

Office of High Energy Physics (HEP)Report

CMB-S4 Collaboration Meeting (zoom)

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Office of High Energy Physics (HEP) →Program Mission

- ... is to understand how the universe works at its most fundamental level:
 - Discover the elementary constituents of matter and energy
 - Probe the interactions between them
 - Explore the basic nature of space and time
- The DOE-HEP fulfills its mission by:
 - Building projects that enable discovery science
 - Operating facilities that provide the capability for discoveries
 - Supporting a research program that produces discovery science





HEP Program Layout

HEP is carried out along 3 Frontiers:

Advancements at all 3 frontiers are needed to achieve the long-term goals of the field. →HEP is primarily a Particle Accelerator based program: Energy & Intensity Frontiers



\rightarrow Cosmic Frontier is an increasingly important area

for discovery. Experiments use naturally occurring data to provide additional input to the Standard Model picture: <u>Cosmic Acceleration</u> (Dark Energy, Inflation), search for <u>Dark Matter</u> particles, <u>New Physics</u> (neutrino properties, relic particles, etc)

Crosscutting HEP subprograms:

 Theoretical research, High Performance Computing & Computational HEP, Advanced Detector R&D, Quantum Information Science (QIS).



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HEP – follows P5 Strategic Plan

HEP science priorities come from community via HEPAP advisory panel **Particle Physics Project Prioritization Panel ("P5")** strategic plan. The 2014 report:

- provided the critical scientific questions
- recommended a portfolio of facilities and projects in Energy, Intensity, Cosmic Frontiers to optimally address the science within realistic constraints; also investments in Theory, Detector R&D, Accelerator R&D
- 10 year plan, with 20 year vision

P5 recommended **Cosmic Frontier** science & project priorities in Dark Energy, Dark Matter (direct detection), and CMB

- Dark Energy: build LSST (Rubin) & DESI
- **Dark Matter**: suite of "generation 2" direct detection experiments
- **CMB**: support as part of the core program within multi-agency context; carry out multi-agency CMB-S4 project later in the decade
- Maintain a portfolio of small projects: e.g. ADMX-G2, SPT-3G, Dark Matter New Initiatives

HEP Community support of this process is a critical part of its success



HEP by the Numbers

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Budget

FY 2021 Appropriation - HEP

HEP Funding Category (\$ in K)	FY 2019 Actual	FY 2020 Actual	FY2021 Request	FY2021 House	FY2021 Senate	FY 2021 Appropriati on	FY 2021 Appropriat ion - FY 2020 Actual
Research	384,286	389,577	328,906	397,259	385,685	409,370	+19,793
Facilities/ Operations	258,364	317,929	285,725	313,702	325,315	303,130	-14,799
Projects	337,350	337,494	203,500	339,039	339,000	333,500	-3,994

Total 980,000 1,045,000 818,131 1,050,000 1,050,000 1,046,000 +1,000

FY 2021 Appropriations supports the SC and P5 priorities

- > SC: Interagency & international partnerships, national labs, R&D initiatives
- HEP's P5: preserve vision, modifications as needed to progress
- Strong support in QIS and Artificial Intelligence/Machine Learning Research.
- Flat construction funding for LBNF/DUNE and PIP-II. Strong support for HL-LHC projects.
- Appropriations specified budget amounts in a number of areas.
- Increased support, up \$4M, from \$2M to \$6M for Cosmic Microwave Background-Stage 4.

FY 2021 Appropriation Language for HEP, related to Cosmic Frontier

HEP is directed to provide:

- not less than \$30M for the Sanford Underground Research Facility
- not less than \$6M for Cosmic Microwave Background-Stage 4 (\$5M is R&D/planning)
- \$12M for the Dark Energy Spectroscope Instrument; 6M for LZ
- not less than \$18.5M for Vera C. Rubin Observatory operations

HEP Budget guidance:

- The agreement supports activities toward the completion of the Large Synoptic Survey Telescope and Super Cryogenic Dark Matter Search projects.
- The agreement notes the longstanding planning and contributions of resources by partner organizations with respect to data management on the Vera C. Rubin Observatory.
- The Department is directed to employ the computational expertise and existing capabilities in data management of the Vera C. Rubin Observatory, potentially in partnership with the national laboratories, to ensure the successful operation of this project and access for the broad research community.
- The Department is directed to brief the Committees on Appropriations of both Houses of Congress not later than 30 days after enactment of this Act on the status of the project, including plans for management of the data facility.
- The Department is strongly urged to maintain a balanced portfolio of small-, medium-, and large scale experiments and to ensure adequate funding for research performed at universities and the national laboratories. The Department is encouraged to fund facility operations at levels for optimal operations.



HEP Budget (\$k) FY 2012-2021



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Cosmic Frontier

Cosmic Frontier Experimental Research Program

Address 2014 "P5" strategic plan science drivers using naturally occurring cosmic phenomena via ground-based telescopes & arrays, space missions, and deep underground detectors

Cosmic Acceleration:

- Imaging & Spectroscopic surveys to determine the nature of <u>Dark Energy</u>
- Study the Inflationary era using its imprint on the cosmic microwave background (CMB) at energies near the Planck scale (with NSF)



Dark Matter: Primary efforts are direct-detection searches for particle dark matter

- (WIMPs; axions) through deep underground experiments
- Also indirect searches using cosmic-ray & gamma-ray data

Neutrino Mass: Unique constraints from Dark Energy and CMB experiments

Explore the unknown: search for New Physics, e.g. relic particles

<u>Most projects have partnerships</u> with NSF-PHY, NSF-AST, NSF-OPP, NASA, and international institutions/agencies.



Cosmic Frontier Budget History (FY12-21)



Projections:

- Experimental Operations: As the current Projects complete, estimated needs ramps up to ~ \$55M to \$60M by FY2024; levels to ~ \$40M by FY2030.
- Future opportunities: Compelling Cosmic Frontier Projects will be considered and supported within available overall HEP Project funds. Guidance from Astro2020, next P5



Cosmic Microwave Background



P5 Strategic Plan (2014):

- DOE should support CMB experiments as a core part of the particle physics program
- CMB-S4 intended to be a flagship DOE Cosmic Frontier project, starting in 2nd half of the P5 decade.
 - **Recommended in all funding scenarios.**
 - Last P5 project recommended for development.



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Cosmic Microwave Background Stage 4 (CMB-S4) Project \rightarrow Discovery Science!

Goal: cross critical science thresholds

Highlights:

2 sites: Chile, South Pole

- Ultra-deep "r" survey ≥ 3% of sky + delensing
- Deep & wide N_{eff} & Legacy Survey ~60% of sky
- Large & small telescopes
- 500,000 cryogenic sensors, superconducting readout



Ultra-precision measurement of

Science	Stage 2	Stage 3	Stage 4	Top Level goal for CMB-S4
Inflation "r"	≤0.1	≤0.01	≤0.001	Detect/rule out classes of inflationary models
σ(Neff)	0.14	0.06	0.03	Detect/rule out light relic particles w/ spin
σ(Mv)	0.15eV	0.06eV	0.02eV	3σ detection
# detectors	~1000	~10,000	~500,000	Deployed on multiple telescopes
Sensitivity (μK^{-2})	105	108	10 ⁸	2° to 1' angular scales



CMB-S4 History at DOE

Early 2010's: CMB-S4 Community-based Collaboration brought together ground based community to plan future; Collaboration Science, Technology Books: Detector wafers

https://arxiv.org/abs/1610.02743; https://arxiv.org/abs/1706.02464

2014: P5 recommended HEP participation with NSF in CMB-S4, starting in middle of P5 decade.

- P5 recognized the huge discovery potential; priority in all funding scenarios
- Significant HEP community interest
- Envisioned as a unified DOE-NSF project, DOE/HEP, MPS/PHYS, MPS/ASTRO, GEO/OPP
- 2015: HEP labs/community ramped up efforts on technology R&D and concept planning to align with P5.
- HEP moved forward in planning, in coordination with NSF
- **2016:** Science collaboration established
- DOE & NSF charged the Astronomy & Astrophysics Advisory Committee (AAAC) to carry out a subpanel study: Concept Definition Taskforce (CDT) Transition Edge Sensors
- **2017:** CDT report provided science goals, initial strawperson concept design, cost, schedule
- → Subsequently Interim Project Office set up
- **2018:** pre-Project Design Group (pPDG) established by DOE labs to focus on project development and coordination.
- **2018:** CMB-S4 science collaboration was formalized.



SOUID

Transition

Signal: µK

width: mK

~1000 pixels per

waver

0.8

0.6 ΔR

0.4

0.2

CMB-S4 History at DOE

- July.2019 CMB-S4 submission to the National Academies of Sciences Astronomy & Astrophysics Decadal Survey (Astro2020) <u>https://arxiv.org/abs/1907.04473</u>
- ▶ July.2019 Project received Critical Decision 0 (CD-0) "Mission Need" approved by Office of Science Leadership → Project Start!
- Aug.2020, LBNL chosen as DOE Lead lab

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- Will manage DOE/HEP roles & responsibilities
 - Currently developing project management, personnel, R&D plan, cost, & schedule in association with Univ. of Chicago 2019 NSF MSRI-1 award; moving towards CD-1.
- Aug.2020 DOE/HEP held a status review of project planning
- Dec.2020, FY21 budget appropriation provides \$5M for R&D and project management and \$1M in equipment "EQU" funding
 - Congress approved it as a Major Item of Equipment (MIE) "project start" by providing EQU funding; can't use until CD-3.

Detector wafers ~1000 pixels per waver







CMB-S4 \rightarrow future

Spring 2021 Astro2020 report finalized

Late Summer 2021 DOE review of status

Continuing: ~ weekly DOE & NSF Joint Oversight Group (JOG) meetings – work well together!

Short term challenge: slow ramp up of funding compared to Project's request; limits the planned R&D, especially on detectors and readout

Longer term challenge: Synchronizing the NSF and DOE parts; Experience with partnerships on LSST and HL-LHC will prove useful



Summary

- Excellent science results continue to be produced from our operating experiments!
- P5 strategic plan is supported by Community and broad support is enabling it to be fully implemented.
- FY2021 Budget Appropriation provided Congressional approval for the CMB-S4 project
- HEP and community are working to balance research and operations needs with project funds to carry out an optimal program



Take Away Message: CMB-S4 is a flagship project for the DOE/HEP Cosmic Frontier and a priority for DOE/HEP → We are very excited to be part of it and look forward to the next steps!



