Imaging the work, dissipation and topological protection in the quantum Hall state

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Topology is a powerful recent concept asserting that quantum states could be globally protected against local perturbations [1,2]. Dissipationless topologically protected states are thus of major fundamental interest as well as of practical importance in metrology and quantum information technology. Although topological protection can be robust theoretically, in realistic devices it is often fragile against various dissipative mechanisms, which are difficult to probe directly because of their microscopic origins. By utilizing scanning nanothermometry [3], we visualize and investigate microscopic mechanisms undermining the topological protection in the quantum Hall state in graphene. Our simultaneous nanoscale thermal and scanning gate microscopy reveals that the dissipation is governed by crosstalk between counterpropagating pairs of downstream and upstream channels that appear at graphene boundaries because of edge reconstruction. Instead of local Joule heating, however, the dissipation mechanism comprises two distinct and spatially separated processes. The work generating process that we image directly and which involves elastic tunneling of charge carriers between the quantum channels, determines the transport properties but does not generate local heat. The independently visualized heat and entropy generation process, in contrast, occurs nonlocally upon inelastic resonant scattering off single atomic defects at graphene edges, while not affecting the transport. Our findings offer a crucial insight into the mechanisms responsible for the breakdown of topological protection and suggest venues for engineering more robust quantum states for device applications.

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Tailored optical potentials for Cs atoms above waveguides with focusing dielectric nano-antenna

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Abstract:

Tuning the near-field using all-dielectric nano-antennae offers a promising approach for trapping atoms, which could enable strong single-atom/photon coupling. Here we report the simulation results of an optical trapping concept, in which a silicon nano-antenna produces a trapping potential for atoms in a chip-scale configuration. Using counter-propagating incident fields, bichromatically detuned from the atomic cesium D-lines, we numerically investigate the dependence of the optical potential on the nano-antenna geometry. We show that the near-field potential landscape can be tailored by tuning the evanescent field of the waveguide.

Nanoscale imaging of equilibrium quantum Hall edge currents in graphene

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Abstract

The recently predicted topological magnetoelectric effect [1] is a fundamental attribute of topological states of matter with broken time reversal symmetry, and is the underlying mechanism of the quantum Hall effect. Using a scanning SQUID-on-tip [2], acting as an ultrasensitive nanoscale magnetometer, we directly image the equilibrium currents of individual quantum Hall edge states in single layer graphene for the first time [3]. We reveal that the edge states, which are commonly assumed to carry only a chiral downstream current, in fact carry a pair of counter-propagating currents [4], in which the topological downstream current in the incompressible region is counterbalanced by a heretofore unobserved non- topological upstream current flowing in the adjacent compressible region. The intricate patterns of the counter-propagating equilibrium-state orbital currents provide insights into the microscopic origins of the topological and non-topological charge and energy flow in quantum Hall systems.

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Almost Public Quantum Coins

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Abstract

In a quantum money scheme, a bank can issue money that users cannot counterfeit. Similar to bills of paper money, most quantum money schemes assign a unique serial number to each money state. Though the use of serial numbers can thwart counterfeiters, they can also be tracked by third parties, thus potentially compromising the privacy of the users of quantum money. However, in a quantum coins scheme, there are no serial numbers and all the money states are exact copies of each other, therefore providing a better level of privacy for the users.

In a private quantum money scheme, only the bank can verify the money states, whereas, in a public scheme, all users can verify the money using the bank's public key. In this work, we propose a way to lift any private quantum coin scheme (which is known to exist based on the existence of one-way functions) to an almost public quantum coin scheme. It satisfies all the properties of a public quantum money scheme but in a limited way. Verification of a new coin is done by comparing it to the coins the user already possesses by using a projector to the symmetric subspace.

This is the first construction that is provably secure based on standard assumptions and has almost all the properties of a public coin scheme and a public quantum money scheme. The lifting tech- nique can also be used on a known private quantum money scheme to obtain an inefficient (almost) public quantum money scheme that is secure against nonadaptive computationally unbounded ad- versaries.

Large spin Hall effect in sputtered thin films of non-collinear Mn3Sn antiferromagnet

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The detection and manipulation of electron spin currents is a key focus in spintronics. The spin Hall effect (SHE) is a relativistic spin-orbit coupling (SOC) derived phenomena by which electrical current generates transverse spin currents. In heavy metals SOC breaks the spin rotational symmetry, thereby resulting in SHE. However, spin rotation symmetry can also be broken without relying on the SOC as, for example, in non-collinear magnetic textures. This was first proposed and experimentally reported in non-collinear antiferromagnetic (AFM) thin films of Mn_3Ir [1]. This can be understood as due to a non-vanishing Berry curvature which also gives rise to an anomalous Hall effect (AHE). Recently, evidence of a large AHE has been reported for several non-collinear antiferromagnetic (AFM) systems including Mn_3Ge [2] and Mn_3Sn [3]. Thus, a significant SHE can be anticipated in these materials. In this work we report on the observation of a SHE in thin films of Mn_3Sn that does not rely on the SOC that exhibit a charge to spin conversion efficiency that is comparable found in platinum thin films [4].
Our work marks another step towards the integration of the spin Hall effect in practical devices in a controllable manner.

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Randomly Rotate Qubits Compute and Reverse --- IT-Secure Non-Interactive Fully-Compact Homomorphic Quantum Computations over Classical Data Using Random Bases

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Abstract: Homomorphic encryption (HE) schemes enable processing of encrypted data and may be used by a user to outsource storage and computations to an untrusted server. A

plethora of HE schemes has been suggested in the past four decades, based on various assumptions, and which achieve different attributes. In this work, we assume that the user and server are quantum computers, and look for HE schemes of classical data. We set a high bar of requirements and ask what can be achieved under these requirements. Namely, we look for HE schemes which are efficient, information-theoretically (IT) secure, perfectly correct, and which support homomorphic operations in a fully-compact and non-interactive way. Fully-compact means that decryption costs O(1) time and space. To the best of our knowledge, there is no known scheme which fulfills all the above requirements. We suggest an encryption scheme based on random bases and discuss the homomorphic properties of that scheme. We demonstrate the usefulness of random bases in an efficient and secure QKD protocol and other applications. In particular, our QKD scheme has safer security in the face of weak measurements.

Long-Range Spin-Dependent Conduction in Bioinspired Organometallic Crystals

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Abstract

Spintronics, the utilization of electron spin to carry out logic and electronic operations, is an attractive field as it allows for harnessing the spin degree of freedom to realize new functionalities while the energy needed for manipulation of the spin is relatively low compared to classical electronics. Since spintronics is usually realized using magnetoresistance effects,[1–3] organic and bio-inspired building blocks are often considered inapplicable for spin-selective transport. This is mainly due to their characteristic weak spin-orbit coupling (SOC) and their closed-shell electronic structures leading to the absence of ferromagnetism at ambient temperature. Recently, however, chiral-induced spin-selective (CISS)[4] electronic conduction through bio-inspired chiral thin organic films, such as dsDNA, peptides, and proteins was demonstrated.[5–8] Several theoretical models, relying on SOC and scattering theory were presented to explain this phenomenon.[9–13] These suggest that the underlying spin-dependent transport mechanism is independent of magnetoresistance effects and relies on the interaction between the electron spin and the chiral electric field induced by the chiral medium. The effect was demonstrated so far on a

length scale of up to few tens of nanometers in dsDNA oligomers. In the present work, we show how this length-scale glass ceiling can be broken to achieve long-range (>200 nm) spin-selective conduction in chiral bio-inspired organometallic semiconducting systems. To realize this, we utilized chiral amino acids. Moreover, we had recently demonstrated the self-assembly of single amino acids into ordered supramolecular assemblies, making them attractive candidates for chiral supramolecular applications.[14,15] We also show that the crystals formed are ferromagnetic at room temperature, leading us to the hypothesis that the spin-polarization seen here is a combination of CISS and magnetoresistance effects.

The long range spin selectivity is demonstrated for four different copper containing chiral phenylalanine-based semiconducting crystals. The structures of the studied crystals are solved using X-ray crystallography and circular dichroism (CD) spectroscopy. Their electronic structure calculated with density functional theory (DFT). These crystals show magnetic properties due to the large spin anisotropy that causes all the spins to be aligned either parallel or anti-parallel to the z axis of the crystal. This work may pave the way towards the realization of applicable spintronics, based on simple self-assembled bio-inspired crystalline systems.

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Realization of a complete Stern-Gerlach interferometer

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We demonstrate the first full-loop Stern-Gerlach interferometer, based on accu- rate magnetic fields, originating from an atom chip [1]. The Stern-Gerlach (SG) effect, discovered almost a century ago, has become a paradigm of quantum me- chanics. Surprisingly there is little evidence that the original scheme with freely propagating atoms exposed to gradients from macroscopic magnets is a fully co- herent quantum process. Specifically, no full-loop SG interferometer has been realized with the scheme as envisioned decades ago, namely, with 4 magnetic gradients where the last two reverse the splitting operation of the first two to achieve recombination. On the contrary, numerous theoretical studies explained why it is a near impossible endeavor which would require exceptional precision [2–5]. We have previously presented the first spatial SG interference pattern [6, 7] which later allowed us to put a clock in a spatial superposition [8, 9]. Recently the full-loop SG interferometer allowed us to realize a T^3 interfrometer, in which the interferometric phase scales as the third power of the interferometer time [10]. Achieving this high level of control over magnetic gradients may facili- tate technological applications such as large-momentum-transfer beam splitting for metrology with atom interferometry, and ultra-sensitive probing of electron transport down to shot noise and squeezed currents.

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Dynamics of Charge-Resolved Entanglement after a Local Quench

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Abstract:
Quantum entanglement and its main quantitative measures, the entanglement entropy and entanglement negativity, play a central role in many body physics. An interesting twist arises when the system considered has symmetries leading to conserved quantities: Recent studies introduced a way to define, represent in field theory, calculate for 1+1D conformal systems, and measure, the contribution of individual charge sectors to the entanglement measures between different parts of a system in its ground state. In this paper, we apply these ideas to the time evolution of the charge-resolved contributions to the entanglement entropy and negativity after a local quantum quench. We employ conformal field theory techniques, the time-dependent density matrix renormalization group algorithm, and exact solution in the noninteracting limit, finding good agreement between all these methods.

Non-Equilibrium Phase Transition of Alkali Vapor

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Abstract

At room temperature and above, alkali vapor is in thermal equilibrium, disordered and unpolarized. Usually in critical-phenomena models, the decrease of an external parameter (e.g. temperature) results in order. We found a system where the opposite is happening. Not only this system gains order and undergoes a phase transition as we increase the cell temperature, but also this effect only happens with linearly-polarized light, which is optical pumping without a deliberate orientation. As we increase temperature, the spin exchange rate also increases and the combination of spin exchange and linear optical pumping drives all spins to the same state, while without spin exchange interaction we would simply get a mixed state.

If we consider the mean spin of the vapor $< F_z >= \sum_{\mathrm{F,M}} \mathrm{P_{F,M}} \mathrm{M}$ as the order parameter and choose the optical power of the laser or the spin-exchange collision rate as the normalized temperature in the critical-phenomena model, we find critical exponents, symmetry breaking and a critical slowing down. As the system approaches the critical point, we measure 'life-time' that is 1-2 order of magnitude larger than the typical life-time.

This system can be widely used to investigate critical phenomena and out of equilibrium physical questions, with a very simple experimental setup.

Title: Spin filtering in chiral organic molecules – the role of electron-phonon interactions

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Abstract

Many organic molecules are strong spin filters at room temperature. Scattering experiments performed on such molecules have found that their transmission of electrons differs between spin up and spin down. Recent experiments have focused on the current through chiral molecules in a two-terminal setup. When one of the leads was magnetic, the current was sensitive to reversing the orientation of the lead's magnetic moment, in apparent violation of Onsager's relation. We show that interactions with phonons are essential to generating magnetoresistance that is asymmetric in the lead's magnetic moment beyond linear response. The asymmetric magnetoresistance of chiral molecules was also found to diminish as temperature was decreased, a feature captured by our model. Our results demonstrate the diode-like properties of chiral organic molecules, paving the way to future electronic applications.

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Mapping the twist angle and unconventional Landau levels in magic angle graphene

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Abstract

The emergence of flat electronic bands and strongly correlated and superconducting phases in twisted bilayer graphene [1,2] crucially depends on the interlayer twist angle upon approaching the magic angle

$\theta \approx 1.1°$. Utilizing a scanning nanoSQUID-on-tip, we attain tomographic imaging of the Landau levels in the quantum Hall state in magic angle twisted bilayer graphene (MATBG) [3], which provides a highly sensitive local probe of the charge disorder, twist angle θ and the band structure. We obtain a map of the local θ variations in hBN encapsulated devices with relative precision better than 0.002° and spatial resolution of a few moiré periods. We find that devices exhibiting high-quality global MATBG features including superconductivity, display significant variations in the local θ with a span close to 0.1°. Devices may even have substantial areas where no local MATBG behavior is detected, yet still display global MATBG characteristics in transport, highlighting the importance of percolation physics. The derived θ maps reveal substantial gradients and a network of jumps. We show that the twist angle gradients generate large unscreened electric fields that drastically change the quantum Hall state by forming edge states in the bulk of the sample, and may also significantly affect the phase diagram of correlated and superconducting states.

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Universal phase diagram of topological superconductors subjected magnetic flux

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(Dated: September 18, 2019)

Abstract

We perform a theoretical study of the orbital effect of a magnetic field on a proximity-coupled islands array of $p_x + ip_y$ topological superconductors. To describe the system, we generalize the tight-binding model of the Hofstadter butterfly to include the effect of the superconducting islands. The quantum Hall topological phases, appearing in the absence of superconductivity, have different integer fermionic Chern numbers corresponding to the number of occupied bulk Landau levels. As the strength of the superconducting pairing increases a series of transitions occurs, with one less chiral Majorana edge mode (half a chiral fermion edge mode) at each consecutive phase. When the pairing potential exceeds the tight-binding model bandwidth, Cooper pairs are localized in the islands and there are no edge modes. We identify domains in the model parameters space for which the system is topological and supports chiral Majorana edge modes. While the precise shape of the domains depends on the details of the model, the general structure of the phase diagram is robust: We obtain it via full numerical treatment of the model and also in simplified tractable models, implying universality of the phase diagram. This study is relevant to recent experimental research of two-dimensional superconductor arrays on semiconductor systems.

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<u>Generating entangled photons with tailored correlations for real-time quantum wavefront shaping</u>

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Quantum technologies hold great promise for revolutionizing photonic applications such as cryptography and imaging. Yet their implementation in real-world scenarios is held back, mostly due to sensitivity of quantum states of light to scattering. Recent developments in shaping of single photons introduce new ways to control scattering of quantum light. Here we cancel scattering of entangled photons, by shaping the classical laser beam that stimulates their creation. We show that when the laser beam and the entangled photons pass through the same diffuser, focusing the laser using classical wavefront shaping recovers the unique correlations of entangled photons, which were scrambled by scattering. Since the shaping is done exclusively on the classical laser beam, it does not introduce loss to the entangled photons, and it is not limited by the low signal-to-noise ratios associated with quantum light, opening the door for real-time wavefront shaping for photonic quantum applications.

Guided Dipolar Exciton Polaritons

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Exciton-polaritons (polaritons) are quantum superpositions of light and matter resulting from the strong coupling between confined optical modes and confined electronic excitations (excitons). Polaritons carry a unique set of properties, including extremely small effective masses ~$10^{-5}m_e$ and high propagation velocities, which are inherited from its' photonic counter-part. On the other hand, polaritons maintain the ability to interact with each other, as well as with external electric or magnetic fields, inherited from its' exitonic counter-part. This conjunction of properties induces effectively strong nonlinearities to the medium leading to "interacting photons". As such, the polariton quasi-particles hold promise for realizations of light-based quantum devices with new functionalities.

In the present research, we demonstrate a system of optically guided, and electrically polarized polaritons (“dipolaritons”) that display up to 200-fold enhancement of the polariton-polariton interaction strength compared to unpolarized polaritons. The magnitude of the dipolar interaction enhancement can be turned on and off and can be easily tuned over a very wide range by varying the applied polarizing electric field. The large interaction strengths and the very long propagation distances of these fully guided dipolaritons open up new opportunities for realizing complex quantum circuitry and quantum simulators, as well as topological states based on dipolaritons, for which the interactions between polaritons need to be strong and spatially or temporally controlled.

The results also raise fundamental questions on the origin of these large enhancements.

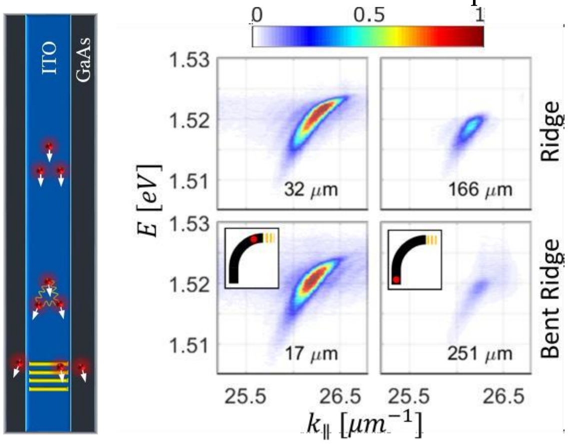

Figure 1: Illustration of Polaritons interacting within a channel. Results of guiding Polaritons in bent waveguide Channel.

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Multiplicative Bell Inequalities

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Bell inequalities are important tools in contrasting classical and quantum behaviors. To date, most Bell inequalities are linear combinations of statistical correlations between remote parties. Nevertheless, finding the classical and quantum mechanical (Tsirelson) bounds for a given Bell inequality in a general scenario is a difficult task which rarely leads to closed-form solutions. Here we introduce a new class of Bell inequalities based on products of correlators that alleviate these issues. Moreover, by being nonlinear the proposed inequalities are less sensitive to technical noise and more resistant to several loopholes. Each such Bell inequality is associated with a non-cooperative coordination game. In the simplest case, Alice and Bob, each having two random variables, attempt to maximize the area of a rectangle and the rectangle's area is represented by a certain parameter. This parameter, which is a function of the correlations between their random variables, is shown to be a Bell parameter, i.e. the achievable bound using only classical correlations. We continue by generalizing to the case in which Alice and Bob, each having now *n* random variables, wish to maximize a certain volume in *n*-dimensional space. We term this parameter a multiplicative Bell parameter and prove its Tsirelson bound. We further investigate the case of local hidden variables and show that for any deterministic strategy of one of the players the Bell parameter is a harmonic function whose maximum approaches the Tsirelson bound as the number of measurement devices increases. Some implications of these results are discussed.

This work is based on a paper currently under review in *PRL*, as well as on [A. Carmi, E. Cohen, Relativistic independence bounds nonlocality, accepted to *Science Advances*]

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Chaos induced breakdown of Bose-Hubbard modeling

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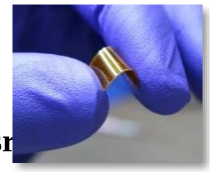
Abstract

We show that the Bose-Hubbard approximation fails due to the emergence of chaos, even whenexcited modes are far detuned and the standard validity condition is satisfied. This is formally identical to the Melnikov-Arnold analysis of the stochastic pump model. Previous numerical ob-servations of Bose-Hubbard breakdown are precisely reproduced by our simple model and can beattributed to many body enhancement of chaos.

Reference: Sayak Ray, Doron Cohen, Amichay Vardi, arXiv:1908.01987 (2019).

Flexible, Foldable and Transferrable Superconducting Quantum Devices



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Superconductors serve as a key platform for quantum computing, sensing and communicating technologies. The main building blocks for these applications are **s**uperconducting **qu**antum **i**nterference **d**evices (SQUIDs). A major challenge regarding the advancement from devices to integrated systems, is finding convenient methods to modulate SQUIDs and address them individually.

As opposed to semiconductors, superconducting devices operate on magnetic fields and not on electric voltage, imposing a strong restriction on the device scale. We aim to allocate methods to modulate the quantum state of individual SQUIDs. Here, we show (Figure 1) for the first time that amorphous superconductors can be processed reliably on a large variety of substrate, including flexible substrate. We demonstrate that (i) the quantum state of the superconductors (ii) the sensitivity to magnetic fields in these devices are tunable by means of mechanical flexing.

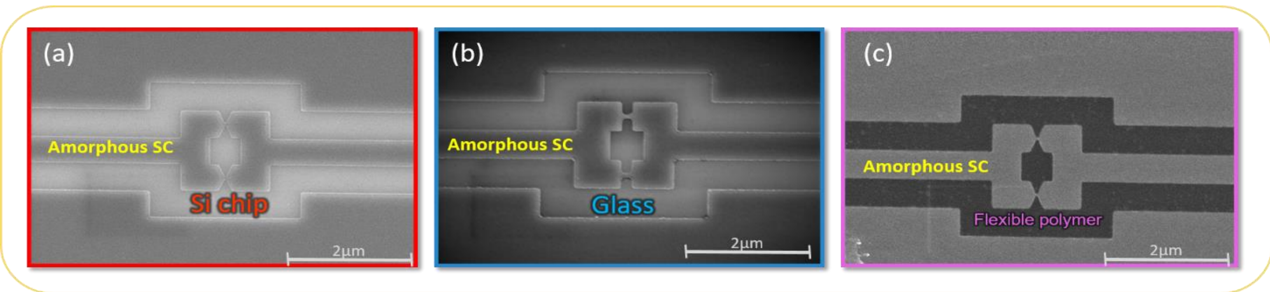

Figure 1| Devices made of amorphous superconducting coatings on various substrates. Electron micrographs of nanoscale amorphous superconducting quantum interference devices (SQUIDs) that are fabricated on (**a**) a SiO/Si chip, (**b**) a transparent glass substrate, and (**c**) an adhesive flexible polymer.

Modal decomposition of Laguerre Gaussian beams with different radial orders using optical correlation technique

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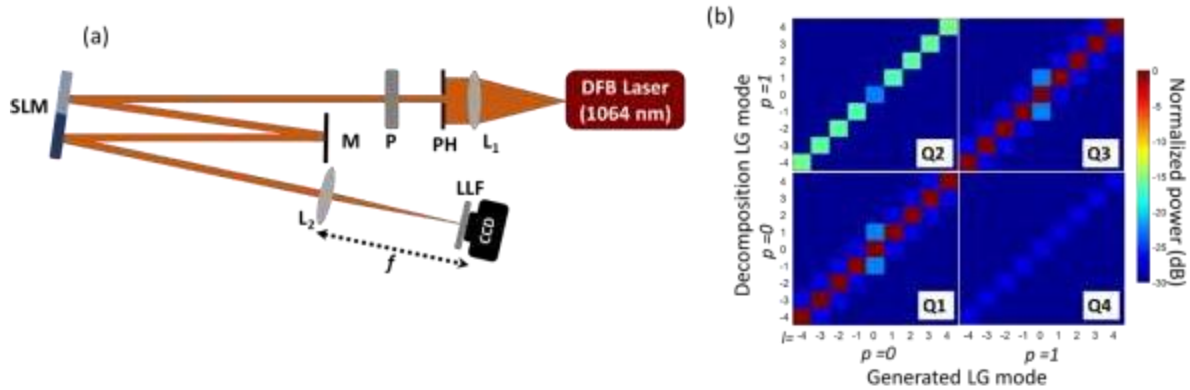
Abstract: Here, we explore the use of an optical correlation technique to decompose different radial as well as azimuthal order modes of Laguerre Gaussian (LG) beams. We report the modal decomposition with 27 dB extinction over several radial and azimuthal orders. Finally, we show that our modal decomposition is capable of sorting mode spectrum consisting of up to 10 LG modes with an accuracy of better than 97.8%.

Theory and Results: Laguerre Gaussian (LG) beams with different radial and azimuthal modal numbers are widely exploited in the optical communications [1]. Recently, it has been argued that radial modal number should also be used to increase the space-bandwidth product [2] of an optical system. One of the key issues in tracking the propagation of such beams as well as their demodulation is the quantification of their purity. To accomplish this, we need robust mode sorters or modal decomposition algorithms that accommodate a wide range of the modal spectrum with high accuracy. While excellent results have been demonstrated with practical mode sorters [3], they have been limited in the number of modes that they can sort.

In this work, we demonstrate the use of an optical correlation technique that incorporates both amplitude as well as phase structures of LG modes to accomplish the modal decomposition. Any scalar light beam (U) can be represented by a superposition of $LG_{l,p}$ modes with corresponding complex weights. The complex weight of a mode is calculated by optically correlating the input beam with the complex conjugate of the mode. To perform the optical correlation function



experimentally [4], we use a spatial light modulator (SLM) and convex lens as shown in Fig. 1(a).

Figure 1: (a) Experimental setup for implementing the optical correlation technique. (b) Normalized power measured from optical correlation technique for different combinations of generated and decomposition LG modes with radial mode order $p = 0, 1$ and azimuthal mode order $l = -4$ to $+4$.

We initially implement the optical correlation algorithm for LG modes with different radial (p = 0, 1) and azimuthal numbers (l = -4 to +4). We observed 27 dB extinction between the generated LG mode and the detected LG mode. Finally, we demonstrate the use of the optical correlation algorithm for decomposing a composite beam consisting of 10 different LG modes (azimuthal mode indices $l = -2$ to +2 and radial mode indices $p = 0, 1$) with an accuracy of better than 97.8% [4].

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Large fluctuations of the first detected quantum return time

R. Yin September 5, 2019

How long does it take a quantum particle to return to its origin? As shown previously under repeated projective measurements aimed to detect the return, the closed cycle yields a geometrical phase which shows that the average first detected return time is quantized. For critical sampling times or when pa- rameters of the Hamiltonian are tuned this winding number is modified. These discontinuous transitions exhibit gigantic fluctuations of the return time. While the general formalism of this problem was studied at length, the magnitude of the fluctuations, which is quantitatively essential, remains poorly character- ized. Here, we derive explicit expressions for the variance of the return time, for quantum walks in finite Hilbert space. A classification scheme of the diverging variance is presented, for four different physical effects: the Zeno regime, when the overlap of an energy eigenstate and the detected state is small and when two or three phases of the problem merge. These scenarios present distinct physical effects which can be analyzed with the fluctuations of return times investigated here, leading to a topology-dependent time-energy uncertainty principle.

Immiscible and miscible states in binary condensates in the ring geometry

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Superfluid mixtures are currently routinely probed in experiments with ultracold atomic gases. An interesting geometry which keeps drawing much interest in studies of ultracold atomic gases is represented by annular, which are of potential use to the field of atomtronics. In this context, mixtures of atomic condensates in annular traps and the possibility of sustaining stable persistent currents in them have been previously considered, but there are still some problems that need to be solved, such as expansion of the stability area for such states. Therefore, we aim to perform a full classification of accessible stable mixture states in such a geometry, including examination of their stability and decay channels of their unstable counterparts, both in the absence and presence of overall rotation. Given the potential significance of multi-component states in ring-shaped traps for applications such as rotational sensors, such a classification is relevant.

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