

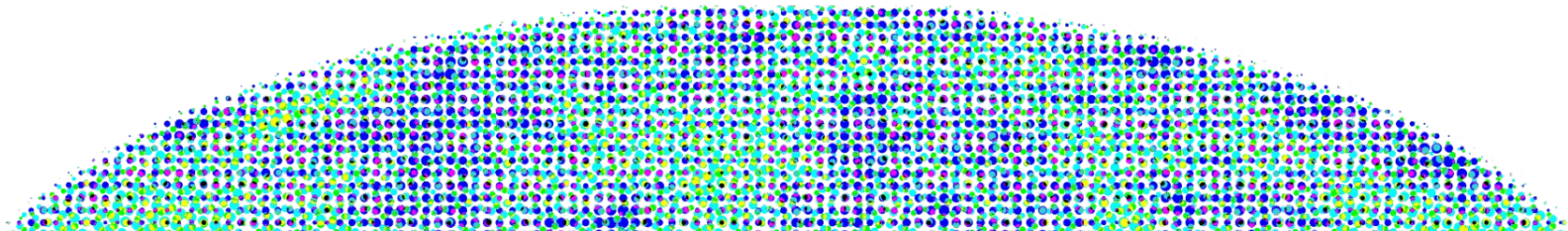


CMB-S4's untapped science potential

Panel on Astro2020 Priorities for Cosmic Microwave
Background Science

Kevin M. Huffenberger, CMB-S4 co-spokesperson

7 October 2025



What is (was) CMB-S4... ?

- Comprehensive ground-based experiment to realize the promise of the CMB to make transformational discoveries in astrophysics and cosmology.
- Sets of Small Aperture Telescopes (SATs) and Large Aperture Telescopes (LATs)—based on common technology—sited at the South Pole and the Atacama in Chile or (in a later concept) only in Chile.
- Large and well-developed Project and Collaboration organizations (>500 people)
- Strongly endorsed by high-level advisory committees
- Ultimately canceled in 2025 by supporting agencies, NSF and DOE.

Pillars of the CMB Science Program

Inflation: CMB-S4 will discover or rule out the “natural models” of inflation.

Design threshold: $\sigma_r < 0.0005$

Relic Particles: CMB-S4 will cross a critical threshold to discover or rule out light thermal relic particles that freeze out during and after the QCD phase transition and extending our knowledge of relic particles by orders of magnitude in the freeze out temperature.

Design threshold: $\sigma_{\text{Neff}} < 0.03$

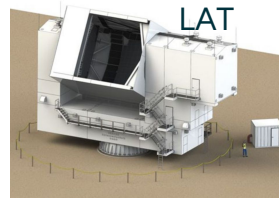
Matter Mapping: CMB-S4 will provide legacy lensing and gas maps that probe cosmology and astrophysics and that enable diverse new science including dark energy and dark matter studies and neutrino mass scale, complementing LSST DESC, DESI and the proposed Spec-S5.

Enabled by relic particle search and a deep searches for galaxy clusters via SZ effect

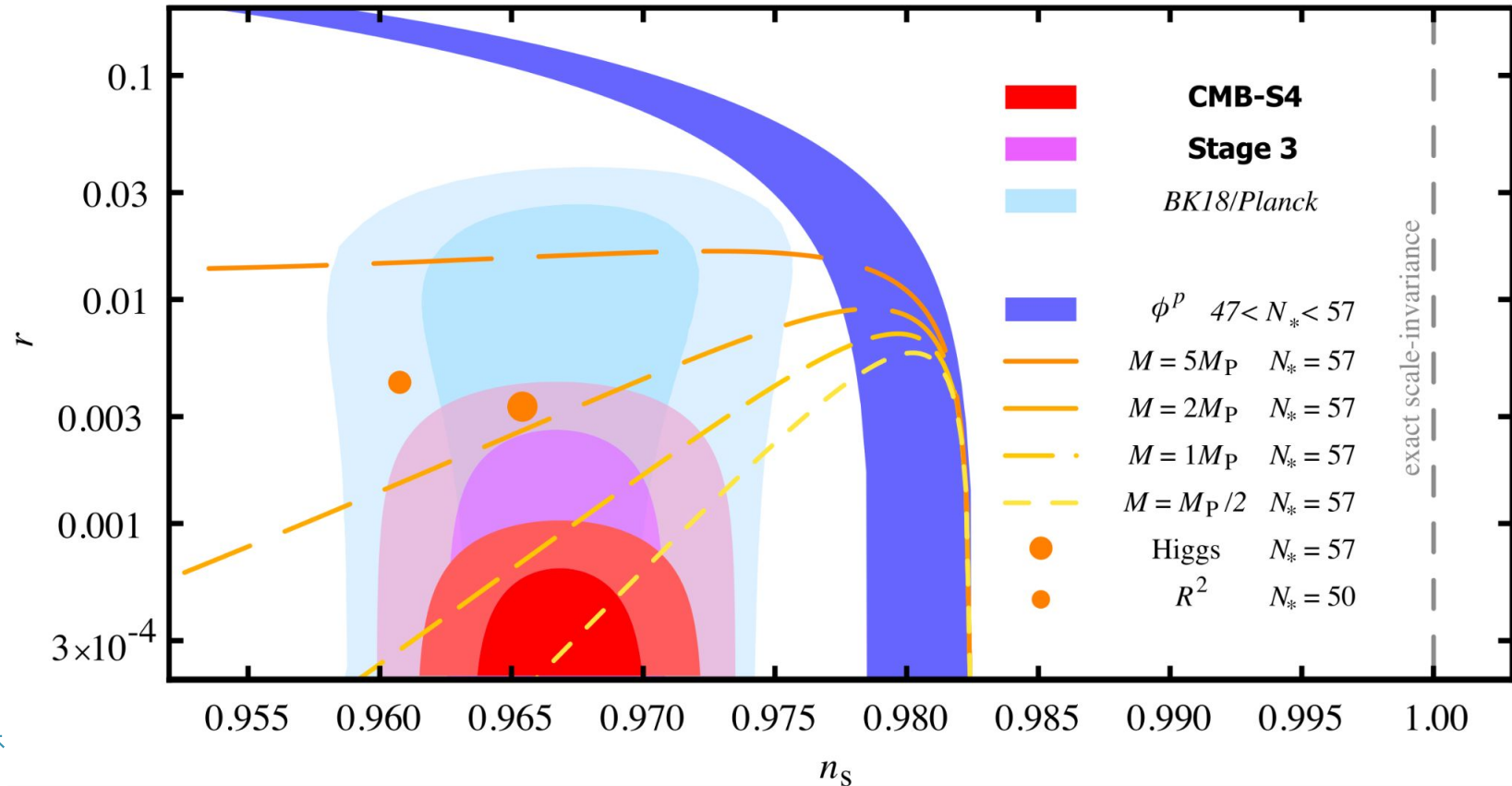
Time Domain: CMB-S4 will provide ~hourly maps which detect millimeter wave transients relevant for wide range of astrophysics and allow and multi-tracer studies with LSST, IceCUBE, and LIGO.

Enabled by deep searches for GRBs

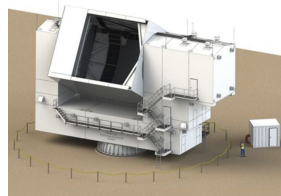
Inflation limits



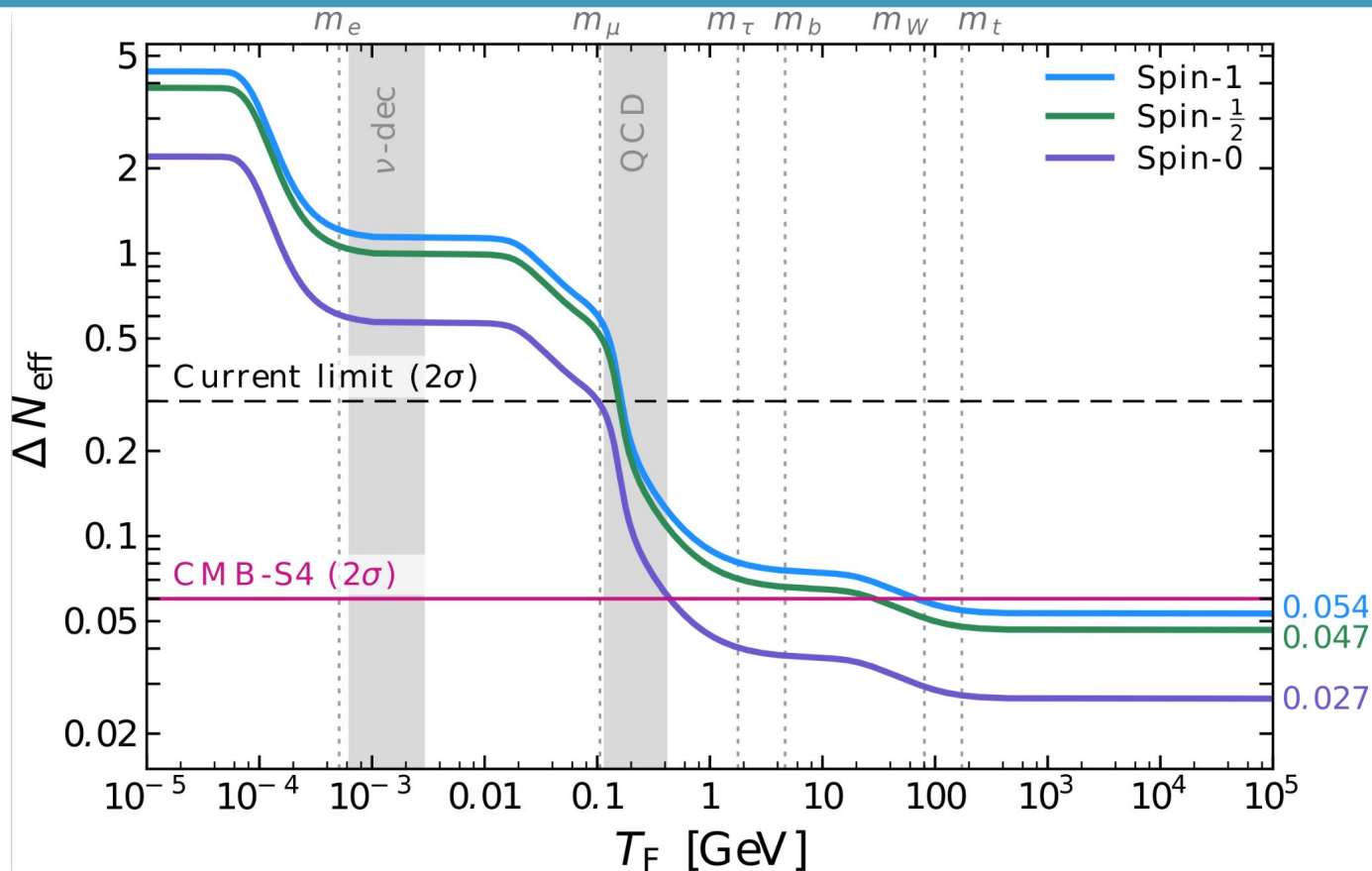
ultra-deep survey



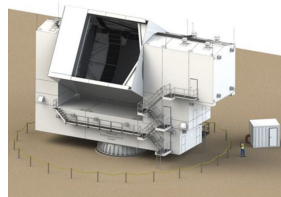
Light relics / N_{eff}



deep-wide survey



Mapping matter / transients



deep-wide survey

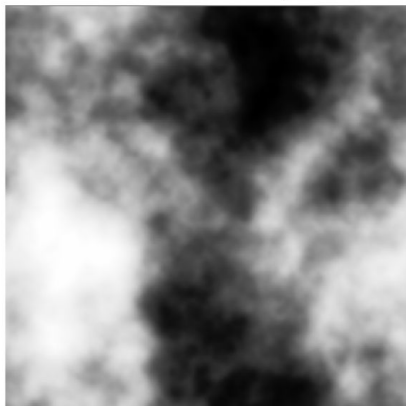
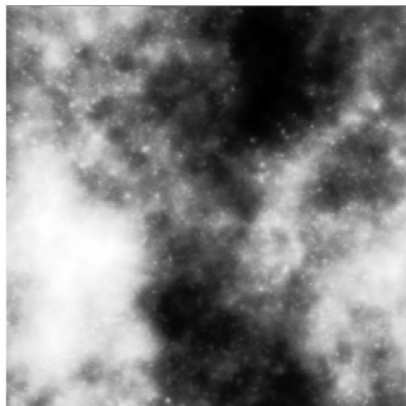


Planck fidelity

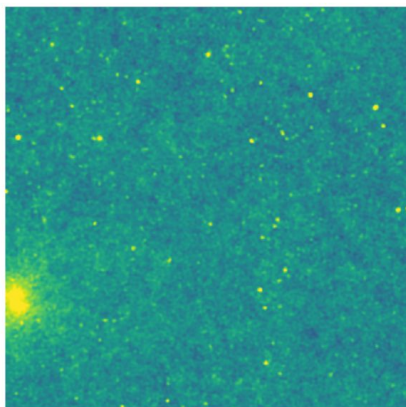
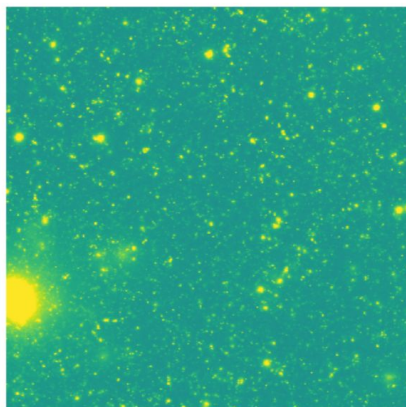
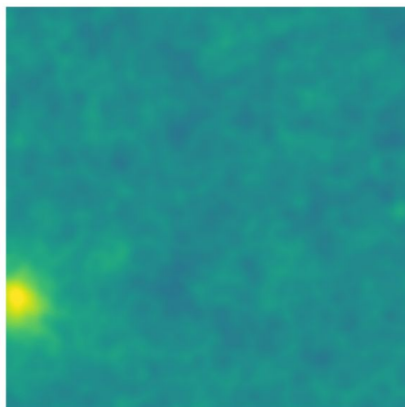
Simulated sky

CMB-S4 fidelity

Lensing



Compton- y



GRB

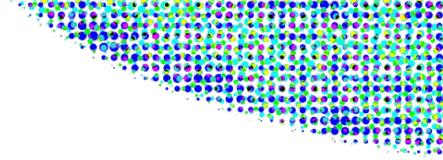


AGN



Flare

Enabling an extremely broad science program



Primary CMB anisotropy: Inflationary gravitational waves • Inflation energy scale • Quantum Gravity • Light relics • BSM particles • Primordial power spectrum • Cosmic census (baryons-dark matter-dark energy) ...

Secondary anisotropies and using the CMB as a backlight: Neutrino mass • Dark Energy • Cosmic birefringence • Axion dark matter • Dark matter-baryon scattering • Sunyaev-Zeldovich scattering effects • Galaxy clusters • Galaxy evolution and feedback • Gravitational lensing • Cross-correlations with gas/mass/galaxies • Cosmological momentum field • Reionization/1st stars ...

Time-domain, deep, wide-area, millimeter-wave survey: Gamma ray bursts • Tidal disruption events • Fast blue optical transients • Supernovae • Time-variable active galactic nuclei • Multi-messenger correlations with time-domain observatories • Dusty star-forming galaxies • Stellar flares • Galactic black hole flares • Fast radio bursts • Interstellar medium • Galactic magnetic field • Exo-Oort Clouds • Planet 9 • Asteroids...

History

- 2013: Launch at Snowmass Summer study
- 2014: Strong endorsement by P5 report
- 2017: Concept Definition Task Force
- 2018: Collaboration formally established with bylaws, elections, officers
- 2019-2020: Project forms; DOE approves CD-0 (mission need); LBNL selected as the lead lab; NSF awards to U Chicago
- 2021: Strong endorsement by Decadal Survey report
- 2022: Descoping due to South Pole Infrastructure (“Dear Colleague letter”)
- 2023: Another strong endorsement by P5 report
- 2024: South pole unavailable on a decade timescale; S4 rescoped to Chile
- 2025: Agencies issue statement ending the CMB-S4 project

10 July 2025 notice from agencies

DOE and NSF Statement on the CMB-S4 Project

Scientific research using data from the Cosmic Microwave Background (CMB) continues to be a priority for the DOE, Office of Science, Office of High Energy Physics, and the U.S. National Science Foundation, providing crucial information on the fundamental nature of matter and energy in the universe.

As recommended by P5 and Astro2020, DOE and NSF have been partnering on funding the design and development of a proposed next generation project, CMB-S4, with precision instrumentation at two sites, the South Pole and the Atacama Desert in Chile, dedicated to detecting primordial gravitational waves that would confirm the model of the Universe with a Big Bang followed by a period of rapid Inflation.

DOE and NSF have jointly decided that they can no longer support the CMB-S4 Project. DOE and NSF will continue to partner with the CMB science community to explore the potential science that can be achieved with limited upgrades to existing experiments to further this important U.S.-led research.

**CMB ...
a priority**

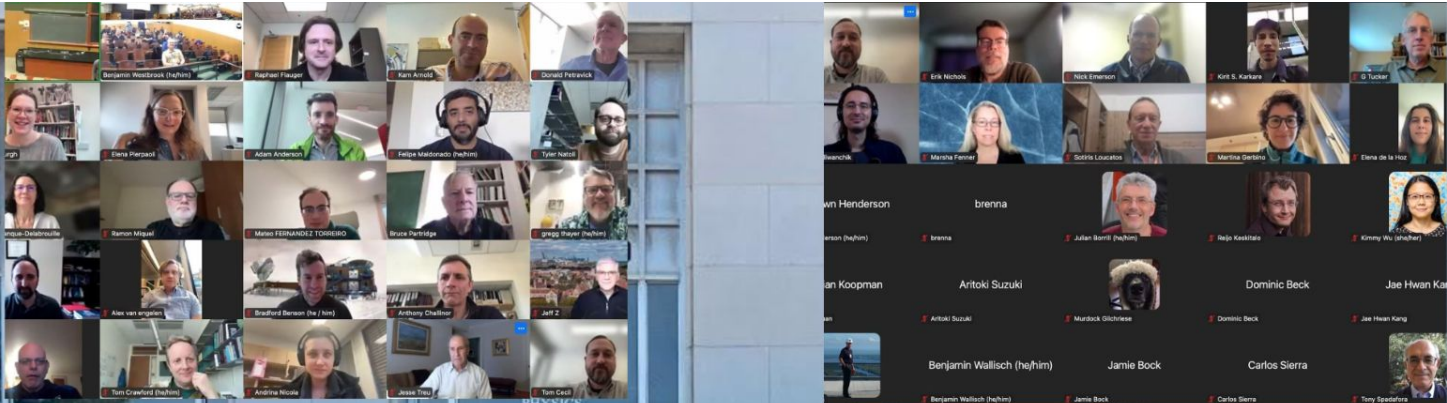
**explore ...
limited upgrades**

Strong Heritage Of Community Endorsements

- 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.”***
- 2022: Snowmass Cosmic Frontier report: ***“Complete the CMB-S4 cosmic microwave background experiment.”***
- 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).”***
- 2019: DOE CD-0: There is a ***“need for the U.S. to continue to lead research in particle physics, dark matter, dark energy, and inflation by mounting a stage 4 CMB discovery-focused project.”***
- 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



Strong and Enthusiastic CMB Science Community



**Spring 2025 Collaboration Meeting at the University of California, Berkeley, March 2025
>200 Participants**

Envisioning the future

For a long time, **CMB-S4 was the long-term future of our field**. CMB-S4 is gone, but the near term of the field is still very bright (see following talks).

But **after the next generation of SO and SPO, what is next for CMB?** (And for non-interferometric mm-wave astronomy generally?)

- **The CMB-S4 science program takes hardware that looks a lot like CMB-S4.** It requires new hardware beyond what stage-3 is fielding, even with upgrades.
- (My view) many ideas: **continued upgrades to existing facilities**, and alternatives with pluses and minuses like space missions for anisotropies or spectral distortions, line intensity mapping, or very large apertures for high resolution.

Priorities



- Ensure continued federal support for the CMB science case: it continues to have field-defining applications across cosmology and astrophysics
- Make it easier for national lab scientists to work on the various CMB projects. (Some progress is being made.)
- CMB-S4 membership was very open; we need to find a place for CMB-S4 members who are not in SO or SPO.



BACKUP

What the collaboration is doing now

The collaboration is an independent organization and the cancellation of the project cut it adrift.

Focusing on two main tasks:

1. Converting the draft of the Science Book 2nd ed into a series of papers that capture updates to the science case since 2016.
2. Figuring out what the future of the collaboration organization or successor organizations may look like. Positive features of the collaboration:
 - Very open and democratic structure
 - Annual meetings
 - Deep commitment to fairness and integrity
 - Junior science advancement career and professional development activities
 - Education and public outreach activities