DOE Office of Science (SC), Office of High Energy Physics (HEP) Cosmic Frontier Report

to the

Astronomy & Astrophysics Advisory Committee

February 23, 2023

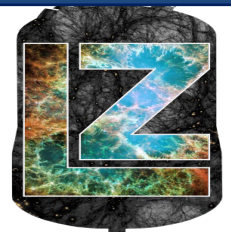
Kathy Turner

Cosmic Frontier Program Managers: Karen Byrum, Bryan Field, Chris Jackson, Kathy Turner

U.S. DEPARTMENT OF ENERGY | Office of Science

VERA C. RUBIN OBSERVATORY

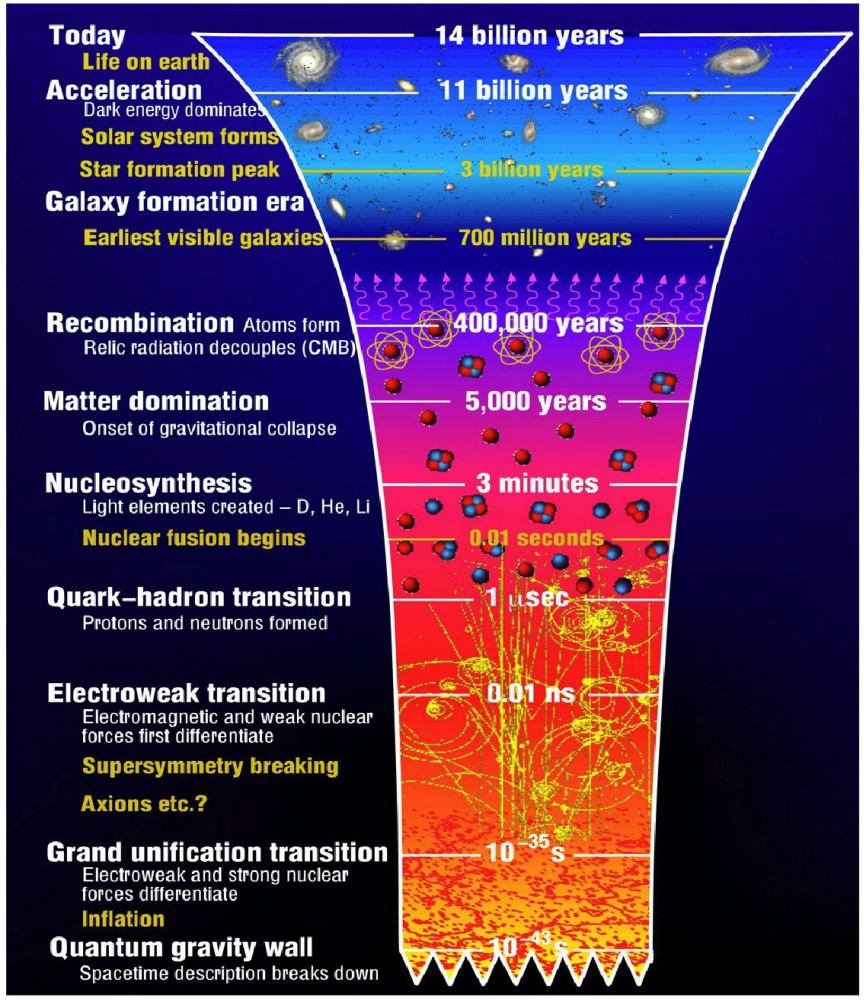
ADMX AXION DARK MATTER EXPERIMENT



SUPER CDMS Cryogenic Dark Matter Search

Cosmic Frontier – Experimental Program

Cosmic Frontier: Naturally occurring data is used to study of the fundamental nature of matter, energy, space and time in areas complementary to accelerator experiments.



Experiments to reveal the nature of **dark energy** and search for **dark matter** particles, comprising ~95% of the universe, understand the **cosmic acceleration** caused by dark energy and inflation, infer **neutrino** properties, and explore the unknown.

→ Cosmic Frontier is carrying out specific projects recommended by the 2014 P5 strategic plan.

- **Cosmic Acceleration:**
  - **Dark Energy**: build **LSST (Rubin) & DESI**
  - **CMB:** carry out multi-agency **CMB-S4** project
  - **Dark Ages**: **LuSEE-Night** pathfinder – small project
- **Dark Matter:** suite of "generation 2" direct detection experiments to detect DM particles; Dark Matter New Initiatives (DMNI) concept development for small projects

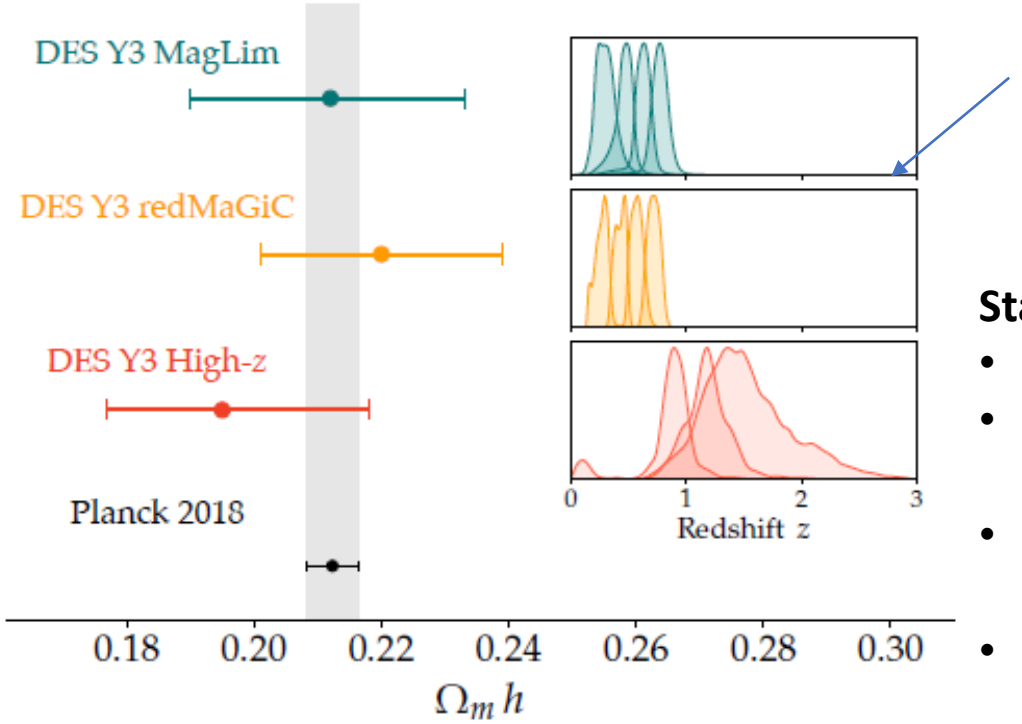
- Partnerships w/NSF (PHY, AST, OPP) NASA (AST, ISS, CLPS), and/or International.
- Overlap with other HEP areas (e.g. Theory, Advanced Detector Development, Computational HEP, QIS, AI/ML) and other SC areas (e.g. ASCR Supercomputing)

Dark Energy Survey (DES), Dark Energy Camera (DECam)

DARK ENERGY SURVEY

DOE and NSF partnership

- Fermilab led fabrication of 570Mpix DECam; NSF led telescope upgrades, data man. system
- Both agencies supported operations on NSF's Blanco telescope at CTIO in Chile
- 6-year imaging survey of 5100 sq-deg **completed Jan. 2019**
- *Collaboration > 400 scientists; 25 institutions in 7 countries;* >416 publications; >100 PhD's



A recent result:

- Year 3 High-z galaxy-galaxy correlation cosmology paper submitted.
- It greatly extends the redshift range compared to the Y3 Key Project results (which were called MagLim and redMaGiC).
- Plot shows constraints on W_M h for the three lens samples https://arxiv.org/abs/2211.16593

Status

- Year 3 value-added cosmology catalog was made public in March 2022.
- Year 6A2 "Gold" catalog has been released to the collaboration and they are working on cosmology analyses.
- As of end of 2022, 416 papers submitted, 386 accepted or published, 22,780 citations.
- Working on cosmology from 1650 photo-z typed SN1a, with spectroscopic z's of host galaxies and cosmology from the Y6 BAO measurements.

Dark Energy Spectroscopic Instrument (DESI) Experiment

DOE's DESI is in its 2nd year of operations (since May 2022).

- World's premier multi-object spectrograph w/5,000 fibers, positioned robotically

First **Stage IV dark energy;** Will measure spectra of > 40 million galaxies

DOE/LBNL Project: Instrumentation, Data Management System, & Upgrades of NSF's Kitt Peak Mayall telescope (including MOSAIC camera).

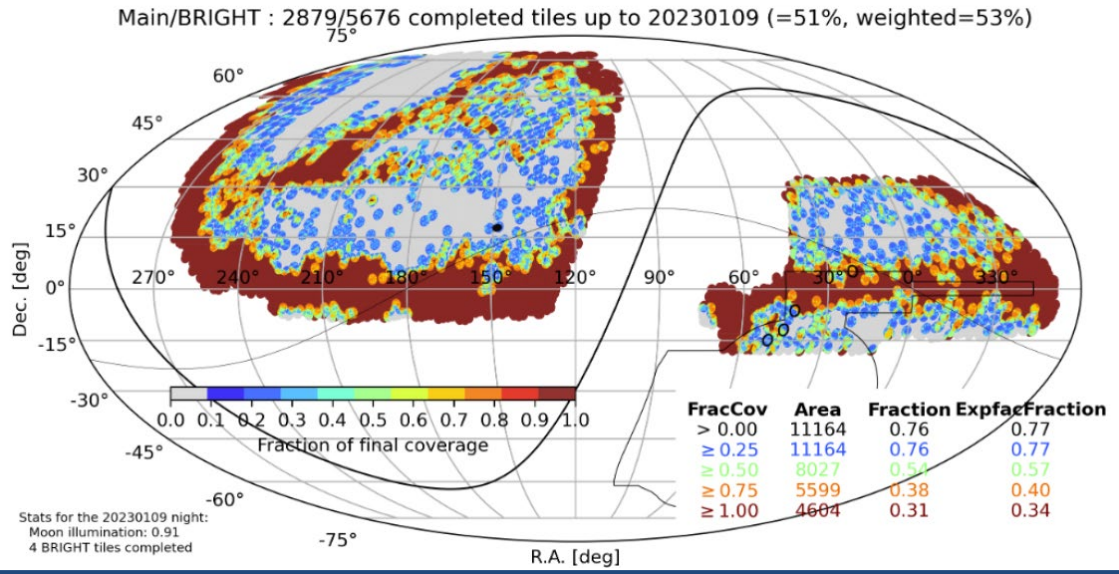
Operations: DOE provides full support for NSF's Mayall telescope.

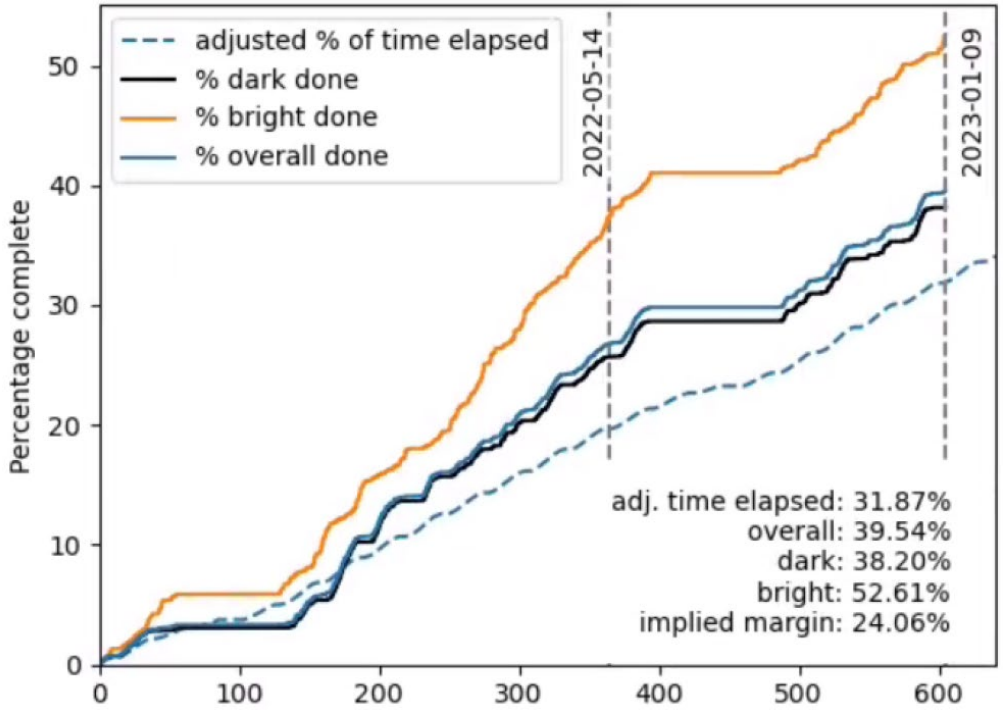
Bright-time survey > 50% complete

Dark-time survey almost 40% complete

Through early January 2023 – DESI is running ahead of schedule

Successful data-taking: ~ 17 Million extra-galactic redshifts recorded (more than all other surveys combined)

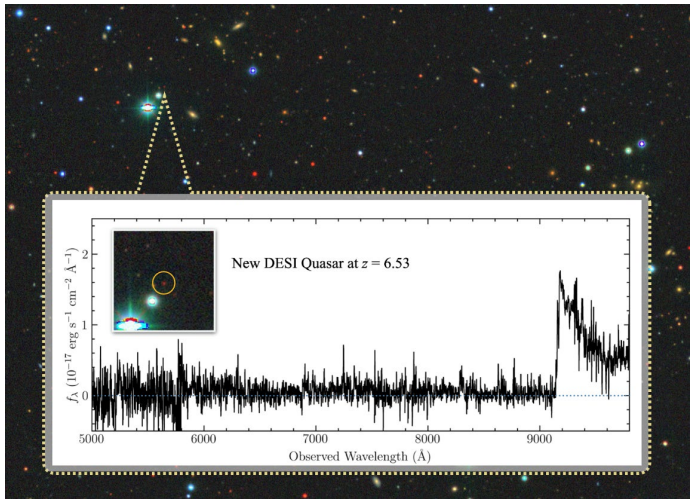




DESI - status

2022 June Contreras Fire

- NEWS ➔ DESI is back on-sky as of Sept. 16, 2022
- As of now, main-line power and fiber internet are restored
- Road access to KPNO continues to be restricted.
- Still assessing whether the Mayall aluminum coating may have a loss of reflectivity due to fire-borne particulates.



Example of the throughput of DESI's near-infrared spectroscopy in finding DESI's highest redshift, z=6.53, quasar

Collaboration efforts:

- First Cosmology results shown at Cosmopalooza in Jan. 2022
- Seminal paper on Instrumentation - published
- 37 refereed and published papers so far
- Survey Validation (SV) results: 8 papers submitted in support of the primary goals and conclusions including
  - optimization of target selection
  - redshift of the BGS, LRG, ELG, and quasar target samples relative to the projections
- Working on early science results including competitive BAO results based on first 2 months of data

➔First year data released to the collaboration in early February 2023; will eventually go public.

The DR includes all data up until the fire last year (through June). It just took 7 months to release this finished processed data with calibrations, subtractions, Q/A, and catalogs created from when the last bit was taken at Kitt Peak. There are over 14 Million main survey extra-galactic redshifts; including 6.4M BGS, 2.9M LRG, 4.0M ELG, and 1.4M QSO main survey target spectra and redshifts.

Vera C. Rubin Observatory

- A next-generation, ground-based facility, providing time-lapse imaging of faint astronomical objects across the half the whole sky every few nights.

NSF (AURA) & DOE (SLAC) partnership, with private, international contributions

Construction Project: DOE responsibilities → **Project construction complete expected in late 2024.**

- **LSST Camera** MIE fabrication completed Sept. 2021; all key performance parameters demonstrated
- **Commissioning roles -** LSST Camera assembly, test, shipment, integration; effort on the 9-CCD Commissioning Camera (ComCam); data quality and verification studies

Facility Operations

Pre-Operations activities have started; Full operations planning continues; Joint DOE/NSF review is scheduled for late February

DOE-supported operations efforts are primarily:

- Camera maintenance and operations
- US Data Facility → SLAC selected to be the managing organization
  - Will carry out the full data facility efforts & deliver all the data products to all researchers and collaborations

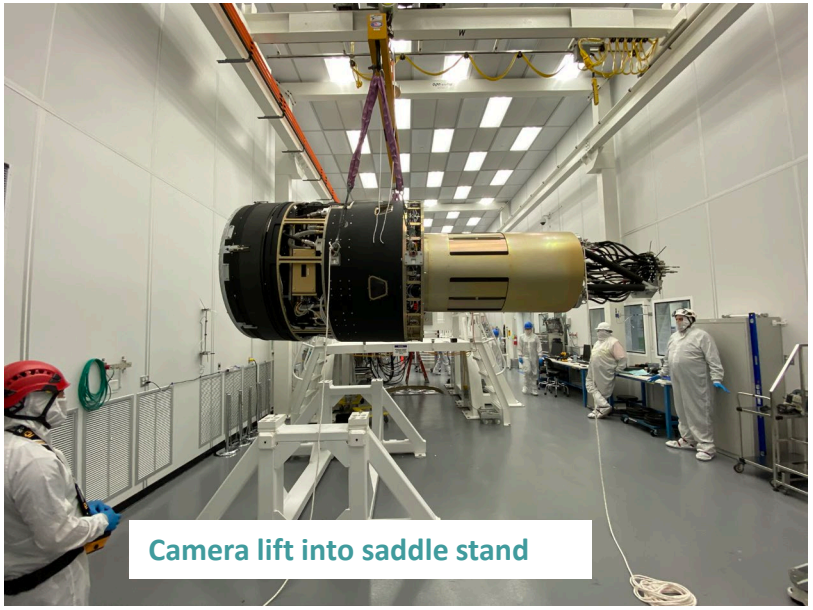
DOE people at Rubin, Sept 2022

Integration, Test & Commissioning

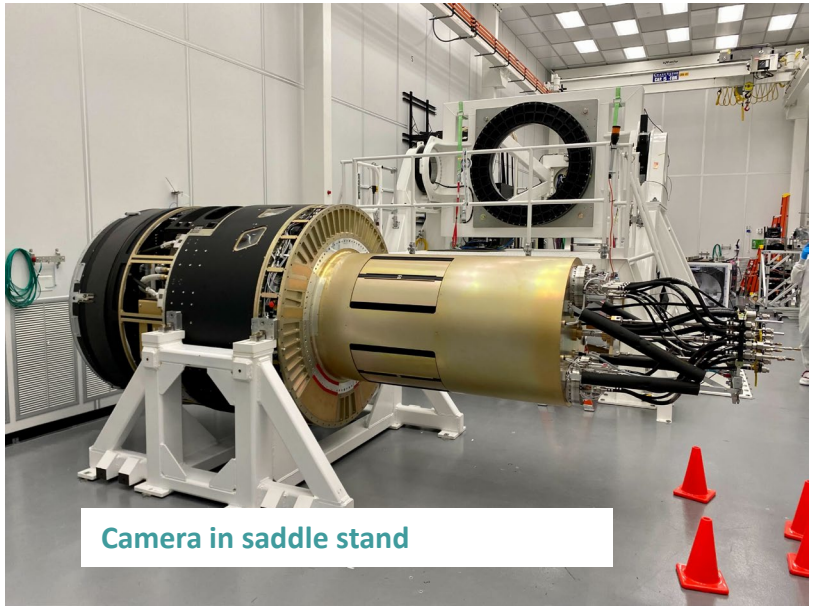
At SLAC: Camera now fully assembled; See video of Filter operation (https://drive.google.com/file/d/19uQ14LRCP3RvCDzjgKjOAkVETWtAp_YC/view?usp=share_link)

- Camera Cold Refrigeration system needed to be replaced due to instabilities; the new pumped-coolant system modifications are now complete
- Preparing for final verification testing at SLAC this spring
- Current schedule has shipment to Chile in May/June

In Chile: ComCam mounted on Telescope, being used to exercise observatory systems



Camera lift into saddle stand



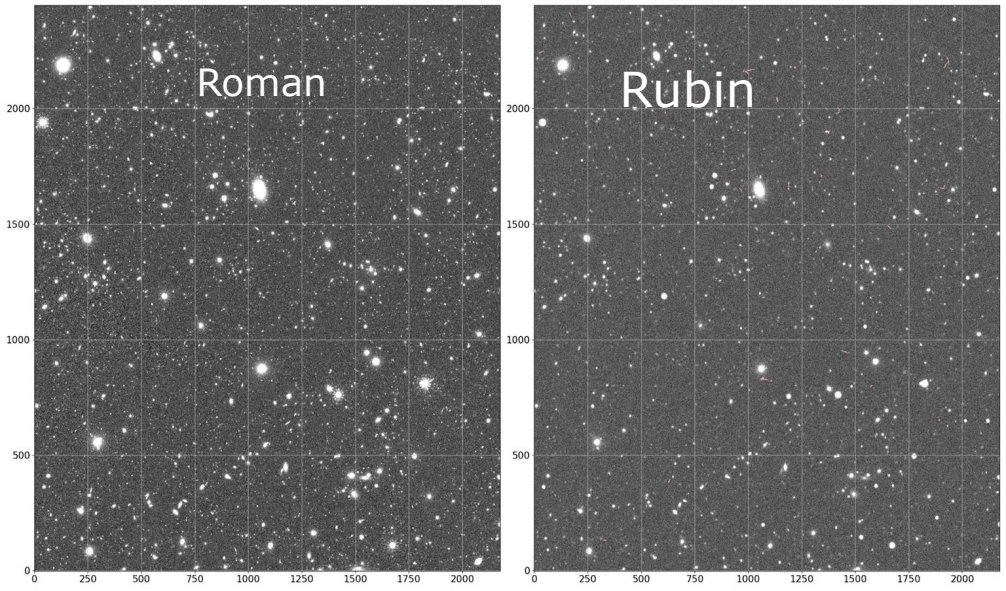
Camera in saddle stand

ComCam and the white M2 surrogate.

Dark Energy Science Collaboration (DESC) will use the Rubin Observatory's Legacy Survey of Space and Time

Scientific Research - Both NSF and DOE will support community efforts

- **DOE's research efforts are organized through DESC**; planning, pipeline building and readiness activities are continuing.
- Fruitful collaboration between **DESC and Rubin** on many fronts, including simulations, image coaddition and deblending, and commissioning



Simulations of the same patch of sky as seen by NASA's Roman mission and Rubin, based on DESC DC2, arXiv:2209.06829, Image credit: Sanchez, Troxel

Study of the nature of Dark Energy via complementary probes: SNe, Strong and weak Lensing, Large-scale Structure, Galaxy Clusters

These probes also provide constraints on the nature of inflation, modifications to GR, the masses of neutrinos, the nature of dark matter.

Collaboration ~ 1150 members;

- 238 full members; from 20+ countries
- Since 2018, 52 journal publications + 16 papers under review

Astro2020 Science Theme:
New Messengers and New Physics ➔ CMB-S4

Recommendation(p. 7-26): DOE/NSF partnership on CMB-S4

NSF & DOE should jointly pursue the design & implementation of the next generation ground-based cosmic microwave background experiment. "An important requirement for our strong endorsement is that the project broadly engage astronomers beyond the traditional CMB community.

FY2021 - Congress approved DOE **Major Item of Equipment "project start"**

CMB-S4 goal: cross critical science thresholds, including definitive tests of Inflation

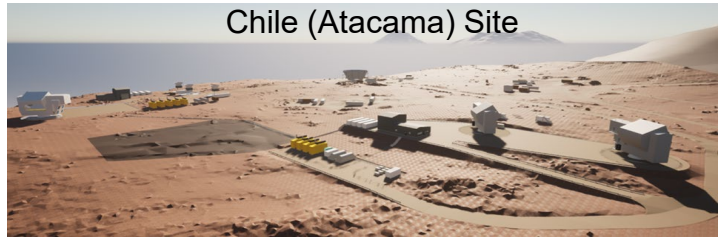
DOE/HEP embraces the Astro2020 recommendation and is working with NSF to move CMB-S4 forward.

- Well aligned with P5 science drivers.
- Technology, high performance computing needs, and project roles are well matched to DOE lab expertise and capabilities

➔DOE & NSF continue regular meetings on CMB-S4; now every 2 weeks

South Pole Site

Chile (Atacama) Site



CMB-S4 status, planning

Early FY2022 – Project's expectations for Antarctic infrastructure & logistics (I&L) aren't sufficient for the original concept.

➔Project begins development of alternative concept(s) that fit within I&L constraints AND still delivers the full science.

Dec. 2022 – Project briefed agencies on the results of their Analysis of Alternatives.

Alternative 1:

- South Pole: 3 Small-Aperture Telescopes and 1 Large-Aperture Telescope
- Chile: 2 Large Aperture Telescopes
- Renewable energy and energy storage on an independent grid to supplement the power available at the South Pole

DOE/HEP is supportive of the Project moving forward on developing Alternative 1

- ✓ **assessed as meeting science goals, with precision and systematic error checks needed for Inflation**
- ✓ **cost effective;** construction and lifecycle costs are the lowest
- ✓ **close to Project's estimate of I&L availability**

DOE Funding:

- FY22 $8M + FY22 IRA $10M
- FY23 $1M
- Expect to be able to provide funds sufficient to move them forward to a conceptual design and Critical Decision 1 (CD-1) review by end of FY24.

DOE/NASA Partnership on LuSEE-Night → Pathfinder to the Dark Ages

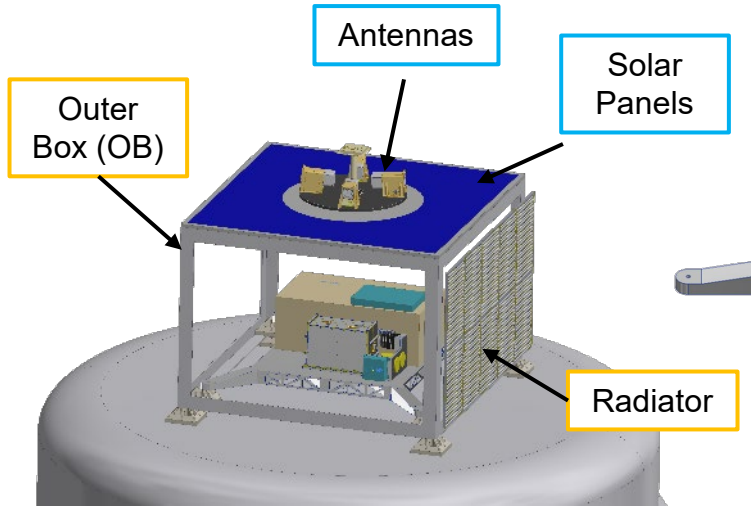
The **Panel on Cosmology** identified as a **Discovery Area** using the **Dark Ages as a cosmological probe with great potential.**
"The panel sees 21 cm and molecular line intensity mapping of the Dark Ages and reionization era as both the discovery area for the next decade and as the likely future technique for measuring the initial conditions of the universe in the decades to follow."

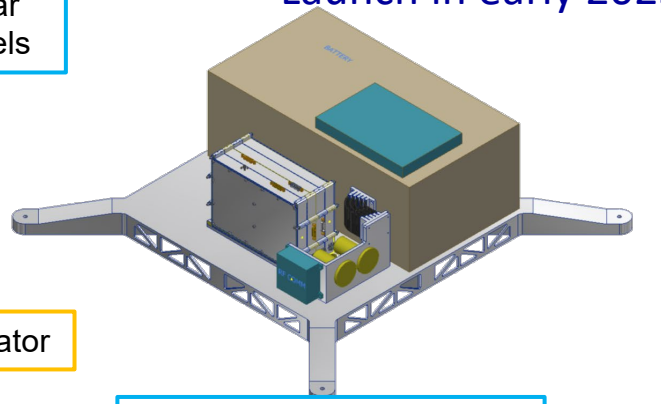
➔**The Dark Ages signal has never been observed. A first discovery would be a significant step in understanding this phase after CMB and when stars & galaxies form.**

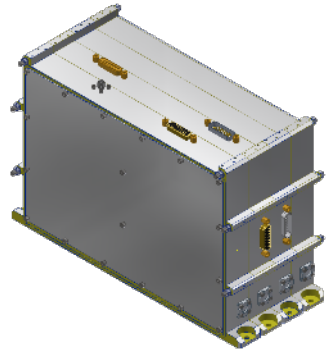
- LuSEE-Night is a pathfinder mission to place the most sensitive constraints to date on the **Dark Ages signal**
- Capability to measure the radio environment and observe the long-wavelength radio signal through the lunar night (launch early 2025).

UCB/SSL is overall lead (for **LuSEE-Night** & **LuSEE-Light)**
DOE LuSEE-Night Project started in FY 2022 (all funds provided)

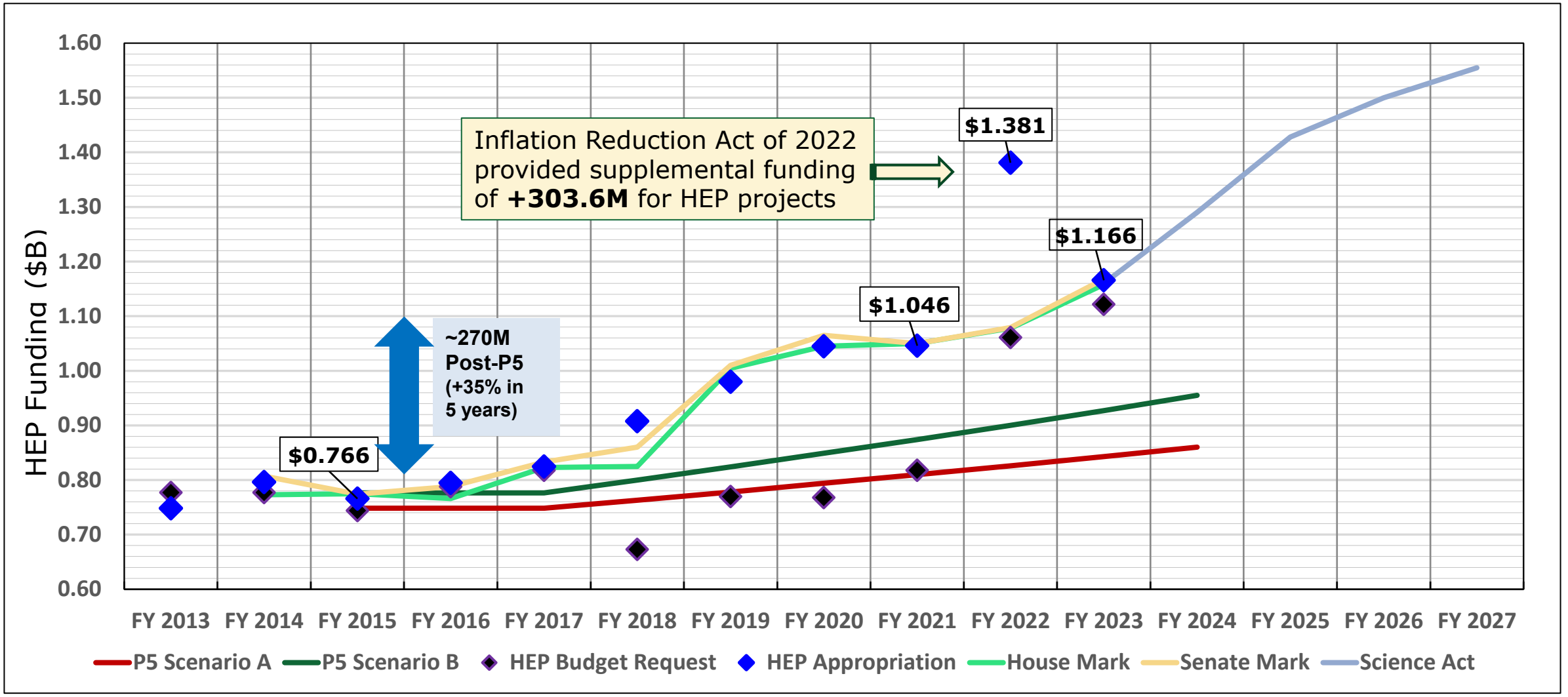
- deliver to the UCB/SSL project office by early 2024
- Launch in early 2025 by NASA's Commercial Lunar Payload Service.




Inner Equipment Assembly (IEA)


Main Electronics Crate (MEC)

HEP Budget History 2013 to Present



- U.S. Congress continues to show strong support for executing the P5 strategy, and for accelerating the pace of projects

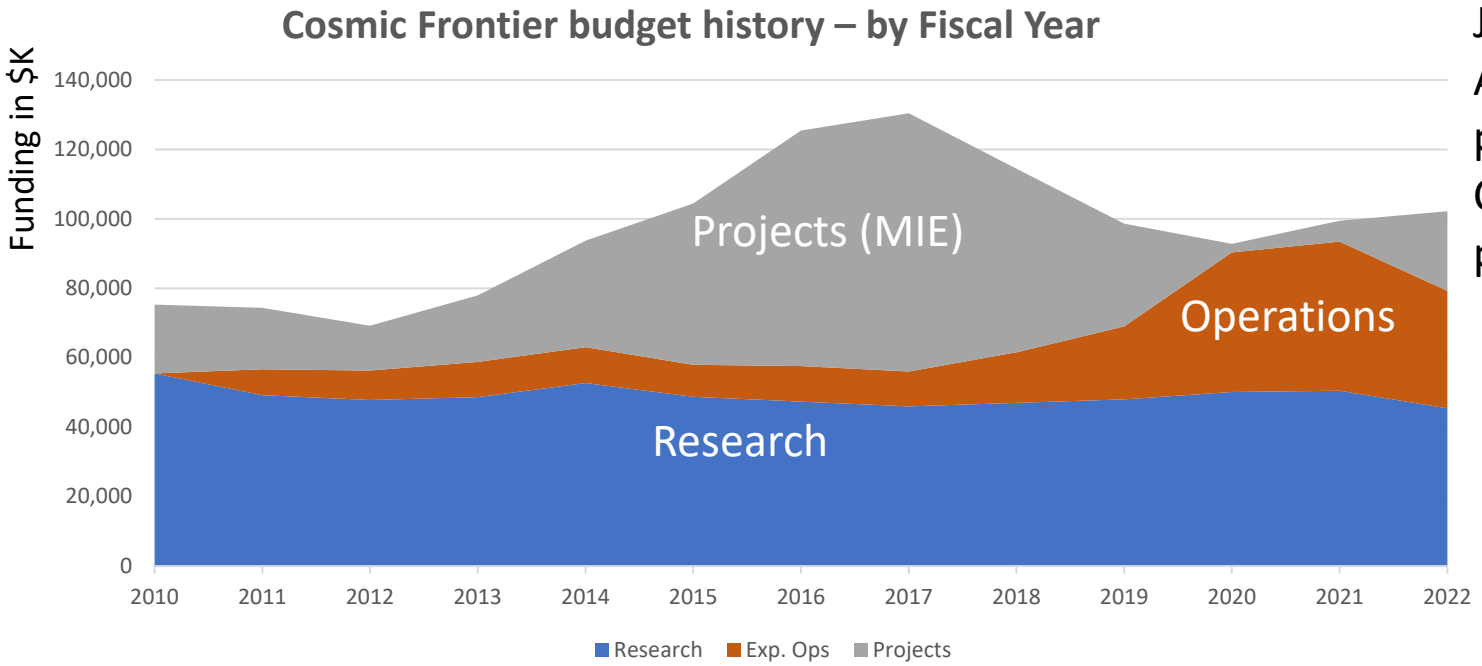
Initiatives (HEP budget)

HEP budget (in $K)	FY20 Enacted	FY21 Enacted	FY22 Enacted	FY23 Enacted
BE: Reaching a New Energy Sciences Workforce (RENEW)	0.0	0.0	4.0	8.0
BE: Funding for Accelerated, Inclusive Research (FAIR)				1.9
BE: EPSCOR				1.9
Artificial Intelligence & Machine Learning (AI/ML)	15.0	33.5	35.8	38.5
Traineeships (GARD, Computing, Detector R&D)	4.0	4.0	5.0	6.0
Advanced Computing (was Integrated Computational & Data Infrastructure)			4.1	5.0
Microelectronics		5.0	7.0	6.7
Quantum Information Science (QIS)	23.5	20.1	26.6	24.5
Quantum Center	15.0	25.0	25.0	24.4
Accelerate [Accformerlyelerate Innovations in Emerging Technologies]				3.8
Accelerator Science and Technology Initiative (ASTI) [formerly SATI]		6.3	17.4	9.6

SC efforts:

- **RENEW**: SC selections from the FY 2022 ($32M); in FY 2023, SC has committed to nearly doubling the funding to $56M
- **FAIR**: SC announced the FY 2023 FAIR solicitation, **committing $35M** to support research capacity at MSIs and non-R1 institutions.
- See details at https://science.osti.gov/Initiatives/RENEW and https://science.osti.gov/Initiatives/FAIR.

Cosmic Frontier Budget History



July 2022: The CHIPS and Science Act 2022 is an Authorization bill (DOE ~ $67B over 5 years), a prerequisite under House and Senate rules for the Congress to appropriate budget authority for programs.

Experimental Operations: Commissioning and facility operations planning for LSST/Rubin; operations of FGST/LAT, SPT-3G, ADMX-G2, DESI, LZ; pre-operations activities for SuperCDMS-SNOLAB. As the current Projects complete, estimated needs ramps up to ~ $55M to $60M by FY2024; levels to ~ $40M by FY2030.

Projects: CMB-S4, LuSEE-Night; SuperCDMS completing in FY23

Future opportunities: Compelling Cosmic Frontier Projects will be considered and supported within available overall HEP project funds. Guidance from Astro2020, Snowmass, P5 (2023)

Cosmic Frontier ($K)	FY2021 Actual	FY2022 Actual	FY2022 IRA	FY2023 Enacted
Research (Univ+Lab)	*43,901*	*42,513*		*44,237*
Future R&D	*1,700*	*1,475*		*1800*
AI/ML Research for CF	4,920	5,407		4,640
Experimental Ops.	42,880	44,350		56,550
Projects	6,000	23,000	10,000	1,000
DESI	*0*			*0*
LZ	*0*			*0*
SuperCDMS	*0*			*0*
CMB-S4	*6,000*	*8,000*	*10,000*	*1,000*
LuSEE-Night		*15,000*		
Total	**99,401**	**116,745**	**10,000**	**108,227**

Astro2020/AAAC – Recommendations (in addition to CMB-S4) ➔DOE, SC and HEP Efforts and Responses

Diversity, Equity, Inclusion, Harassment, Discrimination

- DOE is on the Task Force responding to White House 2021 memo Restoring Trust in Government Through Scientific Integrity and Evidence-Based Policy Making; now developing response to recommendations following OSTP 2022 memo.
- SC is deeply committed to supporting Diverse, Equitable, Inclusive and Accessible work environments and funding
  - (see SC Statement of Commitment: https://science.osti.gov/SW-DEI/SC- Statement-of-Commitment and The Roadmap to Equity and Justice at the Department of Energy | Department of Energy)
- In Sept. 2022, DOE released our first-ever Diversity, Equity, Inclusion, and Accessibility (DEIA) Strategic Plan, which outlines actions to strengthen efforts and initiatives to address these principles.
- Starting FY 2023, all SC FOAs require a Promoting Inclusive and Equitable Research (PIER) plan in proposals, with an associated merit review metric.
- New SC-hosted or -funded conference requirements -- including a code-of-conduct (with consequences if not followed) recruitment, and accessibility.
- New or enhanced programs to broaden participation:
  - *FY2022:* SC's *Reaching a New Energy Sciences Workforce (RENEW)* provides research opportunities to historically underrepresented groups in the physical and climate sciences through internships, training programs, and mentor opportunities.
  - FY2023: SC's *Funding for Accelerated and Inclusive Research (FAIR)* is aimed at undergraduate students.
  - Programs for work at labs: Community College Internships (CCI); Science Undergraduate Laboratory Internships (SULI); SC Graduate Student Research fellowships (SCSGR); Visiting Faculty Program; Albert Einstein Distinguished Educator Program (K-12)
  - DOE Scholars Program to work at DOE or a lab
  - DOE labs have specific workforce development & community programs aimed at a diversity of educational levels.
  - HEP traineeship FOA's in Instrumentation, Accelerator R&D, and Computing – address critical, targeted workforce development in focused areas. https://science.osti.gov/-/media/grants/pdf/foas/2021/SC_FOA_0002496.pdf

Astro2020/AAAC – Recommendations
➔DOE, SC and HEP Efforts and Responses

Demographics, Proposal Metrics & Reviews

- DOE currently collects demographics as required/allowed by OMB; We are working to improve data collection and reporting capabilities.
- White House study *https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/*
- DOE issued the DOE Equity Action Plan in April 2022; includes actions on overcoming institutional barriers for demographics collection. CHIPS and Science Act includes provision for OSTP to establish consistent guidelines across the Federal agencies for collecting data on applicants/awardees. OSTP is in the early planning stages to address this with federal guidelines.
- HEP specifically considers diversity on review panels for proposals and for projects, experimental operations and facilities.
- Dual anonymous isn't straightforward in HEP since we have "block" grants, a merit criteria is a person's expertise and the grant's cover a person's effort on the project (e.g. in charge of building instrumentation) as well as their research program.

AI/ML

AI/ML techniques in high energy physics are vitally important for advancing the field. HEP funding has increased from $20M (FY20) to $38M (FY23). In FY22, HEP made 16 awards to universities for AI/ML efforts, including for cosmology. Cosmic Frontier has AI/ML efforts at labs, universities & has recent Early Career awards.

Astro2020/AAAC – Recommendations
➔DOE, SC and HEP Efforts and Responses

Data, Science

- SC has a data management policy (being updated) and requires data management plans in proposals.
- HEP is participating in the Future of Astrophysical Research Infrastructure workshop and related efforts.
- All survey projects (DES, eBOSS, DESI, Rubin Observatory, CMB-S4) are making data public after a proprietary period.
- DOE is participating with NSF and NASA on the Three Agency Group (TAG) and have met with Rubin, Roman & US-Euclid to investigate possibilities for joint simulations, data processing and analysis to ensure we provide the best science within available funding levels. This will entail supercomputing resources and personnel to carry out these efforts.

Climate Change, Energy Usage

- Climate change and energy issues are of great importance to the Department of **Energy**. DOE has significant ongoing programs to address climate change, reduce energy usage, enhance energy resiliency and efficiencies, consider energy justice and develop new energy sources and technologies. Efforts include industry and academic partnerships.
- DOE has partnerships with other agencies, e.g. https://www.nsf.gov/news/news_summ.jsp?cntn_id=305100&org=ENG
- DOE labs have sustainability plans, and carry out significant technology development for renewable energy, storage, etc.
  - ANL, in collaboration with NREL, is studying deployment of renewable energy and energy storage at unique remote sites to support HEP Cosmic Frontier experiments, e.g. for CMB-S4.
- Many of our experiments now have remote data-taking and most workshops and meetings now have zoom participation.

Budgets –

Community Engagement - HEP labs work with their local communities - employment opportunities and outreach efforts.

Tracking Progress – working on this

HEP Cosmic Frontier – Strategic Planning Process

- HEP community-wide "**Snowmass"** study process to identify key science questions and options to address them. Workshop held July 2022. Final report at https://www.slac.stanford.edu/econf/C210711/
  - The community's top Cosmic Frontier priority is to complete construction of **CMB-S4,** while launching new projects to delve deep and search wide for dark matter and make the next leap in dark energy and cosmic acceleration research, including cross-survey science leveraging the recently-completed projects DESI and LSST (Rubin).
- HEPAP **International Benchmarking** subpanel (reports ~ end of 2023) https://science.osti.gov/-/media/hep/hepap/pdf/202203/HEPAP_202203_Charge_G_Crawford.pdf
- National Academy of Sciences (NAS) **Elementary Particle Physics (EPP) Decadal Survey**
  - running concurrently with and complementary to the P5 process.

NAS/Astro2020 + Snowmass + International Benchmarking + NAS/EPP + European Strategy etc

➔ Input to the DOE/NSF HEPAP/P5 subpanel – HEP's Strategic Plan

P5 convened in December 2022 – develop the grand, long-term, and global vision and strategy of particle physics.

- Reports ~ end of 2023 with 10 year plan in 20 year context
- See http://hitoshi.berkeley.edu/P5/

➔ Cosmic Frontier Town Hall at LBNL on Feb. 22-23.

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