DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES (MPS) **$1,448,320,000**
-$42,290,000 / -2.8%

MPS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Astronomical Sciences (AST)	$287.01	-	$242.10	-$44.91	-15.6%
Chemistry (CHE)	247.27	-	218.71	-28.56	-11.6%
Materials Research (DMR)	302.99	-	280.22	-22.77	-7.5%
Mathematical Sciences (DMS)	237.03	-	214.79	-22.24	-9.4%
Physics (PHY)	285.23	-	257.83	-27.40	-9.6%
Office of Multidisciplinary Activities (OMA)	131.08	-	234.67	103.59	79.0%
Total	**$1,490.61**	**-**	**$1,448.32**	**-$42.29**	**-2.8%**

About MPS

Research in the foundational physical sciences is the central theme of work supported by MPS. The core areas of MPS science (astronomical sciences, chemistry, materials research, mathematical sciences, and physics) continue to advance and transform knowledge and support the development of the next generation of scientists. Science funded by MPS spans an enormous range: from the smallest objects and shortest timescales ever studied to distances and timescales that are the size and age of the universe. MPS continues to foster and support interdisciplinary scientific programs that span in scope and complexity, ranging from individual investigator awards to large, multi-user facilities. Individual investigators and small teams receive most awards, but centers, institutes, and facilities are all integral to MPS-funded research. This convergence of disciplines and various ways to organize researchers allows MPS to invest in compelling basic science that will underpin and enable advances in the technologies of the future and helping to support a strong U.S. economy for decades to come.

Through its Centers and Institutes programs, MPS will continue to support leading-edge science and the development of the next generation of scientists engaged in research covering fundamental basic science through translational science. The MPS Centers and Institutes span a broad range, from addressing challenges in fundamental mathematics to the development of new materials.

Research tools and infrastructure are key priorities that MPS will continue funding. Mid-scale research infrastructure in astronomical sciences, chemistry, materials research, and physics continue to be critical to the advancement of these disciplines. Large scale research infrastructure is also critical and provides opportunities for partnerships with international groups, other federal agencies, and private foundations, as is evidenced by facilities such as the Atacama Large Millimeter/submillimeter Array (ALMA), the Gemini Observatory, and the Large Hadron Collider (LHC). Since the major scientific breakthrough of the first direct detection of gravitational waves, by the Laser Interferometer Gravitational Wave Observatory (LIGO) in 2015, the facility reports event alerts on a regular basis. In 2017, LIGO detected for the first time a neutron star-neutron star merger, initiating the era of multi-messenger astrophysics research. With recent improvements in the instrumentation, detection of gravitational waves has become routine, with 25 candidate detections in the first four months of the observing run that began in April 2019. The Event Horizon Telescope (EHT)—a planet-scale array of eight ground-based radio telescopes forged through international collaboration—announced the successful capture of the first direct visual evidence of a supermassive black hole and its shadow on April 10, 2019. More than $28.0 million in direct funding,

provided to EHT researchers from NSF over two decades, was a major factor in achieving this accomplishment. Scientists at the National High Magnetic Field Laboratory made a pivotal discovery in superconducting responses in materials—"reentrant Lazarus superconductivity" at world record ultra-high magnetic fields—that promises to finally reveal the mysteries of how superconductivity works. The Vera C. Rubin Observatory, formerly known as the Large Synoptic Survey Telescope, is an ongoing construction project and the High Luminosity Upgrade to LHC is expected to receive construction funding beginning in FY 2020. For more details about these construction projects, see the MREFC chapter. NSF's Daniel K. Inouye Solar Telescope will transition from construction to operations in FY 2020, becoming the world's most powerful solar observatory.

MPS' FY 2021 Request builds on past efforts and aligns with NSF's priorities articulated for FY 2021. There are exciting new opportunities emerging, research efforts that are maturing, and established programs and activities that continue to meet important goals and support science that will transform the Nation's future. MPS investments are influenced by the following key priorities: (a) sustaining core research programs, (b) supporting the highest priority facilities, (c) supporting early-career investigators, (d) providing funding for targeted basic research in NSF-wide investments including the NSF Big Ideas, and (e) advancing support for industries of the future, such as quantum information science (QIS), advanced manufacturing, the spectrum innovation initiative, and artificial intelligence (AI).

In partnership with other research directorates and offices, MPS will continue to provide support for the following research Big Ideas: QL, WoU, HDR, and URoL. These are the outcome of numerous community workshops and reports, as synthesized by NSF into robust and far-reaching programs. MPS is the steward of funds designated for NSF's Big Ideas QL and WoU. These convergent activities will enable pursuit of fundamental research in quantum-enabled sciences and technologies and in multi-messenger astrophysics. By exploiting quantum phenomena such as superposition, entanglement, and squeezing, QL activities will develop the foundations for and enable quantum computing, quantum sensors, quantum communications, quantum simulators, and other inherently quantum technologies. In addition, these activities will contribute to the development of the Nation's quantum-ready workforce. WoU activities will bring together fundamental research in electromagnetic waves, high-energy particles, and gravitational waves; advance the study of the universe; and grow the Nation's multi-messenger astrophysics, engineering, and data science workforce. While financial stewardship for these investments will be the responsibility of MPS, these convergent activities will be overseen and managed collaboratively by QL and WoU leadership and management teams. MPS is also the steward of funds designated for two administration priority areas, QIS and the Spectrum Innovation Initiative. For more information about the QL, WoU and QIS, see the related narratives in the NSF-Wide Investments chapter.

MPS provides approximately 49 percent of the federal funding for basic research at academic institutions in the mathematical and physical sciences.

Major Investments

MPS Major Investments
(Dollars in Millions)

Area of Investment[1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Advanced Manufacturing	$113.94	-	$113.78	-$0.16	-0.1%
Advanced Wireless[3]	-	-	$17.20	$17.20	N/A
Artificial Intelligence	23.52	-	87.34	63.82	271.3%
Bioeconomy	27.00	-	25.00	-2.00	-7.4%
BRAIN Initiative	17.04	-	7.94	-9.10	-53.4%
Microelectronics and Semiconductors	19.28	-	12.73	-6.55	-34.0%
NSF I-Corps™	1.70	-	1.61	-0.09	-5.3%
Quantum Information Science	82.50	-	180.80	98.30	119.2%
SaTC	1.70	-	0.95	-0.75	-44.1%
NSF's Big Ideas					
QL Stewardship	*30.02*	*-*	*50.00*	*19.98*	*66.6%*
WoU Stewardship	*30.00*	*-*	*30.00*	*-*	*-*

[1] Major investments may have funding overlap and thus should not be summed.

[2] This table reflects this directorate's support for selected areas of investment. In other directorate narratives, areas of investment displayed in this table may differ and thus should not be summed across narratives.

[3] Includes $17.0 million for the Spectrum Innovation Initiative.

- Advanced Manufacturing: MPS will invest in activities that develop new methods, processes, analyses, tools or equipment for new or existing manufacturing products, supply chain components, or materials. These will yield advantages such as reduced time to market, new performance attributes, improved small-batch production, cost and energy savings, and reduced environmental impact.
- Advanced Wireless—Spectrum Innovation Initiative: MPS will work alongside other NSF directorates to invest resources and research that support the development of new insights capable of making wireless communication faster, smarter, more responsive, more robust, and more secure—with profound implications for science and society. As stewards of the Spectrum Innovation Initiative, MPS will coordinate agency-wide investments that catalyze research and development in spectrum research, addressing key challenges related to an increasingly congested radio frequency environment and outdated approaches to spectrum allocation. The additional funding will primarily support three cross-cutting initiatives: (1) a novel mechanism for piloting, testing, and rolling out the most innovative approaches to dynamic spectrum sharing in specialized geographic regions, "National Radio Dynamic Zones"; (2) collaborative, center-scale institutes for sustained R&D in the most challenging areas to bring together diverse science and engineering perspectives; and (3) education and public outreach funding for the much needed workforce development specifically related to spectrum research.
- AI: Together with other NSF directorates/offices, MPS will increase support for AI research and development, with a focus on supporting basic research in machine learning and deep learning.
- Bioeconomy: MPS, together with other NSF directorates/offices, will invest in fundamental research, infrastructure, and education that advance foundational knowledge needed to understand and harness biological processes for societal benefit.
- BRAIN Initiative: MPS will continue to invest in the scientific understanding of brain complexity.
- Microelectronics and Semiconductors: MPS will support research that addresses fundamental science questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor-microelectronic technologies, with a focus on materials. This research is critical to future advances and security in information technology, communications, sensing, smart electric grid, transportation, health, advanced manufacturing, and other areas.
- NSF I-Corps™: Together with other NSF directorates and offices, MPS will support this program which connects NSF-funded science and engineering research with the technological, entrepreneurial,

and business communities, and fosters a national innovation ecosystem that links scientific discovery with technology development, societal needs, and economic opportunities.

- QIS: As the steward for QIS, MPS will work together with other NSF directorates and offices to increase support for quantum information science research and development. These investments align with the National Quantum Initiative[1] to coordinate and expand the United States' world-leading position in fundamental quantum research. QIS investments will deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts. Research in QIS examines uniquely quantum phenomena that can be harnessed to advance information processing, transmission, measurement, and fundamental understanding in ways that classical approaches can only do much less efficiently, or not at all. Current and future QIS applications differ from prior applications of quantum mechanics, such as lasers, transistors, and magnetic resonance imaging, by using distinct quantum phenomena—superposition and entanglement—that do not have classical counterparts.
- SaTC: MPS will continue to invest in fundamental research in cybersecurity.
- Spectrum Innovation Initiative: As the steward of this initiative, MPS will coordinate agency-wide investments that catalyze research and development in spectrum research, addressing key challenges related to an increasingly congested radio frequency environment and outdated approaches to spectrum allocation. The additional funding will primarily support three cross-cutting initiatives: (1) a novel mechanism for piloting, testing, and rolling out the most innovative approaches to dynamic spectrum sharing in specialized geographic regions, "National Radio Dynamic Zones"; (2) collaborative, center-scale institutes for sustained R&D in the most challenging areas to bring together diverse science and engineering perspectives; and (3) education and public outreach funding for the much needed workforce development specifically related to spectrum research.
- QL: MPS is the steward for QL, an NSF Big Idea that builds upon and extends our existing knowledge of the quantum world to observe, manipulate, and control, from first principles, the behavior of particles at atomic and subatomic scales. Investments will enable discoveries in both naturally occurring and engineered quantum systems and develop next-generation quantum technologies and devices for sensing, information processing, communications, and computing. Advances will unleash the potential of the Nation's quantum-based scientific enterprise to enhance our well-being, economy, and security.
- WoU: MPS is the steward for WoU, and together with GEO/OPP, will support research in the "windows"—electromagnetic waves, high-energy particles, and gravitational waves—of multi-messenger astrophysics (MMA). Through WoU investments, NSF will also grow the workforce not only for multi-messenger astrophysics but also for engineering, data science, and many other areas in our modern society.

MPS Funding for Centers and Facilities

MPS Funding for Centers Programs
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$86.35**	**-**	**$87.66**	**$1.31**	**1.5%**
Centers for Chemical Innovation (CHE)	19.10	-	21.00	1.90	9.9%
Materials Centers (DMR)	52.51	-	52.51	-	-
STC: Center for Integrated Quantum Materials (DMR)	5.00	-	4.15	-0.85	-17.0%
STC: STC on Real-Time Functional Imaging (DMR)	5.00	-	5.00	-	-
STC: Center for Bright Beams (PHY)	4.74	-	5.00	0.26	5.5%

For additional information on NSF's centers programs, please see the NSF-Wide Investments chapter.

[1] www.congress.gov/bill/115th-congress/house-bill/6227

MPS Funding for Major Multi-User Facilities

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$362.62**	**-**	**$288.58**	**-$74.04**	**-20.4%**
Arecibo Observatory[1]	14.78	-	1.50	-13.28	-89.9%
Cornell High-Energy Synchrotron Source (CHESS)[2]	5.00	-	-	-5.00	-100.0%
Green Bank Observatory (GBO)[3]	10.26	-	7.30	-2.96	-28.8%
IceCube Neutrino Observatory (IceCube)	3.50	-	3.50	-	-
Large Hadron Collider (LHC)	16.00	-	20.00	4.00	25.0%
Laser Interferometer Gravitational Wave Observatory (LIGO)[4]	66.72	-	45.00	-21.72	-32.6%
National High Magnetic Field Laboratory (NHMFL)[5]	40.62	-	37.74	-2.88	-7.1%
National Radio Astronomy Observatory (NRAO)	95.04	-	88.13	-6.91	-7.3%
NRAO O&M[6]	*49.83*	*-*	*39.45*	*-10.38*	*-20.8%*
Atacama Large Millimeter Array (ALMA) O&M[7]	*45.21*	*-*	*48.68*	*3.47*	*7.7%*
National Solar Observatory (NSO)	18.39	-	21.79	3.40	18.5%
NSO O&M[8]	*7.89*	*-*	*4.25*	*-3.64*	*-46.1%*
Daniel K. Inouye Solar Telescope (DKIST)[9]	*10.50*	*-*	*17.54*	*7.04*	*67.0%*
National Superconducting Cyclotron Laboratory (NSCL)[10]	28.50	-	15.50	-13.00	-45.6%
NSF's National Optical-Infrared Astronomy Research Laboratory[11]	63.81	-	48.12	-15.69	-24.6%
NSF's National Optical-Infrared Astronomy Research Laboratory O&M (formerly the National Optical Astronomy Observatory (NOAO))[12]	*29.16*	*-*	*22.23*	*-6.93*	*-23.8%*
Gemini Observatory (Gemini) O&M[13]	*34.65*	*-*	*20.89*	*-13.76*	*-39.7%*
Vera C. Rubin Observatory O&M[14]	*-*	*-*	*5.00*	*5.00*	*N/A*

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] ARECIBO: FY 2019 Actual includes $12.30 million in carryover funds from the FY 2018 emergency supplemental appropriation -- Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) -- for hurricane damage repairs and $530,000 for continuity of operations into FY 2020. It excludes $1.80 million of FY 2019 O&M costs obligated in FY 2018.

[2] CHESS: In FY 2019, NSF stewardship of CHESS ended as NSF transitioned to funding the Center for High Energy X-Ray Sciences (CHEXS), a sub-facility at CHESS operated in partnership with Cornell University. This table does not include CHEXS as it is not a major facility.

[3] GBO: Previously under "Other AST Facilities". FY 2019 Actual includes $2.17 million for continuity of operations into FY 2020.

[4] LIGO: FY 2019 Actual includes $10.47 million for Advanced LIGO Plus enhancement and $11.25 million for continuity of operations into FY 2020.

[5] NHMFL: FY 2019 Actual includes $14.20 million for continuity of operations into FY 2020. Excluded is $9.34 million of FY 2019 O&M costs obligated in FY 2018.

[6] NRAO: As of Oct. 1, 2018, the Long Baseline Observatory (LBO) was reintegrated into NRAO as the Very Long Baseline Array (VLBA) at $3.82 million in FY 2019 and $3.43 million in FY 2021. Also included in FY 2019 is $3.16 million for continuity of operations into FY 2020 and $4.0 million for development of a next generation Very Large Array (ngVLA).

[7] ALMA: The FY 2019 Actual includes $4.93 million for continuity of operations into FY 2020.

[8] NSO: FY 2019 Actual includes $3.50 million for development of DKIST level 2 (advanced) data products.

[9] DKIST: FY 2019 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the DKIST environmental compliance process. Excluded is $8.0 million of FY 2019 O&M costs for DKIST obligated in FY 2018.

[10] NSCL: FY 2019 Actual includes $4.50 million for continuity of operations into FY 2020. FY 2021 is the final year of NSF stewardship of NSCL, after which NSCL will transition into the Department of Energy's Facility for Rare Isotope Beams.

[11] NSF's National Optical-Infrared Astronomy Research Laboratory was established at the start of FY 2020. The Lab encompasses operations of the Mid-Scale Observatories (MSO) and Community Science & Data Center (CSDC), which formerly comprised NOAO, together with operations of the Gemini Observatory and the Vera C. Rubin Observatory.

[12] NSF's National Optical-Infrared Astronomy Research Laboratory: FY 2019 Actual includes $5.73 million for continuity of operations into FY 2020, $2.50 million to support NSF transition activities associated with the creation of the Lab, approximately $412,000 in supplemental funding for U.S. Extremely Large Telescope program planning, and $1.18 million for other special projects.

[13] Gemini: FY 2019 Actual includes $12.99 million to enhance Gemini's adaptive optics system, software capabilities, and public information and outreach activities in the era of multi-messenger astronomy.

[14] Vera C. Rubin Observatory: Excluded is $11.10 million in FY 2019 - FY 2021 pre-operations ramp up costs obligated in FY 2018.

For detailed information on individual facilities, see the Facilities and MREFC chapters.

Funding Profile

MPS Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,045	-	8,050
Number of New Awards	2,415	-	2,340
Funding Rate	30%	N/A	29%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,015	-	7,000
Number of Research Grants	1,921	-	1,800
Funding Rate	27%	N/A	26%
Median Annualized Award Size	$130,000	-	$130,000
Average Annualized Award Size	$151,303	-	$150,000
Average Award Duration, in years	3.2	-	3.2

In FY 2021, the number of research grant proposals is expected to remain level with FY 2019 Actual estimates. MPS expects to award approximately 1,800 research grants to support research and infrastructure activities in both core and crosscutting areas. Average annual award size and duration as well as funding rate are not expected to materially fluctuate from FY 2019 to FY 2021. In FY 2021, MPS maintains its commitment to Science and Technology Centers, Materials Centers, and Centers for Chemical Innovation and will invest $87.66 million, accounting for roughly six percent of the total MPS budget. Operations and maintenance funding for MPS-supported major multi-user facilities comprises approximately 20 percent of MPS's FY 2021 Request.

Program Monitoring and Evaluation

External Program Evaluation and Studies

- For AST, the strategic advice of greatest impact in FY 2021 will be the Decadal Survey of Astronomy and Astrophysics.[2] This survey will be executed by the National Academies of Science, Engineering, and Medicine (the National Academies). It will outline external advice from the astronomy community regarding the level of support for a variety of observational facilities, and the balance between support of facilities and individual investigator programs.
- An external evaluation of the Centers for Chemical Innovation (CCI) Program (2004-2016) was completed in FY 2020. It is currently under review by CHE and expected to be published mid-FY 2020. The study will shape the growth of interdisciplinary team science in chemistry, while helping to inspire faculty and students at all levels to address the most pressing global STEM challenges.
- Pivotal for DMR, the National Academies published their final report on the "*Frontiers of Materials Research: A Decadal Survey.*"[3] The report identifies future directions for materials science for NSF and the U.S. Department of Energy (DOE). In addition, MPS charged the MPS Advisory Committee to form a subcommittee to assess Materials Science opportunities at the interface with Synthetic Biology. The subcommittee is expected to deliver a report of its findings in FY 2020.
- In PHY, a subcommittee of the MPS Advisory Committee was charged with studying the

[2] www.sites.nationalacademies.org/DEPS/Astro2020/index.htm
[3] www.sites.nationalacademies.org/DEPS/materials-decadal/index.htm

implementation of the Physics Frontiers Centers program and the final report was approved in August 2019.[4] The Decadal Assessment on Atomic, Molecular, and Optical Science was also completed and the pre-publication report was posted in December 2019.[5]

Workshops and Reports

In FY 2019, every MPS division sponsored or co-sponsored workshops covering an expansive range of emerging and leading-edge research topics. Examples of these workshops are below:

- MPS sponsored a workshop entitled "Broadening Participation: 2019 MPS Workshop for New Investigators" in September 2019 that targeted investigators early in their careers, from small colleges, and/or underrepresented groups, with a goal of de-mystifying the NSF merit review process and encouraging future applications to NSF opportunities and improved interactions with the foundation. A total of 98 individuals representing all MPS divisions participated in the workshop.
- In FY 2020, MPS/CHE, DOE/Basic Energy Sciences (BES)/Chemical Sciences, Geosciences and Biosciences (CSGB), and the American Chemical Society plan to initiate a consensus study through the National Academies Board on Chemical Sciences and Technologies on "Enhancing the U.S. Chemical Economy through Investments in Fundamental Research in the Chemical Sciences." Results from the study, planned for FY 2022, are expected to inform the scope of core funding activities in the chemical sciences.
- In May 2019, MPS/CHE, ENG/Chemical, Bioengineering, Environmental and Transport Systems (CBET) and DOE/BES/CSGB co-sponsored the National Academies Chemical Sciences Roundtable (CSR) on "Closing the Loop on the Plastics Dilemma"[6] and in November 2019, they co-sponsored a CSR Roundtable on "Advances, Challenges, and Long-Term Opportunities for Electrochemistry."[7] Workshop reports, expected in 2020, will outline high-priority global challenges related to sustainability in the fields of chemistry, engineering, and materials science.
- In FY 2019, through the Designing Materials to Revolutionize and Engineer our Future program, MPS, ENG, and CISE sponsored a study by The Minerals, Metals and Materials Society on creating the next-generation Materials Genome Initiative (MGI) Workforce.[8] In FY 2020 DMR, in collaboration with the National Science and Technology Council interagency subcommittee on MGI, is developing the MGI Strategic Plan 2.0, which will incorporate the MGI Workforce study.
- In October 2019, DMS sponsored a PI workshop for the Algorithms for Threat Detection (ATD) program and the Algorithms for Modern Power Systems (AMPS) program. The ATD program is a partnership between DMS and the National Geospatial Intelligence Agency and AMPS is a partnership between DMS and the Office of Electricity Delivery & Energy Reliability at DOE.
- In November 2019, the MPS/CHE, PHY, DMR and CISE/Computing and Communication Foundations (CCF) workshop report "Enabling the Quantum Leap: Quantum Algorithms for Chemistry and Materials," was published.[9] This report featured significant industrial input from IBM, Microsoft, Google, Rigetti Computing, and 1Qbit to identify targeted problems for testing quantum computers as well as to describe current and future workforce needs. A follow-up workshop is in planning for FY 2020 to continue to define and refine urgent challenges in quantum information sciences over the next several decades especially in shaping the growth of university departments and inspiring the next generation of scientists and engineers participating in quantum computing.

[4] www.nsf.gov/mps/advisory/active_subcommittees.jsp
[5] www.sites.nationalacademies.org/BPA/BPA_185654
[6] www.nas-sites.org/csr/closing-the-loop-on-the-plastics-dilemma/
[7] www.nas-sites.org/csr/advances-challenges-and-long-term-opportunities-for-electrochemistry/.
[8] www.tms.org/portal/Publications/Studies/MGIworkforce/MGIworkforce.aspx
[9] www.nsf.gov/mps/che/workshops/quantum_algorithms_for_chemistry_and_materials_report_01_21-24_2019.pdf

Committees of Visitors (COVs)

In 2019, COVs for AST, DMR, and PHY were conducted, all charged with assessing and preparing a report on division activities and priorities over the period of FY 2015 – FY 2018.

- The PHY COV convened in June 2019. The report provided recommendations related to topics including PHY's support of post-docs and grad students as well as information provided to NSF reviewers during the merit review process. The report of the 2019 COV to PHY was accepted by the MPS Advisory Committee in a virtual meeting held on August 23, 2019.[10]
- The AST COV also convened in June 2019. The COV made 15 formal recommendations. The COV report provided detailed assessments of AST's responses to the previous COV as well as to the Decadal Survey and portfolio review. The report of the 2019 COV to AST was accepted by the MPS Advisory Committee in a meeting held on October 23-24, 2019.[11]
- The DMR COV was convened in September 2019. The COV emphasized findings from the 2019 Decadal Survey and other publications that emphasized the need for the United States to remain competitive in materials research. The committee made nine recommendations to DMR, including addressing the context of materials research within the agency, exploring new partnerships, and investigating additional means to fund research infrastructure. The report of the 2019 COV to DMR was accepted by the MPS Advisory Committee in a meeting held on October 23-24, 2019.[12]
- In 2020, COVs will be conducted for CHE and DMS.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external COVs and directorate Advisory Committees. Please refer to this chapter for additional information.

People Involved in MPS Activities

Number of People Involved in MPS Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	8,335	-	7,900
Other Professionals	2,531	-	2,400
Postdoctoral Associates	1,868	-	1,700
Graduate Students	8,583	-	8,200
Undergraduate Students	5,510	-	5,200
K-12 Teachers	-	-	-
K-12 Students	-	-	-
Total Number of People	**26,827**	**-**	**25,400**

[10] www.nsf.gov/mps/advisory/covdocs/PHY_2019_COV_final_report.pdf
[11] www.nsf.gov/mps/advisory/covdocs/AST_COV_Report.pdf
[12] www.nsf.gov/mps/advisory/covdocs/DMR_COV_Report_Final.pdf

DIVISION OF ASTRONOMICAL SCIENCES (AST)

$242,100,000
-$44,910,000 / -15.6%

AST Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$287.01**	**-**	**$242.10**	**-$44.91**	**-15.6%**
Research	**68.60**	**-**	**61.57**	**-7.03**	**-10.2%**
Education	**4.43**	**-**	**4.69**	**0.26**	**5.9%**
Infrastructure	**213.98**	**-**	**175.84**	**-38.14**	**-17.8%**
Arecibo Observatory[1]	14.25	-	1.50	-12.75	-89.5%
AST Portfolio Review Implementation	0.14	-	-	-0.14	-100.0%
GBO[2]	10.26	-	7.30	-2.96	-28.8%
Midscale Research Infrastructure	15.59	-	1.00	-14.59	-93.6%
NRAO	86.95	-	88.13	1.18	1.4%
NRAO O&M[3]	*46.67*	*-*	*39.45*	*-7.22*	*-15.5%*
Atacama Large Millimeter Array (ALMA) O&M[4]	*40.28*	*-*	*48.68*	*8.40*	*20.9%*
NSO	18.39	-	21.79	3.396	18.5%
NSO O&M[5]	*7.89*	*-*	*4.25*	*-3.64*	*-46.2%*
Daniel K. Inouye Solar Telescope (DKIST)[6]	*10.50*	*-*	*17.54*	*7.04*	*67.0%*
NSF's National OIR Astronomy Research Laboratory[7]	58.08	-	48.12	-9.96	-17.1%
NSF's National Optical-Infrared Astronomy Research Laboratory O&M (formerly the National Optical Astronomy Observatory (NOAO))[8]	*23.43*		*22.23*	*-1.20*	*-5.1%*
GEMINI Observatory (Gemini) O&M[9]	*34.65*	*-*	*20.89*	*-13.76*	*-39.7%*
Vera C. Rubin Observatory O&M (formerly the Large Synoptic Survey	*-*	*-*	*5.00*	*5.00*	*N/A*
Research Resources	10.31	-	8.00	-2.31	-22.4%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] ARECIBO: FY 2019 Actual includes $12.30 million in carryover funds from the FY 2018 emergency supplemental appropriation -- Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) -- for hurricane damage repairs. It excludes $1.80 million of FY 2019 O&M costs obligated in FY 2018. Funding for continuity of operations into FY 2020 ($530,000) was provded by OMA.

[2] GBO: Previously under "Other AST Facilities". Funding for continuity of operations into FY 2020 ($2.17 million) was provded by OMA.

[3] NRAO: As of Oct. 1, 2018, the Long Baseline Observatory (LBO) was reintegrated into NRAO as the Very Long Baseline Array (VLBA) at $3.82 million in FY 2019 and $3.43 million in FY 2021. Also included in FY 2019 is $4.0 million for development of a next generation Very Large Array (ngVLA). Funding for continuity of operations into FY 2020 ($3.16 million) was provded by OMA.

[4] ALMA: Funding for continuity of operations into FY 2020 ($4.93 million) was provded by OMA.

[5] NSO: FY 2019 Actual includes $3.50 million for development of DKIST level 2 (advanced) data products.

[6] DKIST: FY 2019 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the DKIST environmental compliance process. Excluded is $8.0 million of FY 2019 O&M costs for DKIST obligated in FY 2018.

[7] NSF's National Optical-Infrared Astronomy Research Laboratory was established at the start of FY 2020. The Lab encompasses operations of the Mid-Scale Observatories (MSO) and Community Science & Data Center (CSDC), which formerly comprised NOAO, together with operations of the Gemini Observatory and the Vera C. Rubin Observatory.

[8] NSF's National Optical-Infrared Astronomy Research Laboratory: FY 2019 Actual includes $2.50 million to support NSF transition activities associated with the creation of the Lab, approximately $412,000 in supplemental funding for U.S. Extremely Large Telescope program planning, and $1.18 million for other special projects. Funding for continuity of operations into FY 2020 ($5.73 million) was provded by OMA.

[9] Gemini: FY 2019 Actual includes $12.99 million to enhance Gemini's adaptive optics system, software capabilities, and public information and outreach activities in the era of multi-messenger astronomy.

[10] Vera C. Rubin Observatory: Excluded is $11.10 million in FY 2019 - FY 2021 pre-operations ramp up costs obligated in FY 2018.

About AST

AST is the federal steward for ground-based astronomy in the United States, funding research via cooperative agreements for the operation of large telescope facilities and through awards to individual investigators and small research groups. The telescope facilities provide world-leading, one-of-a-kind observational capabilities on a competitive basis to thousands of astronomers each year. These facilities also enable scientific advances by ensuring enormous volumes of data are available to researchers. AST supports the development of advanced technologies and instrumentation and manages the electromagnetic spectrum for scientific use by the entire NSF community.

The AST portfolio includes research to understand the origins and characteristics of planets, stars, and galaxies, as well as the structure that has evolved in the universe since its origin more than 13 billion years ago. The results of this research will lead to a better understanding of the cosmos, the possibility of life existing on planets circling other stars, and the nature of the mysterious dark matter and dark energy that comprise more than 95 percent of the mass-energy of the universe. AST also supports research intended to probe the universe through several powerful and diverse "windows"—electromagnetic waves, high-energy particles, and gravitational waves.

In general, about 22 percent of the AST portfolio is available for new research grants. About 73 percent of AST's budget supports the instrumentation and facilities needed for progress at the frontiers of observational astronomy, while 27 percent supports the research of individual investigators. Through the MREFC appropriation, AST also oversees the construction of the Vera C. Rubin Observatory. For detailed information on AST's individual facilities, see the Facilities chapter. For detailed information on the construction of the Vera C. Rubin Observatory, see the MREFC chapter.

DIVISION OF CHEMISTRY (CHE) **$218,710,000**
-$28,560,000 / -11.6%

CHE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$247.27**	**-**	**$218.71**	**-$28.56**	**-11.6%**
Research	**223.36**	**-**	**207.16**	**-16.20**	**-7.3%**
Centers Funding (total)	19.07	-	21.00	1.93	10.1%
Centers for Chemical Innovation	*19.07*	*-*	*21.00*	*1.93*	*10.1%*
Education	**5.47**	**-**	**3.57**	**-1.90**	**-34.7%**
Infrastructure	**18.44**	**-**	**7.98**	**-10.46**	**-56.7%**
Midscale Research Infrastructure	5.50	-	0.60	-4.90	-89.1%
NHMFL	1.73	-	1.73	-	-
National Nanotechnology Coordinated Infrastructure (NNCI)	0.30	-	-	-0.30	-100.0%
Research Resources	10.91	-	5.65	-5.26	-48.2%

About CHE

CHE supports discovery research and workforce development in chemistry that have the potential to be transformative to major commercial sectors of the U.S. economy: energy, pharmaceuticals, medical applications, plastics, electronics, food, agriculture, and transportation. CHE investments also support highly competitive and rapidly evolving fields that include advanced manufacturing, quantum information sciences, data mining and artificial intelligence, and sensor and instrument development. Experimental, computational and theoretical chemical research is integrated into core programs focused on new synthetic and catalytic methods; measurement/imaging tool and technique development; understanding the structure, dynamics and mechanistic relationships between function and reactivity; environmental chemical sciences; the chemistry of biological processes; and macromolecular, supramolecular and nanochemistry leading to higher ordered structures and materials. CHE programs have a strong emphasis on sustainability and the protection of natural resources. The division uses multiple funding mechanisms to support individuals and team science as well as interdisciplinary user facilities.

CHE encourages researchers to apply chemical understanding and tools to other fields, including biology, engineering, materials research, geosciences, mathematics/statistics, computing, and social sciences. Investments across fields not only expedite chemical learnings, invention, and innovation, but also have significant ramifications for training and employment of the workforce of the future.

In general, about 74 percent of the CHE portfolio is available to support new research grants. The remaining 26 percent supports research grants made in prior years and the research infrastructure needed by the chemistry community.

DIVISION OF MATERIALS RESEARCH (DMR) $280,220,000
-$22,770,000 / -7.5%

DMR Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$302.99**	**-**	**$280.22**	**-$22.77**	**-7.5%**
Research	**245.73**	**-**	**215.34**	**-30.39**	**-12.4%**
Centers Funding (total)	62.51	-	61.66	-0.85	-1.4%
Materials Centers	*52.51*	*-*	*52.51*	*-*	*-*
STC: Center for Integrated Quantum Materials	*5.00*	*-*	*4.15*	*-0.85*	*-17.0%*
STC: STC on Real-Time Functional Imaging	*5.00*	*-*	*5.00*	*-*	*-*
Education	**5.92**	**-**	**2.00**	**-3.92**	**-66.2%**
Infrastructure	**51.34**	**-**	**62.88**	**11.54**	**22.5%**
Center for High Energy X-Ray Sciences (CHEXS)[1]	5.00	-	9.00	4.00	80.0%
CHESS[1]	5.00	-	-	-5.00	-100.0%
Center for High Resolution Neutron Scattering (CHRNS)	2.79	-	3.00	0.21	7.5%
Midscale Research Infrastructure	-	-	11.00	11.00	N/A
NHMFL[2]	34.89	-	36.01	1.12	3.2%
NNCI	2.58	-	2.42	-0.16	-6.2%
Research Resources	1.08	-	1.45	0.37	34.3%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] In FY 2019, NSF stewardship of the CHESS ended as NSF transitioned to funding the CHEXS, a sub-facility at CHESS that is operated in partnership with Cornell University.

[2] NHMFL: FY 2019 Actual includes $10.20 million for continuity of operations into FY 2020; $4.0 million was provdied by OMA. Excluded is $9.34 million of FY 2019 O&M costs obligated in FY 2018.

About DMR

Materials Research is the field of science where physics, chemistry, materials science, and engineering naturally converge in the pursuit of understanding the properties of materials and the phenomena they host. Materials are abundant and pervasive, serving as critical building blocks in technology and innovation. This research impacts life and society, as it shapes our understanding of the world and enables significant advances in electronics, communications, transportation, and health-related fields. The development and deployment of advanced materials are major drivers of U.S. economic growth.

DMR invests in the discovery of new materials and the explanation of materials phenomena, and in the development of the next generation of materials scientists. DMR supports fundamental experimental and theoretical materials research and education via programs focused on condensed matter physics, solid-state and materials chemistry, and the science of materials that are ceramic, metallic, polymeric, nanostructured, biological, electronic, photonic, and multifunctional. This enterprise is dependent on investments across scales, including single investigators, teams, and centers; singularly focused research and areas requiring interdisciplinarity; and infrastructure ranging from small instruments to large-scale facilities. DMR supports materials-relevant instrumentation and technique development broadly in x-ray and neutron science as well as in nanofabrication. Specifically, DMR investments have contributed to U.S. leadership in high-field magnet science and further aims at democratizing national access to high-magnetic fields.

In general, about 38 percent of the DMR portfolio is available to support new research grants. The remaining 62 percent supports research grants made in prior years and the research infrastructure needed by the materials research community.

DIVISION OF MATHEMATICAL SCIENCES (DMS) **$214,790,000**
-$22,240,000 / -9.4%

DMS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$237.03**	**-**	**$214.79**	**-$22.24**	**-9.4%**
Research	**225.45**	**-**	**205.31**	**-20.14**	**-8.9%**
Education	**11.58**	**-**	**9.48**	**-2.10**	**-18.1%**

About DMS

DMS provides the major U.S. federal support for fundamental research at the frontiers of mathematical sciences. Modern communication systems, medicine, manufacturing, energy, transportation, finance, and national security all rely on advances in the mathematical sciences. DMS investments support research at the forefront of fundamental, applied and computational mathematics, and statistics that accelerates discovery and innovation. DMS partnerships with science and engineering in turn inspire development of effective mathematical and statistical theories and methodologies applicable to future national priority areas. The advancement of future researchers in the mathematical sciences, through dedicated training opportunities, remains a DMS priority.

DMS also supports the Mathematical Sciences Research Institutes program, which advances mathematics and statistics research through thematic programs and workshops on current and emerging trends.

Through strong partnerships, DMS can expand the impact of its research investments, including a partnership with CISE on data science through the Transdisciplinary Research in Principles of Data Science program. DMS also partners with the NIH on two programs in biosciences: the Joint DMS/National Institute of General Medical Sciences Initiative to Support Research at the Interface of the Biological and Mathematical Sciences, and the Joint DMS/National Library of Medicine Initiative on Generalizable Data Science Methods for Biomedical Research. Other partnerships include a program with the National Geospatial Intelligence Agency to develop the next generation of mathematical and statistical algorithms for analysis of large datasets; and a program on algorithms for modern power systems with DOE. Another program with the Simons Foundation and BIO supports research centers on the Mathematics of Complex Biological Systems.

In general, about 54 percent of the DMS portfolio is available to support new research grants each year. The remaining 46 percent supports research grants made in prior years.

DIVISION OF PHYSICS (PHY)

$257,830,000
-$27,400,000 / -9.6%

PHY Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$285.23**	**-**	**$257.83**	**-$27.40**	**-9.6%**
Research	**163.37**	**-**	**162.81**	**-0.56**	**-0.3%**
Centers Funding (total)	4.74	-	5.00	0.26	5.5%
STC: Center for Bright Beams	*4.74*	*-*	*5.00*	*0.26*	*5.5%*
Education	**5.52**	**-**	**4.56**	**-0.96**	**-17.5%**
Infrastructure	**116.33**	**-**	**90.46**	**-25.87**	**-22.2%**
IceCube	3.50	-	3.50	-	-
LHC	16.00	-	20.00	4.00	25.0%
LIGO[1]	55.47	-	45.00	-10.47	-18.9%
Midscale Research Infrastructure	13.34	-	6.46	-6.88	-51.6%
NSCL[2]	28.00	-	15.50	-12.50	-44.6%
Research Resources	0.02	-	-	-0.02	-100.0%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] LIGO: FY 2019 Actual includes $10.47 million for Advanced LIGO Plus enhancement. Funding for continuity of operations into FY 2020 ($11.25 million) was provded by OMA.

[2] NSCL: FY 2019 includes $4.0 million for continuity of operations into FY 2020; $500,000 was provided by OMA. FY 2021 is the final year of NSF stewardship of NSCL, after which NSCL will transition into the Department of Energy's Facility for Rare Isotope Beams.

About PHY

PHY supports fundamental research addressing frontier areas of physics that lead to the understanding of the make-up of the universe, from the formation of stars and galaxies to the principles of life processes on Earth. This research covers a range of physics subfields: atomic, molecular, optical and plasma physics, elementary particle physics, gravitational physics, nuclear physics, particle and nuclear astrophysics, physics of living systems, physics at the information frontier, and theoretical physics.

PHY is the primary supporter of all U.S. research in gravitational physics and the leading supporter of fundamental research in atomic, molecular, and optical physics in the United States. PHY is a major partner with DOE in support of elementary particle physics, nuclear physics, and plasma physics. PHY also has the only U.S. program designed for the support of physics research in living systems. The development of the most advanced cutting-edge computational resources, innovative technology, and new instrumentation is a key part of physics research. Tools developed by the physics community continuously have major impacts in other scientific and engineering fields, allowing PHY to contribute in major ways to emerging new frontiers such as QIS and AI.

In general, about 17 percent of the PHY portfolio is available for new research grants. The remaining 83 percent is used primarily to fund continuing grants made in previous years and to support operations and maintenance for four facilities that are a key part of the division portfolio (about 33 percent). Through the MREFC appropriation, PHY also oversees the construction of HL-LHC. For detailed information on PHY's individual facilities, see the Facilities chapter. For detailed information on the construction of HL-LHC, see the MREFC chapter.

OFFICE OF MULTIDISCIPLINARY ACTIVITIES (OMA) **$234,670,000**
+$103,590,000 / 79.0%

OMA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$131.08**	**-**	**$234.67**	**$103.59**	**79.0%**
Research	**94.16**	**-**	**234.67**	**140.51**	**149.2%**
Spectrum Innovation Initiative	-	-	17.00	17.00	N/A
NSF's Big Ideas	60.02	-	80.00	19.98	33.3%
QL	*30.02*	*-*	*50.00*	*19.98*	*66.6%*
WoU	*30.00*	*-*	*30.00*	*-*	*-*
Education	**6.68**	**-**	**-**	**-6.68**	**-100.0%**
Infrastructure[1]	**30.24**	**-**	**-**	**-30.24**	**-100.0%**

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] Reflects funding for MPS facilities as one-time support for continuity of operations into FY 2020.

About OMA

In partnership with MPS division and programs, OMA strategically invests in research and education to support novel, challenging, or complex projects of varying scale that are not readily accommodated by traditional organizational structures and procedures.

OMA funding priorities continue to focus on MPS-relevant Big Ideas: QL, WoU, HDR, and URoL. As the steward for QL, OMA will support investments from all MPS divisions, BIO, ENG, CISE and OISE that engage several relevant disciplines in a convergent and interdependent manner to advance quantum science and technology. Societal benefits of this science and technology are expected to be significant, as it is poised to include proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts. MPS is also the steward for WoU, supporting AST, PHY, and GEO/OPP in activities that bring together fundamental research in electromagnetic waves, high-energy particles, and gravitational waves; advance the study of the universe; and grow the nation's multi-messenger astrophysics, engineering, and data science workforce. In addition to the Big Ideas, OMA is the steward for other administration priorities, including QIS and the Spectrum Innovation Initiative. OMA will also invest in other multidisciplinary research that advances the basic foundations of mathematical and physical sciences. OMA will foster broadening participation through support of HBCUs and other MSIs and will continue to place high priority on the Alliances for Graduate Education and the Professoriate Graduate Research Supplement program and the MPS Graduate Research Supplements to Veterans program.

In general, about 60 percent of the OMA portfolio is available to support new research grants. The remaining 40 percent supports multidisciplinary research infrastructure and education activities needed by the MPS community.