



National Science Foundation Division of Physics Update

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Acting Division Director, Physics
Directorate for Mathematical and Physical Sciences

Board on Physics and Astronomy
November 8, 2023

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. Each award in the portfolio supports 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 a diverse, 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

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; Quantum Information and Revolutionary Computing

Center-Scale Activities – About 8% of total portfolio

Physics Frontiers Centers – Currently 9 Centers across Multiple Sub-Areas in Division
Science & Technology Center – “Center for Bright Beams” at Cornell University
AI Institute - Institute for Artificial Intelligence and Fundamental Interactions at MIT with
Harvard, Northeastern, and Tufts

Mid-scale Infrastructure – Varies

Support for construction and operations of midscale research infrastructure

Operations & Maintenance of Major Facilities – About 25% of total portfolio

Laser Interferometry Gravitational Wave Observatory (LIGO) (NSF/PHY only);
ATLAS and CMS Detectors at LHC (jointly with DoE);
IceCube Neutrino Observatory (Jointly with NSF Office of Polar Programs)

Fostering Connections



We partner whenever possible to promote progress of science

Partnerships between programs within PHY Division

Partnering with other NSF divisions on individual awards and centers: **MPS/AST, CHE, DMR, DMS; BIO/MCB, IOS, DBI; GEO/OPP, AGS, EAR; ENG/ECCS, CBET, CMMI; CISE/CCF, OAC; EDU/DUE**

Partnering in NSF priority areas: QISE, AI, WoU, etc.

Partnering with DOE Office of Science and NNSA in Particle Physics, Nuclear Physics, Plasma Physics

Partnering with AFOSR in Plasma Physics

Partnering with NASA in Gravitational Physics and Plasma Physics

Partnering with Gordon & Betty Moore Foundation in Gravity

Lead agency agreements with BSF, ANR, DFG, UKRI, GACR, SNSF ...

Partnerships with international agencies and organizations: CERN, Laboratori Nazionali del Gran Sasso (LNGS), CONACyT, VIRGO & KAGRA



Laser Interferometer Gravitational Wave Observatory

- 4th Observing Run (O4) started on May 24, 2023, and will last 20 months, including a two-month break will start mid-January 2024
- Virgo and KAGRA will resume observations after LIGO's commissioning break
- LIGO is performing at a sensitivity of 160 Mpc, an increase of 30% over O3
- 58 significant detections have been announced during O4 [GraceDB | LVK Public Alerts \(ligo.org\)](https://www.ligo.org/public/alerts)

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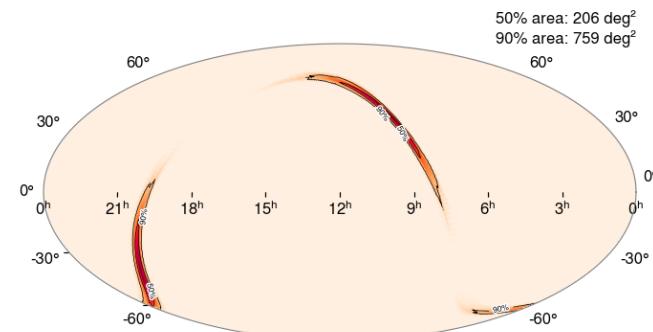


Image Credits: LIGO.org



LIGO A+ Upgrades



O4 implements the first set of upgrades of A+

- Frequency-dependent squeezing, including construction of 300m Filter Cavities and End stations.
(<https://journals.aps.org/prx/abstract/10.1103/PhysRevX.13.041021>)
- Better stray-light control with new baffles
- New lasers and test masses

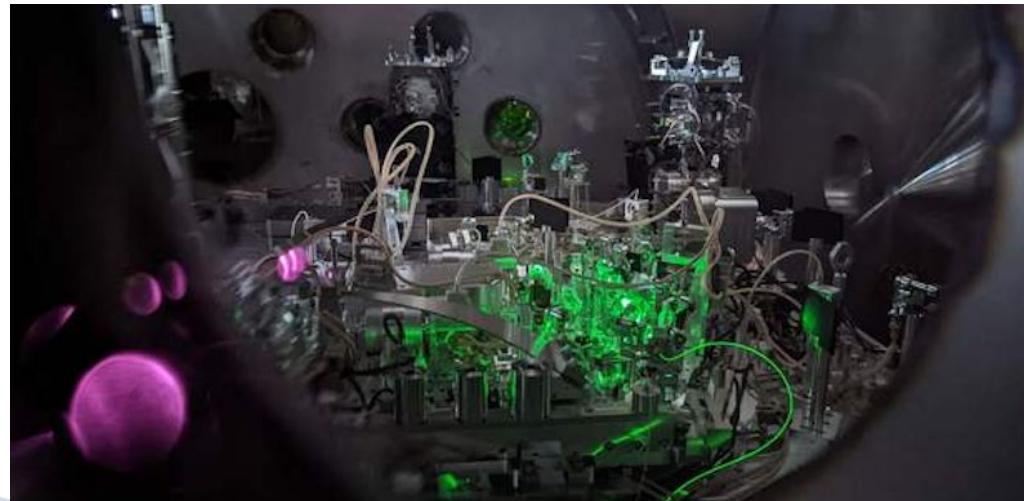
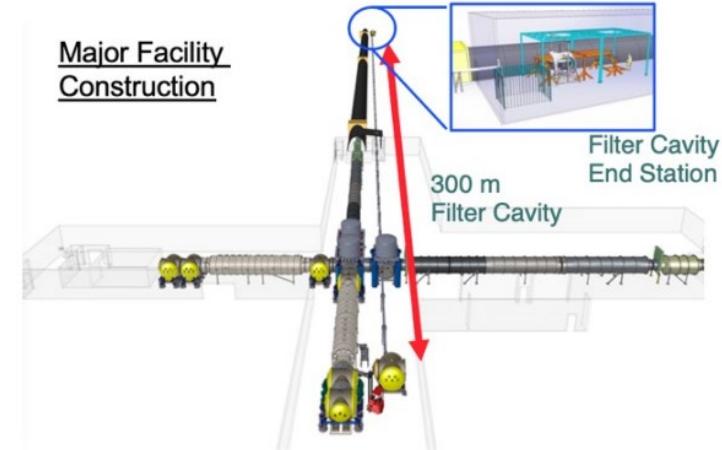


Photo Credit: G. Mansell/LIGO Hanford Observatory

Major Facility Construction



Major O4 Detector Improvements/A+ Upgrades

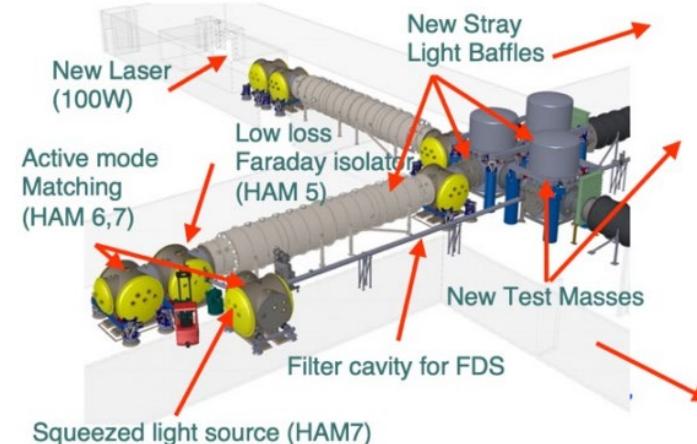
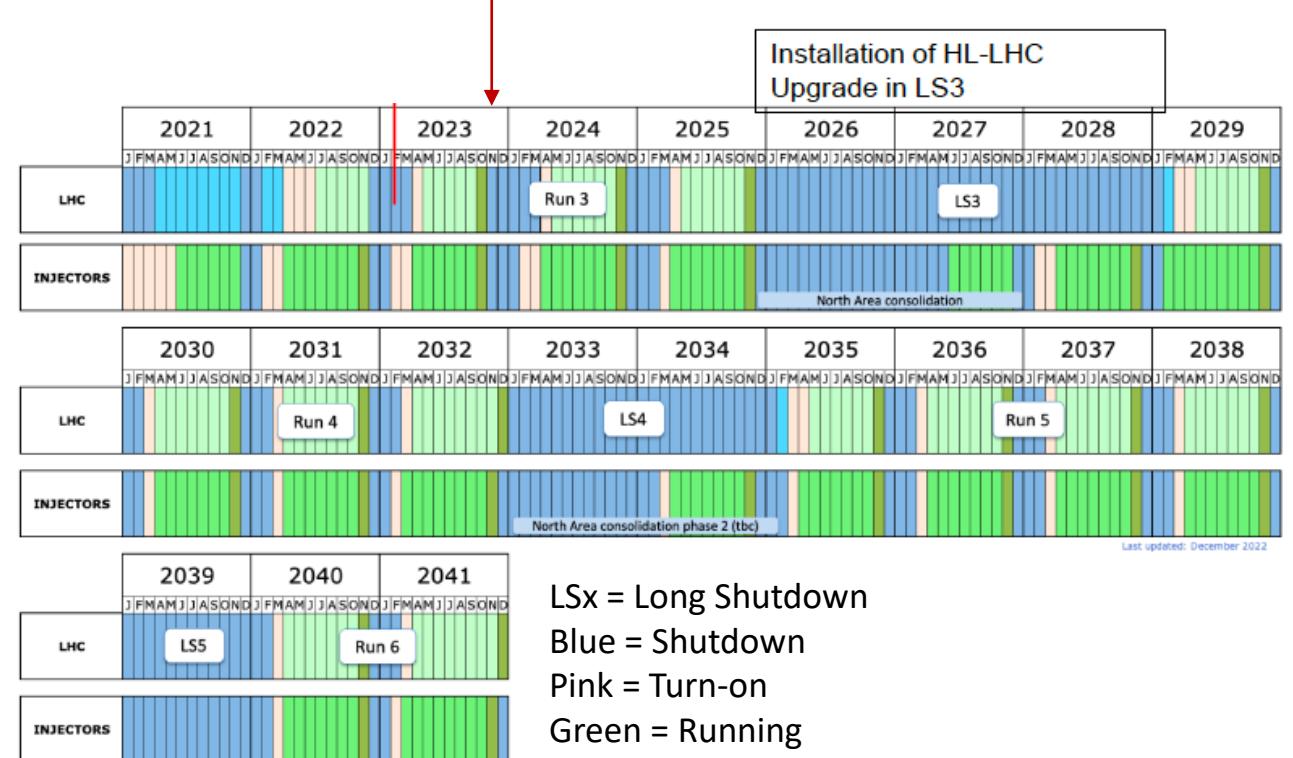


Image Credits: LIGO Lab

Large Hadron Collider



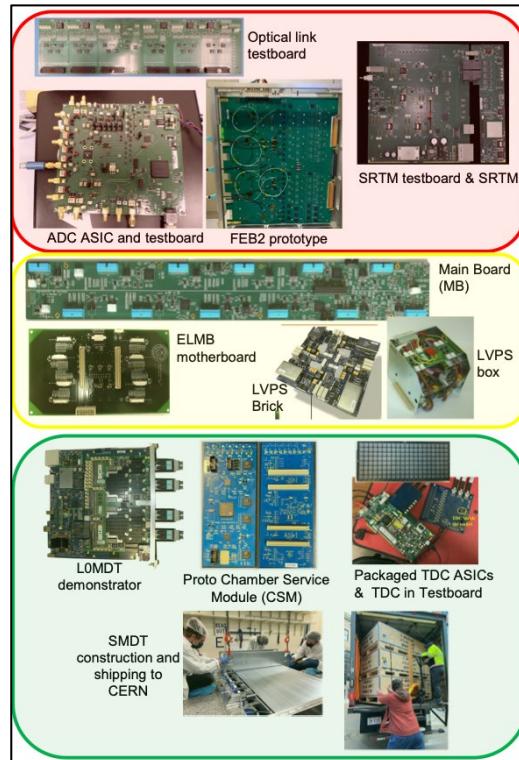
- The Large Hadron Collider (LHC) is the world's largest and most powerful particle accelerator, consisting of a 27-kilometre ring of superconducting magnets.
- NSF funds operations of 3 experiments at the LHC: ATLAS, CMS & LHCb.
- The main discovery at the LHC has been the observance of the predicted Higgs boson in 2012. Emphasis has since been the search for physics beyond the Standard Model.
- LHC is currently completing CY2023 run and expects the normal continuation of Run 3 beginning in April 2024.



LHC – High Luminosity LHC

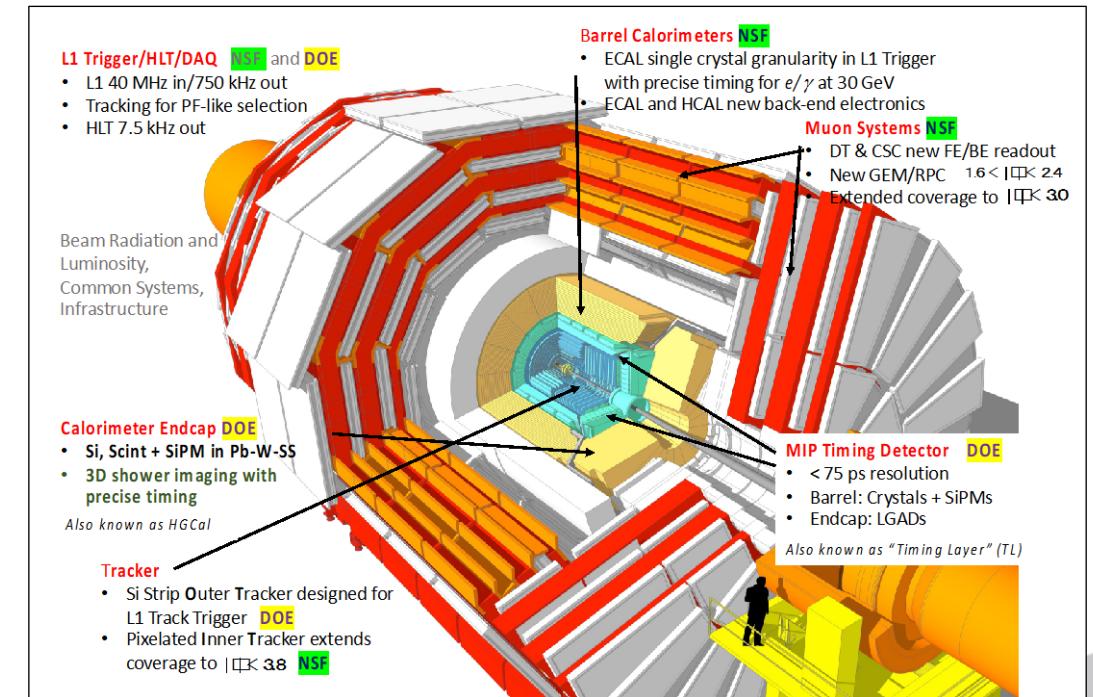


- The LHC accelerator complex is undergoing an upgrade that will provide a ten times greater collision rate. The upgrade is scheduled to be completed by the end of 2028 with operations beginning in 2029 (Run 4).
- The accelerator upgrade requires a major upgrade of the detectors ATLAS and CMS. The NSF MREFC project (HL-LHC) is providing key components. Both projects are on schedule for on time delivery to CERN.



ATLAS

Image Credits: US ATLAS and CMS

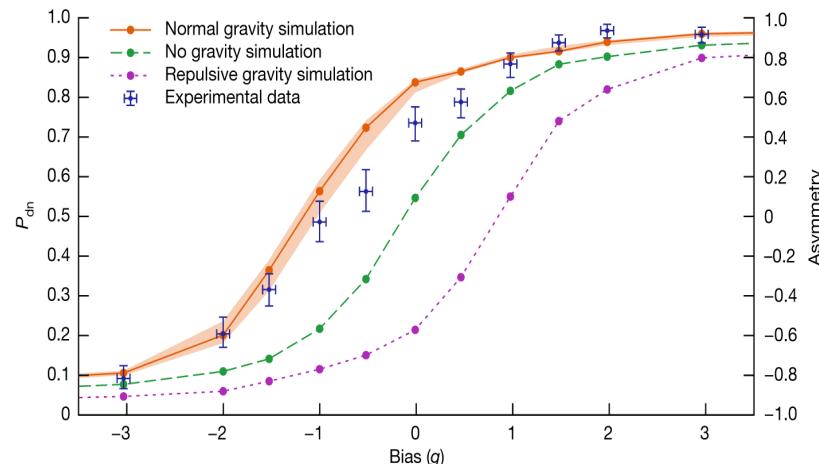


CMS

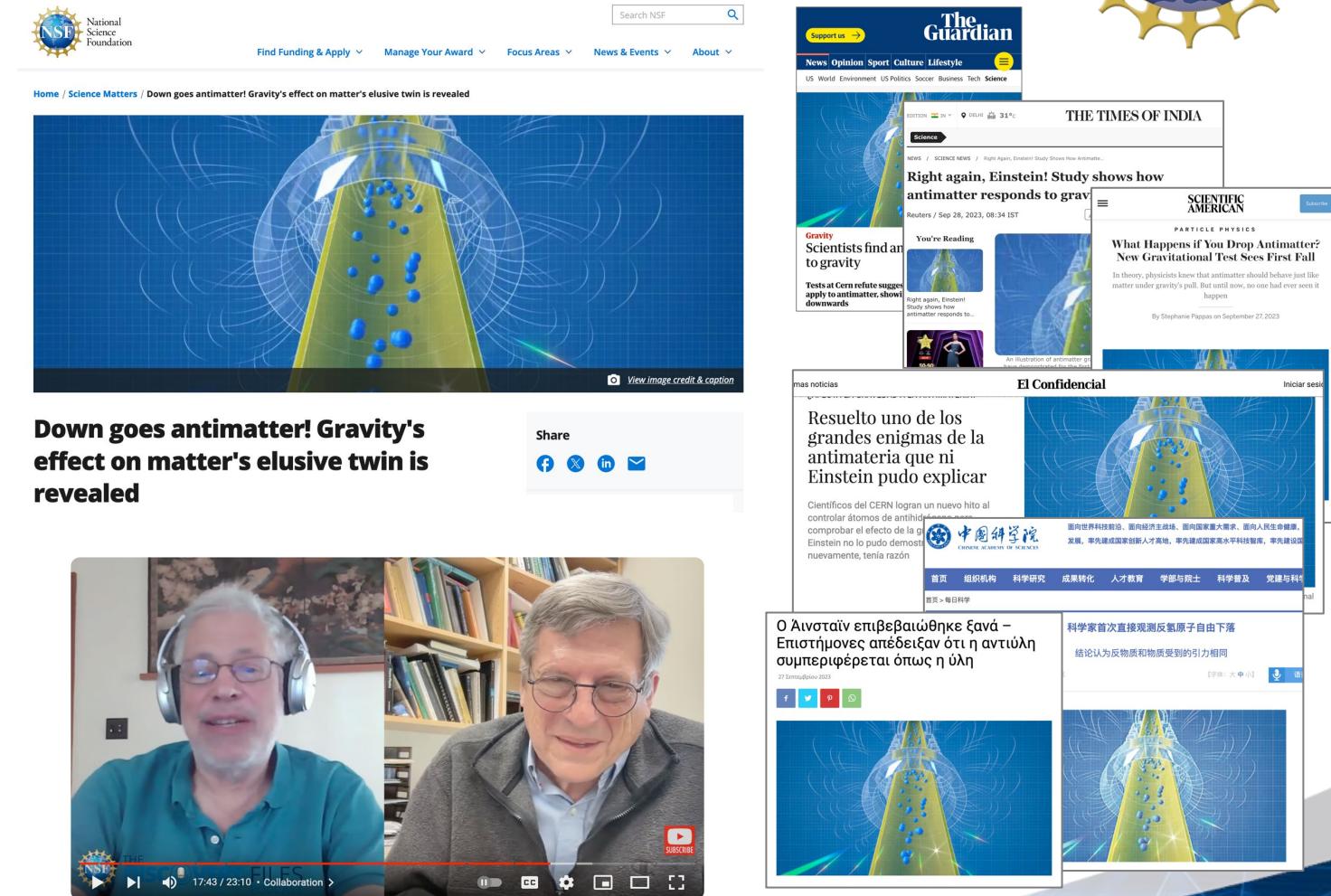
ALPHA-g: Antihydrogen Gravity Measurement



- The Antihydrogen Laser Physics Apparatus (ALPHA) collaboration at CERN has reported the first direct measurement of effect of gravitational attraction on antimatter.
- High impact result that received public exposure worldwide.



Anderson *et al.*, Nature 621 (2023)



The figure shows a collage of news articles and a video from the Discovery Files Podcast. The top left is the NSF website. The top right is The Guardian. Below The Guardian are The Times of India, Scientific American, and El Confidencial. The bottom left is a video from the Discovery Files Podcast. The bottom right is a news article from the Chinese Academy of Sciences.

NSF National Science Foundation

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Down goes antimatter! Gravity's effect on matter's elusive twin is revealed

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Normal gravity simulation
No gravity simulation
Repulsive gravity simulation
Experimental data

BREAKTHROUGH: Antimatter's Motion in Gravity [CERN] | Discovery Files Podcast

<https://www.youtube.com/watch?v=AMwN2C7qfxs>

IceCube Neutrino Observatory

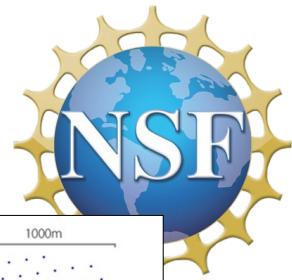


- 2011-2023: 12 years of IceCube
- 1 cubic kilometer of instrumented clear ice beneath the South Pole to capture the highest energy cosmic neutrino interactions
- International IceCube Collaboration
 - Institutions: 30 U.S. & 28 International
 - Scientists: 176 U.S. & 189 International
 - Faculty: 57 & 53
 - Postdocs: 55 & 44
 - Graduate Students: 64 & 92
- Continuous data collection (99% uptime). Staff deploying for 2024 season in addition to 2 “winter-overs.”

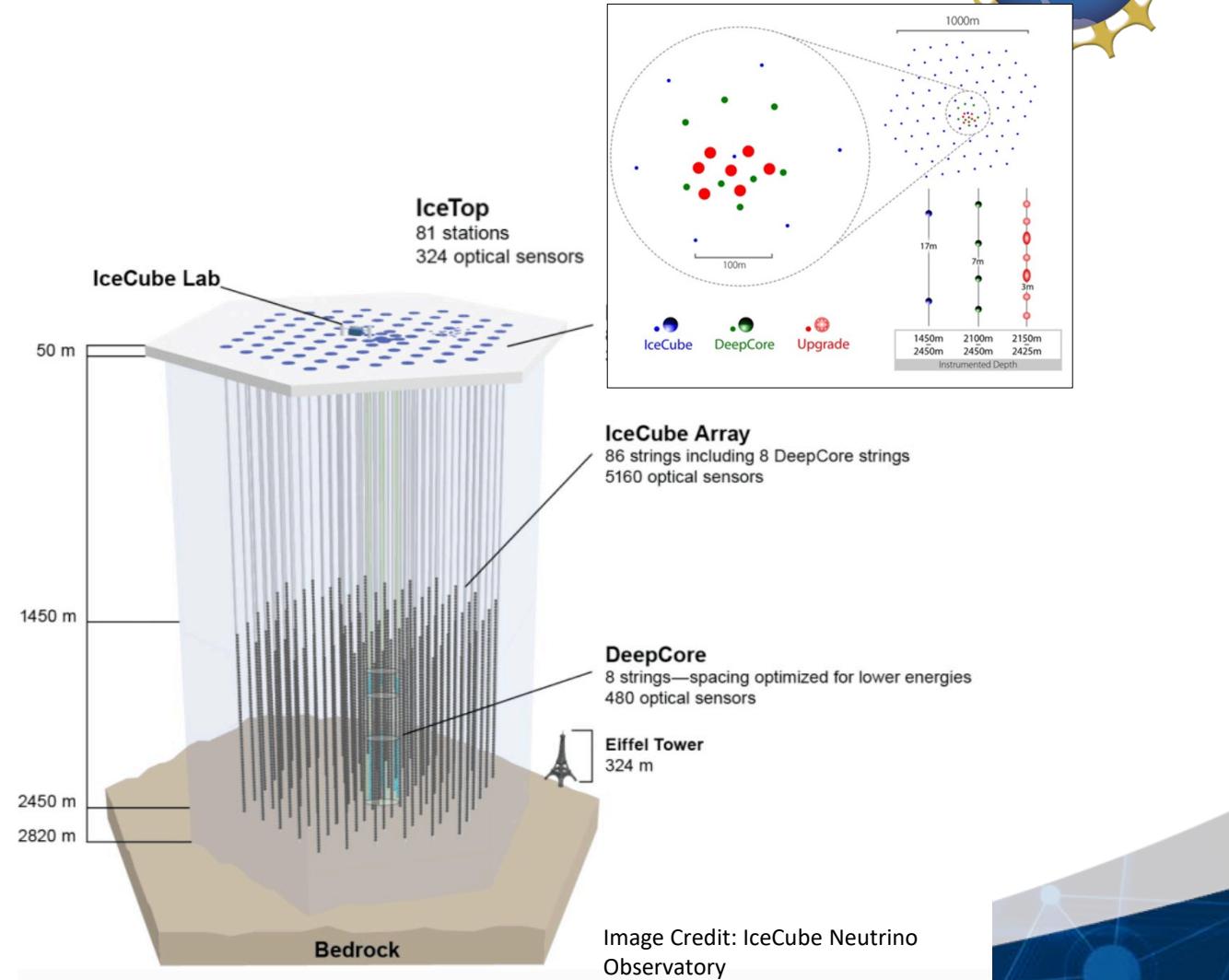


Josh Veitch-Michaelis, IceCube/NSF

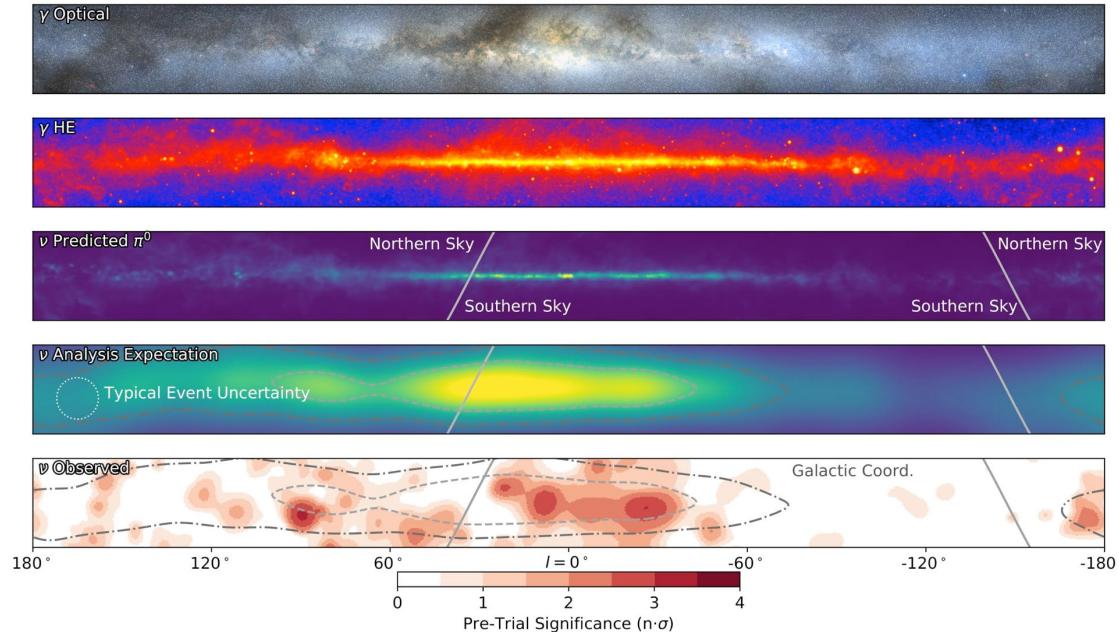
IceCube Upgrade



- Funded in 2018 to add 7 additional strings of sensors to enable:
 - Observations of lower energy neutrinos
 - Improved calibration to apply to new and 12+ years of archival data
- COVID impacts for work at the South Pole has added 3 years delay
- Project is on track to install the 7 upgrade strings over the next 3 field seasons. Team is currently deploying for the first season.



Imaging the Milky Way in Neutrinos



- Provides quantitative information on neutrino-“quietness” from our central black hole.
- Opens new studies of our galaxy, nearby sources of neutrinos, and the diffuse neutrino background.
- Another major advance in neutrino astrophysics!

- On June 28, 2023 IceCube unveiled the first image of the milky way in neutrinos.
- Naoko Kurahashi Neilson (Drexel) led the development of new techniques to extract pointing information from neutrino events and machine learning algorithms for reconstruction.



Mid-scale Instrumentation



Division Mid-scale Instrumentation Fund:

- Division support for construction of projects with TPC from ~\$4M to ~\$20M. Proposals are submitted to and reviewed in the disciplinary programs. Science must be determined to be of high priority in disciplinary program.
- Mid-scale Instrumentation Fund resources are one-time, non-renewable investments for construction only. MSIF funds cannot be used to support R&D or operations.
- **Examples:** SCDMS, LEGEND-200, ZEUS, Moller, IceCube Upgrade; Darkside-20K; BL3

NSF-wide Mid-scale Research Infrastructure Programs:

- Mid-scale RI-1: Supports the design and implementation of research infrastructure with TPC less than \$20 million. **Examples:** ZEUS, EP-OPAL
- Mid-scale RI-2: Supports the implementation of research infrastructure with TPC between \$20 million and \$100 million.

NSF ZEUS Laser User Facility



Zettawatt Equivalent Ultrashort pulse laser System

- First dedicated open US high field user facility with the highest power laser in the U.S. (3 PetaWatt)
- Will enable exploration of fundamental physics of non-linear QED and high energy astrophysical phenomena.
- Facility Inauguration on October 16, 2023. ZEUS is now open to users.

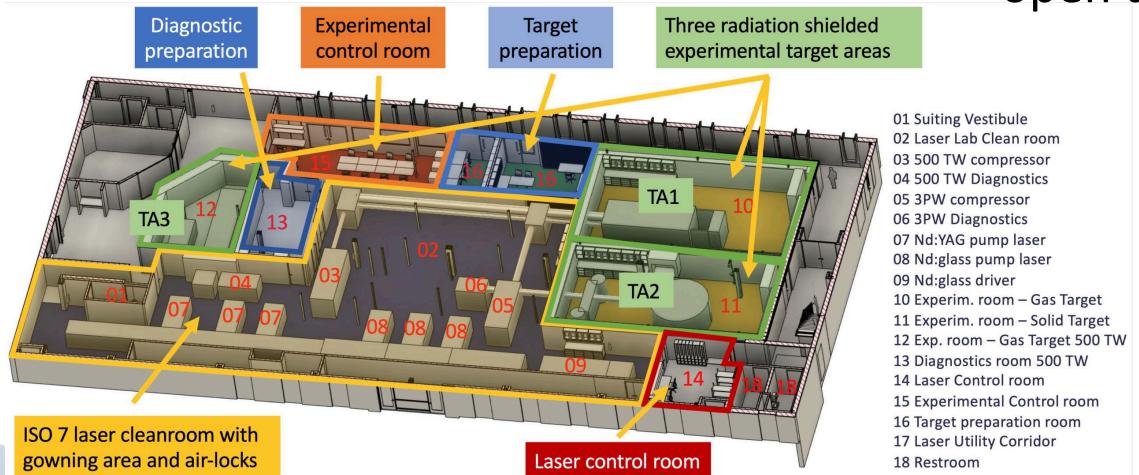
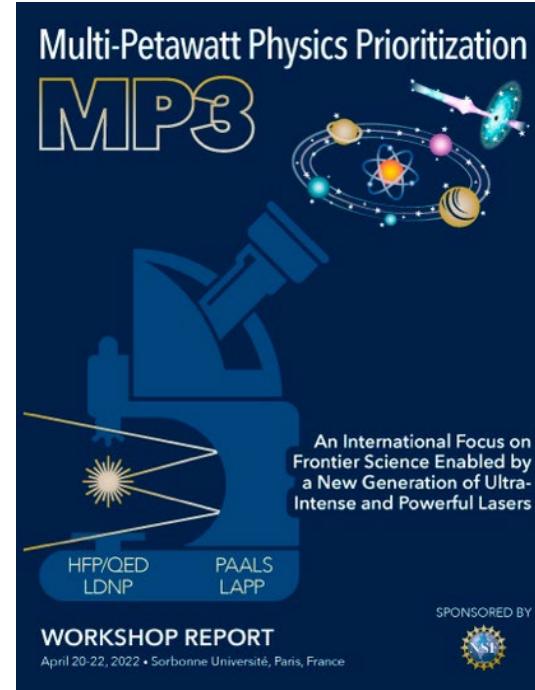


Photo Credits: University of Michigan

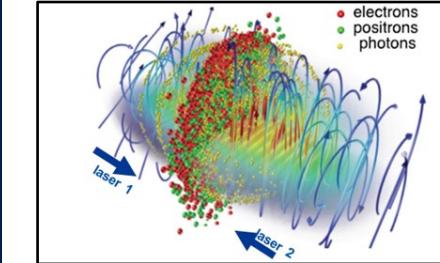
EP-OPAL MSRI-1 Award



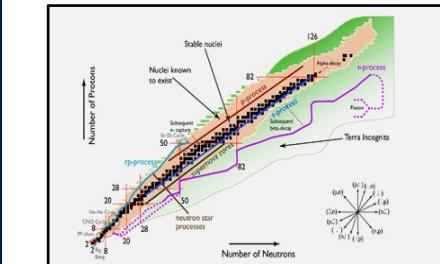
- Mid-scale RI-I award for design and prototyping for the OMEGA Extended Performance Optical Parametric Amplifier Line (EP-OPAL) 2x25 PetaWatt laser system
- Led by the University of Rochester, EP-OPAL includes the University at Buffalo, University of California – Irvine, University of Notre Dame, University of Maryland, University of Michigan, Ohio State University
- Guided by frontier science opportunities identified during the Multi-Petawatt Physics Prioritization (MP3) workshop (<https://arXiv.org/abs/2211.13187>)



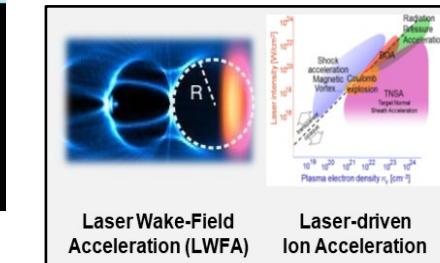
High-Field Physics and Quantum Electrodynamics (HFP/QED)



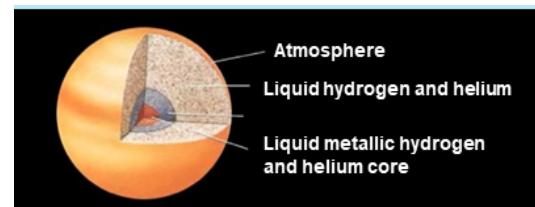
Laser-Driven Nuclear Physics (LDNP)



Particle Acceleration and Advanced Light Sources (PAALS)



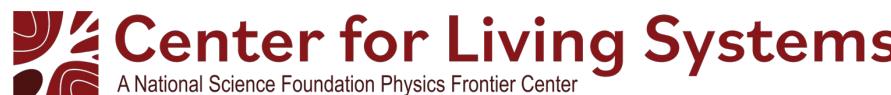
Laboratory Astrophysics and Planetary Physics (LAPP)



Physics Frontiers Centers



Center for the Physics
of Biological Function



Network in Neutrinos, Nuclear Astrophysics, and
Symmetries

Center for Theoretical Biological Physics (with MPS/DMR&CHE,
BIO/MCB&IOS)

North American Nanohertz Observatory for
Gravitational Waves (with MPS/AST)

Center for Ultracold Atoms (with CISE/CCF)

Center for the Physics of Biological Function (with MPS/CHE,
BIO/MCB & IOS)

The Center for Matter at Atomic Pressures (with GEO/EAR)

Institute for Quantum Information and Matter (with CISE/CCF)

JILA Physics Frontiers Center

Center for Living Systems (with BIO/MCB & IOS)

NANOGrav Detects GW Background



- On June 28, 2023, NANOGrav announced the detection of the stochastic gravitational wave background
- Data set included 15-years of observations of 68 ms pulsars using the NSF facilities Arecibo, Green Bank, and the Very Large Array
- NANOGrav and IPTA observations give powerful insights into galaxy formation, large scale structure of the Universe, and cosmology



Image Credit: Aurore Simonnet for the NANOGrav Collaboration



Arecibo



Green Bank



Very Large Array

Image Credits: NANOGrav

Partnerships for Research and Education in Physics (PREP)



Goal of PREP Program is to increase the participation of members of underrepresented groups through excellent research and education endeavors.

- Awards to Minority Serving Institutions to partner with Physics Frontiers Centers
- Full intellectual engagement on both sides
- Six awards made in FY 2022 (Solicitation NSF 21-610)
- Next competition expected in FY2024



TEXAS SOUTHERN UNIVERSITY



CALIFORNIA
STATE UNIVERSITY
NORTHRIIDGE

CSUN/Caltech-IQIM Partnership
(PI: Yang Peng)



Understanding & Controlling Rydberg States in Solid-State Platforms for Quantum Technologies (PI: Carlos Meriles)



NANOGrav@UPRM: Growing and Characterizing the NANOGrav Gravitational-Wave Detector (PI: Henri Radovan)



Partnership for Research and Education on Molecules at High Pressures (PI: Guang-Lin Zhao)

Diversity, Equity and Inclusion



Solving the cutting-edge problems in Physics requires engaging the nation's human talent and resources in their entirety, and developing and supporting the diverse Physics workforce that is critical for continued progress in scientific discovery.

PREP: Partnerships for Research and Education in Physics

LEAPS-MPS: Launching Early-Career Academic Pathways in the Mathematical and Physical Sciences

MPS-Ascend: Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowships

MPS-AFCA: Mathematical and Physical Sciences Ascending Faculty Catalyst Awards

AGEP-GRS Supplements: for organizations that are part of the Alliances for Graduate Education and the Professoriate (AGEP)

PHY-GRS Supplements: “Growing a Strong, Diverse Workforce” for all other organizations

MPS-High: High School Student Research Assistantships

Advisory Committee Activities – Future Directions



NSF/PHY Committee of Visitors 2023 - Report **approved** by MPSAC April 2023

<https://www.nsf.gov/mps/advisory.jsp>

NSAC - Nuclear Physics Long Range Plan - Report **approved** by NSAC October 2023

<https://nuclearsciencefuture.org/>

HEPAP – Particle Physics Project Prioritization Panel - Report expected December 2023

<https://www.usparticlephysics.org/p5/>

Next-Generation Gravitational Wave Observatory Subcommittee - Report expected January 2024

<https://www.nsf.gov/mps/phy/nggw.jsp>

NASEM Elementary Particle Physics: Progress and Promise Survey - Report expected Spring 2024

<https://www.nationalacademies.org/our-work/elementary-particle-physics-progress-and-promise>



Questions?