DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES (MPS)

$1,255,820,000
-$247,590,000 / -16.5%

MPS Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Percent
Astronomical Sciences (AST)	$311.16	-	$217.08	-$94.08	-30.2%
Chemistry (CHE)	246.29	-	214.18	-32.11	-13.0%
Materials Research (DMR)	337.14	-	273.78	-63.36	-18.8%
Mathematical Sciences (DMS)	237.69	-	203.26	-34.43	-14.5%
Physics (PHY)	310.75	-	247.50	-63.25	-20.4%
Office of Multidisciplinary Activities (OMA)	60.39	-	100.02	39.63	65.6%
Total	**$1,503.41**	**-**	**$1,255.82**	**-$247.59**	**-16.5%**

About MPS

The MPS FY 2020 Request builds on past efforts and aligns with NSF priorities for FY 2020. The programs in MPS span from individual investigator awards to large, multi-user facilities. MPS-funded science spans an enormous range as well: from the smallest objects and shortest times ever studied to distances and times that are the size and age of the universe. Individual investigators and small teams receive most awards, but centers, institutes, and facilities are all integral to MPS-funded research.

The MPS FY 2020 Request is influenced by four key priorities: (1) sustaining core research programs, (2) supporting the highest priority facilities, (3) supporting early-career investigators, and (4) providing funding for targeted basic research in NSF-Wide Investments, including the NSF Big Ideas.

MPS continues to support its core areas of science (astronomical sciences, chemistry, materials research, mathematical sciences, and physics) as well as thet next generation of scientists. Early-career investigators continue to be a priority, and are supported via the CAREER program, MPS core programs, and by crosscutting programs in which MPS participates.

MPS is the steward of funds designated for NSF Big Ideas: QL and WoU. These convergent activities will enable pursuit of fundamental research in quantum-enabled sciences and technologies and multi-messenger astrophysics. By exploiting quantum phenomena such as superposition, entanglement, and squeezing, the 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 workforce in quantum information sciences. The 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. For more information about the NSF Big Ideas, see the NSF-Wide Investments chapter.

MPS provides approximately 50 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	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Advanced Manufacturing	$112.37	-	$112.37	-	-
Artificial Intelligence (AI)	25.51	-	32.33	6.82	26.7%
CAREER	82.86	-	68.39	-14.47	-17.5%
I-Corps™	1.70	-	1.70	-	-
Microelectronics and Semiconductors	13.40	-	13.40	-	-
Quantum Information Sciences (QIS)	56.65	-	58.12	1.47	2.6%
SaTC	1.49	-	1.00	-0.49	-32.9%
UtB	22.02	-	11.80	-10.22	-46.4%
BRAIN Initiative	*22.02*	*-*	*11.80*	*-10.22*	*-46.4%*
NSF's Big Ideas					
QL Stewardship	*-*	*-*	*30.00*	*30.00*	*N/A*
WoU Stewardship	*-*	*-*	*30.00*	*30.00*	*N/A*

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

- Advanced Manufacturing: In FY 2020, MPS will focus advanced manufacturing investments on activities that develop new methods, processes, analyses, tools or equipment for new or existing manufacturing products, supply chain components, or materials. These developments will yield advantages such as reduced time to market, new performance attributes, improved small-batch production, cost savings, energy savings, or reduced environmental impact from the manufacturing of products.

- AI: MPS, together with other NSF directorates/offices, will increase support for artificial intelligence research and development. A key focus will be on supporting basic research in machine learning and deep learning.

- CAREER: Supporting the next generation of researchers remains a priority for MPS, and the CAREER Program continues to be a mechanism for recognizing the most innovative early career investigators. MPS anticipates approximately 130-150 CAREER awards.

- 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.

- Microelectronics and Semiconductors: MPS, together with other NSF directorates/offices, will continue to support research to address fundamental science questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor and microelectronic technologies, with a focus on materials. Research in semiconductors and microelectronics is critical to future advances and security in information technology, communications, sensing, smart electric grid, transportation, health, advanced manufacturing, and other areas. The investment will strengthen America's capabilities and capacity for revolutionary microelectronics design, architecture, and fabrication, as well as high-performance computing.

- QIS: MPS, together with other NSF directorates/offices, will increase support for quantum information science research and development, which strongly aligns with the Administration's National Quantum Initiative to consolidate and expand the U.S.' world-leading position in fundamental quantum research and 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 the laser, transistor, 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.

- UtB including the BRAIN Initiative: MPS will continue to invest in the scientific understanding of the full complexity of the brain.

- QL: MPS is the steward for QL, an NSF Big Idea that will build upon and extend our existing knowledge of the quantum world to observe, manipulate, and control, from first principles, the behavior of particles at atomic and subatomic scales. It 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. These advances will unleash the potential of the Nation's quantum-based scientific enterprise to enhance the Nation's well-being, economy, and security.

- WoU: MPS is the steward for WoU, and together with GEO/OPP, will increase support for research in the "windows"—electromagnetic waves, high-energy particles, and gravitational waves, of multi-messenger astrophysics (MMA). Through WoU investments, the MMA research community will understand the universe as never before and enable the U.S. to maintain leadership at the forefront of the astronomical sciences. NSF will 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 Facilities and Centers Programs

In FY 2020, MPS will invest $88.0 million for Centers, accounting for roughly seven percent of the MPS budget. MPS is maintaining commitments to Science and Technology Centers, the Materials Centers, and the Centers for Chemical Innovation. Operations and maintenance funding for MPS-supported major multi-user facilities comprises approximately 24.0 percent of MPS's FY 2020 Request. MPS has increased operations budgets for facilities to maintain current operational capacity. Where increases were not possible, MPS has maintained operations budgets as close to constant as possible.

MPS Funding for Centers Programs
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$83.22**	**-**	**$88.00**	**$4.78**	**5.7%**
Centers for Chemical Innovation (CHE)	22.01	-	19.00	-3.01	-13.7%
Materials Centers (DMR)	46.40	-	54.00	7.60	16.4%
STC: Center for Integrated Quantum Materials (DMR)	5.00	-	5.00	-	-
STC: STC for Real-Time Functional Imaging (DMR)	5.00	-	5.00	-	-
STC: Center for Bright Beams (PHY)	4.81	-	5.00	0.19	4.0%

For detailed information on NSF Centers programs, please see the NSF-Wide Investments chapter.

MPS Funding for Major Multi-User Facilities
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$388.06**	**-**	**$297.82**	**-$90.24**	**-23.3%**
Arecibo Observatory[1]	8.10	-	2.13	-5.97	-73.7%
Atacama Large Millimeter Array (ALMA)	38.55	-	47.26	8.71	22.6%
Cornell High Energy Synchrotron Source (CHESS)[2]	14.00	-	5.00	-9.00	-64.3%
Daniel K. Inouye Solar Telescope (DKIST)[3]	24.00	-	19.01	-4.99	-20.8%
Gemini Observatory[4]	34.02	-	20.28	-13.74	-40.4%
IceCube Neutrino Observatory (IceCube)	3.50	-	3.50	-	-
Large Hadron Collider (LHC)[5]	32.46	-	20.00	-12.46	-38.4%
Large Synoptic Survey Telescope (LSST)[6]	11.10	-	-	-11.10	-100.0%
Laser Interferometer Gravitational Wave Observatory (LIGO)[7]	49.43	-	45.00	-4.43	-9.0%
National High-Magnetic Field Laboratory (NHMFL)[4,8]	54.16	-	36.78	-17.38	-32.1%
National Optical Astronomy Observatory (NOAO)[4]	26.76	-	22.91	-3.85	-14.4%
National Radio Astronomy Observatories (NRAO)[4,9,10]	44.46	-	38.40	-6.06	-13.6%
National Solar Observatory (NSO)[4]	8.82	-	4.13	-4.69	-53.2%
National Superconducting Cyclotron Laboratory (NSCL)	24.00	-	22.00	-2.00	-8.3%
Other MPS Facilities	14.70	-	11.42	-3.28	-22.3%
Center for High Resolution Neutron Scattering (CHRNS)	2.79	-	3.00	0.21	7.5%
Long Baseline Observatory (LBO)[10]	3.49	-	-	-3.49	-100.0%
Green Bank Observatory (GBO)	8.42	-	8.42	-	-

[1] FY 2018 Actual includes $2.0 million of supplemental funding provided in Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) for repairs related to damage from Hurricane Maria, $1.80 million to fund part of FY 2019 costs, and $580,000 for one-time costs associated with the change in management organization.

[2] FY 2018 Actual includes $10.0 million to fund part of FY 2019 costs. The FY 2020 Request reflects the transition of CHESS from an NSF stewardship to a partnership model.

[3] Includes $2.0 million for cultural mitigation activities per year, as required by the compliance process, through FY 2020. FY 2018 Actual includes $8.0 million to fund part of FY 2019 costs.

[4] FY 2018 Actual includes additional FY 2018 one-time funding above the requested amount: $13.0 million for Gemini; $10.08 million for NHMFL, $7.08 million for NOAO, $3.50 million for NRAO, and $3.50 million for NSO.

[5] FY 2018 Actual includes $16.60 million for High Luminosity-LHC development and design, of which $7.50 million funds FY 2019 and FY 2020 activities.

[6] FY 2018 Actual obligations are intended to fund pre-operations costs for the first three years of the pre-operations ramp up, FY 2019-FY 2021.

[7] FY 2018 Actual includes $10.0 million for Advanced LIGO Plus (LIGO A+) development and design.

[8] FY 2018 includes $9.34 million to fund part of FY 2019 costs.

[9] FY 2018 Actual includes $2.0 million of supplemental funding provided in Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) for repairs related to damage from Hurricane Maria.

[10] FY 2020 Request includes reintegration of the Long Baseline Observatory (LBO) into NRAO as the Very Long Baseline Array (VLBA) at $3.43 million per year.

For detailed information on individual facilities, please see the Facilities and the Major Research Equipment and Facilities Construction chapters.

Funding Profile

MPS Funding Profile

	FY 2018 Actual Estimate	FY 2019 (TBD)	FY 2020 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,804	-	9,000
Number of New Awards	2,594	-	2,200
Funding Rate	29%	N/A	24%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,619	-	8,000
Number of Research Grants	2,072	-	1,700
Funding Rate	27%	N/A	21%
Median Annualized Award Size	$123,319	-	$120,000
Average Annualized Award Size	$145,679	-	$140,000
Average Award Duration, in years	3.2	-	3.2

Program Monitoring and Evaluation

External Program Evaluations and Studies:

- AST, together with the NASA Astrophysics Division and the High Energy Physics Branch of the DOE Office of Science, commissioned a study (Review of Progress Toward the Decadal Survey Vision in New Worlds, New Horizons in Astronomy and Astrophysics) of the mid-term status of agency responses to the 2010 decadal survey in astronomy and astrophysics, through the Space Studies Board of the National Academies of Science, Engineering, and Medicine (the National Academies). The resulting National Academies mid-term review committee report was published in August 2016.[1] Findings and recommendations of the "mid-decadal" report will guide AST decision making and prioritization until superseded by the next "decadal" report, expected in 2021.
- The Astronomy and Astrophysics Advisory Committee (AAAC) met on three occasions during early FY 2018, subsequently completing and delivering its annual report[2] in March 2018 on interagency activities by NSF, the Department of Energy (DOE), and the National Aeronautics and Space Administration (NASA). Findings and recommendations of this annual report help guide AST decision making and prioritization.
- DMR co-sponsored, with DOE/BES, a National Academies Decadal Study, entitled *Frontiers of Materials Research: A Decadal Study*.[3] This study, initiated in FY 2016 and completed and published in FY 2019, produced several large and overarching findings and recommendations. The report cited infrastructure, including materials growth and synthesis and advanced characterization and measurement instruments, as areas that need more sustained support. The report also endorsed the recommendations found in the Interagency 2017 Polymer Decadal Study, *Frontiers in Polymer Science and Engineering*,[4] including emphasis on materials sustainable development.
- Pursuant to the National Environmental Policy Act of 1969, AST prepared an Environmental Impact Statement (EIS) for Green Bank Observatory, which was published in February 2019.[5] The Green Bank

[1] http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_161177
[2] www.nsf.gov/mps/ast/aaac.jsp
[3] www.nap.edu/catalog/25244/frontiers-of-materials-research-a-decadal-survey
[4] www.iprime.umn.edu/sites/g/files/pua2396/f/frontiers_in_polymer_science_and_engineering_2016_nsf_workshop_report.pdf
[5] www.nsf.gov/mps/ast/env_impact_reviews/env_rev_greenbank.jsp

EIS studies and evaluates the potential environmental effects of proposed operational changes to Green Bank Observatory due to funding constraints. During the process of preparing the final report the general public has several opportunities to review draft documents and provide external, independent formal input into the formulation of the final EIS.

- The CHE CCI program is currently being assessed, with the evaluation being conducted by Abt Associates, Inc. The study final results are expected in 2019.
- At the request of AST and the DOE, in August 2018 the AAAC established an ad hoc subcommittee to consider and advise AST regarding the evolving roles of the Gemini, Blanco, and SOuthern Astrophysical Research telescope facilities in the area of Multi-Messenger and Time Domain astronomy and astrophysics. The subcommittee held several meetings and provided its report to the AAAC in FY 2019.
- In FY 2018, PHY charged the MPS Advisory Committee to form a subcommittee to assess the Physics Frontiers Centers program. The subcommittee is expected to deliver a report of its findings in FY 2019.
- In FY 2019, NSF and DOE jointly charged the Nuclear Science Advisory Committee (NSAC) to identify unique opportunities for U.S. nuclear physics research to contribute to advances in Quantum Computing and QIS. The report from NSAC is expected later in FY 2019.
- In FY 2018, PHY made an award to the National Academies to initiate the next Decadal Assessment of Plasma Science. The NSF award was co-funded by AST, GEO Division of Atmospheric and Geospace Sciences, and ENG Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET). The study is also co-sponsored by DOE, the Air Force Office of Scientific Research (AFOSR), and the Office of Naval Research. The National Academies report is expected in FY 2020.
- In FY 2019, PHY charged the National Academies with a Decadal Survey of Atomic, Molecular, and Optical Physics, together with DOE/BES. The National Academies report is expected in FY 2020.
- In FY 2019, MPS/CHE, in collaboration with the DOE/Basic Energy Sciences (BES)/Chemical Sciences, Geosciences and Biosciences will initiate an evaluation of overall grand challenges in the field of chemistry. Results are expected to be used to inform the scope of core funding activities and future solicitations and DCLs. Final results from this study are expected in 2020.

Workshops and Reports:

- In January 2018, the current NSF Astronomy and Astrophysics Postdoctoral Fellows organized their 16th annual AST-funded symposium[6] just prior to the American Astronomical Society meeting at National Harbor. Each fellow made two presentations, one on current research and the other on creative contributions to education and outreach.
- In March 2018, the CHE workshop report on "Framing the Role of Big Data and Modern Data Science in Chemistry" was published.[7] The workshop report articulates the role of big data research and modern data science in chemistry. The report addresses the short- and long-term needs that should be met to fully develop this potential and offers suggestions on how this development could be supported.
- In May 2018, Columbia University held a symposium, funded in part by AST, to celebrate and assess 10 years of its NSF-funded Bridge Program, a structured post-baccalaureate transition program for underrepresented minority STEM students interested in admission to competitive PhD programs.
- In May 2018, AST, PHY, and CISE Office of Advanced Cyberinfrastructure sponsored a workshop titled *Cyberinfrastructure for Multi-Messenger Astrophysics* to develop concepts for new community-scale data cyberinfrastructure for timely handling, processing, analysis, and modeling of multi-messenger astrophysical data. The workshop report was published[8] in July 2018.
- In May 2018, a PHY-sponsored workshop[9] on *Developing Flexible and Robust Software in Computational Atomic and Molecular Physics* was held at the Institute for Theoretical Atomic

[6] http://aapf-fellows.org/symposium/2018

[7] www.nsf.gov/mps/che/workshops/data_chemistry_workshop_report_03262018.pdf

[8] https://arxiv.org/abs/1807.04780

[9] www.cfa.harvard.edu/itamp-event/developing-flexible-and-robust-software-computational-atomic-and-molecular-physics-0

Molecular and Optical Physics. The workshop's aim was to identify and prioritize outstanding problems in atomic, molecular and optical physics, which would benefit from a focused community effort to develop new software tools and algorithms. A workshop report is planned for FY 2019.

- DMR sponsored several educational and outreach activities, such as a Young Investigators Workshop[10] in June 2018, and the Quantum Science Summer School,[11] at Cornell University in June 2018, which was supported by NSF, DOE, and AFOSR.
- In October 2018, AST funded a workshop for the PIs of all the NSF Research Experience for Undergraduates Astronomy sites. It was held in conjunction with the Council on Undergraduate Research meeting in Alexandria, Virginia. The purpose was to exchange best practices on key issues, such as recruitment of underrepresented minorities.
- In October 2018, PHY cosponsored a workshop titled *Deep Learning for Multi-messenger Astrophysics: Real-time Discovery at Scale*. A workshop report was published[12] in February 2019.
- In October 2018, DMS sponsored a workshop titled "Statistics at a Crossroads: Challenges and Opportunities in the Data Science Era." The workshop focused on identifying the emerging frontiers of research in statistics and their connections to HDR. The final report will be available in 2019.
- In FY 2018, AST, DMR, and PHY co-funded the 2018 Conference of the National Society of Black Physicists, held in Columbus, Ohio, November 4-7, 2018. Other NSF sponsors are GEO and EHR.
- In November 2018, PHY and BIO Division of Molecular and Cellular Biosciences sponsored a workshop titled *Quantum Biology and Quantum Processes in Biology* that brought together biologists and physical scientists to discuss the role of quantum phenomena in biological systems.
- In November 2018, DMS sponsored a PI workshop on the DMS Research Training Groups (RTG) program. The workshop focused on evaluating the program in terms of broadening participation, innovation, vertical integration, and sustainability and on developing best practices in these areas. The report for RTG has been completed and published.[13]
- In November 2018, DMS sponsored a workshop titled "Graduate Statistics Curriculum at a Crossroads." The workshop focused on identifying challenges and barriers in graduate education in statistics and workforce development in connection to HDR. The final report will be available in 2019.
- In November 2018, DMS sponsored a workshop titled "Rules of Life in the Context of Future Mathematical Sciences". The workshop focused on identifying the emerging frontiers of research in Mathematical Biology and their connections to URoL. The final report will be available in 2019.
- In December 2018, CHE and DMS co-sponsored a Data Science Innovation Lab "Learning the Power of Data in Chemistry" to promote new collaborations between data scientists and chemists for effective collection, analysis, and interpretation of chemical data. This Lab catalyzed new research directions in chemical and mathematical research for solving transformative chemical challenges of the 21st century.
- In FY 2018, CHE partnered with DOE and CBET to support a National Academies consensus study to advance topics for fundamental research in chemical separations science across many application areas—chemical analysis, energy production, waste management, water treatment, chemical manufacturing, recovery of critical resources, mining, paper production, and more. The final report is anticipated in FY 2021.
- DMR organized and sponsored meetings in collaboration with other government agencies and across NSF. Working with DOE/BES, DMR co-sponsored meetings of the Condensed Matter and Materials Research Committee, a standing committee of the National Academies, and in collaboration with ENG Division of Civil, Mechanical & Manufacturing Innovation and AFOSR, DMR organized a joint NSF-

[10] http://reg.conferences.dce.ufl.edu/Physics/1482
[11] http://qs3.mit.edu/index.php/qs3-school-2017/2018-program
[12] https://arxiv.org/abs/1902.00522
[13] www.nsf.gov/mps/dms/documents/RTG_Program_Meeting_Report.pdf

AFOSR-Air Force Research Laboratory workshop in the summer of 2018 focused on Additive Manufacturing.

- In support of the NSF Big Idea QL, DMR, in collaboration with other agencies, sponsored or organized several events, including: (1) a special outreach session focused on Quantum Leap[14] at the American Physical Society Meeting; (2) an invited session chaired by Nobel Prize winner Anthony Leggett, focused on Majorana fermions,[15] at the Materials Research Society Spring Meeting; (3) the Chicago Quantum Summit,[16] devoted to the Quantum Exchange and Triplets programs, where the NSF director and the DMR division director delivered presentations; and (4) a Principal Investigator's Meeting on Moore's Law.[17]
- In 2018 and 2019, DMR sponsored several Gordon Research Conferences covering a wide range of topics, both disciplinary and interdisciplinary, such as granular matter, molecular materials research at high pressure, correlated electron systems, spin dynamics in nanostructures and liquid crystals, as well as several regional meetings in focused areas such as two-dimensional materials, nanomechanical systems, quantum materials, and electronic and photonic materials.
- In January 2019, CHE, PHY, DMR and CISE supported a workshop on "Enabling Quantum Leap: Quantum algorithms for quantum chemistry and materials." The workshop brought together researchers in the fields of chemistry, materials, physics, and computer science to explore mechanisms to advance the science, collaboration, education, and broad impacts of quantum computing as applied to quantum simulation. Industrial participants (e.g., IBM, Microsoft, and Google) demonstrated their quantum computing technologies. The workshop report is expected in summer of 2019.
- In January 2019, a PHY-sponsored workshop titled *Large Ultrahigh-Vacuum Systems for Frontier Scientific Research Instrumentation* was held at the LIGO Livingston site. The goals were to compare vacuum needs of future research facilities and to explore recent advances, new insights, and novel concepts that could render major cost savings in their realization. A report will be published in FY 2019.
- CHE's fourth annual Early Career Investigator Workshop will be held on May 20-21, 2019 in Alexandria, Virginia. The workshop is designed to help about 80 early career faculty in chemistry better design and integrate research, education and outreach goals, while obtaining personalized formative feedback on their research ideas, projects, and plans. The National Institutes of Health (NIH), DOE, AFOSR, Environmental Protection Agency, and other federal agencies will participate.

Committees of Visitors (COV):

- In 2018, there were no COVs in MPS.
- In 2019, COVs will review AST, DMR and PHY.
- In 2020, COVs will review CHE and DMS.

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

[14] https://meetings.aps.org/Meeting/MAR18/Session/D04

[15] https://mrsspring2018.zerista.com/event/member/464431

[16] https://quantum.uchicago.edu/events/summit2018/

[17] https://sites.google.com/georgetown.edu/nsfworkshop2018/home

People Involved in MPS Activities

Number of People Involved in MPS Activities

	FY 2018 Actual Estimate	FY 2019 (TBD)	FY 2020 Estimate
Senior Researchers	8,954	-	7,600
Other Professionals	3,562	-	3,000
Postdoctoral Associates	2,276	-	1,900
Graduate Students	9,224	-	8,200
Undergraduate Students	5,668	-	5,400
Total Number of People	**29,684**	**-**	**26,100**

DIVISION OF ASTRONOMICAL SCIENCES (AST) **$217,080,000**
-$94,080,000 / -30.2%

AST Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$311.16**	**-**	**$217.08**	**-$94.08**	**-30.2%**
Research	**65.35**	**-**	**43.44**	**-21.91**	**-33.5%**
CAREER	4.17	-	5.00	0.83	19.9%
Education	**4.73**	**-**	**4.70**	**-0.03**	**-0.6%**
Infrastructure	**241.08**	**-**	**168.94**	**-72.14**	**-29.9%**
Arecibo Observatory[1]	8.10	-	2.13	-5.97	-73.7%
ALMA	38.55	-	47.26	8.71	22.6%
AST Portfolio Review Implementation	0.24	-	-	-0.24	-100.0%
DKIST[2]	24.00	-	19.01	-4.99	-20.8%
Gemini Observatory[3]	34.02	-	20.28	-13.74	-40.4%
LSST[4]	11.10	-	-	-11.10	-100.0%
Midscale Research Infrastructure	32.98	-	5.00	-27.98	-84.8%
NOAO[3]	25.09	-	22.91	-2.18	-8.7%
NRAO[3,5,6]	44.46	-	38.40	-6.06	-13.6%
NSO[3]	8.82	-	4.13	-4.69	-53.2%
Other AST Facilities	11.91	-	8.42	-3.49	-29.3%
LBO[6]	*3.49*	-	-	*-3.49*	*-100.0%*
GBO	*8.42*	-	*8.42*	-	-
Research Resources	1.81	-	1.40	-0.41	-22.5%

[1] FY 2018 Actual includes $2.0 million of supplemental funding provided in Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) for repairs related to damage from Hurricane Maria, $1.80 million in fund part of FY 2019 costs, and $580,000 million for one-time costs associated with the change in management organization.

[2] Includes $2.0 million for cultural mitigation activities per year, as required by the compliance process, through FY 2020. FY 2018 Actual includes $8.0 million to fund part of FY 2019 costs.

[3] FY 2018 Actual includes additional FY 2018 one-time funding above the requested amount: $13.0 million for Gemini; $5.42 million for NOAO, $3.50 million for NRAO, and $3.50 million for NSO.

[4] FY 2018 Actual obligations are intended to cover pre-operations costs for the first three years of the pre-operations ramp up, FY 2019-FY 2021.

[5] FY 2018 Actual includes $2.0 million of supplemental funding provided in Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) for repairs related to damage from Hurricane Maria.

[6] FY 2020 Request includes reintegration of the Long Baseline Observatory (LBO) into NRAO as the Very Long Baseline Array (VLBA) at $3.43 million per year.

About AST

AST is the federal steward for ground-based astronomy in the United States, funding research with awards to individual investigators and small research groups and via cooperative agreements for the operation of large telescope facilities. These 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 making archived data products 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, of the possibility of life existing on planets circling other stars, and of the nature of the mysterious dark matter and dark energy that comprise more than 95 percent of the mass-energy of the universe.

AST is substantially engaged in NSF's Big Ideas, including WoU, Mid-scale RI, HDR, and QL. AST co-leads WoU which will probe the universe through several powerful and diverse "windows"—electromagnetic waves, high-energy particles, and gravitational waves. Breakthroughs in astronomical sciences are often enabled by the availability of new facilities and instrumentation. Additionally, with the enormous volumes of data produced by individual astronomical facilities (e.g. 20 terabytes per night at LSST), AST programs are directly relevant to HDR, engaging the research community in pursing data science research toward solving AST related data science problems.

In general, about 23 percent of the AST portfolio is available for new research grants. About 78 percent of AST's budget supports the instrumentation and facilities needed for progress at the frontiers of observational astronomy, while 20 percent supports the research of individual investigators. Through the MREFC appropriation, AST also oversees the construction of LSST and DKIST. For detailed information on individual facilities, please see the Facilities and the Major Research Equipment and Facilities Construction chapters.

DIVISION OF CHEMISTRY (CHE) **$214,180,000**
-$32,110,000 / -13.0%

CHE Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Percent
Total	**$246.29**	**-**	**$214.18**	**-$32.11**	**-13.0%**
Research	**231.98**	**-**	**199.68**	**-32.30**	**-13.9%**
CAREER	28.68	-	21.57	-7.11	-24.8%
Centers Funding (total)	22.01	-	19.00	-3.01	-13.7%
Centers for Chemical Innovation	22.01	-	19.00	-3.01	-13.7%
Education	**4.33**	**-**	**2.60**	**-1.73**	**-40.0%**
Infrastructure	**9.98**	**-**	**11.90**	**1.92**	**19.2%**
NHMFL	1.73	-	1.73	-	-
NNCI[1]	0.30	-	-	-0.30	-100.0%
Midscale Research Infrastructure	-	-	5.00	5.00	N/A
Research Resources	7.95	-	5.17	-2.78	-35.0%

[1] The FY 2020 Request reflects the completion of CHE's contribution to NNCI in FY 2019.

About CHE

The chemical industry is one of the largest and most important industries worldwide both in terms of impact on the economy and employment. This industry includes sectors in energy, pharmaceuticals and medical applications, electronics, agriculture, textiles, plastics, coatings, building products, and numerous other commercial and consumer products. Specifically, CHE enables research on the synthesis and characterization of new molecules, surfaces, and nanostructures (by both theoretical and experimental methods) that leads to usable products beneficial to all of society.

CHE contributes to several of NSF's Big Ideas including: HDR, by promoting data sciences to effectively and efficiently use the extensive volumes and varieties of chemical data in order to advance new chemical discovery and innovation; QL, by contributing to the understanding and use of quantum phenomena in computing and sensing applications, to understanding quantum functions in living and synthetic systems, and to providing chemical algorithms suitable for testing the supremacy of quantum versus digital computing; and URoL, by increasing knowledge of the structure-function relationships in biological systems leading to important advances in understanding the human body and improving health. CHE also participates actively in convergence research encouraging researchers to integrate chemical learning and understanding with biology, engineering, materials research, geosciences, computing, and other scientific and technical fields. All of these areas not only drastically expedite chemical discovery but also have significant ramifications for training the next generation of scientists and engineers.

CHE will continue to support the REU program in FY 2020, with projected funding rates for REU Sites expected to be similar to proposals submitted to CHE core research programs.

CHE is also actively engaged in the development of new mid-scale instrumentation to examine and solve complex chemical problems including the synergistic combinations of multiple types of measurement (including remote access and cyber-enabled tools) and the development of novel, new instruments. Involvement in midscale research infrastructure programs enables tool development, which is essential for

continuing progress in fields as diverse as understanding the brain, sensing for agriculture and defense applications, discovering new chemical compounds for microelectronics and environmentally-friendly plastics, and improving the sustainable and responsible advanced manufacturing of chemical feedstocks as they transition from the lab bench to commercial scales. The importance of these investments is reflected in CHE's FY 2020 funding profile with a shift in funding from small instrument to midscale chemistry infrastructure investments. CHE midscale investments are expected to impact priority areas including URoL, QL, HDR, and other frontier areas critical to chemistry.

In general, about 75 percent of the CHE portfolio is available to support new research grants. The remaining 25 percent supports research grants made in prior years and the research infrastructure needed by the chemistry community.

DIVISION OF MATERIALS RESEARCH (DMR) **$273,780,000**
-$63,360,000 / -18.8%

DMR Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$337.14**	**-**	**$273.78**	**-$63.36**	**-18.8%**
Research	**244.68**	**-**	**204.37**	**-40.31**	**-16.5%**
CAREER	23.95	-	23.04	-0.91	-3.8%
Centers Funding (total)	56.40	-	64.00	7.60	13.5%
Materials Centers	46.40	-	54.00	7.60	16.4%
STC: Center for Integrated Quantum Materials	5.00	-	5.00	-	-
STC: Real-time Functional Imaging	5.00	-	5.00	-	-
Education	**5.14**	**-**	**2.13**	**-3.01**	**-58.6%**
Infrastructure	**87.31**	**-**	**67.28**	**-20.03**	**-22.9%**
CHESS[1]	14.00	-	5.00	-9.00	-64.3%
CHRNS	2.79	-	3.00	0.21	7.6%
Midscale Research Infrastructure[2]	9.71	-	20.20	10.49	107.9%
NHMFL[3]	52.43	-	35.05	-17.38	-33.1%
NNCI	2.58	-	2.58	-	-
Research Resources[4]	5.80	-	1.45	-4.35	-75.0%

[1] FY 2018 Actual includes $10.0 million to fund part of FY 2019 costs. The FY 2020 Request reflects the transition of CHESS from an NSF stewardship to a partnership model.

[2] FY 2018 Actual includes forward funding of $6.0 million to support the Materials Innovation Platform program. FY 2020 reflects a new competition, with up to four Materials Innovation Platform awards to be funded.

[3] FY 2018 Actual includes additional FY 2018 one-time funding in the amount of $10.08 million above the requested amount for facility upgrades, and $9.34 million to fund part of FY 2019 costs.

[4] FY 2018 Actual includes an investment of $4.35 million to support additional Major Research Instrumentation awards. This investment will not be funded in FY 2020.

About DMR

DMR invests in the discovery of new materials and the explanation of materials phenomena. Materials are ubiquitous and pervasive, serving as the critical building block to modern technology and innovation. DMR supports basic experimental and theoretical materials research via programs focused on condensed matter physics; solid-state and materials chemistry; and the science of materials that are ceramic, metallic, polymeric, nano-structured, biological, electronic, photonic, and multifunctional. The discovery and deployment of new materials have shaped our understanding of our world and enabled significant advances in electronics, communications, transportation, and health fields. This enterprise is dependent on investments across scales: from single investigators to teams and centers, from singularly focused research to that requiring interdisciplinarity, and from small instruments to large-scale facilities.

DMR contributes to several Big Ideas, including QL, HDR, and URoL, as well as maintaining divisional programs in midscale research infrastructure and convergence research that complement the Mid-scale RI and GCR. In addition, DMR advances administration priorities in Advanced Manufacturing and the Materials Genome Initiative through the Designing Materials to Revolutionize and Engineer our Future and the Materials Innovation Platform programs.

In general, about 34 percent of the DMR portfolio is available to support new research grants. The remaining 66 percent supports research grants made in prior years and the research infrastructure needed by materials research community.

DIVISION OF MATHEMATICAL SCIENCE (DMS) **$203,260,000**
-$34,430,000 / -14.5%

DMS Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$237.69**	**-**	**$203.26**	**-$34.43**	**-14.5%**
Research	**225.34**	**-**	**192.36**	**-32.98**	**-14.6%**
CAREER	15.42	-	12.00	-3.42	-22.2%
Education	**12.35**	**-**	**10.90**	**-1.45**	**-11.7%**

About DMS

DMS provides major U.S. federal support of basic research at the frontiers of mathematical sciences. Modern communication, transportation, medicine, manufacturing, energy, security, and finance all depend on new developments in the mathematical sciences. DMS investments catalyze research at the forefront of fundamental, applied and computational mathematics, and statistics necessary to support discovery and innovation in these national priority areas as well as many science and engineering fields. In turn, advances in science and engineering inspire development of more sophisticated and effective mathematical and statistical methodologies, theories, and tools. DMS investments also support the training of future researchers in the mathematical and statistical sciences.

In addition to supporting a vibrant research community through core programs in mathematics and statistics, DMS supports the Mathematical Sciences Research Institutes program that advances mathematics and statistics research, and expands the U.S. talent base engaged in mathematical and statistical research.

Through strong partnerships with other entities, DMS is able to support foundational research across a much broader set of programs. In partnership with other divisions at NSF, DMS provides support for several of the NSF Big Ideas, including HDR, URoL, and QL. Other partnerships include two joint programs in biosciences with NIH; a joint program with the National Geospatial Intelligence Agency to develop the next generation of mathematical and statistical algorithms for analysis of large spatiotemporal datasets; and a joint program on Algorithms for Modern Power Systems with DOE. Additional examples of partnerships include a joint program in data sciences with CISE to support the development of institutes called the Transdisciplinary Research in Principles of Data Science, as well as a joint program with BIO and the Simons Foundation to support research centers on the Mathematics of Complex Biological Systems.

In general, about 48 percent of the DMS portfolio is available to support new research grants each year. The remaining 52 percent supports research grants made in prior years and the research infrastructure needed by the mathematics and statistics communities.

DIVISION OF PHYSICS (PHY) **$247,500,000**
-$63,250,000 / -20.4%

PHY Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$310.75**	**-**	**$247.50**	**-$63.25**	**-20.4%**
Research	**182.35**	**-**	**145.63**	**-36.72**	**-20.1%**
CAREER	10.14	-	6.78	-3.36	-33.1%
Centers Funding (total)	4.81	-	5.00	0.19	4.0%
STC: Center for Bright Beams	4.81	-	5.00	0.19	4.0%
Education	**4.50**	**-**	**4.70**	**0.20**	**4.4%**
Infrastructure	**123.90**	**-**	**97.17**	**-26.73**	**-21.6%**
IceCube	3.50	-	3.50	-	-
LHC	15.86	-	20.00	4.14	26.1%
LIGO	39.43	-	44.60	5.17	13.1%
Midscale Research Infrastructure	14.42	-	6.67	-7.75	-53.7%
NSCL	24.00	-	22.00	-2.00	-8.3%
Research Resources	0.09	-	-	-0.09	-100.0%
Facilities Design Stage Activities (total)	26.60	-	0.40	-26.20	-98.5%
High Luminosity-LHC[1]	16.60	-	-	-16.60	-100.0%
Advanced LIGO Plus (LIGO A+)	10.00	-	0.40	-9.60	-96.0%

[1] FY 2018 Actual reflects $7.50 million of funding for FY 2019 and FY 2020 development and design. No additional funds are expected in these years.

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. As a result, the division contributes to building the foundation for several of NSF's Big Ideas including: WoU, QL, URoL, and HDR. PHY is also initiating an MREFC project to upgrade the A Toroidal LHC ApparatuS Detector (ATLAS) and Compact Muon Solenoid (CMS) detectors at the European Organization for Nuclear Research (CERN) to take advantage of the high luminosity expected in 2026 at the LHC.

In general, about 22 percent of the PHY portfolio is available for new research grants. The remaining 78 percent is used primarily to fund continuing grants made in previous years (about 42 percent) and to support operations and maintenance for four facilities that are a key part of the division portfolio (about 36 percent).

OFFICE OF MULTIDISCIPLINARY ACTIVITIES (OMA) **$100,020,000**
+$39,630,000 / 65.6%

OMA Funding
(Dollars in Millions)

	FY 2018 Actual	FY 2019 (TBD)	FY 2020 Request	Change over FY 2018 Actual Amount	Change over FY 2018 Actual Percent
Total	**$60.39**	**-**	**$100.02**	**$39.63**	**65.6%**
Research	**49.37**	**-**	**95.02**	**45.65**	**92.5%**
CAREER	0.50	-	-	-0.50	-100.0%
Big Idea: QL	-	-	30.00	30.00	N/A
Big Idea: WoU	-	-	30.00	30.00	N/A
Education[1]	**9.11**	**-**	**-**	**-9.11**	**-100.0%**
Infrastructure	**1.91**	**-**	**5.00**	**3.09**	**162.4%**
AST Portfolio Review Implementation	0.24	-	5.00	4.76	1948.0%
NOAO[2]	1.66	-	-	-1.66	-100.0%

[1] NSF INCLUDES and NSF Research Traineeship are centrally funded by EHR in FY 2020; no OMA funding is contributed to these programs.

[2] FY 2018 Actual reflects additional one-time funding above the requested amount.

About OMA

OMA co-funds research that is relevant to the broad swath of scientific disciplines represented in the five disciplinary divisions of MPS. OMA enables and facilitates MPS support of novel, challenging, or complex projects of varying scale, in both research and education, which are not readily accommodated by traditional organizational structures and procedures. This is done primarily in partnership with MPS disciplinary divisions and is especially directed at activities undertaken by multi-investigator, multidisciplinary teams, as well as cross-NSF and interagency activities.

In FY 2020, OMA funding priorities will focus on MPS-relevant Big Ideas. MPS is the steward for the NSF-wide investment of funds designated for QL. Investments will emphasize projects that engage several relevant disciplines in a convergent and interdependent manner. An important focus for OMA in FY 2020 will be strategic investments in QL, co-funding research projects to advance quantum science and technology. This Big Idea will involve, in addition to all five of the MPS divisions, ENG, CISE, and BIO, among others. 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 NSF-wide investment of funds for WoU. Participants include AST, PHY, and OPP in GEO. The 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. OMA will also invest in other multidisciplinary research that advances the basic foundations of mathematical and physical sciences and furthers NSF's investments in the Big Ideas.

OMA will also provide leadership and support for I-Corps™ activities within MPS, which began in FY 2016. OMA, in partnership with MPS disciplinary programs, purposefully invests in grants to principal investigators at Historically Black Colleges and Universities (HBCUs) to foster excellence in research. Finally, in FY 2020, OMA will continue to provide targeted support for graduate students from historically underrepresented groups via the Alliances for Graduate Education and the Professoriate (AGEP) - Graduate

Research Supplement program, which provides research supplements to projects at institutions that have an active or legacy AGEP award, and the Graduate Research Supplements to Veterans program.

In general, about 70 percent of the OMA portfolio is available to support new research grants. The remaining 30 percent supports multidisciplinary research infrastructure and education activities needed by the MPS community.