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Department of Physics

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Quantum simulations with strongly interacting photons:
Merging condensed matter with quantum optics for quantum technologies

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ABSTRACT

Classical computers require enormous computing power and memory to simulate even the most modest quantum systems. That makes it difficult to model, for example, why certain materials are insulators and others are conductors or even superconductors. R. Feynman had grasped this since the 1980s and suggested to use instead another more controllable and perhaps artificial quantum system as a "quantum computer" or specifically in this case a "quantum simulator".

Working examples of quantum simulators today include extremely cold atoms trapped with lasers and magnetic fields and ions in electromagnetic traps. Photons and polaritons in light-matter systems have also recently emerged as a promising avenue especially for simulating out of equilibrium many-body phenomena in a natural driven-dissipative setting.

I will briefly review in non-specialist terms the main results in this area including the early ideas on realizing Mott insulators, Fractional Hall states and Luttinger liquids with photons [1,2,3]. After that I will present in more detail a recent experiment realizing the Hoeftstaedter butterfly and the many-body localization (MBL) transition using interacting photons in the latest superconducting quantum chip of Google [4]. A simple method to study the energy-levels-and their statistics - of many-body quantum systems as they udergo the ergodic to the MBL transition, was proposed and implemented. The formation of a mobility edge of an energy band was observed and its shrinkage with disorder toward the center of the bands was measured.

Beyond the applications in understanding fundamental physics, the potential impact of quantum simulators in different areas of quantum and nano technology, material science as well as machine learning and big data processing will be touched upon.

References

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2. "Quantum Simulations with Photons and Polaritons: Merging Quantum Optics with Condensed Matter Physics" by D.G. Angelakis (ed), Quantum Science and Technology Series, Springer, 2017, ISBN 978-3-319-52023-0.
3. P. Roushan, C. Neill, J. Tangpanitanon, V.M. Bastidas,…, H. Neven, D. G. Angelakis, J. Martinis, "Spectral signatures of many-body localization with interacting photons" Science, 358, I6367, 2017

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