

## Appunti di Fisica '25

**16 Giugno ore 15:00**

Sala Seminari, CNR-IPCF

### Engineering and Exploring Ultrastrong and Superstrong Coupling Regimes in Quantum Electrodynamics

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Quantum electrodynamics (QED) is key to understanding light-matter interactions and underpins technologies from quantum computing to precision sensing. Recent advances have expanded QED studies into extreme coupling regimes. Specifically, the ultrastrong coupling (USC) regime occurs when the light-matter interaction becomes comparable to the system's bare frequencies, even with a single mode. The superstrong coupling (SSC) regime emerges when this interaction exceeds the free spectral range in multimode environments, introducing distinct phenomena and requiring new theoretical and experimental approaches. In this talk, I will present two recent studies that distinctly investigate these regimes:

Firstly, we present a renormalized quantum Rabi model (RQRM) that improves accuracy in the USC regime, where standard models fail to capture key dynamics due to strong coupling. We demonstrate its effectiveness with examples involving double-well atoms and fluxonium qubits.

Secondly, we explore the SSC regime using a giant atom coupled to a high-impedance coupled cavity array (CCA). Exploiting interference effects, we reach record coupling strengths ( $g/\Delta\omega > 11$ ) and observe multimode dynamics and directional emission via spatial localization in the CCA.

These results deepen our understanding of USC and SSC physics and support progress in quantum technologies.