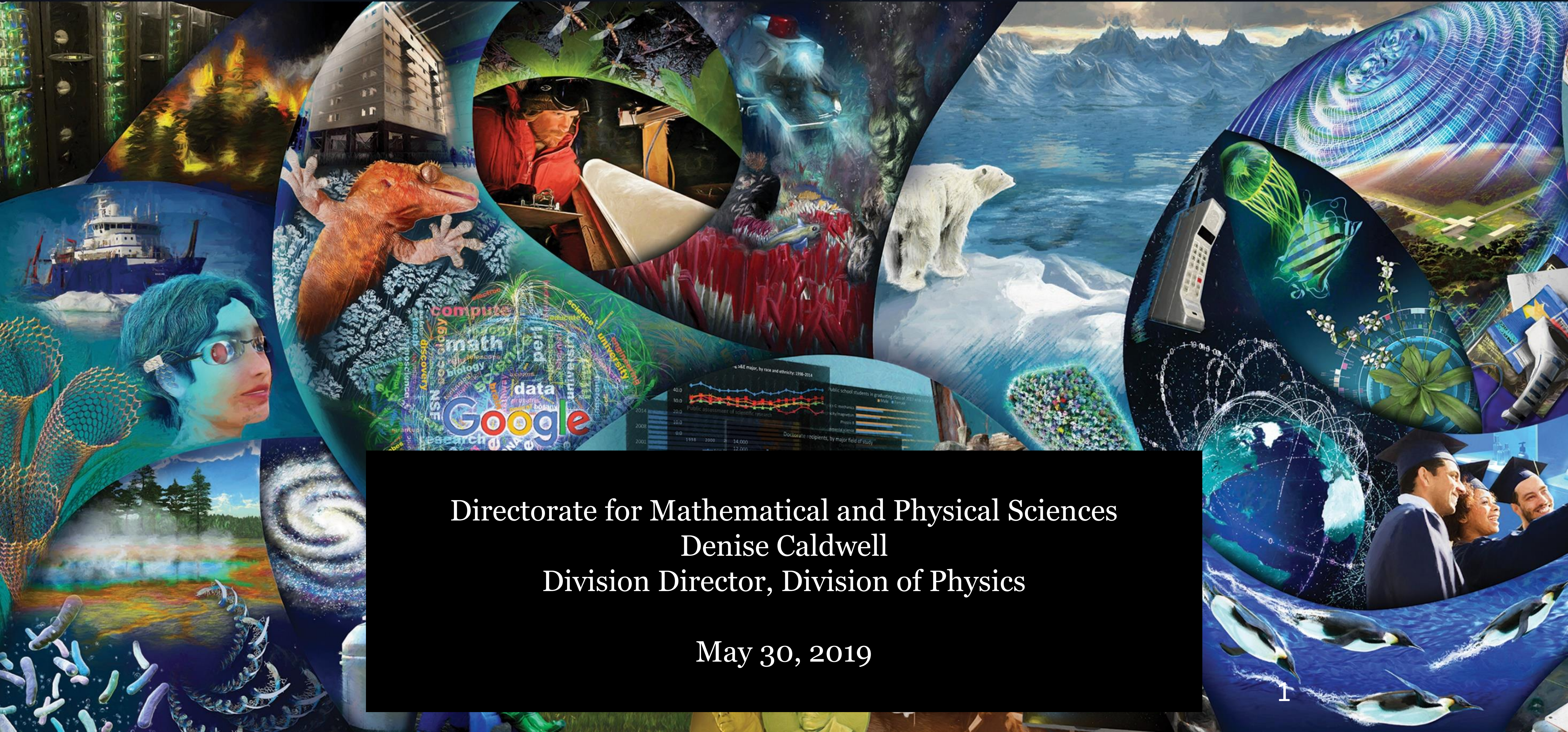
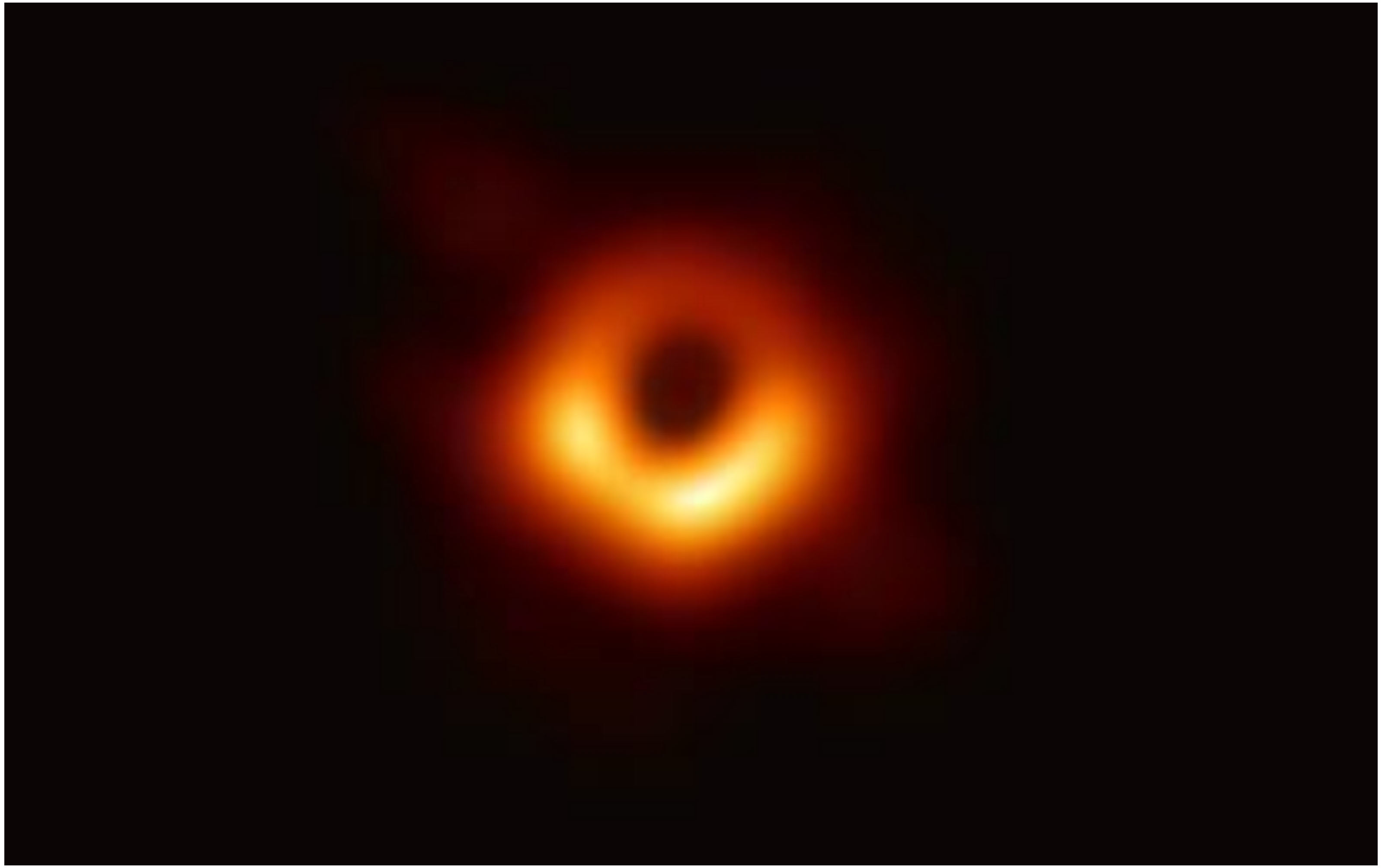
National Science Foundation
HEPAP May 2019



Directorate for Mathematical and Physical Sciences
Denise Caldwell
Division Director, Division of Physics

May 30, 2019

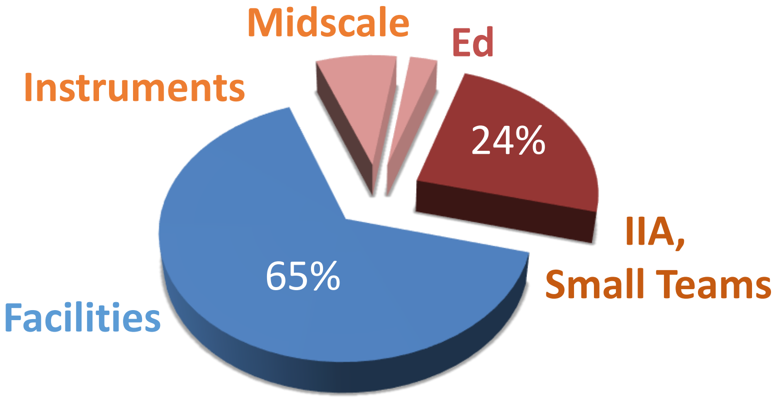
Black hole at the center of Messier 87

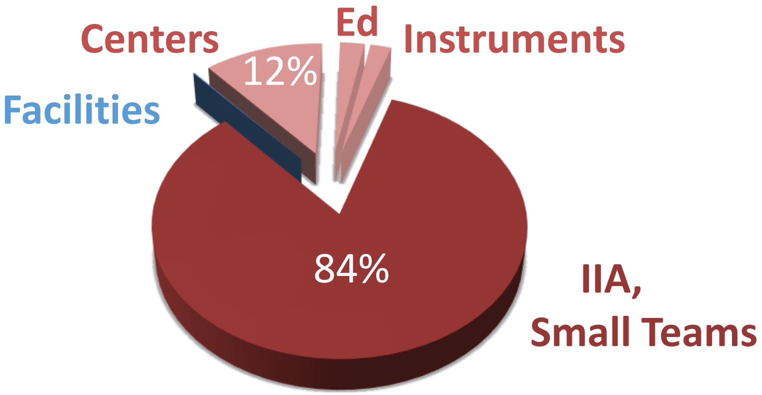


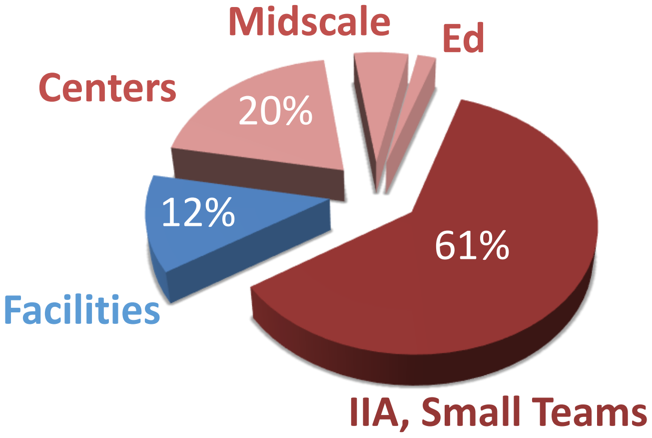
Credit: *Event Horizon Telescope collaboration et al.*

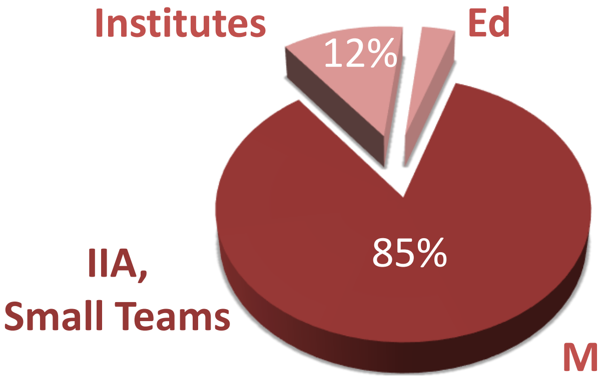
Mathematical and Physical Sciences (MPS)

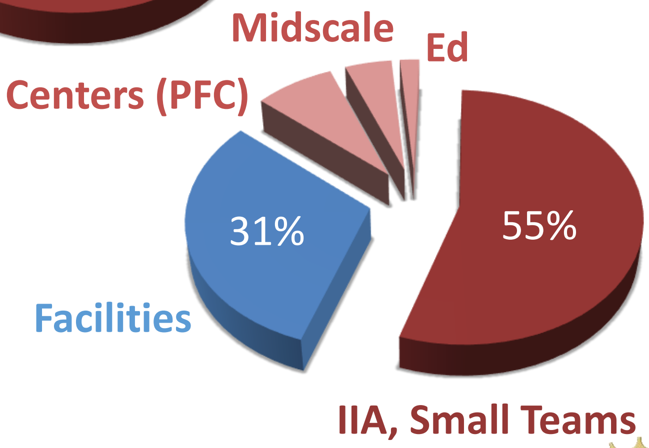
- Astronomical Sciences (AST)
- Chemistry (CHE)
- Materials Research (DMR)
- Mathematical Sciences (DMS)
- Physics (PHY)



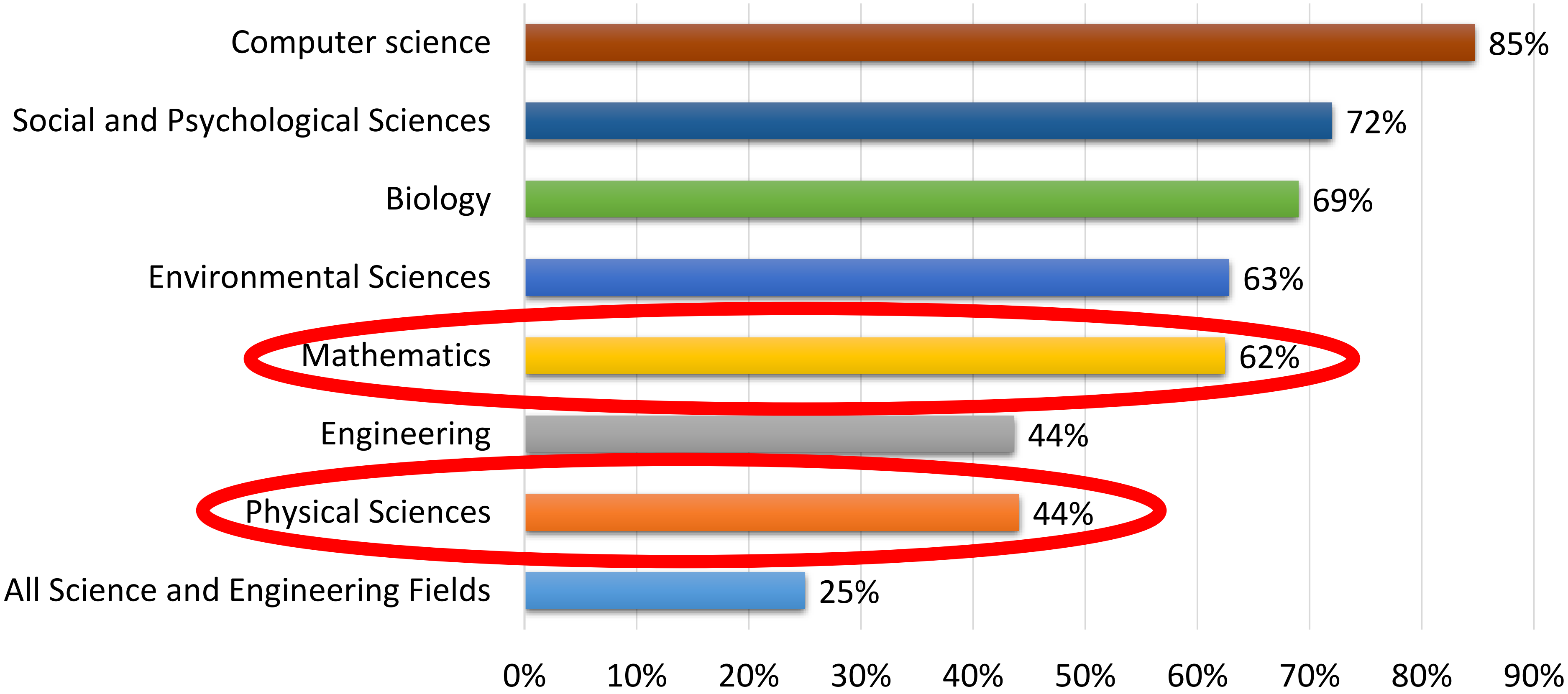








NSF Support of Academic Basic Research in Selected Fields
(as a percentage of total federal support, FY 2016)



Note: Biology includes Biological Sciences and Environmental Biology. Biology and Psychological Sciences exclude National Institutes of Health funding from the total amount of federal support.

Source: NSF/National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development

MPS by the Numbers: FY 2018

$ 1.50 B FY 2018 CP

7,619 research proposals

305 panels

27% Research award funding rate

2,072 research awards

29,684 people supported

8,954 senior researchers

3,562 other professionals

2,276 postdoctoral associates

9,224 graduate students

5,668 undergraduate students

NSF Budget Status ($M)

NSF Actual FY 2018	$ 8,040
R&RA Actual FY 2018	$ 6,380
MPS Actual FY 2018	$ 1,503
NSF Appropriated FY 2019	$ 8,339
Operating Plan under Review	
NSF Request FY 2020	$ 7,226
R&RA Request FY 2020	$ 5,663
MPS Request FY 2020	$ 1,256

Directorate Funding – FY 2020 Request

MPS 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
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%**

Includes $30M extra for Special projects

MPS is the $60 M steward of **Quantum Leap** and **Windows on the Universe** Big Ideas

MPS Priorities – FY 2020

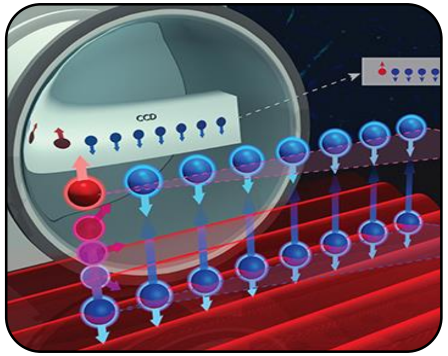
- **Emphasis on Big Ideas**
  - NSF Stewardship: Quantum Leap & Windows on the Universe
  - Expanded Participation: Harnessing the Data Revolution, Mid-Scale Research Infrastructure, and Understanding the Rules of Life
- **Strategic investments** in:
  - Fundamental research
  - Artificial Intelligence, Advanced Manufacturing, and Quantum Information Science
  - Next generation workforce
  - Large, multi-user research facilities
  - Mid-scale research infrastructure
  - External partnerships

NSF's Big Ideas for Future NSF Investments

- *Bold questions that will drive NSF's long-term research agenda*
- *Catalyze investment in fundamental research*
- *Collaborations with industry, private foundations, other agencies, universities*
- *Solve pressing problems and lead to new discoveries*

MPS FY 2020 Big Idea Investments

Steward Directorate



•**Quantum Leap** (QL) *$30.0 million*

- MPS stewards NSF's ($30 million) investment to enable fundamental research in quantum-enabled sciences and technologies, in collaboration with 11 divisions across NSF
- Develop the foundations for and enable quantum computing, sensing, communications, simulation, and other quantum technologies, including the development of the national workforce

Windows on the Universe (WoU) *$30.0 million*

- MPS stewards NSF's ($30 million) investment in multi-messenger astrophysics
- Bring together fundamental research in electromagnetic waves, high-energy particles, and gravitational waves
- Advance the study of the universe
- Grow the nation's MMA, engineering, and data science workforce

10
10

Windows on the Universe

The goal of “Windows on the Universe” is to bring electromagnetic waves, high-energy particles, and gravitational waves together to study the universe and probe events in real time in a way that was previously impossible.

Credit: LIGO Laboratory

Credit: IceCube

Credit: AURA

Neutron Star – Neutron Star Merger

GW170817

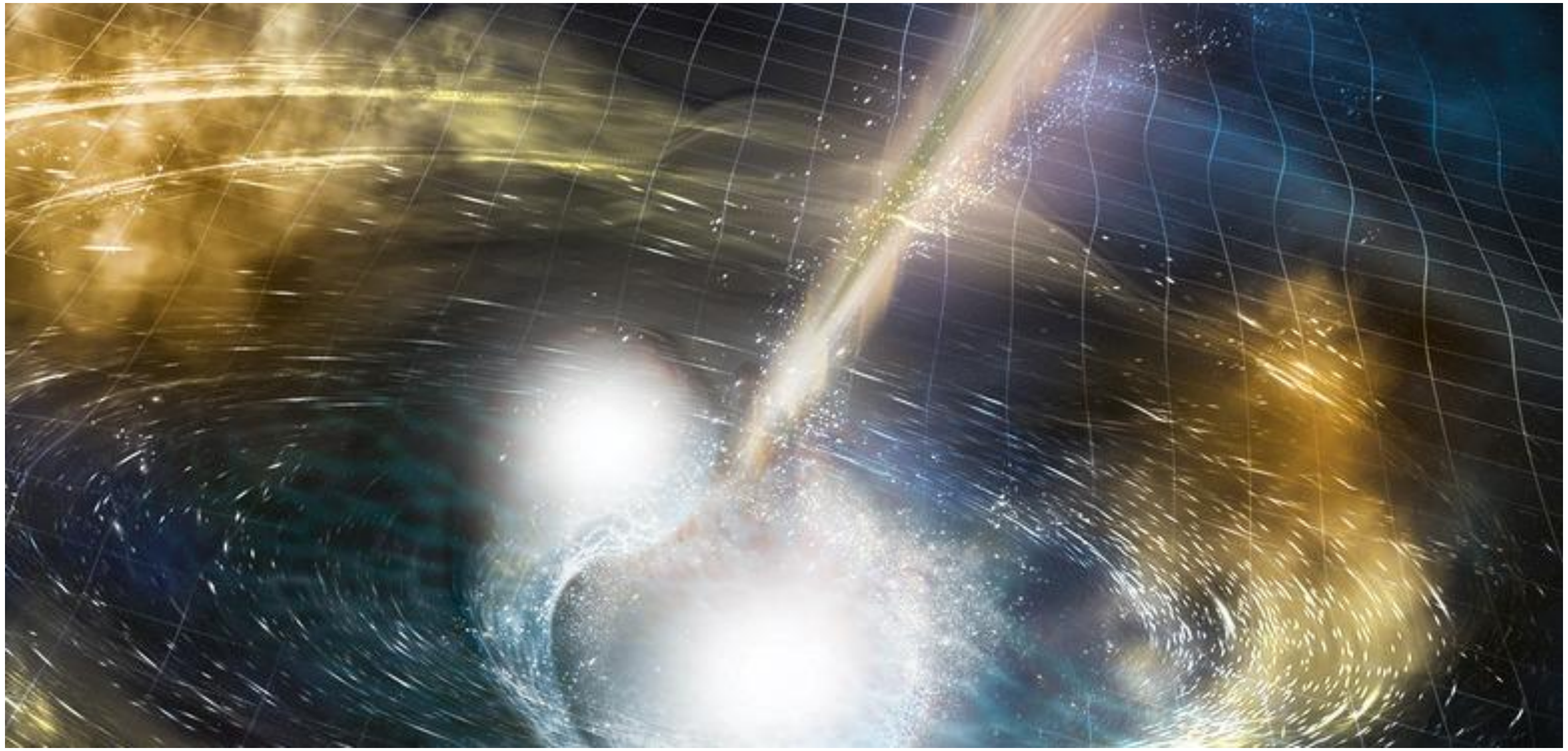
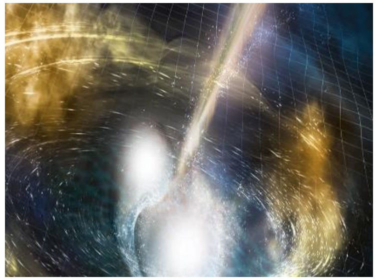


Image credit: NSF/LIGO/Sonoma State University/A. Simonnet

WINDOWS ON THE UNIVERSE: THE ERA OF MULTI-MESSENGER ASTROPHYSICS (WoU-MMA)



Metaprogram PD 18-5115

The goals of WoU-MMA are to build the capabilities and accelerate the synergy and interoperability of the three messengers to realize integrated, multi-messenger astrophysical explorations of the Universe. It has three broad areas of emphasis:

Enhancing and accelerating the theoretical, computational, and observational activities within the scientific community

Building dedicated midscale experiments and instrumentation

Exploiting current facilities and developing the next generation of observatories

MREFC Projects Status

- DKIST
  - Well into Integration, Testing, and Commissioning phase
  - On track for operations by June 2020
- LSST
  - M1M3 mirror now at telescope site
  - On track for operations in late-2022
- HL-LHC
  - In FY2020 Budget Request
  - Final Design Review (FDR) in September 2019
  - Projected start in April 2020

Status

- NSF total project cost $473 million.
- DOE LSST Camera $168 million.
- NSF construction 69% complete (March 2019).
- Remaining contingency $30.7 million (21% of Estimate to Completion) (NSF).
- 6 months schedule contingency remain.
- Survey scheduled to begin October 2022.
- Cost and schedule tight but on track.

Many Critical Activities

M1M3 system integrated and optically tested.

TMA Team in Spain. Completed; disassembly and shipping in progress.

Summit 80 Ton lift completed.

Dome panel installation begins.

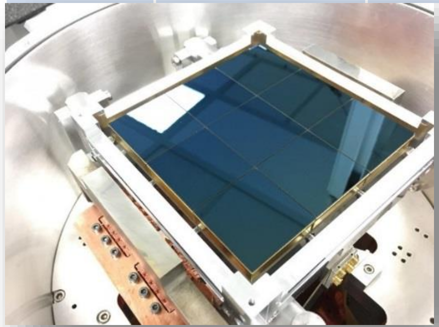
Coating Chamber arrived on summit; commissioning has begun.

M2 arrived on the summit

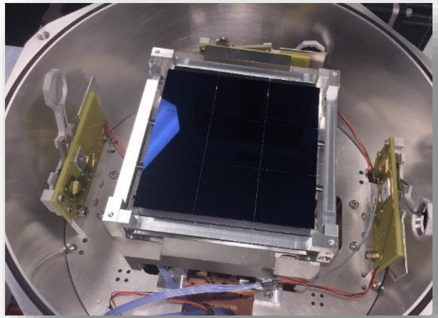
M1M3 arrived on summit and stored.

Key Camera Activities

Vendor	Received	Science Grade	Reserve	Engineering Grade
e2v	125	121	4	0
ITL	256	109	59	88
Total	381	230	63	88



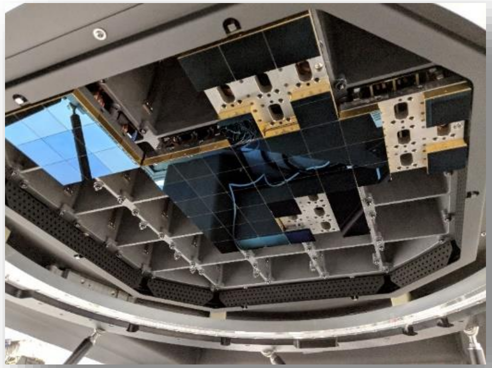
RTM8 (ITL sensors)



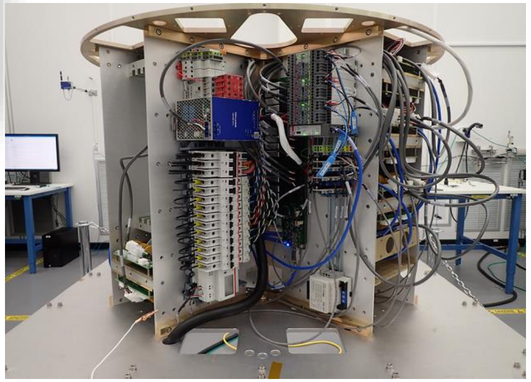
RTM6 in test Dewar (e2v sensors)

L2 lens coated and assembled in its structure

L1 Lens Coated and returned to AOS, L1 and L2 mounted



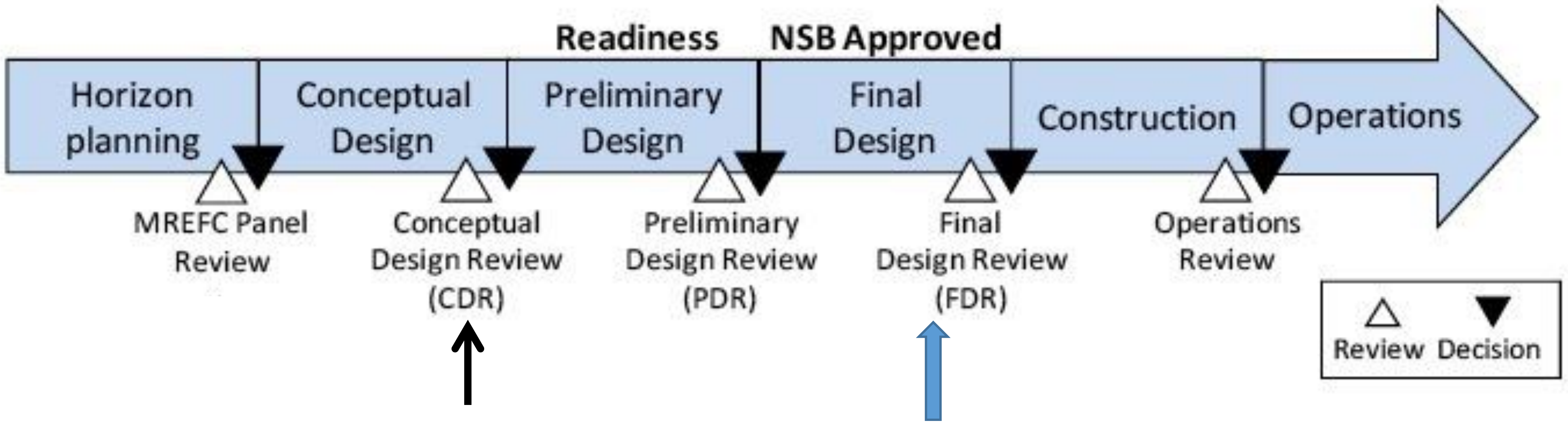
5 mechanical rafts and 2 engineering rafts inserted in the production cryostat



Utility trunk quad box during assembly

High-Luminosity LHC Upgrade

Planning for a possible MREFC in support of the high-luminosity upgrades of the ATLAS and CMS detectors at CERN; Final design review – Fall 2019



Coordinating with the DOE in support of the US-CMS and US-ATLAS Teams

NSF has identified well-defined scope independent of DOE scope

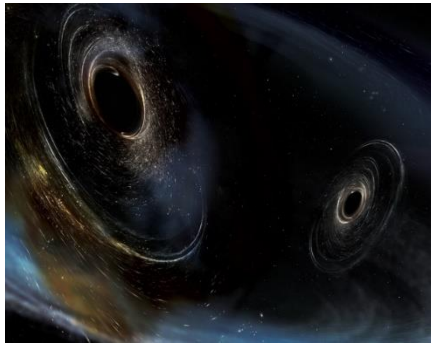
Cosmic Microwave Background (CMB)

- CMB Stage 4 goals: testing inflation, determining the number and masses of the neutrinos, constraining possible new light relic particles, providing precise constraints on the nature of dark energy, and testing general relativity on large scales.
- Two sites: South Pole and Atacama
- Fourteen small (0.5m) telescopes and three large (6m) telescopes, with 512K total detectors
- Report released to AAAC by its subcommittee on 10/23/17.
- Prioritized for DOE support in P5 report.

CMB-S4 status and near-term activity

- CMB-S4 collaboration focused on submission(s) to NRC decadal survey, due in July.
- CMB-S4 project continuing preparations; set up Integrated Project Office (IPO) under Jim Yeck.
- Interagency (NSF-DOE) coordination group meeting bi-weekly to share information, monitor, and review.

Current Status of LIGO



Third science run (O3) began April 1, 2019
Livingston detector operating at 130 MPc
Hanford detector operating at 100 MPc
Virgo detector operating at 55 Mpc
Three-way concurrent operation – 57% overall
15+ alerts released to date

All O2 data available to community; Immediate alert release

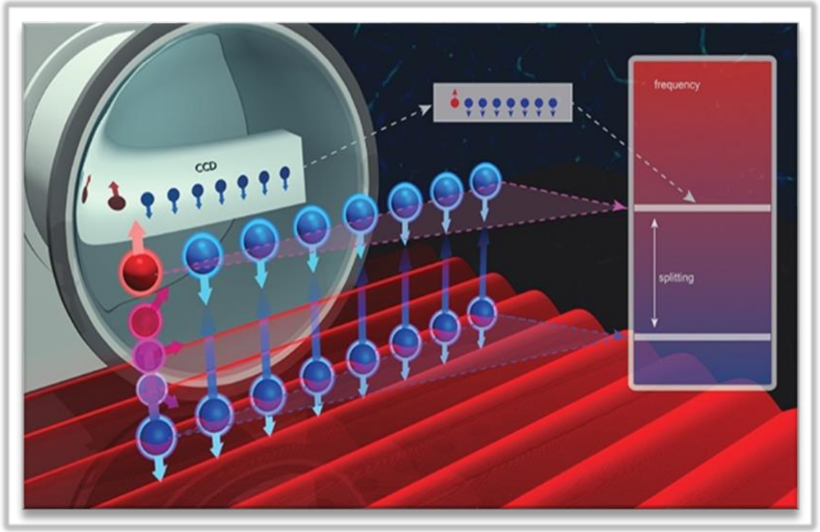
LIGO Coating Facility Funded – PHY-1707866 –Co-Funding from Gordon and Betty Moore Foundation

A+ Upgrade initiated – Co-support from UK and Australia

Generation 3 under discussion by international community

Photo Credits: LIGO Lab

Quantum Leap: Leading the next Quantum Revolution



Trapped ion computation (JQI – University of Maryland)

Today:

- lasers, atomic clocks, GPS, semiconductors, storage media

Tomorrow:

- Ultra-secure communication
- Ultra-precise sensing, measurement
- Quantum simulators
- Computing beyond the scale of supercomputing

"The Quantum Leap": Why Now?

- Advances in science & technology are enabling new opportunities for rapid advances
- International competition is extremely high. Success has implications for U.S. *economic competitiveness* and *national security.*
- Strong industrial and government interest globally.

IBM

Google

Honeywell
Microsoft
HRL Labs
Lockheed

AO Sense
Cold Quanta
Zapata
Ion Q, etc…

GORDON AND BETTY MOORE FOUNDATION

TITLE I—NATIONAL QUANTUM INITIATIVE

SEC. 101. NATIONAL QUANTUM INITIATIVE PROGRAM.

(a) IN GENERAL.—The President shall implement a National Quantum Initiative Program.

(b) REQUIREMENTS.—In carrying out the Program, the President, acting through Federal agencies, councils, working groups, subcommittees, and the Coordination Office, as the President considers appropriate, shall—

(1) establish the goals, priorities, and metrics for a 10-year plan to accelerate development of quantum information science and technology applications in the United States;

(2) invest in fundamental Federal quantum information science and technology research, development, demonstration, and other activities to achieve the goals established under paragraph (1);

(3) invest in activities to develop a quantum information science and technology workforce pipeline;

EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

NATIONAL STRATEGIC OVERVIEW FOR QUANTUM INFORMATION SCIENCE

ADVANCING QUANTUM INFORMATION SCIENCE: NATIONAL CHALLENGES AND OPPORTUNITIES

A JOINT REPORT OF THE
Committee on Science and
Committee on Homeland and National Security
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

Produced by the
Interagency Working Group on Quantum Information Science
of the Subcommittee on Physical Sciences

NSF

Recap: Enabling the Quantum Leap

DCL-RAISE-EQuIP: Engineering Quantum Integrated Platforms for Quantum Communication

DCL-RAISE-TAQS: Transformational Advances in Quantum Systems

Ideas Lab: Practical Fully-Connected Quantum Computer Challenge (PFCQC)

Enabling Practical-scale Quantum Computing: *Expeditions in Computing*

DCL: : Achieving Room-temperature quantum logic through improved low-dimensional materials

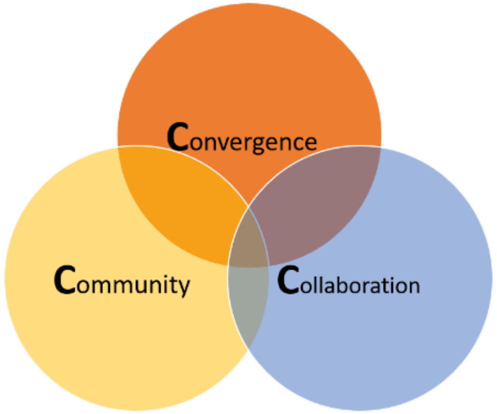
DCL: A Quantum Leap Demonstration of Topological Quantum Computing

DCL: Quantum Leap in Chemistry: molecular approaches

QISE-Net: Quantum Information Science and Engineering Network – "TRIPLETS"

NSF/DOE/AFOSR: Quantum Science Summer School; 2017-2020

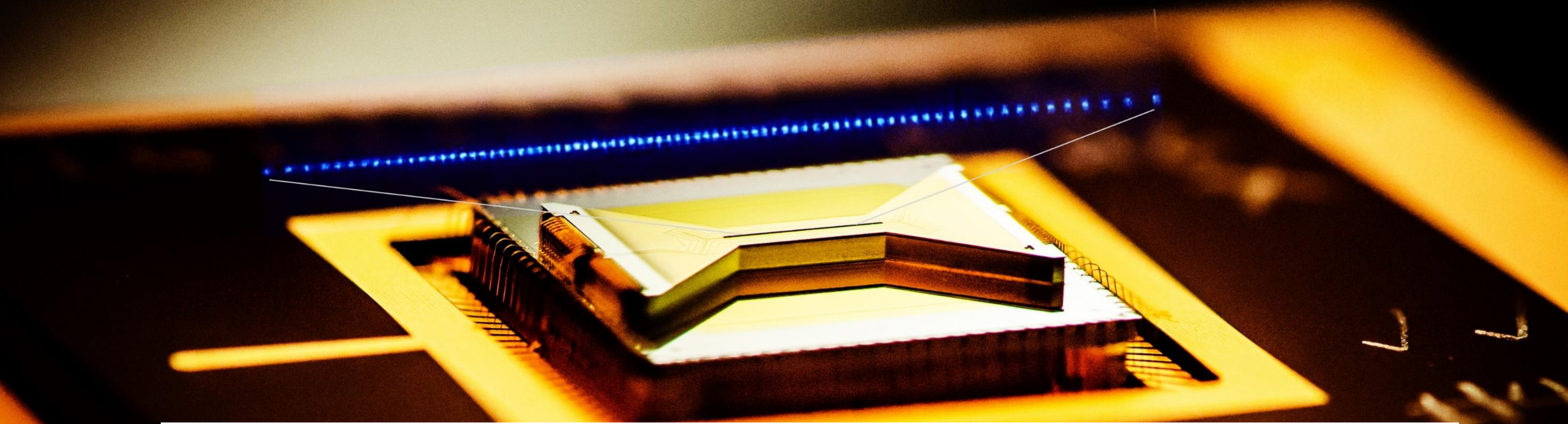
EFRI-ACQUIRE (2016); *Advancing Communication Quantum Information Research in Engineering*



2016 -2018

NSF 17-548 Ideas Lab: Practical Fully-Connected Quantum Computer

brings together physicists, computer scientists, and engineers to construct a quantum computer capable of showing an advantage over current computer technology.



NSF Award 1818914 PFCQC: STAQ: Software-Tailored Architecture for Quantum co-design

$15 million grant for a multi-institution quantum research collaboration. [News Release 18-058]

Trapped ions (superimposed) above a fabricated trap to capture and control ion qubits (quantum bits).
Image Credit: *K. Hudek, Ion Q&E / E. Edwards, JQI*

25

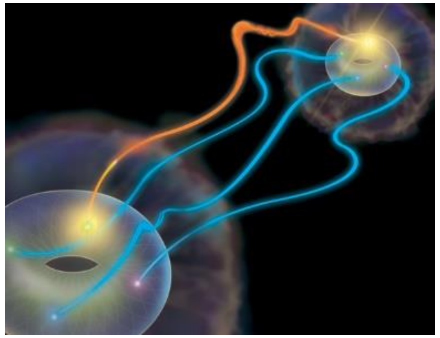
Taking the Leap (2019 and Beyond)

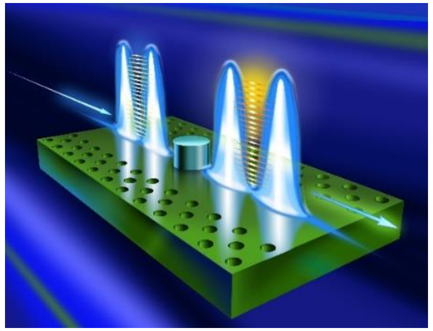
Q-AMASE-I - Enabling Quantum Leap: Convergent Accelerated Discovery ***Foundries*** for Quantum Materials Science, Engineering and Information (NSF 18-578)

Foundries: up to $25M over 6 years

QII – TAQS - Enabling Quantum Leap: Quantum Idea Incubator for Transformational Advances in Quantum Systems (NSF 19-532)

Small teams: up to $2M for 3 to 5 years





QCIS-FF - Quantum Computing & Information Science Faculty Fellows (NSF 19-507)

QLCI - Quantum Leap Challenge ***Institutes*** (NSF 19-559)

Institutes: up to $25M over 5 years, FY2020 funding

All require convergence across multiple disciplines

Harnessing the Data Revolution

Engaging NSF's research community in the pursuit of fundamental research in data science and engineering, the development of a cohesive, federated, national-scale approach to research data infrastructure, and the development of a 21st-century data-capable workforce.

- Harnessing the Data Revolution (HDR): Transdisciplinary Research in Principles of Data Science Phase I (Program Solicitation, Feb. 11, 2019)
- Harnessing the Data Revolution (HDR): Institutes for Data-Intensive Research in Science and Engineering - Frameworks (I-DIRSE-FW) (Program Solicitation, Feb. 7, 2019)
- Harnessing the Data Revolution (HDR): Institutes for Data-Intensive Research in Science and Engineering - Ideas Labs (I-DIRSE-IL) (Program Solicitation, Dec. 21, 2018)
- Harnessing the Data Revolution (HDR): Data Science Corps (DSC) (Program Solicitation, Oct. 31, 2018)

Understanding the Rules of Life

Elucidating the sets of rules that predict an organism's observable characteristics, its phenotype.

- Understanding the Rules of Life: Epigenetics (Program Announcement, Sept. 28, 2018)
- Understanding the Rules of Life: Building a Synthetic Cell (Program Announcement, Sept. 28, 2018)

Why MPS?

Research at the Physical – Life Sciences Interface in four Divisions in MPS

Chemistry of Life Processes (CHE)

Biomaterials (DMR)

Mathematical Biology (DMS)

Physics of Living Systems (PHY)

Mid-scale Research Infrastructure (Mid-scale RI) Opportunities

- Mid-scale RI is an NSF Big Idea to address the growing needs for RI to advance research.
- NSF-wide program will support projects in the MRI – MREFC gap (~$6 to $70 million range).
- RI is broadly defined, from disciplinary instrumentation to mid-scale facilities, upgrades, cyberinfrastructure, and others.

- Two solicitations released: one for projects between ~$6 M and ~$20 M and one for ~$20 - $70 million.
- Full proposals for former are in and under review; Invitations for full proposals for second have been issued

Mid-scale Research Infrastructure (MSRI)

- MSRI-1 ($6M to <$20M),
  - Preliminary proposal process completed
  - Invitations for full proposals sent out in April
  - Deadline for full proposals: May 20, 2019
  - Expected number of awards = 3 to 10
- MSRI-2 ($20M to <$70M)
  - Preliminary proposal process completed
  - Invitations for full proposals are out
  - Deadline for full proposals: August 2, 2019
  - Expected number of awards = 4 to 6

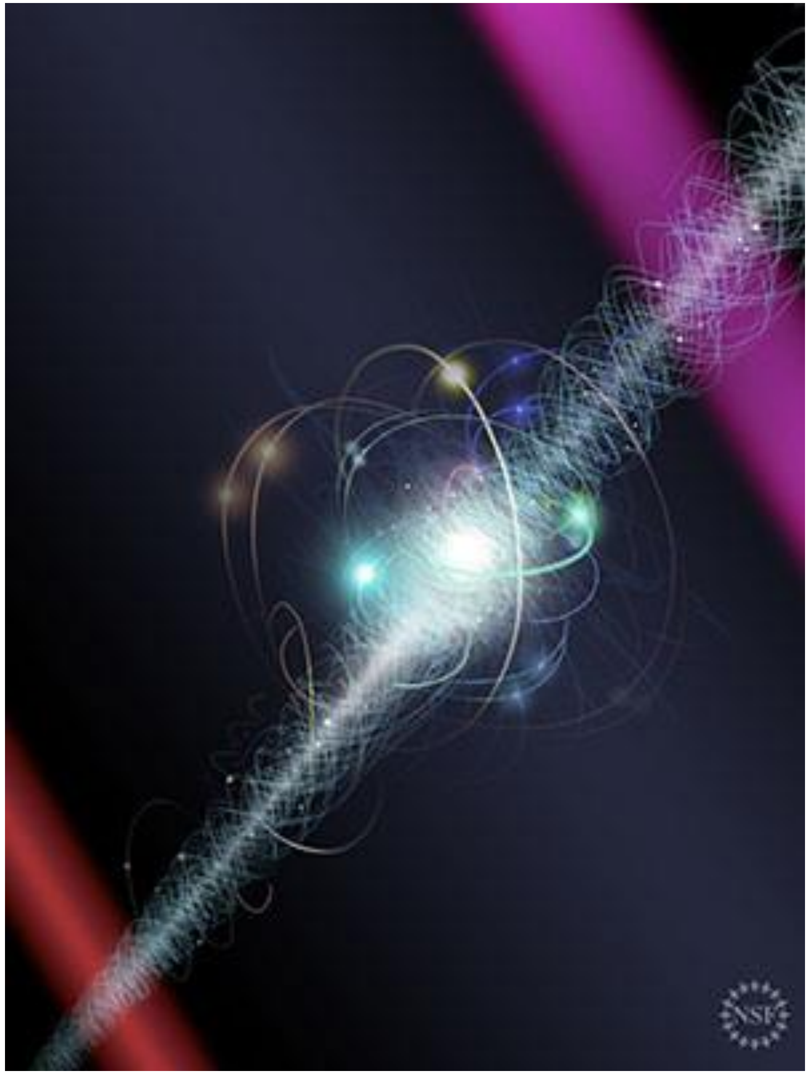
Advanced Cold Molecule Electron Dipole Moment (ACME)

Sets new lower limit on electron dipole moment

$|d_e| < 1.1 \times 10^{-29}$ ecm

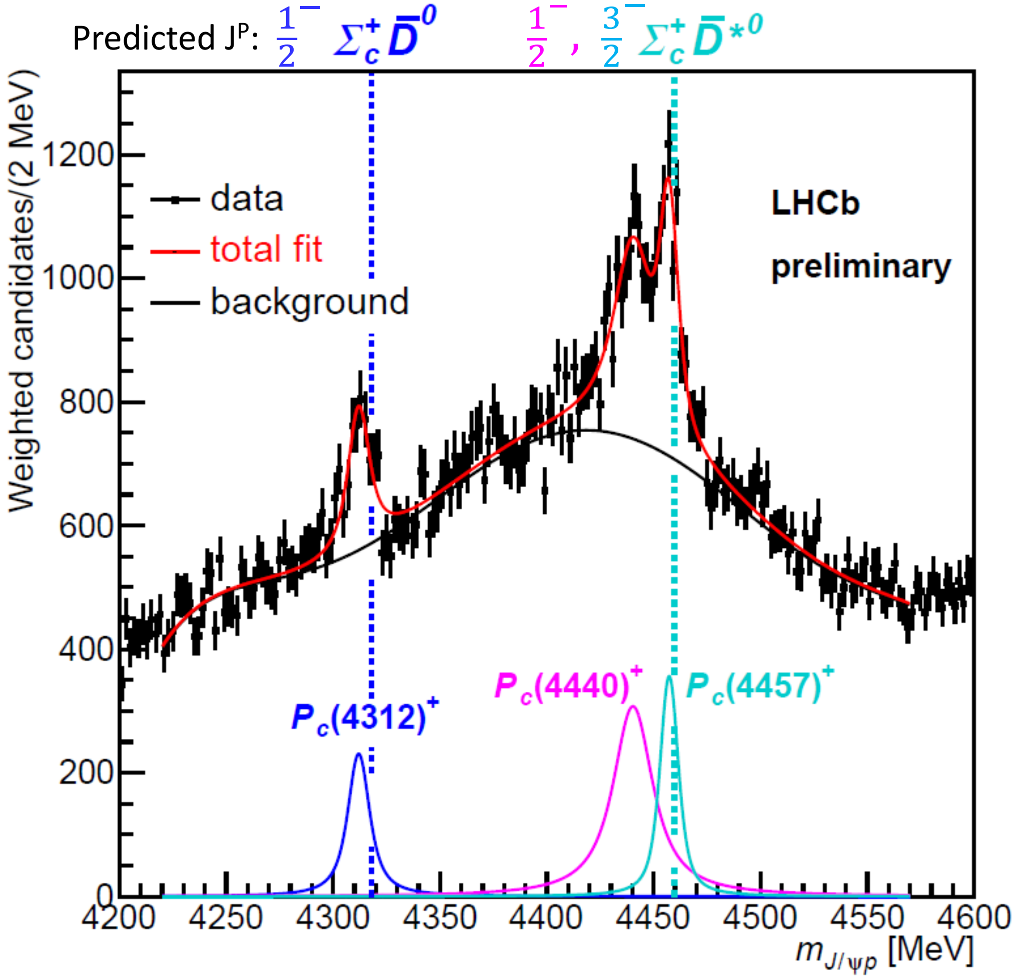
This is 8.6 times smaller than the best previous limit, from ACME I, at 90% confidence level.

Result typically limits time-reversal-symmetry-violating new physics to energy scales above $\Lambda \approx 30$ TeV or $\Lambda \approx 3$ TeV

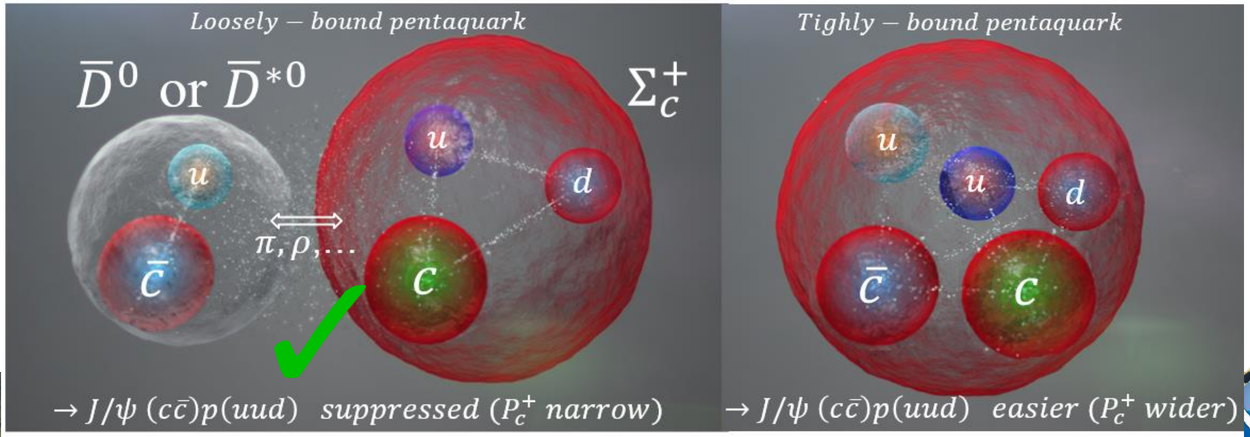


Credit: Nicolle R. Fuller/National Science Foundation

Pentaquarks in LHCb



- Discovery of additional pentaquark states in Run 1+2
  - Previously reported $P_c(4450)^+$ structure now resolved at 5.4σ significance into two narrow states: the $P_c(4440)^+$ and $P_c(4457)^+$ exotic baryons
  - A narrow companion state, $P_c(4312)^+$, discovered with 7.3σ significance
  - Near-threshold masses and narrow widths of $P_c(4312)^+$, $P_c(4440)^+$ and $P_c(4457)^+$ favor “molecular” pentaquarks with meson-baryon substructure



[T. Skwarnicki, Moriond QCD, 2019]

LIGO Catalogue of Detections through 2017

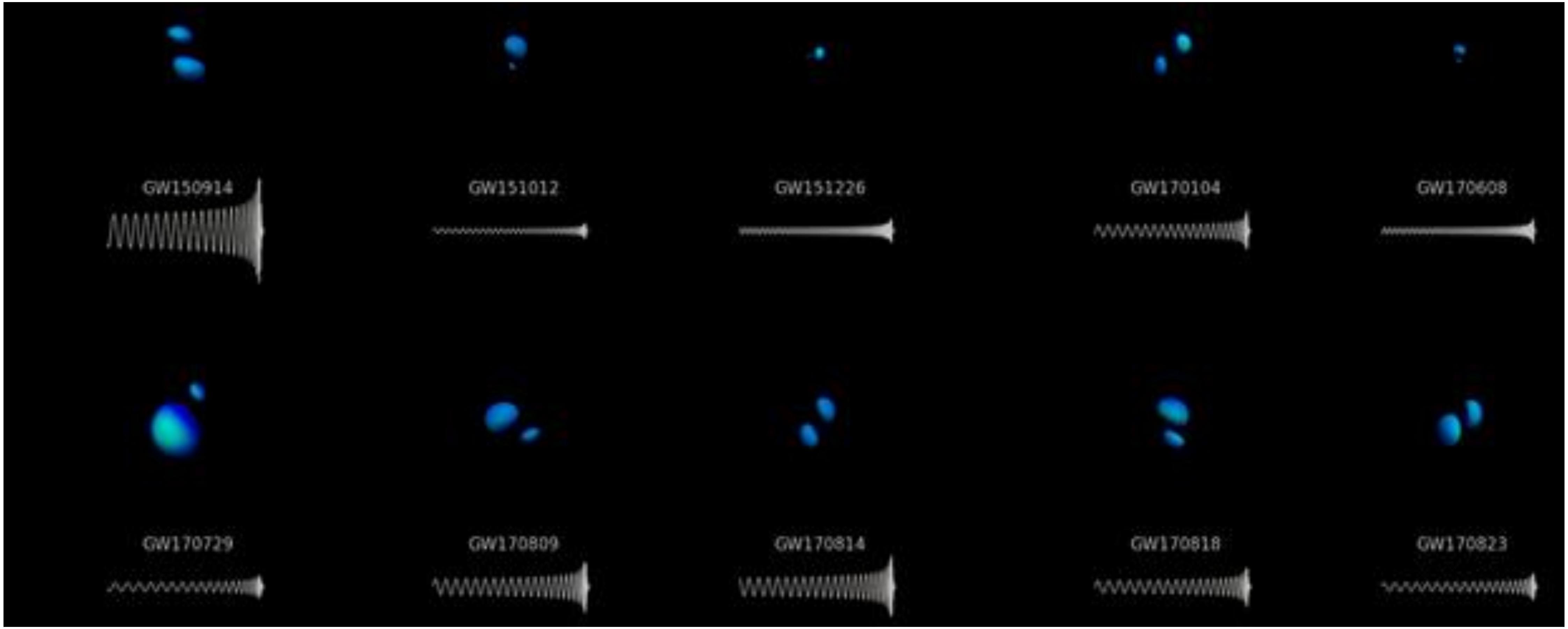


Photo Courtesy LIGO Laboratory