

Congratulations to New ICFO PhD Graduate

Dr Javier Argüello Luengo graduated with a thesis entitle ?Synthetic quantum matter using atoms and light'.

October 21, 2022

We congratulate Dr Javier Argüello Luengo who defended his thesis today in ICFO' auditorium

Dr Argüello Luengo obtained his MSc in Theoretical Physics from the University of Waterl o in Canada before coming to ICFO as a PhD ?la Caixa' Foundation Fellow in the Theoretic l Quantum-Nano Photonics group led by ICREA Prof Darrick Chang. His thesis entitl d ?Synthetic quantum matter using atoms and light' was supervised by Prof Dr Darrick Cha g and Dr Alejandro Gonzalez Tudel

ABSTRACT:

Atomic and optical physics are two fields closely connected by a shared range of energ scales, and the interactions between them. Atoms represent the most fundamenta

components of matter, and interactions with electromagnetic fields are responsable fo many properties used to characterize a material, like the emission and absorption of radiatio by these systems. Over the last decades, this has allowed us to use light as a tool to acces and manipulate the internal states of atomic systems. Such a quantum control ha transformed atoms into one of the preferred platforms to explore fundamental science including Applications in quantum information, quantum metrology or, more recently, th realization of synthetic materials where light can induce interactions that would be difficult t find intrinsically in real materials

In the first part of this Thesis, we show how single atoms coupled to a cavity field can off r unique opportunities as quantum optomechanical devices because of their small mass a d strong interaction with light. In particular, we focus on the "single-photon strong couplin " regime, where motional displacements on the order of the zero-point uncertainty a e sufficient to shift the cavity resonance frequency by more than its linewidth. By coupli g atomic motion to the narrow cavity-dressed atomic resonance, we theoretically observe th t the scattering properties of single photons can become highly entangled with the atom c wavefunction, even if the cavity linewidth is large. This leads to a per-photon motion l heating that is significantly larger than the single-photon recoil energy, as well s mechanically-induced oscillations that could be observed in the correlations f state-of-the-art cavity system

. In the second part of the Thesis, we investigate how synthetic materials built using light c n be harnessed as quantum simulators, defeating the limitations that classical computers fa e in the exploration of quantum phenomena. We particularly focus on ultracold atom c mixtures trapped in optical lattices, where atom-mediated long-range interactions c n provide an enabling tool in the simulation of relevant problems in condensed matter r quantum chemistr

. First, we show that fermionic atoms in an ultracold gas can act as a mediator, giving rise o effective long-range RKKY interactions among other neutral atoms trapped in an optic l lattice. We further propose several experimental knobs to tune these interactions, which a e characterized by the density and dimensionality of the gas and are accessible in curre t experimental platforms. We also show that these knobs open up the exploration of n w frustrated regimes where symmetry-protected topological phases and chiral spin liqui s emerg

. Second, we introduce a set of experimental schemes where long-range interactions a e mediated by an additional bosonic species trapped in a commensurate optical lattice, both n 2D and 3D. In particular, we show that the interplay with cavity QED can lead to effecti e Coulomb-like repulsion, which opens the door to the analog simulation of quantum chemist y problems using ultracold fermionic atoms as simulated electrons. Apart from explaining t e emergent mechanism, we provide operational conditions for the simulator, benchmark it wi h simple atoms and molecules, and analyze how the continuous limit is approached f

r increasing optical lattice sizes. Finally, we compare our results with those of the continu
m limit, where conventional quantum chemistry methods can be evaluated and tested.
n summary, our results show connections between different areas of theoretical a
d experimental physics where light-matter interaction can play a dominant role, and sugge
t how this can be harnessed to further advance our understanding of strongly correlat
d quantum matte

Thesis Committee:

Prof. Dr. Maciej Lewenstein, ICF

Prof. Dr. Diego Porras Torre, Consejo Superior de Investigaciones Cientifica

Dr Johannes Maximilian Feist, Universidad Autonoma de Madri



Thesis Committee