# From Stage 3 to Stage 4:

## South Pole Observatory, Simons Observatory, & CMB-S4

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# Disclaimers & Acknowledgements

- Given the expert audience and the breadth/depth of the preceding week's talks, this will *not* just be a description of the design and goals of 3 planned experiments, but rather an account of our past to inform our future.
- This is a personal, CMB-S4 centered, perspective on the events and analyses described.
- Given the scope and brevity of this talk, many details are simplified and numbers rounded, though always with the intent to illuminate not obfuscate.
- Very many people have contributed to the work described here - all credit is theirs, all blame is mine.

# The Biggest Challenge For CMB Experiments

## Calibration, Calibration, Calibration

# The Biggest Challenge For Future Experiments

## Funding, Funding, Funding

“Cosmologists make experiments, but not in circumstances of their choosing”

# 2013: Snowmass

The US ground-based community realized that reaching the sensitivity required for next-generation CMB science goals would require a major transition:

- From multiple, competing, small-team, experiments
- To a single, community-wide, project

Goals:

- take the best technologies and techniques of all the existing experiments, combine them, and “simply” scale them to the degree required by the science
- add the capabilities of the DOE labs to the longstanding NSF programs

By analogy with the DTF characterization of Dark Energy experiments, this was deemed a “Stage 4” CMB experiment.

# Experiments vs Projects

| EXPERIMENT | PROJECT |
| --- | --- |
| Grant-funded<br>● Scope driven by the cost cap<br>● Selection by annual/biannual peer review committees<br>● Oversight through annual reports<br>● Management by the PI<br>● “Best effort” | Project-funded (MIE, MREFC, … )<br>● Scope driven by science goals<br>● Recommendation by community(s) through decadal survey report(s) + agency(s) gates<br>● Oversight through multiple reviews<br>● Professional project management<br>● “Can’t fail” |

Decadal surveys necessary for CMB-S4:

- Particle Physics Project Prioritization Panel (DOE High Energy Physics + NSF Physics)
- NAS Antarctic & Southern Ocean Research (NSF Polar Programs)
- Decadal Survey of Astronomy & Astrophysics (NSF Astrophysics)

# 2014: P5 Report

“Recommendation 18: Support CMB experiments as part of the core particle physics program. The multidisciplinary nature of the science warrants continued multiagency support.”

DOE HEP ✅✅

NSF Physics ✅

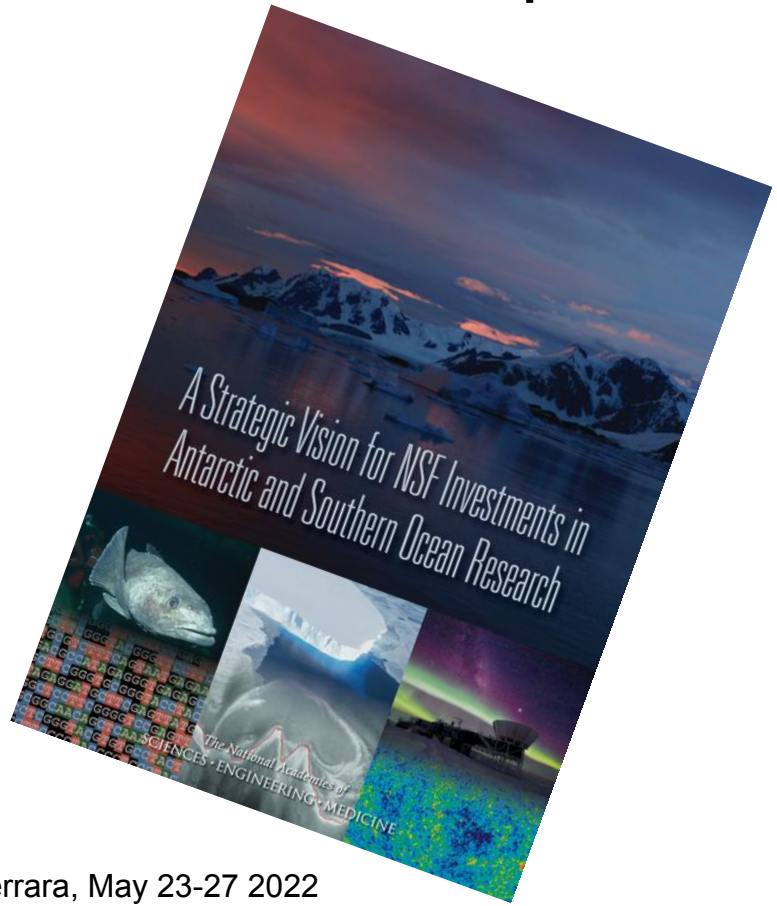
# 2015: NAS Antarctic & Southern Ocean Report

“Recommendation: NSF should pursue the following [three] strategic priorities in Antarctic and Southern Ocean research for the coming decade:

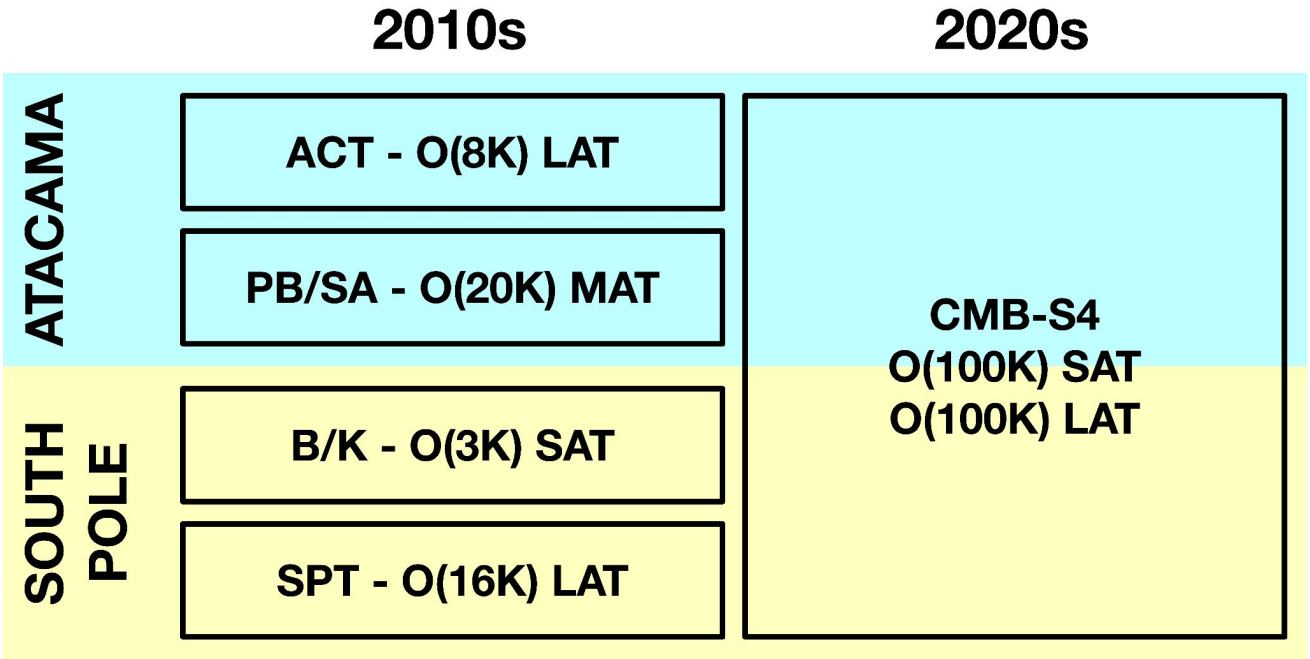
...

III. How did the universe begin and what are the underlying physical laws that govern its evolution and ultimate fate? A next-generation cosmic microwave background program.”

NSF OPP ✅



# 2015 Landscape



# Reality Check

1. NSF needed an Astro2020 recommendation to proceed & DOE needed an NSF commitment to proceed
    - CMB-S4 operations would not start till the late 2020s
    - The “Founding Four” Stage 3 experiments needed to fill the gap
2. The level of r we needed to target *required* precise foreground cleaning and delensing
    - All experiments needed to be multi-frequency and multi-scale

- The community was asked by the agencies (AAAC) to develop a Concept Definition for the CMB-S4 project
- The Atacama experiments (ACT, PB/SA) joined forces and obtained private funding for the all-new Simons Observatory
- The South Pole experiments (BK, SPT) joined forces and coupled their existing/planned resources as the South Pole Observatory

# South Pole Observatory

1 LAT (SPT-3G)

+

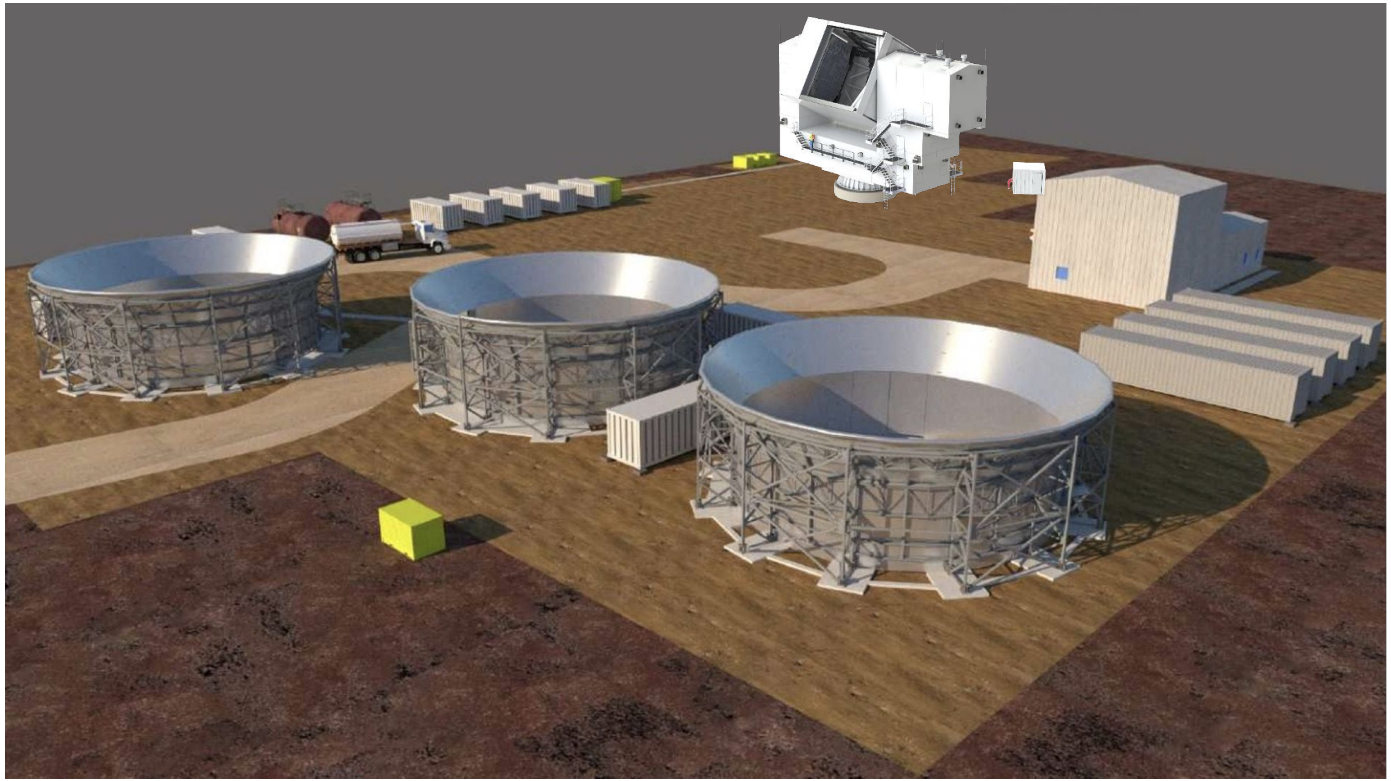
4 SATs (BA)

# Simons Observatory

½ LAT

+

3-4 SATs



# CMB-S4 Science Goals

The Concept Definition Taskforce identified 4 *driving* 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.

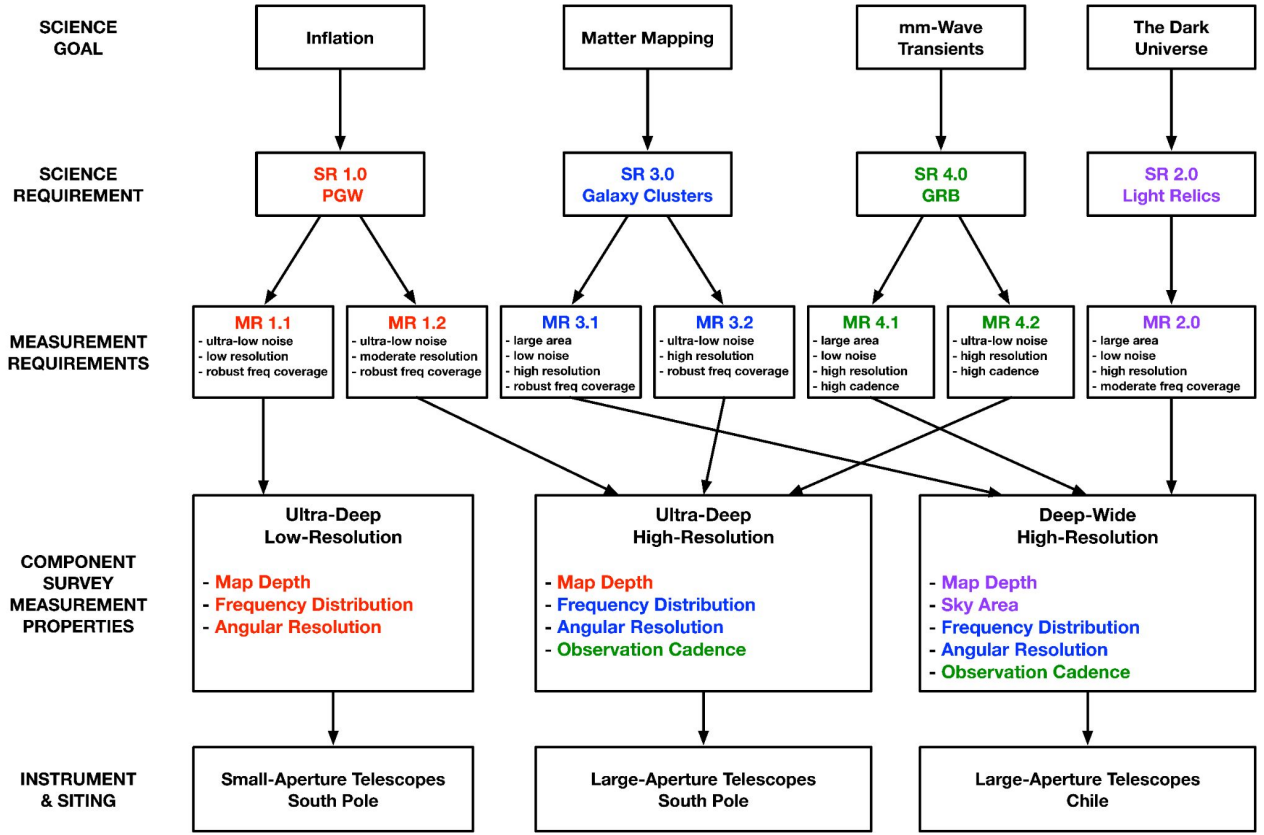
GOAL 3: Measure the emergence of galaxy clusters as we know them today. Quantify the formation and evolution of the clusters and the intracluster medium during the crucial early period of galaxy formation.

GOAL 4: Explore the millimeter-wave transient sky. Use the rate of mm-wave Gamma-Ray Bursts (GRB) to constrain GRB mechanisms. Provide mm-wave variability and polarization measurements for stars and active galactic nuclei.

# CMB-S4 Design Process

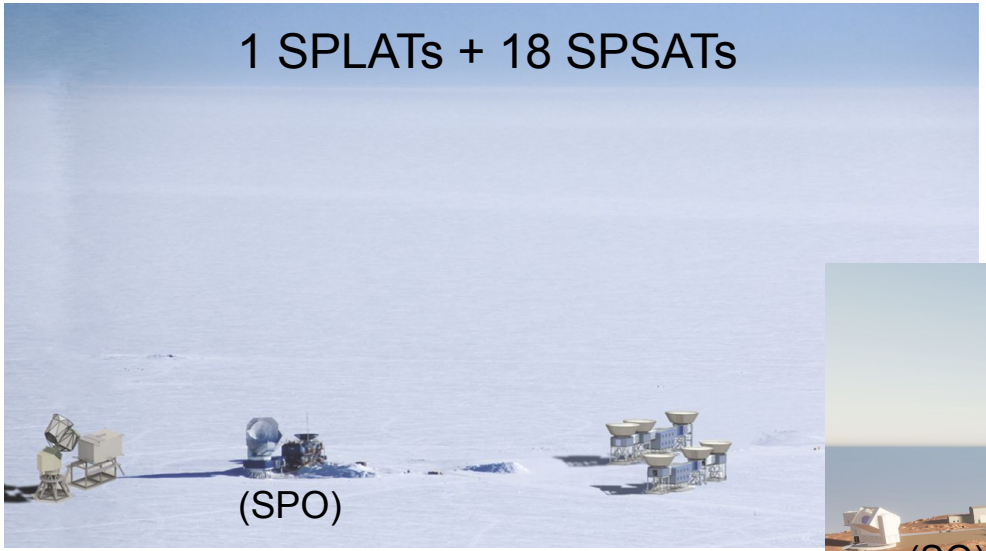
Requirements Flowdown

Experiment Design

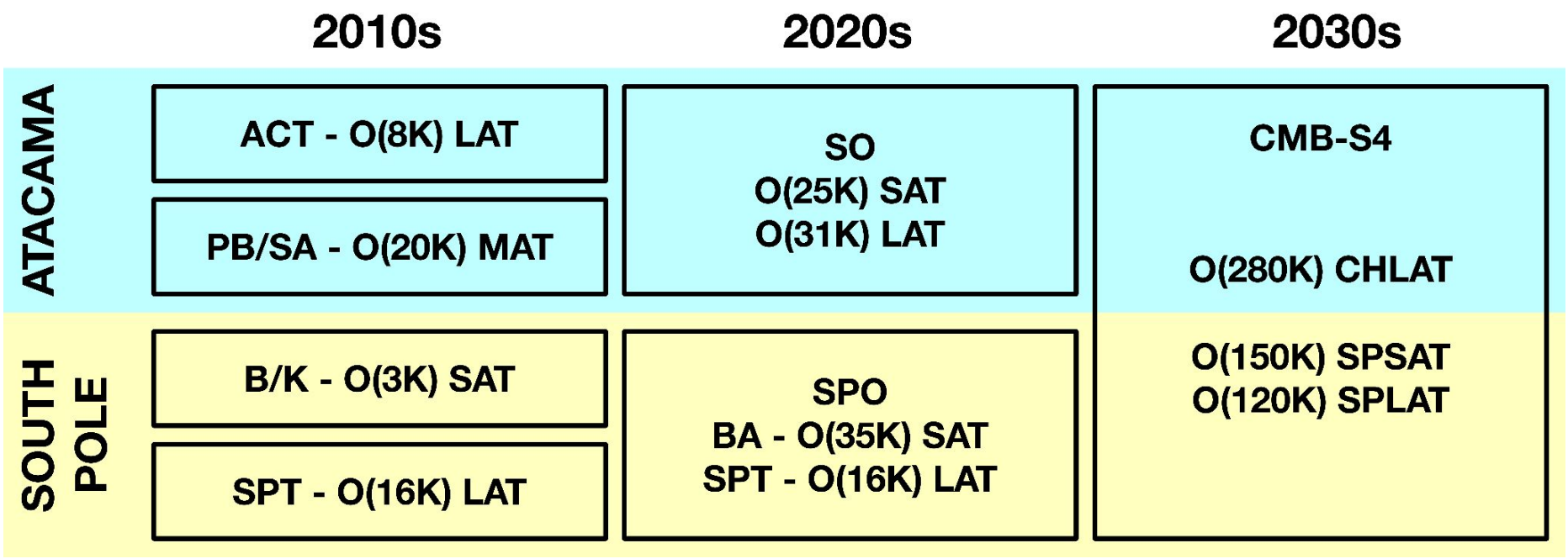



From Planck to the Future of CMB - Ferrara, May 23-27 2022

# CMB-S4 Baseline Design




# 2020 Landscape

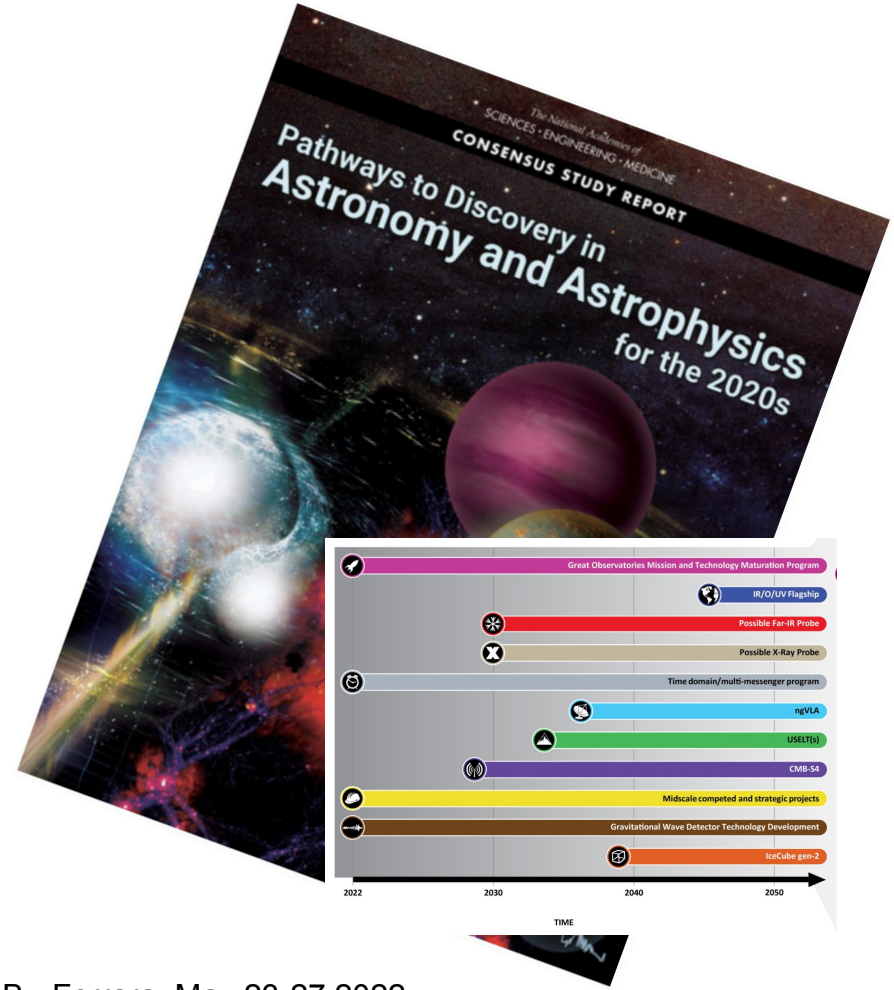


# 2021: Decadal Survey

“Recommendation: The National Science Foundation and the Department of Energy should jointly pursue the design and implementation of the next generation ground-based cosmic microwave background experiment (CMB-S4).”

“The panel suggests that third-generation CMB experiments aligned with CMB-S4 - specifically, the SPO and the nominal version of the SO - be high priorities for federal support.”

NSF Astrophysics ✅✅



# Thank You

# Forecasting On The Fly

- We are often asked for very rapid forecasts for other experimental configurations (including CMB-S4, SO and SPO resources) by agency managers, review committees, etc.
- Since CMB-S4 covers both sites, we can provide quick, qualitative, answers by scaling from forecasts provided by the CMB-S4 analysis working groups.
- These can be scaled by effort (detector-years), including the per-detector efficiency relative to CMB-S4, and setting the start and end dates of any particular experiment.

*These forecasts can provide guidance on the scientific return of candidate configurations, but cannot replace detailed analyses of point designs*

https://webapp.cmb-s4.org/Science-With-Effort/

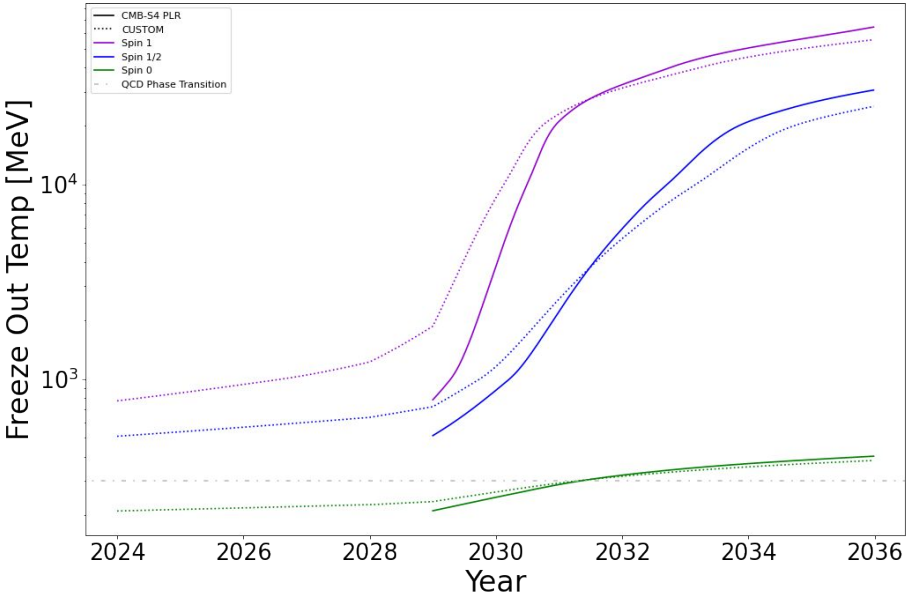
App developer: Cooper Jacobus

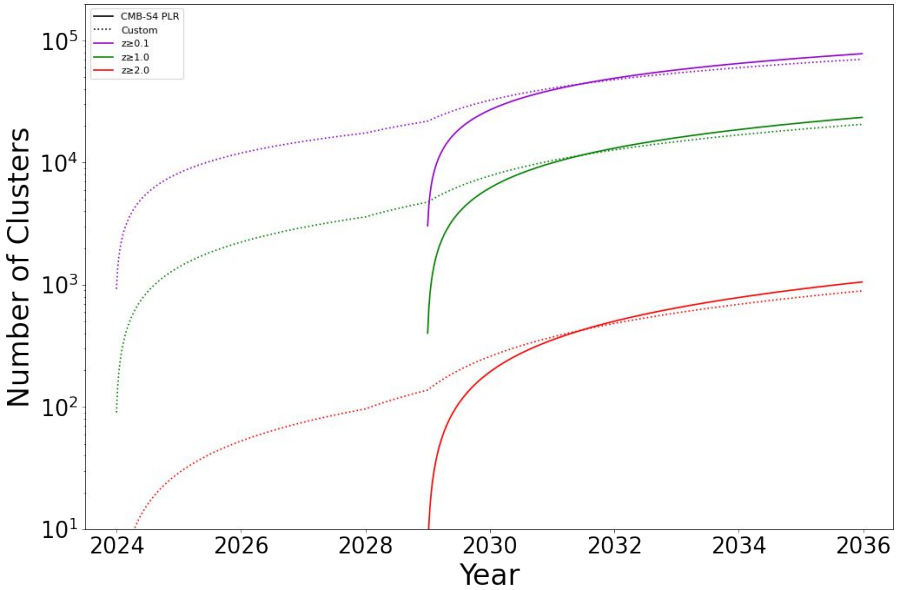
# 2022: The Good …

- The Simons Observatory proposal (endorsed by CMB-S4) to
  - fill out the LAT focal plane
  - deploy a solar power array
  - enable rapid delivery of astrophysical maps

  is under consideration at NSF.
- Even though the fully-filled SO LAT would still be smaller than a CMB-S4 CHLAT, when the previous observations are included it would be sufficient to replace a CMB-S4 CHLAT.
- The SO and CMB-S4 teams are having positive discussions about the ways their programs can productively be aligned.

# Replacing One CMB-S4 CHLAT With The ASO LAT




Light relic freeze-out temperatures and galaxy cluster counts:

Solid lines: 2 x CMB-S4 CHLATs

Dashed lines: 1 x CMB-S4 CBLT + SO/ASO LAT

# 2022: … The Bad …

- 10 years have passed us by, and the P5 decadal process is starting up again!
- Given the lack of progress on the construction project, it is important that CMB-S4 gets another strong endorsement.

- The CMB community needs to be active in the Snowmass process that will feed into P5.
- Many dedicated and joint white papers have already been submitted.
- Please consider attending the Community Summer Study Workshop

http://seattlesnowmass2021.net/

# 2022: … And The Ugly

"South Pole Station is saturated with already-funded projects, and required critical infrastructure and maintenance activities that can no longer be deferred, until late in the decade. South Pole Station will continue to host its current suite of large-scale science projects, such as the IceCube Neutrino Observatory; *however, proposers seeking support for new projects at South Pole Station should consult the cognizant program officer to discuss alternative pathways to accomplish science goals.*"

NSF 22-078

Dear Colleague Letter: Update on Science Support and Infrastructure in Antarctica

April 29, 2022

Dear Colleagues:

This letter provides an update on the status and future of science support and infrastructure recapitalization in Antarctica as affected by the COVID-19 pandemic.

To date, protocols intended to prevent COVID-19 transmission to the stations and continent, such as extended periods of quarantine, careful monitoring of COVID-19 exposure, and reductions in personnel, have successfully prevented COVID-19 outbreaks at United States Antarctic research stations and vessels. These precautions, necessitated by the limited medical facilities on station, have constrained the U.S. Antarctic Program's (USAP) capacity to support funded science projects, and halted some construction and maintenance activities, creating a substantial backlog in both.

Despite these challenges, the USAP successfully supported science projects in the 2021-22 season at approximately 30-40% of "normal" levels, in accordance with a tiered system of prioritization. The highest priority science projects included fieldwork involving international collaborations, projects with critical time-series data, and projects involving instrument maintenance to prevent irreversible damage to, or loss of, science infrastructure.

Assuming pandemic restrictions ease in the coming season, the USAP will prioritize efforts to support already-funded science projects, to the greatest extent possible. Working through the extensive backlog may take several years to complete, and will require continued vigilance, thoughtful execution, and patience.

While OPP will continue to accept proposals involving fieldwork, the USAP's ability to support new field deployments will be limited in certain sectors, as described below. OPP also continues to encourage the submission of proposals that promote discovery and innovation but do not require Antarctic deployment. Examples include projects that emphasize model development and validation, advance technology and cyberinfrastructure, or include analysis of already-collected data and/or samples. Under limited circumstances, proof-of-concept projects, e.g., testing instrumentation, may include fieldwork at non-polar sites that offer comparable conditions.

Before the pandemic, the USAP had developed plans (see Blue Ribbon Panel report) to maintain or replace critical infrastructure at all stations through the Antarctic Infrastructure Modernization for Science (AIMS) program, and its successor, the Antarctic Infrastructure Recapitalization (AIR) program. These plans also were disrupted by the COVID-19 pandemic. In the upcoming season, work is expected to continue on these activities, including replacement of a lodging facility and the development of a new Vehicle Equipment and Operations Center at McMurdo Station.

The imperative to address the backlog of funded projects and to improve critical infrastructure at McMurdo will make it difficult to accommodate new initiatives with a large field footprint in some sectors. Specific information concerning the availability of field assets is below:

**McMurdo Station** will be unable to accommodate new, large field teams until the second half of the decade. However, new smaller efforts involving helicopter support from McMurdo Station, starting in the 2022-2023 field season, are potentially supportable. Likewise, new near-field initiatives based out of McMurdo and requiring small fixed-wing support can be implemented starting in the 2024-2025 field season. LC-130 airlift support and both science traverse platforms are highly constrained through the 2026-27 season, due to support of already-funded deep field and South Pole Station activities.

**South Pole Station** is saturated with already-funded projects, and required critical infrastructure and maintenance activities that can no longer be deferred, until late in the decade, South Pole Station will continue to host its current suite of large-scale science projects, such as the IceCube Neutrino Observatory; however, proposers seeking support for new projects at South Pole Station should consult the cognizant program officer to discuss alternative pathways to accomplish science goals.

**Palmer Station** is fully allocated from January to mid-February through 2024, but is able to support smaller projects in the early and late season in 2022-2023, 2023-2024 and 2024-2025, and larger projects overwinters for all seasons.

The **R/V Nathaniel B. Palmer** is fully allocated during the peak summer (November - February) through 2023-2024, but availability exists during the shoulder seasons (i.e., April/May and September/October), and thereafter, for new science proposals. There are opportunities for the **R/V Laurence M. Gould** to support additional science on planned cruises around the Antarctic Peninsula in 2022-2023 and 2023-2024.

As we navigate the COVID-19 pandemic's impacts, OPP will provide regular updates about resource capabilities. OPP encourages prospective investigators to consult program officers concerning projects requiring field support. In addition, we will soon launch, with input from the scientific community, a South Pole Station Master Planning effort, similar to the master planning effort that established infrastructure renewal priorities for McMurdo and Palmer Stations. More information will be available at USAP.gov, through the OPP quarterly newsletter, Antarctic Community Office Hours, and the OPP Advisory Committee.

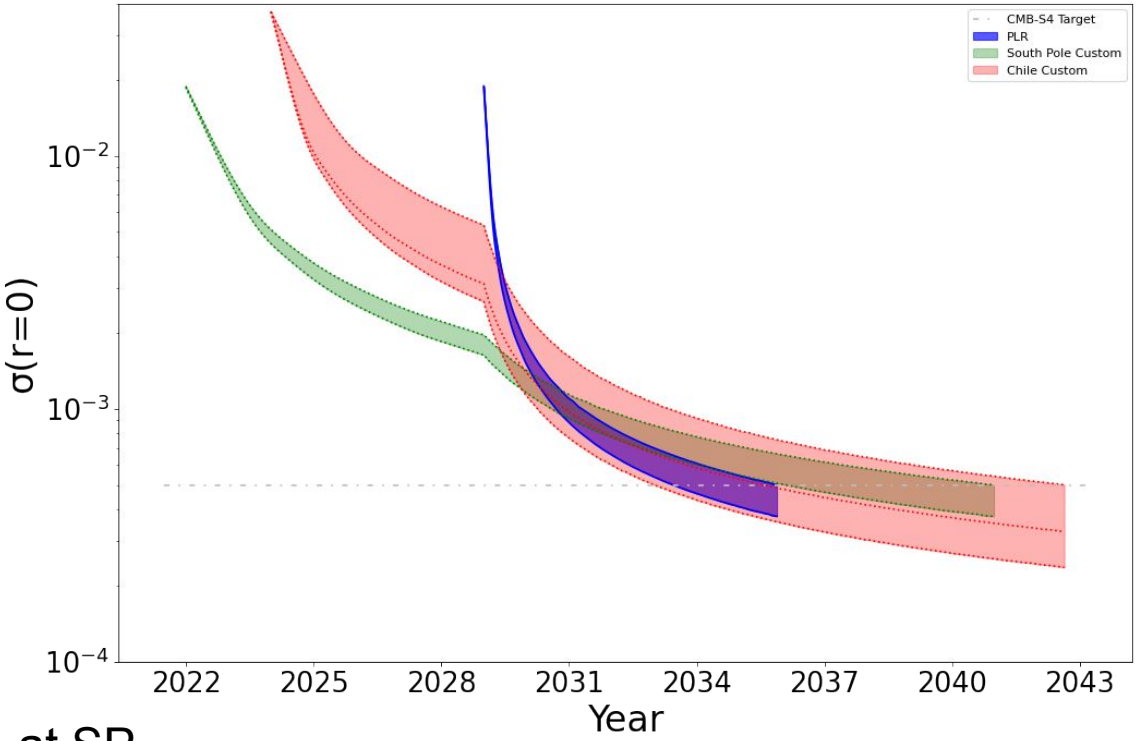
Sincerely,

Alexandra R. Isern
Assistant Director for Geosciences

# Analysis of Alternatives

- Given the unexpected restriction on deployments at the South Pole, we must *rapidly* assess possible alternative configurations.
- These will necessarily involve some combination of higher risk, higher cost, and reduced science.
- Examples:
  - using a SPLAT for both primordial and lensing B-modes
  - using a more aggressive SPSAT design
  - using CHSATs
  - using delensing CHLATs for SPSATs
  - extending operations beyond 7 years
  - dropping the two-tier cluster & transient surveys

# Examples:




Ranges include foreground complexity and (for Chile) performance uncertainty:

- Blue: CMB-S4 at SP
- Green: SPO + ½ x CMB-S4 at SP
- Red: SO + 2 x CMB-S4 in Chile

# Summary

- CMB-S4 is the first ground-based CMB project, designed from the outset to reach key scientific thresholds.
- The gap from the end of the “Founding Four” Stage 3 experiments to the start of CMB-S4 operations have been filled by SPO and SO.
- These are important standalone experiments in their own right *and* valuable pre-Stage 4 activities:
  - Maintaining community continuity and scientific advancement
  - Informing the design of the CMB-S4 instrument and operations
  - Potentially providing data/software/hardware to augment CMB-S4
- Despite bumps in the road, we do still have a (cobblestone) path to CMB-S4 operations through the 2030s.

*International support - from endorsement to participation - is extremely valuable*