SPT-3G:
A new instrument on the South Pole Telescope

TeVPA

August 7, 2017

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University of Chicago / KICP

SPT-3G Collaboration

Argonne NATIONAL LABORATORY

Berkeley Lab

NIST

Fermilab

University of Toronto

KICP Kavli Institute for Cosmological Physics at the University of Chicago

Berkeley University of California

Case Western Reserve University

McGill

Colorado University of Colorado at Boulder

Cardiff University / Prifysgol Caerdydd

UC Davis University of California

The University of Chicago

LMU Ludwig-Maximilians-Universität München

Harvard-Smithsonian Center for Astrophysics

University of Illinois

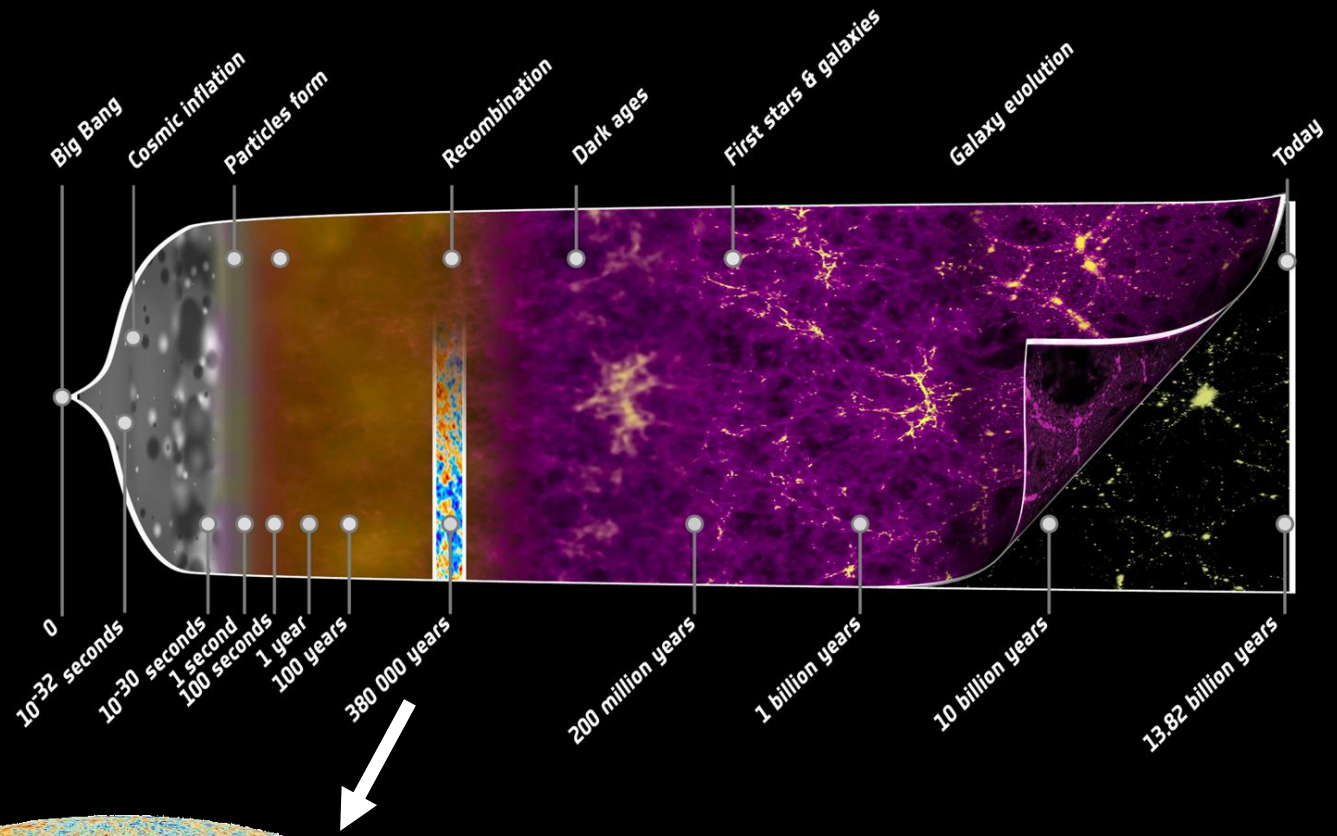
SLAC National Accelerator Laboratory

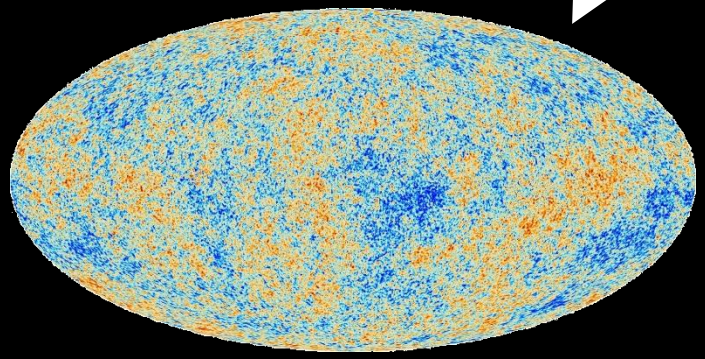
Funded By:

National Science Foundation

U.S. Department of Energy

The Universe as a Laboratory





ΛCDM parameters
r : tensor-to-scalar ratio
N_{eff}

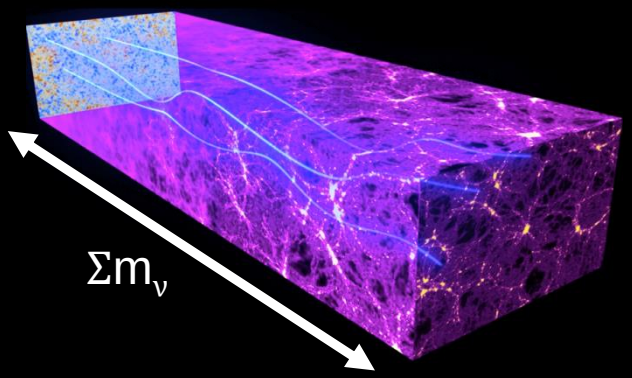
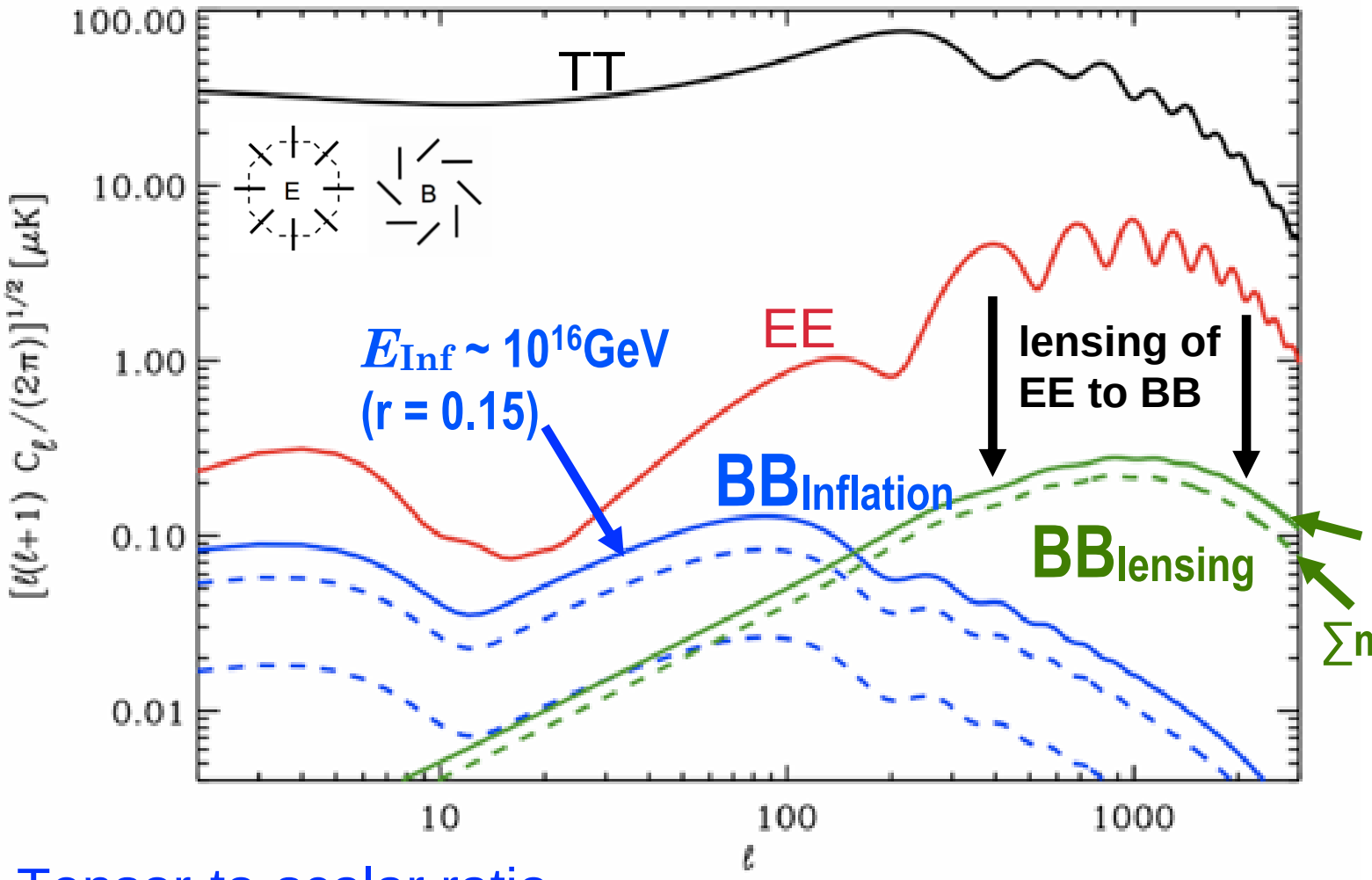


Image Credit: Planck/ESA

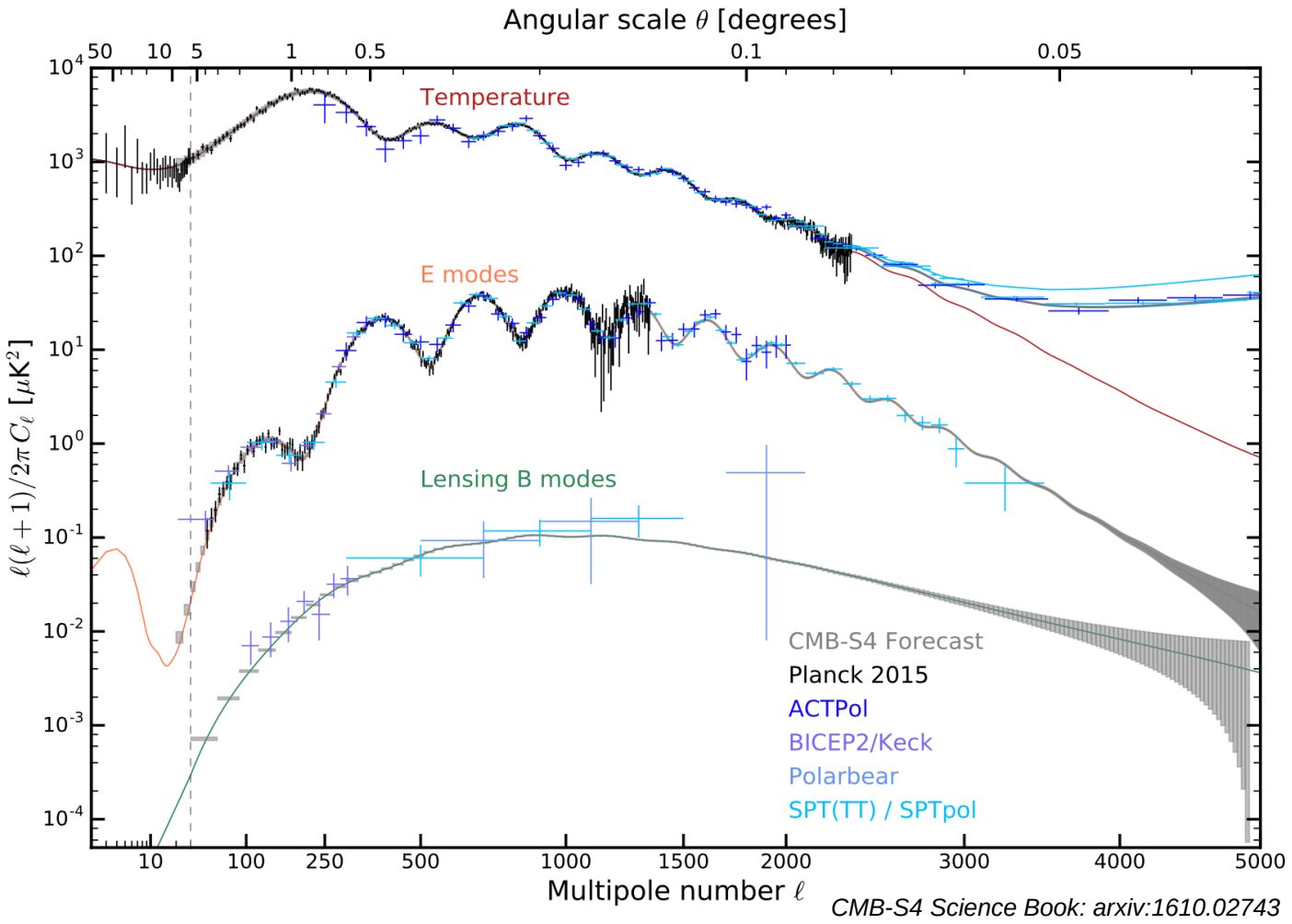
CMB Power Spectra: Intensity and Polarization



r == Tensor-to-scalar ratio

$E_{\rm Inf}$ == Energy scale of Inflation

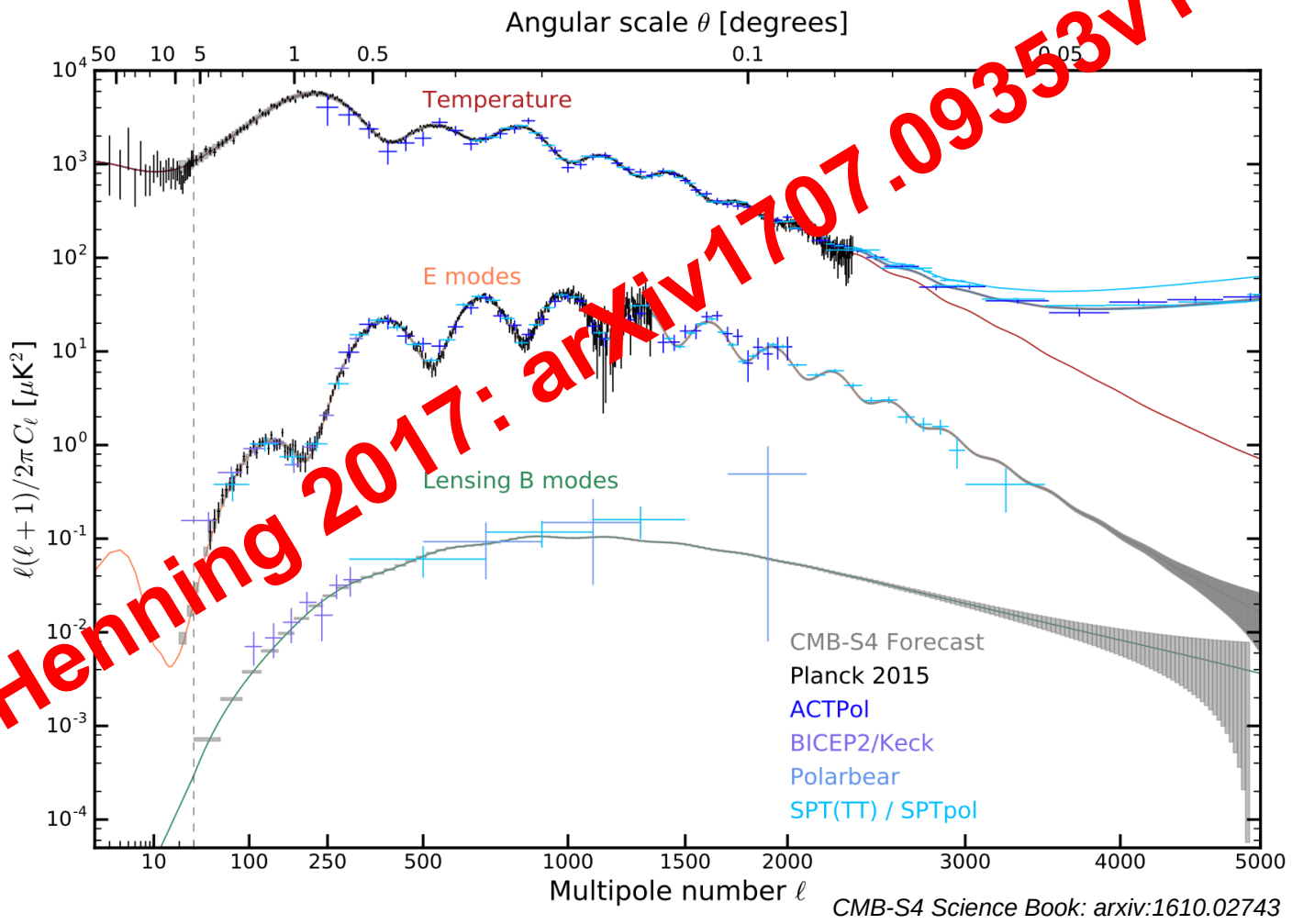
Oct. 2016: CMB Power Spectra



CMB-S4 Science Book: arxiv:1610.02743

- To improve measurements, need more detectors

Oct. 2016: CMB Power Spectra



CMB-S4 Science Book: arxiv:1610.02743

Henning 2017: arXiv1707.09353v1

- To improve measurements, need more detectors

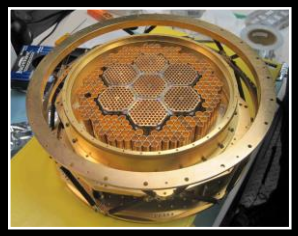
The South Pole Telescope (SPT)

10-meter sub-mm quality wavelength telescope

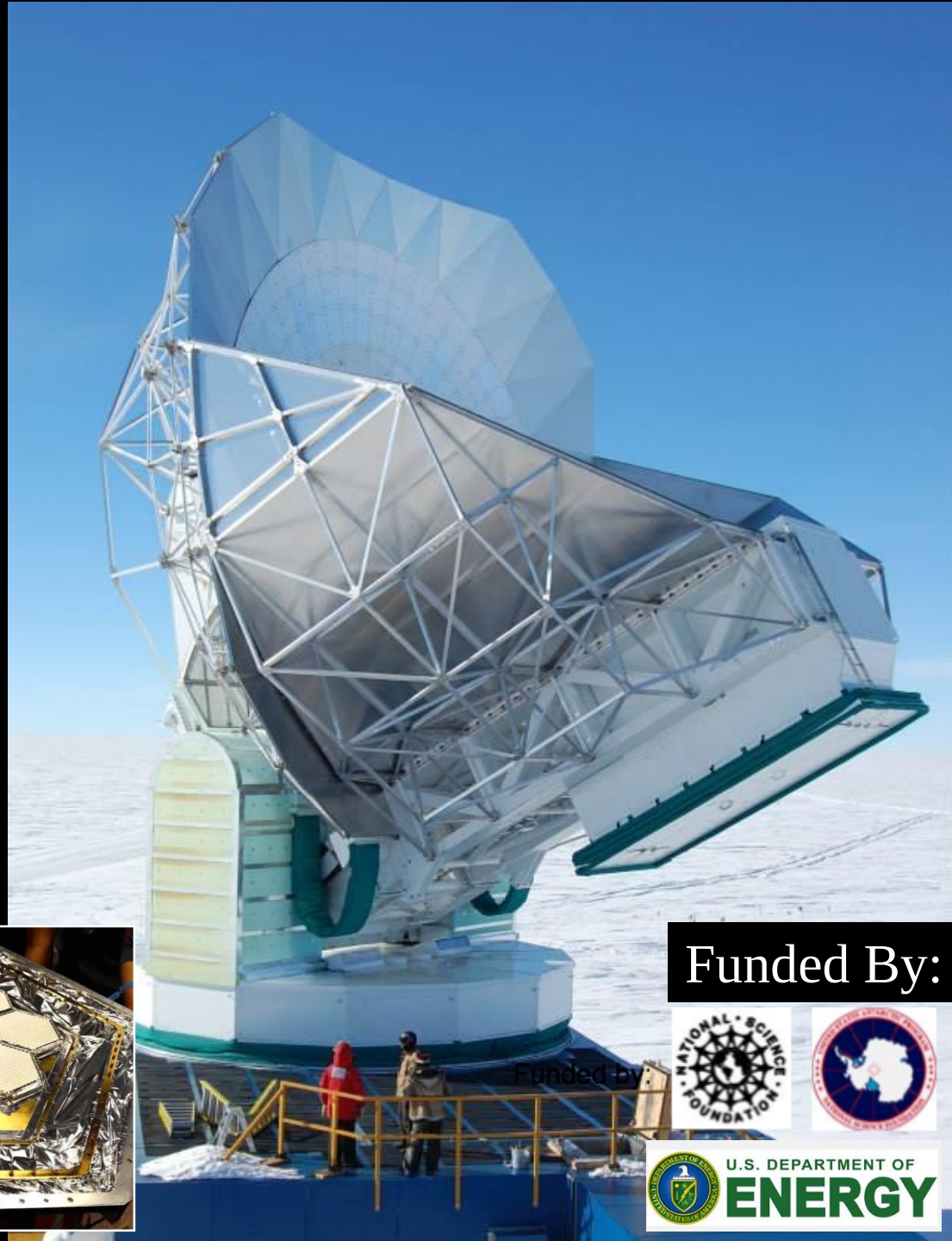
95, **150**, **220** GHz and
1.6, **1.2**, **1.0** arcmin resolution

2007: SPT-SZ
960 detectors
95,150,220 GHz

2012: SPTpol
1600 detectors
95,150 GHz
+Polarization



2017: SPT-3G
~16,000 detectors
95,150, 220 GHz
+Polarization



Funded By:

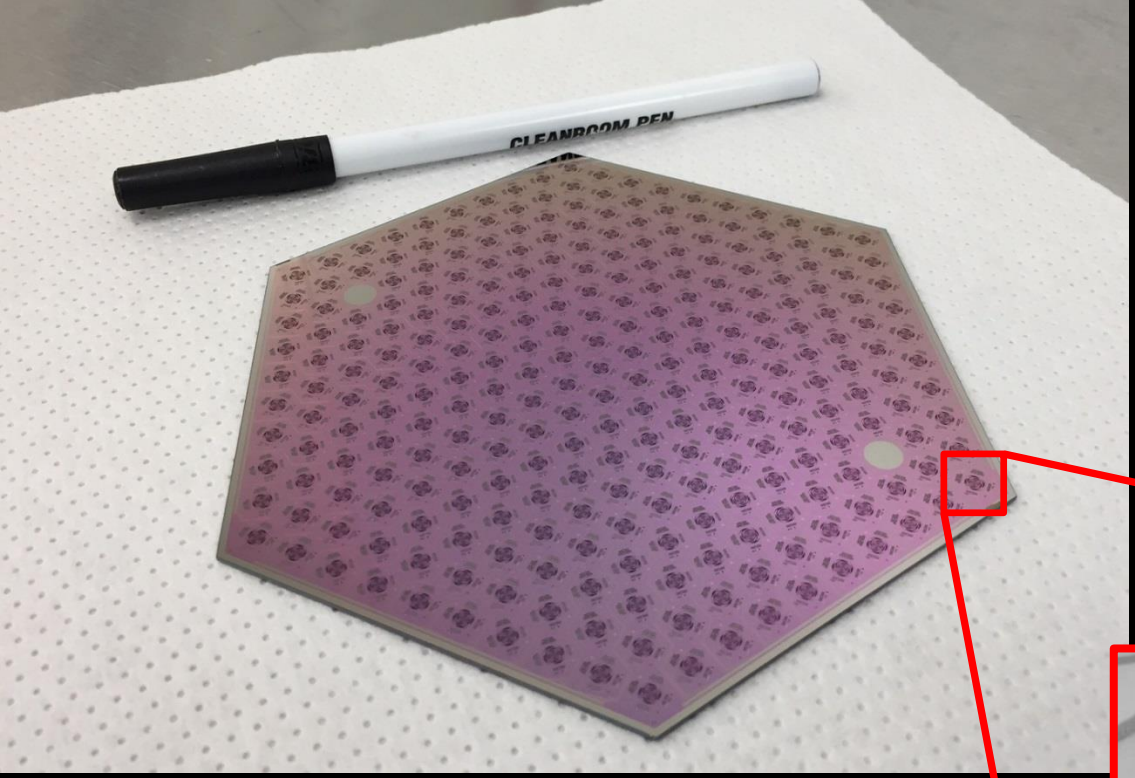
Funded by:

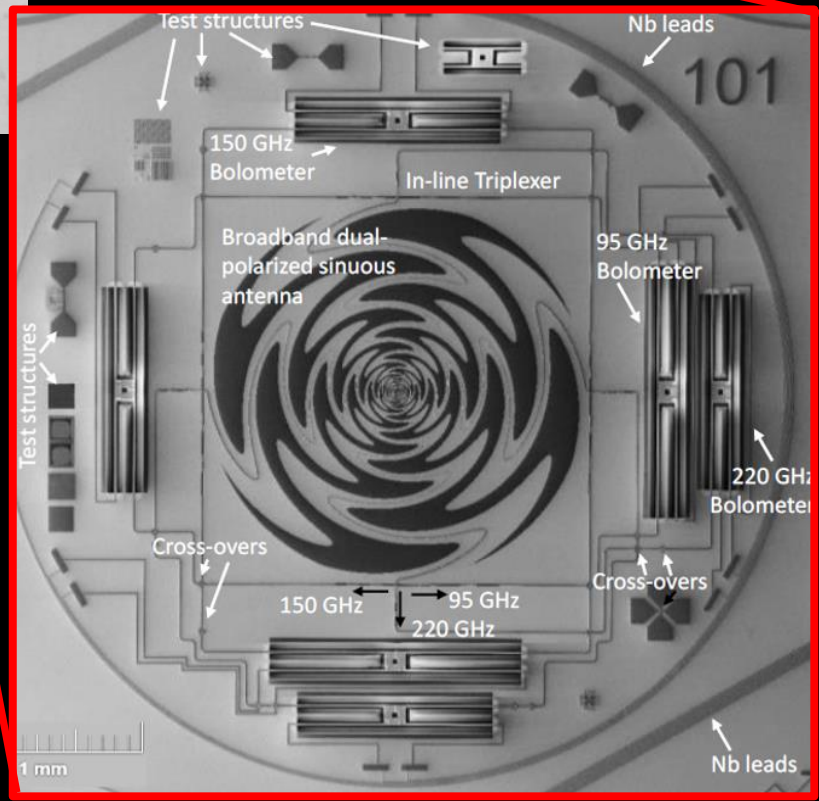
U.S. DEPARTMENT OF ENERGY

Detectors

- Detector wafers fabricated at ANL
- 271 pixels on each 6” wafer
- Ten wafers in SPT-3G focal plane

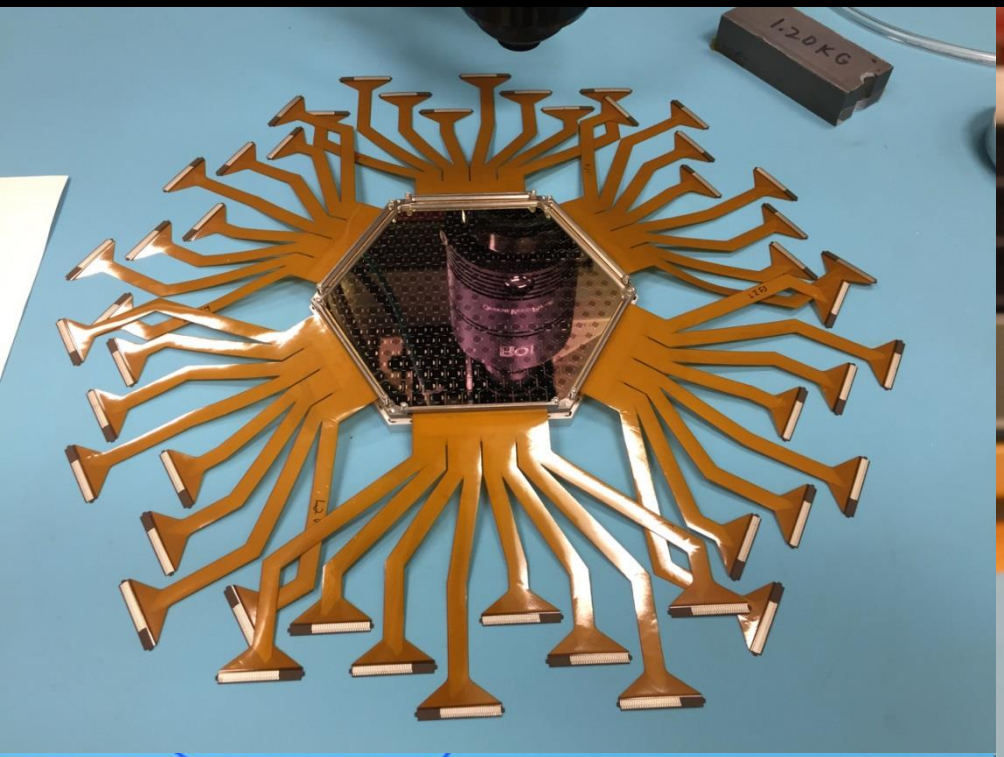
Argonne NATIONAL LABORATORY

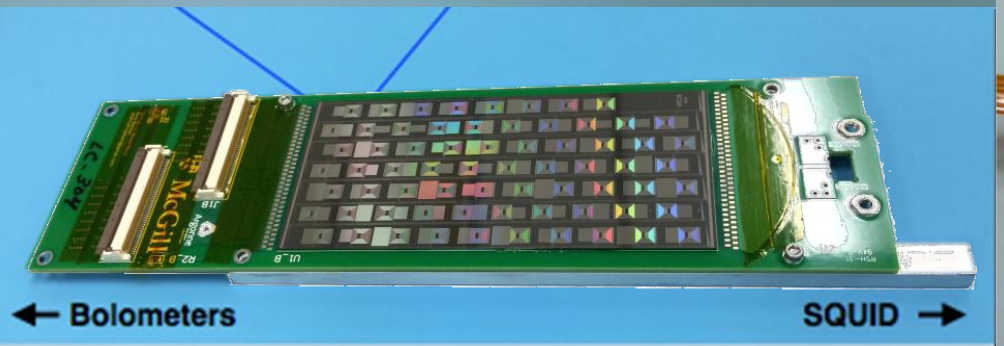


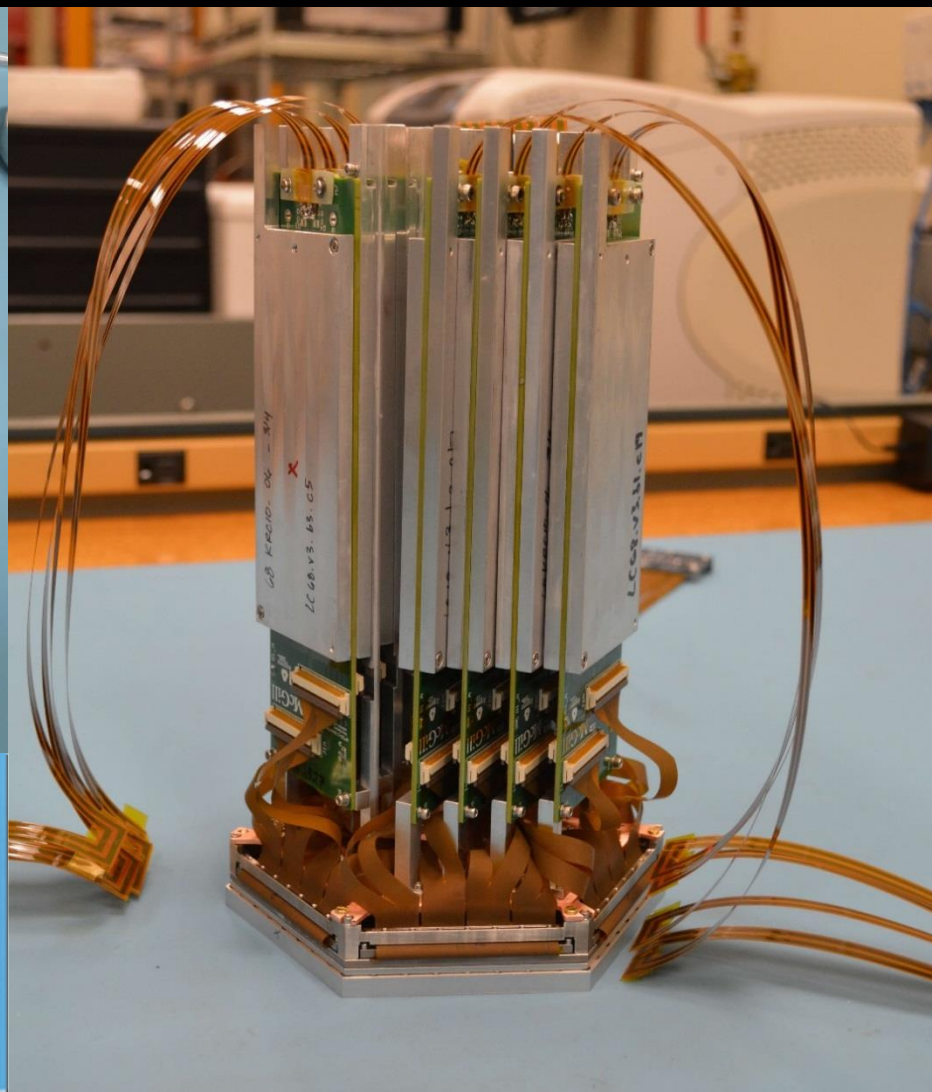


- Broad-band sinuous antenna coupled to TES bolometers via superconducting microstrip and in-line filters
- Three frequency bands
- Two orthogonal linear polarizations

- Lithographed inductor-capacitor boards set up 68 resonant frequency channels
- Channels summed and read-out through SQUID amplifier

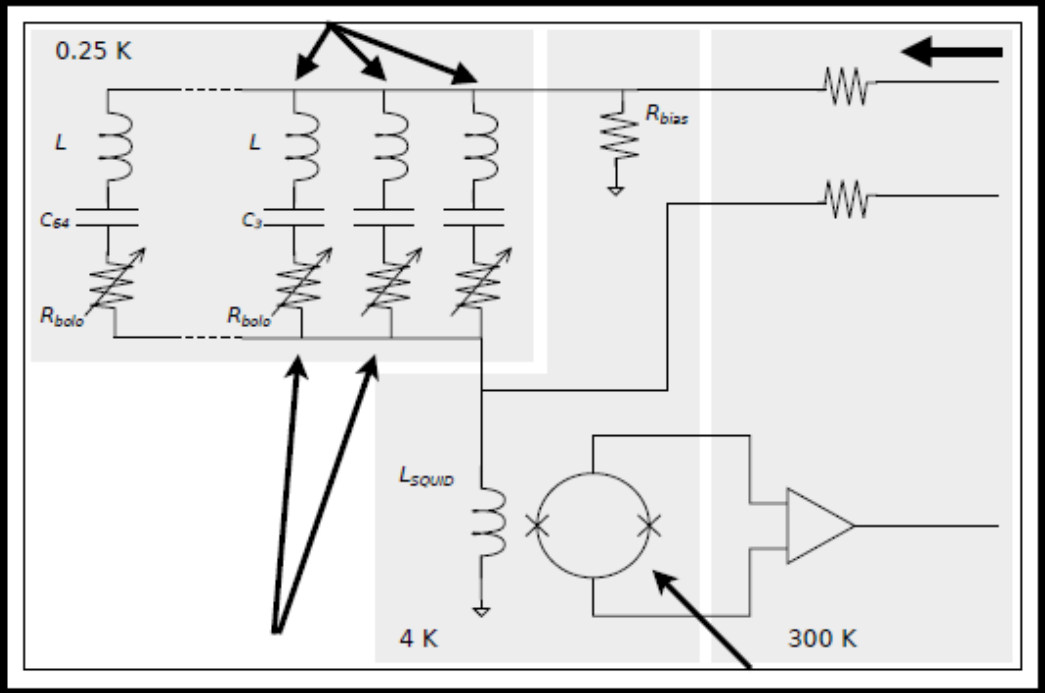






Readout Circuit

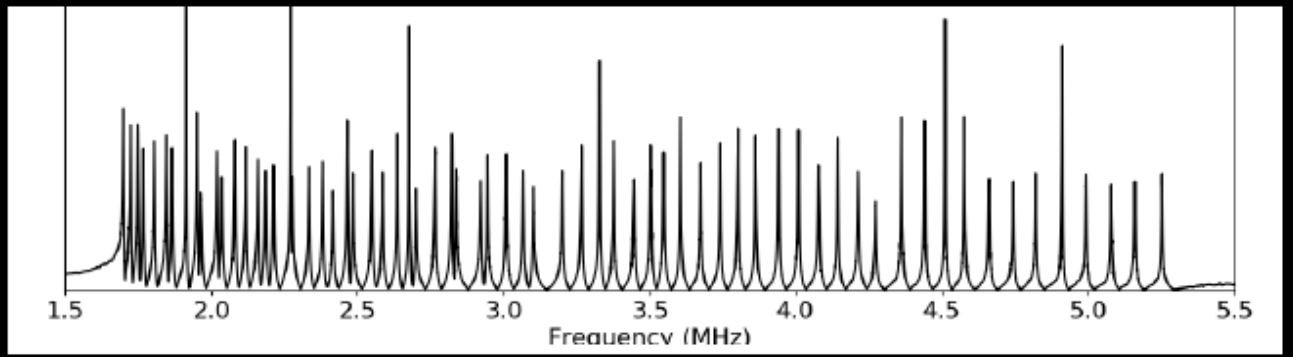
LC Filters



AC Bias

TES Bolometers

SQUID Amplifier



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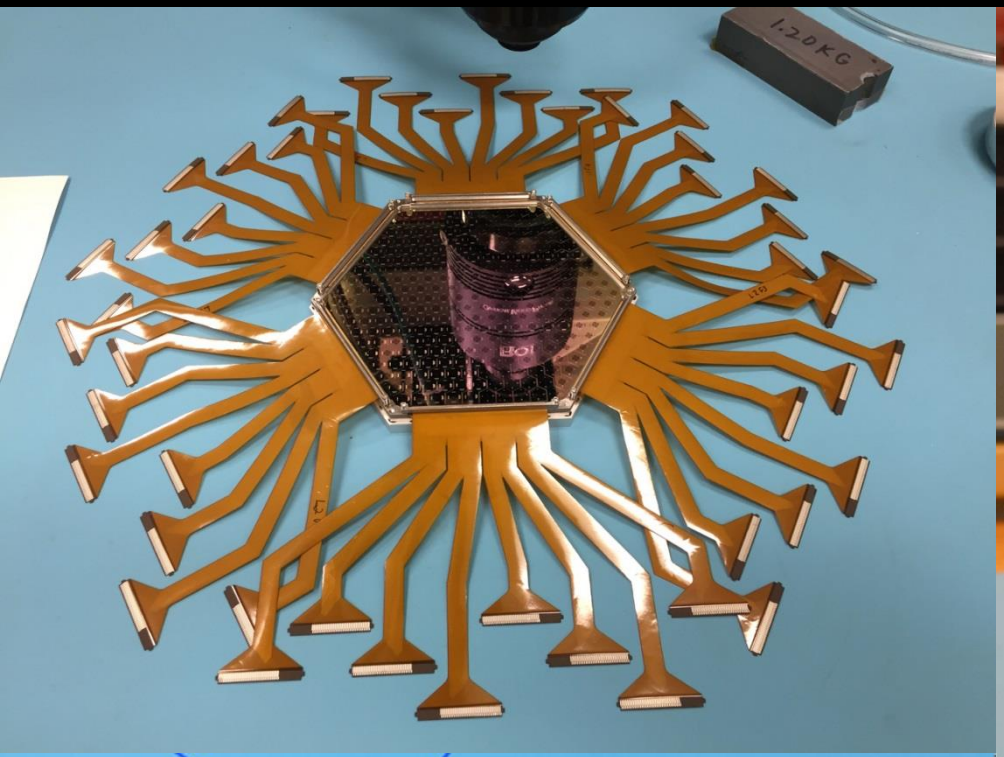
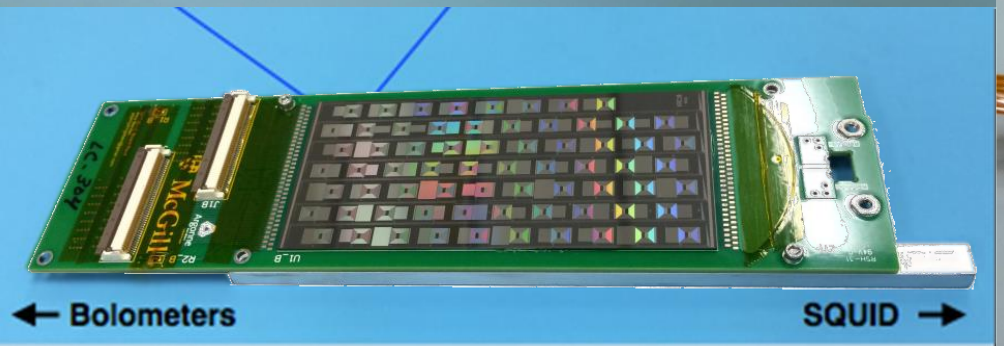
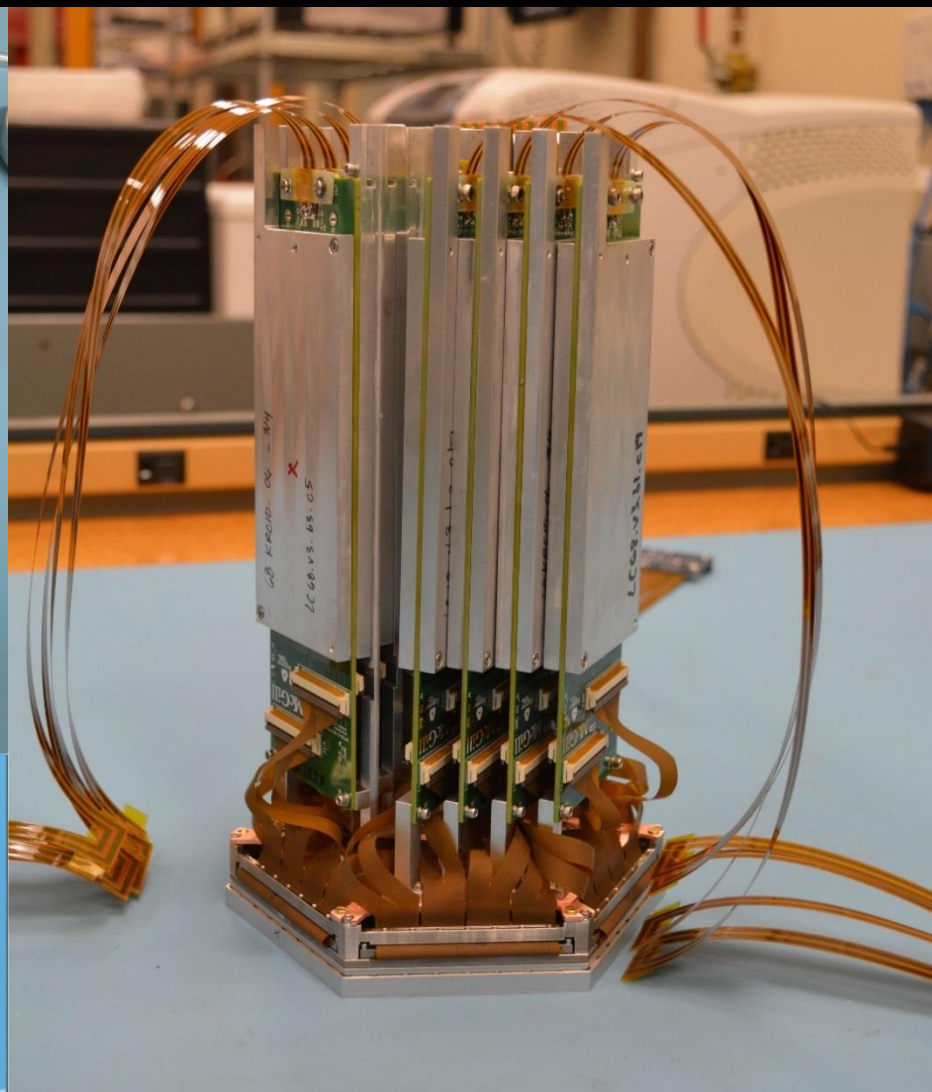
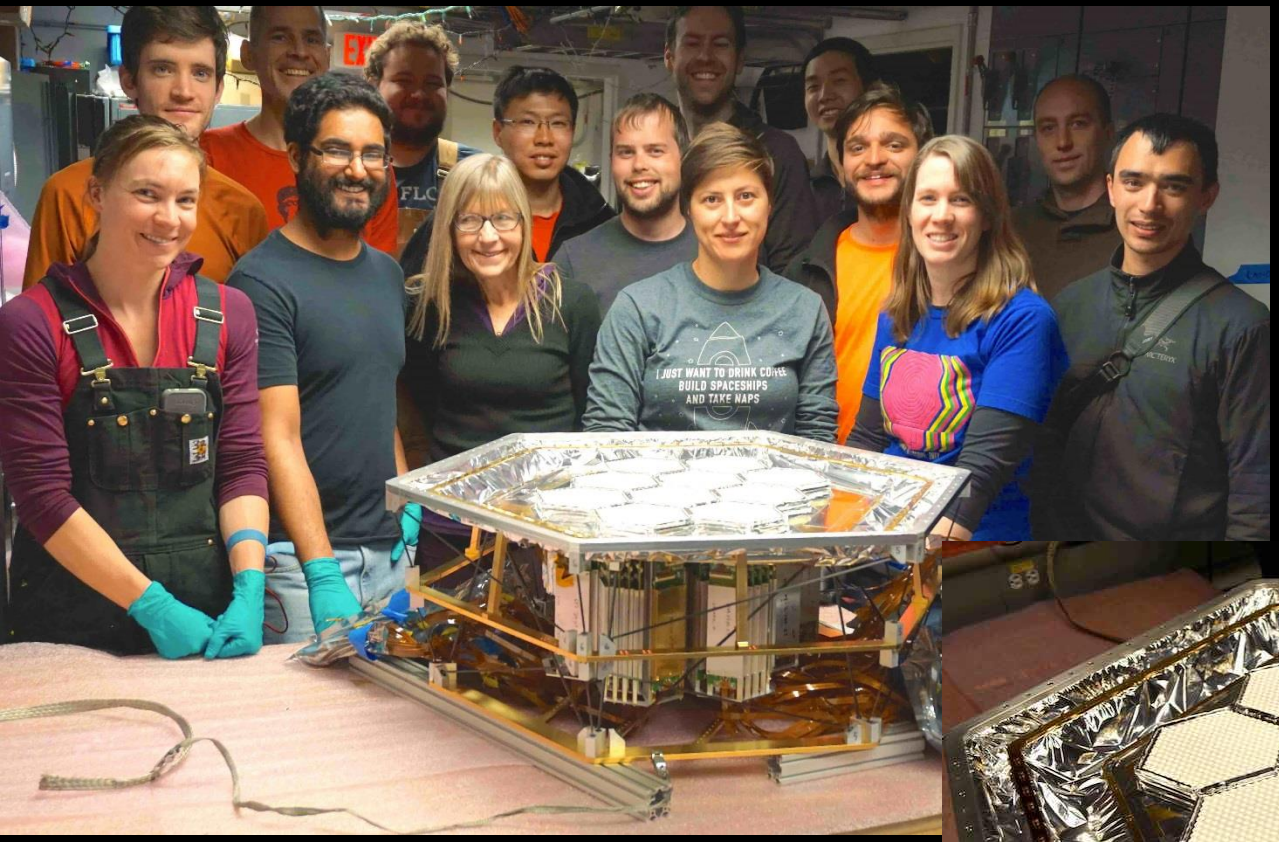




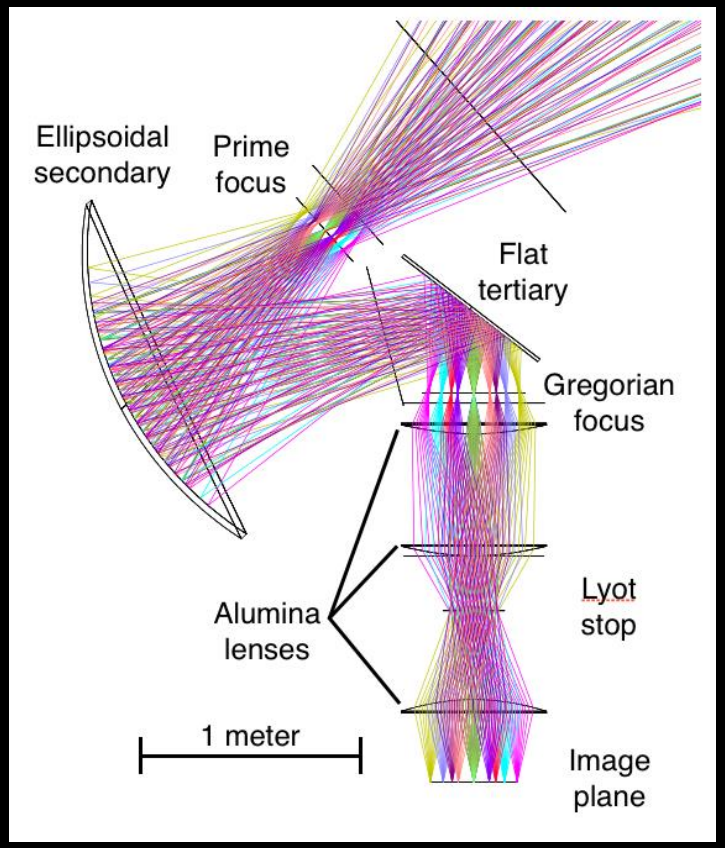


Full Focal Plane Assembled South Pole January 2017



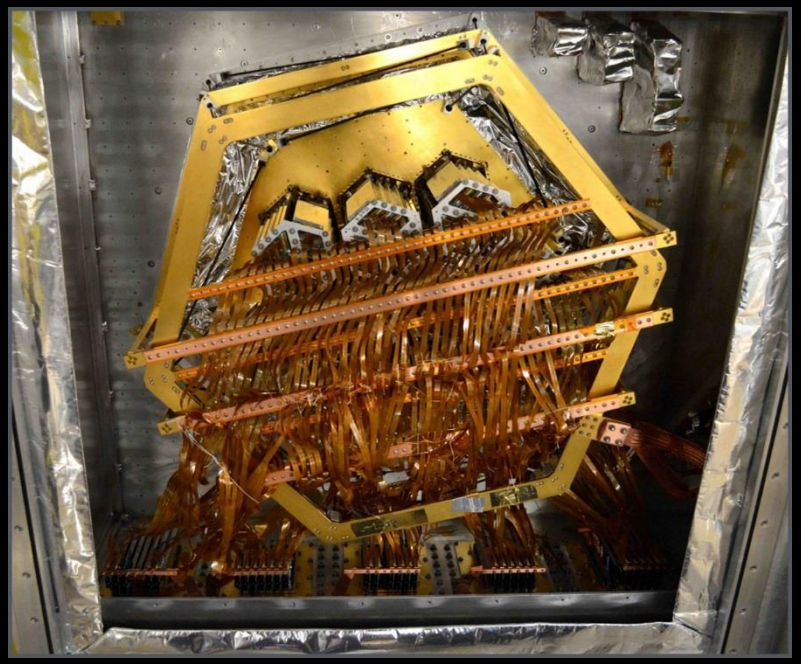
New Optics Design

- Optical coupling redesigned to maximize focal plane area
- New optics bench, and optics cryostat, and cold alumina lenses

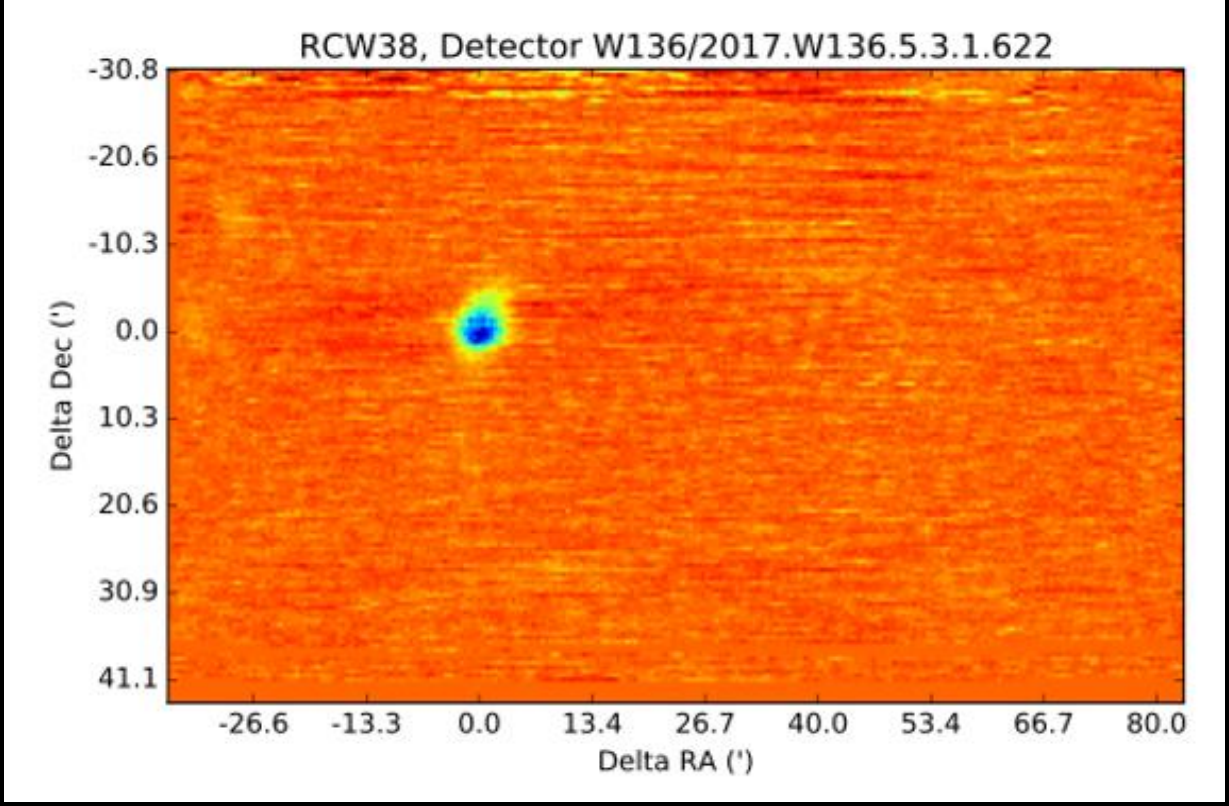


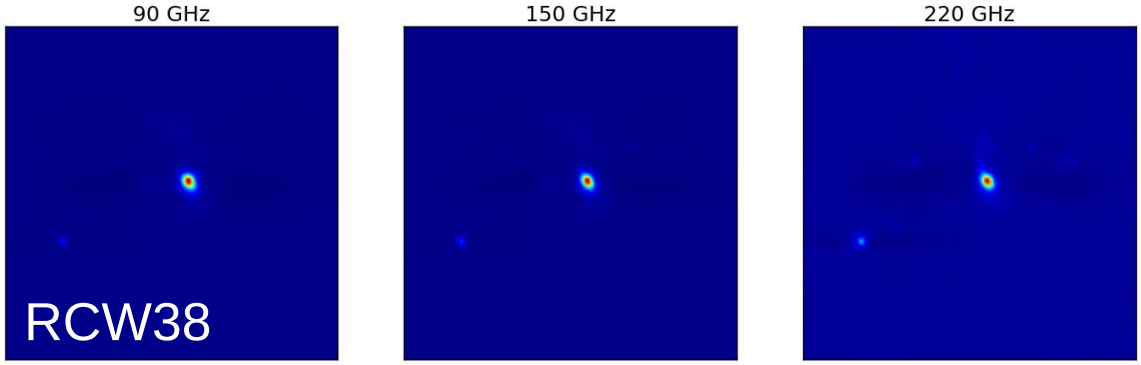
Align and Install Secondary Optics

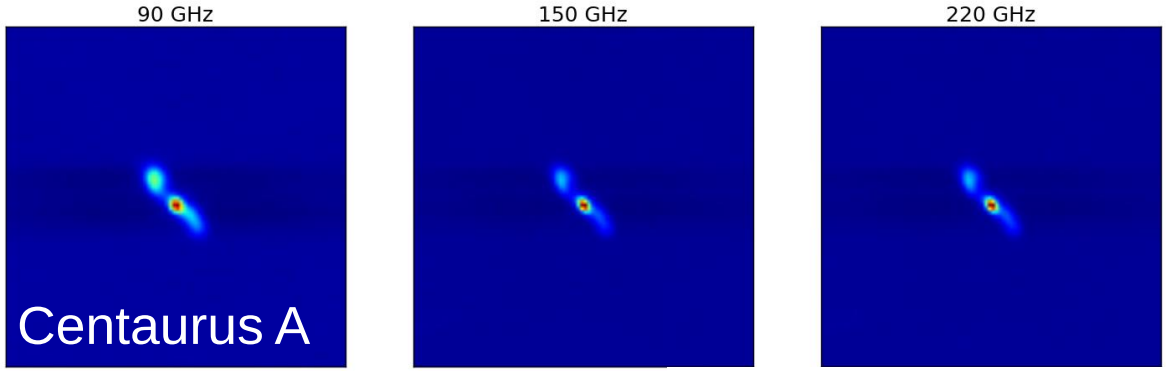
Installation of Focal Plane in Receiver and Receiver on Telescope



First Light on January 30, 2017





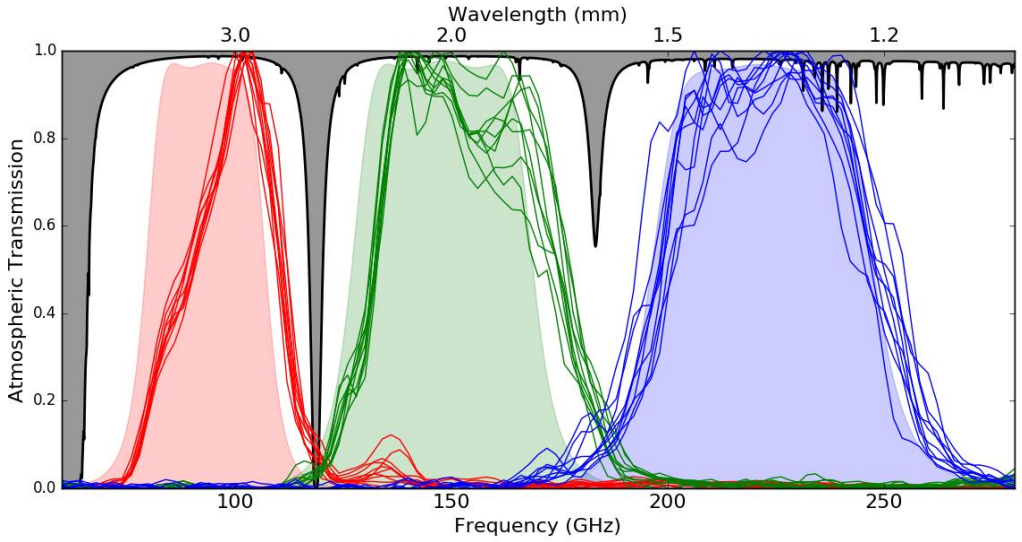


Source Observations

- RCW38 for pointing, flux calibration
- CenA for polarization calibration

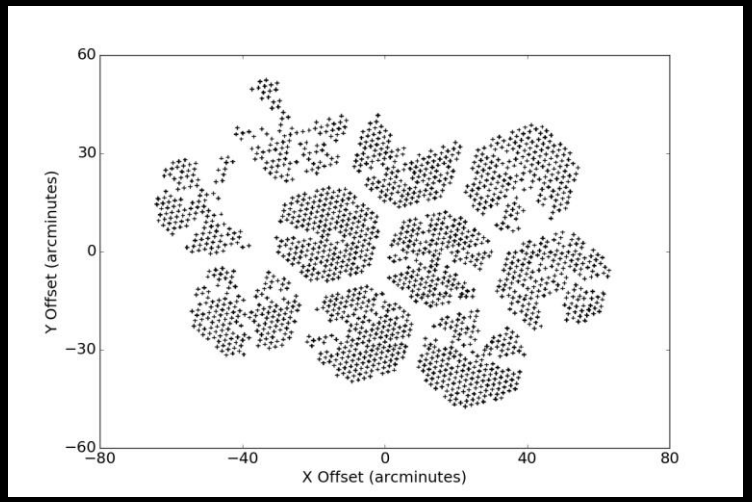
Detector band measurements

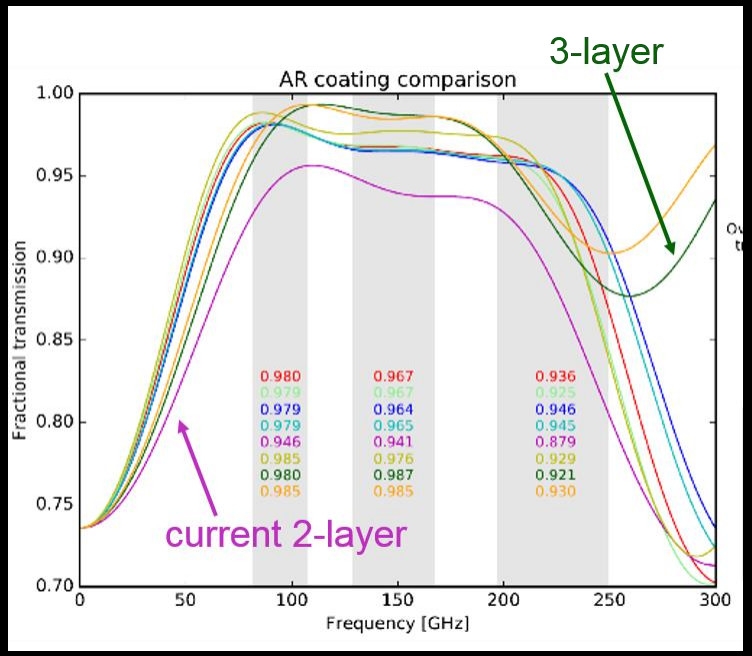
- Good uniformity across wafers



Current Status and Improvements for Next Season

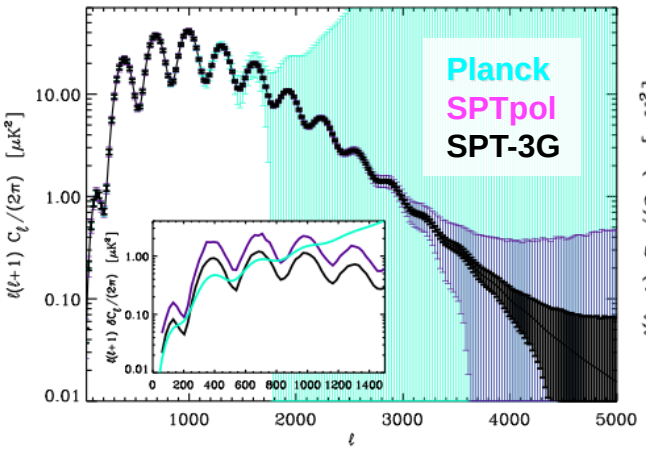
- Operable detector yield ~ 74%
  - Replace non-functioning or low yield detectors and readout
- Elevated readout noise
  - Replace SQUID amplifiers with lower input impedance versions
- Two-layer AR coating on alumina lenses has higher loss
  - Replace with three-layer coating



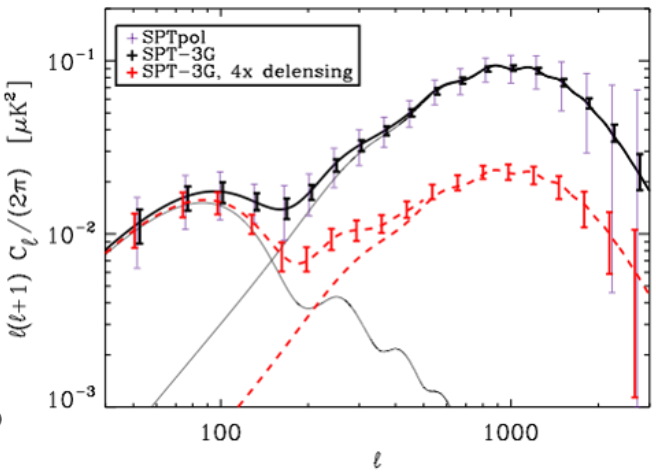


SPT-3G Survey Projections

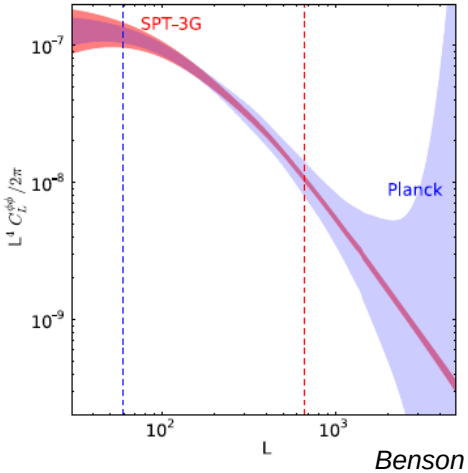
EE



BB



Lensing



Benson 2014

Parameter Constraints

(with Planck, BOSS priors)	SPT-3G (2021)
$\sigma(r)$	0.011
$\sigma(N_{eff})$	0.058
$\sigma(\Sigma m_\nu)$	0.061 eV

Survey depth

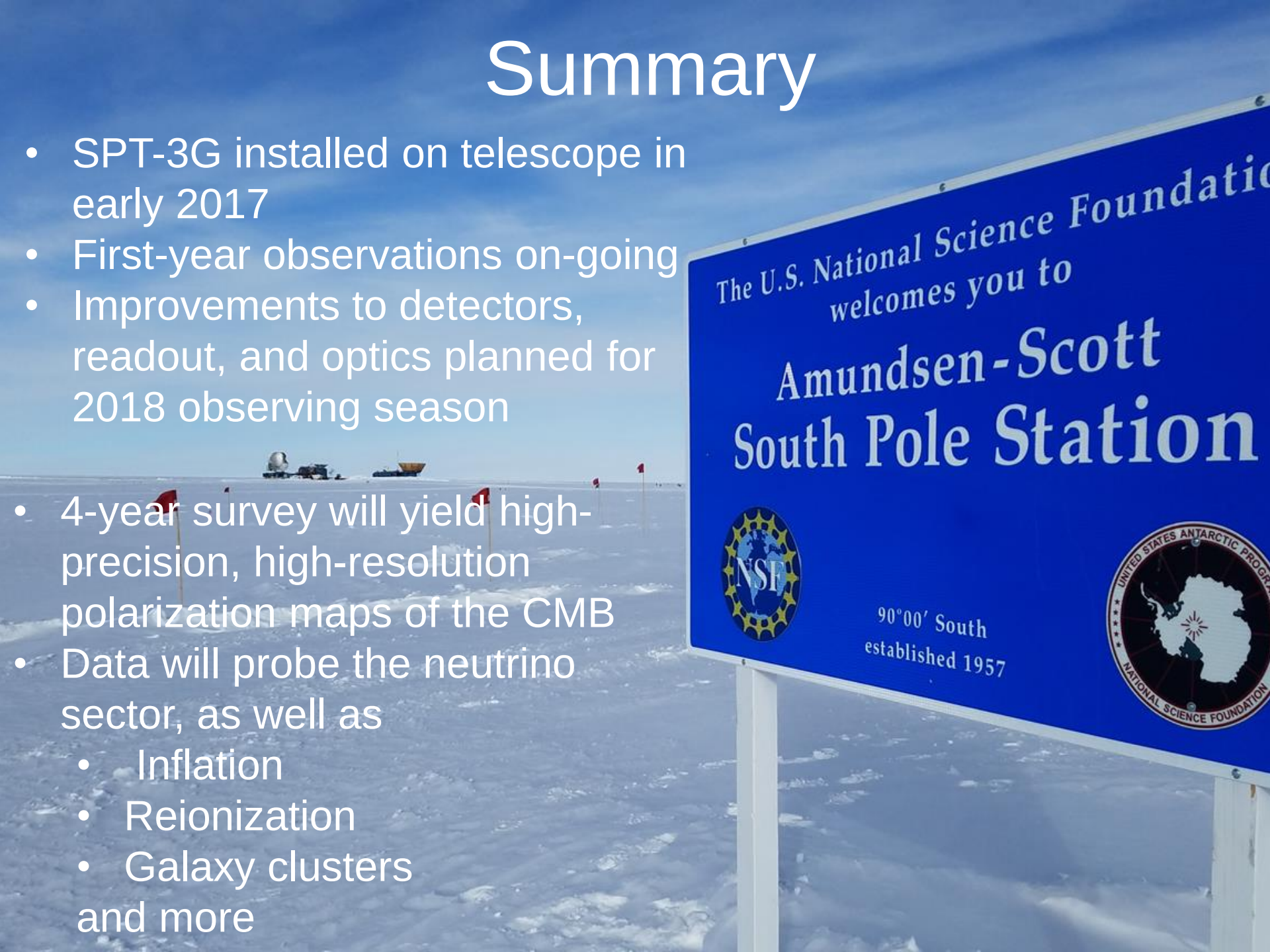
2500 sq deg, Four years	95 GHz	150 GHz	220 GHz
T (uK-arcmin)	3.6	3.3	8.5
P (uK-arcmin)	5.1	4.7	12

Summary

- SPT-3G installed on telescope in early 2017
- First-year observations on-going
- Improvements to detectors, readout, and optics planned for 2018 observing season

- 4-year survey will yield high-precision, high-resolution polarization maps of the CMB
- Data will probe the neutrino sector, as well as
  - Inflation
  - Reionization
  - Galaxy clusters

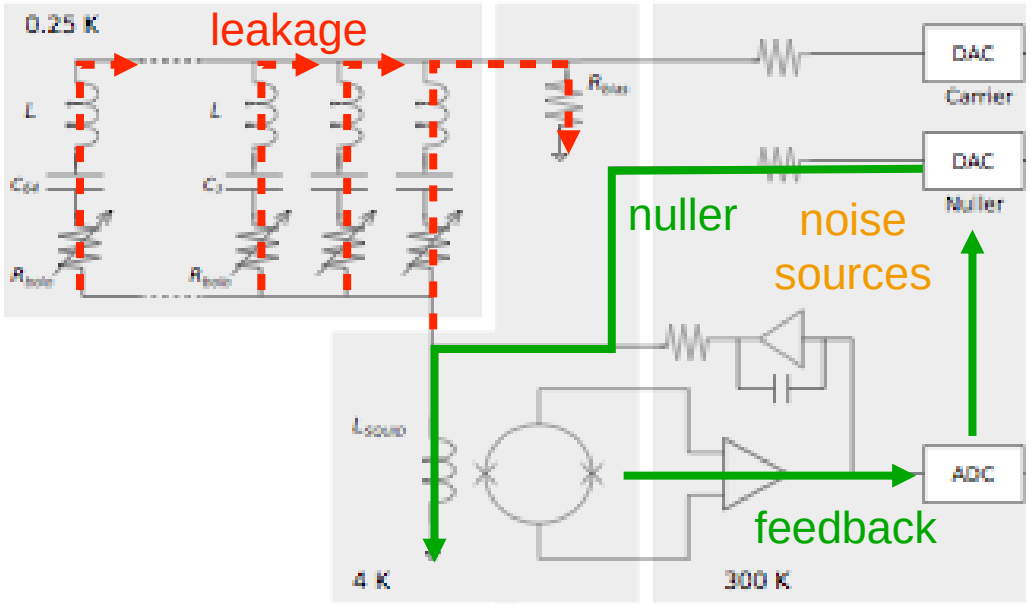
  and more




Thank you

Readout Noise Enhancement

- ***Noise enhancement from current division with SQUID input coil:***
  - Current at SQUID canceled by "digital active nulling" feedback loop (nuller = science signal)
  - ***BUT*** nuller current for noise ***INSIDE LOOP*** is divided between comb and SQUID coil
  - Over 1.8 to 5.2 MHz readout bandwidth, noise internal to ADC chain enhanced by:



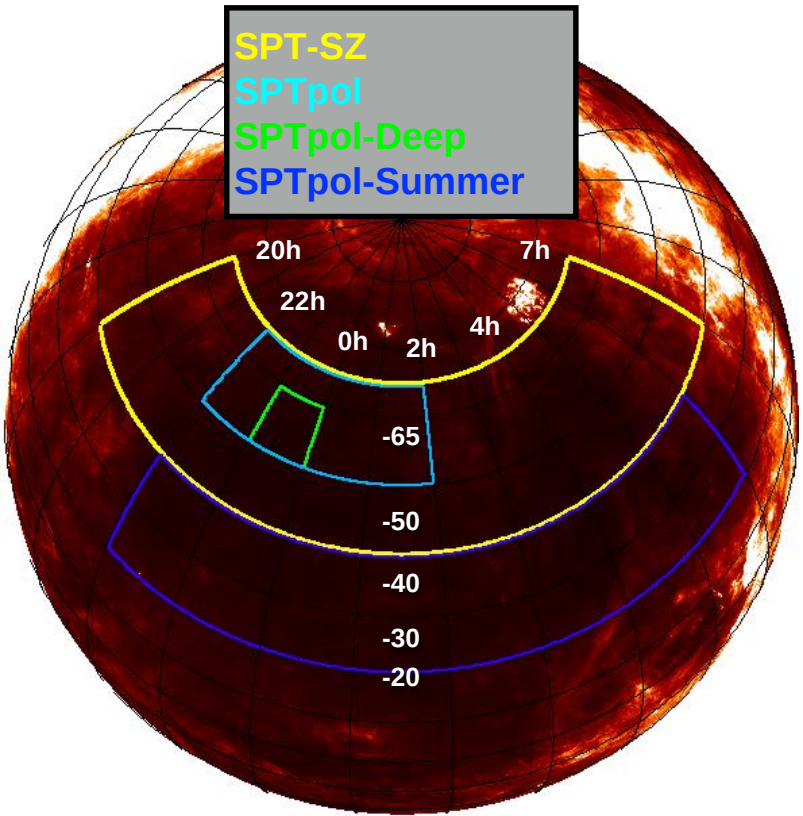
$$\text{factor} = 1 + \frac{Z_{\text{squid}}}{Z_{\text{comb}}} \simeq 2 \text{ to } 7$$

Want low input coil inductance!
Replacing SQUIDs next season

	L_{input}
current NIST SQUIDs	~300 nH
NIST, StarCryo SQUIDs under study	10-50 nH

Projected Sensitivity

Significant increase in sensitivity following installation of 3-layer AR coating and low-inductance SQUIDs



2018 season projected

band	NET (bolo) [uK rtsec]	NET (array) [uK rtsec]	mapping speed (x SPTpol)
90 GHz	509	7.4	16.4
150 GHz	460	6.5	5.3
220 GHz	1188	17	inf.

	Obs. Years	Area (deg2)	95 GHz (uK-arcmin)	150 (uK-arcmin)	220 (uK-arcmin)
SPT-SZ	2007-11	2500	40	17	80
SPTpol-Main	2012-16	500	13	5	-
SPTpol-Deep	2012-16	100	10	3.5	-
SPTpol-Summer	2012-16	2500	47	28	-
SPT-3G *(projected)*	***2017-21***	***2500***	***3.6***	***3.3***	***8.5***