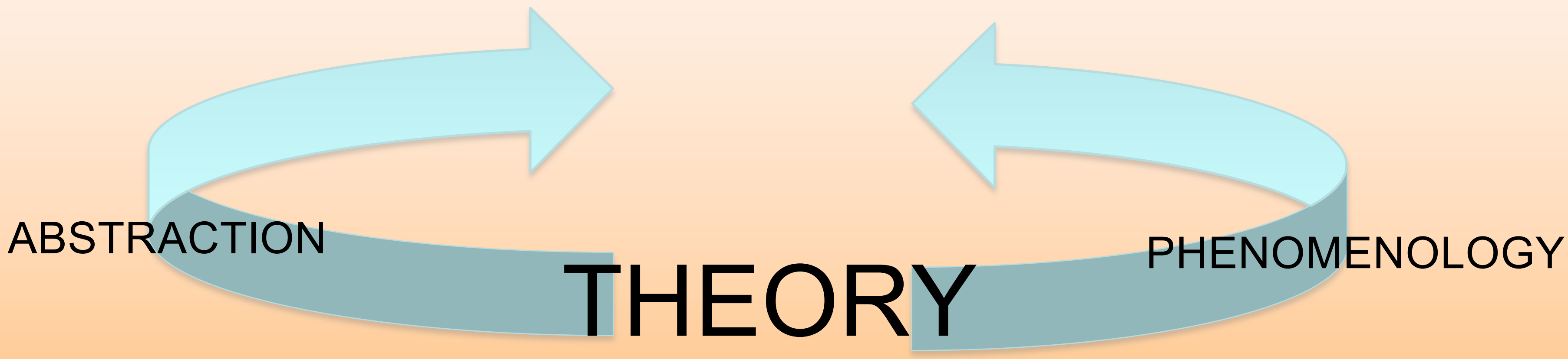
THEORETICAL PHYSICS

in Particle Physics, Nuclear Physics,
Gravity and Cosmology

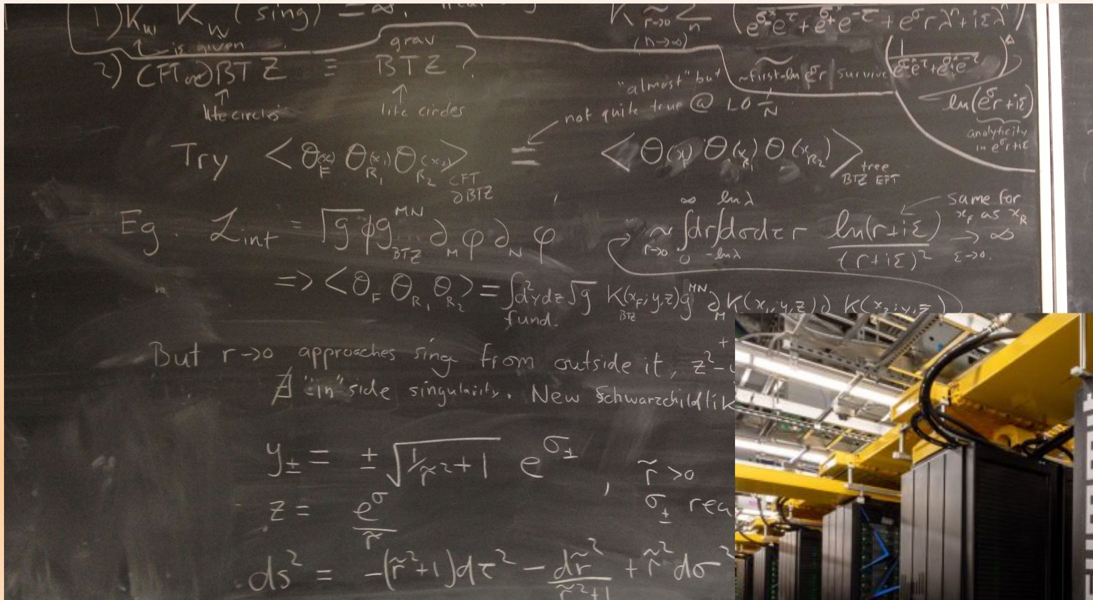
BIG QUESTIONS

Core Principles: Quantum + Relativity + Gravity

- Structure and Dynamics of Spacetime
- Origins, Evolution of Universe
- Fundamental constituents of Universe
- Unity of Forces and physical laws
- Origins of Matter (vs. anti-matter)
- Fundamental Symmetries
- Phases of matter and neutron star physics
- Quantum structure underlying fundamental laws

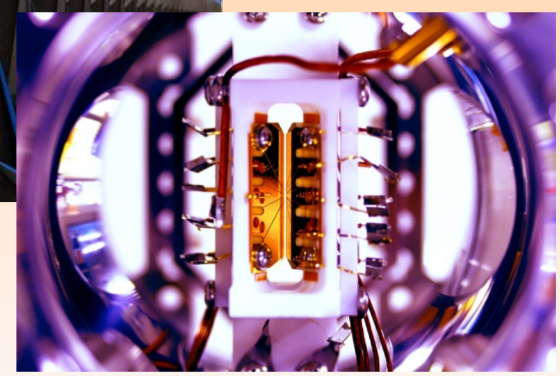

ABSTRACTION
THEORY
PHENOMENOLOGY

A mix of standing at the black board plus computation and simulation



MCFP blackboard

Summit supercomputer at Oak Ridge National Laboratory



An ion-trap quantum computer at UMD/JQI

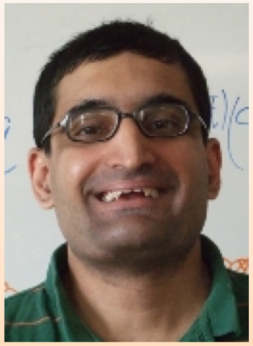
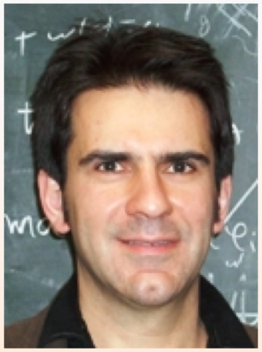
(Right now with coronavirus, we’re interacting remotely with zoom and skype)

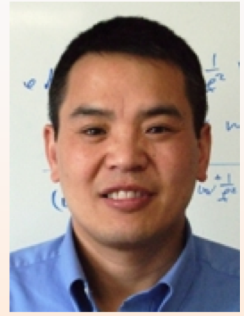
EXPERIMENTS pursued at UMD

- **Large Hadron Collider- Baden, Belloni, Eno, Hadley, Skuja**
- **LHCb- Jawahery, Franco Sevilla**
- **IceCube- Sullivan, Hoffman**
- **LIGO - Shawan**
- **Lux, EXO - Hall**
- **HAWC - Goodman**
- **AMS – Seo**
- **Quantum simulation experiments: Monroe, Linke**
- **Analog gravity/cosmology experiments in Bose condensates: Campbell, Spielman**

State of Fundamental Physics

- Experimentally
  - **Large Hadron Collider testing Higgs boson**
  - **Cosmology is rich and precise science**
  - **Underground labs/Astrophysics probes**
  - **Novel, diverse small-scale high-precision expts.**
  - **Tests of General Relativity, gravitational waves discovered**
  - **Fundamental symmetries probed. E.g., electric dipole moment, neutrinoless double-beta decay, proton decay and N-Nbar oscillations**
  - **Quark and gluon structure of hadron and nuclei to be studied with unprecedented precision at EIC**
  - **The most exotic neutron-rich isotopes to be made and studied to learn about origin of heavy elements and equation of state of neutron stars**
  - **Small programable quantum simulators are being realized**
- Theory:
  - **Competing paradigms for new particle physics**
  - **New testable cosmological theories, extreme energy**
  - **New theoretical approaches to explain dark matter**
  - **Large-scale computing that connects nuclear physics to the underlying SM**
  - **New theoretical and computational tools, such as machine learning and quantum computing, allow us to attack previously intractable problems/regimes**
  - **New connections Quantum Gravity/Info/AdS-CFT**

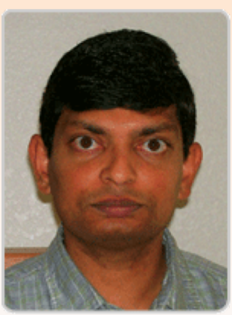





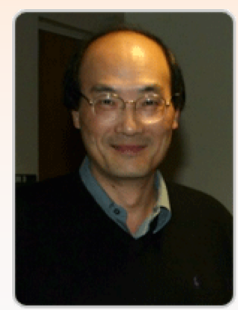

Particle, Nuclear and Gravity Theory Faculty

+ ~ 10 postdocs
~ 20 students







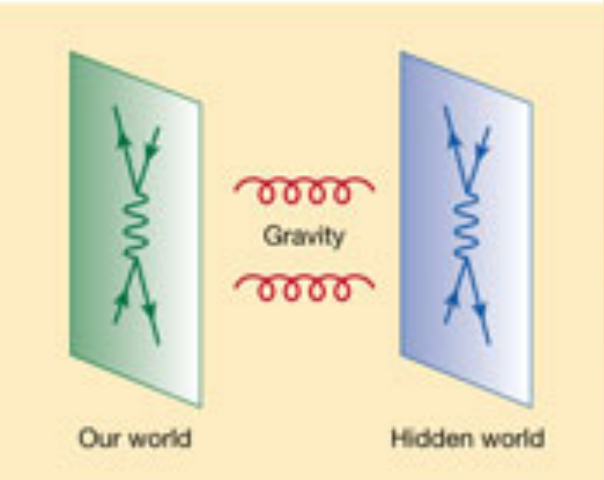
Particle Theory

Kaustubh Agashe

Phenomenology; extra-dimensional theories; model building, dark matter at colliders; composite leptogenesis

Anson Hook

Phenomenology and model-building; new experiments for dark matter, axions; new symmetries; cosmology



Chacko

Model building; Twin Higgs models; mediation of SUSY breaking; dark matter, quirks; particle astrophysics

Raman Sundrum

Models; extra dimensions; Compositeness; SUSY; Dark Energy; QFT; AdS/CFT; cosmology

Rabi Mohapatra

neutrino masses and mixings; GUTS; Leptogenesis, dark matter, model building

Nuclear Theory; QCD

Xiangdong Ji

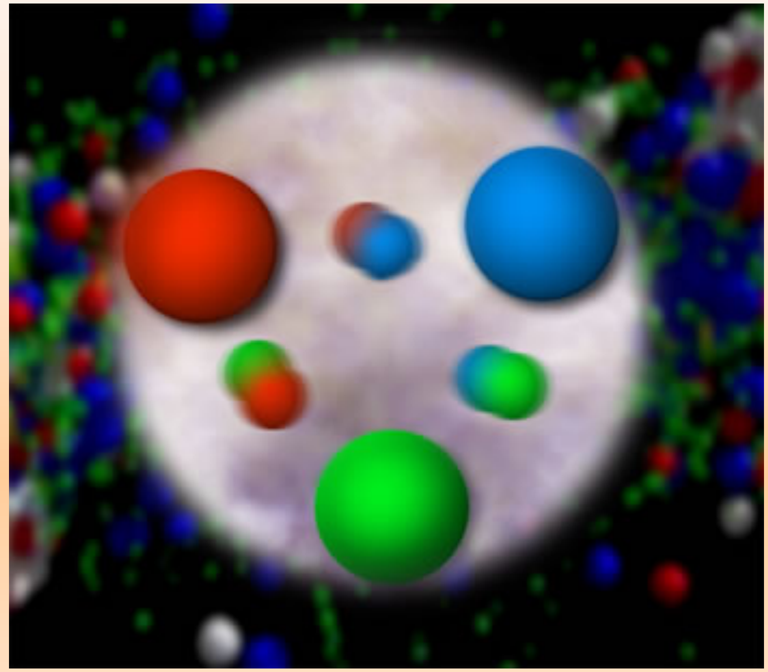
Hadron structure and electron-ion collider physics. Perturbative QCD. Neutrinos. GUTS. Leptogenesis. Dark matter experiments

Paulo Bedaque

Nonperturbative QCD. large Nc QCD. Effective theories. Lattice QCD. Neutron stars. Quantum computing and machine learning for nuclear physics

Tom Cohen

Nonperturbative QCD. Heavy-ion collisions. large Nc. Effective field theories



Zohreh Davoudi

Nuclear physics and SM tests via lattice QCD simulations and effective field theories. Quantum simulation for strongly interacting theories and interface with AMO simulator technologies.

Gravity; GR

Alessandra Buonanno MPI Potsdam & 15% at UMD

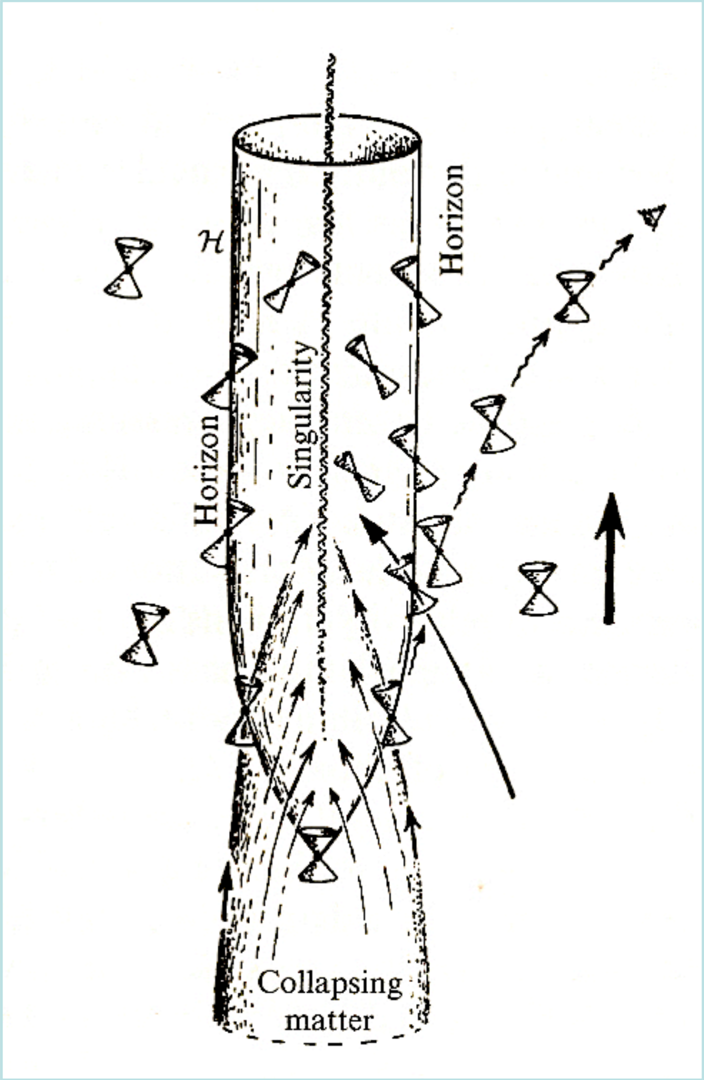
Gravitational wave analyses and modeling of astrophysical sources; test of GR; black holes & neutron stars

Ted Jacobson

Quantum gravity; black hole thermodynamics; BEC analogs of Hawking radiation and cosmological QFT

Brian Swingle

Quantum Gravity, quantum matter, Quantum information

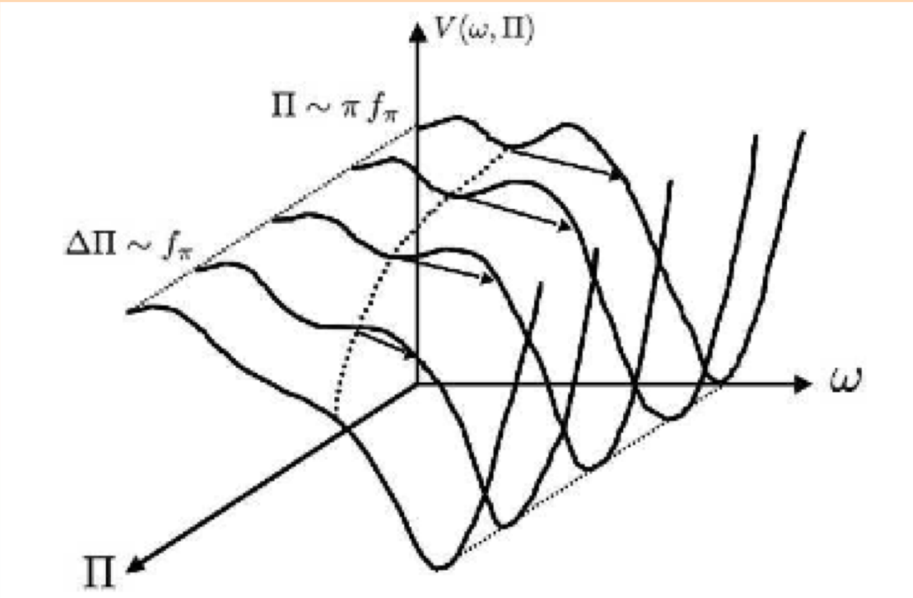


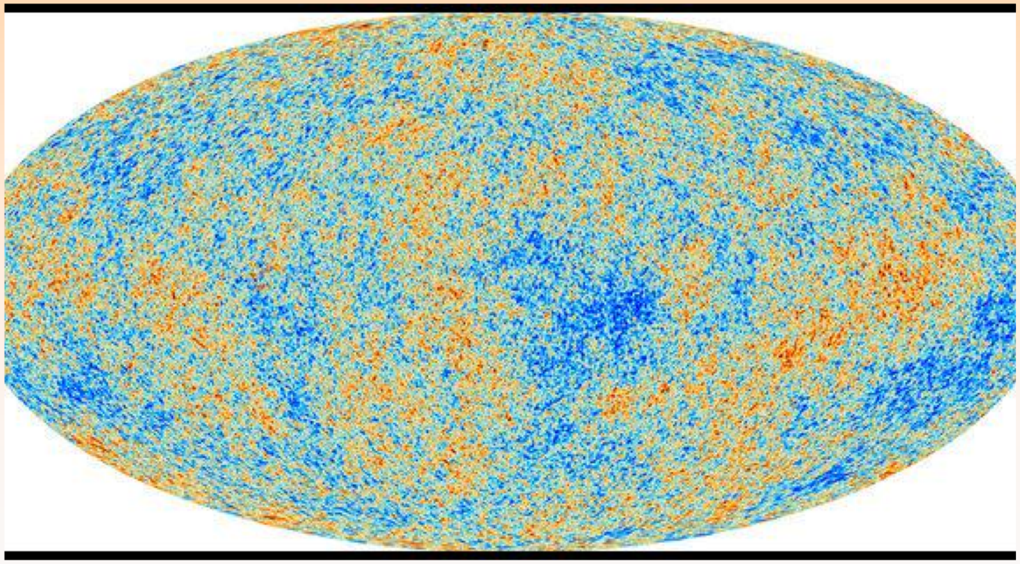
Bei-lok Hu

Quantum field theory in curved space, out of equilibrium

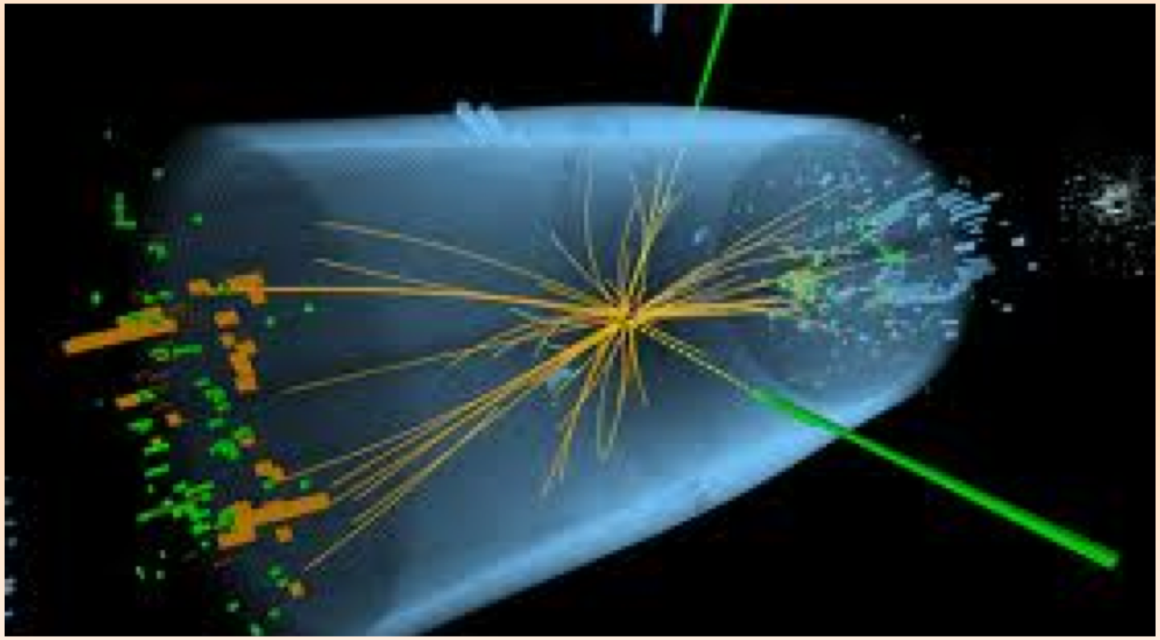
Cosmic Microwave Background

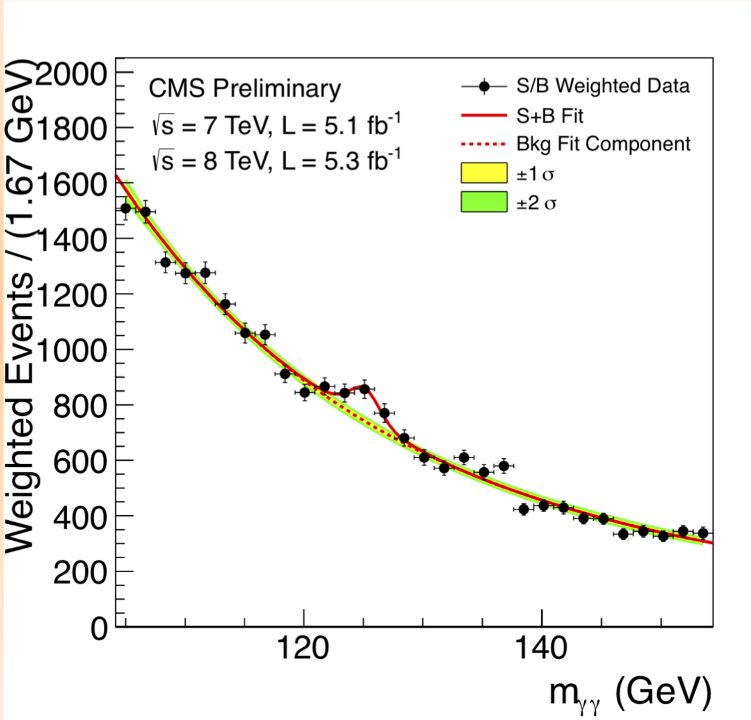
- as seen by Planck Satellite
- Temperature fluctuations contain “quantum fossils” of Cosmic Inflation





Higgs Boson:
Missing Link of Electro-Weak Unification

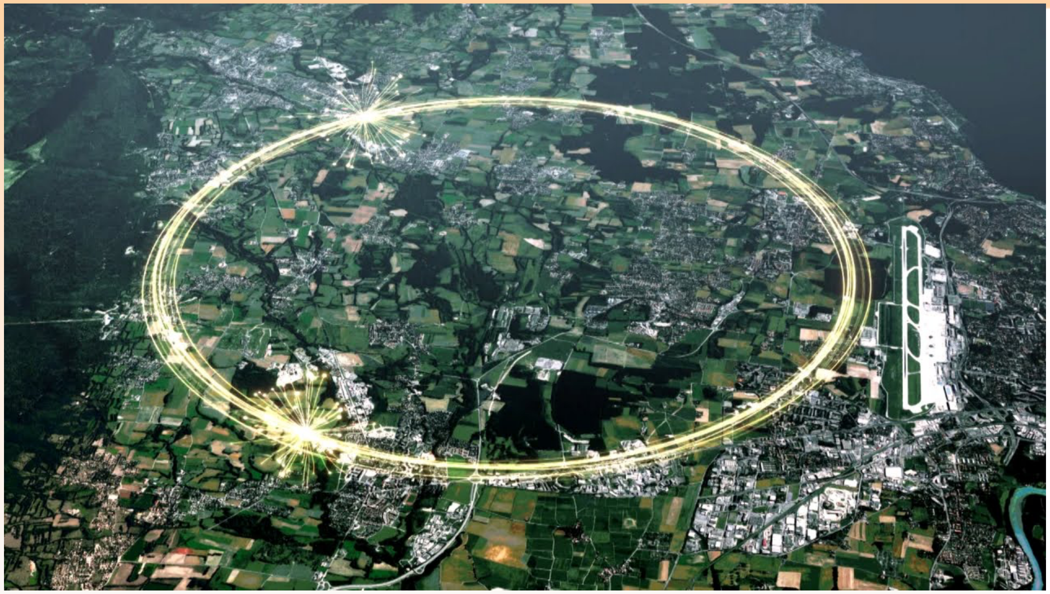


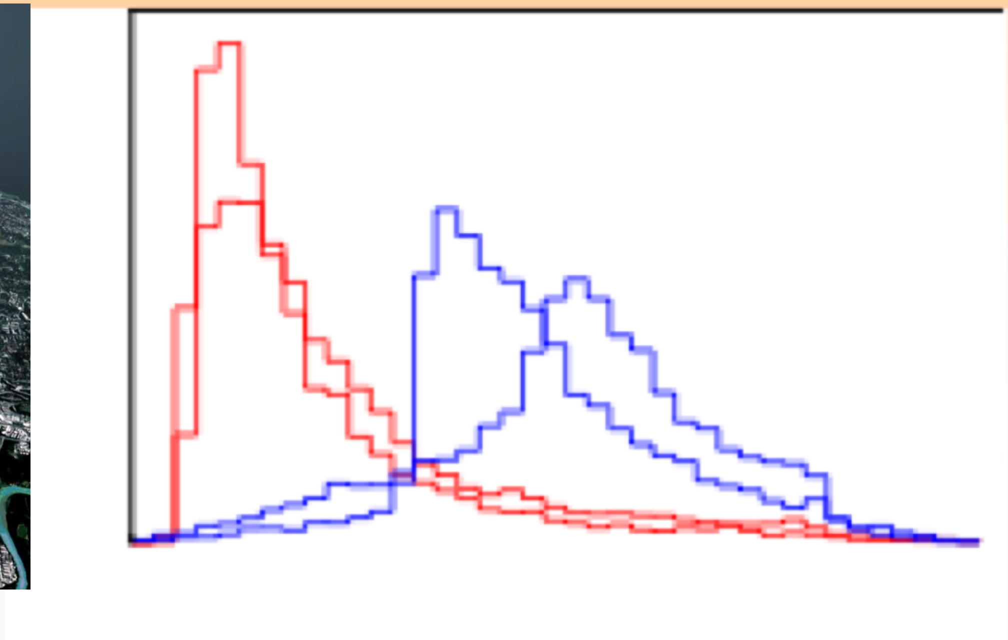


Exotic non-standard Higgs decays?
"Portal" to other sectors beyond standard model?

Echoes of the Fifth Dimension

LHC Phenomenology of
extra-dimensional resonances

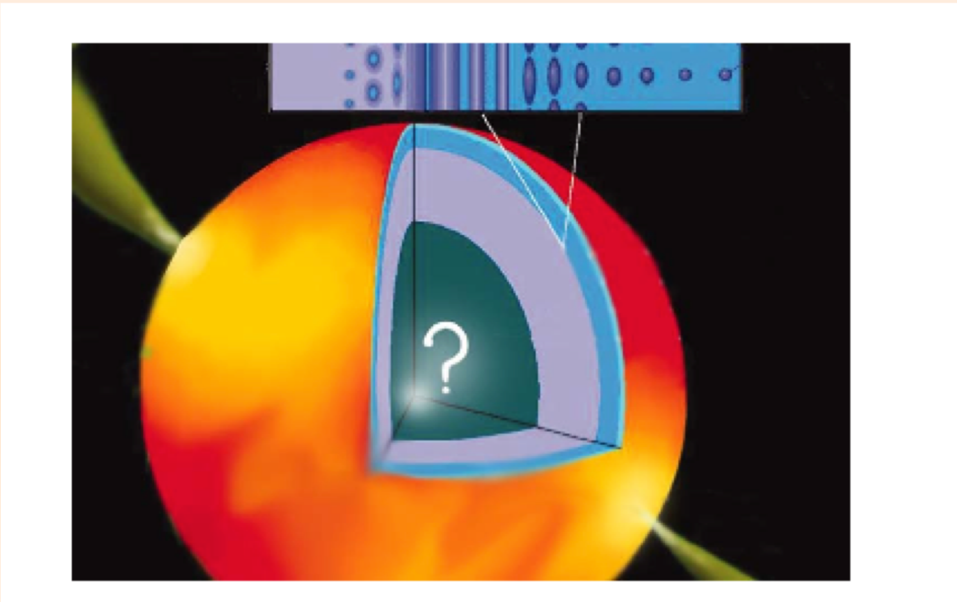


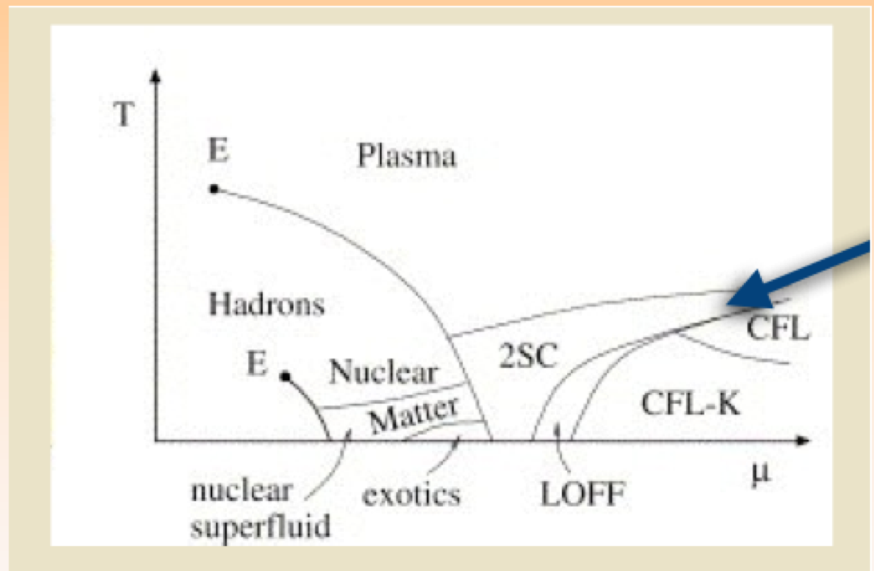


Dark Matter, Dark Energy, Dark Aethers

- Theoretical Modeling of Universe's most mysterious ingredients
- Proposing new ways of discriminating their properties experimentally

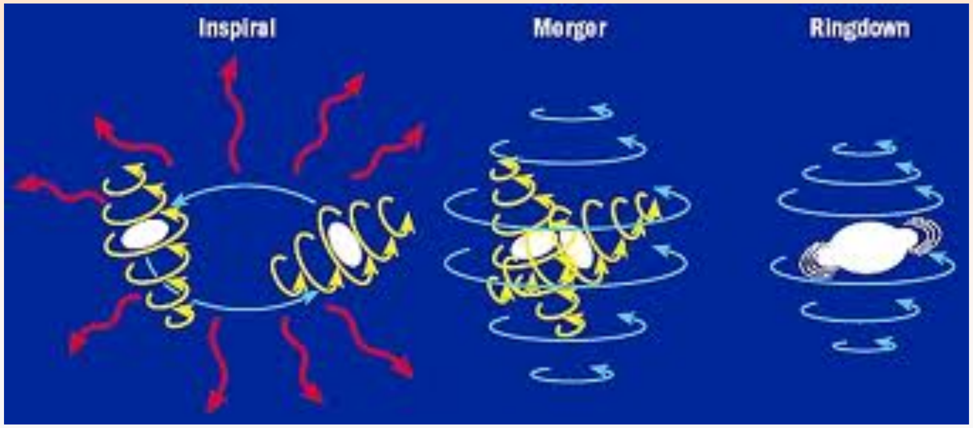
Neutron Stars:
Strongly-Coupled Superfluid

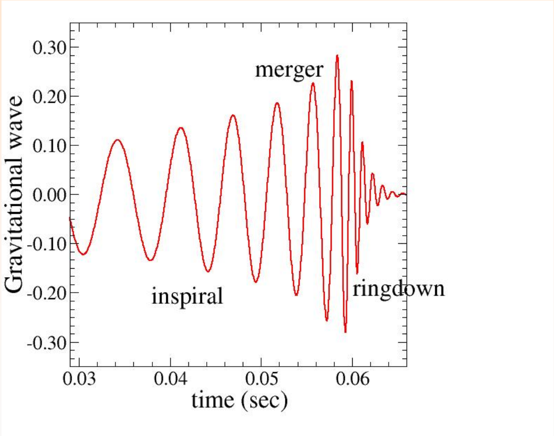




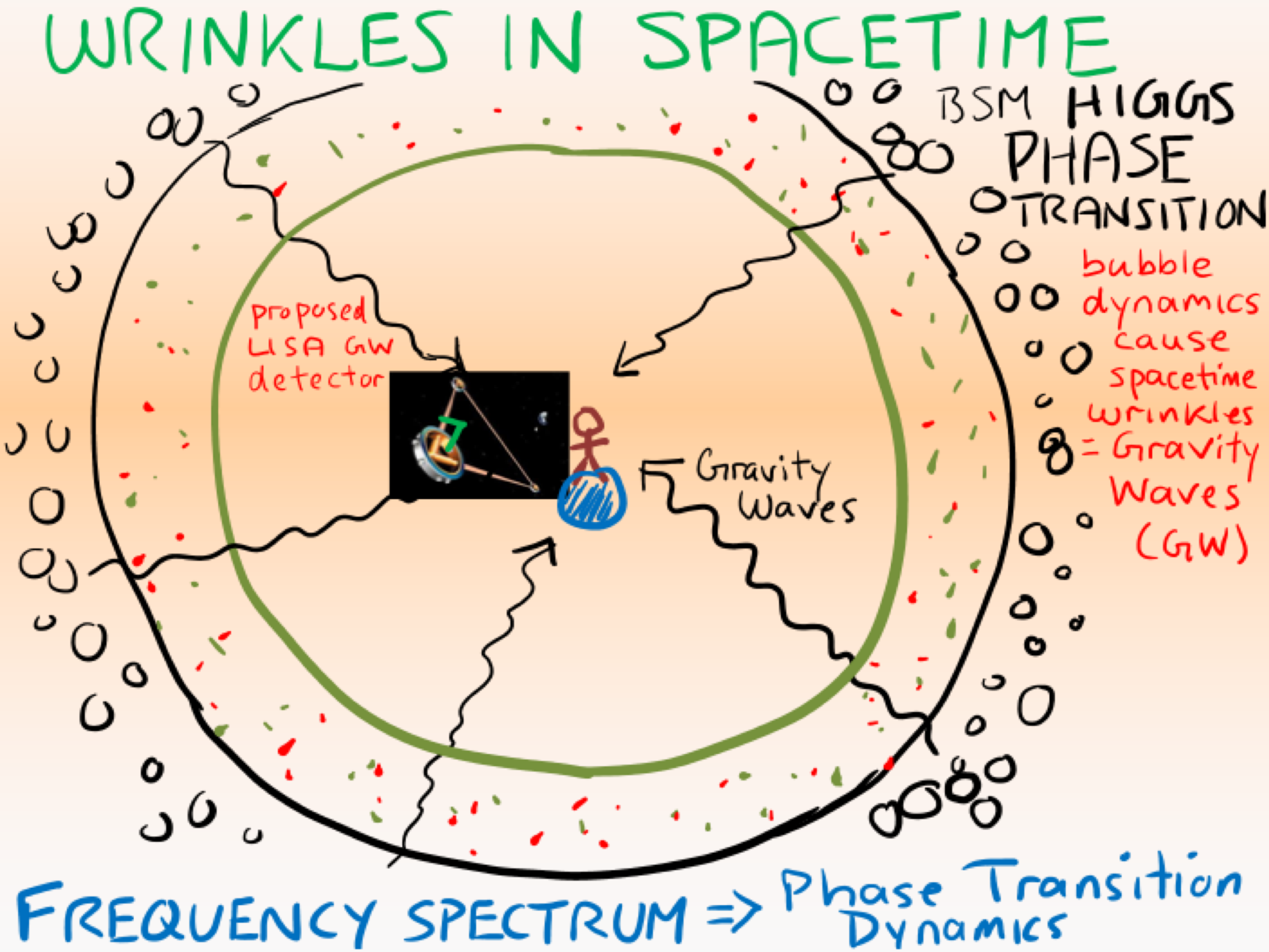
Gravitational Waves

- Theoretical templates for signals by modeling and understanding likely sources
- Testing GR and sensitivity to NEW long-range forces and physics



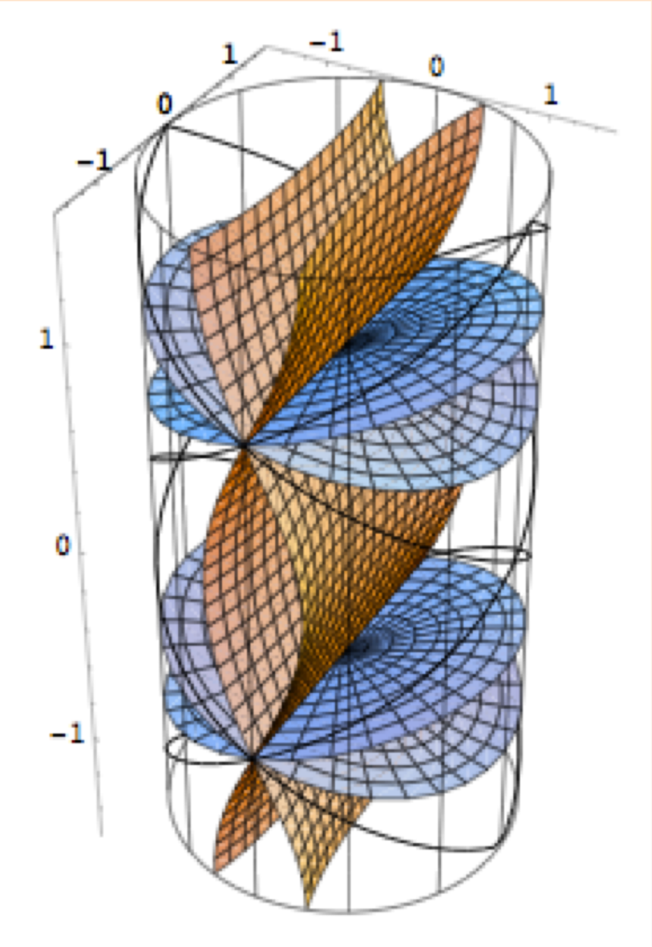


Gravitational Wave Cosmology:



Quantum Mechanics and Black Holes

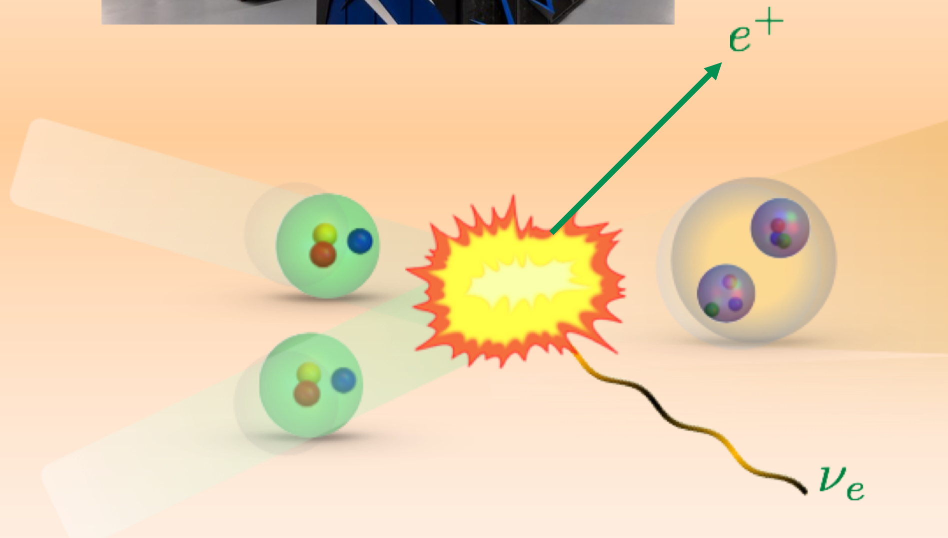
- Information Paradox
- Quantum Entanglement
- Hawking Radiation
- Black Hole Singularity
- AdS/CFT dualities to other systems



Lattice gauge theory for first-principle studies of nuclei and matter

Lattice QCD for nuclear physics

- Large-scale simulations of structure and reactions
- Theory developments for interpreting the results



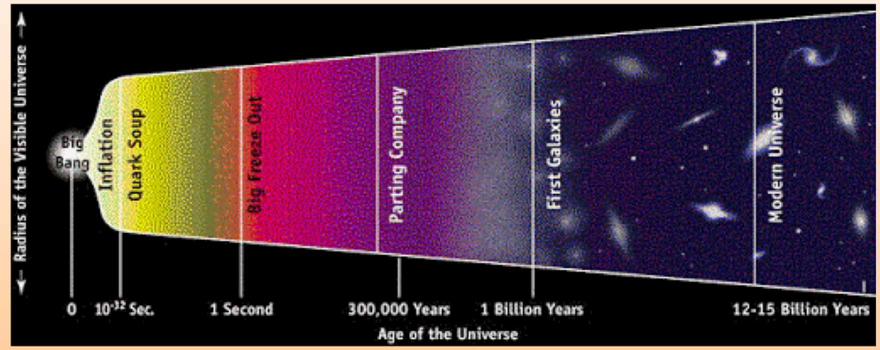
New classical algorithms to alleviate the sign problem

- Thimbles and other ideas
- Machine-learning assisted approaches

Quantum simulation and quantum computing

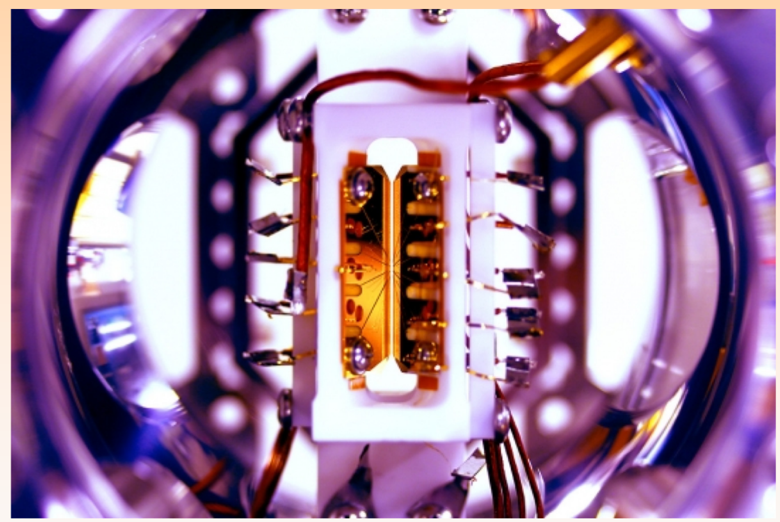
To defeat sign problem in classical simulations of:

- Real-time dynamics after Big Bang and in heavy-ion collisions.
- Phases of matter in universe



Our approach

- Theory and algorithm developments
- Benchmarking on available quantum simulators and quantum computers



Maryland Center for Fundamental Physics

- MCFP began in June 2007

The University puts significant money into the MCFP to allow science to be done at the highest level in these exciting fundamental areas.

The nature of the fields are changing; the traditional boundaries between subfields are breaking down. Need for a new structure to exploit synergies between subfields, host workshops, bring in visitors, seminars, theory colloquiua, lecture series

Many of our students and postdocs go on to top postdocs and faculty positions

Aron Wall
Graduated: 2011, Black Holes
Faculty at the University of Cambridge

Srimoyee Sen
Graduated: 2015, Neutron stars
Faculty at Iowa State University

Aleksandr Azatov
Graduated: 2010, particle theory
Faculty at SISSA ,Trieste, Italy

Ryan Behunin
Graduated: 2010, non-equilibrium QFT
Faculty at Northern Arizona University

Aleksey Cherman
Graduated: 2010, Nuclear QFT
Faculty at University of Minnesota

Prateek Agrawal
Graduated: 2012, Dark Matter Theory
Postdoc at Harvard, accepted faculty
position at Oxford University

PARTNERS/Nearby Institutions

- Joint Space Institute (JSI) – Goddard Space Flight Center, UMD Astronomy
- Johns Hopkins University Department of Physics and Astronomy – joint particle theory+experiment seminars, joint particle theory postdoc
- Hubble Space Telescope Science Institute
- Max Planck Institute for Gravitational Physics, Potsdam
- Joint Quantum Institute (JQI) and Joint Center for Quantum Information and Computer Science (QUICS), NIST/UMD partnerships