Astrophysics in the NSF Physics Division

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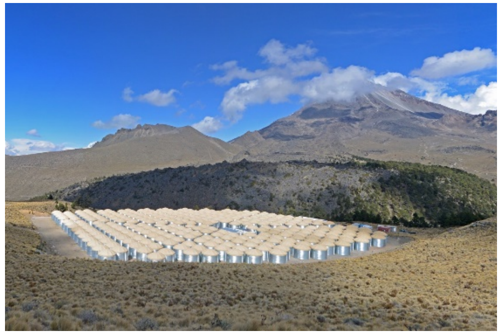
Division Director

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



Credit: HAWC

Credit: LIGO Lab

AAAC January 2018

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)

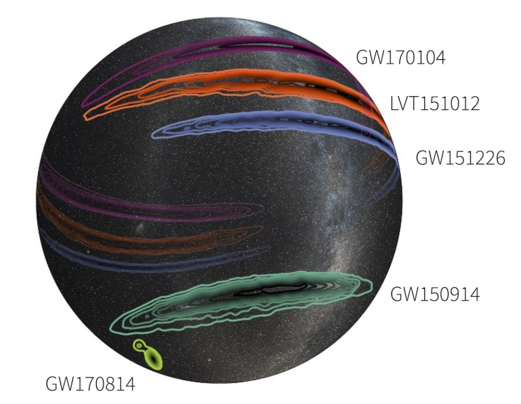
Origin and Structure of the Universe – Star formation and creation of the elements, dark matter and dark energy, modeling of black holes, gravitational waves, magnetic fields (Gravitational Physics; Nuclear Physics; Particle Astrophysics; Plasma Physics)

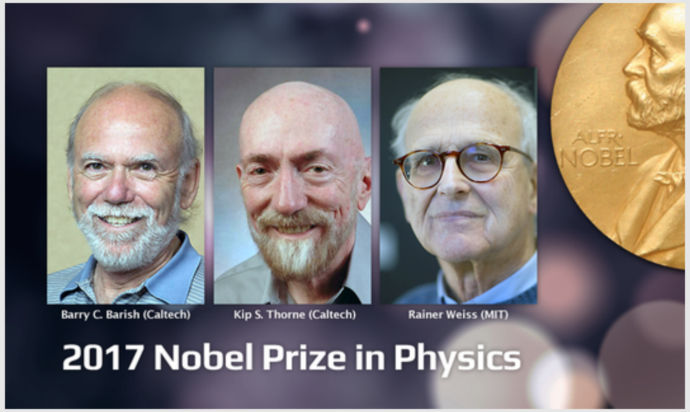
Strongly-Interacting Systems– QCD computations, quark structure of baryons, high-field laser-matter interactions, supernovae, strong gravity (Nuclear Physics; Gravitational Physics; Plasma Physics)

LIGO
An amazing year!

The 2nd Observational Run (O2) ended in August 2017 with an impressive collection of achievements

- Jan. 4: LIGO detects the 3rd binary black hole merger (BBH)
- June 8: LIGO detects the 4th BBH merger
- Aug. 14: First triple detection of a BBH merger (LIGO + Virgo)
- Aug. 17: First detection of a binary neutron star (BNS) merger
- Oct. 3: Weiss, Thorne and Barish win the 2017 Nobel Prize in Physics

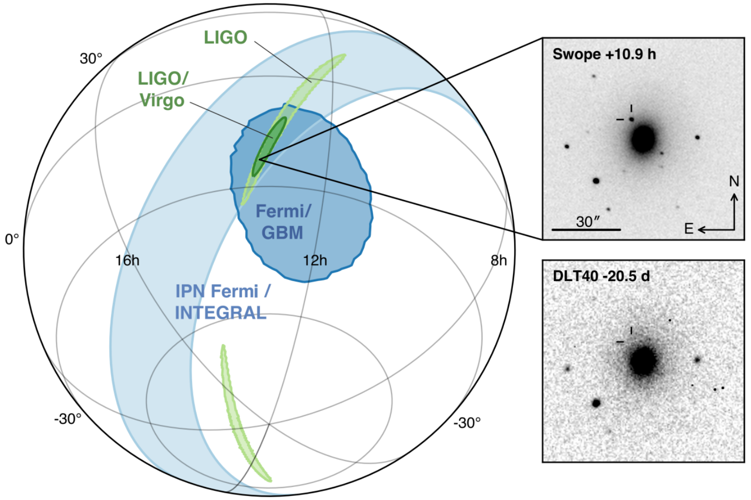


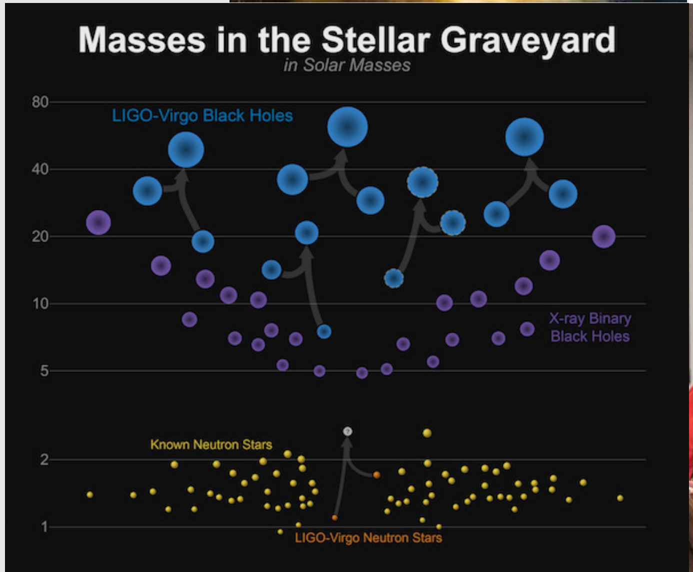


LIGO
The first binary neutron star merger detection

The joint observation of the first BNS merger by GW and EM observatories was a milestone in astronomical history, heralding the new era of Multimessenger astronomy

- Only 1.7 seconds after the GW detection, a gamma-ray burst (GRB) was detected by NASA Fermi satellite
- A massive EM follow up campaign determined that the event was located in the galaxy NGC 4993 (40 Mpc, 130 Mly)
- First direct evidence of the BNS merger as progenitors of short duration GRBs
- First clear observation of a kilonova (emissions of the radioactive decay of the BNS merger ejecta)
- New determination of the Hubble constant, independent of any form of the cosmic “distance ladder”

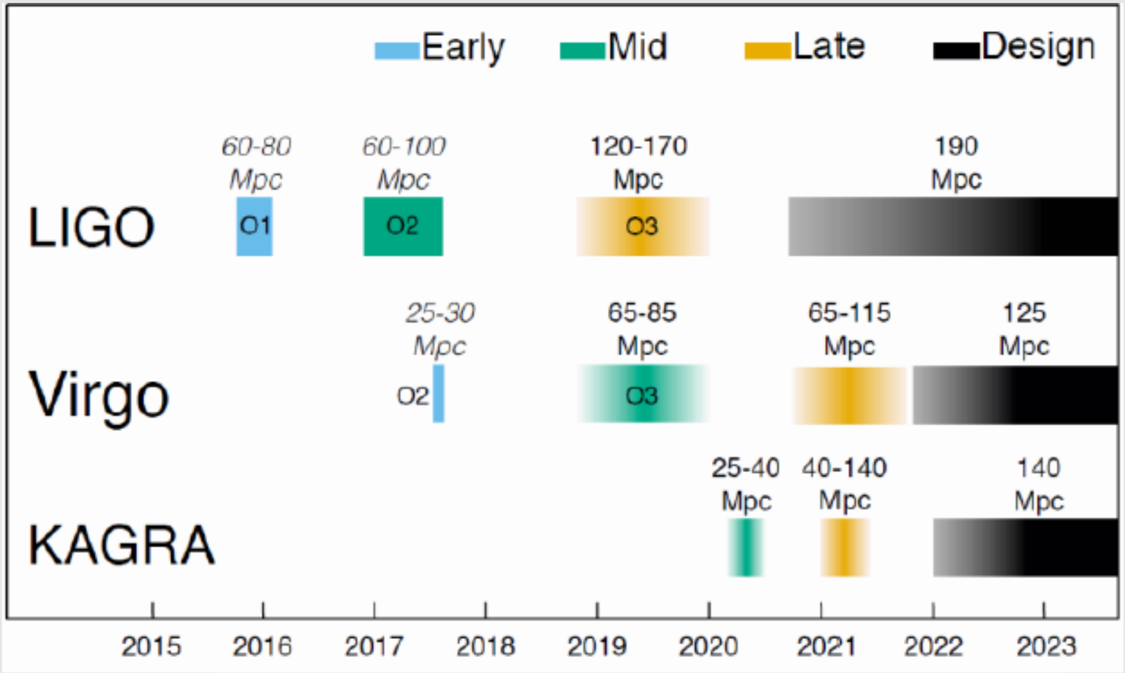




LIGO
Schedule for 2018

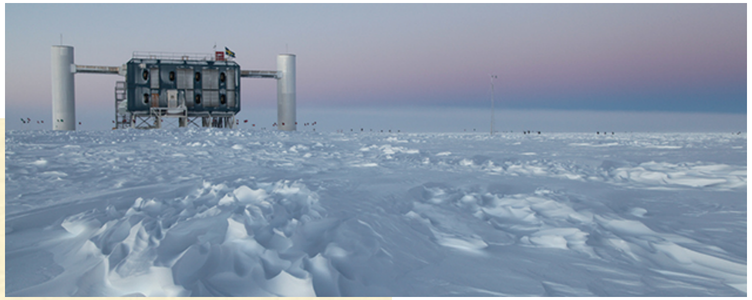
LIGO and Virgo are currently undergoing commissioning tasks to prepare for O3

- O3 Start in late Fall 2018
- Planned duration: 9 months
- Sensitivity at 2/3 of design level
- Virgo expected join in from the start
- LIGO India currently in land acquisition process. Ground breaking planned for mid 2018



IceCube UHE Neutrino on Sept. 22, 2017

Last year, had another "first" in multi-messenger discoveries, when MAGIC and Fermi-LAT measured VHE gamma rays coming from a direction consistent with a UHE neutrino event detected by the IceCube Neutrino Observatory in Antarctica.



ICECUBE-170922A

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

```
Date: 22 Sep, 2017
Time: 20:54:30.43 UTC
RA: 77.43 deg (-0.80 deg/+1.30 deg  90% PSF containment) J2000
Dec: 5.72 deg (-0.40 deg/+0.70 deg 90% PSF containment) J2000
```

E proxy of about 120 TeV

EM activity follow-up of the IceCube telegram

#1 **Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.**

They found one source TXS 0506+056 – a flaring blazar, also known as 3FGL J0509.4+0541

#2 **AGILE confirmation of gamma-ray activity from the IceCube-170922A error region**

They found a 4σ significance centered less than 1 degree from both the IceCube centroid and the position of 3FGL j0509.4+0541

#3 **VLA Radio Observations of the blazar TXS 0506+056 associated with the IceCube-170922A neutrino event**

They observed TXS 0506+056 over 4 epochs and frequency bands. They detect it significantly in all bands/epochs

#4 **First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A**

They observed this source and found a 5σ detection above 100 GeV after 12 hrs

#5 **IceCube-171106A: Swift observations**

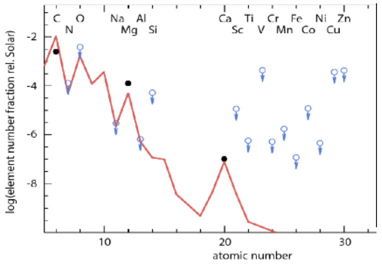
VERITAS, HAWC, ANTARES set upper limtis More details to come in a paper.

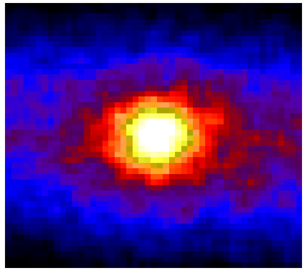
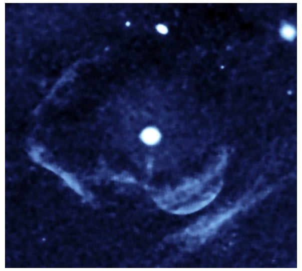
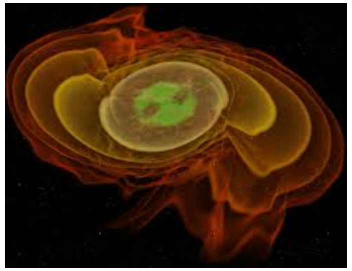
SWIFT notes 5 X-ray sources in the IceCube error box!! 2 of which are luminous blazars.

Nuclear Astrophysics

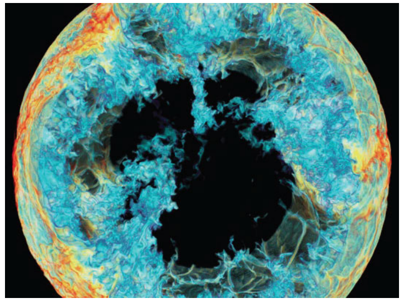
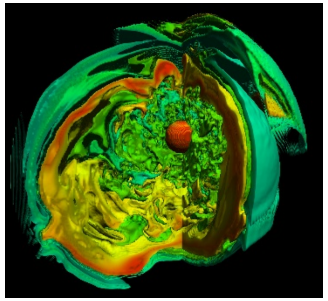
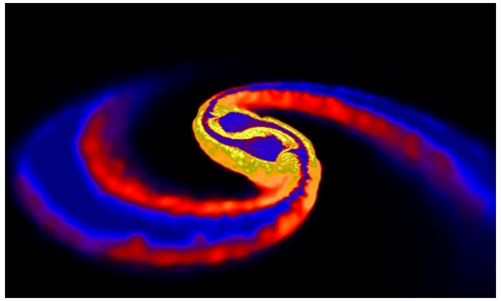
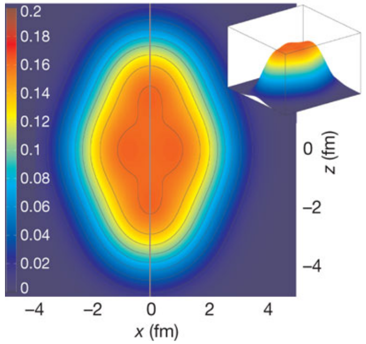
A field at the interface of Astrophysics and Nuclear Physics

- Observational tools, signatures, and developments

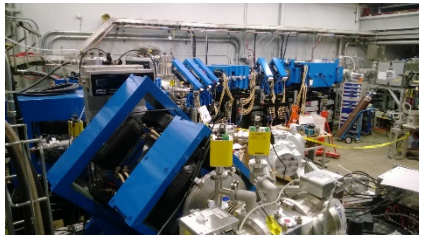



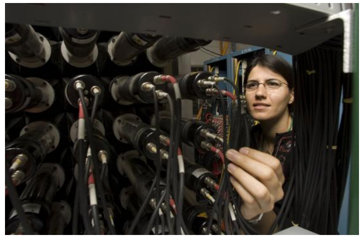
- Large computational modeling for stellar and nuclear systems

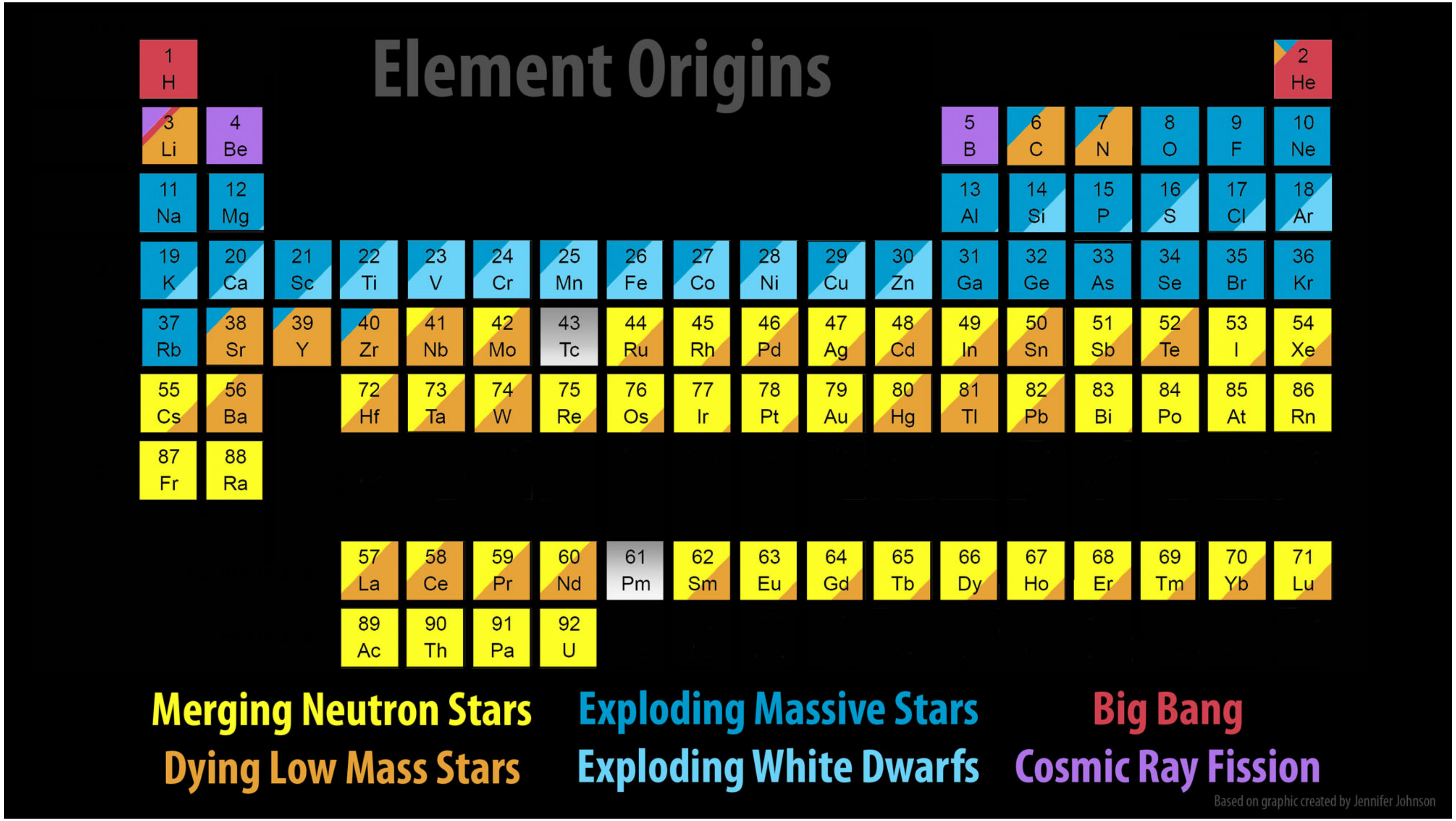
- Laboratory tools for experimental evidence





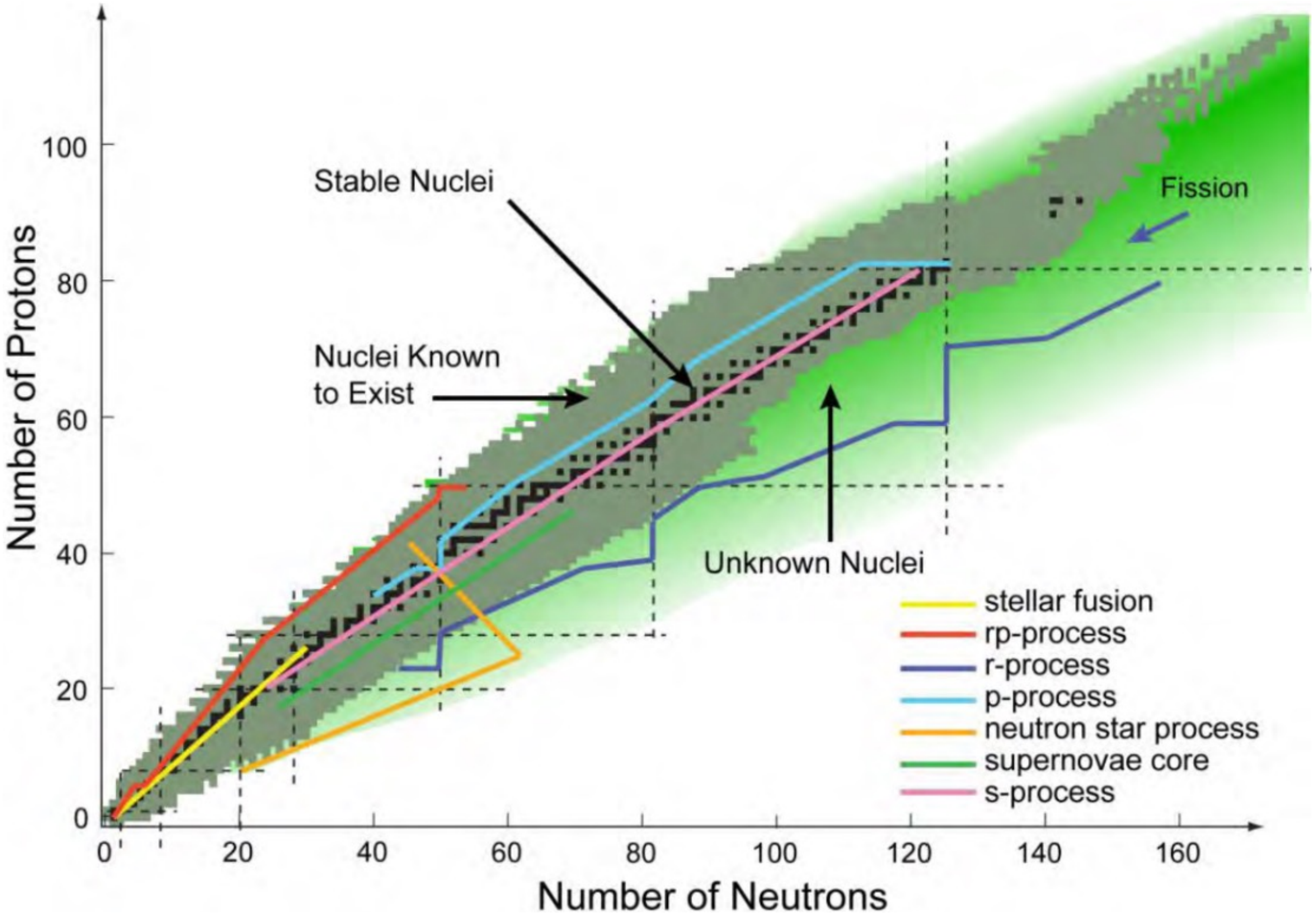


Products of Neutron Star Merger



Credit: Jennifer Johnson/SDSS

Much more complicated!



Credit: NSCL/FRIB

JINA-CEE LIVESTREAM

FRIDAY, 1 DECEMBER 2017
12:30 PM US/EST
View the Recorded Event

Talks and Panel Discussion:
The Impact of the LIGO/VIRGO Neutron Star Merger Discovery on Research in Nuclear Science and Nuclear Astrophysics
#GWNuclear

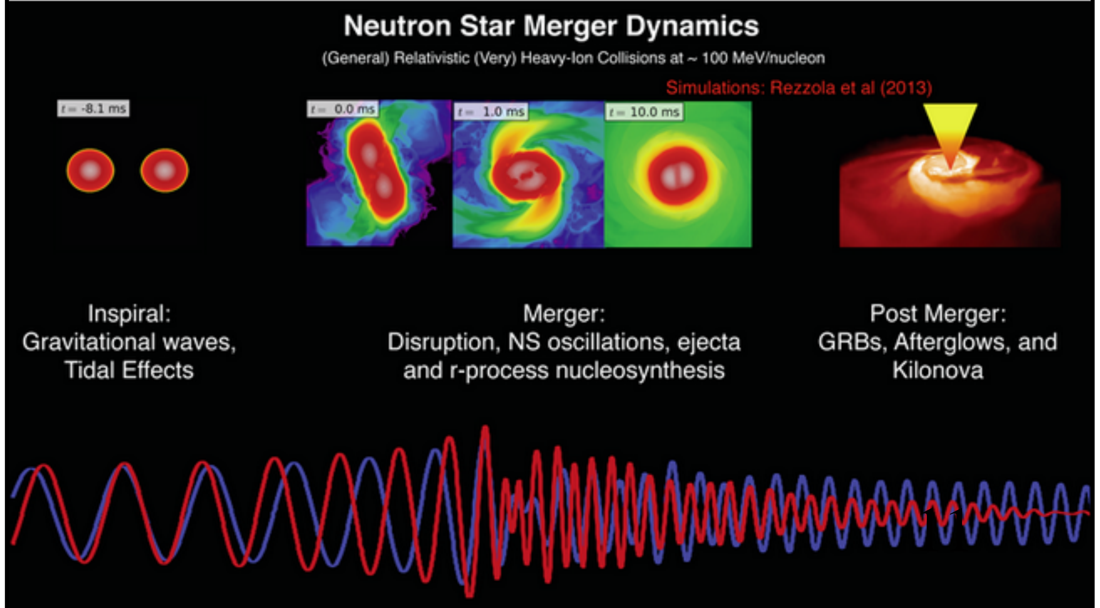
JINA–CEE

#GWNUCLEAR   Program   Conclusions

INT-JINA Symposium INT-18-72R

First multi-messenger observations of a neutron star merger and its implications for nuclear physics

March 12 - 14, 2018

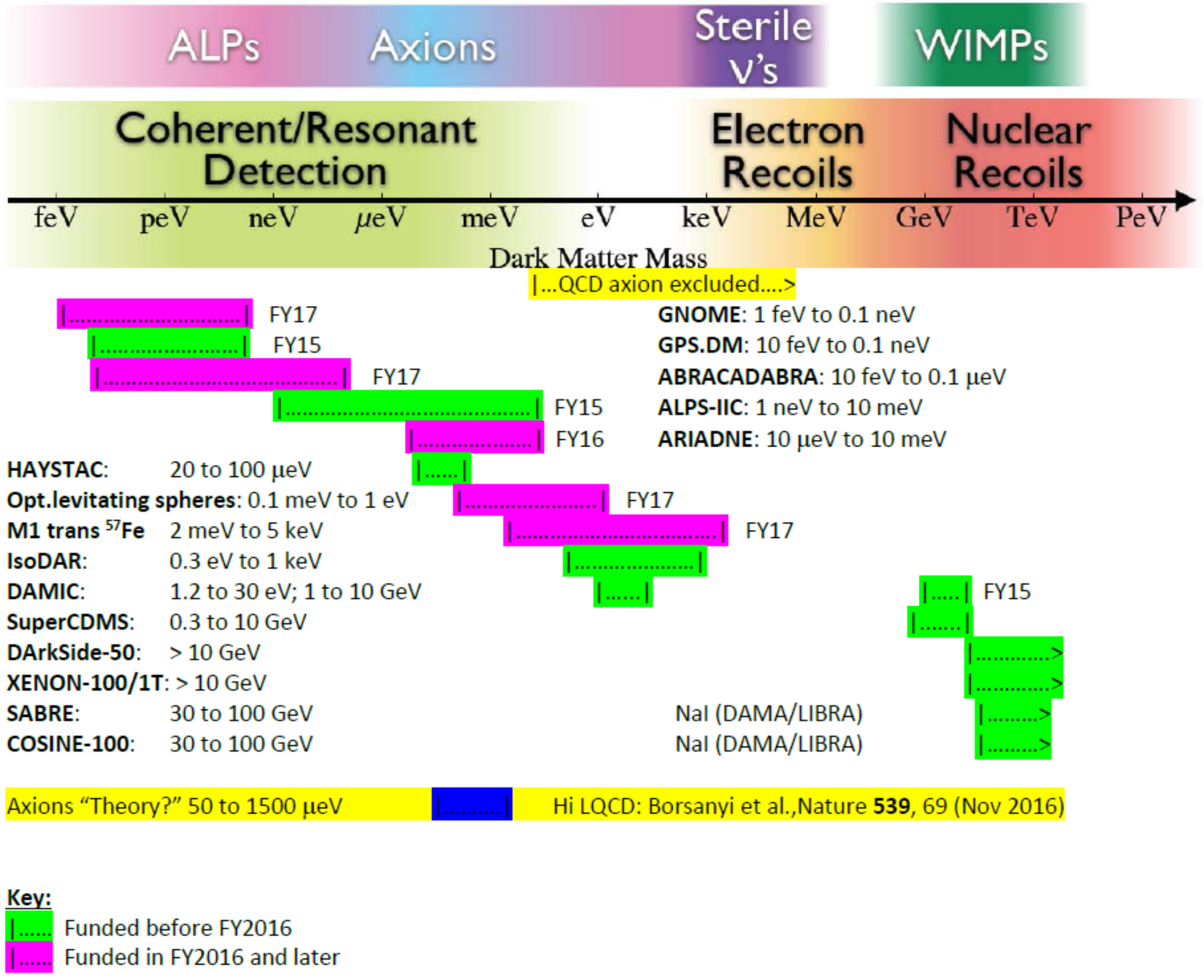


Dark Matter Candidates (Update)

Dark Matter experiments funded by the NSF-Particle Astrophysics Program

We need to search for low mass Dark Matter:
We are funding the following projects searching in the region for masses < 1 MeV

(**Purple** are newly funded in the last 2 years)



Focus on New Connections Across Disciplines

AMO Coupled with PA and Gravitational Physics
Very-Low Mass Dark Matter & Gravity at Small Distances

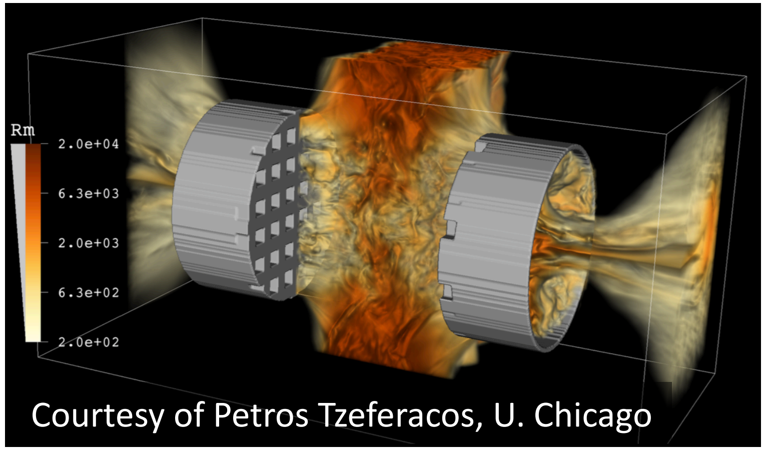
Blewitt and Derevianko: “Search of Topological Dark Matter with Atomic Clocks and GPS Constellation”: Analyze clock data from the 30 GPS satellites, which use atomic clocks for everyday navigation. Topological defect dark matter would cause initially synchronized clocks to become desynchronized, causing time discrepancies between spatially separated clocks to exhibit a distinct signature.

Geraci: “Measuring Gravity at the Micron Scale with Laser-Cooled Trapped Microspheres”: Uses levitated spheres of silica to search for hidden forces - sensitivities of a few zeptonewtons. Distinguishes between whether gravity will be much weaker than expected at short range, or stronger.

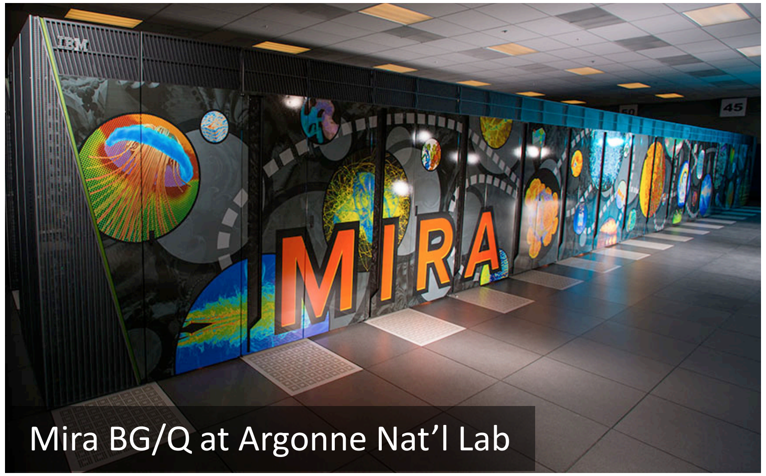
Advances in Laboratory Plasma Astrophysics


Courtesy of Lawrence Livermore Nat'l Lab

3D MHD Simulations and High Power Laser Experiments Study the Turbulent Origin of Cosmic Magnetic Fields



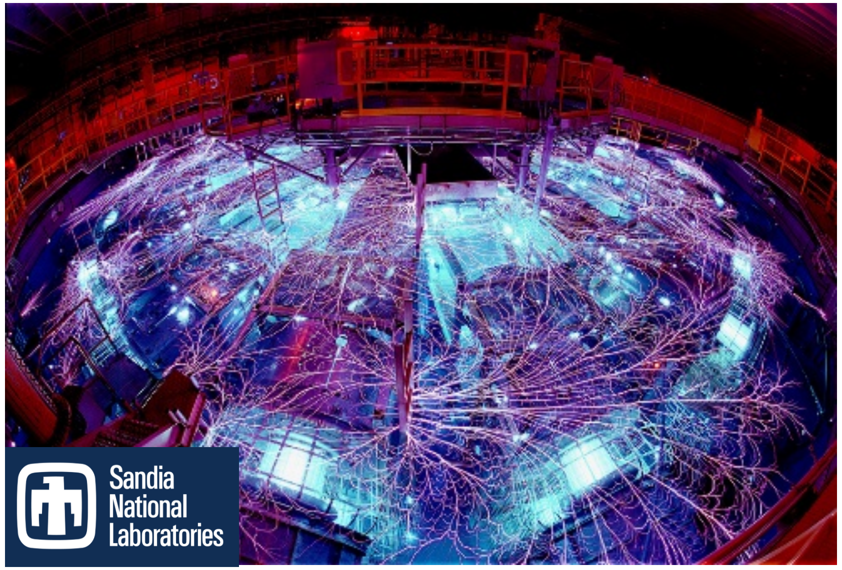
Courtesy of Petros Tzeferacos, U. Chicago



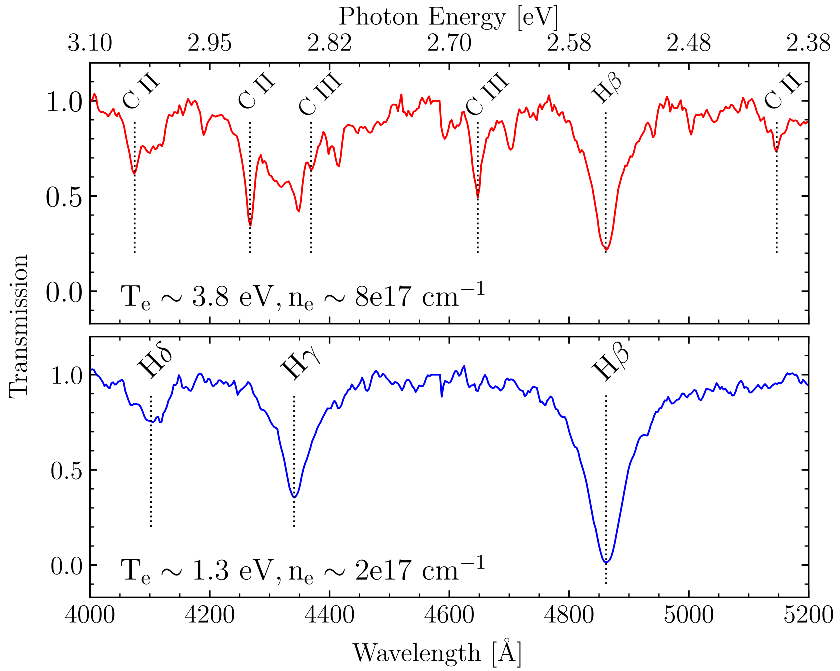
Mira BG/Q at Argonne Nat'l Lab

- A key astrophysical mechanism that is responsible for generation of the cosmic magnetic fields is being recreated in a terrestrial laboratory.
- Guided by three-dimensional numerical simulations with the FLASH code, experiments are being conducted in the largest laser facilities in the world – LLNL's National Ignition Facility and CEA's Megajoule Laser Facility – to demonstrate and characterize the turbulent dynamo mechanism.

Advances in Laboratory Plasma Astrophysics



White Dwarf Photospheric Plasmas on the Z-machine at Sandia Nat'l Lab



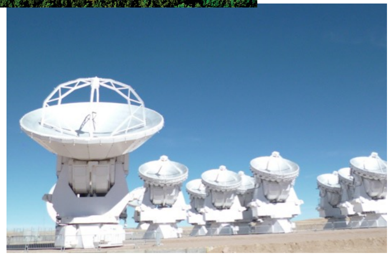
- The plasmas have long path lengths, allowing measurements of simultaneous absorption and emission over a range of densities and temperatures characteristic of WD photospheres.
- Critical aspects of the atomic line-broadening theory of hydrogen, helium, and carbon are being examined. One goal is to improve the ability to diagnose the plasma conditions at the surface of WD stars to unlock their potential as cosmic chronometers.

McDonald Observatory
THE UNIVERSITY OF TEXAS AT AUSTIN

Courtesy of Don Winget, Center for Astrophysical Plasma Properties, University of Texas at Austin


NSF
Looking Ahead: Ten Big Ideas
Navigating the New Arctic
STATISTICAL COMPUTATIONAL FOUNDATIONS
EDUCATION WORKFORCE
ANALYTICS
DATA MINING
DATA SCIENCE
Harnessing Data for 21st Century Science and Engineering
Work at the Human-Technology Frontier: Shaping the Future
RESEARCH IDEAS
Understanding the Rules of Life: Predicting Phenotype
The Quantum Leap: Leading the Next Quantum Revolution
Windows on the Universe: The Era of Multi-messenger Astrophysics
PROCESS IDEAS
Growing Convergent Research at NSF
NSF-Includes: Enhancing Science and Engineering through Diversity
Mid-scale Research Infrastructure
NSF 2050
NSF 2050: Seeding Innovation

Windows on the Universe



Multiple Forms of PHY Investment;
Individual Investigators, Facilities, Centers;
Partnerships guided by strong intellectual overlap

PHY Programs: Particle Astrophysics; Gravitational Physics; Nuclear Physics; Plasma Physics; Astrophysics & Cosmology Theory; Nuclear Theory

NSF Facilities: IceCube (GEO/PLR;MPS/PHY); NSCL (MPS/PHY)

Physics Frontiers Centers: NanoGrav (MPS/PHY/AST); JINA (MPS/PHY);

KICP (MPS/PHY;GEO/PLR); KITP (MPS/PHY/AST/DMR;BIO/MCB)

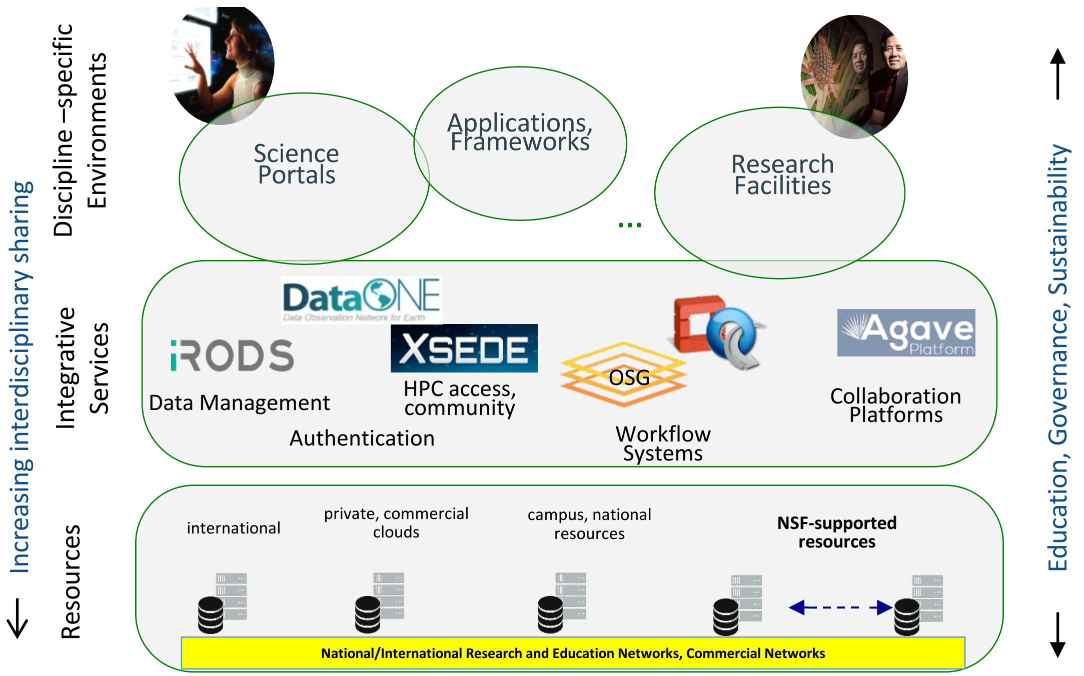
Large Experiments: SPT, ACT, CMB (Especially appreciate CMB CDT), etc.

DOE Partnerships: LHC, SuperCDMS, HAWC, Plasma Partnership, etc.

International: LHC, XENON1T, VIRGO, IceCube, etc.

Cyber infrastructure

Harnessing Data



Developing HDR cyberinfrastructure within a shared architectural vision

Harnessing Data

Domain Science ↔ Computation and Data Challenges

Connecting domain scientists with computer scientists

Essential for Handling Large Data Sets from LIGO, LHC, LSST

Efforts closely coordinated with OAC in CISE Directorate

Stay tuned for announcements of any special programs that offer possibilities for joint efforts related to Windows on the Universe