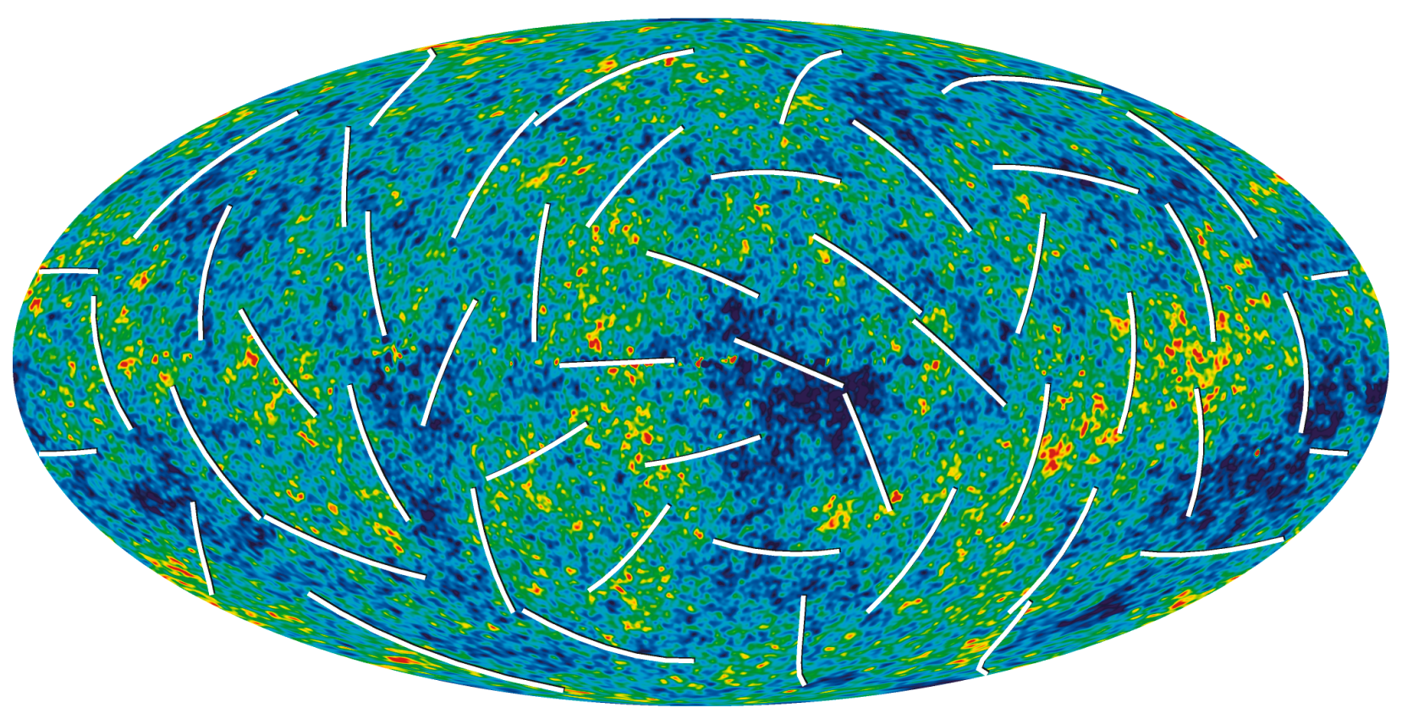
Space-flight Optimized Feedhorn-coupled Sensor Arrays for CMB Polarization Measurements

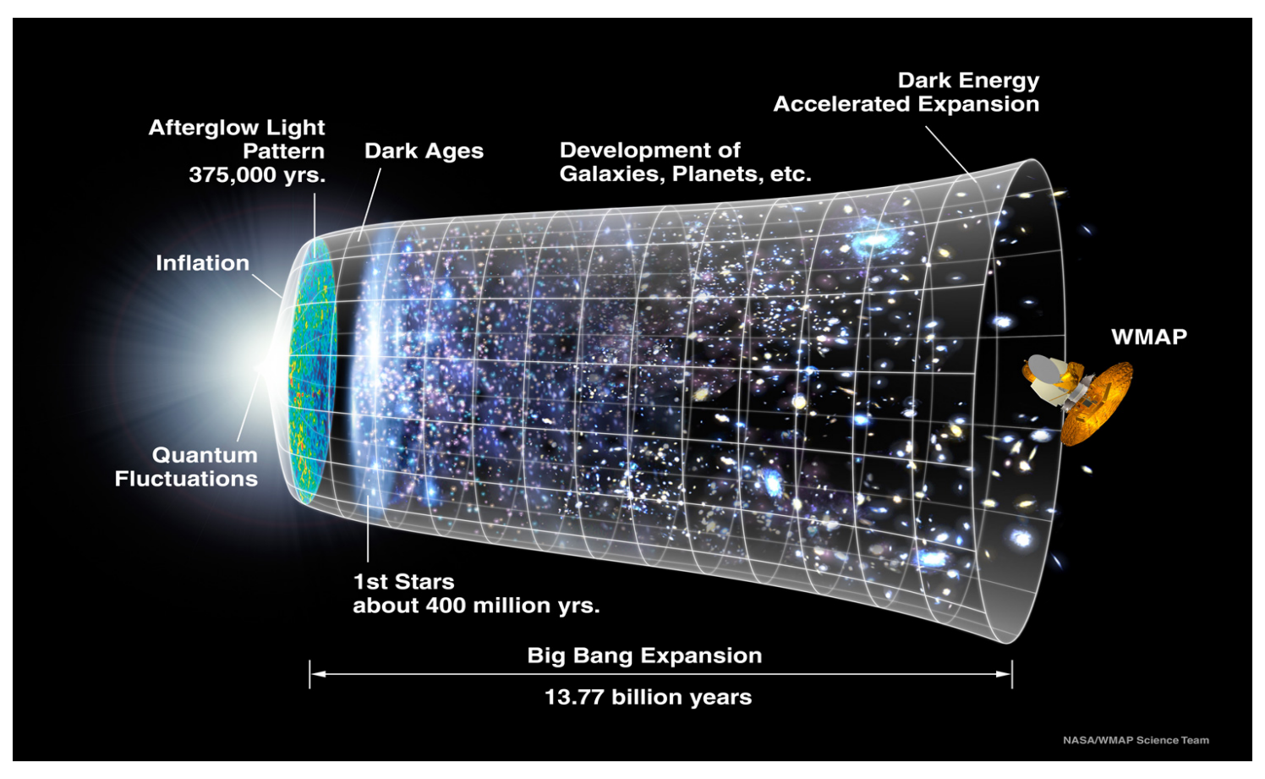
K. Helson[1], A. Ali[2], J. Appel[3], B. Bulcha[1], C.L. Bennet[3], M.P. Chang[1], D.T. Chuss[4], N. Costen[1], S.Dahal[3], K.L. Denis[1], T. Essinger-Hileman[1], R. Hu[1], T. Marriage[3], K. Rostem[1,5], M. Sagliocca[1], K. U-Yen[1], E.J. Wollack[1]
[1]NASA / Goddard Space Flight Center, Greenbelt, MD, USA
[2]University of California Berkeley, Berkeley, CA, USA
[3]Johns Hopkins University Department of Physics and Astronomy, Baltimore, MD, USA
[4]Villanova University Department of Physics, Villanova, PA, USA
[5]University of Maryland Baltimore County, Baltimore, MD, USA

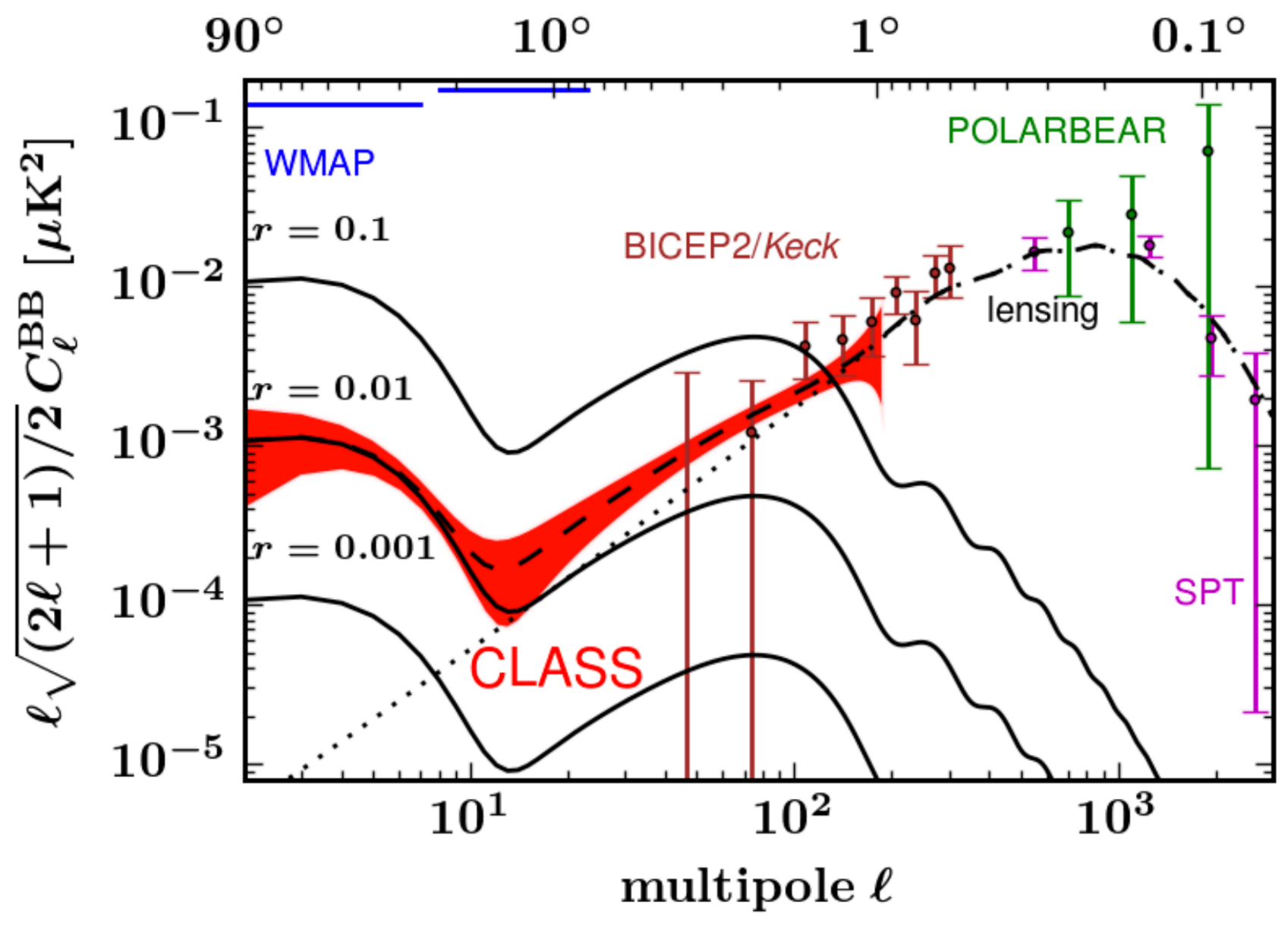
Introduction



Polarization measurements of the Cosmic Microwave Background (CMB) provide constraints on the origin and seeds of large scale structure of the Universe.

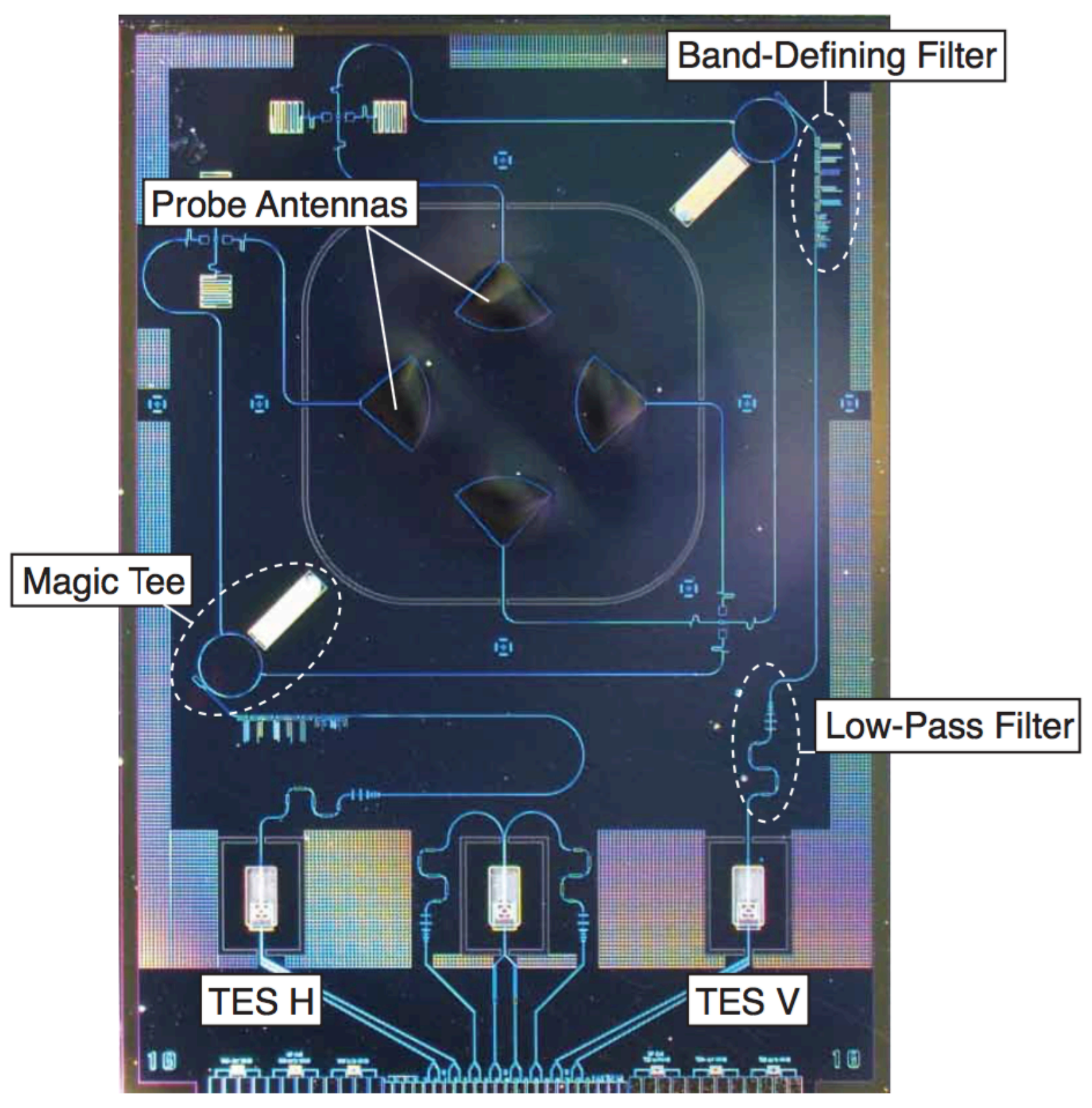
In particular, measurements of the B-mode, or divergence-free, component of the linear CMB polarization provides constraints on Cosmic Inflation [1,2]. Cosmic Inflation was a period of rapid, exponential expansion in the early Universe.



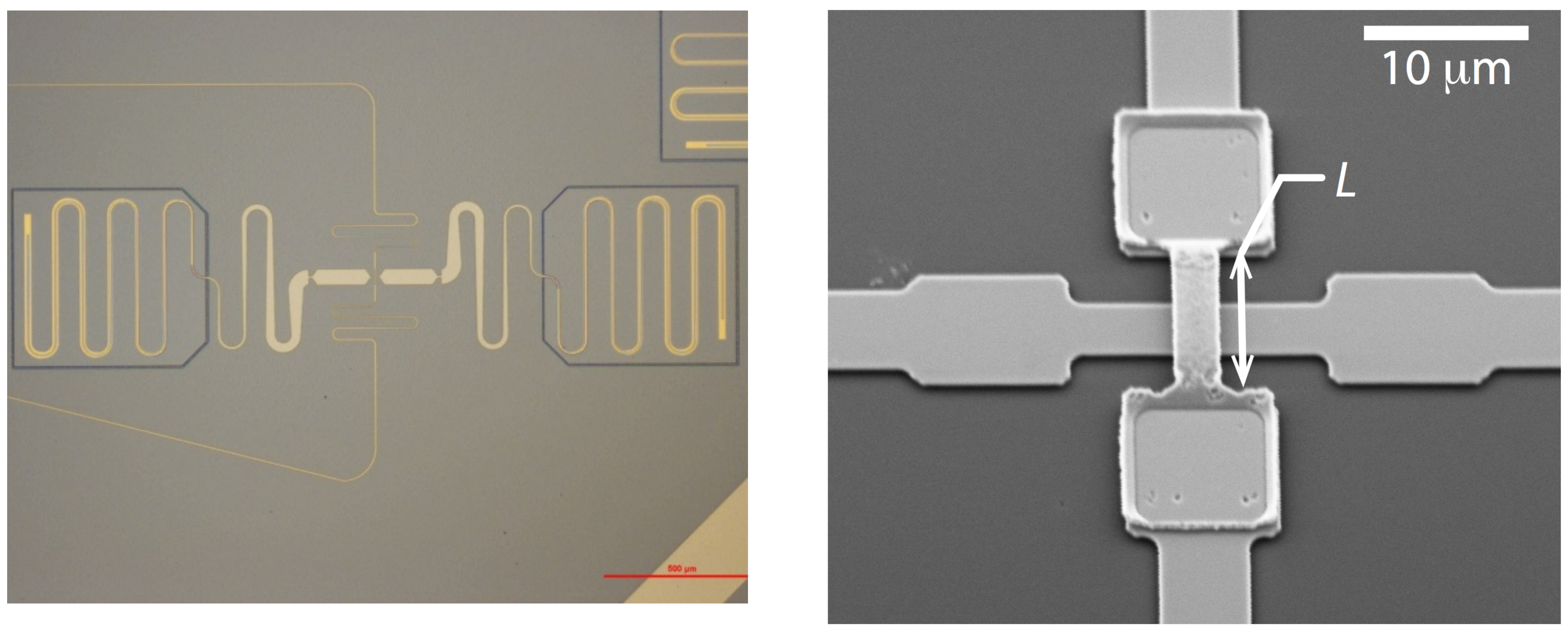


Gravitational waves generated during Inflation would imprint B-mode polarization in the CMB [1,2]. The amplitude of B-mode polarization is proportional to the energy scale of Inflation. No detection of Inflationary B-mode polarization has been made to date.

We have developed state-of-the-art polarization sensitive microwave detectors for measurements of the CMB and polarized galactic foregrounds. The sensors have a dual-polarization design with on-chip filtering and detection. The orthogonal linear polarization states are simultaneously measured in each sensor. The incident power is measured by superconducting MoAu transition-edge sensor (TES) bolometers. Space flight optimized versions of these sensors are under development.



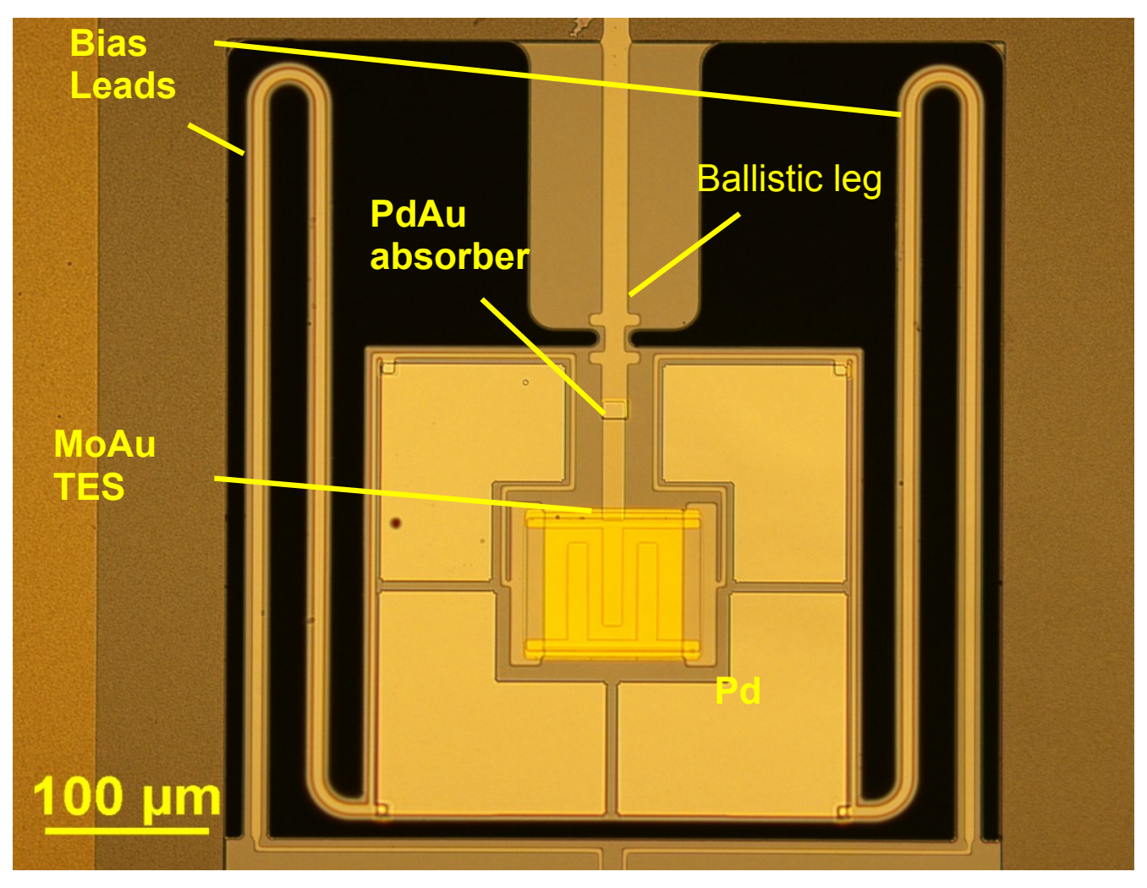
40 GHz Pixel [3]



One realization of the detector topology employs via-less crossovers (left) [4]. A variation on this theme uses air-bridge crossovers which have greater bandwidth (right)[7]. The air-bridge crossover design pictured is suitable for DC-500 GHz operation. Vias to the ground plane are used to maintain an RF grounding between the layers of the device and allow flexibility in the ground scheme.

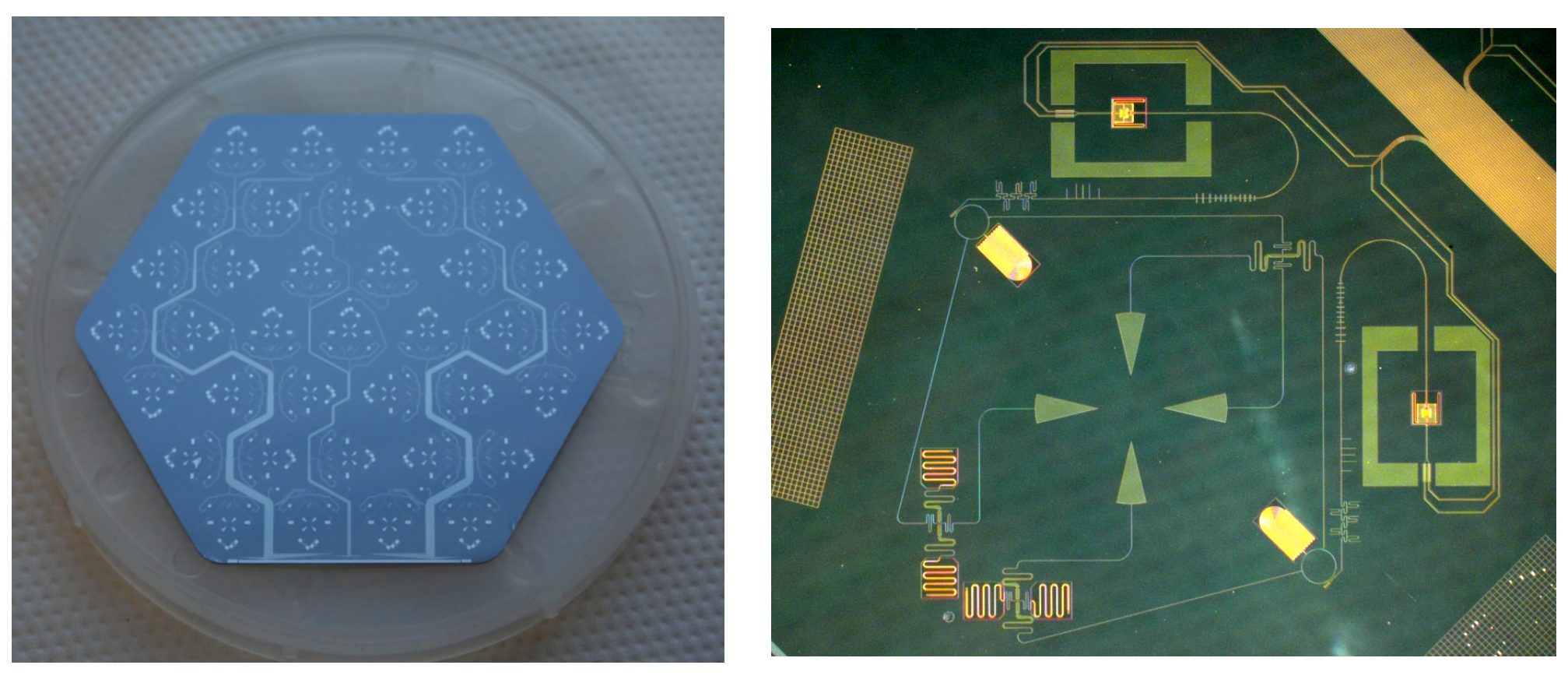
Design and Deployment

This sensor architecture is utilized by the Cosmology Large Angular Scale Suveryor (CLASS) at multiple frequencies. A 40 GHz focal plane is currently in operation, 90 GHz arrays are being tested, and a dichroic high frequency receiver is under development [4].

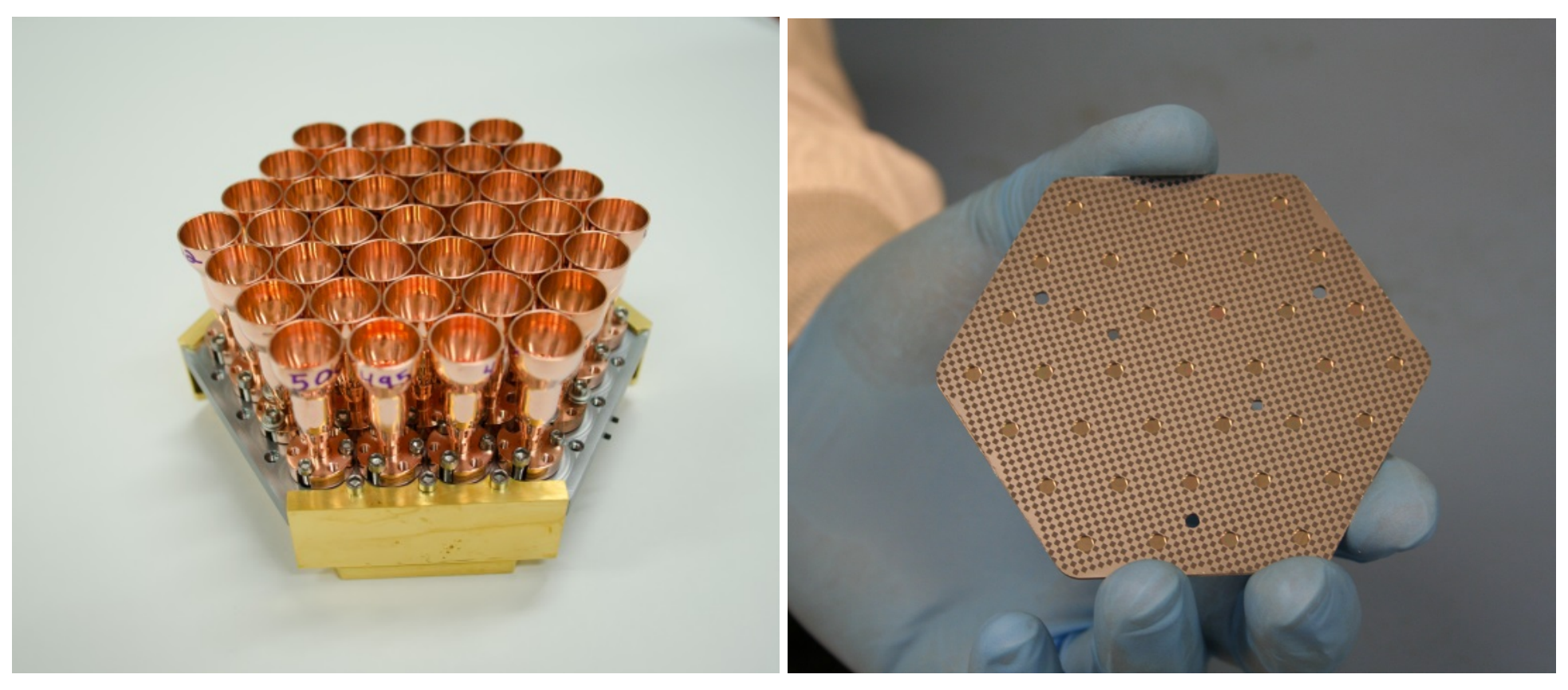


The single-crystal silicon dielectric in these detectors is unique and enables high efficiency and repeatability of microwave circuit components. The TES is deposited on a silicon membrane that is thermally isolated from the bath by a set of silicon legs. Ballistic phonon propagation through a short silicon leg dominates the thermal conductance and enables uniformity [5].

The heat capacity of the silicon membrane is negligible. The Pd layer raises the membrane heat capacity to meet design targets while working within the confines of the microwave circuitry. PdAu absorber is electrically coupled to the TES.



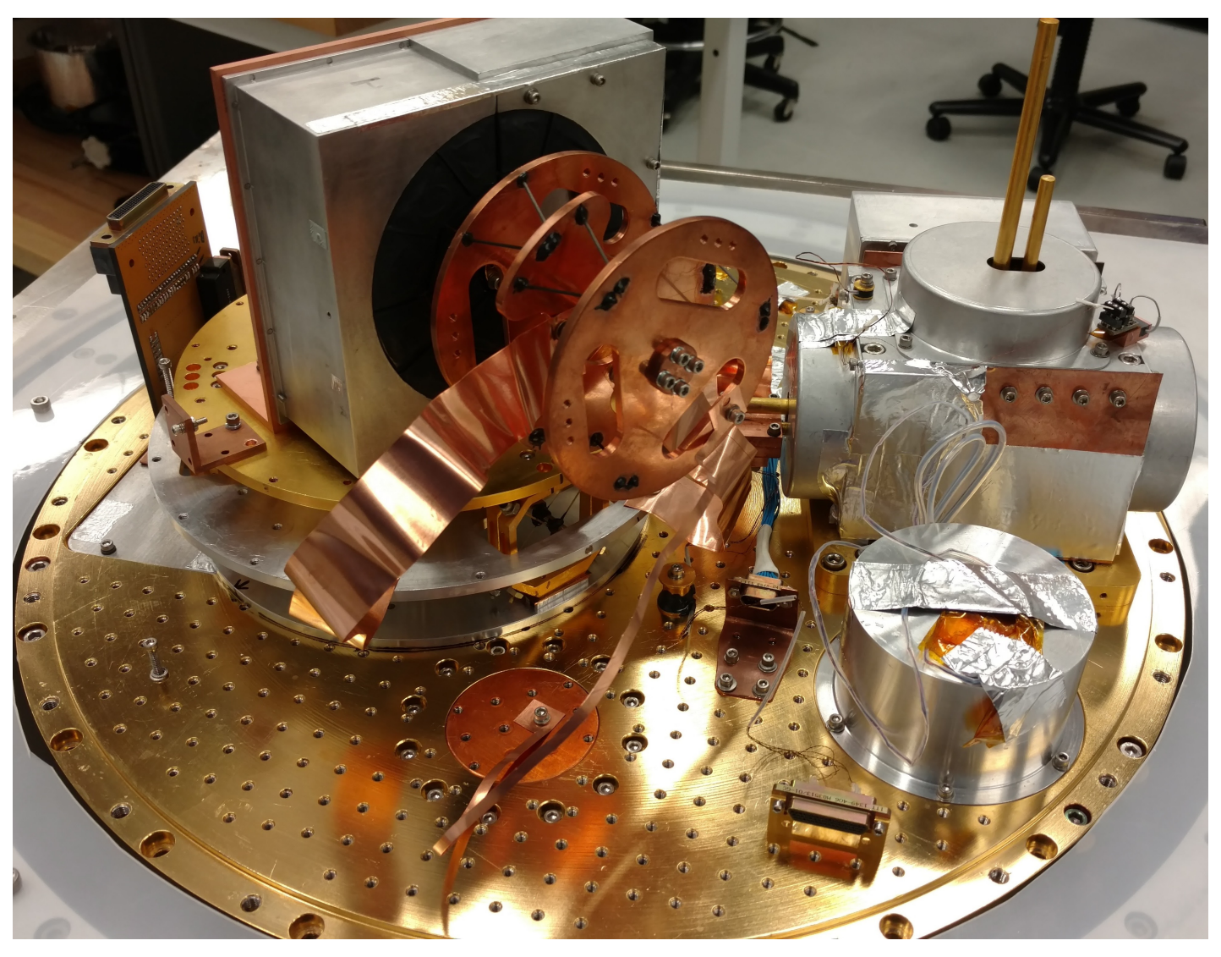
Left: A 90 GHz detector wafer with 37 pixels [6].
Right: Close-up view of single 90 GHz pixel. Probes are visible in the center of the image, with two TES structures to the right and above.

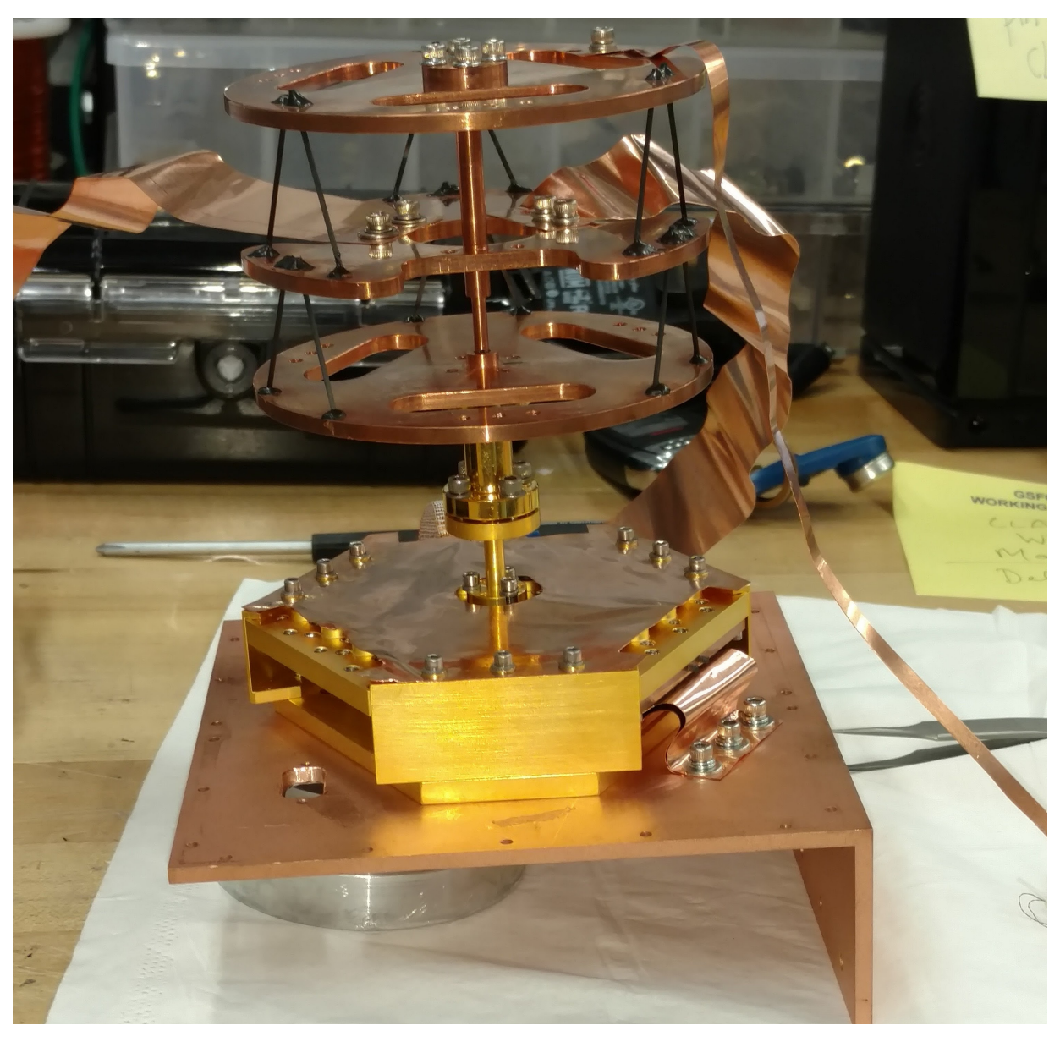


Left: A fully assembled detector module with smooth-wall feedhorns [7].
Right: Photonic choke pillars micro-machined into silicon wafer [8]. The choke wafer is indium bonded to the feedhorn side of the detector wafer.

On-going Work

Current characterization of the 90 GHz detector arrays includes measurements of the detector efficiency, TES I-V curves, heat capacity, *C*, and thermal conductance, *G*. Detector efficiency is measured using a cryogenic thermal blackbody calibrator.





90 GHz detector modules are characterized with a thermal source mounted to the center pixel of the detector array assembly [9]. The waveguide thermal source is constructed from a cone-shaped absorber mounted to a multi-stage, thermally isolating hexapod. The blackbody calibrator is heated to the desired temperature using a electrically resistive heater block and sensed using a zirconium oxy-nitride thin-film thermometer.

References:
[1] U. Seljak and M. Zaldarriaga, “Signature of gravity waves in polarization of the microwave background,” Phys.Rev.Lett. 78 (1997) 2054–2057, arXiv:astro-ph/9609169 [astro-ph].
[2] M. Kamionkowski, A. Kosowsky, and A. Stebbins, “A Probe of primordial gravity waves and vorticity,” Phys.Rev.Lett. 78 (1997) 2058–2061, arXiv:astro-ph/9609132 [astro-ph].
[3] Crowe, E.J., Bennett, C.L., Chuss, D.T., et al., “Fabrication of a Silicon Backshort Assembly for Waveguide-Coupled Superconducting Detectors” 2013, IEEE Transactions on Applied Superconductivity, Vol. 23, No. 3, p. 2500505; doi: 10.1109/TASC.2012.2237211.
[4] U-Yen, K., Wollack, E.J., Moseley, S.H., Stevenson, T., Hsieh, W.-T., Cao, N.T., “Via-less Microwave Crossover using Microstrip-CPW Transitions in Slotline Propagation Mode,” 2009, IEEE MTT-S International Microwave Symposium Digest, pp. 1029 – 1032.
[5] Harrington, K., Ali, A., Amiri, M., et al., “The Cosmology Large Angular Scale Surveyor (CLASS),” 2016, Proc. SPIE, “Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation VII,”, Vol. 9914, p. 99141K; doi: 10.1117/12.2233125.
[6] Rostem, K., Chuss, D.T. Colazo, F.A., et al., “Precision control of thermal transport in cryogenic single-crystal silicon devices,” 2014, Journal of Applied Physics, Vol. 115, No. 12, p. 124508; doi: 10.1063/1.4869737.
[7] Denis, K., Ali, Al, Appel, J., et al., “Fabrication of Feedhorn-Coupled Transition Edge Sensor Arrays for Measurement of the Cosmic Microwave Background Polarization”, Journal of Low Temperature Physics, 2015, Volume 184, Issue 3-4, pp. 668-673
[8] Zeng, L., Bennett, C.L., Chuss, D.T., Wollack, E.J., “A Low Cross-Polarization Smooth-Walled Horn with Improved Bandwidth,” 2010, IEEE Transactions on Antennas & Propagation, Vol. 58, No. 4, pp. 1383-1287.
[9] Wollack, E.J., U-Yen, K. and Chuss, D.T., “Photonic Choke-Joints for Dual-Polarization Waveguides,” 2010, IEEE MTT-S International Microwave Symposium Digest, pp. 177-180.
[10] Rostem, K., Chuss, D.T., Lourie, N.P., Voellmer, G.M., Wollack, E.J., “A Waveguide-Coupled Thermally-Isolated Radiometric Source,” 2013, Review of Scientific Instruments, Vol. 84, No. 4, p. 044701; doi: 10.1063/1.4795556.

We acknowledge the National Science Foundation Division of Astronomical Sciences for their support of CLASS under Grant Numbers 0959349, 1429236, and 1636634. The sensor technology was developed under a series of NASA SAT and ROSES/APRA grants.