CMB Experiments in Chile

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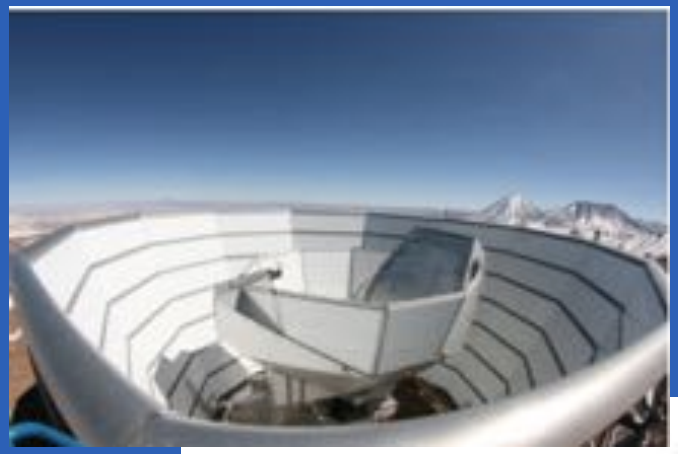
9/7/17

Current Experiments

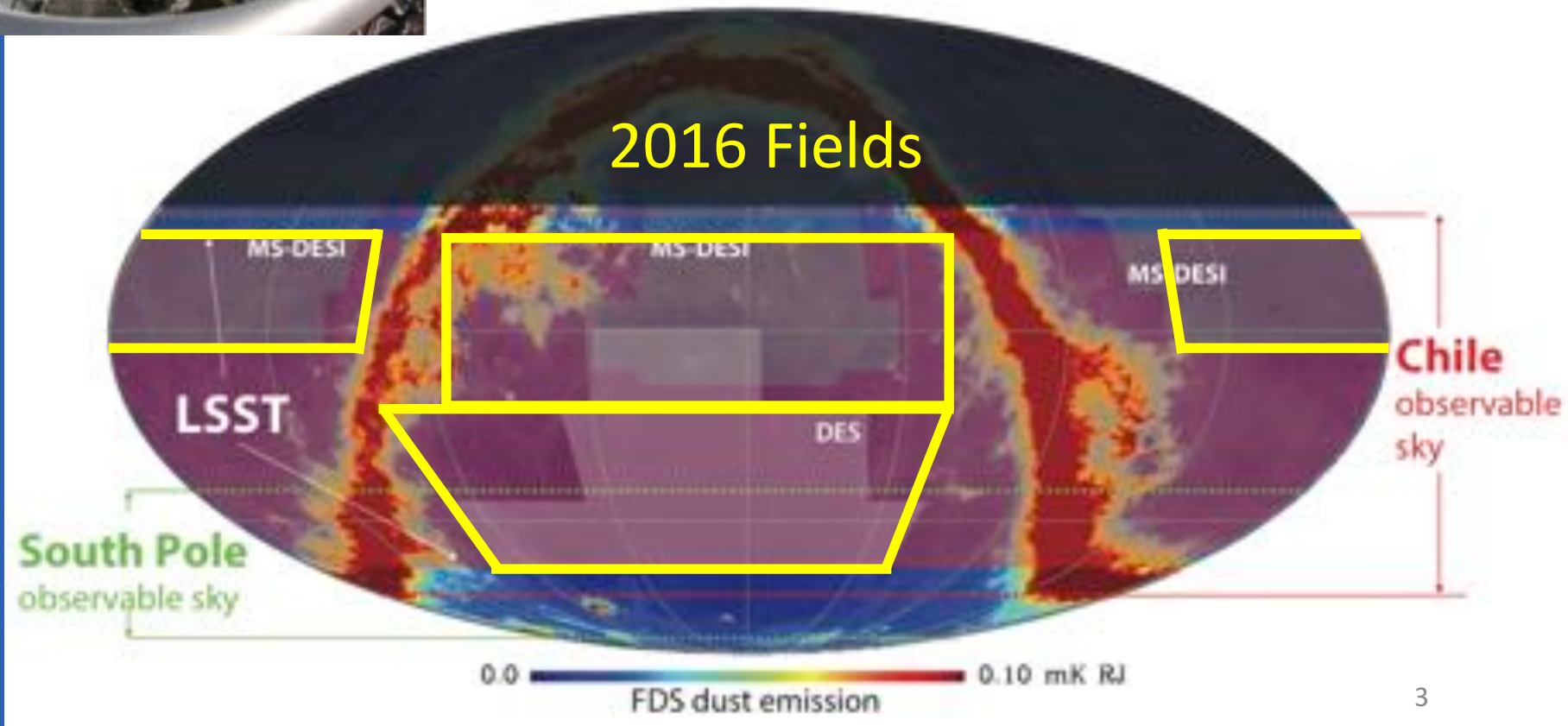
- Advanced ACT (AdvACT)
  - 6000 bolometers, 1.4 arc-min at 150 GHz
  - Bands: 25, 40, 90, 150, 220 GHz
- POLARBEAR → Simons Array
  - 23,768 bolometers, 3.4 arc-min at 150 GHz
  - Bands: 90, 150, 220, 270 GHz
- CLASS
  - 5108 Bolometers, 24 arc-min resolution at 150 GHz
  - Bands: 38, 93, 148, 217 GHz

Atacama Cosmology Telescope



ACT: 6m telescope at 5200 m in Chile
ACTPol Camera: 2013-2015, 150 & 90 GHz

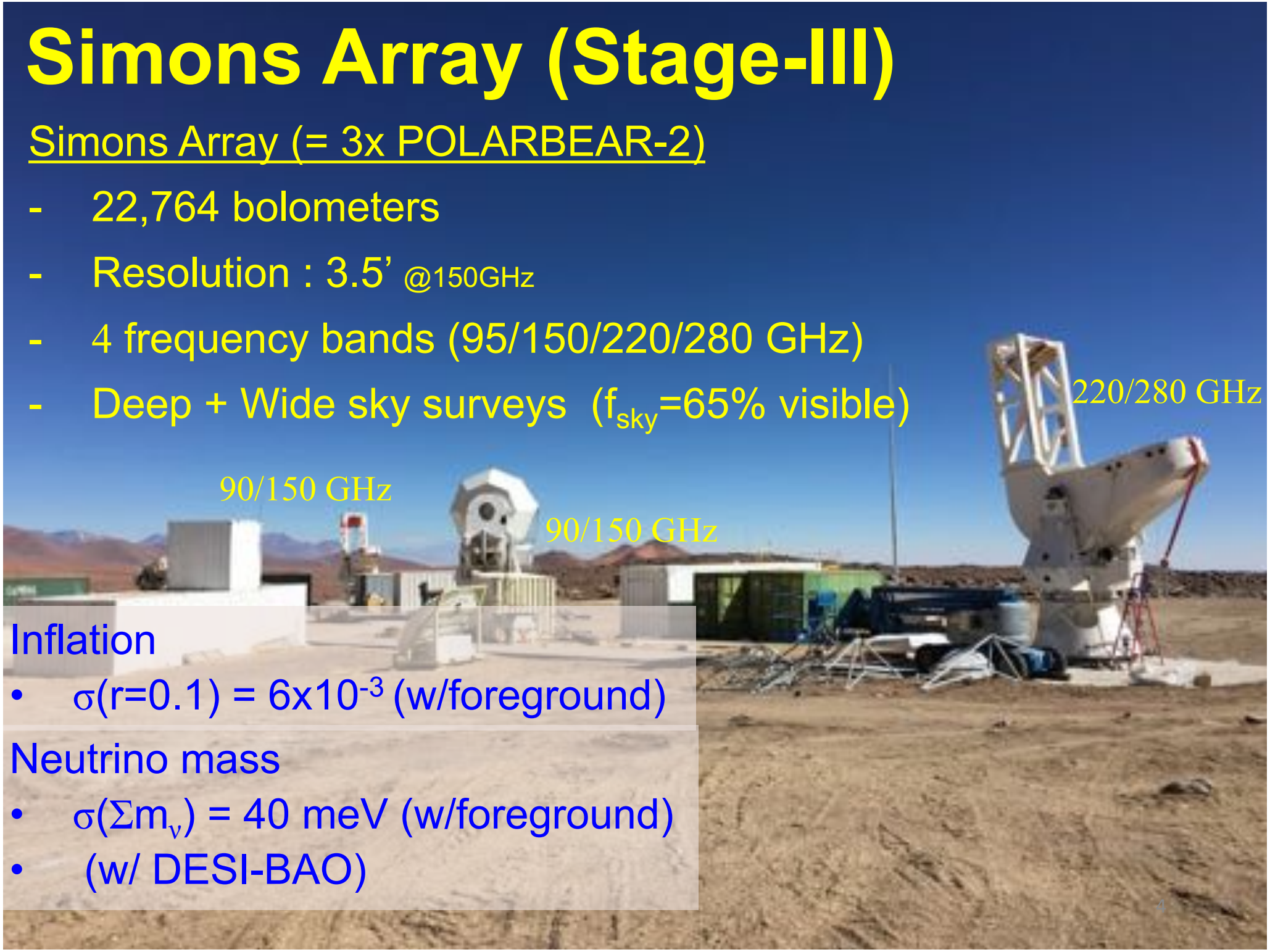
NEW CAMERA -- 5 bands (25-280 GHz) – Advanced ACTPol



Simons Array (Stage-III)

Simons Array (= 3x POLARBEAR-2)

- 22,764 bolometers
- Resolution : 3.5' @150GHz
- 4 frequency bands (95/150/220/280 GHz)
- Deep + Wide sky surveys (f_{sky}=65% visible)



Inflation

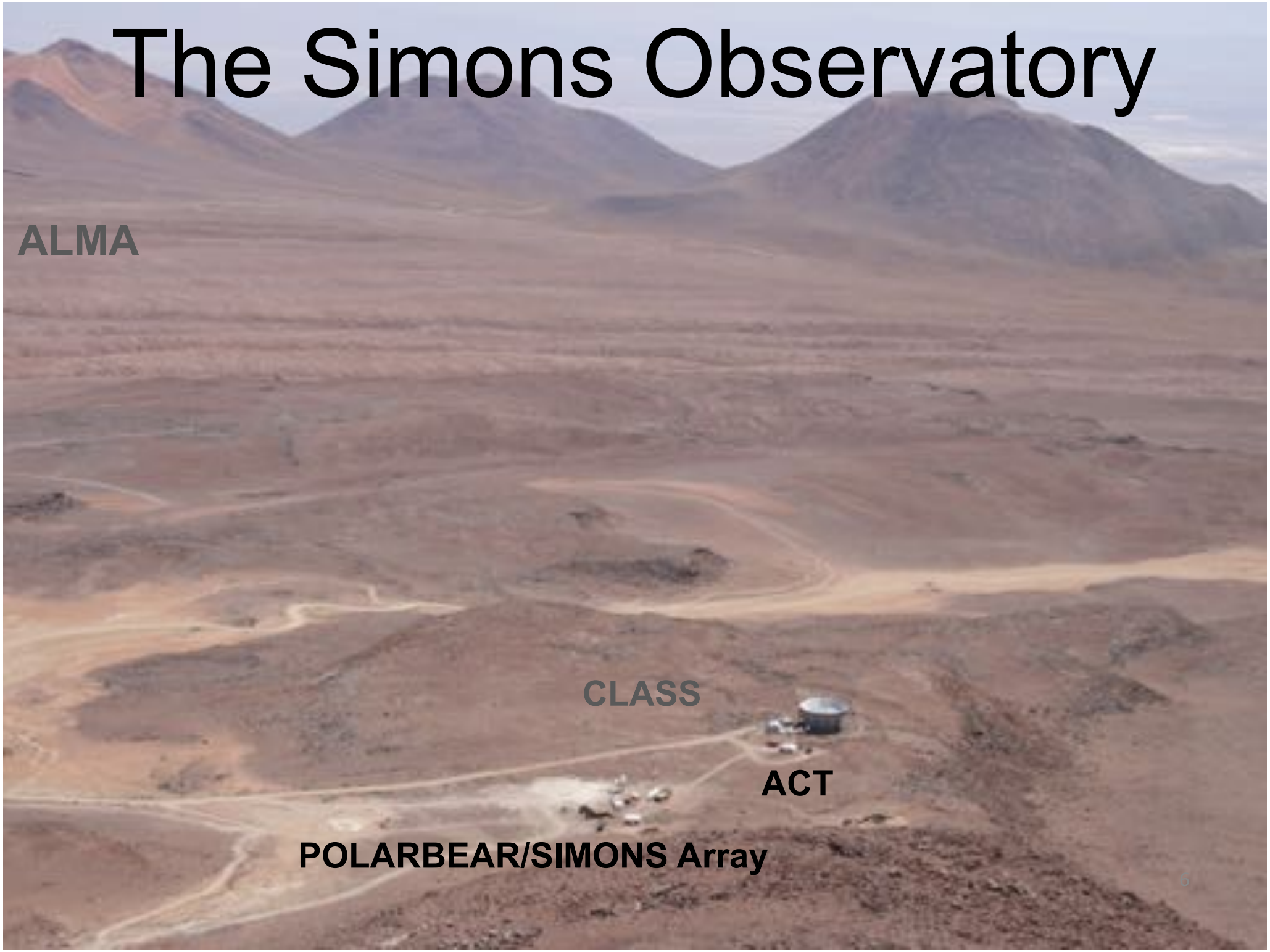
- $\sigma(r=0.1) = 6\times10^{-3}$ (w/foreground)

Neutrino mass

- $\sigma(\Sigma m_\nu) = 40$ meV (w/foreground)
- (w/ DESI-BAO)

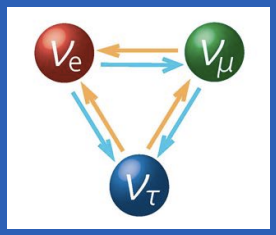
Cosmology Large-Angular Scale Surveyor (CLASS)

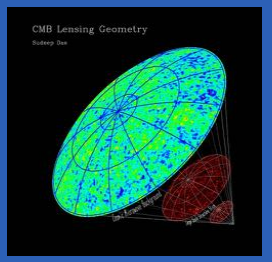
The Simons Observatory

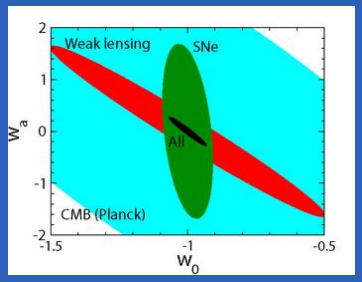


Simons Observatory Science Goals

- PRIMORDIAL GRAVITATIONAL WAVES (B-MODE TENSOR FLUCUTATIONS)
- NEUTRINO MASS
- N_{eff}
- DYNAMIC HISTORY (w, modified gravity) via:
  - CMB lensing
  - Cross-correlations
  - Cluster survey to trace matter; kSZ to trace velocity fields
- OTHER WINDFALLS -- primordial magnetic fields, parity violation







What is the Simons Observatory?

A GROUND-BASED CMB OBSERVATORY IN CHILE, UNDER DEVELOPMENT

1) ACT + SIMONS ARRAY TEAMS ++
2) SIMONS FOUNDATION FUNDING: $40M
3) UNIVERSITY & LAB FUNDING: $5M
   - UCSD
   - BERKELEY/ LBNL
   - U PENN
   - PRINCETON
- FUNDING IN JAPAN $2M

The Simons Observatory

United States

- Carnegie Mellon University
- Columbia University
- Cornell University
- Florida State
- Haverford College
- Johns Hopkins University
- Lawrence Berkeley National Laboratory
- NASA/GSFC
- NIST
- Princeton University
- Rutgers University
- Stanford University/SLAC
- Stony Brook
- University of California - Berkeley
- University of California – San Diego
- University of Colorado
- University of Illinois at Urbana-Champaign
- University of Michigan
- University of Pennsylvania
- University of Pittsburgh
- University of Southern California
- West Chester University

- 8 Countries
- 45+ Institutions
- 150+ members

Canada

- CITA/Toronto
- Dalhousie University
- Dunlap Institute/Toronto
- McGill University
- University of British Columbia

Chile

- Pontificia Universidad Catolica
- University of Chile

Europe

- APC - France
- Cardiff University
- Imperial College
- Manchester University
- Oxford University
- SISSA – Italy

Japan

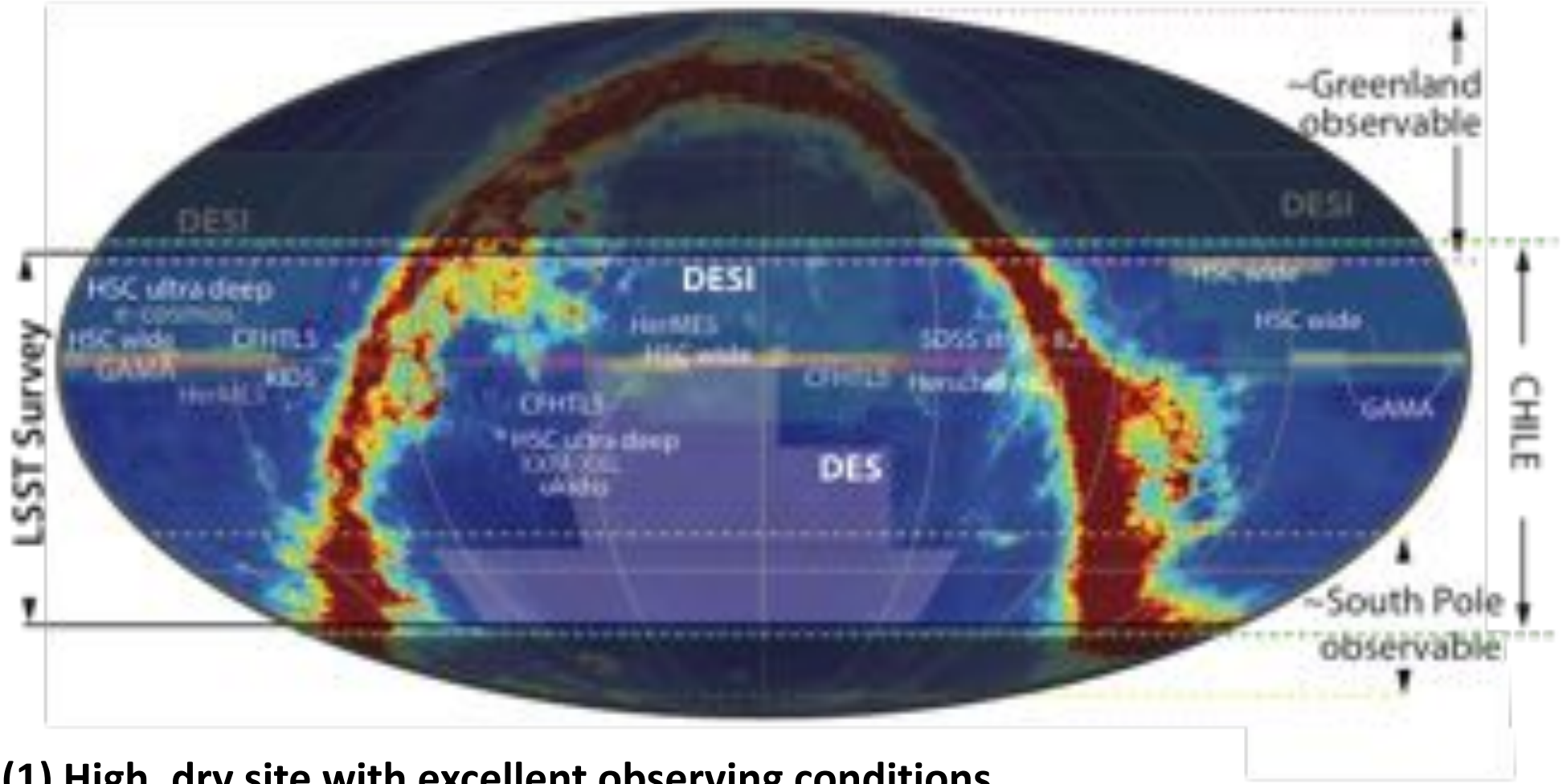
- KEK
- Univ. of Tokyo (Physics, Kavli IPMU)
- Kyoto University
- Tohoku University

South Africa

- Kwazulu-Natal, SA

Why CMB Observations From Chile?

Foreground + optical survey coverage map



(1) High, dry site with excellent observing conditions
(2) Access to over half the sky
(3) Overlap with optical surveys to maximize impact of LSS measurements for neutrinos, dark energy, dark matter, and astrophysics.

Simons Observatory Plans

- New telescopes
  - A 6m-class telescope
  - 3-6 0.5 “small aperture” telescopes
- Significant Infrastructure Upgrades.
  - Power, internet, and logistics.
- Technology Development:
  - Detectors, Optics, Telescopes, Receivers.
  - Total detector count 50-80K

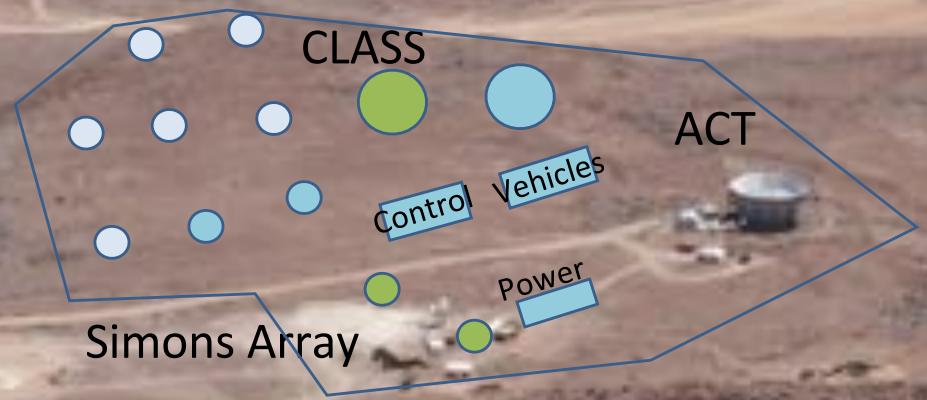
Simons Observatory

ALMA

Infrastructure in Preparation for CMB-S4.

- 500 KVA power plant or ALMA power
- Combined control room
- Telescope/receiver staging building
- High bandwidth internet connection to ALMA

Two Site Engineers + Technician

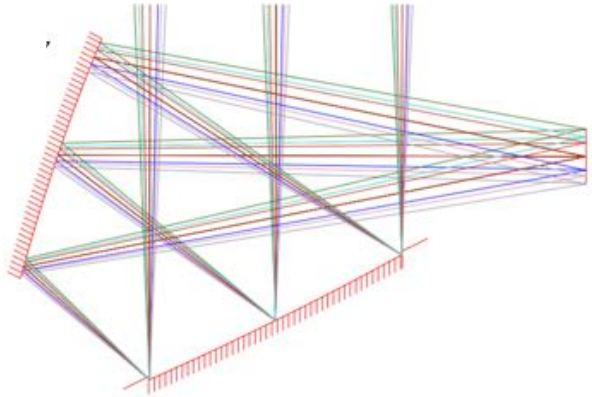


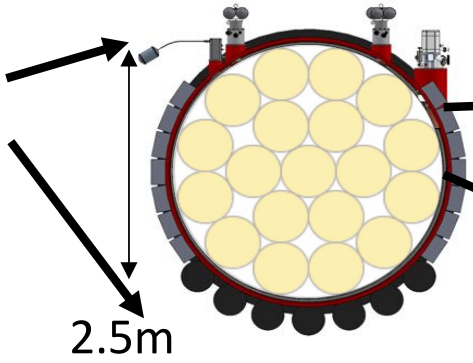
Existing

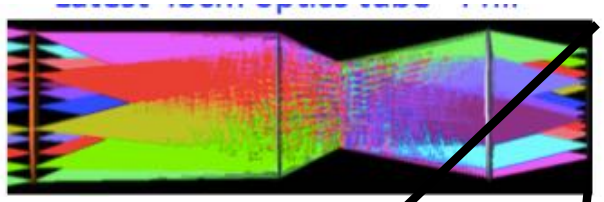
Notional Simons Observatory Phase 1

Notional Pads for Simons Observatory Phase 2 and CMB S4

6-meter Aperture Telescope

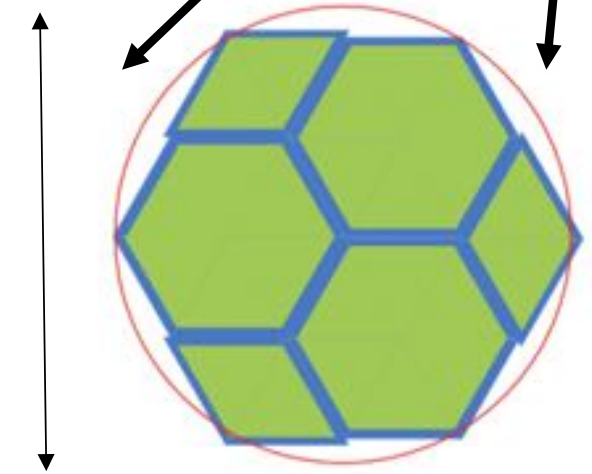




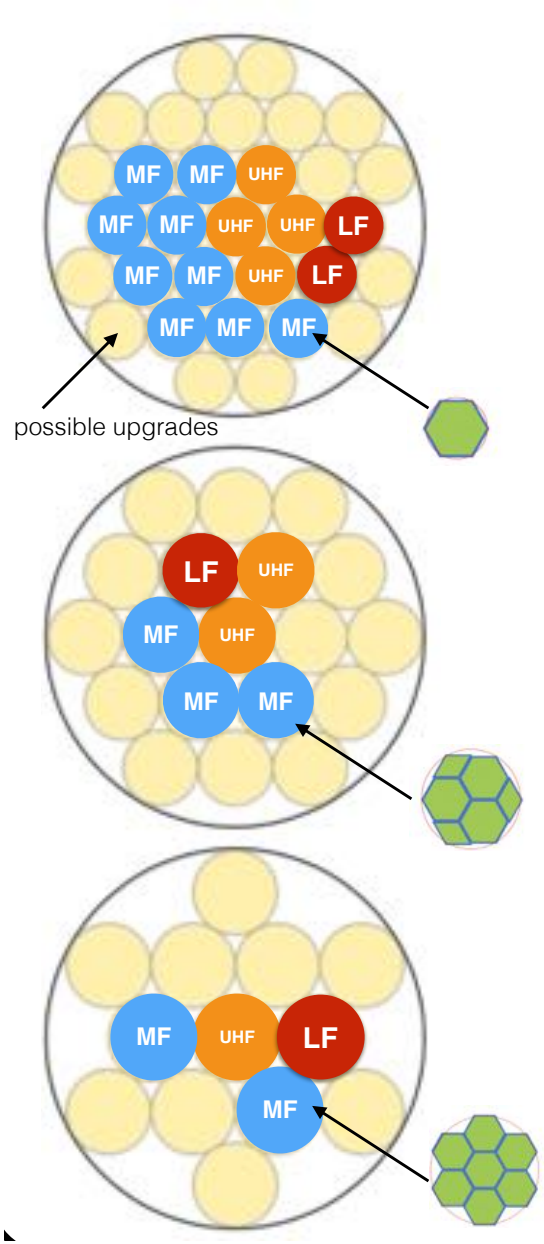


Simons Observatory Baseline

- 6m diameter Cross Dragone design
  - Considered: Three Mirror Anistigmat, offset Gregorian
- Single ~2.5 m diameter receiver
- 19 36-cm diameter optics tubes
- 40,000 detectors for SO deployment
  - Design capable of containing 100,000 detectors



Focal Plane Optimization for 6m Telescope

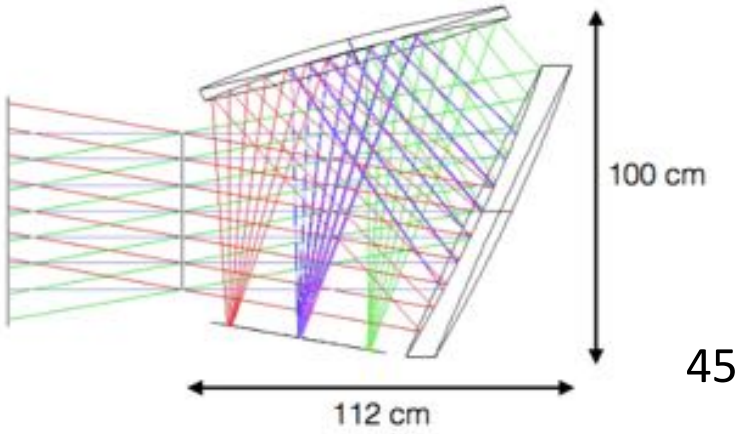


- Parameters that are optimized together
  - Optics Tube Diameter
  - Focal Plane Diameter
  - Focal ratio (f/#) at focal plane
  - Sensitivity per detector
  - Sensitivity per silicon wafer

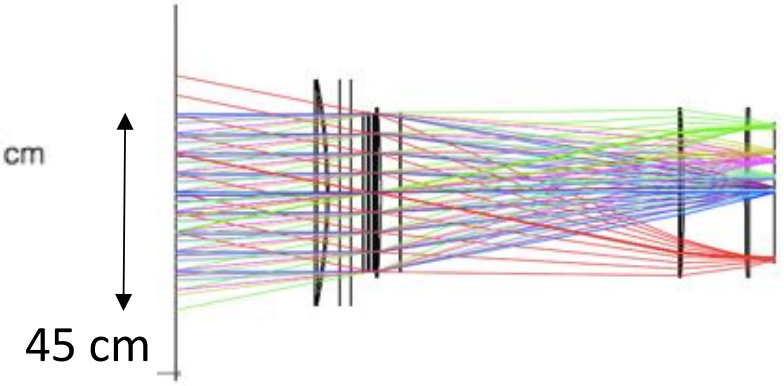
45 cm Optics Tube, Silicon Lenses

Receiver	Channel	NET_{Det}	NET_{Tube}
LF	30 GHz	370	20.8
	40 GHz	254	14.3
MF	90 GHz	275	6.5
	150 GHz	343	8.1
HF	150 GHz	344	6.9
	220 GHz	785	15.8
UHF	230 GHz	786	13.8
	280 GHz	2019	35.6

0.5-m Aperture Telescopes



Crossed Dragone Reflector Design



Two-lens Refractor Design

Simons Observatory Baseline

- Multiple 45-cm Apertures
  - Reflector and refractor designs being considered
  - Cryogenic Half-wave plate
  - Larger apertures considered for f < 75 GHz
- Multichroic detectors at 100 mK
  - 30-300 GHz with all apertures combined

Detector Arrays

Horn-Coupled OMT Pixel

Lenslet-Coupled Sinuous-Antenna Pixel

5 mm

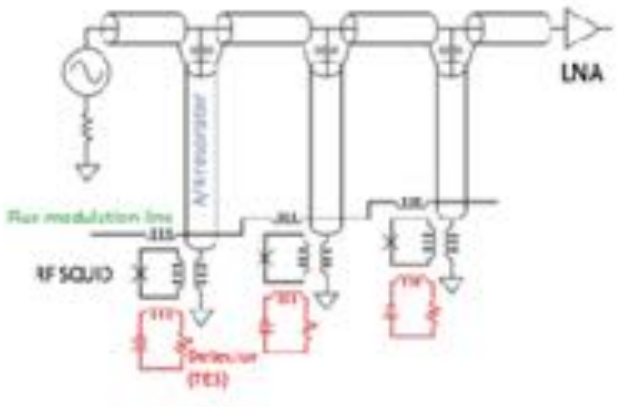
Horn-Coupled OMT Array

Lenslet-Coupled Sinuous-Antenna Array

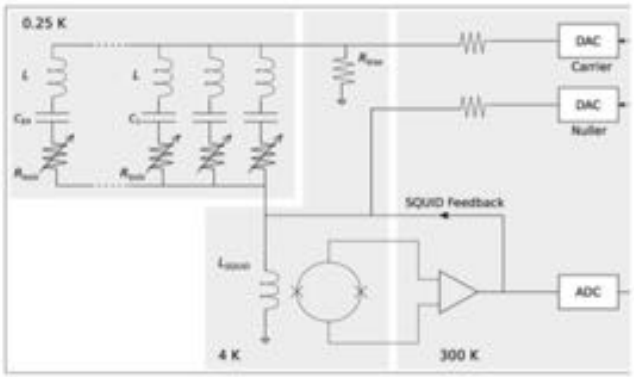
- Multichoric Focal Planes for 6m and 0.5m telescopes
  - Combination of horn-coupled and Lenslet-coupled Pixels
  - Optimization of focal-planes under active study

Readout Electronics

Microwave MUX



Frequency Domain Multiplexing (FDM)



Conceptual 2D readout board

- A single multiplexer Technology will be used in SO
  - Microwave MUX (aka MSQUIDs)
  - Frequency Domain Multiplexing (aka fMUX)

The Simons Observatory and CMB-S4

SIMONS OBSERVATORY: STEPPING STONE TO FUTURE CMB-S4 CHILE SITE

- Simons Observatory prototypes to **accelerate** S4 process
  - S4-capable telescopes, shielding, cold optics
  - S4-capable cryostats, focal planes, muxing

- Prototyping jumpstarts the S4 Chile site, but aims to **aid** CMB-S4 globally
- Work designed to **complement** CMB-S4 funding from NSF and the DOE

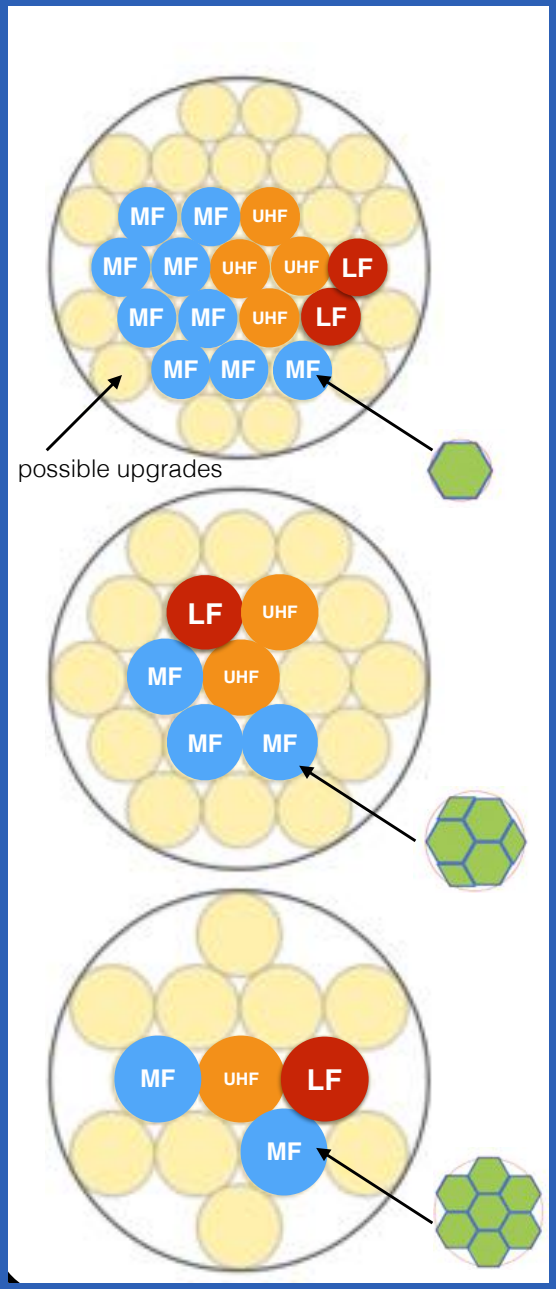
Proposals for collaborative work from European group(s) welcome!

Simons Observatory: Rough Timeline

- Planning and Technology Development: 2016-2017
- Logistical upgrades to the site infrastructure: 2016-2018
- Construction and installation of Telescopes by end of 2020.
- Production of new CMB-S4-type receivers with partially filled focal planes by end of 2020.
- Observing: 2021-2022

Backup

Focal Plane Optimization for 6m Telescope



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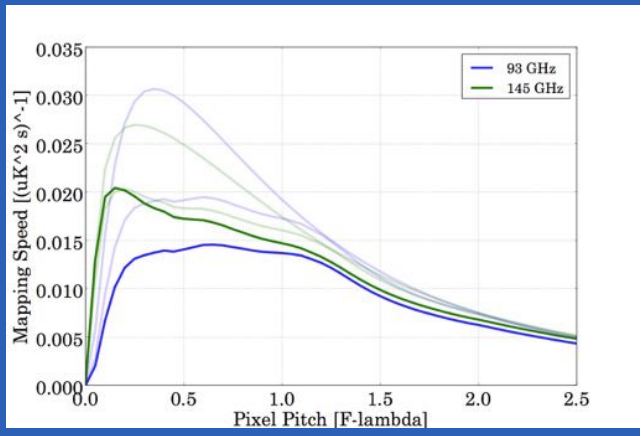
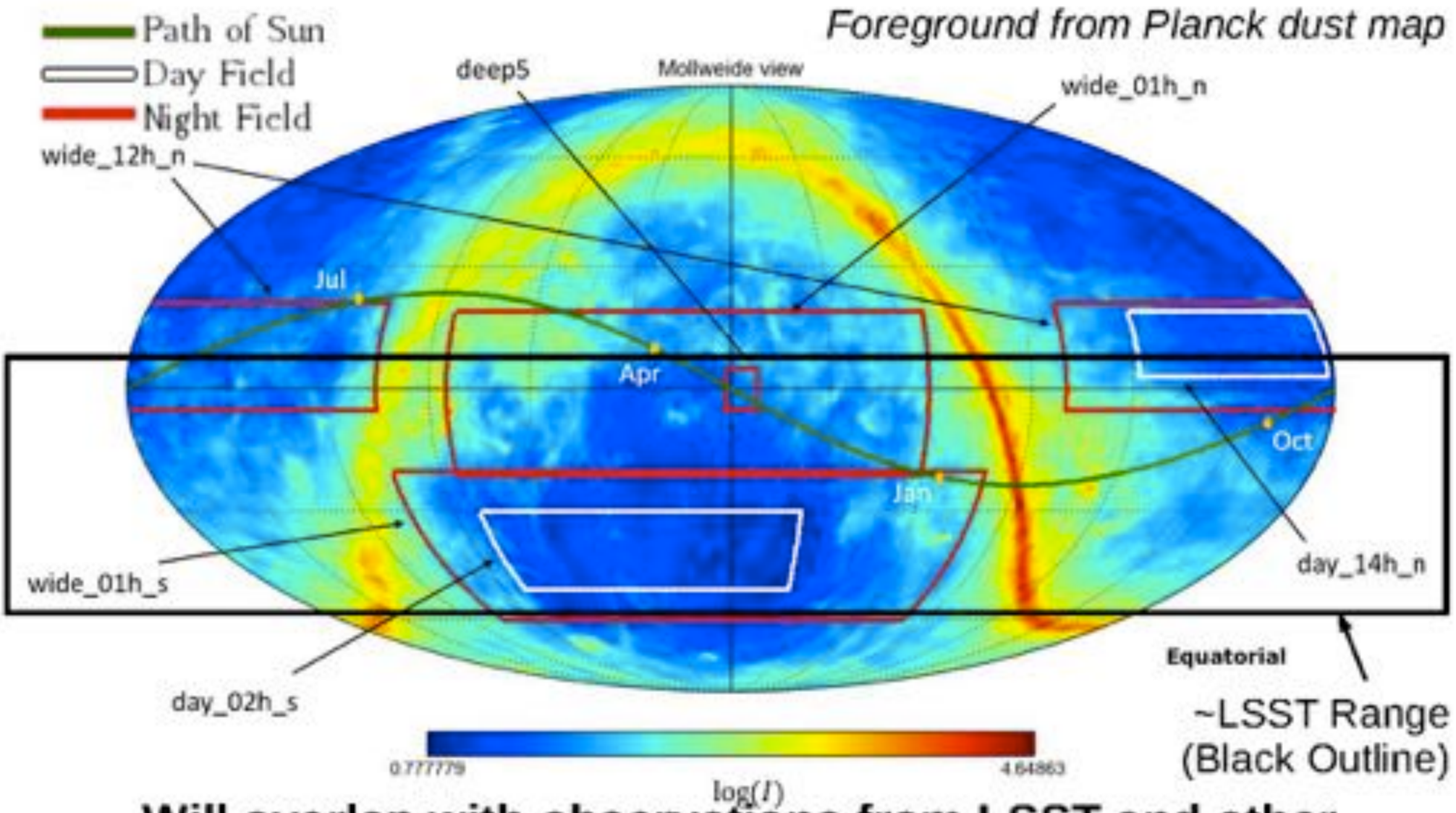
Mapping Speed vs. Pixel Diameter



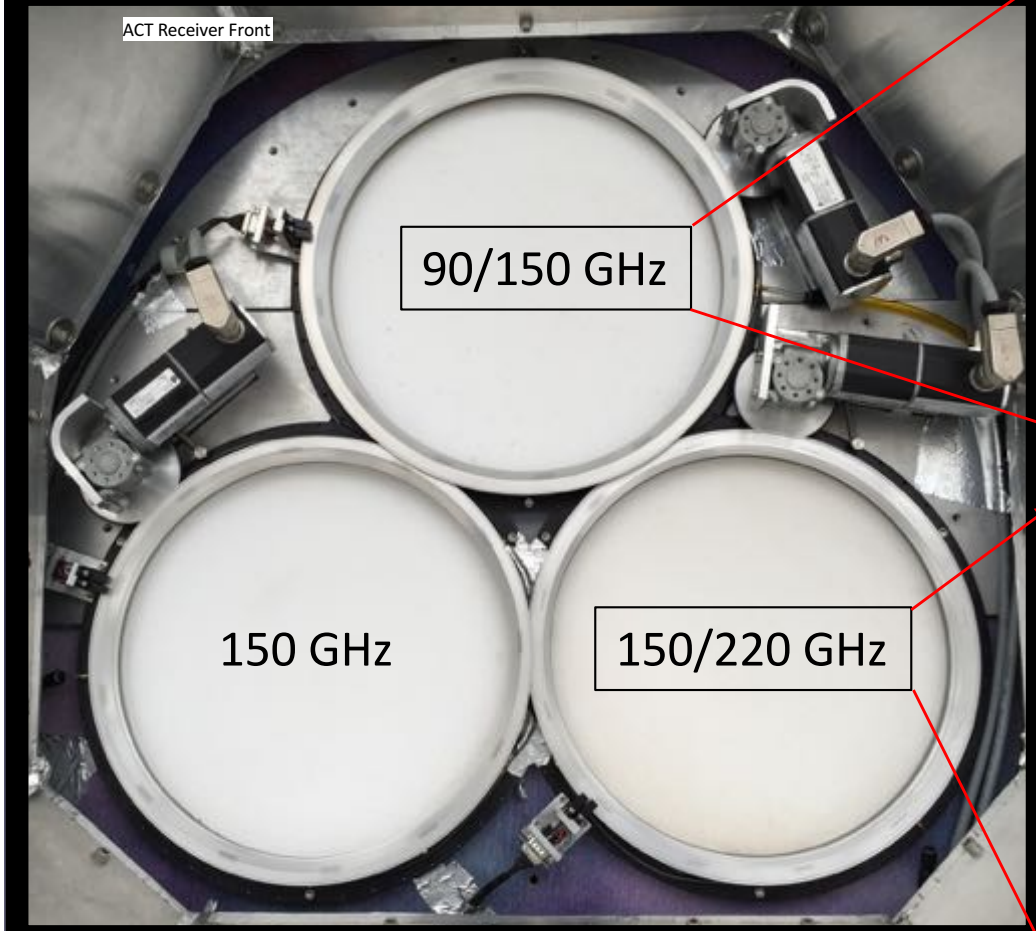
Pixel Diameter (D/(f*λ)

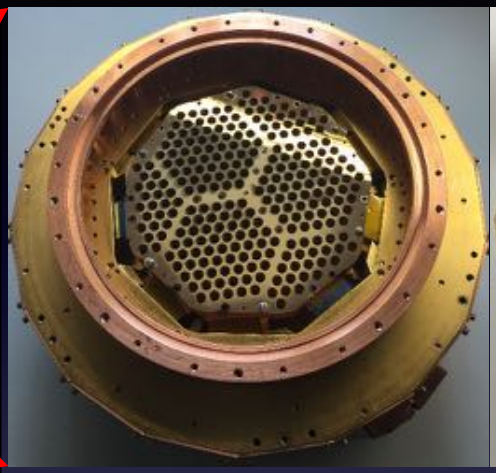
Fields Observed by AdvACT

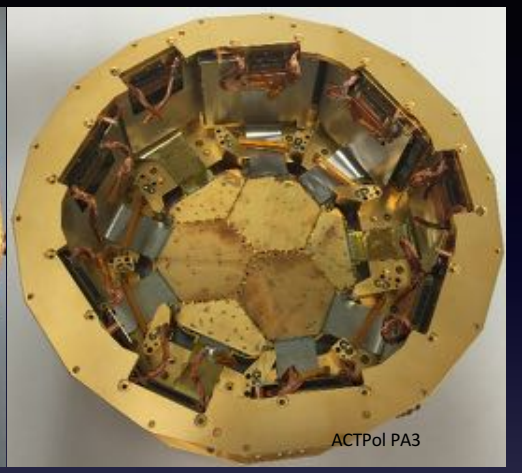


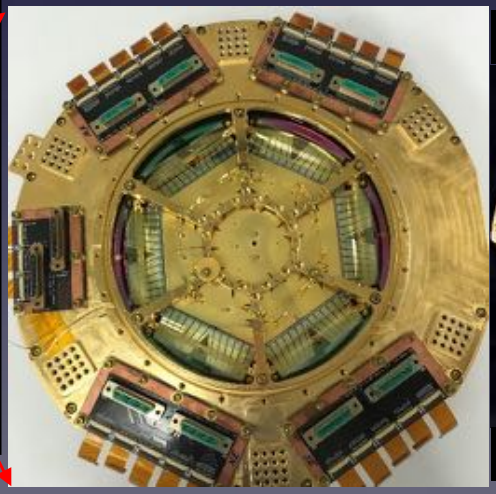
Will overlap with observations from LSST and other optical surveys

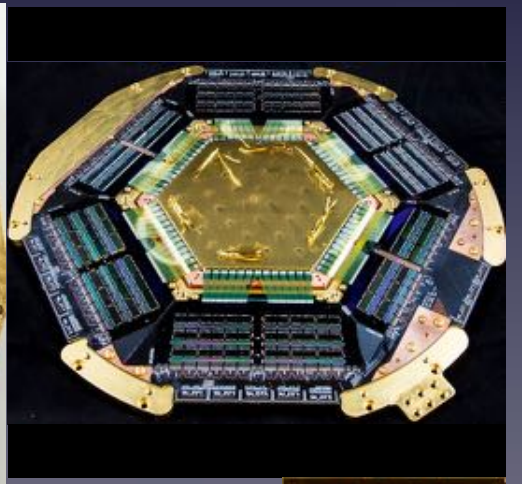
Atacama Cosmology Telescope Multichroic Detector Arrays



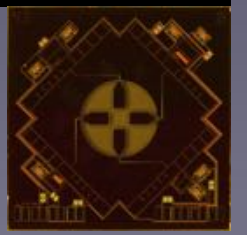






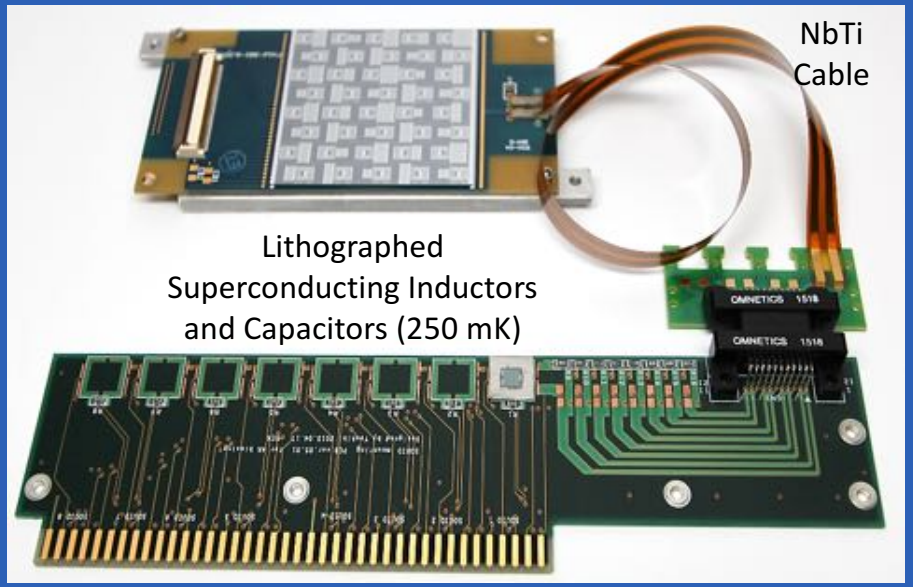


Rotating Half Wave Plates (8 Hz Modulation) not installed in this picture.

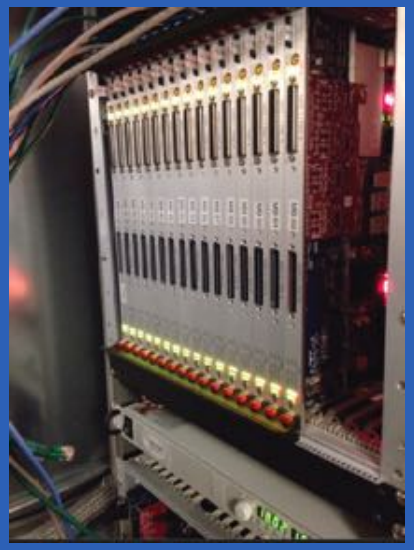


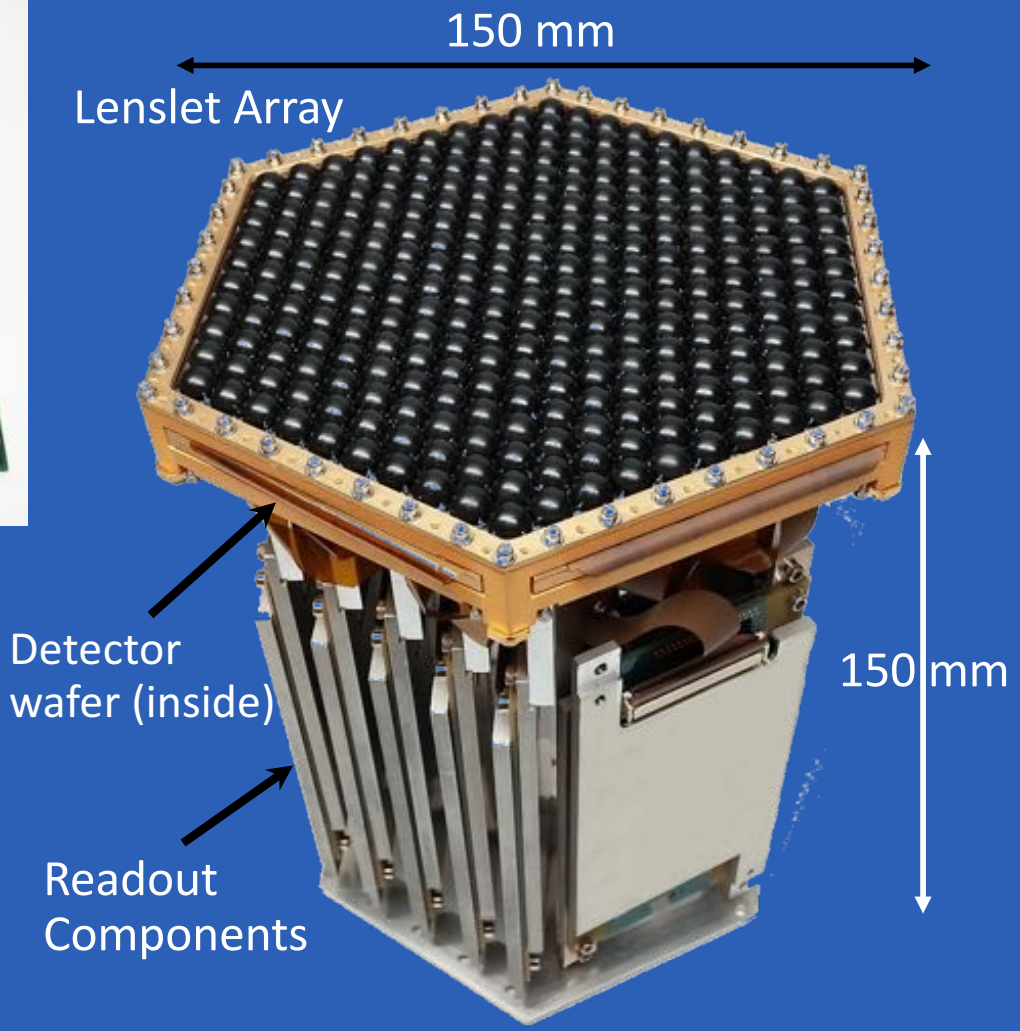
90/150 arrays were installed for 2015
150/220 installed in July 2016

Focal Plane and Readout



SQUID Printed Circuit Board
(4 K)





Detector Module Photograph

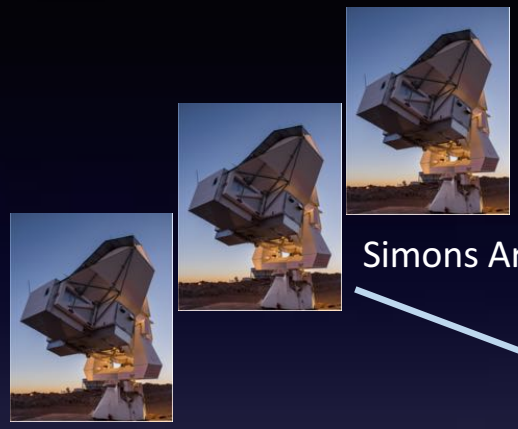
Simons Observatory Low Altitude Research Station [SOLARS] and Chile Logistics

Expand Facility to accommodate combined team.

Develop common use infrastructure such as trucks.

Hire SOLARS Manager and Site Manager

The Simons Observatory Combines the ACT and Simons Array Teams



Simons Array/POLARBEAR

Atacama Cosmology Telescope

- ACT and the Simons Array will continue to operate independently until the end of the current MSIP awards (2018/2019).
- In the meantime, they will begin to develop and share site infrastructure.
- CLASS is not currently part of the Simons Observatory. We will work to share infrastructure.