U.S. DEPARTMENT OF ENERGY | Office of Science

Office of High Energy Physics (HEP) Program

Astronomy & Astrophysics Decadal Survey (Astro2020)

Radio, Millimeter, Submilliter (RMS) Meeting

Nov. 6, 2019

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Office of High Energy Physics

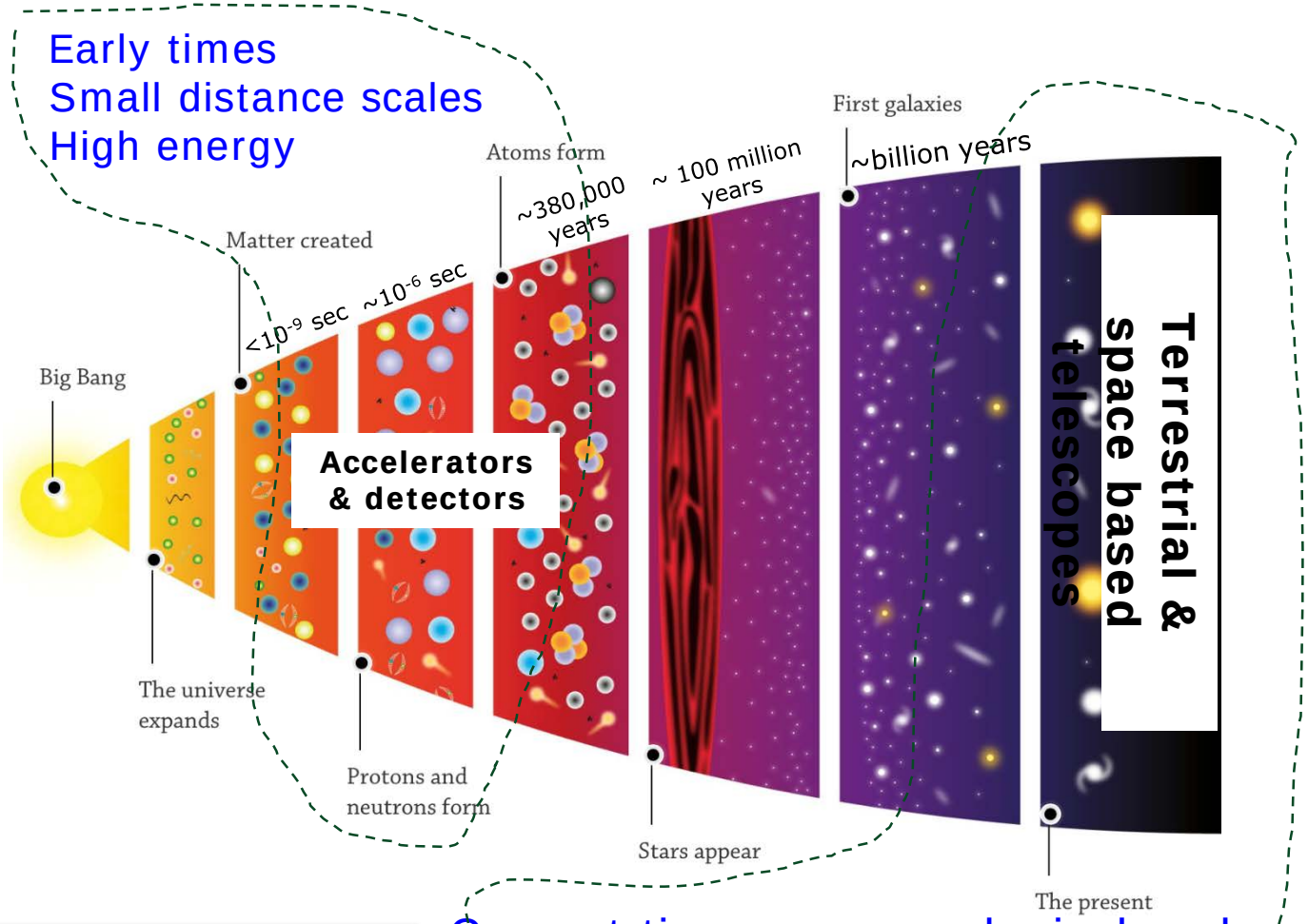
OUTLINE

- Astro2020 study
- DOE, SC, HEP Mission
- Program Guidance
- Strategic Plans, Reports
- Partners, Coordination
- Program Execution
- HEP Budget
- Cosmic Frontier Program, Budget
- Astro2020: CMB-S4
- Astro2020: Dark Energy
- Related Efforts
- Summary

Total Solar Eclipse over
Cerro Pachon, July 2, 2019
Photo: K. Reil LSST/DOE/SLAC

From Quarks to the Cosmos

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



Astro2020 – Statement of Task

NASA, NSF and DOE worked together to deliver a statement of task (SOT) to the National Academy of Sciences for Astro2020 (https://sites.nationalacademies.org/DEPS/Astro2020/DEPS_192912)

- Identify the most compelling science challenges and frontiers in astronomy and astrophysics, which shall motivate the committee's strategy for the future
- Develop a comprehensive research strategy to advance the frontiers of astronomy and astrophysics for the period 2022-2032…
  - …For each recommended activity the committee will lay out the principal science objectives and activity capabilities, including assumed or recommended activity lifetime.
- Utilize and recommend decision rules…

HEP & Astro2020 Considerations

➔Guidance from Astro2020 will inform HEP on

- Compelling, high impact science directions and research strategies
- Opportunities that HEP can consider for contributions, including*:
  - select, high impact experiments with discovery potential
  - that address HEP science goals
  - where DOE HEP researchers and investments can play a significant role in & make unique, significant & necessary contributions
- Potential partnerships with NASA, NSF & international collaborators

DOE/HEP & our community are always looking for high scientific impact opportunities that align with our science goals & make use of capabilities.

** These are the 2009 HEPAP/PASAG report criteria*

HEP & Astro2020 Guidance

Asking for Guidance on:

- *Science justification and directions*
- *Technical specifications to achieve science*
- *Priorities across Astro2020 areas*
- *Why HEP is needed for participation*

Not asking for detailed:

- *Project designs*
- *Prescriptions for how the agencies should split scope, funds.*

***Astro2020 recommendations** – Depending on the opportunity*

- *Larger or longer term efforts will need to feed into the next P5 process to consider priority within larger HEP program.*
- *Smaller or near term efforts may be addressed without going to P5.*

➔When making recommendations, consider the FULL needs, i.e.

Research / Scientist support, Project Design and Fabrication, Experimental Operations, Computing resources, Technology development and readiness, Data Analysis, etc.

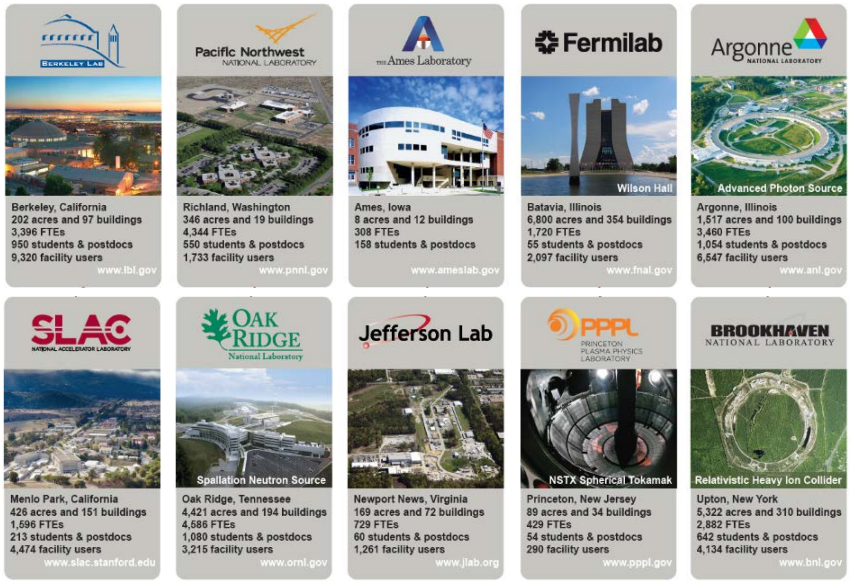
Mission of the Department of Energy (DOE) & its Office of Science (SC)

DOE's mission: ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions. The mission includes **maintaining a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.**

- **SC mission: deliver the scientific discoveries and major scientific tools that transform our understanding of nature** and advance the energy, economic, and national security of the U.S.

SC & its Program Offices provide:

- Science leadership & support to enable significant advances in specific areas
- Development & support of a portfolio of facilities & experiments to obtain science
- **Laboratory System** for comprehensive resources and infrastructure to design, build, operate selected facilities & projects & tech R&D
- Interagency & International partnerships leverage additional science & expertise



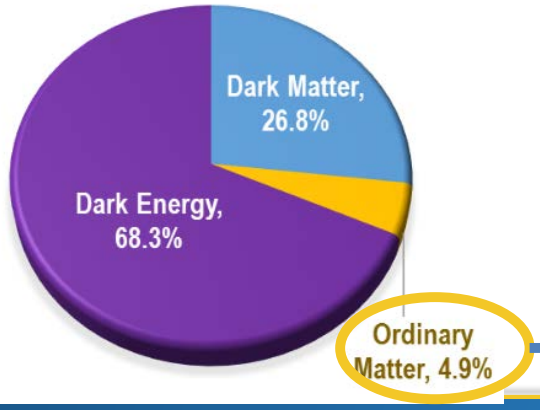
DOE/SC Office of High Energy Physics (HEP) Program Mission

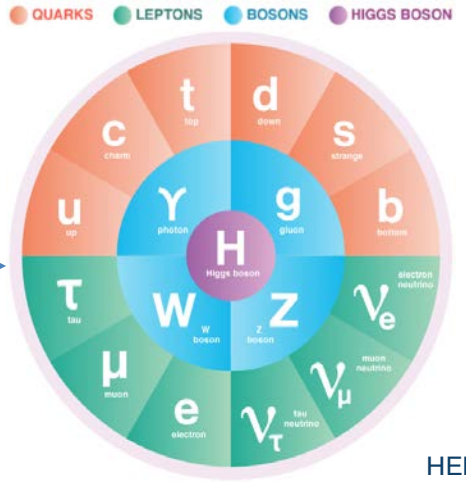
Mission: understand how the universe works at its most fundamental level → Explore the Standard Model of Particle Physics

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

HEP fulfills its mission by

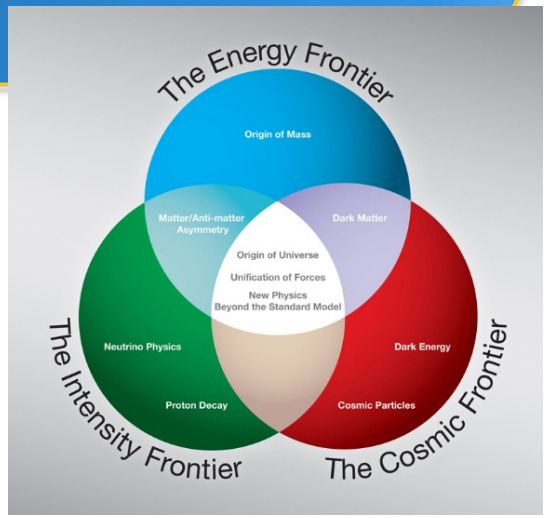
- Building **projects** that enable discovery science
- Operating **facilities and experiments** that provide the capability for discoveries
- Supporting a **research program** to produce discovery science





→ Explore nature all the way up to the Grand Unification and back to the Big Bang.

DOE, Office of Science (SC), Office of High Energy Physics (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**

→ HEP's 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)

HEP additional funding areas to fully carry out the program:

- Theoretical research
- High Performance Computing → Exascale; Machine-learning
- State-of-the-Art Detector and Accelerator technology development
- Quantum Information Science (QIS) is a quickly-growing area.

HEP Program Advice, Guidance

Official Advice: Federal Advisory Committee Act (FACA)

High Energy Physics Advisory Panel (HEPAP)

- Advises **DOE & NSF**: Provides the primary advice for the HEP program; Subpanels:
  - 2009 Particle Astrophysics Science Advisory Group **(PASAG),** Strategic Plan
  - 2014 Particle Physics Project Prioritization Panel **("P5"),** 10-year Strategic Plan

Astronomy and Astrophysics Advisory Committee (AAAC)

- Advises **DOE, NASA, & NSF** on issues of overlap, mutual interest and concern
- Subpanels: CMB-S4 Concept Definition Taskforce (2017)

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

- Decadal Surveys: **Astro2010, Astro2020**, Elementary Particle Physics
- Board on Physics & Astronomy (BPA), Committee on Astronomy & Astrophysics

Community Studies & Input

- Snowmass, APS/DPF
- Basic Research Needs (BRN) studies provide focused HEP science or technology or directions to support initiatives

History of Reports – feeding into DOE HEP Cosmic Frontier planning

NOTE: List of reports (most likely!) not complete, esp. before 2010

2004 HEPAP - Scientific Assessment Group for Experimental Non-Accelerator Physics (SAGENAP)
2006 AAAC - Task Force for CMB Research (TFCR)
2006 AAAC - Dark Energy Task Force (DETF)
2006 NAS - Elementary Particle Physics 2010 (EPP2010)
2007 NAS - Beyond Einstein: An Architecture for Implementation
2007 AAAC - Dark Matter Science Assessment Group (DMSAG)
2008 HEPAP - Particle Physics Project Prioritization Panel (P5)
2009 HEPAP - Particle Astrophysics Science Assessment Group (PASAG)
2010 NAS - Astro2010 NWNH (New Worlds New Horizons)
2012 AAAC - Dark Energy Task Force (Rocky III)
2013 APS/DPF Snowmass report, Planning the Future of Particle Physics
2014 HEPAP - Particle Physics Project Prioritization Panel (P5)
2017 AAAC - CMB-S4 Concept Definition Taskforce
2018 HEPAP HEP Portfolio Review of Operating Experiments
2018 AAAC – Gemini-Blanco-SOAR subpanel
2019 Community Basic Research Needs (BRN) study of new directions in dark matter research

HEPAP / PASAG Report – Oct. 2009

Guidance:

- **Dark energy** funding (recommended for largest budget portion) should not significantly compromise US leadership in dark matter, where a discovery could be imminent
- **Dark energy and dark matter** together should not completely zero out other important activities (except in the lowest funding scenario - **even then a limited CMB participation is recommended**)

HEP Objectives in Planning following PASAG:

The report helped define the HEP Cosmic Frontier and set priorities and scientific deliverables for the future. **Dark Matter (DM) and Dark Energy (DE) remain the highest priorities in this area.**

- Follow **PASAG Criteria** & make contributions to:
  - select, high impact experiments with discovery potential
  - that address particle-astrophysics and cosmology goals
  - where DOE HEP researchers and investments can play a unique, significant role in and make significant contributions
- Achieve earliest, best, and most cost-effective U.S. DE & DM science results
- Partnerships with NASA and NSF and international collaborators as appropriate

2009 PASAG Report: Prioritization Criteria for participation by the HEP Program →

The science addressed by the project is necessary

- Addresses fundamental physics (matter, energy, space, time).
- Anticipated results: either at least one compelling result or a preponderance of solid, important results. Check that anticipated results would not be marginal, either in statistics or in systematic uncertainties, relative to the needed precision for clear science results.
- Discovery space: large leap in key capabilities, significant new discovery space, and possibility of important surprises.

HEP / Particle physicist participation is necessary

- Transformative techniques and know-how to have a major, visible impact; project would not otherwise happen.
- Leadership efforts are higher priority than participation
- The particle physics community participation brings needed expertise in terms of science, technology, or computing, etc.

Scale matters, particularly for projects at the boundary between particle physics, cosmology and astrophysics.

- Relatively small projects with high science per dollar help ensure scientific breadth while maintaining program focus on the highest priorities.

Programmatic issues: International context: cooperation vs. duplication, competition.

Astro2010 "New Worlds New Horizons" Report (August 2010) → DOE/HEP Guidance, Response

NWNH recommended a coordinated Dark Energy program

- Highest priority large project in space: WFIRST (DOE, NASA)
- Highest priority large project on ground: LSST (DOE, NSF)

Specific Recommendations to DOE:

- The optimistic (doubling) funding profile allows investment in:
  - **LSST** – DOE should partner with NSF
  - **WFIRST** – DOE should contribute to the NASA mission
- At lower funding (constant with inflation) level:
  - **LSST** is recommended as the priority because DOE role is critical

"In lower scenarios, DOE should participate in LSST ahead of WFIRST since DOE is making a larger relative $ contribution and its technical role is thought to be relatively more critical".

Astro2010 "New Worlds New Horizons" Report (August 2010) → DOE/HEP Guidance, Response, cont.

Other identified opportunities:

- **Contributions to NSF mid-scale experiments (2nd priority in ground-based)** e.g. BigBOSS, CMB, HAWC experiments, etc.
- **NSF & DOE contribute as a minor partner (4th priority in ground-based)** to a European-led AGIS/CTA ground-based gamma-ray observatory
- **CMB:** technology program to advance detection techniques"
- Joint Agency competed **Research Networks in Theoretical and Computational Astrophysics program** ($2M/year DOE)

"DOE may have opportunities to contribute to mid-scale ground-based projects with NSF (ground priority #2), and should contribute to ACTA with NSF and to the Theory & Computation Network (TCN). These smaller programs and ACTA have lower priority than LSST & WFIRST."

➔**Following the report, NSF and DOE moved forward on a LSST partnership.** DOE later began development of the DESI project (previously "BigBOSS").

HEPAP P5 Strategic Plan (2014)

As a mission agency, HEP uses community-driven strategic planning to identify the science priorities and projects that provide significant leaps in science & capabilities

- 2013: APS-DPF led community scientific input ("Snowmass")
- 2014: HEPAP P5 Subpanel report

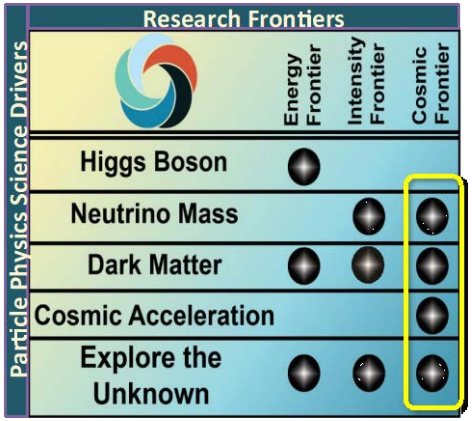
Particle Physics Project Prioritization Panel ("P5") 2014 strategic plan:

- provided the critical scientific questions
- recommended a portfolio of facilities and projects in Energy, Intensity, Cosmic Frontiers to optimally address the science within realistic constraints; also investments in Theory, Detector R&D, Accelerator R&D
- 10 year plan, with 20 year vision; in several funding scenarios
- Balanced across frontiers, projects size, short and long term

➔Enables discovery science with deeply intertwined U.S. and international efforts

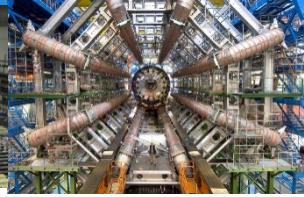
2014 P5 Report: Strategic Plan & Science Drivers

HEP Community support of the P5 process is a critical element of its success



https://www.usparticlephysics.org/wp-content/uploads/2018/03/FINAL_P5_Report_053014.pdf

2014 P5 Strategic Plan



Energy Frontier

Continue strong collaboration in the Large Hadron Collider (LHC) including the High-Luminosity LHC accelerator and detector upgrades - highest priority near-term large project:

- Complete "Phase-1" (2018) upgrades of ATLAS and CMS experiments
- Continue collaborations with the "Phase-2" (High-Luminosity LHC, 2023-25) upgrades of the accelerator and the ATLAS and CMS experiments

Intensity Frontier

P5 recommended substantial investments in the U.S. neutrino program

- Develop a world-leading neutrino program with U.S-hosted (Fermilab) Long-Baseline Neutrino Facility (LBNF) Deep Underground Neutrino Experiment (DUNE) as the centerpiece. The Proton Improvement Plan II (PIP-II) program of updates to the accelerator complex, will provide proton beams with power >1 MW by the time of first operation of the new LBNF.
- Develop, with international partners, a coherent short- & long-baseline neutrino program at Fermilab.

Cosmic Frontier

P5 recommended significant investments in:

- **Dark Energy: build LSST & DESI (affirmed Astro2010 recommendations)**
- **Dark Matter: direct detection search suite of "generation 2" experiments (DM-G2)**
- **CMB: support as part of the core program within multi-agency context; carry out multi-agency CMB-S4 project**

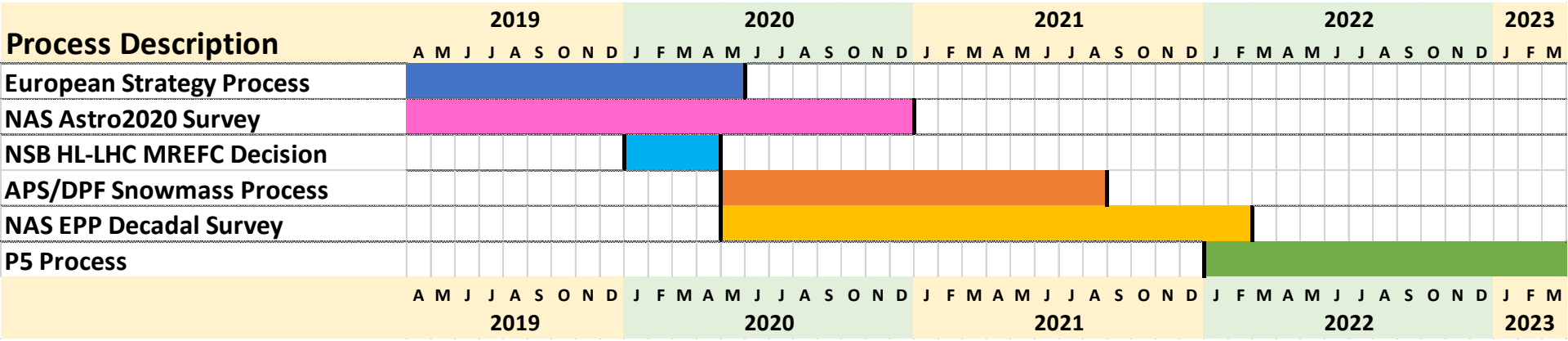
Advanced Technology R&D Strategy

- Leadership role in superconducting magnet technology to increase performance and decrease costs
- Accelerator R&D with a focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term accelerators
- Focus resources toward directed detector instrumentation R&D in the near-term for high-priority projects
- Reassess the Muon Accelerator Program, in consultation with international partners

Strategic Planning Timeline – Next Phase

- **The timeline of processes that impact the next strategic plan:**
  - 2018-20: NAS Astronomy and Astrophysics Decadal Survey for 2020
  - 2019: Start of European Strategy for Particle Physics process
  - 2019/20: Anticipated Japanese decision on ILC
  - 2020: Release of updated European Strategy for Particle Physics
  - 2020: Earliest opportunity for National Science Board to approve obligating HL-LHC MREFC

- **From a DOE perspective, the earliest that new APS/DPF Snowmass, NAS Elementary Particle Physics Decadal Survey, and P5 strategic plan processes could begin is 2020**
  - **Relative timing of Snowmass, P5, and NAS EPP Decadal Survey to be determined**
  - **Enables receiving next P5 recommendations by March 2023, in time to inform FY 2025 budget formulation**



Partnerships, Coordination

Particle Physics is Global!

- Form partnerships or use other agency's/country's facilities when needed
- Most HEP projects have international partners or contributions; also private funds

Interagency Planning & Coordination

With NSF (NSF-AST, -PHY, -OPP)

- Regular and focused meetings
  - Joint Oversight Group (JOG) or Joint Coordination Group (JCG) meetings and close coordination of planning for particular projects or experiments.
  - Joint reviews and/or invited to each other's reviews, program planning
  - Agreements (e.g. MOUs) as appropriate

With NASA - Meetings and coordination as needed; similar to NSF

Three Agency Group (TAG) – DOE, NASA, NSF-AST meetings on LSST, WFIRST, Euclid coordination

International: Agency to Agency level agreements and regular meetings

- International Resource Committees support coordination of needs & resources
- Astro-Particle International Forum (APIF) – Agency-level

Program Execution, Priorities

DOE is a mission-oriented agency→
The **science drivers** and **projects** are selected by the (P5) community-based strategic plan that will provide significant leaps in science. Then we **support the community to carry out** these projects/experiments.

- **The priority is to support efforts directly in line with HEP program & project priorities, responsibilities & science goals**
- HEP model is for a science collaboration to carry out experiment in all phases to deliver the best science results.

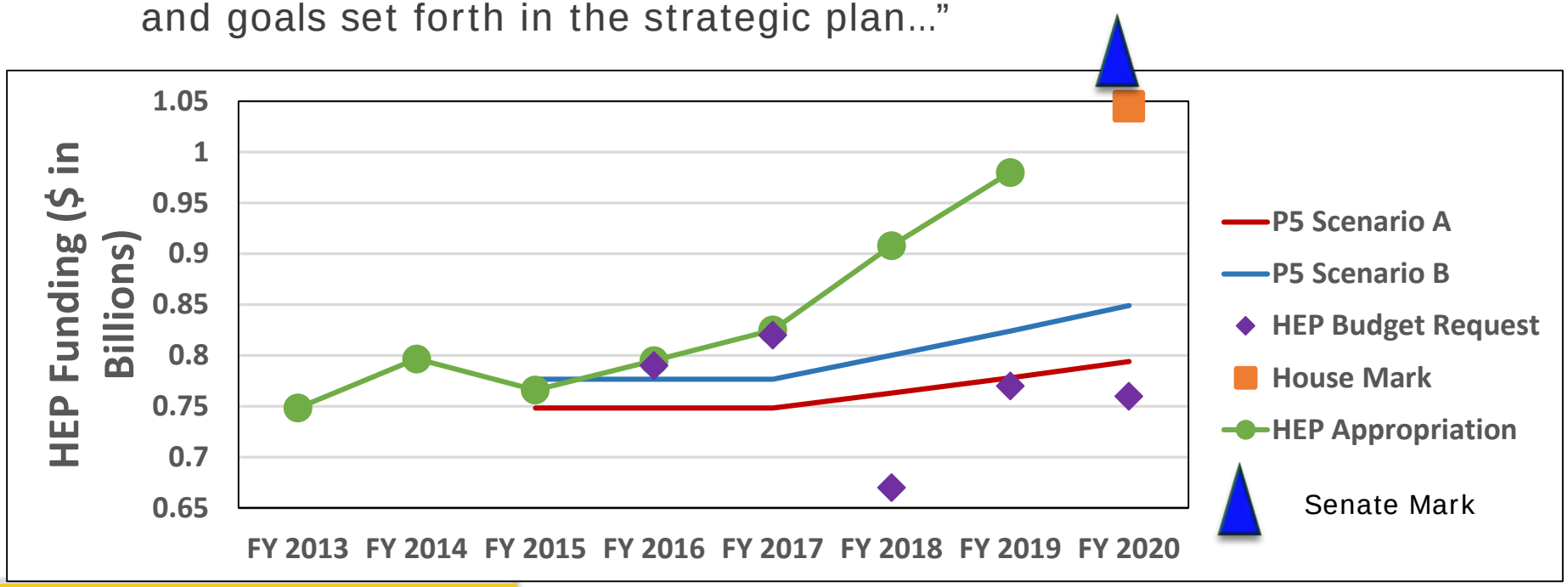
All types of funding, efforts and phases need to be considered:

- Research funds to support scientists all phases
- Project Design, Fabrication, Experimental Operations
- Technology development and readiness
- Computing needs and availability
- Data planning, analysis

DOE/HEP is not a unique supporter of HEP science goals; but HEP community does bring some particular scientific expertise and technical resources.
→Especially for the Cosmic Frontier, the **2009 HEPAP/PASAG report criteria** guides determination of where, and at what level HEP participates in specific projects

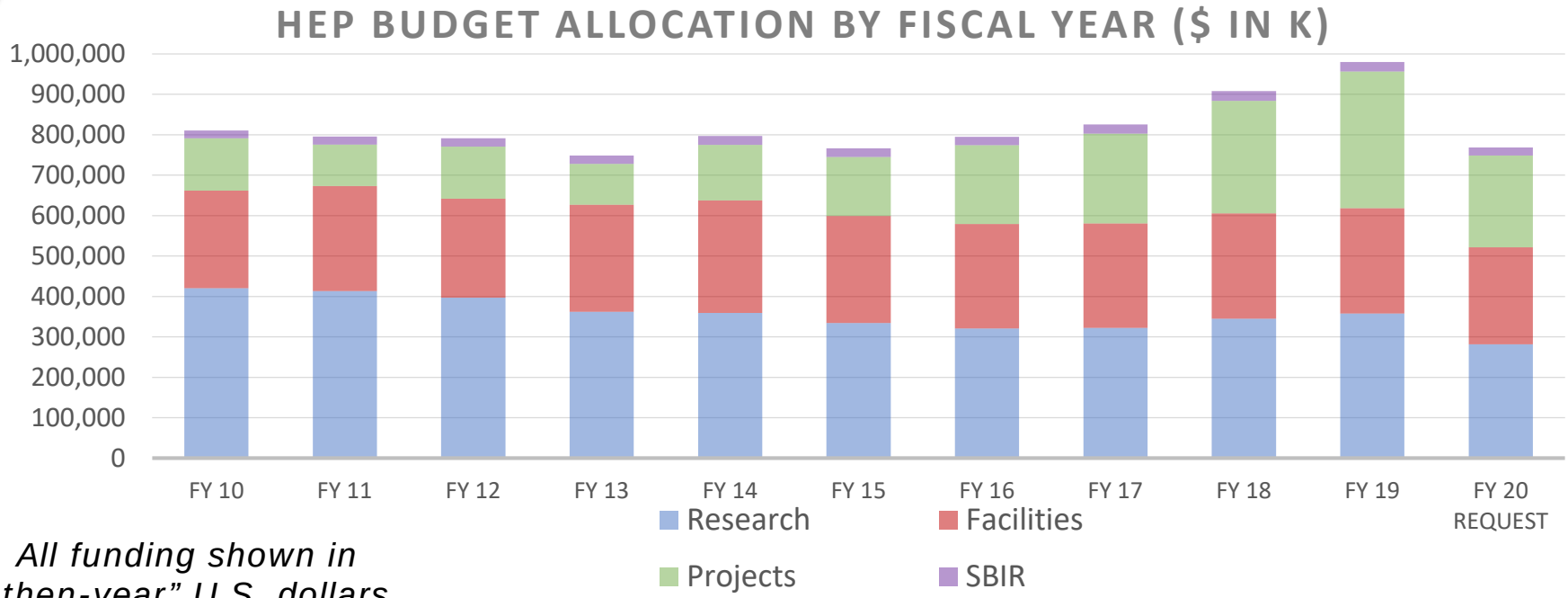
U.S. Congress Supports P5 Strategy

- Congressional appropriations reflect strong support for P5
- 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…"



HEP Budget: Overall Trends

- P5 strategy continues to define investments for the future



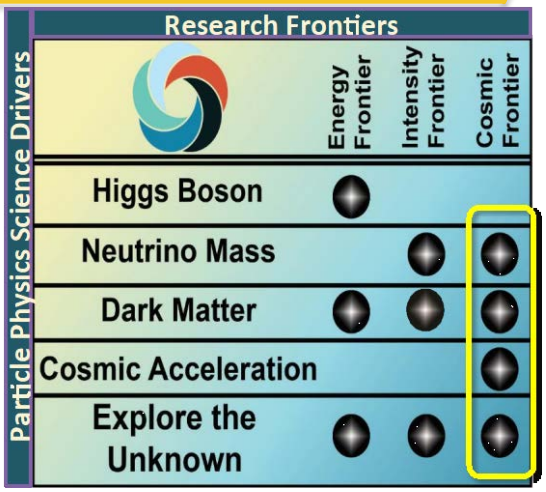
All funding shown in "then-year" U.S. dollars

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

Cosmic Frontier Experimental Research Program →Follows the P5 Strategic Plan

Address P5 science drivers using naturally occurring cosmic phenomena via deep underground detectors, ground-based telescopes & arrays, space missions.

→ Specific set of projects are carried out to provide significant leaps in science and capabilities, based on P5 strategic plan.



P5 recommended Cosmic Frontier science & project priorities in Dark Energy, Dark Matter (direct detection), and CMB

- **Dark Energy**: build LSST & DESI
- **Dark Matter**: direct detection search suite of "generation 2" experiments
- **CMB**: support as part of the core program within multi-agency context; carry out multi-agency CMB-S4 project later in the decade
- Maintain a portfolio of **small projects**: e.g. ADMX-G2, SPT-3G, Dark Matter New Initiatives

→ Cosmic Frontier has evolved over the last decade from primarily operations of small experiments, and following Astro2010/P5, to fabrication of mid-size projects, now moving to operations

Dark Energy – Current Program

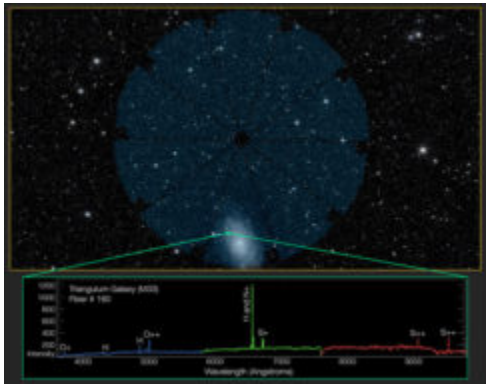
Precision measurements to differentiate between cosmological constant or new fields, or modification to General Relativity

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

Stage 3 - Completed Data-Taking:

eBOSS (spectroscopic) started in 2015, ended Feb 2019

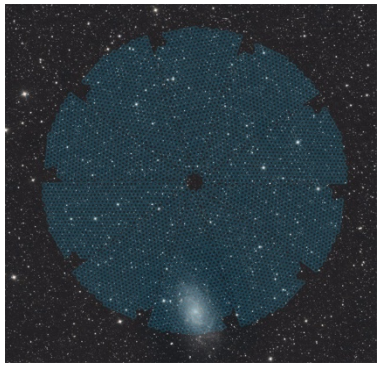
DES (imaging) started 5-year survey in late FY13, ended Jan 2019



Stage 4 - Projects in Fabrication phase:

Large Synoptic Survey Telescope (LSST)

- DOE responsible for camera, then commissioning and observatory operations joint with NSF



Dark Energy Spectroscopic Instrument (DESI)

FIRST LIGHT Oct. 2019!

Cosmic Microwave Background

Study cosmic acceleration (inflation) at energies near the Planck scale, dark energy and neutrino properties with the cosmic microwave background (CMB) (partnership with NSF)

Research efforts:

- Science and major NERSC supercomputing efforts on many ground-based experiments and space-based Planck

SPT-pol → SPT-3G → CMB-S4

SPTpol: Development of 90 GHz TED individually packaged detectors
SPT-3G: monolithic wafers, major upgrade, greatly increases sensitivity

- Early fMux readout work at LBNL, SPT-3G readout is DOE scope
- Operations started Feb 2017

CMB-S4: Planning next generation array with 10x more sensitive:


South Pole Telescope (SPT) and BICEP/Keck Array

Cosmic Frontier Program – Dark Matter, Explore the Unknown

Direct-detection searches for **dark matter** particles with staged suite experiments over a wide mass range using multiple technologies

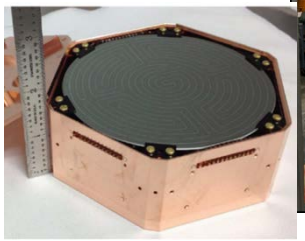
Dark Matter Generation 2 (DM-G2) suite:

- High- and low-mass WIMP sensitivity: ***LZ*** and ***SuperCDMS-SNOLAB*** *(with NSF-PHY)*, in fabrication
- Axion (ultralow mass) experiment: ***ADMX-G2*** in operation

New Initiatives - Small project concept studies: **ADMX 2-4, DM-Radio, Skipper CCD** (+ **LANSCE** in Intensity Frontier)

Explore the unknown using cosmic-ray and gamma-ray surveys, e.g. high energy particles from **dark matter** annihilations in cores of galaxies; ground-based arrays, space telescopes, and an experiment on the International Space Station (in partnership with NSF, NASA)

- *HAWC*, *Fermi/GLAST*, *AMS* in operation



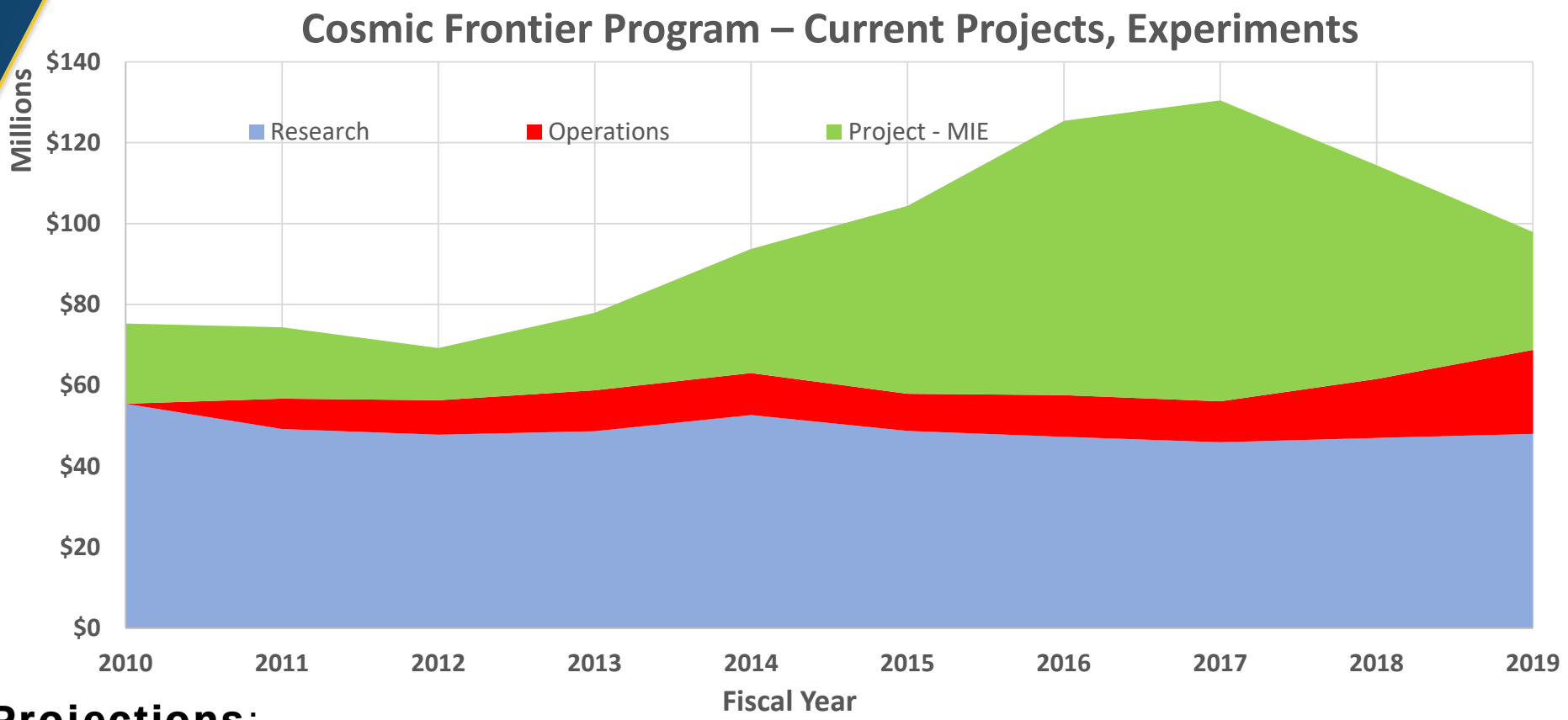
Cosmic Frontier – Activities by Year

→ Cosmic Frontier has evolved over the last decade from primarily operations of small experiments, and following Astro2010/P5, to fabrication of mid-size projects, now moving to operations

Year	Funded Activity	Dark Matter	Dark Energy	Cosmic, Gamma	CMB
FY10-14	Operating	SuperCDMS-Soudan, COUPP, DMTPC, DarkSide-50, LUX	DES(2013), eBOSS(2014)	AMS(2011), Auger, FGST-LAT, HAWC(2013), VERITAS	SPTpol
FY10-14	Design, Fabrication	ADMX-G2, LZ, SuperCDMS-SNOLAB	DESI, LSST		SPT-3G
FY15	Operating	SuperCDMS-Soudan, COUPP, DMTPC, DarkSide-50, LUX	DES, eBOSS	AMS, Auger, FGST-LAT, HAWC, VERITAS	SPTpol
FY15	Design, Fabrication	ADMX-G2, LZ, SuperCDMS-SNOLAB	DESI(CD2), LSST(CD2)		SPT-3G
FY16	Operating	SuperCDMS-Soudan, COUPP, DMTPC, DarkSide-50, LUX	DES, eBOSS	AMS, Auger, FGST-LAT, HAWC, VERITAS	SPTpol
FY16	Design, Fabrication	ADMX-G2, LZ(CD2), SuperCDMS-SNOLAB	DESI, LSST		SPT-3G
FY17	Operating	ADMX-G2, LUX	DES, eBOSS	AMS, Auger, FGST-LAT, HAWC	SPT-3G
FY17	Design, Fabrication	LZ, SuperCDMS-SNOLAB	DESI, LSST		
FY18	Operating	ADMX-G2	DES, eBOSS	AMS, FGST-LAT, HAWC	SPT-3G
FY18	Design, Fabrication	LZ, SuperCDMS-SNOLAB(CD2)	DESI, LSST		
FY19	Operating	ADMX-G2	DES, eBOSS	AMS, FGST-LAT, HAWC	SPT-3G
FY19	Design, Fabrication	LZ, SuperCDMS-SNOLAB	DESI, LSST		CMB-S4
FY20	Operating	ADMX-G2, LZ	DESI	AMS, FGST-LAT, HAWC	SPT-3G
FY20	Design, Fabrication	LZ, SuperCDMS-SNOLAB	DESI, LSST		CMB-S4

Critical Decision 2 (CD2) → baseline

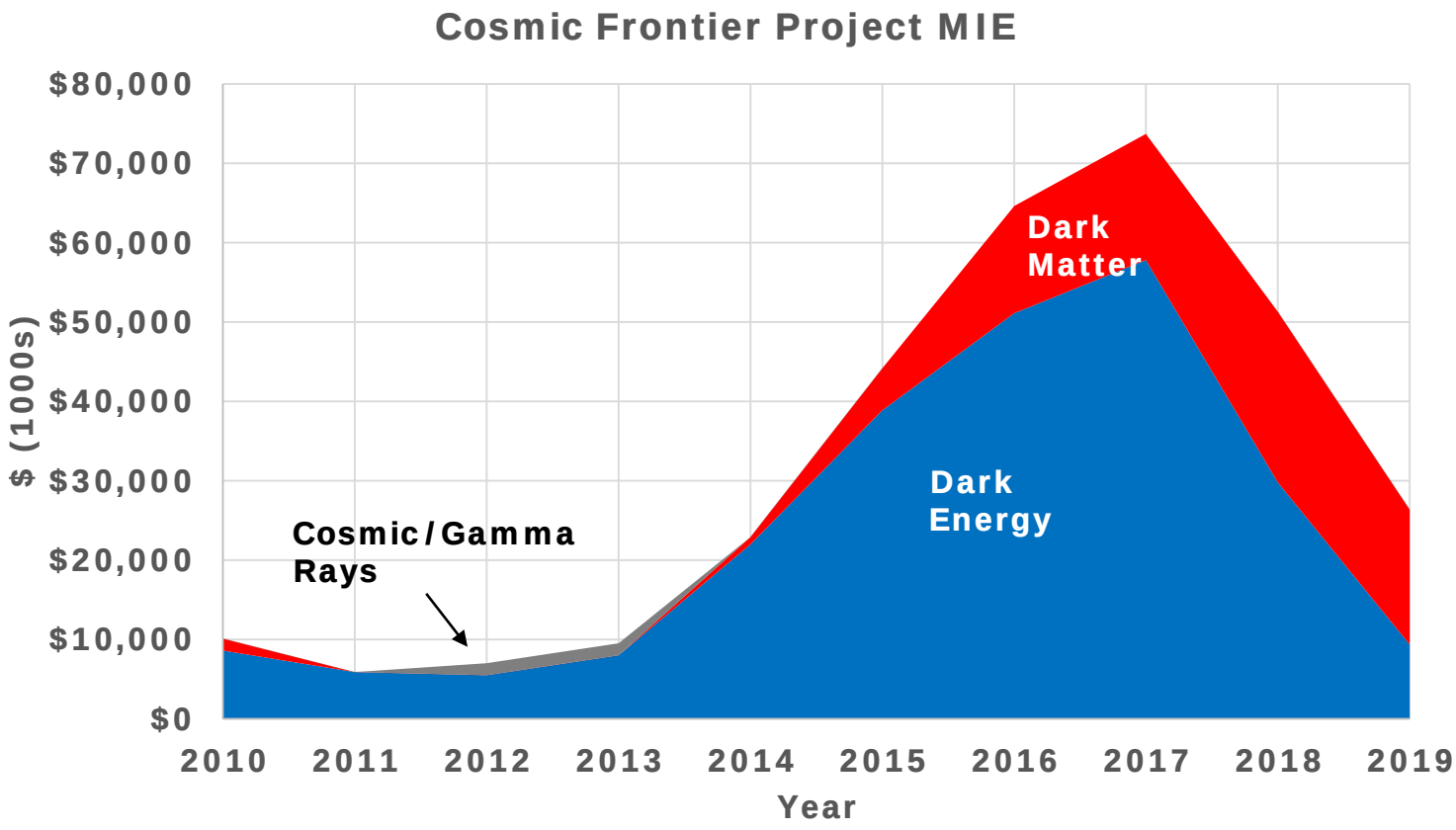
Cosmic Frontier Budget History (FY10-19)



Projections:

- As the current Projects complete, estimated costs for Experimental Operations 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.

Cosmic Frontier – Project Budget by Activity Type



Cosmic Frontier – Planning Relevant for Astro2020

P5 science drivers: Cosmic Inflation, Neutrino Properties, New Physics

- **CMB-S4** is being proposed to Astro 2020 as a partnership of DOE-HEP, NSF-AST/PHY/OPP **→HEP is moving forward on CMB-S4 as recommended in our 2014 P5 strategic plan**

- **Dark Energy:**

Requires development in theory, simulations, joint data analyses, technologies for Stage-V, methods to increase redshift range, accuracy and statistics.

- **Dark Matter Direct Detection –** excluded in SOT due to purview of HEP/Particle Physics community; fully informed by HEPAP/P5

HEP Cosmic Frontier is dynamic → the community & HEP are always looking for high scientific impact opportunities that align with our science goals & make use of HEP community's capabilities.

CMB-S4 Science

CMB-S4 will directly probe Inflation by detecting evidence of primordial gravitational waves in B-mode polarization of CMB.

Structure in angular power spectra encodes fundamental physics that CMB-S4 will probe →

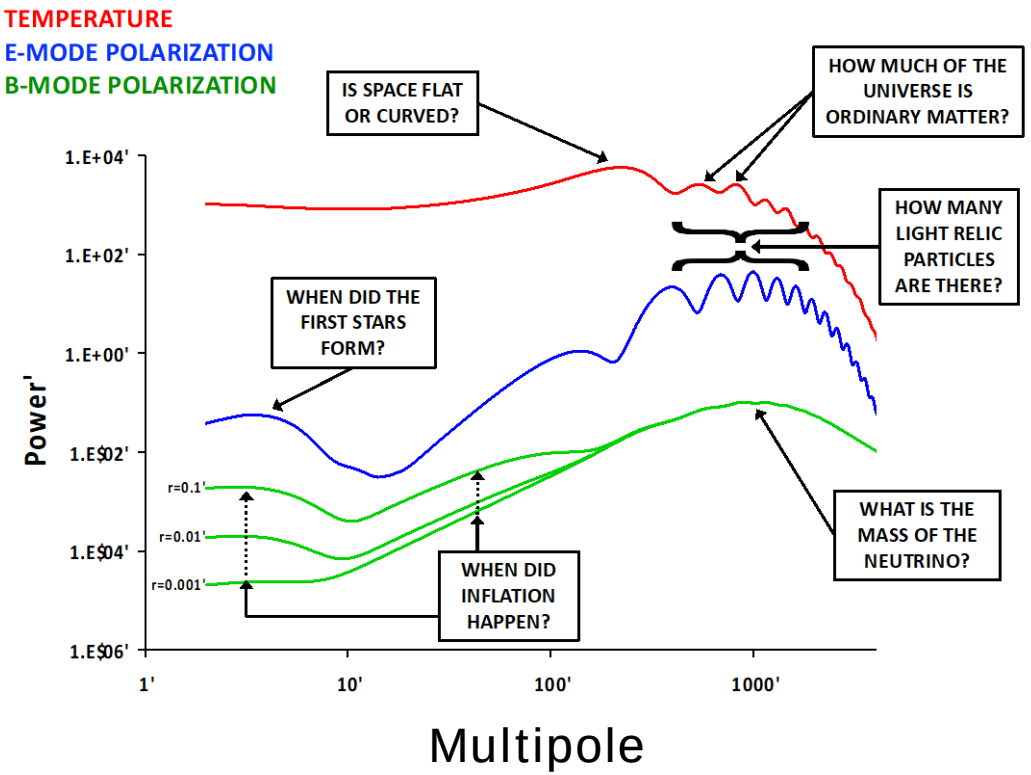
<u>Wide science reach:</u>

Cosmology
- Six parameters of ΛCDM + extensions

Fundamental Physics
- number of light relic species,
- total neutrino mass

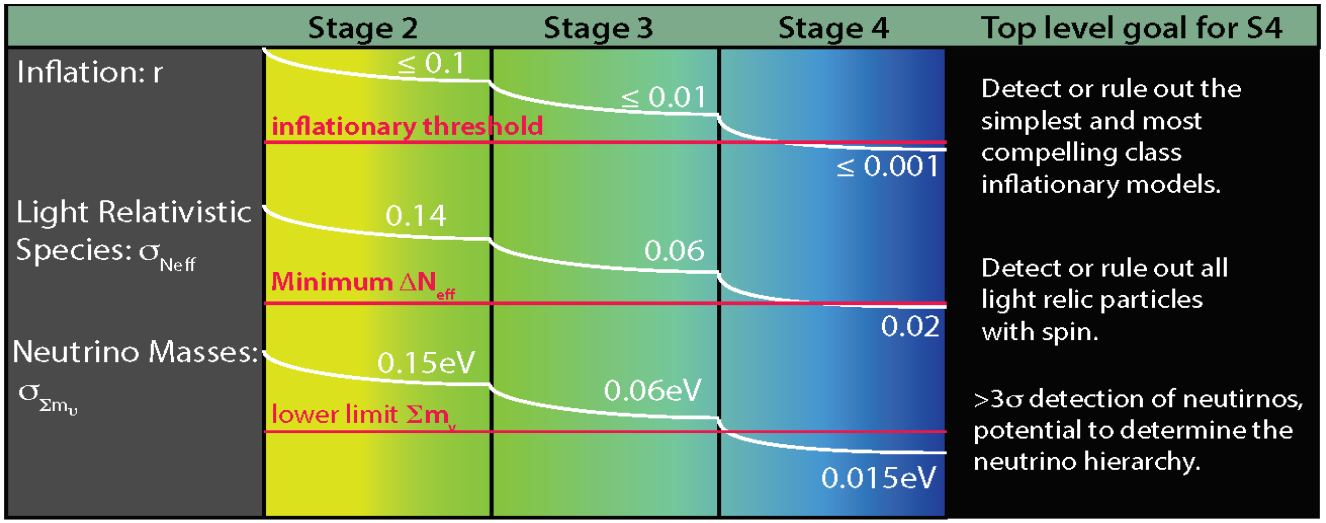
Astrophysics/Astronomy
galaxy formation and evolution

...and the unknown surprises...



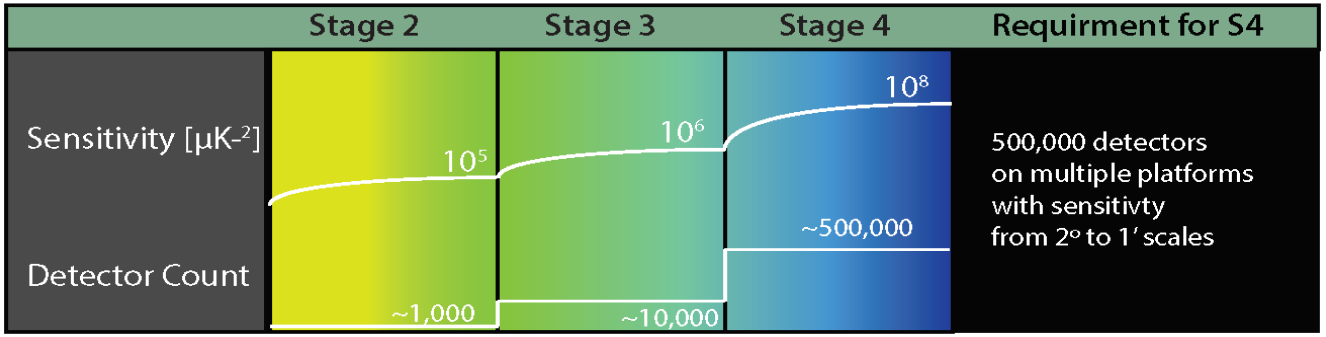
CMB-S4 discovery potential

Cross critical science thresholds (red lines) – transformational!



Inflation

New particles



Neutrino mass

Sensitivity for discovery
- x100 increase

Stage 4 precision measurements requires: 2 sites, variety of small, large telescopes, wide range of frequencies, order 500,000 detectors on the sky

CMB-S4 Progress to date

Following P5:

- HEP labs and community ramped up efforts on technology development and concept planning to align with P5.
- HEP moved forward in planning for CMB-S4
- HEP coordinating planning with NSF-AST/OPP/PHY

2016:

- Science collaboration established, spokespersons elected
- DOE & NSF charged AAAC subpanel: CMB-S4 Concept Definition Taskforce (CDT)

2017:

- CDT report provided science goals, initial strawperson concept design, cost, and schedule (Oct)

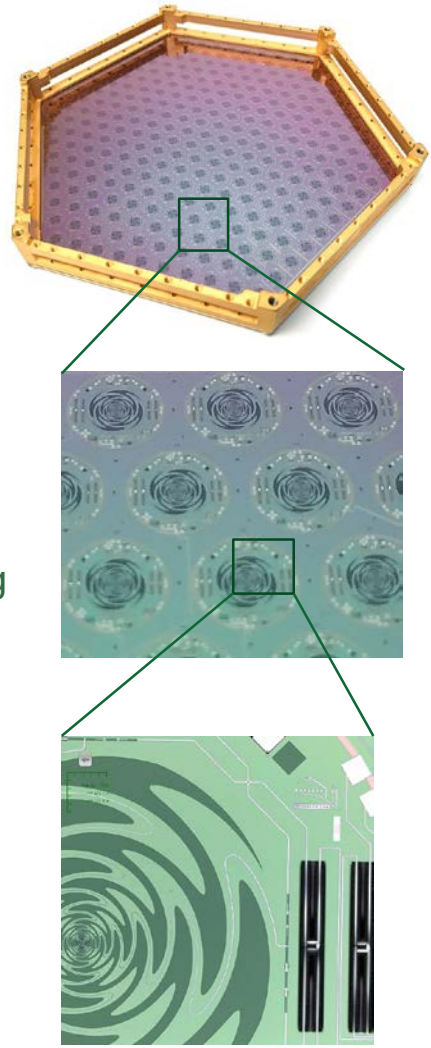
2018:

- Following CDT, pre Project Design Group (pPDG) established by DOE labs: Focus on project development, coordination, and path to CD1
- CMB-S4 collaboration & pPDG working together to develop concept for Decadal Survey and to make progress on technology & concept design.
- Independent review Dec.2018

CMB-S4 Project and Collaboration Planning Status – 2019,2020

Formed Integrated Project Office (IPO) in FY2019 (Jim Yeck interim PM)

- Refine cost, plan for detectors, concept & layout of scope
- Detector fabrication & readout issues at the forefront of R&D/planning - No new technology, but scale-up needed.



DOE → approved Critical Decision 0 "Mission Need" on July 25, 2019; now being planned as a project

- HEP provided FY19 funds for R&D and concept planning; working to provide FY20 funds; NSF MSRI award (Oct'19)

Project (IPO and Collaboration) efforts:

- July 2019 submission(s) to NAS Astro2020 decadal survey (done)
- Detector fabrication and readout Task Force, refine concept and planning (done, work in progress); August 2019 review
- Developing technically-driven plan to meet CD-1 and NSF PDR requirements on the same timeline (mid CY2021)
- Nov. 2019 independent review of project status
- RFI report to this committee (in progress)

Interagency (NSF-DOE) Joint Oversight Group (JOG)

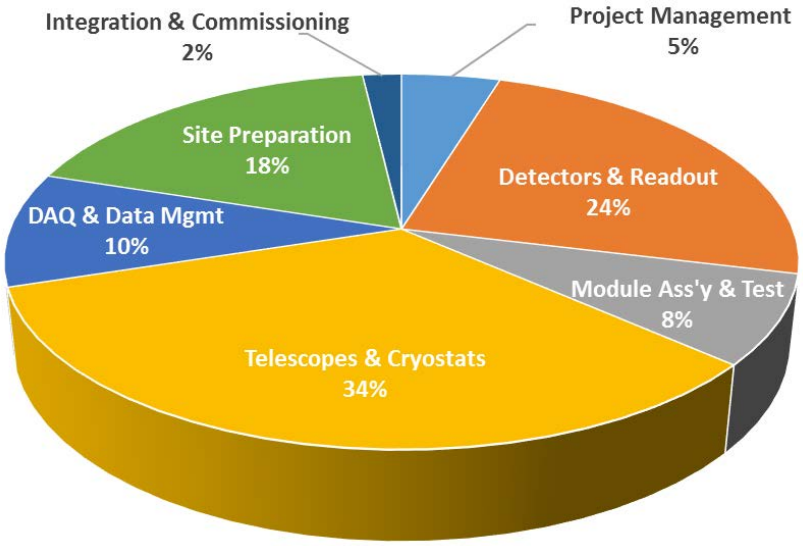
- Bi-weekly ad hoc NSF/DOE meeting to share information, monitor, and review; Bi-monthly meeting with IPO to review status

CMB-S4 Planning – Current Status

Current cost estimate

~$590M w/35% contingency

Agencies & Project will work out scope distribution, leadership; depends on project needs and capabilities plus agency considerations



Schedule Drivers:

- Keep to P5 timeline; ready to start after Astro2020 report
- Maintain synchronization between NSF and DOE processes

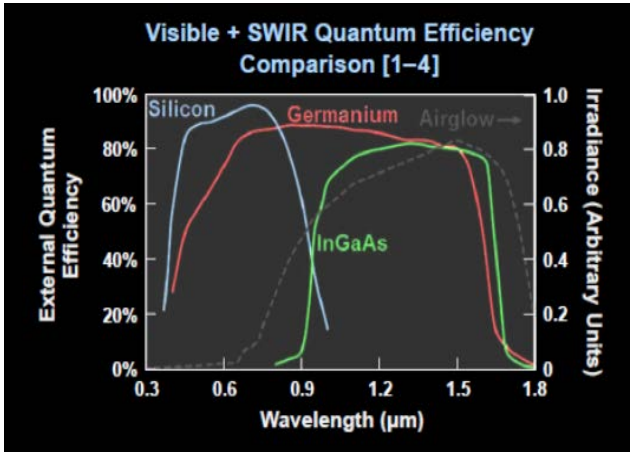
Agency\FY	19	20	21	22	23	24	25	26	27
DOE	CD0		CD1/3a	CD2	CD3b			CD4/Ops	First Light
NSF	MSRI-1		PDR	FDR		MREFC Start			
Decadal Survey			Results						

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 galaxy surveys
  - Germanium CCD R&D
  - Fiber positioner designs to increase density
- Leading or participating in some concepts – White Papers submitted to Astro2020

Astro2020 – Potential Dark Energy Future

➔Consider science opportunities and concept capabilities across all Astro2020 subpanels.

Radio, Millimeter, Submillimeter

- 21 cm Cosmology - Baryon Mapping eXperiment (BMX) testbed, Packed Ultra-wideband Mapping Array (**PUMA**)

- **CMB-S4** – of great interest to dark energy community
  - Many cross-cutting science topics

Optical

- Massively multiobject spectroscopy – 3D mapping the cosmos
  - Pushing to high redshift, large volumes; synergy with LSST
  - Implementations: 6.5m **MegaMapper**, 11.4m **SpecTel**, Mauna Kea Spectroscopic Explorer (MSE), extending existing projects (DESI+, DESI-South, LSST spectroscopy)

- Exascale Cosmological Simulations
  - Joint (interagency) projects input, joint science output
  - Expanding the nonlinear structure frontier, pushing to smaller scale

The Packed Ultrawideband Mapping Array (PUMA)

A next-generation cosmic survey using intensity mapping of the 21-cm emission from neutral hydrogen; Primary science goals:

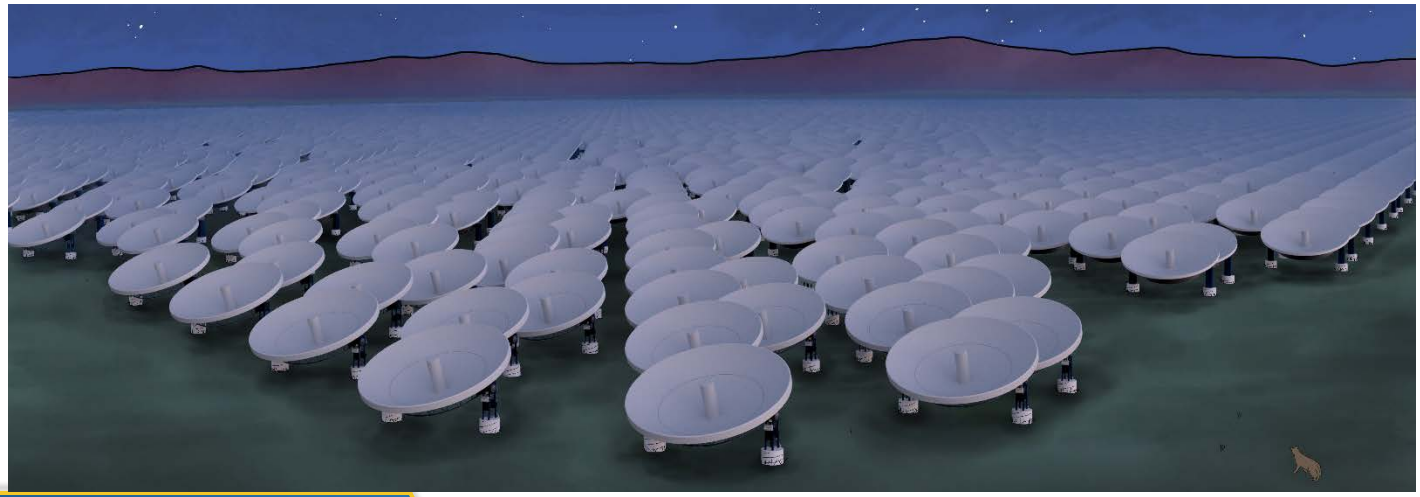
- Probing physics of dark energy in the pre-acceleration era
- Searching for signatures of inflation
- Probing the transient radio sky (fast radio bursts and pulsars)

Technique

- integrated emission observed as a function of redshift; only low angular resolution needed
- different from traditional galaxy survey that observes individual sources one at a time

Design:

- Interferometric array of 32,000 six-meter dishes closely packed
- Dual-polarization feeds, compact on-antenna electronics
- Redshift range $0.3 < z < 6$ corresponding to $1100 < n < 200$ MHz



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.
- CD-0 for CMB-S4 approved & DOE is moving forward on project planning

Significant planning for the future – looking forward to Astro2020 for exciting directions and opportunities!

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