Astrophysics in the NSF Physics Division

C. Denise Caldwell
Division Director

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

AAAC January 2017

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)

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

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 (AAAC Subcommittee on CMB-S4), etc.

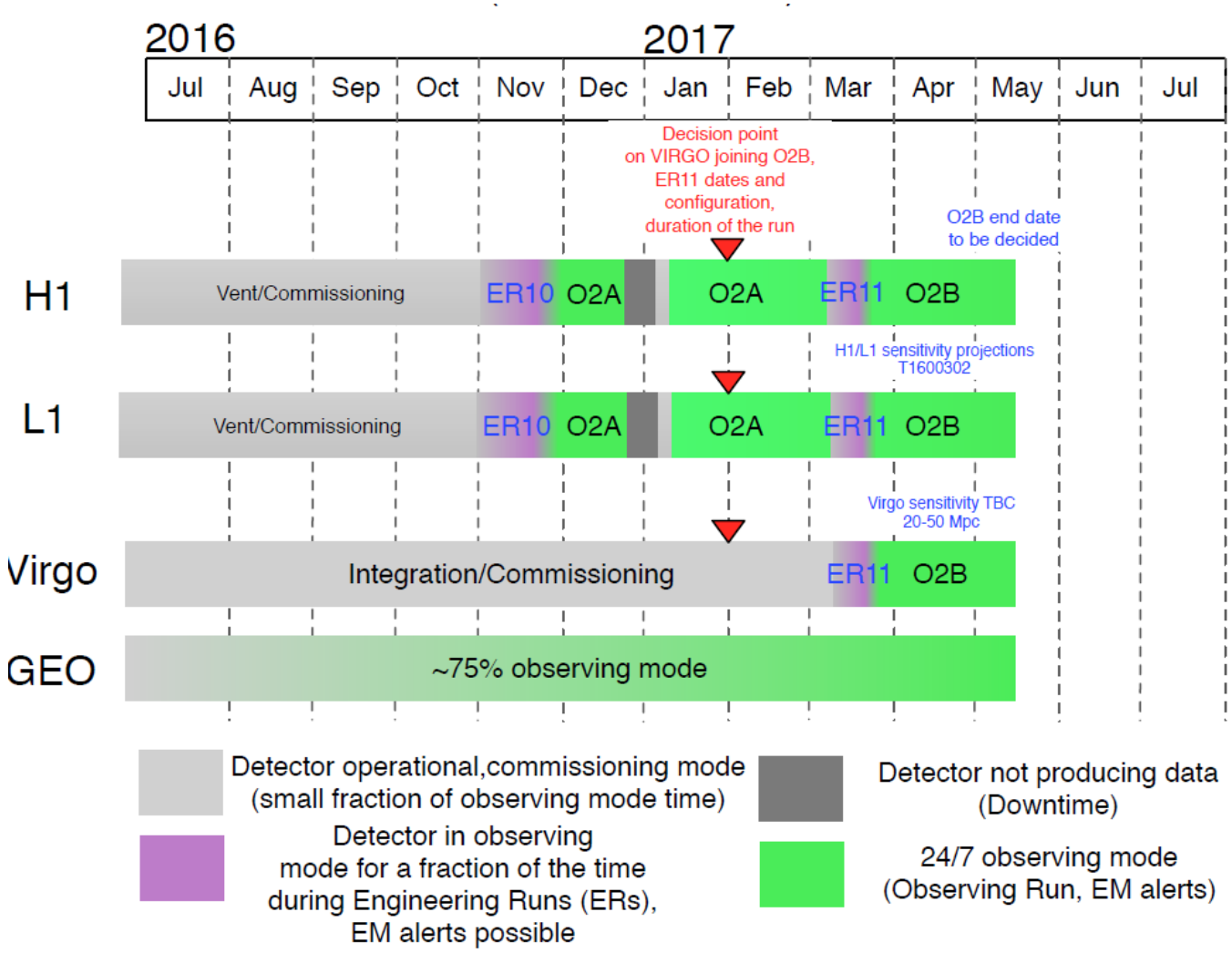
DOE Partnerships: LHC, SuperCDMS, HAWC, Plasma Partnership, etc.

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

LIGO is currently in second scientific observation run after Advanced LIGO upgrade (O2)

- O2 began first week of December 2016
- After a holiday break, O2 resumed in January and will continue during spring 2017
- LIGO sensitivity is expected to be 10% to 30% greater than first run (1.3 to 2.2 increase in event rate)
- Virgo operation planned to overlap with LIGO in spring 2017. Virgo sensitivity TBD

Credit: LIGO Lab



Top 12 Astronomy News Stories of 2016

[#6 as listed] **Dark Matter Remains Elusive**

It has been a rough year for dark matter. The newest searches for weakly interacting massive particles (WIMPs) have come up empty-handed. First, an underground detector in South Dakota called the Large Underground Xenon detector failed to detect any WIMPs. Then, the **Antarctic observatory known as IceCube** ruled out a fourth type of neutrino and dark matter contender. Physicists might soon be turning toward more exotic theories.

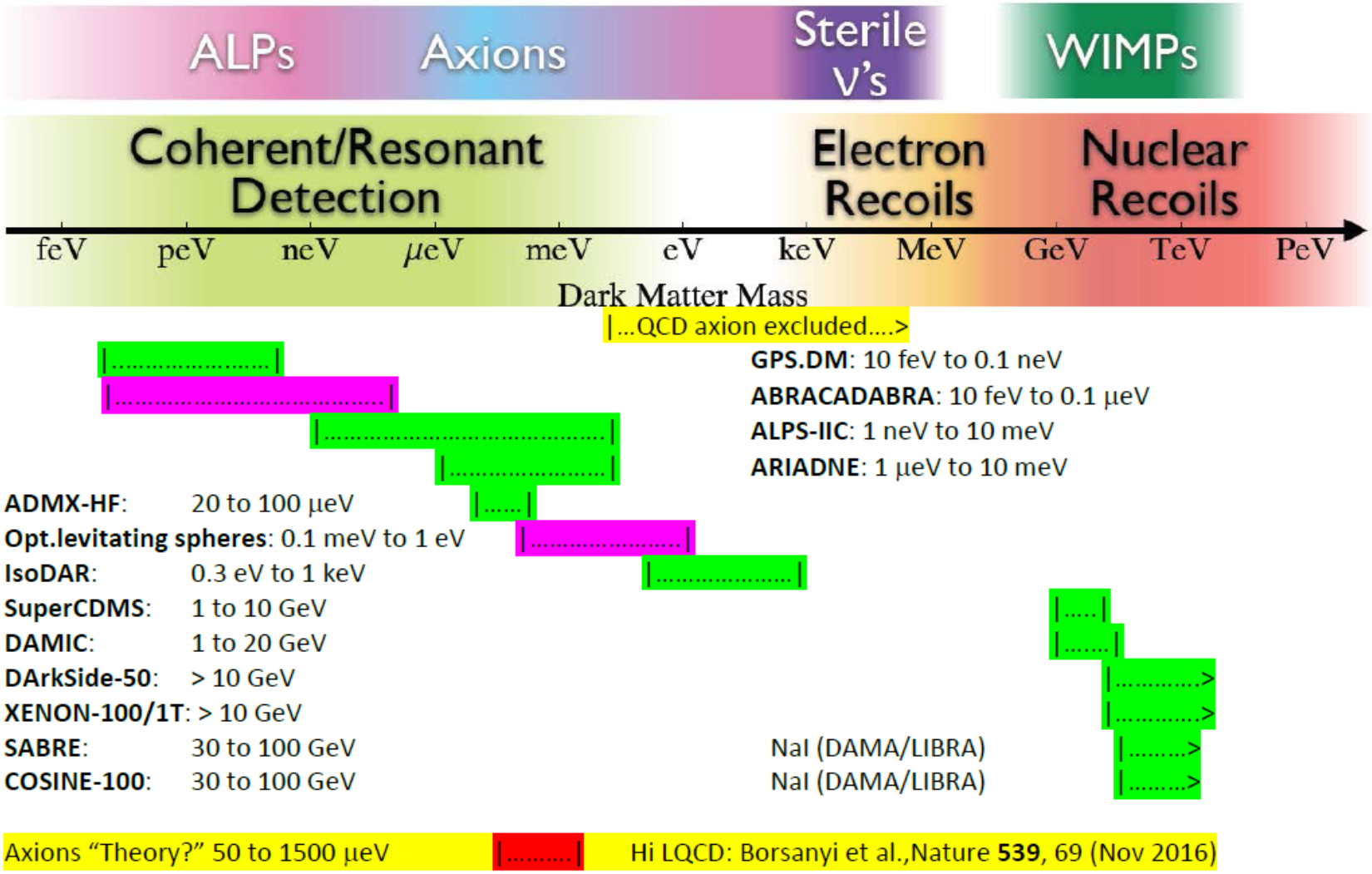
http://www.skyandtelescope.com/astronomy-news/top-astronomy-news-stories-of-2016/

Dark Matter Candidates (2)

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 this year)

Dark Matter experiments funded by the NSF-Particle Astrophysics Program:

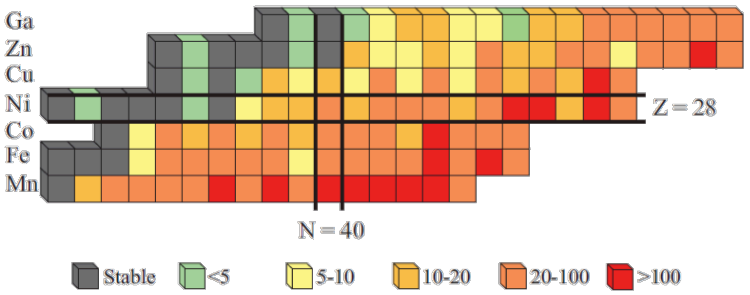


Plasma Astrophysics

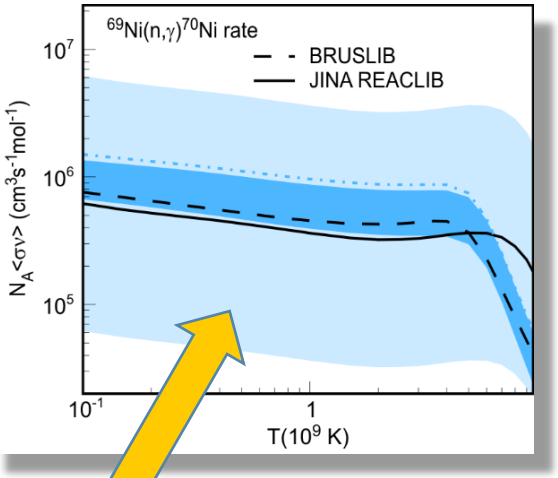
- In early January, chaired by Ellen Zweibel (U. Wisconsin) and co-funded by NSF/AST, NSF/PHY hosted a Workshop to celebrate 20 years of the NSF/DOE Partnership in Basic Plasma Science and Engineering.
  - Talks and posters presented at the workshop included several on laboratory astrophysics, cosmic rays, and particle acceleration via magnetic reconnection in astrophysical plasma
  - Workshop panel discussions frequently referenced the desire of the community for the NSF/DOE Partnership to better coordinate support for plasma astrophysics research with NASA
- Along with several other PHY programs, Plasma Physics is looking forward to contributing to the "Windows on the Universe" effort. E.g.:
  - Mergers of neutron stars are a prime target of LIGO, and the leading candidate for producing short, sub-second duration, gamma-ray bursts due to highly relativistic outflows. The formation mechanism of the relativistic outflows is a major unsolved problem, with the leading model being a jet produced by strong ordered magnetic fields in the accretion disk. The origin of such magnetic fields is still uncertain and constitutes a key plasma physics problem presently being addressed using first principles numerical simulations.* [*with input from Eliot Quataert (UC Berkeley)]

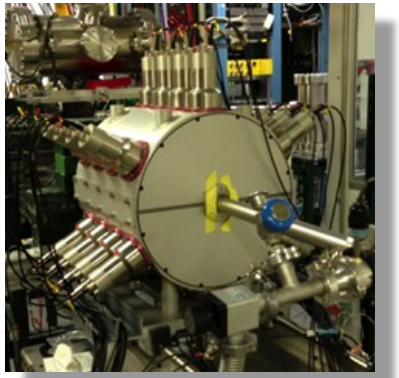
Constraints on Neutron Capture Rates – Key to Modeling Stellar Explosions

- Nuclear physics & structure → element abundances from stellar events
- Need reaction rates(esp. those far from stability) to test r-process models
- Color = uncertainty of neutron-capture rates.

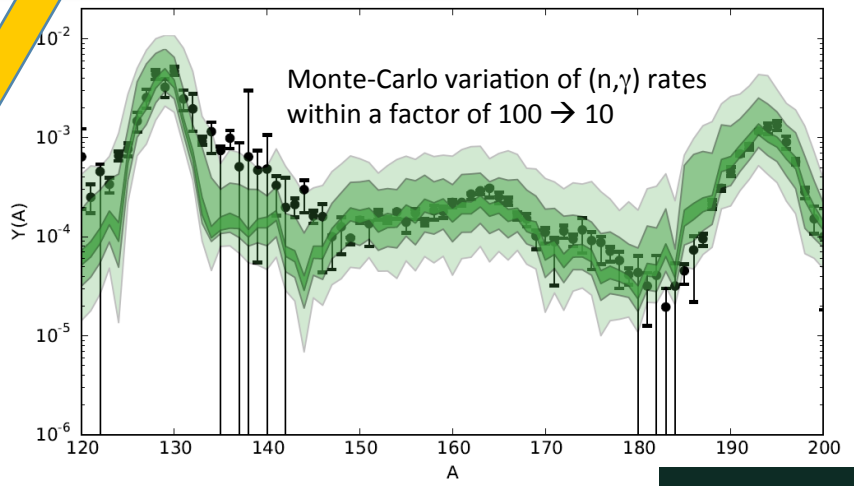


- New technique: γ-ray calorimetry developed by MSU and Univ of Oslo with SuN detector at NSCL used to extract $^{69}Ni(n,\gamma)^{70}Ni$.
- Uncertainty now ~ 2-3 (dark blue band) – achievable for rare isotopes far from stable
- Accurate rates allow model comparisons. With error of 2-3 dark green band is possible





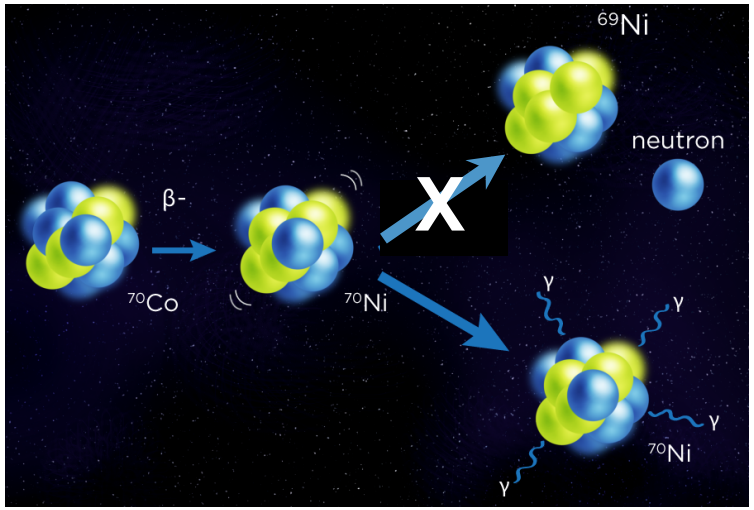
SuN detector at NSCL



S.N. Liddick, A. Spyrou et al., Phys. Rev. Lett 116, 242502 (2016)
http://physics.aps.org/synopsis-for/10.1103/PhysRevLett.116.242502

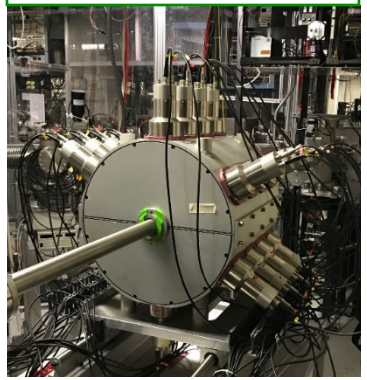
New Results Indicate Past Assumptions Key for Astrophysical Models Incorrect

- β-delayed neutron emission is important for r-process nucleosynthesis.



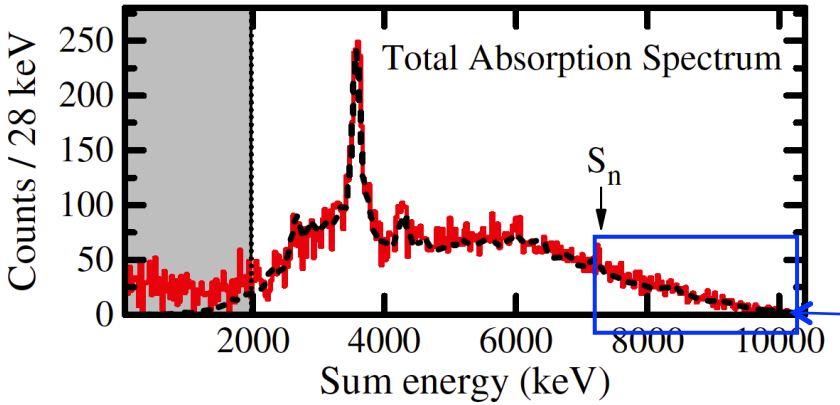
- *Neutron emission weaker than previously thought*
- This particular case can only be explained using shell model calculations & mismatch between populated states in ^{70}Ni and the neutron daughter ^{69}Ni.
- ***Hindered*** neutron emission is likely to divert the reaction flow from the projected path and → shift the final abundance distribution.

Experiment used the SuN detector at NSCL



- β-decay intensity of ^{70}Co studied using Total Absorption Spectroscopy
- Strong γ-ray emission was observed above the neutron threshold.

A. Spyrou, S.N. Liddick, et al.,
Phys. Rev. Lett 117, 142701 (2016)



Unexpected γ-emission above neutron threshold

NSCL: Five-year Renewal Award – Transfer to DOE FRIB

- Operation & Maintenance
  - National User Facility
- Research Program of MSU Nuclear Science Faculty
- Smooth & Efficient Transfer from NSF/NSCL → DOE/FRIB
  - MOU