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Isolating Bosonic, Fermionic and Vacuum Dynamics of Plasmonic Waves

Surface plasmons emerge when photons (bosons) couple with electrons (fermions) on the surface of metals. However, previous experiments have shown that these near-field waves exhibit bosonic properties in the limit of many electrons. In recent work, we reported the isolation of the quantum multiparticle dynamics responsible for the emergence of classical macroscopic properties of surface plasmons.[1] The experiments achieved the first extraction of both bosonic and fermionic quantum multiparticle dynamics of plasmonic waves, and enabled the direct observation of plasmonic fields excited by the vacuum fluctuations of the electromagnetic field.[1,2]

Known for their ability to confine light to subwavelength scales, surface plasmons have shown potential for various technological applications, ranging from sensing to information processing.[3] Interestingly, the possibility of distilling multiparticle plasmonic systems with bosonic or fermionic coherence properties could enable the development of hybrid devices for quantum simulation of bosonic or fermionic dynamics. Achieving this has been one of the primary goals of technologies for quantum information processing.[3,4]

By examining the interactions within multiparticle plasmonic systems, our team observed that, while the collective behavior of these systems often appears classical, isolating the subsystems reveals underlying quantum behaviors that contradict classical predictions.[1] This dual nature uncovers the complex interplay between the classical and quantum realms, providing insights into the fundamental mechanisms of light–matter interactions.[2]

The research employed a unique experimental setup involving a gold nanostructure designed to probe the quantum properties of plasmons. Through photon-number-resolving detection, we manipulated and measured the plasmonic fields generated by light interacting with this nanostructure. Our observations confirmed that the quantum dynamics of surface plasmons involve both bosonic and fermionic behaviors.

We believe these findings establish a new paradigm for how surface plasmons operate at the quantum level, potentially leading to more effective and scalable quantum devices.[3] The research, in our view, not only paves the way for the development of advanced quantum technologies but also suggests new methods for integrating quantum phenomena into plasmonic platforms for sensing and simulation.[2–4] OPN

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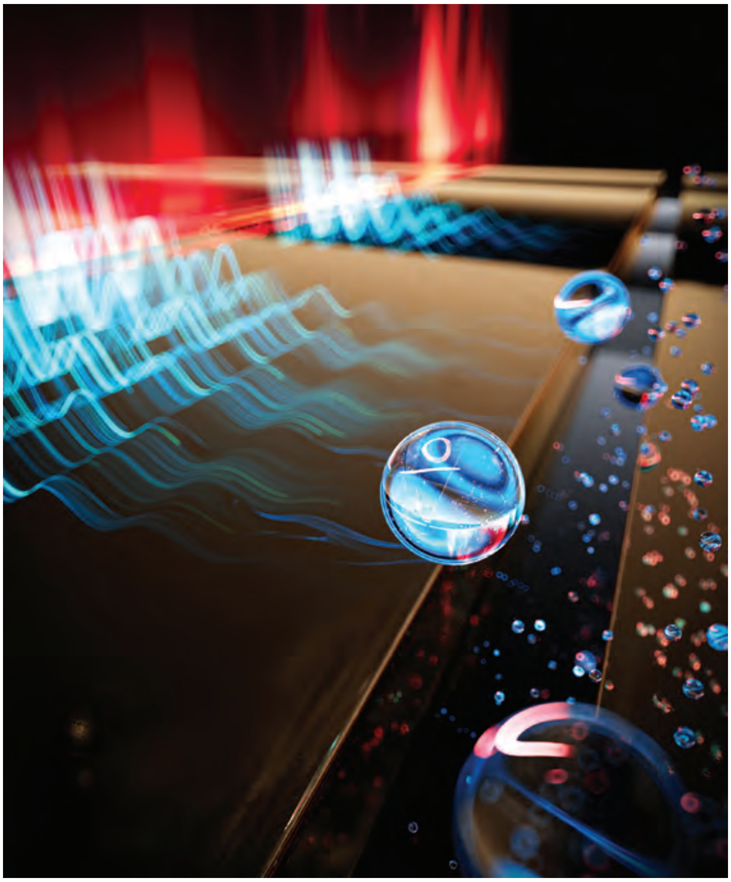

A metallic nanostructure hosts plasmonic waves produced by vacuum fluctuations of the electromagnetic field. The illustration also depicts the scattering of surface plasmons, which produces multiparticle systems with either bosonic or fermionic coherence properties.