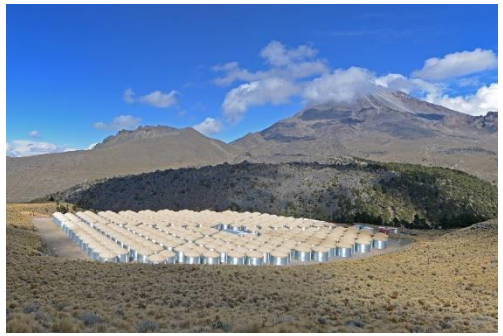
Astrophysics in the NSF Physics Division

A Snapshot

C. Denise Caldwell
Division Director

With input from Jean Cottam, Jim Whitmore, Keith Dienes,
Pedro Marronetti, Mark Coles, Allena Opper, and Slava Lukin



Credit: HAWC

Credit: IceCube

Credit: LIGO Lab

AAAC January 2020

Perspectives on the Frontiers of Physics

Controlling the Quantum World– Electromagnetic radiation in the non-classical limit, Entanglement, Cavity QED, QIS, Optomechanics (Optical Physics; Quantum Information Science)

Complex Systems and Collective Behavior – Living cells, biological systems, ultracold fermions and bosons, quark-gluon liquid (Physics of Living Systems; Atomic and Molecular Dynamics; Nuclear Physics; Plasma Physics)

Neutrinos and Beyond the Higgs – Neutrino mass, new particles, unification of quantum mechanics and gravity, electron and neutron dipole moments (Particle Astrophysics; Gravitational Physics; Nuclear Physics; Precision Measurements; Elementary Particle Physics)

Origin and Structure of the Universe – Star formation and creation of the elements, dark matter and dark energy, modeling of black holes, gravitational waves, magnetic fields (Gravitational Physics; Nuclear Physics; Particle Astrophysics; Plasma Physics)

Strongly-Interacting Systems– QCD computations, quark structure of baryons, high-field laser-matter interactions, supernovae, strong gravity (Nuclear Physics; Gravitational Physics; Plasma Physics)

PHY Budget Status

FY 2019 Actual	$ 285.2 M
FY 2020 Current Plan	Under Development
FY 2021 Request	Under Development

FY 2019 PHY Astrophysics Funding $ 110.4 M

O&M Costs (LIGO, IceCube, NSCL)	$ 54.5 M
LIGO A+ Enhancement	$ 10.5 M
Research Program (Experimental)	$ 33.7 M
Research Program (Theory)	$ 6.9 M
Physics Frontiers Centers (JINA, NanoGrav)	$ 4.8 M

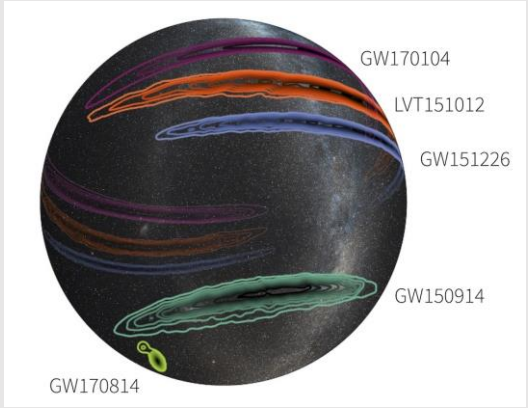
LIGO - Virgo
Observation Run 3 (O3)

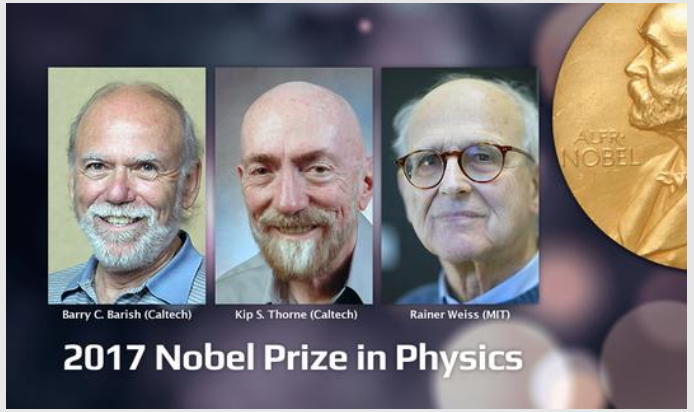
The 3rd Observational Run (O3) started in April 2019 and it is currently undergoing with an increase in sensitivity over O2 of about 30%.

Its first part (O3a) ended at the end of September 2019 and, after a month-long break for maintenance and upgrades, the second part (O3b) started on November 1, 2019. O3 will conclude on April 30, 2020.

So far, 65 public alerts have been issued, 21 of which have been retracted. This leaves 44 detections or about a GW event per week.

So far, no EM counterparts have been reported.



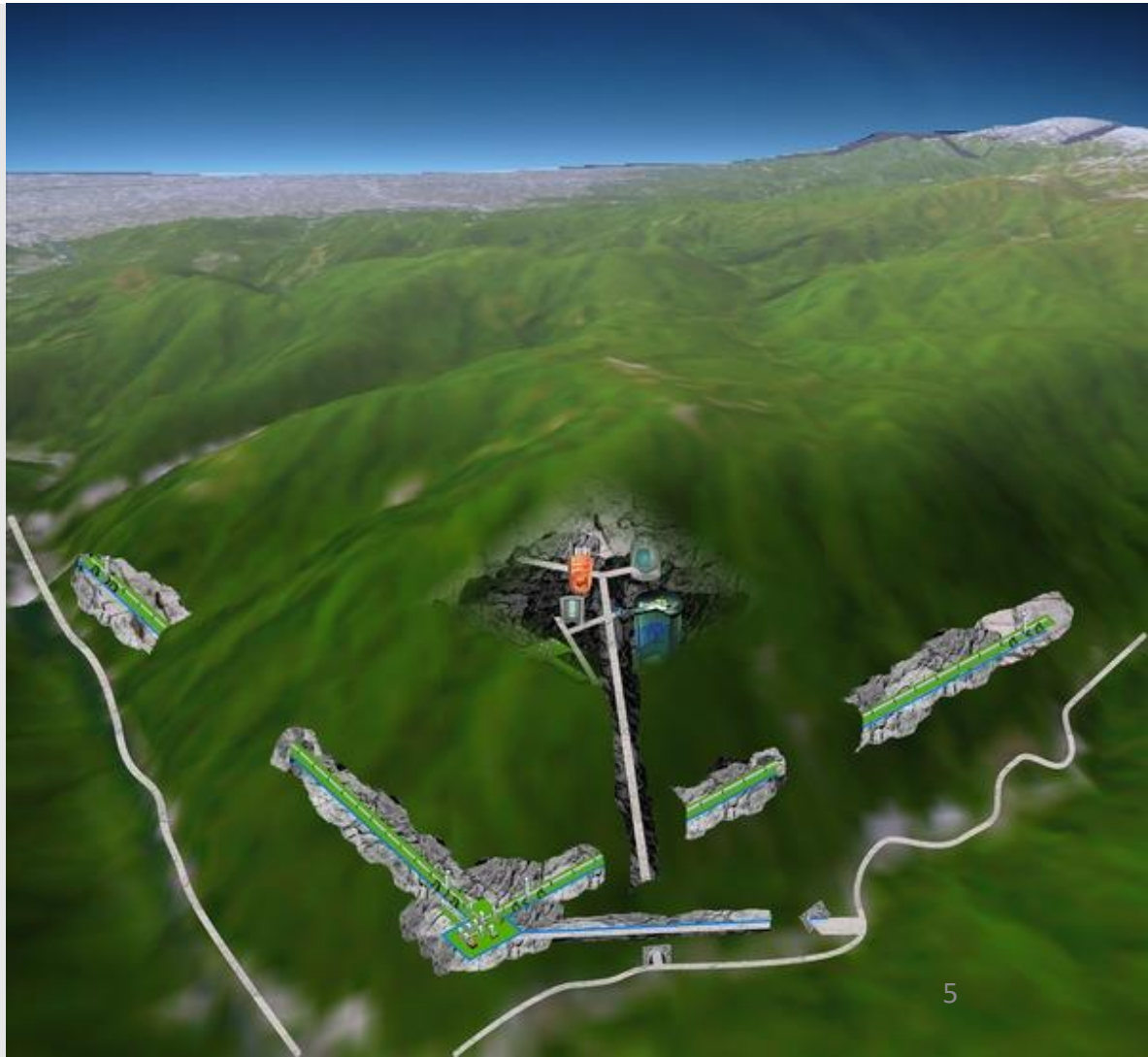


LIGO – Virgo
News and Upgrades

KAGRA joined the LIGO – Virgo collaboration through the signing of a joint MOU in October 2019. KAGRA is a Japanese based observatory that is built underground in the Kamioka site.

KAGRA is currently undergoing commissioning.

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.]

LIGO - Virgo
O3 Highlights

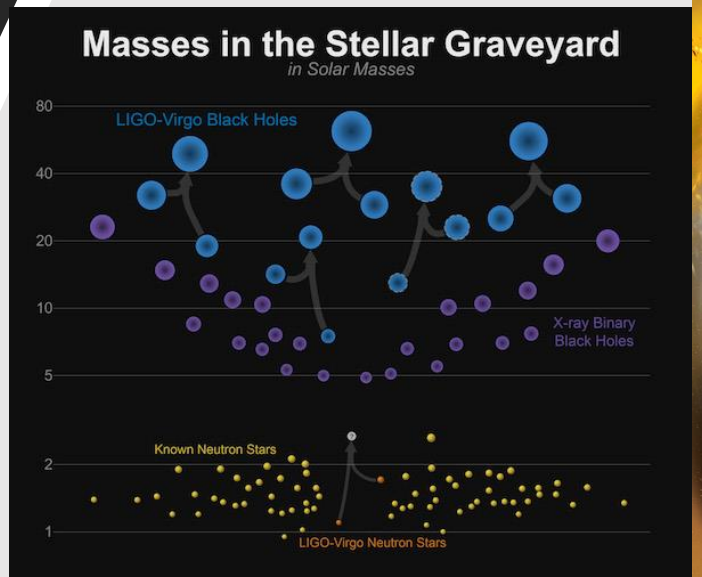
Few of the GW observations obtained so far by LIGO/Virgo have been made public.

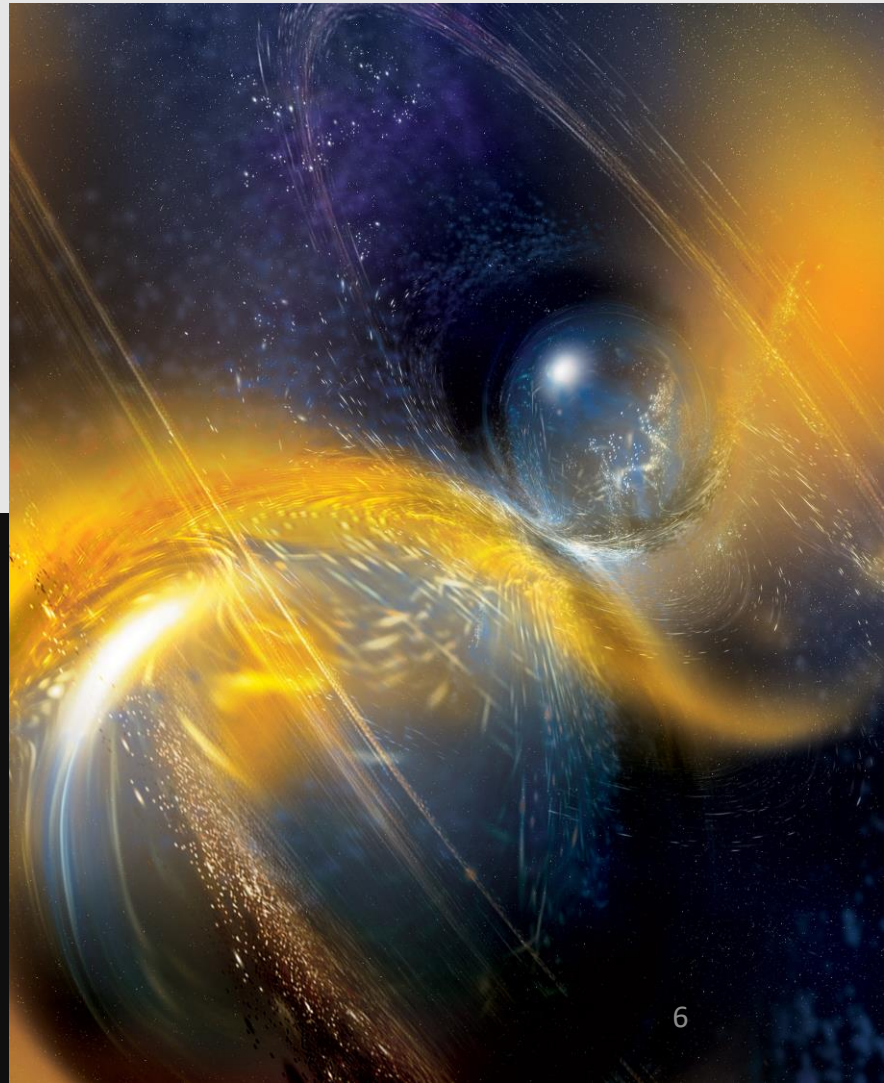
One was the detection of a new neutron star merger on April 25, 2019. No EM counterpart was detected.

This event was detected only by LIH+GO Livingston: Hanford was off-line and the event was too faint for Virgo (500 M light-years away).

The combined mass of this binary is the largest of any neutron star binary known to date: 3.4 solar masses vs the largest galactic binary mass of 2.9 solar masses.

It is possible that one of the objects was a black hole. But, if so, this BH would be exceptionally small for its class

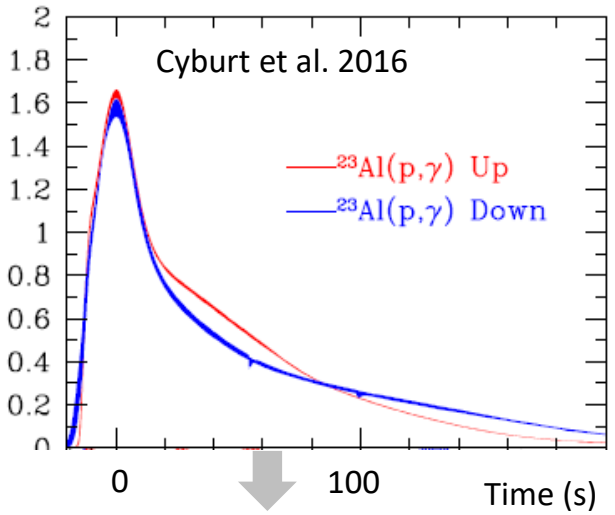




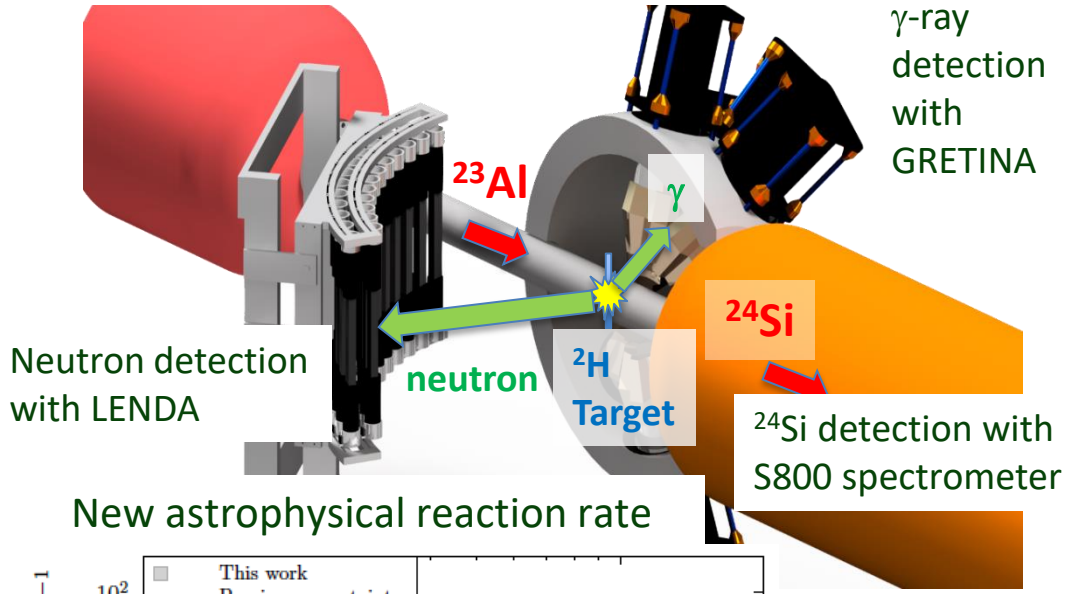
Removed ^{23}Al(p,γ) Uncertainty in X-ray Bursts at NSCL/JINA-CEE

The ^{23}Al(p,γ)^{24}Si reaction is among the most important reactions driving the energy generation in type-I x-ray bursts.

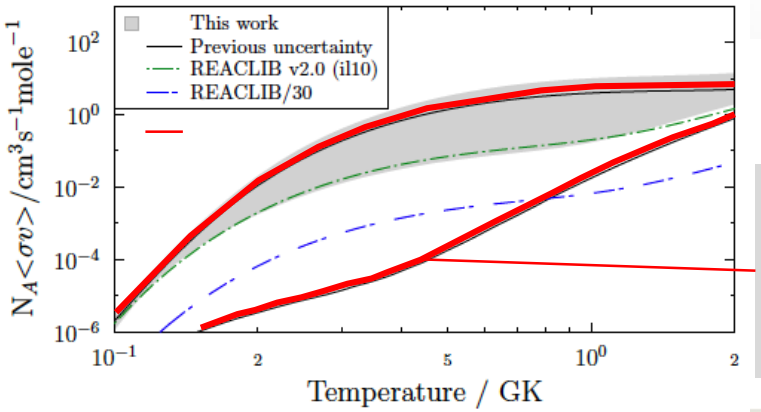
X-ray Burst Model Studies



Rate uncertainty prevents extraction of neutron star surface redshift from observed X-ray burst light curves



New astrophysical reaction rate

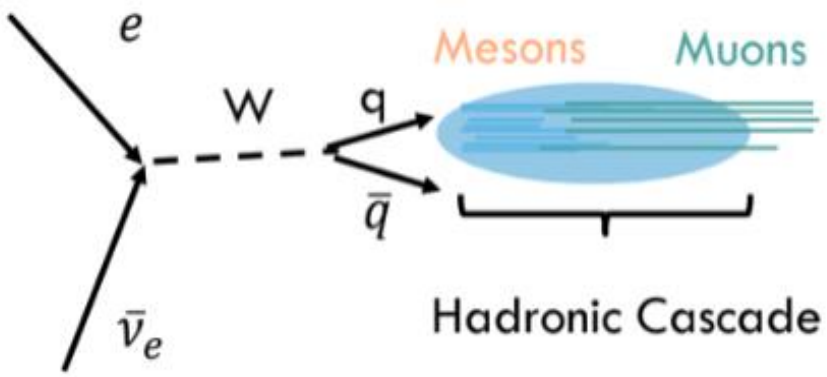


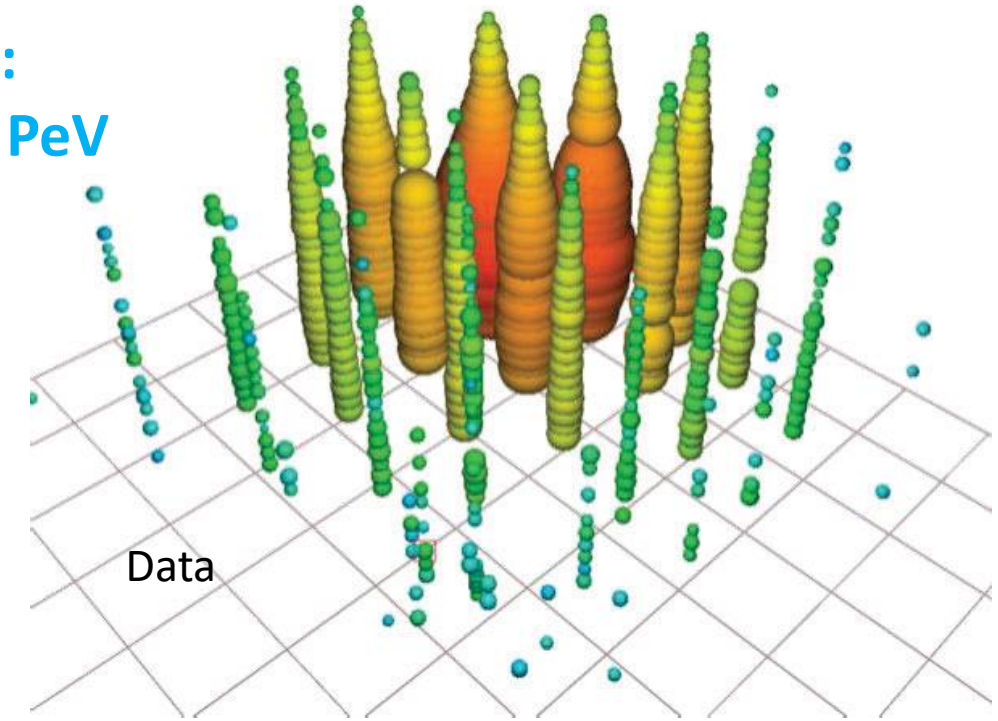
Old lower limit now excluded → Removes the uncertainty

C. Wolf et al., Phys. Rev. Lett. 122, 232701

An IceCube Result

A possible first Glashow resonance event:
anti-ν_e + atomic electron → real W at 6.3 PeV





About 5 years (2012-2016) of data. One event is at Glashow bin!

It is brighter than all IceCube PeV events even only partially-contained

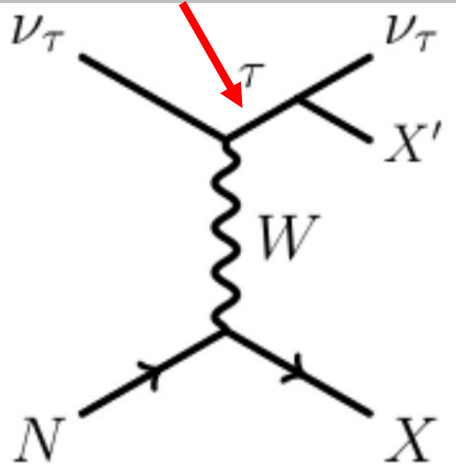
- Partially-contained PeV search
- Deposited energy: 5.9±0.18 PeV
- Detector efficiency is 93%

- → resonance: E_ν = 6.3 PeV

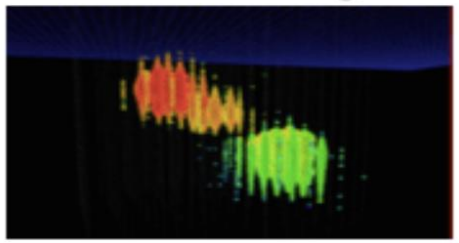
An IceCube Result

Cosmic *tau* neutrino appearance in IceCube

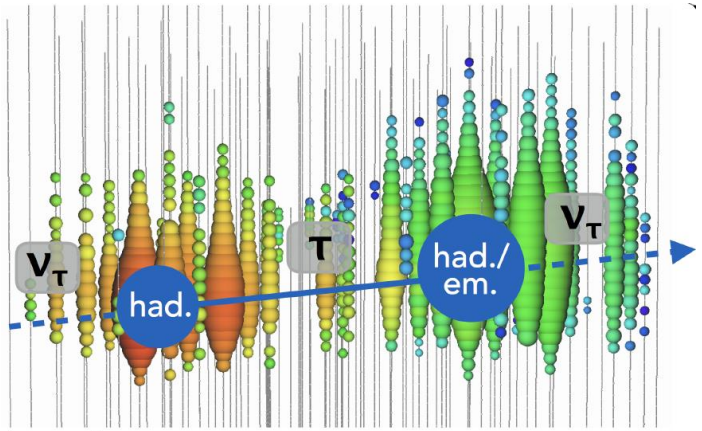
Tau decay length:
50 m per PeV



double bang*



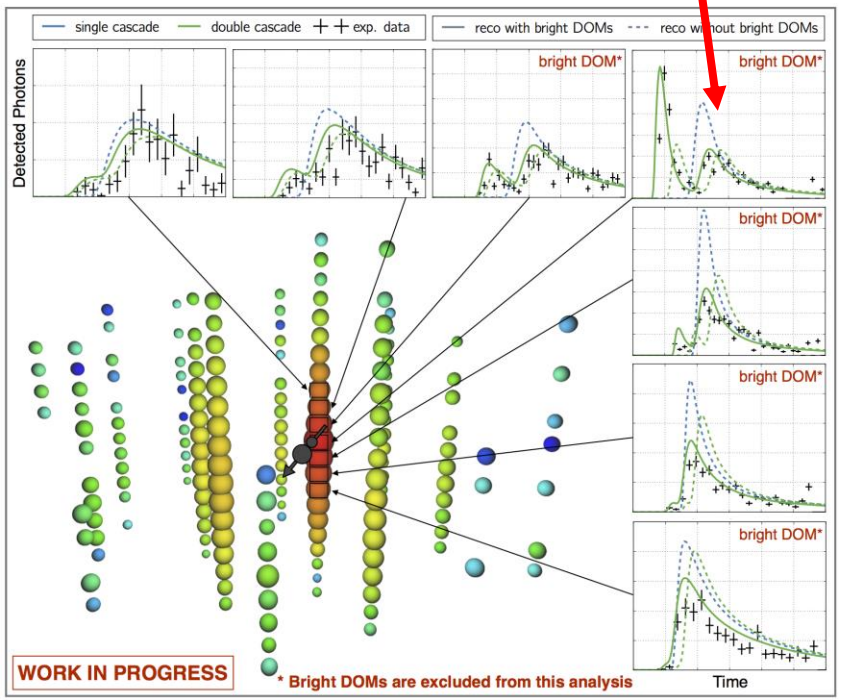
Charged-current (CC) neutrino interactions are required to determine the flavor of the interacting neutrino. *Tau* neutrinos become distinguishable from other flavors above a few hundred TeV, when the cascade from the *tau* neutrino CC interaction becomes resolvable from the cascade from the *tau* lepton decay.



S(ICRC2017)973

A cosmic *tau* neutrino:
livetime 17 m (for 300 TeV)

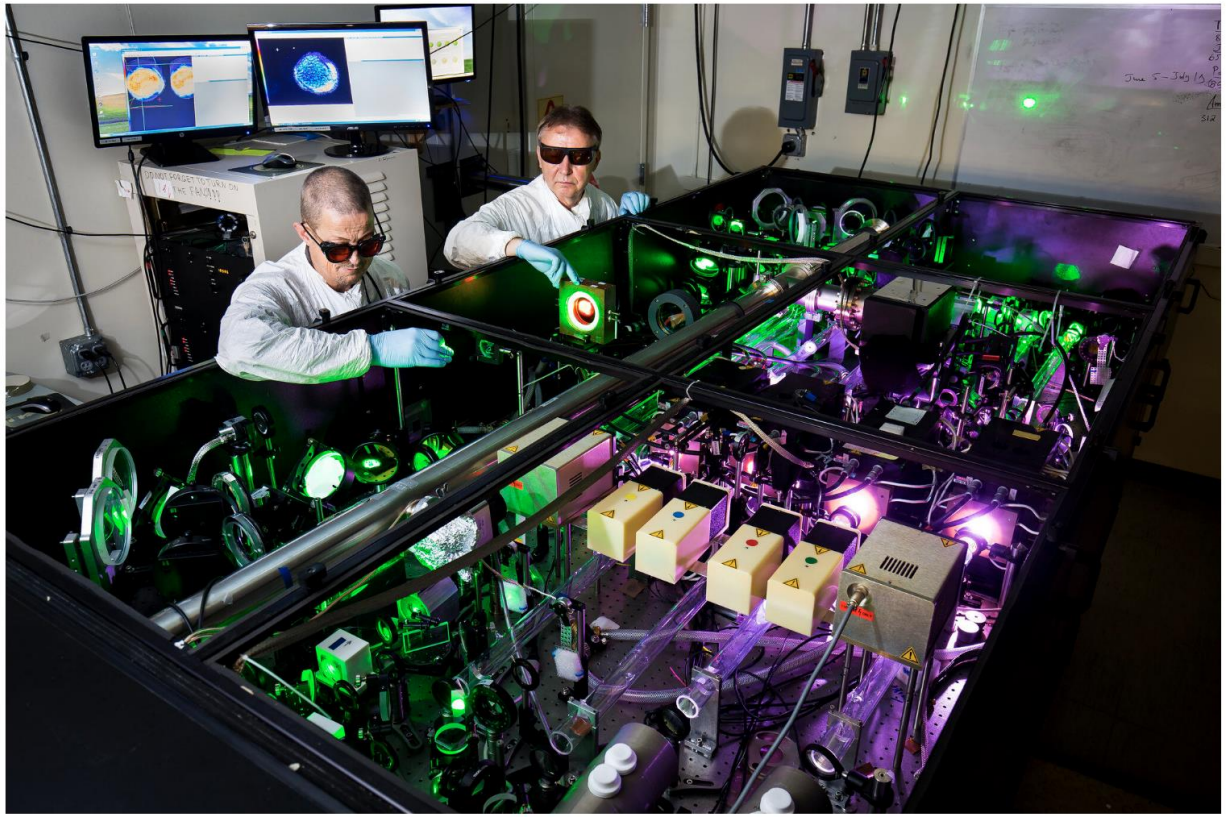
Note secondary peak
in time distribution



New Laboratory Astrophysics Capability:

ZEUS -- NSF Mid-Scale Laser User Facility

Most powerful laser in the US to be built at U-M



Anatoly Maksimchuk, EECS Research Scientist, and John Nees, EECS Associate Research Scientist, demonstrate use of the HERCULES 300 TW laser. Image credit: Joseph Xu, College of Engineering

https://news.umich.edu/most-powerful-laser-in-the-us-to-be-built-at-u-m/

https://zeus.engin.umich.edu/

- Builds on prior NSF investments, including a Science and Technology Center led by 2018 Nobel Prize winner Prof. Gerard Mourou.
- Intended to be supported by NSF for operations as a User Facility.
- Will enable better understanding of the physics of high energy astrophysical systems and phenomena, from astrophysical jets and black holes to cosmic rays.

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NSF-NASA Pilot Program on Space Weather

Next Generation Software for Data-driven Models of Space Weather with Quantified Uncertainties (SWQU)

PROGRAM SOLICITATION
NSF 20-519

National Science Foundation

Directorate for Mathematical and Physical Sciences
Division of Physics
Division of Astronomical Sciences
Division of Mathematical Sciences

Directorate for Geosciences
Division of Atmospheric and Geospace Sciences

Directorate for Computer and Information Science and Engineering
Office of Advanced Cyberinfrastructure

National Aeronautics and Space Administration

Full Proposal Deadline(s) *(due by 5 p.m. submitter's local time):*

March 20, 2020

- Addresses the objectives of the National Space Weather Strategy and Action Plan and the National Strategic Computing Initiative Update.
- Aims to transform predictive modeling of the coupled evolution of the solar atmosphere and the solar wind, with the Earth's magnetosphere and atmosphere.
- NSF's MPS, GEO, and CISE Directorates have partnered with NASA/Heliophysics behind PHY leadership
- Proposals are expected to leverage new data streams from NSF's DKIST and NASA's Parker Solar Probe among other in situ and remote sensing ground and space-based data.

NASEM Plasma 2020 Decadal Survey Nearing Completion

- Plasma 2020 Decadal Survey report is expected in the next 2-3 months.
- Co-sponsored by NSF (MPS, GEO, ENG), DOE (SC, NNSA, ARPA-E), and DOD (AFOSR, ONR); co-chaired by Prof. Gary Zank (U. Alabama-Hunstville) and Prof. Mark Kushner (U. Michigan).
- There is topical scope overlap between Plasma 2020, Astro 2020, and the mid-decadal for Solar and Space Physics in the areas of plasma astrophysics and space plasma physics.
- Plasma 2020 is expected to make recommendations on coordination of support and stewardship of plasma astrophysics [and plasma science more broadly] between NSF, NASA, and DOE. No such mechanism for coordination among multiple agencies currently exists.

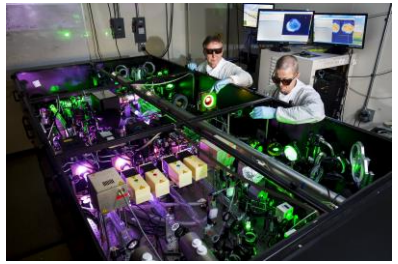
Mid-scale Research Infrastructure (Mid-scale RI) Opportunities

- 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 (MSRI-1) and one for ~$20 - $70 M (MSRI-2).
- Awards for first group have been made; Full proposals for second are in and under review.

Mid-Scale RI-1 Awards Related to MPS

Mid-scale RI-1 (M1:IP): A world-class Neutron Spin Echo Spectrometer for the Nation:
UD-NIST-UMD Consortium; Award Number: 1935956;
Principal Investigator: Norman Wagner; University of Delaware

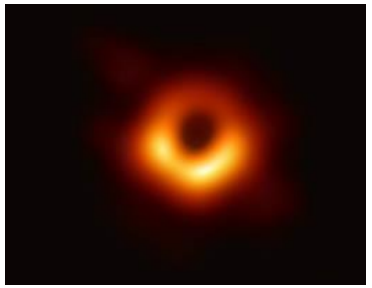


Maksimchuk, Nees @ HERCULES;
Credit: Joseph Xu

Mid-scale RI-1 (M1:IP): Zettawatt-Equivalent Ultrashort Pulse Laser System (ZEUS): Award Number: 1935950;
Principal Investigator: Karl Krushelnick; U of Michigan Ann Arbor

Mid-scale RI-1 (M1:IP): NSF National EXtreme Ultrafast Science (NEXUS) Facility: Award Number: 1935885;
Principal Investigator: Lawrence Baker; Ohio State University

Mid-scale RI-1 (M1:DP): Next Generation Event Horizon Telescope Design:
Award Number: 1935980; Principal Investigator:
Sheperd Doeleman; Smithsonian Institution Astrophysical Observatory



EHT Black Hole

Mid-scale RI-1 (M1:DP): Consortium Proposal for CMB-S4 Design Development:
Award Number: 1935892: Principal Investigator: John Carlstrom; U Chicago

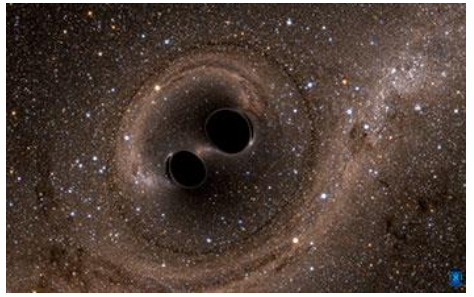
PD 18-5115

Program Description: Windows on the Universe: The Era of Multi-Messenger Astrophysics

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

- Proposals submitted to participating programs in MPS/AST, MPS/PHY and GEO/OPP.
- Proposals funded through “Big Idea” 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.

Fiscal 2019 – WoU-MMA



$30M from WoU-MMA awarded in FY19
66 awards (full or co-funded w/ MPS/PHY/AST/OMA; GEO/PLR)
Roughly 2/3 went for support of individual investigators
The remaining 1/3 was split between Instrumentation and Facilities

Examples: (Full List at https://www.nsf.gov/awardsearch/)

PI Community (individual investigators) Ice Cube– F. Halzen (Univ. of Wisconsin)
Support for 19 institutions to do the scientific analysis of data taken with the IceCube neutrino detector

Instrumentation SNEWS: a Super Nova Early Warning System - R. Lang et al. Analysis of neutrino detector data to provide a prompt alert for an impending supernova … hours before it will be visible in the sky

Facilities SCIMMA – P. Brady et al. Scalable Cyberinfrastructure Institute for Multi-Messenger Astrophysics

Relevant Harnessing the Data Revolution Awards

1934700: Collaborative Research: Advancing Science with Accelerated Machine Learning; Philip Harris, PI (+ collaborators); MIT; $1.8 M

1940209: Collaborative Research: Science-Aware Computational Methods for Accelerating Data-Intensive Discovery: Astroparticle Physics as a Test Case; Christopher Tunnell, PI (+ collaborators), Rice University; $1.0 M

1934752: A Framework for Data Intensive Discovery in Multimessenger Astrophysics; Patrick Brady, PI (+co-workers); U Wisconsin-Milwaukee; $2.8 M

All are 2-year planning/conceptualization for FY 2021 Institutes Solicitation

National AI Research Institutes

- **National nexus points** for universities, federal agencies, industry and nonprofits **to advance AI research and education**
- In FY 2020:
  - *Planning grants* for future Institutes
  - Launching up to six multidisciplinary, multi-institutional research *Institutes*
- Anticipated investment: ~$200M over six years, beginning in FY 2020