Year	Name	Institution	Brief Description
2020	Michael Bishof	Argonne National Laboratory	**“A Neutral-atom Quantum Simulator for uclear Physics”** Quantum devices are poised to have a transformational impact on nuclear physics because they present an opportunity to solve significant problems that are intractable for classical computers. Such problems lie at the heart of nuclear physics: to fundamentally understand how properties of nucleons and nuclei emerge from the underlying theory of quantum chromodynamics (QCD). While general purpose quantum computers have demonstrated rapid progress in recent years, they are still many years away from addressing these challenges. To accelerate the impact of quantum information science on nuclear physics, this research will develop a quantum simulator that is tailored to address specific challenges in this field. In contrast to a quantum computer, which maps each problem to a set of standard operations on quantum bits, a quantum simulator manipulates an experimental apparatus to behave like the system under investigation. Quantum simulators can be extremely powerful tools for discovery when they efficiently reproduce key characteristics from the system of interest. This research will leverage neutral ytterbium atoms trapped in reconfigurable optical tweezer arrays to simulate quark-level effective theories for QCD. This experimental platform offers resource- efficient simulations of a simplified but rich theoretical framework, which will enable more rapid progress toward simulations of poorly understood phenomena in nuclear physics and inform future simulations of more complex theories as quantum devices improve.

2020	Ronald Fernando Garcia Ruiz	Massachusetts institute of Technology	**“Laser Spectroscopy of Exotic Atoms and Molecules Containing Octupole-Deformed Nuclei”** Atomic nuclei with certain numbers of protons and neutrons can exhibit large variations in their nuclear density distributions. The region of actinide nuclei – those having more than 88 protons (Z > 88) - is especially interesting, as it is expected to exhibit unique pear-like nuclear shapes (octupole deformation). This exotic deformation causes a large enhancement of their symmetry-violating nuclear properties. Measurements of these nuclear properties can provide answers to some of the most pressing questions of modern physics, such as the origin of the matter-antimatter asymmetry of our universe, and the properties of dark matter. Hence, these nuclei offer distinct laboratories to investigate the emergence of nuclear phenomena, to study the fundamental symmetries of nature, and to search for new physics beyond the Standard Model of particle physics. Despite their importance, our experimental knowledge of these nuclei is severely lacking. These exotic forms of matter belong to a frontier of the nuclear chart that has been particularly challenging to produce and to study with necessary detail. This proposal aims to perform precision laser spectroscopy measurements of atoms and molecules containing short- lived exotic actinide nuclei, which will be uniquely produced at the new Facility for Rare Isotope Beams (FRIB) in the US. Precision measurements of atoms containing exotic actinide nuclei will provide their nuclear electromagnetic properties. These properties are critical to understand the microscopic and collective structure of octupole deformed nuclei, and will establish important benchmarks for the development of

			theoretical models. A complementary part of this project will be focused on the study of molecules containing exotic isotopes of Th (Z=90) and Pa (Z=91). These molecules are of particular interest for the study of fundamental symmetries, as their octupole-deformed nuclei produce an enhancement of more than three orders of magnitude for their parity- and time-reversal violating properties. This nuclear enhancement is further amplified by the exceptionally high sensitivity of molecular systems to these effects, providing ideal laboratories to explore the violation of fundamental symmetries.
2020	Kyle Leach	Colorado School of Mines	**"The BeEST: A Search for keV-Scale Sterile Neutrinos using Superconducting Quantum Sensors"** The search for sterile neutrinos is perhaps the brightest possibilities in our quest for understanding the microscopic nature of the observed dark matter (DM) in our Universe. Sterile neutrinos – unlike the active neutrinos in the Standard Model – do not interact with normal matter as they move through space, and are thus best observed using their mass signature. In this work, complete momentum reconstruction of electron-capture (EC) nuclear decay is employed to perform a search for sterile neutrinos in the keV mass range that is 10,000 times more sensitive than previous experiments. This is achieved using the EC decay of radioactive beryllium-7 atoms implanted into sensitive superconducting tunnel junctions (STJs) - an experiment nicknamed the BeEST ("beast") for *Be*ryllium *E*lectron capture in *ST*js. A discovery signature in the BeEST experiment would be a small fraction of these decays where the daughter (lithium-7) atomic recoil peaks are shifted to lower

			energies from momentum conservation with these new, heavy sterile neutrinos. This approach is a uniquely powerful experimental method since it relies only on the well-motivated existence of this new type of neutrino, and not on how they might hypothetically interact with normal matter.
2020	Alessandro Lovato	Argonne National Laboratory	**“A Unified Picture of Long- and Short-range Dynamics of Atomic Nuclei”** Atomic nuclei are self-bound systems of fermions that display emergent quantum-mechanical phenomena. Testing their structure and reactions at low energies is the primary focus of domestic experimental facilities, including the Argonne Tandem Linac Accelerator System, the National Superconducting Cyclotron Laboratory, and the Facility for Rare Isotope Beams. Experiments at Thomas Jefferson Laboratory and the forthcoming Electron-Ion Collider probe the internal structure of the nucleus and the interplay between nucleonic and partonic degrees of freedom by examining short-distance phenomena. The main objective of this research is to connect the physics scope of the domestic nuclear experimental program. It provides a unified theoretical picture of the long-range structure and short-range dynamics of atomic nuclei starting from the individual interactions among their constituents: neutrons and protons. The research project enables breakthrough developments of the nuclear Green’s Monte Carlo methods, currently limited to nuclei with up to A=12 nucleons. This project capitalizes on high-performance computing resources, including the forthcoming exascale machines, and entails the development of novel representations of the nuclear wave functions in terms of artificial neural networks. Besides covering many areas in nuclear physics, this research has critical applications in high- energy physics, specifically on the neutrino-oscillation programs. It also impacts multi-messenger astrophysics, as high-density nuclear dynamics is imprinted in the gravitational-waves and

			neutrino-emission signals of merging neutron stars.
2020	David Radice	Pennsylvania State University	**"Exascale Simulations of Neutron Str Mergers"** Gravitational waves and electromagnetic radiation from colliding neutron stars (NSs) encode precious information about the internal structure and composition of NSs and reveal the explosions in which some of the most heavy elements, such as gold, platinum, and uranium are formed. Relativistic heavy-ion collisions and experiments such as PREX here on Earth are probing the nature of matter under extreme conditions. The nuclear physics involved in the creation of the heavy elements will be more tightly constrained as FRIB comes online in the next years. However, as observations and laboratory measurements improve, so must the theoretical understanding of NS mergers in order to maximize the science return from these large scale investments. Ab-initio supercomputer simulations are the only tool able to bridge astronomical observations and laboratory experiments and connect them to the merger dynamics. However, current simulation results are affected by large systematic errors stemming from the inability to resolve all spatial and temporal scales in mergers and by their approximate treatments of neutrinos. This project aims to overcome these limitations by developing a new simulation infrastructure able to leverage next-generation supercomputer hardware, enabling calculations at unprecedented resolutions and extending over long timescales. One of the key deliverables is a new neutrino transport solver including general-relativistic and quantum kinetic effects using the filtered spherical harmonics and Galerkin methods, some of the most sophisticated approaches developed in the applied mathematics and computational physics communities. This project develops the theory foundations needed to address some of the most pressing questions in nuclear astrophysics such as the nature of matter inside NSs and the astrophysical site of production of the heavy elements.

2020	Nobuo Sato	Thomas Jefferson National Accelerator Facility	**"Next Generation of QCD Global Analysis for Hadronic Physics"** Understanding the internal structure of protons and neutrons, which are the fundamental building blocks of atomic nuclei and thus of all the stars, planets and most visible matter in the universe, is one of mankind's major challenges. With more than 50 years of experimental and theoretical effort, we now understand that protons and neutrons (or collectively "nucleons") are composed of more fundamental quark constituents bound together by gluons with strong forces governed by the theory of Quantum Chromodynamics (QCD). Unlike any other known phenomenon in Nature, the confinement property of QCD means that quarks and gluons can never be observed in isolation in any particle detector. Moreover, in contrast to other systems, such as atoms or molecules, there is no "still" picture for the internal quark and gluon structure of nucleons and nuclei, and the internal structure can only be characterized through quantum correlation functions (QCFs), such as parton distribution functions, transverse momentum dependent distributions, and generalized parton distributions. The greatest challenge is therefore to map out these QCFs using data from experiments that only detect particles such as hadrons, photons and leptons. With the ongoing 12 GeV nuclear physics program at Jefferson Lab, the Relativistic Heavy Ion Collider at Brookhaven National Lab, and other facilities around the world, as well as the future Electron-Ion Collider (EIC) in the US, we are at the threshold of imaging the nucleon's internal 3-dimensional quark and gluon structure in the theoretical framework of QCD for the first time. The new facilities will deliver unprecedented quantities of high-precision data, posing new opportunities and challenges for accessing a variety of QCFs. The goal of this project is to meet these challenges by developing the next generation QCD "FemtoAnalyzer" to assimilate information about various types of QCFs from experimental data at the femtometer scale. The project integrates modern developments in nuclear theory, data

			handling and artificial intelligence to develop the most advanced theoretical and phenomenological tools to visualize the internal landscape of nucleons and nuclei with unprecedented resolution. The achievements of this project will help to accomplish the mission of DOE's Nuclear Physics program to analyze the enormous amounts of data from the Jefferson Lab 12 GeV and future EIC facilities.
2020	Phiala Shanahan	Massachusetts Institute of Technology	**"The QCD Structure of Nucleons and Light Nuclei"** Atomic nuclei, built of protons and neutrons, constitute more than 99% of the visible mass in our universe. Quantitatively describing the structure of protons, neutrons, and nuclei in terms of their quark and gluon constituents is a defining challenge bridging hadronic and nuclear physics research. The ultimate goal is to map the complete spatial, momentum, spin, flavor, and gluon structure of the proton and neutron, to be able to predict their interactions and resonances precisely, and to understand how their structures change as they form a nucleus. Not only is this map the key to interpreting observations of nature in terms of the currently-accepted fundamental theory, but it is essential to inform searches for new physics. This research program furthers this mission by revealing aspects of the gluon structure of the proton, and of the quark and gluon structure of light nuclei, using first-principles calculations of the strong interactions. The results will provide essential information for current and future nuclear physics experimental programs, in particular those at the Thomas Jefferson National Accelerator Facility and at the planned Electron-Ion Collider at Brookhaven National Laboratory. The results will also provide input to nuclear physics experiments searching for violation of fundamental symmetries and new physics, including laboratory-based experiments searching for dark matter.