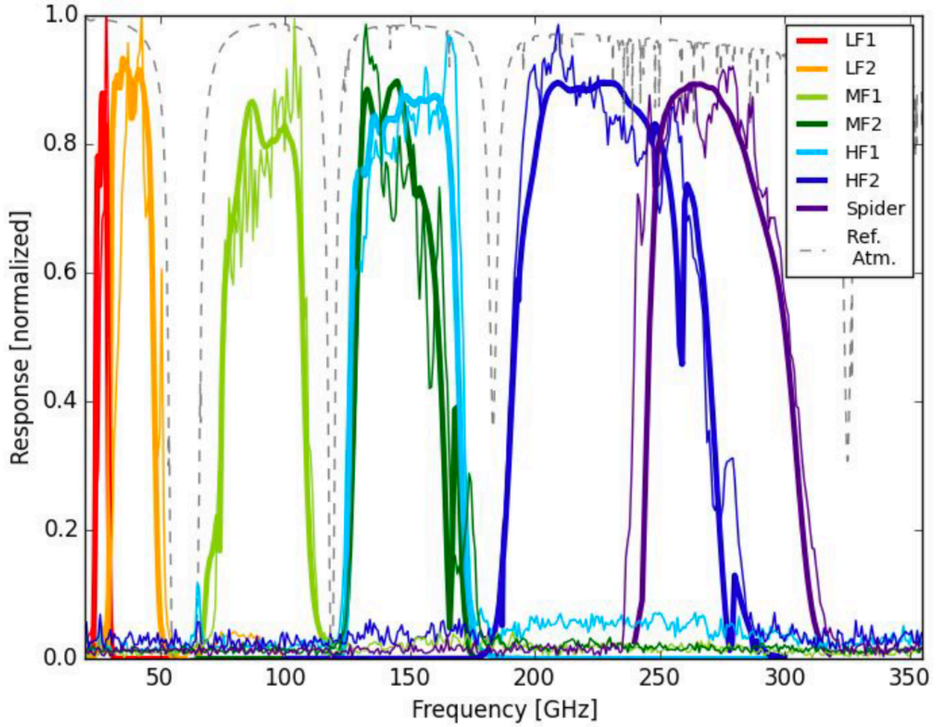
150/220GHz



280 GHz

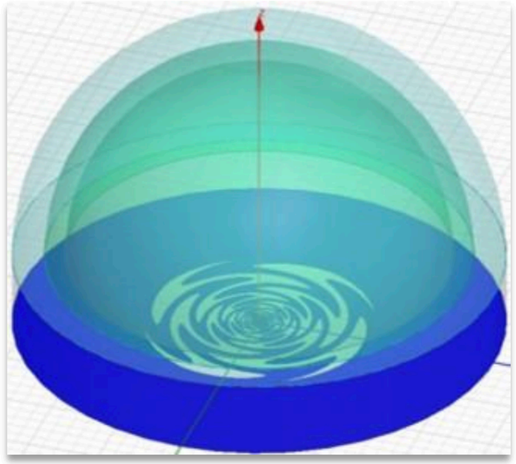


- A single wafer ~ 15 cm
- ~2000 TES
- Range of frequencies

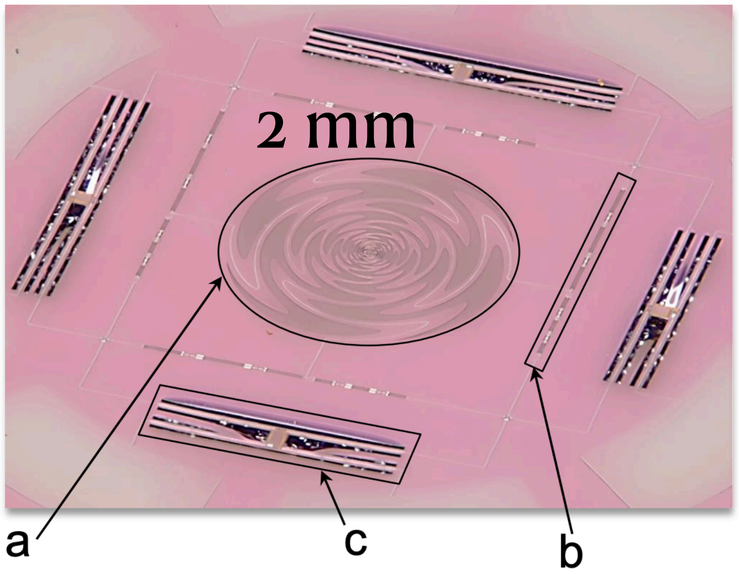


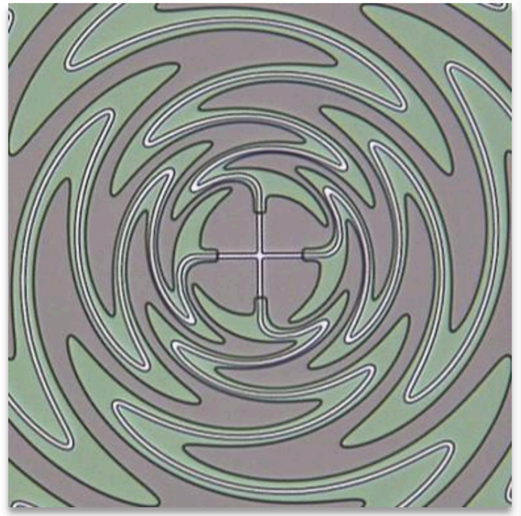
NIST: OMT technology, feed-horn: ACT, SPT, SO, LiteBIRD (High frequency)

Lenslet-couple sinuous antenna TES

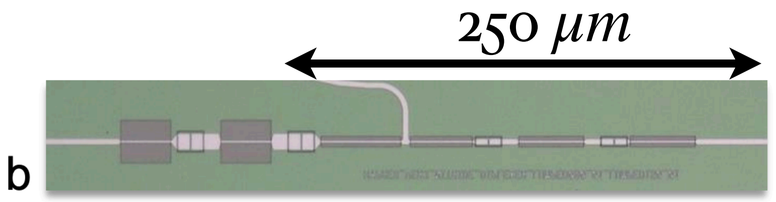


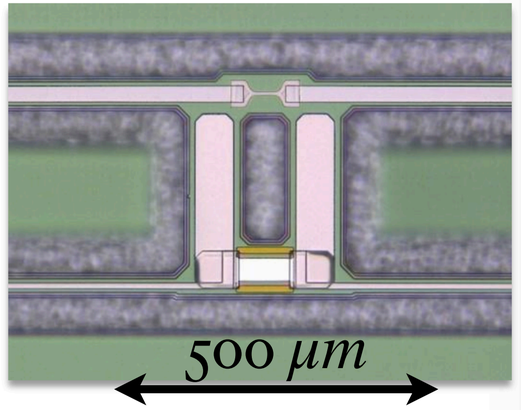
AR-coated silicon lenslet





Silicon lenslet array



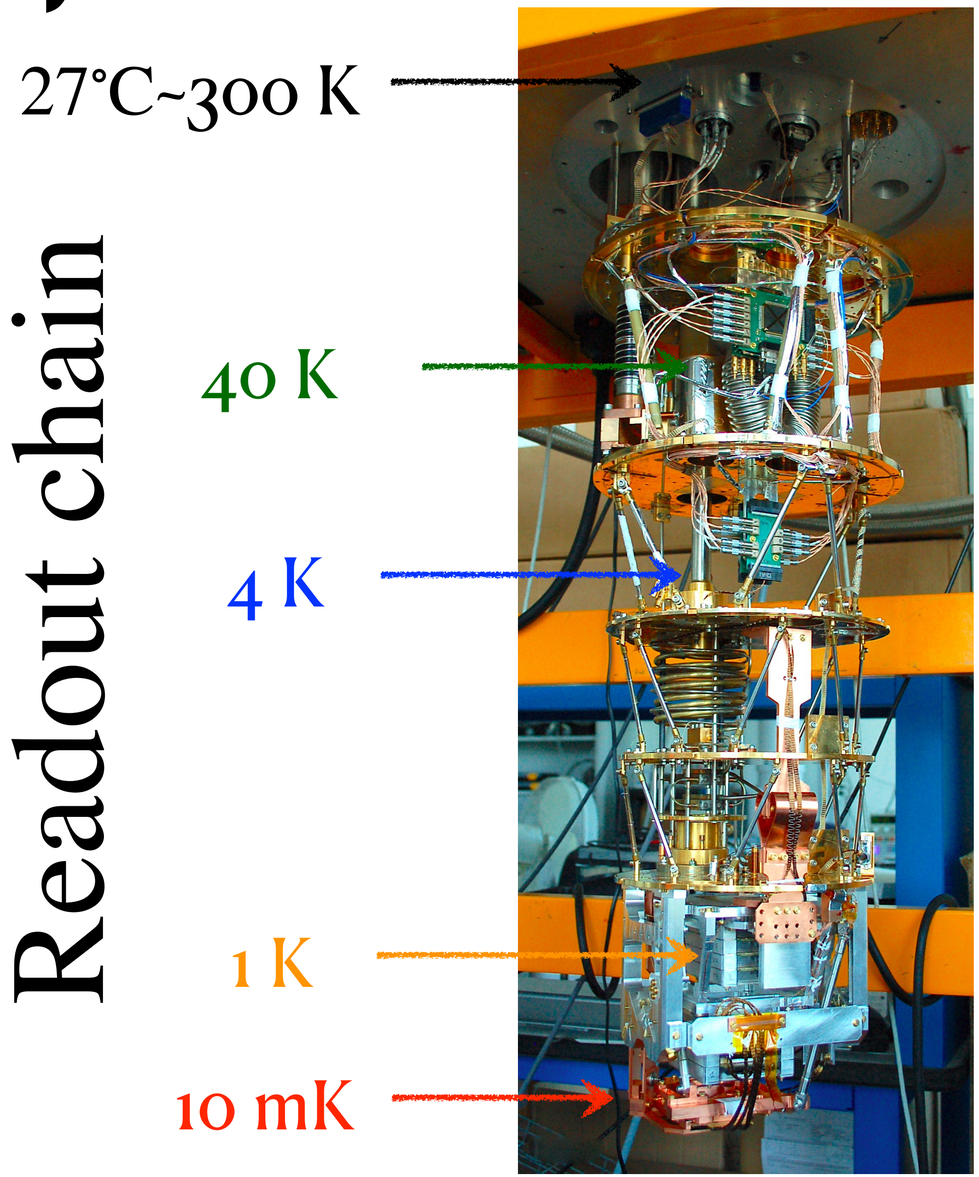


a) Sinuous antenna collects photons over wide frequency range.
b) On-chip filters which separate into two frequency bands (e.g. 90/150 GHz).
c) TES, superconducting AlMn (160 mK).

Berkeley: Planar sinuous antenna coupled TES: ACT, POLARBEAR, LiteBIRD (low-mid frequency)

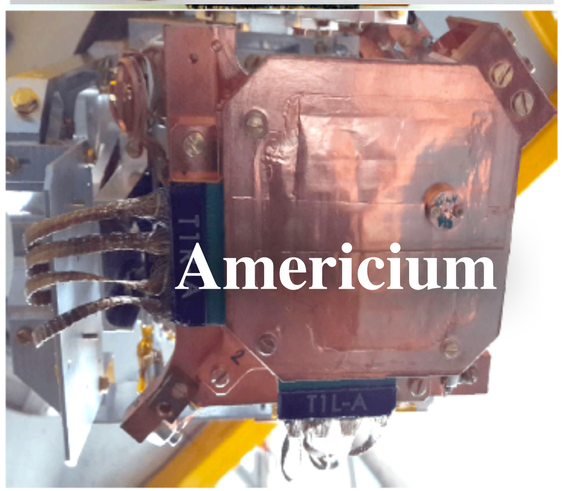
TES electronic system

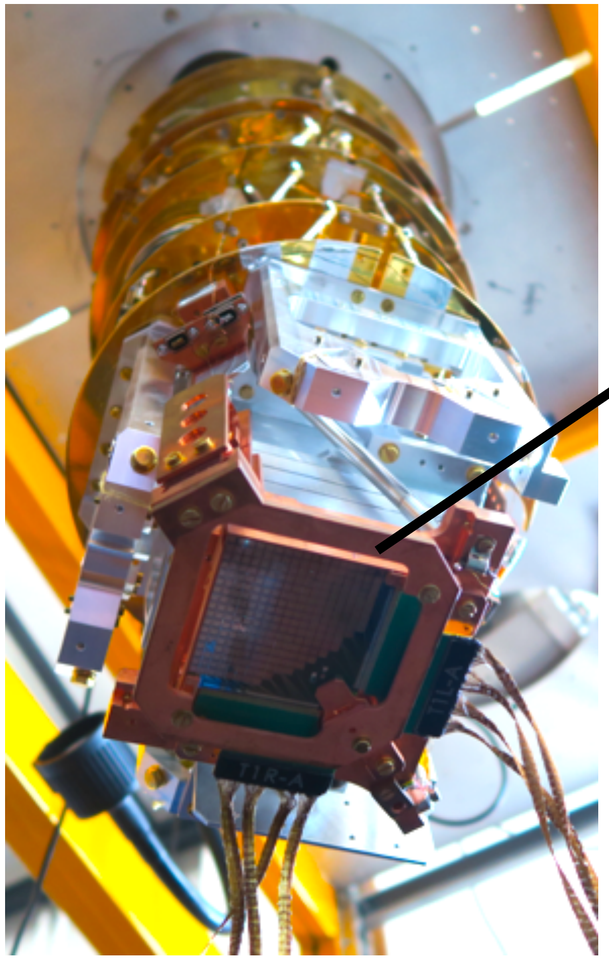
- TES operates at very low temperature, electronic system to read data from thousand of TES is a challenge.
- There are a lot of developments of electronic system.
- Need careful tests at the laboratory.

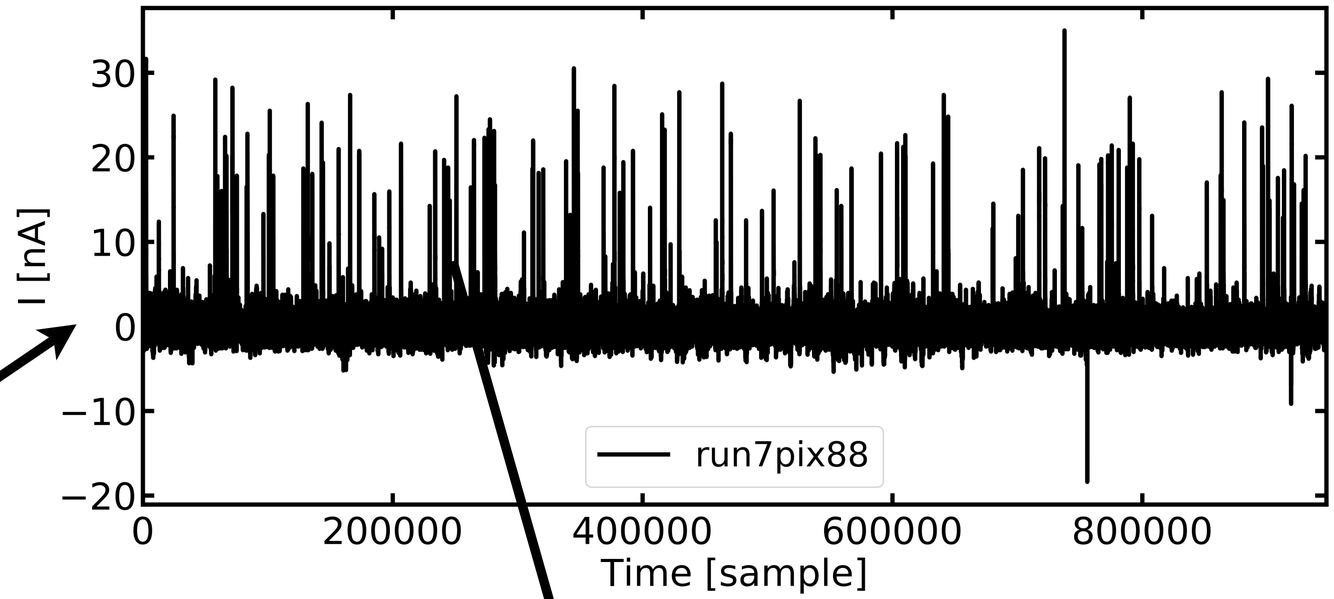


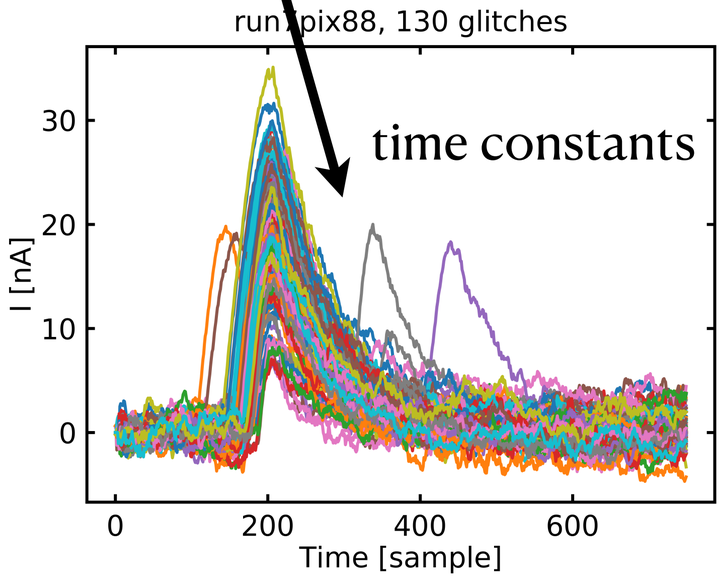
Cryogenics system

Testbed example on ground:
Particles with Transition Edge Sensor array.



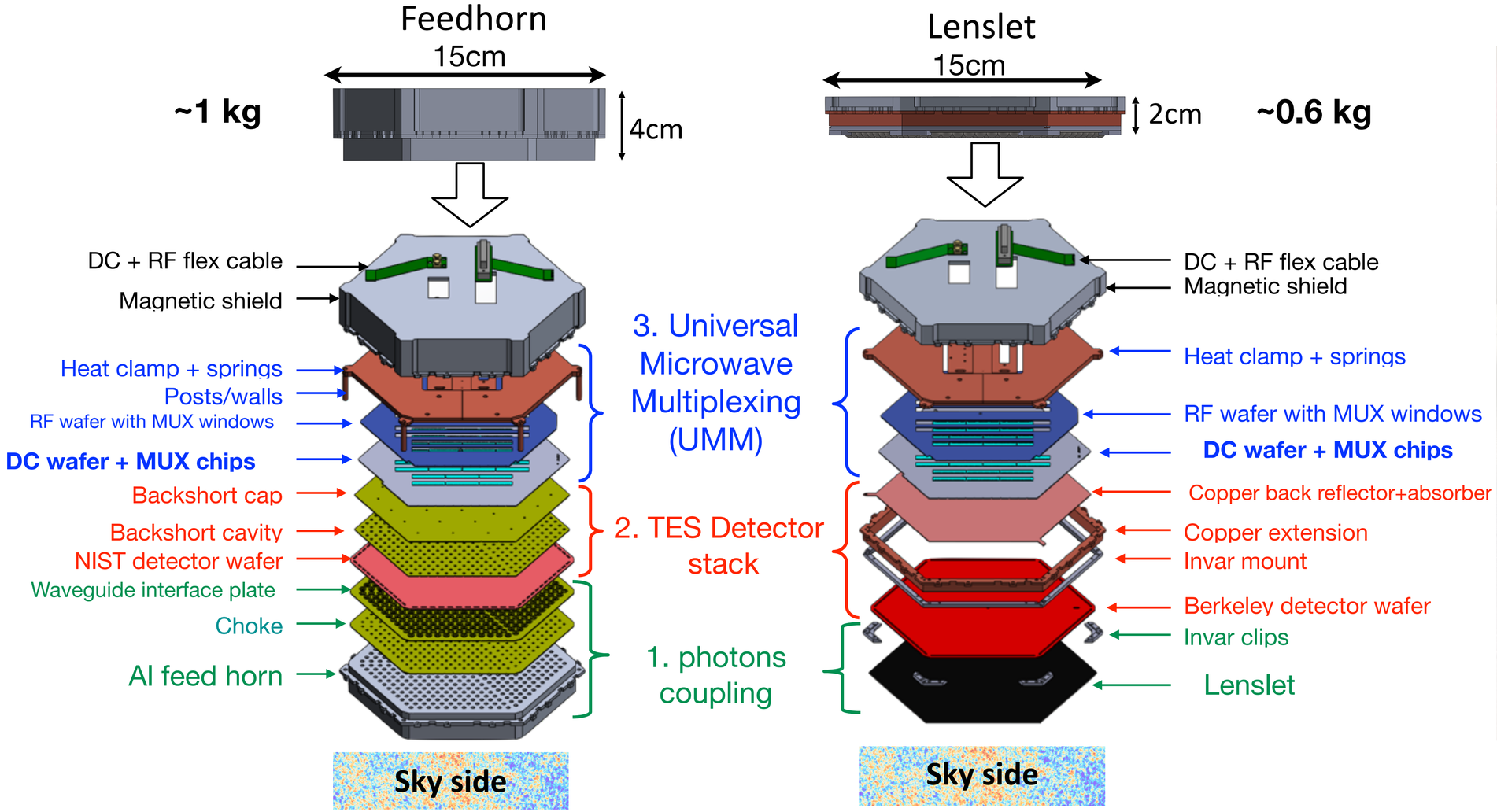


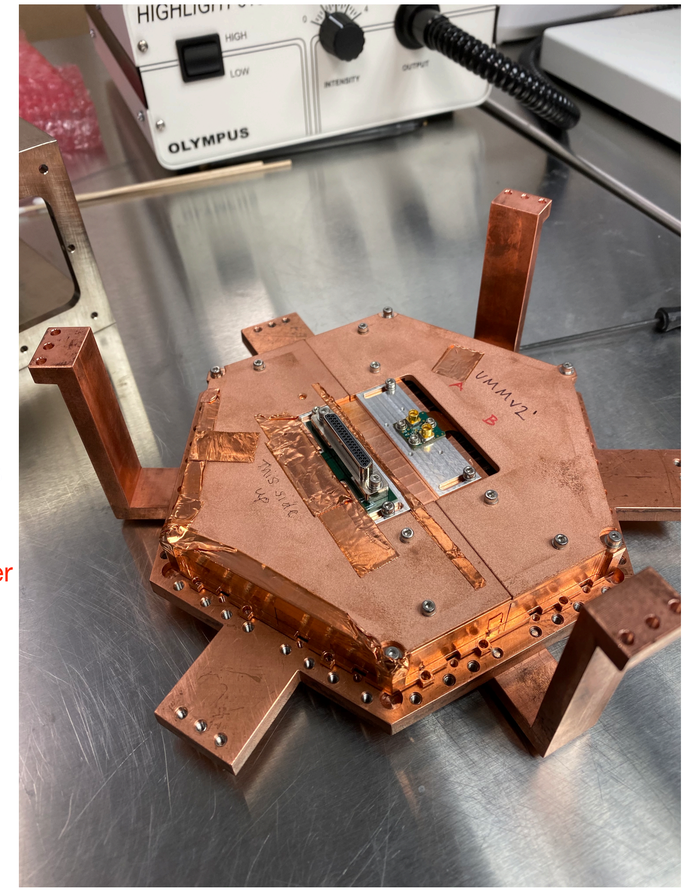




- 256 pixels array with radioactive Americium.
- When particles hit the TES, similarly CMB photons hit TES.

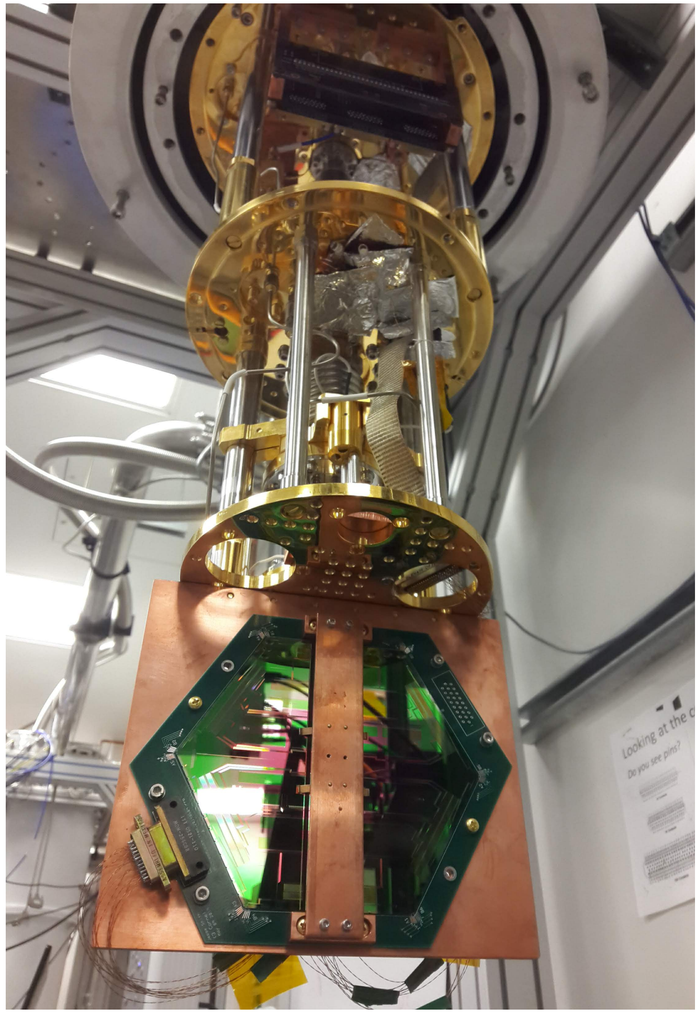
Testbed example on ground for TES array

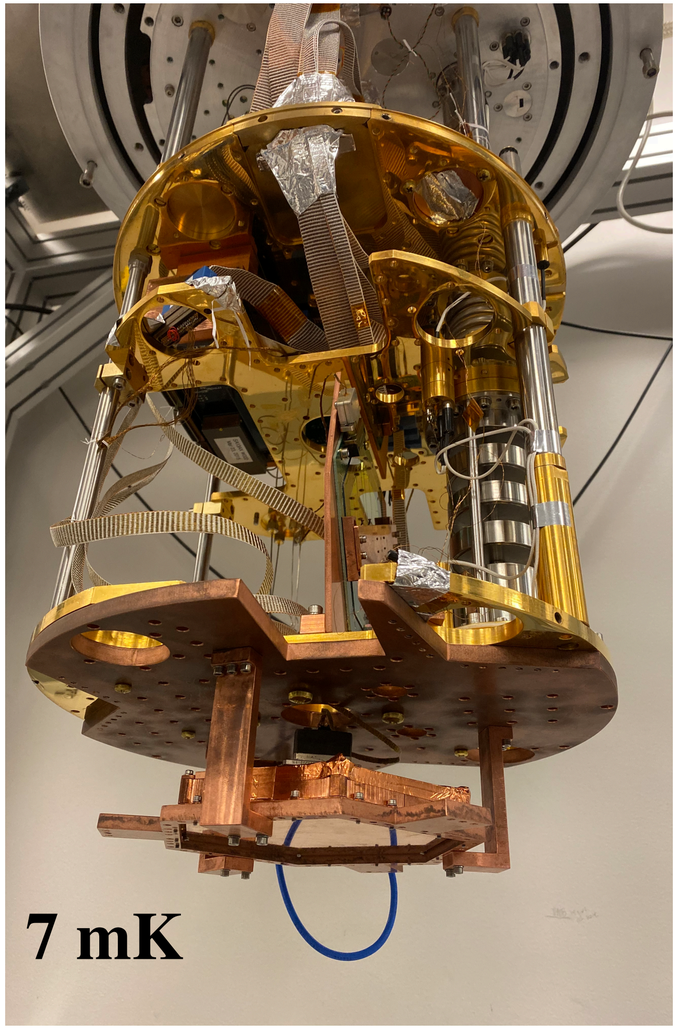


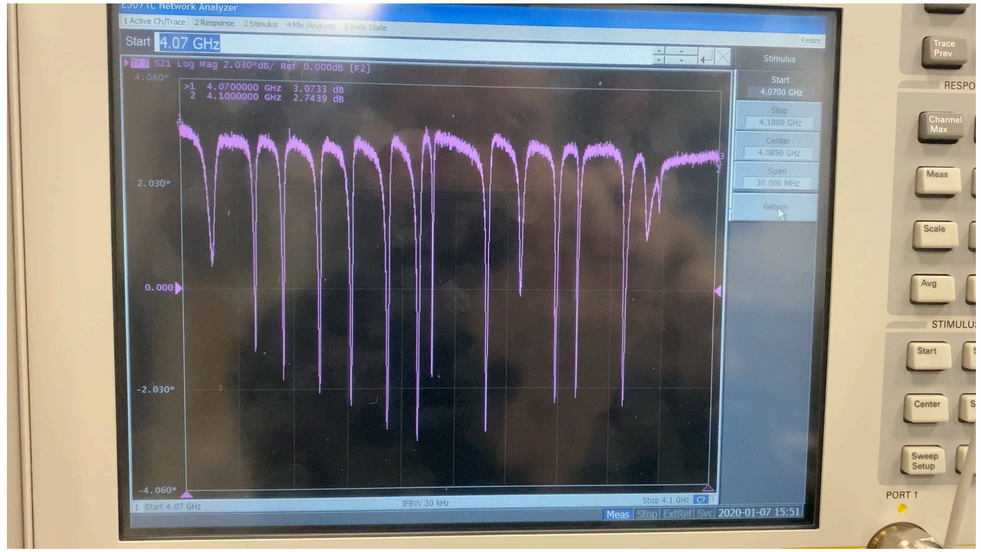


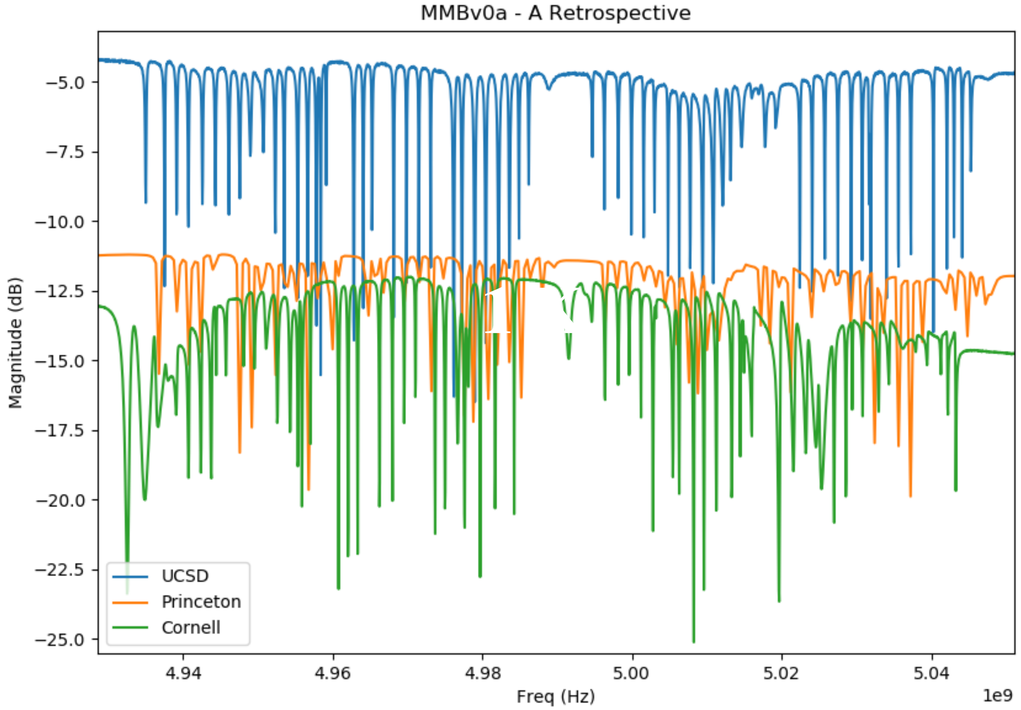
- ***Many stacked wafers to improve bolometer efficiency***
- The Transition Edge Sensor (TES) will be AlMn alloys with critical temperature 160 mK
- ~ 2000 TES per detector wafer, the normal resistance target is 8 $\mathrm{m}\Omega$

Testbed system for TES array



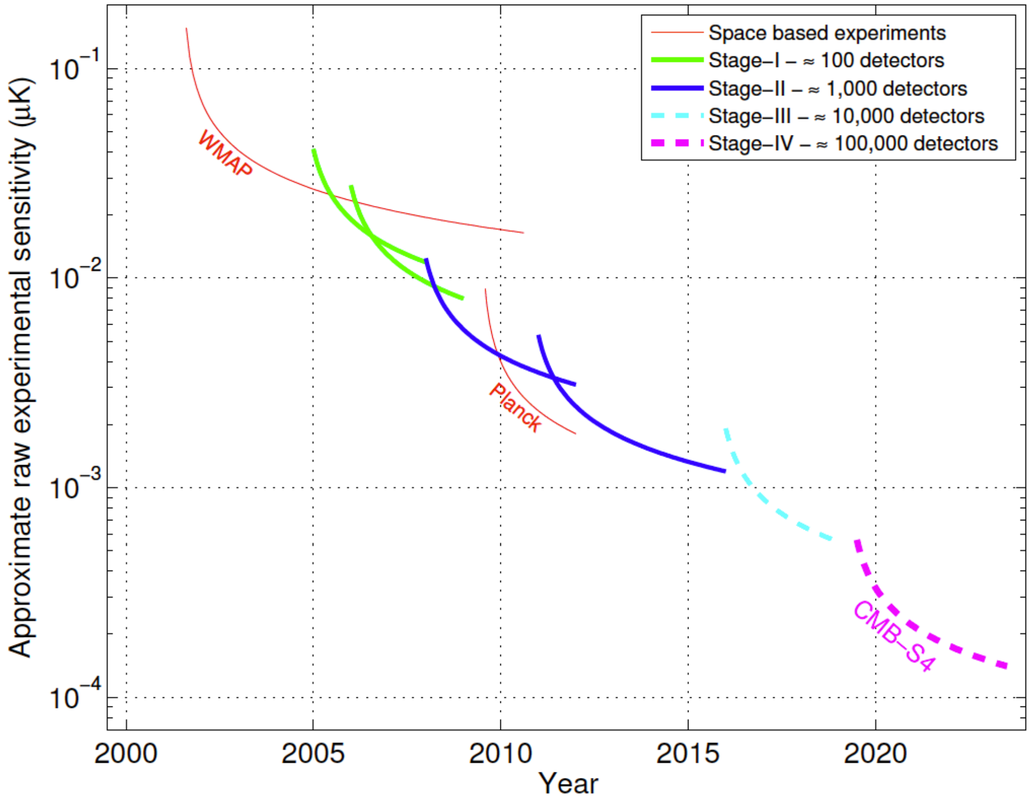






- Characterize the focal plane system at Cornell U.

Summary



- Detector sensitivity has been limited by photon shot noise. Increase number of detector to improve sensitivity.

- TES is a very sensitive detector operating at very low temperature.
- TES readout is a complex system that requires a lot of testing, characterizations, especially for a satellite mission.
- We don't have TES testbed facilities in Vietnam. CMB-Inflate project brings USTH-researchers a chance to work at advanced institutes in Europe, Japan.

CMB S4 Science book: arXiV.1610.02743