CMB-S4: Present status and next steps

Jacques Delabrouille

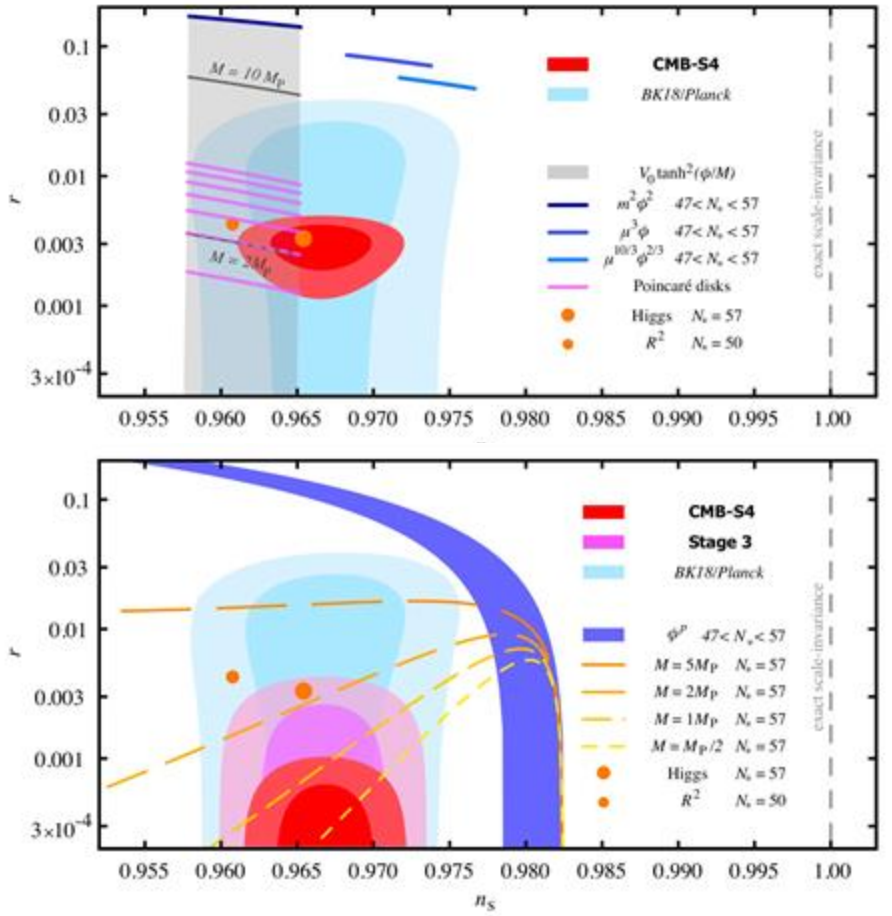
CPB, CNRS/IN2P3, Berkeley
and
LBNL, Berkeley

from/with input and slides from Jim Strait (and others)

For the CMB-S4 collaboration

Outline

- Science Objectives reminder
- Chilean path forward
- Next steps



The Science Case

- The microwave sky is an extraordinarily rich source of information about our Universe
- The CMB carries the imprint of processes in the very early universe, and of interactions of CMB photons across the Hubble volume
- CMB-S4: Four broad science themes

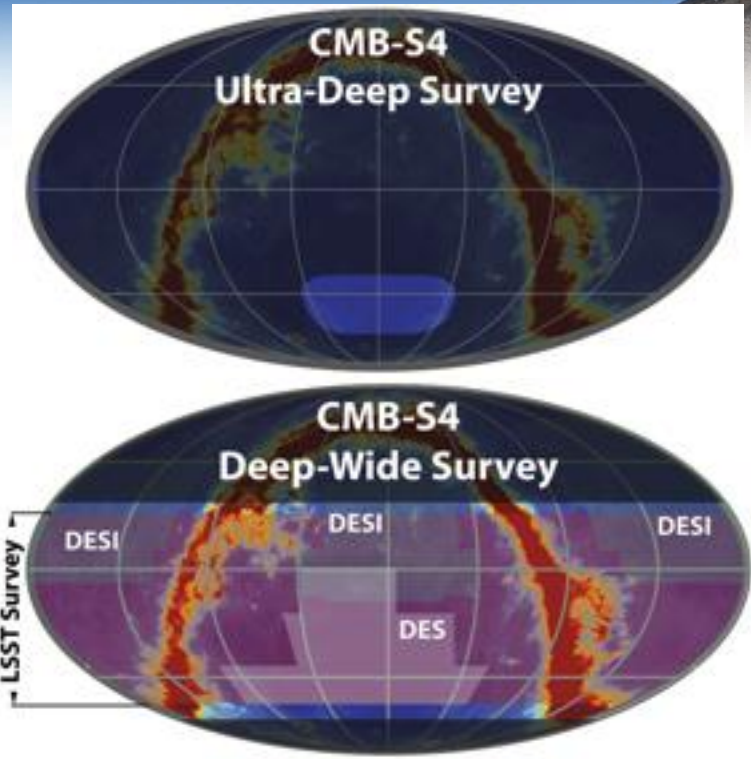
Primordial Gravitational Waves and Inflation	The Dark Universe	Mapping Matter in the Cosmos	The Time-Variable Millimeter-Wave Sky

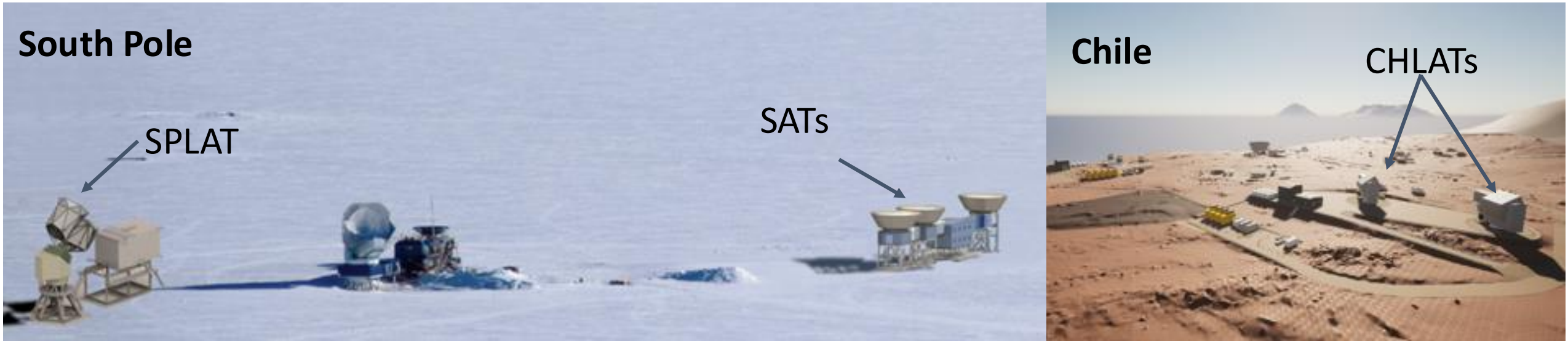
Science Case design drivers

- **Science Theme 1: Primordial GW, Inflation**
  - *Design-driver:* **Confirm inflation!!** >5σ detection of r > 0.003 (95% CL upper limit r<0.001 if r=0)
- **Science Theme 2: The Dark Universe**
  - *Design-driver:* Determine N_{eff} with an uncertainty < 0.06 at 95% CL
- **Science Theme 3: Mapping Matter in the Cosmos**
  - *Design-driver 1:* On >50% sky, detect at 5σ clusters at z>1.5 with $Y>2.4\ 10^{-5}$ arcmin^2
  - *Design-driver 2:* On >3% sky, detect at 5σ clusters at z>1.5 with $Y>1.2\ 10^{-5}$ arcmin^2
- **Science Theme 4: Time-variable mm-wave Sky**
  - *Design-driver 1:* On >50% sky, detect GRB afterglows > 30 mJy @ 90 & 150 GHz
  - *Design-driver 2:* On >3% sky, detect GRB afterglows > 9 mJy @ 90 & 150 GHz
  - *Design-driver 3:* Timely alerts for follow-up

Original baseline

- Ultra-Deep Survey from the South Pole and Deep-Wide Survey from Chile with arcmin angular resolution
- 7-8 frequency bands (20-300 GHz) for foreground subtraction
- Uses mature technology successfully demonstrated in current experiments (ACT, Polar Bear, SPT, BK Array, etc ..)
- Exceeds current generation by a factor 10 in detector count





A strong heritage of endorsements

- 2024: HEPAP Facilities Subpanel: **CMB-S4's potential to contribute to world-leading science is "absolutely central."**
- 2023: P5: "***Plan and start the following major initiatives in order of priority: a. CMB-S4****, which looks back at the earliest moments of the universe to probe physics at the highest energy scales.*"
- 2023: AAAC: "*Coordination between NSF-OPP, NSF-AST, and DOE is critical* ***to ensure the success of CMB-S4 and enable the world-leading science and exciting discoveries that will be achieved with the project.***"
- 2021: Astro2020: "***The NSF and the DOE should jointly pursue the design and implementation of the next generation ground-based cosmic microwave background experiment (CMB-S4).***"
- 2015: NAS report recommended CMB-S4 science case as 1 of 3 strategic investments for Antarctic Research
- 2014: P5 recommended CMB-S4 under all budget scenarios

The project is jointly supported by the DOE and by NSF, signaling a strong federal commitment

With active French involvement

Involvement in the Collaboration and in the Project

- Data Management
- Simulations and Analysis
- Coordination and Governance
- Study of atmosphere mitigation

- Readout Hardware:
  - Warm Electronics (APC and LPSC)
  - Superconducting cables (CEA, APC with an ANR)

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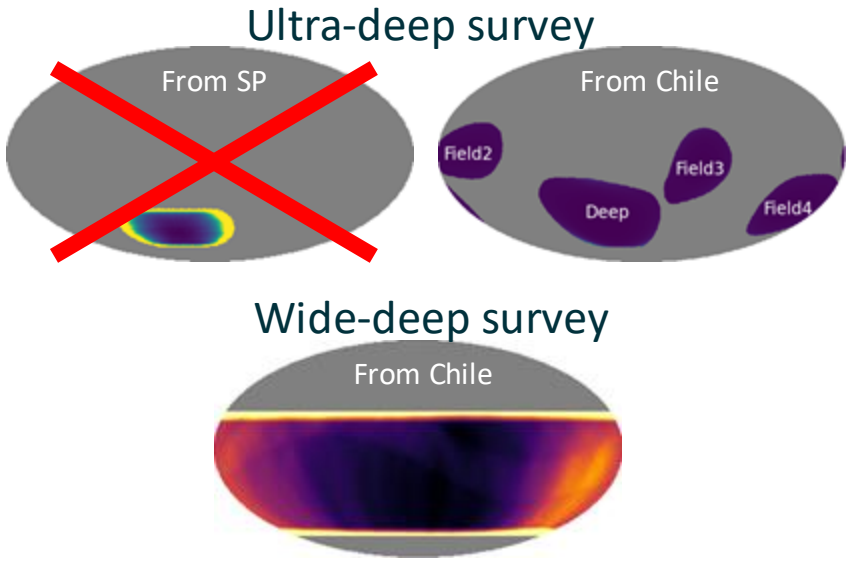


CMB-S4 path towards Major Facility design stage

CMB-S4 achieved DOE CD-0 approval (Mission Need), and secured NSF MSRI-1 design funding, advancing the project's foundational design phase.

In May 2024 however, “The NSF has made the decision **not to move the CMB-S4 project in its current form into the NSF Major Facility Design Stage at this time**” due to the need to “prioritize the recapitalization of **critical infrastructure at the South Pole**”.

Following this decision, CMB-S4 is developing an all-Chile option, in which the ultra-deep survey also conducted in Chile.

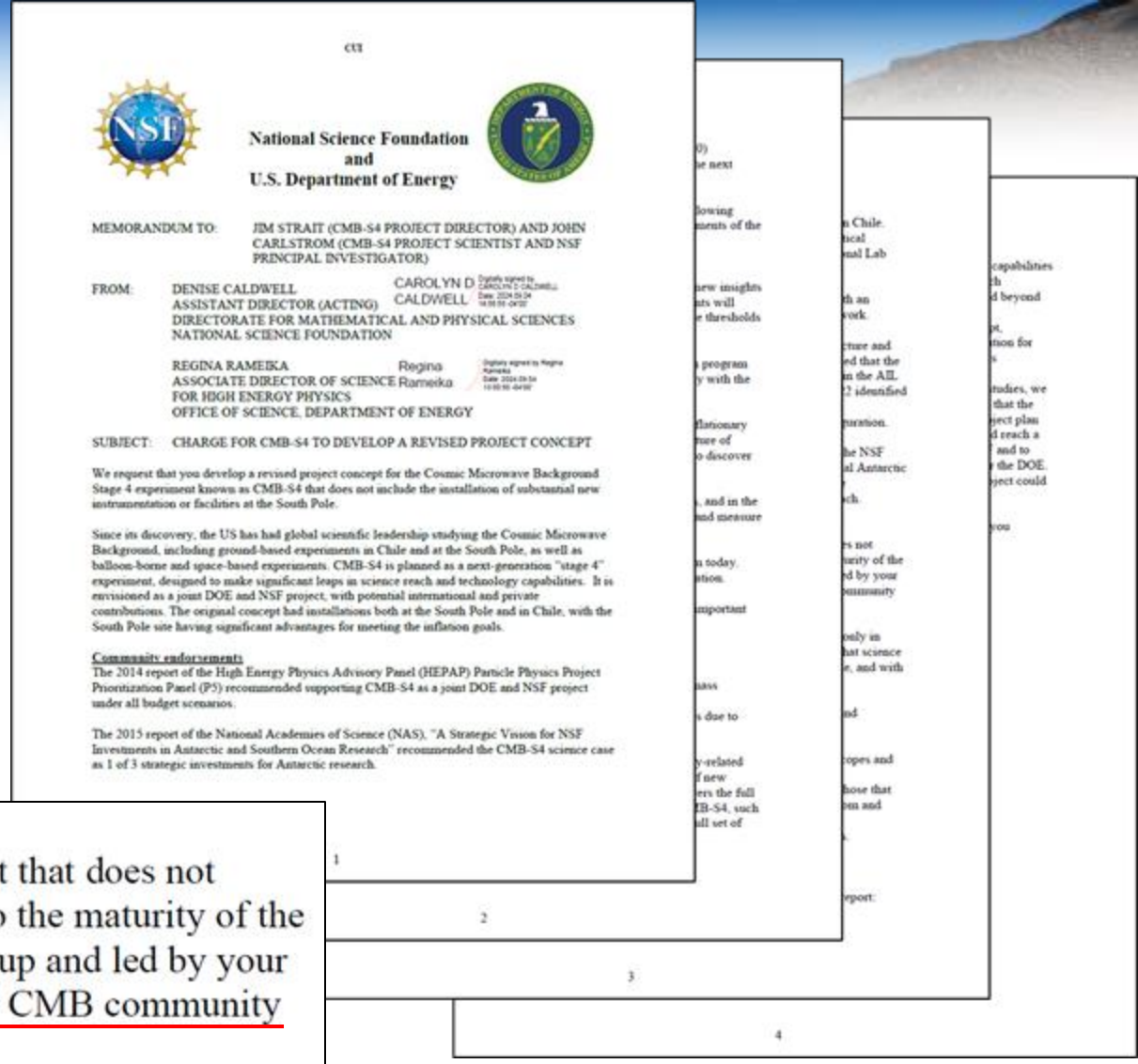
Charge letter to that effect from the DOE and NSF to the CMB-S4 project.

The DOE and NSF combined are providing continuous support at approximately **$8 million per year**, sustaining critical development activities after the recent NSF reconfiguration decision.

Funding agency charge

A formal charge, signed by the Directors of NSF/MPS and DOE/HEP, was sent to CMB-S4 on Sep 4, 2024

The charge is consistent with the work that was already in progress.



National Science Foundation
and
U.S. Department of Energy

MEMORANDUM TO: JIM STRAIT (CMB-S4 PROJECT DIRECTOR) AND JOHN CARLSTROM (CMB-S4 PROJECT SCIENTIST AND NSF PRINCIPAL INVESTIGATOR)

FROM: DENISE CALDWELL
ASSISTANT DIRECTOR (ACTING)
DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES
NATIONAL SCIENCE FOUNDATION

REGINA RAMEIKA
ASSOCIATE DIRECTOR OF SCIENCE
FOR HIGH ENERGY PHYSICS
OFFICE OF SCIENCE, DEPARTMENT OF ENERGY

SUBJECT: CHARGE FOR CMB-S4 TO DEVELOP A REVISED PROJECT CONCEPT

We request that you develop a revised project concept for the Cosmic Microwave Background Stage 4 experiment known as CMB-S4 that does not include the installation of substantial new instrumentation or facilities at the South Pole.

Since its discovery, the US has had global scientific leadership studying the Cosmic Microwave Background, including ground-based experiments in Chile and at the South Pole, as well as balloon-borne and space-based experiments. CMB-S4 is planned as a next-generation "stage 4" experiment, designed to make significant leaps in science reach and technology capabilities. It is envisioned as a joint DOE and NSF project, with potential international and private contributions. The original concept had installations both at the South Pole and in Chile, with the South Pole site having significant advantages for meeting the inflation goals.

Community endorsements
The 2014 report of the High Energy Physics Advisory Panel (HEPAP) Particle Physics Project Prioritization Panel (P5) recommended supporting CMB-S4 as a joint DOE and NSF project under all budget scenarios.

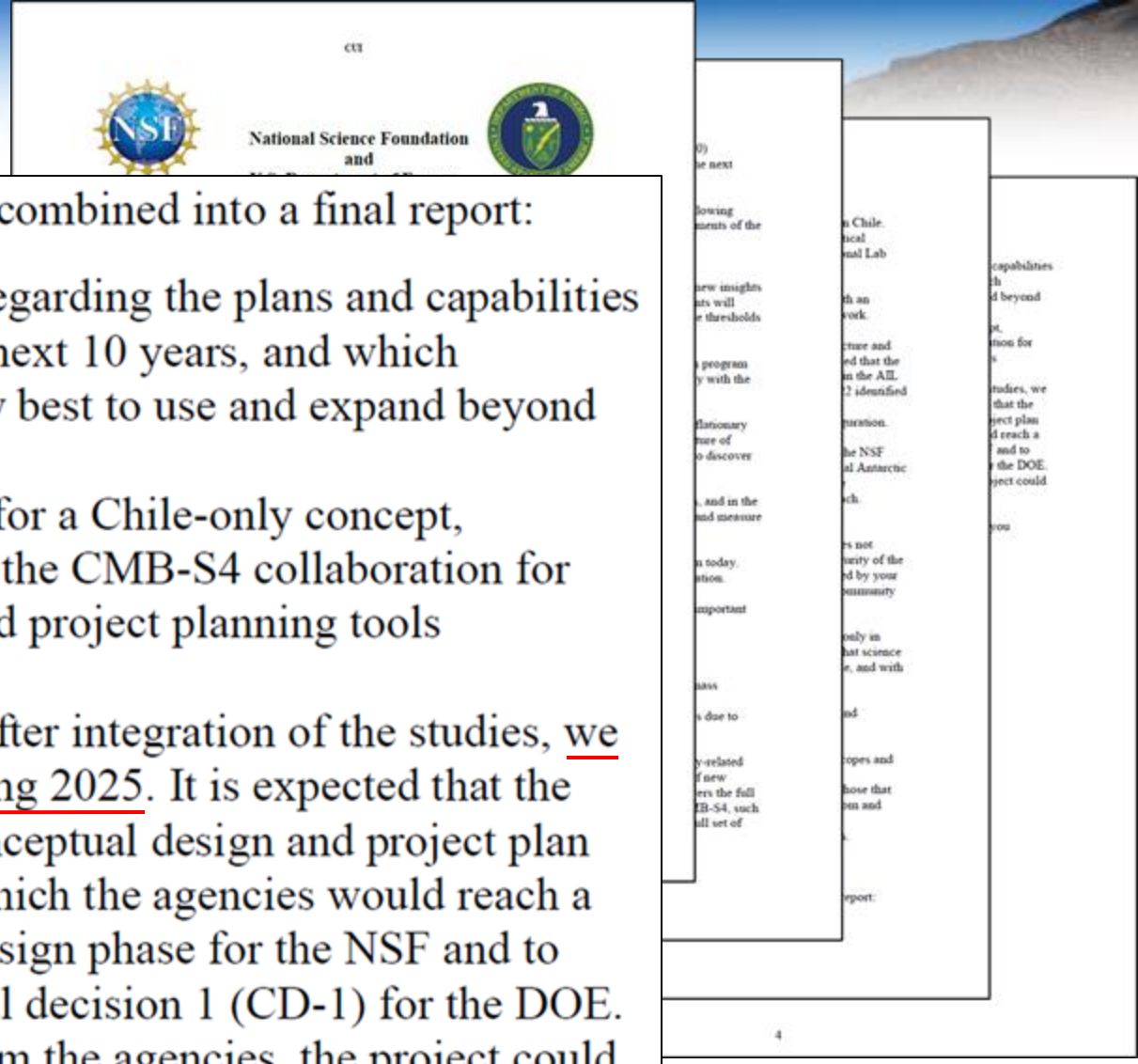
The 2015 report of the National Academies of Science (NAS), "A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research" recommended the CMB-S4 science case as 1 of 3 strategic investments for Antarctic research.

Charge

The agencies request that you develop a revised plan for the CMB-S4 project that does not include significant new instrumentation or facilities at the South Pole. Due to the maturity of the CMB-S4 project team, collaboration, and concept, the process should be set up and led by your project team and collaboration, and co-chaired by you. Input from the wider CMB community should be included in developing the plan as appropriate.

The goal is to refocus on planning a configuration, with new project instrumentation only in Chile, that is capable of meeting the full set of CMB-S4 science goals, or to define what science goals can be reached, both within a reliable and reasonable lifecycle cost and schedule, and with an acceptable level of scientific risk.

Funding agency charge



The study is envisioned as requiring two parallel efforts, to be combined into a final report:

1. Survey the Landscape: Collect and evaluate information regarding the plans and capabilities of CMB experiments that are expected to take data in the next 10 years, and which contribute to the CMB-S4 science goals, to determine how best to use and expand beyond those capabilities.
2. Optimize an all-Chile design: Develop the revised design for a Chile-only concept, incorporating the significant design work already done by the CMB-S4 collaboration for both sites, using well-developed scientific, engineering and project planning tools

We anticipate receiving draft reports by the end of CY2024. After integration of the studies, we expect to receive the report on a revised design concept in spring 2025. It is expected that the concept would form the basis for the development of a full conceptual design and project plan over an approximately two-year period, at the conclusion of which the agencies would reach a decision on whether to move the project into the conceptual design phase for the NSF and to fully develop the project conceptual design and approve critical decision 1 (CD-1) for the DOE. Within this timeframe, and allowing for a positive decision from the agencies, the project could be ready for a joint DOE and NSF review of the conceptual design by early FY2027.

We sincerely appreciate your efforts in carrying out these studies and will meet with you regularly to stay informed of your progress.

Developing a revised CMB-S4 configuration

- Ongoing **rapid study of the design space** for CMB-S4 in Chile, including:
  - Numbers and types of telescopes, frequency bands and FP detector designs;
  - Survey strategies;
  - Site layout options and constraints.
- Goal: be able to propose an all-Chile configuration that can address **all of the CMB-S4 science goals,** and meets the inflation science goal for an acceptable cost.

  - ***WG1:*** A **Coordination Group** oversees the rapid study of the design space to optimize the design concept. For the moment, 2 CD-LATs for wide survey (unchanged) for 14 total years of observation, configuration space for SATs being investigated for increased sensitivity, up to 3 delensing LATS. Deep survey based on a selection of deep patches observable at different times.

  - ***WG2:*** Another Working Group ensures that the design of CMB-S4 takes account of the **plans and capabilities of other experiments** that will be running between now and when CMB-S4 will begin observations, which is charged to collect and evaluate information regarding the plans and capabilities of current CMB experiments (Focus: SO, SPO (BICEP+SPT), LiteBIRD, PICO)

Developing a revised CMB-S4 configuration

Immediate goal is to determine the scope, costs, and risks of an all-Chile configuration that is able to address *all of the CMB-S4 science goals*, and is optimized to meet the inflation science goal of $\sigma(r) \leq 5 \times 10^{-4}$ within a reasonable survey duration ($\lesssim$ 10 years).

Work organized in 5 main areas, utilizing the existing Project and Collaboration structures: Simulations and Forecasting; SAT Design; LAT Design; Site Design, Cost Modeling

Practical organization and Status:

- Coordination group meeting weekly (open to CMB-S4 collaboration members);
- Many weekly sub-group meetings;
- Progress is being paced by the Simulations and Forecasting, which have incorporated improved SAT models and scan strategies;
- Cost and schedule impacts are being captured in the project plan, at a detailed level;
- Draft report is in progress...

We hope to collaborate with the Simons Observatory and the South Pole Observatory (SPT and BICEP Array) to combine analyses with them to reduce the total data required to be taken by CMB-S4.

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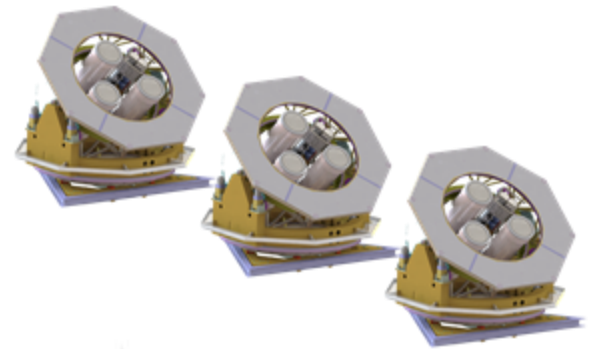

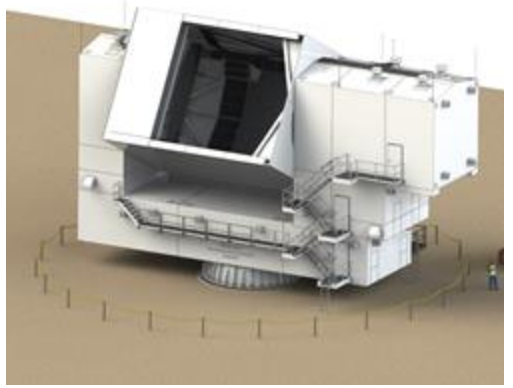

Next steps (following conclusions of WGs)

- The combined results of the two working groups will be evaluated against the goals of the studies and will be used to define **a revised configuration** that, *building on the expected results of current experiments*, allows CMB-S4 **to achieve the goals set out in Astro2020, the 2023 P5 Report, and the CMB-S4 Program-Level Requirements**.

- The process for converging on a revised CMB-S4 configuration includes the following elements:

  - The Project and Collaboration leadership, working closely with the Project L1 Team and the Collaboration Science Council, will propose a revised configuration.
  - A draft document will be made available to the full Collaboration describing: the revised configuration; its science capabilities, risks, and cost; how it fits into the landscape of other experiments; and the rationale for choosing it.
  - The revised configuration will be vetted during the CMB-S4 Collaboration Meeting (March 24-26, Berkeley).
  - The report will be revised, if necessary, following the collaboration discussion.
  - Finalization of the process expected by spring 2025 (i.e. mid-June).

Next steps (following conclusions of WGs)

- The final report will be presented to the Funding agencies in Spring 2025, both as a written document and in an in-person briefing.

- Assuming a favorable outcome (in terms of scientific capabilities, cost, schedule and risk) of the design studies carried out by CMB-S4, and following the briefing, CMB-S4 will request that the Funding Agencies give the Project approval to proceed to develop the revised concept to the level required for NSF CDR and DOE CD-1 and will request that NSF propose to the NSF Director that CMB-S4 be placed into the Major Facilities Design Stage.

- Assuming adequate funding from the DOE and the NSF, the Project will fully develop the revised conceptual design and project plan to the level required for CDR and CD-1 by the end of FY2026, and the Funding Agencies will schedule a joint CDR / CD-1 Review to take place in early FY2027.

- A substantial increase in funding above current levels ($4.5M and $4.0M from DOE and NSF respectively this year) will be required in FY 2026 to achieve readiness for CD-1 and CDR in early FY 2027.

Summary of the planned timeline

FY25 Q1:	Complete studies by the two Working Groups
FY25 Q2:	Analyze results and conclude on the revised configuration of CMB-S4
Spring 2025:	Brief the NSF and DOE on the revised configuration and seek concurrence
FY25 Q3-Q4:	Value engineering studies to optimize the revised configuration for cost while maintaining scientific capability
FY26:	Develop the conceptual design to readiness for CDR and CD-1, to the extent that funding permits
FY27 Q1	CDR and CD-1 Review (goal)

Conclusions and Summary

- **We have a focused action plan for reconfiguring CMB-S4 in Chile**, which we are executing and which is consistent with a written charge jointly signed by the two funding agencies, DOE and NSF:
  - Developing and optimizing the all-Chile configuration;
  - Surveying the landscape of CMB experiments to determine CMB-S4's role in it;
  - Combining the two studies to determine a revised configuration that will form the basis for a complete conceptual design, in conjunction with expected capabilities other experiments;
  - Moving toward readiness for CD-1 and CDR by the end of FY 2026, if funding permits.
- The current funding situation of approximately $8 million per year is at a level sufficient to execute this plan, while sustaining critical technical development activities in key areas after the recent NSF reconfiguration decision.