Panel discussion:
Cosmic Explorer connection with DOE science

Emanuele Berti, Johns Hopkins University

Second Cosmic Explorer Symposium
April 25 2024

JOHNS HOPKINS
UNIVERSITY

Session topic: CE overlap with DOE science

Premise:

- Snowmass Community Summer Study (2021) collected input from APS Division of Particle and Fields (DPF): see https://www.slac.stanford.edu/econf/C210711/
- Recommendations to DOE/NSF from Particle Physics Project Prioritization Panel (P5) https://www.usparticlephysics.org/2023-p5-report/

> Gravitational waves are a powerful new tool for exploring a range of astronomical and particle physics topics, including probing the expansion history of the universe using standard sirens. NSF has been an excellent steward of this program and should support the development of new capabilities and a next-generation project. The particle physics case for studying gravitational waves at all frequencies should be explored by expanded theory support.

- DOE-NP (Office of Nuclear Physics) has their own Nuclear Science Advisory Committee Long-Range Planning exercise (NSAC LRP): https://nuclearsciencefuture.org/

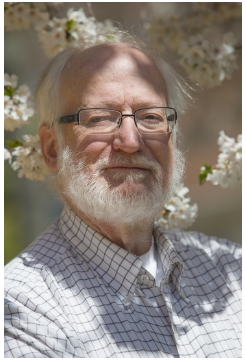
Pedro Marronetti ("The perspective from NSF", Tuesday):

- Answering question from Jenne Driggers on involvement of other agencies besides NSF: *"We are open to the idea, but so far no other agency has shown interest. I don't expect things to change in the next year or two, but they may change in the next P5."*
- Strongly recommended international collaboration

Panelists

Jesse Thaler, MIT
DOE-HEP and the
P5 recommendation

Marc Kamionkowski, JHU
CE and cosmology



James Lattimer, SBU
CE and nuclear physics

Lindley Winslow, MIT
DOE-NP
NSAC LRP

Cosmic Explorer Connections to DOE Science

Jesse Thaler

MIT

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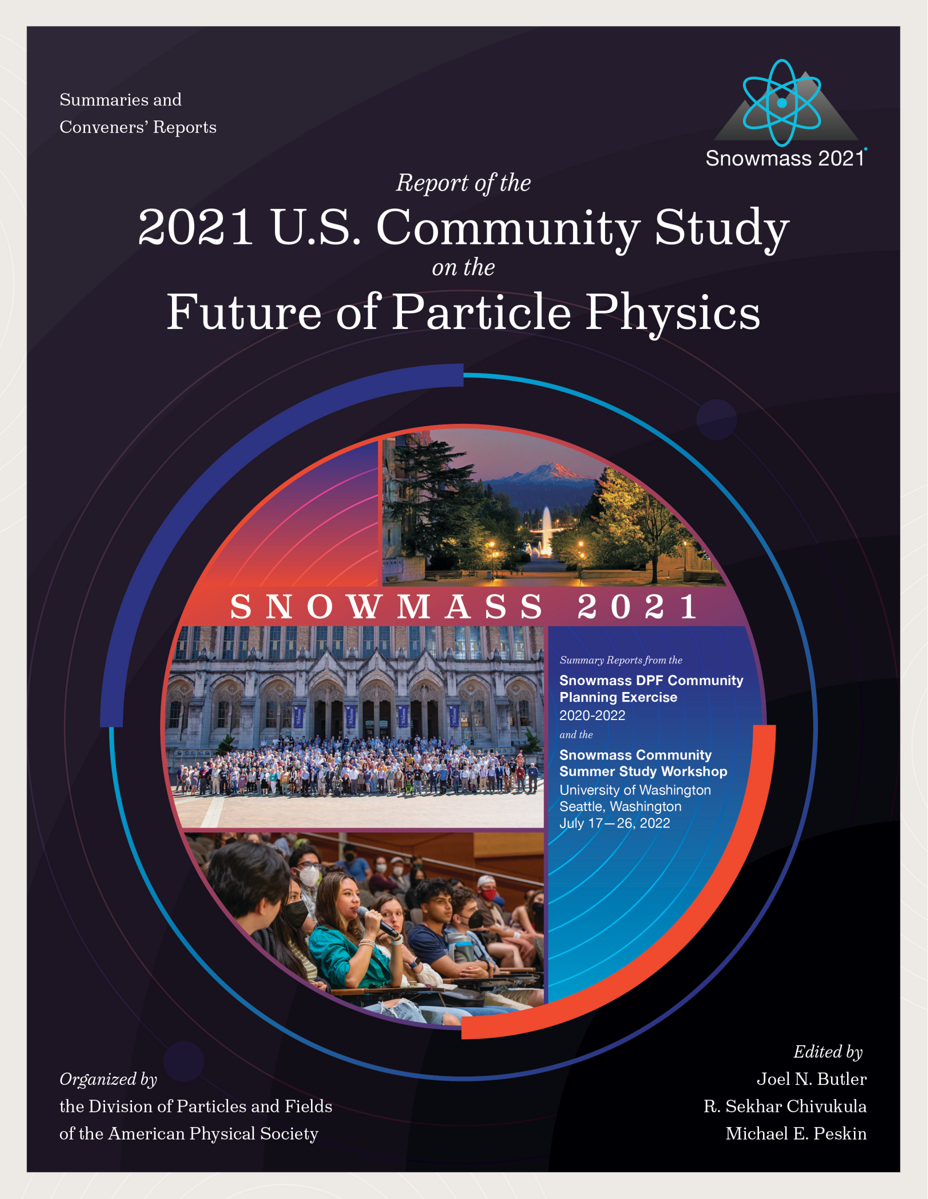
Obligatory disclaimer: While my research is supported by the DOE and I am a member of HEPAP and P5, the following slides represent my personal views

Strategic Planning in the Particle Physics Community

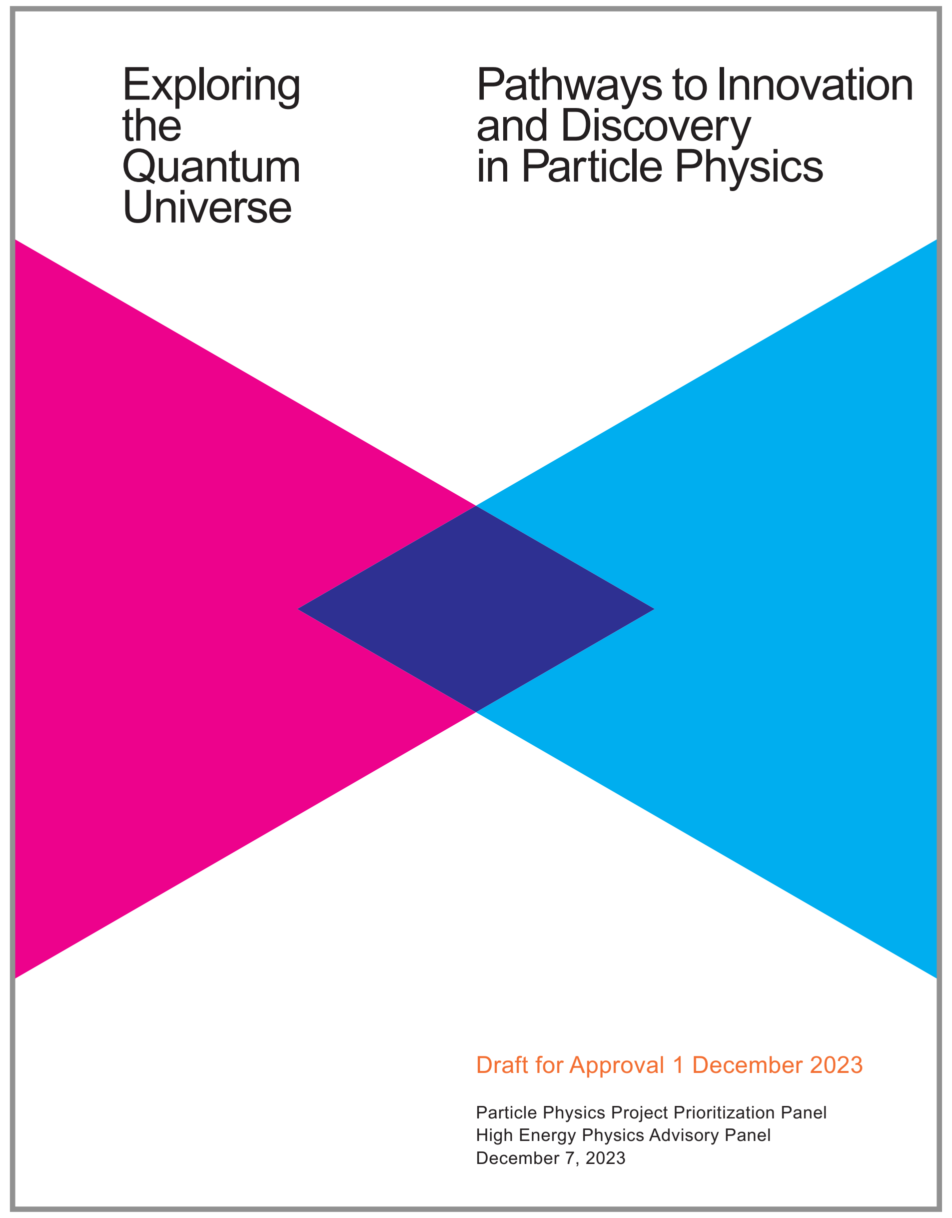
Broad Blue Sky Input from APS DPF “Snowmass Community Summer Study”

Division of Particles and Fields



Concrete Recommendations to DOE/NSF from Particle Physics Project Prioritization Panel (P5)

(which is a subpanel of HEPAP: High Energy Physics Advisory Panel)



Office of High Energy Physics

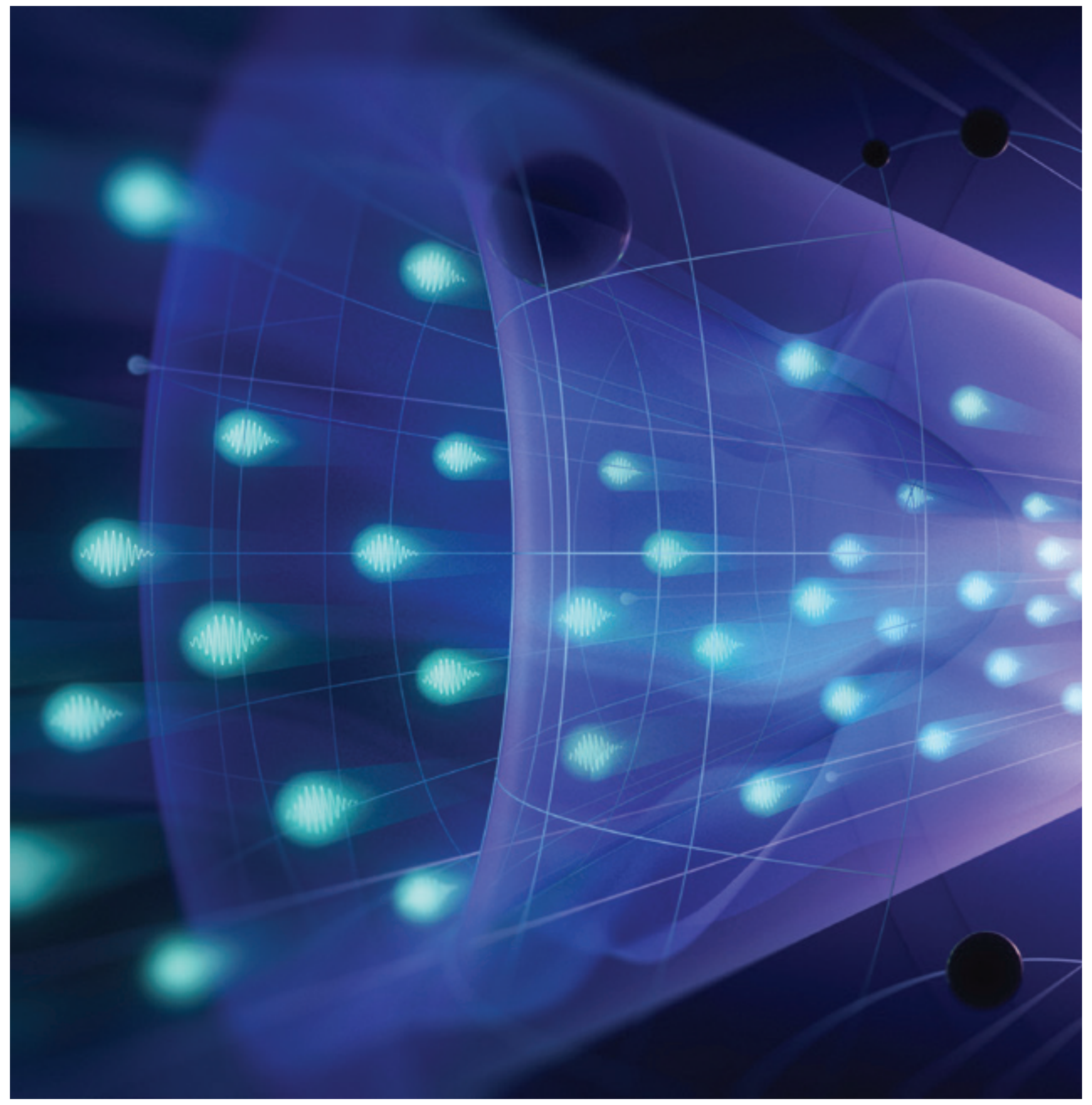
Mathematical & Physical Sciences Directorate

see also 2023 HEPAP International Benchmarking Panel; upcoming National Academies EPP2024

2023 P5: Science Themes/Drivers for Particle Physics

Exploring the Quantum Universe

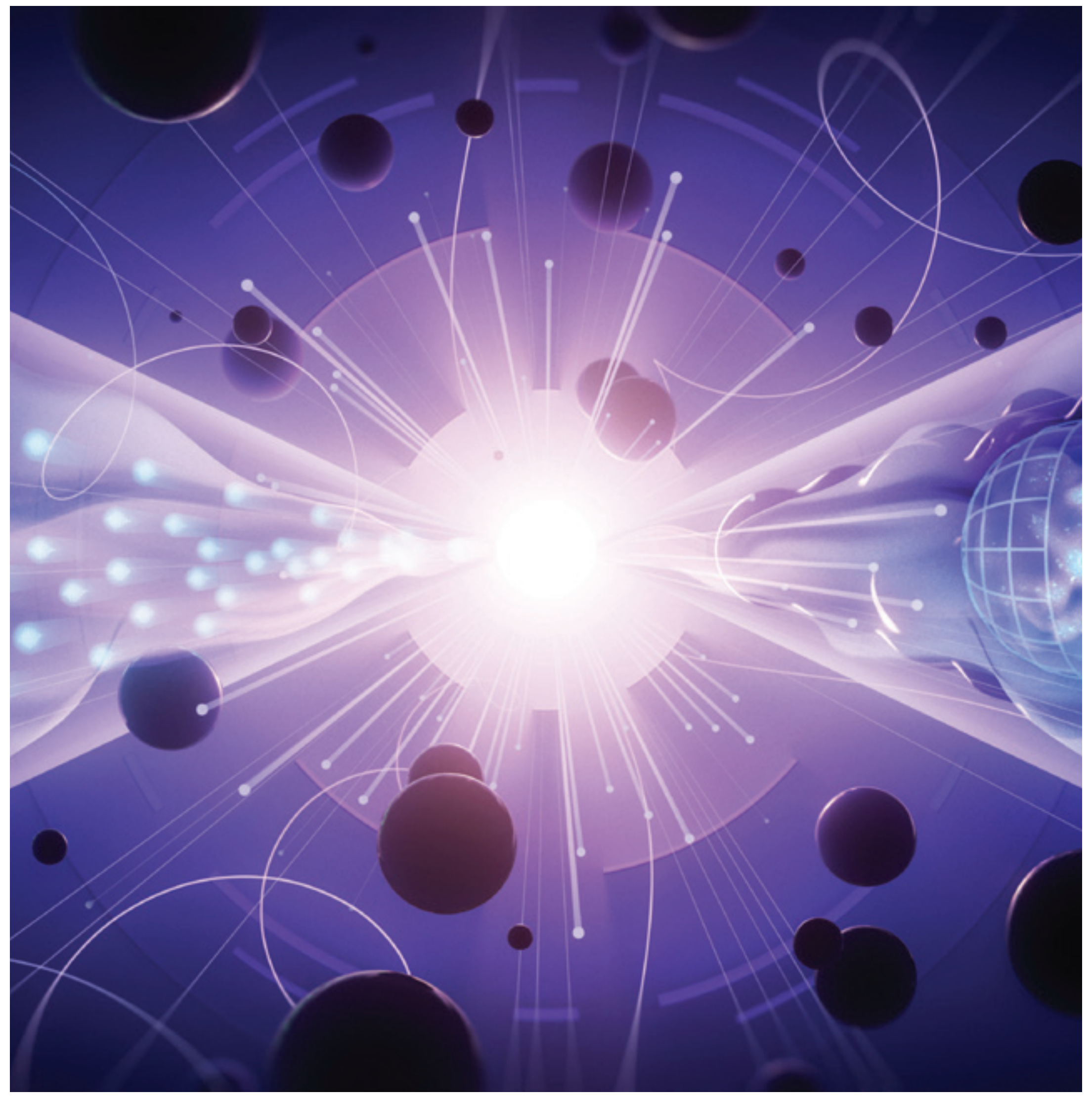
Decipher the Quantum Realm



Elucidate the Mysteries of Neutrinos

Reveal the Secrets of the Higgs Boson

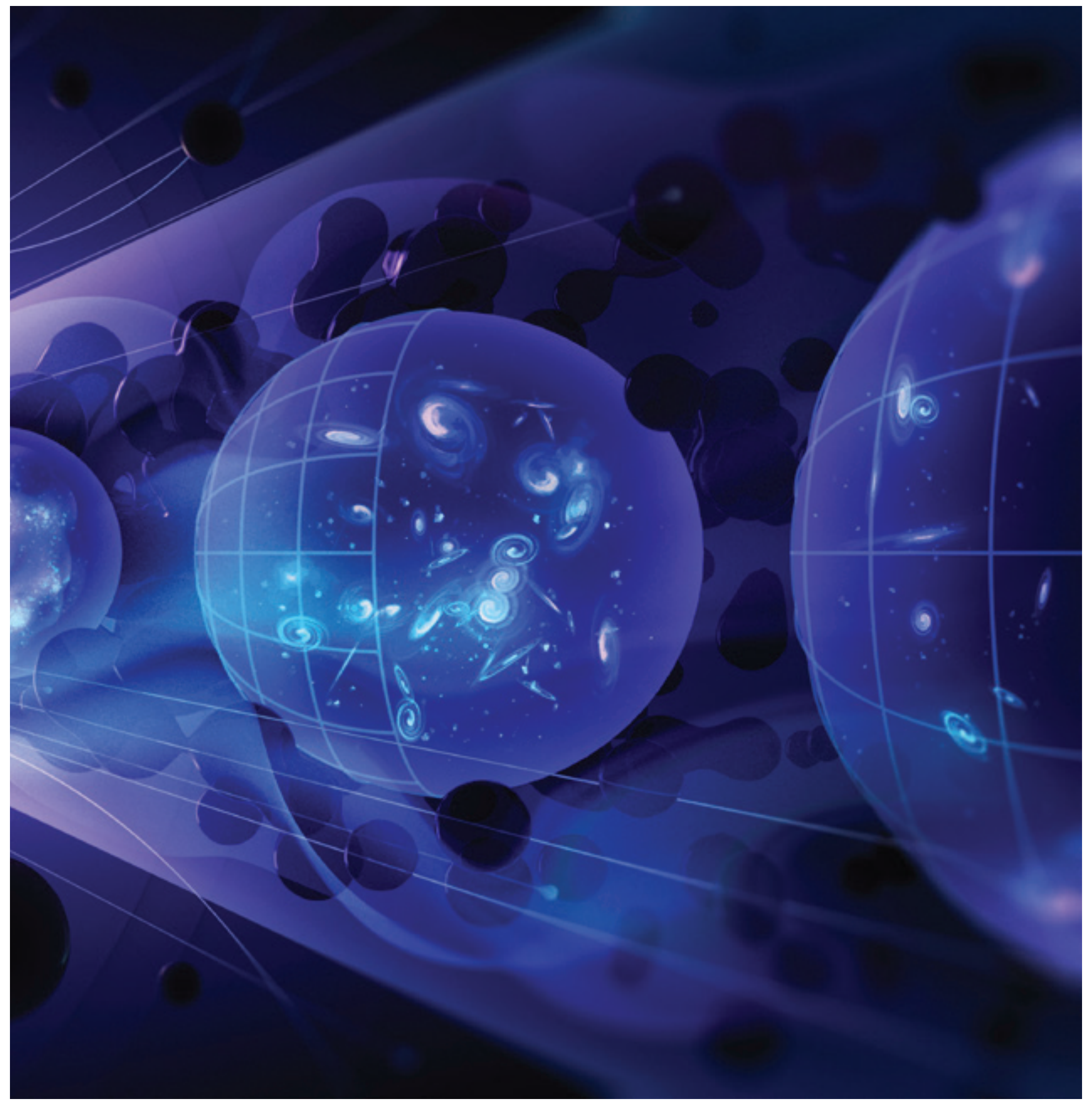
Explore New Paradigms in Physics



Search for Direct Evidence of New Particles

Pursue Quantum Imprints of New Phenomena

Illuminate the Hidden Universe



Determine the Nature of Dark Matter

Understand What Drives Cosmic Evolution

Gravitational Waves Featured Prominently in Snowmass/P5!

Snowmass:

Decadal Overview of Future Large-Scale Projects		
Frontier/Decade	2025 - 2035	2035 -2045
Energy Frontier	U.S. Initiative for the Targeted Development of Future Colliders and their Detectors	
		Higgs Factory
Neutrino Frontier	LBNF/DUNE Phase I & PIP- II	DUNE Phase II (incl. proton injector)
Cosmic Frontier	Cosmic Microwave Background - S4	Next Gen. Grav. Wave Observatory*
	Spectroscopic Survey - S5*	Line Intensity Mapping*
	Multi-Scale Dark Matter Program (incl. Gen-3 WIMP searches)	
Rare Process Frontier		Advanced Muon Facility

* = Project funding may come from sources other than HEP

P5 Report:

Exploring the Quantum Universe

Contains ~15 mentions of "gravitational waves"

High Energy Physics Opportunities in Gravitational Waves

- ✓ Physics of compact objects and dense matter
- ✓ Hidden particle sectors and dark matter
- ✓ Structure and history of our universe
- ✓ New theoretical insights and techniques
- ✓ Unexpected surprises!

Masha Baryakhtar: P5 Town Hall, April 2023

Parsing the Key P5 Paragraph (Section 4.2.6)

A lot of considerations packed into 67 words…

Gravitational waves are a powerful new tool for exploring a range of astronomical and particle physics topics, including probing the expansion history of the universe using standard sirens. NSF has been an excellent steward of this program and should support the development of new capabilities and a next-generation project. The particle physics case for studying gravitational waves at all frequencies should be explored by expanded theory support.

(Reminder: the following are my views, not those of HEPAP/P5/DOE/etc.)

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NSF already supports world-class research in multi-messenger astronomy and astrophysics

How would investments in gravitational wave research/facilities advance the DOE-HEP mission?

(And how might you capture that through a new/updated science driver for P5 in 2030s?)

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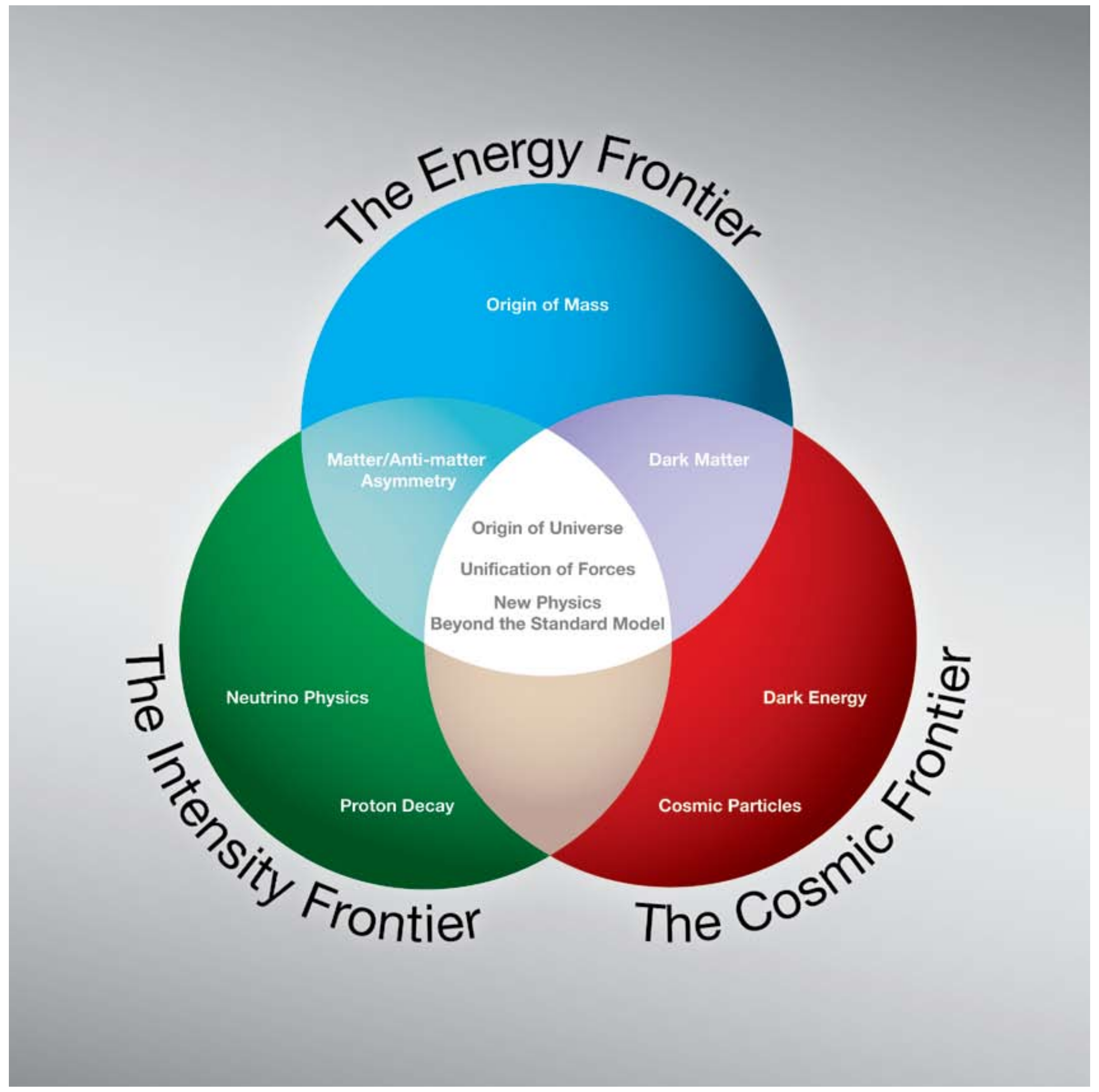

"Particle Physics" continues to evolve in the U.S.

2008 P5: Embraced the "Cosmic Frontier"
2014 P5: "Understand Cosmic Acceleration: Dark Energy & Inflation"
2023 P5: "Understand What Drives Cosmic Evolution"

Gravitational wave physics does have some overlap with DOE-HEP priorities, but given budgetary constraints and anticipated projects, targeted investments would require further evolution of the field

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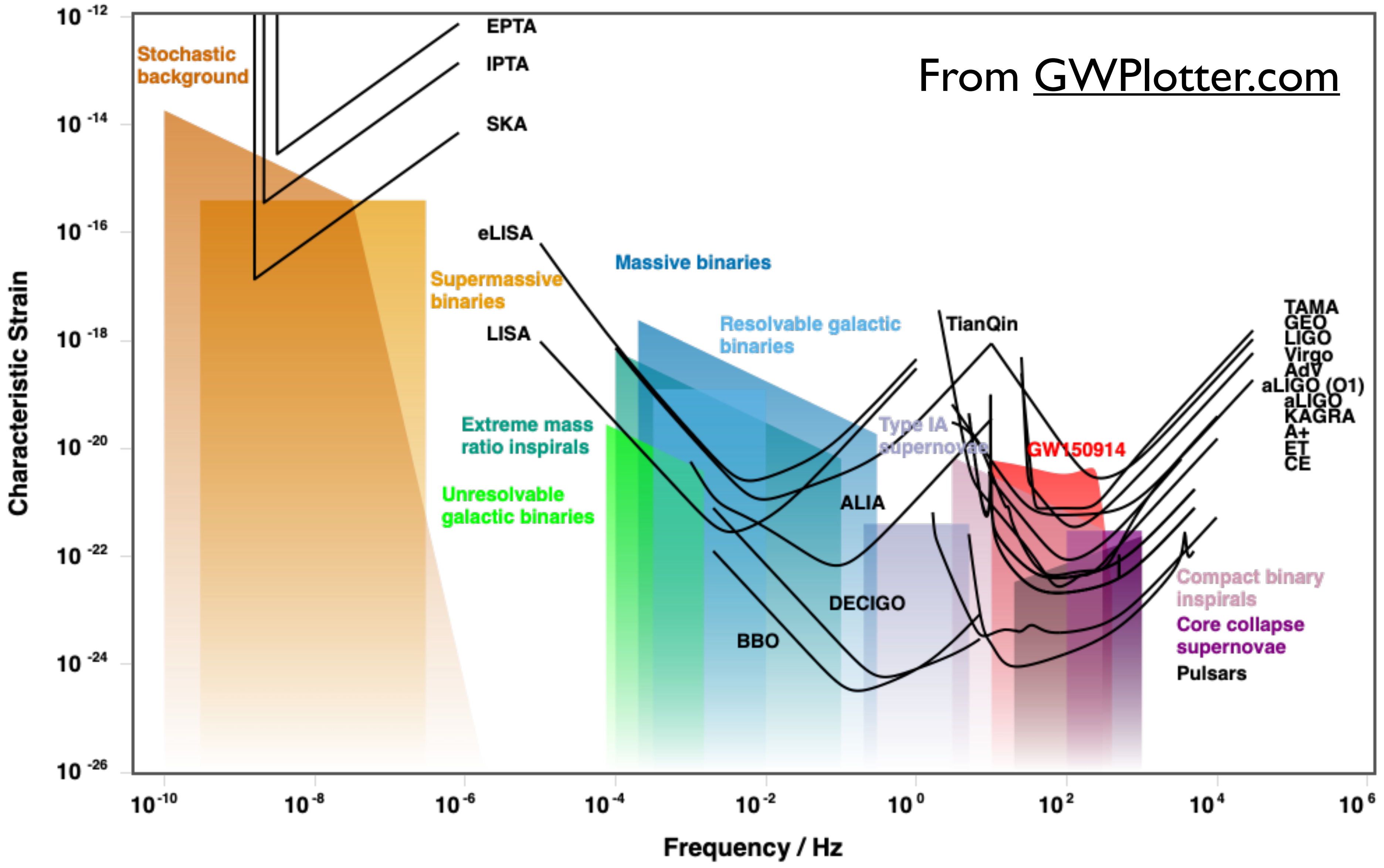

The gravitational wave spectrum is as rich as the electromagnetic wave spectrum, with different frequencies sensitive to different phenomena

If DOE-HEP makes a strategic investment into gravitational waves, which frequencies/technologies are best aligned with current particle physics priorities as well as with emerging opportunities?

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High Energy Physics Opportunities in Gravitational Waves

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Theory research often transcends the (artificial) boundaries between fields, especially for studies of physics beyond the Standard Model

Independent of the question of DOE support, what theory studies/insights could help bolster the science case for Cosmic Explorer?

MK on CE, DM, cosmology, and fundamental physics

2nd Cosmic Explorer symposium

25 April 2024

Gravity=physics → tests of gravity = tests of fundamental physics

- Strong-field gravity
- Nonluminal propagation; vector/scalar polarizations; parity effects

Dark matter

- BH superradiance
- PBHs
- ULA-field effects
- DM in neutron stars

Cosmology

- Hubble tension; expansion history
- Stochastic background

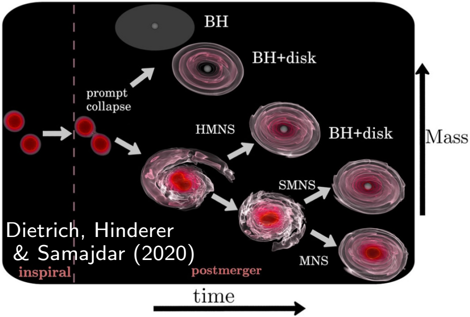
Lensing

- Time delays
- Wave-optics effects
- PBHs....

DOE Nuclear Astrophysics With CE

Gravitational Wave detection of mergers involving neutron stars will probably be CE's greatest contribution to nuclear astrophysics. With 40 km and 20 km observatories, CE40 will be able to essentially observe all binary neutron star (BNS) and neutron star-black hole (NSBH) mergers in the Universe. With a few years of observations, CE could

- observe about 100,000 mergers per year, with about 100 BNS having SNR of 100 or better,
- constrain the radii of $1.4 M_\odot$ neutron stars to within 10 m,
- constrain the neutron star maximum mass M_{max} to within $\lesssim 0.1 M_\odot$,
- detect 500 BNS mergers with $z > 5$,
  - locate 100 BNS mergers within 1 square degree, allowing a multitude of multi-messenger observations,
  - map several hundred GRB progenitors,
  - observe several BNS systems 300 s before merger.



Specific Science Goals Relevant to DOE Projects

- During inspiral, measurements of radii (coupled to the nuclear symmetry energy) from chirp masses and tidal deformabilities
- Possible signatures of phase transitions or dynamical tidal corrections during inspiral
- The chirp mass constrains M_{max} depending on whether or not a long-lived ($\gtrsim 1$ s) supra-massive neutron star is formed
- The post-merger gravitational wave frequency spectrum has peaks highly correlated with the equation of state, enhancing inspiral information and exposing possible exotic degrees of freedom and thermal and magnetic field effects
- Multi-messenger events shed light on gamma-ray bursts, constrain r-process nucleosynthesis, and provide further constraints to M_{max}
- Component mass measurements constrain the neutron star mass distribution and provide important clues for binary star evolution and population synthesis studies

Cosmic Explorer and Nuclear Physics

Lindley Winslow

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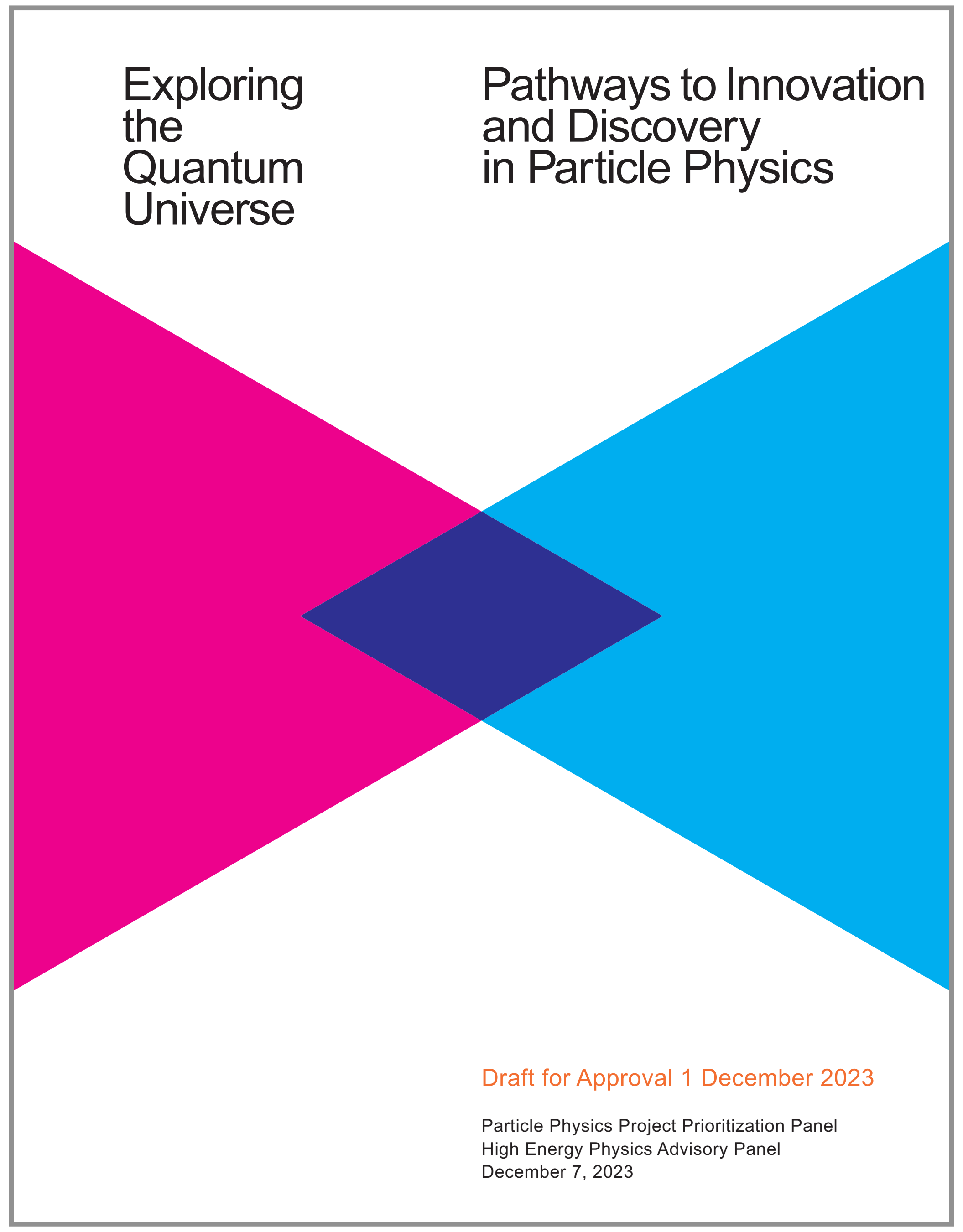
2023: Strategic Plans for U.S. Nuclear and Particle Physics



Department of Energy

Office of High Energy Physics
Office of Nuclear Physics

National Science Foundation

Mathematical & Physical Sciences Directorate

Prioritize research directions over the next 10 years, in the context of a multi-decade vision

Make fiscally responsible recommendations to federal funding agencies

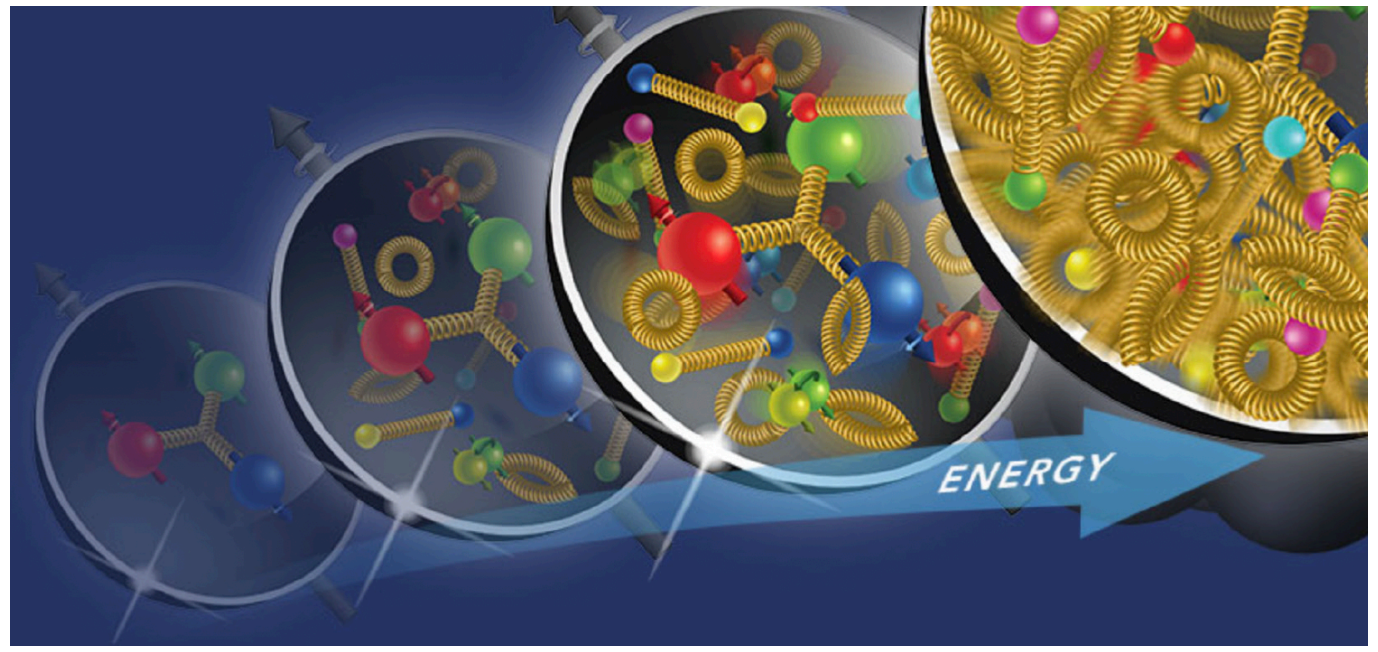
Communicate the vibrancy of nuclear/particle physics to a broad audience

What is "Nuclear Physics"?

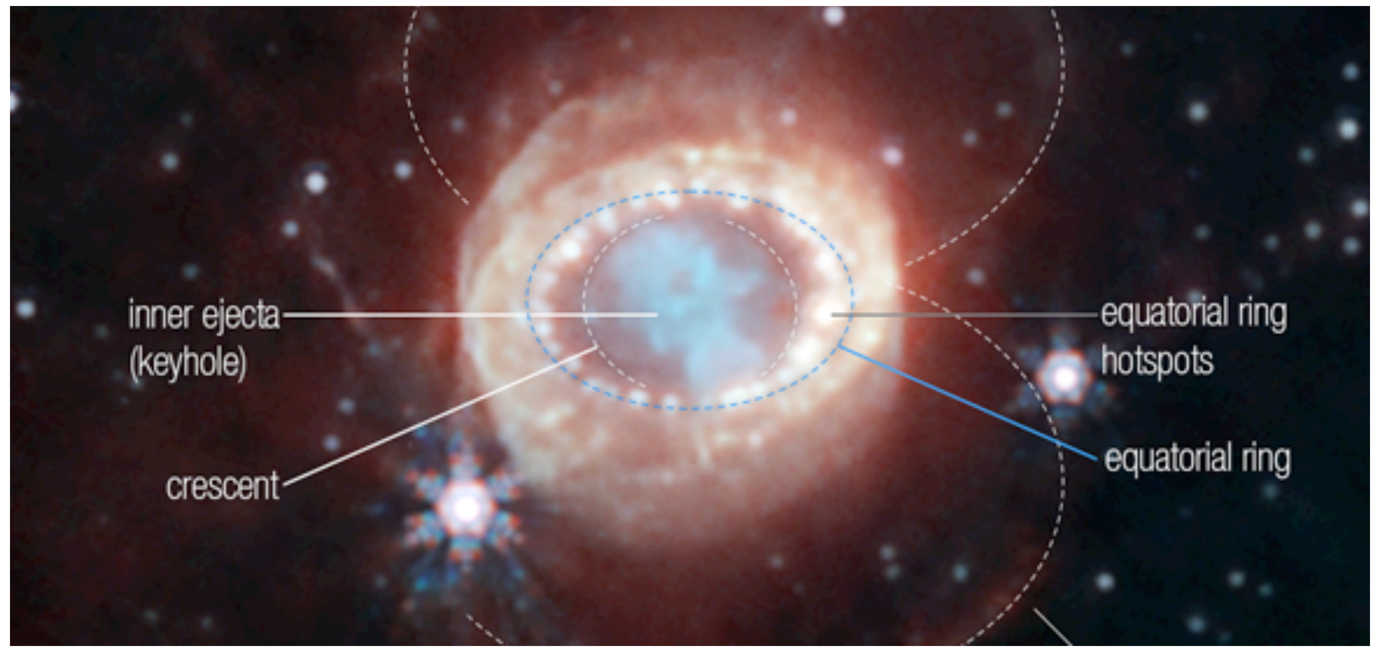
Nuclear science is the investigation of how protons and neutrons formed from elementary particles and how the forces between those particles produce both nuclei and the vast variety of nuclear phenomena that occur in the universe

Four Communities in Nuclear Science

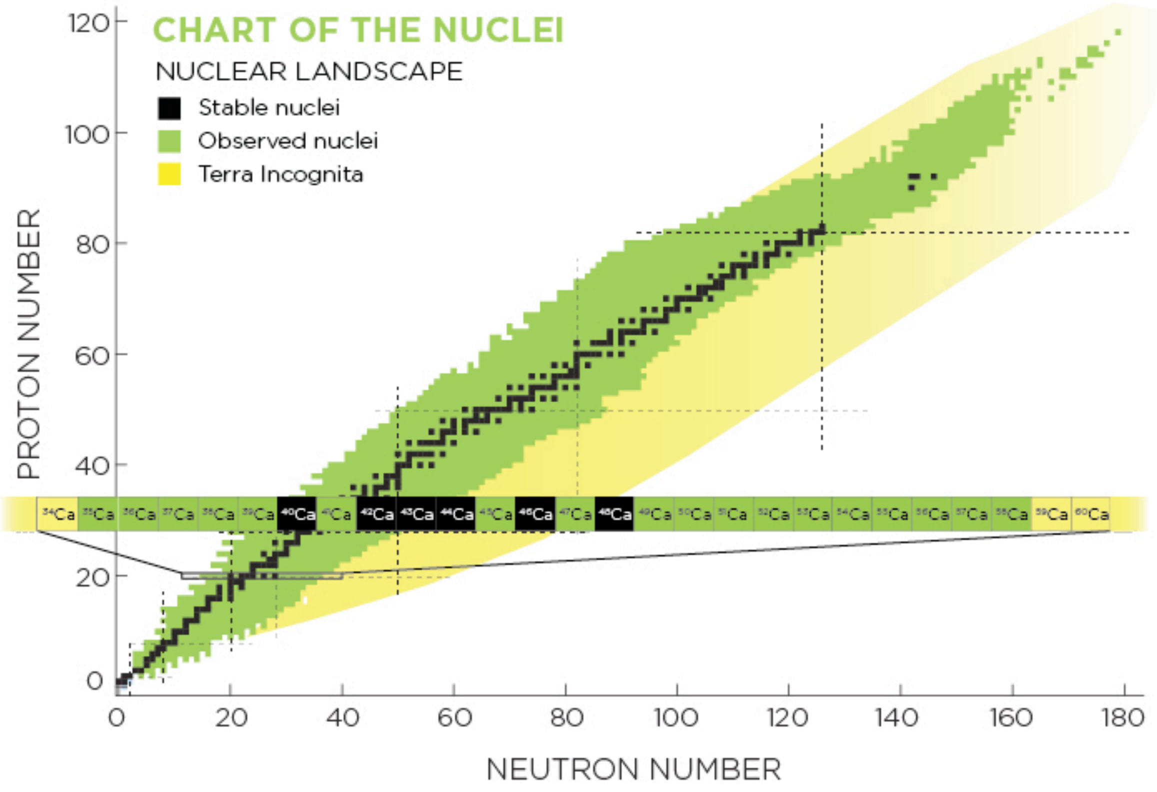
Quantum Chromodynamics



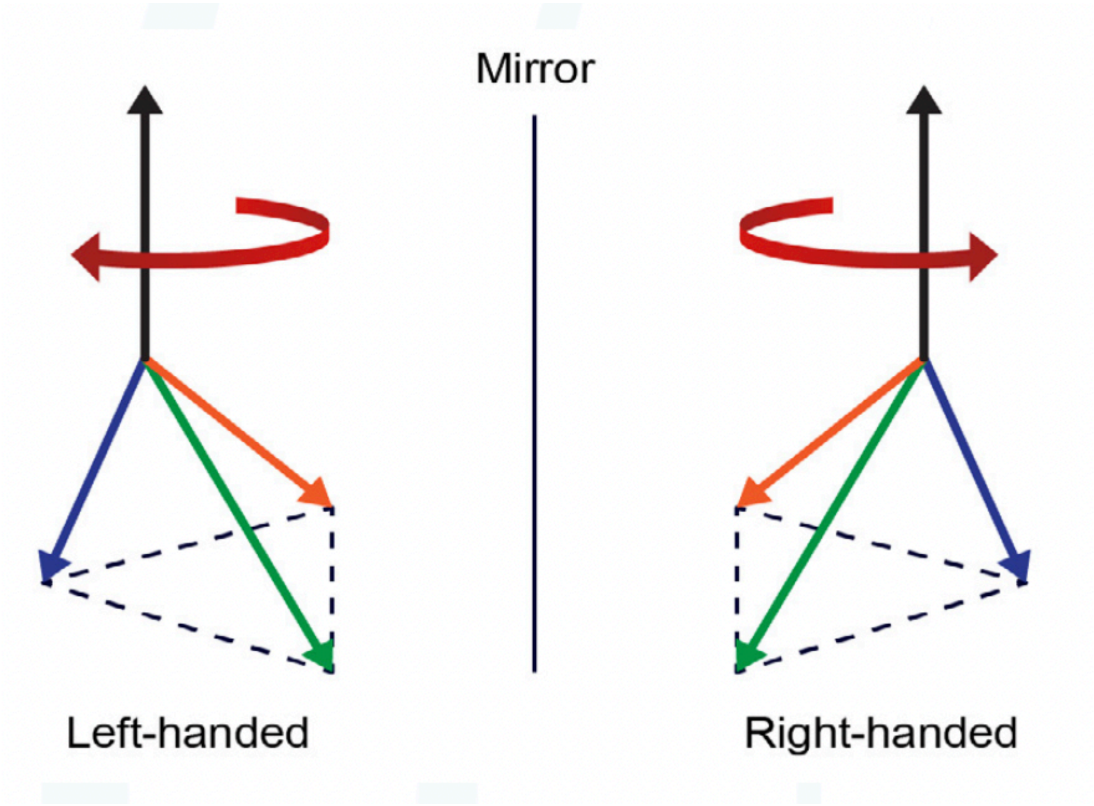
Nuclear Astrophysics



Nuclear Structure and Interactions



Fundamental Symmetries



Connections to Cosmic Explorer

A huge triumph has been determining where in the universe the nucleosynthesis of the heavy elements is occurring.

The focus of nuclear physics is now perfecting our understanding of the reactions that govern these processes with its flagship facility FRIB (located at Michigan State University).

There is nice synergy between Cosmic Explorer and Nuclear Physics but there is a stronger science case with High Energy Physics.

Thoughts from a researcher at the border:

My research program (Lindley) is funded by NSF Particle Astrophysics, NSF Nuclear Physics, DOE Nuclear Physics and hopefully soon DOE HEP Cosmic Frontier.

Each program and community have slightly different needs and priorities. For moving to DOE, the interface with the priorities of the individual National Labs becomes another key variable.