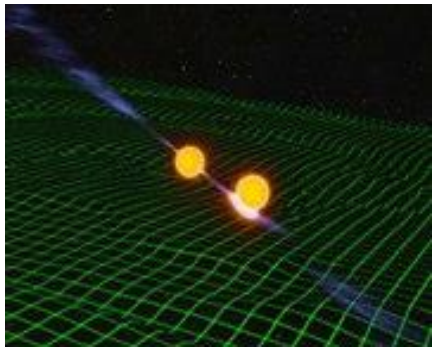
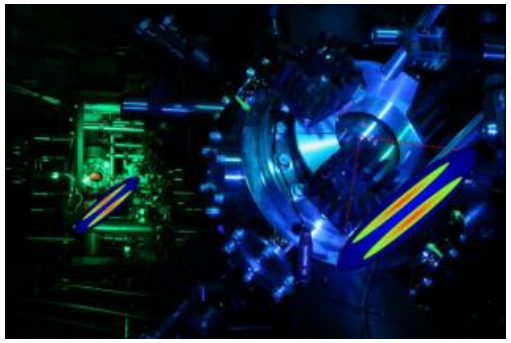
News from NSF Physics

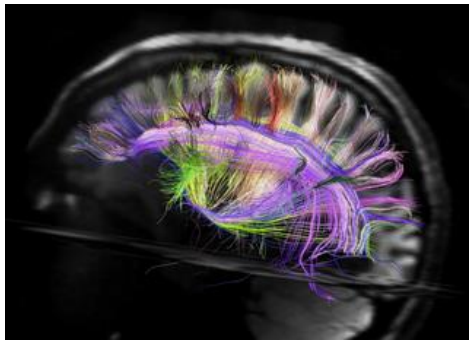
Denise Caldwell

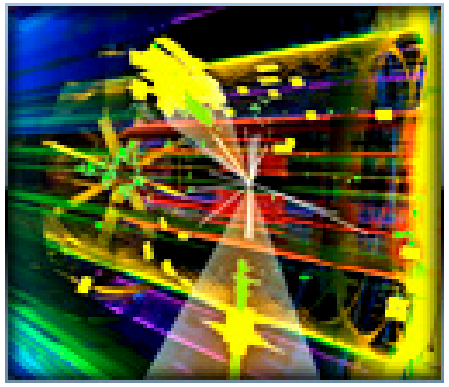
Division Director
Division of Physics





With Preliminary Comments from NSF
Mathematical and Physical Sciences Directorate



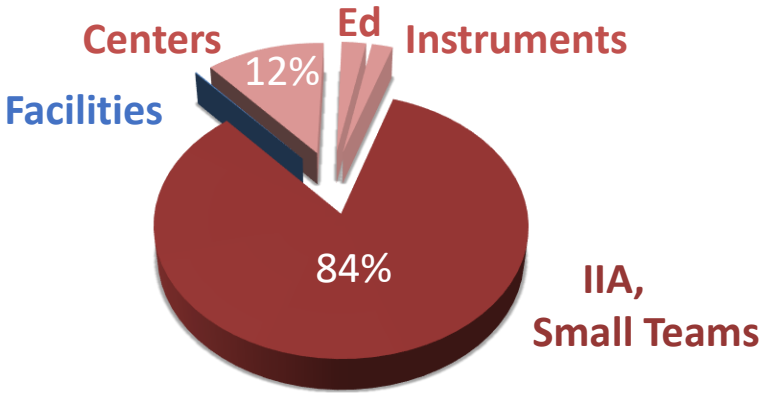


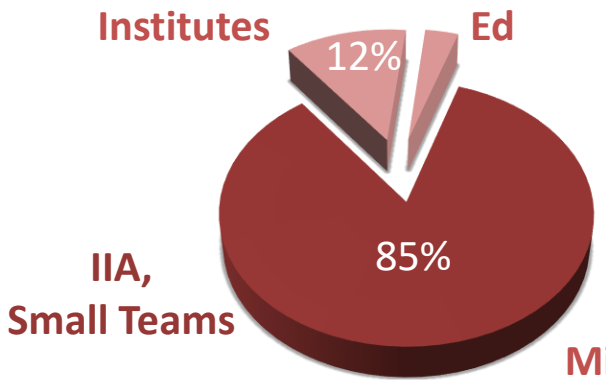
BPA 25 April 2019

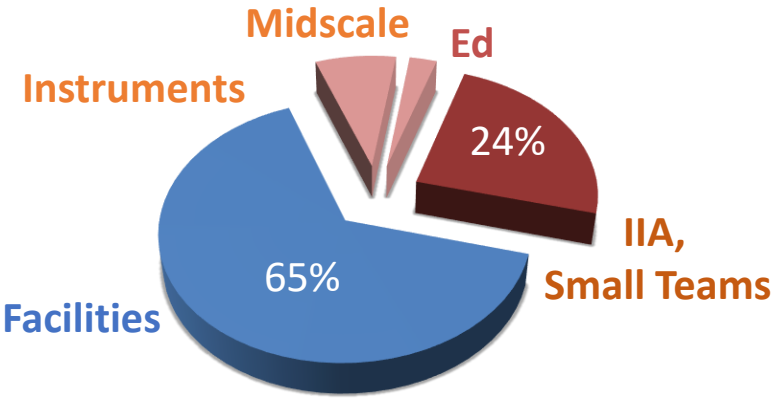
National Science Foundation
Mathematical
and
Physical Sciences

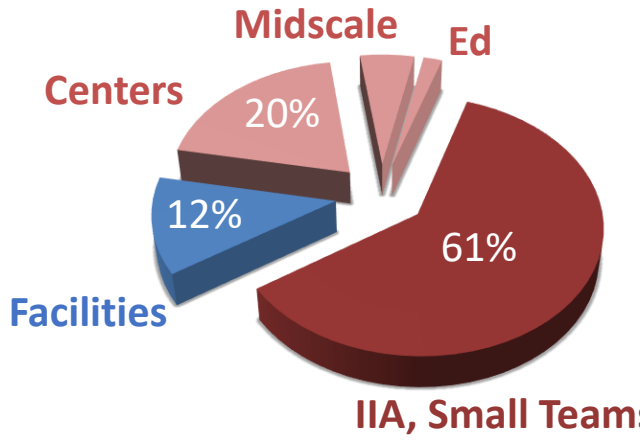
Mathematical and Physical Sciences (MPS)

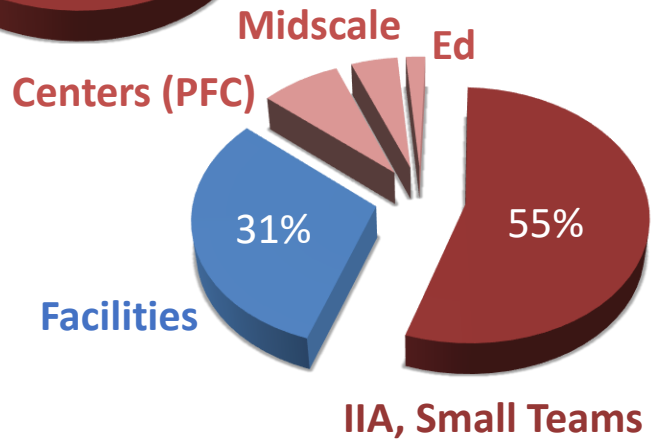
- Astronomical Sciences (AST)
- Chemistry (CHE)
- Materials Research (DMR)
- Mathematical Sciences (DMS)
- Physics (PHY)



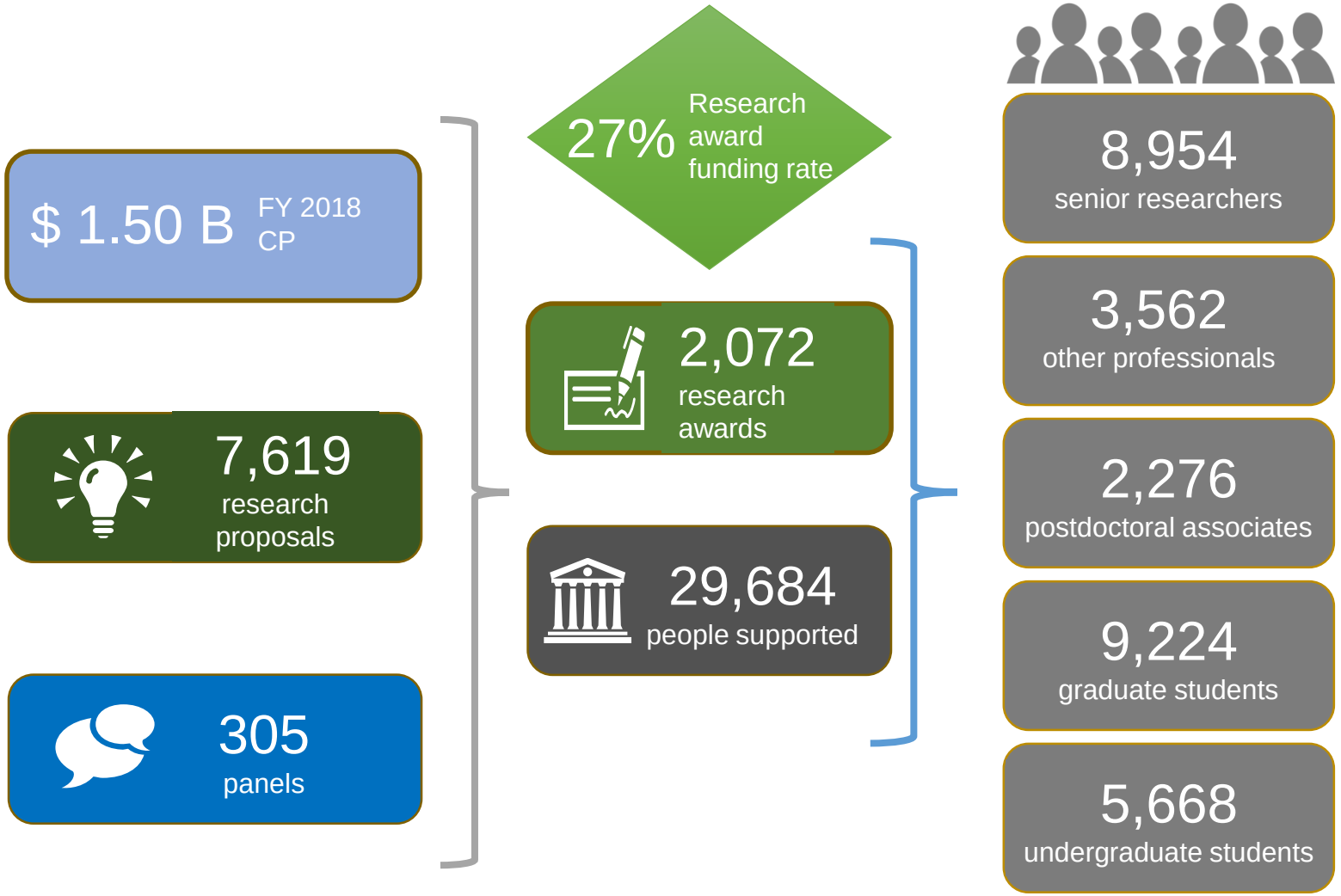








MPS by the Numbers: FY 2018



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

Current Plan under Development

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	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%**

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

MPS Priorities – FY 2020

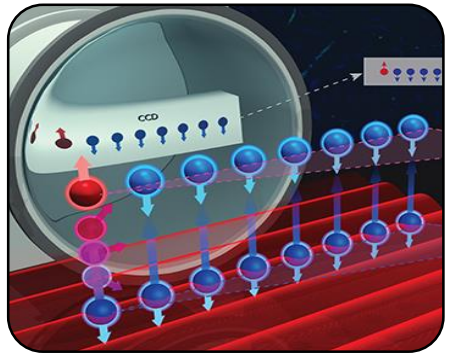
- **Emphasis on Big Ideas**
  - NSF Stewardship: Quantum Leap & Windows on the Universe
  - Expanded Participation: Harnessing the Data Revolution, Mid-Scale Research Infrastructure, and Understanding the Rules of Life
- **Strategic investments** in:
  - Fundamental research
  - Artificial Intelligence, 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

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

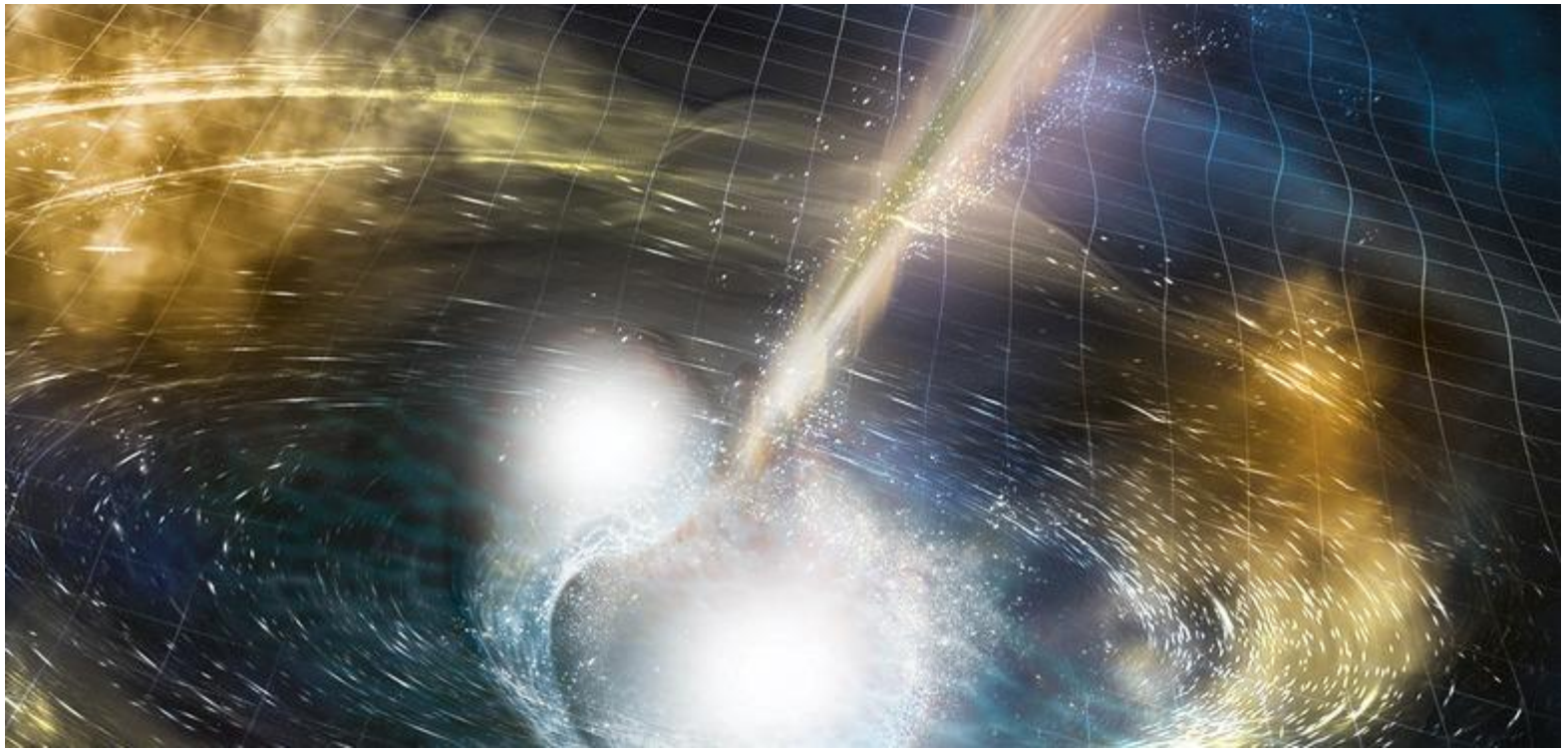
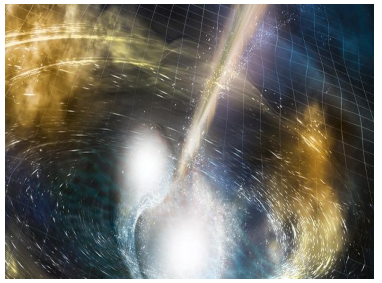


Image credit: NSF/LIGO/Sonoma State University/A. Simonnet

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



Metaprogram PD 18-5115

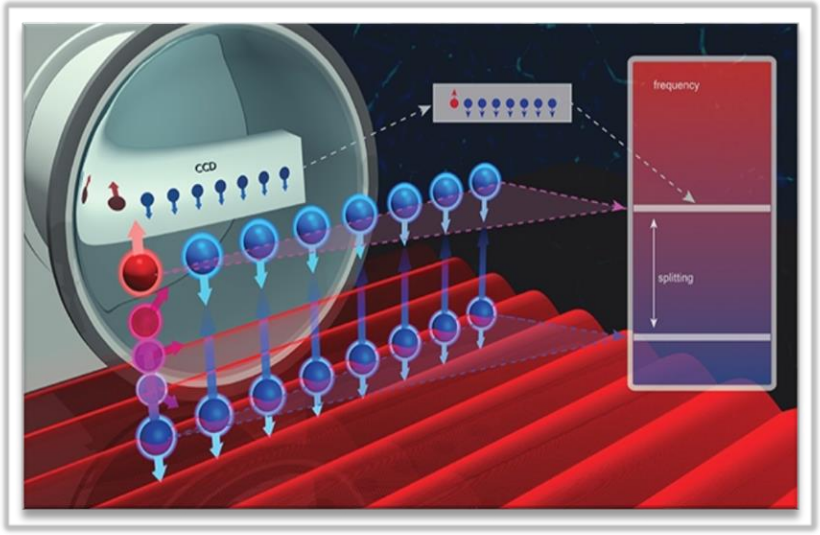
The goals of WoU-MMA are to build the capabilities and accelerate the synergy and interoperability of the three messengers to realize integrated, multi-messenger astrophysical explorations of the Universe. It has three broad areas of emphasis:

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

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

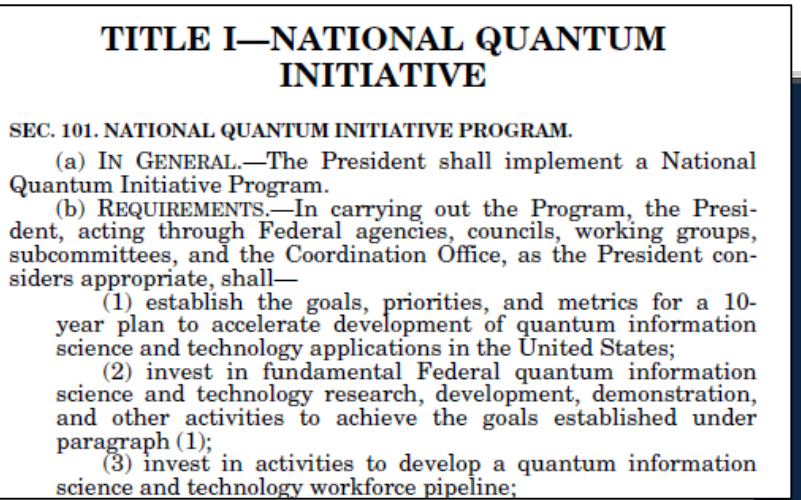
31 "quantum" Nobels supported by NSF (since '64)

IBM

Google

Honeywell
Microsoft
HRL Labs
Lockheed

AO Sense
Cold Quanta
Zapata
Ion Q, etc…



TITLE I—NATIONAL QUANTUM INITIATIVE

SEC. 101. NATIONAL QUANTUM INITIATIVE PROGRAM.

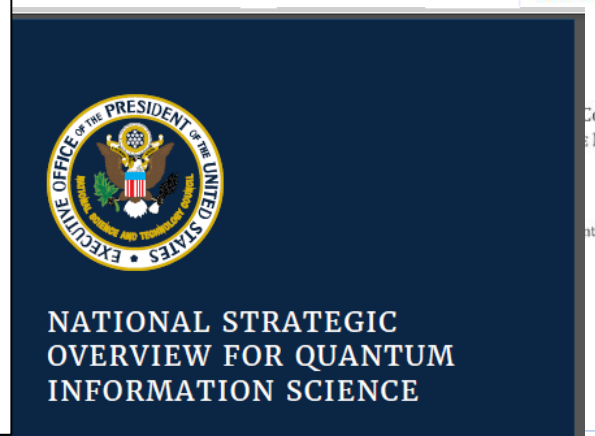
(a) IN GENERAL.—The President shall implement a National Quantum Initiative Program.

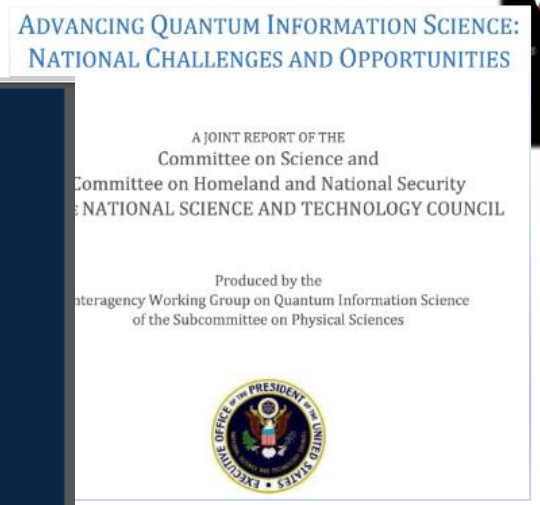
(b) REQUIREMENTS.—In carrying out the Program, the President, acting through Federal agencies, councils, working groups, subcommittees, and the Coordination Office, as the President considers appropriate, shall—

(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;





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

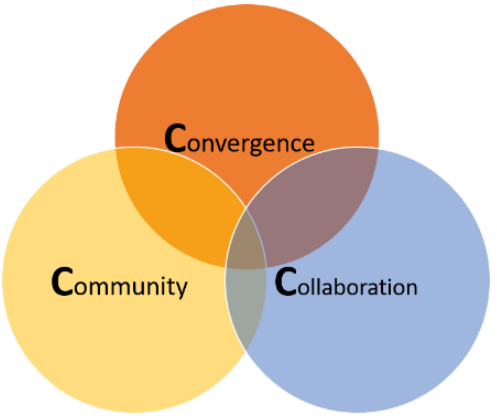
DCL: A Quantum Leap Demonstration of Topological Quantum Computing

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

Taking the Leap (2019 and Beyond)

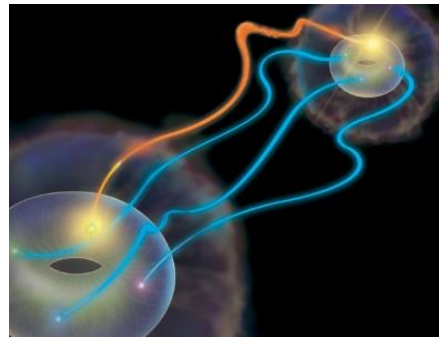
Q-AMASE-I - Enabling Quantum Leap: Convergent Accelerated Discovery ***Foundries*** for Quantum Materials Science, Engineering and Information (NSF 18-578)

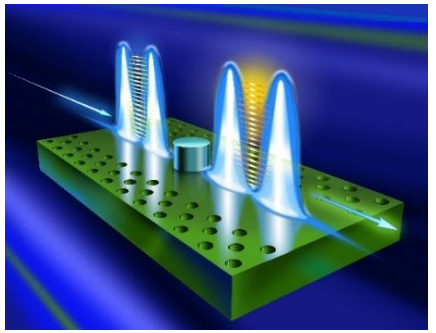
Foundries: up to $25M over 6 years

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

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





All require convergence across multiple disciplines

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

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

Mid-scale Research Infrastructure (MSRI) Opportunities

Bridge the Gap

- 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.
- Preproposals for former have been reviewed, Full proposals invited; Preproposals for second are in and under review

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)

Mathematical Biology (DMS)

Biomaterials (DMR)

Physics of Living Systems (PHY)

Division of Physics

Physics Division Portfolio

The portfolio of awards made through the Physics Division has as primary goal "to promote the progress of science", as expressed in the NSF act. Awards in the portfolio support the research needed to address a scientific question that is at the frontier of knowledge as it is currently known, while at the same time extending and redefining that frontier. Inherent in the implementation of this portfolio, which includes significant support for students and junior scientists, is the preparation of the next generation of the advanced high tech workforce and the development of innovative new technologies that arise in the quest to answer some of the hardest questions that Nature can pose.

Implementation:

Begin with new ideas generated by the physics community
Inform the process through workshops, input from advisory committees, proposal reviews, and the scientific expertise of the Program Directors

Division of Physics

Funds Through Three Funding Modalities

Individual Investigator Awards > 50% of total through "Disciplinary" Programs in:

Gravitational Physics; Atomic, Molecular, and Optical Physics; Nuclear Physics; Elementary Particle Physics; Particle Astrophysics; Plasma Physics; Physics of Living Systems; Computational Physics; Quantum Information and Revolutionary Computing

Physics Frontiers Centers – Currently 9 Centers across Multiple Sub-Areas in Division – Multiple Co-Funds from Divisions across NSF

Major Facilities - LIGO (NSF/PHY only); ATLAS and CMS Detectors at LHC (jointly with DoE); NSCL (NSF/PHY only); IceCube (Jointly with NSF Polar Programs)

Integrative Activities in Physics - REU Sites, Outreach, Education, Broadening Participation

Major Thrust: Fostering Connections across Physics, across NSF, and across agencies

International: All major facilities, PFC's, and Individual Investigator Awards

Major Thrust – Fostering Connections

Focus on Science Question, not Discipline or Subarea

Partner with Others whenever Possible to Promote Science

Partnering within Division – AMO-Nuclear, AMO-Particle, AMO-Gravity

Partnering with other NSF divisions on individual awards and centers –
MPS/AST,CHE,DMR,DMS; BIO/MCB,IOS,DBI; GEO/PLR,AGS;
ENG/ECCS,CBET; CISE/CCF,OAC

Participation in NSF priority areas jointly with other Directorates/Divisions -e.g. Four Big Ideas

Partnering with DOE in Particle Physics, Nuclear Physics, Plasma Physics

Partnering with NASA in Gravitational Physics and Plasma Physics

Partnering with SU2C in PoLS and Gordon & Betty Moore Foundation in Gravity

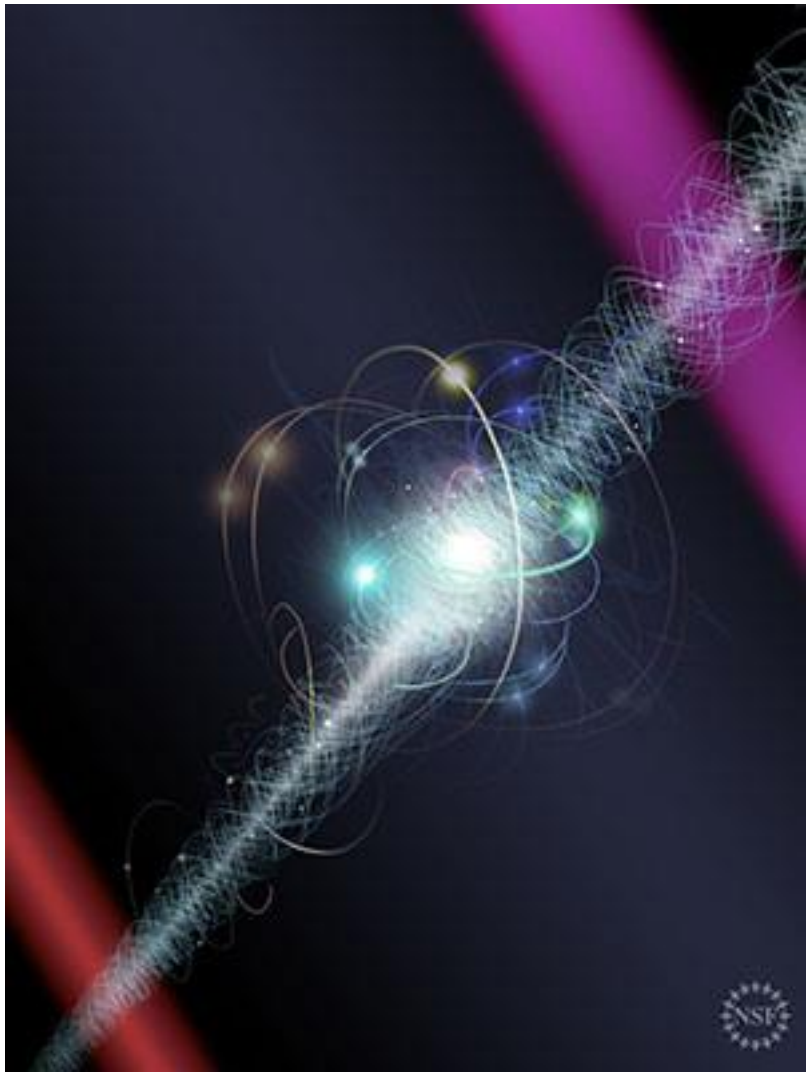
Advanced Cold Molecule Electron Dipole Moment (ACME)

Sets new lower limit on electron dipole moment

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

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

International Activities in Division of Physics

Large Scale Efforts at Facilities

CERN – Joint with US DoE in US Support of ATLAS and CMS; Funding for Nuclear Physics Experiments on ALICE; Sole US Support for Research on LHCb

Laboratori Nazionali del Gran Sasso (LNGS) – XENON-1T, DarkSide-50, SABRE, BOREXINO, CUORE

LIGO - VIRGO and LIGO Scientific Collaboration

NSCL, IceCube – International engagement as users and partners

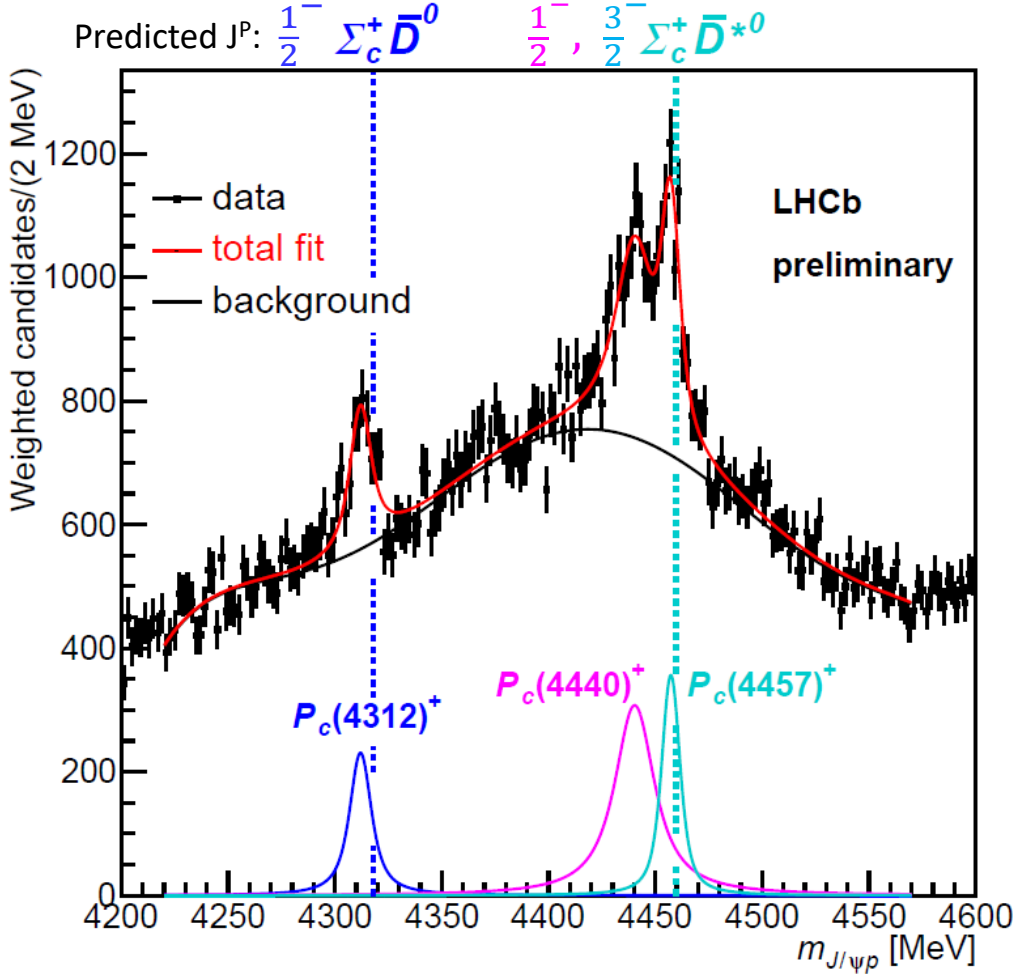
Interactions at Individual Investigator Level

Physics of Living Systems Student Research Network – 30 Institutions, 8 Countries

NSF 14-099 **Dear Colleague Letter - International Activities within the Physics Division – Potential International Co-Review**

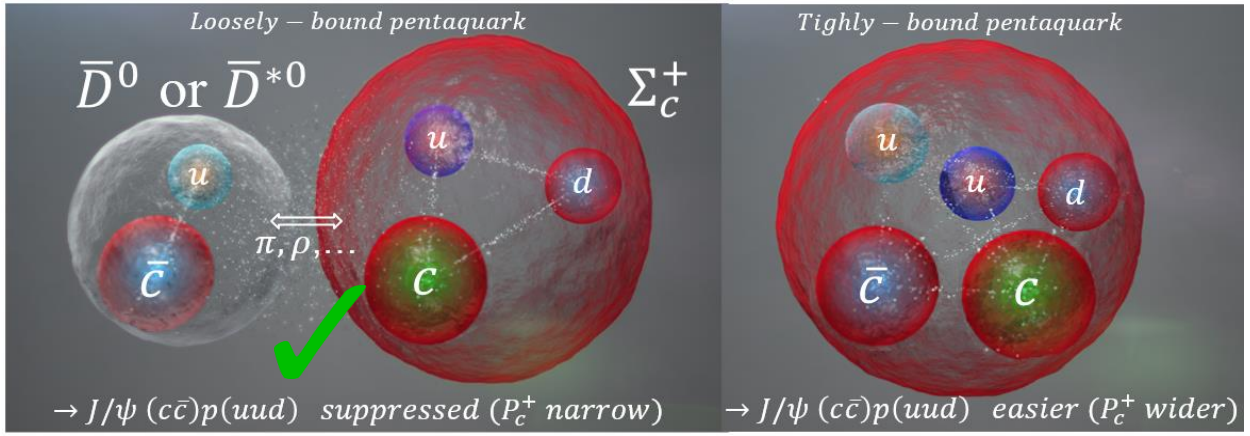
Gravitational Physics - Lead-Agency Agreement with DFG in Germany

Pentaquarks in LHCb



[T. Skwarnicki, Moriond QCD, 2019]

- 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



Think Boldly– 2019-2020

Prominent role in Quantum Leap and Quantum Information Science
(Disciplinary program in QIS plus 4 PFC's, IQIM, CUA, JQI, and JILA)

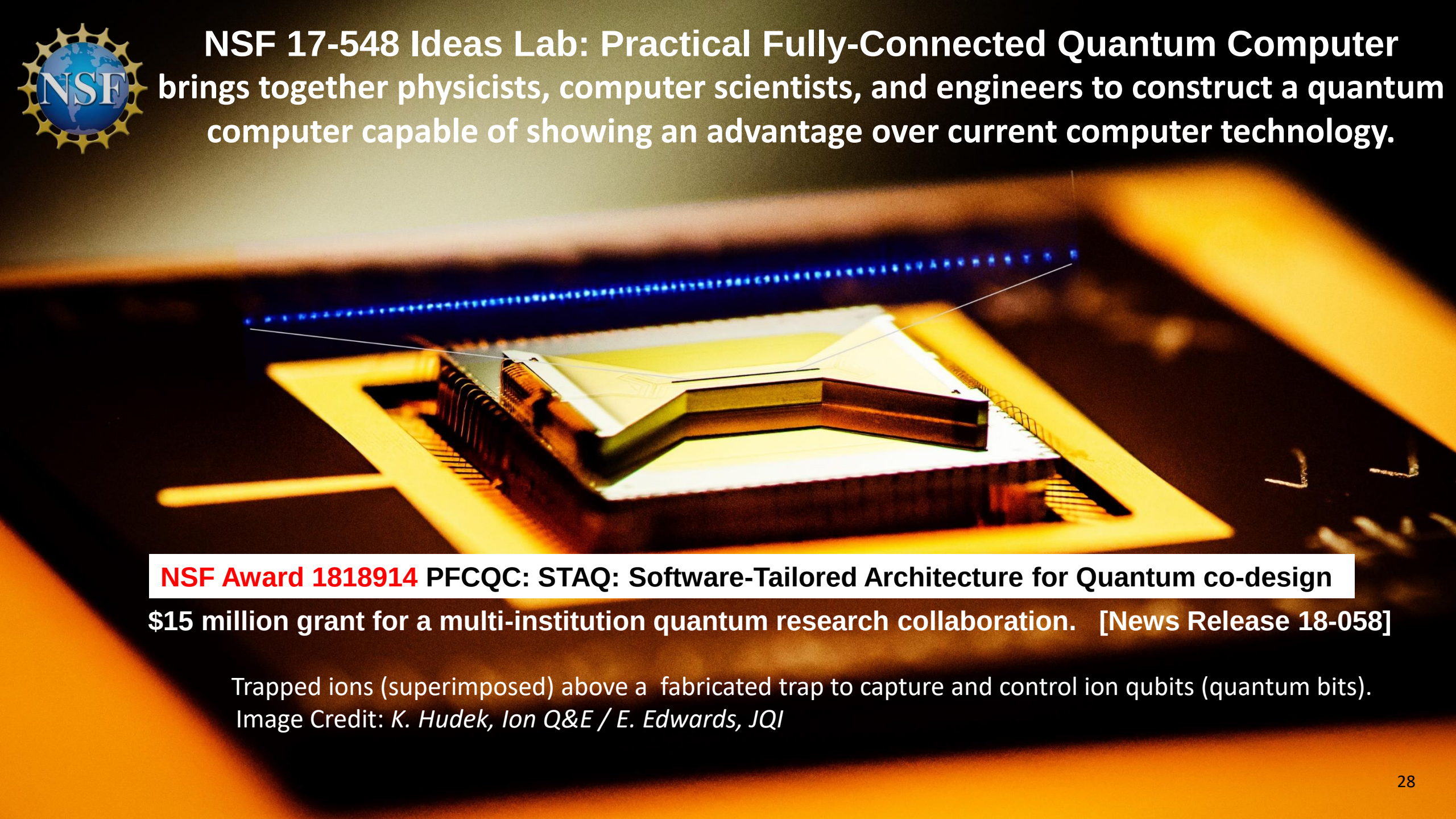
Prominent role in Windows on the Universe and Multi-Messenger Astrophysics
(Steward of LIGO and Co-Steward of IceCube)

Upgrades of ATLAS and CMS detectors at LHC (HL-LHC), IceCube, LIGO (A+)

Physics Frontiers Centers competition in FY 2020

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]

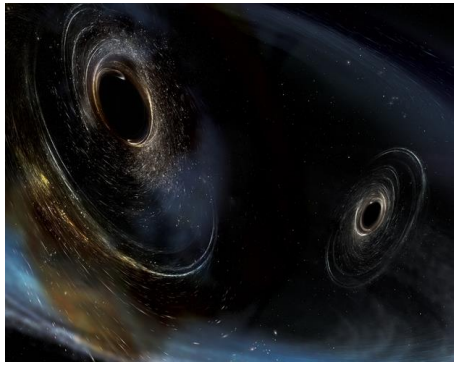
Trapped ions (superimposed) above a fabricated trap to capture and control ion qubits (quantum bits).
Image Credit: *K. Hudek, Ion Q&E / E. Edwards, JQI*

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
Two alerts released for BH mergers

All O2 data available to community

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



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

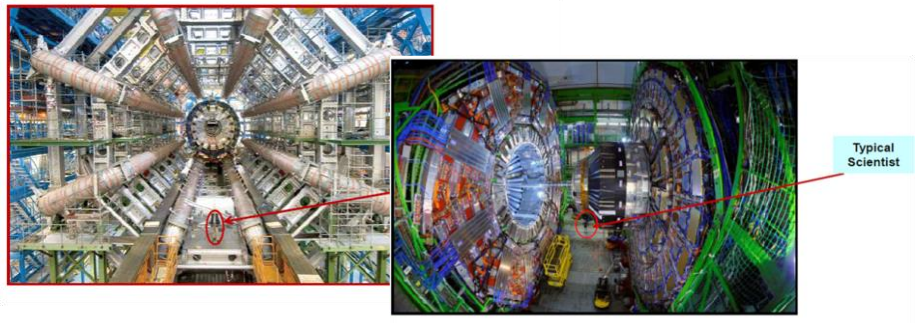
Generation 3 under discussion by international community

Photo Credits: LIGO Lab

Current State of Facilities

Laser Interferometer Gravitational Wave Observatory (LIGO)

O3 Run Started April 1 ; A+ Upgrade underway



ATLAS

CMS

ATLAS and CMS Detectors at Large Hadron Collider (LHC)

Planning for MREFC High-Luminosity Upgrade Underway

IRIS Award to Address Computational Challenges

National Superconducting Cyclotron Laboratory (NSCL)

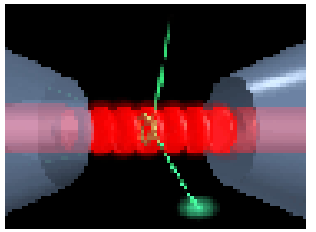
Transfer to FRIB in 2021 Progressing Smoothly

IceCube

Upgrade Underway

Physics Frontiers Centers

Competition in FY 2020 – Pre-Proposals due August 2019

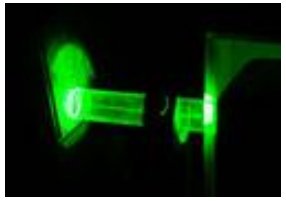


IQIM

PFC@JILA, University of Colorado

Institute for Quantum Information and Matter, CalTech (With CISE/CCF)

Center for Theoretical Biological Physics, Rice U (In Partnership with MPS/DMR, BIO/MCB)



JQI

PFC@JQI, U Maryland

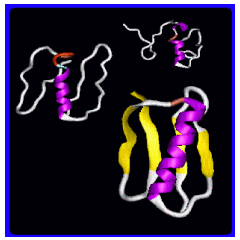
NANOGrav, U Wisconsin Milwaukee (With MPS/AST)

Center for the Physics of Living Cells, UIUC (In Partnership with MPS/CHE, BIO/MCB)

Center for Ultracold Atoms, MIT/Harvard (With CISE/CCF)

JINA: Joint Institute for Nuclear Astrophysics, Michigan State

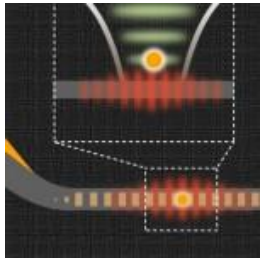
Center for the Physics of Biological Function, Princeton (In Partnership with BIO/MCB;IOS)



CTBP

NanoGrav

CUA



What to Expect– 2019-2020

Prominent role in Quantum Leap and Quantum Information Science

Multi-Disciplinary Awards in QIS with Physics Partners

Prominent role in Windows on the Universe and Multi-Messenger Astrophysics

Growing number of LIGO alerts

Upgrades of ATLAS and CMS detectors at LHC (HL-LHC), IceCube, LIGO (A+)

Initiation of Final Design for HL-LHC Upgrade

Physics Frontiers Centers competition in FY 2020

Revised Slate of Awards in FY 2020

People who make the Division run

Program Directors

Permanent

Krastan Blagoev
Jean Cottam-Allen
Keith Dienes
John Gillaspy
Saul Gonzalez
Vyacheslav Lukin
Pedro Marronetti
Kathy McCloud
Bogdan Mihaila
Allena Opper
Jim Whitmore

Temporary

Mike Cavagnero
Alex Cronin
Jim Thomas
Randy Ruchti

Administrative Professionals

Sabrina Caraway
Kim Pigford
Michele Johnson
Azyta Ahmadi
Denise Henry
Shannon Scrivner
L.C. Berry
Khoren Claiborne

Senior Managers: Denise Caldwell, Vacant (Jean Cottam-Allen, Acting), Mark Coles

BACKUP

LIGO Catalogue of Detections through 2017

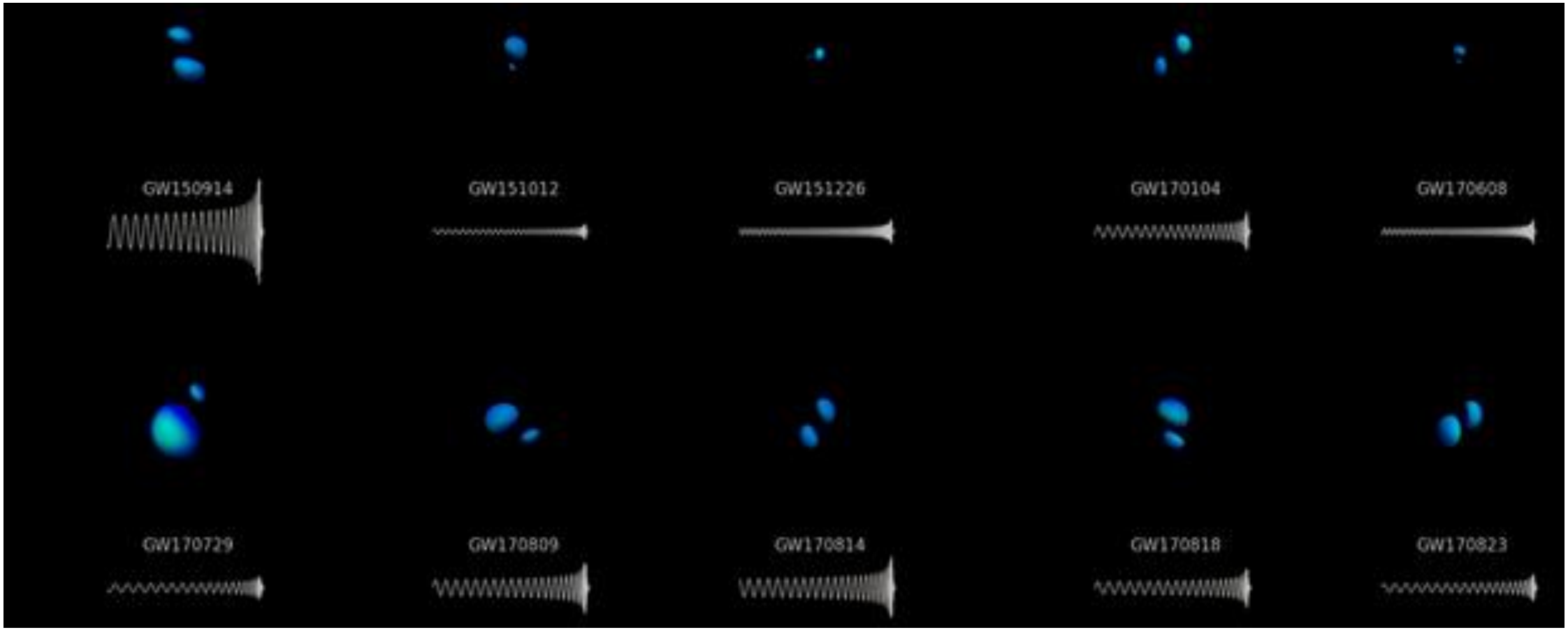
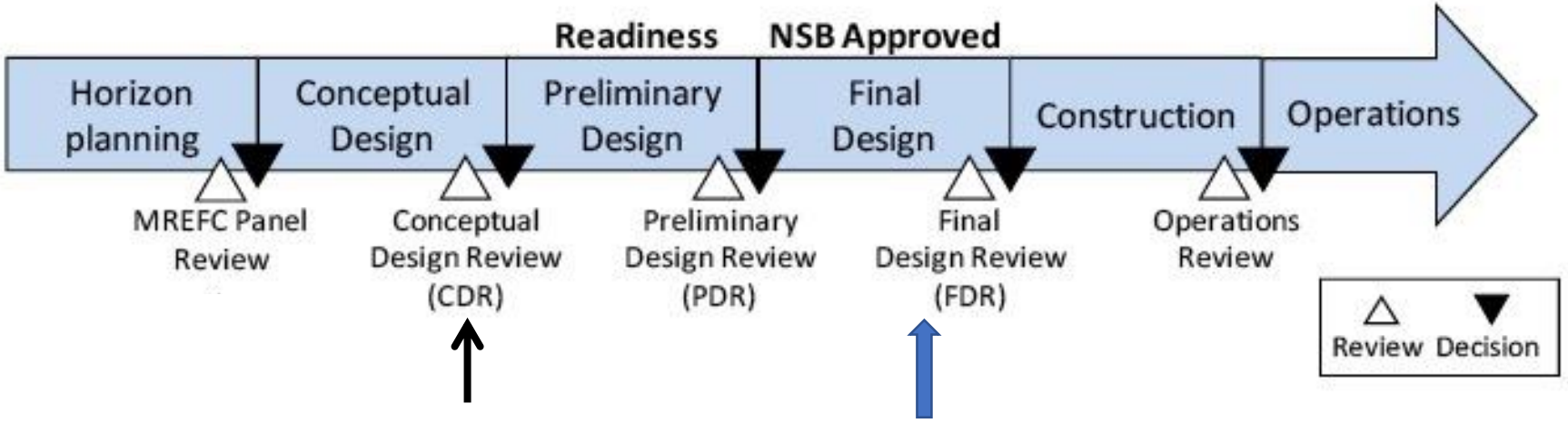


Photo Courtesy LIGO Laboratory

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

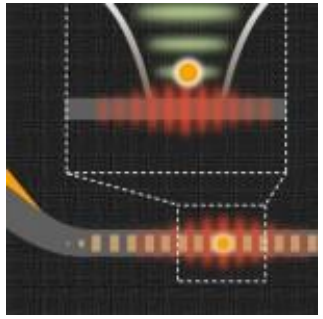


Coordinating with the DOE in support of the US-CMS and US-ATLAS Teams

NSF has identified well-defined scope independent of DOE scope

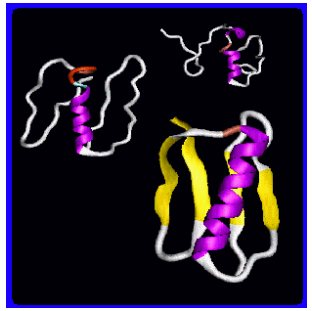
Physics Frontiers Centers

JILA – Colorado – Cornell



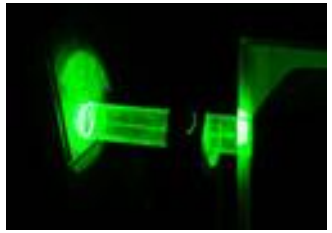
Center for Ultracold Atoms – MIT/Harvard – Ketterle (MPS/PHY/CISE/CCF)

Center for Theoretical Biological Physics – Rice – Onuchic
(Joint MPS/PHY/CHE/DMR and BIO)



Joint Institute for Nuclear Astrophysics – Michigan State - Schatz

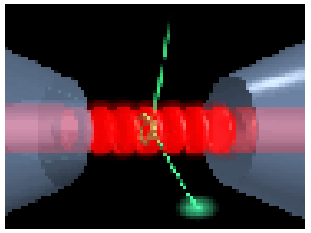
PFC at JQI (Joint Quantum Institute) – Maryland/NIST – Phillips



Physics Frontiers Centers (Cont'd)

Center for the Physics of Living Cells – U Illinois – Chemla
(Joint MPS/PHY/CHE and BIO/MCB)

Institute for Quantum Information and Matter – Caltech
- Preskill (MPS/PHY/CISE/CCF)



North American Nanohertz Observatory for Gravitational Waves –
U Wisconsin Milwaukee – Siemens (PHY/AST)

Center for the Physics of Biological Function - CUNY/Princeton – Bialek
(Joint MPS/PHY/CHE and BIO/MCB/IOS)

Competition in FY 2020 – Pre-Proposals Due August 2019