U.S. DEPARTMENT OF ENERGY | Office of Science

DOE Office of Science (SC) Office of High Energy Physics (HEP) Program

Astronomy & Astrophysics Decadal Survey Meeting

August 25, 2020

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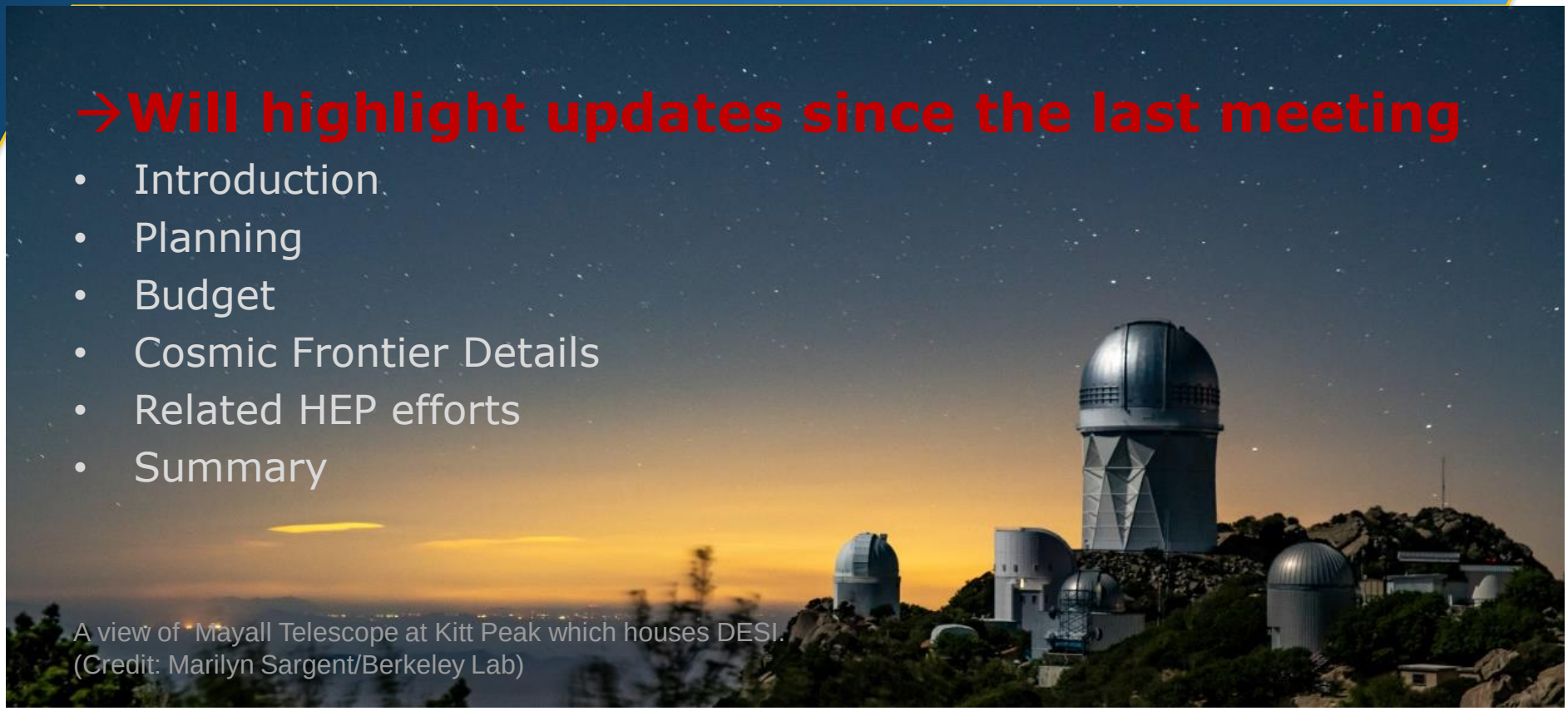
Office of High Energy Physics

OUTLINE



For overall status and details of the HEP program, see Jim Siegrist's talk and talks on Research, Funding Opportunities and Budget on 8/24/20 at the 2020 PI meeting: https://www.orau.gov/heppi2020/agenda.htm

COVID-19 pandemic discussed in HEP Project overview and COVID Pandemic talks and a Diversity Equity, Inclusion on 8/25/20

DOE/SC Policies, Procedures → Diversity, Equity, Inclusion

The DOE Office of Science (SC) is fully committed to fostering safe, diverse, equitable, and inclusive work, research, and funding environments that value mutual respect and personal integrity

In 2016, SC established a process for an SC Headquarters-led annual evaluation of National Laboratories' efforts in diversity, equity, and inclusion (DEI)

In 2018, the Office of Science initiated an internal review of its business practices to identify opportunities to better promote diversity, equity, and inclusion in our award making and awards management processes, and better communicate policies, practices, and procedures to our research community

DOE has long had policies in place prohibiting discrimination and harassment by institutions that we fund (at academic institutions, small businesses, and DOE national labs), and by employees. A new www site is in place to consolidates DOE's policies and procedures:

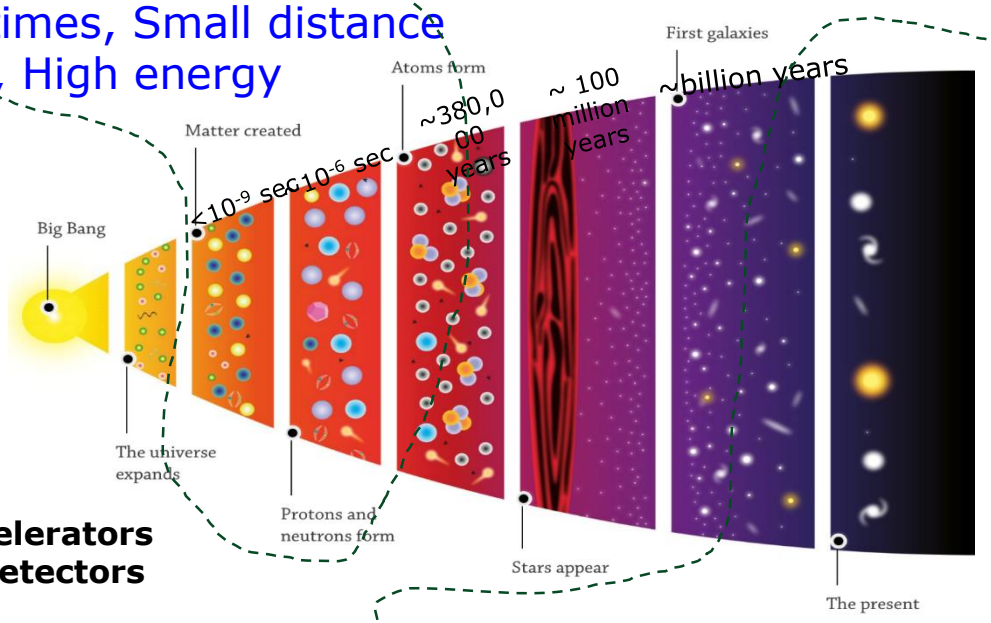
- https://science.osti.gov/sc-2/Research-and-Conduct-Policies/Diversity-Equity-and-Inclusion

HEP's Mission: From Quarks to the Cosmos

Mission: Understand how the universe works at its most fundamental level; Discover & understand the elementary constituents of matter & energy, space & time - from the Big Bang to Grand Unification

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

Early times, Small distance scales, High energy



Accelerators & detectors

Terrestrial & space based telescopes

Current times = cosmological scales

DOE, HEP Program Mission & Processes

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

- **HEP carries out projects and a program described in our ["P5" community-based] strategic plan to provide significant leaps in particular areas**
- Carries out projects to design, build, operate facilities & experiments
  - Typically a staged suite of projects and experiments with a variety of technologies, methods, etc. to make significant progress in scientific capabilities and results.
  - Support priorities are those directly in line with our program & project priorities, responsibilities & science goals
- Form partnerships or use other agency's/country's facilities when needed (most projects have interagency or international partners or contributions
- DOE/HEP is not a unique supporter of the HEP science goals….but HEP community does bring some specific scientific expertise and technical resources to Astronomy/Astrophysics.

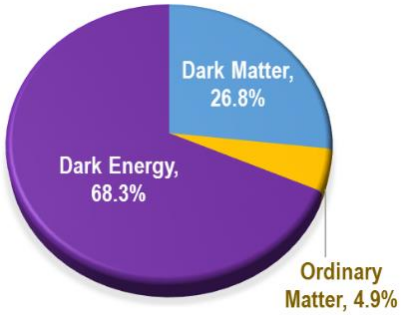
HEP's current "P5" strategic plan

Primary steps on the way to development of the HEPAP* 2014 P5 plan:

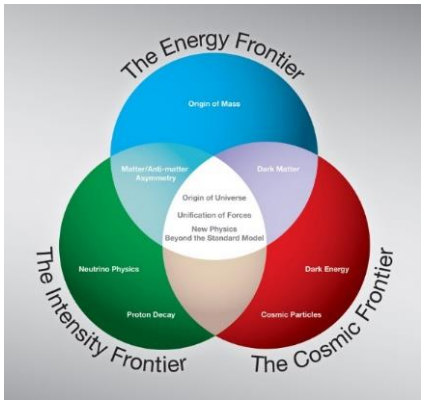
2006 NAS study: Elementary Particle Physics 2010 (EPP2010)
2008 HEPAP Particle Physics Project Prioritization Panel (P5) subpanel
2009 HEPAP Particle Astrophysics Science Assessment Group (PASAG) subpanel
2010 NAS study: Astro2010 NWNH (New Worlds New Horizons)
2013 APS/DPF Community "Snowmass" report, Planning the Future of Particle Physics
2014 HEPAP - Particle Physics Project Prioritization Panel (P5)

*FACA advisory panels provide input to HEP:
High Energy Physics Advisory Panel (HEPAP) panel provides the primary advice for our program; advises both DOE and NSF.
Astronomy and Astrophysics Advisory Committee (AAAC) Advises DOE, NASA, and NSF on selected issues in astronomy & astrophysics of overlap, mutual interest and concern

HEP Program Execution



The **Standard Model (SM) of particle physics** describes 3 of 4 known fundamental forces (em, weak, & strong interactions; not gravity) in the universe, as well as classifying all known elementary **particles**.



<u>HEP is carried out along 3 Frontiers</u>: Advancements at all 3 are needed to achieve the long term goals of the field.

→HEP is primarily a Particle Accelerator based program: **Energy & Intensity Frontiers**

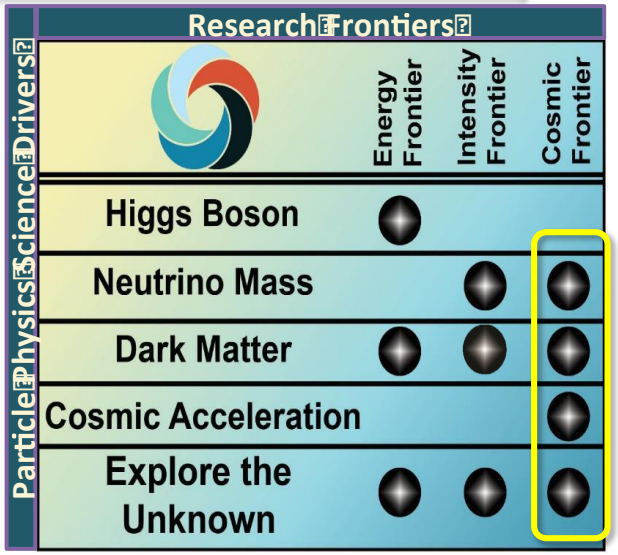
→Cosmic Frontier is an increasingly important area for discovery. Experiments use naturally occurring data to provide additional input to the SM.

2009 HEPAP/PASAG report <u>criteria</u> guides determination of the scope and funding level for HEP participation in specific projects.

- For projects that make significant leaps in addressing HEP goals, we consider unique/leadership participation and contributions that makes use of our expertise and capabilities

Cosmic Frontier Experimental Research Program

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



Cosmic Acceleration:

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

Dark Matter: Search for particle dark matter (high- and low-mass WIMPs; axions) through direct detection experiments deep underground (with NSF/PHY)

- Cosmic-ray & Gamma-ray studies provide indirect searches for dark matter particles & searches for New Physics
- Future planning: Dark Matter New Initiatives (DMNI) – concept development small projects

Neutrino Mass: Unique constraints from Dark Energy and CMB experiments

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

HEP & Astro2020

Astro2020 – Statement of Task:

- Identify the most compelling science challenges and frontiers in astronomy and astrophysics, which shall motivate the committee's strategy for the future;
- Develop a comprehensive research strategy to advance the frontiers of astronomy and astrophysics for the period 2022-2032.

➔Guidance from Astro2020 will inform HEP on

- Compelling, high impact opportunities that align with our science priorities and make use of HEP community's capabilities
  - where DOE HEP researchers and investments can play a significant role in and make unique, significant and necessary contributions (PASAG criteria) that make use of our capabilities and expertise
- Partnerships with NASA, NSF & international collaborators as appropriate
- Consider need for Research support, Experimental Operations, Computing resources, technology development, etc.

HEP Strategic Planning Timeline

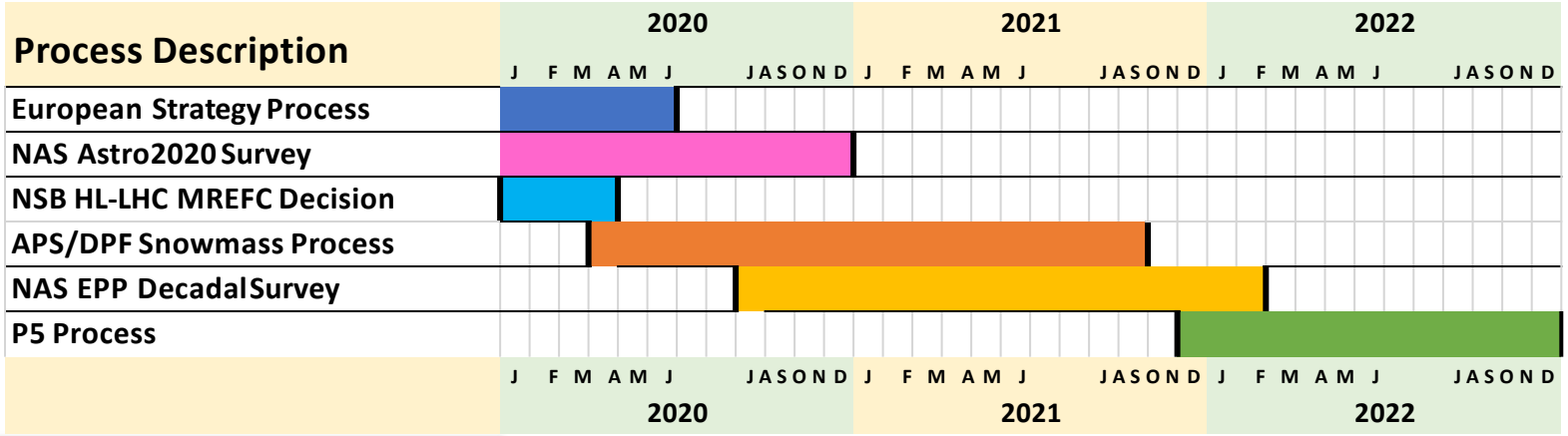
➔Preparing for next Strategic Plan:

- HEP community-wide "Snowmass" study process organized by the Division of Particles and Fields (DPF) of the American Physical Society (APS) has begun

☐ Status (see Snowmass page: https://snowmass21.org/start)

- Kick-off at the 2020 Virtual April APS meeting
- Several Snowmass working group meetings & study sessions now progressing…
- Final "large" Snowmass Meeting scheduled for July 11-20, 2021, at University of Washington
- New National Academy of Sciences (NAS) Decadal Survey planned to overlap with Snowmass process to enable addressing full breadth of particle and astroparticle physics

☐ Next P5 strategy/prioritization process to begin after Snowmass and NAS Decadal Survey, circa end of CY 2021: **P5 report by Nov-Dec 2022 to inform FY 2024 & 2025 budgets**



FY 2021 President's Request Budget for DOE Office of Science

SCIENCE

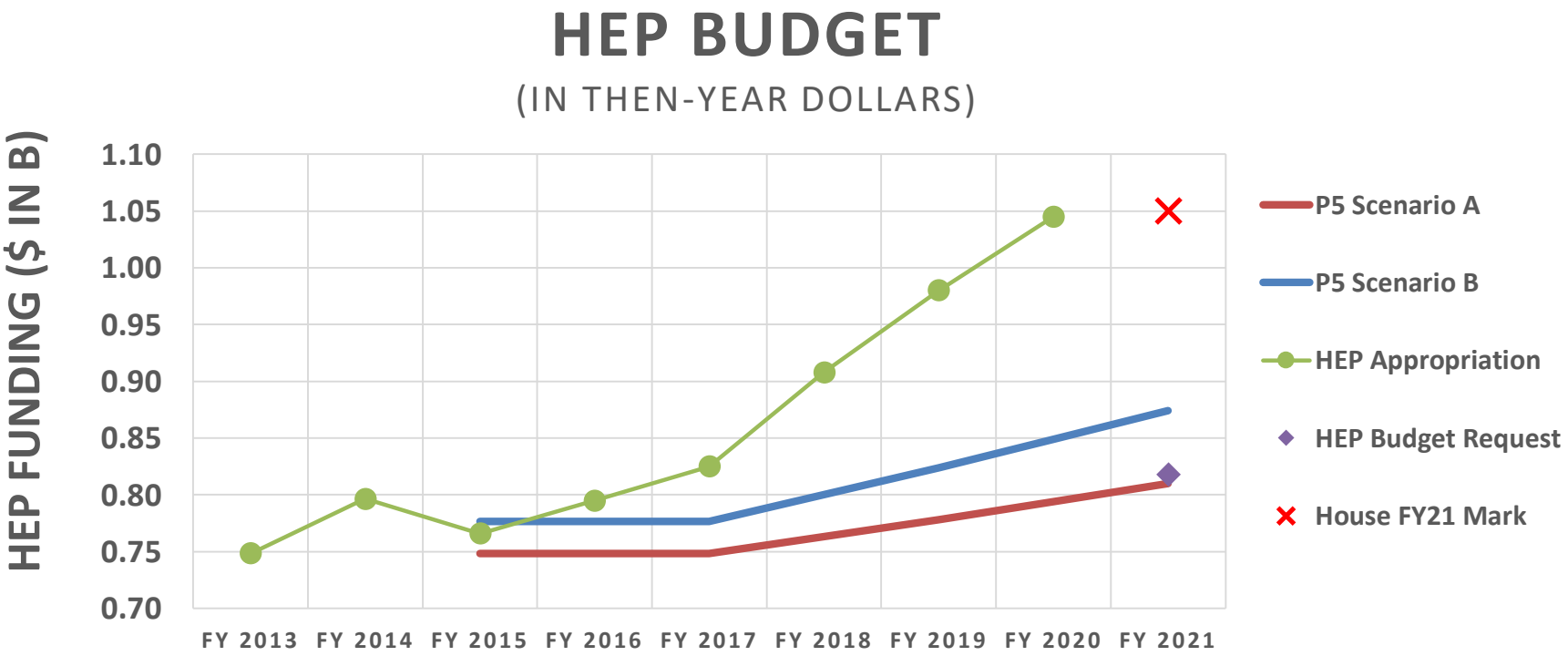
(collars in thousands)

	FY 2019 Enacted	FY 2020 Enacted	FY 2021 President's Request	FY 2021 Request vs. FY 2020 Enacted	
				$	%
Office of Science					
Advanced Scientific Computing Research	935,500	980,000	988,051	+8,051	+0.8%
Basic Energy Sciences	2,166,000	2,213,000	1,935,673	-277,327	-12.5%
Biological and Environmental Research	705,000	750,000	516,934	-233,066	-31.1%
Fusion Energy Sciences	564,000	671,000	425,151	-245,849	-36.6%
High Energy Physics	980,000	1,045,000	818,131	-226,869	-21.7%
Nuclear Physics	690,000	713,000	653,327	-59,673	-8.4%
Workforce Development for Teachers and Scientists	22,500	28,000	20,500	-7,500	-26.8%
Science Laboratories Infrastructure	232,890	301,000	174,110	-126,890	-42.2%
Safeguards and Security	106,110	112,700	115,623	+2,923	+2.6%
Program Direction	183,000	186,300	190,306	+4,006	+2.2%
Total, Office of Science	**6,585,000**	**7,000,000**	**5,837,806**	**-1,162,194**	**-16.6%**

The SC Request includes ongoing investments to support the Administrations Industries of the Future (IOTF) initiative through research in **quantum information sciences (QIS)** and **artificial intelligence (AI) and machine learning (ML)**. The Request also supports research efforts in next-generation **microelectronics**, genomic sciences to inform biosecurity research, and critical scientific infrastructure needs at DOE laboratories. The Request also initiates several new multidisciplinary research initiatives including: data and computational collaboration with NIH, integrated computational and data infrastructure for scientific discovery, next generation biology, rare earth and separation science, revolutionizing polymer upcycling, and **strategic accelerator technology**. These new initiatives position SC to meet new research demands in an enhanced collaborative effort.

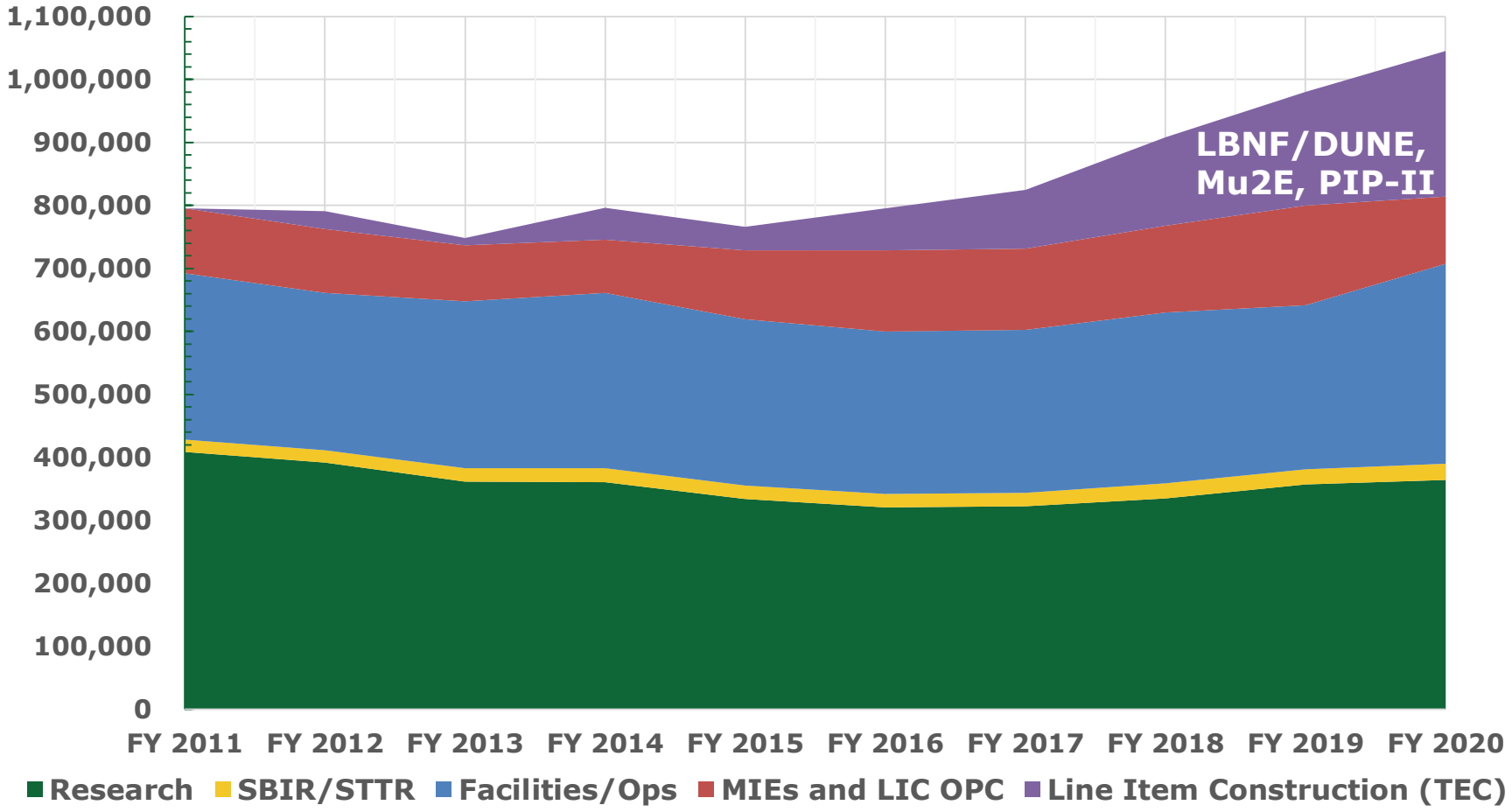
U.S. Congress Supports P5 Strategy

- 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 FY 2016 budget was being formulated
- Arguably the first impact (success!) of the P5 report was not seen until FY 2016, and continues today…



HEP Budget ($k) FY 2011-2020

Research, Operations, Projects: (Construction and MIEs)



FY 2021 HEP Budget Request

HEP Funding Category ($ in K)	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	FY 2021 vs. FY 2020
Research	372,629	390,077	328,903	-61,171
Facilities/Operations	266,556	316,429	285,725	-30,704
Projects	340,815	338,494	203,500	-134,994
Total	**980,000**	**1,045,000**	**818,131**	**-226,869**

FY 2021 President's Budget Request is overlay of Administration, SC, P5 priorities

- SC: interagency partnerships, national laboratories, accelerator R&D, QIS, AI/ML
- HEP: continue successful P5 execution, advance Administration and DOE/SC initiatives

FY 2021 HEP Budget continues support for P5-guided investments

- Research: Continue U.S. leadership in LHC, muon experiments, international neutrino experiments at Fermilab, dark matter, dark energy, and vibrant theory program; QIS; AI/ML; Microelectronics centers (with ASCR, BES, and FES); Strategic Accelerator Technology Initiative; Traineeships in accelerator science
- Operations: Support HEP user facilities and running P5-recommended experiments
- Line Item Construction and Projects: HL-LHC Accelerator and ATLAS & CMS Detectors, LBNF/DUNE, PIP-II, **new MIE start for CMB-S4**

FY 2021 House Mark: $1.050B for HEP. Additional infrastructure package under House consideration.

HEP Funding - Research Areas Ramping Up or New Initiatives; Partnership within SC

HEP ($K) - Research Initiatives	FY19 enacted	FY20 enacted	FY21 request
AI/ML	3,750	15,000	34,500
QIS	27,500	28,500	43,809
Microelectronics			5,000

	FY19 Enacted	FY20 Enacted	FY21 Request
AI/ML			
ASCR	15,000	36,000	56,000
BES	3,214	10,000	20,000
BER	-	3,000	3,000
FES	-	7,000	7,000
HEP	3,750	15,000	34,500
NP	-	-	4,000
AI/ML SC Total	**21,964**	**71,000**	**124,500**

	FY19 Enacted	FY20 Enacted	FY21 Request
QIS			
ASCR	33,666	54,680	86,162
BES	49,517	72,270	72,270
BER	4,500	12,000	12,000
FES	-	7,520	9,520
HEP	27,500	38,500	43,809
NP	8,300	10,300	13,000
QIS SC Total	**123,483**	**195,270**	**236,761**

Final Appropriation Report Language Matters!

- Congress will usually specify top-line budget for a program and sometimes direct specific project or subprogram budget levels
  - It is up to program management to make things work "within available funds"

Example: HEP received $1,045M in the FY 2020 Congressional Appropriation, about $277M above the FY 2020 President's Budget Request

- Congressional "Research" line includes everything other than Line Item Construction, or what HEP traditionally calls Research, Operations, and Projects
- Congressional direction included specific amounts for Line Item Construction, Projects, Vera C. Rubin Observatory, and SURF; HEP cannot adjust what is spent on those items

High Energy Physics (HEP).—Within available funds, $30,000,000 is for the Sanford Underground Research Facility, $100,000,000 is for the HL–LHC Upgrade Projects, and $15,000,000 is for the Large Synoptic Survey Telescope.

The agreement provides $71,000,000 for Artificial Intelligence and Machine Learning for the six Office of Science programs to apply those capabilities to the Department's mission.

The agreement provides $195,000,000 for Quantum Information Sciences across the Office of Science programs to advance early-stage fundamental research in this field of science, including $120,000,000 to carry out a basic research program on quantum information science and $75,000,000 for the establishment of up to five National Quantum Information Science Research Centers. To the greatest extent practical, this effort shall be undertaken in coordination with the National Science Foundation and the National Institute of Standards and Technology.

DEPARTMENT OF ENERGY
(Amounts in thousands)

	FY 2019 Enacted	FY 2020 Request	Final Bill
High energy physics:			
Research	800,000	648,038	814,000
Construction:			
18-SC-42 Proton Improvement Plan II (PIP-II), FNAL	20,000	20,000	60,000
11-SC-41 Muon to electron conversion experiment, FNAL	30,000	---	---
11-SC-40 Long baseline neutrino facility / deep underground neutrino experiment (LBNF/DUNE), FNAL	130,000	100,000	171,000
Subtotal, Construction	180,000	120,000	231,000
Subtotal, High energy physics	980,000	768,038	1,045,000

FY 2021 House Marks

FY 2020 House Mark is $7.05B for DOE SC, $1.050B for HEP

- Senate Mark has not yet been released

Additional infrastructure package also under House consideration brings:

- At SC level:
  - $75,000,000 shall be for equipment and infrastructure for the Quantum Information Science Research Centers;
- At HEP level: (total ~$1,305M)
  - $641,000,000 shall be for Long Baseline Neutrino Facility;
  - $284,380,000 shall be for the Proton Improvement Plan II
  - $200,300,000 shall be for Large Hadron Collider computing and equipment;
  - $100,000,000 shall be for Wilson Hall renovations;
  - $62,000,000 shall be for Cosmic Microwave Background - Stage 4;
  - $9,000,000 shall be for Muon to Electron Conversion Experiment equipment;
  - $6,000,000 shall be for Super Cryogenic Dark Matter Search equipment;
  - $2,100,000 shall be for the Large Synoptic Survey Telescope project;
- In SLI program, two projects benefit Fermilab: (total $82.5M)
  - $77,000,000 shall be for the Utilities Infrastructure Project;
  - $5,500,000 shall be for the Integrated Engineering Research Center;

HEP Budget – Challenges, Effects of Success

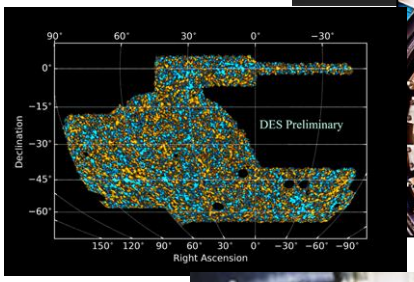
Most of the recent HEP budget growth is in Projects, without similar increases in Operations and Research

- HEP-style Projects depend heavily on Research and Operations support for R&D, QA/QC, integration, installation, commissioning, data-taking operations
- Given that there is a lot of current Research and Operations effort committed to active experiments, this is not optimal for successful project execution
- Balancing Research and Ops with the needs of current and future projects will require careful prioritization – HEP continues to work to ensure adequate balance.
  - Efforts by various community-led forums to communicate the message that healthy growth of the program requires Research and Operations growth in addition to Project support

Dark Energy

Precision measurements to differentiate between: cosmological constant and/or new fields; or modification to General Relativity

Staged, complementary suite of imaging and spectroscopic surveys to determine its nature (in partnership w/NSF-AST)



Final Analysis:

– ***eBOSS*** (spectroscopic) final analysis complete July 2020

– ***DES*** (imaging) data release 2 (6 yrs data) in early 2021;

- final analysis completes 2021

In Fabrication phase:

– ***Vera C. Rubin Observatory*** (Stage IV imaging)

- DOE Camera fabrication 97% complete
- Planning well underway for Rubin Observatory Facility Ops and Dark Energy Science Collaboration (DESC) Ops

Ready for Operations

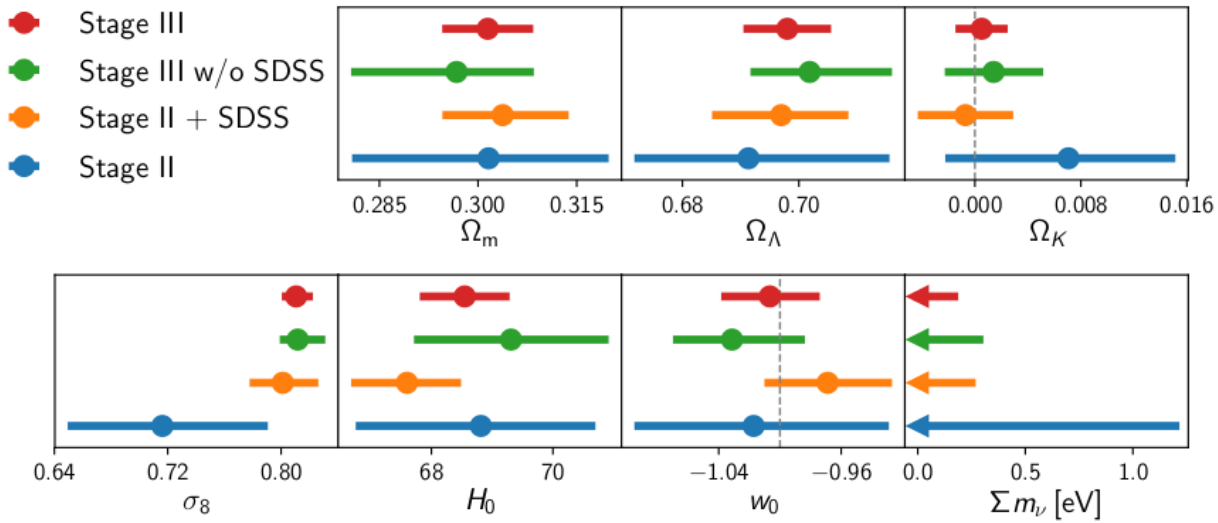
– ***Dark Energy Spectroscopic Instrument*** (Stage IV)

- DESI commissioning complete March 2020
  - CD-4 May 2020, fabrication complete, ready to operate

Cosmic Frontier Highlight:
Extended Baryon Oscillation Spectroscopic Survey (eBOSS)

eBOSS - Stage 3 Spectroscopic Survey for Dark Energy

- Survey ran 2014-19, precursor to DESI
- Component of the Sloan Digital Sky Survey (SDSS-IV) at Apache Point Obs., NM
- DOE-HEP partnership with Sloan Foundation, U.S. Universities, international institutions
- **DOE/HEP: provided new spectrograph for BOSS & eBOSS**



Major Milestone: Final results and papers released July 2020

- BAO/RSD from objects over 0<z<2; BAO from Lyman-α forest and quasars at z=2.35
- Implications for Cosmology:
  - 50X improvement relative to Stage-II in 5-parameter likelihood
  - Stage-III (Planck, SDSS, Pantheon SNe Ia, DES yr1) is 1000X decrease in likelihood volume

Dark Energy Spectroscopic Instrument (DESI)

DOE's DESI is ready to take data!

- premier multi-object spectrograph and the first **Stage IV dark energy** project to start operations
- designed and built through the efforts of a large international collaboration ~ 500 researchers at 75 institutions in 13 nations.
  - Partners: STFC, Heising-Simons, Gordon and Betty Moore, France, Mexico, Spain, NSF

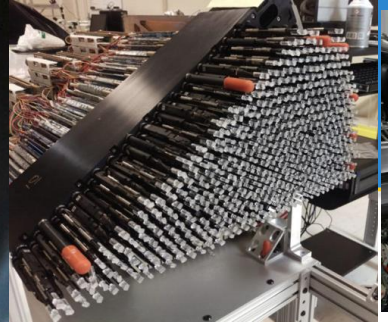
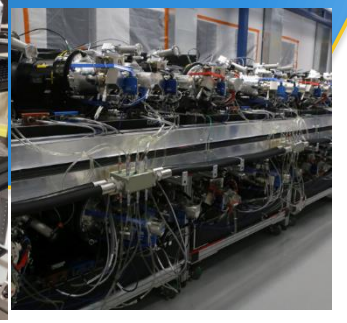
DOE/LBNL-led Major Item of Equipment Project to fabricate instrumentation & data management system, upgrades of NSF's Mayall telescope; Total Project Cost $56.3M

- HEP has MOU w/NSF-AST to "lease" the Mayall telescope
- Full support for Mayall dark energy operations started in 2019

LBNL continues to lead the Operations Phase & Scientific Collaboration

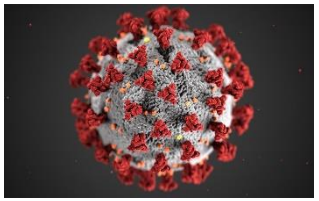
See https://vimeo.com/422889846

DESI Timeline

Sept. 2012 CD-0 Mission Need
March 2019: All imaging surveys for target selection completed (16,000 sq deg)
Oct. 2019 First light; Commissioning started
March 2020: Mini-SV survey obtained 100K's science quality spectra
March 16, 2020: All Project Deliverables complete, including Commissioning
April 2, 2020: CD-4 review – passed
May 11, 2020: CD-4 approved, fabrication complete, ready to operate

COVID-19 impacts – Survey Operations are on hold



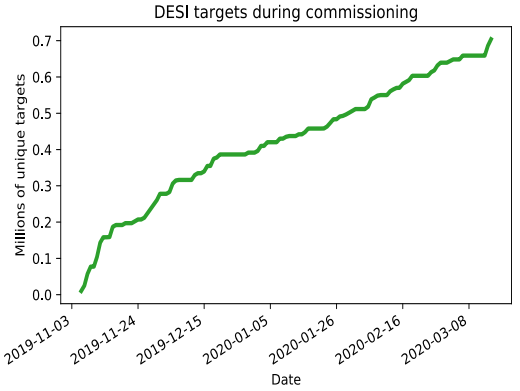
- **March 16-22, 2020: DESI was closed up; put into safe mode**
- April 17, 2020: Inauguration event postponed
- Kitt Peak developing a restart plan for the site
- DESI will require a short recommissioning and restart to operations after a 4-month survey validation run
  - Work continuing during shutdown: Targeting survey public data will be out soon; analysis ongoing, remote system testing, planning

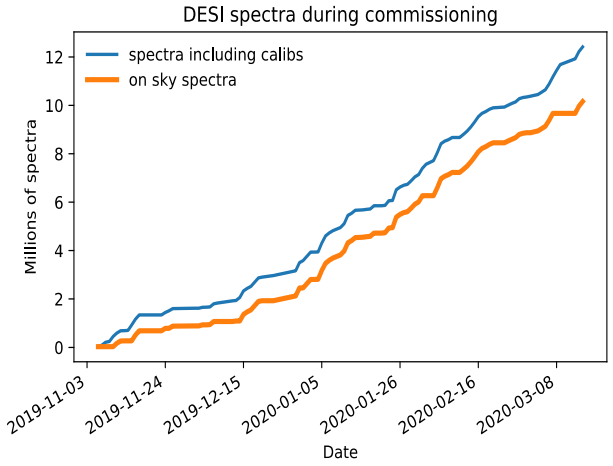
Early Operations - needed items identified: Spares, Safety systems upgrade, Dry air system - - contamination monitor found that even though there was new air compressors, it turns out the pipes were old & will need to be replaced

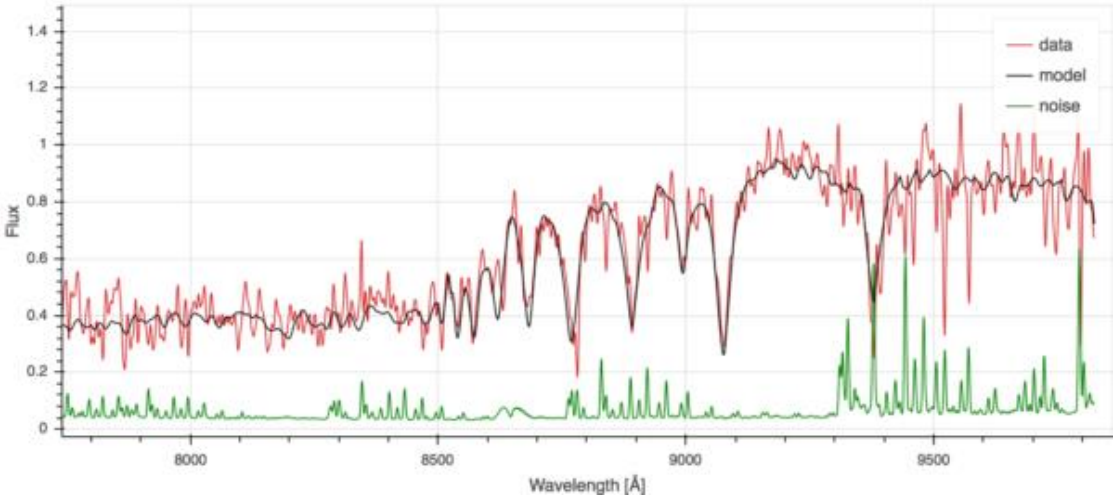
DESI Commissioning Successful

5-month Commissioning went as planned – completed mid-March 2020

- Key Performance Parameters all met and exceeded performance
  - 8 sq deg Corrector Mechanical Systems & Optics – installed, commissioned
  - Focal plane system – installed, commissioned
    - high-precision (10 micron) positioning of the fibers under active feedback
  - Spectrograph system – installed, commissioned
  - Instrument control system – installed, commissioned
  - Offline system infrastructure – installed, commissioned
  - Commissioning and demonstration of End-to-end function
- 12 Million On-sky Spectra taken, 700K unique objects







Vera C. Rubin Observatory

Large Synoptic Survey Telescope
→ **now Vera C. Rubin Observatory (Dec. 2019)**

- New state of the art observatory on Cerro Pachon in Chile
- For the first ten years of operations, the observatory will perform the wide-field, optical and near-infrared imaging **Legacy Survey of Space and Time (LSST)**, using the **LSST Camera** and the **Simonyi Survey Telescope**.

NSF (AURA) and DOE (SLAC) partnership

- Project: DOE responsible for the Camera
- Facility Operations: supported by both agencies

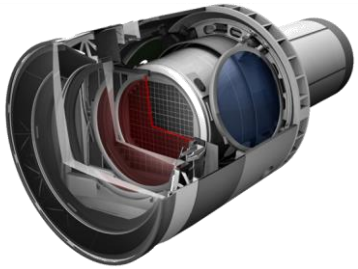
4 main science themes: probing dark energy and dark matter, inventory of the solar system, exploring the transient optical sky, & mapping the Milky Way.

- DOE is participating for the Stage IV Dark Energy capabilities

Project Status (as of mid-March 2020)

Project was going well & significant progress made

- Continues to meet technical requirements in support of the Science Requirements Document. Significant progress on dome and telescope mount



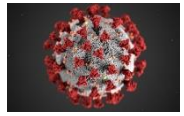
The 3.2 Gigapixel LSST Camera will be the largest electronic camera ever built for ground-based facilities.

DOE responsibilities – as of mid-March 2020 →

LSST Camera Project: 96.6% complete – on track for success

All MIE funding provided by FY18, TPC $168M; MIE completes when Camera is integrated and tested at SLAC; Planned to complete May 2021 [CD-4 March 2022]

COVID-19 in mid-March



- Observatory reduced construction activities in Chile to essential work. Site was secured as safely as possible; Small crews doing intermittent inspections.
- Chile closed its borders; Offices in La Serena telework only.
- Due to the California shelter-in-place order and the resulting SLAC shutdown, **Camera fabrication halted; left in safe mode.** Remote work continued.

Impacts: Rubin Observatory & Camera seriously impacted; ~ 12-month delay????

DOE's LSST Camera – Current Status

Starting mid-May

- Gradual and phased re-start of activities at SLAC
- Strict personnel safety measures and reduced work efficiency increased duration and cost of remaining work significantly; at the same time risks have increased dramatically due to the continuing COVID pandemic

August status

- Only remaining scope is completion of filter deliveries - last remaining filter glass, the u-band, was shipped from France to coating vendor in Boston.
- All 7 Key Performance Parameters met at threshold level.
- Due to delays, uncertainties, new plan is Project completion at sub-system level; early CD-4 completion date planned March 2021
- Complete assembly, verification at SLAC moved to Commissioning effort

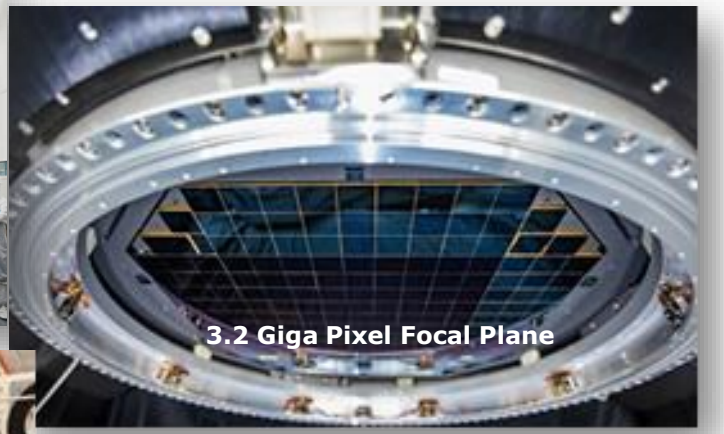
DOE responsibilities for Commissioning

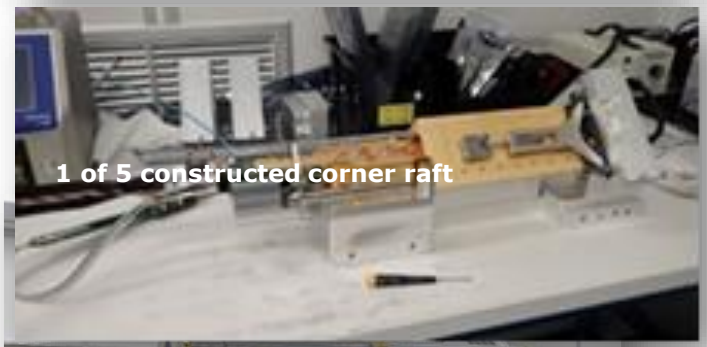
- Supported on HEP program funds (started FY18); lined up to complete with NSF's MREFC at the end of FY2022.
- Camera assembly, verification at SLAC, ship to Chile, I&T; Commissioning observatory systems

LSST Camera Status in Pictures – All hardware has been fabricated at the sub-system level and most has been assembled


1 of 22 constructed science raft


L1 and L2 lenses in their assembly


3.2 Giga Pixel Focal Plane


1 of 5 constructed corner raft


L3 lens in its mount

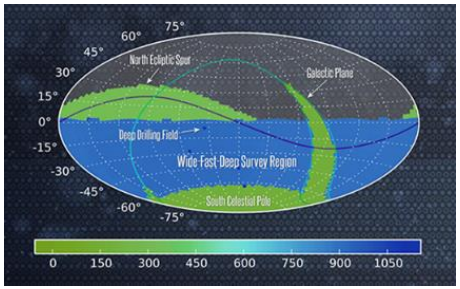

Constructed filter exchange system


Shutter operating on the camera


Commissioning camera in Chile delivered by MIE and MREFC and being reverified prior to installation on the summit (Apr 2020)

Rubin Observatory: Facility Operations Planning

→18,000 sq deg, 6 filter bands, ~ 1000 visits per sky patch
- Catalog of more than 20 billion galaxies & 17 billion stars



- FY19: NSF and DOE funding started ramp-up.
- May 2019: DOE & NSF agree to provide ~ equal support for operations.

DOE & NSF, with input from the Operations planning team, have been investigating options for laying out DOE & NSF scope and budgets
- DOE will support the US Data Facility; plan is in development

International in-kind contributions considered in exchange for data rights/access during the 2-year proprietary period; Agencies make final decisions.
- Priority is operations cost offsets; 2nd is to enhance US science, esp. LSST science.
- Proposals due end of Sept. 2020. Goal is agreements by end of CY2020.

Joint NSF/DOE Operations Planning status review, April 2020 - successful

Related efforts continuing, e.g. impacts from satellite mega-constellations

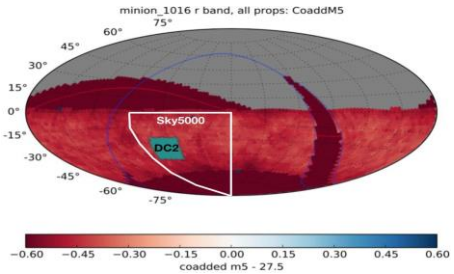
Rubin Observatory Legacy Survey of Space and Time (LSST) → Dark Energy Science Collaboration (DESC)

Scientific Research - Both NSF and DOE will support community efforts

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

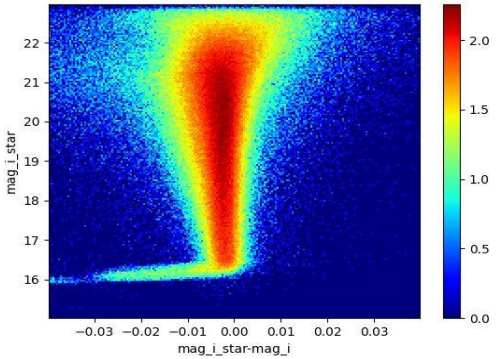
Collaboration ~ 1000 members; > 225 full members; from 15 countries

- Data Challenge 2: Production of image simulations for DESC's second simulated data challenge (used to test dark energy analysis pipelines) is complete and analysis in progress".
  - Image simulations for 300 sq deg wide-fast-deep over 5 years finished
  - Transient modeling for deep drilling field, image simulations concluded
  - Focusing on using DC2 images to evaluate next-generation data access middleware from Rubin Observatory for data processing and building a new workflow set-up
- Collaboration is carrying out Science Readiness activities.

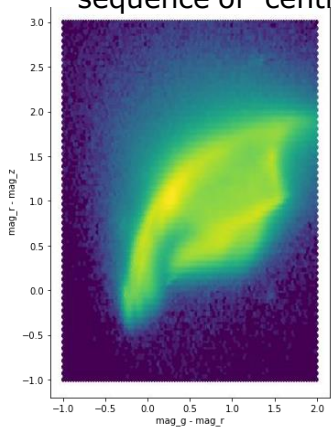


Extended area for new extragalactic catalog

Simulated flux accurately recovered.



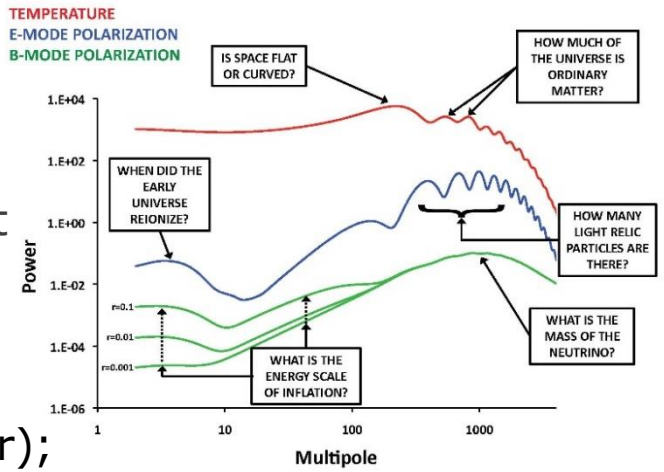
Successfully recover the red sequence of central cluster galaxies



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

CMB-S4 recommended by P5 in all scenarios
Goal: cross critical science thresholds

Ultra-precision measurement of CMB power spectrum



Highlights:

- 2 sites: Chile, South Pole
  - Large & small telescopes
  - 500,000 cryogenic sensors, superconducting readout

CMB-S4 Project Office is planning unified ~$600M TPC multiagency project

- As recommended by P5 (2014) and AAAC/CDT (2017)
- Planned Partnership DOE (lead) & NSF (AST, PHY, Polar);
- Detailed scope split in planning; expect ~ 60/40 DOE/NSF

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	Detector/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 planning, status

Interim Project Office (IPO) – set up after 2017 AAAC Concept Definition Taskforce
- Developed a technically driven schedule
- Carrying out technical studies, concept design, planning
- Proposed timeline is for DOE CD-1/3a and NSF-PDR in 2021
- Technology assessments: Detector fab 2019, Optical coupling May 2020, Readout June 2020

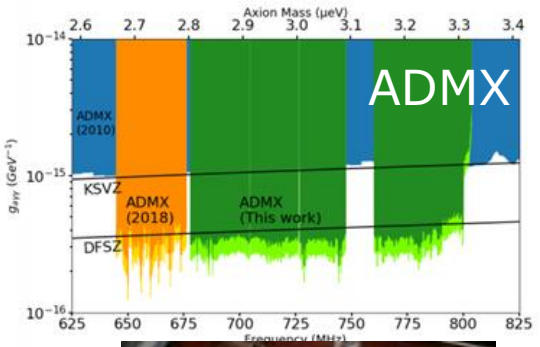
NAS Astro2020 Decadal Survey underway
- July 2019 White Paper; Fall 2019 RFI, Feb. 2020 Q&A, TRACE March 2020

- **DOE & NSF**: Weekly Joint Oversight Group (JOG) meetings
- **NSF** MSRI-R1 to U. Chicago (Sept 2019) to begin work on Preliminary Design

DOE Status (Aug 2020):
- **Approved Critical Decision 0 (CD-0) "Mission Need" in July 2019**
  - HEP support for Project planning (FY20 $2.4M) technology and Lab R&D
  - Working to support the IPO timeline of FY2021 CD-1/3a
- **Selected LBNL to lead our efforts Aug. 2020**
- **Status review, Aug 18-20**, successful
- **FY21 President's Request – new MIE Project start**
- **HEP is excited about moving forward!**

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

Operating: ADMX-G2 axion search (μeV-meV mass) at UWash (HEP)

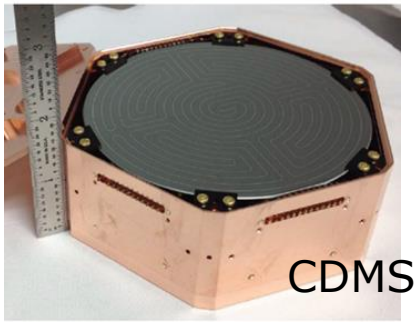
Projects in Fab/Commissioning:

LZ at Homestake Mine in South Dakota (HEP)

- WIMP search using dual phase liquid Xe; ~10-1000 GeV mass
- Threshold deliverables complete; CD-4 review Aug 2020, CD-4 approval expected Sept. 2020

SuperCDMS-SNOLab in Canada (HEP+NSF-PHY partnership)

- WIMP search using cryogenic solid-state crystals; ~1-10 GeV
- Project in fabrication; Delays due to cryostat procurement and COVID-19; CD-4 ~ FY22

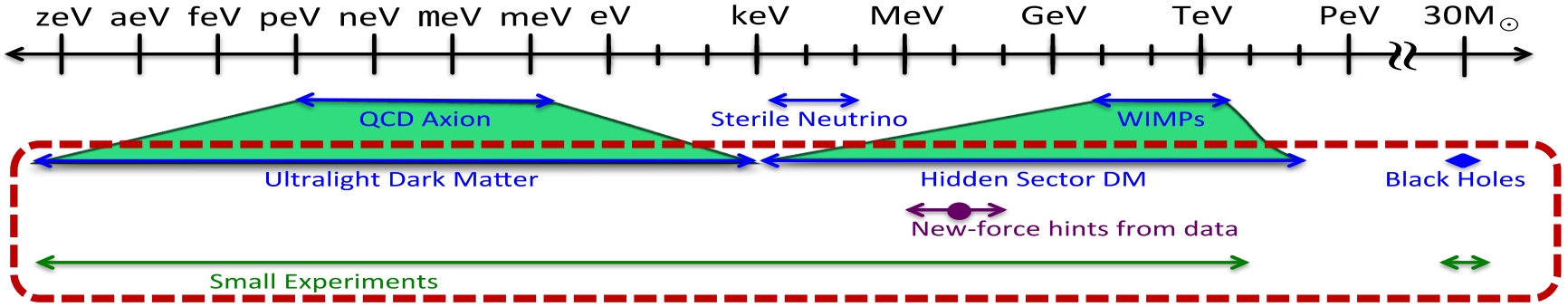


Future Planning: Dark Matter New Initiative (DMNI) for small projects in new areas of phase space

Dark Matter New Initiatives (DMNI) – Concept Studies

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



➢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/

➢**2019-2020: Funding Opportunity Announcement (FOA); Six proposals aligned with the PRD's selected to develop concept & execution plans for potential small projects**

Following completion of Concept & Execution plans, small projects will be reviewed before advancing to fabrication phase.

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)

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

Exploring the Unknown

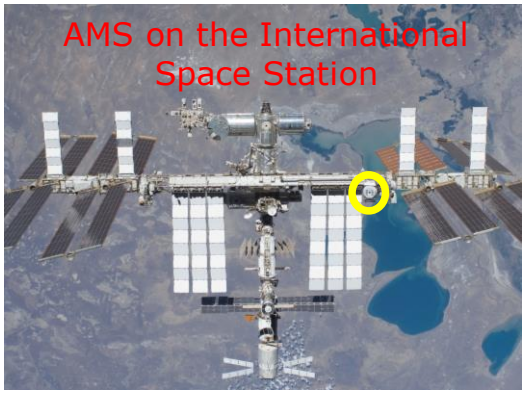
Use ground-based arrays, space telescopes, and an experiment on the International Space Station to explore the unknown, e.g. indirect searches for dark matter

- Many significant inter-agency & international partnerships

Operations continuing:

Fermi/GLAST *(w/NASA)*

- Gamma-ray survey (~20 MeV to >300 GeV) using rays with particle physics detector technology in space
- HEP, in coordination with NASA, continues to support critical efforts at the Instrument Science Ops Center at SLAC
- No COVID-19 impacts!



AMS *(w/NASA)*

- Operations continue on ISS: study cosmic rays, antimatter in space, and the cosmos.
- NASA astronauts carried out a series of EVAs in Fall 2019 to install a replacement cooling system; operating successfully
- No COVID-19 impacts!

HAWC *(w/NSF)*

- 5 year operations started early 2015
- COVID-19 remote operations but had to get data via Uber!

Lower program priority for new experiments

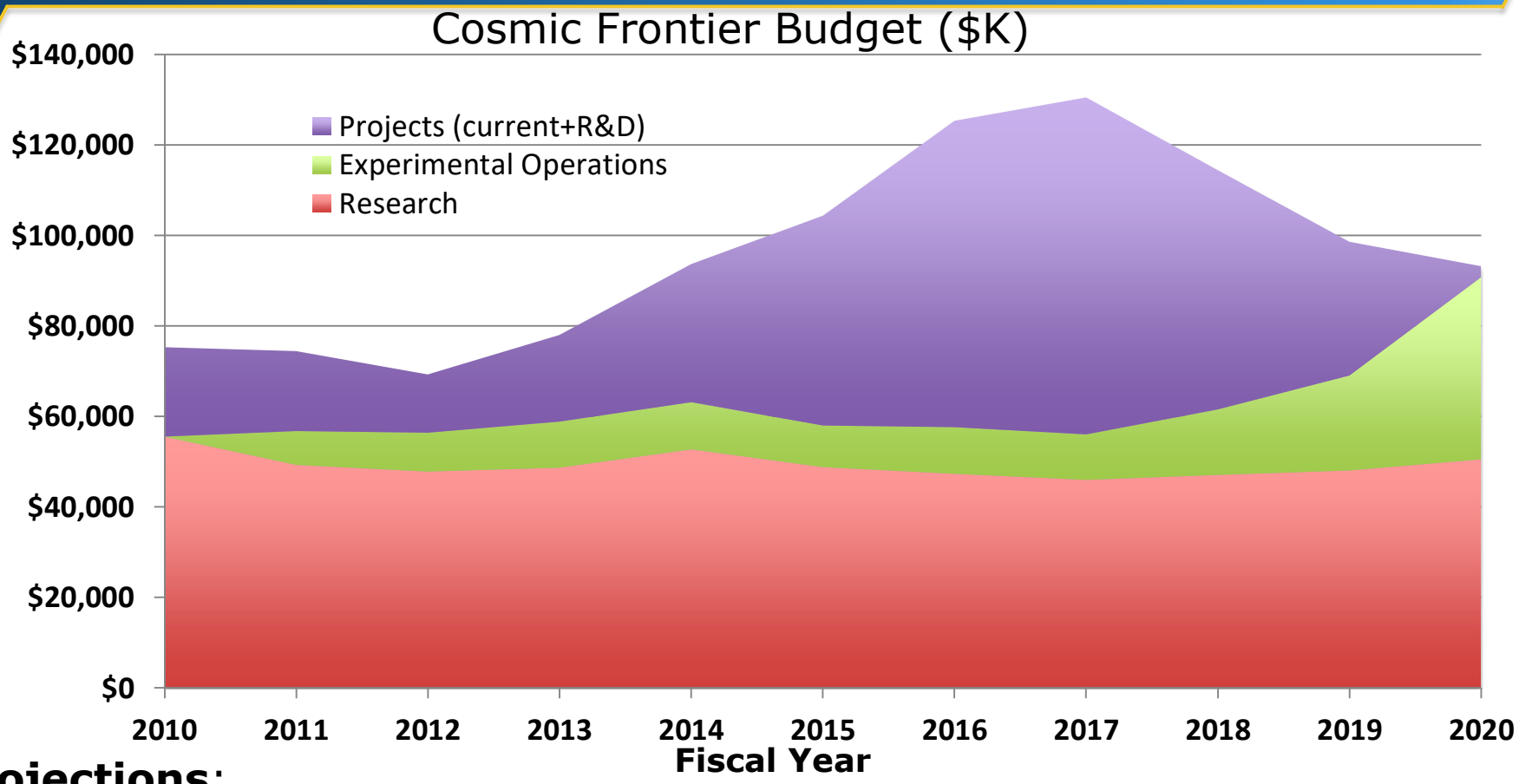
HEP Cosmic Frontier Budget: FY 18-21

HEP ($K) Cosmic Frontier	FY18 Actual	FY19 Actual	FY20 enacted	FY20 Actual	FY21 request
Research	47,008	48,053	48,072	50,545	29,220
Facility Ops	14,570	20,957	41,358	40,235	37,400
Projects	52,835	29,615	2,000	2,450	1,000
SBIR	2,487	2,869	3,471	3,524	2,300
TOTAL	**116,900**	**101,494**	**94,901**	**96,754**	**69,920**

FY20 appropriation:
Cosmic Project changes: -26.35M DESI, LZ, SuperCDMS-SNOLAB projects; +2M CMB-S4
Cosmic Operations ramps up > $20M for Rubin Observatory, LZ, DESI, SuperCDMS-SNOLAB

HEP Cosmic Frontier MIE Projects ($K)	FY18 Actual	FY19 Actual	FY20 Actual	FY21 request
LSST Camera	9,800			
DESI	20,000	9,350		
LZ	14,100	14,450		
SuperCDMS SNOLAB	7,400	2,550		
CMB-S4			2,450	1,000

Cosmic Frontier Budget History (FY10-20)



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 Budget History (FY10-20)

Cosmic Frontier budget ($K)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Research	55,487	49,252	47,843	48,681	52,712	48,779	47,327	45,990	47,008	48,053	50,545
Experimental Operations	0	7,460	8,505	10,111	10,357	9,185	10,274	10,055	14,570	20,957	40,235
Projects (current+R&D)	19,828	17,652	12,891	19,159	30,660	46,403	67,780	74,375	52,835	29,615	2,450
TOTAL	**75,315**	**74,364**	**69,239**	**77,951**	**93,729**	**104,367**	**125,381**	**130,420**	**114,413**	**98,625**	**93,230**

Funding types:

- Research: primarily supports scientists participating in all aspects of an experiment (design, fabrication, operations, data planning & analysis)
- Experimental/Facility Operations and Projects: primarily supports technical personnel, materials, supplies, procurements, consumables

Cosmic Frontier Budget History (FY10-20) – Major Item of Equipment (MIE) Projects

Cosmic Frontier MIE Projects ($K)		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Dark Matter	SuperCDMS -Soudan	1,500	0	0	0	0	0	0	0	0	0	0
	SuperCDMS -SNOLAB	0	0	0	0	0	2,250	3,000	3,400	7,400	2,550	0
	LZ	0	0	0	0	900	3,050	10,500	12,500	14,100	14,450	0
Dark Energy	DES	8,610	4,000	0	0	0	0	0	0	0	0	0
	DESI	0	0	0	0	0	3,878	10,300	12,800	20,000	9,350	0
	LSST	0	1,900	5,500	8,000	22,000	35,000	40,800	45,000	9,800	0	0
Gamma-ray	HAWC	0	0	1,500	1,500	0	0	0	0	0	0	0
CMB	CMB-S4											2,450
	TOTAL	**10,110**	**5,900**	**7,000**	**9,500**	**22,900**	**44,178**	**64,600**	**73,700**	**51,300**	**26,350**	**2,450**

Cosmic Frontier Budget History & *DRAFT* Projections (FY10-FY30)

Research: $50,545 in FY20
→ Could assume it goes up 2% per year

Experimental Operations (Current Projects), $40,235 in FY20
→ As the current Projects complete, estimated needs by Project Teams ramps up to ~ $55M to $60M by FY2024; levels to ~ $40M by FY2030.

Experimental Operations (Dark Matter New Init, CMB-S4): Very rough estimate from Project Teams few $M in FY24-25, ramping up to ~ $30M/yr

Project: Dark Matter New Initiatives
- Draft planning is few $M/year starting ~ FY23 or 24.

Project: CMB-S4
- Their planned request for DOE/HEP funds is as listed in the Astro2020 RFI, ~ $300M. HEP is working to identify the funding required.

Projects: Blue Sky???

There is not a project "funding line" for Cosmic Frontier and instead projects are considered across the HEP program and Office of Science.

Lifecycle costs need to be taken into account: concept design, technology R&D, Project fabrication/construction, experimental operations, computing, and research support (for scientists to participate in all phases).

HEP Efforts related to the Cosmic Frontier

Theory program

- Vibrant Theory Program supporting all areas including astrophysics, cosmology

Advanced Detector Development & Accelerator R&D programs:

Active R&D developing next generation detectors, including CCDs, TES superconducting bolometers, MKIDs, readout electronics, optics, fiber positioners.

DOE-aligned Computing in HEP

- **HEP Computing Infrastructure Working Group** formed in 2017 to develop a strategy for addressing current and future computing challenges and needs
- **DOE Supercomputer allocation** coordination via ASCR and DOE Competitions
  - Computational HEP, SCIDAC – focused computational challenges
  - NERSC facility allocations for Cosmic Frontier Simulations, Data Processing, Analysis
- **High Performance Computing** → Exascale; Comp HEP & ASCR coordination & partnerships on some efforts, including Cosmic Simulation and Data analytics
- **HEP Center for Computational Excellence (CCE**) led by ANL & interfaces with ASCR Resources, expertise to advance HEP computing goals
- **SciDAC** is an Office of Science program where ASCR and HEP jointly fund HEP computing; currently HEP-ASCR SciDAC 4.

New Initiatives in SC & HEP – rapidly growing areas

- Quantum Information Science (QIS)
- Artificial Intelligence, Machine Learning
- Microelectronics Initiative (in FY2021 request)

Summary

Excellent science results continue to be produced from our operating experiments! 2014 P5 strategic plan continues strong support from all stakeholders.

HEP budget increased 7% in FY20; Cosmic operations ramp up, research flat. FY21 President's request has been released.

HEP Cosmic Frontier projects from Astro2010 and P5 are about to commence observations and deliver Stage 4 dark energy science – and much more!

- **DESI fabrication & commissioning completed, ready to operate!**
- **LSST** camera project is 99% complete!
- **CMB-S4** has DOE CD-0 and NSF MSRI-1. LBNL selected as Lead Lab for DOE scope; Ready to continue progress

- HEP looks forward to Astro2020 assessment of the most compelling science challenges, a comprehensive research strategy, and articulated decision rules with an eye to where DOE HEP researchers and investments can play a significant role in & make unique & necessary contributions.
- Snowmass is starting, leading to next P5