U.S. DEPARTMENT OF ENERGY | Office of Science

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

Astronomy & Astrophysics Advisory Committee (AAAC)

January 23, 2020

Kathy Turner, Cosmic Frontier Program Manager

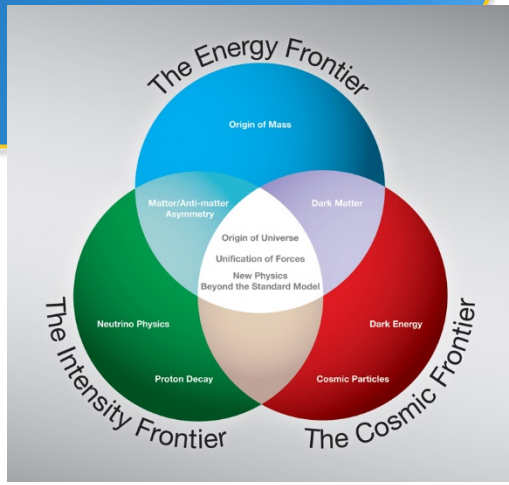
+ Karen Byrum (Detailee), Drew Baden (IPA), Eric Linder (IPA)

OUTLINE

→ Providing updates since the September 2019 AAAC 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) is a quickly-growing area.
- Artificial Intelligence/Machine Learning efforts are a growing area.

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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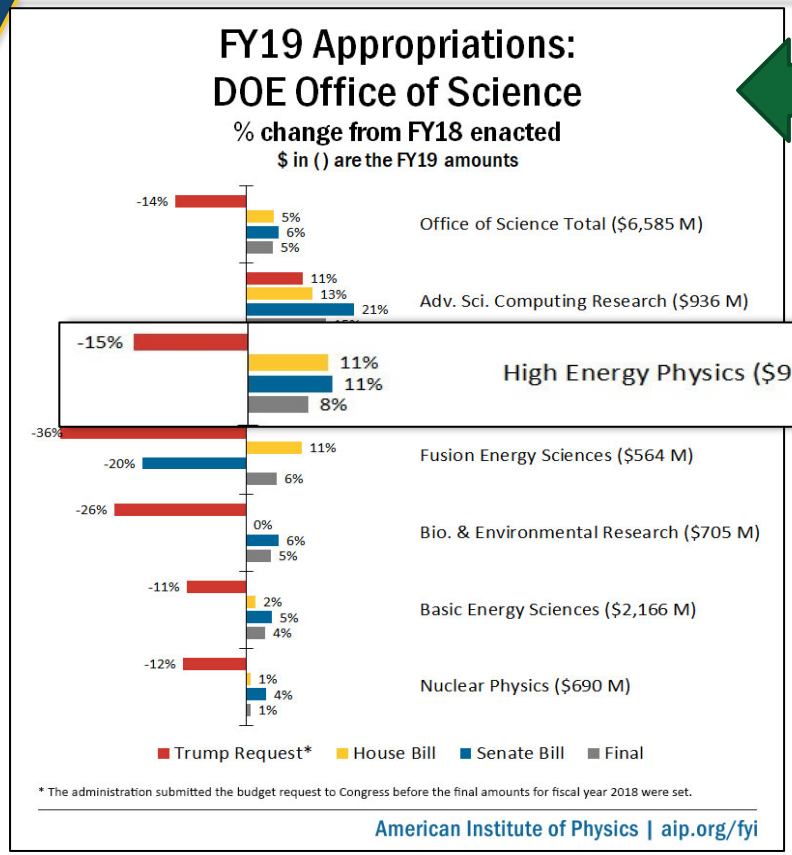
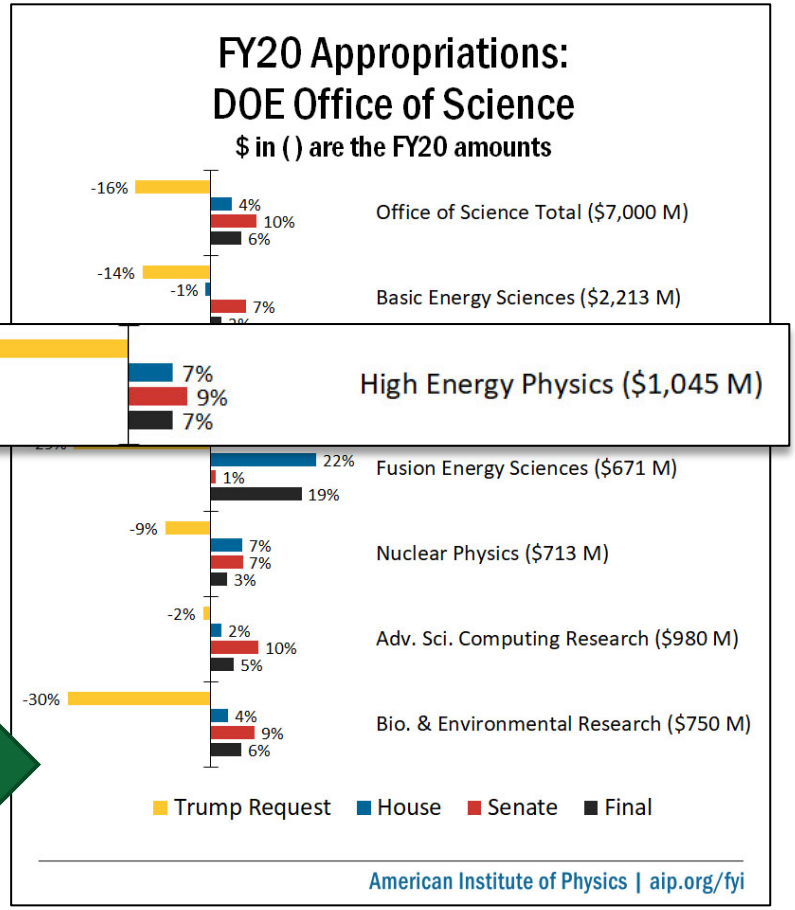
Budget

FY 2019 vs FY 2020 Office of Science



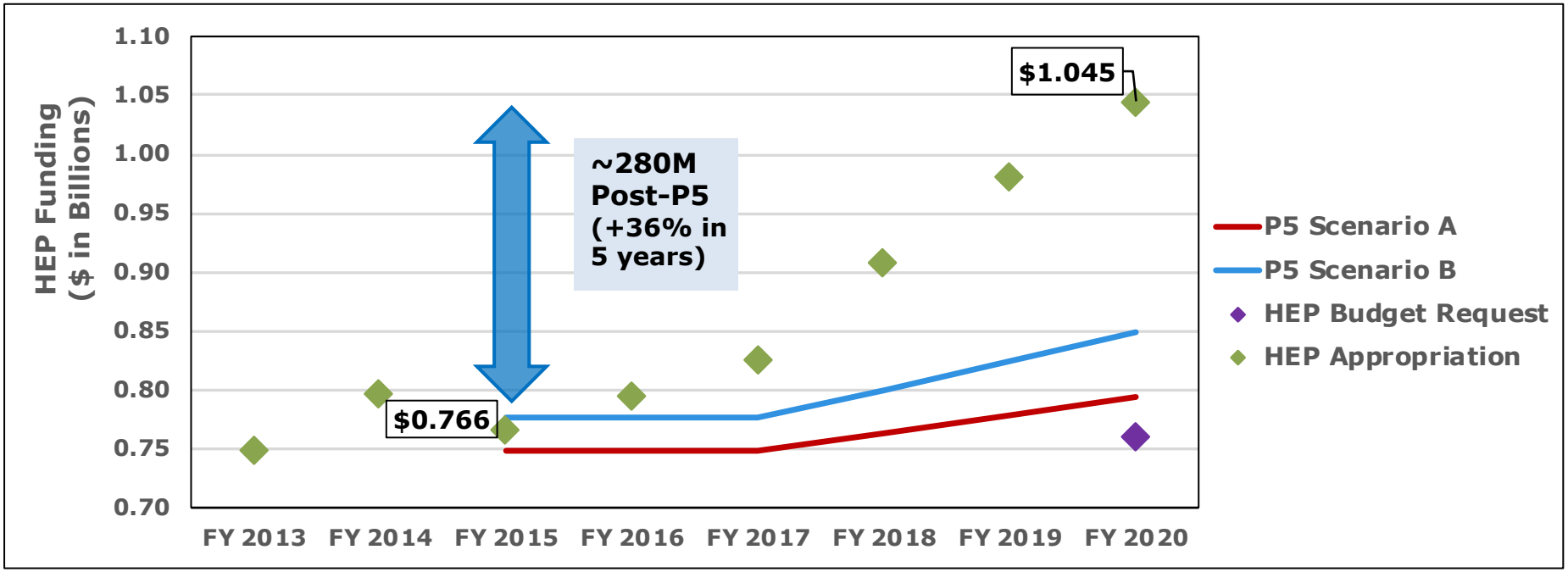
- HEP **increase of +8%** from 908M in FY 2018 to 980M in FY 2019
- All projects were addressed at their baseline levels. Five projects receive final planned funding:
  - Mu2e, LZ, DESI, SuperCDMS-SNOLAB, and FACET-II



- 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

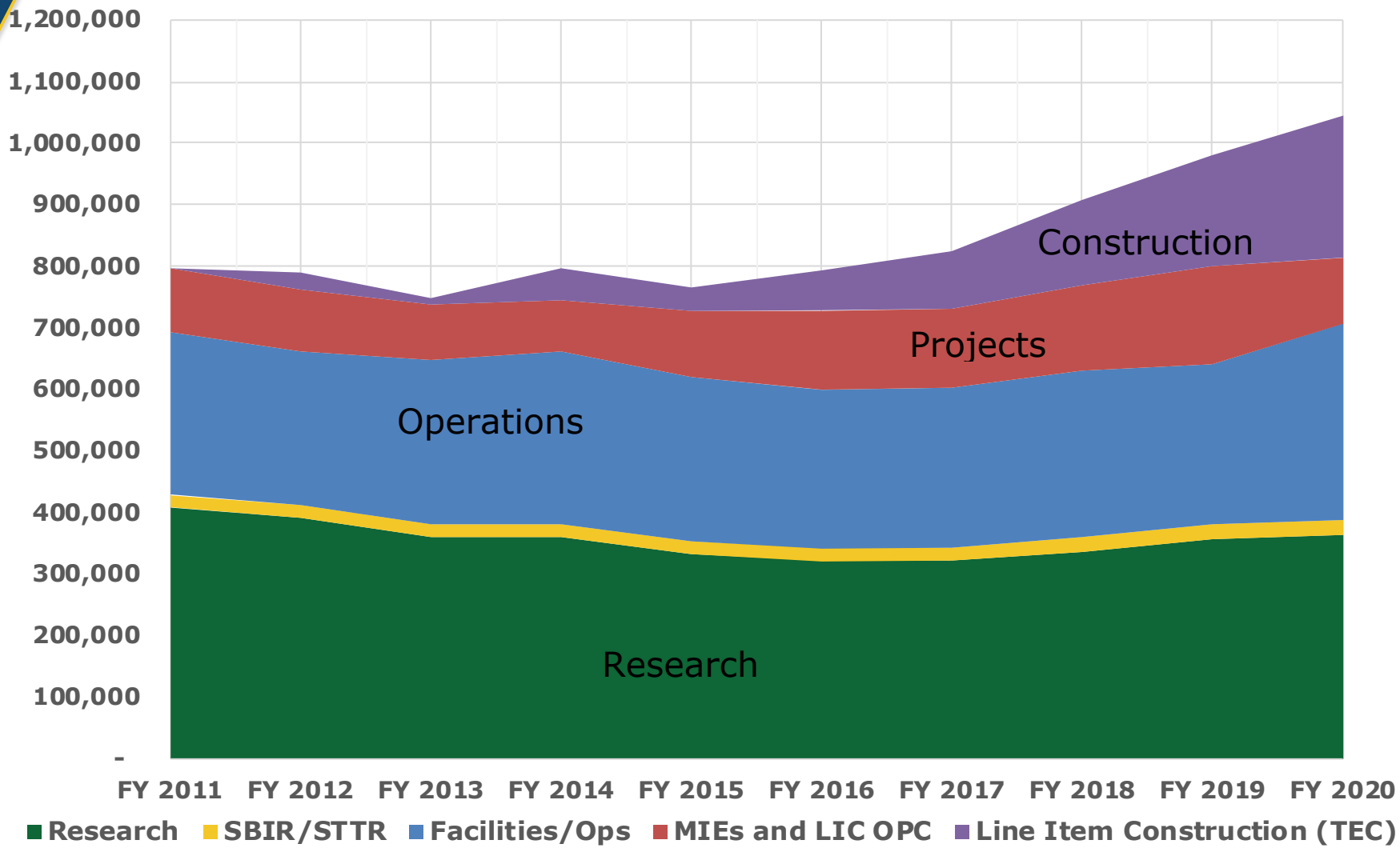
HEP Budget: U.S. Congress Supports P5 Strategy

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

HEP Budget ($k) FY 2011-2020



FY 2020 HEP Appropriation

HEP Funding Category ($ in K)	FY 2018 Actual	FY 2019 Actual	FY2020 Request	FY2020 House	FY2020 Senate	FY 2020 Appropriation	FY 2020 Appropriation - FY 2019 Actual
Research	359,177	384,286				389,577	+5,291
Facilities/Operations	270,488	258,364				317,929	+59,565
Projects	278,335	337,350				337,494	+144
Total	**908,000**	**980,000**	768,038	1,045,000	1,065,000	**1,045,000**	**+65,000**

- **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

FY 2020 Appropriations supports the SC and P5 priorities

- SC: Interagency and international partnerships, national laboratories, R&D initiatives
- HEP's P5: preserve vision, modify execution

FY 2020 HEP Appropriation, cont.

The FY 2020 HEP Budget continues support for P5-guided investments in mid- and long-term program

- "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)

Four Major Item of Equipment (MIE) projects received final funding in FY 2019: **LZ, DESI, SuperCDMS-SNOLAB**, and FACET-II.

→These four projects require a ramp up in Experimental Operations in FY 2020. For Cosmic Frontier, Operations for the **Rubin Observatory (formerly LSST)** are also ramping up in FY2020.

FY 2020 Funding by Subprogram

HEP Funding Category ($ in K)	FY 2018 Actual	FY 2019 Actual	FY 2020 Appropriation	FY 2020 Appropriation - FY 2019 Actual
Energy Frontier	183,219	235,403	229,666	-5,737
Intensity Frontier	247,048	247,256	251,666	+4,410
Cosmic Frontier	119,630	105,084	95,858	-9,226
Theoretical, Computational, and Interdisciplinary Physics	76,176	87,043	112,560	+25,517
Advanced Technology R&D	125,643	109,190	107,711	-1,479
Accelerator Stewardship	15,885	16,024	16,539	+515
Construction (Line Item)	140,400	180,000	231,000	+51,000
Total	**908,000**	**980,000**	**1,045,000**	**+65,000**

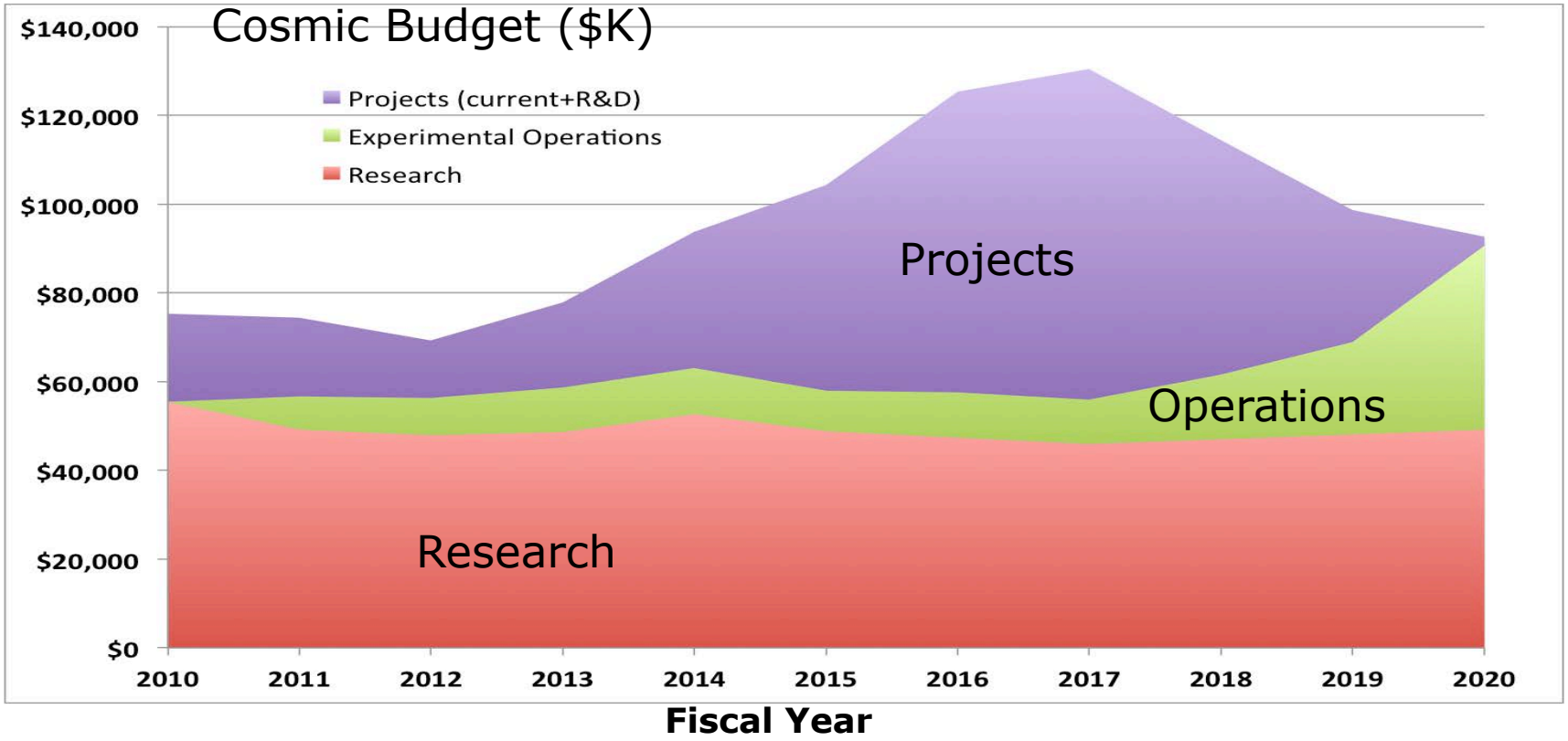
- Energy: -5M HL-LHC Projects
- Intensity: -14.5M PIP-II OPC; +3M DUNE OPC; Fermilab Acc Complex ramps up
- Cosmic: -26.35M DESI, LZ, and SuperCDMS-SNOLAB projects; +2M CMB; Operations ramps up +20.4M
- Theory, Computational, and Interdisciplinary: +11M QIS; +10M AI/ML; +2.5M LQCD
- Advanced Technology: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

Cosmic Frontier FY 2020 Program

Cosmic Frontier ($ in K)	FY 2018 Actual	FY 2019 Actual	FY 2020 Appropriation	FY 2020 Appropriation – FY 2019 Actual
Research	47,008	54,908	49,272	-5,636
Facilities/Operations	17,300	20,957	41,358	+20,401
Projects	52,835	26,350	2,000	-24,350
LSSTcam	*9,800*	*-*	*-*	*-*
DESI	*20,000*	*9,350*	*-*	*-*
LZ	*14,100*	*14,450*	*-*	*-*
SuperCDMS	*7,400*	*2,550*	*-*	*-*
CMB-S4	*-*	*-*	*2,000*	*+2,000*
SBIR/STTR	2,487	2,869	3,228	+359
Total	**119,630**	**105,084**	**95,858**	**-9,226**

- **Research:** World-leading research efforts in support of design and optimization on dark matter and dark energy experiments in their fabrication and commissioning phases, as well as on planning for future experiments, including CMB-S4.
- **Operations:** Start of installation and commissioning activities for the LSSTcam, as well as early planning for LSST facility and science operations. Planning, commissioning, and pre-operations activities will begin for DESI, LZ, and SuperCDMS-SNOLAB. Support for the currently operating experiments will continue.
- **Projects:** Completion of fabrication and installation of the LZ dark matter project, and will support the fabrication of the DESI dark energy project and the SuperCDMS-SNOLAB dark matter project.

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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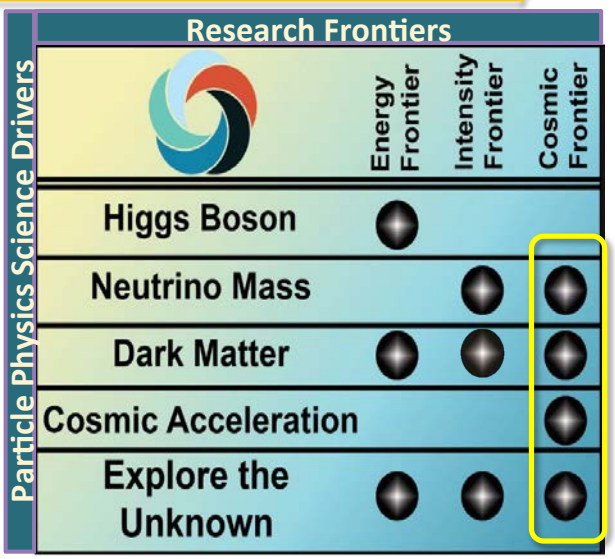
Cosmic Frontier

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

- 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

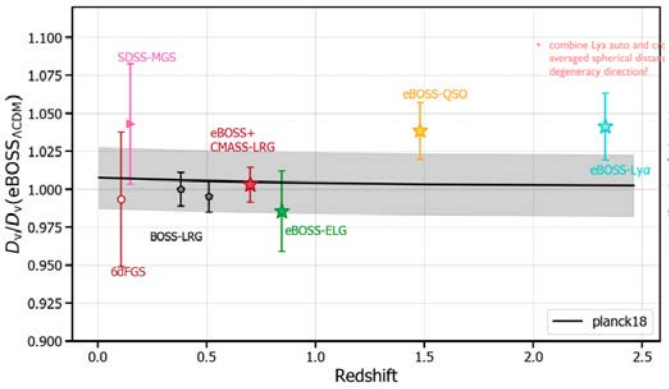
Science Highlights – eBOSS

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

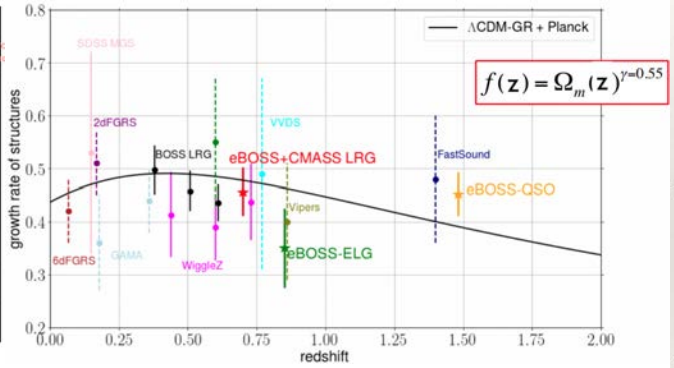
- BAO/RSD from LRG, ELG, and quasars over 0<z<2
- BAO from Lyman-alpha forest and quasars at z=2.35
- Preliminary cosmology constraints using distances, growth & combined analyses
- Roughly 15 papers expected in Spring 2020

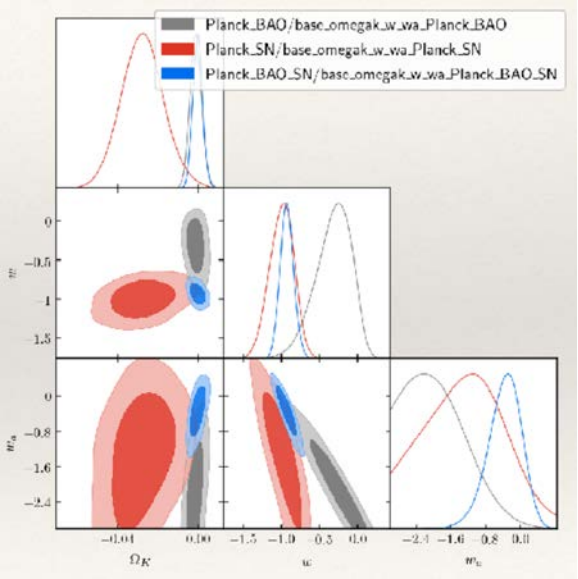
Implications for Cosmology: significant improvement on dark energy equation of state compared to SNe+CMB; robust estimates of H0 using inverse distance ladder; tests of GR; tighter bounds on summed neutrino mass

BAO from SDSS, BOSS, and eBOSS



RSD from BOSS, eBOSS and competition



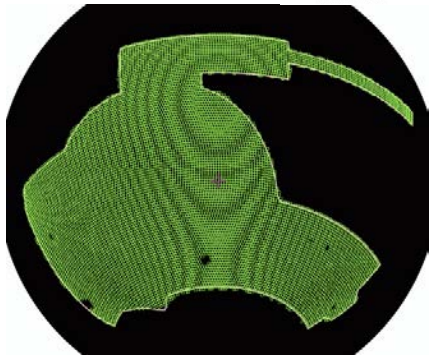


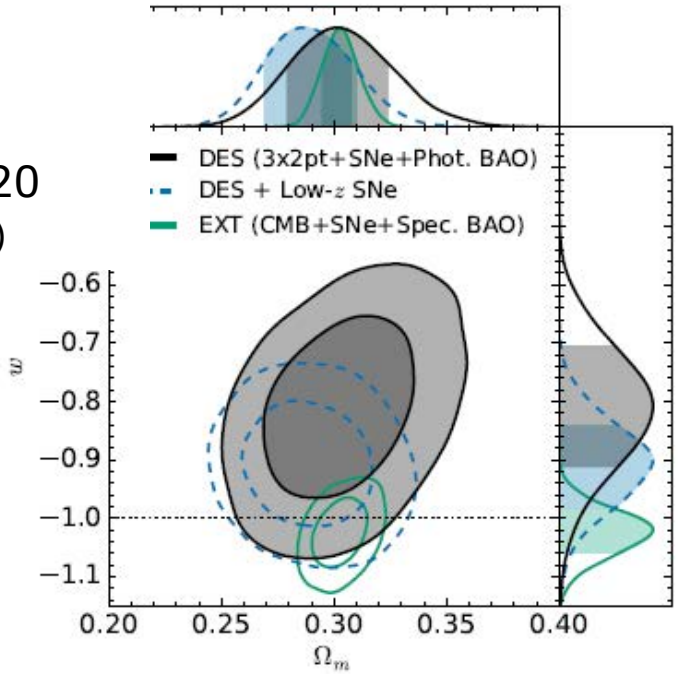
Dark Energy Survey (DES)

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 2020
- 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

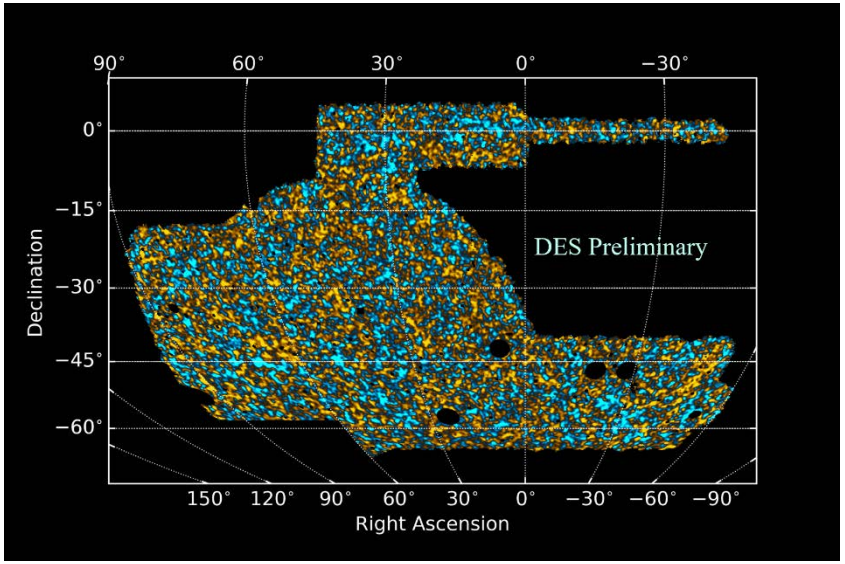
DARK ENERGY SURVEY

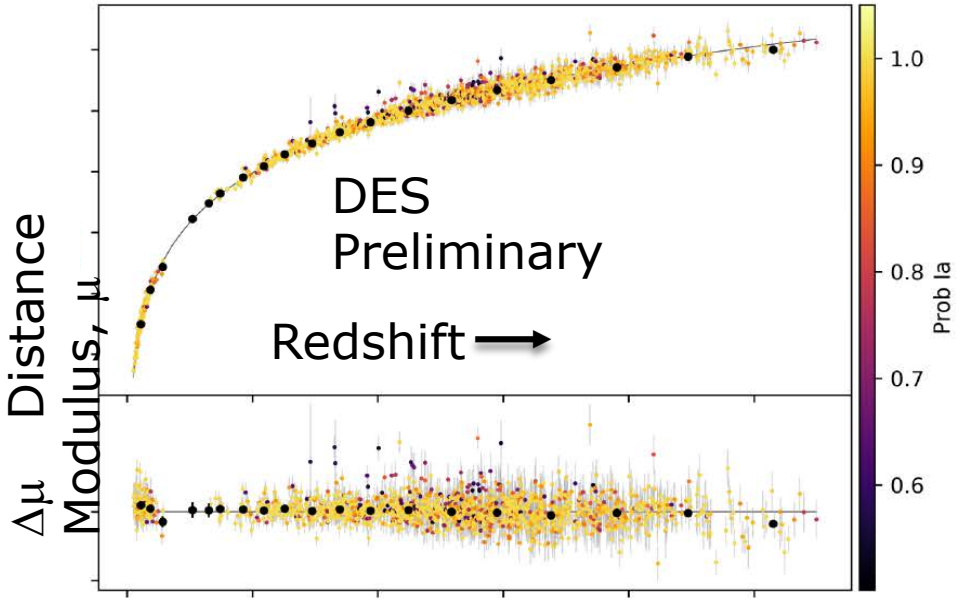
Now concentrating on Y3 "3x2pt" weak lensing, Y5 SN1a, and Y3 cluster cosmology analyses with Y6 cosmological results to follow

- **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.

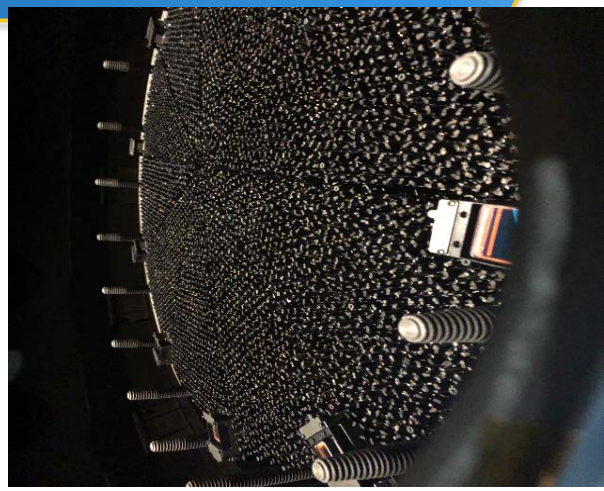




"3x2pt" Weak Lensing Analysis Y1-Y3 data

- 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 Dark Energy Spectroscopic Survey
- 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, Schedule:

- All imaging surveys for target selection completed (16,000 sq deg)
- Oct. 2019 First light; commissioning started
- March 2020: All project deliverables planned to complete
- July 2020: 5-year dark energy science survey starts

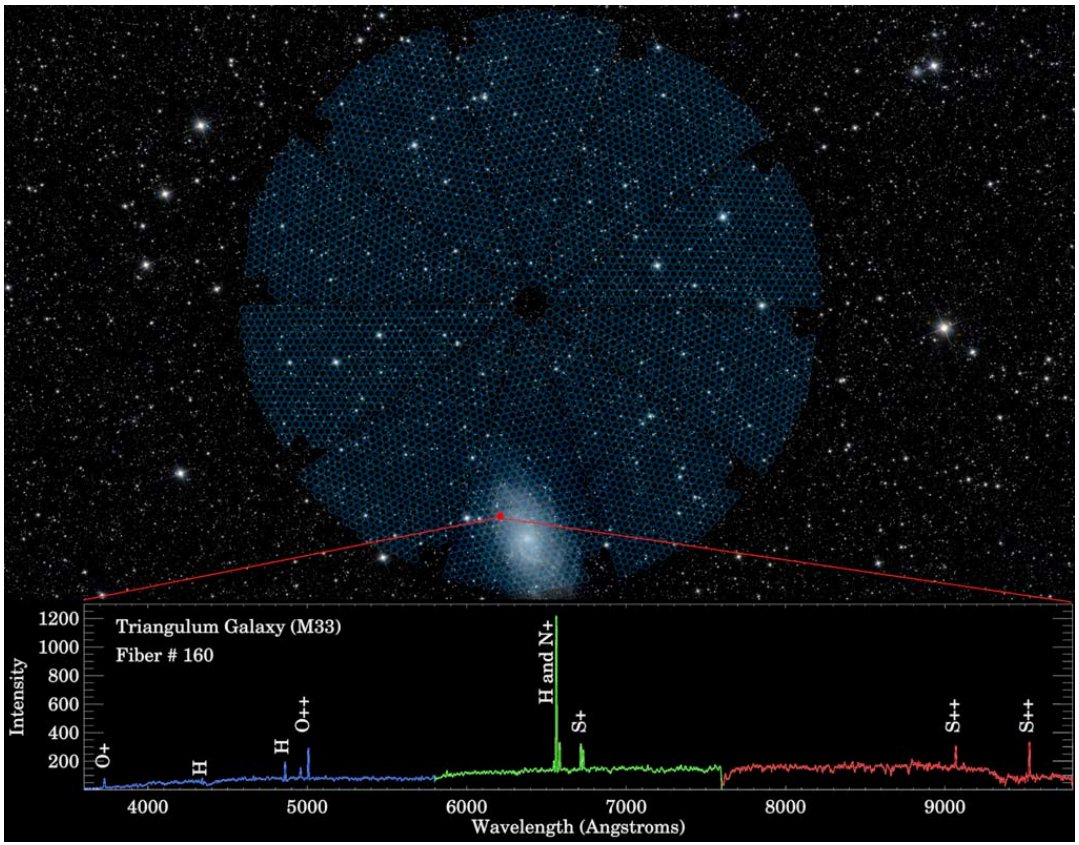
Science Highlight - DESI First Light

- **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.

- Commissioning is expected to last for 5 months, ending in March, 2020

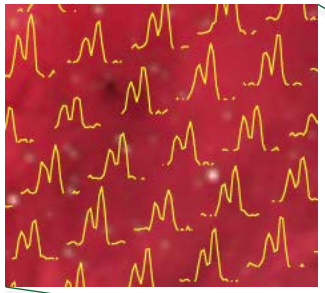
- Measured instrument performance so far surpasses requirements and expectations!

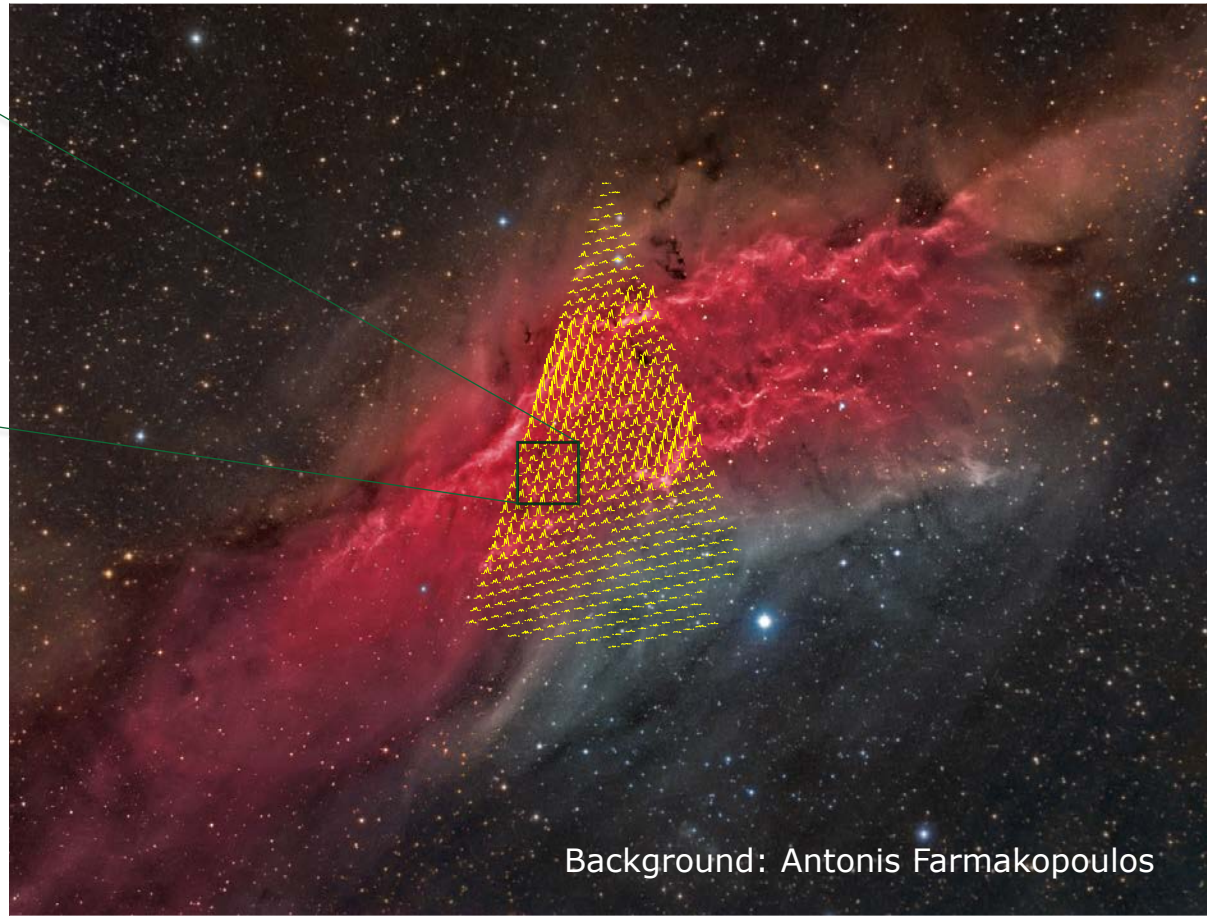
- **When DESI turns on, it will be the most powerful multi-object spectrograph on the planet.**



Science Highlight - DESI First Light

OII map of the California Nebula from 1st light



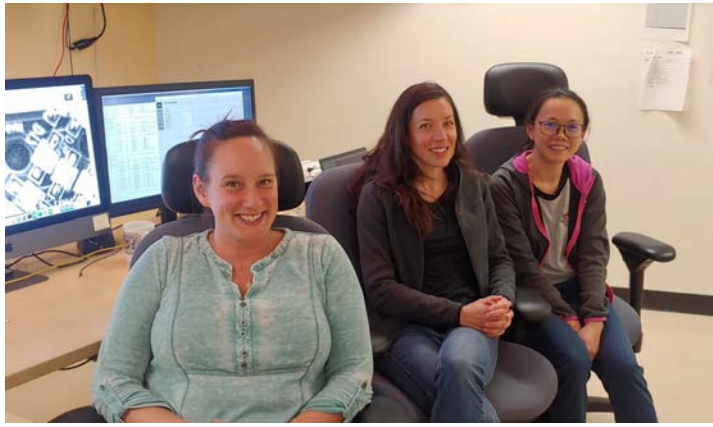


The OII oxygen emission-line doublet is a "signature" line that will be used for most of the DESI redshift mapping

DESI: Collaboration & Career Development

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 at Boston U).
- Code-of-conduct policy
- Diversity – DESI is 24% women scientists. LBNL technical staff on DESI is 15 men:15 women; Fraction is higher at early career
  - Diversity is improved by promoting Early Career Scientists, e.g. subsidized travel to meetings

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 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 are joint partners for the Project & Operations
- NSF roles led by AURA; DOE roles led by SLAC.
- Both agencies will support Research efforts.

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

Project:

NSF: 8.4m wide-field Telescope & Site, Data Management, EPO
DOE: 3.2 giga-pixel Camera with 9.6 sq deg field of view

Construction is going well & significant progress being made → ready for full science operations at start of FY2023.
- Continues to meet technical requirements in support of the Science Requirements Document
- Optimization of commissioning effort in progress
- Cadence optimization in planning

Rubin Observatory – Recent Photos

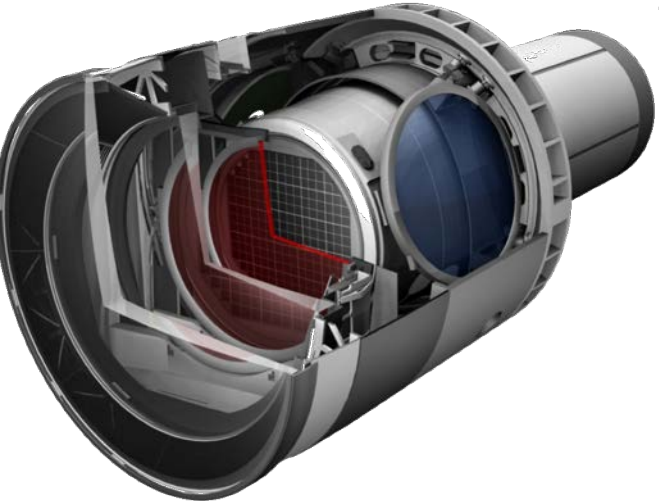
Telescope Mount factory tested & shipped to site.

Dome & Site progress

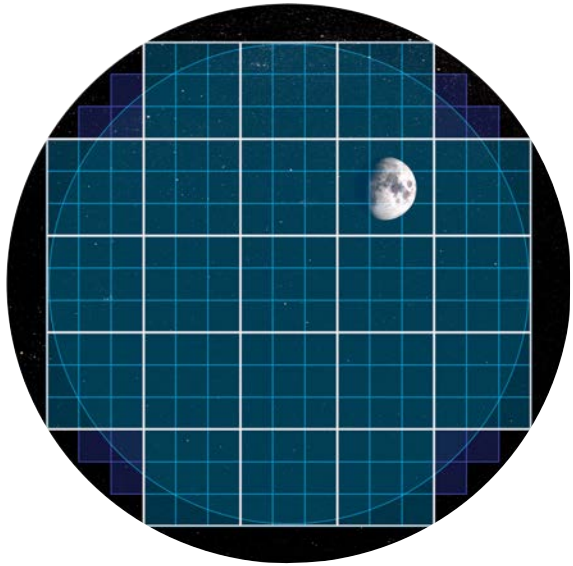
DOE Project & Commissioning: Roles & Responsibilities

LSST Camera Project: All MIE funding provided by FY18, TPC $168M
- MIE completes when Camera is integrated and tested at SLAC; Planned to complete April 2021 [Critical Decision 4 (CD-4) in March 2022]
- Currently 96% complete with adequate cost & schedule contingency

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 of entire observatory systems



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

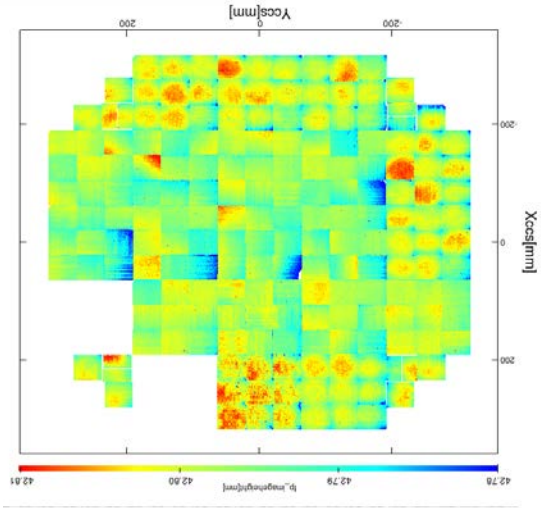


DOE LSST Camera - Status

Camera focal plane is nearly complete

Camera Lenses completed and at SLAC

Filter Exchange system was completed and tested in France and now at SLAC



As of 1/14/20, all 21 rafts installed!!

Rubin Observatory: Facility Operations

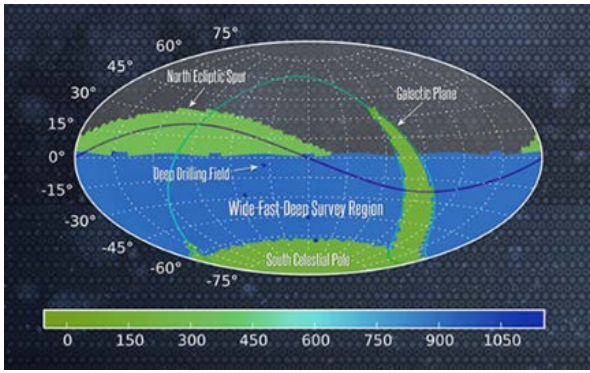
The Rubin Observatory will conduct a 10-year deep, wide, fast, optical imaging Legacy Survey of Space and Time (LSST) using DOE's LSST camera and the Simonyi Survey Telescope
→18,000 sq deg, 6 filter bands, ~ 1000 visits per sky patch
- Catalog of more than 20 billion galaxies & 17 billion stars with

- NSF and DOE funding for planning activities started ramp-up in FY19.

May 2019: DOE & NSF agree to provide ~ equal support for Operations.

Status:
Ops Team carrying out pre-operations planning and activities
- Investigating options for DOE & NSF scope, and to optimize resources

Data Policy: http://ls.st/LDO-013
Data Management Principle summary: http://ls.st/LPM-151



Upcoming:
- April 2020: Joint NSF/DOE Operations proposal review
- FY2023 - Full science operations starts

Rubin Observatory: Facility Operations In-kind planning

May 2019: DOE & NSF agreed to 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-kinds are designed to enhance US science, esp. LSST science

Process is underway:

- Operations team is carrying out process on behalf of NSF/DOE/AURA/SLAC
- Offsets to operations will be few (critical to operations)
- Community-based Contribution Evaluation Committee (CEC) will evaluate other in-kinds in coordination with LSST (SC chairs, at large).
- 40+ Letters of Interest (LOI) submitted 11/22/19 (~500 PIs). Iterating details as agencies review and consider those to move forward to next stage.
- Detailed proposals due March 2020.
- Goal: CEC recommendations by May 31, 2020, and team recommendations ready for NSF and DOE review June 2020.
- https://community.lsst.org/t/update-on-international-lsst-data-rights-and-in-kind-contributions/3903

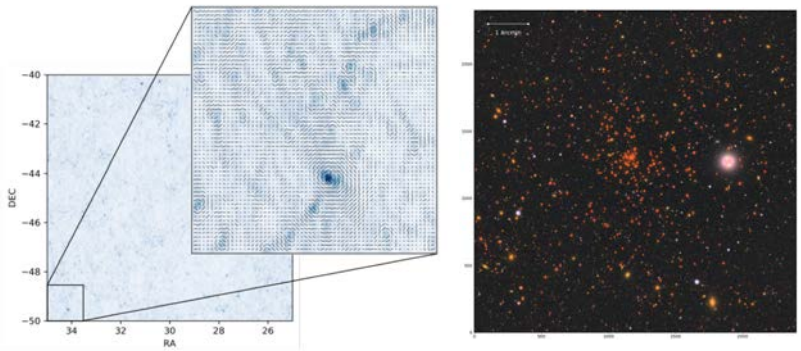
Agencies will make final decisions on international in-kinds and carry out (or delegate) the official agreements.

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

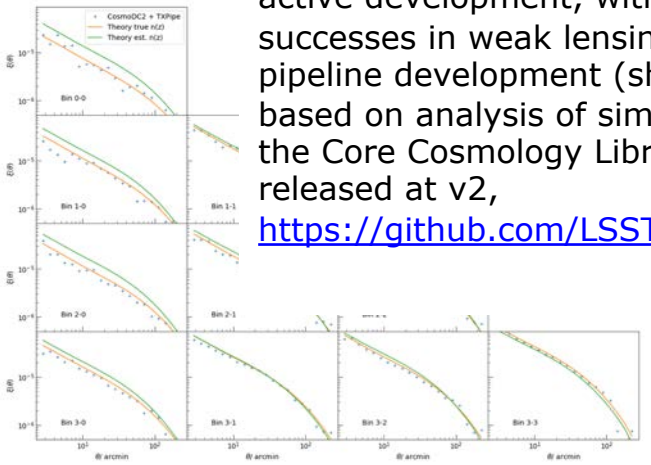
Large international collaboration, set up to carry out planning, preparations and eventual data analysis to make high accuracy measurements of fundamental cosmological parameters using data from the LSST. See www.lsstdesc.org

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

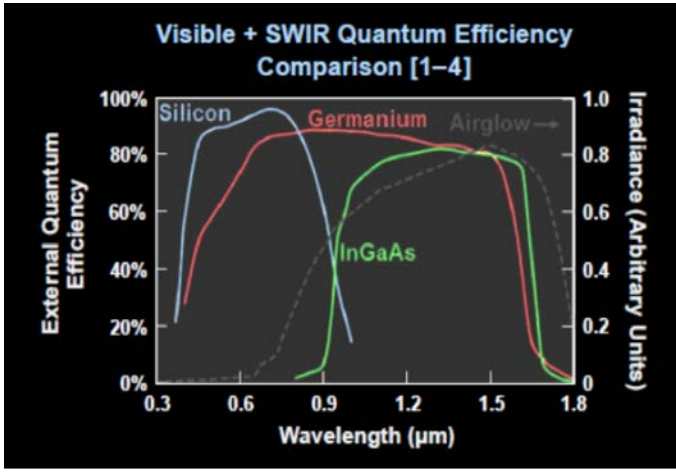
Power of a cosmic survey for precision measurements of cosmological parameters is limited by Redshift accuracy, Redshift range, Statistics

To fully exploit current program of ground- and space-based experiment will require advances in theory, 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

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



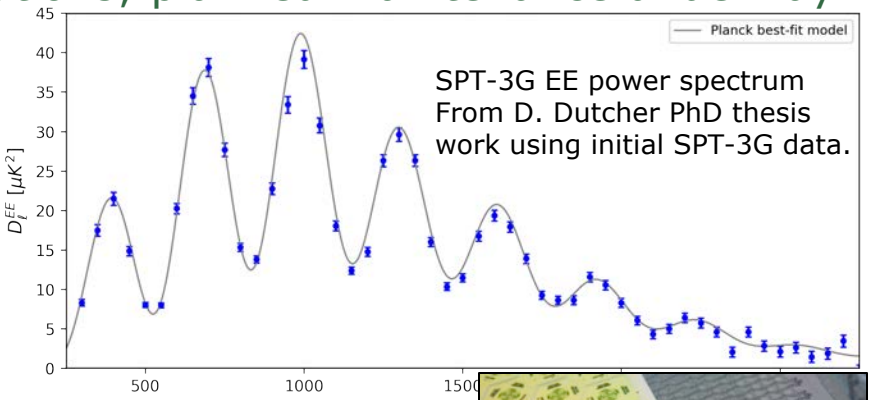
South Pole Telescope Generation 3 (SPT-3G)

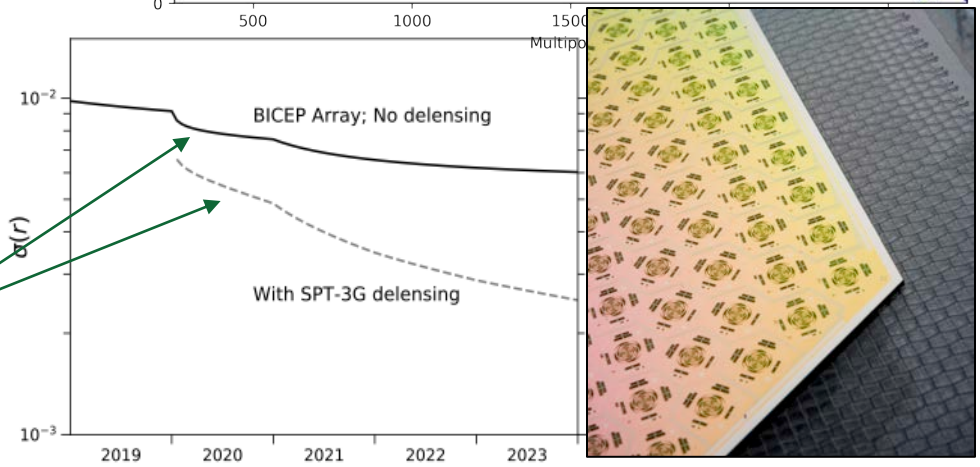
DOE-HEP partnership with NSF-OPP lead and NSF-PHY, NSF-AST

- HEP provided major upgrade of the camera to greatly increase sensitivity, 16,000 detector focal plane, and contributes to operations (led by ANL)
  - Science ops started 2018: 15,000 sq deg 5-year survey, deep survey with arcminute angular scales
  - Successfully 2019 Austral Winter observations; planned maintenance underway

<u>Science Goals</u>:

- Constraints on Dark Energy and Modified Gravity from CMB lensing and SZ effects
- Constrain properties of neutrinos and other light relics
- Search for evidence of primordial inflationary gravitational waves together with BICEP/Keck
- Tensor-to-scalar ratio r of sigma(r) ~ 0.0025. Without the SPT-3G data, the r limit would be limited by lensing at over a factor of two higher.

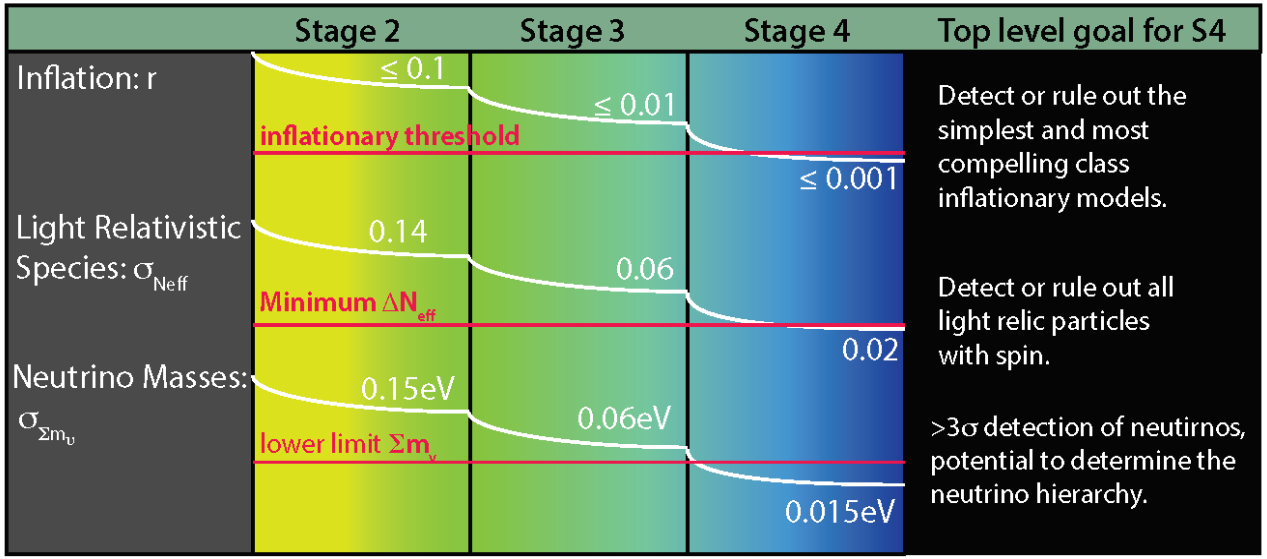




Cosmic Microwave Background Stage 4 (CMB-S4) project → discovery science!

P5: Recommended CMB-S4 in all funding scenarios

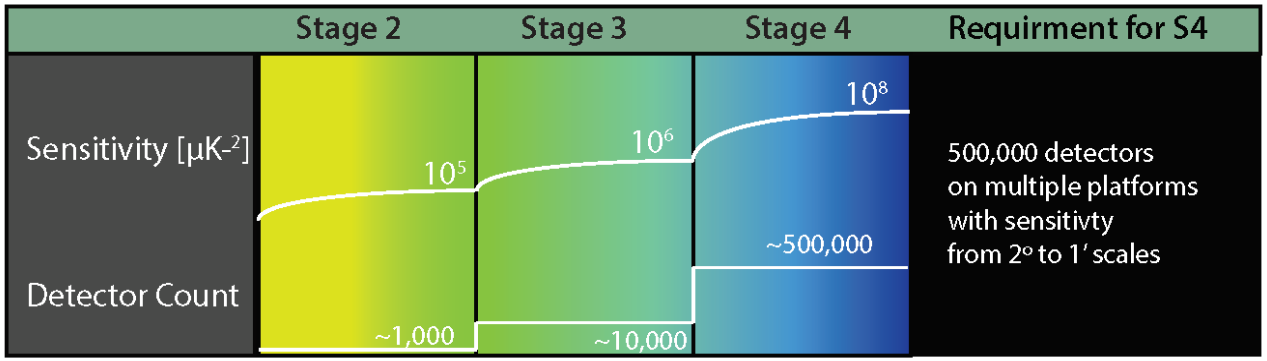
The goal: cross critical science thresholds (red lines)



Inflation

New particles

Neutrino mass

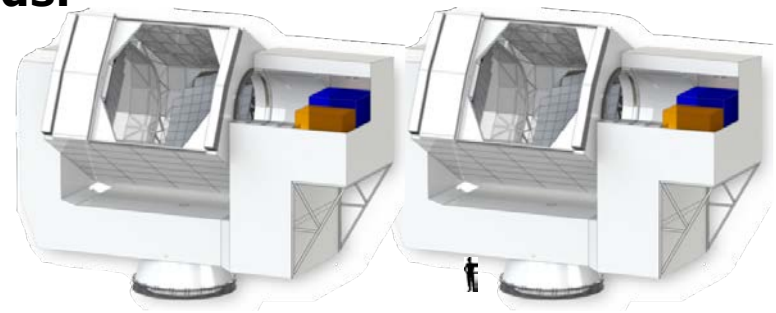


Sensitivity for discovery
- x100 increase

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: DOE and NSF

CMB-S4 proposed as a single ~$600M TPC project multiagency project
- Building and operating microwave telescopes at South Pole and Chile
- As recommended by P5 (2014) and AAAC/CDT (2017)

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

Agency Joint Oversight Group (JOG) set up; meetings continue; working to synchronize DOE and NSF processes

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 awarded 2-year MSRI-R1 to U. Chicago (Sept 2019) to begin work on Preliminary Design

NAS Astro2020 Decadal Survey
- July 2019 submission of White Paper
- Fall 2019 Astro2020 requested RFI, submitted, Q&A scheduled for Feb 4, 2020

Proposed timeline DOE CD-1/3a and NSF-PDR in 2021; DOE is working to support this plan.

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

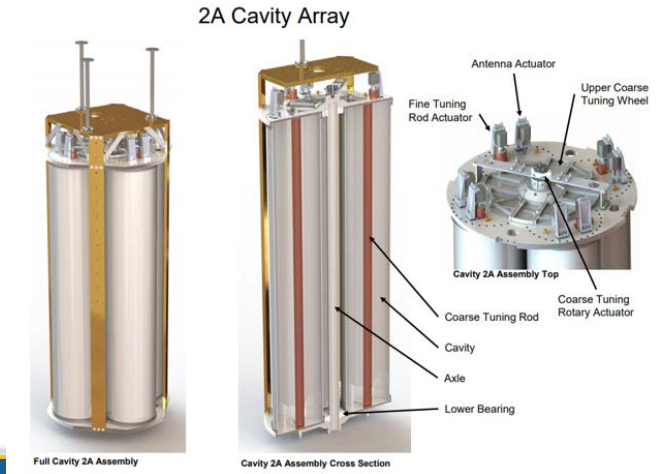
Stage 2 Direct Detection Dark Matter Axion Search

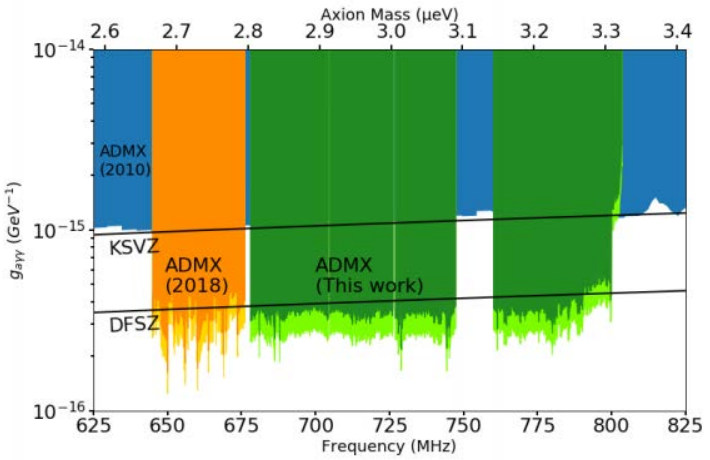
DOE-HEP experiment located at Univ of Washington; Managed by Fermilab; contributions by UK, Germany, Australia and private.

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

Currently: Run 1B (680-800MHz) analysis submitted; Run 1C (800-1020 MHz) continues; Run 2 Cavities and cold electronics under development.

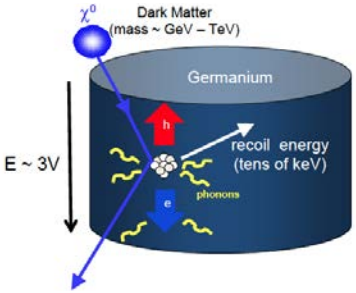




Super Cryogenic Dark Matter Search at SNOLab (SuperCDMS SNOLab)

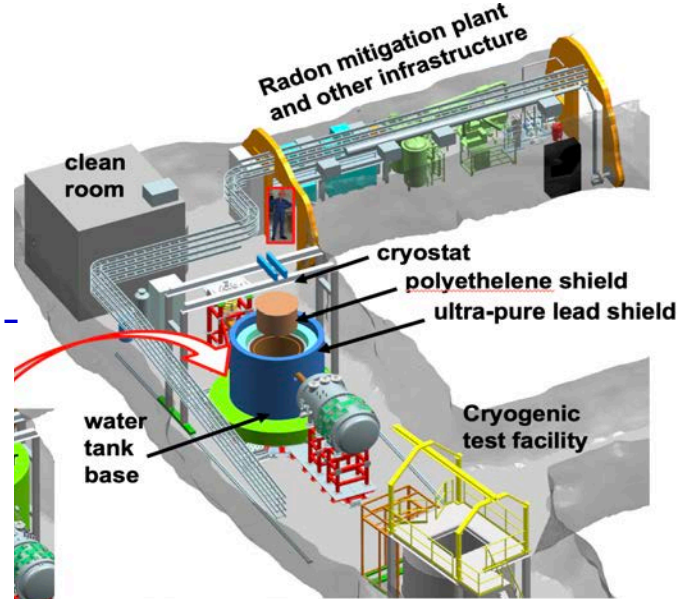
Stage 2 Direct Detection Dark Matter WIMP Search.
HEP and NSF/PHY project, with contributions from Canada (CFI, NSERC).

- 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 Status:

- MIE Project currently in fabrication (led by SLAC, significant effort by FNAL and 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).
- All Deliverables complete planned for March 2021; CD-4 9/21; 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

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

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

Project Status, Schedule

- MIE Project, currently in fabrication
- TPC (HEP) $55.5M; All funding provided by FY19
- Installation, commissioning in progress.
- All Deliverables planned to complete Aug. 2020; CD-4 March 2022
- Operations planning & pre-ops activities ongoing

Outer Detector delivery expected Feb.2020

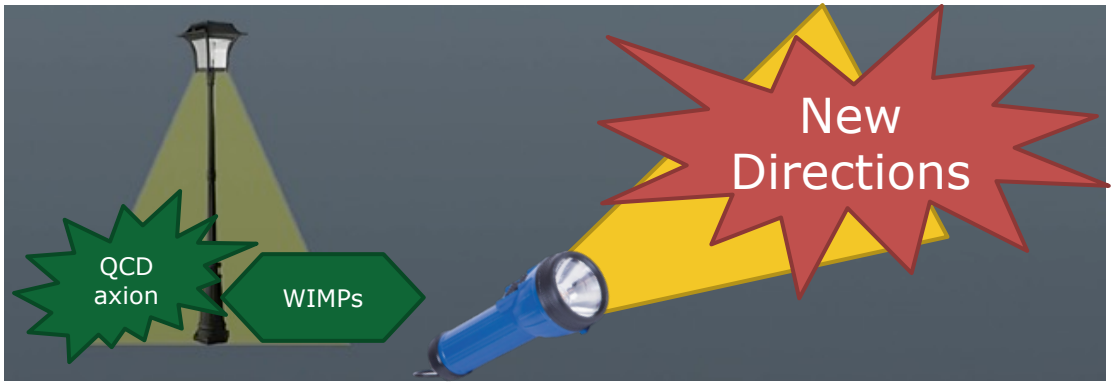
TPC/ICV inside OCV in water tank (Dec. 2019)

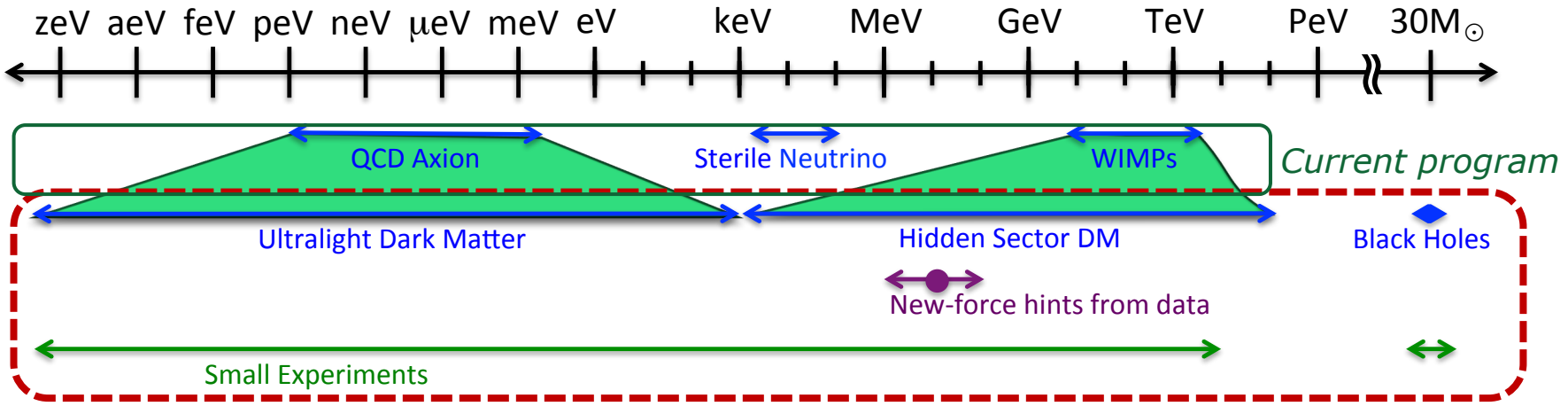
Dark Matter Searches - New Opportunities

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

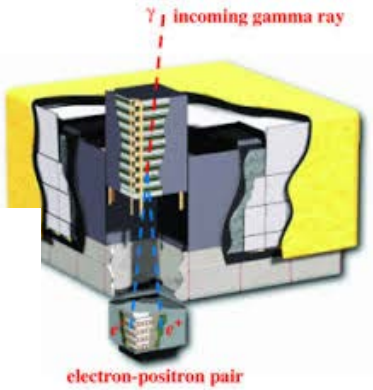
Dark Matter New Initiatives for Small Projects – Timeline & Funded Proposals

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

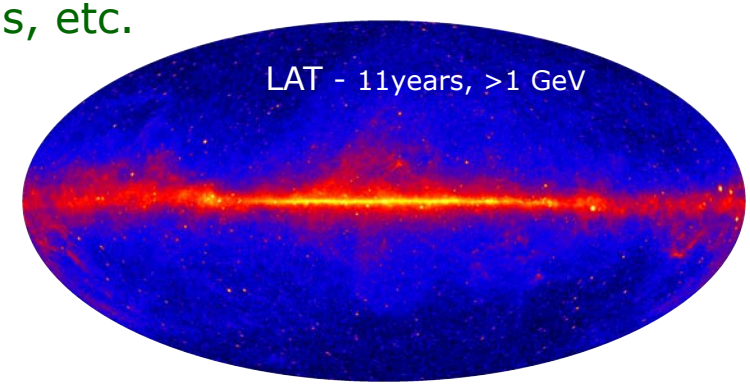
- 2017 Community Workshop -> White paper at https://arxiv.org/abs/1707.04591
- 2018: Basic Research Needs (BRN) study which led to 3 Priority Research Directions (PRD) in Dark Matter. See https://science.energy.gov/hep/community-resources/reports/
- FY19: Funding Opportunity Announcement (FOA); Four proposals selected to develop concept and execution plans for potential small projects. 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**

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.

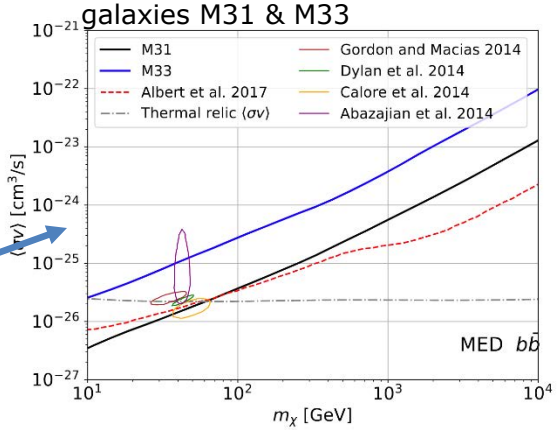
Science: Study high-energy (~20 MeV->300 GeV) gamma-rays using particle physics detector technology in space. Indirect Dark Matter (DM) detection; high-energy acceleration mechanisms, etc.



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

Dark matter limits from Local Group galaxies M31 & M33



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

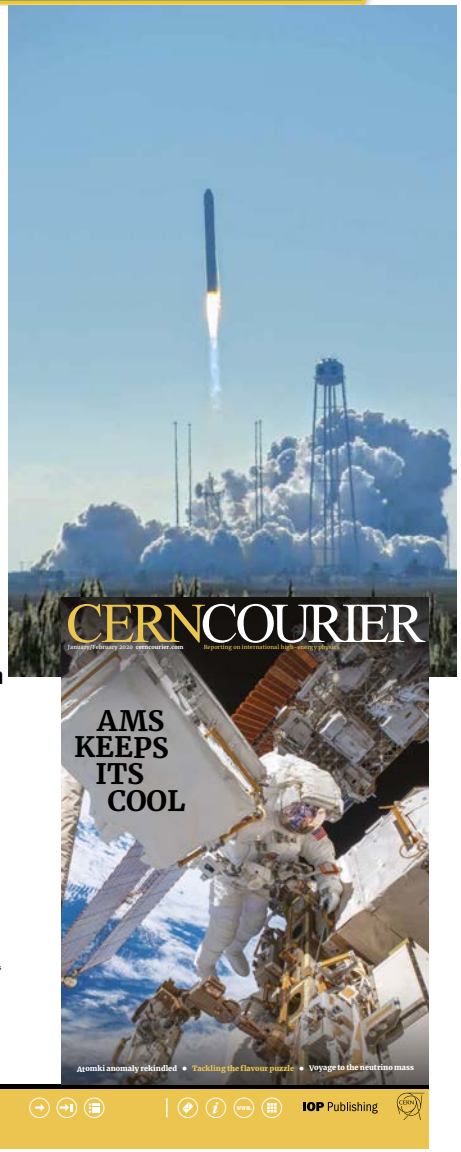
Alpha Magnetic Spectrometer (AMS-02)

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;

Status: Launched in May 2011 and installed on International Space Station (ISS)
Dec.2019: Launch & 4 astronaut EVAs to replace cooling pumps, allows continued operations through end of the decade.

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



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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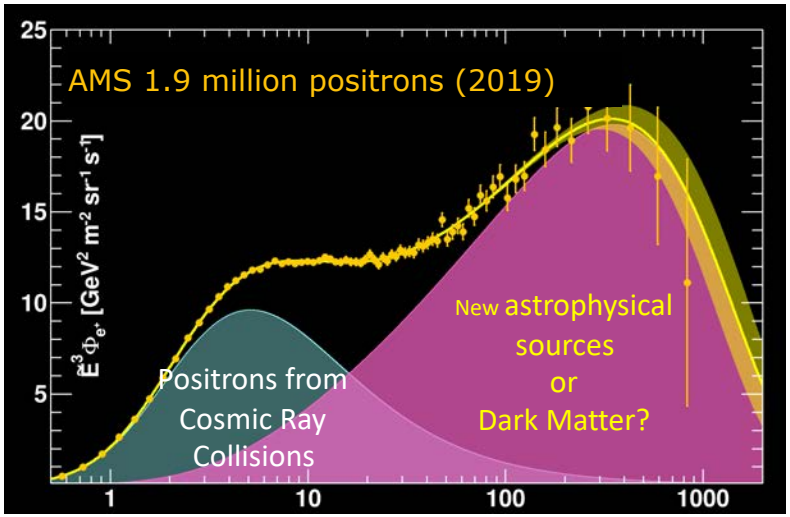
http://comms.iop.org/k/iop/cerncourier

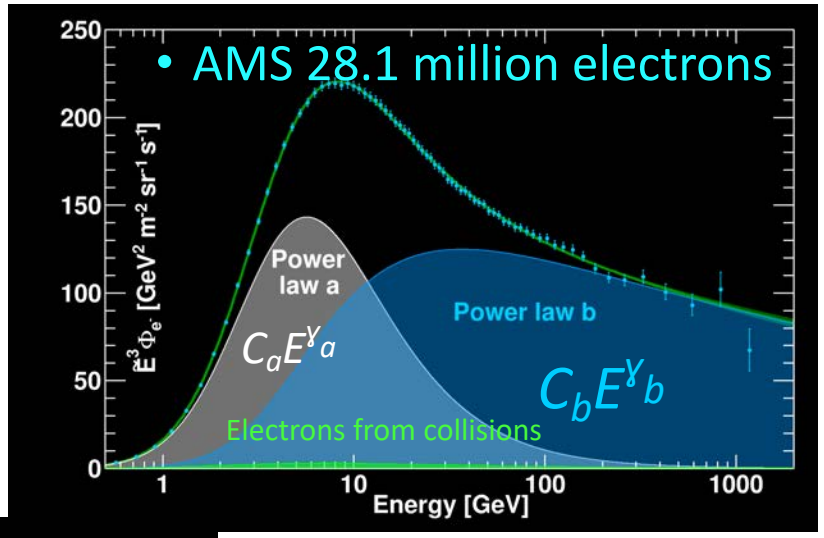
To subscribe to the magazine, please visit:
https://cerncourier.com/p/about-cern-courier

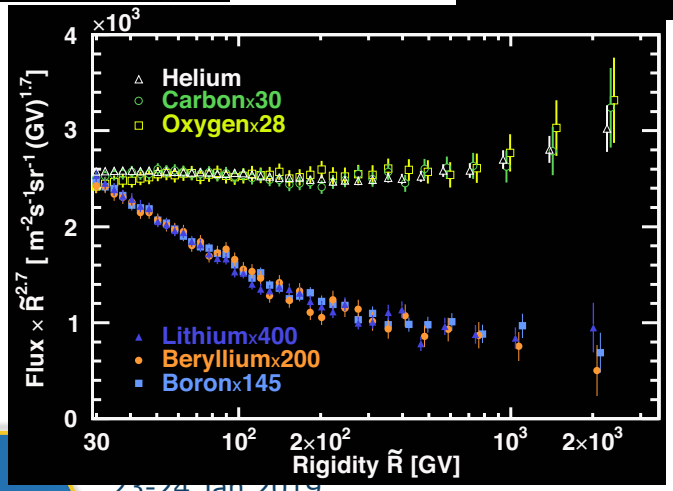
Science Highlight - Alpha Magnetic Spectrometer (AMS-02)

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.**







Above 30 GeV, the primary cosmic rays have identical rigidity (P/Z) dependence and Secondary cosmic rays Li, Be, and B also have identical rigidity dependence but they are different from primaries.

High Altitude Water Cherenkov (HAWC)

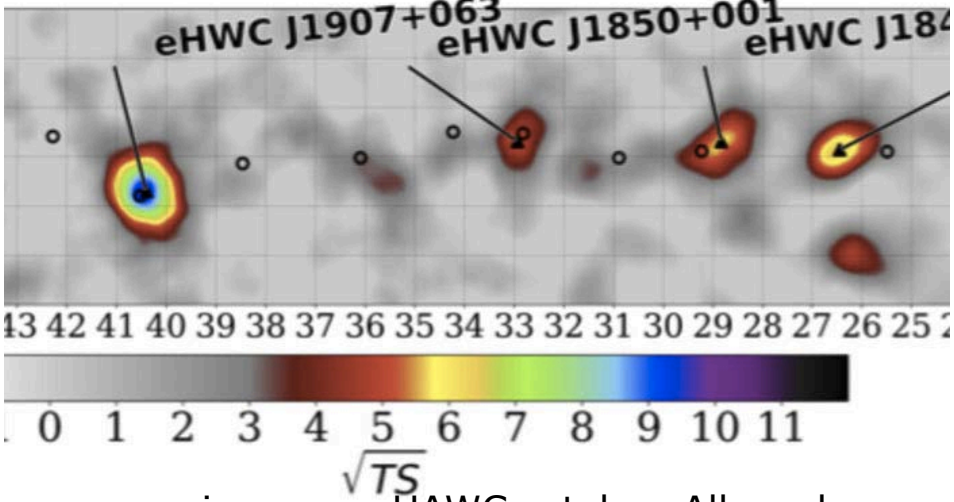
Gamma/cosmic-ray observatory located on the Sierra Negra in Mexico: Water Cherenkov Air Shower Detector, now with Outrigger array

- 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.

Jan.2020, 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



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.

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Other Efforts & SUMMARY

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. (**See talk at HEPAP, 5/31/19)**
- 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

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
- FY2020 Budget Request includes funds in HEP, BES (Basic Energy Sciences), and ASCR (Advanced Scientific Computing Research) for at least one jointly-supported and multidisciplinary QIS Center, as per the National Quantum Initiative Act (Dec 2018)

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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