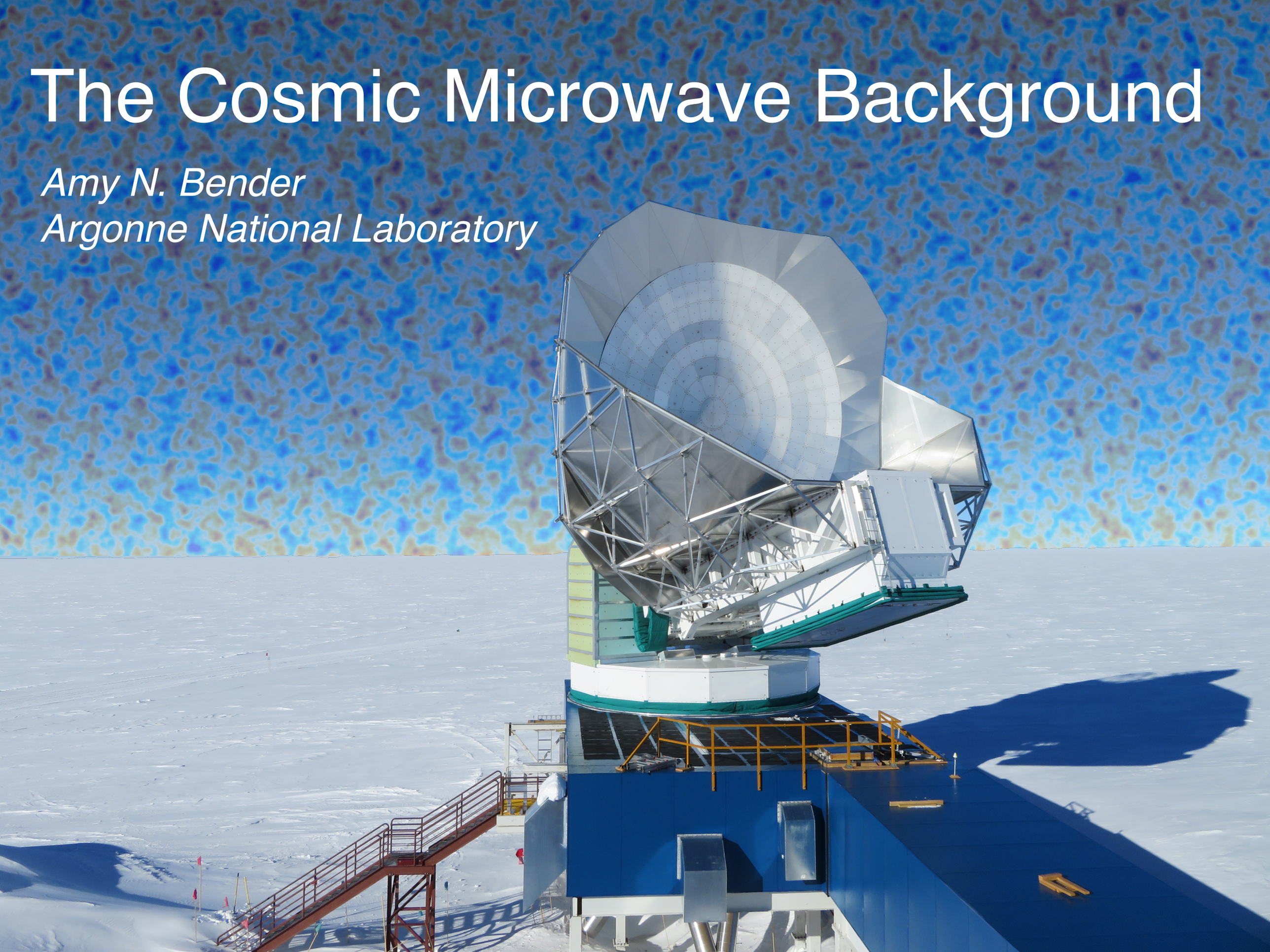
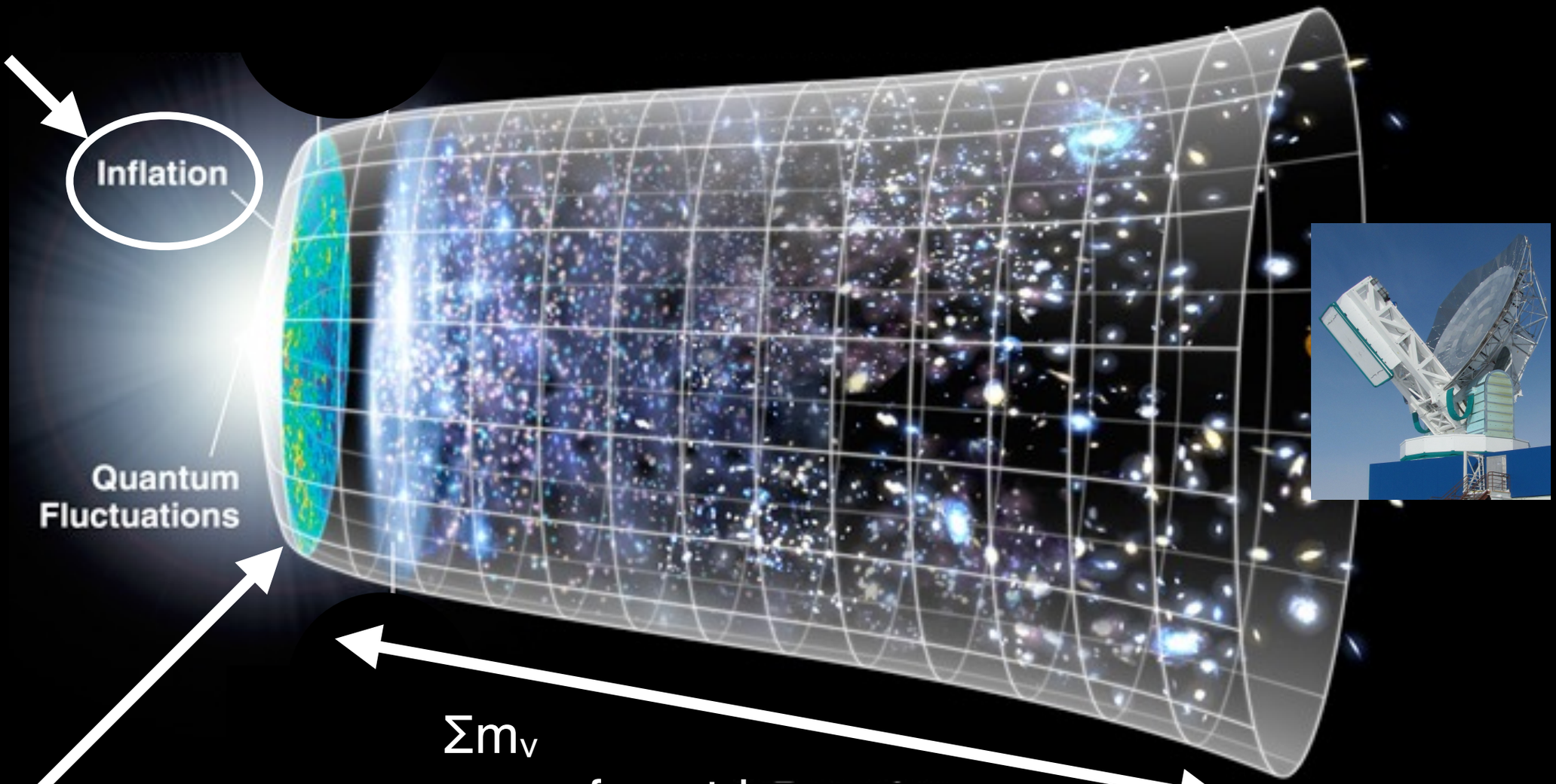
The Cosmic Microwave Background

Amy N. Bender
Argonne National Laboratory



The Universe as a Laboratory

r: tensor to scalar ratio

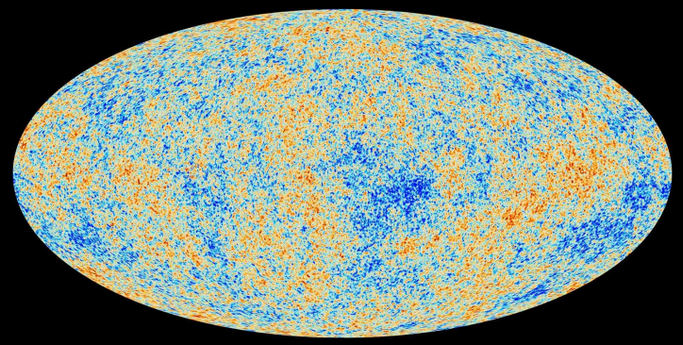


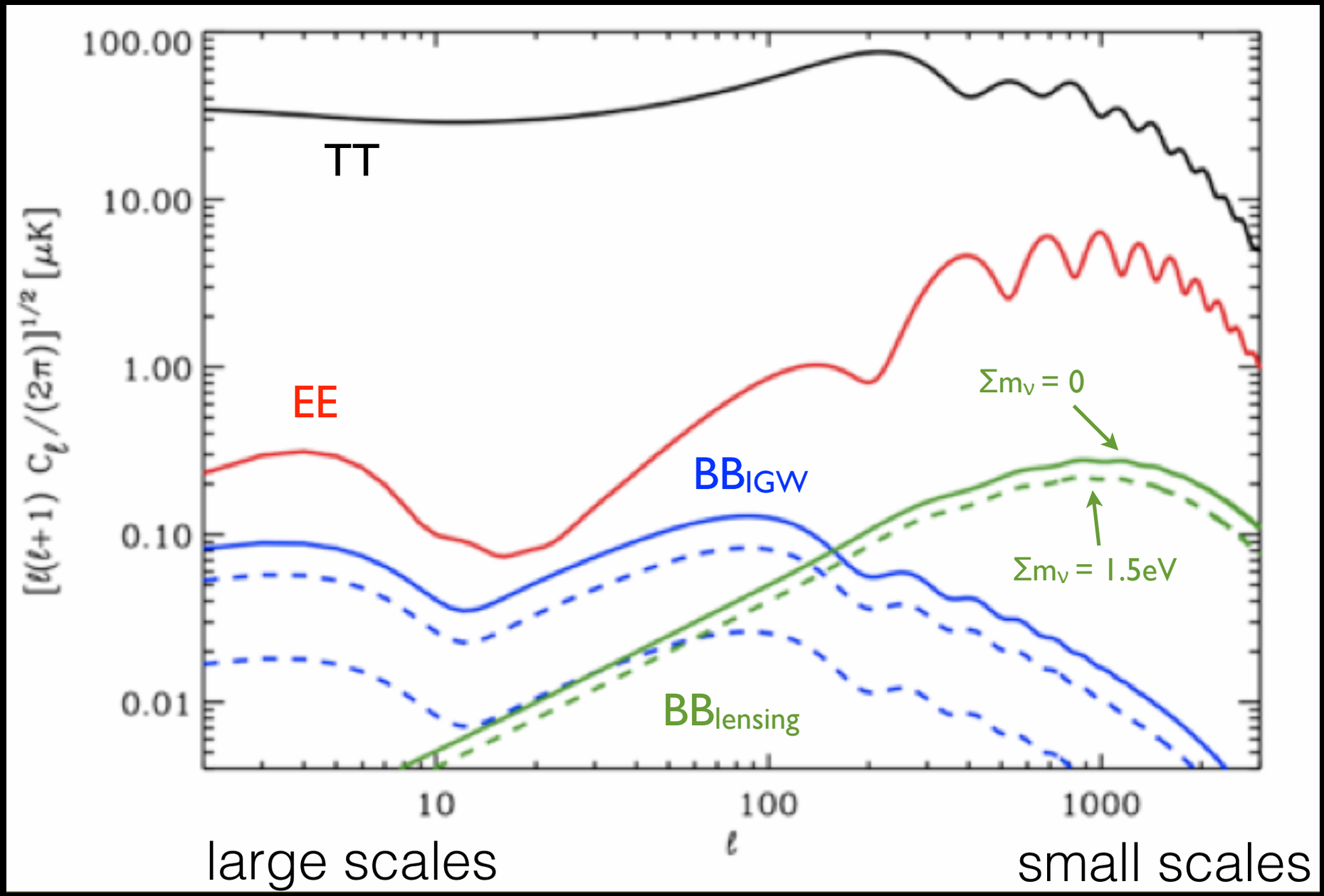
Σm_ν
sum of neutrino mass

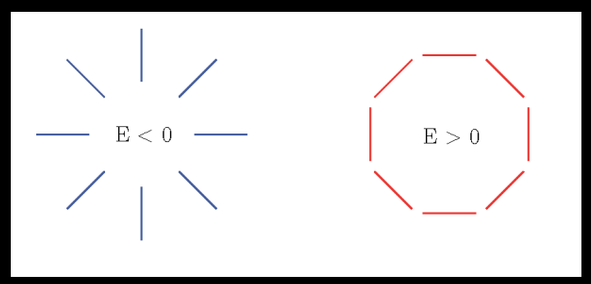
N_{eff}:
effective number of neutrino species

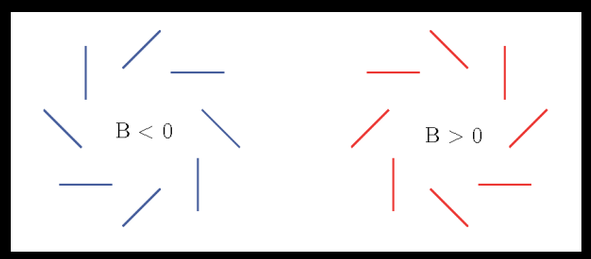
credit: NASA/WMAP Science Team

The Cosmic Microwave Background

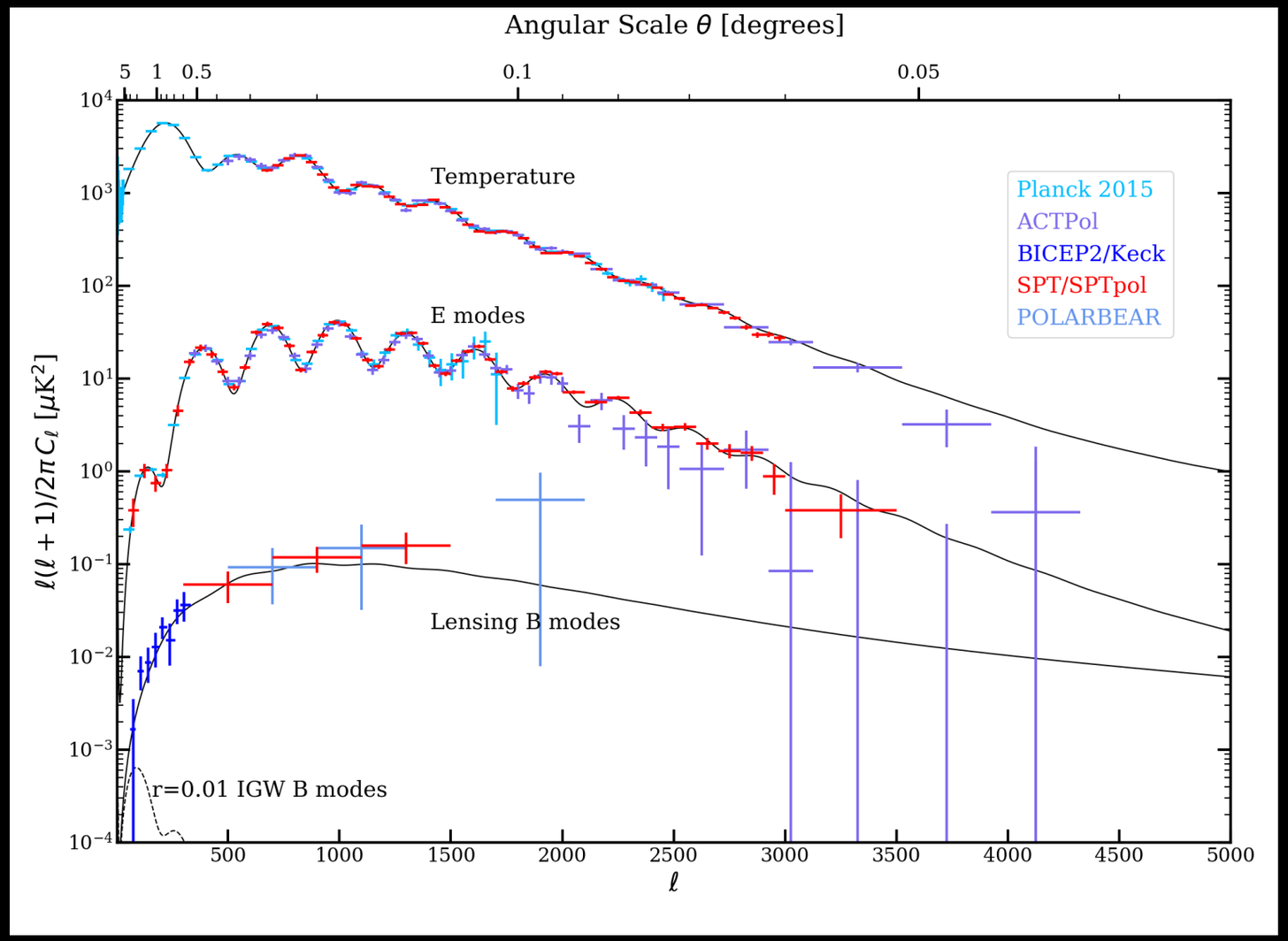
FFT () →

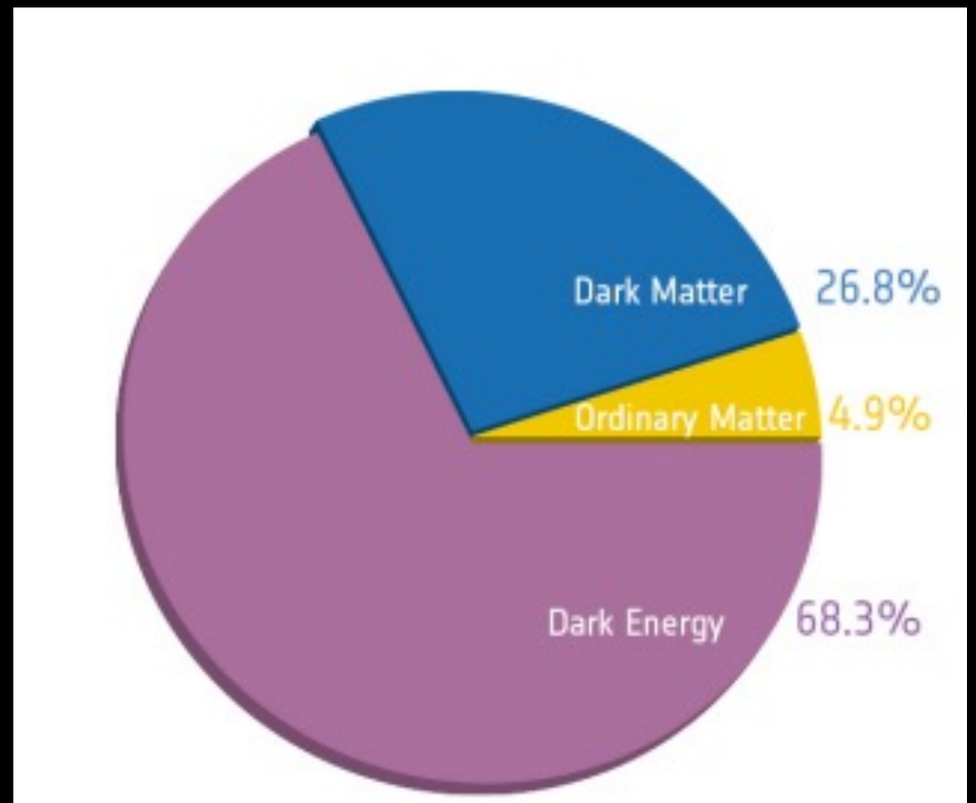






Precision Cosmology



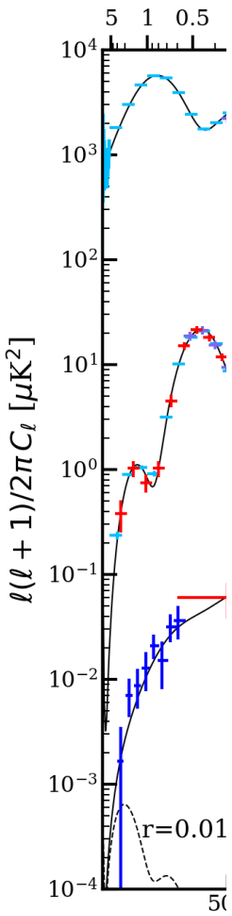


Credit: ESA and the Planck Collaboration

Parameter	[1] *Planck* TT+lowP
$\Omega_b h^2$	0.02222 ± 0.00023
$\Omega_c h^2$	0.1197 ± 0.0022
$100\theta_{MC}$	1.04085 ± 0.00047
τ	0.078 ± 0.019
$\ln(10^{10} A_s)$	3.089 ± 0.036
n_s	0.9655 ± 0.0062
H_0	67.31 ± 0.96
Ω_m	0.315 ± 0.013
σ_8	0.829 ± 0.014
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014

Planck XIII 2015

Precision Cosmology



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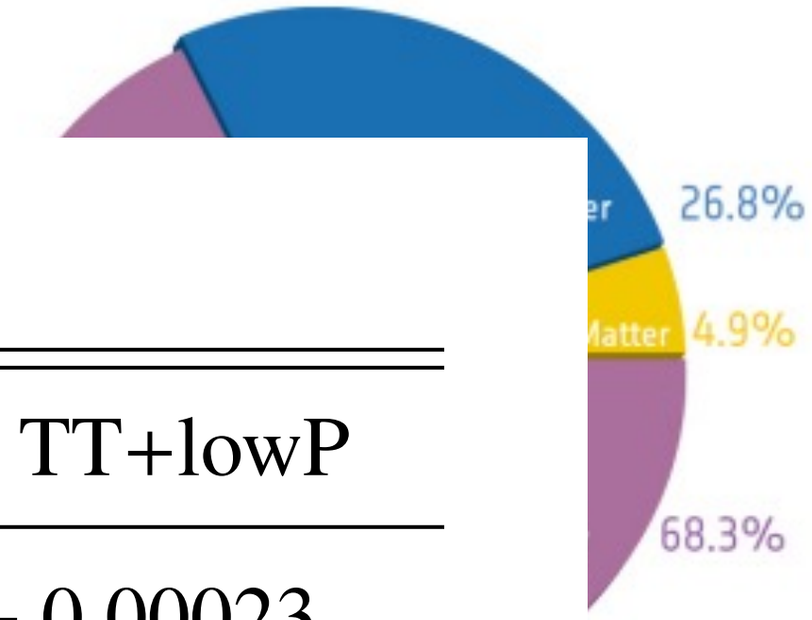
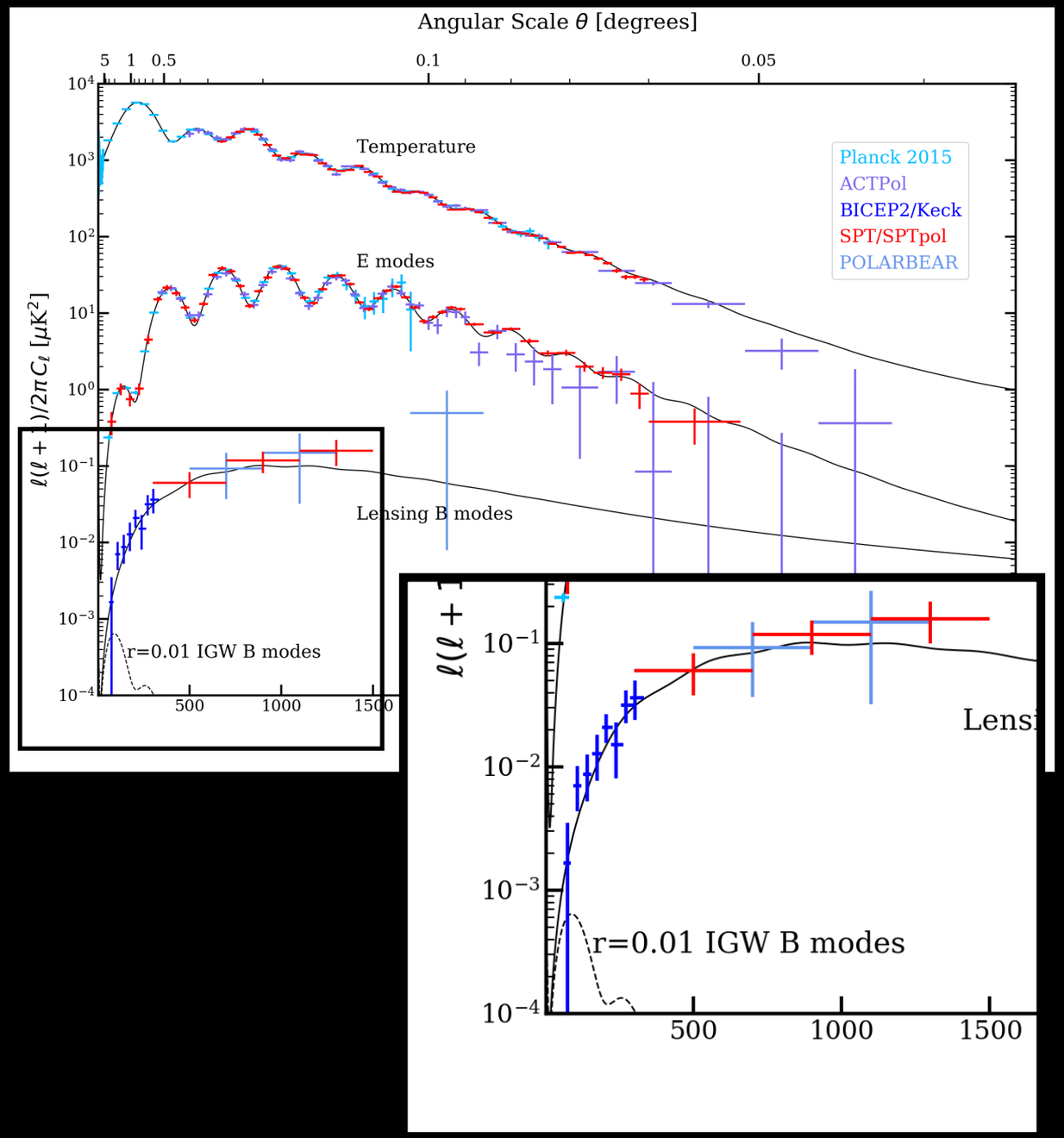


llaboration

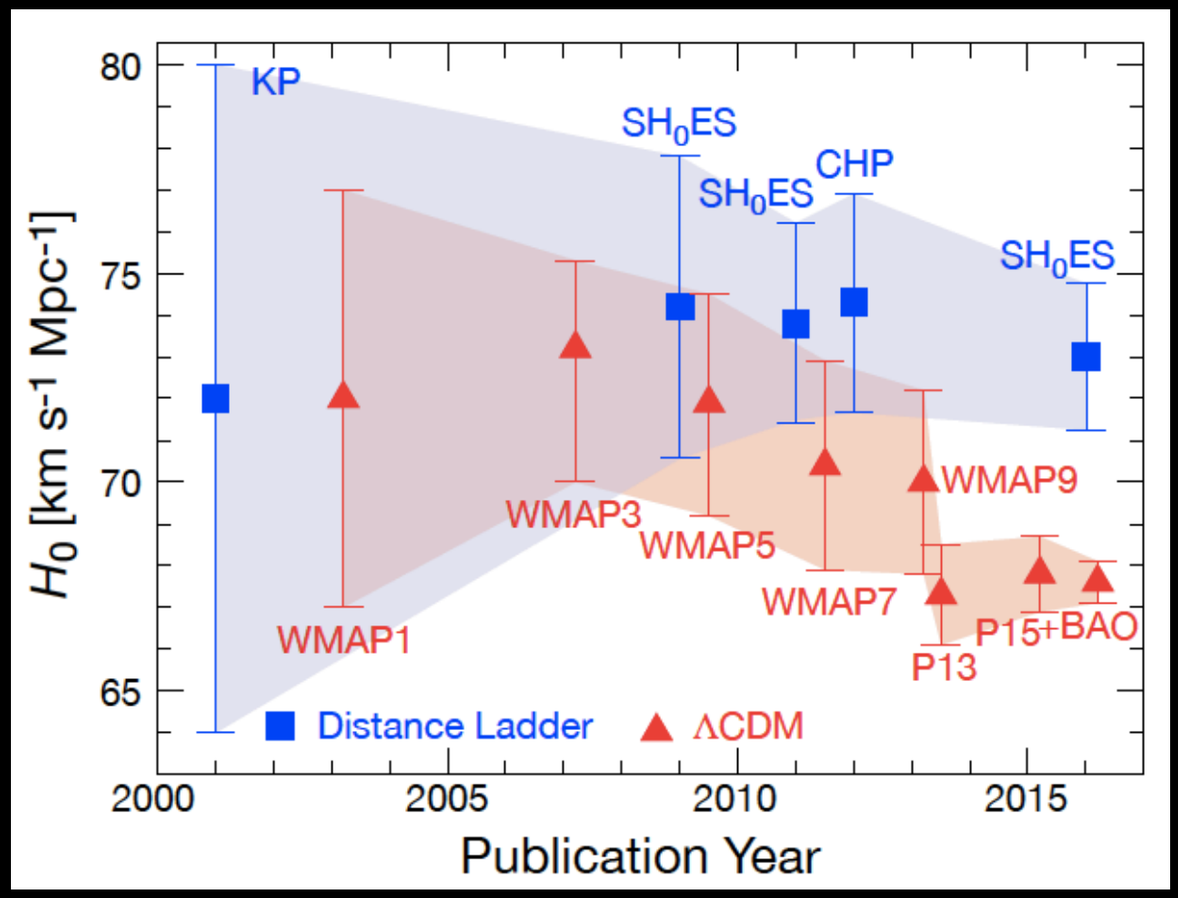
2% !!

Planck XIII 2015

Put down the champagne!



More precise B-mode measurements needed to constrain fundamental physics!



Freedman 2017

Are there cracks in ΛCDM?

.....

or systematics in the data?

The South Pole Telescope (SPT)

10-meter sub-mm quality telescope

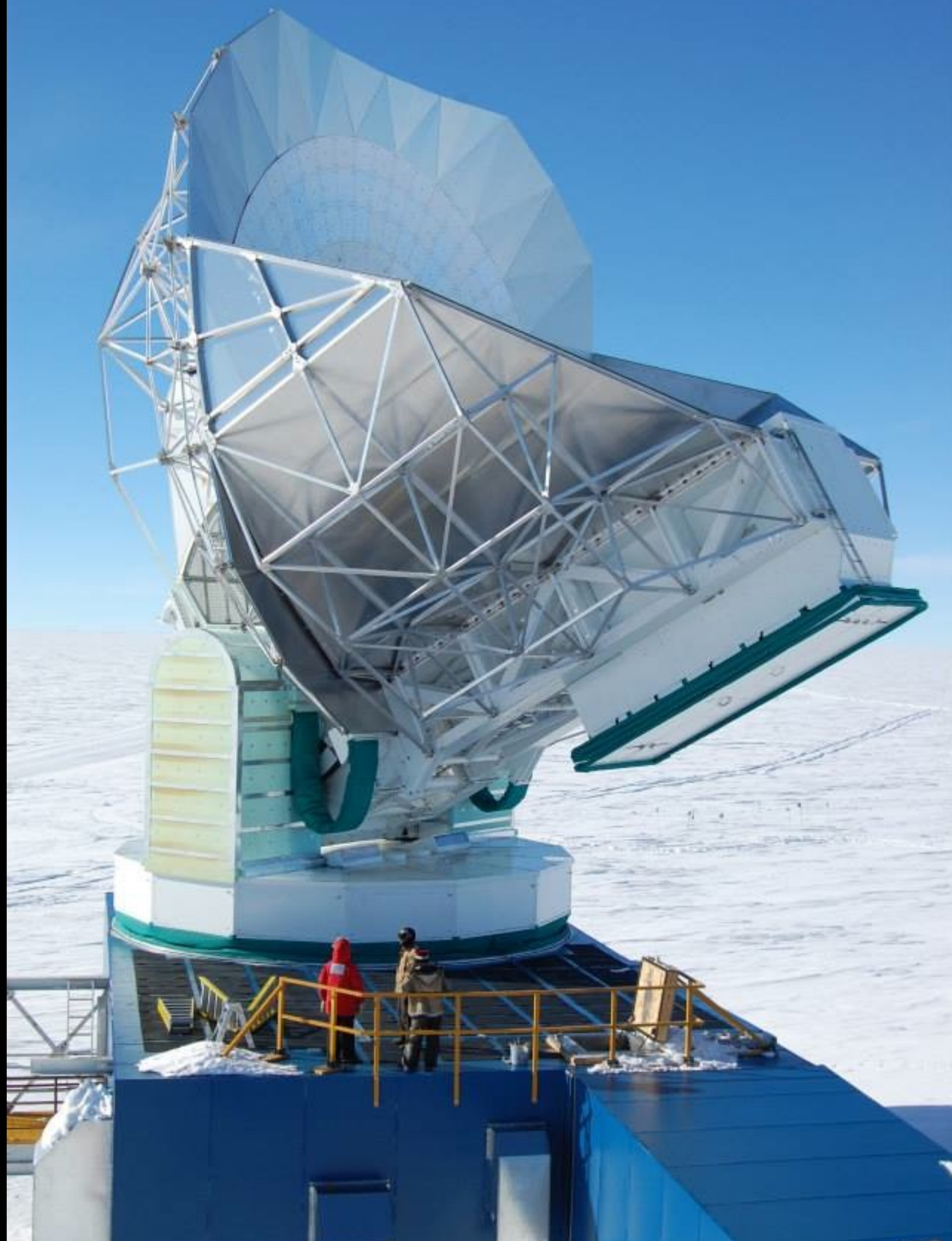
arcminute resolution at 150 GHz

Three CMB receivers

SPT-SZ

SPTpol

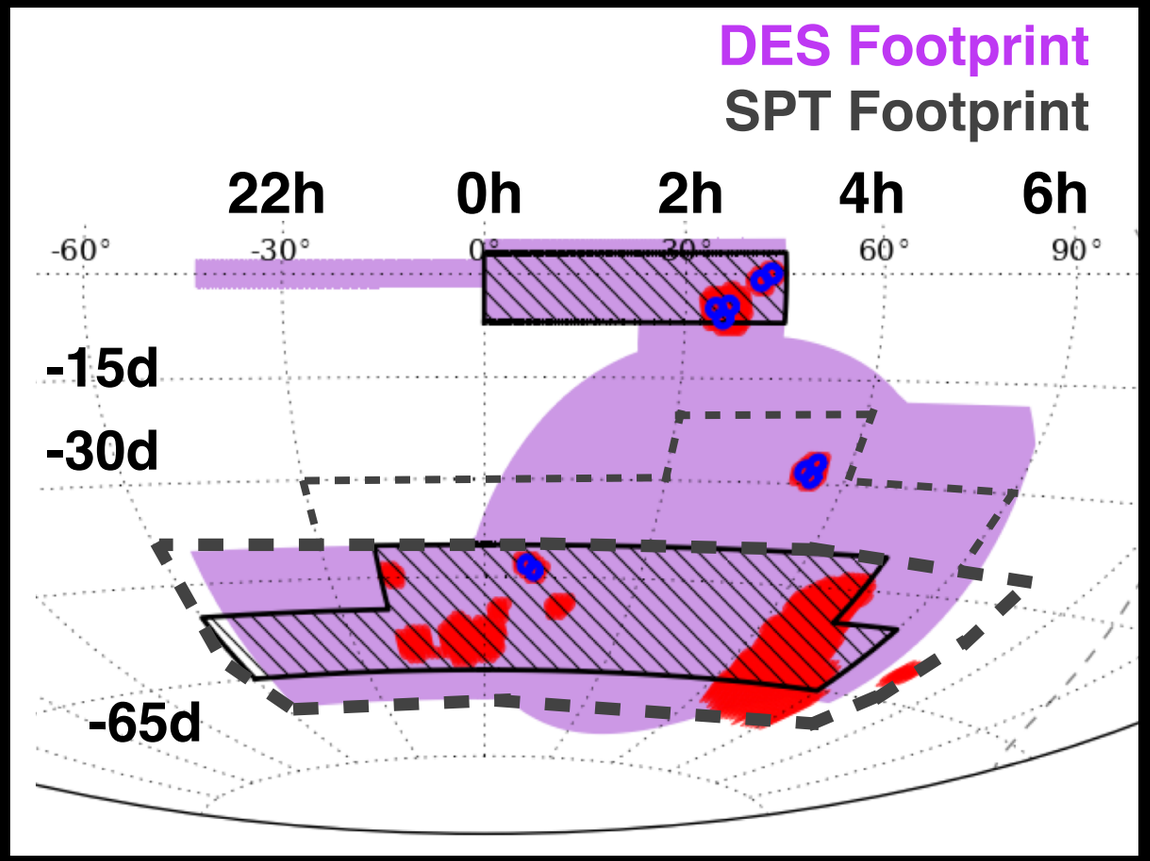
SPT-3G

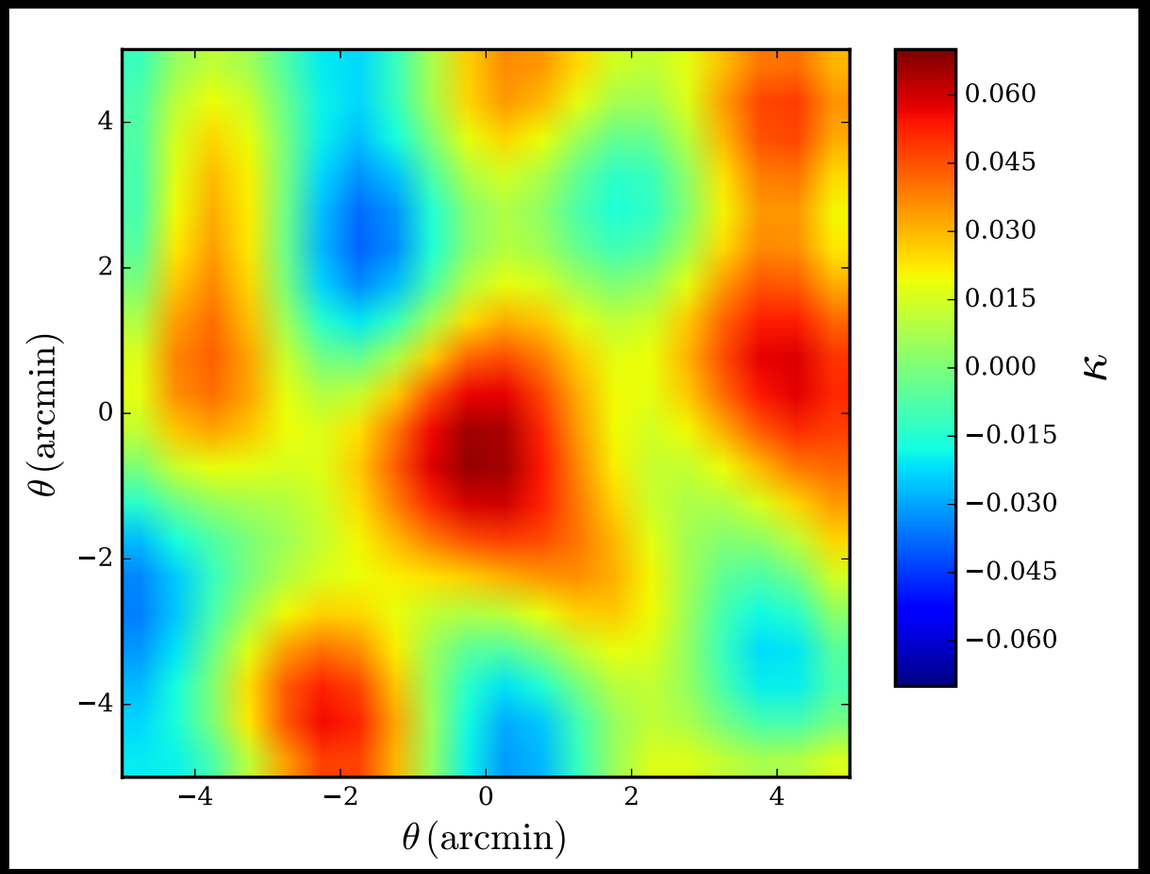


SPT-SZ + DES

Significant overlap with DES field!

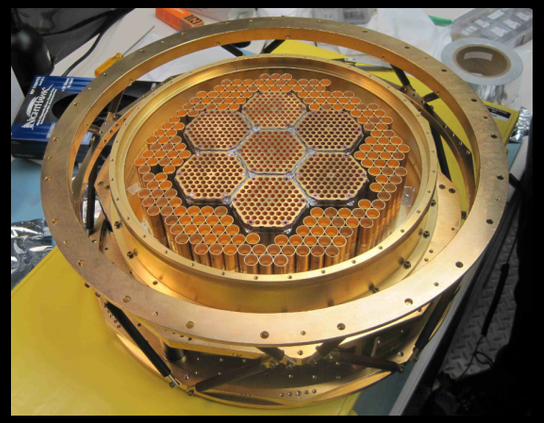
- CMB cluster lensing for mass calibration
  - Baxter 2018 (MNRAS 476, 2674)
- 5 x 2 cross correlation analysis: galaxy clustering, weak lensing shear, CMB lensing
  - Baxter 2018 (arXiv1802.05257)
- Cluster cosmology
  - SPT selection, DES redshifts & weak lensing mass calibration

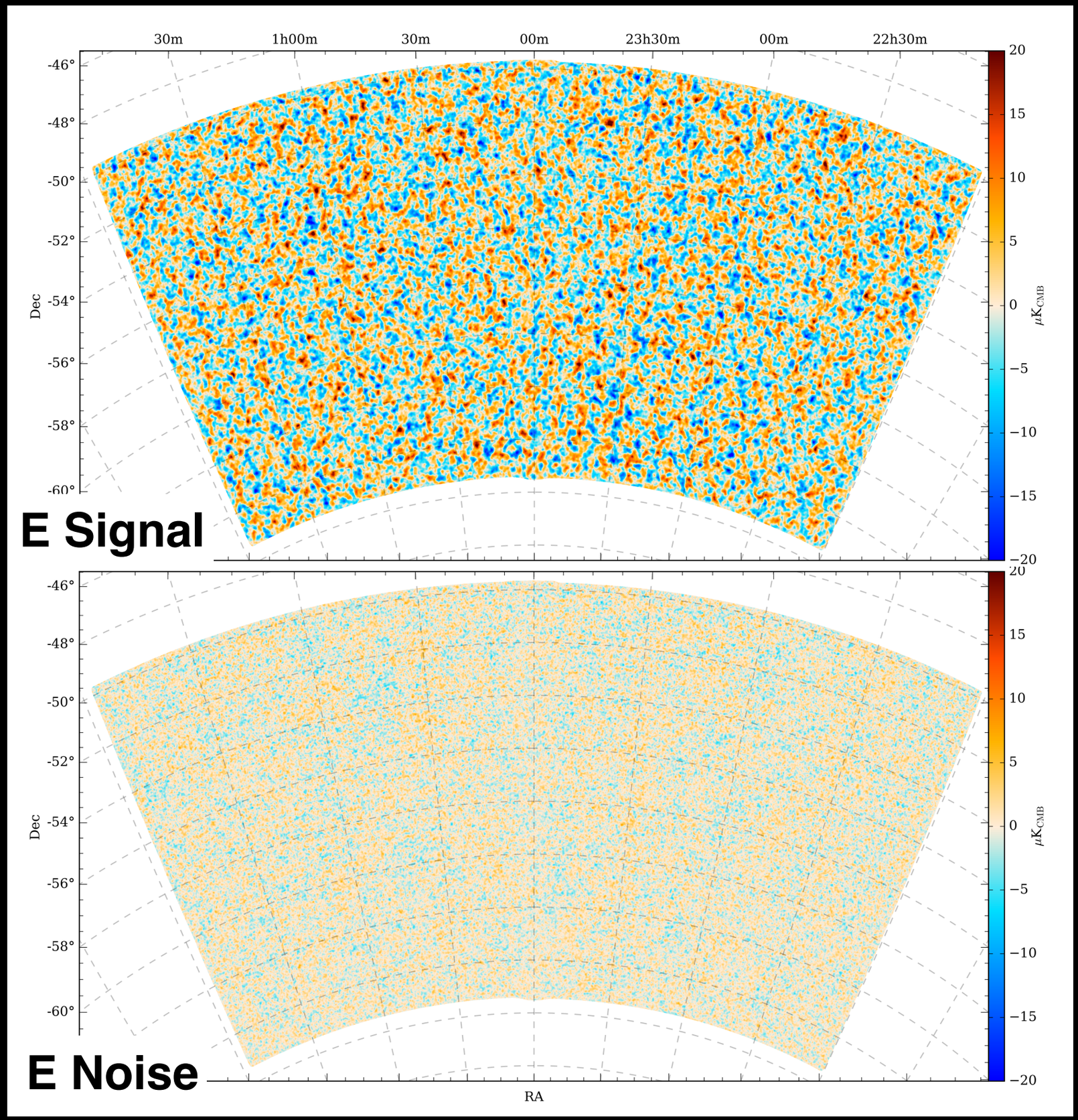




SPTpol 500 deg² Survey

Henning 2018
ApJ 852, 97



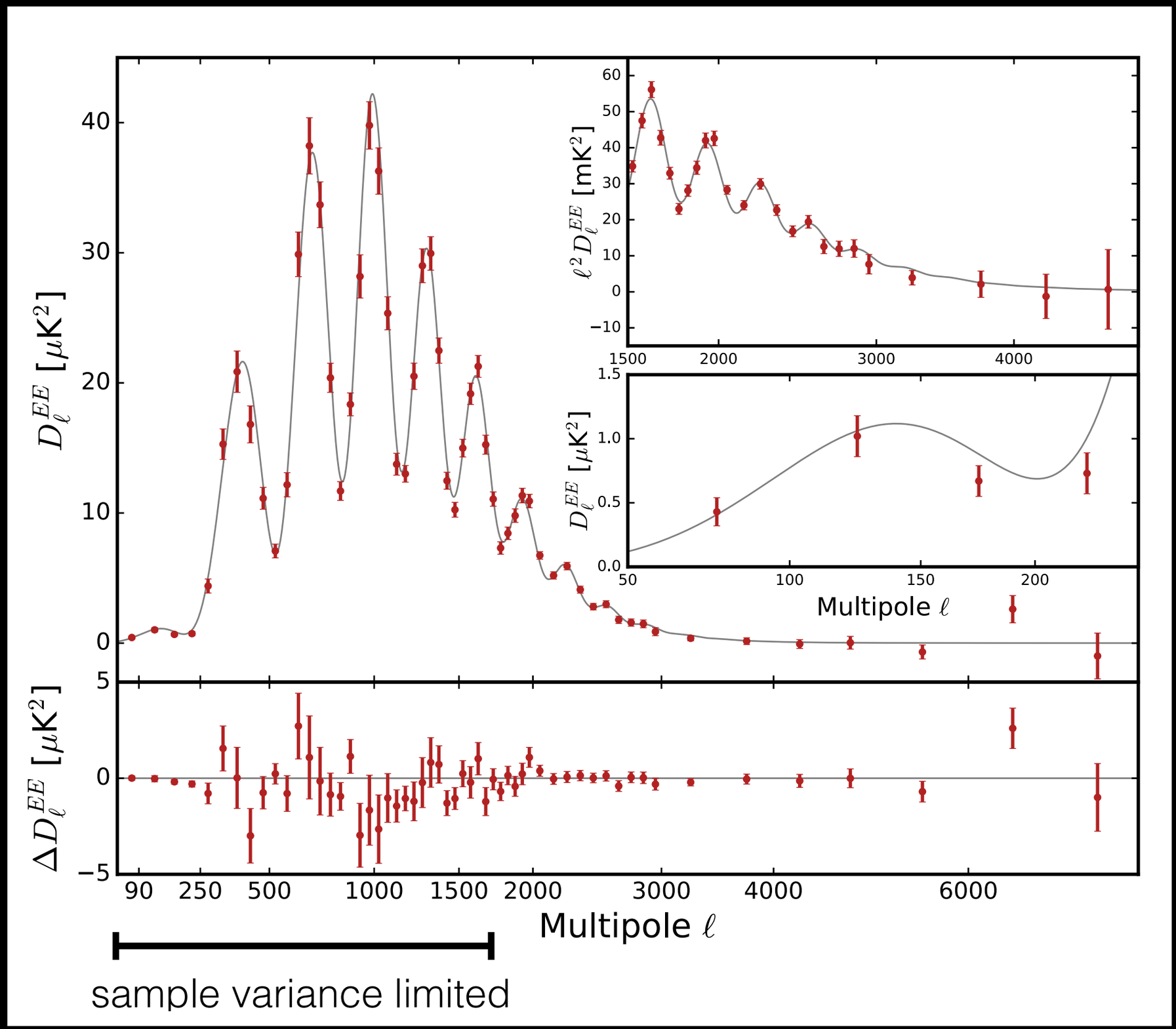


Polarized Power Spectra

Henning 2018
ApJ 852, 97

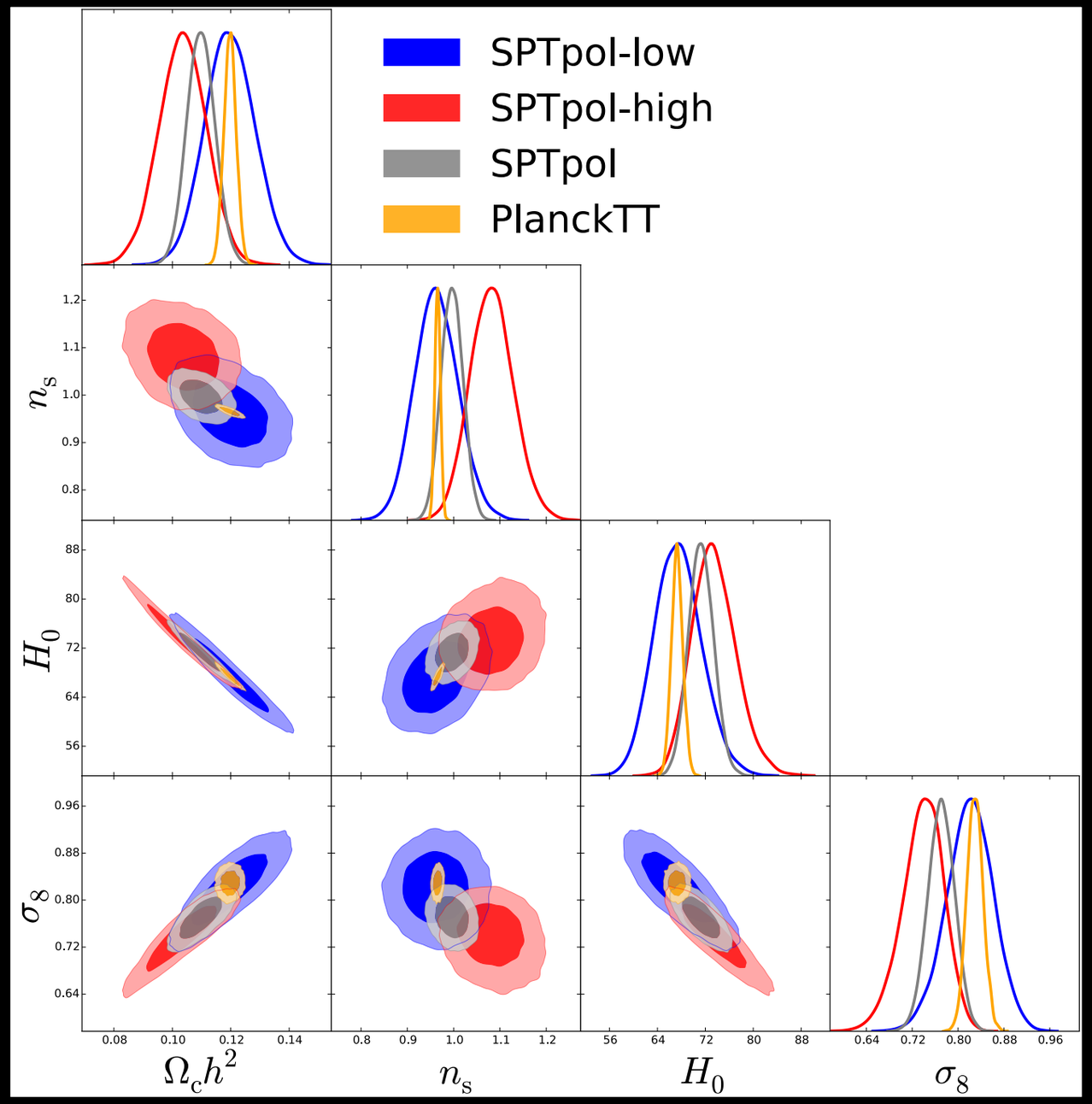
Sensitive to both large and small angular scales in CMB polarization

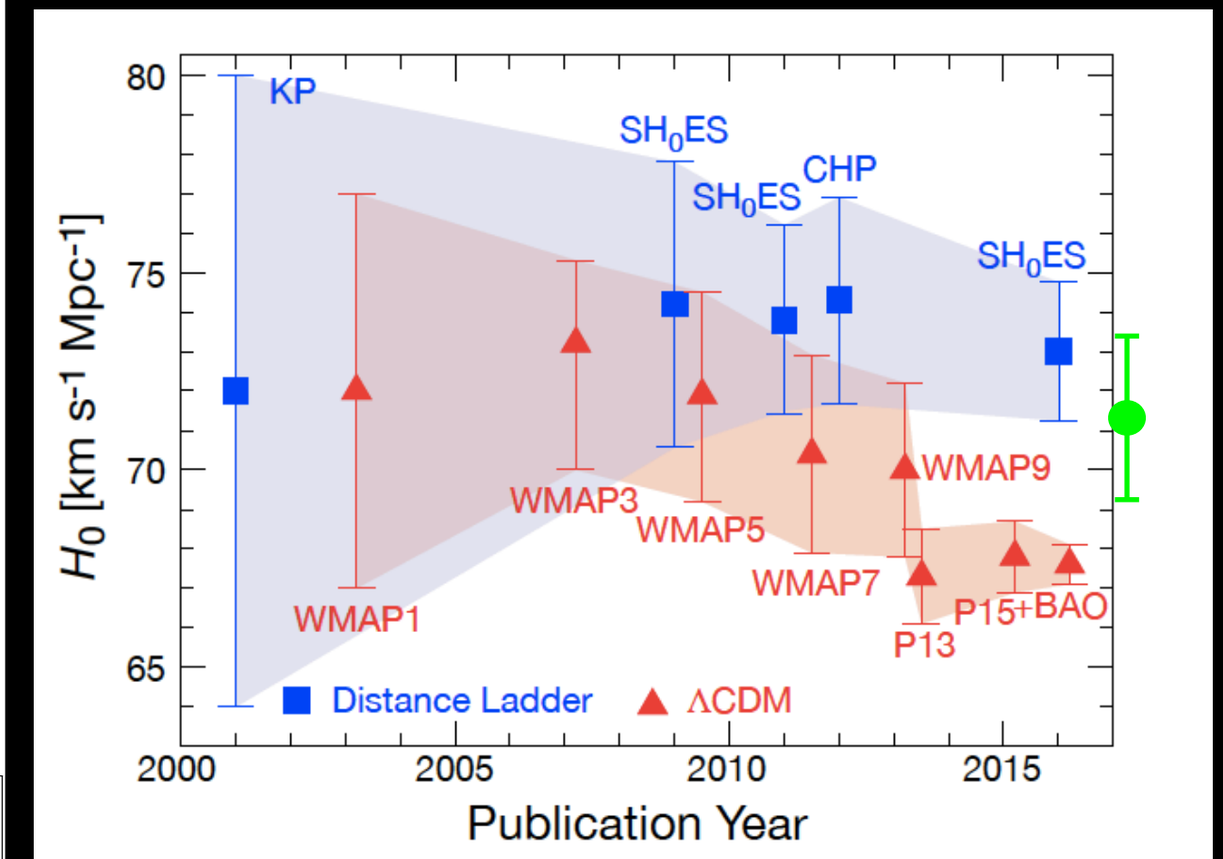
Constrains polarized point sources.



Constraining ΛCDM

Henning 2018
ApJ 852, 97



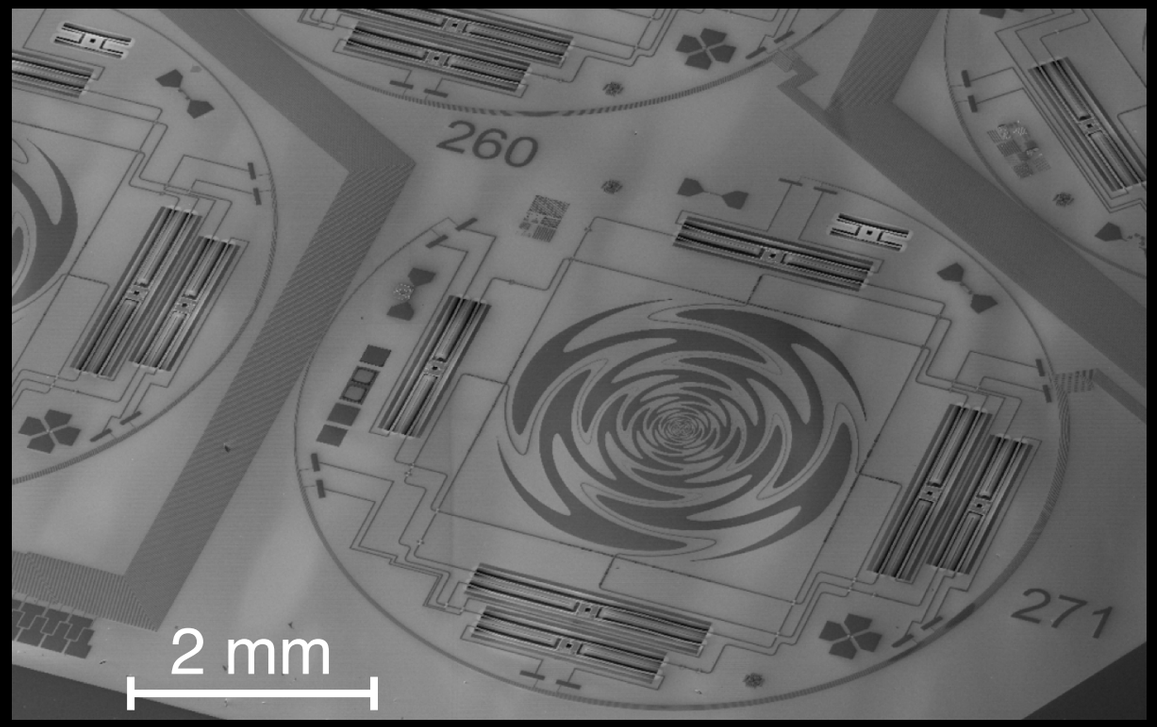


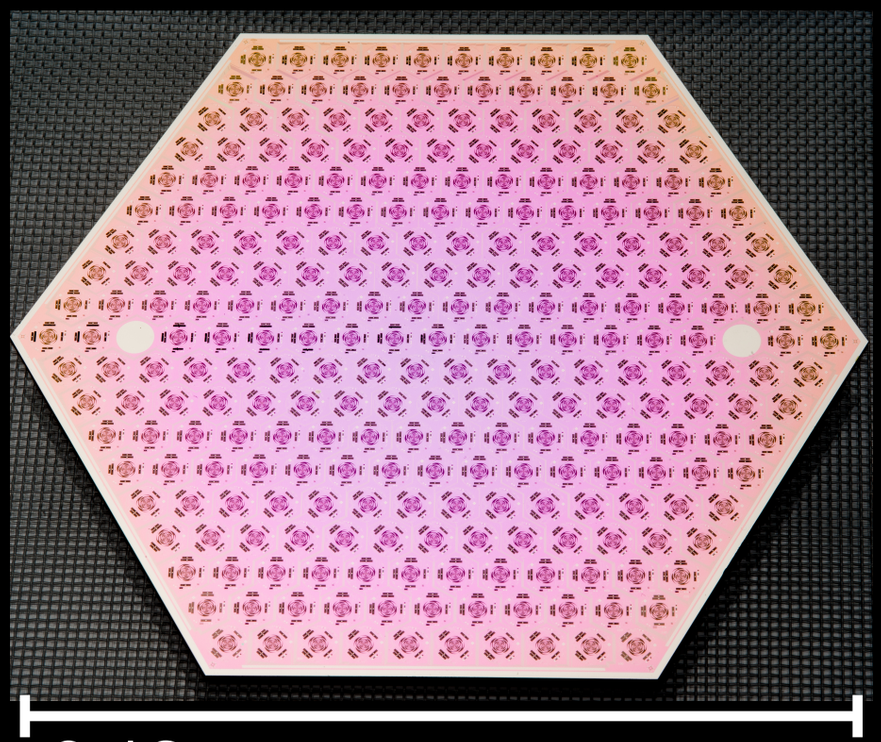
$$H_0 = 71.2 \pm 2.1\,\mathrm{km\,s^{-1}Mpc^{-1}}$$

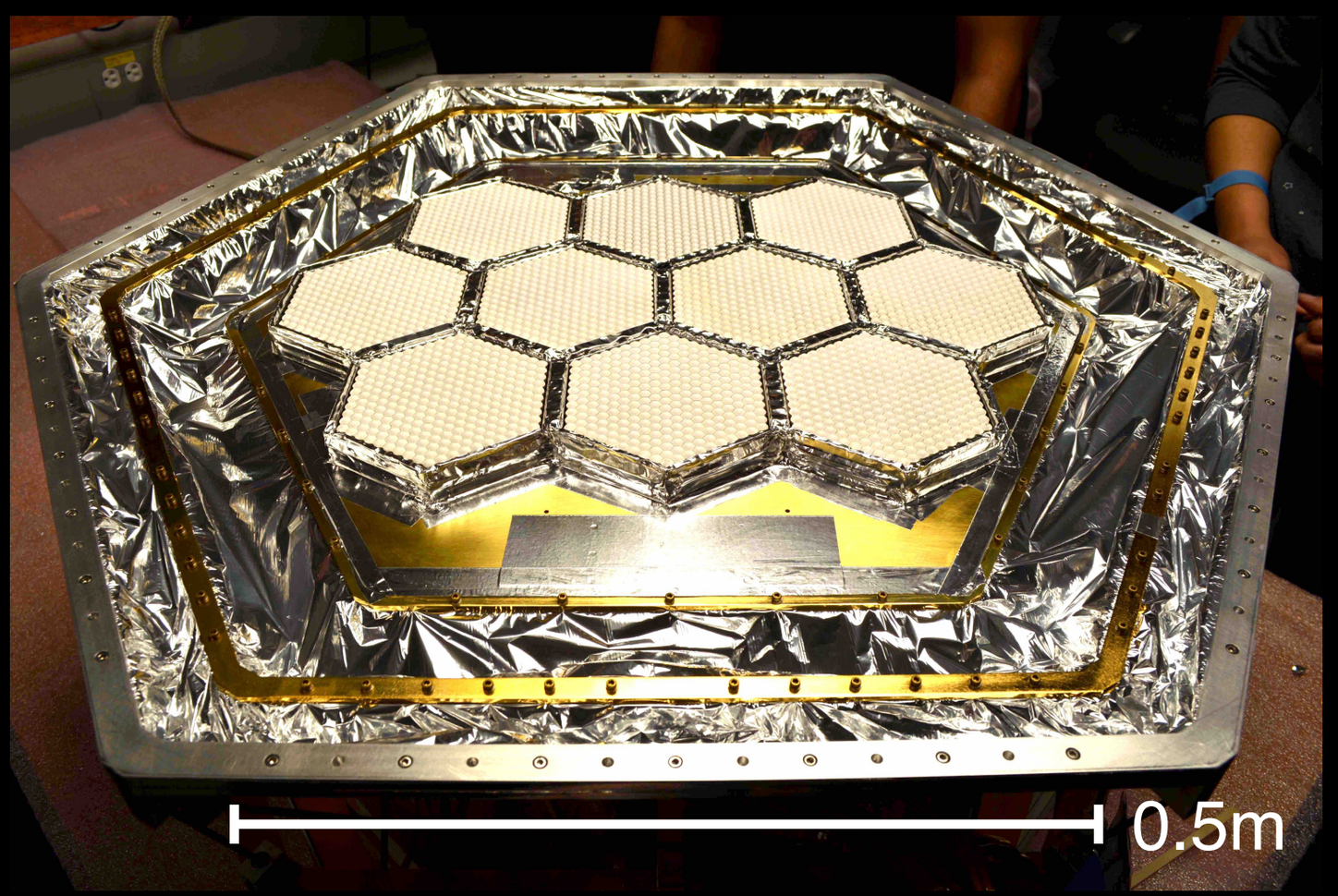
SPTpol full ell range

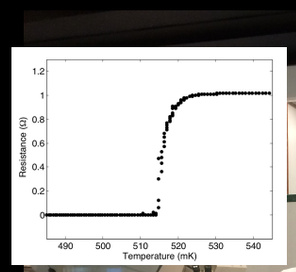
SPT-3G

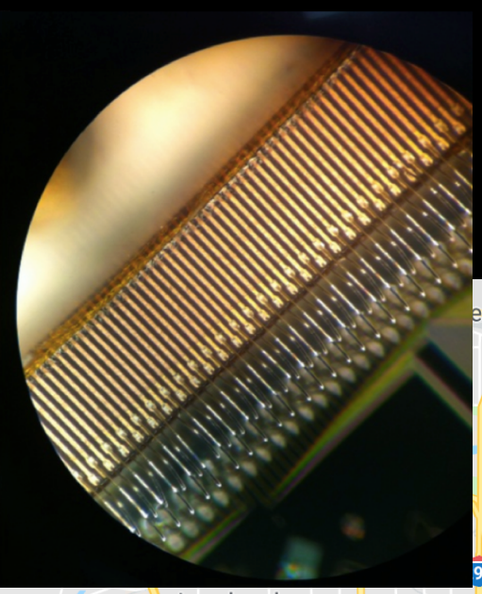
- TES bolometers
- sensitive to 2 orthogonal polarizations & 3 bands (95/150/220 GHz)
- 16,140 TES in the SPT-3G focal plane

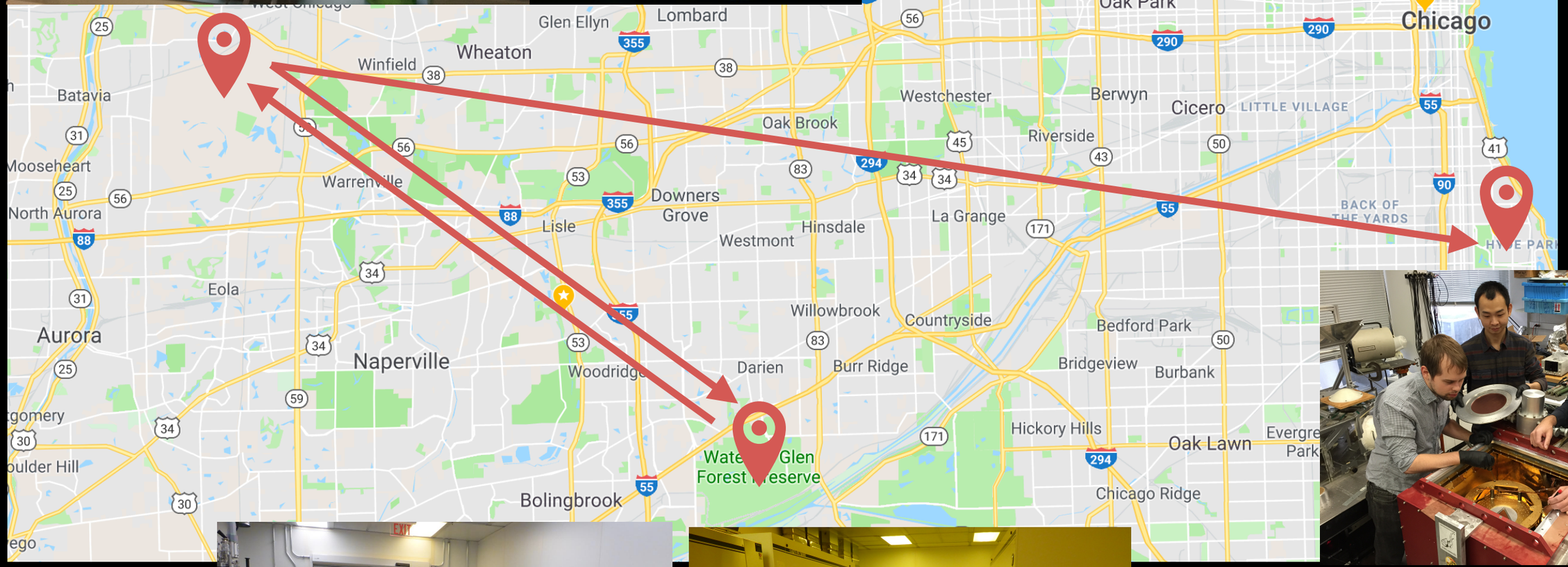






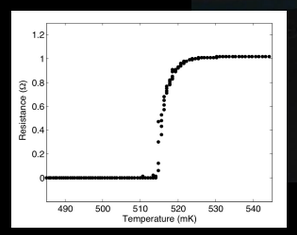

Resistance (Ω)
1.2
1
0.8
0.6
0.4
0.2
0
490
500
510
520
530
540
Temperature (mK)




Franklin Park
Northlake
Melrose Park
Oak Park
Chicago
LAKE VIEW
LOGAN SQUARE
LINCOLN PARK
NEAR NORTH SIDE
Glen Ellyn
Lombard
Wheaton
Winfield
Batavia
Westchester
Berwyn
Cicero
LITTLE VILLAGE
Oak Brook
Riverside
Mooseheart
Warrenville
North Aurora
Downers Grove
Lisle
Westmont
Hinsdale
La Grange
BACK OF THE YARDS
Eola
Aurora
Naperville
Willowbrook
Countryside
Bedford Park
Burbank
Bridgeview
Woodridge
Darien
Burr Ridge
Hickory Hills
Oak Lawn
Chicago Ridge
Bolingbrook
Forest Preserve


EXIT


BLUE GLOVES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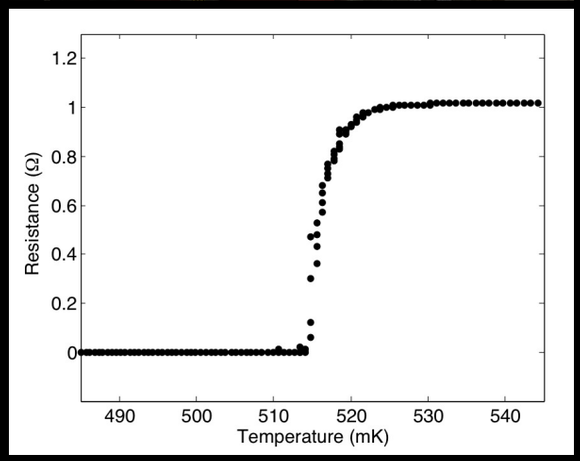
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0.8
0.6
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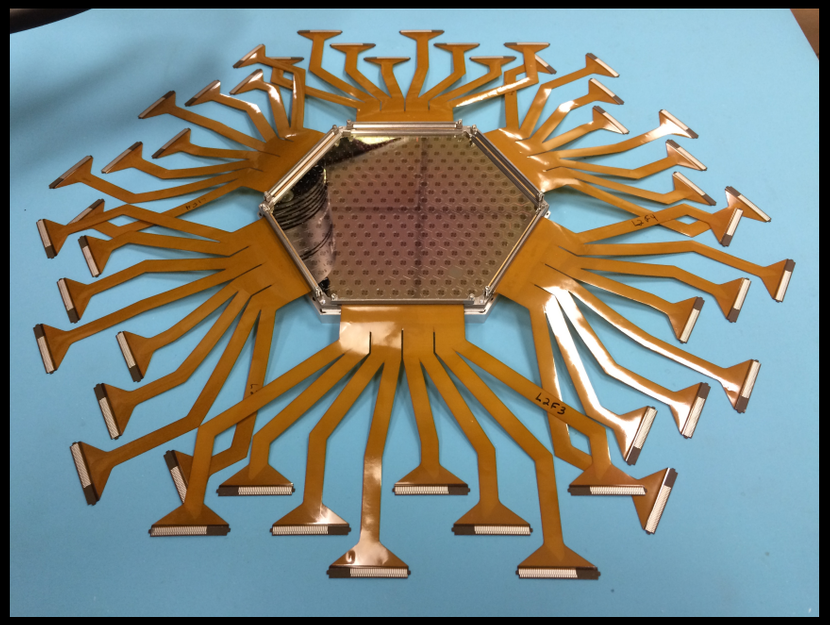
500
510
520
530
540
Temperature (mK)

Detectors & Readout

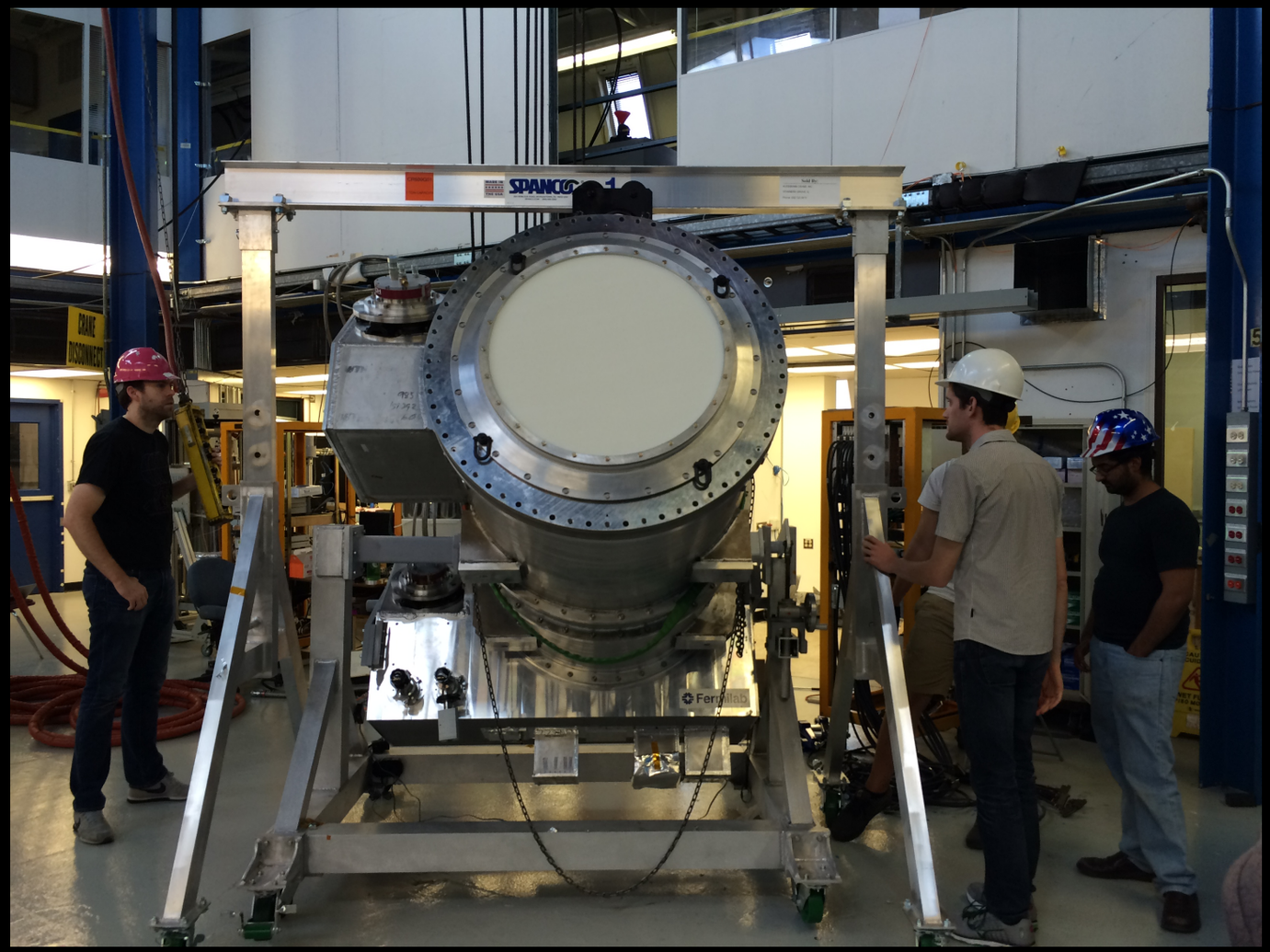
- Collaborative effort between ANL & FNAL was critical for SPT-3G
  - Fabrication at ANL
  - Assembly & packaging at FNAL (both detectors and readout)

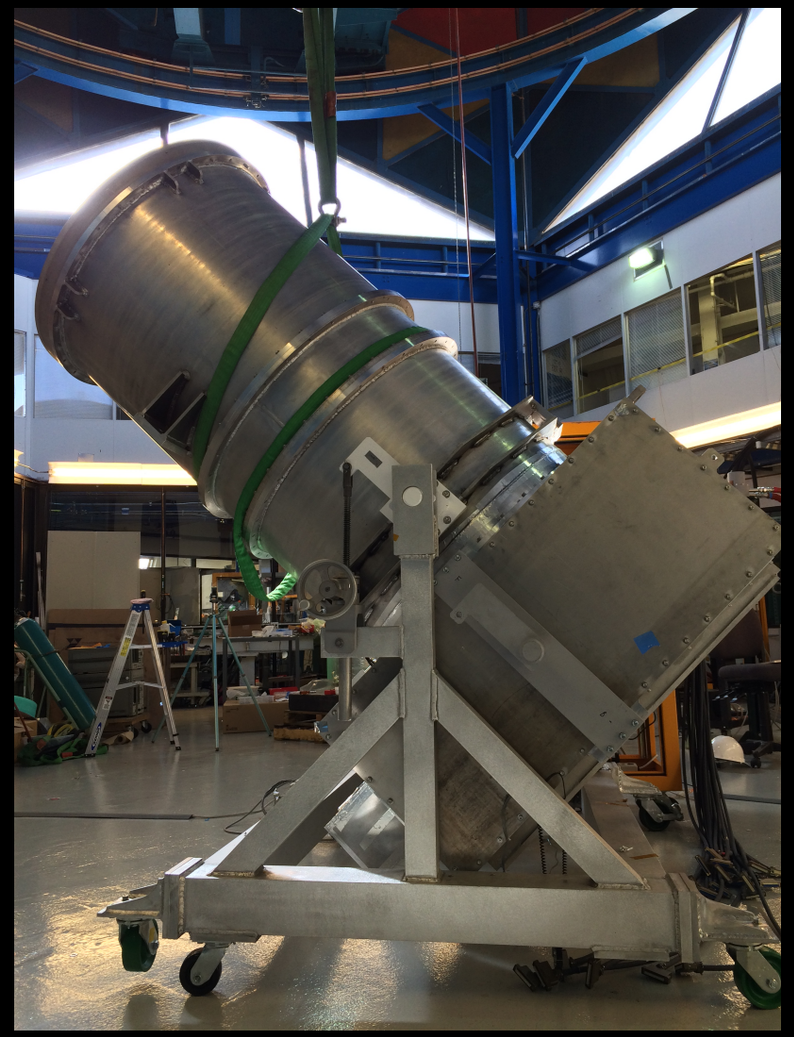


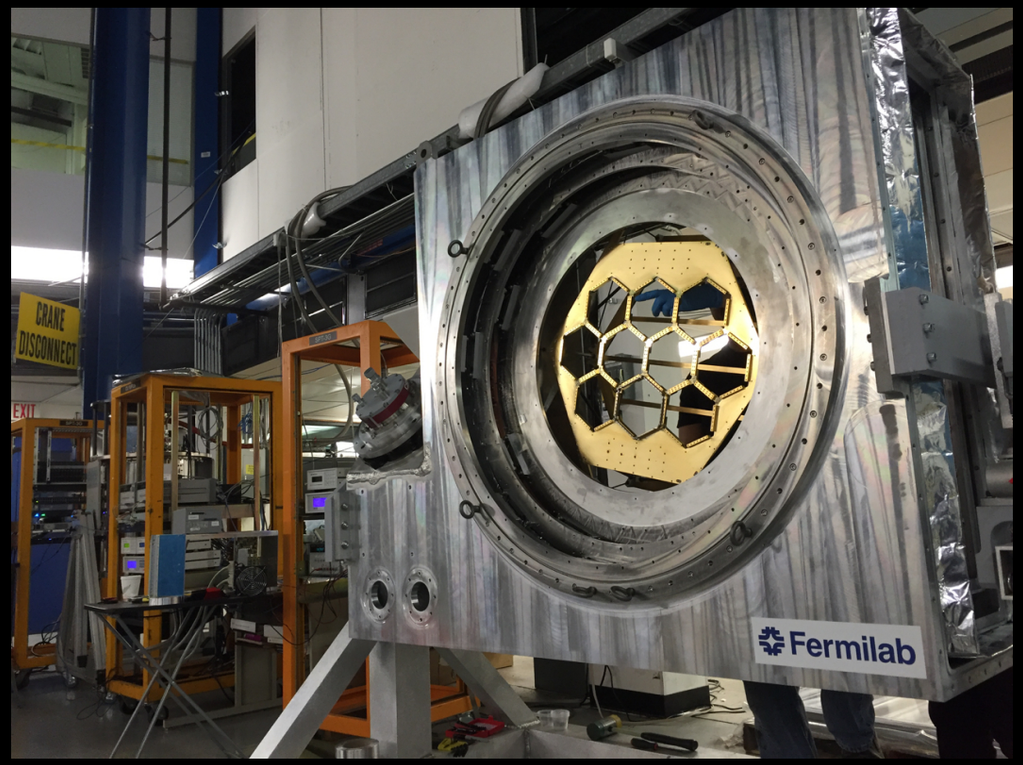
- Combined ‘Chicagoland’ group performing quality control and characterization.

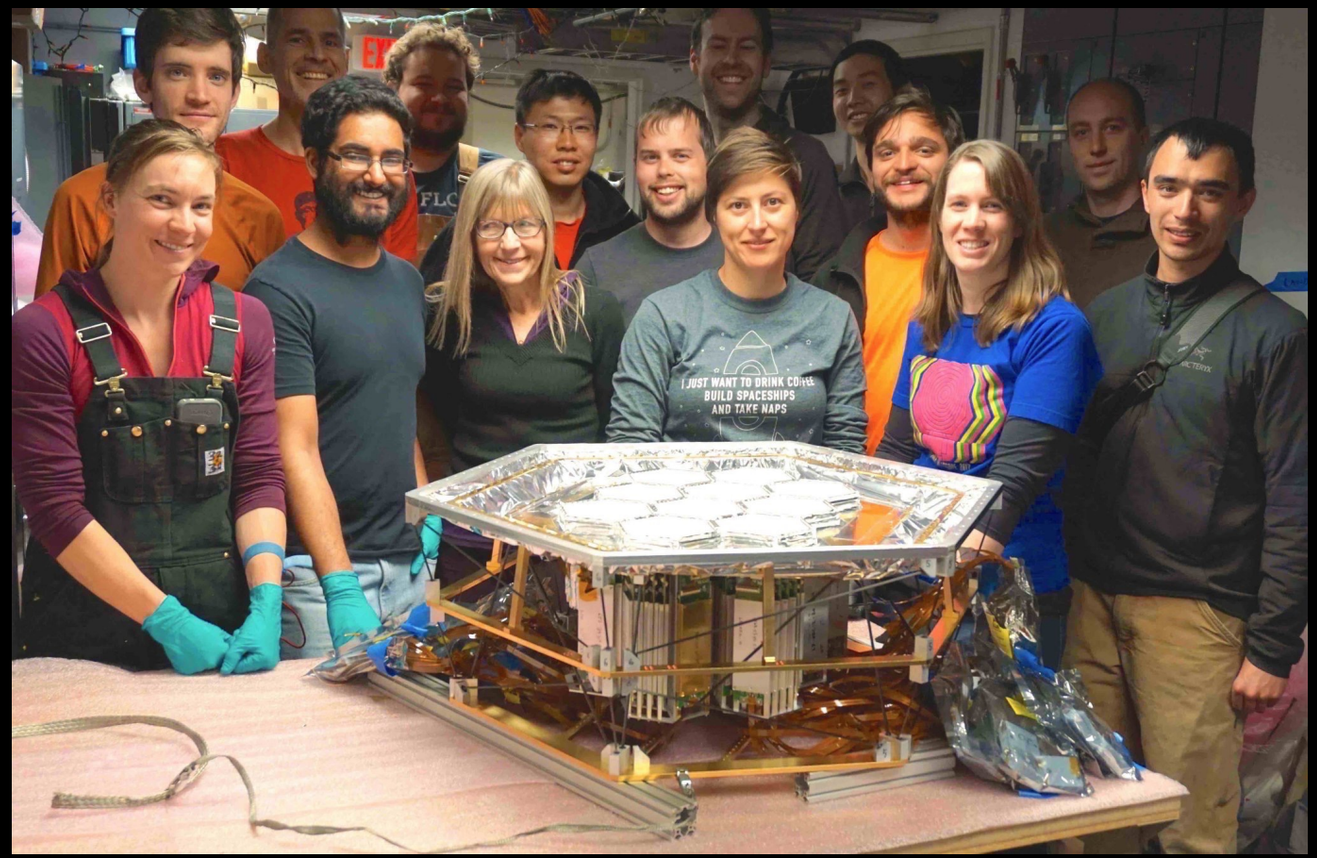
SPT-3G Lab Operations

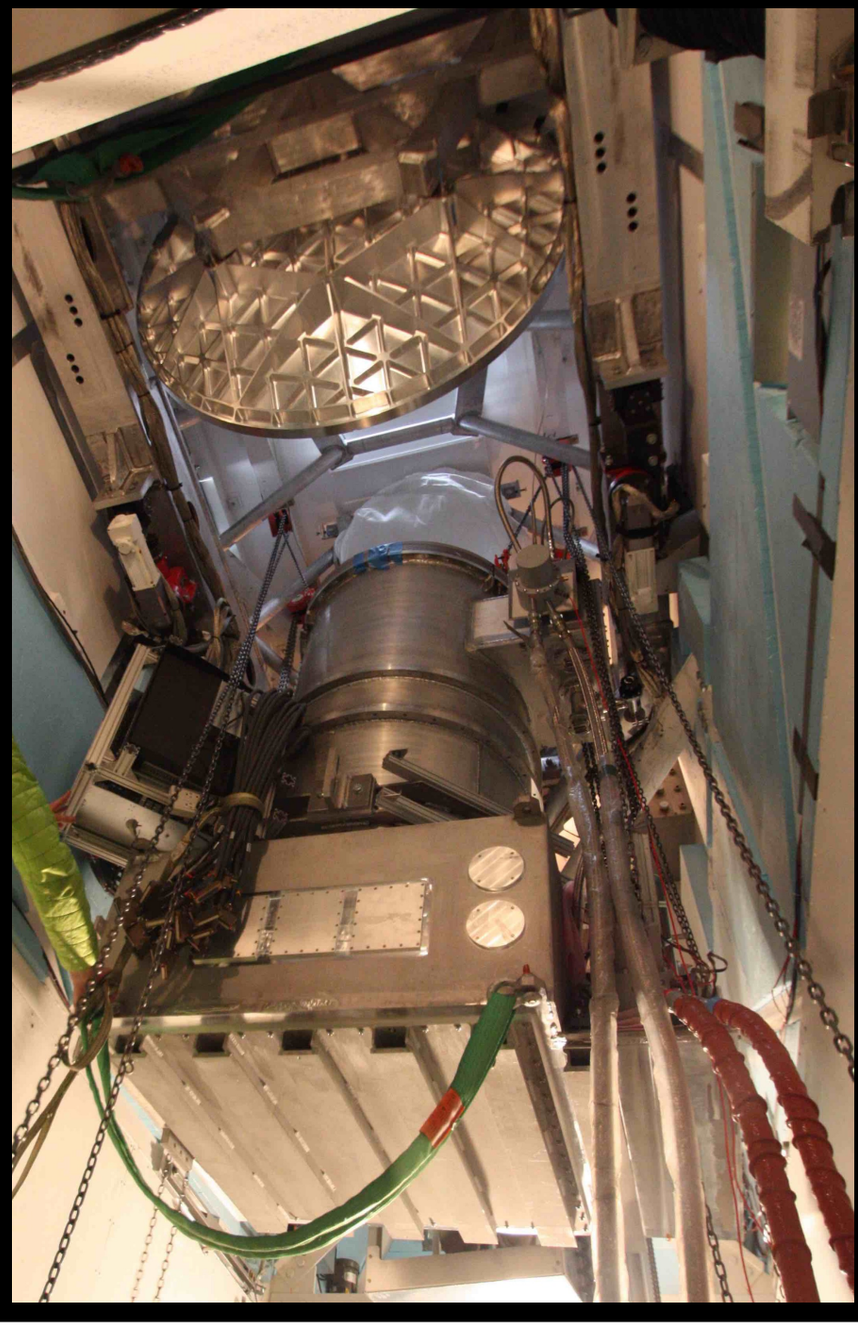
- Cryogenic performance
- Optical characterization
- Integrated readout performance
- Basic operations techniques

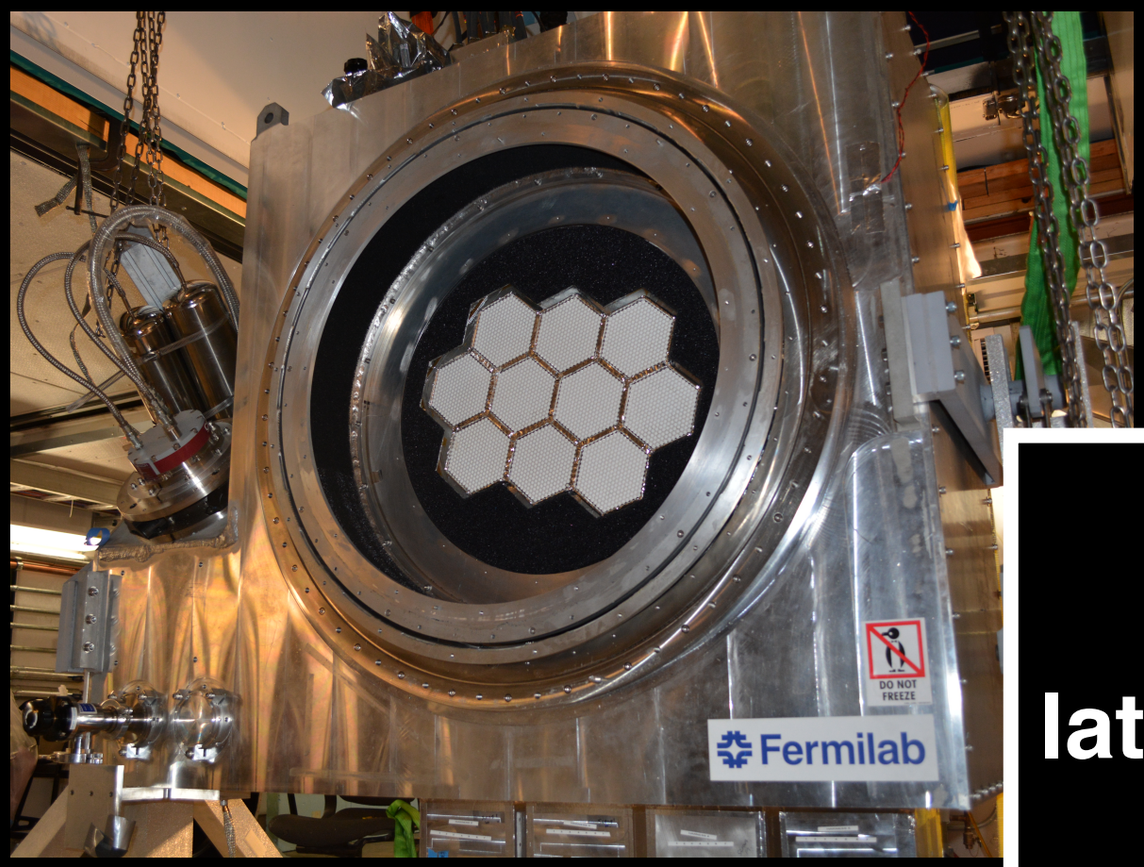








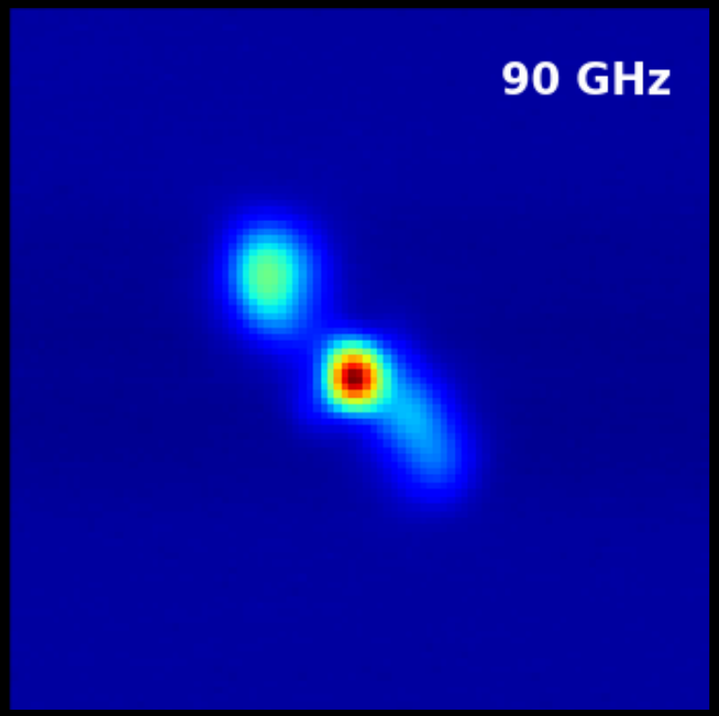


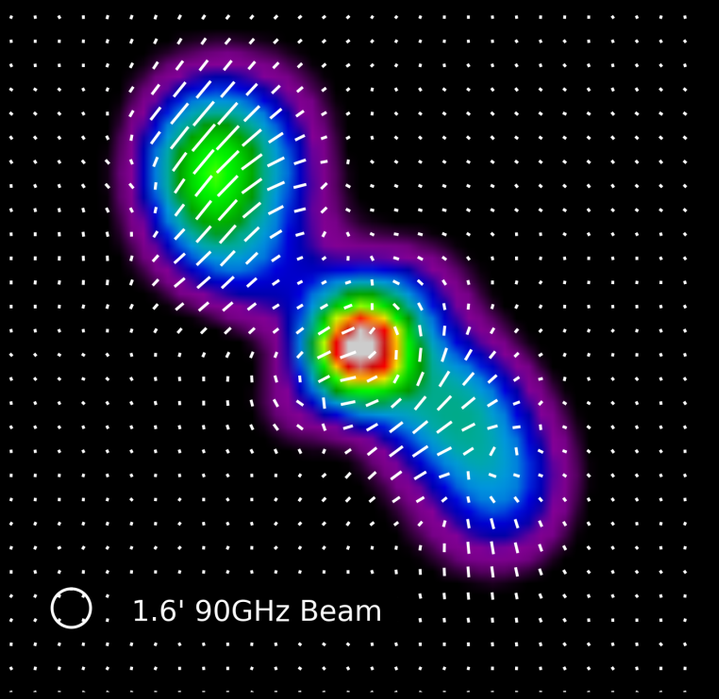


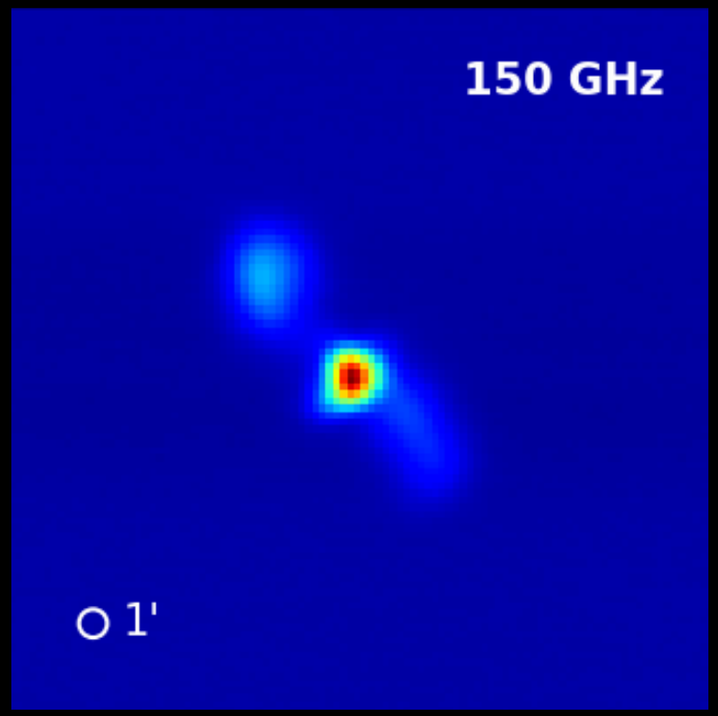
First Light Jan. 2017 !!
2017: calibration campaign
late 2017: system improvements
2018: science survey

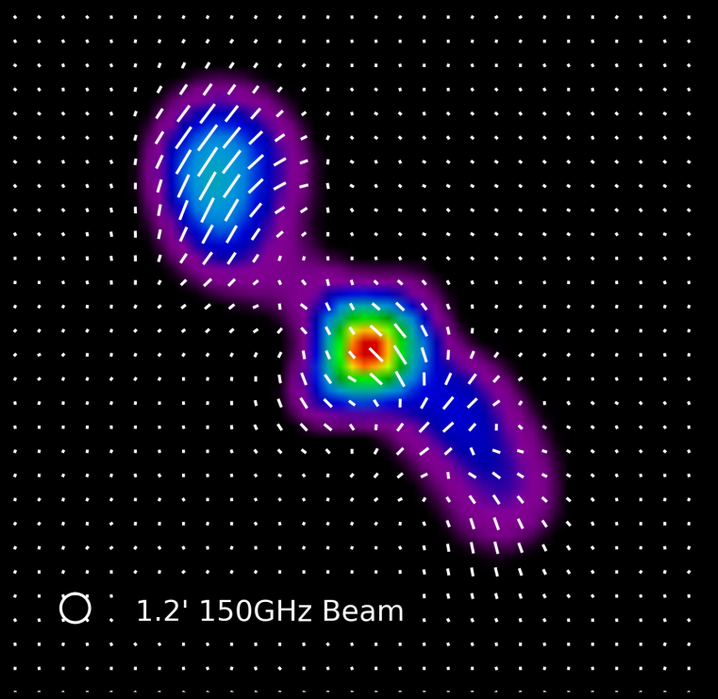
Polarized Source Maps

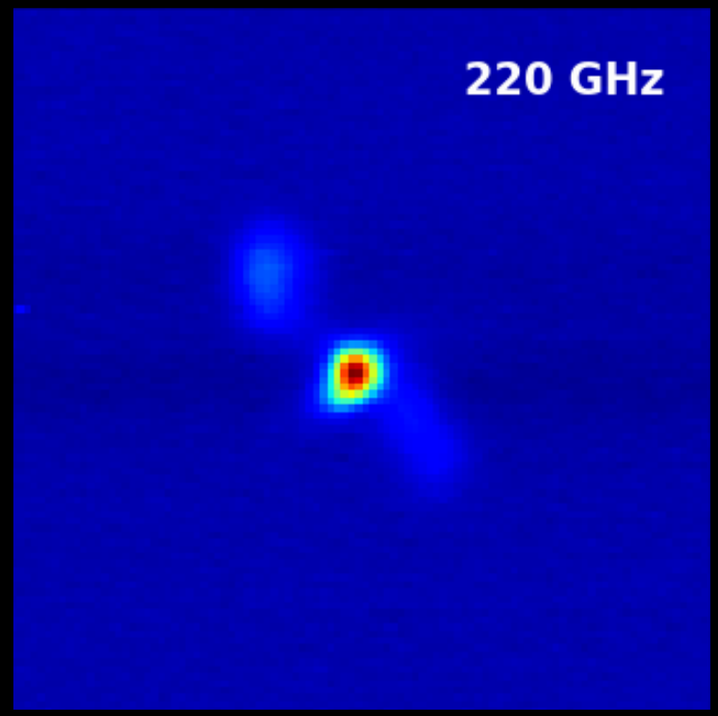
Centaurus A

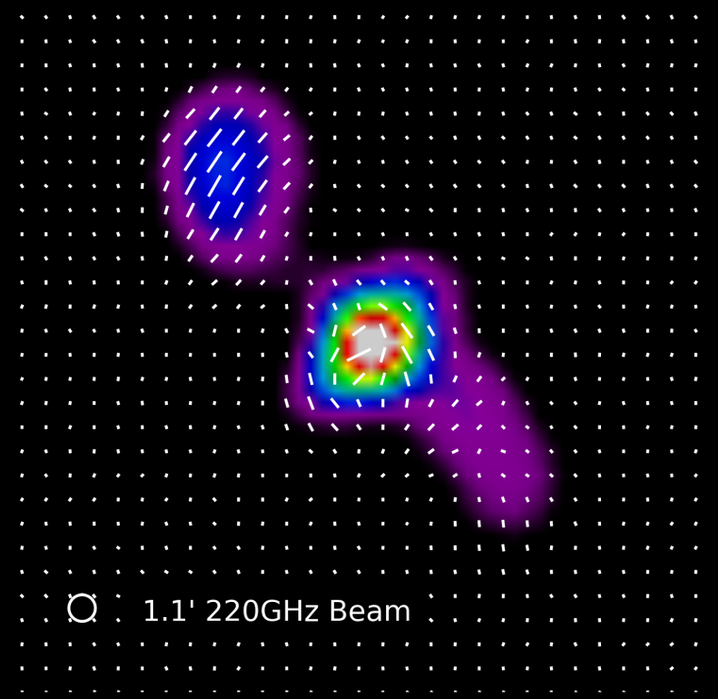




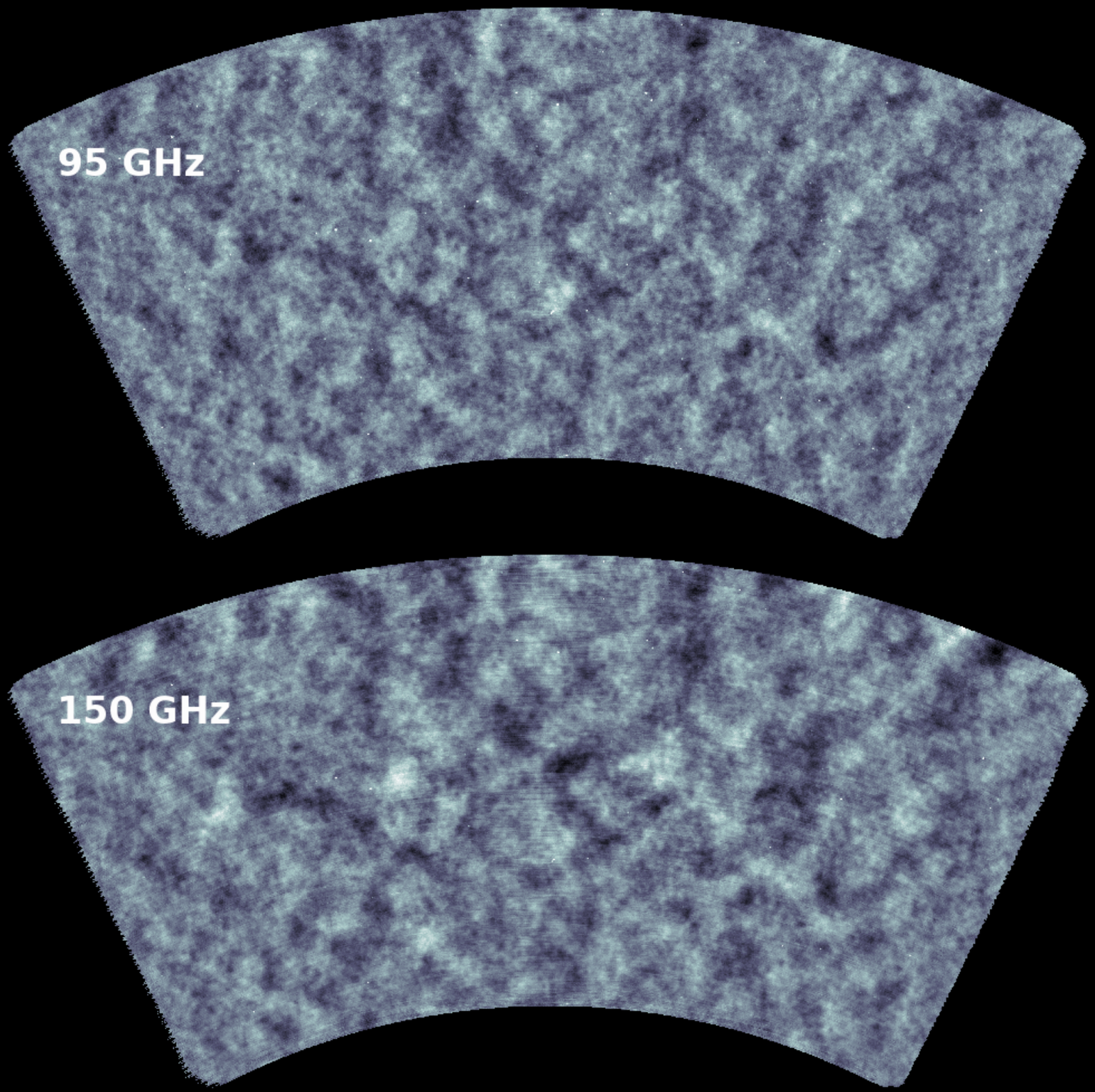


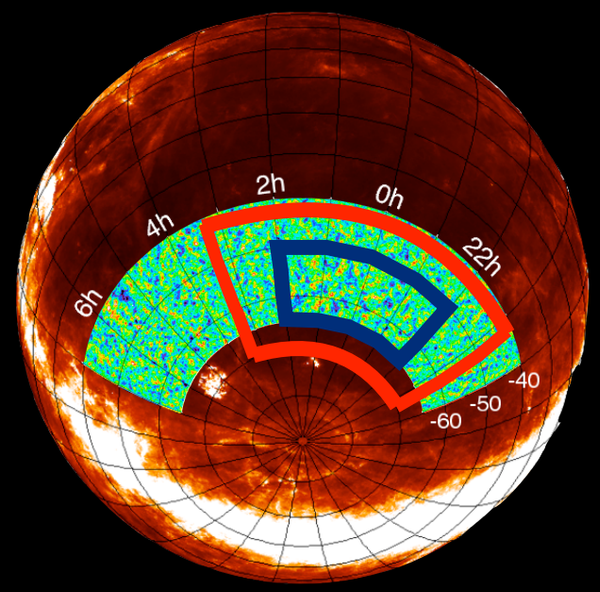






Example CMB Temperature Map





500 sq deg
commissioning field

Common CMB structures &
point sources clearly visible
between the two bands

1500 sq deg
4 year survey ongoing

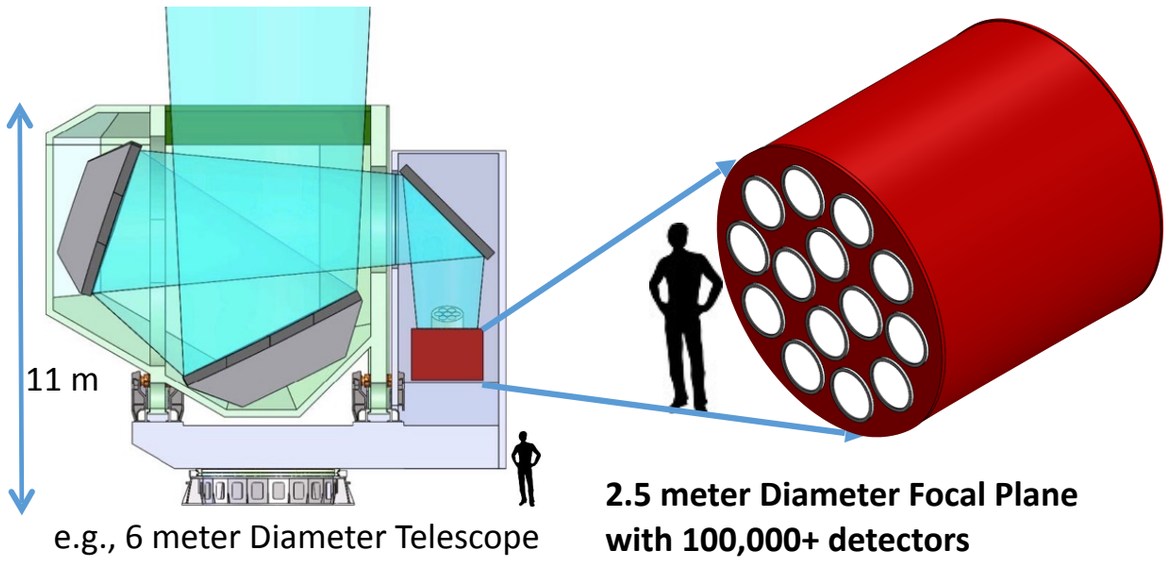
Stay tuned.

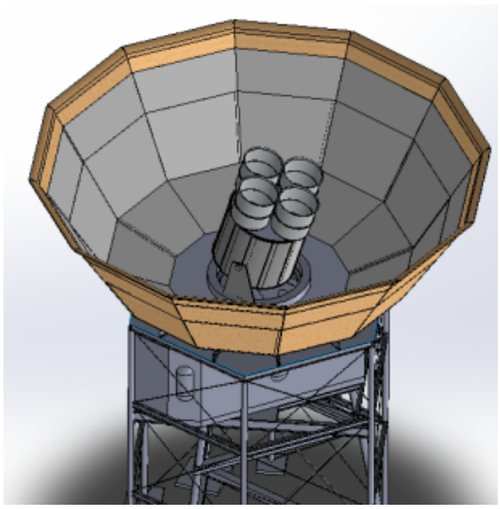
The CMB-S4 Experiment

CMB-S4
Next Generation CMB Experiment

•Endorsed by DOE/NSF P5 report, NRC (NSF) Antarctic Science report, Concept Definition Taskforce (CDT) report accepted by AAAC panel

- CMB-S4 concept:
  - 400,000 detectors split between 3x 6-m aperture, 14x 0.5-m aperture telescopes
  - **Two sites:** Spread between Chile and South Pole
  - **Two surveys:** Inflation survey on ~3-8% of sky, Cross-correlation survey on ~40% of sky.





High resolution Science + de-lensing:
300,000 Detectors on 3-4 large telescopes

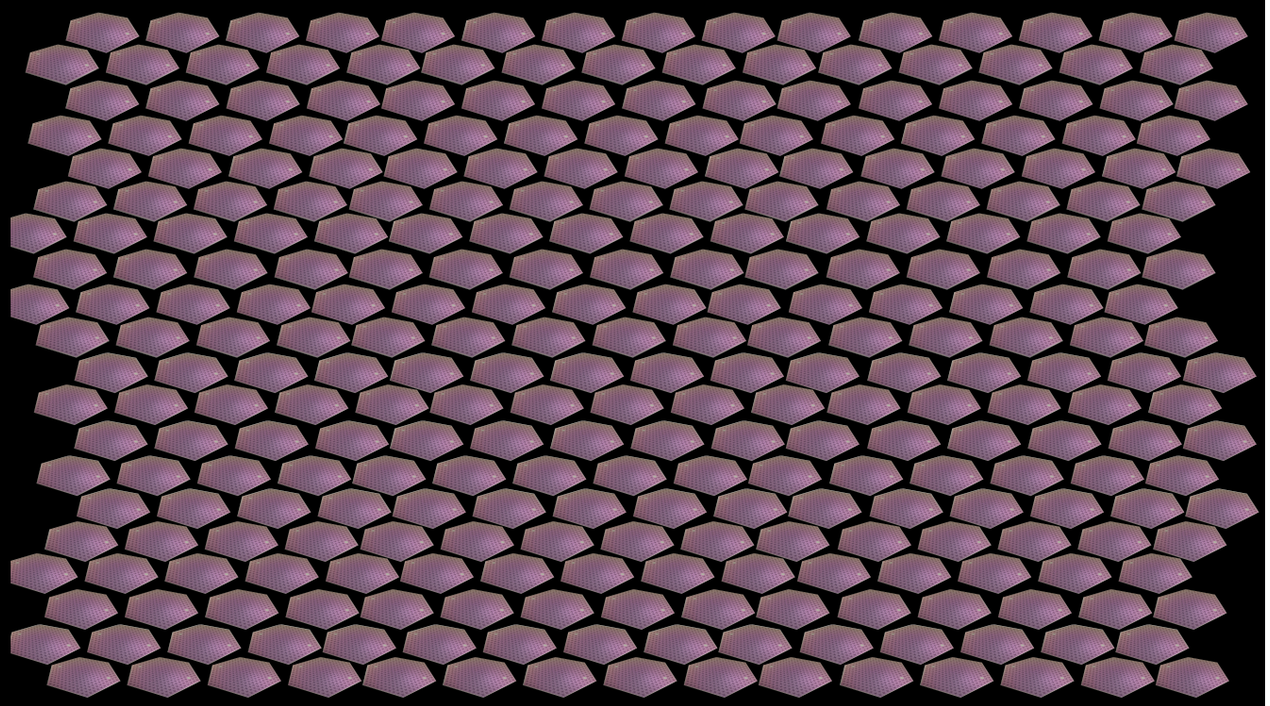
Low resolution B-mode Science:
200,000 Det. on ~12 small telescopes

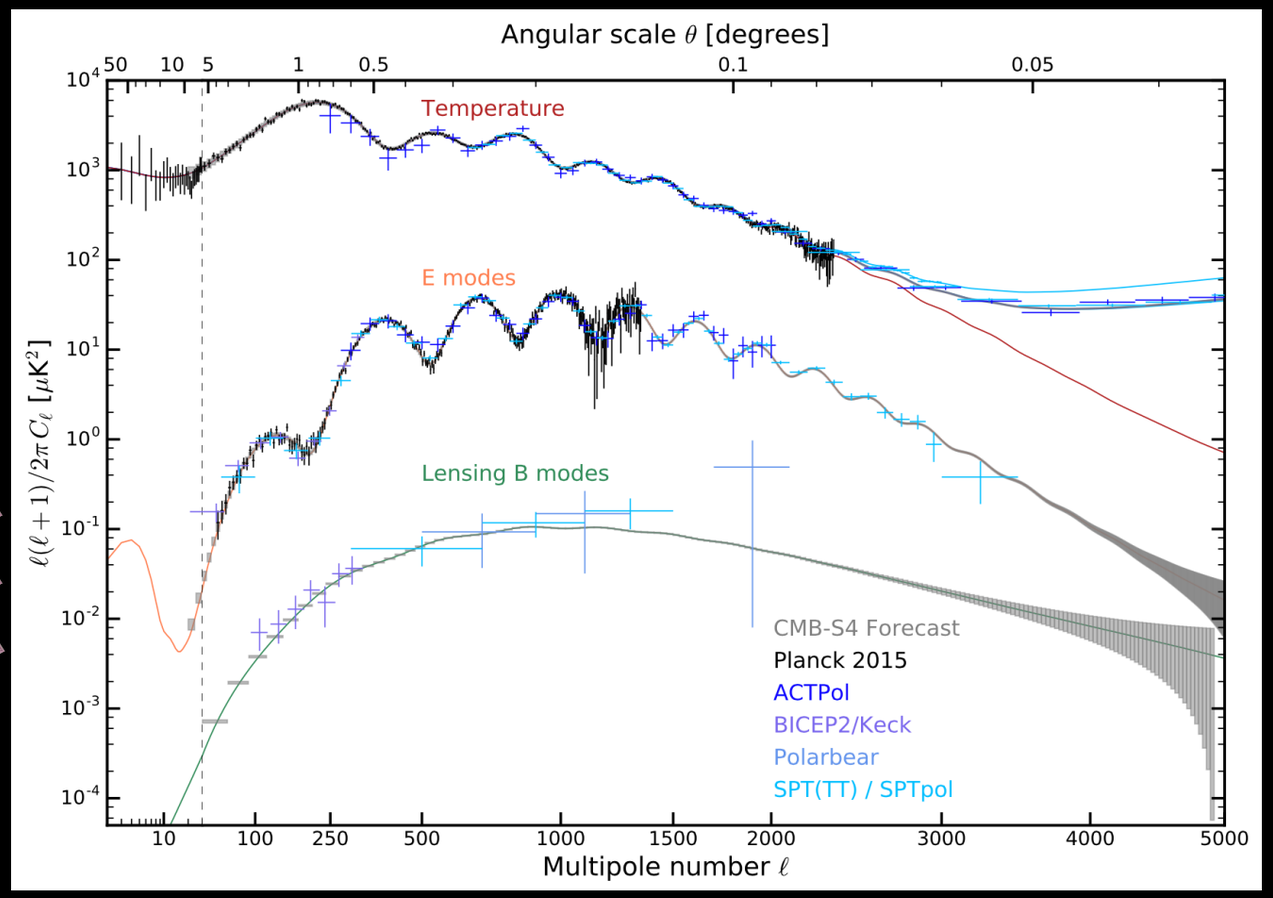
Figure from Mark Devlin / Mike Niemack

Figure from BICEP Array

CMB-S4 Opportunities

- Detector & ****Readout**** development
  - Optimize instrumental sensitivity
- Develop techniques for improved scalability
- Continued collaborative effort between ANL & FNAL
  - ‘In-house’ experts on detectors, readout, fabrication, integration, systems, etc.
  - Facilities (CNM, SiDet)
- Scientific analysis of the data!





NSF

United States Antarctic Program
National Science Foundation

Department of Energy
United States of America

Argonne
National Laboratory

KICP
Kavli Institute
for Cosmological Physics
at the University of Chicago

Berkeley Lab

Case
Case Western
Reserve University

UC Davis
University of California

University of Toronto

The University of Chicago

Berkeley
University of California

McGill

Fermilab

Illinois
University of Illinois at Urbana-Champaign

Colorado
University of Colorado at Boulder

UCLA

NIST

Harvey Mudd College

Cardiff University
Prifysgol Caerdydd

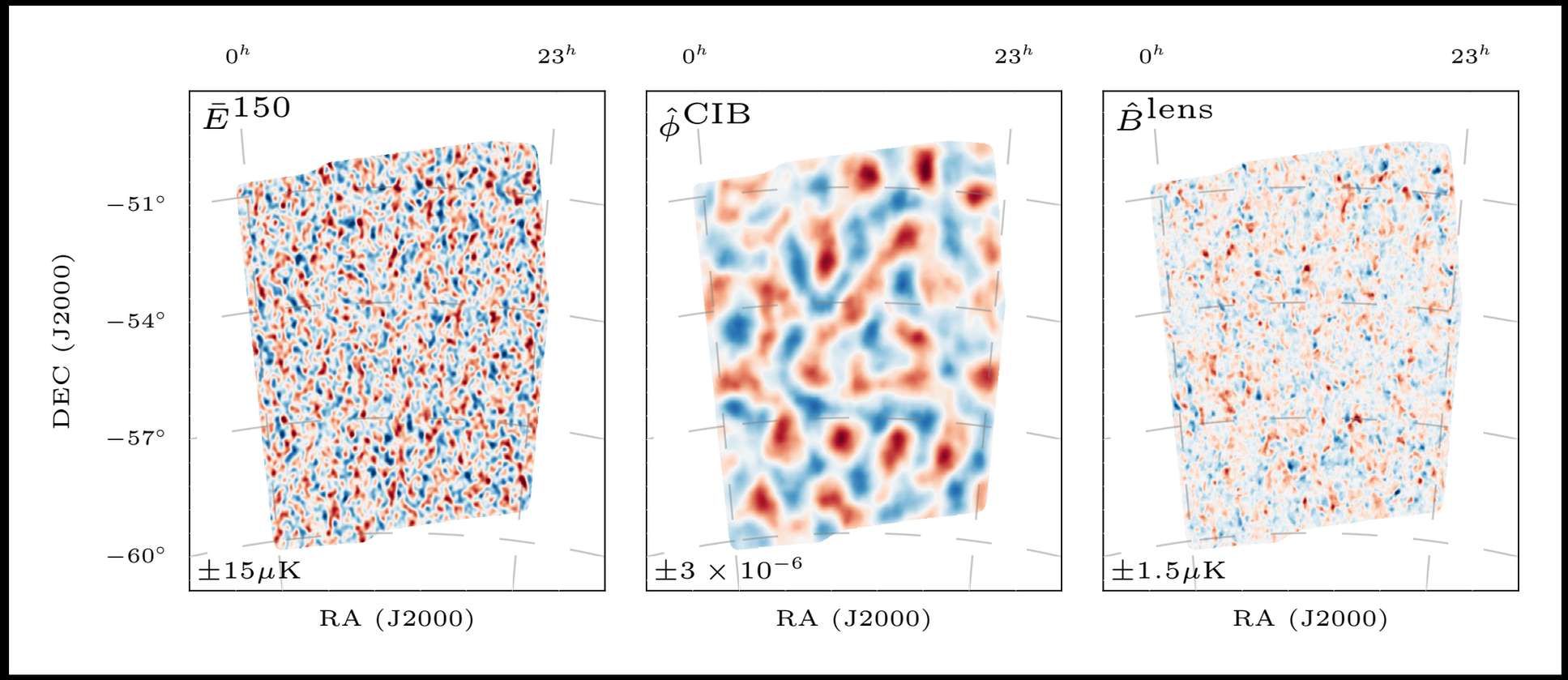
LMU
Ludwig-Maximilians-Universität München

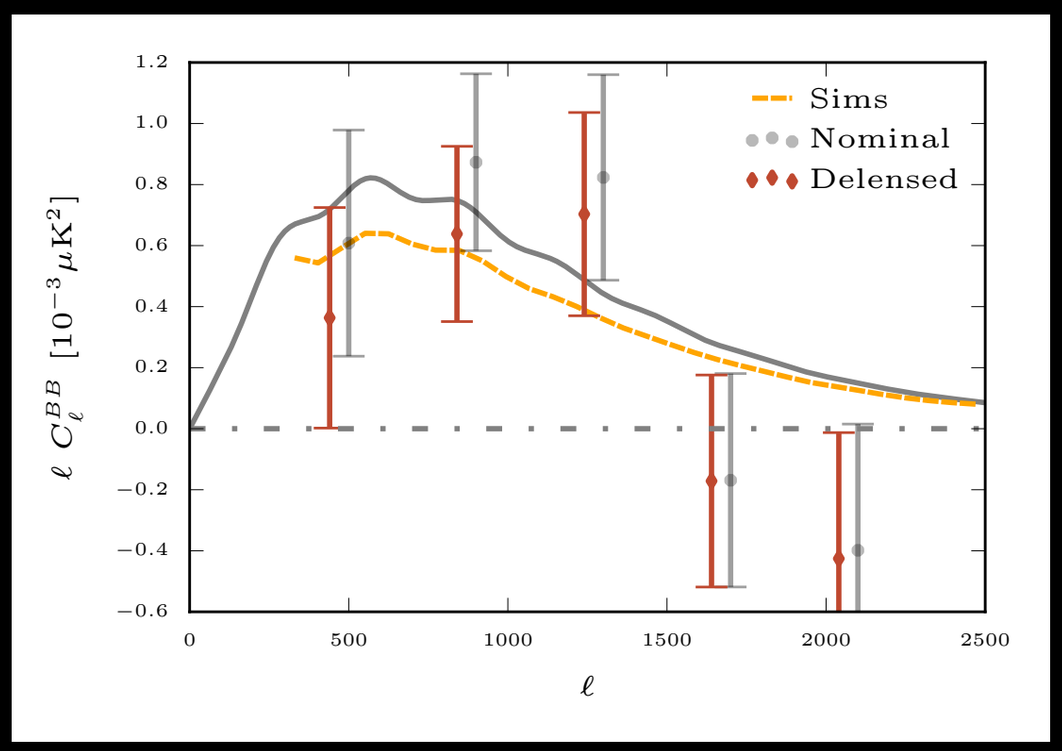
Harvard-Smithsonian
Center for Astrophysics

Backup

De-lensing with SPTpol

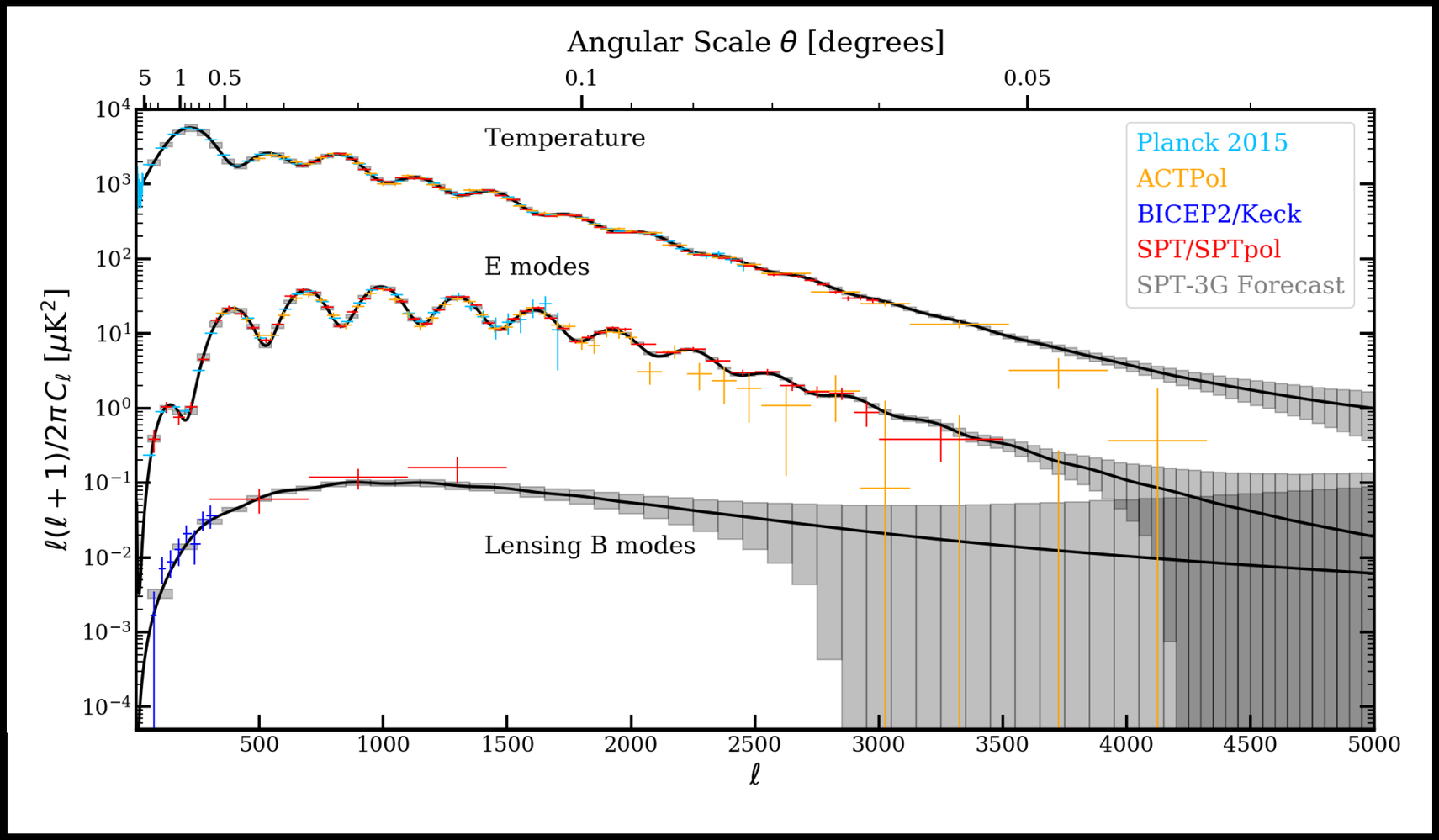
Manzotti 2017
ApJ 846, 85

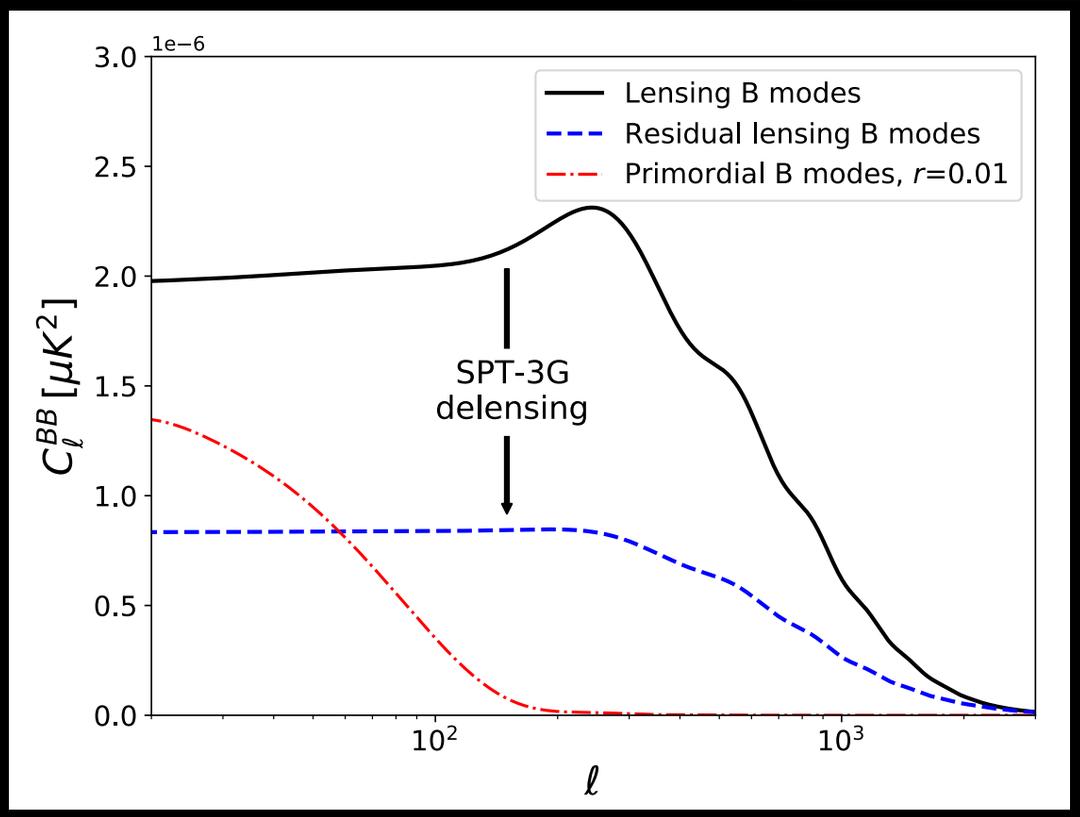




28% reduction in lensing power using Herschel to trace the cosmic infrared background

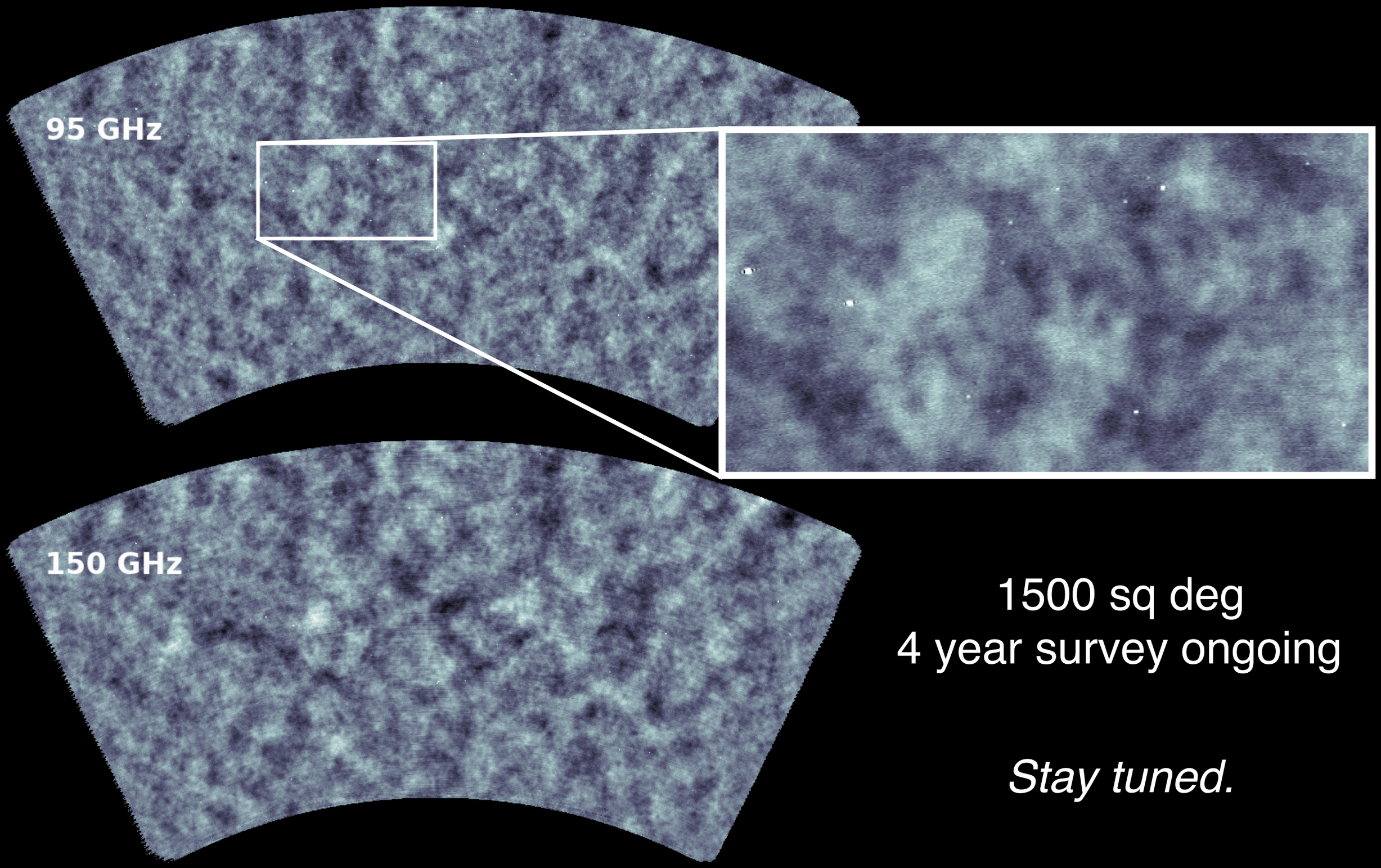
Forecasts





- High S/N measurement on the small scale (lensing) B-modes
  - Ability to ‘delens’ and clean B-mode maps!
  - 100% overlap with BICEP/Keck field
- Test ΛCDM
- Thousands of new galaxy clusters

Example CMB Temperature Map



1500 sq deg
4 year survey ongoing

Stay tuned.