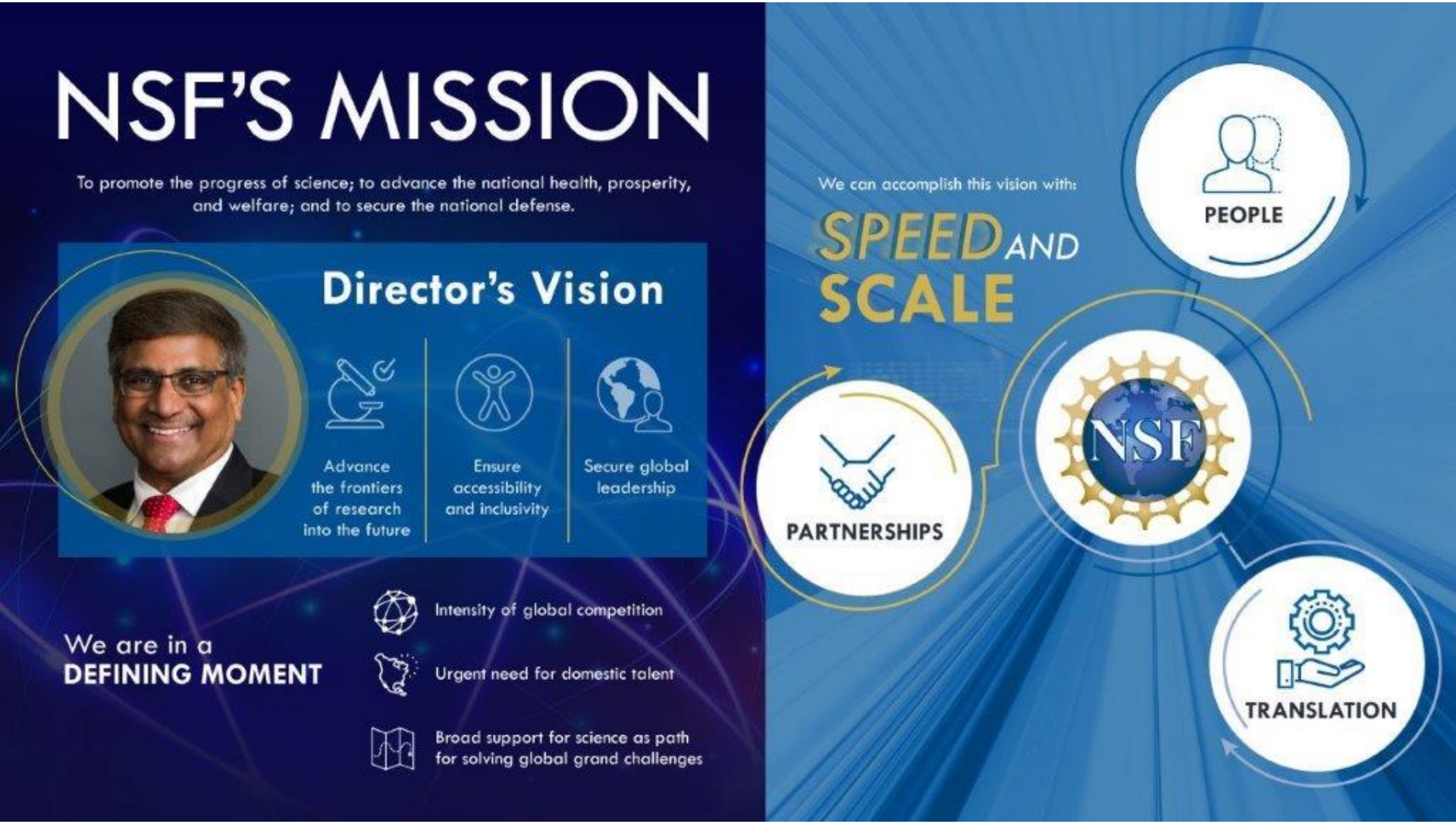
National Science Foundation Mathematical and Physical Sciences Update

Nuclear Science Advisory Committee
March 18, 2021

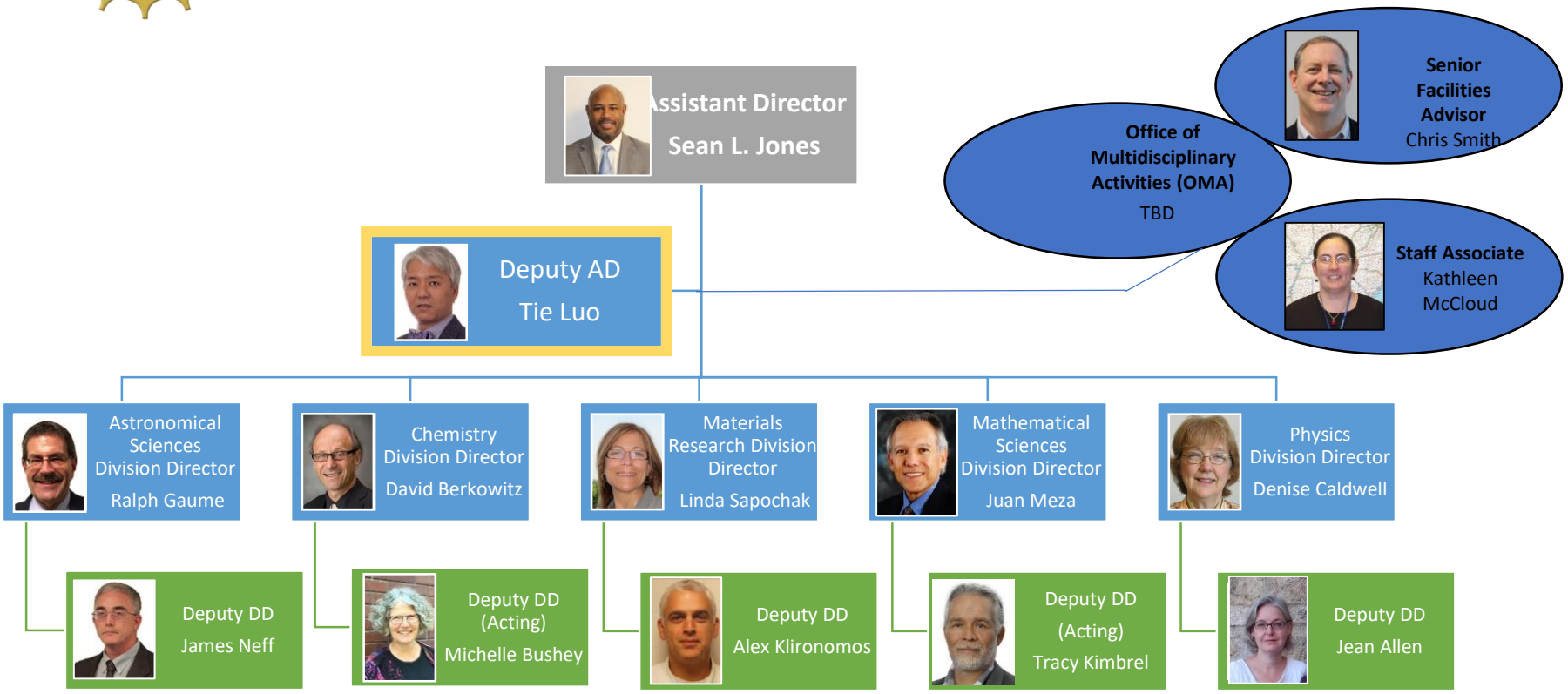
Denise Caldwell
Division Director, Physics
Directorate for Mathematical and Physical Sciences

Welcome: **Dr. Sethuraman Panchanathan**

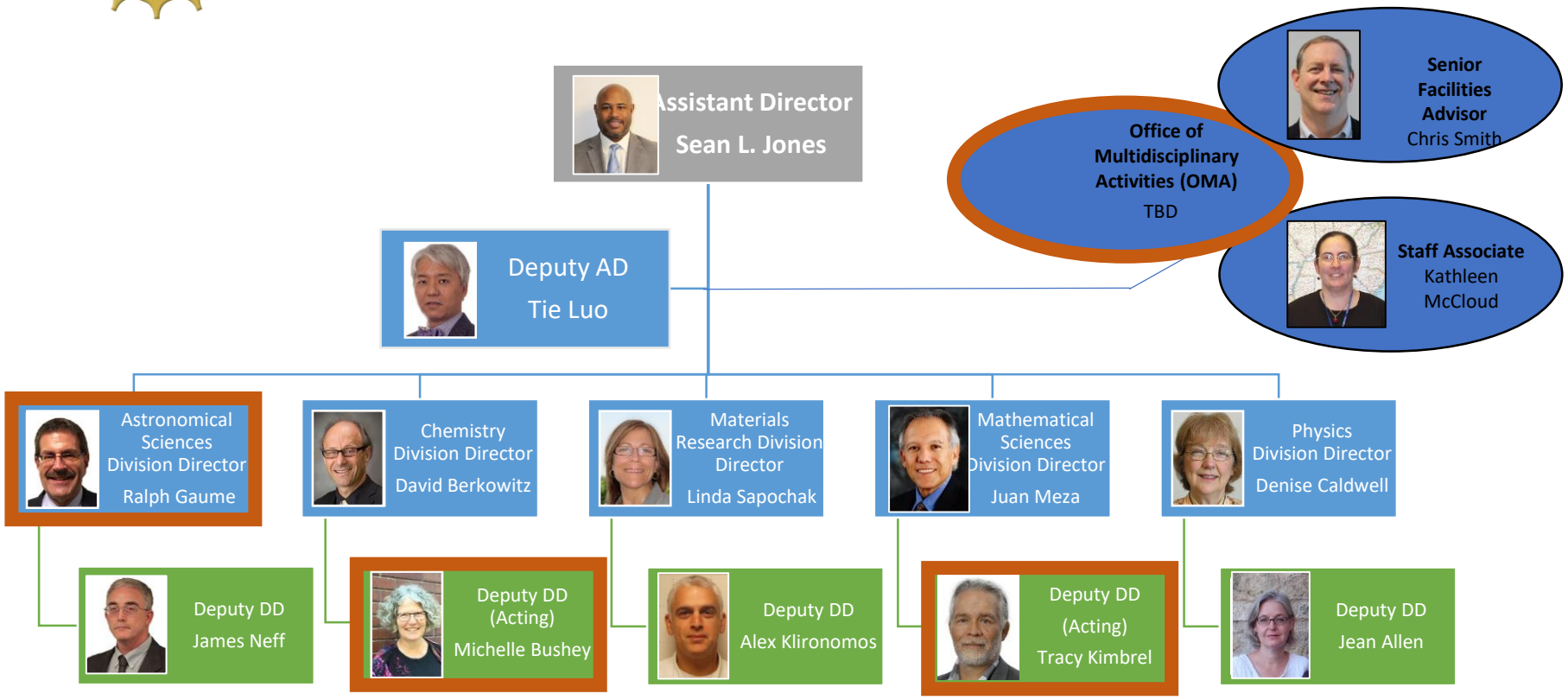


15th Director of National Science Foundation

Staff Changes in MPS



Staff Changes in MPS



FY 2021 Budget

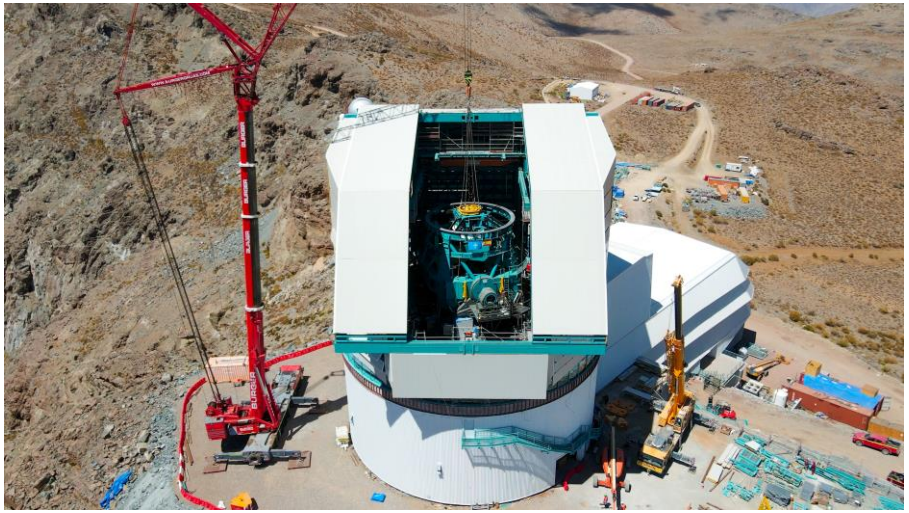
NSF budget request = $7.741 billion

- House: $8.548 billion
- Senate: $8.478 billion
- Omnibus: $8.487 billion

Current Plan under Consideration

MPS Facilities update

- MREFC Projects: COVID impacts
  - DKIST, Rubin, and HL-LHC delayed, but making progress



- Facilities Operations

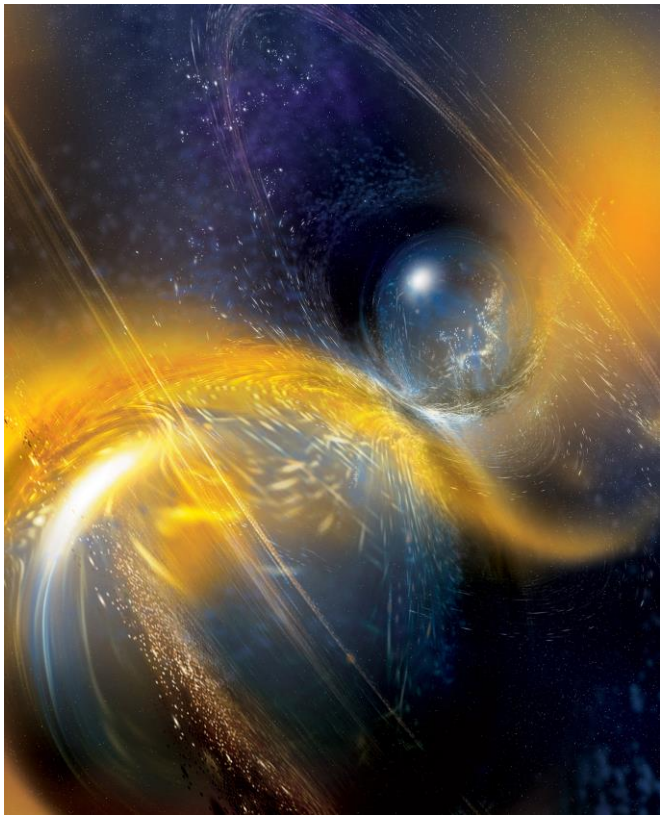
  Operations continuing after adjustments
  - Arecibo Update:
    - Congressional Report just released
    - Cleanup proceeding well
    - Innovative “workshop” planned (Apr-Jun) to identify ideas for future of the Observatory

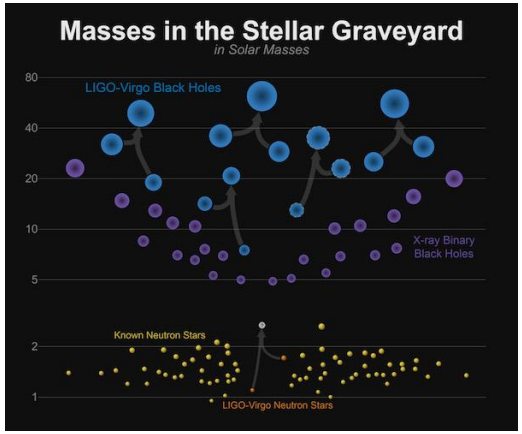
LIGO – Virgo
O3 Highlights

Several “exceptional” GW events detected in O3a have been published:

2nd Neutron Star Merger (GW190415, ApJL 892 (2020) L3)

- Very distant (500 Mly). No EM counterpart
- Total binary mass (3.4 $M_\odot$) larger than any known galactic NS binary (17 have been detected with a Maximum mass of 2.9 $M_\odot$)





LIGO – Virgo
O3 Highlights

The object in the "mass gap" (GW190814, *ApJL 896 (2020) L44)*

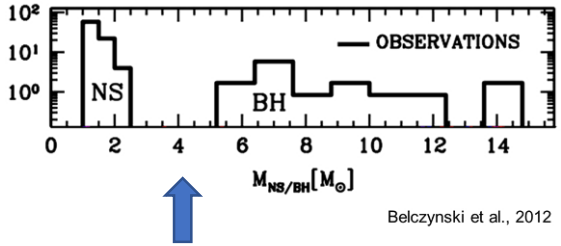
Binary with a 23 $M_\odot$ BH and a 2.6 $M_\odot$ object

The most extreme mass ratio (9!)

No EM counterpart

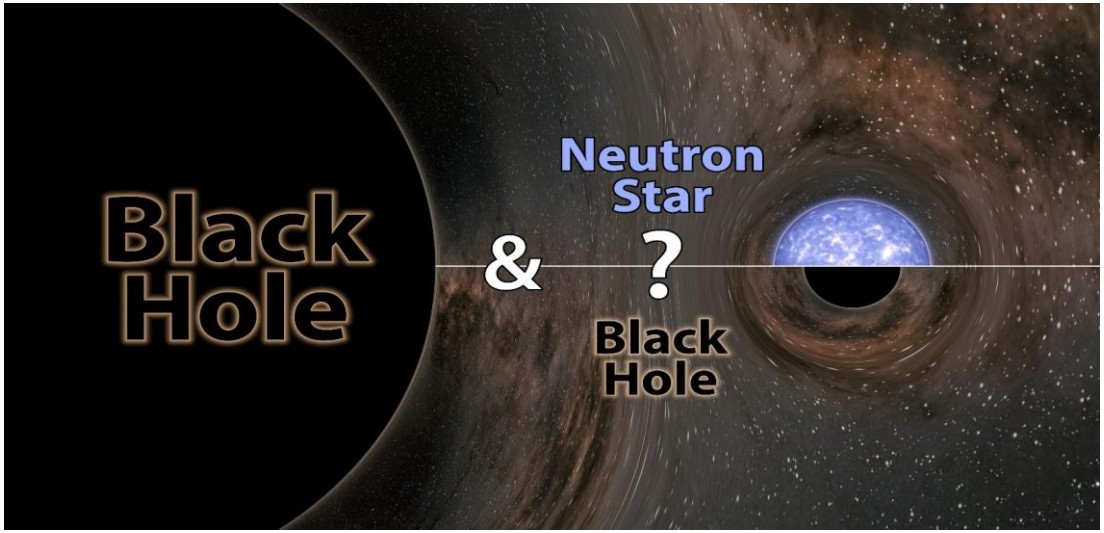
Not clear if the small object is a black hole or a neutron star

Low mass gap:
~2.5 to 5 $M_\odot$



If NS: First BH/NS detected and
Heaviest NS ever observed

If BH: Lightest BH ever observed



LIGO – Virgo
O3 Highlights

The most massive BH binary yet
(GW190521, *PRD 125 (2020) 101102)*

Binary with a 66 $M_\odot$ BH and a 85 $M_\odot$ BH merge to create a 142 $M_\odot$ monster

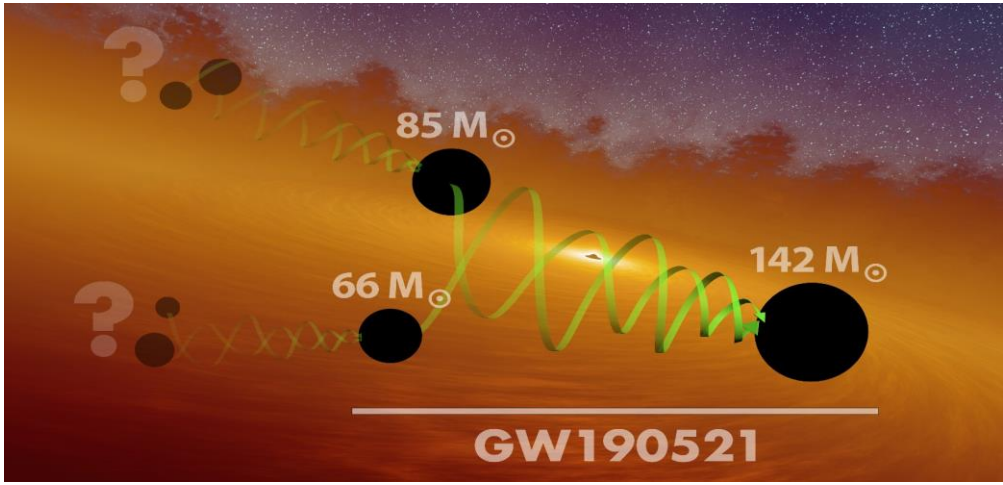
One (or two) BH found in the high mass gap

The heaviest BH (not counting the supermassive BH at galactic centers)

The merger created the first intermediate mass BH ever observed

The most powerful explosion detected since the Big Bang: 8 $M_\odot$!

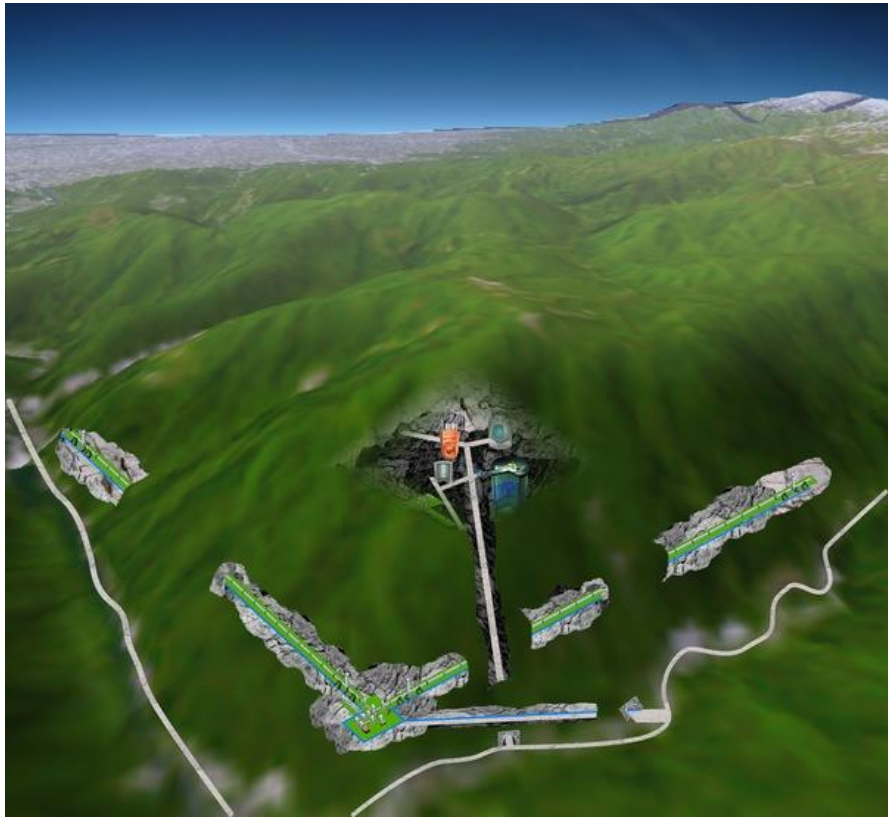
High mass gap: ~65 to 120 $M_\odot$



LIGO – Virgo
News and Upgrades

LIGO is now preparing for a fourth observing run, possibly as early as June 2022, depending on COVID impacts on the schedule. Detector improvements now being implemented are expected to improve sensitivity by at least 25%.

LIGO continues the development of the upgrade known as A+, funded by NSF, UKRI and ARC in 2018. A+ is expected to be fully operational by 2024, increasing Advanced LIGO sensitivity by 70%.



An illustration of the underground KAGRA gravitational-wave detector in Japan. [Image credit: ICRR, Univ. of Tokyo.]

Windows on the Universe:
The Era of Multi-Messenger Astrophysics
PD 18-5115

- Proposals submitted to participating programs in MPS/AST, MPS/PHY and GEO/OPP.
- Proposals funded through central allocation as well as existing programs.
- Criteria: <u>any area of research supported through the participating divisions that address at least one of the following:</u>
  - *Coordination:* Hardware, software, or other infrastructure to coordinate observations involving more than one messenger.
  - *Observations:* Observations of astrophysical objects or phenomena that are potentially sources of more than one messenger, including the use of existing observatories, experiments, and data archives, as well as the development and construction of new capabilities for advancing multi-messenger astrophysics.
  - *Interpretation:* Theory, simulations and other activities to understand or interpret observations of astrophysical objects that are sources of more than one messenger.

https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505593

Mid-scale Research Infrastructure

- Mid-scale RI is designed to address the growing needs for RI to advance research.
- NSF-wide program will support projects in the MRI – MREFC gap (~$6 to $100 million range).
- RI is broadly defined, from disciplinary instrumentation to mid-scale facilities, upgrades, cyberinfrastructure, and others.

- Two Levels of Proposal: MSRI-1 for projects between ~$6 M and ~$20 M; MSRI-2 for projects between ~$20 and $100 M (new MREFC threshold).
- Alternate years for proposal submission. MSRI-1 ongoing in FY 2021;

  MSRI-2 planned for FY 2022

Industries of the Future

FY 2021 Administration R&D Budget Priority Memo:

"These industries promise to fuel American prosperity, improve quality of life and national security, and create high-paying jobs for American workers."

Quantum Information Science

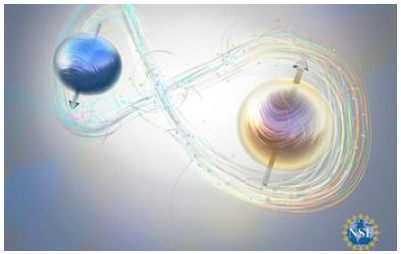
Artificial Intelligence

Advanced Wireless/5G

Biotechnology

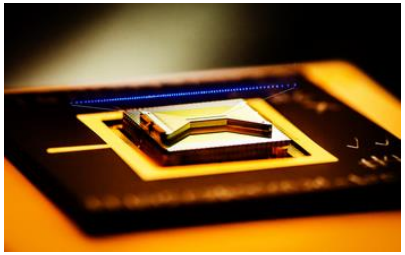
Advanced Manufacturing

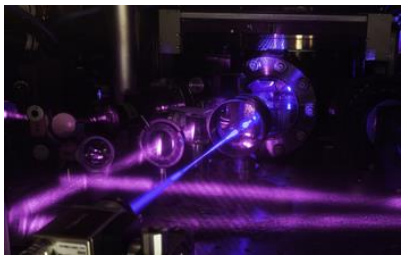
NSF and the National Quantum Initiative (NQI)



Sec. 301: The Director of the National Science Foundation shall carry out a basic research and education program on quantum information science and engineering, including the competitive award of grants to institutions of higher education or eligible nonprofit organizations (or consortia thereof).

Sec. 302: The Director of the National Science Foundation, in consultation with other Federal departments and agencies, as appropriate, shall award grants to institutions of higher education or eligible nonprofit organizations (or consortia thereof) to establish at least 2, but not more than 5, Multidisciplinary Centers for Quantum Research and Education (referred to in this section as ‘‘Centers’’).





Quantum Leap Challenge Institutes (QLCI)

NSF 19-559

- The QLCI program will support **large-scale projects** driven by a ***cross-disciplinary challenge research theme*** for advancing the frontiers of quantum information science and engineering.

- Timely and bold research agenda aimed at making breakthroughs on compelling challenges in a 5-year period.

- Conceptualize, develop, and implement **revolutionary** new approaches and technologies for quantum information processing.

- Research will span the focus areas of **quantum computation**, **quantum communication**, **quantum simulation, and quantum sensing.**

QLCI Phase One Awardees

NSF Quantum Leap Challenge Institute for Hybrid Quantum Architectures and Networks

Lead PI: Brian DeMarco, University of Illinois Develop practical hardware & software for multi-node heterogeneous quantum processors & short-scale quantum networks

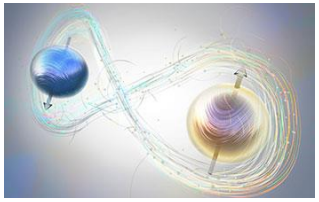
NSF Quantum Leap Challenge Institute for Present and Future Quantum Computing

Lead PI: Daniel Stamper-Kurn, University of California, Berkeley Tackle far-reaching questions at the heart of general-purpose quantum computation

NSF Quantum Leap Challenge Institute for Enhanced Sensing and Distribution Using Correlated Quantum States

Lead PI: Jun Ye, University of Colorado Develop fundamental improvements in quantum sensing with broader implications for quantum simulation and information processing

Current Activities



Quantum Leap Challenge Institutes (QLCI)

Second phase underway

Enabling Quantum Leap: Quantum Interconnect Challenges for Transformational Advances in Quantum Systems (QuIC-TAQS)

Support interdisciplinary teams that will explore highly innovative, original, and potentially transformative ideas for developing and applying quantum science, quantum computing, and quantum engineering in the specific area of quantum interconnects.

Dear Colleague Letter: Enabling Quantum Computing Platform Access for NSF Researchers with Amazon Web Services, IBM, and Microsoft Quantum

Support for students to implement quantum computing calculations on cloud-based platforms

Dear Colleague Letter: International Collaboration Supplements in Quantum Information Science and Engineering Research

Support to add a new - or strengthen an existing - international dimension to an award

NSF Convergence Accelerator Phase I and II — Quantum Technology (Track C)

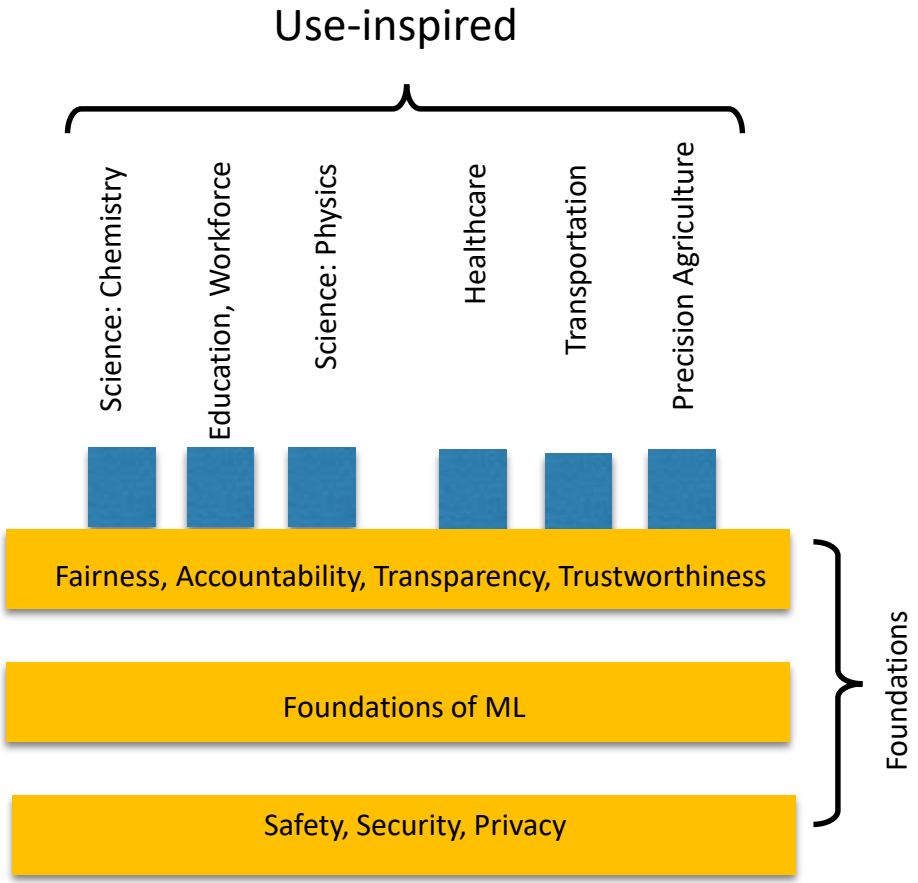
Support for projects that bridge the gap between state-of-the-art fundamental research generating lab proof of concept architectures, devices, and theories and current industry efforts.

The NSF National AI Research Institutes

National nexus points for universities, federal agencies, industry and nonprofits to **advance AI research and education**

In FY 2020 (NSF 20-503):

- Issued planning grants for future institutes
- Launched seven multidisciplinary, multi-institutional research institutes
- Ongoing in FY 2021



The NSF AI Institute for Artificial Intelligence and Fundamental Interactions (IAIFI)

"eye-phi"

Advance physics knowledge — from the smallest building blocks of nature to the largest structures in the universe — and galvanize AI research innovation

Physics Theory

Physics Experiment

AI Foundations

Build strong multidisciplinary collaborations
Advocacy for shared solutions across subfields
Training, education & outreach at Physics/AI intersection
Cultivate early-career talent (e.g. IAIFI Fellows)
Foster connections to physics facilities and industry


The New York Times

By Dennis Overbye Nov. 23, 2020

Can a Computer Devise a Theory of Everything?

$20 million over 5 years – cofunding from MPS/PHY, CISE/IIS, and MPS/AST

NSF COVID Response

Identified Areas of Need

Most Strongly Affected Groups

- MSIs, Less Affluent Institutions
- Women Researchers
- Underrepresented Groups
- Early-career Faculty
- Post-docs, Trainees, Fellows

Vulnerable Transition Points

- Undergraduate Students
- Graduate Students
- Post-docs, Trainees, Fellows
- Early-career Faculty
- Mid-career Faculty

NSF Late-Breaking News

Launching Early-Career Academic Pathways in the Mathematical and Physical Sciences (LEAPS-MPS)
PROGRAM SOLICITATION **NSF 21-570**

Designed to launch the careers of pre-tenure faculty in Mathematical and Physical Sciences (MPS) fields at minority-serving institutions (MSIs), predominantly undergraduate institutions (PUIs), and Carnegie Research 2 (R2) universities, and with the goal of achieving excellence through diversity

https://www.nsf.gov/pubs/2021/nsf21570/nsf21570.htm