Office of High Energy Physics (HEP) Report

CMB-S4 Collaboration Meeting (zoom)

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Cosmic Frontier group members:
- Karen Byrum (Detailee), Drew Baden (IPA)
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 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

→ Cosmic Frontier is an increasingly important area for discovery. Experiments use naturally occurring data to provide additional input to the Standard Model picture: Cosmic Acceleration (Dark Energy, Inflation), search for Dark Matter particles, New Physics (neutrino properties, relic particles, etc)

Crosscutting HEP subprograms:
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

## HEP Research Spans
- More than 160 Academic, Nonprofit, and Industrial Institutions
- 12 DOE National Laboratories
- 42 States and Washington, D.C.
- 13 Core Research Thrusts
- Over 400 Annual HEP Publications in Peer-Reviewed Scientific Journals

## Supported Researchers
- 1,115 Ph.D Scientists (325 Post-Docs)
- 595 Graduate Students

## HEP by the Numbers (FY 2020)
- HEP’s mission is to understand how the universe works at its most fundamental level by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time.
- $390 Million Research Budget
  - $25M SBIR/STTR, $118M Universities, $247M DOE Labs
- 15 Presidential Early Career Awards for Scientists and Engineers (PECASE)
- Over 300 Active Awards
- $317 Million Scientific User Facilities and Experimental Operations Budget
  - LHC, SURF, Rubin/LSST, DESI, LZ, AMS, Test Facilities, etc.
- $338 Million Line-Item Construction Project and Major-Item of Equipment Budget
## FY 2021 Appropriation - HEP

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<td><strong>1,050,000</strong></td>
<td><strong>1,046,000</strong></td>
<td><strong>+1,000</strong></td>
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**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.
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 Spectroscopic 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.
Cosmic Frontier
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 **Dark Energy**
- 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

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

Gain insight into **inflationary epoch, dark energy, neutrino properties** and other science topics by studying oldest visible light.

**Current Experiments w/HEP involvement**

- **SPT-3G:** DOE-HEP partnership with NSF. HEP supported major upgrade: fabrication of the 16,000-detector focal plane, greatly increasing instrument sensitivity.
- Research-only efforts in science collaborations (**BICEP, PolarBear**)
- Significant role in **Planck** (via NERSC computing).

**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 2\(^{nd}\) half of the P5 decade.
  - Recommended in all funding scenarios.
  - Last P5 project recommended for development.

\[ \text{SPT-3G continues operations at full power and high observing efficiency.} \]

\[ \text{Good and consistent efficiency} \]

\[ \text{Stable sensitivity} \]

\[ \text{Cumulative map depth improving as expected} \]

\[ \text{Graph showing cumulative map depth over time} \]
Cosmic Microwave Background Stage 4 (CMB-S4) Project → Discovery Science!

**Goal:** cross critical science thresholds

**Highlights:**
2 sites: Chile, South Pole
- Ultra-deep “r” survey ≥ 3% of sky + delensing
- Deep & wide Neff & Legacy Survey ~60% of sky
- Large & small telescopes
- 500,000 cryogenic sensors, superconducting readout

### 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(Mν) | 0.15eV | 0.06eV | 0.02eV | 3σ detection
# detectors | ~1000 | ~10,000 | ~500,000 | Deployed on multiple telescopes
Sensitivity (μK^2) | 10^5 | 10^8 | 10^8 | 2° to 1’ angular scales
CMB-S4 History at DOE


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)

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.
CMB-S4 History at DOE


- **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
  - 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.
CMB-S4 → 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
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!