

Windows on the Universe: the Era the Multi-Messenger Astrophysics

Jean Cottam Allen (PHY) & Ralph Gaume (AST)

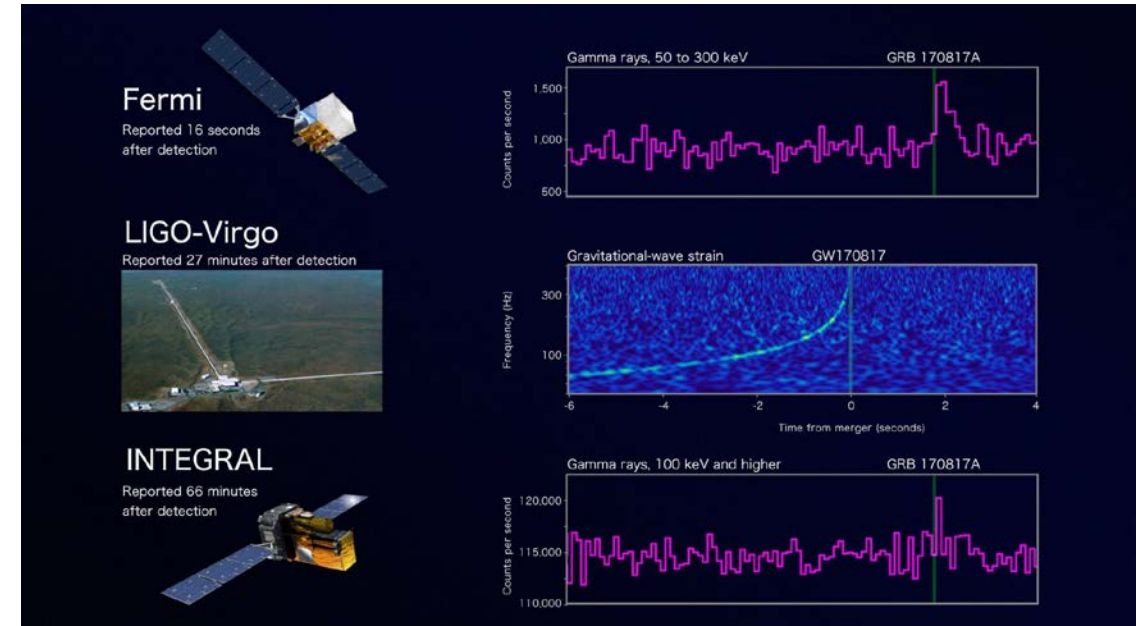
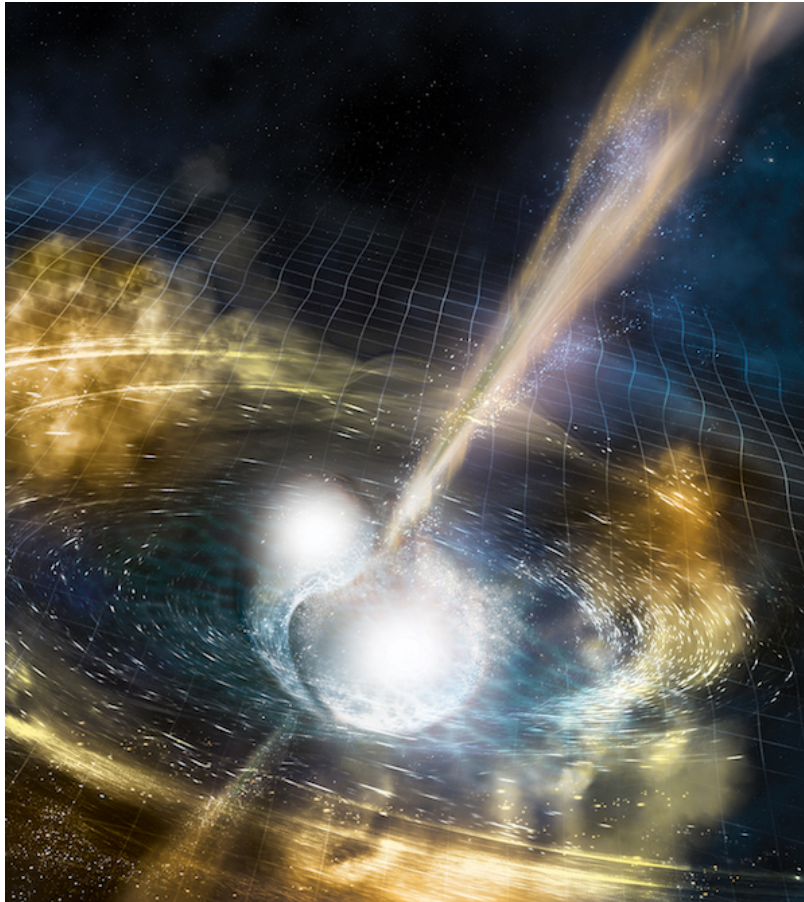
Jim Whitmore (PHY) & Pedro Marronetti (PHY)

Matthew Benacquista (AST) & Rita Sambruna (NASA)

AAAC Meeting – September 20, 2018



Binary Neutron Star Merger (08/17/2017)

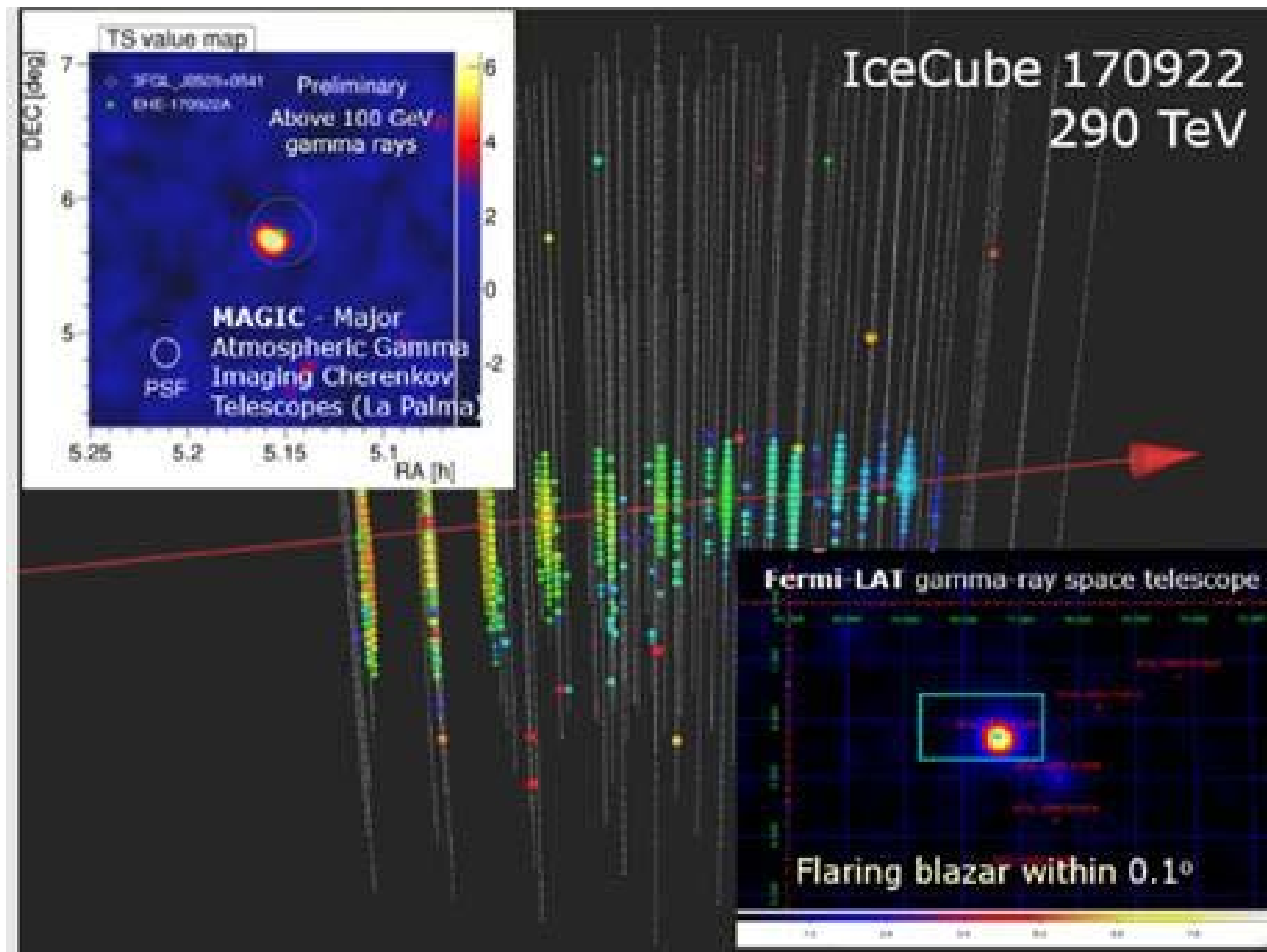


Images: [LIGO.org/NASA/INTEGRAL/ESA](https://ligo.org/NASA/INTEGRAL/ESA)

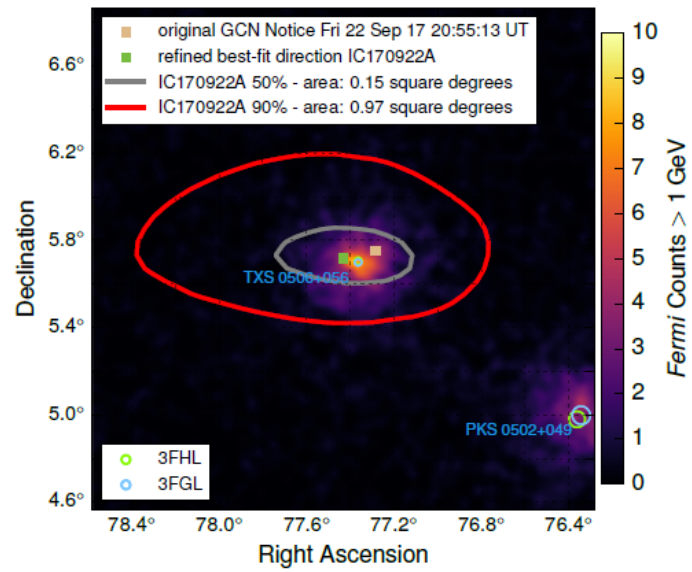
Images: LIGO.org/NASA/INTEGRAL/ESA



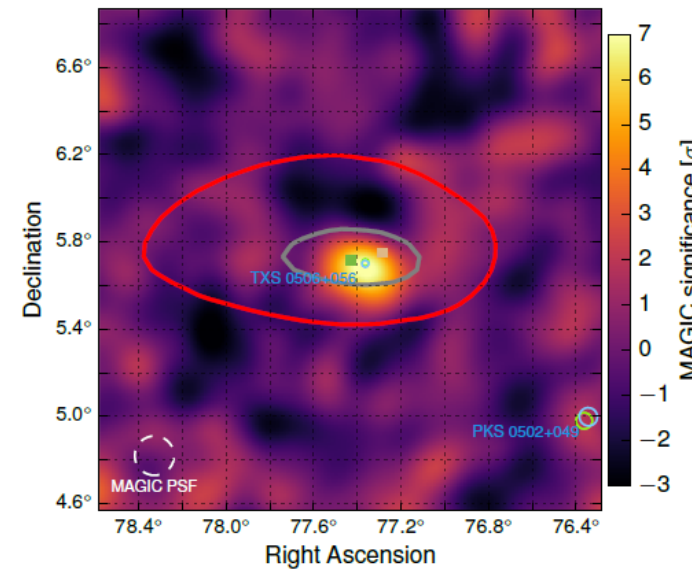
Flaring Blazar (09/22/2017)



Fermi-LAT

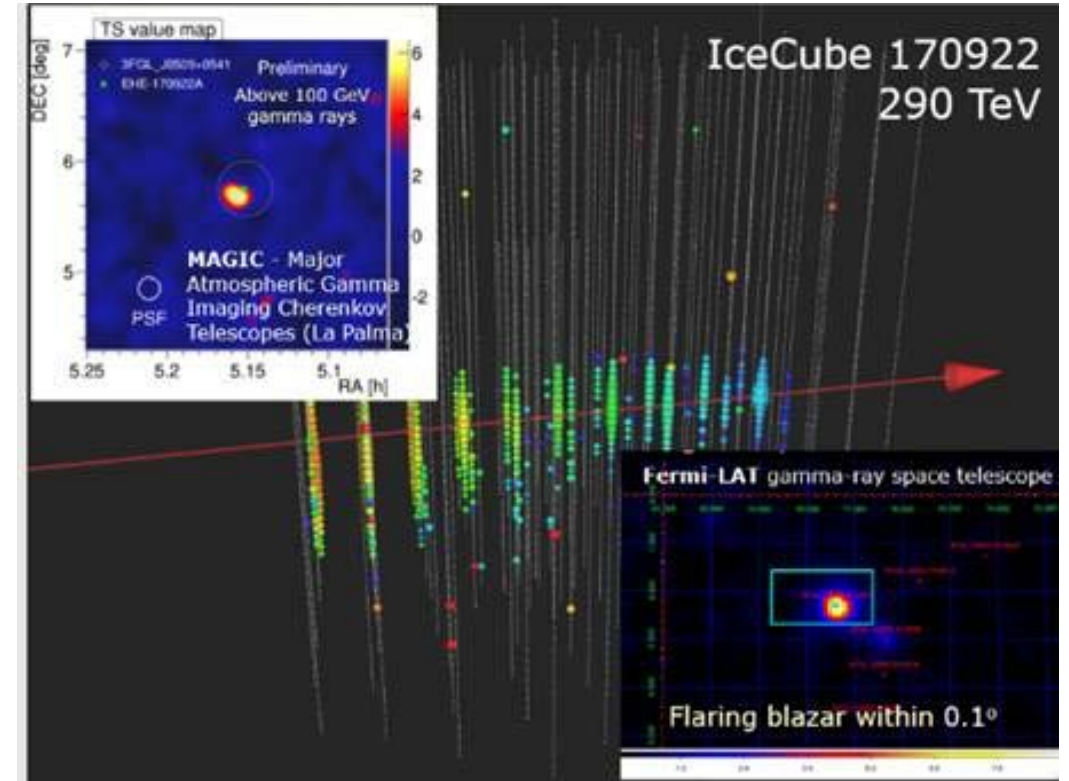


MAGIC



The Era of Multi-Messenger Astrophysics

The universe is the ultimate laboratory! We can now probe it as never before through several powerful and diverse windows – electromagnetic waves, high-energy particles, and gravitational waves. Each of these windows provides a different view. Together they reveal a detailed picture of the Universe that will allow us to study matter, energy, and the cosmos in fundamentally new ways.



WoU-MMA Goals

To build the capabilities and accelerate the synergy and interoperability of the three messengers to realize integrated, multi-messenger astrophysical explorations of the Universe

Three areas of focus:

- 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



Scientific Community

Enhanced investments in the activities of the scientific community will build the observational, computational, and analysis capabilities in each of the three window areas, integrate the different research communities to develop full interoperability between the three windows, and develop a new workforce that is skilled in this new paradigm.

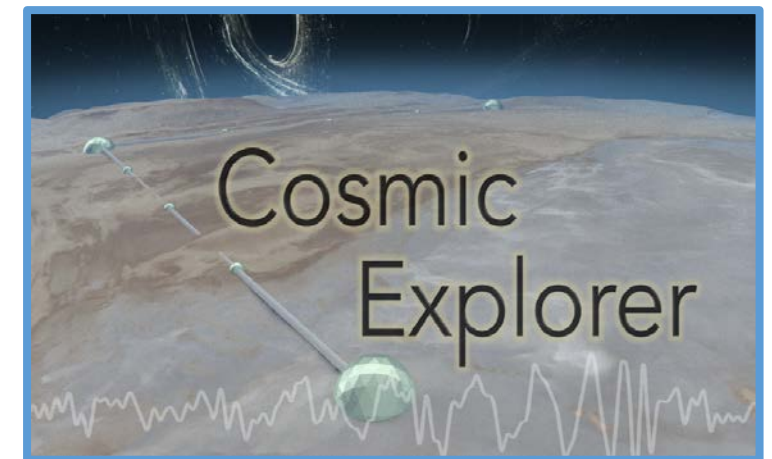
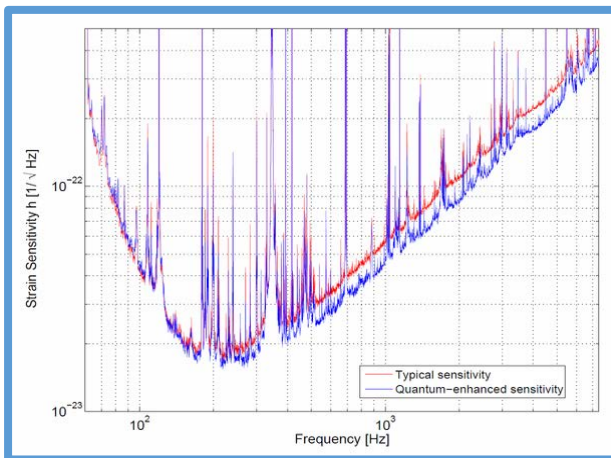
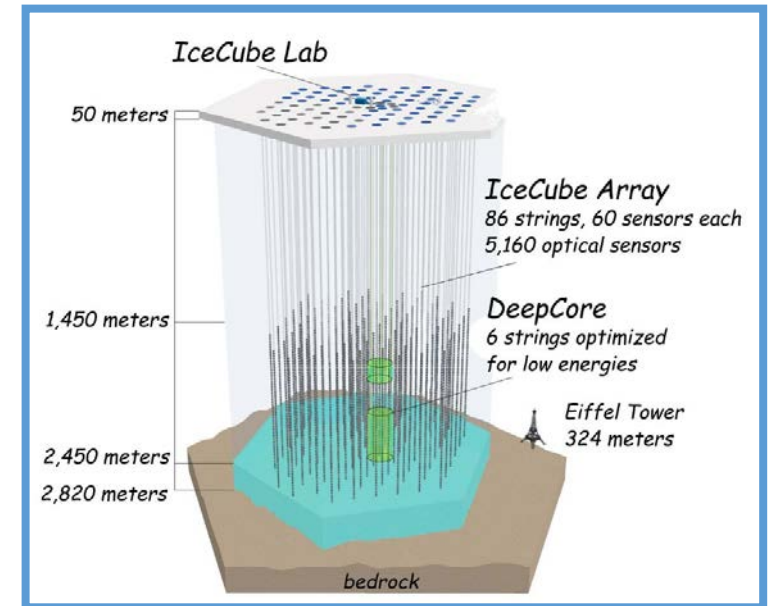


Credit: Optical Society/NCSA/



Current and Future Facilities

Enhanced infrastructure and modest upgrades will enable the full utilization of the current generation of multi-messenger facilities. Investments in the planning and development for the next generation of observatories will accelerate progress to realize significantly greater capabilities and extend our scientific reach.



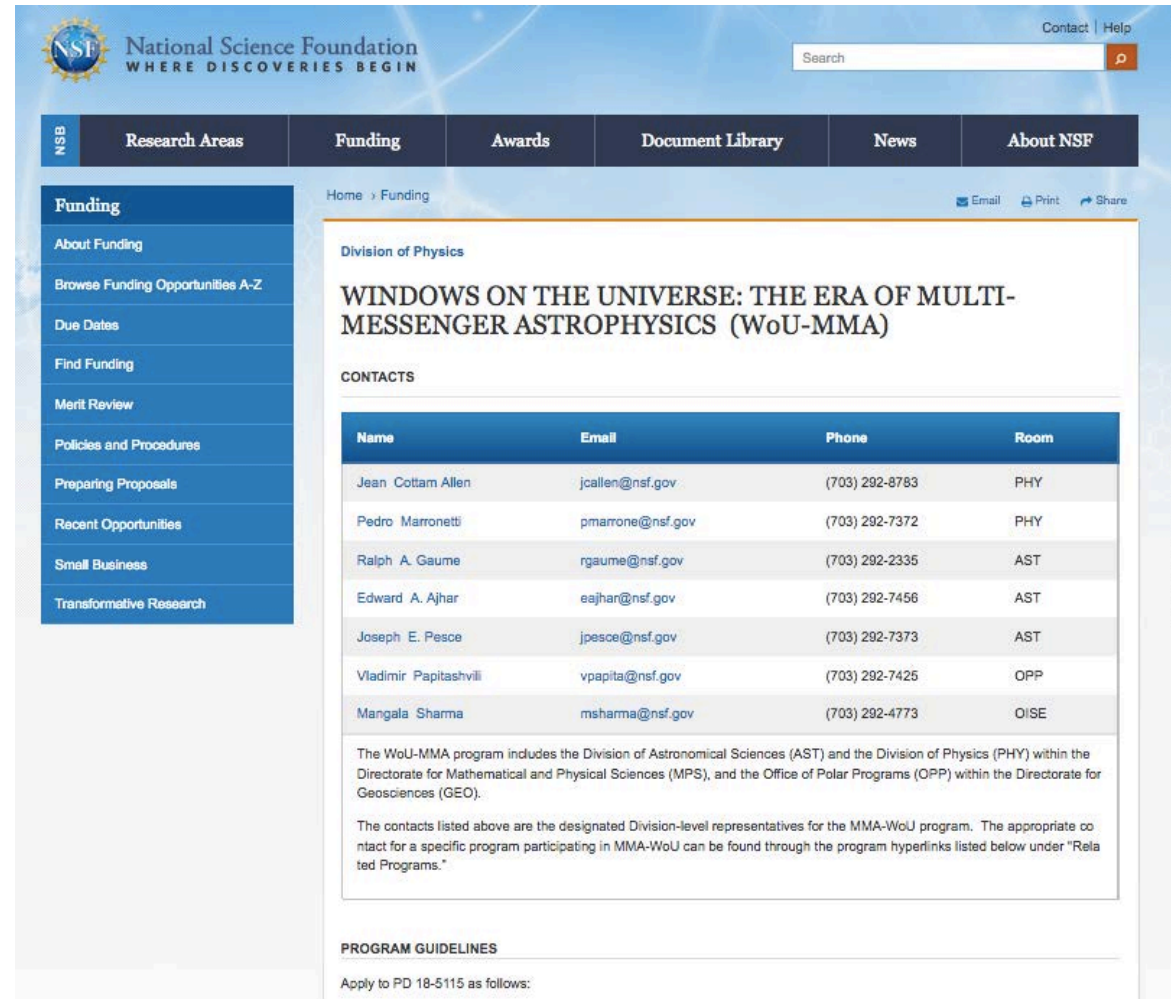
Credit: Evan Hall-MIT/



WoU-MMA Implementation

WoU-MMA Program Description [18-5115](https://www.nsf.gov/funding/pgm_summ.jsp?piims_id=5055593) - Posted July 31, 2018.

- Proposals submitted to participating programs in MPS/AST, MPS/PHY and GEO/OPP.
- Common criteria must be addressed for all WoU-MMA proposals.
- Coordination Group facilitates and coordinates WoU-MMA activity across Divisions/Offices.
- Proposals funded through “Big Idea” allocation as well as existing programs.



The screenshot shows the NSF website with the following structure:

- Header:** NSF logo, "National Science Foundation WHERE DISCOVERIES BEGIN", search bar, and links for Contact and Help.
- Navigation Bar:** NSF, Research Areas, Funding, Awards, Document Library, News, About NSF.
- Left Sidebar (Funding):**
 - About Funding
 - Browse Funding Opportunities A-Z
 - Due Dates
 - Find Funding
 - Merit Review
 - Policies and Procedures
 - Preparing Proposals
 - Recent Opportunities
 - Small Business
 - Transformative Research
- Main Content Area:**
 - Breadcrumb: Home > Funding
 - Section: Division of Physics
 - Section Title: WINDOWS ON THE UNIVERSE: THE ERA OF MULTI-MESSENGER ASTROPHYSICS (WoU-MMA)
 - Section: CONTACTS
 - Table of contacts (see below).
 - Text: "The WoU-MMA program includes the Division of Astronomical Sciences (AST) and the Division of Physics (PHY) within the Directorate for Mathematical and Physical Sciences (MPS), and the Office of Polar Programs (OPP) within the Directorate for Geosciences (GEO)."
 - Text: "The contacts listed above are the designated Division-level representatives for the MMA-WoU program. The appropriate contact for a specific program participating in MMA-WoU can be found through the program hyperlinks listed below under 'Related Programs.'"
 - Section: PROGRAM GUIDELINES
 - Text: "Apply to PD 18-5115 as follows:"

Name	Email	Phone	Room
Jean Cottam Allen	jcallen@nsf.gov	(703) 292-8783	PHY
Pedro Marronetti	pmarrone@nsf.gov	(703) 292-7372	PHY
Ralph A. Gaume	rgaume@nsf.gov	(703) 292-2335	AST
Edward A. Ajhar	eajhar@nsf.gov	(703) 292-7456	AST
Joseph E. Pesce	jpesce@nsf.gov	(703) 292-7373	AST
Vladimir Papitashvili	vpapita@nsf.gov	(703) 292-7425	OPP
Mangala Sharma	msharma@nsf.gov	(703) 292-4773	OISE

(https://www.nsf.gov/funding/pgm_summ.jsp?piims_id=5055593)



Participating Programs

Proposals should be submitted to one of the following participating programs:

Program	Due Date
Astronomy and Astrophysics Postdoctoral Fellowships	August 15, 2018 - October 24, 2018
Antarctic Astrophysics and Geospace Sciences	October 1, 2018 - September 30, 2019
Astronomy and Astrophysics Research Grants	October 1, 2018 - November 15, 2018
Advanced Technologies and Instrumentation	October 1, 2018 - November 15, 2018
Plasma Physics	October 19, 2018
Gravitational Physics - Theory; LIGO Research Support	November 28, 2018
Particle Astrophysics - Experiment	December 4, 2018
Nuclear Physics - Theory and Experiment	December 4, 2018
Particle Astrophysics and Cosmology - Theory	December 11, 2018



WoU-MMA Criteria

The WoU-MMA program welcomes proposals in any area of research supported through the participating divisions that address at least one of the following criteria:

- *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.



Cyberinfrastructure for MMA

- NSF/MPS Division of Physics (PHY) together with the Office of Advanced Cyberinfrastructure (OAC) funded a Workshop in May 2018 at UMD
 - Cyberinfrastructure for Multi-Messenger Astrophysics
- Workshop identified WoU-MMA challenges:
 - Highly heterogeneous, high-volume datasets, globe-spanning cross-disciplinary teams of researchers engaged in transient collaborations, extraordinary breadth and depth of required computing resources to anticipate, model, and interpret observations, need for adaptive , distributed, and rapid-response observing campaigns
- Workshop conclusion:
 - Formation of Institute for Multi-Messenger Astrophysics
 - Coordinate resources to address challenges



Cyberinfrastructure for MMA

- Summary of Workshop is documented (astro-ph):
 - arXiv:1807.04780
- NSF received set of Collaborative Research proposals
 - *Community Planning for a Scalable Cyberinfrastructure to Support Multi-Messenger Astrophysics*
 - Patrick Brady, Lead PI, Univ. Wisconsin-Milwaukee
 - Funded by MPS/OMA, MPS/PHY, MPS/AST, CISE/OAC
 - Develop a concept for the Institute:
 - Conduct community-building activities to document cyber needs for MMA
 - White paper delivered April/May 2019
 - Develop a strategic plan for the Institute:
 - Proposed mission for Institute
 - Highest priority areas for cyber research and development
 - Strategy for managing and evolving services that benefit and engage the MMA community
 - Completed by July 2019





IceCube UHE Neutrino on Sept. 22, 2017

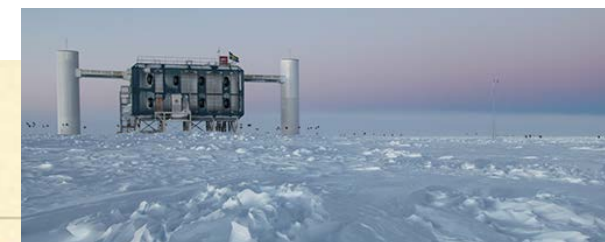


To take advantage of multimessenger opportunities, the IceCube Neutrino Observatory (ICNO) has established a system of real-time alerts that rapidly notify the astronomical community of the direction of astrophysical neutrino candidates. From the start of the program in April 2016 through October 2017, 10 public alerts have been issued for high-energy neutrino candidate events with well-reconstructed directions.

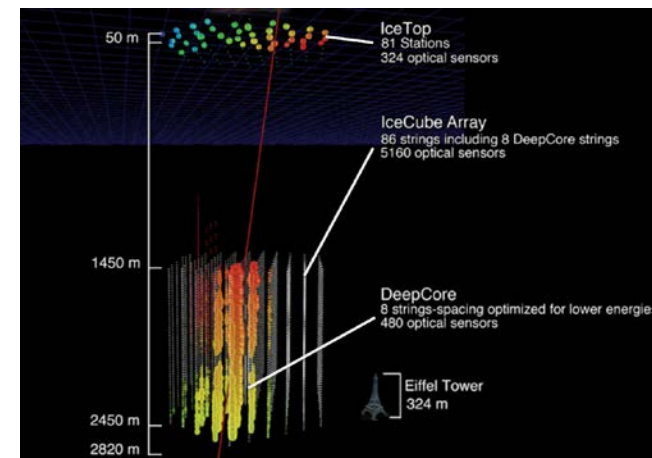
Telegram:

ICECUBE-170922A

GCN AMON notice:https://gcn.gsfc.nasa.gov/notices_amon/50579430_130033.amon



The detector consists of 86 vertical strings frozen into the ice 125 m apart, each equipped with 60 digital optical modules (DOMs) at depths between 1450 and 2450 m to detect the Cherenkov radiation produced by the muon (and other particles) from the neutrino interaction in the ice – O(km) long light emission regions.



NOVA

PBS

WGBH

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IceCube real-time alert system

- IceCube performs a quick reconstruction at South Pole selecting “Track” or “Shower” events.
- Based on this, several alerts can be issued: Optical and X-ray (OFU) and Gamma-Ray (GFU) can be shared with MOU partner observatories, or in the case of a likely astrophysical event, a public GCN (Gamma-ray Coordinates Network) alert is issued.
- On 22 September 2017 at 20:54:30.43 (UTC), a high-energy neutrino-induced muon track event (EHE – extremely-high-energy event) was detected in this automated analysis that is part of IceCube’s real-time alert system. An automated alert was distributed to observers 43 s later, providing an initial estimate of the direction and energy of the event.
- The IceCube GCN Notices (or alerts) are sent using the AMON alert system infrastructure.
- A sequence of refined reconstruction algorithms (in the Northern Hemisphere) was automatically started at the same time, using the full event information. A followup GCN circular was issued ~4 hours after the initial notice, with reference to it, including the refined directional information (offset 0.14° from the initial direction).
- For details, see *M.G.Aartsen et al, Astroparticle Physics 92 (2017) 30-41 “The IceCube realtime alert system” (May 2017)*





New award PHY- 1719277



Title: IceCube Gen2 Phase 1: an IceCube Extension for Precision Neutrino Physics and Astrophysics **PI:** Kael Hanson, Univ. of Wisconsin – Madison

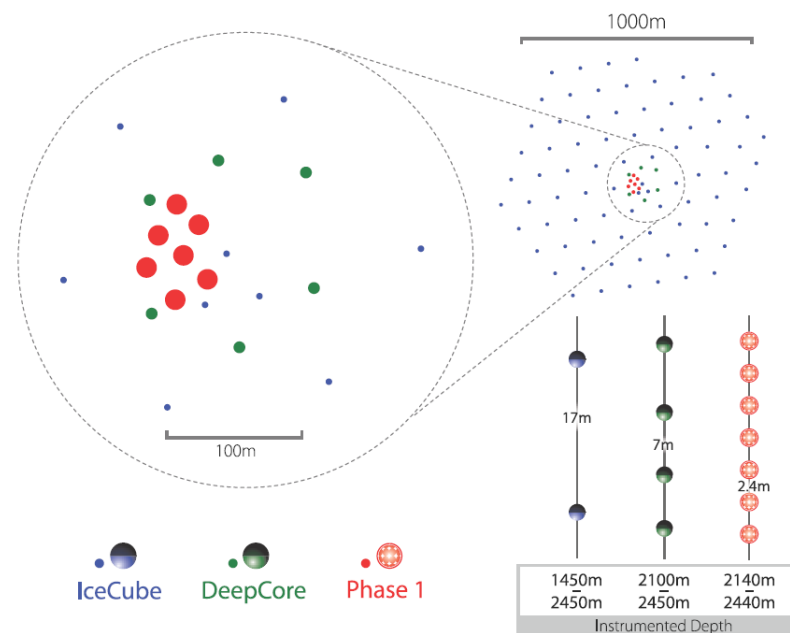
NSF Budget: \$ 22,983,324 (60 months) **U.S. & Non-U.S. institutions (in-kind):** \$14,158,420

Deploying: additional 7 strings (each 100+ DOMs) in the center of the IceCube Deep Core array

Main Science Objective: Multimessenger Astrophysics: A new Window on the PeV Universe

Science Topics:

- ✓ Tau neutrino appearance and tests of SM and the unitarity of the PMNS matrix
- ✓ Neutrino oscillations, sterile neutrinos, and indirect dark matter (lower threshold to $O(5)$ GeV)
- ✓ Improving IceCube's capabilities for neutrino astronomy by inserting additional calibration devices (apply to 10 years of archived data):
 - Better tracking angular resolution (\sim factor of 4)
 - Tau neutrino appearance on cosmic baselines
 - Neutrino astronomy with high-energy cascades



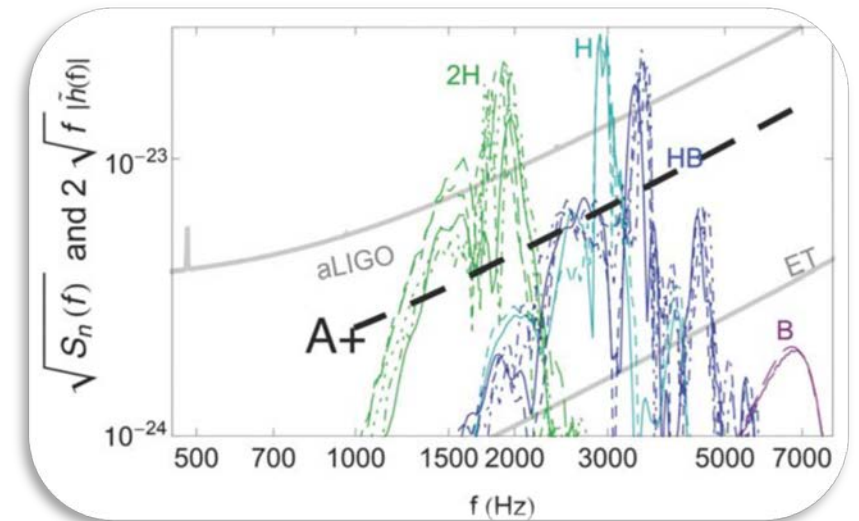
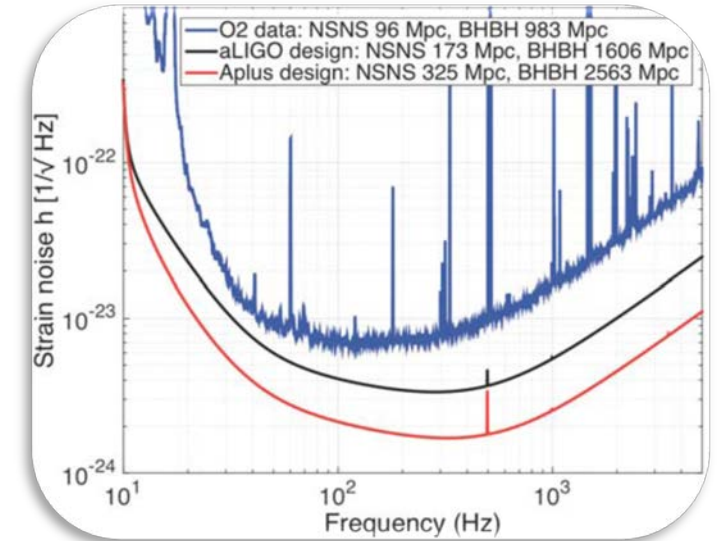
Advanced LIGO Plus (A+)

First upgrade of aLIGO, done in collaboration with UK and Australia. NSF has made an award for the US contribution (~\$20M), STFC is currently reviewing the UK proposal (~£10M) and ARC is currently supporting the Australian team.

Construction will start in full in 2020. Operations in 2023/24.

A+ will increase aLIGO design sensitivity by a factor of 1.5 – 2.0 (freq. dependent), leading to an event rate ~ 5 times larger (i.e., over 20 times O2 rate or **an event every other day or more!**).

A+ will have improved capacity for constraining the neutron star equation of state (EOS)

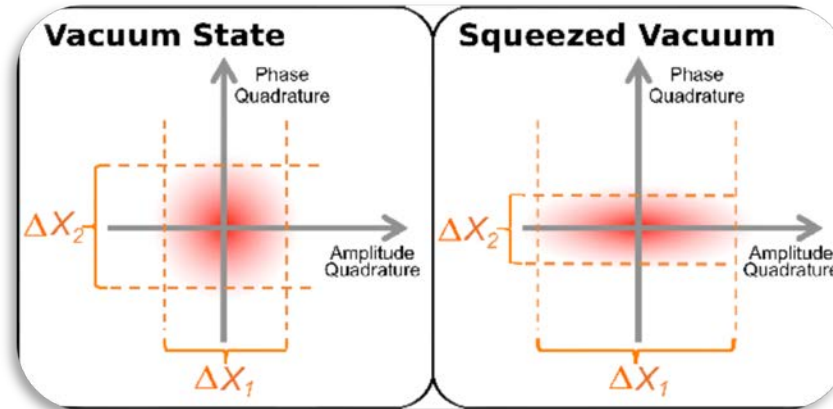
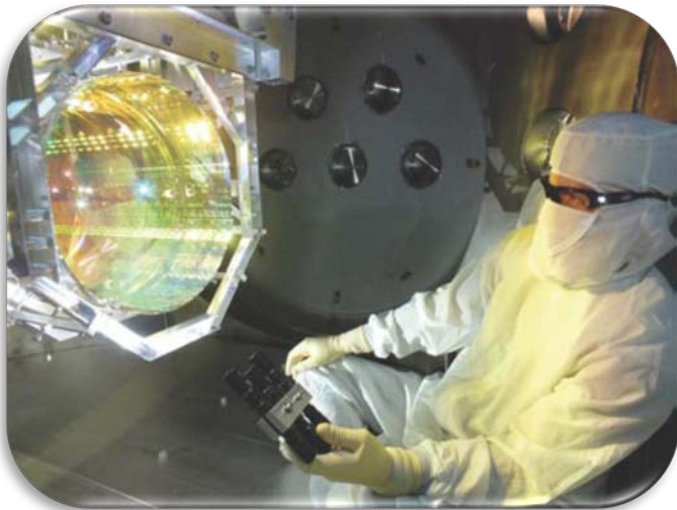


Images: LIGO



Advanced LIGO Plus (A+)

Frequency-dependent *squeezed light* injection: allows the reduction of quantum phase noise at high frequencies and quantum radiation pressure noise at low frequencies



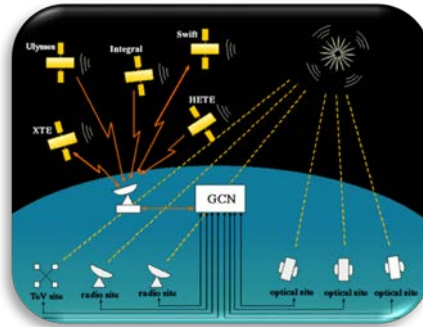
Improved mirror coatings: will reduce Brownian thermal fluctuations in the middle of the frequency range

Images: LIGO



Open Public Alerts(OPA)

GW triggers notices are sent through the Gamma-ray Coordinates Network (GNC)



This process, in place for the first aLIGO runs (O1 and O2), is being revamped

Why? Because the increased sensitivity in the next LIGO run (O3 starting Feb 2019) may lead to **two triggers / one GW event per week!**
O2 procedures will not scale for O3

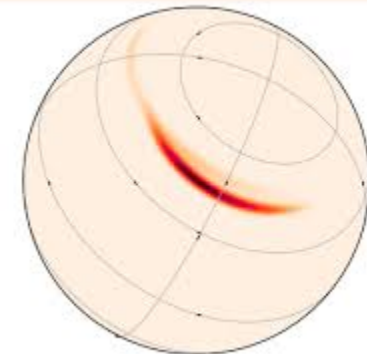
New in O3

Automatic GNC notices (~mins.) for all candidates with *False Alarm Rate* (FAR) > 1/month to 1/year

After human vetting, notices will be followed by either:

- a retraction of GNC Notice(1 – 4 hrs.)
- a GCN Circular confirming the event (< 4 hrs.)

If the event is confirmed, the GCN Circular will include an updated Sky map.



Images: NASA/LIGO L. Singer



Interagency Multimessenger Taskgroup (IMT)

- Proposed during May 11 NASA-NSF Program Scientist/Program Officer Meeting
- Responsible leads: Matt Benacquista (NSF) Rita Sambruna (NASA)
- Membership drawn from both civil servant and IPA workforce at the agencies
- Working out organization and agency reporting details
- Enhance communication between agencies
 - Designed to be flexible enough to include other agencies (e.g., DOE)
 - Gather information about the facilities, policies, and processes for MMA at the agencies
 - Identify best practices, lessons to be learned, and gaps in support
 - Interact with astrophysics community to gather input on needs for interagency cooperation
 - Propose solutions to strengthen interagency cooperation



Summer AAS Joint NSF/NASA Townhall on MMA

- Four Invited Panelists:
 - John Conklin
 - Ryan Foley
 - Daniel Holz
 - David Kaplan
- Needs identified:
 - Improved communication between collaborations
 - Computational and data sharing infrastructure
 - Interagency cooperation in review and funding of MMA proposals
 - Improved joint scheduling of observations from NASA and NSF facilities
 - Improved support for modeling, simulations, and predictions



Windows on the Universe Team

MPS AD – Anne Kinney
GEO AD – William Easterling

Windows Working Group

Co-Chairs: Jean Cottam Allen (MPS/PHY) and Ralph Gaume (MPS/AST)

MPS/AST: Ed Ajhar, Joe Pesce
MPS/PHY: Pedro Marronetti
GEO/OPP: Vladimir Papitashvili
OD/OISE: Mangala Sharma
ENG/IIP: Richard Schwerdtfeger

