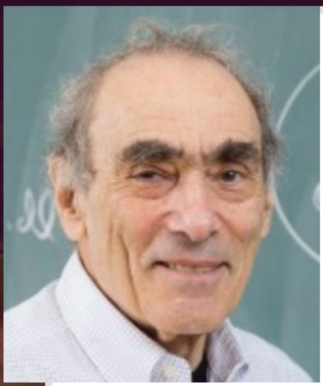
Oral Session C3 (Thursday, February 15)

Chair: Naoki Yamamoto, Keio University

Special Session Talk



13: 30 - 14 : 10

Gordon Baym

The University of Illinois at Urbana-Champaign (UIUC)

Matter under extreme conditions in neutron stars

Neutron stars -- of masses up to a little more than twice that of the sun, and yet compressed by gravity down to tens of kilometers -- are the densest objects in the universe [1]. As such they are natural laboratories for studying the properties of matter under extreme conditions of density and pressure not readily achievable on Earth. Indeed, very shortly after the discovery of the BCS theory of superconductivity, familiar ideas of condensed matter physics began to play an important role in unraveling the physics of neutron stars -- from the existence of a solid crust to superfluid states of the nucleons, neutrons and protons, in the interior. In this talk I will give a general overview of the condensed matter physics in neutron stars interiors, including cutting edge questions of the role of quarks (the internal constituents of neutrons and protons) in the deep interior. For example, how does a superfluid of neutrons and protons transition to superfluid quark matter in the deep interior, and how can such superfluid quark matter carry angular momentum [2].

References

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[2] M. G. Alford, G. Baym, K. Fukushima, T. Hatsuda, and M. Tachibana, Phys. Rev. D 99, 036004 (2019).

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Contributed Oral

14: 10 - 14 : 30

Nonrelativistic trace anomaly and its impact on equation of state in dense fermionic matter: Toward understanding hadron-quark crossover via analogue quantum simulation

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Recent observations of neutron stars suggest that nuclear matter gradually changes into dense quark matter with increasing density [1]. A remarkable feature of this structural change lies in the presence of a sound velocity peak in the hadron-quark crossover regime [2]. However, the microscopic mechanism of the hadron-quark crossover is elusive because it is observationally difficult to obtain detailed information on the properties of matter in the star. Recent lattice two-color quantum chromodynamics simulation [3] shows the existence of such a peak and implies similarities with the Bose-Einstein-condensation (BEC) to Bardeen-Cooper-Schrieffer (BCS) crossover realized in ultracold atoms. In this regard, analogue quantum simulation could be a promising route to elucidate the crossover mechanism. According to the quantum Monte Carlo simulation of one-dimensional three-component nonrelativistic Fermi gases [4], this system simultaneously exhibits a sound velocity peak and a crossover from deeply to loosely bound trimers, which has been discussed in connection with the three-body counterpart of Cooper pairs, namely, Cooper triples [5]. In this contribution, we discuss effects of trace anomaly involving three-body correlations on the equation of state in this system by using the Brueckner G-matrix approach known to successfully describe the equation of state in the BCS-BEC crossover [6].

References

[1] T. Kojo, G. Baym, and T. Hatsuda, ApJ 934 46 (2022).
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[5] H. Tajima, S. Tsutsui, T. M. Doi, and K. Iida, Phys. Rev. Research 4, L012021 (2022).
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14: 30 - 15 : 10

Surjeet Rajendran

Department of Physics and Astronomy, Johns Hopkins University

Fundamental physics with quantum sensors

The search for new physical laws and particles has largely been driven by the expectation that the new physics lies at high energies with reasonably strong interactions with the standard model. However, the existence of dark matter and dark energy, as well as the potential new physics that could be discovered using gravitational waves, suggests that there is a strong case to search for phenomena that do not interact much with the standard model. The discovery of such phenomena requires precision sensing. The remarkable advances that have occurred in the field of quantum metrology in the past three decades have made it possible to deploy a wide variety of quantum sensors to detect such ultra-weakly coupled physics. In this talk, I will discuss a variety of new experimental methods that can be used to detect gravitational waves in the 1 Hz frequency band between LIGO and LISA and probe a wide variety of dark matter candidates in the laboratory.

Oral Session C3 (Thursday, February 15)

Chair: Naoki Yamamoto, Keio University

Contributed Oral

15: 10 - 15 : 30

Braiding and fusion of Majorana fermions in minimal Kitaev spin liquid on a single hexagon with 5 qubits

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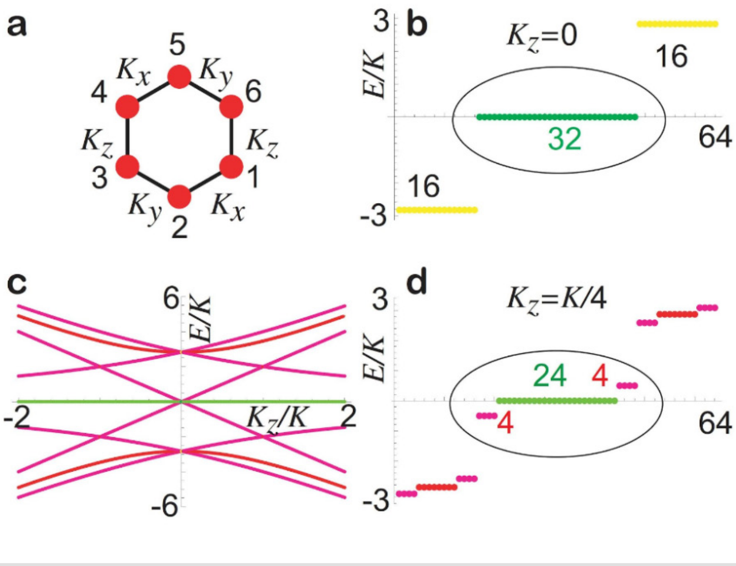
We propose the minimal Kitaev spin liquid on a single hexagon with three Ising-type exchange interactions proportional to K_x, K_y and K_z. In the limit K_z=0, we find 32-fold zero-energy states, leading to 10 free Majorana fermions, and hence, 5 qubits are constructed. These qubits are protected by particle-hole symmetry even for $K_z \neq 0$. Braiding of these Majorana fermions is possible by temporally controlling a spin-correlation Hamiltonian. In addition, the fusion is possible by measuring spin correlations. By switching on the Heisenberg interaction together with magnetic field, only one zero-energy state persists, which can be used as an initialization of qubits. Furthermore, it is shown that $3L+2$ qubits are constructed on the Kitaev spin liquid model on connected L hexagons. All the processes of initialization, operation and readout of qubits are executable in terms of spin operators.

References

[1] Motohiko Ezawa, Braiding and fusion of Majorana fermions in minimal Kitaev spin liquid on a single hexagon with 5 qubits, arXiv:2401.01051



Oral Session C3 (Thursday, February 15)

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Contributed Oral

15: 30 - 15 : 50

Integrating ultrafast switches into a single molecule

<u>Hirofumi Yanagisawa</u>

Shizuoka University, Japan

Irradiating a sharp metallic needle with femtosecond light pulses generates electron emissions from the apex[1], as depicted in Figure 1(a). These emissions serve as ultrafast switches, significantly surpassing the speed of current computer switching devices by three to six orders of magnitude. Concurrent plasmonic effects enable precise spatial control of electron emission on a 10-nm scale[2]. Leveraging this phenomenon allows the selection of emission sites A or B in Figure 1(b), resembling two integrated transistor switches independently controlled by light in the accompanying diagram. Consequently, this site selectivity aids switch integration. However, further miniaturization of such an electron source through plasmonics poses challenges. Here, we propose a new approach utilizing the quantum nature of a single-molecule. In this setup, fullerene molecules are positioned on a metallic substrate[3], as illustrated in Figure 1(c). Electrons, supplied from the substrate, are emitted from the single molecules after traversing specific molecular orbitals (MOs). Depending on the involved MOs, the emission sites vary. Our research demonstrates the potential to optically manipulate the MOs that electrons pass through, thus enabling the creation of an electron source with subnanometric emission site-selectivity[4]. This technique facilitates the integration of switches into a single molecule.

References

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[3] H. Yanagisawa, et al., Sci. Rep. 12, 2174 (2022).
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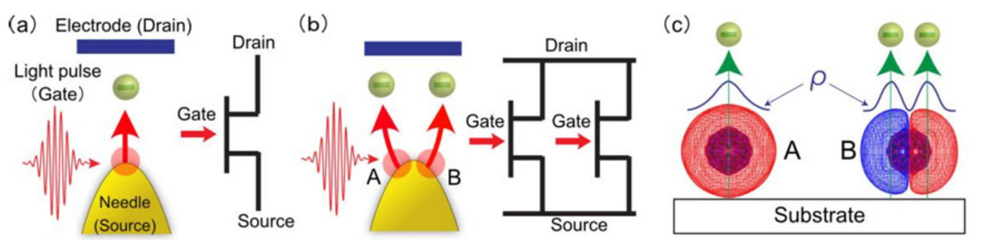

Fig. 1: Conceptual diagrams illustrating the ultrafast emission of electrons from a nano-object upon irradiation with a light pulse (a) and the optical control of emission sites (b). (c) Conceptual diagram showcasing the spatial modulation of an electron source through resonant electron emissions using a molecule.