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T01

Non-hermitian Dynamics and Nonreciprocity of Two Optically Coupled Nanoparticles

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Optical levitation of dielectric objects in vacuum provides a unique optomechanical platform due to versatile optical control of potentials and good isolation from the environment. Recently, tunable and nonreciprocal optical interactions have been measured between two nanoparticles, levitated in two distinct optical tweezers, with single-site readout of particle motion [1]. I will present our experimental platform for tweezer arrays of nanoparticles, and show our recent results on non-Hermitian collective dynamics of two nonreciprocally interacting nanoparticles [2]. We also observe a mechanical lasing transition once a threshold coupling rate is achieved, supported by our nonlinear theory model. Nonreciprocal interactions are expected to result in an even richer phase diagram of nonequilibrium dynamics for larger arrays of nanoparticles. This work paves the way towards upscaling this platform to such multiparticle arrays, in view of studying their nonequilibrium and collective mechanical behaviour in the quantum regime.

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T02

Enhancing the performance of photonic integrated circuits: Remote and Cascaded Synchronization of Optomechanical Crystal Oscillators

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Despite nature's inherent tendency toward disorder, systems that adjust their rhythms to oscillate in harmony—referred to as synchronization—are found everywhere. Synchronization can be observed in various contexts, from planetary orbits and cardiac rhythms to chemical reactions, wherever oscillating systems and weak interactions among them exist. Advances in the electronics industry have harnessed this phenomenon to improve the performance of digital processing elements. As integrated photonic technology now aims to process optical signals on a chip, the need for reference signals to synchronize actions becomes crucial to prevent errors in optical systems and communication interfaces. Here, optomechanics, the branch of physics that explores interactions between light and mechanical excitations, can provide a solution. Optomechanical oscillators (OMOs) can generate high-amplitude, self-sustained mechanical motion driven and controlled by optical fields, making them ideal for serving as clock reference signals in photonic integrated circuits.

Among the various optomechanical devices [2], silicon optomechanical crystal cavities (OMCs) stand out as promising candidates for this task. They are compatible with routing microwave phonons [3], allowing for the extension of this approach to phonon-photon hybrid circuits, where multiple OMOs can interact with each other. However, the large optical resonant frequency dispersion between nominally equivalent OMCs due to fabrication disorders complicates all-optical synchronized operation of these devices.

In this work, we present two different approaches for achieving the synchronization of the dynamics of two chip-integrated OMCs acting as OMOs. In our platform, the cavities support separated optical resonances, enabling the independent driving and monitoring of each resonator. The two configurations are distinguished by their interaction mechanisms. In one approach, oscillators communicate through an external optical feedback where the output modulation generated by one of the OMOs modulates the laser light driving the other. In the other approach, the geometries interact through a weak mechanical link that enables the spontaneous synchronization of their dynamics over a certain range of detuning between their natural mechanical frequencies. Additionally, we demonstrate the cascaded locking of the dynamics of both oscillators to an external reference signal injected into one of the OMOs.

The results, which are supported by a numerical model, lay the ground work for the distribution of reference signals among large networks of OMOs in photonic integrated circuits.

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T03

Nanomechanical logic with atomically thin resonators

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Nanomechanical computers provide efficient and low-energy information processing capabilities. As electronic computing encounters escalating challenges in sustained scaling and performance improvement, there is a growing interest in mechanical computing. Leveraging the mechanical degrees of freedom and nonlinearities inherent in nanoscale mechanical resonators have the potential to offer alternative solutions for upcoming memory and computing systems. In our work, we utilize the bistability of atomically thin membranes to establish logical states. Additionally, our objective is to showcase parametron based computing by harnessing the substantial tunability of resonance frequency and spring constant modulation in ultrathin resonators. Our CMOS-compatible architecture, coupled with atomic-scale miniaturization, aims to minimize energy consumption, approaching the fundamental Landauer limit. This paves the way for large-scale reconfigurable nanomechanical computers and neuromorphic networks capable of simulating computationally challenging problems and understanding complex interactions.

T04

Fluctuating drive of coupled classical oscillators can simulate dissipative qubits

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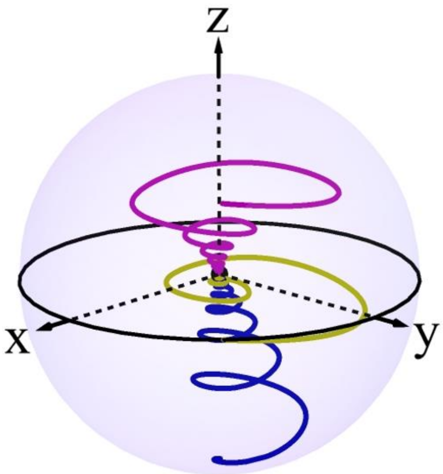
We investigate a system composed of two coupled oscillators subject to stochastic fluctuations in its internal parameters. In particular, we answer the question whether the well-known classical analogy of the quantum dynamics of two-level systems (TLS), i.e. qubits, provided by two coupled oscillators [1] can be extended to simulate the dynamics of dissipative quantum systems. In the context of nanomechanics, the analogy in the dissipation free case has already been tested in multiple experimental setups, e.g., doubly clamped or cantilever string resonators and optically levitated particles [2,3]. A well-known result of this classical analogy is that the relaxation and decoherence times of the analog quantum system must be equal, i.e. $T_1=T_2$, in contrast to the general case of quantum TLS. We show that this fundamentally quantum feature, i.e. $T_1 \neq T_2$, can be implemented as well in the aforementioned classical systems by adding stochastic fluctuations in their internal parameters. Moreover, we show that these stochastic contributions can be engineered in the control apparatus of those systems, discussing, in particular, the application of this theory to levitated nanoparticles and to nanostring resonators. However, a limit of this improved quantum-classical analogy is that the analog Bloch vector of our system (see figure) always collapses to the center of the sphere, i.e., the state corresponding to an effective infinite temperature. Eventually, we investigate how to extend the present model to simulate finite temperature states.



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T05

Optical control of the time-crystalline phases in a polariton condensate with a mechanical clock

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Time crystals (TCs) are many-body systems that display spontaneous breaking of time translation symmetry. Microcavity exciton-polaritons are bosonic quasiparticles resulting from the strong coupling between excitons and photons in a driven-dissipative open system and exhibit a transition to a nonequilibrium Bose-Einstein condensate state. The platform for this study is a polaromechanical (Ga,Al)As microcavity, where micrometer traps confine polaritons and $\sim$ 20 GHz mechanical vibrations that are very efficiently coupled. Polaritons exhibit a pseudospin degree of freedom, with its dynamics manifested through the polarization of the emitted light. Recently, under nonresonant continuous wave excitation, a robust time crystal behavior of the polariton condensate was observed: spontaneous and stable oscillation in the spinor dynamics occurs and locks to the rhythm of the GHz-cavity phonons. Different time-crystalline phases were observed as a function of the applied laser excitation power: i) Larmor-like precession of the condensate pseudospins; ii) locking of the precession frequency to self-sustained coherent phonons; and iii) doubling of the TC period by phonons.[1]

In this work, we demonstrate the tuning of the time-crystalline phases in a polariton state of a micrometer trap, through two additional control parameters, that evidence and exploit the critical role of the exciton reservoir that feeds the polariton condensate in the trap. Namely, i) the polarization ellipticity of the continuous wave excitation laser, that is able to induce a spin imbalance in the reservoir and thus induce a synthetic magnetic field affecting the condensate; and (ii) the position of the excitation spot laser respect to the trap, which determines the spatial distribution of the reservoir and is shown to favor a mechanically driven dynamics of the reservoir. These results establish microcavity polaritons affected by mechanics as a platform for the investigation of time-broken symmetry in nonhermitian systems. In addition, it is argued that the mechanically induced time modulation of the coupling between spinor modes could be used to control quantum gates based on polariton fluids proposed for classical and quantum computing.

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T06

Quantized Acoustoelectric Floquet Effect in Quantum Nanowires

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External coherent fields can drive quantum materials into non-equilibrium states, revealing exotic properties that are unattainable under equilibrium conditions -- an approach known as “Floquet engineering.” While optical lasers have commonly been used as the driving fields, recent advancements have introduced nontraditional sources, such as coherent phonon drives. Building on this progress, we demonstrate that driving a metallic quantum nanowire with a coherent wave of terahertz phonons can induce an electronic steady state characterized by a persistent quantized current along the wire. The quantization of the current is achieved due to the coupling of electrons to the nanowire's vibrational modes, providing the low-temperature heat bath and energy relaxation mechanisms. Our findings underscore the potential of using non-optical drives, such as coherent phonon sources, to induce non-equilibrium phenomena in materials. Furthermore, our approach suggests a new method for the high-precision detection of coherent phonon oscillations via transport measurements.

T07

Quantum squeezing in a nonlinear mechanical oscillator

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Mechanical resonators offer many applications in quantum information processing due to their bosonic nature. The modes of these resonators can be manipulated using tunable bilinear interactions, including beamsplitter and squeezing operations. To engineer these interactions, bosonic modes can be coupled to a nonlinear element, such as a transmon ancilla, driven by two parametric drives [1]. Recently, a beamsplitter-type interaction has been demonstrated in our circuit quantum acoustodynamics (cQAD) system [2]. To provide a universal gate set for continuous variable quantum information processing within one cQAD device, we also introduced single-mode squeezing (SMS) to our tool box [3].

In this poster, we present SMS and two-mode squeezing of bosonic modes of a mechanical resonator. We show that off-resonant coupling to the qubit leads to a tunable nonlinearity in our resonator mode. This allows us to prepare non-Gaussian quantum states with high quantum Fisher information, with applications in for example quantum metrology and sensing [3].

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T08

A mechanical qubit

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Strong nonlinear interactions between quantized excitations are an important resource for quantum technologies based on bosonic oscillator modes. However, most electromagnetic and mechanical nonlinearities arising from intrinsic material properties are far too weak compared to dissipation in the system to allow for nonlinear effects to be observed on the single-quantum level. To overcome this limitation, electromagnetic resonators in both the optical and microwave frequency regimes have been coupled to other strongly nonlinear quantum systems such as atoms and superconducting qubits, allowing for the demonstration of effects such as photon blockade [1, 2] and coherent quantum protocols using the Kerr effect [3]. Here, I will present the realization of a single-phonon nonlinear regime in a solid-state mechanical system. The single-phonon anharmonicity in our system exceeds the decoherence rate by a factor of 6.8, allowing us to use the lowest two energy levels of the resonator as a mechanical qubit, for which we show initialization, readout, and a complete set of direct single qubit gates. This work adds another unique capability to a powerful quantum acoustics platform for quantum simulations [4], sensing [5, 6], and information processing [7, 8, 9].

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T09

Abstract template for Double-Quantum-Dot Qubit Strongly Coupled to Mechanical Vibrations in a Suspended Carbon Nanotube

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Mechanical resonators are systems which present high quality factors and can easily couple to a wide range of forces, which makes them excellent candidates for quantum information processing and quantum sensing. In our group, we are developing a hybrid platform where a charge qubit defined in a double-quantum-dot is coupled to the mechanical vibrations of a suspended carbon nanotube. The nature of the coupling allows to reach the so-called ultrastrong coupling regime, that could open the possibility of exploring and realizing new regimes in a circuit quantum electrodynamics (cQED) framework.

In particular, the anharmonicity induced by the qubit in the mechanical vibrations when the system is in the ground state could allow the realization of a mechanical qubit, i.e. a qubit based on phonon's fock state transitions [1]. The effective mechanical non-linear potential in the ultrastrong coupling regime can also serve to realize a macroscopic quantum superposition similar to the one proposed in [2], with potential applications of studying collapse models in quantum mechanics, or the interplay of quantum effects and gravity, among others.

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