RESEARCH PROGRAM

Science and Engineering Abstracts
for Grants Awarded in December 2018

Purdue University
West Lafayette, IN
Chen-Lung Hung, Sergei Khlebnikov, Martin Kruczenski, Qi Zhou
$1,000,000
December 2018

The existence of space, time, and gravity is a mainstay of conventional wisdom. However, a profound idea initially proposed in string theory indicates that an analog of space and time can emerge from the dynamics of strongly coupled quantum systems. Testing this description based on emergent space-time and gravity demands new experimental capabilities to engineer a highly accessible, strongly coupled quantum material. A primary candidate to carry out such an experimental test is an atomic quantum gas trapped in an optical lattice, formed by intersecting laser beams, and prepared near a quantum phase transition that occurs at absolute zero temperature. A team from Purdue University will develop a quantum gas platform that creates such quantum samples with unprecedented spatiotemporal control over the system parameters. The team will make and test predictions of the dynamical properties of the samples and test them based on emergent space-time and gravity in extreme non-equilibrium situations such as in shock waves and in conditions that mimic those of black holes. These experiments can provide a comprehensive test on many related dynamical phenomena. It would offer a unique opportunity to demonstrate, for the first time in a laboratory, that a strongly coupled quantum system may be described by a theory of gravity. This project has the potential to transform research in quantum matter and impact the way we view gravity and our universe.

University of California, Berkeley
Berkeley, CA
Stephen Leone, Norman Yao
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A central goal of modern physics is the discovery and characterization of all phases of matter allowed by nature. Certain phases, such as solid ice or liquid water, and the associated melting transition between them, are described by classical physics, while others, including the formation of superfluids and superconductors are intrinsically quantum mechanical. The key difference between them is the idea of "many-body entanglement," which describes a specific type of quantum mechanical correlation. A pair of researchers at the University of California, Berkeley proposes to experimentally realize two novel types of quantum matter that only occur outside the traditional venue of thermal equilibrium. These two non-equilibrium quantum phases can only be stabilized in the presence of a strong periodic external driving force. In addition, they will utilize a new technique, ultrafast X-ray spectroscopy, to probe these non-equilibrium states of matter with unprecedented temporal resolution. Experiments will be carried out to realize an example of an interacting topological phase stabilized by laser driving, as well as a disorder-free pre-thermal time crystal in diamond. In the process, the researchers will address several outstanding scientific questions facing the field of non-equilibrium quantum matter: whether such matter is only stable in the presence of disorder, i.e., random impurities, defects, or dislocations, and whether, due to the interplay between symmetry and topology, one can observe different material properties at the lattice scale. Realizing new strongly-interacting, non-equilibrium phases in driven laboratory experiments will open the door to a new forum for understanding and classifying quantum matter.

University of California, Santa Barbara
Santa Barbara, CA
Andrea Young
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Nonabelian states of matter in two dimensional systems host emergent excitations with fundamentally different quantum statistics than those found in our three-dimensional world. A young investigator at the University of California, Santa Barbara proposes to build and deploy a scanning probe tool—the Ultra-Low Temperature Magneto-Thermal Microscope (ULT-MTM)—designed to facilitate discovery of nonabelian ground states. The new instrument integrates an ultra-sensitive scanning superconducting sensor in a superfluid helium-4 immersion cell, providing nanoscale thermal and magnetic imaging at millikelvin temperatures. The ULT-MTM probe will be used to find signatures of nonabelian order in van der Waals heterostructures, consisting of layered stacks of atomically thin two-dimensional materials in which a wide variety of promising candidate states have been identified. These experiments will provide unprecedentedly detailed information about the microscopic structure of many-body quantum states, while paving the way for breakthroughs in quantum information science that harness the long-predicted decoherence protection of quantum bits based on braiding of nonabelian quasiparticles.

University of Colorado, Boulder
Boulder, CO
Dan Dessau, Gang Cao, Josef Michl, Charles Musgrave, Sean Shaheen
$1,000,000
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Room-temperature superconductivity is a goal that could deliver powerful magnets (levitating trains), exquisitely sensitive magnetic-field sensors (MRI machines), lossless power transmission lines, quantum computing, and more. The critical processes needed for superconductivity are (a) the formation of Cooper pairs of electrons and (b) the condensation of these pairs into the superconducting state. Organic (carbon-based) superconductors hold great promise for obtaining room-temperature superconductivity because of the huge diversity of compounds that might enable strong Cooper pairing on individual molecules. This field took a major leap forward this past year with the observation of the onset of Cooper pairing at 120 K – a factor of four increase in temperature from the previous record superconducting temperature for an organic material and 40% of the way to room temperature. This result unveiled a major direction forward for achieving true high temperature superconductivity – increasing the intermolecular coupling strengths to entice the condensation of pairs existing on individual molecules. This project brings together a team of physicists, chemists, and engineers with a diverse set of knowledge, toolsets, and ideas aimed at achieving this goal.