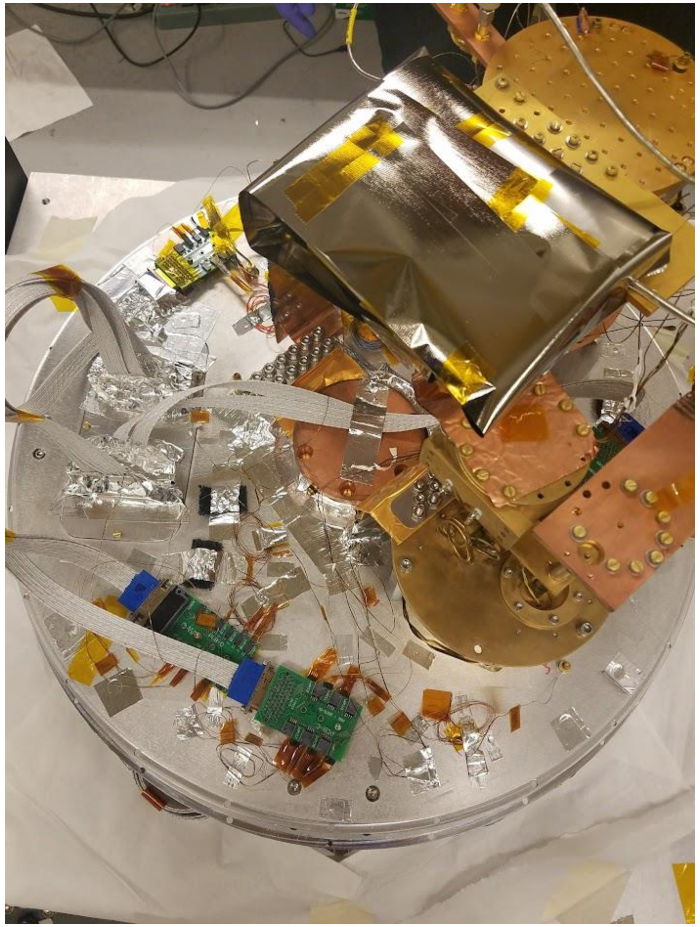
Wide-Area E-mode Science with BICEP3

Cyndia Yu (she/her), Stanford/SLAC

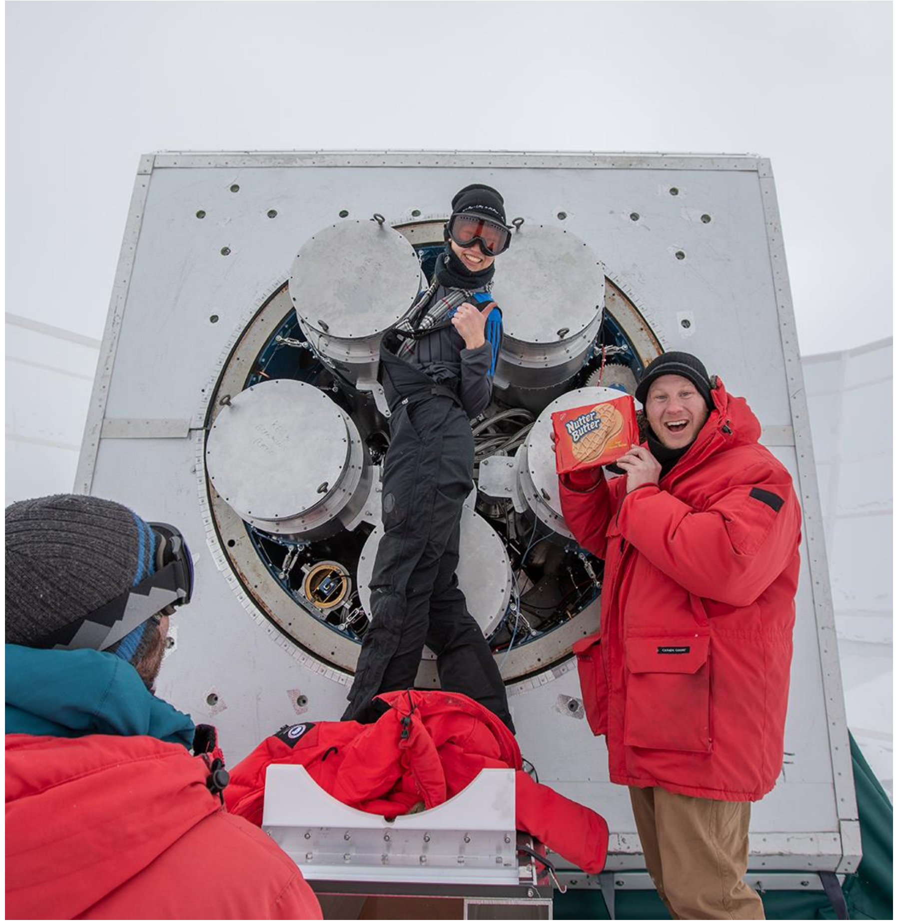
CMB-S4 Summer Collaboration Meeting 2022

cyndiayu@stanford.edu

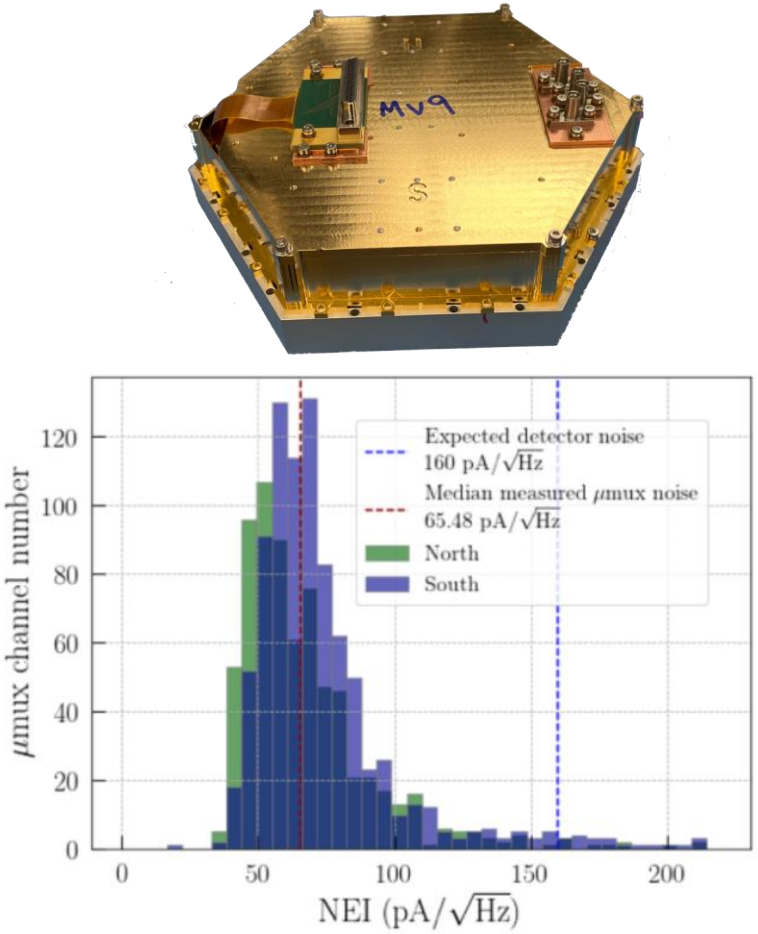
Superconducting microwave resonator and RF readout development



Henderson et al. 2018



Cukierman et al. 2019



McCarrick et al. 2021

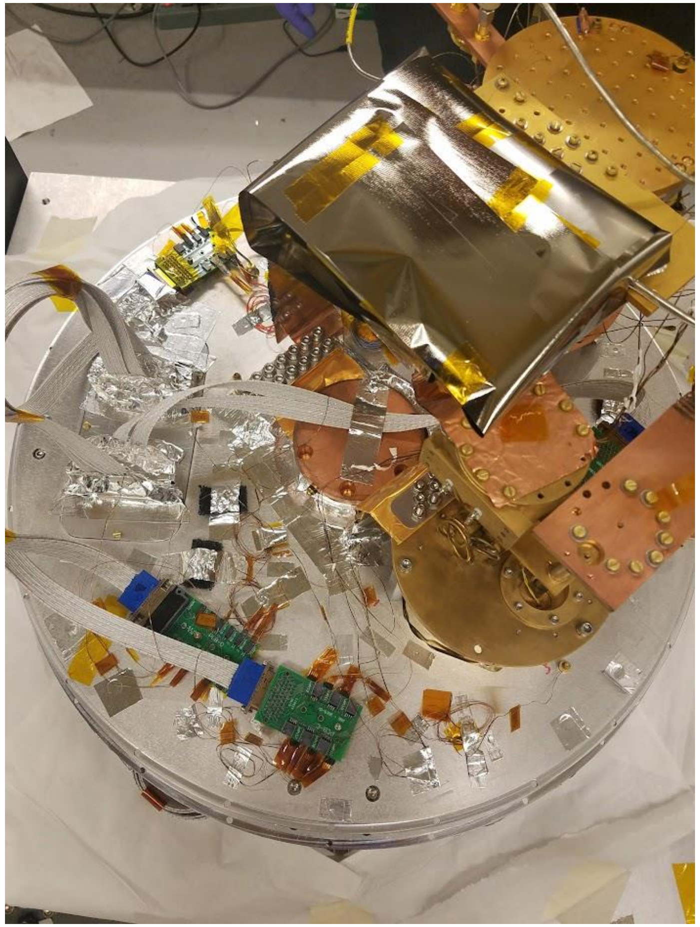
Superconducting mi
RF readout develop

SLAC Microresonator RF (SMuRF) Electronics: A tone-tracking readout system for superconducting microwave resonator arrays

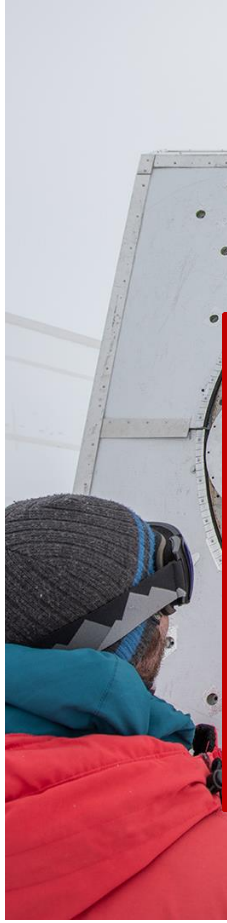
Cyndia Yu,[1,2,a)] Zeeshan Ahmed,[2,3] Josef C. Frisch,[3] Shawn W. Henderson,[2,3] Max Silva-Feaver,[4] Kam Arnold,[4] David Brown,[3] Jake Connors,[5] Ari J. Cukierman,[1,2] J. Mitch D'Ewart,[3] Bradley J. Dober,[5] John E. Dusatko,[3] Gunther Haller,[3] Ryan Herbst,[3] Gene C. Hilton,[5] Johannes Hubmayr,[5] Kent D. Irwin,[1,3] Chao-Lin Kuo,[1,3] John A.B. Mates,[5] Larry Ruckman,[3] Joel Ullom,[5] Leila Vale,[5] Daniel D. Van Winkle,[3] Jesus Vasquez,[3] and Edward Young[1,2]
[1)]*Department of Physics, Stanford University; Stanford, CA 94305; USA*
[2)]*Kavli Institute for Particle Astrophysics and Cosmology; Stanford, CA 94305; USA*
[3)]*SLAC National Accelerator Laboratory; Menlo Park, CA 94025; USA*
[4)]*Department of Physics, University of California San Diego; La Jolla, CA 92093; USA*
[5)]*National Institute of Standards and Technology; Boulder, CO 80305; USA*

(Dated: 11 August 2022)

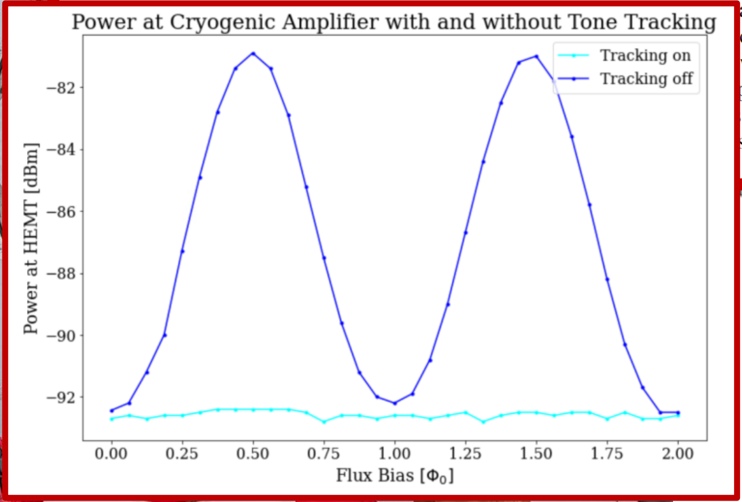
We describe the newest generation of the SLAC Microresonator RF (SMuRF) electronics, a warm digital control and readout system for microwave-frequency resonator-based cryogenic detector and multiplexer systems such as microwave SQUID multiplexers (µmux) or microwave kinetic inductance detectors (MKIDs). Ultra-sensitive measurements in particle physics and astronomy increasingly rely on large arrays of cryogenic sensors, which in turn necessitate highly multiplexed readout and accompanying room-temperature electronics. Microwave-frequency resonators are a popular tool for cryogenic multiplexing, with the potential to multiplex thousands of detector channels on one readout line. The SMuRF system provides the capability for reading out up to 3328 channels across a 4-8 GHz bandwidth. Notably, the SMuRF system is unique in its implementation of a closed-loop tone-tracking algorithm that minimizes

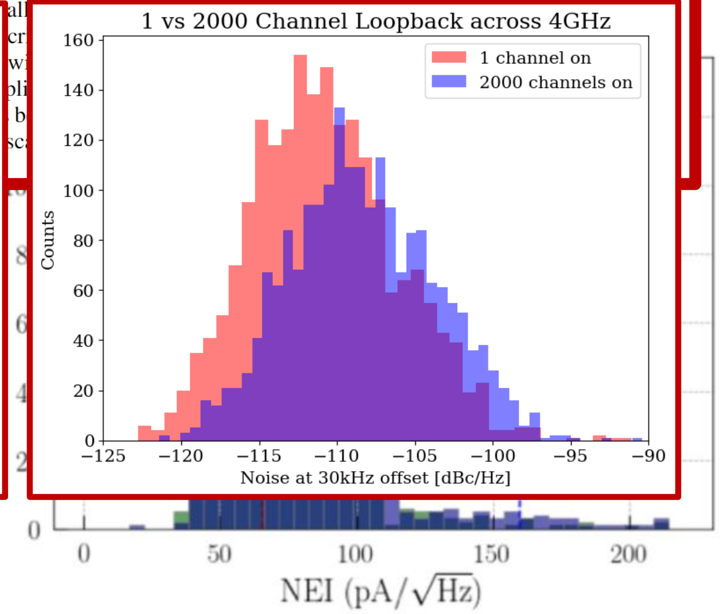


Henderson et al. 2018



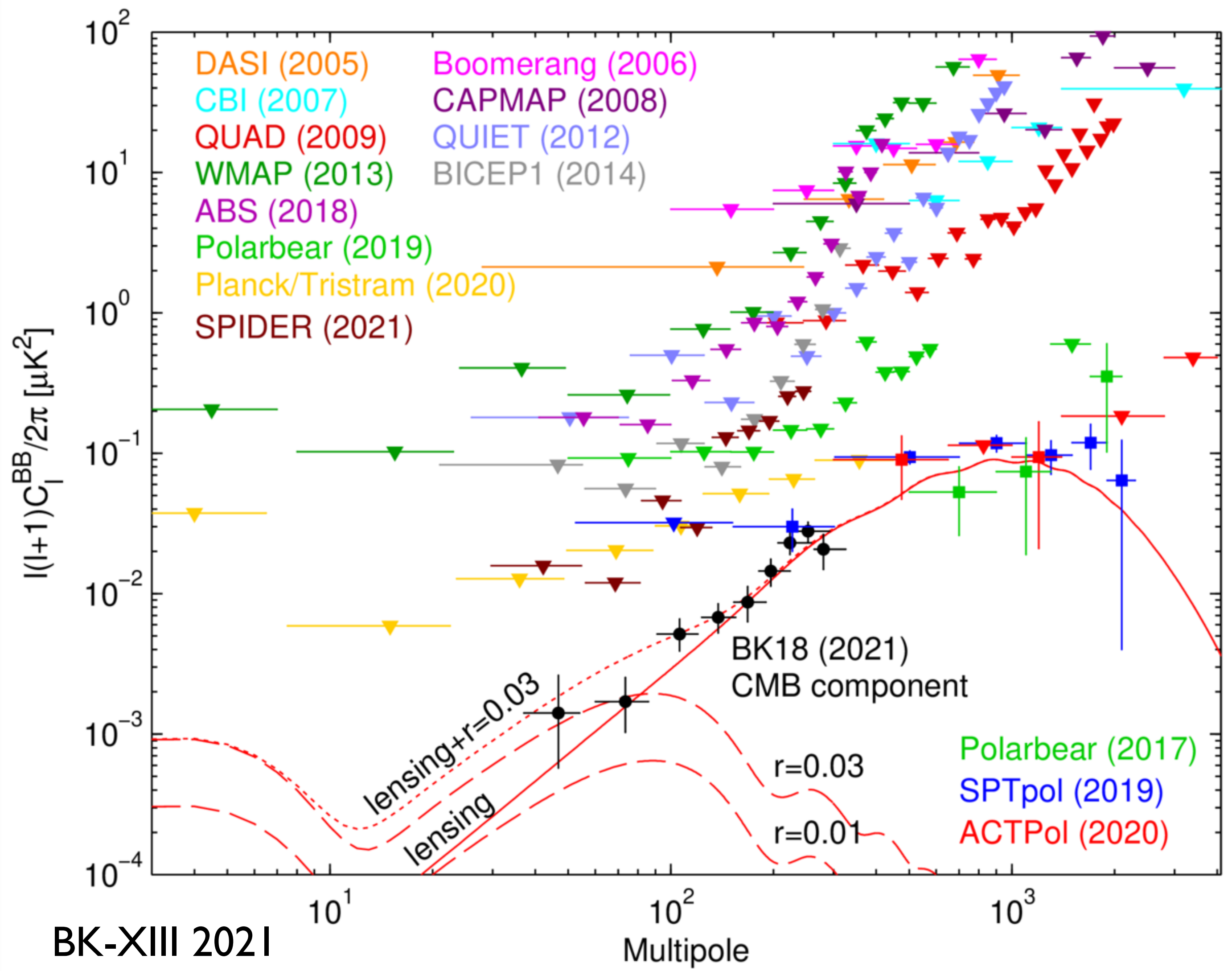
Cukierman et al. 2019





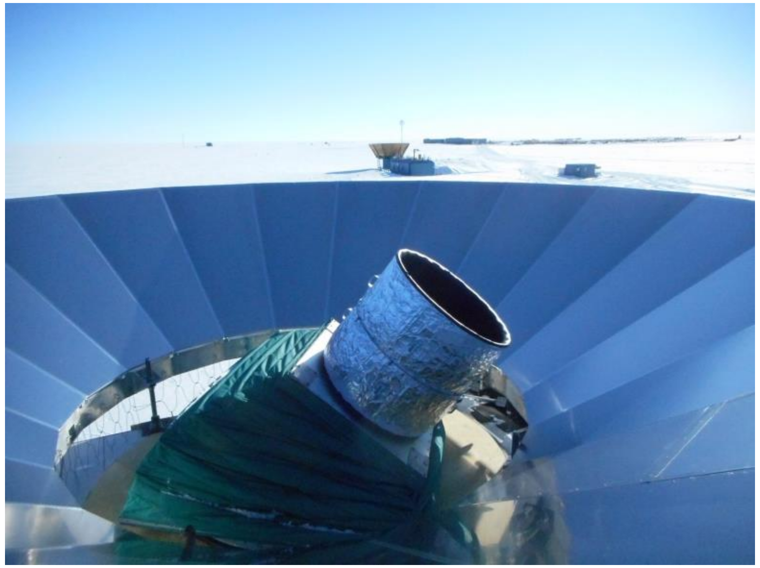
McCarrick et al. 2021

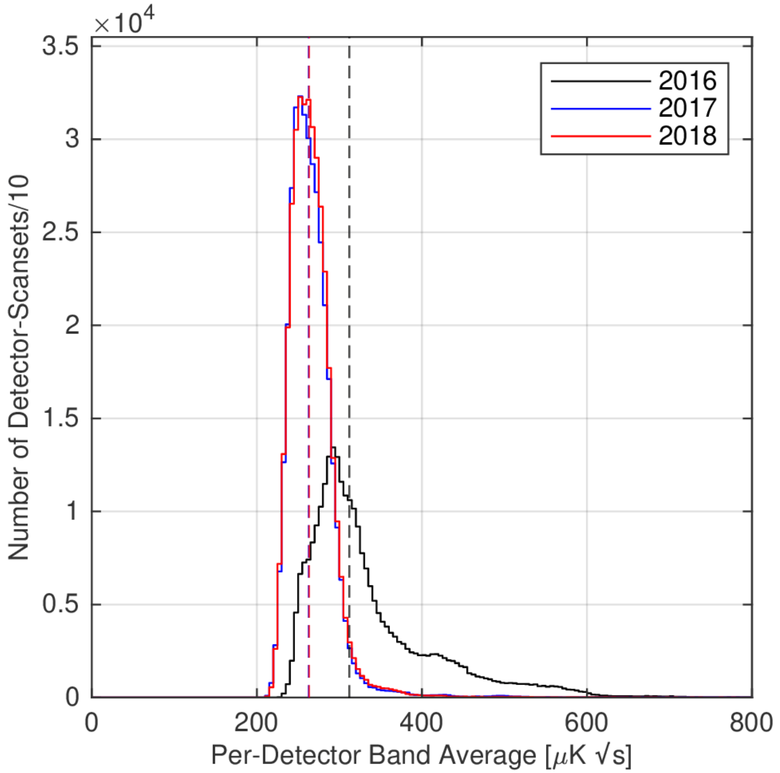
BICEP/Keck is a highly successful small-aperture program targeting inflationary gravitational waves…



BK-XIII 2021

BICEP3 is a fantastic small-aperture polarimeter!

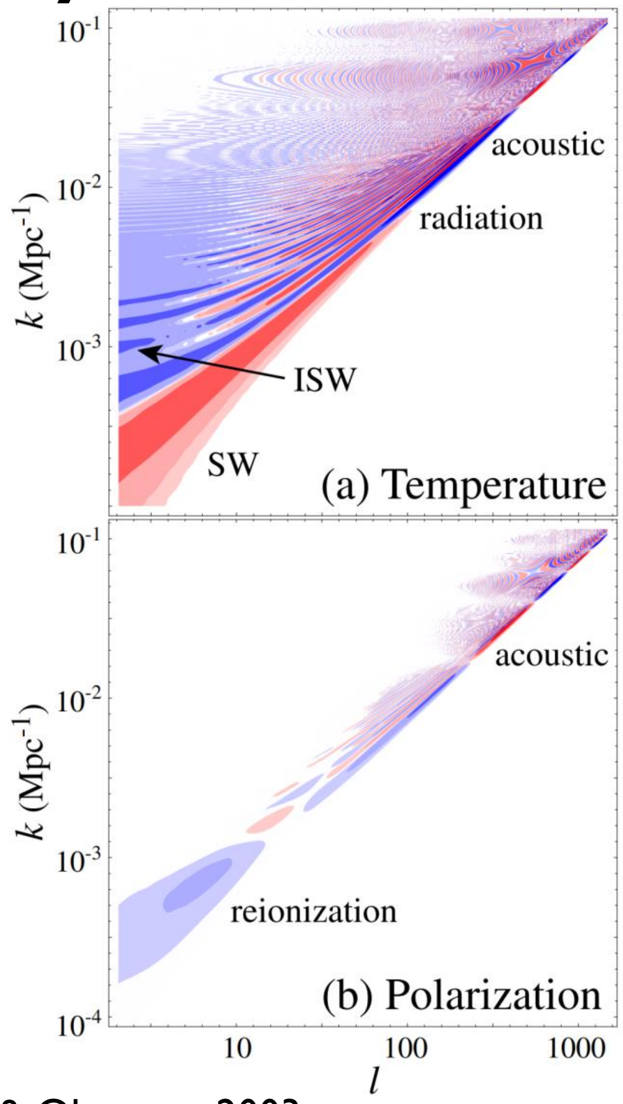




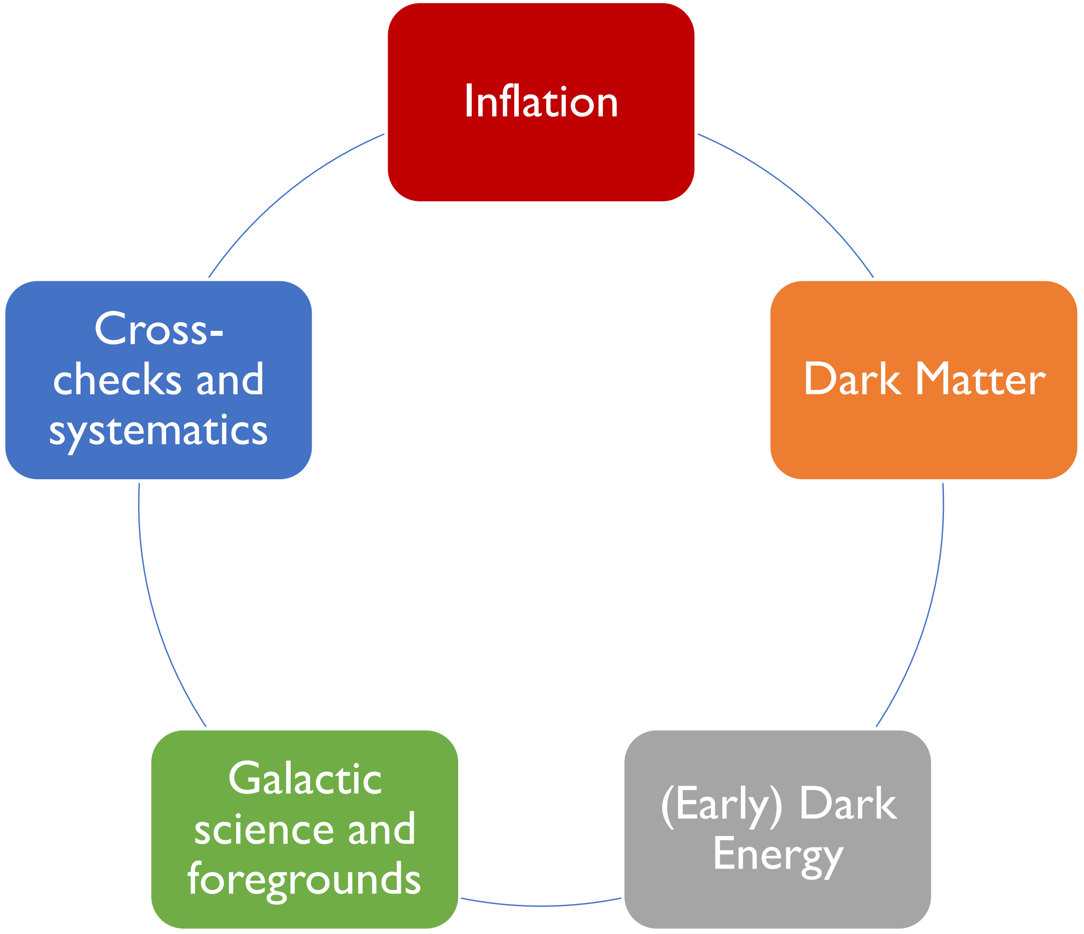
BK-XV 2022

- 2400 dual-polarization 95GHz TESs
- 24' beam, 27.4° FOV
- Science observations since 2016

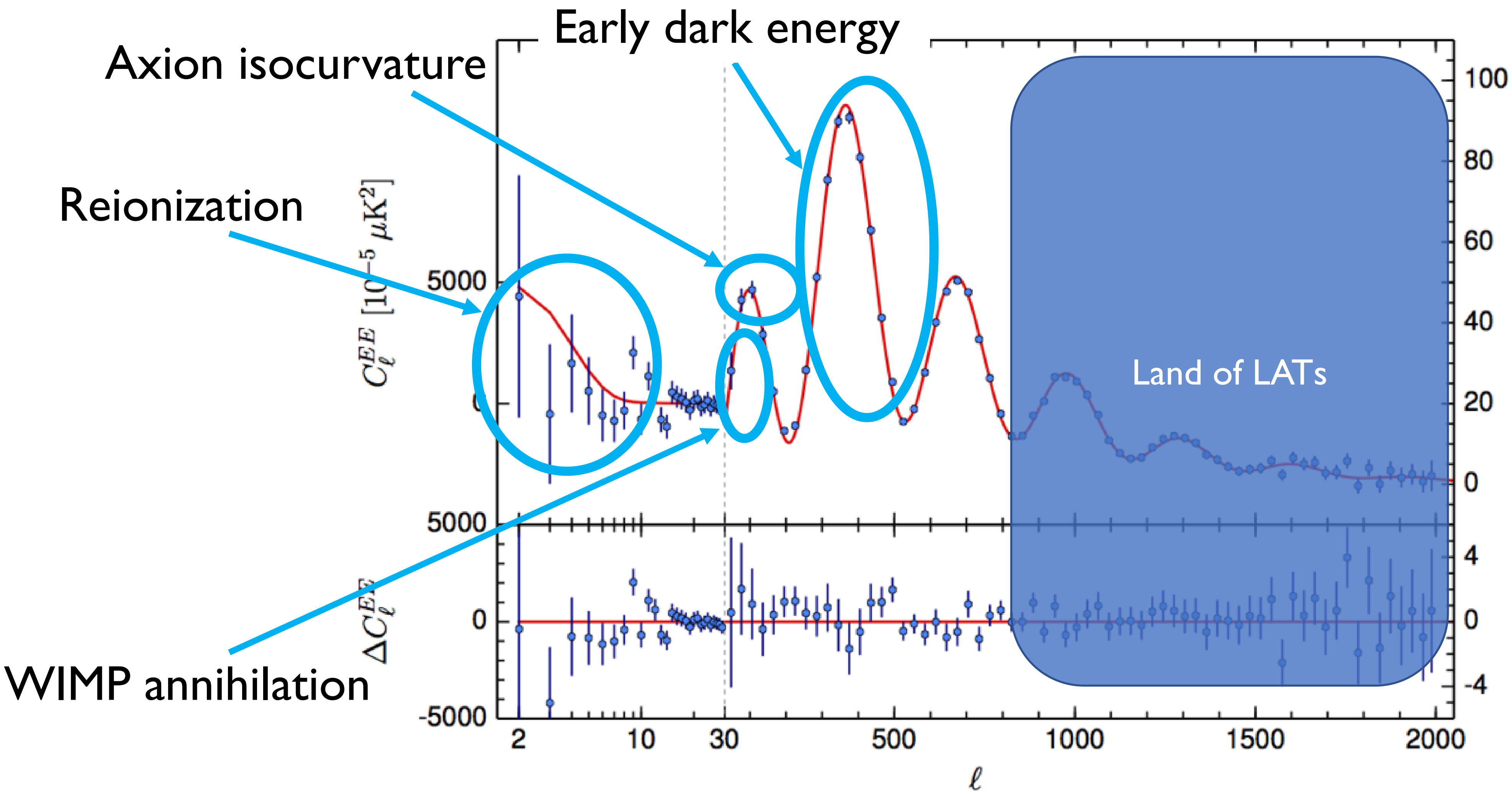
Why bother with large-scale polarization?



Hu & Okamoto 2003

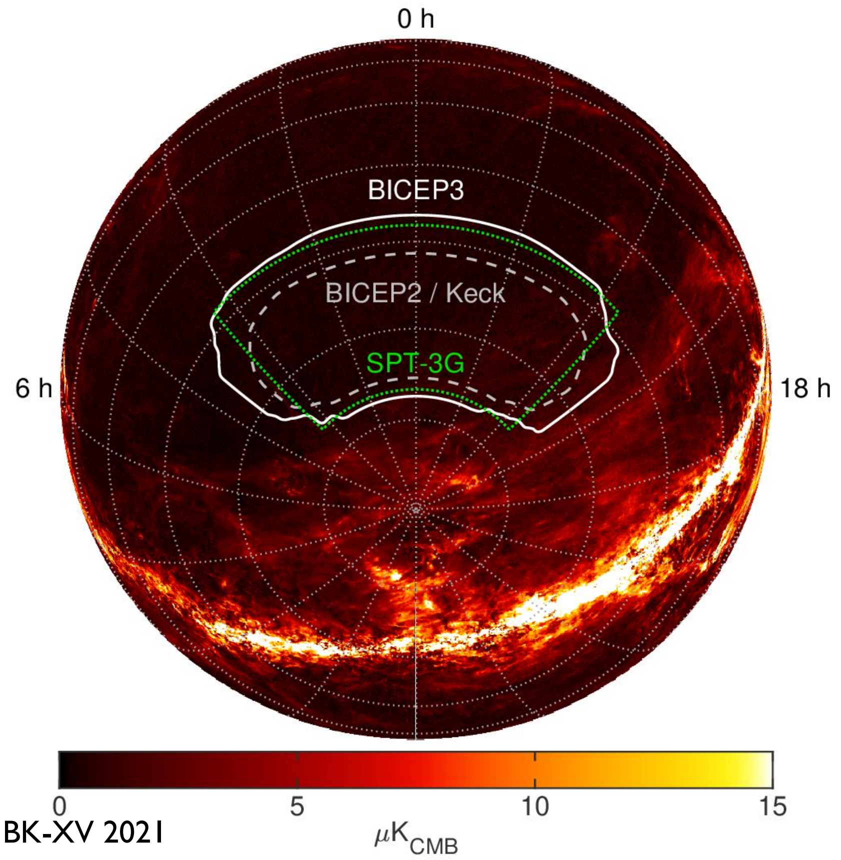


Cosmology in Low-ℓ E-modes

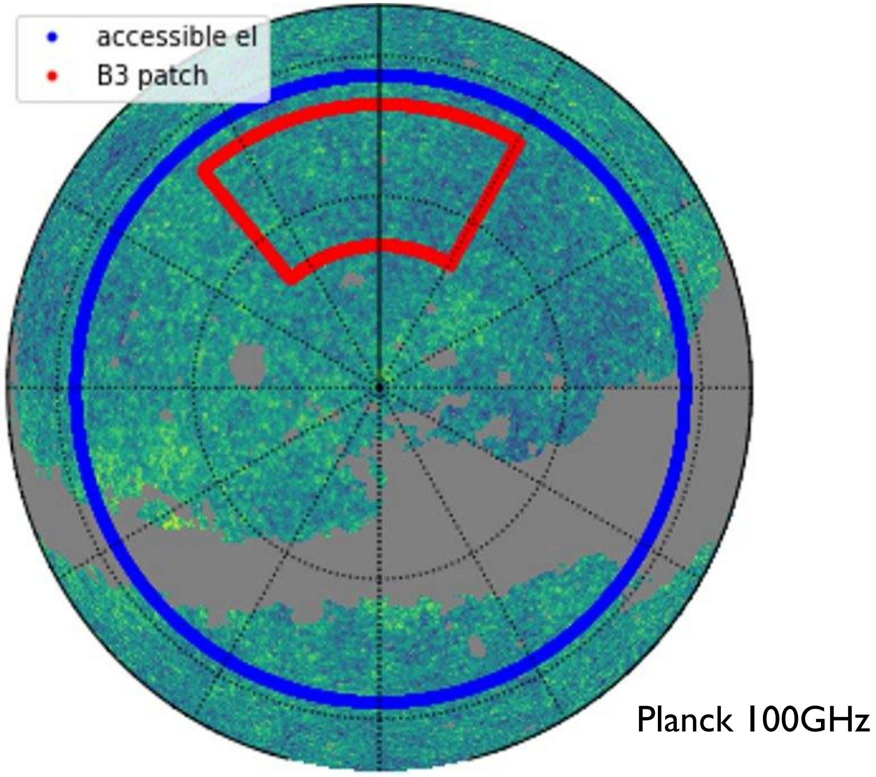


Planck 2018

f_{sky} from Pole is not huge but not a showstopper…



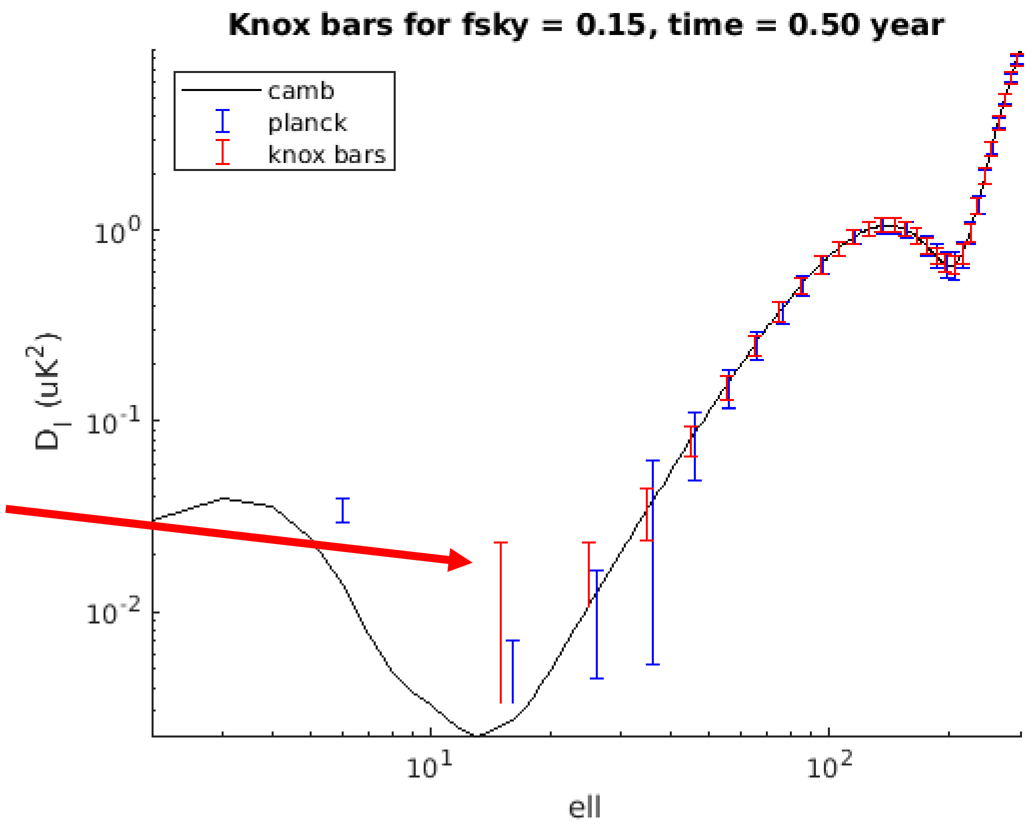
Regular BK patch:~3%



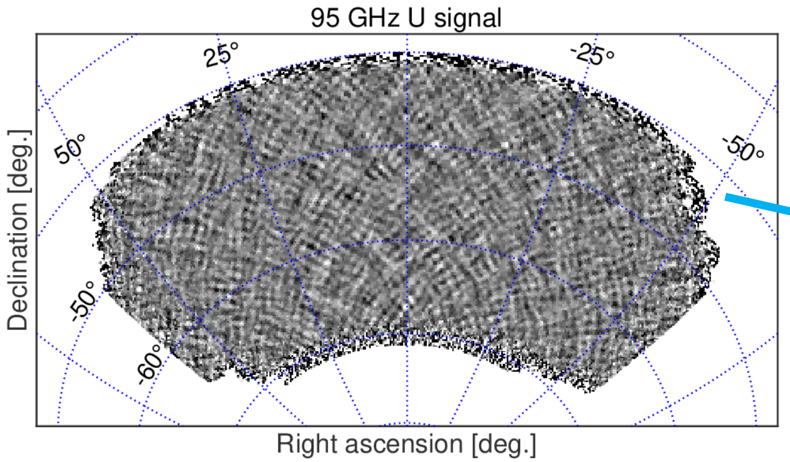
Available above groundshield and with masked galaxy: ~20%

BICEP3 can quickly reach Planck-like sensitivities

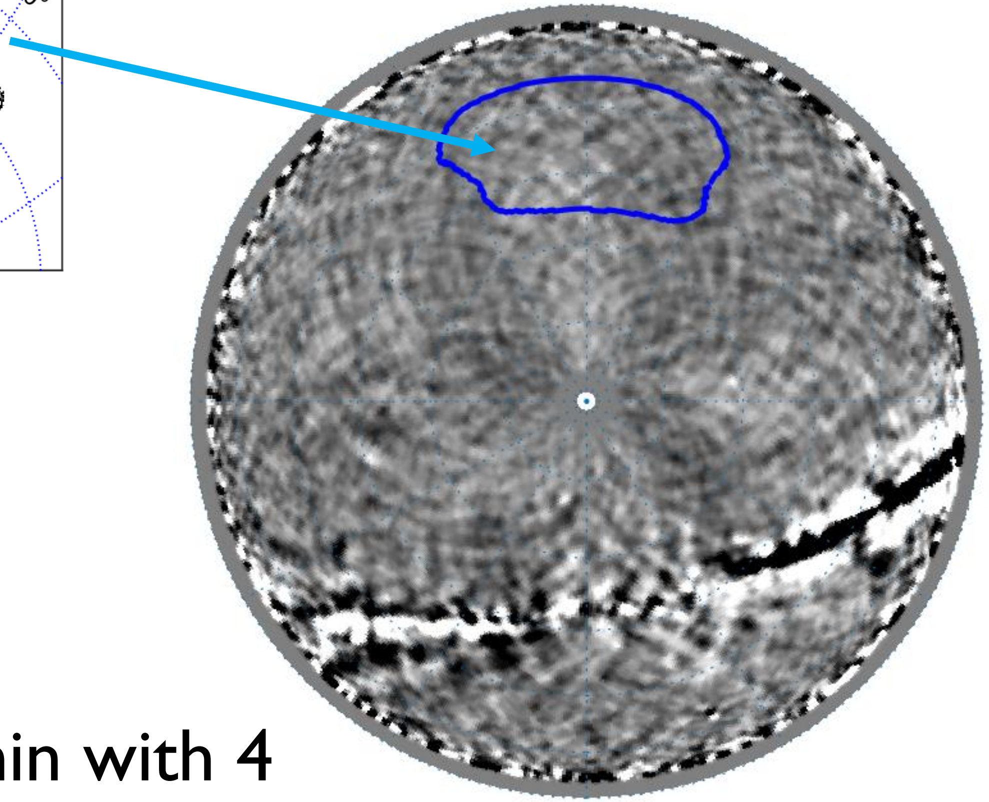
- Scaling from achieved BICEP3 performance
- Scaled integration time accounts for usual observing efficiency hits
  - “1 year” = March - October
- Low-ell modes traditionally heavily filtered for B-mode science, but (in principle) recoverable



E-modes observed at high signal-to-noise!

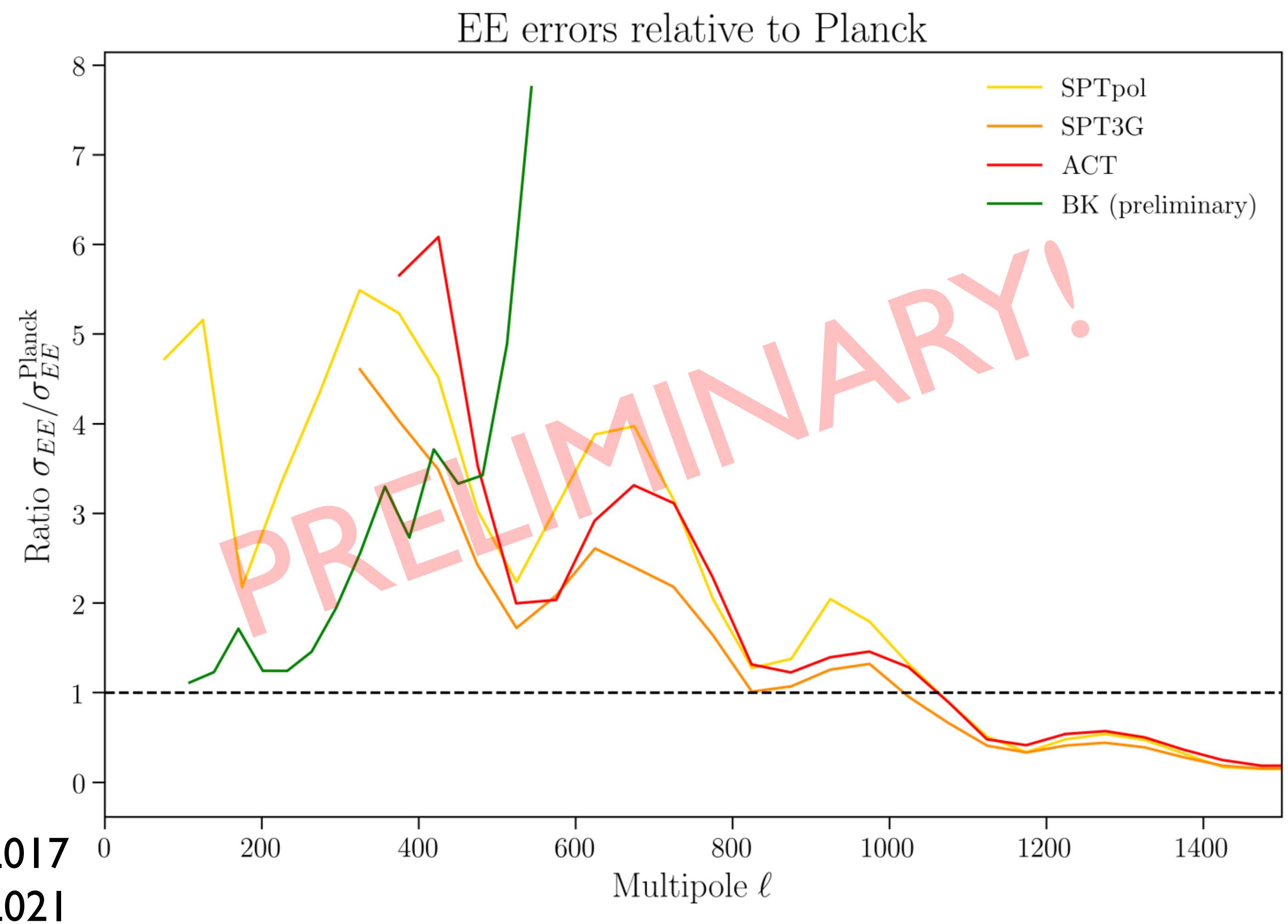


BK collaboration 2021



Over 8000 sq deg < 20uK-arcmin with 4 months of (mostly summer) integration!

Preliminary sensitivity

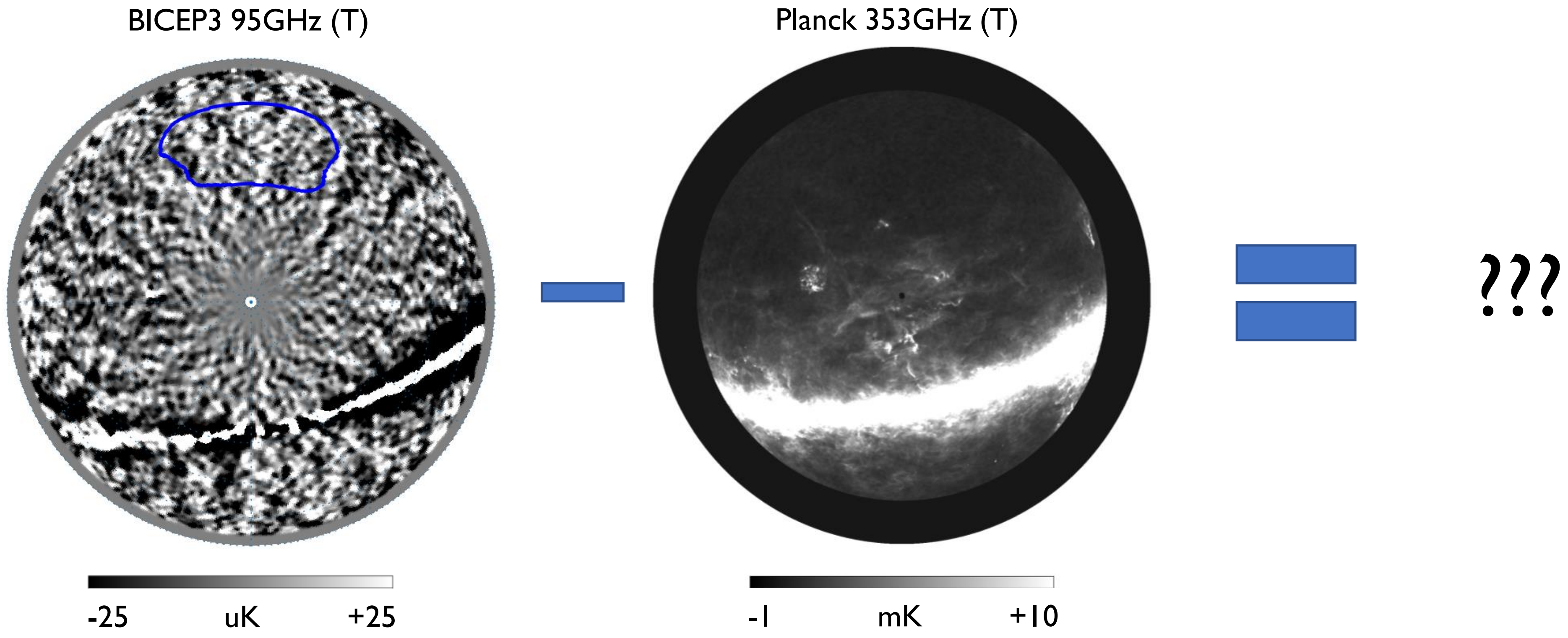


Caveats:

- Very few (n=45) sims
- Filtering, binning choices not totally final
- Null tests look fine for ℓ >100, working on ℓ <100 null tests now

SPTpol: Henning et al. 2017
SPT3G: Dutcher et al. 2021
ACT: Aiola et al. 2021

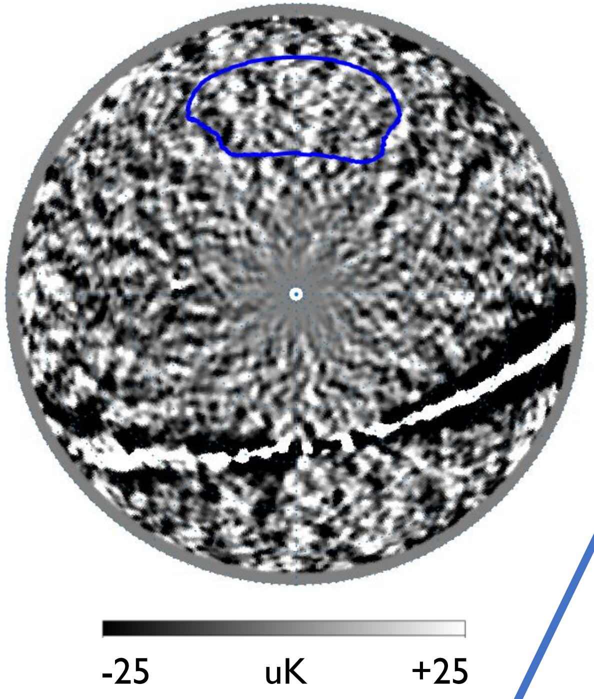
What's next? Component separation

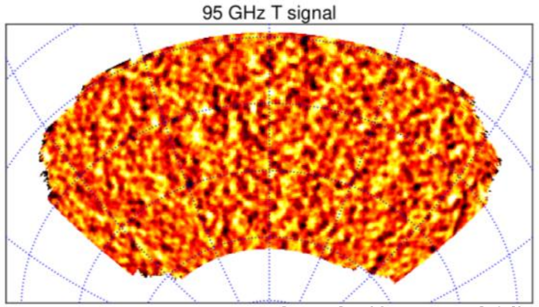


Single-frequency measurements and very inhomogenous dust field mean we can't do usual BK multicomponent analysis…

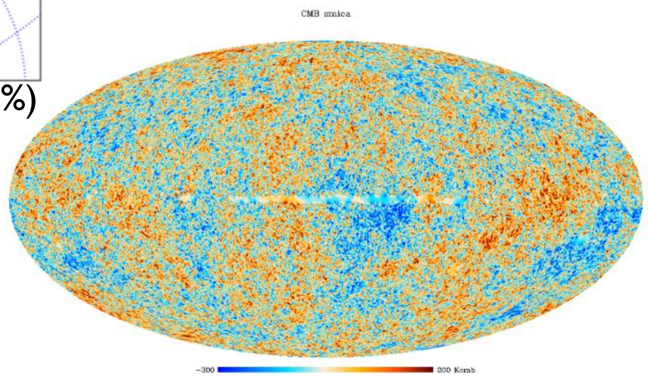
What’s next? Dataset combination

BICEP3 95GHz (T)



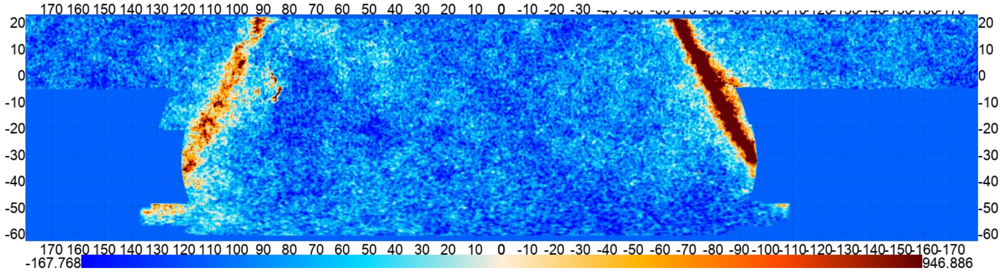


BICEP3 (fsky ~ 3%)



Planck (fsky ~ 80%)

= ???



ACT DR4 (fsky ~ 40%)

Map space? Power spectrum space? Likelihood only? Non-trivial covariances over these areas…

Outlook

- Low-ℓ EE (and TE) science has lots to offer
- Large-scale E-mode studies can leverage instruments optimized for inflationary B-mode searches to great effect
- New analysis questions allow us to stress-test existing pipelines
- Data on disk look very promising! Stay tuned!