CMB-S4

An Introduction

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What Is CMB-S4?

- The 4th generation ground-based CMB experiment.
- The 1st ground-based CMB *project*:
  - Designed to meet critical science thresholds, not to do the best we can under a particular budget cap.
  - Can’t fail, not best effort.
- Making the full scope of CMB science available to the entire community:
  - Using the best technologies & techniques of all previous experiments.
  - Making the full scope of CMB science available to the whole community.
- Planned as a joint DOE (HEP) and NSF (Astronomy + Physics + Polar Programs) project:
  - Adding DOE capacities and capabilities to the longstanding NSF program.
  - Enabling unprecedented scaling (10x any previous experiment).

History

- 2013 - CMB community converges around CMB-S4 in Snowmass process.
- 2014 - P5 recommends CMB-S4 “under all budget scenarios”.
- 2015 - First CMB-S4 workshop held; biannually ever since.
- 2015 - NAS identifies CMB as one of 3 strategic Antarctic science priorities.
- 2016 - AAAC convenes the CMB-S4 Concept Definition Taskforce.
- 2017 - AAAC unanimously accepts the CDT report.
- 2018 - The CMB-S4 collaboration adopts its bylaws and is officially formed.
- 2019 - DOE takes CD-0 identifying the need for CMB-S4; NSF provides pre-project funding through U Chicago to develop the preliminary design.
- 2020 - CMB-S4 is TRACEd by Astro2020; DOE selects LBNL as the project lead lab.

Primary Science Goals

GOAL 1: Test models of inflation by measuring or putting upper limits on r, the ratio of tensor fluctuations to scalar fluctuations.

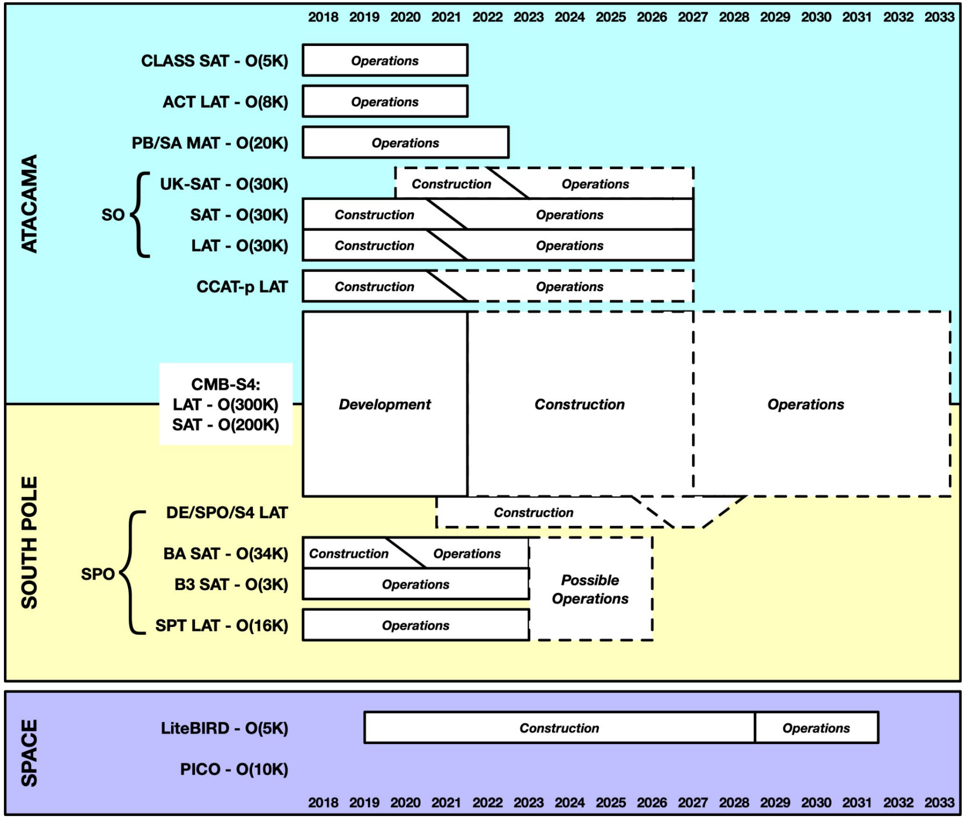
GOAL 2: Determine the role of light relic particles in fundamental physics, and in the structure and evolution of the Universe.

GOAL 3: Measure the emergence of galaxy clusters as we know them today. Quantify the formation and evolution of the $z \geq 2$ clusters and intracluster medium during this crucial period in galaxy formation.

GOAL 4: Explore the mm-wave transient sky and measure the rate of transients. Use the rate of mm-wave GRBs to constrain their mechanisms. Provide mm-wave variability and polarization measurements for stars and active galactic nuclei.

Meeting these goals will enable a wealth of other CMB/mm-wave science.

Context



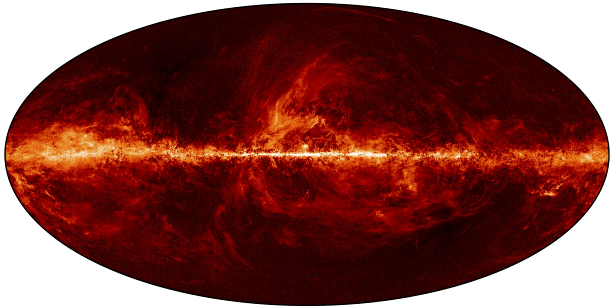
US CMB landscape in the 2020s as of 2018 (pre-COVID)

Experiment Design

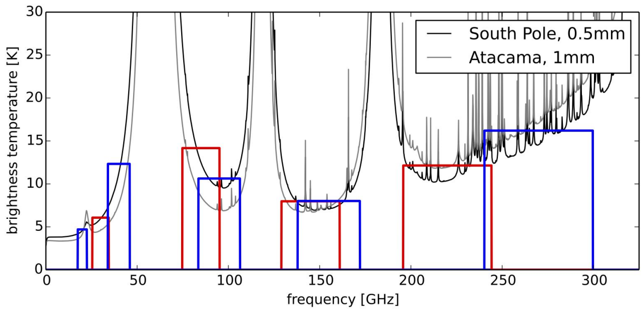
Science Goal / Design Parameter	Inflation	Light Relics	Galaxy Clusters	Transients
Map Depth (Detector-Years)	Ultra-Deep	Deep	Deep	Deep
Sky Area (Sites, Survey Strategy)	Small	Large	Large	Large
Angular Resolution (Mirror Size & Quality)	Low + Moderate	Moderate	High	High
Observing Cadence (Survey Strategy)	-	-	-	Daily
Frequency Coverage (Sites, Bandpasses)	Wide	Moderate	Moderate	Moderate

Bandpasses

- Microwave foreground emission (particularly Galactic dust and synchrotron) contaminate our CMB measurements across the sky.
- Removing such contaminants is essential to meet many of our science goals.
- Foreground cleaning relies on the difference in the way each component scales with frequency.
- We must occupy all of the available atmospheric windows, possibly splitting them on the SATs too.



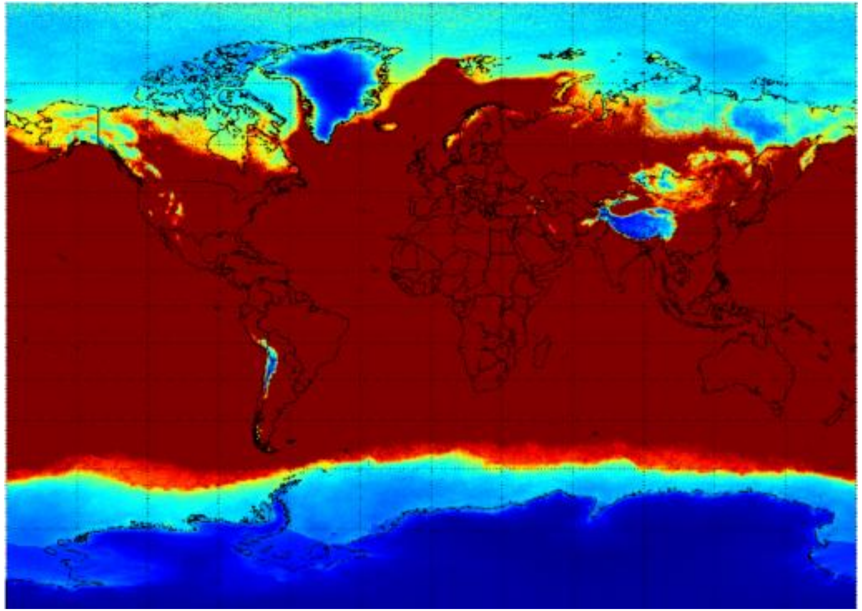
Planck map of polarized dust emission



Tophat bands populating the available atmospheric windows

Sites

- Ground-based CMB observations are limited by the atmosphere: we need high, dry, sites.
- The South Pole and Chilean Atacama are the highest, driest sites.
- The US CMB community has a long history of working at both, and significant infrastructure is already in place for CMB-S4 precursors (South Pole Observatory; Simons Observatory & CCAT-prime)



Mean precipitable water vapor across the globe. Candidate sites (dark blue) are the South Pole, Chilean and Argentinian Atacama Desert, Tibetan Plateau & Greenland.

Survey Strategies

- CMB-S4 is unique in having *two* exceptional observing sites available.
- The biggest difference between the sites is in the types of sky surveys their latitudes can support.
  - Wide-area surveys can only be performed from the Atacama.
  - Compact ultra-deep surveys can only be performed from the South Pole.
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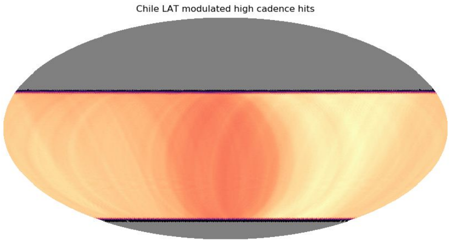
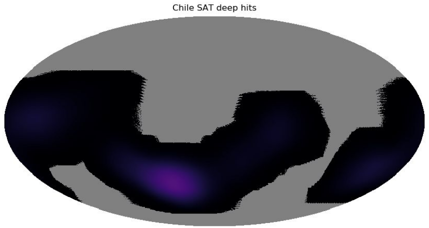
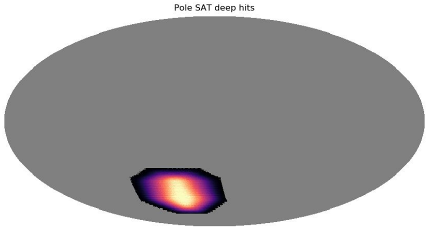


Chile wide survey hitmap



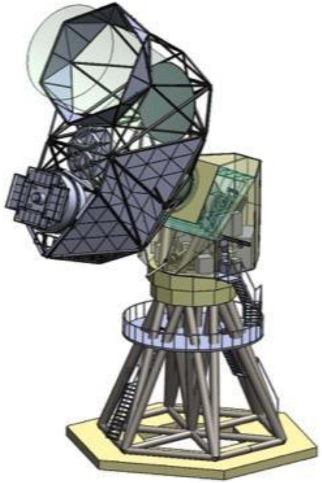
Chile deep survey hitmap



South Pole ultra-deep survey hitmap

Telescopes

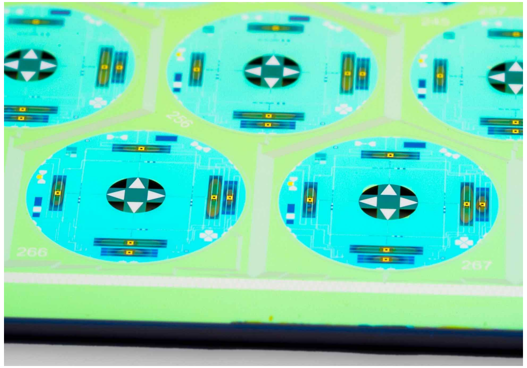
- Large Aperture Telescopes
  - 2 x 6m segmented mirror in Chile
  - 1 x 5m monolithic mirror at South Pole
- Small Aperture Telescopes
  - 6 x 3 x 0.5m at South Pole
  - Possible to relocate to Chile

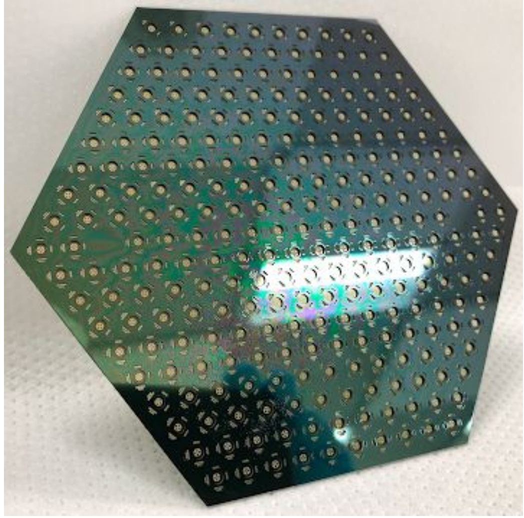


Map Depths

- Detectors
  - 500,000 cryogenically-cooled superconducting transition edge sensors
  - 125,000 dual-polarization dichroic pixels
  - 500 wafers.
- Years
  - 7-year observation duration for all surveys

Survey	Detectors	Detector-Years
SAT	150K	1100K
South Pole LAT	115K	800K
Chile LATs	245K	1700K





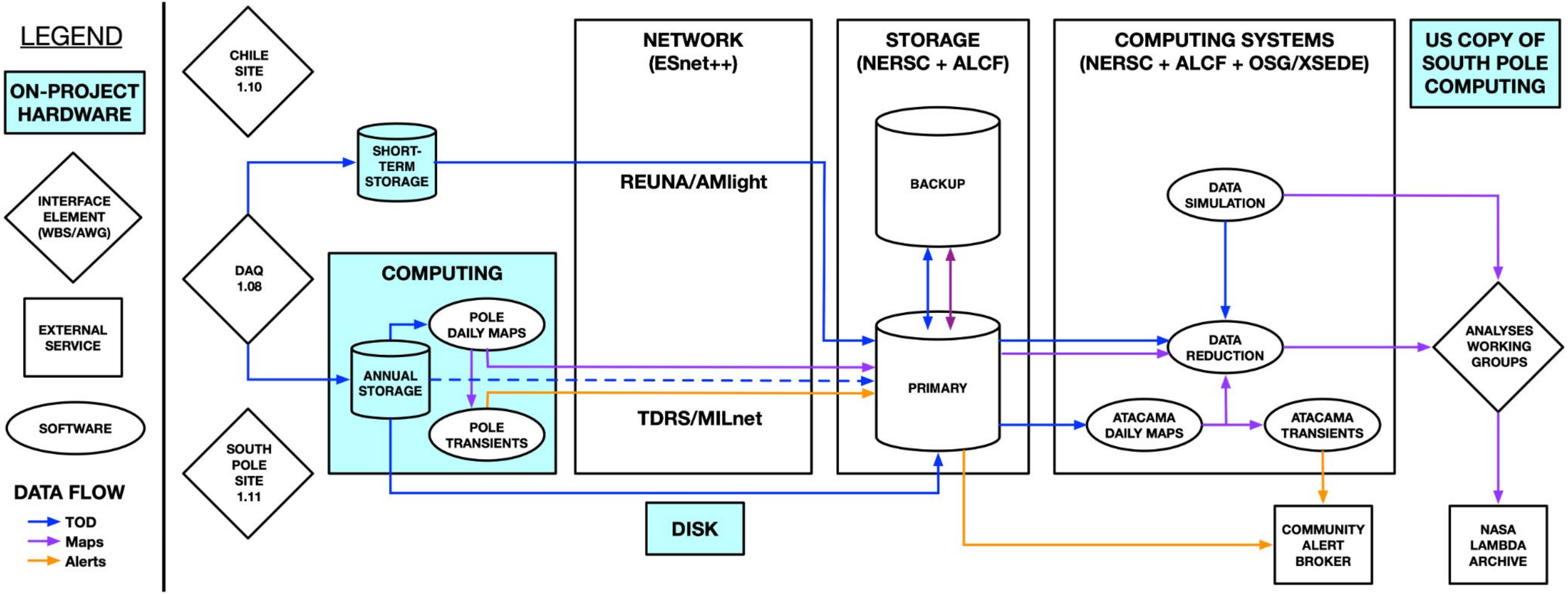
Timeline

- Construction project: 2019-27 (Astro2020 & federal budget permitting)
- Staggered deployment across both sites: 2027-29
- Operations: 2029-36

Natural progression:

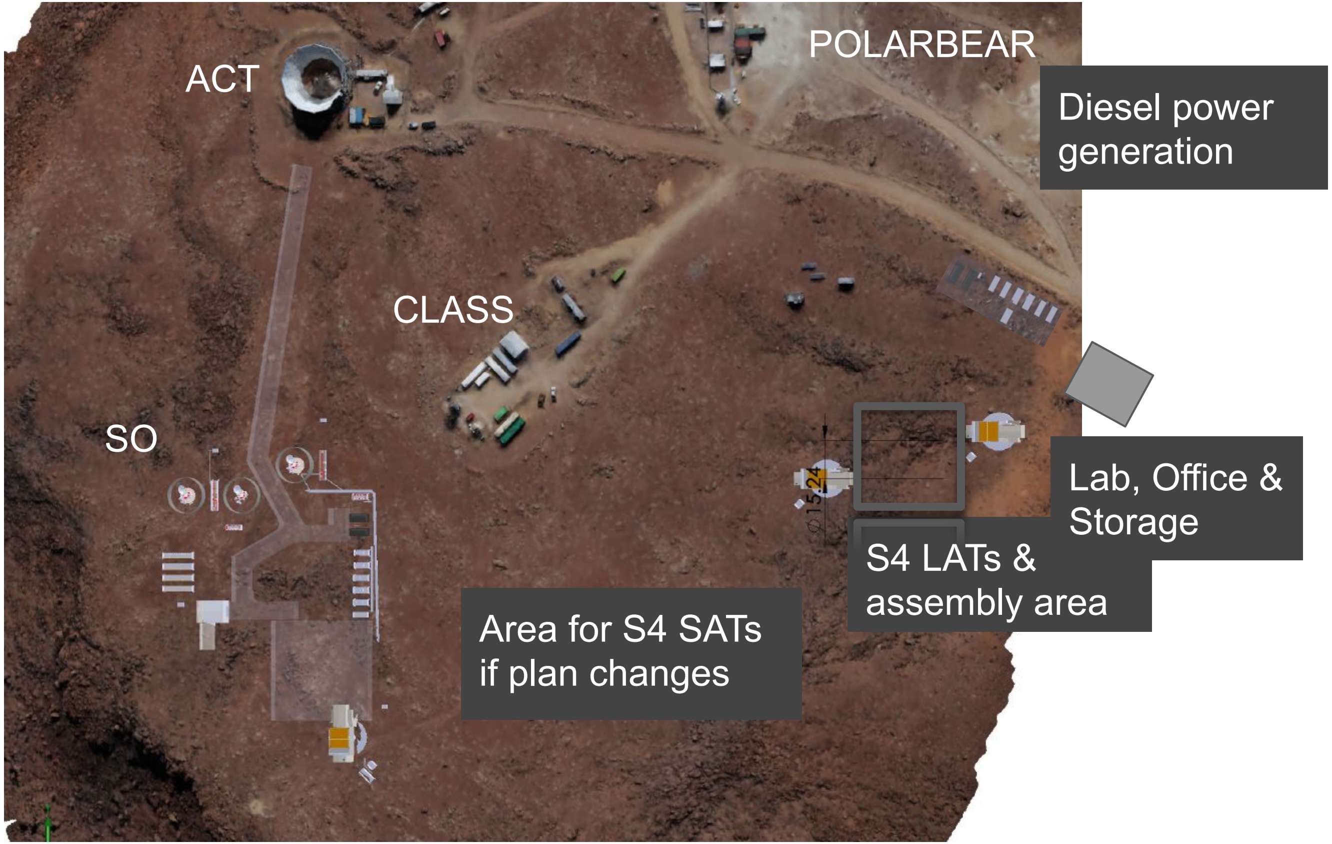
- Late 10s: 4 x single-site, single-aperture (ACT, BICEP, POLARBEAR, SPT)
- Early 20s: 2 x single-site, dual-aperture (SO, SPO)
- Late 20s: 1 x dual-site, dual-aperture (CMB-S4)

Data Management Schematic



Note: named resources are anticipated, not confirmed.

Atacama Site: Pre-Conceptual Design



The current site design does not include any re-use of SO site facilities or telescope.

Discussions about that possibility are ongoing.

Atacama Site: Networking

- Compressed data rate ~1.2 Gbps
- Real-time data transfer to US data center (NERSC)
  - Transient alert analysis may be performed in transit on FABRIC nodes
- Scoping up to 1 month of on-site storage ~400TB
  - With 10 Gbps available, 4 days to clear a month-long backlog.
- Working closely with Simons Observatory to coordinate site networking
  - Eli Dart of ESnet as CMB-S4 Atacama data movement lead.