- **Darrick Chang** (Institute of Photonic Sciences – ICFO, Spain): *Atom-Light Interactions as a Dissipative Spin Model*

Our textbook theories of quantum atom-light interactions have been long established, and constitute the underlying formalism to describe the vast majority of the quantum applications and phenomenology pursued up to now. In free space, for example, the theory takes the form of a wave equation for the quantum photonic field, which is coupled to a smooth quantum matter field describing the atoms. Despite the prevalence of this model, this out-of-equilibrium field theory remains notoriously hard to solve except in limited circumstances. Furthermore, the errors predicted by this model, which physically arise from spontaneous emission of excited atoms and the corresponding loss of quantum information, remain much too high for many practical applications of interest.

Within this context, in these lectures we present an alternative theoretical formulation of quantum atom-light interactions that has been advanced in recent years. Here, the granularity of atoms is kept, and the photonic field is integrated out to arrive at a many-body "spin" model involving the atomic degrees of freedom, which features both long-range coherent interactions and collective dissipation. Interestingly, the collective dissipation encodes the interference of emission from different atoms, which requires granularity and cannot appear within a smooth field theory. After introducing this theory, these lectures aim to show some of the important consequences, which include:

- New techniques to solve for and understand atom-light quantum dynamics, which are not available within smooth field theoretic descriptions

- The possibility to encode certain applications in portions of Hilbert space with significantly reduced spontaneous emission due to destructive interference, resulting in sometimes exponentially better performance bounds compared to what was previously known

- New quantum optical phenomena driven by collective dissipation, which cannot emerge within conventional theories even in principle

At the same time, this field of research remains very open, and we aim to give a flavor of the limits of our current understanding and possible future opportunities.