U.S. DEPARTMENT OF ENERGY | Office of Science

Office of High Energy Physics (HEP) Cosmic Frontier

Astronomy & Astrophysics Advisory Committee

Sept. 28, 2021

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Experimental Research at the Cosmic Frontier
Office of High Energy Physics

OUTLINE

- HEP Program: Mission, Planning and Budgets
- Cosmic Frontier Program Details
- DOE/HEP Research Support

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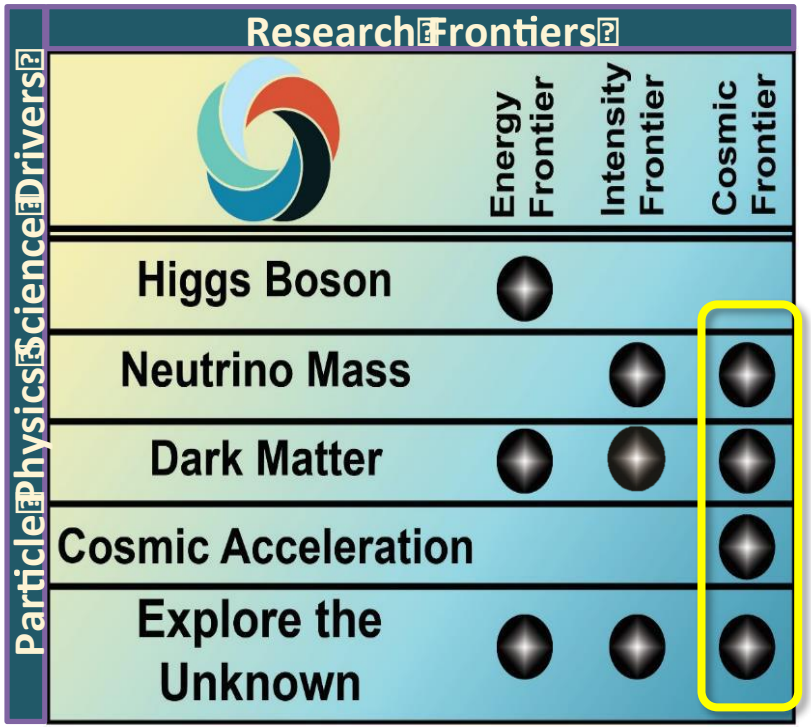
HEP Program

Cosmic Frontier Experimental Research Program

→ Cosmic Frontier Experimental researchers use naturally occurring cosmic particles and phenomena to reveal the nature of dark energy and dark matter, comprising ~95% of the universe, understand the cosmic acceleration caused by dark energy and inflation, infer neutrino properties, and explore the unknown.



Program Areas:

- Study the nature of Dark Energy using imaging & spectroscopic surveys
- Direct Detection searches for Dark Matter particles
- CMB – Inflationary Epoch,

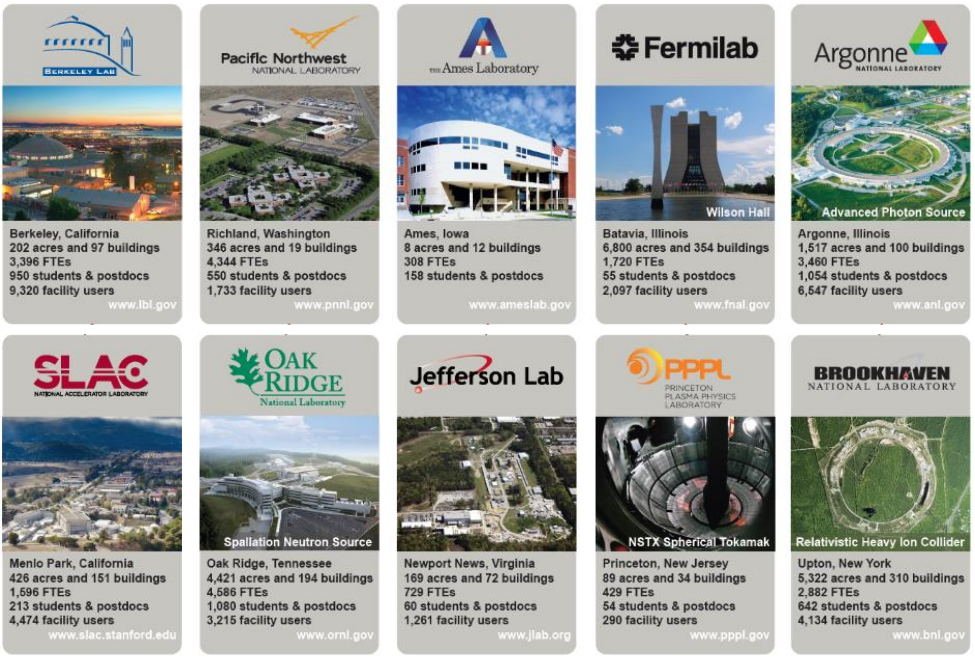
Dark Energy, Neutrino Properties

Always interested in Exploring the Unknown and New Physics!

Mission -DOE & Office of Science (SC)

DOE Mission includes maintaining a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity, with clear leadership in strategic areas.

SC Mission is to deliver the scientific discoveries and major scientific tools that transform our understanding of nature and advance the energy, economic, and national security of the United States

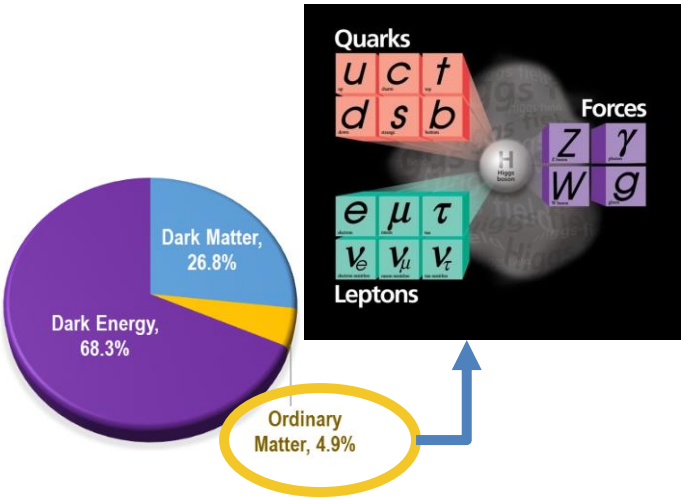


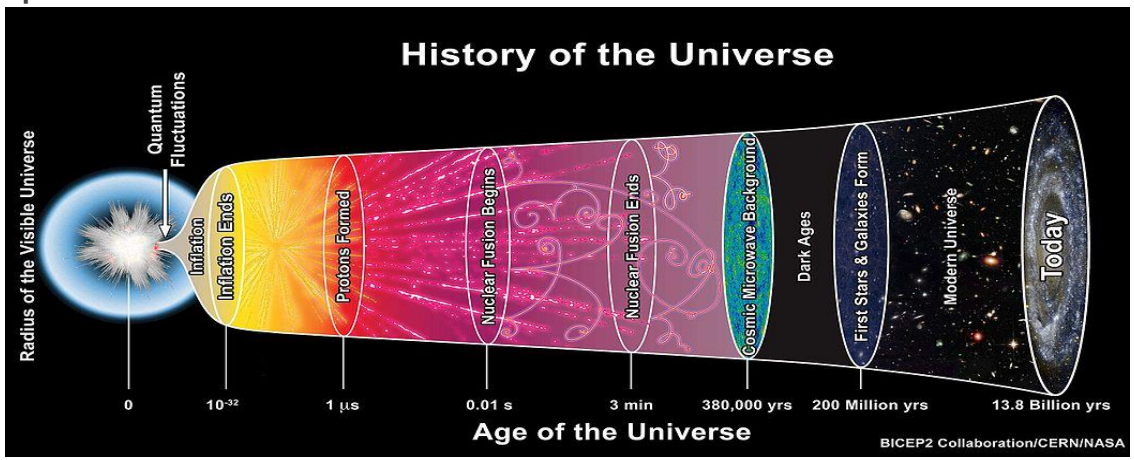
The Office of High Energy Physics (HEP) Program Mission

DOE is a mission-oriented agency → mission includes **maintaining a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.**

HEP's mission is to understand the universe at the most fundamental level:

- Discover the elementary constituents of matter and energy
- Probe the interactions between them
- Explore the basic nature of space and time

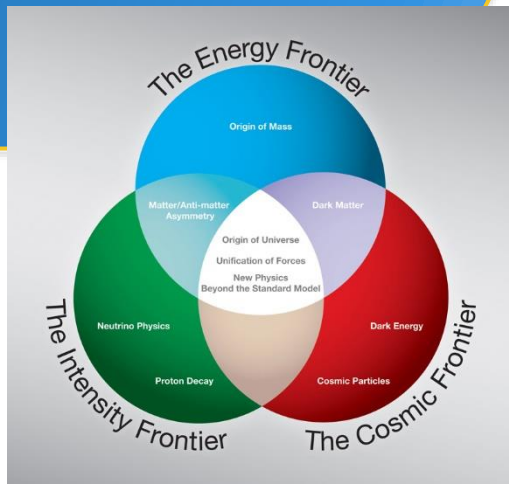




➔Scientific Areas are intertwined: High Energy/Particle Physics, Cosmology, Astrophysics, and Astronomy.

DOE supports ~ 85% of the U.S. HEP effort (in $) at Universities + National Labs

HEP Program Layout



<u>HEP is carried out along 3 Frontiers</u>:
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: <u>Cosmic Acceleration</u> (Dark Energy, Inflation), search for <u>Dark Matter</u> particles, <u>New Physics</u> (neutrino properties, relic particles, etc)

<u>Crosscutting HEP subprograms</u>:

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

HEP Program Guidance

FACA panels & subpanels provide official advice:

- **High Energy Physics Advisory Panel (HEPAP)**
  - Advises **DOE & NSF**: Provides the primary advice for the HEP program
  - Subpanels: **The Particle Physics Project Prioritization Panel ("P5") provides the Strategic Plan for HEP**

- **Astronomy and Astrophysics Advisory Committee (AAAC)**
  - Advises **DOE, NASA, & NSF** on issues of overlap, mutual interest and concern
  - Subpanels: CMB-S4 Concept Definition Taskforce (2017), Gemini-Blanco-SOAR Telescopes roles (2019)

Advice Also Provided by: National Academy of Sciences (NAS)

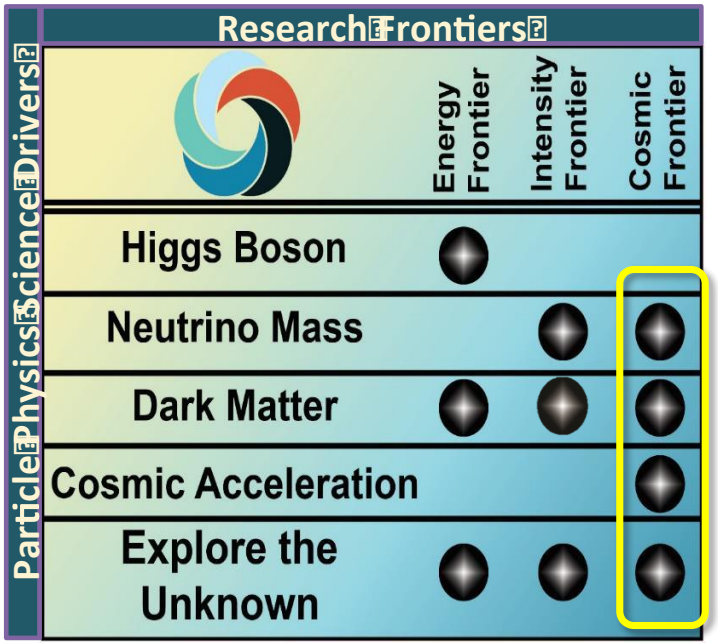
- **Decadal Surveys in Astronomy & Astrophysics (Astro2020 will report soon)**, Elementary Particle Physics
- Board on Physics & Astronomy (BPA), Committee on Astronomy & Astrophysics (CAA)

Other Input & Coordination

- Community studies & input, e.g. Snowmass, Dark Energy Task Force, APS/DPF,
  - Basic Research Needs (BRN) studies to start development of new HEP initiatives

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

→The **projects** selected for the (P5) strategic plan make significant leaps in addressing HEP science goals.

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

HEP Program Execution

HEP carries out the DOE mission and objectives through a **specific, balanced portfolio of projects and facilities**

- Make significant, coherent contributions to **projects;** managed under the DOE project system
- Operate **experiments and facilities** that provide discovery capability
- Support **data analyses** to produce discovery science aligned with our goals
- Development of **key technologies** and **trained personnel** needed to work at the cutting edge of science.
  - R&D for detectors, accelerators, QIS, AI/ML

- Form partnerships with other US and International agencies (*e.g.*, NASA, NSF, international) to help deliver our mission

→**HEP works proactively with labs & university community to carry out the P5 portfolio of facilities, projects & experiments.**

HEP Program Execution – Priorities & Collaboration Model

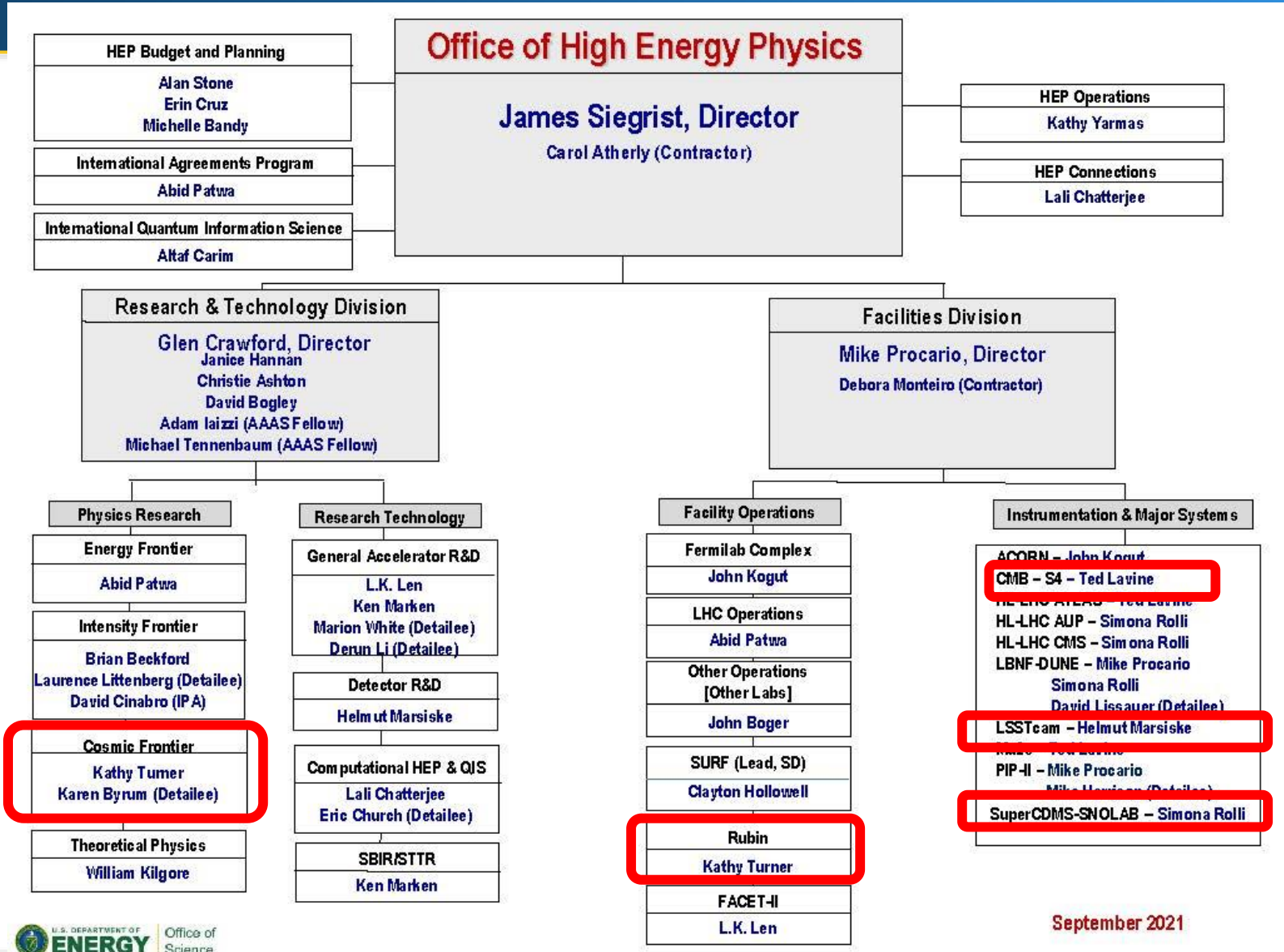
Priority for selecting and supporting roles & responsibilities on partnership projects or experiments

- Make significant, coherent, efforts on the projects & experiments directly in line with our program and priorities, responsibilities and science goals.
- We select roles & responsibilities that make use of our expertise, capabilities, resources and infrastructure & are commensurate with the science return expected (for multi-science projects)

HEP strength is our Science Collaboration Model!

- Support structured science collaborations that participate in all stages, leading to the best possible results from state-of-the art projects.
- Scientists are intimately involved & have roles & responsibilities in project design & fabrication (hardware, software), commissioning, experimental operations, science planning & data analysis
- Students & postdocs are trained by participation in all phases to gain experience and expertise; can be stationed at a lab or at the experiment site as needed.
  - **Peer Reviews reflect HEP collaboration model & work style**
  - **Priority for Research support is for efforts directly in line with HEP roles and responsibilities as well as our science goals.**

DOE Office of HEP



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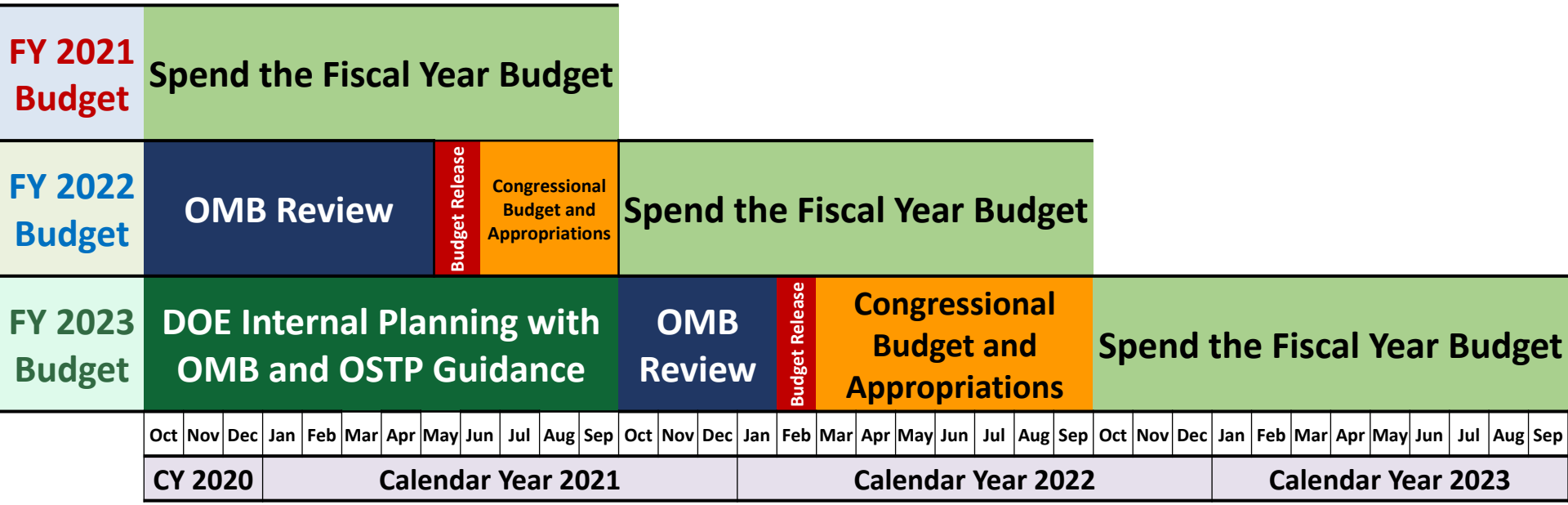
HEP Budget

The U.S. Federal Budget Cycle

Typically, three budgets are being worked on at any given time

- Executing current Fiscal Year [FY; October 1, 202*x* – September 30, 202(*x*+1)]
  - Can be delayed if the budget is not passed; go into a Continuing Resolution
- Office of Management and Budget (OMB) Review and Congressional Appropriation for the upcoming FY
- Agency internal planning for the second FY from now



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FY 2022 Budget Request - HEP

HEP Funding Category (in $K)	FY 2019 Actual	FY 2020 Actual	FY2021 Request	FY 2021 Appropriation	FY2022 Request
Research	380,847	389,646	328,906	409,370	419,605
Facility & Exp. Operations	260,803	317,310	285,725	303,130	309,395
Projects	338,350	338,044	203,500	333,500	332,000
Total	**980,000**	**1,045,000**	**818,131**	**1,046,000**	**1,061,000**

FY 2021 Budget →

- U.S. Congress continued to show strong support for the P5 strategy
- Increased (new) funding for QIS, AI/ML, Accelerator R&D, and MicroElectronics
- Appropriations specified budget amounts in a number of areas, thereby constraining other parts of the budget.
- **New Major Item of Equipment (MIE) project start for CMB-S4**

FY 2022 Budget

President's Request (late…transition year) - overlay of Administration, SC, P5 priorities
SC: interagency partnerships, national labs, accelerator R&D, QIS, AI/ML, microelectronics
HEP: continue successful P5-guided program; advance Administration, DOE, SC initiatives;
Working to ensure an optimal balance between Research, Operations, & Projects.

- Research: Continue U.S. leadership in LHC, muon experiments, international neutrino experiments at FNAL, **dark matter, dark energy, increased CMB-S4 efforts**, and vibrant theory program; QIS; AI/ML; Microelectronics (with ASCR, BES, and FES); Accelerator Science and Technology Initiative; Traineeships in accelerator science, instrumentation, high-performance scientific computing

- Operations: Support HEP user facilities and planning, then subsequent running of P5-recommended experiments

- Projects: Project support for HL-LHC Accelerator and ATLAS & CMS Detectors, CMB-S4, and ACORN (new start); LIC support for LBNF/DUNE, PIP-II, and Mu2e
  - The construction budget is slightly less than FY21.

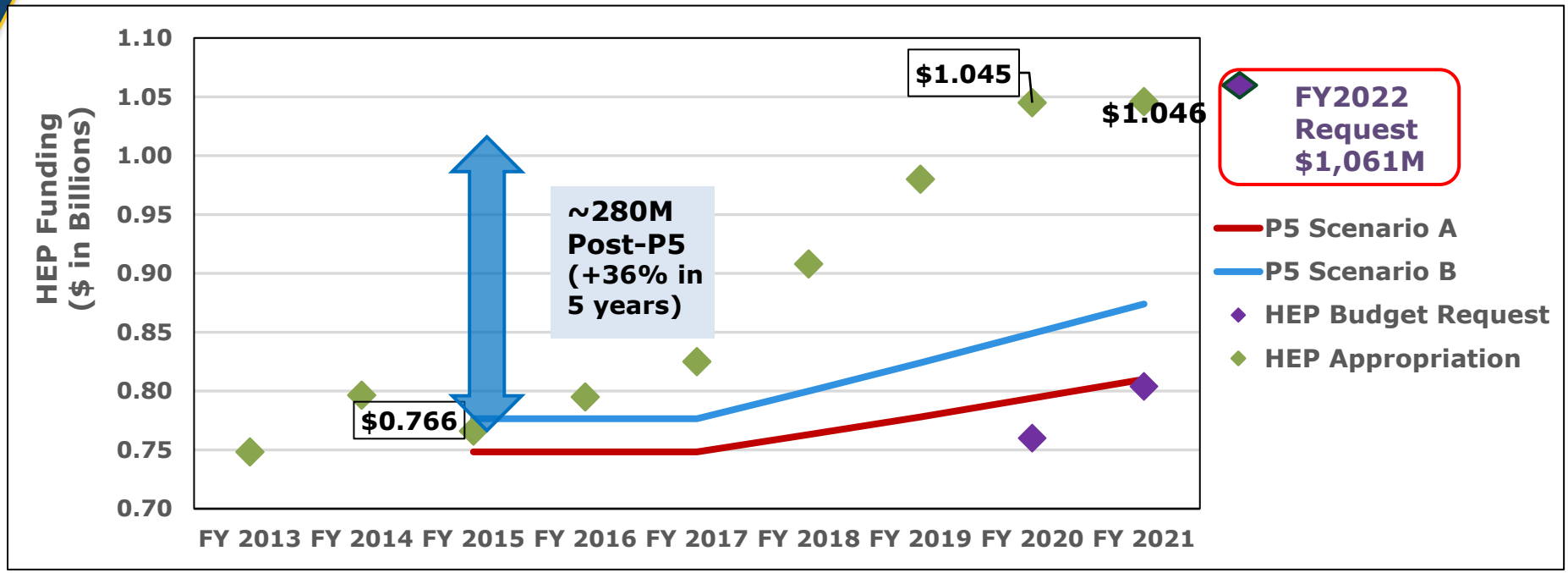
Marks

— The House and Senate marks are about +1.7% above the FY 2022 Request and about+3.2% above the FY 2021 Appropriation

Final Budget

— Need to await final budget language in an appropriation
— We will go into a CR until a budget is passed by Congress.

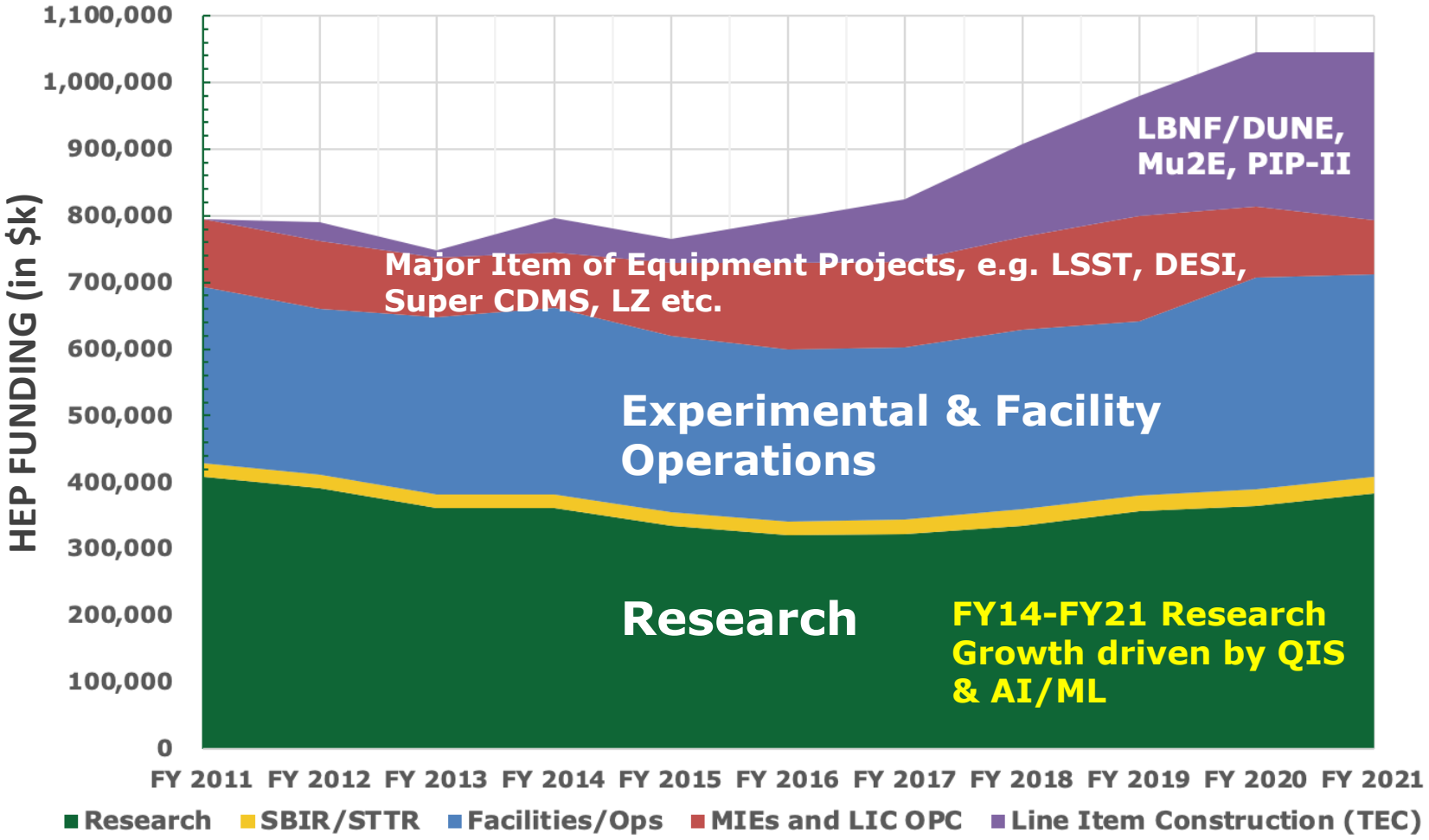
HEP Budget: HEP Community support of this process is a critical part of its success



- U.S. Congress continues to show strong support for executing the P5 strategy, and for accelerating the pace of projects
- When the P5 report was released in May 2014, the FY 2015 budget was already in Congress and the FY 2016 budget was being formulated
- Arguably the first impact (success!) of the P5 report was not seen until FY 2016, and continues today…

DOE-HEP Budget ($k): FY 2011-2021
Research, Operations, Projects (Construction and MIEs)

HEP Funding ($ in k)	FY 2017 Actual	FY 2018 Actual	FY 2019 Actual	FY 2020 Actual	FY 2021 Enacted	FY 2022 Request *(for Reference)*	FY 2022 House Mark *(for Reference)*	FY 2022 Senate Mark *(for Reference)*
TOTAL	825,000	908,000	980,000	1,045,000	1,046,000	1,061,000	1,078,000	1,079,000



HEP report, AAAC mtg, Sept.2021

SC – [New] Initiatives

HEP budget (in $K)	FY20 enacted	FY21 enacted	FY22 request
Accelerator Science & Technology		6,411	17,432
Artificial Intelligence & Machine Learning (AI/ML)	15,000	33,488	35,806
Integrated Computational & Data Infrastructure			**4,146**
Microelectronics		5,000	7,000
Quantum Information Science (QIS)	38,500	45,072	51,566
Reaching a New Energy Sciences Workforce			**4,000**
TOTAL	**53,500**	**89,971**	**119,950**

The President has placed a high priority on **American leadership in the Industries of the Future (IOTF):**

artificial intelligence (AI), quantum information science (QIS), advanced manufacturing, biotechnology, and 5G/advanced wireless technologies

SC New Initiatives – RENEW and Integrated Computational & Data Infrastructure

Reaching a New Energy Sciences Workforce (RENEW):

SC is fully committed to advancing a diverse, equitable, and inclusive research community. This commitment is key to providing the scientific and technical expertise for U.S. leadership. **HEP will participate in the SC-wide RENEW initiative which** leverages SC's unique national laboratories, user facilities, and other research infrastructures to provide undergraduate and graduate training opportunities for students and academic institutions not currently well represented in the U.S. S&T ecosystem.

- This includes Minority Serving Institutions and individuals from groups historically underrepresented in STEM, but also includes students from communities with environmental justice impacts and the EPSCoR jurisdictions.
- The hands-on experiences gained through the RENEW initiative will open new career avenues for the participants, forming a nucleus for a future pool of talented young scientists, engineers, and technicians with the critical skills and expertise needed for the full breadth of SC research activities, including DOE national laboratory staffing.

Integrated Computational & Data Infrastructure for Scientific Discovery:

In coordination with SC, HEP will support development of data storage capabilities to handle tens of exabytes of data from future experiments; cross-cutting efforts in AI/ML and edge computing to seek solutions for real-time and extremely high data rate environments; and investments in software development to improve the interface with SC infrastructure and ASCR-supported middleware.

SC Initiative
- Artificial Intelligence & Machine Learning

As part of the AI initiative, FY21 SC appropriation included $100M for AI

- SC has prioritized investments in AI/ML for user facilities focusing on accelerator optimization, control, prognostics, and data analysis

HEP FY2021 AI/ML funding contributed to:

- Awards from dedicated FOAs ("Data, AI, and Machine Learning at DOE Scientific User Facilities")
- New Early Career Research Awards
- Ongoing Laboratory research programs
- New and renewal applications under standard HEP FOAs (including "HEP Comparative Review")

HEP will continue to support dedicated new AI/ML efforts while enhancing support for existing AI/ML embedded in the ongoing research program.

FY22 Request: "Research to tackle the challenges of managing increasingly high volumes and complexity of HEP experimental and simulated data, and to address cross-cutting challenges across the HEP program in coordination with DOE investments in exascale computing and associated AI efforts."

SC Initiative – Microelectronics

"Thanks to microelectronics, transformational technologies that used to swallow up entire buildings now fit in the palms of our hands—and it's time to take this work to the next level," said **Secretary of Energy Jennifer M. Granholm**.
"Microelectronics are the key to the technologies of tomorrow, and with DOE's world-class scientists leading the charge, they can help bring our clean energy future to life and put America a step ahead of our economic competitors."

Research & Potential Applications:

- clean energy technologies to combat the climate crisis and make the nation's grid more efficient, more responsive to fluctuations in energy demand, and more resilient to extreme weather events.
- help revive American production of semiconductors (recent global shortages have threatened to disrupt major U.S. industries)

FY21 – There were 10 SC-wide multi-program awards (HEP is co-funding 2). See: https://science.osti.gov/-/media/bes/pdf/Funding/2020/2491_Microelectronics_Awards.pdf

FY22 Request: "HEP will work together with Advanced Scientific Computing Research (ASCR), Basic Energy Sciences (BES), and Fusion Energy Sciences (FES) programs to support multi-disciplinary microelectronics research, including 5G, to accelerate the advancement of microelectronic technologies."

SC Initiative – QIS

https://science.osti.gov/Initiatives/QIS

- **HEP competed the first round of QuantISED (Quantum Information Science Enabled Discovery) in FY 18 as part of the Office of Science QIS Initiative, with a second call in FY19.**
- **HEP supports one of the National QIS Research Centers (SQMS led by FNAL)**

HEP-QIS QuantISED research synthesizes *QIS for HEP* & *HEP for QIS* in alignment with SC theme and connects to the HEP frontiers/thrusts

QuantISED supports interdisciplinary teams at DOE National Labs and at Universities

Topics: Cosmos and Qubits, Foundational Theory, Quantum Computing & Communication, Quantum Sensors, QuantISED Experiments, and QIS Technology

More Information is available at: https://science.osti.gov/hep/Research/Quantum-Information-Science-QIS

National QIS Research Centers established by DOE: 2020

- https://science.osti.gov/Initiatives/QIS/QIS-Centers

Q-NEXT NEXT GENERATION QUANTUM SCIENCE AND ENGINEERING

C²QA Co-design Center for Quantum Advantage

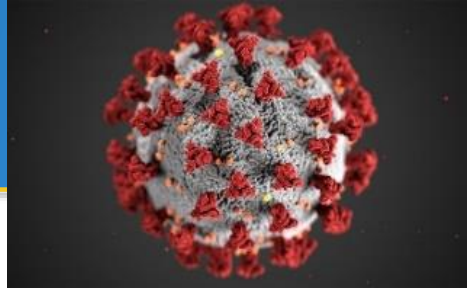
QUANTUM SCIENCE CENTER

SQMS

- https://sqms.fnal.gov/ (HEP Supported)

QIS is an all-of-government effort → see www.quantum.gov

Dealing with COVID-19



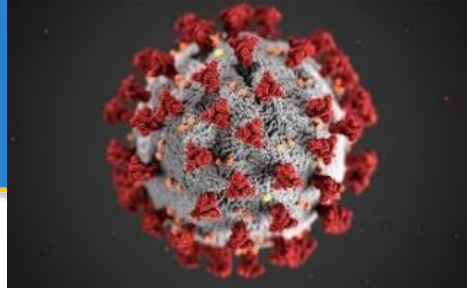
Experimental Operations:

- Mature experiments can mostly operate remotely with limited staff support on site - so are in reasonably good shape. (e.g. SPT-3G, HAWC, Fermi, ADMX-G2)
- Experiments just starting operations (e.g. LZ at SURF, DESI at Kitt Peak) faced larger delays & challenges as they worked to update procedures and gain access. DESI has now started full operations and LZ expects to within a few months.

Projects:

- Several projects (e.g. LSST Camera, LZ) were able to finish fabrication and push some tasks to commissioning/operations, due to the uncertainties about the pandemic.
- Others need to be rebaselined, with timing adjusted as needed (e.g. SuperCDMS SNOLAB due to covid and other issues).

Dealing with COVID-19



Research:

- HEP PI's have flexibility within the existing grant awards
  - Can reallocate funds, extend their schedule, and/or re-plan their scope of work to accommodate research tasks that have been cut short or delayed by the pandemic
  - This includes extending support for junior scientists (primarily students, postdocs) with existing support to ensure they have time to complete their planned program. This is one of our highest priorities.

- We have been working with PIs on a case-by-case basis to address these issues as needed

➔The need to continue support for existing students and postdocs may impact the availability of research funds for new and renewal proposals.
Info at: https://www.energy.gov/science/downloads/doe-sc-accommodating-interruptions-applicants-awardees-due-covid-19

NOTE: HEP has not received any extra funding to deal with COVID.

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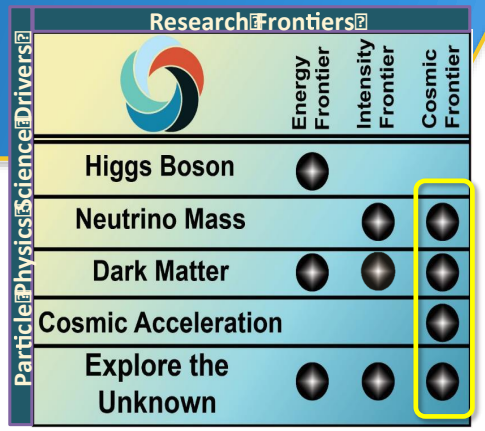
Cosmic Frontier

Cosmic Frontier Experimental Program



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

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

Notes:

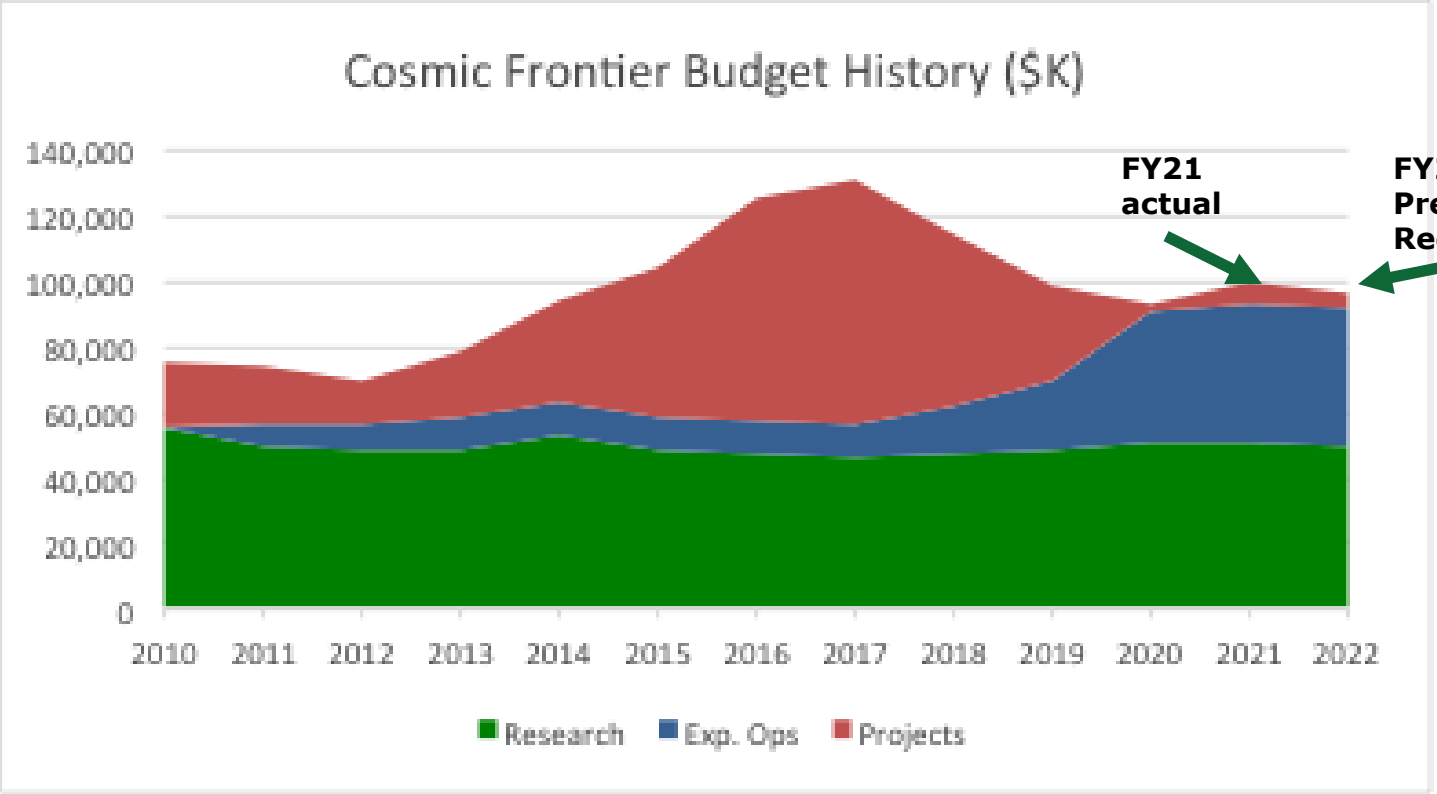
- Most Experiments are done in partnership with NSF-PHY, NSF-AST, NSF-OPP, NASA, and/or International agencies/institutions.
- Significant contributions & support from other HEP areas, including Theory, Advanced Detector Development, Computational HEP, QIS, AI/ML
- Also from other SC areas → ASCR Supercomputing resources

FY 2019-2022 Budget – Cosmic Frontier

Cosmic Frontier ($K)	FY2019 Actual	FY2020 Actual	FY2021 Approp.	FY2021 end	FY2022 Pres. Req.
Research (Univ+Lab)	48,053	44,264	39,634	43,901	42,012
Research AI/ML		3,351	3,920	4,920	5,000
Future R&D	3,265	2,480	2,000	1,700	2,000
Exp. Operations	20,957	40,235	43,897	42,880	42,500
Projects	26,350	2,450	6,000	6,000	5,000
DESI	*9,350*	*0*	*0*	*0*	*0*
LZ	*14,450*	*0*	*0*	*0*	*0*
SuperCDMS	*2,550*	*0*	*0*	*0*	*0*
CMB-S4	-	*2,450*	*6,000*	*6,000*	*6,000*
Total	**98,625**	**92,780**	**95,451**	**99,401**	**96,512**
Office support	3,667	4,181	4,436	4,970	
SBIR/STTR	2,869	3,524		1,624	
Total Full	**105,161**	**100,485**	**99,887**	**105,995**	**96,512**

- **Research:** World-leading research efforts in support of design and optimization on dark matter and dark energy experiments in their fabrication and commissioning phases, R&D and planning for CMB-S4, planning for future experiments.
- **Operations:** Commissioning and facility operations planning for LSST/Rubin, commissioning and operations for LZ, operations for DESI, pre-operations activities for SuperCDMS-SNOLAB. Support for the currently operating experiments continues (SPT-3G, ADMX-G2, FGST; HAWC ops support ended 2021)
- **Projects:** CMB-S4

Cosmic Frontier Budget History



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

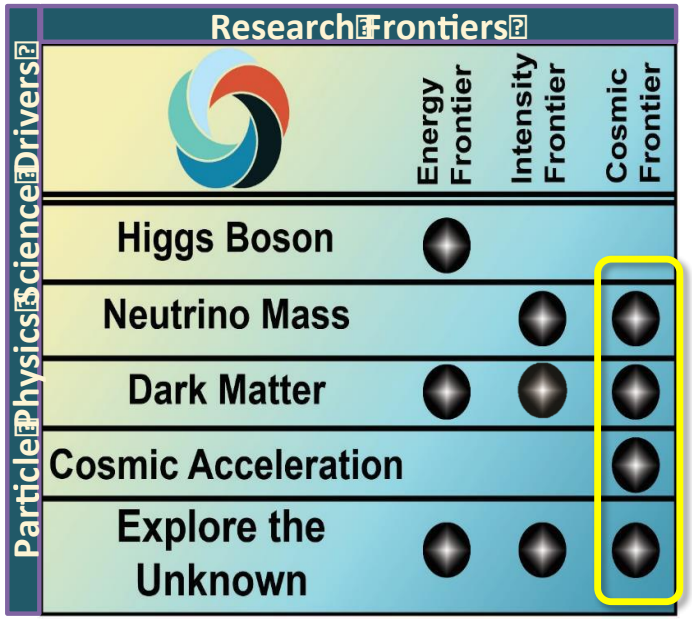
Cosmic Frontier – Cosmic Acceleration

Cosmic Acceleration:

- Imaging & Spectroscopic surveys to determine the nature of **Dark Energy**

  Stage 3
  - extended Baryon Oscillation Spectroscopic Survey (**eBOSS**), Dark Energy Survey **(*DES*)**

  Stage 4
  - Dark Energy Spectroscopic Instrument (***DESI***)
  - ***Vera C. Rubin Observatory,*** w/DOE's ***LSST Camera*** MIE project and the Dark Energy Science Collaboration **(DESC)**



- Study the Inflationary era using its imprint on the cosmic microwave background (**CMB**) at energies near the Planck scale (with NSF)
  - South Pole Telescope 3rd Generation (***SPT-3G***)
  - *CMB-stage 4 (**CMB-S4**)*

Dark Energy Survey (DES)

DARK ENERGY SURVEY

DOE and NSF partnership

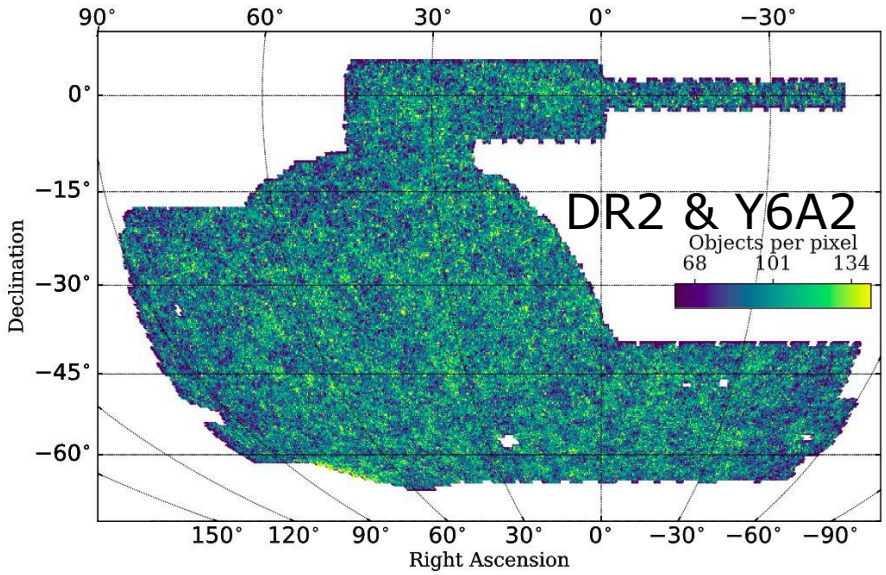
- Fermilab led fabrication of 570Mpix Dark Energy Camera (DECam); NSF led telescope upgrades, data man. system
- Both agencies supported operations on NSF's Blanco telescope at CTIO in Chile.
- 6-year imaging survey of 5100 sq-deg completed Jan. 2019

- *Collaboration > 400 scientists from 25 institutions in 7 countries*
- Over 350 publications; > 90 PhD's

<u>Cosmology 6 ways</u>:

Growth rate of structure and Expansion History: Weak Gravitational Lensing, Galaxy Clustering, & Galaxy Cluster Abundance

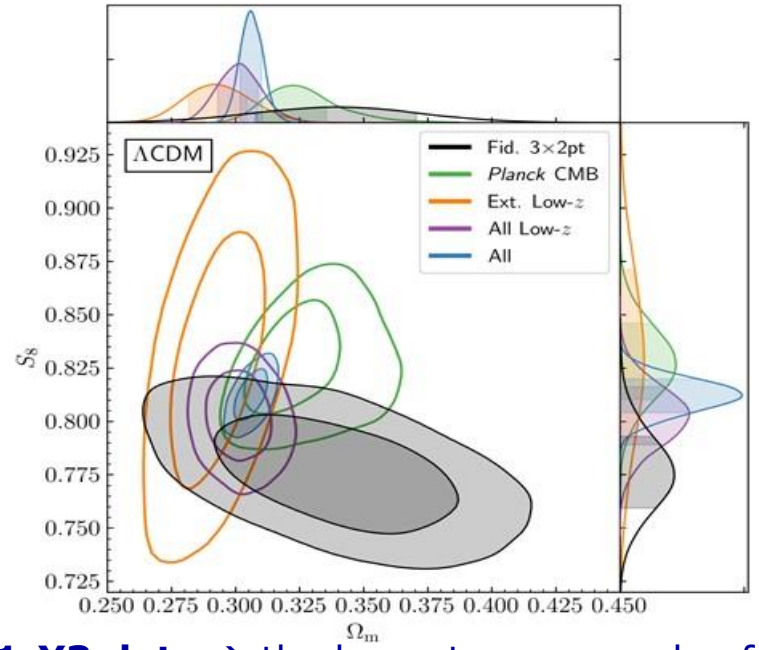
Expansion History: BAO (standard rulers), SNIa (standard candles), Gravitational Wave Follow up (standard sirens), Strongly-Lensed Transients.



Dark Energy Survey (DES)

Jan. 2021: Public Data Release 2 (Y1-Y6 data). 690M objects with unprecedented photometric, astro-metric precision & uniformity.
Fall 2021 Y3A2 "Gold" public release
FY2022: Y1-6 data processing with cosmology-added ("Gold") data products
FY2023: Y1-6 Gold to Collaboration
FY2024: Y1-6 Gold made public; Cosmology analyses complete

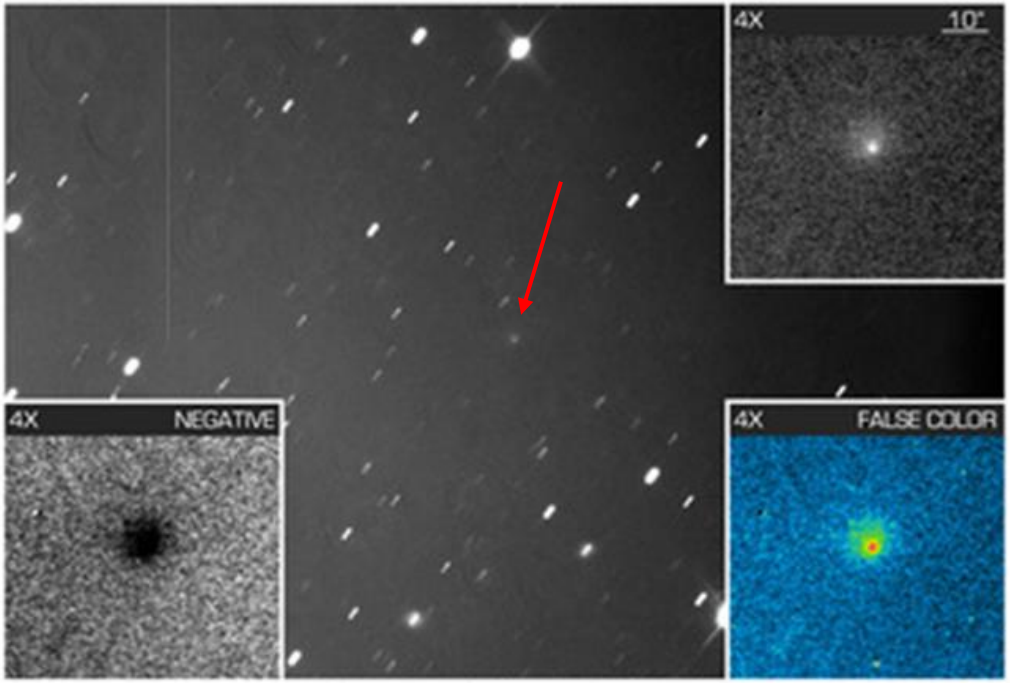
ΛCDM	$S_8 = 0.812^{+0.008}_{-0.008}$	(0.815)
	$\Omega_m = 0.306^{+0.004}_{-0.005}$	(0.306)
	$\sigma_8 = 0.804^{+0.008}_{-0.008}$	(0.807)
	$h = 0.680^{+0.004}_{-0.003}$	(0.681)
	$\sum m_\nu < 0.13$ eV	(95% CL)
*w*CDM	$\sigma_8 = 0.810^{+0.010}_{-0.009}$	(0.804)
	$\Omega_m = 0.302^{+0.006}_{-0.006}$	(0.298)
	$w = -1.03^{+0.03}_{-0.03}$	(−1.00)

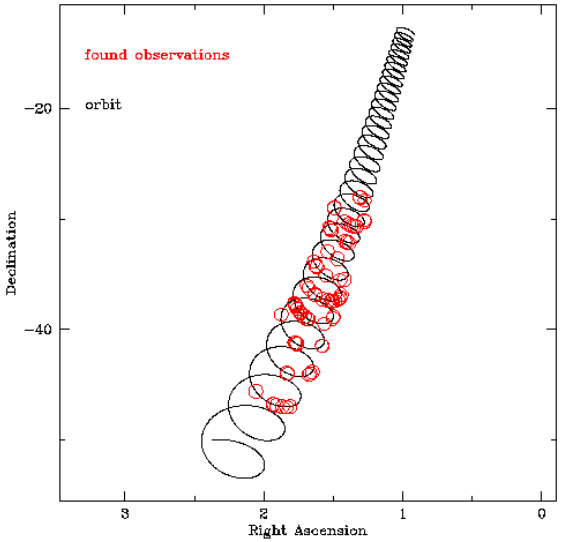


Y3 Weak Lensing Cosmology Results from Y1-Y3 data → the largest ever sample of galaxies (226 million) over an enormous piece of the sky to produce the most precise measurements of the universe's composition and growth to date.

DES – other exciting science topics
➔ Discovery of New Comet!

- A new comet, the most massive and most distant ever discovered, found using DES data
- C/2014 UN271 "Bernardinelli-Bernstein"



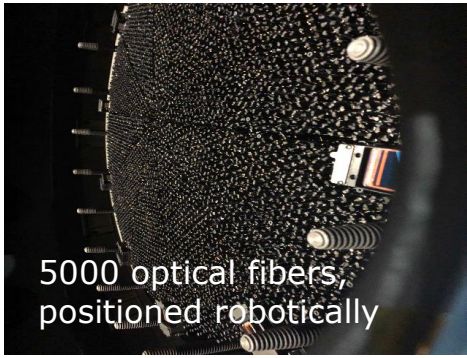


- Comet C/2014 UN271 was detected as it came in from the Oort cloud at 29 to 23 AU
- Massive (~200 km wide) comet
- Early studies of the coma show sub-mm sized grains at 7 m/s as well as sublimation of CO
- Perihelion at 11 AU in 2031, so we'll watch this one "turn on" for a long time

Dark Energy Spectroscopic Instrument (DESI) Experiment

DOE's DESI is taking data!

- World's premier multi-object spectrograph and the first **Stage IV dark energy** project **started full science operations May 2021**
- Achieved design plans in performance and survey depth/parameters.
- Will measure spectra of > 40 million galaxies



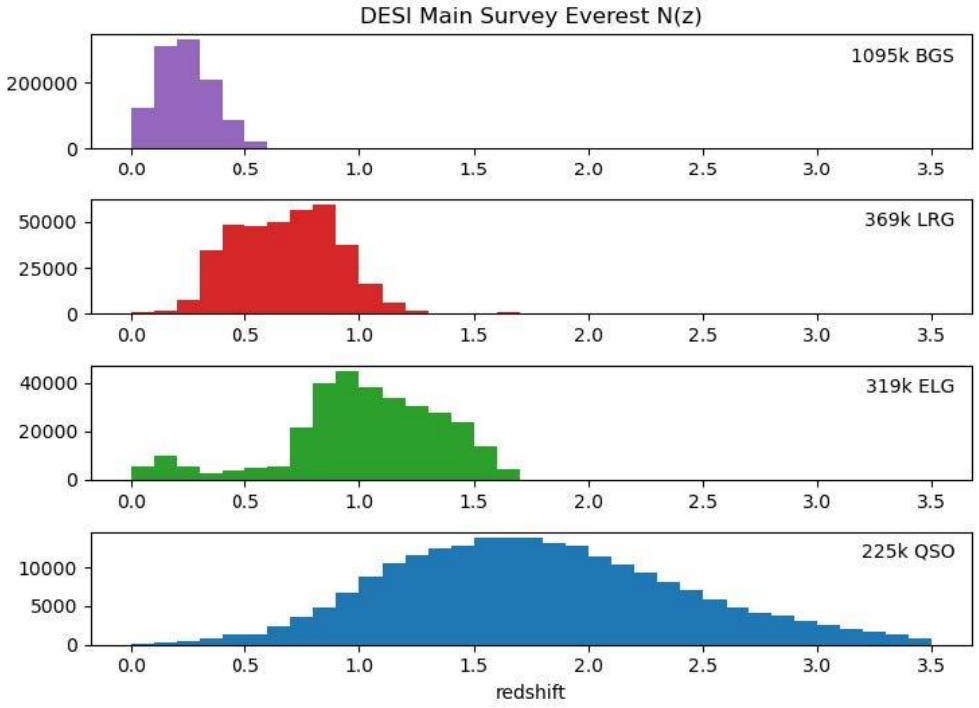
DOE/LBNL-led project:

- **Project:** Instrumentation, Data Management System, & Upgrades of NSF's Kitt Peak Mayall telescope (including MOSAIC camera)
- Continues to lead Operations phase & science Collaboration.
- Commissioning complete & ready to take data in March 2020; then had to shut down due to covid-19
- Project CD-4 received May 2020; re-commissioning, survey validation started Dec.2020

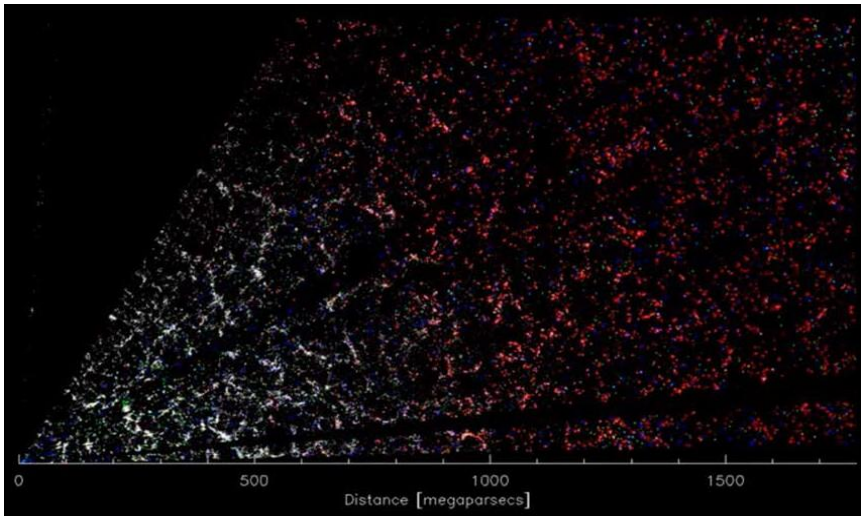
- Designed and built by large international collaboration
  - 500 researchers, 75 institutions, 13 countries, ~ 160 grad students
- Partners
  - STFC, Heising-Simons, Gordon & Betty Moore, France, Mexico, Spain, NSF
  - HEP has MOU w/NSF-AST to "lease" the Mayall telescope for operations

DESI – survey status

Redshift distribution of 2M spectra taken by DESI in each target class



- "Pie diagram" slice through the universe, with earth in the lower left, looking out to distances beyond 5 billion light years.
- Each point represents a DESI target.
  - bright galaxy sample - white points
  - luminous red galaxies in red
  - emission line galaxies - in green
  - quasi-stellar objects - blue
- Each target ~ 100 billion - 1 trillion stars
- Gravity has clustered the galaxies into structures called the "cosmic web", with dense clusters, filaments and voids.



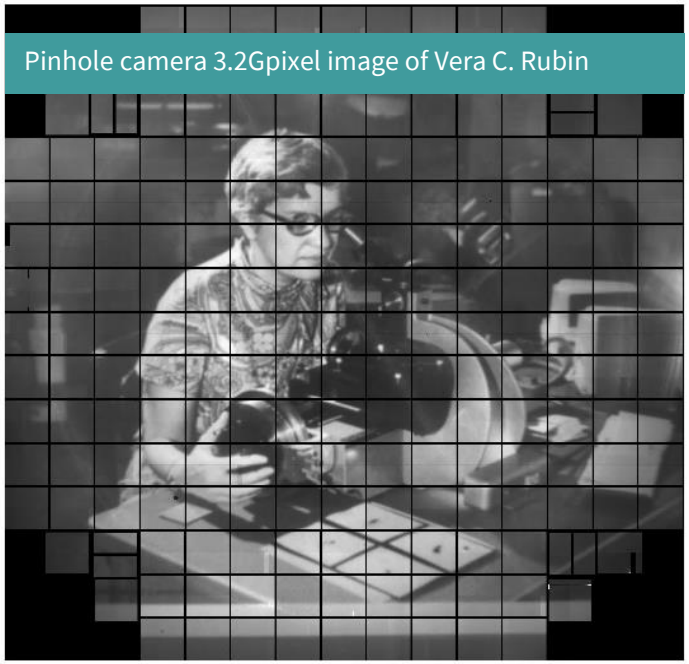
See film at
https://youtu.be/w_DD1z9Iqk8

Vera C. Rubin Observatory

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

Discovery Science! 4 primary themes:

- Probing Dark matter and **Dark Energy**
- Mapping the Milky Way
- An Inventory of the Solar System
- The Transient Optical Sky


Pinhole camera 3.2Gpixel image of Vera C. Rubin

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

- Project: DOE responsible for the Camera fabrication & commissioning
- Facility Operations: 50/50 DOE & NSF split

For the first ten years of operations (prime survey), the **Vera C. Rubin Observatory** will carry out the **Legacy Survey of Space and Time (LSST)**, using the **DOE's LSST Camera** and the **Simonyi Survey Telescope**.

DOE's LSST Camera

HEP Camera Project Fabrication:

- Due to covid-19 delays & uncertainties, the MIE was restructured to complete at the subsystem level (CD-4 review Aug. 2021; CD-4 approval expected by end Sept. 2021)

HEP Commissioning roles

- Assembly and verification at SLAC
- Camera will be shipped to Chile (~ summer 2022) and be ready for for installation and commissioning on telescope (~ late 2022)

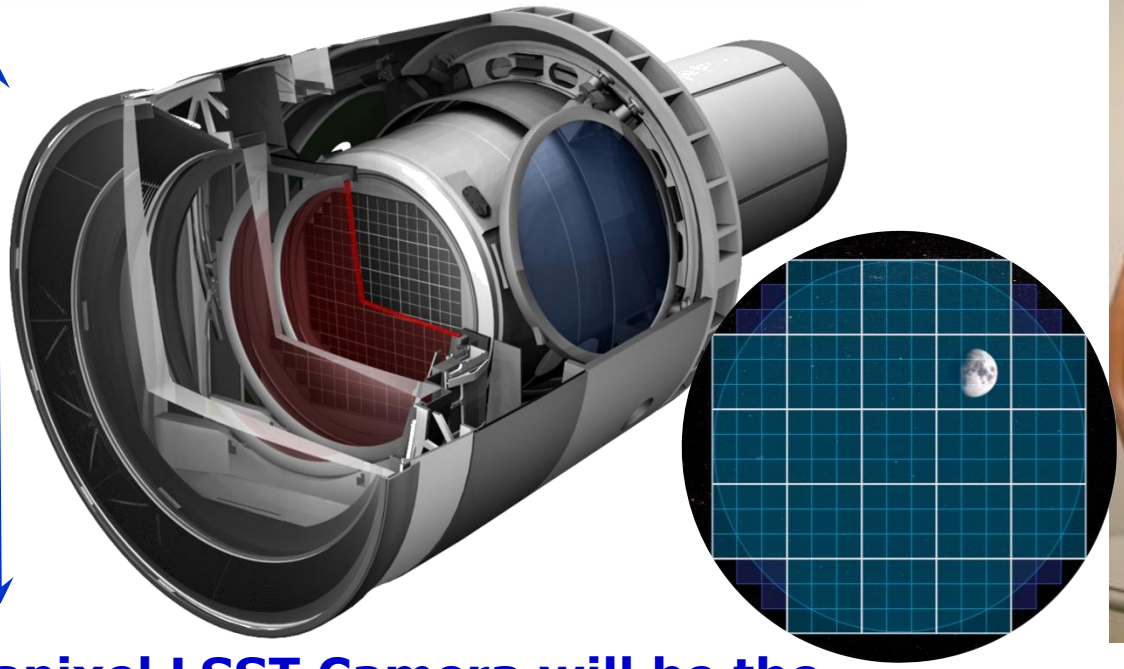
Guinness Book of World Records!

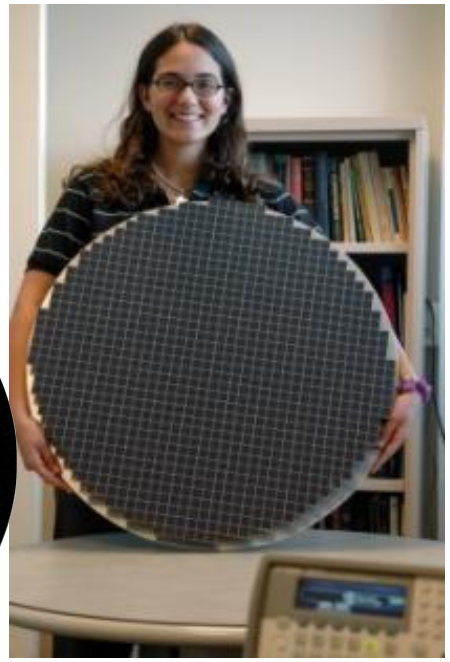
- World's largest digital camera
- L1 lens is world's largest lens

Due to covid-19, expect delay of about ~ 16 months for overall Observatory completion & data-taking start (now in 2024)

LSST Camera for the Rubin Observatory – What's So Special?

Enormous **Camera** to exploit the wide field of view (FOV)





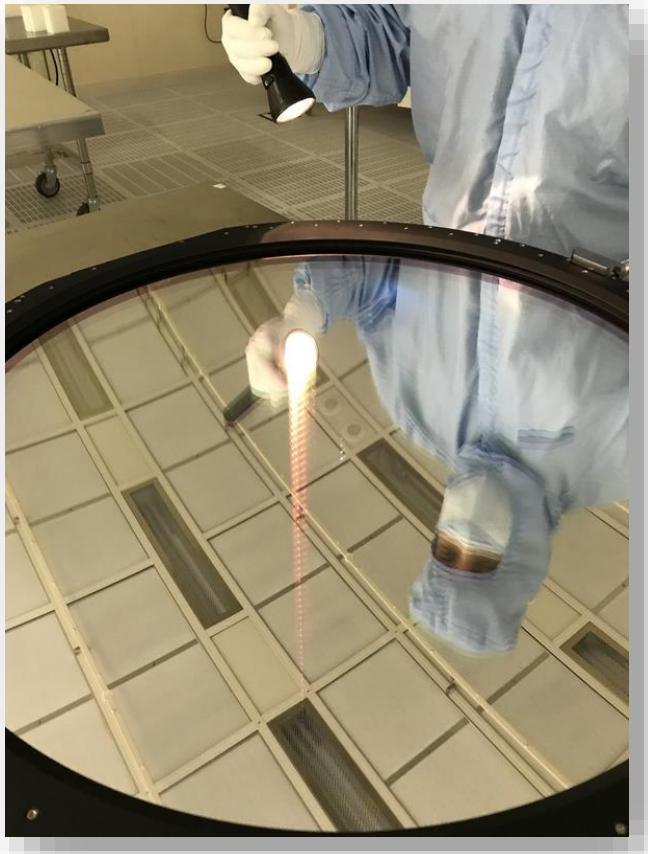
The 3.2 Gigapixel LSST Camera will be the largest electronic camera ever built for ground-based astronomy.

There are six optical filters, five of which are resident in the camera on any given night.

3.2 GigaPixel Camera

- 63 cm focal plane
- 2 second readout (fast!)
- 3060 kg
- 1.65 M front Lens
- 6 filters 0.3 – 1.1μ
- 189 sensors in 21 rafts

LSST Camera – Fabrication Complete!



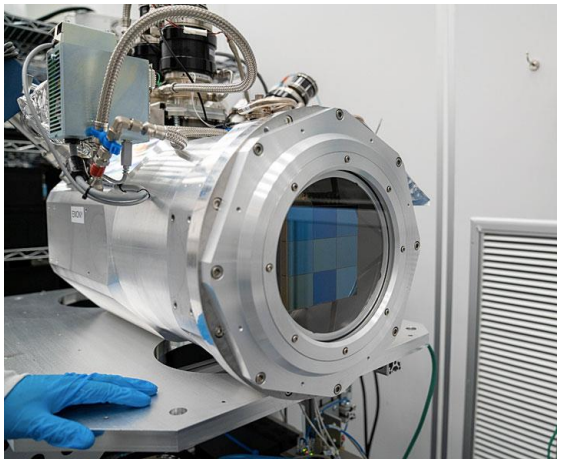
y-band during inspection at LLNL after completion of the mounting in the frame.

All filters have been delivered to SLAC as of Sept. 2021.

→With delivery of the u-band filter, all the Camera project scope has been delivered.

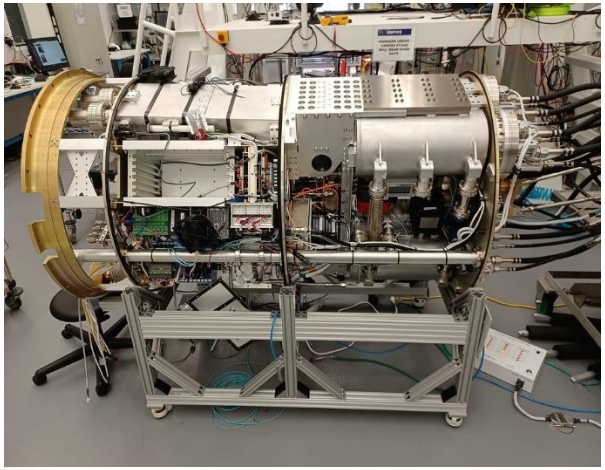
LSST Camera – Commissioning

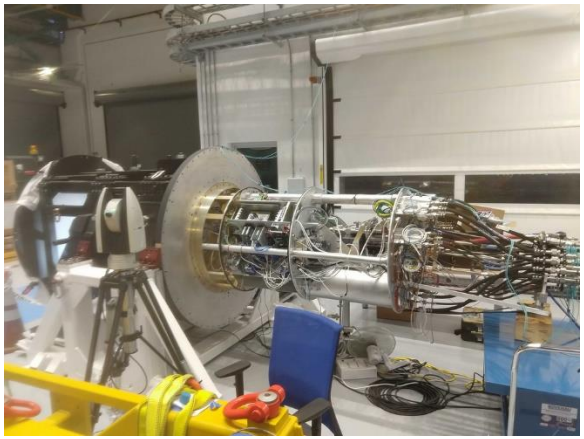
The mass simulator for the LSST Camera arrived successfully on the summit of Cerro Pachón on Sept. 13th.
- Important to test shipping and systems on the mountain



The commissioning camera (ComCam) is in Chile & has been mated successfully with the refrigeration pathfinder and the quad box.

The utility trunk integration and test was completed; ready for integration with the cryostat

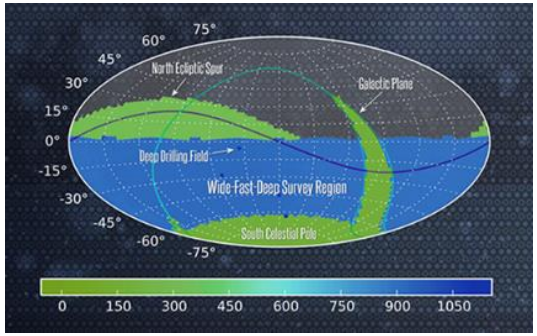




The cold refrigeration pathfinder (chamber seen in the middle of the picture) is running within the commissioning camera.

Rubin Observatory: Facility Operations Planning

The Rubin Observatory will conduct a 10-year deep, wide, fast, optical imaging Legacy Survey of Space and Time (LSST) using DOE's LSST Camera & the Simonyi Survey Telescope



DOE & NSF will provide 50/50 support for operations
- Joint review of Operations plan scheduled for Jan. 2022

DOE-supported operations efforts are primarily:

- Camera maintenance and operations
- US Data Facility (USDF) → 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

International in-kind contributions to operations are in the process of being agreed to - in exchange for early access to data. Types of contributions:

- Offsets to US Operations costs - Priority
- Also consider enhancements to US Science, e.g.
  - science collaboration software, simulations, data analysis tools
  - telescope time to US scientists
  - other data sets or appointments to other collaborations w/o current US access

➔Rubin Operations Team is working with contributors to carry out the planning; **NSF & DOE will have final approval.**

Rubin Observatory Legacy Survey of Space and Time → Dark Energy Science Collaboration (DESC)

Scientific Research - Both NSF and DOE will support community efforts

- **DOE's research efforts are organized through DESC**; planning and readiness activities are continuing.

Multiband subfield of Data Challenge 2, from Dark Energy Science Collaboration *et al.*, 2021.

Collaboration ~ 1100 members;
> 235 full members; from 15 countries

Data enable study of the nature of Dark Energy via complementary probes:

- SNe Ia's as "standard candles"
- Baryon acoustic oscillations as "standard rulers"
- Studies of growth of structure via weak gravitational lensing
- Studies of growth of structure via clusters of galaxies

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

Connections with Rubin Observatory

- Provided DESC Data Challenge 2 simulations for use in Rubin Data Preview 0, which is enabling 'delegates' from all LSST Science Collabs to test analyses
- Submitting 4 photometric redshift letters of rec. in response to Rubin call
- Preparing several LOIs for participation in technical validation of Rubin Observatory during Commissioning

See public release of DC2 at: https://lsstdesc-portal.nersc.gov/

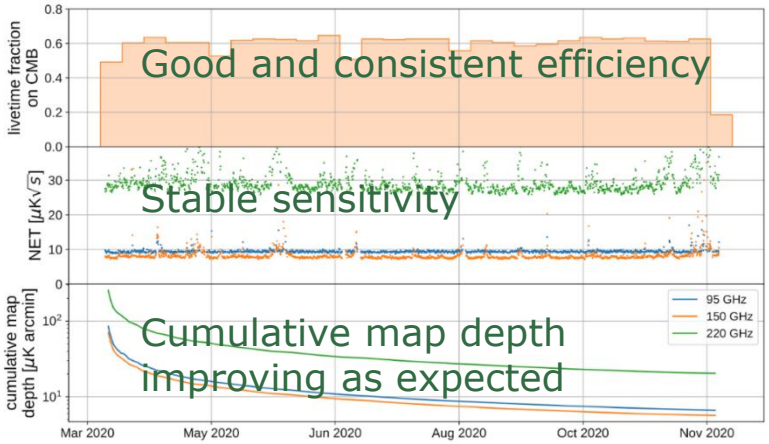
Cosmic Microwave Background

Gain insight into inflationary epoch at the beginning of the universe, dark energy & neutrino properties by studying oldest visible light.

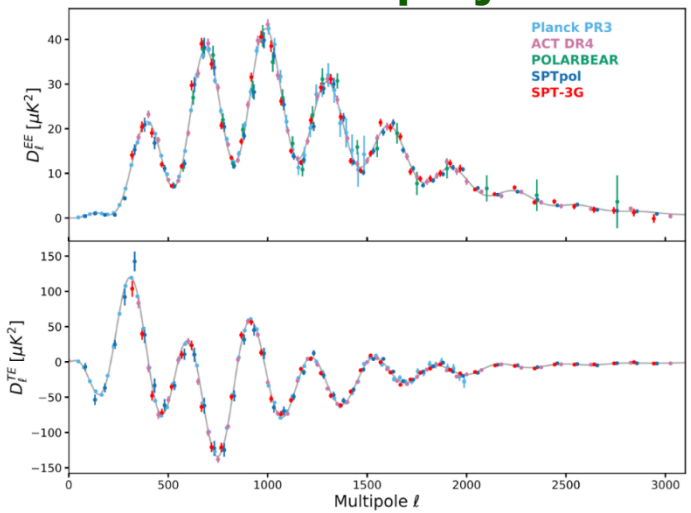
- **P5 recommended DOE should support CMB experiments as in the core particle physics program.**
- **CMB-S4 is intended to be the next flagship Cosmic Frontier project**

South Pole Telescope 3rd Generation - operating

- NSF & DOE partnership: HEP supported major upgrade: fabrication of the 16,000-detector focal plane, greatly increasing sensitivity



Survey started 2018; continues to operate smoothly with high observing efficiency



First SPT-3G science publication

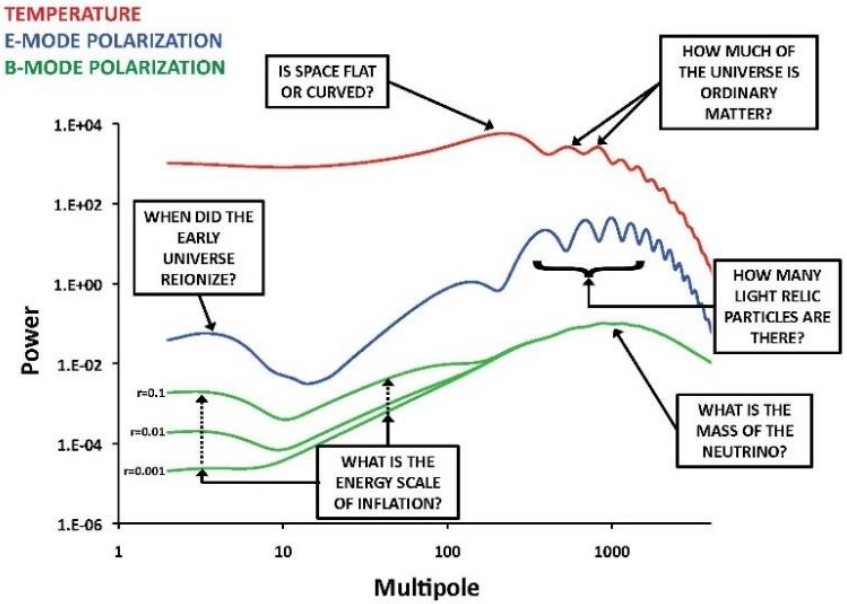
- Measurement of TE/EE power spectra with 2018 data

Dutcher et al.
https://arxiv.org/abs/2101.01684
Submitted to Physical Review D

Cosmic Microwave Background – Stage 4 (CMB-S4)

CMB-S4 recommended by P5 in all scenarios
- HEP/Cosmic Frontier's next flagship project

Goal: cross critical science thresholds



Highlights: 2 sites, Chile & South Pole

- Being planned as a joint DOE/NSF project,
- Chile: 2 large aperture (6m) telescopes
  - Deep & wide N_{eff} & Legacy Survey ~60% of sky
- South Pole: 1 large (5m), 18 small (0.5m)
  - Ultra-deep survey ≥ 3% of sky + delensing
- Total 500,000 cryogenic sensors, superconducting readout

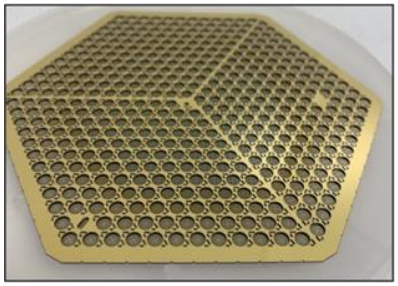
Collaboration has > 250 members!

- **Aug.2019** Project received Critical Decision 0 (CD-0)
- **Aug.2020**, LBNL chosen as DOE Lead lab; HEP status review
- **Dec.2020, FY21** budget appropriation provided $6M for R&D, project development
  - Congress approved it as a Major Item of Equipment (MIE) "project start"

CMB-S4 Status & Plans

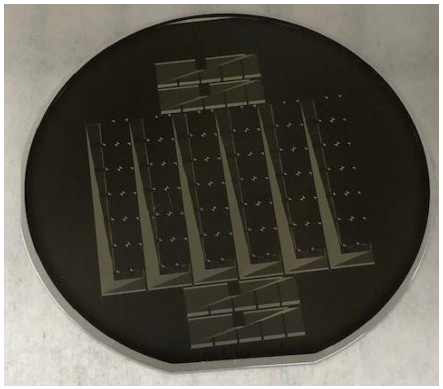
Short term challenge:
- slow ramp up of funding compared to Project's request has limited the planned R&D, especially on detectors and readout.

Longer term challenge:
- Synchronizing possible DOE & NSF roles.
- Experience with partnerships on Rubin/LSST and HL-LHC will prove useful.

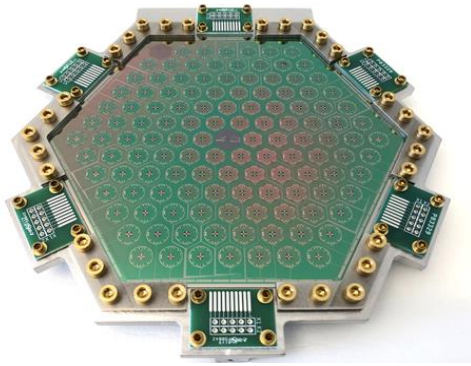


Metalized back side of a prototype CMB-S4 wafer fabricated at ANL

Status:
- Series of 8 subsystem conceptual design reviews from late May through early August.
- Planning a status review led by DOE Office of Project Assessment in February 2022.
- Team is working towards CD-1 in late 2022.



Prototypes of TES signal routing chips fabricated on 6" Si wafer at SLAC.

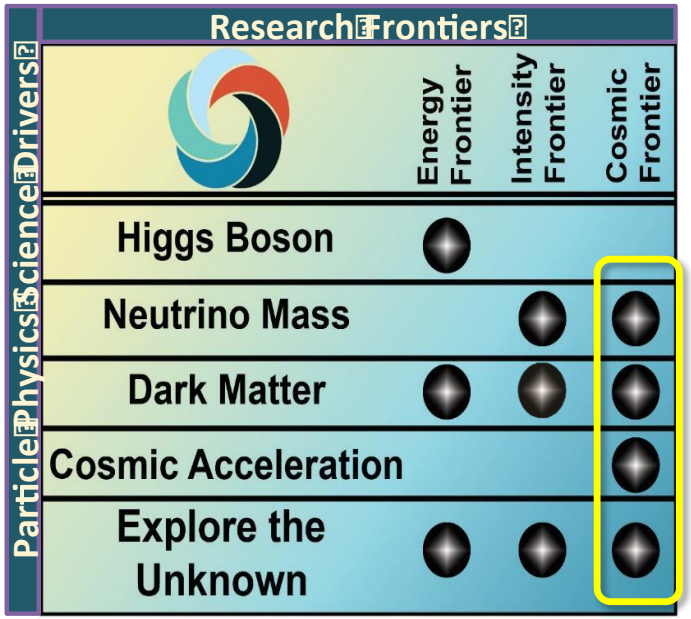


Fabrication of a detector array holder by LBNL; it will be used to screen completed detector arrays for dark TES properties using DC SQUID readout systems.

Cosmic Frontier – Dark Matter, Neutrino Mass, Explore the Unknown

Dark Matter: Primary efforts are direct-detection searches for particle dark matter (WIMPs; axions) through deep underground experiments

- Generation 2 projects in process
- Doing concept development for Dark Matter New Initiatives (DMNI) for new small projects to investigate new areas of phase space.

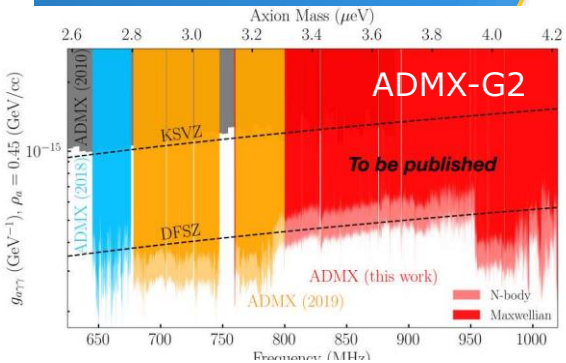


Neutrino Mass: Unique constraints from Dark Energy and CMB experiments

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

Direct Detection of Dark Matter

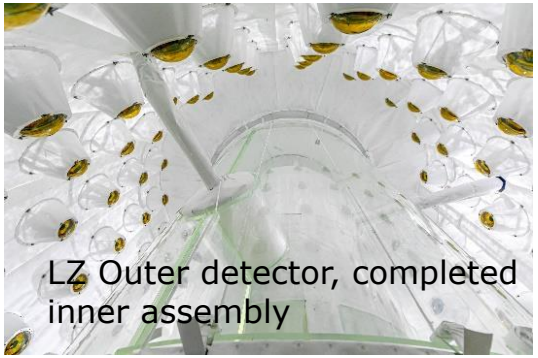
Staged suite of complementary direct detection experiments with multiple technologies to search for dark matter particles



3 Dark Matter 2nd Generation (DM-G2) projects

ADMX-G2

- axion search (μeV-meV mass) currently operating at Uwashington
- planned upgrades continue as they step through frequencies

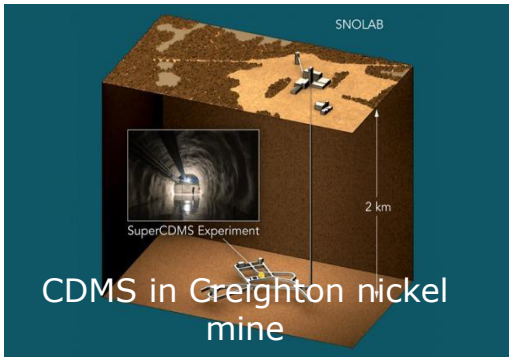

LZ Outer detector, completed inner assembly

LZ at Homestake Mine in South Dakota

- Dual phase liquid Xe WIMP search; ~10-1000 GeV mass
- Project fabrication complete; Commissioning near completion
- *LZ will start physics runs in late 2021*

SuperCDMS-SNOLab in Canada (HEP+NSF partnership)

- Cryogenic solid-state crystal WIMP search; ~1-10 GeV mass
- Project fabrication is being restructured due to cryostat procurement & covid-19; Rebaseline review was held the end of Aug. 2021
- Expect full fabrication completion and full operations start in 2023; Can start operating with partial detector beforehand.

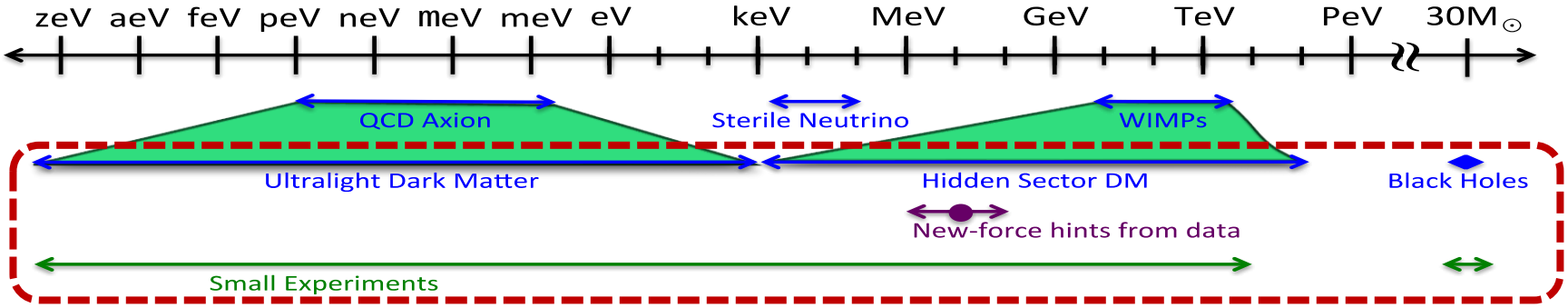


CDMS in Creighton nickel mine

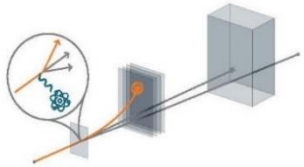
Future Planning:
- Dark Matter New Initiatives (DMNI) for small projects

P5 recommended the search for Dark Matter particles as a high priority & also that the program should include small projects

- Recent theoretical advances and development of new technologies opened new avenues to explore dark matter

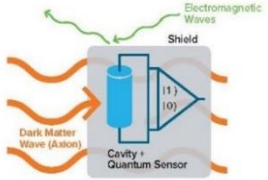


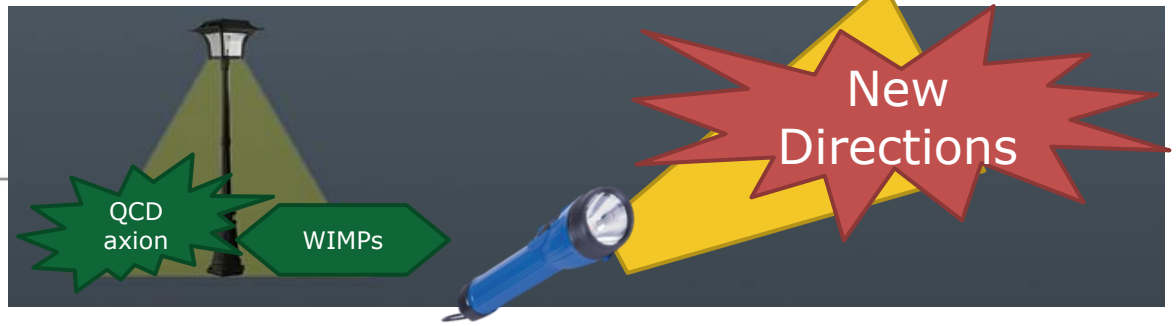
PRD 1
Create and Detect DM at Accelerators.



PRD 2
Detect Galactic DM Underground.

PRD 3
Detect Wave DM in the Laboratory





➢**2017** Community Workshop, https://arxiv.org/abs/1707.04591

➢**2018-2019**: Basic Research Needs (BRN) study developed 3 Primary Research Directions (PRD) https://science.energy.gov/hep/community-resources/reports/

Dark Matter New Initiatives (DMNI) – Concept Studies

➢**2019-2020: Funding Opportunity Announcement (FOA); Six proposals aligned with the PRD's selected to develop concept & execution plans for potential small projects to search for dark matter particles in new areas of phase space.**

→Since late 2019, HEP is supporting 6 concept teams to carry out near-term technology R&D and to develop design and execution plans that can be reviewed and considered for advancing to potential small project fabrication phase.

- Most will need to be a Major Item of Equipment (MIE) project, meaning we have to request it in our budget and have it approved by Congress.

Cosmic Frontier:

- **ADMX Extended** (axions 2-4GHz), 9-17 μeV, A. Sonnenschein (FNAL)
- **OSCURA** (low noise "Skipper" CCD detector) 1MeV-1GeV, J. Estrada (FNAL)
- **DM-Radio** (axion search), <μeV, K. Irwin (SLAC)
- **TESSERACT** (Multiple detectors, w/TES readout), >10 MeV, D. McKinsey (LBNL)

Intensity Frontier (accelerator based)

- CCM Beam Dump exp at FNAL, ~1-40 MeV, R. van der Water (LANL)
- Light Dark Matter Experiment (LDMX) ~ 10-300 MeV, T. Nelson (SLAC)

Annual status review of the DMNI concepts held June 2021.

Exploring the Unknown

Use ground-based arrays, space telescopes, & an experiment on the International Space Station to explore the unknown, e.g. indirect searches for dark matter

Operations continuing – no major covid-19 impacts

Fermi/GLAST - Large Area Telescope (LAT) (w/NASA)

- Space-based gamma-ray observatory, launched in 2008
- HEP/SLAC led the fabrication of the LAT; Continues to support critical efforts at the LAT Instrument Science Ops Center at SLAC

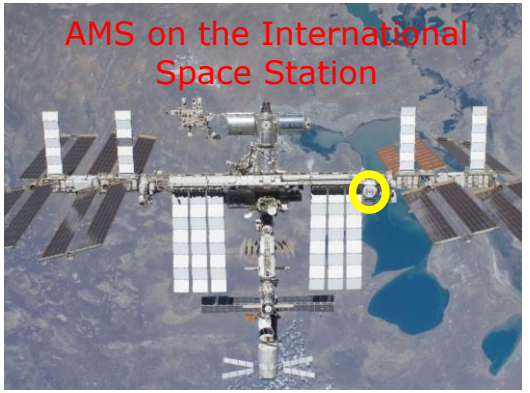
AMS *(w/NASA)*

- Launched and mounted on International Space Station in 2011
- DOE-HEP is responsible for management of the science program, led by Prof. Ting (MIT) and has roles in operations
- Can continue through 2028+
- Review of MIT/AMS science and operations in Oct. 2021
- Multi-purpose particle-physics spectrometer detects cosmic-rays up to multi-TeV; search for anti-matter, dark matter etc.

HAWC *(w/NSF)*

Gamma rays and cosmic rays between 100 GeV and 100 TeV

- HEP operations support completed early FY2021.



Joint DOE-NASA RFI - status

In Jan.2021, DOE Office of Science and NASA Science Mission Directorate jointly released a **Request for Information (RFI).** Responses were due March 8th.

- Goal: gather information from the community in 3 specific focused areas
  …aligned with the science goals of both of the program offices in partnerships that make use of both agency capabilities and infrastructure to enhance the science.

- DOE & NASA are currently reviewing the comments to inform and consider any next steps in development of mutually beneficial partnerships or collaborative activities.

FYI: This RFI is part of a wider DOE/NASA effort to investigate collaborative activities:
https://www.energy.gov/articles/department-energy-and-nasa-sign-memorandum-understanding

The 3 focused areas are:

1. Moon (11 papers received)
   - Sensitive radio telescopes or sensors on the Moon's far side to explore the early eras of the universe or test the standard cosmological model

2. ISS (7 papers received)
   - Small experiments to carry out space-based probes of fundamental physics in a microgravity environment of the International Space Station

3. Rubin+Roman+Euclid joint efforts (13 papers received)
   - Enhance or extend dark energy science data reach from the Rubin Observatory, Roman Space Telescope and the Euclid observatory when considered together

Cosmic Frontier – Future Planning

Coordination between Rubin, Roman and Euclid

- Community input has been provided via the DOE/NASA RFI (2021).
- In the anticipation that Astro2020 will recommend coordination and leveraging efforts, the Three Agency Group (DOE/NASA/NSF) has asked the Roman and Rubin leadership, along with the US Euclid leadership, to investigate and prioritize leveraging possibilities.

Astronomy & Astrophysics "Astro2020" Decadal Survey

- Identify the most compelling science challenges and frontiers
- Develop a comprehensive strategy for 2022-2032.
- Results out soon!

DOE & NSF charged the National Academy of Science to carry out an **Elementary Particle Physics (EPP) decadal survey**; starting ~ summer 2021

- Assess the current state of the field, identify the fundamental questions that motivate research and tools necessary to answer these questions in context of international landscape; consider cross-disciplinary aspects and societal benefits

Cosmic Frontier – Future Planning

"Snowmass" process led by APS/DPF & DPB for High Energy/Particle Physics community

- To identify science questions and directions for the coming decade.
- Process started summer 2019; paused due to COVID and restarted Sept. 2021; and culminates in a workshop in summer 2022.

The multi-year community-driven processes culminates in the HEPAP **Particle Physics Project Prioritization Panel (P5)** to lay out a strategic plan.

- Input includes: Astro2020, European Strategy for Particle Physics, Japanese planning, "Snowmass" community workshops, NAS EPP, etc.

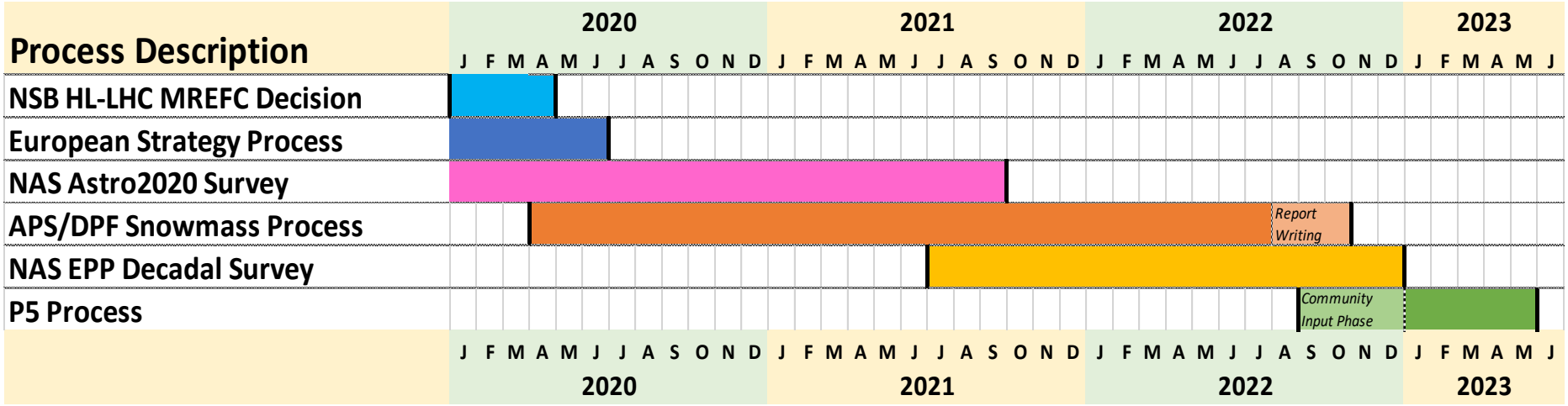
→P5 report by May 2023 will inform FY 2024 Congressional actions & FY 2025 U.S. budget formulation

Strategic Planning Timeline

HEP community-wide "Snowmass" study process organized by the Division of Particles and Fields (DPF) of the American Physical Society (APS) has begun (https://snowmass21.org/start)

- Snowmass process was paused/slowed down due to the COVID-19; resumes full activities in Sept. 2021
- "Community Summer Study" (CSS) will take place July 17–27, 2022 at UW-Seattle (in person)
- Full Snowmass reports will be available by the end of October 2022

- New National Academy of Sciences (NAS) Decadal Survey planned to overlap with Snowmass process to enable addressing full breadth of particle & astroparticle physics
- Next P5 process to begin after Snowmass and NAS Decadal Survey, circa late 2022:
  - **P5 report by May 2023 will inform FY 2024 Congressional actions & FY 2025 U.S. budget formulation**



We will continue to work with the community and our international partners as we begin the next phase of long-term community planning

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Research (Scientist) Support

HEP University Program – Grant Statistics

Cosmic Frontier – Grant statistics

Cosmic Funding ($M)	FY16	FY17	FY18	FY19	FY20	FY21
Request (all years)	$26.47	$24.60	$27.61	$18.28	$29.31	$26.01
Request (Year 1)	$7.80	$7.60	$14.32	$5.22	$9.15	$8.32
Funded Year 1, w/FFF	$4.3M w/FFF	$4.7M w/FFF	$5.4M w/FFF	$3.4M w/FFF	$4.94 w/FFF	4.72 w/FFF
Cosmic - proposal counts						
received	43	31	30	23	30	27
reviewed	36	26	28	20	30	26
funded	21	18	23	17	23	20
success rate	58%	69%	82%	85%	77%	77%
Cosmic - PI counts						
received	65	49	56	37	51	48
reviewed	55	43	54	34	51	47
funded	25	26	38	27	36	36
success rate	38%	53%	68%	73%	71%	75%

SC Early Career program (Univ + Lab)
➔ FY16-21 Cosmic Frontier Awards

Cosmic Frontier - Early Career awards	FY16	FY17	FY18	FY19	FY20	FY21
#Proposals Received	**13**	**13**	**16**	**17**	**16**	**19**
Proposals Reviewed Univ	7	8	11	13	11	10
Proposals Reviewed Lab	6	5	5	4	5	9
Funded Univ	**1**	**1**	**2**	**3**	**3**	**3**
Funded Lab	**0**	**1**	**0**	**0**	**0**	**2**

Color code: **Dark Energy** **Dark Matter** **CMB**

FY16	**Eduardo Rozo** **U. Arizona** 	**Anja von der Linden** **StonyBrook** 			
FY17	**Michael Schneider** **LLNL** 				
FY18	**Hee-Jong Seo** **Ohio U** 	**Alexie Leauthaud** **UCSC** 			
FY19	**Tim Eifler** **U. Arizona** 	**Elisabeth Krause** **U. Arizona** 	**Scott Hertel** **U. Mass** 		
FY20	**Hugh Lippincott** **UCSB** 	**Lado Samushia** **Kansas State** 	**Michael Troxel** **Duke** 		
FY21	**Lindsey Bleem** **ANL** 	**Chihway Chang** **U. Chicago** 	**Brian Nord** **Fermilab** 	**Dan Scolnic** **Duke** 	**Heidi Wu** **Boise State** 

HEP Research Program – For University Grants Funding Opportunity Announcement (FOA) & FAQ

DE-FOA-0002546 issued: August 2, 2021

- **Six HEP research subprograms**
  - Energy, Intensity, and **Cosmic Frontiers**
  - HEP Theory, Accelerator R&D, and Detector R&D
- **Letter of Intent (strongly encouraged) due: August 31, 2021**
- **Final Proposal deadline: October 5, 2021**
- **Review and Selection processes: October 2021 to February 2022**

Please read the FOA carefully and comply with all requirements! There is an associated FAQ.

See *https://science.osti.gov/hep/Funding-Opportunities FOA # 2546*

HEP's Annual PI meeting was held Aug. 9-12th.

- Talks by HEP staff on overall program, budget, new initiatives, DEI, funding opportunities, and details of each area, e.g. Cosmic Frontier.
- We encourage you to read over these talks and contact the relevant program manager regarding program details and opportunities.
- See https://www.orau.gov/heppi2021 -- go to agenda and find the linked talks.

Note: Comparative Review of DOE Lab Research Programs (typically every 4 years; Cosmic Frontier June 2021)

Requirements in the FY2022 HEP FOA

New Appendix:
Recruitment and Retention of Students and Early-Stage Investigators

- Included in research efforts is training of junior scientists (students & postdocs) to enable them successfully complete their research and move to next career step.
- Further, we want to broaden and diversify the HEP research community and increase opportunities for everyone to contribute.

  - A new merit criterion has been added for proposal evaluation: Quality and Efficacy of Recruitment and Mentoring Plan

Data Management Plan (DMP)
All Research proposals submitted to DOE SC must have a DMP

- Data management involves all stages of the digital data life cycle: capture, analysis, sharing, and preservation. The SC Digital Data Management Statement focuses on sharing and preserving digital research data.

Other DOE Funding Opportunities

Workforce Development (WDTS) programs:
https://science.osti.gov/wdts

- **Office of Science Graduate Student Research fellowships (SCSGR)**
  - Supports grad student research at a DOE lab, 3 to 12 months
  - Two calls per year, usually Feb/Aug
  - Applications typically due May/Nov for following Fall or Summer start
- **Science Undergraduate Laboratory Internships (SULI)**
  - Supports undergraduate research at a DOE lab, 10 to 16 weeks
  - Three calls per year, for following Spring/Summer/Fall terms
- **Visiting Faculty Program**
  - Summer research support for faculty/students from historically underrepresented institutions
  - One call per year, usually in Oct. Applications due in Jan.

Available funds have been increasing!

Office of Science programs:

- **Early Career Research**: https://science.osti.gov/early-career
  - FY 2022 FOA #2563 released 9/9/21; pre-applications due 10/21/21, full proposals due 1/20/22.
- **SC "Open Call"** [DE-FOA-0002414] – new version posted annually
  - HEP uses this primarily for conferences, supplements, experimental operations, and emergencies (e.g. equipment failure).

Summary

HEP continues to carry out the 2014 P5 strategic plan; Strong support from the scientific community and the Hill

→Cosmic Frontier continues to produce excellent, world-leading science results

- **DES** completing data analyses
- **ADMX-G2, SPT-3G, Fermi-LAT, AMS, HAWC** operating
- **DESI** has started it science survey operations (May 2021)
- **LZ** (dark matter) fabrication complete, now in commissioning; operations start soon

- **LSST Camera** complete, Commissioning ongoing
- **Rubin Observatory** Facility Ops planning to be ready for data in 2024.
- **DESC** planning Rubin Observatory dark energy studies

- **CMB-S4** – LBNL selected as lead DOE lab; Approved as a fabrication project for DOE in the FY2021 budget; working towards planning for CD-1 and beyond.

- **Dark Matter New Initiatives** – concept design & planning
- **DOE/NASA RFI on** focused, potentially collaborative areas.
- **Future Planning** – Astro2020, Snowmass → P5

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