



U.S. DEPARTMENT OF  
**ENERGY**

Office of  
Science

# Office of Science Update

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Space Studies Board / Board on Physics and Astronomy  
Joint Session

November 17, 2021

*Dr. Harriet Kung*  
*Deputy Director for Science Programs*  
*Office of Science*  
*Department of Energy*

# DOE's Office of Science: World Leading Science

To Meet the Nation's Challenges Today and into the 21st Century

The DOE Office of Science (SC) mission is the delivery of scientific discoveries and major scientific tools to transform our understanding of nature and advance the energy, economic, and national security of the United States.

## ▶ **Advancing the frontiers of science**

- ▶ Providing largest Federal support in the physical sciences
- ▶ Supporting nearly 28,000 PhDs, graduate students, undergraduates, engineers, and support staff at more than 300 universities and at all 17 DOE laboratories

## ▶ **Advancing DOE missions**

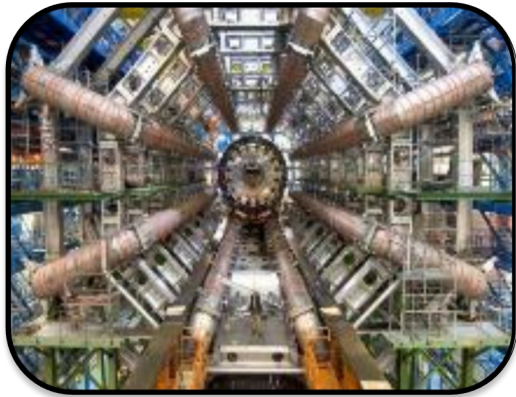
- ▶ Supporting energy and environmental research including Energy Frontier Research Centers, Energy Innovation Hubs, Bioenergy Research Centers, and High Performance and Leadership Computing Facilities

## ▶ **Serving the Nation's scientists**

- ▶ Providing world-leading scientific user facilities to nearly 36,000 users per year

# Office of Science at a Glance

FY 2022 Request: \$7.440B



Largest Supporter of Physical Sciences in the U.S.



Funding at >300 Institutions, including 17 DOE Labs



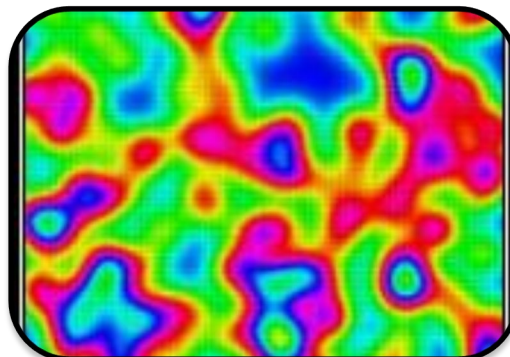
**Nearly 28,000** Researchers Supported



**Nearly 36,000** Users of 28 SC Scientific Facilities



~38% of Research to Universities



Research: 40.6%, \$3.023B



Facility Operations: 36.4%, \$2.709B



Projects/Other: 23.0%, \$1.708B

# DOE National Laboratories

- ▶ The 17 DOE National Laboratories comprise a preeminent federal research system, providing the Nation with strategic scientific and technological capabilities
- ▶ SC stewards 10 DOE laboratories that provide essential support to the missions of the SC science programs

## Office of Science Laboratories

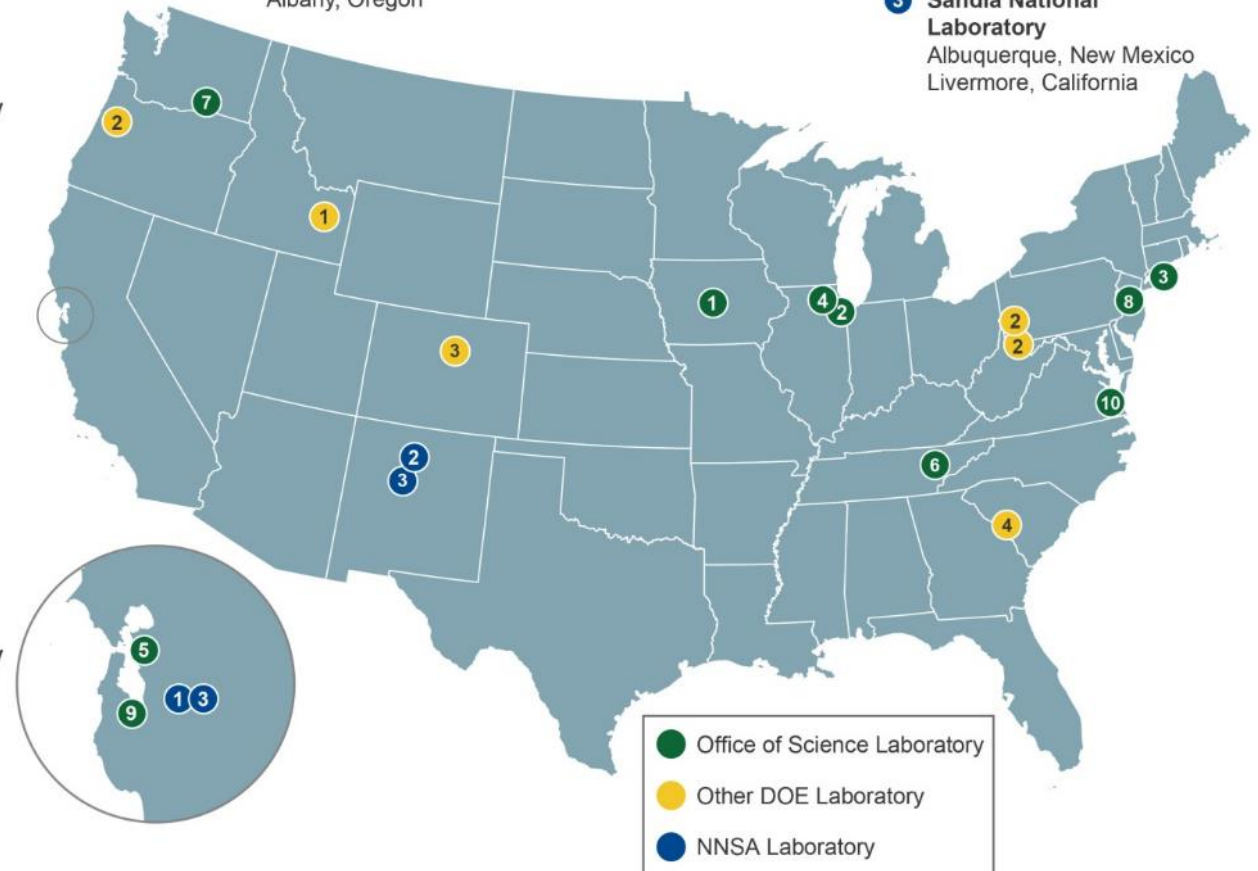
- 1 Ames Laboratory  
Ames, Iowa
- 2 Argonne National Laboratory  
Argonne, Illinois
- 3 Brookhaven National Laboratory  
Upton, New York
- 4 Fermi National Accelerator Laboratory  
Batavia, Illinois
- 5 Lawrence Berkeley National Laboratory  
Berkeley, California
- 6 Oak Ridge National Laboratory  
Oak Ridge, Tennessee
- 7 Pacific Northwest National Laboratory  
Richland, Washington
- 8 Princeton Plasma Physics Laboratory  
Princeton, New Jersey
- 9 SLAC National Accelerator Laboratory  
Menlo Park, California
- 10 Thomas Jefferson National Accelerator Facility  
Newport News, Virginia

## Other DOE Laboratories

- 1 Idaho National Laboratory  
Idaho Falls, Idaho
- 2 National Energy Technology Laboratory  
Morgantown, West Virginia  
Pittsburgh, Pennsylvania  
Albany, Oregon
- 3 National Renewable Energy Laboratory  
Golden, Colorado
- 4 Savannah River National Laboratory  
Aiken, South Carolina

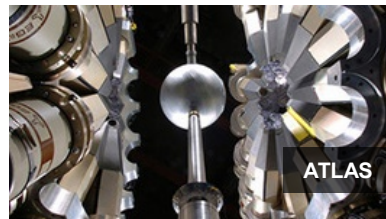
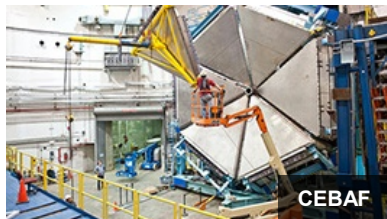
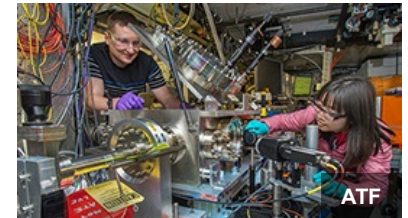
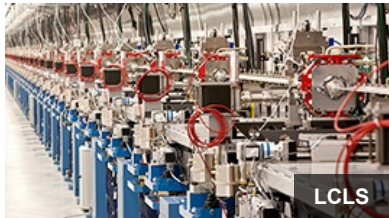
## NNSA Laboratories

- 1 Lawrence Livermore National Laboratory  
Livermore, California
- 2 Los Alamos National Laboratory  
Los Alamos, New Mexico
- 3 Sandia National Laboratory  
Albuquerque, New Mexico  
Livermore, California



# DOE SC Scientific User Facilities

FY 2021  
**28** scientific  
user facilities  
**33,500+** users



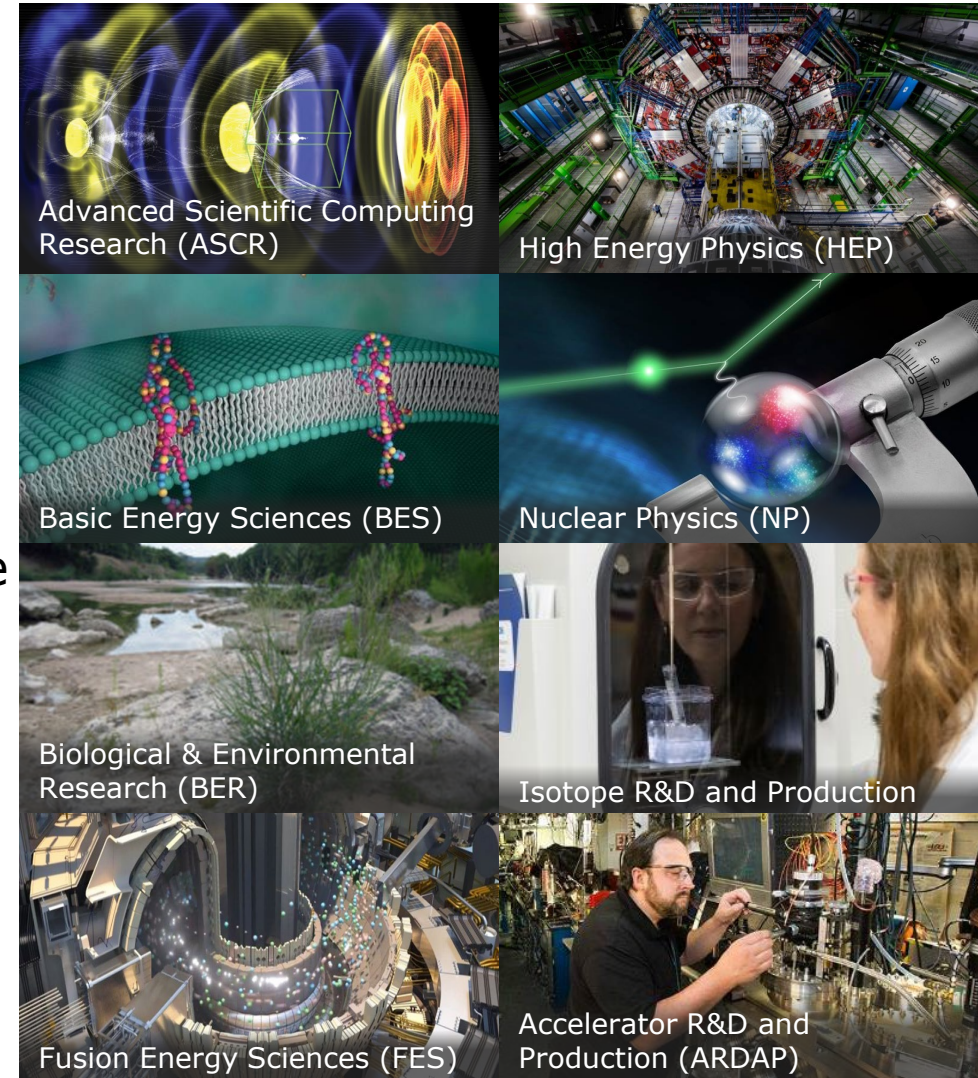
# Office of Science Guiding Principles

**FY 2020 Enacted: \$7.000B**

**FY 2021 Enacted: \$7.026B**

**FY 2022 Request: \$7.440B**

- ▶ Office of Science supports a **balanced research portfolio**, focused on cutting edge, **early-stage research and development, probing some of the most fundamental questions** in areas such as: high energy, nuclear, and plasma physics; materials and chemistry; biological and environmental systems; applied mathematics; next-generation high-performance computing and simulation capabilities; isotopes; and basic research for advancement in new energy technologies.
- ▶ **FY 2022 Budget Request includes:**
  - ▶ New research investments
  - ▶ Increase investments in cybersecurity
  - ▶ Reduce deferred maintenance with upgrades/improvements to infrastructure

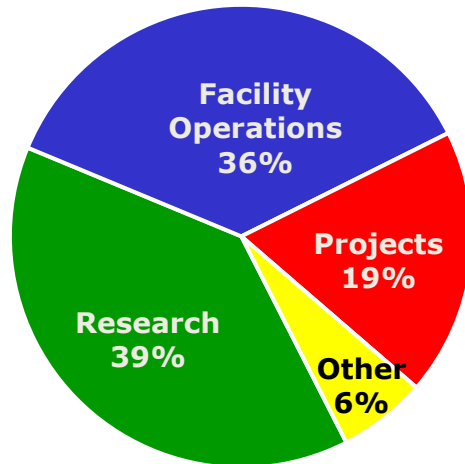


# FY 2020 to FY 2022 Request by Budget Element (Dollars in Thousands)

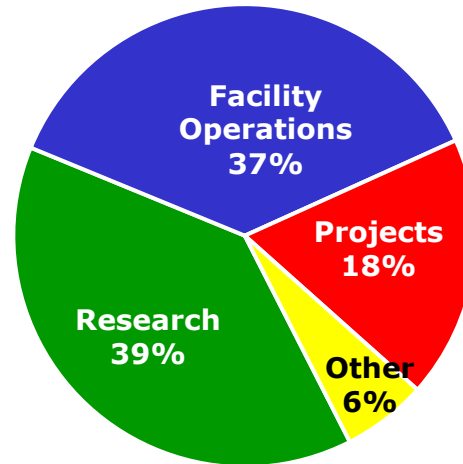
	FY 2020		FY 2021		FY 2022 President's Request					
	Enacted	% of Total	Enacted	% of Total	Request	% of Total	vs. FY 20 Enacted		vs. FY 21 Enacted	
							\$ Change	% Change	\$ Change	% Change
Research	2,713,198	38.8%	2,752,942	39.2%	3,022,991	40.6%	309,793	11.4%	270,049	9.8%
Facility Operations	2,545,988	36.4%	2,582,154	36.8%	2,709,247	36.4%	163,259	6.4%	127,093	4.9%
Projects	1,309,214	18.7%	1,277,180	18.2%	1,246,003	16.7%	-63,211	-4.8%	-31,177	-2.4%
Other	431,600	6.2%	413,724	5.9%	461,759	6.2%	30,159	7.0%	48,035	11.6%
<b>Total</b>	<b>7,000,000</b>	<b>100.0%</b>	<b>7,026,000</b>	<b>100.0%</b>	<b>7,440,000</b>	<b>100.0%</b>	<b>440,000</b>	<b>6.3%</b>	<b>414,000</b>	<b>5.9%</b>

\*Other includes GPP/GPE, WDTS, S&S, and PD.

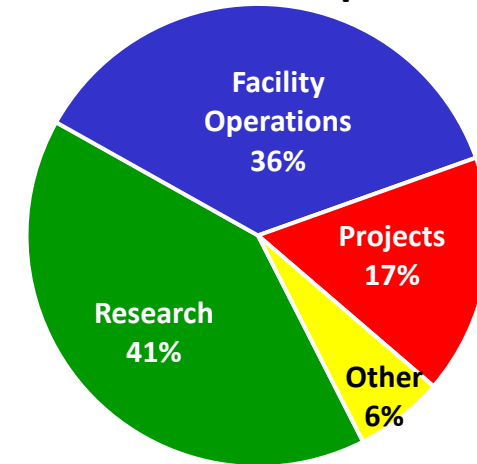
**FY 2020 Enacted**



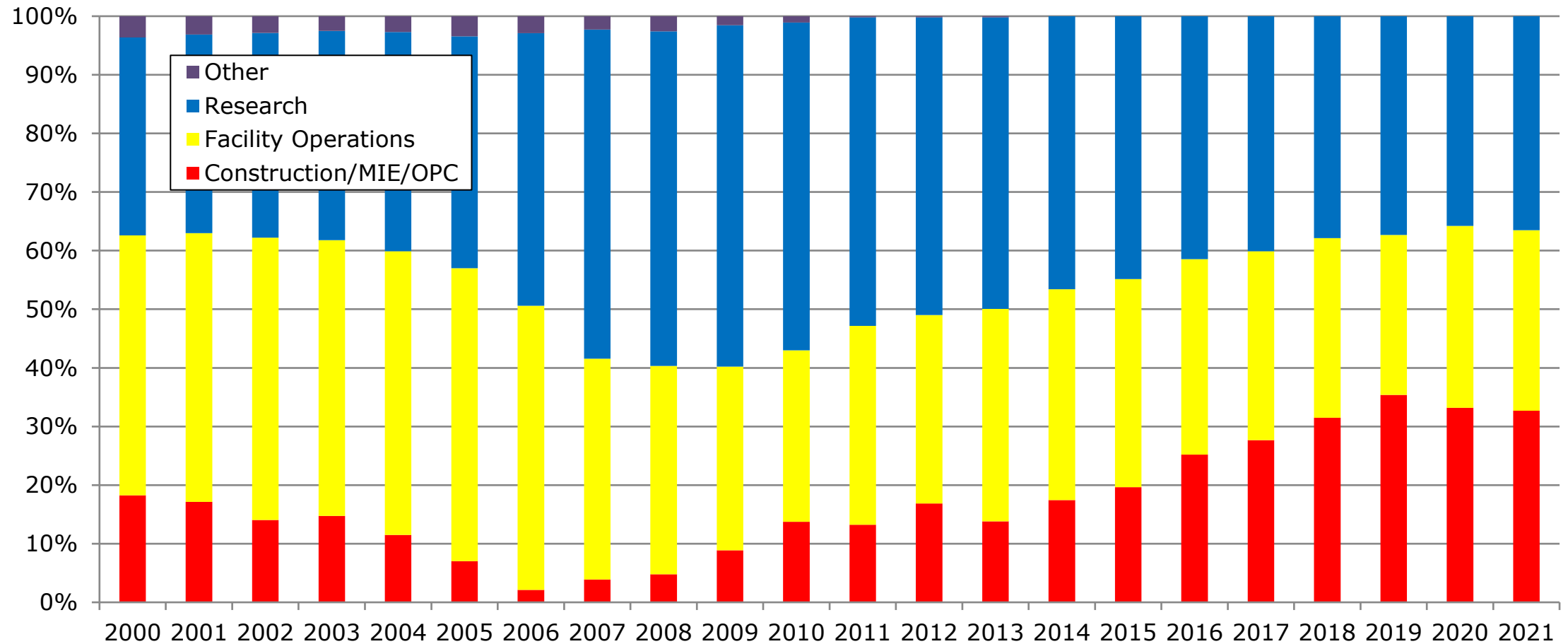
**FY 2021 Enacted**



**FY 2022 Request**

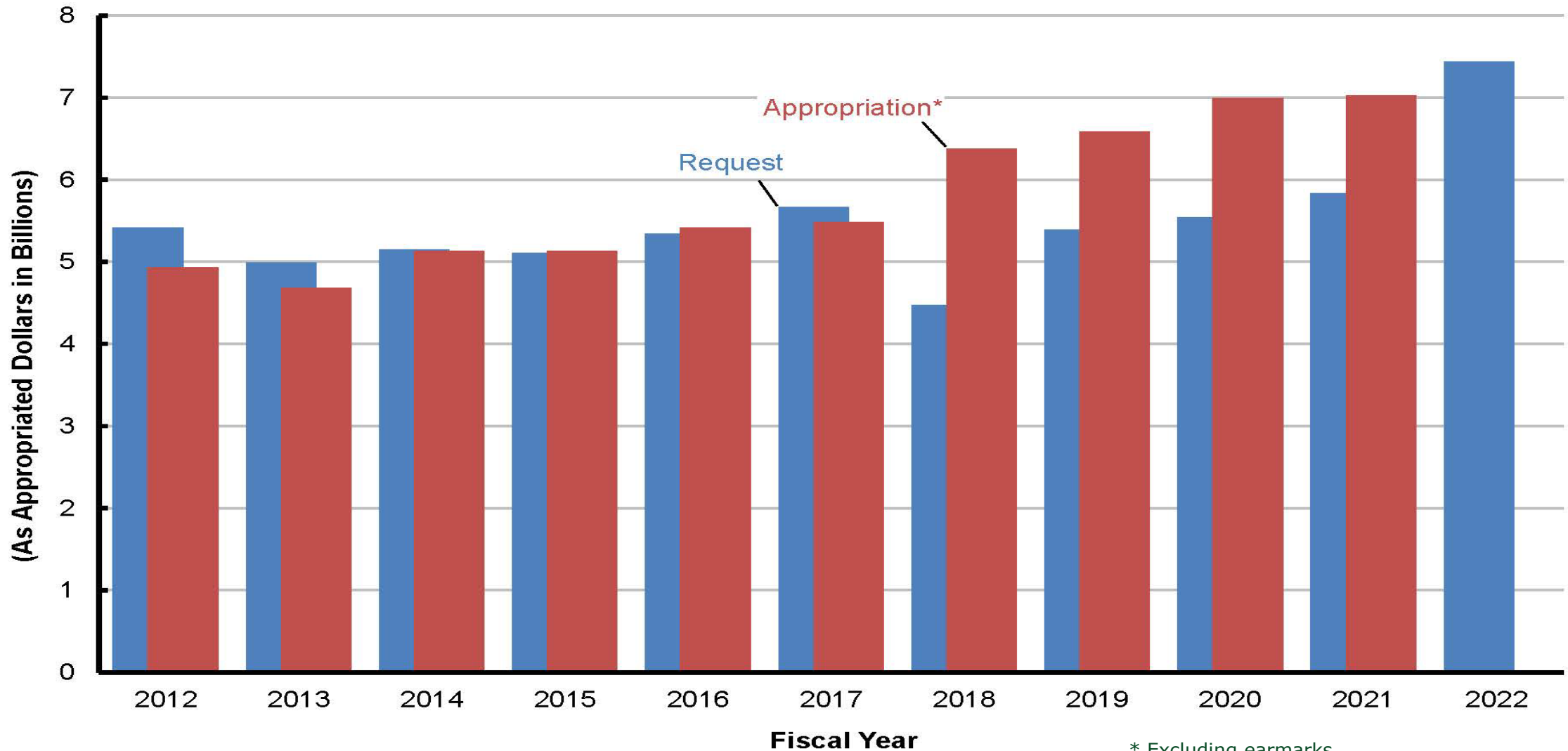


# HEP Budget by Component



**Annual Budget** **\$683M**  **\$1,021M**

# Office of Science Request vs. Appropriation History\*



\* Excluding earmarks

# FY 2022 House and Senate Marks

	FY 2020 Enacted	FY 2021 Enacted	FY 2022 Request	FY 2022 House Mark	FY 2022 Senate Mark
<b>Office of Science</b>					
Advanced Scientific Computing Research	980,000	1,015,000	1,040,000	1,025,000	1,040,000
Basic Energy Sciences	2,213,000	2,245,000	2,300,000	2,293,000	2,323,000
Biological and Environmental Research	750,000	753,000	828,000	805,000	828,000
Fusion Energy Sciences	671,000	672,000	675,000	698,000	660,000
High Energy Physics	1,045,000	1,046,000	1,061,000	1,078,000	1,079,000
Nuclear Physics	713,000	713,000	720,000	665,000	744,000
Isotope R&D and Production	...	...	90,000	82,000	90,000
Accelerator R&D and Production	...	...	24,000	18,000	24,000
Workforce Development for Teachers and Scientists	28,000	29,000	35,000	35,000	35,000
Science Laboratories Infrastructure	301,000	240,000	295,000	249,000	295,000
Safeguards and Security	112,700	121,000	170,000	170,000	170,000
Program Direction	186,300	192,000	202,000	202,000	202,000
<b>Grand Total - Office of Science</b>	<b>7,000,000</b>	<b>7,026,000</b>	<b>7,440,000</b>	<b>7,320,000</b>	<b>7,490,000</b>

# FY 2022 Research Initiatives

## New Initiatives

- ▶ Clean Energy and Climate
- ▶ Reaching a New Energy Sciences Workforce (RENEW)
- ▶ Fundamental Science to Transform Manufacturing
- ▶ Biopreparedness Research Virtual Environment (BRaVE)
- ▶ Urban Integrated Field Laboratory
- ▶ National Virtual Climate Laboratory (NVCL)
- ▶ Climate Resilience Laboratories

## Ongoing Initiatives

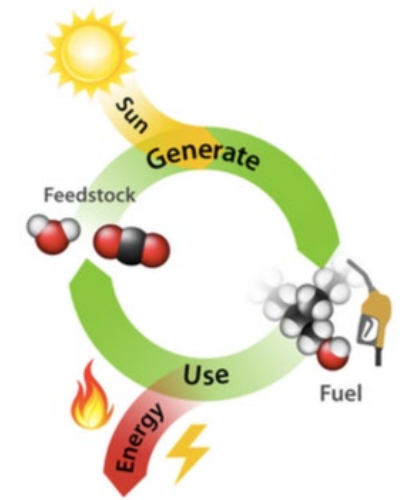
- ▶ Microelectronics Innovation
- ▶ Critical Materials
- ▶ Quantum Information Science
- ▶ Artificial Intelligence and Machine Learning
- ▶ Exascale Computing
- ▶ Revolutionizing Polymer Upcycling
- ▶ Integrated Computational and Data Infrastructure for Scientific Discovery
- ▶ Accelerator Science & Technology



# Fundamental Science for Clean Energy

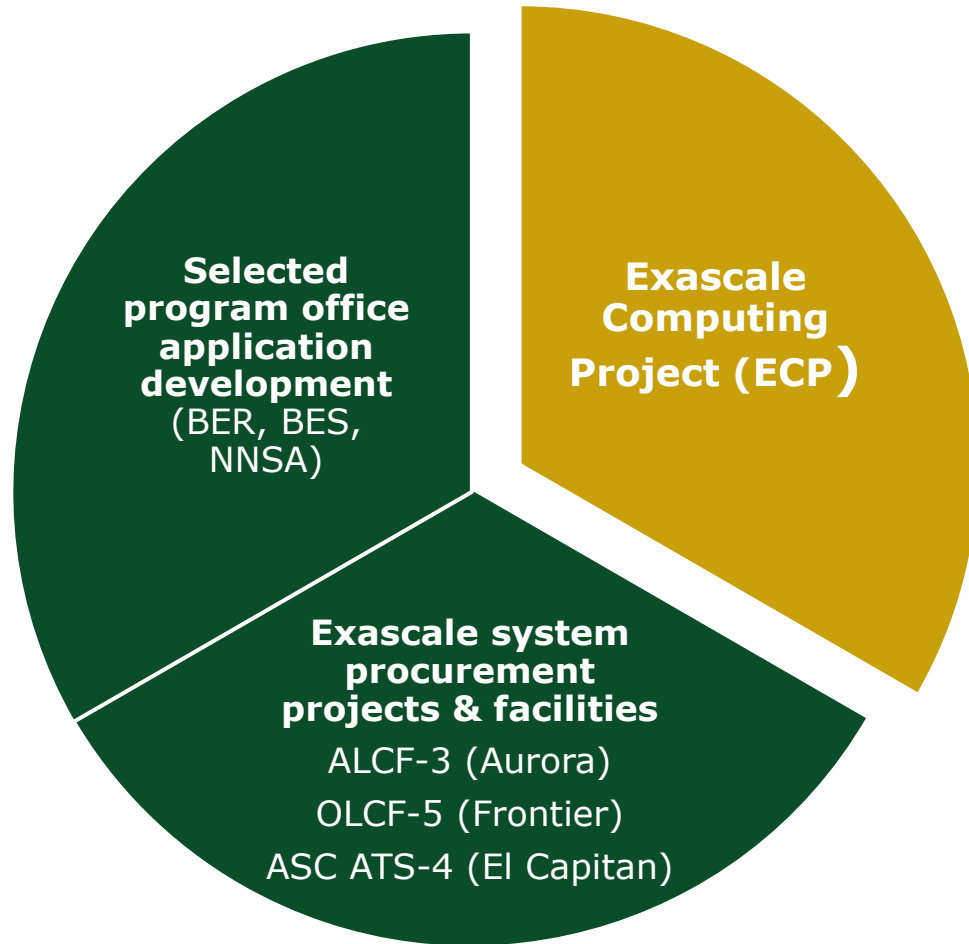
FY 2022 Request = \$2.7B,  $\Delta$ +\$225M

- ▶ **SC** will participate in the DOE Climate and Clean Energy Crosscut in FY 2022, bringing strong science capabilities to advance Administration priorities for clean energy
- ▶ **Emphasis areas** include electrical energy storage; stable supplies of critical materials; harnessing biology in clean energy technologies; carbon dioxide removal, capture and sequestration; durable carbon-neutral hydrogen generation, storage, and use; renewable energy, such as solar energy; energy storage; future nuclear fission and fusion energy; and low-carbon, efficient, sustainable, circular manufacturing.
- ▶ **ASCR** will establish new partnerships to enable exascale computing, AI/ML, and data infrastructure to support predictive models for new clean energy solutions
- ▶ **BES's** broad clean energy portfolio includes leadership roles in most of the above emphasis areas; investments in these areas will continue in Energy Innovation Hubs and will expand in Energy Frontier Research Centers, EPSCoR State-Lab Partnerships, and core research
- ▶ **BER** advances predictive understanding of biological and environmental processes for clean energy; investments in the Bioenergy Research Centers will study methods to convert plant biomass to improved biofuels and bioproducts supporting a broader, more sustainable and decarbonized bioeconomy
- ▶ **FES** continues support for foundational research to develop fusion as a clean energy source, supplementing intermittent renewables and fission
- ▶ **DOE IP** focuses on developing techniques for producing isotopically tailored low-activation materials for fusion and fast fission nuclear reactors and isotopes to optimize the fuel cycle.



# Exascale Computing Initiative

FY 2022 Request = \$445M,  $\Delta$ -\$35M



ECI partners

US DOE Office of Science (SC) and National Nuclear Security Administration (NNSA)

ECI mission

Accelerate R&D, acquisition, and deployment to deliver exascale computing capability to DOE national labs by the early- to mid-2020s

ECI focus

Delivery of an *enduring and capable exascale computing capability for use by a wide range of applications* of importance to DOE and the US

ECP by the numbers

7-year, \$1.8B R&D effort launched in 2016; Six core labs: ANL, LANL, LBNL, LLNL, ORNL and SNL; three focus areas: Application Development, Software Technology, Hardware and Integration; 100 R&D Teams with 1000 participants



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# Accelerator Science & Technology Initiative

## FY 2022 Request = \$41M, $\Delta$ +\$29M

**GOAL:** Ensure the U.S. continues to provide the world's most comprehensive and advanced accelerator-based facilities for scientific research and attract and train an inclusive workforce to design and operate these facilities.

### **R&D is focused on five strategically important technology areas:**

- ▶ Advances in **superconducting accelerator systems**, including SRF, superconducting magnets, and cryogenic engineering.
- ▶ **Beam physics** and **high-fidelity computer modeling & control**, including better diagnostics, (AI/ML-based) control systems, advanced focusing, and beam cooling techniques.
- ▶ Advances in high intensity **electron, proton, and ion sources**, also including **megawatt-class targets** for secondary particle sources.
- ▶ Higher average power **radiofrequency** and **ultrafast laser sources**, including **power handling devices**, and **high accuracy x-ray optics**.
- ▶ **High-risk high-reward R&D** in advanced materials, particle sources, beam dynamics, acceleration techniques, and other advanced topics.



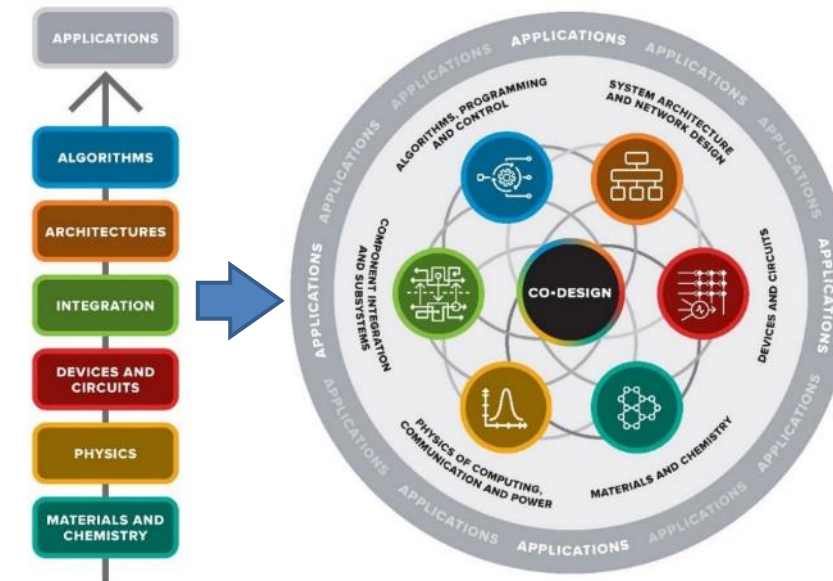
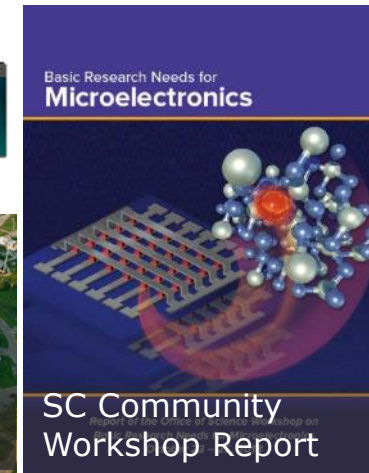
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# Microelectronics

## FY 2022 Request = \$48M, $\Delta$ +\$18M

- ▶ SC has been at the leading edge of microelectronics for decades, both as a consumer and as an engine of scientific understanding that has enabled many technological breakthroughs
  - ▶ **High performance computing** enables advances in science/technology for energy and national security
  - ▶ Future computing technologies (quantum, neuromorphic, probabilistic, etc.) hold promise for **next-generation DOE applications**
  - ▶ SC facilities require **edge computing** to manage the projected high volumes and rates of data
  - ▶ Advanced microelectronics and power electronics will be **necessary to enable future** high performance computers (exascale and beyond) and a smart electricity grid
- ▶ Advanced microelectronics are necessary to enable DOE facilities/instruments
  - ▶ Future high-performance computing
  - ▶ Sensors and front-end electronics
  - ▶ Real-time data collection, analysis, and compression
- ▶ SC workshops defined priority research areas to address microelectronics challenges for science that will broadly impact the DOE mission space

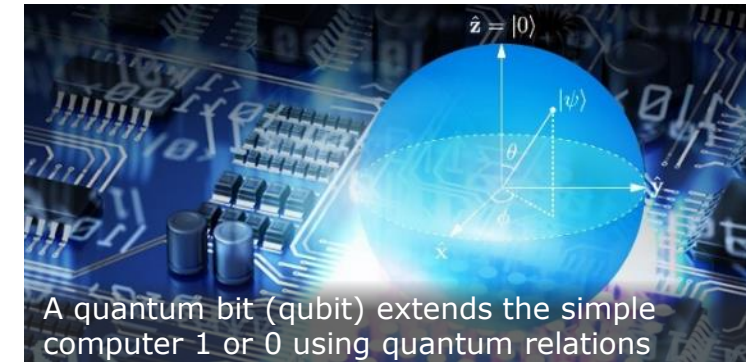


Co-design Framework

# Quantum Information Science (QIS)

## FY 2022 Request = \$301M, $\Delta$ +\$30M

- ▶ Advances in QIS seek to harness the effects of the quantum world to transform our daily lives by enabling new forms of computing, simulation, communication, and sensing
  - ▶ QIS exploits distinct, non-classical behavior: superposition, entanglement, and squeezing
- ▶ SC has unique capabilities for understanding and taking advantage of these quantum effects and offers opportunities for major leaps forward in key areas:
  - ▶ Quantum sensing, computing, and networking research and applications
  - ▶ Infrastructure and supporting technology development
- ▶ SC supports five National QIS Research Centers and a diverse portfolio of QIS research projects that advance the DOE mission and benefit the National Quantum Initiative
  - ▶ QIS research programs are coordinated across SC
  - ▶ SC fosters collaboration within the multidisciplinary ecosystem
  - ▶ DOE Isotope Program develops and produces isotopes of interest for QIS



### National QIS Research Centers



# Reaching a New Energy Sciences Workforce (RENEW)

FY 2022 Request = \$30M



- ▶ Outreach
- ▶ Listening tours & round tables to:
  - ▶ Gain understanding about challenges
  - ▶ Develop evidence-based solutions

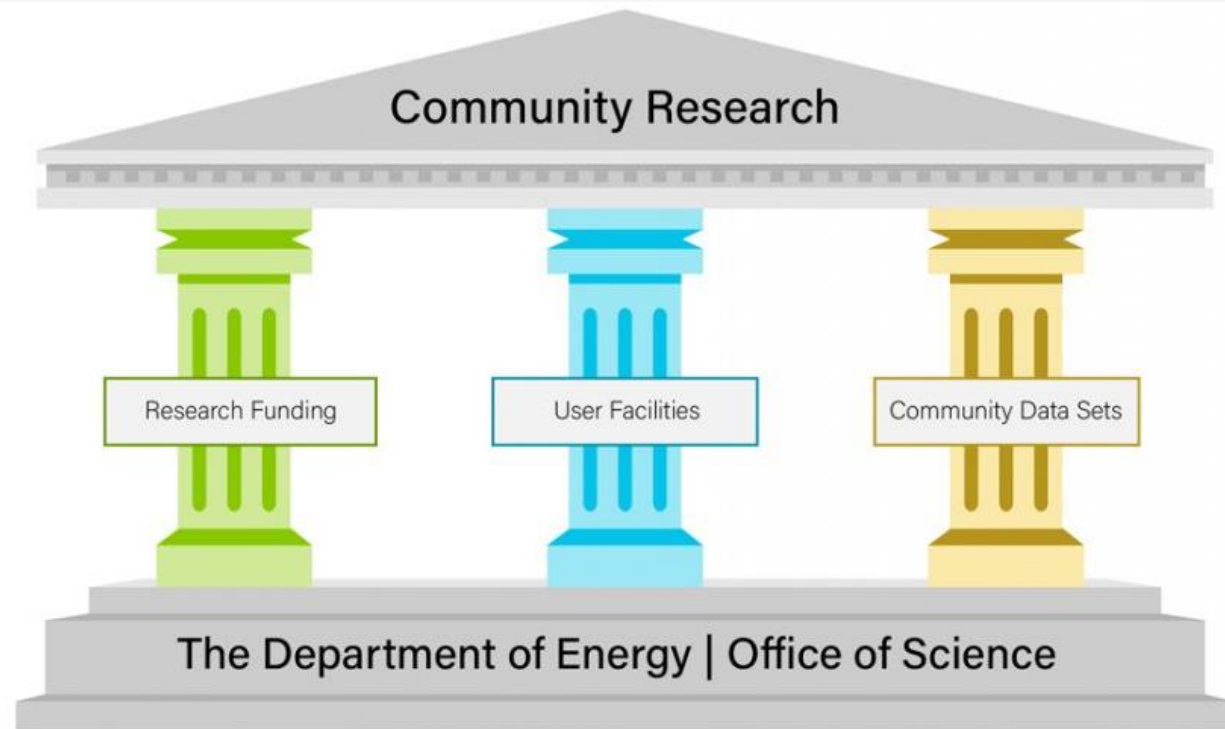


- ▶ Identify unique SC Lab opportunities
- ▶ Partner with MSIs & professional societies
- ▶ Implement action plan

- ▶ Competitively support new traineeship awards resulting in:
  - ▶ “Hands on” experiences, mentoring, enhanced workforce DEI
  - ▶ Tracking of post-traineeship outcomes
  - ▶ Assessing program effectiveness



# Data is the Third Pillar of the DOE SC Enterprise




**Public Reusable Research (PuRe) Data Resources** are data repositories, knowledge bases, analysis platforms, and other activities that aim to make data **publicly available** in order to advance scientific or technical knowledge.

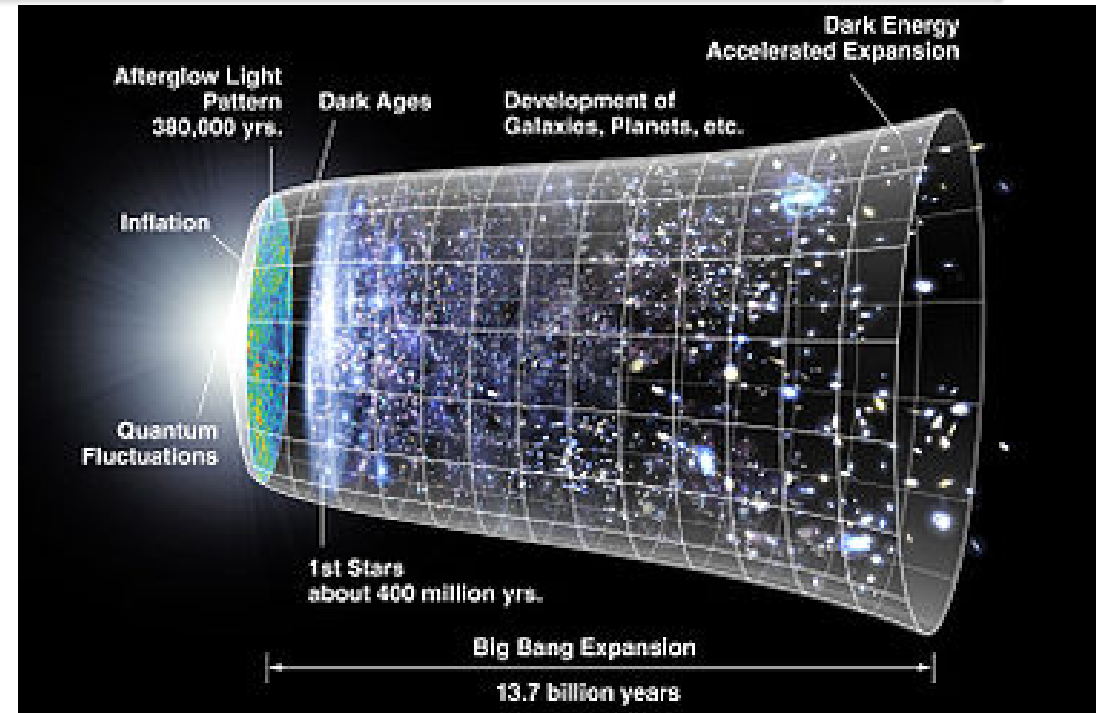
**PuRe Data Resource** designations **highlight** and **improve stewardship** of SC-supported community data efforts with strategic impact on the SC mission.



<https://www.energy.gov/science/office-science-pure-data-resources>

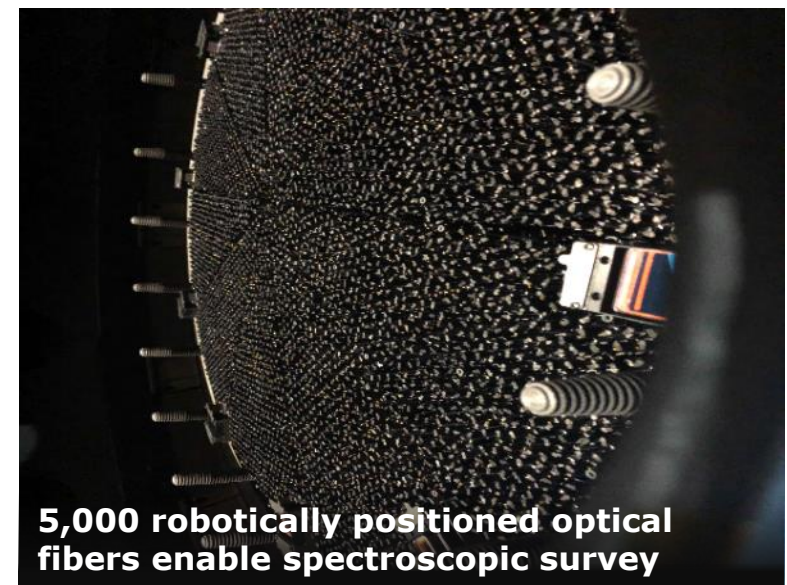
# Cosmic Acceleration: Inflation and Dark Energy

- ▶ Our universe has two major phases of cosmic acceleration:
  - ▶ The moment of “inflation” right after the Big Bang
  - ▶ Ongoing accelerating expansion, beginning  $\sim 8$  billion years later; before that it was decelerating due to gravity
- ▶ Inflation aims to explain why the universe appears the same in all directions and the uniformity of the cosmic microwave background (CMB)
  - ▶ Its existence and the physics process hasn't been verified
- ▶ Ongoing expansion caused by dark energy, which accounts for  $\sim 70\%$  of the content of our universe
  - ▶ 2011 Nobel Prize in Physics 
- ▶ The 2014 Particle Physics Project Prioritization Panel (P5) Report identified Cosmic Acceleration as a science driver of particle physics and recommend projects to advance our understanding
  - ▶ Vera C. Rubin Observatory and Dark Energy Spectroscopic Instrument (DESI) will address dark energy science
  - ▶ CMB-S4 will probe the era of Inflation



# Dark Energy Spectroscopic Instrument (DESI)

- ▶ DOE's Berkeley Lab successfully led the 13-nation team in the design, fabrication, and commissioning of DESI -- instrumentation, data management and the upgrades of the NSF's Mayall telescope and the MOSAIC camera .
- ▶ DESI will study the nature of dark energy, which is causing acceleration of the expansion of the universe
  - ▶ DESI will obtain optical spectra for about 40 million galaxies and quasars, constructing a 3D map spanning the nearby universe to 11 billion light years ago
- ▶ May 2021: World's premier multi-object spectrograph and the first Stage IV dark energy project started full science operations

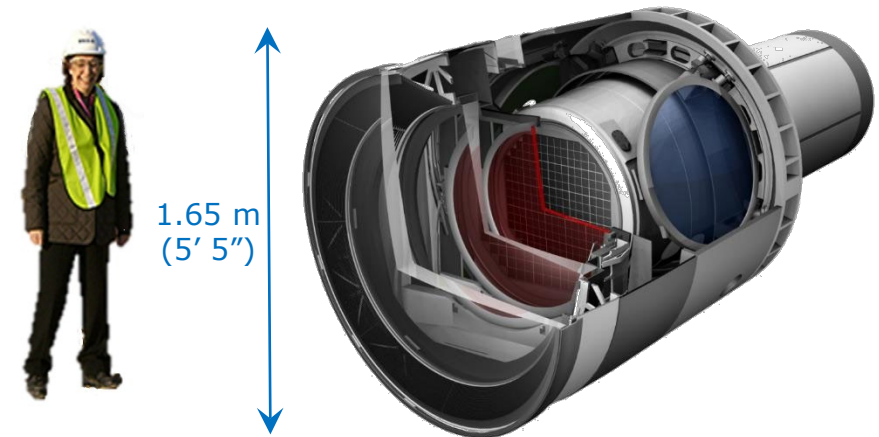


# Vera C. Rubin Observatory & LSST Camera

- ▶ A next-generation, ground-based facility, providing time-lapse imaging of faint astronomical objects across the entire visible sky every few nights to:
  - ▶ Probe dark matter and dark energy
  - ▶ Map the Milky Way
  - ▶ Inventory the Solar System
  - ▶ Study the transient optical sky
- ▶ NSF (AURA) and DOE (SLAC) partnership, with private, international contributions
  - ▶ Project: DOE responsible for camera fabrication (MIE) & commissioning
  - ▶ Facility Operations: 50/50 DOE & NSF split
- ▶ For the first ten years of operations (prime survey), the Vera C. Rubin Observatory will carry out the Legacy Survey of Space and Time (LSST), using the DOE's LSST Camera and the Simonyi Survey Telescope



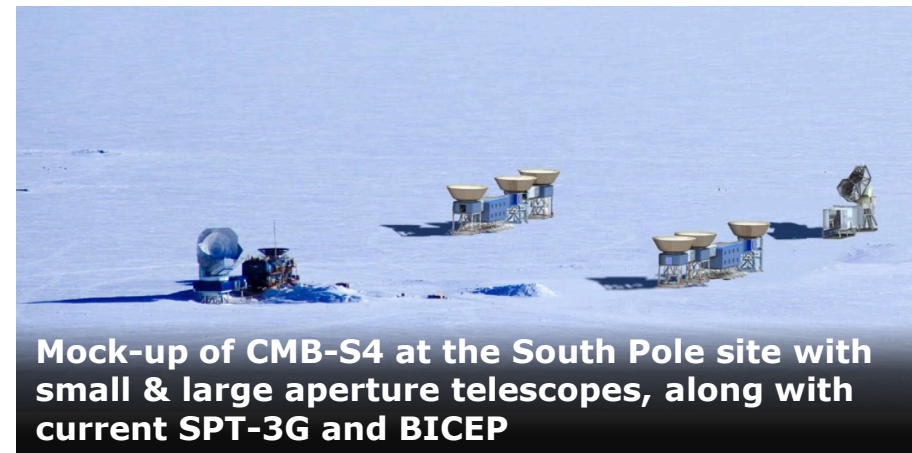
Vera C. Rubin Observatory under construction in Chile



**The 3.2 Gigapixel LSST Camera is the largest electronic camera ever built for ground-based astronomy & astrophysics**

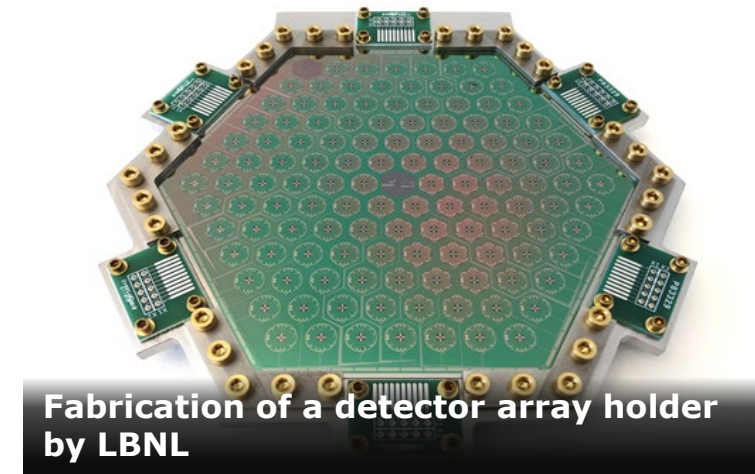
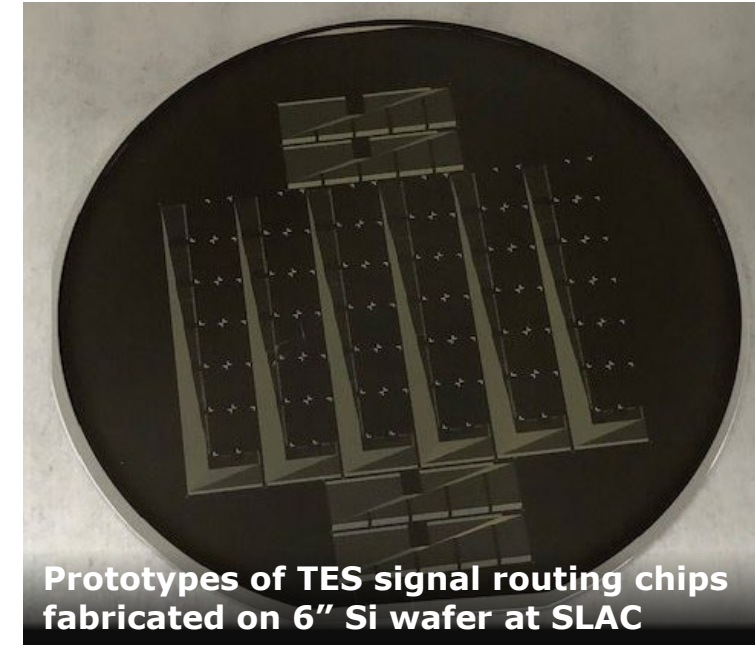
# Cosmic Microwave Background – Stage 4 (CMB-S4)

- ▶ CMB-S4 is being planned as a DOE and NSF partnership that will provide CMB measurements at unprecedented precision and permit fundamental new insights and broad impacts across physics, astrophysics and cosmology.
- ▶ CMB-S4 will cross critical science thresholds, including peering into the inflationary era for the first time by detecting primordial gravitational waves. It will also:
  - ▶ Produce calibrated maps in all bands and on all angular scales
  - ▶ Capture transient phenomena in the microwave sky
  - ▶ Place constraints on light relic particles, neutrino properties, dark energy and dark matter
- ▶ Two sites, Chile & South Pole:
  - ▶ Combination of large (6m) and small aperture (0.5m) telescopes
  - ▶ Total 500,000 cryogenic sensors with superconducting readout



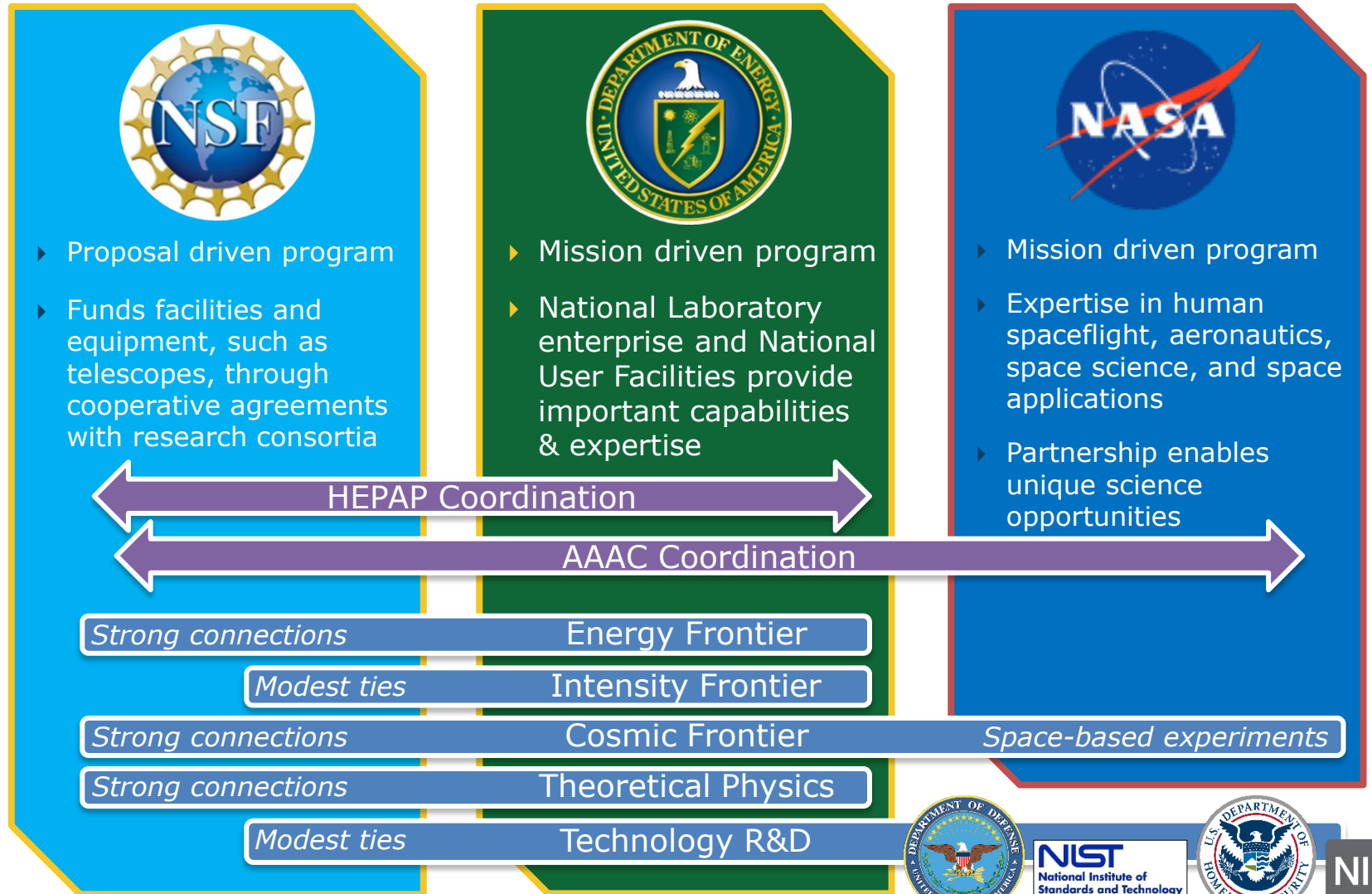
# CMB-S4 and Astro2020

- ▶ Astro2020 recommended a DOE/NSF partnership on CMB-S4:  
***NSF & DOE should jointly pursue the design & implementation of the next generation ground-based cosmic microwave background experiment.***
- ▶ DOE has been developing CMB-S4 since it was recommended in the 2014 P5 report
  - ▶ July 2019: Project received Critical Decision 0 (CD-0) approval at \$300 to \$400M cost range
  - ▶ Aug 2020: LBNL selected as DOE Lead Laboratory for project
  - ▶ Dec 2020: FY21 budget approved an MIE Project Start
  - ▶ May – Aug 2021: Completed 8 subsystem conceptual design reviews
  - ▶ Feb 2022: Next scheduled DOE status review
- ▶ Following Astro2020 and the agencies' considerations of its recommendations, DOE & NSF can start discussions to consider potential paths forward



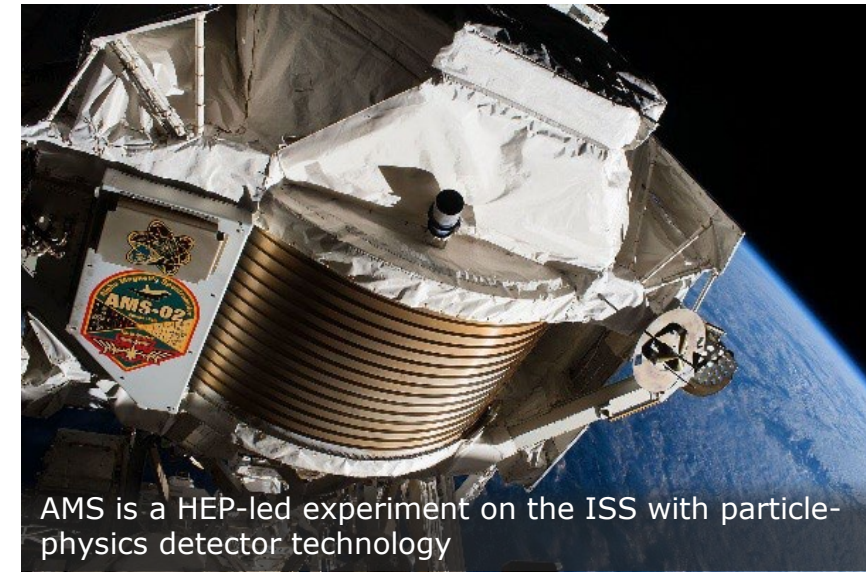
# DOE Interagency Partnerships

- ▶ DOE partners with other agencies to bring together capabilities and expertise to advance areas of national interest
  - ▶ QIS, AI/ML, HPC
- ▶ Partnerships with NSF and NASA are an important aspect of DOE efforts in particle physics



# DOE and NASA Collaboration

- ▶ DOE and NASA have long history of successful collaboration
  - ▶ Including the Alpha Magnetic Spectrometer (AMS) and the Fermi Gamma-ray Space Telescope (FGST)
- ▶ An MOU signed between DOE and NASA in October 2020 highlights potential areas for future collaboration, including:
  - ▶ Scientific observations of the early universe from the Moon
  - ▶ High-performance computing, modeling and simulation
  - ▶ Planetary defense from near-Earth objects
  - ▶ Sensor and satellite development
  - ▶ Space nuclear power and propulsion
  - ▶ Space situational awareness
  - ▶ Space weather
- ▶ DOE Office of Science and NASA Science Mission Directorate jointly released a Request for Information (RFI) in Jan. 2021
  - ▶ Responses (due in March) informing potential next steps in development of mutually beneficial partnerships or collaborative activities



AMS is a HEP-led experiment on the ISS with particle-physics detector technology



HEP led fabrication of the particle-physics based Large Area Telescope (LAT) on FGST

# Program Advice and Coordination

- ▶ Federal Advisory Committee Act (FACA) panels advise each SC program
  - ▶ High Energy Physics Advisory Panel (HEPAP) jointly serves DOE and NSF
    - ▶ HEPAP provided the 2014 Particle Physics Project Prioritization Panel (P5) long-term strategy report
  - ▶ Astronomy and Astrophysics Advisory Committee (AAAC)
    - ▶ Advises DOE, NSF, and NASA on selected issues of mutual interest within the fields of astronomy and astrophysics (e.g. CMB-S4 Conceptual Design Team)
- ▶ National Academies of Science informs strategy
  - ▶ Astro2010 served as important input to the 2014 P5 strategy, new Astro2020 report is still being processed internally
  - ▶ New Elementary Particle Physics Decadal Survey will identify the fundamental questions in particle physics that could motivate research in the next decade and beyond
- ▶ Additional Community Input
  - ▶ DOE Workshops inform program implementation by providing R&D Roadmaps, Basic Research Needs reports, and more
  - ▶ Community efforts, such as the APS/DPF Snowmass process for particle physics are important elements in long-term strategic planning process





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