Many-body QED with atoms and photons: A new platform for quantum optics

CHOI Kyung Soo

An exciting frontier in quantum information science is the creation and manipulation of quantum systems that are built and controlled quanta by quanta. In this context, there is active research worldwide to achieve strong and coherent coupling between light and matter as the building block of complex quantum systems. Despite the range of physical behaviours accessible by these QED systems, the low-energy description is inherently masked by mean fields or renormalization group. In contrast, I describe our comprehensive theory/experiment program towards synthetic quantum matter, where highly-correlated Rydberg quantum material is strongly coupled to quantized optical cavity fields. We call this new domain of quantum optics, “many-body quantum electrodynamics,” where locally gauged quantum materials are entirely driven by quantum optical fluctuations. I describe our initial laboratory effort towards realizing a 2D U(1) lattice gauge theory with a quantum spin liquid by real-time configurable Rydberg atomic tweezer arrays in strongly coupled cavity QED and the observation of multiparticle plaquette dynamics, corresponding to an emergent visonic topological defect excitation, for the quantized magnetic flux of the compact U(1) dynamical gauge field. From a broader perspective, our work towards many-body QED will open exhilarating opportunities in atomic and condensed matter physics, and quantum information science to explore the universal features of macroscopic universes living within strongly-correlated quantum systems, and to help answer some of the most profound questions in physics and computer science — from Baryonic asymmetry, to quantum gravity, and to the quantum Church-Turing thesis. We believe that many-body QED is an essential endeavour for our very instinct to explore genuinely surprising phenomena arising from highly-entangled quantum matter, by light.