U.S. DEPARTMENT OF ENERGY | Office of Science

# Office of High Energy Physics (HEP) Program and Budget Report

National Academies Committee on Astronomy and Astrophysics (CAA)

March 31, 2020

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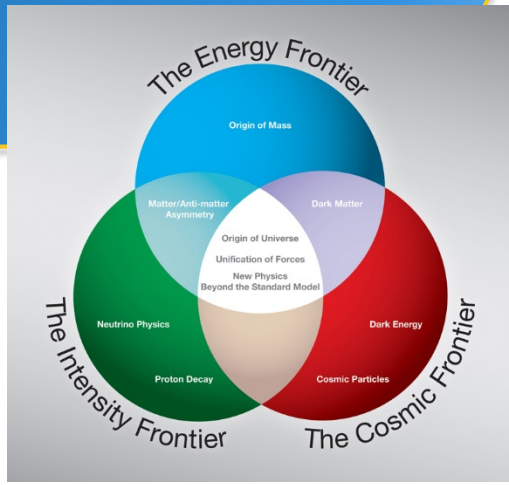
*+ Karen Byrum (Detailee), Drew Baden (IPA), Eric Linder (IPA)*

# OUTLINE

→ Providing updates since the November 2019 CAA presentation

- Budget
- Cosmic Frontier Details
  - Dark Energy
  - CMB
  - Dark Matter
  - Cosmic, Gamma
- Other HEP efforts
- Summary

# HEP Program Layout




**HEP is carried out along 3 Frontiers:**

Advancements at all 3 frontiers are needed to achieve the long term goals of the field.

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

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

**Areas of study to fully carry out the program**:

- Theoretical research
- High Performance Computing → Exascale
- State-of-the-Art Detector and Accelerator technology development
- Quantum Information Science (QIS) and Artificial Intelligence/Machine Learning ramping up
- New initiative in Microelectronics Innovations in FY21 Request

# HEP Program Planning, Execution

Use staged suite of projects and experiments with a variety of technologies, methods, etc. to make significant progress in scientific capabilities and results.

HEP continues to follow HEPAP's **2014 "P5" strategic plan**.

- Input to next P5: Astro2020, European Strategy for Particle Physics, Japanese decision on International Linear Collider, "Snowmass" community workshops, NAS EPP, etc.

→ Leads to P5 recommendations by March 2023 to inform FY 2025 budget formulation.

Project/Experiment Planning & Execution:

- Carry out a series of reviews of projects as they move the different phases (at each Critical Decision, annually, and as needed).
- Carry operations-planning reviews to ensure readiness as each experiment transitions from project fabrication to the science operations phase.

Partnerships:

Most experiments and projects are done with interagency (NSF, NASA) and/or international partners or contributors; some have private contributions.

- Interagency: Regular meetings; Joint Oversight Groups (JOG) enable close coordination of planning/issues and joint reviews of projects or experiments.
- International: Regular meetings with partners; Finance Boards for some projects.

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# Budget

# 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 Scicence** | **6,585,000** | **7,000,000** | **5,837,806** | **-1,162,194** | **-16.6%** |

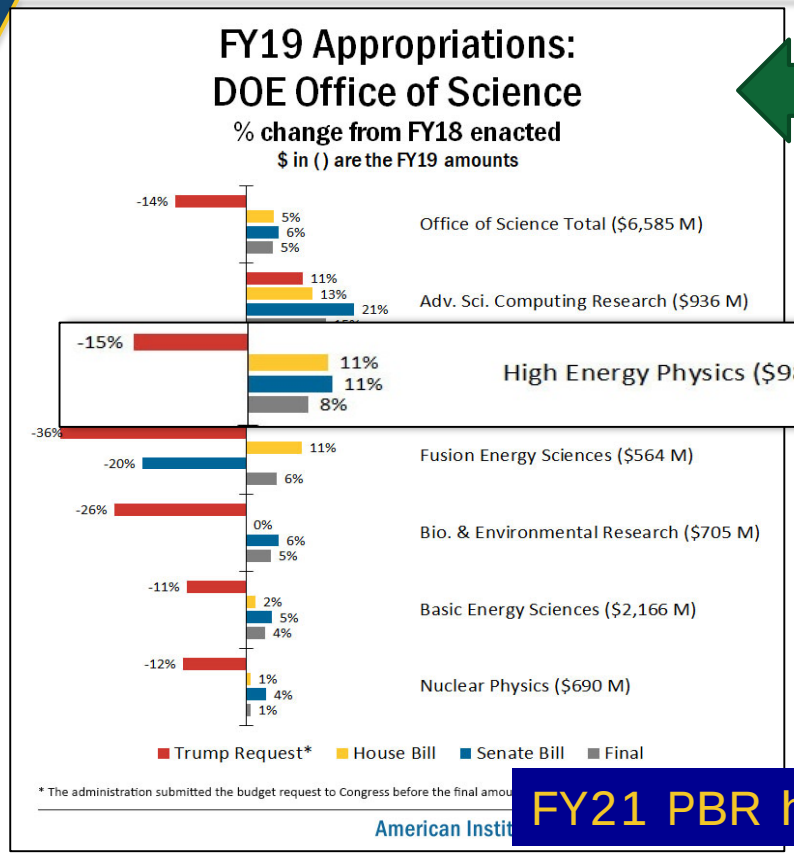
The SC Request includes ongoing investments to support the Administrations Industries of the Future (IOTF) initiative through research in **quantum information sciences (QIS)** and **artificial intelligence (AI) and machine learning (ML)**. The Request also supports research efforts in next-generation **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.

# FY 2021 President's Request Budget for HEP

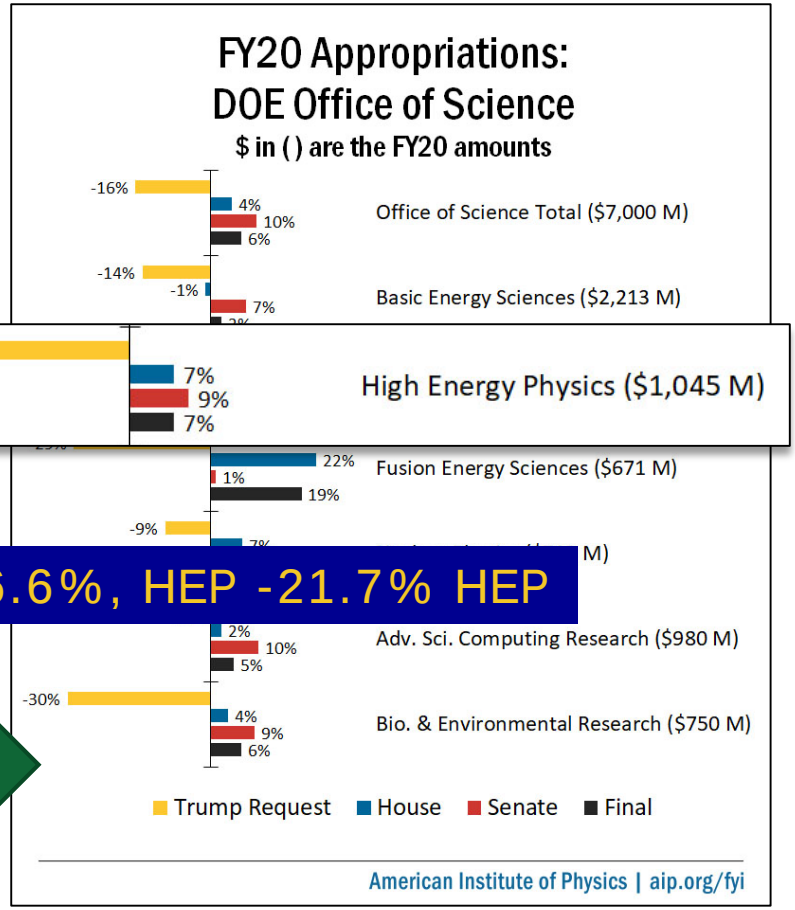
| HEP Funding Category ($ in K) | FY 2019 Actual | FY 2020 Enacted | FY 2021 Request | FY 2021 vs. FY 2020 |
|---|---|---|---|---|
| Research | 372,629 | 390,077 | 328,906 | -61,171 |
| Facilities/Operations | 266,556 | 316,429 | 285,725 | -30,704 |
| Projects | 340,815 | 338,494 | 203,500 | -134,994 |
| **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 is new initiative (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 2019, 2020, 2021 DOE Office of Science




- HEP **increase of +8%** from 908M in FY 2018 to 980M in FY 2019
- All projects were addressed at their baseline levels. Five projects receive final planned funding:
  - Mu2e, LZ, DESI, SuperCDMS-SNOLAB, and FACET-II

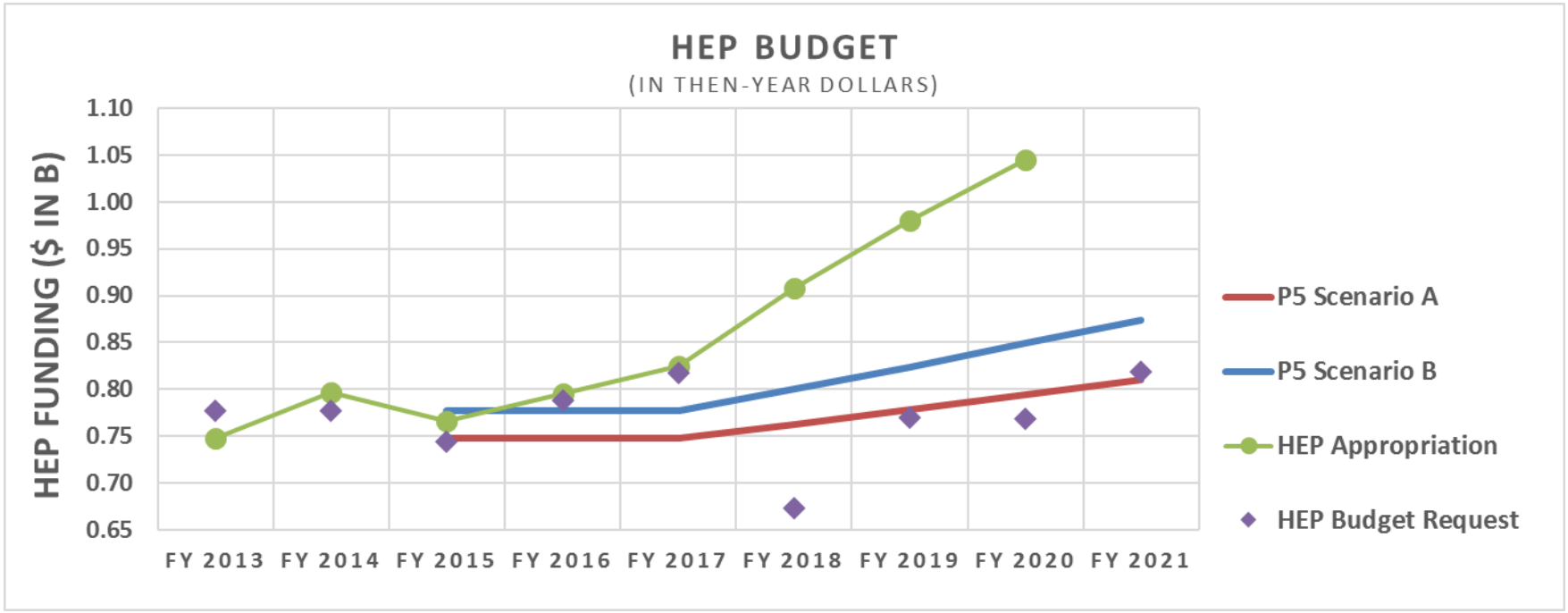



FY21 PBR has SC -16.6%, HEP -21.7% HEP

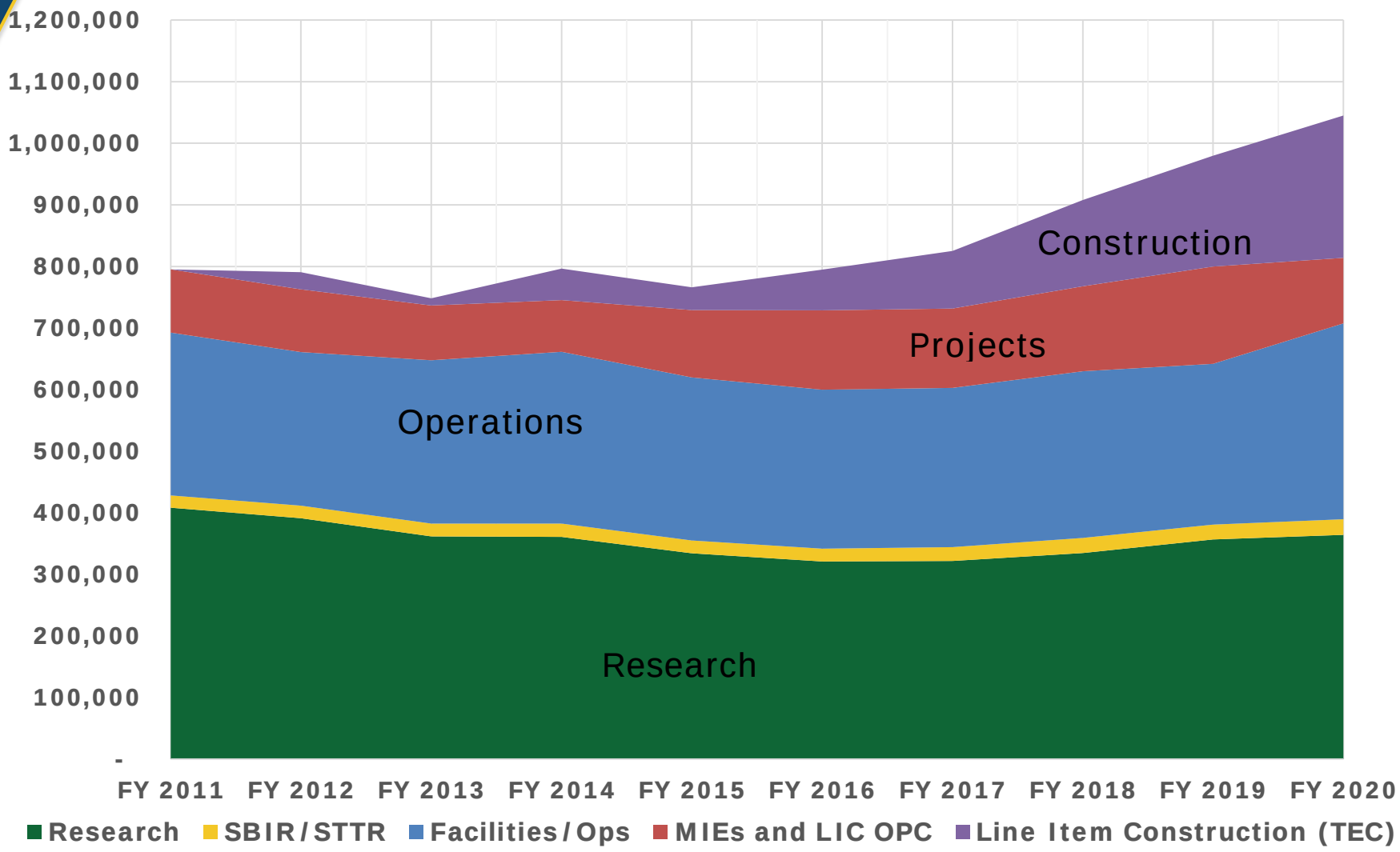
- HEP **increase of +7%** from 980M in FY 2019 to 1045M in FY 2020
- Strong support in QIS and Artificial intelligence Research
- Increased construction funding for LBNF/DUNE and PIP-II. Strong support for HL-LHC projects.
- Increased support for Sanford Underground Research Facility

# U.S. Congress Supports HEP's P5 Strategy

- Recent appropriations reports include language recognizing community's efforts:
  - FY19 Senate EWD: "Four years into executing the P5, the Committee commends the Office of Science and the high energy physics community for achieving significant accomplishments and meeting the milestones and goals set forth in the strategic plan…"
  - FY 2020 appropriations continued strong support for the P5 strategy



# HEP Budget ($K) FY 2011-2020



# FY 2020 HEP Appropriation notes

The FY 2020 HEP Budget continues support for P5-guided investments:

- "Building for Discovery" by supporting **P5 projects** to enable future program
- **Research support** advances P5 science drivers and world-leading, long-term R&D in Advanced Technology, Accelerator Stewardship, Quantum Information Science, and Artificial Intelligence & Machine Learning
- **Operations support** enables world-class research at HEP User Facilities:
  - Fermilab Accelerator Complex, Brookhaven Accelerator Test Facility (ATF), SLAC Facility for Advanced Accelerator Experimental Tests (FACET)

**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**

In FY2019, 4 Major Item of Equipment (MIE) projects received final funding: **LZ, DESI, SuperCDMS-SNOLAB**, and FACET-II.

In FY2020, these 4 projects require a ramp up in Experimental Operations.

- For Cosmic Frontier, Operations for the **Rubin Observatory (formerly LSST)** also ramps up in FY2020. The operations funds support commissioning efforts as well as observatory operations

# FY 2018, 2019 Actuals and 2020 Appropriation - HEP Funding Rollups

| HEP ($K) | FY18 ACTUAL | FY19 ACTUAL | FY20 enacted | FY21 request |
|---|---|---|---|---|
| **Research** | 359,177 | 372,629 | 390,077 | 328,906 |
| **Facility Ops** | 270,488 | 266,556 | 316,429 | 285,725 |
| **Projects** | 278,335 | 340,815 | 338,494 | 203,500 |
| **HEP Total** | **908,000** | **980,000** | **1,045,000** | **818,131** |

**FY2020 appropriation**

- Energy: -5M HL-LHC Projects
- Intensity: -14.5M PIP-II OPC; +3M DUNE OPC; Fermilab Acc Complex ramps up
- Cosmic: -26.35M DESI, LZ, and SuperCDMS-SNOLAB projects; +2M CMB-S4; Operations ramps up +20.4M
- Theory, Computational, and Interdisciplinary: +11M QIS; +10M AI/ML; +2.5M LQCD
- Advanced Technology: -10M FACET-II SLAC; Operations ramps up

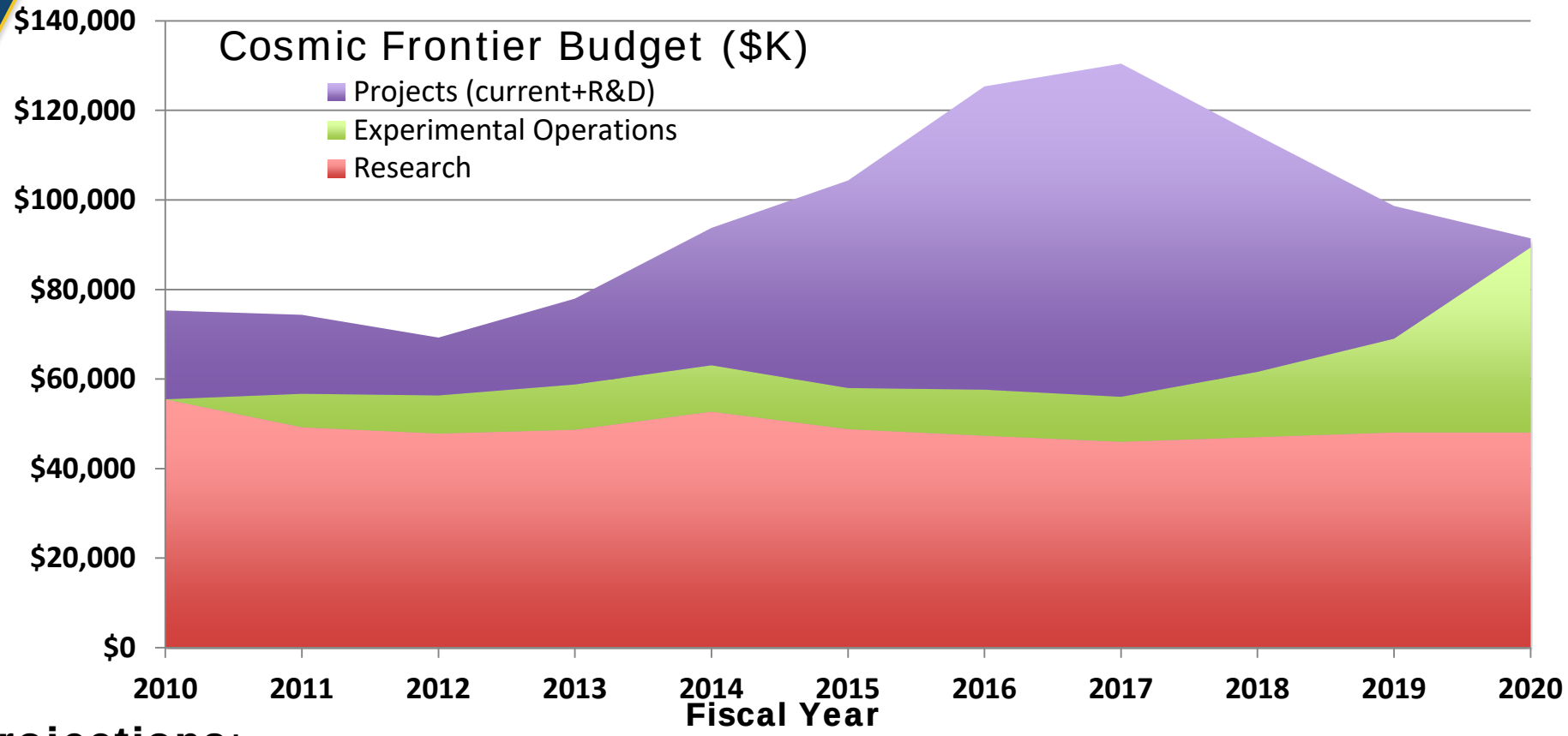
# HEP Funding - Research Areas Ramping Up or New Initiatives

| 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 |

# HEP Cosmic Frontier Budget: FY 18-21

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

# 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.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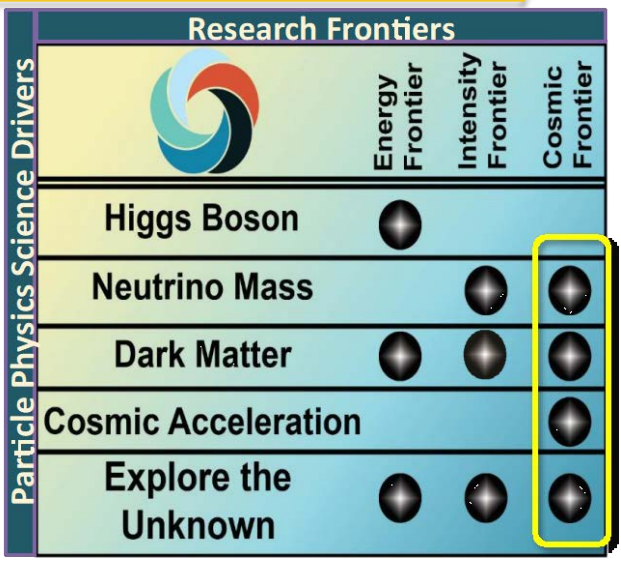
# Cosmic Frontier

# Cosmic Frontier Experimental Research Program

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




**Cosmic Acceleration:**

- Imaging & Spectroscopic surveys to determine the nature of **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: New Initiative for Dark Matter – 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

# Extended Baryon Oscillation Spectroscopic Survey (eBOSS)

***Stage 3 Dark Energy Spectroscopic Survey* - on the Sloan Digital Sky Survey at Apache Point Observatory, New Mexico**

- **DOE-HEP partnership with Sloan Foundation, U.S. Universities and international institutions.**
- HEP provided a spectrograph upgrade for SDSS-III (BOSS); operations of BOSS (2009-2014) then eBOSS (2015 – Feb.2019)

**→Focus on Dark Energy; also many general astronomy studies**

**eBOSS**:

- Observations complete and data reductions are final;
- arXiv:1912.02905 public data release of final eBOSS sample
- 68 papers published as of Jan.2020; most recent 2019 ApJ,883,14
- FINAL results papers have been planned for spring 2020.

- Dark Energy Science Reach:
  - Baryon acoustic oscillation (BAO) measurements with six different tracers
  - Redshift space distortion measurements over interval $0.6<z<2$
  - Tightest constraints on non-Gaussianity from any optical/IR probe

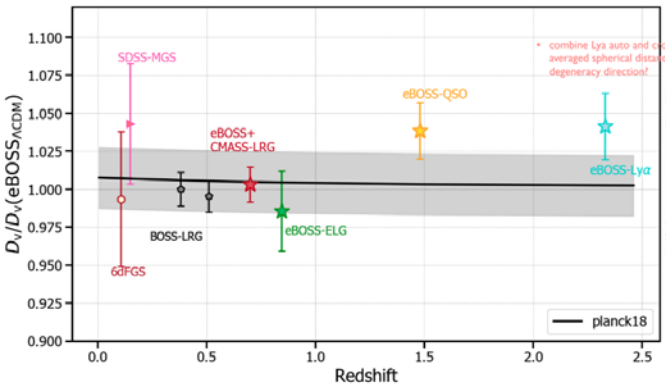
# Science Highlights – eBOSS

**Major Milestone:** Near-final results presented at January AAS meeting

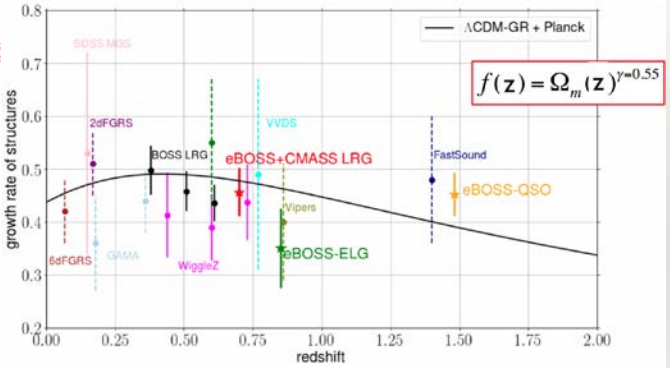
- BAO/RSD from LRG, ELG, and quasars over 0<z<2
- BAO from Lyman-alpha forest and quasars at z=2.35
- Preliminary cosmology constraints using distances, growth & combined analyses

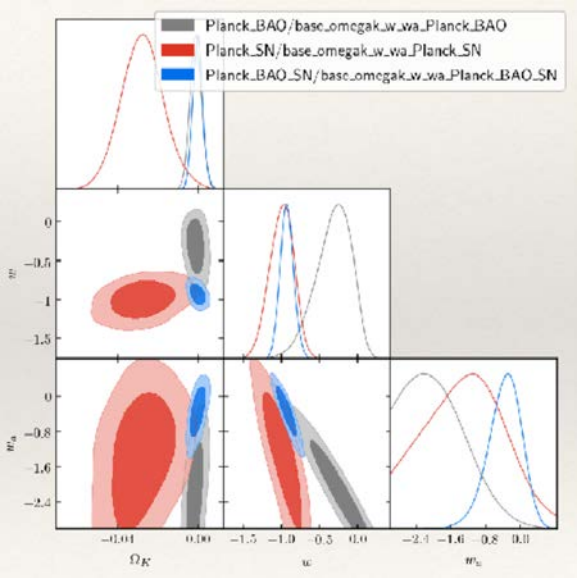
**Implications for Cosmology**: significant improvement on dark energy equation of state compared to SNe+CMB; robust estimates of H0 using inverse distance ladder; tests of GR; tighter bounds on summed neutrino mass

BAO from SDSS, BOSS, and eBOSS




RSD from BOSS, eBOSS and competition



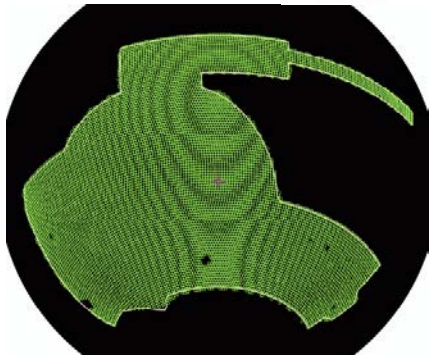



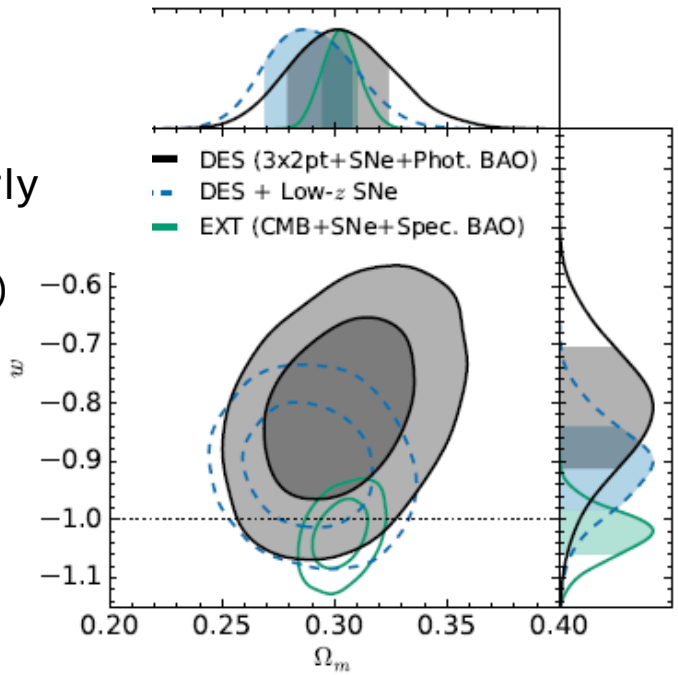
# Dark Energy Survey (DES)

DARK ENERGY SURVEY

***Stage 3 Dark Energy Imaging survey:* new camera and data systems on Blanco Telescope at CTIO**

- **DOE-HEP partnership with NSF-AST:** HEP provided Camera (DECam); NSF provided data system; both participate in operations, science
- Completed Observations Jan.2019; Met all survey metrics
- Completed the combined Y1-Y6 "Y6A1" Coadd Processing
  - 5085 sq. deg. in 5 filters (grizY), each w/ ten 90s exposures → 691M cataloged objects. Catalogs and coadded images delivered to DES collaboration.
- Public "DR1" based on 1st 3 years data (Y1-Y3)
- Public "DR2" based on 1st 6 years data (Y1-Y6) in early 2021
- 254 science publications on range of topics (Dec.2019)






**Cosmology results:**

- Constraints on Extended cosmological models from DES Y1 Weak Lensing and Galaxy Clustering (WL)
- Cross Correlation of DES WL signal w/ Planck & SPT
- Cosmology from 207 DES Y1-Y3 spect.-typed SN1a
- Combined DES Y1 WL & Y1 LSS & SN1a cosmology

# Science Highlight - Dark Energy Survey

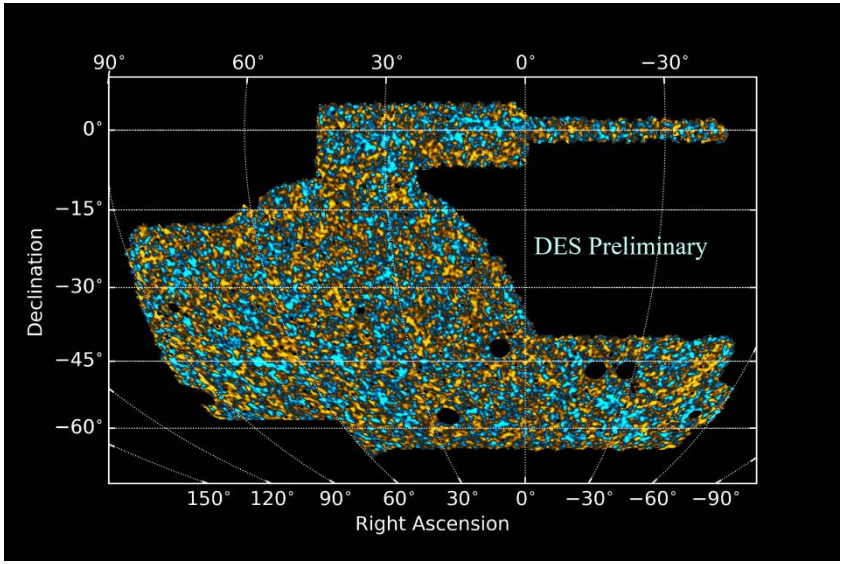
DARK ENERGY SURVEY

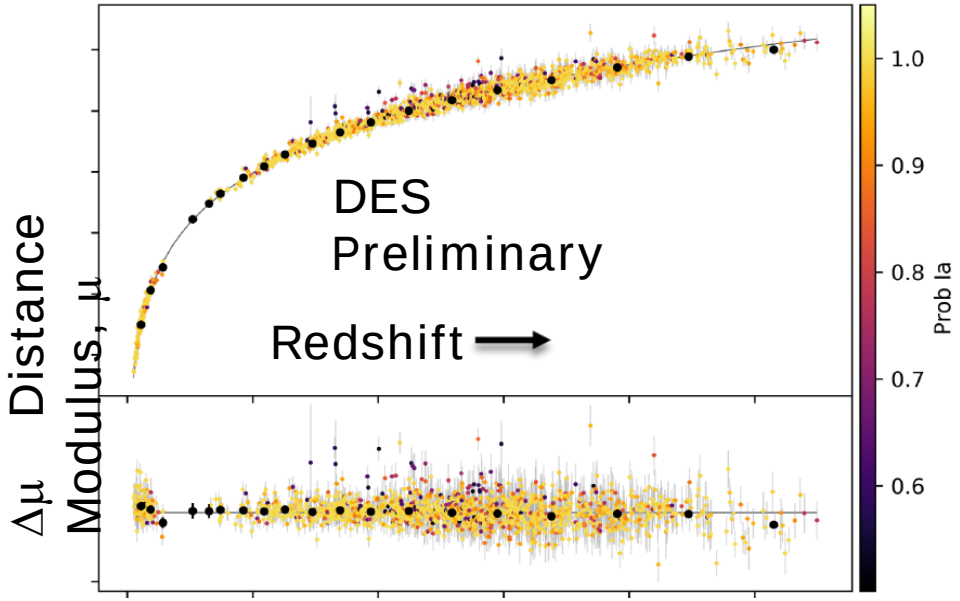
**Now concentrating on Y3 "3x2pt" weak lensing, Y5 SN1a, and Y3 cluster cosmology analyses with Y6 cosmological results to follow**

- **AAS Meeting Jan.2020**: included preview of upcoming cosmology results

**Photometric-Typed Y1-Y5 SN1a**

- Blinded Hubble Diagram has ~2000 SN
- Excellent light curves & host galaxy spectroscopic z, largest high-z SN sample.
- New preliminary results: SN systematics studies where host galaxies have > 1 SN.




**"3x2pt" Weak Lensing Analysis Y1-Y3 data**

- Weak lensing Mass Map shows regions with more (red), less (blue) mass compared to average
- Now working on precise calibration of photometric redshifts, simulations, covariances, and systematics.
- ~ 3x area, # galaxies, statistical power over Y1.

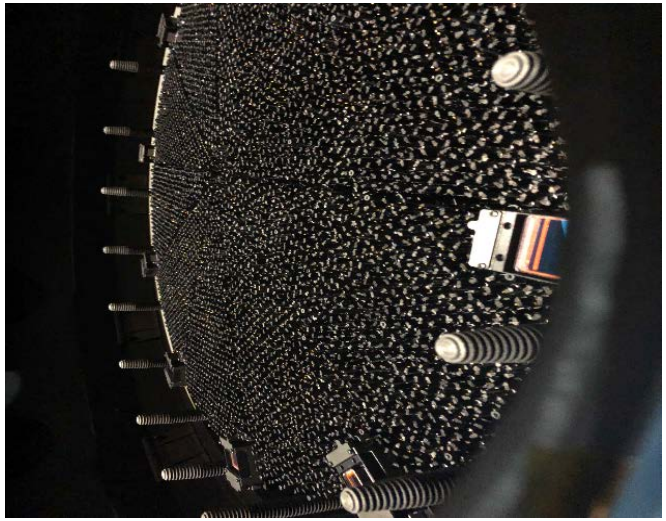
# Dark Energy Spectroscopic Instrument (DESI)

***Stage 4 DESI***

**- DOE-HEP experiment (led by LBNL), mounted & operated on NSF's Mayall telescope at Kitt Peak.**

- MIE project (funding complete FY19), led by LBNL, to fabricate instrumentation & data management system

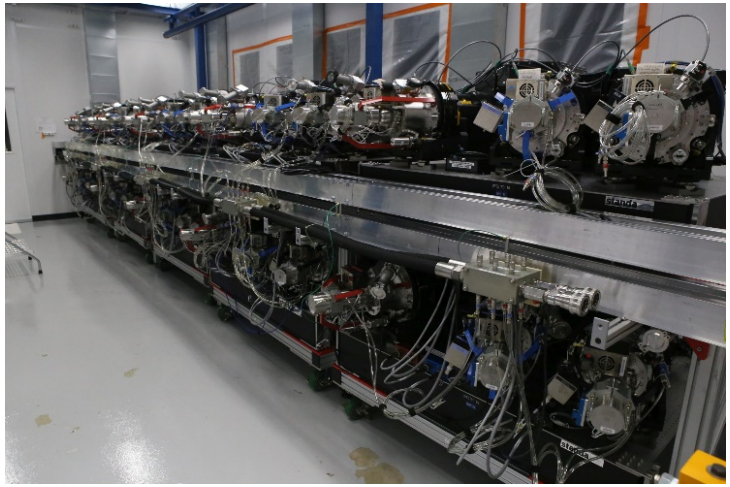
→8 sq deg FOV, 10 3-channel spectrographs w/5000 fiber-fed robotic positioners



- HEP has MOU w/NSF-AST to "lease" the Mayall telescope
- Full support for Mayall dark energy operations started FY19

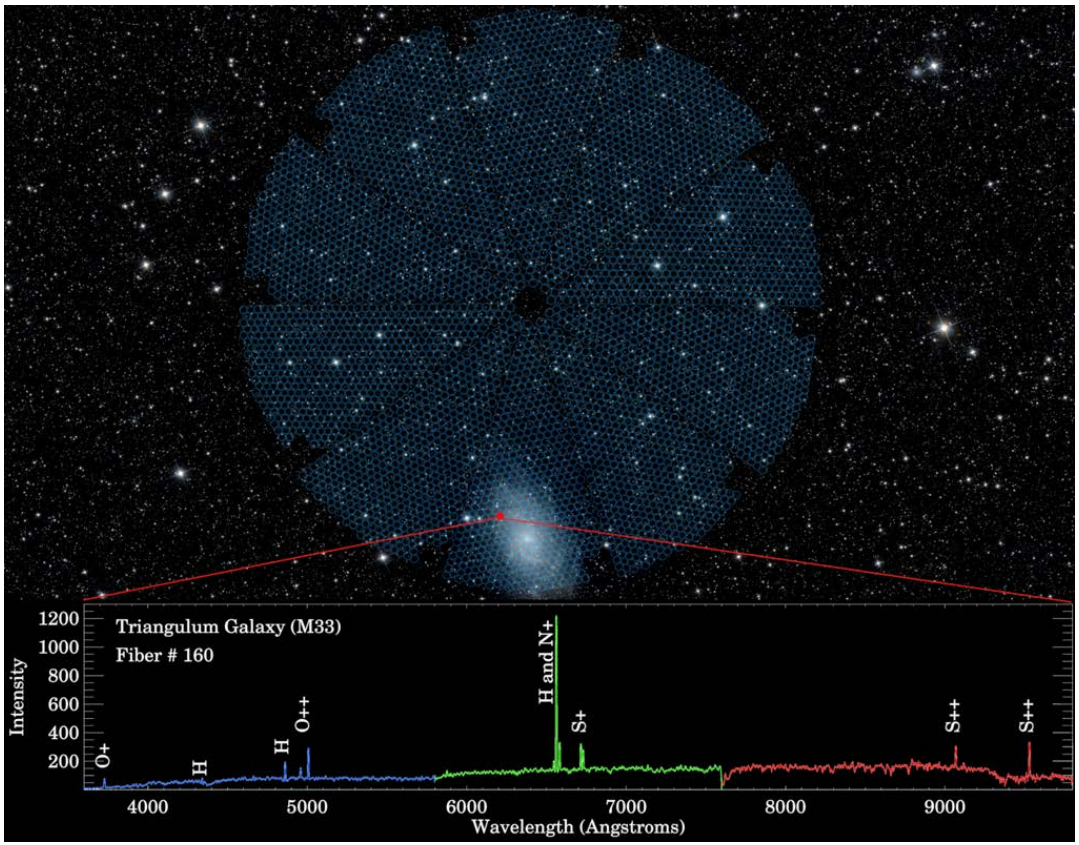
**STATUS:**

- All imaging surveys for target selection completed (16,000 sq deg)
- Oct. 2019 First light; Commissioning started
- March 16, 2020: All Project Deliverables complete, including Commissioning



# Science Highlight - DESI First Light

- **First Light achieved on Oct 22, 2019**, on the first day of the start of commissioning. The spectrum shown was collected by one fiber from a small section of the Triangulum Galaxy. The blue circles represent the sky footprint of the 5000 fiber positioners on the DESI focal plane.




- Measured instrument performance so far surpasses requirements and expectations!

- **When DESI turns on, it will be the most powerful multi-object spectrograph on the planet.**

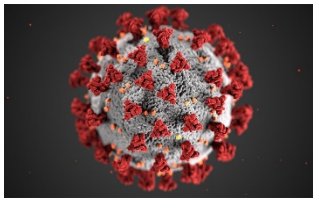
# Dark Energy Spectroscopic Instrument (DESI)

**Schedule that was planned**

- April 2, 2020: CD-4 review (by zoom)
- April 17, 2020: Inauguration event in Tucson and Kitt Peak
- April 2020: Science Validation (4 months) starts
- July 2020: 5-year dark energy science survey starts

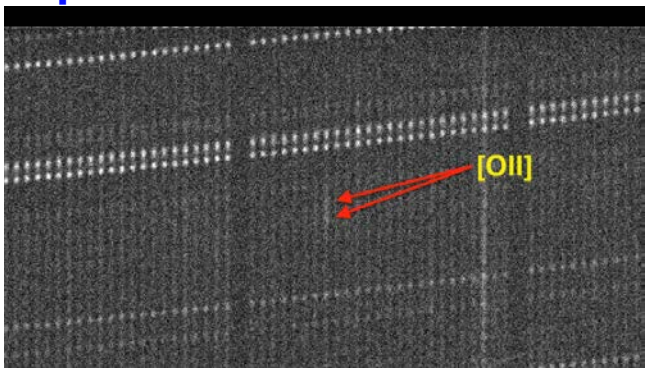
**Current Timeline**

- March 16 - 22, 2020: due to COVID-19, DESI was closed up and put into safe mode
- April 2, 2020: CD-4 review (by zoom) – **still on**.
- April 17, 2020: Inauguration event postponed
- Science survey will start when possible.

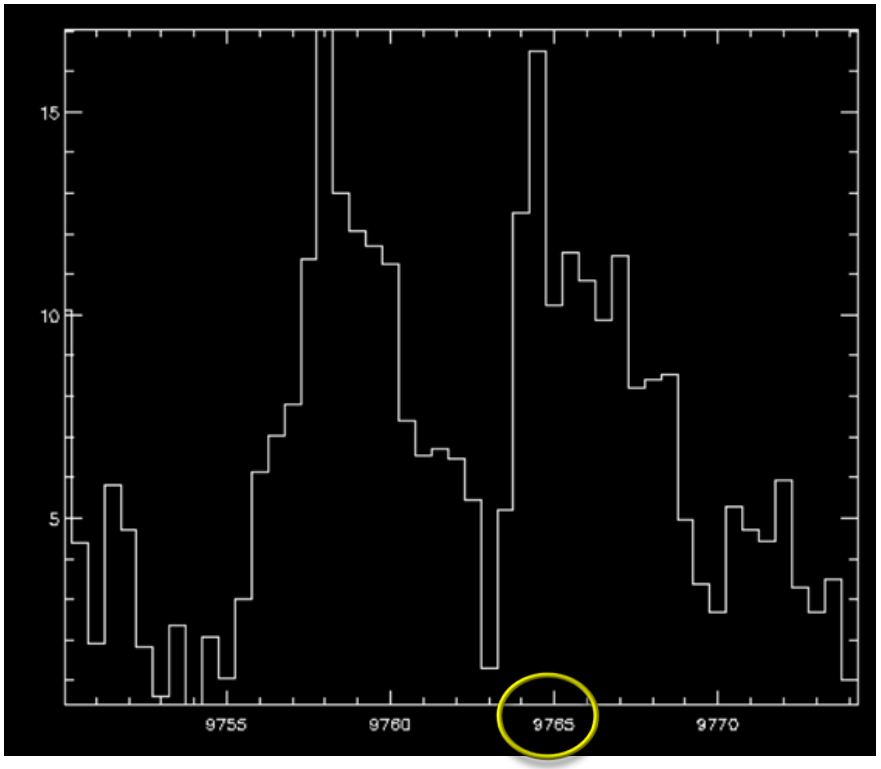


# Science Highlight - DESI Operations

- **First Light achieved on Oct 22, 2019.** Commissioning was a great success!
- 5-day "mini-survey" to exercise downstream software components. Mini-SV run#2 completed. ELG, QSO, LRG, BGS, MWS, standard stars.
- **Data looks great! Looking forward to starting science survey when possible.**




Many fibers (across), each w/spectrum (down)



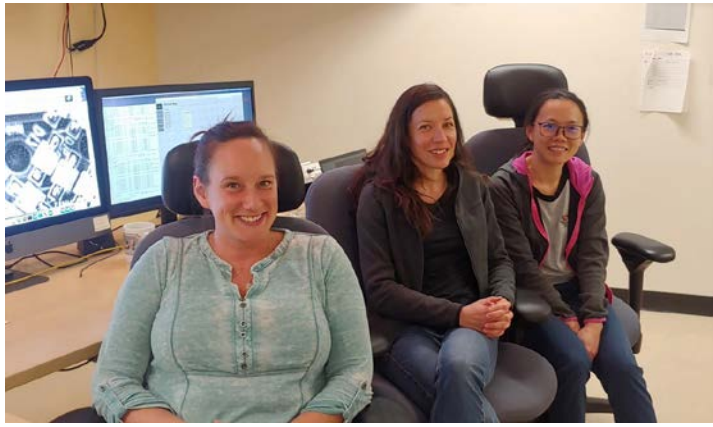

Beautiful OII spectral lines – but look at axis. DESI tested and succeeds at its highest redshift limit!

Emission Line Galaxy [O II] doublet at z=1.619. This is at the very edge of DESI wavelength range at 976 nm (limit is ~980 nm).

# DESI: Partnership & Collaboration

**Countries: US + 8 international w/significant contributions**

- 70+ institutions, 500 scientists, including 140 graduate students!
- US has: LBNL (lead), with FNAL, SLAC, ANL, BNL, LLNL plus 21 Universities
- Foreign partners built the corrector optics, the cryostats for the spectrographs plus all of the acceptance testing of the spectrographs while in France, the focal plane guiders, the entirety of the fiber system and calibration system.



Claire Poppett (Lead Observer), Stéphanie Juneau (NOAO) & Suk Sien Tie (OSU)

- Robust university-laboratory partnership with numerous important instrumentation subsystems developed and built at universities, e.g.fiber positioners (Umichigan), instrument control system, commissioning camera, & sky monitor (Ohio State U), fiber view camera (Yale), and petal-bodies (machined a
- Many significant roles for young people during project fabrication phase, and as Lead Observers during science survey.

# Large Synoptic Survey Telescope
# → now Vera C. Rubin Observatory

- Official name signed into law on 12/20/19
- Announced at AAS Town Hall meeting 1/6/20
- **First major national observatory to be named after a woman!**
- Especially fitting since her work provided critical evidence of dark matter → of major importance to fields of astronomy & physics.

How we refer to it:
For the first ten years of operations, the **Rubin 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**.

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

# Vera C. Rubin Observatory



## → New state of the art wide-field imaging observatory on Cerro Pachon in Chile

NSF (lead agency) and DOE partnership
- NSF roles led by AURA; DOE roles led by SLAC.

**Construction** to build and commission the observatory; have 2012 MOA

- **NSF MREFC Project** Telescope and Site, Data Management, Education & Public Outreach; **Simonyi & Gates** contributions to long-lead items. **Chile** partnership.

- **DOE Camera MIE Project;** completes when Camera is integrated and tested at SLAC; Commissioning in Chile is lined up to complete with MREFC. **France / IN2P3** contributions.

**Facility Operations** supported by both agencies; plan addendum to the 2012 MOA

**Scientific Research -** Both NSF and DOE support community science.
- Dark Energy Science Collaboration (DESC) organizes DOE's efforts.

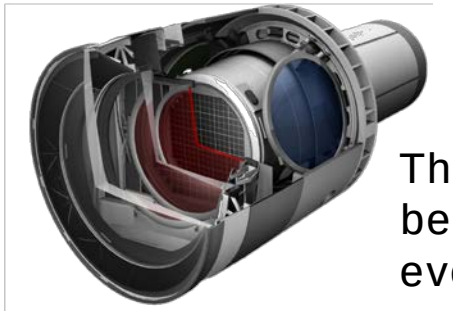
Agency Oversight and Reviews:
- Weekly NSF/DOE Joint Oversight Group (JOG) meetings
- Joint reviews of Project and Facility Operations plans

# Rubin Observatory – Construction Project Status (mid-March)

➔**Status up until mid-March**

Construction is going well & significant progress has been made

- Continues to meet technical requirements in support of the Science Requirements Document



In Chile: 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** ➔

**LSST Camera Project**: **96.6% complete**

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

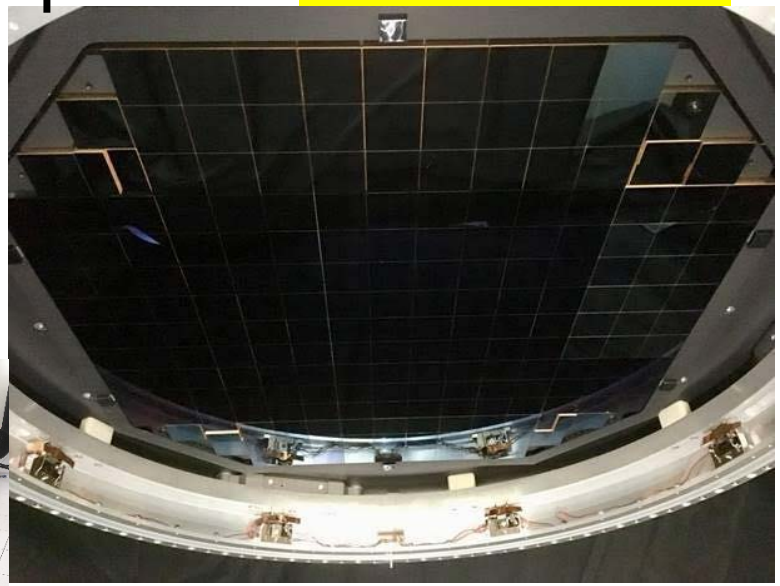
**Rubin Observatory Commissioning** is supported on HEP program funds; lined up with NSF's MREFC to complete at end of FY2022. HEP support for commissioning started FY18: camera I&T, commissioning observatory systems

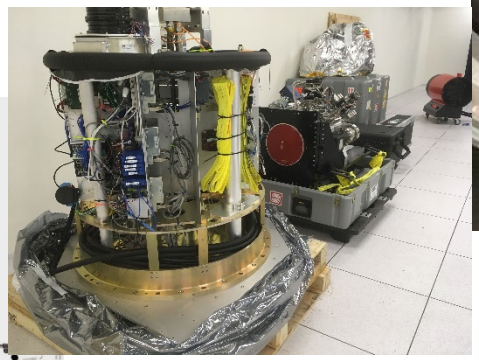
# DOE Camera Status (mid-March)

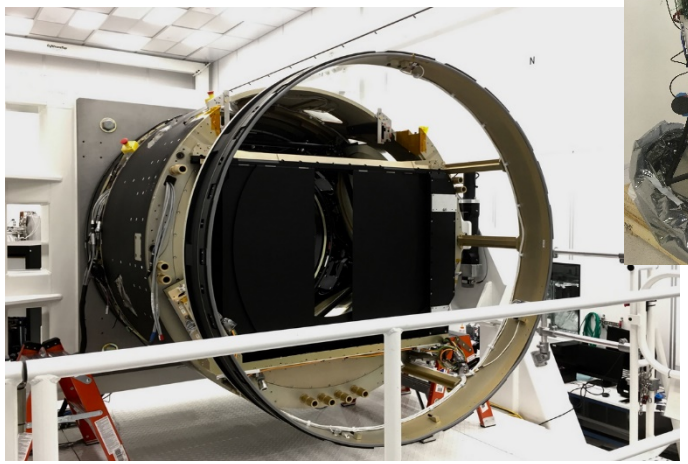
## Camera focal plane is complete

**All 21 rafts installed!!**

- 189 sensors packed in 21 rafts of 9 sensors
- 63 cm focal plane
- 2 second readout (fast!)
- 3060 kg
- 1.57 m front Lens
- 6 optical filters 0.3 – 1.1μ





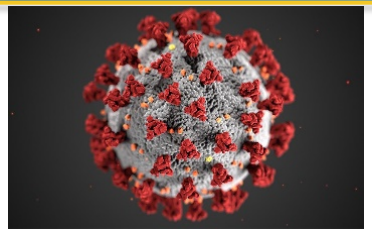


**ComCam has arrived in La Serena**

**Shutter installed successfully on the camera body.**

Camera Lenses completed and at SLAC

# Rubin Observatory – Current Status



➔As of March 21st

Vera C. Rubin Observatory reduced construction activities at the site in Chile to essential work. It was secured as safely as possible by the weekend. Small crews are expected to be able to do intermittent inspections.

Chile closed its borders and the Observatory offices in La Serena are telework only.

Due to the California shelter-in-place order and the resulting SLAC shutdown, Camera fabrication activities were halted. The camera has been left in a safe mode and is being monitored remotely. Only essential security/safety personnel can go to SLAC.

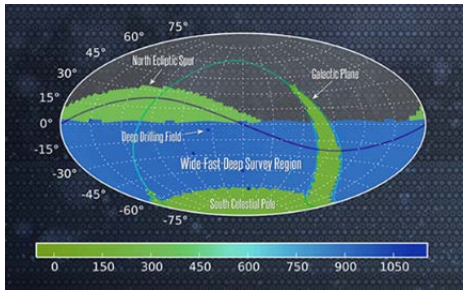
Software, computing, and other work that can be done remotely/by telework is continuing.

# Rubin Observatory: Facility Operations

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 and the Simonyi Survey Telescope

→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.

- DOE and NSF will consider international in-kind contributions in exchange for data rights/access during the 2 year proprietary period (same rights as US and Chilean scientists). In-kind priority is to offset operations costs; 2nd priority is to enhance US science, esp. LSST science. Agencies will make final decisions on in-kind contributions and agreements.
- DOE & NSF, with input from the Operations planning team, has been investigating options for laying out DOE & NSF scope and budgets

**Status:**

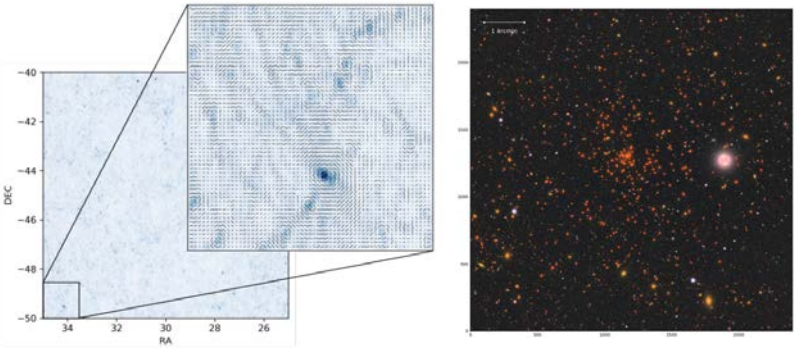
- DOE will support the US Data Facility; selection in process
- In-kind planning: 40+ Letters of Interest (LOI) submitted late 2019; Now moving forward on next step which is developing the detailed plans by end of June.
- Ops Team carrying out pre-operations planning and activities
- April 2020: Joint NSF/DOE Operations Plan status review (now by ZOOM)

# Science Highlight – Legacy Survey of Space and Time (LSST) Dark Energy Science Collaboration (DESC)

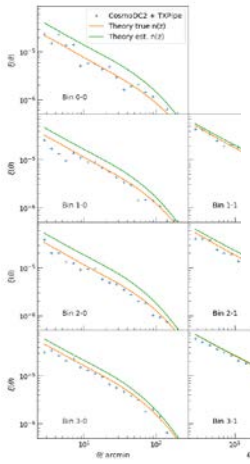
Large international collaboration, set up to carry out planning, preparations and eventual data analysis to make high accuracy measurements of fundamental cosmological parameters using data from the LSST. See www.lsstdesc.org

Currently ~ 1000 members, including > 200 Full Members

15 DESC papers published or submitted in 2019. DESC is actively preparing for cosmological analysis with LSST!




DESC has produced state-of-the-art extragalactic catalogs (https://arxiv.org/abs/1907.06530) and image simulations of the LSST survey (above right, 1-year survey depth) that are being used to test the dark energy analysis pipelines that DESC is developing in preparation for real LSST data.



DESC analysis software is under active development, with recent successes in weak lensing analysis pipeline development (shown here, based on analysis of simulations) and the Core Cosmology Library (recently released at v2, https://github.com/LSSTDESC/CCL).

# Determining the Nature of Dark Energy – Next Generation

**Power of a cosmic survey for precision measurements of cosmological parameters is limited by Redshift accuracy, Redshift range, Statistics**

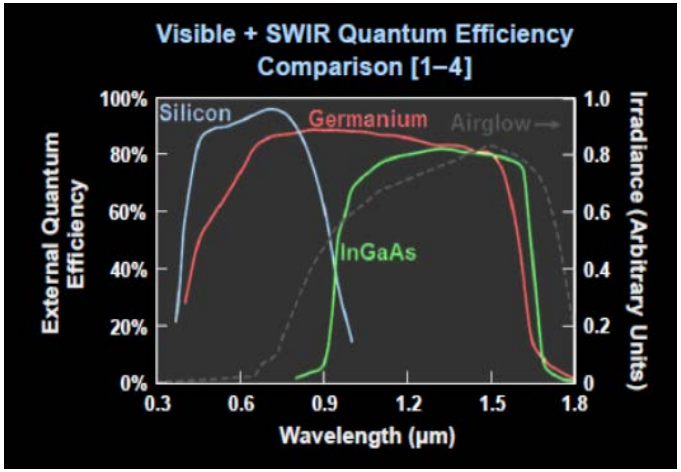
To fully exploit current program of ground- and space-based experiment will require advances in theory, simulations, joint data analysis and computing

- Cross-cutting theory and simulations efforts
- Joint modeling and analysis of imaging, spectroscopic, CMB and other data
- Exascale Cosmological Simulations - Expanding the nonlinear structure frontier, pushing to smaller scales

For the future, we will also need advances in technologies for Stage 5, methods to increase redshift range, accuracy and statistics.

Community efforts:

- Cosmic Visions Dark Energy group investigating ways to optimize science in DESI/LSST era
  - White paper on small "enhance" efforts in Jan 2018 arXiv:1802.07216
- Technology development for Stage-V surveys, e.g.
  - Germanium CCD R&D
  - Fiber positioner designs to increase density
- HEP community is leading or participating in some concepts – White Papers submitted to Astro2020



# Cosmic Microwave Background

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



**Current Experiments:**

***SPT-3G:*** DOE-HEP partnership with NSF-OPP lead and NSF-PHY, NSF-AST.

- HEP provided support for major upgrade of the camera to greatly increase sensitivity: Fabrication of 16,000-detector SPT-3G focal plane
- HEP now supporting operations and science research

HEP is participating in other science collaborations – ground-based & Planck through NERSC computing

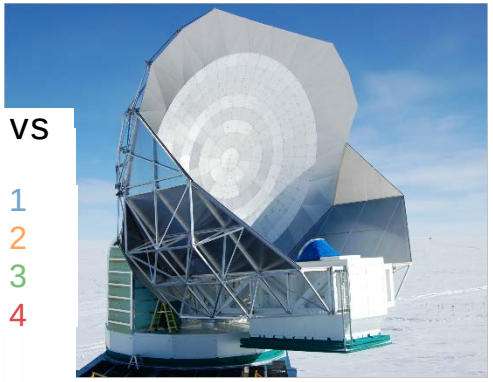
**Future Planning – CMB-S4 in P5 plan:**

- DOE should support CMB experiments as a core particle physics program
  - CMB-S4 intended to be flagship DOE project for Cosmic Frontier last half 2020s
- Multidisciplinary nature of the science warrants multi-agency support
  - NSF astronomy & DOE particle physics communities
  - DOE lab tech capability for detector fab, DAQ, HPC

# South Pole Telescope 3rd Generation (SPT-3G) - operating smoothly

**SPT-3G → Third-generation Receiver for the South Pole Telescope**

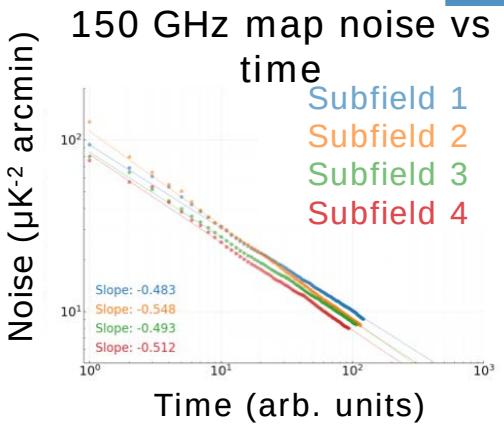
- Science ops started 2018, goes until 2023
- 15,000 sq deg 5-year survey, deep survey with arcminute angular scales

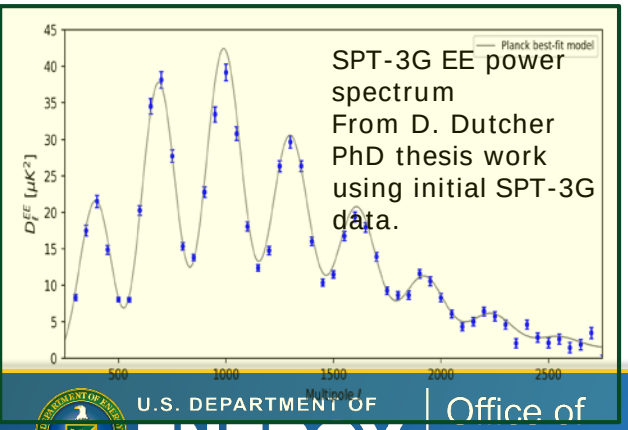


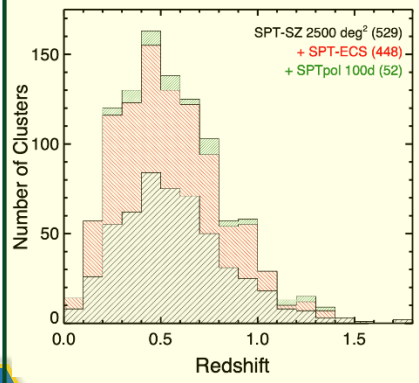
## Running smoothly:

- Observing at full power and high efficiency
- Completed 2019 Austral Winter observations
  - Field noise integrates down as expected
- Completed Austral summer maintenance and summer observations.
- Now conducting routine 2020 Austral winter observations

***SPT (SZ+POL+3G+EHT) >30 papers and 500 citations last year alone***



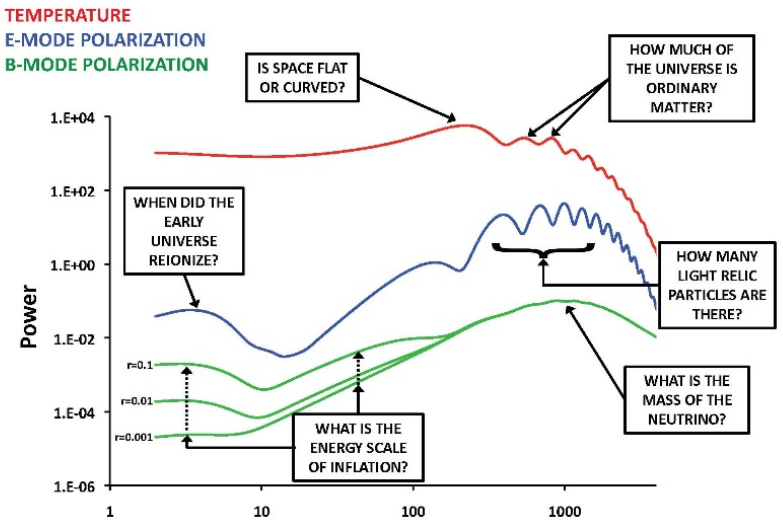

L.E. Bleem et al.
The SPTpol Extended Cluster Survey
*Accepted to ApJS,* arXiv:1910.04121

- Number of clusters vs redshift for the SPT surveys: SPT-SZ 2500d, SPTpol 100d, SPT-ECS (Extended Cluster Survey)
- >1000 confirmed clusters out to z>1.5 spanning the Dark Energy accelerating epoch
- With 5.5 months of SPT-3G, have >1600 clusters

# Cosmic Microwave Background Stage 4 (CMB-S4) project → discovery science!

CMB multipole power spectrum structure:

- Rich in topics, progression in stages has made great progress
- Deep synergy with other DE and optical survey efforts
- Continue to Stage 4 with significant increase in sensitivity to cross critical science thresholds




P5 recommended CMB-S4 in all scenarios

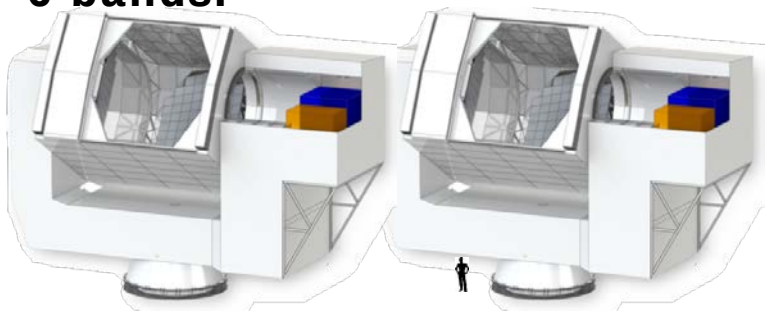
**Goal: cross critical science thresholds**

| Science | Stage 2 | Stage 3 | Stage 4 | Top Level goal for CMB-S4 |
|---|---|---|---|---|
| Inflation "r" | ≤0.1 | ≤0.01 | ≤0.001 | Detect or rule out compelling 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 ($\mu K^{-2}$) | $10^5$ | $10^8$ | $10^8$ | 2° to 1' angular scales |

# CMB-S4 Reference Design in a nutshell -nested deep/wide & ultra-deep/narrow surveys

**Deep & wide $N_{eff}$ and Legacy Survey with 2 x 6m telescopes targeting ~60% of sky with 240,000 detectors over 6 bands.**

**At Atacama in Chile…**

6m Large Aperture Telescopes

**Ultra-deep "r" survey with 18 x 0.55m small refractor telescopes targeting ≥ 3% of sky with 150,000 detectors over 8 bands and a dedicated de-lensing 6m telescope with 120,000 detectors.**

**At South Pole…**


18 x 0.55m small telescopes (3 per cryostat)

# CMB-S4 planning, status

CMB-S4 planned as a single ~$600M TPC multiagency project
→ As recommended by P5 (2014) and AAAC/CDT (2017)

- Envisioned as a DOE/HEP & NSF (AST, PHY, Polar) partnership
- Scope distribution ~ 50/50 (±10%)

Interim Project Office (IPO)

- Continues technical studies, concept design and planning
- Proposed timeline is for DOE CD-1/3a and NSF-PDR in 2021

NAS Astro2020 Decadal Survey underway

- CMB-S4 July 2019 submission of White Paper; Fall 2019 RFI, Feb.2020 Q&A

DOE & NSF: Weekly Joint Oversight Group (JOG) working to synch processes

- Awaiting DS recommendations in early 2021

DOE approved Critical Decision 0 (CD-0) in July 2019
→ Mission need, and facility to be built to meet the mission.
→ HEP providing R&D support for Project planning, technology R&D

NSF MSRI-R1 to U. Chicago (9/2019) to begin work on Preliminary Design

**DOE Status (March 2020):**

- **Working to support the IPO timeline of FY2021 CD-1/3a**
- **DOE/HEP is carrying out a process to select a lab to lead our efforts.**

# Axion Dark-Matter eXperiment Generation 2 (ADMX-G2)

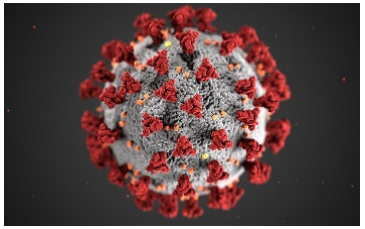
***Stage 2 Direct Detection Dark Matter Axion Search***

DOE-HEP experiment located at Univ of Washington; Managed by Fermilab; contributions by UK, Germany, Australia and private.

- Uses a strong magnetic field and resonant cavity to convert dark matter axions into detectable microwave photons

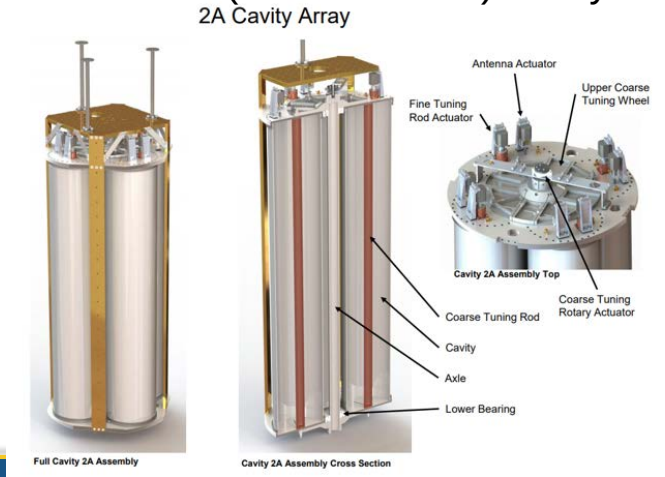
**In Operations**:

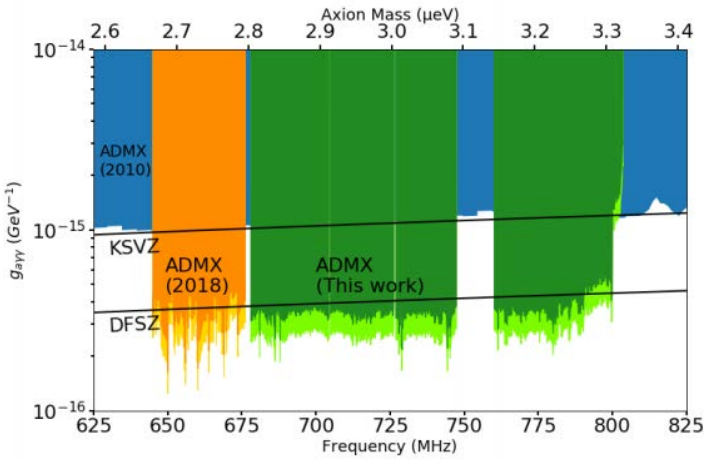
- Run1A-2B (6 runs) covering 0.5 - 2 GHz (~ 2 to 8 micro-eV mass) started Aug. 2016; complete ~ 2022.
- Now in Run 1C (2019/2020) covering 800-1020 MHz.
- Run 2 Cavities and cold electronics under development.



**Science Results:** Run 1A (2017), Run 1B (2018), Run 1C (2019/2020) - all reached "invisible" axion (DFSZ model) sensitivity.

- Run 1B (680-800MHz) analysis submitted.



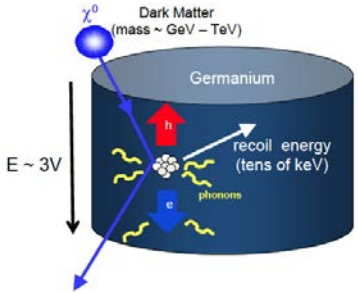




3/31/20: ADMX-G2 continues fully automated data-taking; have plan in place to put it in hibernation if needed

# Super Cryogenic Dark Matter Search at SNOLab (SuperCDMS SNOLab)

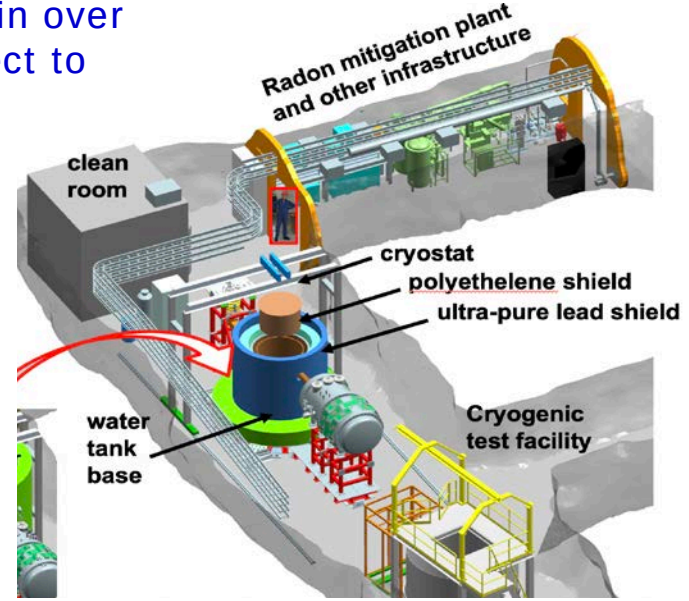
***Stage 2 Direct Detection Dark Matter WIMP Search.***
**HEP and NSF/PHY project, with contributions from Canada (CFI, NSERC).**

- Cryogenic solid-state germanium and silicon crystals with sensors that detect ionization & phonon signals; ~1-10 GeV mass
- Will be located 2km underground at SNOLAB, Sudbury, Canada.



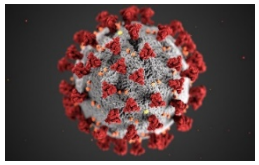

## Project Fabrication Status:

- Led by SLAC, significant effort by FNAL, universities
- TPC (HEP) $18.6M; all funding provided by FY19
- Detector Fabrication ongoing; Cryostat procurement bid came in over cost and schedule; mitigations and replan are in progess; expect to reduce cryostat to hold 7 towers (was 31).
- Plan to complete March 2021 with CD-4 milestone Sept.2021; Commissioning starts FY2021.




**Operations** planning and pre-ops ongoing;

- Pre-operations effort to calibrate, characterize, and test detectors up and running: NEXUS at FNAL, CUTE at SNOLAB



3/31/20: Many efforts on hold due to restricted access; Remote efforts in design, planning continue. Reviews on hold (incl. April status review)

# LUX - ZEPLIN (LZ) Experiment

***Stage 2 Direct Detection Dark Matter WIMP Search.***

- **HEP experiment (led by LBNL); Collaboration of 5 countries, 37 institutions**
- Uses a dual phase liquid Xe 10-ton TPC; sensitivity ≤ 2 x $10^{-48}$ $cm^2$ , close to where astrophysical neutrinos become irreducible background.
- Located nearly 1 mile underground in the Sanford Underground Research Facility (SURF) in Lead, SD.

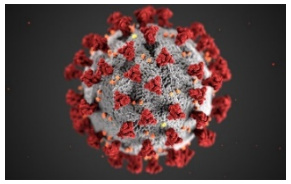
Xenon: Kr Removal Plant at SLAC

## Project Status, Schedule

- MIE Project, currently in fabrication
- TPC (HEP) $55.5M; All funding provided by FY19
- Installation, commissioning in progress.
- Objective Key Performance Parameter (KPP) Deliverables planned to complete Sept. 2020;Threshold KPP's almost complete now; CD-4 March 2022
- Operations planning & pre-ops activities ongoing

TPC & inner-cryostat vessel (ICV) lowered into shaft (Oct.2019)

TPC/ICV inside OCV in water tank (Dec. 2019)



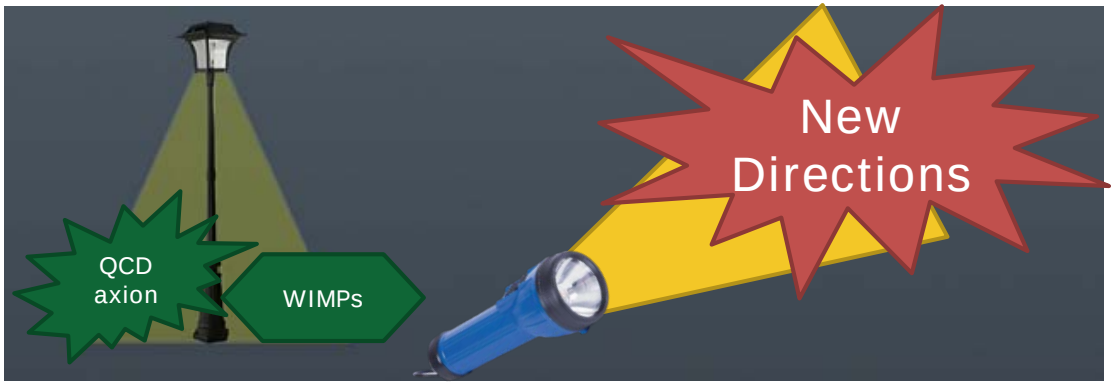
3/31/20: Most efforts on hold due to restricted access and shelter-in-place at SURF, labs, industry, universities; Remote efforts in design, planning continue.

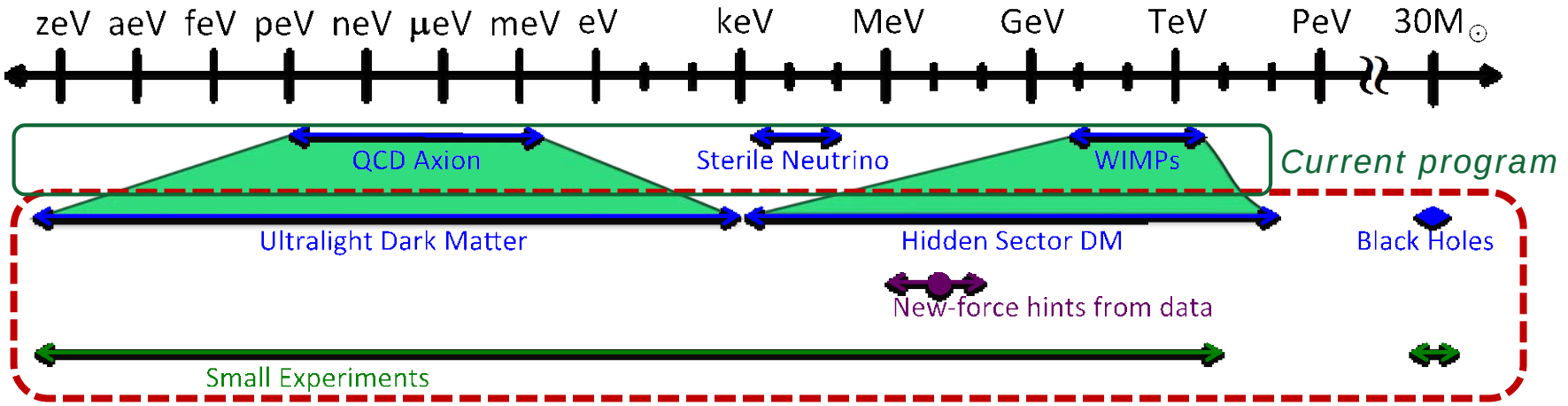
# Dark Matter Searches - New Opportunities

Recent theoretical studies highlight well-motivated frameworks with sharp, predictive targets from cosmology, fundamental physics, and anomalies in data

- WIMPs, QCD axions central ideas that will be studied with current & planned experiments
- Generalized theories have led to new paradigms that small experiments could address

Technological advances allow new experimental methods




***New Directions in Dark Matter***

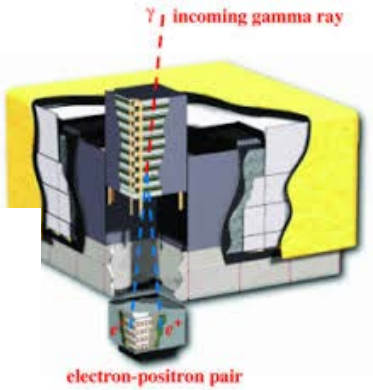
# Dark Matter New Initiatives for Small Projects – Timeline & Funded Proposals

**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

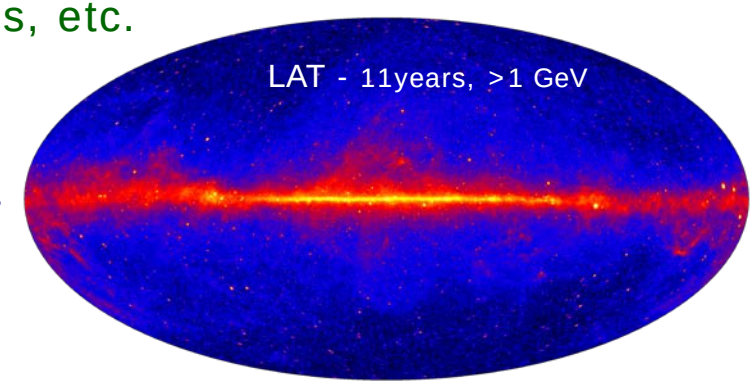
- 2017 Community Workshop -> White paper at https://arxiv.org/abs/1707.04591
- 2018: Basic Research Needs (BRN) study which led to 3 Priority Research Directions (PRD) in Dark Matter. See https://science.energy.gov/hep/community-resources/reports/
- FY19: Funding Opportunity Announcement (FOA); Four proposals selected to develop concept and execution plans for potential small projects. Two additional proposals may be awarded in FY20 depending on funding availability.
- **ADMX Extended (2-4GHz) – A. Sonnenschein (FNAL)**
- **OSCURA (Skipper CCD detector) – J. Estrada (FNAL)**
- **DM-Radio axion search – K. Irwin (SLAC)**
- **Beam Dump exp at FNAL – R. van der Water (LANL) – Intensity Frontier**
- **LDMX exp at SLAC – T. Nelson (SLAC) Intensity Frontier (FY2020)**

# Fermi Gamma-ray Space Telescope: Large Area Telescope (LAT) Collaboration




DOE HEP partnered with NASA on fabrication of the LAT at SLAC, together with international contributors: France, Italy, Japan, Sweden.

**Science:** Study high-energy (~20 MeV->300 GeV) gamma-rays using particle physics detector technology in space. Indirect Dark Matter (DM) detection; high-energy acceleration mechanisms, etc.




**Status:**

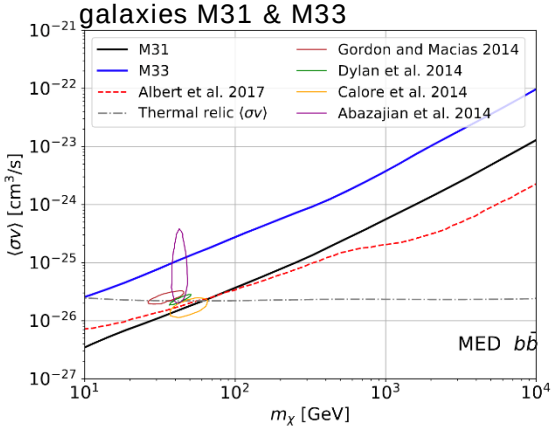
- Launched June 2008, 5-year mission with 10-year goal
- LAT Operations: HEP, in coordination with NASA, continues support of critical efforts at Instrument Science Ops Center SLAC, as operations continue past 10 years.
- 2019 July: NASA extended Fermi through FY22 based on the 2019 Senior Review, invited *Fermi* to propose for the next Senior Review in 2022

**LAT Collaboration Science Results (as of Jan. 2020)**

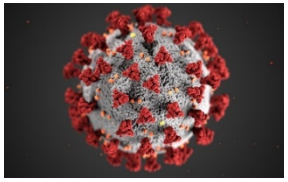
LAT Collaboration has published 606 papers

- Spectral and spatial analysis of the dark matter subhalo candidates among unidentified sources, Coronado-Blazquez et al. 2019, JCAP, 11, 045
- Competitive limits on DM annihilation based on LAT detection of Andromeda (M31, which has a large g-ray contribution from pulsars and interstellar diffuse) and non-detection of Triangulum (M33); Di Mauro et al. 2019, PRD, 99, 123027

Dark matter limits from Local Group galaxies M31 & M33




**3/31/20:** FGST continues operations (all remote!). Safe mode possible if needed.



# Alpha Magnetic Spectrometer (AMS-02)

**Physics:** Search for antimatter, dark matter annihilations & New particle phenomena on International Space Station (ISS).

→ Multi-purpose particle-physics spectrometer detects cosmic-rays up to 1 TeV; uses non-superconducting magnet

→ 95% of construction costs from Europe and Asia;

**International Collaboration**, with DOE/HEP leading US roles

- ~ 250 scientists from 46 institutions in 16 countries
- **Under the agreement with NASA, DOE-HEP is responsible for management of the science program**
- DOE-HEP supports MIT group and their roles in Leadership, Science and Project Fabrication and Experimental Operations, led by Prof. Sam Ting
- NASA provided launches and continues to provide the use of the ISS resources (power, data, etc), maintenance services and mission management
- CERN hosts the Payload Operations Control Center

**Recent Highlights** ~ 100 billion cosmic ray events collected.

- **high precision results in anti-matter nuclei searches and measurements, dark matter searches, antiproton, proton fluxes, etc.**

WELCOME

CERN Courier – digital edition

Welcome to the digital edition of the January/February 2020 issue of *CERN Courier*.

On the cover of this issue, NASA astronaut Drew Morgan is photographed 400 km above Earth's surface installing a new coolant system for the Alpha Magnetic Spectrometer (AMS) during a crucial spacewalk on 2 December. Masterminded by charm-quark co-discoverer Sam Ting of MIT, and assembled and overseen by an international team at CERN, AMS has been attached to the International Space Station since 2011. Its various subdetectors, which include a silicon tracker embedded in a 0.15 T magnet, have so far clocked up almost 150 billion charged cosmic rays with energies up to the multi-TeV range and produced results that contradict conventional understanding. The new coolant system (which was delivered by an Antares rocket on 2 November) will extend the lifetime of AMS until the end of the decade, allowing more conclusive statements to be made about the origin of the unexpected observations. A full report on the unprecedented AMS intervention – and a taste of the experiment's latest results – will appear on cerncourier.com following the final extravehicular activity by Drew and his colleagues in mid-January.

Meanwhile, in this issue we investigate an intriguing anomaly in nuclear decay rates seen by the "Atomki" experiment, learn about the wider value of anomalies to phenomenologists, talk to theorist John Ellis about the past, present and future of the field, and explore high-level attempts to solve the flavour puzzle. KATRIN's quest for the neutrino mass, outreach for visually impaired audiences, the latest results from the LHC experiments and careers in visual effects are among other highlights of this first issue of the 2020s.

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Reporting on international high-energy physics

AMS KEEPS ITS COOL

Atomki anomaly rekindled • Tackling the flavour puzzle • Voyage to the neutrino mass

CERN COURIER

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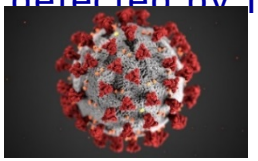
IOP Publishing

# High Altitude Water Cherenkov (HAWC)

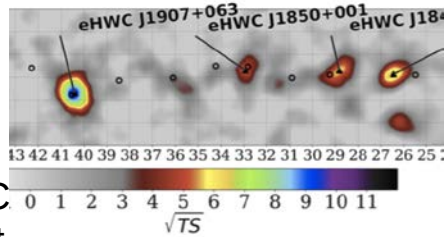
**Gamma/cosmic-ray observatory located on the Sierra Negra in Mexico: Water Cherenkov Air Shower Detector, now with Outrigger array**

- Partnership with NSF-PHY, Mexico
- 5 year ops. started early 2015
- HEP operations support planned to complete in FY2020

**Science:** All sky γ-ray survey 100 GeV to > 100 TeV; Wide FOV and high energy sensitivity places limits and constrains: dark matter cross sections, origin of high energy neutrinos detected by IceCube; highest energy e- in solar neighborhood.



3/31/20: HAWC continues its current remote monitor and control of operations. Some concern about




Nine sources of extremely high-energy gamma rays comprise a new HAWC catalog. All produce gamma rays with energies over 56 TeV and three emit gamma rays extending to 100 TeV and beyond, making these the highest-energy sources ever observed in our galaxy.

## Recent Results:

- Galactic gamma-ray sources reveal the birthplace of high energy gamma-rays, See: https://www.lanl.gov/discover/news-release-archive/2020/January/0114-galactic-gamma-ray-sources.php
- HAWC detects > 100 TeV g-rays which puts strongest constraints on **Lorentz Invariance;** HAWC's proof of the existence of g-rays >100 TeV provides ~ 2 orders of magnitude better constraints on superluminal Lorentz Invariance

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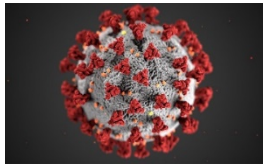

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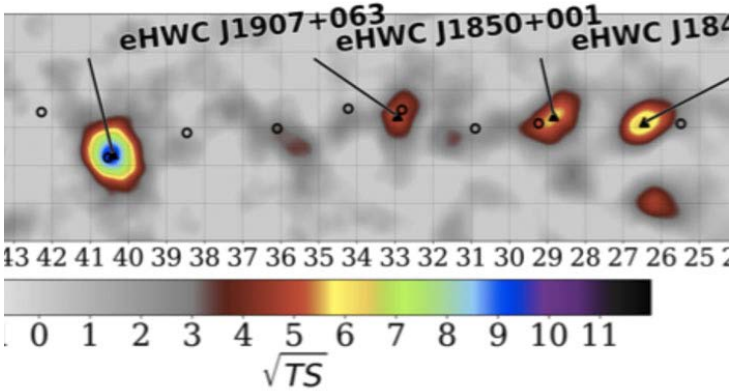


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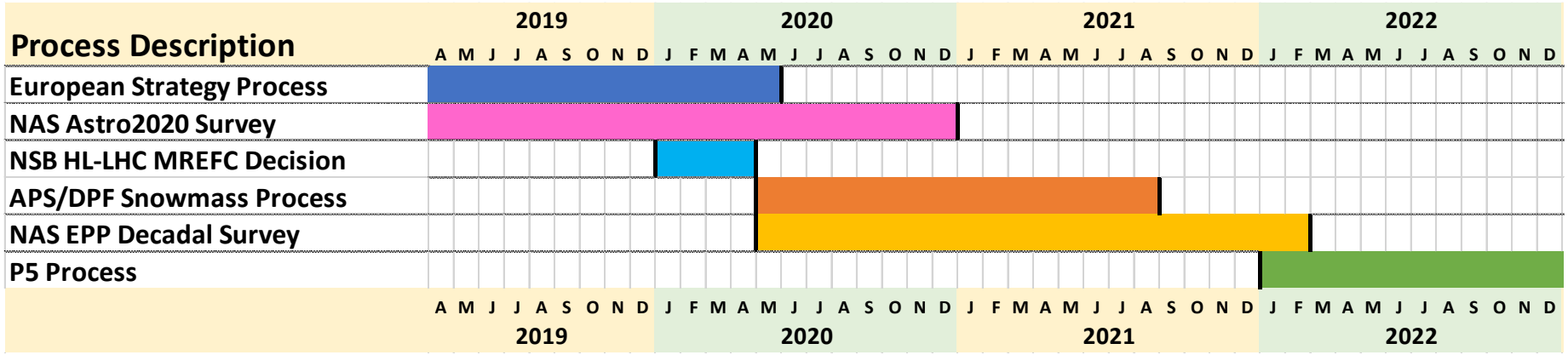
# Other Efforts & SUMMARY

# Possible Strategic Planning Timeline

- To provide timely input to the FY25 budget formulation, the next P5 report will be required by early 2023
- U.S. Community planning a Snowmass process with major meeting occurring in summer 2021
- Potential timeline for the next NAS EPP Decadal Survey could be mid-2020 through early-2022
  - Overlap with Snowmass could enable synergy with Snowmass processes and delivery of report as P5 process begins



# HEP Efforts related to the Cosmic Frontier

## Theory program

- Vibrant Theory Program supporting all areas including Cosmic Frontier

## 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.

## Computational HEP program

- **DOE Supercomputer allocation** coordination via various 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
- **Artificial Intelligence / Machine-learning** becoming an agency area of particular interest
- **HEP Center for Computational Excellence (CCE)** investigates ways to optimize code
- **HEP Computing Infrastructure Working Group** formed in 2017 to develop a strategy for meeting the computing needs, since projected needs are larger than availability

## Quantum Information Science (QIS) – quickly growing area

- Powerful new windows to accomplish HEP mission & advance QIS Foundational theory, computing, sensors (enable dark matter searches, CMB), technology, experiments; DOD, NIST

## Microelectronics Initiative

SC offices (ASCR, BES, FES, HEP) partnering to support multi-disciplinary microelectronics research that will promote basic research to accelerate the advancement of microelectronic technologies in a co-design innovation ecosystem in which materials, chemistries, devices, systems, architectures, algorithms, and software are developed in a closely integrated fashion.

# Summary

Excellent science results continue to be produced from our operating experiments!

P5 strategic plan is supported by Community and broad support is enabling it to be fully implemented.

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

- DESI is in commissioning, returning astrophysical spectra! DESI & LZ start science operations in FY2020.
- LSST camera project is 96% complete!
- CMB-S4 has DOE CD-0 and a NSF MSRI-1. The NSF-DOE Joint Oversight Group meets biweekly. The Project Office & Collaboration are working hard toward preparing for DOE CD-1 and NSF PDR, ready to start after Astro2020.

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, significant & necessary contributions.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# BACKUPS

# HEP Computing Challenges


- P5 recommended a program of challenging scientific experiments that have equally challenging computing needs
  - As an example, in FY2019 year NERSC requests were up 50% over 2018
  - ASCR's Exascale Computing project will play an important role in satisfying this demand, but much of HEP code is not ready for Exascale
- We have charged the Center for Computational Excellence (CCE) to be a matchmaker between HEP and ASCR experts to look at several example codes
- The HEP Computing Infrastructure Working Group was formed in 2017 to develop a strategy for meeting the computing needs.
- Successfully addressing computing challenges will require continued effort from the community and coordination with ASCR and NSF's Institute for Research and Innovation in Software for High-Energy Physics (IRIS-HEP) which is tackling similar issues from the university perspective

# Research Funding Challenges

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 Ops support for R&D, QA/QC, integration, installation, and commissioning
- Given that there is a lot of current Research and Ops 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

This is a complex interlocking problem with many contributing factors

- Cannot simply "trim the big projects" (or other "simple" solutions) without having impacts elsewhere
- **HEP PMs work on this ~every day**

# Appropriators Noticed the P5 Report

- FY 2014 House Energy and Water Development Appropriations Report:
  - "the Committee supports the Office of Science's challenge to the High Energy Physics community to identify an LBNE construction approach that avoids large out-year funding spikes or to identify viable alternatives with similar scientific benefits at significantly lower cost."
- FY 2015 House Energy and Water Development Appropriations Report:
  - "The Committee notes that the high energy physics research community is currently engaged in developing a ten-year plan for U.S. particle physics, which will include a ten-year report by the Particle Physics Project Prioritization Panel under various budget scenarios. The Committee applauds the Department for this undertaking . . ."
- FY 2016 House Energy and Water Development Appropriations Report:
  - "The Committee strongly supports the Department's efforts to advance the recommendations of the Particle Physics Prioritization Panel and urges the Department to maintain a careful balance among competing priorities and among small, medium, and large scale projects."
- FY 2017 House ($823M) and Senate ($833M) marks above President's Request ($818M), final appropriation for DOE High Energy Physics was $825M


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