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Multiphoton Quantum Rabi Oscillations in Ultrastrong Cavity QED ANTON FRISK KOCKUM, Center for Emergent Matter Science, RIKEN, Saitama 351-0198, Japan, LUIGI GARZIANO, ROBERTO STASSI, VINCENZO MACRì, SALVATORE SAVASTA, Dipartimento di Fisica e di Scienze della Terra, Università di Messina, I-98166 Messina, Italy, FRANCO NORI, Center for Emergent Matter Science, RIKEN, Saitama 351-0198, Japan — When an atom is strongly coupled to a cavity, the two systems can exchange a *single* photon through a coherent Rabi oscillation. This process enables precise quantum-state engineering and manipulation of atoms and photons in a cavity, which play a central role in quantum information and measurement. Recently, a new regime of cavity QED has been reached experimentally where the interaction between light and artificial atoms (qubits) becomes ultrastrong, *i.e.*, its strength is comparable to the atomic transition frequency or the resonance frequency of the cavity mode. Here we show that this regime can strongly modify the concept of vacuum Rabi oscillations, enabling multiphoton exchanges between the qubit and the resonator. We find that experimental state-of-the-art circuit-QED systems can undergo *two*- and *three*-photon vacuum Rabi oscillations. These anomalous Rabi oscillations can be exploited for the realization of efficient Fock-state sources of light and complex entangled states of qubits.

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