

Superconducting Focal Plane Technology for CMB Probe+

Johannes Hubmayr, NIST

Astra Workshop, Day 2, Sept 2, 2026

CMB Probe+ and Astro2020

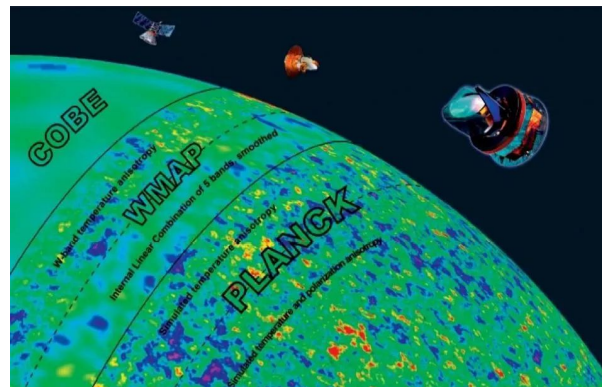
Understanding the birth and evolution of the Universe requires measurements of the CMB

CMB Probe+: A full sky millimeter/submillimeter-wave polarimetric imager and spectrometer that is designed to be equivalent to 10,000 Planck missions, 2x the number of frequency bands and 5x angular resolution

Astro2020:

“space observations will unquestionably be needed for the best foreground separation and the lowest systematic errors on all angular scales, and especially on angular scales of greater than about ten degrees”

“With investment in technologies this decade, combined with ground measurements, a CMB probe mission could potentially be a compelling candidate for the future probe call in the 2030s”



NASA/ESA and the COBE, WMAP and Planck teams

“Recommendation: NASA should increase funding levels for the Detector Development and Supporting Technology components of the Astrophysics Research and Analysis Program...The total increase needed ... is estimated to be about 50 percent above inflation.” (Section 6.1.1.1)

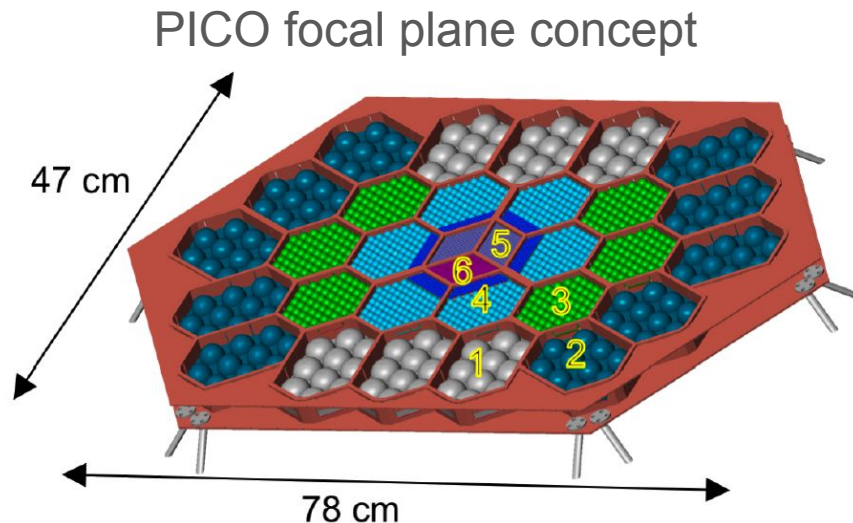
“Recommendation: “NASA should continue funding for the Strategic Astrophysics Technology Program, and should expand proposal calls to include intermediate-level technology maturation targeted in strategic areas identified for the competed probe-class missions.” (Section 6.1.1.2)

Critical enabling technology: detectors and multiplexed readout

Requirements

- High sensitivity: multi year survey produces map depths with $\sim nK$ rms noise / pix
- Broad frequency coverage to separate signals (~ 10 -1000 GHz)
- Sensor polarization sensitivity
- Strong rejection of systematic errors

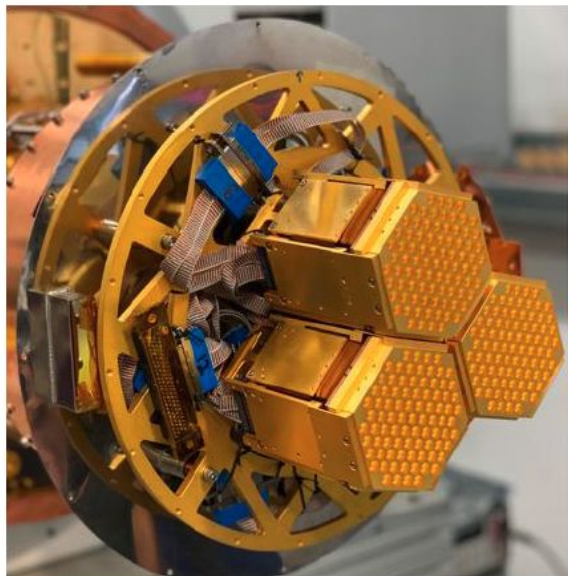
Background-limited and
frequency-scalable detector arrays
cooled to 100 mK needed



[Hanany+ 2019](#)

CMB Focal Plane Units (FPUs)

Feedhorn/OMT

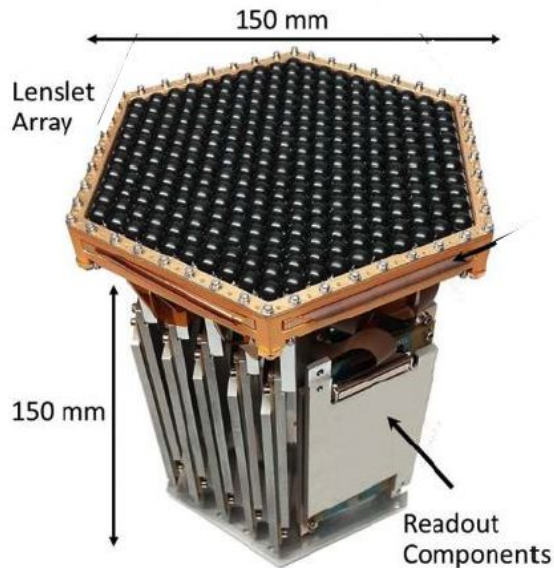


[Dahal+ 2020](#)

NASA/Goddard; NIST

CLASS, Advanced ACTPol,
Simons Observatory, SPIDER, ...

Lenslet/Antenna

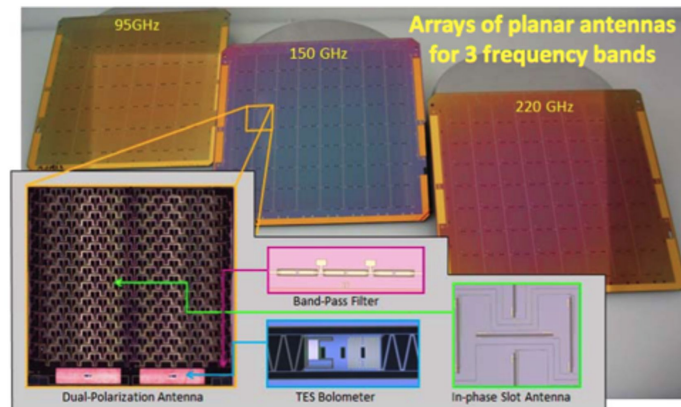


[Suzuki+ 2015](#)

UC, Berkeley; ANL

PolarBear, PolarBear2/Simons
Array, SPT-3G

Planar phased antenna arrays

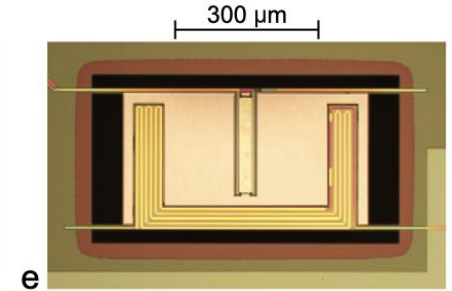
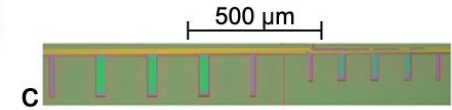
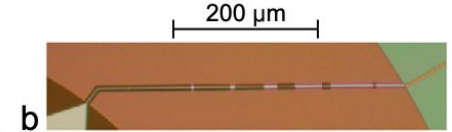
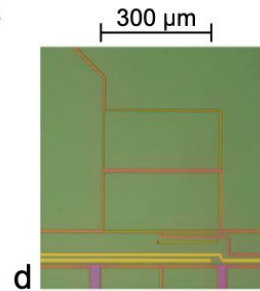
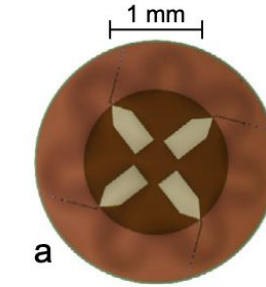
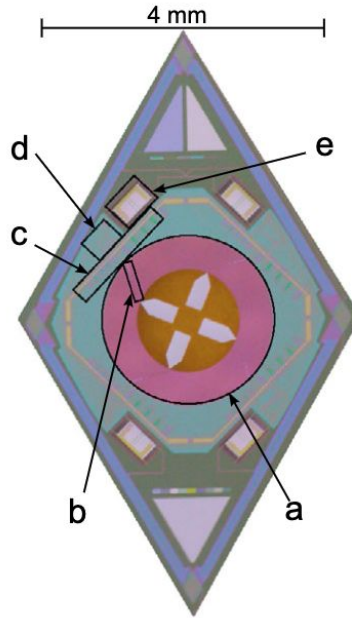
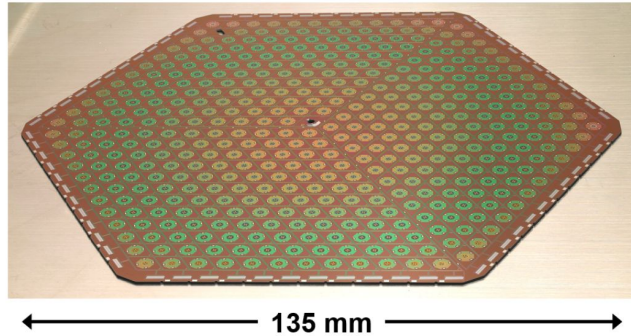


[Ade+ 2015](#)

Caltech/JPL

BICEP-series, SPIDER

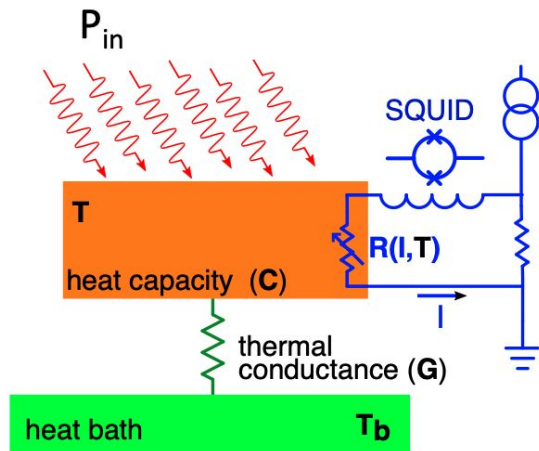
Detectors: Arrays of Superconducting ICs



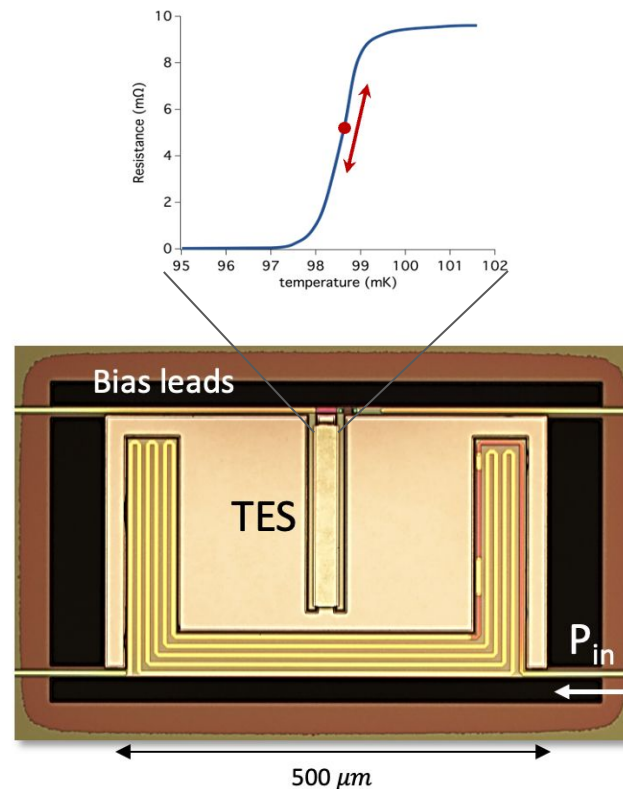
[Duff+ 2016](#), [Duff+ 2025](#)

Transition-edge-sensor (TES) Bolometers

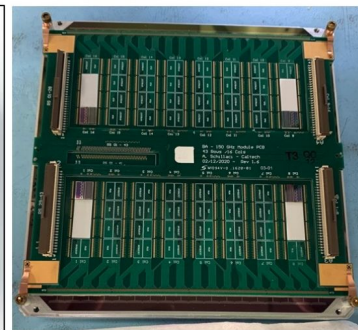
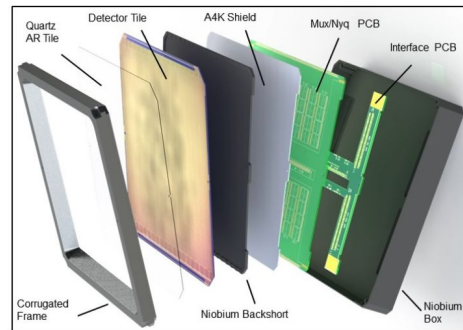
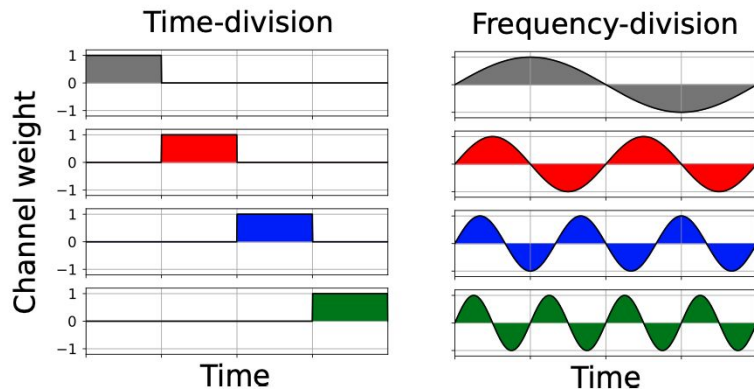
Voltage-biased TES Bolometer



- Relative power meter
- Can be fabricated into large arrays
- Sensor noise subdominant to photon noise
- Thermal conductance (G) determines dynamic range and sensitivity



Multiplexed readout: combine N signal channels into single wiring/amplification chain



[Schillaci+ 2023](#)

Type (mux factor; largest focal plane to date)

Time division (64x; SCUBA2: 10,240)

MHz Frequency division (68x; SPT-3G: 16,000)

Microwave SQUID multiplexer (910x; SO: 100,000)

Requirements for CMB Probe+

- Capable of 10^4 channel readout
- Noise subdominant to detector/photon noise
- Low power consumption
- Facilitate compact packaging (small volume and low mass)

Development Plan

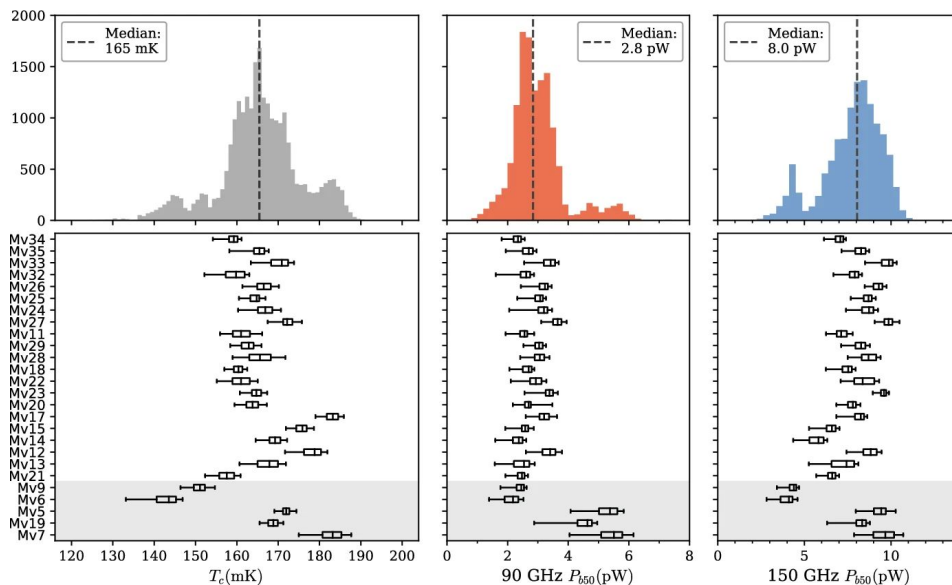
Design/build/characterize FPU as sub-system level to CMB Probe+ like specifications

General specifications

- 100mK operation
- Background limited sensitivity (detector NEP $\sim$ few 10^{-18} W/ $\sqrt{\text{Hz}}$)
- ~ 1 ms time constant

Put through paces toward space qualification (Cosmic Ray testing, vibration testing, low 1/f demonstration ...)

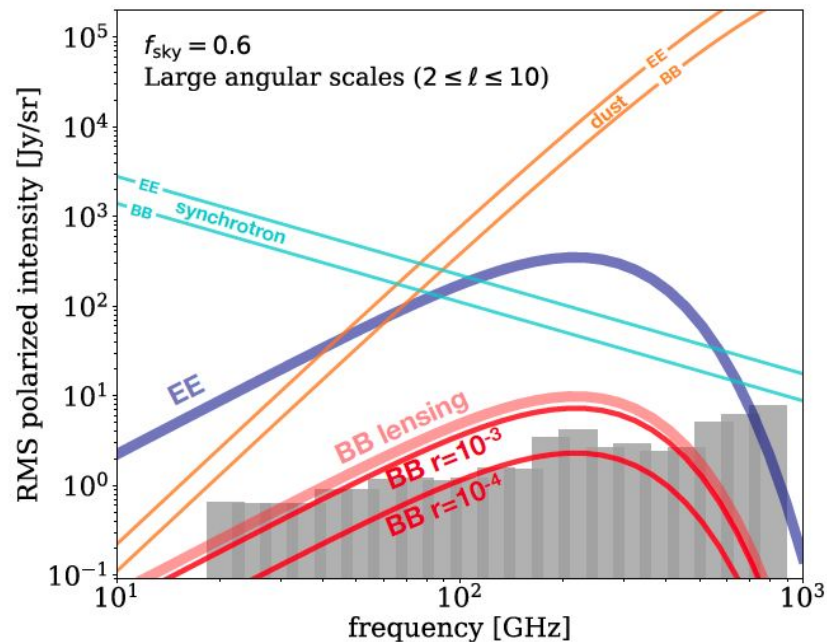
Distribution of parameters shown to specifications



[Dutcher+ 2024](#)

Frequency Scalability

- Very large frequency range required ($f_{\text{max}}/f_{\text{min}}$ ~100x), challenging for any single sensor technology
- Highest frequencies require different detectors or new materials
 - Current designs use Nb wiring, which imposes a ~650 GHz upper limit
 - Solutions:
 - Higher gap superconductor
 - Arrays of Planck-like polarization sensitive bolometers (PSBs).
- Microwave Kinetic Inductance Detectors (MKIDs) offer higher packing density at higher frequencies and potentially simplified packaging / readout. MKID implementation should be studied and developed.
- At low frequencies, coherent differential polarimeter arrays made possible by near QL kinetic inductance traveling wave parametric amplifiers



[Hanany+ 2019](#)

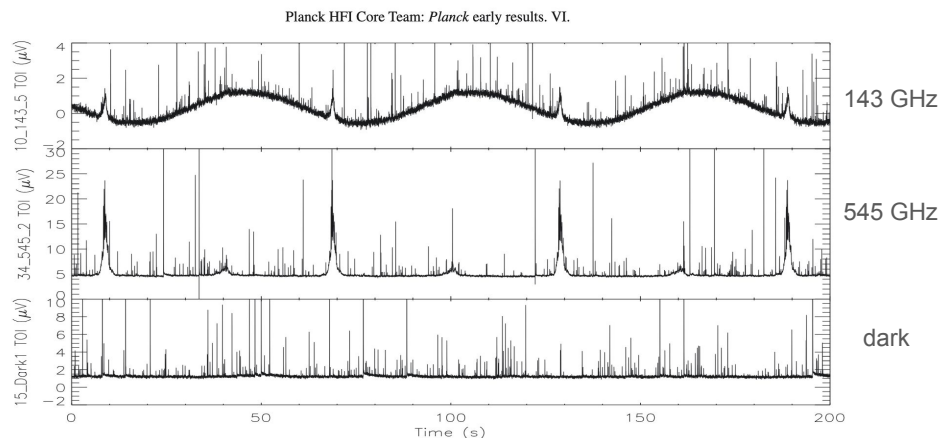
Cosmic Ray Glitches

Unanticipated cosmic ray glitches affected 95% of raw data in Planck HFI

Planck experience has resulted in multiple studies

- Analysis of phased antenna-array coupled TES arrays in SPIDER flight ([Osherson+ 2020](#))
- Phonon down conversion with added materials to detector arrays ([Beckman thesis 2023 UC, Berkeley](#))
- Multiple studies of mm-wave detector response to high energy particles in lab facilities (LiteBIRD, PRIMA,...)

CMB Probe+ detection chain must limit effects of cosmic rays such that science reach not impacted



[Planck VI \(2021\)](#)

Conclusions

CMB Probe+ enables ground-breaking science.

A critical enabling technology is the cryogenic focal plane unit (FPU), which integrates optical coupling, arrays of sensors, and multiplexed readout components.

High TRL in suborbital implementations

Space readying does not require new sensing paradigms / new detector ideas but straightforward adaptation of ground-based FPU architectures for CMB Probe+ like specifications

Astro2020 recommended CMB-related technology development in this decade such that CMB Probe+ can be competed in the 2030s.

