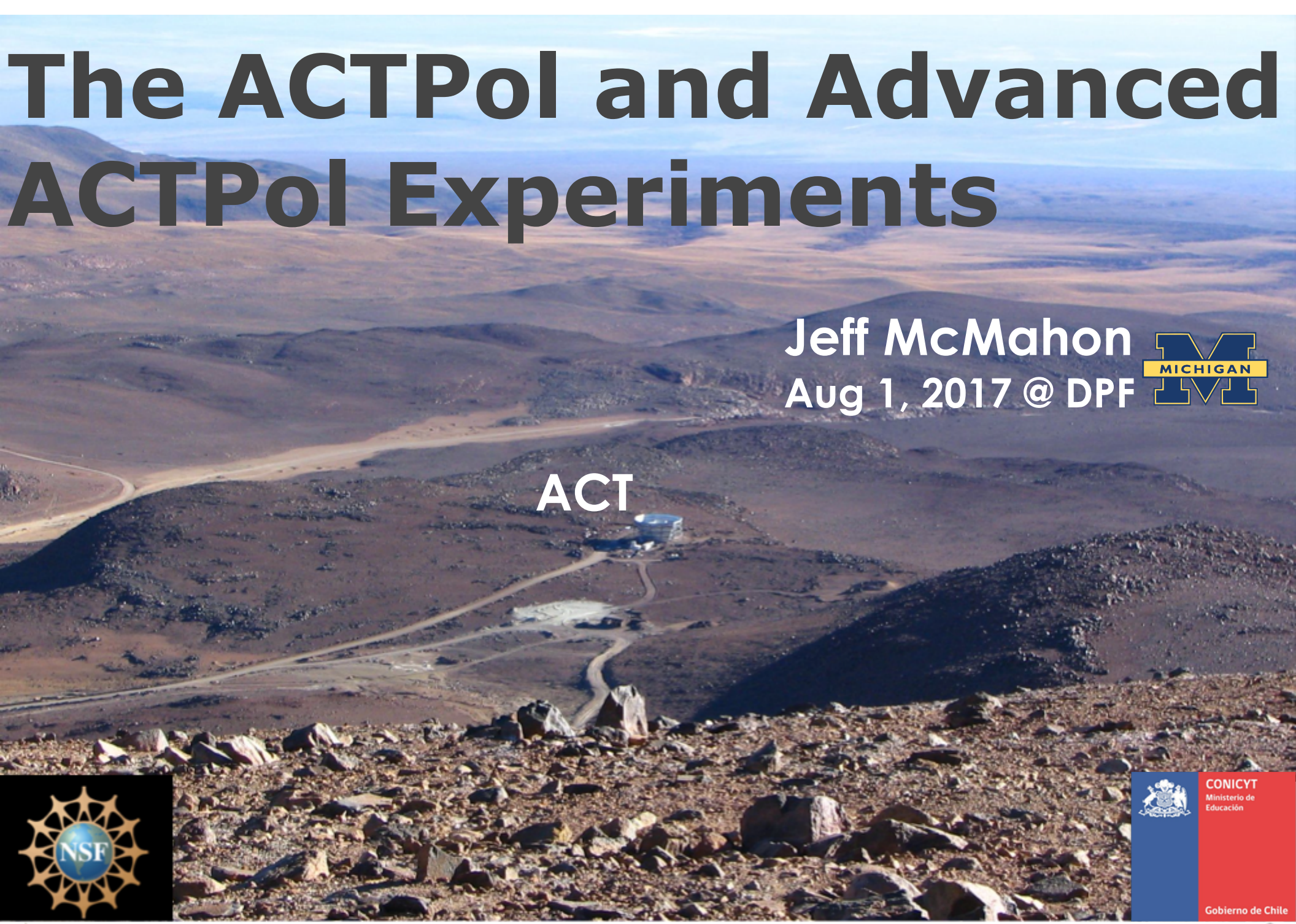
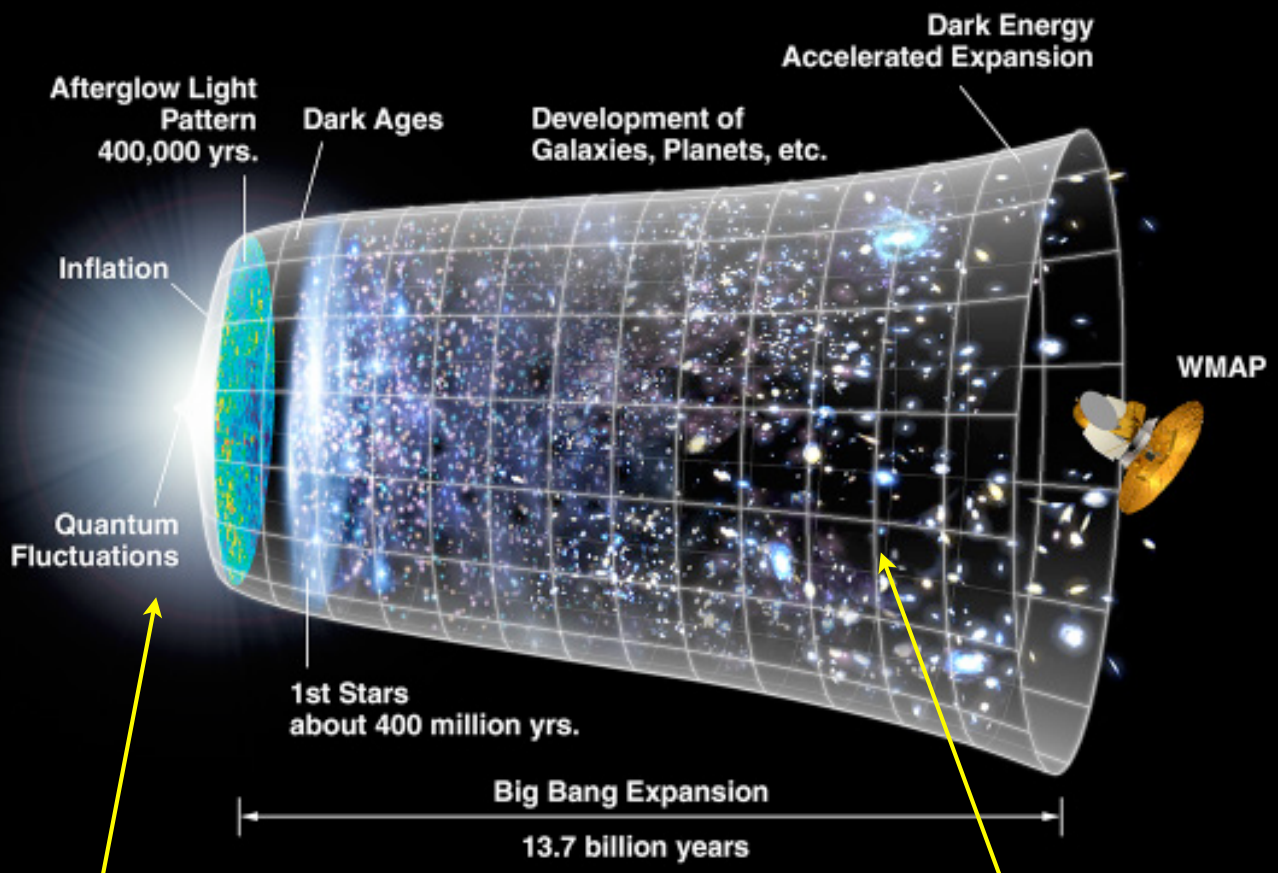
The ACTPol and Advanced ACTPol Experiments

Jeff McMahon

Aug 1, 2017 @ DPF

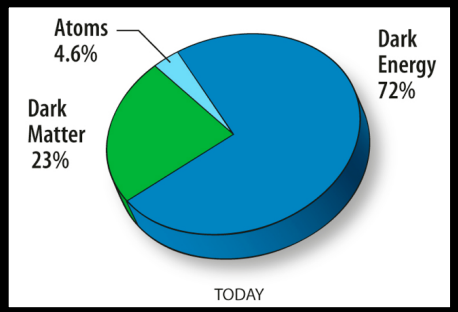


ΛCDM: the Standard Cosmological Model



Physics at an energy scale of
$\sim 10^{16}$ GeV

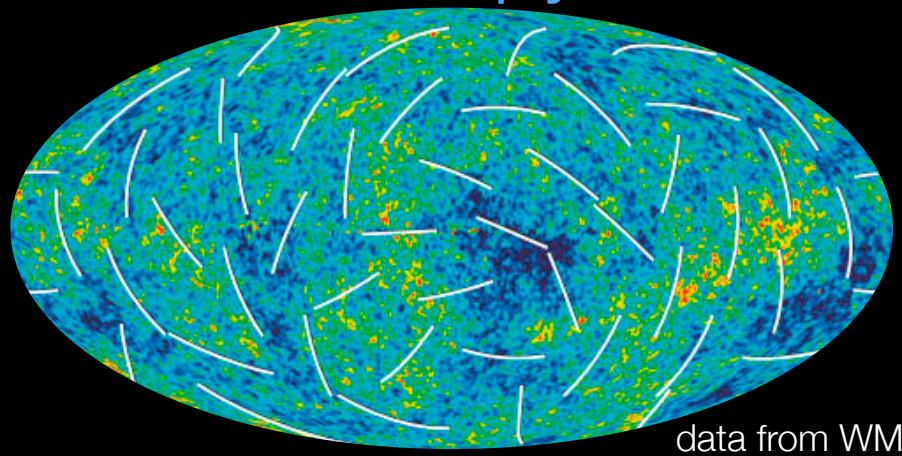
Present energy density



- **6 parameters:**
  - content: Ω_b, Ω_c, Ω_Λ
  - Hubble: H
  - reionization: τ
  - inflation: A_s, n_s
- **reproduces all observations**
  - BBN
  - CMB
  - SN1a
  - BAO
- **among the most pressing questions for physics this century**
  - inflation
  - dark energy
  - dark matter
  - neutrinos
  - light relativistic species

Cosmological Measurements with the CMB

CMB anisotropy

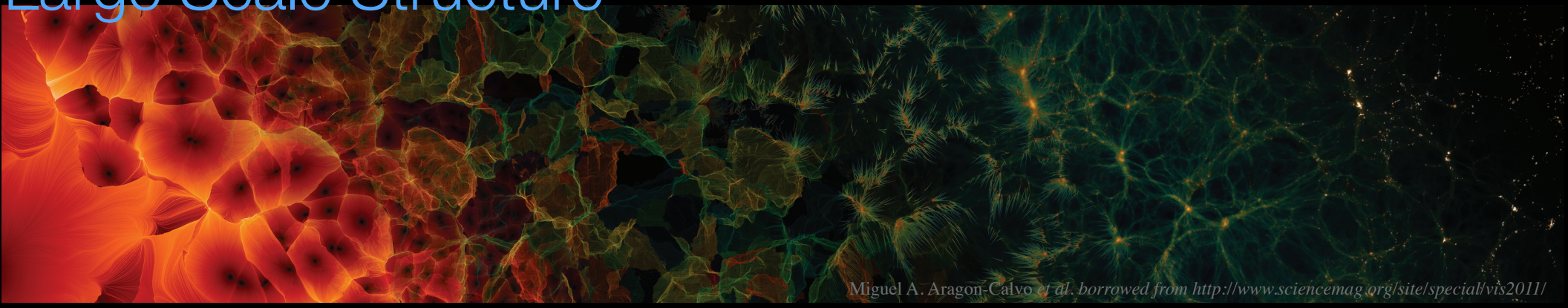


data from WMAP

Snapshot of our universe at 380,000 years

carries the imprint of inflationary parameters, the number of neutrino species, and more

Large Scale Structure



Probes our universe from age ~1 to ~13.8 Billion Years

sensitive to dark energy and dark matter (neutrinos), and other parameters.

Atacama Cosmology Telescope

Stage 1 ‘MBAC’: 2007-10

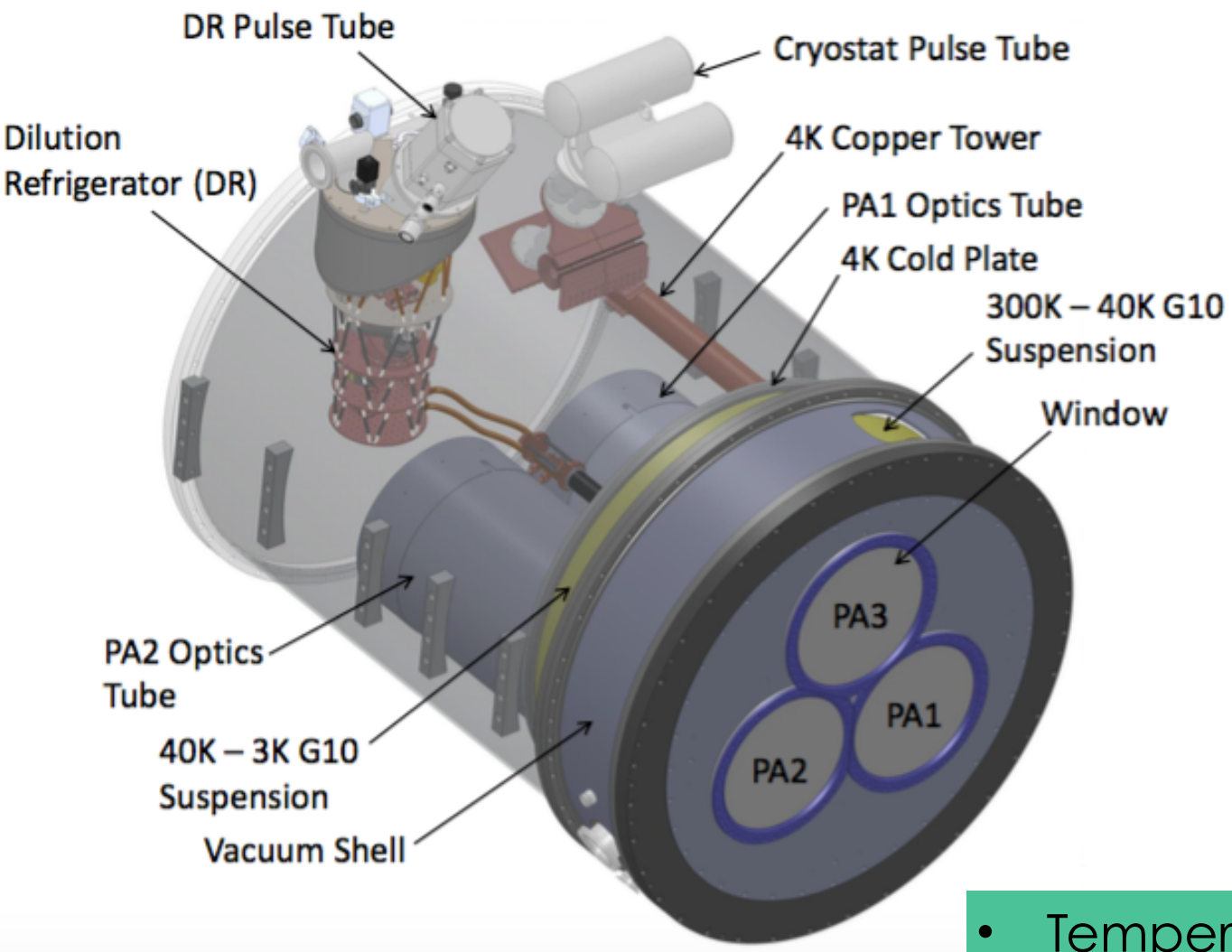
Stage 2 ‘ACTPol’: 2013-15

Stage 3 ‘AdvACT’: 2016-19

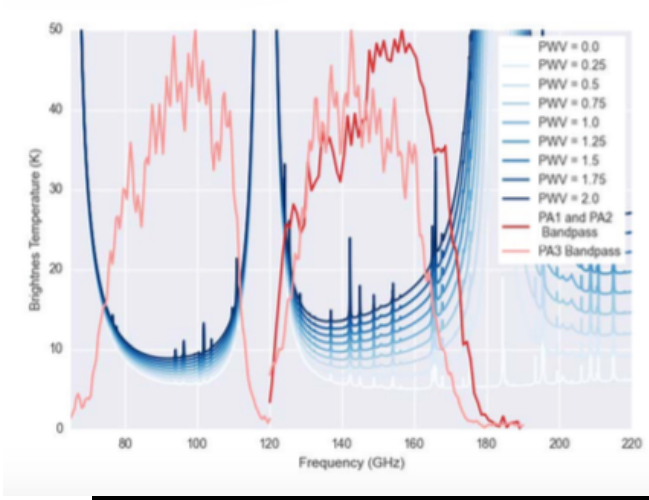
5200m, 1.4’ resolution, 6m telescope

THE ACTPOL CAMERA

2013-2015



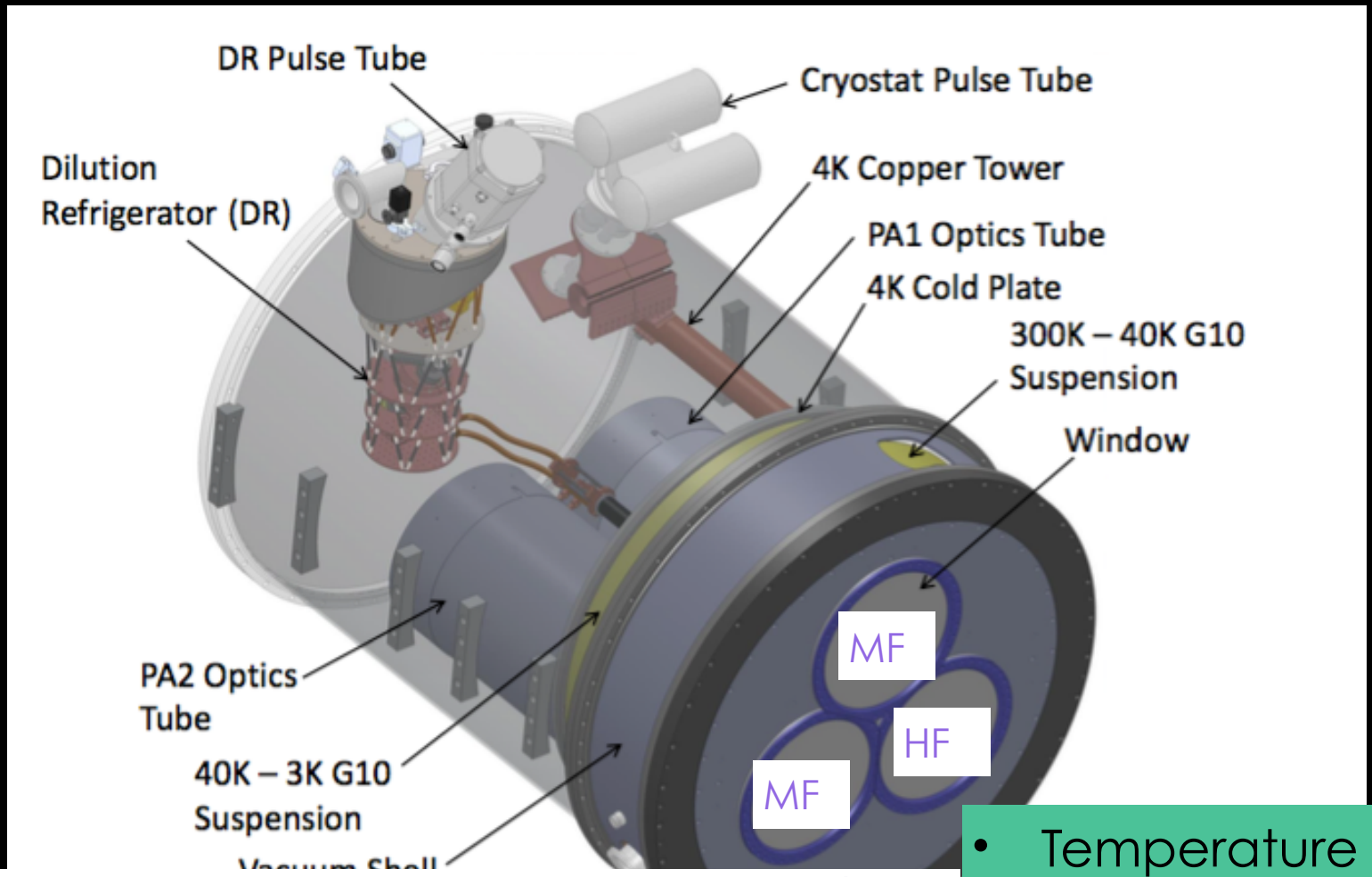
Two 150 GHz camera
PA1/PA2
highlight: PA3
first multichroic array



- Temperature & polarization
- Two bands: 90 & 150 GHz
- 90 mK dilution fridge
- Round the clock observing

THE ADVACT CAMERA

2016 -

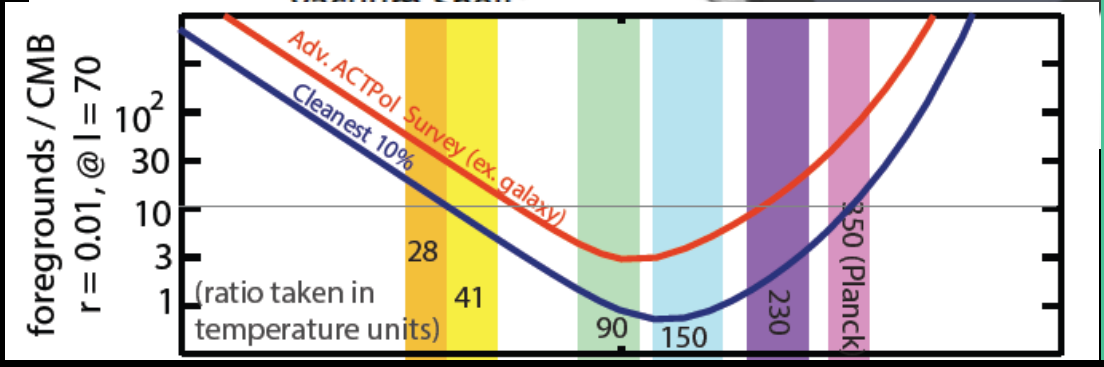


SAME CRYOSTAT!

new bands

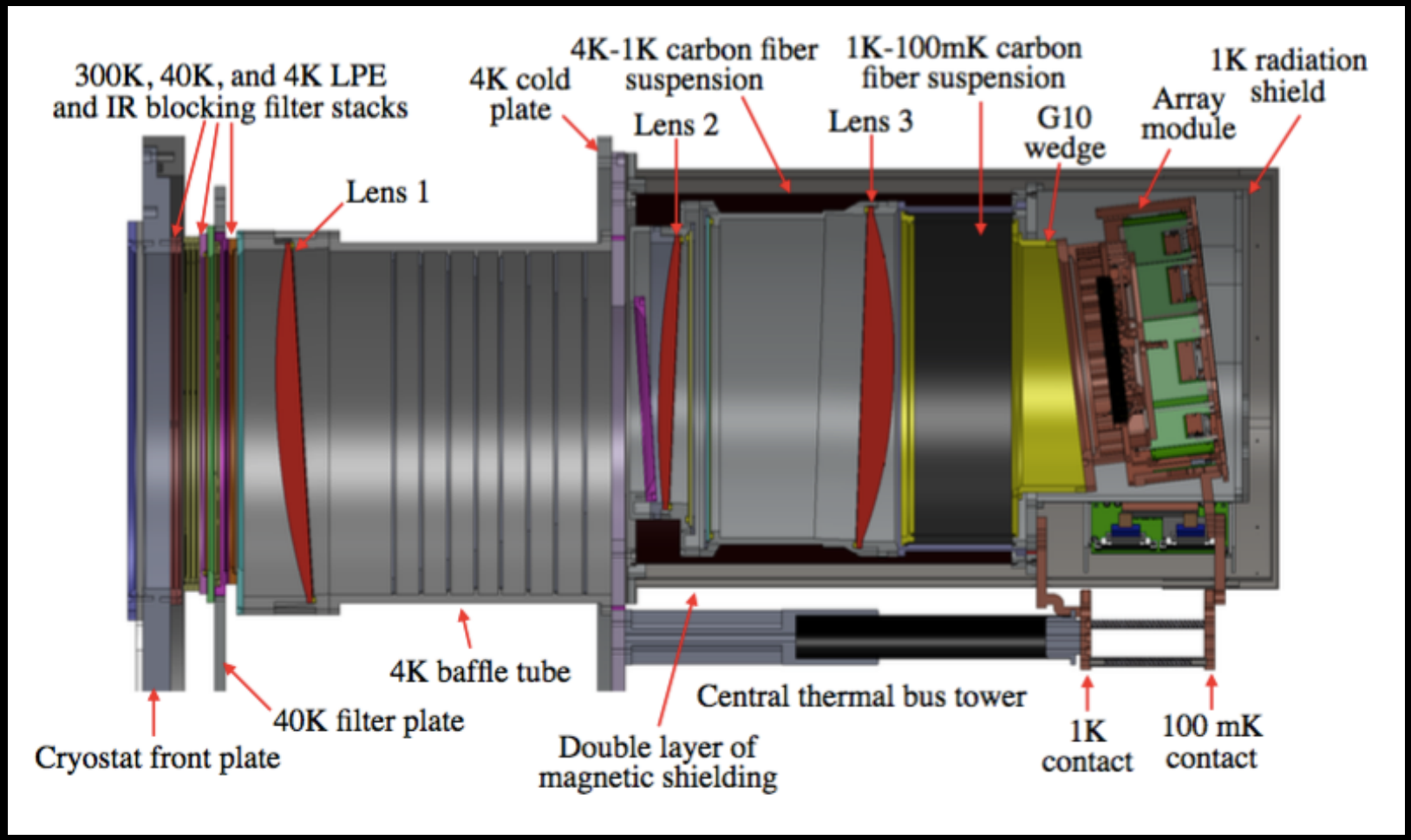
new arrays

new optics



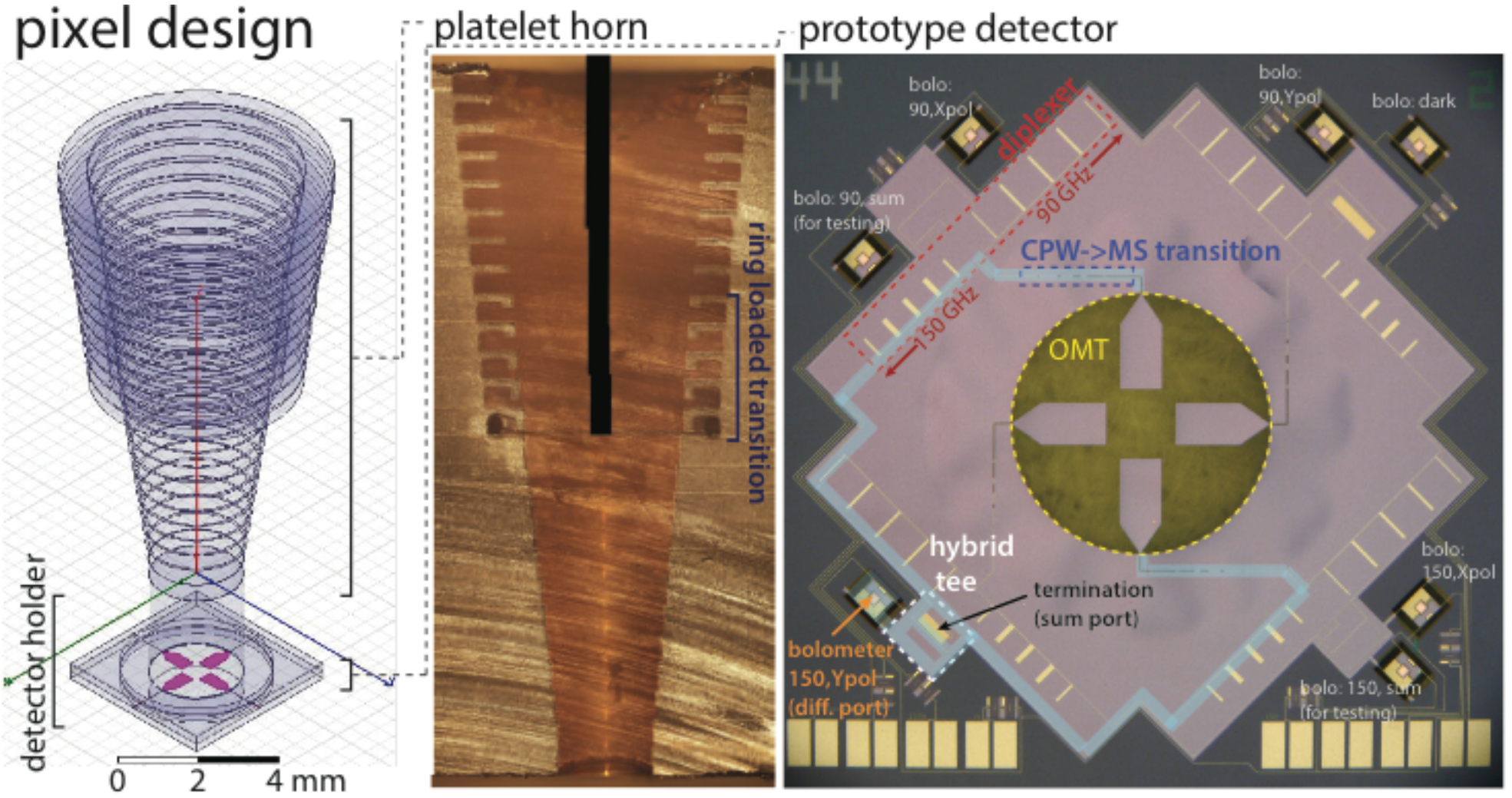
- Temperature & polarization
- **Five** bands: 28, 40, 90, 150 & 220 GHz
- MF arrays are second generation multichroics with higher pixel count (256 vs 403)

OPTICS TUBE



Three independent optics "tubes" with high-index silicon lenses match the f2.5 off-axis 6m Gregorian telescope to the ~ 6" detector arrays (with Lyot stop)

90/150 GHz Multichroic Polarimeter Design

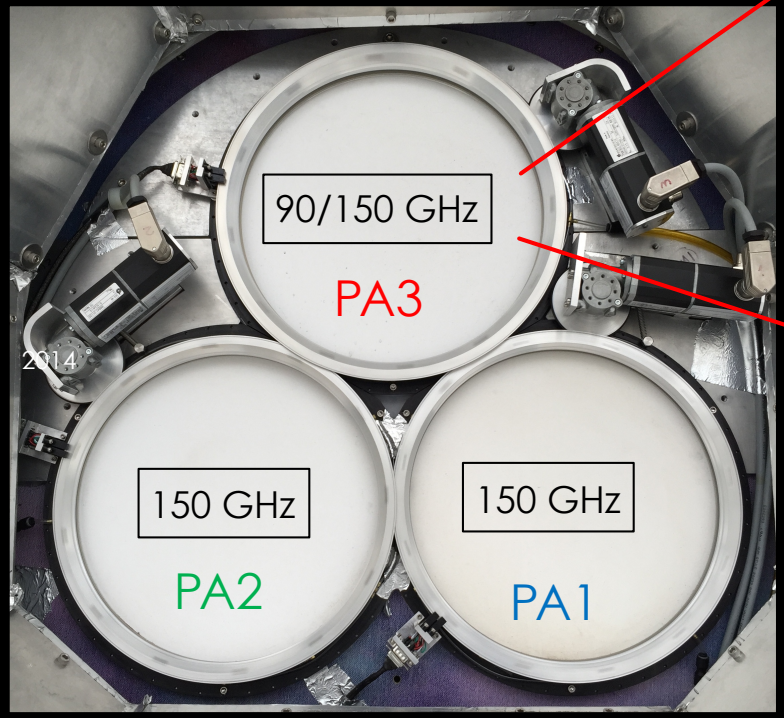


A polarimeter designed to simultaneously measure the 90 and 150 GHz CMB bands.

- excellent control of beam systematics with a corrugated feed horn
- frequency independent detector angles

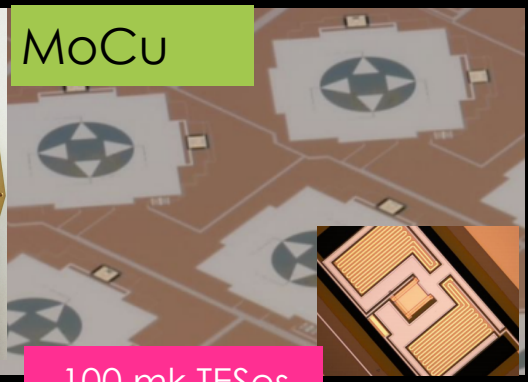
ACTPOL & ADVACT DETECTOR ARRAYS (FABRICATED AT NIST)

2015




FEEDHORNS


3" WAFERS

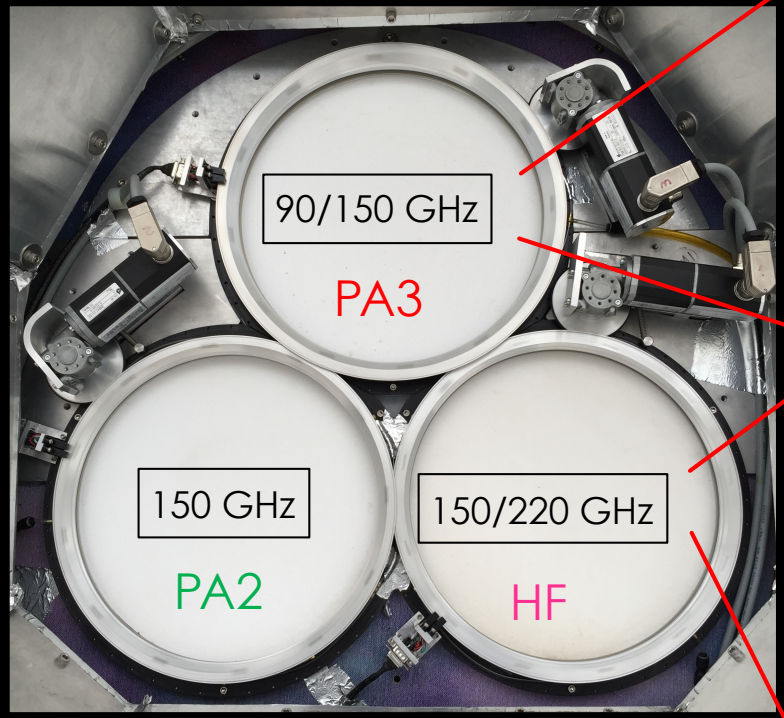


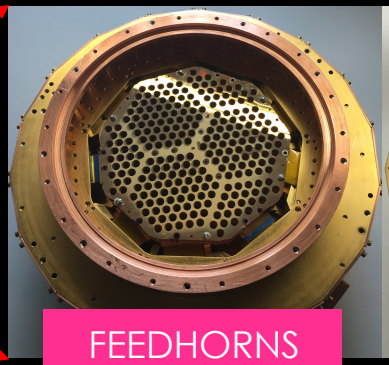
100 mk TESes

ACTPOL:
PA1 & PA2 operate(d) at 150 GHz.
PA3 is dichroic: 90 and 150 GHz.

ACTPOL & ADVACT DETECTOR ARRAYS (FABRICATED AT NIST)

2016





FEEDHORNS

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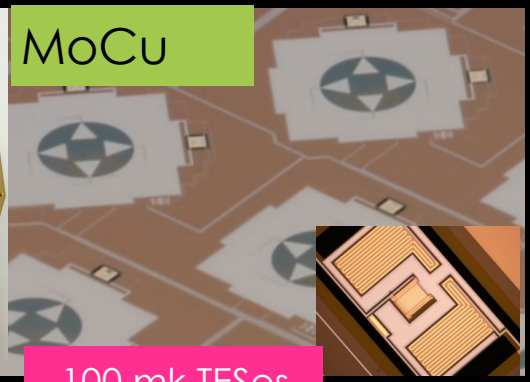
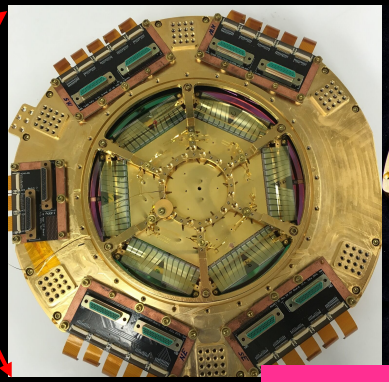
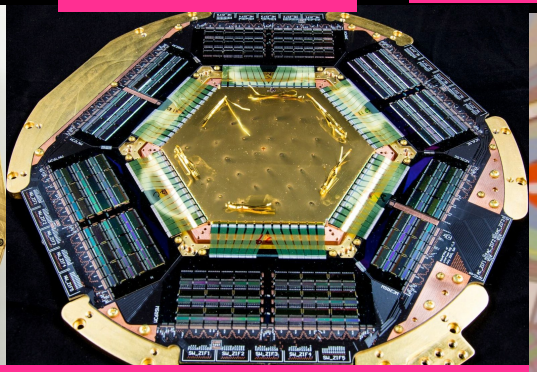
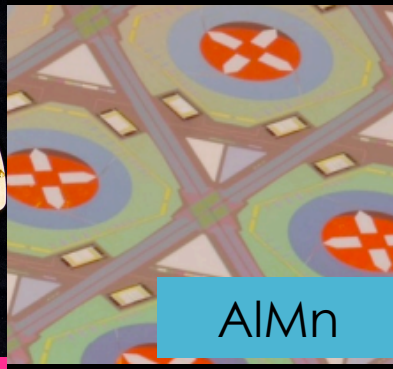


100 mk TESes





6" WAFERS; PLANAR READOUT

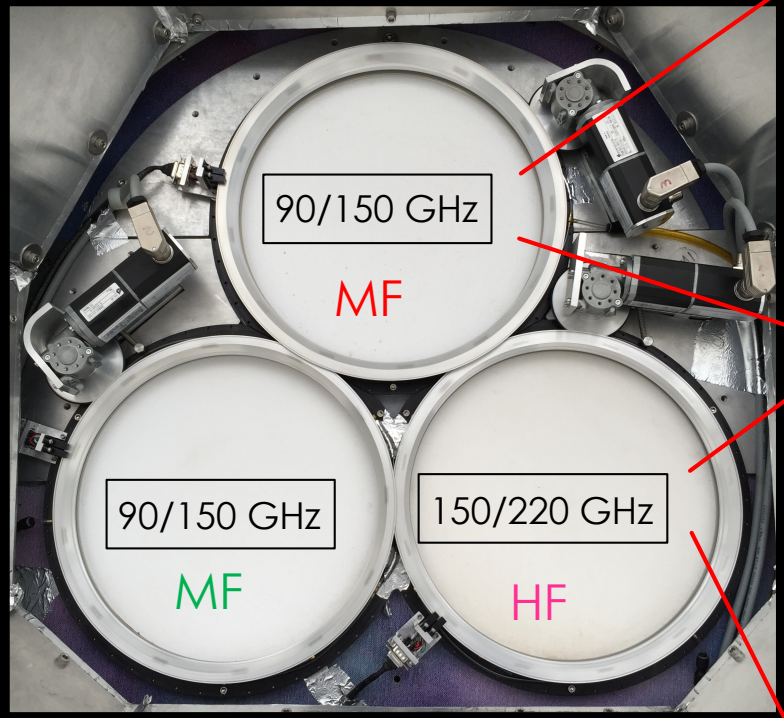


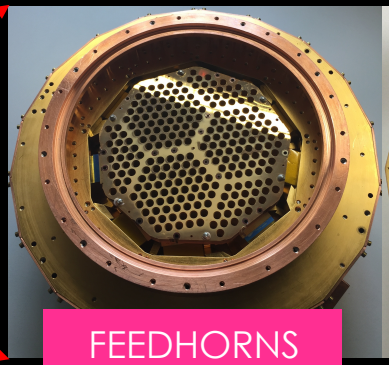
AdvACT:

- 1 HF: 150 & 220 GHz. Installed, 7/2016.
- 2 MF: 90 & 150 GHz. Installed, 4/2017.
- 1 LF: 28 & 41 GHz. Designed / prototyping.

ACTPOL & ADVACT DETECTOR ARRAYS (FABRICATED AT NIST)

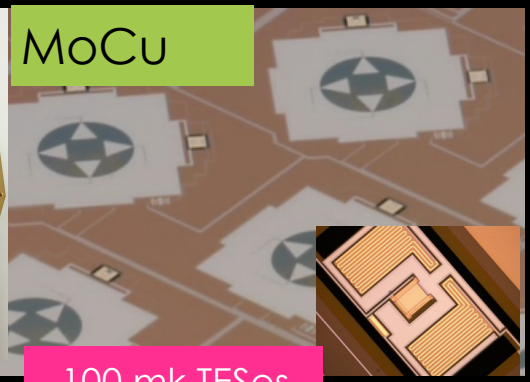
2017



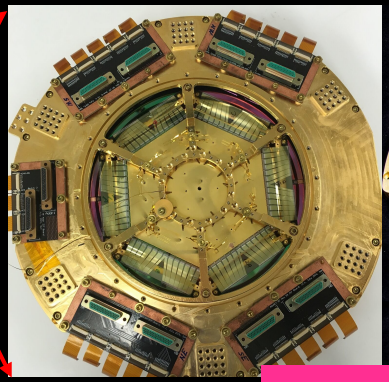


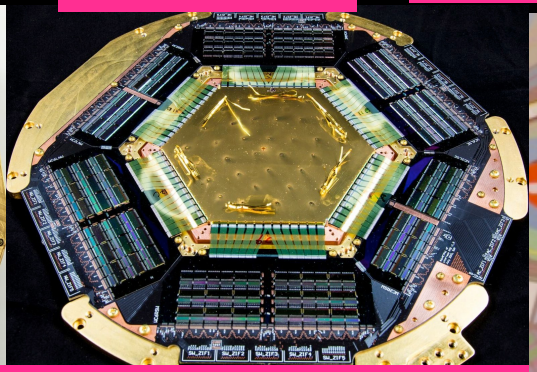
FEEDHORNS

3" WAFERS



100 mk TESes





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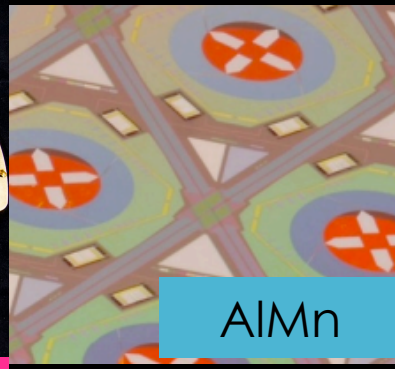

AdvACT:

- 1 HF: 150 & 220 GHz. Installed, 7/2016.
- 2 MF: 90 & 150 GHz. Installed, 4/2017.
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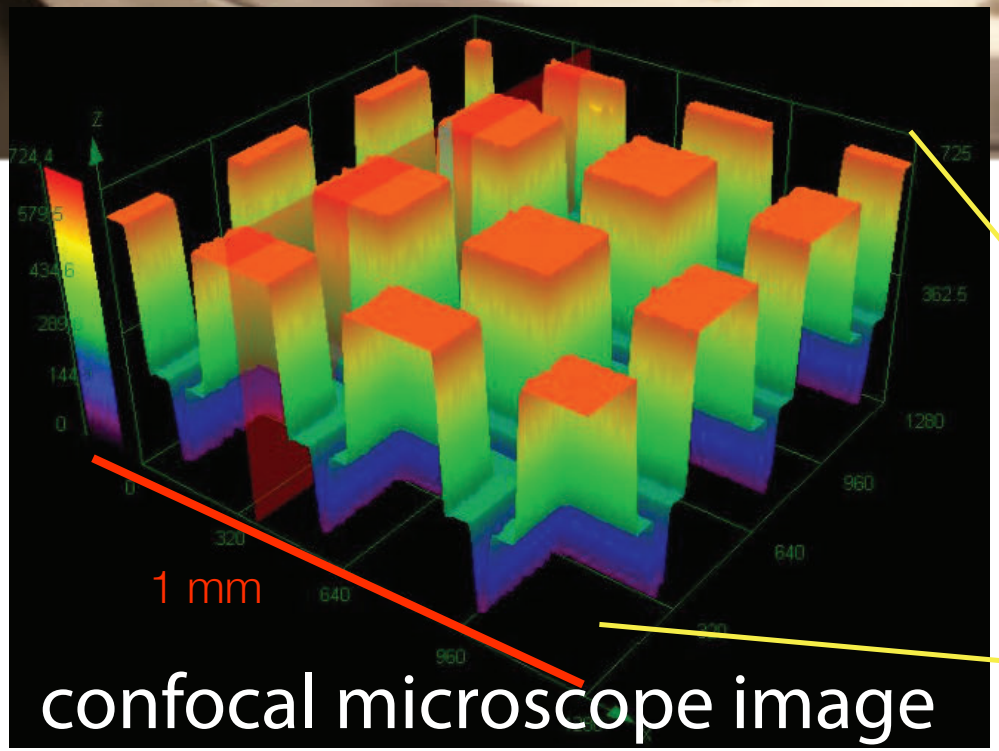
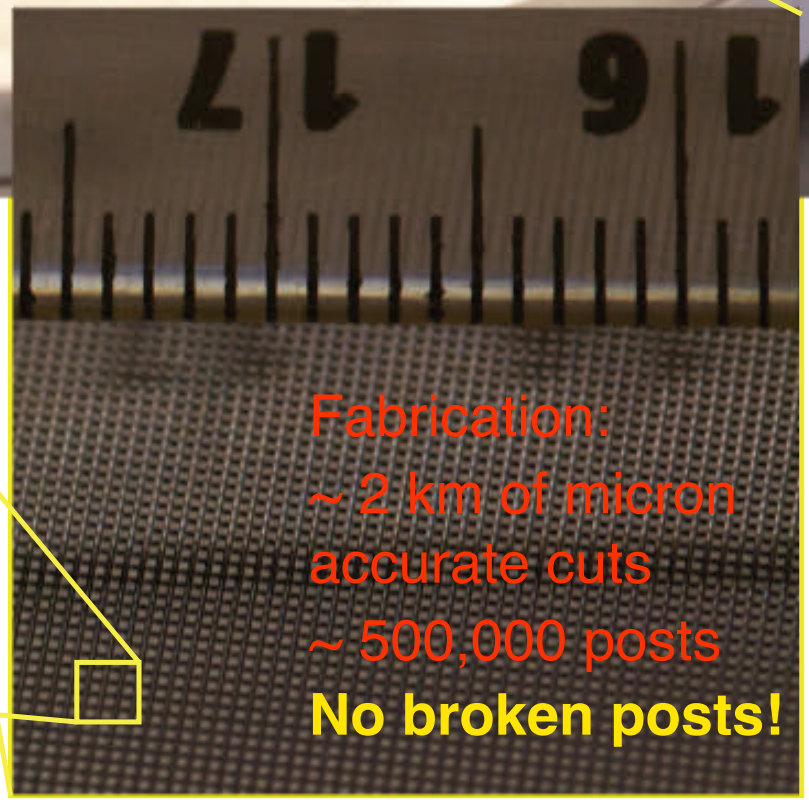
NEW 3-LAYER COATED METAMATERIAL SILICON LENSES TOO.

An ACTPol lens





90 GHz band
150 GHz band
230 GHz band
measurements
simulations
AdvACT MF (90/150)
AdvACT HF(150/230)
PIPER 200
1% reflectance
5 layer
preliminary design
prototype 50% complete
Reflectance (dB)
Frequency (GHz)
0
−5
−10
−15
−20
−25
−30
−35
−40
100
150
200
250
300

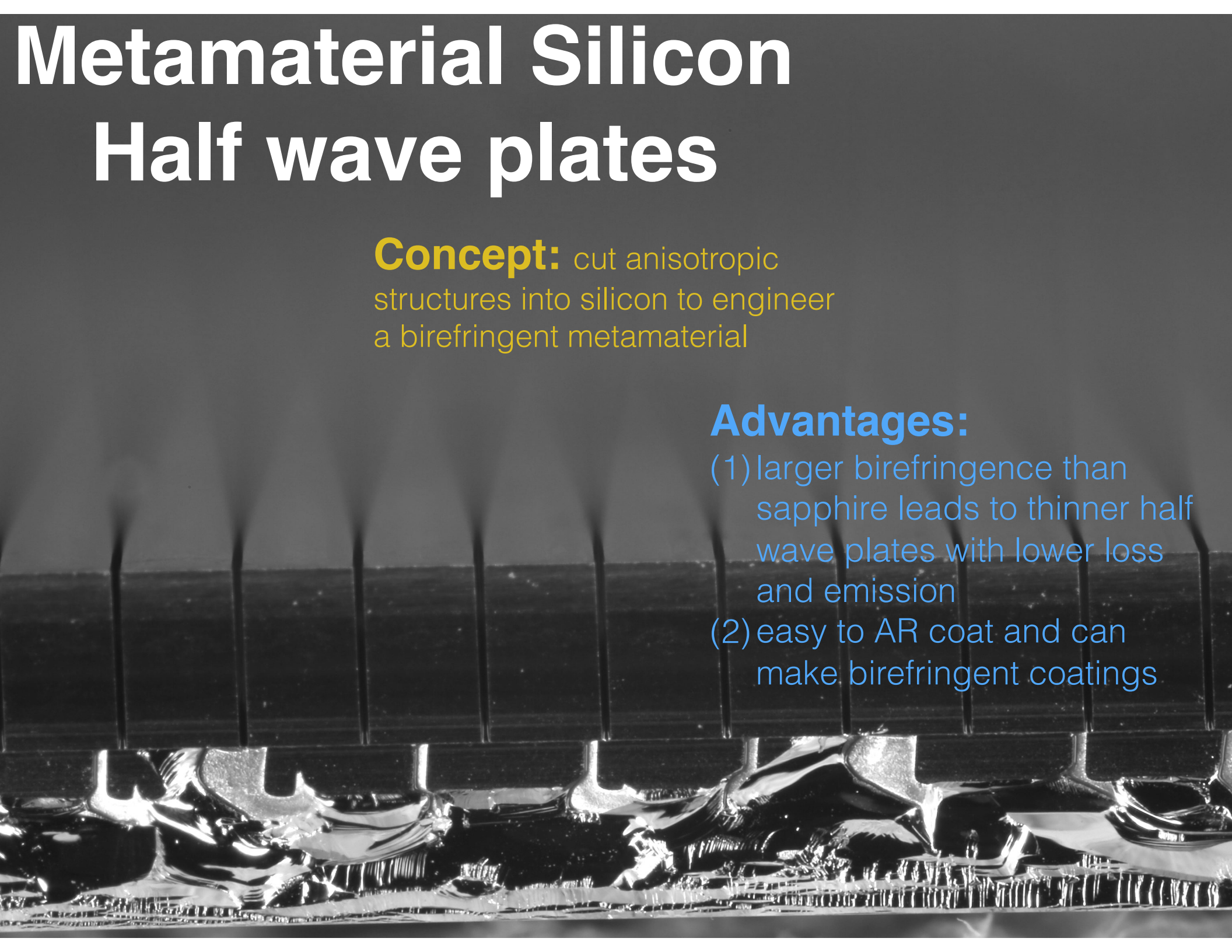
Metamaterial Silicon Half wave plates

Concept: cut anisotropic structures into silicon to engineer a birefringent metamaterial

Advantages:

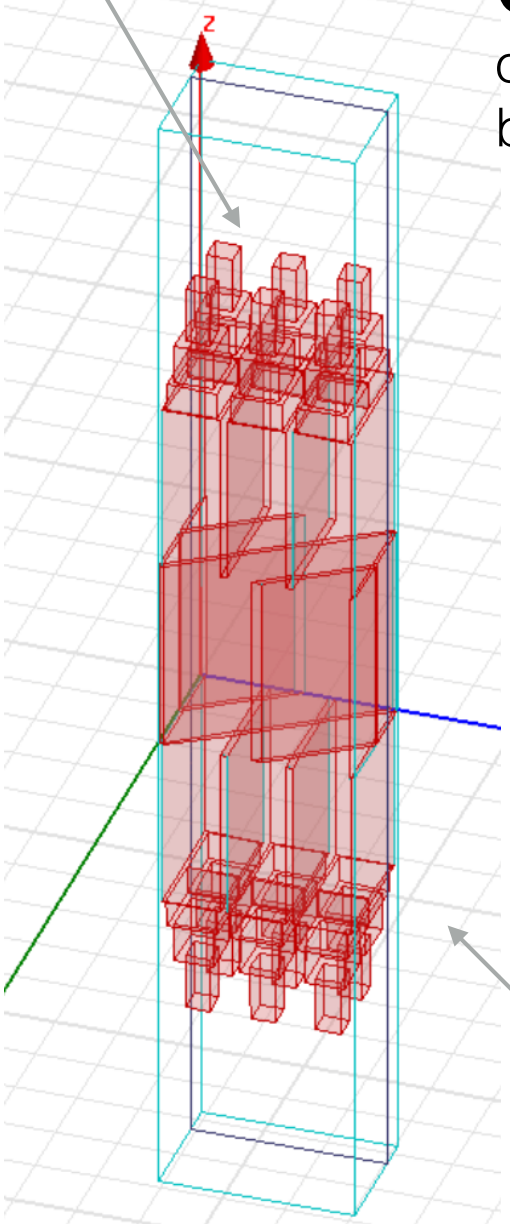
(1) larger birefringence than sapphire leads to thinner half wave plates with lower loss and emission

(2) easy to AR coat and can make birefringent coatings



Broad-Band Metamaterial Silicon Half wave plates

90-150 broad band geometry



Concept: an achromatic stack of three halfwave plates with birefringent AR coatings.

Key Design choice

$\Delta n \sim 0.8$

- reduces thickness and loss
- keeps reflections manageable

Simulation Trick

use a 3x2 lattice to embed the rotated layer into a square grid

Assembly

cut internal rotated HWP first, glue this onto a second wafer, cut the outer layers

Optimization

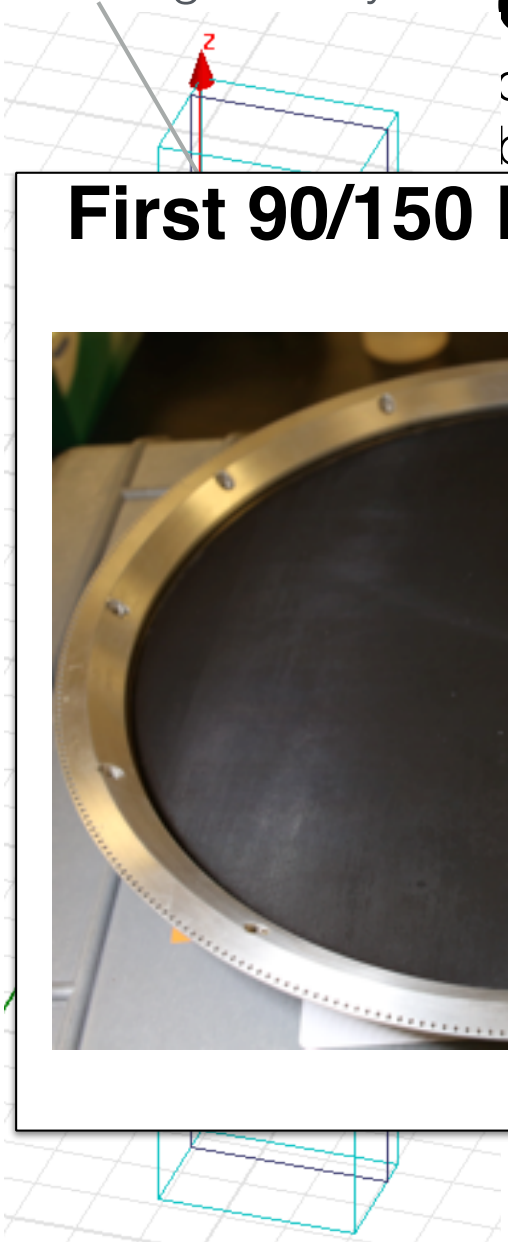
minimize differential reflection

predicted performance:

- <1.5 K emission @ 300K
- > 95% modulation efficiency
- <2% averaged reflections

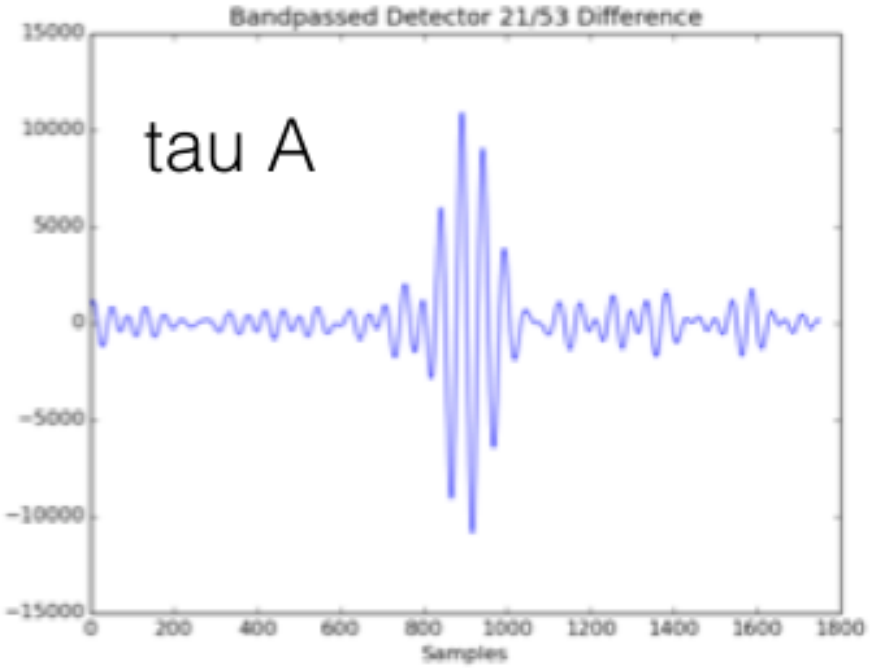
Broad-Band Metamaterial Silicon Half wave plates

90-150 broad band geometry



Concept: an achromatic stack of three halfwave plates with birefringent AR coatings.

First 90/150 Multichroic HWP



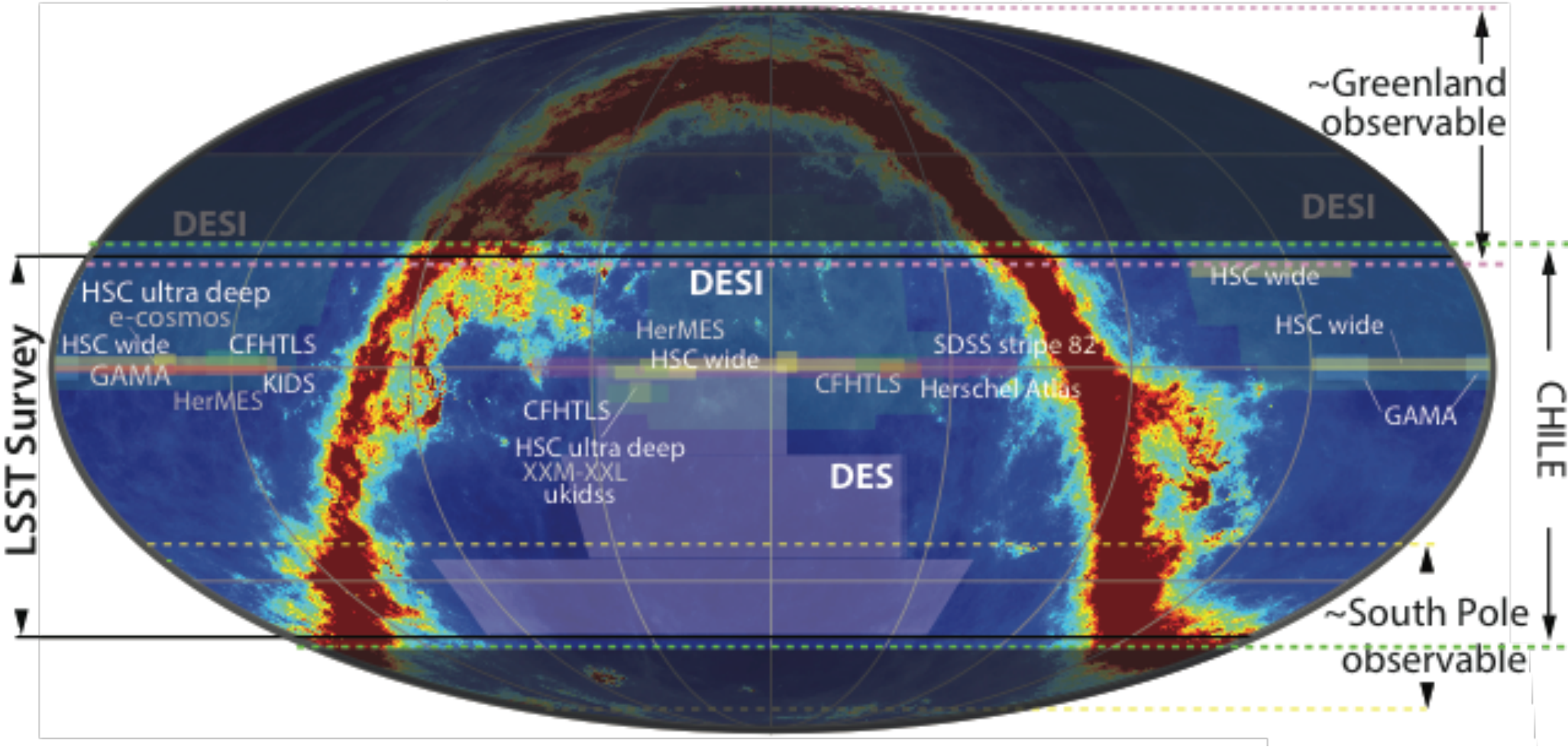
- <1.5 K emission @ 300K
- > 95% modulation efficiency
- <2% averaged reflections

Optimization

minimize differential reflection

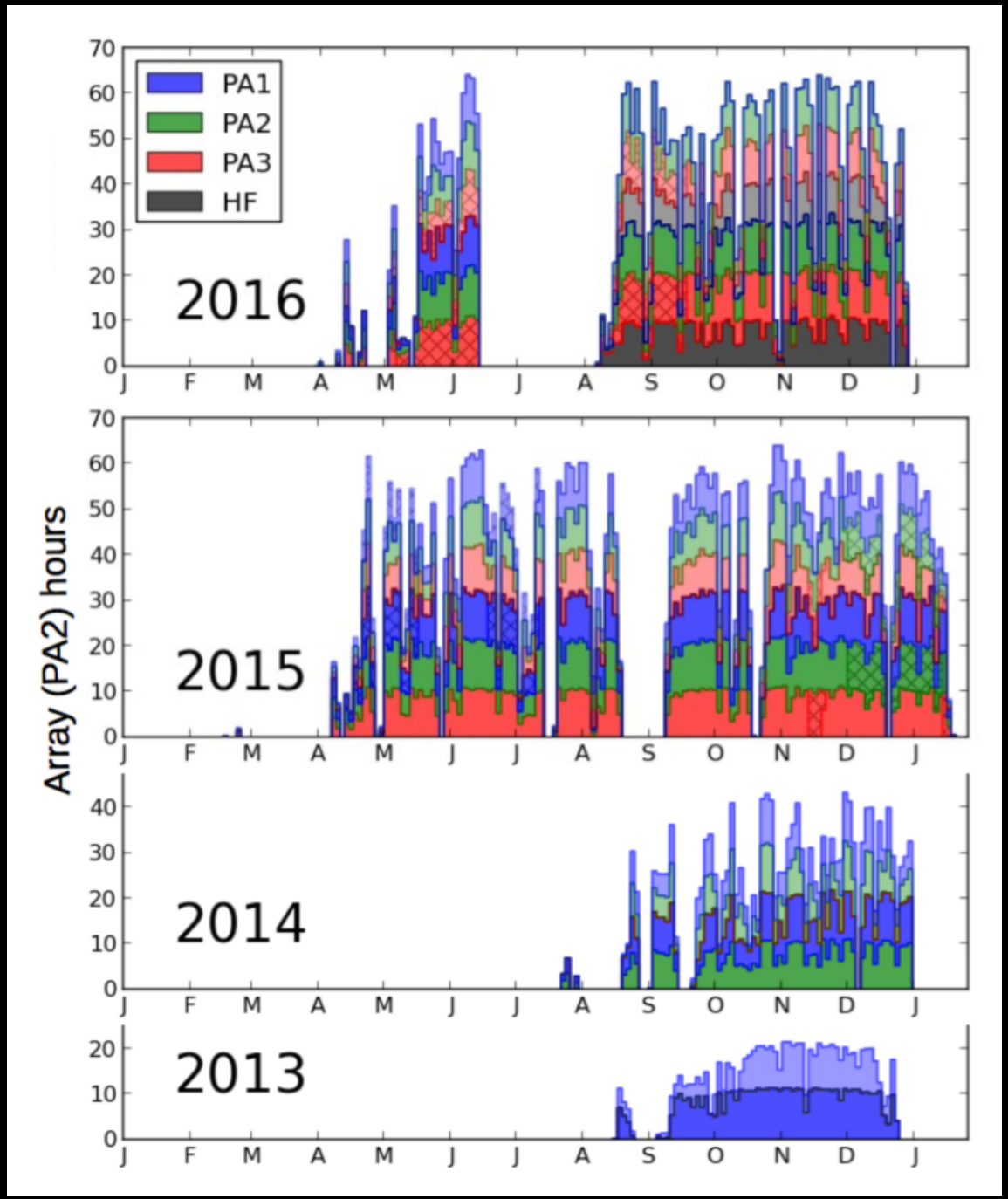
The Chilean Sky

Foreground + optical survey coverage map



We can overlap completely with DES and LSST , observe much of DESI

ACTPOL & ADVACT DATA (2013-2016)



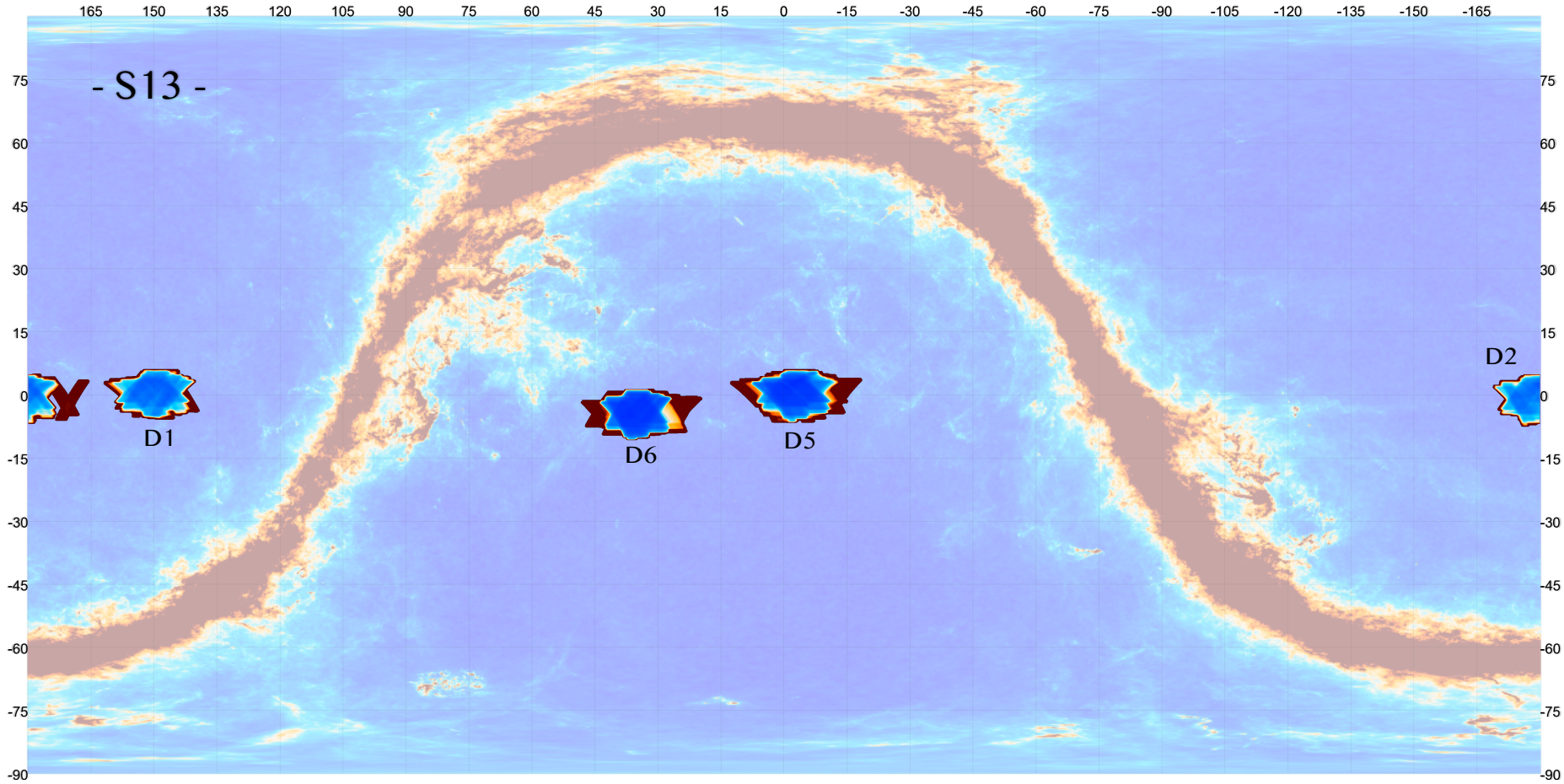
- These show all real on-sky detector data (CMB or planets).

- When things are going well, our efficiency is ~22 hours/day/array.

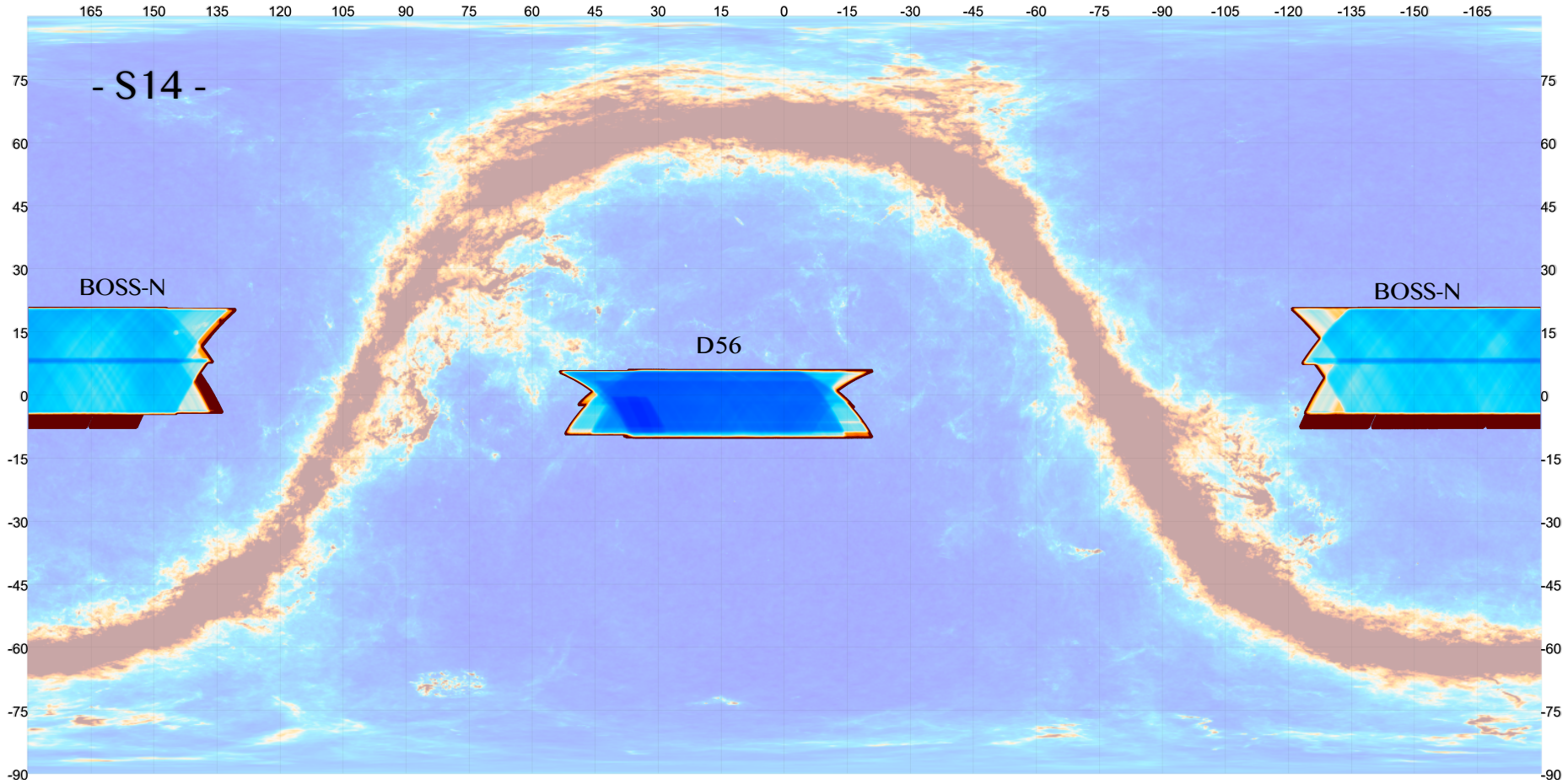
42 TB of raw data
AdvACT ~ 185 GB/day

- y-axis maximum is 3*24 hrs for 3 arrays
- Lower/dark = night
- Upper/light = day

ACT Footprint



ACT Footprint



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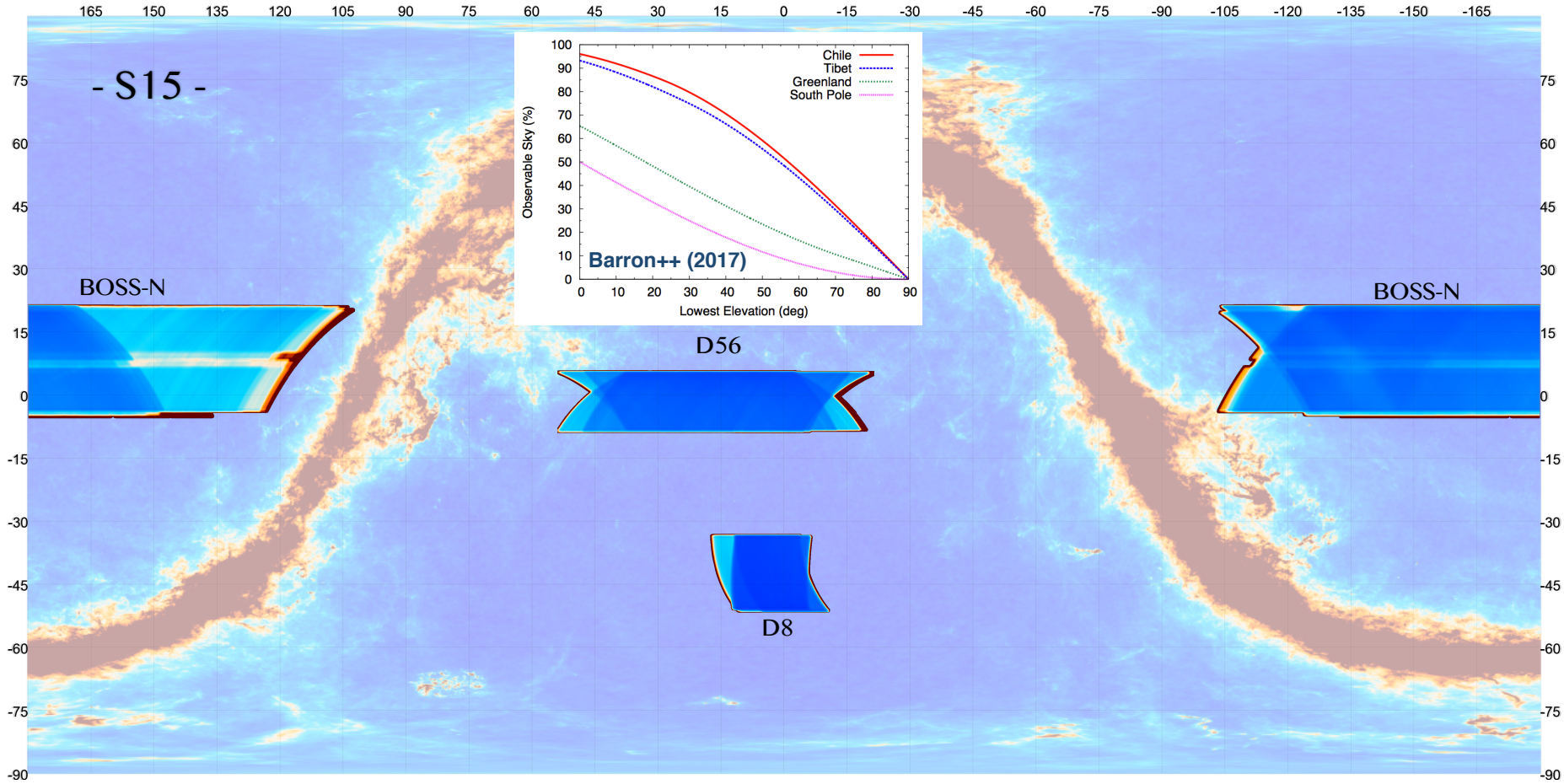

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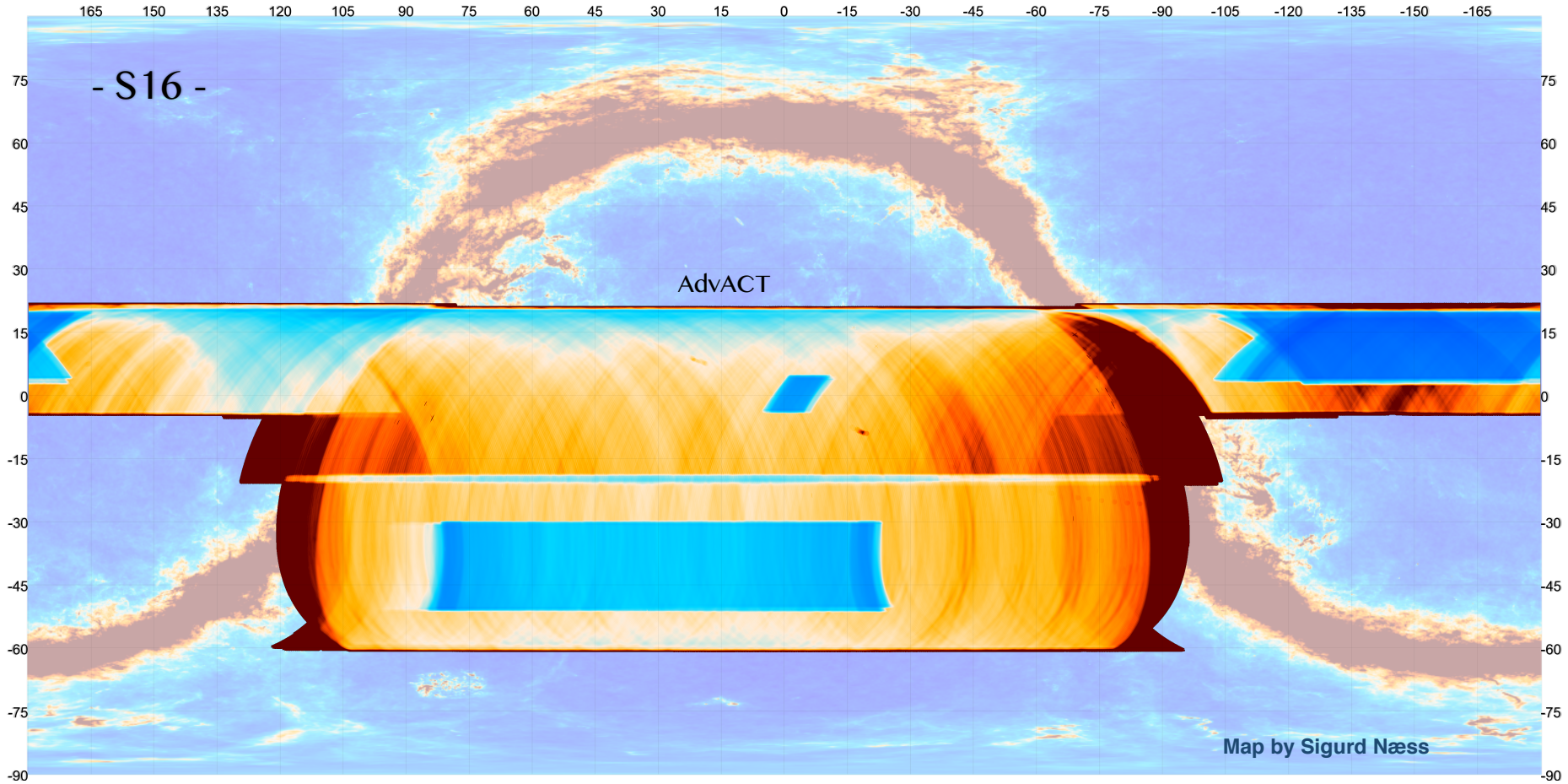
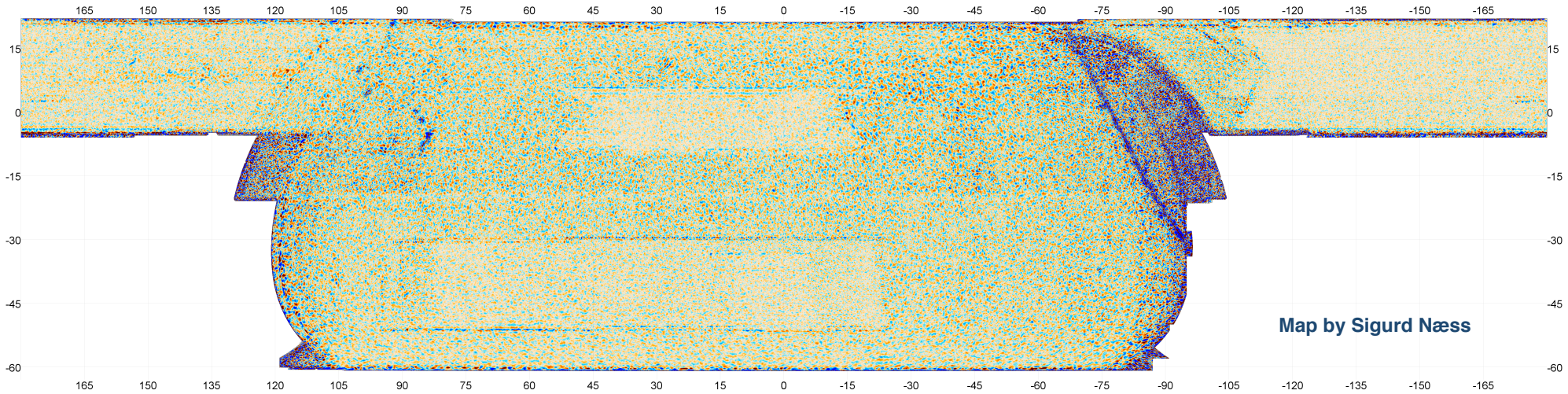


AdvACT Survey: wide field will improve many measurements beyond what was achieved with Planck

Temperature Map @ 150GHz

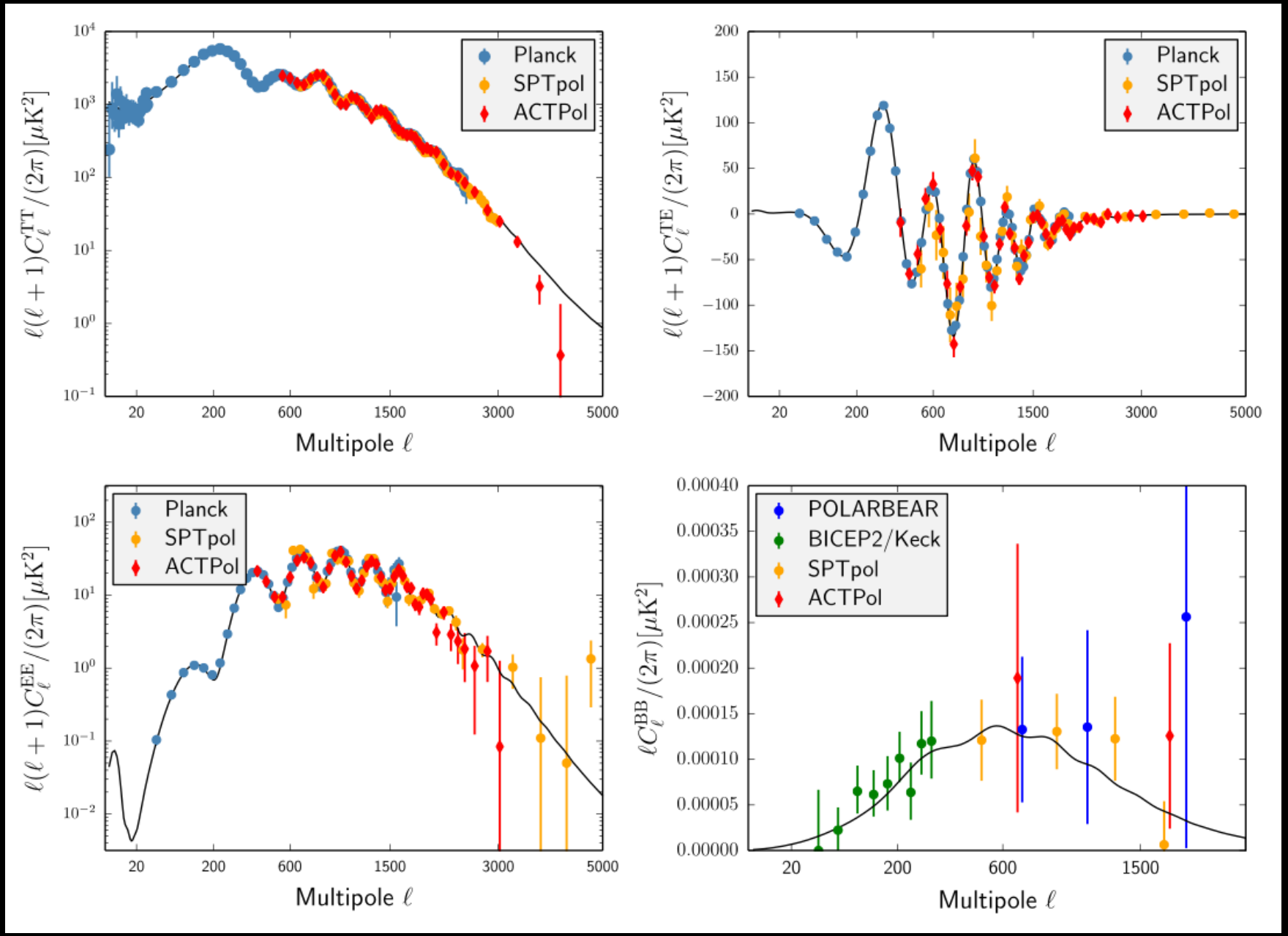
18,000 sq-deg mapped on 0.5 arcmin pixels → 330 x 10^6 pixels !



S16	S17	S18
PA2 @ 150 GHz **PA3** @ 90 / 150 GHz HF @ 150 / 220 GHz	MF @ 90 / 150 GHz MF @ 90 / 150 GHz HF @ 150 / 220 GHz	LF @ 28 / 41 GHz MF @ 90 / 150 GHz HF @ 150 / 220 GHz

AdvACT Maximum Liklihood Mapmaking: A full scale demonstation of what will be required for SO and S4

ACTPOL CMB SPECTRA: 2013-2014



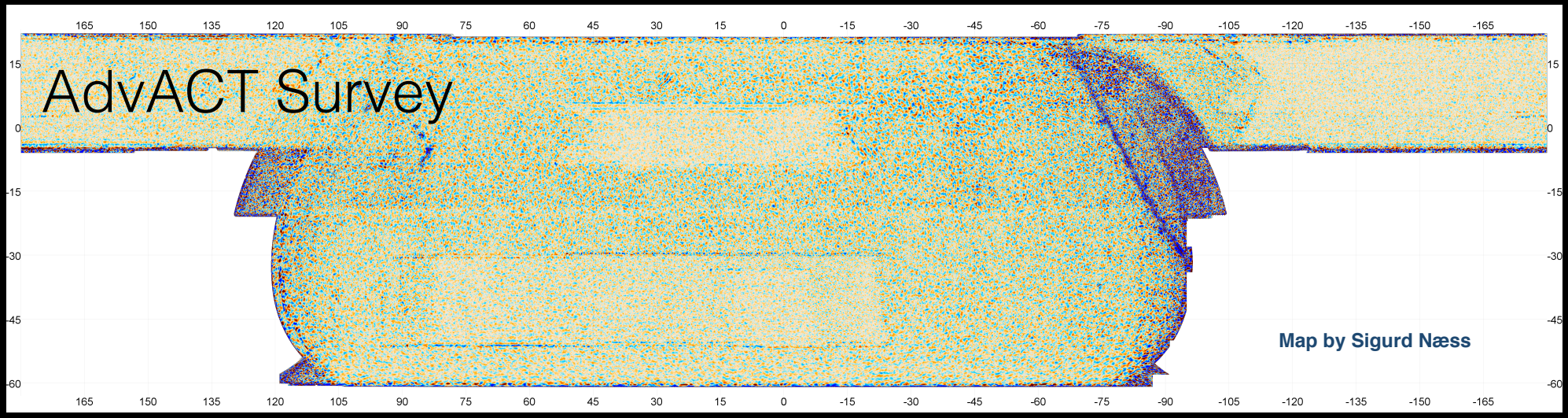
FIRST ACTPOL RESULTS

- **First polarization maps & spectra with PA1:**
  - Naess, Hasselfield,McMahon, Niemack et al 2014
- **Cluster lensing of the CMB (with BOSS)**
  - Madhavacheril, Sehgal et al, 2015
- **CMB lensing (with Planck CIB)**
  - Van Engelen, Sherwin, Sehgal et al 2015
- **kSZ detections (with BOSS)**
  - Schaan, Ferraro et al 2016
  - de Bernardis, Aiola, Vavagiakis, Niemack et al 2016
- **Year 1 & 2 spectra & parameters**
  - Louis, Grace, Hasselfield,Lungu, Maurin et al 2017
- **Instrument paper + many technical reports**
  - Thornton, et al 2016
  - (Many)

MORE COMING!

NOTE THAT ANALYSES WITH ACT DATA CONTINUE – 4 NEW RESULTS IN 2016…

Image courtesy of Jon Ward



- AdvACT fully operational, demonstrating advanced technologies: multichroic detectors, metamaterial lenses, metamaterial wave plates
- The maximum likelihood mapmaking and analysis codes will demonstrate analysis algorithms at scale for Simons Observatory and CMB-S4
- With data in hand we can improve cosmological constraints including: N_{eff}, ΣM_{ν}, and more
    - In particular, with the full AdvACT data set, we can improve constraints on the Hubble constant for which there is currently a 3 sigma tension between CMB and distance ladder measurements
- Survey maps will enable cross-correlations (lensing, clusters, etc) which will lead to additional constraints, and legacy value